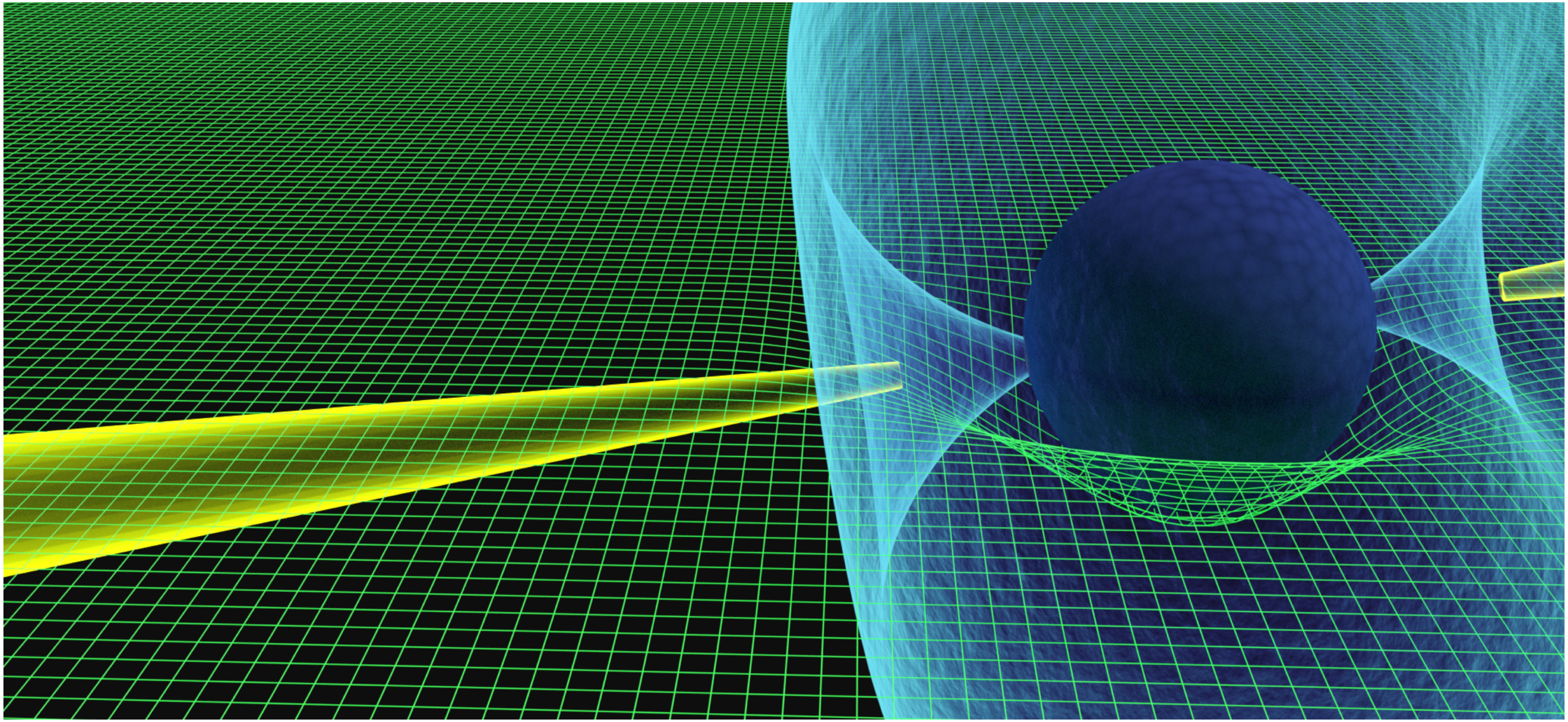
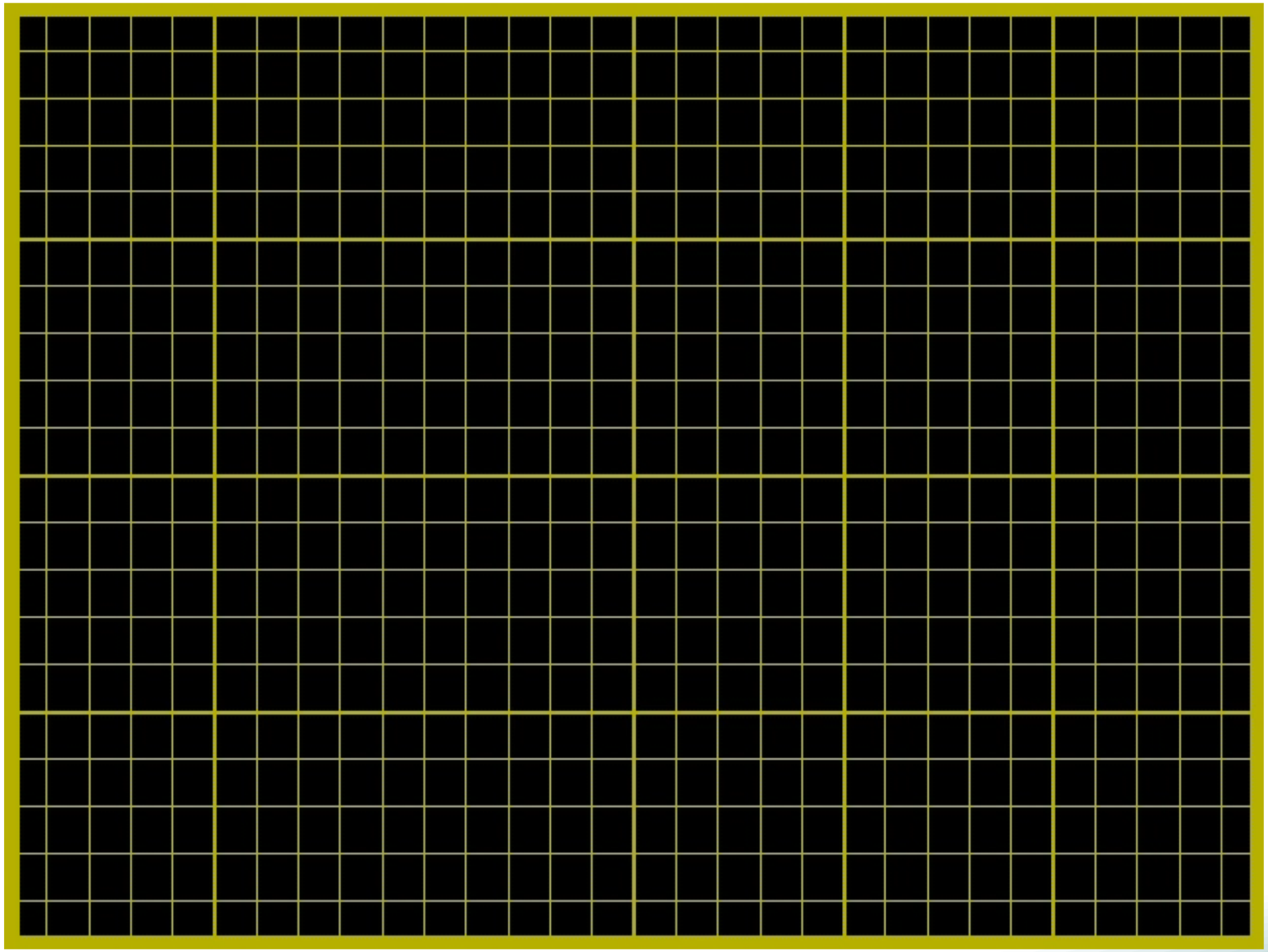
Pulsar Emission Mechanism



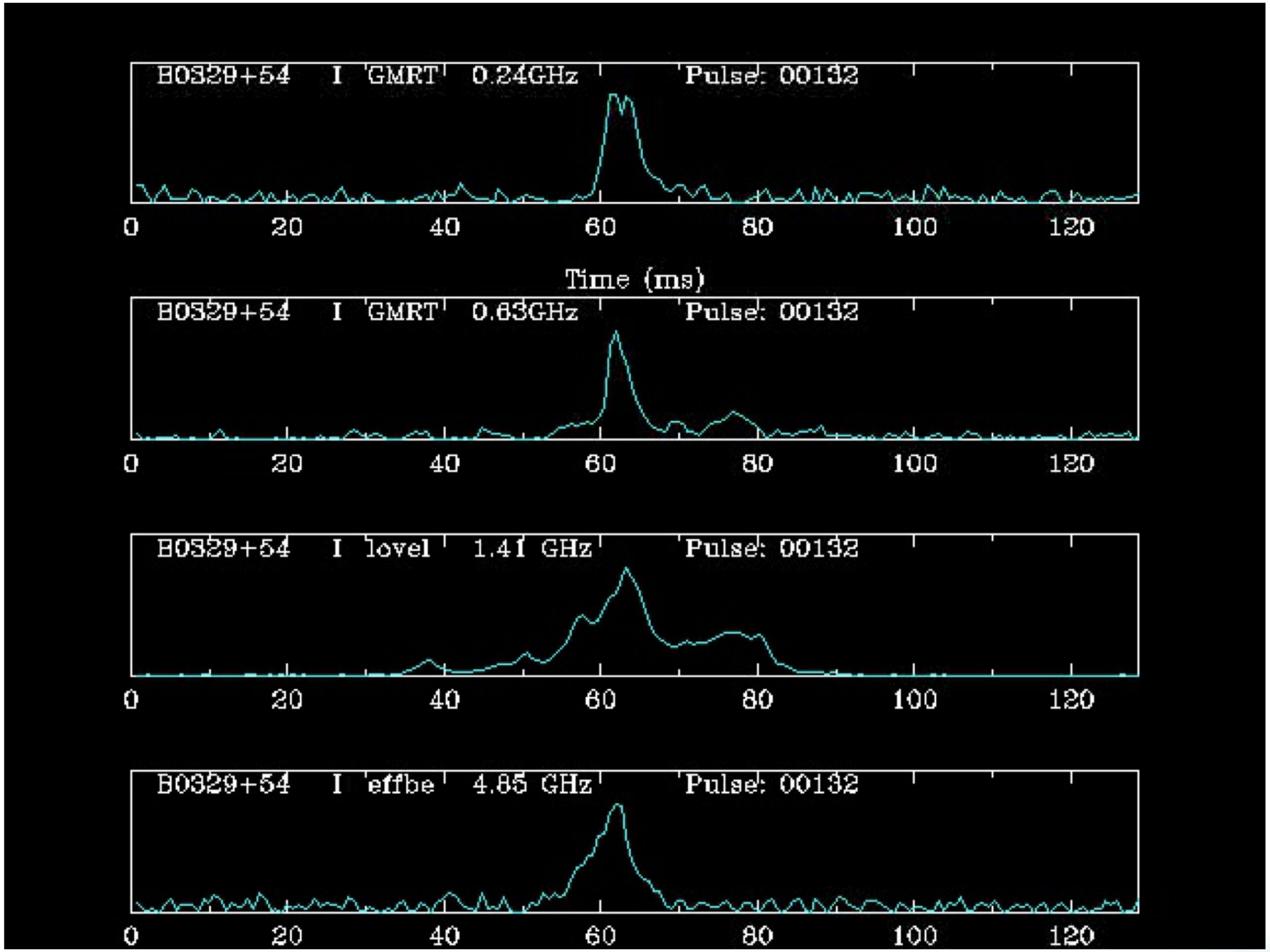
Michael Kramer

Max-Planck-Institut für Radioastronomie

A pulsed signal from space



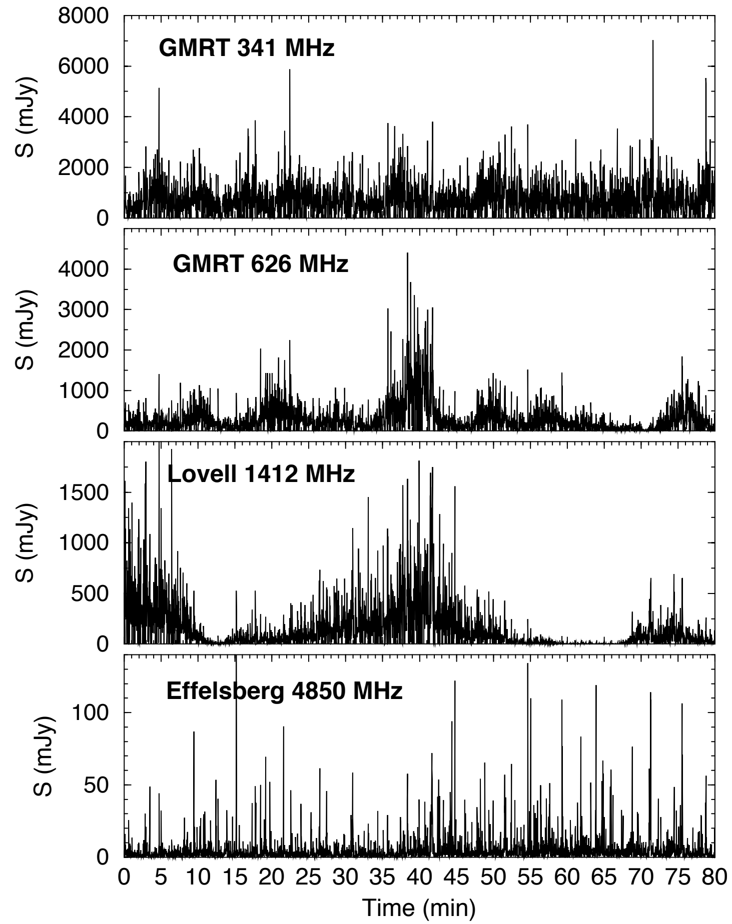
...and the emission is broadband



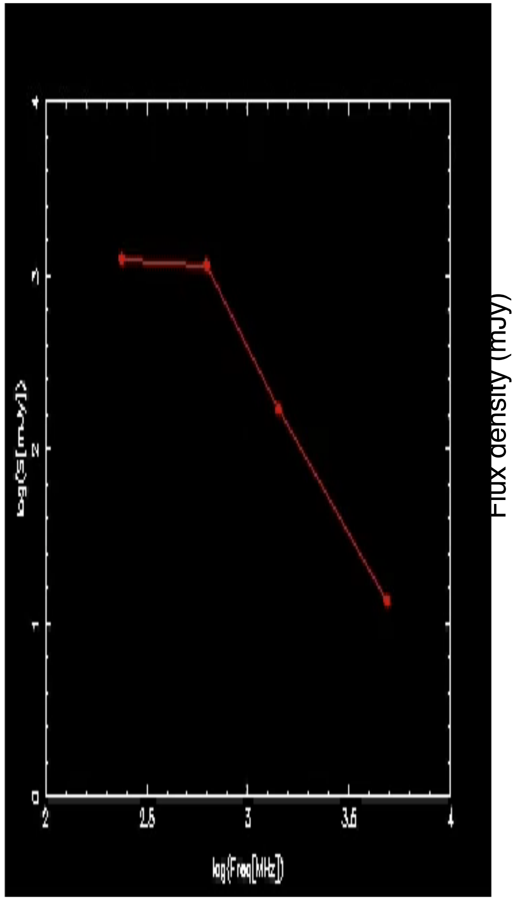
with exceptions...

Flux density across frequencies

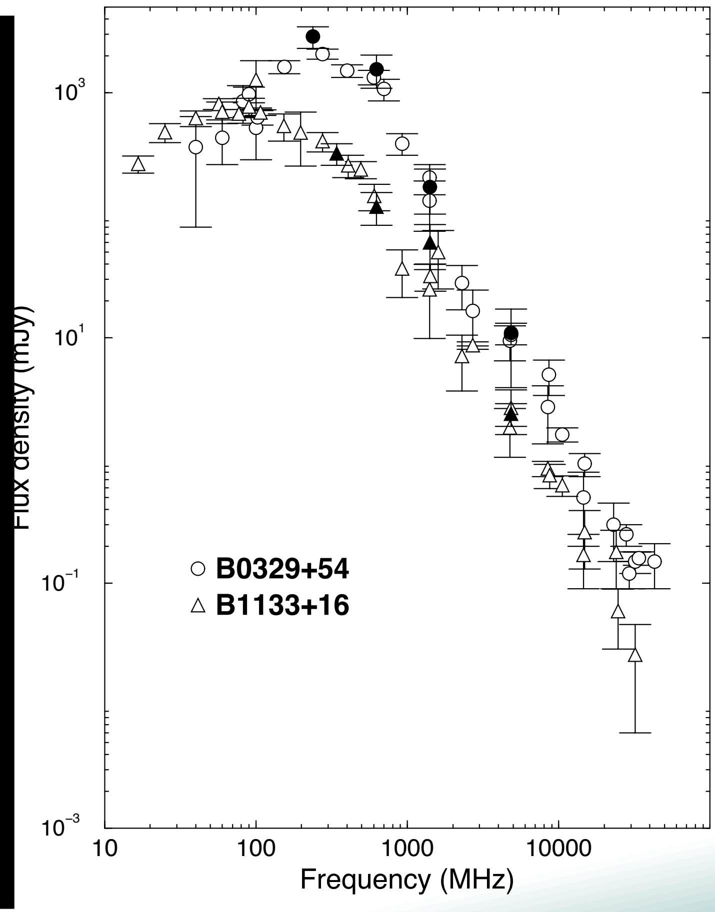
Extrinsic modulation:



Single pulses:



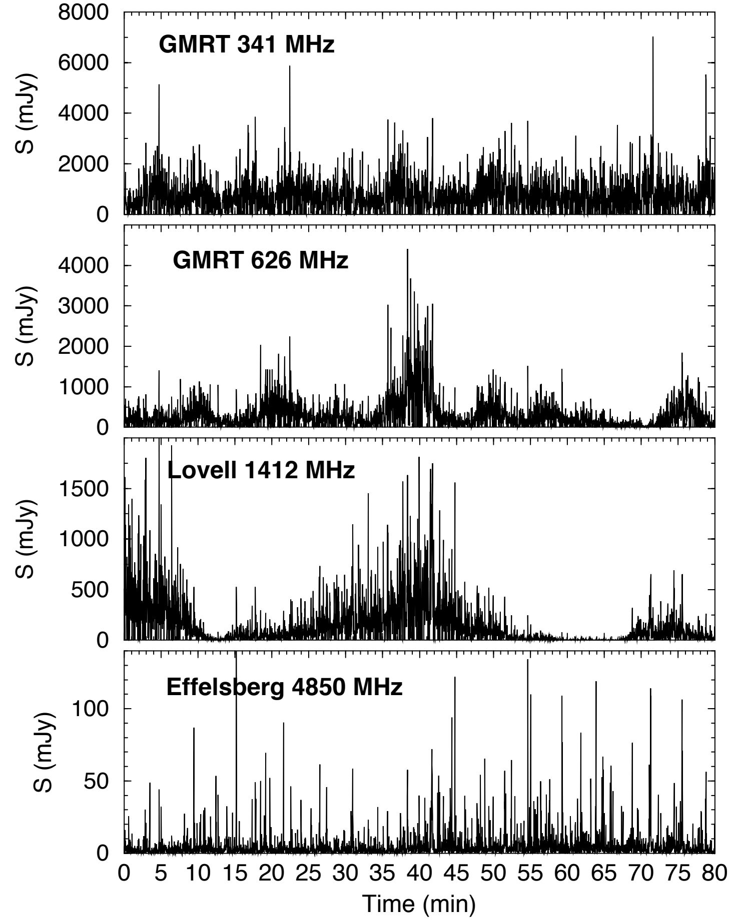
Average spectra:



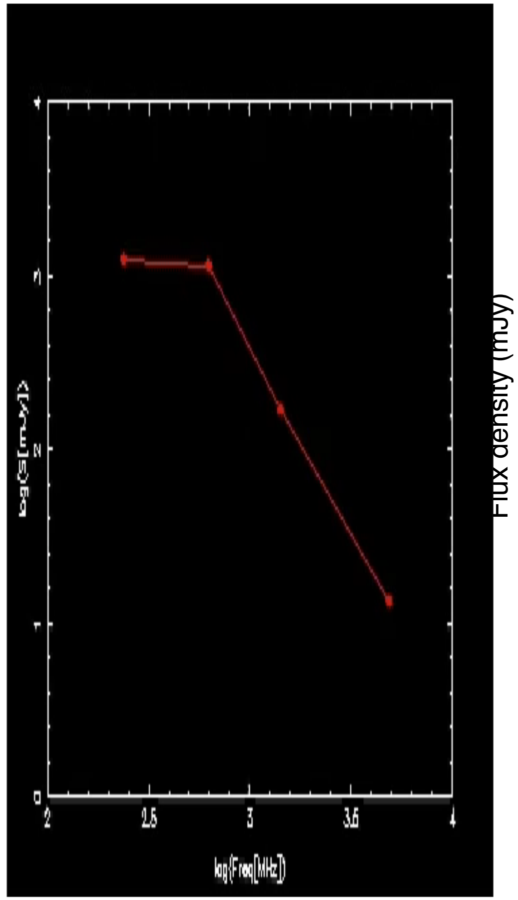
Kramer et al. (2003)

Flux density across frequencies

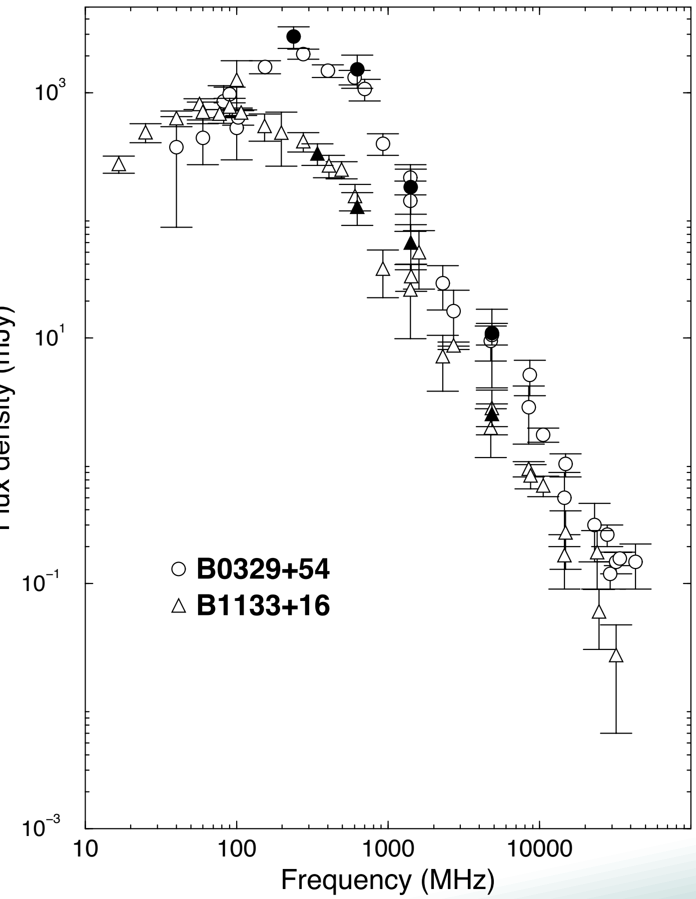
Extrinsic modulation:



Single pulses:

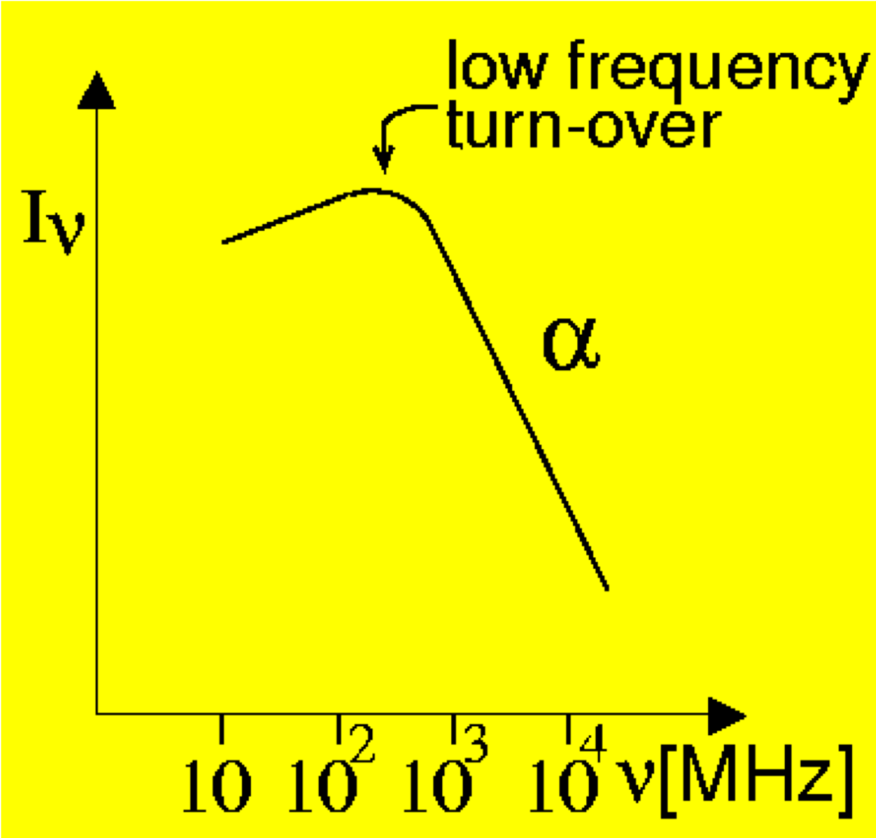


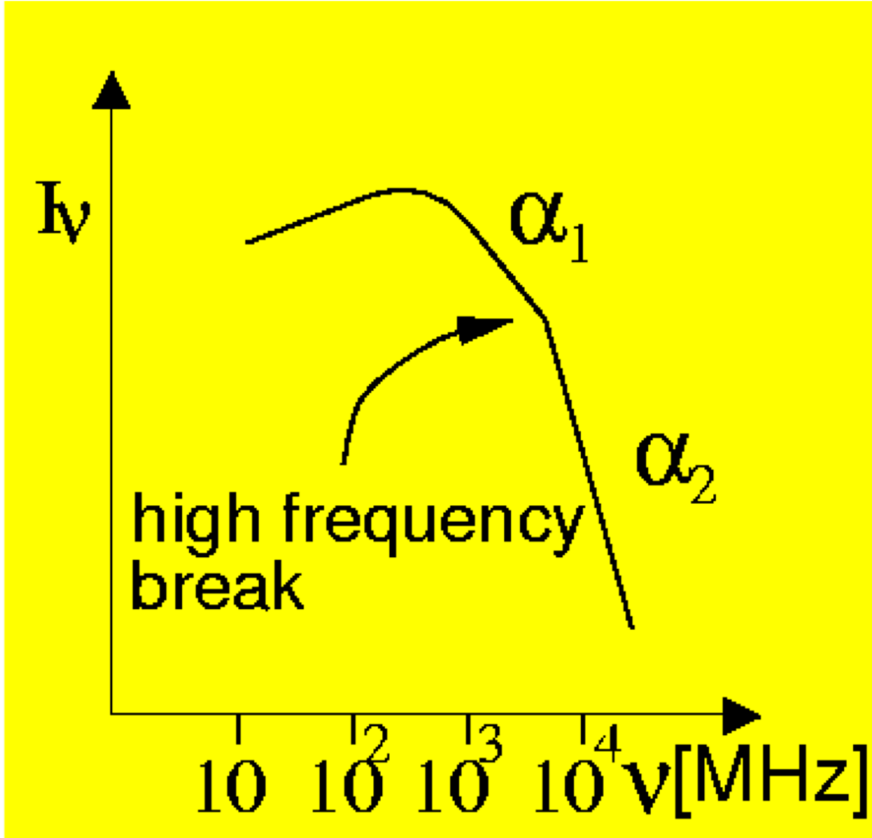
Average spectra:



Kramer et al. (2003)

Spectra: normal pulsars

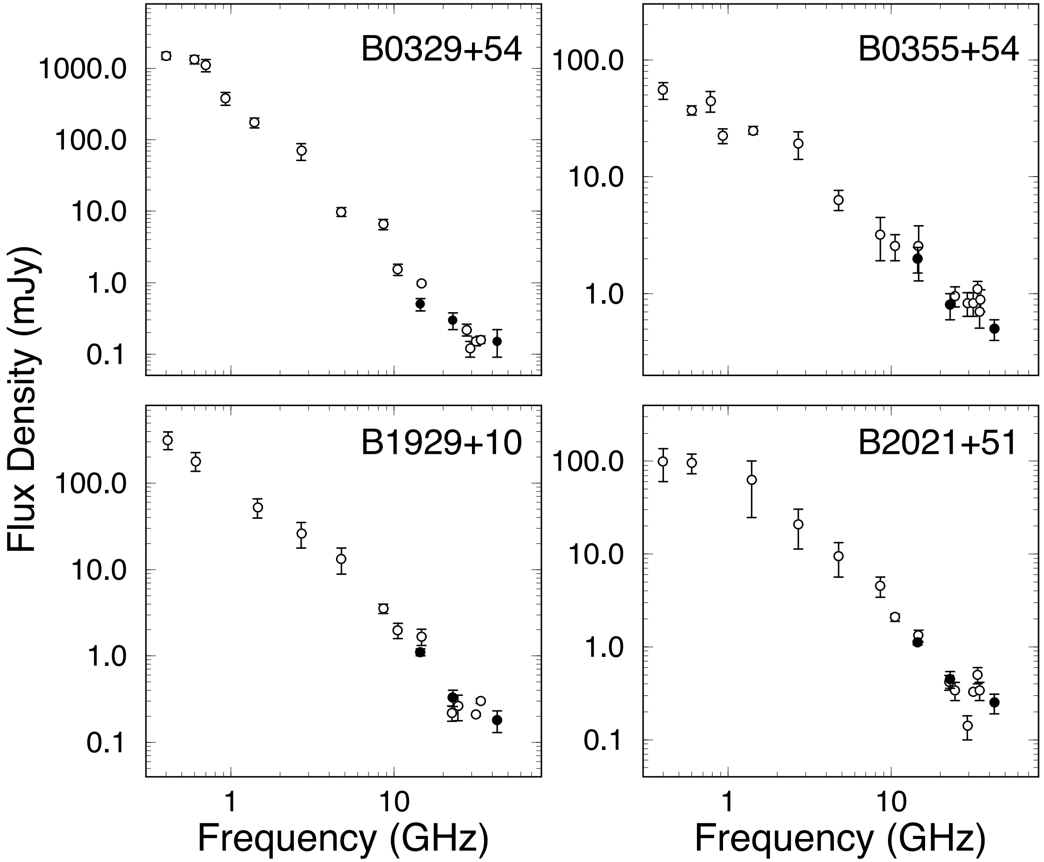




See Maron et al. (2000) – Spectral index mean -1.7

Spectral change at mm-wavelengths? (e.g. Kramer et al. 1997)

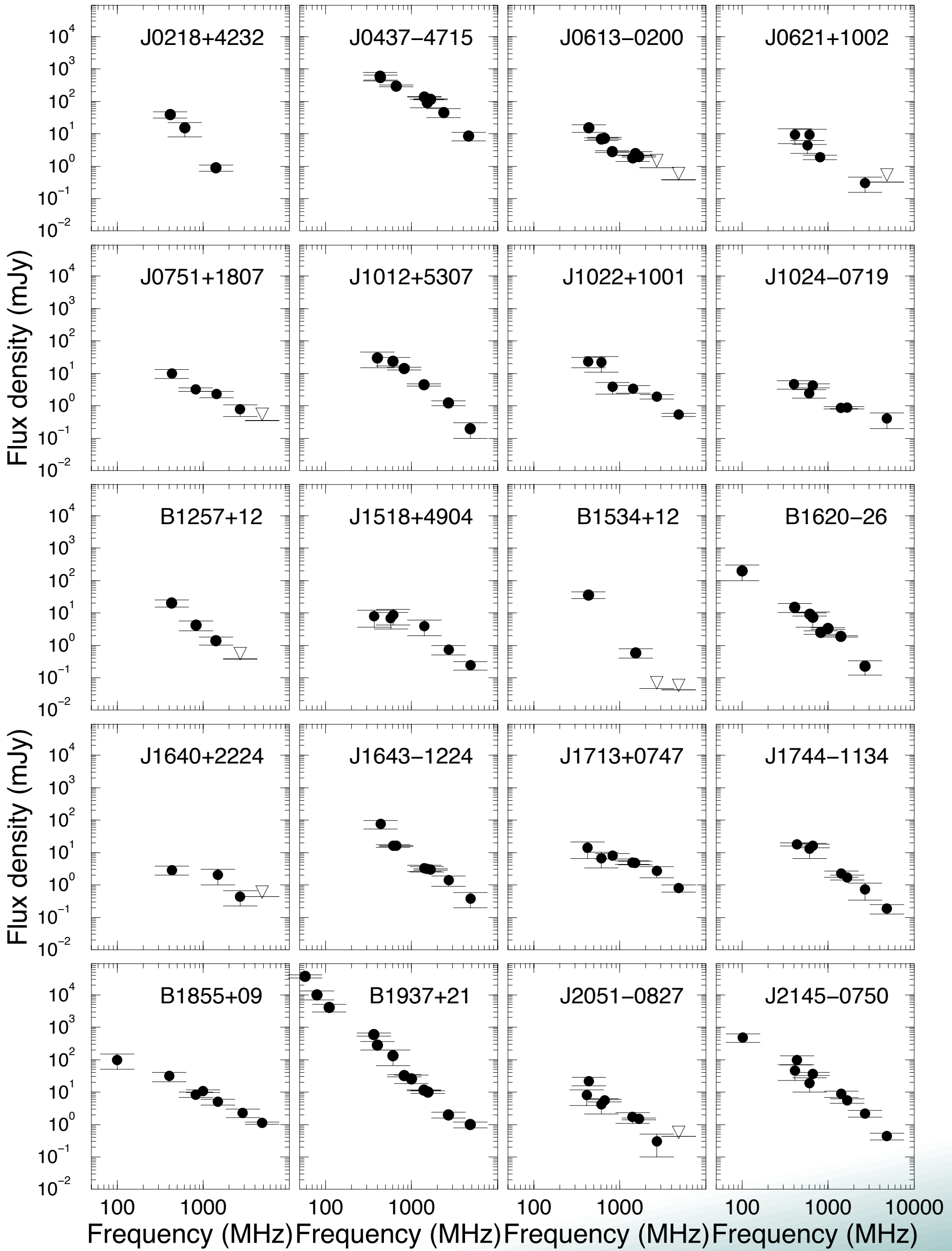
Spectra: normal pulsars



See Maron et al. (2000) – Spectral index mean -1.7

Spectral change at mm-wavelengths? (e.g. Kramer et al. 1997)

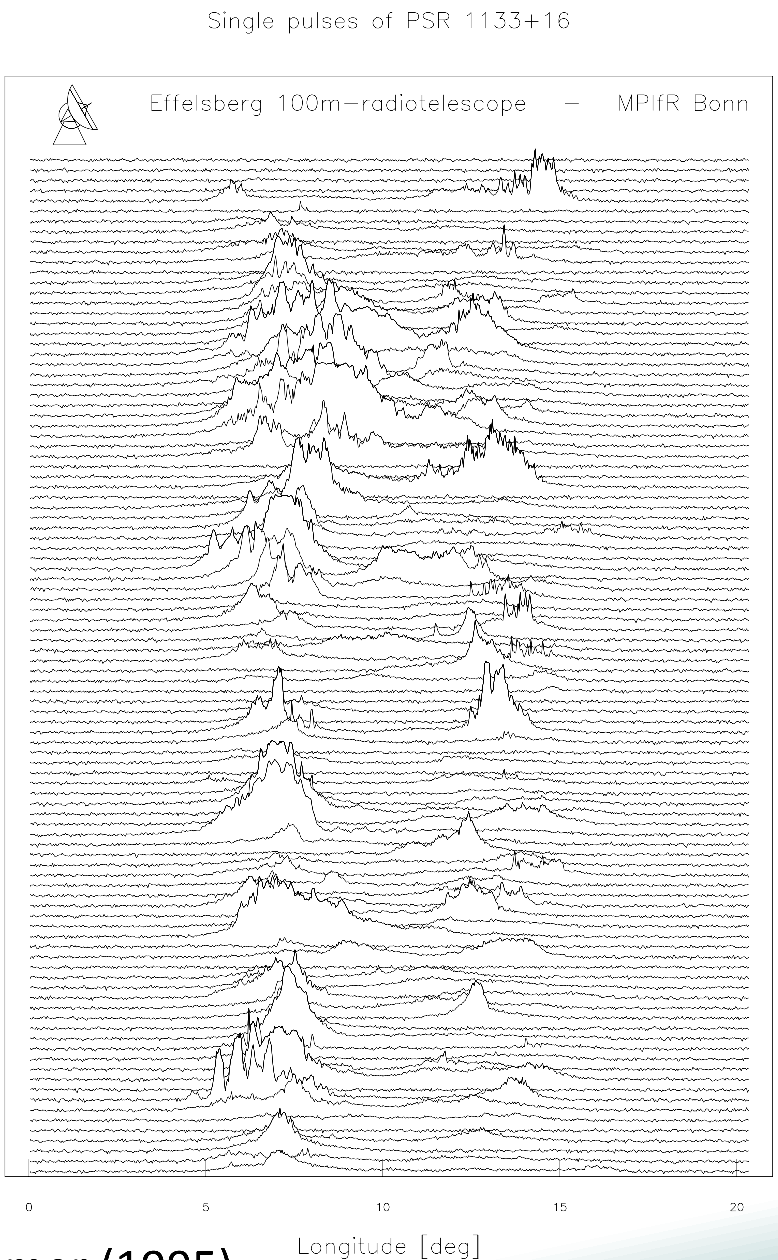
Spectra: millisecond pulsars



Mostly simple power laws

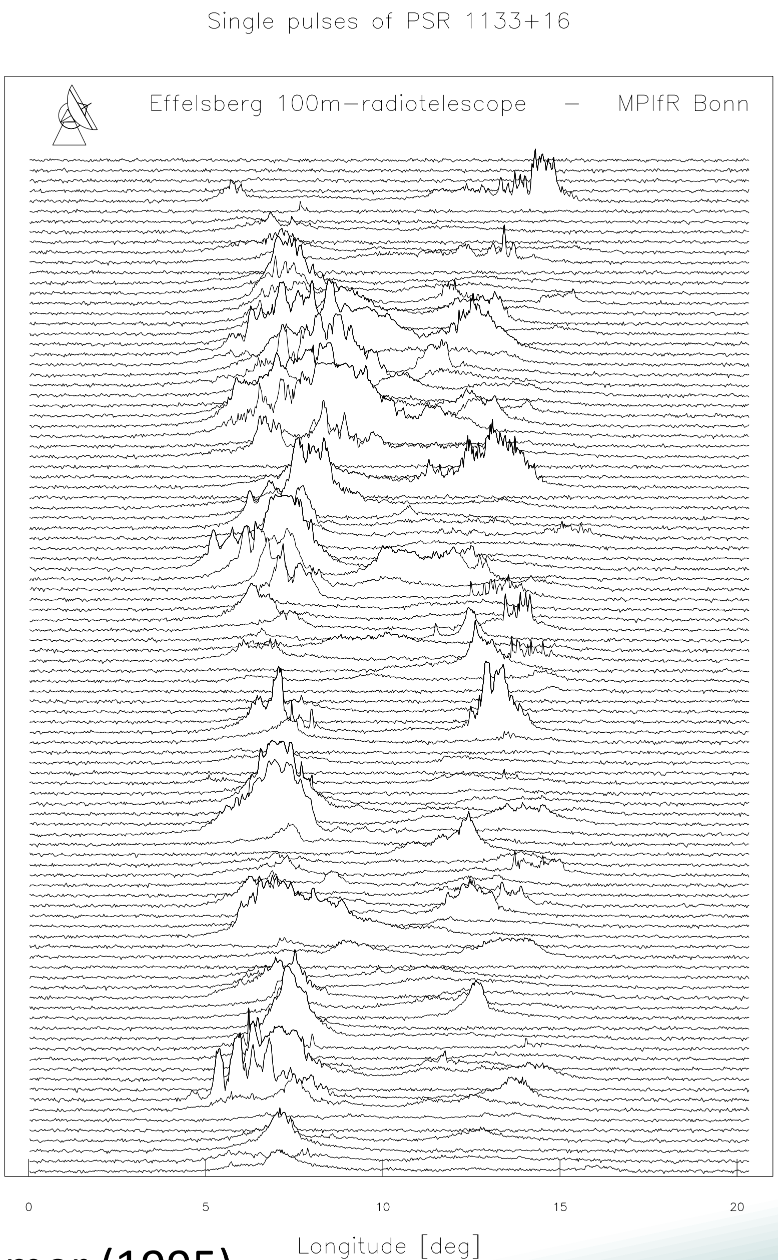
Kramer et al. (1999)

Nulling



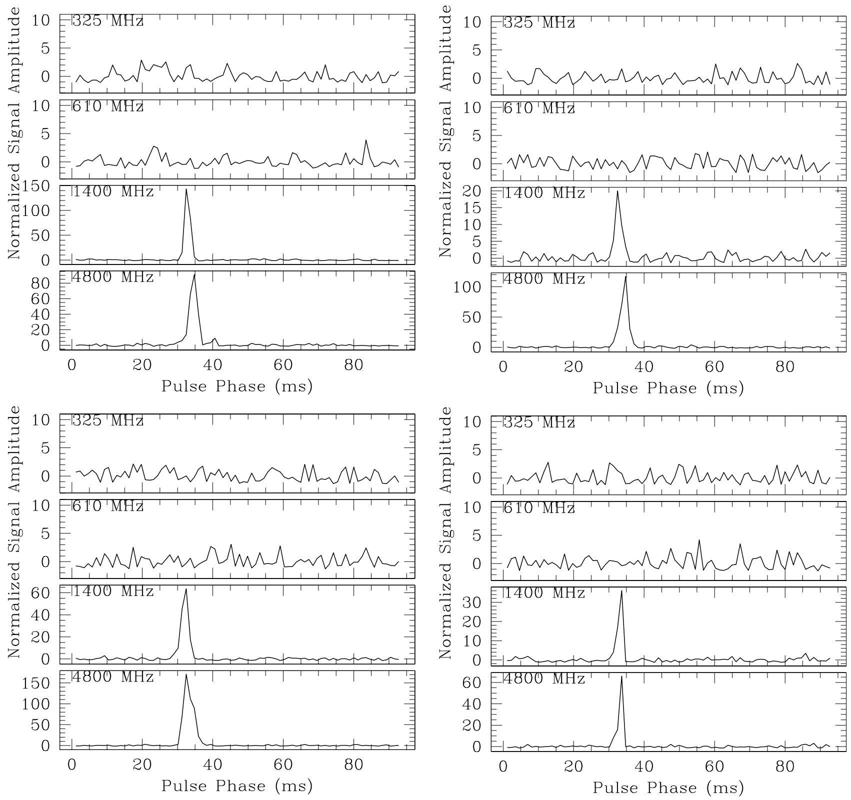
Kramer (1995)

Nulling



Kramer (1995)

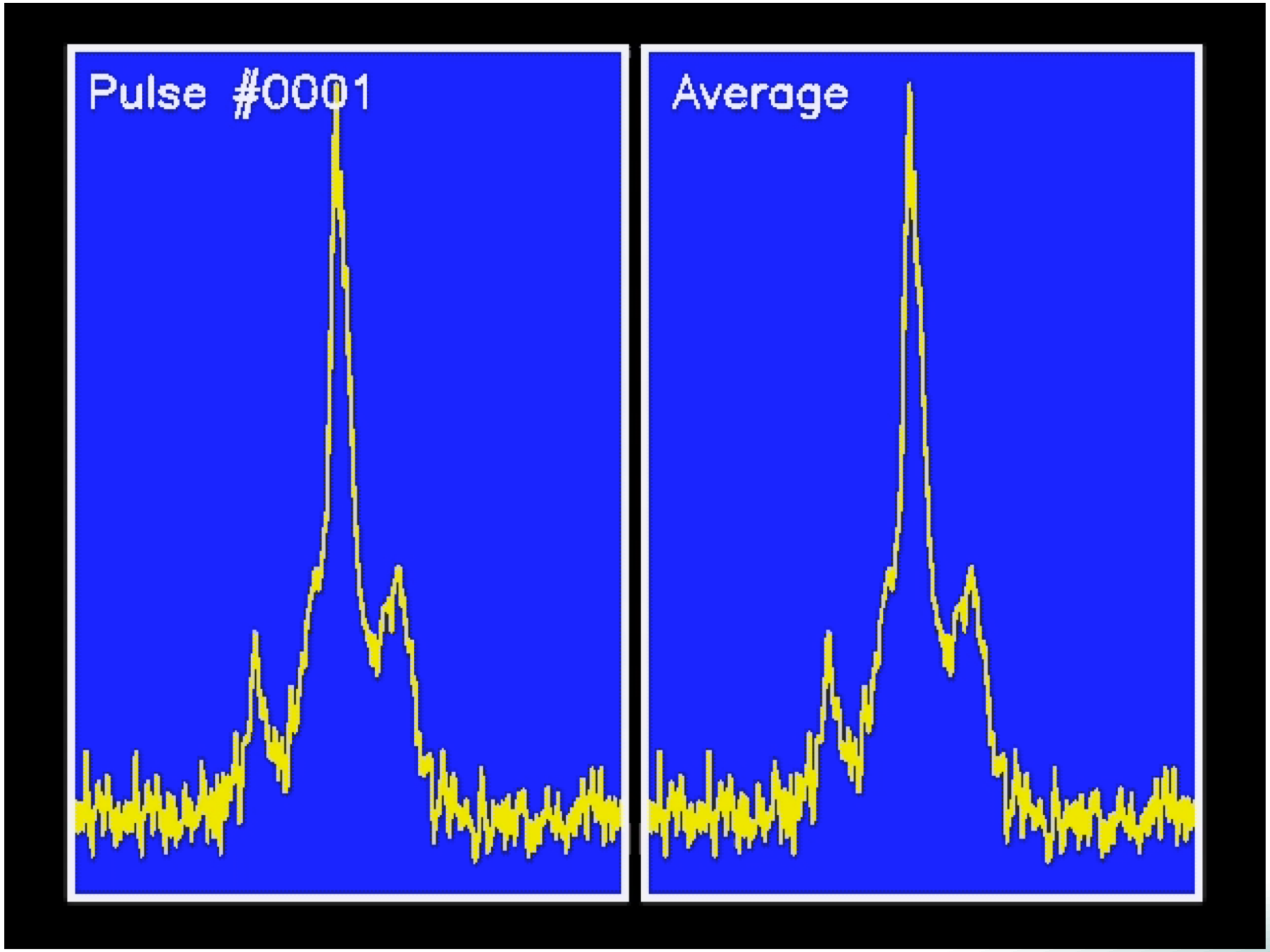
Bhat et al. (2007)



Not always broadband

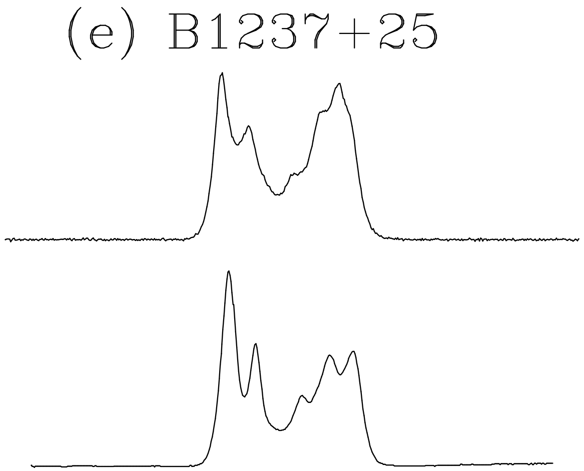
Nulling more common at low frequencies?

Average pulse shape is (usually) stable



Profile changes: moding

See Backer (1970)

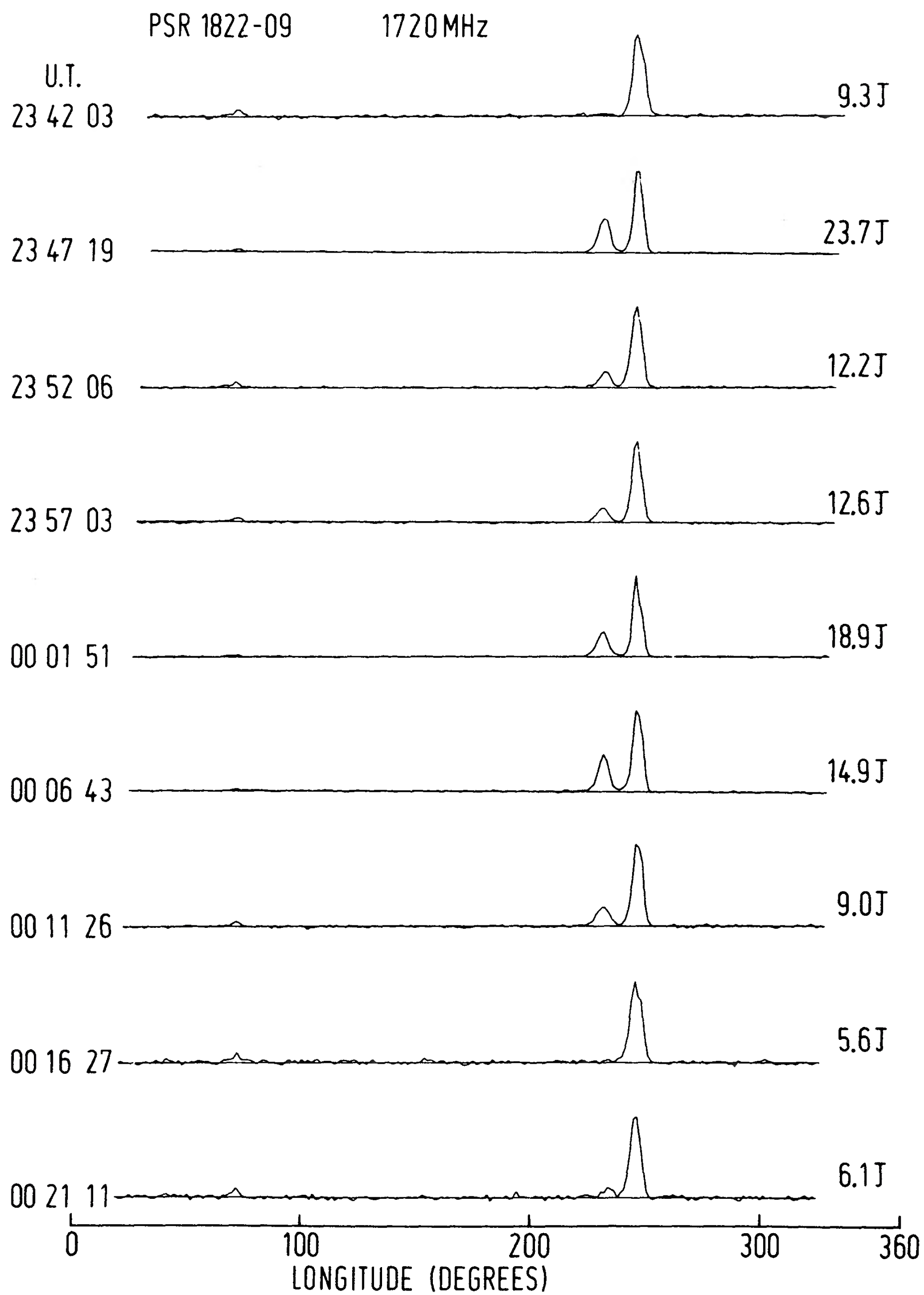


A mode change in the radio emission from the pulsar PSR 1822 – 09

D. Morris*, D. A. Graham and N. Bartel *Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-5300 Bonn 1, Federal Republic of Germany*

Received 1980 October 6

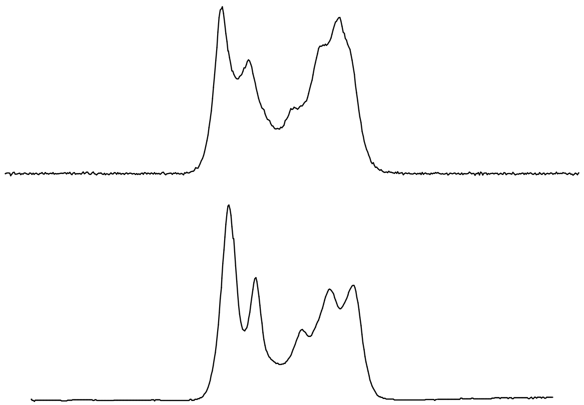
Summary. A mode change has been detected in the 1720-MHz and 2650-MHz radiation from PSR 1822 – 09. At low average intensities the first component of the main pulse abruptly drops to very small intensity. To within our measurement errors the interpulse remains unchanged. The evidence is consistent with a model in which the main pulse and interpulse originate at opposite magnetic poles.



Profile changes: moding

See Backer (1970)

(e) B1237+25



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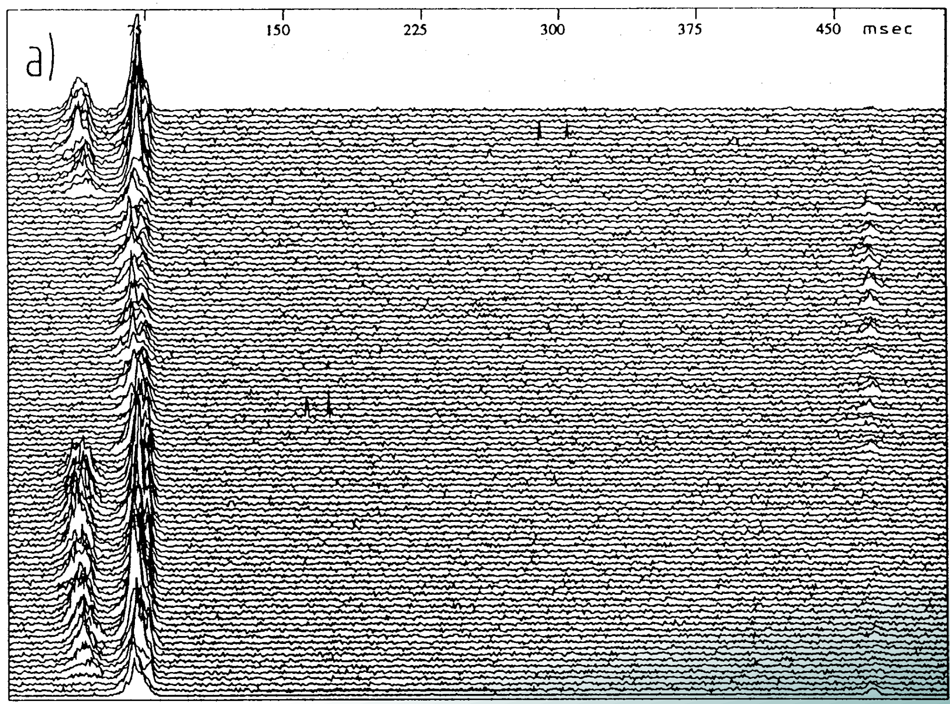
Multifrequency study of PSR 1822–09

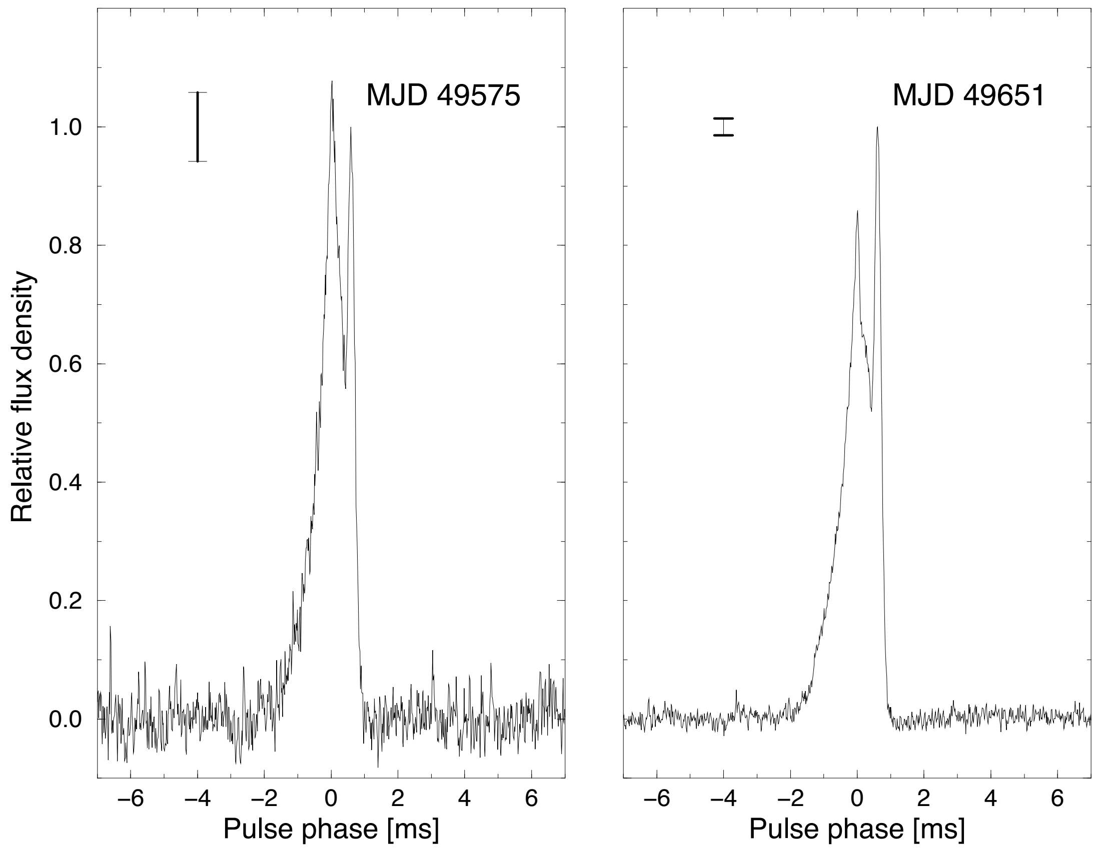
J.A. Gil[1,2], A. Jessner[1], J. Kijak[1,2], M. Kramer[1], V. Malofeev[1,3], I. Malov[3], J.H. Seiradakis[1,4], W. Sieber[5] and R. Wielebinski[1]

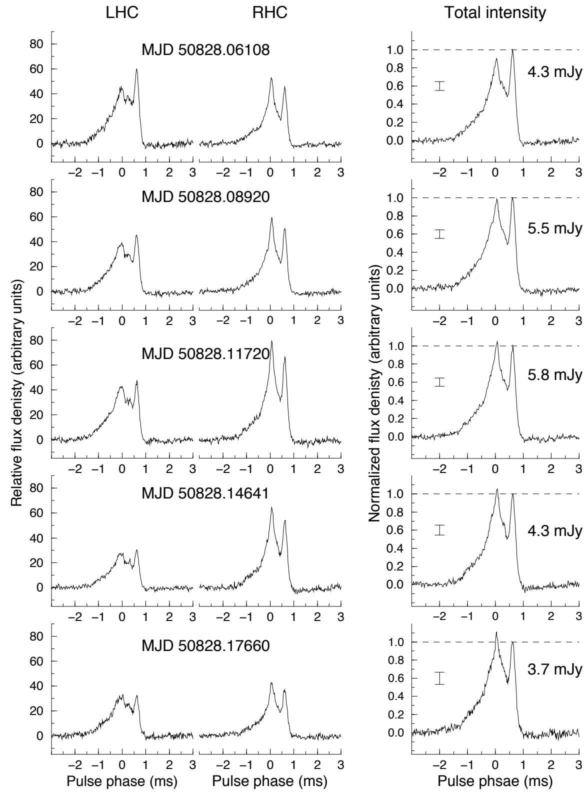
[1] Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
[2] Astronomical Centre, Pedagogical University, Lubuska 2, 65-265 Zielona Góra, Poland
[3] Radio Astronomy Department, P.N. Lebedev Physical Institute, Academy of Sciences, 117924, Moscow, Russia
[4] Department of Physics, Section of Astrophysics, Astronomy and Mechanics, University of Thessaloniki, GR-54006 Thessaloniki, Greece
[5] Fachhochschule Niederrhein, Fachbereich Elektrotechnik, Reinarzstrasse 49, D-4150 Krefeld 1, Germany

Received February 4, accepted August 6, 1993



Profile changes: millisecond pulsars





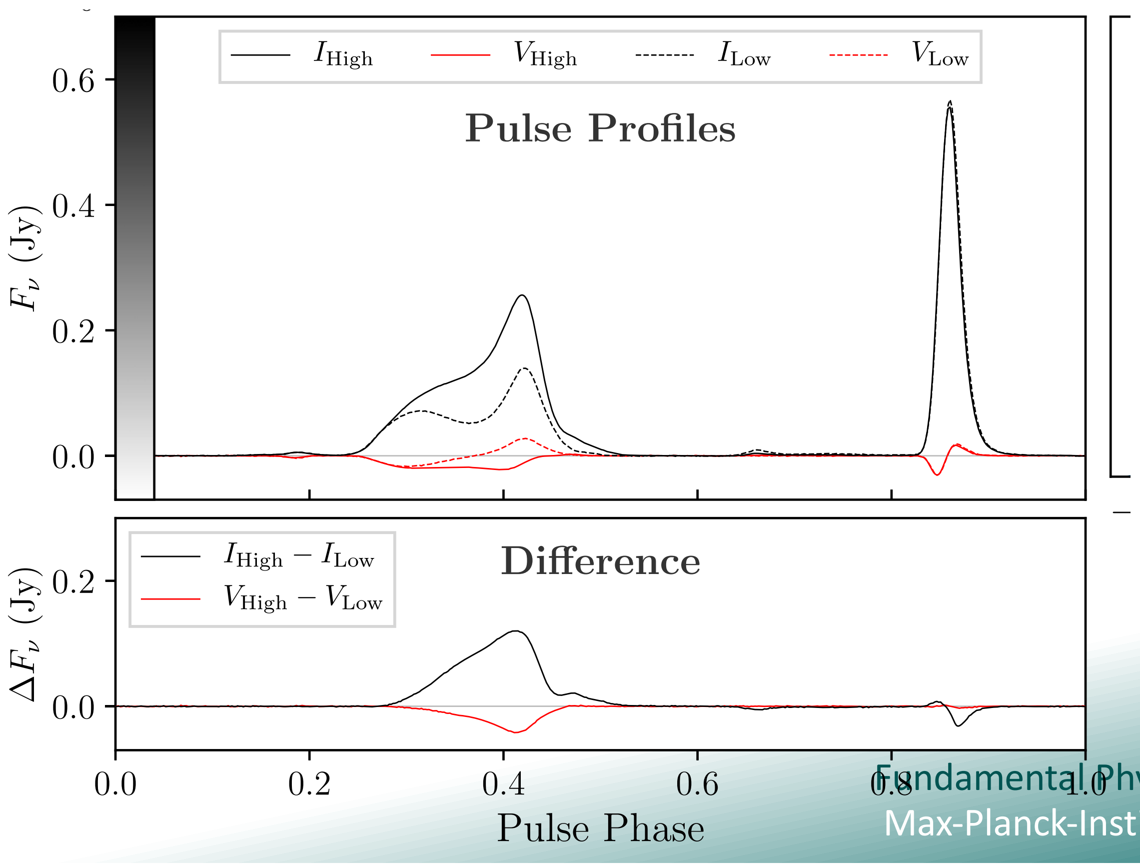
Kramer et al. (1999)

Profile changes: millisecond pulsars

The Astrophysical Journal Letters, 867:L2 (7pp), 2018 November 1
https://doi.org/10.3847/2041-8213/aae713

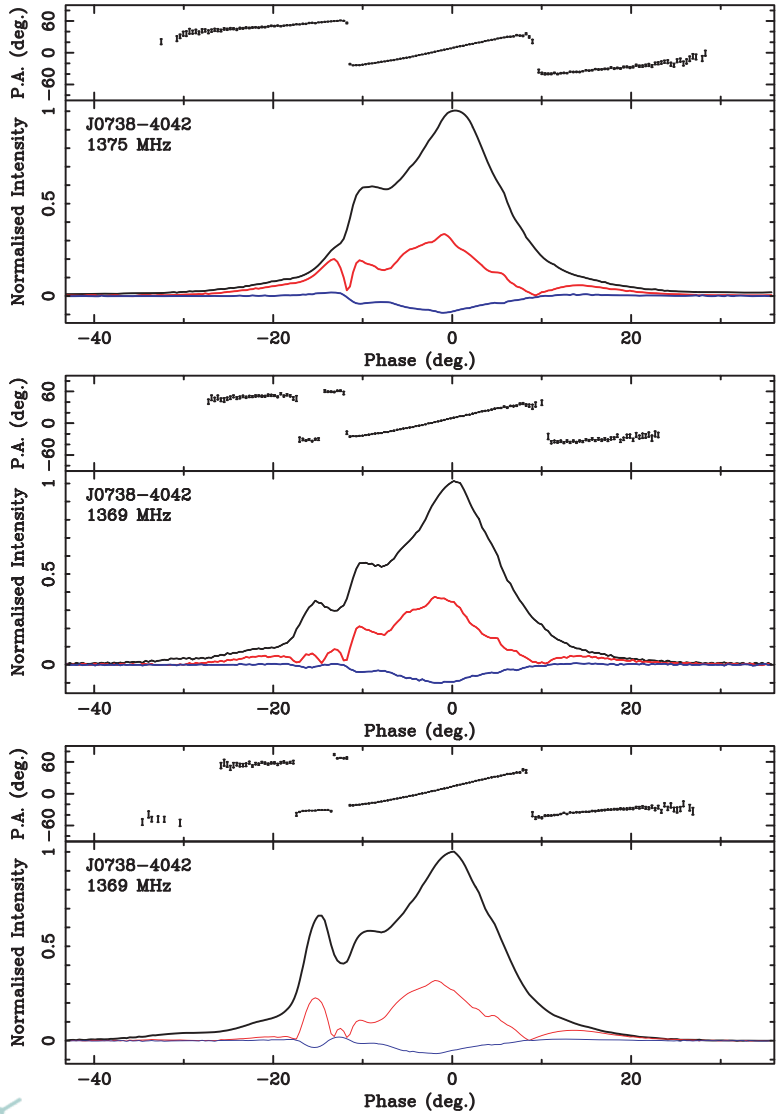
Mode Changing and Giant Pulses in the Millisecond Pulsar PSR B1957+20

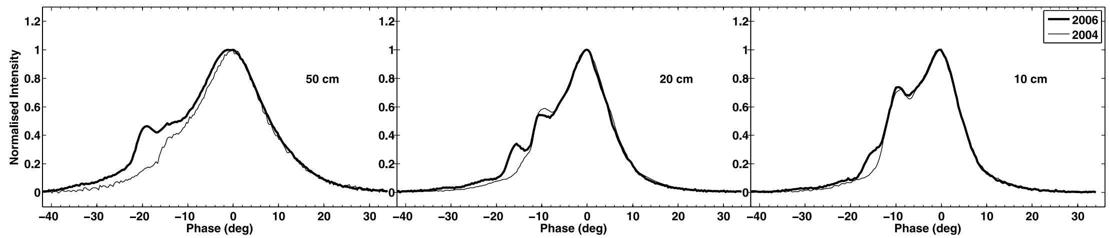
Nikhil Mahajan[1], Marten H. van Kerkwijk[1], Robert Main[1,2,3], and Ue-Li Pen[2,3,4,5]
[1] Department of Astronomy and Astrophysics, University of Toronto, 50 St. George Street, Toronto, ON M5S 3H4, Canada; mahajan@astro.utoronto.ca
[2] Canadian Institute for Theoretical Astrophysics, University of Toronto, 60 St. George Street, Toronto, ON M5S 3H8, Canada
[3] Dunlap Institute for Astronomy and Astrophysics, University of Toronto, 50 St George Street, Toronto, ON M5S 3H4, Canada
[4] Perimeter Institute for Theoretical Physics, 31 Caroline Street North, Waterloo, ON N2L 2Y5, Canada
[5] Canadian Institute for Advanced Research, 180 Dundas Street West, Toronto, ON M5G 1Z8, Canada
Received 2018 July 1; revised 2018 October 1; accepted 2018 October 8; published 2018 October 24



Profile changes: long-term changes

A transient component in PSR J0738−4042   253

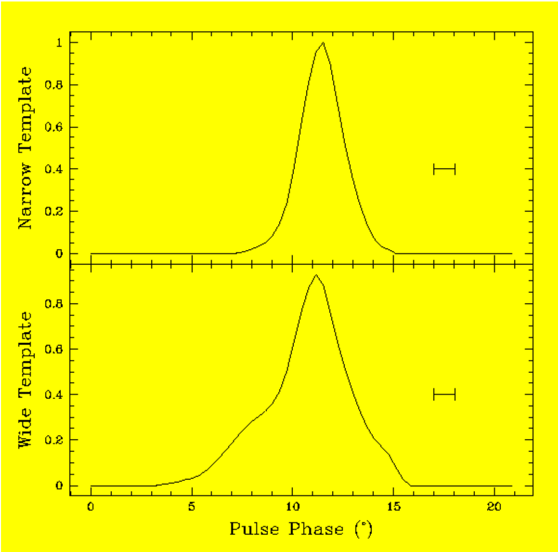




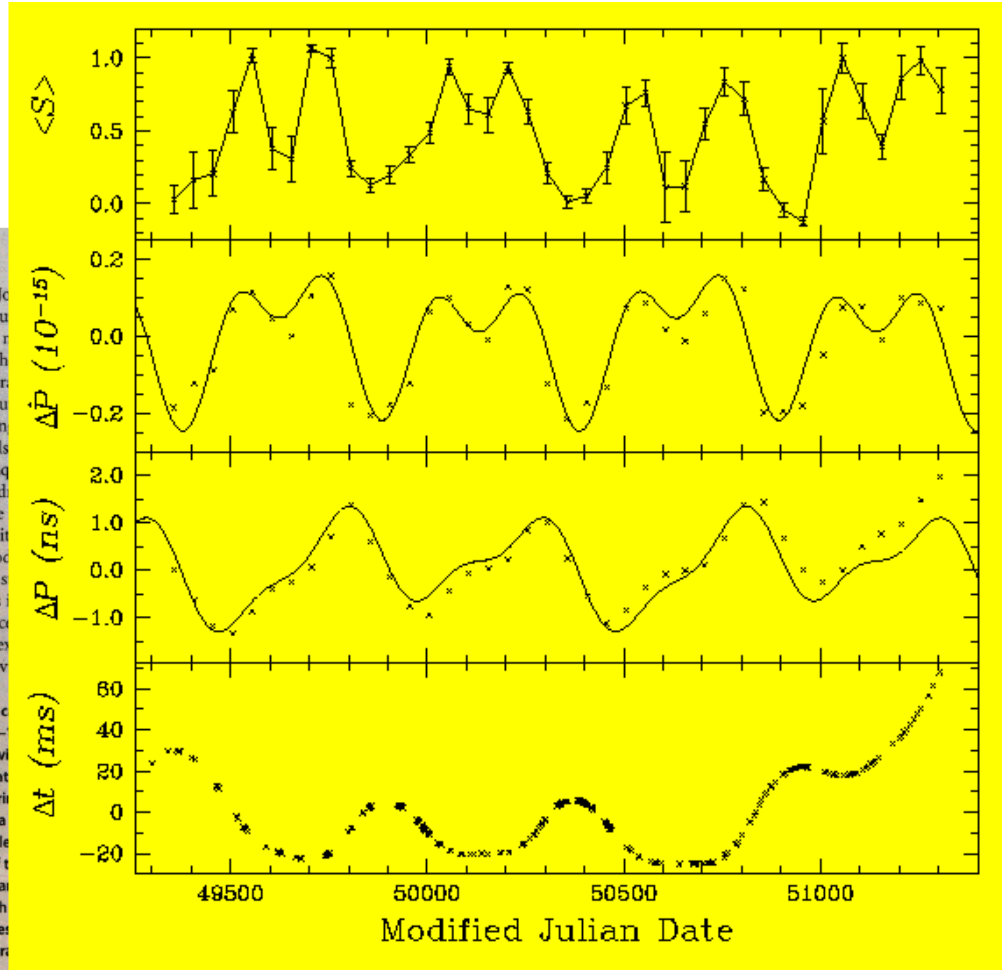
- Impact on timing!
- See also Keith et al. (2013)

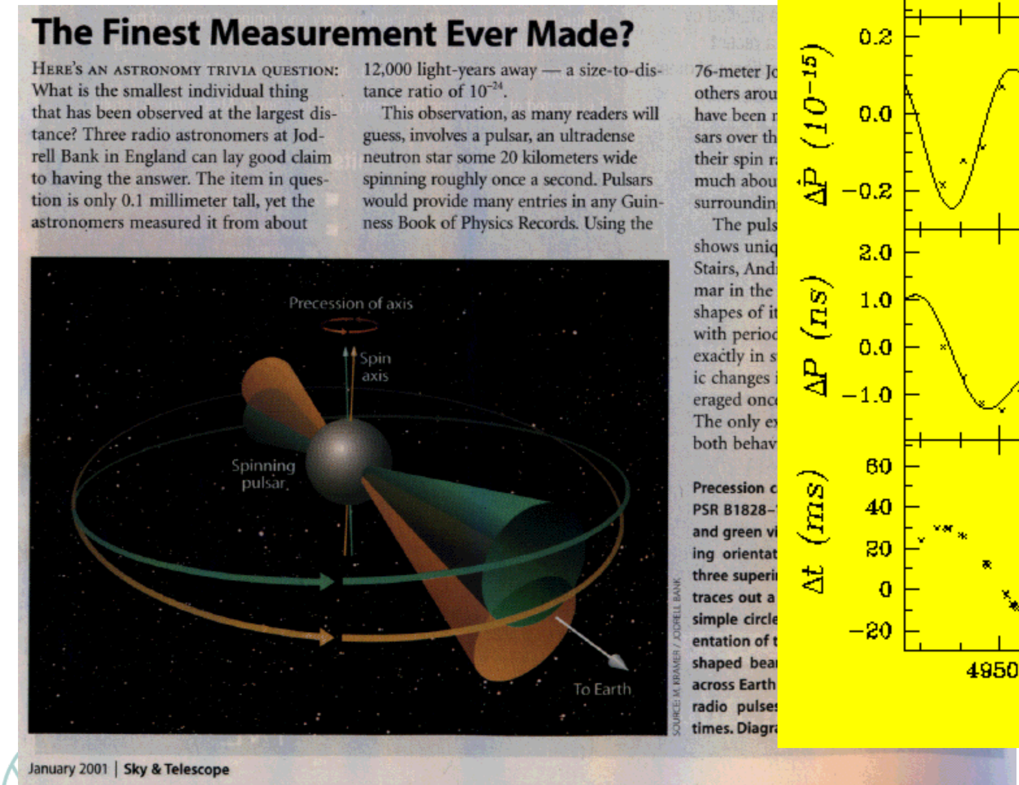
Karastergiou et al. (2011)

Profile changes: periodicities



PSR B1828-11





The Finest Measurement Ever Made?

HERE'S AN ASTRONOMY TRIVIA QUESTION: What is the smallest individual thing that has been observed at the largest distance? Three radio astronomers at Jodrell Bank in England can lay good claim to having the answer. The item in question is only 0.1 millimeter tall, yet the astronomers measured it from about 12,000 light-years away — a size-to-distance ratio of 10^{-24}.

This observation, as many readers will guess, involves a pulsar, an ultradense neutron star some 20 kilometers wide spinning roughly once a second. Pulsars would provide many entries in any Guinness Book of Physics Records. Using the 76-meter Jo… others arou… have been r… sars over th… their spin r… much abou… surroundin…

The puls… shows uniq… Stairs, And… mar in the … shapes of it… with period… exactly in s… ic changes i… eraged onc… The only ex… both behav…

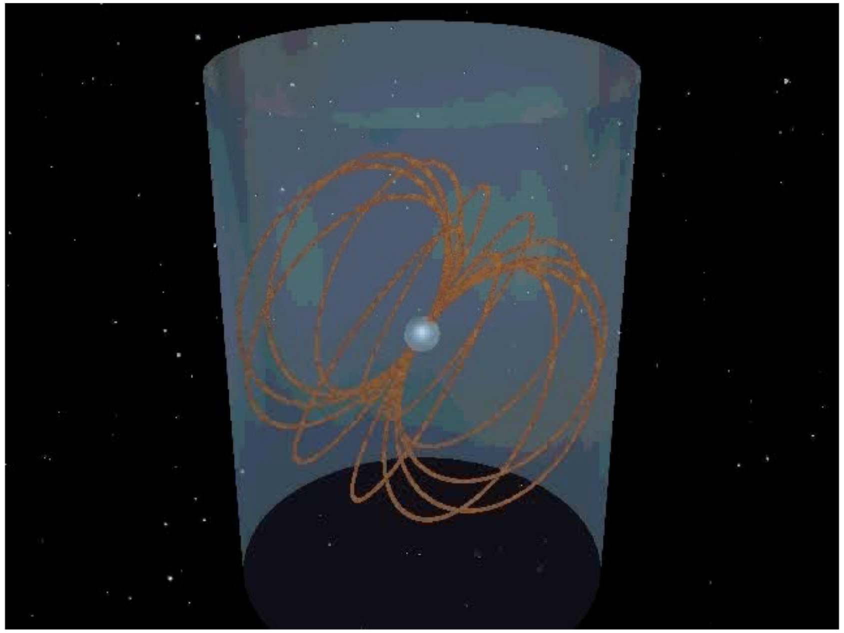
Precession c… PSR B1828-… and green vi… ing orientat… three superi… traces out a… simple circle… entation of t… shaped bea… across Earth… radio pulses… times. Diagra…

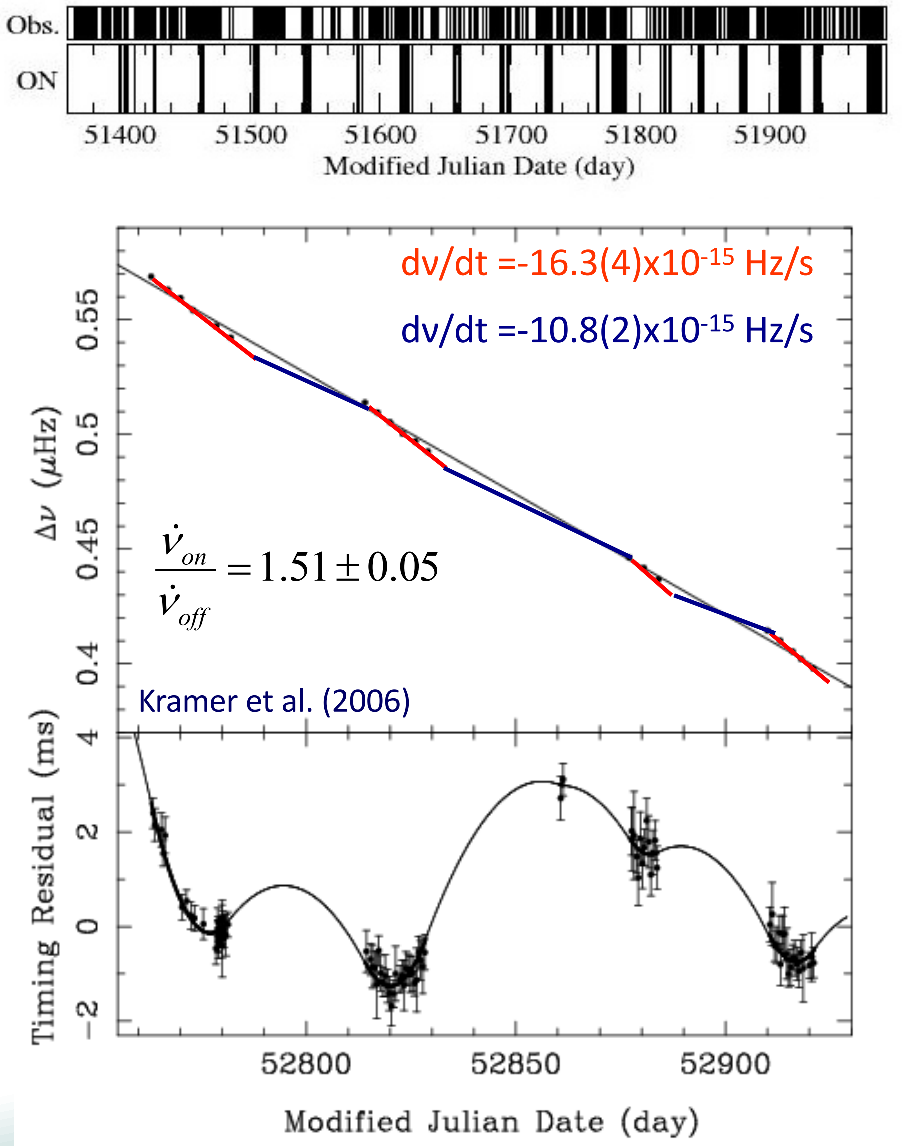
January 2001 | Sky & Telescope

Stairs et al. (2000)

Intermittent pulsars

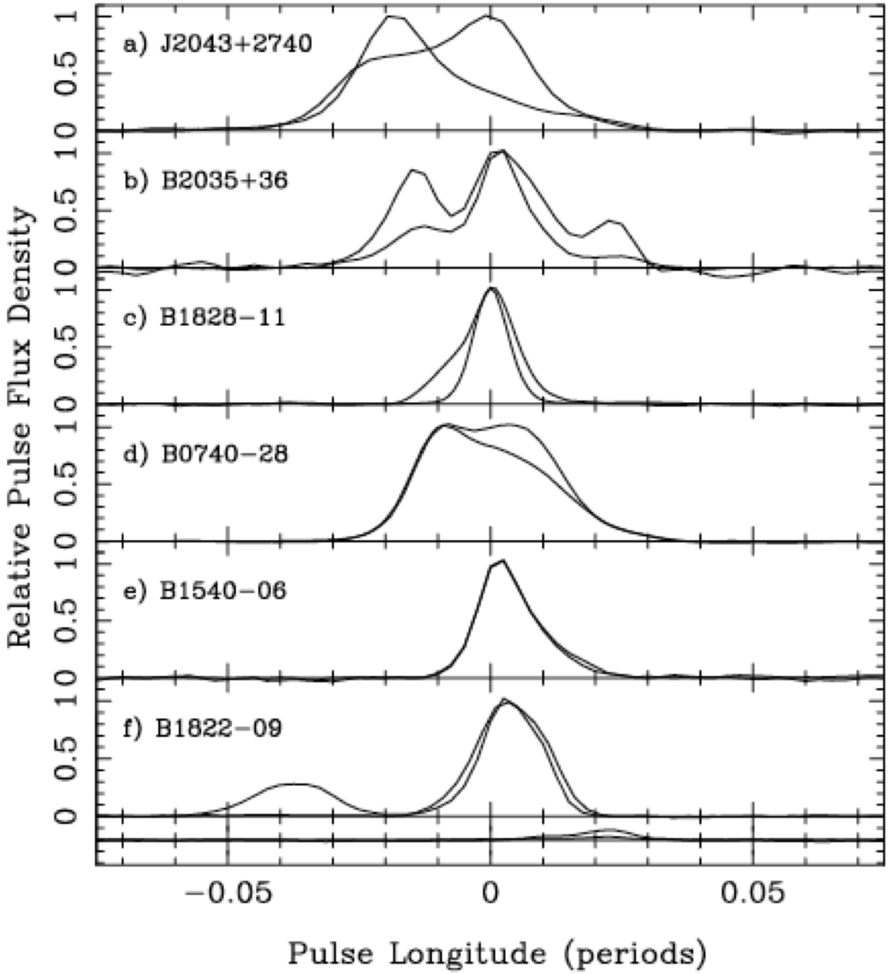
- Distinct phases of radio silence, up to two years!
- First, B1931+24, week/month timescale
- Spin-down changes with changing plasma
- Unique insight into magnetosphere
- Several more now known
- Difficult to find (and confirm)
- Significant fraction of population?

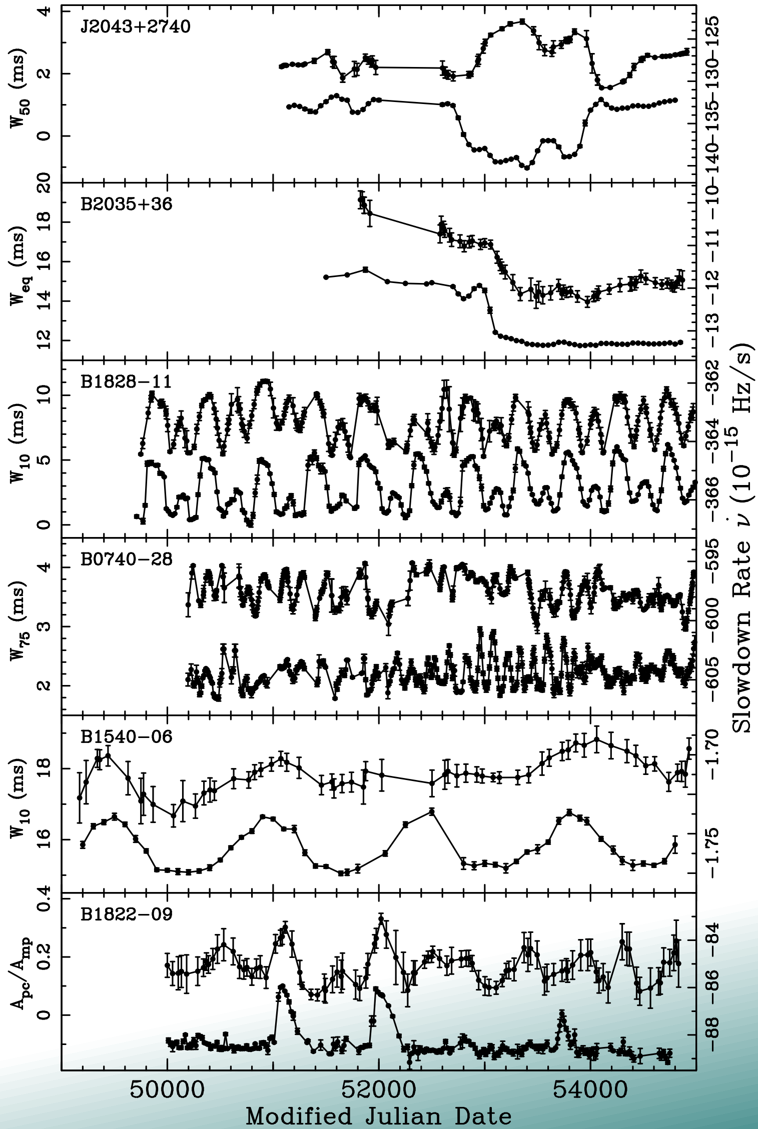




Timing noise, mode changing, nulling & intermittency

Lyne et al. (2010)

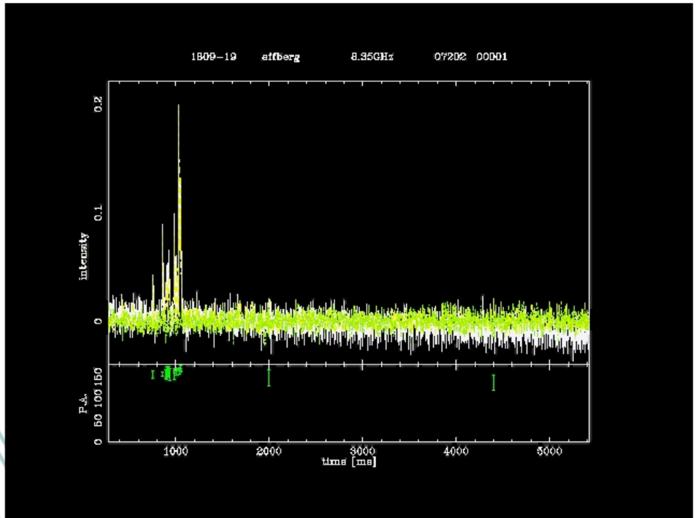




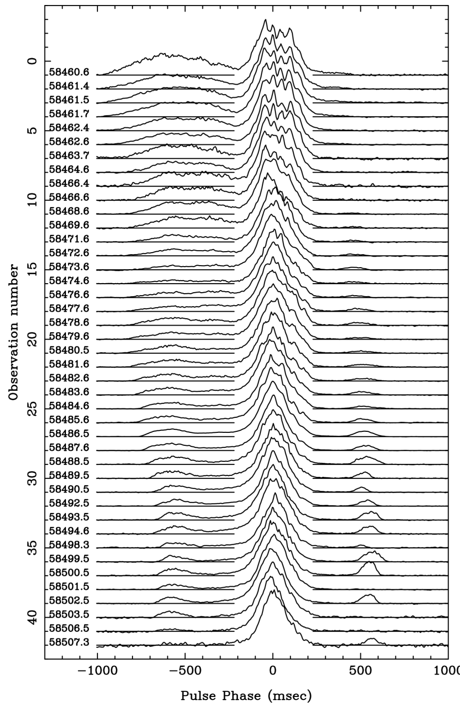
Magnetars: almost all radio quiet

- Some magnetars visible as transient radio sources
- Radio triggered by outburst?
- Emission properties with similarities to pulsars but also different
- Complementary information to high energies
- First discovery of magnetar in radio blind search (Levin et al. 2010)
- Four radio-loud magnetars known, one in Galactic Centre (Eatough et al. 2013, Torne et al. 2015, 2016)
- Timing very noisy – related to profile changes?

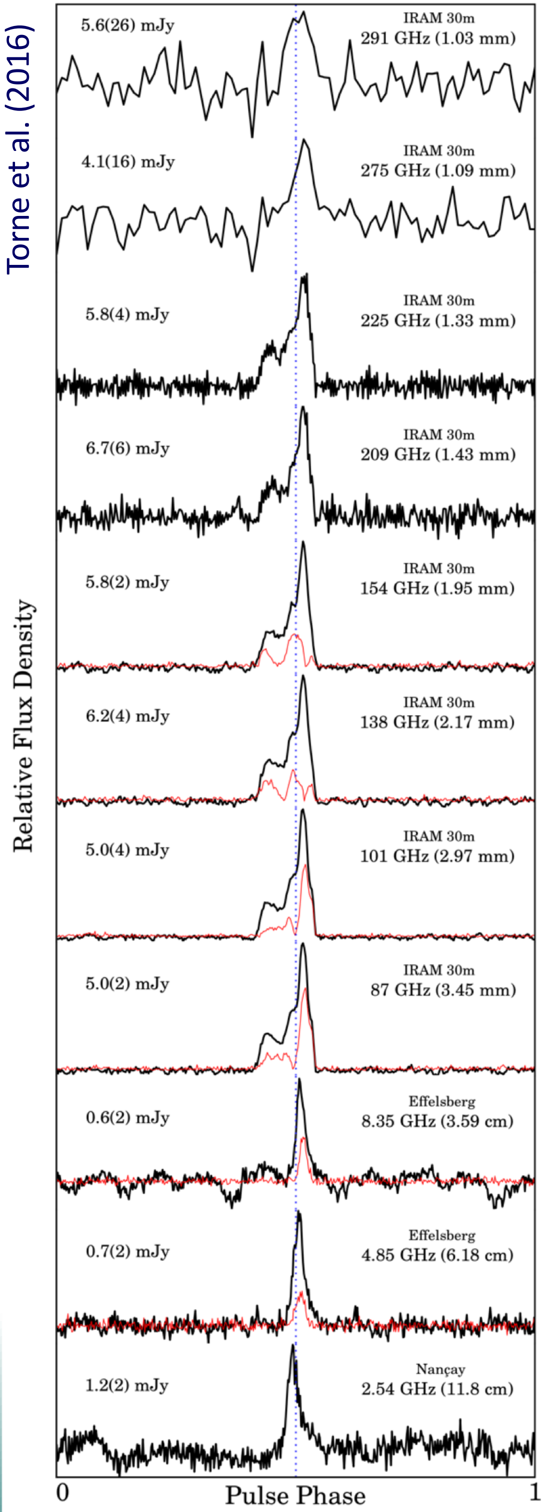
Kramer et al. (2007)



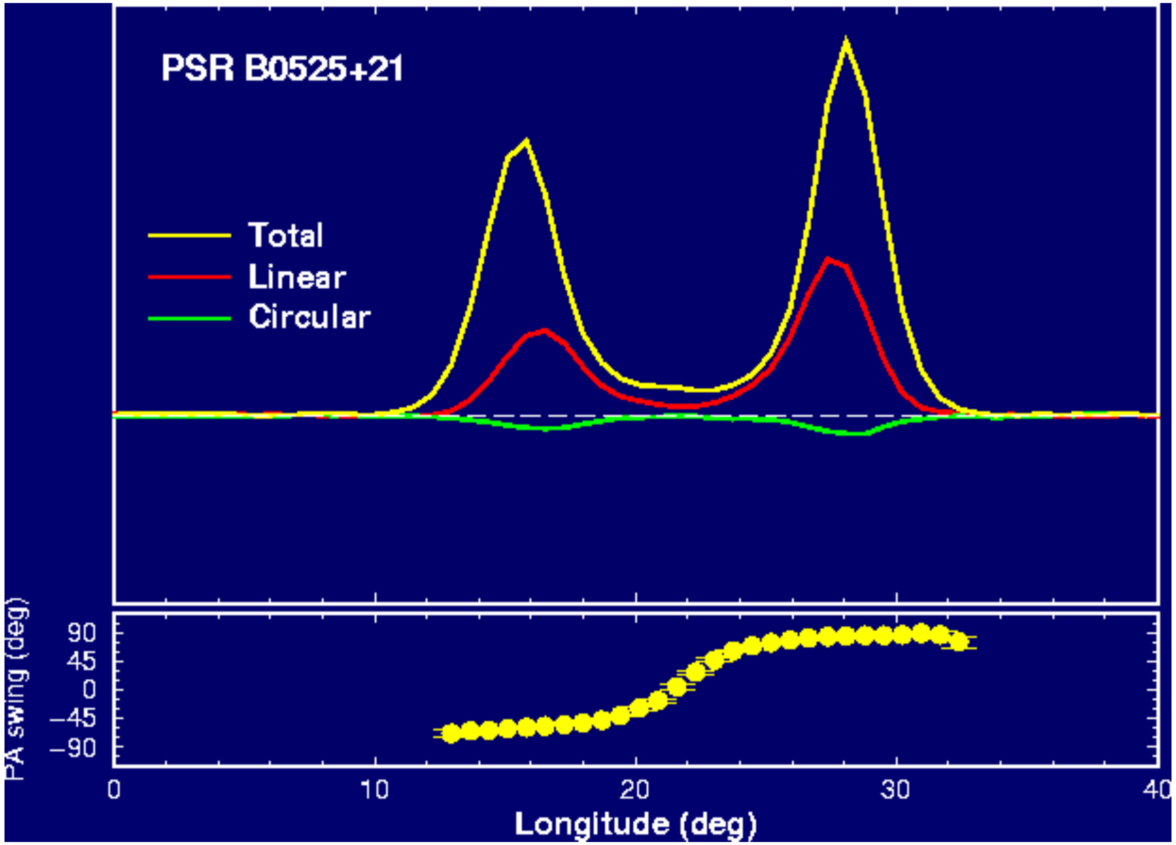
Levin et al. (2019)

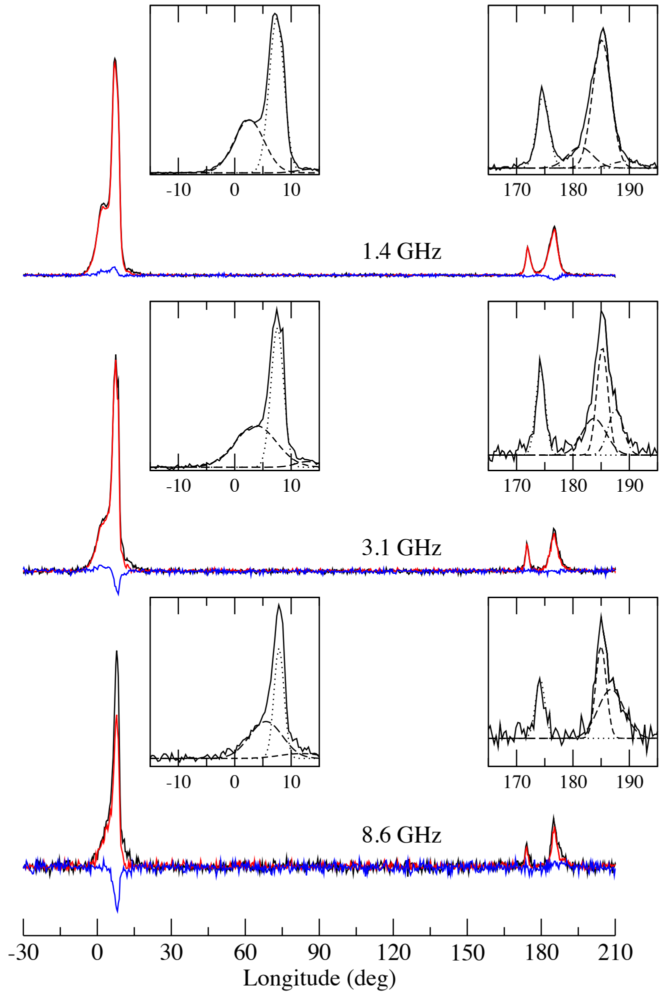


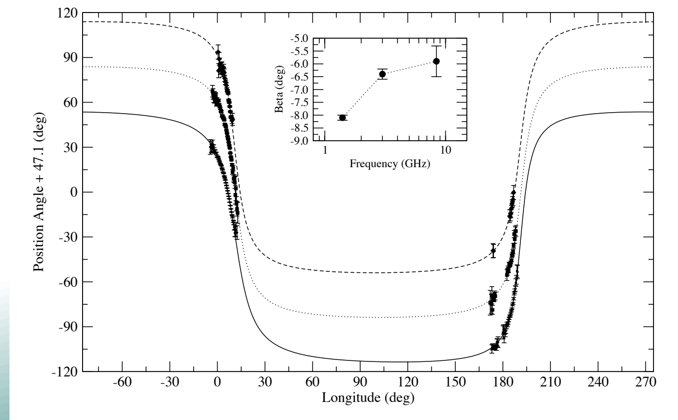
Torne et al. (2016)



Emission is highly polarised

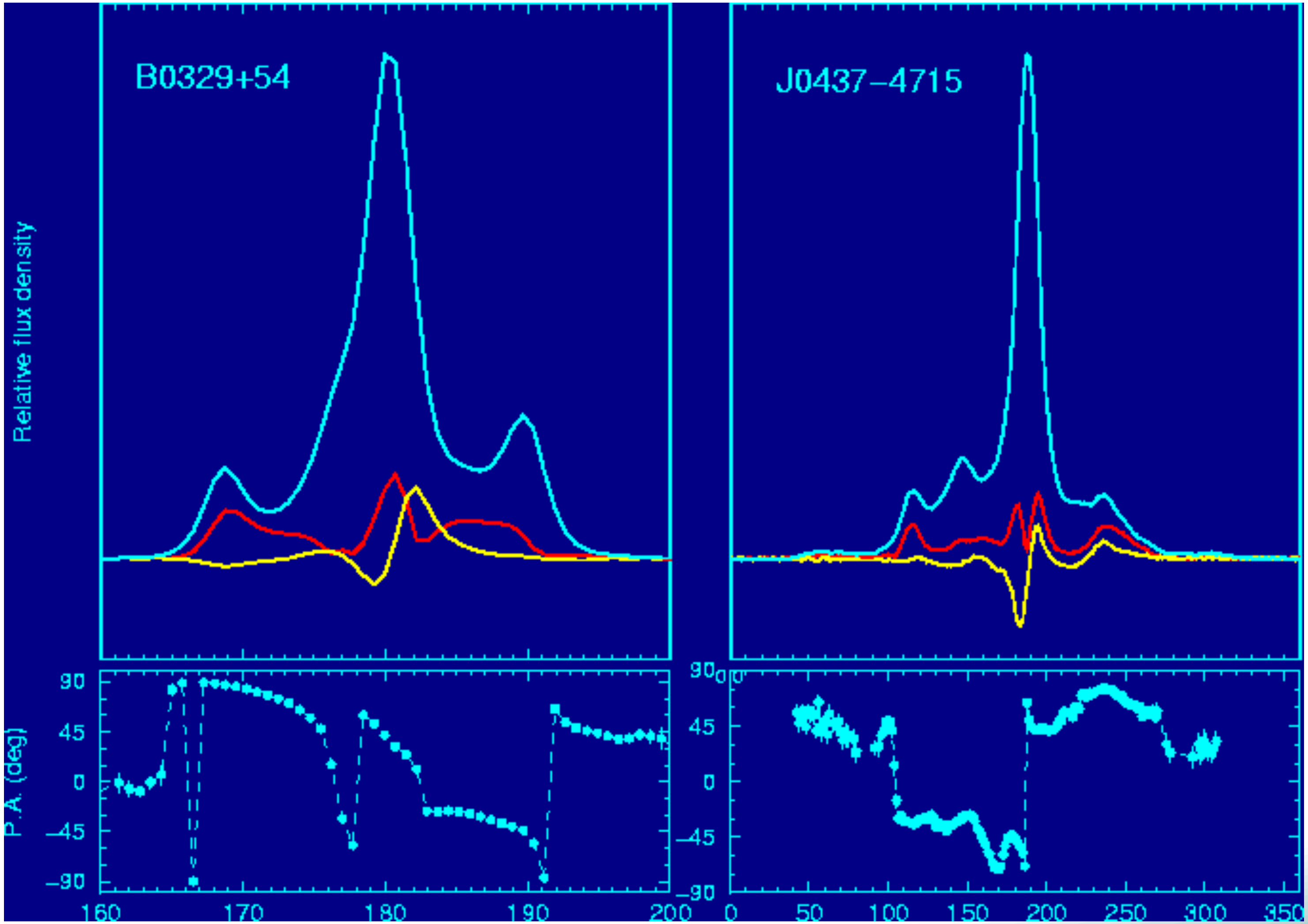




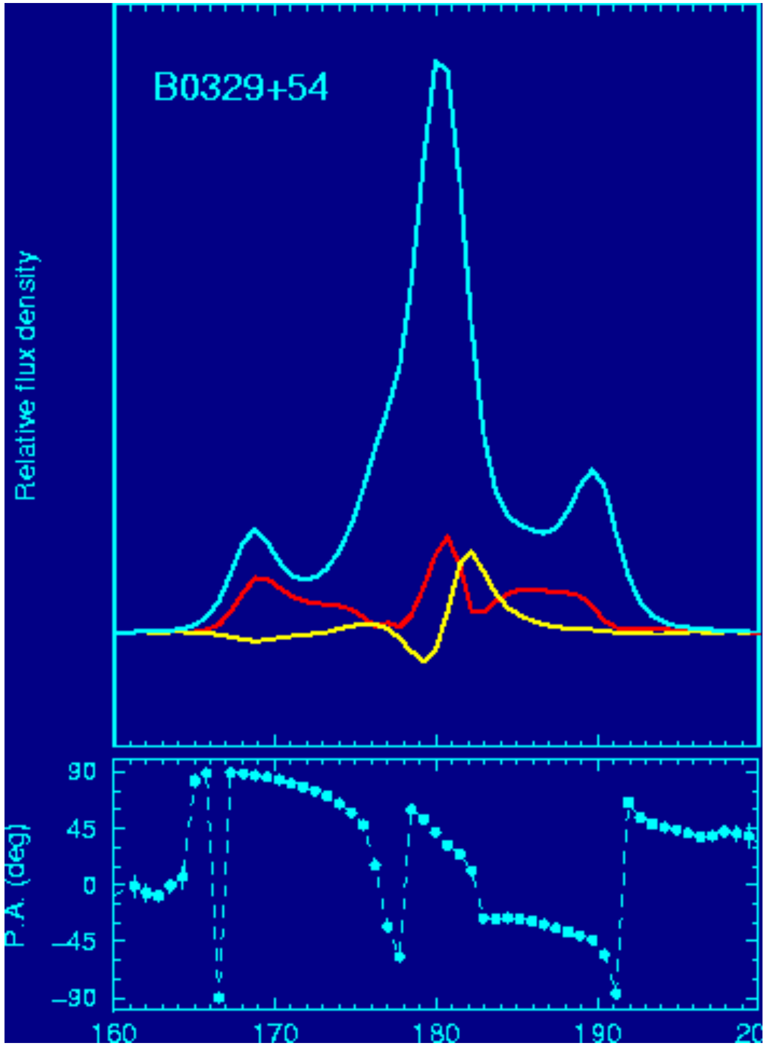


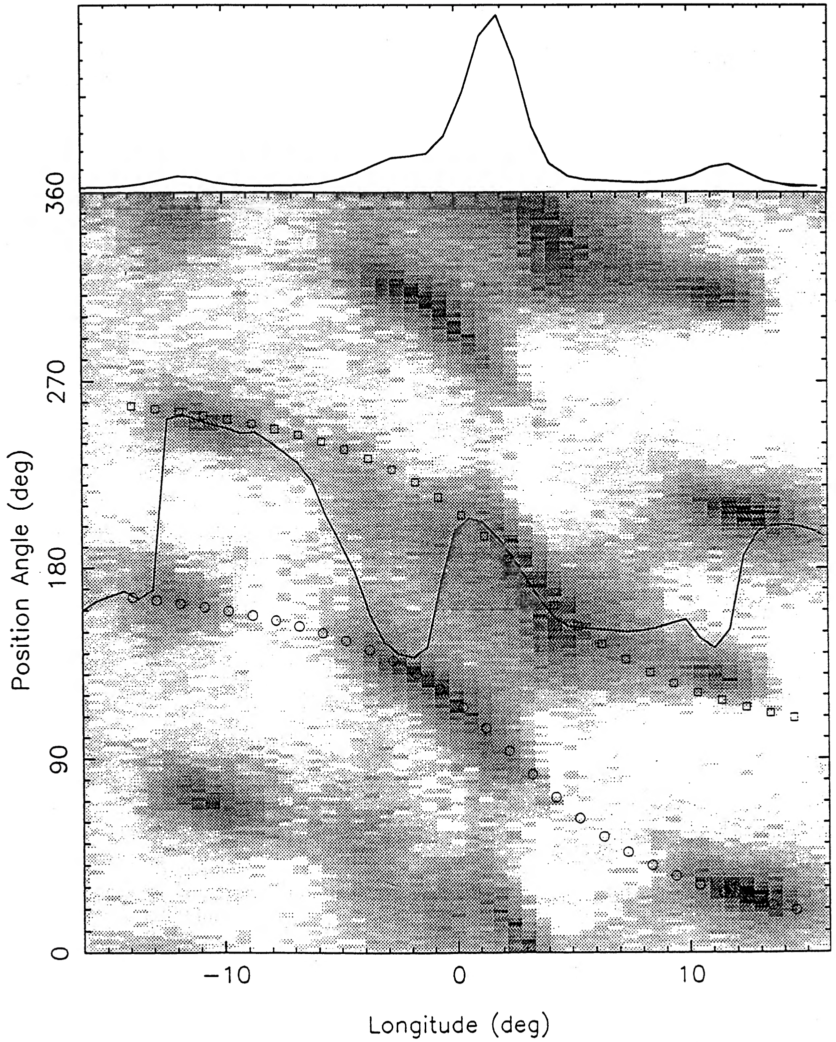
- Elliptically polarised
- Up to 100%
- Often S-like PA swing
- Degree of polarisation lower at high freq.

Orthogonal modes



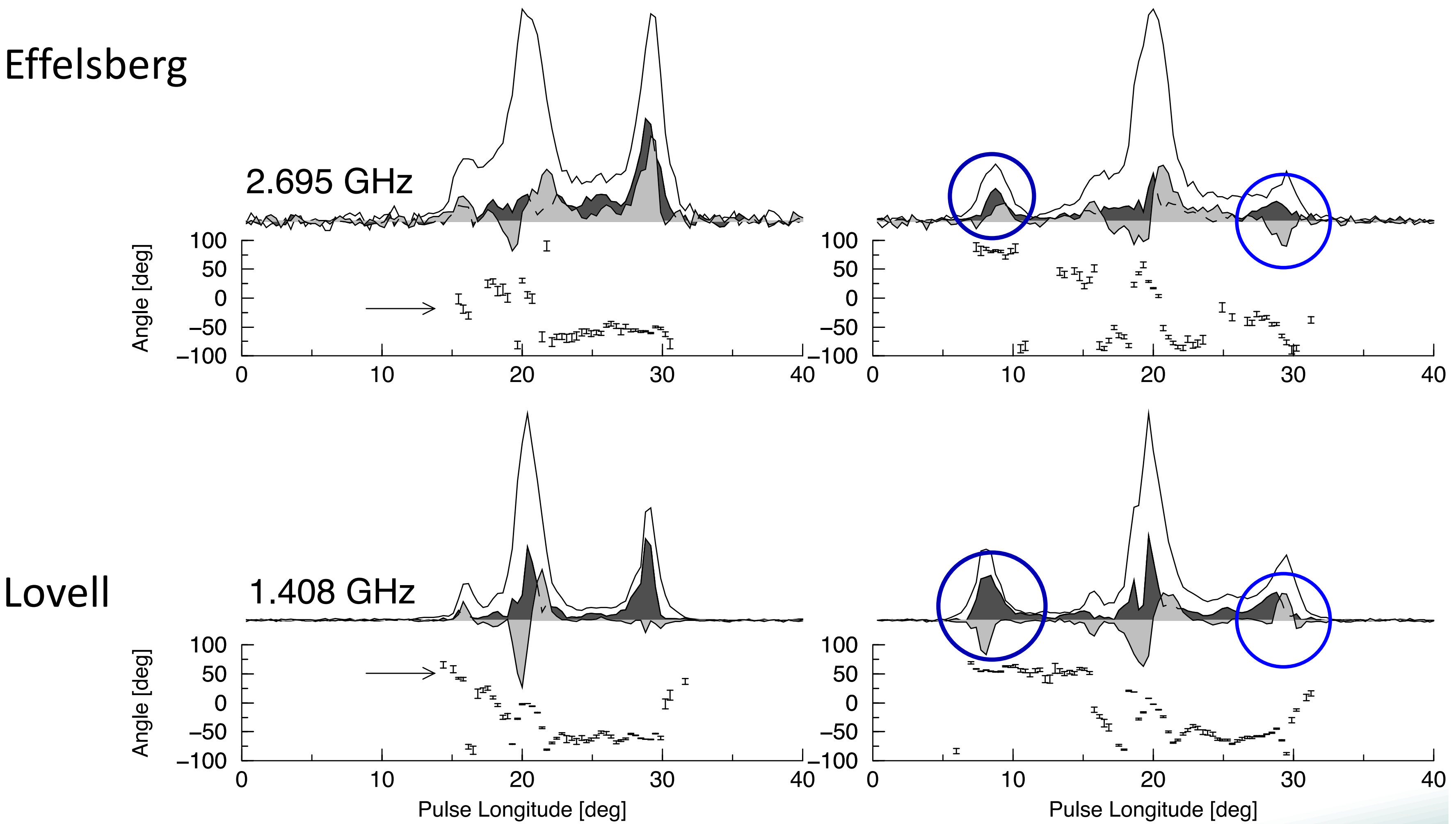
Orthogonal modes





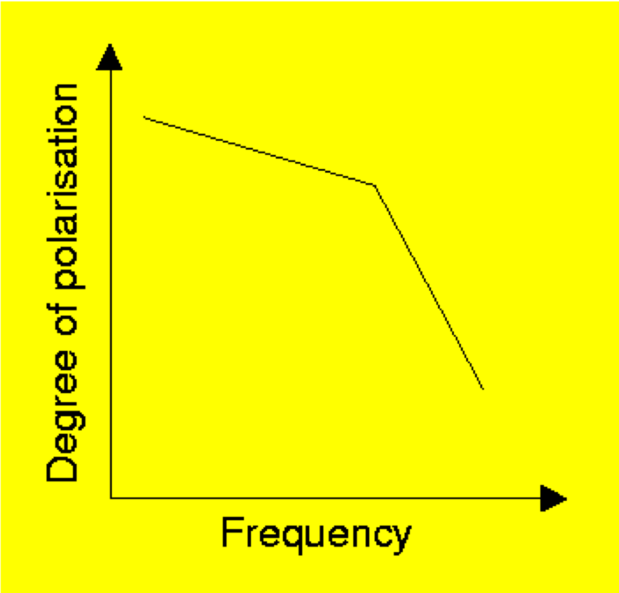
Gil & Lyne (1995)

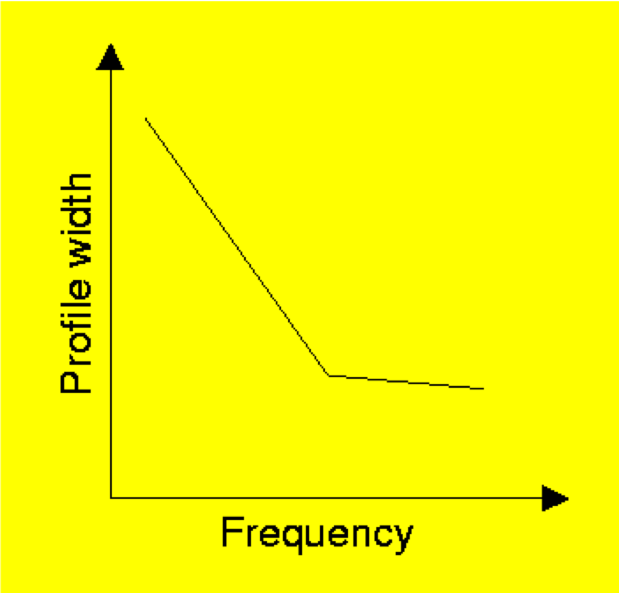
Orthogonal modes – not always broadband

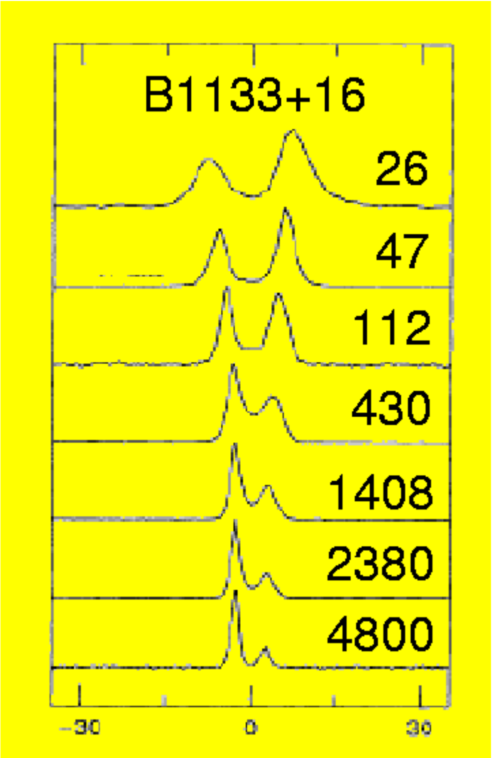


Karastergiou et al. (2001)

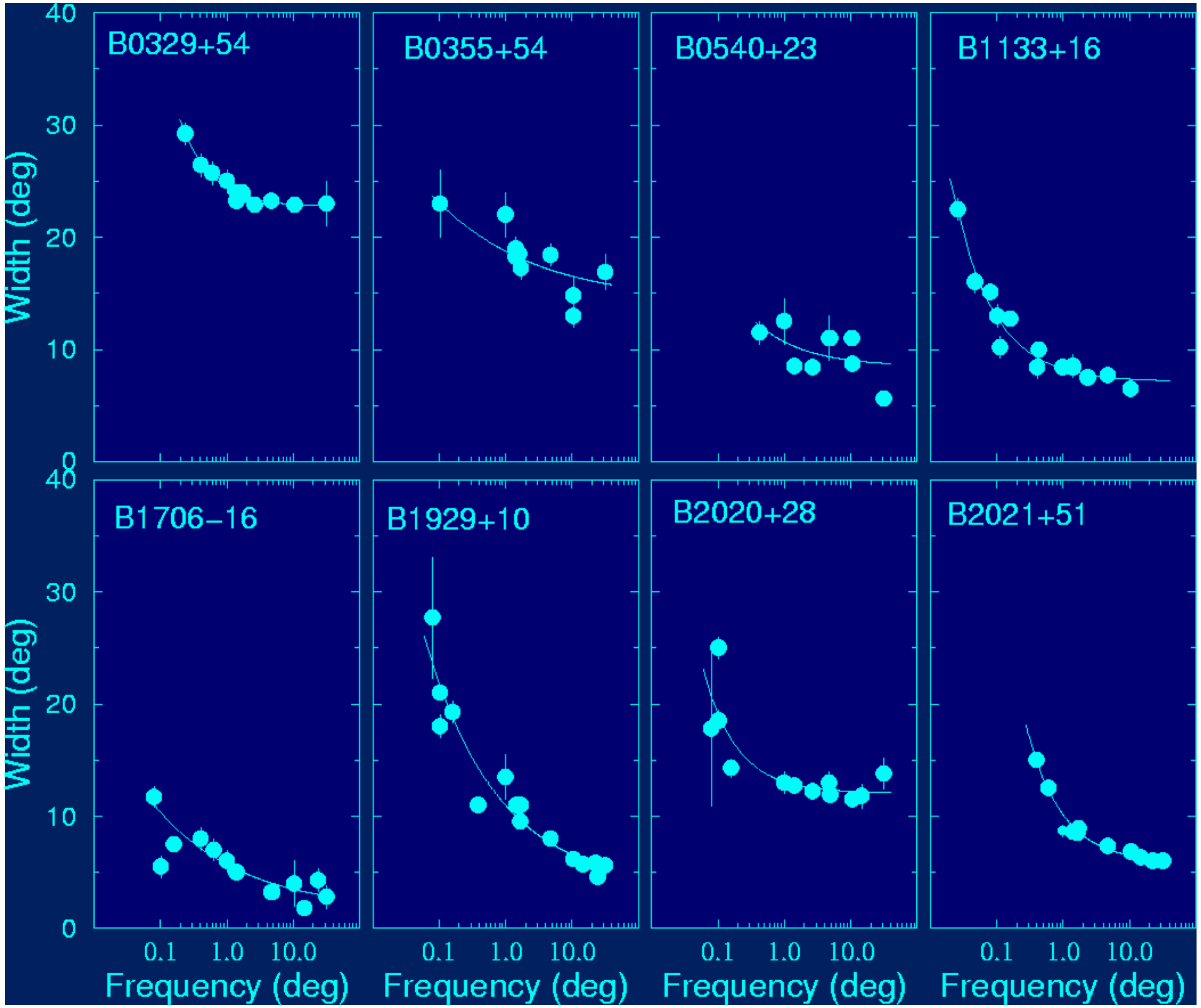
Profile properties

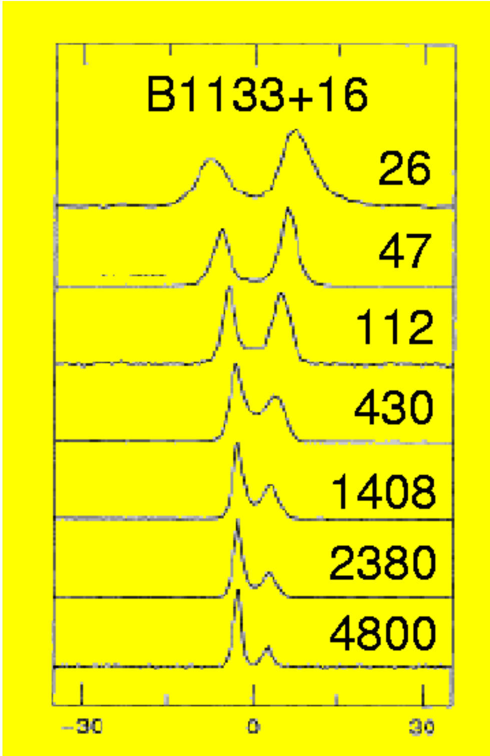




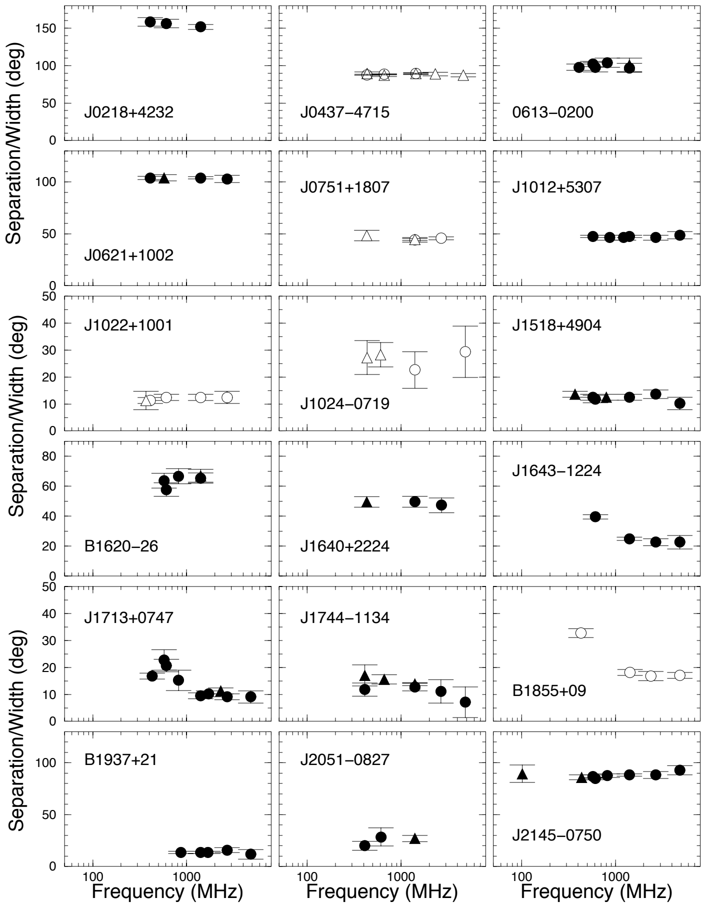


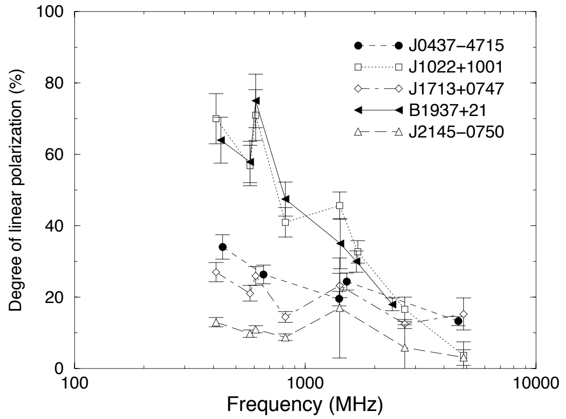
Profile properties



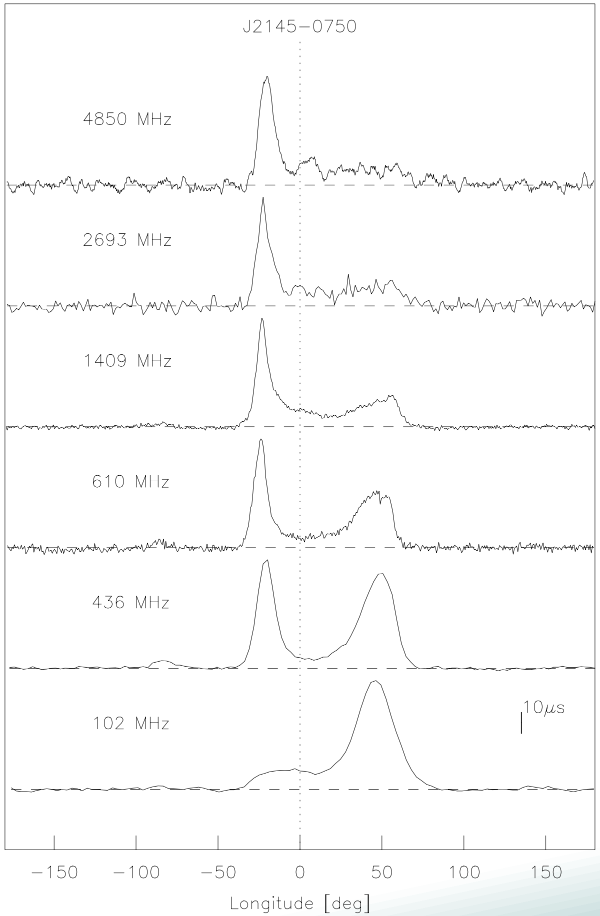


Profile properties - MSP

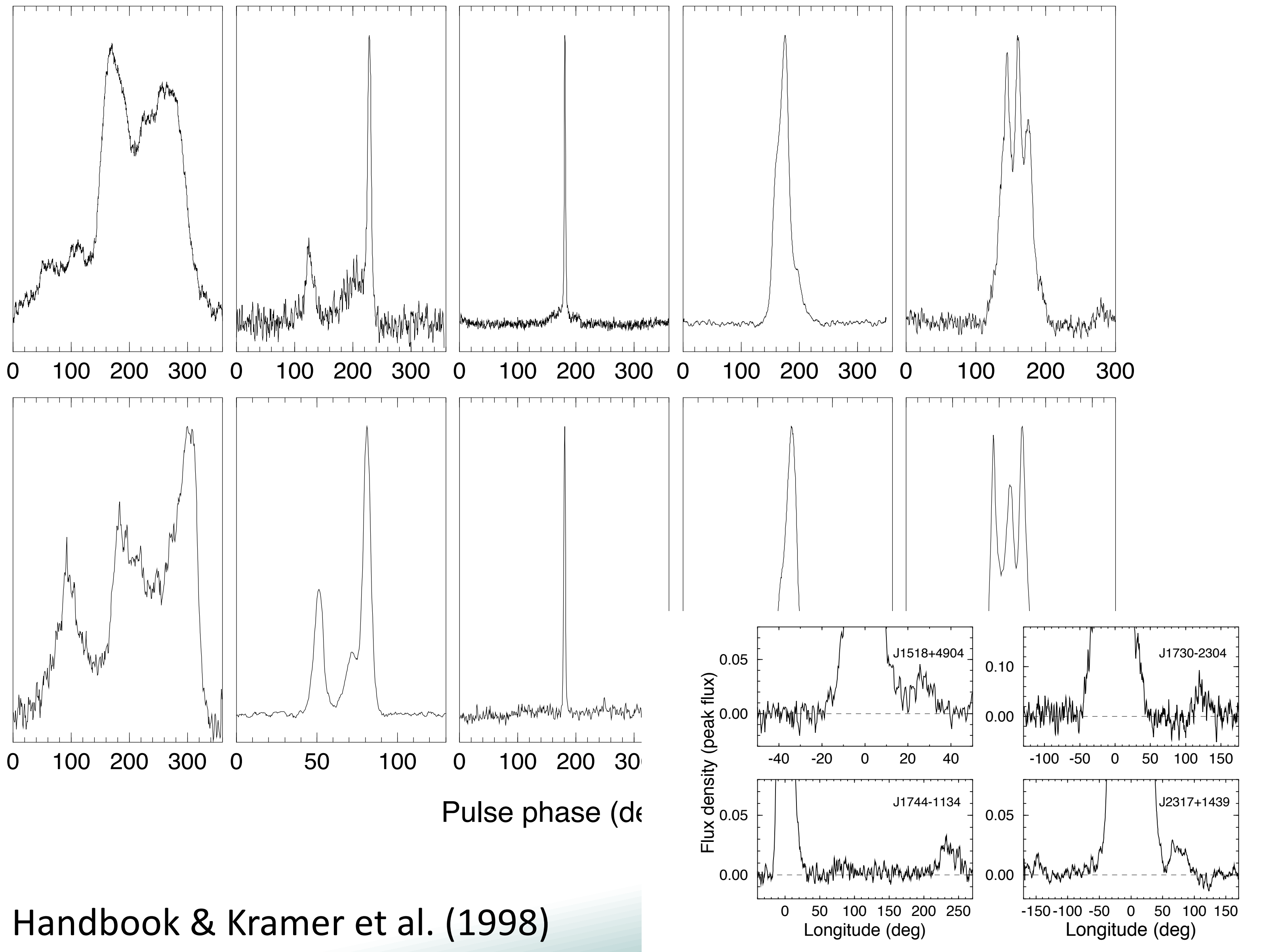




Kramer et al. (1999)

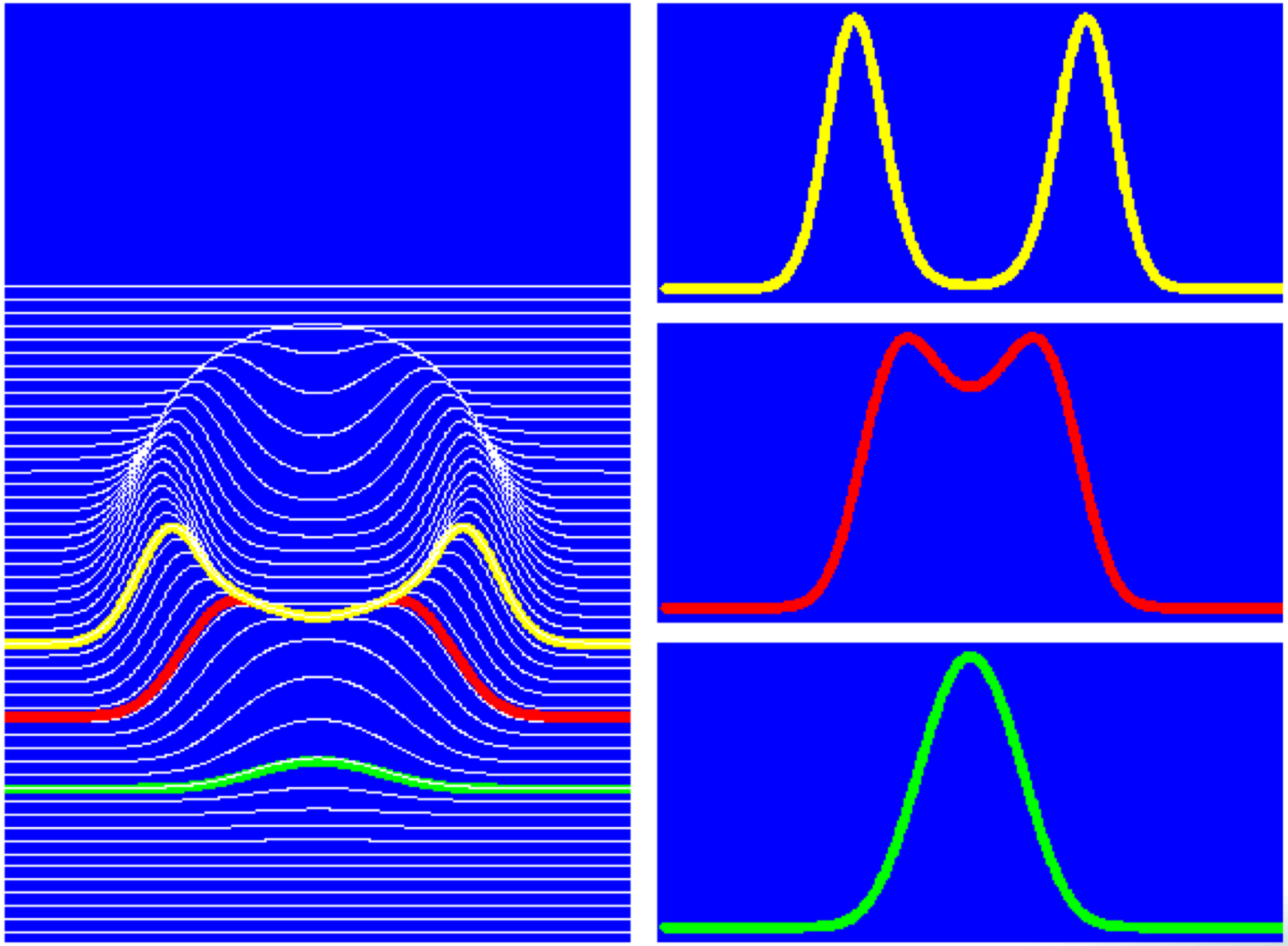


Profile properties – A comparison



Handbook & Kramer et al. (1998)

Profile determined by line-of-sight



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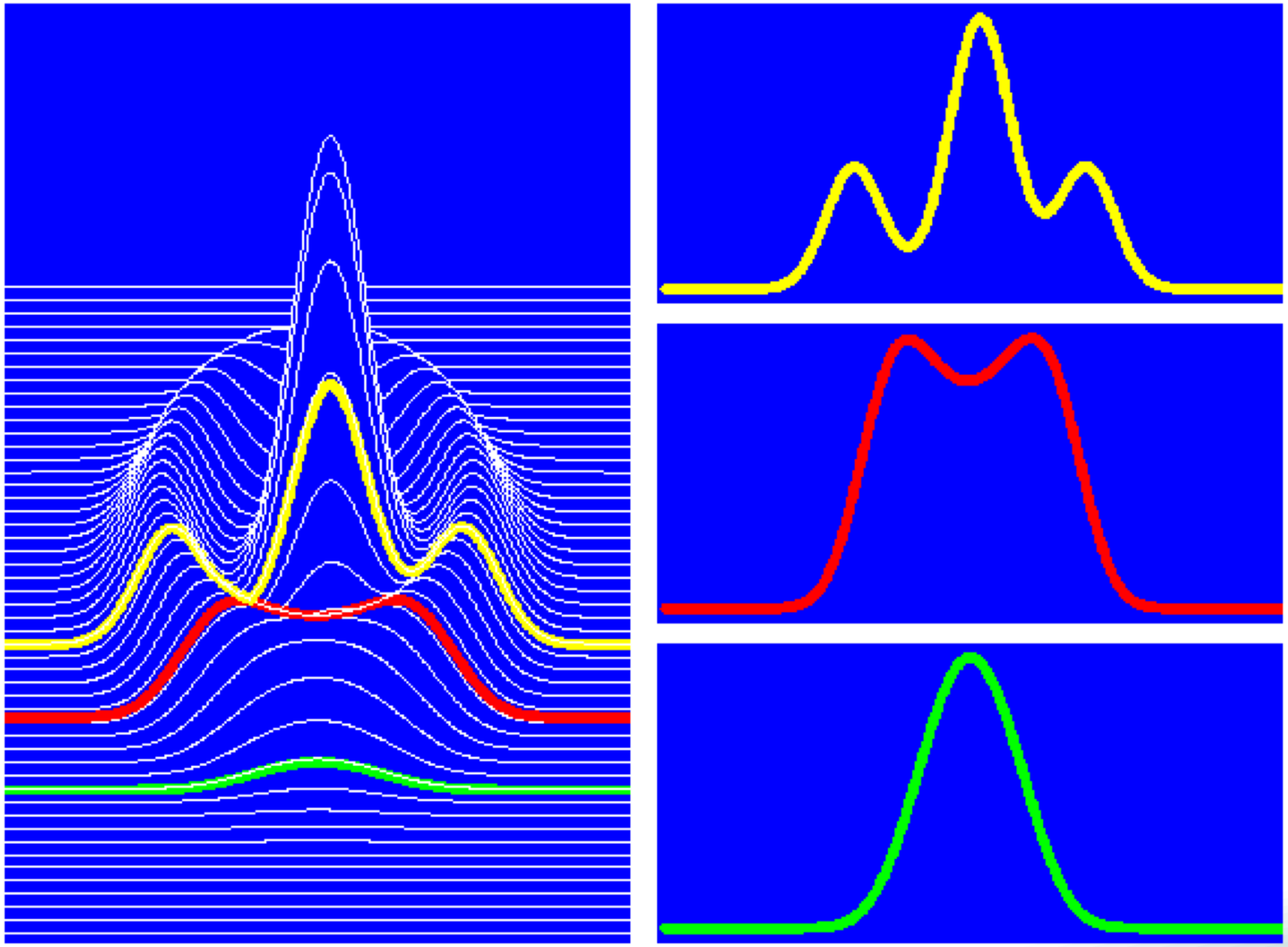
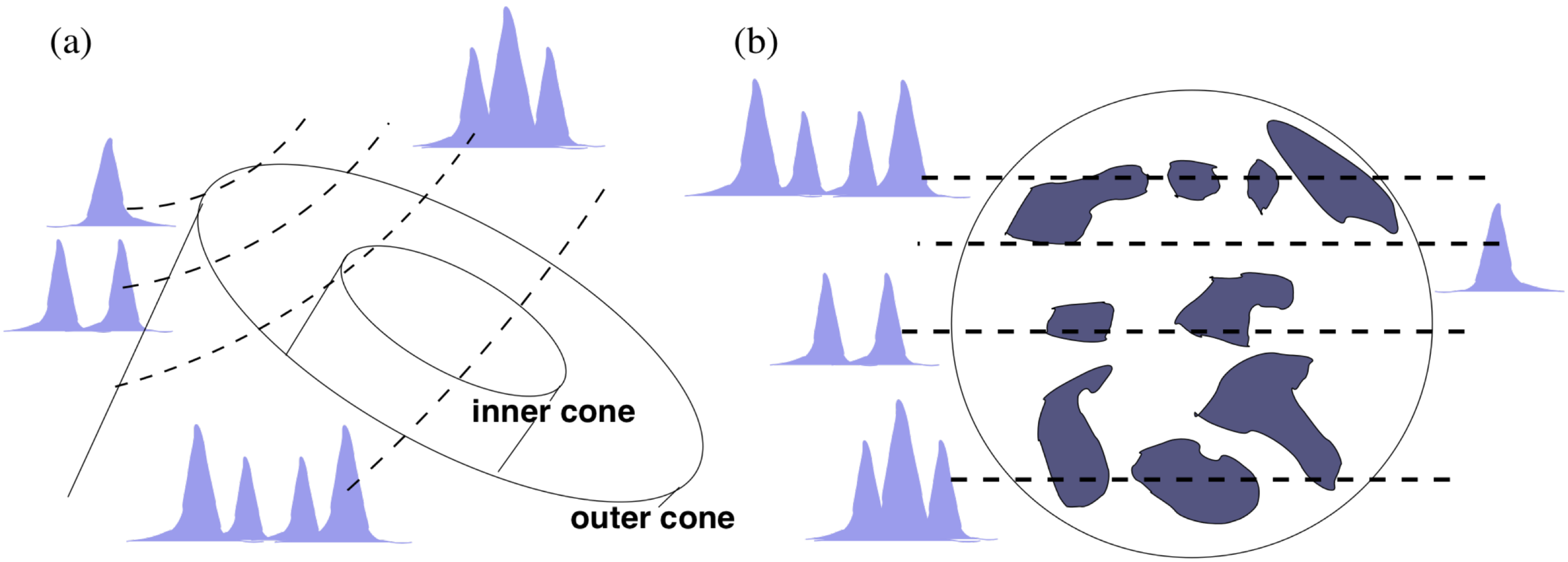
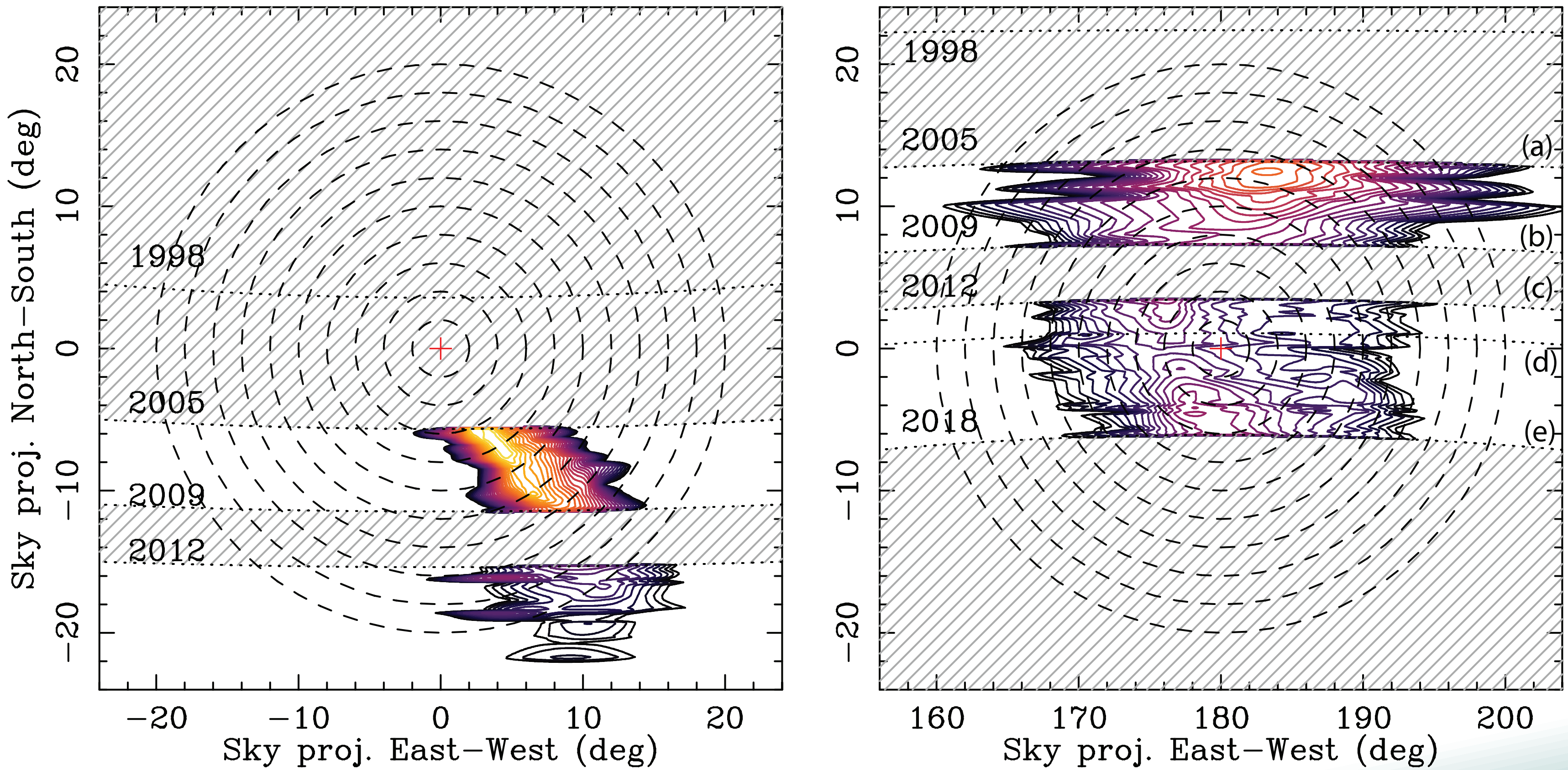


Patchy vs cone

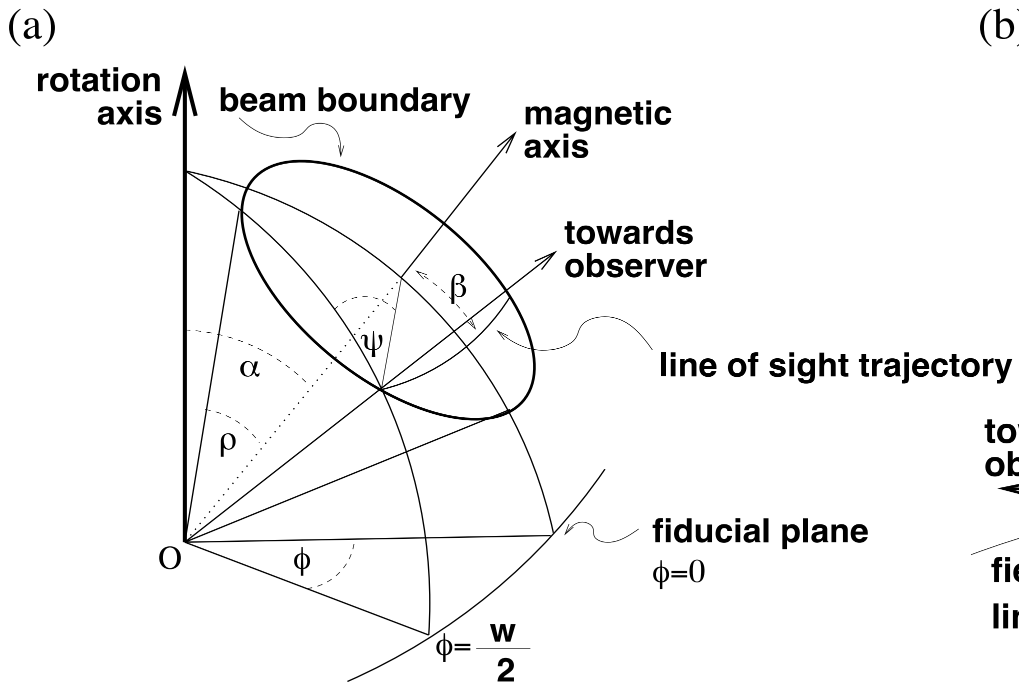


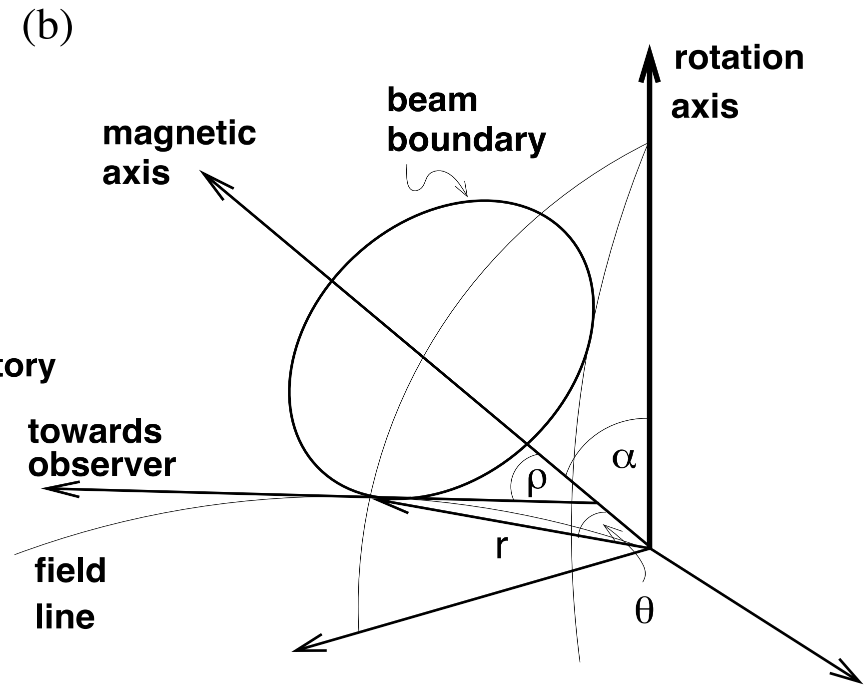
In reality

Desvignes et al. (2019)



(Spherical) Geometry





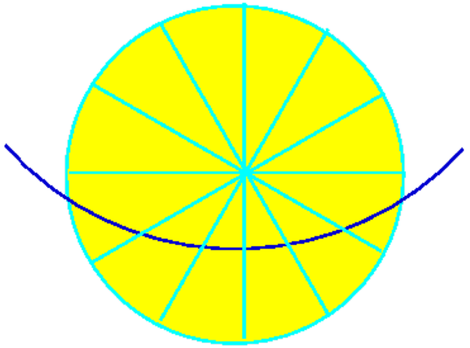
$$\sin^2\left(\frac{W}{4}\right) = \frac{\sin^2(\rho/2) - \sin^2(\beta/2)}{\sin\alpha \cdot \sin(\alpha+\beta)}$$

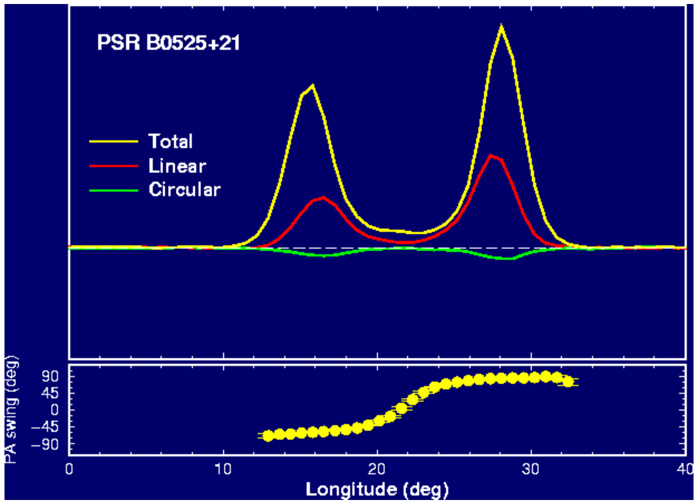
(Gil *et al.* 1984). Sometimes, the equivalent form

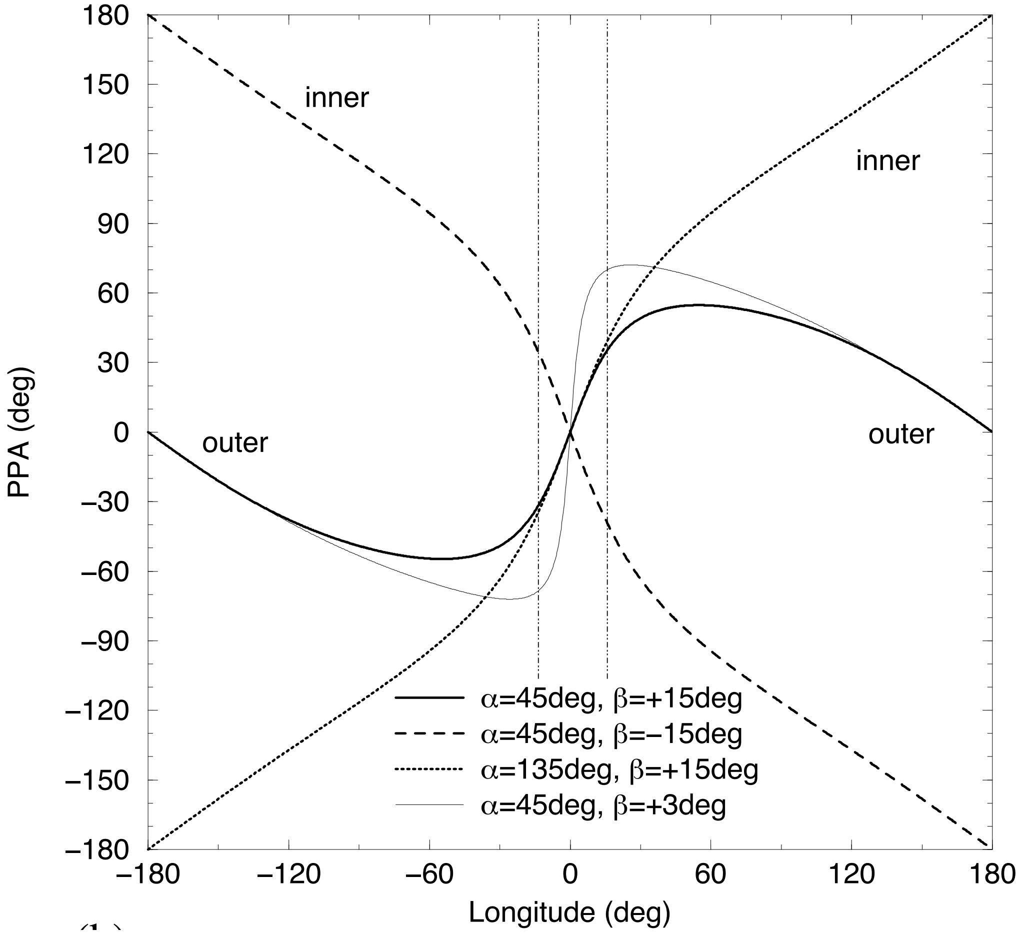
$$\cos\rho = \cos\alpha\cos(\alpha+\beta) + \sin\alpha\sin(\alpha+\beta)\cos\left(\frac{W}{2}\right)$$

$$\tan\theta = -\frac{3}{2\tan\rho} \pm \sqrt{2 + \left(\frac{3}{2\tan\rho}\right)^2}$$

Rotating Vector Model







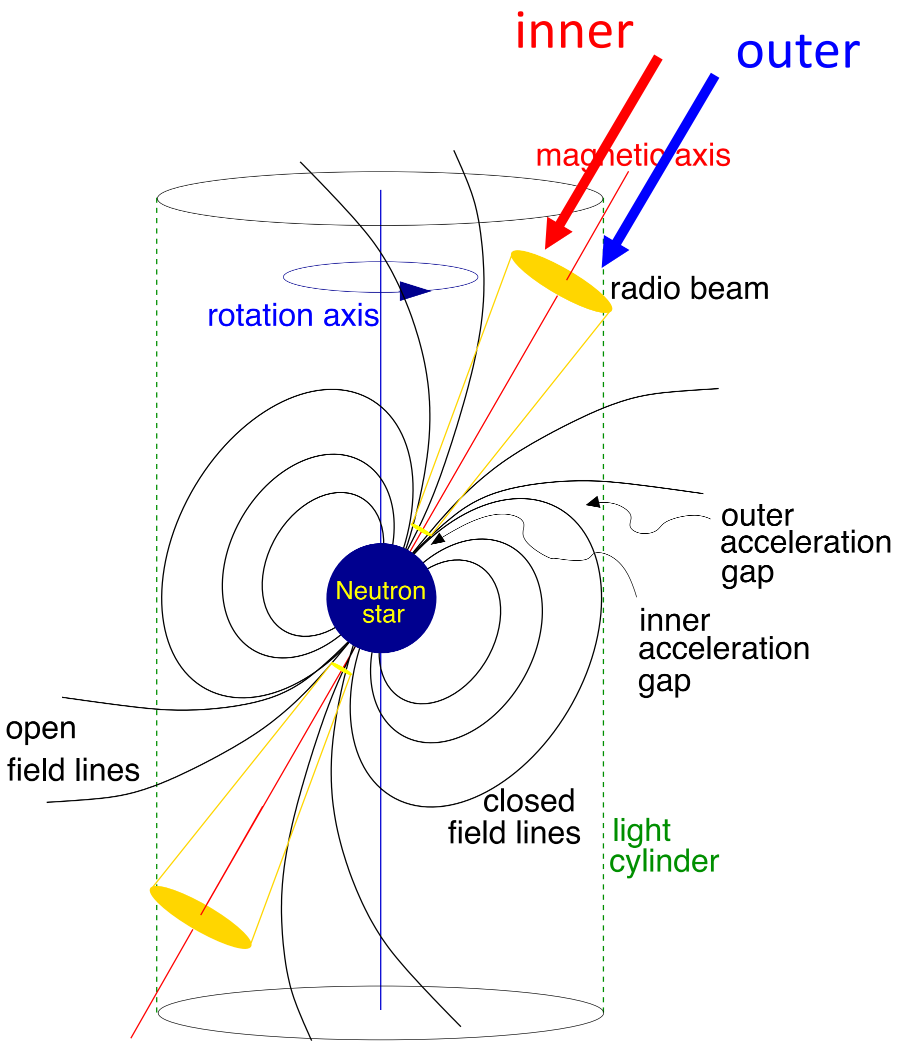
RC69:

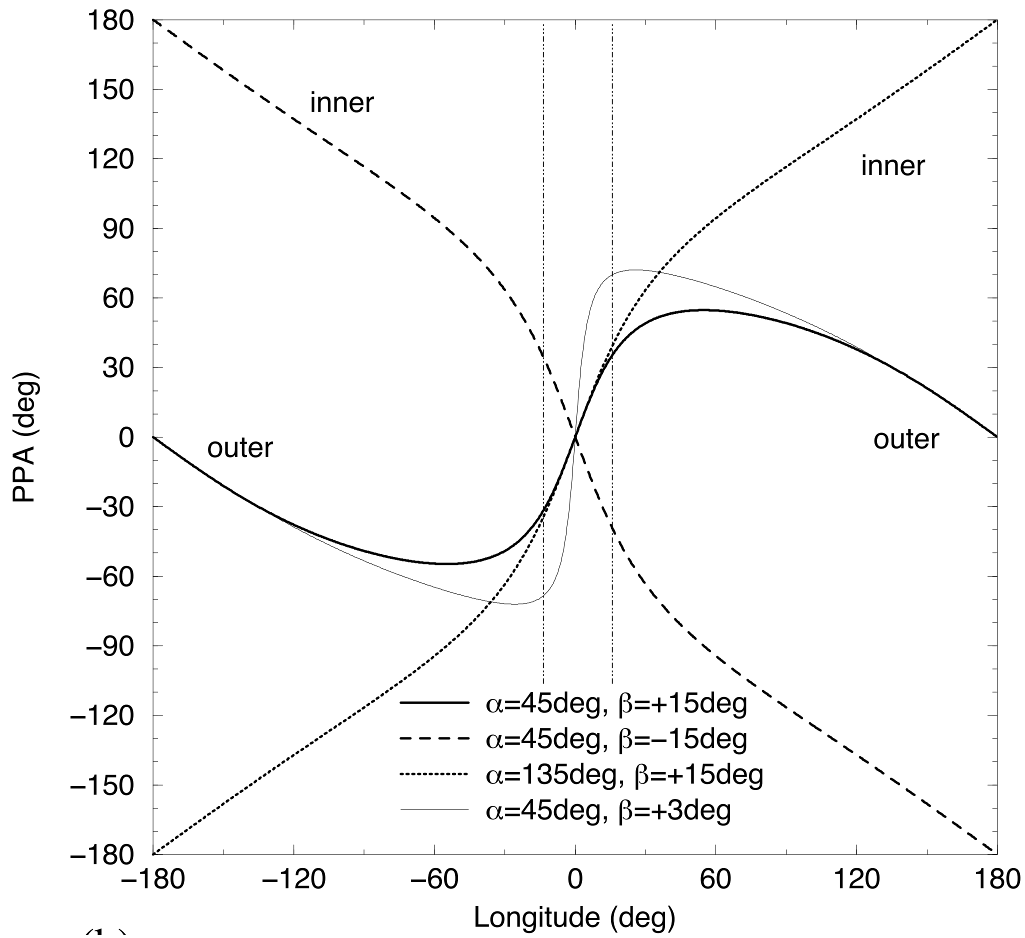
$$\tan(\Psi - \Psi_0) = \frac{\sin\alpha \;\sin(\phi - \phi_0)}{\sin(\alpha+\beta)\;\cos\alpha - \cos(\alpha+\beta)\sin\alpha\cos(\phi-\phi_0)},$$

$$\left(\frac{d\Psi}{d\phi}\right)_{\max} = \frac{\sin\alpha}{\sin\beta}$$

Important: psrchive convention is reversed!

Rotating Vector Model





RC69: $$\tan(\Psi - \Psi_0) = \frac{\sin\alpha\ \sin(\phi-\phi_0)}{\sin(\alpha+\beta)\ \cos\alpha - \cos(\alpha+\beta)\sin\alpha\cos(\phi-\phi_0)},$$

$$\left(\frac{d\Psi}{d\phi}\right)_{\max} = \frac{\sin\alpha}{\sin\beta}$$

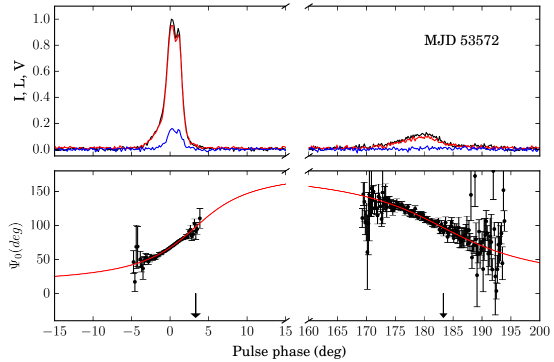
Important: psrchive convention is reversed!

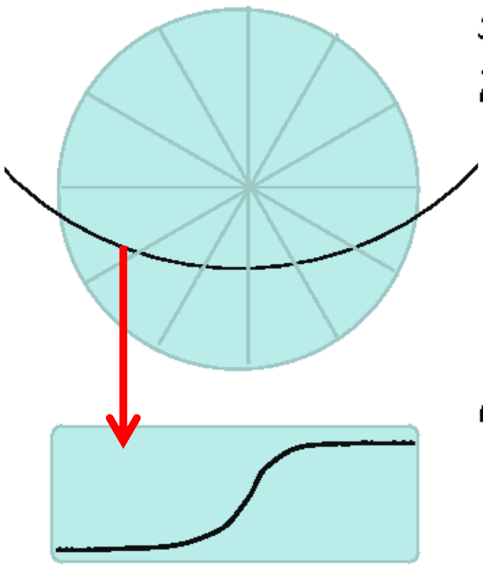
Best evidence for RVM interpretation

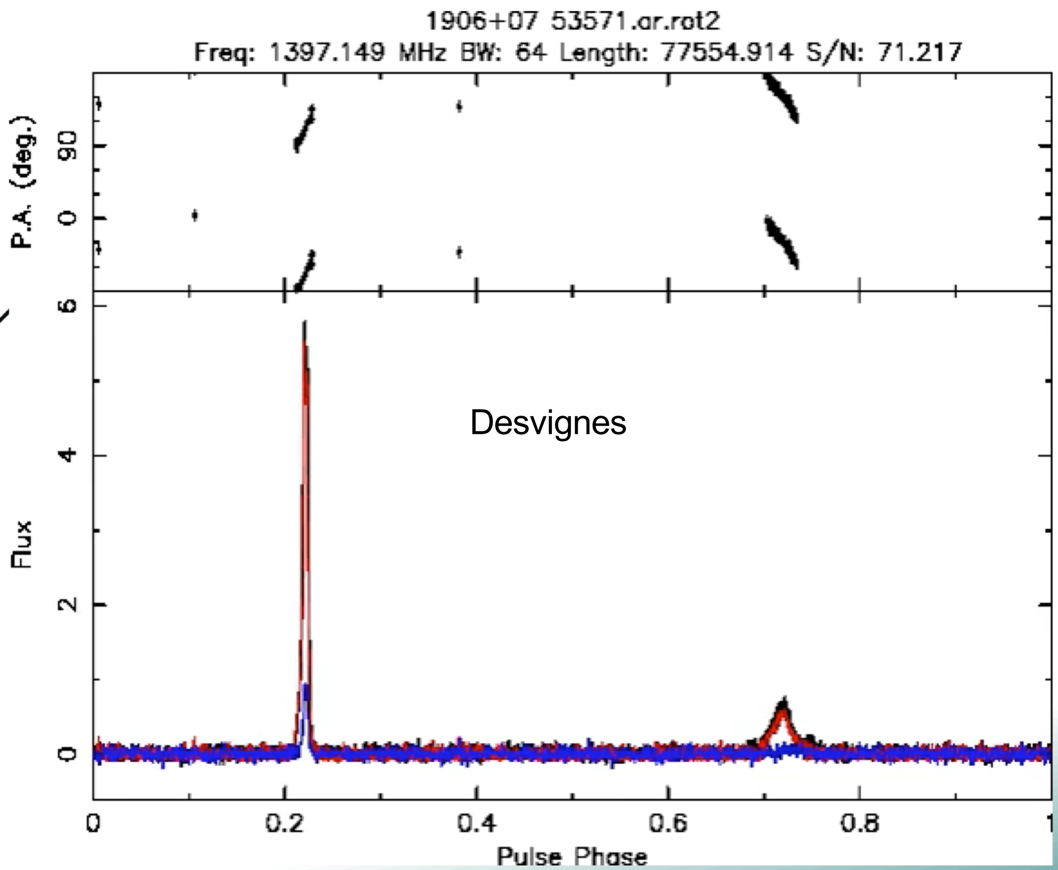
New results on relativisitic binary (Desvignes, et al. 2019)

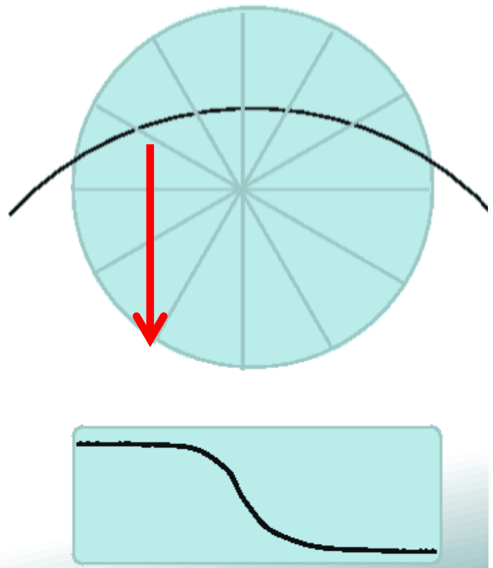
- Our line-of-sight has crossed the pole of interpulse!

-









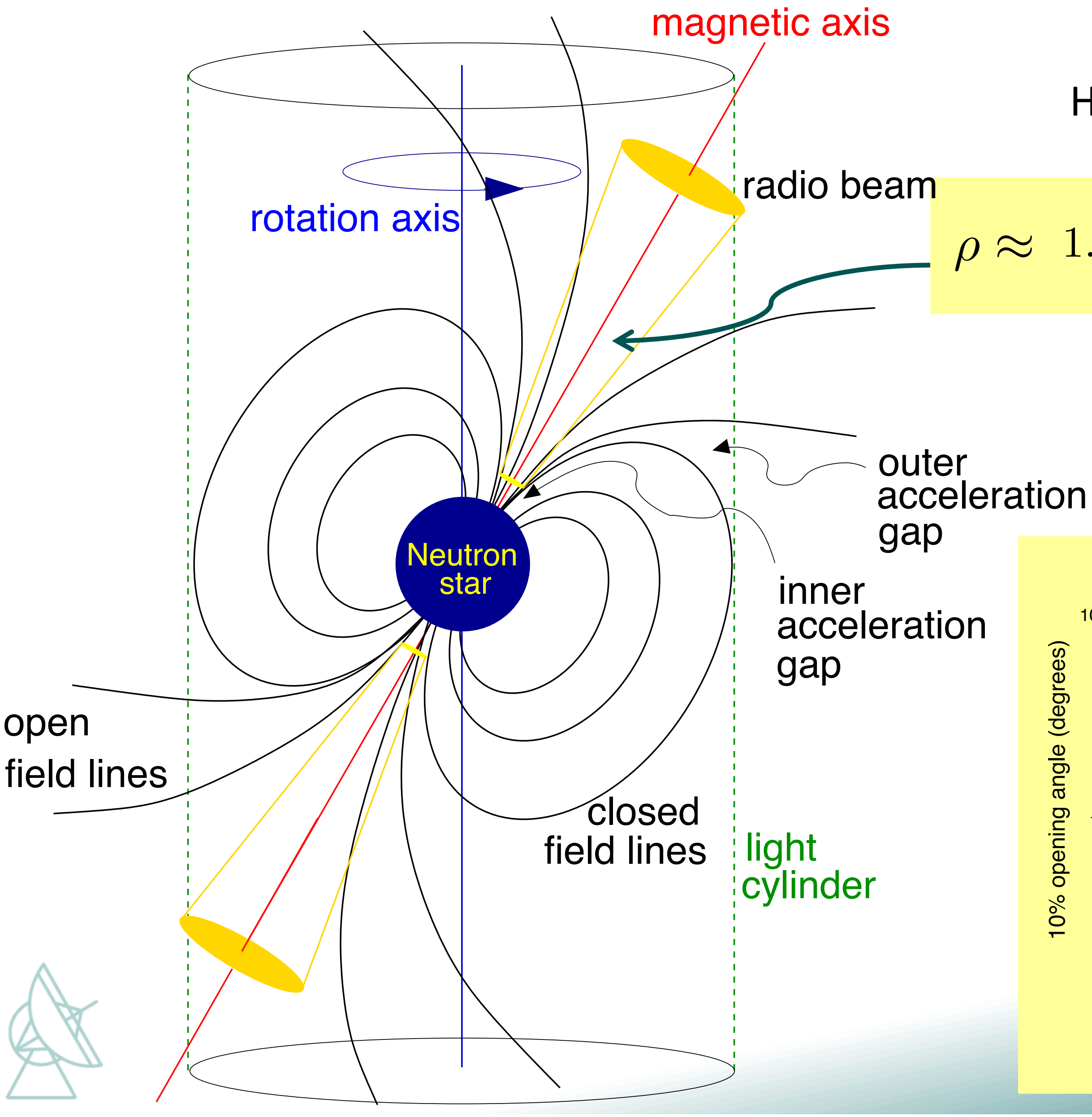
Emission heights: geometrical

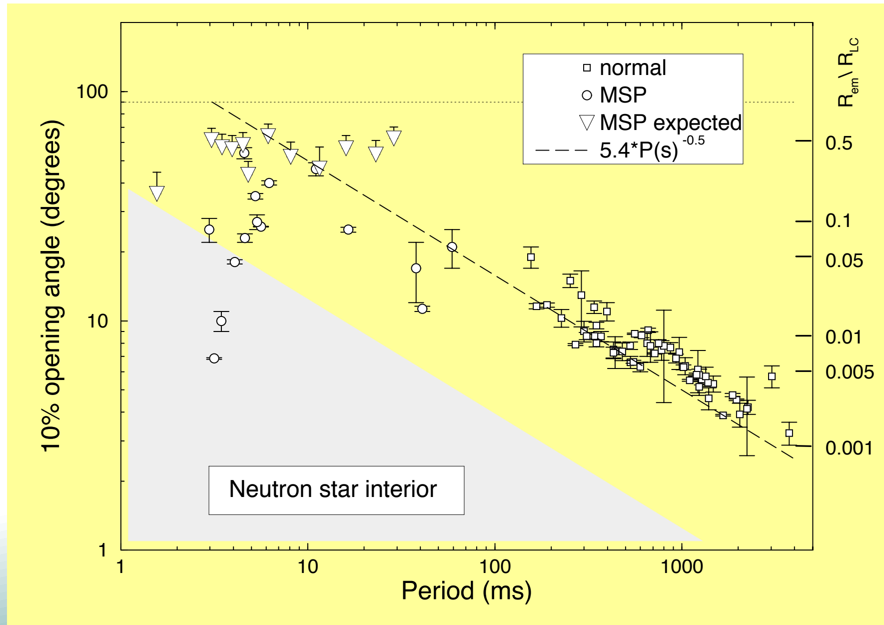
Emission height...?

Handbook: dipolar field $\sin^2\theta/r=\mathrm{const}$:

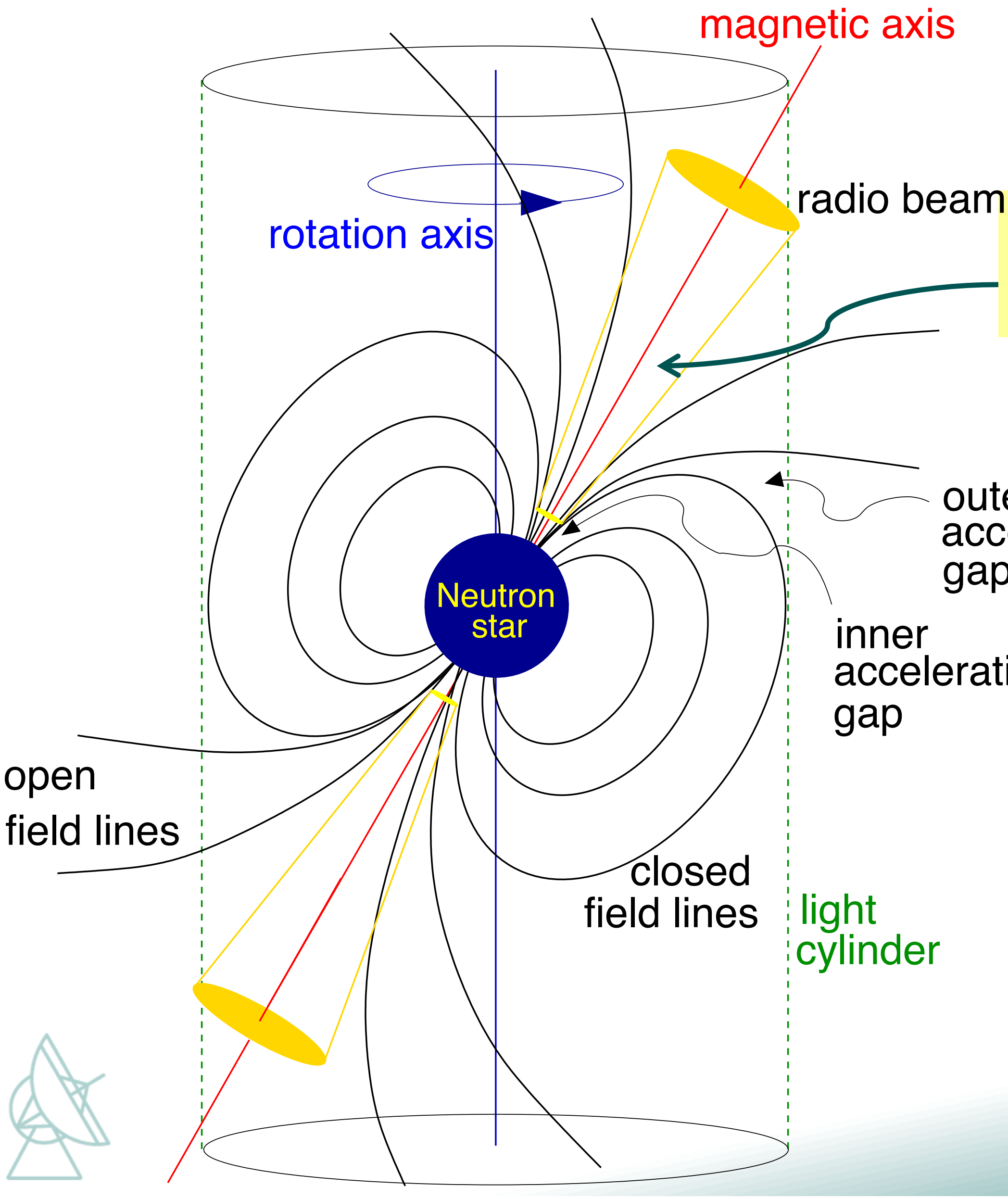
$$\rho \approx 1.24^\circ \left(\frac{r_{\rm em}}{10\ \rm km}\right)^{1/2} \left(\frac{P}{\rm s}\right)^{-1/2}, \quad (3.29)$$

or $$r_{\rm em} \approx k\rho^2, \quad k = k(P)$$





Emission heights: geometrical



Emission height...?

Handbook: dipolar field $\sin^2\theta/r$=const:

$$\rho \approx 1.24^\circ \left(\frac{r_{\rm em}}{10\ {\rm km}}\right)^{1/2} \left(\frac{P}{\rm s}\right)^{-1/2}, \quad (3.29)$$

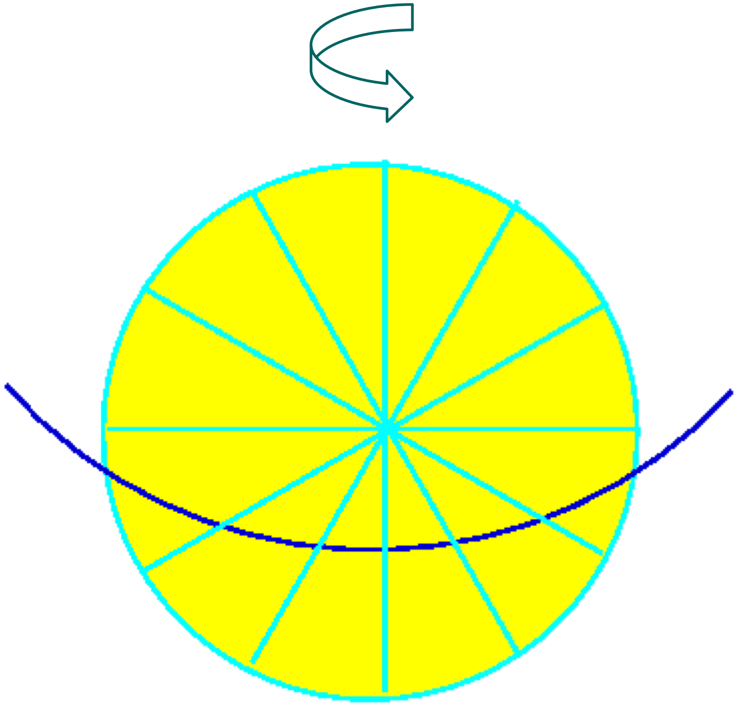
or $\quad r_{\rm em} \approx k\rho^2, \quad k = k(P)$

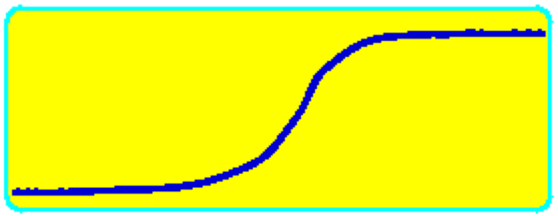
Only other method: BCW'91

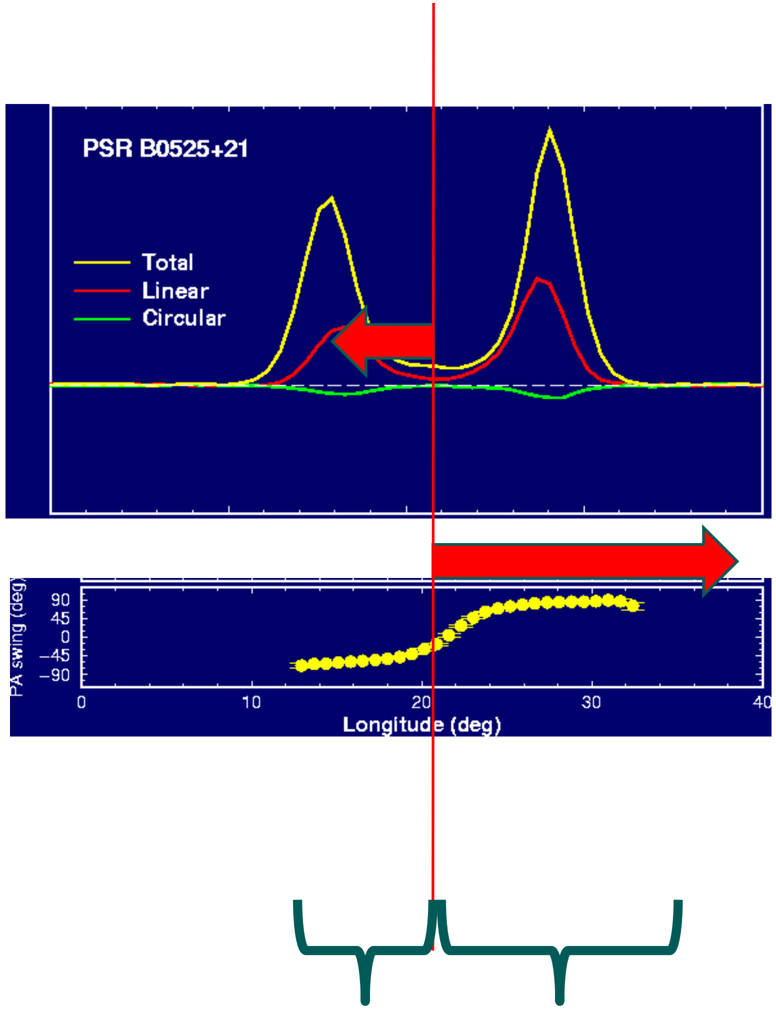
$$r_{\rm em} = \frac{4}{cP}\Delta\Phi$$

Special relativistic effect
in polarisation data...

Aberration effects: PA vs Profile shifts





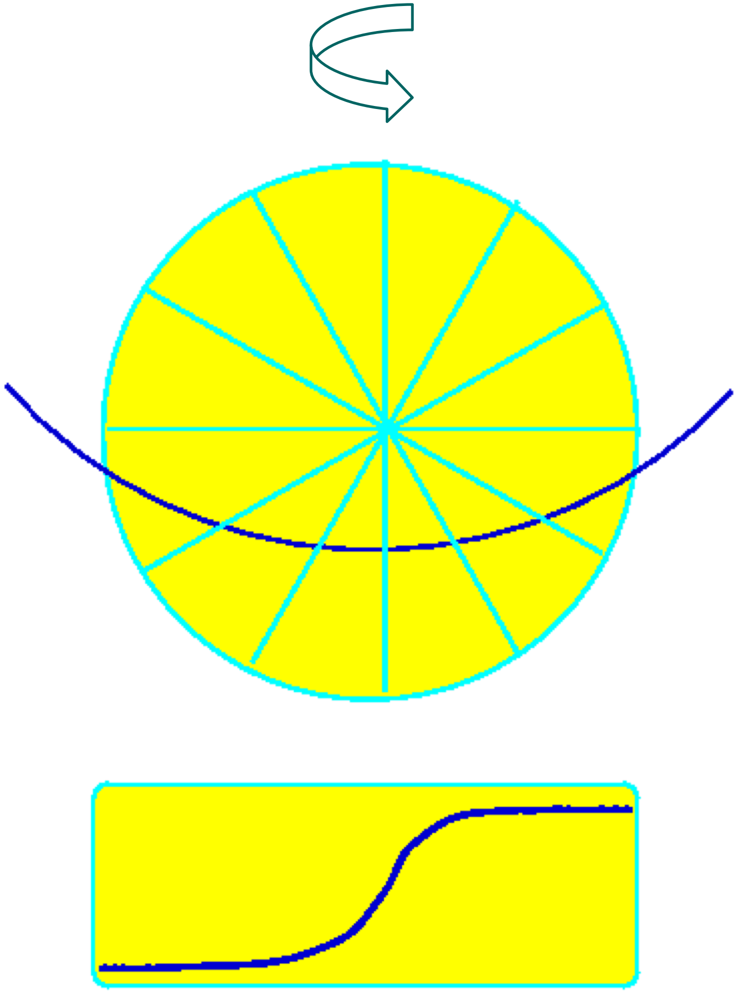


$\Delta\Phi_{\rm Prof}$ $\Delta\Phi_{\rm PA}$

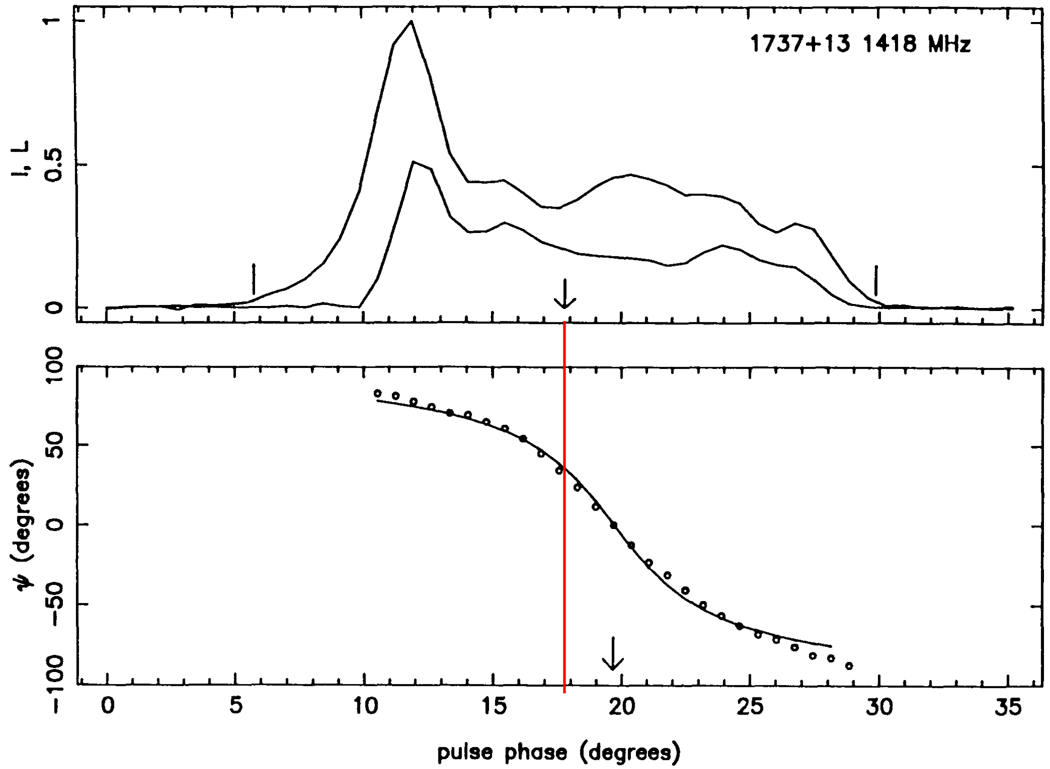
$$r_{\rm em} = \frac{4}{cP}\Delta\Phi$$

$$\Delta\Phi = \Delta\Phi_{\rm Prof} + \Delta\Phi_{\rm PA}$$

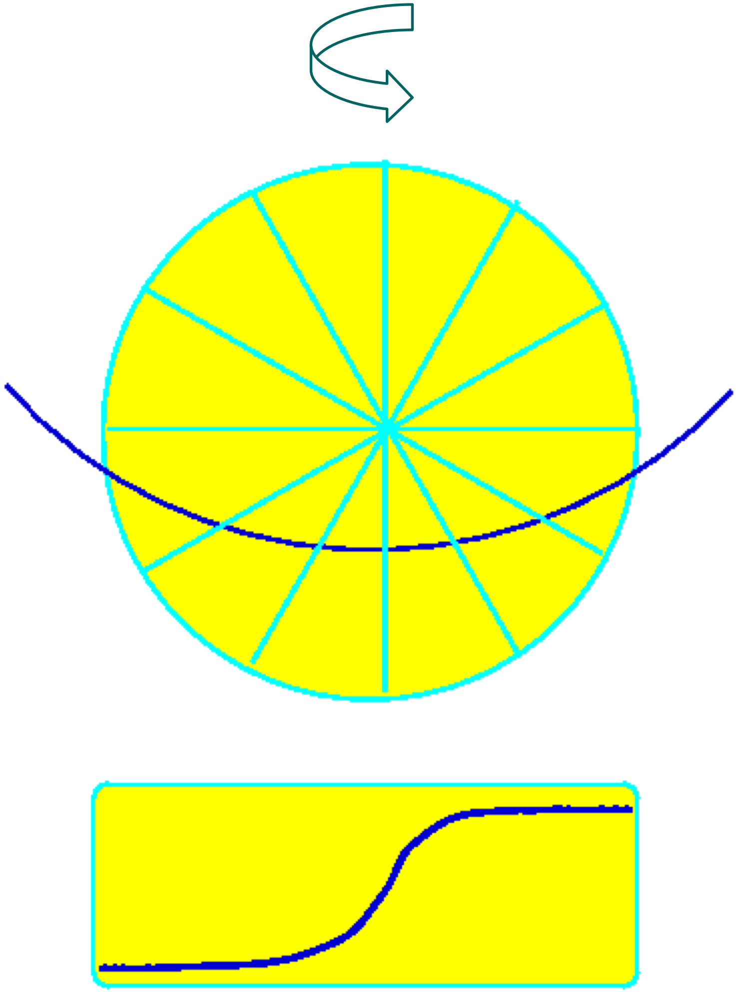
Aberration effects: PA vs Profile shifts

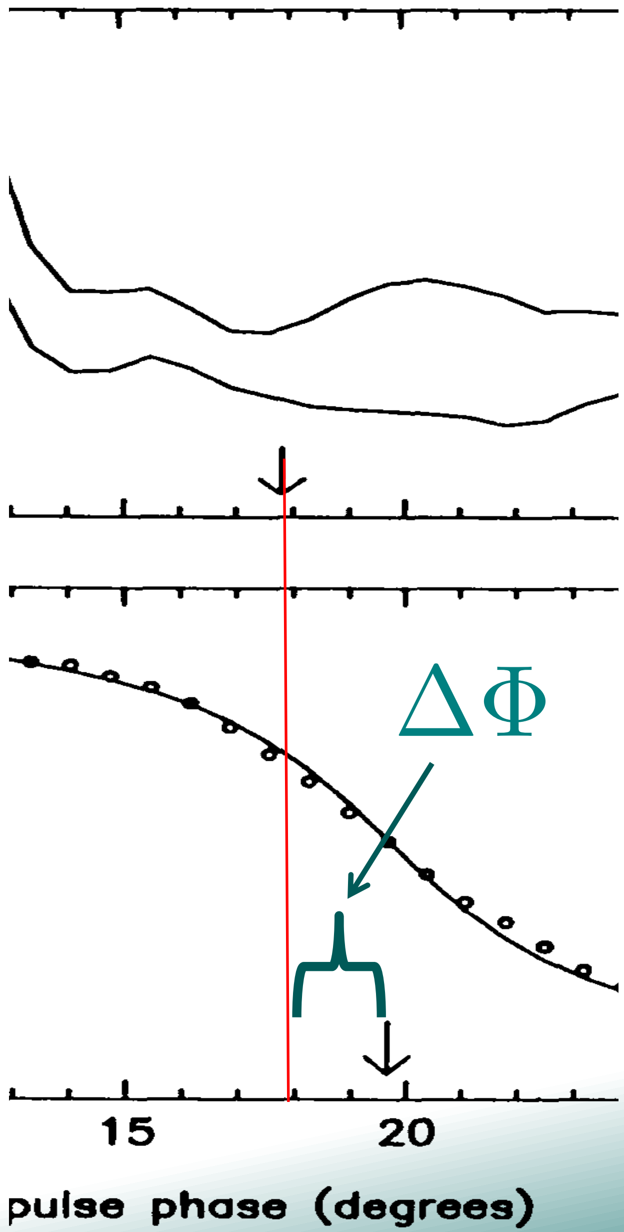


Shift observed: BCW (1991)



Aberration effects: PA vs Profile shifts

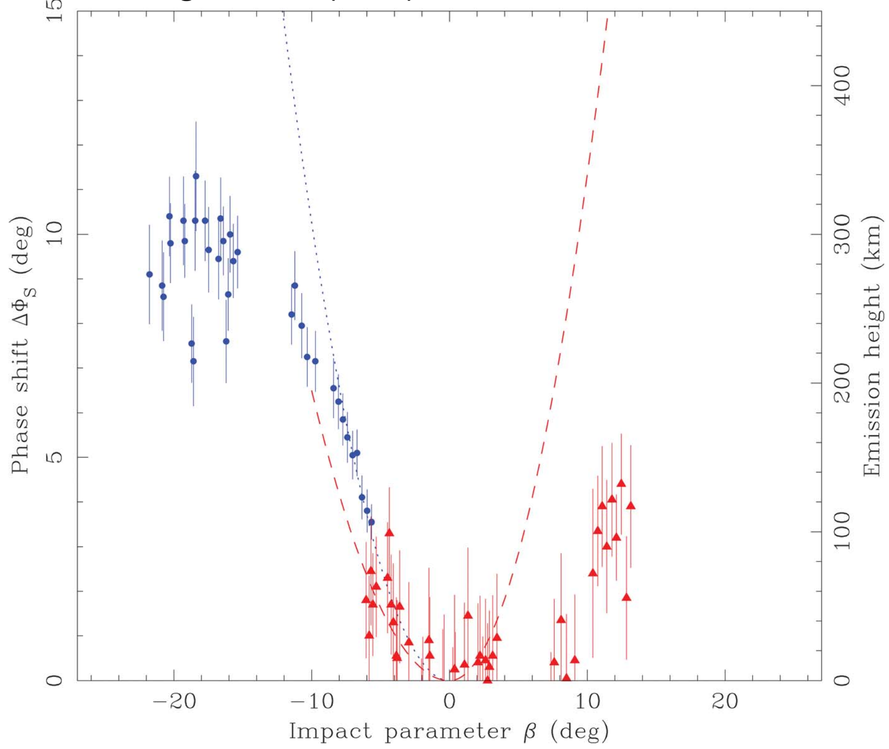


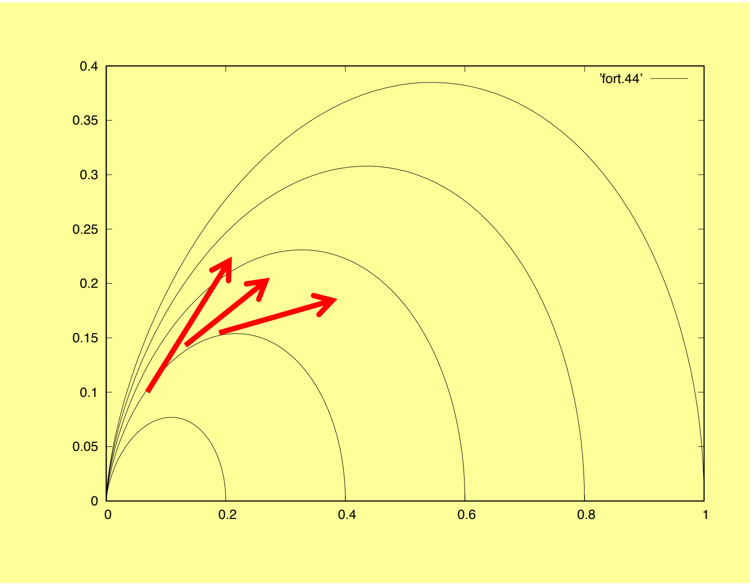


$$r_{\rm em} = \frac{4}{cP}\Delta\Phi$$

Emission heights as function of distance to pole

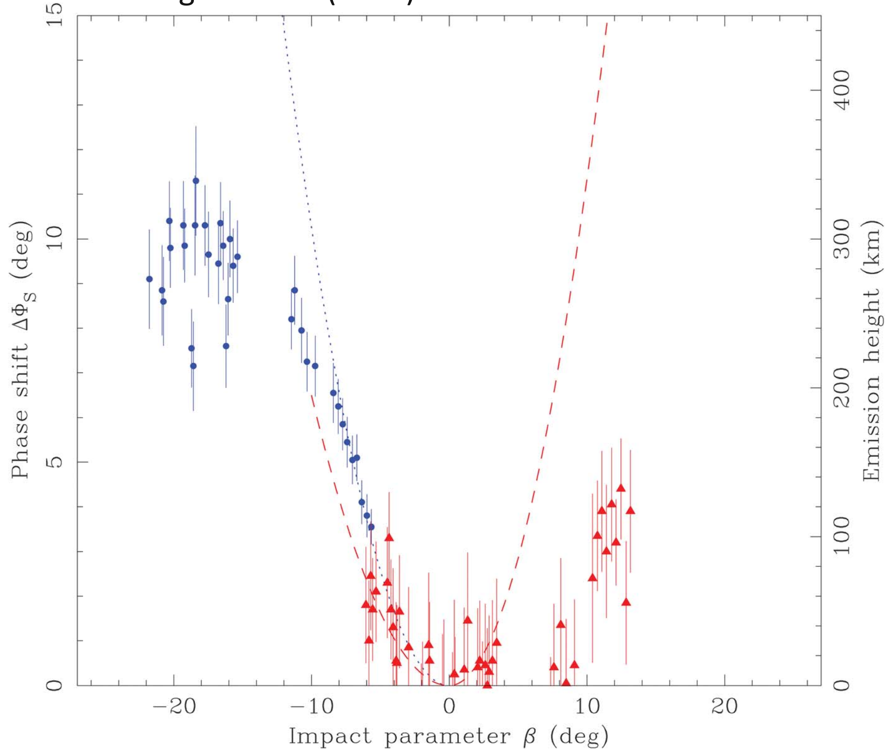
Desvignes et al. (2019)



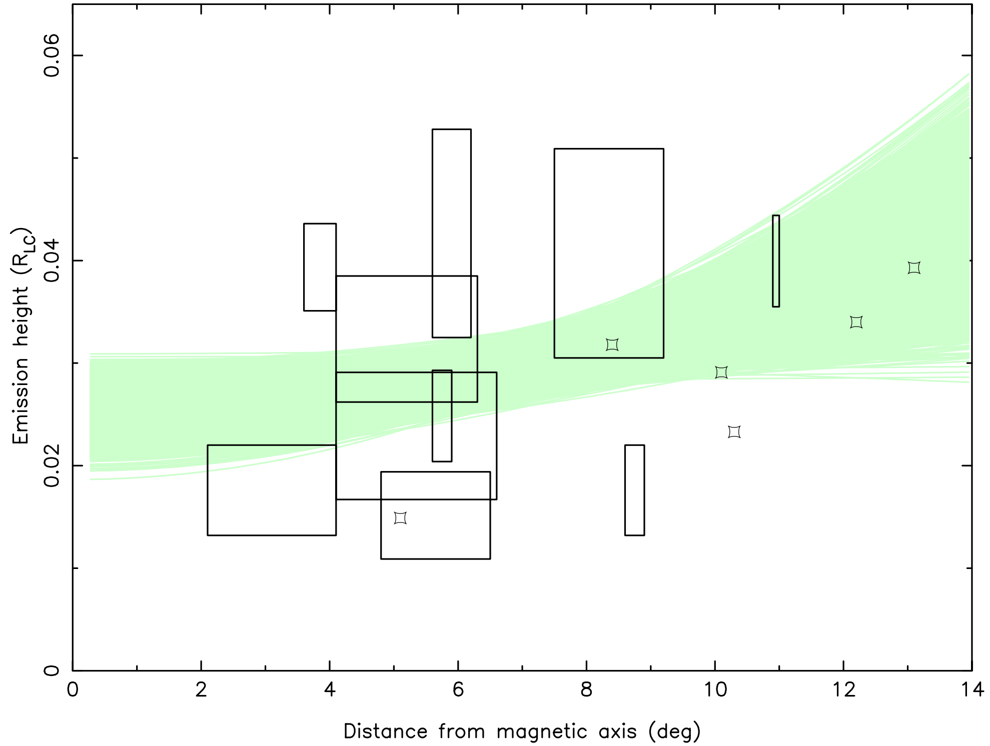


Emission heights as function of distance to pole

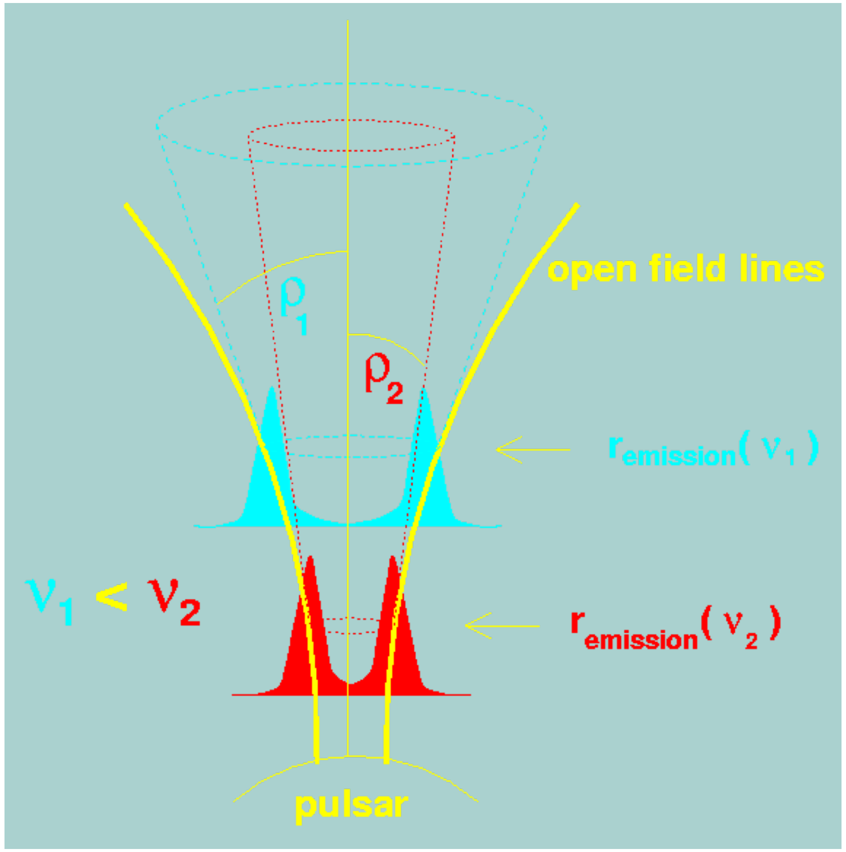
Desvignes et al. (2019)

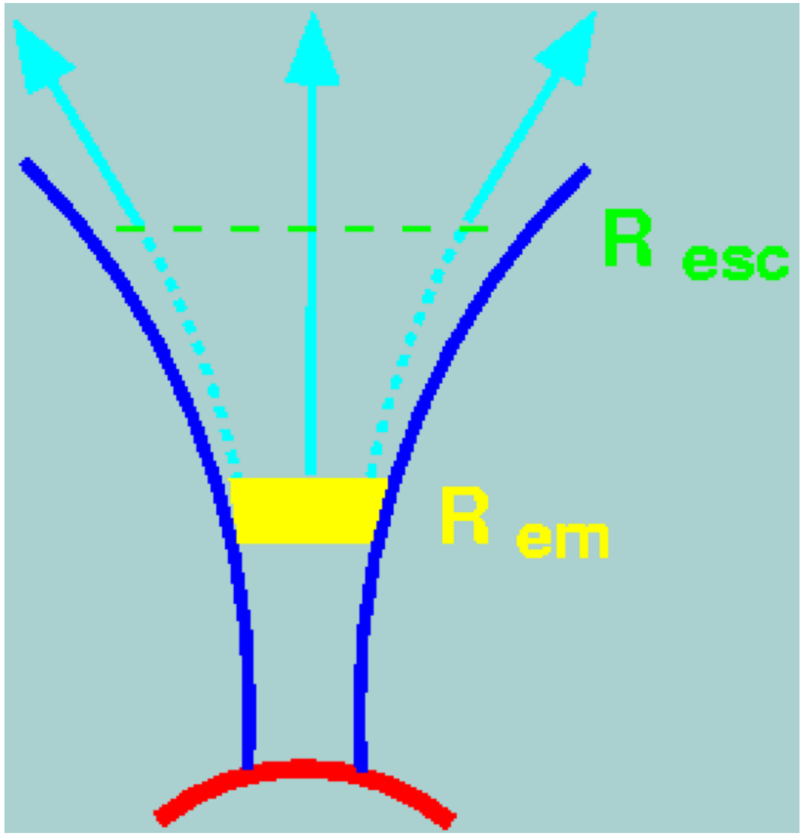


Johnston & Kramer et al. (2019)

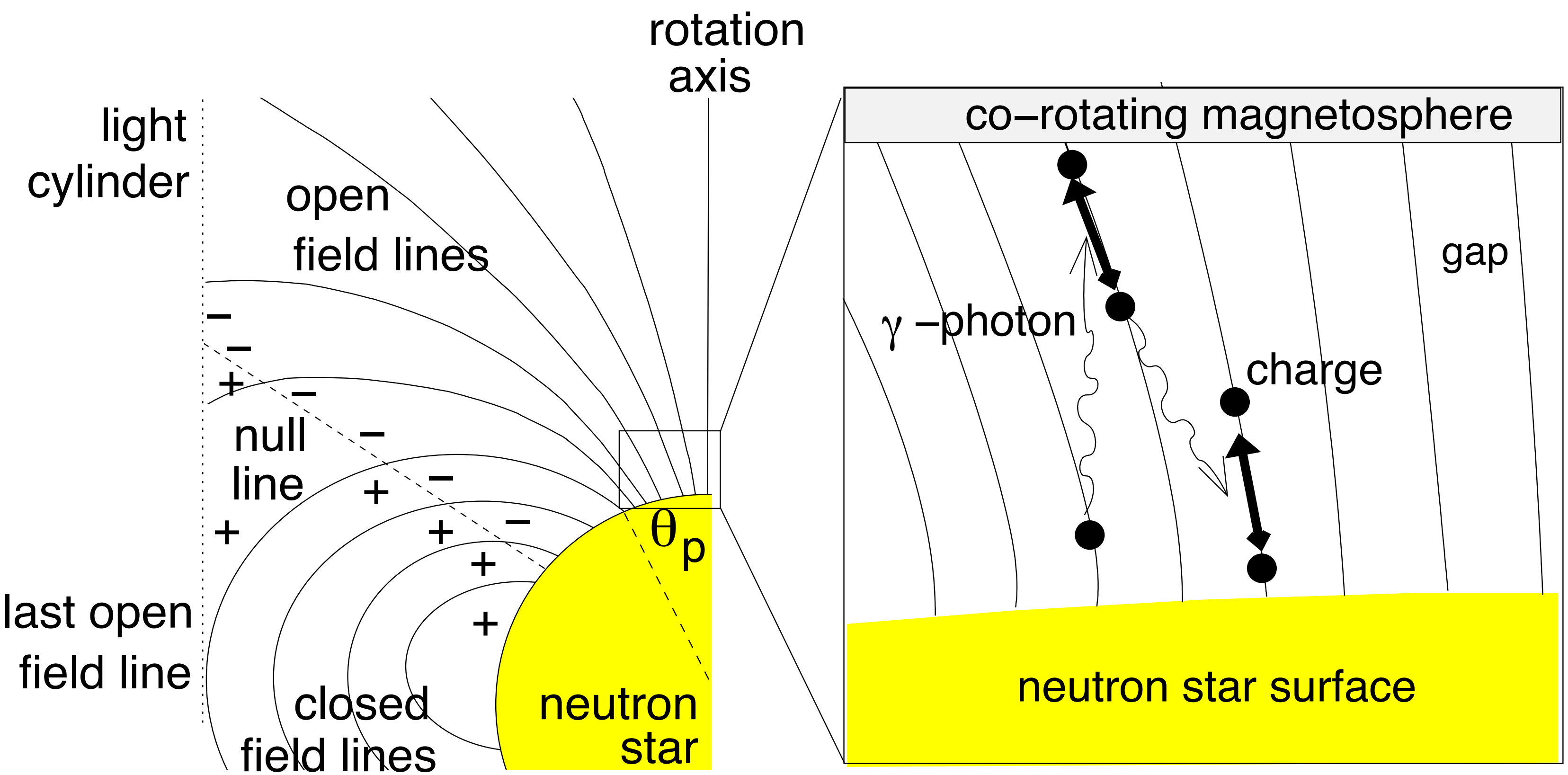


Emission heights as function of frequency

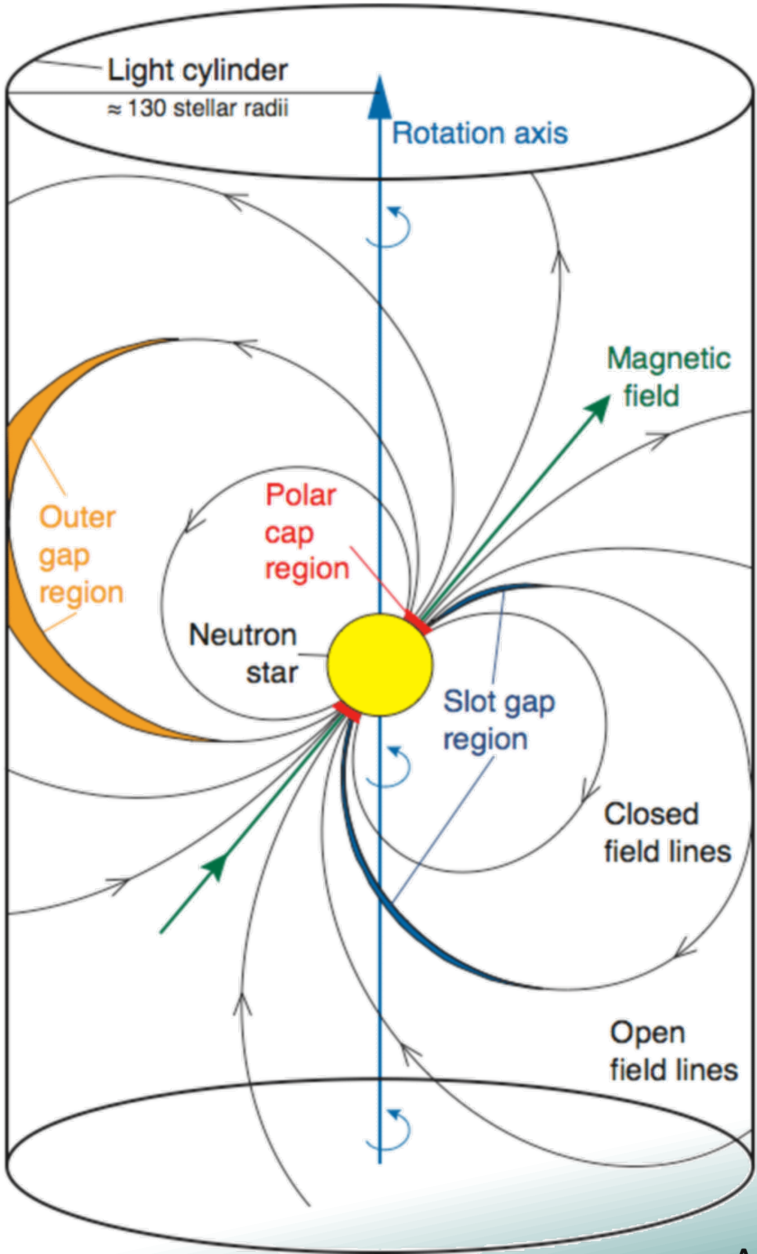




Acceleration gaps



Acceleration gaps



Aliu et al. (2008)

On the emission mechanism

- Radio is only tiny fraction of energetics
- It has to be coherent
- Properties are determined by coherent mechanism
- It may (must) break down at a certain frequency
- It cannot be synchrotron emission
- There is always curvature radiation, but not sufficient
- Plasma radiation process, e.g. free electron maser?
- Current flow is understood
- New computations are promising

- Questions remain:

  beam structure, nulling/moding/drifting, emission height