The shape of a pulsar radio beam:

fan beams, not the nested cones

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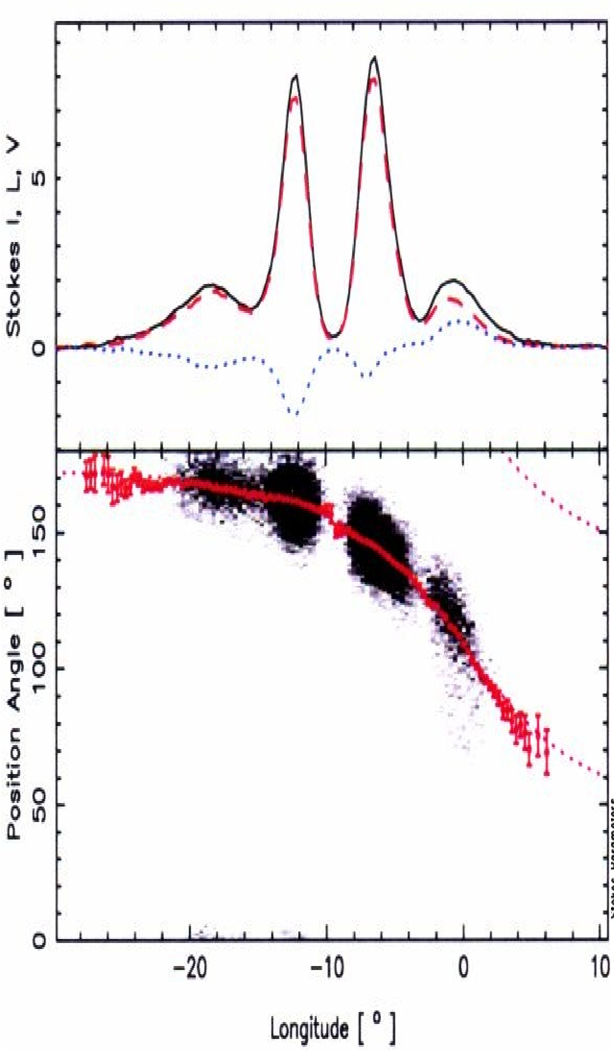
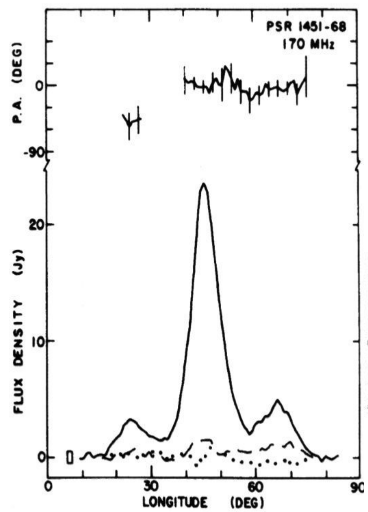
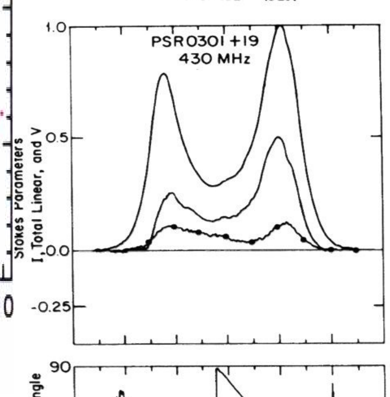
Lyne & Manchester 1988: beams are **patchy**
(random distribution of radio-bright spots)

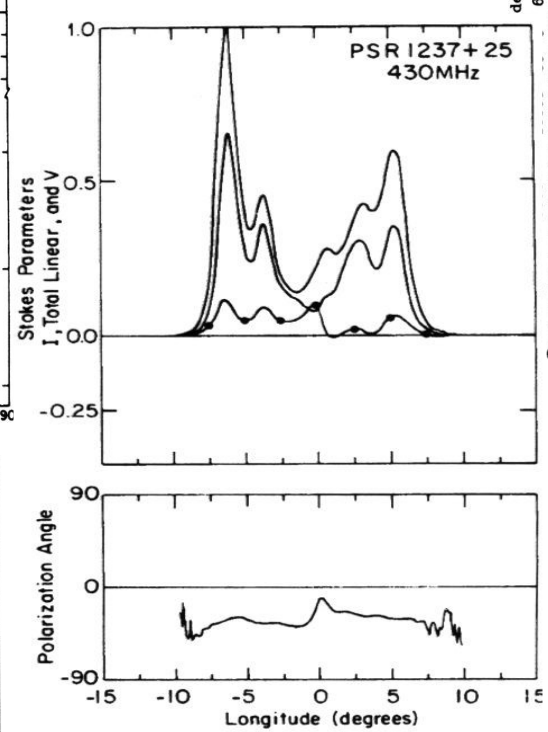
Sure they are, however:

How the patches are elongated?
Azimuthally? Or in colatitude?

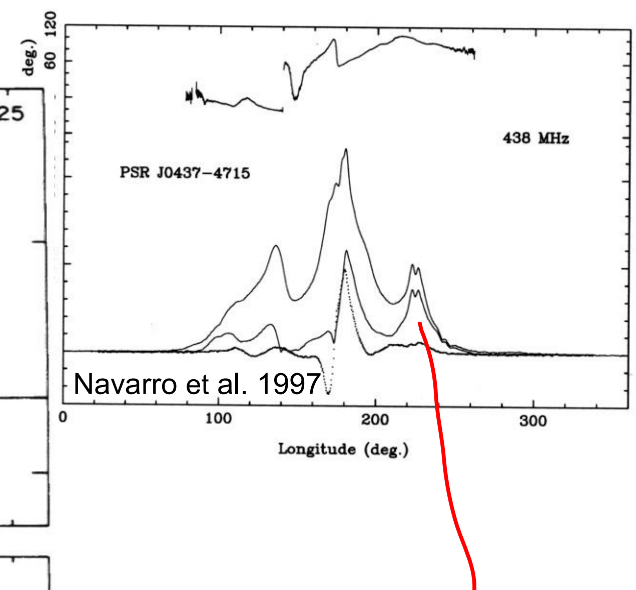






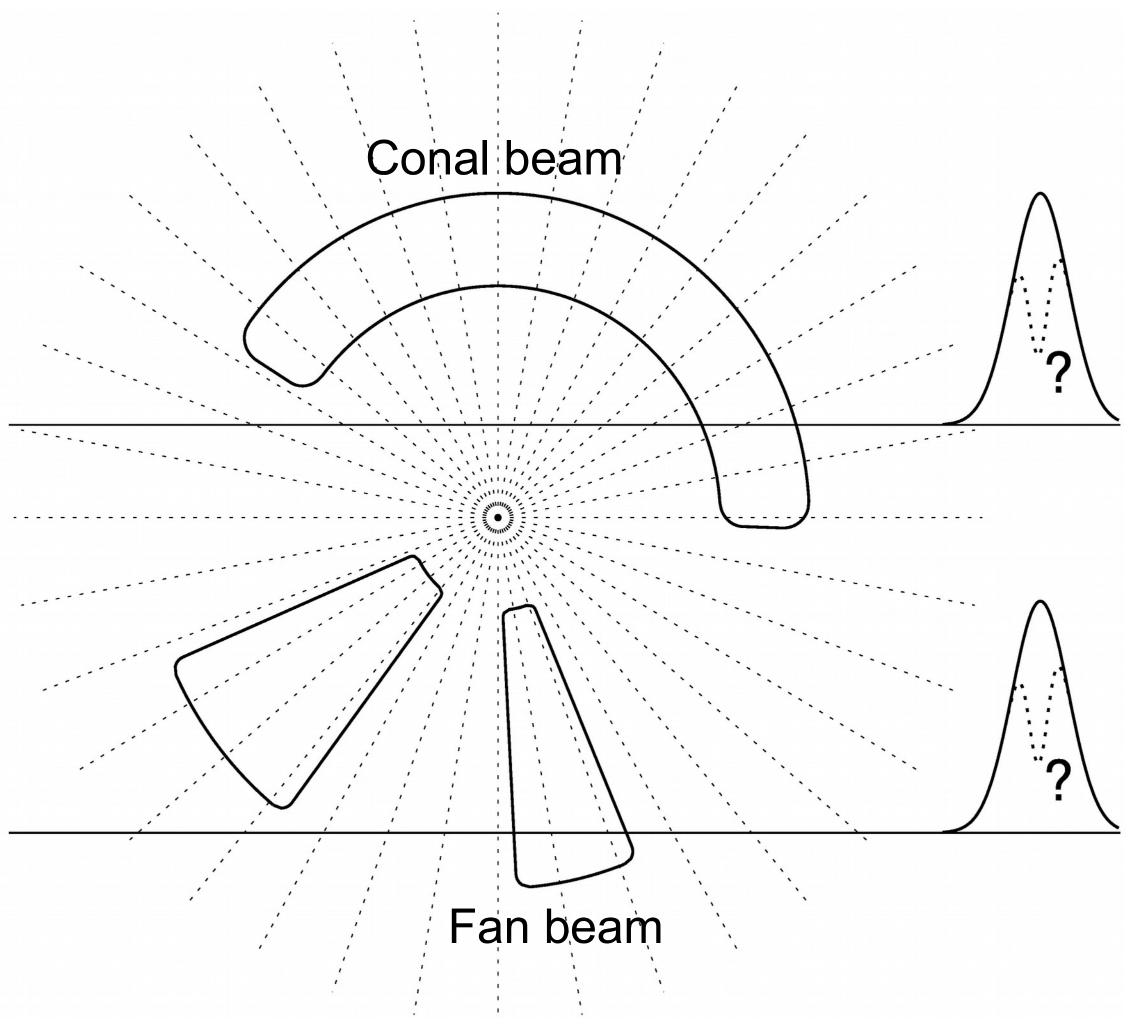


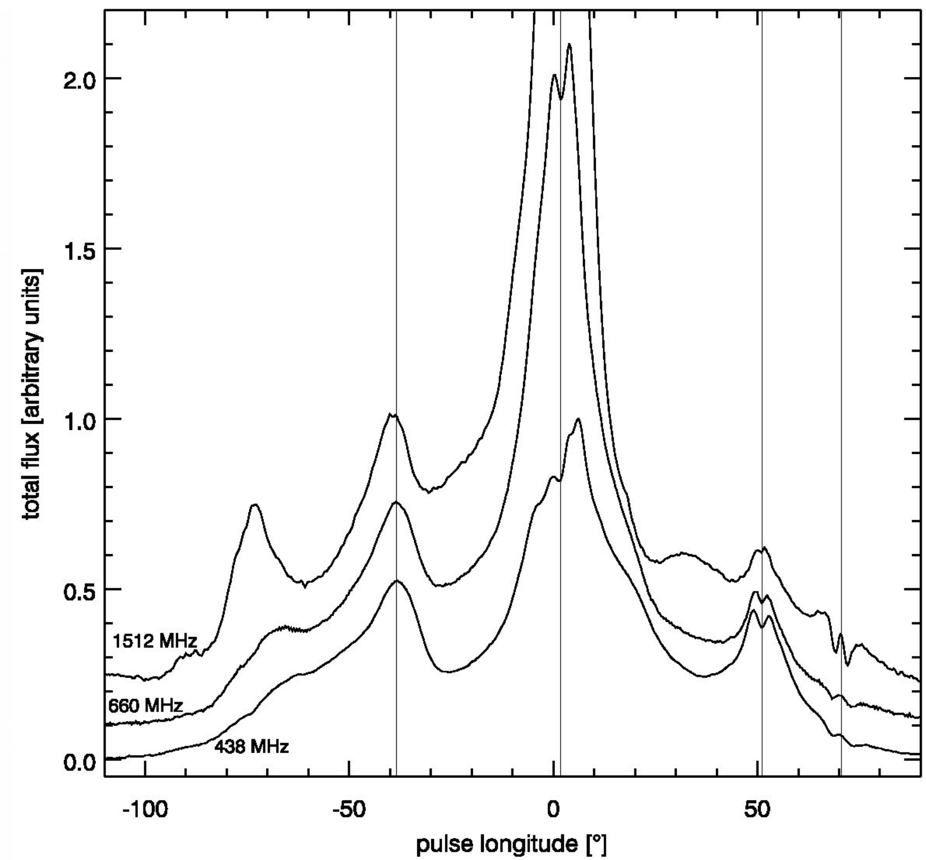
Rankin 83, Teixeira et al. 2015

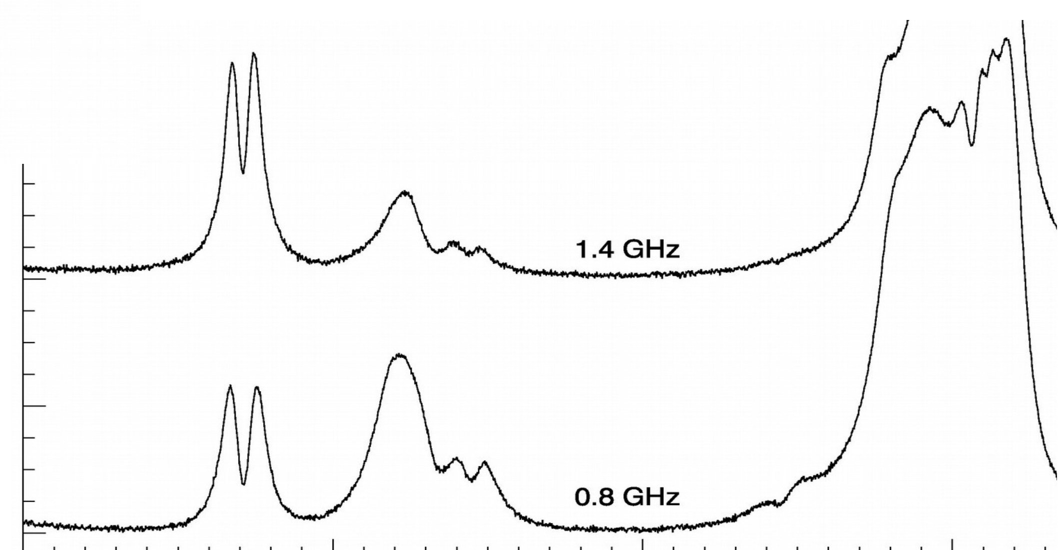


bifurcation

Bifurcations do not survive if beam geometry is conal

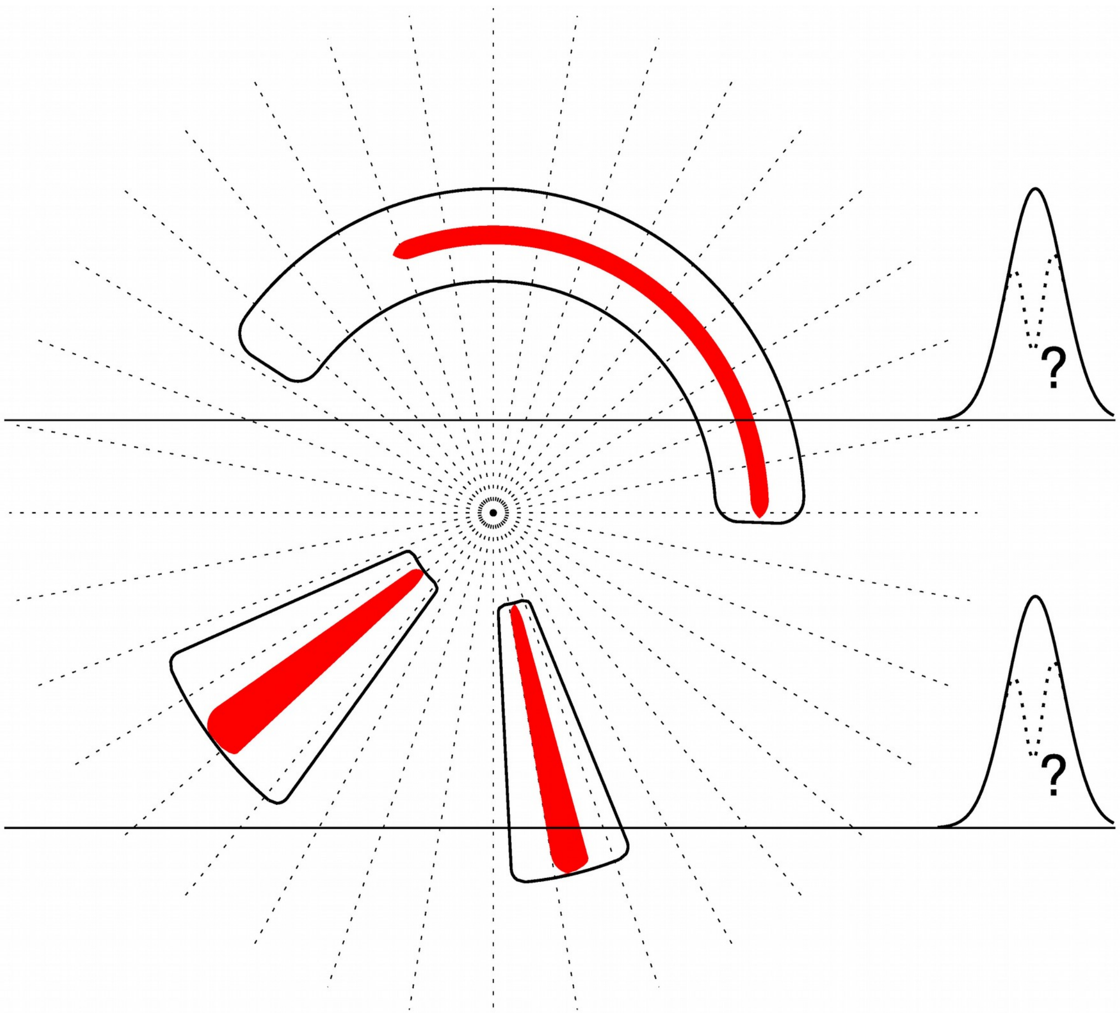


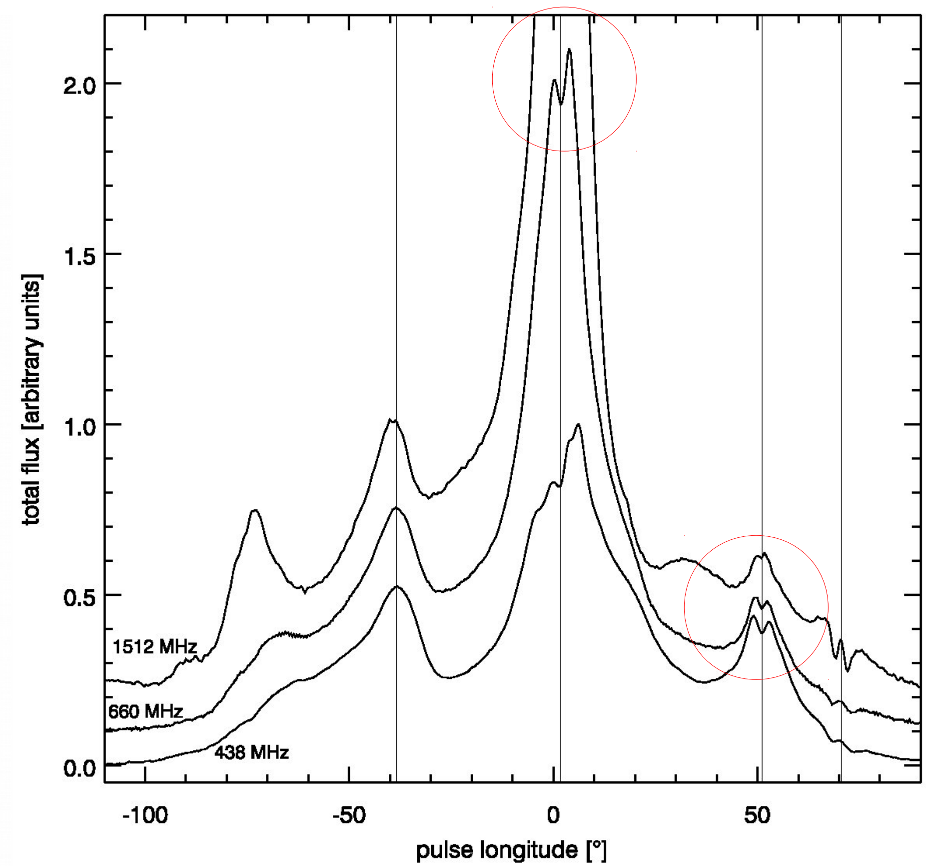


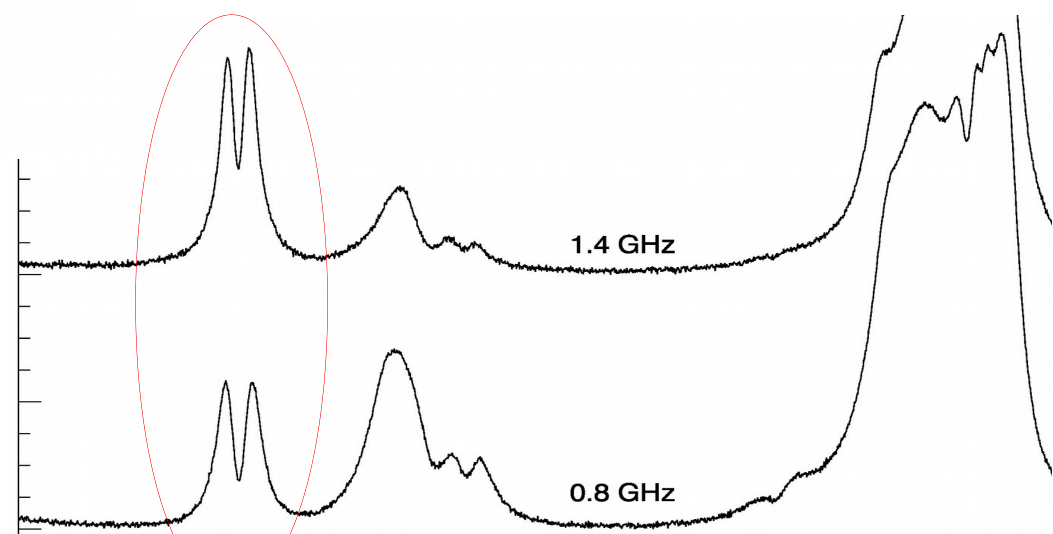


Dyks, Rudak & Demorest 2010

Bifurcations do not survive if beam geometry is conal







Dyks, Rudak & Demorest 2010

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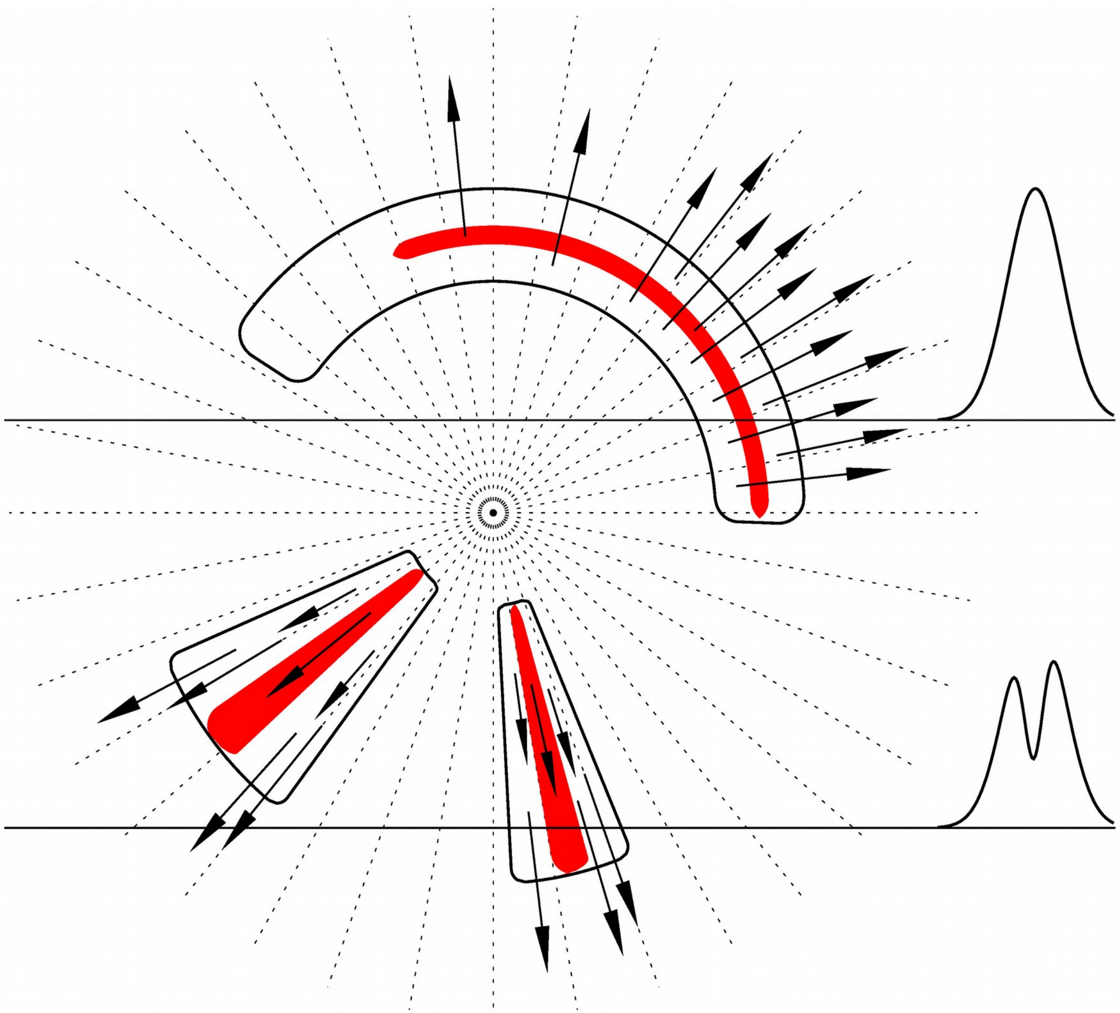
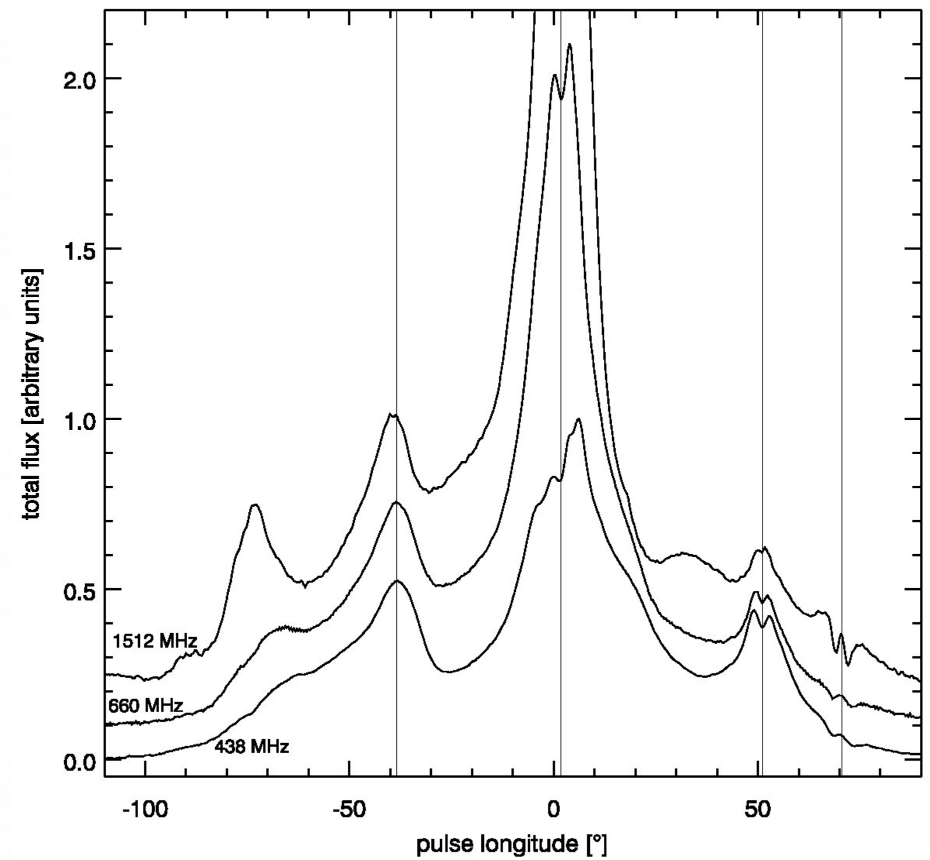
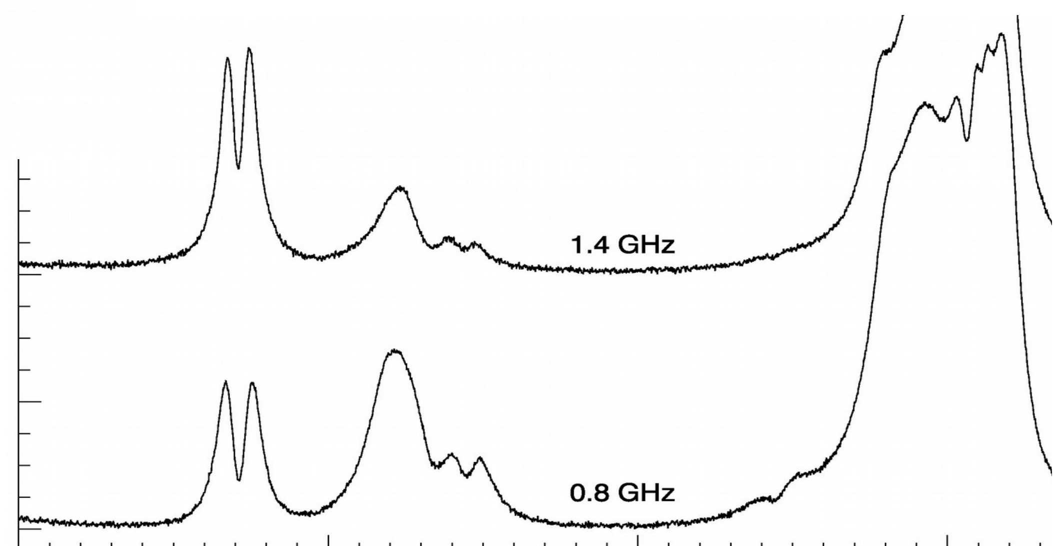
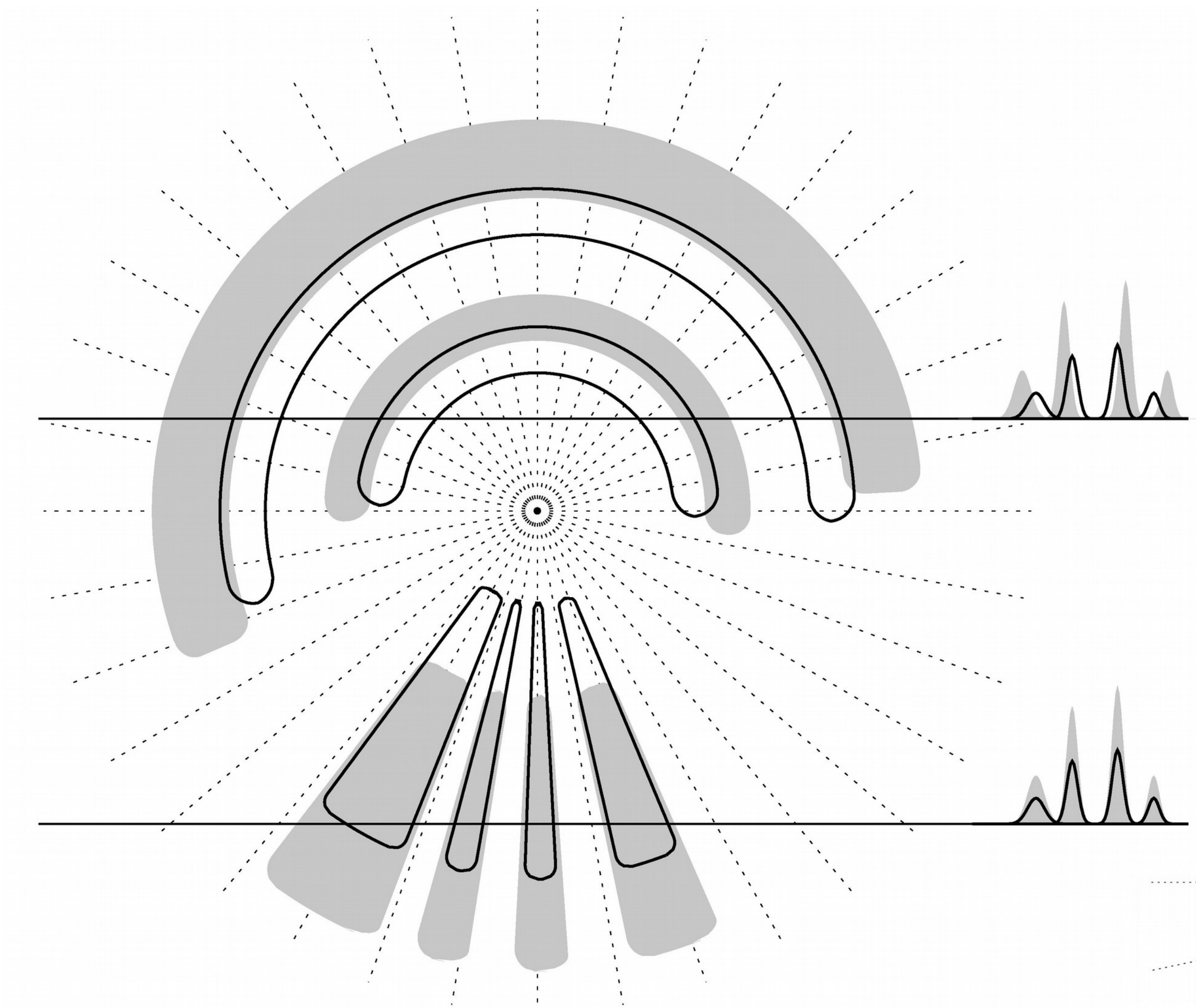


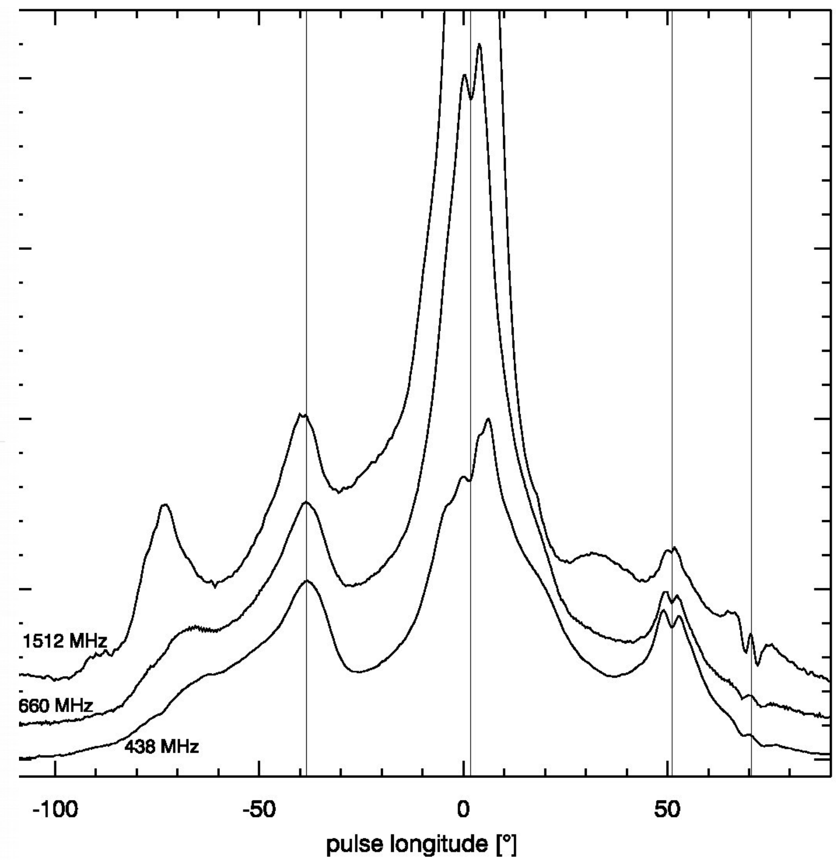


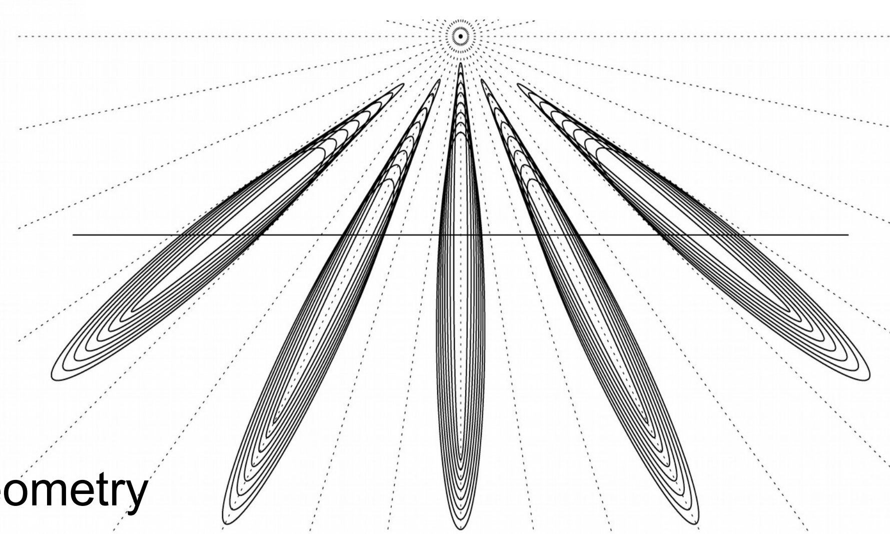


Dyks, Rudak & Demorest 2010

Weak RFM is natural for stream-shaped / fan-beam emitters







Dyks, Rudak & Demorest 2010
Navarro et al. 1997
Oslowski et al. 2014

spoke-like geometry

Prediction: all / most pulsars, including the normal ones (non-millisecond) may have profiles created by fan beams which point at the dipole axis

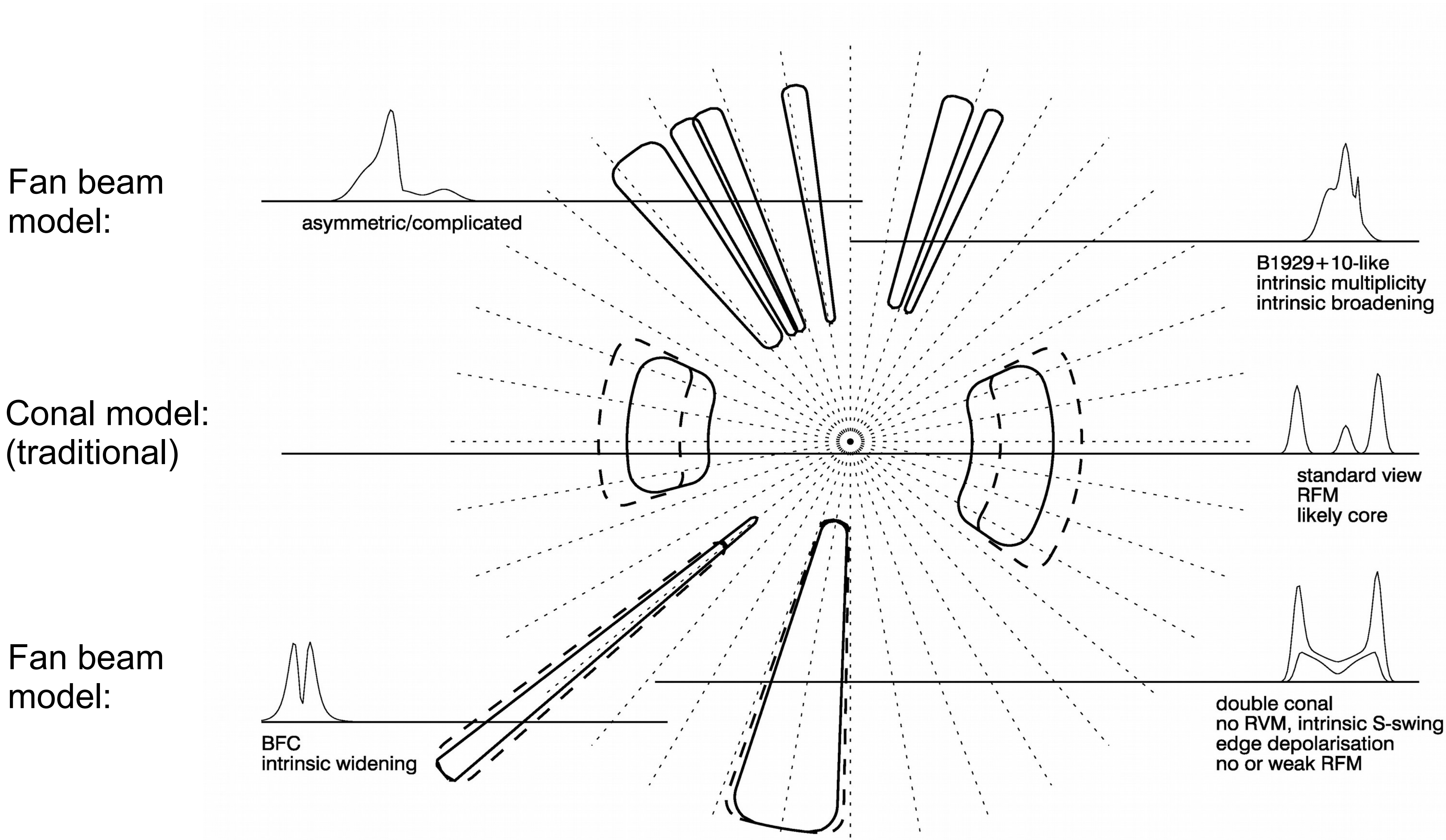
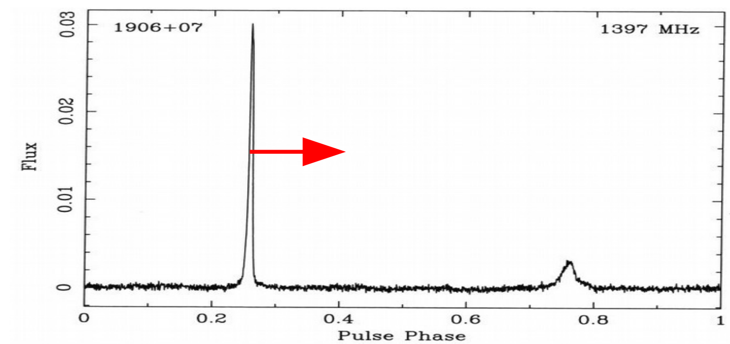
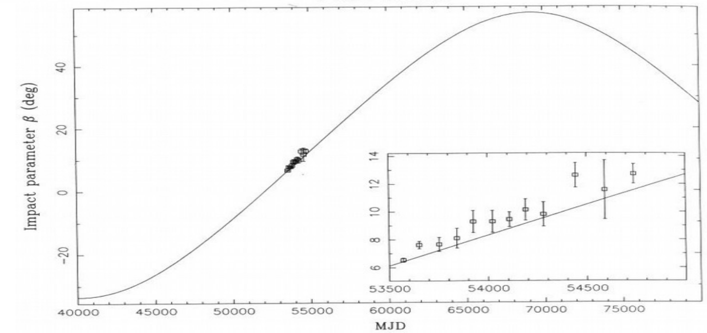


Fig. from Dyks, Rudak & Demorest 2010

Beam mapping for precessing pulsars: J1906+0746

Young pulsar: P = 0.14 s, age = 10^5 yr
P_{orb} = 4 hr, P_{prec} = 165 yr, t_{obs} = 4 yr

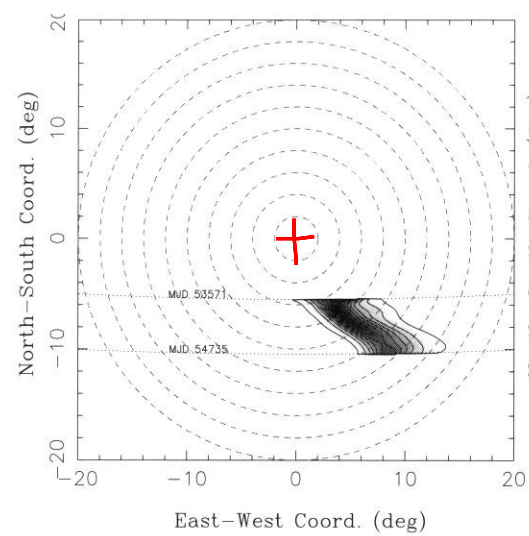


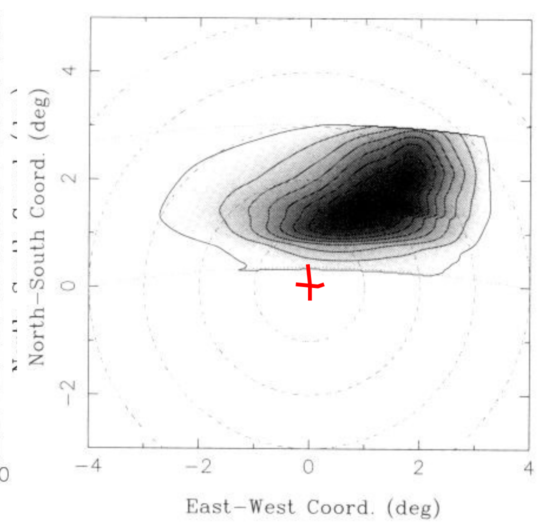


Desvignes et al. 2012

Observed beam maps:

red cross: magnetic dipole axis





J1141-6545
Manchester et al. 2010

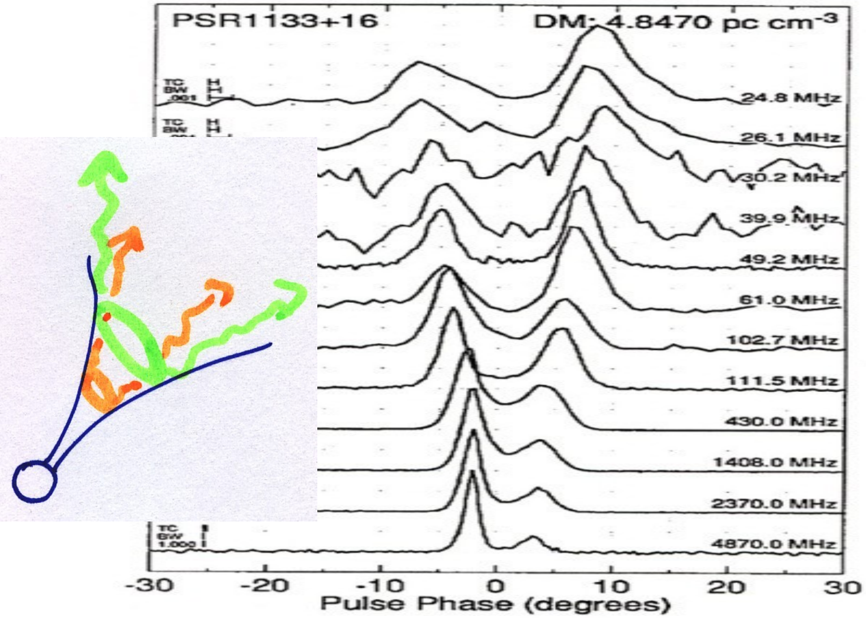
Well, aren't all these pulsars:

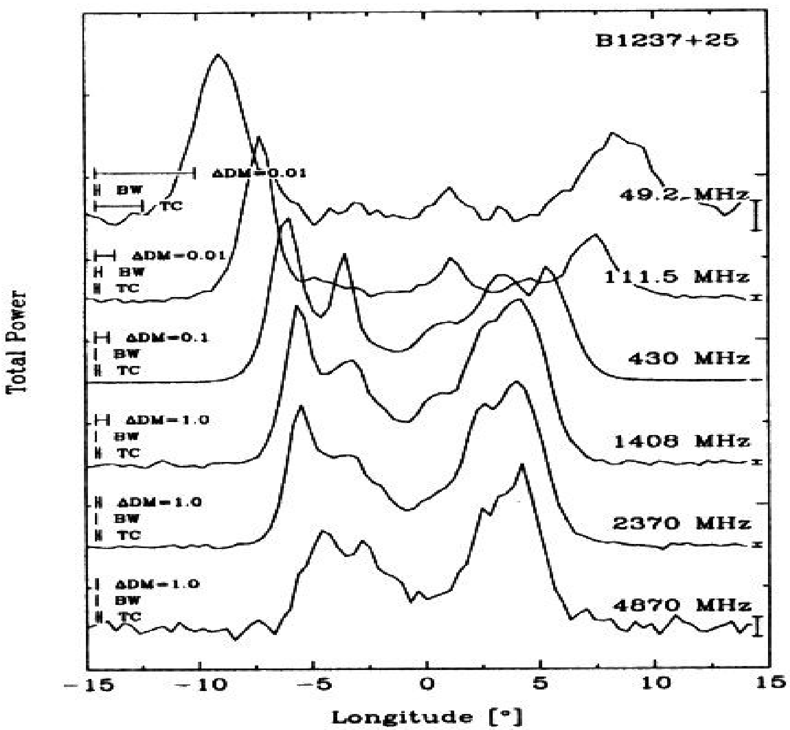
- with notches
- with bifurcated components,
- young,
- precessing,
- and millisecond

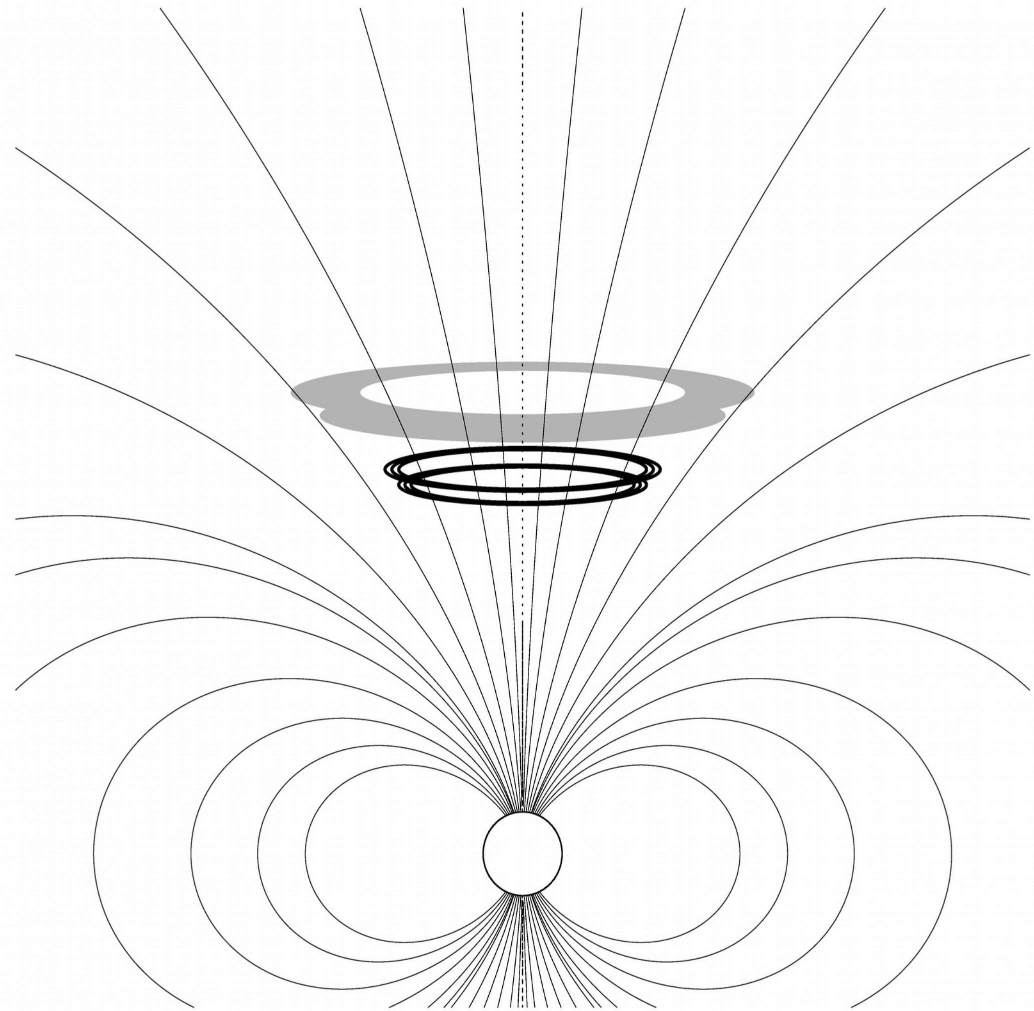
just peculiar?

The stream model also works better for normal pulsars

Radius-to-frequency mapping – conal version





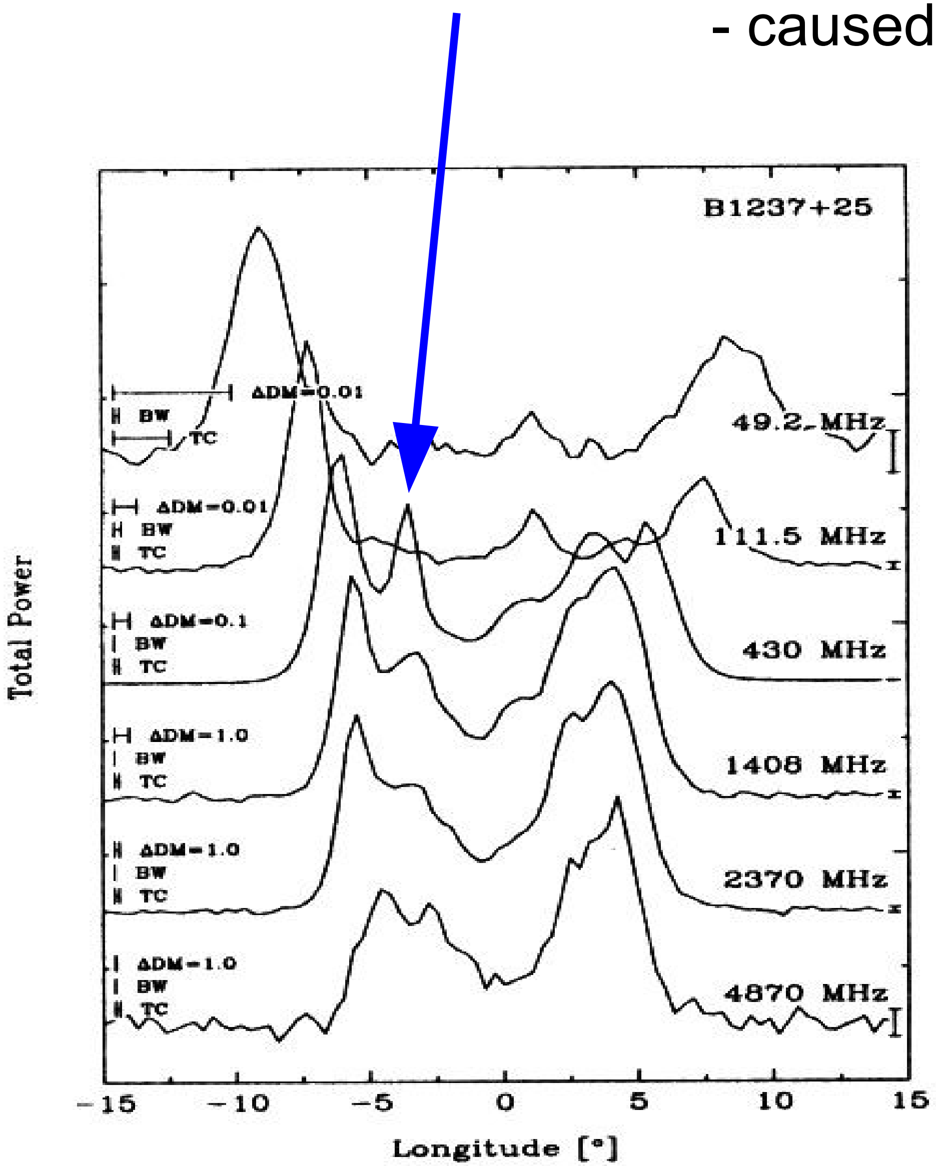


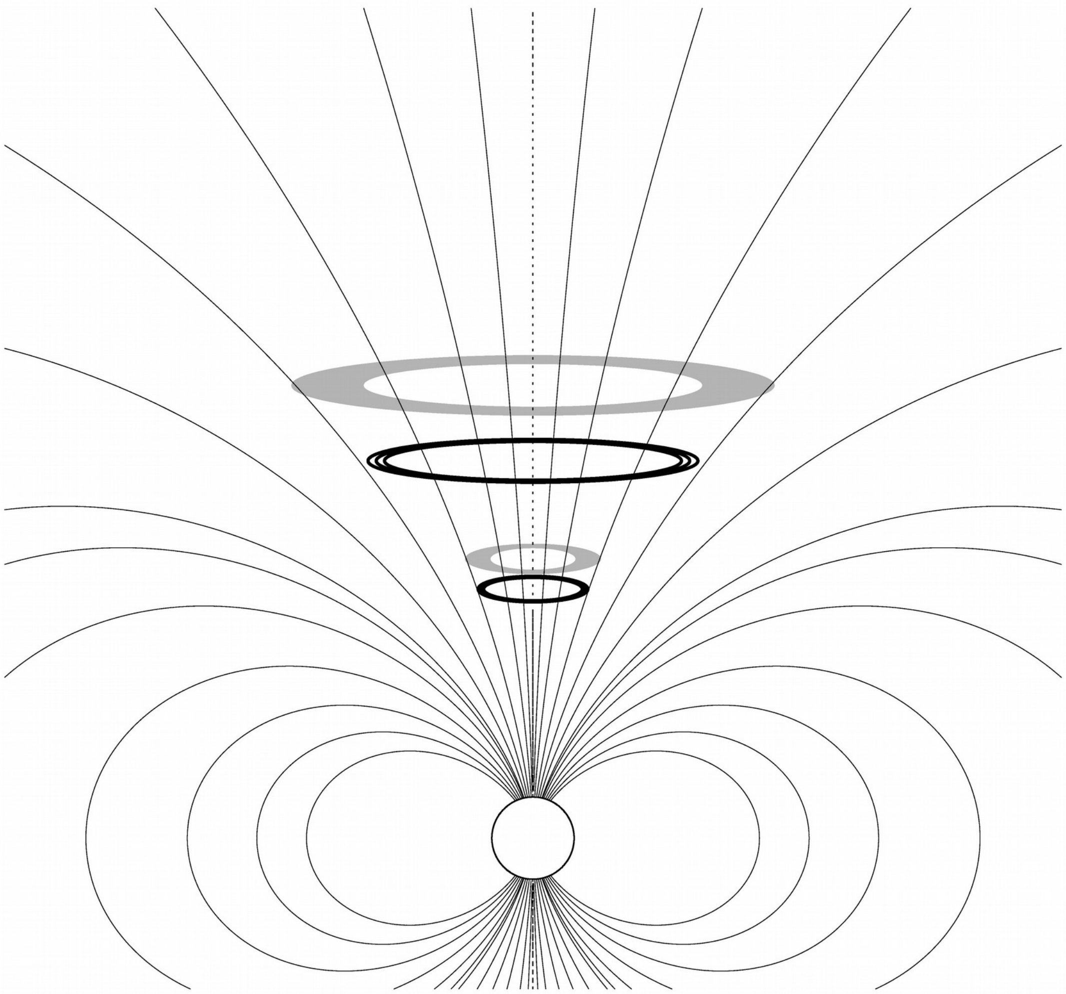
Grey: low nu

Black: high nu

Hankins & Rankin 2010

RFM is weaker for the inner pair of components -
- caused by less spreading inner B-field lines?





RFM is weaker for the inner pair of components -

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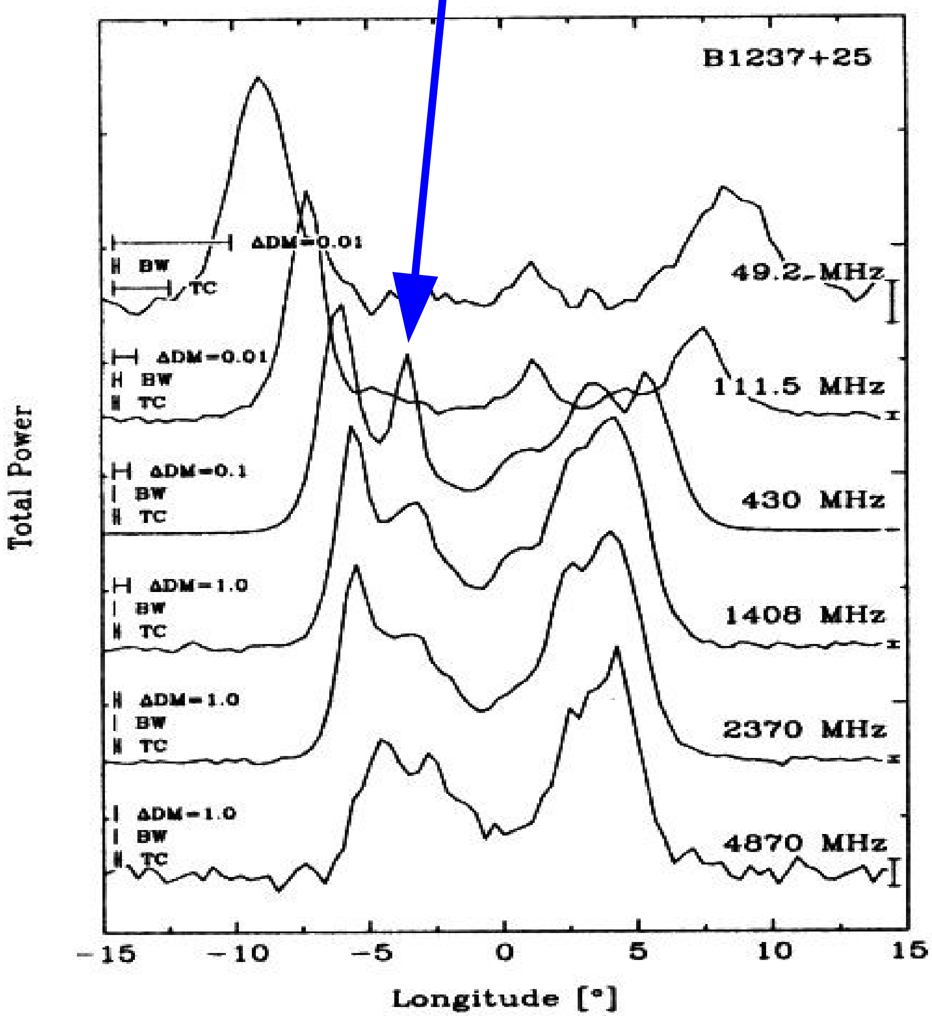
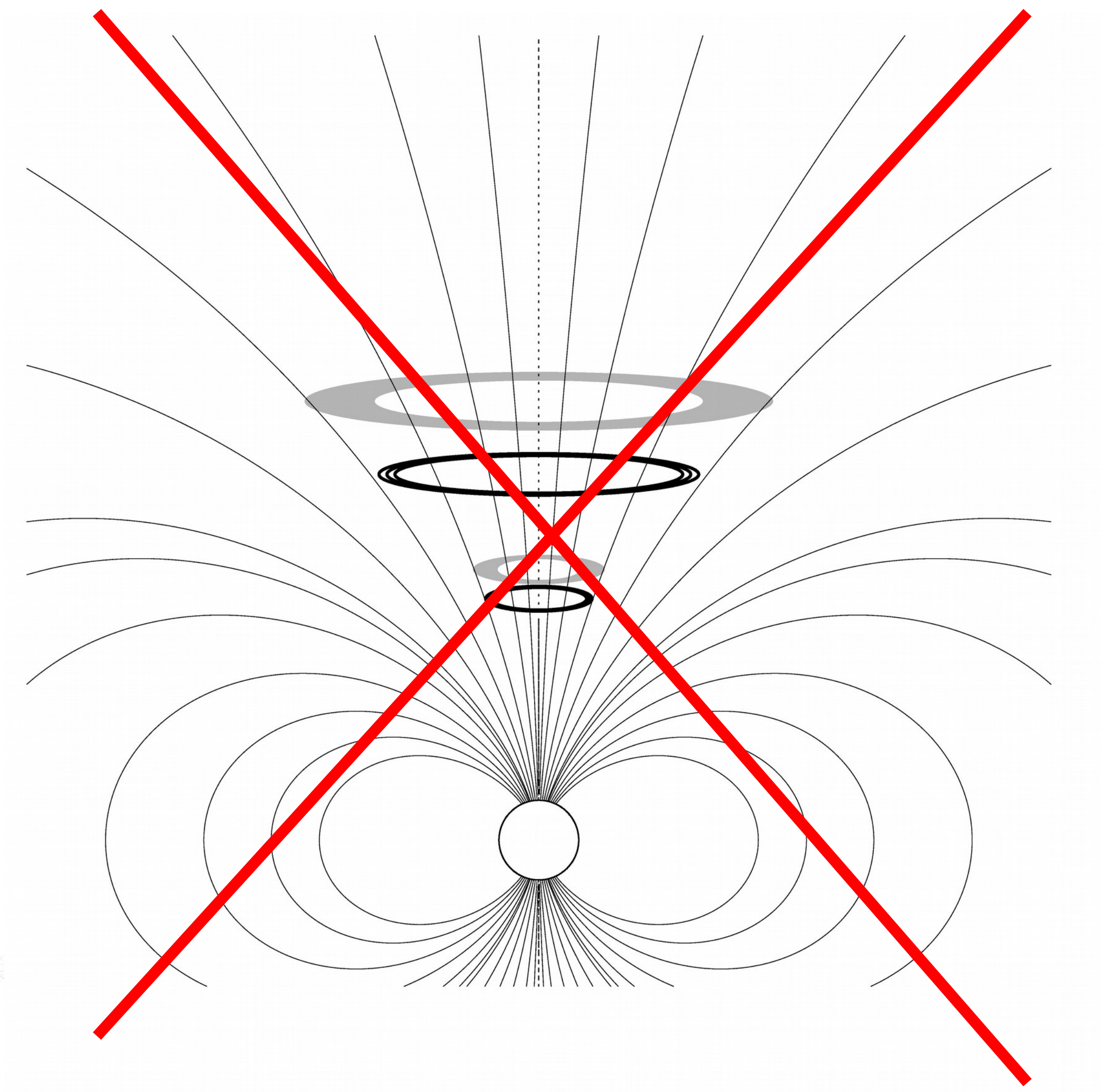
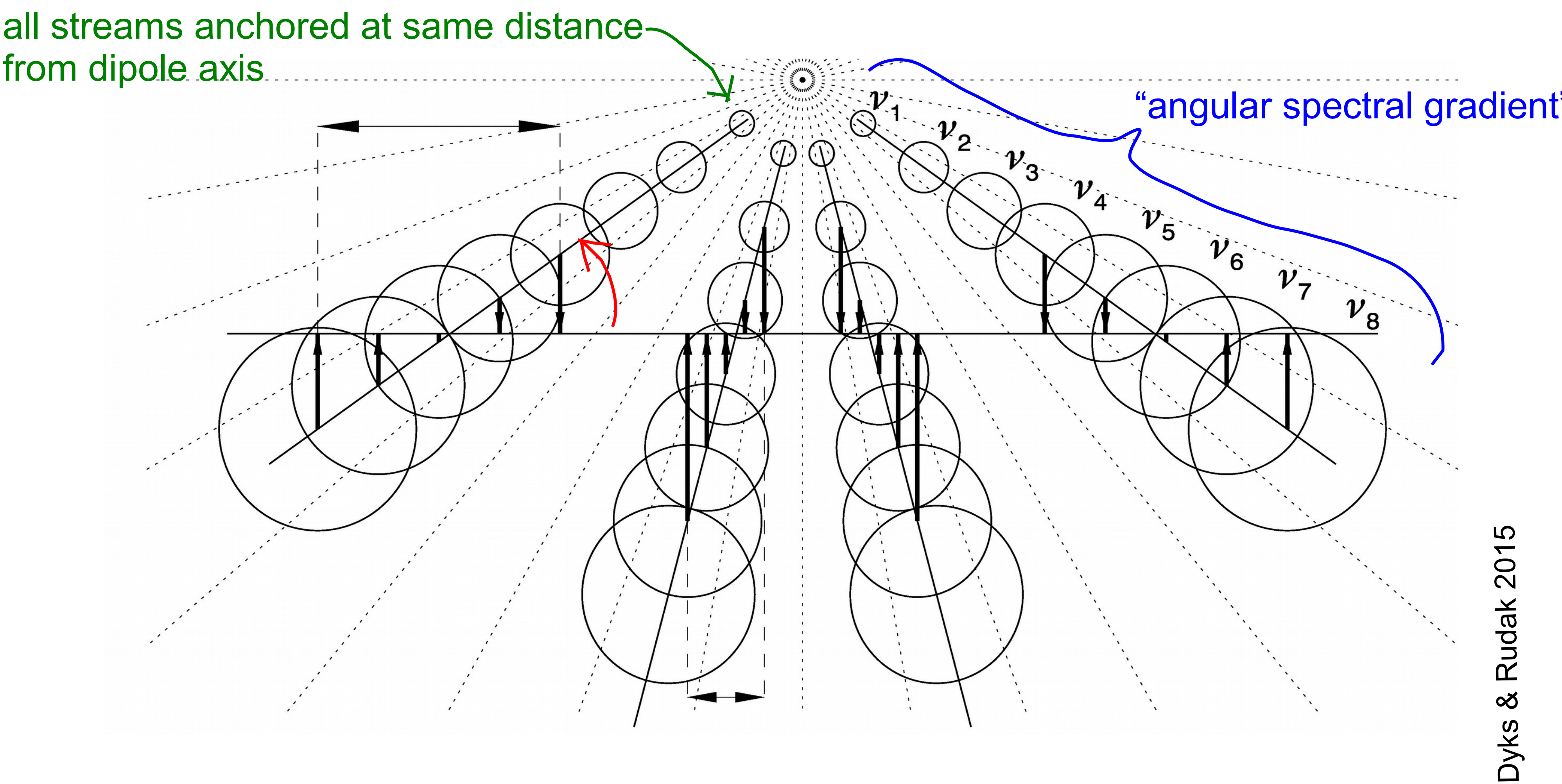




Radius-to-frequency mapping – stream model version

circles = fixed intensity contours at a given nu

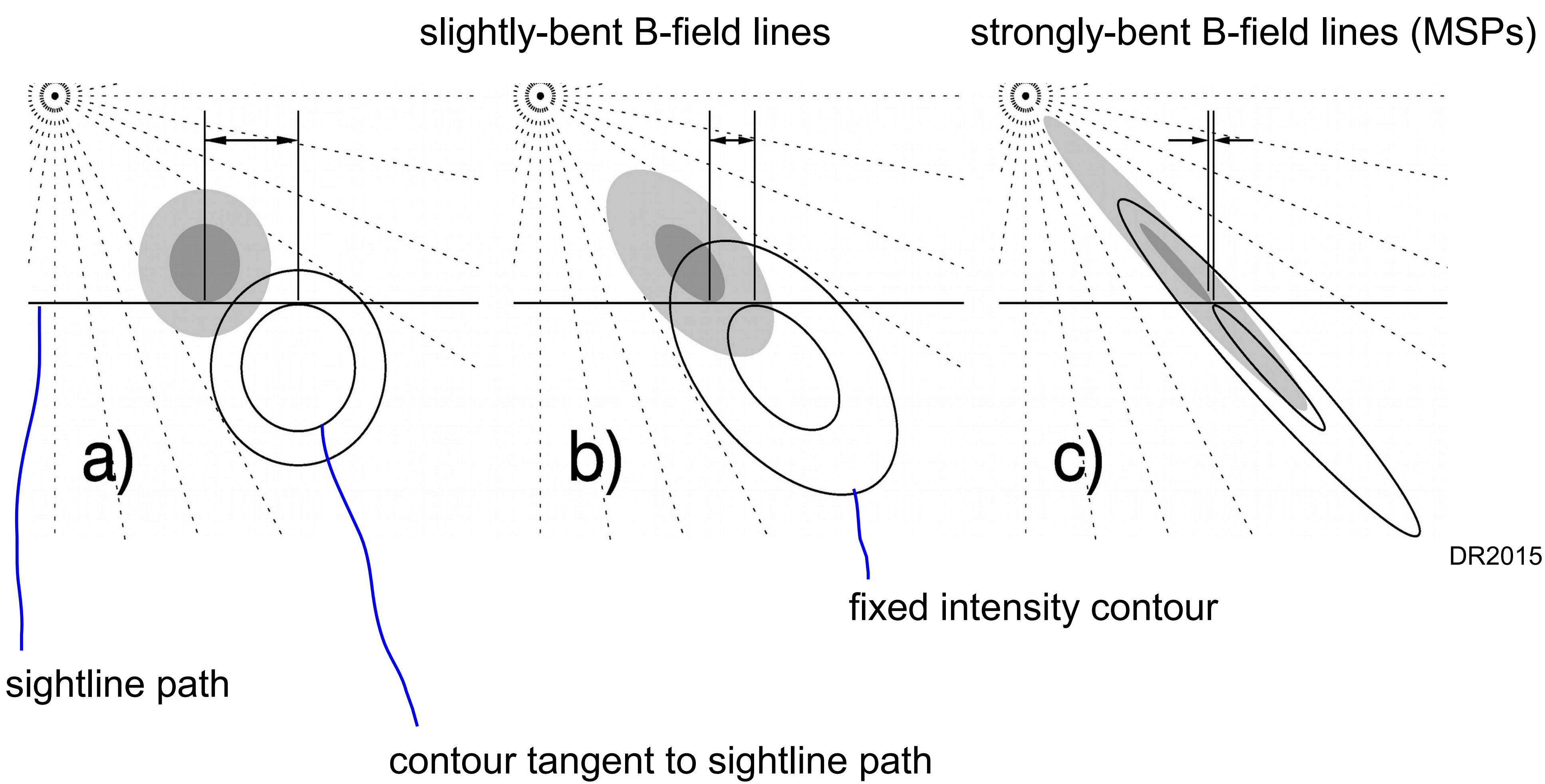


Red arrow: Cut angle

Inner streams are cut more orthogonally => smaller RFM

Fan beam geometry also works for the statistics of outer profile widths – Chen & Wang 2014

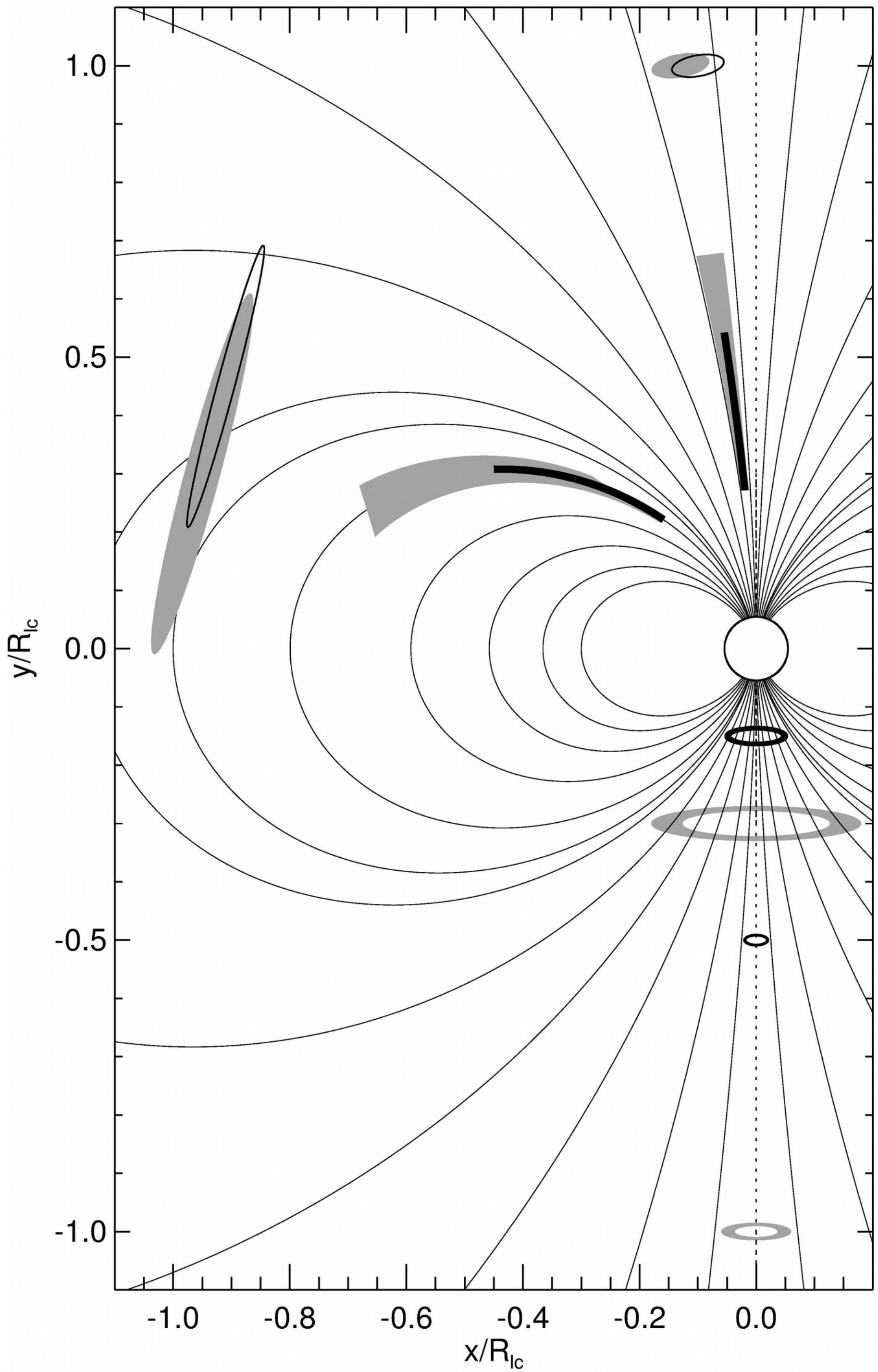
The fixed-nu beams are not expected to be circular:



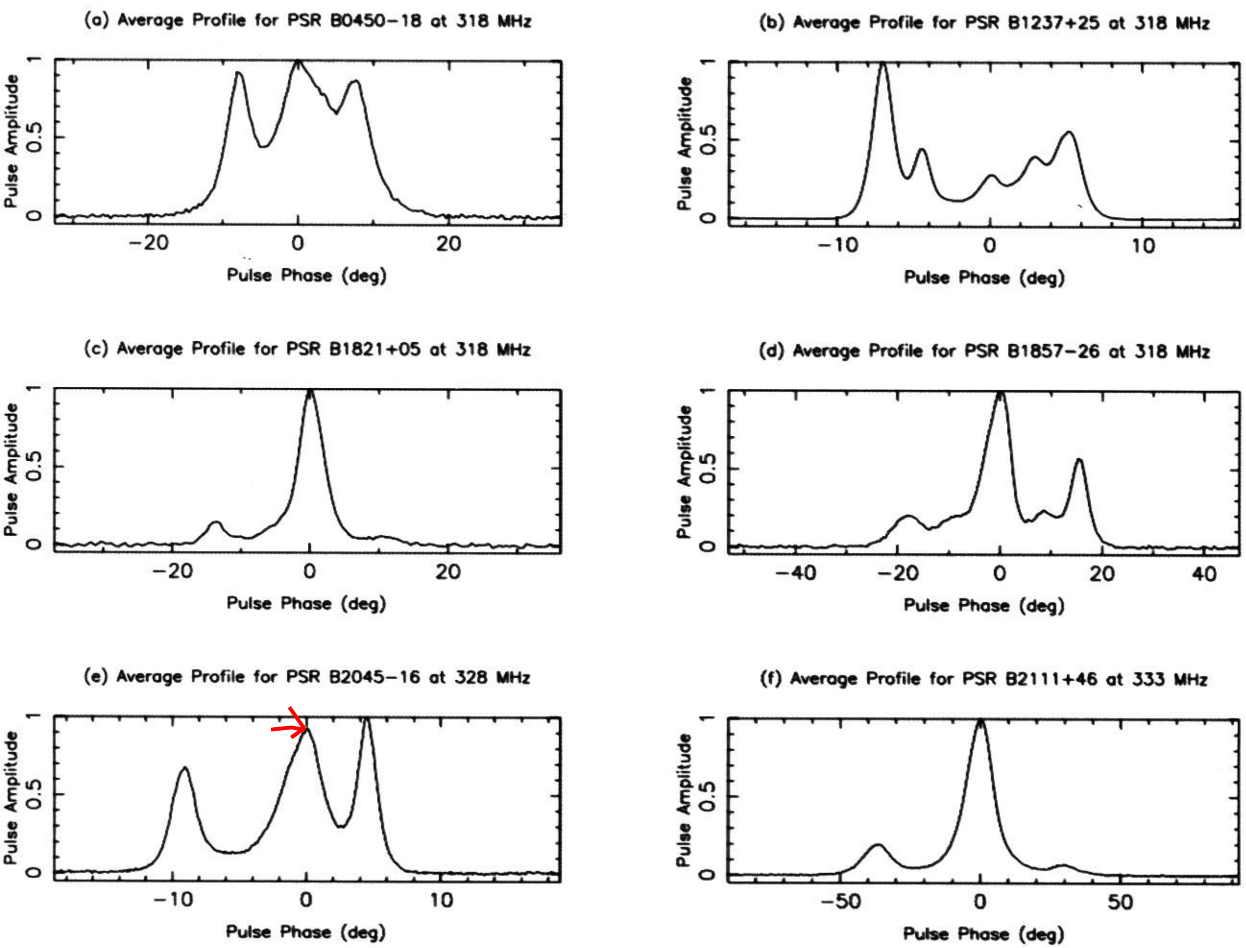
Fixed-intensity contours at two frequencies are shown
for three beam elongtions.

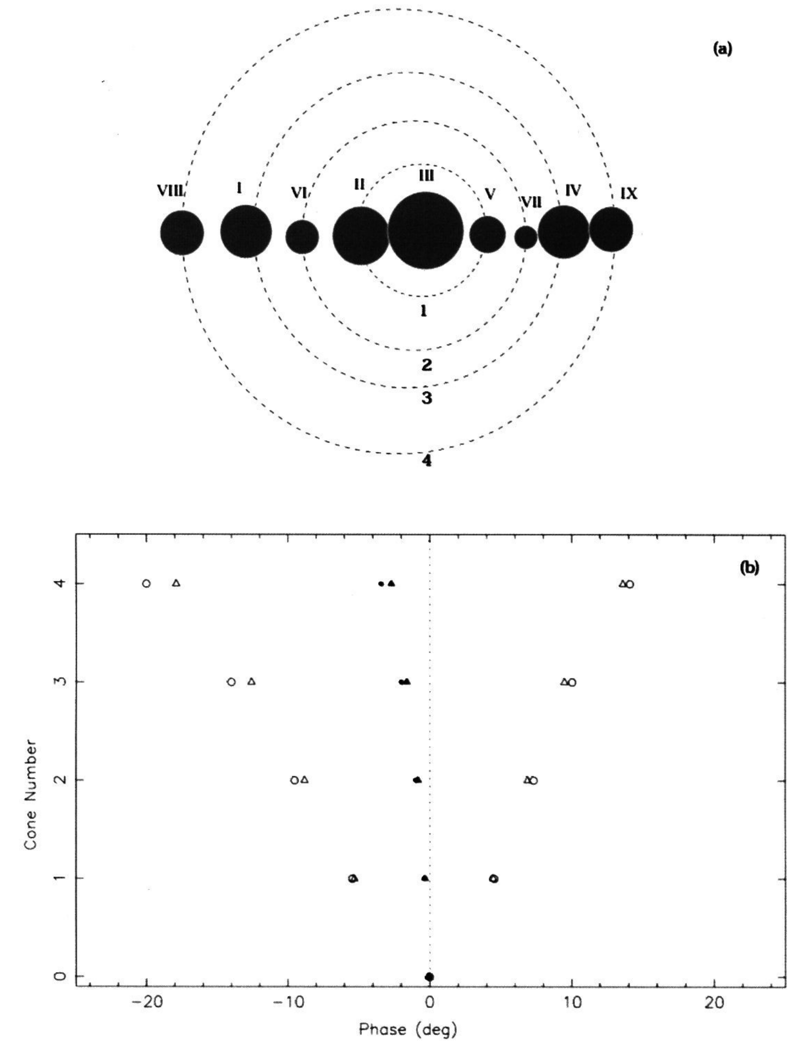
MSPs have more flaring B-field lines
=> why do they exhibit so weak RFM?

Because the streams flowing along
their bent B-field lines
more easily produce fan-beams!



Lag of ‘core’ with respect to the centroid of ‘conal’ pairs





B0329 + 54
Gangadhara & Gupta 2001

Core lags the centroid of flanking components

The lag is larger:

- **for more peripheric pairs of components**
- **at a lower frequency.**

Lag of 'core' with respect to the centroid of 'conal' pairs

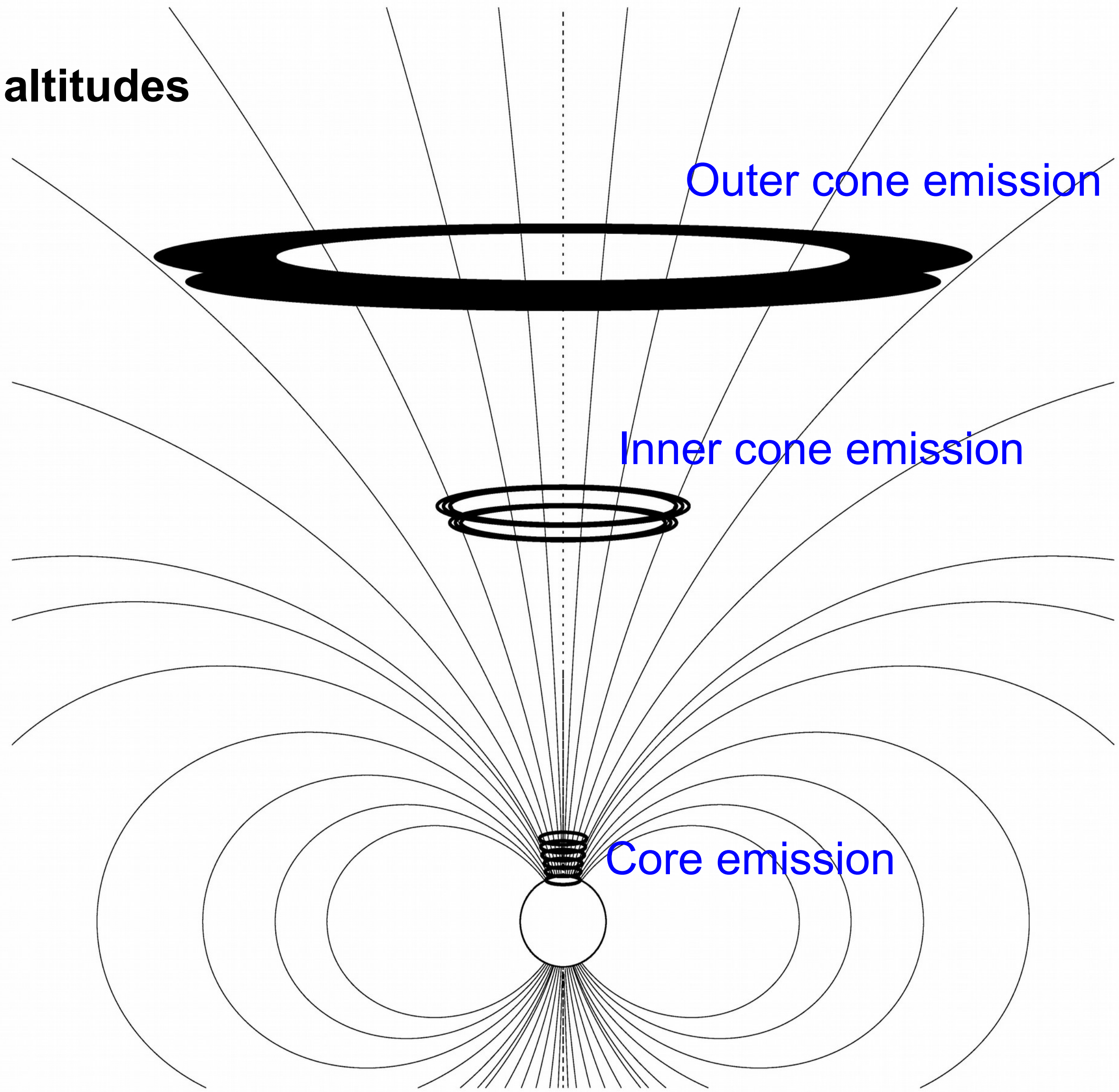
Conal interpretation:

separate emission rings at different altitudes

Aberration-retardation (AR) shift:

Higher = closer to the observer =
= detected earlier in the profile

Higher = corotating faster =
= aberrated more forward =
= observed earlier in the profile



Gangadhara and Gupta 2001; D&R2004

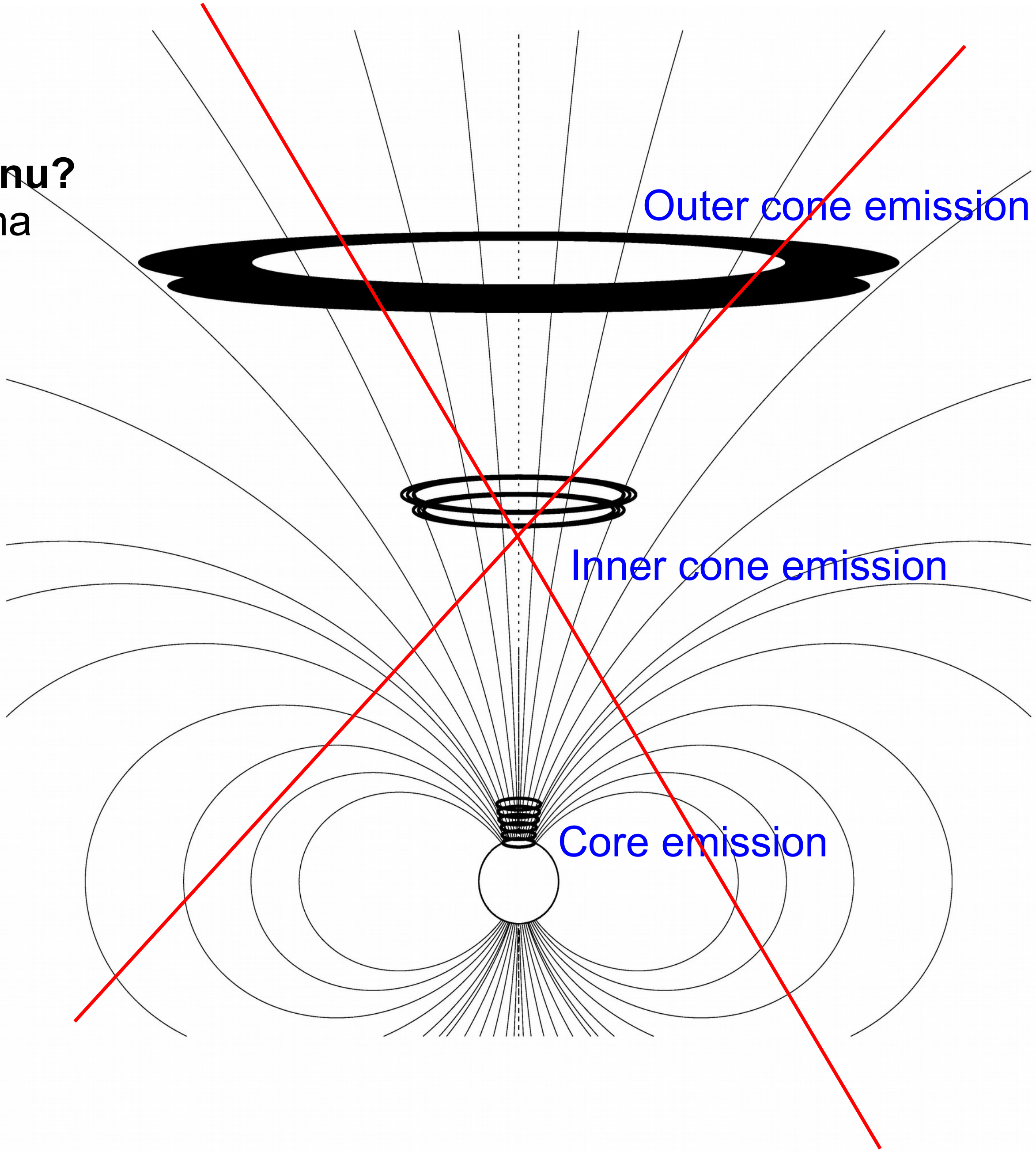
Lag of ‘core’ with respect to the centroid of ‘conal’ pairs

Problems:

Why disparate altitudes despite same nu?
Why core from small region of high plasma density?

Might there be any
natural reason for the smaller shift
of inner components?

The **Ptolemaic complexity** disappears
when a bunch of streams is used
instead of cones



Lag of 'core' –
- stream version

5 similar / identical streams

AR shift = 2 r / Rlc = k θ^2

θ – angular distance from dipole axis

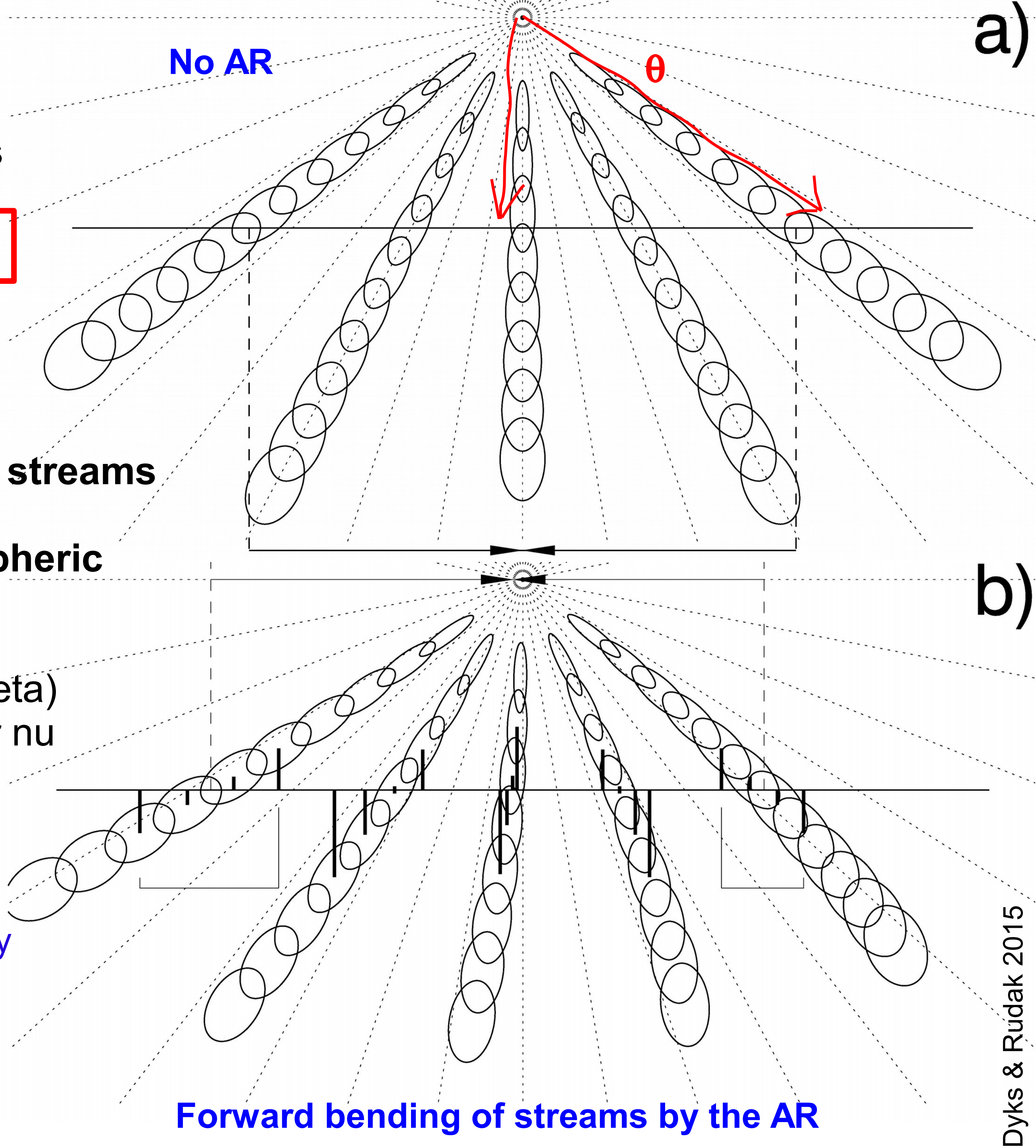
Theta is smaller for inner streams

=> stronger shift for peripheric components

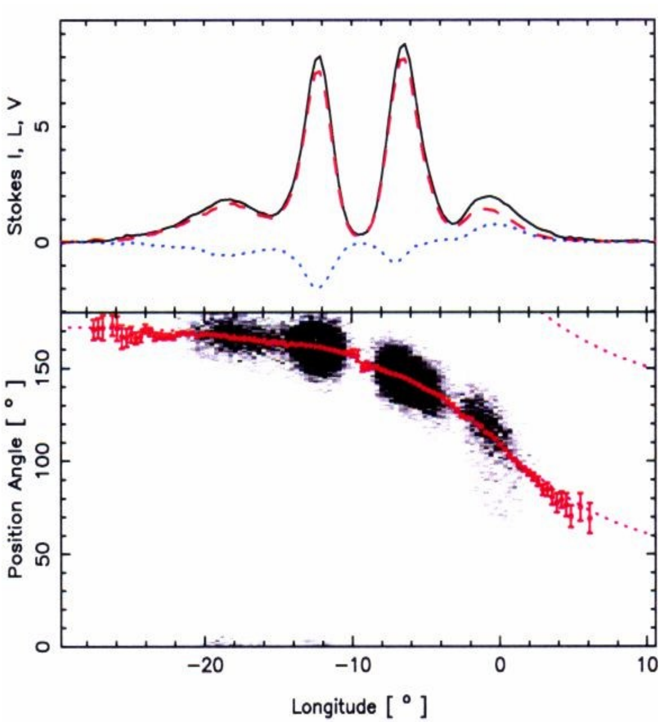
lower nu at larger r (and theta)
=> shift is stronger at lower nu

Note: Core lag results naturally from the stream geometry

You do not need to put your rings at disparate heights!



PSR J0631+1036 – isn't this an obvious nested cone profile?



Teixeira et al. 2014

Traditional conal model: **No** the profile **does not seem** to have conal origin.

Cone size ratio: R_{rho} = rho_{in} / rho_{out} = 0.74 – 0.87 (observed)

	MD	R93	G93	K94 ($P^{-\kappa}$)			K94 ($P^{-0.5}$)		
ν (GHz)	1.0	1.0	1.4	1.4	4.75	10.55	1.4	4.75	10.55
R_F (per cent)	100	50	10	10	10	10	10	10	10
ρ_{in} (°)	4.1	4.3	4.9	5.3	4.5	4.77	4.9	4.4	4.5
ρ_{out} (°)	5.1	5.8	6.3	6.23	5.76	5.48	6.3	5.9	5.5
R_ρ	0.8	0.74	0.78	0.85	0.78	0.87	0.78	0.75	0.82

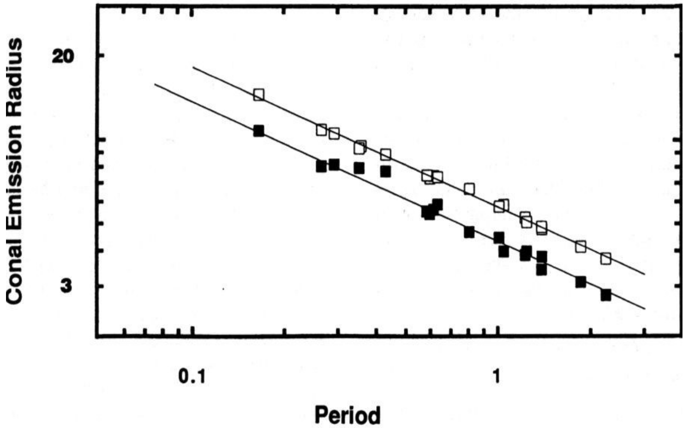
Rankin, Gil, Kramer, Mitra and their collaborators (1993 - 1999)

All observers find the same average cone size ratio:

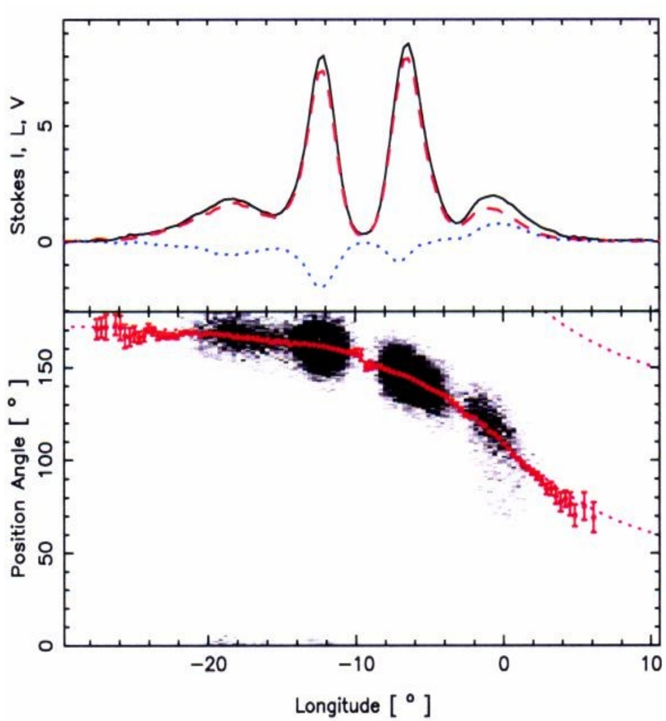
R_{rho} ~ 0.8

(for slightly different pulsar samples,
but for Rankin's assumptions about the core component).

Theoretically supported by the geometry of critical field lines (Wright 2003)

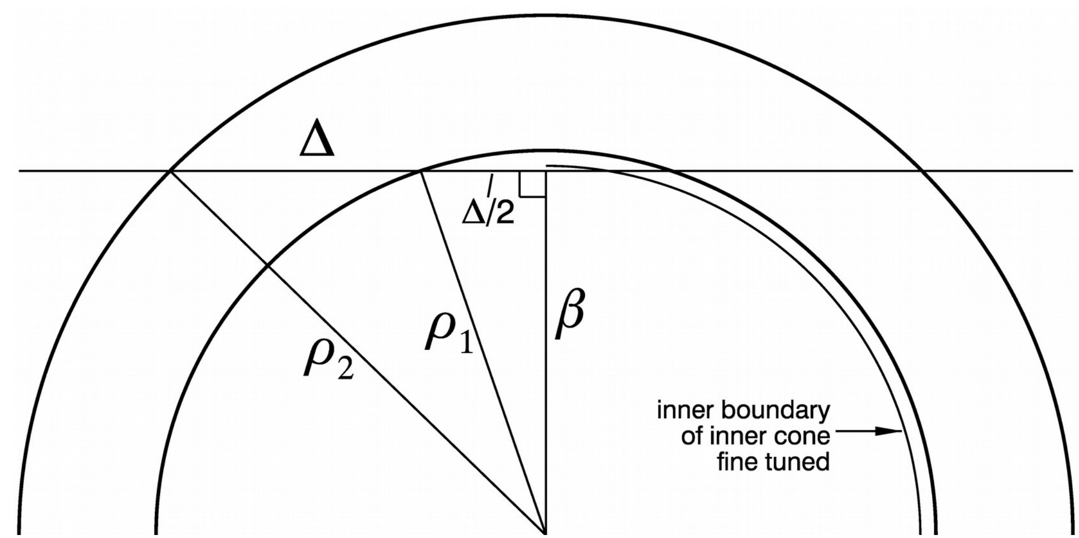


PSR J0631+1036 – a profile that should not have been observed
(according to the conal model)



Teixeira et al. 2016

Win / Wout = 1 / 3 (observed) => **beta / rho_in = 0.95 !**

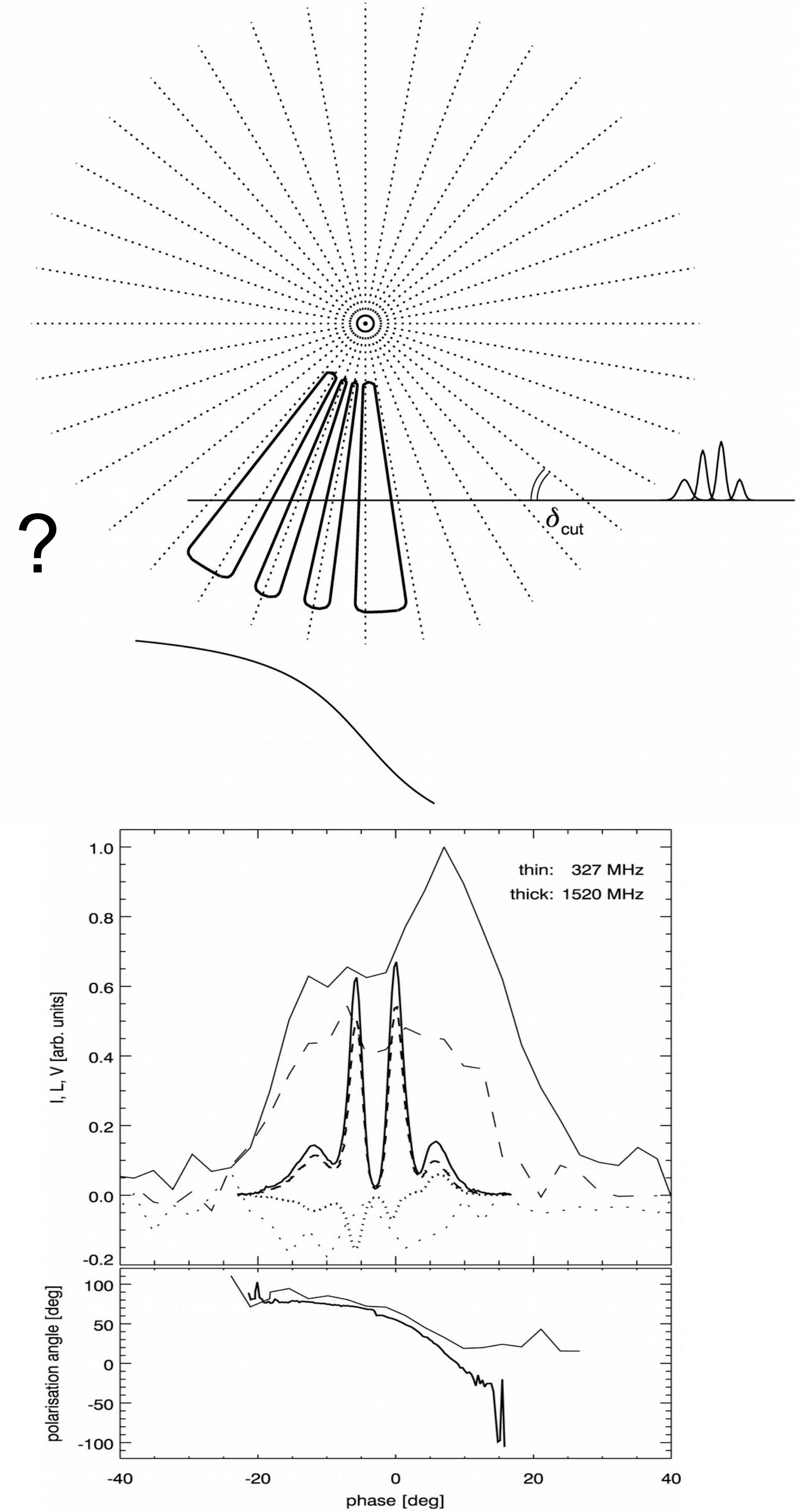


Sightline path nearly tangent to inner cone => extremely fine tuning to get Rw = 1 / 3

Deep central minimum unexpected: inner boundary of inner cone
needs to be **squeezed** between rho_1 and beta = 0.95*rho_1
=> even smaller chance to observe such a profile

One profile with equal peak separations is expected per 330 M+Q type profiles
(assuming delta_phi = 6 deg +/- 0.5 deg)

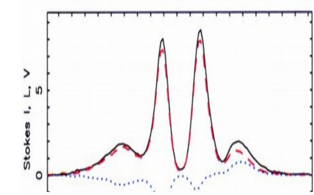
A more reasonable beam model for J0631+1036

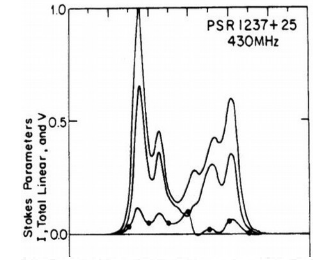


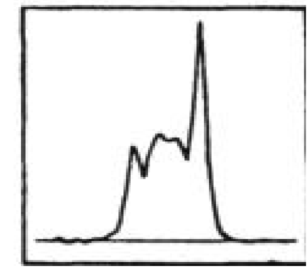
Teixeira et al. 2016

Is J0631 an exception with Rrho << 0.75?

Let us check Rw distribution for the whole population of Q and M pulsars (with 4 and 5 components):





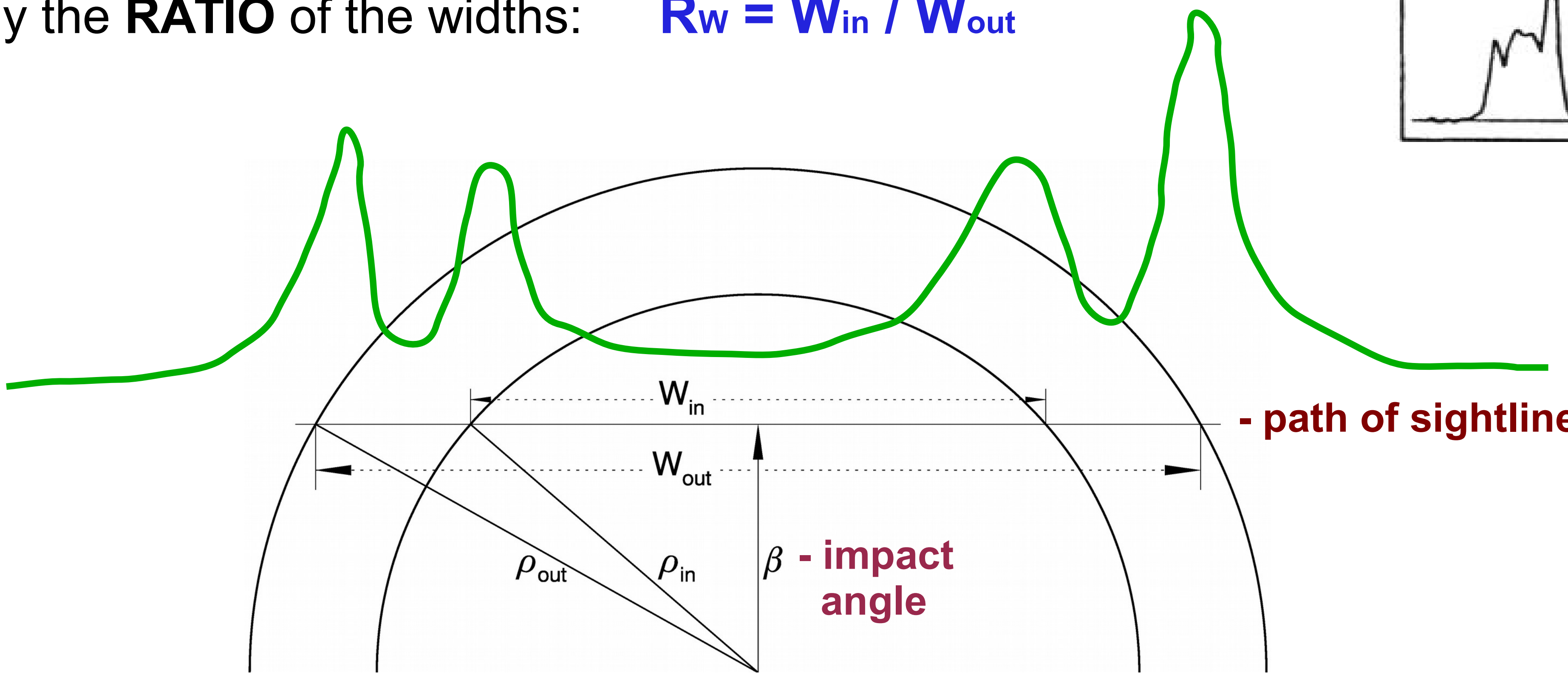


Conal radii: **rhoin, rhoout** - not measurable (directly)

Peak-to-peak separations (widths): **Win, Wout** - directly measurable for inner and outer pair of components.

Innovation: do **not** study the distribution of widths.

Study the **RATIO** of the widths: **$R_W = W_{in} / W_{out}$**



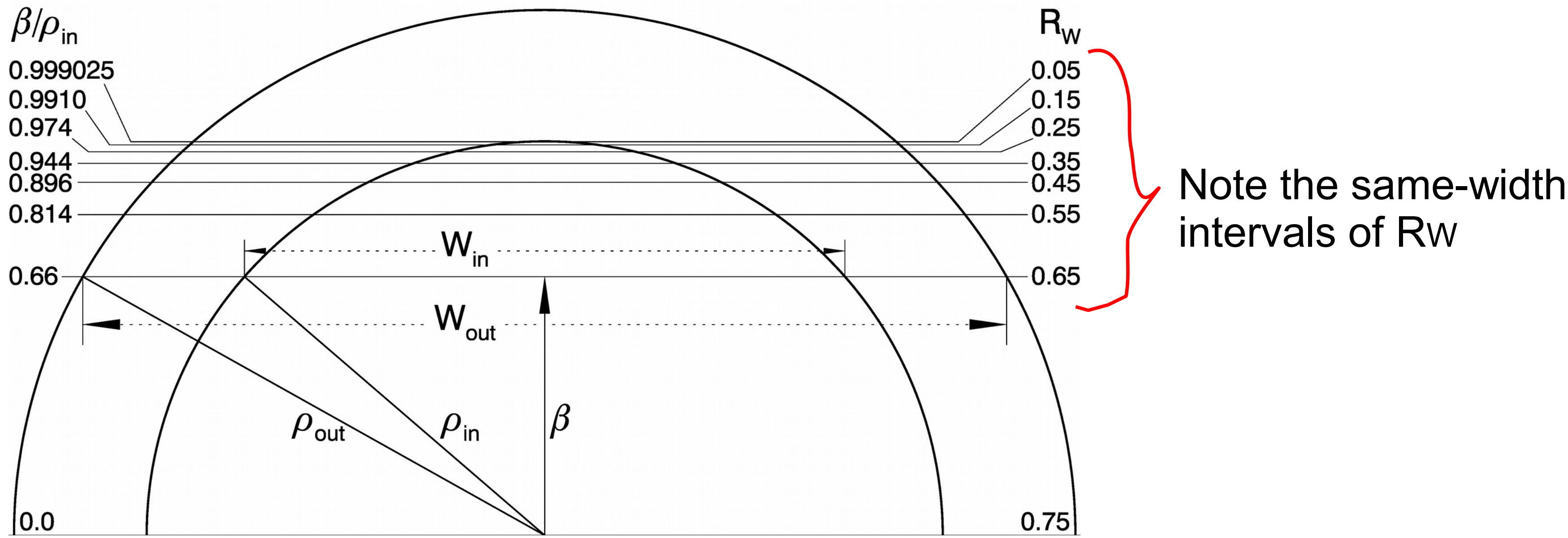
Cone size ratio fixed => Ratio of peak-to-peak separation **(Rw) depends only on beta**

Average cone size ratio Rrho is determined based on the conal model

=> **definite prediction for Rw distribution**

Intervals of viewing angle that correspond to a fixed interval in Rw (ΔRw = 0.1)

Rw = W_in / W_out

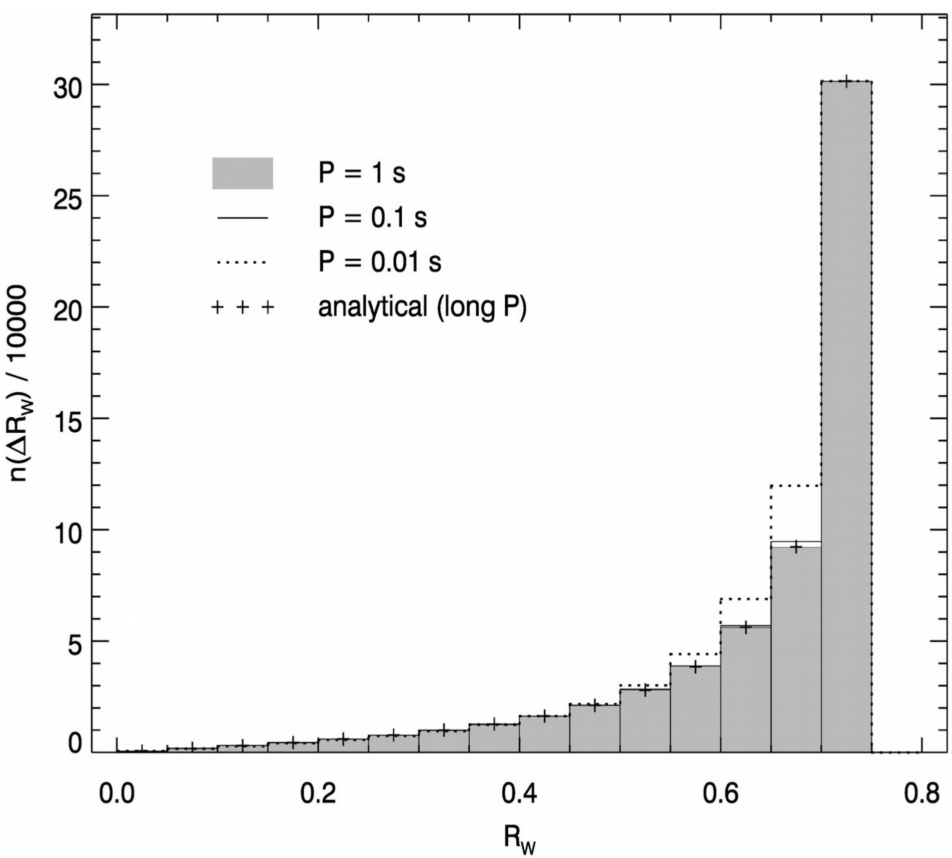


Except from the peripheric region, **Rw = ~0.7 should vastly dominate in the data**

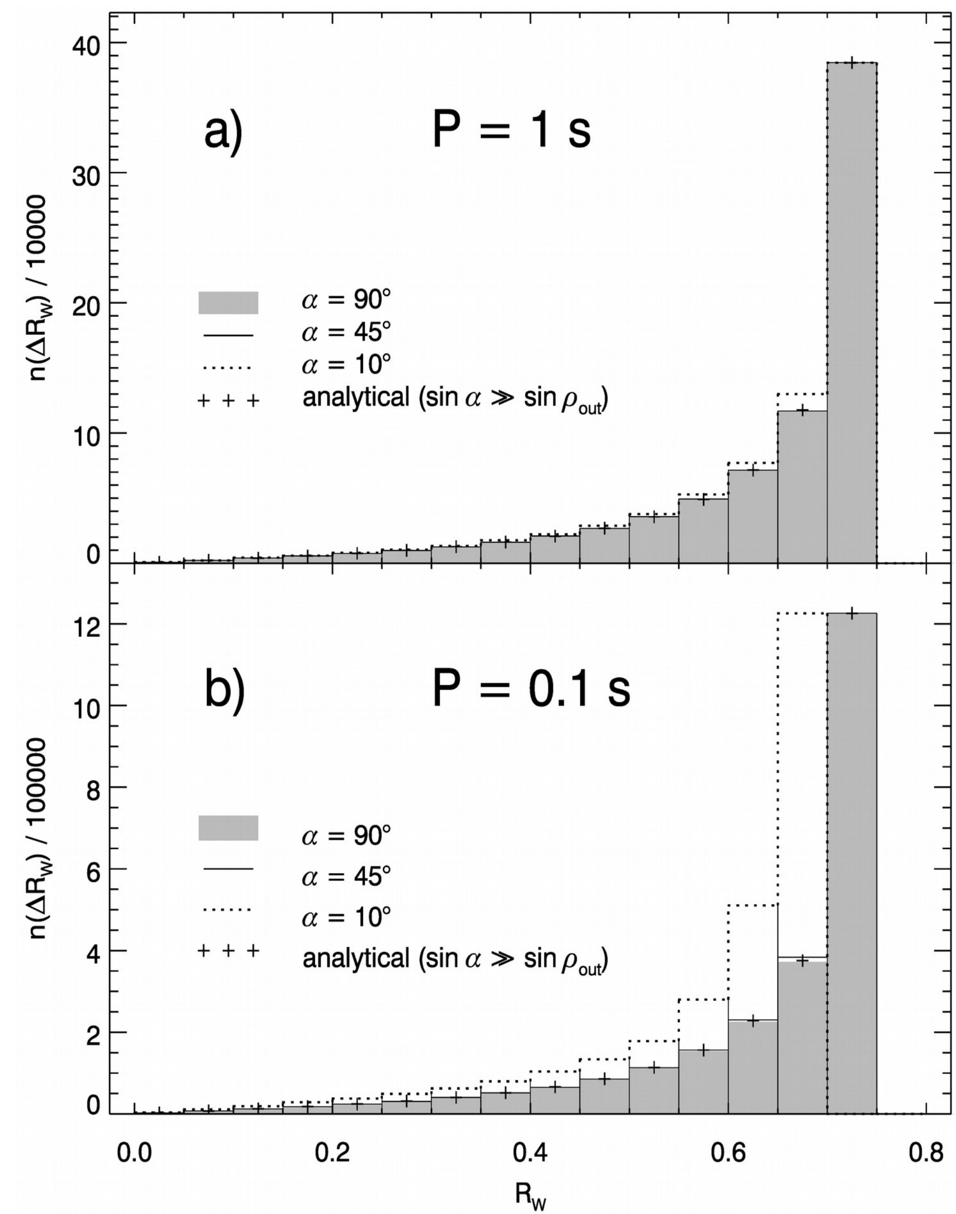
D&Pierbattista 2015

Ratios of widths instead of widths => method sensitive only to beam shape
but **independent of all parameters that just rescale the beam**
(period, dipole tilt, frequency, emission altitude)

Marginal dependence on period



Marginal dependence on dipole tilt (alpha)

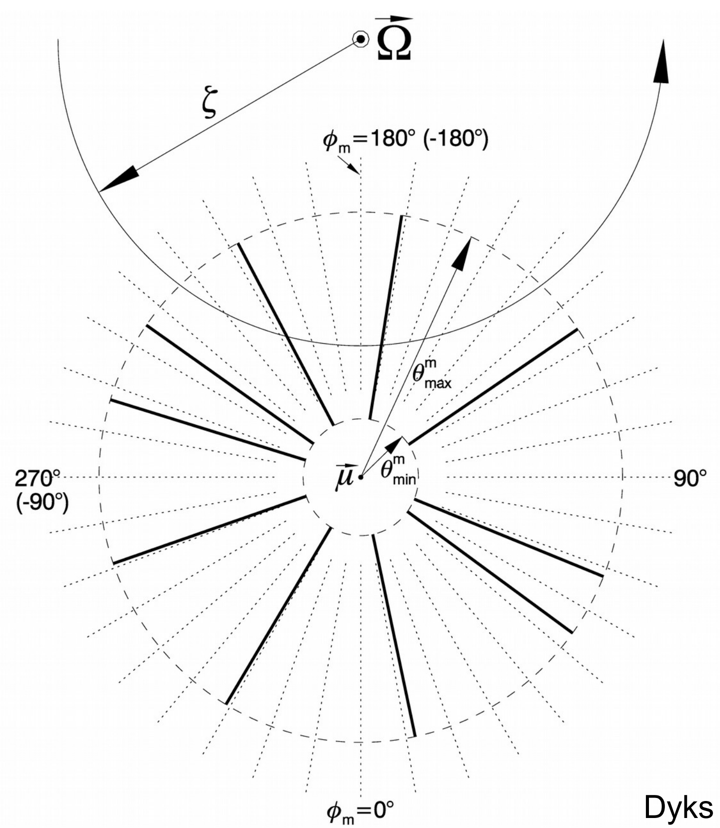


D&Pierbattista 2015

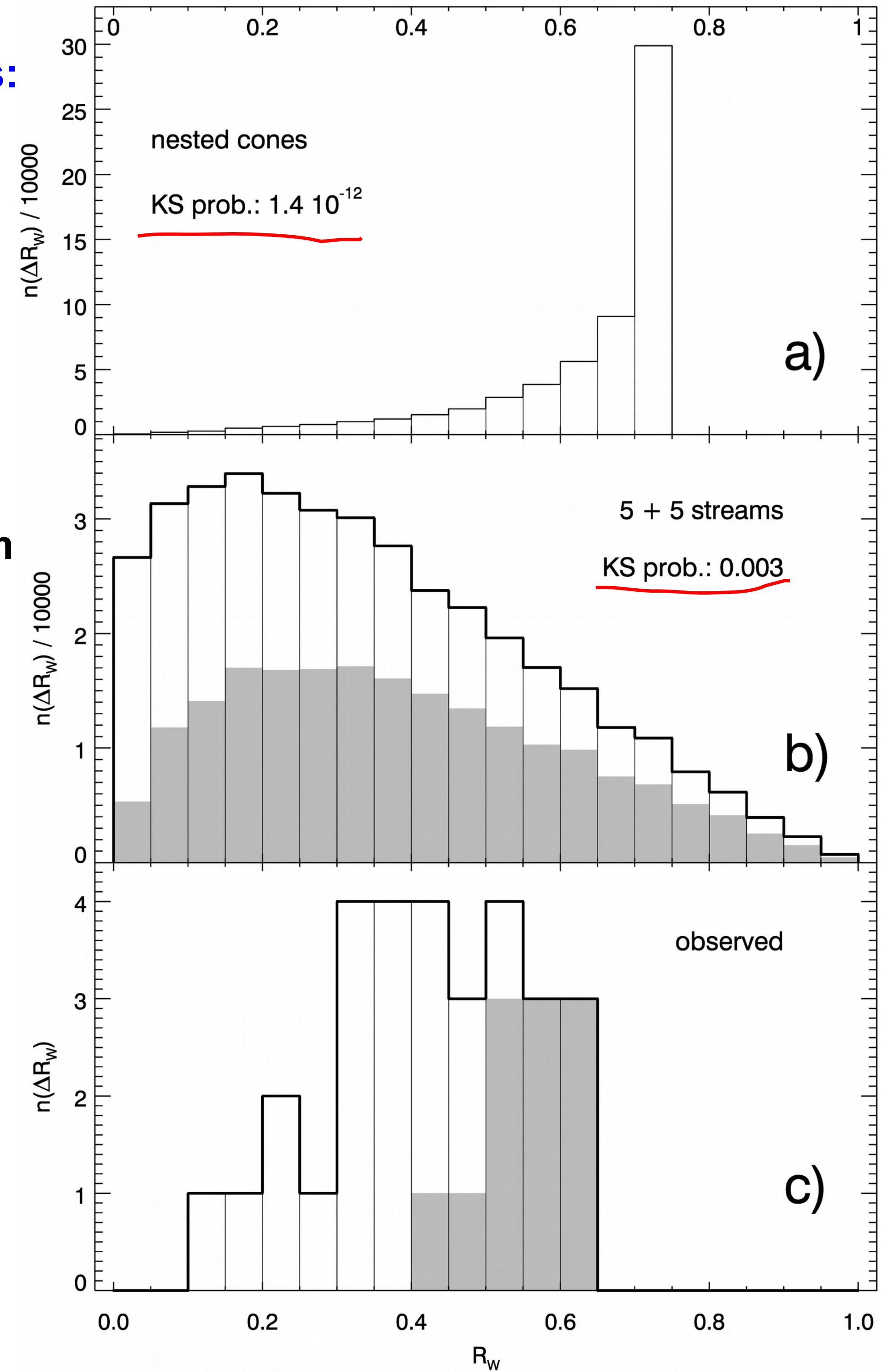
Nested cones:
(R_{rho} = 0.75)

Fan beams
(5 + 5 random streams):

Observed:
(30 pulsars of Q and M type)



Dyks & Pierbattista 2015



CONCLUSIONS

Fan beam geometry **works better in explaining the main nu-dependent phenomena** in both the normal and millisecond pulsars (RFM, core lag, lack of RFM in MSPs).

Fan beams provide a **better model for the observed Rw statistics**.

Fan beams are also able to **explain 'peculiarities'** such as the bifurcated components, double notches and polarisation distortions (see poster by Lab Saha).

Plasma streams (columns) **more natural than rings at disparate altitudes.**

Several important implications, eg.:

- outer boundary of radio beam not circular => existing estimates of r wrong

- dipole tilt distributions based on circular core shape not valid anymore

- radio pulse may lag the dipole axis phase (not just precede due to AR)

The conal beams may well not exist in pulsars at all.