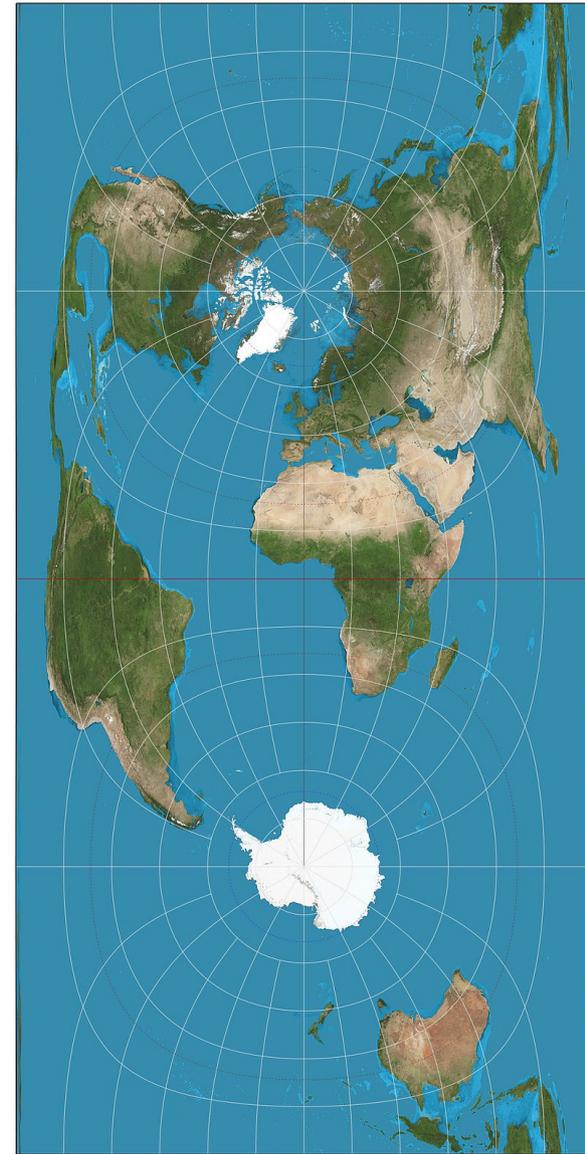
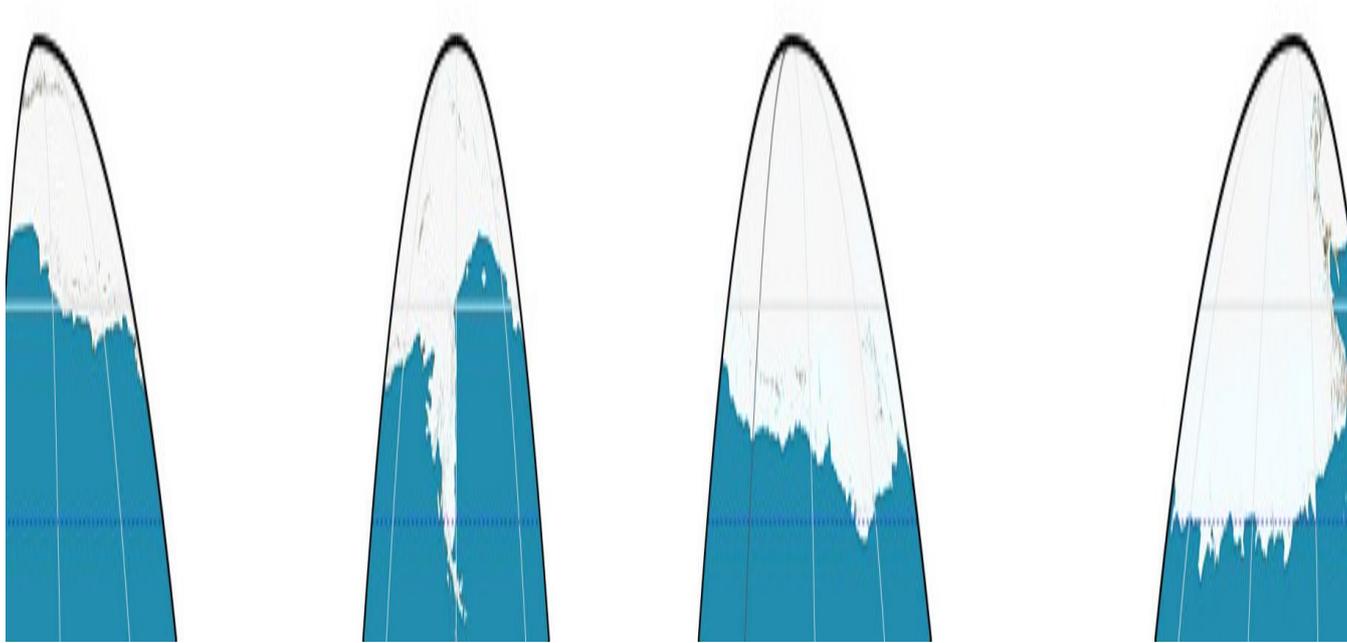


# Finding pulsar magnetosphere geometry from radio polarization data

Jaroslav Dyks  
Nicolaus Copernicus Astronomical Center, Torun



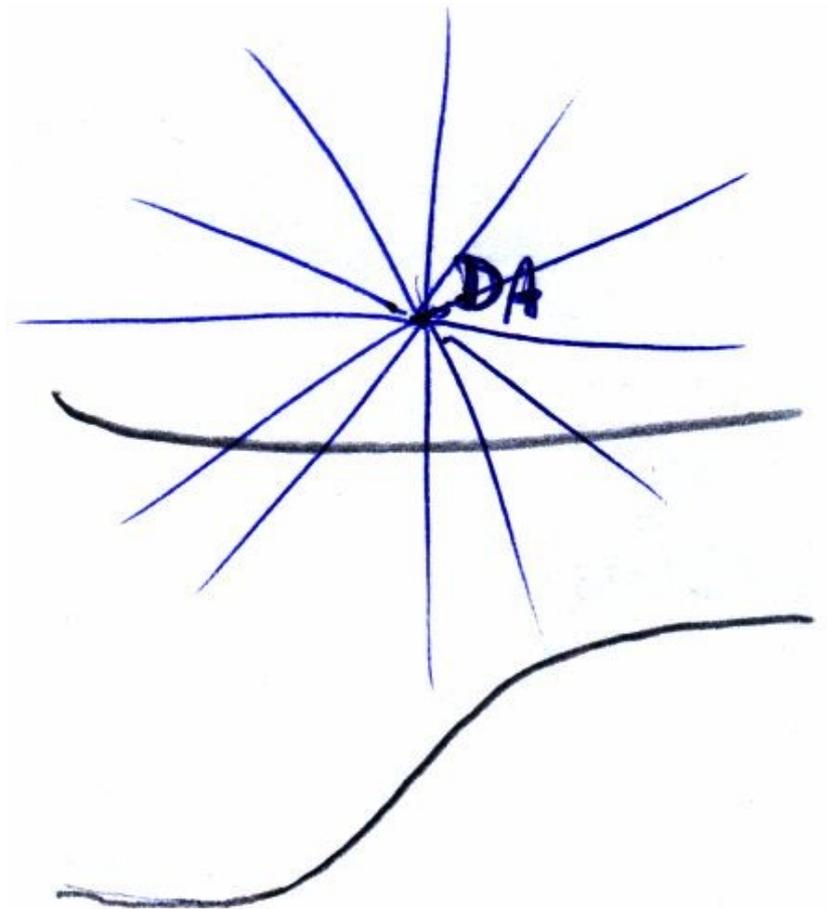
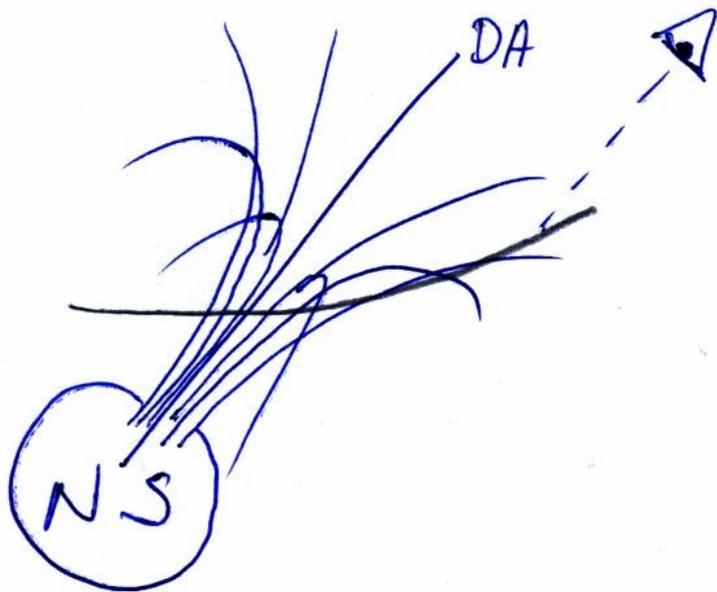
## Artifacts of circumpolar cartography in radio pulsar polarization



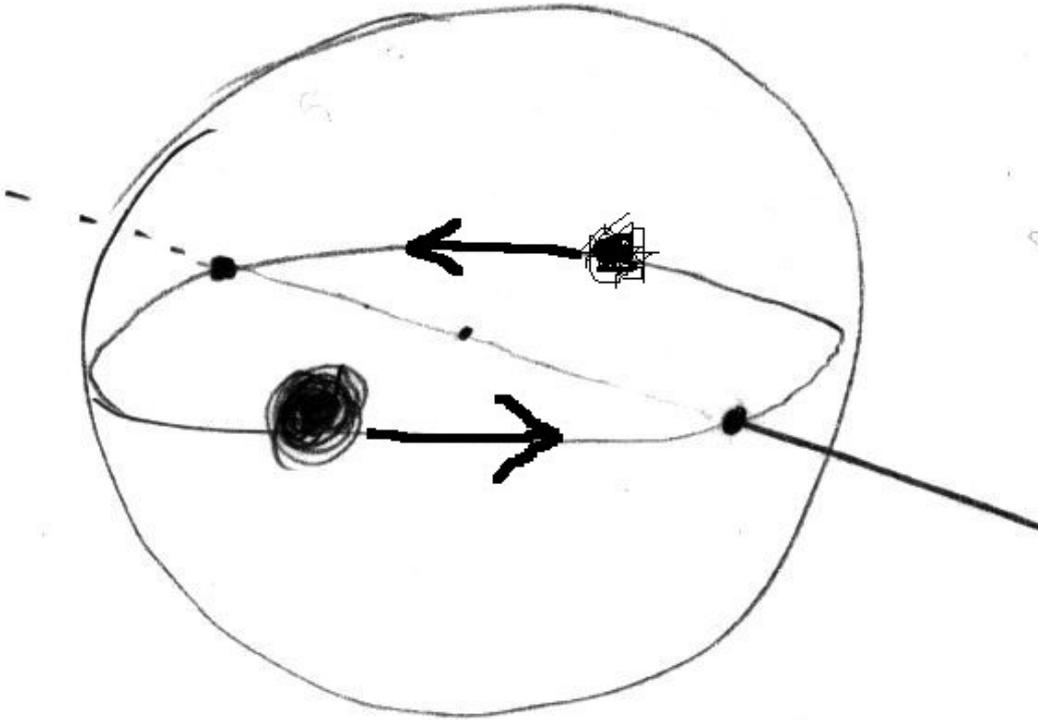
RVM model = rotating vector model = PA from sky-projected B-field

Field lines turn around near the magnetic pole => S-swing

=> fit the RVM curve to find orientation of dipolar B-field and observer w.r.t. rotation axis



PA vs time



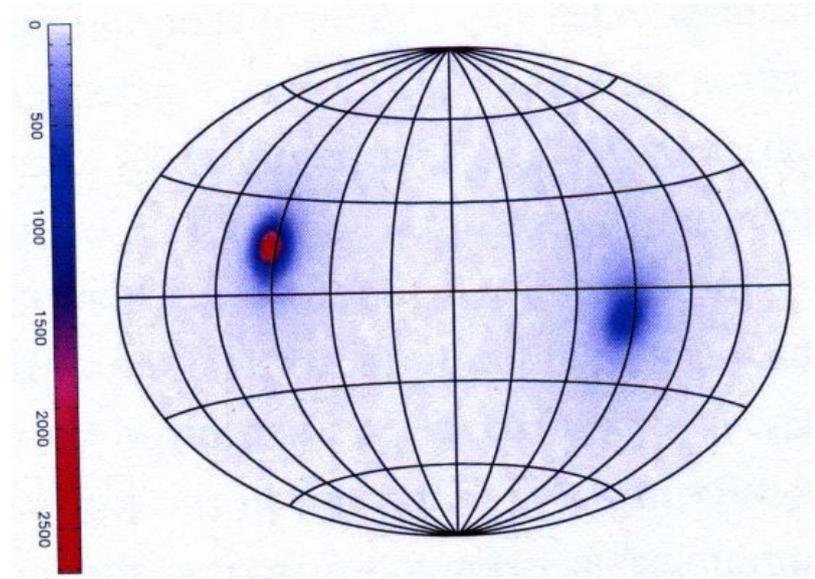
Sky-projected B rotates  
 => PA traces S-swing  
 => modal patches move horizontally  
 on P. sphere  
 (within equator)

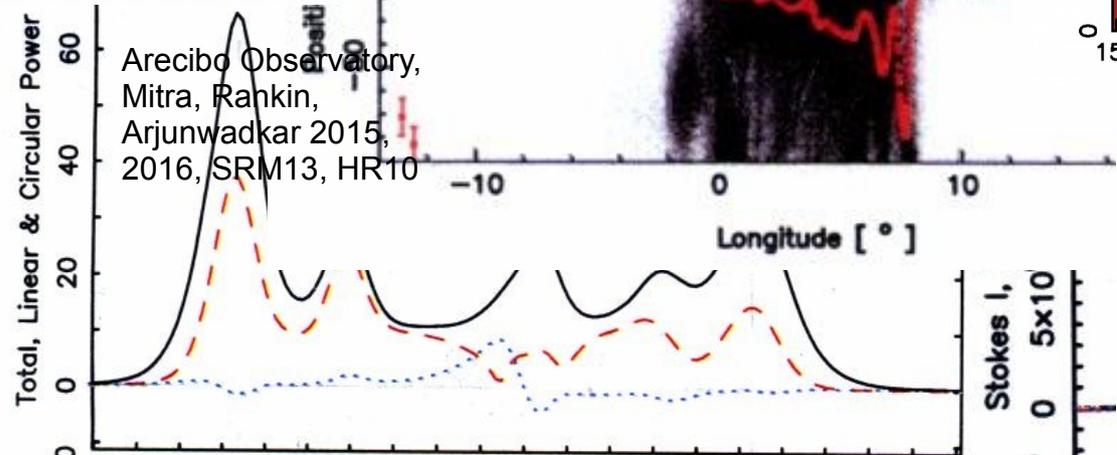
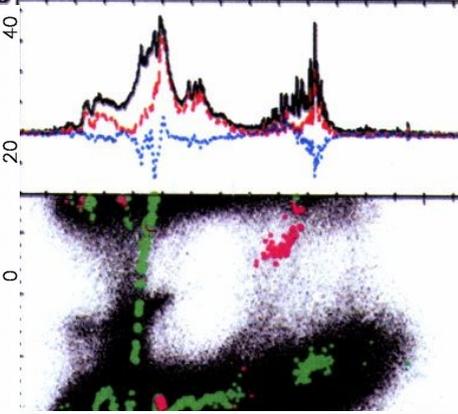
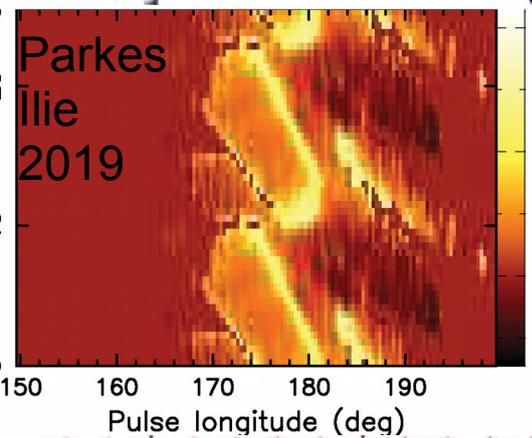
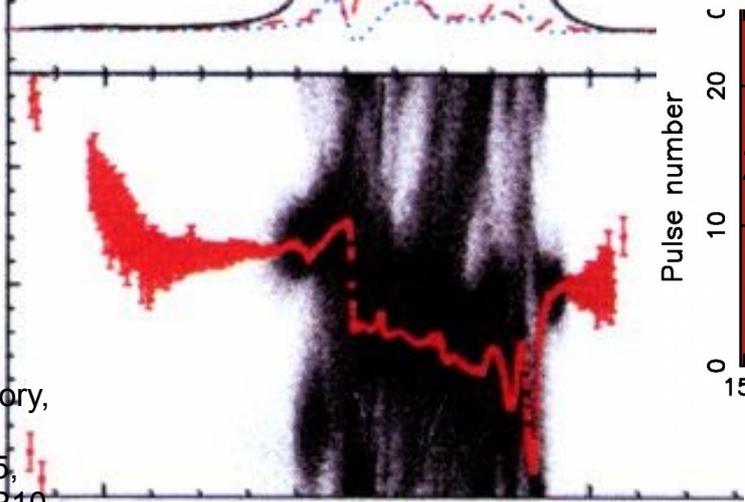
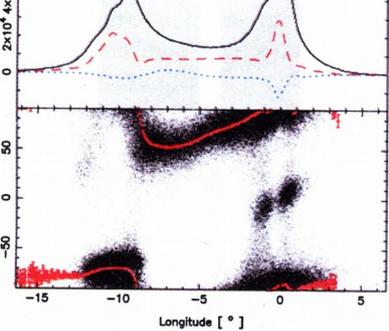
$$2*PA = \text{azimuth}$$

(orthogonal polarization = opposite azimuth)

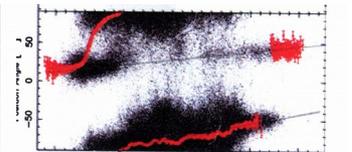
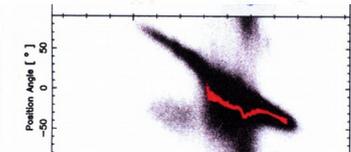
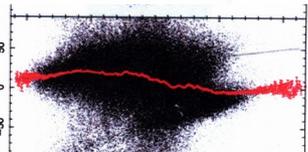
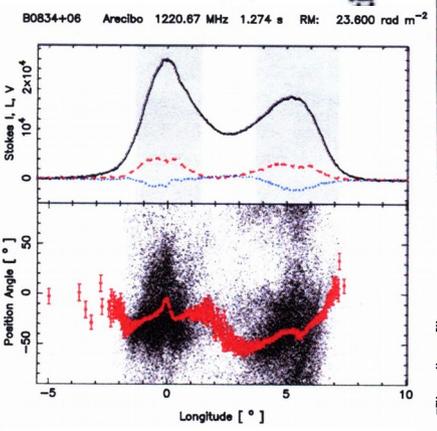
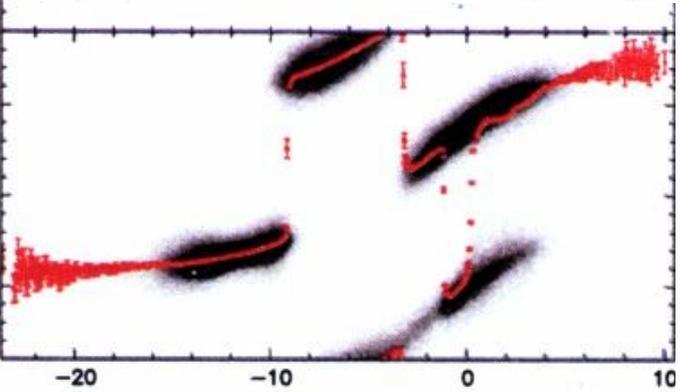
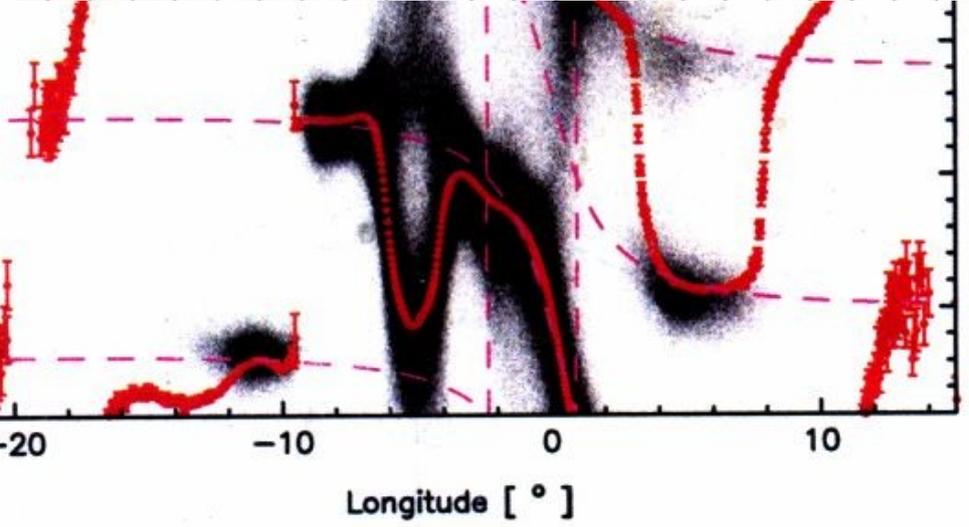
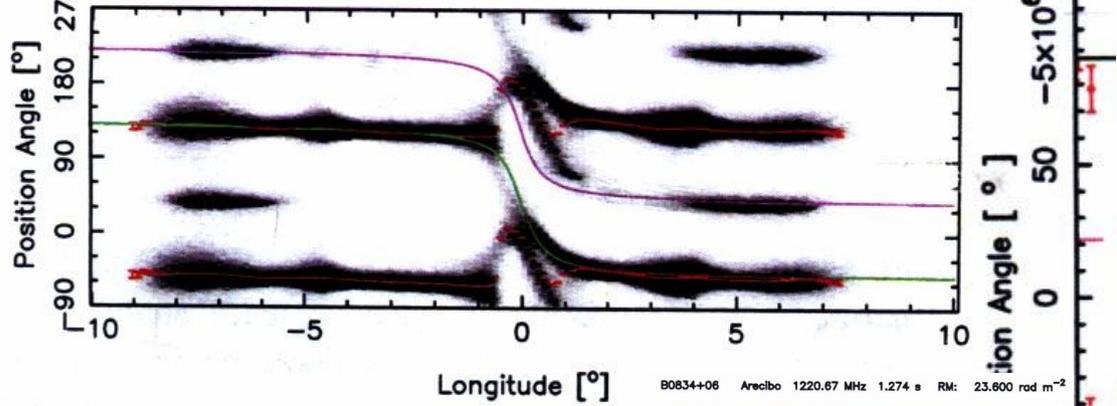
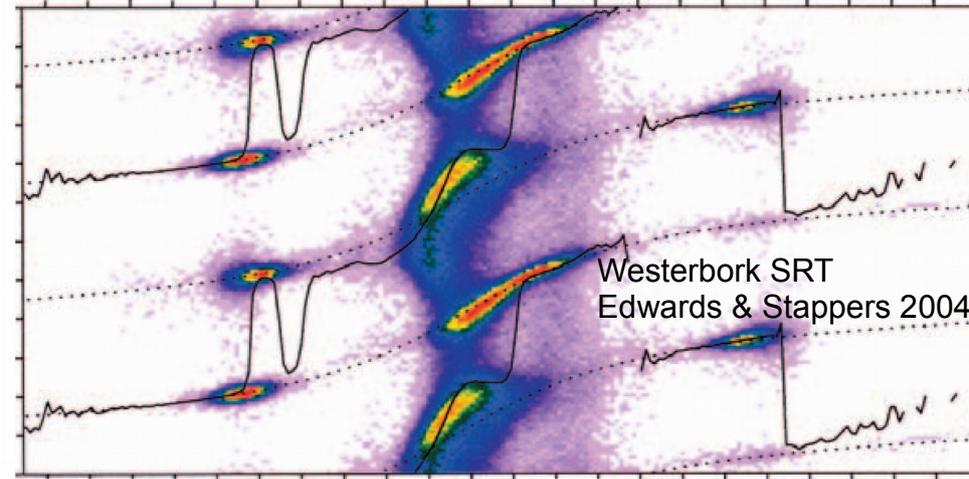
PA = polarization angle

But... PA data do not follow the S-swing

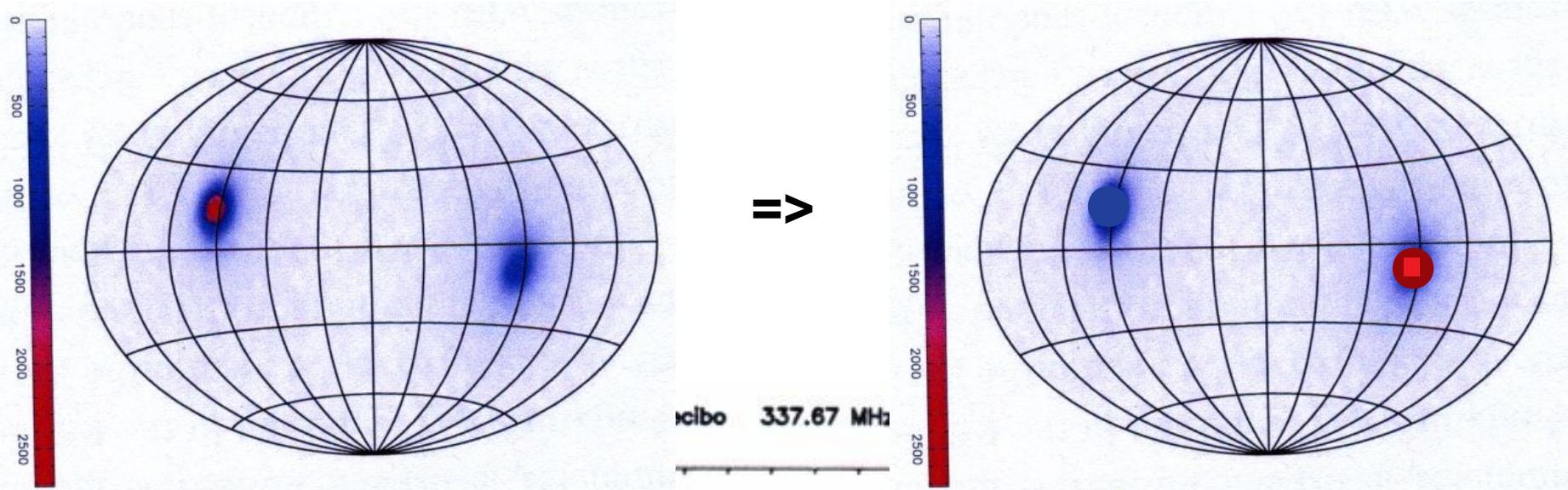




Arecibo Observatory,  
Mitra, Rankin,  
Arjunwadkar 2015,  
2016, SRM13, HR10



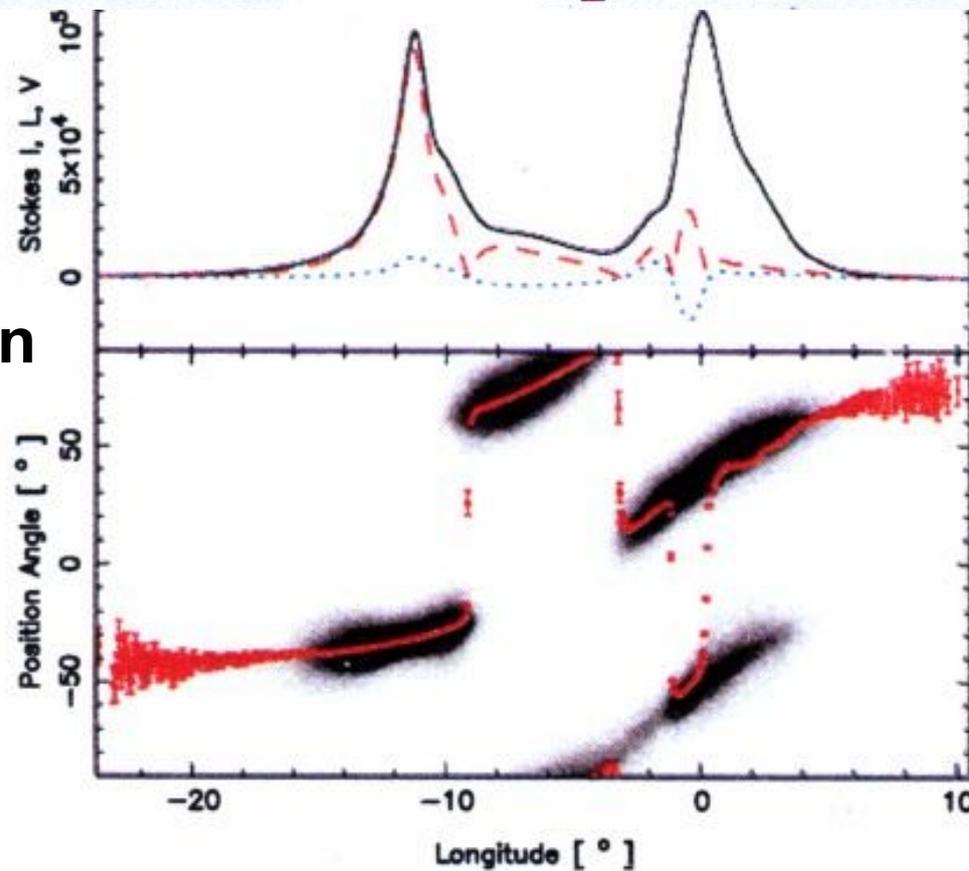
# Orthogonal polarization mode jump (OPM jump, the standard one)



Total depolarization  
at OPM jump:

$$L/I \sim 0$$

$$V/I \sim 0$$



# 1. Distortions of PA curves under central components

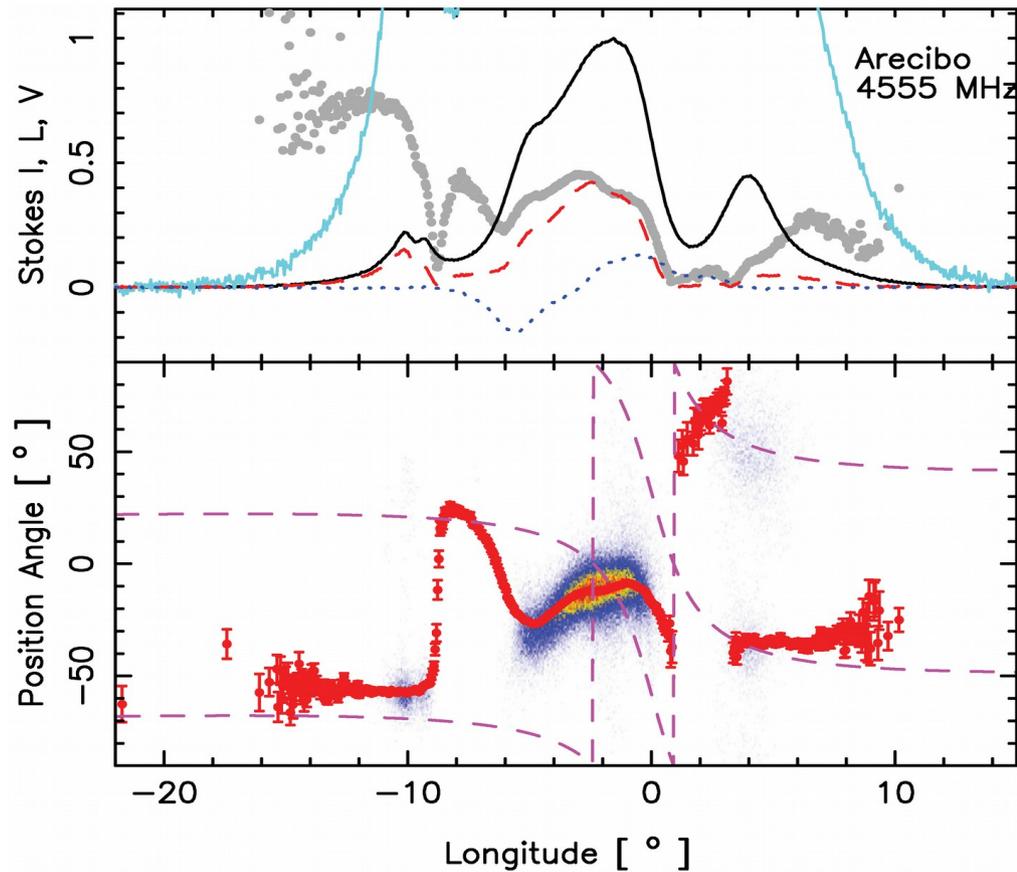
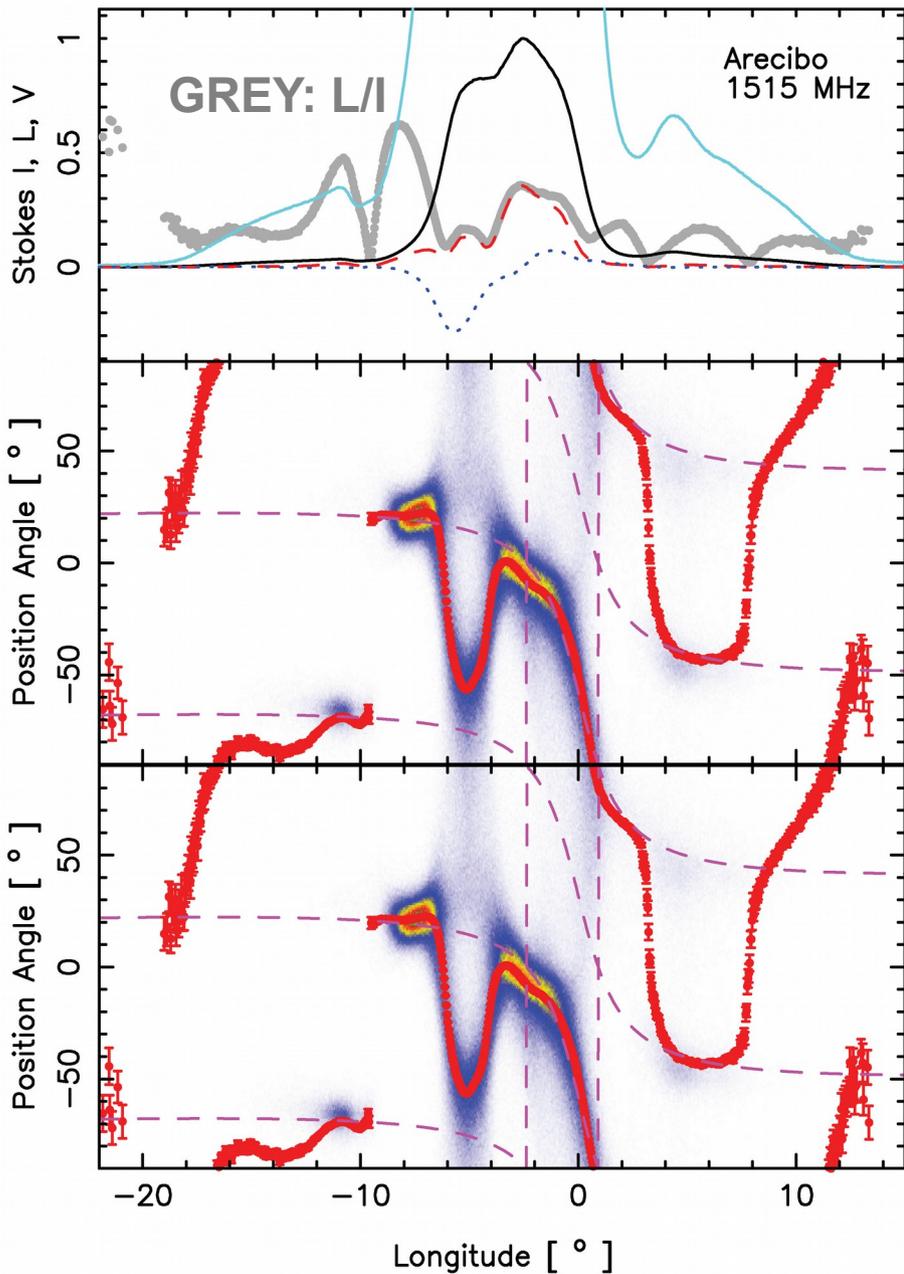
**1.5 GHz B1933+16**

Arecibo, Mitra, Rankin, Arjunwadkar 2016

PA loop with 'tongue and horns'

+ twin minima in L/I

**4.5 GHz**



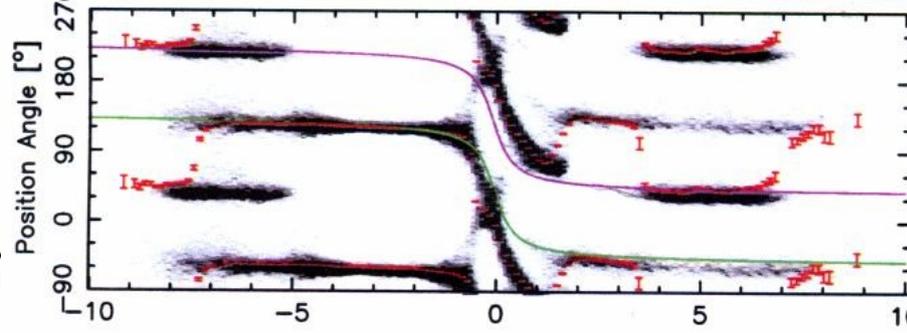
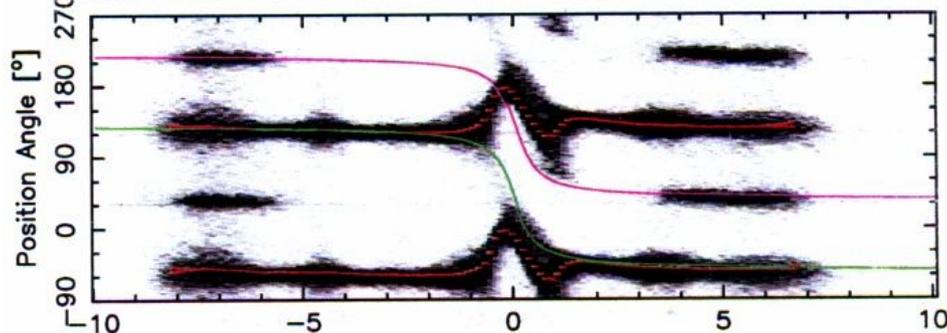
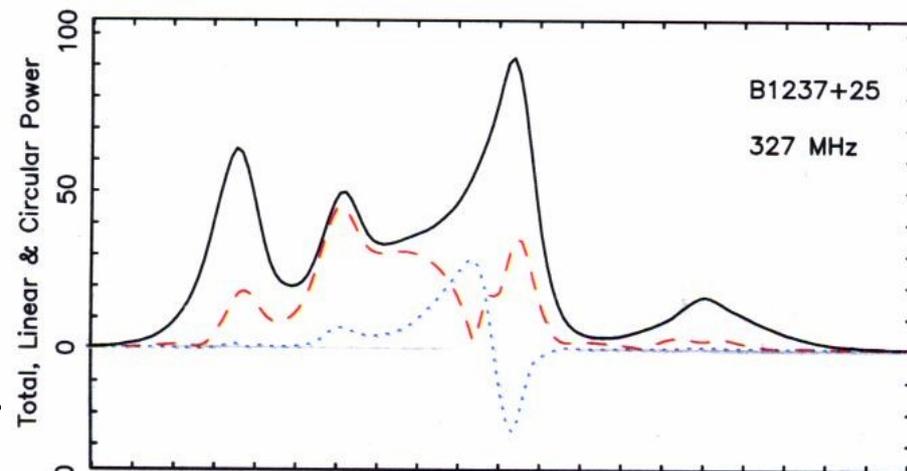
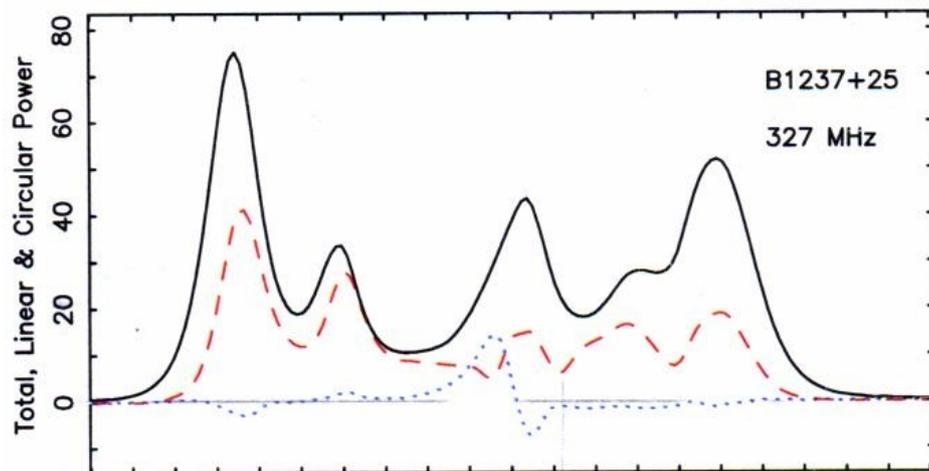
Distortions due to superposition of modes and other effects.

**Not caused by complex B.**

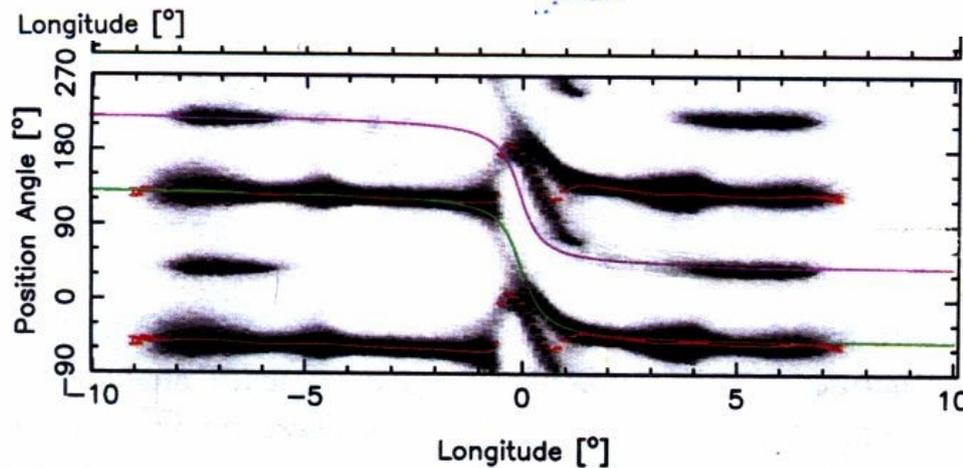
## 2. Bifurcations of PA curve: B1237+25 Smith et al. 2013 Two pulsation modes:

Flaring normal mode

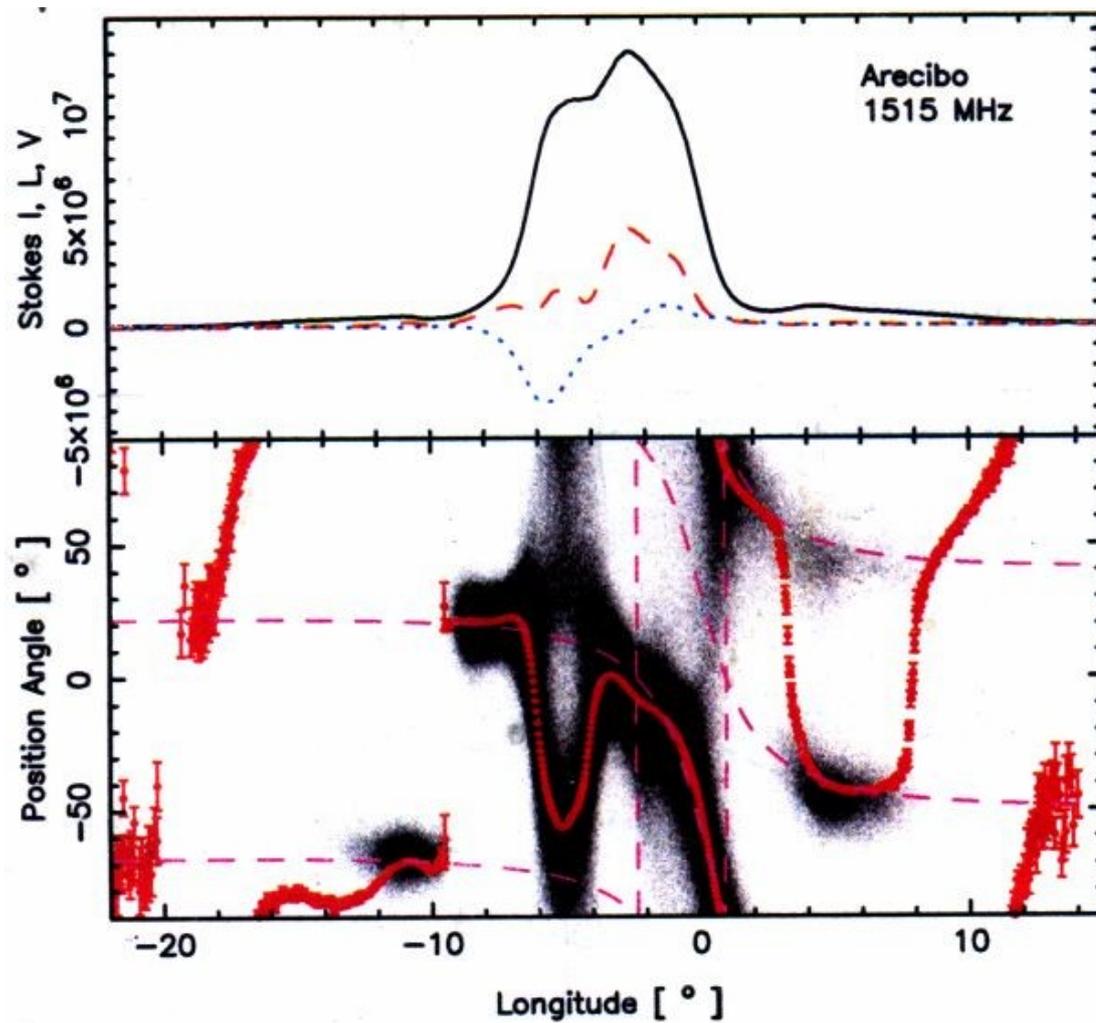
Abnormal mode



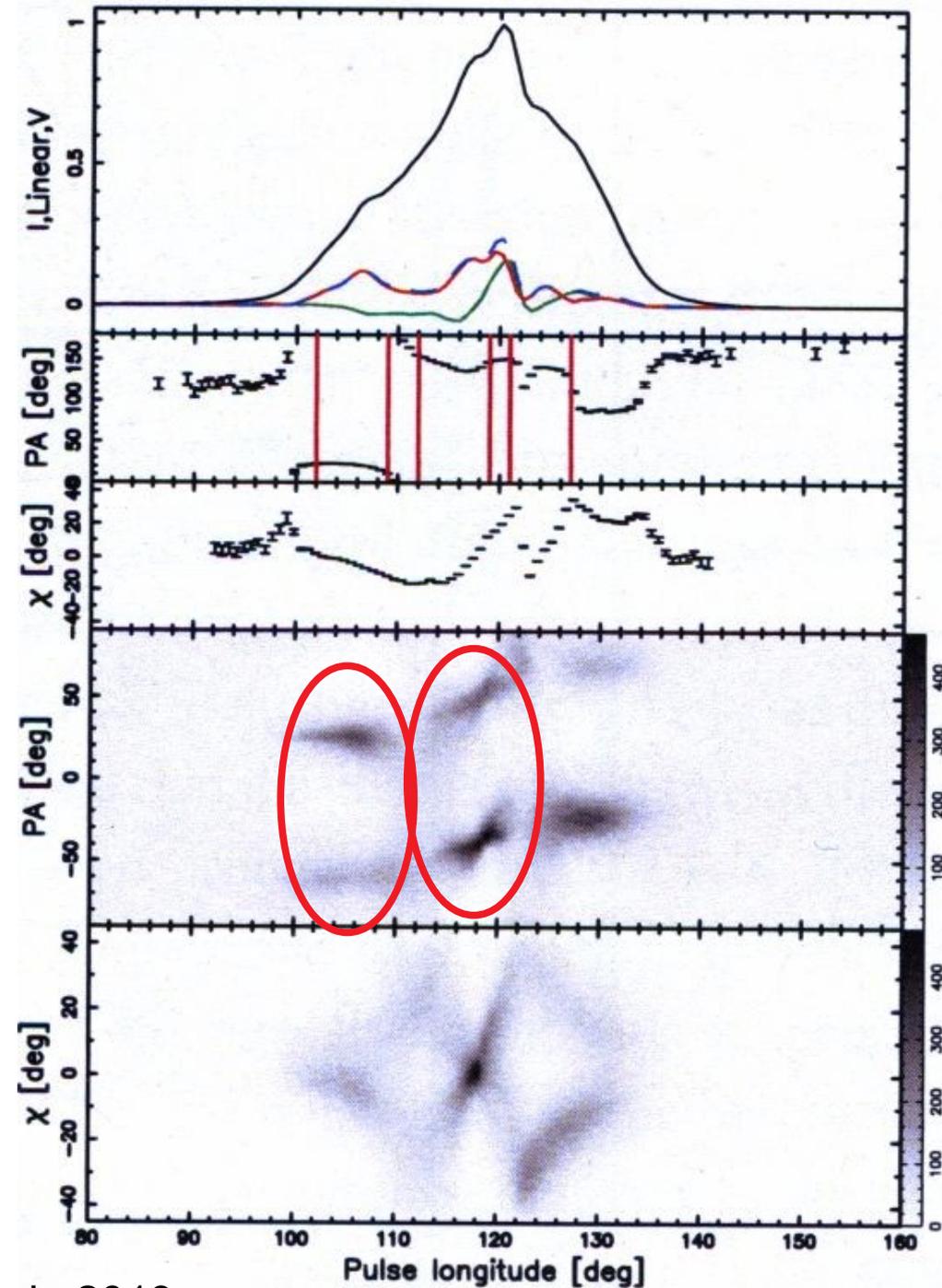
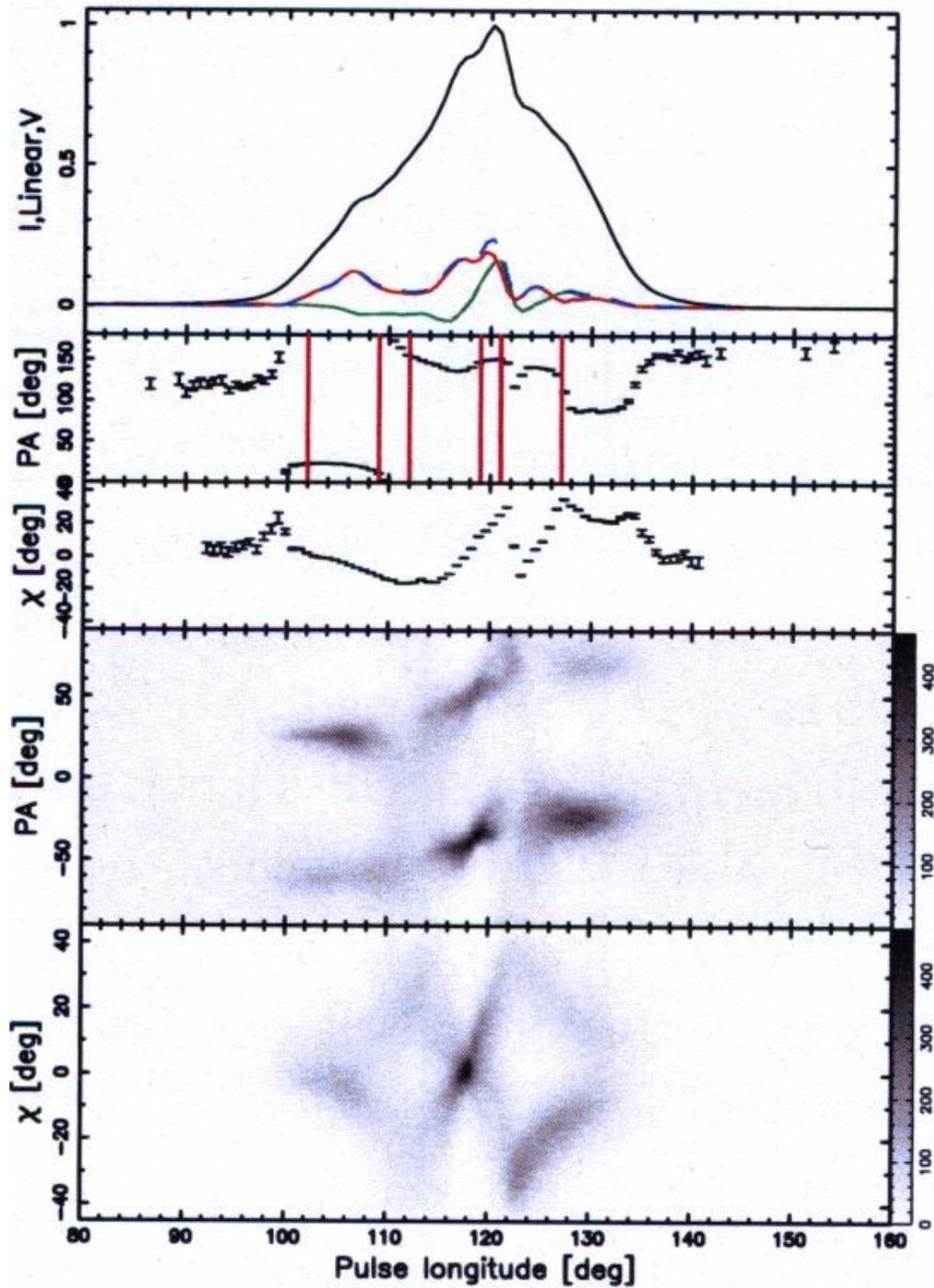
Total:



### 3. Vertical spread of flux at all PA values

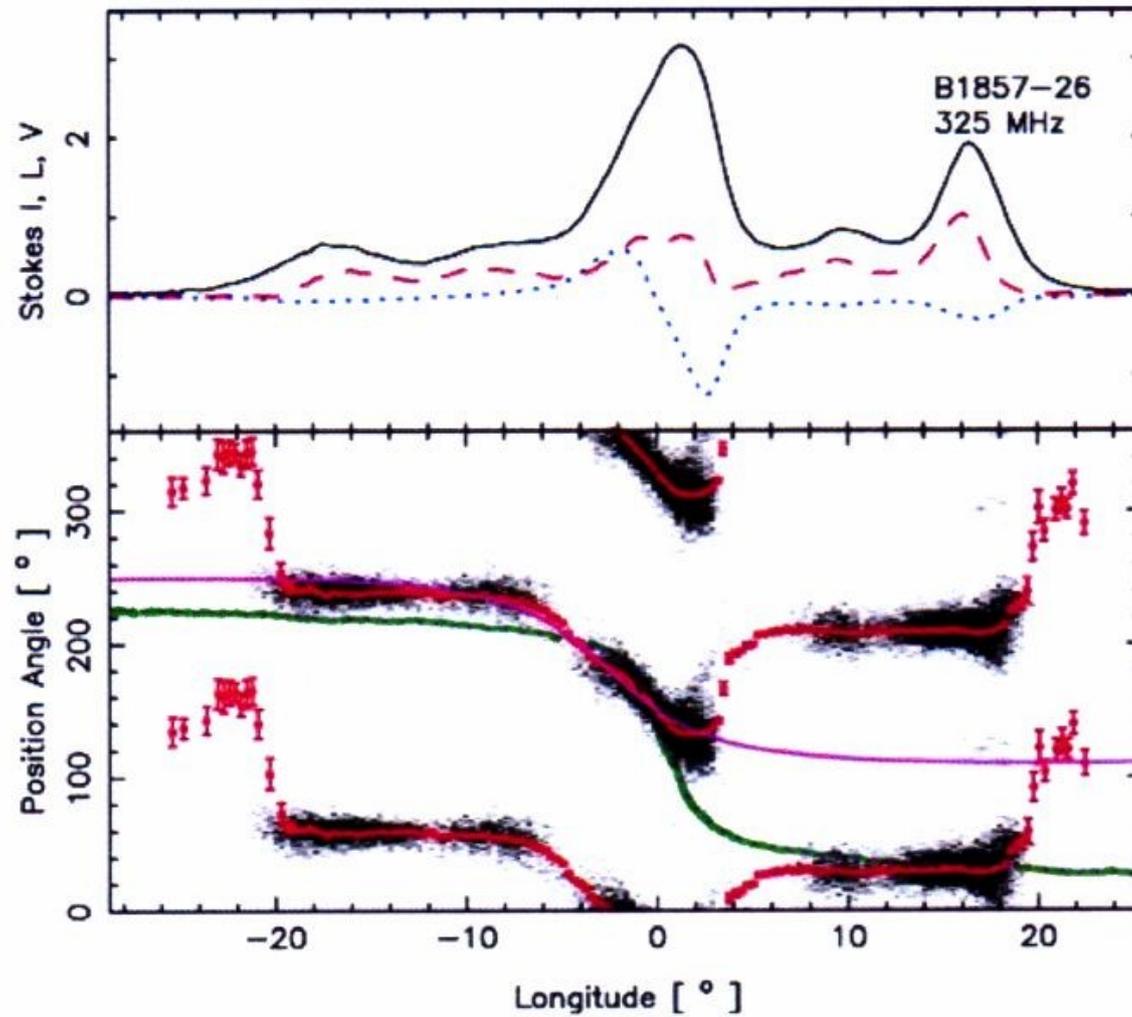


## 4. Exchange of power content between orthogonal PA tracks



## 5. Peripherically-flat PA swings that span more than 180 degrees

(inconsistent with RVM / B-field projection)



Circularization:  $V/I$  up to  $\sim 100\%$

- emission of curvature/synchrotron radiation beam (Michel)  
(vacuum beam not possible for plasma in teragauss  $B$ , Melrose)
- mode coupling at polarization limiting radius (Cheng, Ruderman, Lyubarskii, Petrova, Beskin, Philippov)
- coherent superposition of linear natural modes (Edwards, Stappers, Dyks)

Whatever the physical cause:

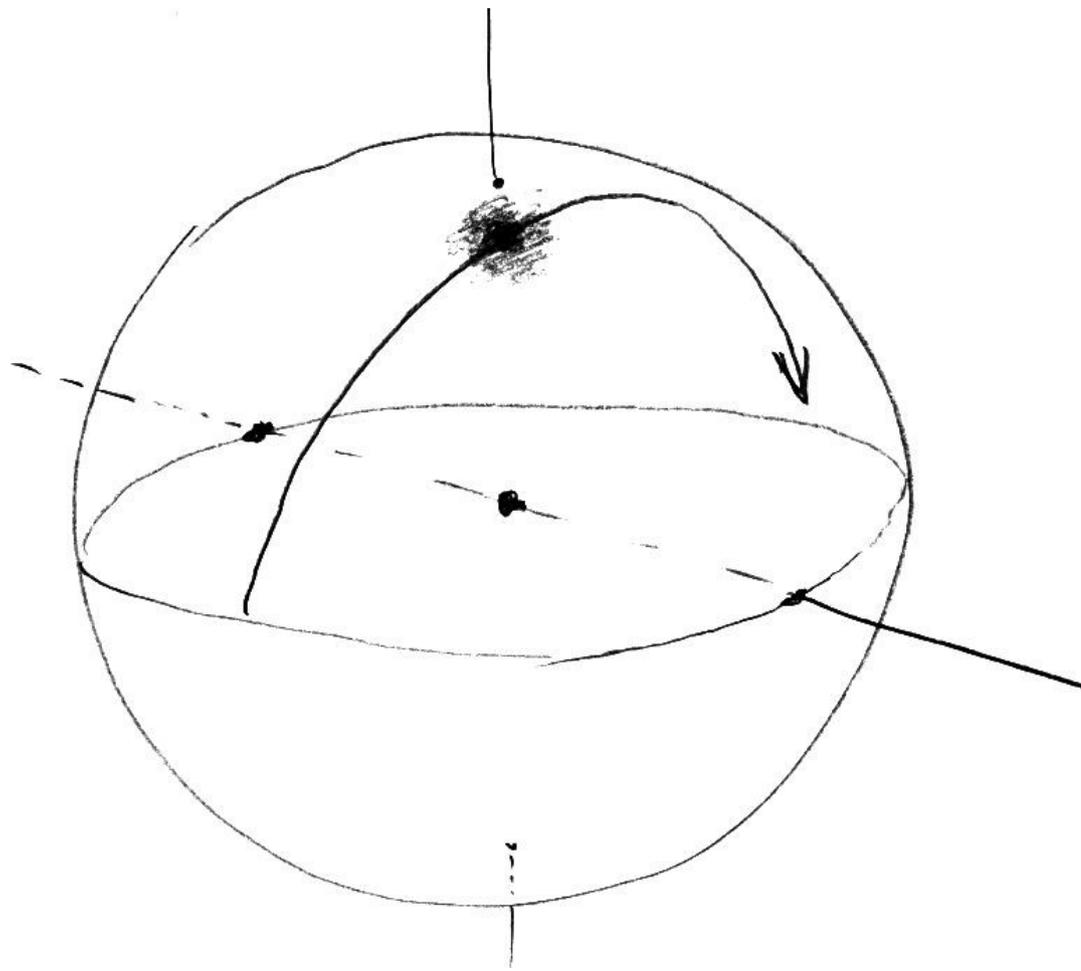
**near-meridional motion** of polarization state across the Poincare sphere

(vertical motion in the Stokes parameter space)

Complex look caused by passage of polarization state through the  $V$  pole

**Enigmatic look of these effects on the (PA – pulse longitude) plane**

**has cartographic origin!**

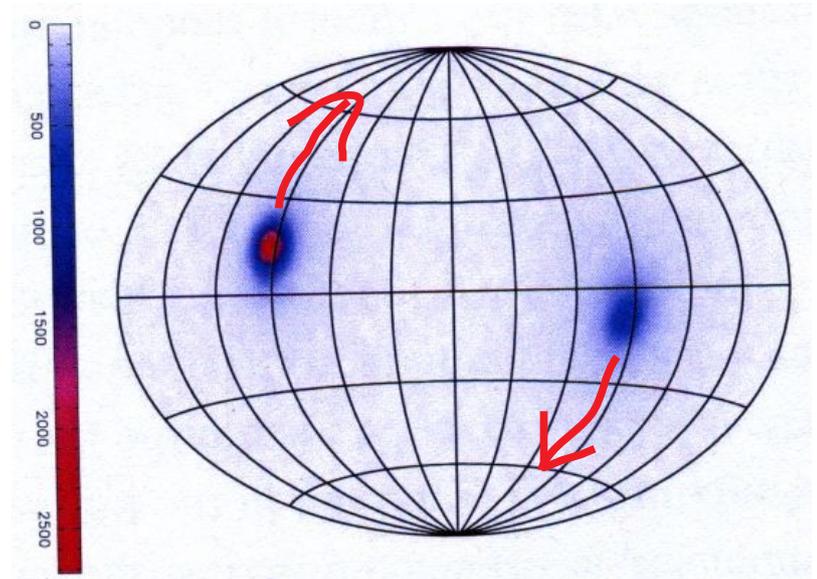


Polarization state rotates around the axis of natural propagation modes (eg. due to phase lag increase)

$$2 * PA = \text{azimuth}$$

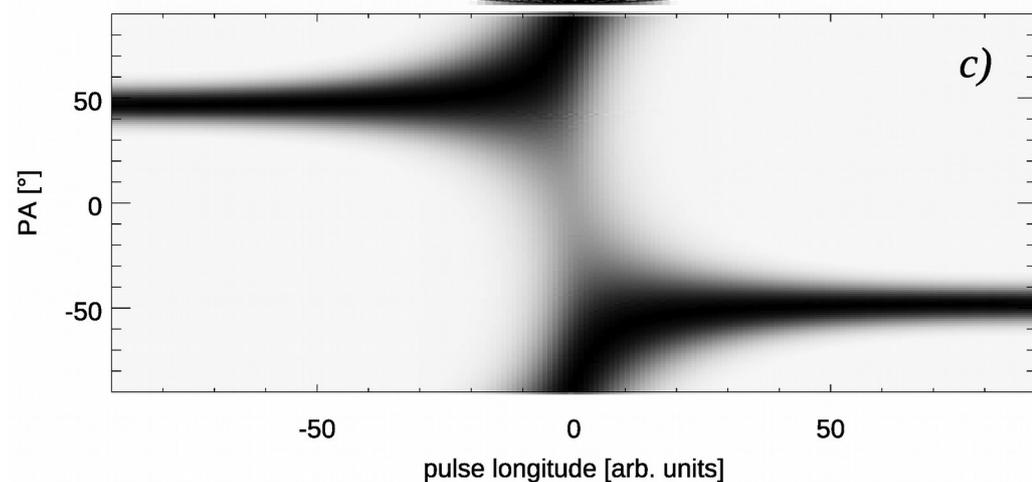
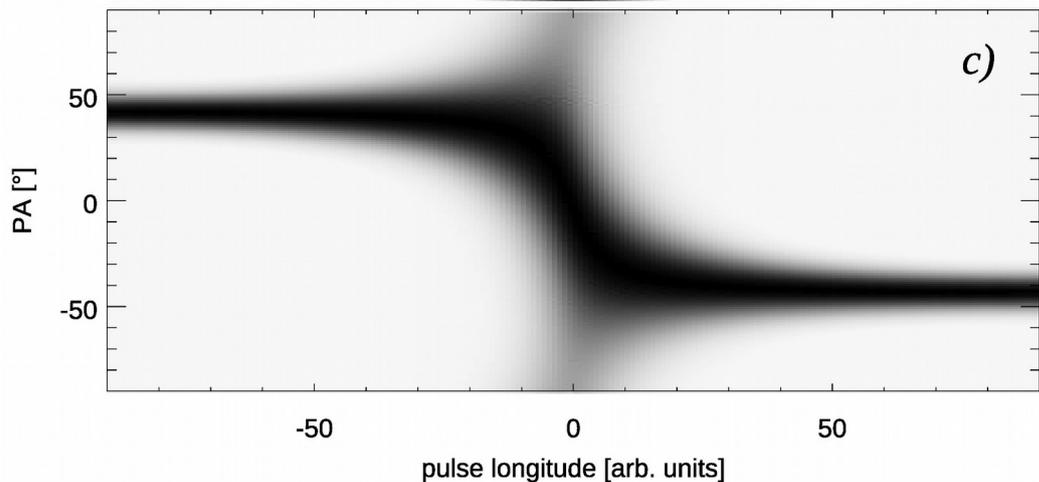
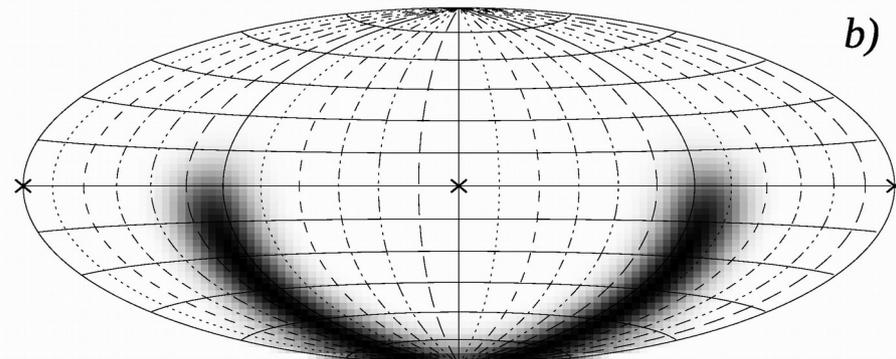
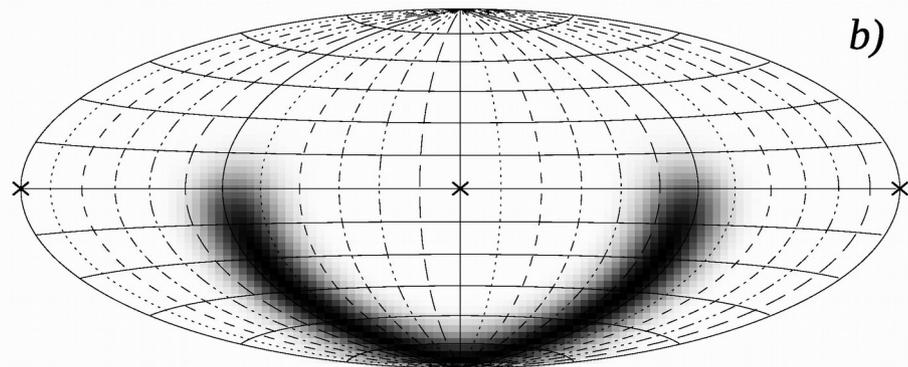
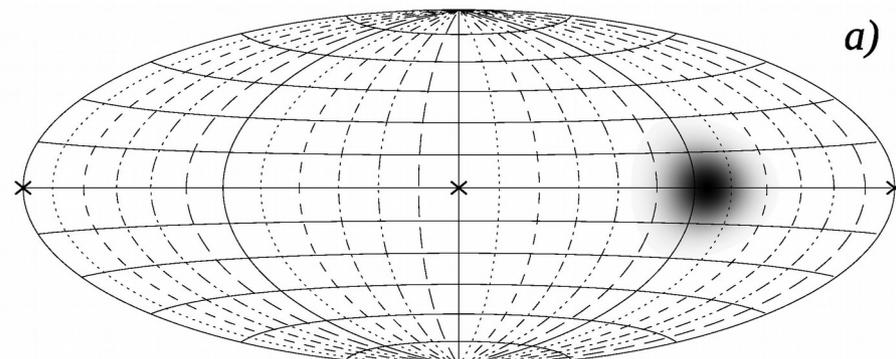
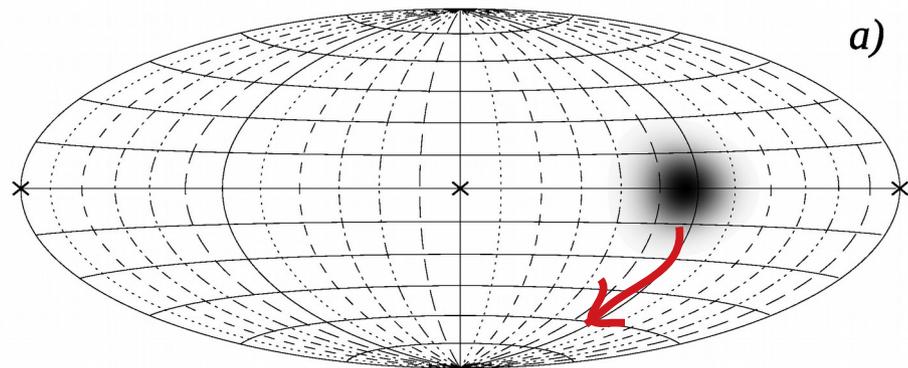
(orthogonal polarization = opposite azimuth)

PA = polarization angle

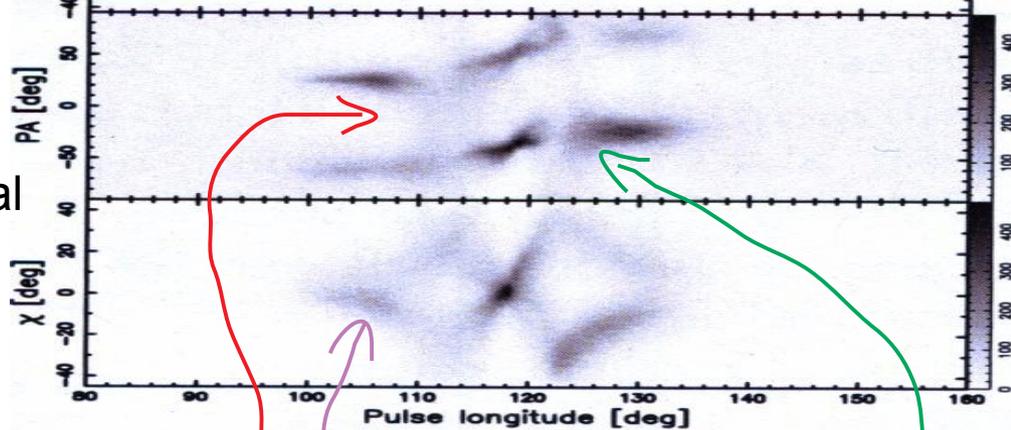


## Passage of polarization state near the pole of Poincare sphere (pure-V pole):

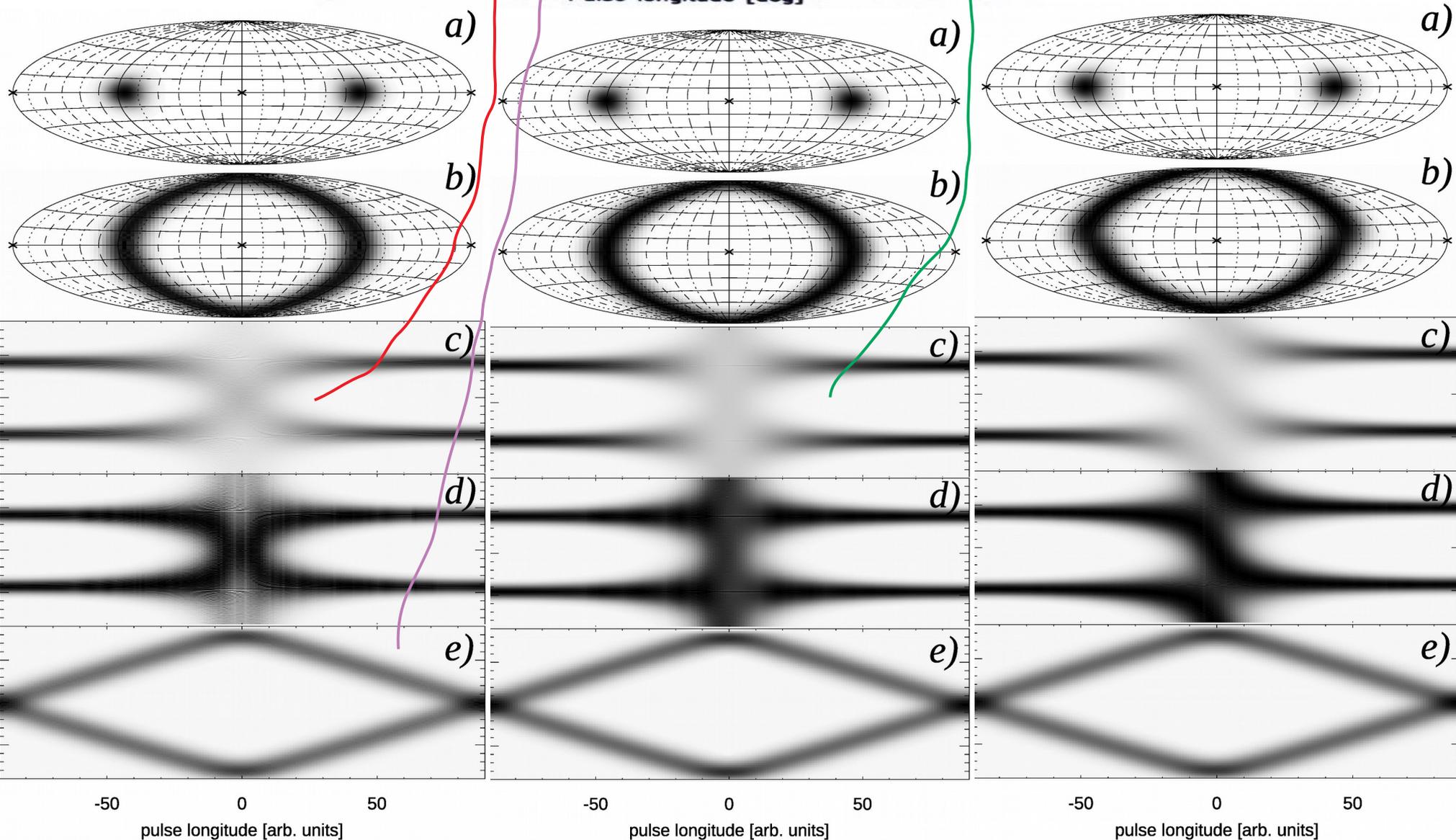
1. Orthogonal PA transition without mode change
2. Same polarization smeared at all PAs (at all azimuths)
3. Oppositely directed projections of flux ('horns') due to flux passing on the other side of pole
4. PA curve turn opposite on opposite sides of V pole



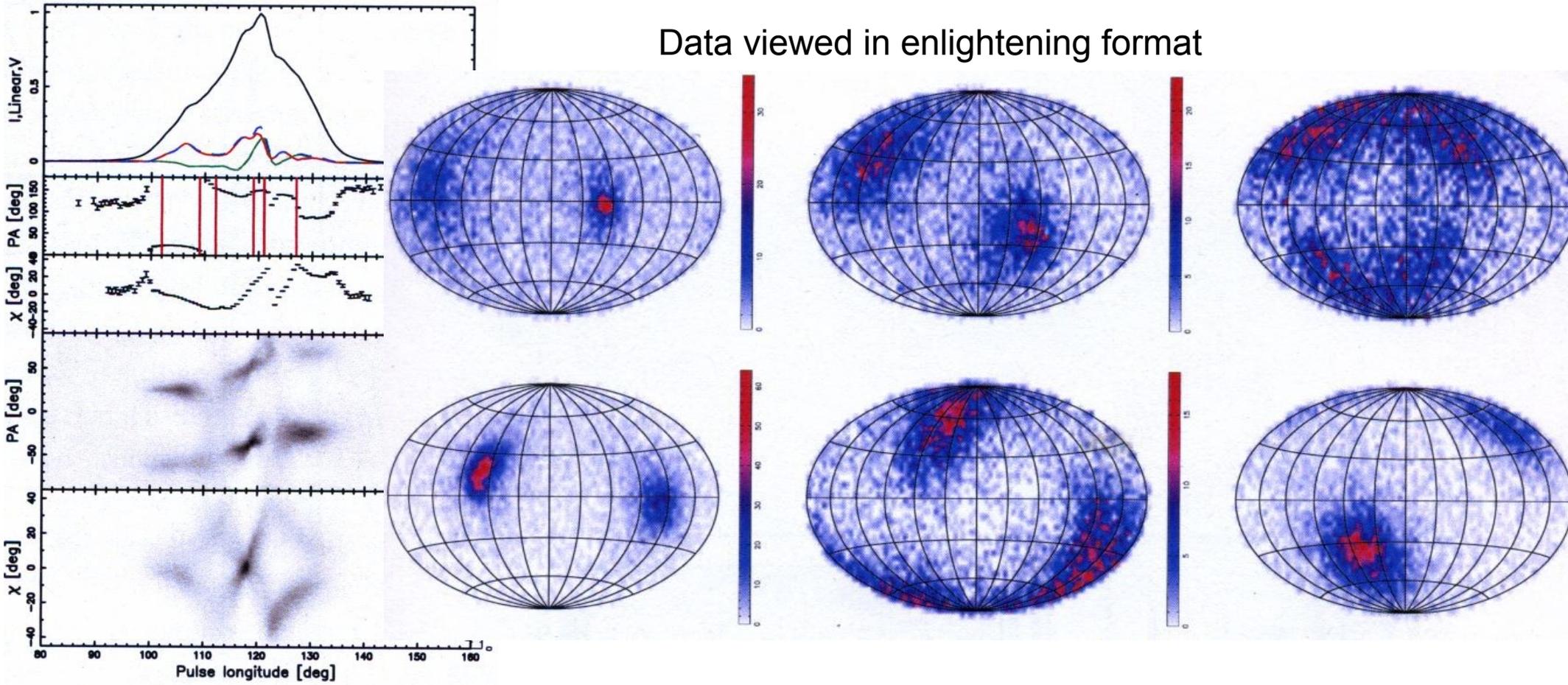
Two modes  
not precisely orthogonal



Ilie 2019



# Data viewed in enlightening format



Parkes, J1456, Ilie 2019 (PhD thesis)

## Conclusions

Polarization state follows **off-equatorial motion** (eg. meridional) on the P. sphere

(plus the azimuthal RVM motion)

**Single mode (single flux patch on P. sphere) can produce two** orthogonal 'modes' on the longitude-PA diagrams (because of the V pole passage the radiative flux makes transition between orthogonal PA tracks)

There are **two types of orthogonal jumps** of polarization modes

Radiative power flows between the PA tracks

=> single RVM curve can follow both strong and weak PA track in different parts of profile

=> to isolate orthogonal polarization modes, patches on P. sphere must be isolated (not the PA tracks on the longitude-PA diagram)

Large part of the complexity understood geometrically:

- coherent circularization with artifacts of pole passage
- noncoherent superposition of orthogonal modes
- RVM

What is the physics of pulsar polarization?

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