Using linearly polarized pulsars to calibrate ionospheric Faraday rotation and absolute TECs: the case of PSR0531+21

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Lofar-Status-Meeting

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Outline

- Biggest challenge for LOFAR is the ionosphere
- Magnetism KSP / polarization science: need very accurate RM(t)
- Need for absolute and relative ionospheric TEC's
- Use of pulsars !
- WSRT LFFE datasets on TauA - PSR0531+21
- Some properties of PSR0531+21 and TauA

- LOFAR polarization commissioning work/tests

LOFAR and the ionosphere

1) Both refraction and Faraday rotation depend on absolute TEC which changes relatively slowly with time and position

1) Selfcalibration/imaging depend on relative TEC which varies rapidly (1-10s) --> selfcal/peeling takes (partly) care of this

1) Ways to measure absolute TEC:

— differential angles in large FOV images (--> Nov12 LSM)

— Faraday rotation (todays LSM)

— GPS data (not accurate enough ??)

— snapshot all-sky observation sequences (e.g. 10s every 120s) and combining absolute+relative delays

Some linearly polarized pulsars (pulse averaged !)

PSR1937+21 (P=1.6 ms)

$S_{150\ MHz}$ ~ 1-2 Jy RM = + 8 rad/m^2 50-70% polarized

PSRJ0218+4232 (P= 2.2 ms)

S_{150MHz} ~ 0.4 Jy RM = - 61 rad/m^2 50-70% polarized

PSR0531+21 in the Crab Nebula (P=33 ms)

$S_{150\ MHz}$ ~ 10 - 20 Jy RM = - 42 rad/m^2 ? % polarized

NB: Using time-resolved observations (‘gating’) we can probably use many more pulsars for ionospheric RM and TEC monitoring …

How do polarized pulsars appear in images ?

Case of PSR J0218+4232 (Mar89)

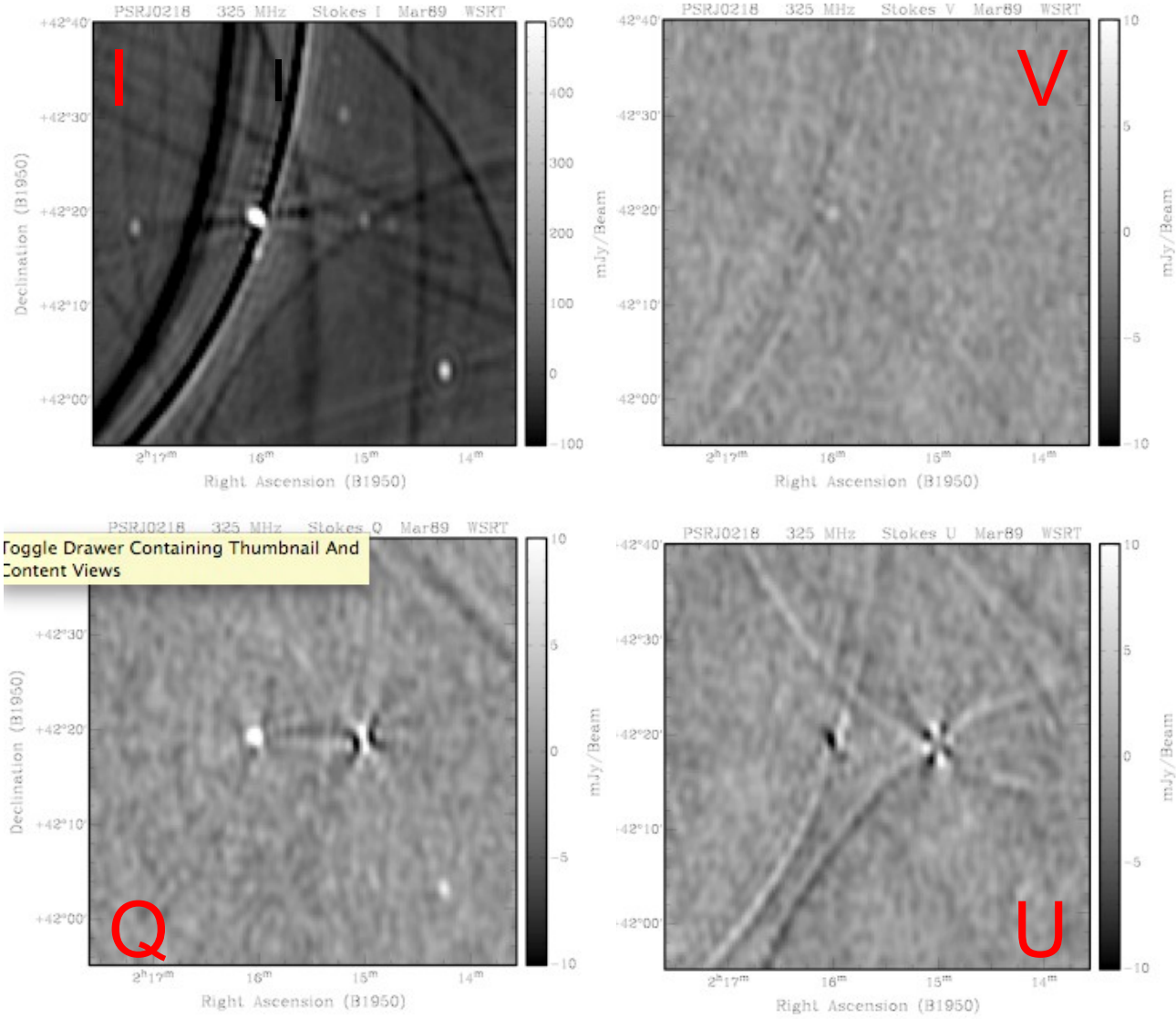
Time variable RM leads to very distorted Q/U images

During the 1989-1992 Solar Maximum we often observed

ΔRM_{ion} ~ 3 rad/m !!

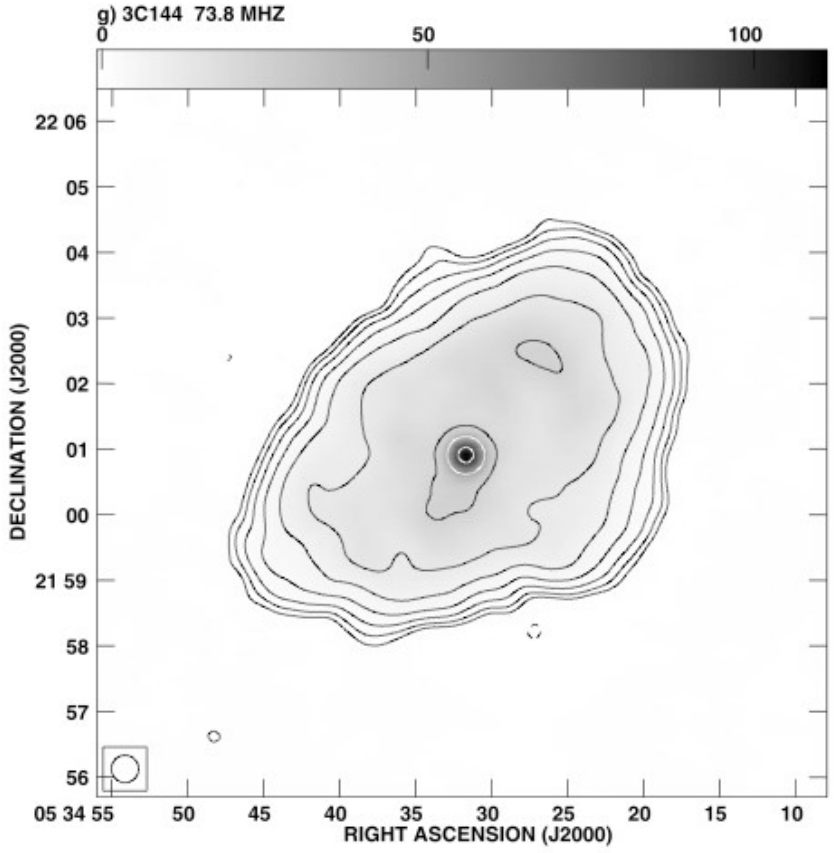
This corresponds to:
~ 20 rad at 120 MHz
(~ 80 rad at 60 MHz !)

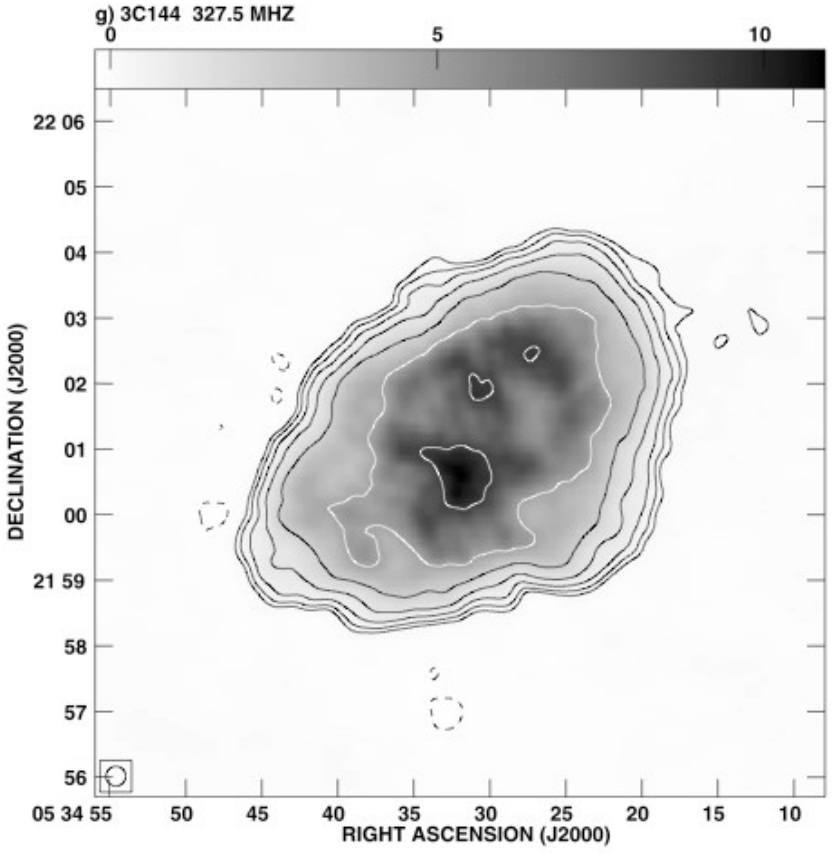
At 120 MHz we require
ΔRM_{ion} ~ 0.1 rad/m2
accuracy or ~ 3%



High resolution VLA images of TauA at 74 / 327 MHz

Note how the pulsar shows up strongly at 74 MHz !





Kassim et al, 2007

The radio spectrum of TauA and PSR B0531+21

2000 Jy

20 Jy

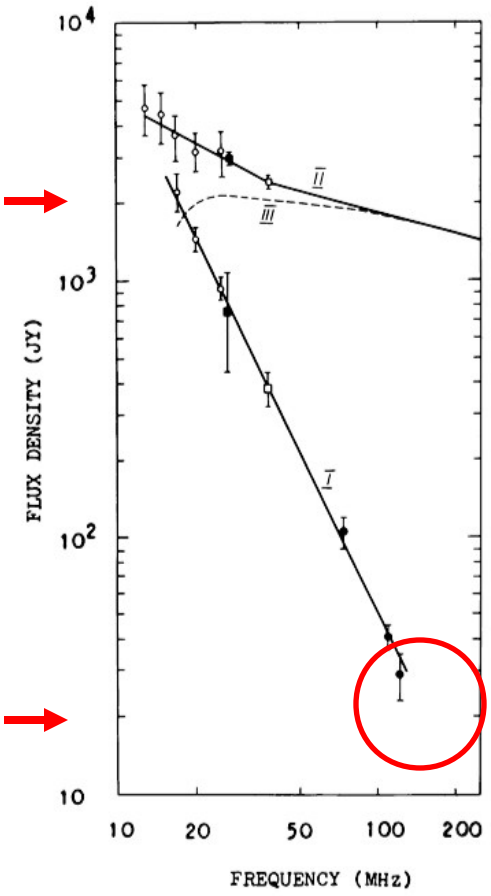


Fig. 5. The Crab nebula emission spectra in the range 16.7–122 MHz: I – of the compact source, II – of the entire nebula, III – of the nebula without the compact source.

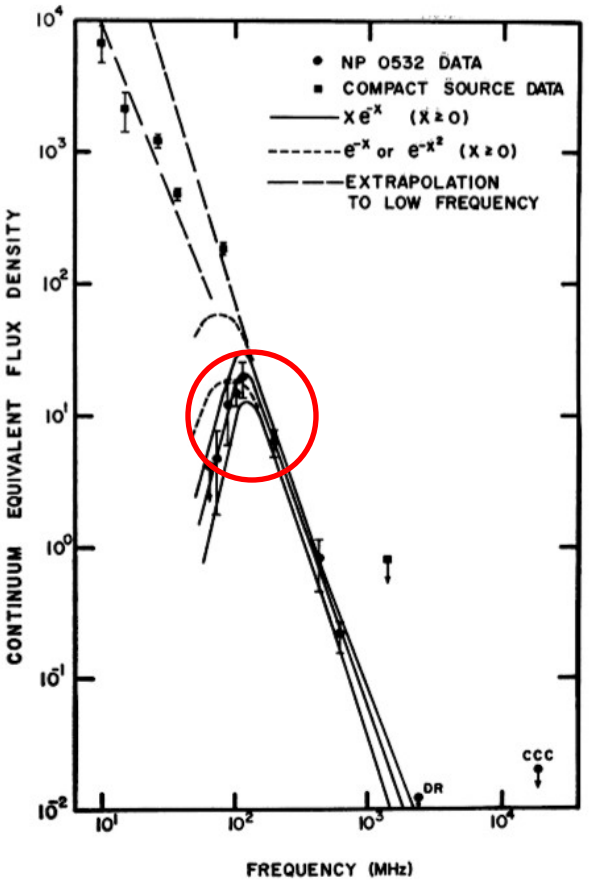


FIG. 4.—Radiofrequency spectra of pulsar NP 0532 and the compact source in the Crab Nebula. *olid curve*, fit to the pulsar's spectrum by using the xe^{-x} broadening function; the parallel curves denote ie associated error envelope. Short dashed curves give the error envelope of a similar fit if the exponential r half-Gaussian density functions are assumed; long dashed lines denote the range of possible extrapola- ons of the pulsar's high-frequency spectrum. Compact-source flux-density measurements are from Bridle (1970). Upper limits on the pulsar's flux density are by Downs and Reichley (1970) and by one of us (C. C. C.)

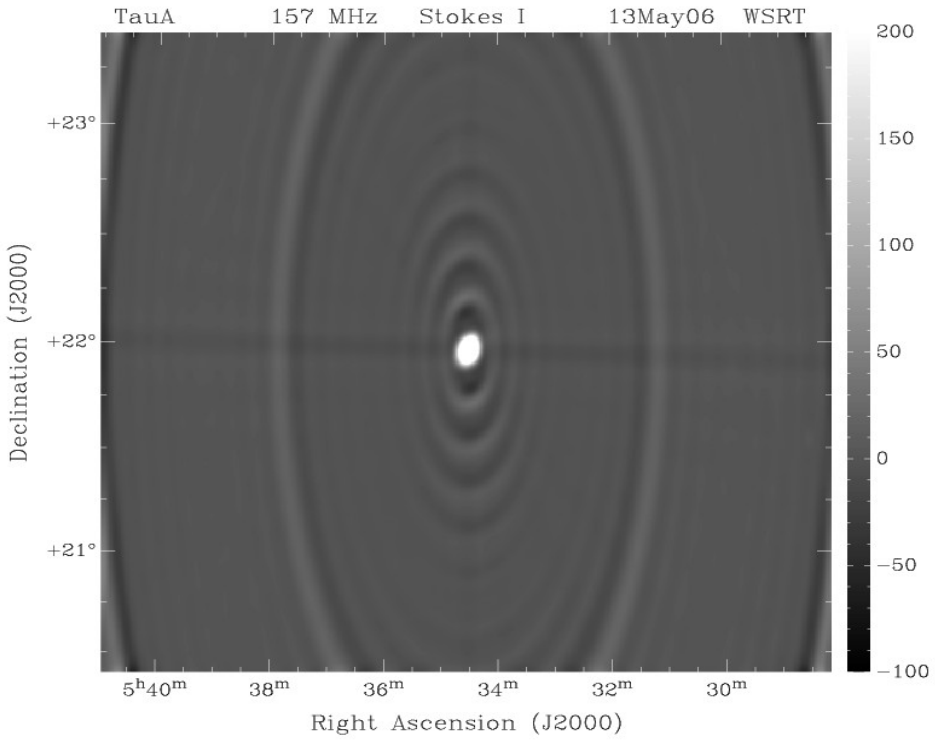
Bobeikoe et al, 1979

Rankin et al, 1970

WSRT (2'x5' PSF) TauA images around 157 MHz.

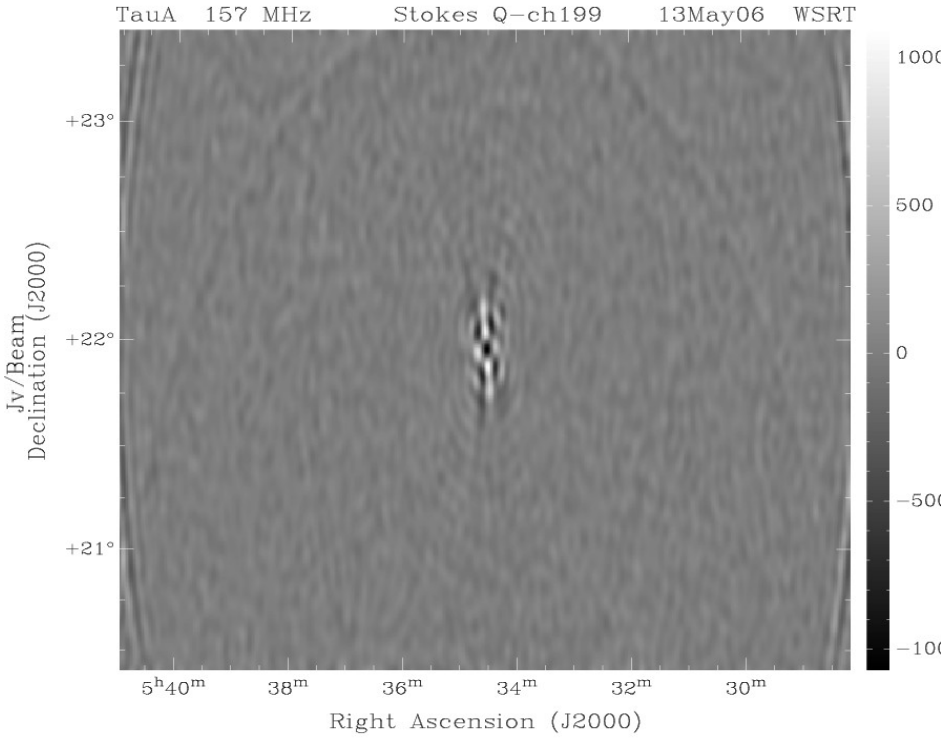
Stokes I

peak ~ 700 Jy



Stokes Q

peak ~ +- 3Jy



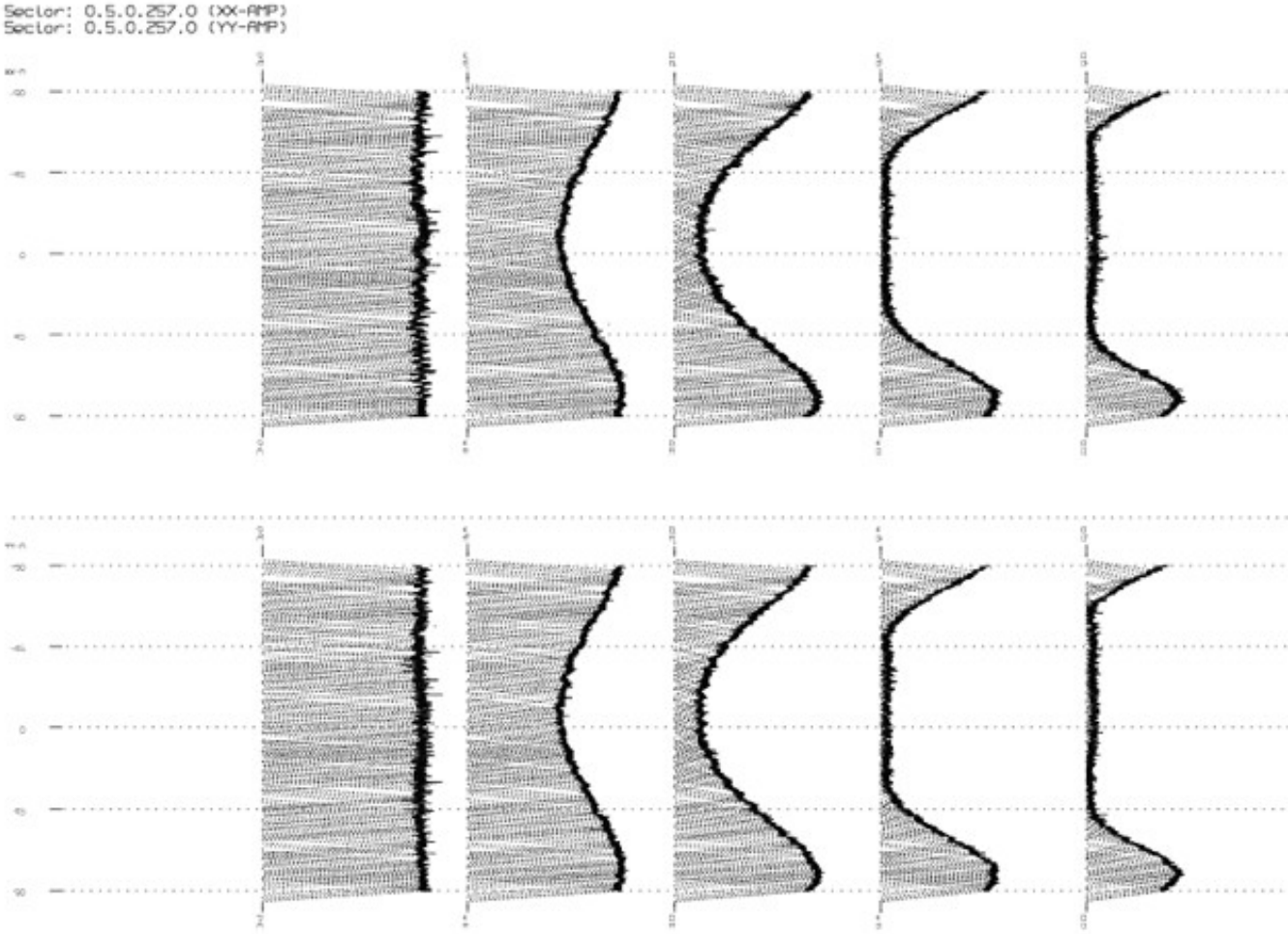
TauA is heavily resolved:

selfcal using unpolarized CLN-model removes Stokes Q on short baselines but NOT on long baselines

XX HA

Q = (YY-XX)/2

YY HA



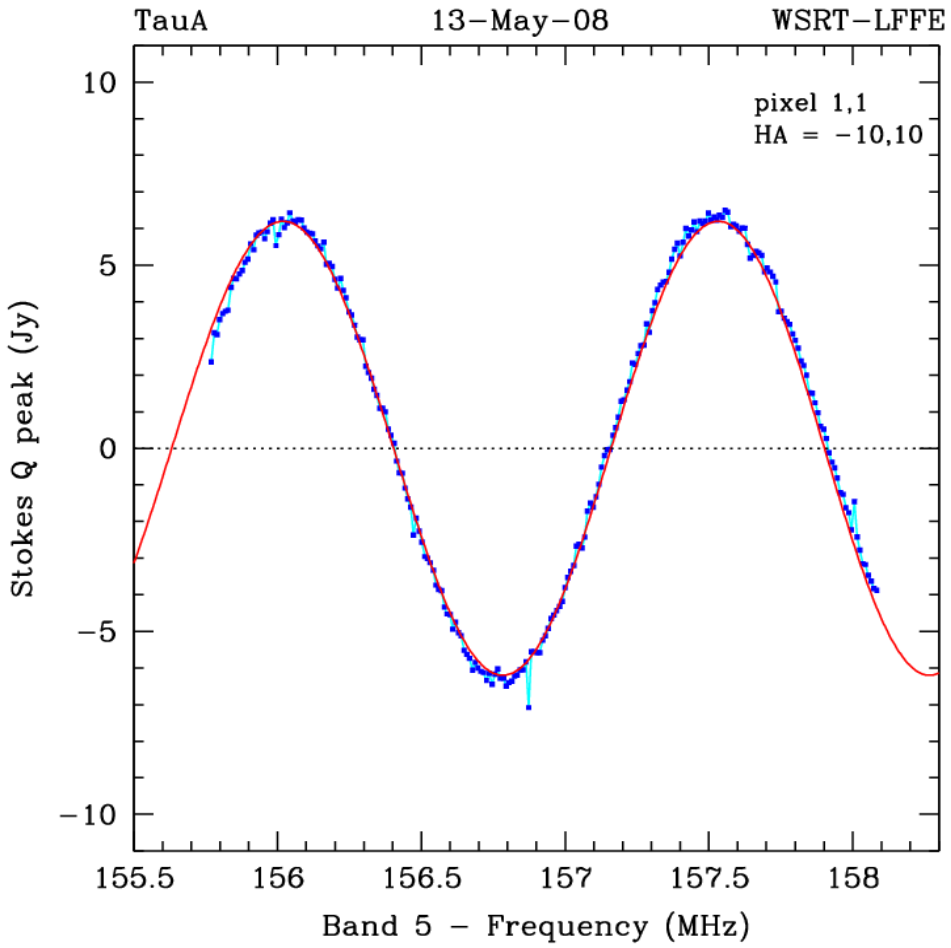
baselines 0.1 - 2.7 km

For each 2.5 MHz WSRT LFFE band I made a cube and plotted the peak intensity in Stokes Q at the PSR position

Note that because of the intense nebular flux (700 Jy peak) it is not easy to make an accurate Stokes U.

Simple leakage calibration would destroy Stokes U/V

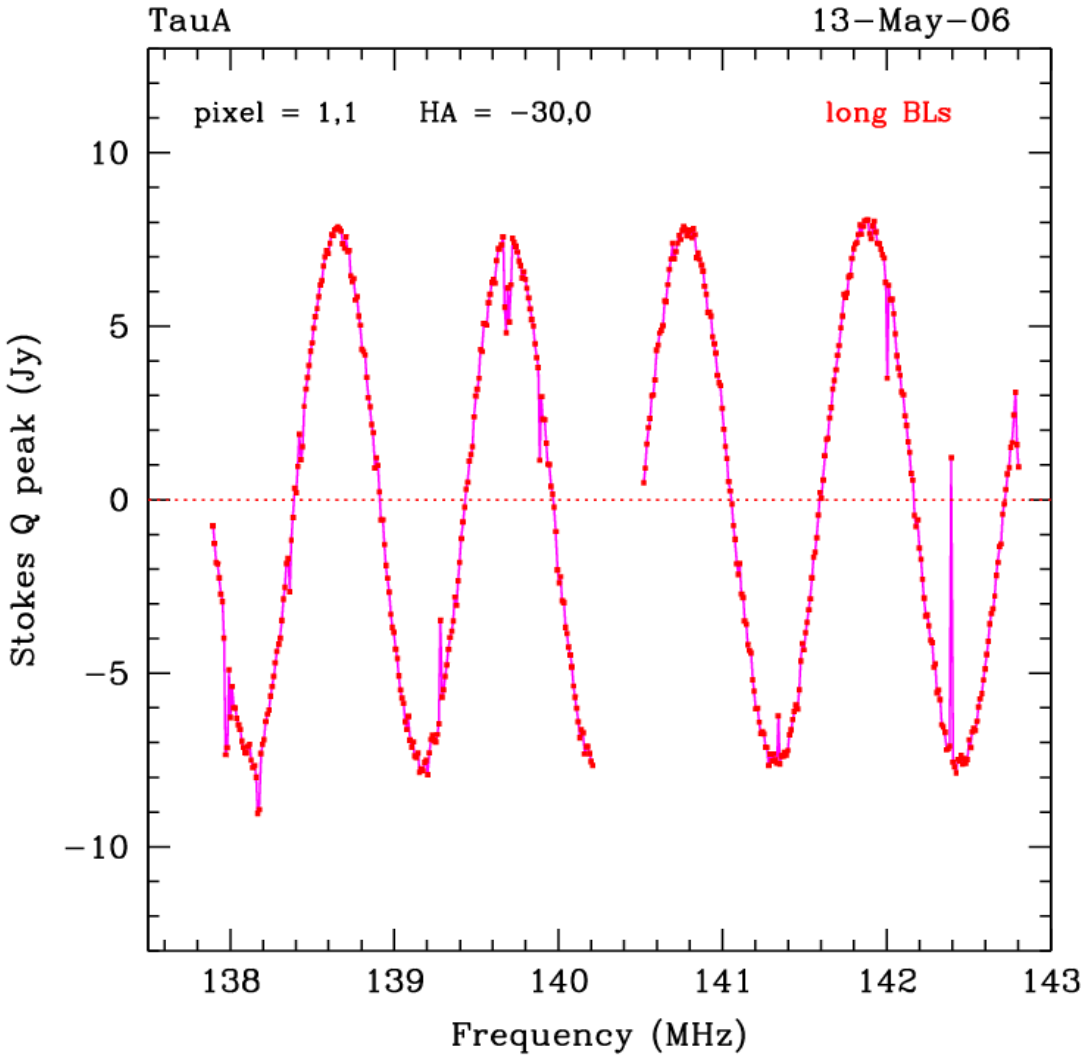
'Normal' RM synthesis is therefore not possible. But RM-synthesis with Q only will be attempted ….



The period of the sinusoid (in MHz) increases as ν^{-3} consistent with Faraday rotation

Results for two adjacent bands agree perfectly

PSR0531+21 had > 8 Jy polarized flux in May 2006 !!!



Faraday rotation in frequency space: ν^{3} dependence !

For RM in rad/m^2 and λ in meter

$$\theta_{Far} = RM\ \lambda^2$$

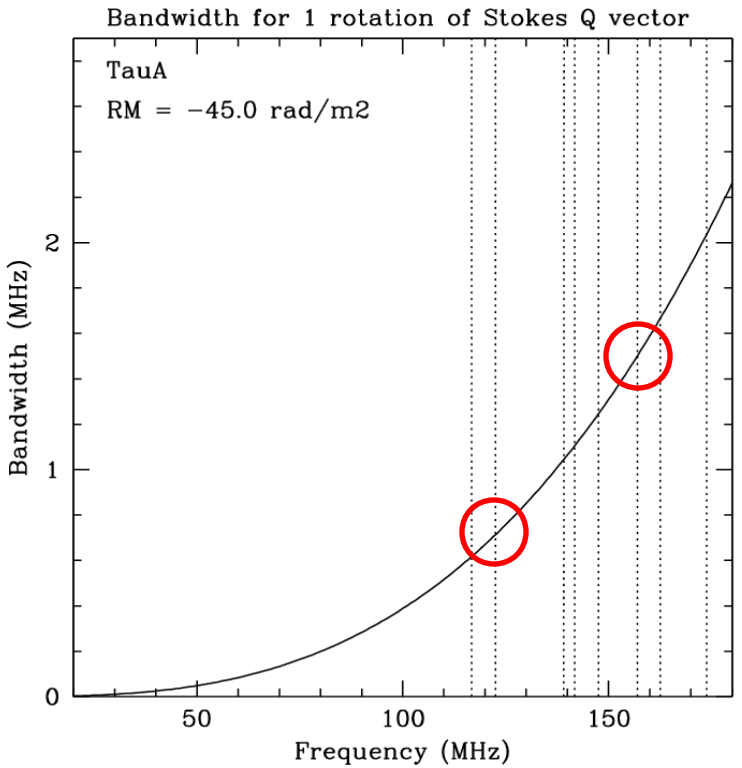
$$d\theta_{Far} = -2\ RM\ c^2/\nu^3\ d\nu/\nu$$

we get π radians rotation in Q/U plane for:

$$d\nu = (-2c^2/\pi\ \nu^3)\ RM$$

or for an observed $d\nu$ the inferred RM is:

$$RM = (-\pi\ \nu^3/2c^2)\ d\nu$$



At 157 MHz we measure $d\nu$ = 1.50 MHz, at 122 MHz $d\nu$ = 0.70 MHz
==> RM = - 45.0 +- 0.5 rad/m2 . Accurate fitting can probably increase this by an order of magnitude.

(NB: ATCA PSR catalog value is RM= - 42.6 +- 0.3 rad/m^2)

Has this approach practical applicability for LOFAR ?

The accuracy of the RM value depends on the SNR

Consider the superstation coherent addition in many simultaneous directions:

HBA SEFD ~ 250 Jy (but need to stay within 25^{o} tile FOV, split-array?)

LBA SEFD ~ 5000 Jy ('all-sky' possible)

For a Bt $=10^{8}$ product (B=10 MHz, t=10s) we reach a noise σ ~ 0.025 Jy in HBA. On a 0.5 Jy polarized pulsar this yields a ΔRM ~ 0.05 rad/m^2 using wideband RM synthesis. A similar accuracy can be reached in the LBA.

Assuming an earth-magnetic field model + height distribution (GPS+ COSMIC satellites) we can deribe the absolute TEC.

So if we can find ~ 10 pulsars we are in business !!

Some other issues related to the use of PSR B0531+21

1) Observations on 28nov06 showed MUCH weaker polarized signal ! Possibly due to long term variability of the pulsar due to refractive scintillation in the ISM (Sieber,1982; Rickett et al, 1984)

2) Resolution effects: on baselines <~ 2 km the Crab nebula dominates the total flux density --> calibration issues (like those discussed) cause complications

Commissioning issues to be investigated (Magnetism and Pulsar KSPs)

١) Conduct HBA CS-1 observation on Crab pulsar? (TauA is now night time object)

٢) Is PSR0531+21 still polarized at (say) 60 MHz ?

٣) How many pulsars lend themselves to this kind of work (3+..)

٤) If necessary develop ‘(pulse) phase-resolved’ polarimetry ?

٥) How accurate are Earth B-field models ? Needed to convert RM --> DM = TEC