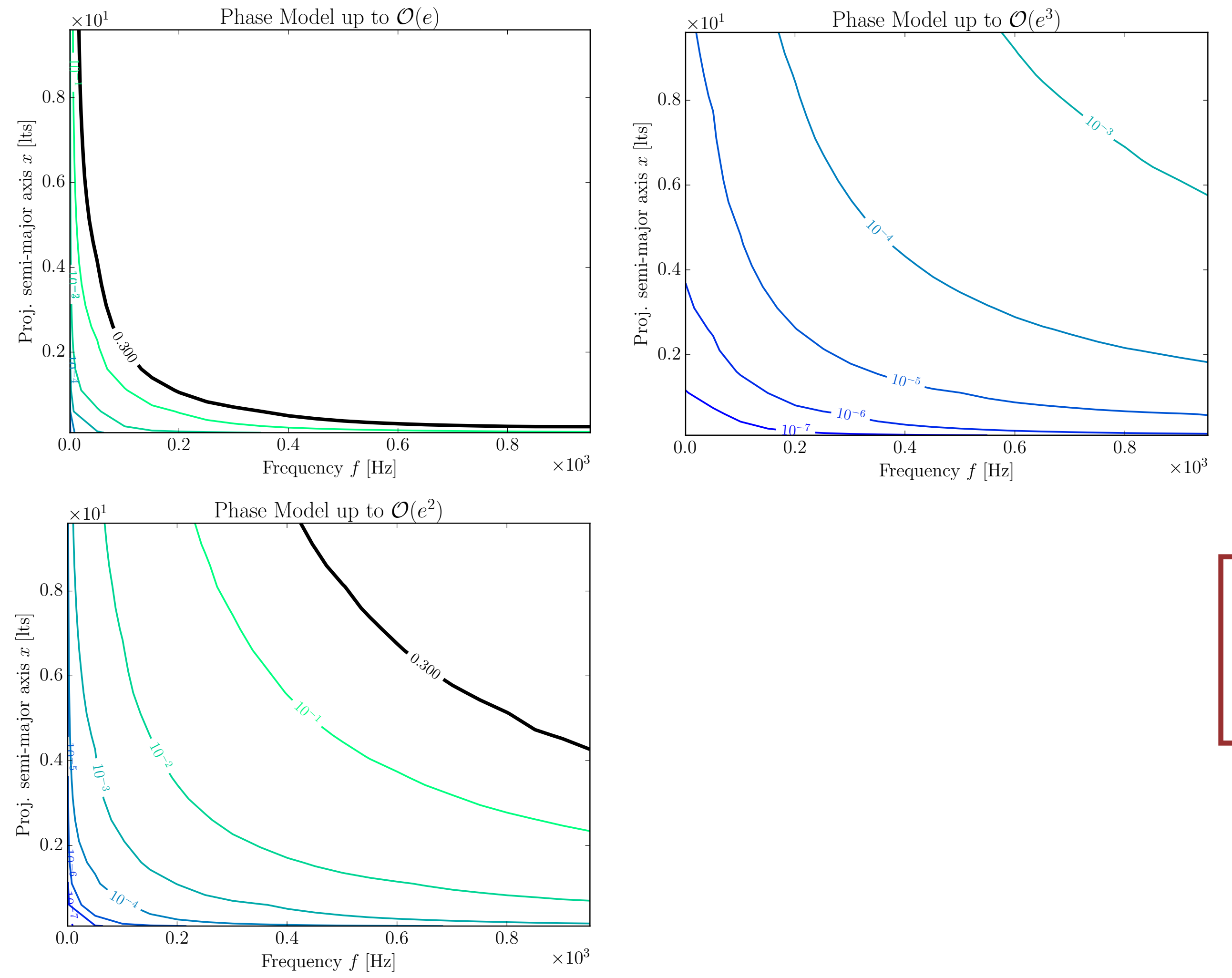
Blind Search Methods for Binary Gamma-ray Pulsars

- Problem: Binary MSPs are sometimes undetectable in radio due to eclipses or the radio beam not pointing towards Earth. But blind searches for their gamma-ray pulsations have been infeasible until recently.
- Solution:
  - New methods (Slide 2):
    - Efficient multistage search, optimised search grids using parameter space metric, orbital constraints from optical counterpart
  - Search design (Slide 3):
    - Very sensitive for fixed amount of computing resources
    - Use of ATLAS Cluster in Hannover and *Einstein@Home*
- Applications (Slide 4):
  - Blind searches exploiting orbital constraints
  - Targeted searches (for recently detected radio pulsars)
  - Long-term timing (of eclipsing binary pulsars)

Lars Nieder and Colin J. Clark on behalf of the *Fermi* LAT Collaboration

Search Methods

Loss of signal power



Credits: Nieder, L., Pletsch, H. J., Clark, C. J. in prep

- Semicoherent first stage
- Coherent follow-up
- Final stage with H-test

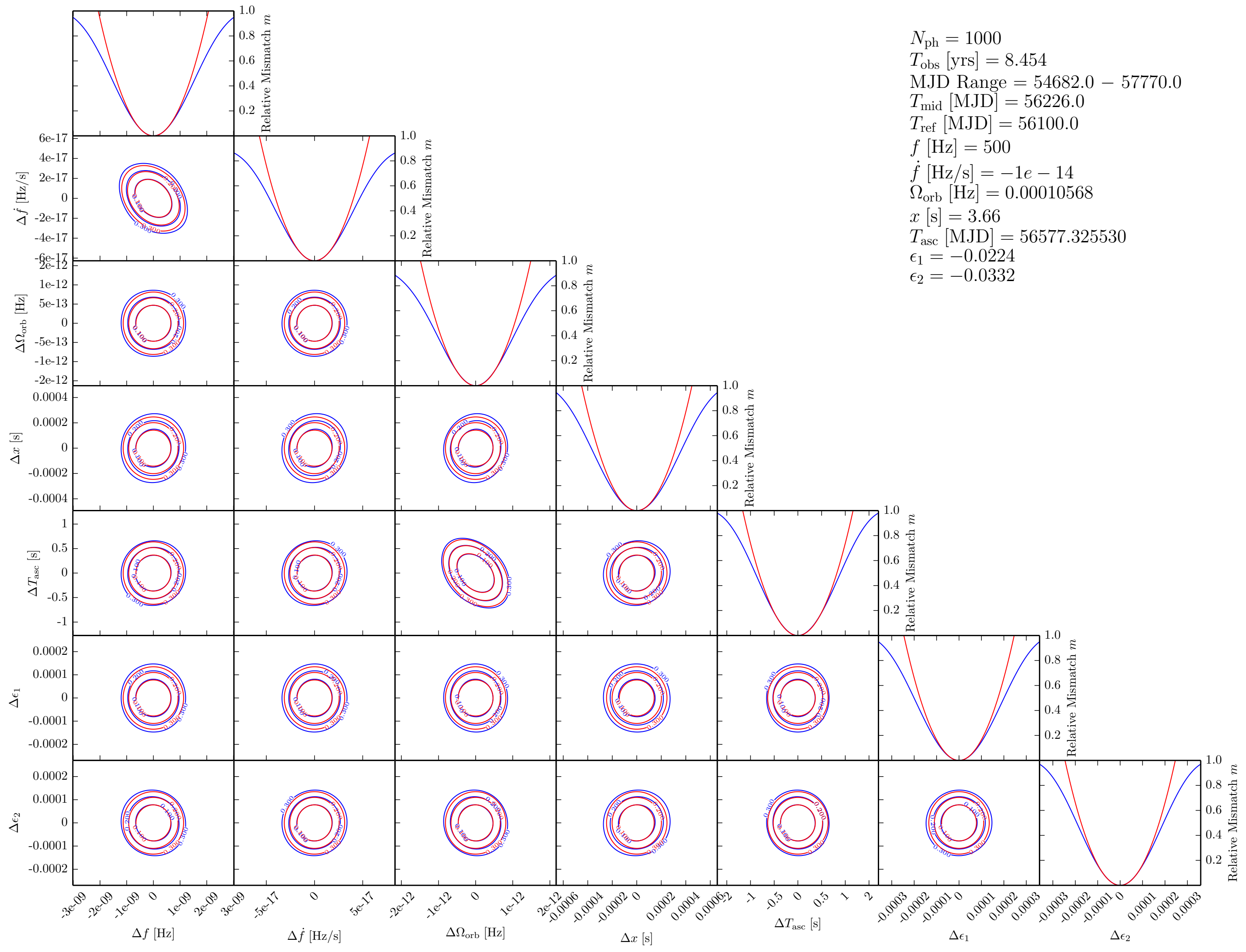
Credits: Pletsch, H. J., & Clark, C. J. 2014, ApJ, 795, 75

Phase Model

Multistage Scheme

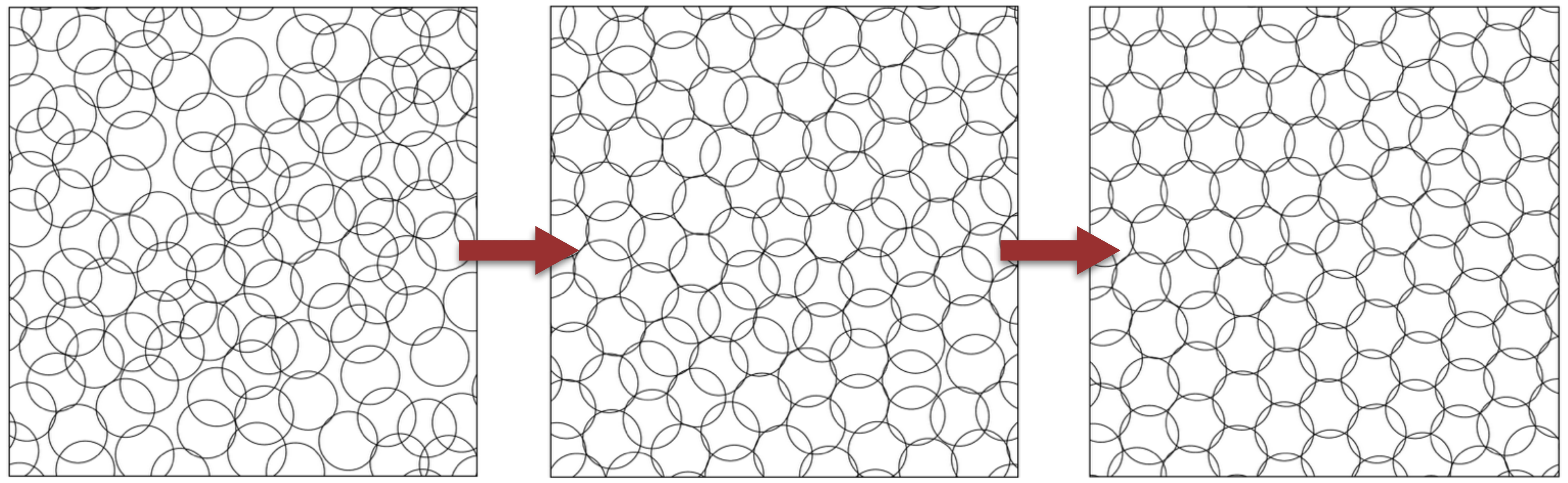
Distance Metric

Orbital Constraints

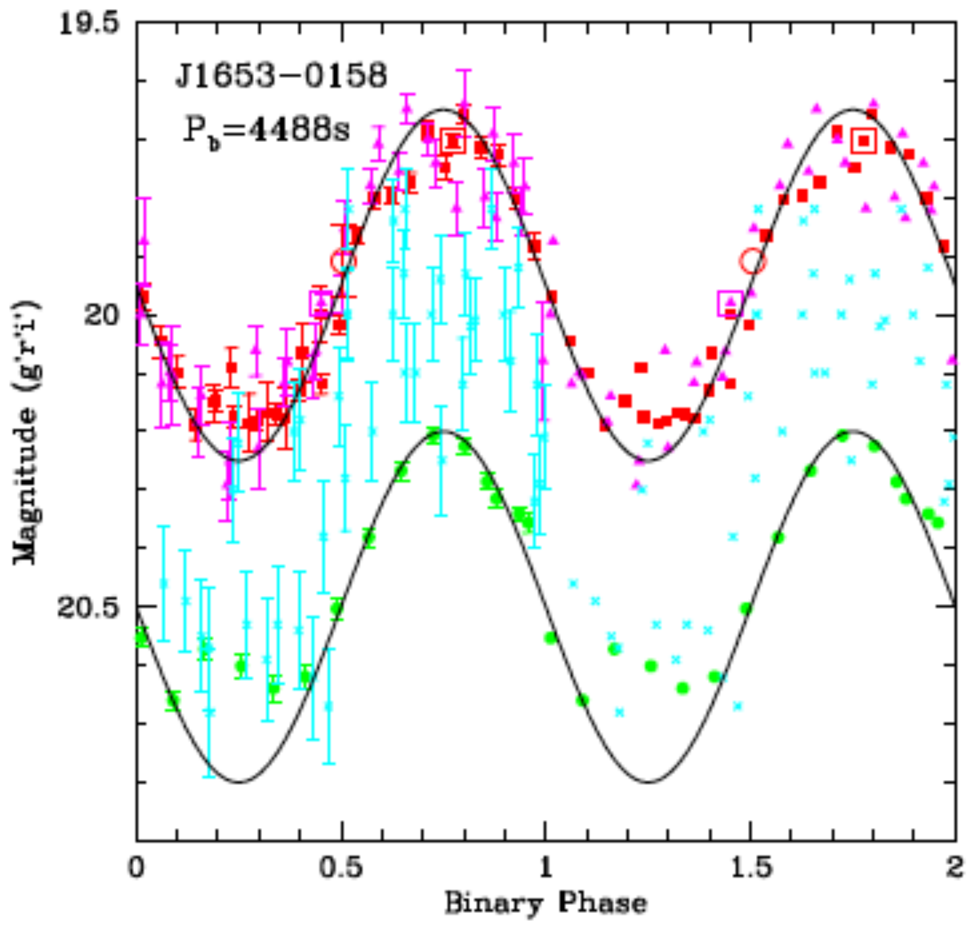


Credits: Nieder, L., Pletsch, H. J., Clark, C. J. in prep

Stochastic Grid



Credits: Fehrmann, H., & Pletsch, H. J. 2014, PhRvD, 90, 124049



Credits: Romani, R. W., Filippenko, A. V., & Cenko, S. B. 2014, ApJL, 793, L20

Search Design with Limited Computing Resources

Mismatch: fractional loss in signal-to-noise ratio due to offsets from pulsar parameters or approximated phase model

Metric: analytical approximation to the expected mismatch as function of the distance to the nearest grid point

Orbital constraints: from optical observations of companion and crucial to reduce the relevant parameter space

Search design: optimized sensitivity (minimized average mismatch and long coherence time) for limited computing resources

Einstein@Home: an distributed volunteer computing system used in searches for pulsars and for continuous gravitational waves

Number of grid points:

$$N \propto m_{\max}^{-7/2} \int_{\Lambda} \sqrt{\det\, g(\vec{\lambda})}\; \mathrm{d}\vec{\lambda}$$

$$\vec{\lambda} = \left\{ f, \dot{f}, \Omega_{\mathrm{orb}}, x, T_{\mathrm{asc}}, \eta, \kappa \right\}$$ and $$\sqrt{\det\, g(\vec{\lambda})} = T_{\mathrm{obs}}^2\, T_{\mathrm{coh}}^2\; f^5\, \Omega_{\mathrm{orb}}\, x^4$$

Search parameters:

- Observation time $\equiv T_{\mathrm{obs}}$
- Coherence time $\equiv T_{\mathrm{coh}}$
- Maximum mismatch in grid $\equiv m_{\max}$

Pulsar parameters:

- Spin frequency $\equiv f$
- Spin-down rate $\equiv \dot{f}$

Orbital parameters:

- Orbital frequency $\equiv \Omega_{\mathrm{orb}}$
- Projected semi-major axis $\equiv x$
- Epoch of ascending node $\equiv T_{\mathrm{asc}}$
- Eccentricity of orbit $\equiv e$
- Longitude of periastron $\equiv \omega$
- $\epsilon_1 = e \sin \omega$
- $\epsilon_2 = e \cos \omega$

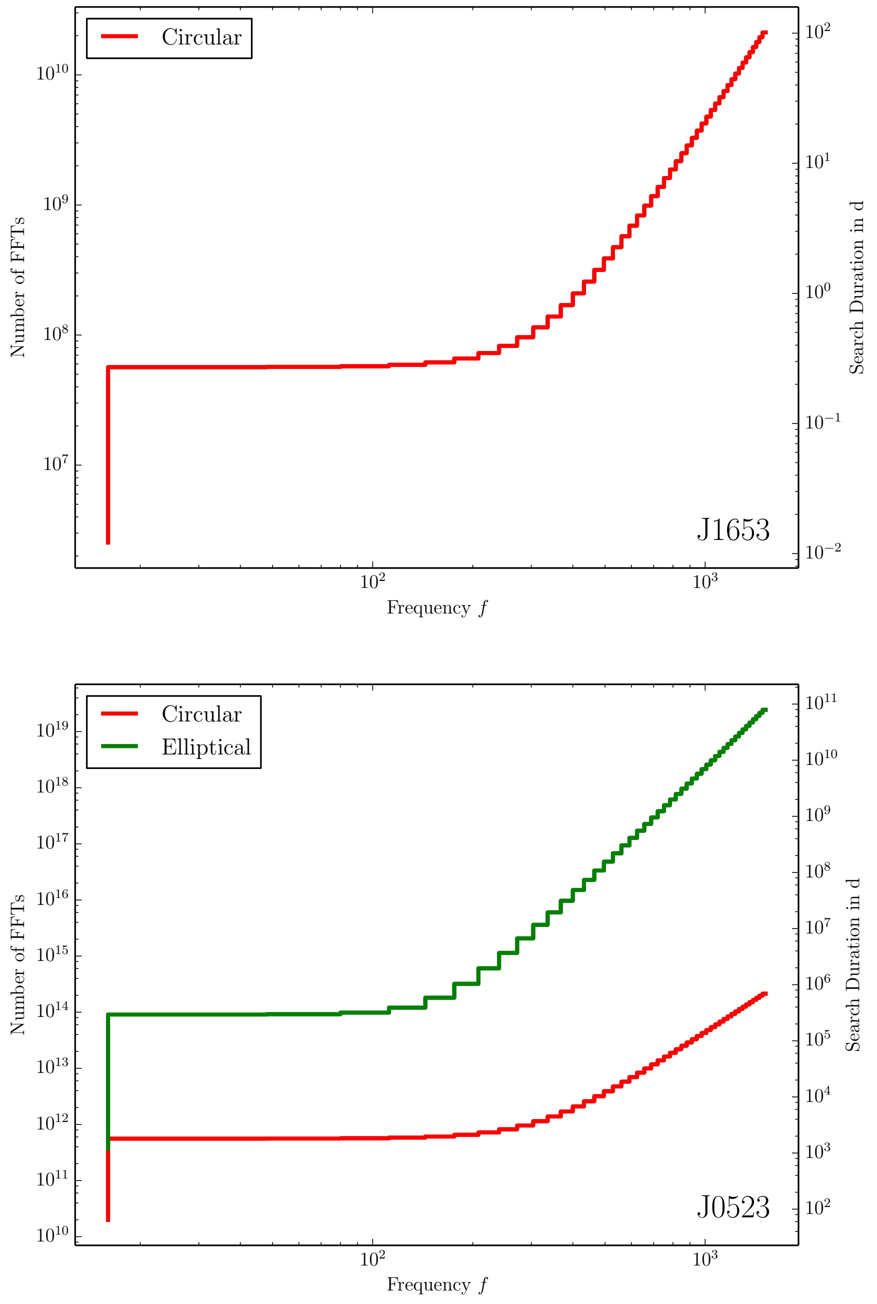
Recovered signal-to-noise ratio:

$$S/N \propto (1 - m)\sqrt{T_{\mathrm{coh}} T_{\mathrm{obs}}}$$

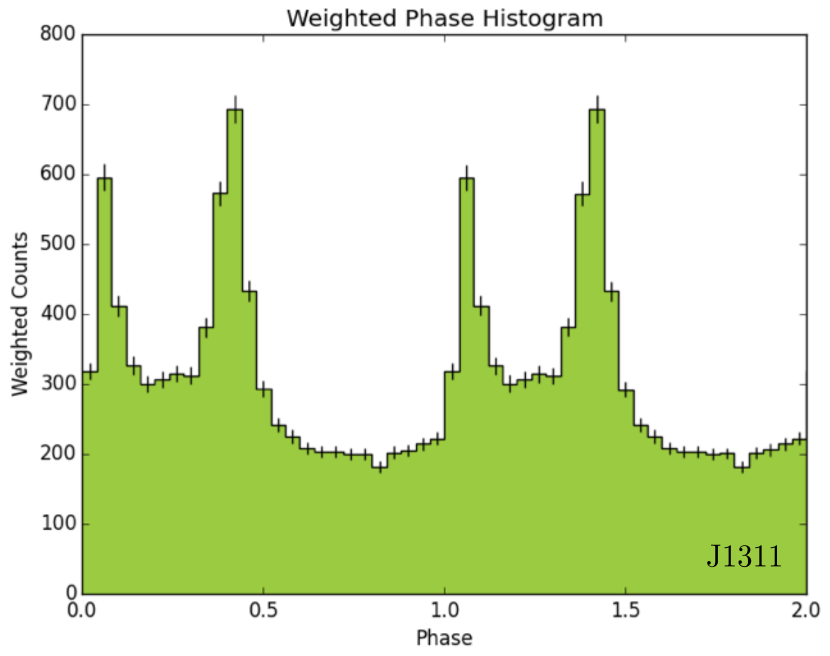
Applications of Methods

Blind Searches:

Candidates: Computing cost for search on *Einstein@Home*



Detection of Black Widow

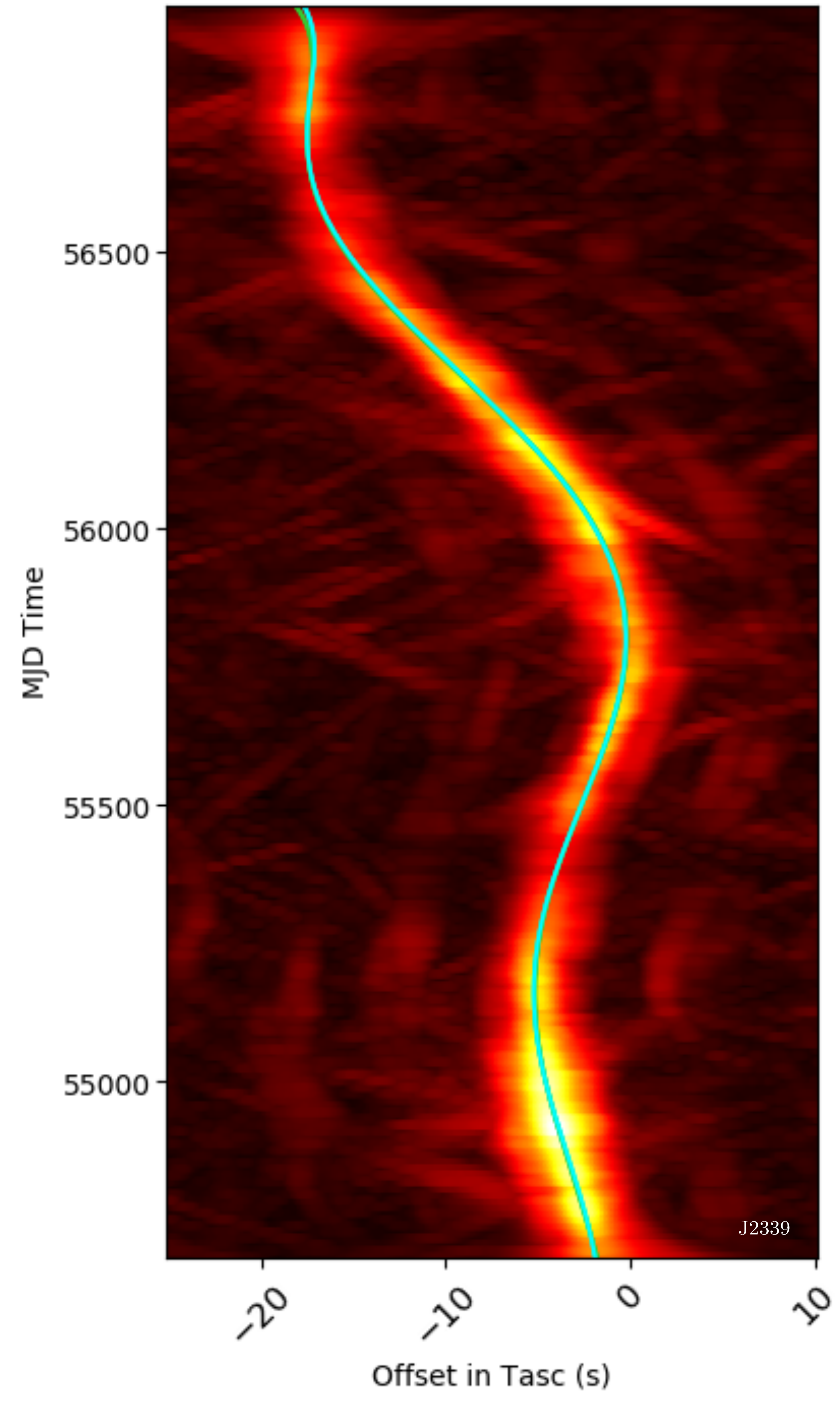


Credits: Pletsch, H. J., Guillemot, L., Fehrmann, H., et al. 2012, Science, 338, 1314

Targeted Searches:

- Precise timing solutions require frequent observations of a radio pulsar over several years
- The measurement uncertainty of some pulsar parameters (e.g. spin frequency, orbital period) is inversely related to the total observation time
- In the case of detected gamma-ray pulsations *Fermi* LAT's on-going all-sky survey allows us to extend the solution of a radio detection over 9 years of gamma-ray data
- The distance metric can assist here with the building of an efficient search grid while the phase model can be used even for eccentric pulsars

Long-term Timing:



Timing of Redback pulsars with orbital period variations

Credits: Pletsch, H. J., & Clark, C. J. 2015, ApJ, 807, 18