Puzzling ejections from the high mass gamma-ray binary PSR B1259-63

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Variable Galactic Gamma-ray Sources
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High mass Gamma-ray Binary LS 2883

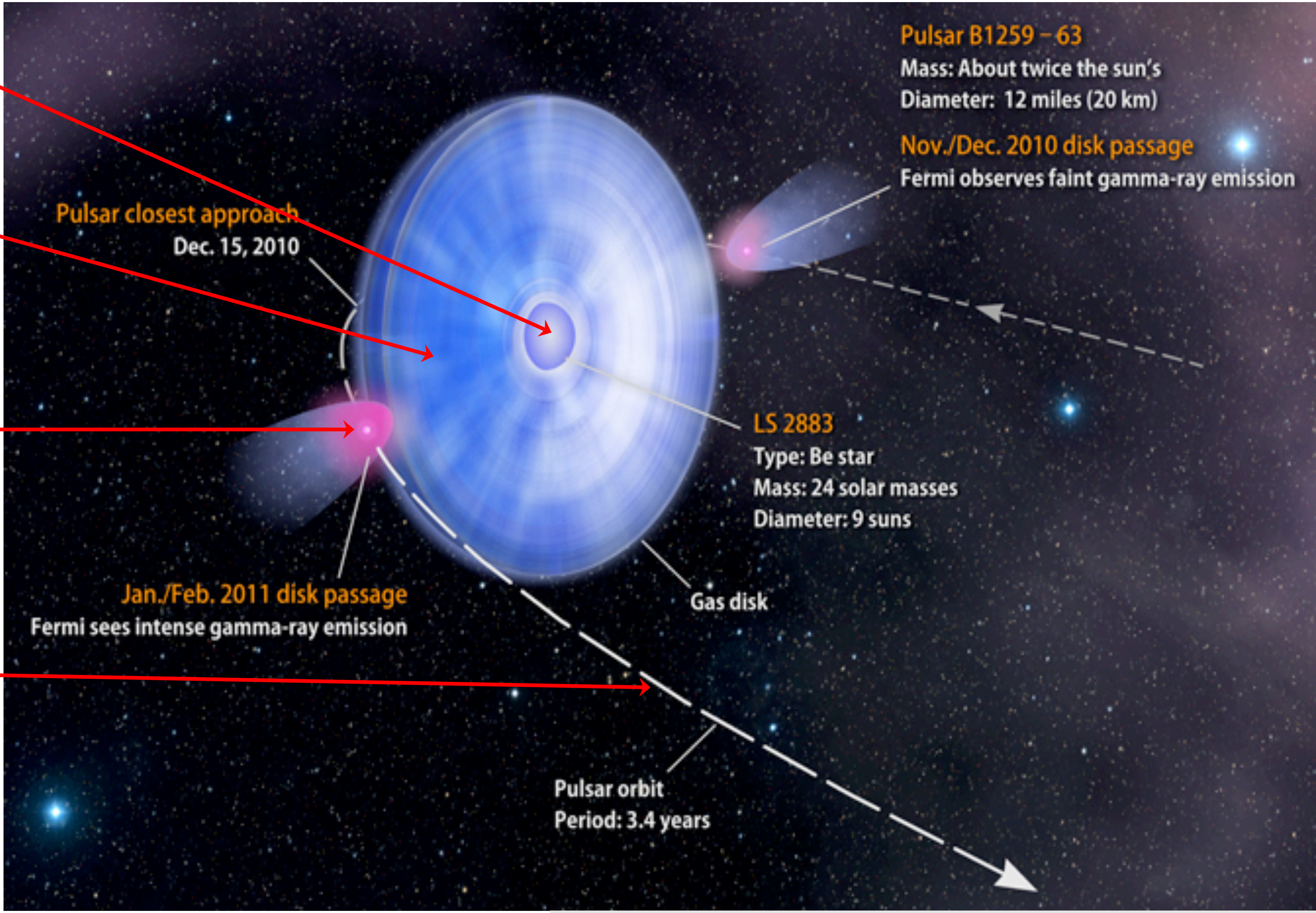
Fast-spinning, **massive (M~30 $M_\odot$, L=6 × $10^4 L_\odot$) star** with a strong wind.

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

Pulsar B1259-63:
Spin period = 48 ms
Edot = 8 × 10^{35} erg/s
Spin-down age =330 kyr
Should emit pulsar wind

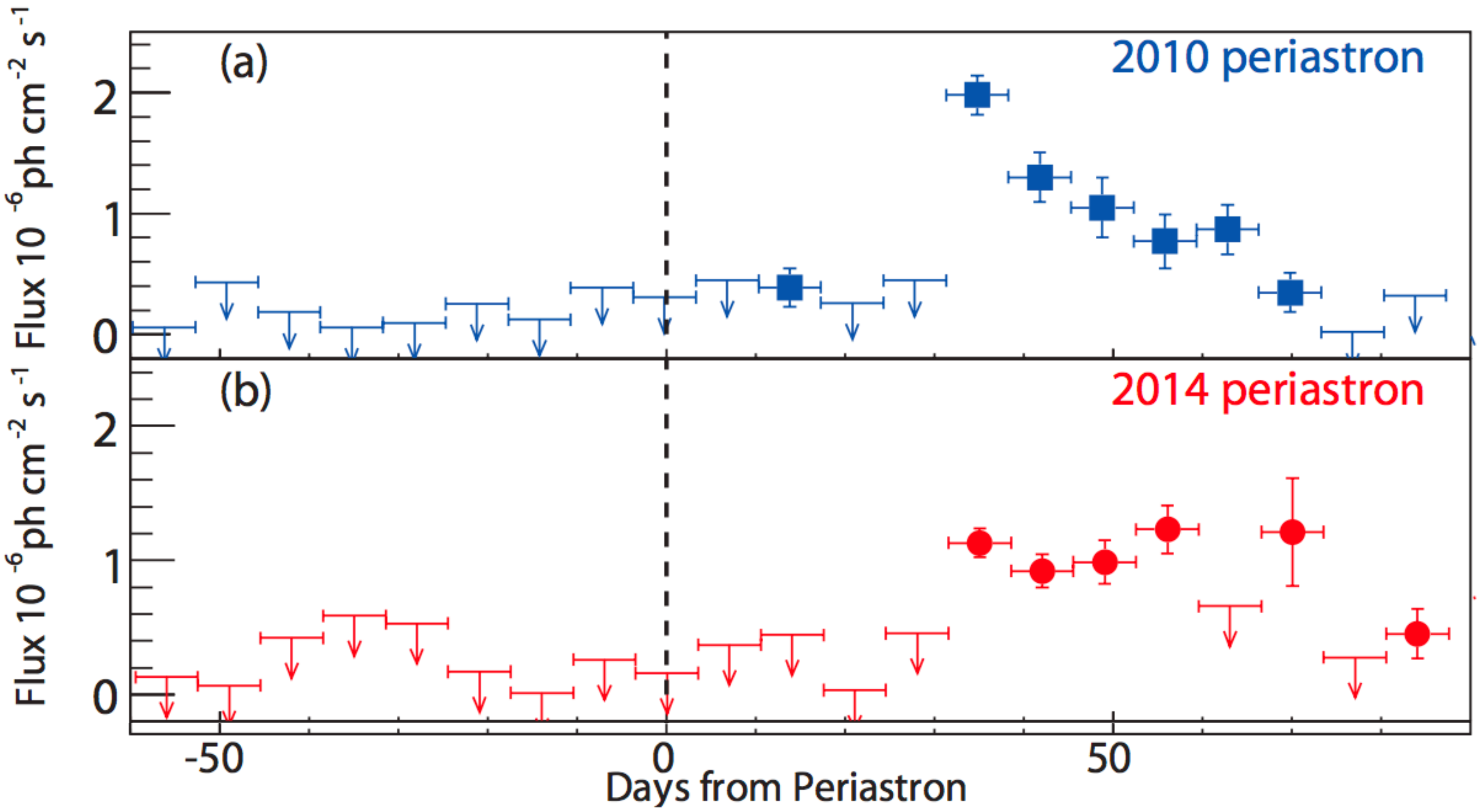
Orbit:
3.4 yr orbital period
7 AU (3 milliarcsec) max. separation
0.87 eccentricity

Distance:
2.3 kpc
Orbital inclination ~23°



(Credit: NASA's Goddard Space Flight Center/Francis Reddy)

Fermi GeV Emission

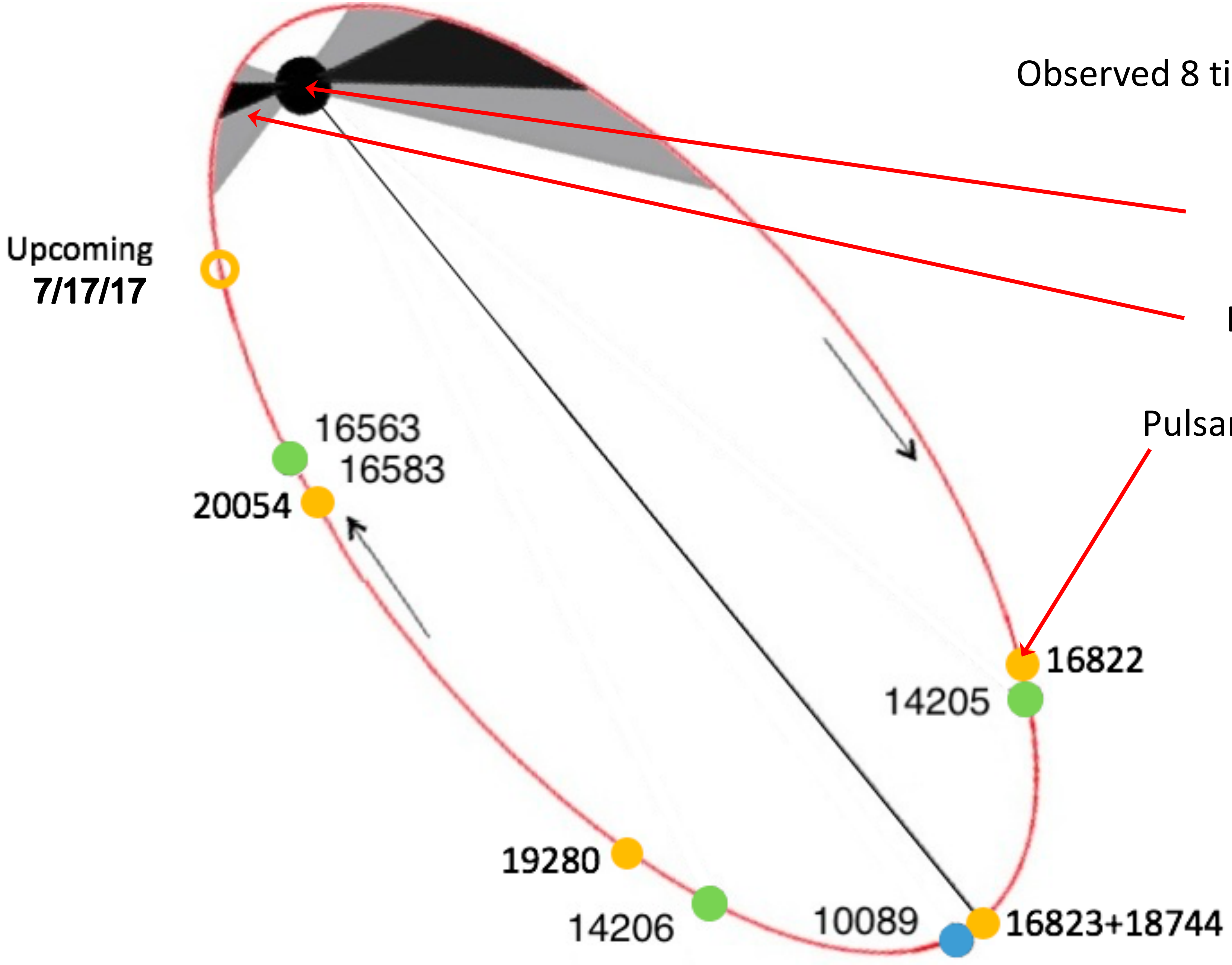


Adopted from Caliandro et al. (2015)

Flares occurring ~30 days after periastron passage

Flares last ~50 days

Chandra Campaign



Observed 8 times with ACIS-I spanning 3 orbital cycles

$M \sim 30\ M_{\odot}$ star

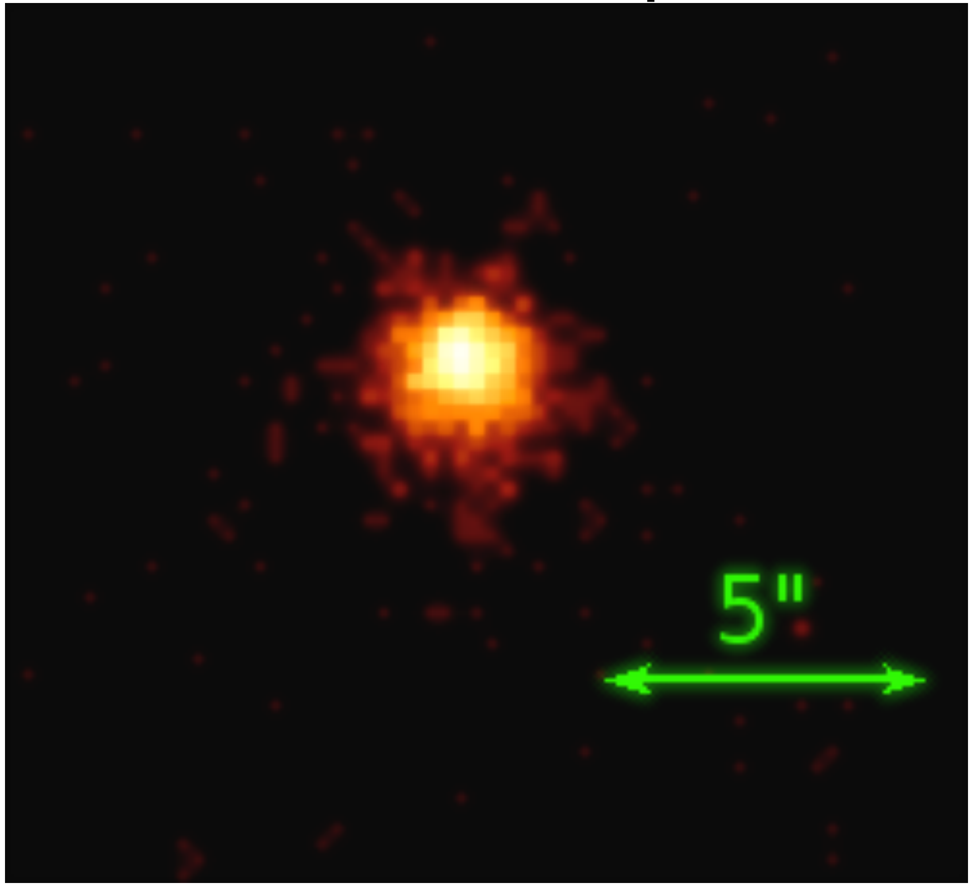
Equatorial disk

Pulsar position at time of observation

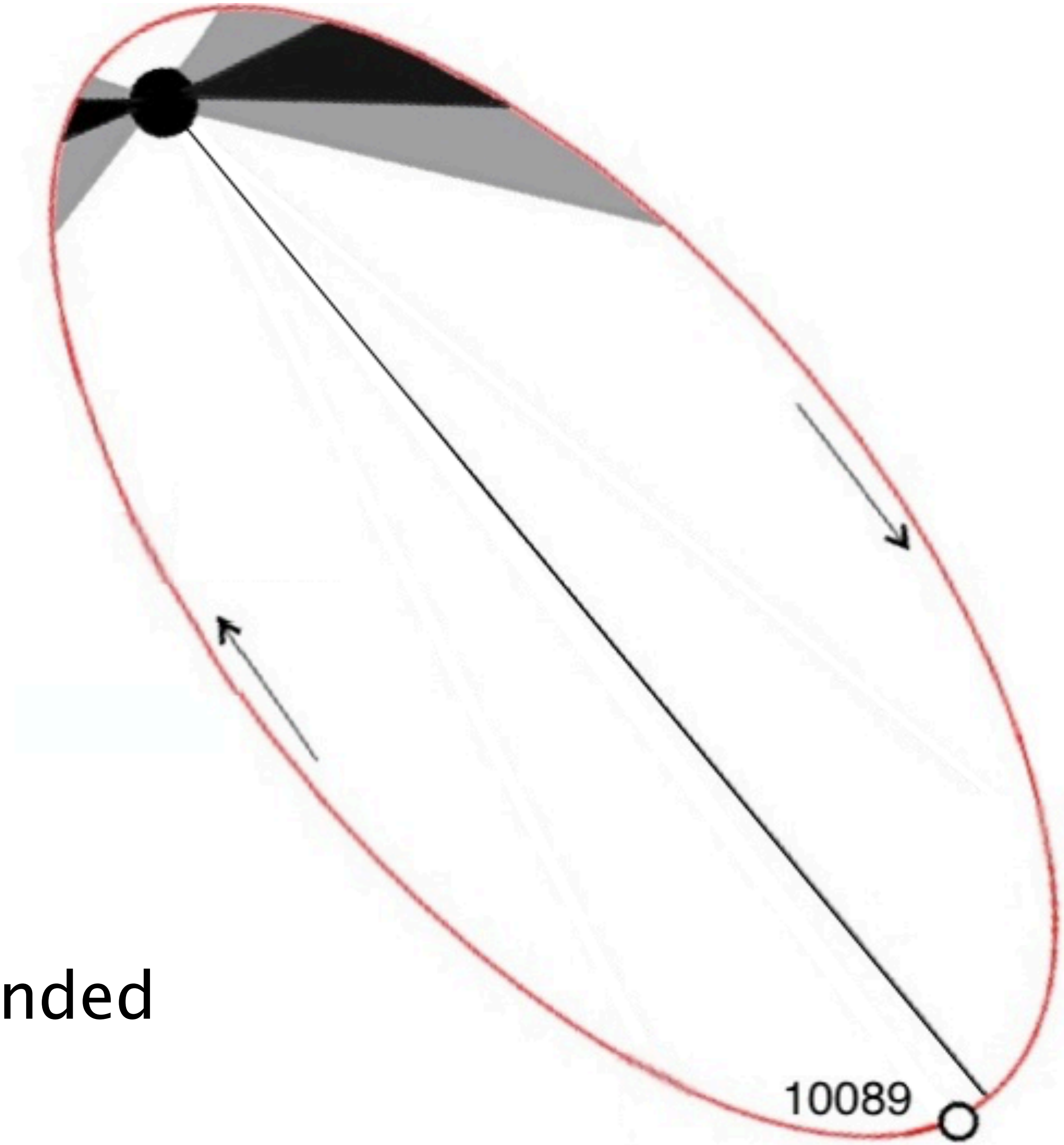
Blue→2009
Green→2011-2014
Orange→2015-2017

2009 May 14

25 ks ACIS-I exposure



(Pavlov et al. 2011)

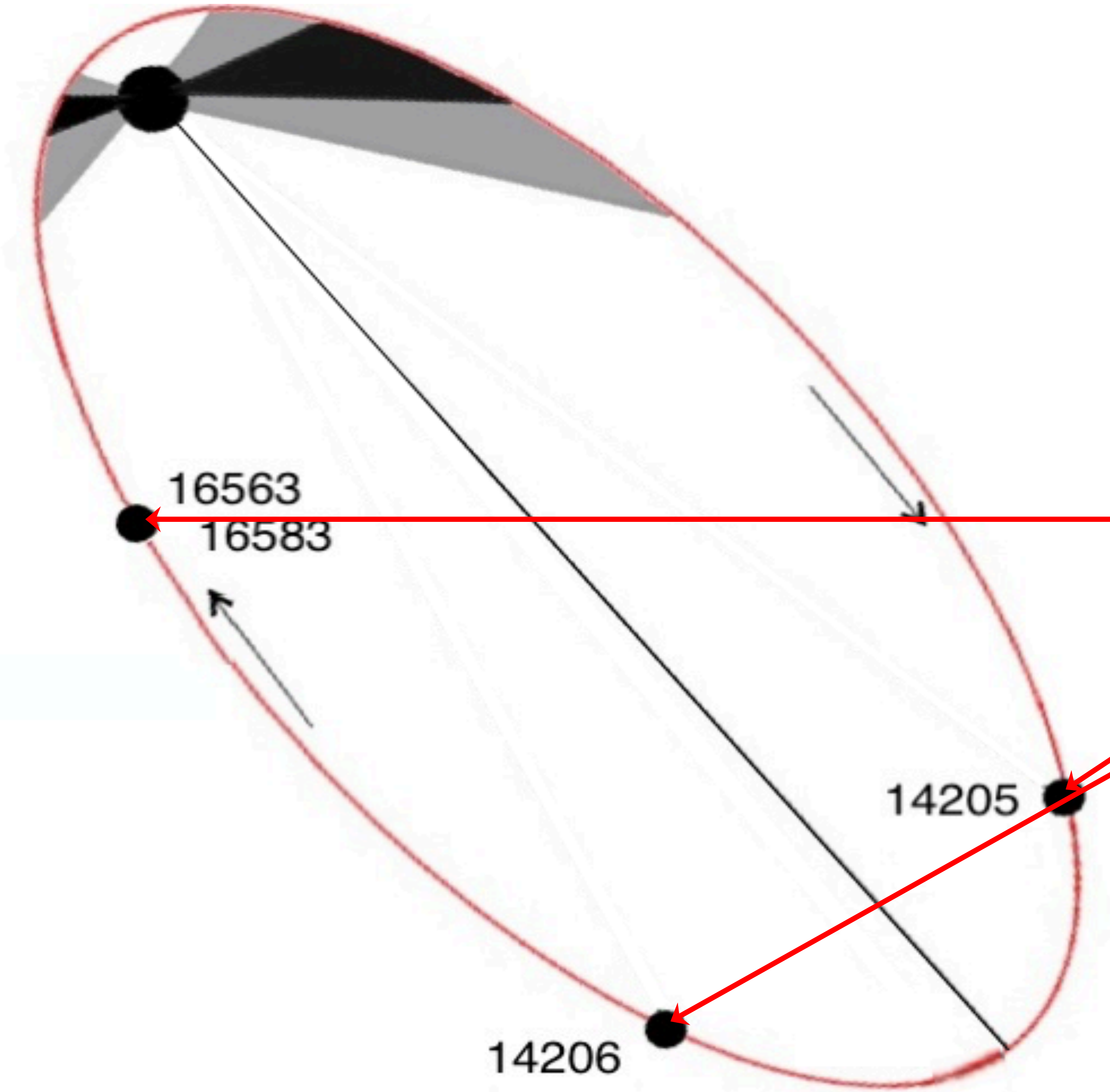


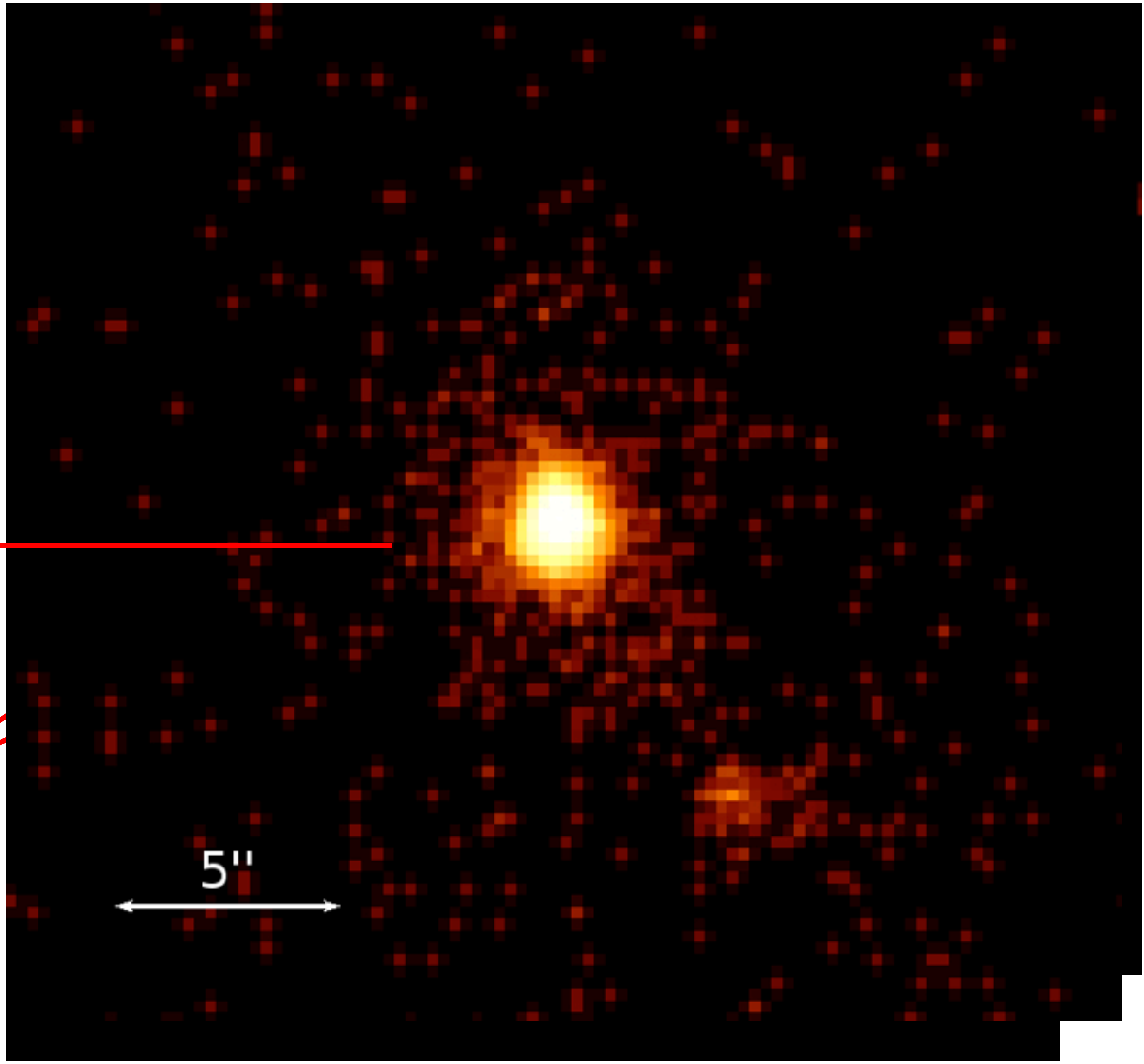
~4σ detection of asymmetric extended emission

Three observations in 2011 - 2014

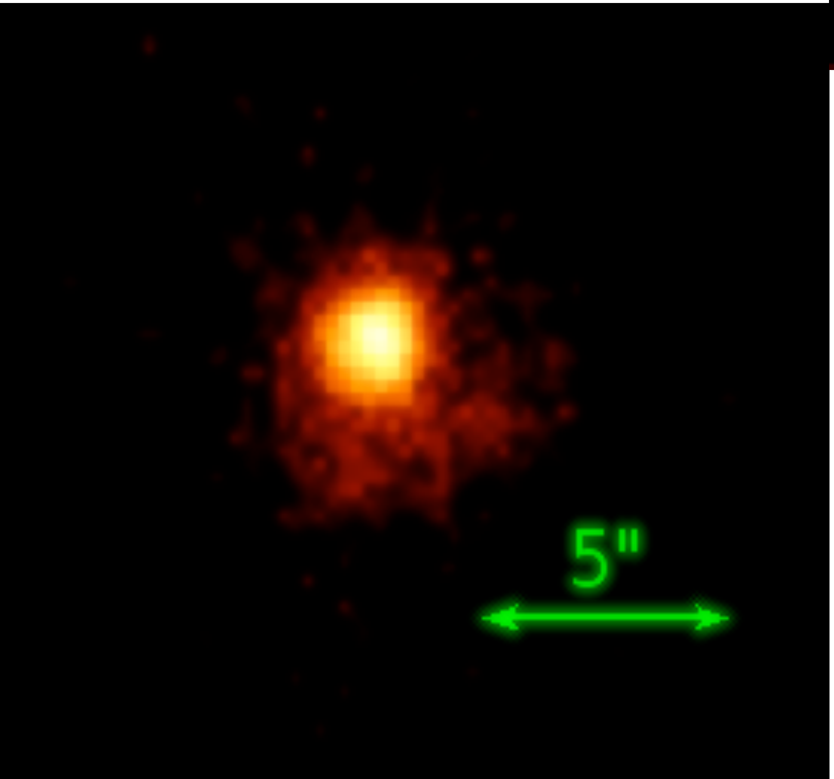
~60 ks exposures

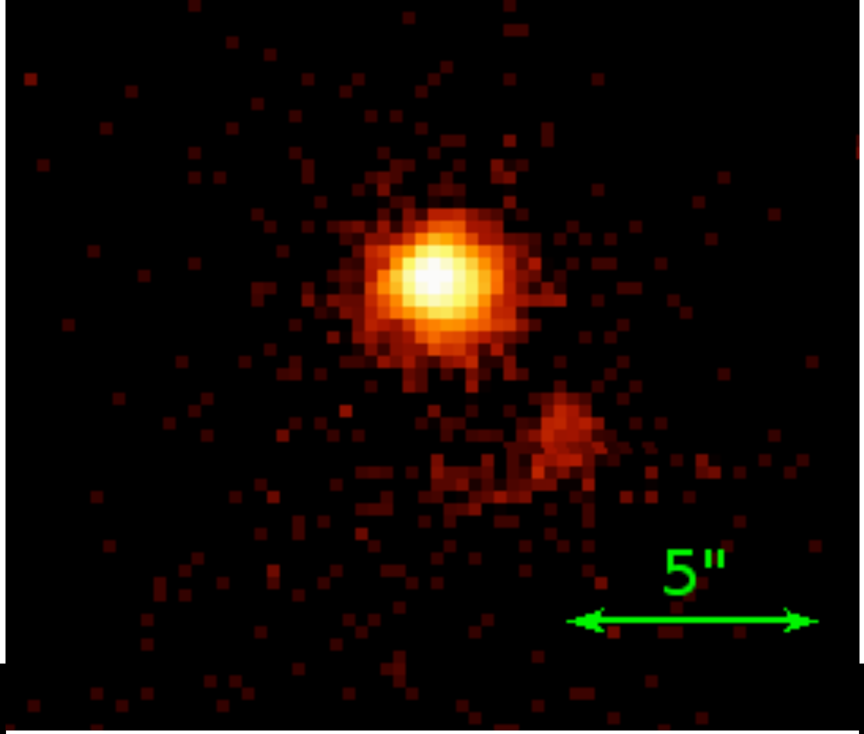
02/08/2014





12/17/2011





05/19/2013

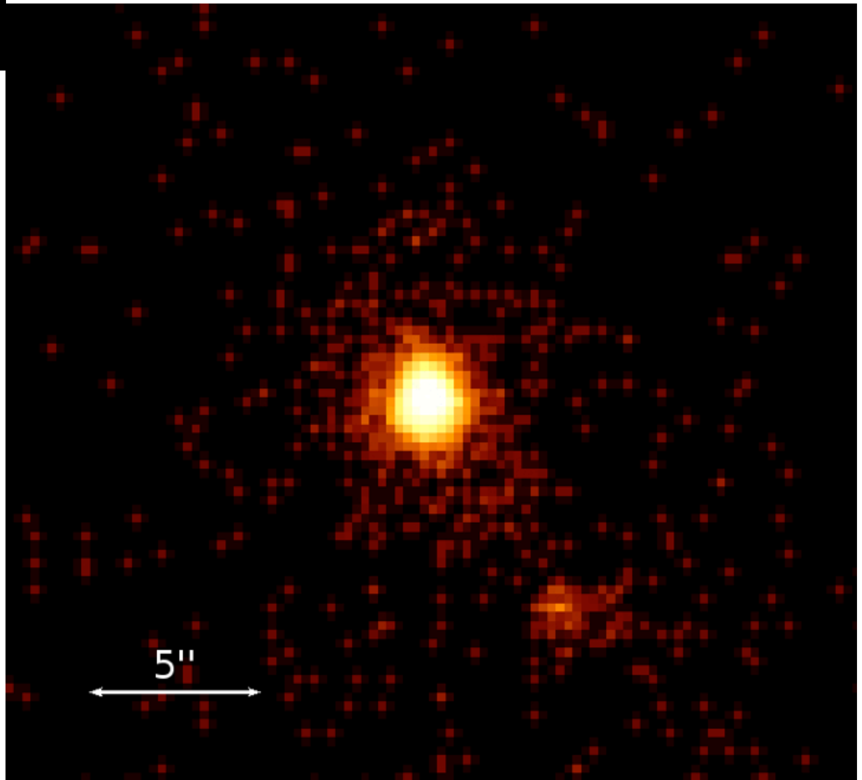
Extended object moving
from the binary along its major axis

(Kargaltsev et al. 2014; Pavlov et al. 2015)

High apparent velocity, ~0.1 c,
perhaps with acceleration.

No evidence of deceleration

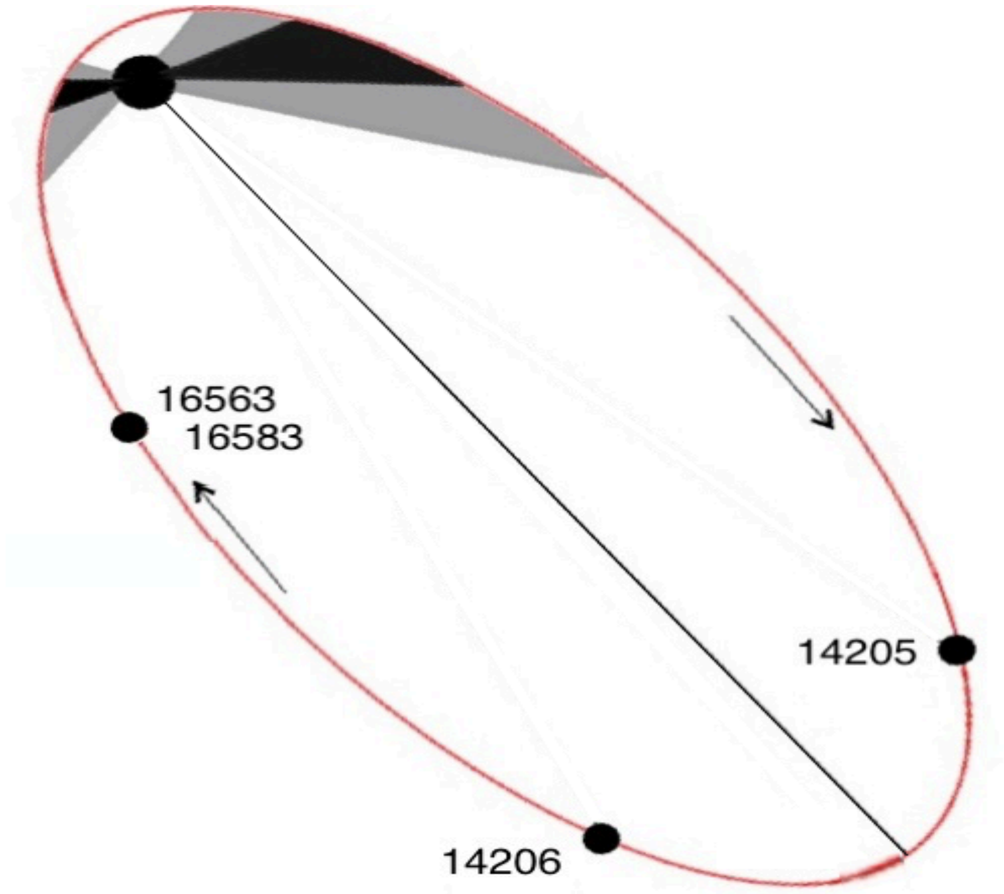
02/08/2014

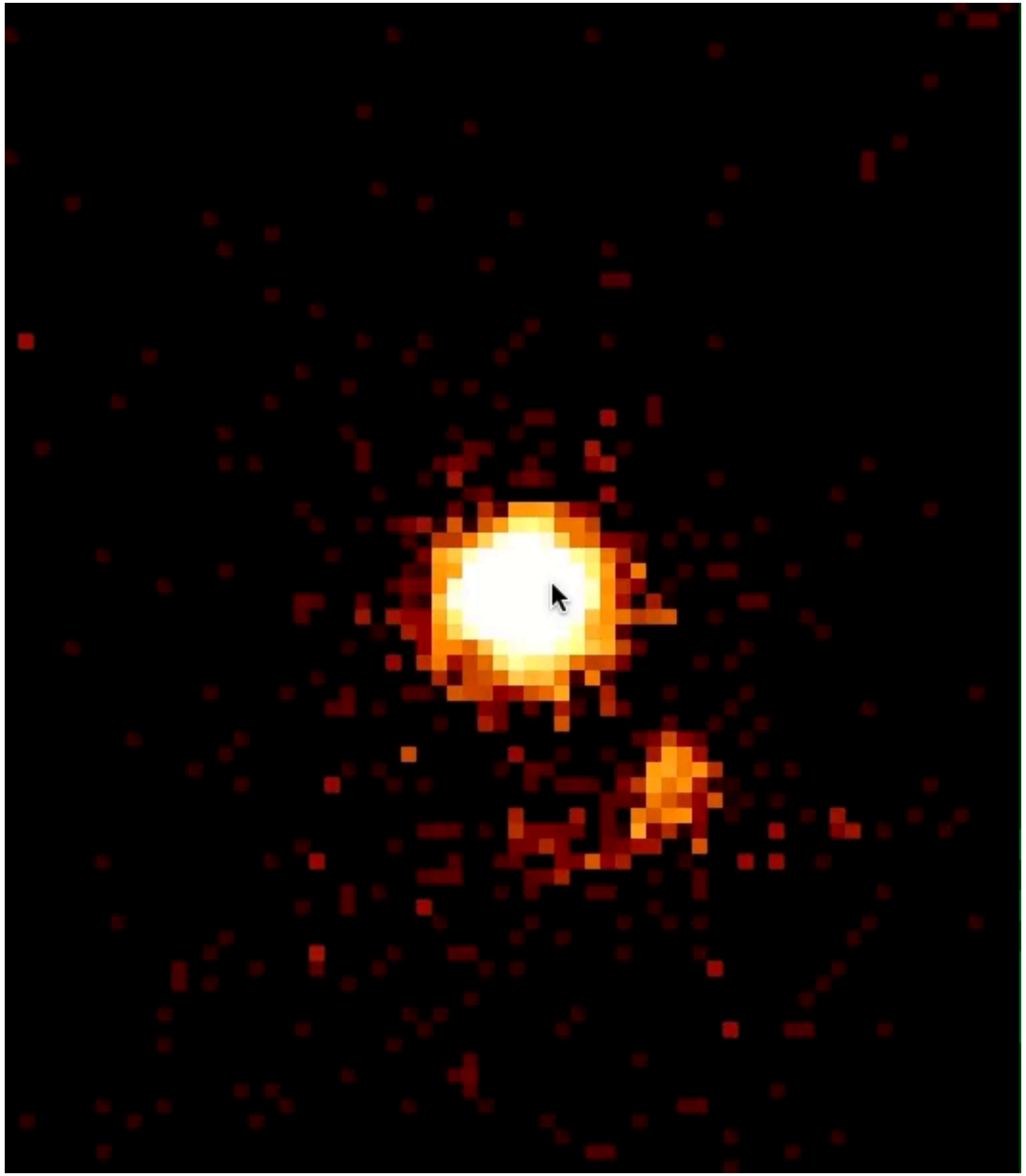


30”x35” images taken on
Dec 2011, May 2013
and Feb 2014

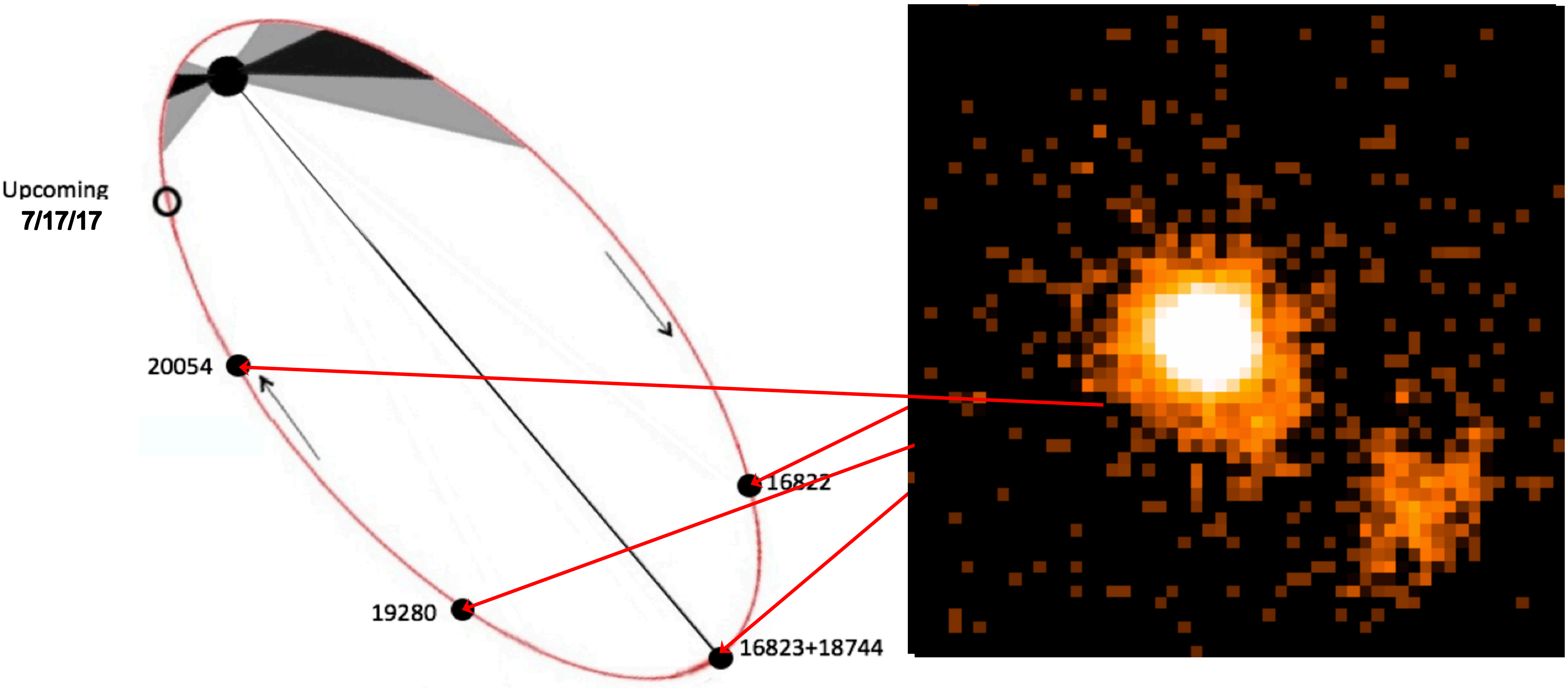
2011-2014

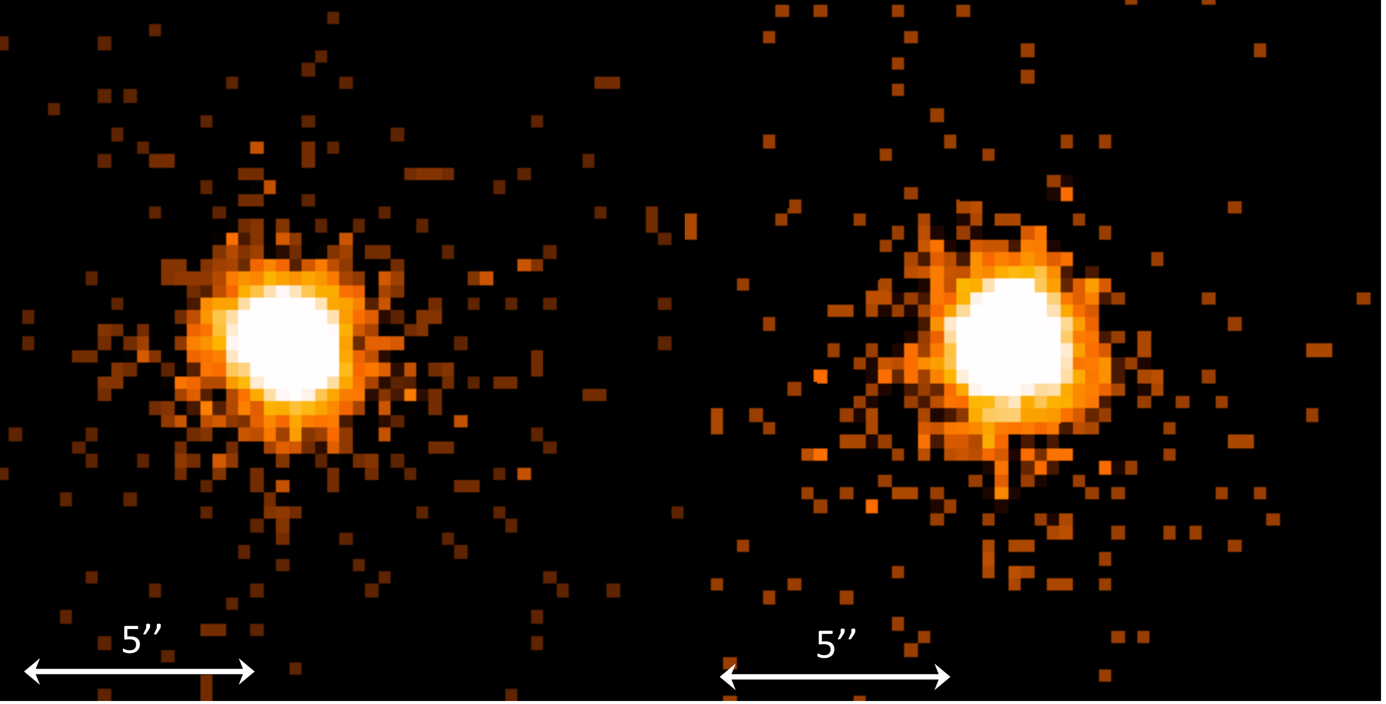
“Clump” is moving away and fading





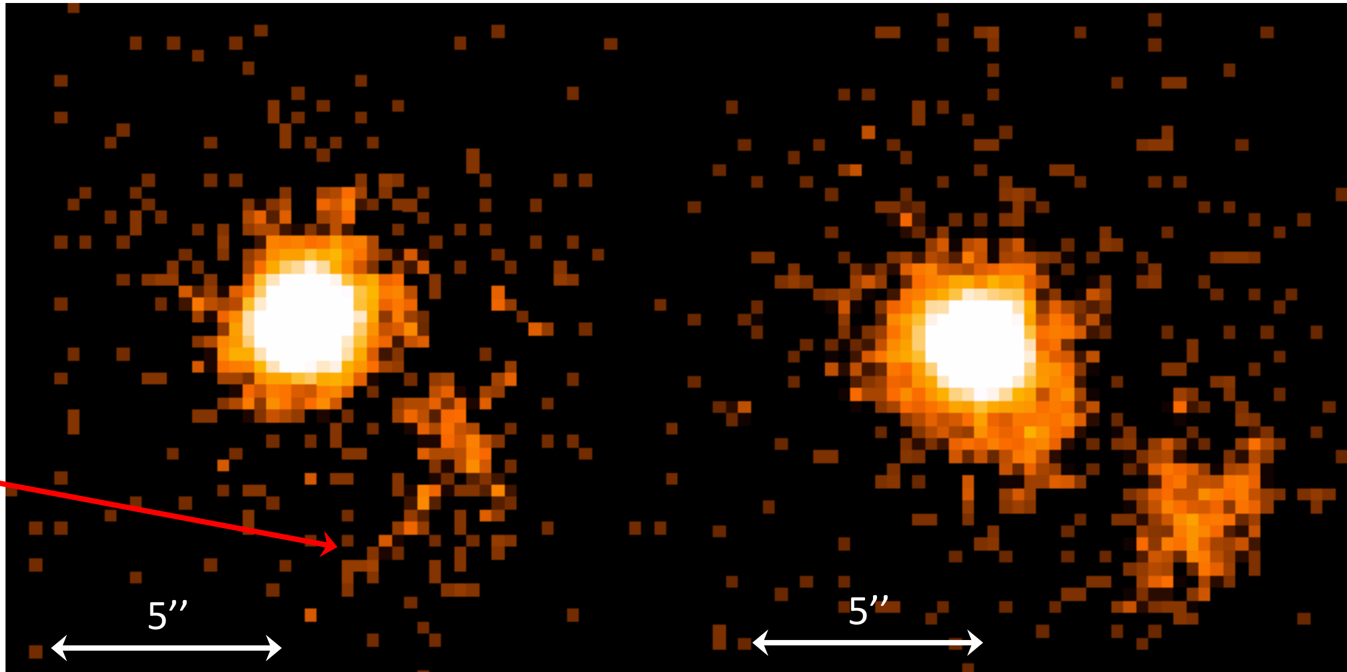
Four observations: Apr 2015, Jan 2016, Jan 2017, Apr 2017





04/21/2015 01/12/2016

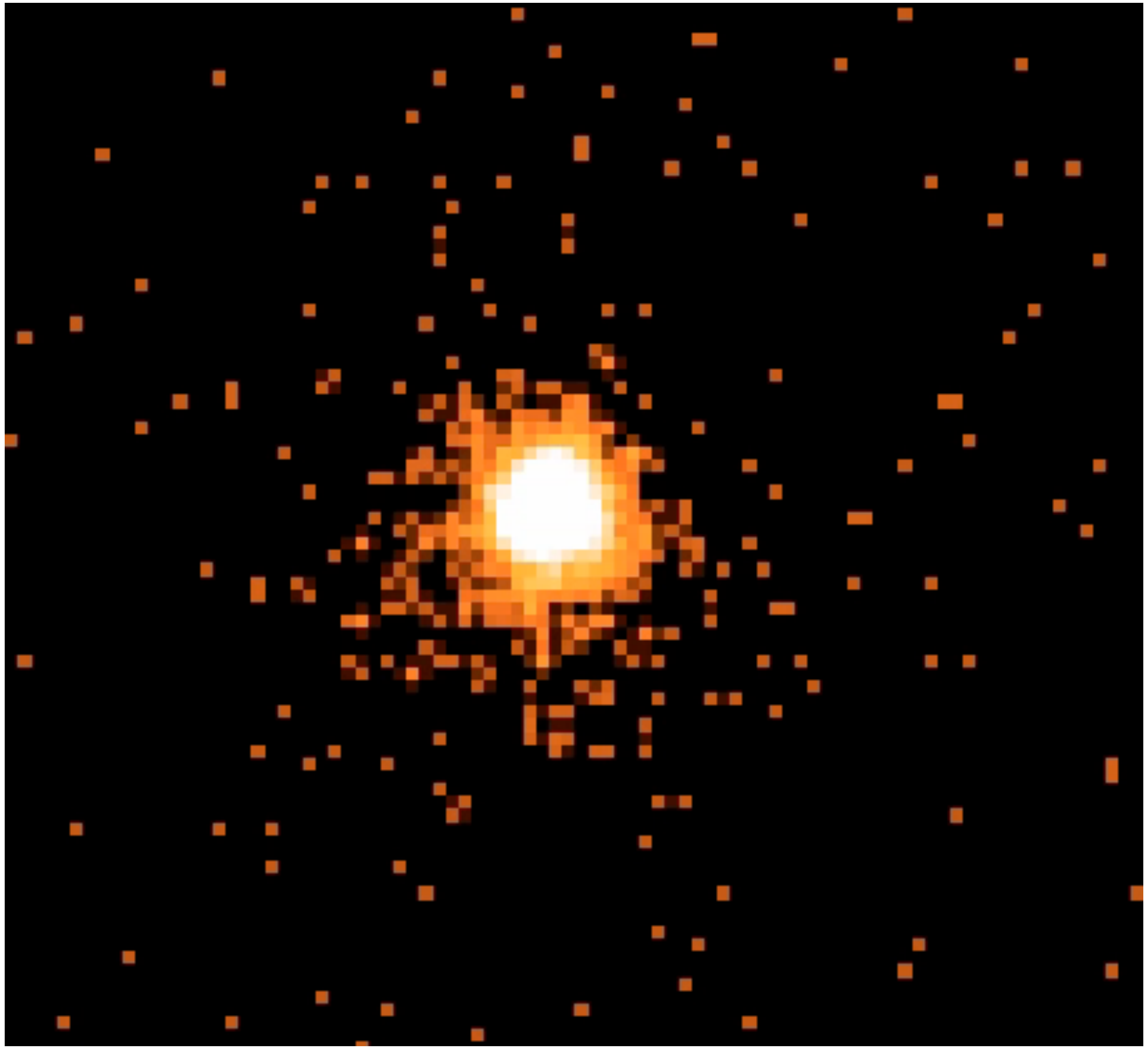
01/06/2017 04/24/2017



New clump detected moving in same direction with same velocity

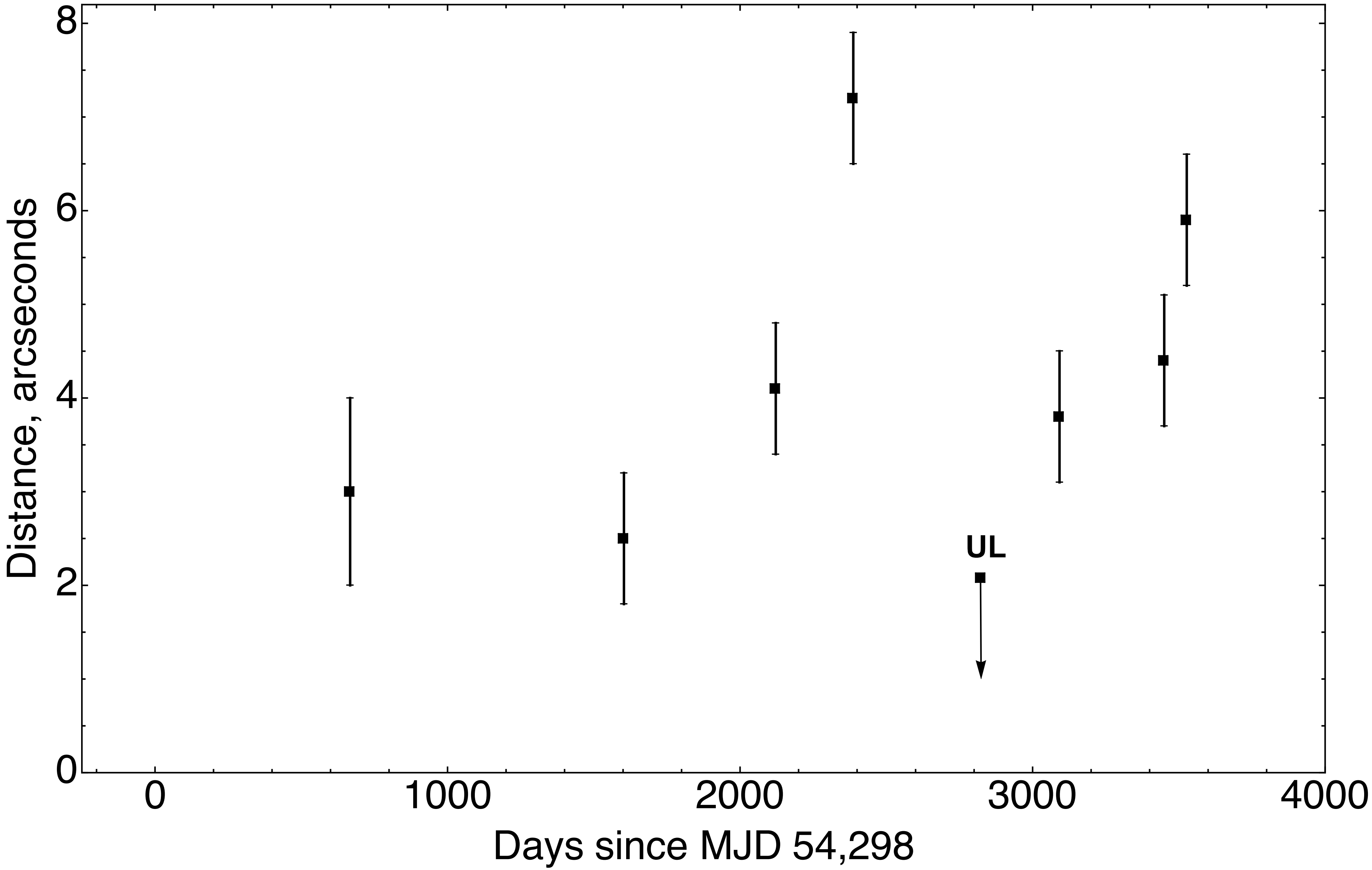
Shows strange "whiskers" in Jan 2017, brightens in Apr 2017

Movie of 4 observations from Apr 2015 – Apr 2017



Extended emission changes its shape and brightens!

Clump separation from the binary vs time.



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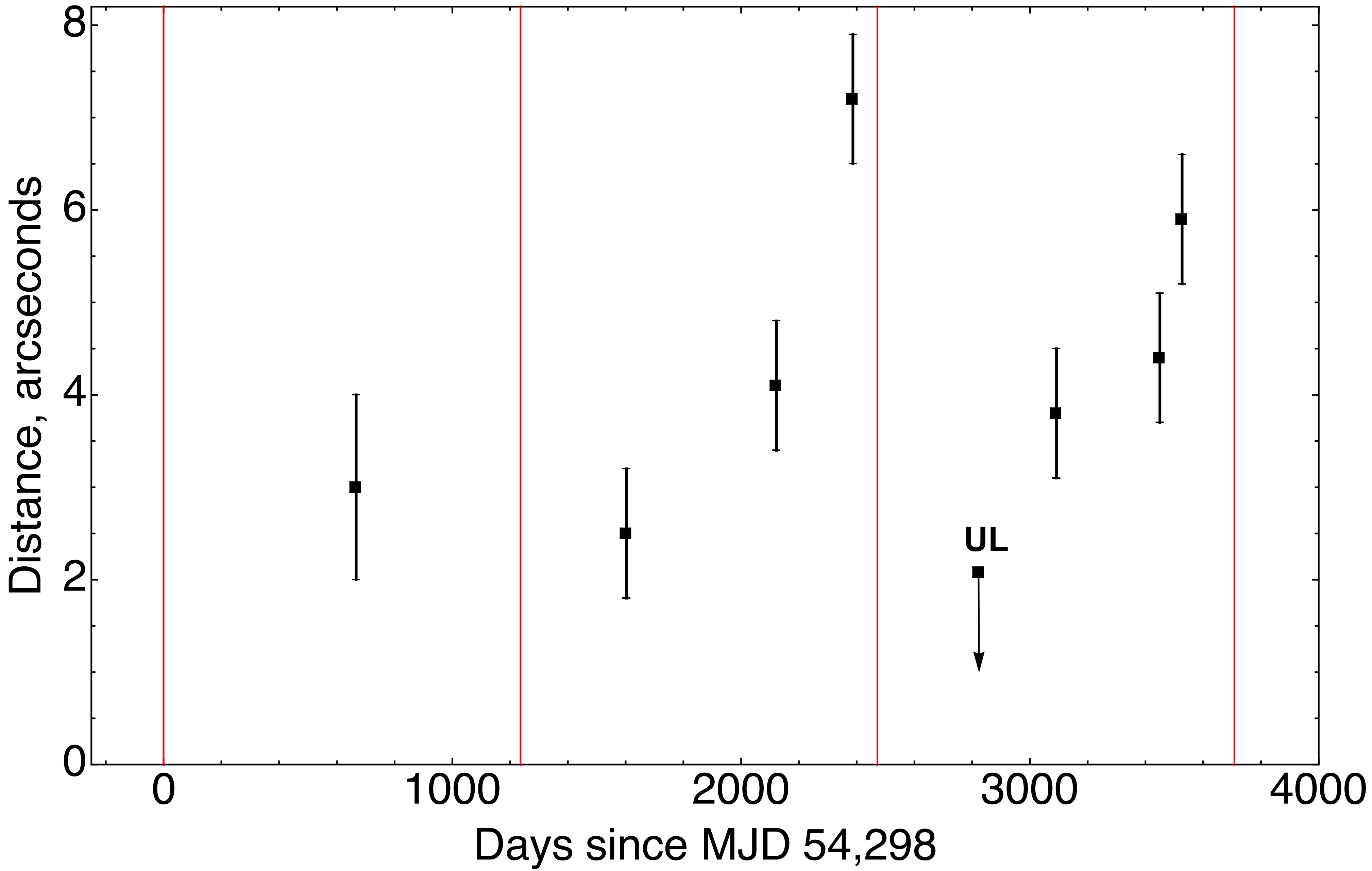

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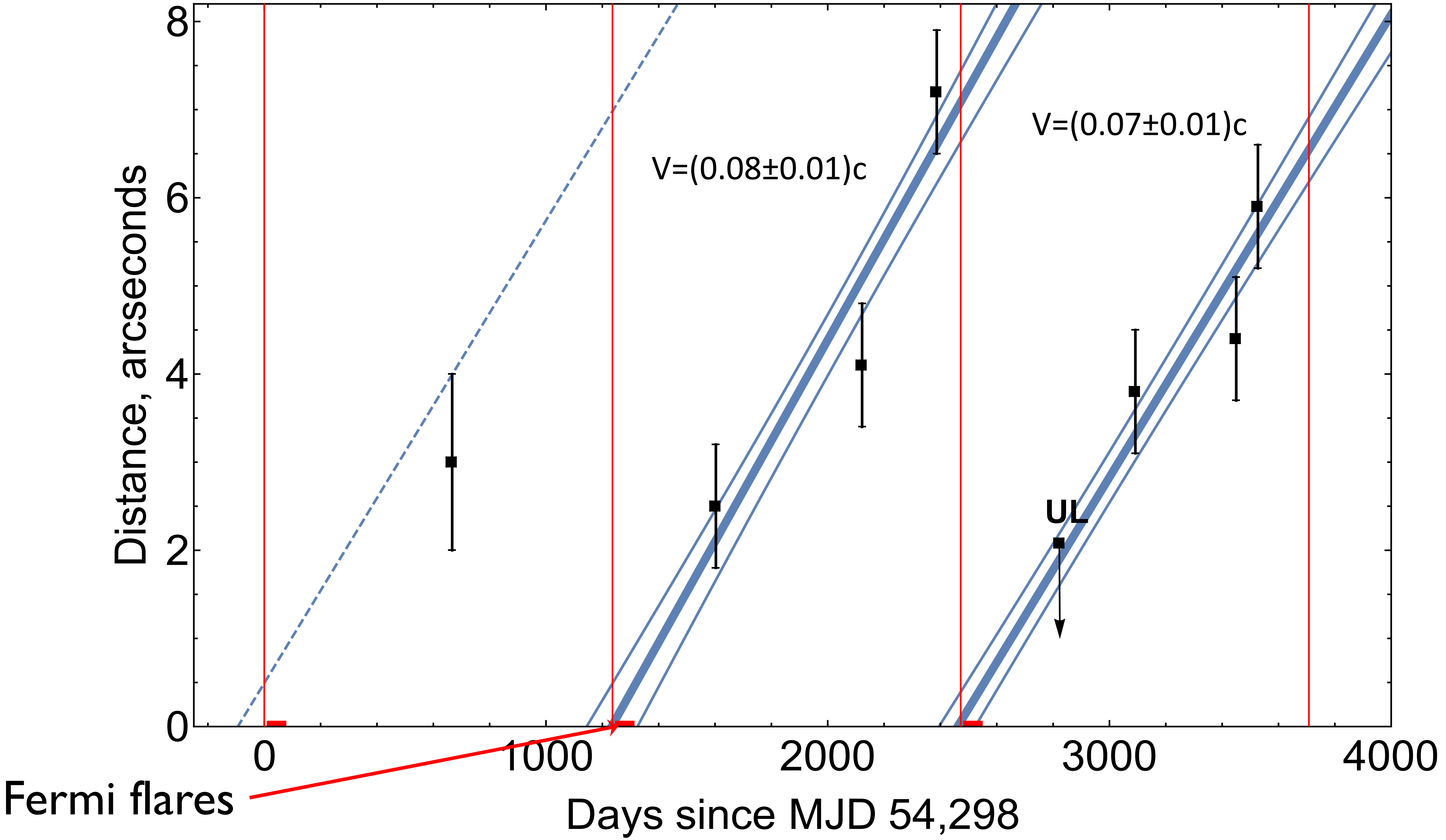
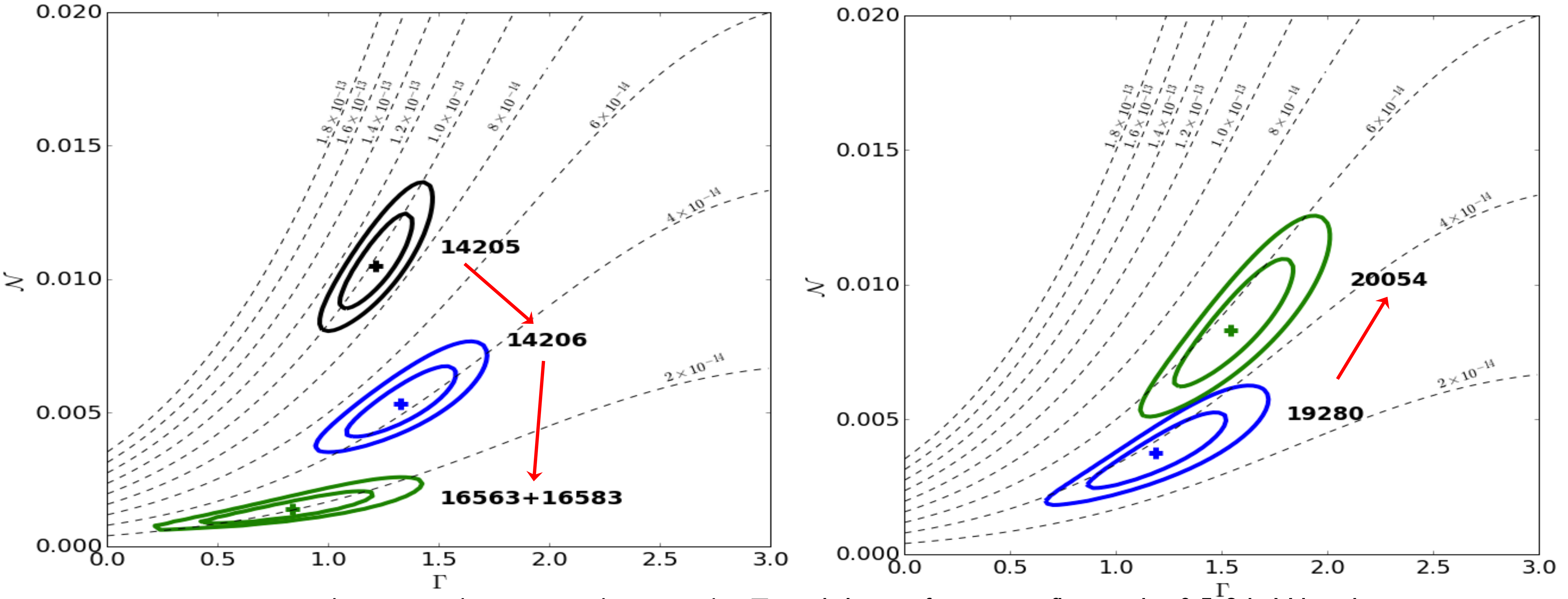




Power-law normalization vs photon index Γ, with lines of constant flux in the 0.5-8 keV band

Luminosities L_X ~ (0.2 – 1) × 10^{31}erg/s, at d = 2.3 kpc
~0.7% - 3% of the binary's X-ray luminosity far from periastron.

Characteristic size of the "clump" ~3"~ 10^{17} cm

Emission Mechanisms: Synchrotron radiation from an e^+/e^- cloud

Physical Parameters:

$B \sim 100\ \mu G$
$E_{electron} \sim 10 - 100$ TeV
Total energy $W \sim 10^{41}$ erg in volume $\sim 10^{51}$ cm^3
$W << P_{disk}$ Edot = 7×10^{42} erg

Possible solution:
Cloud loaded with ions from stellar wind/disk

Problem:

Cloud would be decelerated and destroyed by drag force in the ambient medium: $f \sim \rho_{amb}\, v^2 A$

Deceleration time:
$t_{dec} \sim W\, v\, f^{-1}\, c^{-2} \sim 20\, n_{amb}^{-1}$ s

Cloud shows no signs of deceleration!

Another Consideration:
Ejected mass would need to be a substantial fraction of the disk mass, if clump is moving in stellar wind blown bubble.

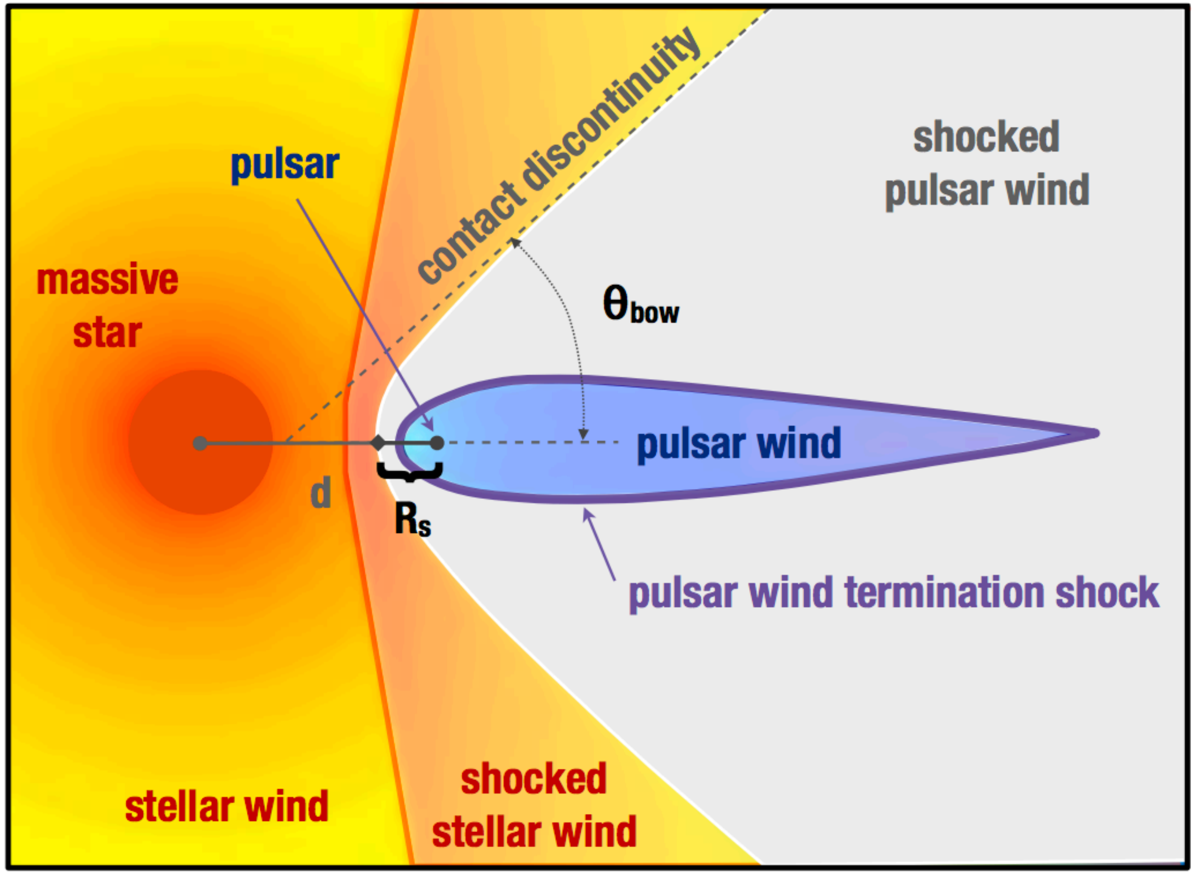
Kinetic energy of clump $E_{cl} \sim 4.5\text{x}10^{39}(v/0.1c)^2$ erg (assuming a mass of $m_{cl} \sim 10^{21}$ g)

Possible solution: Clump moving in the unshocked pulsar wind

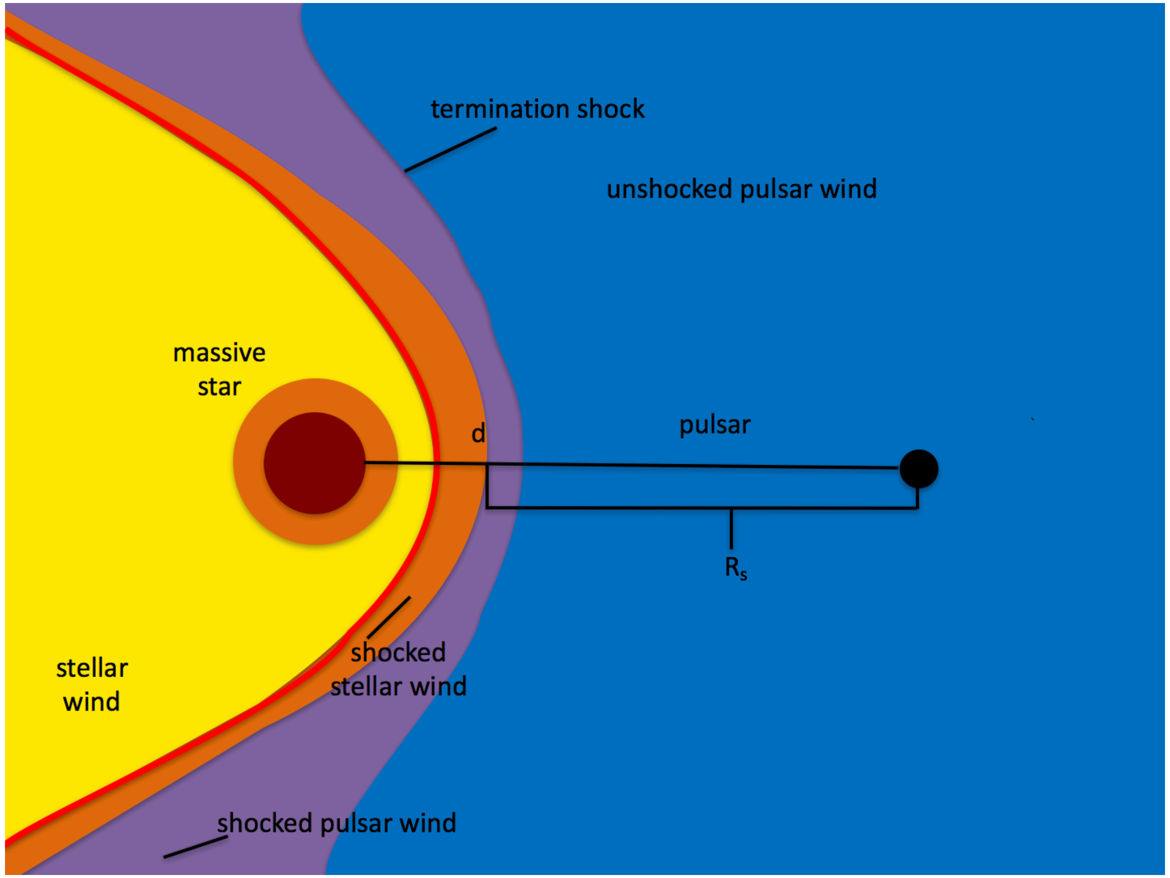
More plausible at larger values of the momentum flux ratio

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

$\eta<1$ Dubus et al. (2013)



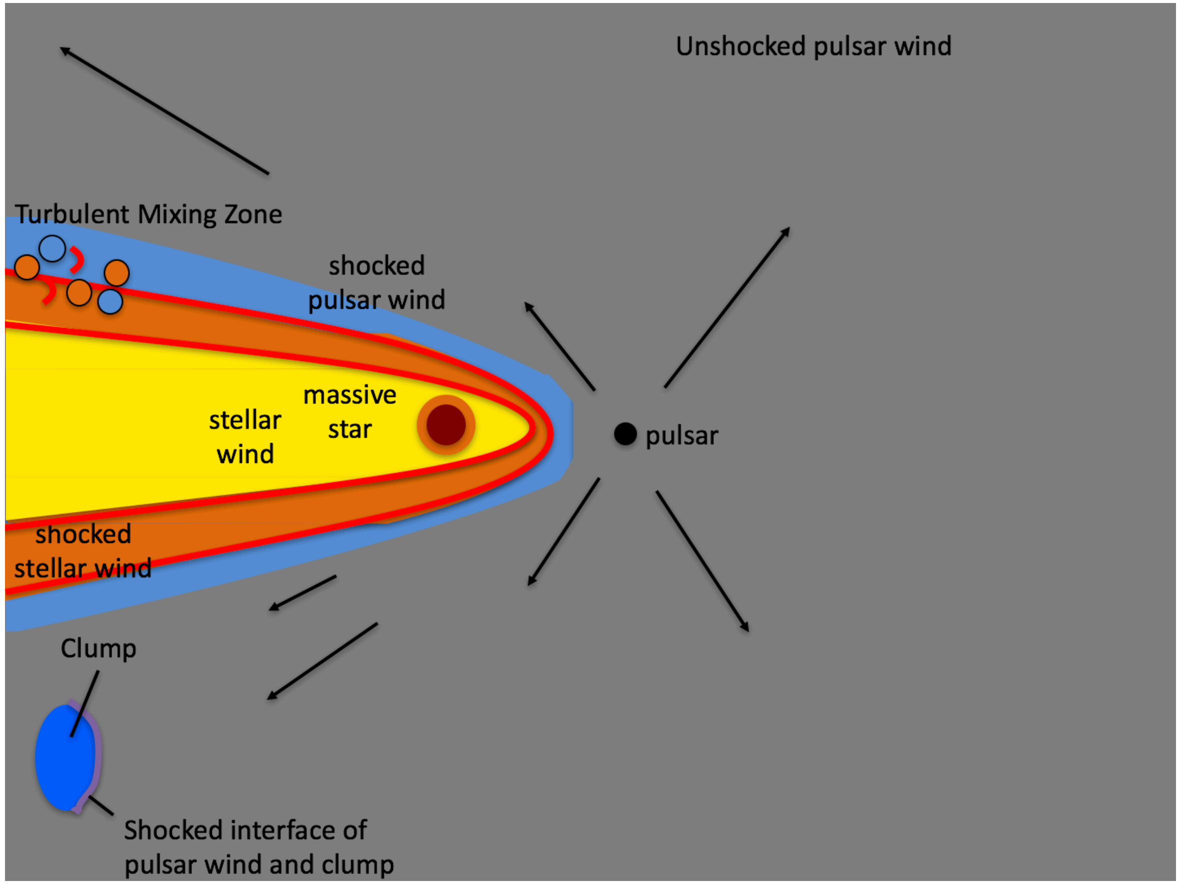
$\eta>1$



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

Can also **accelerate** the clump: $\mathbf{vdot \sim p_{pw}\ A\ m_{cl}^{-1}}$.

$\mathbf{m_{cl} \sim 10^{21}\ g}$ for the apparent (low-significance) estimated acceleration.



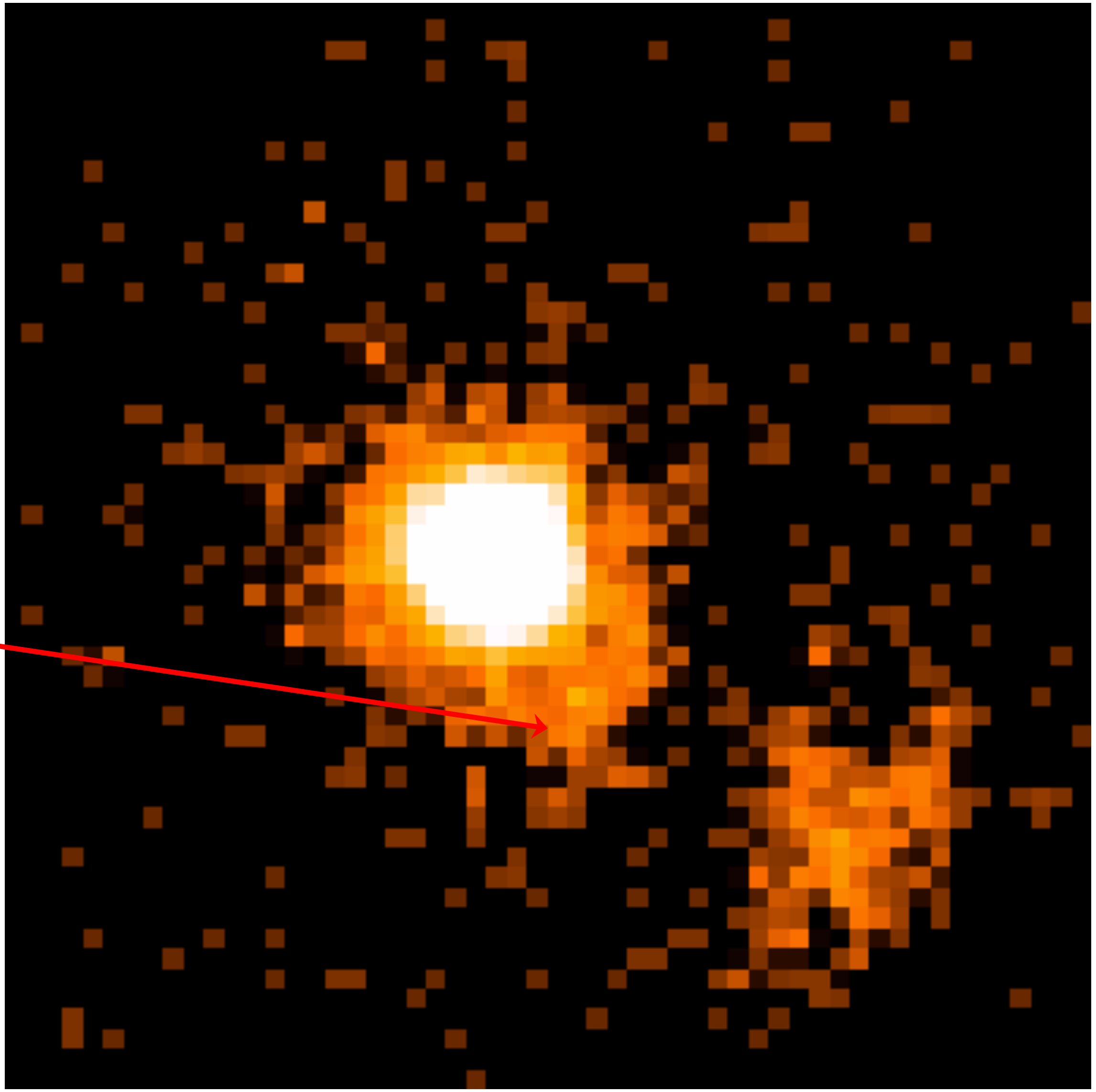
(Unnamed, for good reason, artists rendition)

- **Clump could be ejected due to interaction of pulsar with equatorial disk**.
- Pulsar enters the dense disk and creates a shock, with a radius exceeding the disk’s vertical size
- Disk disrupted in first passage
- further fragmentation and ejection in the second passage
- γ-ray flares from shocked pulsar wind
- entrainment of clumps in the pulsar wind
- acceleration by the pulsar wind ram pressure to ~0.1 c.

Alternative scenario next talk! (Barkov & Bosh-Ramon 2016)

Next Steps

04/24/2017

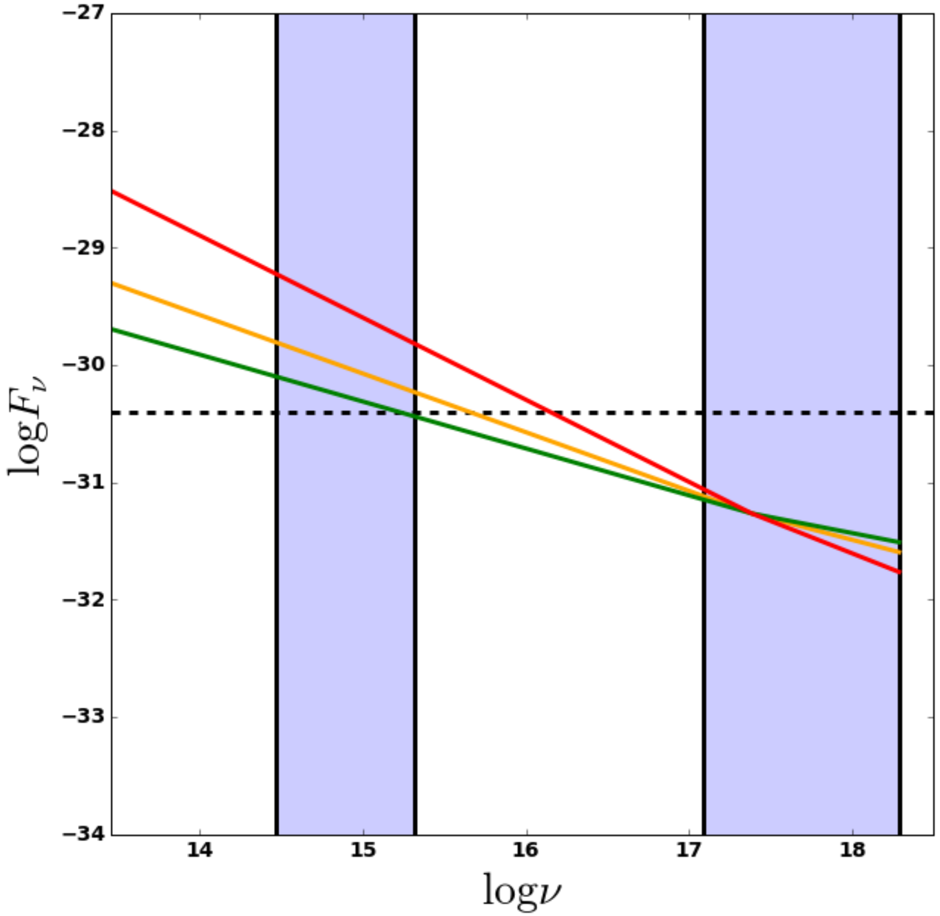


Possible new clump
2''

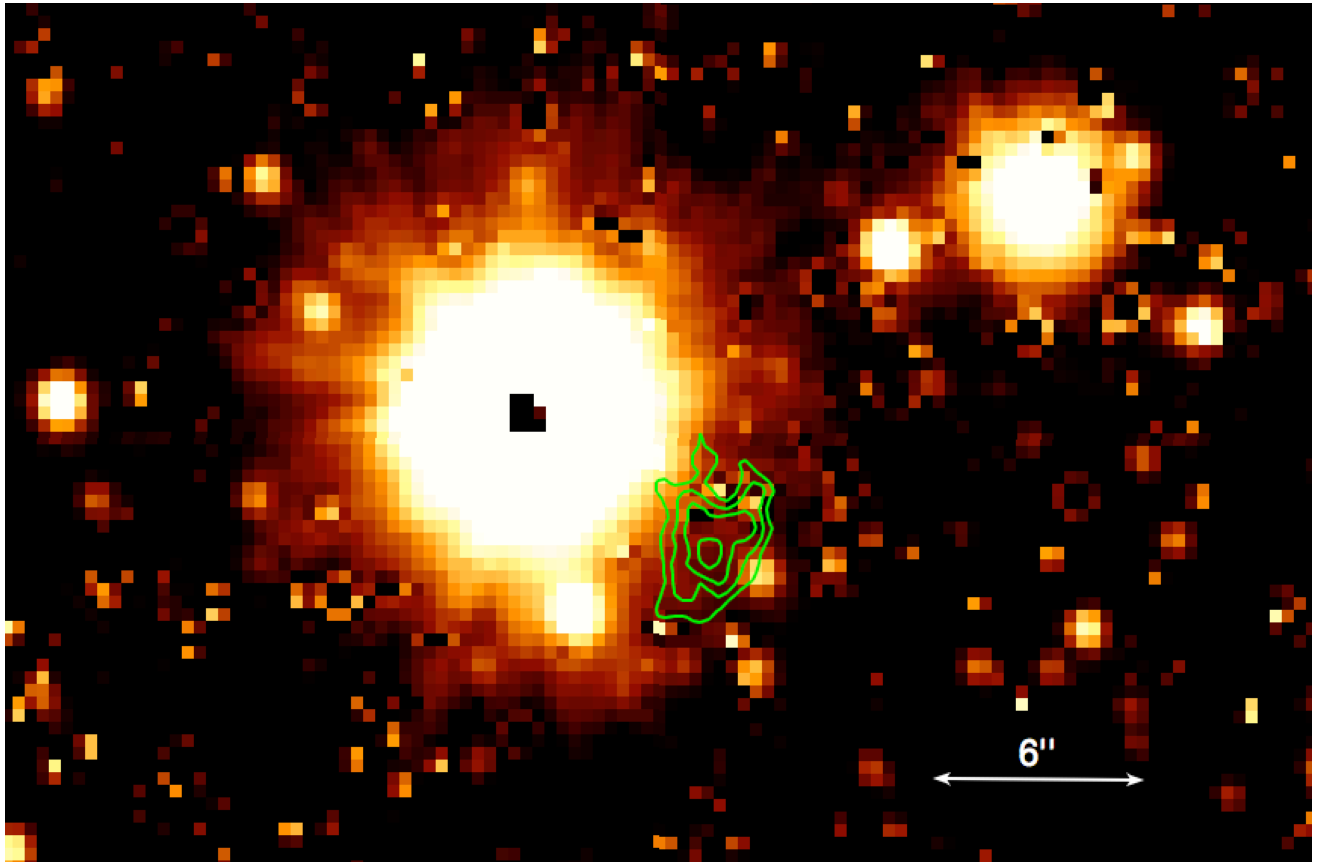
Possible ejection of another, slower moving clump?
Or launched at a later date? Upcoming obs in July will shed light!

Next Steps

Extrapolation of the X-ray spectrum from latest observation to the optical



Detection of faint extended emission in the PSF wings of the 10-th mag star is challenging but not impossible



HST observation with coronagraph planned for late July

Open Questions to think about/discuss

- Large amount of kinetic energy is likely deposited somewhere, can we locate where this happens?
- Do other HMGBs have similar extended emission?
- Younger pulsar more likely to have $\eta > 1$, what happens in those systems?

Summary

- New phenomenon discovered: Ejection of X-ray emitting clumps from a high-mass γ-ray binary with a high velocity v ~ 0.1c.
- Clumps ejected around periastrons due to interaction of the pulsar wind with the equatorial disk of the high-mass star.
- Clump has shown somewhat different behavior between the two epochs Fading (brightening) and no (a hint of) spectral softening.
- Emission mechanism is likely synchrotron radiation of relativistic electrons of the shocked pulsar wind and/or shock-heated stellar matter.
- Possibility of clumps moving in the unshocked pulsar wind, whose pressure accelerated the clump to the very high speed, or they could be accelerated by stellar wind.
- Upcoming Chandra observation and HST observation in July will hopefully help to explain the nature of this emission

Thank you!!

Illustration: NASA/CXC/M.Weiss