Dusting gravitational waves off spider pulsars' cobwebs

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And PhD students / team: Elliott Polzin, James Stringer, Tinn Thongmeearkom, **Adipol Phosrisom**, Oli Dodge, Pengyue Sun, **Soheb Mandhai**, John Paice

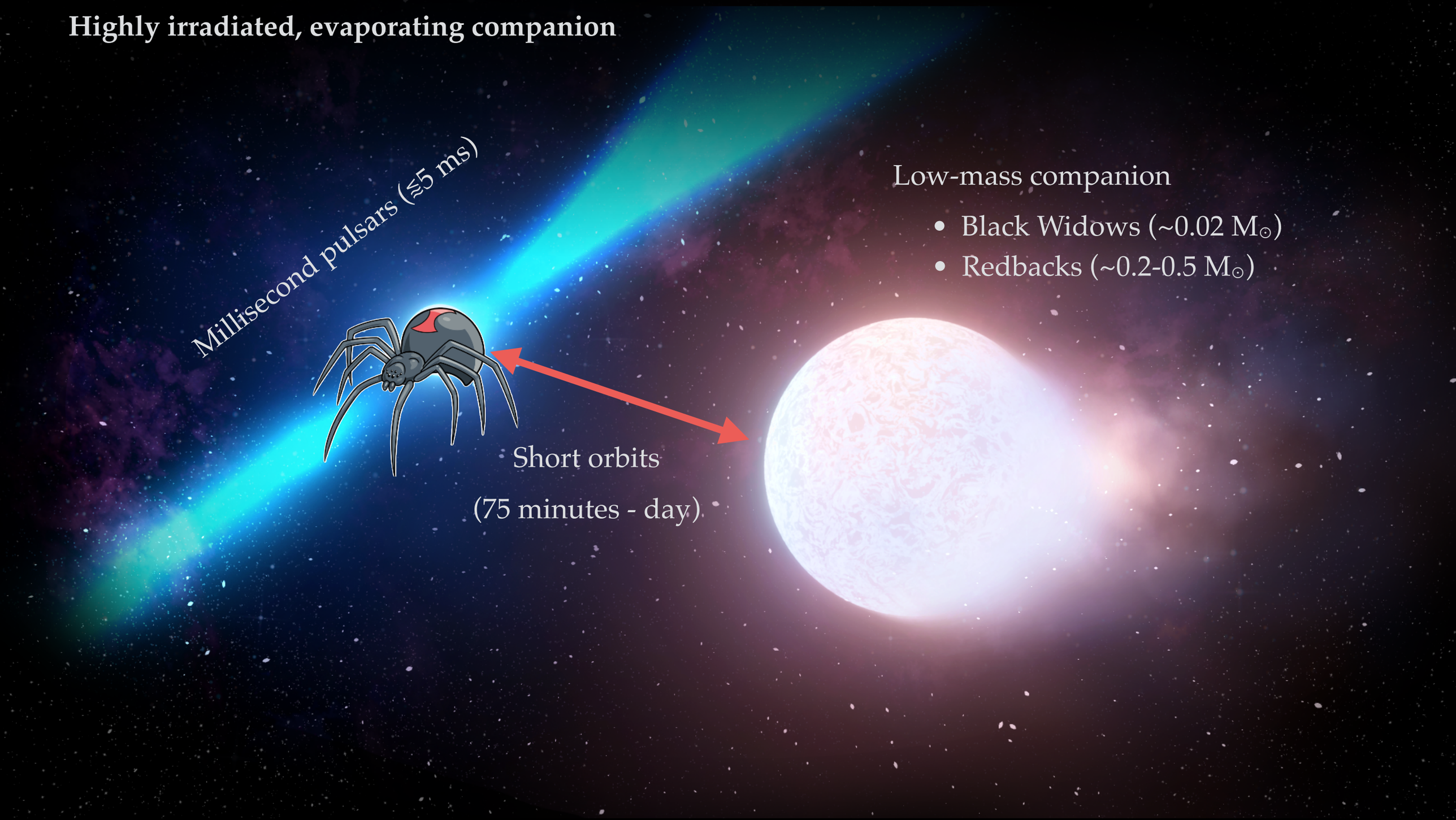
TRAPUM Collaboration

Artwork from Soheb Mandhai

Spider Binary Pulsars

Large spin-down luminosity (E_{dot} = few 10^{34} erg/s)

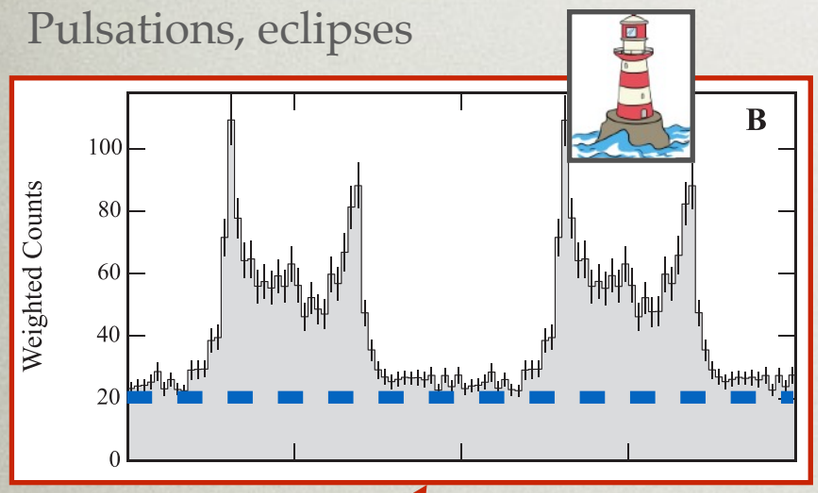
Highly irradiated, evaporating companion



Artwork from Soheb Mandhai

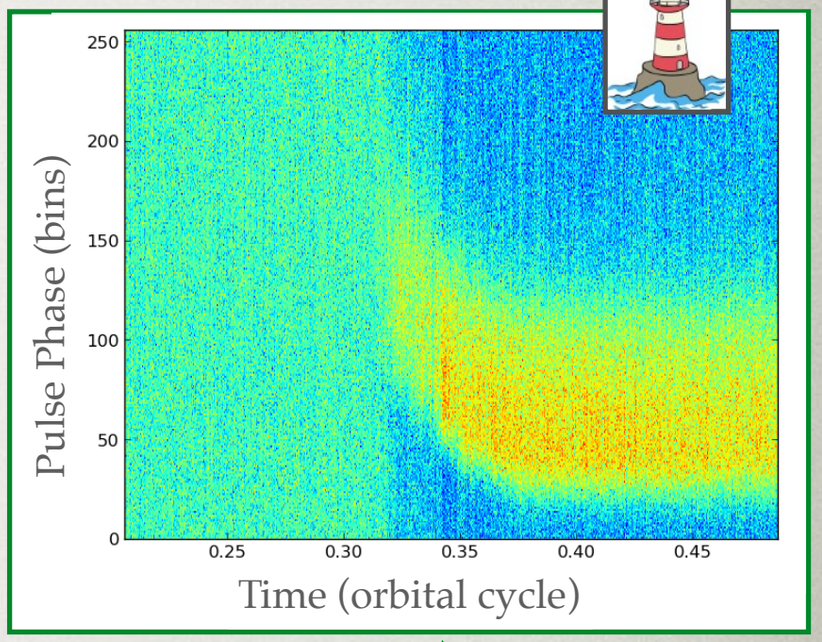
Across the EM Spectrum

Pulsations, eclipses

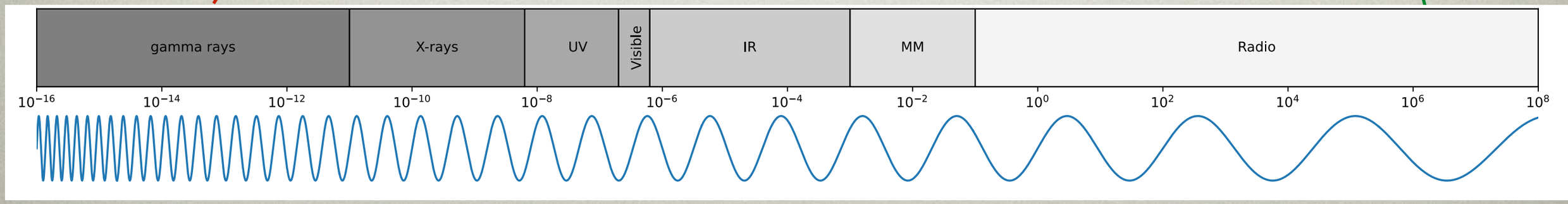


Pletsch & Clark 2015

Pulsations, eclipses

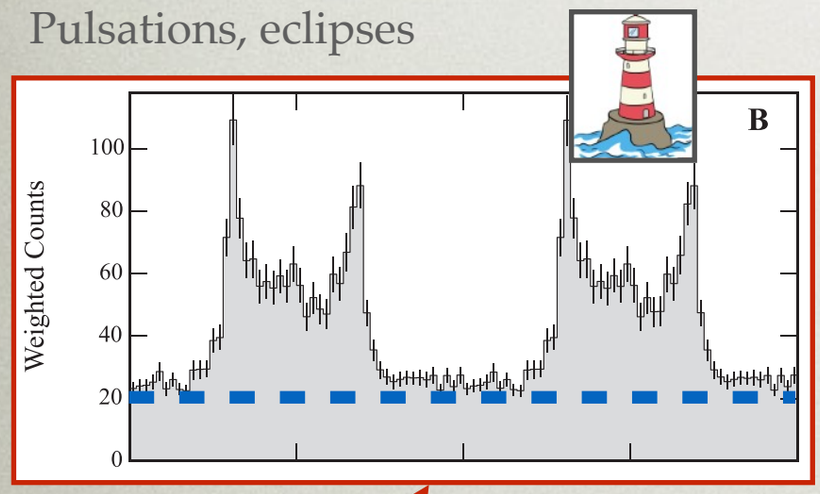


Polzin et al. 2018



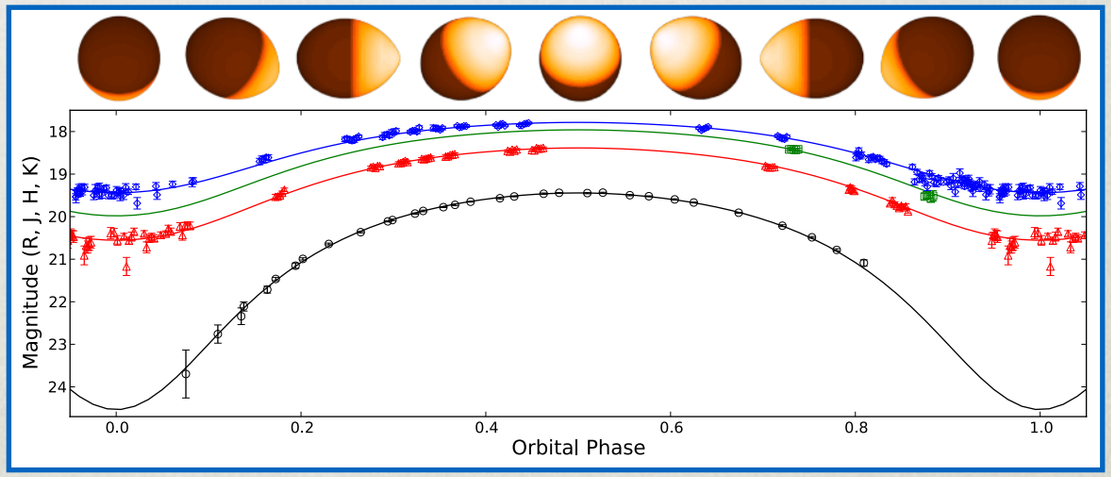
Across the EM Spectrum

Pulsations, eclipses

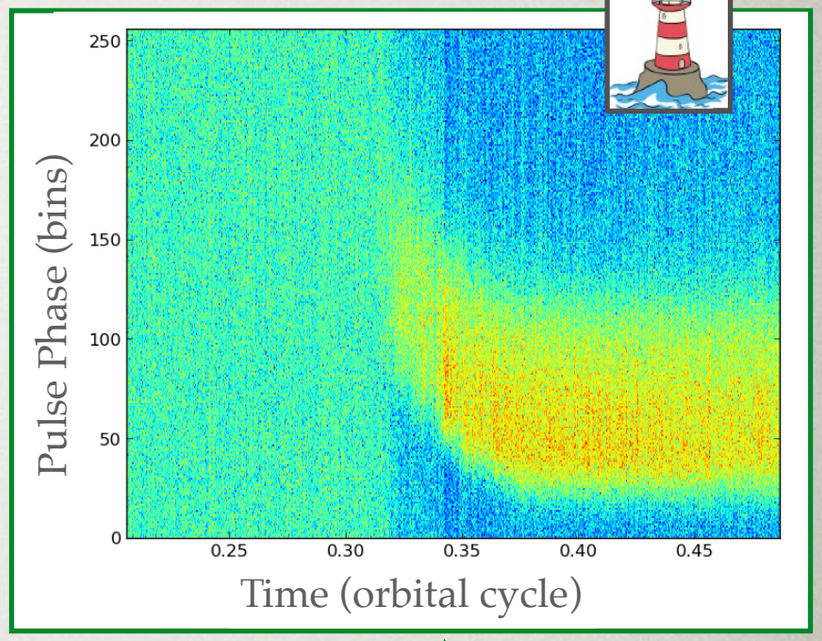


Pletsch & Clark 2015

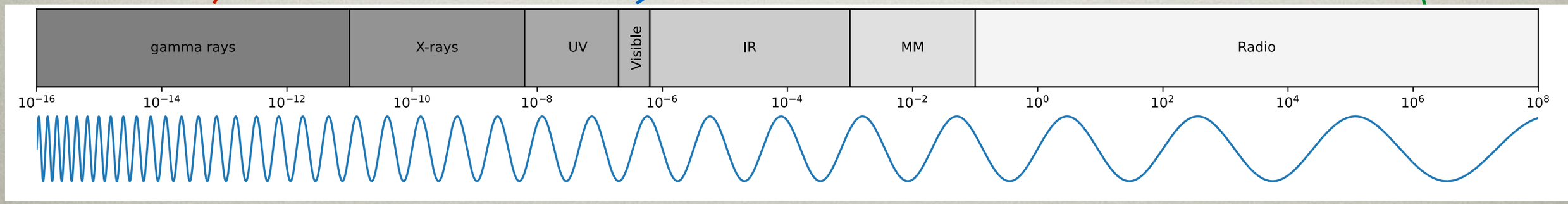
Companion variability



Pulsations, eclipses

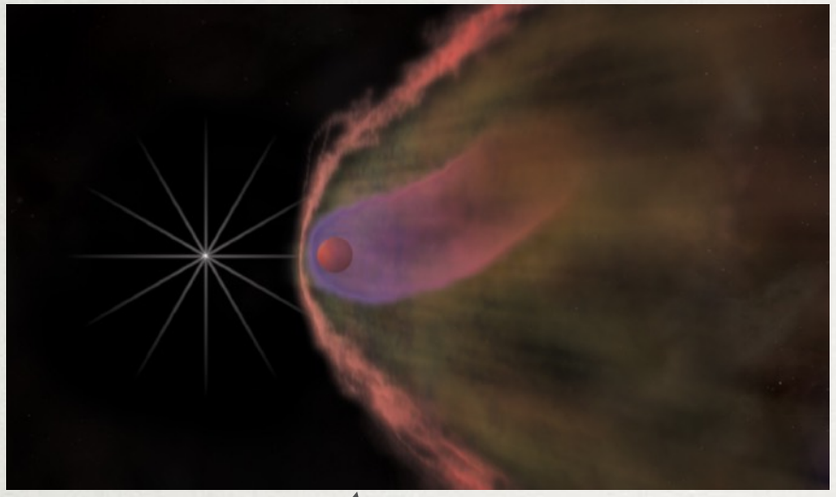


Polzin et al. 2018

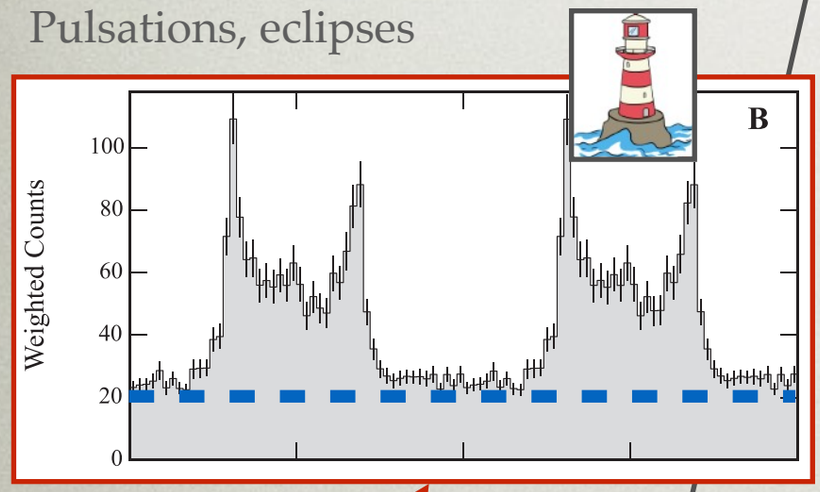


Across the EM Spectrum

Intrabinary shock

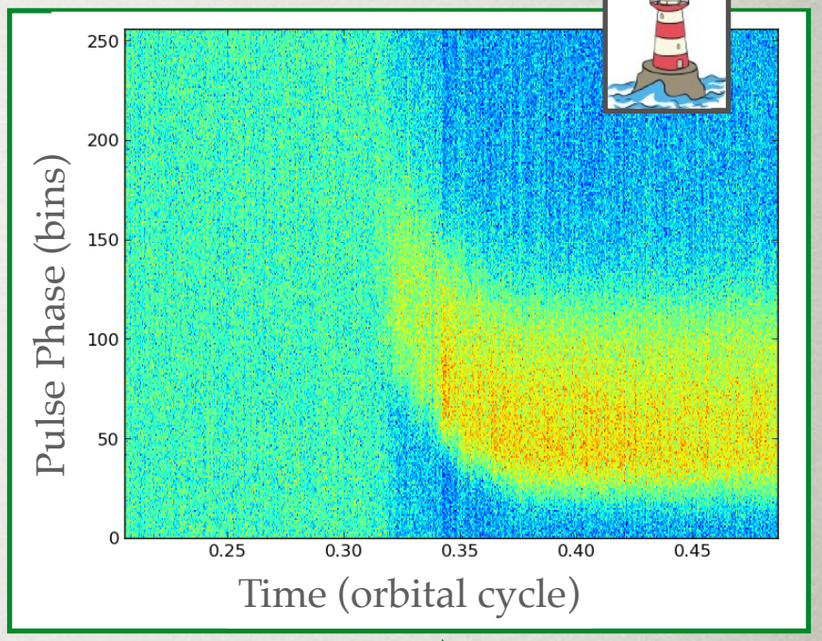


Pulsations, eclipses



Pletsch & Clark 2015

Pulsations, eclipses



Polzin et al. 2018

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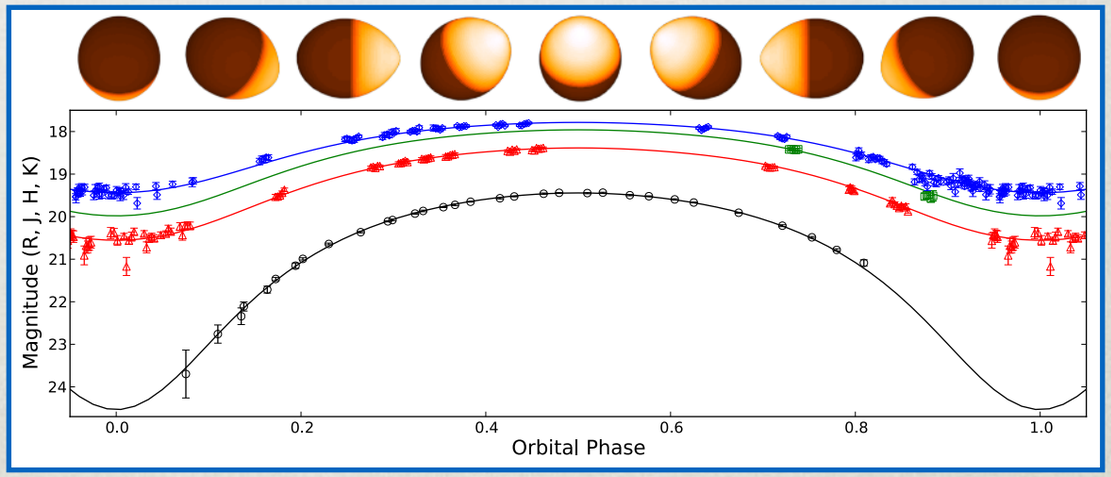
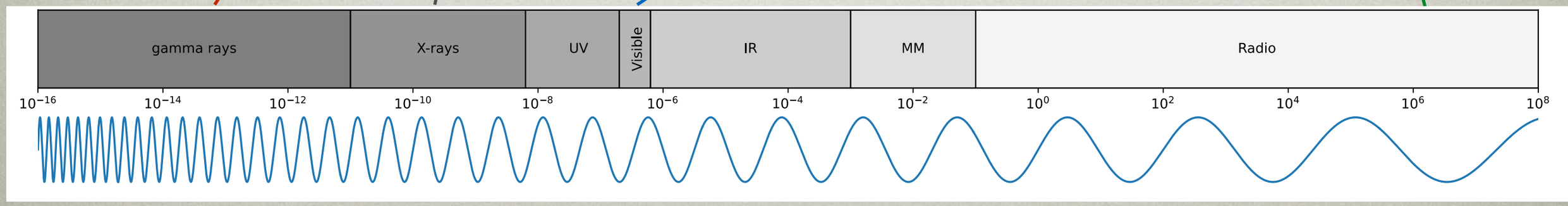
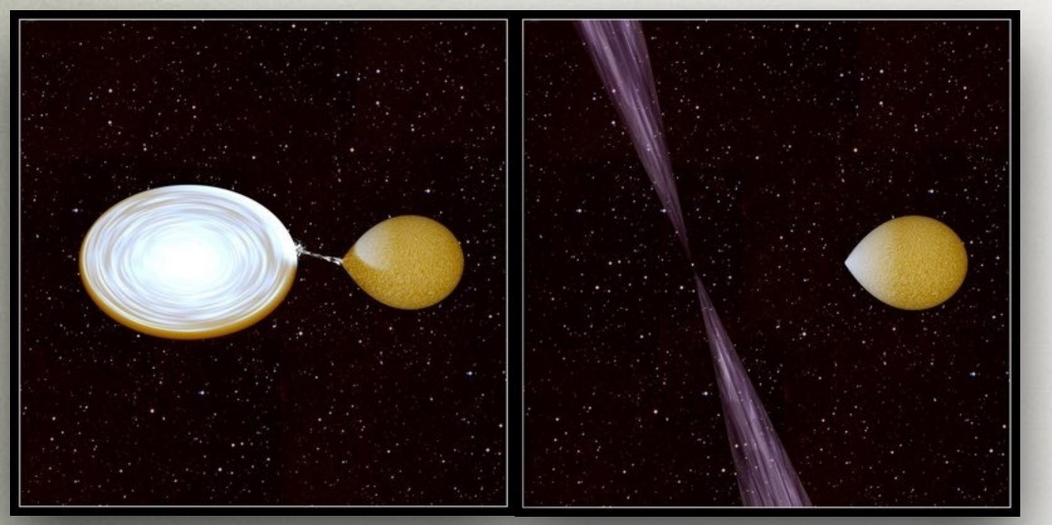




Transitional MSPs



Canonical MSP evolution

Transitional MSPs

tMSP evolution

Three ‘spiders’ known to transition between ‘LMXB’ and ‘pulsar’ states

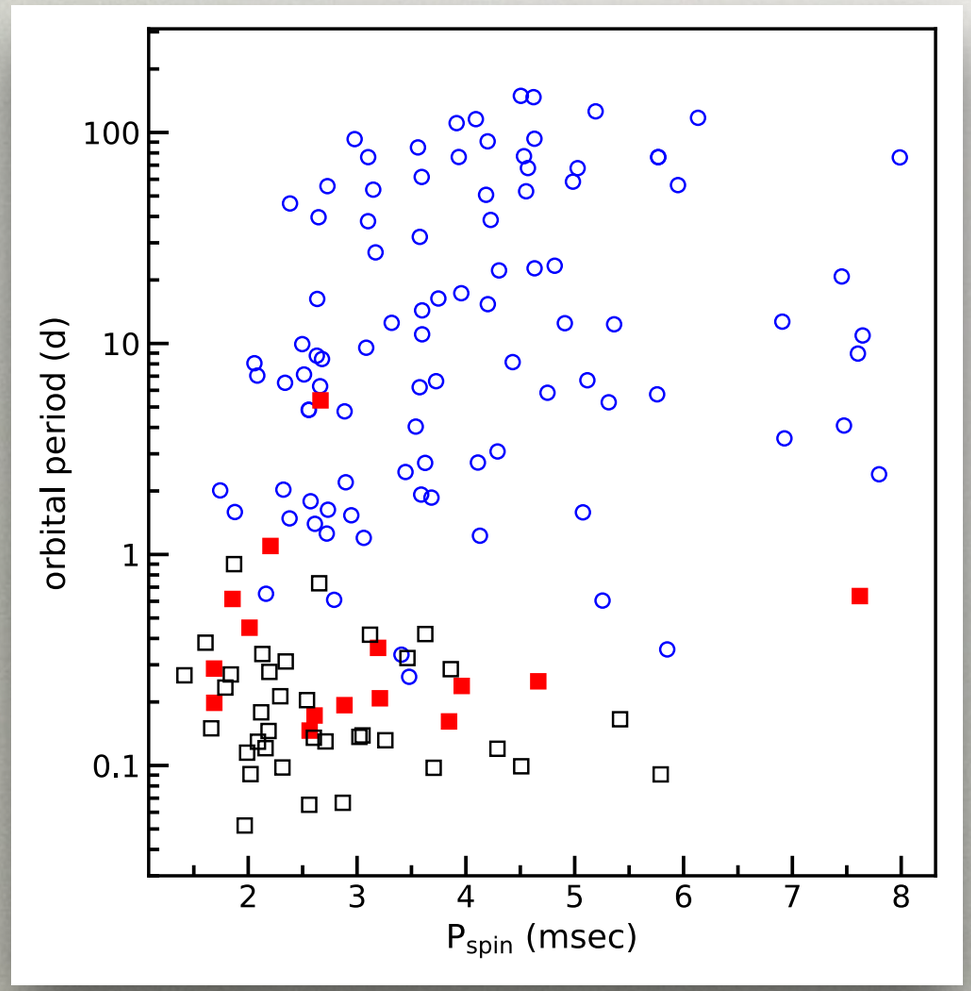
Transitions within ~week(s)

- PSR J1023+0038 (Archibald et al. 2009, Stappers et. 2013)
- IGR J1824-24525 / M28I (Papitto et al. 2013)
- XSS J12270-4859 (Bassa et al. 2014)

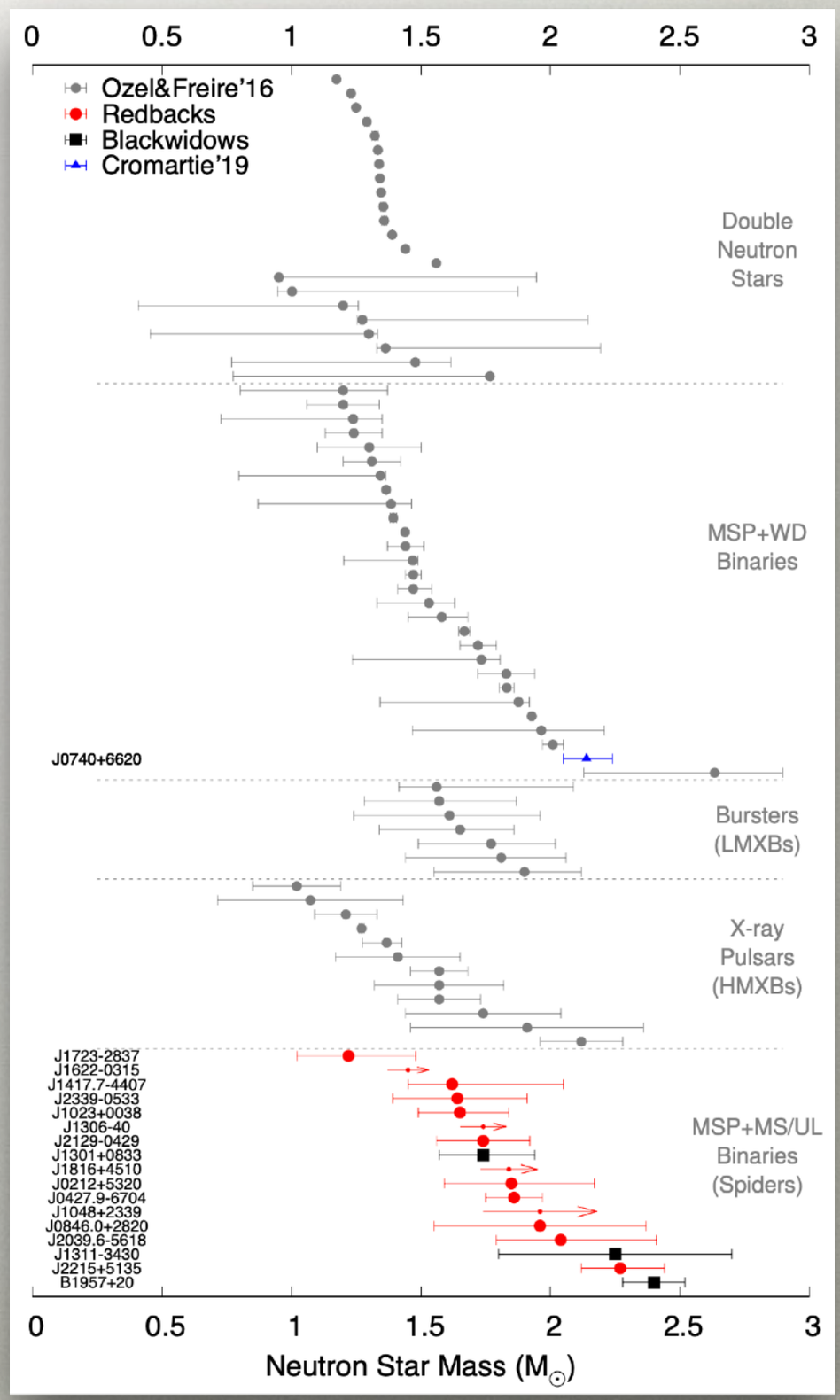
GW Entangled Into Spider Webs

Five reasons why Spiders are important for GW

1. Fastest spinning NS
2. Tightest orbits
3. Heavy NS
4. Have accreted mass
5. Failed systems might merge



Swihart et al. (2022)

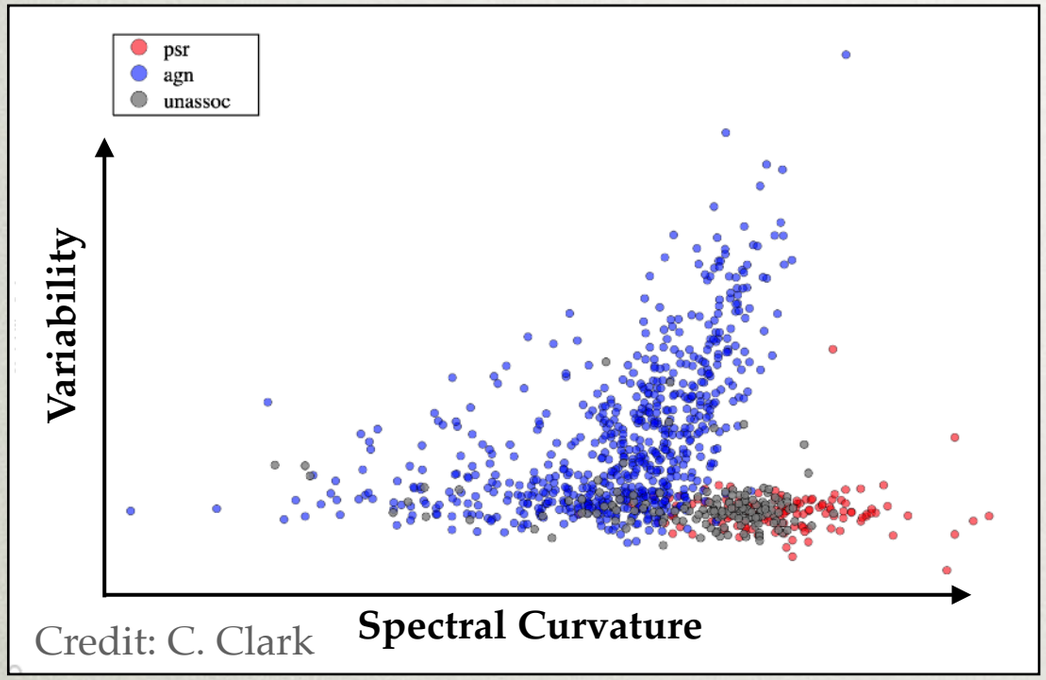


Linares (2020)

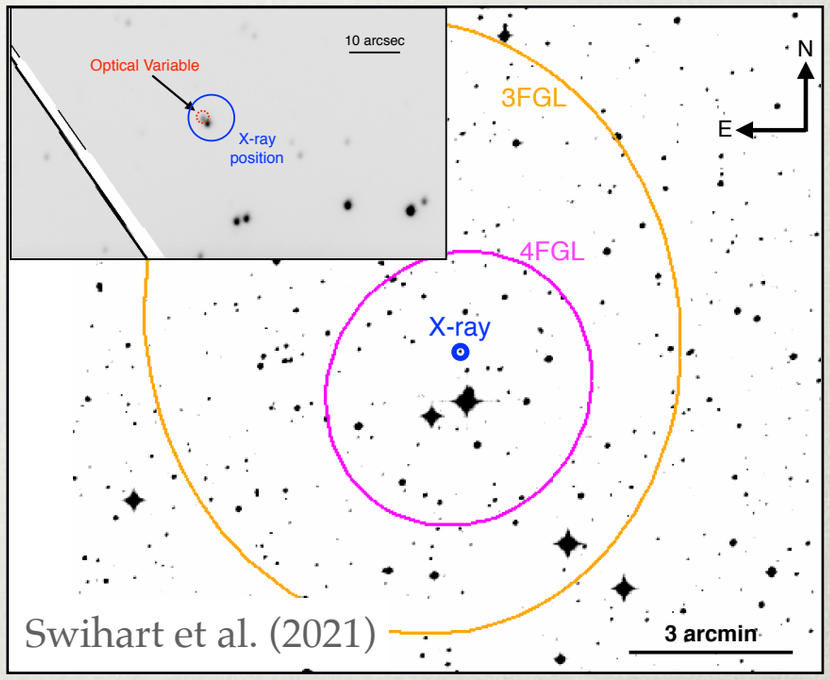
TRAPUM Fermi Surveys

Shallow survey
- 2x 10min L-band
- 2x 10min UHF
- Fields selected based on gamma-ray properties

Deep survey
- 2x 60min L-band
- 2x 60min UHF
- Fields selected for having likely optical from spider companion



Credit: C. Clark



Swihart et al. (2021)

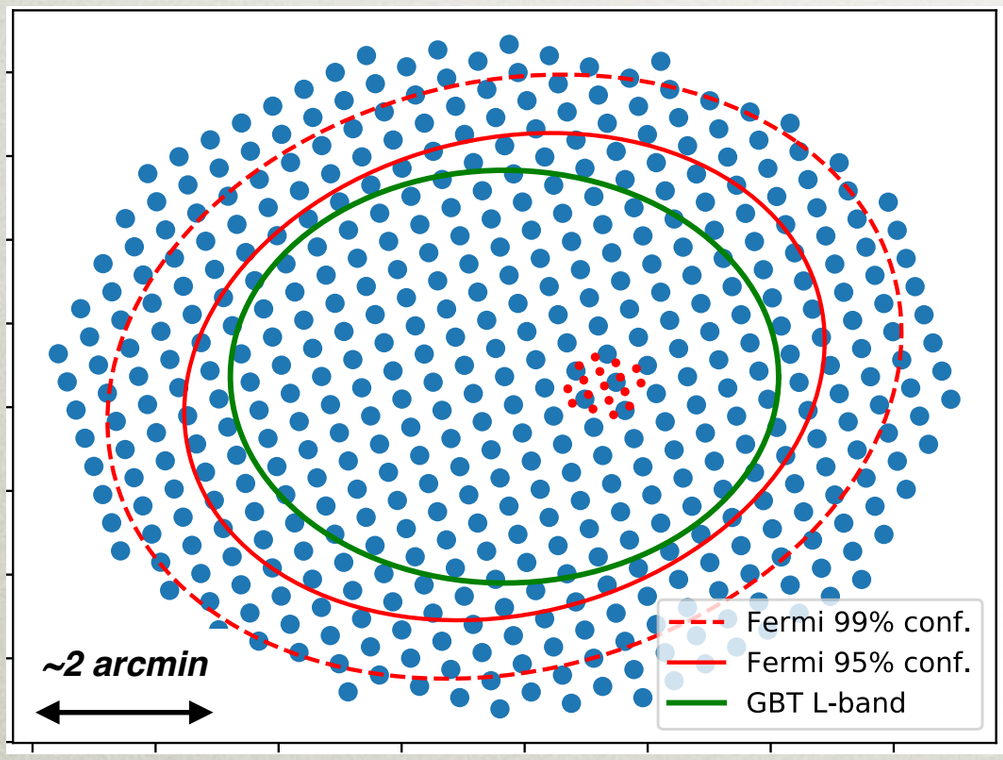
MeerKAT Power

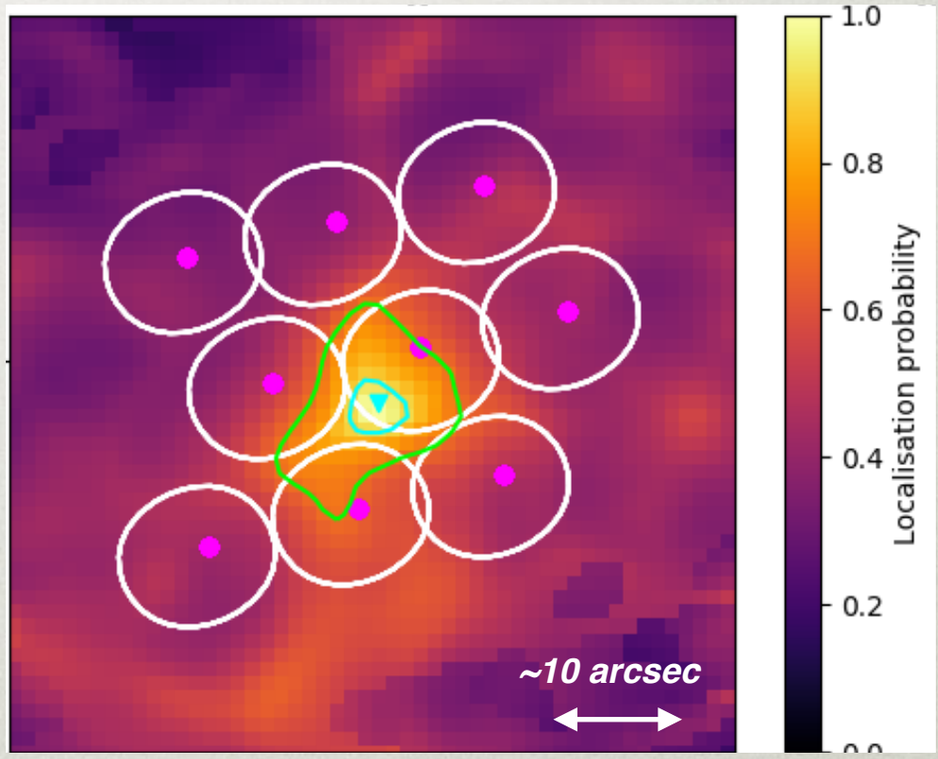
MeerKAT is an interferometer:

- Small dishes => large FoV
- Tied-array beams tiling
  - 480 coherent beams (tuneable)
  - RFI robustness
  - RFI mitigation
  - Localisation

Parameter	Parkes	GBT	Arecibo	MeerKAT
Frequency (MHz)	1390	820	327	1284 / 816
FoV @ survey (arcmin)	11	12	11	53 (0.09 for TAB)

[See Prajwal Padmanabh's talk]





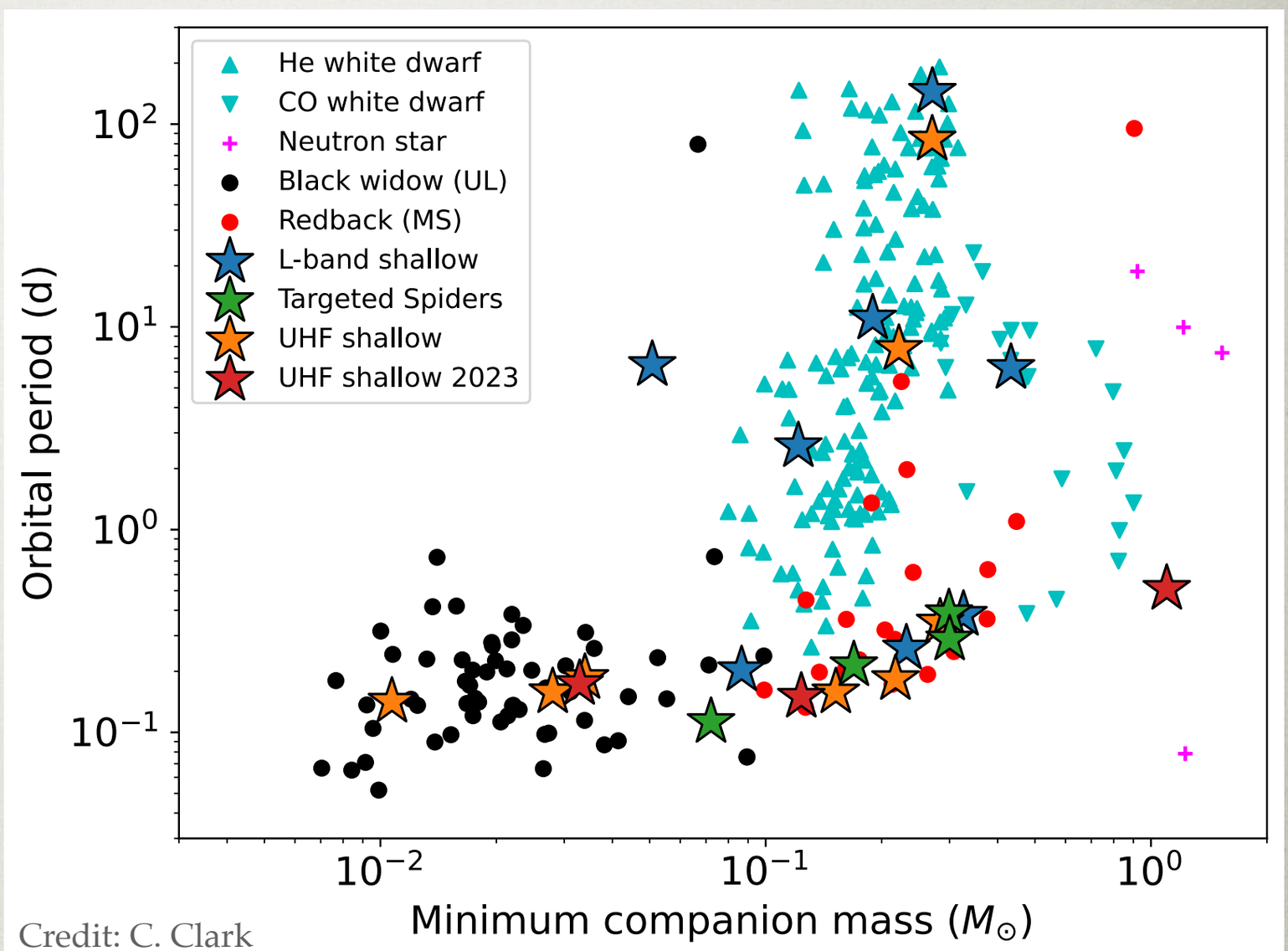
Credit: T. Thongmeearkom & T. Bezuidenhout

Coverage of entire $r_{95\%}$ region for several Fermi UNIDs in a single pointing.
Instantaneous localisation using detection in multiple beams.

Survey Results at a Glance

Shallow survey (in progress)
- 160 fields surveyed
- 40 new pulsars
  - 5 slow pulsars
  - 35 MSPs
  - 12 spider binaries

Deep survey (in progress)
- 10 fields surveyed
- 4 new spider (redback) binaries



Credit: C. Clark

TRAPUM Collaboration

Phase 1 L band (Clark et al. 2023)
Phase 1 Deep survey (Thongmeearkom et al. 2024)
Phase 1 UHF (Thongmeearkom et al. in prep)
Phase 1 Timing (Burgay et al. in prep)
Phase 2 (Thongmeearkom et al. in prep)

Multi-EM follow-up (Belmonte Diaz, Thongmeearkom, Phosrisom et al in prep)
Optical follow-up (Dodge et al. 2024)
Optical follow-up (Dodge et al. in prep)
Optical follow-up (Phosrisom et al. in prep)

C(G)W from J1526-2744

Pulsar + WD companion in circular orbit

- f = 401 Hz
- df/dt = -5×10^{-16} Hz / s
- P_{orb} = 0.2 d
- $M_{c,min}$ = 0.083 M_{sun}
- D_{DM} = 1.3 kpc

Coherent search for C(G)W in aLIGO O1, O2 and O3 using pulsar ephemeris at

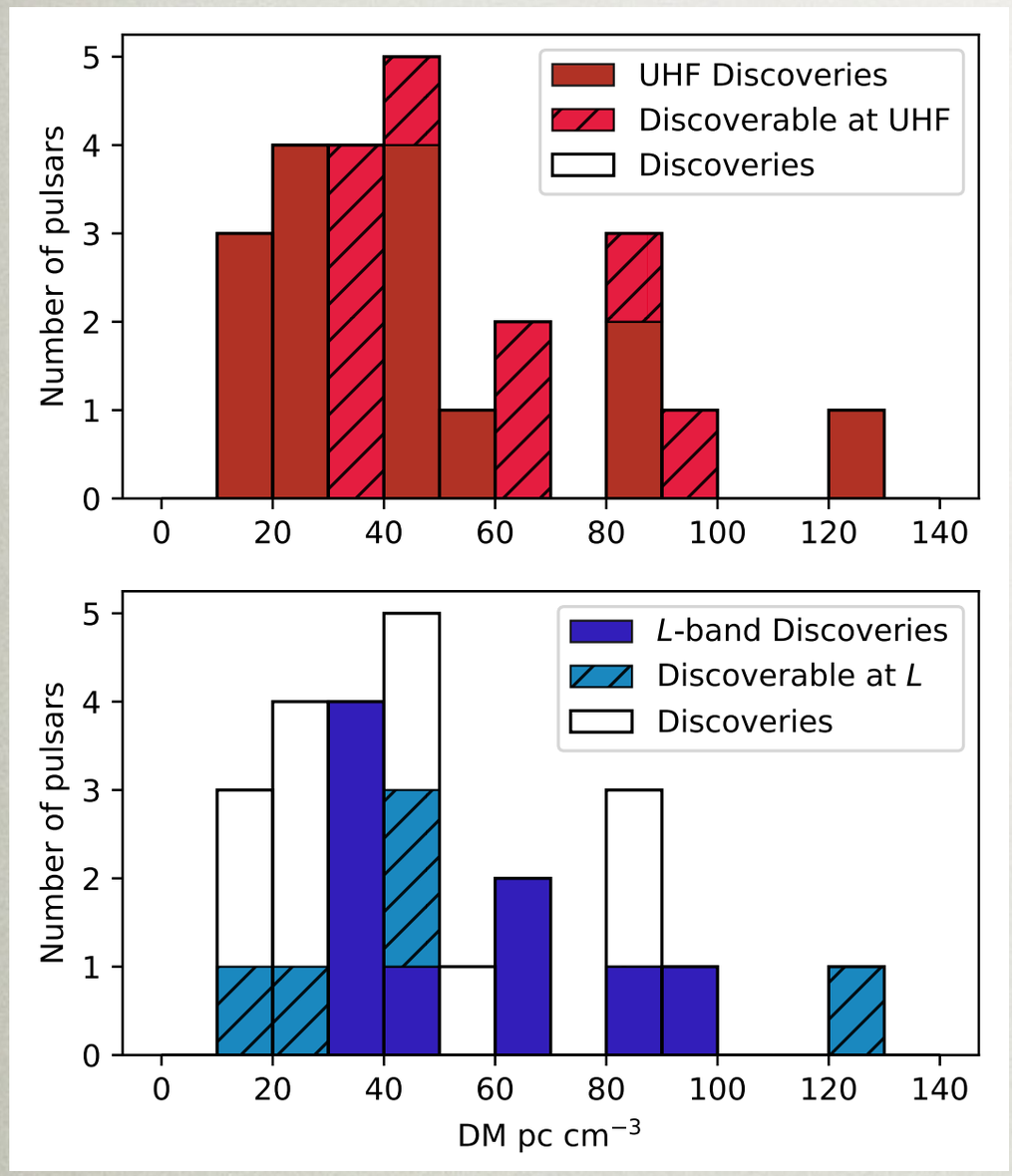
- f = 802 Hz
- df/dt = -1×10^{-15} Hz / s

No expected detection as aLIGO

- h ~ 2 dE/dt
- $h_{95\%} < 1.25 \times 10^{-26}$
- $\varepsilon < 2.45 \times 10^{-8}$

Clark et al. (2023), also Ashok et al. (2024)

Pinning Down the Right Survey Strategy



Thongmeearkom et al. (in prep)

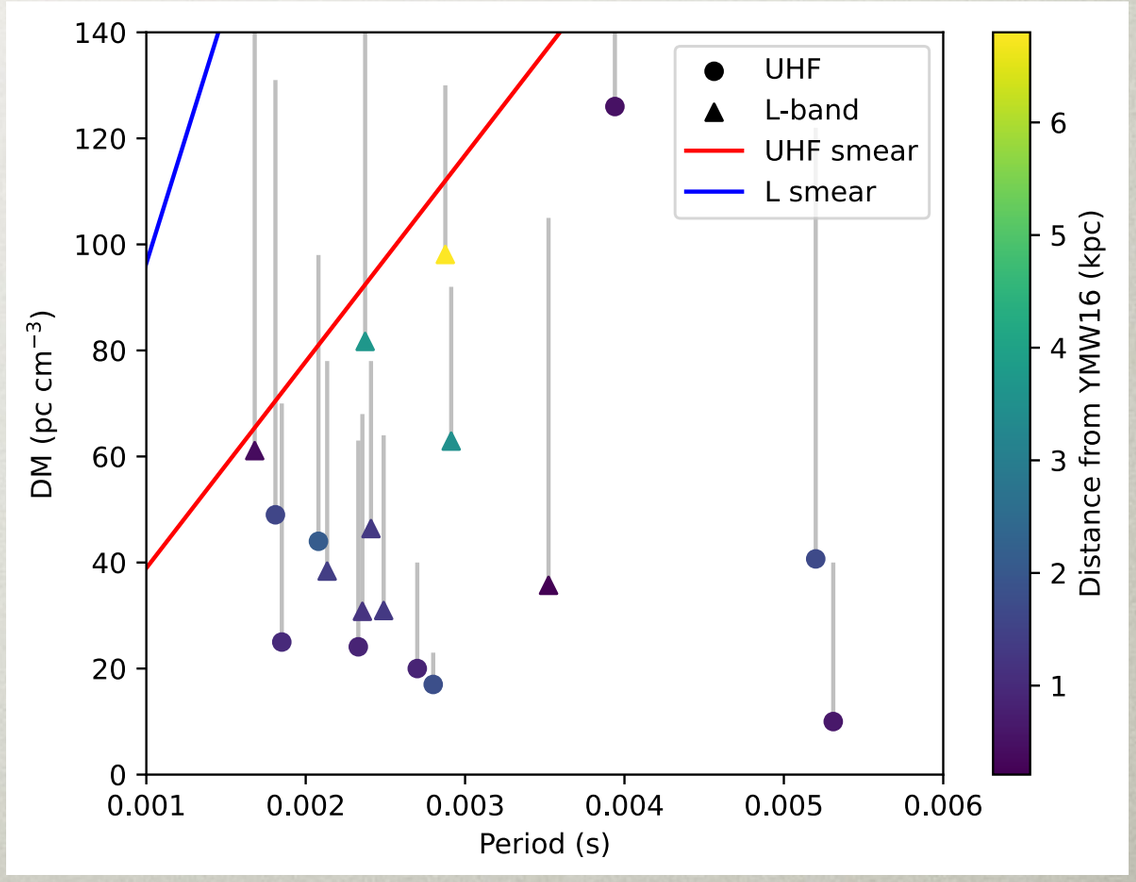
Fermi pulsars found in shallow survey

- Most discoverable at UHF
- Not all discoverable at L band

- Low frequency brightness
- Spatial coverage

VS

- Eclipses
- DM Smearing



Thongmeearkom et al. (in prep)

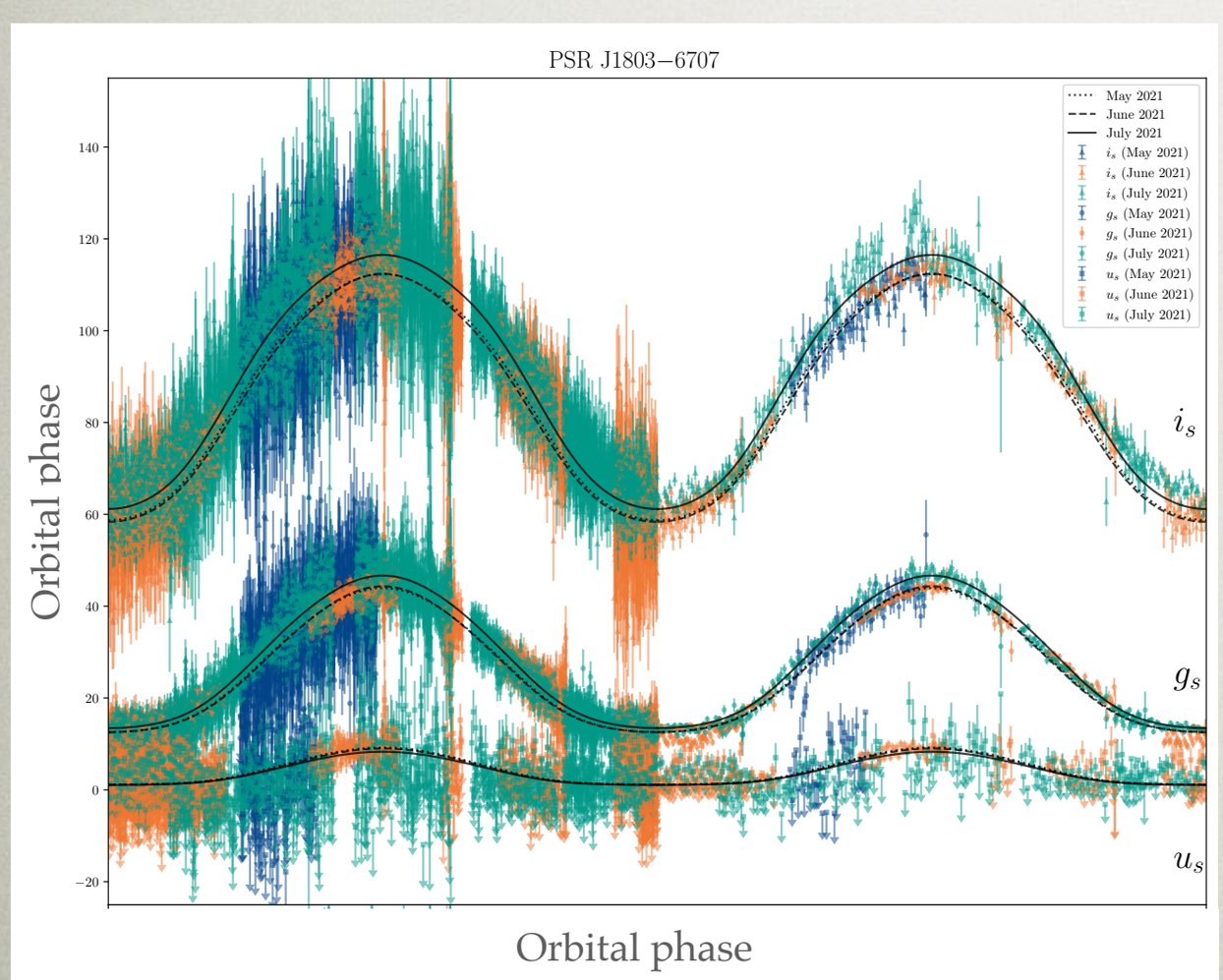
A Failed Transitional MSP?

PSR J1803-6707

- 2.14 ms redback in 9.1 hr orbit

- ULTRACAM observations June and July 2021
  - Modelling requires change in T_{irr} and R_{comp}

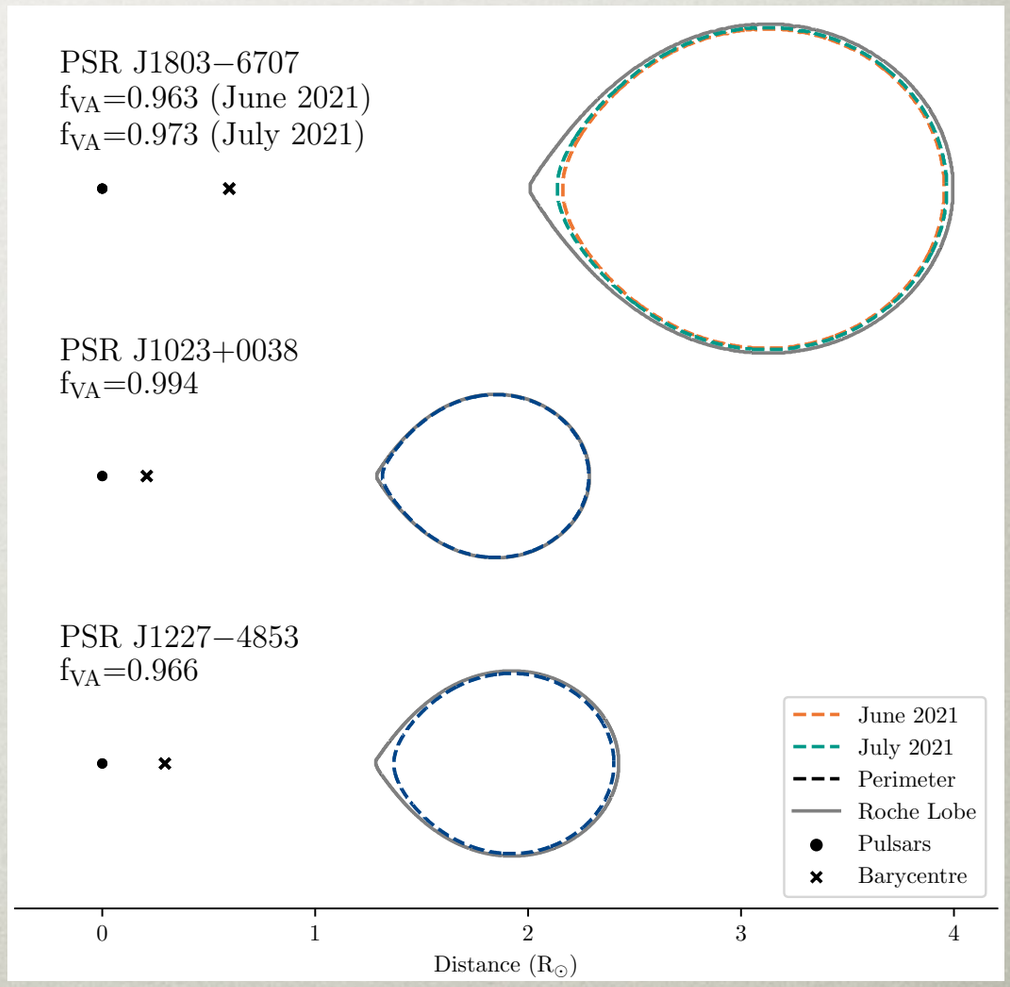
[See Adipol Phosrisom's talk]



Phosrisom et al. (in prep)

Failed tMSP?

- Known tMSP have a comparable Roche lobe filling factor in quiescence



Phosrisom et al. (in prep)

Dramatic Radio Eclipses

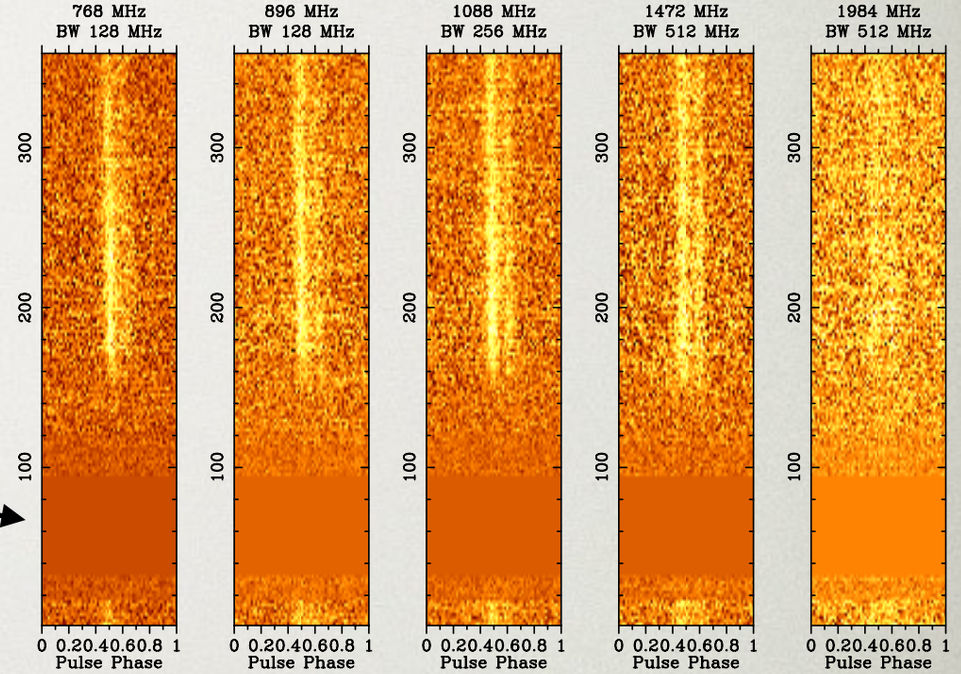
Heavy selection bias due to radio eclipses

Motivates radio searching with:
- High instantaneous sensitivity
- Short observations times
- Multiple revisits

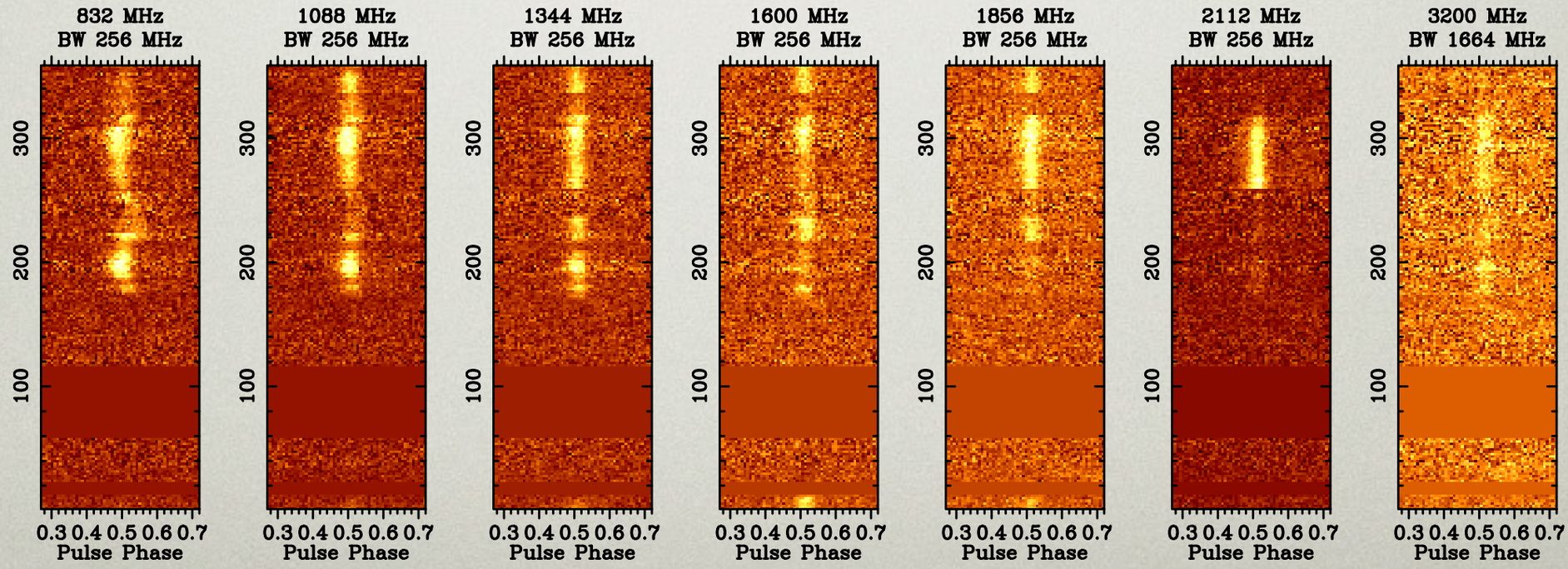
Eclipses visible above 3 GHz
- Presumably high plasma density

Eclipse fraction

PSR J1036-4353



PSR J1803-6707



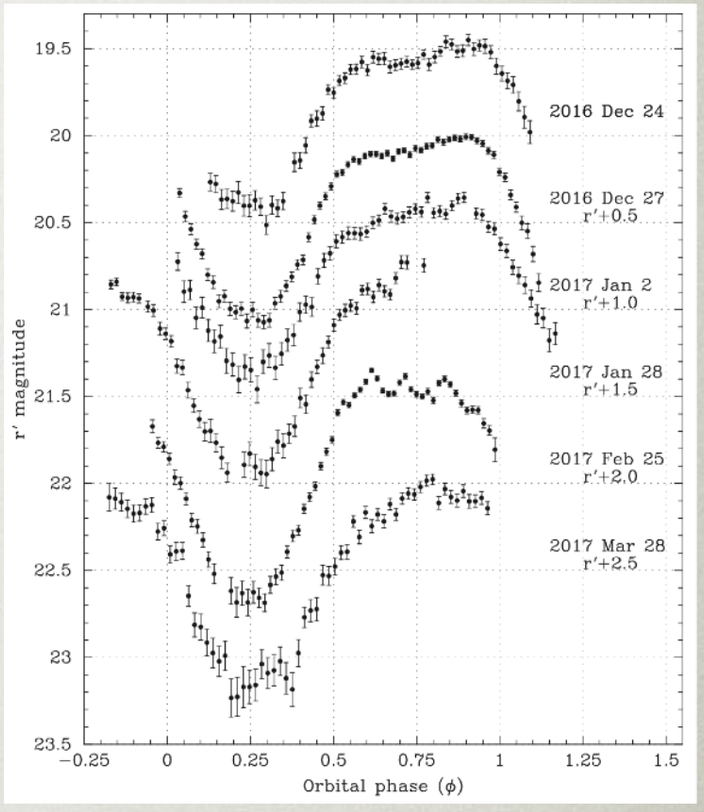
Burgay et al. (in prep)

Ludicrous Radio Eclipses

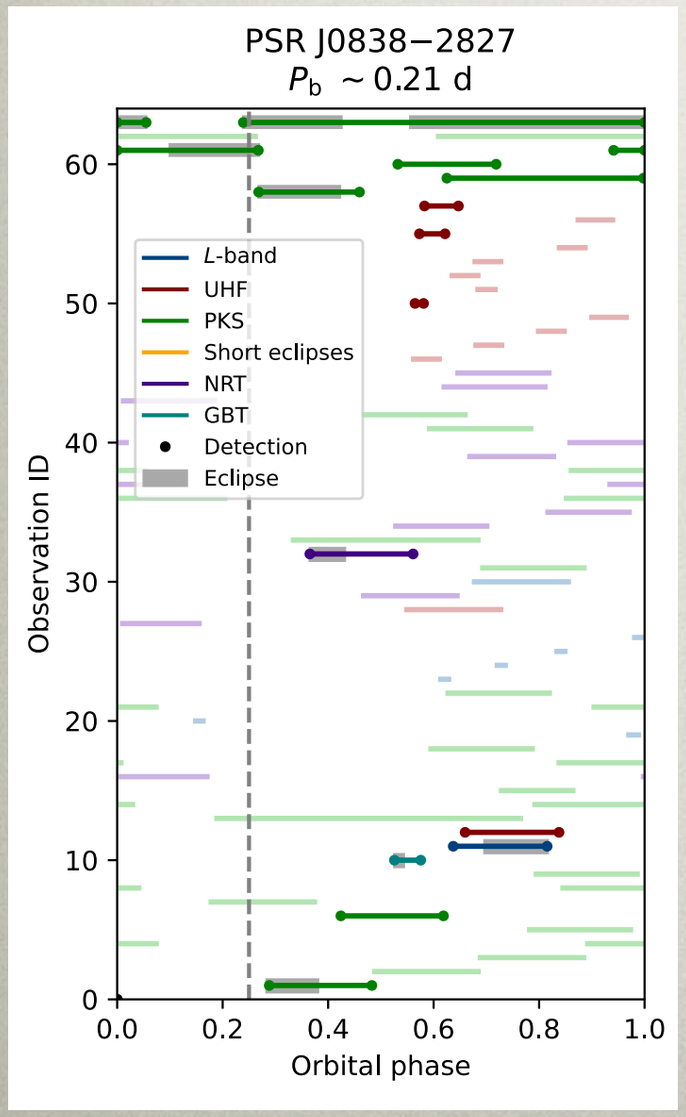
PSR J0838-2827
- Disappeared for 2 years!
- Eclipses all over the orbit

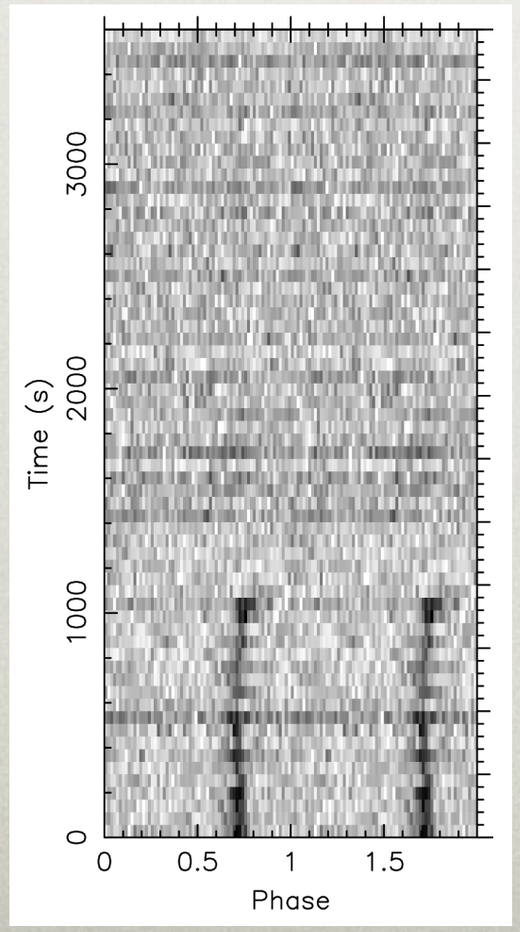
tMSP state transition?
- No change in X-ray/gamma ray

Optical R band



Halpern et al. (2017)





Thongmeearkom et al. (2024)

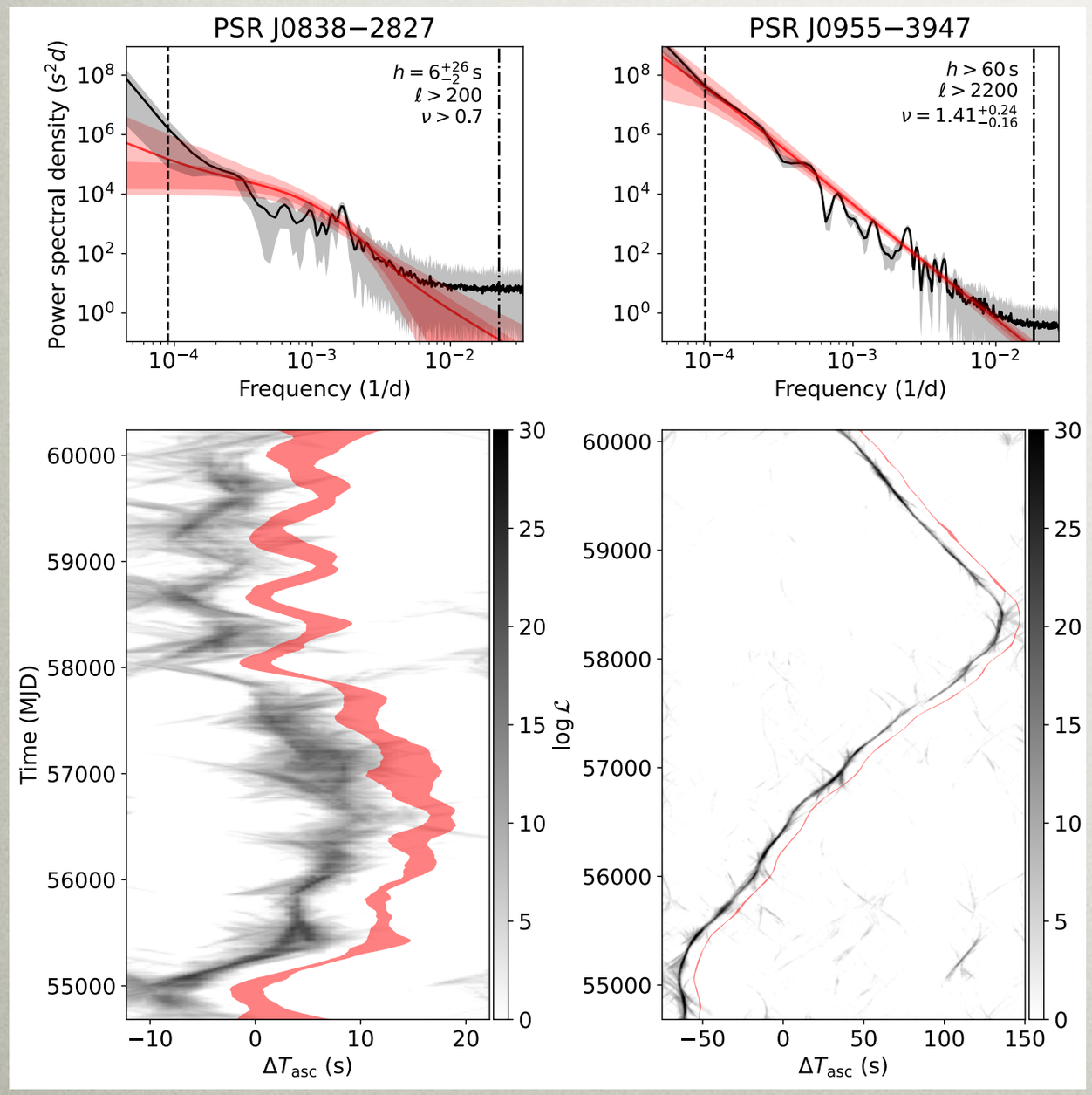
Prior optical knowledge
- Missed in previous Parkes observations
- Pulsar nearly impossible to detect without optical

Gamma Ray Timing

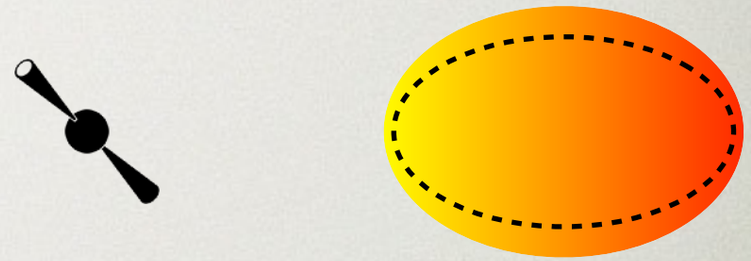
Fermi gamma ray timing provides immediate 15 year baseline

[See Lars Nieder's talk]

Spiders binaries display large, stochastic orbital variability



Thongmeearkom et al. (2024)

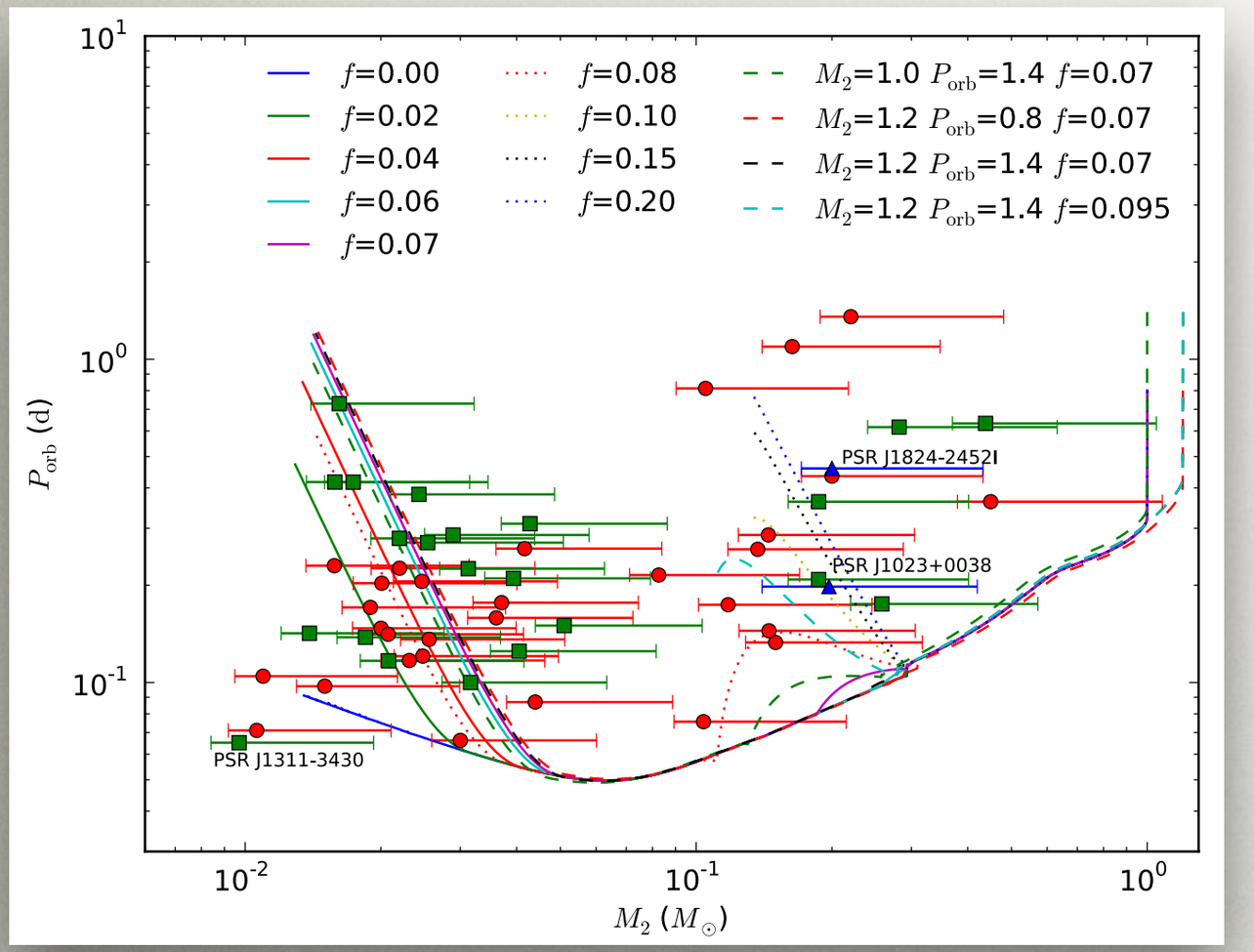


Possibly quadrupole moment changes akin to"Appelgate" mechanism
(Voisin et al. 2020a,b)

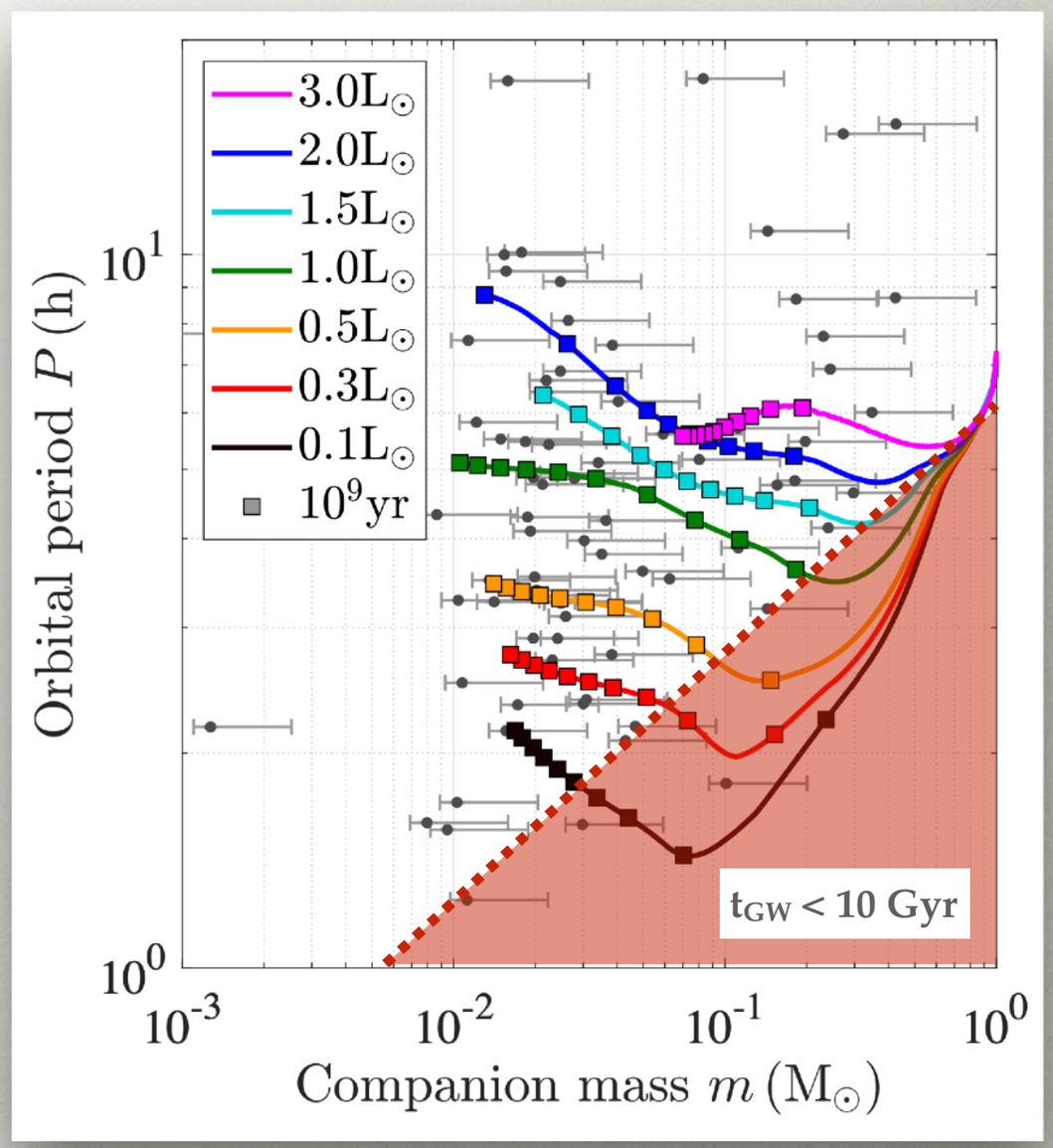
Prospects for GW

Ultrashort period systems might be detectable as CW

Some failed systems might merge



Chen et al. 2013



Conrad-Burton et al. 2023

Next Step: Spider Population

- Self-consistent binary population synthesis tracking
  - Stellar mass distribution
  - Binary population mixture
  - Orbital dynamics
  - New binary evolution ingredients

- How many spiders?
- Where are they located?
- How many mergers?

[See Soheb Mandhai's talk]

Summary

- Known spider population is booming
  - Heaviest, fastest spinning pulsars
  - Major selection biases against radio
    - Multi-wavelength now key ingredient
- Multi-wavelength follow-up key
  - Unravelling population
  - Providing timing and physical parameters

Credit: Knispel/Clark/Max Planck Institute for Gravitational Physics/NASA