44. ASTRONOMY FROM SPACE
L'ASTRONOMIE À PARTIR DE L'ESPACE

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1. Introduction

Edward B. Jenkins

The 1987-90 triennium has been a prosperous one for space astronomy. The field has benefited from diverse activities, ranging in style from the continued operation of some old instruments, such as uv spectrographs aboard IUE and Voyager, to the introduction of completely new observing techniques, such as the Hipparcos mission to perform astrometry over large angles and the radio Very Long Baseline Interferometry (VLBI) demonstration with the NASA's Tracking and Data Relay Satellite System (TDRSS). We have witnessed some important highlights in space astronomy which significantly enhanced our understanding of some fundamental problems in astrophysics. For instance, the COBE satellite offered a tremendous gain in the precision of measuring the cosmic background radiation, and initial results seem to authenticate the simple character of this microwave radiation. As noted in the previous report of Commission 44, Supernova 1987A in the Large Magellanic Cloud was the brightest supernova since the one sighted by Kepler in 1604. There have been remarkable improvements in astronomical instruments since Kepler's time, and the fruits of our good fortunes with 1987A are now appearing in the literature. Finally, the long anticipated launch of our biggest enterprise in space astronomy, the Hubble Space Telescope, occurred in the spring of 1990.

Along with successes there are occasional setbacks and disappointments. The losses of Phobos 1 and 2 were significant misfortunes in solar system exploration. The Hipparcos satellite failed to achieve its intended geostationary orbit, but a bold reorganization of the operations promises to recapture most of the mission objectives. A major hardship has been inflicted on a broad astronomical constituency by the spherical aberration in the primary mirror of Hubble Space Telescope. We anticipate that this problem with HST will be overcome when new focal plane instruments are installed, but over the next few years the potential of this major observatory in space will be hampered. Even though the hiatus in Shuttle launches precipitated by the *Challenger* tragedy is behind us, we still encounter some problems delivering payloads into space, as evidenced by the multiple postponements of the Astro mission and the delay in the scheduled launch for the Gamma Ray Observatory. Generally, space astronomy is an ambitious enterprise – its large rewards are derived from complex machinery operating under difficult circumstances. Occasional malfunctions, some of them serious, are the price we pay in pursuing our bravest ventures.

D. McNally (ed.), Reports on Astronomy, Vol. XXIA, 505–540.

Following this introduction, this report from Commission 44 begins with commentaries which survey the accomplishments in different energy bands of the electromagnetic spectrum, progressing from the highest (γ-ray) to lowest (radio) bands. It then continues with some sections which highlight investigations in specific subjects, namely, the solar system, solar physics, and Supernova 1987A. Two final sections give interim reports on two prominent missions: Hipparcos and COBE. In total, this report mentions over 40 different space experiments which are either operating right now, are under construction, or are seriously being planned. The principal support for these missions comes from France, Germany, Japan, the Soviet Union, the United States and, collectively, the European countries represented by ESA.

Along with the tangible missions and the exciting results they produce, there are other activities in space astronomy which are essential to its health but may be less conspicuous. Long range plans formulated by the space agencies and recommendations from science panels supply a vital coherence to the overall effort and help to optimize the return. Contemporary examples of such guidance may be seen in program outlines or reports, which, to name a few, include a *Strategic Plan 1989* defined by NASA's Office of Space Science and Applications[1], ESA's *Horizon 2000* program[2], and a study by task groups organized under the Space Science Board of the US National Research Council[3]. The USNRC is also sponsoring a study by the Astronomy and Astrophysics Survey Committee (J. N. Bahcall, chairman) which will soon make recommendations for project priorities and explore some broad policy issues for the US astronomy effort, including space astronomy. Recently, some advisory panels have given guidance on how to create a more centralized system of data management and support for computations[4,5,6]. Specialized workshops have also galvanized thoughts on ambitious ventures in the more distant future, such as the Next Generation Space Telescope[7] and observatories on the moon[8].

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2. GAMMA-RAY ASTROPHYSICS BEYOND THE SOLAR SYSTEM

D. A. KNIFFEN

A. INTRODUCTION

One of the great triumphs of observational gamma-ray astronomy has been the verification of nucleosynthesis theory, which has been shown to have been remarkably accurate in its predictions. There has also been further progress in the understanding of the galactic ^{26}Al emission as well as the .511 MeV source near the galactic center. The Soviet-French GRANAT mission with the low energy gamma-ray experiment, SIGMA, has been operating on orbit since late 1989. The GAMMA spacecraft with a high energy spark chamber telescope, GAMMA-1, was launched on July 7, 1990. The Gamma-Ray Observatory (GRO) is scheduled for a March 1991 launch, and gamma-ray burst detectors will be included on the Ulysses, Mars Observer and WIND spacecraft.

B. THE MILKY WAY GALAXY

Analysis of the SAS-2 and COS-B galactic plane data, uncertain because of the difficulty in separating the relative contributions of diffuse and discrete sources, has continued with the application of more sophisticated techniques. A recent study (Bailes and Kniffen, 1991) has concluded that discrete sources contribute 30 percent or less to the galactic emission at 100 MeV. A reanalysis of the COS-B data has brought into question all but eight of the sources given in the 2CG Catalog (Mayer-Hasselwander and Simpson, 1988) and has suggested nine new sources.

Apparent conflicts in the observations of galactic .511 MeV fluxes and longitude distributions can, at least in part, be explained by differences in the instrument fields of view (Leventhal, et al., 1989). A model by Lingenfelter and Ramaty (1989) has suggested that observations are explained by a distributed source of positrons, probably from supernova, which annihilate in the interstellar medium, and the time variable source at or near the center. In the case of the ^{26}Al line a discrete source has been reported (Von Balmoos, Diehl, and Schönfelder, 1987) following earlier reports of extended emission (Mahoney, et al., 1984; Share, et al., 1985).

Gamma-ray burst observations from the Ginga spacecraft (Murakami, 1988) of multiple low energy spectral features, appear to give evidence of first and second cyclotron harmonics (Fenimore, et al., 1988) supporting the concept of a highly magnetized neutron star origin for at least some gamma-ray bursts.

There has been progress in understanding the Soft Gamma Repeaters (SGRs). While only three have been identified, a consistent picture seems to emerge. The chief characteristic is the stochastic appearance of burst recurrences. First observed for 05266-66 (Golenetskii, Il'inskii, and Mazets, 1984), additional repeaters have been observed at 1900+14 (Mazets, Golenetskii, and Guryan, 1979) and at 1806-20 (Laros,et al., 1986). The events appear to be quite short (~100ms), with similar spectra from event to event, no cyclotron features, and little time variability. The burst profile is characterized by a rapid risetime (Norris, et al., 1991).

Development of new observing capabilities and facilities has characterized the activity in VHE (10^{10} -10^{14} eV) and UHE (10^{14}-10^{17} eV) gamma-ray astronomy. The new Whipple Observatory High Resolution Camera, which allows discrimination between proton and gamma-ray induced events , has produced the most statistically significant result yet in ground based gamma-ray astronomy, a 15 sigma detection of the Crab nebula (Lang, et al., 1990). Less compelling detections of x-ray binaries such as Cygnus X-3 and Hercules X-1 have been reported by many observers. In total, there have been about ten different source detections with independent confirmation at over 30 VHE and UHE facilities (Weekes, 1988). All except the ones mentioned are of marginal significance.

C. EXTRAGALACTIC GAMMA RADIATION

The remarkable direct confirmation of the synthesis of radioactive nuclides in the Type II supernova, SN1987A in the LMC (Matz, et al., 1988) is the major result of the last three years. Observations of the time history (Leising and Share, 1990) and the spectral and spatial features (Cook, et al., 1988; Sandie, et al., 1988; Rester, et al., 1988; Mahoney, et al., 1988; Tueller, et al., 1990) have provided confirmation of predictions (Clayton, Colgate, and Fishman, 1969) and important information on details of the event (See e.g. Woosley, 1988). More details on SN1987A are given by Sonneborn in this Report.

At least three active galaxies have now been observed at gamma-ray energies (Bassani, et al., 1990). The prospect for additional detections with the Gamma-Ray Observatory is very good (Bignami and Mereghetti, 1989). These observations are most important for understanding the central engine powering these dramatic emitters of electromagnetic energy. The prospects are also good for detecting and resolving near-by galaxies with the Gamma-Ray Observatory with sufficient resolution to begin to study the distribution of cosmic-rays within them (Ozel and Fichtel, 1988).

D. FUTURE PROSPECTS FOR GAMMA-RAY ASTRONOMY

The future of gamma-ray astronomy has arrived with the recent launch of GRANAT and GAMMA. Next will be GRO, covering six decades of energy from 20 Kev to 30 GeV. Further, a major effort is underway to ensure that observations are coordinated and analyzed over the full range of wavelengths available to astronomy.

i. GRANAT/SIGMA

The GRANAT spacecraft, now operating successfully on orbit, contains a low energy (30 KeV to 2 MeV) gamma-ray experiment, SIGMA, which has a sensitivity of several millicrabs and a resolution of about 10 arcminutes (Laudet, et al., 1986). The experiment consists of a two dimensional coded mask and an NaI Anger Camera as a position sensitive detector.

ii. GAMMA

The GAMMA Satellite was launched on July 7, 1990. The GAMMA-1 instrument (Akimov, et al., 1987) consists of two wide-gap spark chambers, a directional triggering telescope, a lead-plastic calorimeter and a coded mask which can be commanded in place. The coded mask improves the angular resolution from a few degrees to about 20 arcminutes. The sensitivity to point sources is about 2.5 times that of SAS-2 or COS-B. GAMMA also contains DISK, a collimated NaI detector covering the range 0.1-10 MeV.

iii. The Gamma-Ray Observatory

The Gamma-Ray Observatory represents the gamma-ray portion of NASA's four "Great Observatories". GRO provides over an order of magnitude improvement in sensitivity over its full range of energies. Details are available in many reviews (e.g. Kniffen, 1988; Schönfelder, 1990).

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3. X-Rays

G. W. Clark

1. Introduction

During the period covered in this report (1987 July - 1990 June) the Japanese X-ray observatory GINGA, and the Soviet Röntgen International Observatory on the KVANT module of the MIR space station were operating in orbit. They were launched just in time to enable observations of the entire early development of X-ray emission from supernova SN1987a, the subject a separate section of this report. Here we will focus on other results from GINGA and recent studies based on the data archives of SAS 3, HEAO 1, HEAO 2 (the Einstein Observatory), and EXOSAT.

Looking to the future, the German X-ray observatory, ROSAT, was launched in May of 1990 and will begin its planned program of observations following several weeks of tests and calibrations. The American EUVE (Extreme Ultraviolet Explorer) is now scheduled for launch in 1991. Construction has begun on the Soviet SPECTRUM-X-Gamma, the American XTE (X-Ray Timing Explorer), and three observatories with imaging telescopes, the Japanese ASTRO-D, the European XMM, and the American AXAF (Advanced X-Ray Astrophysics Facility). Thus the decade of the nineties promises to be extremely active in X-ray astronomy, with orbiting observatories that achieve greatly increased sensitivity, imaging and spectrum analysis capabilities.

2. The Interstellar Medium

The soft X-ray background (0.1-1.0 keV) was measured during the past decade in three separate all-sky surveys with angular resolutions ranging from 3 to 7°. A comprehensive review of the results by McCammon and Sanders (1990) shows good agreement as to the distribution and absolute values of the soft X-ray intensities. A principal conclusion is that much, and possibly all, of the flux in the energy range from 0.1 to 0.28 keV (C-band) is emitted by a tenuous ~1×10^6 K plasma within a "hot bubble" that surrounds the solar system out to a distance of about 100 pc. Whether some portion of the C-band radiation comes from more distant sources such as the galactic halo or from hot gas mixed with cold clouds in the disk remains an open question. A definitive answer will probably be derived from the sky survey of ROSAT which will show in much finer detail the degree of correlation between soft X-ray intensities and the column densities of interstellar hydrogen. The origin of the apparently diffuse background in the 0.5-1.0 keV energy range is not as well understood because of the difficulty of determining the relative proportions of galactic and extragalactic components, and the contributions of unresolved discrete or concentrated sources. Here again the ROSAT survey should clarify the situation. In addition, one can anticipate major advances in understanding the origins of the soft X-ray background and the physical conditions and composition of the hot component of the ISM when observations of line emission are made with microcalorimeters and Bragg reflection spectrographs during the coming decade.

New information about the size and composition of interstellar dust has been derived from measurements of the dust-scattering halos around X-ray images of stars in GINGA observations of lunar occultations of X-ray stars near the galactic center. Intensity variations observed just before and after the sharp ingress and egress transitions are interpreted as profiles of the dust-scattering halos. Data in the energy range above 4 keV were obtained for the first time and provided evidence for the existence of iron in grains with typical sizes of 0.06 μm with an iron abundance relative to the interstellar hydrogen consistent with standard cosmic abundance (Mitsuda et al. 1990).

3. X-Ray Emission by Single Stars

Systematic studies of X-ray emission by ordinary single stars has continued with the large data samples from the Einstein and EXOSAT observations, most recently with coeval stars in the Hyades and Pleiades clusters (Micela et al. 1988; Micela et al. 1990), late-type giants and supergiants (Maggio et al. 1990) and nearby flare stars (Pallavicini, Tagliaferri and Stella 1990). Substantial progress has been made in sorting out the complex phenomenology of coronal X-ray emission and its correlations with convection, stellar rotation, magnetic fields, age, and radiatively driven winds.

4. X-Ray Binaries

The following are a few highlights of the many results derived from recent observations and archival studies of X-ray binaries. Detailed information and discussions can be found in the recent reviews of X-ray binaries in general (White 1989) and accretion-powered X-ray pulsars in particular (Nagase 1989). The latter contains extensive tabulations of the properties of X-ray pulsars.

QPO and Noise Spectra of Low-Mass X-Ray Binaries (LMXB)

Measurements of intensity and spectral variations of LMXB in X-ray data obtained from large-area proportional counters on EXOSAT and GINGA have revealed numerous regularities in the complex phenomenology of quasi-periodic oscillations (QPO) and noise spectra that hold promise for revealing details of the mechanisms involved in accretion and spin up of weakly magnetic neutron stars in contact binaries where millisecond radio pulsars are believed to be born. QPO appear as broad peaks superposed on noise continua in the power density spectra obtained by Fourier analysis of counting rates recorded by large-area proportional counters. The most striking regularities are those found in the so-called Z sources which include GX5-1, Sco X-1, Cyg X-2 and several other of the bright LMXB. When plotted in a color-color diagram, the representative point of a Z source spectrum traces out a trimodal distribution with a pattern resembling the letter "Z". Over times of hours and days a typical Z source moves continuously along the Z, presumably in response to changes in its accretion rate. If it exhibits QPO, then its QPO frequencies and noise characteristics are tightly correlated with the position of its representative point on its Z pattern. It appears that at least two distinct mechanisms produce QPO. A widely discussed model for variable-frequency QPO on the upper, or "horizontal", branch of the Z pattern is the modulated-accretion magnetospheric beat-frequency model in which the QPO frequency is identified with the difference between the highly stable spin frequency of the neutron star and the variable Keplerian orbital frequency at the inner-boundary of the accretion disk the radius of which changes according to the accretion rate. For details of QPO phenomena and their interpretation see the review by van der Klis (1989).

The Black Hole of A0620-00

The identification of the 1975 X-ray transient A0620-00 as a 7.8-hour binary system consisting of a >3 $M_\odot$ compact object with a K star companion (McClintock and Remillard 1986) was confirmed and extended in detailed optical spectroscopic studies of the double-peaked emission lines from the rotating accretion disk that remains around the collapsed star more than ten years after the X-ray outburst died away (Johnston, Kulkarni and Oke 1989). Analysis of the system in the light of the possible mass of the K star and the dynamical constraints implied by the velocities derived from the measured Doppler shifts at the outer edges of the accretion disk yielded a conservative lower limit of 4 $M_\odot$ for the mass of the compact object, and a possible mass as large as 25 $M_\odot$. Since the theoretically firm upper limit on the mass of a neutron star is 3 $M_\odot$, A0620-00 is probably the strongest candidate for identification as a stellar-mass black hole.

Globular Cluster X-Ray Sources

The 685-second orbital period of the X-ray burst source 4U 1820-30 is the shortest of any known binary system. An analysis of the secular change in the period from 1976 to 1989 showed that it *decreased* at a rate of 0.074±0.013 ms/yr corresponding to $\dot{P}/P = -1.08\pm0.19\ 10^{-7}\ \mathrm{yr}^{-1}$ (Tan et al. 1990). The system is believed to consist of an accreting neutron star with a low-mass (~0.07 $M_\odot$) degenerate helium star companion, with mass transfer driven by loss of angular momentum through gravitational radiation. According to the standard model, the orbital period of such a system must increase. Therefore, other causes of the apparent orbital period decrease have been sought, of which the most likely is believed to be acceleration of the system in the gravitational field of the dense core of the globular cluster NGC 6624 in which it is located.

The X-ray source in M15 is the only globular cluster X-ray source of which the optical counterpart has been identified. Optical spectroscopy has discovered binary motion with a period of 9.1 hours, and a systemic velocity relative to the rest of the cluster of 150 km s^{-1}. This greatly exceeds the escape velocity from the cluster, and implies that the binary is very young (Naylor et al. 1988).

Cyclotron Lines in Neutron-Star Spectra

Detection of cyclotron features in the X-ray spectra of several additional sources and extensive theoretical work on the formation of cyclotron lines has advanced the utilization of these spectral features in the analysis of the physical conditions of accreting neutron stars. GINGA observations revealed a strong cyclotron absorption line varying in amplitude with pulse phase at 20 keV in the spectrum of the massive binary pulsar 4U1538-52 (Clark et al. 1990), and evidence of a cyclotron feature near 7 keV in the X-ray pulsar 1E 2259+586 associated with a supernova remnant (Koyama et al. 1989). The theory of cyclotron line formation in relativistic plasmas was extended to include the effects of gravitational light bending on the spectra and directions of X-ray emission from accretion caps and columns (Mészáros and Riffert 1988). Detailed comparisons can now be made between theoretical models and the phase resolved spectra of X-ray pulsars.

First and second harmonic cyclotron absorption lines at 20 and 40 keV in the X-ray spectrum of a gamma ray burst were reported in observations by GINGA (Fenimore et al. 1988). This and the previous evidence of a cyclotron features in the X-ray spectra of gamma-ray bursts (Mazets et al. 1982) support the conclusion that at least some of the sources of gamma ray bursts are nearby and highly magnetized ($\sim 2 \times 10^{12}$ G) neutron stars.

X-Ray Eclipse Phenomena of X-Ray Binaries

The analysis of X-ray eclipse transitions in X-ray binaries to define the atmospheric structure of the occulting star began in the earliest studies of Cen X-3 with UHURU in which the run of density in the atmosphere of the primary O-type supergiant was characterized by an exponential scale height of 5×10^{10} cm. Since then studies of Cen X-3 with SAS 3 (Clark, Minato, and Mi 1988) and EXOSAT (Day 1990) have confirmed and refined this characterization of the deep atmospheric structure of an early-type supergiant for which the current theories of radiation pressure-driven winds, representing extensions and refinements of the CAK theory (e.g. Friend and Abbott 1986), predict an entirely different form of the density function. In the case of Her X-1, the companion of which is an evolved F star with an X-ray heated face of spectral type A, EXOSAT observations of eclipse transitions show an atmospheric density profile which is also well described by an exponential density function, but with a scale height much larger than expected for a hydrostatic atmosphere at the observed temperature of the F star (Day, Tennant and Fabian 1988).

5. Active Galactic Nuclei (AGN)

Seyfert Galaxies

A study of 48 hard X-ray selected Seyfert type AGN's from the EXOSAT spectral survey have demonstrated remarkable uniformity in the spectral indices in the energy range from 2 to 10 keV (Turner and Pounds 1989). Values of the energy index α clustered around 0.7 with no dependence on intrinsic luminosity over four decades of luminosity. At the same time, many exhibit a variable soft excess features attributable to radiation by accretion disks around the central object, and some of lower luminosity show evidence of variable absorption in cold matter that must lie close to the central source.

Quasars

The clearest indicator of the size of the central engines of AGNs in general and quasars in particular is the time scale of variability in their X-ray emissions. GINGA observations of 3C 279, the quasar in which superluminal motion was first identified, detected a 20% increase in the X-ray flux within 45 minutes, implying a value of $\Delta L/\Delta t > 2 \times 10^{42}$ ergs s^{-2}, the highest recorded so far. Makino et al. suggest that the rapidly variable X-ray phenomena are produced by a relativistic jet in its formative stage.

BL Lacertae-Type Objects

BL Lacs comprise about 20% of X-ray selected AGNs, while they are only 2% of radio selected AGNs. Recent studies of AGNs selected from Einstein, EXOSAT, and HEAO 1 data have yielded many new examples of this type of object, extending the catalog of BL Lac objects by more than 60. Giommi et al.(1990) distinguish two subclasses of BL Lacs according to the correlation between the power law indices that characterize their spectra in the radio-optical and optical-X-ray ranges. Most BL Lacs are found to undergo rapid (hours-days) intensity variations about mean values that are generally steady over years, and none show evidence of intrinsic absorption in cold matter at column thicknesses greater than $\sim 10^{20}$ atoms cm^{-2}. A review of current knowledge and extensive references are given in the article of Giommi et al.

6. Cosmological X-Ray Background

Efforts continue to determine what portion of the background can be accounted for in terms of cosmological distributions of known classes of sources with properties determined from the nearby examples, and by analysis of fluctuations in the X-ray flux from fields without resolved sources. Since the spectrum of the X-ray background is flatter than the mean X-ray spectra of low-redshift quasars, the fraction of the X-ray background that can be attributed to quasars depends critically on whether more distant quasars have flatter spectra. Using the best data currently available on the properties of 71 high-redshift quasars from the Einstein IPC archive, Canizares and White (1989) conclude that the average X-ray spectral indices of radio-loud quasars, grouped according to the steepness of their radio spectra, do not vary significantly with redshift in the range $0.1<z<3.5$, while the data on radio quiet quasars is insufficient to justify a conclusion. An analysis of fluctuations in the X-ray background (Barcons and Fabian 1990), carried out on deep Einstein IPC fields in the energy range from 1 to 3 keV, "marginally" confirms a result obtained previously by other means (Hamilton and Helfand 1987), namely, that $N(>S)\sim S^{-1.5}$ curve derived from the intensity distribution of individually detected distant sources in the Einstein Deep Survey must flatten below intensities less than half the survey limit. This implies that this source population cannot account for more than ~35 –45% of the background. At the same time, the exact conformance of the microwave background radiation to a blackbody spectrum, as measured by the COBE satellite, has placed severe upper limits on the portion of the X-ray background that can be produced by a hot intergalactic plasma that would distort the spectrum by Comptonization. Definitive determination of the origins of the X-ray background must await the results from the more powerful imaging telescopes of the coming decade.

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4. Ultraviolet Astronomy

Yoji Kondo

I. INTRODUCTION

Ultraviolet astronomy research during the triennial period from 1987 July 1 to 1990 June 30 was conducted primarily through (A) the geosynchronous International Ultraviolet Explorer (IUE) satellite observatory, (B) the Voyager ultraviolet spectrometers, and (C) several sounding rocket programs.

The Hubble Space Telescope was launched on 1990 April 28 but ultraviolet observations from it were not yet available at the time of the preparation of this report. The Astro mission for Space Shuttle, which includes three ultraviolet experiments, had been scheduled for launch during the first half of 1990 but its flight was postponed.

II. INTERNATIONAL ULTRAVIOLET EXPLORER (IUE)

The IUE continued to operate productively during the present 3-year epoch. The satellite telescope, equipped with a 45-cm primary mirror and ultraviolet spectrographs, had been developed jointly by NASA, ESA and the British Science and Engineering Council and was launched into a geosynchronous orbit on 1978 January 26. It is operated in *real* time 16 hours a day from NASA's Goddard Space Flight Center in the suburb of Washington, D.C. and 8 hours daily from ESA's Villafranca groundstation near Madrid, Spain.

Since 1985, the IUE had been operated with only two of the original six gyroscopes, at least three of which were expected to last for the duration of a projected 3-5 year mission. In anticipation of another gyro failure, a one-gyro control system had been developed and is on hand now. Both the far-ultraviolet (1150-2000Å) and mid-ultraviolet (1900-3200Å) spectrographs are still operational at a high (0.1-0.3Å) and a low (6-7Å) spectral resolution.

By the end of 1989 December, 1870 articles based on IUE observations had been published in refereed journals. During the first 12 years of its operation, in excess of 1800 different guest observers from all corners of the world had used the observing facilities at Goddard and Villafranca. More than 70,000 spectra had been collected by the 12th anniversary of its launch. Reprocessing of the data for its final archive, in order to optimize the quality of the data enhancing the signal-to-noise ratios significantly, is expected to start in 1991.

A. Scientific Highlights of the IUE Since 1987 July.

Highlights of the scientific results from the IUE had recently been summarized in an 800-page volume co-authored by several dozen IUE guest observers (Kondo et al. 1987, 1989) and in a review article (Kondo, Boggess and Maran 1989). The proceedings of the ten IUE symposia, held in the U.S. and Europe over the past twelve years, would also provide good references. One of the important contributions of the IUE during the past three years, observation of the supernova 1987A, is reviewed in a separate section in the current Commission 44 report. I will in the following describe the coordinated synoptic observations of the Seyfert galaxy NGC 4458; a few brief examples of recent observational results from the IUE will also be mentioned below to give the reader a glimpse of the ongoing research.

The Active Galactic Nucleus in NGC 4458. Investigation of the active galactic nuclei took a step forward when it became possible to observe these objects simultaneously in all wavelengths since their spectra change differently at different wavelengths. Synoptic observations of the Seyfert galaxy NGC 4458 were made at a four-day interval over an eight-month period from

1988 to 1989. Some radio, optical, infrared and x-ray observations were also made during this period. These evenly spaced observations yielded very good fluctuation power density spectra, which were quite steep during this epoch, being roughly proportional to the inverse square of the frequency. The largest amplitude variations were observed in the shortest wavelengths; the spectrum was harder when brighter, in agreement with thermal interpretation of the far ultraviolet excess. For the high-ionization broad emission lines the size of the emitting region was determined to be 10 light-days, while the size for the low-ionization emission region was 30 light-days. The size found was an order of magnitude smaller than was predicted from existing models. Variability was much slower than what could be expected from the orbital period of the putative accretion disk. A close synchrony was observed between the ultraviolet and optical variations; the optical maximum lagged by about two days or less. Some fifty astronomers from all over the world took part in this collaborative program.

Spatially-Resolved Mapping of the Transition Region. Using the eclipse of a white dwarf by a G9 II giant star in the binary HR 6902, the first spatially resolved mapping of the transition region in the atmosphere of a late type star was carried out. The binary nature of HR 6902 with a hot compact companion was discovered earlier from IUE observation. The study of the variations in the absorption spectrum of the hot companion star have shown that not only density gradient exists in the chromosphere but also unexpected temperature gradients are present.

Peculiar Object MWC 560. The peculiar emission-line star MWC 560 was observed during its photometric outburst. A broad P-Cygni profile in Mg II indicated ejection velocities in excess of 7000 km/s. The Fe II and Cr II features yielded velocities of 5000- 5300 km/s. These velocities are greater than those reported for cataclysmic variables or recurrent novae during their outbursts but the ultraviolet spectra of MWC 560 did not resemble the spectra of these types of objects (Michalitsianos et al. 1990).

Comet Austin. Pre-perihelion observations of Comet Austin showed that the gas production rate was considerably higher than that for Comet Halley, suggesting this comet to be quite young.

B. Prognosis.

With the successful launching of the x-ray satellite observatory ROSAT, coordinated observations from the IUE and the ROSAT of selected ultraviolet and x-ray variable objects, especially chromospheric variables and active galactic nuclei, will be carried out in 1990 and 1991. In the era of new space observatories, the IUE may continue to play a crucial role in astronomical research, especially in observing astrophysically important variable objects in coordination with other telescopes on or off this planet.

III. VOYAGER ULTRAVIOLET SPECTROMETERS.

Although the ultraviolet spectrometers (UVS) onboard Voyager 1 and 2 were designed primarily to observe extreme- and far- ultraviolet emission from the atmospheres of the outer planets and several of their satellites in the wavelength range 500-1700Å, these spectrometers proved useful in observing various other astronomical sources below 1200Å. For stellar sources, the resolution is about 18Å and for diffuse sources some 30Å.

Highlights. Perhaps the most significant result from the Voyager ultraviolet spectrometers during the three-year period was observations of the nearby quasar 3C 273 in coordination with the IUE (Reichert et al. 1988). It was the first time that observations shortward of 1200Å had been obtained for any extragalactic object. The quasar was detected in all observed wavelengths above 912Å but the flux showed significant drop below 1060Å. This might have been caused by Lyman-α continuum absorption in the rest frame of 3C 273 or may have been due to absorption in an accretion disk within the nucleus of that quasar. Alternatively, the drop below 1060Å might have been caused by a turnover in the underlying continuum radiation. Among the published works from the same period are observations of a peculiar hot helium rich degenerate star KPD 0005+5106 (Holberg 1987) and a study of extreme-ultraviolet emission from a number of cataclysmic variables (Polidan, Mauche and Wade 1990).

IV. SOUNDING ROCKET EXPERIMENTS.

Sounding rocket experiments were conducted by teams located at the University of California Berkeley, the University of Colorado, Goddard Space Flight Center, Johns Hopkins University and Princeton University.

A. Berkeley Experiments.

An extreme ultraviolet spectrometer obtained a spectrum of the nearby hot white dwarf G191-B2B from 400 to 1150Å at about a 15Å resolution (Green, Jelinsky & Bowyer 1990). The stellar effective temperature was determined to be 61,000 (+6000, -4000) K, and the ratio of helium to hydrogen in the photosphere was log(He/H) = -4 (±0.5). A grazing incidence spectrometer, designed to measure the diffuse extreme ultraviolet (80-650Å) background was flown successfully (Labov and Bowyer 1990). These are the first spectral measurements of the background below 520Å. Several emission features were detected including interplanetary He I 584Å emission and geocoronal He II 304Å emission. An imaging far-ultraviolet (1400-1900Å) camera was flown to search for small-scale fluctuations in the far ultraviolet background that would be the signature of an integrated background contribution from normal spiral galaxies (Martin and Bowyer 1990). The results place a strong constraint on the far-ultraviolet evolution of galaxies in the last one-third of a Hubble time. The measurement also provides a constraint on the evolution of weakly clustered galaxies, such as galaxies with active star formation, that is approximately half as strong.

B. Colorado Experiment.

A prototype of the Far-ultraviolet Spectrometer Explorer (FUSE) mission was launched several times by a team led by Webster Cash. The 1988 March flight yielded the spectrum of Spica as well as a diffuse glow in the Large Magellanic Cloud, which was interpreted as the ultraviolet light echo from SN1987A predicted by Chevalier. The 1989 November flight produced an observation of BD+28 4211; the spectrum agreed with the results from the revised Voyager calibration of the same object, with the spectrum dropping off at 930Å rather than at 912Å. They observed 3 B stars in the 1990 April 9 flight, from which were obtained ultraviolet reddening curves. Comet Austin was observed on 1990 April 12; several interesting emission lines were detected including those due to Lyman-β and O I.

C. Goddard Experiment.

An ultraviolet (1250-1750Å band) imaging telescope using a MAMA detector was flown by Andrew Smith. A hot subdwarf HD 269665 (SK-68 110, CPD 168 385) was prominent. Subsequently, low resolution spectra obtained with the IUE show this star to be hotter than 30,000 K. Comparison of the high resolution spectrum at 1150-2000Å with those of other hot subdwarfs indicates a temperature lower than 50,000 K (Hill & Smith 1989). Smith's team also obtained a far-ultraviolet image of NGC 6240 with the purpose of establishing the morphology of O-B stars and hence recent star formation in that galaxy.

D. Johns Hopkins Experiment.

The group led by Feldman obtained low slit ultraviolet spectra of Comet Austin on 1990 April 21 (Sahnow *et al.*). Spectra were obtained in the wavelength range 1250-1850Å along an 8.25 arcmin slit, with a spectral resolution of 5Å and spatial resolution of 10 arcsec. Emissions of O I, C I, S I and CO were detected. Preliminary analysis gave a CO production rate of 1-2$\times 10^{27}$ molecules s^{-1}, indicating an abundance of CO relative to water of approximately 2 percent.

E. Princeton Experiment.

A spectrum of π Scorpii with continuous coverage from 1003 to 1172Å at an unprecedented resolving power of approximately 1.3×10^5 was recorded by an objective-grating echelle spectrograph (Jenkins et al. 1989). In addition to numerous atomic lines the spectrum shows 70 absorption features from the Lyman and Werner transitions of molecular hydrogen in rotational levels $J = 0$ to $J = 5$. Using the spectrum from the same rocket flight, Joseph and Jenkins (1990) were able to distinguish three types of H I as well as two discrete H II regions in velocity space, allowing independent analyses of physical conditions and abundances for the individual gas components. Improving the interpretation of the ground-based observations of Ca II and Ti II with the rocket spectrum, they found that all of the Ti II absorption seen toward π Scorpii arose in the warm, neutral intercloud medium, while other elements have their maximum absorption associated with cold clouds.

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5. INFRARED SPACE ASTRONOMY

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I. INTRODUCTION

During the period from 1987 to 1990 the major event in space infrared astronomy was the successful launch of the Cosmic Background Explorer (COBE) satellite in November, 1989. The initial results published on the temperature and isotropy of the cosmic background radiation have been spectacular. Observations from the Kuiper Airborne Observatory (KAO) of the supernova SN 1987A, in the Large Magellanic Cloud, have continued to yield important new information on dust formation and the chemical composition of the ejecta. The Infrared Astronomical Satellite (IRAS) database, which has improved with continued analysis, when combined with ground-based and space observations at other wavelengths, continues to produce many new results in the study of solar system, stars and stellar systems, galactic structure, the interstellar medium, and extragalactic astronomy.

The COBE results and the KAO observations of SN 1987A are so extensive that they will be treated in separate sections of the report of this Commission. In this section special attention will be given to the IRAS results, as well as other results from balloon-borne, airborne, and rocket observations. In the limited space available only a few highlights of this research can be described.

II. RESULTS FROM NEAR-SPACE OBSERVATORIES

The KAO, a 91-cm telescope mounted in a converted C-141 aircraft capable of reaching altitudes of 12.8 km, continues to remain a premier facility for far-infrared and submillimeter astronomy. Important advances in our knowledge of star formation processes, the interstellar medium and the Galactic center have resulted from these observations.

One of the most exciting discoveries of IRAS was that of circumstellar disks of solid material orbiting around apparently normal stars such as Vega and β Pictoris. In an effort to better understand the distribution of material around the star Fomalhaut (α PsA), Lester et al. (1990), using the KAO, spatially resolved the 100 micron emission around this star and found it to be approximately 100 AU in radius.

Polarimetry of far-infrared and submillimeter thermal emission from aligned interstellar grains can be used to map magnetic fields in regions where embedded or background sources are not available. KAO observations by Werner et al. (1988) detected polarization at 100 microns from Sgr A, which provided the first information about magnetic fields in the 3 pc dust ring which surrounds the Galactic center. Novak et al. (1989) also used the KAO to measure the polarization of far-infrared emission from dust in Mon R2 and the KL nebula in Orion, providing new evidence that the polarizaton is due to emission from magnetically aligned dust grains. The magnetic field direction in the outer parts of the Orion cloud was found to be the same as that in the dense core.

The role of water in the chemistry of molecular clouds remains an important problem. It should be significant in chemical processes, cooling of clouds, and as a reservoir contributing to the oxygen abundance. Knacke et al. (1988) have reported the first evidence for interstellar gas phase water in the infrared spectrum of the BN object in the Orion Nebula, determining the water column density, abundance ratios of water to CO and HDO, and the gas-to-ice ratio. Using the KAO, they searched for lines of neutral gaseous water in absorption in the vibrational-rotation band near 2.63 microns, with an approach similar to that of Larson et al. (1989) who observed gaseous water in comets.

The cooling of molecular clouds occurs through a few spectral lines, of which the C II (157 micron) fine-structure line may be the most important. Observations of this line in the Orion Nebula with an airborne heterodyne spectrometer by Boreiko et al. (1988) velocity-resolved the spectra for the first time, showing multiple velocity components in some locations. Excitation temperatures and column densities were derived for BN/KL, and the ^{12}C II emission was found to be optically thick.

Far-infrared line emission from ^{13}CO at 151 microns was detected from the core of the KL region in Orion (Genzel et al. 1988). About 10 to 30 M_o of dense and warm (>200 K) gas were required to account for the line flux. A hot core of high column density, but low velocity dispersion, could explain the results. Likewise, the first detection of ^{16}OH at 53 microns and ^{18}OH at 120 microns from the KL region was reported by Melnick et al. (1990), who show that the OH shocked gas is expanding outward from the central BN/KL infrared cluster.

In the center of our Galaxy, detailed mapping of the inner few parsecs has been performed in the Si II (34.8 micron) line (Herter et al 1989) and maps of the entire region over the inner 10 arcmin square in C II (157 micron) have been produced by Geis et al (1990). The Si II emission is pervasive, extending well into the neutral gas ring which surrounds the ionized core. The peak emission was found 4 pc north of Sgr A*. C II emission was found from two cloud complexes, one of which connects Sgr A with the Radio Arc.

Many celestial objects show a distinctive set of emission features in the infrared, known for many years as the unidentified infrared emission bands (UIR bands). A new infrared emission feature at 5.25 microns was discovered in the spectrum of BD +30°3639 by Allamandola et al (1989a), who assigned the line to C-H bending modes of polycyclic aromatic hydrocarbons (PAHs). Using the AROME balloon-borne telescope the 3.3 micron UIR feature has been mapped in the diffuse radiation from the Galactic plane by Giard et al. (1988), who have shown that PAHs are a ubiquitous component of the interstellar matter. A comprehensive treatment of the UIR bands and the PAH hypothesis has been presented by Allamandola et al. (1989b).

The 1-meter balloon-borne telescope of the Tata Institute for Fundamental Research has produced high-resolution far-infrared maps of the Eta Carina Nebula and several southern H II regions (Ghosh et al. 1988, 1989).

Using a rocket-born infrared telescope cooled by solid nitrogen, Matsumoto et al. (1988) mapped the diffuse celestial light in the wavelength interval 1 to 5 microns over a large portion of the sky, including the Galactic pole. After subtracting the foreground components, an isotropic diffuse radiation component remained, possibly of extragalactic origin.

The near-infrared region of the spectrum is a particularly advantageous window for observing the distribution of old, evolved stars in the Galactic disk and bulge. The Spacelab-2 Infrared Telescope maps of the large scale distribution of the diffuse 2.4 micron radiation from the Galactic disk and bulge, when combined with CO maps of similar resolution, have been used to make measurements of the global scale parameters of the Galaxy (Fazio et al. 1990).

III. THE INFRARED ASTRONOMICAL SATELLITE (IRAS)

The discoveries by IRAS of circumstellar disks around the main sequence stars Vega and β Pictoris have been followed up by Aumann (1988) who has found that most A, F and G stars within 25 pc have cool dusty disks. The infrared emission from these disks is much larger than that of the solar system, raising the interesting possibility of a presently undetected massive Oort cloud in the outer solar system. The disks are potentially related to planetary systems, but their size, age and the size of the emitting particles remain uncertain.

Theoretical models have predicted that the strong mid-infrared emission observed from young stars could only be explained by the presence of circumstellar disks (Adams, Lada and Shu 1987). The IRAS data have shown that roughly half of T Tauri stars have protostellar disks (Cohen, Emerson and Beichman 1989; Strom et al. 1989). Subsequent observations of the millimeter dust continuum have measured masses for the disks, finding typical values close to the 0.01 solar masses needed to form our own solar system (Beckwith et al. 1990; Adams, Emerson and Fuller 1990). Thus many young stars may possess pre-planetary circumstellar systems.

Several groups have studied the global distribution of the far infrared emission with respect to the molecular and neutral hydrogen distribution (Mooney and Solomon 1988; Scoville and Good 1989). They find that the far infrared emission from molecular clouds is primarily due to heating by OB stars, giving rise to a total far infrared luminosity of 6 x 10^9 solar luminosities for the galactic disk. The luminosity per unit mass of typical galactic molecular clouds is largely independent of cloud mass, arguing against star formation mechanisms which are expected to depend strongly on mass, such as self-induced star formation or cloud-cloud collisions.

Using a color selection method from the IRAS Point Source Catalog, Chester (1986) and Habing (1987) have been able to produce the first images of the bulge of our galaxy. The bulge stars are mostly long period variables (LPVs), which resemble previously known LPVs but are among the reddest known (van der Veen and Habing 1988).

A remarkable IRAS result is the detection of 12 and 25 micron emission from the diffuse interstellar medium on many size scales in our Galaxy and other galaxies (Walterbos 1988; Rice et al. 1990). The emission may be due to very small grains or large molecules (PAHs) which are transiently heated by ultraviolet photons, leading to new models of the dust in the interstellar medium (Draine and Anderson 1985; Puget, Leger and Boulanger 1985; Chlewicki and Laureijs 1988; Desert et al 1990).

The pioneering work of Dwek and coworkers (Dwek, Petre, Szymkowiak and Rice, 1987) has been very influential in revising ideas of the energetics of SNRs. They found that the far-IR emission can be as much as 100 times more powerful than in the x-rays, which means that supernova remnants loose their energy much more rapidly than previously thought due to inelastic collisions of electrons on dust and subsequent thermal emission from the dust. This could affect the overall energetics of the ISM, qualitatively changing our views on its structure.

Two new absorption bands have been found in IRAS Low Resolution Spectrometer data of H II regions and embedded protostellar objects by d'Hendecourt and de Muizon (1989) and Cox (1989). One of these is due to a libration (distorted rotation in a crystal) band of water and the other is a bending mode of carbon dioxide. This is the first observation of carbon dioxide in the interstellar medium.

Studies of the luminosity function in the local Universe have established that far infrared-selected sources bridge the luminosity gap between galaxies and quasars, and outnumber all extragalactic sources in the 10^{11} to $10^{12.5}$ solar luminosity range (Soifer et al. 1987). Infrared-selected galaxies provide about 25% of the total energy density in the local universe. The highest luminosity sources usually show signs of interaction or merger which has raised the possibility that collisions induce shocks, trigger star formation which is visible in the far infrared, and perhaps fuel an active nucleus.

Several quasars have been discovered in the IRAS data, possibly representing a new class of such objects (Beichman et al 1986; Vader et al. 1987; Low et al. 1989). The two most luminous IRAS sources so far discovered are both Seyfert 2 galaxies (Kleinmann et al. 1988; Frogel et al. 1989).

Advantage has been taken of the whole sky coverage, uniform calibration and low foreground extinction of the IRAS survey to take a new look at the distribution of matter in the local Universe. Recent analyses of the galaxy distribution on the sky find a good agreement between its dipole and that of the microwave background (Harmon, Lahav and Meurs 1987; Lahav, Rowan-Robinson and Lyndon-Bell 1988). This supports the hypothesis that the dark and luminous matter in the Universe are distributed similarly. Strauss (1989) has used a large redshift survey of bright IRAS galaxies to map the local gravitational field. Lonsdale et al. (1990) have found evidence for >100 Mpc-scale structures in a deeper IRAS survey.

Far infrared-selected galaxies, whose emission is probably dominated by hot young stars, show signs of significant cosmological evolution. This indicates that either the overall star formation rate or the incidence of starburst events (short-lived episodes of high star formation) has been declining at a rapid rate over the last few billion years (Hacking, Condon and Houck 1987; Lonsdale et al 1990; Saunders et al 1990). The rate of decline in luminosity is quite similar to that observed in quasars, highlighting the likelihood of a physical connection between starbursts and active nuclei.

Sanders et al. (1990) have collected the ultraviolet to radio spectral energy distributions of over 100 PG quasars. They find that 20-40% of the luminosity is emitted in the infrared, and that this emission is thermal from dust reradiation of the nuclear light, with little evidence for nonthermal emission.

Studies of the zodiacal bands of emission seen a few degrees on either side of the ecliptic plane have demonstrated that they are almost certainly due to the break up of asteroids of known families.

In addition to these long-known low latitude bands, several new dust bands have been found in the zodiacal emission at higher latitudes (Sykes, 1988). Sykes has also found several comet trails in the IRAS data. These are debris in the orbits of short-period comets.

The IRAS Minor Planet Survey has been constructed, resulting in IRAS data using 15,390 candidate associations for 5,760 asteroids (Tedesco et al 1989).

IV. FUTURE MISSIONS

The 1990's will see an enormous increase in space activities for infrared and submillimeter astronomy. Some of the major missions planned for the future are described below.

A. Infrared Space Observatory (ISO)

ISO is a 60-cm helium-cooled telescope with four focal plane instruments: a short wavelength camera, a multiwavelength photometer/polarimeter, and short and long wavelength spectrometers, covering the spectral region from 3 to 200 microns. ISO is an intermediate mission between IRAS and SIRTF in both schedule and capability. It will be launched by ESA in 1993 and will provide the first follow-up on the IRAS results and define further scientific questions for the later SIRTF mission.

B. Infrared Telescope in Space (IRTS)

IRTS is a helium-cooled telescope planned for launch in 1993 by Japan's Institute of Space and Astronautical Science. It will carry four experiments: a Fabry-Perot interferometer to map the C II and O I emission from the Galaxy, a submillimeter wavelength radiometer and a near-infrared photometer to measure the extragalactic background radiation, and a mid-infrared spectrometer. Because it shares a platform with other space experiments IRTS will obtain data for only 2 weeks.

C. Submillimeter-wave Astronomy Satellite (SWAS)

SWAS is one of NASA's Small Explorer Class satellites, consisting of a 55-cm ambient temperature telescope with passively cooled detectors, to search for single lines of H_2O, O_2, C I, and ^{13}CO in molecular clouds and to qualify several critical submillimeter wave receiver and spectrometer elements to be used on later missions. The launch date is 1994.

D. NICMOS: The Near Infrared Camera and Multi-object Spectrometer for the Hubble Space Telescope

NICMOS is a second generation NASA instrument for the Hubble Space Telescope that is designed to provide imaging and spectroscopic observations at wavelengths between 0.8 and 3.0 microns. NICMOS contains cryogenically-cooled cameras and spectrometers to cover a wide range of scientific objectives, and has an expected lifetime of greater than five years.

E. RELICT 2 and AELITA

RELICT 2 is a passively cooled telescope which will be operated near the outer (L2) Lagrangian point of the Earth/Sun system to measure the diffuse background radiation. It will carry five radiometers covering the spectral region from 1.5 cm to 1.5 mm wavelength with a 7 degree field of view. The launch date is 1992. AELOTA is a cryogenically cooled telescope using bolometers which will map the diffuse background radiation at submillimeter wavelengths. The launch date is 1994. Both RELICT 2 and AELITA are USSR missions.

F. Stratospheric Observatory for Infrared Astronomy (SOFIA)

SOFIA will be a 2.5-meter ambient temperature telescope mounted in a specially modified Boeing 747 aircraft, which will replace the Kuiper Airborne Observatory in the late 1990's. It will have capabilities throughout the spectrum from 0.3 microns to 1.3 mm wavelength. The planned flight program of 120 8-hour flights per year would support approximately 15 science instruments and 40 principal investigator teams annually. SOFIA will be sponsored by NASA and the German Science Ministry (BMFT).

G. Space Infrared Telescope Facility (SIRTF)

SIRTF, one of NASA's Great Observatories, is a 0.85-meter diameter cryogenically-cooled telescope which will orbit the earth at an altitude of 100,000 km. SIRTF's three focal plane instruments will permit imaging and spectroscopy over most of the infrared spectrum with sensitivities of 100 to 10,000 times their predecessors. It will be operated as a facility for the entire scientific community.

H. Submillimeter Moderate Mission (SMMM)

SMMM would be a moderate mission class instrument with a fixed, ambient temperature telescope approaching 4-meters in diameter and a liquid helium cooled focal plane, to be launched by an Atlas class rocket. The mission is presently in the pre-Phase A stage as a collaboration between NASA and CNES.

I. Pronaos

Pronaos is a 2-meter diameter balloon-borne telescope for submillimeter astronomy being developed in France by CNES (Toulouse). It entered Phase B in 1987. The telescope will accommodate two focal-plane instruments: a multiband photometer and a heterodyne spectrometer.

J. Far Infrared and Submillimeter Space Telescope (FIRST)

FIRST is a cornerstone mission of the ESA long term science program. Currently in a detailed study phase it is a large (4.5 to 10 meter) diameter passively cooled telescope equipped with a combination of photometer/camera and very high resolution spectrometers for far-infrared and submillimeter wavelengths. FIRST is foreseen to be launched shortly after the year 2000.

K. Large Deployable Reflector (LDR)

LDR is an ambient temperature 10 to 20 meter diameter telescope, which will be either deployed or erected in space by NASA, for very high angular resolution (1 arcsec) and spectral resolution observations at far-infrared and submillimeter wavelengths (30 to 600 microns). It is presently under study as a mission in the early 2000's.

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6a. Radioastronomy from Space
Very Long Baseline Interferometry

Bernard F. Burke

The earth's atmosphere can be a barrier to radio astronomy research, just as it is in other astronomical disciplines. For the radioastronomy field of Very Long Baseline Interferometry (VLBI) the earth's finite size is an additional handicap, because VLBI methods can be used to achieve high angular resolution regardless of the separation distance. The only limitation will be the seeing effects imposed by the interstellar medium, and at wavelengths of 2 cm and shorter, these should be negligible even for baseline lengths of several hundred thousand kilometers. IAU Symposium 129 (Reid and Moran, 1988) addressed the technical and scientific issues in detail.

The atmospheric limitations to ground-based radio astronomy appear at very low frequencies because of the ionospheric cutoff and at millimeter and sub-millimeter wavelengths because of water-vapor, oxygen, and ozone absorptions. The previous report of IAU Commission 44 treated research in the solar system at low frequencies in some detail. Unfortunately, there are no new missions in this field to give results from in this report. There is anticipation, however, of forthcoming results from the Galileo and Ulysses missions after their launch, which is expected in 1990.

THE TDRSS DEMONSTRATION

The field of orbiting VLBI went from planning to reality with the successful completion of demonstrative experiments using the NASA-TDRSS satellite, which turned out to be useable for astronomical purposes, even though it was designed for satellite-to-ground communication. The first experiment was carried out at 13 cm, and fringes were detected for several sources (Levy *et al*, 1986; Linfield *et al*, 1988). A more extensive set of 13 cm observations were made in 1987 (Linfield *et al*, 1988), and a set of 2 cm observations were made in 1988 (Levy *et al*, 1989). The ground stations in all experiments were the 70-meter DSN telescope at Canberra (Australia), the 45-meter telescope at Nobeyama (Japan) and the Japanese Space Agency telescopes at Usuda and Kashima. The 13 cm results showed fringes for 23 out of 24 sources, of which ten showed brightness temperatures exceeding the 10^{12} K synchrocompton limit (Linfield *et al*, 1989). The 2 cm results demonstrated clearly that high-frequency orbital VLBI is a technically feasible extension of ground-based methods with no technical barriers to be expected.

THE RADIOASTRON MISSION

The first approved mission for orbital VLBI was RADIOASTRON, which will carry a 10-meter diameter antenna into a highly elliptical 24-hour orbit. The scientific objectives have been summarized (Kardashev and Slysh, 1988) and the fabrication of the components was started in early 1990, for launch in the 1993-1995 time frame. The receiving frequencies will be 327, 1665, 5000, and 23,000 MHz. International participation has been invited; the 1665 GHz receiver is being built by CSIRO in Australia, the 5 GHz receiver by the Dutch and German groups at Dwingeloo and Bonn, the 23 GHz receiver by the Helsinki University of Technology, and the 327 MHz by a collaboration between Bangalore and Leningrad. Ground and tracking and data analysis will be carried out in both the Soviet Union and the USA. The international advisory group meets regularly. Most of the major ground-based radio telescopes are involved in the collaboration.

THE VSOP MISSION

The VSOP (VLBI Space Observatory Program) mission of ISAS (Japan) was given full official approval by Japanese authorities in 1989 and is planned for a 1995 launch. A 10-meter diameter antenna is planned, with observing frequencis at 1.6, 5 and 23 GHz. A preliminary form of the specifications have been given at IAU Symposium 129 (Hirabayashi, 1988). In early 1990, the design was in an advanced state, and international participation has been invited. The ground tracking and data acquisition will be a collaboration between ISAS (Japan) and the NASA-DSN. The planned orbit is at an inclination of 46°, with a 6-hour period, and a large set of ground-based radio telescopes, especially the VLBA (USA) and the EVN (Europe) have been brought into the collaboration in order to achieve mapping with high dynamic range.

OTHER PLANNED MISSIONS

The IVS (International VLBI Satellite) is a new mission being studied by ESA with Soviet, Japanese, and US collaboration, and is a successor to the QUASAT study (Schilizzi, 1988). The planned configuration will use a 25-meter radio telescope, with a wide suite of observing frequencies, from 5 GHz to 85 GHz, and the feasibility of extending operation to 200 GHz is being studied. It will also be capable of functioning as a 5 mm spectrometer, allowing the study of oxygen-line emission from the interstellar medium.

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6b. Radioastronomy from Space: Cosmic Microwave Background Measurements from Balloons

Lyman Page

Balloons can lift payloads above most of the atmosphere for up to 12 hours at a time with a low cost and fast turnaround. Typically, a small experiment group can fly their payload twice per year. The altitude is important for experiments which observe at wavelengths near the peak of the Cosmic Microwave Background (CMB) (about 1.2 mm) where variations in the CMB intensity have an unambiguous spectral signature. Listed below are four groups in the US that have used balloon platforms for CMB measurements in the last three years. There is considerable mixing amongst the participants across these groups.

The MIT experiment (Meyer, Cheng and Page) searches for the CMB anisotropy by observing in four channels simultaneously. In one flight this single-beam experiment can map a quarter of the sky. The passbands, centered on 1.8 mm, 1.1 mm, 0.63 mm, and 0.44 mm, allow the spectral separation of the CMB signal from other non-cosmological signals such as emission from the upper atmosphere, or by dust in the interstellar and interplanetary media. The MIT group has flown three times. The first flight (October 1988) ended prematurely after a balloon burst, data from the second two successful flights (October 1989 and May 1990) are currently being analyzed.

The Princeton/MIT group (Cottingham, Cheng and Boughn *et al.*) flew a single-channel maser to map the anisotropy at 19 GHz (16 mm) on angular scales of 3 to 180 degrees. The observation mode is similar to MIT's. While at Princeton, Cottingham mapped the Northern Hemisphere in May and October 1986, and at MIT mapped the Southern Hemisphere in April and November 1988. The data have been analyzed, but the results are not yet published. Because of the long wavelengths, small balloons can be used at low altitudes since galactic synchrotron radiation is the dominant source of background, rather than atmospheric emission.

The Santa Barbara group (Lubin, Meinhold, Schuster *et al.*) works on both absolute and anisotropy measurements. The absolute experiment is expected to yield results this year. The anisotropy measurements are performed by a large parabolic reflector mounted on a pointing platform. The antenna beam has a FWHM of roughly 0.5 degrees and is switched to either side of a fixed point in the sky by a chopping secondary element. This experiment looks at the difference in sky intensity through two nearby air columns and thus is not as sensitive to the atmosphere as the MIT experiment. In the flight of August 1988, the Santa Barbara SIS mixer (90 Ghz) was used, and in November 1989 and June 1990 the group used the Berkeley multi-channel bolometric radiometer. Data are forthcoming.

The Berkeley group (Bernstein, Cottingham, Fischer, Lange, Richards *et al.*) flew an absolute experiment in April 1987. Although the experiment was designed to pin down possible systematic effects in earlier absolute experiments, it also placed limits on the anistropy because the platform was spinning 1 RPM. The bolometric radiometer observed at 10 degrees FWHM in a single wide passband near the CMB peak (Bernstein *et al.* 1989). In addition to the current efforts with Santa Barbara, the Berkeley group is building a "next-generation" pointing platform, as part of the program of the NSF Center for Particle Astrophysics.

Discussions are now underway on observing from the ground at the South Pole, where long integration times are easily attained and experiments may be repaired *in situ*. The comparison with ballooning methods will come forward over the next several years.

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7. Space Observations of the Solar System

Thomas Morgan and Jurgen Rahe

Voyagers 1 and 2 were launched into space in 1977 and subsequently passed by Jupiter and Saturn. Voyager 2 continued on to successful encounters with Uranus on January 24, 1986 and Neptune on August 25, 1989. Our understanding of Neptune and its rings, satellites, and magnetosphere increased considerably (*Science* Special Issue No. 246, 1989); but the analysis of the results from this encounter is still progressing. In the meantime, the two spacecraft continue to explore the charged particle and magnetic field environment beyond the planets and obtain ultraviolet measurements of stars. On February 14, 1990, Voyager 1 took advantage of a unique and historic opportunity to take from a distance of about 40 AU, a "family portrait" of nearly all of the planets in our solar system. The Voyager program was a great success. The community owes the teams of scientists and engineers that invested a considerable fraction of their careers to it and made it possible, admiration and gratitude.

The two Soviet spacecraft Phobos 1 and 2 were launched in July 1988. Phobos 1 was lost shortly after launch, but Phobos 2 continued to Mars and its satellite Phobos. Phobos was inserted in orbit about Mars in January, 1989 and began rendezvous with Phobos in February. Contact was lost with the spacecraft on March 27, 1989 following a maneuver which obtained images of Phobos from a distance of 200 km. Before that happened, Phobos 2 had e.g., already obtained measurements of the particle and field environment and on the vertical structure and content of the Martian atmosphere (*Nature* Special Issue, No. 19, 1989). Although Phobos 2 fell far short of fulfilling its objectives, the data it returned to Earth provided further insights and posed many new questions about Mars, Phobos and their environment.

The NASA Magellan radar imaging spacecraft was successfully launched on May 4, 1989. Orbit insertion occurred on August 10, 1990, and mapping is expected to start in September 1990. For the next 243 days (one Venus rotation), Magellan will gather radar imaging, altimetry, and radiometry data as it orbits the planet every 3.15 hours. 70 to 90% of the Venus surface will be mapped with a resolution that varies between 250 and 600 meter. The first excellent images were received in August 1990 and proved to be 10-times better than those obtained by any previous spacecraft.

The NASA/FRG Galileo mission was successfully launched towards the Jovian system on October 18, 1989. It will fly by Venus once and Earth twice for gravity assists. The spacecraft consists of two principal parts: an orbiter and a probe. The orbiter will allow scientists to study Jupiter, its satellites, the magnetic and plasma fields as well as particles surrounding Jupiter and its satellites. It will also study Venus, Earth, one or two asteroids, and the interplanetary space en route to Jupiter. The probe will be deployed from the orbiter about 150 days before arrival at the planet and penetrate and measure Jupiter's atmosphere.

8. SOLAR PHYSICS FROM SPACE 1988 - 1990

S. D. Jordan

The previous report on this subject emphasized the growth of worldwide interest in doing solar physics from space, and the new insights gained into solar flares from both the Solar Maximum Mission (SMM) and from HINATORI. The current period has been one of further increases in scientific understanding of the Sun, especially of solar flares, and of considerable hope that the solar community will at last realize its long-range plan for an ultrahigh-resolution capability in the visible, the ultraviolet, and the infrared wavelength regimes. Solar physics in space is in transition from an era when spatial resolution was unable to resolve structures on the scale of the photospheric scale height, or to perform two-dimensional imaging rapidly because of detector limitations, to a new era in which all of these goals are technically realizable, but where programmatic and funding limitations may still impose serious delays. At the same time, studies continue toward understanding the underlying physical processes that govern the Sun. It is also clear that both space data and data obtained from ground-based observatories must be used to provide a complete picture of many of the physical processes being studied.

Solar activity increased dramatically during the first few months of 1987, indicating that the sharp rise of cycle 22 had begun. One of the most dramatic signs of this fast rise was found in white light images of the K-corona obtained with the SMM Coronagraph/Polarimeter: the global coronal magnetic field switched from its dipolar, equatorial, solar minimum form to the highly inclined multipole form characteristic of solar maximum in only four solar rotations. Solar flare activity increased dramatically as well, reaching at least a local peak in March of 1989, when several powerful X-class flares were observed from Active Region 5395.

SMM scientists established a stereoscopic imaging collaboration with the Soviet and Czech solar soft X-ray and coronagraph imaging teams using the TEREK instrument on PHOBOS-1, during a US-USSR Joint Working Group Meeting on solar-terrestrial physics held in May, 1988 and at the international PHOBOS Conference in July, 1988. While strictly simultaneous observations were unfortunately not obtained, due to the loss of the PHOBOS-1 spacecraft at the end of August that year, the TEREK had been turned on early and had acquired some data, to be followed only one week later by SMM soft X-ray observations of one of the active regions that TEREK had observed. These data are now being analyzed by SMM Data Analysis Center and Lebedev Institute scientists.

The Hard X-Ray Burst Spectrometer (HXRBS) continued as the only instrument in space dedicated to monitoring the solar hard X-ray emissions until the reentry of the SMM into the atmosphere on December 2, 1989, thus terminating that scientific mission after almost one decade of observing solar activity. During the entire mission, HXRBS amassed a data base of 12,672 flares - over 4,000 during the rise in activity of Cycle 22 since 1987 - with the capability of detecting time variations on scales as short as a few tens of milliseconds. These observations have proved invaluable in providing the spectral information on the energetic electrons accelerated during the impulsive phase of flares, and in determining the differences in the hard X-ray characteristics of the intense, gradually varying, long duration events as compared to the more frequent impulsive events. These differences have contributed significantly to our understanding that these two types of flares must reflect fundamentally different energy release processes, and that all flares cannot be explained with a single model. An important feature of the scientific advances made during the period of active data acquisition on the SMM was the availability of correlary ground-based data taken simultaneously with the observations from space. New H-alpha imaging observations with much higher time resolution than was previously obtained, down to 0.1 sec in some cases, show a correlation between impulsive X-ray emission and similar impulsive bursts in H-alpha kernels. Also, the H-alpha spectral observations made in Hawaii have revealed a red-shifted component in coincidence with hard X-ray spikes, which has been interpreted as a downward directed motion balancing the upward motion of the chromospheric evaporation detected as a blue shift in the soft X-ray lines from the thermal plasma of the flare.

Radio observations, in conjunction with space data, have also proved of great value in elucidating the physics of flare processes. Correlated studies with metric and decimetric radio emission - 100 MHz to 3 GHz - observed with the digital radio telescope in Zurich have shown significant delays of up to several seconds between the decimetric millisecond spikes and the corresponding hard X-ray spikes, and a proportionality between the rate of elementary radio spike bursts and the hard X-ray flux. Correlated studies with microwave imaging information from the VLA, and imaging and spectroscopy from 2 to 18 GHz at the Owens Valley Radio Observatory are being made to further elucidate the connection between the electron distributions responsible for both emissions.

Extensive work in progress with the SMM data base is establishing further correlations between the hard X-ray and the soft X-ray time profiles. This work is lending further support to the growing evidence for at least two major classes of flares, as noted above, thus providing the basis for further development of sophisticated flare models. These models permit a more detailed evaluation of many physical processes known to occur, or thought to occur, in flares, including, ultimately, mechanisms for "triggering" the flares, a process that probably occurs on too small a spatial scale to be observed directly from satellites in Earth orbit. An extensive data base has been assembled at the SMM Data Analysis Center at the Goddard Space Flight Center, and efforts are underway to make the bulk of the data available to remote users. For example, the full HXRBS data set will be archived on optical disks by the end of 1991, and all the flare data from this experiment are already on optical disks and are available, on line, for remote analysis by anyone with access to SPAN. For extensive reviews of current solar flare research, see Solar Physics, all of vol 118 (1988), and Dennis and Schwartz (1989).

Solar flare studies will be picked up in 1991 by a major space mission, SOLAR-A, currently under development by the Space Agency of Japan, as well as by a number of lesser efforts involving sounding rockets and balloons. The SOLAR-A spacecraft will include both hard X-ray and soft X-ray imaging of solar flares, along with associated spectroscopy, from a complement of instruments provided primarily by Japan, but supplemented by instrumentation from both the United States and the United Kingdom. Launch of SOLAR-A is planned for September of 1991. In addition to SOLAR-A, it is hoped that balloon payloads developed at the University of California, Berkeley and the Goddard Space Flight Center will provide both spectroscopic data and images of unprecedented sensitivity and resolution in the hard X-ray and low energy gamma-ray energy regimes during the same period of operation, which will be on the decline of the current strong maximum.

Another major scientific space program under development for solar physics is the international Solar and Heliospheric Observatory (SOHO) Program for studying both the internal structure of the Sun and the corona and solar wind. The spacecraft and several of the instruments are being built by the European Space Agency and its member countries, with substantial participation from the United States (under management by the National Aeronautics and Space Administration). The planned launch date for the SOHO remains (late in) 1995, using an advanced version of an Arianne rocket. The Helioseismometer to be carried on the SOHO will obtain observations of the comparatively high l-mode oscillations of the Sun, as these afford the best probe of the upper convection zone in which current theory predicts the solar dynamo action is concentrated. However, during actual operation of the SOHO mission, the Global Oscillations Network Group (GONG) net of ground-based observatories should also be in operation, collecting data on the more deeply penetrating, lower l-mode oscillations that probe the structure of the deep interior down to the solar core. Between these two activities, one in space, the other ground-based, a complete model of the Sun's internal structure should emerge if the experiments fulfill their planned objectives (see The SOHO Mission, ESA SP-1104).

The other primary objective of the SOHO mission is to study the corona and solar wind, in order to obtain better models, and to better understand the mechanisms for accelerating the wind, which is already known to consist of at least two major components out to one a.u., one of which - the high speed streams from coronal holes - moves too fast to be accelerated by the thermal pressure gradient of the hot corona alone (the old "Parker" picture). Theoreticians have been working on this problem for several years already, but better data from SOHO are needed.

Another important source of future data for solar coronal studies, and one that involves an ambitious program which, if fully realized, promises to provide what could be a definitive data base for future coronal studies, is the CORONA program in the Soviet Union, with collaborators from a number of other nations, and even further opportunities for collaboration as the program develops. The CORONA program involves a series of satellites that will carry a number of experiments dedicated to studying solar atmospheric phenomena, with particular emphasis on high temperature and high energy processes. The first launch of a CORONA satellite could occur as early as 1992, with a second CORONA currently under development, and a third one planned.

An important scientific problem that reached a stage of incomplete solution in the 1970's and has become a significant topic of research again, after a partial hiatus of about a decade, is that of chromospheric heating. There is renewed interest in the possibility that sound waves generated by turbulence in the low photosphere may play a role in chromospheric heating, though with some important differences from the picture of the mid-1970's that was largely disproved by data from the OSO-8 mission (Anderson and Athay, 1989). In some cases, the heating may occur by shock dissipation of sound waves; in others, a more complex form of hydromagnetic wave may be involved. A facility to obtain visible and ultraviolet spectra and images of subarcsecond spatial resolution is needed to test these ideas, as well as to address many other important problems in solar physics that involve the small-scale structure of the surface magnetic field.

An effort has been underway in the United States for almost two decades to get such an observing facility constructed and launched into orbit. Now called the Orbiting Solar Laboratory (OSL), it is still uncertain whether this facility will be built by NASA in this century. It will be difficult to provide convincing solutions to many of the important problems described above without the kind of data this meter-class solar facility was designed to provide. Meanwhile, some of these problems may lend themselves to at least partial solution using data from existing and planned ground-based facilities, such as the two new solar telescopes that have recently gone on line in the Canary Islands (one German, the other Swedish), or the planned - but still unfunded - Large Earthbased Solar Telescope (LEST), a largely European project, but with substantial international participation.

Solar physics in space continues to be a dynamic, productive discipline, in which scientific progress has continued over the past three years toward a deeper understanding of several important solar, and even more general astrophysical, problems. The discipline continues to attract scientists from a worldwide community, and only the demands of brevity have limited this report to the major programs and scientific developments. Many other, smaller developments of high scientific potential are in progress around the globe. And while it is important to recall that some things are done best, or more economically, from the ground, much of the data needed in the future to solve the problems described herein will have to be collected in space.

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The SOHO Mission, 1989, EAS SP-1104, includes scientific papers by all experiment teams on planned scientific objectives.

9. Supernova 1987A in the Large Magellanic Cloud

George Sonneborn

1. INTRODUCTION

The explosion of SN 1987A in the Large Magellanic Cloud (LMC) on 23 February 1987 is one of the landmark events of Twentieth Century astronomy. Not only is it the brightest supernova in 383 years, it occurred at a time when advanced instruments and analysis techniques could be used to study the fleeting photons on the ground and in space. Indeed, SN 1987A has been observed at all wavelengths from γ rays to the radio.

Significantly, SN 1987A occurred in a nearby galaxy whose distance from Earth (50 kpc) is known to better precision most Galactic distances, in a direction with relatively low reddenning, near the South Ecliptic Pole (facilitating satellite observations) and in a stellar population which has been intensively studied in recent decades. All these factors have contributed to the success of SN 1987A observations from space and their subsequent analysis.

It may be difficult in 1990 to appreciate the confusion surrounding the unexpected optical properties of the supernova in the early days of the outburst. SN 1987A was several magnitudes fainter than expected, the supernova's light curve and colors evolved much faster than normal, the Balmer and Mg II resonance lines showed absorption extending to 30,000 km s^{-1}, whereas 15,000 km s^{-1} is typical for Type II supernovae, and finally, the progenitor appeared to be a luminous blue star, not a red supergiant normally associated with Type II events. We now know that these unusual properties are directly related to the progenitor being an early-type rather than a late-type star.

Observations from above the Earth's atmosphere have produced scientific results fundamentally advancing our understanding of SN 1987A, supernovae, and stellar evolution in general. These include:

- Identification of the progenitor star (Sk −69° 202) by demonstrating its absence from the supernova field at far ultraviolet wavelengths in March 1987.
- Spectroscopic evidence that Sk −69° 202 was in a post red-giant evolutionary phase at time of the explosion.
- Direct confirmation of the theory of stellar nucleosynthesis and the role of radioactivity in powering supernova light curves by measurements of γ-ray emission lines from short-lived radioactive nuclei synthesized in the explosion.
- The presence of large-scale "mixing" of nuclear processed core material into the hydrogen envelope, inferred from the very early appearance of X- and γ-rays, has thrust our understanding of explosion hydrodynamics to new levels of sophistication.
- Kinematics and abundances of radioactive nuclei in the ejecta have been determined from far-infrared emission lines at epochs when the ejecta was optically thick at longer wavelengths.

This short summary can only provide highlights of the extensive research from space in the last three years on SN 1987A. The general review articles by Arnett *et al.* (1989) and Imshennik and Nadezhin (1989) and the proceedings of the 1989 Santa Cruz Summer Workshop on supernovae (Woosley 1990), contain more thorough discussions and bibliographies.

2. HIGH ENERGY EMISSIONS: OBSERVATIONS OF GAMMA-RAYS AND X-RAYS

The search for γ-rays from SN 1987A began immediately, and were first detected by the NASA *Solar Maximum Mission* (*SMM*) satellite in August 1987 (Matz *et al.* 1988). In order to maintain spacecraft power and hence solar array orientation, *SMM* could not turn to observe the supernova directly. Instead, γ rays from SN 1987A were detected through the side of the spacecraft, resulting in a rather low sensitivity. Nevertheless, the Gamma Ray Spectrometer (GRS) "observed" SN 1987A almost continuously, with periodic interruptions from occultation of the LMC by the Earth. Unlike the balloon-borne instruments, *SMM* could integrate many weeks of data to improve detection limits. GRS detected the 847 keV line of ^{56}Co in data collected during the period 1 Aug. - 7 Sept. 1987.

The detection of γ-ray emission from radioactive ^{56}Co in SN 1987A is the first direct confirmation of the theory of stellar nucleosynthesis, the theoretical basis of which goes back two decades when Clayton *et al.* (1969) predicted that γ rays from radioactive ^{56}Co should be detectable in supernovae.

Several NASA-sponsored γ-ray instruments covering energies from 30 keV to 8 MeV were flown on high-altitude balloons launched from Alice Springs, Australia and one over Antarctica. The balloon campaigns carried payloads from (a) Lockheed-Palo Alto and NASA/Marshall Space Flight Center (29 Oct. 1987, Sandie *et al.* 1988), (b) California Institute of Technology (18 Nov. 1987, Cook, *et al.* 1988), (c) Jet Propulsion Laboratory (6 Dec. 1987, Mahoney *et al.* 1988), (d) Florida and NASA/Goddard Space Flight Center (8 Jan. 1988, launched from Antarctica, Rester *et al.* 1989), and (e) the Goddard-Bell-Scandia collaboration (2 May 1988, Barthelmy *et al.* 1988). Payloads (a), (c), and (d) obtained γ-ray spectra with high energy resolution ($E/\Delta E$ in the range $350 - 500$ near 1.2 MeV). Mahoney et al. (1988) find the ^{56}Co line at 1238 keV blue shifted by ~ 900 km s^{-1} with respect to the center of the explosion and a velocity dispersion (FWHM) of ~ 2000 km s^{-1}.

In early August 1987, X-ray emission from SN 1987A was discovered in the 20-300 keV energy range with the instruments on the *Kvant* module of the Soviet space station MIR (Sunyaev *et al.* 1987a,b) and at 4-30 keV by the Japanese satellite *Ginga* (Dotani *et al.* 1987). *Ginga* had been fortuitously launched in early February 1987 and began observing SN 1987A only two days after the explosion, establishing upper limits for soft X-ray emission. The *Kvant* instruments showed a modest ($\sim$ 30 percent) increase in hard X-ray flux over the next six months before going into decline by April 1988. The soft X-ray component grew slightly until early 1988 when it suddenly increased by a factor of 3-4 for a few weeks and then faded. By April 1989 the soft X-ray flux had returned essentially to zero.

From the first detection, the observed hard X-ray spectrum (>15 keV) was consistent with Compton-scattered γ-rays from the radioactive decay ^{56}Co. The strength and evolution of the unusually hard radiation agree well with radioactive model predictions which include substantial mixing of processed material from the core into the hydrogen envelope (e.g. Itoh *et al.* 1987; see also references in Arnett *et al.* 1989). However, the soft X-ray spectrum (<10 keV), assumed to be thermal in origin (e.g. Masai *et al.* 1987) was much brighter than models which best match the hard X-ray spectrum (Pinto and Woosley 1988).

3. ULTRAVIOLET OBSERVATIONS

Ultraviolet observations of SN 1987A with the *IUE* satellite began 14 hours after its discovery. The extensive *IUE* observing program for SN 1987A (>800 spectra obtained to date) has been a coordinated international effort led by R. Kirshner and N. Panagia. The *IUE* results have recently been reviewed by Kirshner and Gilmozzi (1989) and Gilmozzi (1990). The discussion here is limited to summarizing the most important findings. In addition to *IUE*, SN 1987A was also observed by the Soviet astrophysical station ASTRON (Boyarchuk *et al.* 1987) in early March 1987. There were also attempts to detect SN 1987A in the far UV (below 1200Å) with the Ultraviolet Spectrometer on the Voyager spacecraft; the supernova was not seen by Voyager due limited sensitivity and crowded field conditions in the LMC.

Early *IUE* spectra showed SN 1987A to be unlike any other supernova observed in the UV, Type I or II. The UV flux below 2000Å dropped by a factor of 1000 during the first few days, revealing the presence of two hot stars within arcseconds of the supernova's position. Longward of 2500Å the supernova's UV flux changed very slowly, following the initial drop, until late 1988 when it, too, took part in the exponential decline on a radioactivity time-scale. Nevertheless, the UV contribution to the bolometric luminosity has continued to grow, reaching $\sim$ 10 percent of the total in early 1990.

During the first few days of the outburst high-quality high resolution UV spectra were obtained. These data have permitted new studies of the ISM between the Sun and the LMC in far greater detail than possible with previous UV spectra (de Boer *et al.* 1987, Dupree *et al.* 1987, Blades *et al.* 1988, Savage *et al.* 1989).

The discovery of two hot stars (in addition to the supernova) in *IUE* spectra raised urgent questions about which star had actually exploded. Careful spatial analysis of *IUE* spectra (Gilmozzi *et al.* 1987, Sonneborn *et al.* 1987) showed that the early-type supergiant Sk $-69°$ 202 had disappeared. This was the first time that the progenitor of any supernova had been identified by name, clearing the way for computer modelling to understand way the star was blue, not red, at the time of its demise (see Arnett *et al.* 1989 and references therein).

In May 1987 a new aspect of the UV spectrum of SN 1987A was discovered: emission lines of N III], N IV], N V, O III], He II, and C III] (Wamsteker *et al.* 1987). Subsequent analysis of these lines (Fransson *et al.* 1989) showed that they are very narrow ($FWHM$ < 30 km s^{-1}), at rest with respect to the ISM in the LMC, and characteristic of a low density photoionized gas. A nebular analysis revealed that the N/O and N/C abundance ratios are 12 and 37 times solar, respectively, and $N_e \sim 3 \times 10^4 \mathrm{cm}^{-3}$. The line fluxes increased until May 1988 (Sonneborn *et al.* 1988, 1990) and have been decreasing slowly since that time. These properties imply the existence of a circumstellar shell of gas, $\sim$ 0.5 Ly from the supernova, which was photoionized by the intense EUV burst at shock breakout several hours after core collapse on 23 February 1987. The evolution of the line fluxes is consistent with a fluorescent light echo from such a shell. Very recently, narrow-band [O III] images taken with Faint Object Camera on the Hubble Space Telescope have detected an elliptical shell surrounding SN 1987A (Jakobsen *et al.* 1990), confirming many of the inferences drawn from the *IUE* spectra.

This shell probably originated as stellar wind mass loss during a red giant phase of the progenitor's history which was swept up into a shell by a high-velocity stellar wind during its blue supergiant phase in the ~10,000 years prior to the explosion. These observations are the principal line of evidence that the progenitor was in a post-red-giant stage of evolution when it exploded.

4. FAR-INFRARED OBSERVATIONS

SN 1987A was observed at far-infrared wavelengths during deployments of NASA's Kuiper Airborne Observatory (KAO) at roughly six-month intervals, starting in April 1987. Observations were obtained at wavelengths from 1.5 to 95 μm by several instrument teams.

Rank *et al.* (1988a,b) and Witteborn *et al.* (1989) obtained 2 – 13μm spectra. A photospheric continuum in April 1987 gave way to an emission line spectrum by Nov. 1987 ($\lambda/\Delta\lambda$ = 70). Higher resolution spectra from April 1988 ($\lambda/\Delta\lambda$ = 200) showed the Ni II 6.6 μm and Ar II 6.9 μm lines to have asymmetric profiles. They found that the average expansion velocity of the core to be $\sim$ 1400 km s^{-1}. The asymmetry of the lines was produced by electron scattering in the expanding hydrogen envelope. They derive a lower limit for the Ni II mass of 0.003 $M_\odot$.

Erickson *et al.* (1988) and Moseley *et al.* (1989) found the Fe II forbidden lines in the 16-30 μm spectral region to have FWHM $\sim$ 4000 km s^{-1} . The minimum iron mass was found to be 0.02 $M_{\odot}$, indicating that the emission originates in the heavy element mantle and not the H-rich envelope. The large line widths indicate that mixing of ejected iron with lighter elements in overlying layers has occurred.

Harvey *et al.* (1987) reported detections of SN 1987A at 47 μm and 95 μm. Later detections are important data points to establish the bolometric light curve of the supernova at late times.

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10. The Status of the Hipparcos Mission

M. A. C. Perryman

The difficulties faced by the Hipparcos mission in the early days after launch were extensively reported. The problems were due to the non-operation of the apogee boost motor, intended to place the satellite into its foreseen geostationary position. As a result, the satellite was trapped in an elliptical orbit, with a perigee of about 200 km (subsequently raised to about 500 km) and an apogee of about 36,000 km. The orbital period is about 10.6 hours, and twice per day the satellite passes through the Earth's particle radiation belts.

Some of the early concerns about the short expected mission lifetime have proved to be unfounded: measurements of the solar array degradation, which was originally expected to limit the lifetime, and a comparison with theoretical predictions, now suggest that a lifetime of about 3 years may be possible.

The months after launch involved considerable modifications to the satellite operations. Compared with the intended orbit (where relatively short earth occultations caused the only significant loss of useful observing time), the present orbit created considerable problems from the point of view of ground station coverage, radiation belt passages, perturbing torques and consequent attitude perturbations, and longer earth occultations and eclipses.

However, the satellite is now being tracked by four ground stations (Odenwald (D), Perth (AUS), Kourou (French Guiana) and Goldstone (USA)). The satellite is visible by one or other of the ground stations for 93 per cent of the time, and the fraction of useful observing time (after allowing for ground station losses, occultations, attitude initialisations, etc) is now around 60-70 per cent.

On-board the satellite, the payload and spacecraft sub-systems have worked extremely well: the detectors and the contributory error sources (instrumental response, chromaticty, focussing precision, thermal and geometric stability, attitude control, etc) have been typically well within their specified performance values. After a lengthier than nominal calibration and commissioning period, necessitated by the above difficulties, the nominal mission commenced on 26 November 1989. Between then and the end of May 1990, some 300 Gbits of data covering some 2 million stellar observations (including numerous minor planets, Uranus, Neptune, Titan and Europa) have been acquired.

Fortunately, it has been possible to retain the planned observing programme essentially without modification: the impact of the present operational conditions is basically to reduce the number of observations on a given star by some 30-40 per cent (slightly more for the Tycho experiment due to additional perturbing effects of the radiation background). The effect of this on the final expected astrometric accuracies is summarised below. The Input Catalogue, the basis of the star observing programme and satellite attitude control, has performed entirely nominally in all respects.

The present orbit resulted in certain difficulties in the data interfaces between ESOC and the data reduction teams. These difficulties have now been largely overcome, and the satellite data is now passing routinely through the critical elements of the data analysis chain, up to the great-circle reduction level. Data from 12 hours of observation (1Gbit of data covering some 2000 star observations) are now processed routinely by the FAST and NDAC Data Reduction Teams, to derive star abscissae on a great circle with a precision of 5-10 milli-arcsec. Instrument parameters are calibrated with sub-milli-arcsec precision, and are very stable. Comparison procedures, to verify the results obtained by the two processing teams, are progressing well.

Long-term accuracy predictions are now essentially dependent on the mission lifetime. If the mission survives for about 3 years at current performance levels, the original astrometric (and hence scientific) goals (2 milli-arcsec for positions, parallaxes and annual proper motions) should still be achievable.

In line with the expectations before launch, publication of a printed version of the Input Catalogue is expected early in 1991. Representing the definitive compilation of the 120,000 or so stars observed by the Hipparcos satellite, this Catalogue will contain the best available information on the present astrometric and photometric knowledge of the Hipparcos programme stars, and will include information on multiplicity, variability, catalogue cross-references, as well as finding charts for the fainter objects.

11. Results from COBE

M. G. Hauser

A. The COBE Mission

The Cosmic Background Explorer (COBE), NASA's first space mission devoted primarily to observational cosmology, was launched into a circular, 900 km altitude, near-polar orbit by a Delta rocket on Nov. 18, 1989. The satellite carries three scientific instruments: the Far Infrared Absolute Spectrophotometer (FIRAS), designed to make a precision measurement of the spectrum of the cosmic microwave background radiation (CMBR) from 1 cm to 100 micrometers wavelength; the Differential Microwave Radiometers (DMR), designed to measure the anisotropy of the CMBR on large angular scales at frequencies of 31.5, 53, and 90 GHz; and the Diffuse Infrared Background Experiment (DIRBE), designed to search for the cosmic infrared background radiation (CIBR) in 10 photometric bands from 1 to 300 micrometers wavelength. The objective in each experiment is to achieve adequate sensitivity and control of potential systematic errors to obtain definitive measurements of these important cosmological observables from the vantage point of a near-Earth observer. The instrument characteristics, orbit, and mission plan are described by Mather (1982) and more recently by Gulkis et al. (1990).

The FIRAS and DIRBE instruments are cryogenically cooled within a 600 liter superfluid helium dewar. This dewar is expected to maintain the instrument temperatures near 1.5 K for about 11 months. The 31.5 GHz DMR is operated near room temperature, and the higher frequency DMR channels are radiatively cooled to 140 K. These microwave radiometers have no consumable limiting their lifetime; two years of operation are planned, with a potential third year now under discussion. The satellite operates in a routine survey mode, providing highly redundant full sky mapping for all three experiments each 6 months. All instruments and the spacecraft have operated extremely well through the first six months, providing a high quality initial survey. Implications of all three experiments, based upon preliminary reduction of the data, are summarized by Mather et al. (1990b).

B. FIRAS results

The FIRAS experiment is designed to obtain a precision comparison of the CMBR spectrum with a Planckian spectrum, with an intensity accuracy in each spectral element of 0.1% of the peak brightness of a 2.7 K blackbody. The instrument, a polarizing Michelson interferometer, directly measures the difference between the sky signal from a 7-deg beam and that from a stable, temperature-controlled internal reference body. A precision temperature-controlled blackbody (emissivity greater than 0.999) is periodically inserted into the sky horn for absolute calibration. Adjustment of the internal temperature of critical parts of the instrument allows a near-null measurement, minimizing the magnitude of potential systematic errors.

The principal new scientific result in the early COBE data is the finding of a precisely Planckian CMBR spectrum from 1 cm to 500 micrometers wavelength toward the north galactic pole (Mather et al., 1990a). Over this spectral range there is no deviation as large as 1% of the peak brightness, dramatically supporting the prediction of the standard Big Bang model. The implied CMBR temperature is (2.735 ± 0.060) K, where 60 mK is the systematic uncertainty in the preliminary absolute calibration of the FIRAS temperature scale. In particular, there is no submillimeter wavelength deviation from a Planckian curve as previously reported (Matsumoto et al., 1988a). The conservative 1% brightness error limits on spectral distortions imply an upper limit on the Comptonization y parameter of 0.001 (3 σ) and on a dimensionless Bose-Einstein chemical potential μ of 0.01 (3 σ). The absence of a Compton distortion at this level rules out a smooth hot intergalactic medium as the source of the observed x-ray background. Careful analysis of additional FIRAS sky and calibration data should allow detection of spectral distortions of 0.1% or less of the peak brightness.

Study of the FIRAS spectra in other directions and at high frequencies has just begun. Partial sky maps of the total power detected by FIRAS clearly show galactic emission and the dipole anisotropy of the CMBR. The dipole anisotropy has a direction and temperature amplitude (3.3 ± 0.3 mK) consistent with previous results (Cheng et al., 1990). These data show that the difference in spectra between the poles of the dipole is that expected from two Doppler-shifted Planckians, and imply that the FIRAS instrument stability is better than a part in 5000 over long time scales. Preliminary fits to the spectrum of the galactic emission show that the ratio of galaxy to dipole reaches a minimum between 60 and 90 GHz (Wright et al., 1990).

C. DMR results

In order to obtain high sensitivity for detection of spatial anisotropies, each of the receivers of the DMR experiment measures the difference in sky brightness between two 7-degree beams oriented 60 degrees apart. Rotation of the COBE spacecraft at 0.8 rpm interchanges these beams on the sky to remove the effects of small instrumental asymmetries. Multiple observing frequencies were chosen to permit discrimination between the CMBR and local sources such as the Galaxy. The specific frequencies were chosen to separate best the CMBR from the emission by galactic dust and electrons. There are two independent receivers at each frequency for reliability and redundancy. The three pairs of receivers at 31.5, 53, and 90 GHz have noise levels respectively of 43, 42, 15, 16, 28, and 19 mK-sec$^{1/2}$. The experiment design is described by Smoot et al. (1990).

Initial full sky maps prepared from DMR data are dominated by the dipole anisotropy and expected galactic plane emission (Bennett et al., 1990). A preliminary determination of the amplitude and direction of the dipole, 3.3 ± 0.2 mK towards $(\alpha, \delta) = (11.2\text{h}\pm0.2\text{h}., -6^{\circ}\pm2^{\circ})$, is consistent with previously published results (reviewed by Wilkinson, 1986). Conservative upper limits to quadrupole or other large scale anisotropies are at the 10^{-4} level, approaching previously published limits (Fixsen et al., 1983; Lubin et al., 1985; Klypin et al., 1987). The noise level in the DMR maps continues to integrate down as observing time increases. Analysis is under way to obtain more sensitive limits or measure real anisotropies, which would provide the first direct evidence of primordial density fluctuations and large-scale mass clustering.

D. DIRBE results

The DIRBE instrument is a very stable, highly sensitive 10-band absolute photometer, which continuously compares the sky brightness in an 0.7 deg field-of-view with a zero-flux internal reference. A well-baffled, off-axis Gregorian telescope with a 19-cm diameter primary mirror and multiple field and pupil stops provides strong rejection of external off-axis radiation, and a full-beam cold shutter allows periodic measurement of small instrumental offsets. The sky brightness is measured at wavelengths of 1.2, 2.3, 3.4, 4.9, 12, 25, 60, 100, 150, and 240 micrometers, and linear polarization is measured at the three shortest wavelengths. The DIRBE instrument views the sky at 30 degrees from the spacecraft spin axis, thus obtaining redundantly sampled maps of half the sky every day at solar elongation angles ranging from 64 to 124 degrees. The broad spectral coverage, full sky coverage, and polarization capabilities are all designed to facilitate discrimination of solar system and galactic emission from an isotropic CIBR, the expected residual from luminous pregalactic, protogalactic, and early galactic objects.

Initial DIRBE sky maps show the dominant anticipated features of galactic starlight and zodiacal light at short wavelengths, and emission from the interplanetary and interstellar media at long wavelengths (Hauser et al., 1990). The faintest levels of these foreground emissions occur at 3.4 micrometers and longward of 100 micrometers, confirming these as the most sensitive spectral windows for the CIBR search. Careful modelling of the DIRBE data will permit discrimination of foreground sources from the CIBR and enable detailed astrophysical studies.

The preliminary DIRBE absolute sky brightness from 1-5 micrometers and from 100-240 micrometers is similar to that reported from previous rocket experiments (Matsumoto et al., 1988b; Matsumoto et al., 1988a). Comparison with IRAS data toward the ecliptic poles also shows general agreement, except at 100 micrometers where the DIRBE result is nearly 3 times fainter. Preliminary investigation suggests low-frequency gain and offset errors in the IRAS data at 60 and 100 micrometers.

E. Data products

Planned data products from the COBE mission, including calibrated maps and spectra as well as derived models, are described by White and Mather (1990). The products will facilitate both continuing cosmological studies and astrophysical studies of the solar system and Galaxy.

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