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Future Opportunities in Young Binary Star Research with Space Observatories

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Abstract. Ambitious infrared and astrometric space observatories are planned by both NASA and ESA for the first decade of the new millenium. I present a brief overview of their capabilities and suggest some of their likely contributions to research on young binary stars.

1. Introduction

During the past two decades space observatories have made major contributions to our knowledge of young stars. Catalogs of chromospherically active young stars are now more complete than ever before, thanks to X-ray studies with the EINSTEIN and ROSAT satellites. The properties of young stellar envelopes and disks were first revealed in the IRAS infrared sky survey, and have been further developed in studies with ISO. Parallax measurements from the Hipparcos mission have refined our knowledge of the distances to nearby star-forming regions and young clusters, thereby clarifying basic stellar parameters on the pre-main sequence. The high spatial resolution and stable point spread function of the Hubble Space Telescope (HST) have yielded the best images to date of young stellar systems, and have made subarcsecond resolved spectroscopy routine. Simply by paging through this volume, it is easy to see that the results of these and other space missions permeate the field of young binary star research.

Fortunately, both NASA and ESA have extensive plans for new missions that will continue to benefit our field. In the next few years new instrumentation will be installed on HST, a major new infrared observatory (SIRTF) will be launched, and a new all-sky astrometry survey mission will begin (FAME). Even more ambitious large aperture space telescopes and interferometers lie on the horizon toward the end of this decade. To make the most of the major investments these facilities represent, our community should carefully consider how they can be employed in our research. The following is a brief overview of what the new observatories will provide, and where additional information can be obtained.

2. Current Facilities

Chandra and XMM. Two powerful new X-ray observatories, NASA's AXAF/ Chandra and ESA's XMM/Newton, were launched in 1999 and their impact is just beginning to be felt. Both operate from highly elliptical Earth orbits for up to ten years. They represent significant advances in energy range, sensitivity, and

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spatial resolution over their predecessors. **Chandra** carries two instruments: ACIS, a CCD imager and spectrometer for 0.5–10 keV with a 16 ×16 arcmin field of view and spectral resolution R∼15–40; and the HRC, a microchannel plate wide-field (30×30 arcmin) imager for 0.1–10 keV with 16 μsec timing resolution. Both Chandra instruments provide a spatial resolution of 0.4–0.5″, nearly a tenfold improvement over any previous X-ray observatory, and making Chandra uniquely capable of resolving the stellar activity of individual components in young binaries. Chandra proposals are usually due in early June; see http://chandra.harvard.edu. **XMM**'s advantages are its sensitivity to higher energies, its higher spectral resolution, and the large combined collecting area of its three telescopes (in total more than 4 times that of any other X-ray mission, including Chandra). XMM carries three instruments: a CCD imaging camera (EPIC) with a (30×30 arcmin) field of view, 0.1–15 keV energy range, and R∼20–50; the Reflection Grating Spectrometer (RGS) with R∼200–800 over the energy range 0.35–2.5 keV; and the Optical Monitor (OM), a 30 cm telescope providing simultaneous 0.16–0.6 μm imaging. Both of the new observatories, and especially XMM, can be used to identify new members of young stellar populations through deep imaging surveys in molecular clouds and young clusters. XMM proposal information is available at http://xmm.vilspa.esa.es.

Hubble Space Telescope. Continuing opportunities are available for optical and ultraviolet imaging and spectroscopy with the HST. Proposals are usually accepted in early September. Observatory operations are currently planned to extend through 2010, with two more servicing missions taking place in 2001 and 2003. In addition to general upkeep on the spacecraft, these servicing missions will install new instrumentation that will expand HST's capabilities. The Advanced Camera for Surveys (ACS) includes a wide-field optical imager with fine 0.05″/pixel sampling over a $11.3^{\square}$ arcmin field of view. Employing two 2048×4096 CCDs, it will cover twice the sky area of the older WFPC2 camera and with 2–3 times the throughput. Once launched in late 2001, the ACS should become the instrument of choice for binarity surveys in young clusters. Also on the 2001 servicing mission, NASA will install a mechanical cooler to revive NICMOS, HST's near-infrared camera which ceased operations in late 1998 due to the premature exhaustion of its cryogen supply. NICMOS has proven to be useful for studies of the circumstellar matter of young binaries in cases where the lack of bright guidestars prevents adaptive optics imaging. It also accesses spectral features which are blocked by the terrestrial atmosphere, such as H_2O bands which can be used for T_{eff} determinations in substellar candidates. In 2003, a new far-ultraviolet spectrograph will be installed. Further details on all aspects of the HST mission can be found at http://www.stsci.edu.

3. Upcoming Infrared Space Observatories

Space InfraRed Telescope Facility. SIRTF is NASA's next large space observatory mission, launching in 2002 on a Delta rocket into a heliocentric Earth-trailing orbit. It is a pointed observatory featuring a 0.85 m cryogenic telescope and three science instruments. The InfraRed Array Camera (IRAC) provides 3.5–8.0 μm imaging over a 5×5 arcmin field of view using 256^2 InSb and

Si:As array detectors. The Multiband Imaging Photometer for SIRTF (MIPS) instrument provides broadband photometry and imaging over a 5×5 arcmin field of view using a 128^2 Si:As array at 24 μm, a 32^2 Ge:Ga array at 70 μm, and a 2×20 stressed Ge:Ga array at 160 μm. MIPS also includes a R$\sim$20 spectrophotometry mode covering 55 μm $< \lambda <$ 95 μm. SIRTF's InfraRed Spectrograph (IRS) provides R=600 spectroscopy between 10–37 μm, and long slit R=60–120 spectroscopy over 5.3–40.0 μm. SIRTF's point source sensitivity is projected to be nearly 100× better than IRAS and ISO: 2 μJy @ 4.5 μm, 8 μJy @ 8.0 μm, 0.1 mJy @ 24 μm, 0.6 mJy @ 70 μm, and 2 mJy @ 160 μm (all 1-σ in 100 sec). A major fraction of the data during the first year of operations will become immediately available to the astronomical community under the SIRTF Legacy Science Program. The first opportunity for small and moderate sized proposals will come in 2002; more than 70% of SIRTF time will be competitively awarded over the mission's 3–5 year lifetime. Studies of IR excess with SIRTF should fill in the "missing link" in disk evolution between T Tauri and debris disk systems, and identify the youngest, lowest mass protostars in molecular clouds. For additional details on SIRTF, visit http://sirtf.caltech.edu.

Far-InfraRed and Submillimeter Telescope. FIRST is an ESA "cornerstone" mission with NASA participation. It will launch on an Ariane 5 in 2007 to the Earth's anti-Sun Lagrange point L2. The observatory consists of a 3.5 meter diameter antenna passively cooled to 80 K and a cryostat enclosing three instruments in a superfluid He bath. The projected mission lifetime is at least three years. FIRST's PACS instrument will offer broadband photometry and R=1500–2000 spectroscopy using 16×25 Ge:Ga photoconductor arrays over λ = 60–210 μm. The SPIRE instrument includes bolometer arrays for simultaneous imaging at 250 μm, 350 μm, and 500 μm over a 4×8 arcmin field of view, and a Fourier transform spectrometer covering the 200–670 μm band. Very high resolution heterodyne spectroscopy is provided by the HIFI instrument in three bands over 480–2700 GHz. Expected point source sensitivities are about 5 mJy (5σ in 1 hour) using PACS and SPIRE for broadband photometry. FIRST will conduct pointed observations of specific targets and will be open to proposals from the general astronomical community. FIRST's spatial resolution (4–35″ FWHM over 60–500 μm) is best suited for mapping of molecular clouds and young clusters. It should produce spectacular results on the chemistry and kinematics of molecular cores, circumstellar envelopes, and disks. More information on the FIRST missiion is available at http://astro.estec.esa.nl/First.

Next Generation Space Telescope. NGST is a joint US/Europe/Canada development of an 8 meter class telescope for near- and mid-infrared wavelengths. Current plans are for a segmented primary mirror passively cooled to T $<$ 50 K and diffraction limited at $\lambda = 2\,\mu$m. The telescope would be launched in 2009 into an L2 orbit (beyond the reach of shuttle servicing), and designed for a 5–10 year lifetime. This mission concept has significant technical and fiscal issues which are under study. Like HST, the mission science focus is on cosmology. Requirements from a range of astronomical disciplines were also considered in a process which recently identified the instruments to be provided for the observatory. These are a 0.6–5 μm camera with a 4×4 arcmin field of view and 0.03″ pixels; a 1–5 μm multi-object dispersive spectrograph with R$\sim$1000; and a

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5–28 μm camera and slit spectrograph with a 2×2 arcmin field of view. Unfortunately, no coronagraphic capability is planned. The spatial resolution achieved by NGST would be comparable to that of HST or large groundbased telescopes. Its great advantage is the sensitivity it could achieve in the low-background space environment: in a three hour exposure, point sources of 3 nanoJy and 0.1 μJy will be detected at S/N=10 at wavelengths of 2 μm and 10 μm, respectively. This would enable studies of the lower IMF in star-forming regions throughout the Milky Way and its companions, and studies of the composition and distribution of dust in a wide range of protostellar environments. Further details on NGST are available at http://www.ngst.stsci.edu.

4. Upcoming Space Astrometry Missions

Full-sky Astrometric Mapping Explorer. FAME is a recently approved NASA medium explorer ("MidEx") mission planned for launch in mid-2004. Similar to German DIVA mission concept, FAME will survey the sky and measure the position, parallax, proper motion, and brightness (in four Sloan optical bands) of $\approx$ 40 million stars of V<15. FAME will operate from a geosynchronous orbit and make its measurements using large-format CCDs. Like Hipparcos, FAME will produce a massive star catalog at the end of its 3–5 year mission. However, the FAME catalog will go 4 mag deeper than Hipparcos could and will have an astrometric precision 20× better: 50 μas at V=9. This catalog will include most of the T Tauri stars associated with nearby (d<200 pc) molecular clouds. FAME's results should improve our understanding of pre-main sequence evolutionary tracks, the depth of star-forming regions and young clusters along the line of sight, and the kinematics of post T Tauri stars; and should identify new, nearby young stellar groups such as TW Hydrae. The address of the FAME website is http://aa.usno.navy.mil/FAME.

Space Interferometer Mission. SIM is a NASA astrometry mission study which has been strongly recommended for flight by the US astronomical community. It is a 10 meter baseline, fixed-boom optical interferometer with several 0.3 m siderostats. It is a pointed observatory - not a sky survey - and would be launched into an Earth trailing orbit not earlier than 2008. A 5 year mission lifetime is planned. The projected capabilities (V$\leq$20) are wide-angle absolute astrometry to 4 μas accuracy at the end of mission, and narrow-angle ($< 1°$) relative astrometry to 1 μas accuracy. The mission will demonstrate 0.01$''$ space aperture synthesis imaging and interferometric nulling as a pathfinder for the eventual Terrestrial Planet Finder (TPF) mission. Astrometric detection of terrestrial planets in the solar neighborhood is a major science goal for SIM. SIM should be able to detect the astrometric signature of major Jovian planets associated with the nearest T Tauri stars; resolve the orbits of nearby young spectroscopic binaries, thereby removing inclination uncertainties from their mass determinations; and essentially remove the effect of distance uncertainties on our knowledge of pre-main sequence stellar masses. More than half the mission observing time will be devoted to large key projects that were solicited during 2000; most of the remaining time will be allocated to the community in subsequent calls for proposals. Updates on the mission and further details can be found at http://sim.jpl.nasa.gov.