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The Hot Universe

The Hot Universe: An Overview

THE HOT UNIVERSE: AN OVERVIEW

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1. Introduction

The universe contains an extremely wide variety of temperature structures from 3K to 1 billion K and even beyond. This symposium focuses on the hot part of the universe. The "hot universe" is by far the best place to study high-energy astrophysics. In this overview, I shall be based mainly on the results in the X-ray band that best manifests the hot universe. However, needless to say that multi-wavelength investigations, from radio, infrared through gamma-rays, are essential for comprehensive understanding.

The universe consists of hierarchical structures. Regradless of their scales, we find hot objects wherever the gravitational potential is sufficiently deep. However, the observed phenomena and the physics are various, depending on the nature of the potential.

2. Extended Objects

2.1. CLUSTERS OF GALAXIES

Clusters of galaxies contain a huge amount of hot gas (intracluster medium: ICM), far exceeding the total stellar mass. This is a great discovery of X-ray astronomy. X-ray study of clusters has rapidly advanced with the Einstein Observatory and more recently ROSAT and ASCA. Observation of clusters provides crucial tests for the cosmological models. X-ray measurements allow determination of the total gas mass, and also, when hydrostatic equilibrium can be justified, the total gravitational mass that is dominated by dark matter. Thus obtained baryon fraction strongly suggests a low-Ω_0 universe. By observing clusters at various redshifts, we can study the cluster evolution. No obvious evolutionary effects observed after $z \sim 0.5$ also confronts $\Omega_0=1$ universe. Search for more distant clusters is clearly important.

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The ICM is polluted with a large amount of heavy elements believed to originate from early type galaxies. The recent ASCA results of abundances indicate a major contribution from type II supernovae in the early phase of galaxy evolution. Since clusters will retain most of the enriched material, study of the heavy element abundances allows "archaeology" of the history of nucleosynthesis in the universe.

2.2. GALAXIES

Hot halos are commonly present in early type galaxies, as established with the Einstein Observatory. The ASCA results on ellipticals invariably show low abundances of their hot gas, 0.3 to utmost 1 solar. This contradicts seriously the expected high abundances of 2–6. This discrepancy is not easily resolved, and clearly involves some fundamental problems.

Hot gas is not only in early type galaxies. There is increasing evidence for extensive hot gas in the host galaxies of AGN. Could it be related to the central activities? The case of our own Galaxy is suggestive of it. The presence of a 2.6 million $M_\odot$ black hole at our galactic center, though currently inactive, is quite convincing. We find $\sim 10^8$ K plasma as much as several thousand $M_\odot$ within $\sim$100 pc of the center, most probably produced in the past activities of the central black hole. History of its X-ray activities is recorded in the 6.4-keV iron fluorescence line from molecular clouds.

Yet unresolved thermal emission in the temperature range $3 \cdot 10^7 - 10^8$ K extends along the plane of our Galaxy. If it is diffuse emission as the recent ASCA results support, it presents real puzzles. The energy density of the plasma is more than an order of magnitude larger than in other modes, i.e. H I and H II gas, magnetic fields, or cosmic rays. Such a hot plasma cannot be gravitationally bound, therefore must be continuously replenished. The energy rate of the mass outflow is enormous, 10^{42-43} erg s^{-1}. What are the energy source and the production mechanism of such a plasma? Other spiral galaxies may also have such hot plasmas.

2.3. SUPERNOVAE AND SUPERNOVA REMNANTS

A wealth of observational results shows us extreme richness of supernova physics, but on the other hand enormous complexity. (1) A wide variety in morphology; shells, center-filled, and even high-speed shrapnels (Vela SNR). (2) Local abundance anomalies. (3) Non-thermal cases; pulsar-powered synchrotron nebulae, and in some SNR due probably to very efficient particle acceleration in the expanding shell. What causes such distinct varieties?

The nucleosynthesis products of type Ia and II supernovae are the key to understand chemical evolution of galaxies and the ICM. High-quality X-ray spectra of SNR have become available with ASCA. Yet, the abundance determination is not straightforward and still requires a breakthrough.

3. Compact Objects

3.1. ACTIVE GALACTIC NUCLEI

Convincing evidence for supermassive black holes in AGN has finally become available recently. Among others, the broadened iron line from Seyfert nuclei represents the relativistic effects of the direct vicinity of black holes. Finding the mass and spin of the black holes would be the next challenge.

X-ray results on Seyfert 2 galaxies lend strong support to the unified scheme of Seyferts in terms of the viewing angle with respect to a surrounding torus. Could this scheme be extended to QSOs? In fact, observations of some infrared-luminous yet X-ray faint galaxies have shown their intrinsic luminosities as high as a QSO. Many hidden-nucleus QSOs may well exist.

Recent discoveries of low-luminosity AGN in normal galaxies, much lower than typical Seyferts, and a supermassive black hole in our own Galaxy suggest a possibility that every normal galaxy hosts a supermassive black hole. Search for more low-luminosity AGN might find a link to the mystery, "where did QSOs go?".

The long debate on CXB is converging. The ROSAT deep survey shows no lack of sources to account for the CXB flux. The spectral paradox below 20 keV is resolved at least qualitatively. The remaining issue is the high-energy cut-off. While luminous QSOs tend not show a high-energy cut-off, most AGN must show a proper cut-off to form the observed CXB spectrum.

X-ray emission of AGN is powered by mass accretion, and probably comes from an accretion disk, much the same as X-ray binaries, except for Blazars. In fact, there are striking similarities in X-ray properties between AGN and black-hole binaries. Despite huge differences in mass and scale, the accretion phenomena in both systems seem to be essentially the same. The same is also true for relativistic jets. They are observed from both systems. Apart from these, we still need to understand what causes the distinction between radio-loud and radio-quiet AGN.

3.2. STELLAR-MASS BLACK HOLES, NEUTRON STARS, WHITE DWARFS AND STARS

Many black-holes have been discovered among X-ray binaries. So far, ten of them were established from the optical mass functions, giving a dynamical mass exceeding $3M_{\odot}$. In addition, the characteristic ultrasoft X-ray spectrum (in eight of the above ten) is most probably a black-hole signature.

Most black-hole sources are low-mass X-ray binaries, and remarkably all the low-mass black-hole binaries are transients. Transient outbursts occur frequently, and half as many have turned out to be black-hole binaries. RXTE and BeppoSAX will discover many more transients, hence we expect many more black holes. Transients are also valuable for studying accretion phenomena, since the accretion rate sweeps many orders of magnitude. The bizarre objects, such as the Rapid Burster, GRO J1744-28, happen to be transient sources. Is this merely accidental, or giving an important hint?

Are the relativistic jets a signature of black holes? We will know the answer from radio outbursts of future X-ray transients. Galactic transient jets are also precious for studying the condition for jet formation, because of closer distances, frequent occurrence, and short dynamical time scales.

An abrupt transition between a soft thermal and a hard power-law spectral state occurs regardless of whether the compact object is a weakly-magnetized neutron star or a black hole. This is a fundamental property of an accretion disk, and has been suspected as due to a radical change in the disk structure around a certain accretion rate. Yet another change occurs at a further low accretion rate below which sources are turned down to a quiescent state. Whether this is due to a choked flow or a transition into an advection-dominated disk is a subject of current debate.

Concerning short-time variabilities, the recently discovered kHz QPO strongly suggest fast spin of neutron stars in low-mass X-ray binaries.

Physics of neutron star interior is extremely important. Mass and radius of neutron stars that provide a strong constraint on the equation of state can in principle be obtained from X-ray bursts, since they occur on the neutron star surface. For instance, the absorption line at 4.1 keV observed in some bursts from several bursters is most probably a gravitationally redshifted atomic line. If the responsible element is identified, M/r is readily determined. It is worth emphasizing that the static nuclear force that determines the equation of state cannot be measured by ground-based experiments. Neutron star cooling is also an important probe of the interior.

White dwarfs and stars are also part of the hot universe. Among recent advances, I will mention three. (1) New method of mass estimation of white dwarfs from X-ray spectrum of cataclysmic variables, (2) the ROSAT discovery of many more T Tauri stars, and (3) the ASCA discovery of strong X-rays from pre-T Tauri protostars. These discoveries will bring a new scope to physics of star formation.

4. Still Higher Energies

The energy range above 100 keV is dominated by non-thermal processes. In addition to CGRO, RXTE and BeppoSAX, next-generation missions with still higher angular and/or spectral resolution in this energy range will discover new wonders of "superhot" universe.

Last but not least, the gamma-ray burst is still a most enigmatic phenomenon in the universe. Soft X-ray afterglow established with BeppoSAX allows follow-up observations to pin-point the source location. Identification of the optical counterpart is a real crucial step towards the goal of understanding the phenomenon.