

Mode-switching PSR B0943+10 at very low radio frequencies

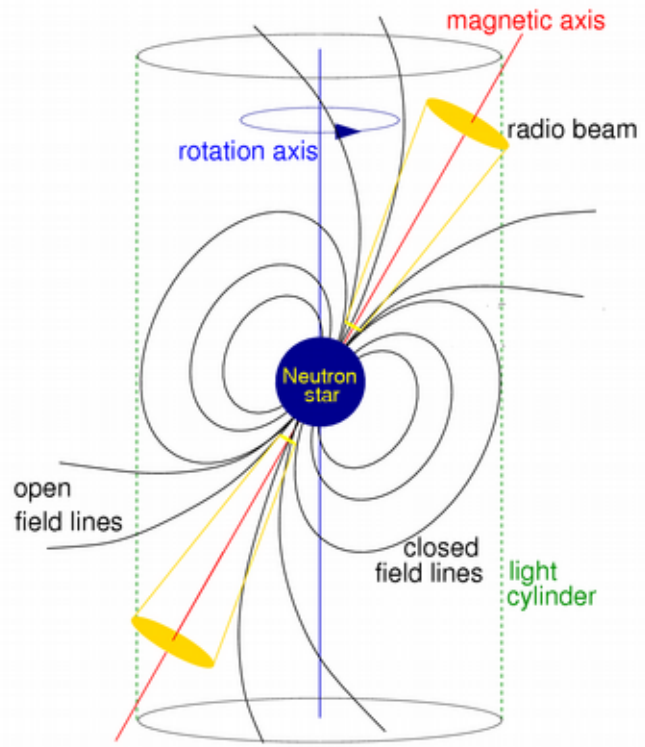
Anya Bilous,

Radboud Universiteit
the Netherlands

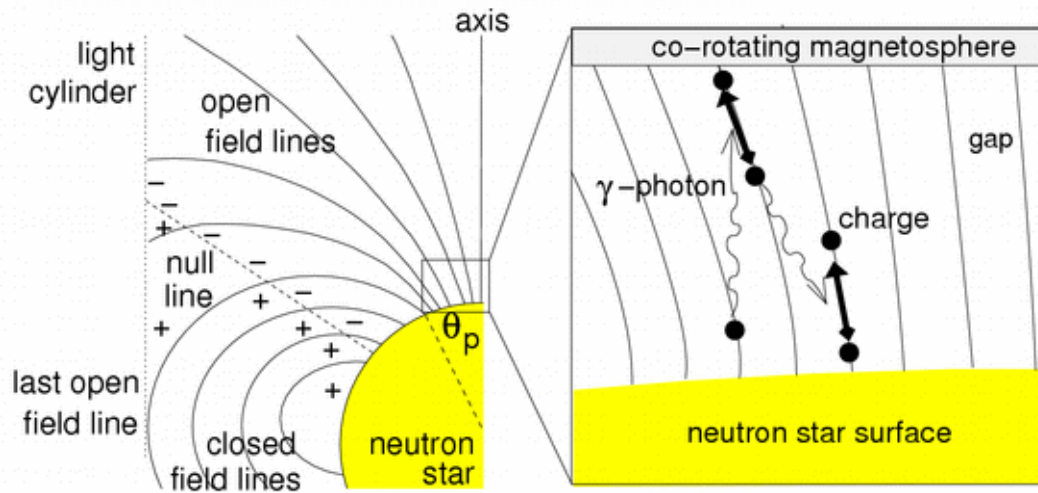
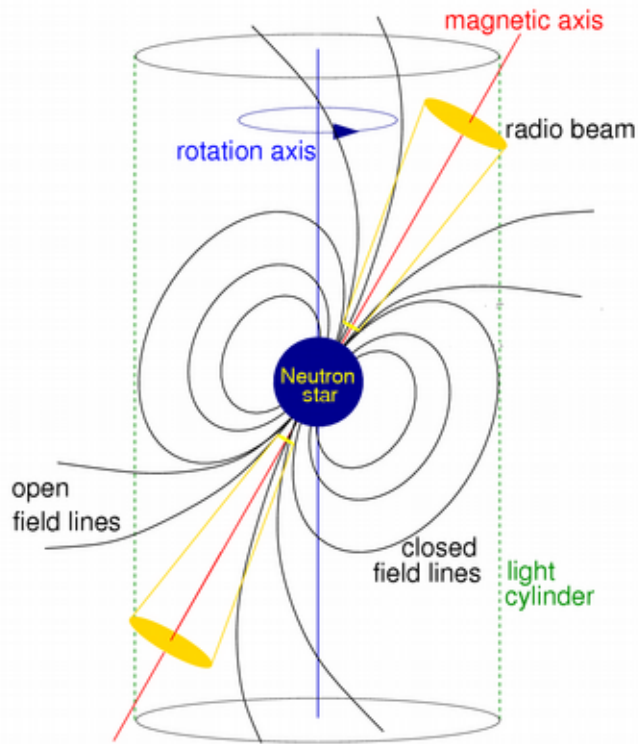
& LOFAR Pulsar Working Group



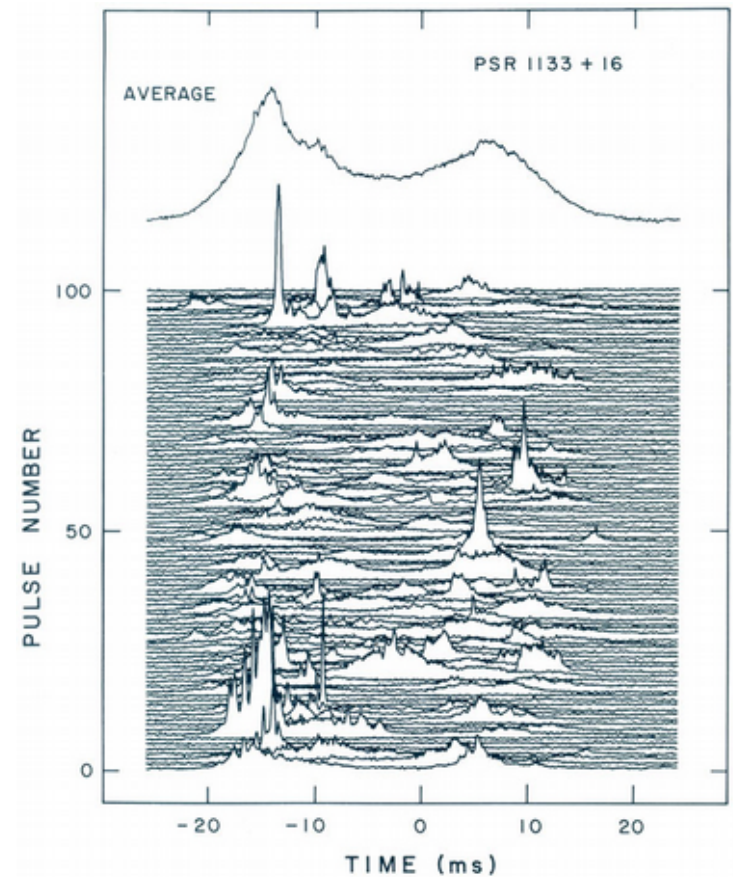
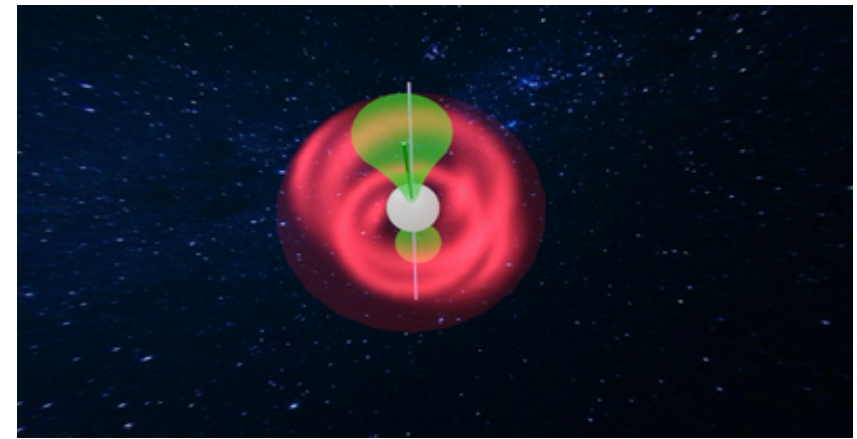
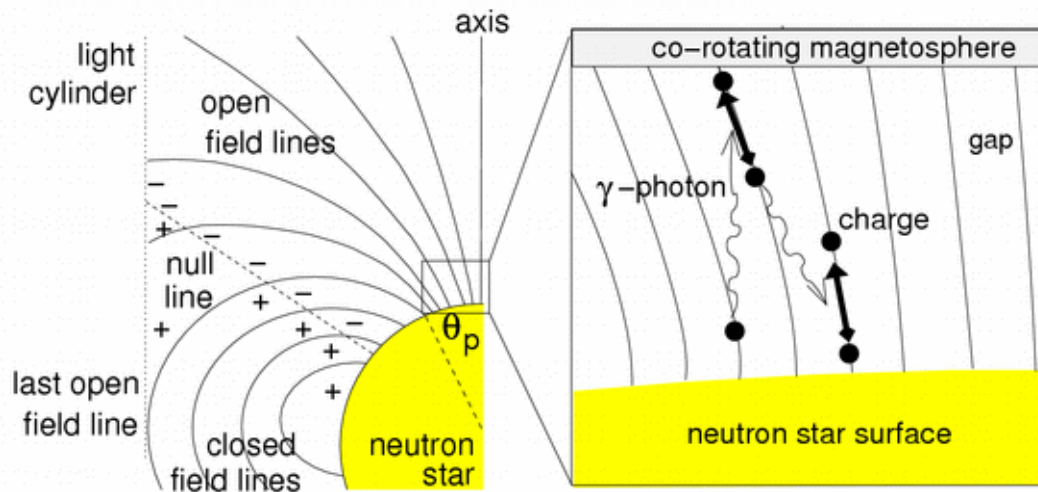
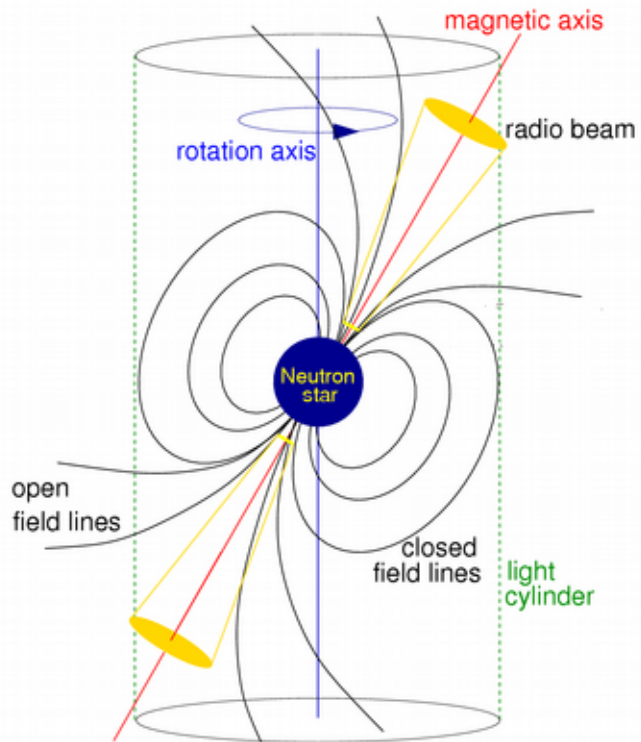
Radio pulsars:



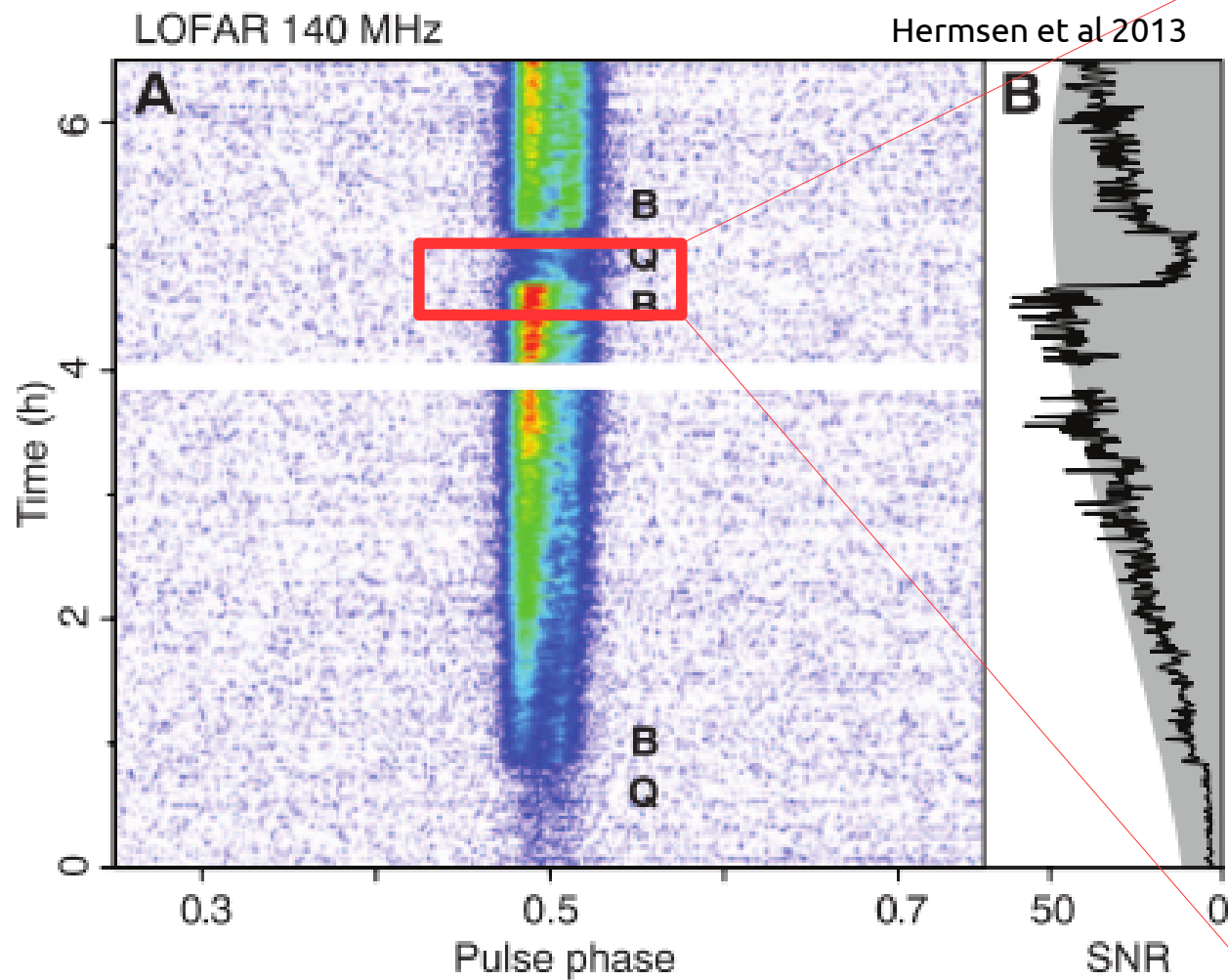
Radio pulsars:



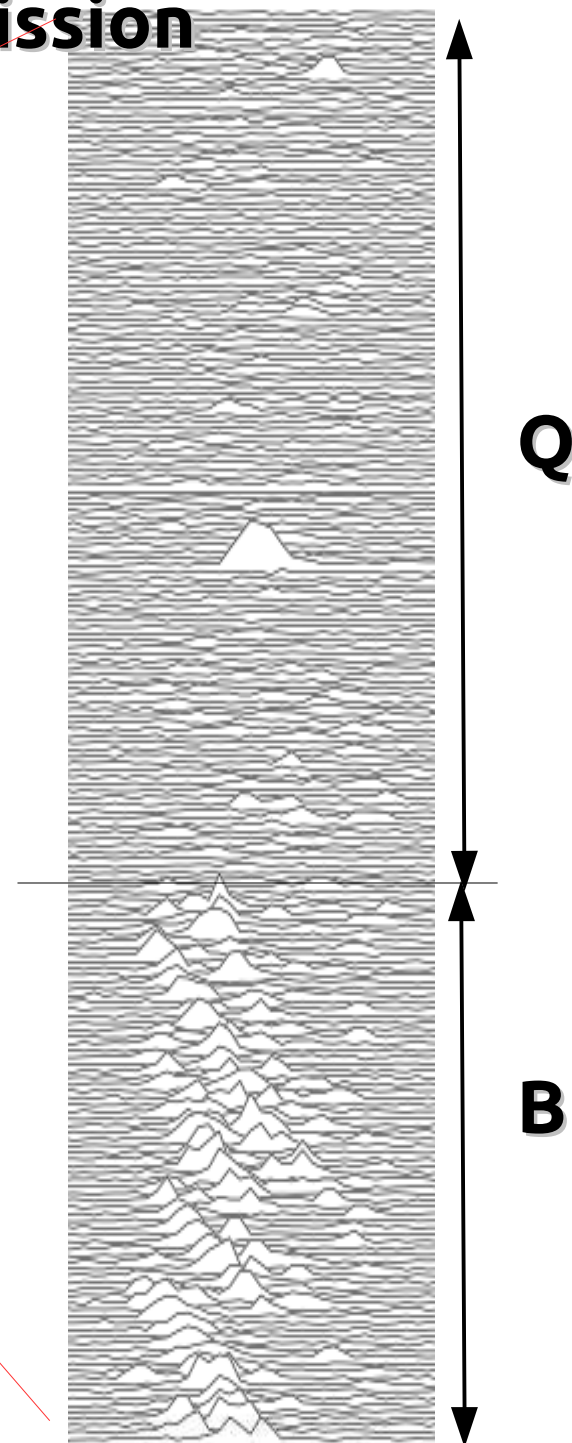
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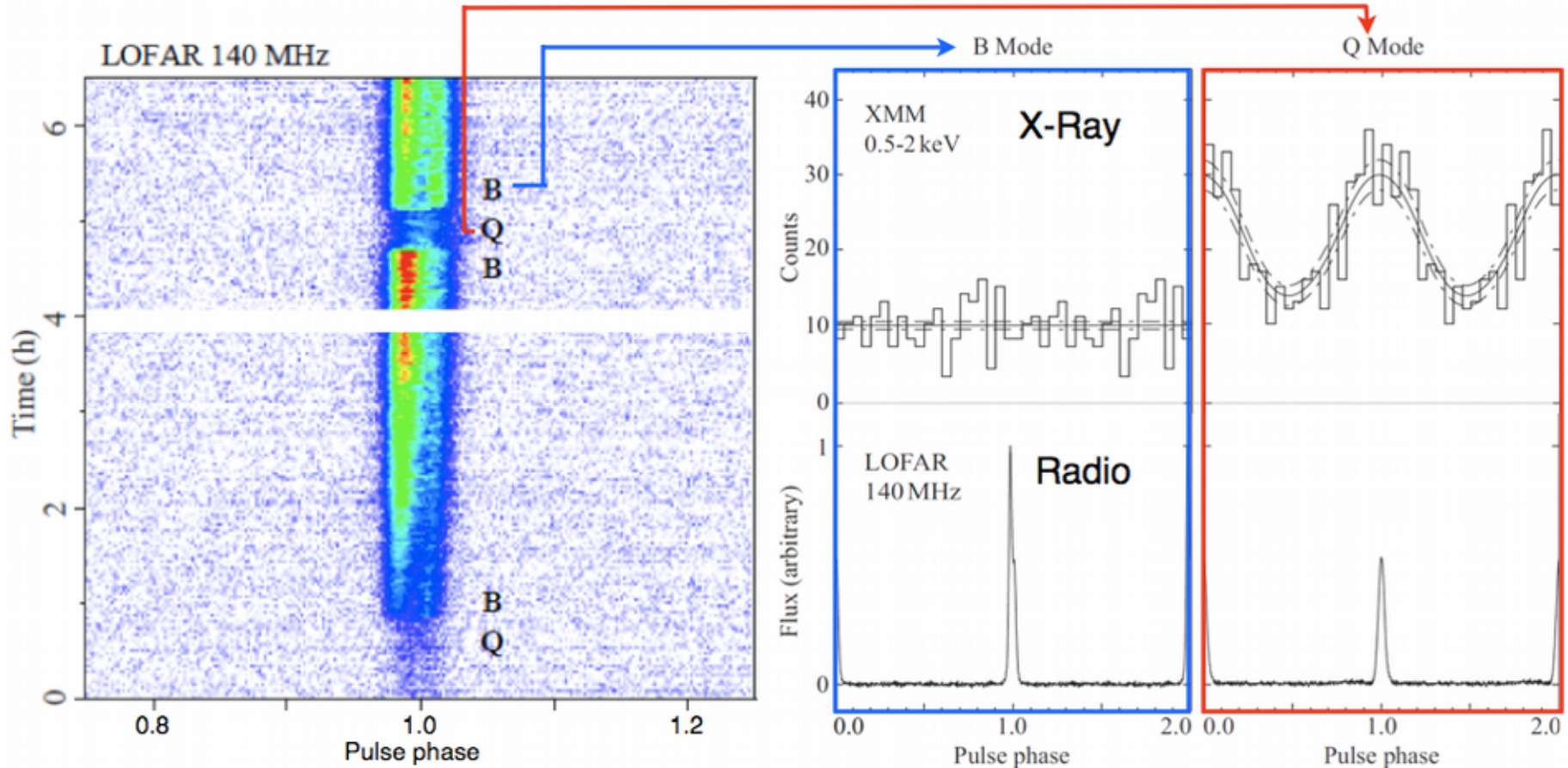
B0943+10: two quasi-stable modes of emission



Abrupt (on a timescale of few spin periods) discrete change in both average and single pulse behavior.



Mode switch: not only in radio!



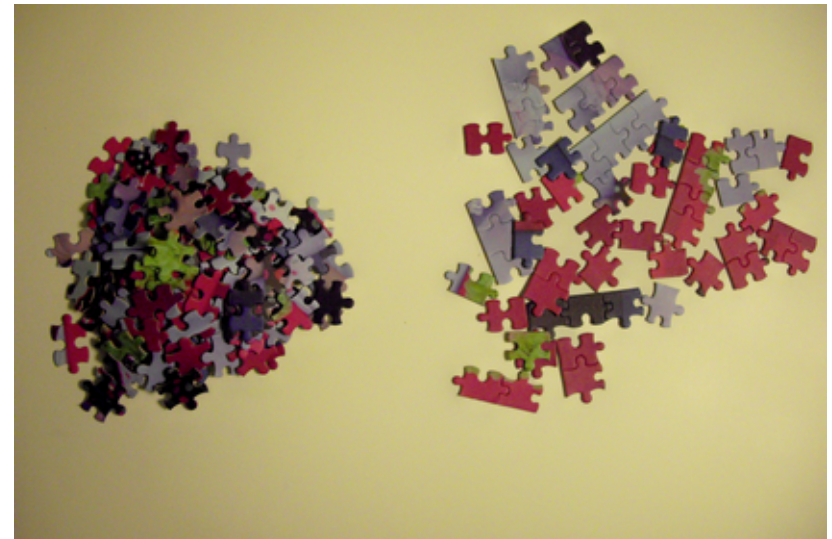
B-mode: non-pulsed X-rays

Q-mode: pulsed + non-pulsed X-rays

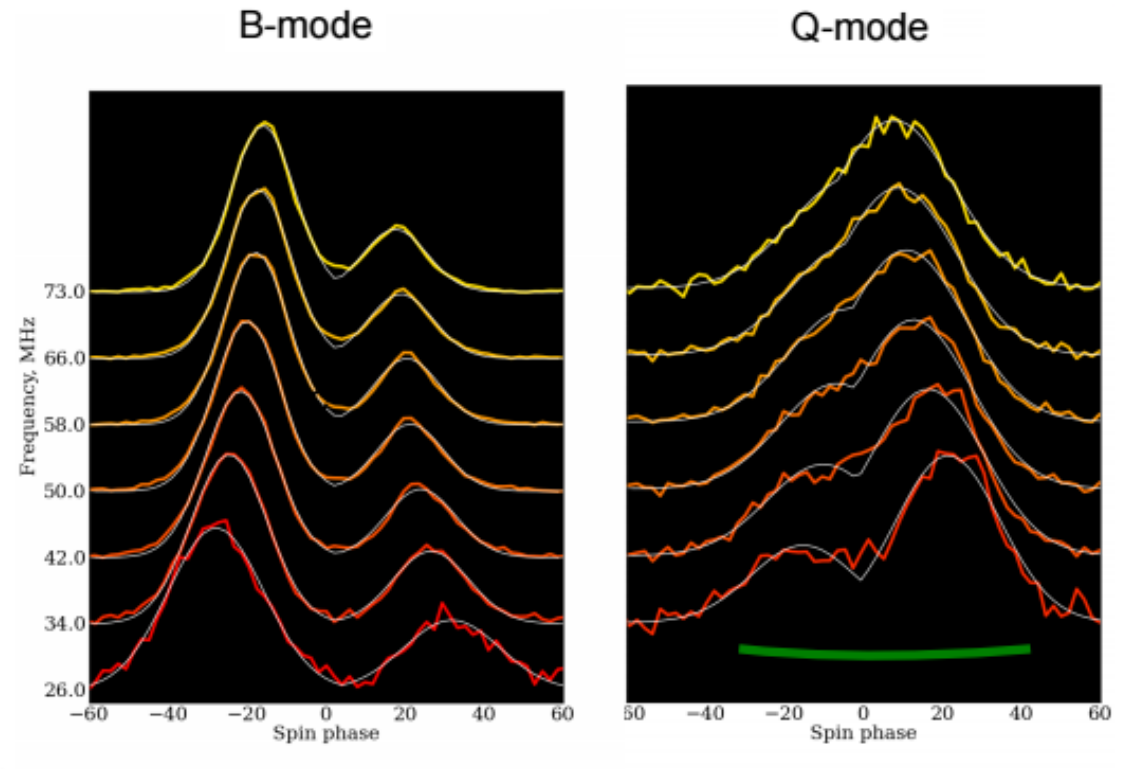
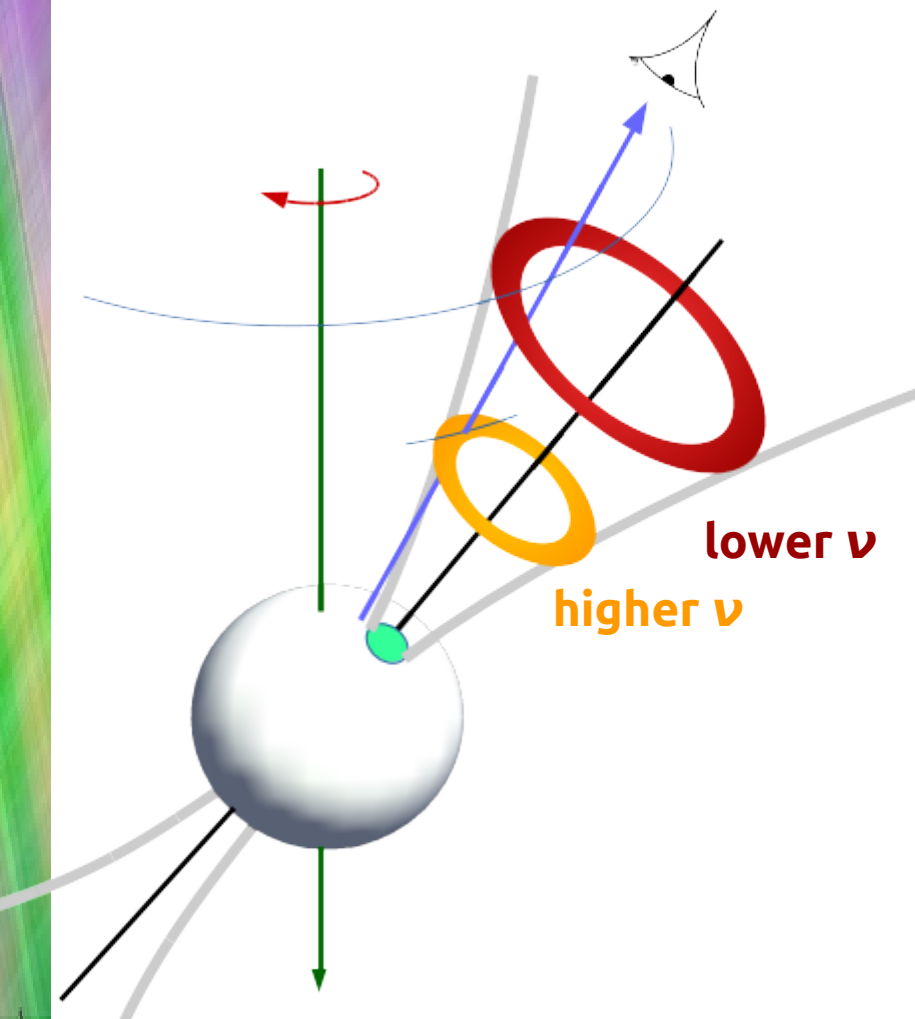
Hermesen et al 2013
Mereghetti et al 2013

What changes in magnetosphere during the mode switch?

Why does the switch happen?



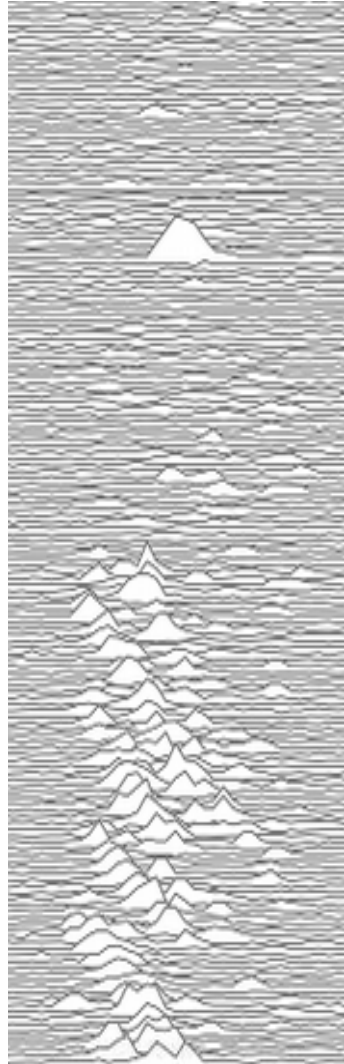
Basic observables: average profile



Radius to frequency mapping:

- Photons are emitted tangentially to field lines
- Emission at given frequency comes from a single height

Basic observables: single pulses



Q-mode

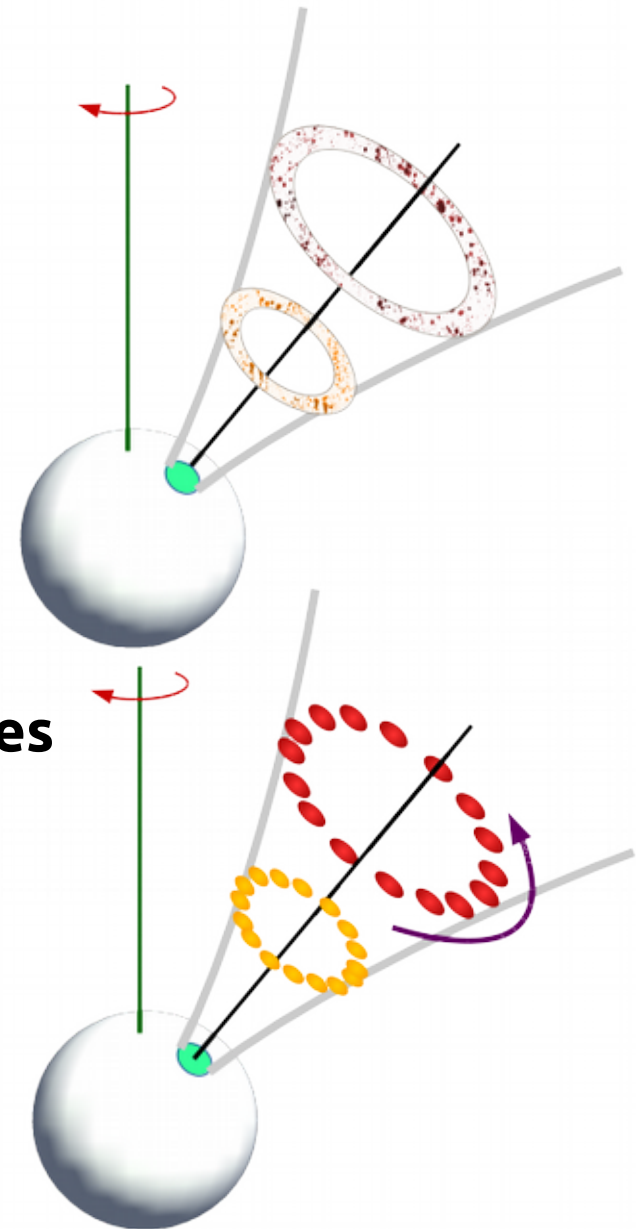
Occasional bright chaotic pulses

B-mode

Regularly drifting subpulses

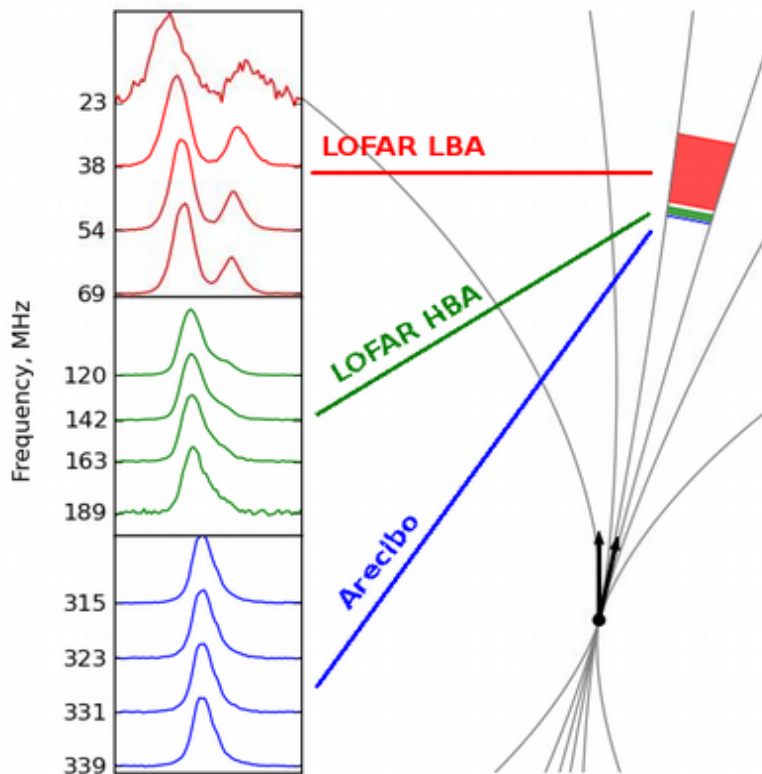
20-spark carousel
slowly rotating around the
magnetic axis ($v \sim E \times B$)

(Ruderman & Sutherland 1975,
Deshpande & Rankin 2001)

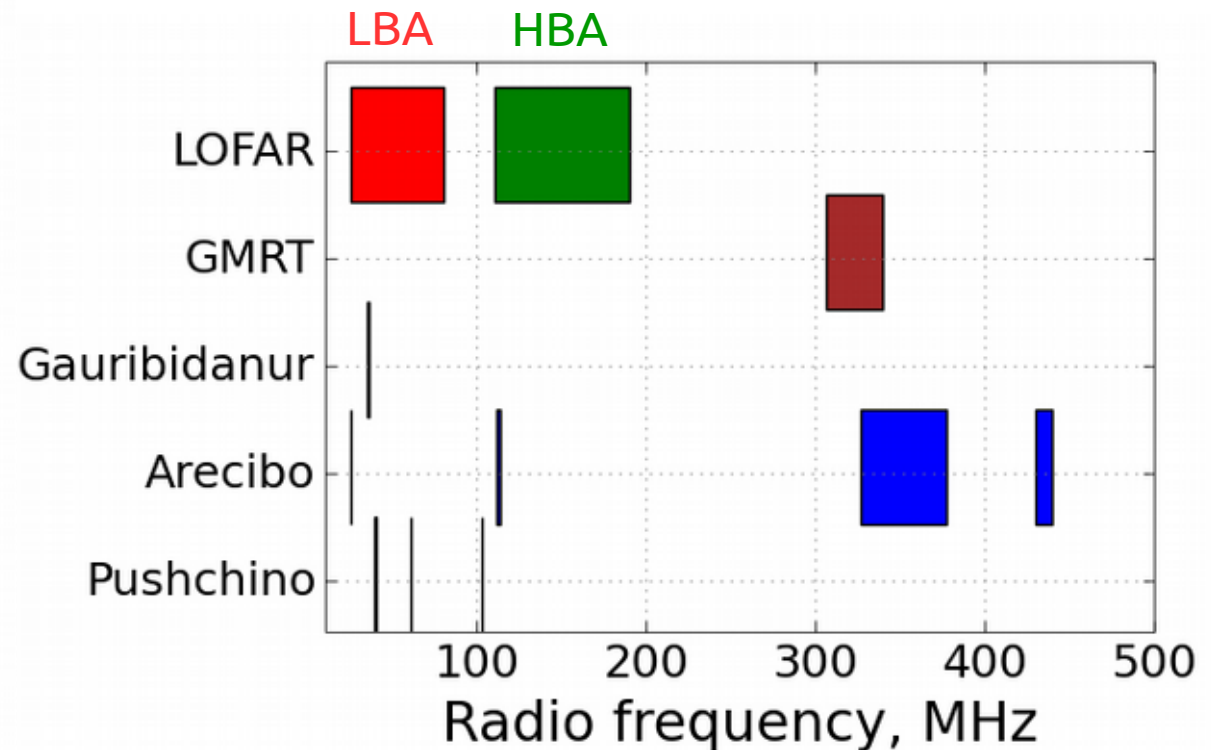


LOFAR's contribution

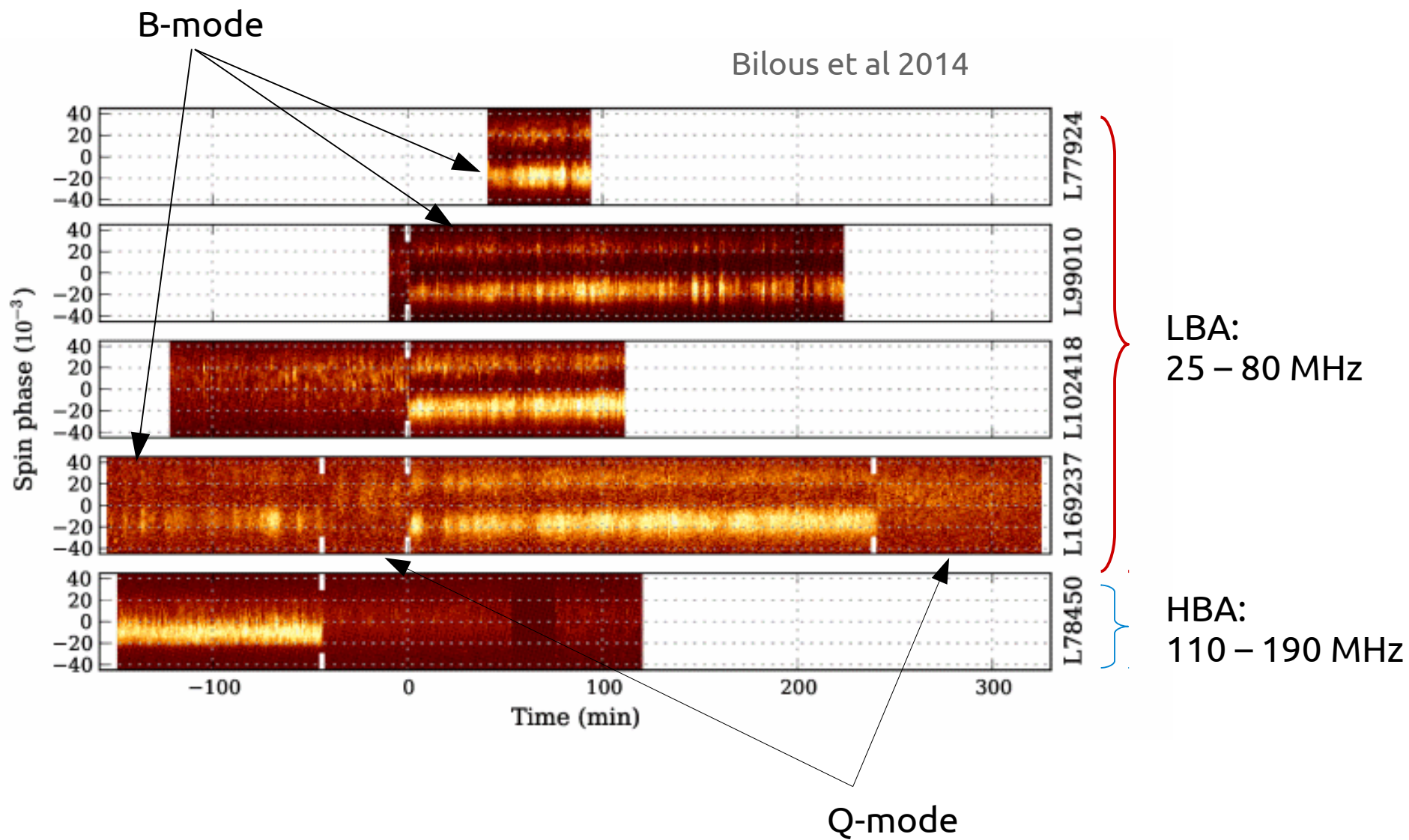
- Low frequencies / huge bandwidth
- Tracking time (up to 6 hours)
- Sensitivity



Frequency coverage of existing B0943's observations

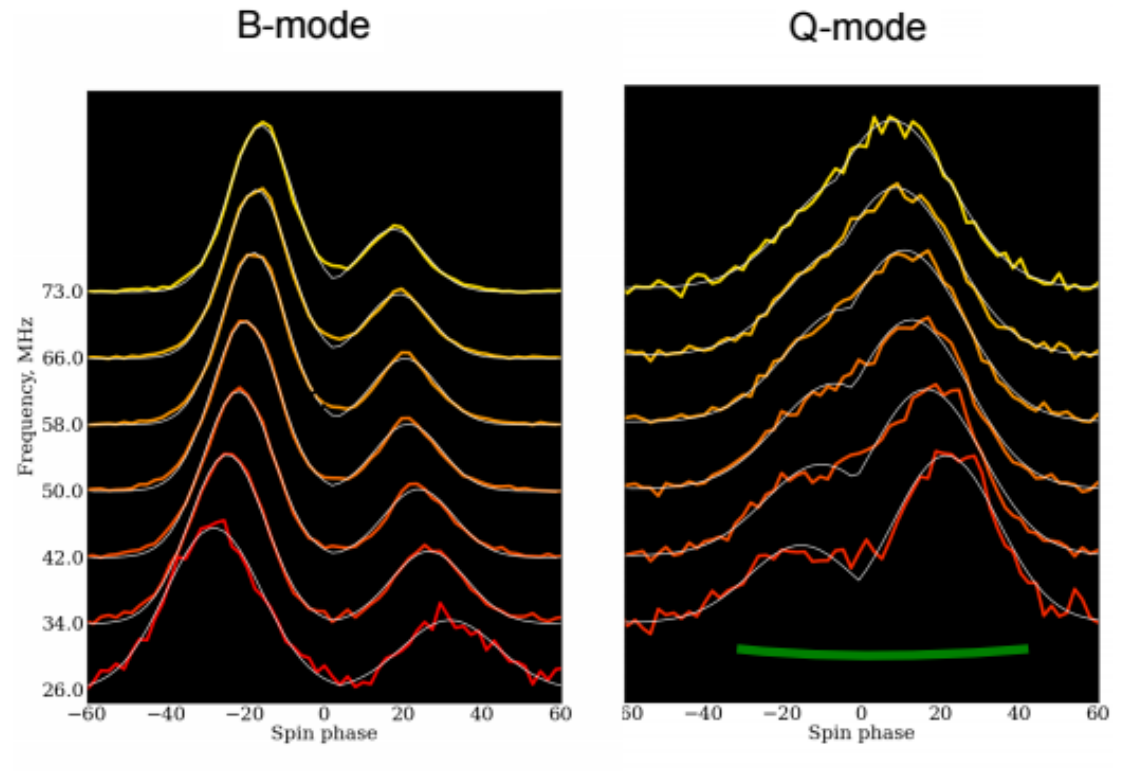
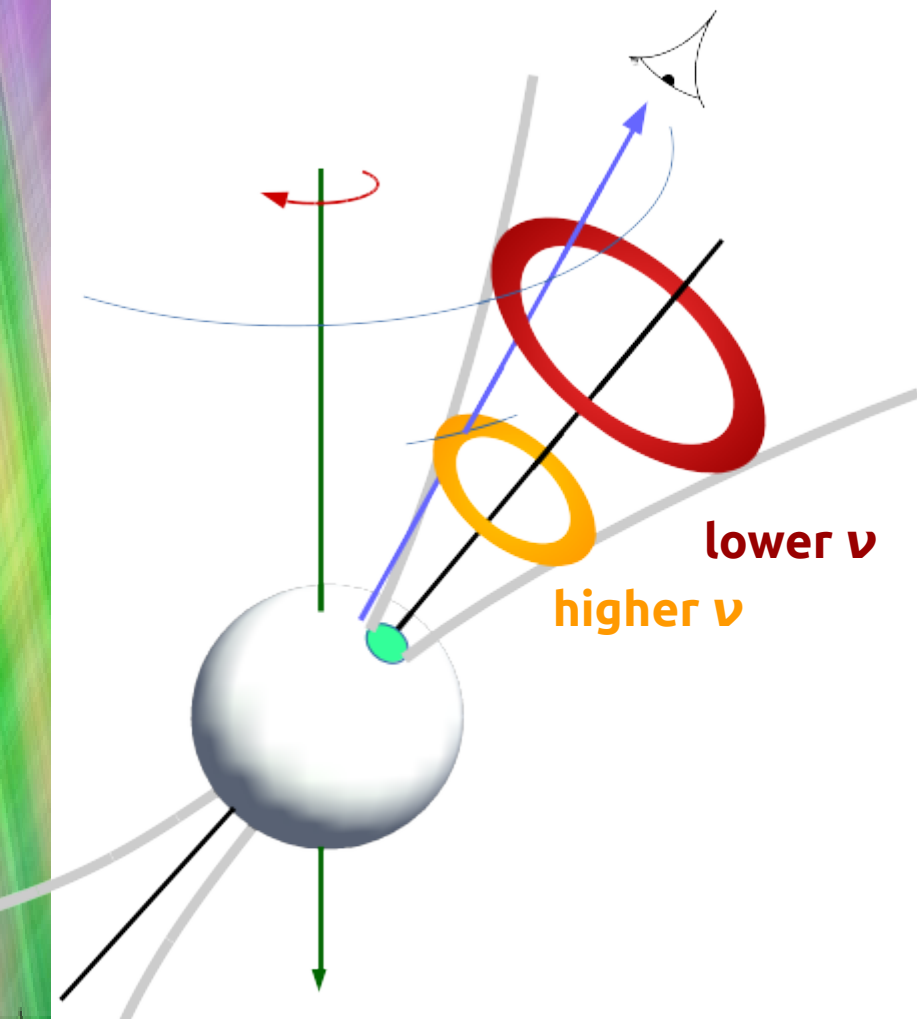


Data:



Here: frequency-integrated

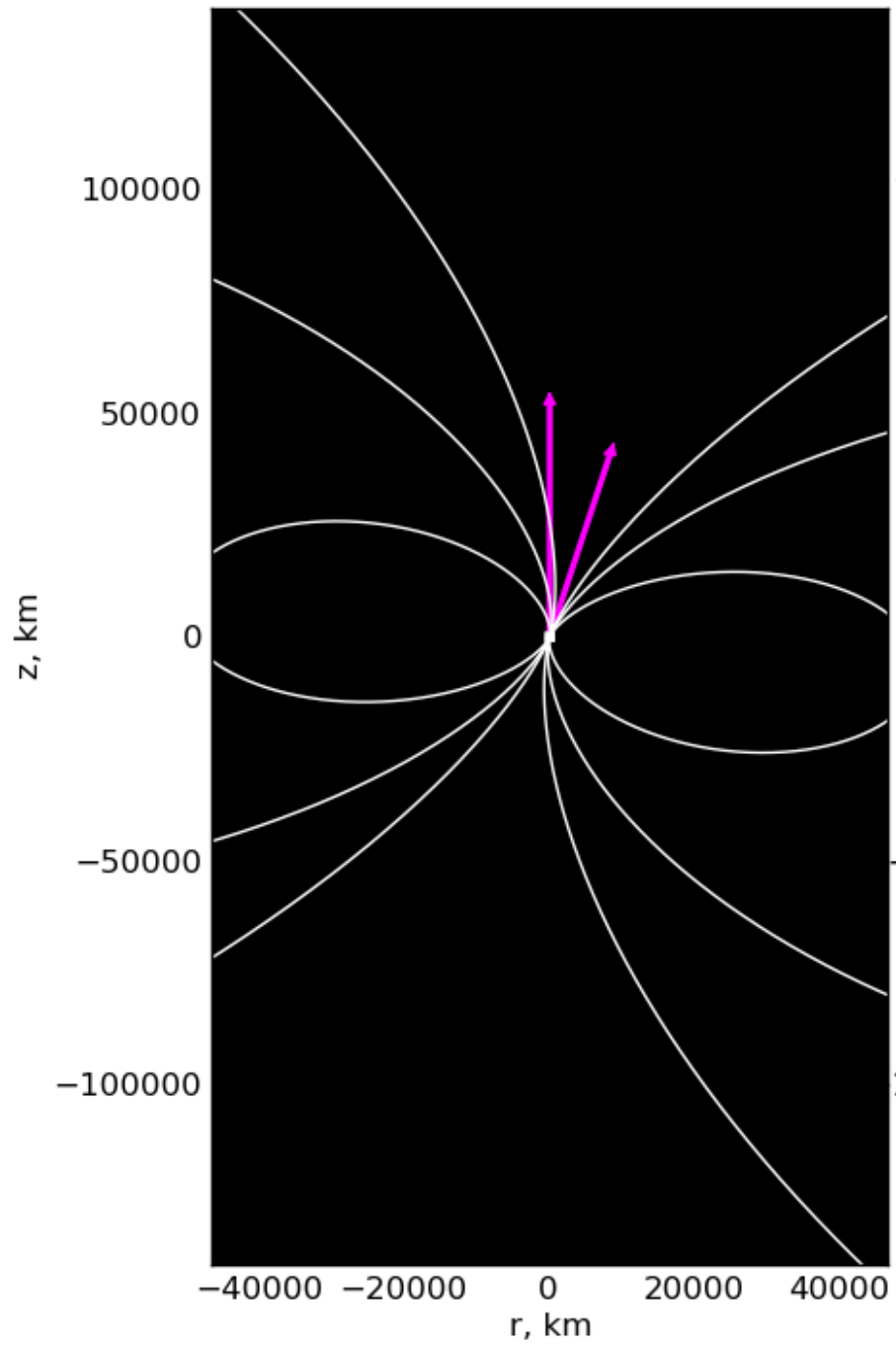
Where does radio come from?



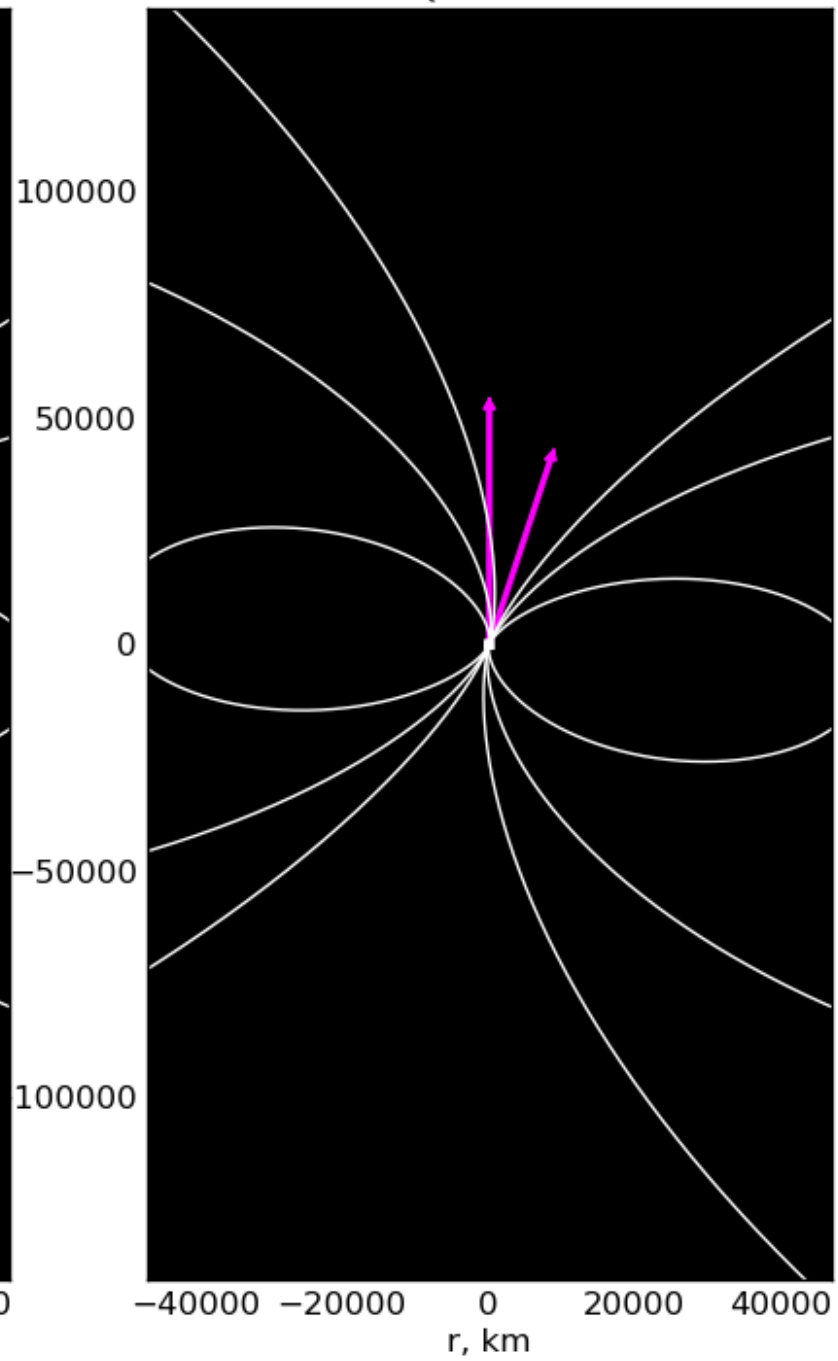
Narrow range of heights close to star surface.

Not from the center of polar cap.

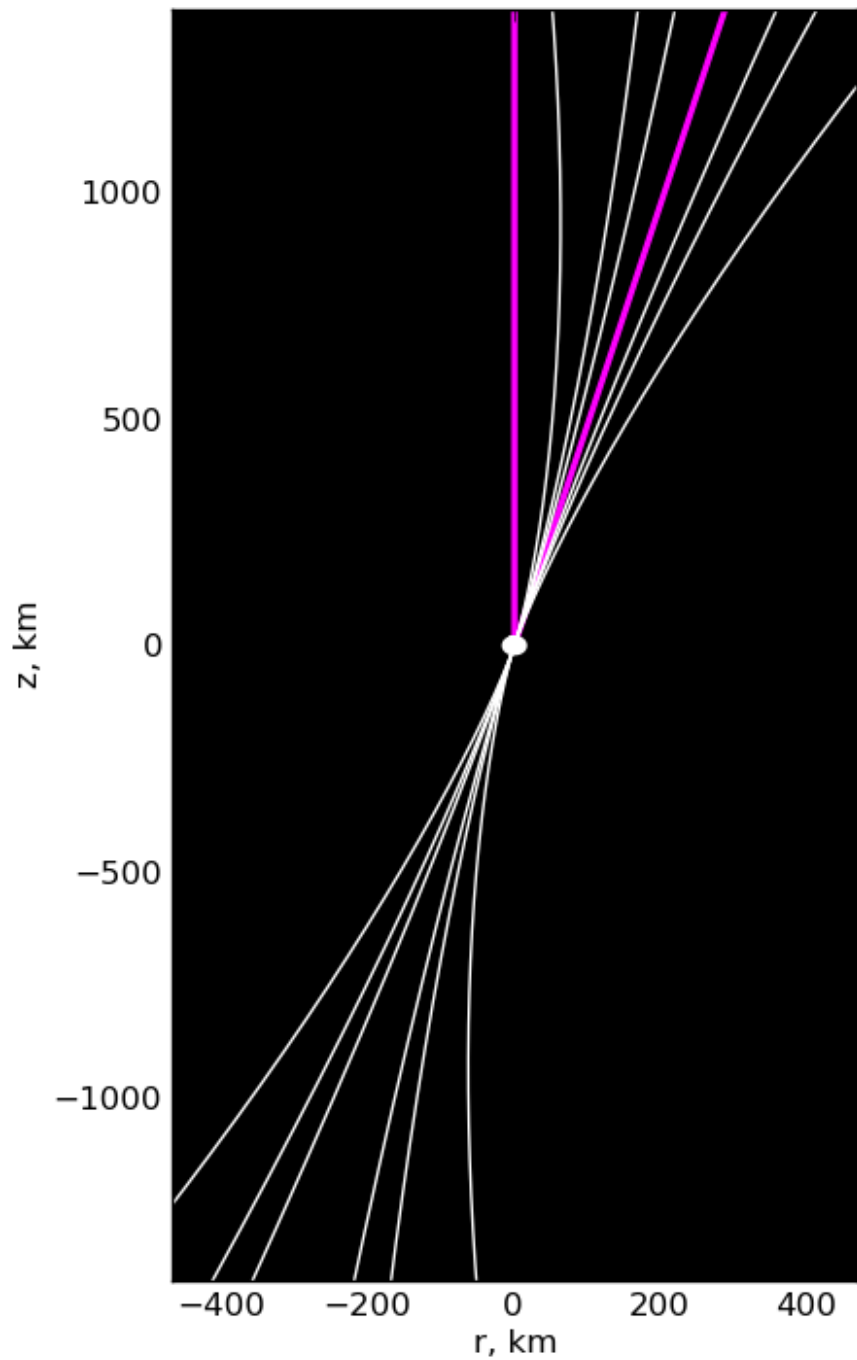
B-mode



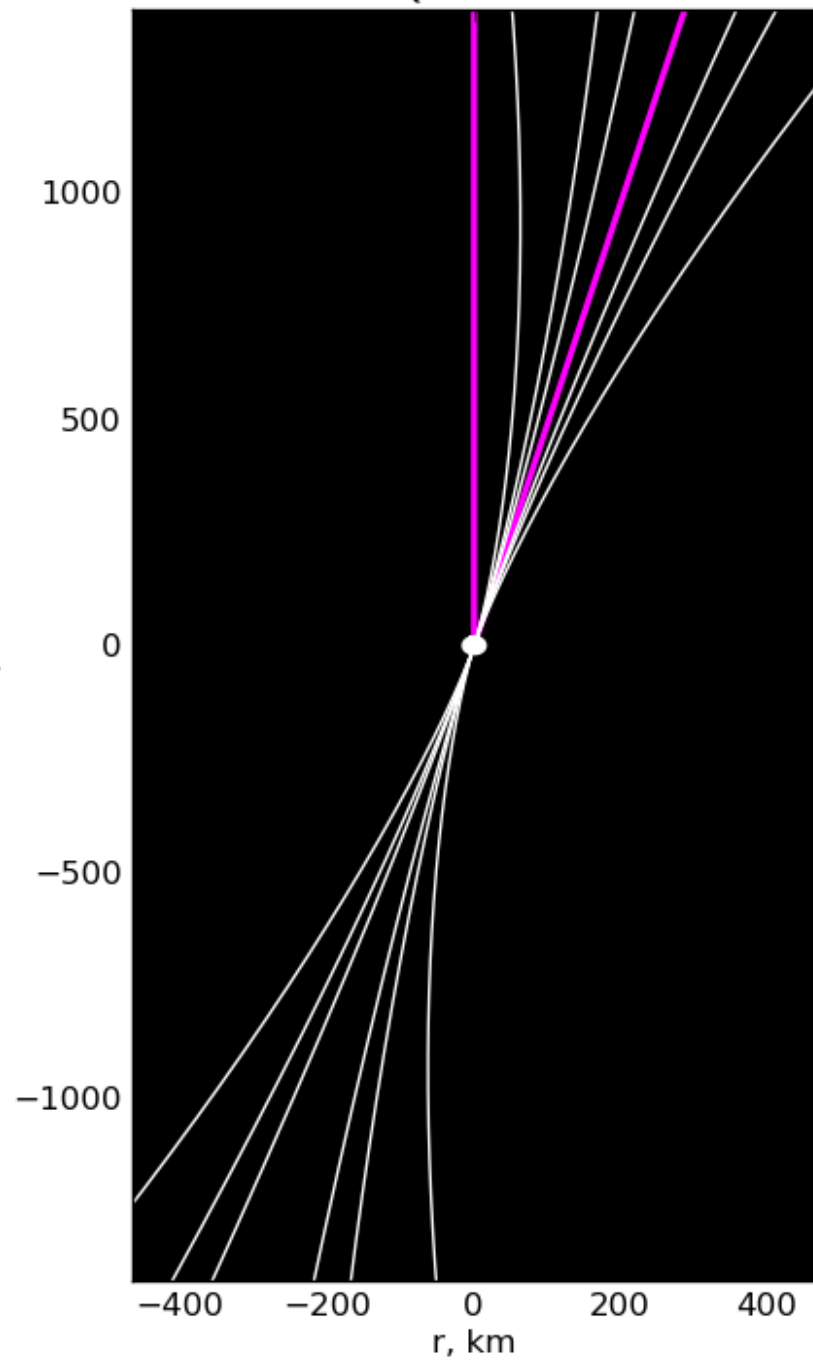
Q-mode

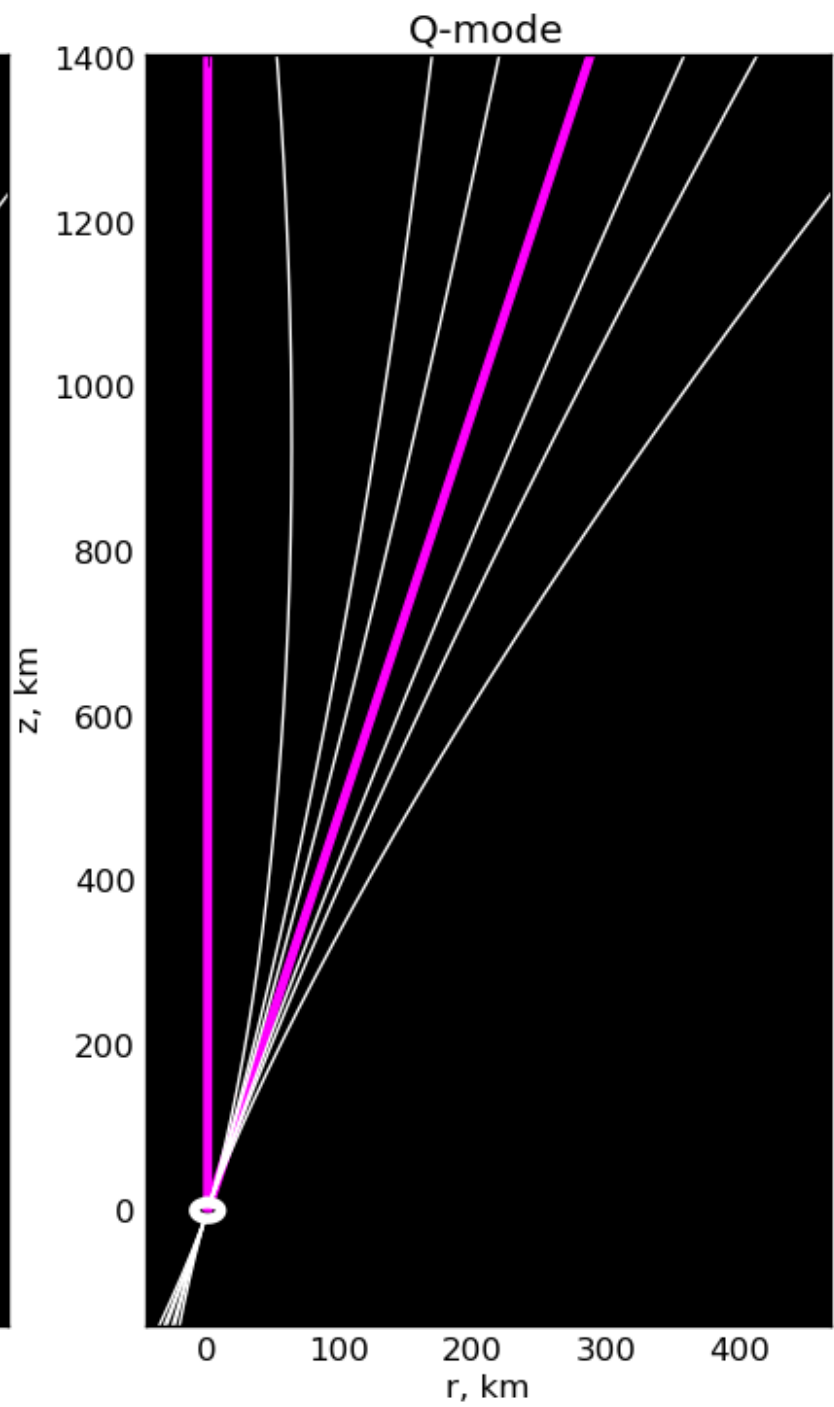
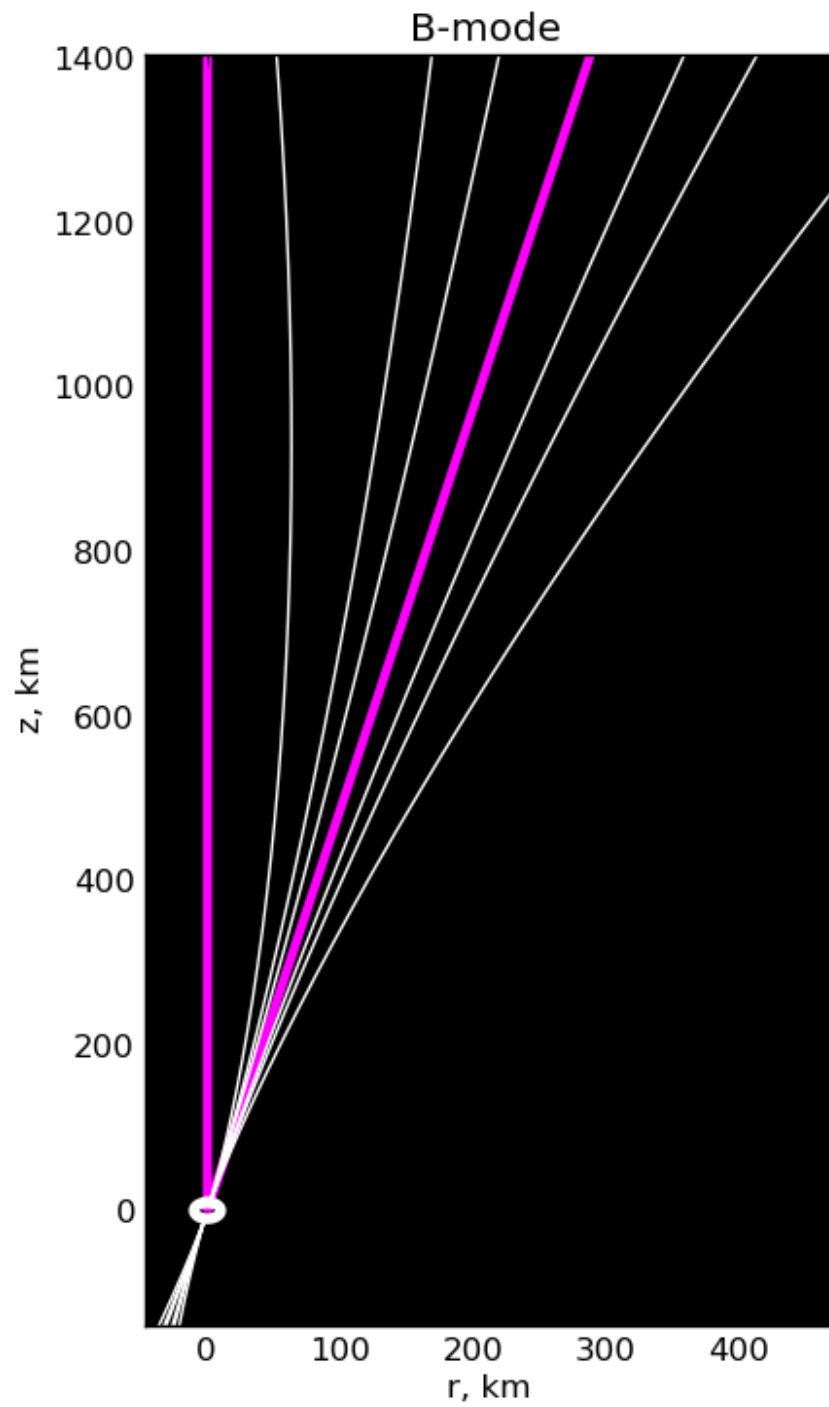


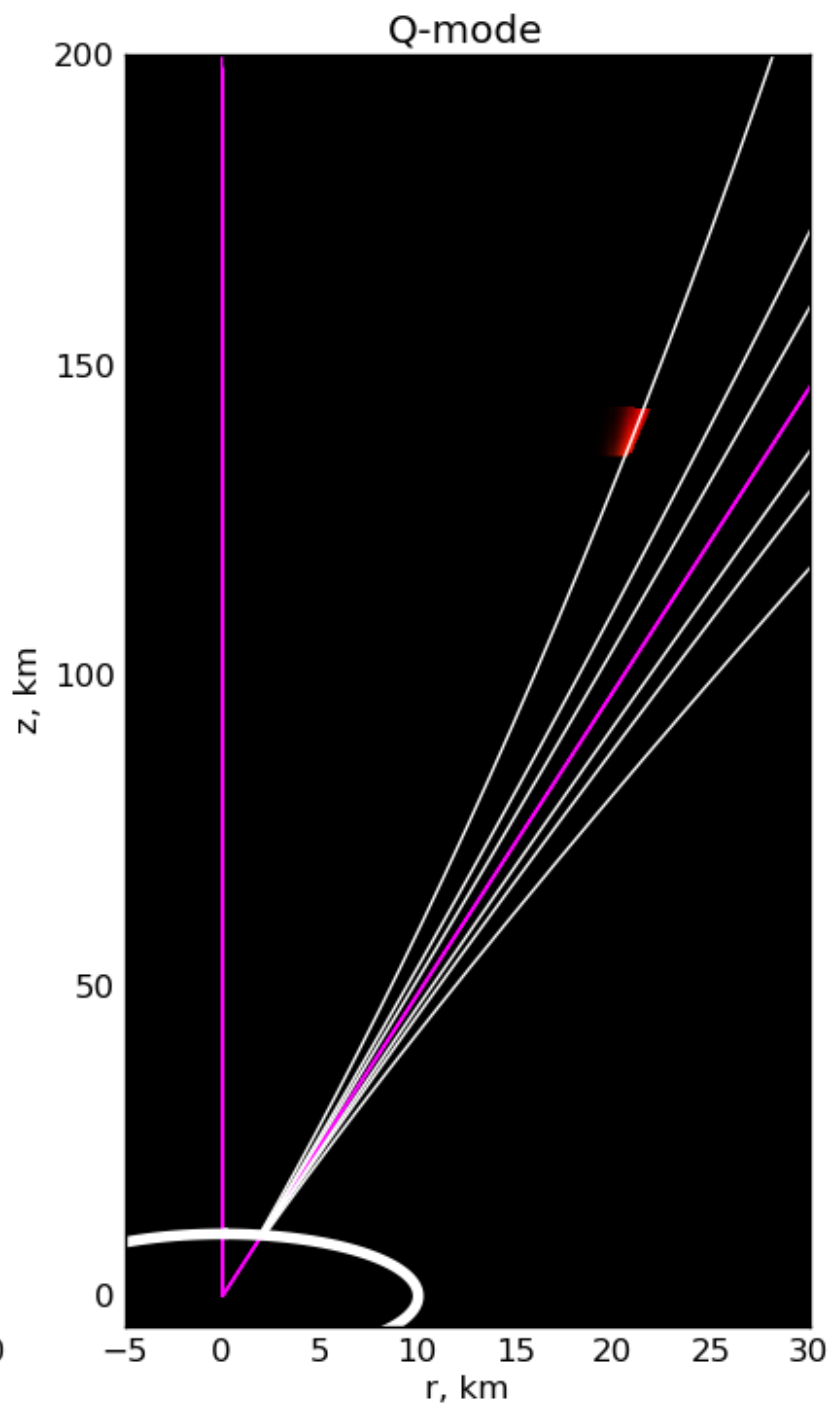
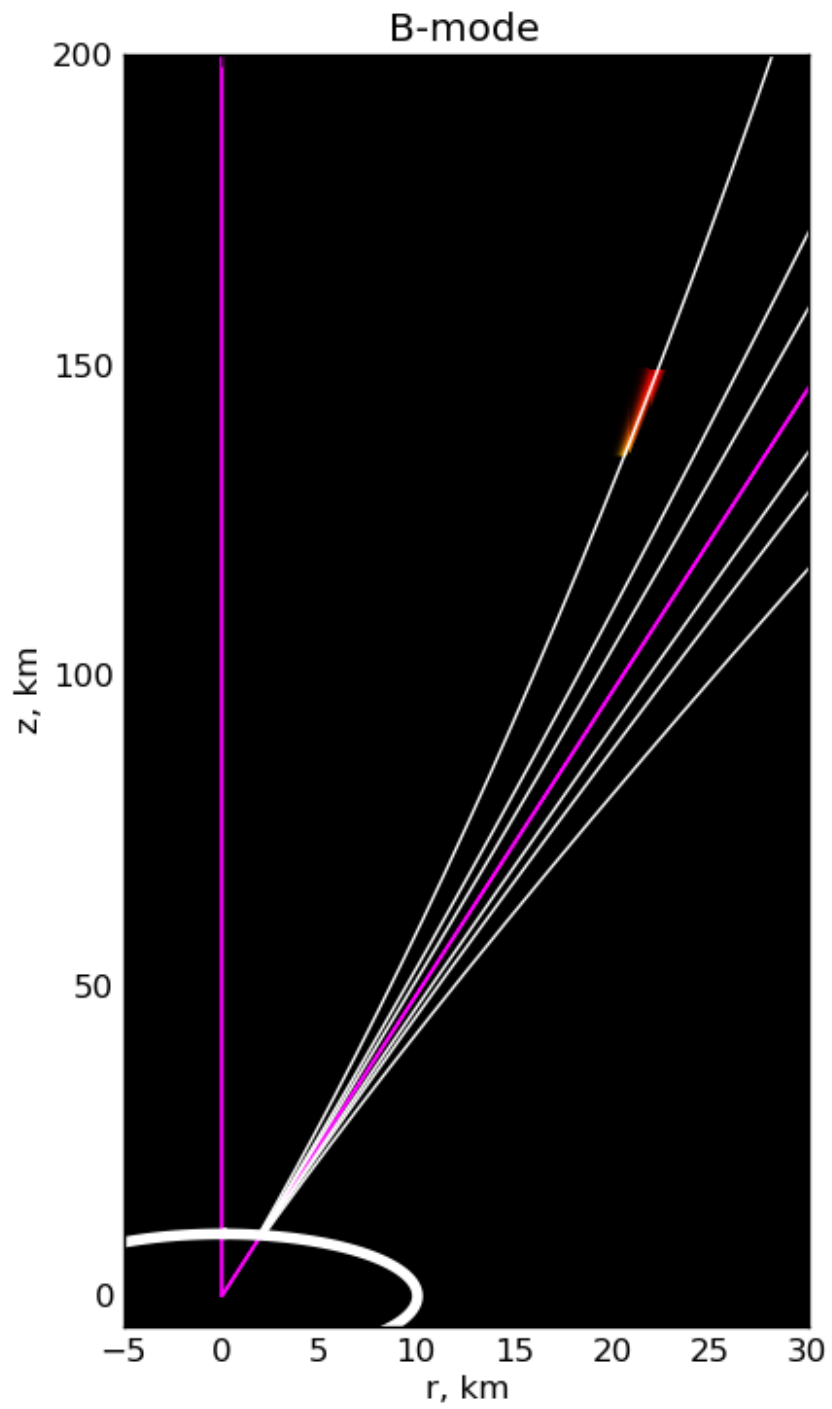
B-mode

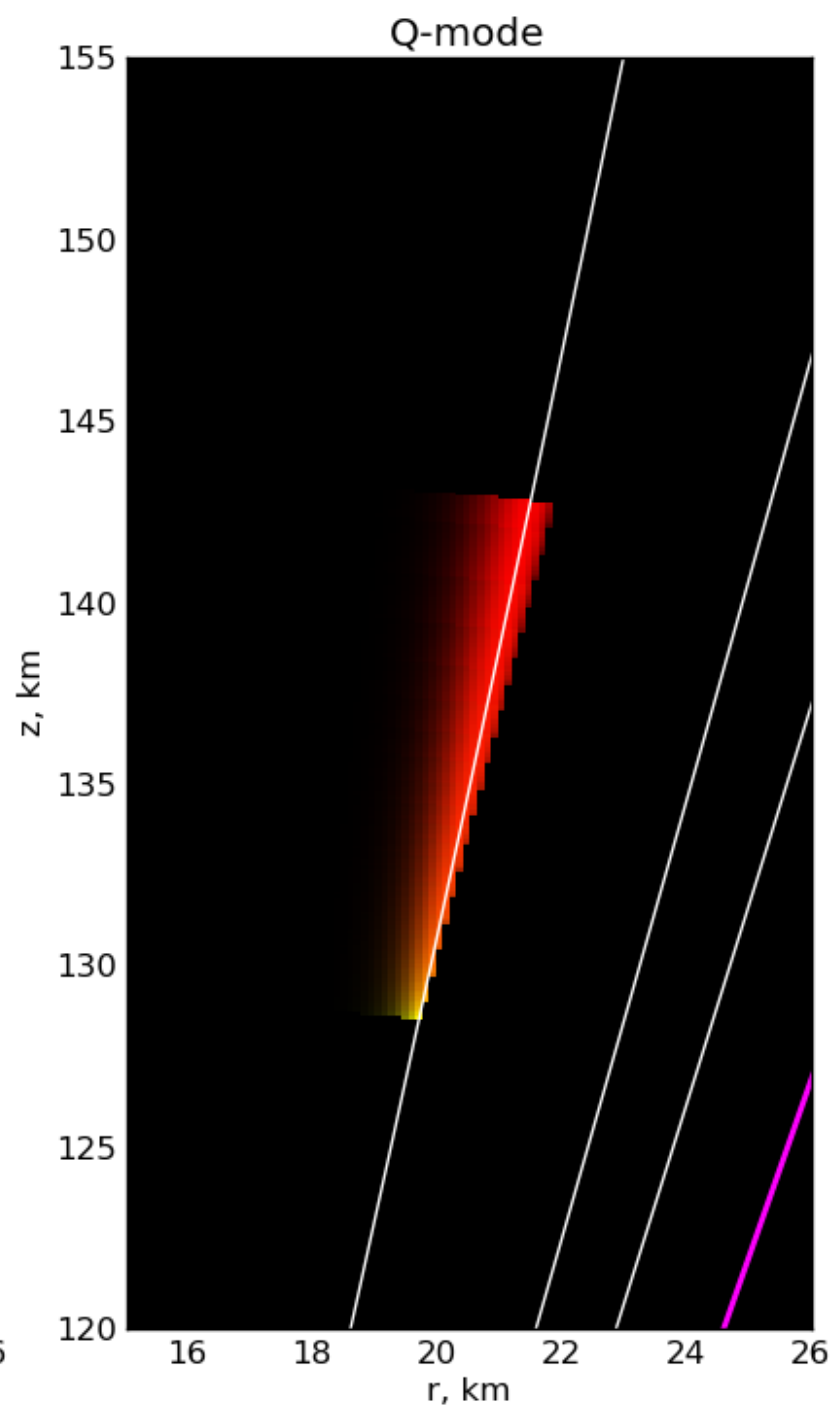
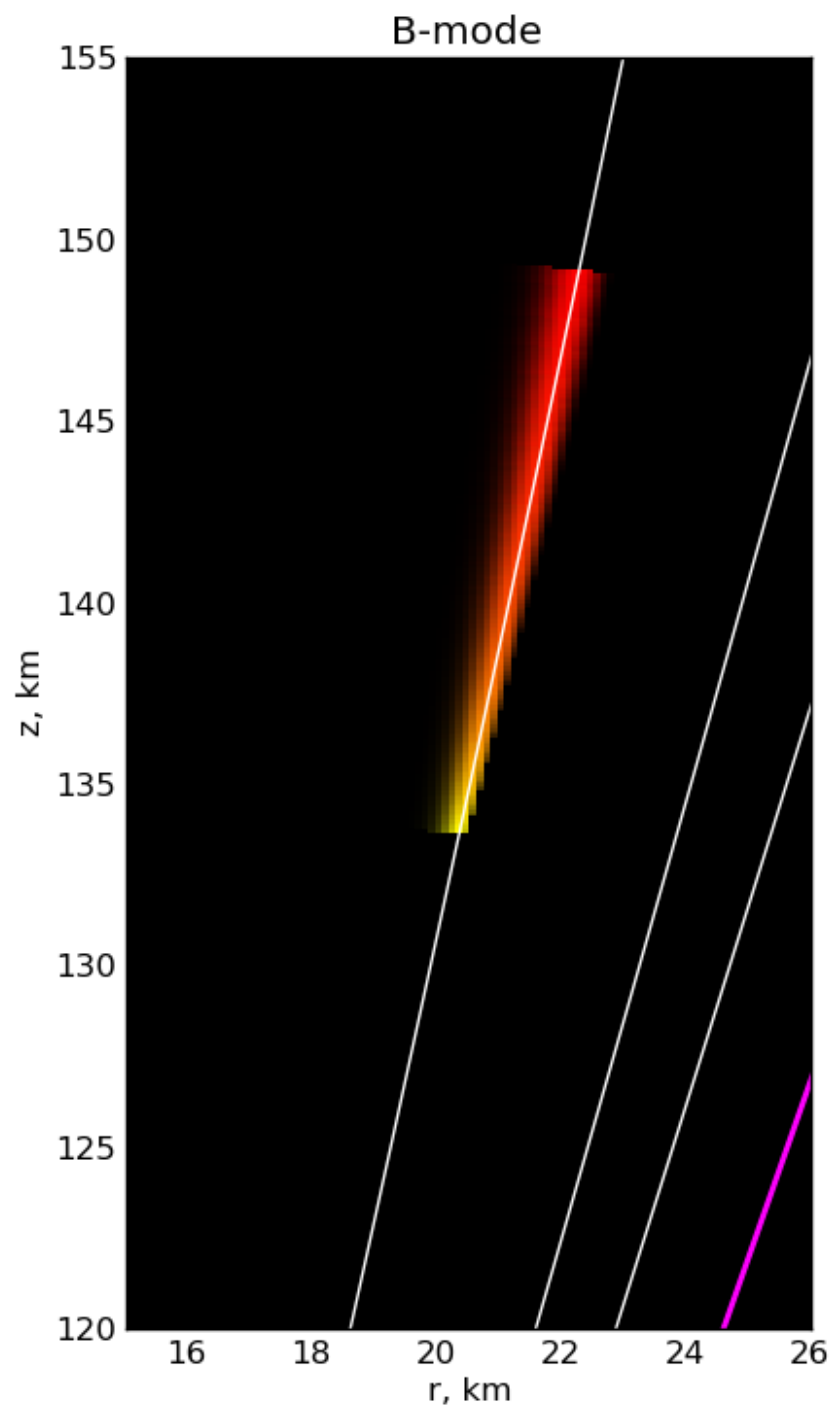


Q-mode







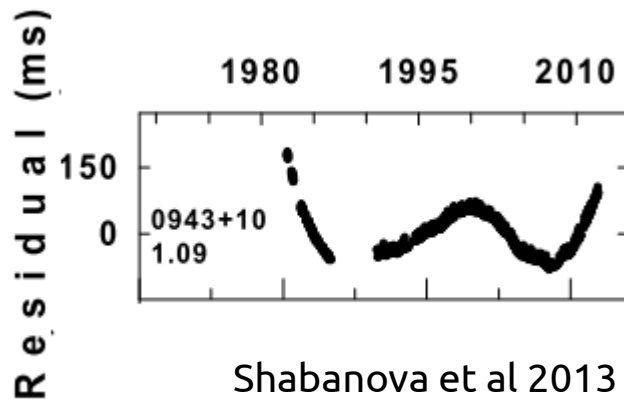


Radio emission: probe of global magnetospheric changes?

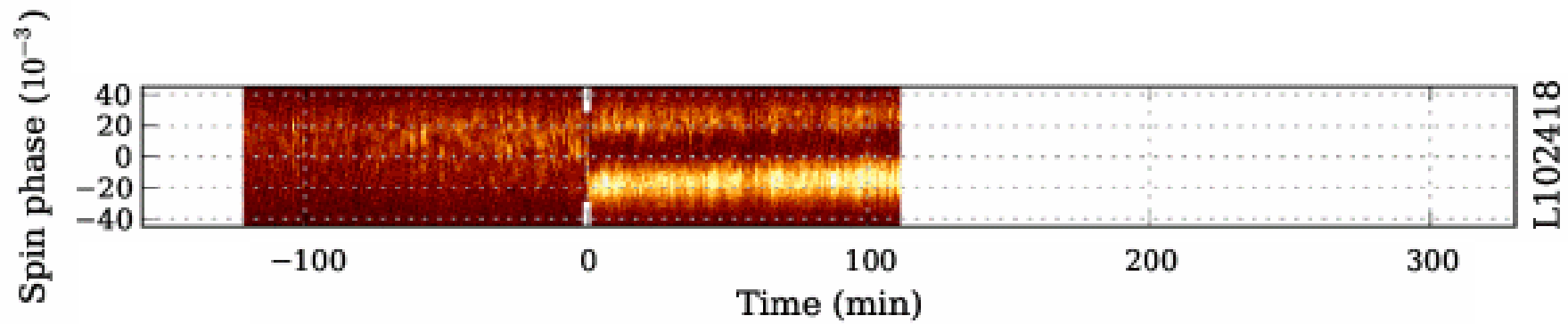
B0943+10: $P = 1.09770570486(7) \text{ s}$

$dP/dt = 3.49339(20)e-15 \text{ s/s}$ or 0.35 ns/day

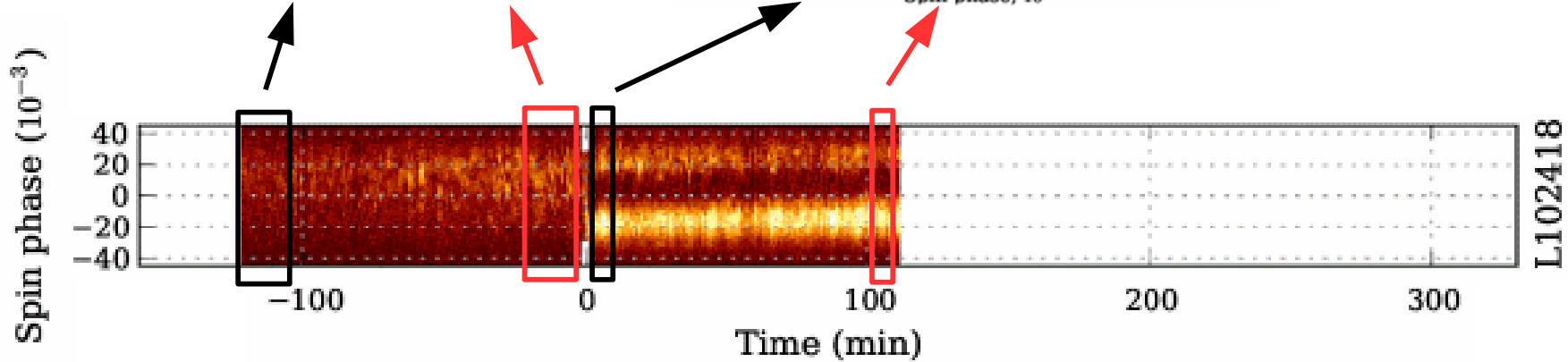
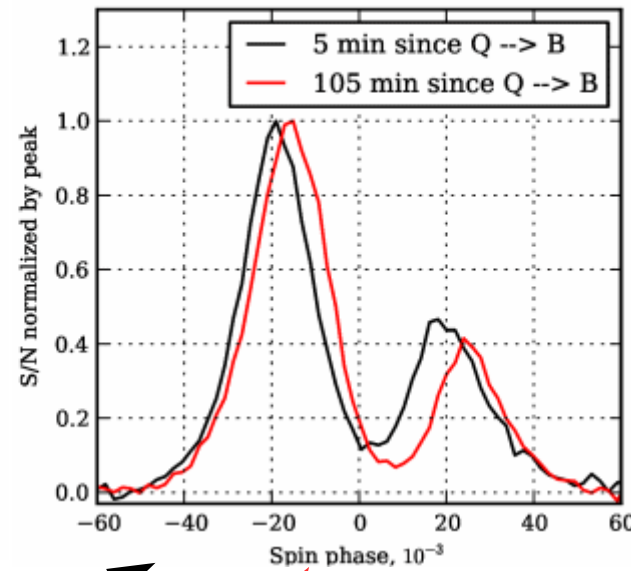
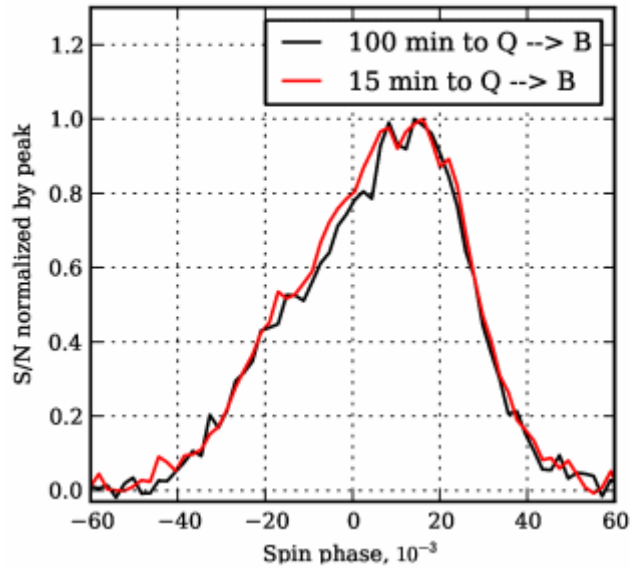
Residuals = (Measured ToA) - (Predicted ToA)



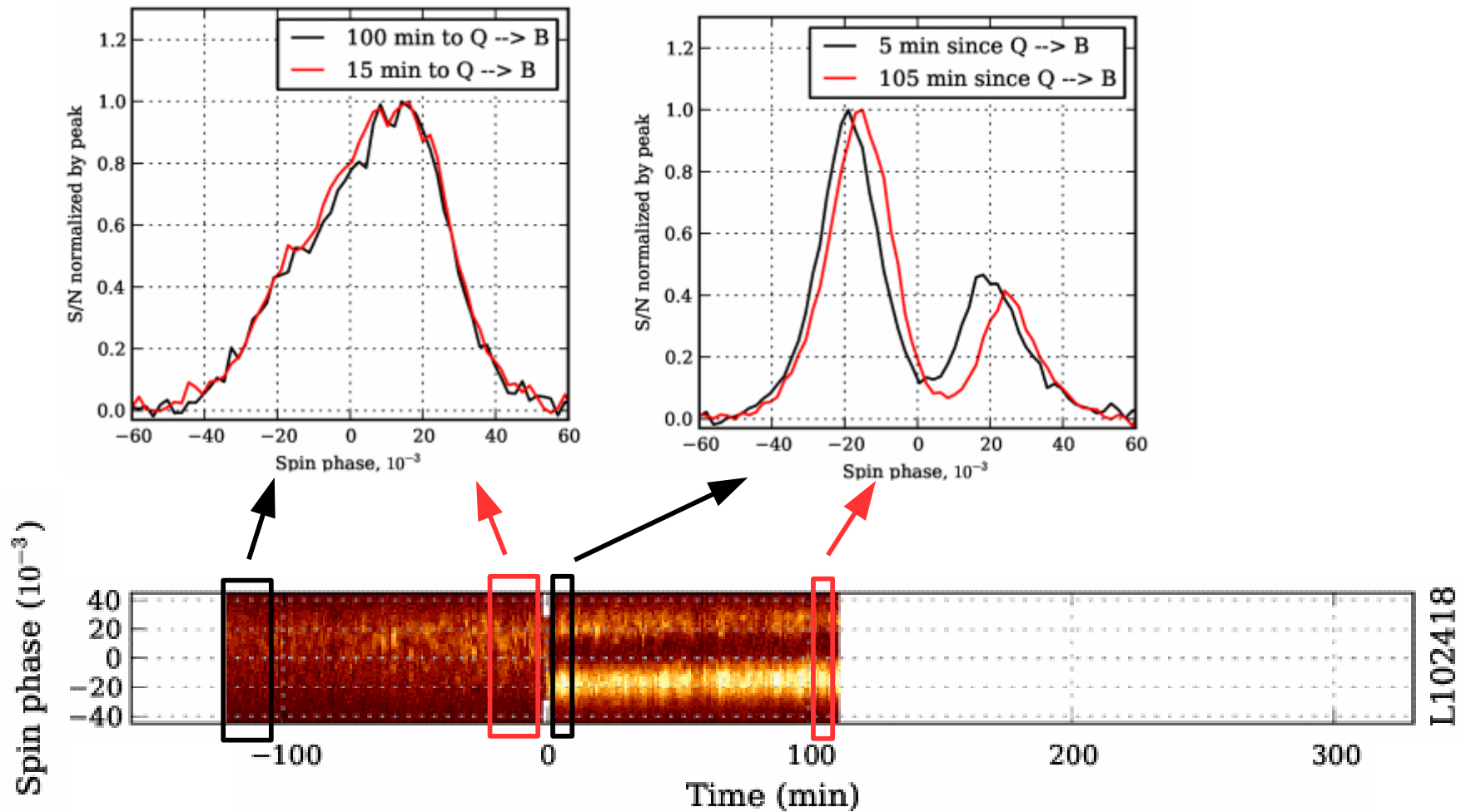
But... weird, mode-dependent timing residuals



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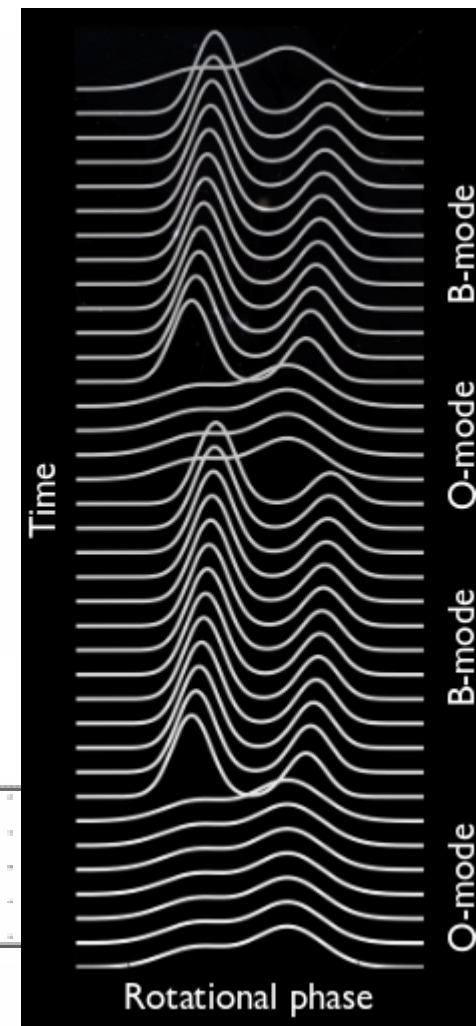
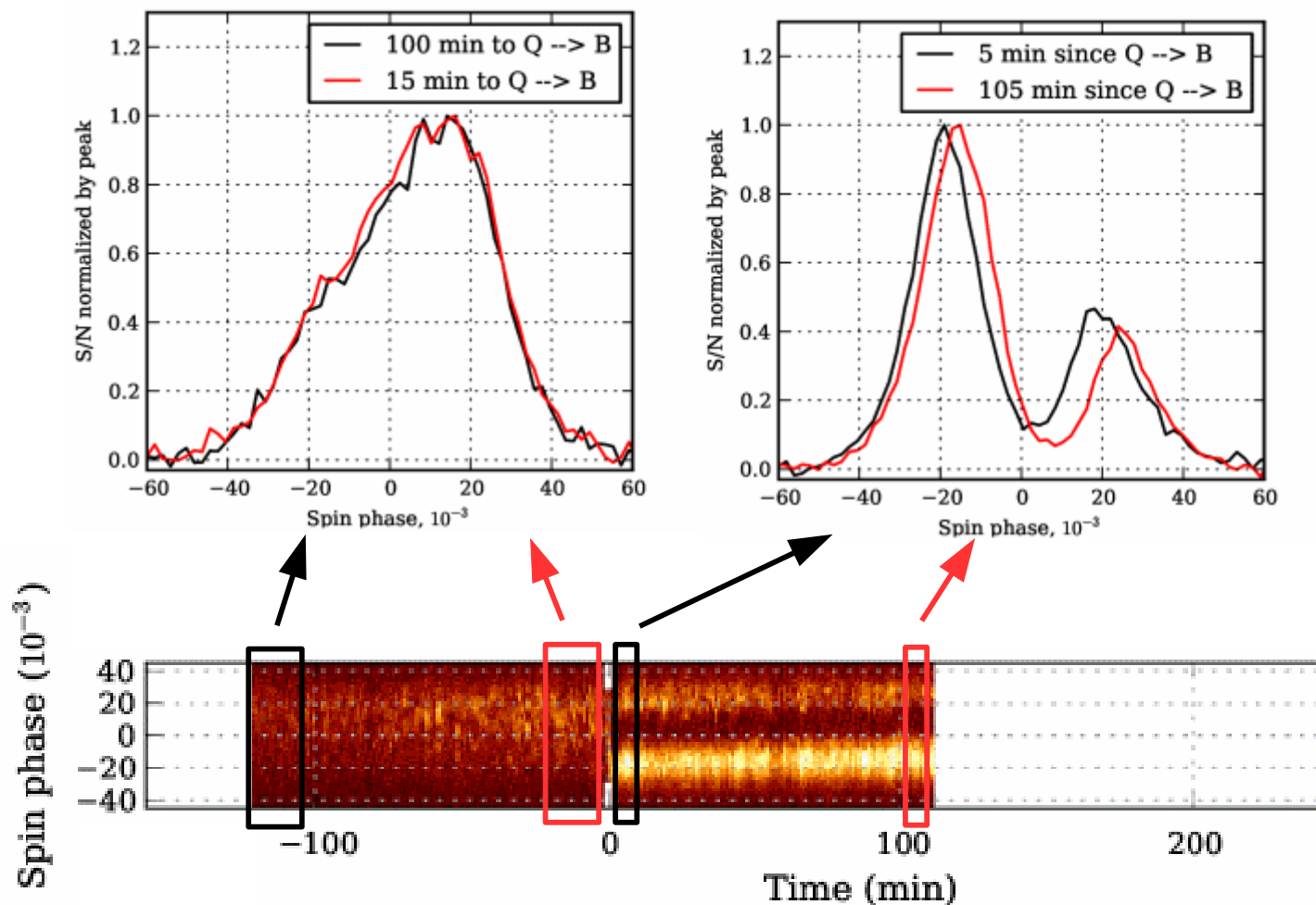


Average profile in B-mode systematically shifts towards later spin phases with the age of the mode

Also independently discovered in Pushchino

(Suleymanova & Rodin 2014)

But... weird, mode-dependent timing residuals

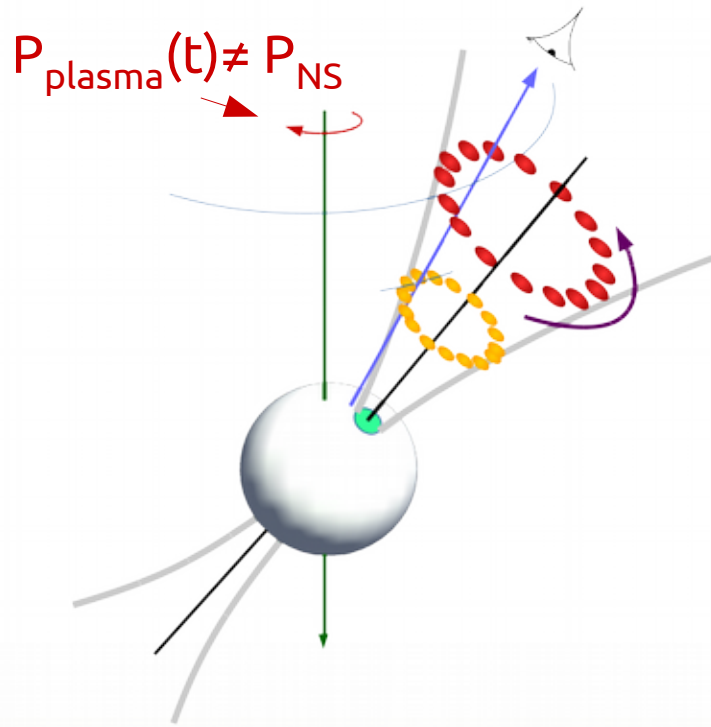


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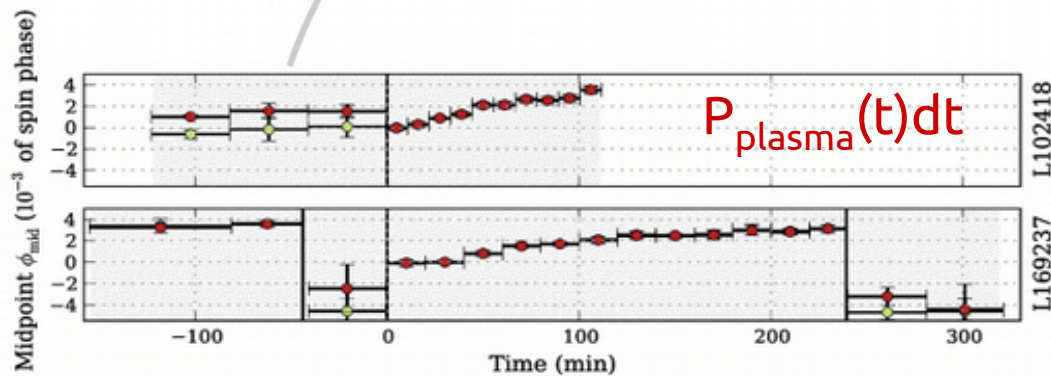
(Suleymanova & Rodin 2014)

Variation of accelerating potential in the polar gap?



In the presence of the gap plasma above the gap will rotate with $P > P_{\text{NS}}$
The discrepancy between the periods depends on the drop of accelerating potential inside the gap.

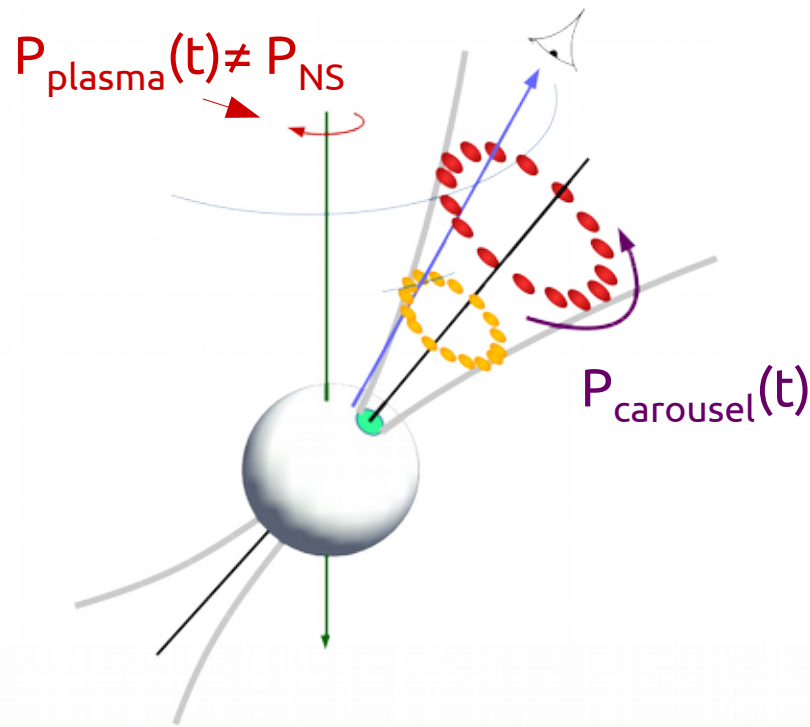
(Ruderman & Sutherland 1975 for aligned rotator, Melrose & Yuen 2014 for $\alpha \neq 0$)



In order to explain the profile delay, by crude estimate:

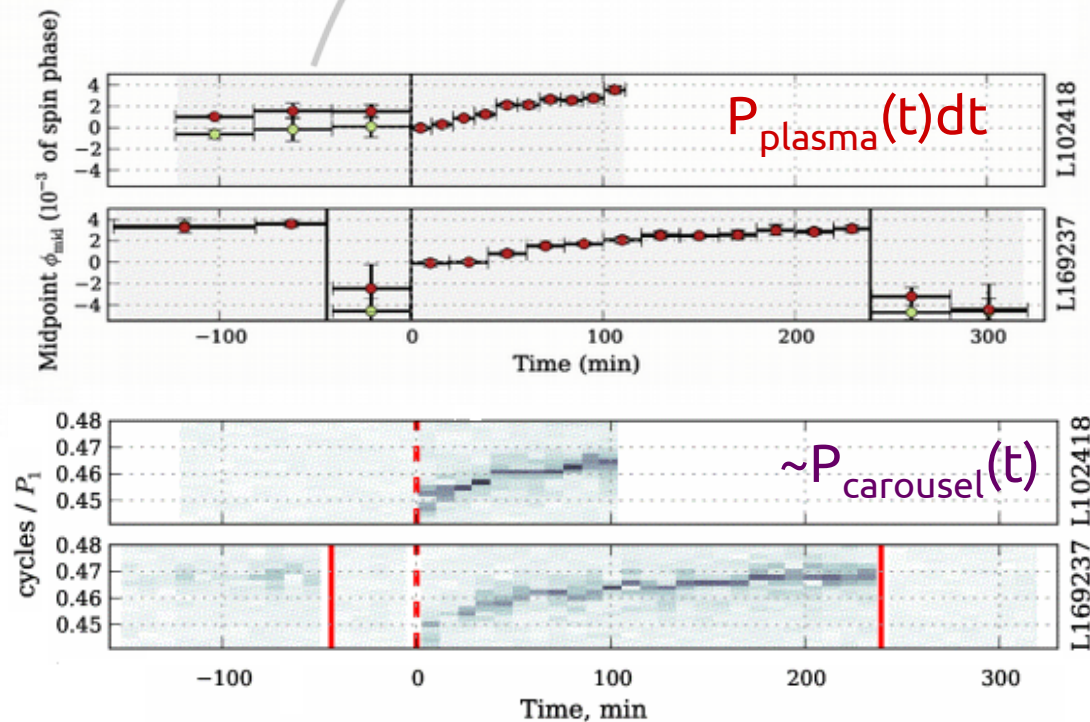
V changes by about 10% throughout B-mode

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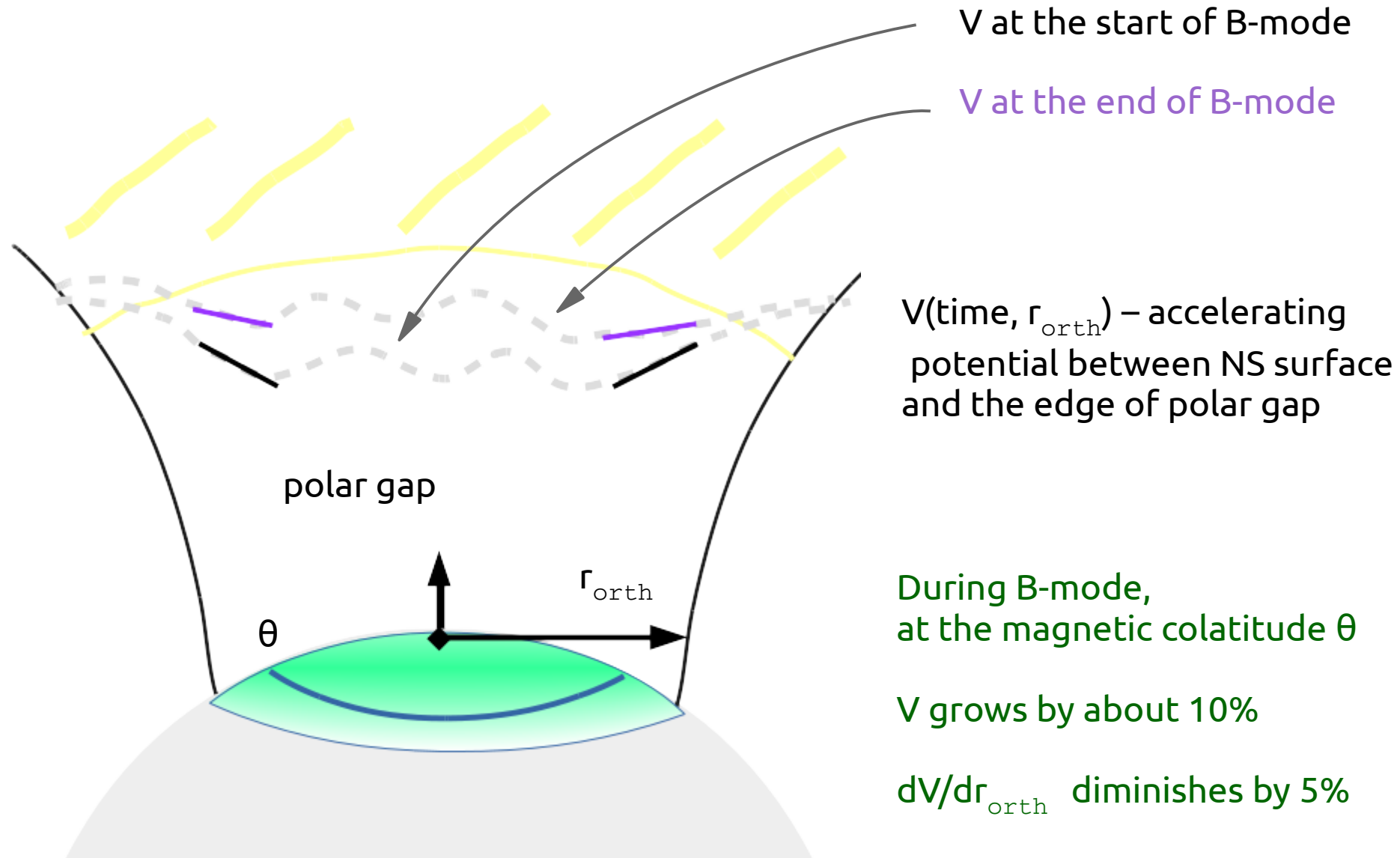
In order to explain the profile delay, by crude estimate:

V changes by about 10% throughout B-mode

$P_{\text{carousel}} \sim (dV/dr_{\text{orth}})^{-1}$
 (gradient of potential across the field lines)
 (Ruderman & Sutherland 1975
 van Leeuwen & Timokhin 2012)

dV/dr_{orth} changes by -5% throughout B-mode

Variation of accelerating potential in the polar gap?



Summary:

- Radio emission: close to stellar surface, not from the field lines in the center of the polar cap.
- Emission region is almost the same in B- and Q-modes.
- Systematic average profile delay in B-mode only. Evidence for variation of accelerating potential inside the polar gap?

Future & ongoing work:

- Deeper analysis of X-ray properties (400 ks of new data)
- Connect inferred variation of accelerating potential to the physical conditions in the polar gap

Geometry

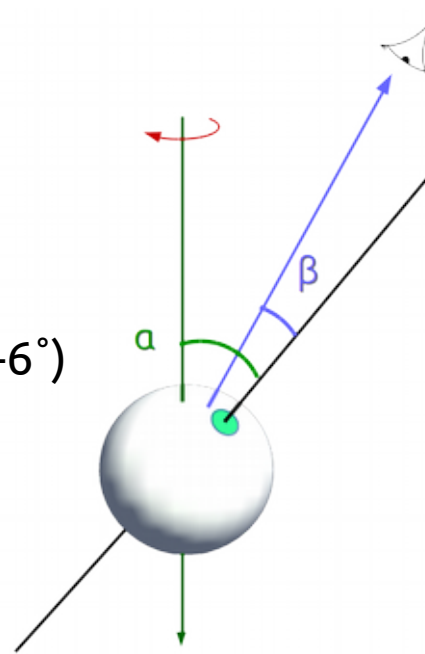
Deshpande & Rankin 2001

Almost aligned rotator

(α, β) between $(12^\circ, -4^\circ)$ and $(16^\circ, -6^\circ)$

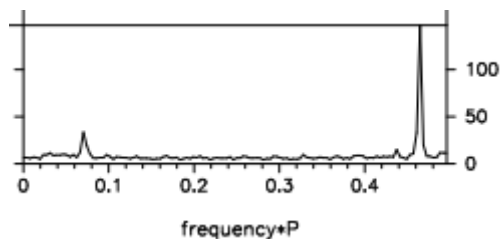
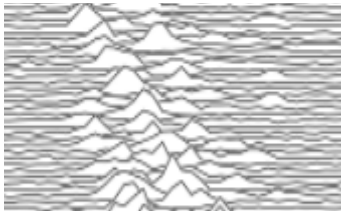
Rotates clockwise

20 sparks



based on:

- observed width of the profile
- average profile polarization
- extra modulation in LRF



Geometry

Deshpande & Rankin 2001

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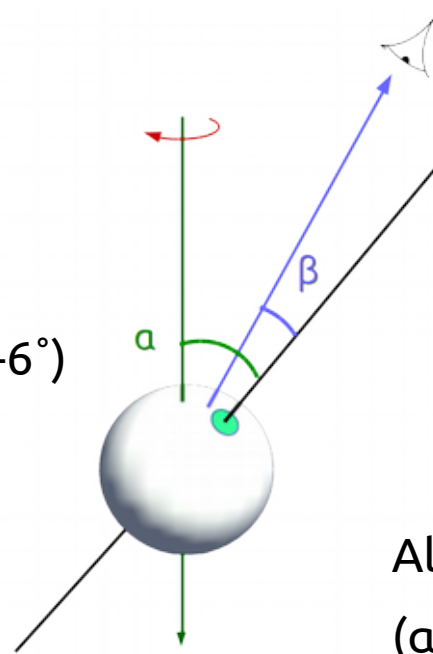
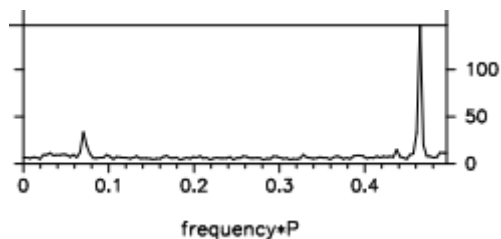
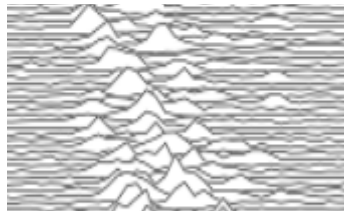
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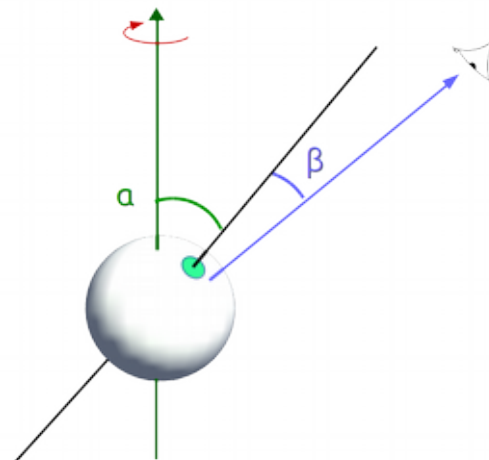


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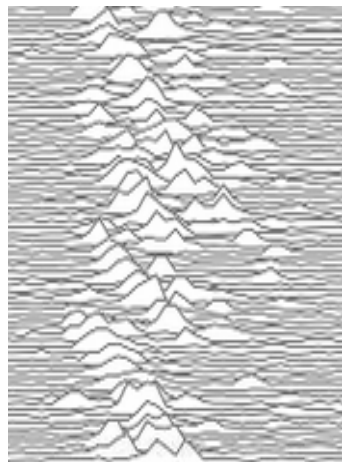
(α, β) between $(12^\circ, 4^\circ)$ and $(16^\circ, 6^\circ)$

Rotates counterclockwise

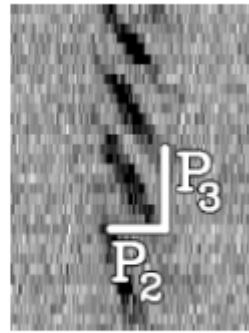
9 sparks



Frequency-dependent phase delay



Pulse #



Spin phase

