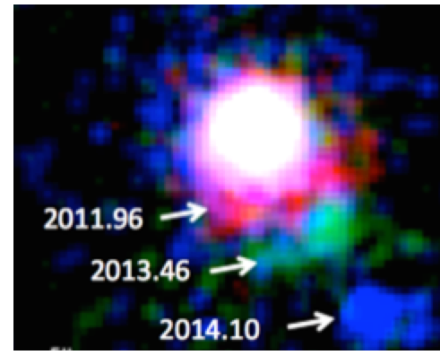
Extended X-ray object ejected from the PSR B1259-63/LS 2883 binary



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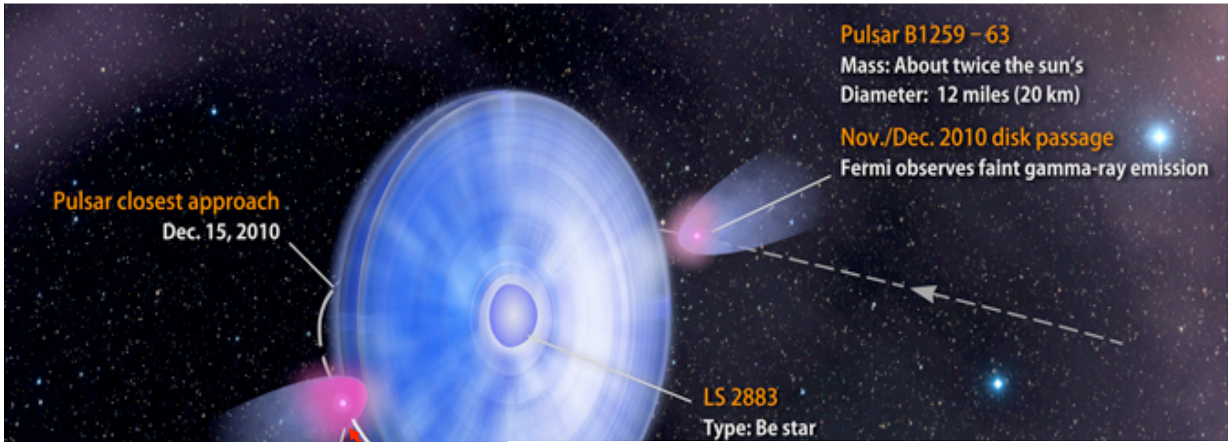
6th Fermi Symposium Washington, D.C. Novemeber 2015

High-mass binary LS 2883 with PSR B1259-63

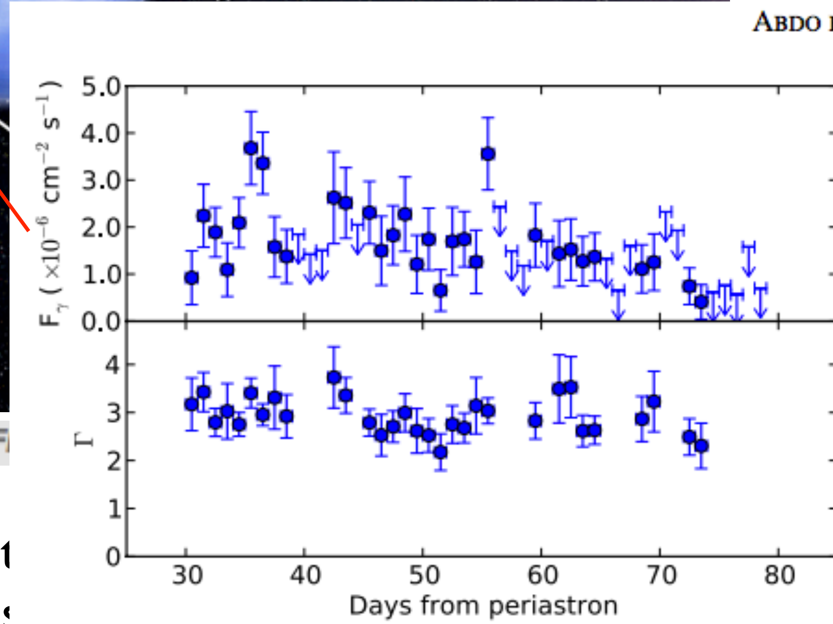


(Credit: NASA's Goddard Space F

Fast-spinning, **massive (M~30 $M_\odot$, L=6×10^4$L_\odot$) star** with a strong wind.

The **wind** is dense and slow in the **decretion disk**, tenuous and fast outside the

Abdo et al.



sar B1259-63:

n period = 48 ms

ɔt = 8×10^{35} erg/s

n-down age =330 kyr

ɔuld emit pulsar wind

ɔd

/ AU (3 milliarcsec) max. separation

0.87 eccentricity

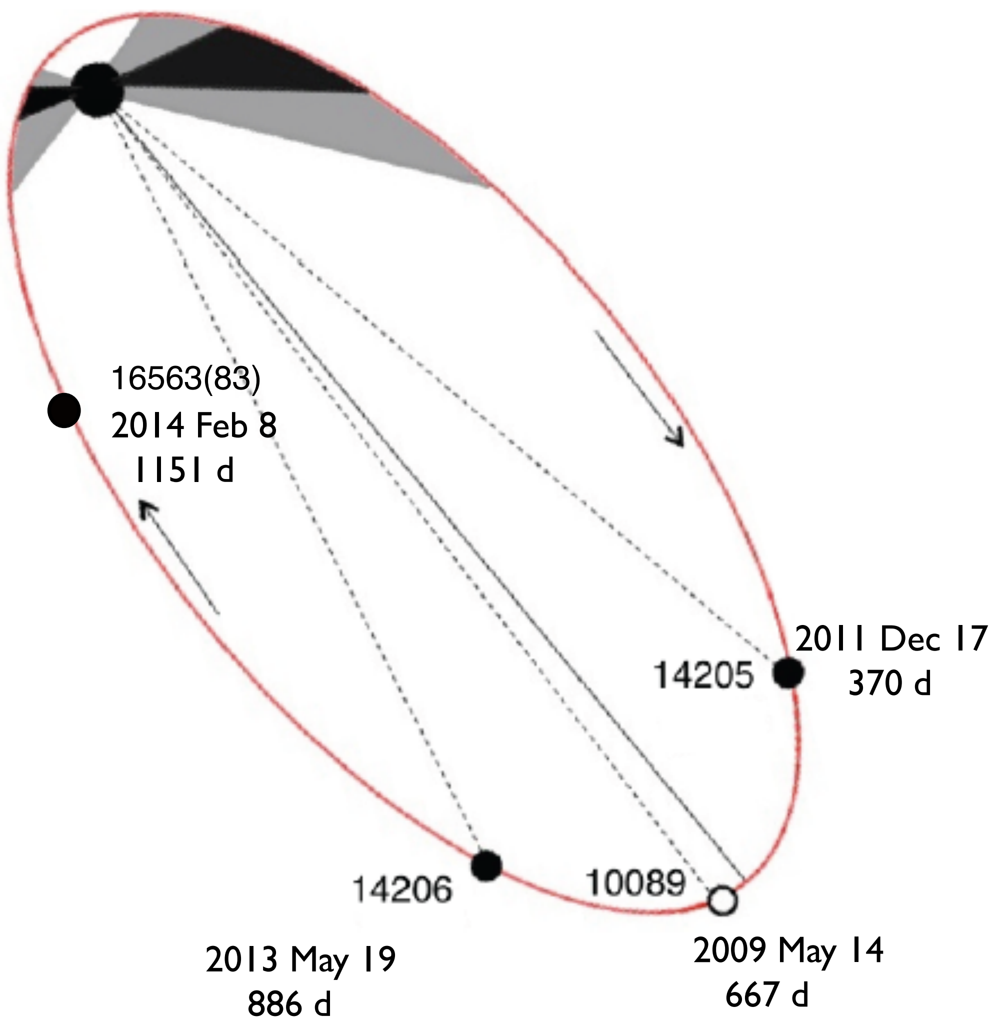
X-ray flux varies wi

Gamma-ray flashe

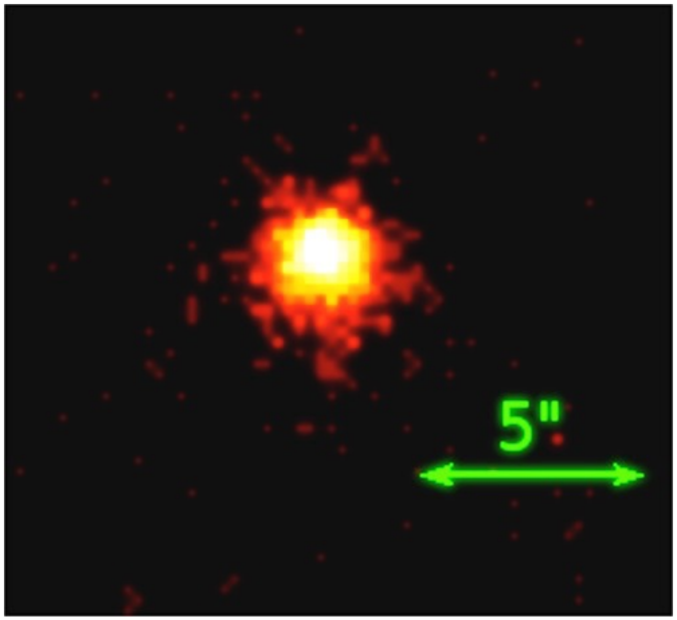
apparently when the pulsar intreacts with the decretion disk during 2nd passage.

Imaging observations with Chandra ACIS

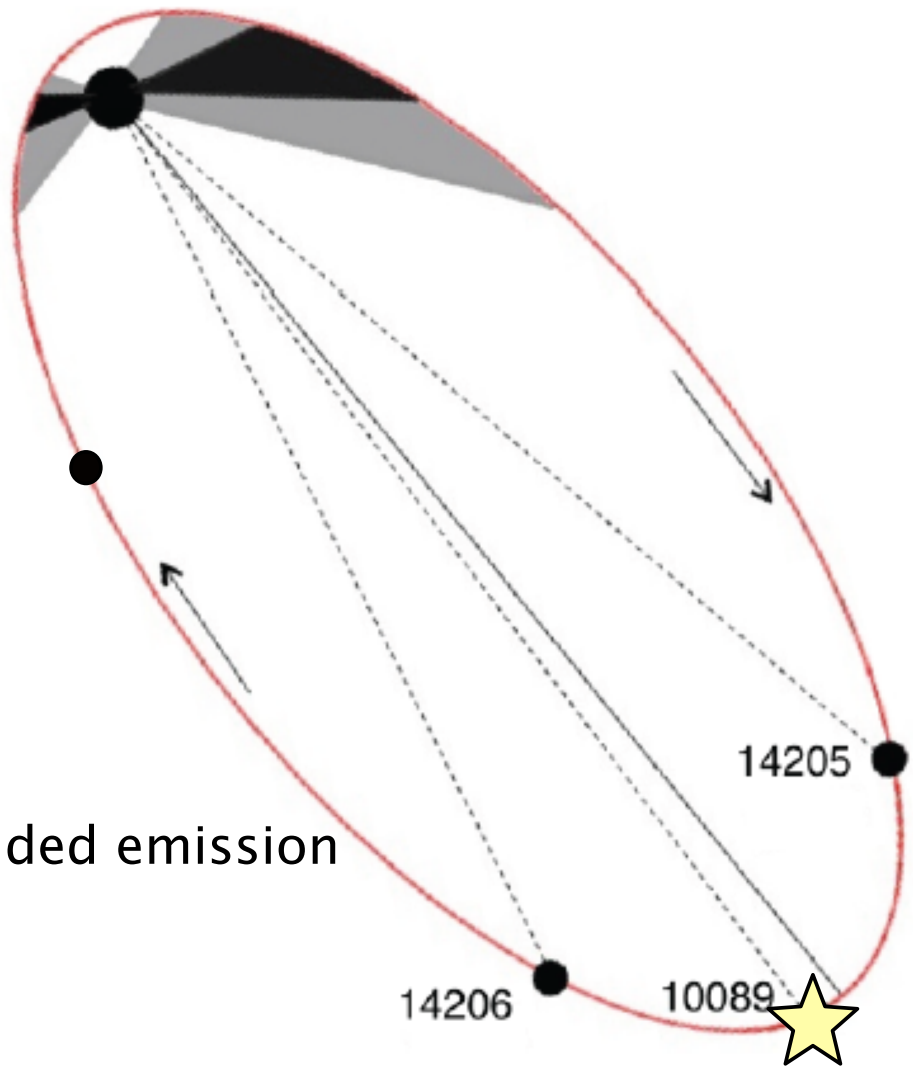
4 observations, May 2009 – Feb 2014



1st Observation (2009 May 14)



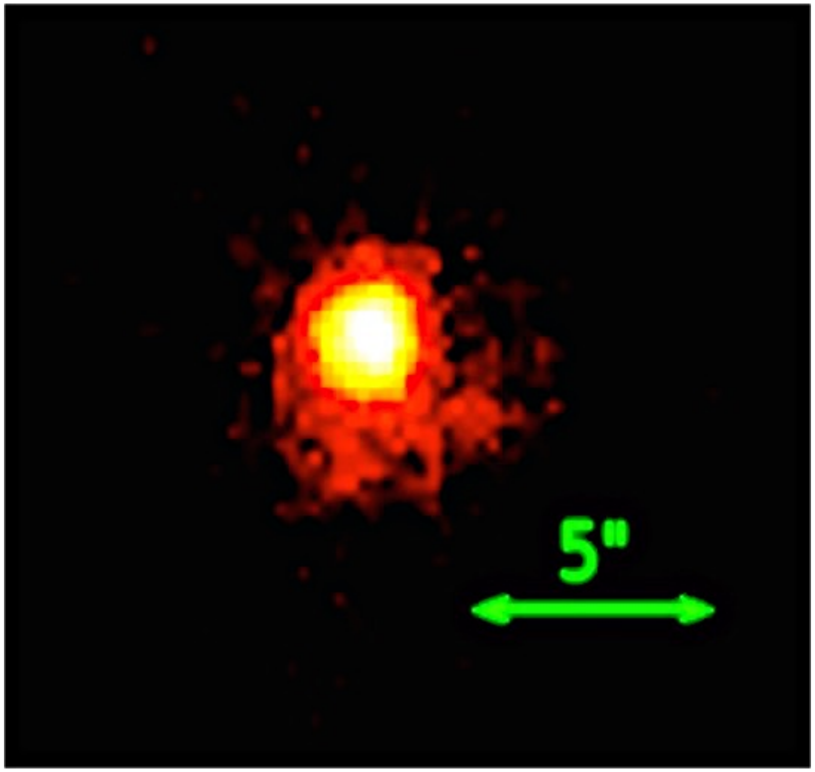
Short 25.6 ks ACIS-I exposure
near apastron, $\theta = 182$ deg



~4σ detection of asymmetric extended emission

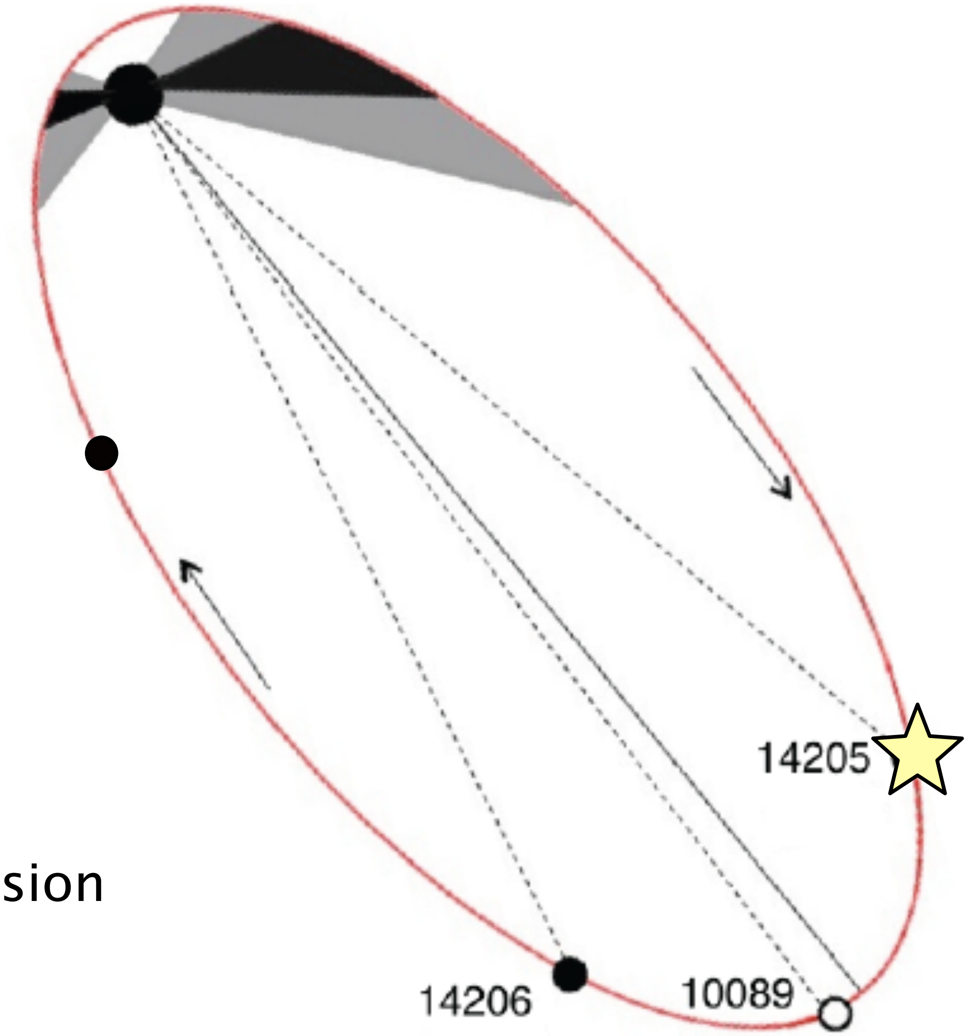
(Pavlov et al 2011)

2nd Observation (2011 Dec 17)

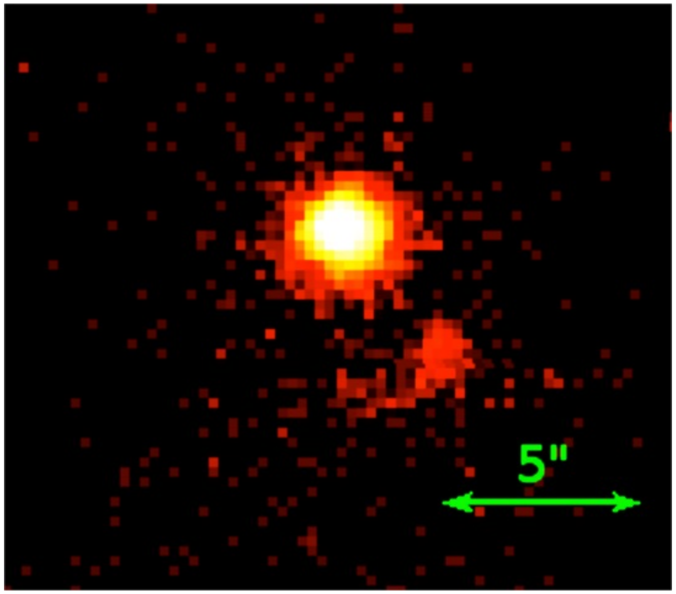


56.3 ks ACIS-I exposure
before apastron, θ =169 deg

Clear asymmetric extended emission

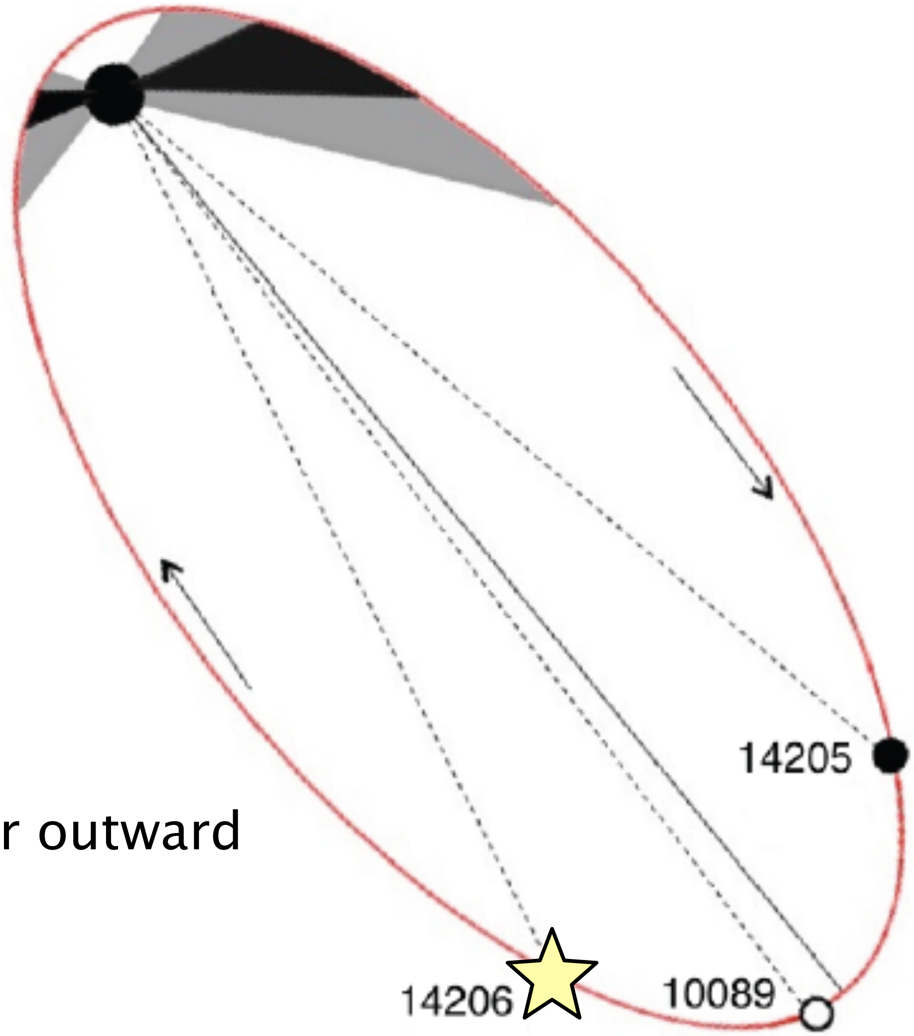


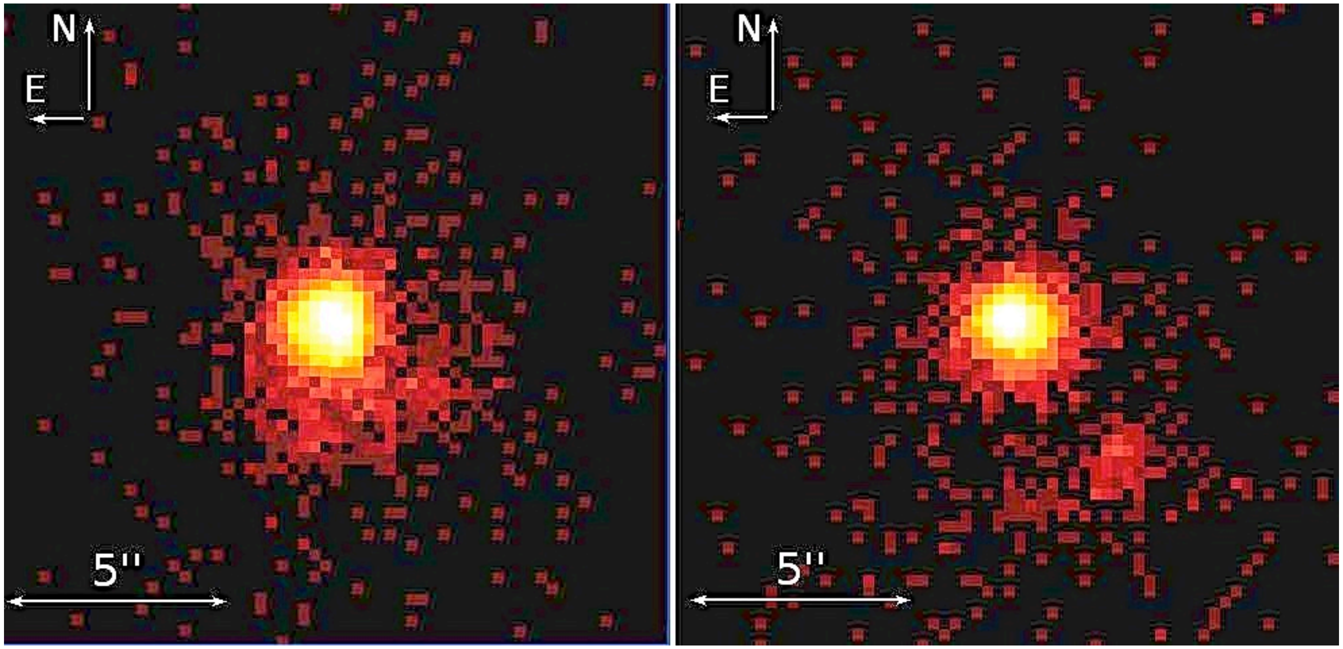
3rd Observation (2013 May 19)



56.3 ks ACIS-I exposure
after apastron, $\theta = 192$ deg

Extended emission moved further outward





2nd and 3rd observations compared

$1''.8 \pm 0''.5$ shift

corresponds to the apparent proper motion

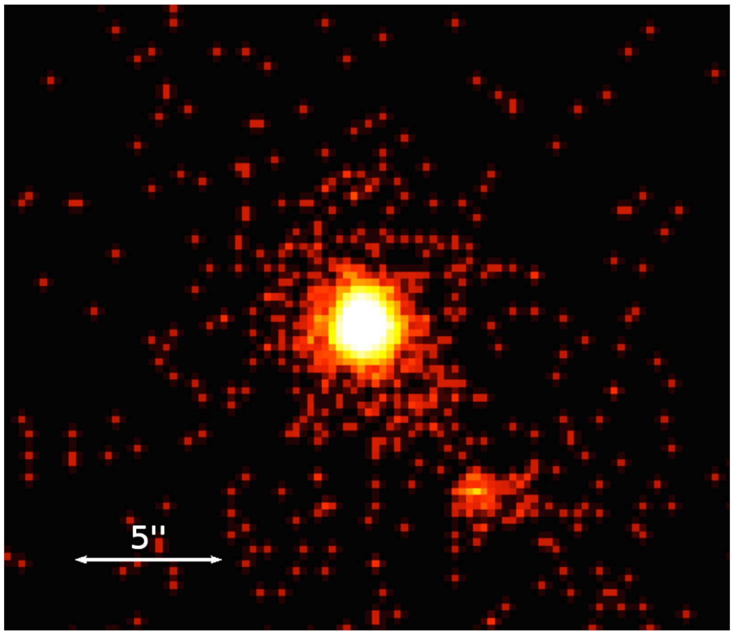
$\mu = 1.27 \pm 0.35$ arcsec yr^{-1}

V = (0.046 +/- 0.013)c

at d = 2.3 kpc

(Kargaltsev et al. 2014)

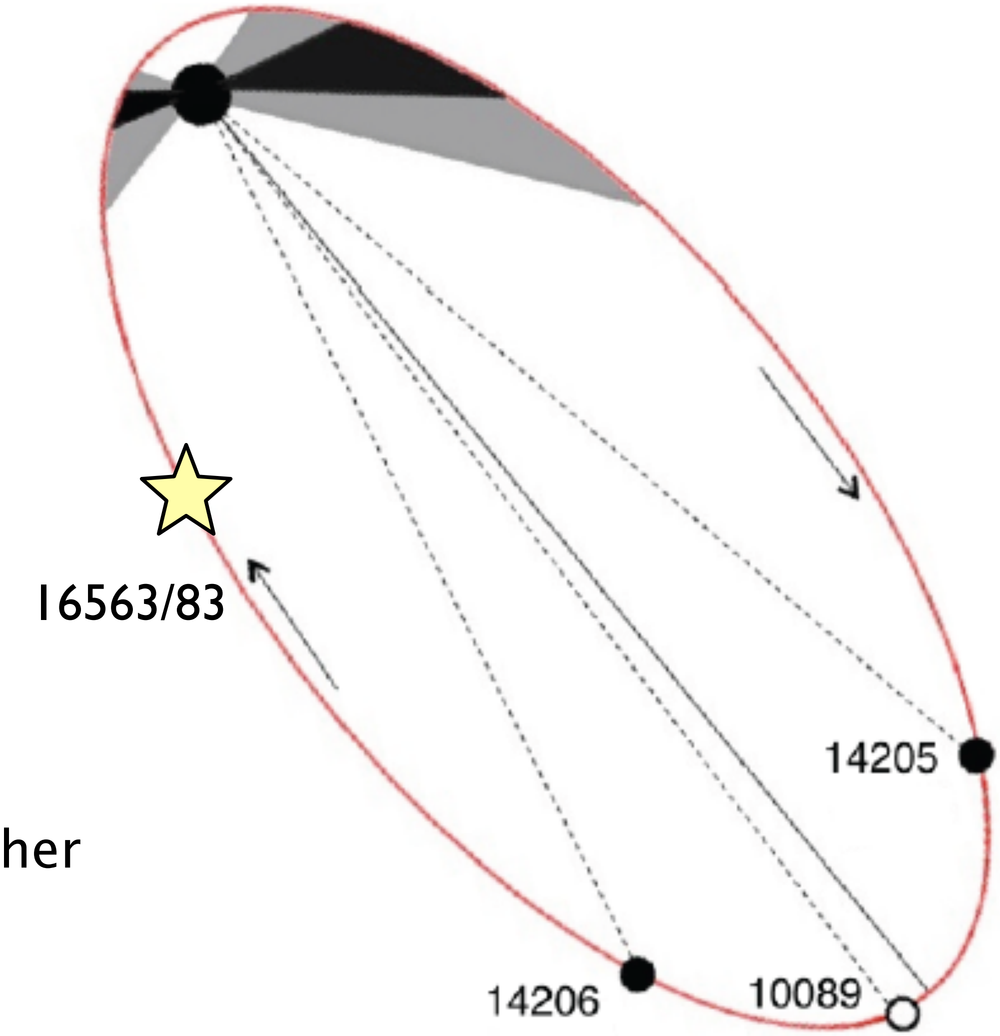
4^{th} Observation (2014 February 8 - 9)

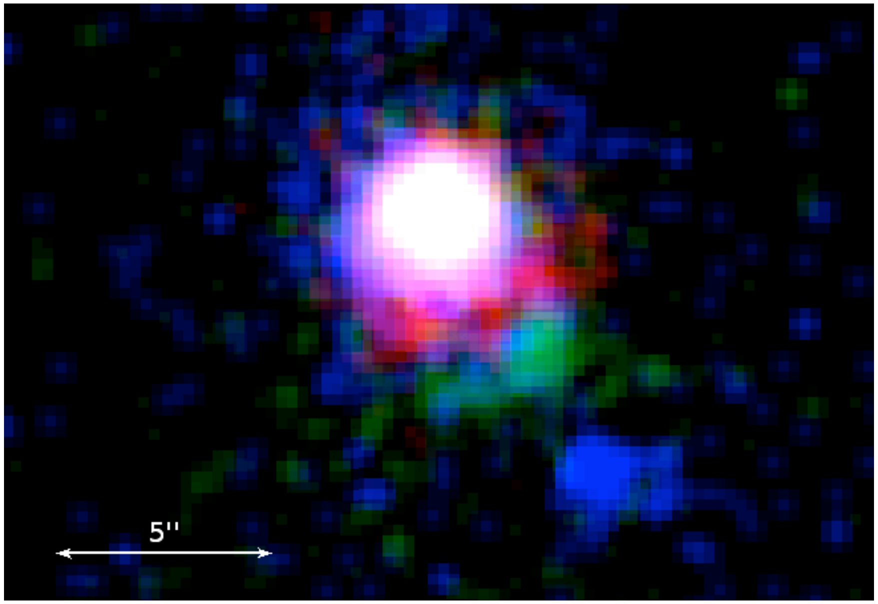


57 ks ACIS-I exposure

approaching periastron

Extended emission moved farther from the binary, apparently faster than expected from the previous 2 observations





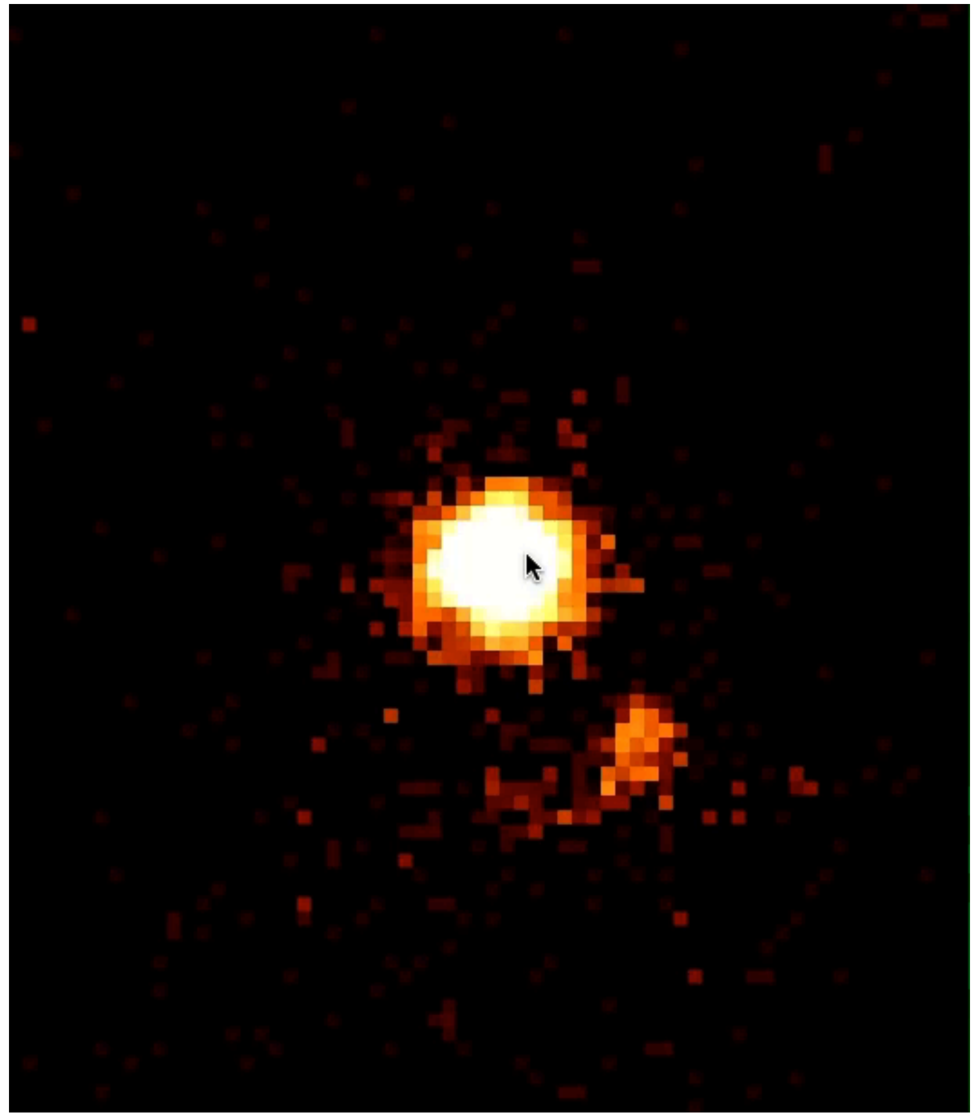
Between 3rd and 4th observations the extended structure moved by 2.5'' ±0.5''.

This corresponds to the apparent proper motion

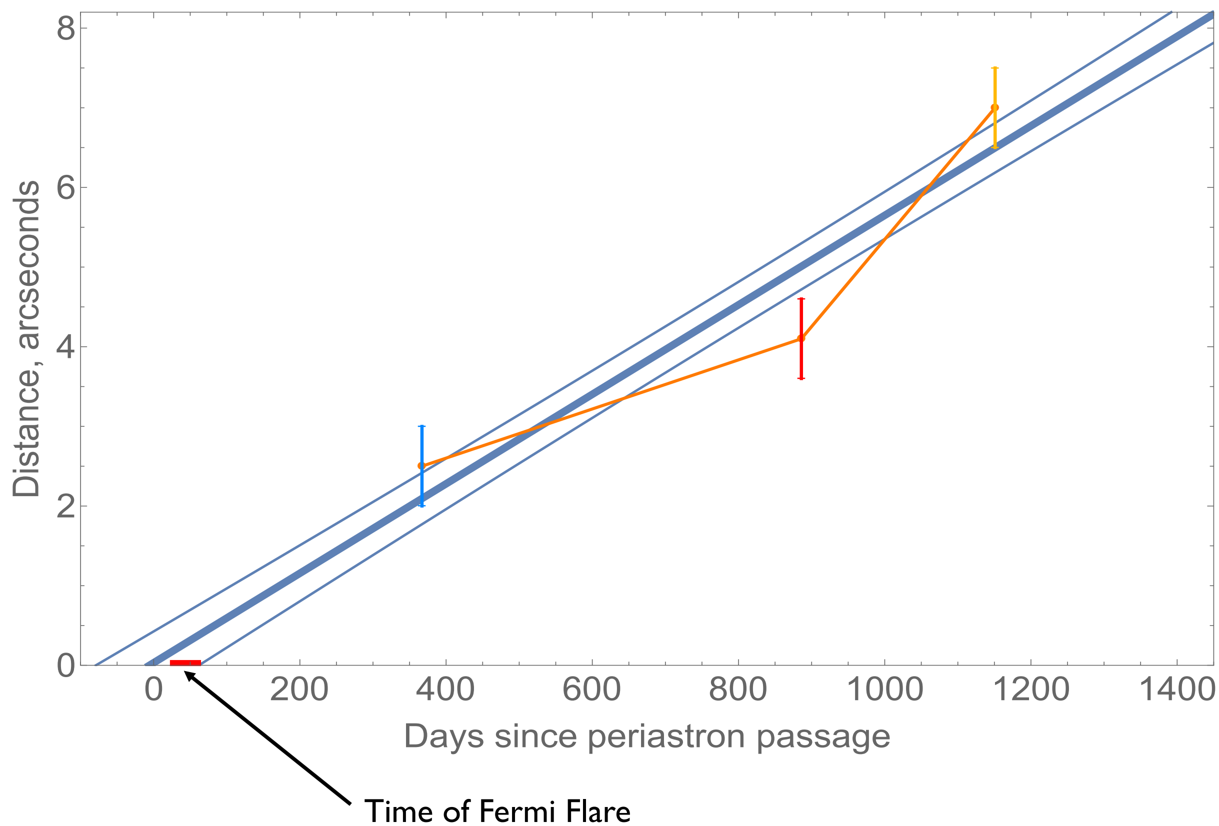
V=(0.13±0.03)c
at d = 2.3 kpc

Apparent **acceleration (?)**
90±40 cm s^{-2}

2nd, 3rd, and 4th observations together:



Distance of the extended source from the binary versus time



Linear fit: V = (0.07+/-0.01)c

If there is no (or little) acceleration, the cloud was ejected from the binary around periastron of 2010 Dec 14

Luminosities and spectra of extended emission

In 3 last observations 0.5 – 8 keV fluxes are

F = 8.5+/-0.5, 3.6+/-0.4, 1.9+/-0.4 × 10^{-14} erg cm^{-2} s^{-1} ,

corresponding luminosities **L ~ (0.2 – 1) × 10^{31}erg/s** at d = 2.3 kpc, ~0.7% - 3% of the binary's luminosity.

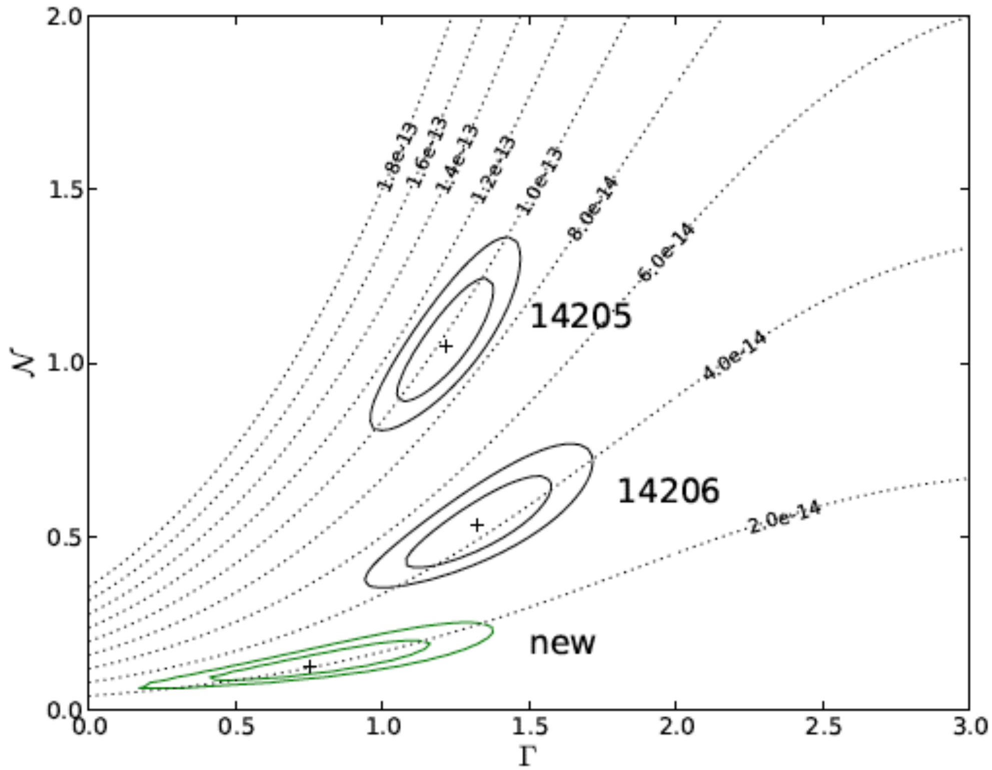
The spectra can be fitted with thermal bremsstrahlung,
kT > 6 keV, n ~ 100 cm^{-3}, **m_{ej} ~10^{28} - 10^{29}** g -- much larger than the mass supplied by the massive star wind during one orbital period, P_{orb} Mdot ~ 10^{26} (Mdot/10^{-8} M_{sol}/yr) g, or a reasonable mass of disk, m_{disk} ~ 10^{24} – 10^{26} g.
Kinetic energy ~10^{46} – 10^{47} erg, improbably large.

The scenario with hot hadronic plasma cloud radiating via bremsstrahlung does not look plausible.

The spectra are also consistent with power laws,
photon indices **Γ = 1.2+/-0.1, 1.3+/-0.2, and 0.8+/-0.4** (no softening!)

Synchrotron radiation?

Confidence contours in Photon Index – Normalization plane



Synchrotron interpretation:

- magnetic field **B ~ 80 μG**
- total magnetic and electron energies $\mathbf{W_{m+e} \sim 1 \times 10^{41}}$ **erg**
- $W_{m+e} << P_{orb}$ Edot = 9×10^{43} erg energy could be supplied by the pulsar.
- if the ejected object were an **e-/e+ cloud**, the large **drag force,** $\mathbf{f \sim \rho_{amb} v^2 A}$ is problematic
- $\mathbf{t_{dec} \sim 10\, n_{amb}^{-1}\, s}$ where n_{amb} is the ambient proton number density
- the e-/e+ cloud must be loaded with a heavy (electron-ion) plasma to explain lack of deceleration
- Even in this case the ejected mass should be a substantial fraction of the disk mass, if clump is moving in a stellar wind blown bubble

- Current explanation: Instead of the companion's wind bubble,

ejected clump is moving in the unshocked pulsar wind

- More plausible at larger values of **η = Edot/(Mdot v_w c) =**

= 4.4 (Mdot/10^{-9} $M_\odot$/yr)$^{-1}$ (v_w/1000 km/s)$^{-1}$

when the companion's wind is confined by the pulsar wind into a narrow cone, while the unshocked pulsar wind fills the rest of the binary volume.

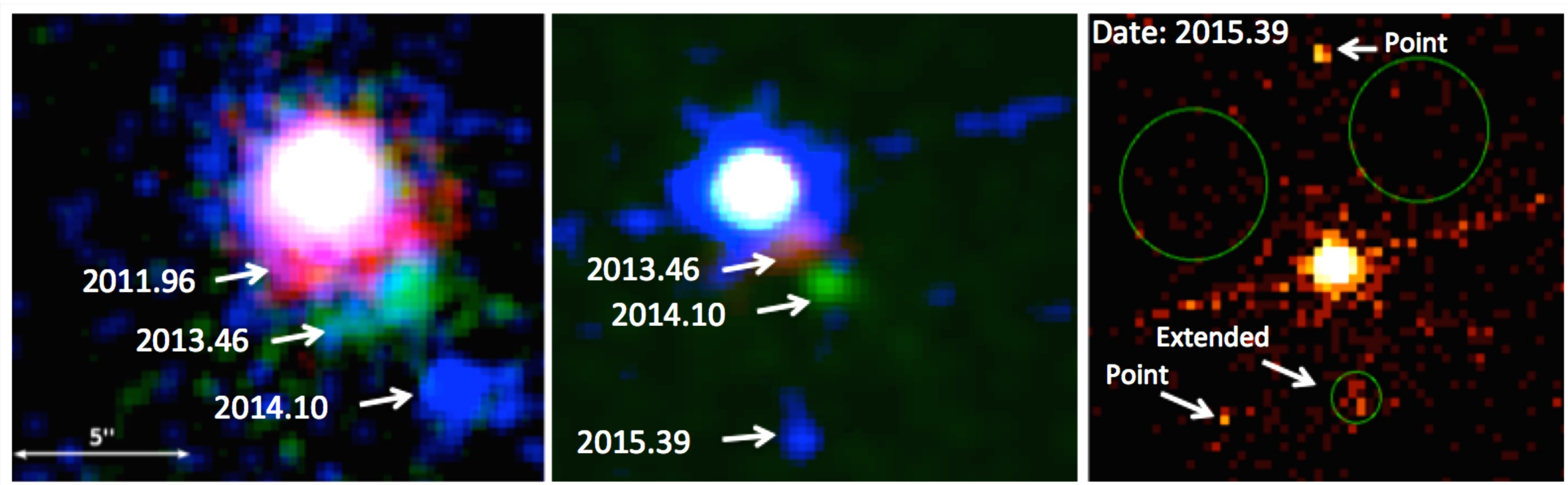
- The X-ray emission is due to synchrotron radiation of the pulsar wind shocked by the collision with the clump.

X-ray luminosity **$L_{X,cl} = \xi_X$ Edot $(r_{cl}/2r)^2$, $\xi_X \sim 1.5\times10^{-3}$**

- The interaction with unshocked pulsar wind with ejected clump can also **accelerate** the clump: **vdot ~ p_{pw} A m_{cl}^{-1}**.
- **m_{cl} ~ 10^{21} g** for the apparent (low-significance) estimated acceleration.
- **The clump could be ejected due to the interaction of the pulsar with the decretion disk**.
- The clump is then acceleration by the pulsar wind ram pressure to ~0.1 c.

Unexpected result from newest observation (April 2015)

The clump (16.4±4.4 counts) apparently moved to 15" (!) from the binary (v ~ 0.5c) in "wrong" direction → If this is indeed the clump, it not only moves with large acceleration but also changes the direction of motion!



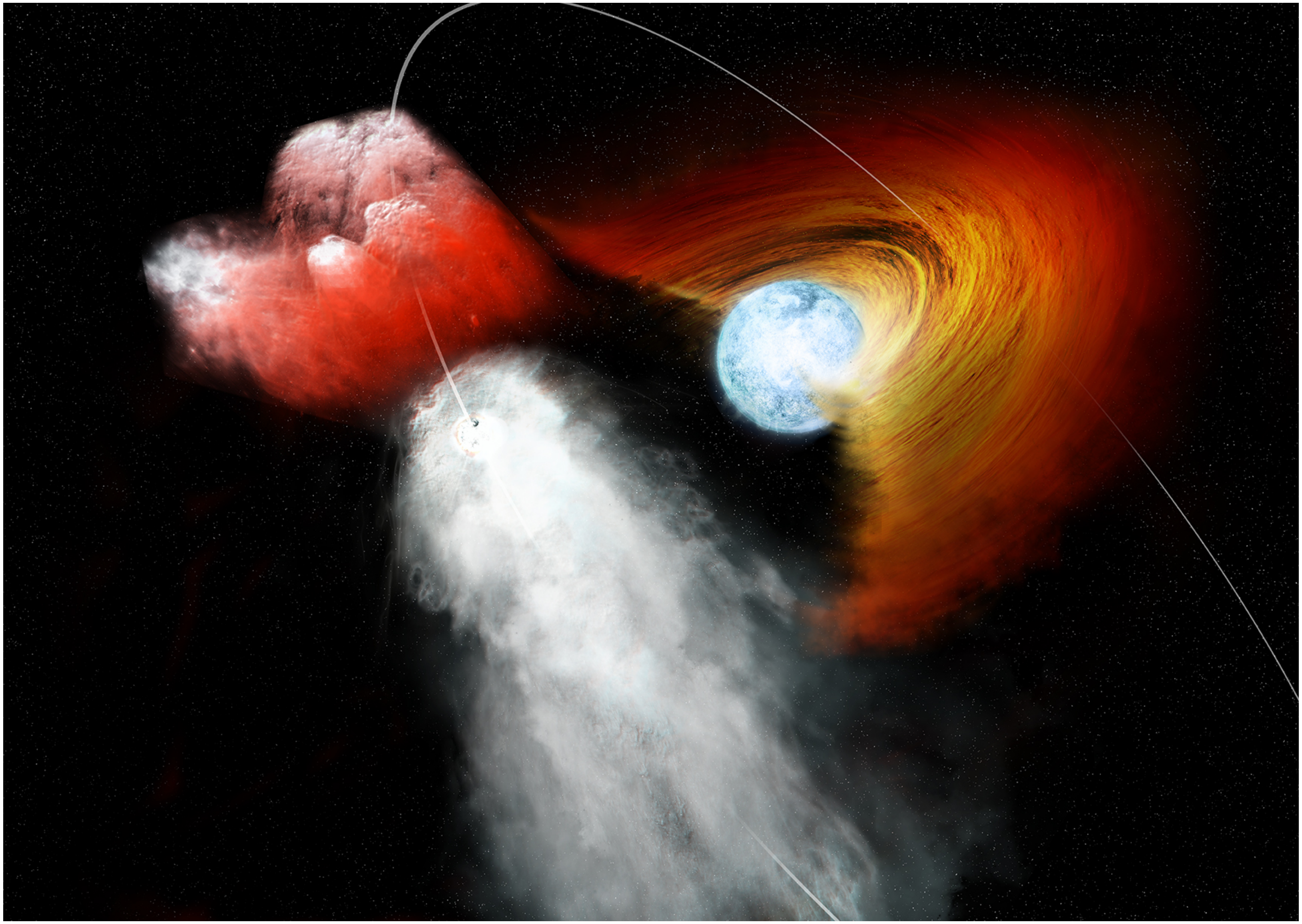
Very puzzling!

The reason is unclear. We will try to check observationally.

Summary

- We discovered a new phenomenon: Ejection of an X-ray emitting clump from a high-mass γ-ray binary with a velocity v ~ 0.1c and a hint of acceleration.
- The clump's luminosity faded with time but the power-law-like spectrum ($\Gamma \sim 0.8 - 1.3$) did not show softening.
- The clump was likely ejected due to interaction of the pulsar (pulsar wind) with the equatorial decretion disk of the high-mass star.
- We suggest that the clump is moving in the unshocked pulsar wind, whose pressure accelerated the clump to the very high speed. This scenario requires large η.
- The most likely emission mechanism is synchrotron radiation of relativistic electrons ($E_e \sim 10$ - 100 TeV, $B \sim 10^2$ μG) of pulsar wind shocked in the collision with clump.
- We expect a new clump has been ejected during the recent periastron passage (December 2015), new Chandra observations are planned.

Thank you for your attention!



Artist interpretation: NASA/CXC press release

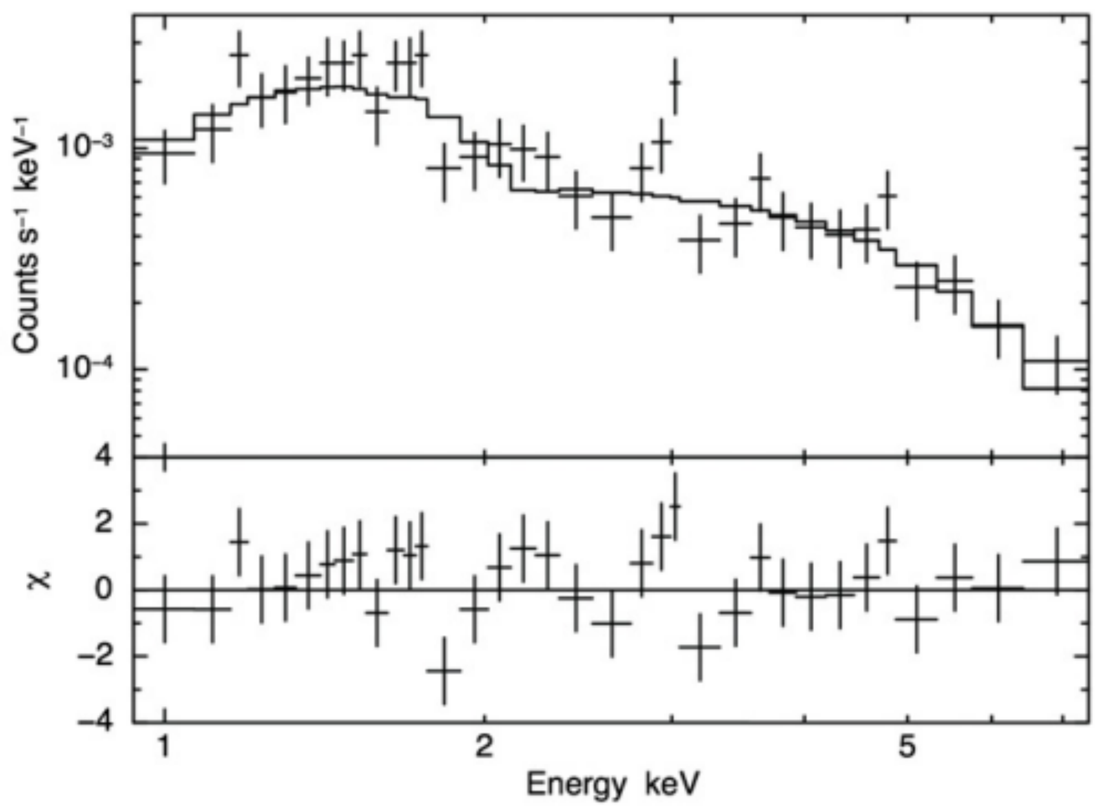
ObsID	MJD	θ[a]	Δt[b]	Exp.[c]	Cts[d]
		deg	days	ks	
10089	54965	182	667	25.6	1825
					61
14205	55912	169	370	56.3	6551
					343
14206	56431	192	886	56.3	4162
					144
new[i]	56696	221	1151	57.6	6257
					58

[a]True anomaly counted from periastron.

[b]Days since latest preceded periastron.

[c]Exposure corrected for deadtime.

[d]Total (gross) counts.



Counts s⁻¹ keV⁻¹
10^{-3}
10^{-4}
χ
4
2
0
−2
−4
1
2
5
Energy keV