AK Sco: evidence of tide driven filling of the inner gap in the circumbinary disk

Ana Inés Gómez de Castro[(1)], Javier López-Santiago[(2)], Antonio Talavera[(3)], A. Yu. Sytov[(4)], Dmitri Bisikalo[(4)]

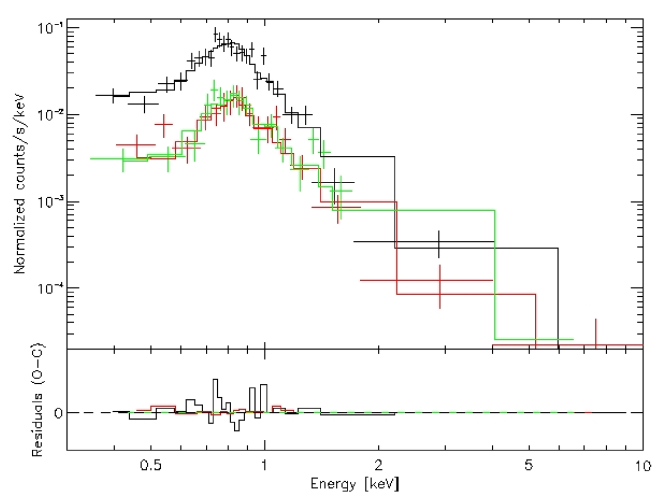
[(1)] AEGORA, Fac. de CC Matemáticas, Universidad Complutense de Madrid, Spain; [(2)]Depart. of Physics of the Earth Astronomy and Astrophysics II, Fac. CC Físicas, Universidad Complutense de Madrid, Spain; [(3)]European Space Astronomy Center, Madrid, Spain; [(4)] Institute of Astronomy of the Russian Academy of Sciences, Moscow, Russia

ABSTRACT: ***AK Sco stands out among pre-main sequence binaries because of its prominent ultraviolet excess, the high eccentricity of its orbit and the strong tides driven by it. AK Sco is made of two F5 type stars that get as close as 11R_* at periastron passage. The presence of a dense (n_e ~ 10^{11} cm^{-3}) extended envelope has been unveiled recently. In this article, we report the results from a XMM-Newton based, monitoring of the system. We show that at periastron, X-ray and UV fluxes are enhanced by a factor of ~3 with respect to the apastron values. The X-ray radiation is produced in an optically thin plasma with T~6.4 MK and it is found that the N_H column rises from 0.35 10^{21} cm^{-2} at periastron to 1.11 10^{21} cm^{-2} at apastron, in good agreement with previous polarimetric observations. The UV emission detected in the OM band seems to be caused by the reprocessing of the high energy magnetospheric radiation on the circumstellar material. Moreover, further evidence of the strong magnetospheric disturbances is provided by the detection of line broadening of 279 km s^{-1} in the N V line with HST/STIS.***

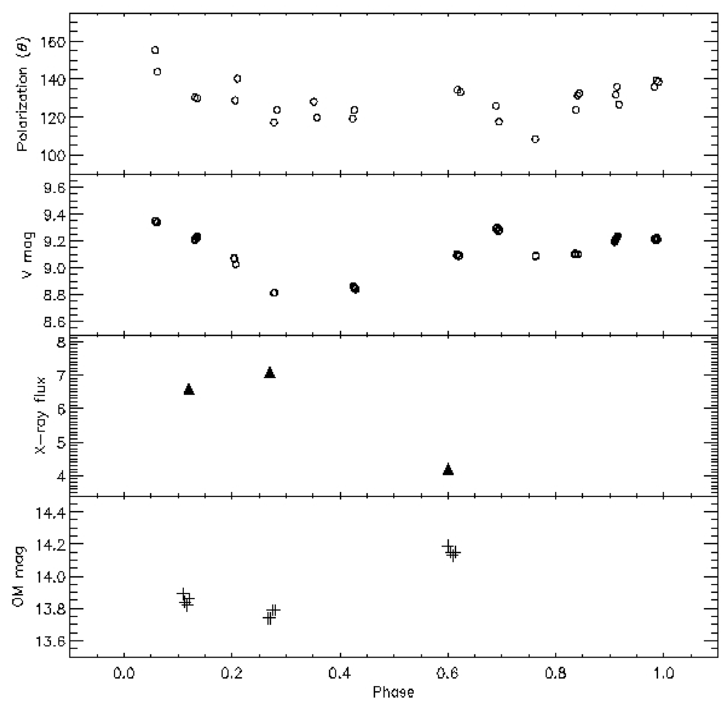
Numerical simulations of the mass flow from the circumbinary disk to the components have been carried out. They provide a consistent scenario to interpret AK Sco observations. We show that the eccentric orbit acts like a gravitational piston. At apastron, matter is dragged efficiently from the inner disk border, filling the inner gap and producing accretion streams that end as ring-like structures around each component of the system. At periastron, the ring-like structures get in contact, leading to angular momentum annihilation, and thus producing an accretion outburst.

1. XMM-NEWTON MONITORING.

The XMM-Newton monitoring of AK Sco was carried out from March 15th, 2011 to March 22nd, 2011. The observations were issued at phases 0.99, 0.15 and 0.48, corresponding to observation identifications, ID. 0651870201, ID. 0651870301 and ID. 0651870401, respectively. The exposure time was approximately 25 ks for each observation. In each observation, the European Photon Imaging Cameras (EPIC) were used in full-frame mode with the thick filter and the Optical and UV Monitor (OM) was operated in User Defined Mode, with the UVM2 filter (2310 Å).



EPIC spectrum at φ=0.
The fit shows an optically thin plasma with:
kT= $0.52^{+0.06}_{-0.06}$ keV, N_H = $0.49^{+0.64}_{-0.49}$ 10^{21} cm^{-2} , $Z/Z_\odot$ = $0.27^{+0.16}_{-0.09}$ and log L_X(erg/s) = 28.9, assuming a distance of 103 pc to AK Sco Errors are at the 90% confidence level.

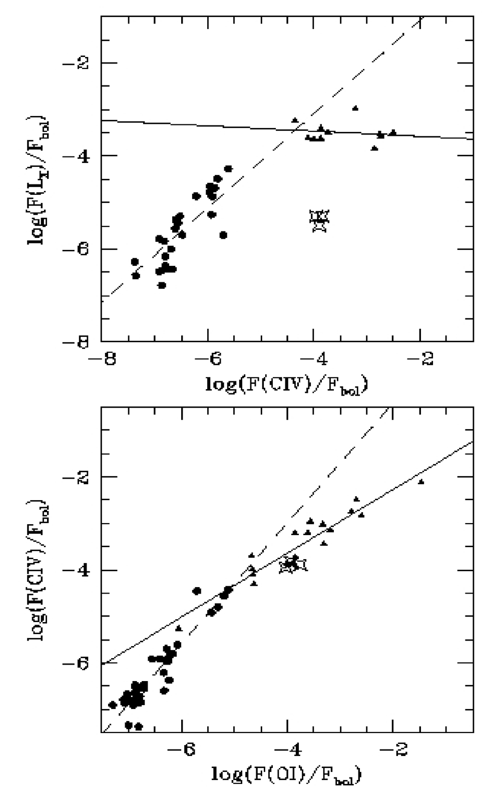


The variation of the radiative energy released during the binary cycle is shown for three channels: X-ray, UV and optical. Optical data have been extracted from the monitoring run by Manset et al (2005), i.e. do not correspond to the same cycle. The flux in all bands is higher at periastron than at apastron: ΔV=0.6 mag, ΔUV = 0.45 mag and ΔX=0.6

However, ΔA_V=0.34mag and the extinction corrected UV flux varies as: ΔA_V=-0.82 mag. This suggests that the UVM2 flux is dominated by the radiation reprocessed in a variable environment.

2. THE UV DATA.

The line fluxes have been normalized to the bolometric flux and represented in the standard flux-flux diagrams for the TTSs atmospheric/magnetospheric diagnostics (Gómez de Castro & Marcos-Arenal, 2012). AK Sco is located on the TTSs regresion line in the CIV versus OI diagram; it displays the characteristic excess emission of neutrals compared to high ionization species. This excess is partially caused by the reprocessing of stellar UV photons in the inner disk. The OI flux close to apastron is about twice the flux observed at periastron.

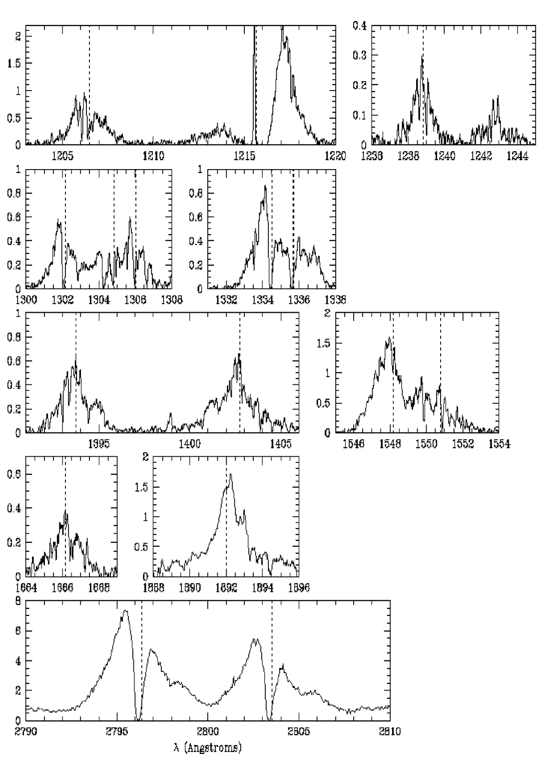


AK Sco, stands out of the TTSs regression line in the X-ray versus C~IV diagram. The source of this X-ray luminosity defect is unclear. The X-ray luminosities of the TTSs plotted in the diagram have been derived from the XEST survey (Guedel et al 2007). The X-ray/UV excess of main sequence stars depends strongly on the spectral type with the largest excess being observed in the latest types. Ayres et al (1995) extended this study to F-type stars and showed that the correlation is broken at late F types; this is assumed to be caused by a decay in the dynamo activity since F-type stars represent an intermediate regime between stars with convective envelopes and stars with radiative envelopes. Typically, the X-ray luminosity of F8-F0 main sequence stars is about an order of magnitude weaker than predicted by the main sequence regression line. AK Sco data seems to extend this behaviour to PMS stars in a more dramatic manner: the X-ray flux drops by two orders of magnitude in spite of the strong tides.

PROFILES OF THE MAIN UV LINES FROM HST/STIS

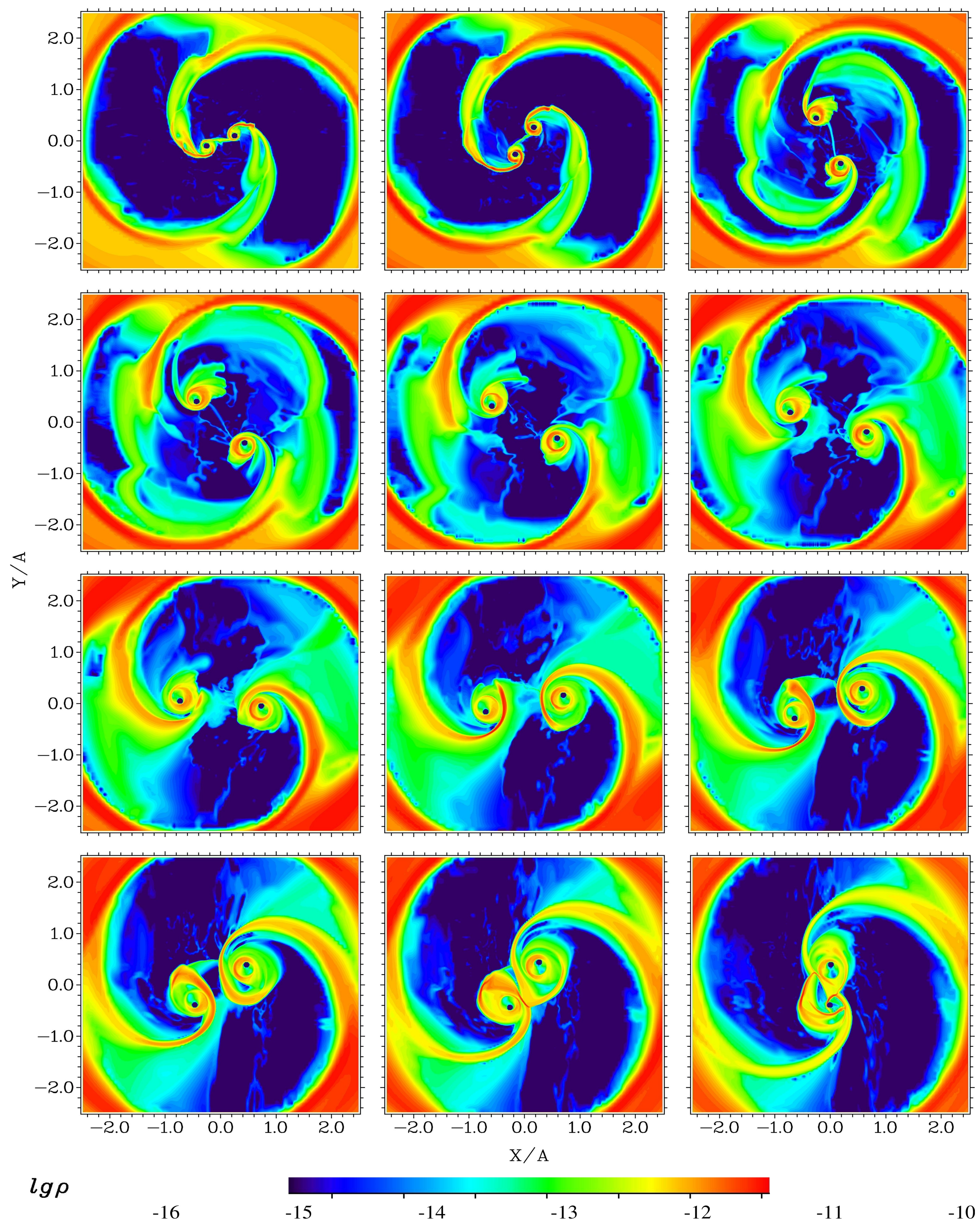
NV has FWHM~279 km s^{-1}; NV is typically excited in the transition region of the cool stars atmospheres at temperatures above some 40,000~K. The large broadening is clearly non-thermal and confirms the existence of disturbed magnetospheres in AK~Sco stellar components (Gómez de Castro 2009b).

The profiles corresponding to semiforbidden transitions of OIII] and SiIII] are asymmetric suggesting warm matter close to the stars is unevenly distributed in a high velocity field alike the expected, for instance, in spiral structures.



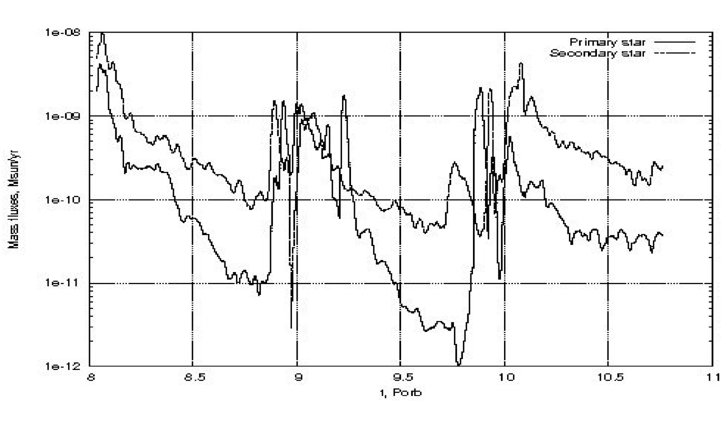
3. NUMERICAL SIMULATIONS

The AK Sco binary system has a substantially elliptical orbit which results in an interesting phenomenon. When the system approaches the periastron, the outer boundaries of the circumstellar disks (and the accretion streams passing by) get close enough one to each other to effectively annihilate the angular momentum, leading to an increase of the accretion rate by a factor of 2-3. Also, at periastron passage, a complex pattern of shock waves appears between the components of the binary system.The details of the numerical scheme are described in Bisikalo et al (2000) and has been adapted to AK Sco parameters. The evolution of the system is parametrized in terms of the orbital phase, ϕ=0 corresponds to the periastron. The panels show the density distribution at different phases evenly distributed over the orbital period, starting at periastron.



The structure of the gas flow consists of a circumbinary disk, a gap, circumstellar accretion disks, and a system of shock waves and tangential discontinuities. We found that in the inner region of the circumbinary disk the velocity distribution is non-Keplerian and gas motion is governed by spiral shock waves (bow shocks) formed due to the supersonic motion of the components of the binary system and their gravity wells inside the circumbinary disk. The bow shock wave has a spiral shape, one end of the bow shock is located near the circumstellar disk, while the other end resides inside the circumbinary disk.

When the matter of the gap passes through the bow shock it forms the dense spiral behind the wave, but some part of it flows to the accretion disk and the rest of it flows back to the circumbinary disk. These two flows are separated by the head-on collision point visible in the velocity field on the forefront of the bow shock. Remarkably, these streams are not distinguishable on the density distribution as two separate streams, indeed, they look like a single thick spiral arm.



Bibliography: Ayres et al 1995,ApJS,96 223; Bisikalo et al 2000,AsR, 44, 26; Gómez de Castro, 2009, ApJ, 698, L108; Gómez de Castro & Marcos-Arenal, 2012, ApJ, 749,190 ; Guedel et al 2007, A&A, 478, 97; Manset et al 2005, AJ, 129, 480