TIME-RESOLVED OPTICAL SPECTROSCOPY OF AM HER X-RAY SOURCES

M. MOUCHET[1], S.F. VAN AMERONGEN[2], J.M. BONNET-BIDAUD[3] and J.P. OSBORNE[4]

[1]Observatoire de Meudon, France

[2]Astronomical Institute, University of Amsterdam, Netherlands

[3]Service d'Astrophysique, C.E.N. Saclay, France

[4]EXOSAT Observatory, ESOC, Darmstadt, F.R.G.

ABSTRACT

We present high-time resolution spectroscopy of two AM Her sources E1405-451 and E1013-477. For E1405-451, the Balmer emission lines profiles can be divided into a narrow component and a broad one. The amplitudes of the radial velocity curves of these components are respectively 265±30 km/s and 390±50 km/s. The orientation of the column determined from polarimetry is not compatible with the broad component being formed in the lowest parts of the column. Photometric and spectroscopic results on E1013-477 do not confirm the previous reported 103 min. period. Rapid variability (<1.5h) as well as long term modulation (>3.3h) is present in these data.

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INTRODUCTION

AM Her sources (polars) consist of a magnetic white dwarf accreting matter from a low mass late type companion (secondary). The flow near the white dwarf is determined by the magnetic field and the matter is funneled onto the magnetic pole(s),emitting X-ray radiation. The rotation is synchronised with the orbital motion. Optical spectroscopic studies of the objects have revealed strong emission lines with rather complex structures. They essentially exhibit a narrow component usually associated with the secondary and a broad one formed in the accretion column. Measurements of the radial velocities can in principle allow the determination of the site of the emitting region and the geometry of the column. A review of these objects is given in Liebert and Stockman (1985).

We present here detailed high-time resolution spectroscopy of two X-ray sources: E1405-451 for which previous studies have revealed its magnetic nature, and E1013-477 suggested to be a polar candidate object, on which only scarce information is as yet available.

OBSERVATIONS

Optical spectra were obtained at ESO (La Silla, Chile) on March 29 and 30 1984 using the Boller and Chivens spectrograph and the Image Dissector Scanner mounted on the 3.6m telescope. On March 29, long series of consecutive spectra covering the wavelength range from 4000A to 7900A were obtained at a dispersion of 224 A/mm (19A FWHM resolution), with integration times of 20s and 1 minute respectively for E1405-451 and E1013-477. More than two orbital periods were covered for both objects. On March 30, 20 spectra of E1013-477 (12 for E1405-451) of 10 min. (resp. 1 min.) were taken at a dispersion

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of 114 A/mm (9A FWHM resolution) covering the range 4300A-6700A. Data were corrected for sky contribution and photometrically calibrated with an accuracy of 15%. The absolute wavelength calibration was achieved with an accuracy of 50 km/s at H_α on March 29, respectively 25 km/s on March 30. Relative radial velocity measurements are accurate to within 35 km/s on March 29 and 15 km/s on March 30 near H_α after correction for drifts during the observation.

E1405-451

This soft X-ray source was identified with a 15 mag. blue object and suggested to be an AM Her source with an orbital period of 101 minutes (Jensen et al.,1982 ,Mason et al.,1983a). This was confirmed from several optical polarisation studies, leading to somewhat discrepant evaluations of the magnetic field value and of the geometrical parameters (inclination angle i, colatitude angle d) (Tuohy et al.,1985, Cropper et al.,1986, Wickramasinghe and Meggitt,1985). This source was observed during two brightness states, allowing a determination of the temperature and size of the two stars (Maraschi et al.,1984a). Extended Exosat observations have shown that the X-ray light is variable on a timescale of months (Bonnet-Bidaud et al.,1985, Osborne et al.,1986, Bonnet-Bidaud et al.,1986).

Orbital modulation of the optical spectrum

The mean optical spectrum of E1405-451, obtained during a high state, exhibits similar features (strong Balmer and helium lines) as already observed by Mason et al.(1983a) and Maraschi et al.(1984a).

The continuum flux measured on individual spectra in 50A or 100A wide line-free regions is plotted against time in Fig.1. The orbital light curve shows an intermediate profile between the

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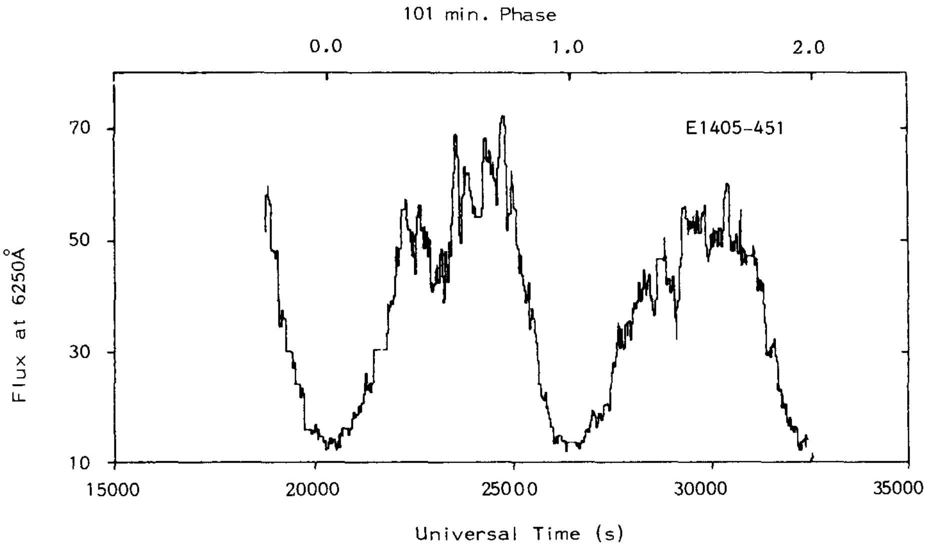

Figure 1 - Continuum at 6250A versus time measured on the 460 individual spectra obtained on March 29 with a 20 sec exposure time.

double-peaked and the sawtooth-shaped ones observed by Cropper et al.(1986). The spectral variations with the orbital phase is illustrated in Fig.2, which shows the average spectra around phases 0.45 and 0.95 (Phase 0 refers to the photometric minimum and is given by the following ephemeris: HJD = 2445141.9970 (±2) + 0.070497312 (±51) day (Mouchet et al.,1986)). The amplitude of the orbital modulation clearly varies with wavelength, being the largest around 5500A. The change of the shape of the continuum, also seen from photometric data, have been tentatively explained in terms of relative amount of cyclotron radiation compared with other components during the orbital cycle (Cropper et al., 1986, Mouchet et al.,1986). Wickramasinghe and Meggitt(1985) have derived the physical and geometrical parameters of the region giving rise to this cyclotron radiation.

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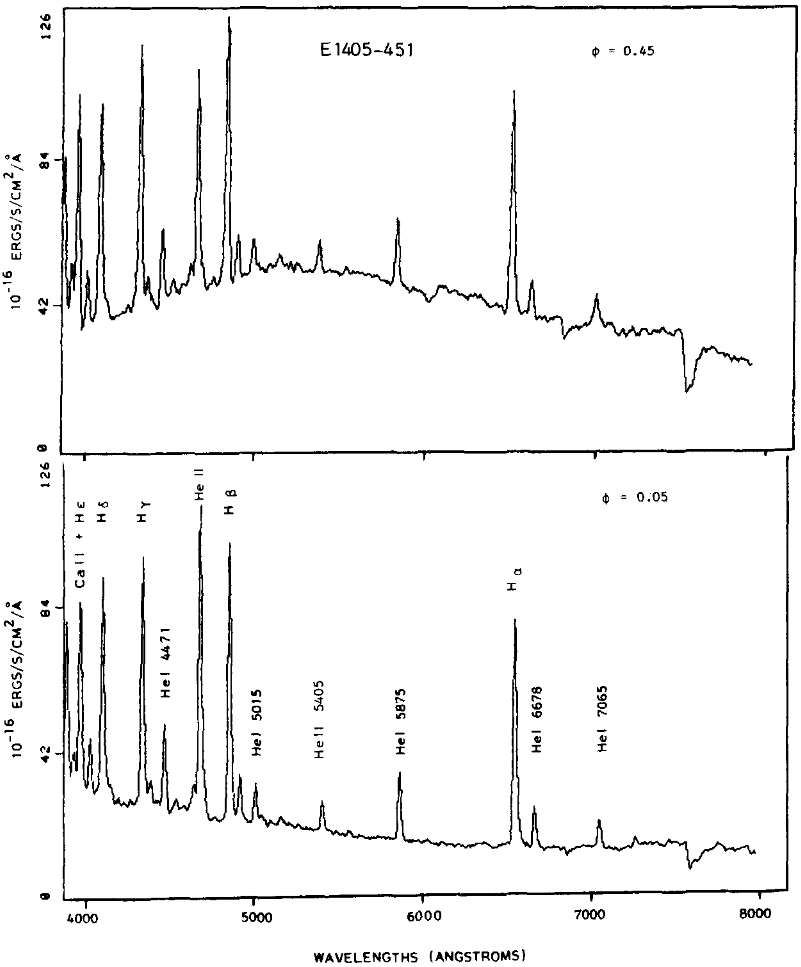

Figure 2 - Optical spectra of E1405-451 (224A/mm) around phases 0.05 (bottom) and 0.45 (top).

The intensities of the Balmer lines do not change appreciably between the two spectra in Fig.2, while the HeII 4686A intensity is clearly variable, being maximum around φ =0. At this phase,there is therefore an additional contribution to this high excitation line. The H_α emission line exhibits an asymetric profile which can be described

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as the superposition of two gaussian profiles, a narrow one (peak) and a broad one (base). A fit of H_α on the 10 binned spectra on March 29 and on the 12 individual spectra on March 30 with these two gaussian components reveals a sinusoidal modulation of the radial velocity of each component with the orbital phase (Fig.3). The amplitudes of the modulation are respectively of 265±30 km/s and 390±50 km/s for the narrow and the broad components with maximum of the radial velocities at phases 0.24±0.05 and 0.03±0.05 . Similar results are found for H_β . The blend of HeII 4686A with the complex CIII-NIII and HeI 4710A prevents such analysis for this line.

Discussion

The multiple components observed in the Balmer line profiles are often present in AM Her sources (see for instance Liebert and Stockman,1985). The characteristics of the broad component allow the determination of the geometrical and physical parameters of the emitting region. Neglecting the orbital motion, the amplitude of the projected velocity on the light of sight is given by vffsinisind, where $vff=(GM/R)^{1/2}$ is the free fall velocity of the gas in the emitting region at a distance R from the center of the white dwarf of mass M, i the inclination angle and d the colatitude angle. Equating the observed amplitude of the radial velocity curve with the above expression gives the distance R for given i and d. Assuming Tuohy et al.(1985) evaluations of i (60±5°) and d (20±5°) lead to an emitting region higher than 10^{10} cm from the white dwarf, while Cropper et al. (1986) values (i=38±10°, d=20±5°) give $R>5.10^{9}$ cm. These lower limits on the altitude of the emitting region are obtained assuming a constant colatitude for the column, while in these region the magnetic field lines are probably more inclined (larger d) than at the base of the column. The true distance would be therefore even larger and then

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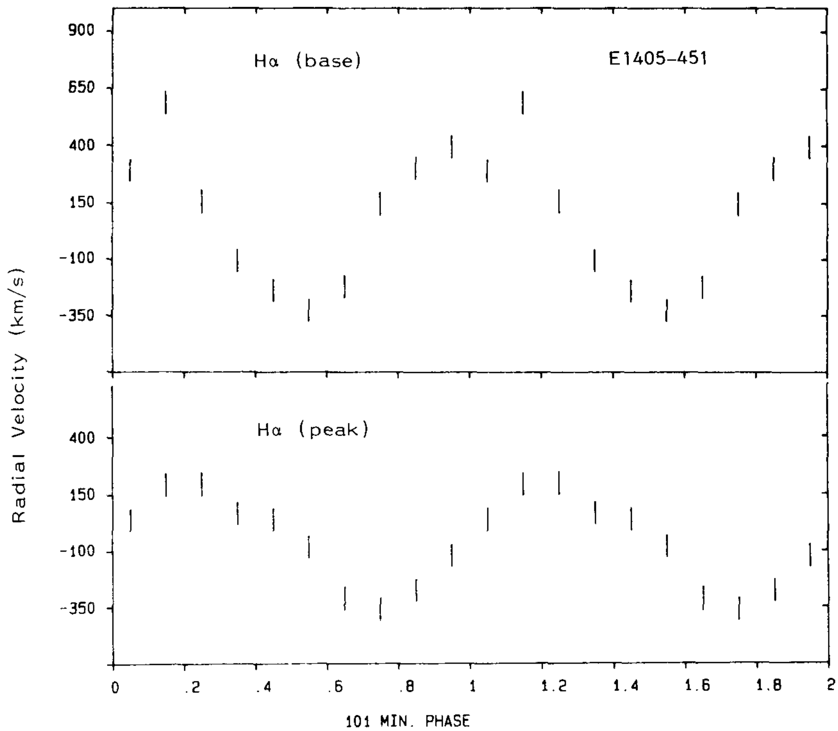

Figure 3 - Radial velocity versus the orbital period of the two components (peak at bottom, base at top) of the H_{α} line measured on the March 29 spectra folded in 10 bins.

incompatible with the broad width (FWHM$\sim$1200.sini km/s) of this component. The phasing of the radial velocity curve indicates no lateral distortion of the column if φ =0 corresponds to superior conjunction of the white dwarf.

With this assumption, the amplitude and phase of the narrow component are consistent with an origin in the vicinity of the secondary . Using Plavec and Kratochvil (1964) relation for the

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distance of the inner Lagrangian point from the white dwarf, the velocity at this point is given by $v_L = 517\ M^{1/3}(1+q)^{1/3}(0.5 - 0.227\log q - q/(1+q))$ where q is the mass ratio of the secondary and the white dwarf. The observed amplitude (265 km/s) is compatible with this emitting region for q<0.2.

Spectra at high resolution are necessary to clearly define the location of both emitting regions.

E1013-477

This X-ray source was identified with a blue object (V=17-18.5) and classified as an AM Her source on the basis of a X-ray emission, a large flickering and strong optical and UV emission lines, including HeII lines (Mason et al.,1983b, Maraschi et al.,1984b). Polarimetric observations failed to detect any circular polarisation (Tapia, private communication). Mason et al.(1983b) have proposed an orbital period of 103.4 minutes based on recurrent dips in the optical light curve. We have obtained rapid photometry in the V filter at the 1.54m Danish telescope in La Silla on March 24. The light curve shown in Fig4. exhibits two dips clearly not separated by 103 minutes. Similar behaviour was also observed by Mason et al.(1983b) , as well as the absence of dips at the expected phase.

Average spectrum

The averaged spectrum is shown in Fig.5. The Balmer emission lines are strong , with equivalent widths of H_α and H_β of 130A. The HeII 4686A line (EW=26A) is weaker than in AM Her sources in high state.Lines are rather broad (1000km/s) and Balmer series exhibit an inverted decrement: the line stength ratios H_α/H_β and H_γ/H_β being equal respectively to 0.63 and 0.80. Similar results were found by

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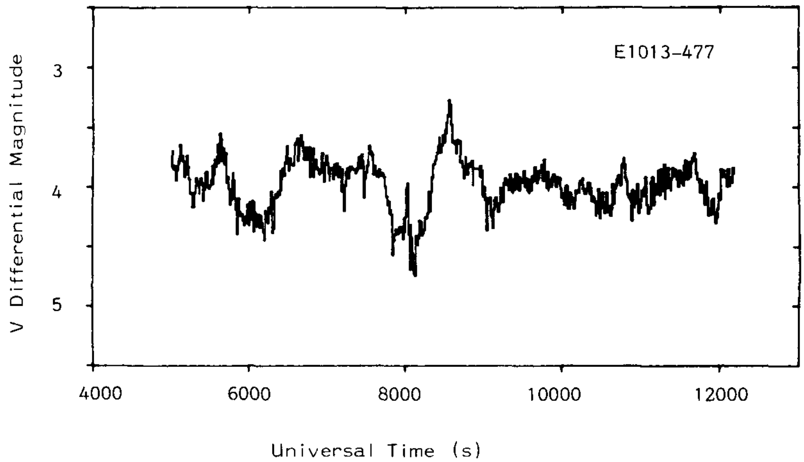

Figure 4 - Photometric light curve (V filter) of E1013-477 obtained on March 24 1984 at the 1.5m Danish telescope (La Silla).

Mason et al.(1983b). In addition the blend CIII-NIII 4640-50A is detected in spectra taken at higher resolution on March 30.

Temporal variability

Fig.6 shows the flux at 6150A and the H α radial velocities measured on the 40 means of 5 consecutive spectra obtained on March 29 and on the 20 individual spectra on March 30. Radial velocity measurements of the OI 5577A sky line are also shown as comparison. A power spectrum analysis leads to a modulation at the 103 minutes period with a significance of 89%. There is an indication of variation on a longer timescale (>3.3h) in the continuum as well as in the radial velocity measurements for which an amplitude greater than 200 km/s would be required. The existence of shorter periods (<1.5h) is not excluded, on the basis of the light curve variations.

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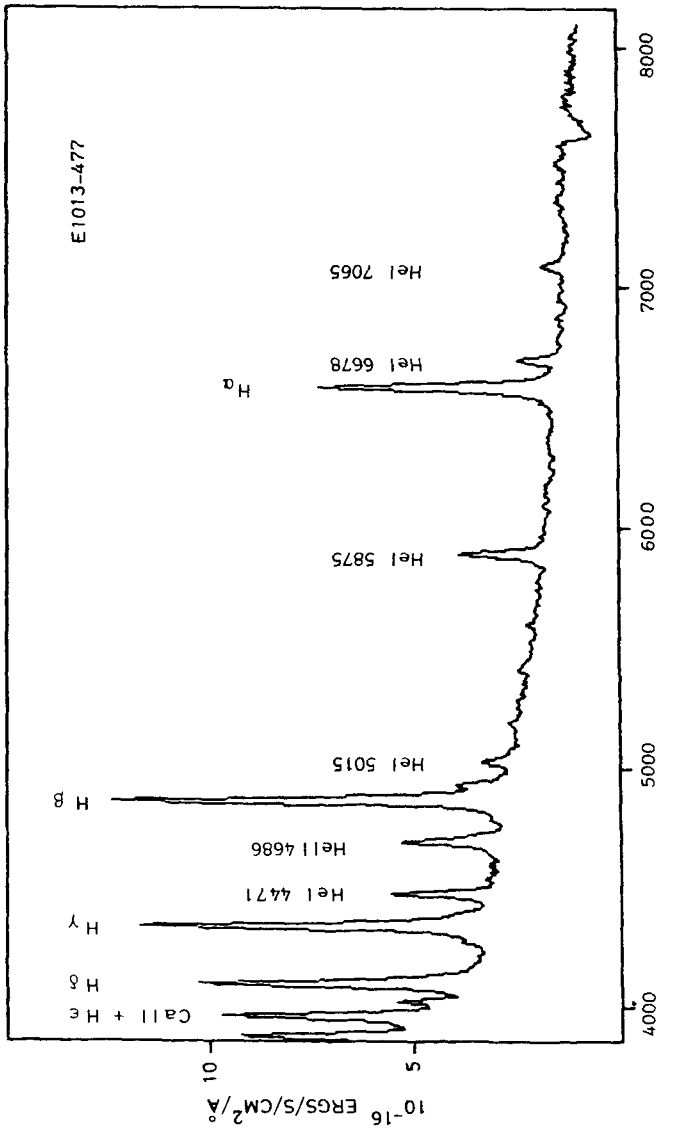

Figure 5 - Average spectrum of E1013-477 obtained on March 29 (224A/mm).

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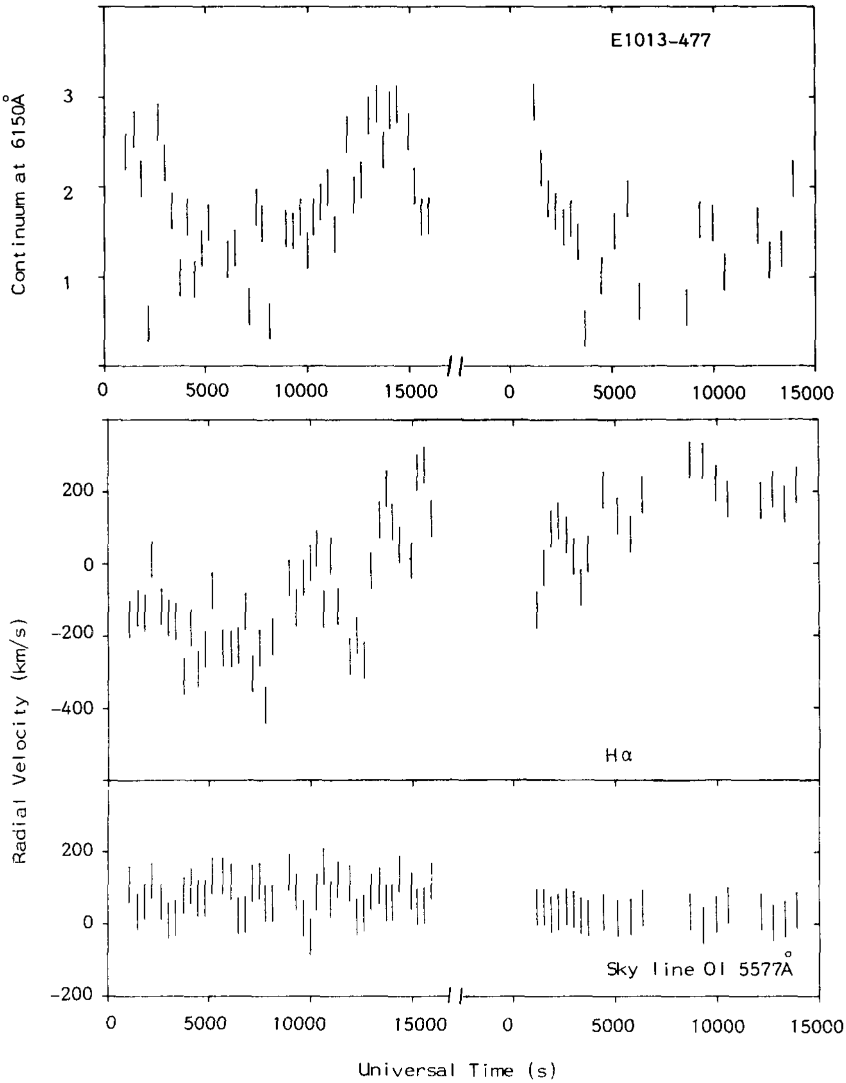

Figure 6 - Continuum at 6150A (top), radial velocity of H_α(middle) and of the OI 5577A sky line (bottom) versus time on March 29 and 30. Note the discontinuity in X-scale.

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The nature of E1013-477 is still a matter of controversy. This object does not exhibit all the usual features of the AM Her sources, either in a high state or in a low one. From spectroscopic and photometric data we do not confirm the proposed period of 103 minutes. More extensive observations are required to test the existence of a longer period.

REFERENCES

Bonnet-Bidaud,J.M.,et al., 1985, in 'Recent Results on Cataclysmic Variables', ESA SP-236, p155

Bonnet-Bidaud,J.M.,et al., 1986, in preparation

Cropper,M., Menzies,J.W.,Tapia,S., 1986, preprint

Jensen,K.A., Nousek,J.A., Nugent,J.J., 1982, Ap.J., 261, 625

Liebert,J., Stockman,H.S., 1985, in 'Cataclysmic Variables and Low Mass X-ray Binaries', eds Patterson and Lamb, Reidel Press, p151

Maraschi,L., et al., 1984a, Ap.J., 285, 214

Maraschi,L., et al., 1984b, 4th European IUE Conference, p247

Mason,K.O., et al., 1983a, Ap.J., 264, 575

Mason,K.O., et al., 1983b, Pub.Ast.Soc.Pac., 95, 370

Mouchet,M., et al, 1986, in preparation

Osborne,J., Cropper,M., Cristiani,S., 1986, this volume

Plavec,M., Kratochvil,P., 1964, Bull.Astron.Inst.Czech., 15, 165

Tuohy,I., Visvanathan,N., Wickramasinghe,D., 1985, Ap.J., 289, 721

Wickramasinghe,D., Meggitt,S., 1985, M.N.R.A.S., 216, 857

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