Coherent effects in radio pulsar polarization

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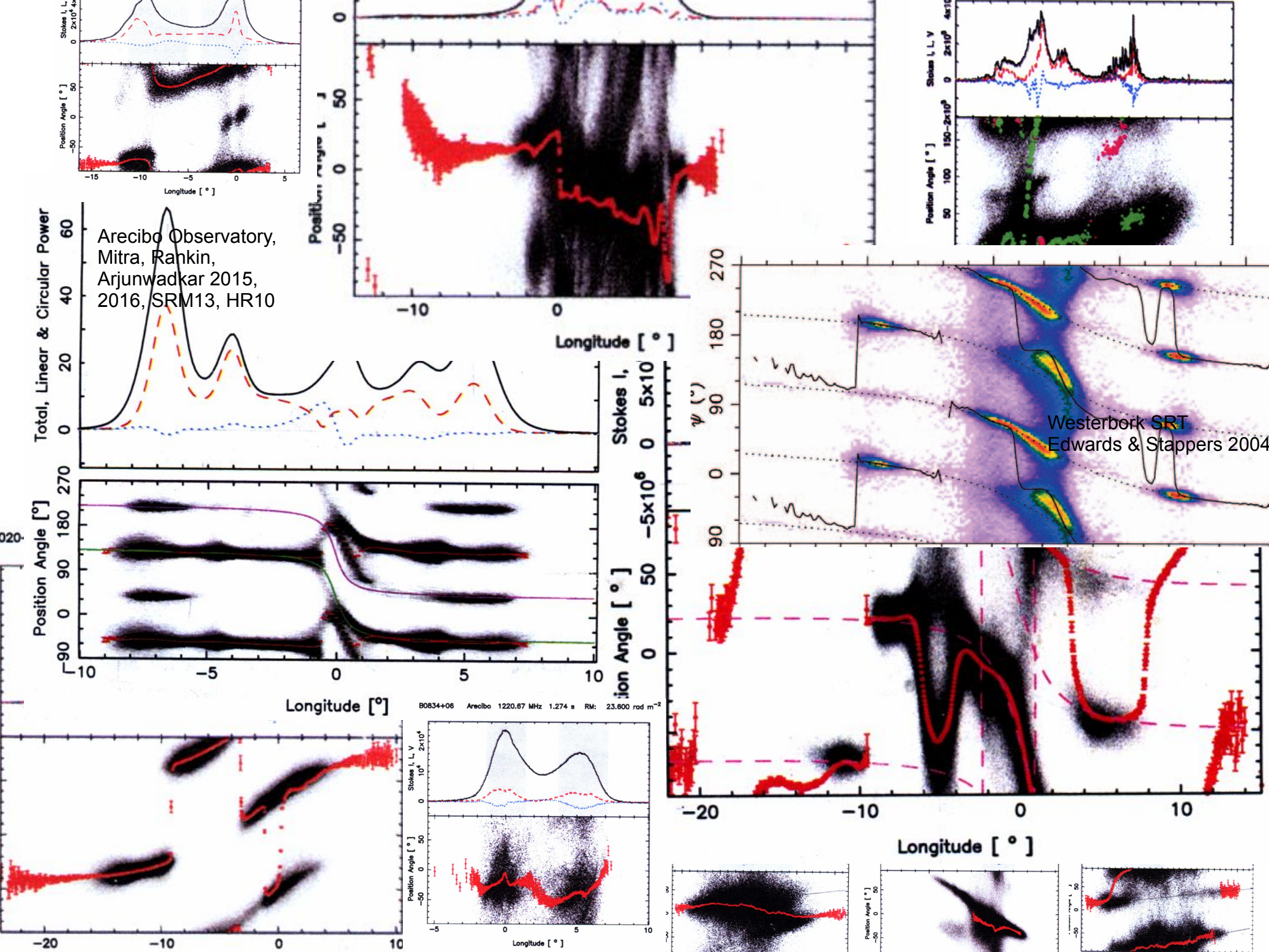

Arecibo Observatory,
Mitra, Rankin,
Arjunwadkar 2015,
2016, SRM13, HR10
Westerbork SRT
Edwards & Stappers 2004
Total, Linear & Circular Power
Position Angle [°]
Longitude [°]
Longitude [°]
Stokes I, L, V
Position Angle [°]
B0834+06 Arecibo 1220.67 MHz 1.274 s RM: 23.600 rad m^{-2}

Coherent emission of two modes and V in strong B improbable

Possibly **mode coupling at polarization limiting radius** Cheng & Ruderman 1979

Mode leaking due to growing scale of intermodal beating
(large w.r.t. scale of medium non-uniformity)

Solution of evolution equation for plasma-wave system necessary

Lyubarsky & Petrova 1999 – approximate analytical estimates:

constant handedness, symmetrical V/I, or
constant V (and handedness)

Wang, Lai & Han 2010 – specific numerical results:

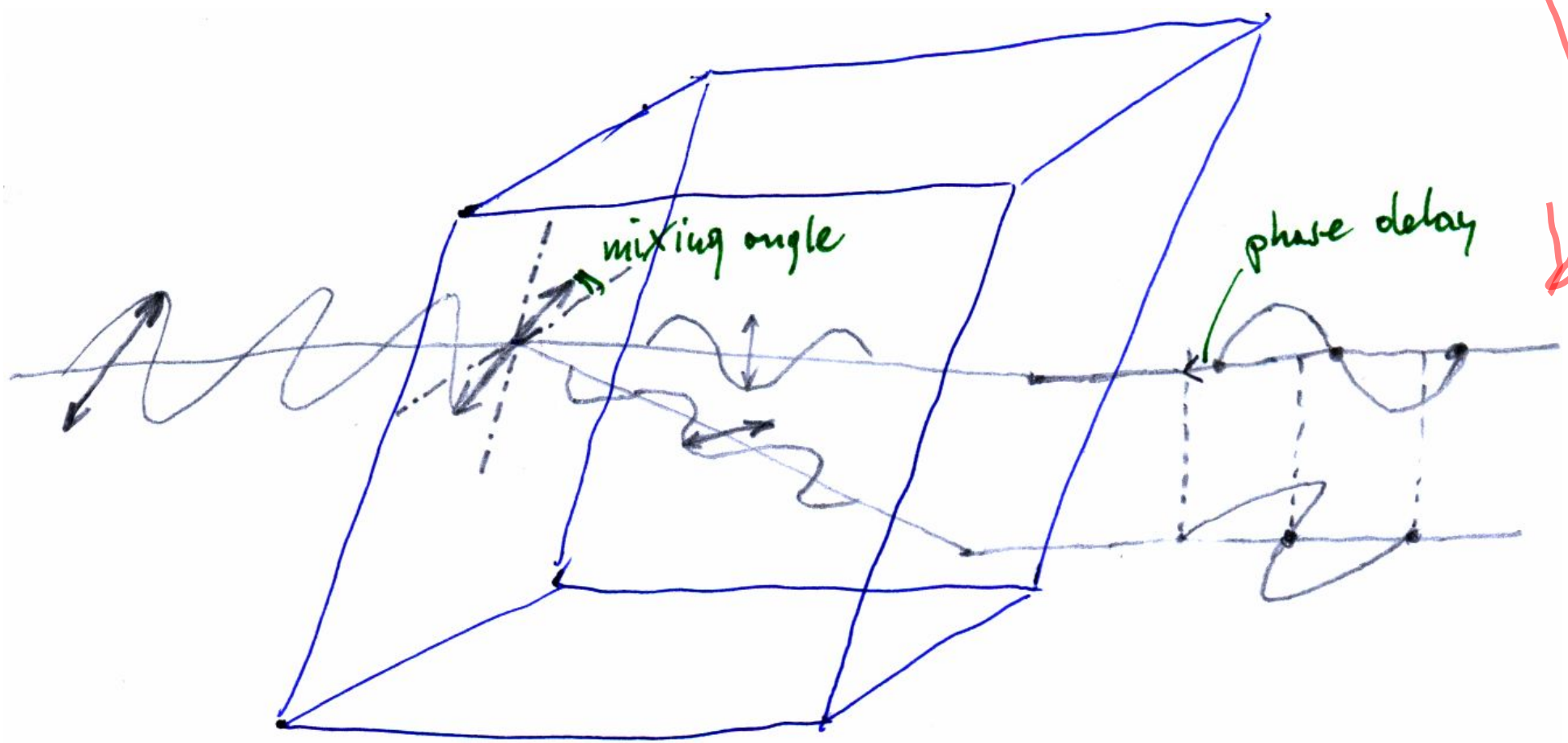
one max-V OPM jump at specific viewing angle

First principle results:
- rough (analytical)
- specific (numerical)

Impressive calculi but results bear vague resemblance to the observed polarized profiles

Empirical way: addition (superposition) of OPMs
- noncoherent, selected longitudes, McKinnon 2003, Melrose et al. 2006
- coherent, single longitude, Edwards & Stappers 2004

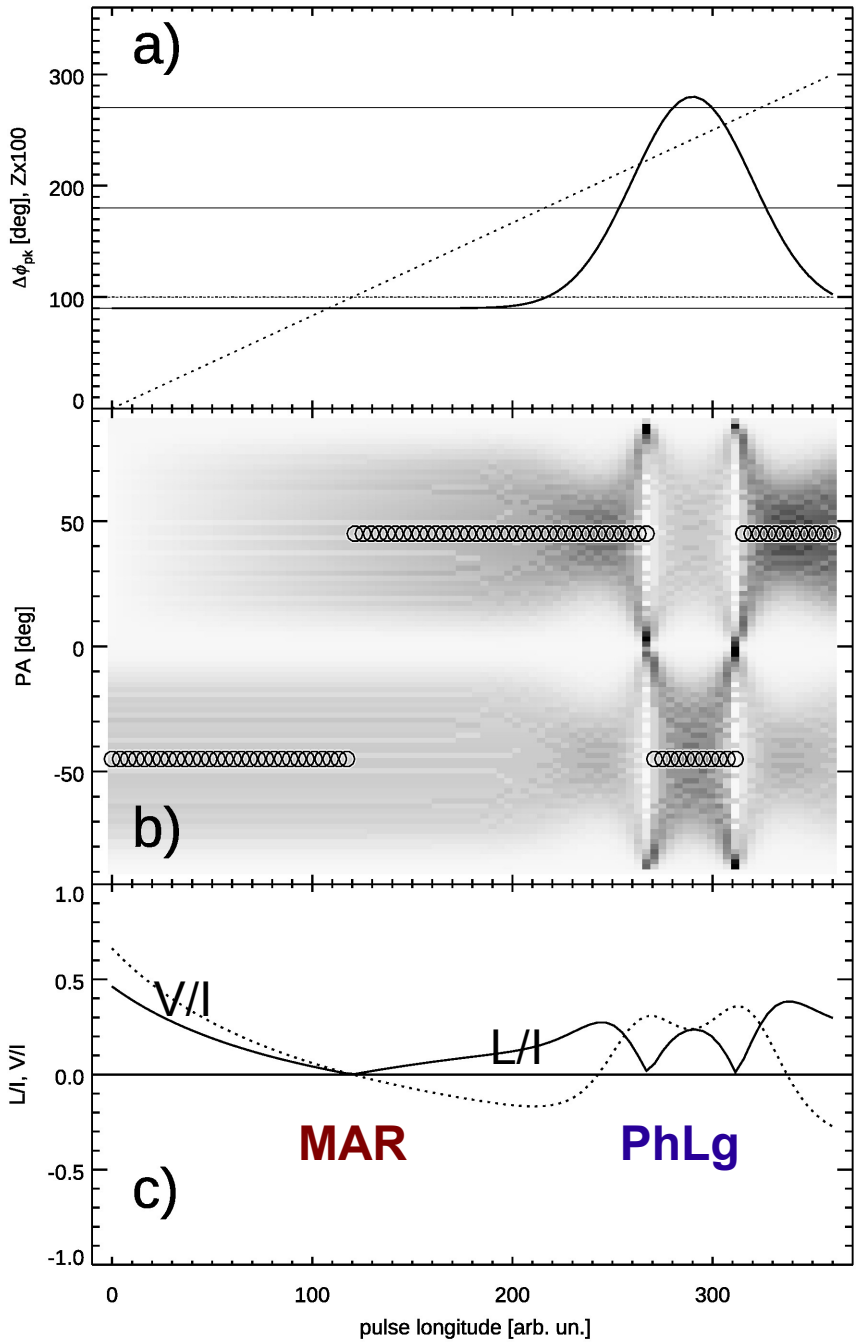
The model: coherent sum of orthogonally polarized waves

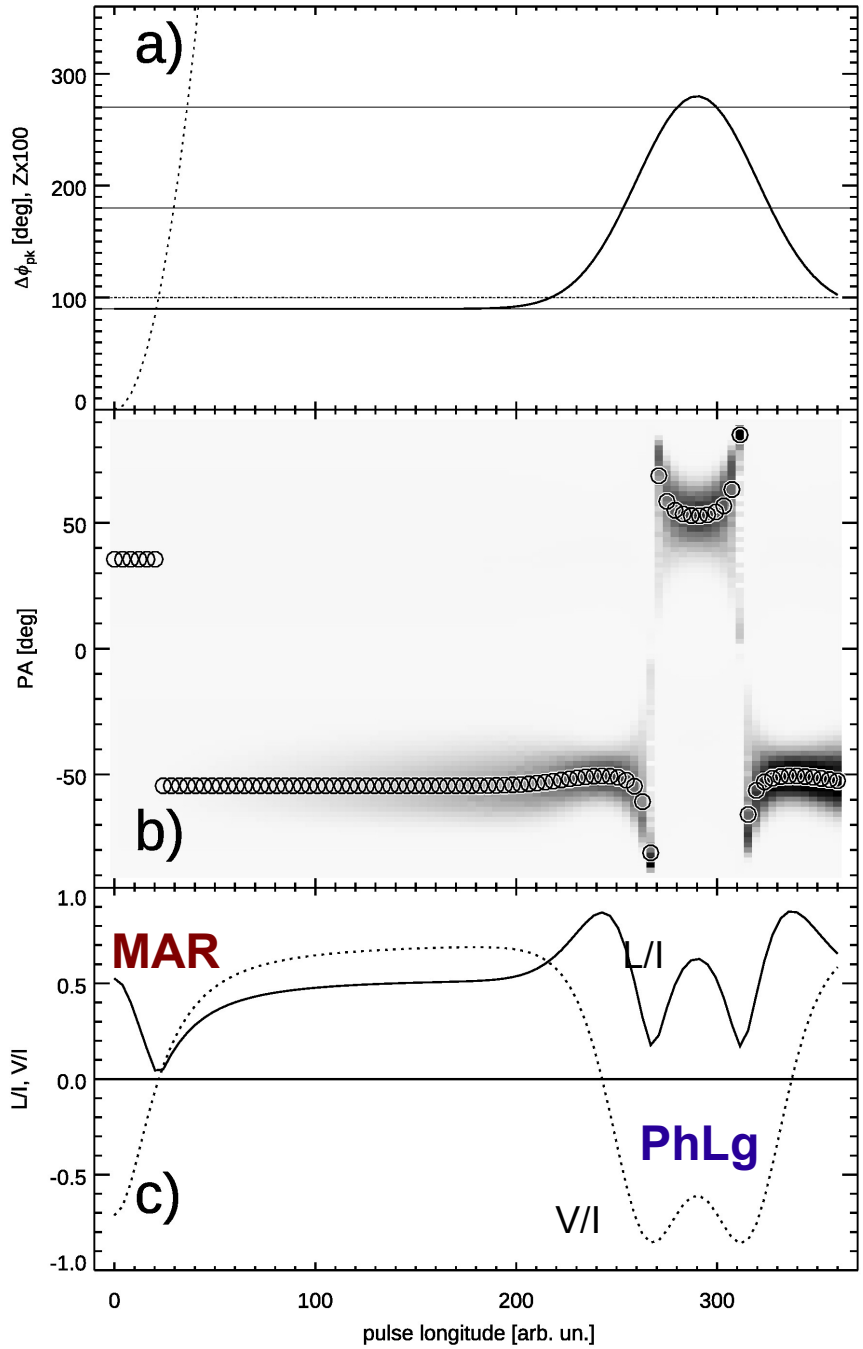


- mode amplitude ratio **MAR** or mixing angle **MA**
- phase lag **PhLg**
- eccentricity of polarization ellipse

+ distribution widths

Two main effects: **MAR**: mode amount ratio (regular OPM jumps)
PhLg: phase lag (quarter-wave plate effects, max-V OPM jumps)



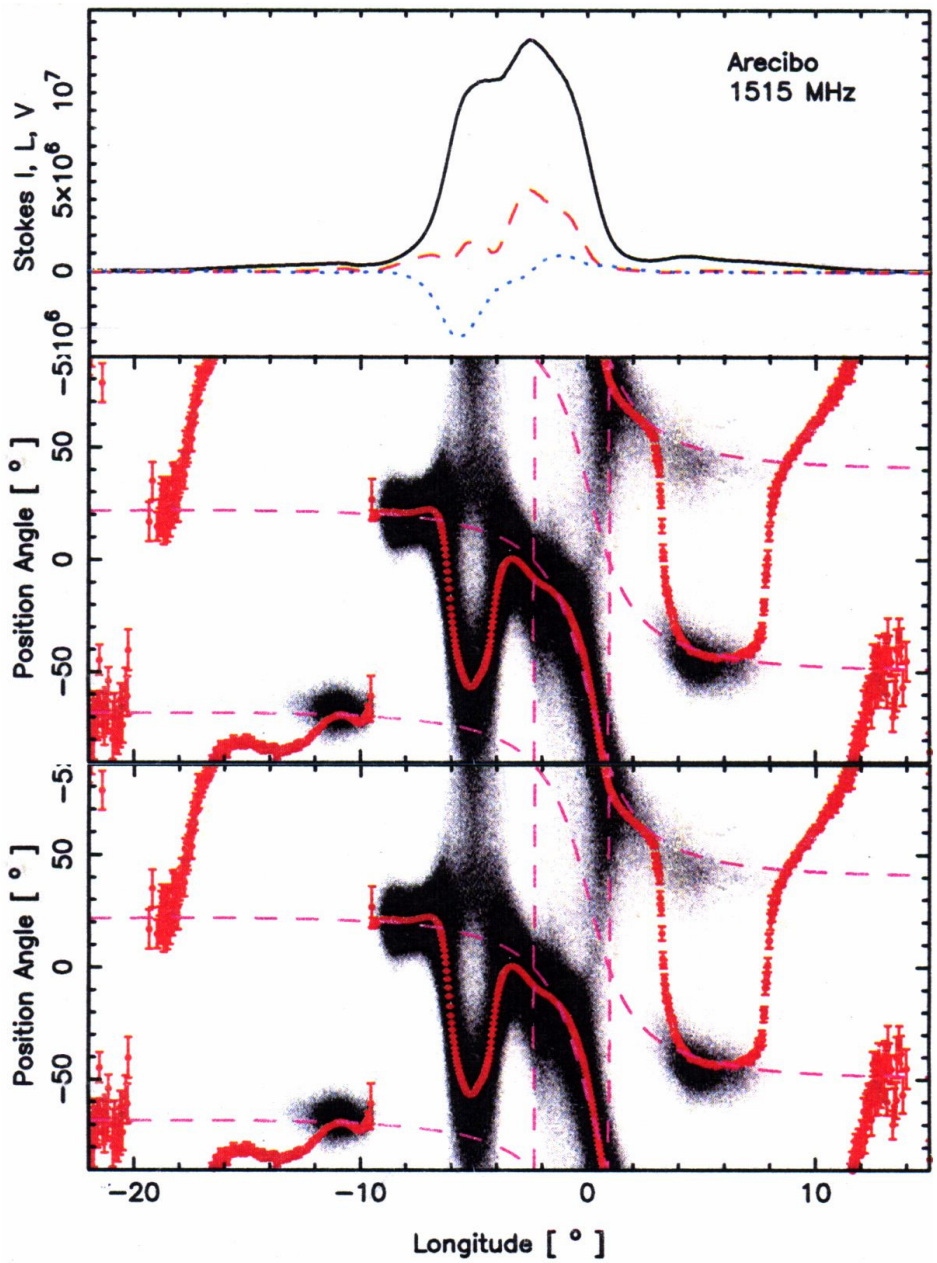


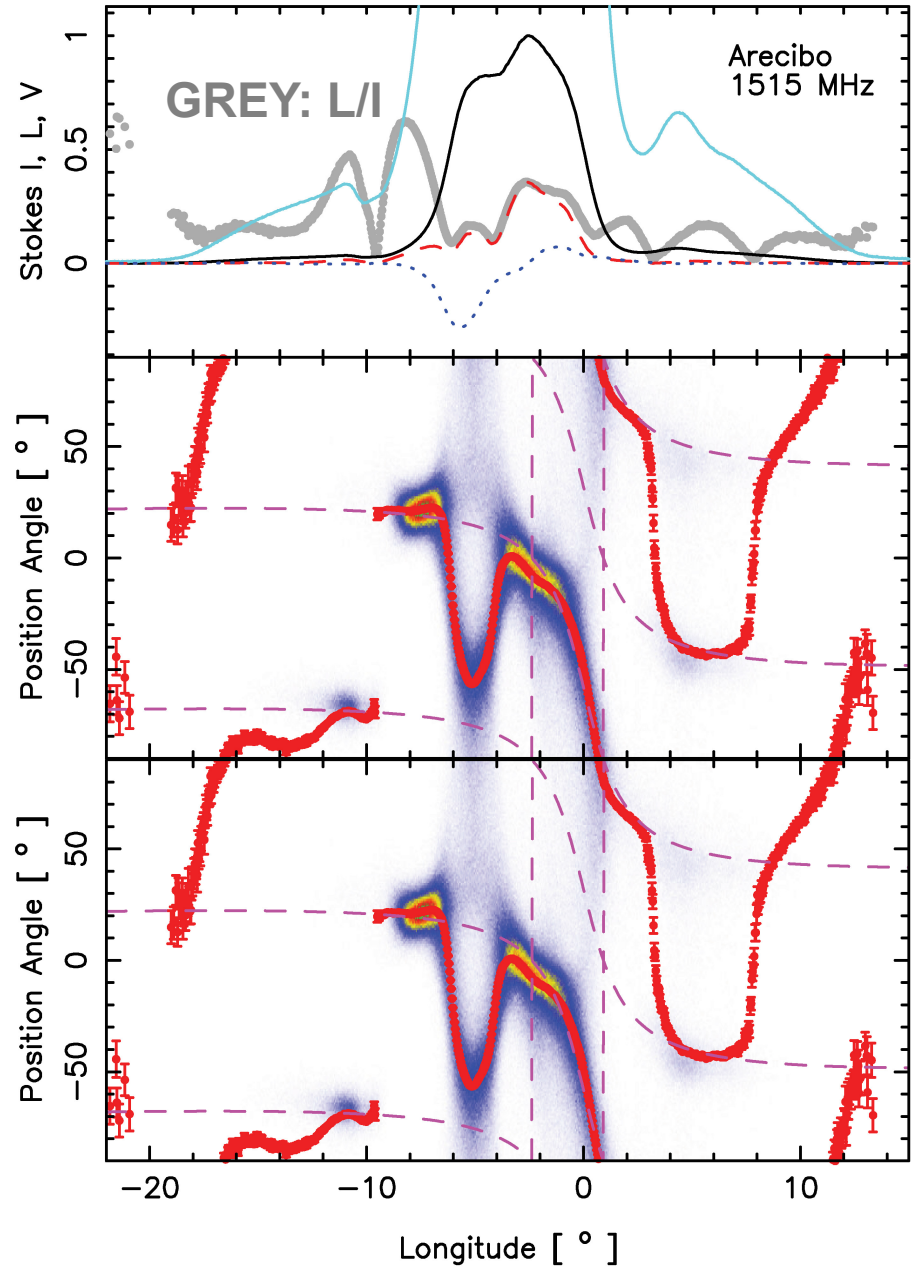
B1933+16:
Arecibo, Mitra et al. 2016

PA loop with `tongue and horns'
+ twin minima in L/I

1.5 GHz

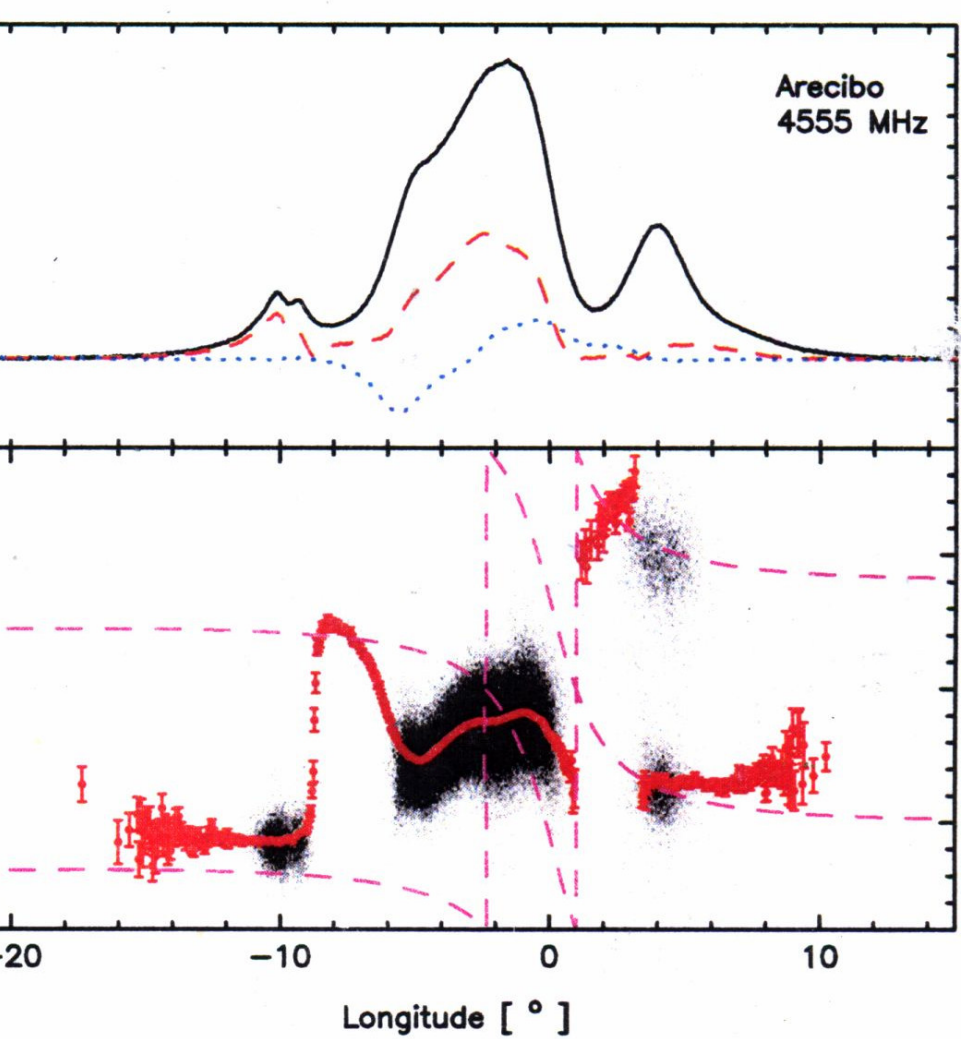
MAR inverted several times

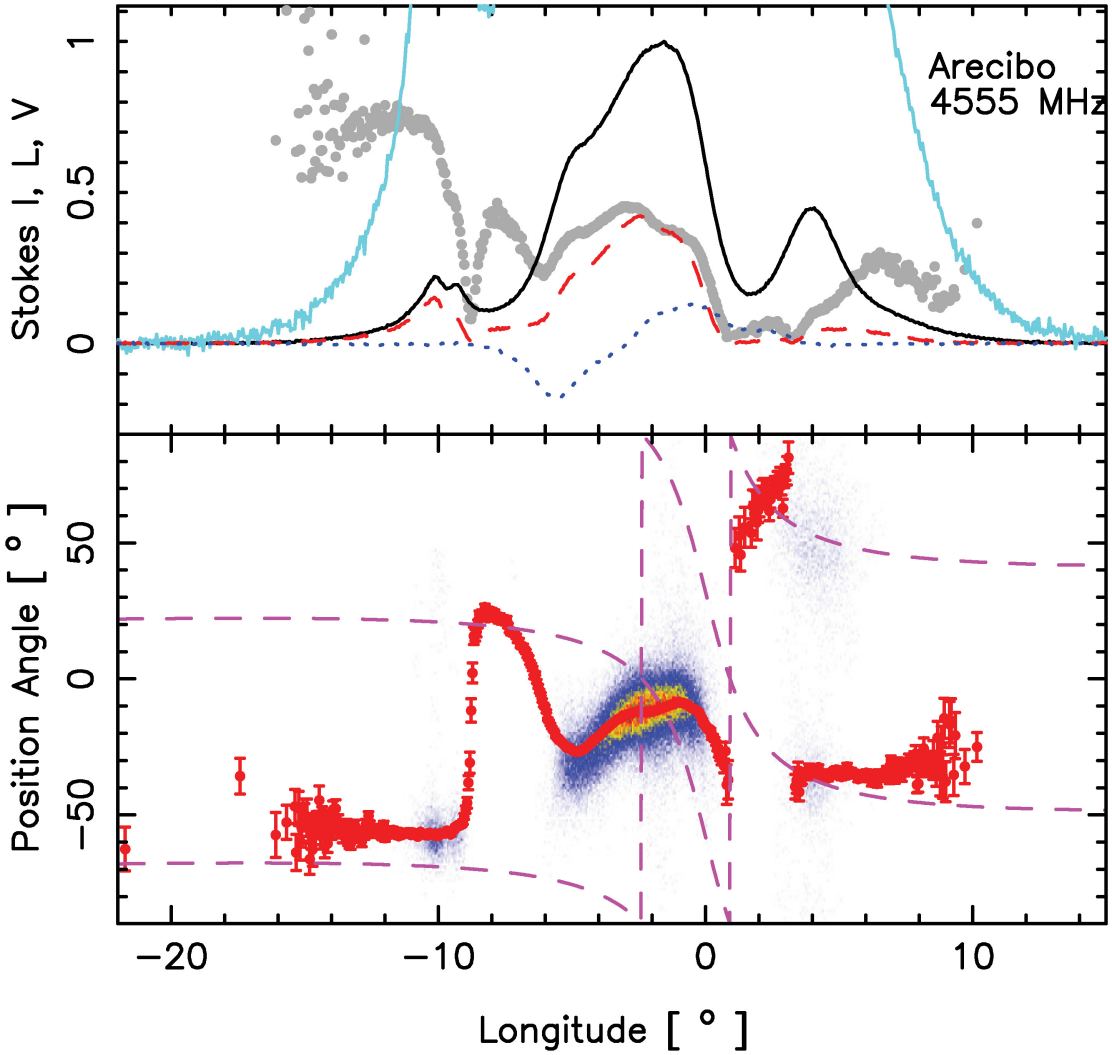




B1933+16: Same feature **4.5 GHz**

No PA bifurcation, U-shaped PA





Mitra et al. 2016

Curse of many parameters:

- mode amount ratio
- phase lag
- eccentricity of modal polarisation ellipse

- 3 widths for their distributions

- parameters for pulse-longitude profiles of thereof

Some of them partially covariant (degenerate), e.g.:

- width of phase lag distribution
- peak position of phase lag distribution

Multiple interpretations possible

=> useful to simultaneously consider:

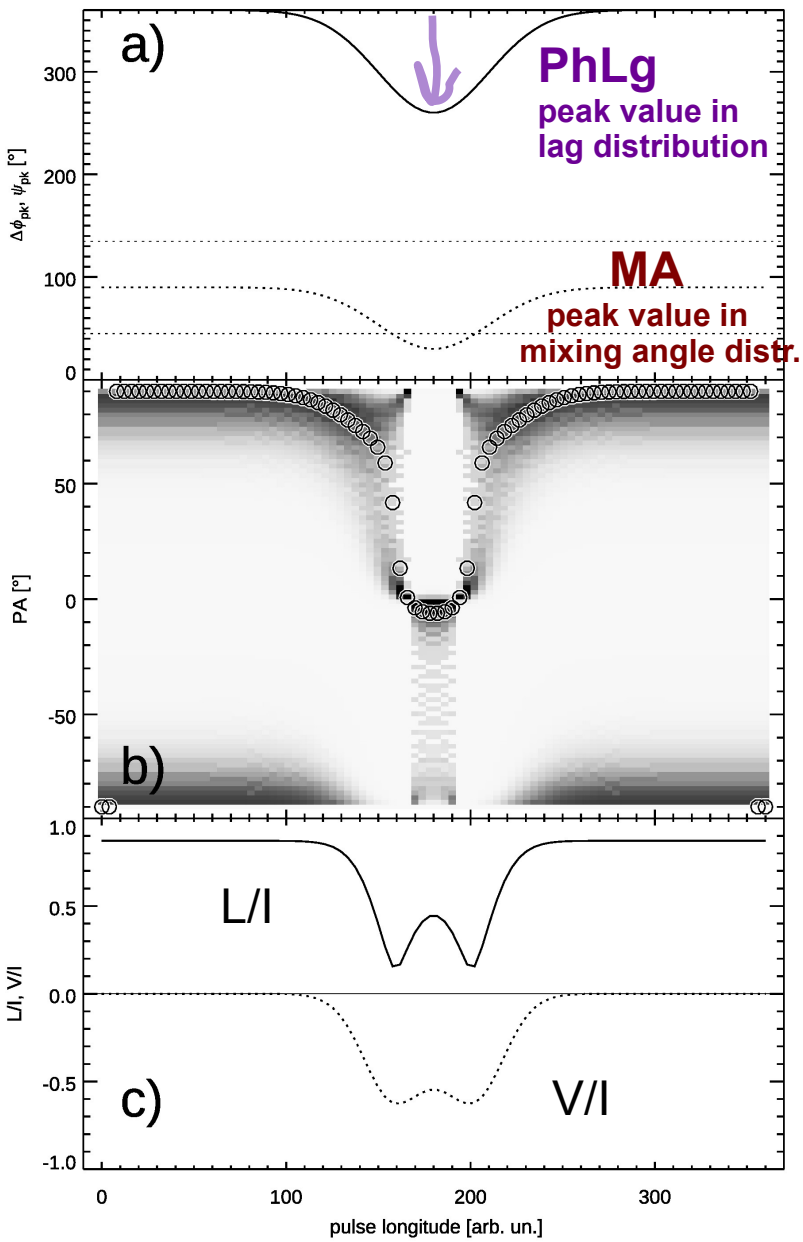
- polarization within a pulse **longitude interval**
- **different frequencies** nu

to break the degeneracy

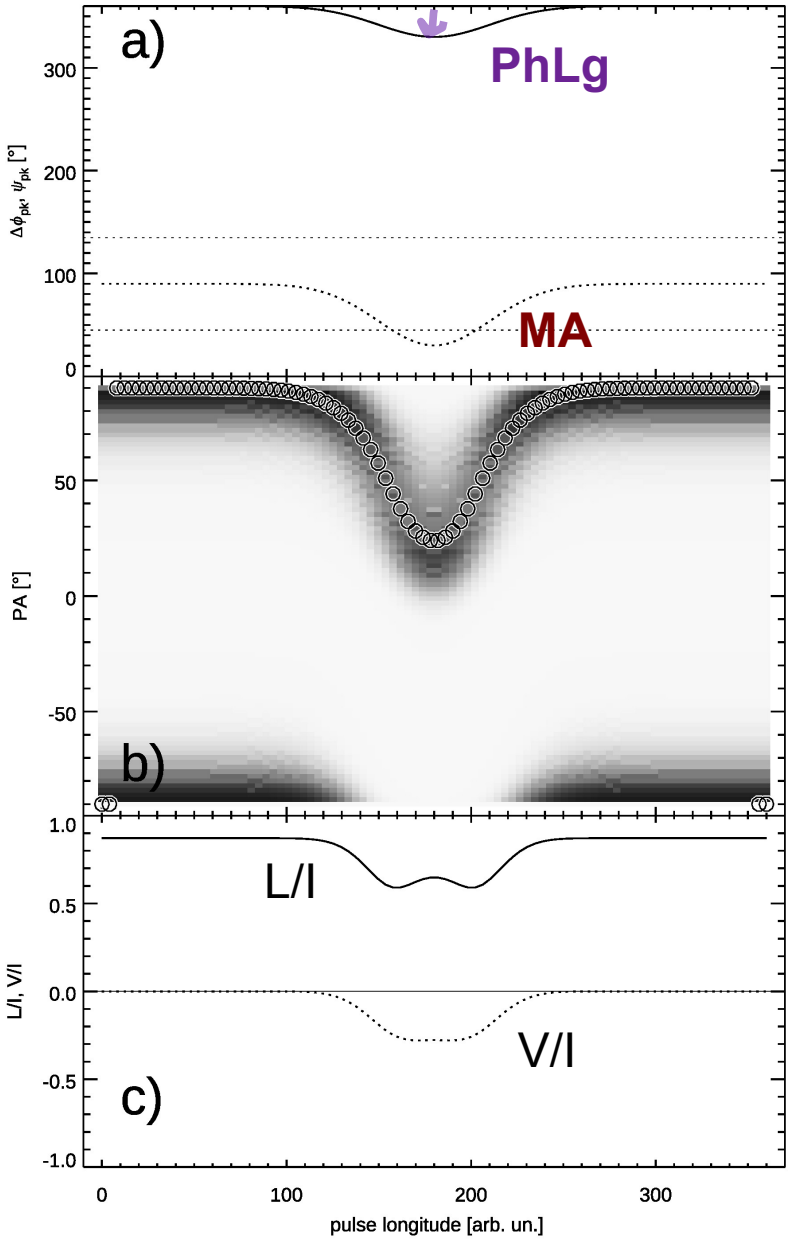
Longitude-dependent mixing angle and phase lag

Phase lag amplitude smaller at high nu

Low nu



High nu



Dyks 2019

Longitude-dependent mixing angle and phase lag

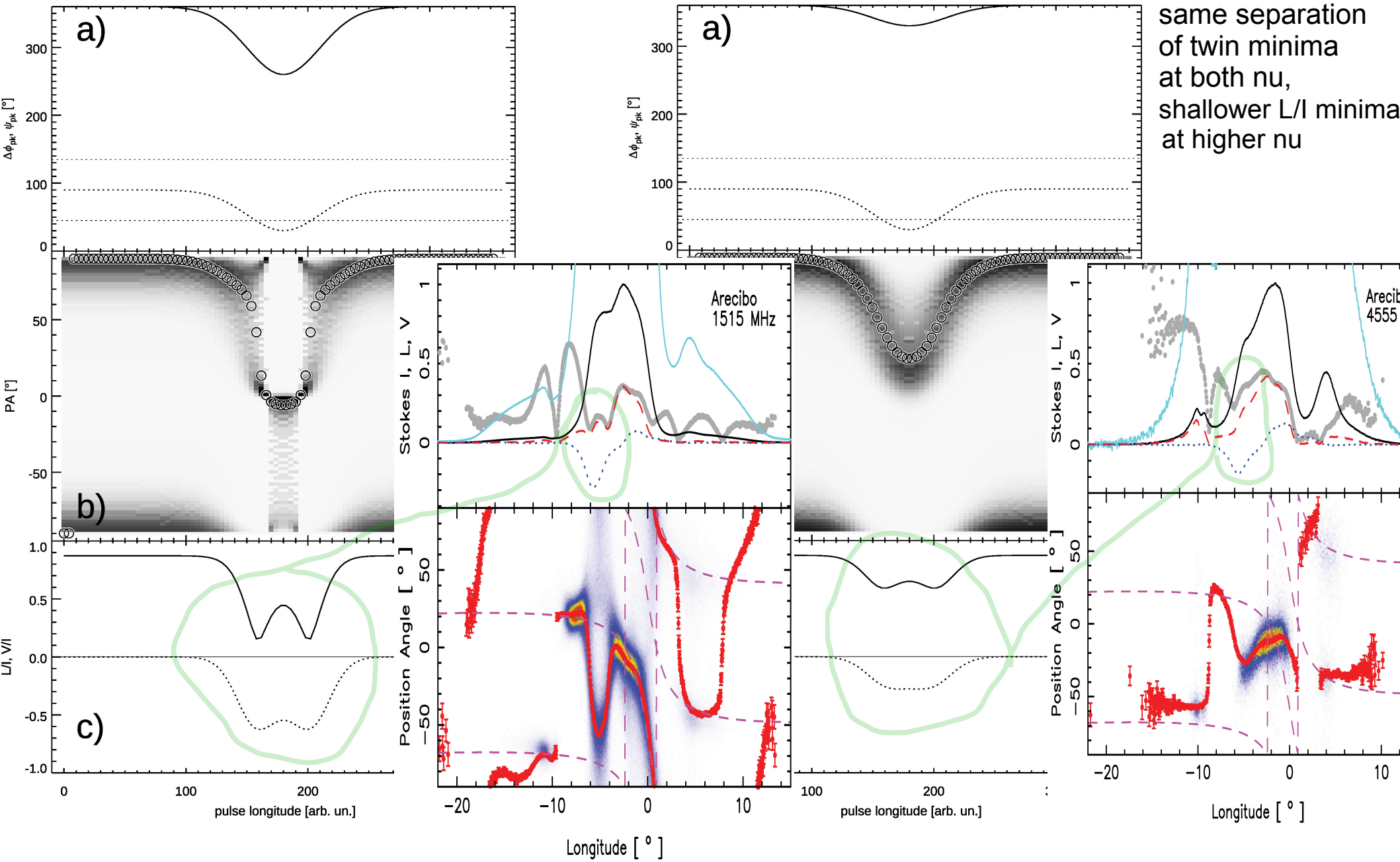
Phase lag amplitude smaller at high nu

Reproduced features:

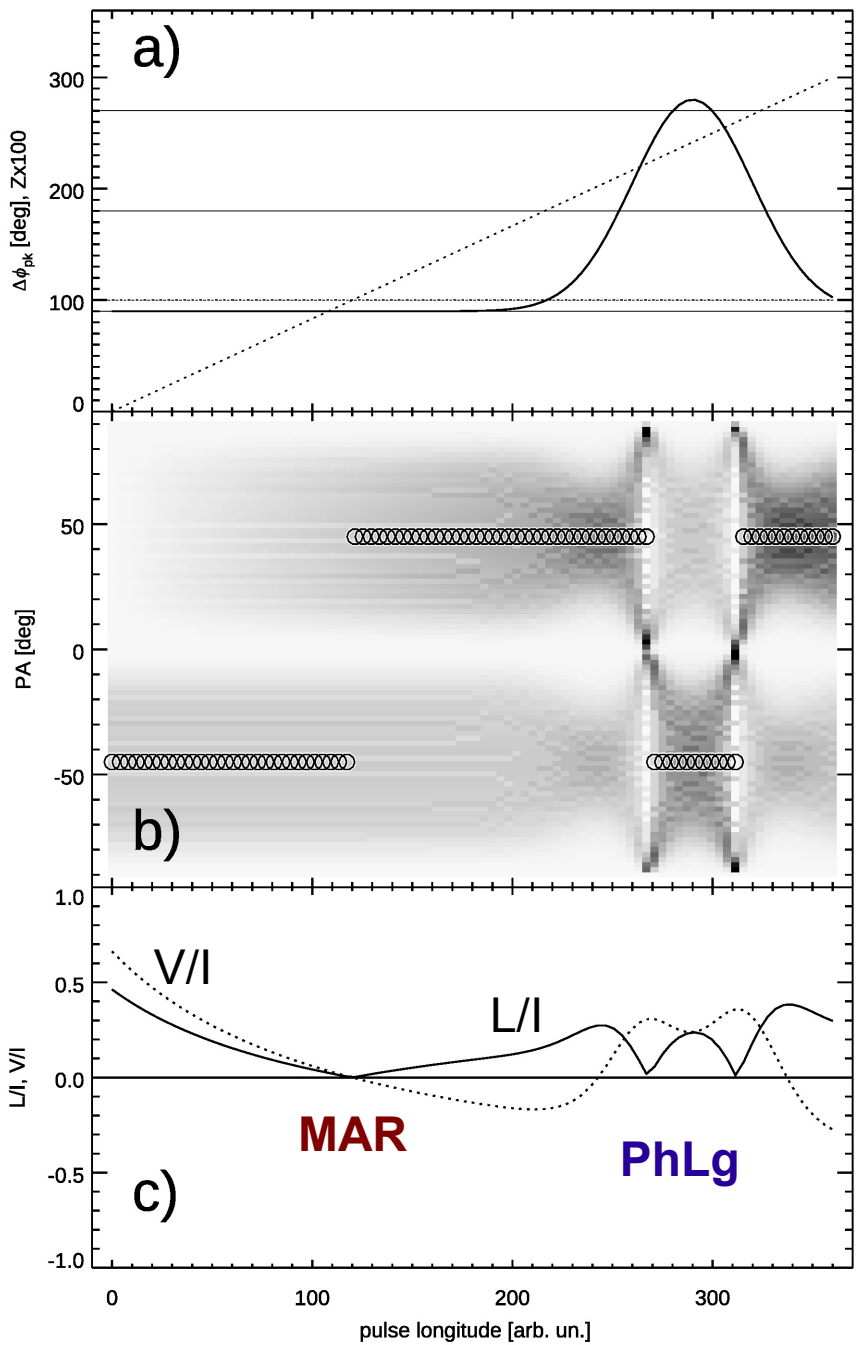
PA Loop/U, twin min. in L/I, single sign V,

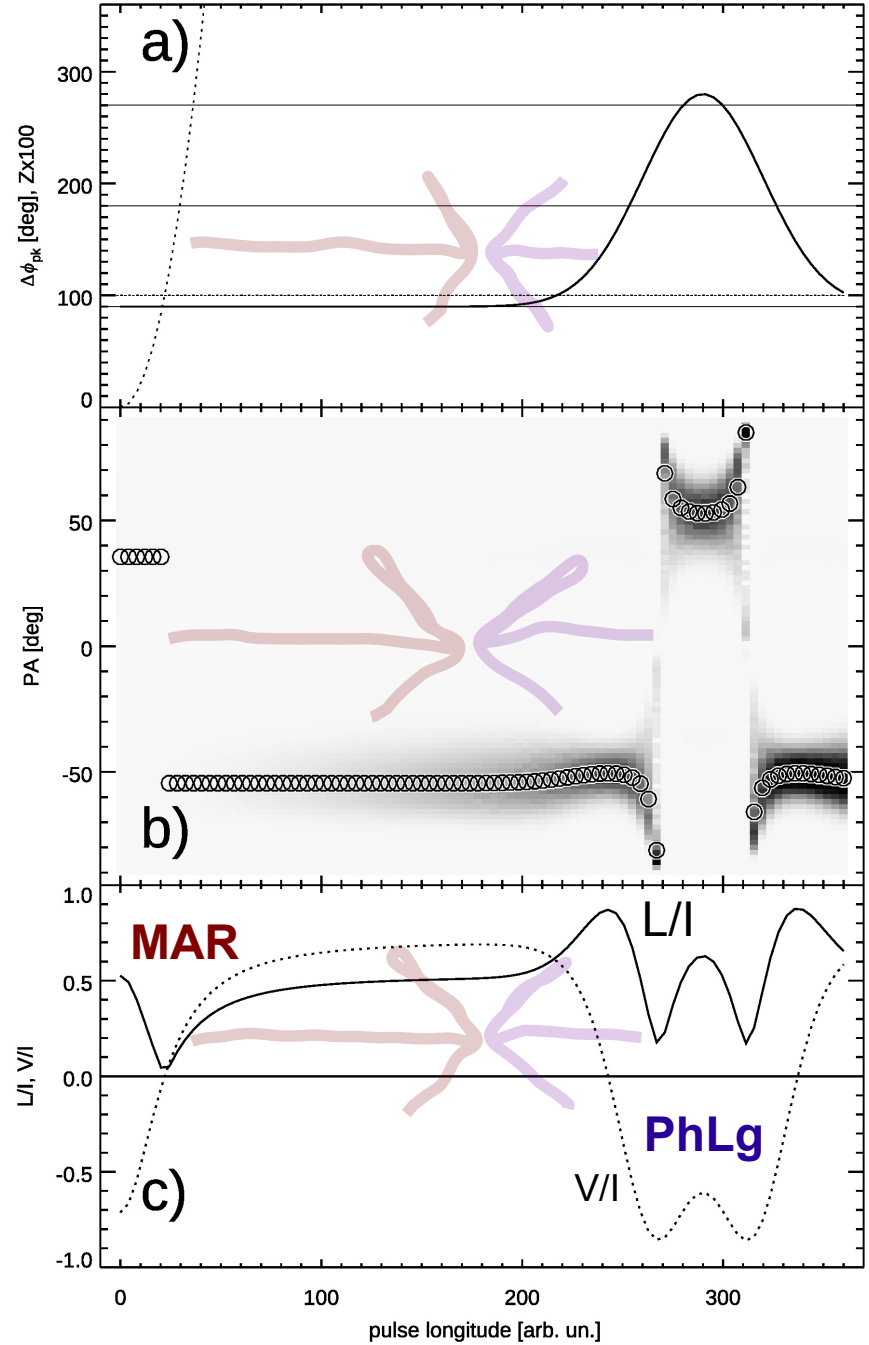
relative amount of L/I and V/I at both nu,

same separation of twin minima at both nu, shallower L/I minima at higher nu

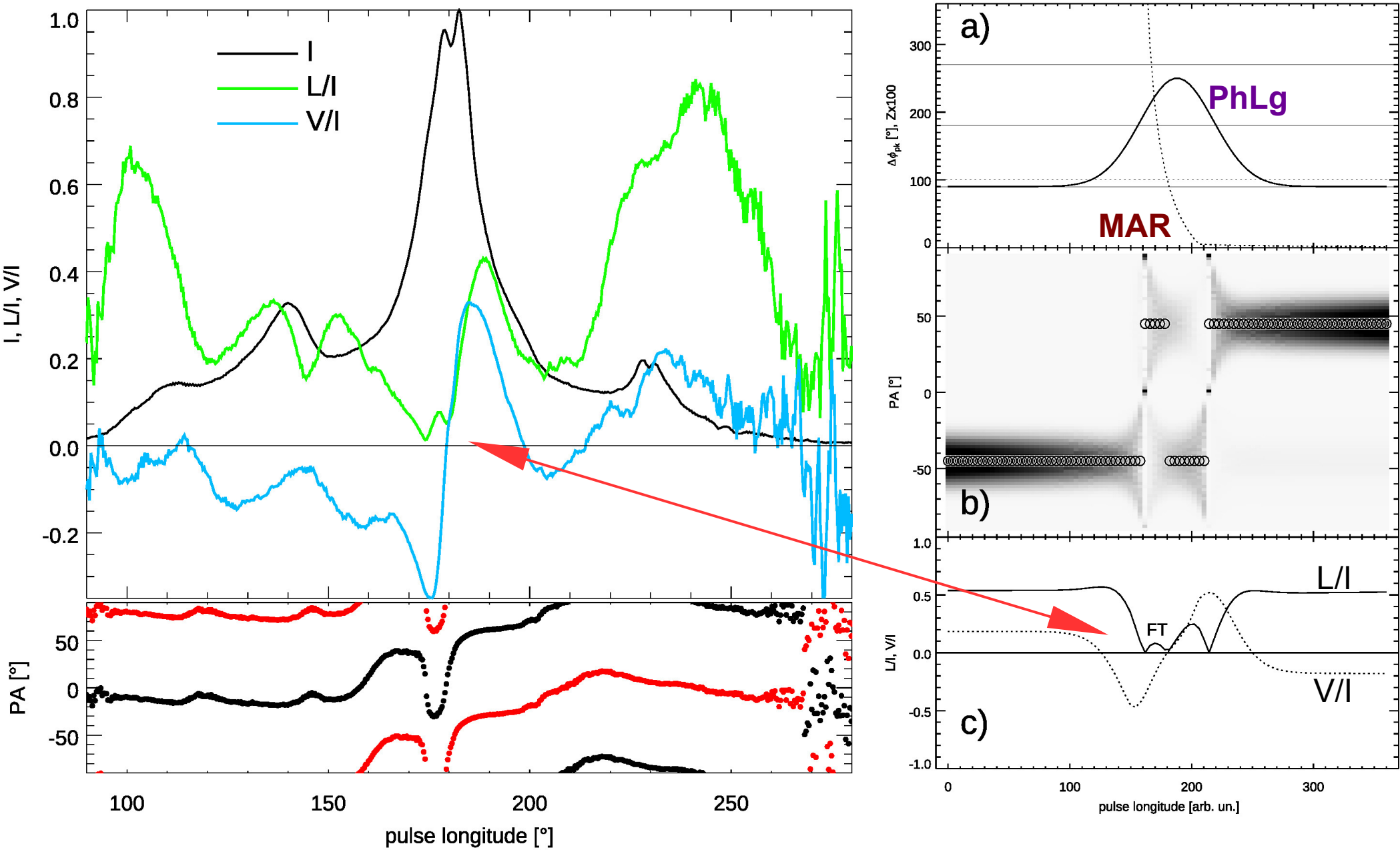


Two main effects: **MAR**: mode amount ratio
PhLg: phase lag





Antisymmetric **MAR** + symmetric **PhLg** (not perfectly aligned)

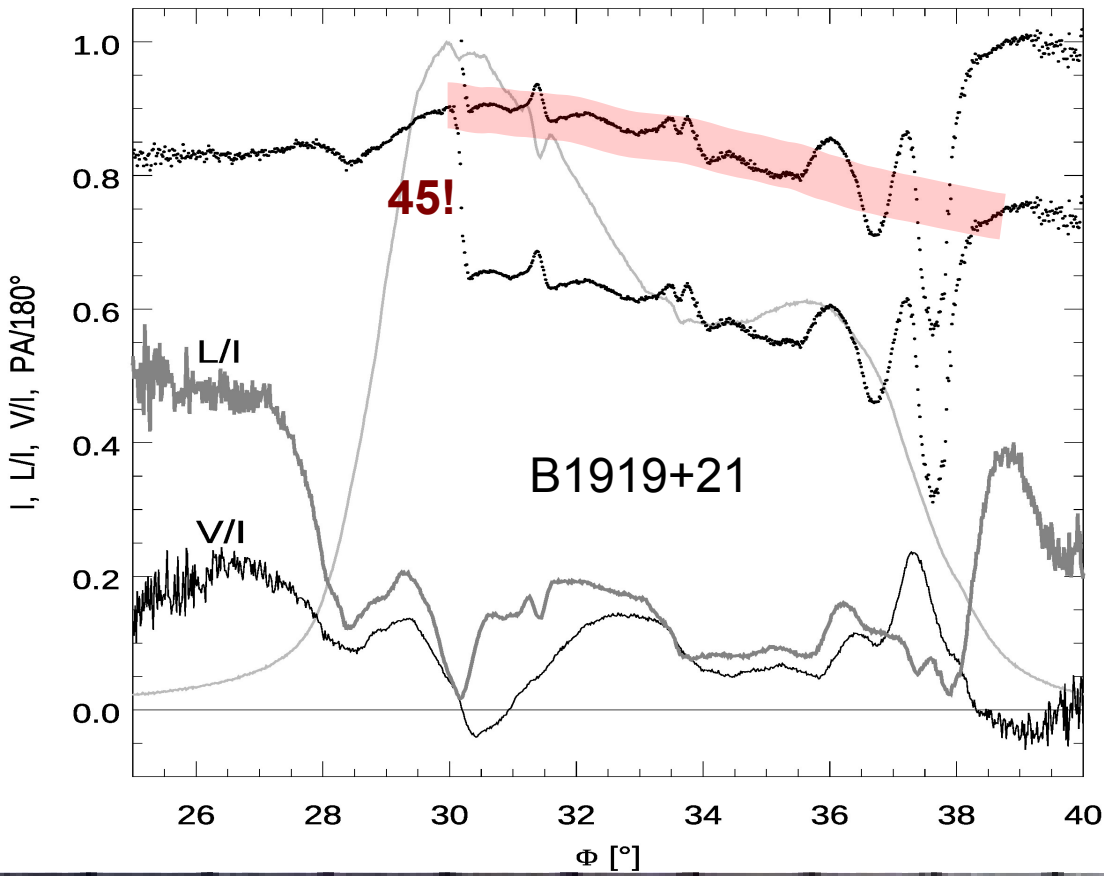


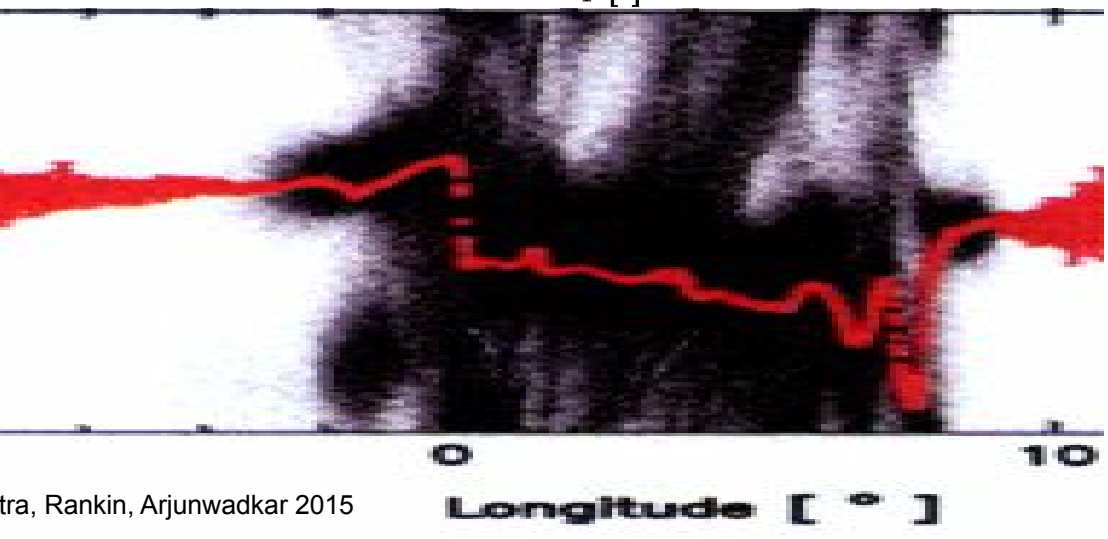
Dyks (2019)

J0437-4715, 660 MHz, Navarro et al. (1997)

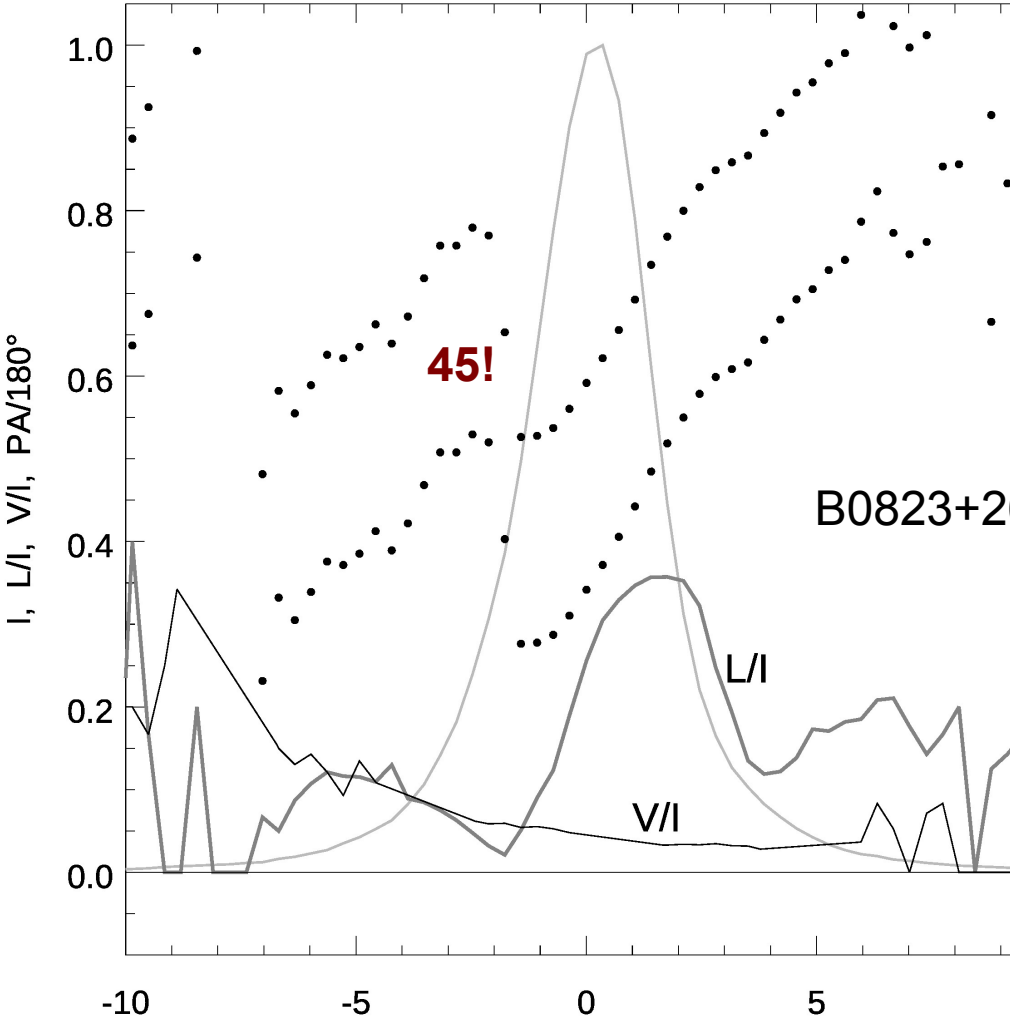
45 deg PA jumps: You have two orthogonal things, either one can dominate, whence the 45 degrees?

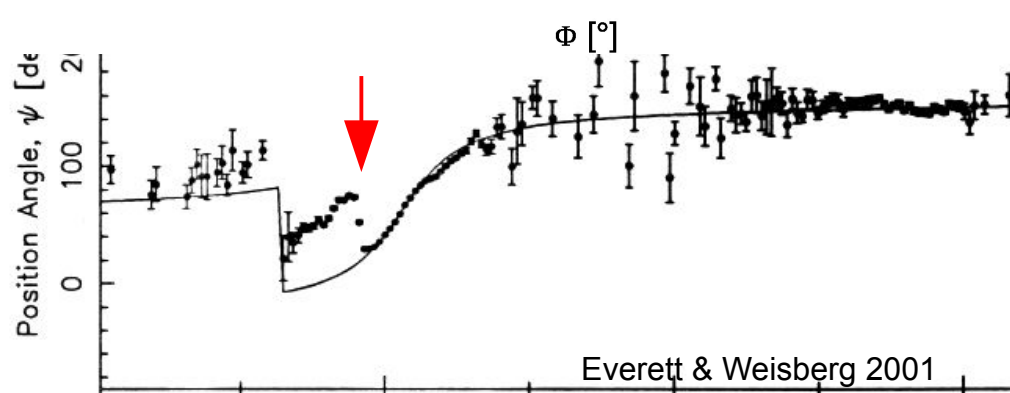
way out: add the modes coherently





tra, Rankin, Arjunwadkar 2015





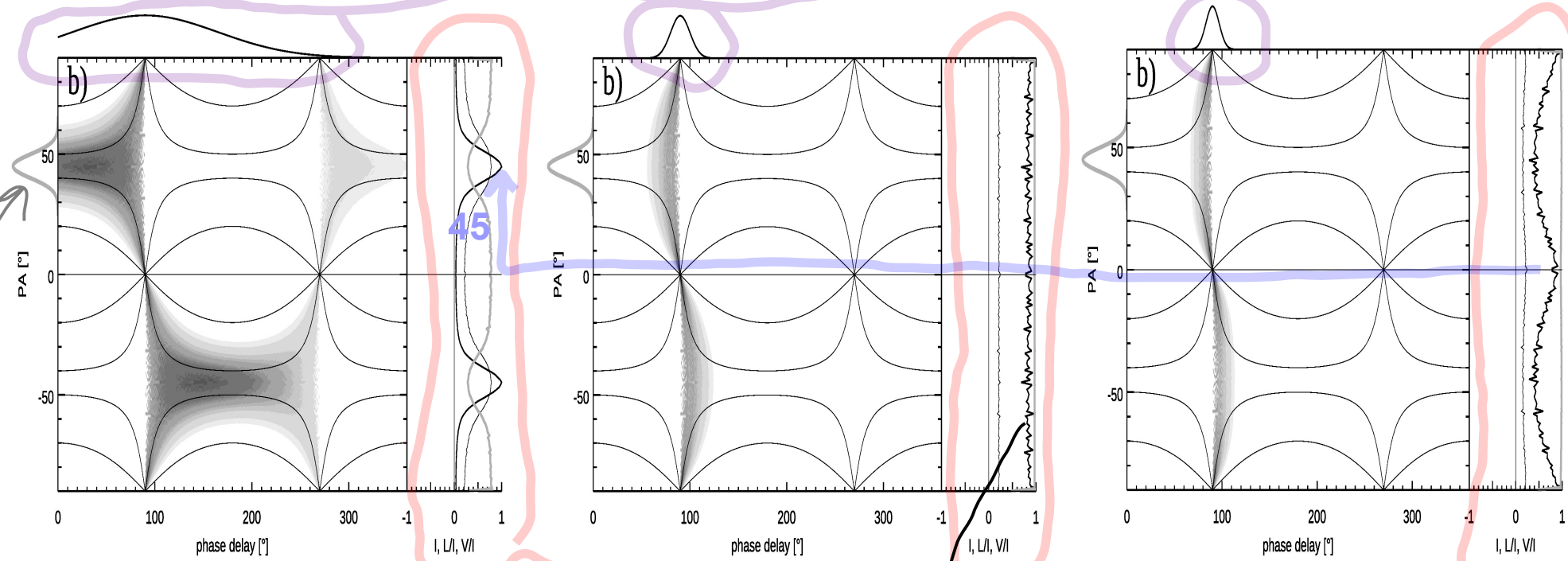
Everett & Weisberg 2001

Narrowing of phase lag distribution

Equal mode amplitudes

Wide phase lag distr.

Narrow lag distr.

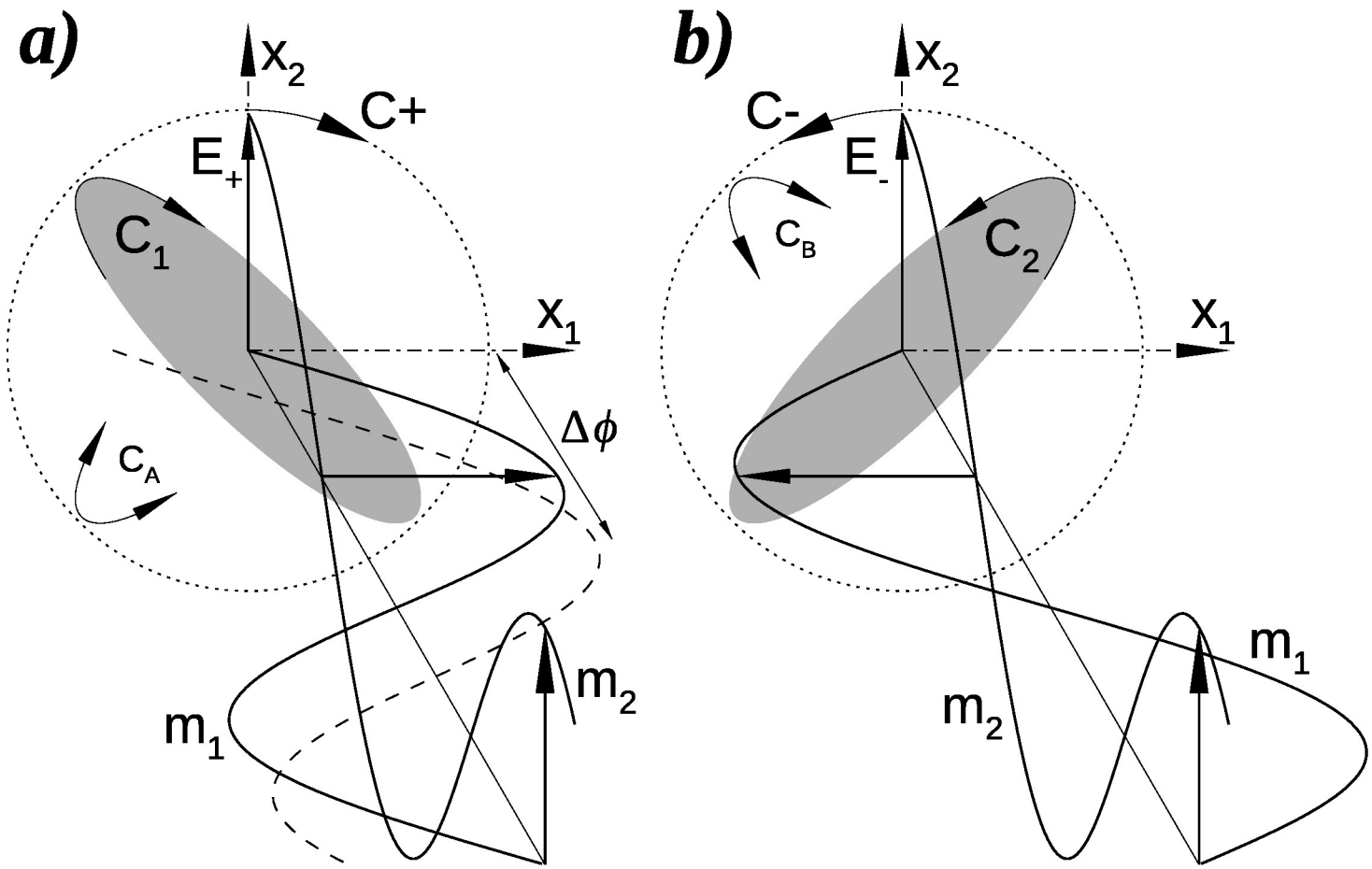


thick solid: PA distr. at fixed longitude

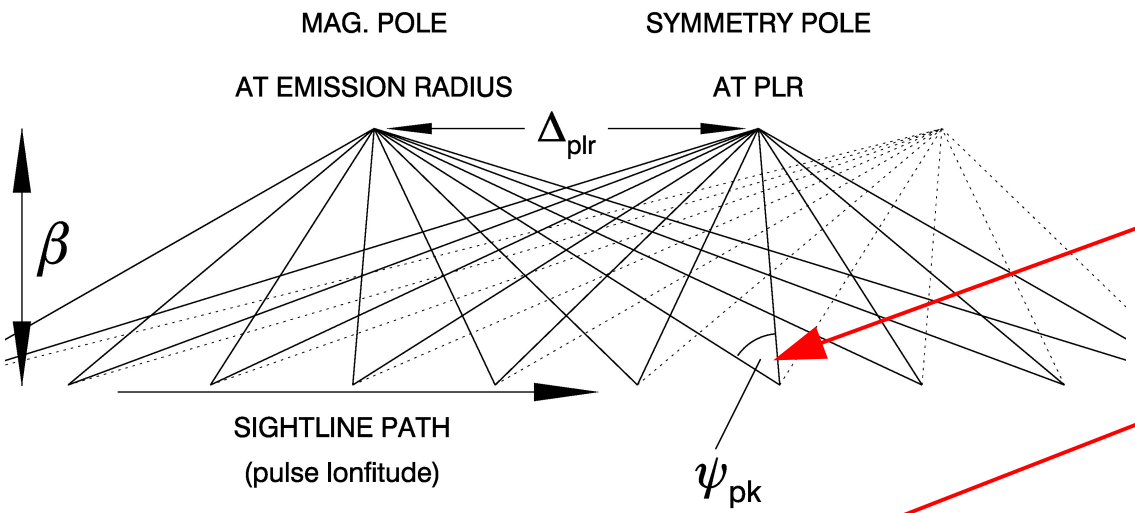
Equal mode amplitudes => mixing angle = 45 deg

Preference for equal amount of modes

Circularly-polarized wave entering linearly birefringent medium

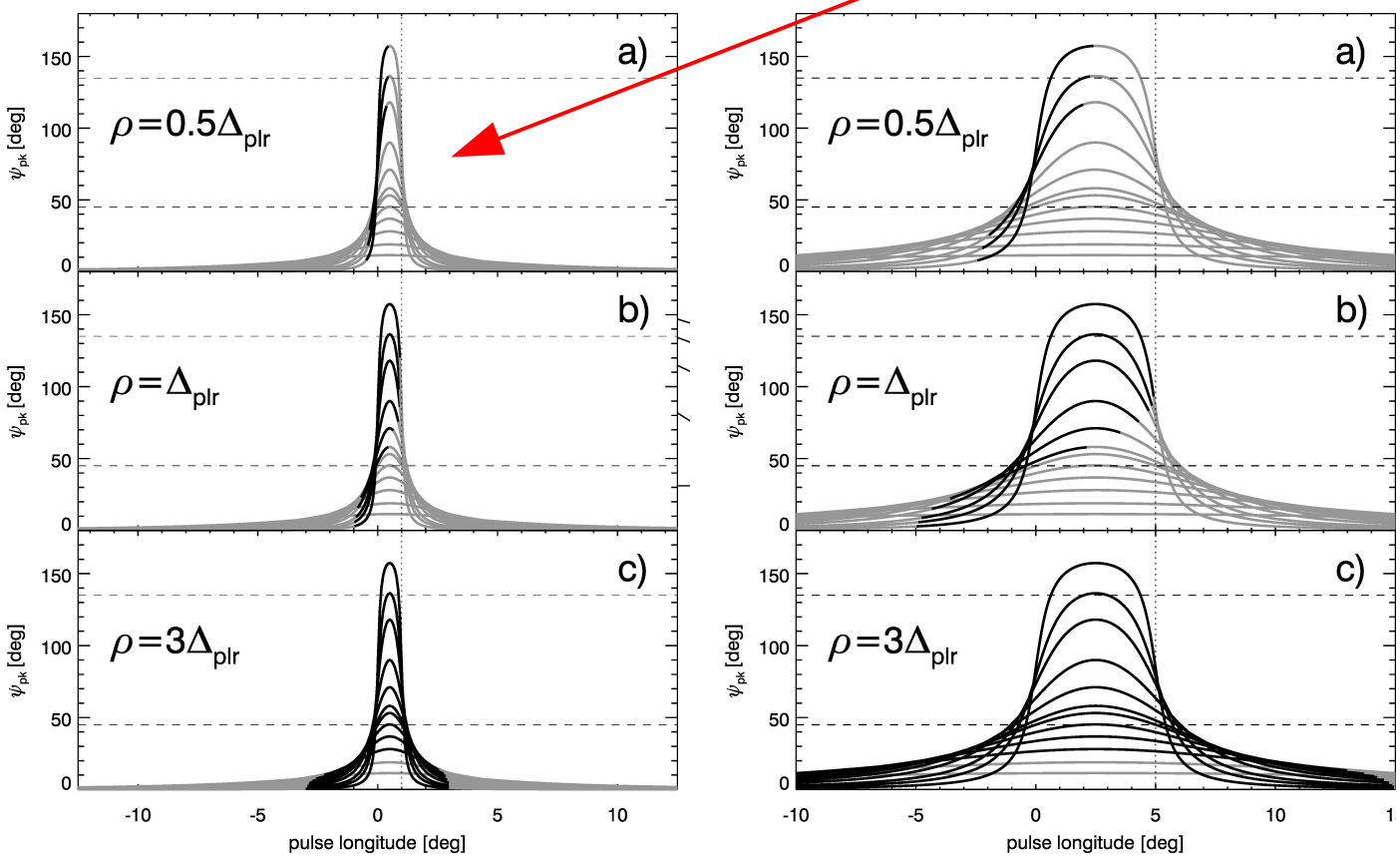


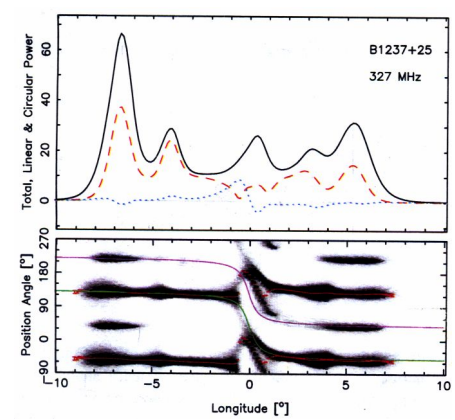
D2019



Mixing angle:

- estimated from the low-r/high-r electron trajectory misalignment
- strong changes in the core region of proflies (for small impact angle)
- hence the core PA distortions eg. in B1237
- high-r "B-field" (electron trajectories) provide the RVM shape





Conclusions

Coherent effects crucial to understand radio pulsar polarization

Phase lag distribution important (+ mode amplitude ratio)

Peculiar/complex polarization effects can be interpreted geometrically

(all polarization components at more than single nu)

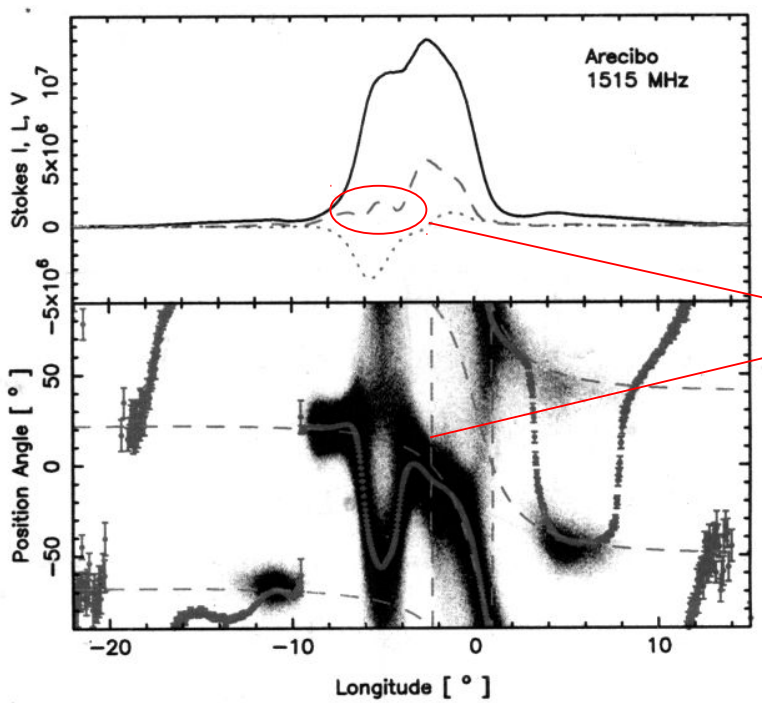
Complex core polarization from both lag-driven and amplitude-driven effects overlapping in the same pulse longitude interval

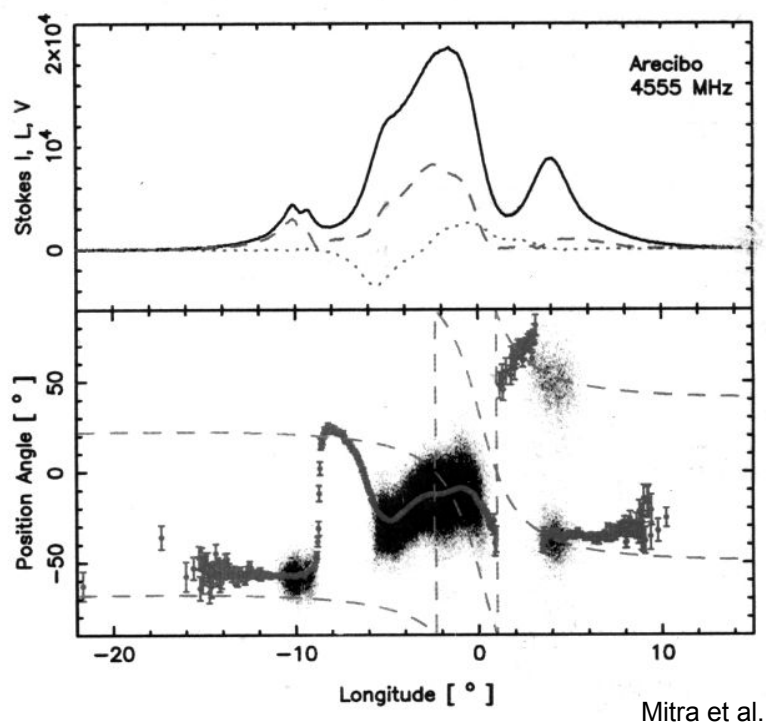
Nu-dependent polarization from phase lag change
(and mode ratio change)

Several parameters, a lot of work to do

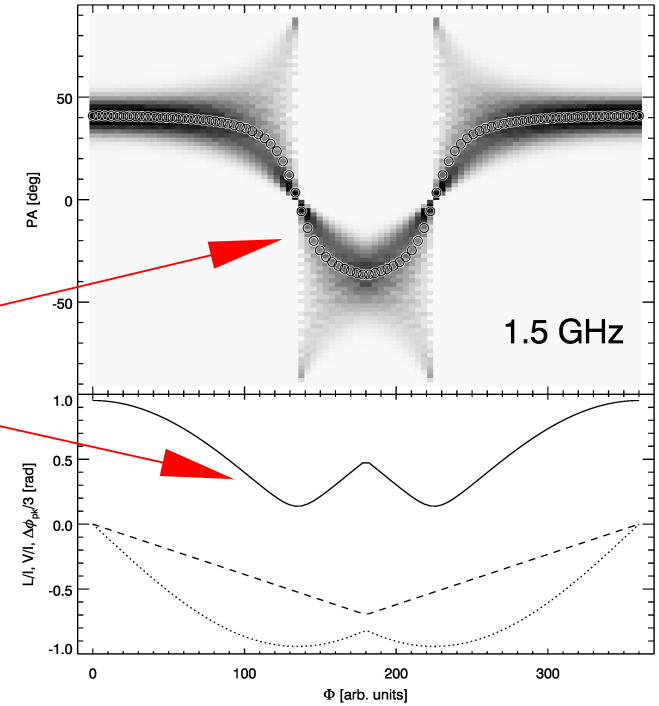
- probing the parameter space,
- average data fitting,
- single pulse data modelling

Multiple interpretations possible: longitude-dependent lag
mix. ang. = f(nu)





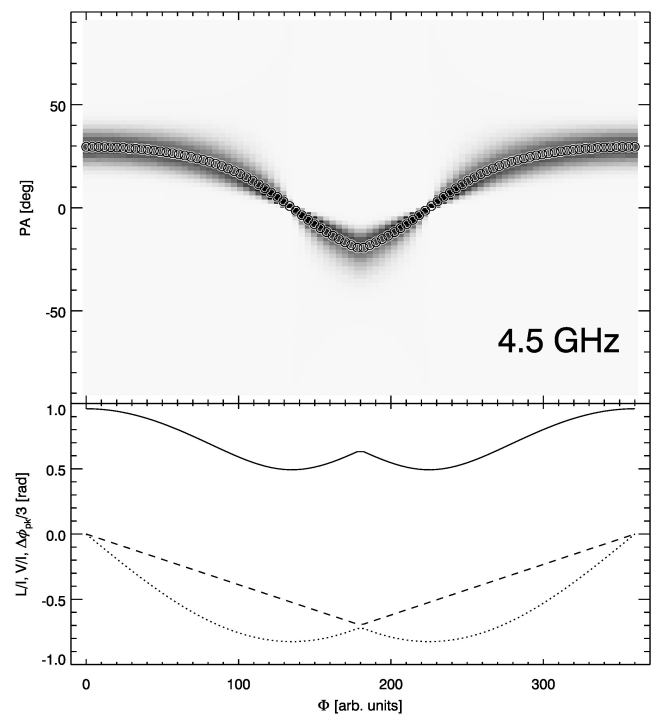
Mitra et al. 2016



Model works at both nu

Features reproduced:

- PA loop/U-distort.
- twin minima in L/I
- large V/I



Dyks 2017