Fast interstellar scintillation of quasars, and PKS 1257-326 revisited

International Centre for Radio Astronomy Research

Hayley Bignall

ICRAR - Curtin University

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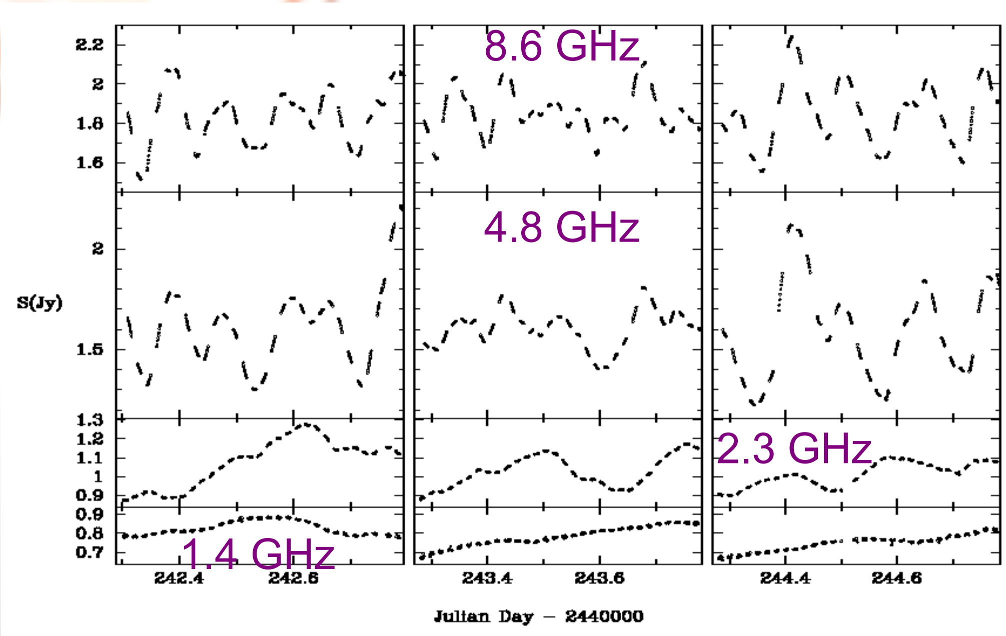
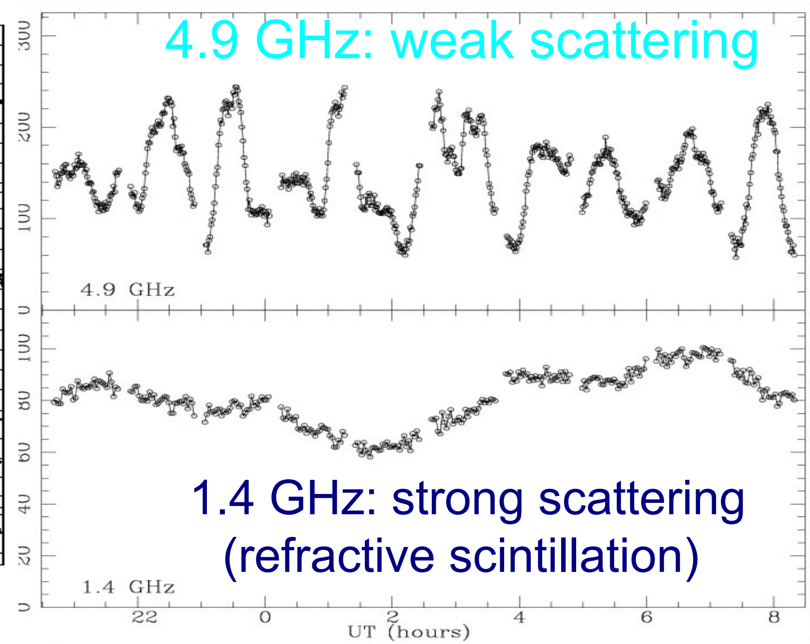
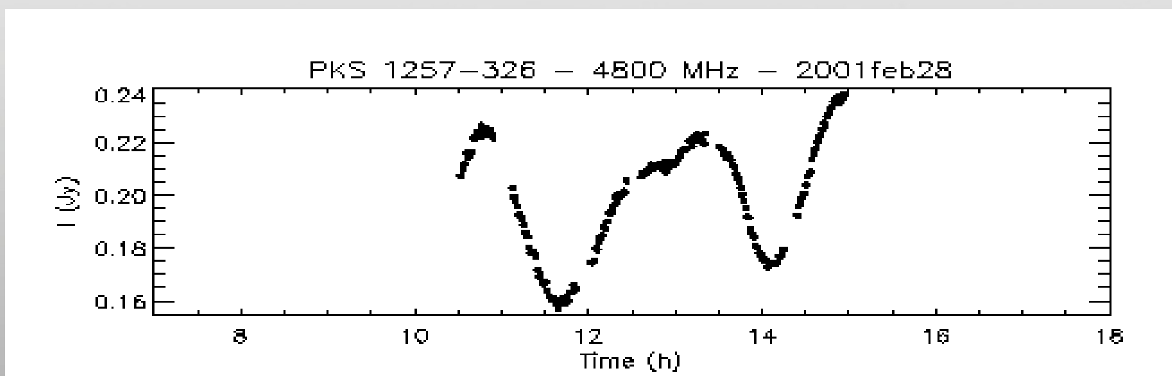
3 well-studied "extreme" scintillating quasars



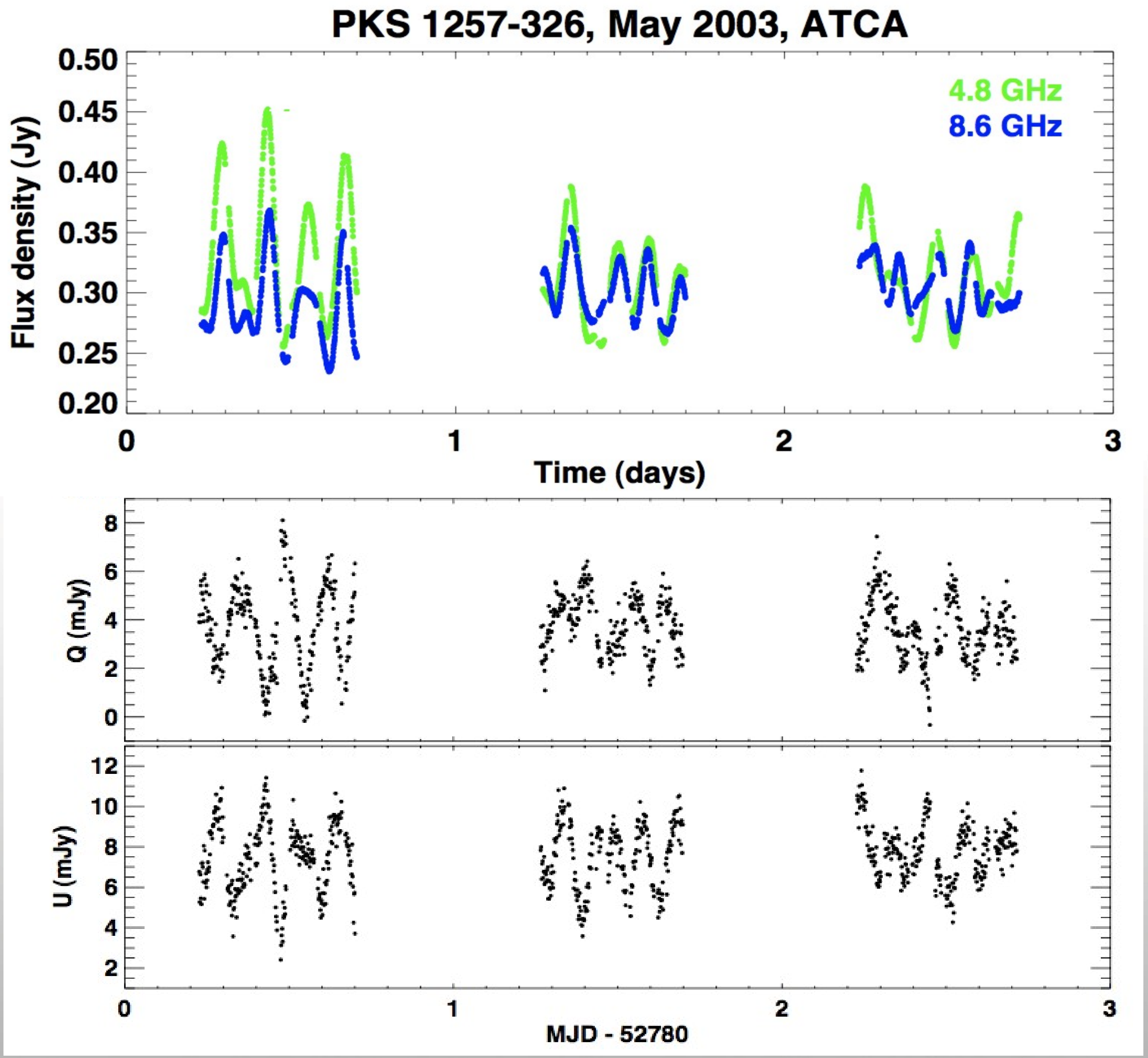
PKS 0405-385 – ATCA (Kedziora-Chudczer et al. 1997, ApJL, 490, L9)



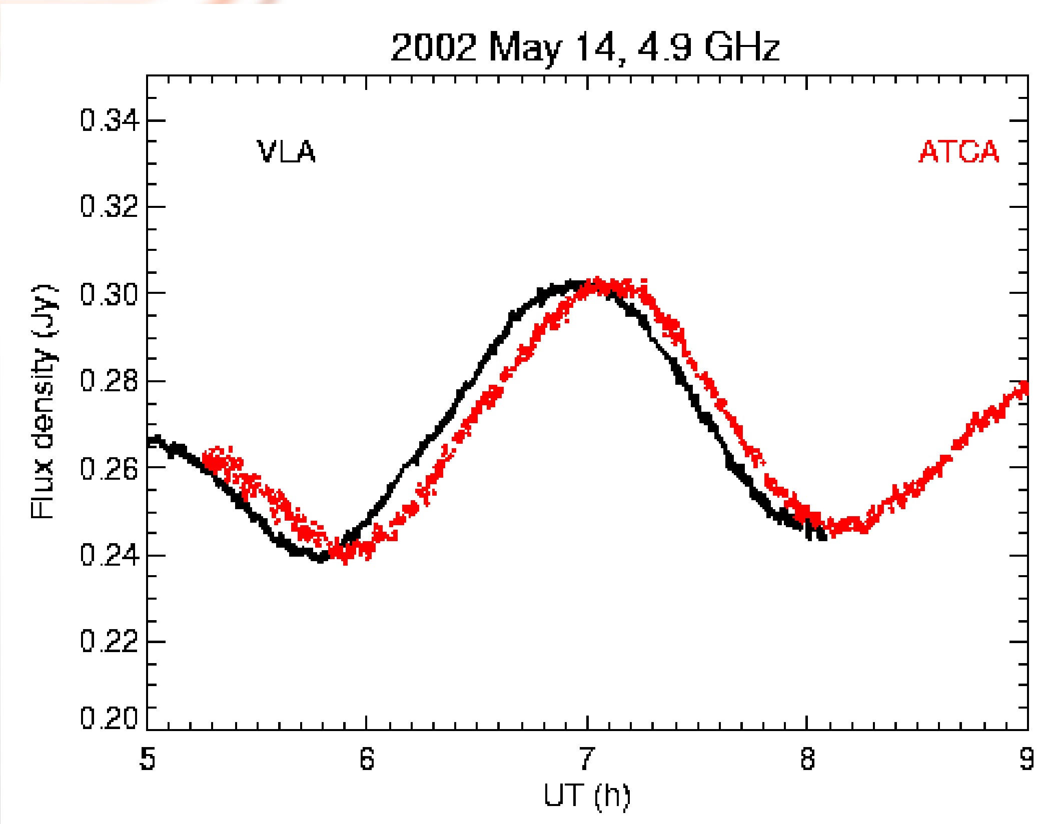
J1819+3845 - WSRT (Dennett-Thorpe & de Bruyn, 2000, ApJL, 529, L65)

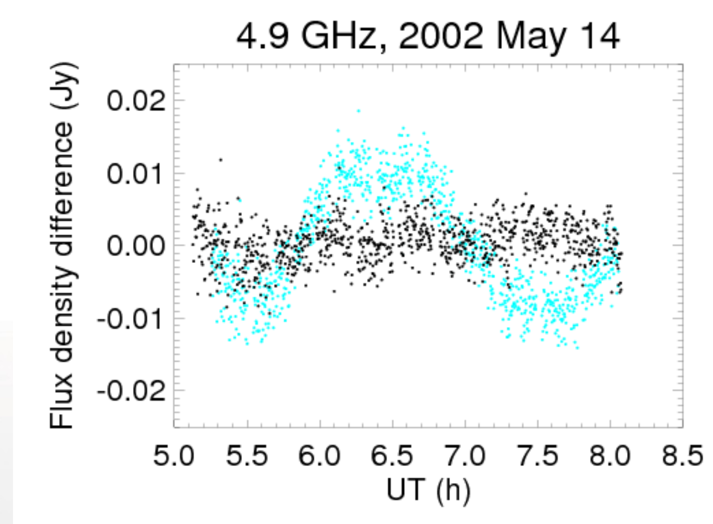


PKS 1257-326 - ATCA (Bignall et al. 2003, ApJ, 585, 653)


PKS 1257-326, May 2003, ATCA
4.8 GHz
8.6 GHz
Flux density (Jy)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0
1
2
3
Time (days)
Q (mJy)
8
6
4
2
0
U (mJy)
12
10
8
6
4
2
0
1
2
3
MJD - 52780

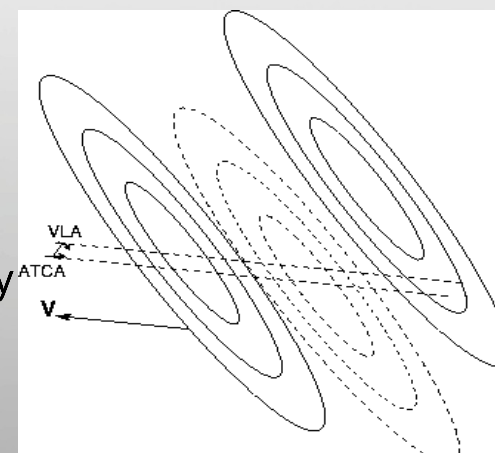
Two-station pattern arrival time delays





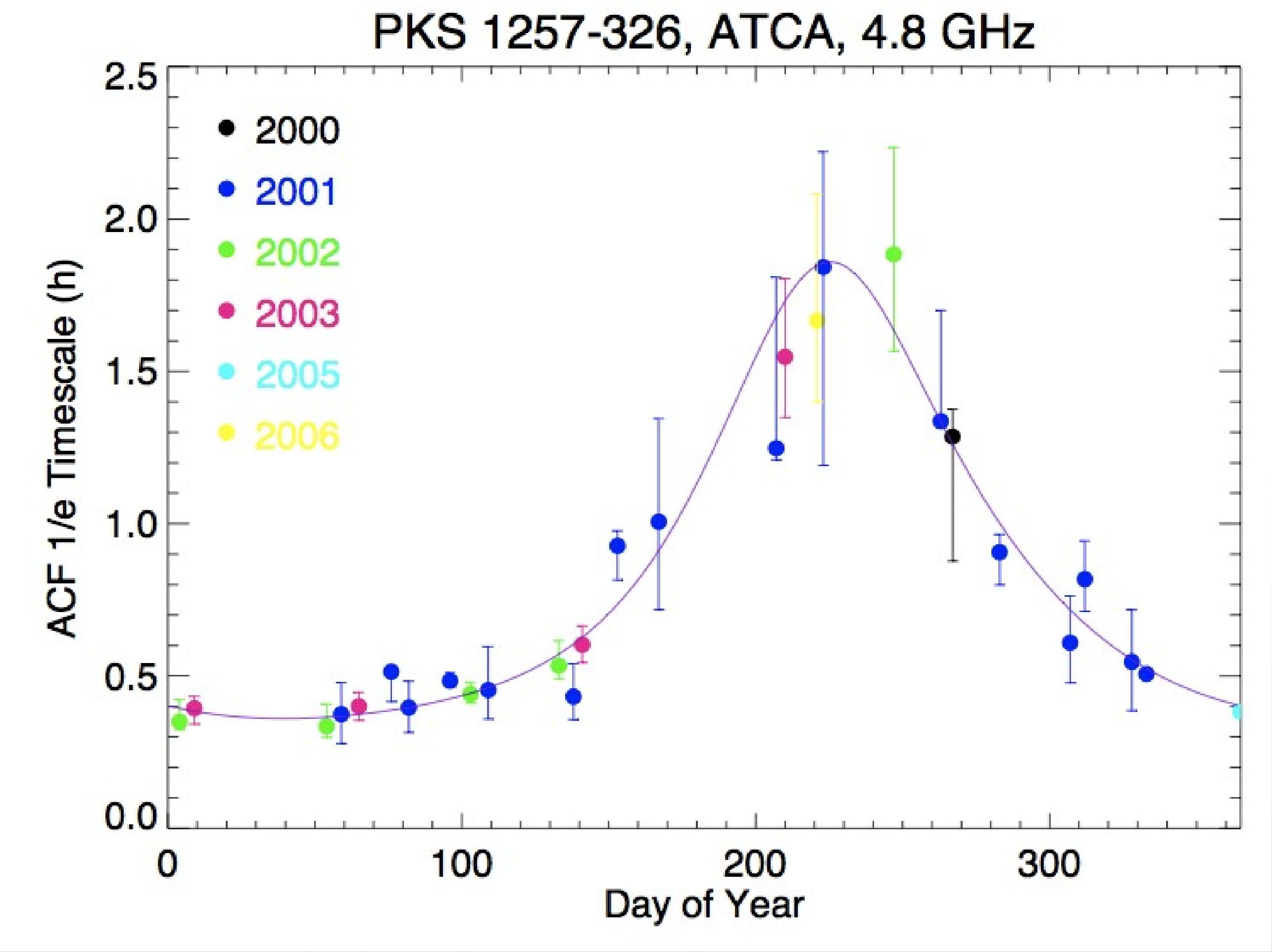
$$\Delta t = \frac{\mathbf{r}\cdot\mathbf{v} + (R^2-1)(\mathbf{r}\times\hat{\mathbf{S}})(\mathbf{v}\times\hat{\mathbf{S}})}{v^2 + (R^2-1)(\mathbf{v}\times\hat{\mathbf{S}})^2}$$

Depends on baseline **r**, scintillation velocity **v**(DOY), position angle and axial ratio R of anisotropy in the scintillation pattern



Annual cycle in scintillation timescale

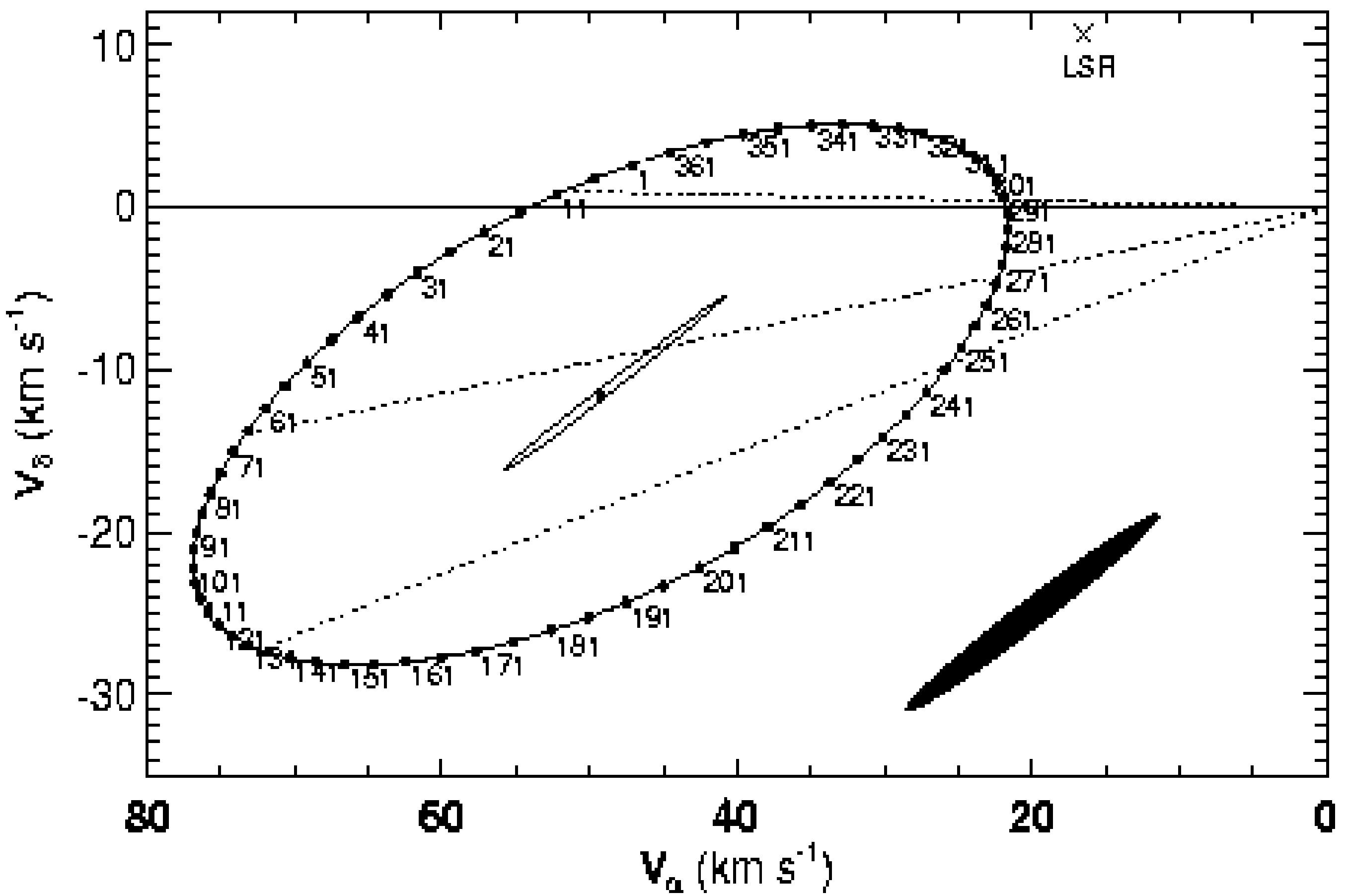
Fit to annual cycle + time delay (at 3 different times of year) implies highly anisotropic scintillation pattern: R>6 but not well constrained.
Bignall et al. (2006)
Walker et al. (2009)



Minor axis scale is well constrained and relating this to Fresnel scale, $r_F = \sqrt{cD/2\pi\nu}$ implied screen distance is D~10pc

$$t_{\rm scint} = \frac{\sqrt{R s_0}}{\sqrt{v^2 + (R^2 - 1)(\mathbf{v} \times \hat{\mathbf{S}})^2}}$$

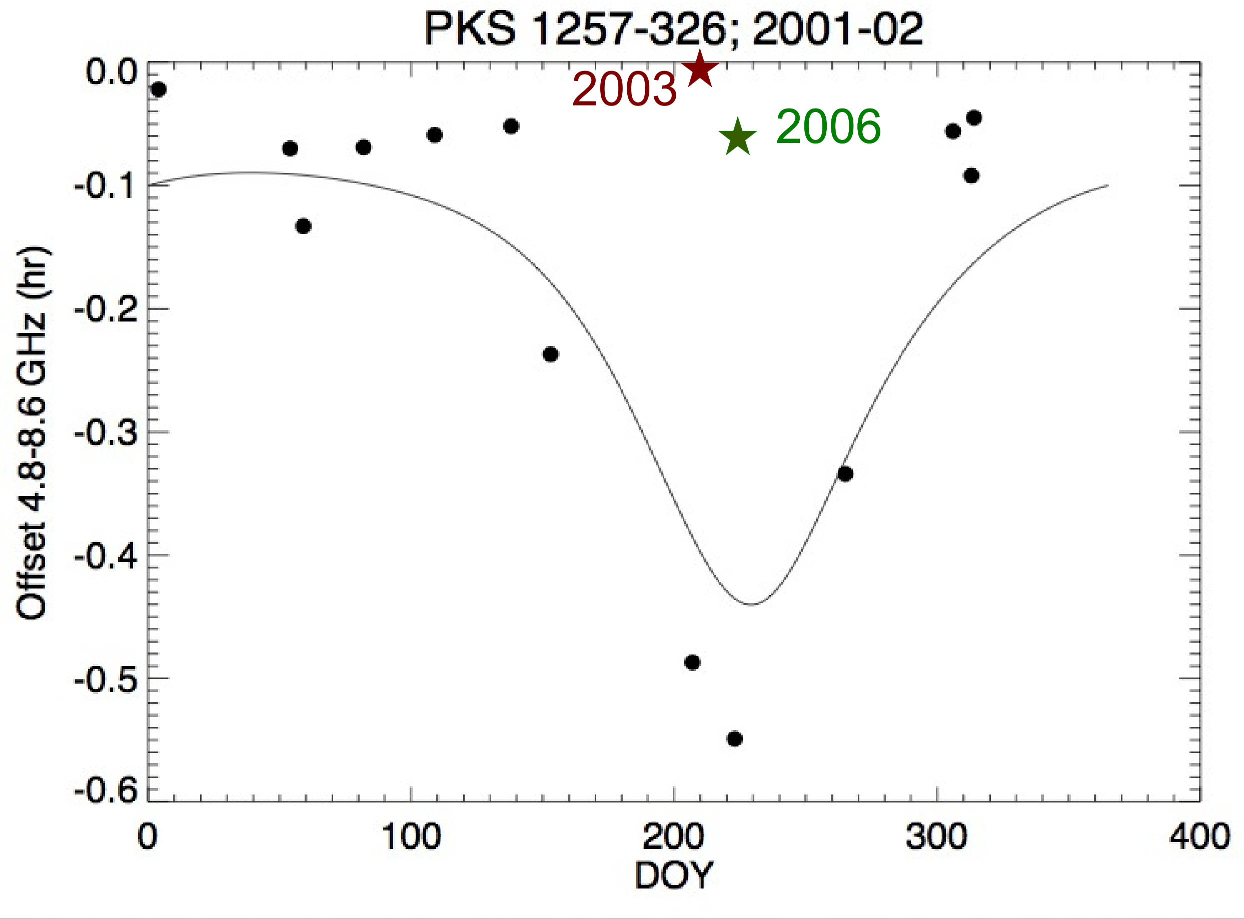
The annual cycle & scintillation pattern projected on the sky



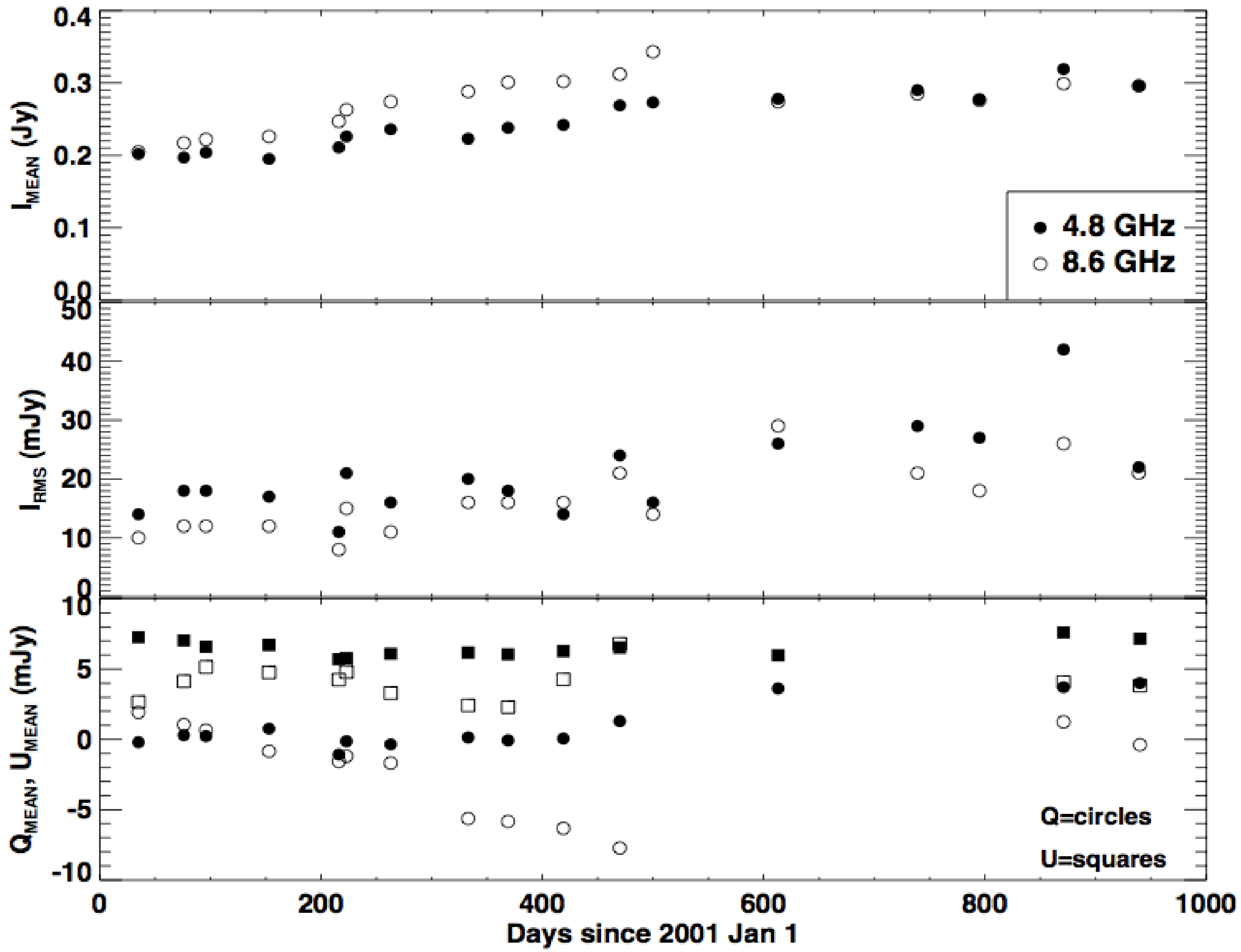
“Core shifts” from multi-frequency scintillation pattern offsets

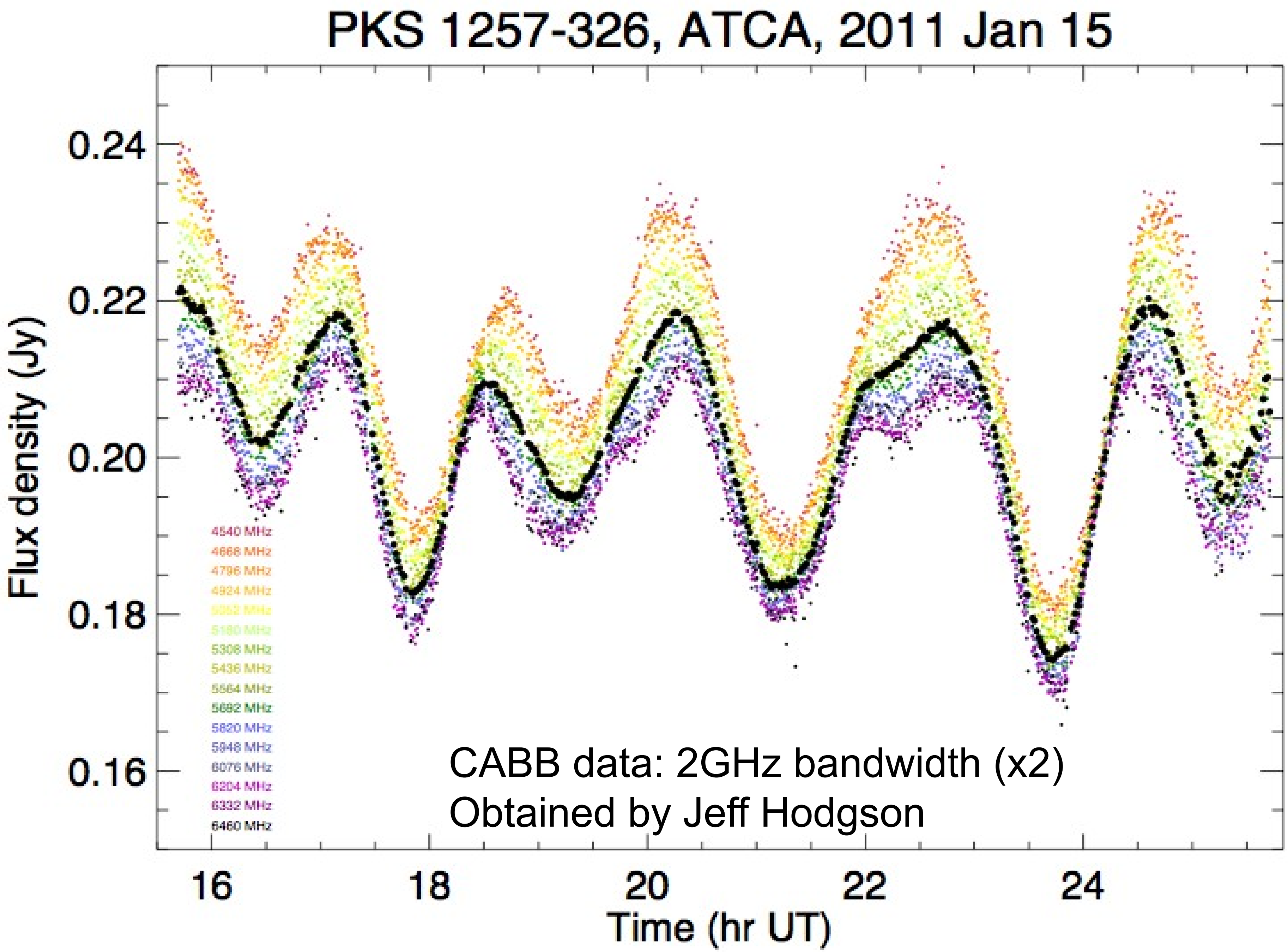
Line corresponds to pattern displacement of 22,000 km for preferred annual cycle model = 15 µas for screen distance of 10pc

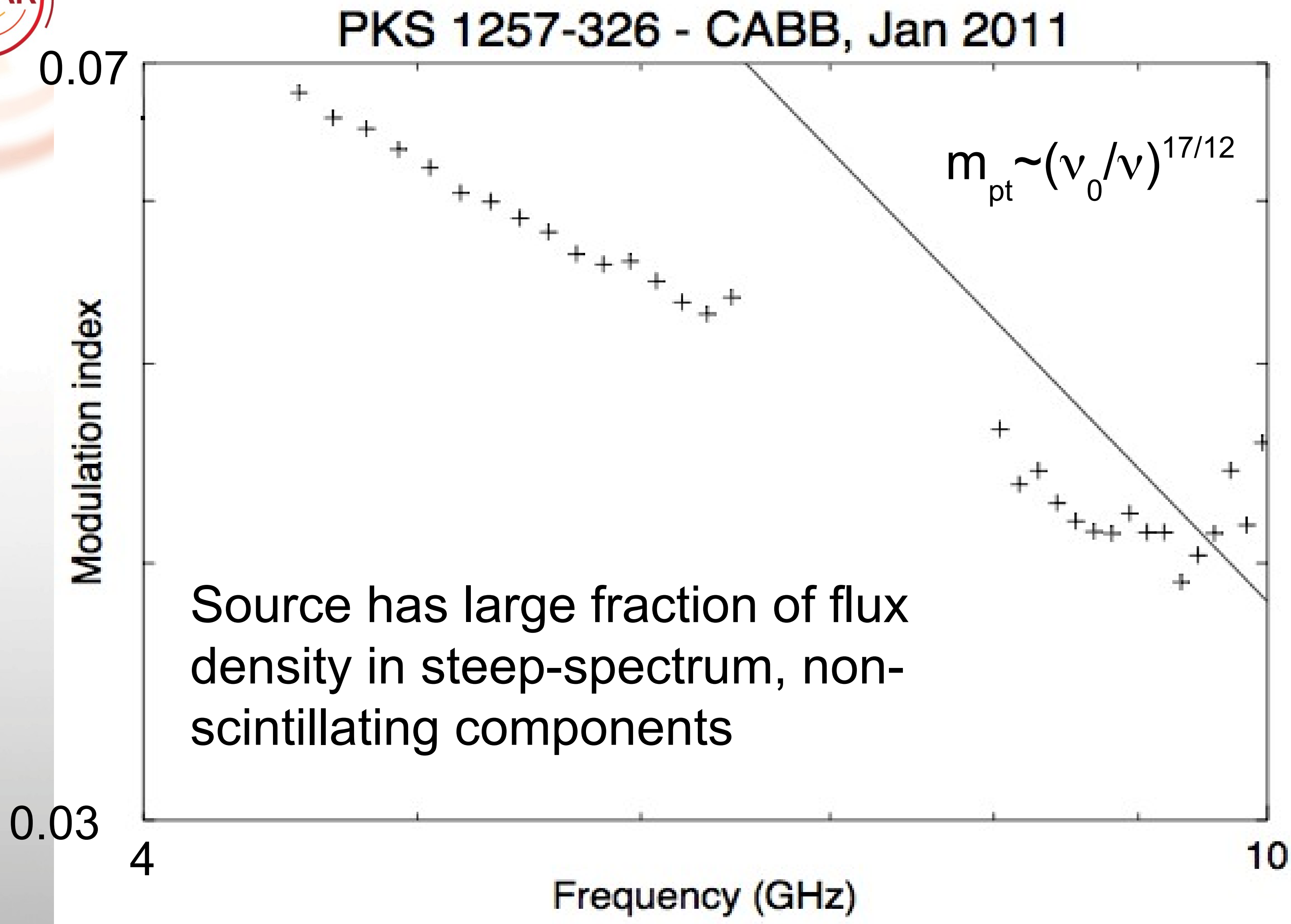
Offset is significantly smaller in subsequent years – optical depth effect post-outburst?

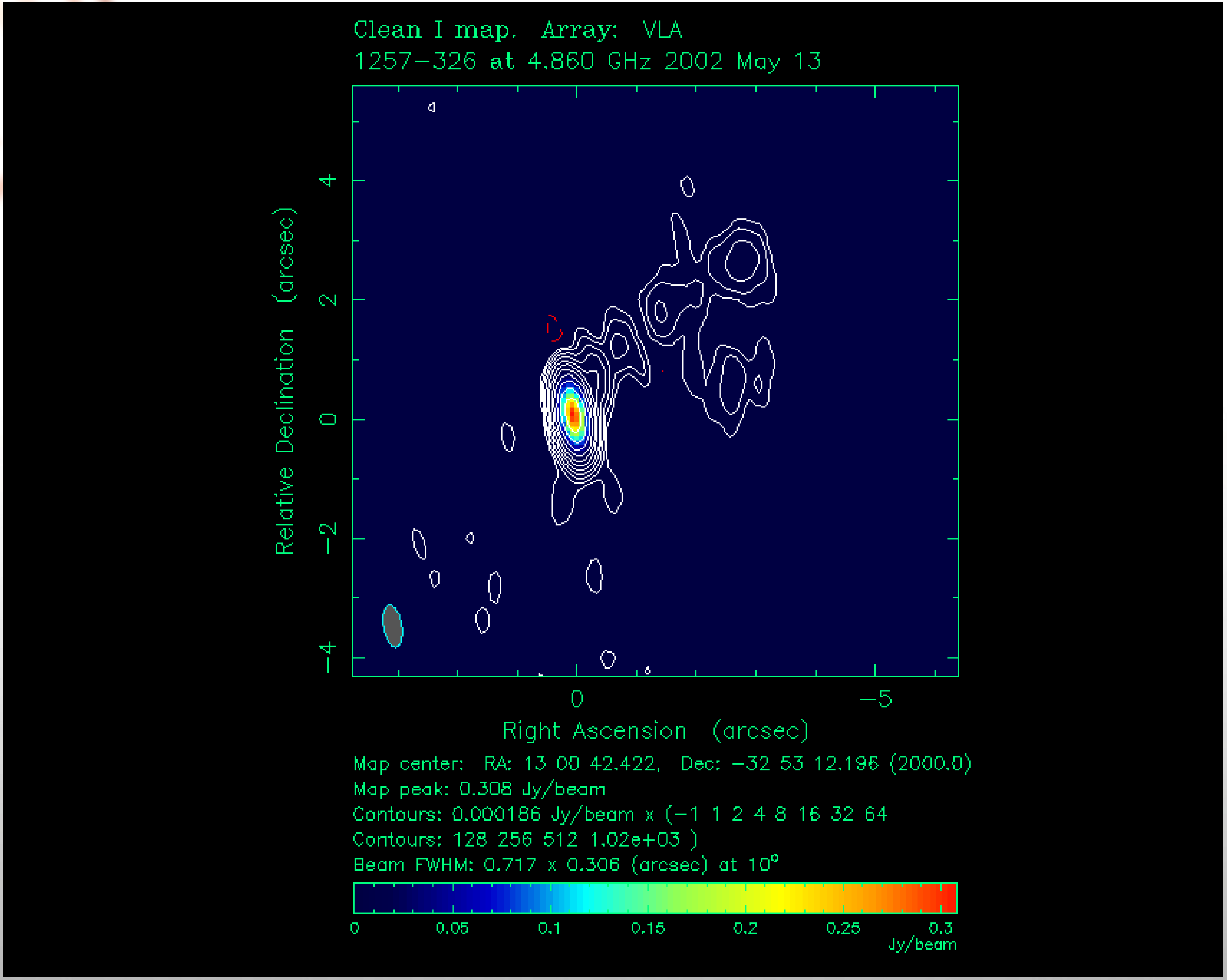


Evolution of PKS 1257-326 during ATCA monitoring programme

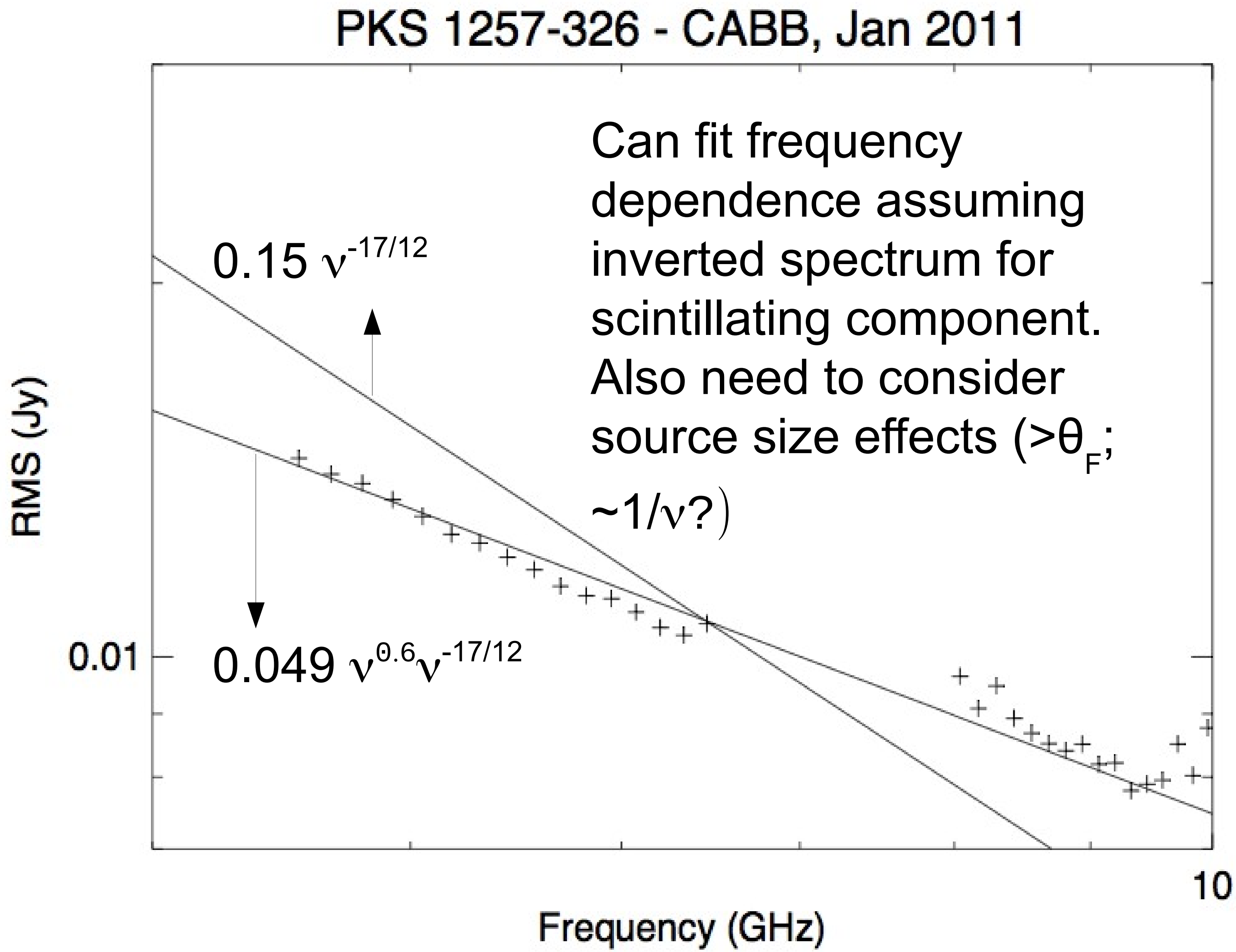


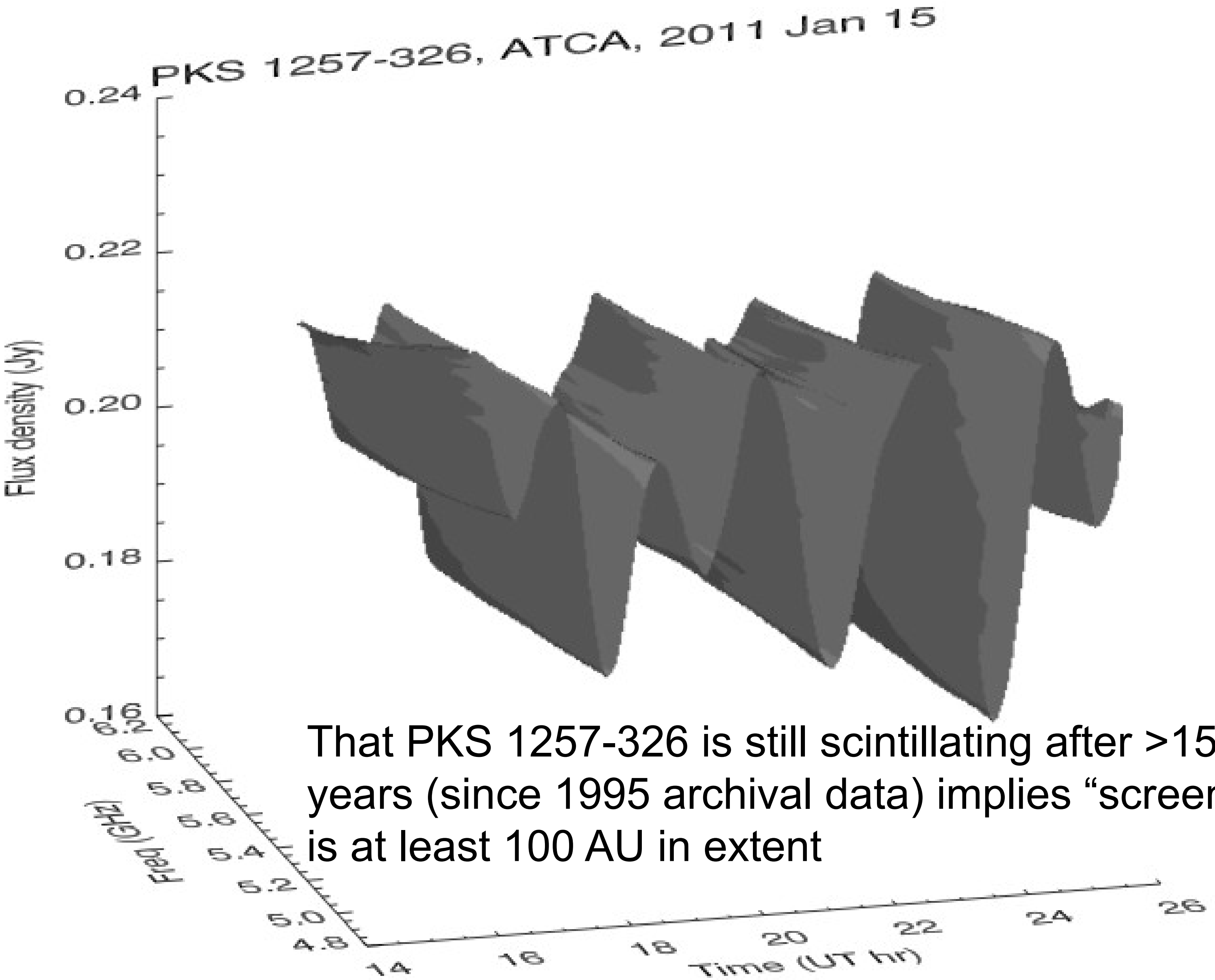

PKS 1257-326, ATCA, 2011 Jan 15
Flux density (Jy)
0.24
0.22
0.20
0.18
0.16
16
18
20
22
24
Time (hr UT)
4540 MHz
4668 MHz
4796 MHz
4924 MHz
5052 MHz
5180 MHz
5308 MHz
5436 MHz
5564 MHz
5692 MHz
5820 MHz
5948 MHz
6076 MHz
6204 MHz
6332 MHz
6460 MHz
CABB data: 2GHz bandwidth (x2)
Obtained by Jeff Hodgson


PKS 1257-326 - CABB, Jan 2011
0.07
0.03
Modulation index
4
10
Frequency (GHz)
$m_{pt} \sim (\nu_0/\nu)^{17/12}$
Source has large fraction of flux density in steep-spectrum, non-scintillating components

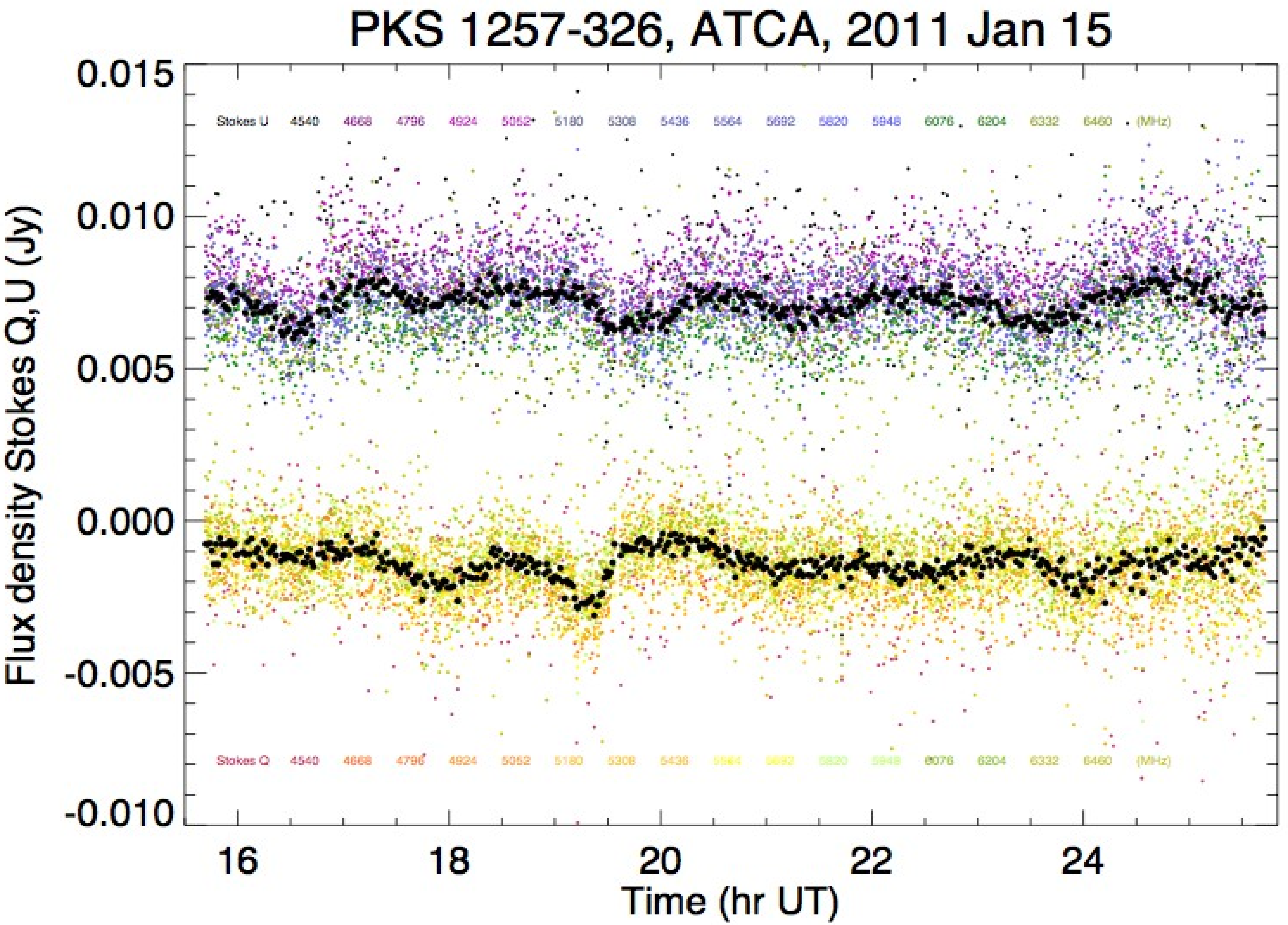


Clean I map. Array: VLA
1257−326 at 4.860 GHz 2002 May 13
Relative Declination (arcsec)
Right Ascension (arcsec)
Map center: RA: 13 00 42.422, Dec: −32 53 12.196 (2000.0)
Map peak: 0.308 Jy/beam
Contours: 0.000186 Jy/beam x (−1 1 2 4 8 16 32 64
Contours: 128 256 512 1.02e+03)
Beam FWHM: 0.717 x 0.306 (arcsec) at 10°
Jy/beam

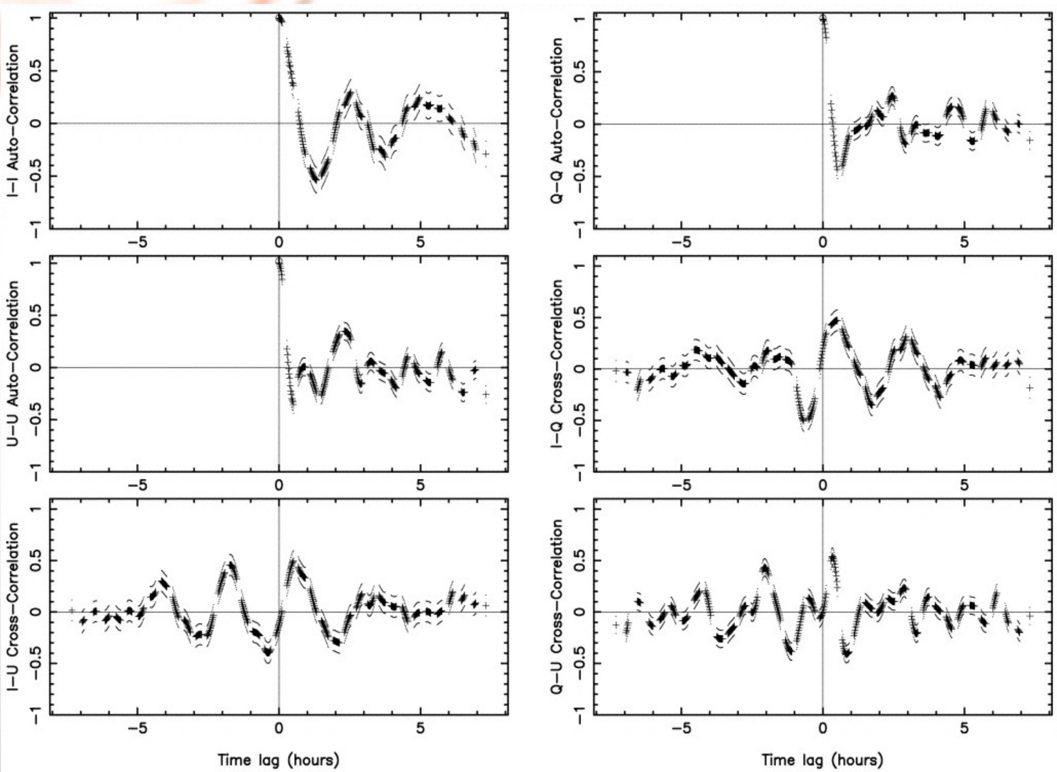

PKS 1257-326 - CABB, Jan 2011
Can fit frequency dependence assuming inverted spectrum for scintillating component. Also need to consider source size effects (>θ_F; ~1/ν?)
0.15 $\nu^{-17/12}$
0.049 $\nu^{0.6}\nu^{-17/12}$
0.01
10
RMS (Jy)
Frequency (GHz)

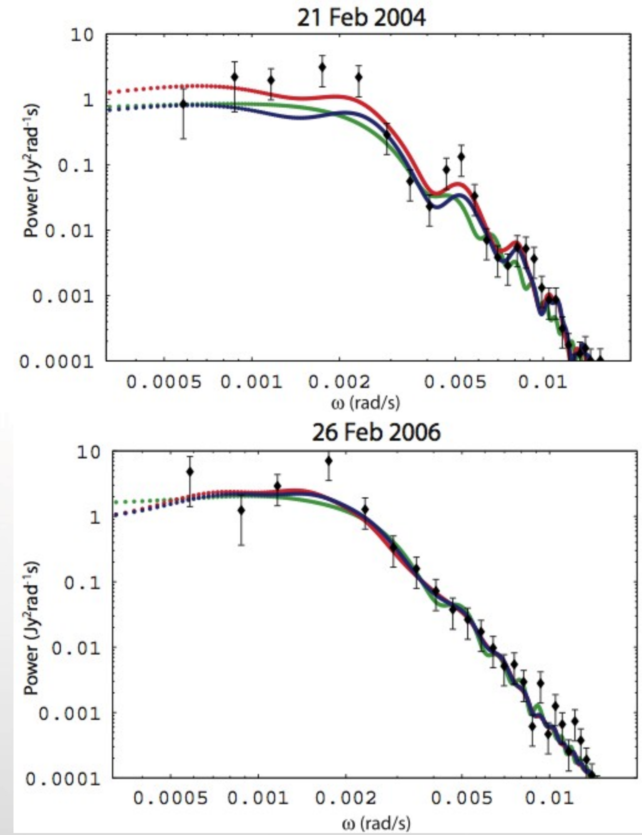


That PKS 1257-326 is still scintillating after >15 years (since 1995 archival data) implies "screen" is at least 100 AU in extent

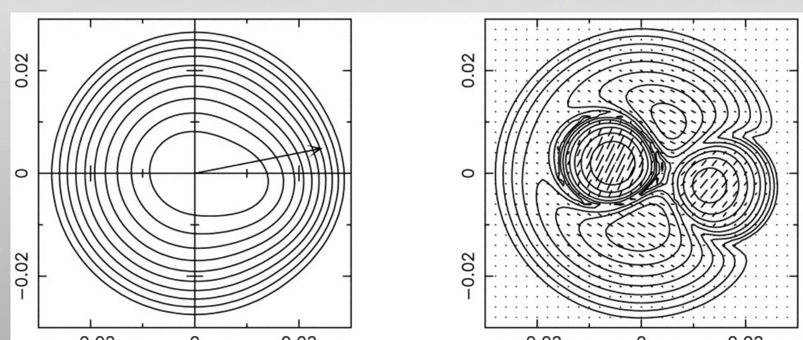

PKS 1257-326, ATCA, 2011 Jan 15
Stokes U 4540 4668 4796 4924 5052 5180 5308 5436 5564 5692 5820 5948 6076 6204 6332 6460 (MHz)
Stokes Q 4540 4668 4796 4924 5052 5180 5308 5436 5564 5692 5820 5948 6076 6204 6332 6460 (MHz)
Flux density Stokes Q,U (Jy)
0.015
0.010
0.005
0.000
-0.005
-0.010
16
18
20
22
24
Time (hr UT)

Resolution "beyond VLBI": some results from other fast scintillators...





Modelling of µas-scale polarization structure in PKS 0405-385 (Rickett et al. 2002)



Power spectral modelling of screen + source evolution in J1819+3845 (Macquart & de Bruyn 2007)

Fast scintillators from the MASIV Survey

Detection of Six Rapidly Scintillating AGNs and the Diminished Variability of J1819+3845

Koay, Bignall, Macquart, Jauncey, Rickett, Lovell.
A&A Letters, accepted 07/09/2011

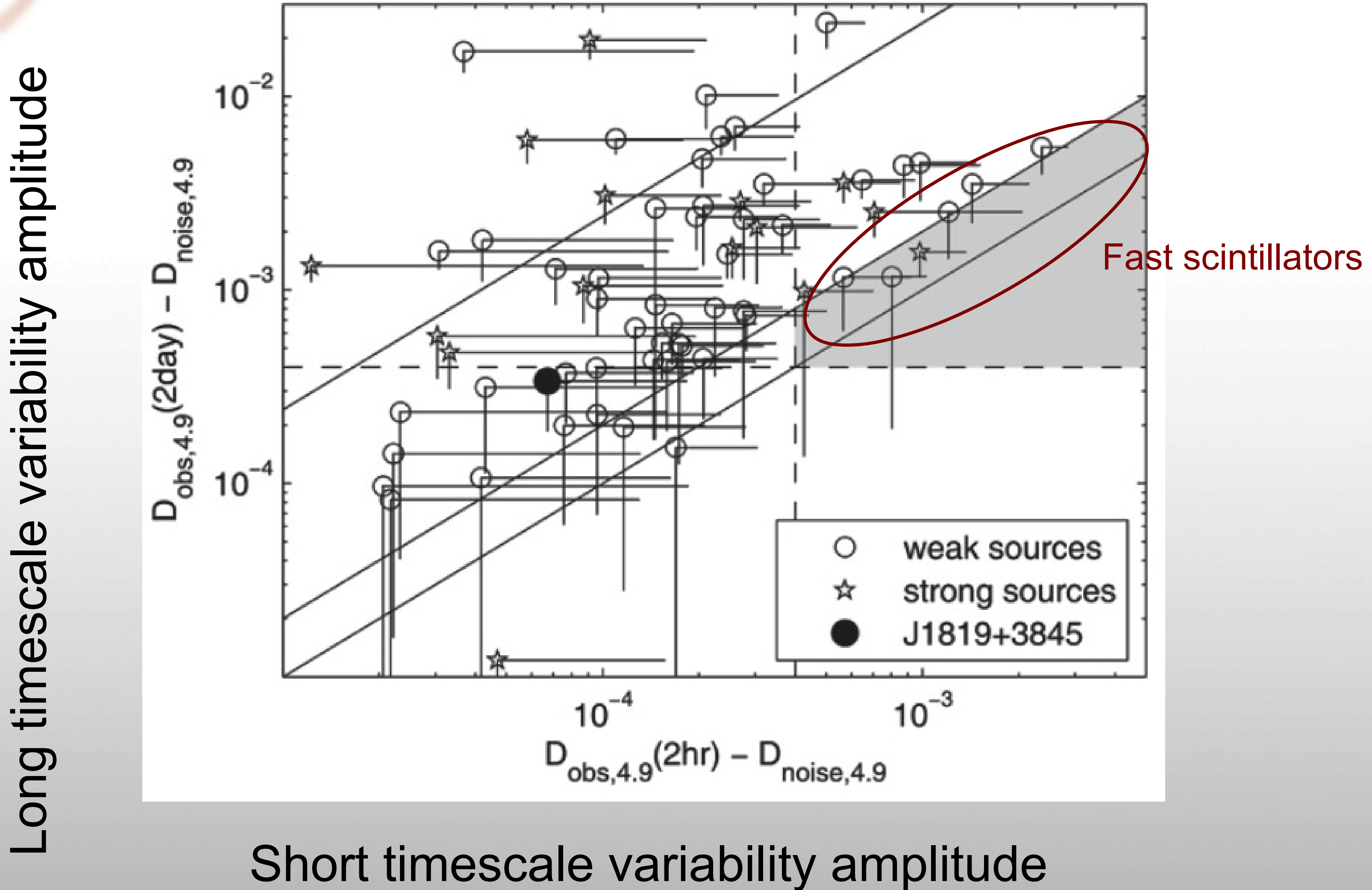
- MASIV 5 GHz VLA Survey: ~18% of 443 compact quasars had characteristic timescales of ISS < 12 hours (Lovell et al. 2008, ApJ, 689, 108)
- J1819+3845 stood out with modulation index of 50% (cf <12% for all other sources in MASIV)
- MASIV Survey follow-up (Koay et al. 2011, AJ, 142, 108)

[Poster "ISS Surveys as a Cosmological Probe: Prospects and Challenges"

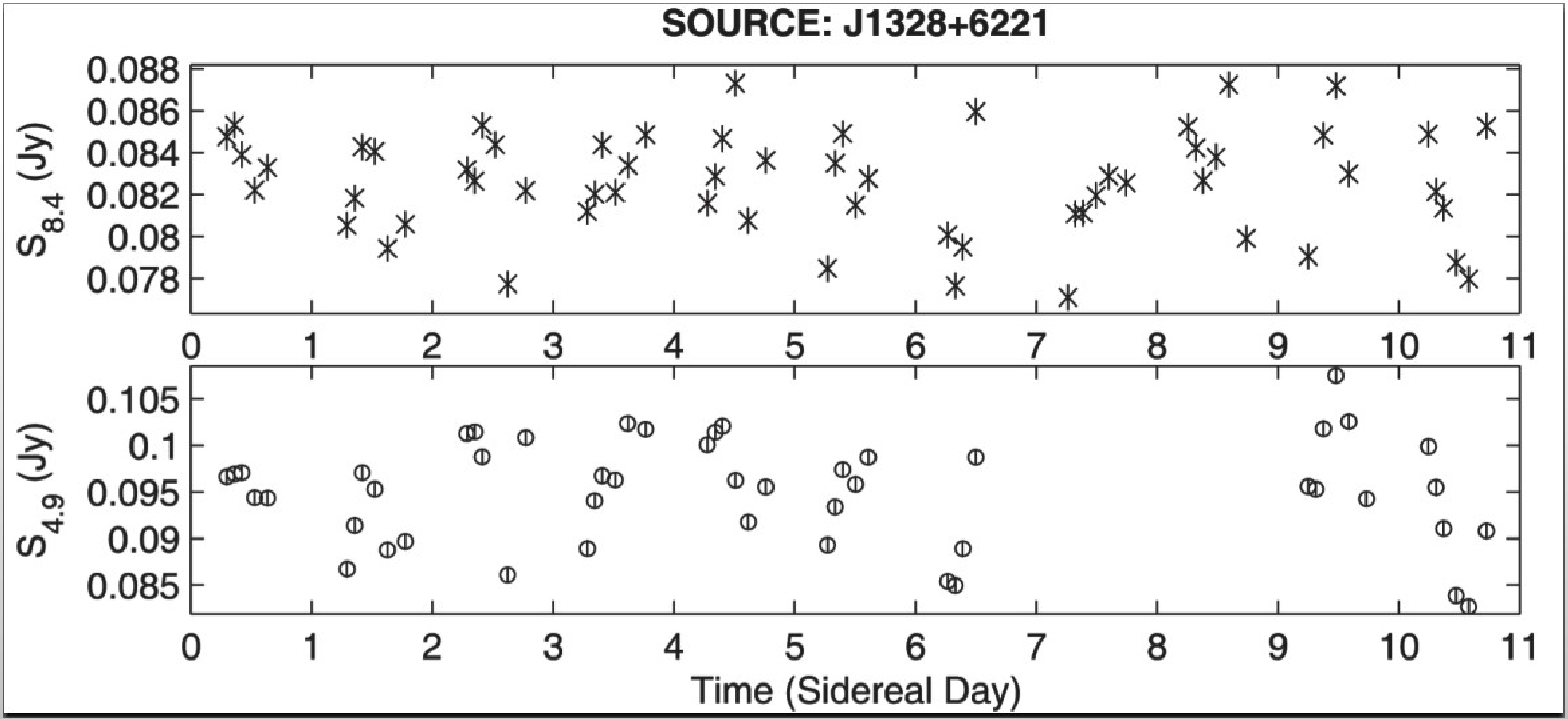
by Kevin Koay, J-P Macquart et al.]

  - 6 out of 128 sources observed over 11 days in Jan 2009 had characteristic timescales < 2 hours (=the sampling interval)
  - J1819+3845 showed diminished variability with 2% variations on ~6 hour timescale (previously reported by Cimò 2008, in Proceedings of the 9th EVN symposium)

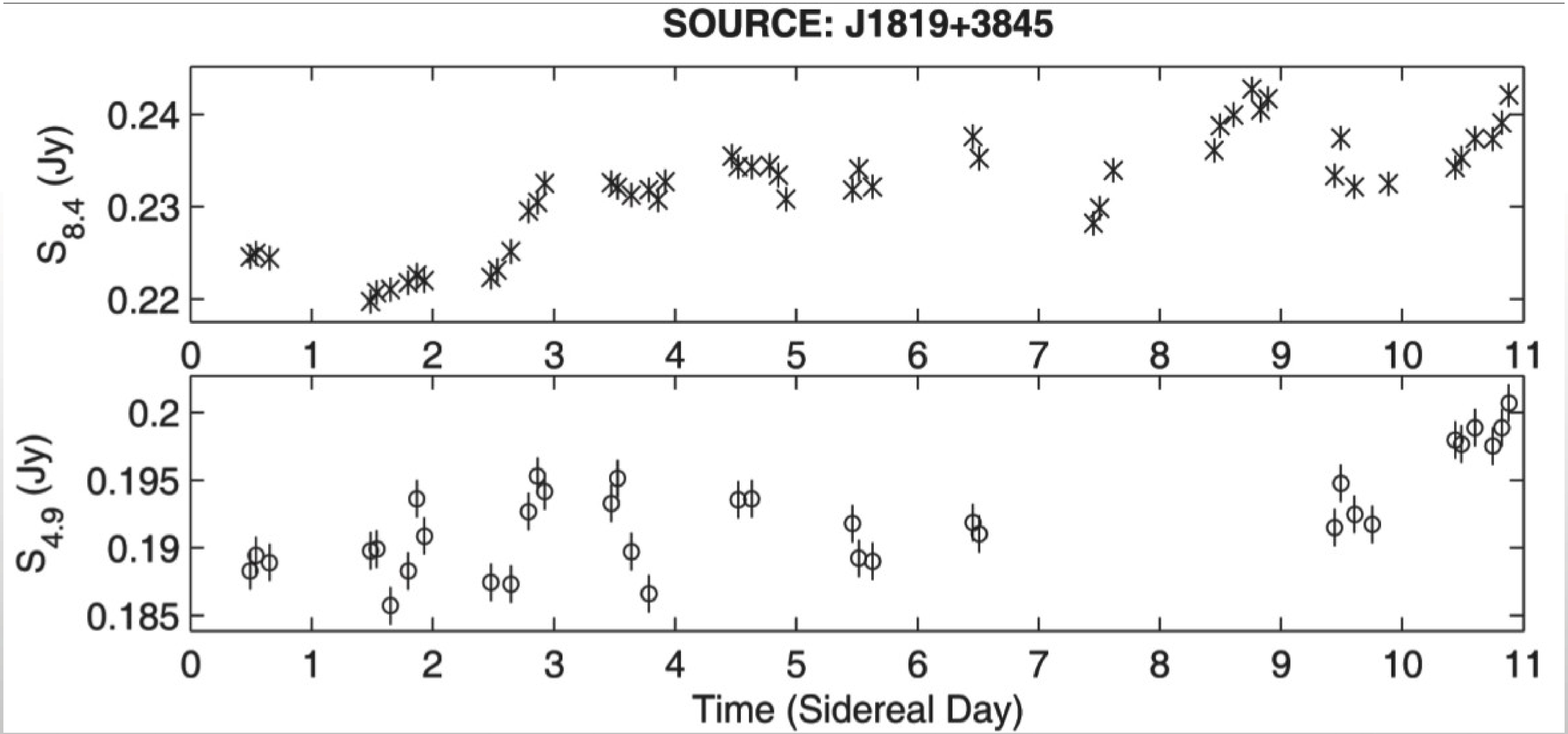
How to find fast variability



Example light curve of a fast scintillator from MASIV Survey VLA follow-up



J1819+3845 no longer shows extreme, fast scintillation



Implications of fast scintillation

- T_{char} < 2 hr attributed to scattering at D<12 pc for a ~200 μas source or D<250 pc for a ~10 μas source
- Can constrain compact fraction and brightness temperature – cf mas-scale structure from VLBI
- Correlation between fast scintillation and low line-of-sight Hα: suggestive of lower effective scattering screen distances (although PKS 1257-326 has high Hα! - multiple screens possible)
- Change in J1819+3845 – interpreted as nearby "screen" drifting out of the line of sight
  - Similar to episodic behaviour of PKS 0405-385

Implications of fast scintillation

- Fast scintillators are not as rare as initially thought, but large-amplitude (>10%) ISS of quasars is rare.
- Quasar ISS is a combination of source and screen.. screen may dominate behaviour!
- Need methods for dealing with variability in synthesis imaging – e.g. Stewart et al. (A&A, accepted, arXiv.org/abs/1107.4282): generalisation of N-beam CLEAN algorithm
- Need to consider the effects of ISS on radio transient population studies

ASKAP simulation including (extreme) variable sources

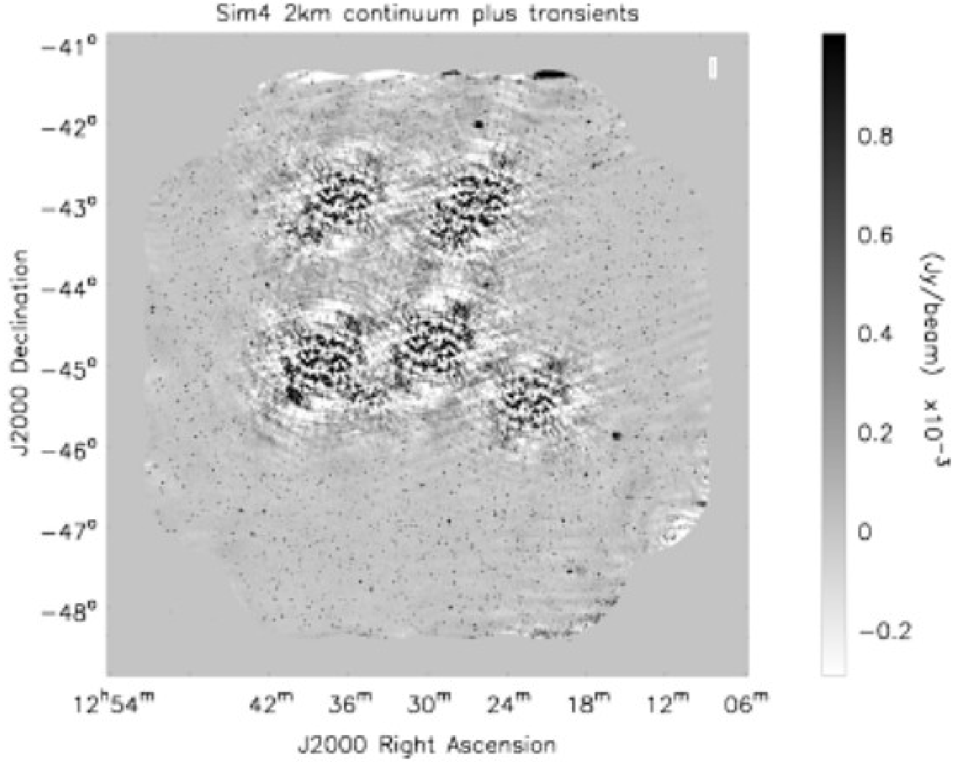
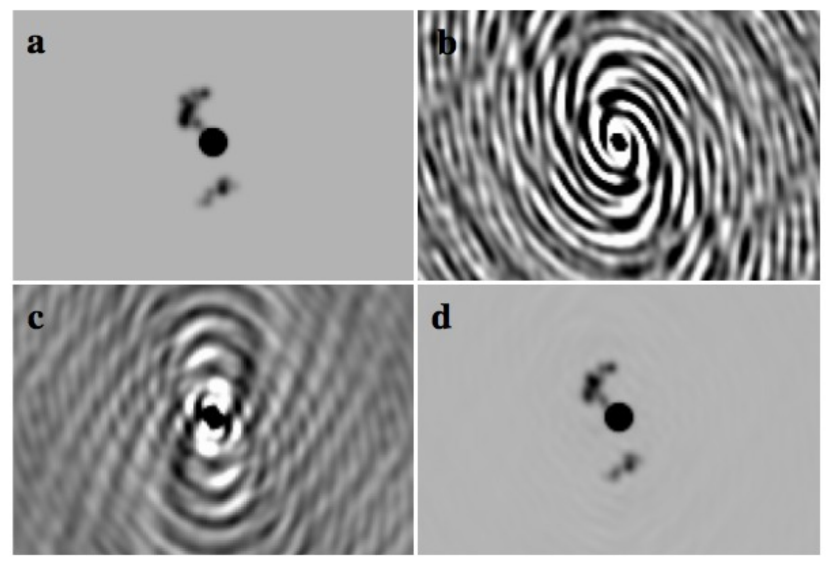


Figure 1: SST4 continuum image showing artefacts caused by the inclusion of variable sources.



Simulation by Stewart et al. (2011) of variable point source + extended emission using (c) standard clean and (d) 2-beam decomposition