Timing HU Aqr

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XRU14, Dublin, June 17, 2014

AIP

or

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How to become a planet-hunter while innocently studying accretion physics in a mCV?

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Collaborators

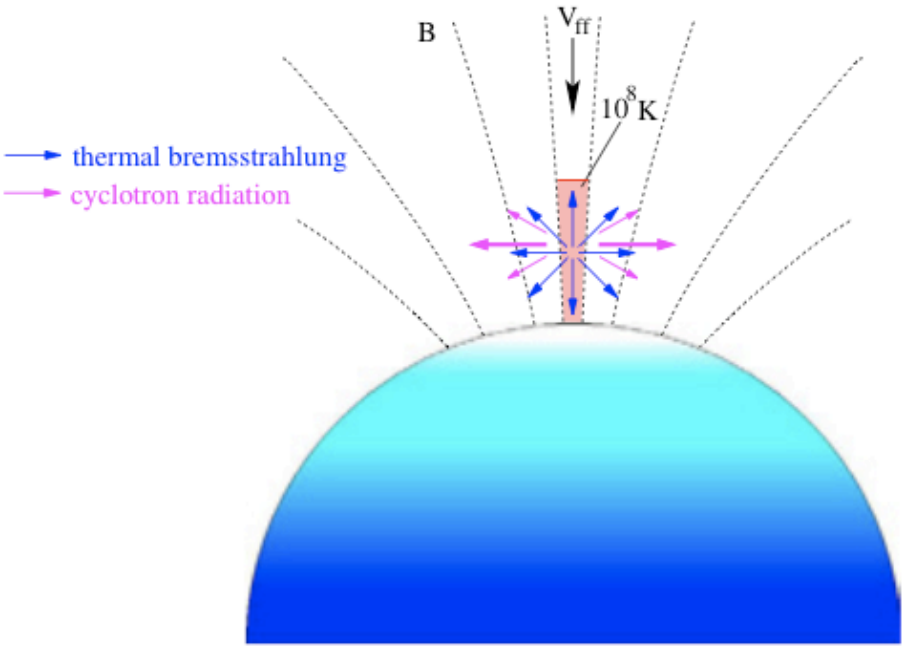
- I. Traulsen, R. Schwarz – AIP Potsdam
- B. Thinius – Inastars obs. Potsdam
- K. Reinsch, F.V. Hessman – Göttingen
- F. Walter – SUNY
- V. Burwitz – MPE Garching

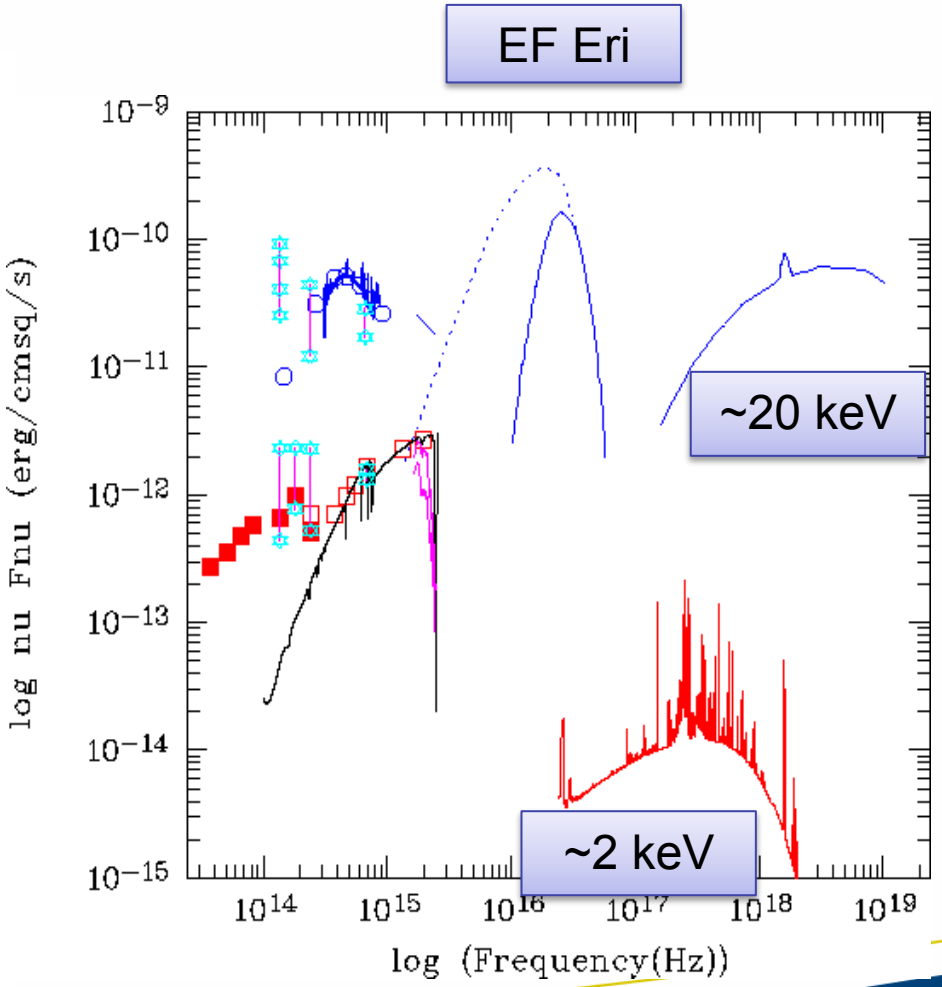
Content

- Intro: Polars
- HU Aqr: The eclipse ephemeris
- XMM/Inastars/MONET: The high state 2013
- XMM/ULTRACAM: The low state 2005
- Conclusions

Accretion column and SED

(Beuermann04, ASP)

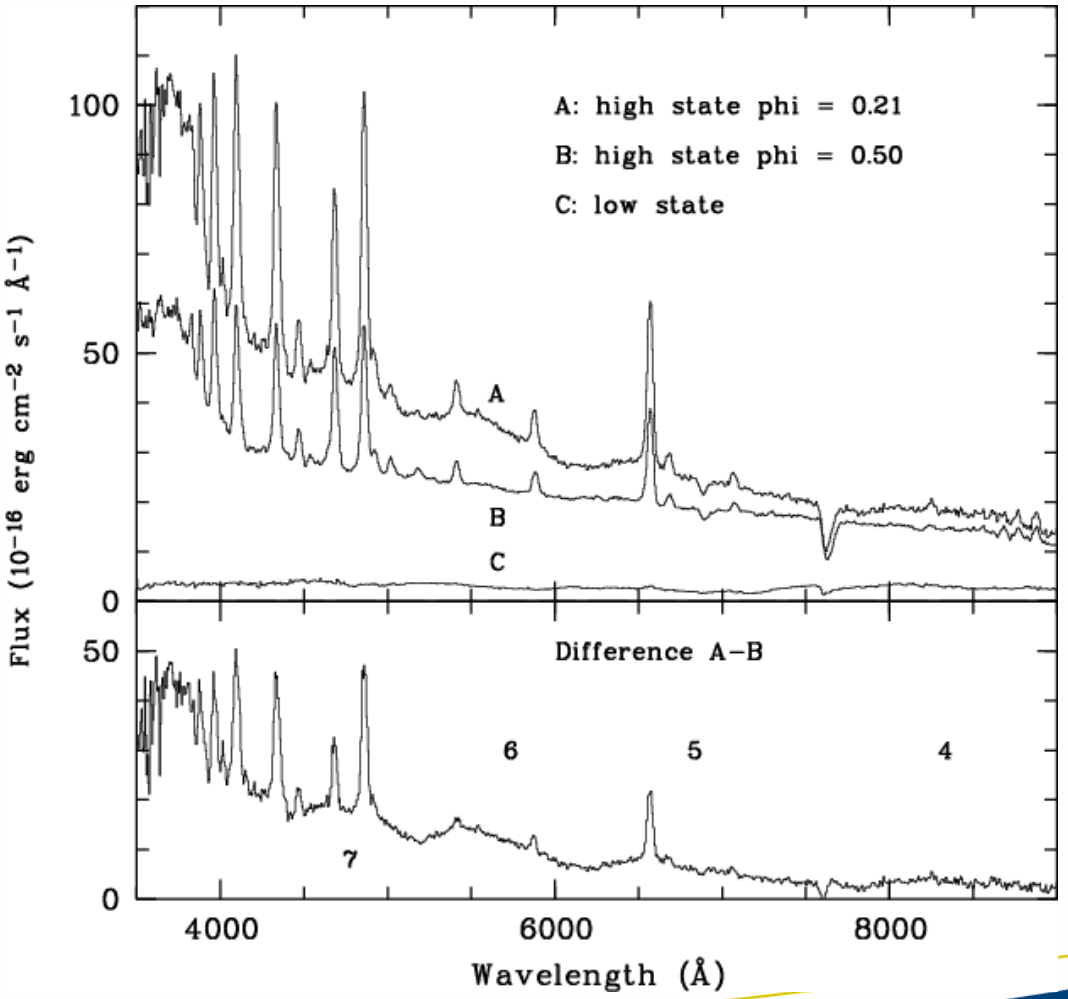




Plasma cyclotron harmonic radiation

- Spacing:
  Magnetic field
  B=37 MG
- Width:
  plasma temperature
  5 – 10 keV
- Moving lines:
  Geometry

Schwope+03, A&A



Discovery of RXJ2107-05 (=HU Aqr) as bright RASS source

- Discovery: P_{orb}= 125 min, linear ephemeris
- Three RASS scans in eclipse
- Eclipse length 580 +- 15 s, $\Delta\phi_{1/2}$ = 0.0397

Schwope+93, AA

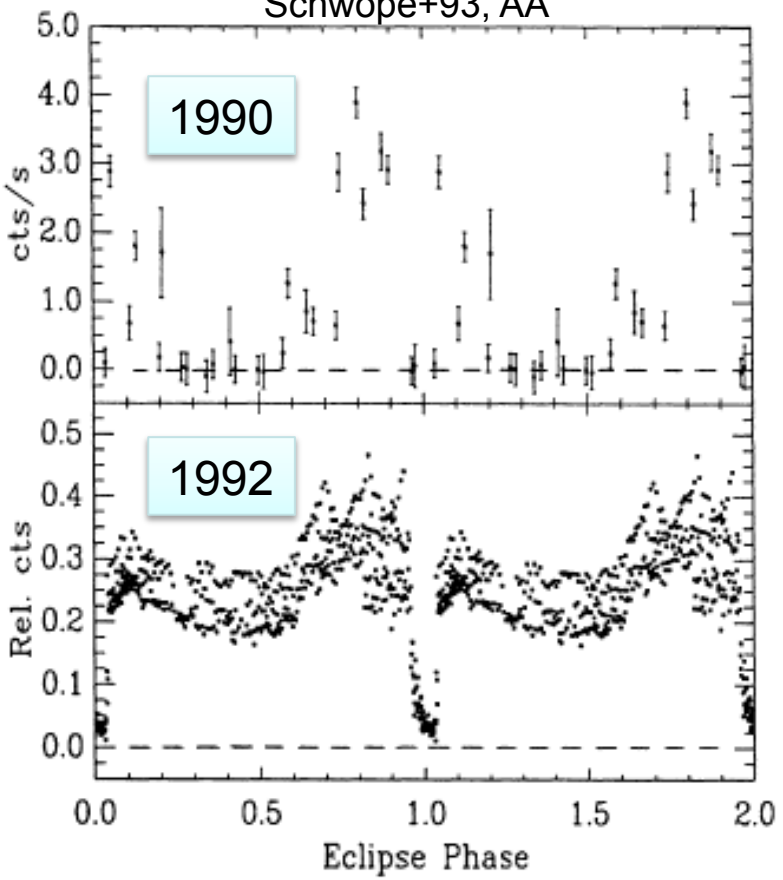
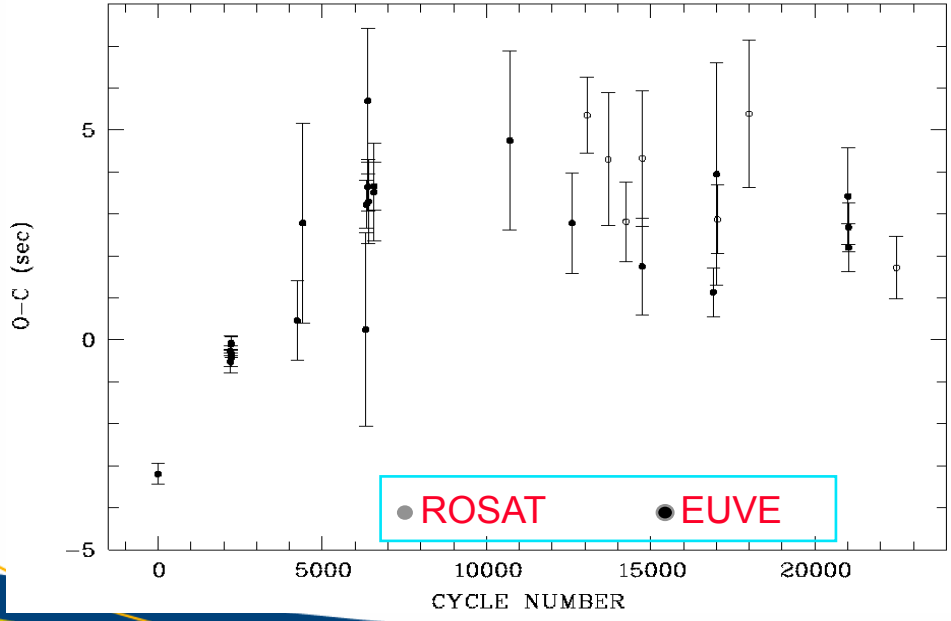


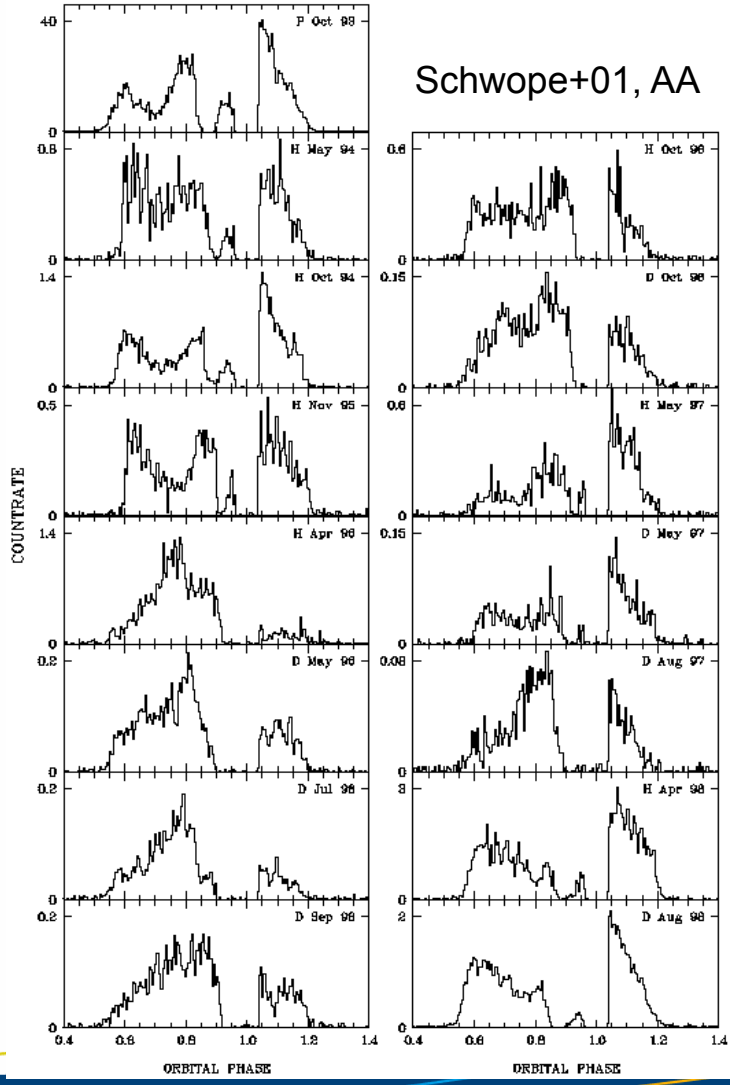
Fig. 4. (a) *(upper panel)* RASS scan light curve of RX21 folded over the ephemeris of Eq. 1. All data are shown twice for clarity. (b) *(lower panel)* White-light and V-filter photometry of RX21 performed in October 1992. Again the data are folded over the eclipse ephemeris and plotted twice

ROSAT (PSPC&HRI) and EUVE monitoring: Status at millenium

- ROSAT&EUVE monitoring: quadratic ephemeris
- Established eclipse egress as fiducial mark to determine period
- Phase jitter still compliant with spot migration over WD surface (size ~ 30-60s)



Schwope+01, AA



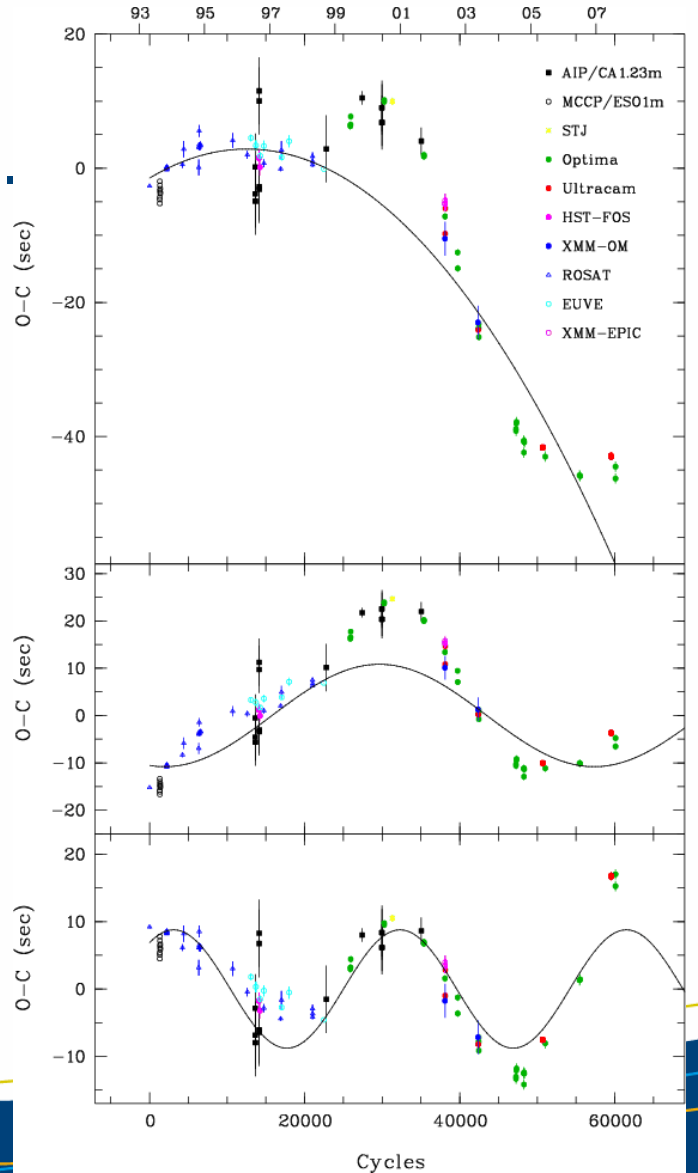
The first decade in the new millenium

- XMM/OPTIMA/ULTRACAM+..

→Complex timing pattern

  - Applegate (solar cycles)?
    Too weak
  - GR?
    Too weak
  - 3rd low mass body?
    Possible

(Schwarz+09)



Detection of a planetary system orbiting the eclipsing polar HU Aqr

Qian S.-B.[1,2,3], Liu L.[1,2,3], Liao W.-P.[1,2,3], Li L.-J.[1,2,3], Zhu L.-Y.[1,2,3], Dai Z.-B.[1,2], He J.-J.[1,2], Zhao E.-G.[1,2],, Zhang J.[1,2] and Li K.[1,2,3]

ABSTRACT

Using the precise times of mid-egress of the eclipsing polar HU Aqr, we discovered that this polar is orbited by two or more giant planets. The two planets detected so far have masses of at least 5.9 and 4.5 M_{Jup}. Their respective distances from the polar are 3.6 AU and 5.4 AU with periods of 6.54 and 11.96 years, respectively. The observed rate of period decrease derived from the downward parabolic change in O-C curve is a factor 15 larger than the value expected for gravitational radiation. This indicates that it may be only a part of a long-period cyclic variation, revealing the presence of one more planet. It is interesting to note that the two detected circumbinary planets follow the Titus-Bode law of solar planets with n=5 and 6. We estimate that another 10 years of observations will reveal the presence of the predicted third planet.

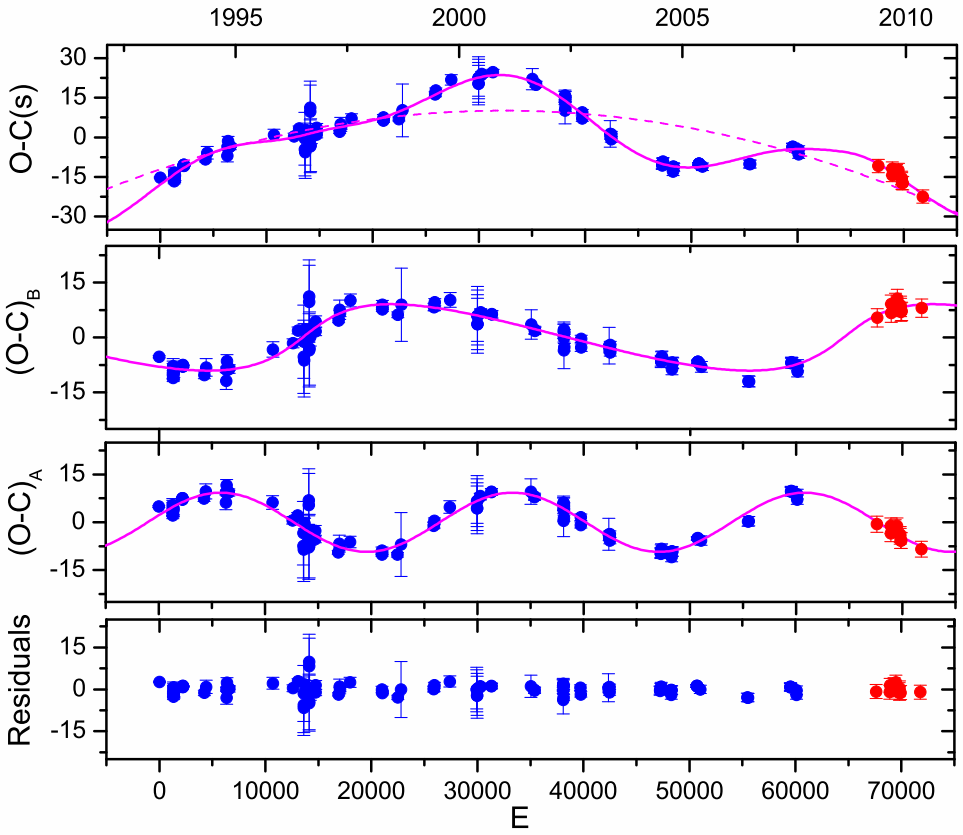


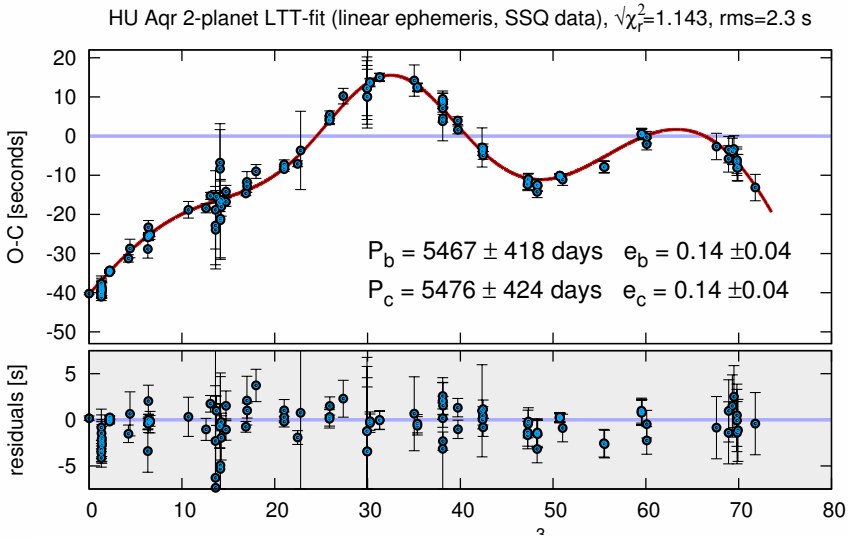
Fig. 2.— O-C diagrams of the eclipsing polar HU Aqr. Blue dots refer to the data compiled from the literat… while red ones to our new observations. It is shown in the top panel that a combinat… ease (dashed magenta line) c… yclic changes (Case A: P_A = … = 10.54 s) are displayed in th… residuals are displayed in the lowest panel where no variations can be traced there.

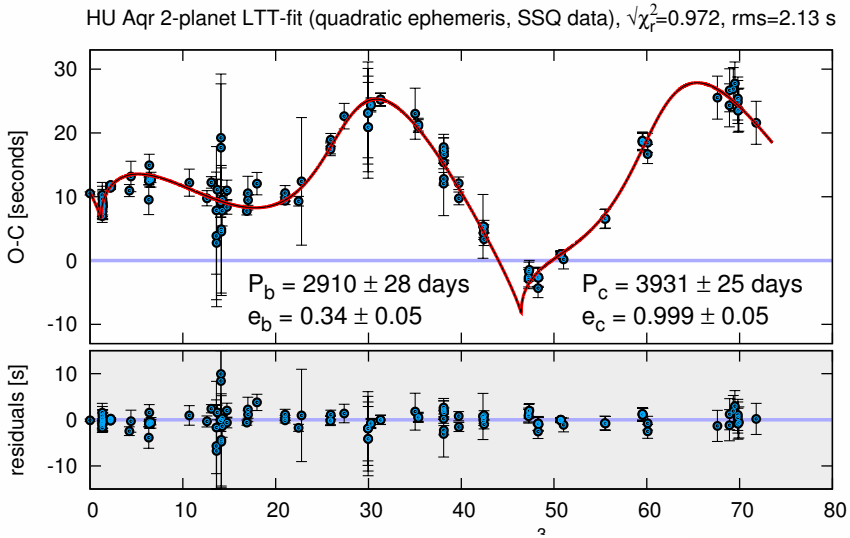
The Qian+11 planets are dynamically unstable on short timescales (Horner+11)

Gozdziewski+12
No valid fit to all literature data

Two equal planets in opposition

One planet with ecc = 0.999



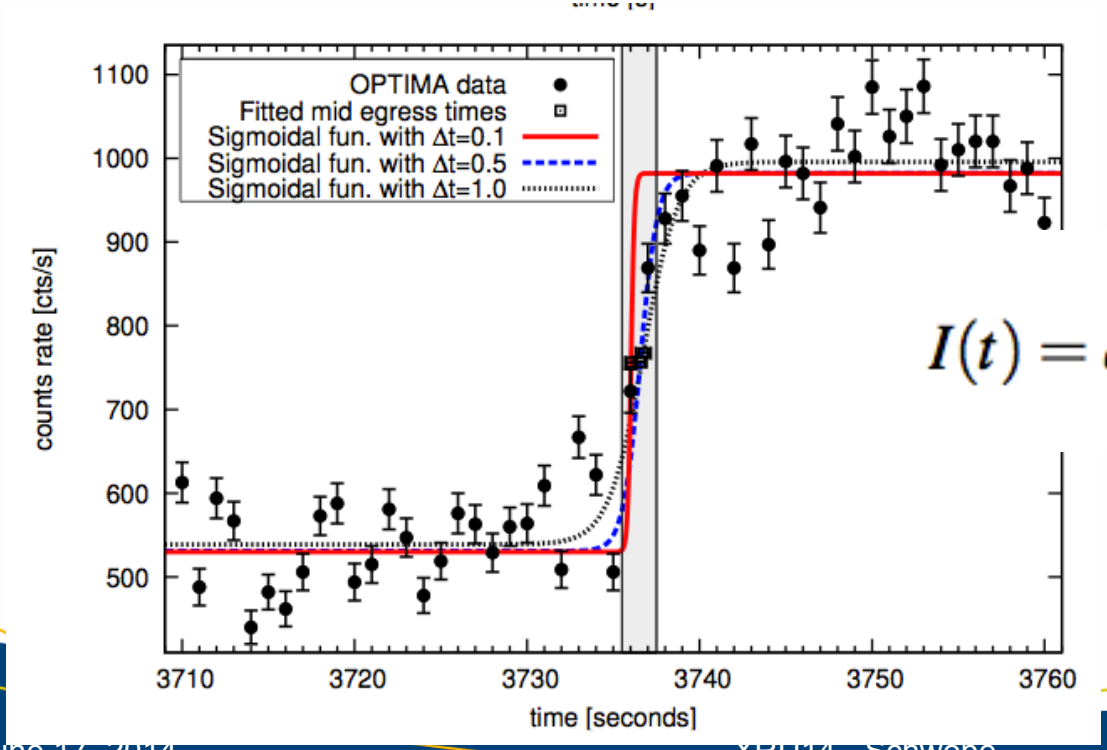


$$(\text{O-C}) = T_{\text{ep}}(l) - t_0 - lP_{\text{bin}} = \tau(t_l, K_{1,2}, P_{1,2}, e_{1,2}, \omega_{1,2}, T_{1,2})$$

$$(\text{O-C}) = T_{\text{ep}}(l) - t_0 - lP_{\text{bin}} - \beta l^2 = \tau(t_l, K_{1,2}, P_{1,2}, e_{1,2}, \omega_{1,2}, T_{1,2})$$

Gozdziewski‘s remedy:

- Add more epochs obtained by OPTIMA
- Select only the ‚best‘ available data, in particular don‘t mix data obtained at optical and other wavelengths



Determination of Egress times via sigmoids:

$$I(t) = a_1 + \frac{(a_2 - a_1)}{(1.0 + \exp([t_0 - t]/\Delta t)}$$

Claimed precision:
Δt_0 >= 0.1 s

One-planet model possible (Gozdziewski+12)

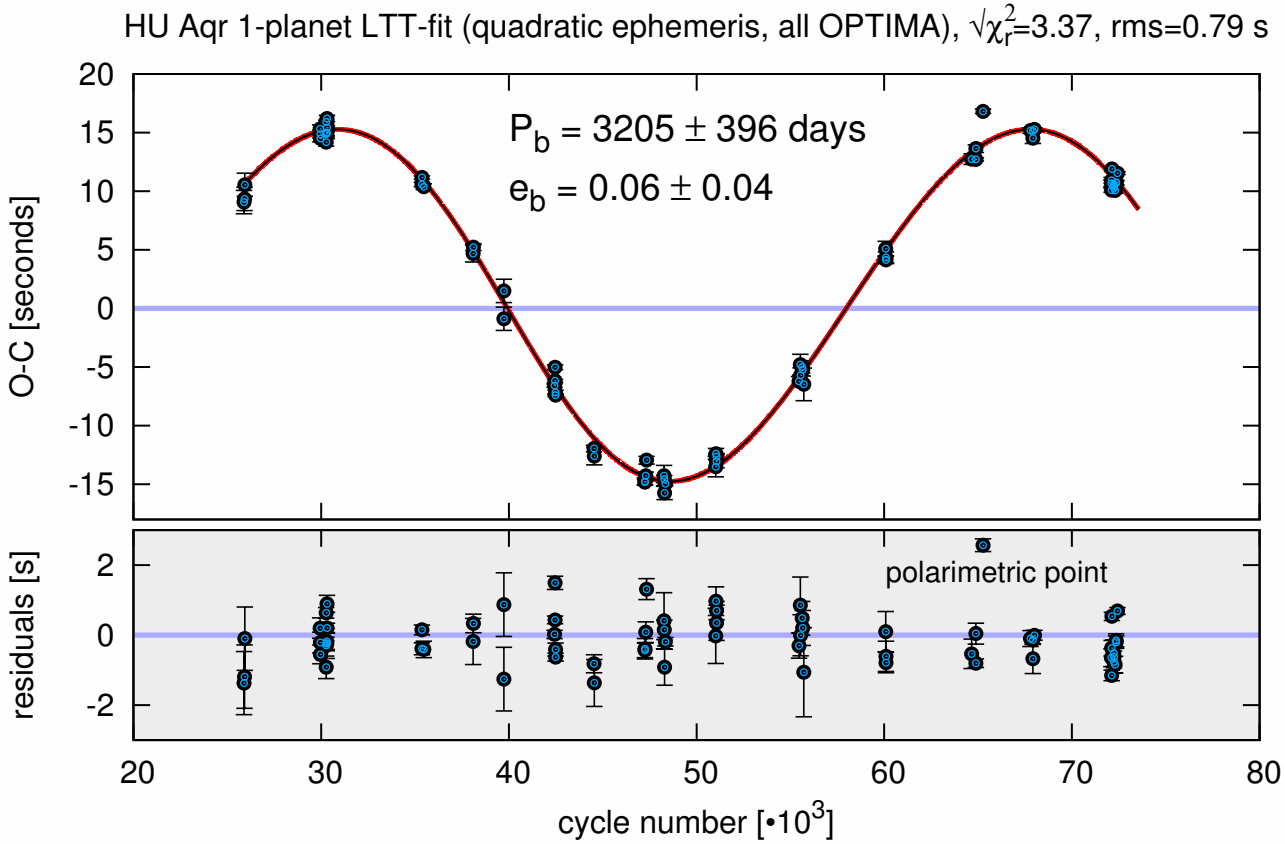
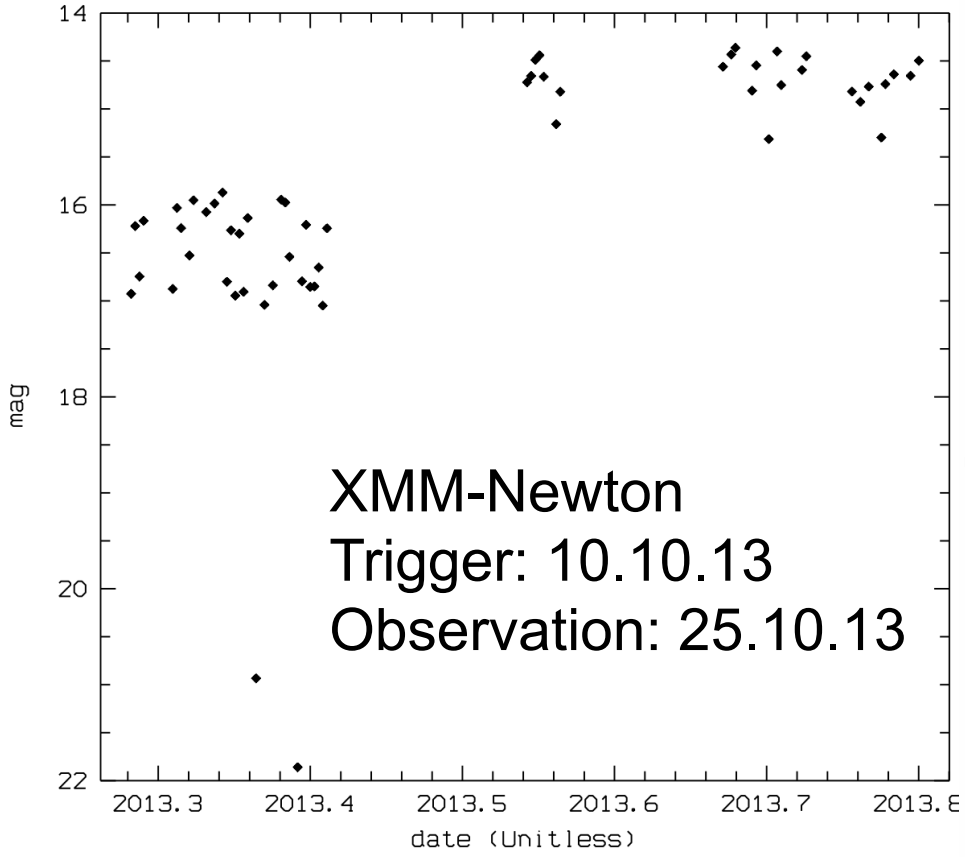
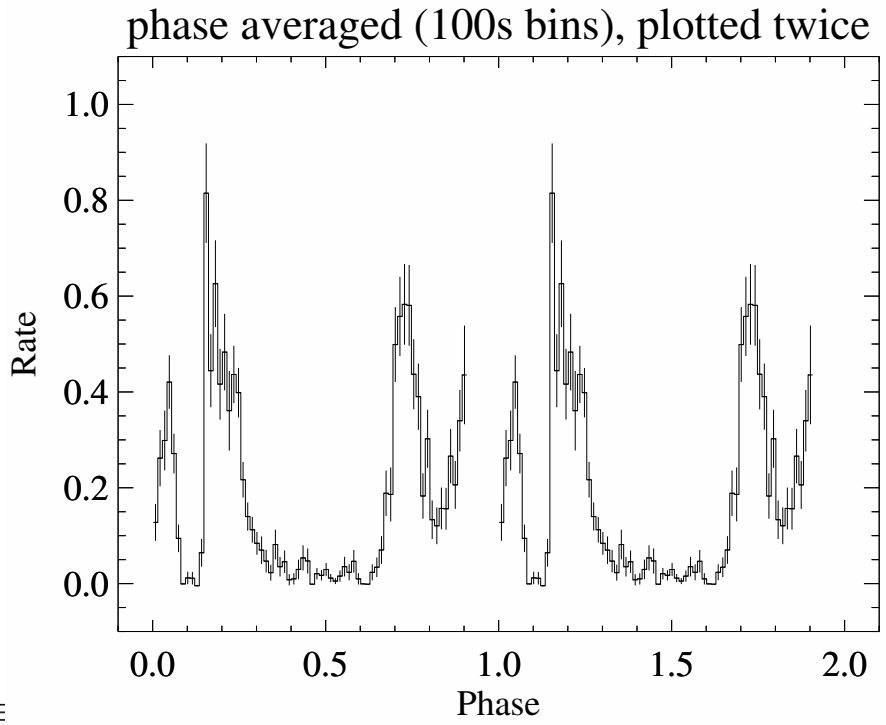


Figure 11. Synthetic curves of the 1-planet LTT quadratic ephemeris models to optical OPTIMA measurements, including polarimetric data One of the most deviating polarimetric points is labeled in the residuals panel.

STELLA Observatory Tenerife

STELLA monitoring in 2013
Swift confirmation Oct 3

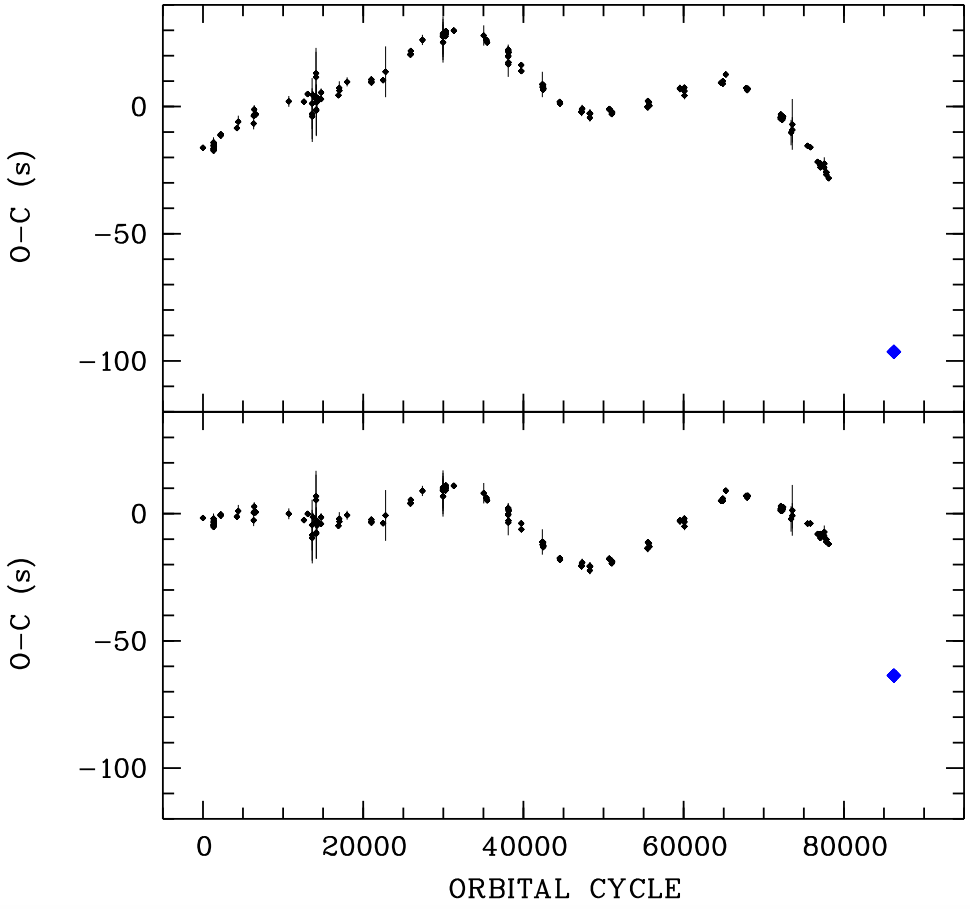




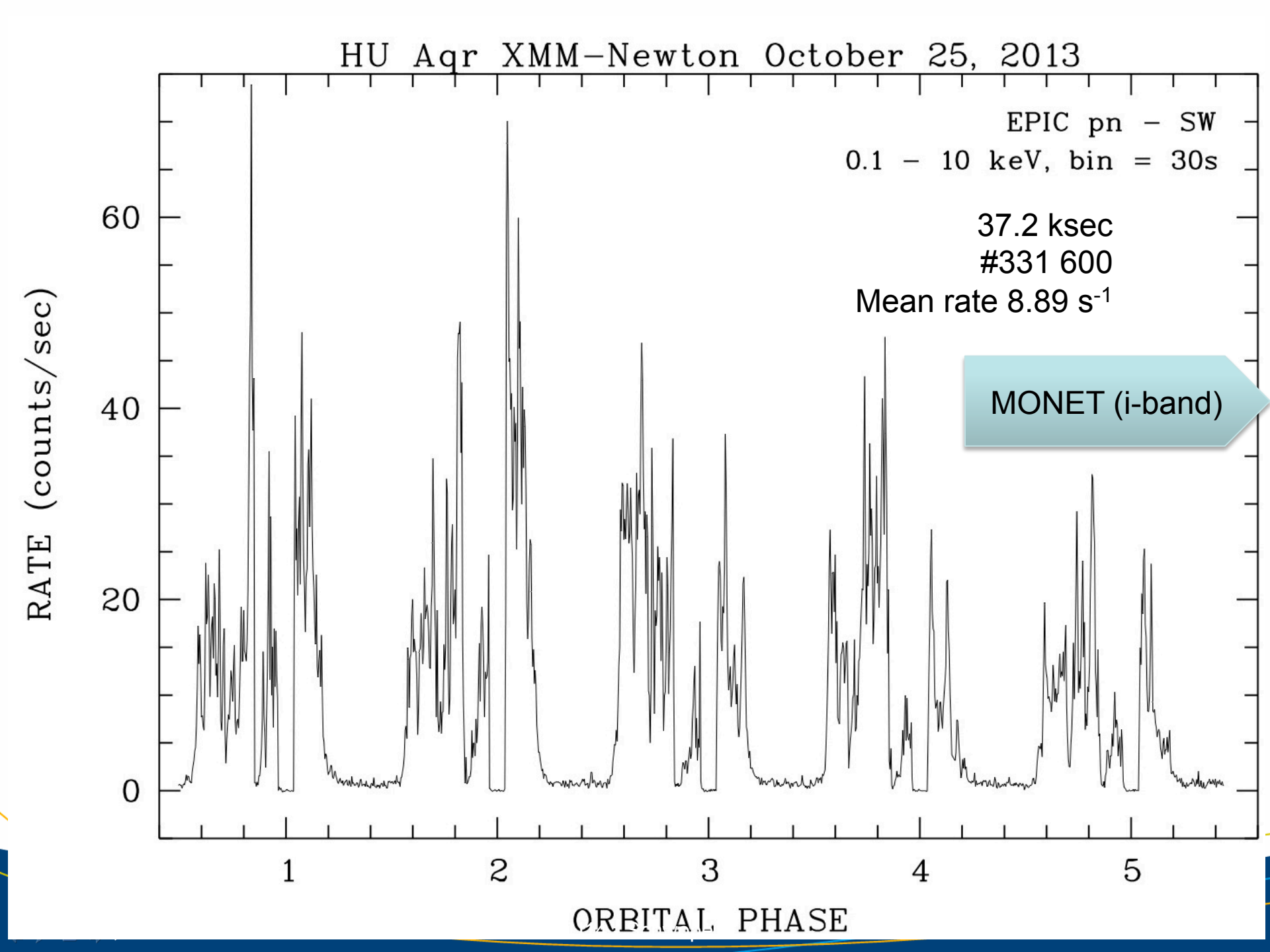
Inastars Observatory

Amateur contribution to the story of HU Aqr b

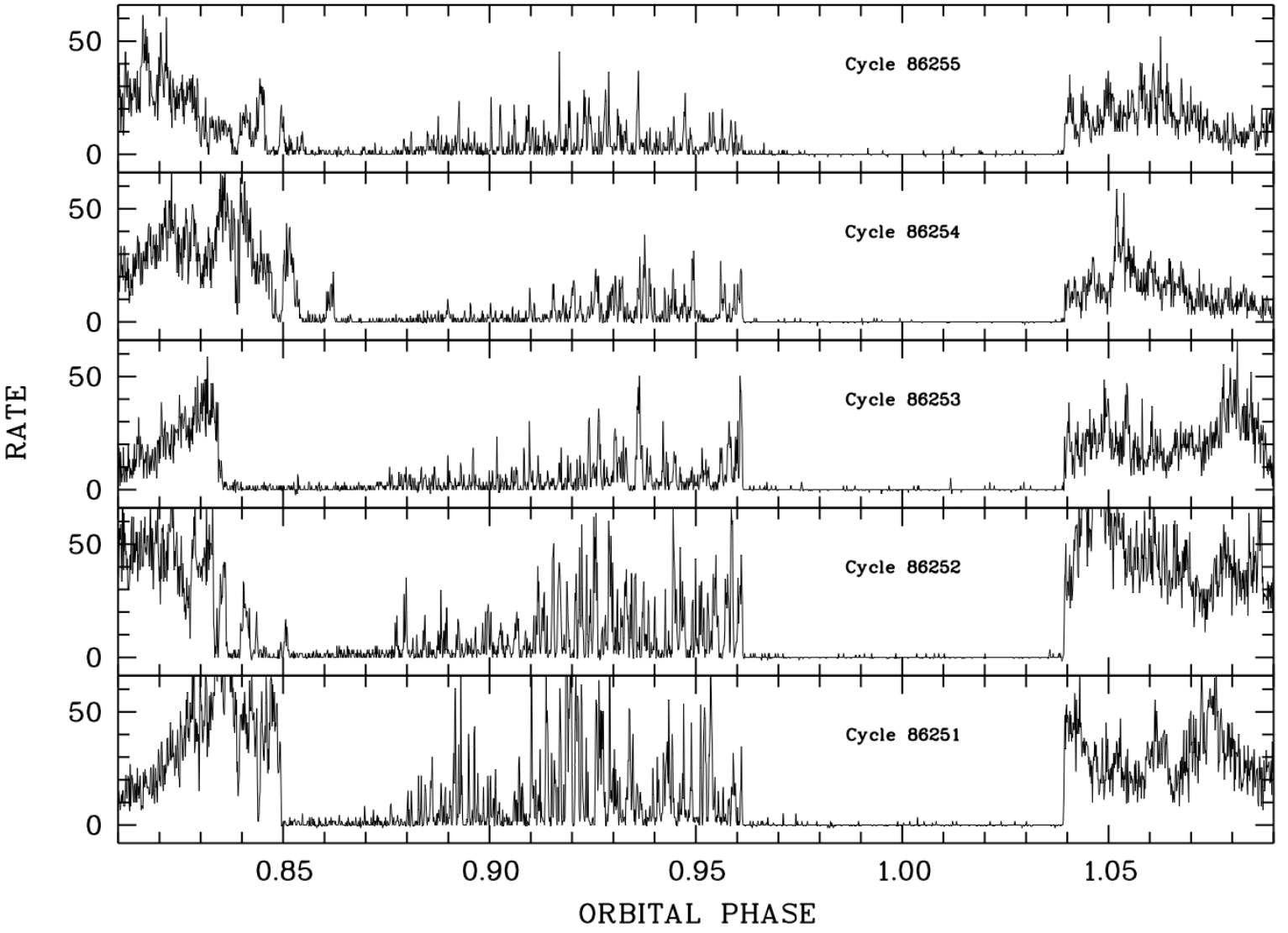
- Any simple planetary model apparently ruled out!
- Confirmed by XMM?
- Phase-relation between optical and X-ray data?



Schwope & Thinius 2014, AN

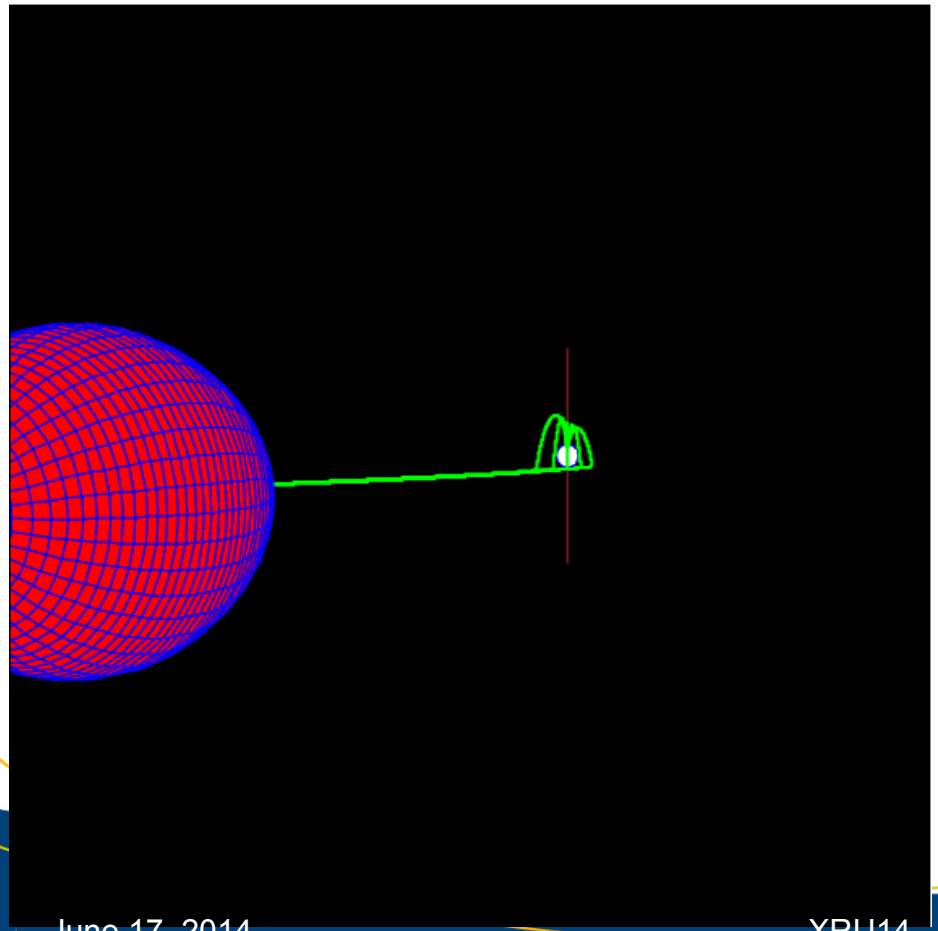

HU Aqr XMM-Newton October 25, 2013
EPIC pn - SW
0.1 - 10 keV, bin = 30s
37.2 ksec
#331 600
Mean rate 8.89 s-1
MONET (i-band)
RATE (counts/sec)
0
20
40
60
1
2
3
4
5
ORBITAL PHASE

Eclipse, dip, and curtain

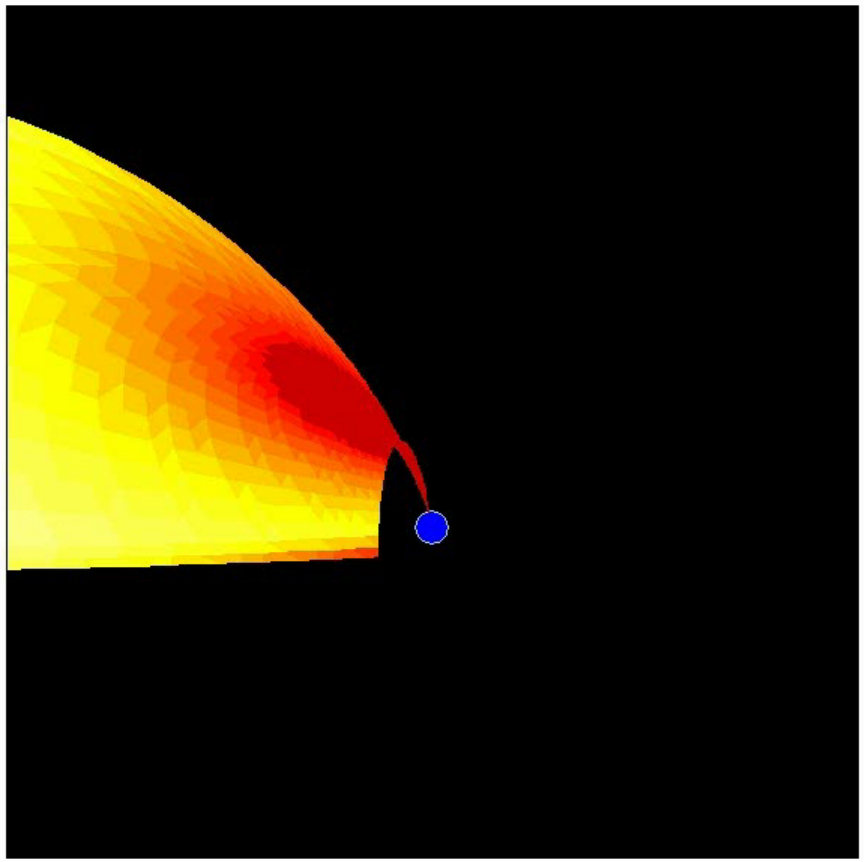


Accretion dip and curtain

Dip phase indicates azimuth of coupling region

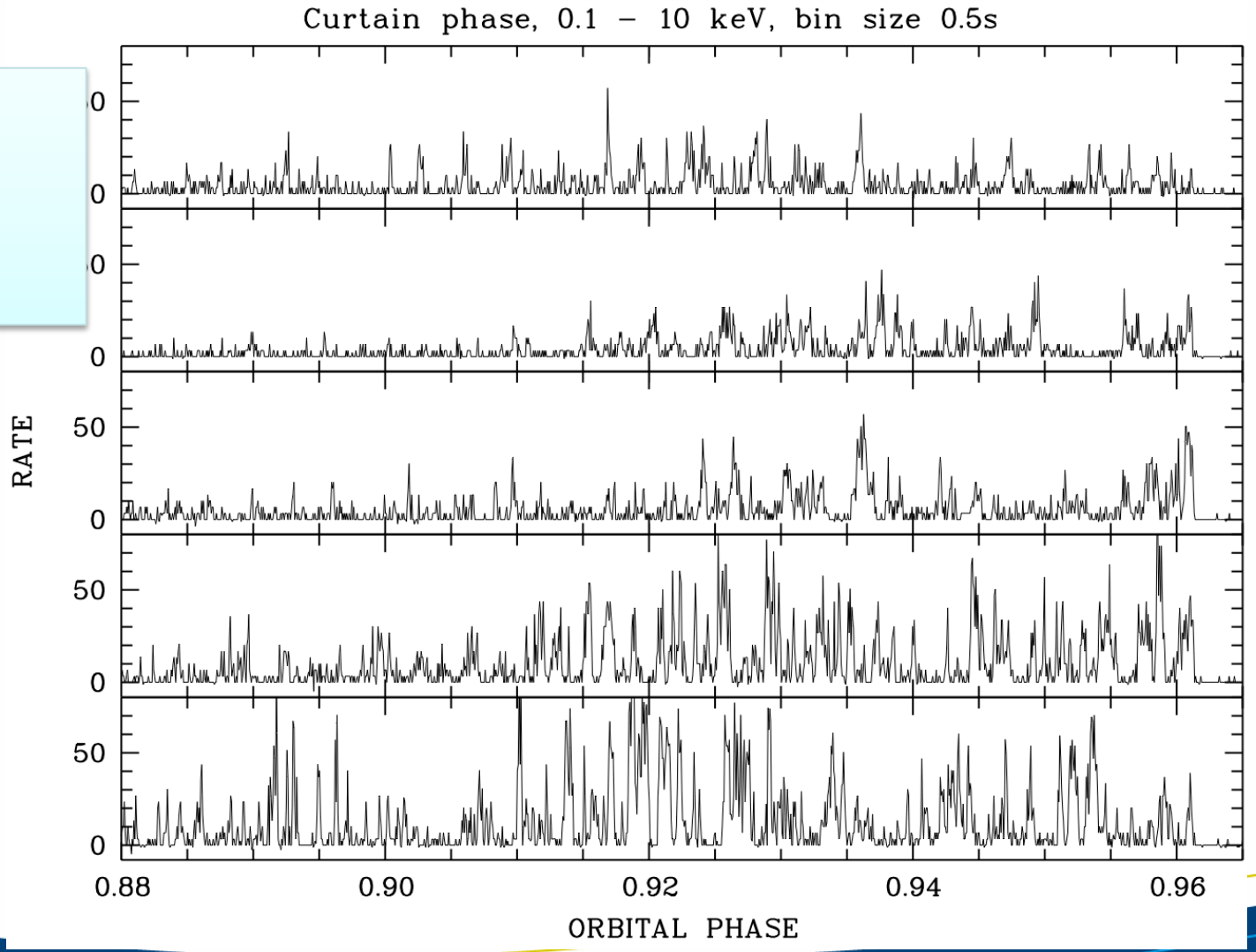


Curtain variability → instabilities along the ballistic trajectory

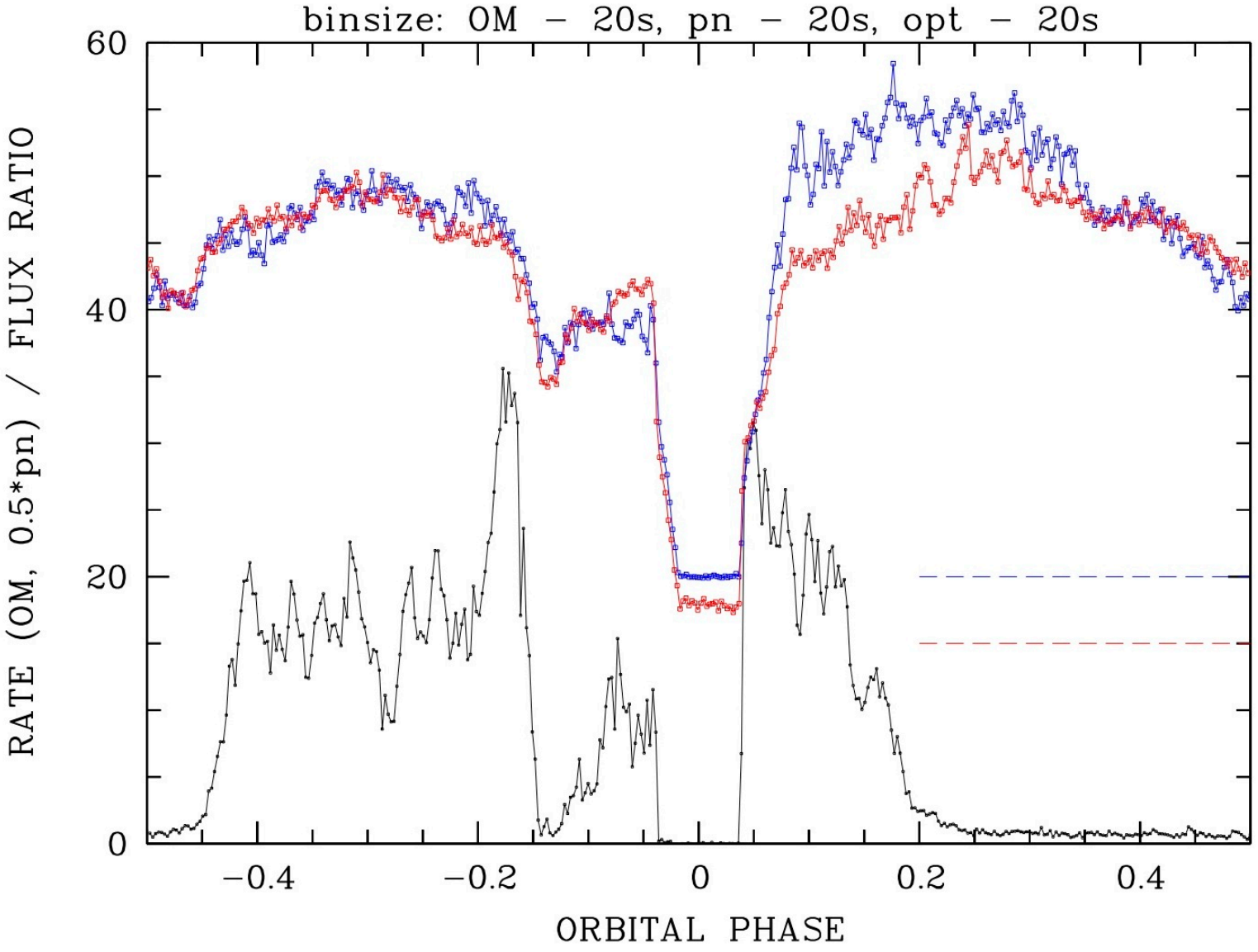


Variable absorption in the curtain

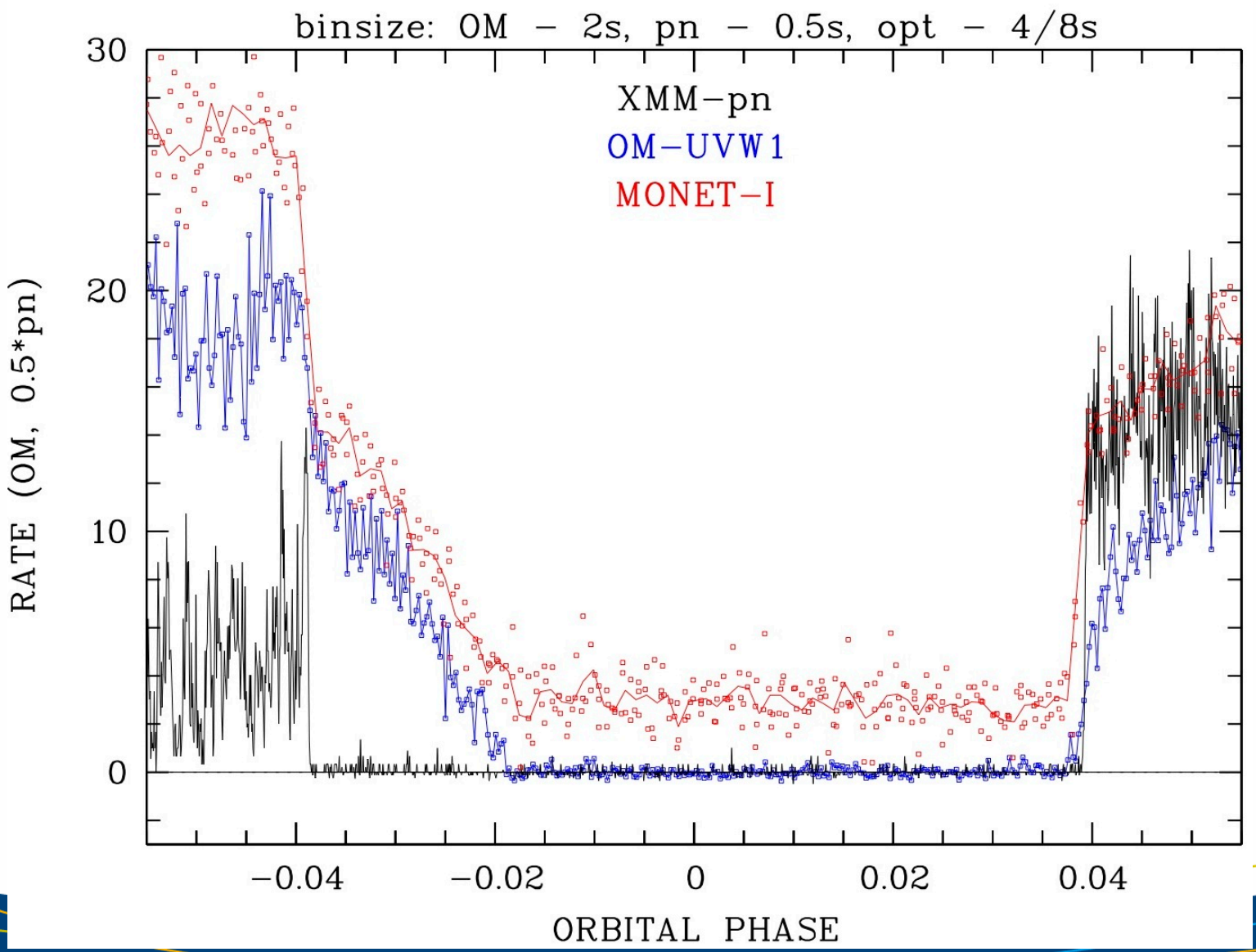
Temporal and/or spatial?



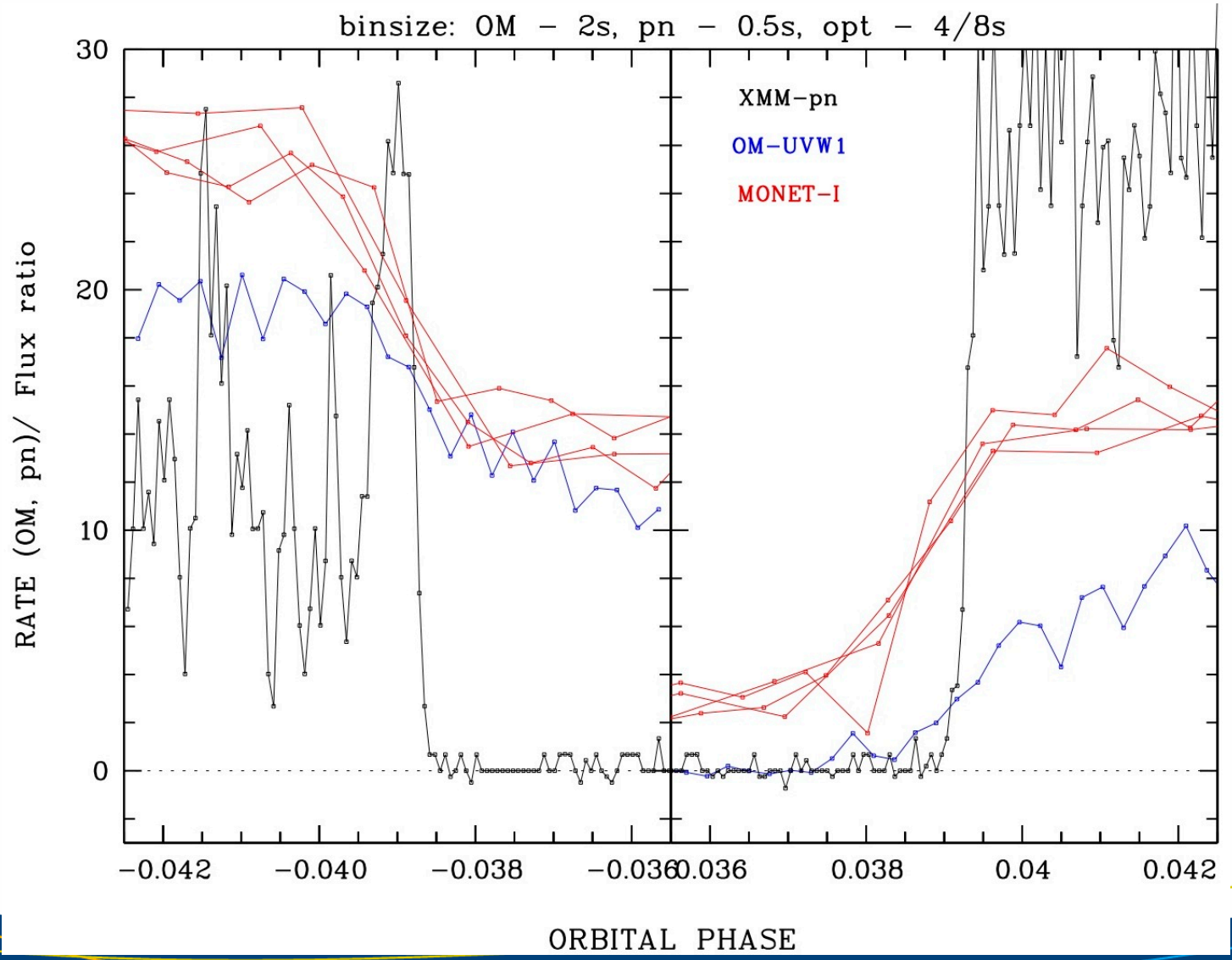
XMM/OM/MONET simultaneous



XMM/OM/MONET simultaneous



XMM/OM/MONET simultaneous



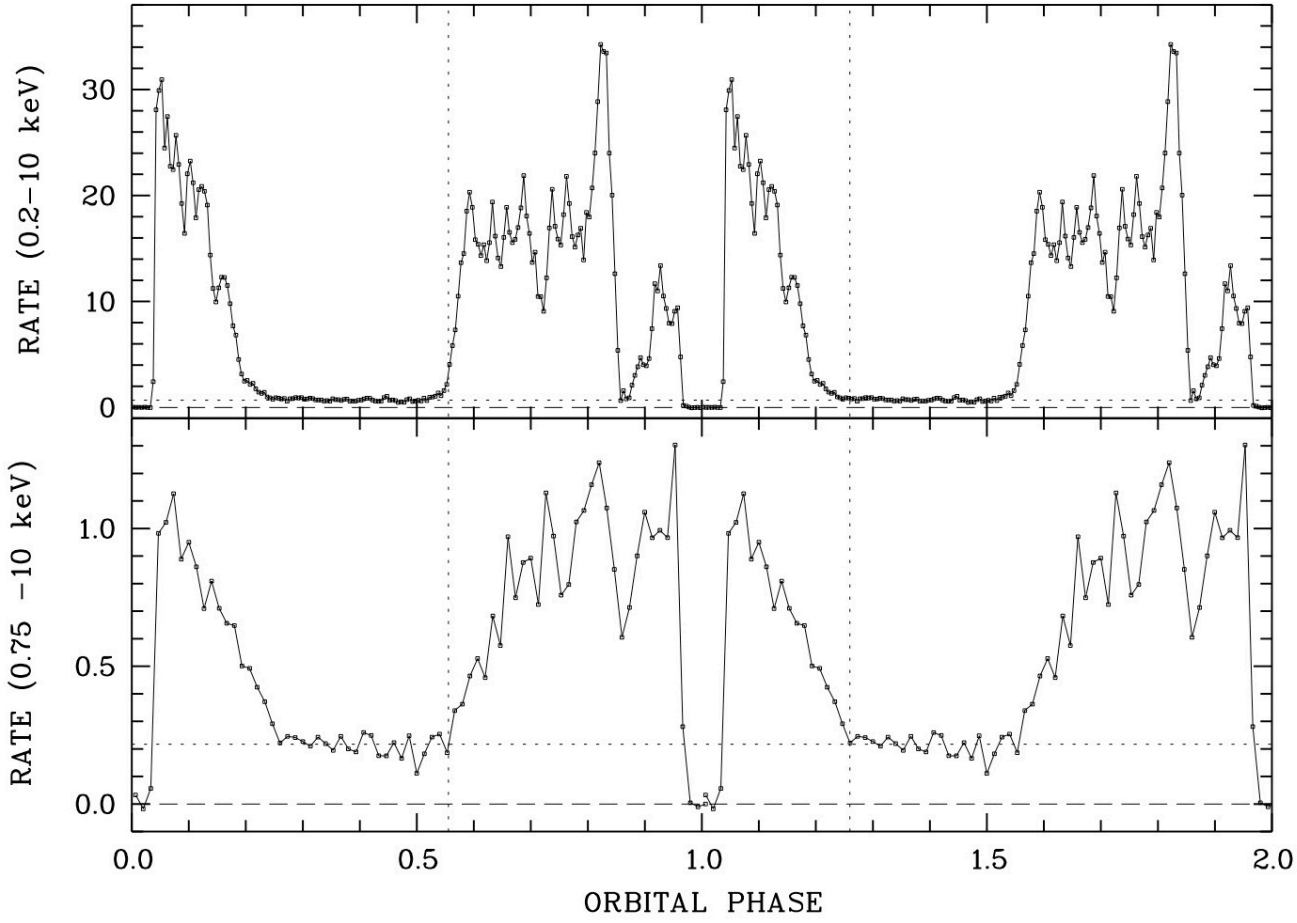
Optical & X-ray eclipse timings 2013

- MONET (80cm) & Inastars (28cm) eclipse timing agree within 0.3+- 3.3 sec
- Optical egress precedes soft X-ray egress by 4.0+-2.0 s

	Ecl length (s)	Egress length (s)
MONET	583.3 (2.8)	6 - 8
XMM	585.62 (0.35)	2

1s == 500 km for given masses, inclination and period

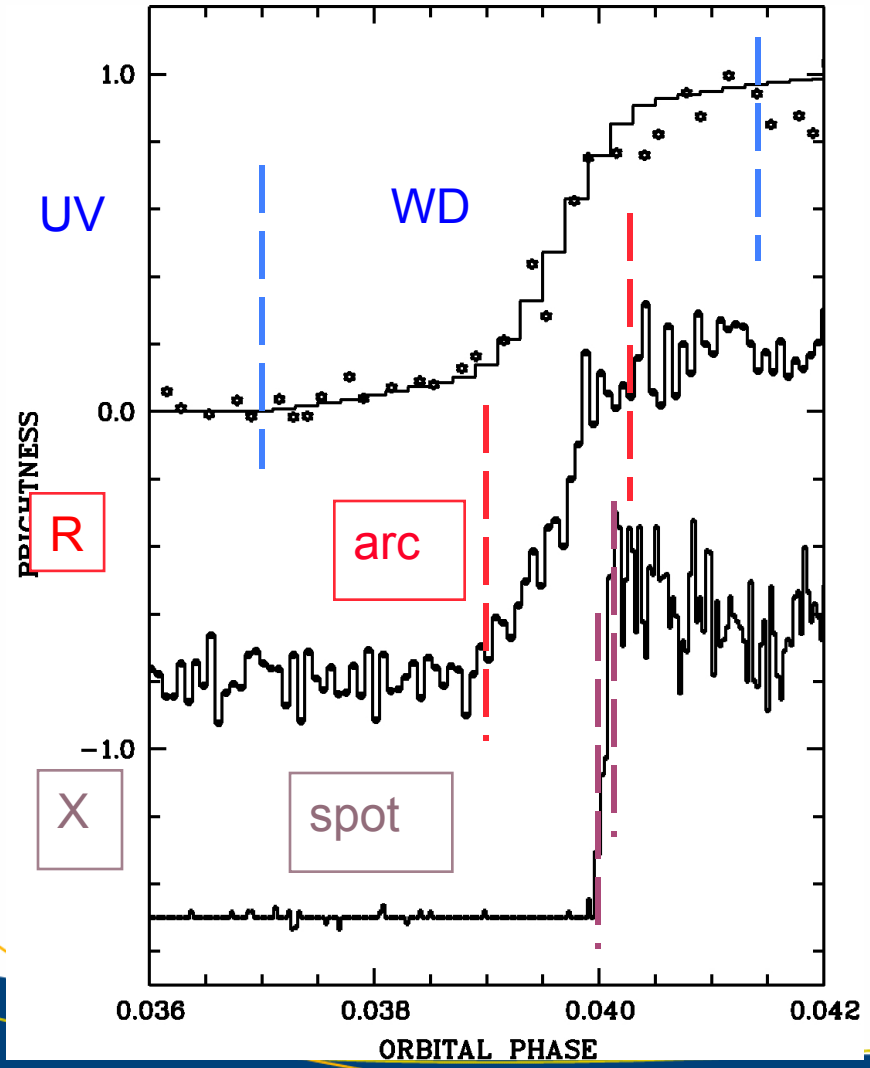
Soft vs hard X-ray emission



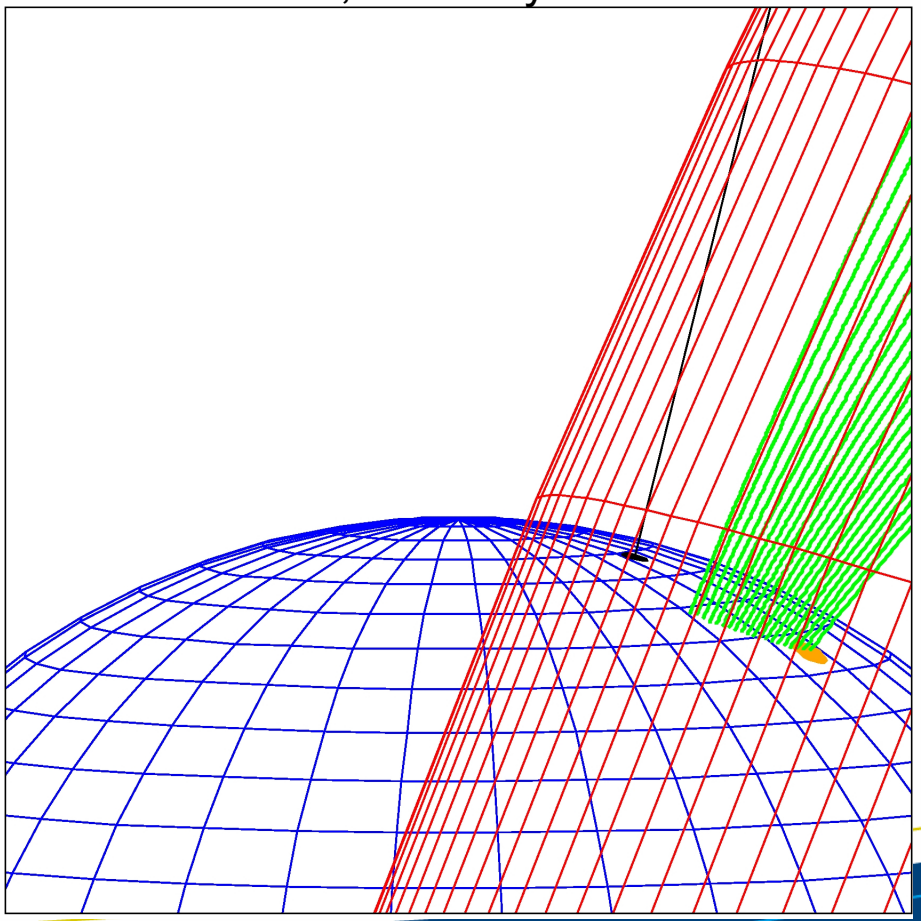
Centroid of LCs → Azimuth/longitude of source

Soft: az = 46^{o} Hard: az = 30^{o}

Accretion arc in HU Aqr



Optical synchrotron emission
kT ~ 5 – 10 keV, no X-rays!



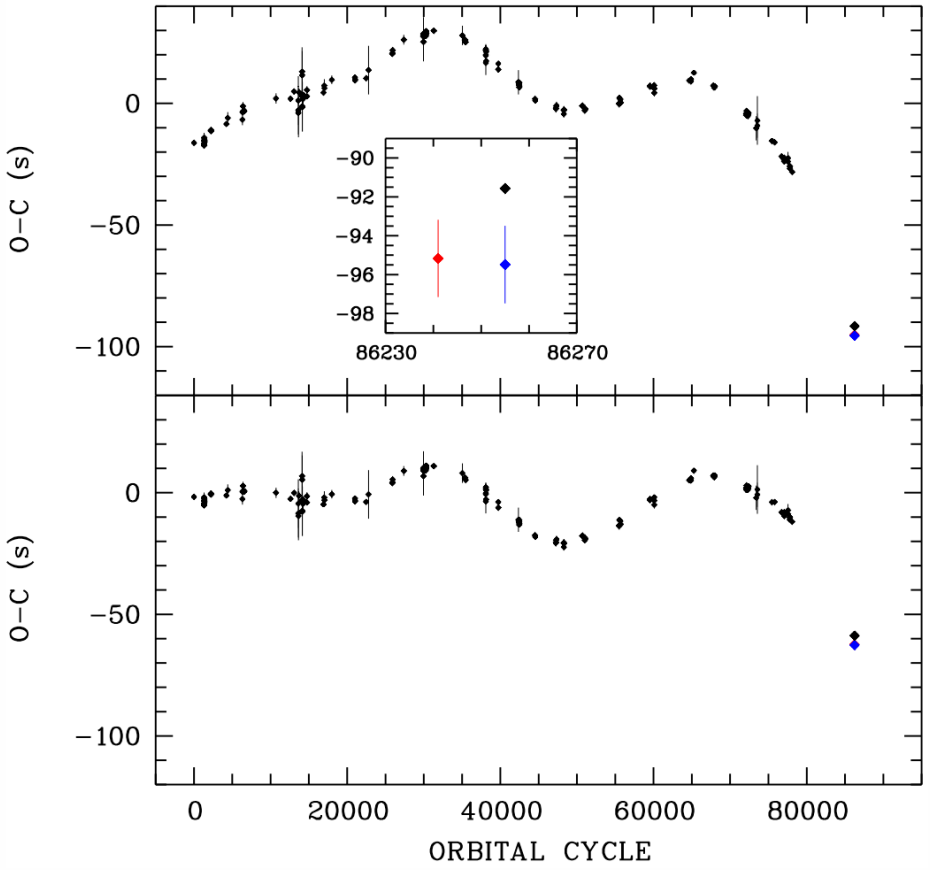
Updated eclipse arrival times

Planetary model needs revision (if applicable at all)

$$\Delta T \simeq \frac{2M_3 G^{1/3}}{c}\left(\frac{P_3}{2\pi(M_1+M_2)}\right)^{2/3}$$

M_3 ~ 0.33 M_{Jup}/s

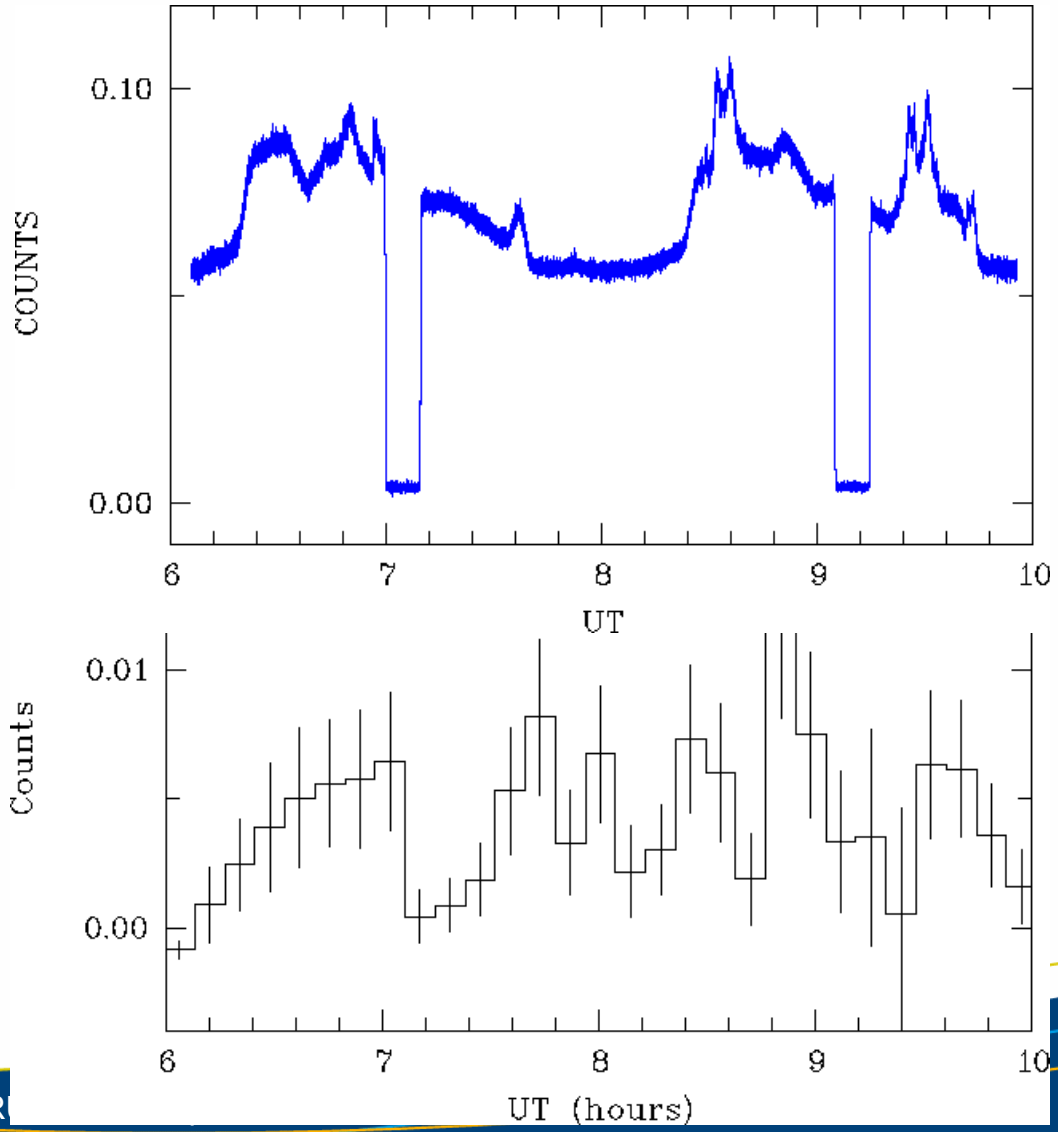
(M_1+M_2=1M_o, P=6.9yrs)



WD and spot timing? XMM/VLT low state observations

I. VLT-UT3 (ULTRACAM g) May 2005

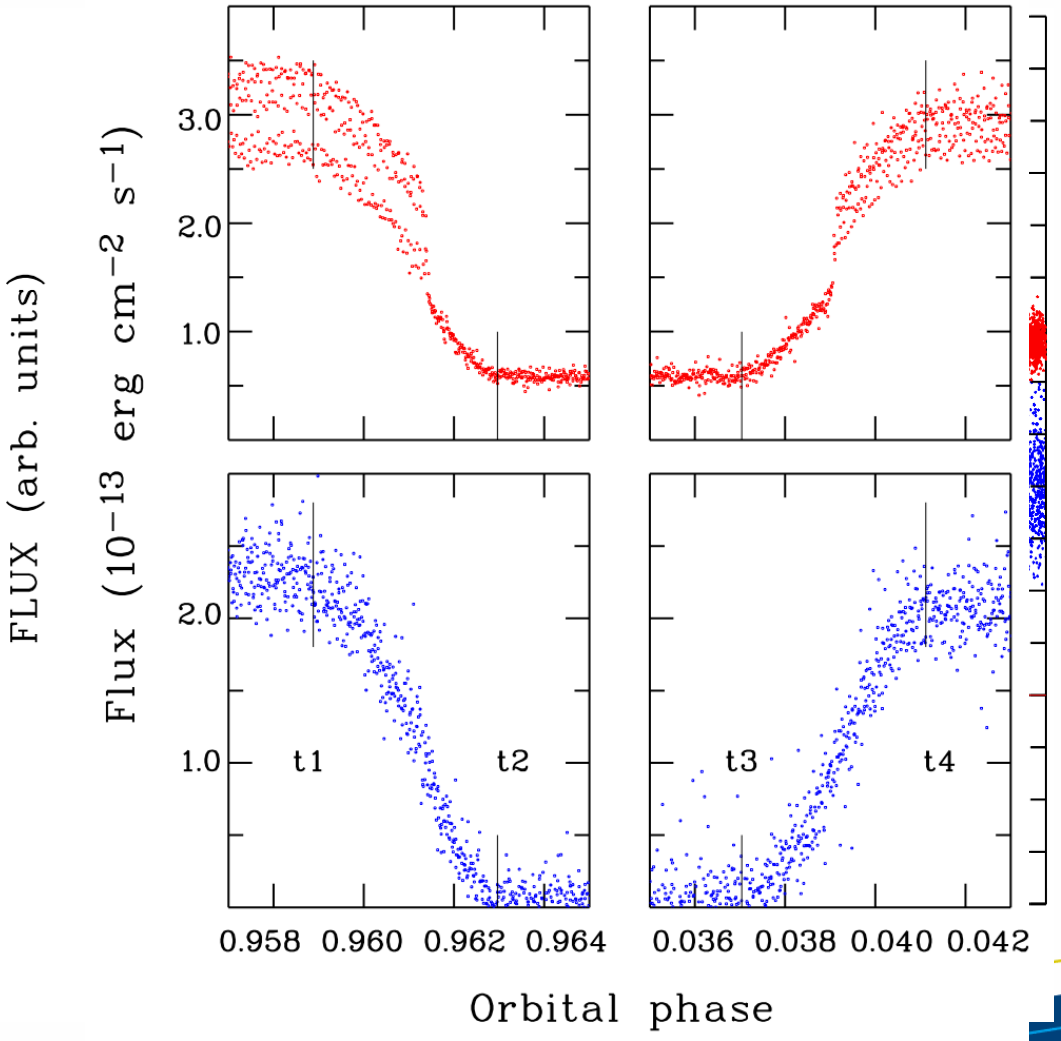
II. XMM EPIC pn



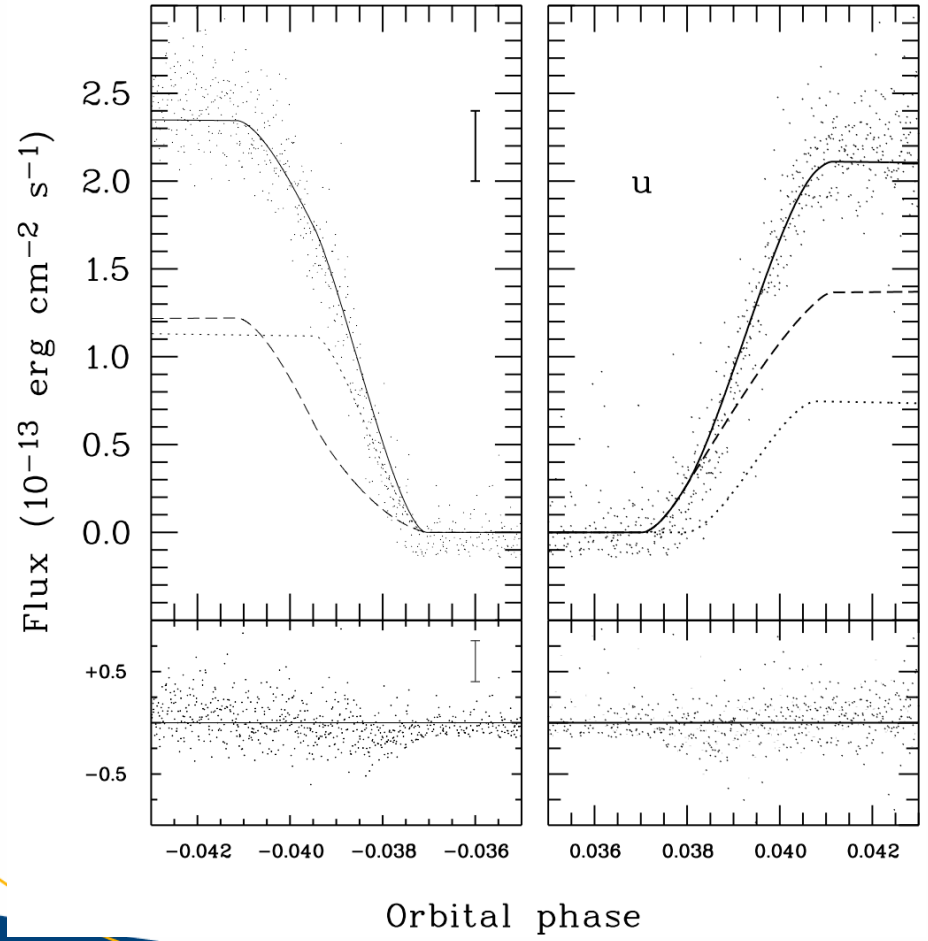
Schwarz et al 2009, A&A

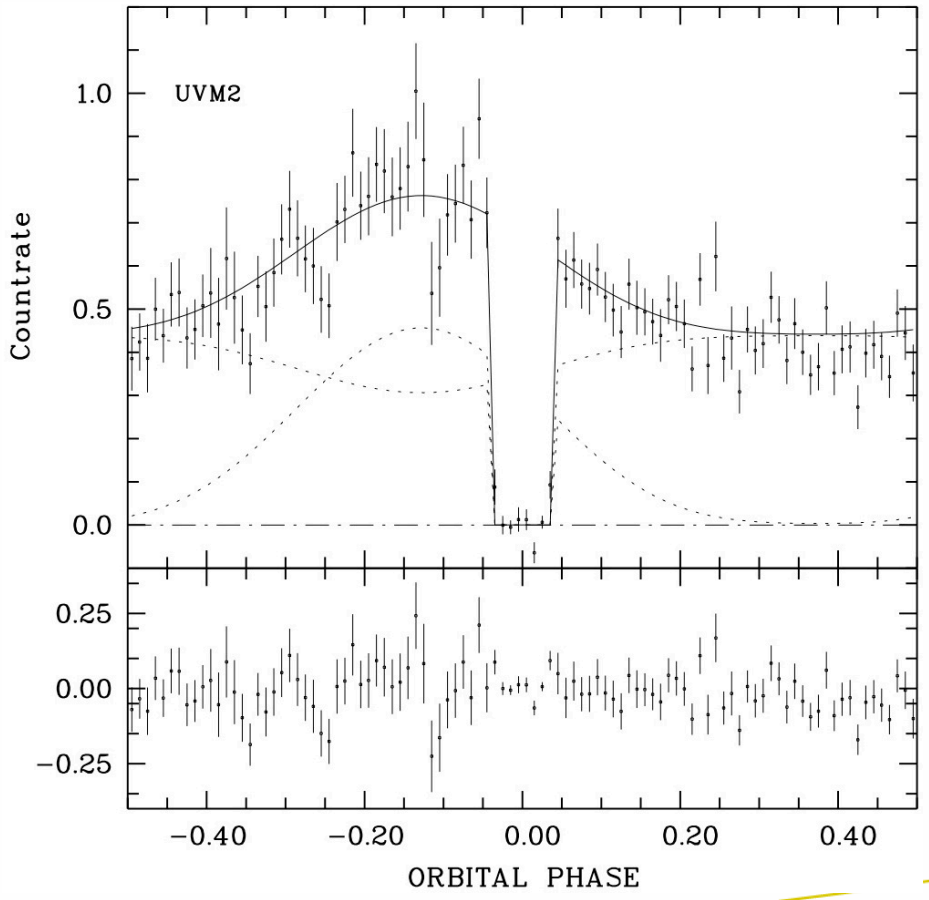
ULTRACAM (r,u) light curves

- Cyclotron radiation Remaining weak accretion (az = 20°)
- Remnant heat from previous accretion episode (az = 46°)

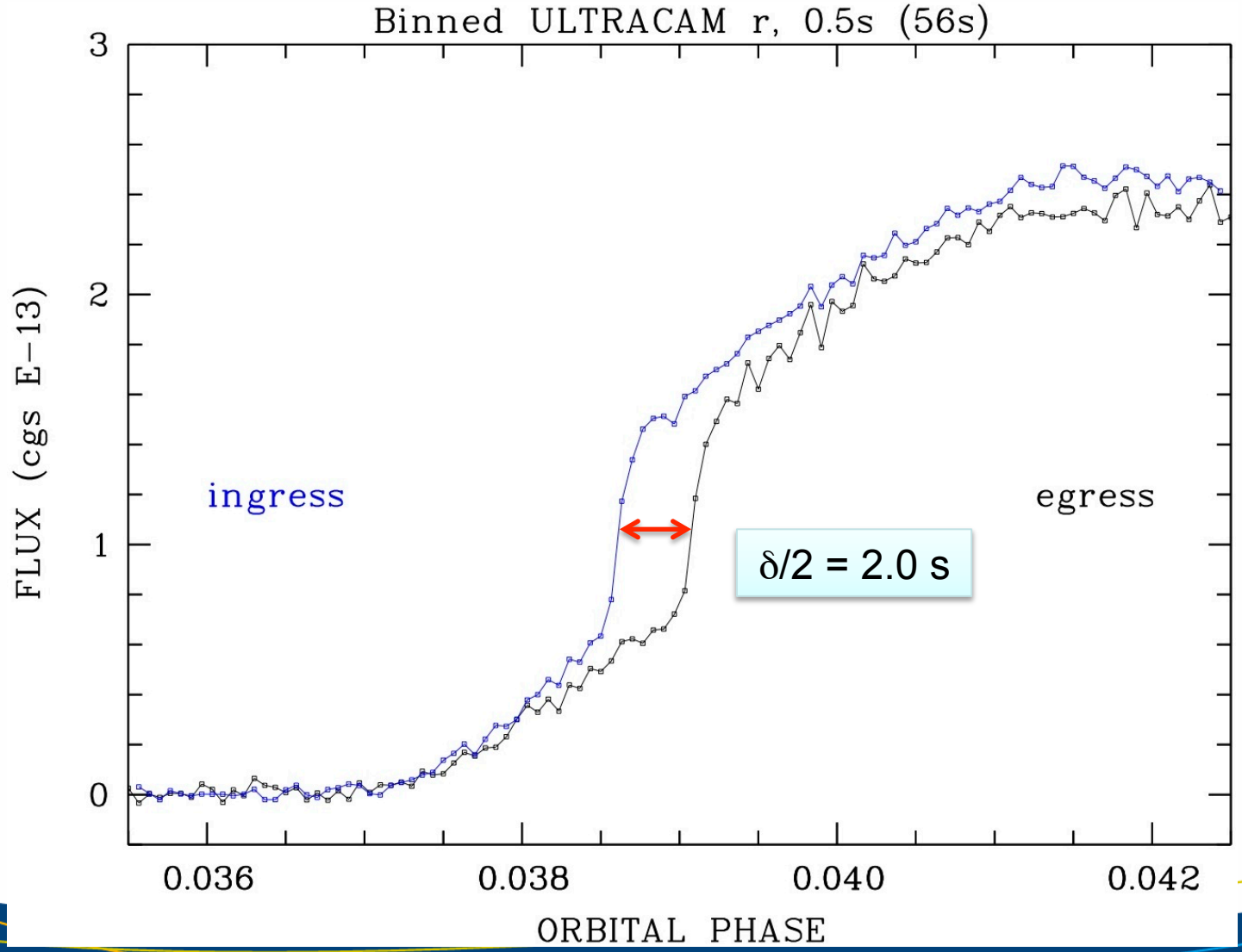


Spot+WD model fits optical eclipse and OM-UV data at same time





Phase offset of accretion spot determines latitude

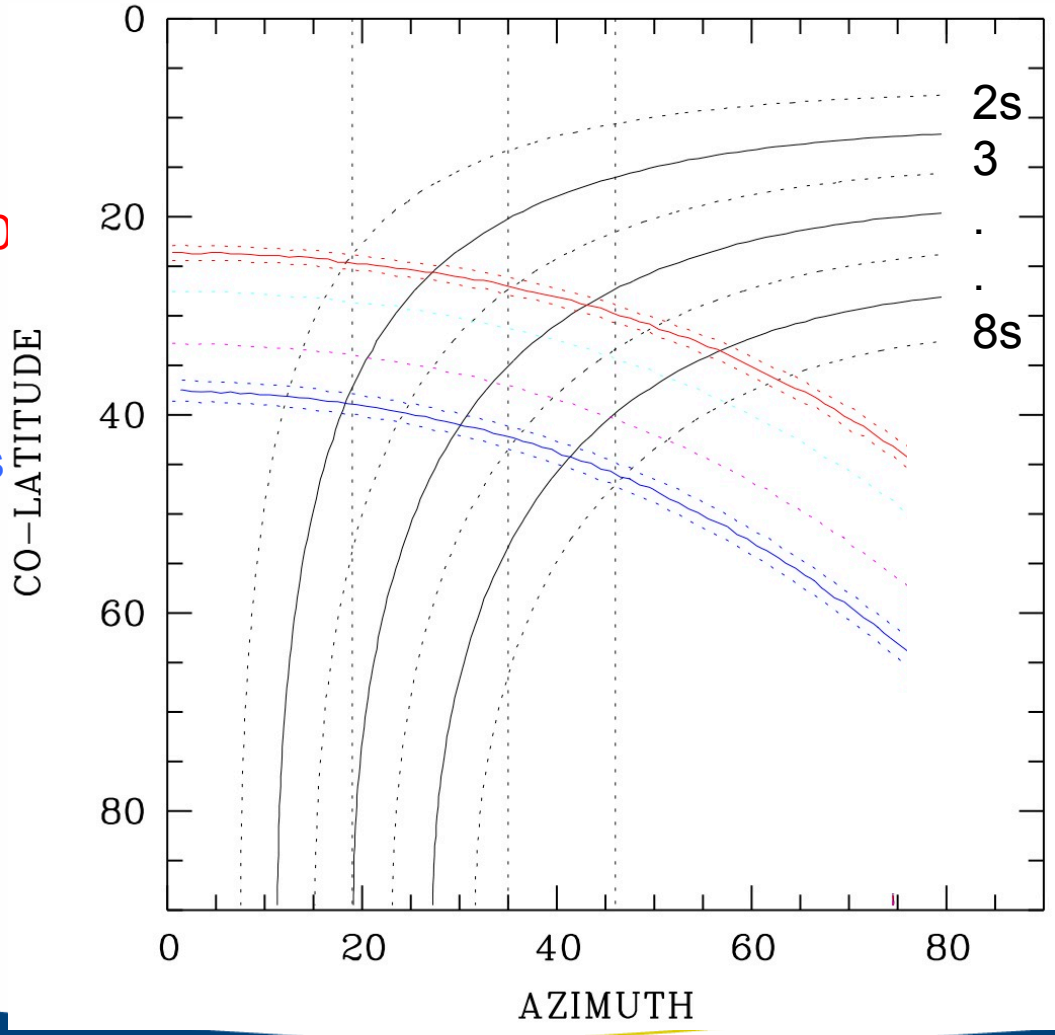


Phase offset & eclipse length determine latitude at given azimuth

Eclipse length

ULTRACAM r 20
582.72 +- 0.2 s

XMM SX 2013
585.62 +- 0.35 s



eclipse offset

$M_1 = 0.83\ M_o$
$M_2 = 0.187\ M_o$
i = 86.6

Resume

- 1st ever high precision X-ray eclipse length measured
- Phase offset determined:
  X-ray vs optical, spots vs. WD
- Scheme developed: Spot timing→ WD timing
- Distinct accretion regions resolved:
  cyclotron arc, HX spot, SX spot at different azim.
- One-planet model ruled out
- Eclipse timing variations not understood