The Radio Polarization Of Young Pulsars And Implications For Gamma-ray Emission

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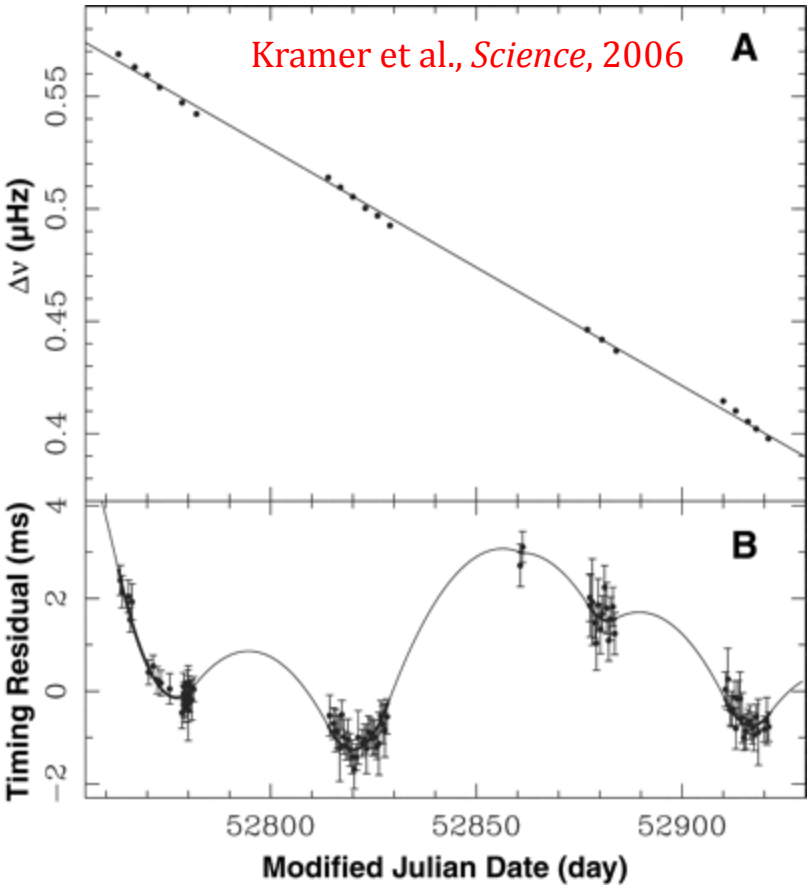
Motivation: The "Pulsar Problem"

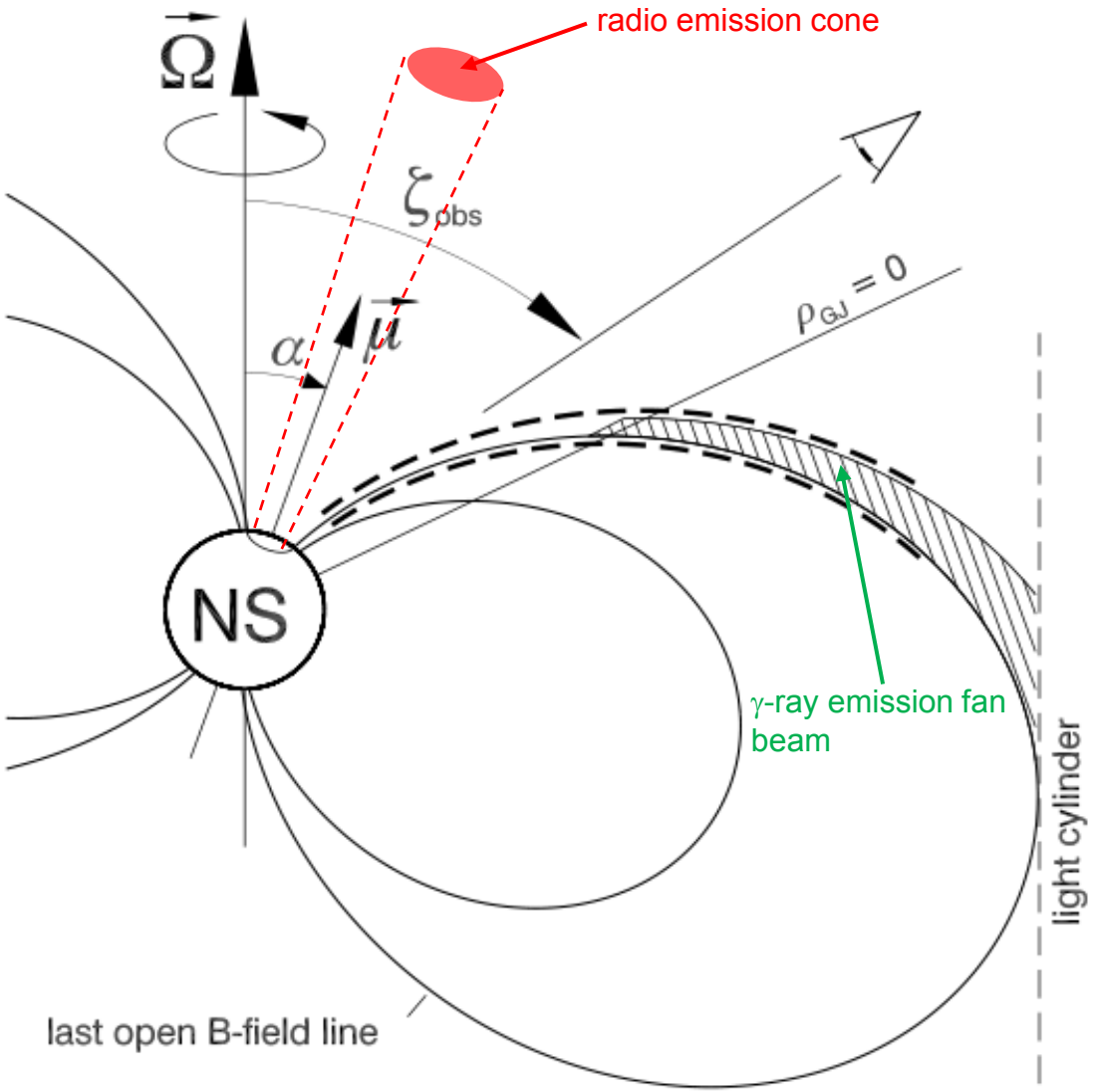
- After 40+ years, we don't know:
  - What the radio emission process is.
  - What the gamma-ray emission process is.
  - What the magnetic field, current density, and plasma configuration is.
  - Not an indictment of observers or theorists! Very difficult, coupled problem.

- Observations are primarily at radio frequencies. Very sensitive, but emission is coherent, from a tiny volume of the magnetosphere.

- Gamma rays are produced incoherently and efficiently (1-100%); a much better tracer of the magnetosphere structure and dynamics.



Pulsar Configuration and Some Models



Polar Cap (PC)
- Harding, ApJ 1982

Outer Gap (OG)
- Cheng, Ho, Ruderman, ApJ 1986
- Romani ApJ 1996

Slot Gap (SG) / Two-pole Caustic (TPC)
- Muslimov & Harding, ApJ 2004
- Dyks & Rudak, ApJ 2003

Separatrix Layer (SL)
- Bai & Spitkovsky 2010

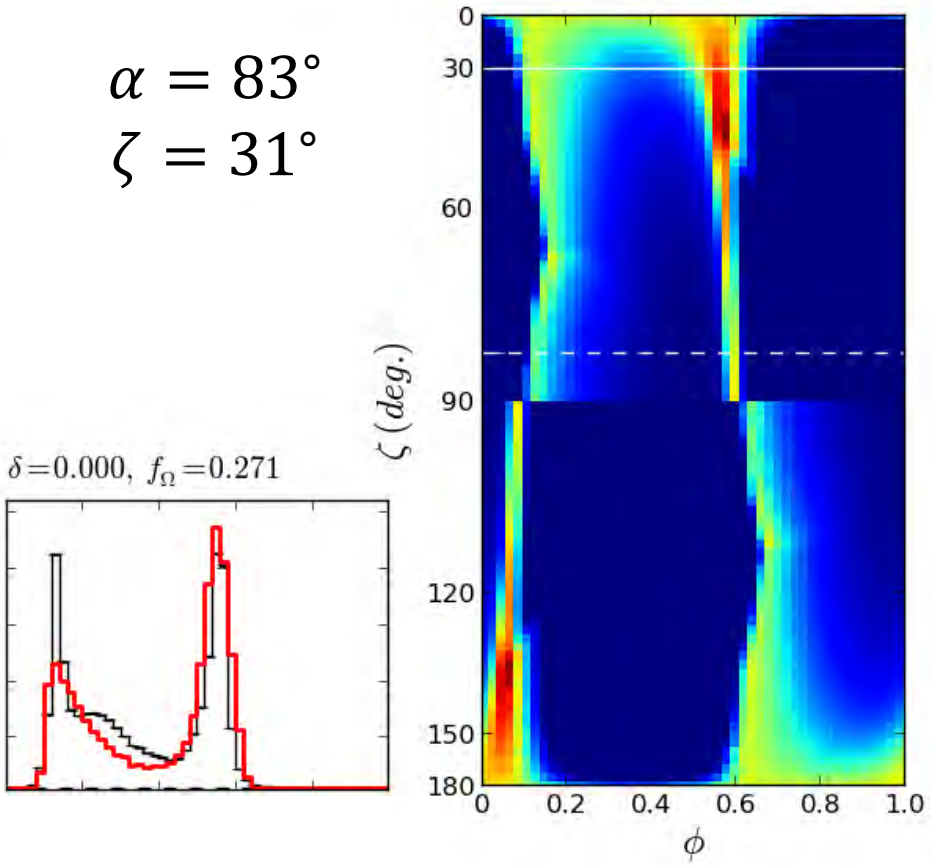
All of above models can be expressed with a generalized, parameterized emitting volume.

Controlling parameters are α and ζ.

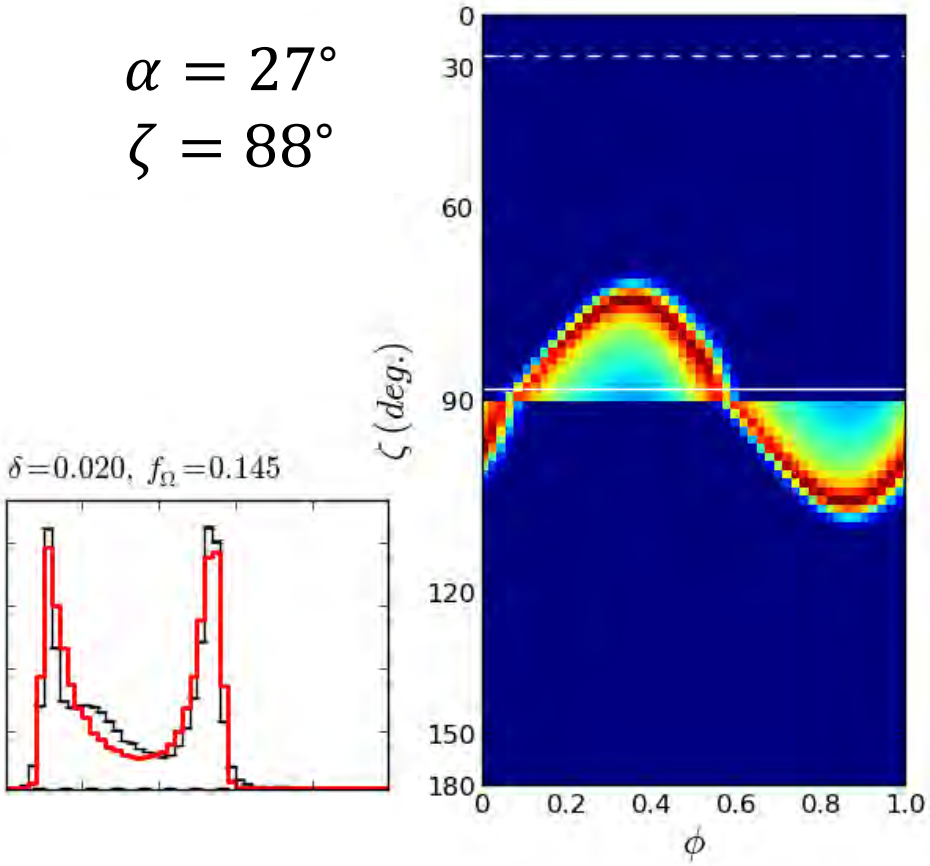
Vela: Tale of Two Geometries

- Two “outer gap”-like (high altitude) models at appreciably different viewing angles / magnetic inclinations give acceptable fits.
- General property of gamma-ray emission models.

$\alpha = 83°$
$\zeta = 31°$



$\alpha = 27°$
$\zeta = 88°$



The Polarization of Pulsars

- The radio emission mechanism of pulsars is poorly understood, but:
  - It must be coherent (brightness temperature):
  - Curvature emission from bunches of particles?
  - Beam instability + unstable growth of longitudinal modes + conversion to a ~transverse mode?
  - Condrichthyan masers?

- What is certain is that the magnetic field dominates the process and sets the axis of symmetry. This motivates the…

- Rotating Vector Model (Radhakrishnan & Cooke, 1969; Everett and Weisberg, 2001) predicts the observed position angle of polarization.

The Rotating Vector Model

- At emission point, plane of polarization is normal to magnetic field line →
- Defines two orthogonal (though arbitrary) modes of emission.
- If one is dominant, angle of polarization swings in an “S” curve as beam cross the line of sight.

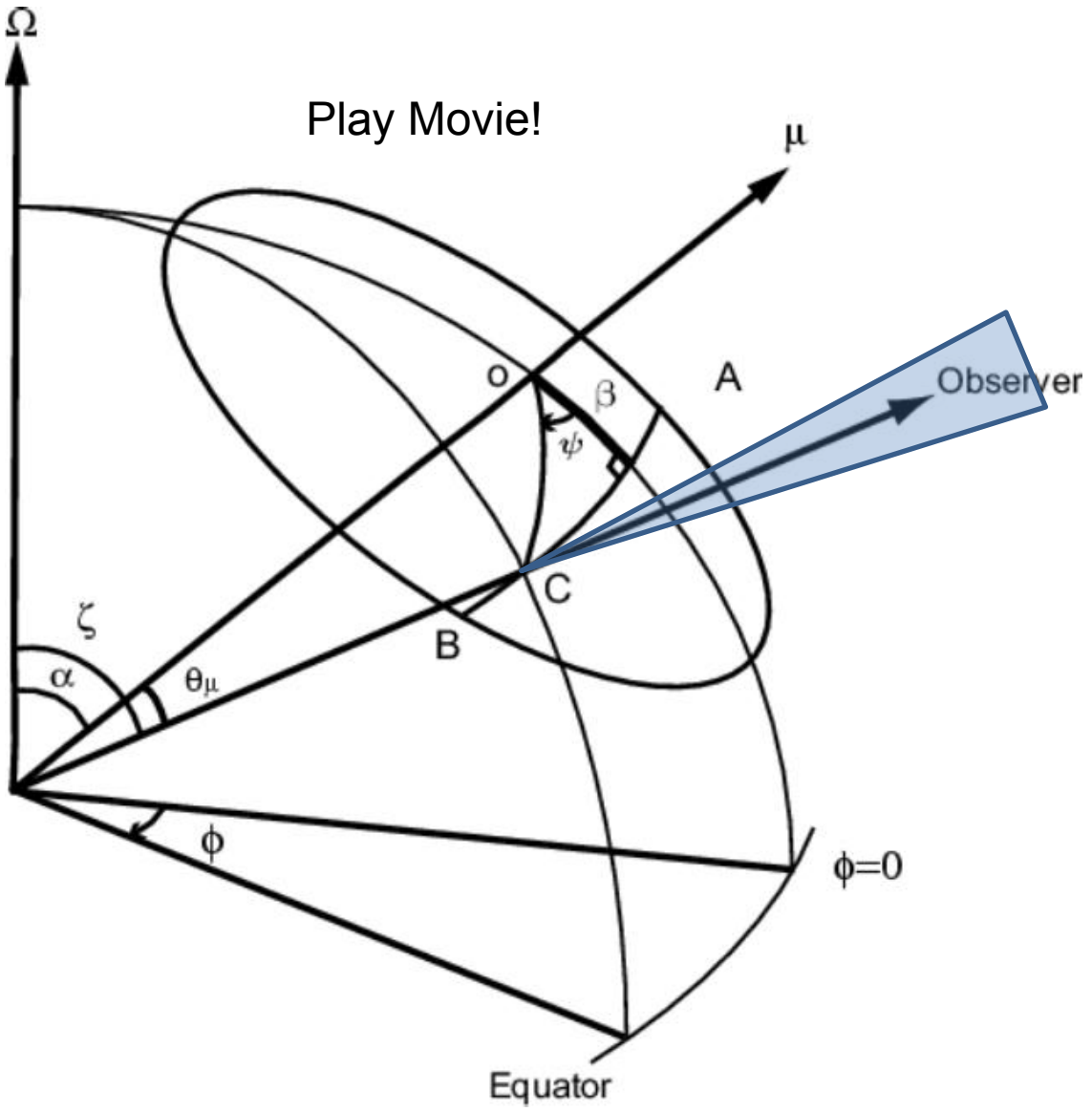
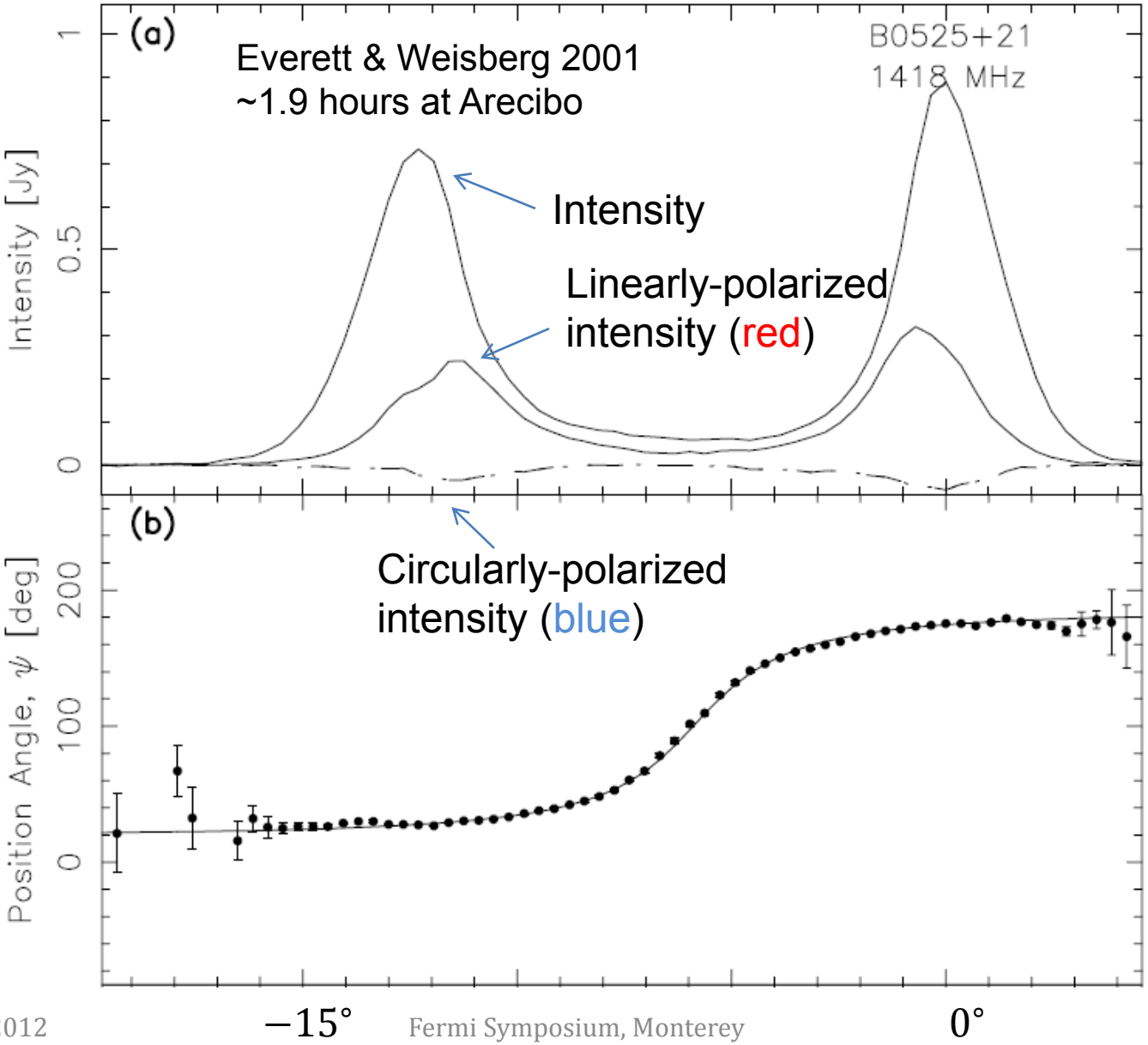
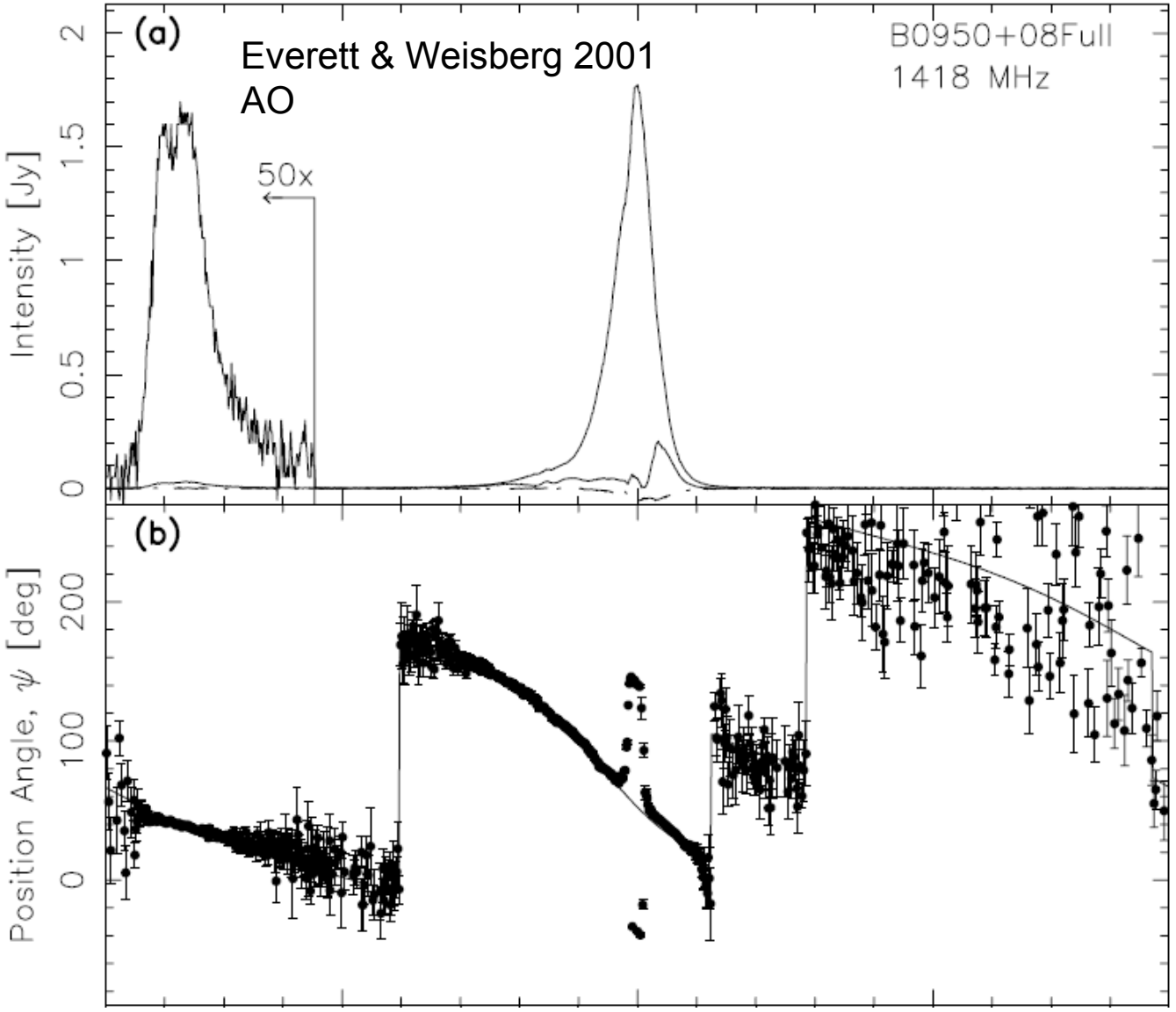


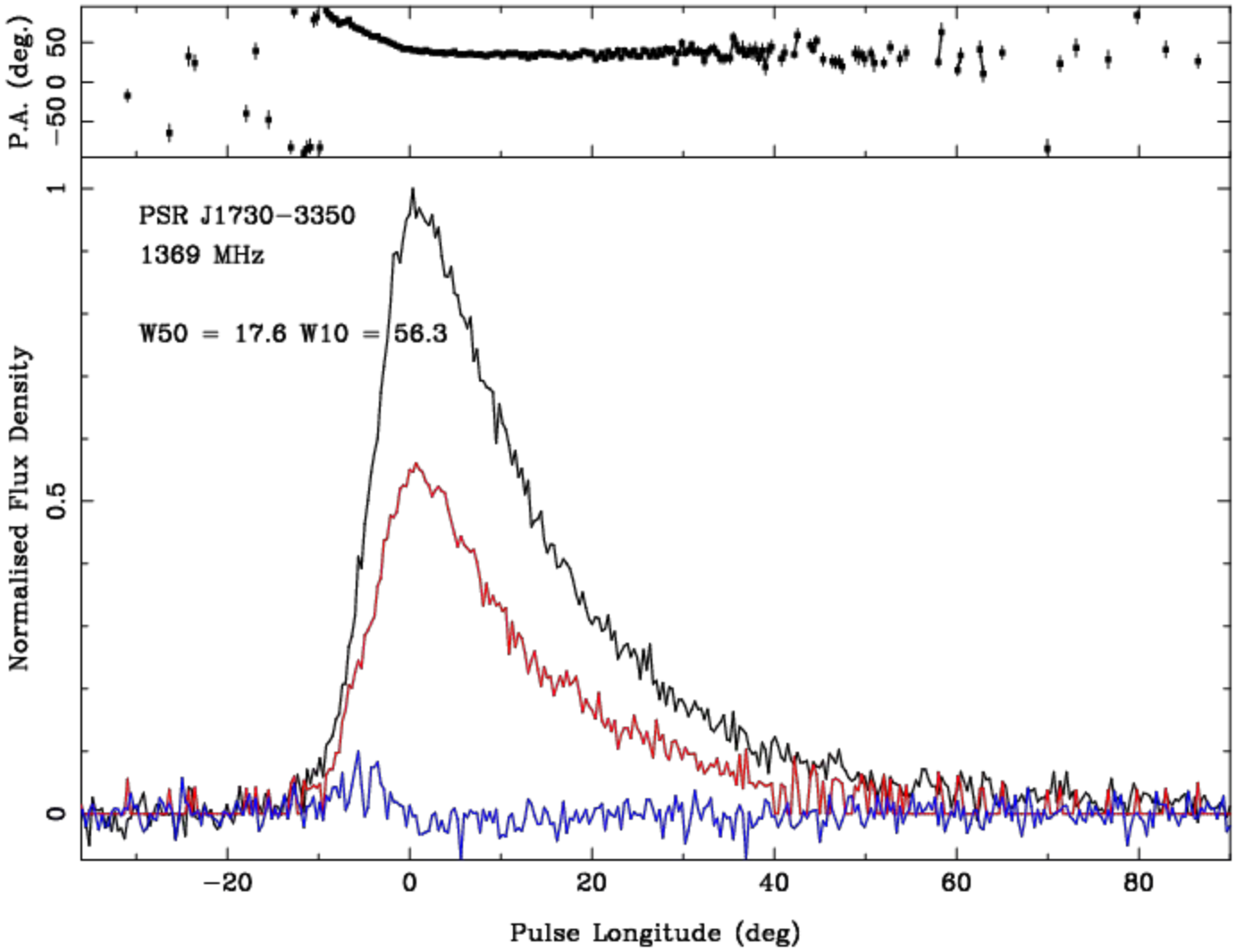
Illustration and Issues



Orthogonal Modes

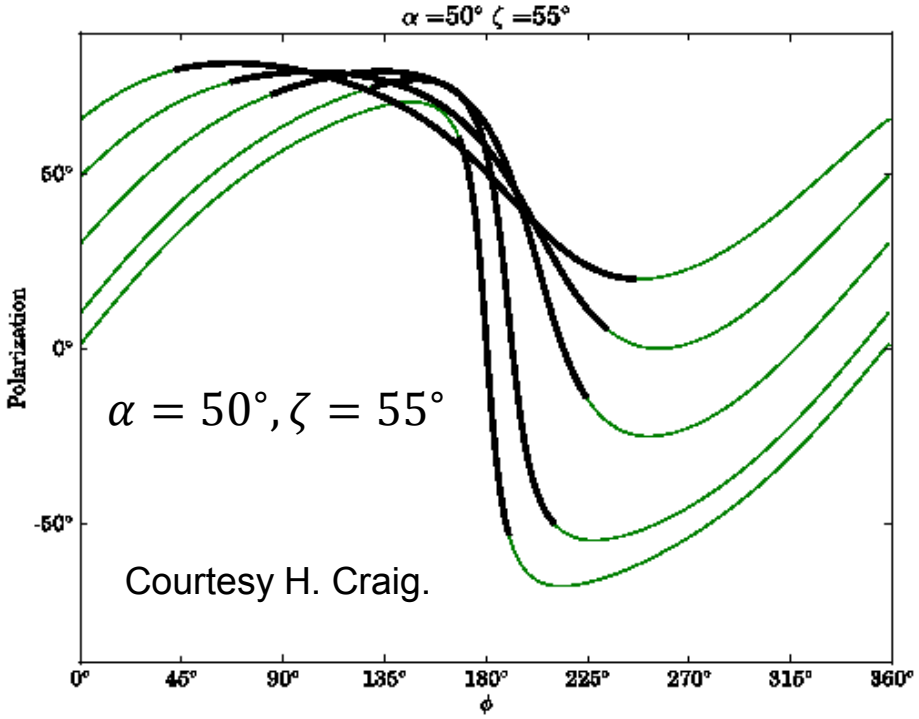


Scattering in the ISM

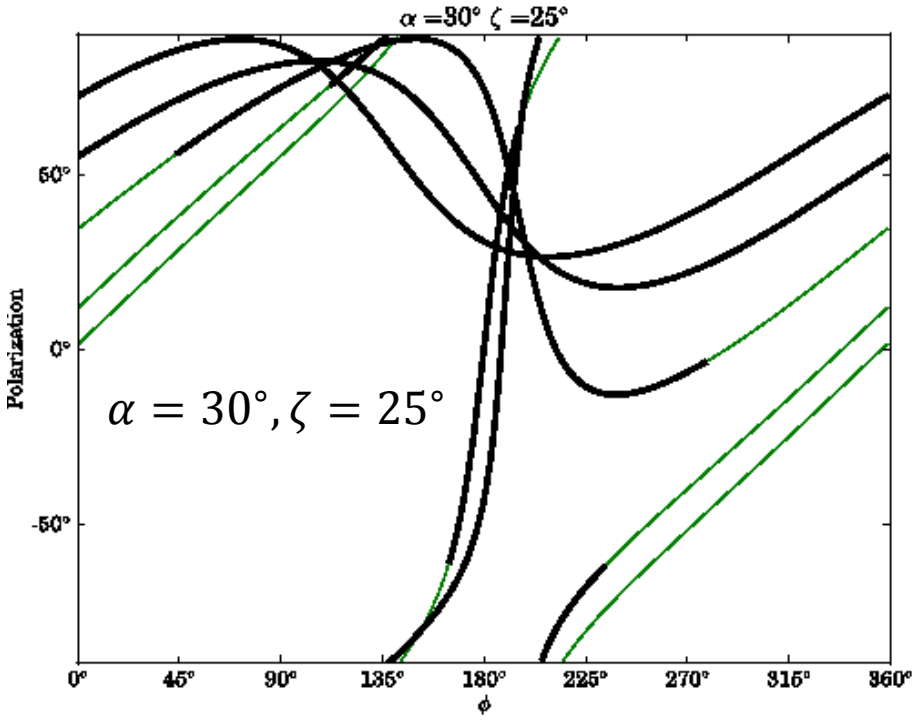


Finite Altitude Effects

- Because RVM is a “projection”, only correct for zero altitude.
  - Emission from modestly higher altitudes is shifted in phase, i.e. the “S” is not centered on the intensity peak.
  - At higher altitudes, the shape of the “S” begins to change.



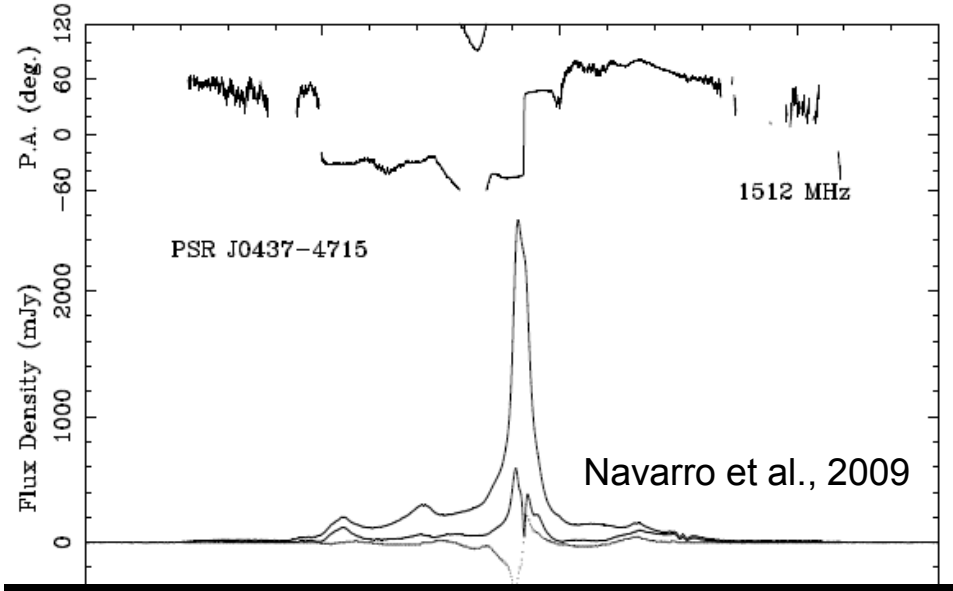
Courtesy H. Craig.

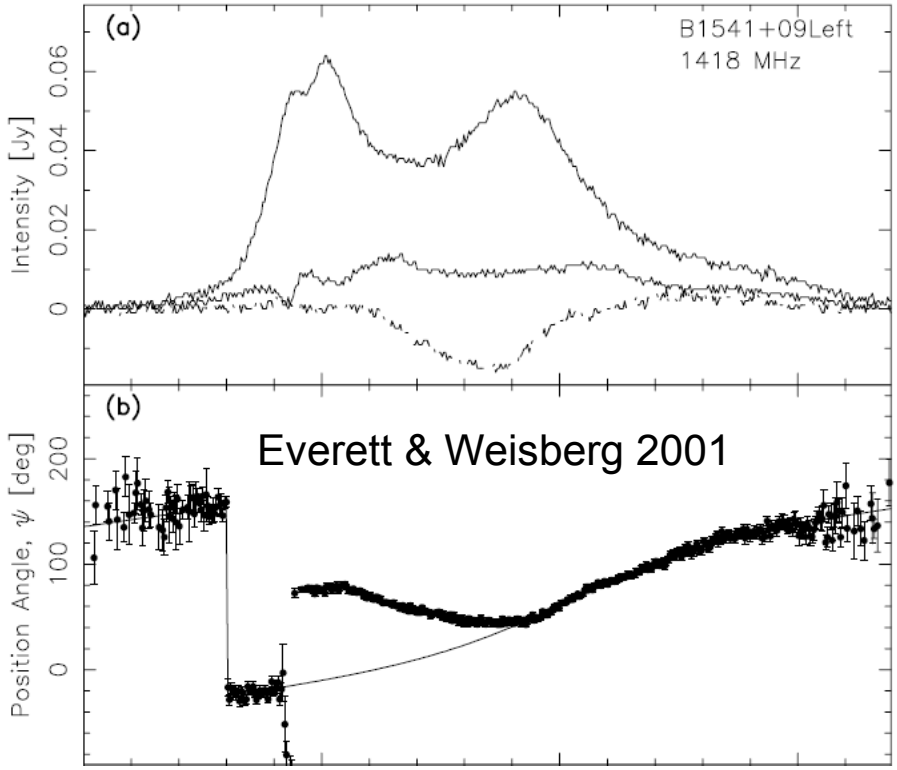


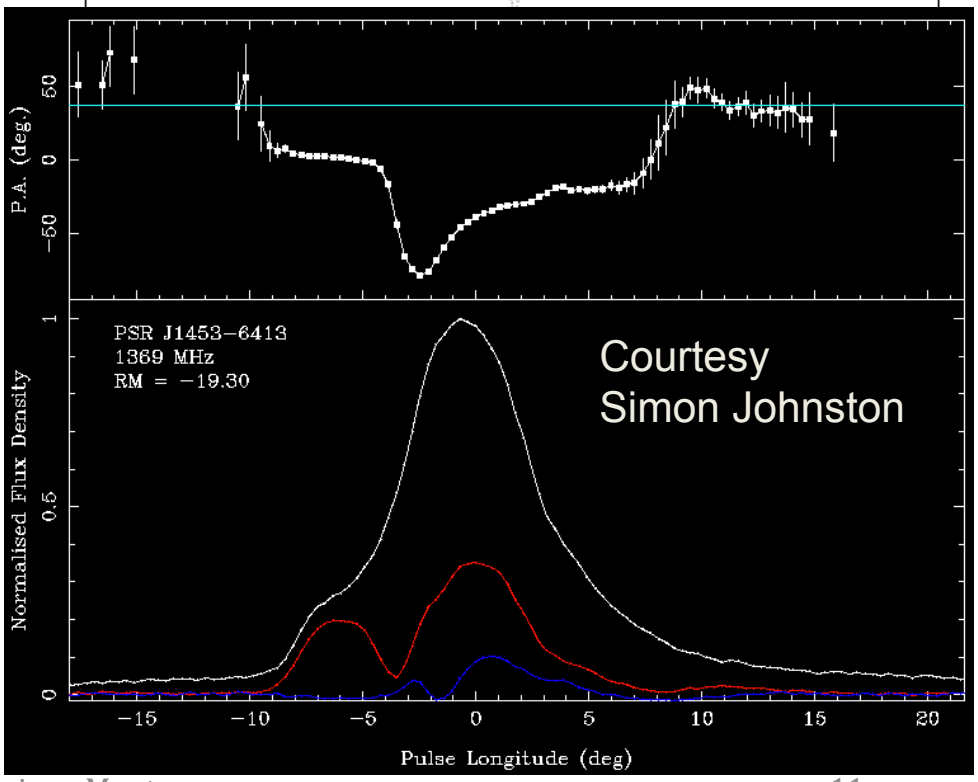
See poster by Helen Craig!

Madness

- Competition between orthogonal models
- Propagation effects
- Multipolar fields
- …

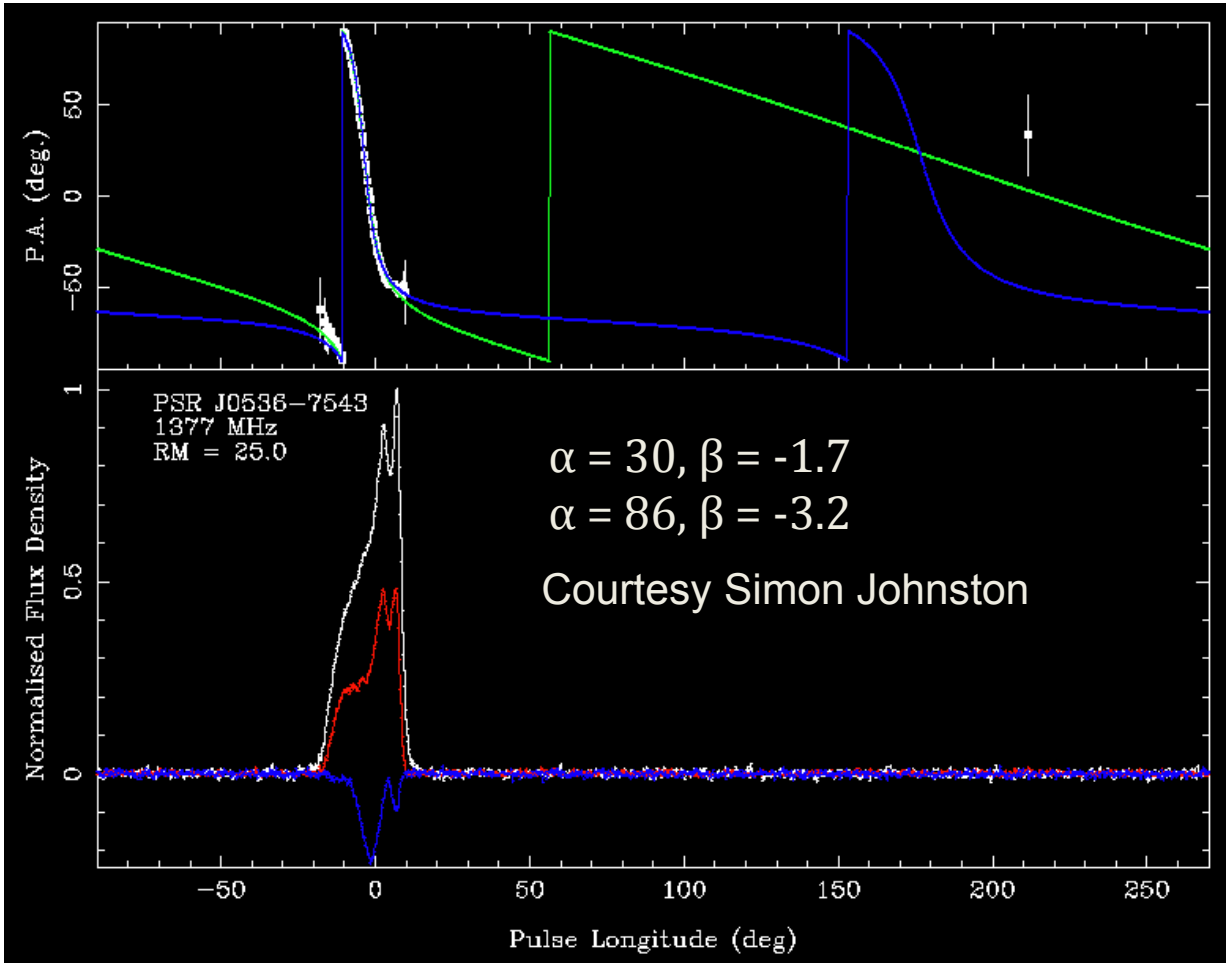




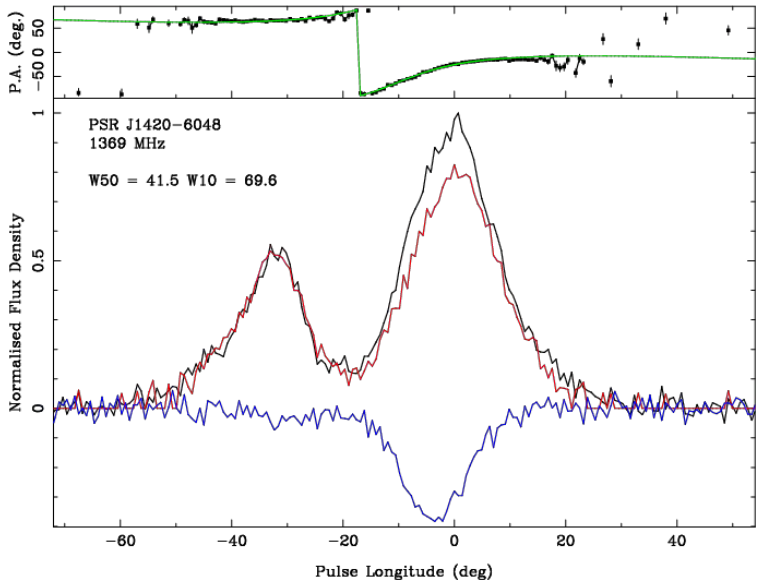


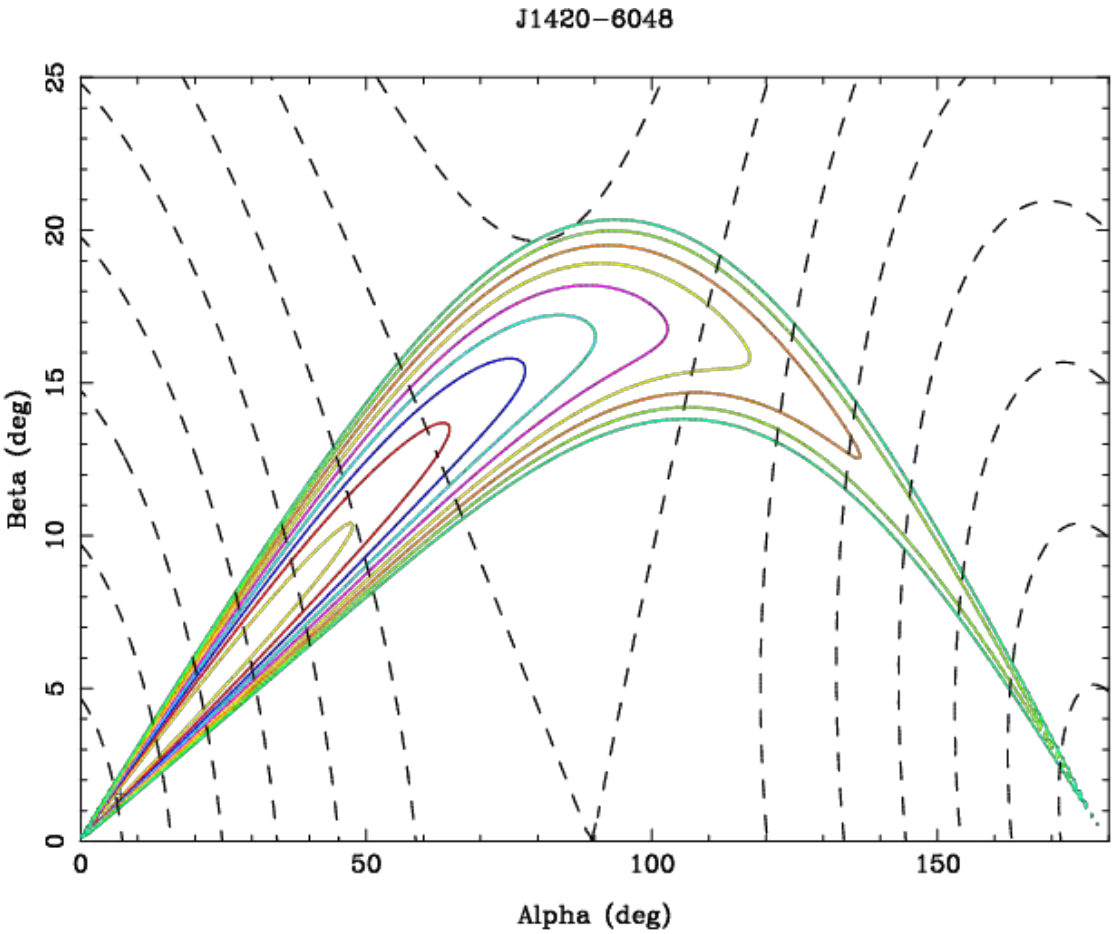
Uniqueness

- Constraints limited by pulsed width.
- With modest duty cycle, $\frac{d\psi}{d\phi_{max}} = \frac{\sin\alpha}{\sin\beta}$.
- With narrow pulses, completely hopeless.



Typical Constraints



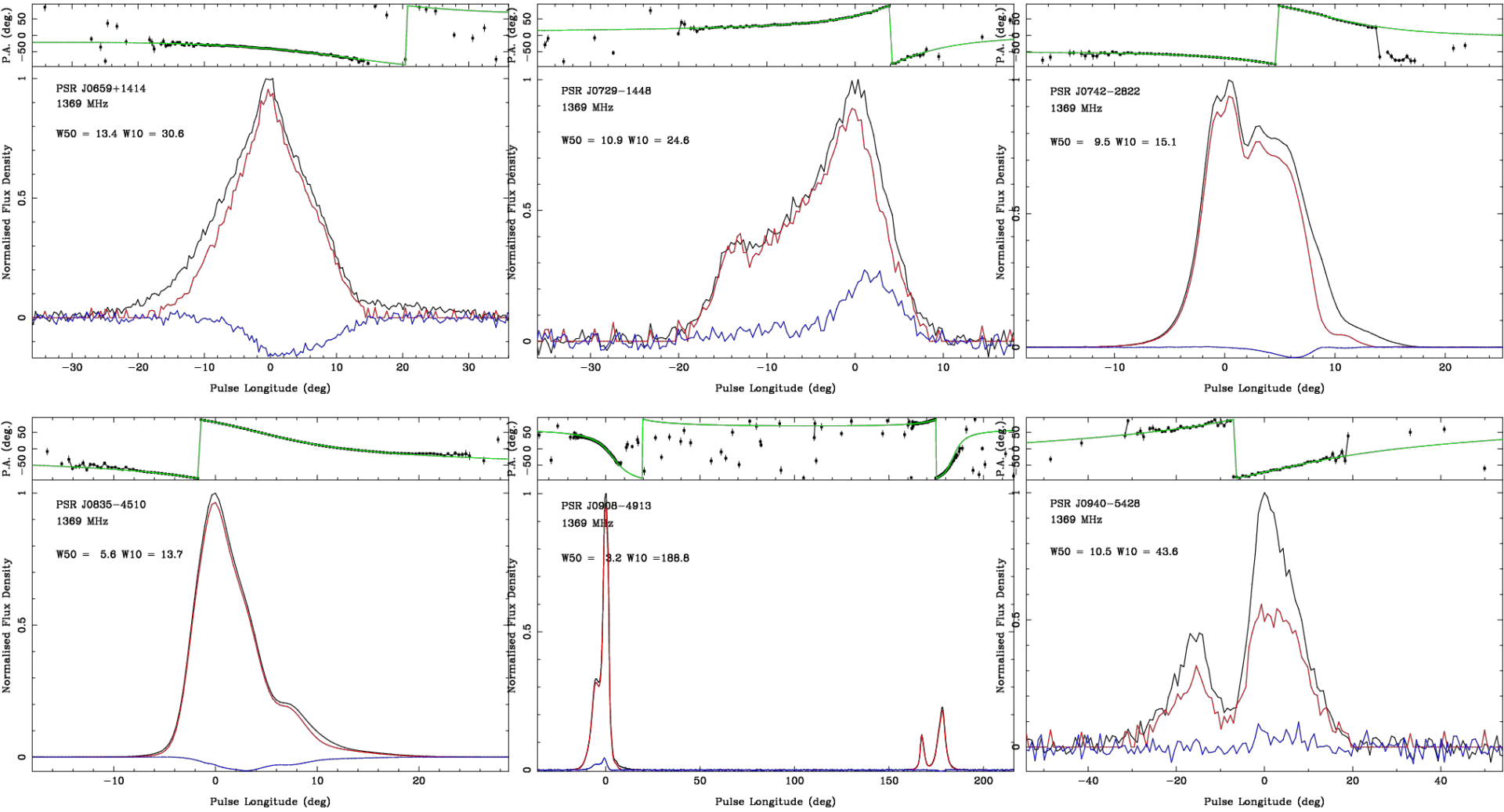


P574: Timing Pulsars with the Parkes Telescope

See talk by
Simon “Ryan Shannon” Johnston
Tuesday, 14:45

- Prior to Fermi, “Pulsar Timing Consortium” formed to secure ephemerides for known, energetic ($\dot{E} > 10^{34}\mathrm{erg\,s^{-1}}$) pulsar (Smith et al. 2008).
- Due to Parkes “Multibeam” survey and declination of Galactic center (-29), most of the pulsars (~160) are in southern sky and timed at Parkes.
- Supported by ongoing project (P574): 24 hours monthly, since late 2007.
- Data taken primarily with Multibeam receiver (at 20cm) with ~300 MHz of bandwidth. Occasional observations with 10/50 cm receiver (1 GHz of bandwidth at 3 GHz).
- If **properly calibrated and coadded**, the timing data provide very long integrations with which to produce high S/N full Stokes light curves.

Some Results

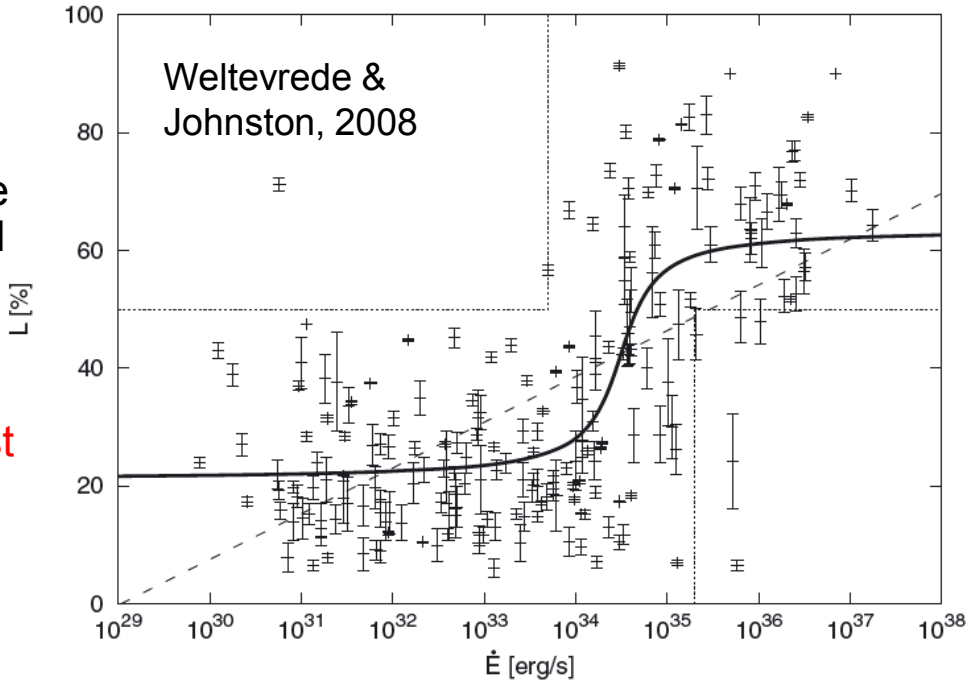


6 of 27 Gamma-ray Loud Pulsars

Things to Note

- The RVM works (perhaps) surprisingly well for this sample.

  - Of the 27 gamma-loud pulsars, only one has even an orthogonal mode!
    - Only 3 too scattered to be of use.
  - Perhaps not surprising after all: emission from young pulsars seems to come from higher altitudes, 0.05-0.15 R_{LC}. Multipole components should be negligible, as well as (potentially) propagation effects.
  - High linear polarization implies a limited range of altitudes involved in emission.
  - On the other hand, the finite altitude must be accounted for in fits!
  - Could gamma-brightness also be a selection effect? Careful study of polarization and upper limits for rest of P574 sample.



- For most pulsars, α and ζ are not independently constrained, but the volume of the allowed parameter space is tiny – very constraining for gamma-ray emission models.

Summary and the Beautiful Future

- We now have high S/N polarimetric light curves for >150 young, energetic pulsars.
  - This is the definitive sample, and is interesting of itself.

- The high linear polarization (dominance of single mode) and modestly high radio emission altitude of young, energetic pulsars are a perfect storm for getting RVM constraints.
  - Must be very careful with systematics and finite altitude effects.

- Of the young γ- and radio-loud pulsars, we have good polarimetry for ~30/~40 (27 Parkes + ~3 in the literature): good motivation to finish the sample!

- For some pulsars, the resulting constraints on gamma-ray emission models are challenging:
  - Explore more general emitting volumes, magnetic fields, effect of currents.

Constraints on Gamma-ray Models