Present and Past Space Programs

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Introduction :

The increase in accuracy of astrometric results has been very limited in the last half century, and improvements of more than about a factor of 3 at best for ground-based observations are not expected for the next two decades. This is largely due to well known error-sources connected with the Earth atmosphere. By moving the observing equipment to a platform aboard a satellite many of these errors would disappear completely,or to a large extent. Unfortunately till now no space astrometric project has been realised. Consequently there are no astrometric observations of visual binary stars from space. Of course, the astrophysical parameters of double stars are as important as their astrometric data. A large number of double stars has been observed from space by measuring their radiation and spectra in different wavelengths regions not attainable from ground based telescopes. A good example is HZ Hercules (Her X-1).

Binary X-Ray Sources :

The binary nature of Her X-1 was discovered in 1971 by a group headed by R. Giacconi who observed repeating eclipses of its X-radiation with the UHURU satellite. The source of the X-rays is a neutron star. Cygnus X-1 is another binary system which is a strong source of X-rays. In this system the X-ray component is probably a black hole. At present, the main and perhaps only hope for finding black holes seems to lie in their possible occurrence in binary star systems.

At the moment several hundreds of strong galactic X-ray sources are known, which can be divided into various subclasses. It is highly probable that these objects are binaries containing a mass accreting X-ray emitting compact star, a neutron star or a black hole. These strong sources can be divided into a group with relatively hard spectra and a group with softer spectra. The same division into two subclasses is found in transients, where the outbursts are probably caused when from time to time the non-compact object exceeds its Roche volume. The hard sources have an X-ray emission of 10 to 100 times less than the

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soft sources, they have strong magnetic fields and for several of these hard sources the compact object is a pulsar. The hard sources are canonical binaries whereas the soft sources probably became binaries by capture.

Transient X-ray sources have been the subject of many studies with several satellites, including UHURU, OSO 7, ARIEL 5, SAS 3 and OSO 8. It is often proposed that these sources are accreting compact stars in binary systems. It has been possible to test conclusively the validity of the binary hypotheses. Orbital periods of approx. 8d and 20d have been suggested for two of the transient sources.

Recently the "hard" transient X-ray source 4U 0115+63 was observed to undergo a new outburst. Shortly thereafter, 3.6 s X-ray pulsations were observed, and precise positional determinations led to a probable indetification with a heavily reddened early-type star. The discovery of short-period X-ray pulses from a transient source presented a unique opportunity to determine a precise binary orbit for a system of this type. The X-ray star in 4U 0115+63 is a member of a binary stellar system that is wider than any other known X-ray binary. Some evidence has previously been presented that other spectrally "hard" X-ray transients are members of binary systems. In view of the present results it now appears almost certain that all of these sources are binaries. The object 4U 0115+63 is the sixth X-ray pulsar for which the orbital elements have been determined by measurements of the variations of pulse period or pulse arrival time, (Rappaport et al. 1978). The values of the projected semimajor axes ($a_x \sin i$) and Eccentricities (e) of the orbits of these six sources are given in table; 4U 0115+63 has the largest values of both parameters among these sources. This finding may lead to an understanding of the transient character of this star and the other hard X-ray transients.

Source	$a_x \sin i$ (lt-s)	$P(orb)$ (d)	$f(M)$ ($M_\odot$)	e
Her X-1	13.19±0.03	1.700	0.85	0.003
Cen X-3	39.73±0.03	2.087	15.5	0.0008
4U 1538-52	55.2 ±7	3.730	13	.....
SMC X-1	53.46±0.05	3.892	10.3	0.0007
4U 0900-40	111.40±3.3	8.966	18.5	0.13
4U 0115+63	140.13±0.2	24.31	5.00	0.3402

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Any close binary system in which matter is accreted either by a main sequence star or by a more compact object, i.e. a white dwarf or neutron star, is a potential source of EUV-XUV emission. The expected luminosity is primarily determined by the rate of matter transfer. Virtually any of the numerous close binary systems in the solar neighbourhood could, therefore, be a potential EUV-XUV source.

Binary Stars in Ultraviolet :

A large number of close binaries has been observed with IUE. Dwarf binaries of the W Ursae Majoris type offer the opportunity to investigate the presence and structure of stellar chromospheres and coronae in contact systems, to assess the influence of rotation upon the atmospheric characteristics and to search for mass motions within the system. IUE spectra of these systems show a strong emission line spectrum. Quiescent surface fluxes of emission lines are among the largest found to date in late-type stars.

High-dispersion ultraviolet spectra of Plaskett´s star (the most massive binary known) were obtained with IUE. Profiles of the wind-lines were then extracted and studied with the purpose of investigating phase-effects of mass exchange and mass loss. The strong wind lines show a phase dependent structure, possibly attributable to mass streams between the secondary and primary.

Also many symbiotic variables have been observed with IUE. They display an emission line spectrum with contributions from different ions. The continua are stellar in appearance, which confirm the existence of hot companions, lending support to the binary hypothesis for the symbiotic stars.

IUE observations have been used to help clarify the nature of the secondary in the variable stars involving a red giant or supergiant and a hot secondary. For example W Cep, o Cet, CH Cyg, AR Mon, BL Tel, BX Mon, TV Gem and others.

IUE observations of R Aqr (M7 + pec) have been obtained in low dispersion in order to study its circumstellar emission, (Hobbs et al. 1980). Strong permitted, semi-forbidden and forbidden emission lines are identified that are superimposed on a bright ultraviolet continuum. The strong emission line spectrum arises from a dense compact nebula the size of which is comparable to the binary system of which R Aqr is the primary star. Low excitation emission lines for Fe II, Mg II, O I and Si II suggest the presence of a warm chromosphere (T = 10.000 K) in the primary M7 late type giant. The secondary is a white dwarf

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comparable to or somewhat brighter than the sun, since a star can produce enough ionizing photons to excite the continuum and emission line spectrum, and yet be sufficiently faint as to escape detection by direct observation.

Also the IUE observations of the late type star RW Hya suggest that this star is a binary system in which the secondary is identified as a star of a central planetary nebulae with $T_{eff} = 10^5$ K. The general absence of strong forbidden line emission suggests that the compact dense nebula in which both primary and secondary stars are embedded has particularly high densities 10^8 to 10^9 cm^{-3}. Tidal interaction rather than steady state mass flow from the M giant is suggested as a means to form a nebula with the characteristic density inferred from the UV spectral line analysis. RW Hya is suggested as possible source of soft X-ray emission if material is accreting onto the surface of the secondary.

New binary stars have been discovered with IUE. The Ba II stars ζ Cap and ζ Cyg have a white dwarf companion.

IUE observations of the class of explosive stars known as cataclysmic variables including classical novae, dwarf novae, and related eruptive stars such as symbiotic variables have been carried out recently. Novae are interacting binaries containing an accreting white dwarf and main sequence type companion. Symbiotics are generally thought to be binaries containing M giants as companions to accreting main sequence, helium or white dwarf stars. The X-ray novae like A0620 are a closely related class probably involving neutron star or black hole binary accretors. Accretion discs are a natural consequence of mass transfer in these binaries.

Finally two visual binaries, Sirius and Antares, have been extensively observed from space. In the last years X-ray emission was detected from the Sirius system. It is not known whether the X-rays come from Sirius A or from the white dwarf Sirius B. No convincing explanation for this emission can be given so far, although Shipman suggested that a pure hydrogen atmosphere with T_{eff} = 32.000 K would have a very low absorption coefficient in the X-ray region. At this temperature the X-rays emitted from the deeper layers are consistent with X-ray observations. At lower temperatures the X-ray flux is insufficient.

A spectrum of Sirius B taken with the IUE satellite (Böhm-Vitense et al. 1979) shows an absolute flux and spectral energy distribution in the continuum in agreement with theoretical white dwarf models with T_{eff} = 26.000K $\pm$ 1000 K for log g = 8.65 and R = 5.08 x 10^8 cm. The L_α profile is also in agreement with these parameters. No emission lines in the spectrum of Sirius B or A are visible which could indicate the presence of a chromosphere or corona in either of the stars. The question where the X-rays come from remains still open.

The visual binary α Scorpii, Antares, is one of a handful of known M type supergiants with a hot companion serving as a convenient probe for the remote parts of their circumstellar envelopes. All these stars are important for our understanding of the evolution of massive stars because they belong to the group of most luminous cool stars and may provide information about the structure and mass loss of fairly evolved stars and the relation between these stars and the interstellar medium.

The system of Antares comprises a first magnitude supergiant M type star and a fifth magnitude dwarf B type star with a separation of 2"9. This corresponds to a projected separation of 522 AU if one adopts a distance of 180 pc to the system. It has always been assumed that Antares is a physical pair, since the components have a common proper motion. Because of the large separation, it can safely be assumed that the components evolved as single stars.

Antares shows systematic asymmetries of lines, especially in the H, K, and D lines. They suggest that the origin may be an envelope around the star expanding with moderate velocity. The enormous extent of the envelope around α^1 Sco has recently again been observed by Swings and Preston (1978) who measured envelope emission lines to a distance of about 10" from the M star corresponding to 1870 AU. Circumstellar absorption lines superposed on the optical spectrum of the M star show blue shifts of -17 to -18 km/s. At the distance of α^2 Sco from the primary this observed expansion velocity exceeds the local escape velocity. Apparently the M star is loosing mass to the interstellar medium via a low velocity wind.

K.A. van der Hucht et al. (1980) have carried out spectroscopic observations of Antares with the Balloon-borne Ultraviolet Stellar Spectrometer which is composed of a 40 cm telescope with an echelle spectrograph. They have derived a mass loss rate of $7.1 \times 10^{-6}\ M_\odot\ yr^{-1}$. With a stellar mass of the order of 8 $M_\odot$ and considering the large uncertainty of the lifetime of the red supergiant phase it is obvious that, if the mass loss of Antares remains constant over its red supergiant phase, the total mass lost during this phase may be of the same order of magnitude as its present mass. Hence, mass loss may be a very important parameter in the evolution of Antares; whether it will ultimately evolve into a white dwarf or into a supernova will depend on its ability to shed mass

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so as to reach the Chandrasekhar limit prior to the exhaustion of its nuclear energy sources.

The astrophysical investigations of double stars from space hav been extremly fruitful and will continue in the future. We instantly hope that HIPPARCOS will finally introduce astrometry into space age, too.

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DISCUSSION

HARRINGTON: Is the expansion envelope around Antares A related to its binary nature, or independent of it? Are there other cases of such envelopes?

RAKOS: This is a binary system, but there is probably no exchange of mass during the red stage. The red giant is losing mass at 7 x 10^{-6} solar masses per year, which means that during the red stage the mass loss will be as high as the total mass of the M-star. We do not know many supergiants with such high mass loss. We can study the mass loss because we have a control in B, since we can see the absorption lines in the spectrum of Antares B.

KREIDL: There are two other cases where large circumstellar envelopes have been detected. One is 119 Tauri, which has a hydrogen envelope at least twice the normal diameter of the star. The other is Alpha Orionis, which speckle work has recently revealed has an envelope between 5 and 10 times the radius of the star. Both cases have asymmetric hydrogen-alpha lines observed, with shifts on the order of 10 km/sec. There is no direct measure of mass loss for either of these stars, but I assume we are dealing with similar such cases.

RAKOS: The special case of Antares A is that we have a B star and we can see that the lines are shifted to the blue, that we have a stellar ring and actual mass loss.

MAZEH: Concerning Cygnus-X1 as a system containing a black hole, there were several papers that tried to avoid the black hole assumption by assuming a triple system. Can you comment on that?

RAKOS: All these problems are awaiting Space Telescope . The literature is very extensive, and it is impossible to discuss these special problems here.

MAZEH: Another X-ray source that would be interesting to the astrometric people is X-Persei which probably has a very wide orbit of 580 days. The present or near future instrumentation might be able to detect its orbit.

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