Once in a lifetime observations of Be X-ray/gamma-ray binary PSR J2032+4127/MT91 213 through periastron

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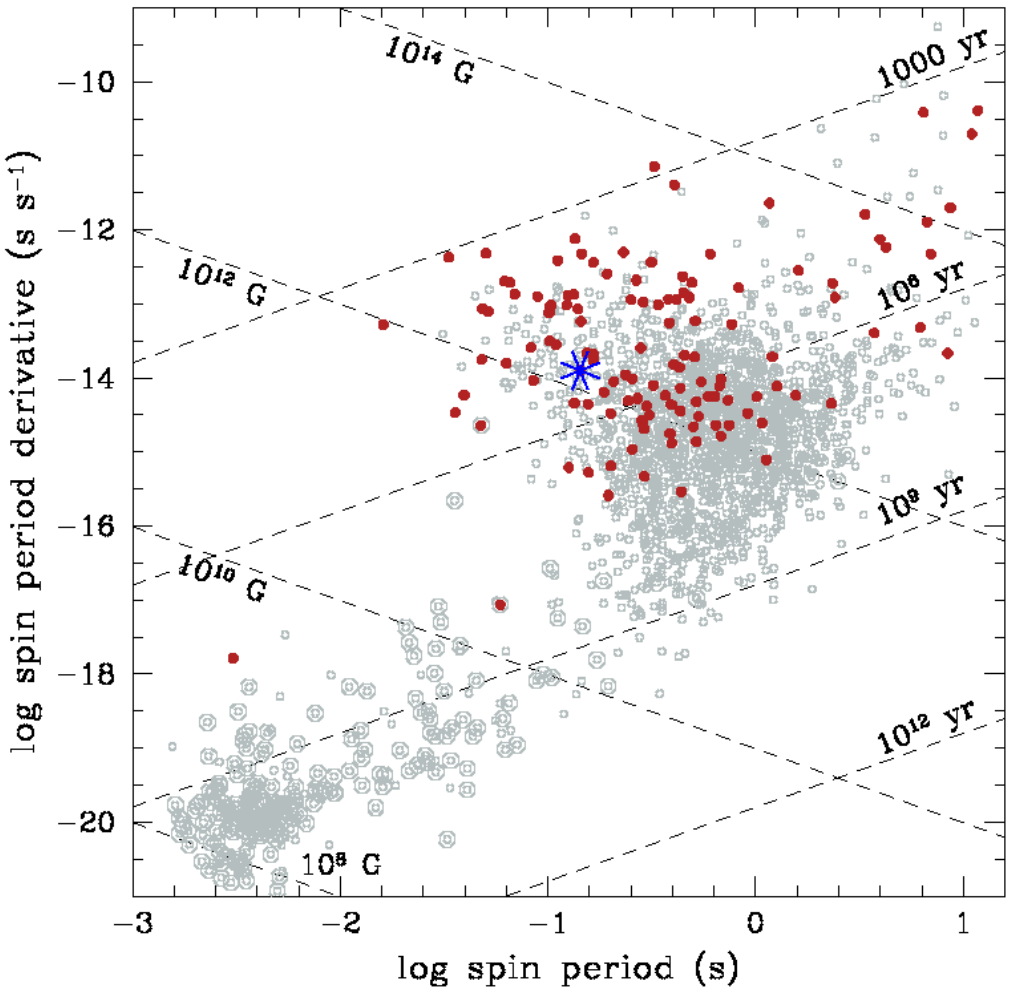
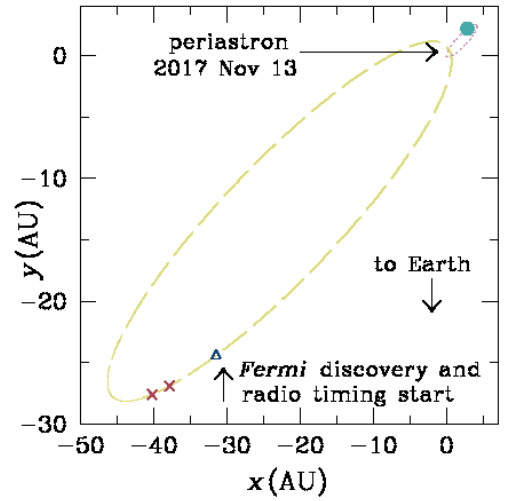
Outline

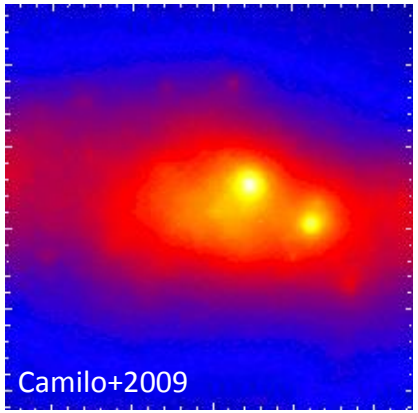
- Introduction
  - 2009 Fermi discovery and radio detection of PSR J2032+4127
  - Be X-ray binary nature established in 2015
  - only one of two gamma-ray/radio binary with high–mass companion (B1259– 63; see talk by Wood)
- Multiwavelength observations before, during, and after 2017 periastron passage in 49 year orbit
  - optical and X-ray
  - no radio and Fermi results presented
  - VHE – see talk by Holder
- Summary and future for Fermi

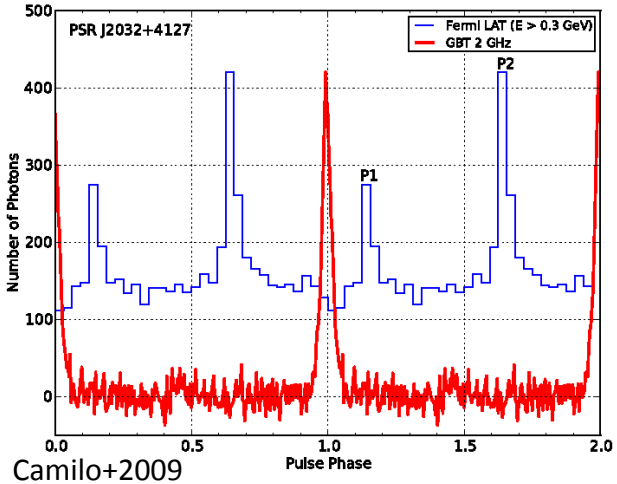


Fermi discovery of PSR J2032+4127

- Abdo+2009; Ray+2011; Abdo+2013: Fermi detects pulsed flux
  - $L_\gamma = 2.4\times10^{34}$ erg/s
  - 143 ms gamma-ray pulsar
  - $dP/dt = 2.0\times10^{-14}$ s/s, $dE/dt = 2.7\times10^{35}$ erg/s, $\tau_c = 110$ kyr
- Camilo+2009: radio detection (X-rays but no pulsations)
  - PWN of J2032+4127 powers TeV 2032+4130 (searches by, eg Mukherjee+2003)
  - Cygnus OB2 association (Gaia DR2 $d = 1.38$ kpc; Jennings+2018)




Camilo+2009

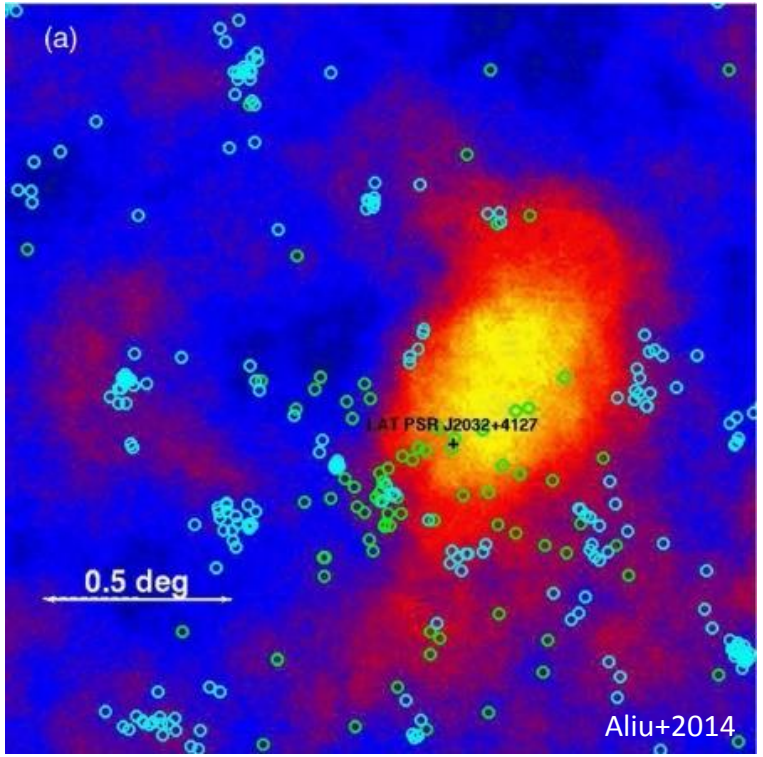


Camilo+2009

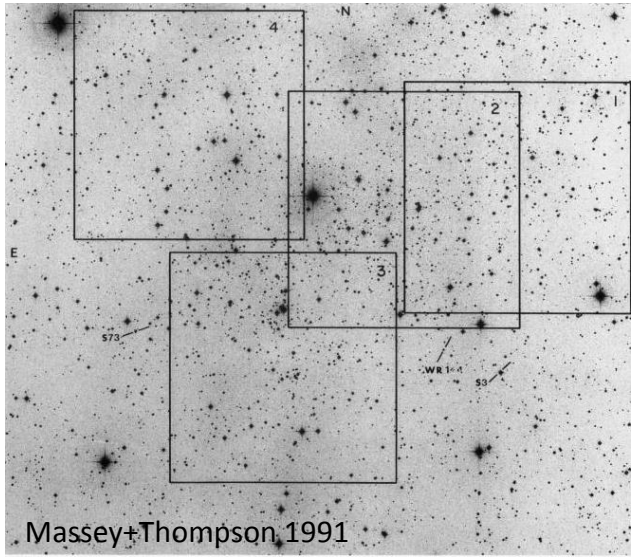
VERITAS – TeV

OB star

star forming region

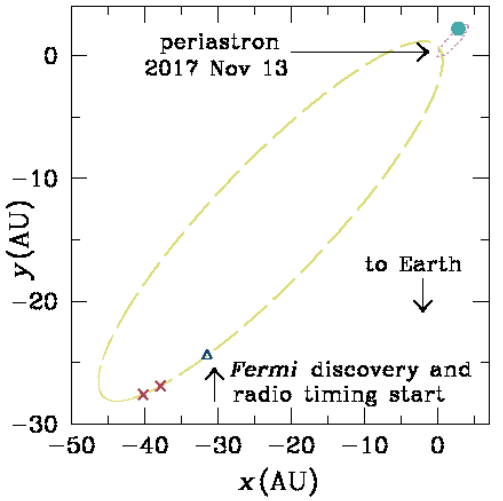


Aliu+2014



Massey+Thompson 1991

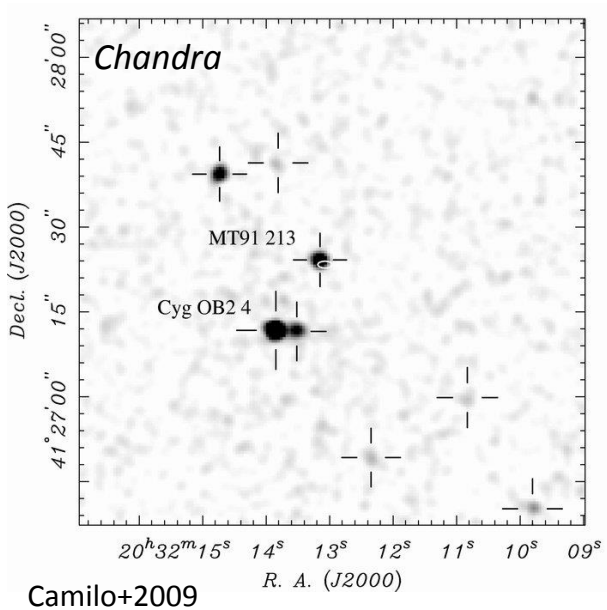
Non-binary nature of PSR J2032+4127

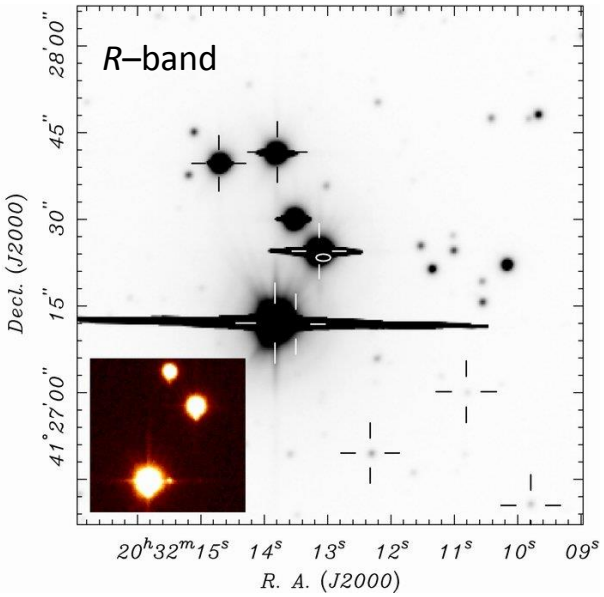


- 143 ms gamma-ray pulsar
- $dP/dt = 2.0\times10^{-14}$ s/s, $dE/dt = 2.7\times10^{35}$ erg/s, $\tau_c = 110$ kyr

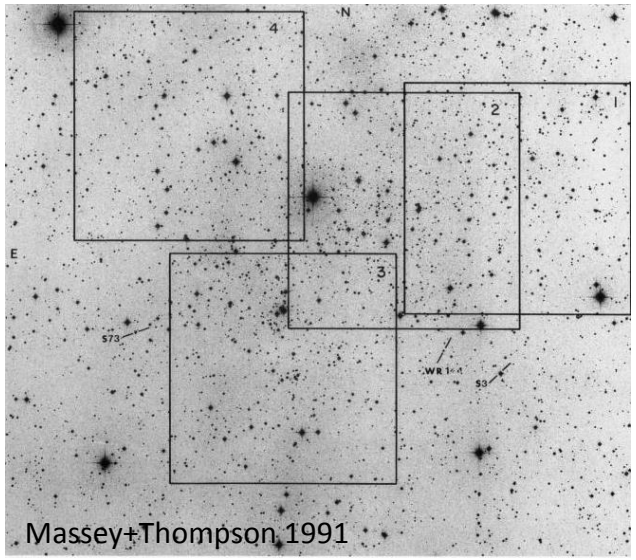
- Camilo+2009: radio detection (X-rays but no pulsations)

- Cygnus OB2 association (Gaia DR2 $d = 1.38$ kpc; Jennings+2018)
- MT91 213: B0 Ve, $M_* \approx 15\ M_{Sun}$
- optical spectra: no binary motion of MT91 213 during 1999–2005 (Kiminki+2007)
- radio timing: no binary motion of J2032+4127
  - if MT91 213 is binary companion, then $P_{orb} \geq 100$ yr
  - other binary systems $P_{orb} <\sim 5$ yr





Camilo+2009



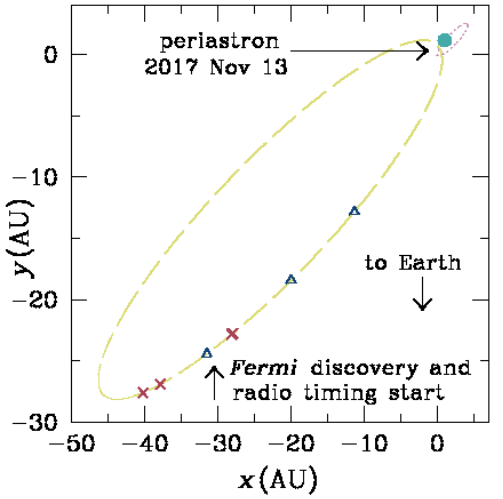
Binarity established for PSR J2032+4127/MT91 213

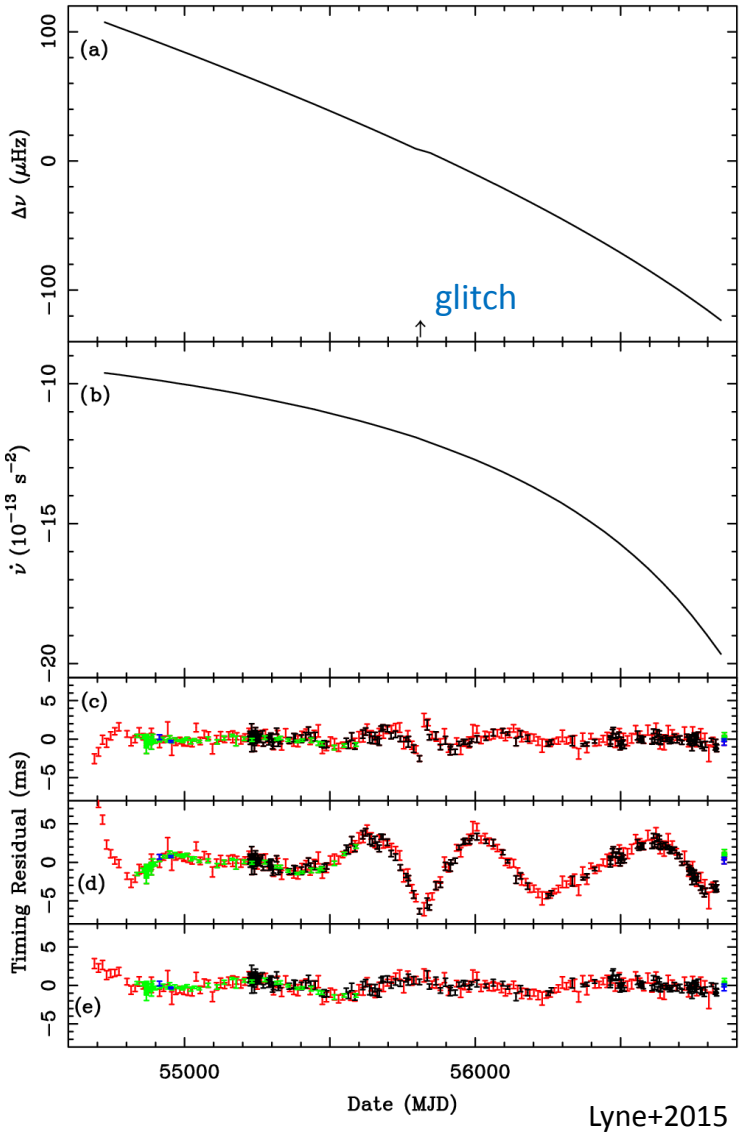
Lyne+2015

- 6 years of Fermi and radio data
- $dP/dt = 1.3\times10^{-14}$ s/s, $dE/dt = 1.7\times10^{35}$ erg/s, $\tau_c = 180$ kyr
- L_γ/Edot ~ 0.1

- unique timing noise
  - (a) increasing spin-down and glitch
  - (b) $d\nu/dt$ doubles
  - (e) binary model (5 extra fit parameters)
  - (d) 6-derivative model (5 extra fit parameters)
  - (c) 7-derivative model (6 extra fit parameters)
- $P_{orb} = 20$–30 yr, $e > 0.94$

- non-binary conclusion from Camilo+2009
  - assumed circular orbit
  - first data near apastron – weak companion gravity





Lyne+2015

Fermi LAT
Lovell
Green Bank

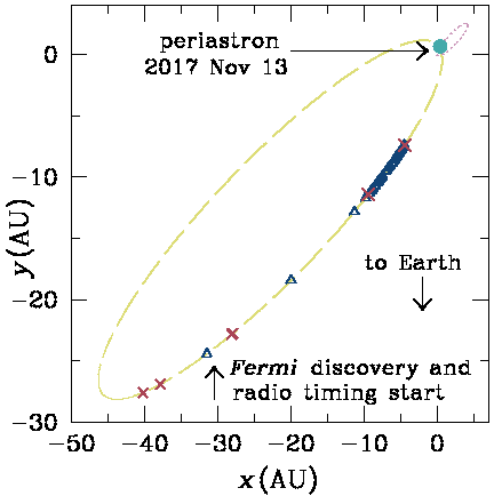
System parameters

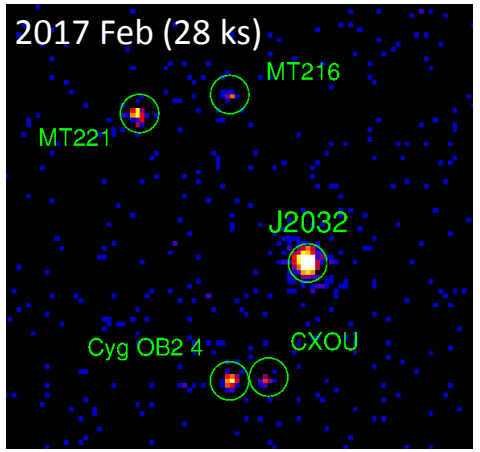
- Gamma-ray and radio pulsar PSR J2032+4127 (143 ms)
  - MT91 213: B0 Ve, $M_* \approx 15\ M_{\rm Sun}$, $R_* \approx 8\ R_{\rm Sun}$, $L_* \approx 10^4\ L_{\rm Sun}$
  - Cygnus OB2 association (d = 1.38 kpc)
  - 49 yr binary period with $e = 0.98$
  - only gamma-ray/radio binary pulsar besides PSR B1259–63

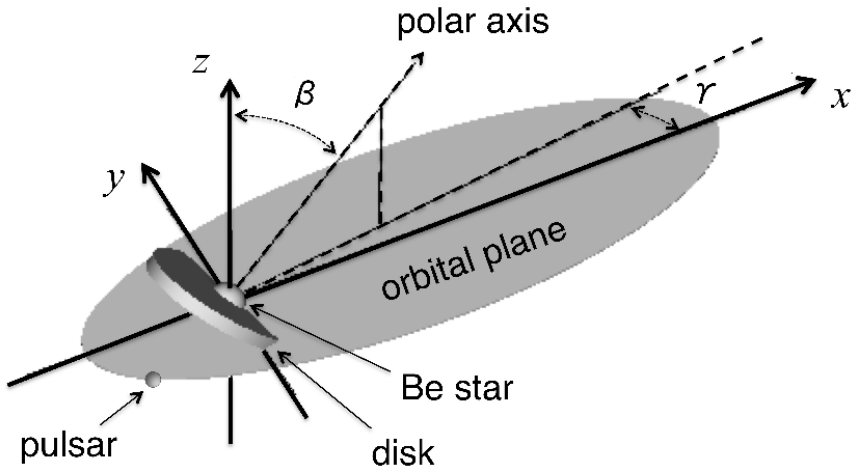
- Binary PSR B1259–63 (48 ms)/LS 2883 (O9.5 Ve)
  - d = 2.3 kpc
  - 3.4 yr binary period with $e = 0.87$
  - multiwavelength observations during each periastron passage (see talk by Wood)

- Be X-ray binaries – outbursts (and jet) during periastron passage

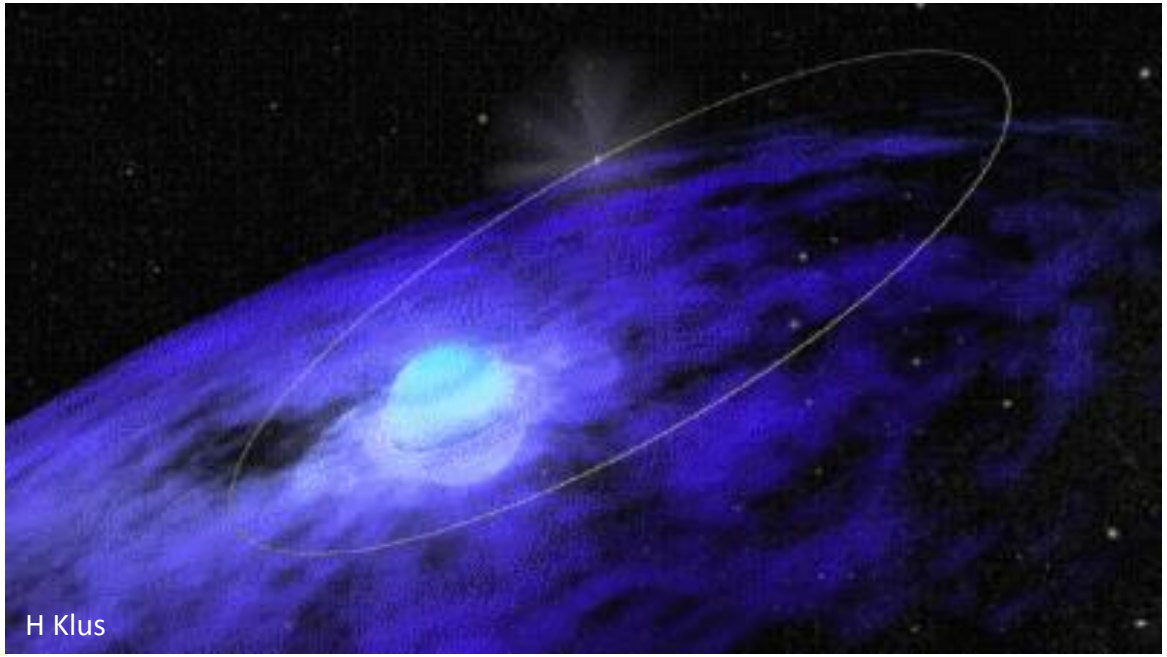
- PSR J2032+4127/MT91 213 periastron passage on 13 November 2017
  - optical emission – circumstellar disk size
  - X-ray emission – brightening wind interaction
  - radio – pulsar detected throughout monitoring campaign except briefly during periastron
  - VHE (see talk by Holder)



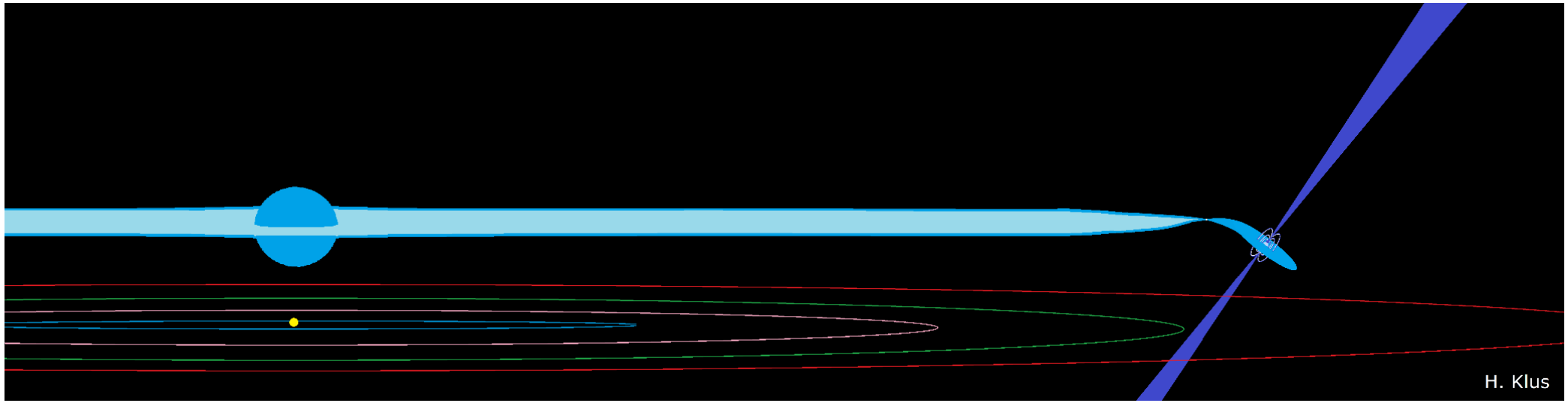


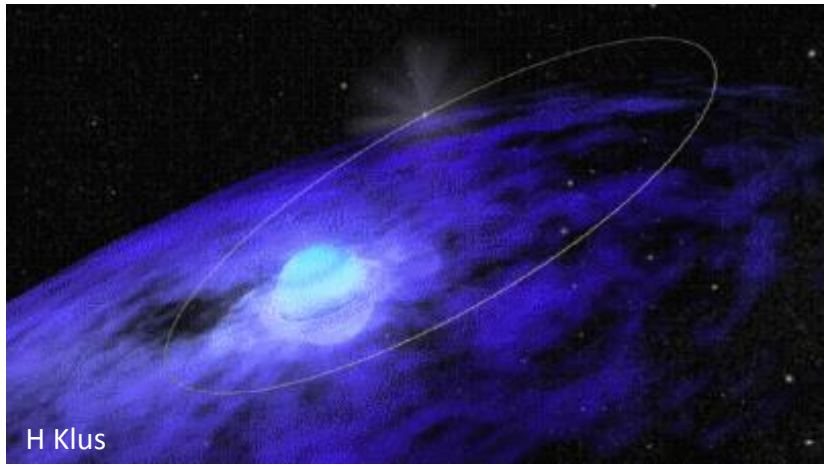


Be X-ray binaries



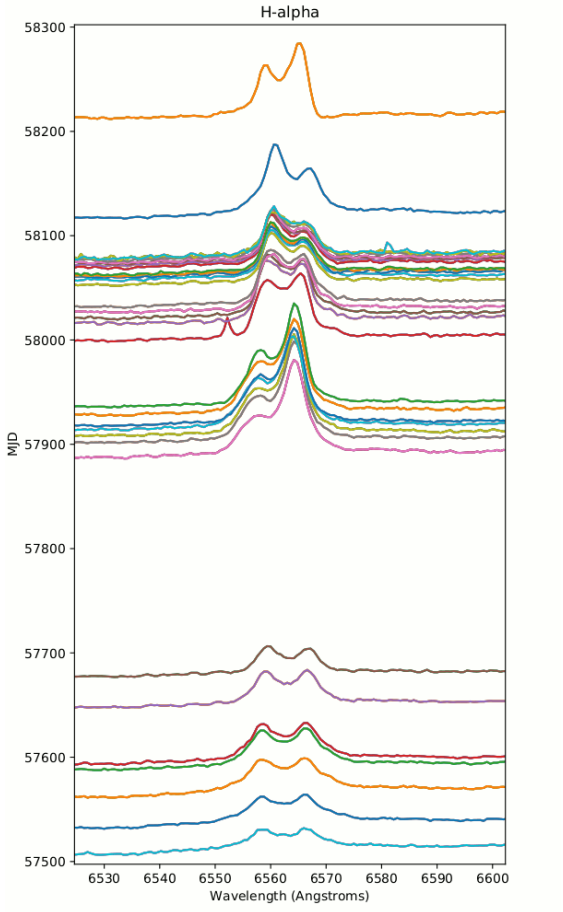
- O or B main sequence star
  - $R_{OB} \sim 10\ R_{Sun}$
  - circumstellar disk produces ‘e’mission lines
    - infer R_{disk} from equivalent width of Hα (Hanuschik 1989)
    - $R_{disk} >\sim 10\ R_{OB} \sim 0.5$ AU
- Neutron star (or black hole)
  - accrete from disk (at periastron) and wind of Be star
  - X-ray outburst $L_X > 10^{37}$ erg/s
- Young system: age $< 10^7$ yr
- ~ 100 BeXBs in Galaxy and LMC/SMC



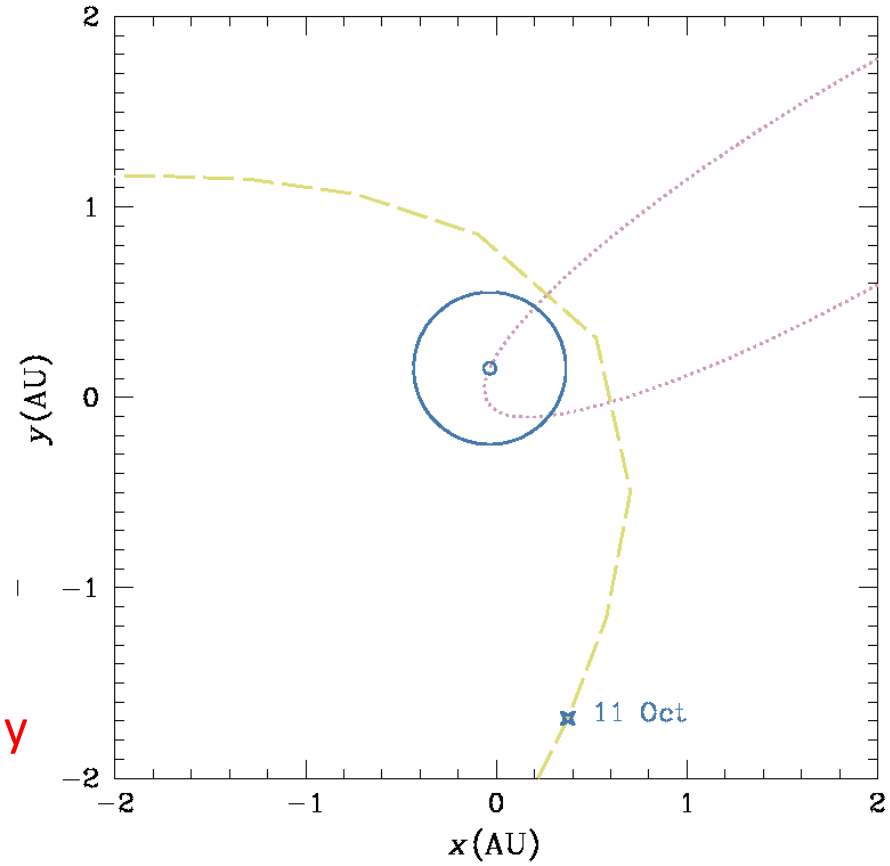


Optical monitoring

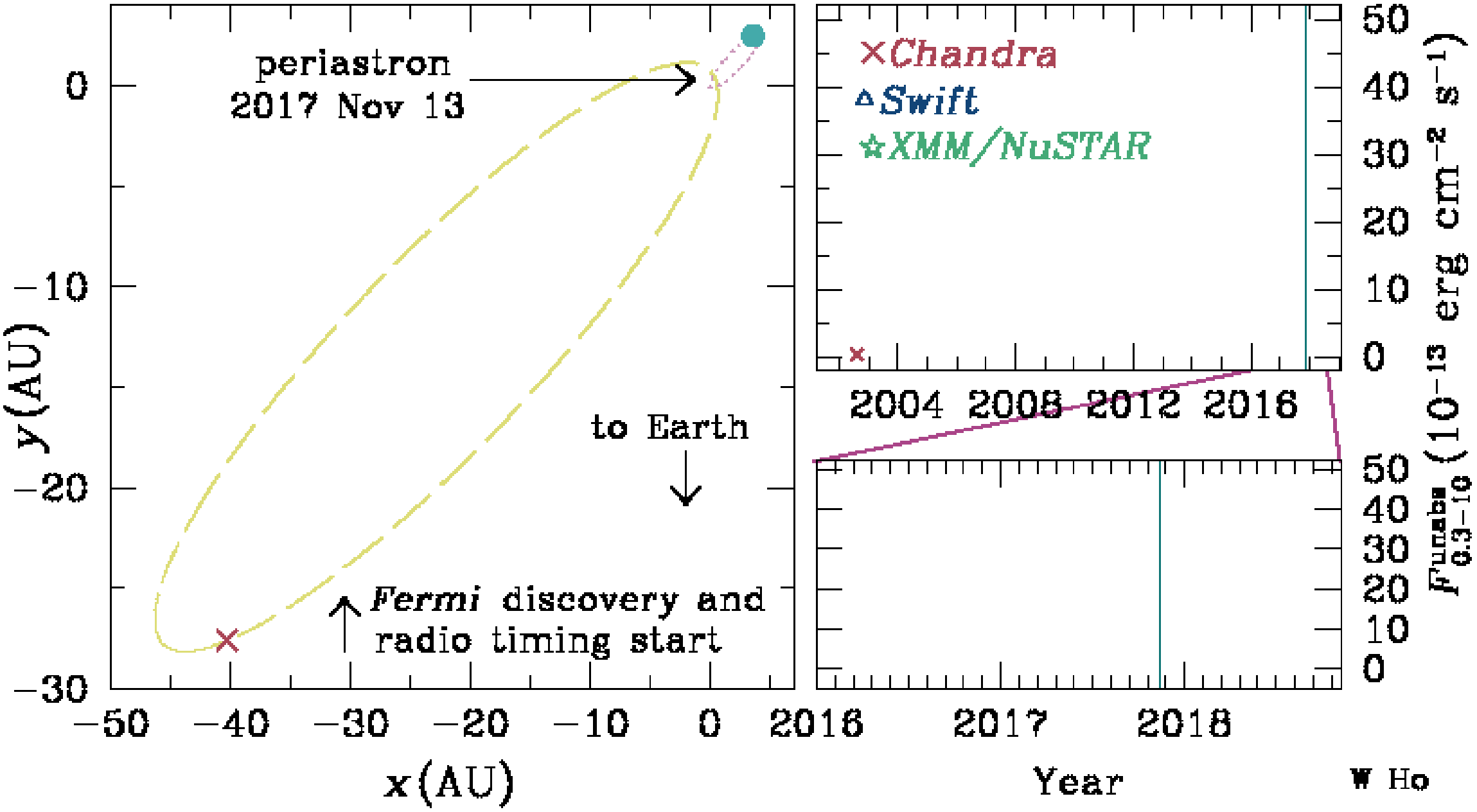
- O or B main sequence star
  - $R_{OB} \sim 10\ R_{Sun}$
  - circumstellar disk produces ‘e’mission lines
    - infer R_{disk} from equivalent width of Hα (Hanuschik 1989)
    - $R_{disk} >\sim 10\ R_{OB} \sim 0.5$ AU
    - $r_p \sim 0.5$ AU



⇒ outburst unlikely



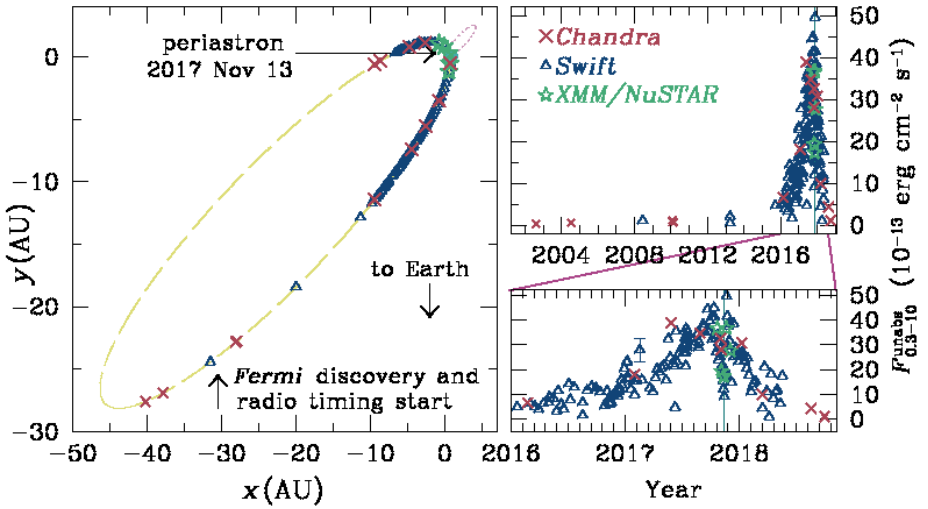
X-ray monitoring by Chandra, Swift, XMM-Newton/NuSTAR

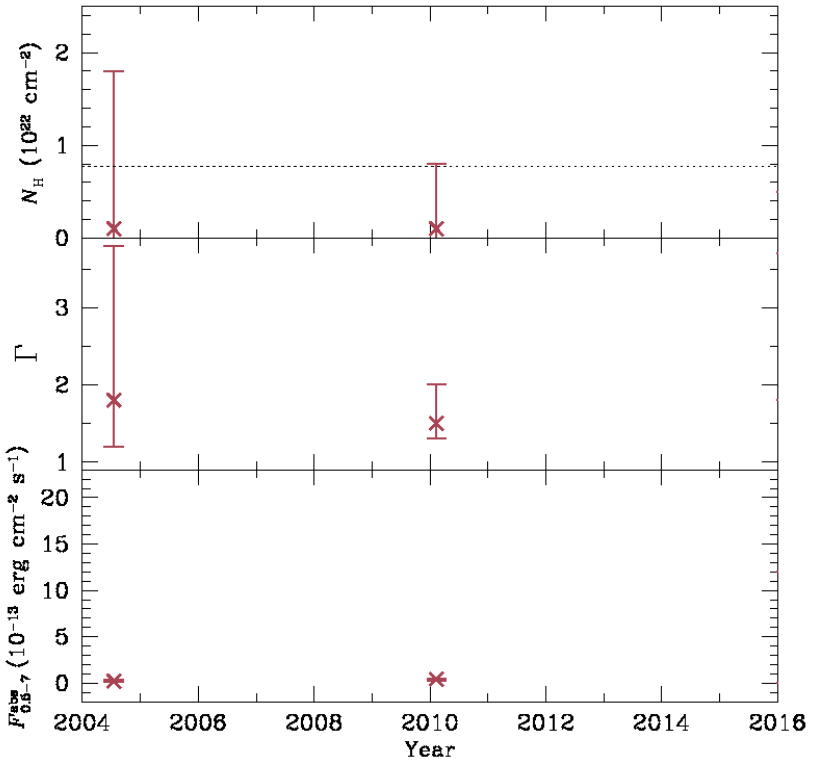


Long-term X-ray spectral variability

Chandra ACIS observations

- 2004 – Cygnus OB2
- 2010 – Cygnus OB2
- 2016 – DDT
- 2017 Feb, May, Aug, Nov – AO18
- 2018 Jan, Mar, Aug, Oct – AO18-19





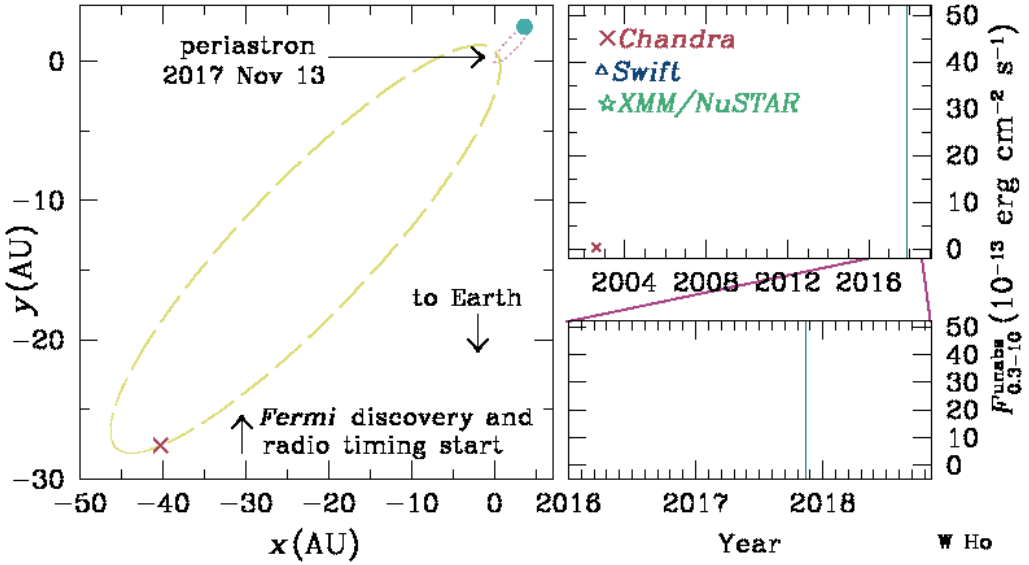
Summary of PSR J2032+4127/MT91 213

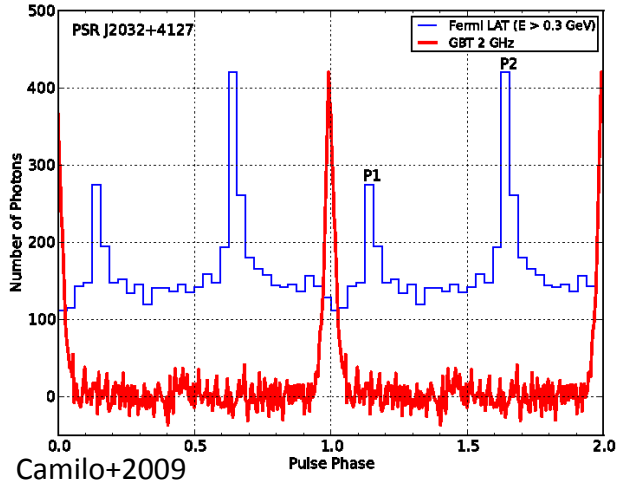
- 49 year binary with 143 ms pulsar and Be companion
- Only one of two gamma-ray/radio pulsar binaries (PSR B1259–63)

- Monitoring in radio, optical, X-ray, gamma-ray
- Not discussed: modeling by eg Takata+2017; Petropoulou+2018

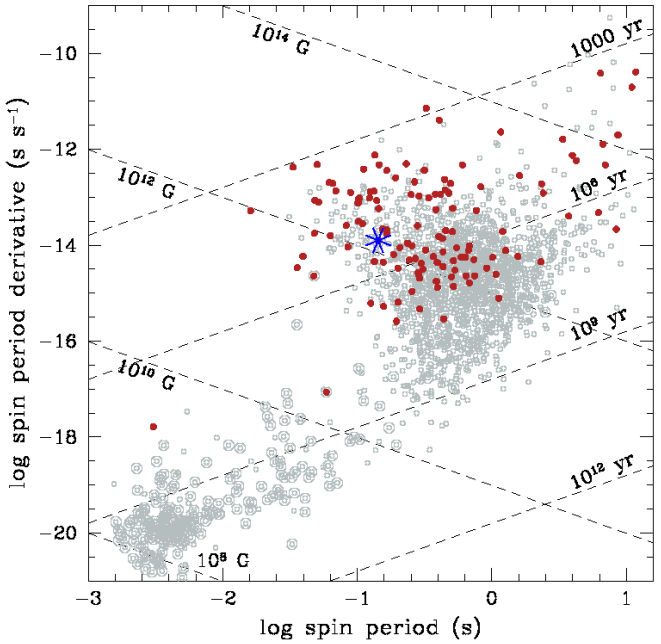
- Papers in preparation
  - radio/Fermi timing and variability – led by Lyne, Stappers
  - X-ray spectra and variability – led by Ng
  - modeling of Swift and optical around periastron – led by Coe

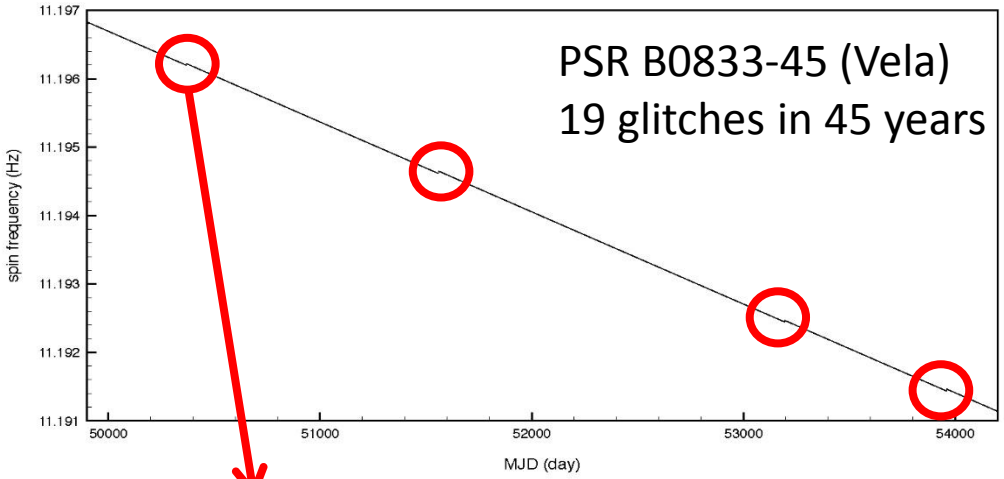
- Future for Fermi
  monitor for glitches in J2032+4127 and young pulsars

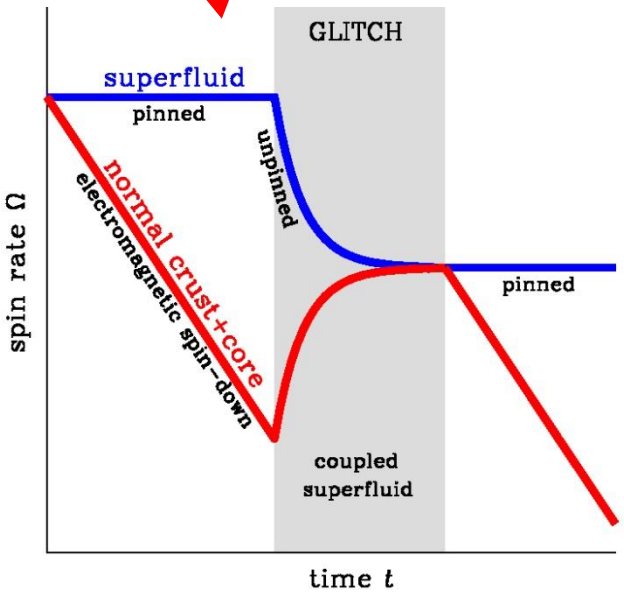




Camilo+2009

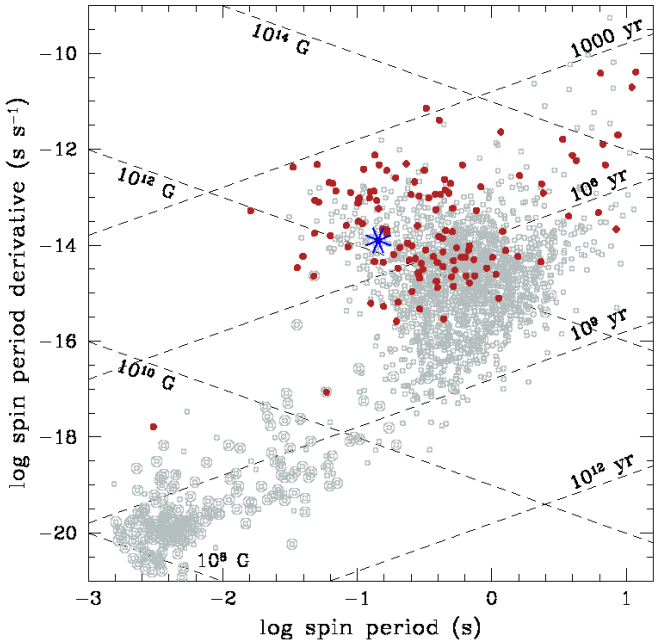






Superfluid glitches and measuring neutron star mass

- Moment of inertia for glitches
  - how much does observed glitch require? EOS models (Link+1999; Andersson,WH+2012; Chamel 2013; Piekarewicz+2014; Steiner+2015; Delsate+2016; Li+2016; Pizzochero+2017)
  - how much superfluid is available? superfluid models: $T_c(n_b)$
  - how much does pulsar have now? temperature from age/X-ray: $T < T_c(n_b)$



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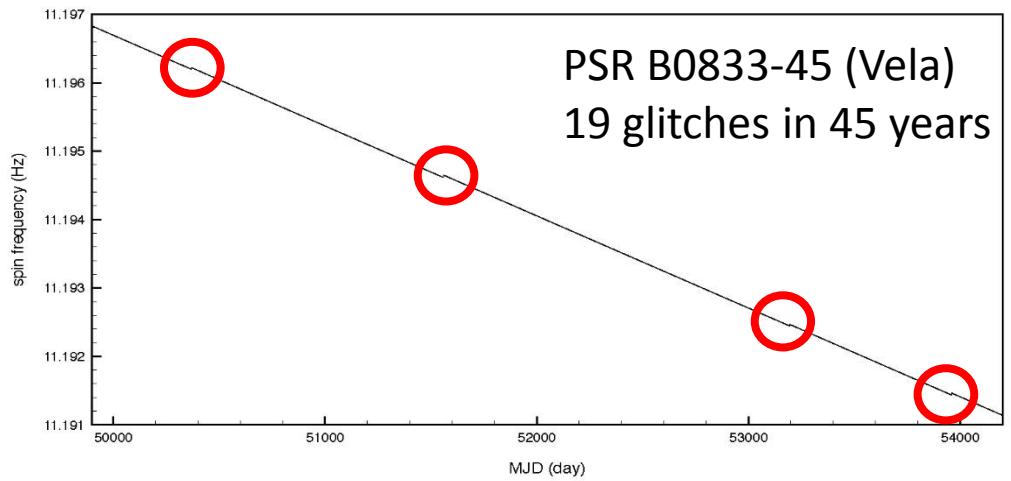

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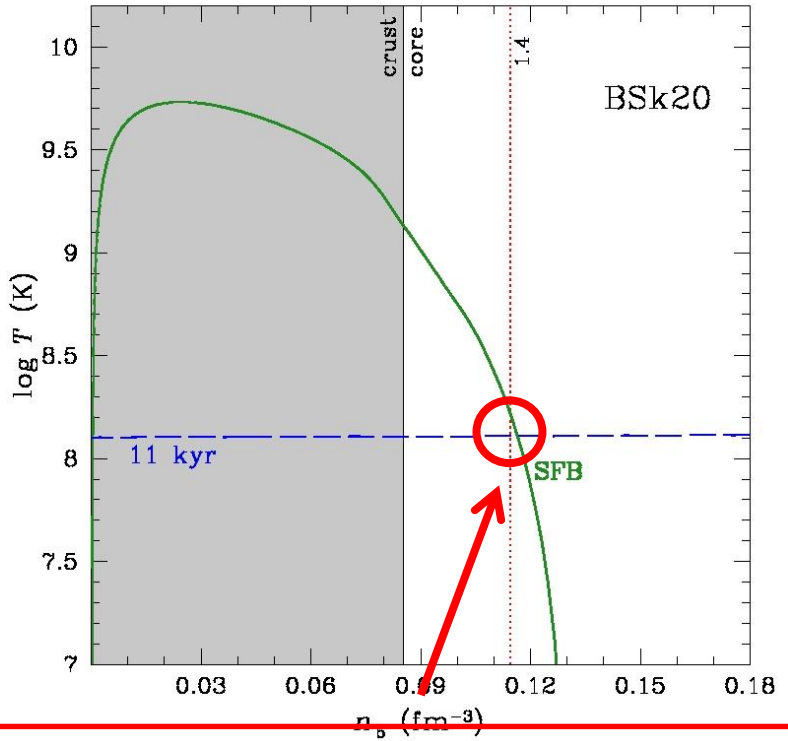
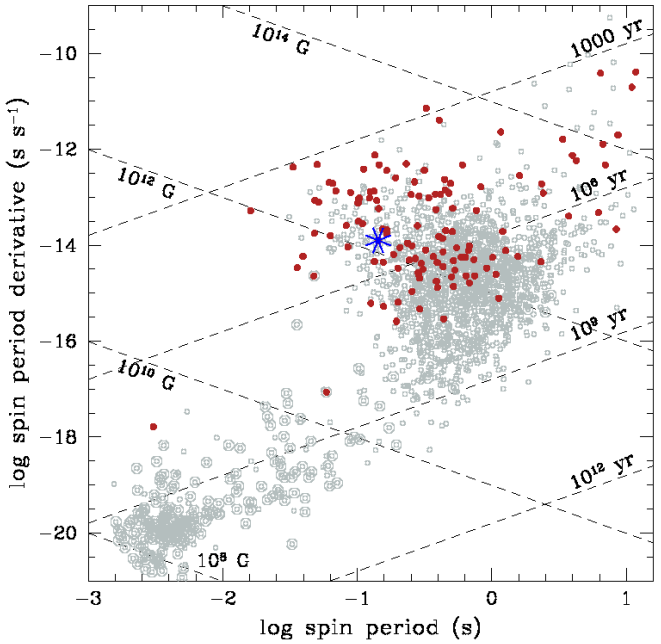


Vela is ≈ 1.4M_{Sun} neutron star and glitch size and frequency due to available superfluid moment of inertia at age 11 kyr



see Ho+2015, 2017b