Multi-frequency imprints of Pulsar radio emission models

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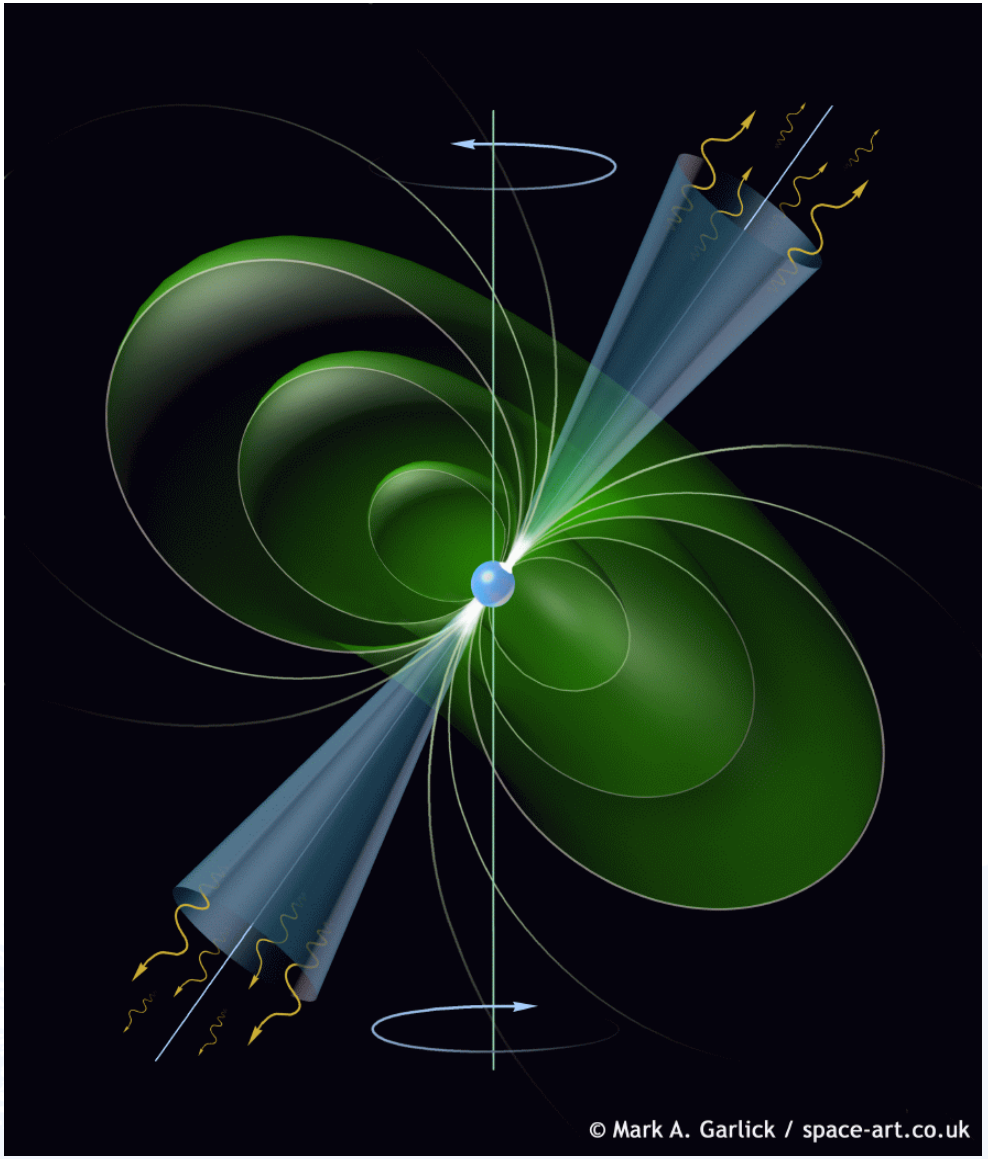
Radio emission from pulsars

Emission from charged particles streaming along the curved magnetic field lines in the open field line region.

Emission at any given frequency comes from a limited range of altitudes.



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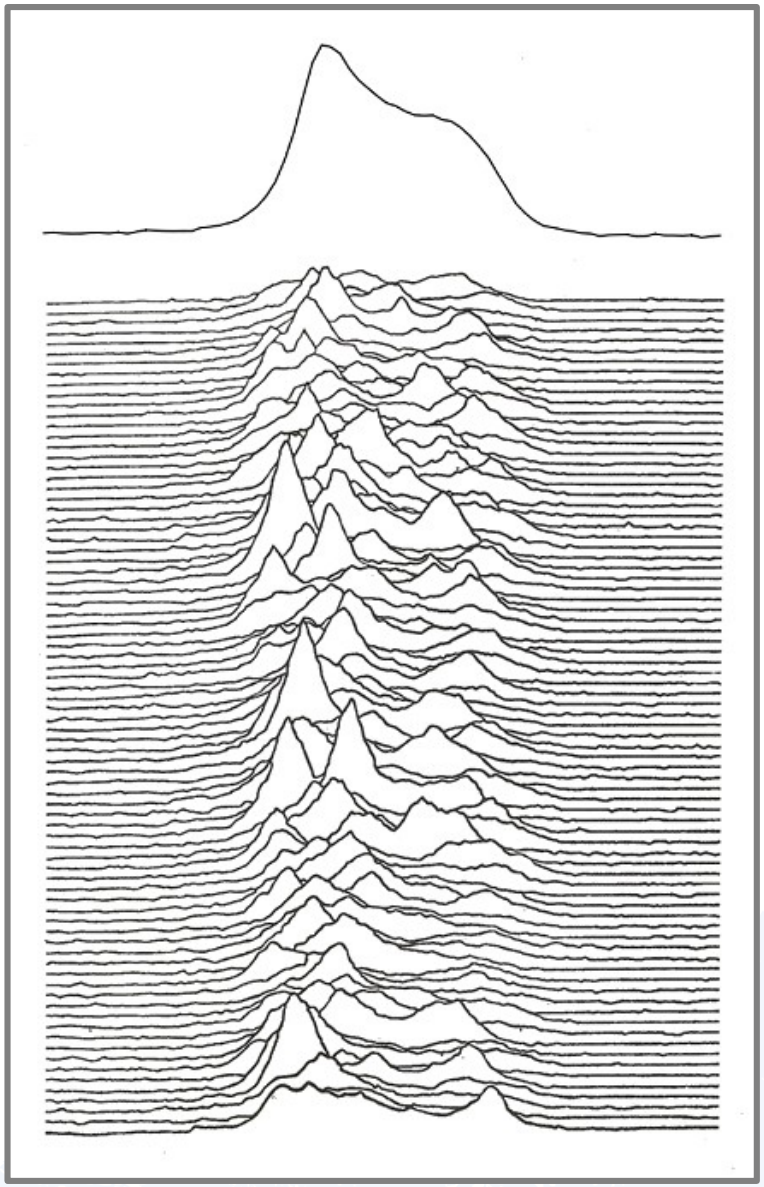
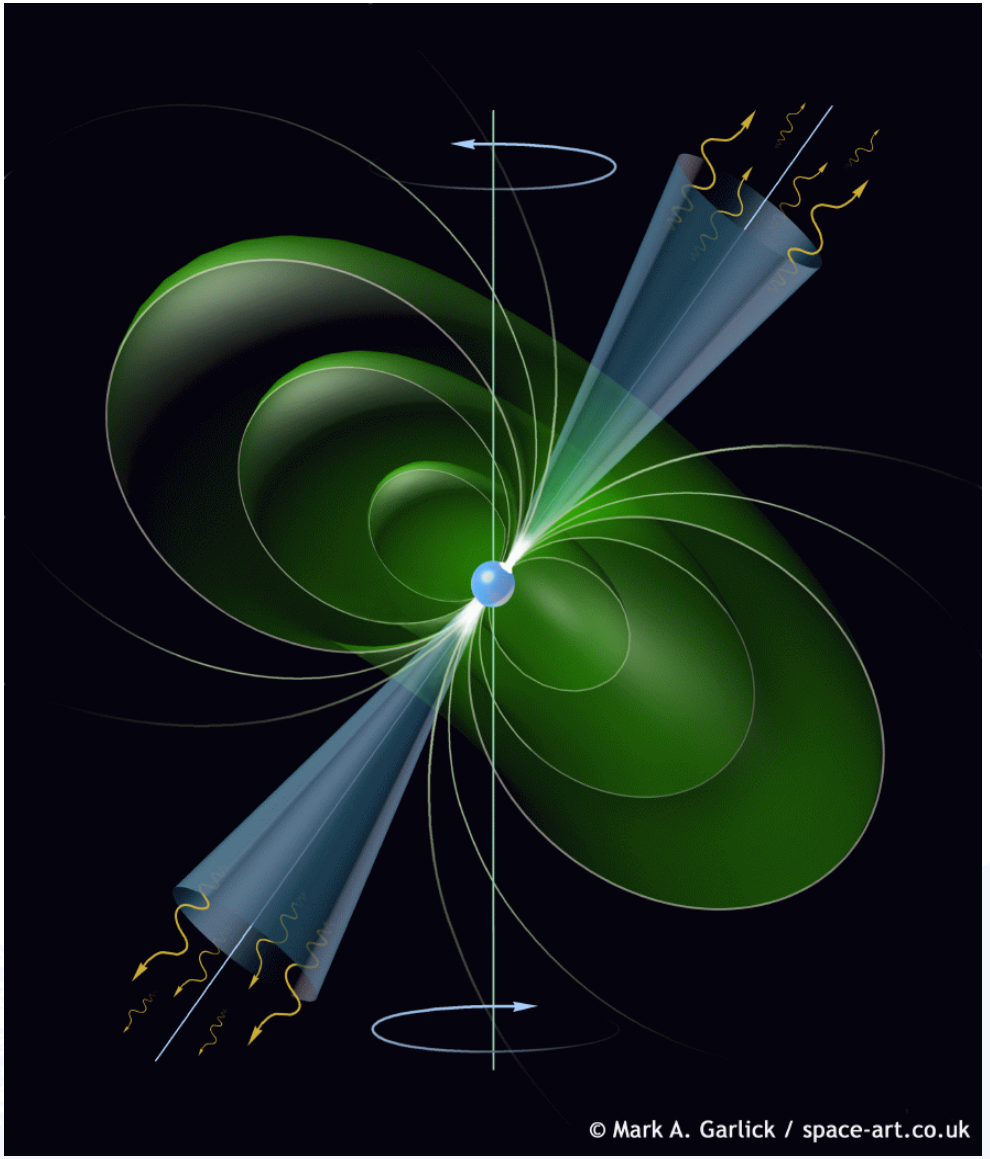
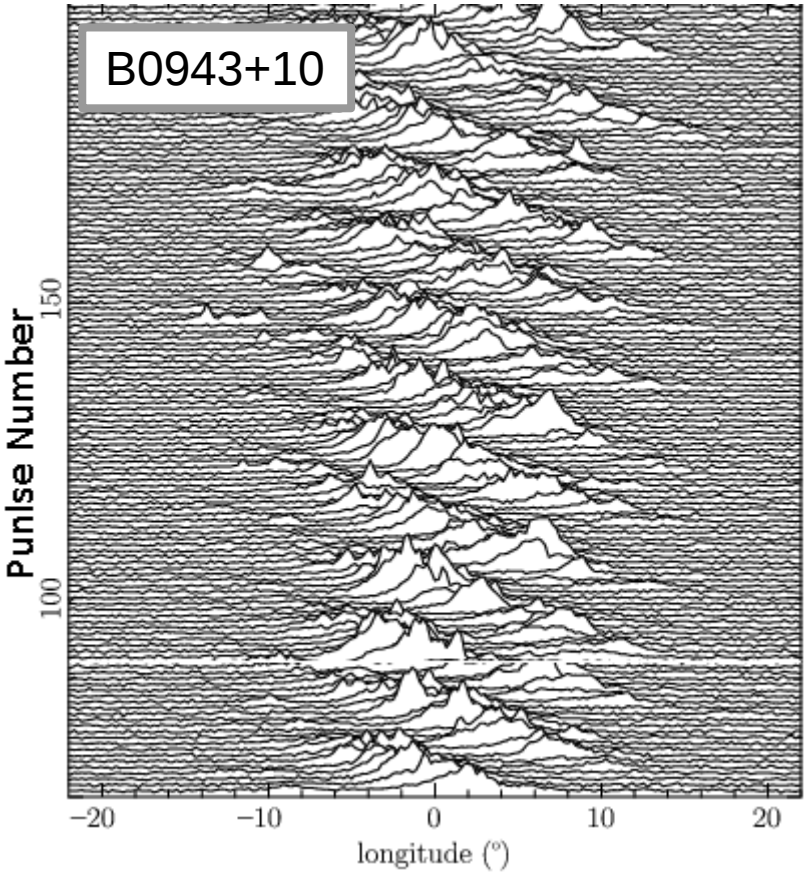
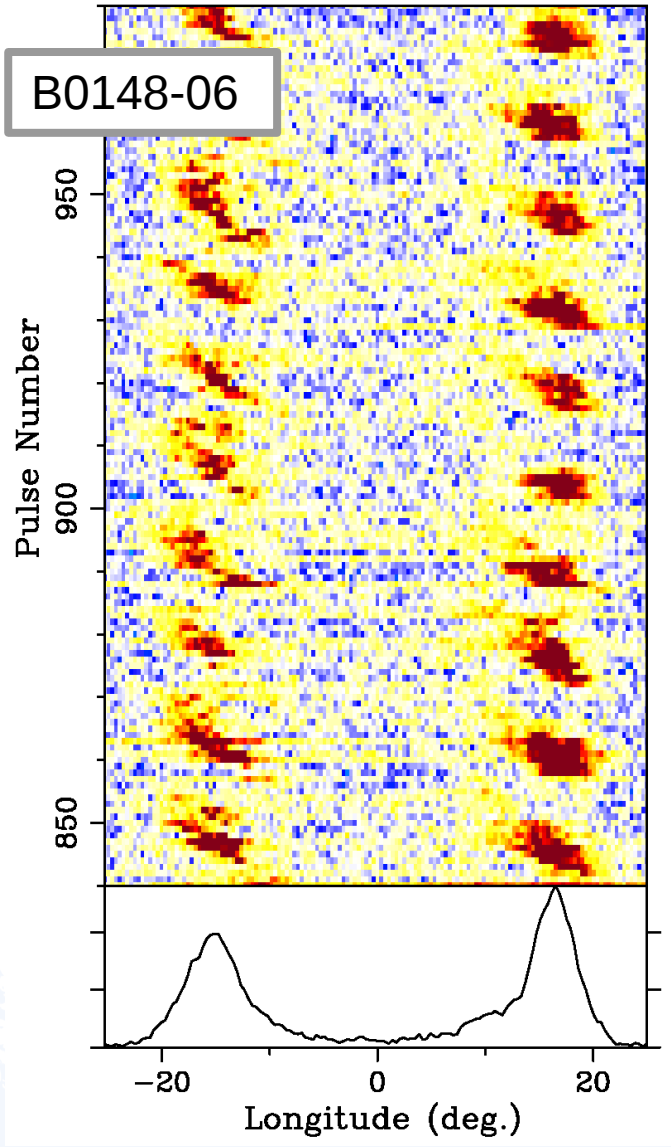




Emission from pulsars: Sub-pulse drifting





Emission from pulsars: Carousel model

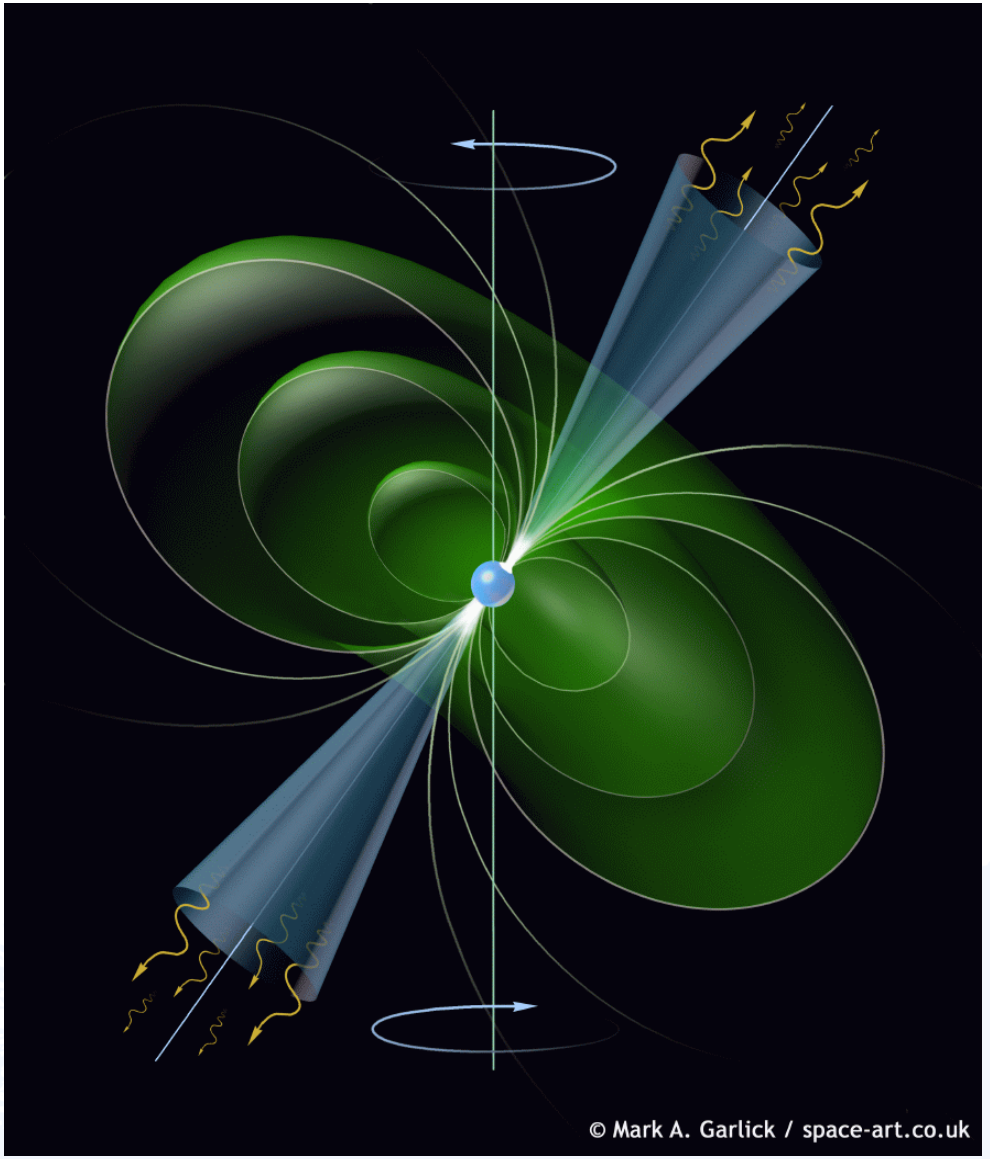
"Spark" discharges in the Acc. Gap (~100 meters, 10^12 eV)

Sparks rotate about the magnetic axis, due to E × B drift ⇒ A carousel of sparks.

A system of emission columns, seeded by a carousel of sparks, appears to rotate about the magnetic axis.

Carousel Model

(Ruderman & Sutherland 1975)



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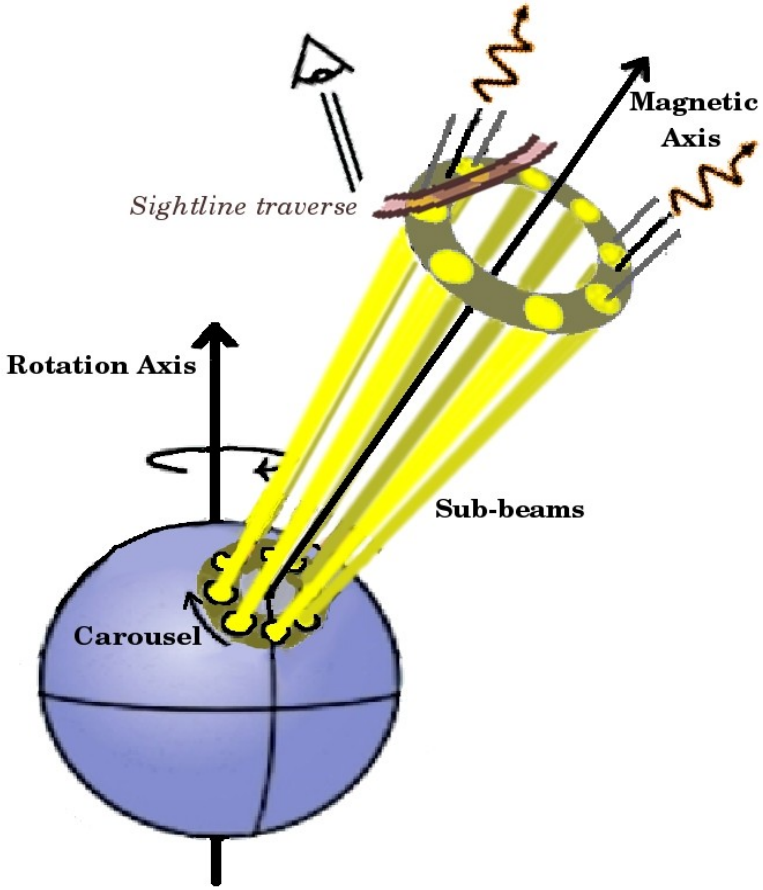

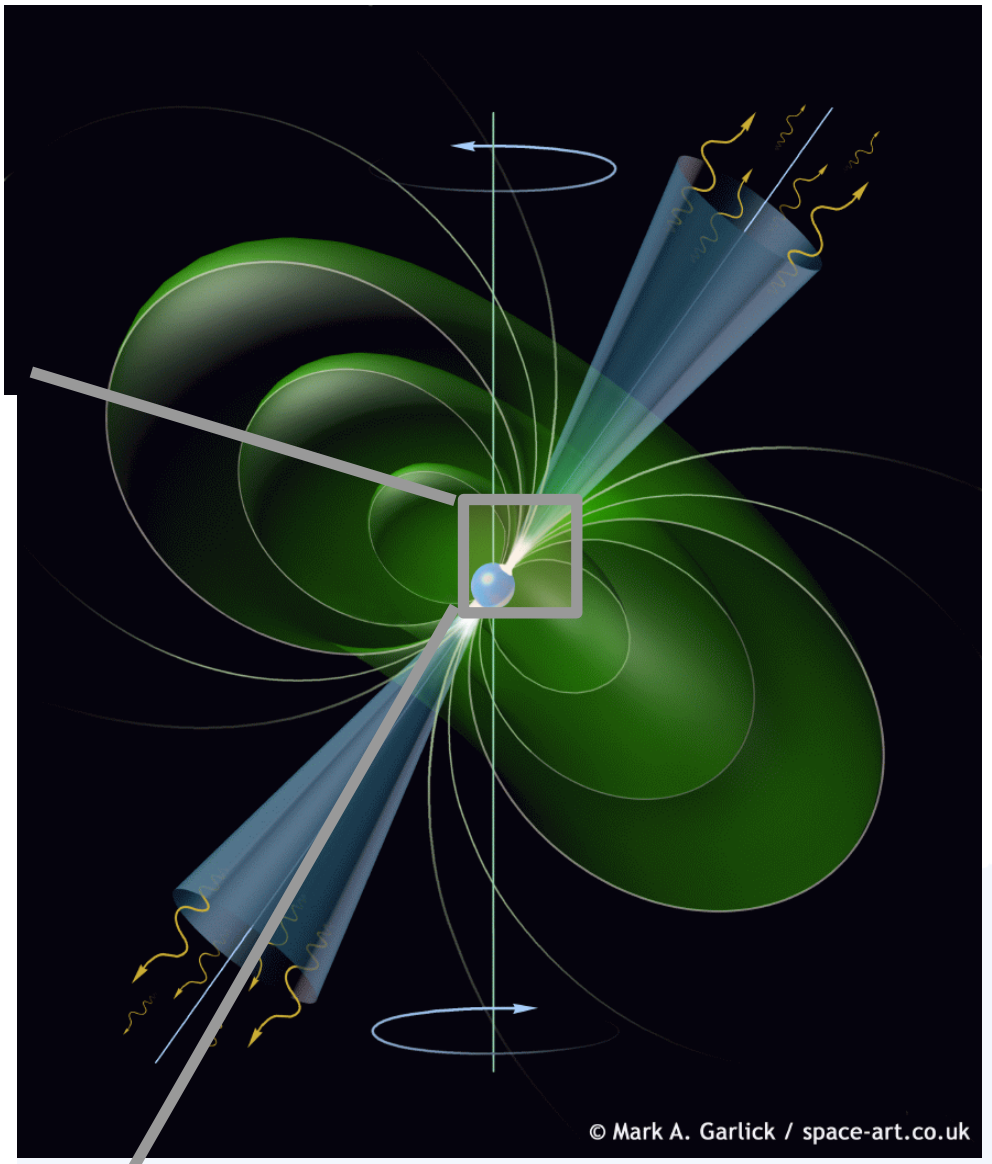

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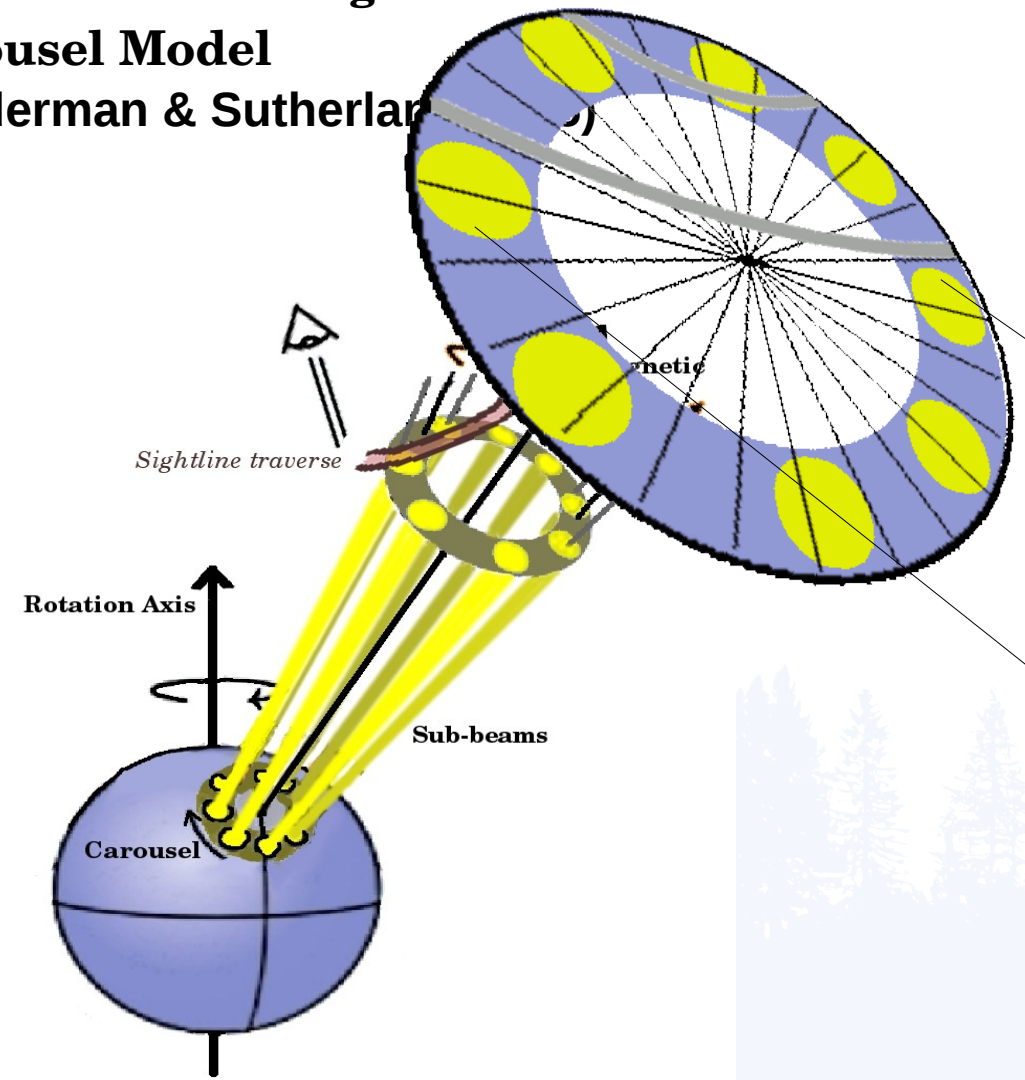

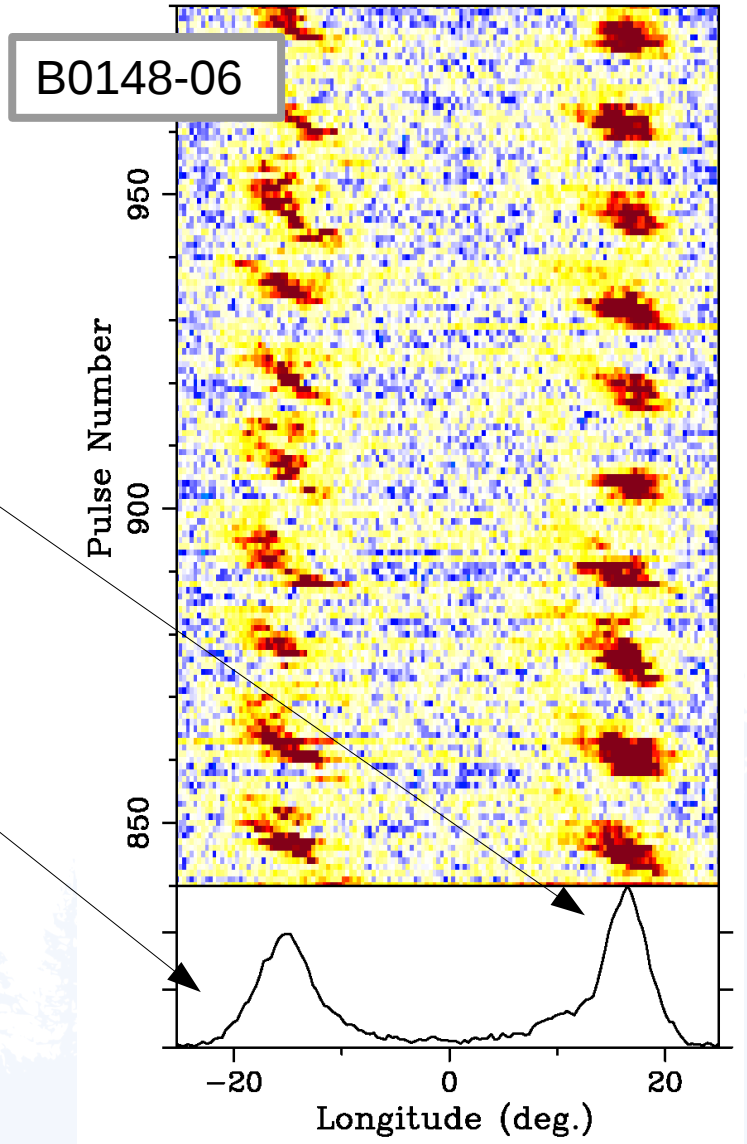

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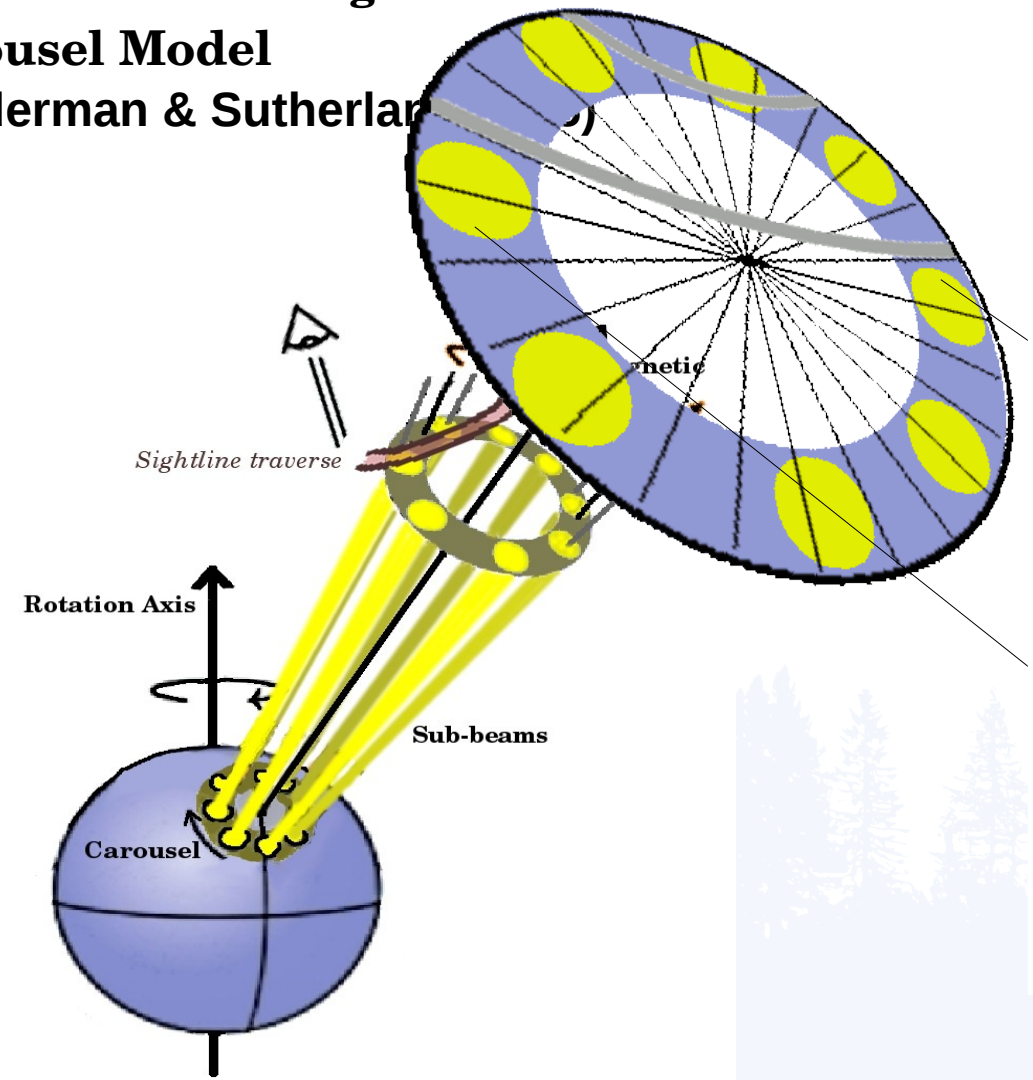
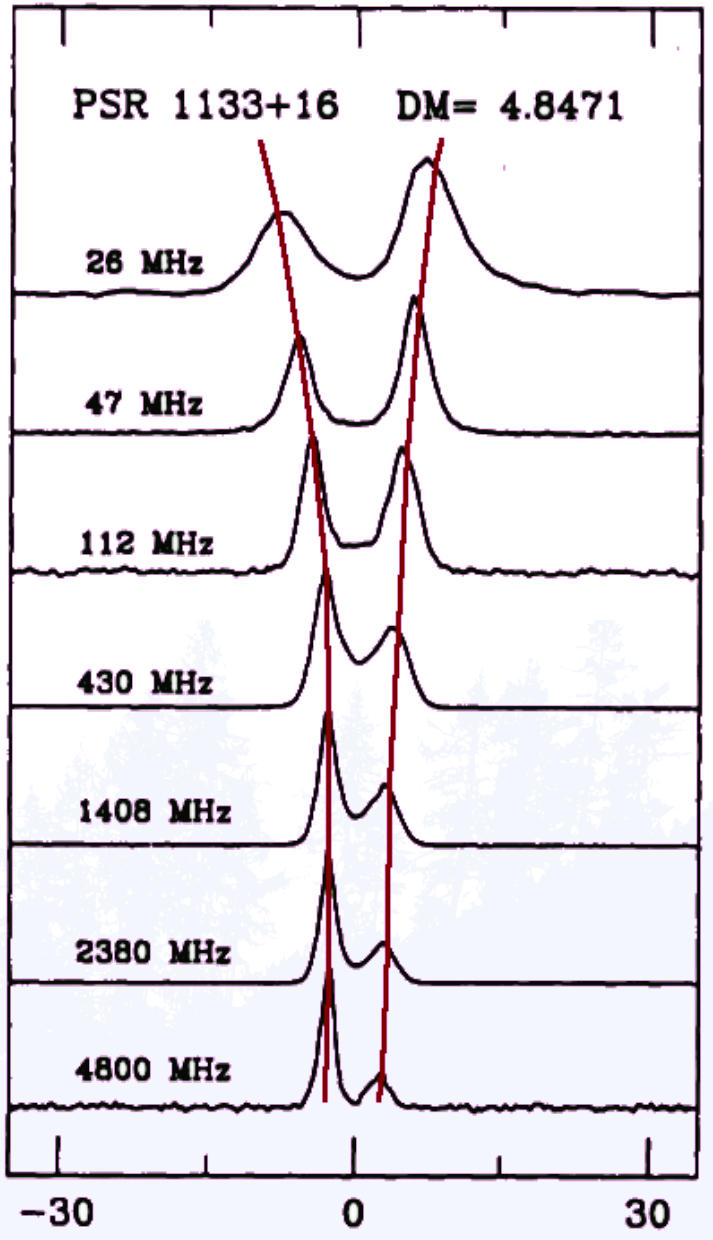


Many observational phenomena unexplained in this model: Bi-drifting, Multiple drift modes, etc.

Recently more questions on the symmetry axis of the carousel.

Expected signatures in multi-frequency observations remain largely unexplored.

Radius-to-frequency mapping (RFM)



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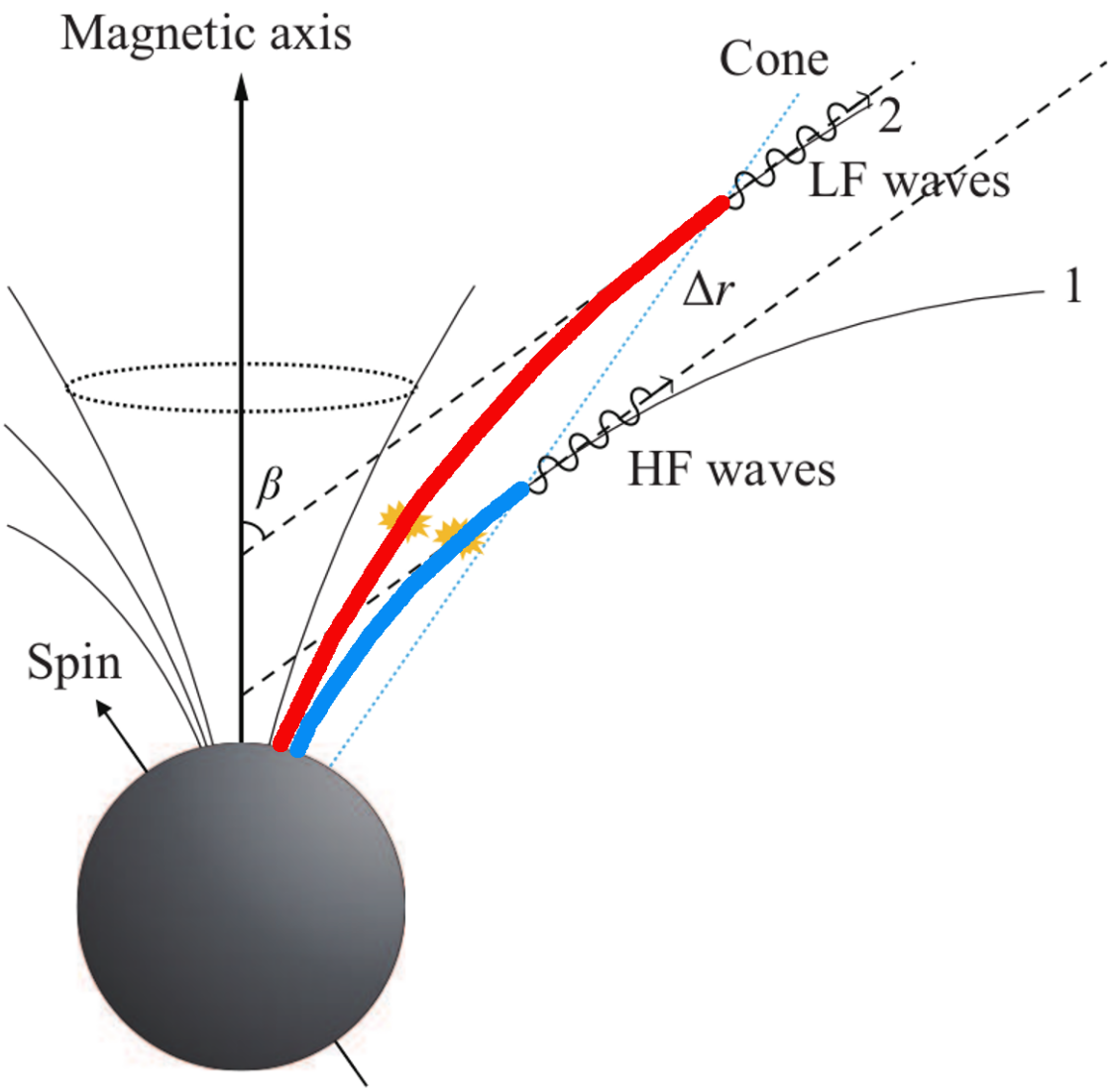
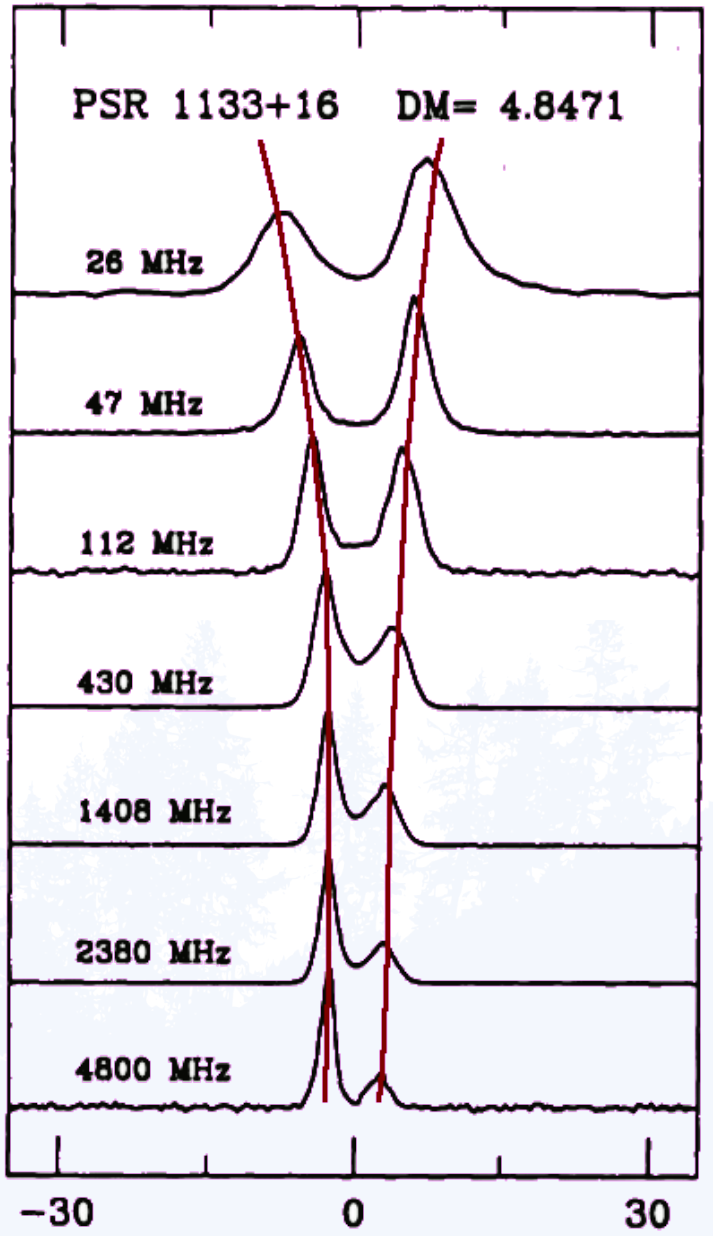
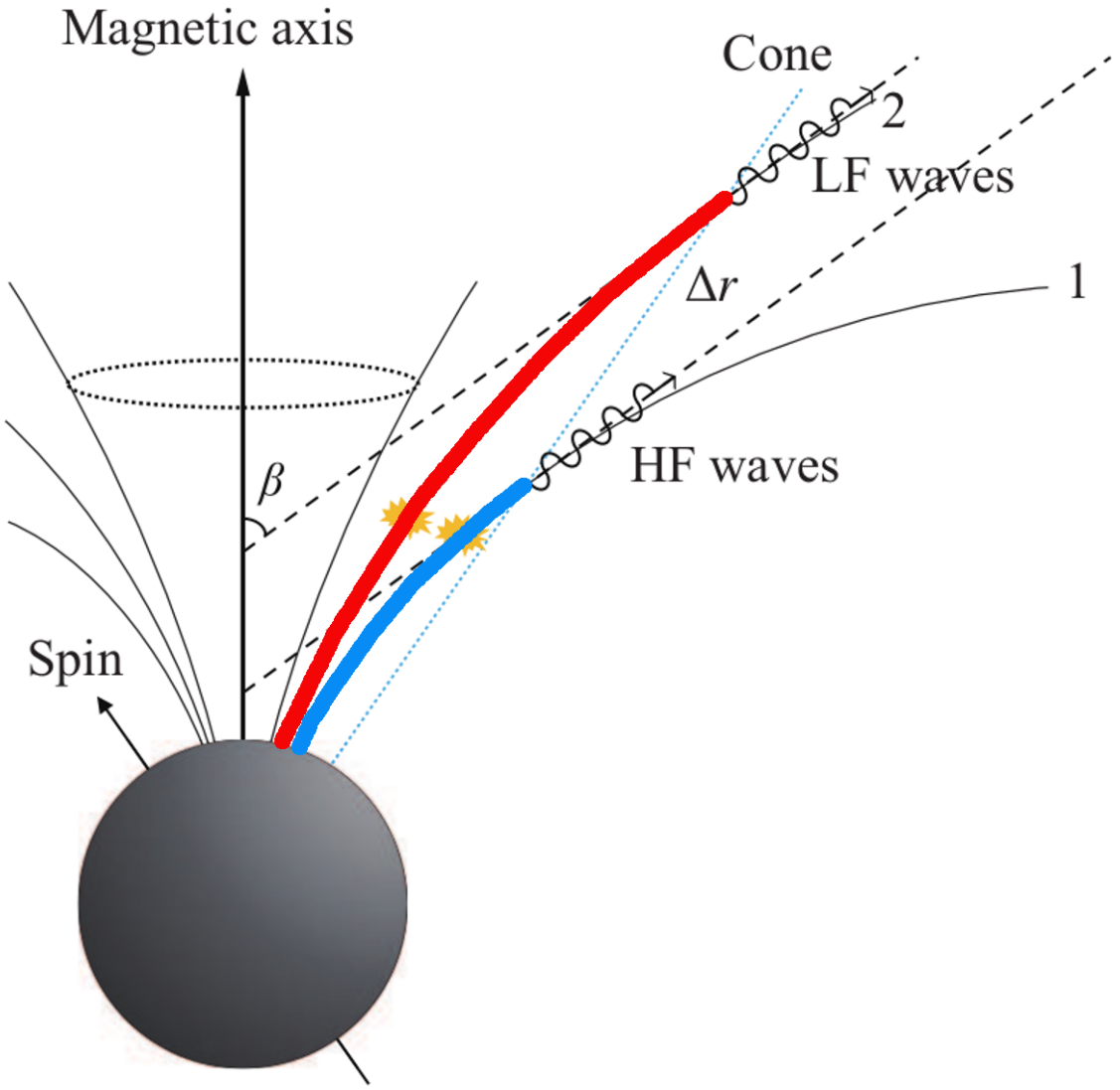




RFM: Implications for the Carousel model

Different frequencies probe slightly different set of field lines.



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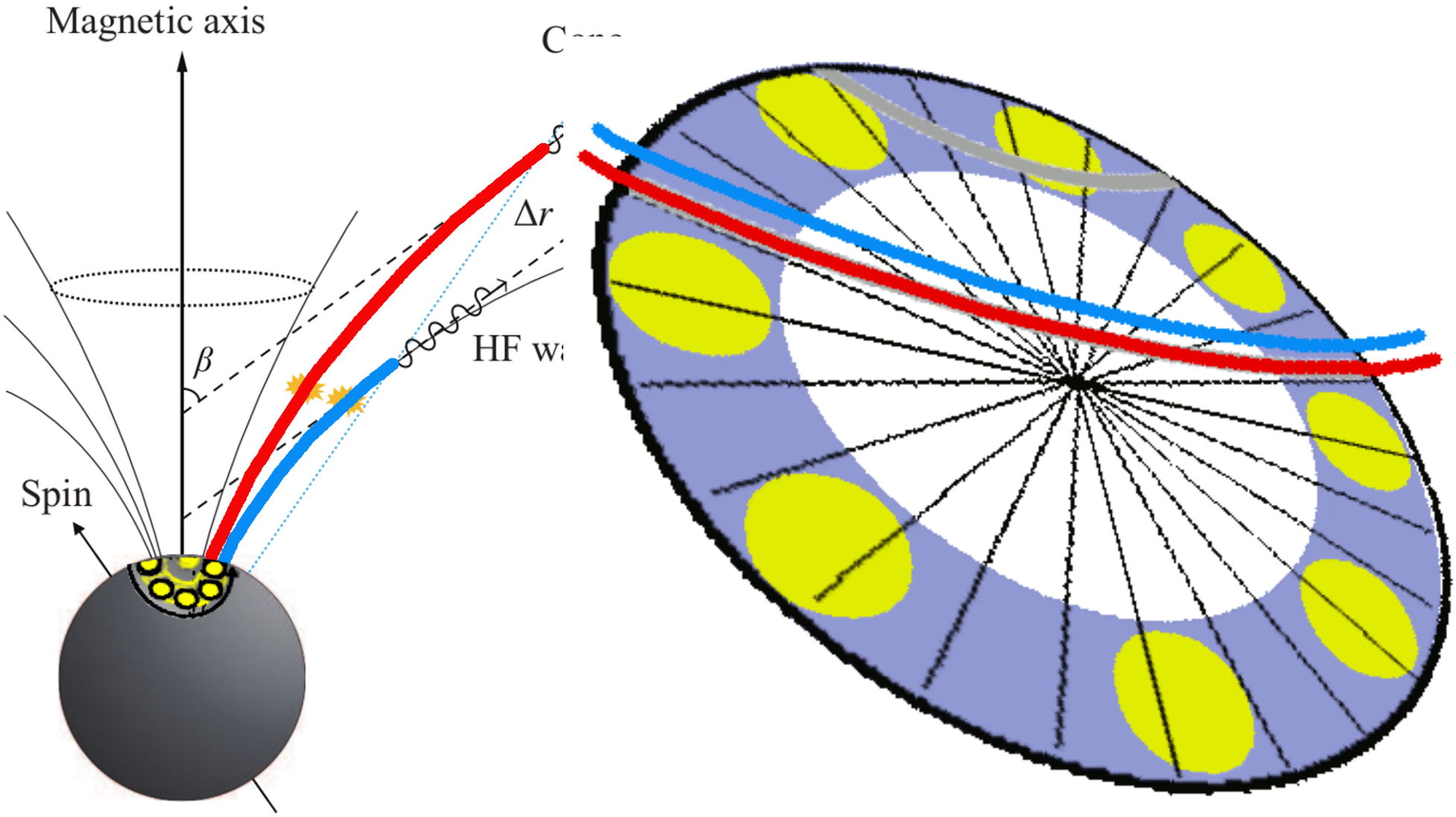
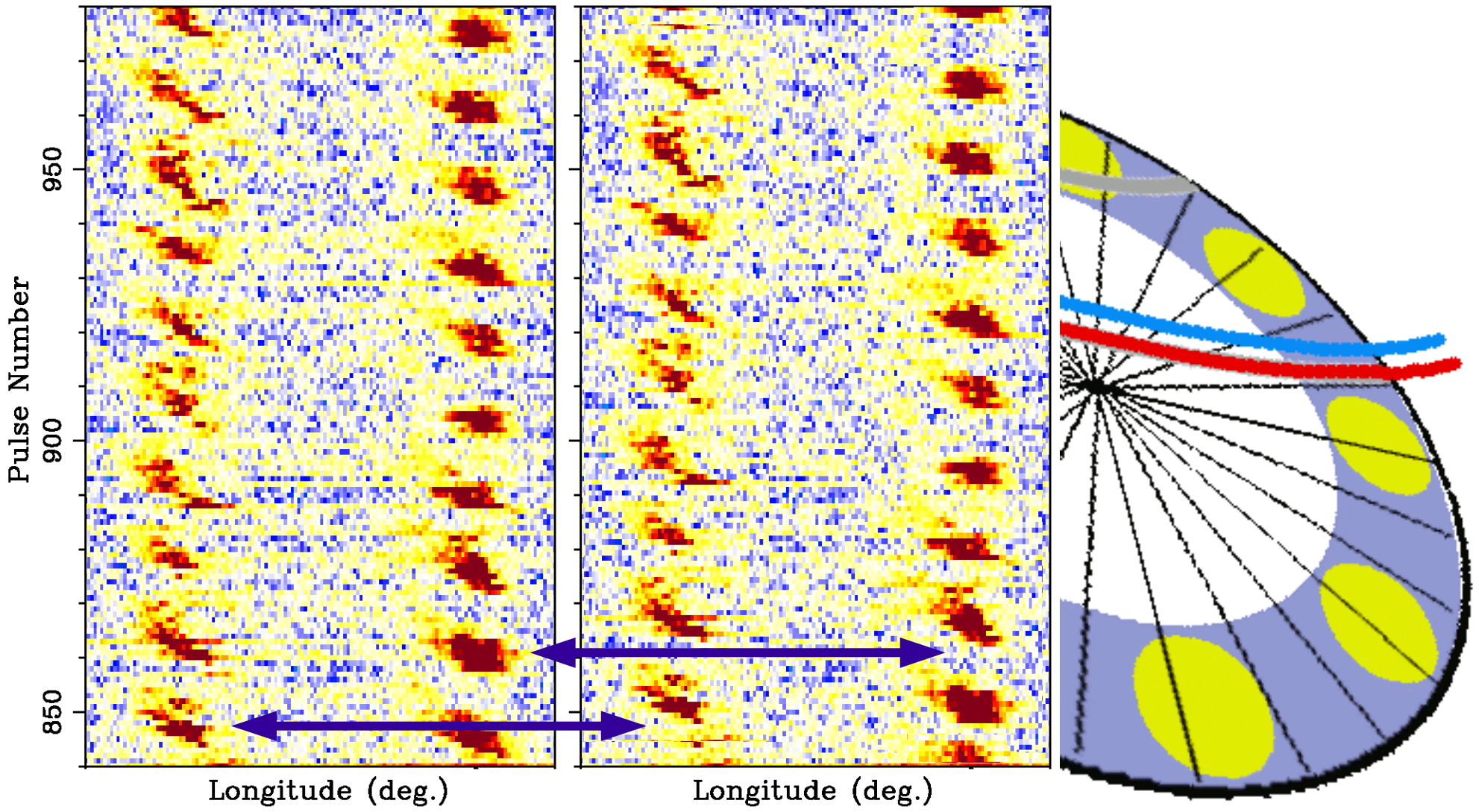


RFM: Expected multi-frequency imprints



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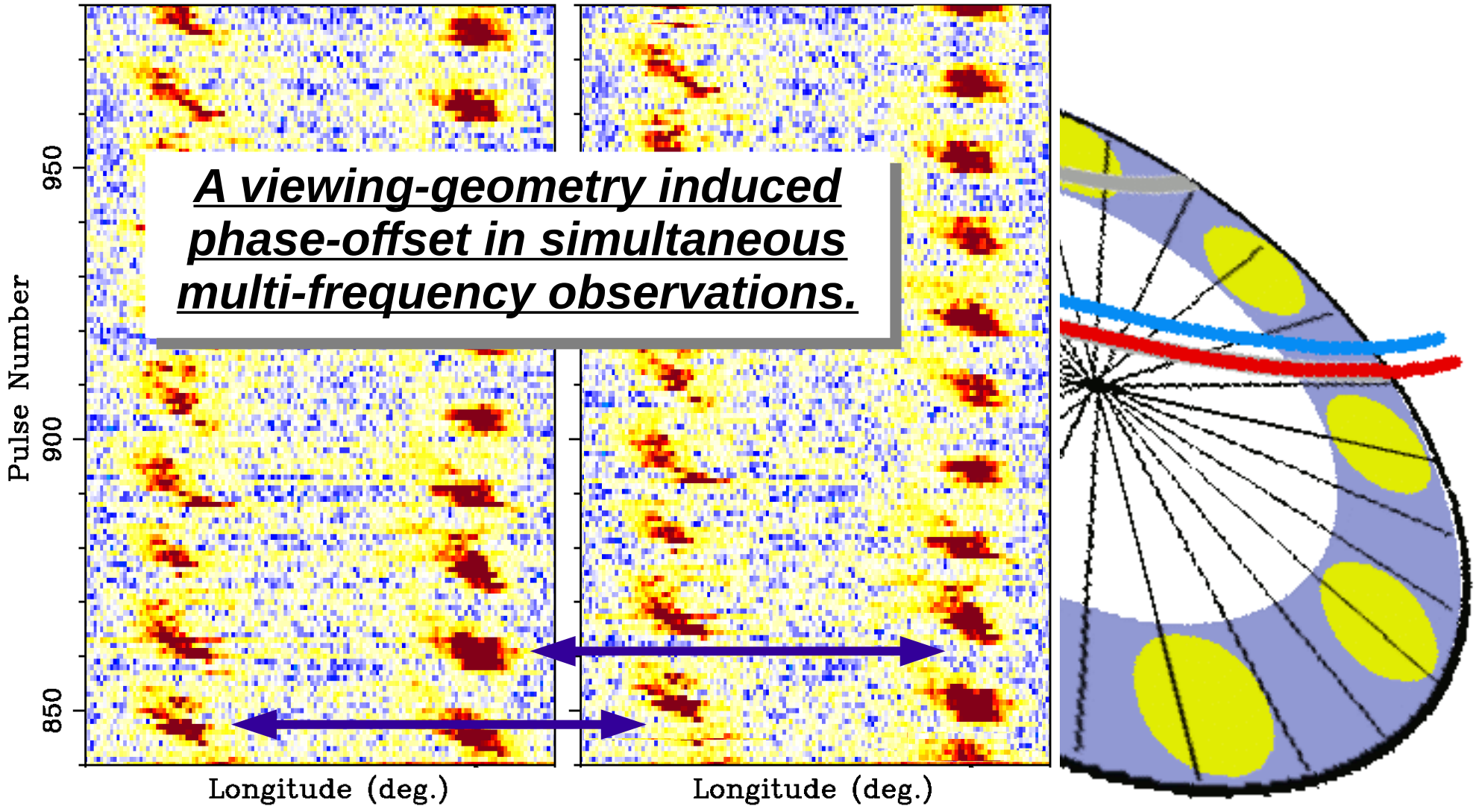
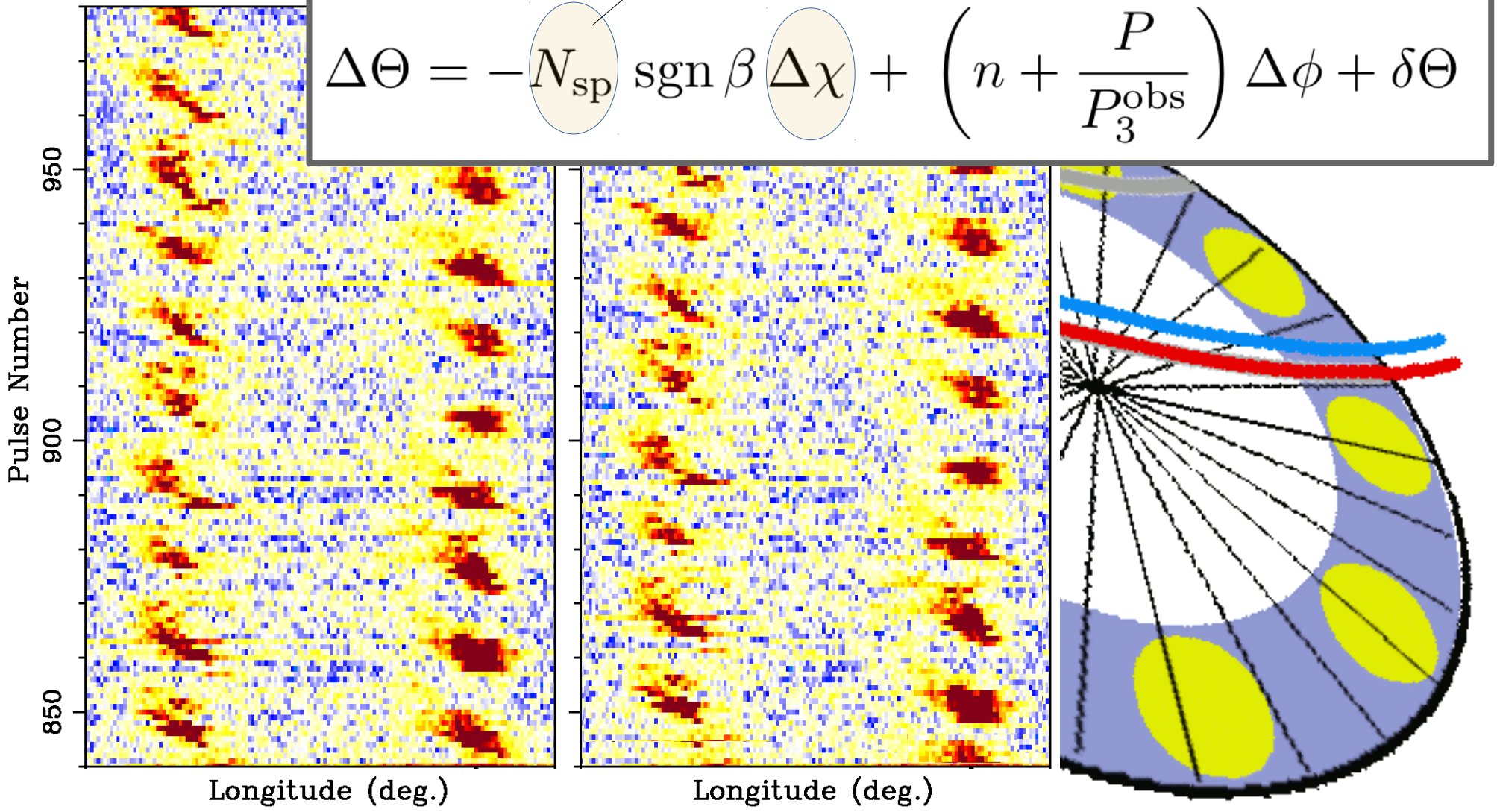


A geometry-induced *phase-offset*

No. of sparks

$$\Delta\Theta = -N_{\rm sp}\,\mathrm{sgn}\,\beta\,\Delta\chi + \left(n + \frac{P}{P_3^{\rm obs}}\right)\Delta\phi + \delta\Theta$$



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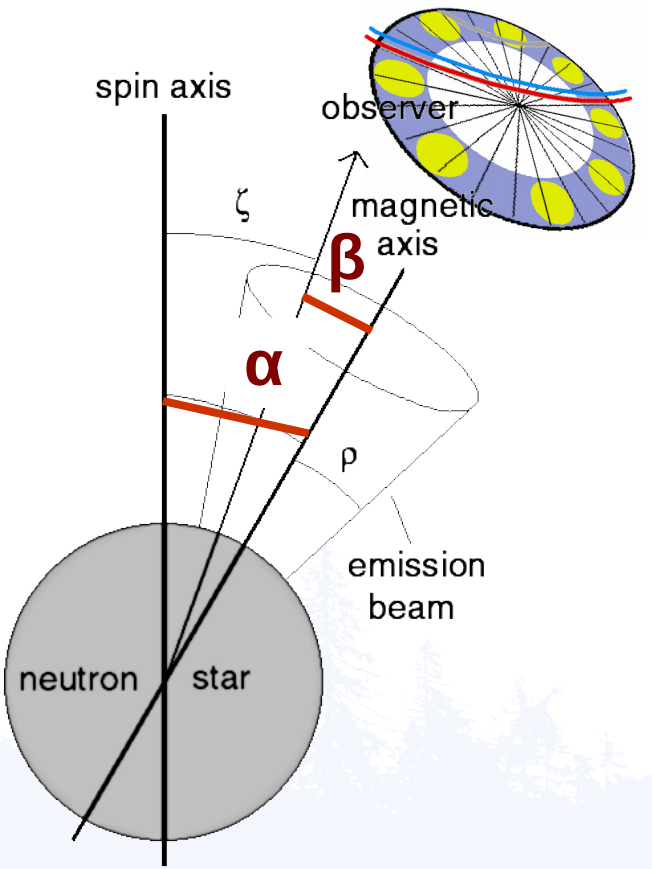


Primary dependence on:

1) No. of sub-beams
2) Magnetic inclination angle (α)
3) The impact angle (β)

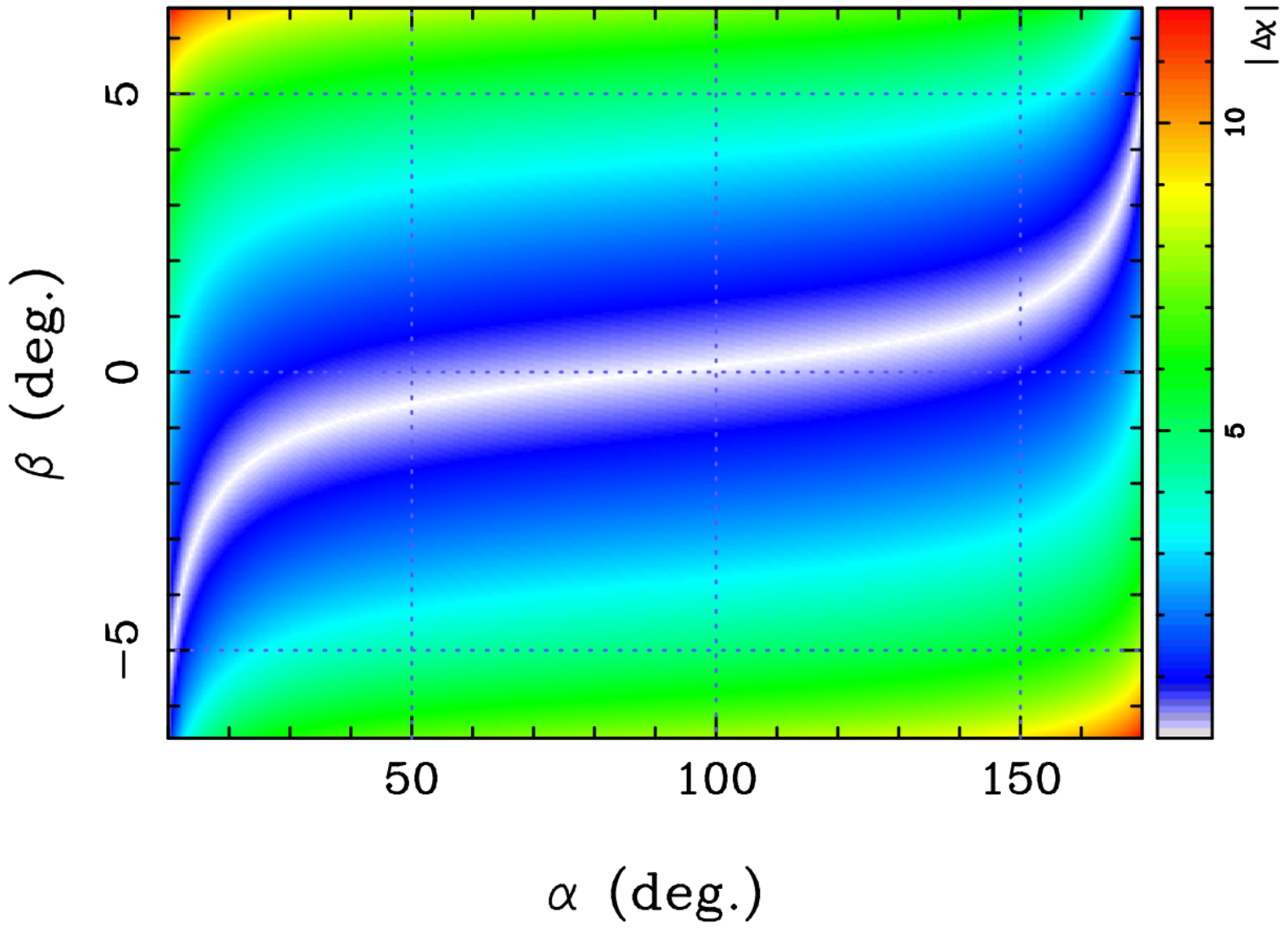
And mildly on:
4)Sub-pulse modulation period,
5) Component position change,
6) Aberration effects.

Maan (2018, 2019)

Subpulse phase-offset: variations with viewing geometry

Change in the magnetic azimuth (Δχ) between 250 and 600 MHz.

$\Delta\Theta \sim N_{sp} \times \Delta\chi$



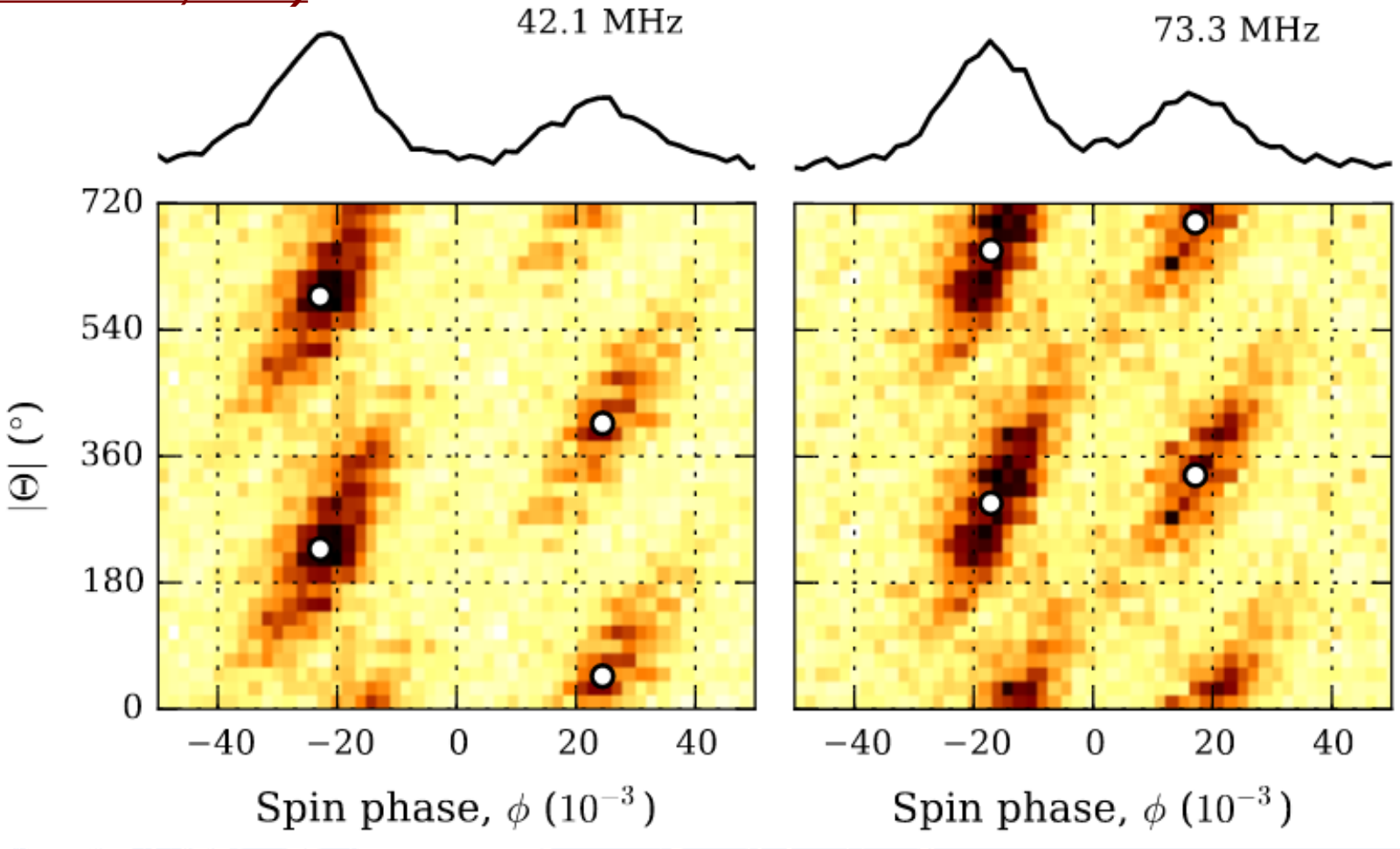
Frequency-dependent subpulse phase-offset: Observable Implications

Observable implications of the geometrical phase-offset

- **1. Testing the Carousel model**
- 2. Test single frequency multi-altitude emission
- 3. Modeling the emission geometry
- 4. Resolving the aliasing in subpulse modulation period
- 5. A clean probe of any twist in the magnetosphere
- 6. Two-dimensional mapping of the polar-cap

Observable Implications…

Observed subpulse phase-offsets for B0943+10 using LOFAR LBA. (Bilous 2018, A&A)



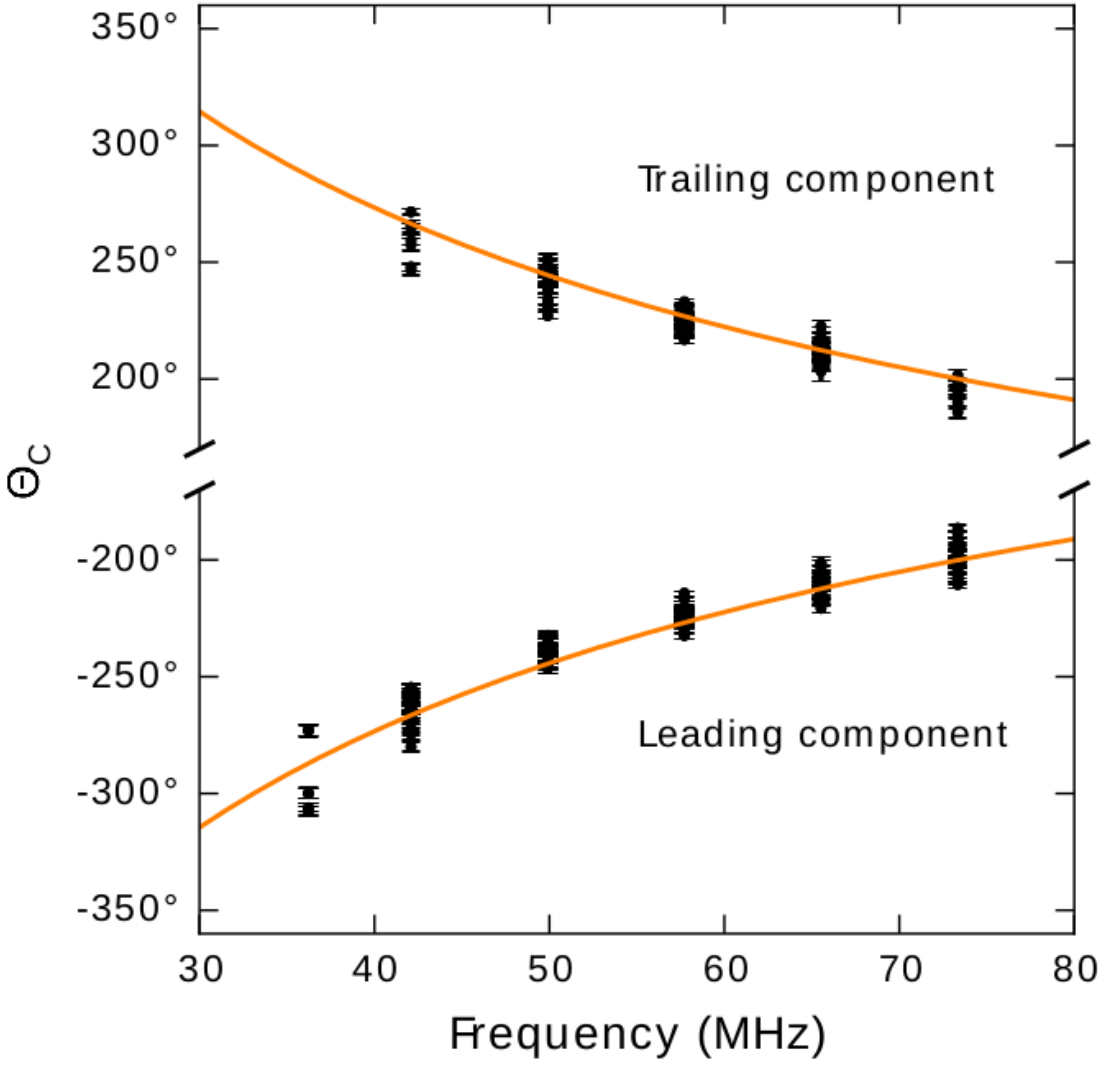
Observable Implications…

- **1. Testing the Carousel model**

B0943+10 observations consistent with the carousel model. ***(Bilous 2018, A&A)***

Magnetic inclination angle (α) for B0943+10 is only about 6° and a grazing line-of-sight.

Stringent tests to be done for pulsars with more central lines-of-sight.



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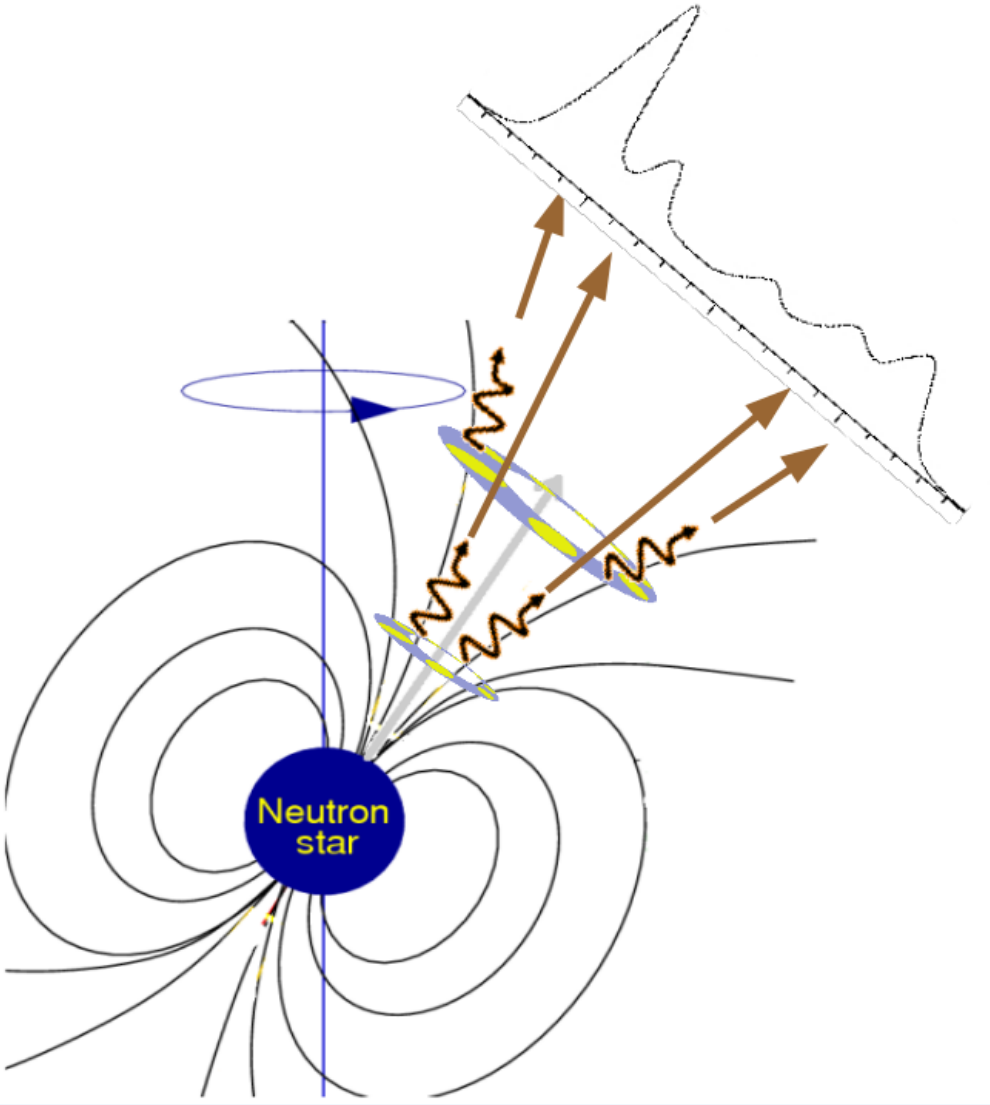
Single-frequency Multi-altitude emission

M-type profiles

- ***Phase-locked*** **modulation between inner and outer cones,**
- **B1237+25: inner cone emitted at lower altitudes compared to outer cone**
- **Number of sub-beams same in the emission patterns of the two cones**

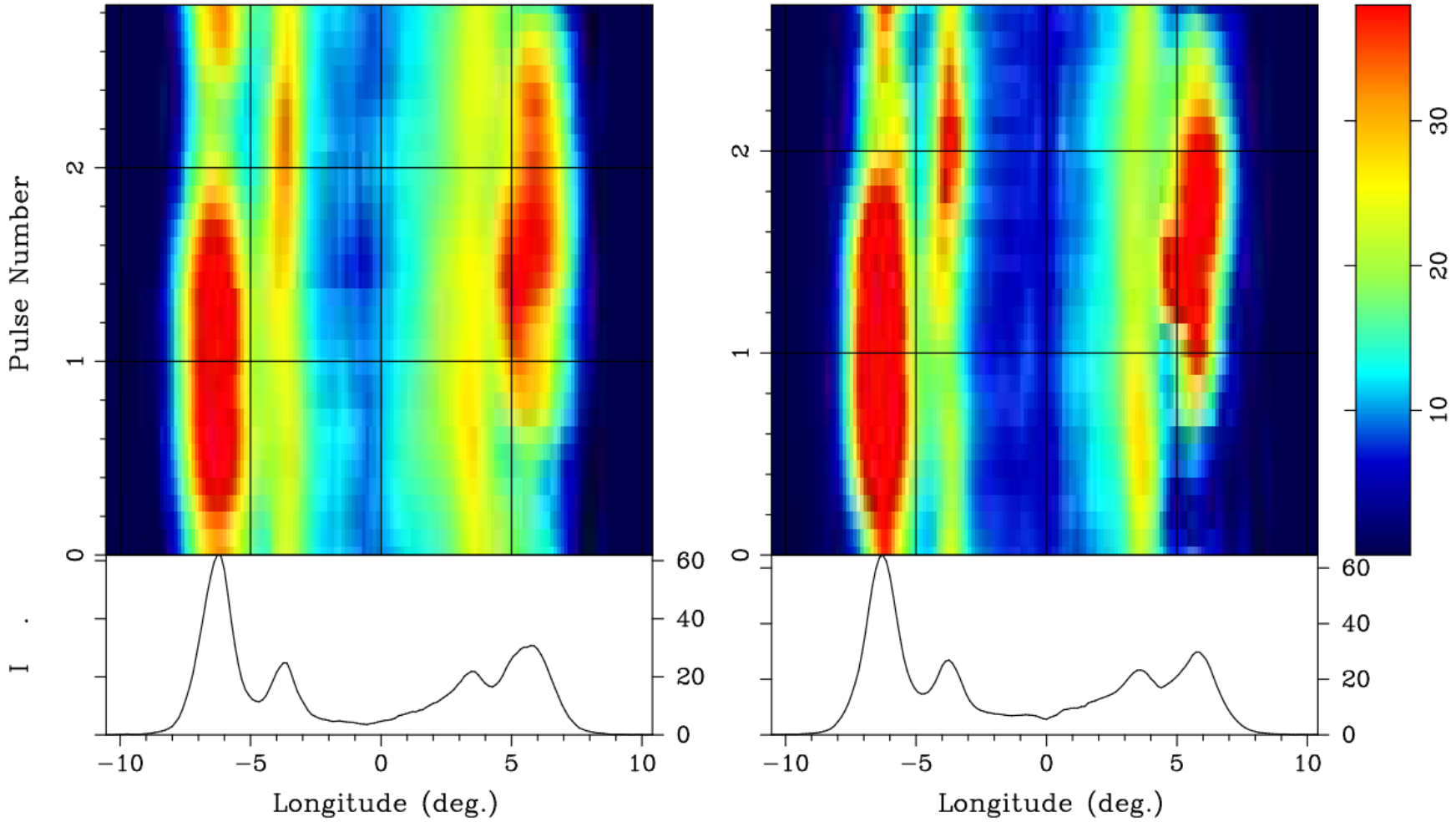
=> Single frequency Multi-altitude emission

Rankin (1993),
Maan and Deshpande (2014)



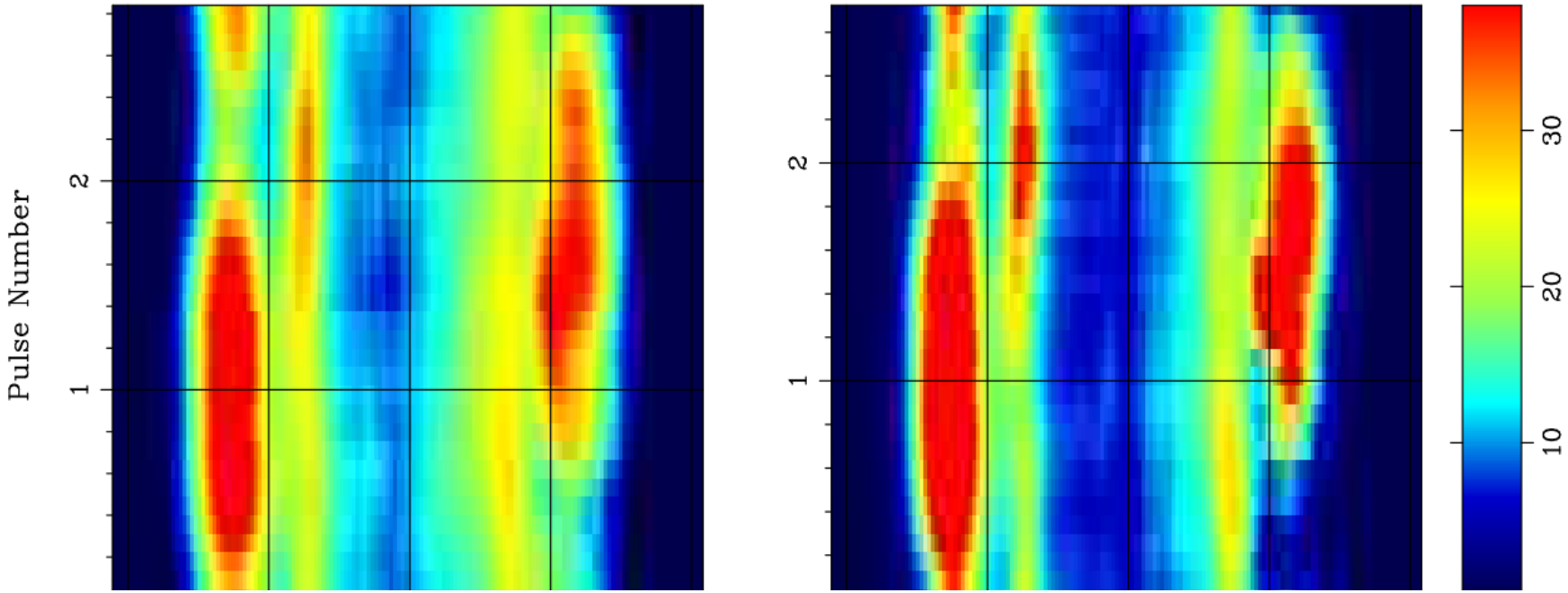
Multi-altitude emission (B1237+25)

Implications for the subpulse phase



Multi-altitude emission (B1237+25)

Expected and observed phase-offsets. *(Maan 2019, ApJ)*



Subseq.	Components I and II		Components IV and V	
	$\rho_{\max}$ (%)	$\Delta\Theta_{\rm obs}(^\circ)$	$\rho_{\max}$ (%)	$\Delta\Theta_{\rm obs}(^\circ)$
S_1	91.0 ± 6.7	$+137 \pm 32$	76.5 ± 16.4	-104 ± 36
S_2	95.6 ± 3.4	$+137 \pm 22$	71.3 ± 19.0	-115 ± 47

Multi-altitude emission (B1237+25)

Within the scope of dipolar geometry,
the observed phase-offsets can be explained by multi-altitude emission scenario.

A firm evidence for multi-altitude emission.

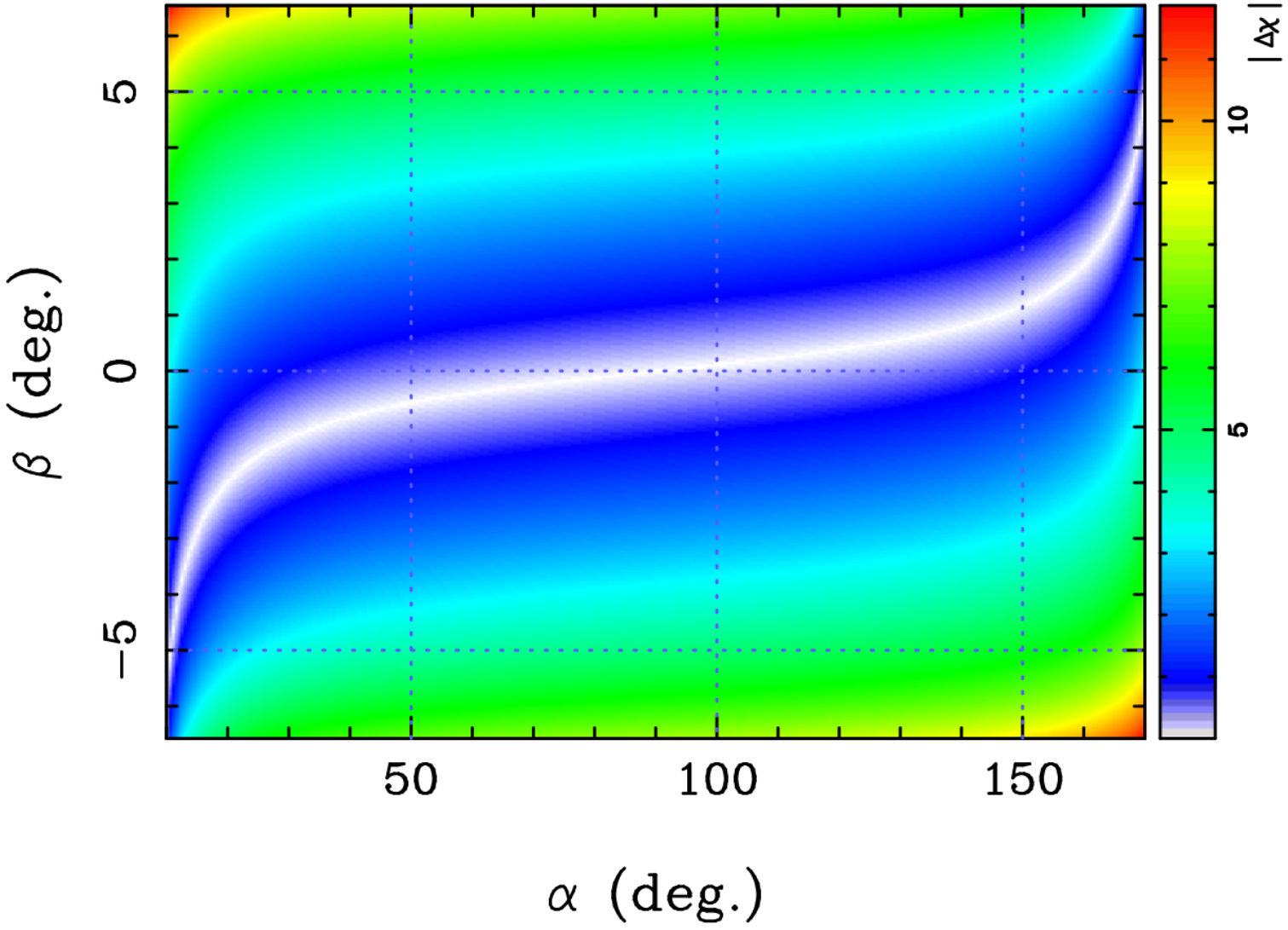
Observable Implications

- 1. Testing the Carousel model
- 2. Test single frequency multi-altitude emission
- **3. Modeling the emission geometry (particularly alpha)**
- 4. Resolving the aliasing in subpulse modulation period
- 5. A clean probe of any twist in the magnetosphere
- 6. Two-dimensional mapping of the emission-beam

Observable Implications…

Modeling the magnetic inclination angle (α) is a difficult task.

Observed phase-offsets could be useful to estimate α, especially for nearly aligned rotators.



Observable Implications

- 1. Testing the Carousel model
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Observable Implications...

- 1. Testing the Carousel model
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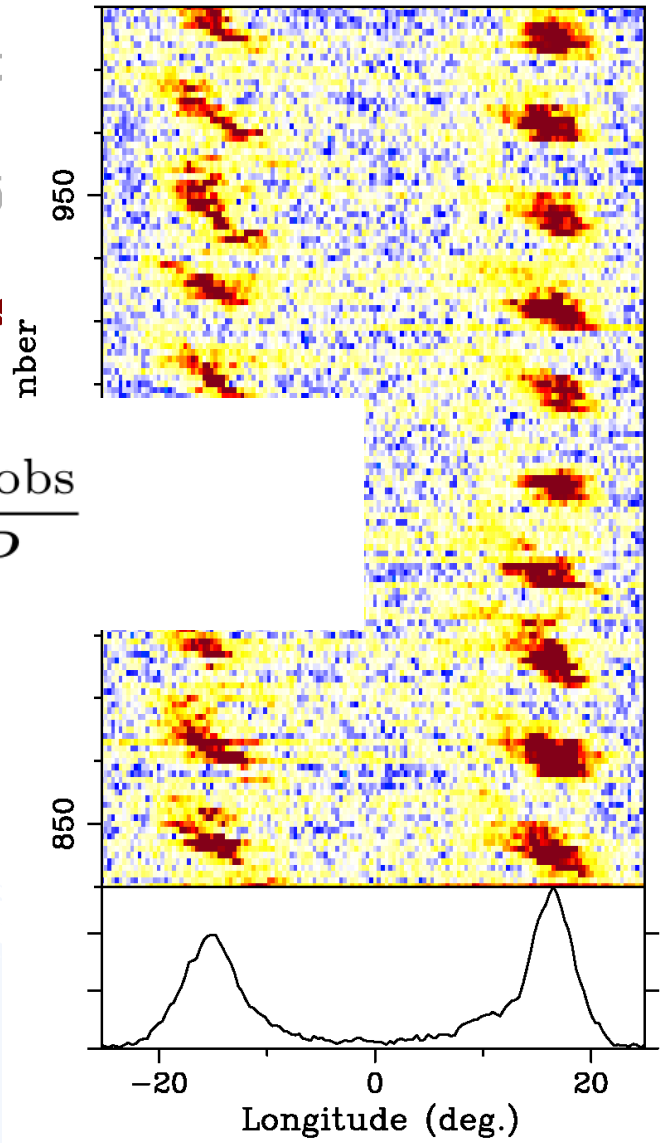
- **4. Resolving the aliasing in subpul**

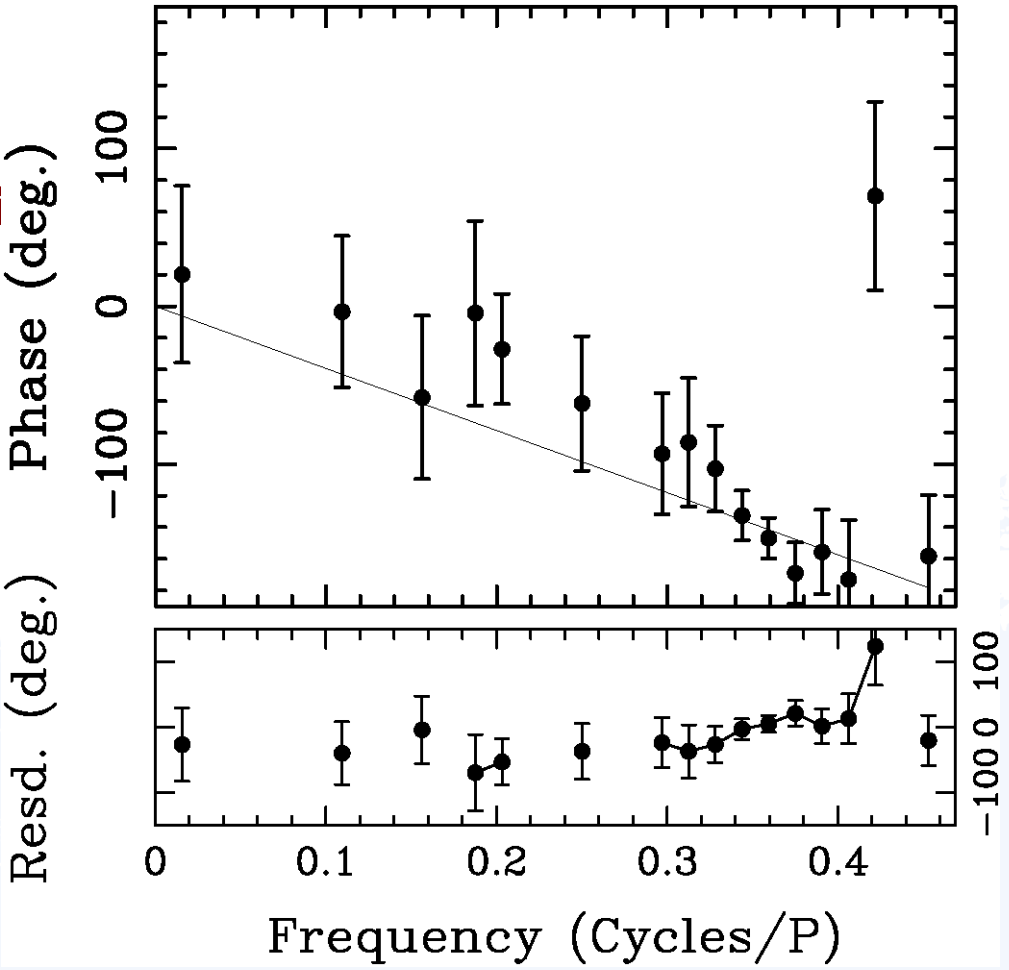
$$\Delta\Theta_{\rm obs} = 2\pi \left(n + \frac{P}{P_3^{\rm obs}} \right) \frac{\Delta t_{\rm obs}}{P}$$



Observable Implications…

- 1. Testing the Carousel model
- 2. Test single frequency multi-altitude emission
- 3. Modeling the emission
- **4. Resolving the aliasing i**

Within multi-altitude emission scenario, modulation in B1237+25 is not aliased.



More implications

- 1. Testing the Carousel model
- 2. Test single frequency multi-altitude emission
- 3. Modeling the emission geometry (particularly alpha)
- 4. Resolving the aliasing in subpulse modulation period
- **5. A clean probe of any twist in the magnetosphere**

$$\delta\chi_{\rm twist} \approx \frac{\delta\Theta_{\rm twist}}{N_{sp}} = \frac{\Delta\Theta_1 + \Delta\Theta_2}{2\,N_{sp}}$$

Observable Implications

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- **6. Two-dimensional mapping of the emission-beam**

Observable Implications

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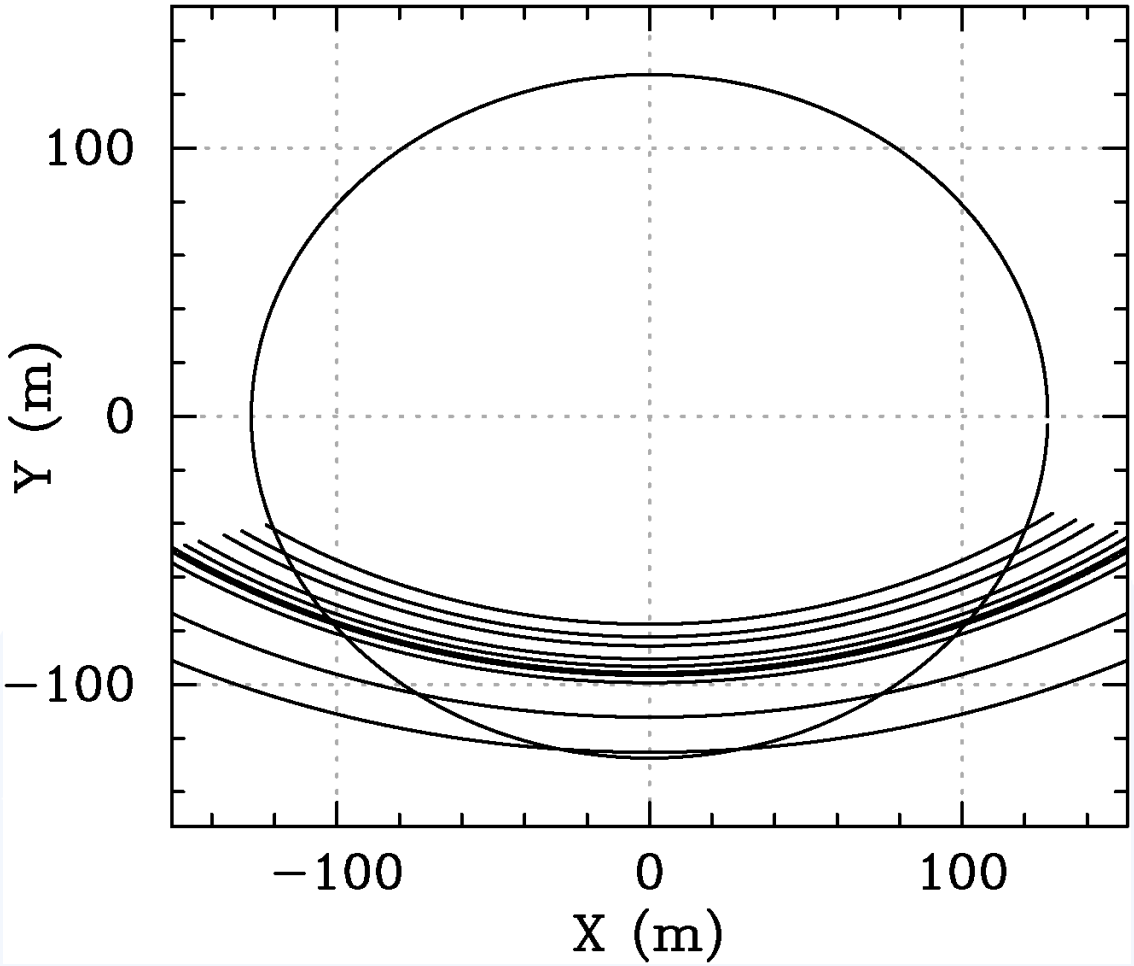
- **6. Two-dimensional mapping of the emission-beam**

Even if the carousel circulation time is unknown.

Scope for making a global map of emission beam using only average profiles.



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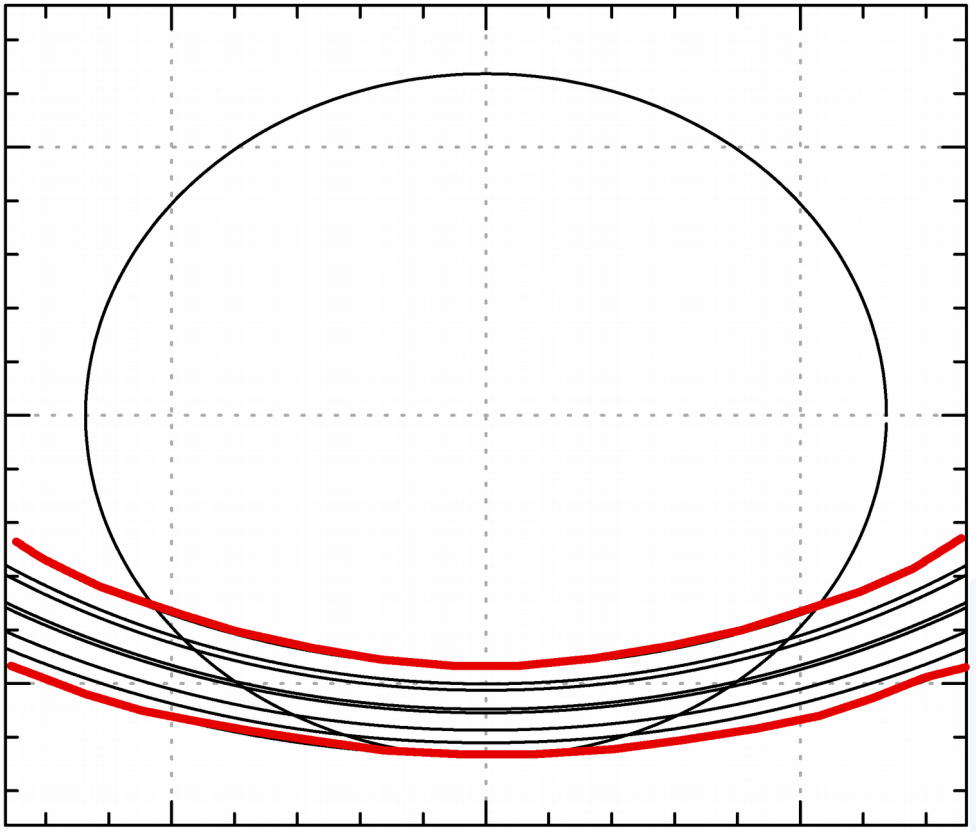

Observable Implications

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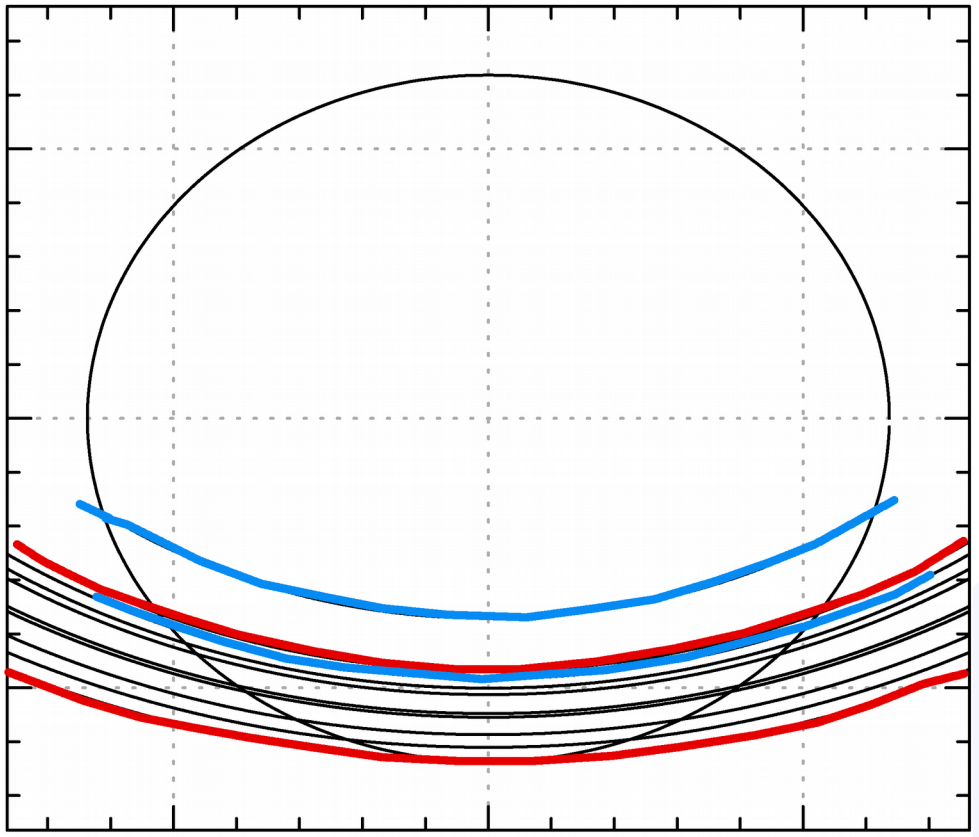
GMRT+LOFAR (30–1500 MHz) would provide a significant coverage of the beam.



Summary

A viewing-geometry induced subpulse phase-offset is predicted in simultaneous multi-frequency observations.

- **Observations of B0943+10 (and B0809+74) already confirm this geometrical effect (Bilous 2018, A&A).**
- **Observed phase-offsets in B1237+25 provide firm support for multi-altitude emission scenario (Maan 2019, ApJ).**
- **This geometrical effect is extremely useful in stringent tests of the carousel model, 2D mapping of the emission-beam and resolving the aliasing of P_3 (work in progress).**