X-Ray Eclipse Time Delays in *4U2129+47*

E. Bozzo

M. Falanga, A. Papitto, L. Stella, R. Perna, D. Lazzati
G. Israel, S. Campana, V. Mangano, T. Di Salvo, L. Burderi

Università di Roma Tor Vergata, Italy

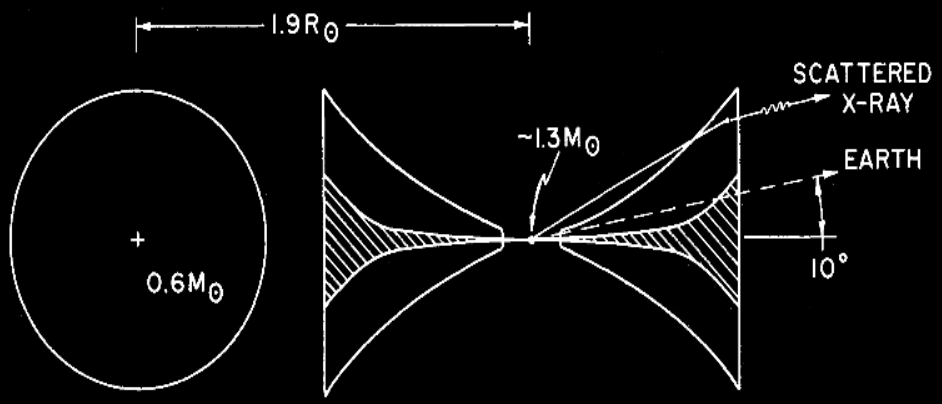
Osservatorio Astronomico di Roma, Italy

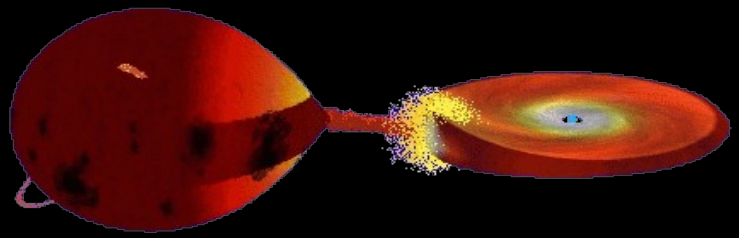
The X-ray Universe - Granada, Spain 2008

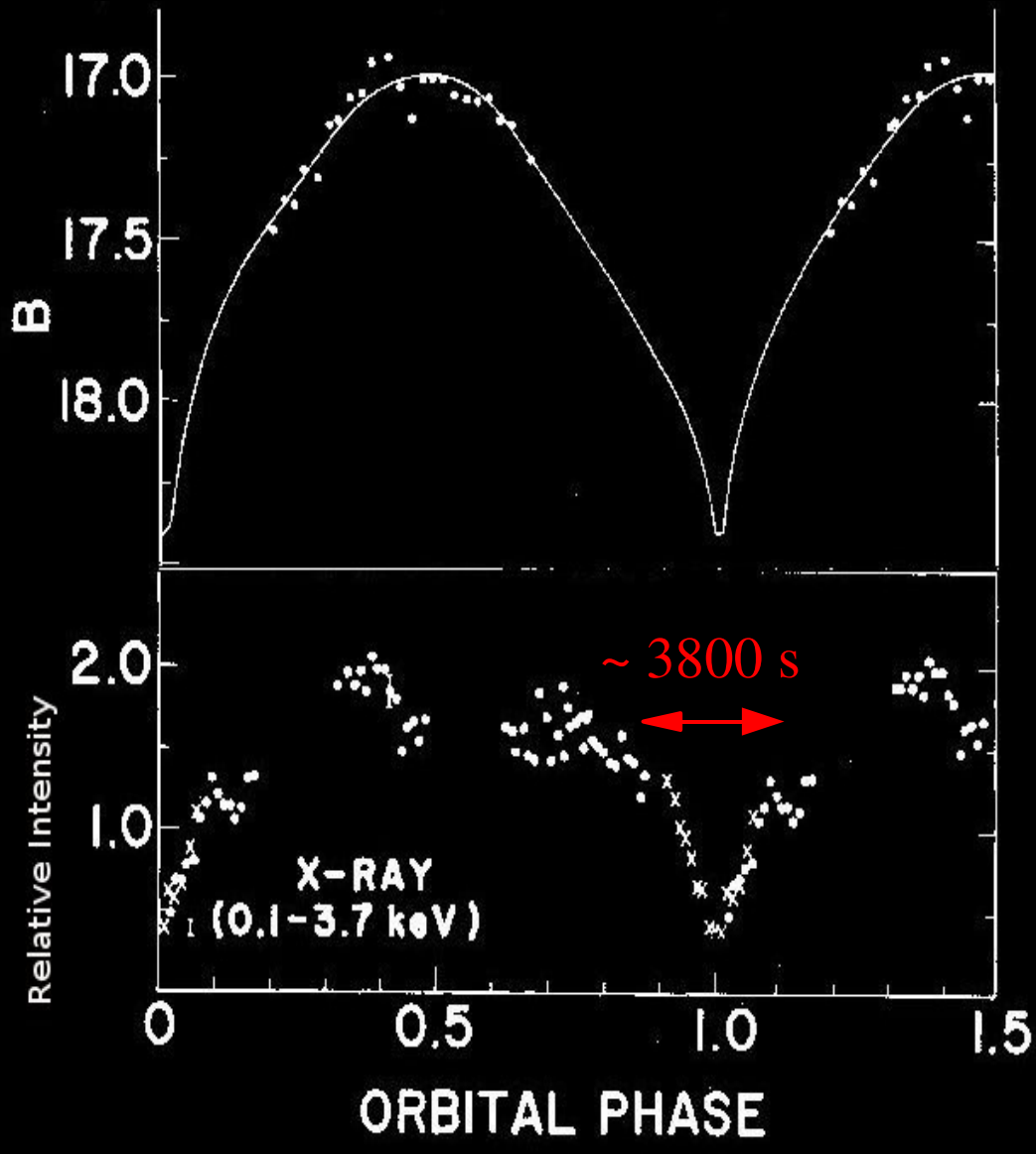
Active State

1978 --> Discovered with Uhuru, Active State, $F_X \sim 3 \times 10^{-10}$ erg cm^{-2} s^{-1} (Formann et al. 1978)

1979-1982 --> Optical + X-ray





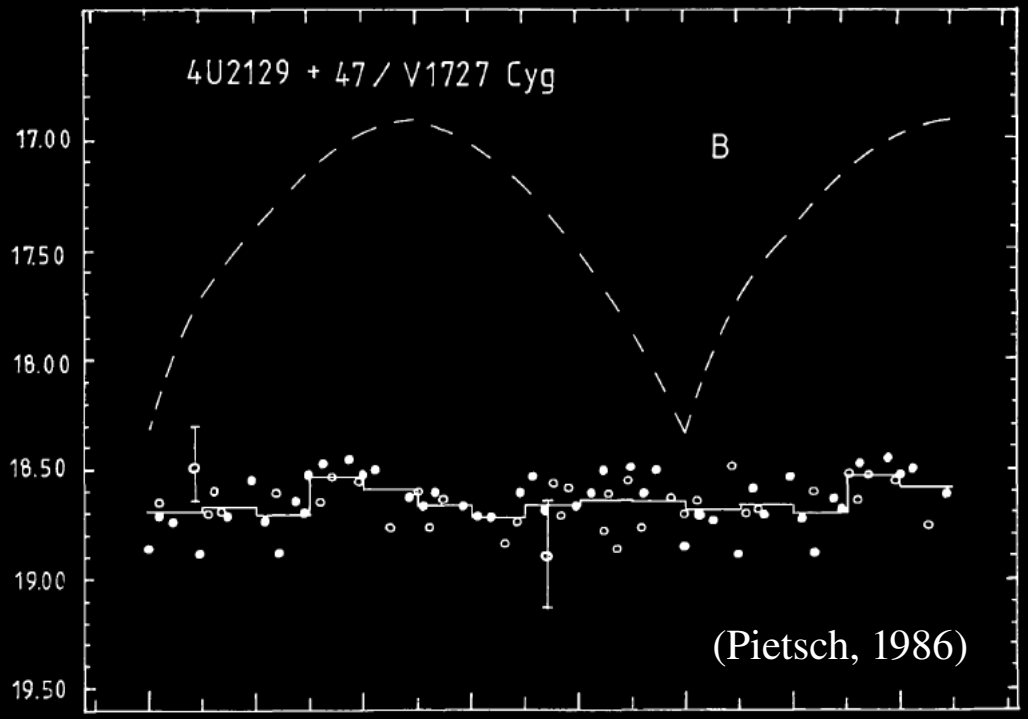


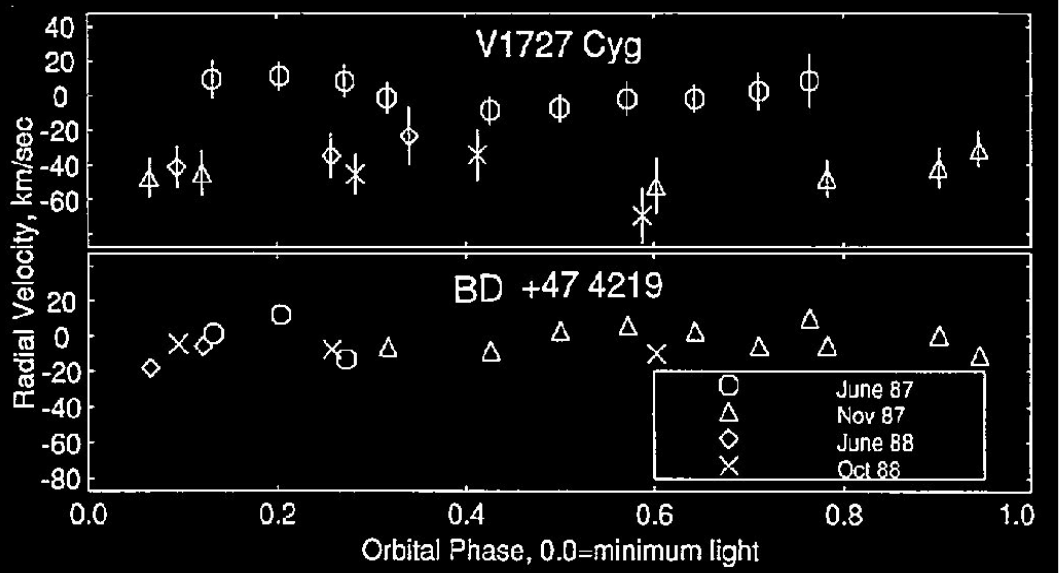
D~6.3 kpc P_{orb} ~ 5.2 hr

Accretion Disk Coronae

(Thorstensen, 1979; McClintok et al., 1982)

Inactive State $F_X \sim 10^{-12}$ --> Spectrum of the Companion Star?





1983 – 1989 --> Flat Light Curve
Spectrum of F IV star

Dynamical Interaction?

Long Term Radial Velocity Shifts
~40 km s^{-1}

--> Orbital period ~30 d

Bothwell et al. (2008); Garcia et al., (1989)

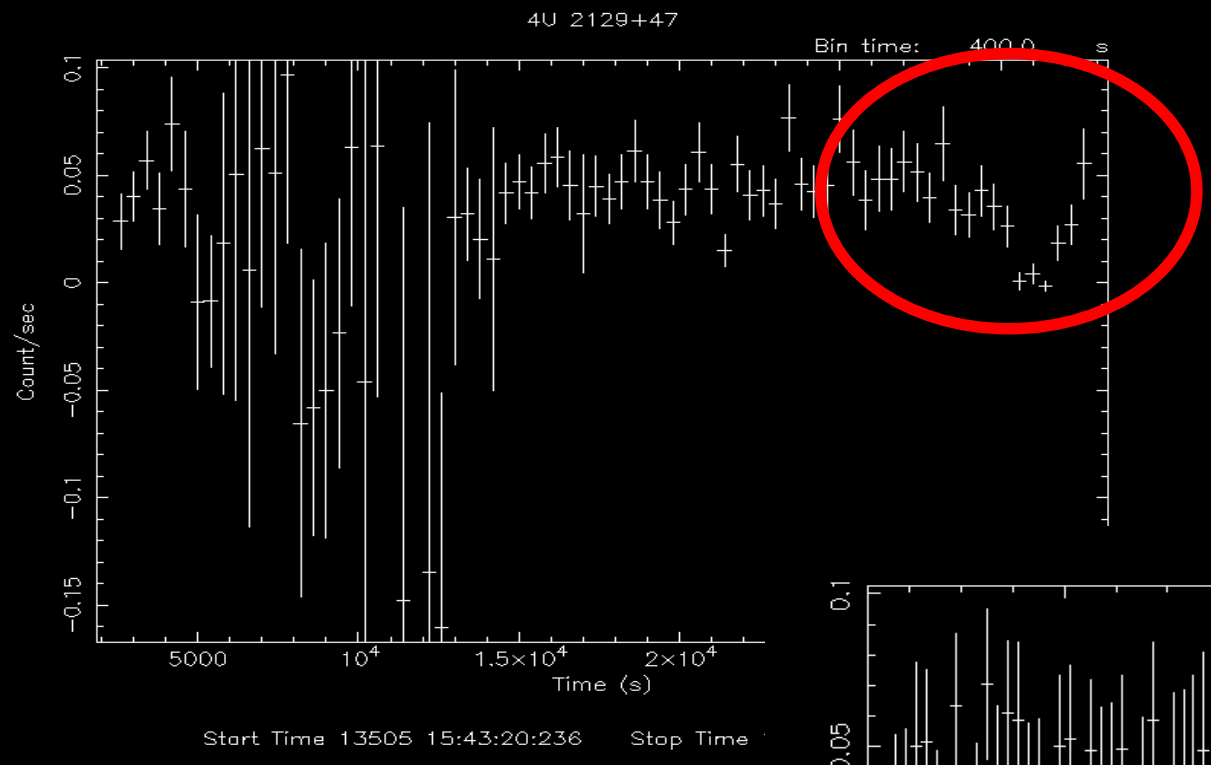
2000 --> CHANDRA POSITION: F star and binary coincident to within 0.1"

(Nowak et al., 2002)

Our XMM-Newton Observations

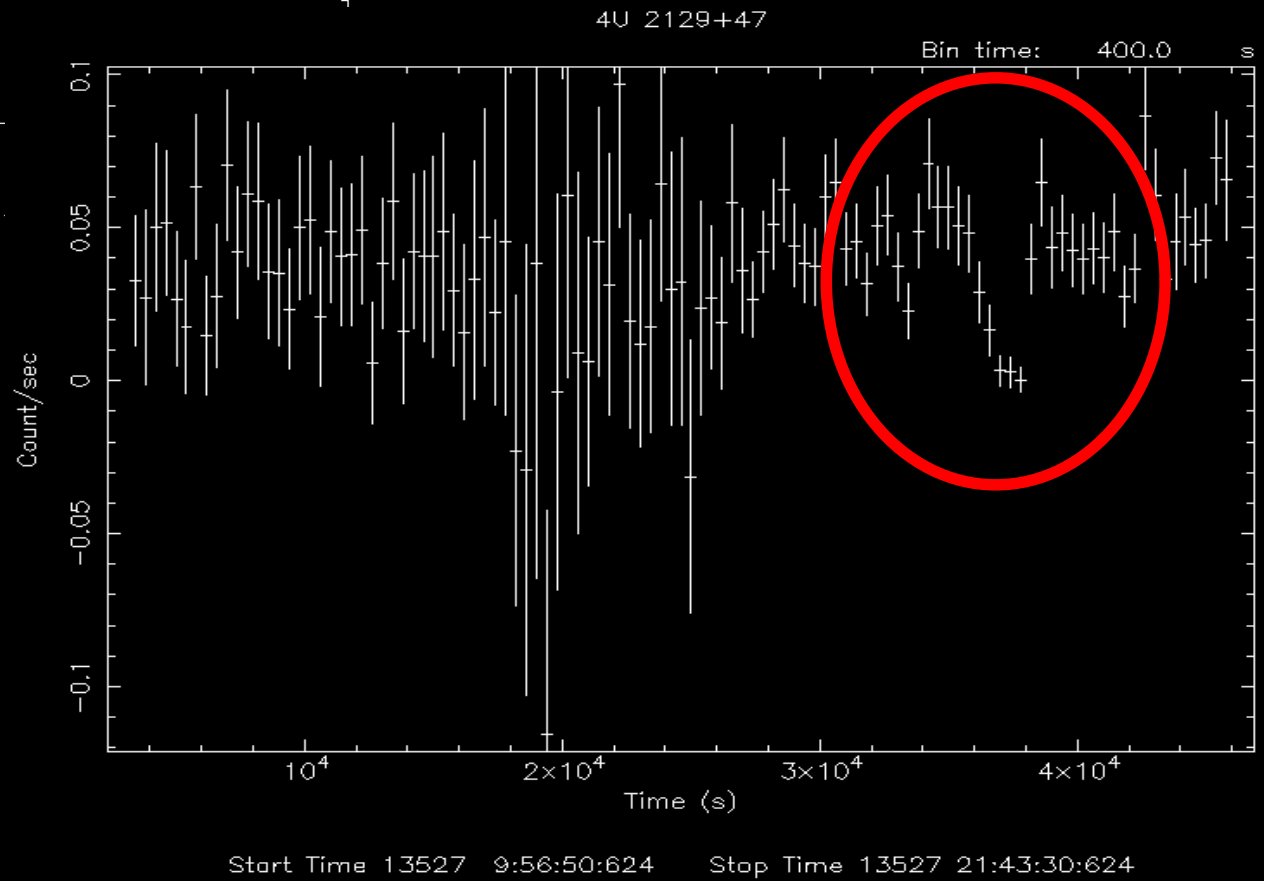
15 May 2005

$T_0 = 2453506.4825(3)$ JD

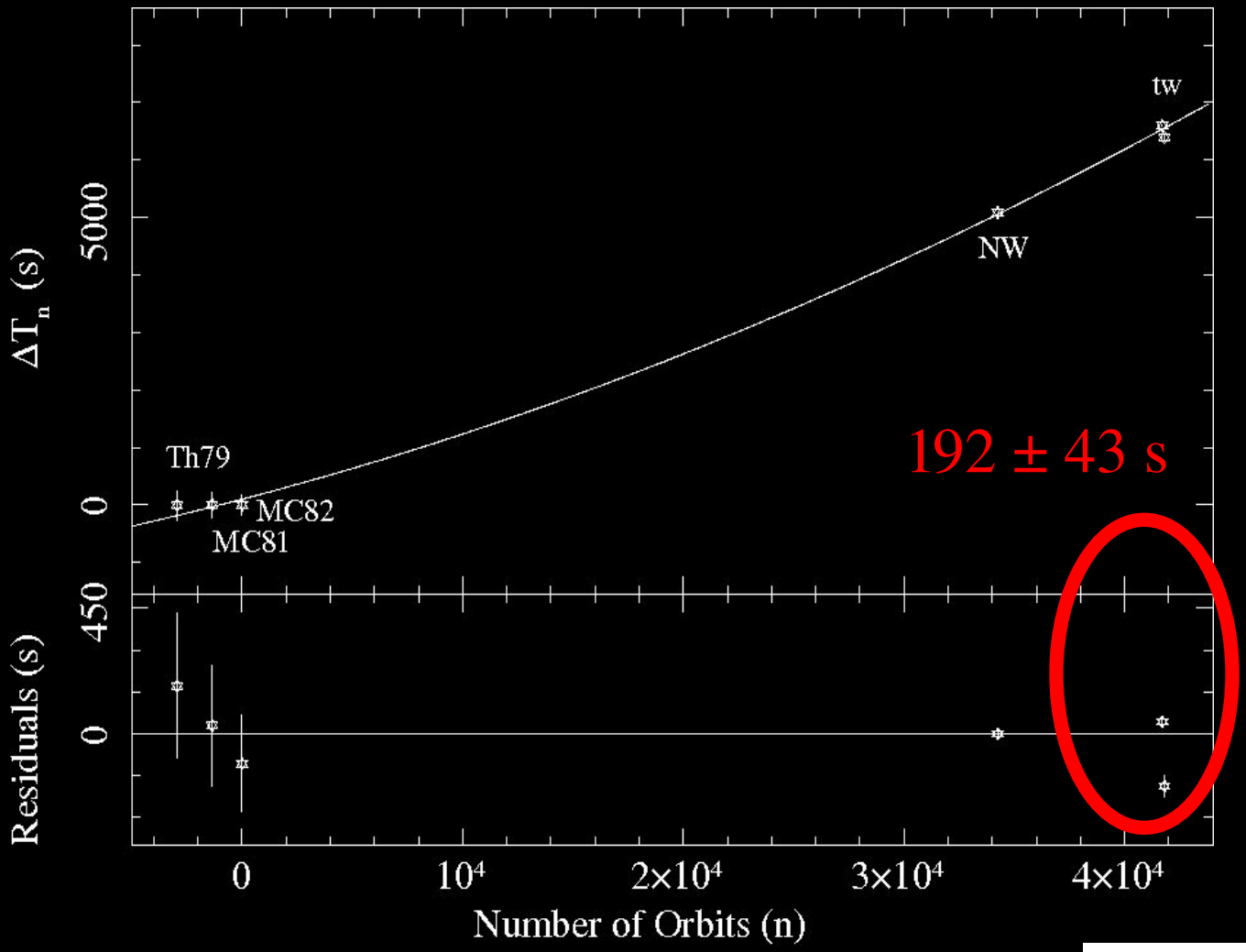


6 June 2005

$T_0 = 2453528.3061(4)$



The Observed-Calculated residuals technique



$$\Delta T = T_n - T_{n\text{-pred}}$$

FIT with:

$$\Delta T = \alpha + \beta n + \gamma n^2$$

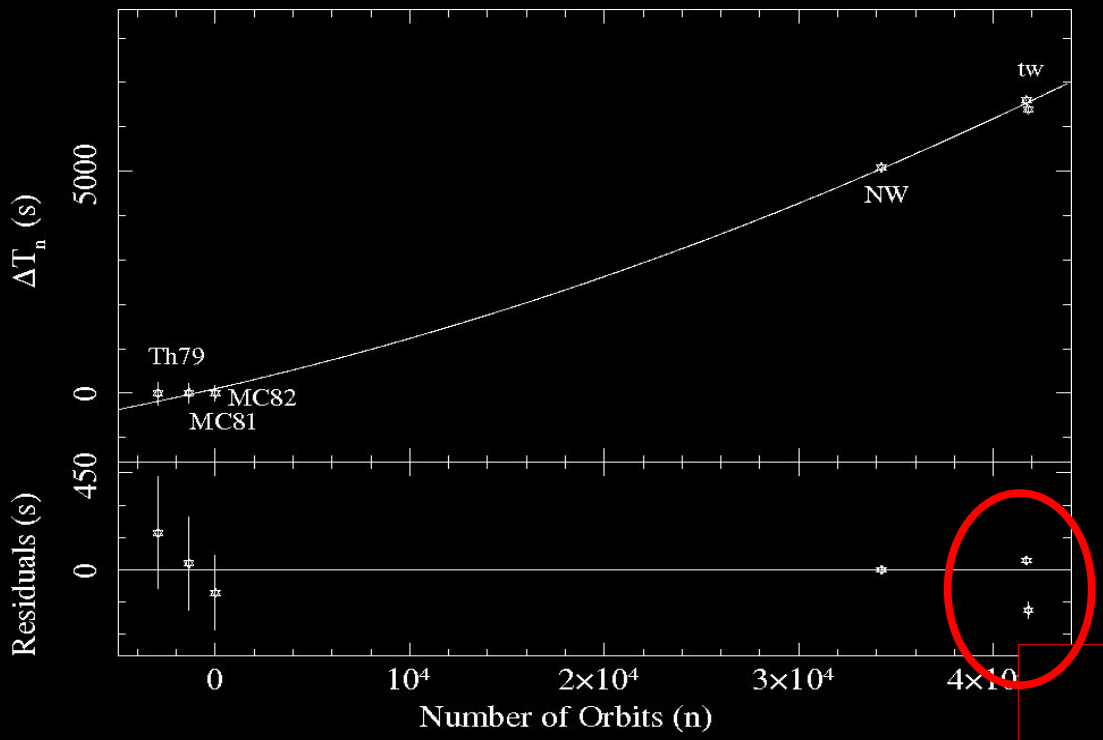
T_{ref} Correction

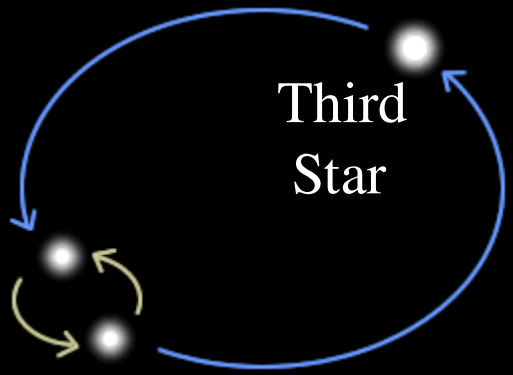
P_{ref} Correction

$\dot{P}_{orb}$

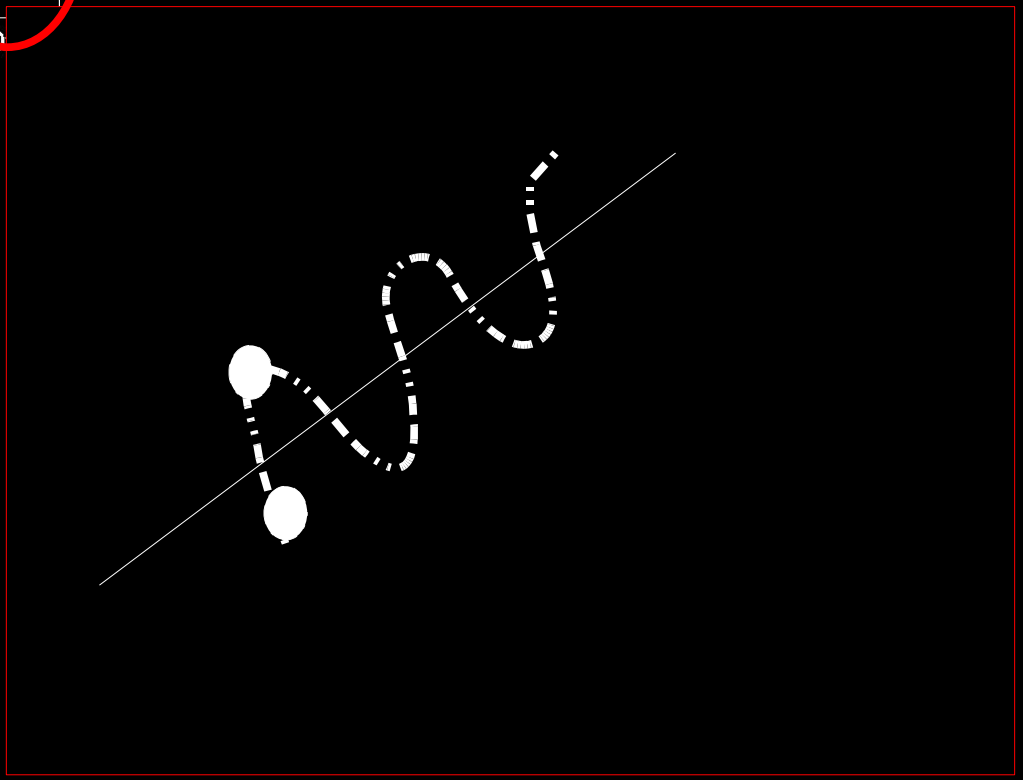
T_{ref} (JD)	2444403.7443±0.0013
P_{orb} (s)	18857.594±0.007
$\dot{P}_{orb}$ (s s^{-1})	(1.03±0.13)×10^{-10}
$P_{orb}\dot{P}^{-1}_{orb}$ (yr)	(5.8±0.7)×10^6
χ^2/d.o.f.	25.6/3

Triple System !

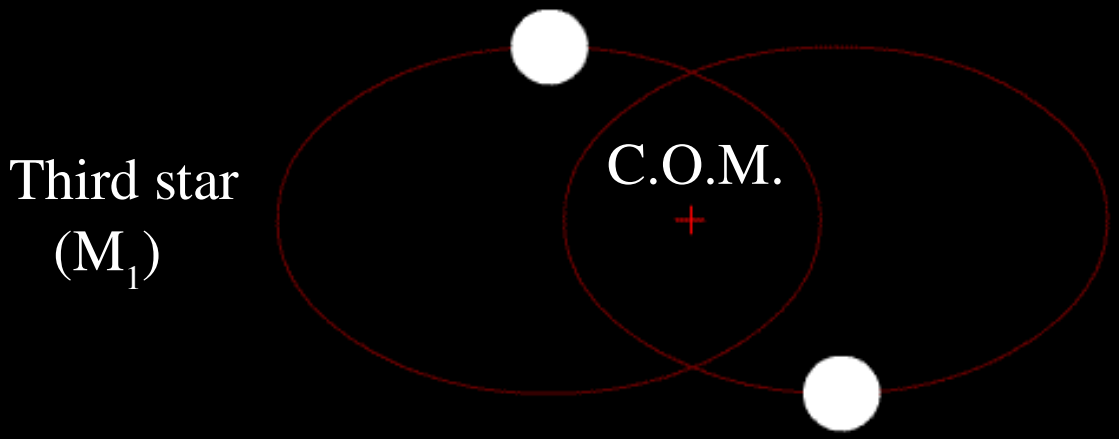


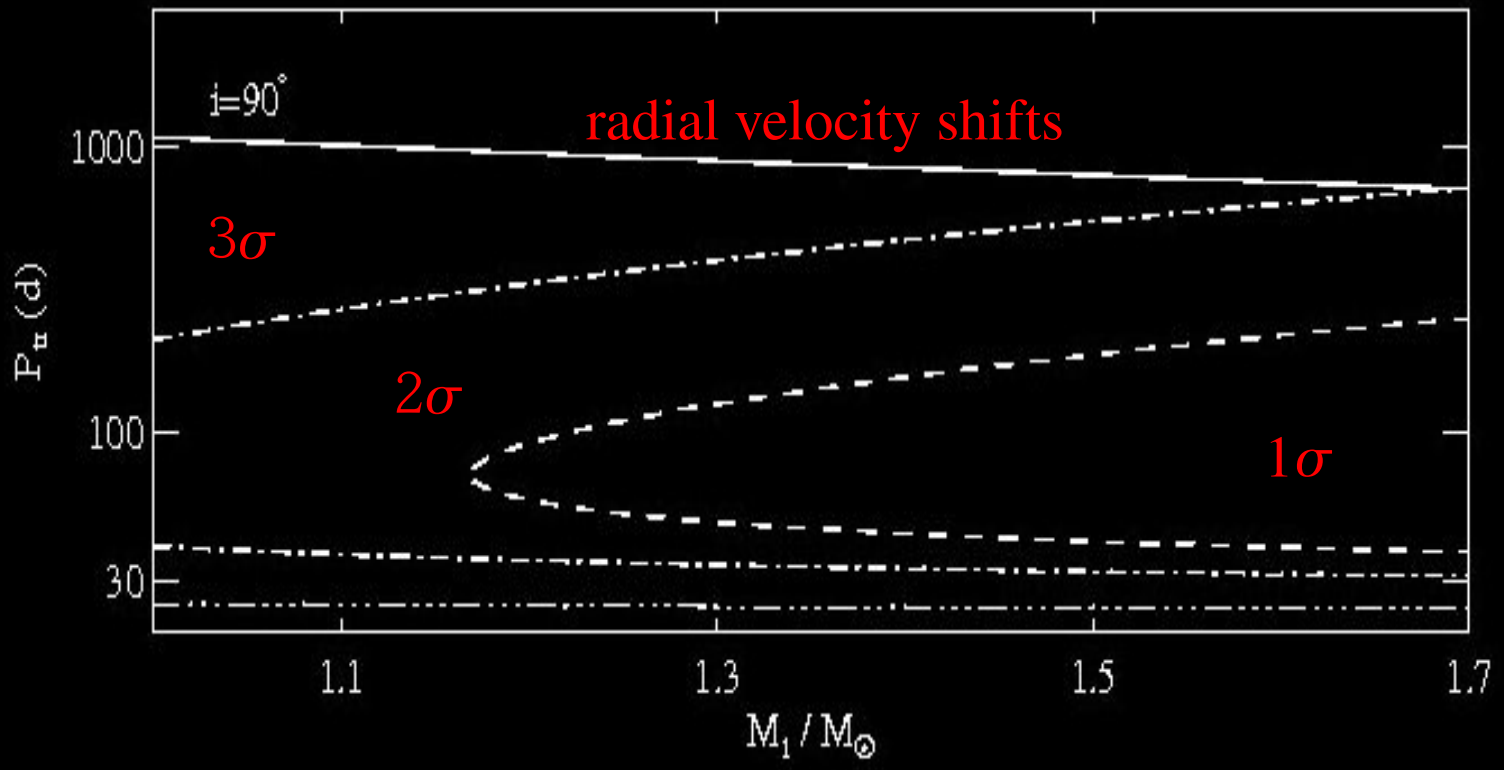


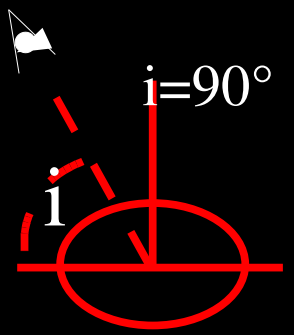
The period of this oscillation
is the period of the eclipsing binary
around the center of mass of the triple
system



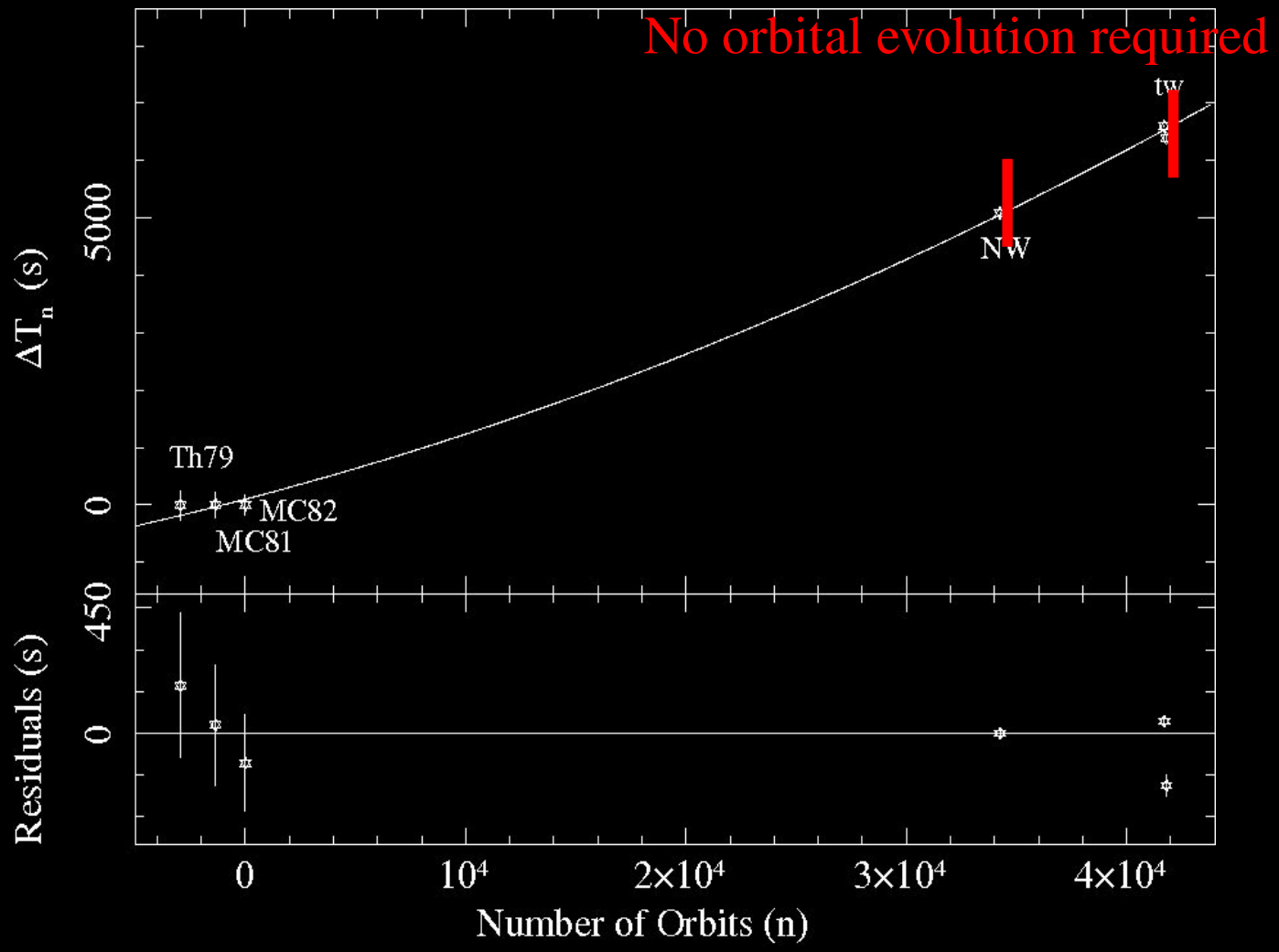
Constraints on the triple system orbital period

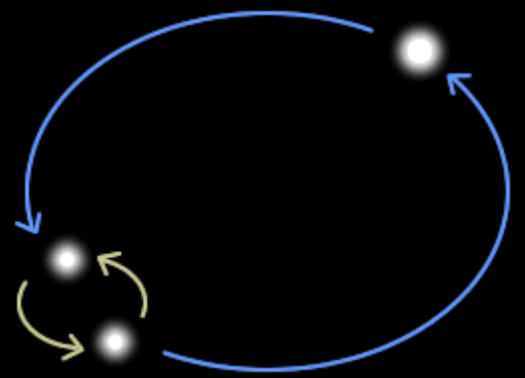






Triple System Consequences...





Third Star

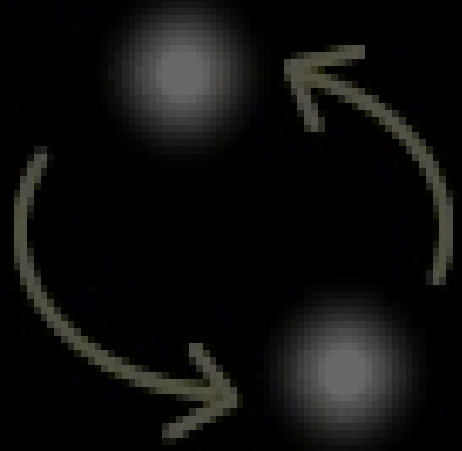
Eclipsing Binary

Conclusions

4U2129+47 is (likely) part of a triple system
(first system of this kind showing this strong evidence)

But we still need...

- Monthly spaced X-ray observations: sinusoidal modulation triple parameters (Mass, Period, ...)
- Optical observations: radial velocity

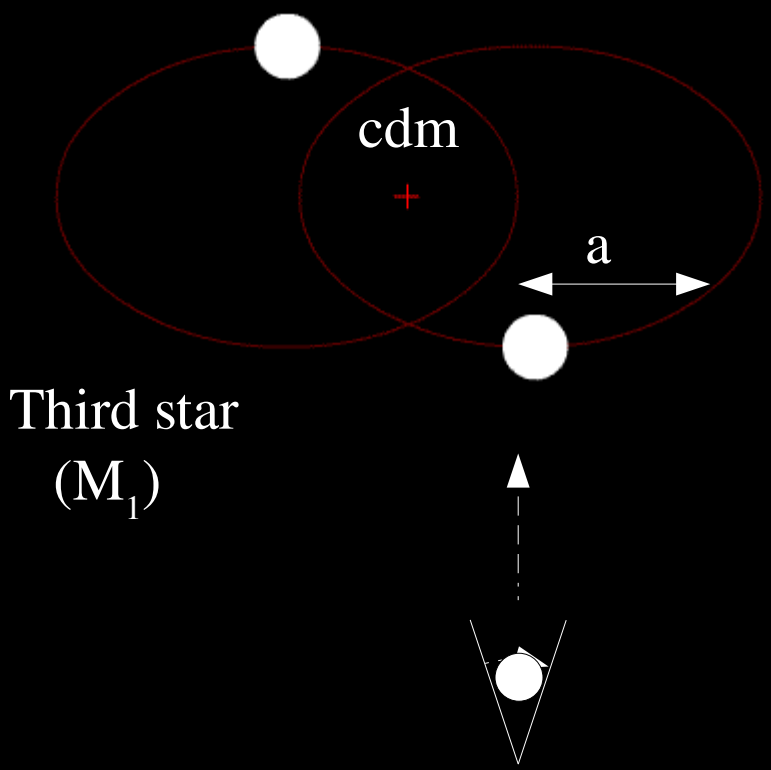


→ To reveal the real nature of the orbital period evolution

→ To measure Modulation in the X-ray eclipse times.

E. Bozzo thanks **ESA** and **ESA Education** for conference grant support.

Constraints on the triple system orbital period

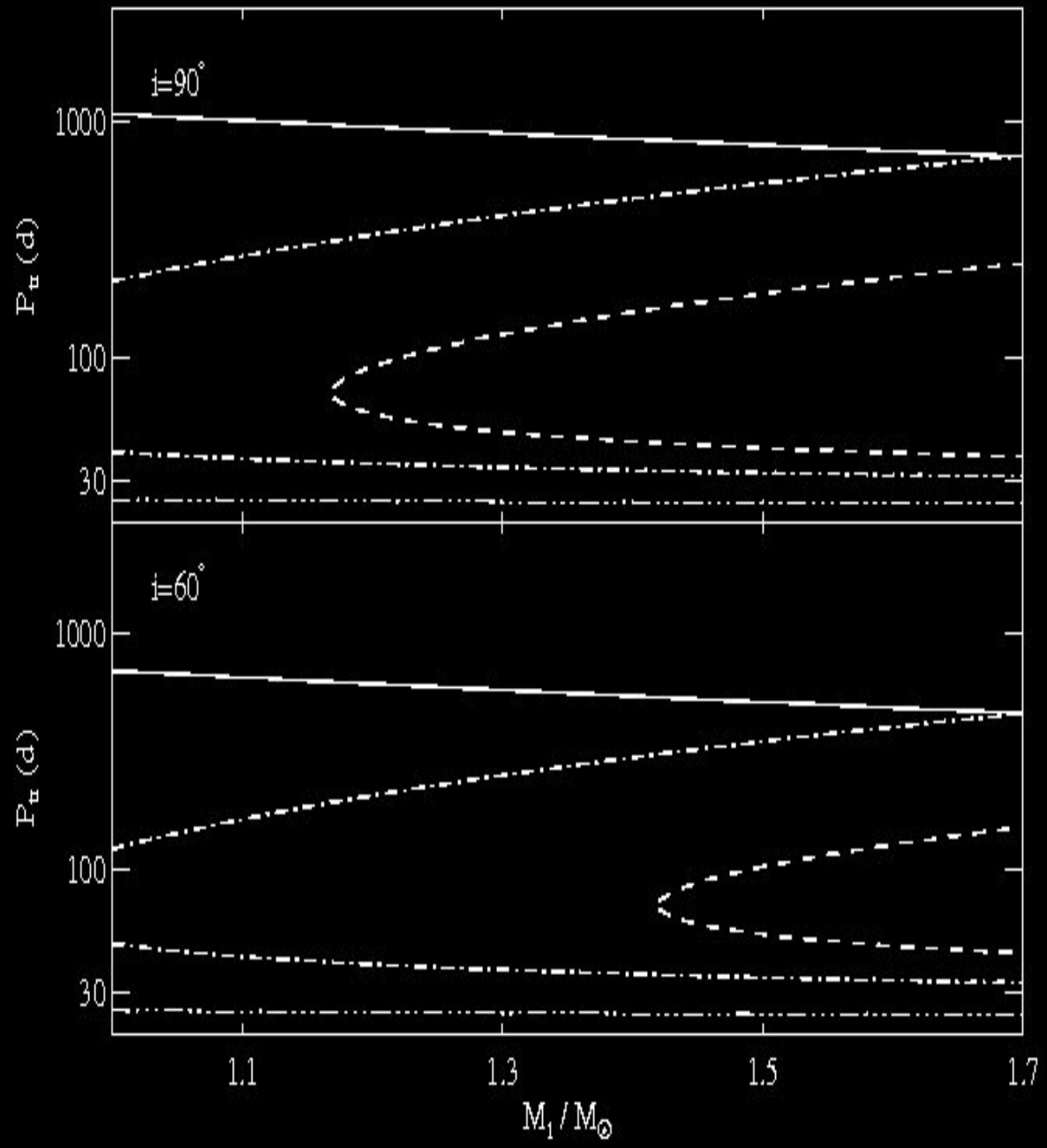


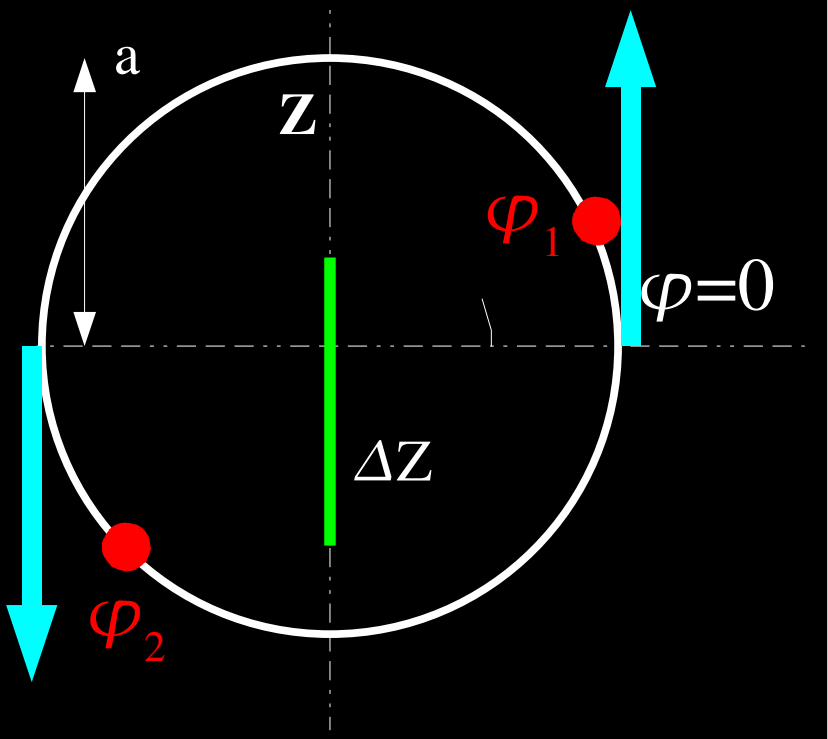
$$\tau = \Delta Z / c$$

$$\Delta Z = a\,[\sin(\varphi+\Delta\varphi)-\sin(\varphi)]$$

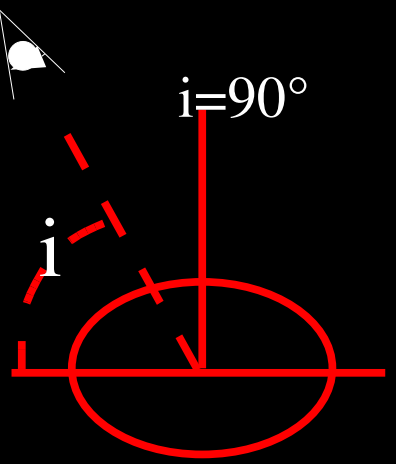
$$\Delta\varphi = \varphi_1 - \varphi_2 \sim 22\ \mathrm{d} / P_{orb}$$

Constraints on the triple system orbital period





$v_R = \Omega a_1 = 2\pi P_{orb}^{-1} a_1 < 20$ km s^{-1}



Summary

- **4U2129+47 history from ~1978 to ~2005**
  - Active State
    - Observations
    - Accretion disk Coronae Source (ADC)
  - Inactive State
    - Observations up to 2000
    - Interpretations

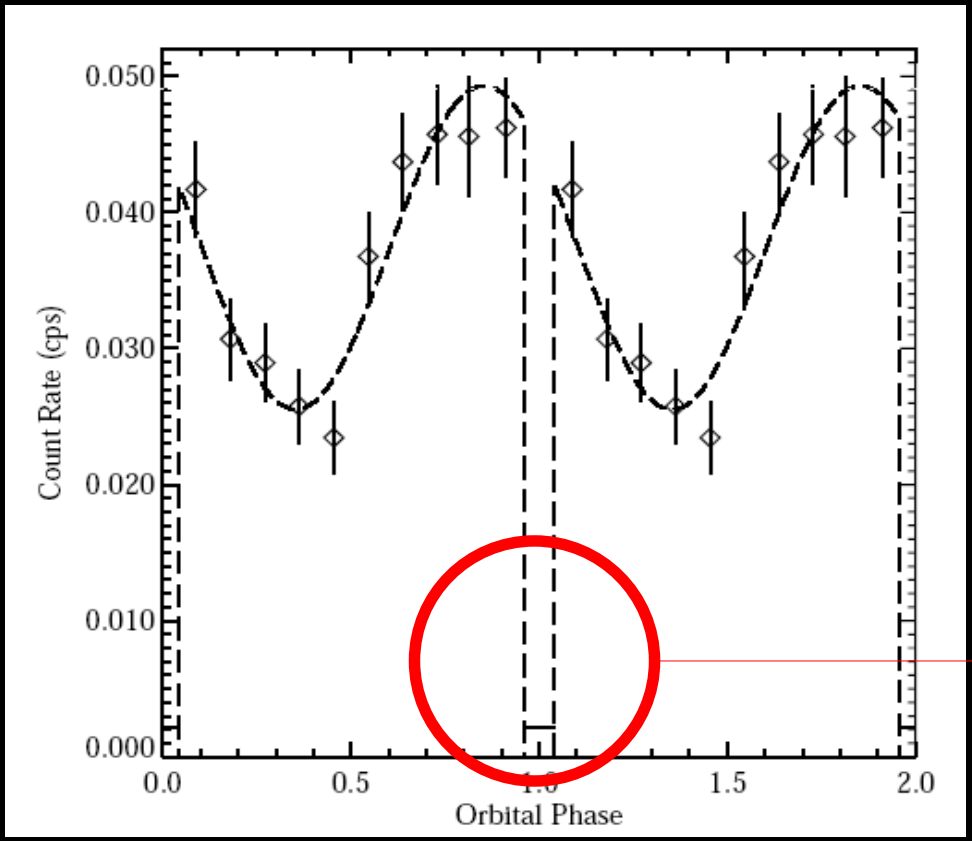
- **Our Lucky XMM-Newton Observations (Inactive State)**

  - Triple System Evidences
  - Constrains on the Triple Object Orbital Period

Inactive State

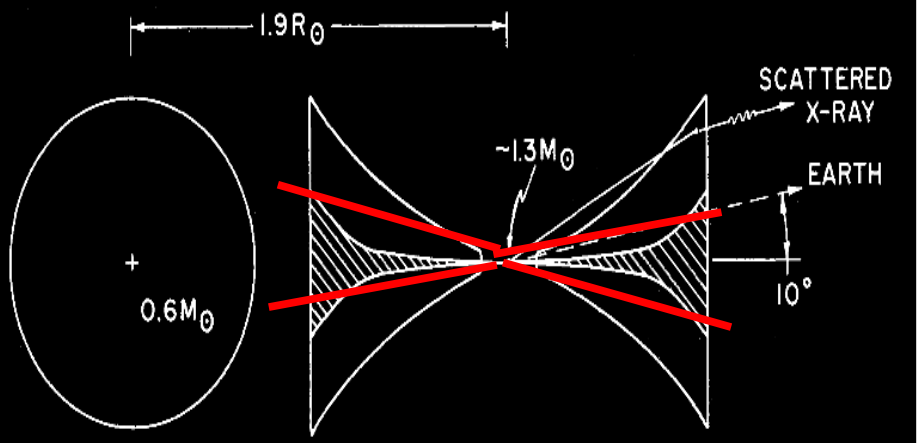
~37 ks Chandra (~2 orbital period)

(Nowak et al., 2002)



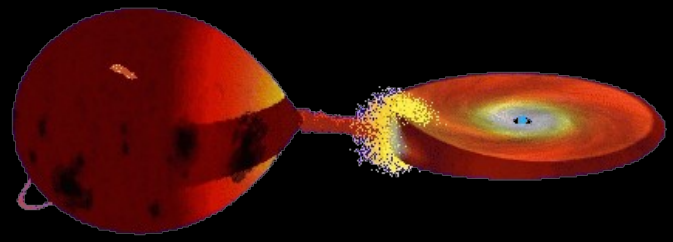
Sharp and total Eclipse:

$$d = 1523^{+30}_{-50}\ \mathrm{s}$$

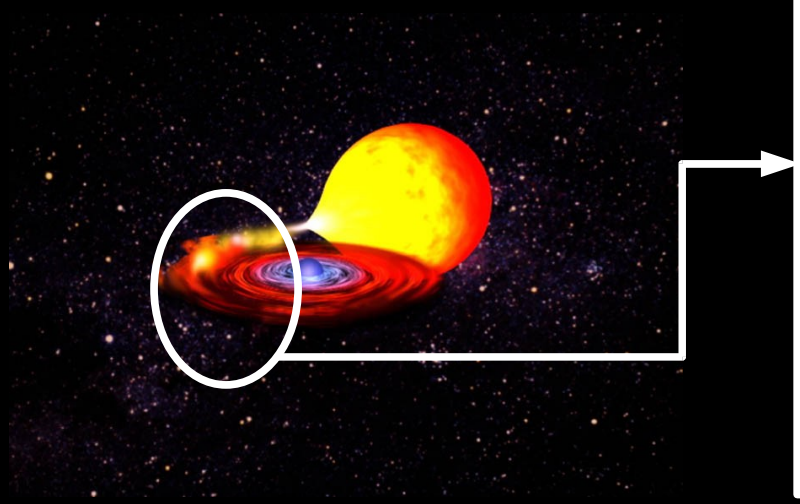


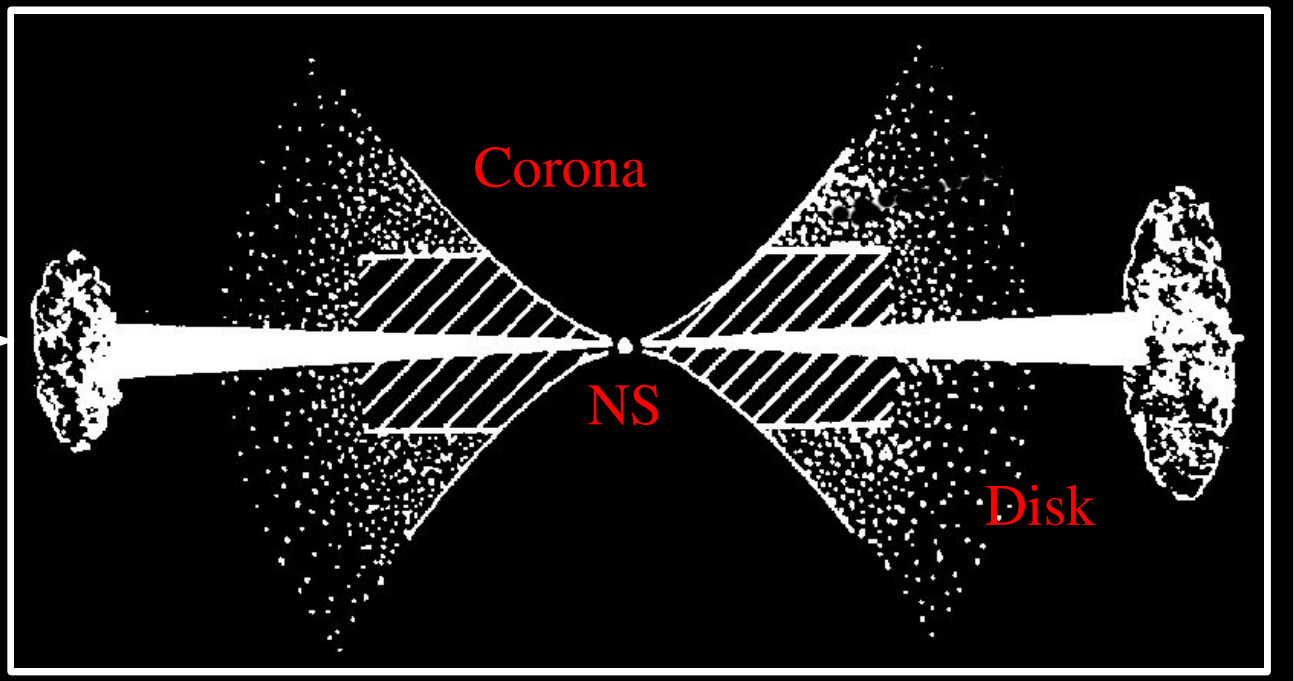
INTERPRETATION

- $F_X \sim 10^{-13}$ erg cm^{-2} s^{-1}
- Collapse of the ADC of a factor ~5
- Thick outer disk rim
- Coincident with the F star to within 0.1''



Accretion Disk Coronae (ADC)





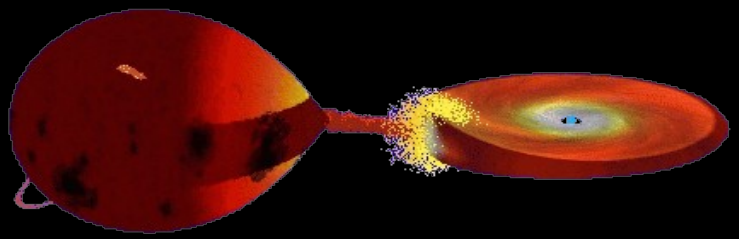
Near Edge-On Accreting Binary System

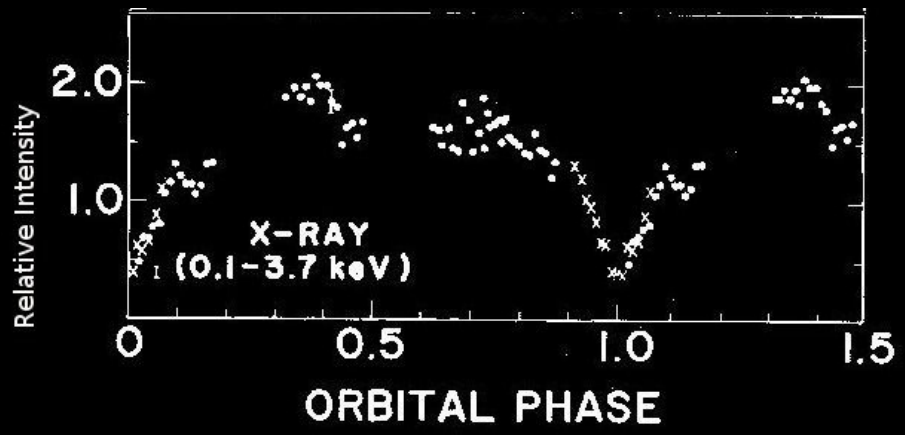
Scattered and Observed X-ray Emission

$L_X \sim 10^{36}$-10^{35} erg s^{-1}

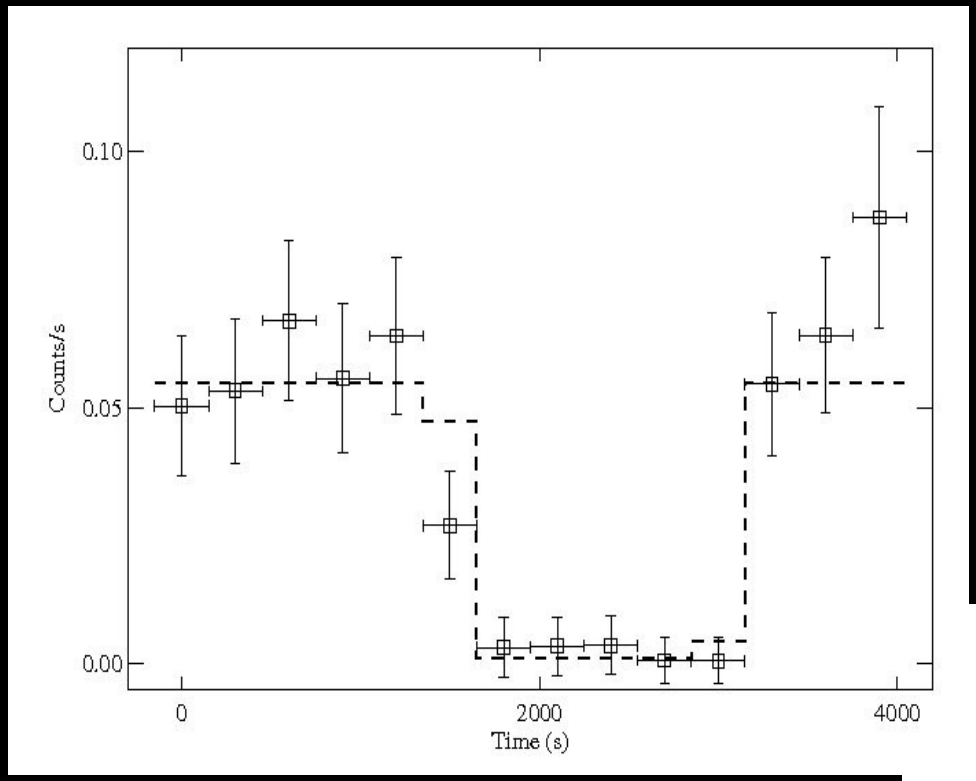
Binary orbital modulation in the light curves

Broad and partial X-ray eclipses



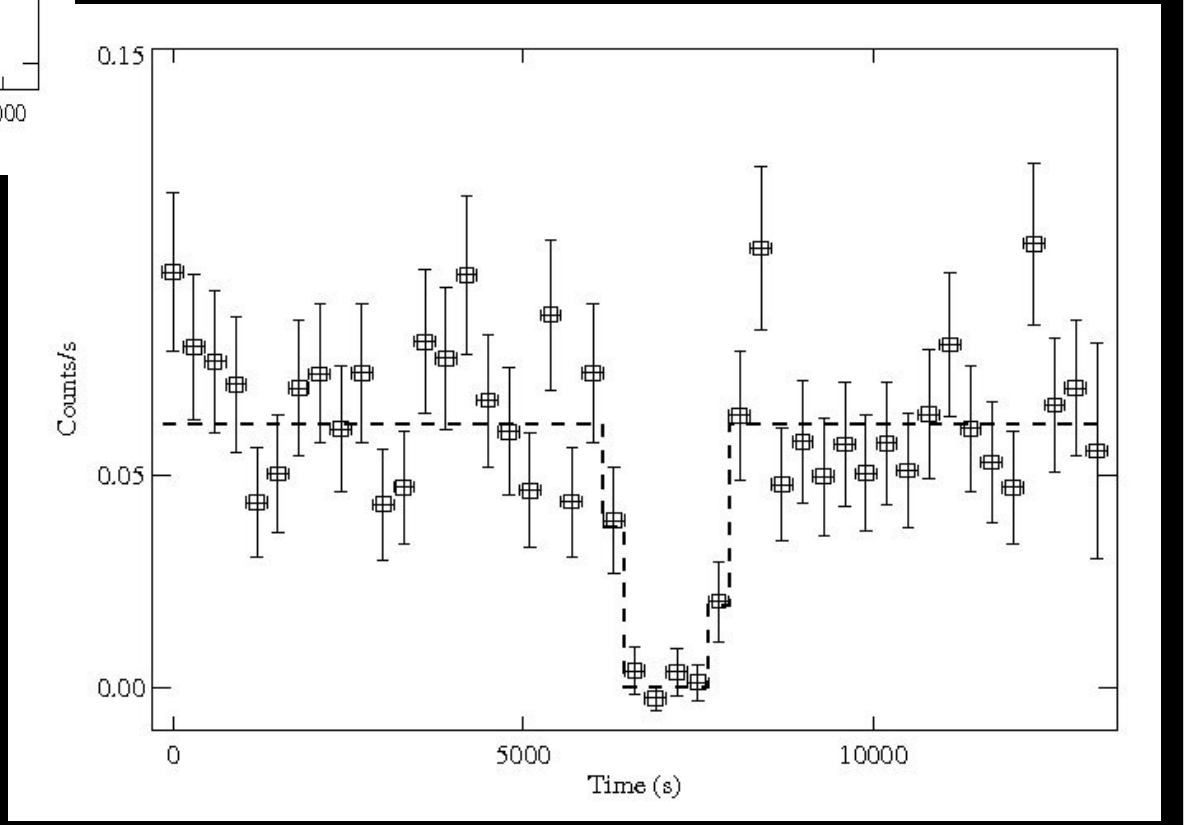


Mid-Eclipse Epochs



$T_0 = 2453506.4825(3)$ JD

(15 May 2007)



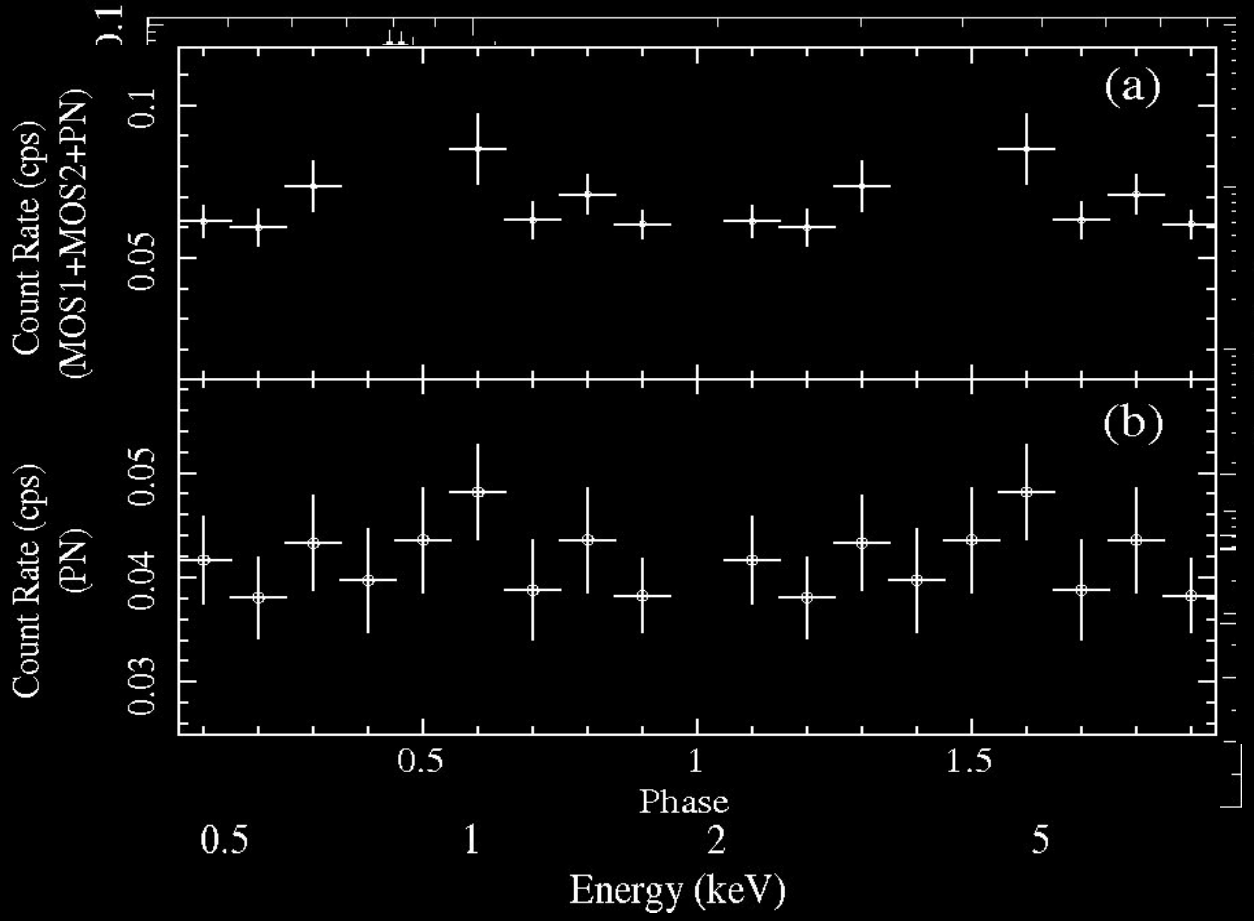
$T_0 = 2453528.3061(4)$

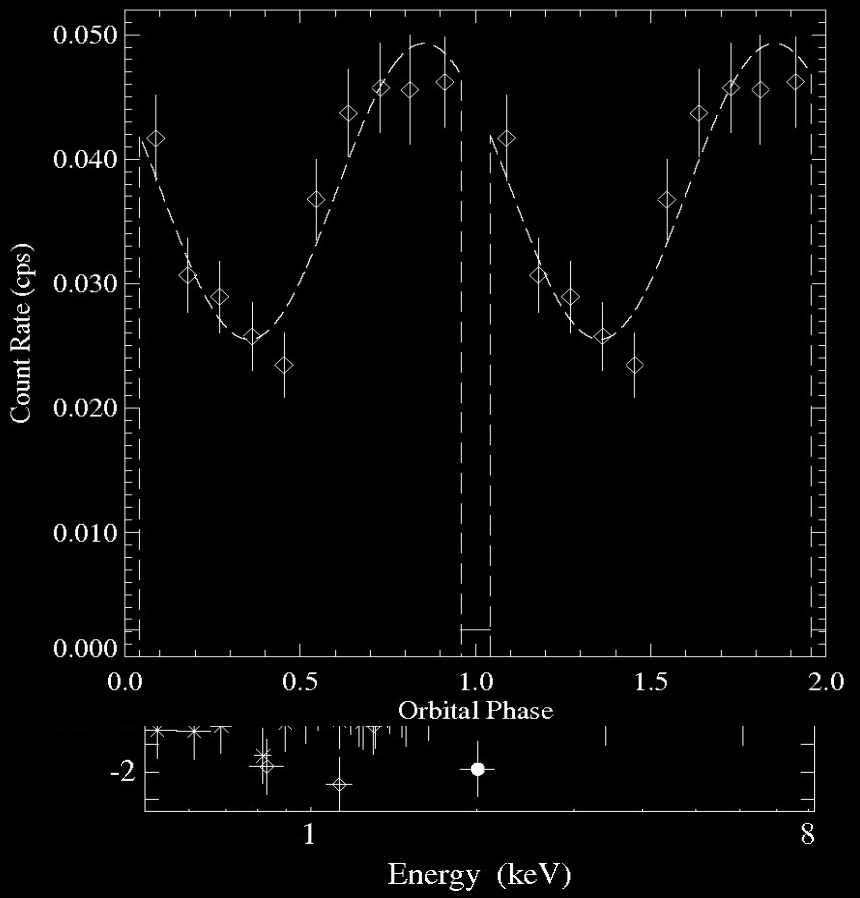
(6 June 2005)

Conclusions: Spectral Analysis

Short Observations --> few photons --> No detailed spectra obtained ...

...mystery on the QUIESCENT EMISSION of 4U2129+47 is still unveiled...





Low statistic, no sinusoidal modulation observed

Active State: OBSERVATIONS

1978 --> Discovered with Uhuru, Active State, $F_X \sim 3 \times 10^{-10}$ erg cm^{-2} s^{-1}

(Formann et al. 1978)

1979-1982 --> Optical and X-ray simultaneous observations:

(McGraw-Hill 1.3 m, Einstein, 63 ms)

- ~5.2 h modulated optical light curve
- Optical and X-ray phase mimima aligned
- ΔB~1.5 mag
- B-V (unknown A_V) + Roche Lobe Geometry

  --> M - K star, d~ 2.2 - 4 kpc
- $L_X/L_O \sim 10$
- X-Ray Spectrum:

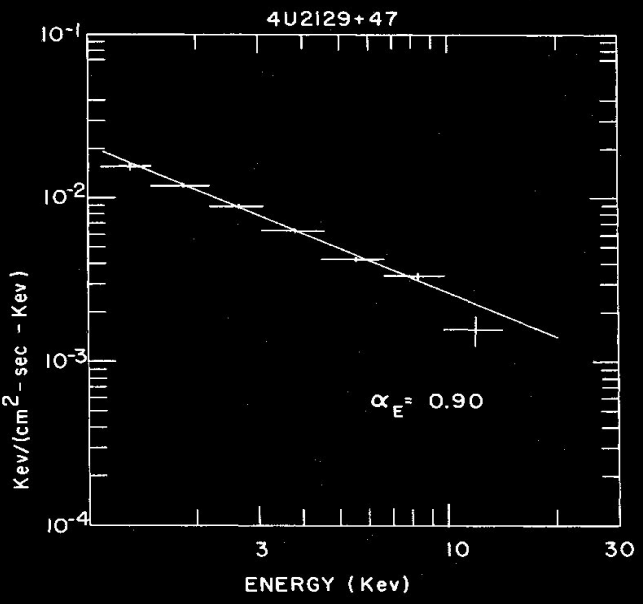
  (2-10 keV)

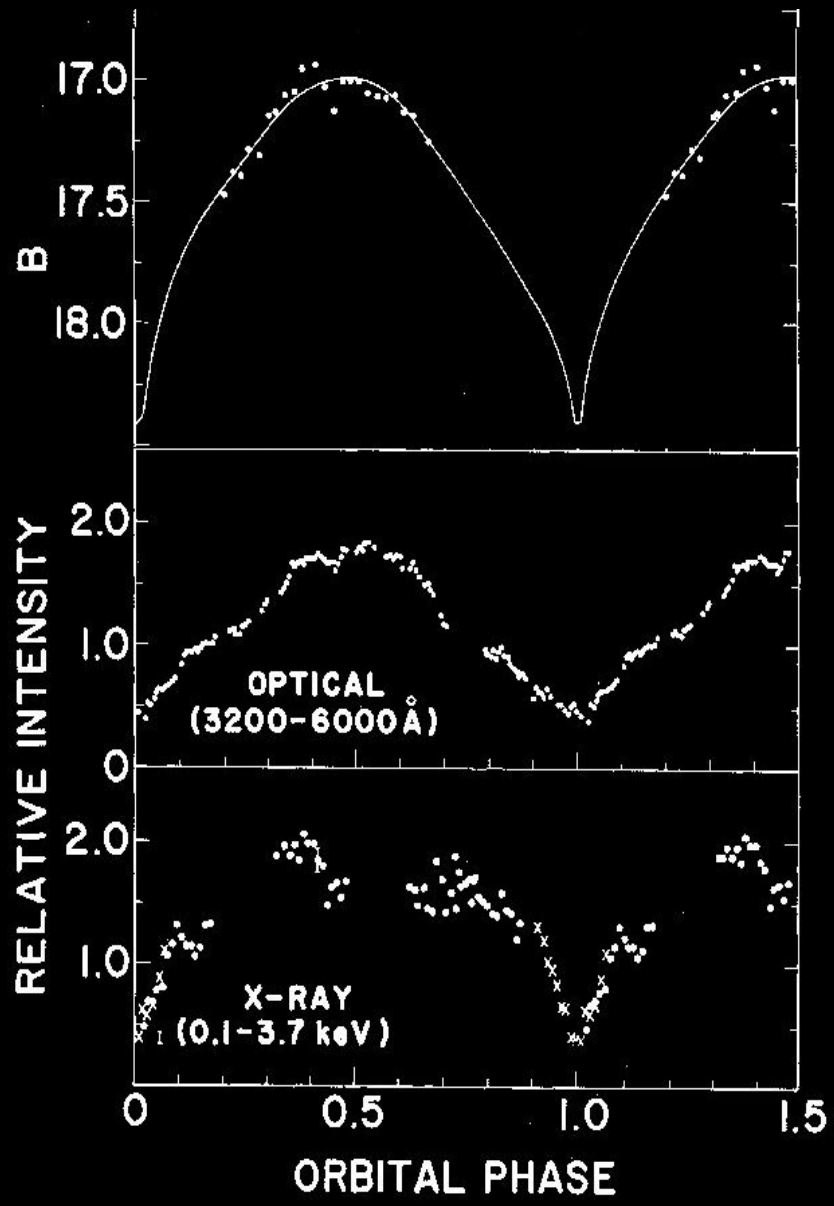
$$\frac{dF}{dE} = C e^{(-E_a/E)^{-2/7}} E^{-\alpha}$$

$E_a < 1.2$

(cut-off)

No Phase Variation



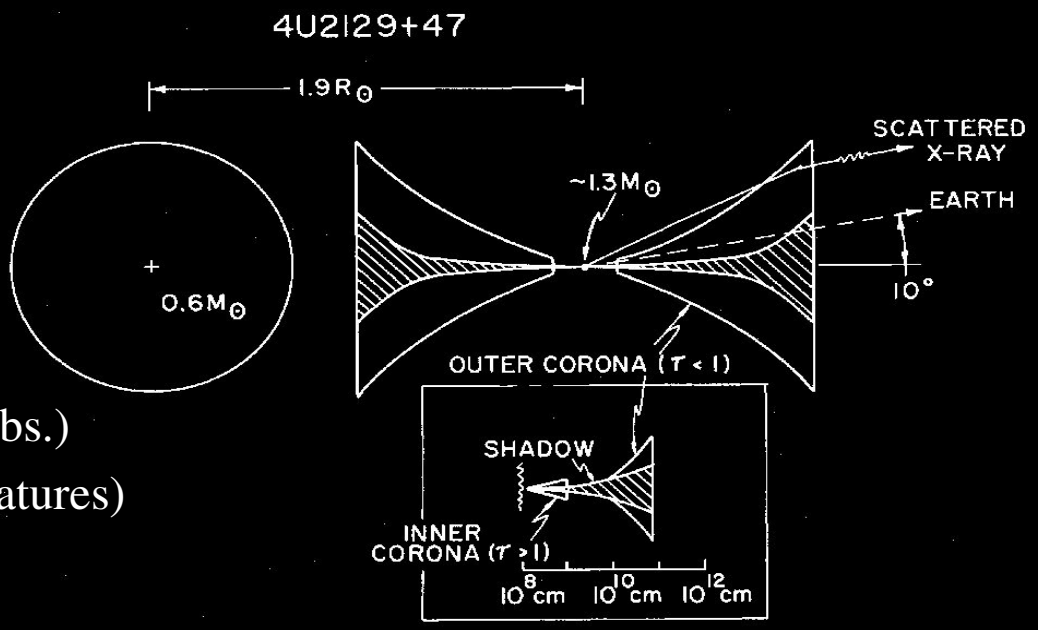


McClintok et al., 1982,1981)

Active State: INTERPRETATION

- Eclipse --> i~82°, parameters see picture
- Flux & Spectrum –>

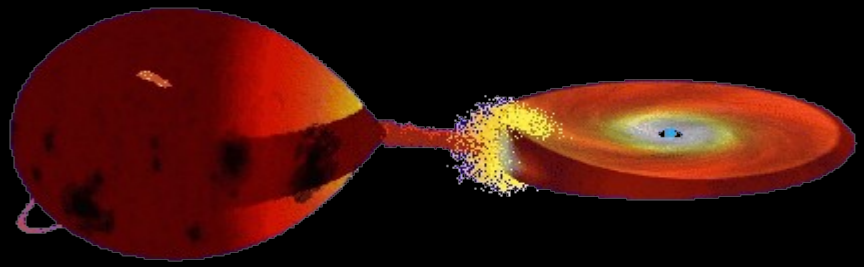
  Compact Source surrounded by a Gas Cloud;
  Smoothness and Depth of the X-ray Eclipse:
  < 0.1 Flux at Max is due to the central source



Single Corona --> required τ high (only 0.1 F_X obs.)
+ highly ionized (no spectral features)
--> required $L_X \sim 10^{38}$ erg s^{-1}
--> unlikely d~8.0 kpc

Double Corona --> optically thick inner corona block central source (90 %)
+ optically thin external corona
(electron scattering, comptonization, power law spectrum)

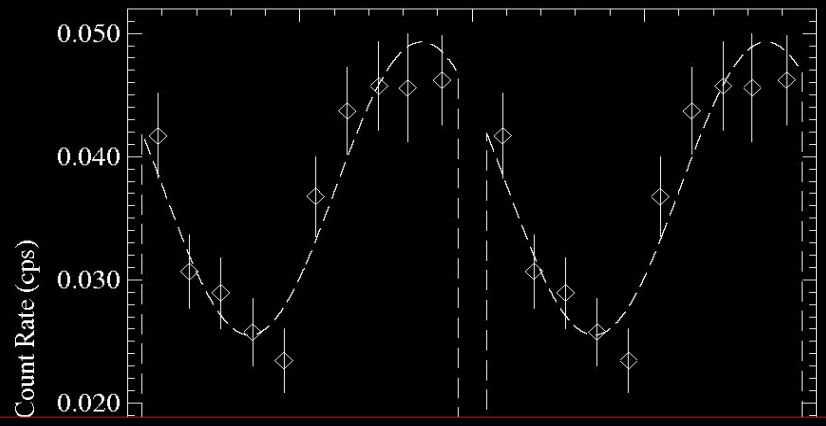
External Corona --> Evaporation from the surface of the companion star, gravitationally bound by the compact star (?)

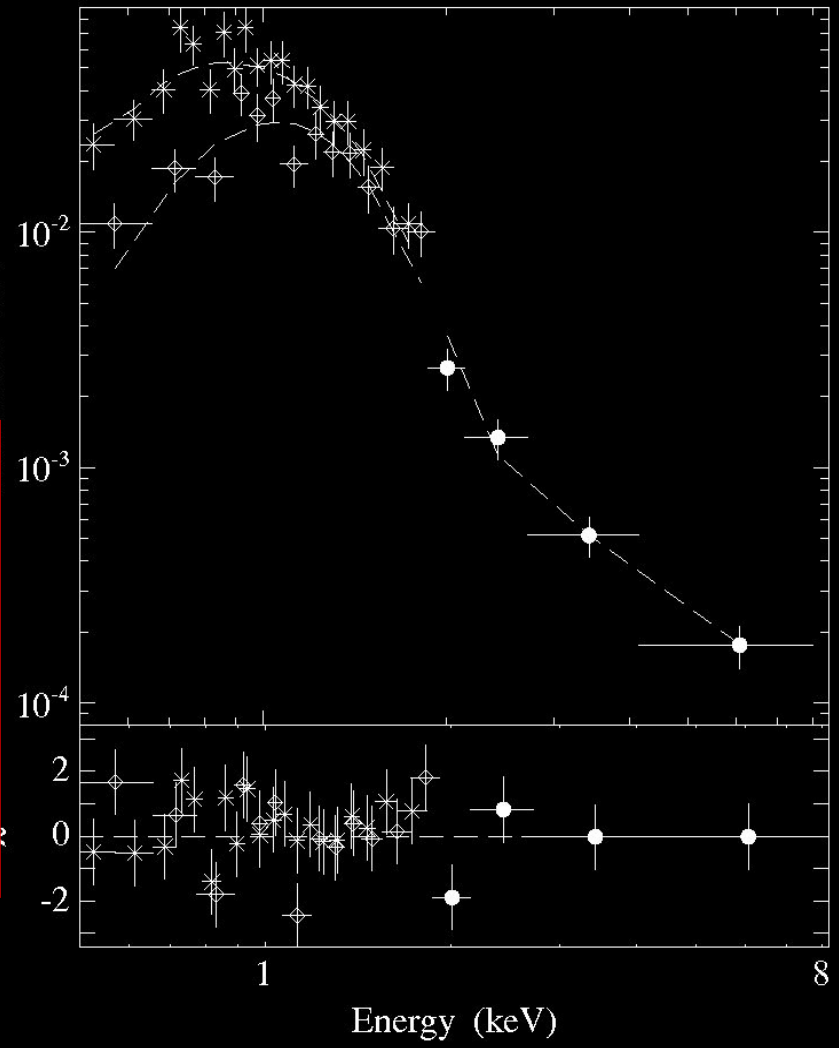


Internal Corona --> Evaporation from the surface of the inner accretion disk

First 4U2129+47 Observation in Quiescence with Chandra

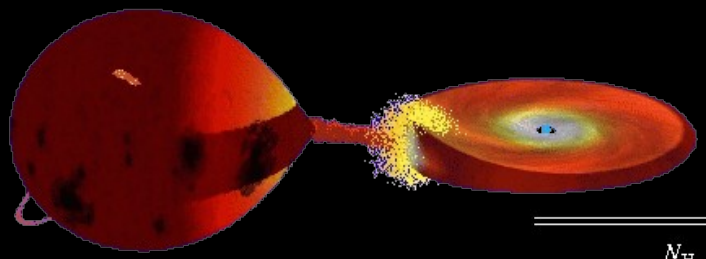
Nowak et al. (2002) --> ~37 Ks Chandra observation (~2 orbital period)





INTERPRETATION

- **Collapse of the ADC of a factor ~5**
- **Thicker outer disk rim**
  modulation of the soft (<2 keV) light curve
- **Coincident with the F star to within 0.1"**



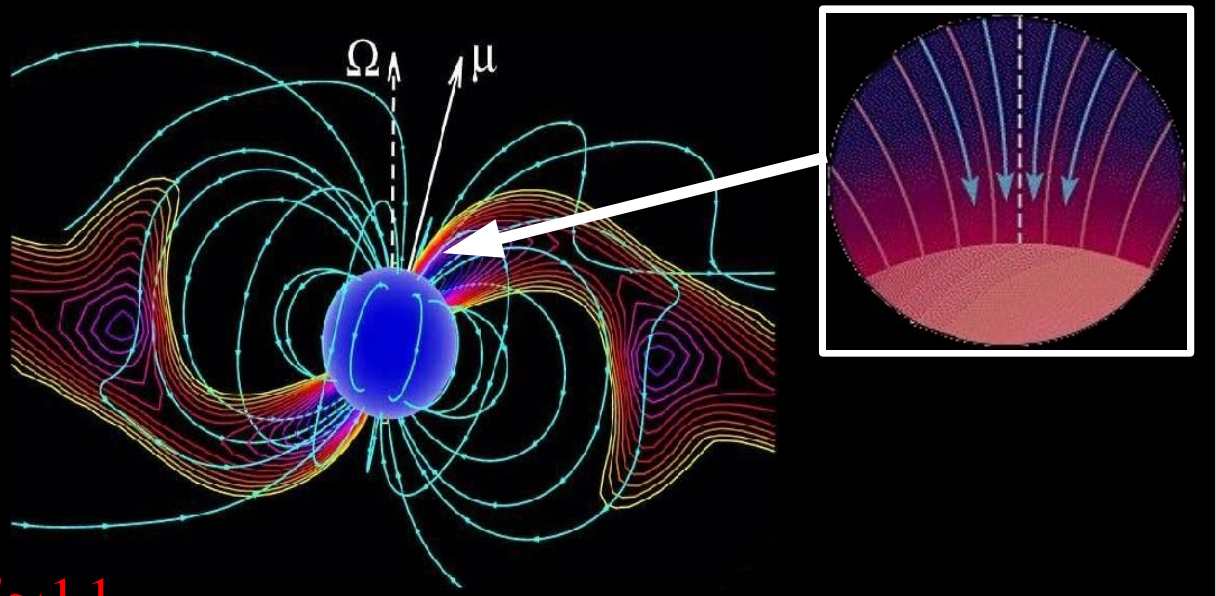
FITS TO THE X-RAY SPECTRA OF 4U 2129+47 (90% CONFIDENCE LEVEL ERROR BARS)

Fit	N_H ($\times 10^{21}$ cm^{-2})	kT (keV)	R or D^a (km or kpc)	A_Γ ($\times 10^{-6}$)	Γ	0.5–2 keV [b] ($\times 10^{-13}$ erg cm^{-2} s^{-1})	0.5–2 keV [c] ($\times 10^{-13}$ erg cm^{-2} s^{-1})	2–8 keV ($\times 10^{-13}$ erg cm^{-2} s^{-1})	χ^2 / dof
A.....	$3.1^{+0.9}_{-0.7}$	$0.21^{0.02}_{0.03}$	$2.5^{1.5}_{0.7}$	$6.4^{20.2}_{5.2}$	$1.1^{1.1}_{1.1}$	1.0	2.5	0.5	38.1 / 33

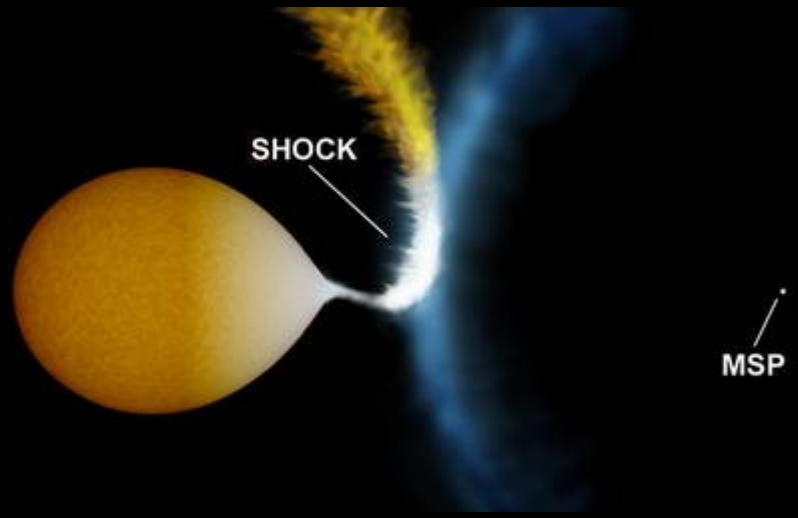
Inactive State: INTERPRETATION

Black Body ~0.2 keV, R~2.5 km

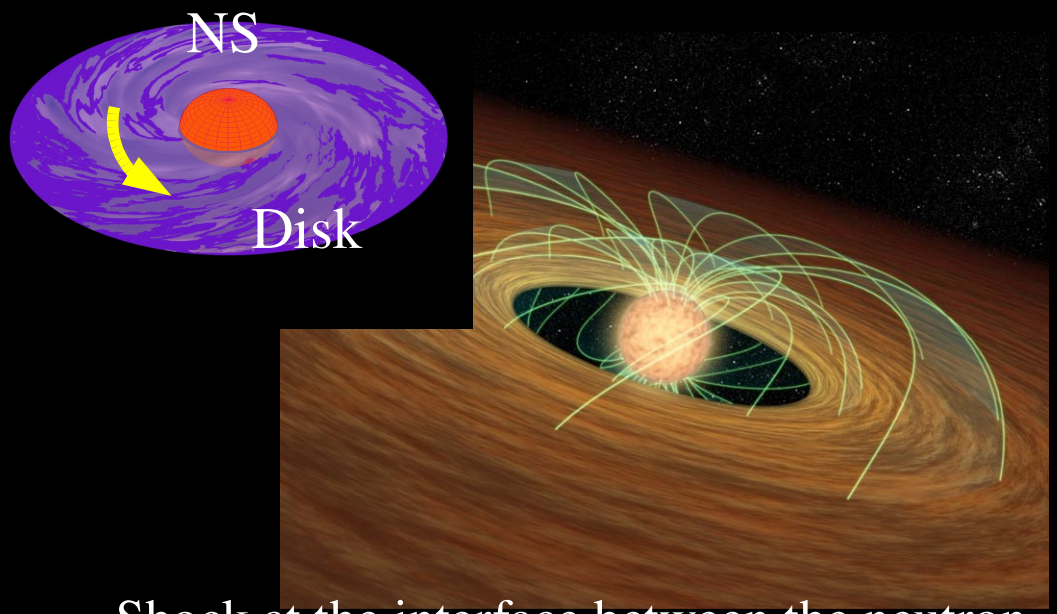
Residual Accretion
(low luminosity) onto the NS



Power-law Component E^{-Γ}, $\Gamma \sim 1.1$



Shock between the pulsar electromegnetic radiation and matter from the companion (~10^{10} cm)
--> Power law during the eclipse $\Gamma \sim 1$-2



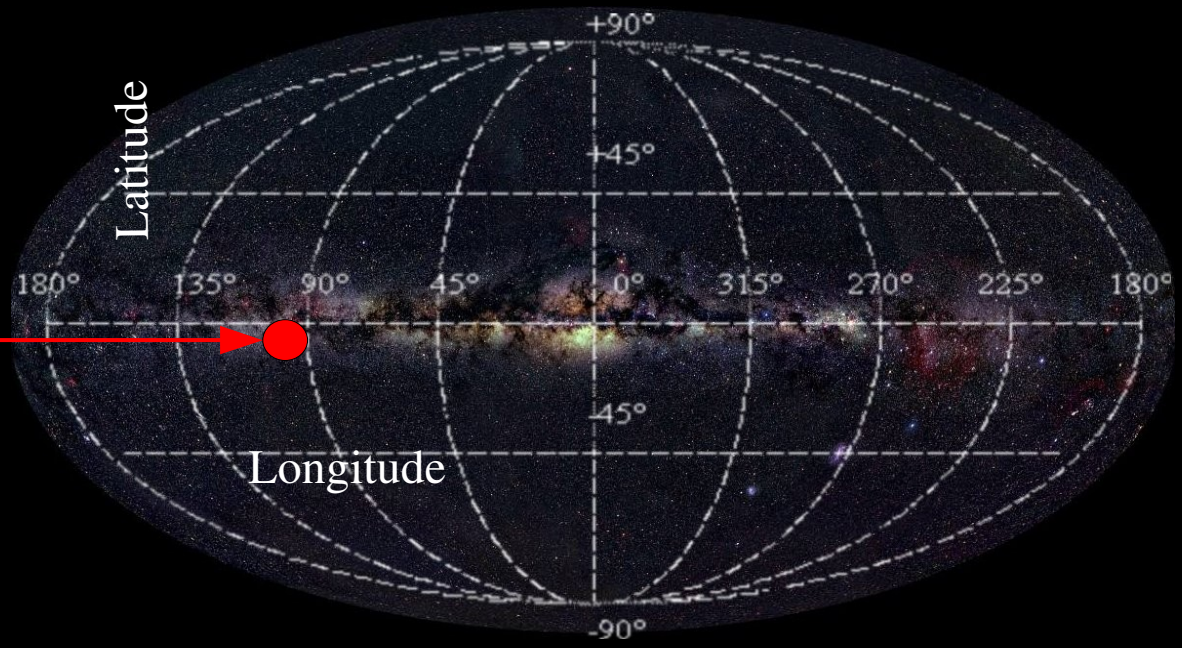
Shock at the interface between the neutron star magnetosphere and the accretion disk (~10^{7} cm) --> No power law in the eclipse

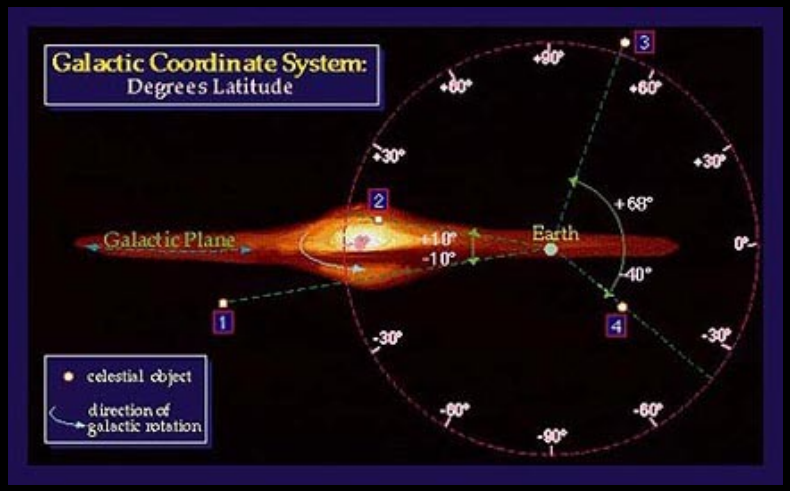
Some Informations

4U2129+47

(eclipsing binary)

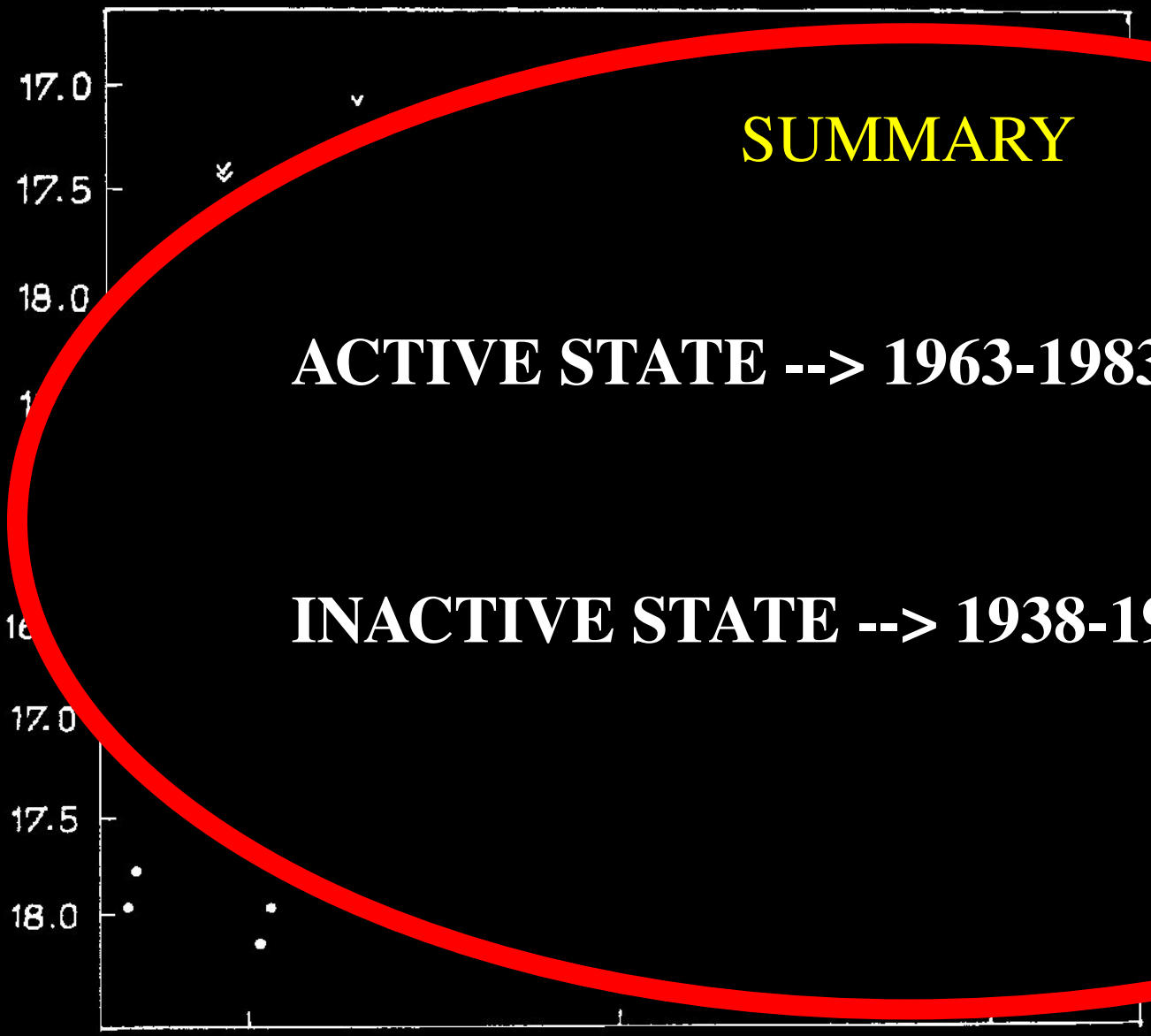
Position in Galactic Coordinate
but..
Uncertainties on the exact distance!!





A look into the past...

Archive Plate Observations
(Sonneberg obs.)



(Wenzel et al, 1983)

SUMMARY

ACTIVE STATE --> 1963-1983

INACTIVE STATE --> 1938-1943; 1983-??

Evolutionary Scenario LMXBs

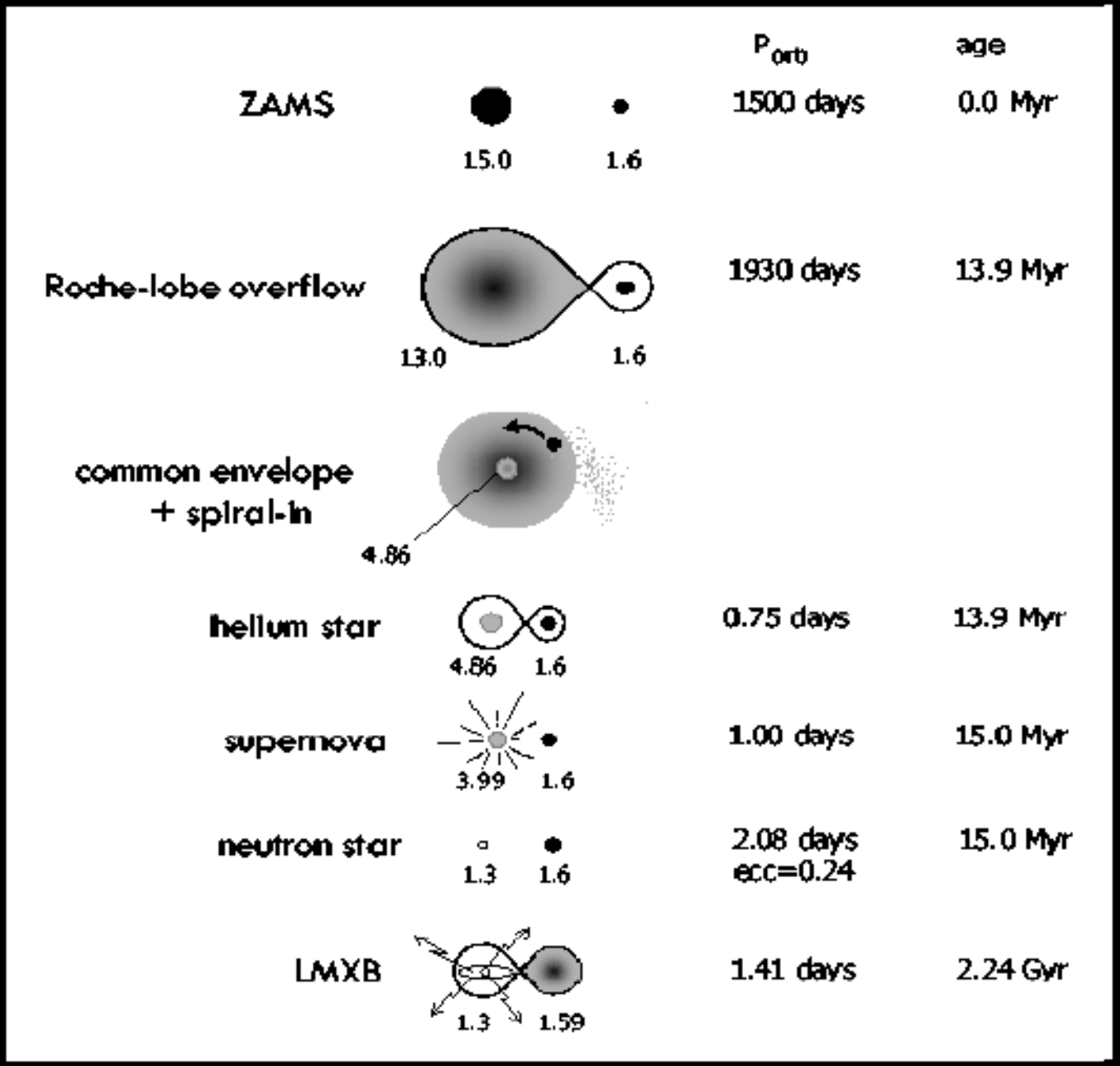
Mechanisms driving mass transfer in LMXBs
(a) Loss of orbital angular momentum
–Gravitational radiation
–Magnetic braking
(b) Nuclear evolution of the companion star

(i) Porb, i > ~1-2 d --> the mass transfer is driven by the internal evolution of the low-mass (sub-)giant companion stars.

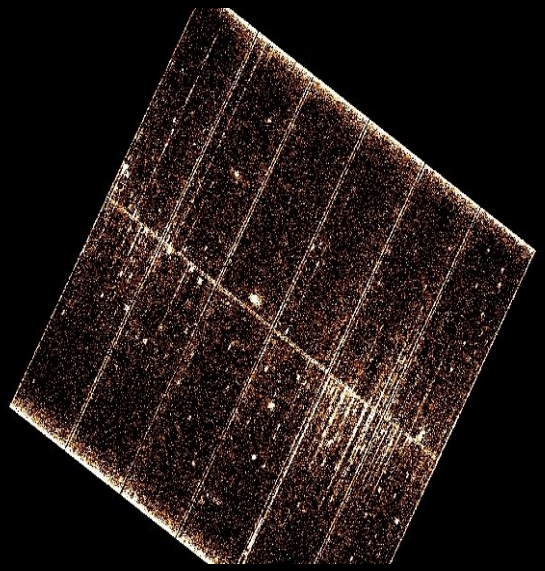
(ii) Porb <~10 hr --> interior evolution of the companion plays a negligible role and the evolution of system is driven by angular momentum losses by magnetic braking and gravitational radiation.

(iii) In the intermediate period range between ~10 hr and ~1-2 d, both angular momentum losses by magnetic braking and the radius expansion due to the interior evolution of the subgiant play a role.

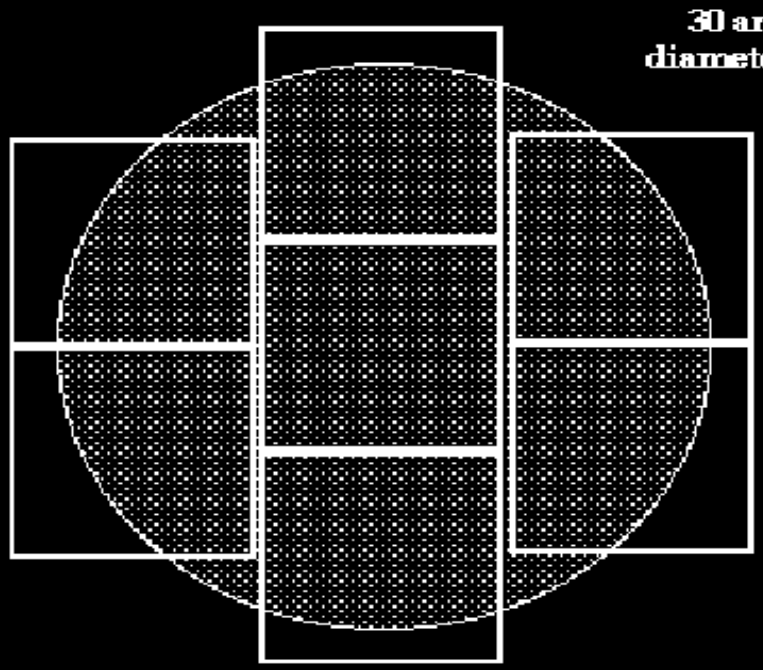
Evolutionary Scenario LMXBs



XMM Detectors

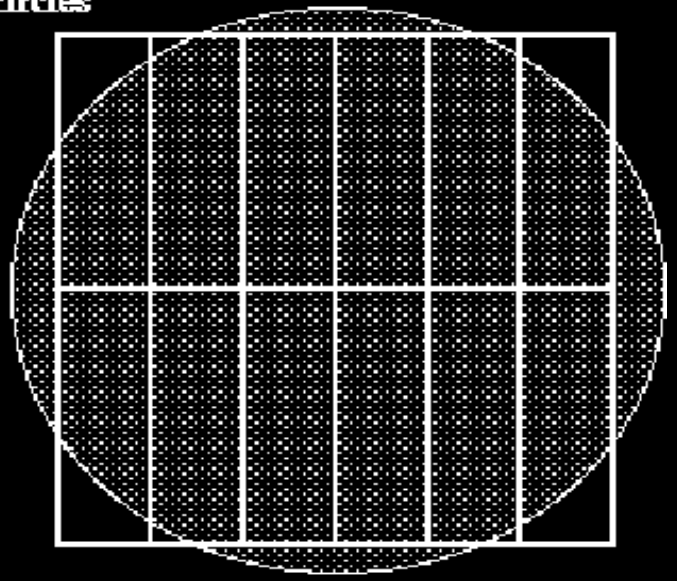


Comparison of focal plane organisation of EPIC MOS and pn cameras



EPIC MOS

7 CCDs each 10.9 x 10.9 arcminutes



EPIC pn

12 CCDs each 13.6 x 4.4 arcmin

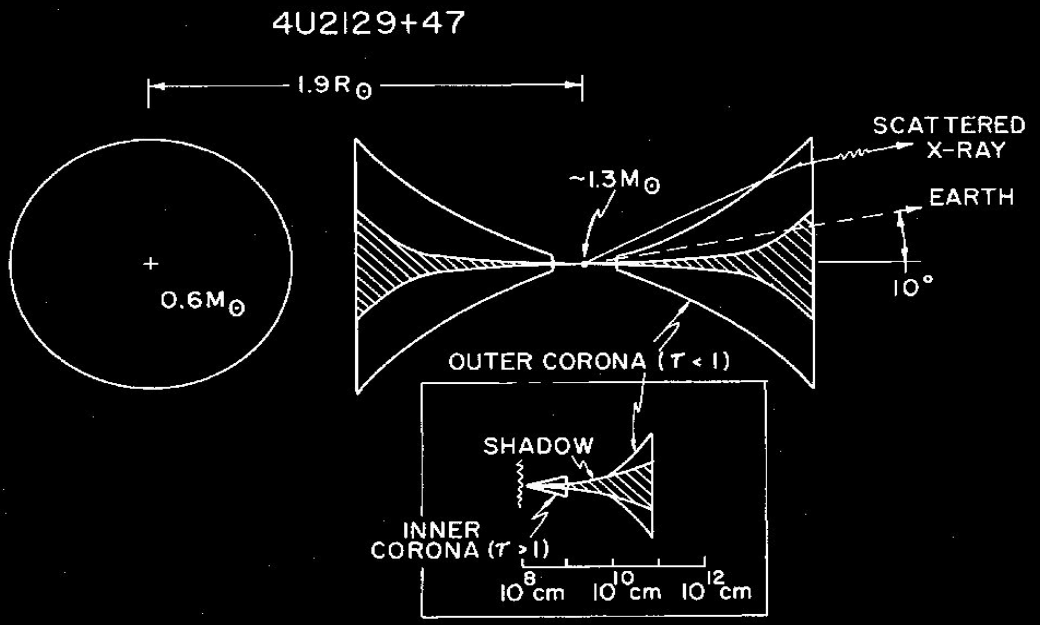
7 CCD
PSF FWHM ~6"/15" (1.5 keV)
F.O.V. ~ 30'
A_{eff} ~400 cm^2 (1.5 keV)
energy range 0.1-15 keV

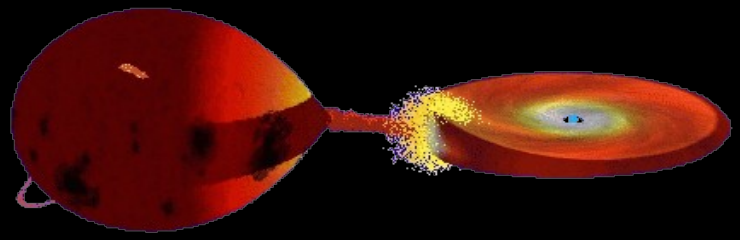
12 CCD
PSF FWHM ~6"/15" (1.5 keV)
F.O.V. ~ 30'
A_{eff} ~1400 cm^2 (1.5 keV)
energy range 0.1-15 keV

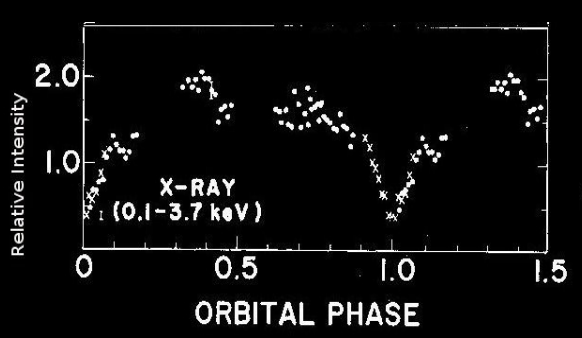
Active State: INTERPRETATION

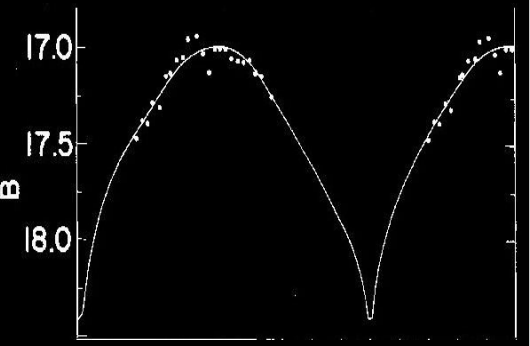
- Eclipse --> i~82°, parameters see fig.
- Partial X-ray Eclipse --> Compact Source surrounded by a Gas Cloud
- Modulation --> orbital period ~5.2 h
- B-V, U-B + Geometry --> M - K star

  d~ 1 - 2 kpc ($L_X \sim 5 \times 10^{34}$ erg s^{-1})
- Heated surface of the companion star (L_{opt})



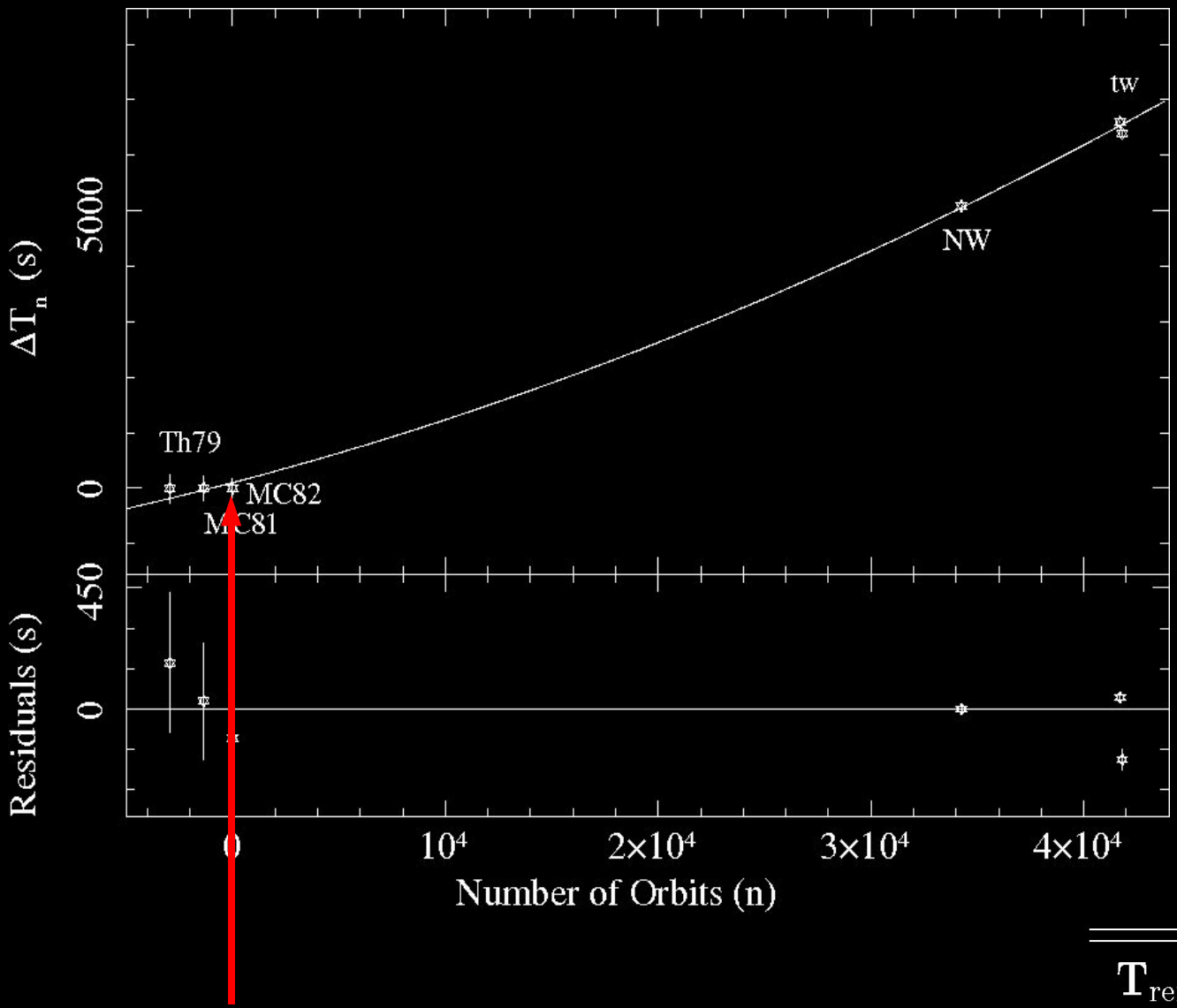






Accretion Disk Corona --> Evaporation from the surface of the companion star, (gravitationally bound by the compact star) and from the inner accretion disk

The O-C residuals technique



$$n \sim (T_n - T_{ref})/P_{ref}$$

$$T_{n\text{-}pred} = T_{ref} + n\,P_{ref}$$

$$\Delta T = T_n - T_{n\text{-}pred}$$

FIT with:

$$\Delta T = \alpha + \beta n + \gamma n^2$$

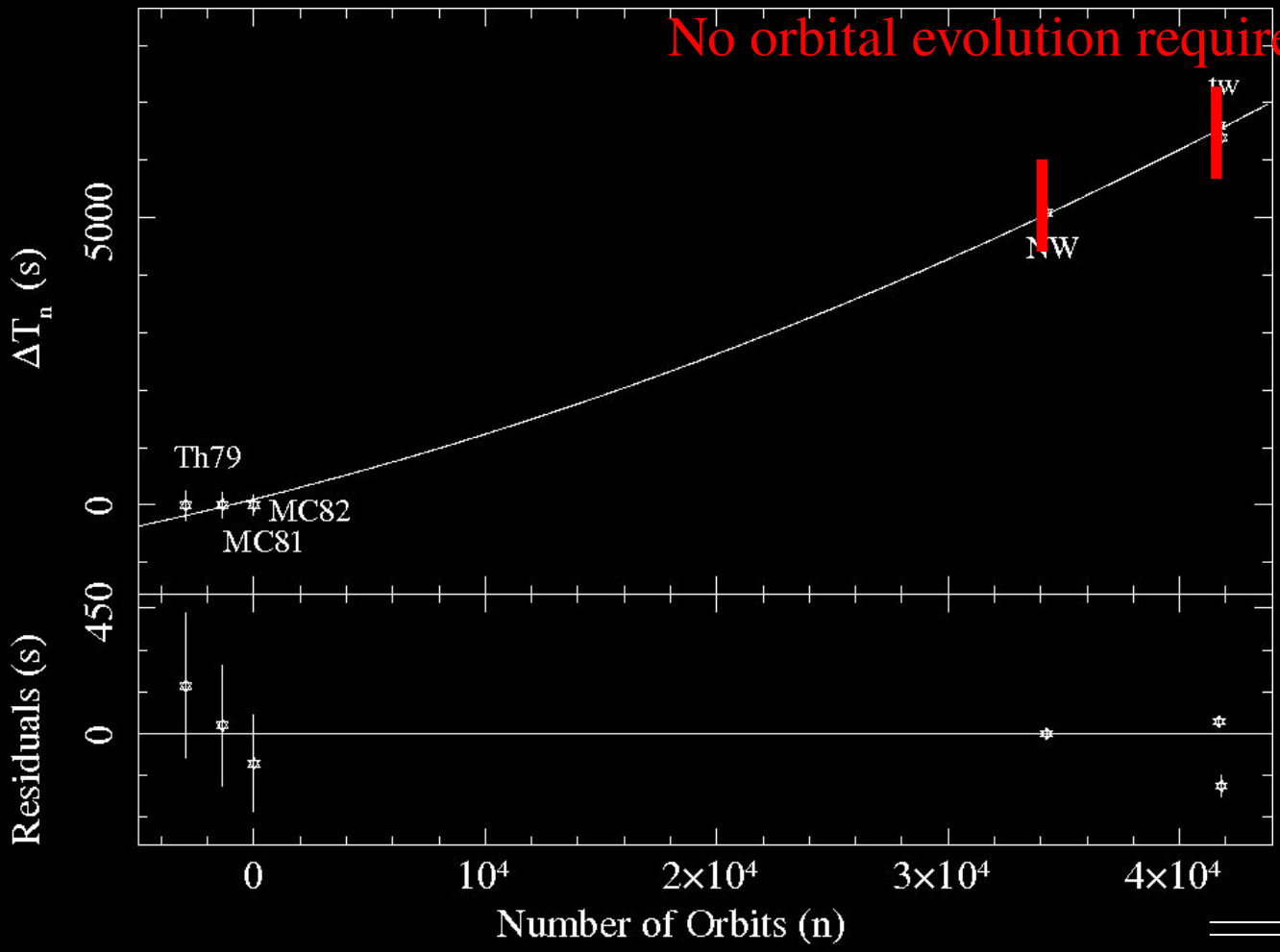
Correzione su T_{ref} — Correzione su P_{ref} — $\dot{P}_{orb}$

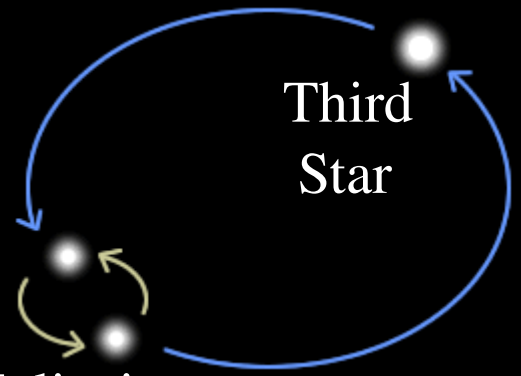
Tref = 2444403 .743 ± 0 .002 JD
Pref = 18857 .48 ± 0 .07 s)

T_{ref} (JD)	2444403.743 ± 0.001
P_{orb} (s)	18857.585 ± 0.007
$\dot{P}_{orb}$ (s s^{-1})	$(1.34 \pm 0.12) \times 10^{-10}$
$P_{orb}\dot{P}_{orb}$ (yr)	$(4.5 \pm 0.4) \times 10^{-6}$
χ^2/d.o.f.	31/3

Triple System Consequences...

An interesting possibility.....





Spin Up expected,
no spin down!!!
(magnetic braking,
gravitational wave)

Solve the problem of the "WRONG" orbital period derivative...

T_{ref} (JD)	2444403.743 ± 0.001
P_{orb} (s)	18857.585 ± 0.007
$\dot{P}_{orb}$ (s s^{-1})	$(1.34\pm0.12)\times10^{-10}$
$P_{orb}\dot{P}_{orb}$ (yr)	$(4.5\pm0.4)\times10^{-6}$
χ^2/d.o.f.	31/3