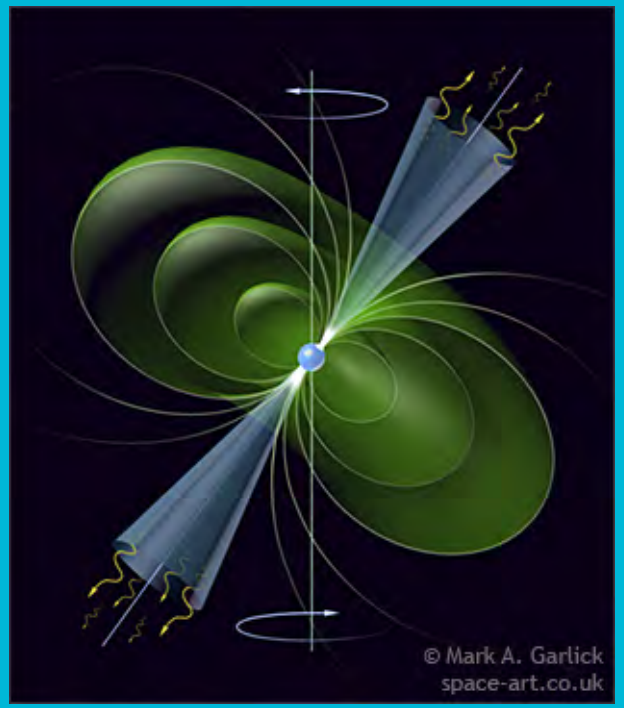


Polarization Observations of Radio Pulsars

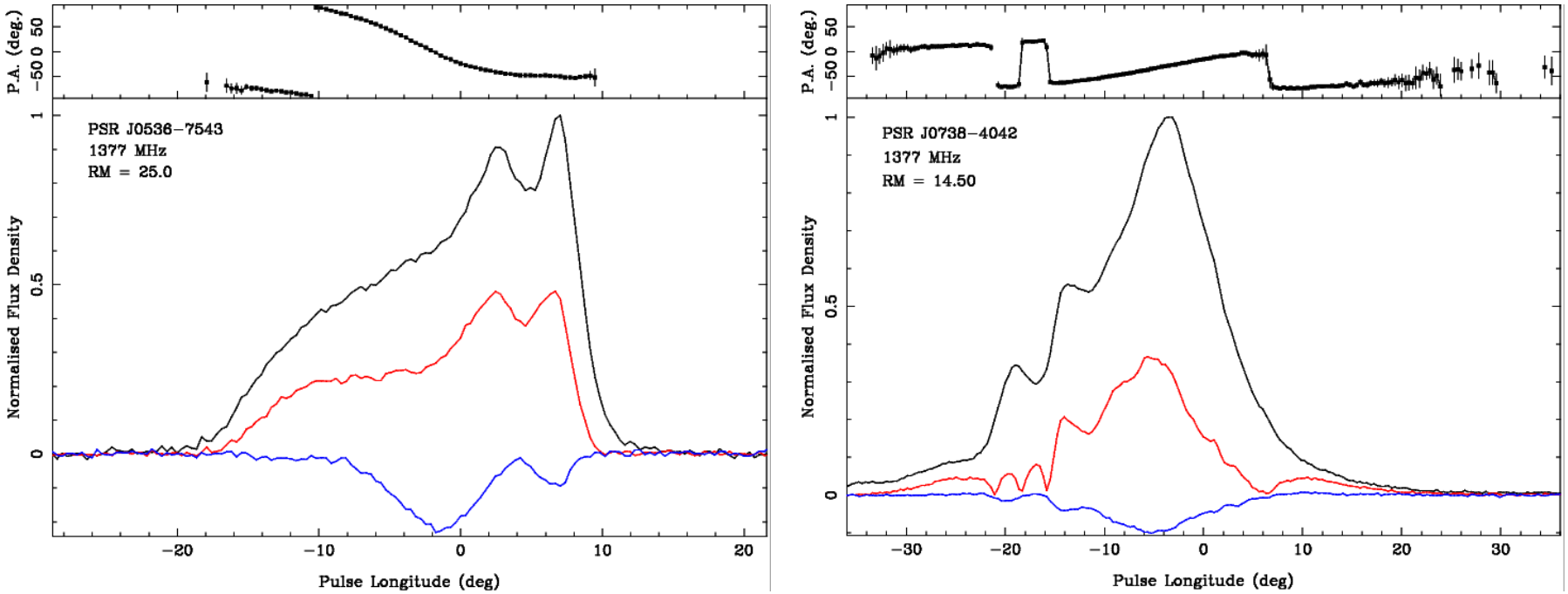
Simon Johnston (for Ryan Shannon) & Matthew Kerr

Head of Astrophysics
CASS, Sydney, Australia

The Parkes Fermi timing programme

- Started in February 2007 [new digital equipment]
- Patrick Weltevrede & Ryan Shannon postdocs
- 165 pulsars, vast majority with Edot > 10^34 erg/s
- Observes every month for 20 hours at 1400 MHz
  - And every 6 months at 700 and 3100 MHz
- Timing solutions sent to Fermi collaboration
- Wealth of science from radio data alone
  - Full polarization profiles
  - Dispersion measure versus time
  - Profile variability versus time
  - Timing noise and glitches
- Independent MSP timing programme (GW search)

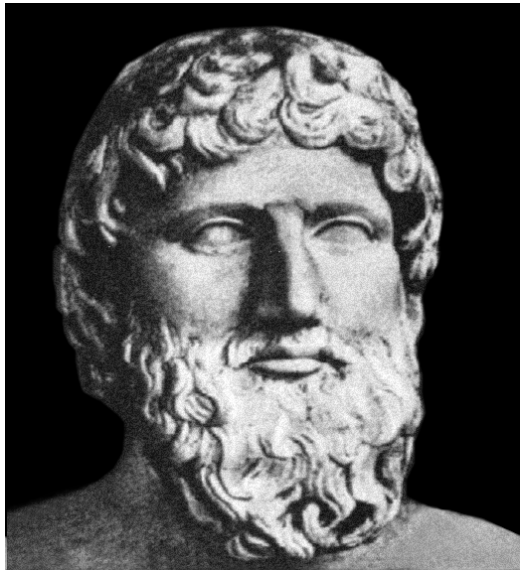
Integrated Pulsar Profiles in Full Stokes



Science: Geometry, emission heights, beam structure, emission physics, beam models, birth physics. Crucial for high precision timing.

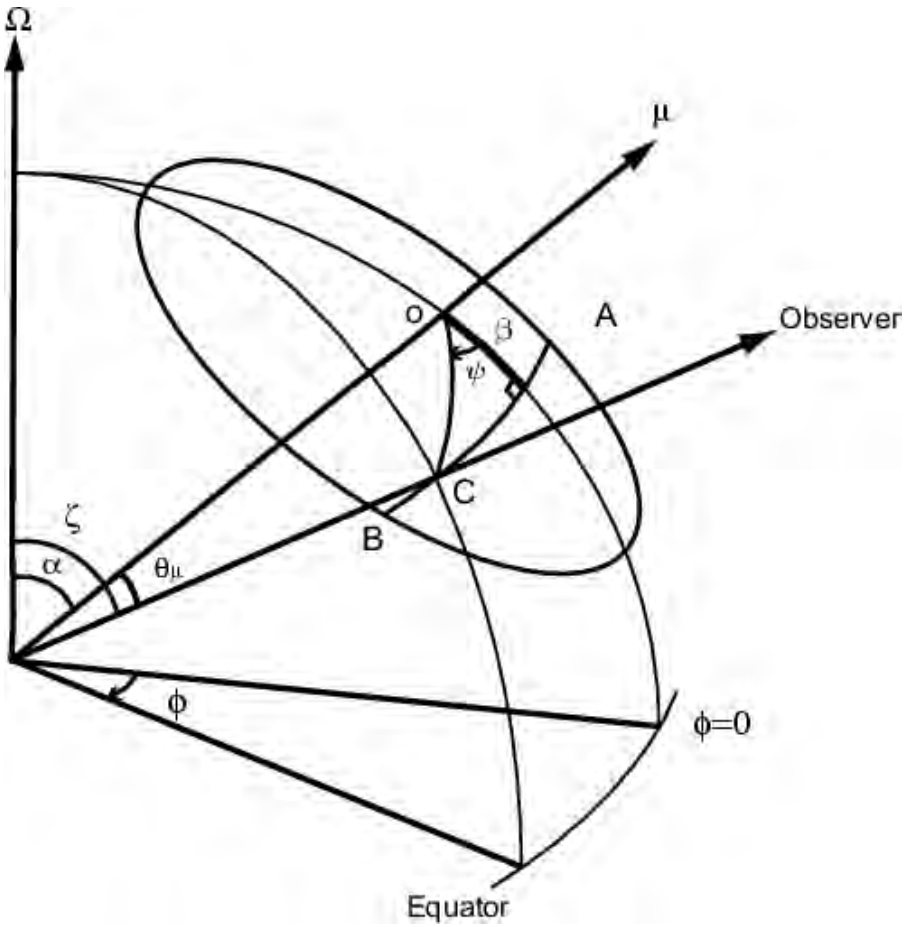
Mapping the magnetosphere

- Aim: To use the radio and high energy observations to make a 3D map of the emission zones
  - Need geometry
  - Need a method of computing altitudes
  - Need a large sample of pulsars
- but
  - Geometry often uncertain
  - Conflicting results from altitude derivations
  - Frequency dependent effects
  - Radio emission mechanism very complex (coherent mechanism)



Let no person ignorant of geometry enter here
(Plato 400 BC)

Pulsar geometry and the rotating vector model

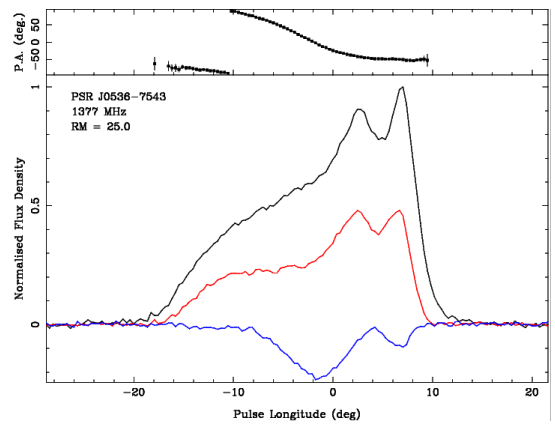


Important angles are:

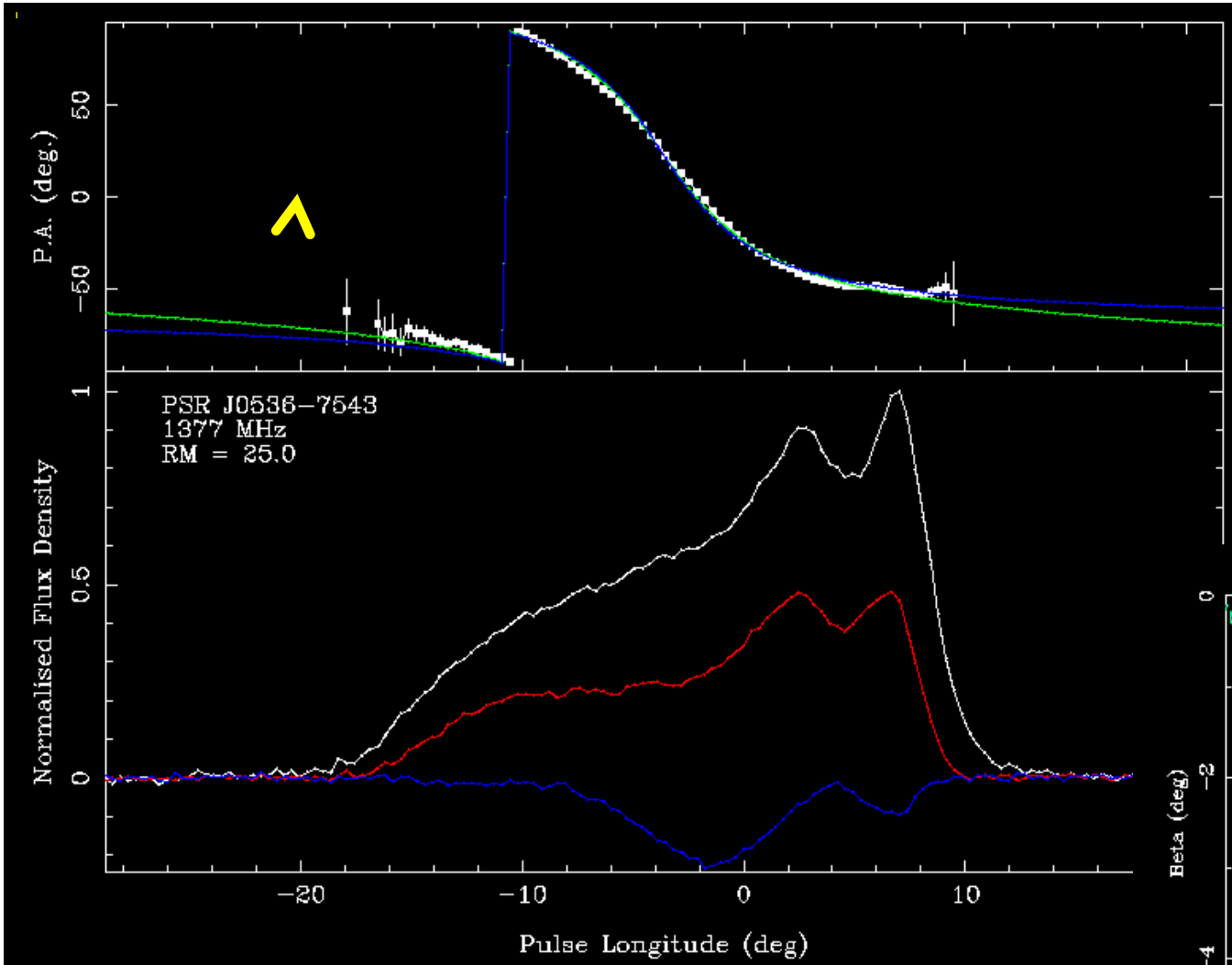
α – angle between the rotation and magnetic axis

β – closest approach of line of sight to magnetic axis

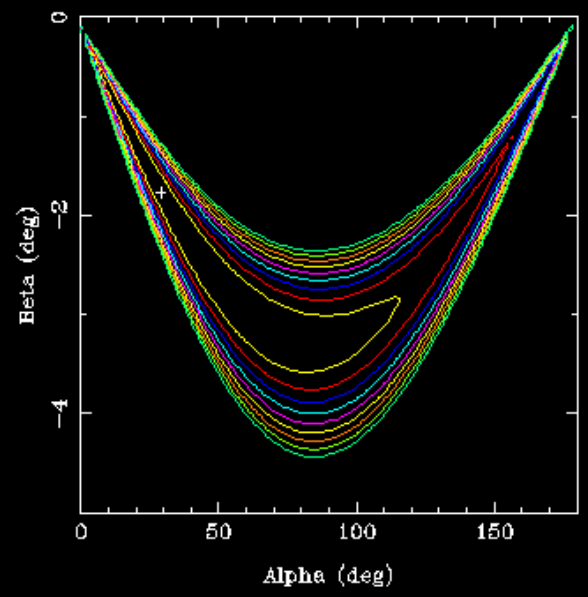
ρ – cone opening angle



The **RVM** uses the PA swing to derive the geometry

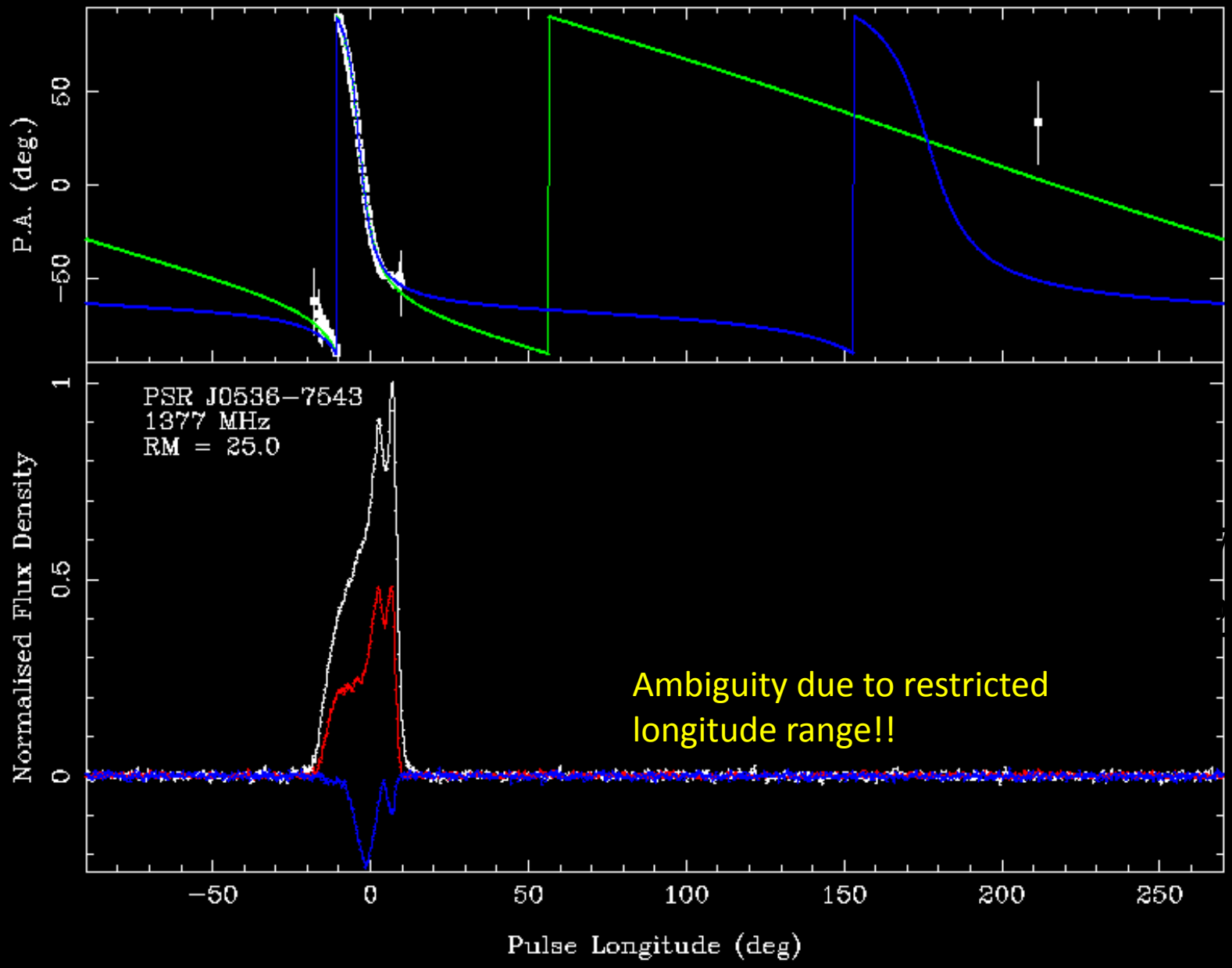


RVM fit in alpha-beta space

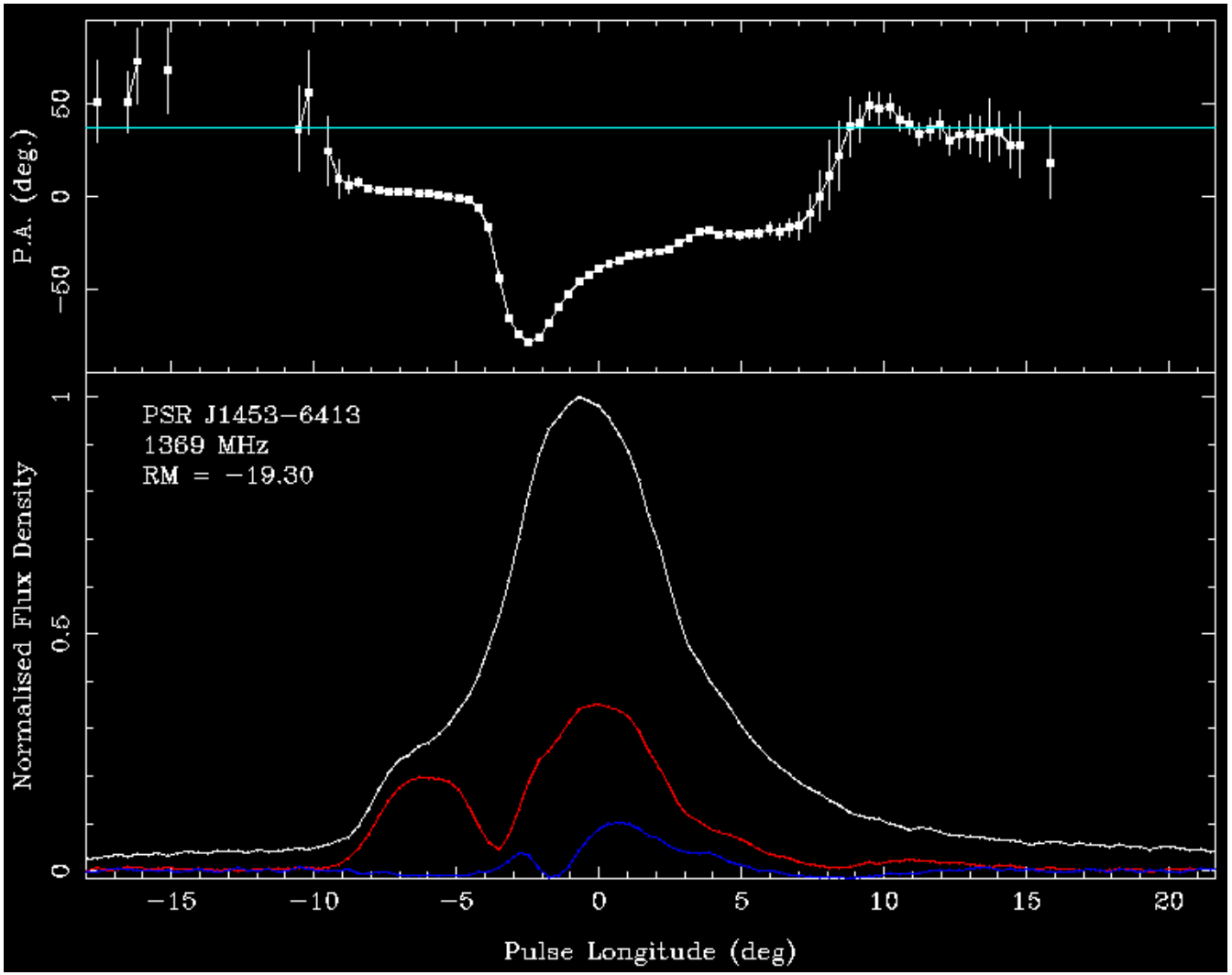


$\alpha = 30, \beta = -1.7$

$\alpha = 86, \beta = -3.2$



Ambiguity due to restricted longitude range!!

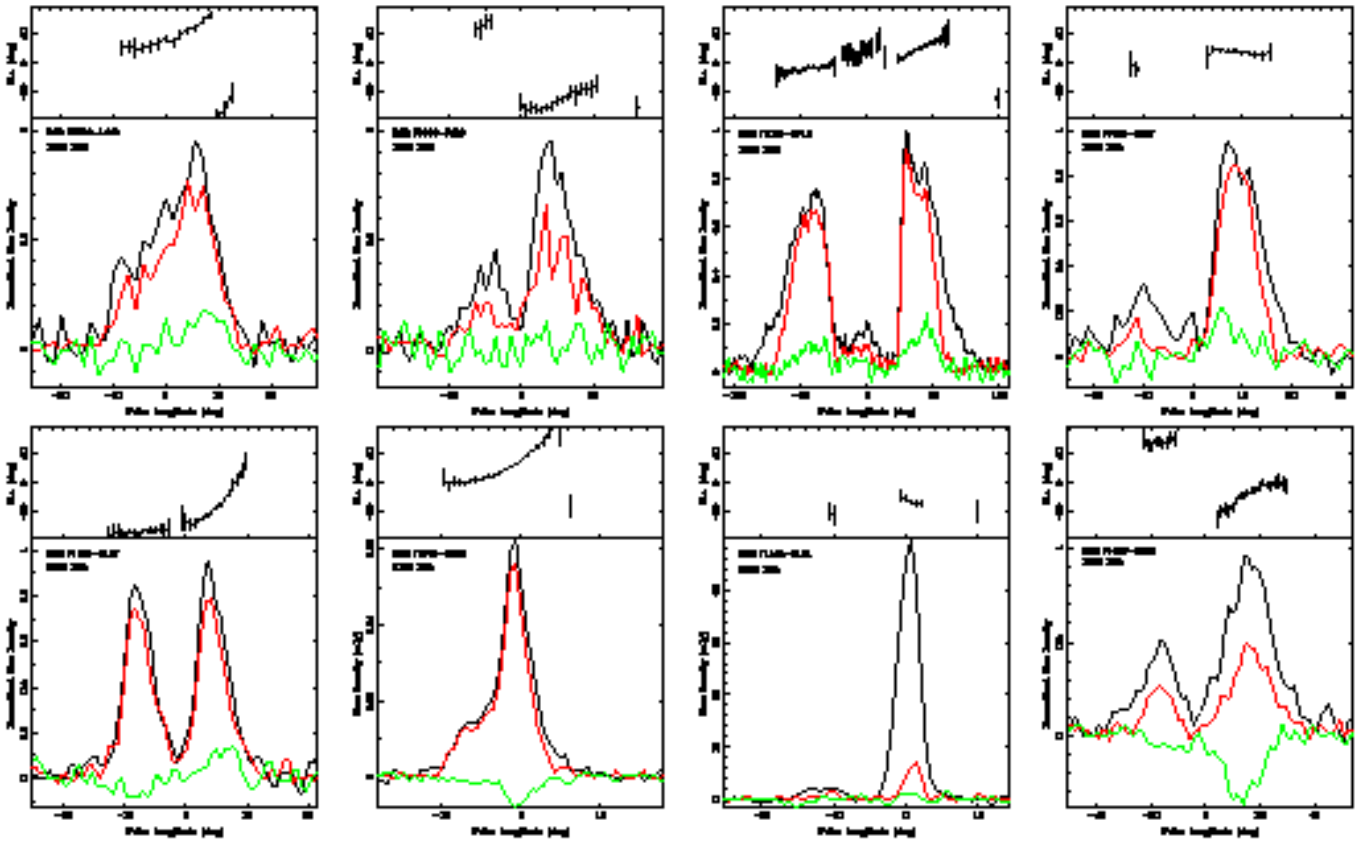


RVM is a useful tool and geometry is crucial for testing models of radio emission. Now with 100+ γ-ray pulsars knowledge of the geometry is even more crucial! In practice, hard to constrain.

This PA swing is "forbidden" by the RVM, and is likely the result of magnetospheric and/or propagation effects (e.g. Karastergiou 2009).

High Edot (young) pulsars

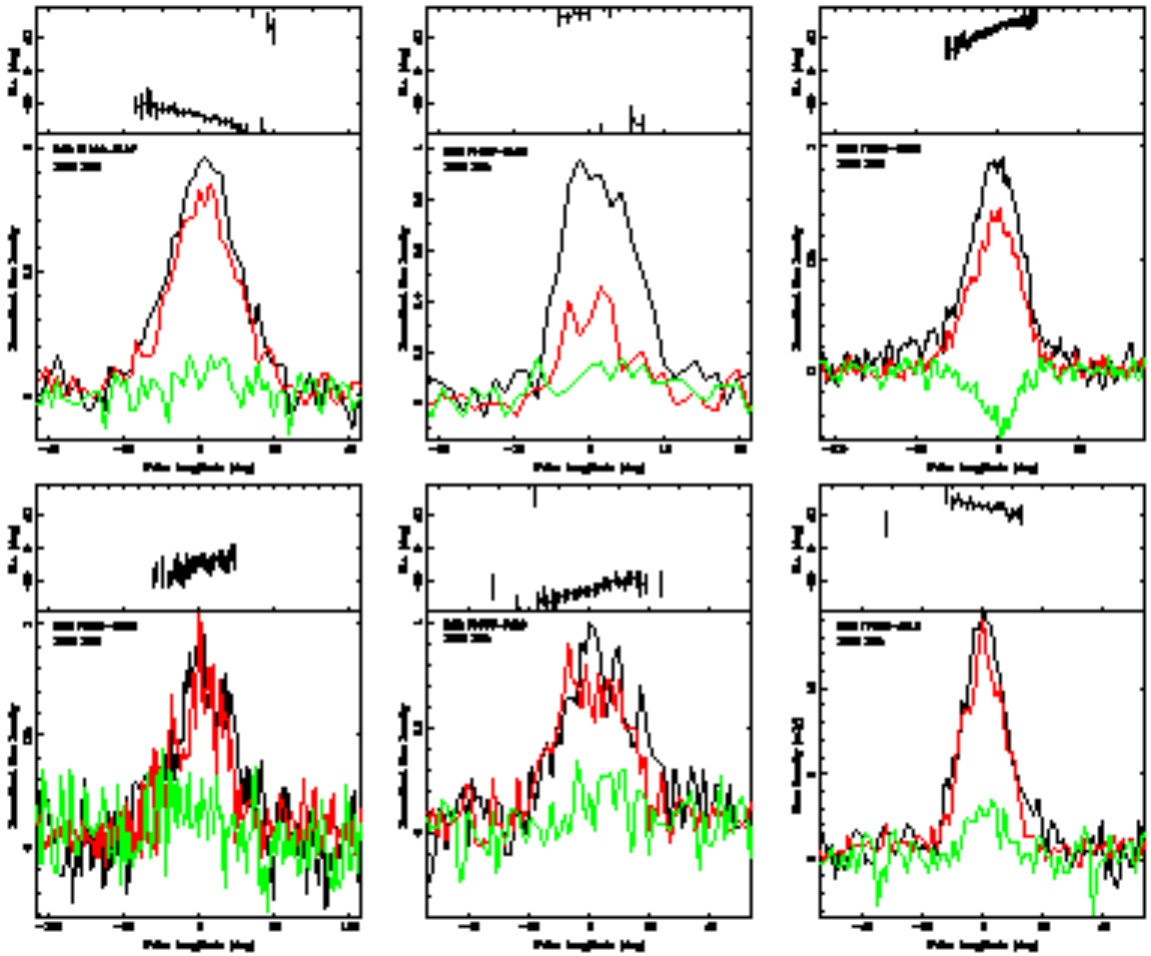
Johnston & Weisberg 2006



8 pulsars: Common features

7/8 highly polarized – all doubles – 2nd component always brighter – reasonably symmetric - PA swing flat then steep – circular polarization generally only under 2nd component – widths ~40 degrees

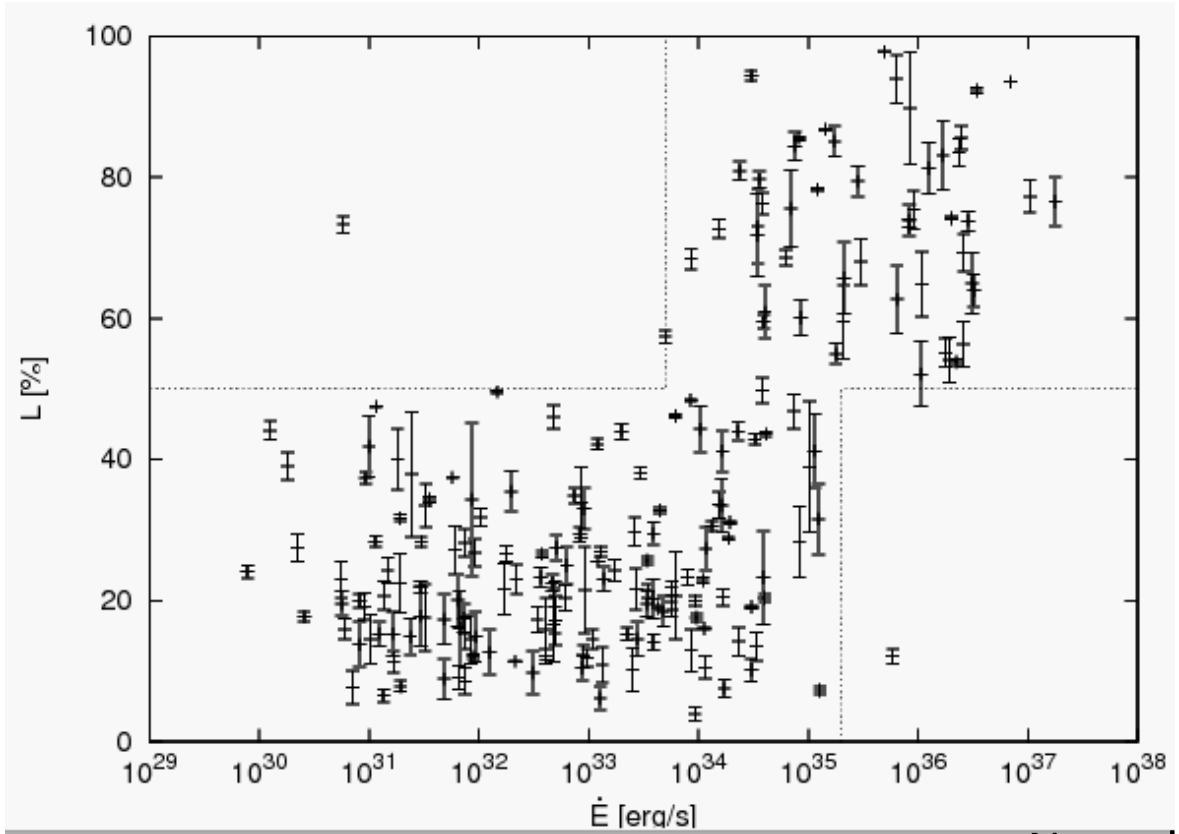
Johnston & Weisberg 2006



6 pulsars: Common features

all highly polarized - all single – circular polarization – shallow swing of position angle – ~40 to ~100 degrees wide – flat spectral index

Linear polarization fraction versus Edot

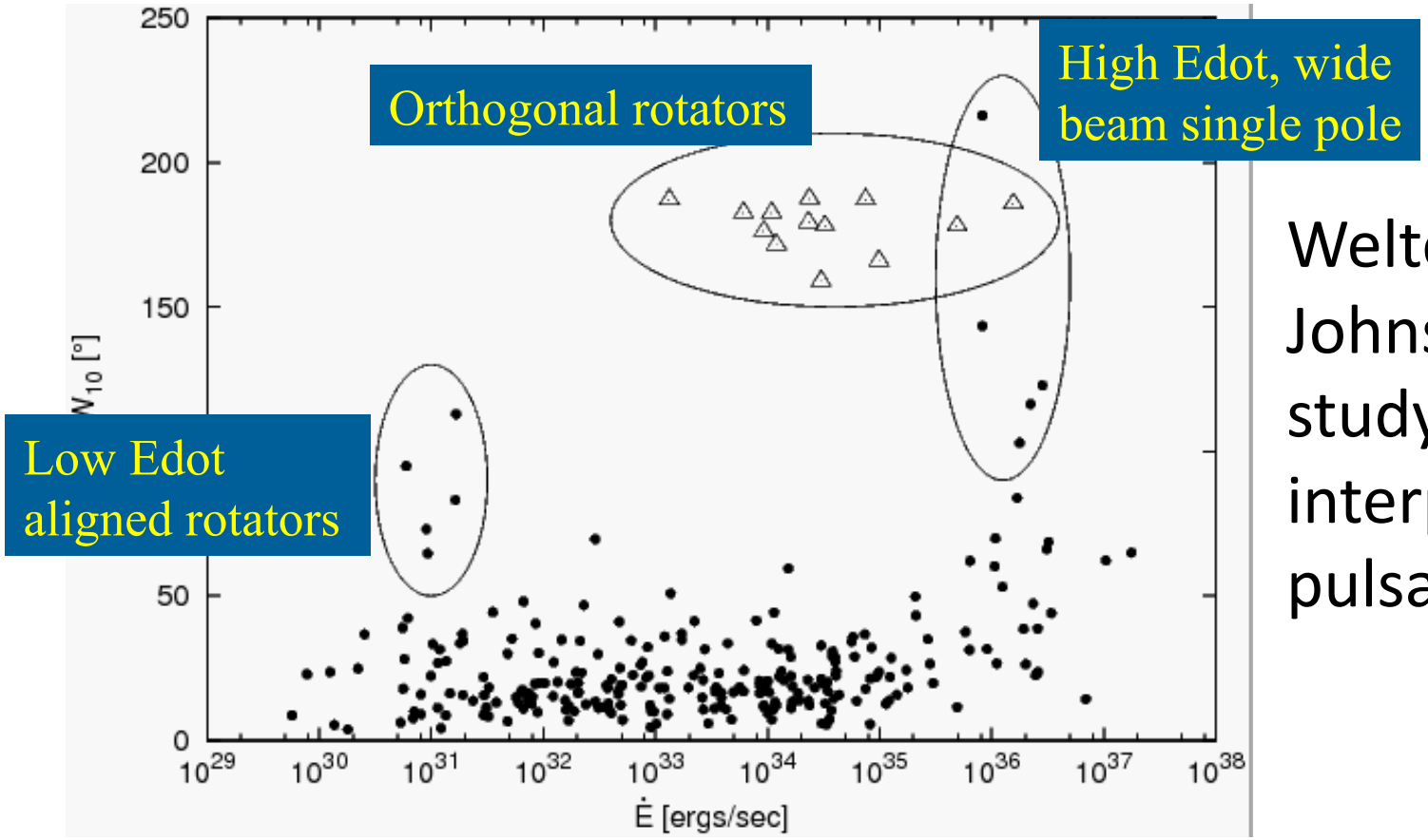


Weltevrede & Johnston (2008). Edot is a crucial parameter!

Abrupt transition between from low to high polarization states around Edot of $10^{34.5}$

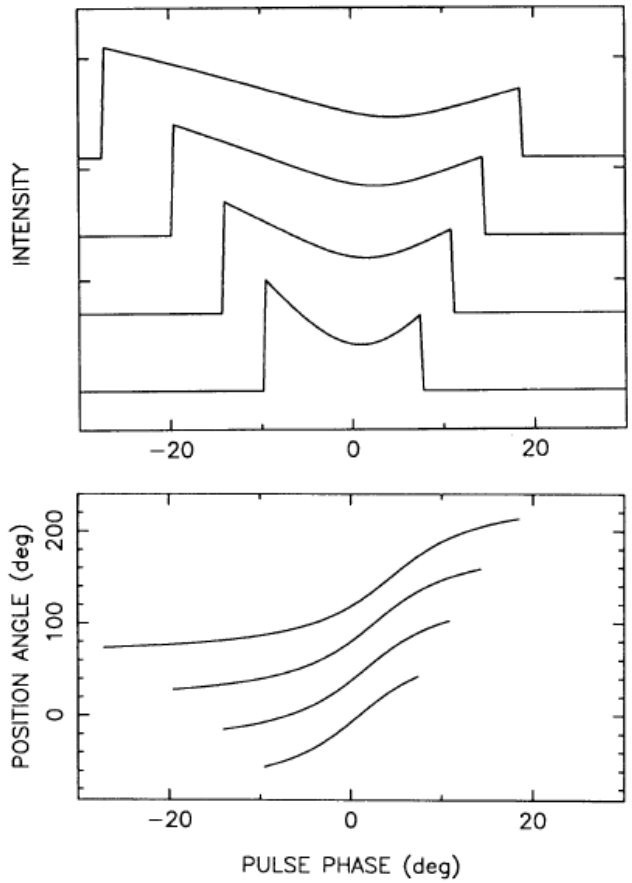
No orthogonal mode jumps. One mode dominates but this is split 50:50 between parallel and orthogonal modes!!

Pulse width versus Edot



Weltevrede & Johnston (2008) study of interpulse pulsars.

Random orientation of B-Ω axis at birth, becoming aligned over time.



Blaskiewicz, Cordes Wasserman (1991). Relativistic modification to the Rotating Vector Model.
See also Dyks (2008).

Location of the inflexion point relative to the profile midpoint allows a determination of the emission height.

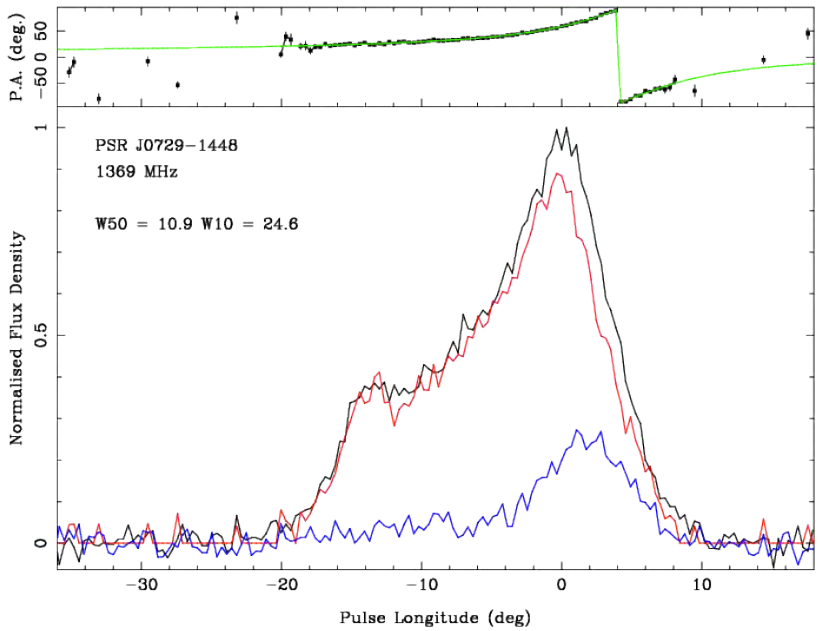
$$h_{\mathrm{P.A.}} = \frac{P\,c}{8\pi}\Delta\phi = \frac{1}{4}R_{\mathrm{LC}}\Delta\phi,$$

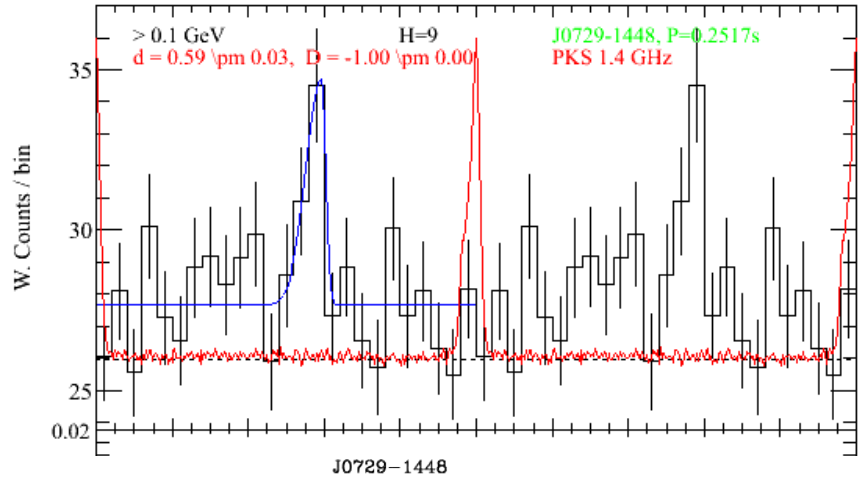
In turn, emission height yields rho and from rho and W get further angle constraints

$$\rho = \sqrt{\frac{9\pi h_{\mathrm{em}}}{2Pc}},$$

$$\cos\rho = \cos\alpha\cos\zeta + \sin\alpha\sin\zeta\cos(W/2),$$

Putting it together: PSR 0729-1448



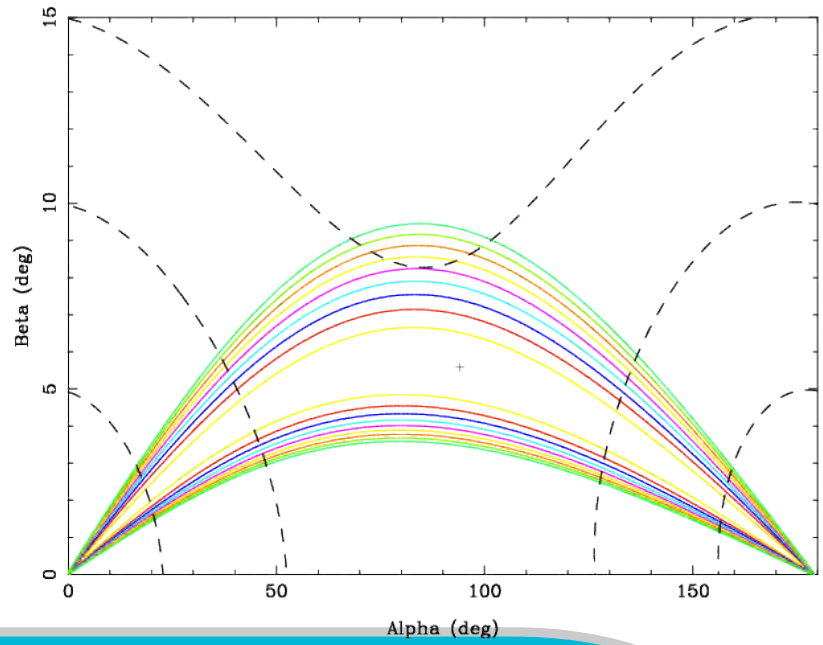


H = 510 km

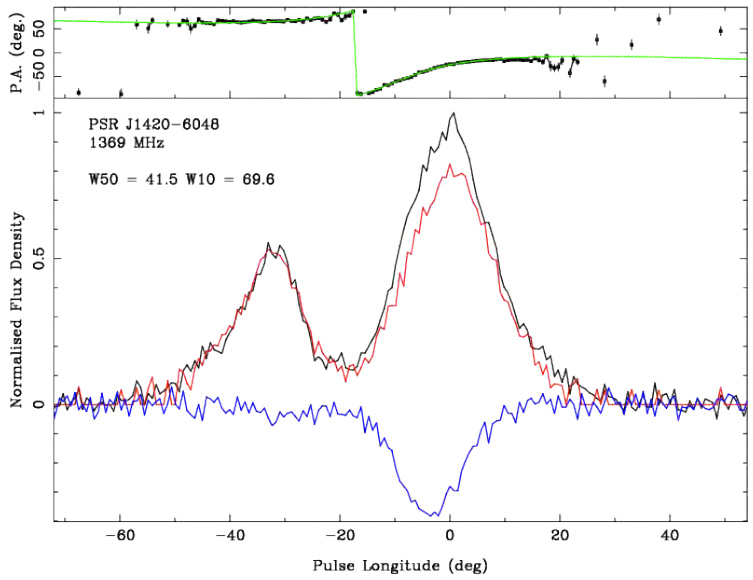
Rho = 17 deg

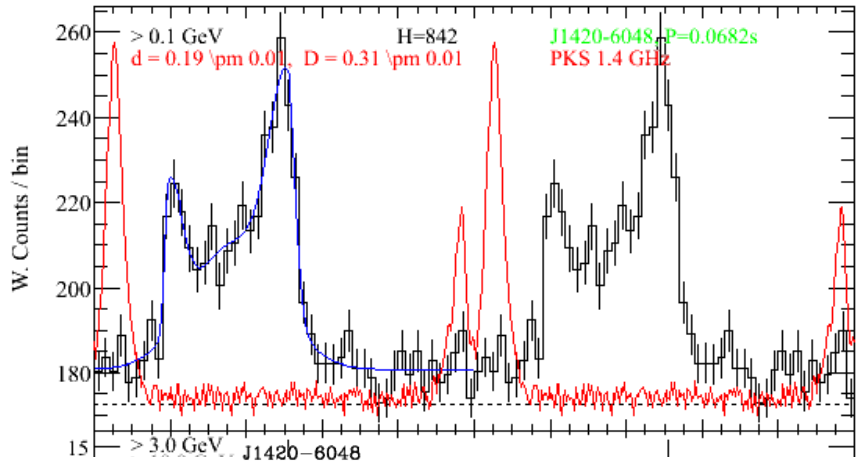
$$\cos\rho = \cos\alpha\cos\zeta + \sin\alpha\sin\zeta\cos(W/2),$$

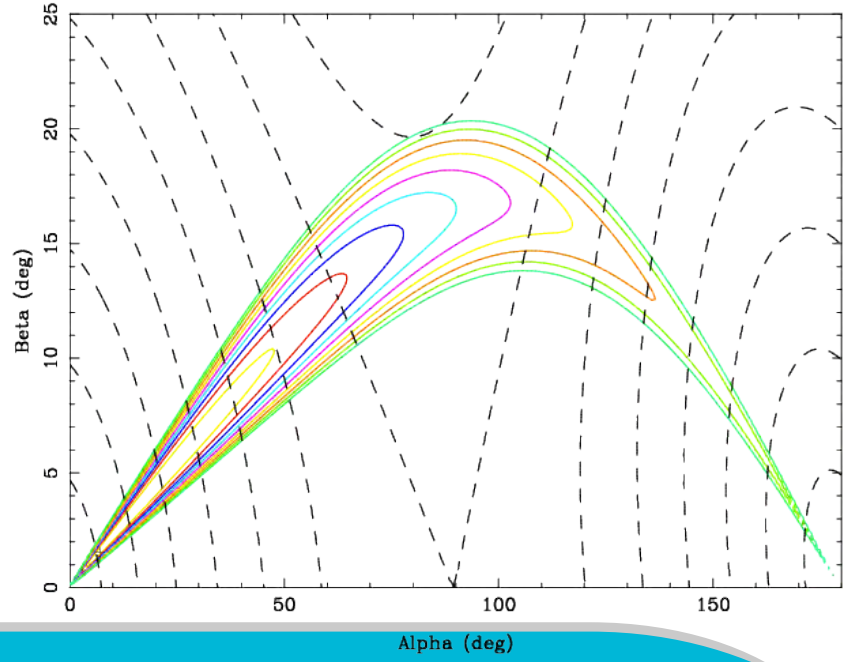
Close to orthogonal rotator



Putting it together: PSR 1420-6048







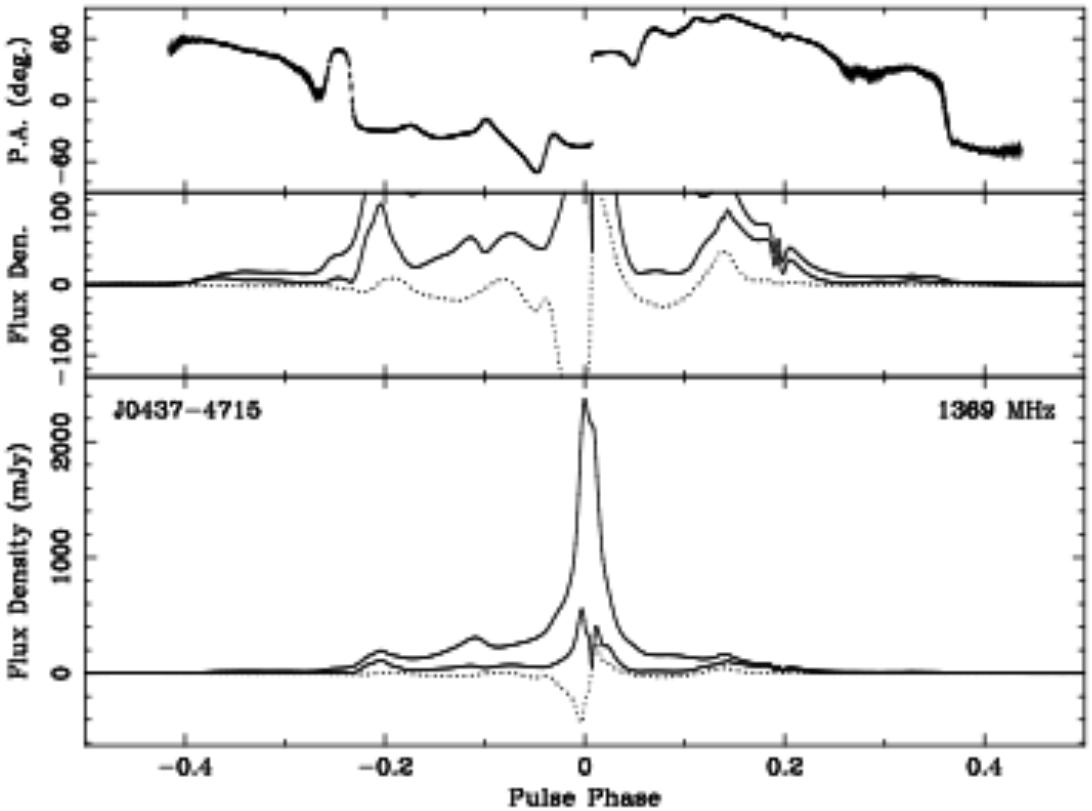
H = 50 km

Rho = 10 deg

Alpha + beta

both small !!

MSP polarization (Yan et al. 2011)



J0437-4715 in polarization

MSPs have very compressed emission zones yet produce radio and g-ray emission. Profiles are often very wide and PA swings highly complex. Aligned rotators? High heights? Caustic emission?

Summary

- Geometry is critical to understanding the emission we see from pulsars
- Radio polarization gives us a handle on geometry via the rotating vector model plus assumptions which appears to work well for young, g-ray pulsars
- This puts serious constraints on g-ray emission locations, gap width etc
- Work in progress with Matthew Kerr to test g-ray models for young pulsars
- See also Helen Craig's poster

Thank you

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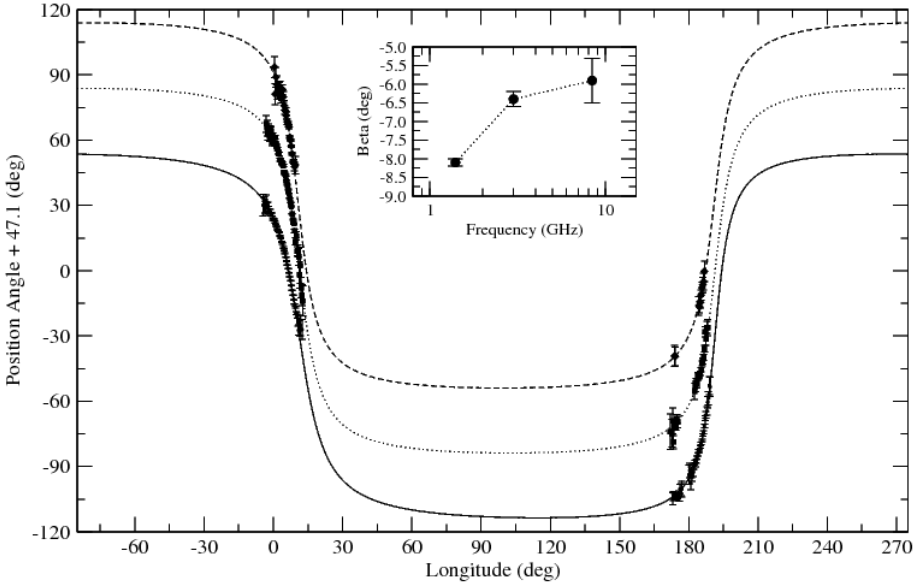
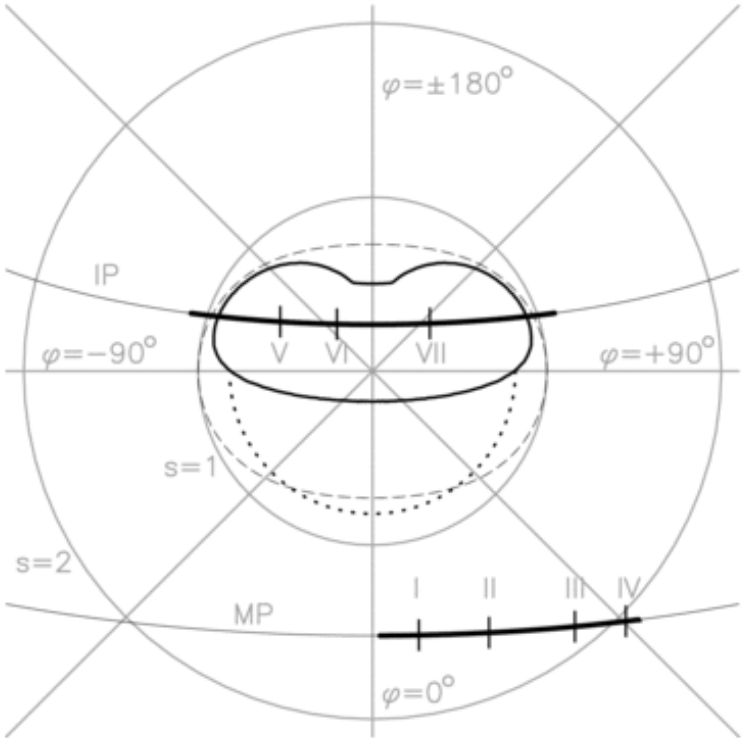
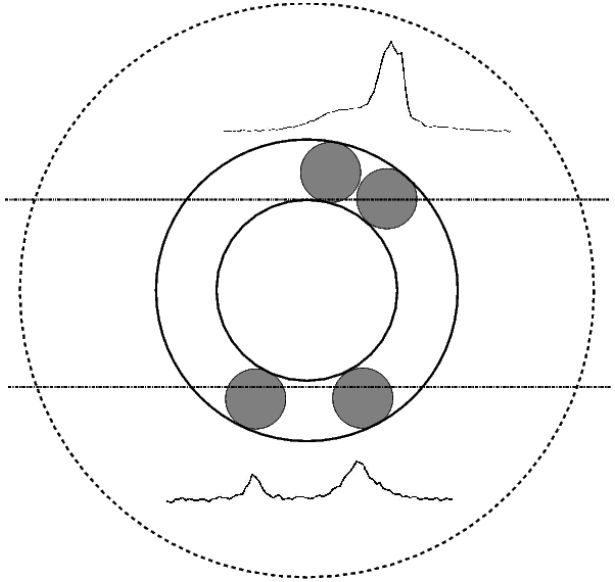
Orthogonal Rotators





Weltevrede & Wright 2009



Kramer & Johnston 2008

Beam mapping of B0906-49 (left) and B1055-52 (above) following RVM fits. Emission heights similar above both poles. Evidence for emission from the closed field lines (see also Keith et al. 2010).