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FINAL TECHNICAL REPORT FOR NAG 5-2991

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Final Technical Report for NAG 5-2991

"EUVE Spectroscopy of the Accretion Region in AM Herculis"

Frederik Paerels, Principal Investigator

The project funded under NAG 5-2991, "EUVE Spectroscopy of the Accretion Region in AM Herculis," set out to determine the gravitational energy conversion balance in accreting magnetic white dwarf stars.

The approach was to obtain detailed photospheric spectra of the white dwarf stars in the brightest magnetic cataclysmic binaries, in the region where most of the energy is radiated by the stellar atmosphere- that is, in the extreme ultraviolet band. The spectrometers on board the Extreme Ultraviolet Explorer (EUVE) were used to obtain a well-resolved stellar spectrum in the 70–120 Angstrom band of the brightest two magnetic CV's, AM Herculis and EF Eridani.

Even though these two binaries are the brightest members of their class, they are fairly faint sources, so the two 100,000 sec exposures also contain a lot of background. Data analysis procedures were therefore developed to perform the background subtraction as accurately as possible, with the aim of preserving as much sensitivity as possible near the lower wavelength cutoff (70 Angstrom) imposed by the edge of the EUVE Short Wavelength Spectrograph detector. Also, since the emission is modulated by the binary period (equal to the rotation period of the white dwarf in these objects), we phase-folded all the photons, and split the spectrum into four orbital phase bins.

These spectra were obtained early on in the EUVE mission, and the spectra were therefore not 'dithered.' That is, the spectra were obtained with steady pointing, which means that photons of a given wavelength always land on the same part of the detector. The monochromatic flux density detected is therefore modulated by whatever uncorrected spatial efficiency variations exist in the detector.

In the case of the EUVE microchannel plate detectors, this modulation is unfortunately fairly strong. Laboratory flat field images show that the efficiency appears spatially modulated on scales on the order of 10 pixels, with a fairly distinct spatial period and phase coherence. The effect is evidently inherent in the manufacturing process of the channel plates, which tends to produce a spatial modulation in the physical size of the channels, which shows up as an apparent spatial efficiency modulation under uniform illumination. Since any of the apparent features we detected in the source spectrum could be due to this detector effect, we spent a fair amount of effort trying to correct for it.

The simplest correction, namely, dividing by a laboratory flat field image, was not possible, because such a flat field image for the region of the detector our spectrum was projected onto does not exist. There are no known bright extended EUVE sources we could have tried to use to obtain a flat field in flight, so we were forced to attempt to model the effect.

We therefore calculated the spatial Fourier transform, and looked for peaks in the spatial power density spectrum near the periods expected. There is definite evidence for excess power in the period range around 10-15 pixels, but we are evidently seeing the superposition of a number of sine waves with slightly different periods and phases. We tried fitting for the amplitude, period, and phase of a discrete set of sine waves in this period region, but found that the process does not converge very well, and so we were not able to find a unique and robust Fourier filtering correction to the measured spectrum. We simply noted the wavelength positions of any features that did seem to sensitive to our attempts to 'correct' the spectrum, and marked those as possibly as of instrumental origin.

With the above limitation on the spectrophotometric reliability of the spectrometer in mind, we searched the spectrum for evidence of absorption features. Here, we imposed a spectroscopic consistency criterion: if a feature appeared to line up with a listed transition in any ion, we required the presence of features one should expect at wavelengths coinciding with other transitions in the same ion. Our search turned up evidence for absorption features due to two high ionization stages of Neon in the spectrum of AM Herculis, and a single ionization stage each of Neon, Oxygen, and Magnesium in EF Eridani.

The quantitative interpretation of these spectra requires a comparison with spectra calculated from model stellar atmospheres, which include the effects of radiative heating by X-rays emitted by hot gas behind the accretion stream. But even at this stage, a qualitative assessment of the spectrum can be made.

In AM Her, we see the simultaneous appearance of two non-adjacent ionization stages of Neon. This would indicate a wider range of ionization leaving strong absorption features in the spectrum than is the case for a 'passive' atmosphere that radiatively conducts heat from the interior. With an additional source of ionizing radiation irradiating the atmosphere, the temperature gradient in the atmosphere is expected to be flatter, and the spectrum is expcetd to exhibit a wider range of ionization. This would indicate that in AM Herculis, the bulk of the accretion energy is indeed radiated away under optically thin conditions, behind the accretion shock outside the stellar atmosphere. Half the resulting hard X-ray flux is reprocessed in the atmosphere directly below the accretion shock, giving rise to the observed intense soft X-ray/EUV radiation. This is the 'classic polar' picture, and it appears to apply to AM Her. Note that this inference does not involve any comparisons between hard and soft X-ray fluxes, with their inevitably large and poorly constrained bolometric corrections. A remaining puzzle is why we do not observe features due to highly ionized Oxygen in the spectrum, this element being more abundant than Neon. The observable band contains strong features from lithium-like Oxygen, with ionization potential comparable to the ionization stages of Neon that we did detect. This is not likely to be an abundance effect, because we know Oxygen is present in the accreting material (it shows up in optical and FUV emission line spectra of AM Her).

EF Eri, on the other hand, shows a spectrum that is qualitatively different. We see only a single ionization stage of Oxygen, Neon, and Magnesium, and there is evidence that the Ne VI ground state absorption edge at 78 Angstrom is very deep. That would be consistent with the qualitative appearance of the spectrum of a 'passive' atmosphere with no external irradiation. EF Eri may therefore be an example of a 'blob accreting polar', where the bulk of the accretion energy is contained in kinetic energy of dense blobs that is dissipated at large depths in the atmosphere – deep enough that the structure of the X-ray/EUV photosphere is not perturbed.

Publications:

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