JD9

Astrotomography

Chairpersons: M. Richards and L. Morales Rueda

Editors: A. Collier Cameron (Chief-Editor), A. Schwope and S. Vrielmann

Highlights of Astronomy, Vol. 13
International Astronomical Union, 2003
O. Engvold, ed.

Joint Discussion 9: Astrotomography

Andrew Collier Cameron

School of Physics and Astronomy, University of St Andrews,North Haugh, St Andrews, SCOTLAND KY16 9SS

Axel Schwope

Astrophysikalisches Institut Potsdam,An der Sternwarte 16, D-14482 Potsdam, GERMANY

Sonja Vrielmann

Hamburger Sternwarte, Universität Hamburg, Gojenbergsweg112, 21029 Hamburg, GERMANY

Abstract. Even in the new millenium, many astronomical objects cannot be resolved spatially with any available telescope. Most stars are too small and galaxies are too far away to be imaged directly or in detail in the foreseeable future. However, advances in data-analysis techniques allow us now to create detailed indirect images using tomographic methods. These images provide unprecedented insights into fundamental processes that drive the evolution of stars and galaxies, such as accretion and magnetic-field generation, on length scales that are of great physical importance but which are otherwise inaccessible.

Joint Discussion 09 was held on two half-days during the General Assembly. The main proceedings will be published in full in a special issue of *Astronomische Nachrichten*, to which the reader is referred, early in 2004. Here we give only a brief listing of subjects addressed and the titles of talks presented at the meeting.

2. Introductory talks and general principles

Astrotomography is a generic term for indirect mapping techniques that can be applied to a huge variety of astrophysical systems, ranging from planets via single stars and binaries to active galactic nuclei. These techniques use the temporal variability and velocity structure of continuum and line emission from astrophysical objects, to infer the spatial distribution of emitting material.

Astrotomography takes advantage of the fact that we can observe a rotating object from different angles, and exploit light travel-time effects across structures of finite size. A series of n-dimensional images of a full cycle can be fed into a computer in order to yield a$(n+1)$-dimensional picture of the object. These methods allow us to obtain for the first time micro-arcsecond resolution images of surfaces of accretion discs and stellar objects. Overview talks covering both the range of science that can be addressed with these techniques, and ways of maximizing the information return from a minimal set of observations, included:

Micro-arcsecond astrotomography (K. Horne)
Few-projections astrotomography (M. Agafonov)

3. Cataclysmic variables and X-ray binaries

Tomographic studies of cataclysmic variables (CVs) adopt four methodically different strategies to discern structure within the accretion disc, along the stream or on the surface of the white dwarf or the red dwarf star. The first, Eclipse Mapping, uses the cool secondary star as an occulting mask, to deduce the spectral emission of the accretion disc at various locations from spectrophotometric variations recorded as the eclipse proceeds. The second approach, Doppler Tomography, entails taking densely-sampled sequences of intermediate- to high-resolution spectra covering one or more full orbital cycles, in order to pin down the locations of individual emitting structures in velocity space. The third technique, Stokes Imaging, maps the cyclotron emission on the surface of the white dwarf by modeling polarimetric observation. Finally, Roche Tomography, models the emissivity on the surface of the red companion, similar to stellar surface mapping (see Section 3.).

Eclipse Mapping studies of CVs have verified the presence of accretion discs and streams, establishing models for the accretion physics. Doppler Tomography has revealed the location of accretion streams and the existence of tidally induced spiral shock waves in accretion discs. Stokes Imaging revealed the shape, size and location of the accretion spots on the white dwarf's surface. And finally, Roche Tomography confirmed thick disc rims shielding the donor star surface from irradiation by the hot inner disc. Talks given in this subject area included:

Eclipse mapping (R. Baptista)
Doppler tomography, including modulated tomography (D. Steeghs)
Roche tomography of CV secondaries (C. Watson)
Doppler mapping of CVs (L. Morales Rueda)
Indirect Imaging of polars (A. Schwope)
Stokes imaging of magnetic CVs (S. Potter)
Selected magnetic CVs (G. Tovmassian)
Mapping the accretion disk of Her X-1 (D. Leahy)
Tomography of X-ray binaries (S. Vrtilek)

4. Stellar surface imaging

Doppler tomography has been in use for two decades to discern the distributions of surface brightness, elemental abundances and magnetic polarities. In any star rotating fast enough that the rotational Doppler effect is the dominant line-broadening mechanism, surface inhomogeneities produce bump-like irregularities in the profiles of spectral lines. As the star rotates, these bumps migrate through the profile, following sinusoidal paths through a trailed spectrogram. The amplitude, phase and modulation of the sinusoid reveals the location of the feature on or (in the case of prominences and accretion streams) above the stellar surface.

The analysis of cool stars has revealed not only that their surface are covered with large cool spots but also with changing magnetic field patterns, and that both are affected by surface differential rotation similar to what we see on the Sun. Eclipse mapping and Doppler tomography of Algols has also provided

https://doi.org/10.1017/S1539299600015793 Published online by Cambridge University Press

detailed insights into the trajectories of the accretion streams, and their emitting properties. Topics covered by talks in this area included:

Stellar surface imaging, including magnetic imaging (G. Hussain)
Differential rotation of stars (P. Petit)
Eclipse mapping of Algols (G. Peters)
Doppler tomography of Algols (M. Richards)
Surface images of the short-period contact binary, AE Phe (J. R. Barnes)
Tomography of stellar non-radial pulsations (S. Berdyugina)
The atmosphere of V471 Tau (F. Walter)

5. Echo-mapping of active galactic nuclei, X-ray binaries and exoplanets

Echo mapping, or reverberation mapping, was developed to analyze the structure and velocity field of the microarcsecond-scale emission-line regions in active galactic nuclei or quasars via time delays between continuum and emission-line variations caused by reflection and re-processing of radiation. In both X-ray binaries and active galactic nuclei, a compact irradiating source varies in brightness on time scales that are short compared to the light-travel time across the region in which line-emitting gas responds to the variations in the central engine. By monitoring changes in both the brightness and velocity structure of emission lines formed in AGN and XRBs, it is possible to measure both the location and velocity field of the emitting gas. A related tomographic technique, used for searching for starlight reflected from extra-solar planets, relies on the orbital Doppler shift of the planet.

Echo-mapping is beginning to yield information on accretion-disc structure. To date, application of this technique has yielded sizes of the emission-line regions and demonstrated radial ionization stratification, and has led to measurements of the masses of the super-massive black holes that power these sources. The next generation of reverberation mapping experiments, using dedicated facilities, will resolve finer-scale structures, such as temperature-radius profiles, and settle definitively the origin of the emission-line gas and clarify how quasars are fueled. The three talks given on echo-mapping and related techniques were:

Echo mapping of active galactic nuclei (B. Peterson)
Echo mapping of X-ray binaries (K. Horne)
Tomographic studies of exoplanet atmospheres (A. Collier Cameron)