Interstellar scintillation as a probe of μas-scale structure in quasars

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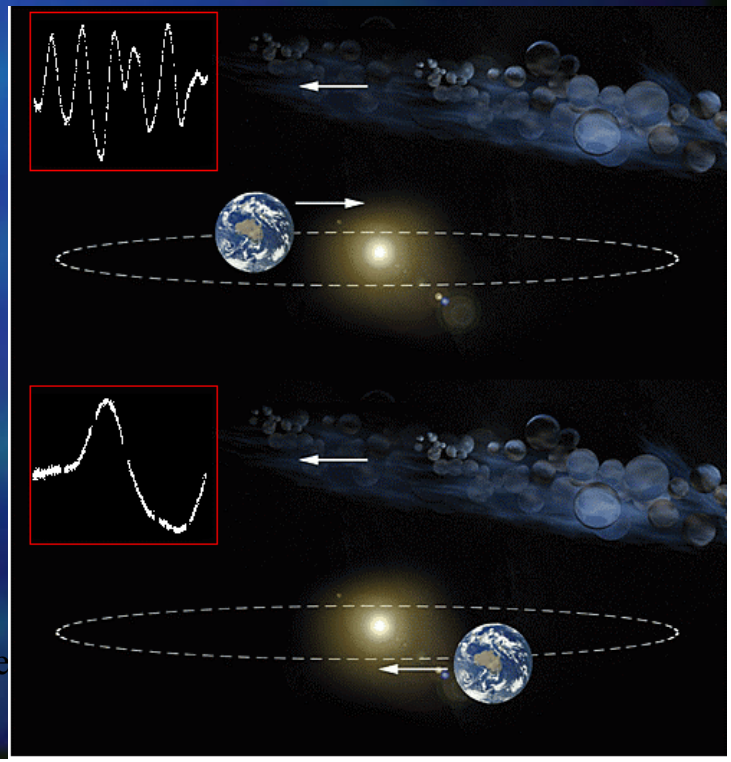


People involved:

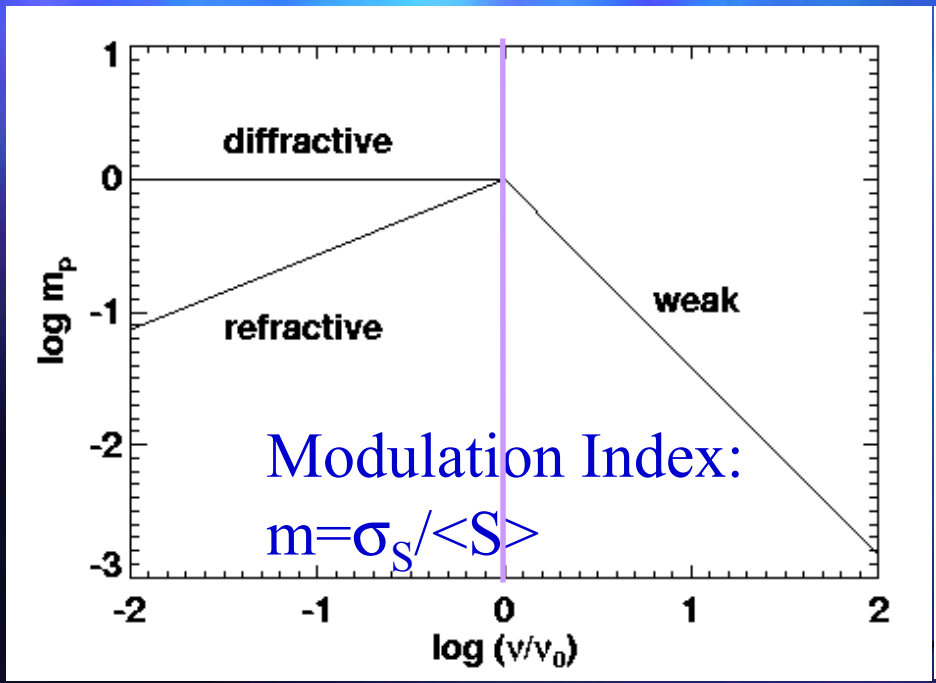
- Dave Jauncey, Jim Lovell, Tasso Tzioumis, Roopesh Ojha (ATNF)
- Lucyna Kedziora-Chudczer (U. Sydney)
- Jean-Pierre Macquart (now at NRAO/Caltech)
- Barney Rickett (UC-San Diego)
- Steve Carter, Giuseppe Cimó, Simon Ellingsen, Peter McCulloch (U. Tasmania)

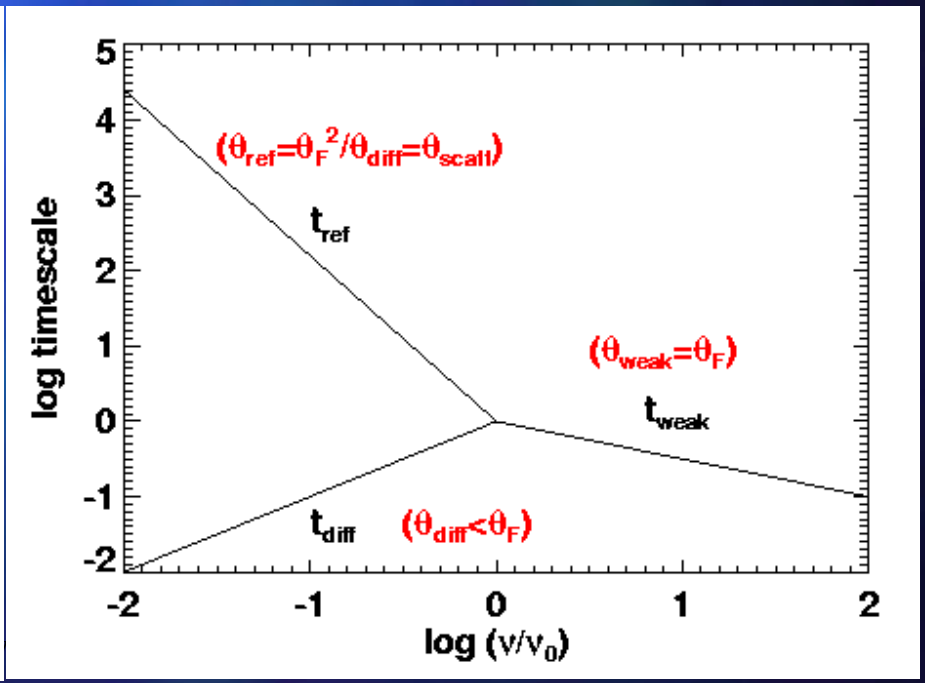
Outline

- Background: scintillation regimes
- Recent observations:
  - The fast scintillators, PKS 0405-385, J1819+3845, PKS 1257-326
  - the MASIV picture: ISS statistics
  - Slower scintillators: dedicated monitoring
- Summary and conclusions:
  - *What are ISS observations useful for?*

Background: scintillation

- Regimes of strong and weak scattering
  - transition occurs where medium introduces rms phase changes ~1 radian over 1st Fresnel zone $r_F=\sqrt{(\lambda L/2\pi)}$
- Point source behaviour:

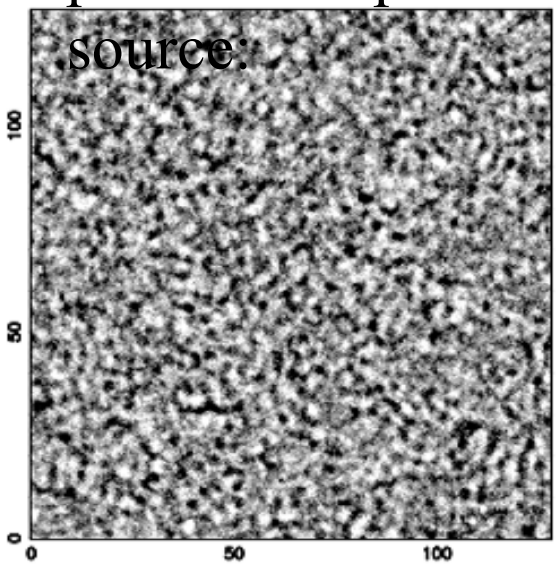




Scintillation of an extended source

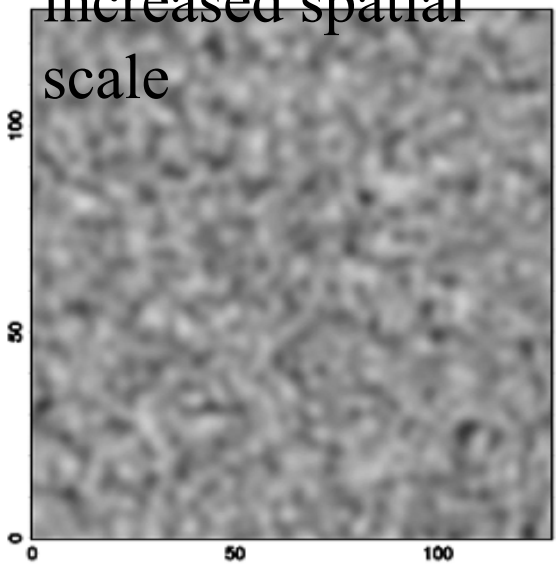
Simulation (Rickett)

Scintillation pattern of a point source:



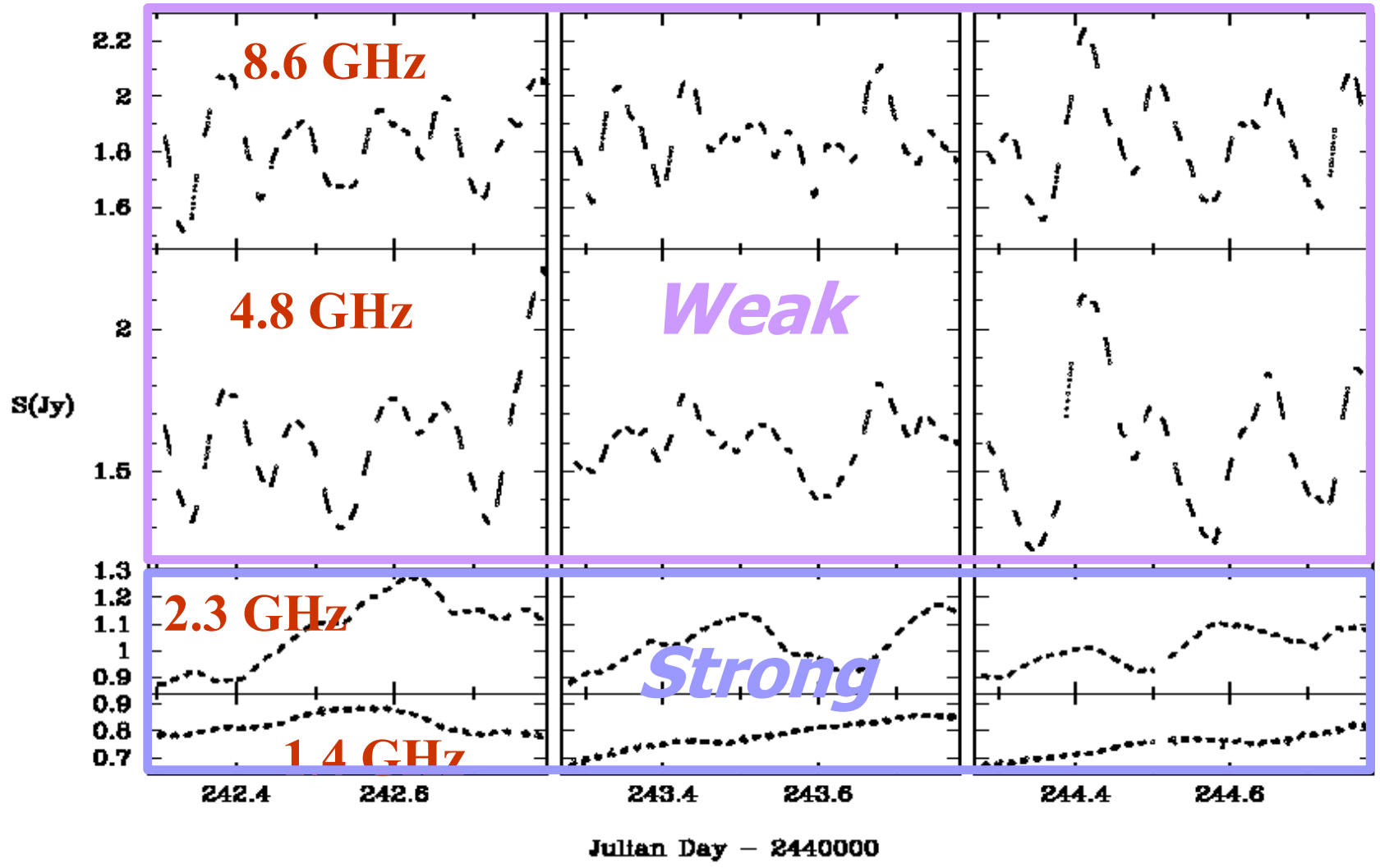
Extended source:

Reduced amplitude, increased spatial scale



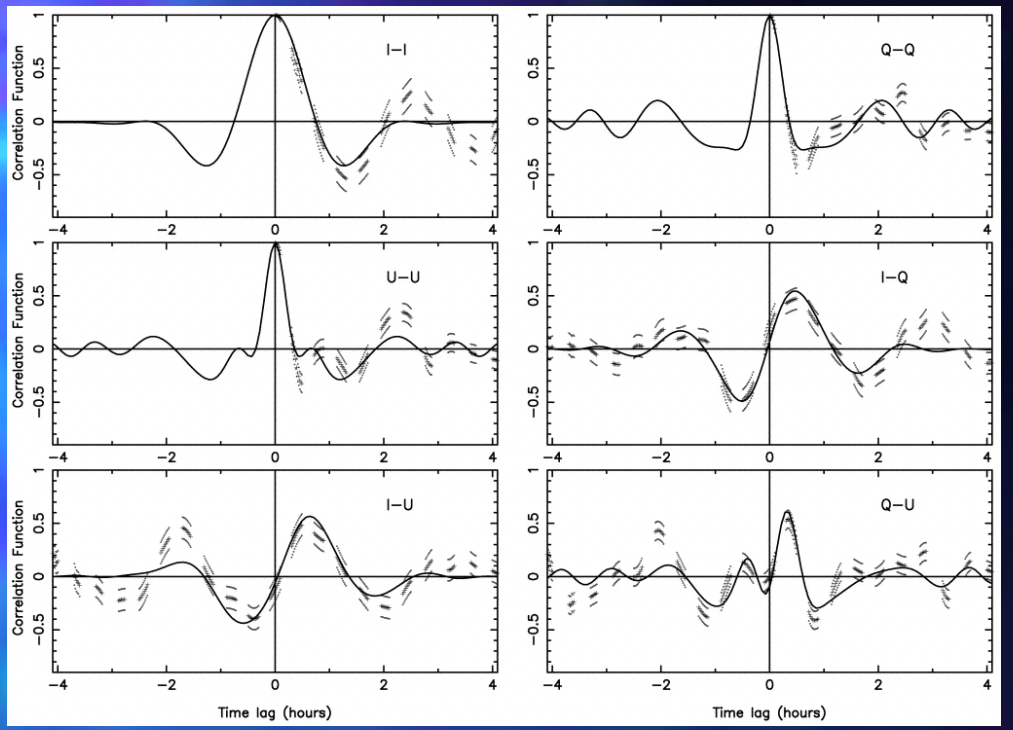
PKS 0405-385: the first "intra-hour variable"

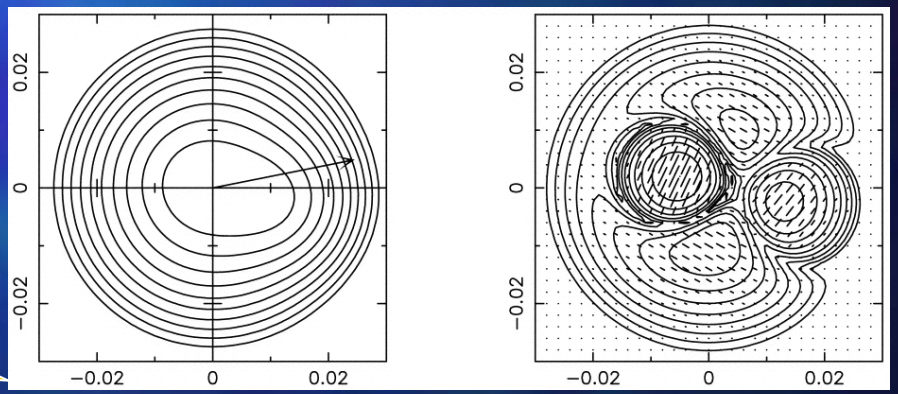
Kedziora-Chudczer et al. (1997)



PKS 0405-385

- Rickett, Kedziora-Chudczer & Jauncey (2002) used cross-correlations between Stokes parameters to model μas-scale polarized structure

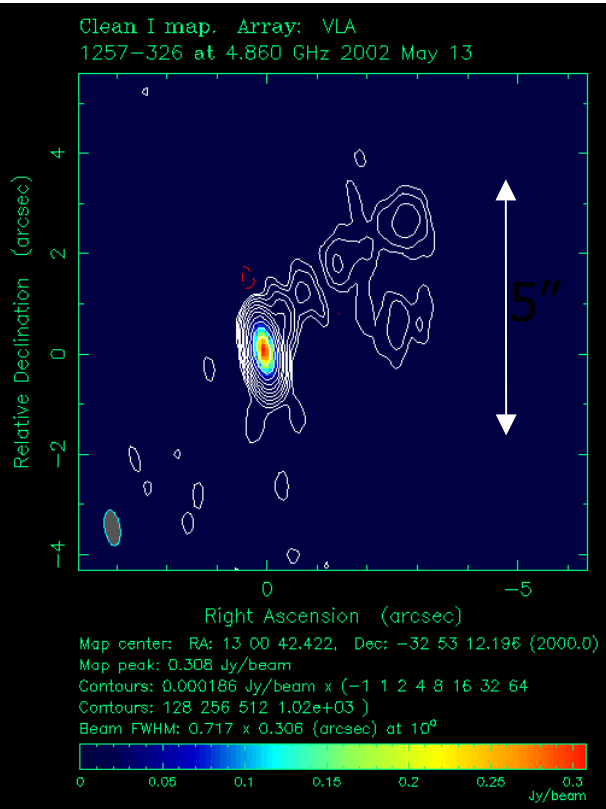


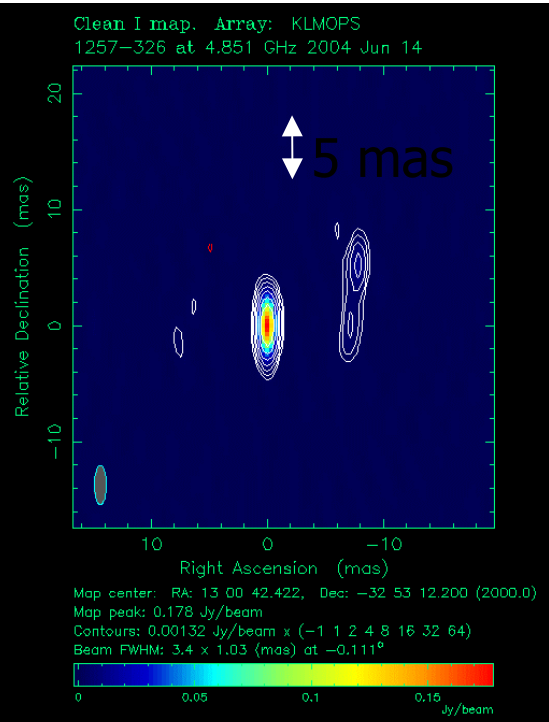


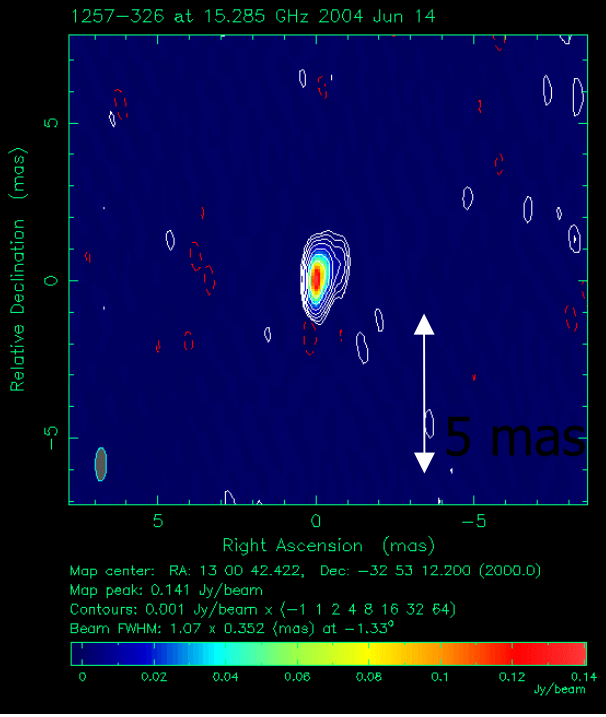
ISS observed again in 2004 after quiescent period > 4 years! (Cimó et al., MNRAS 2003)

PKS 1257-326

- 3rd intra-hour variable discovered, after PKS 0405-385 and J1819+3845 (Dennett-Thorpe & de Bruyn 2000, .., 2003)
- X-ray emitting quasar at z=1.256 (Perlman *et al.* 1998), B=18.7
- Flat radio spectrum; <S> ~ 0.3 Jy (1-22 GHz)
- Radio structure: compact core + extended emission on arcsec and mas scales *unlike other 2 fast scintillators*





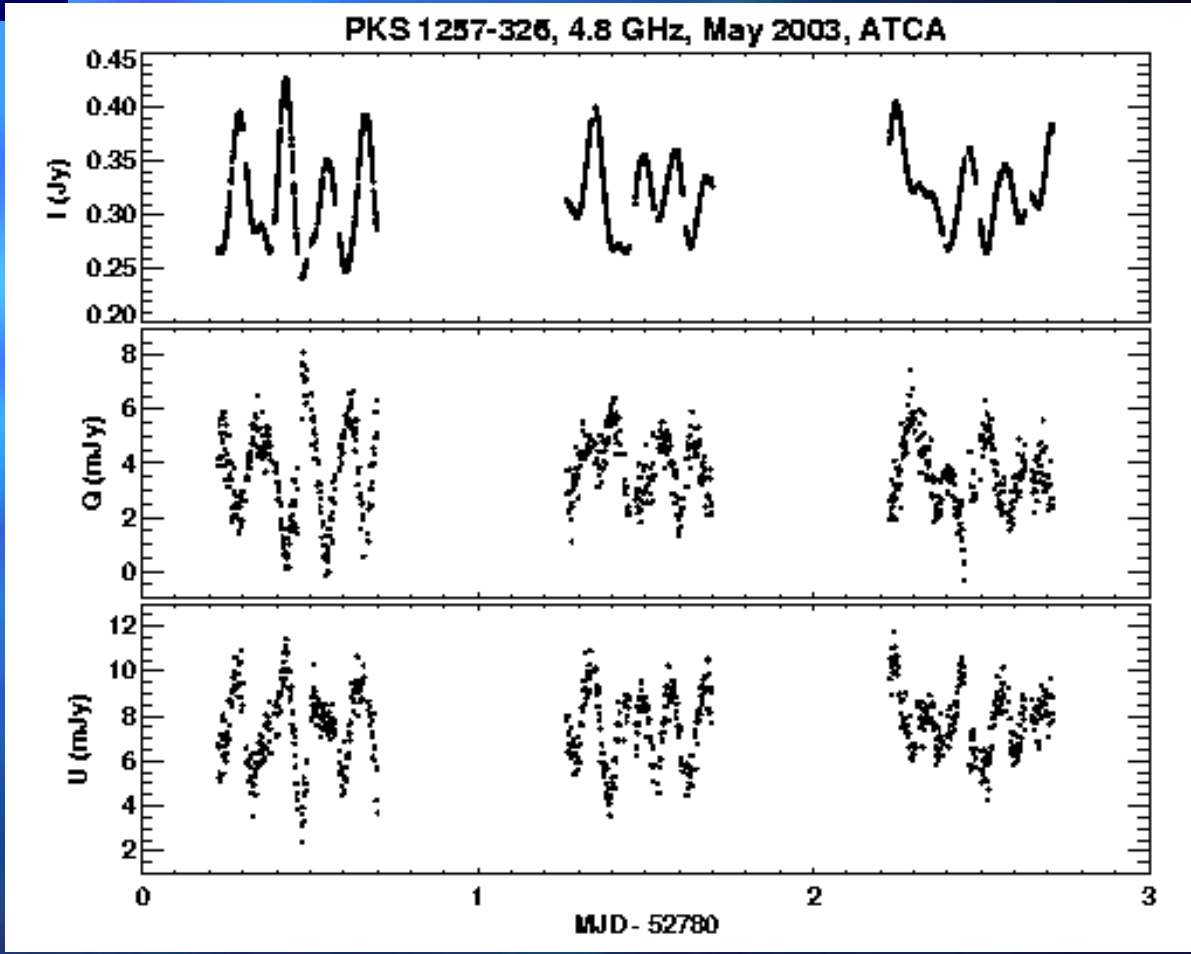


PKS 1257-326:

Structure on various spatial scales

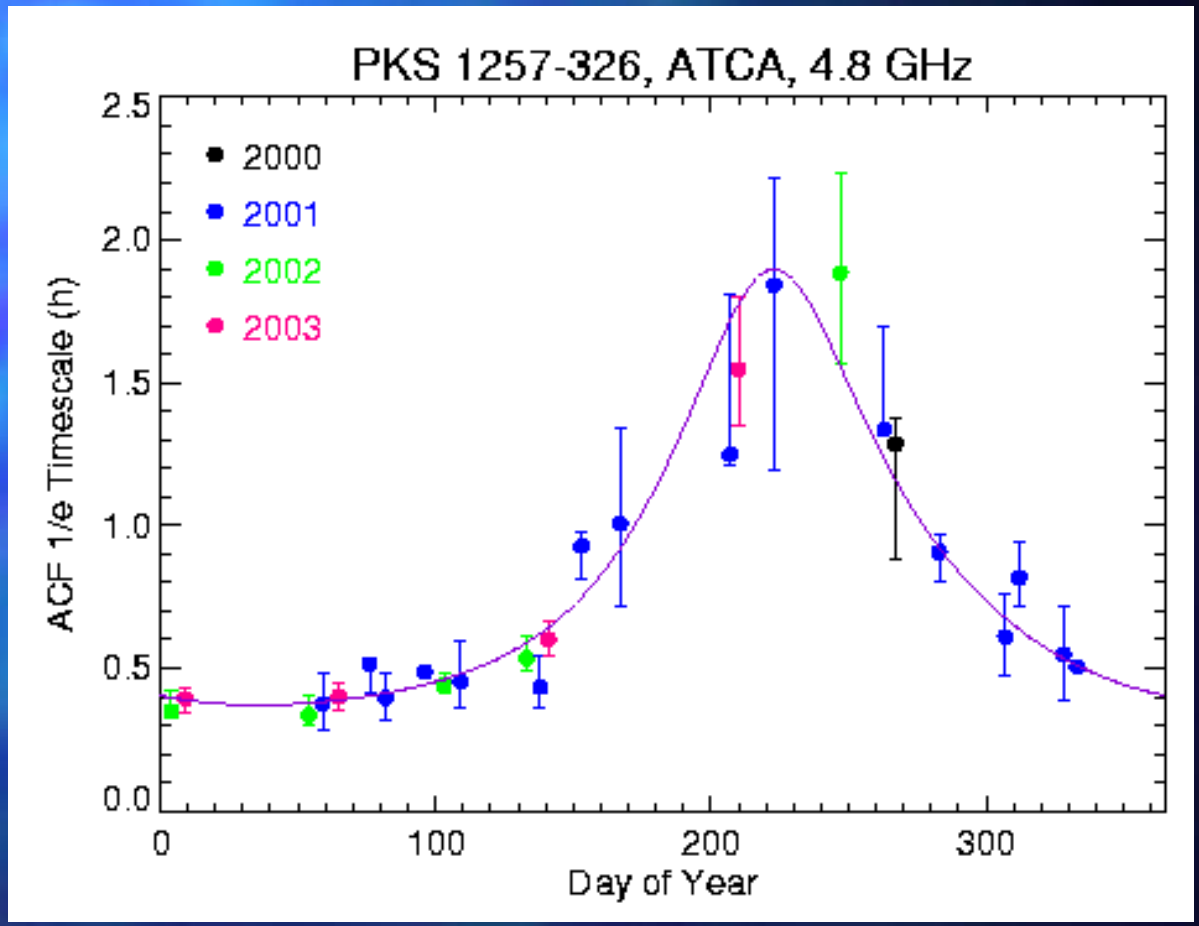
PKS 1257-326

- Rapid variations observed in ATCA data since mid-2000



PKS 1257-326

- Annual cycle in characteristic timescale (Bignall *et al.* 2003)
- Combined with 2-station time delays, measured at 3 different times of the year...



PKS 1257-326

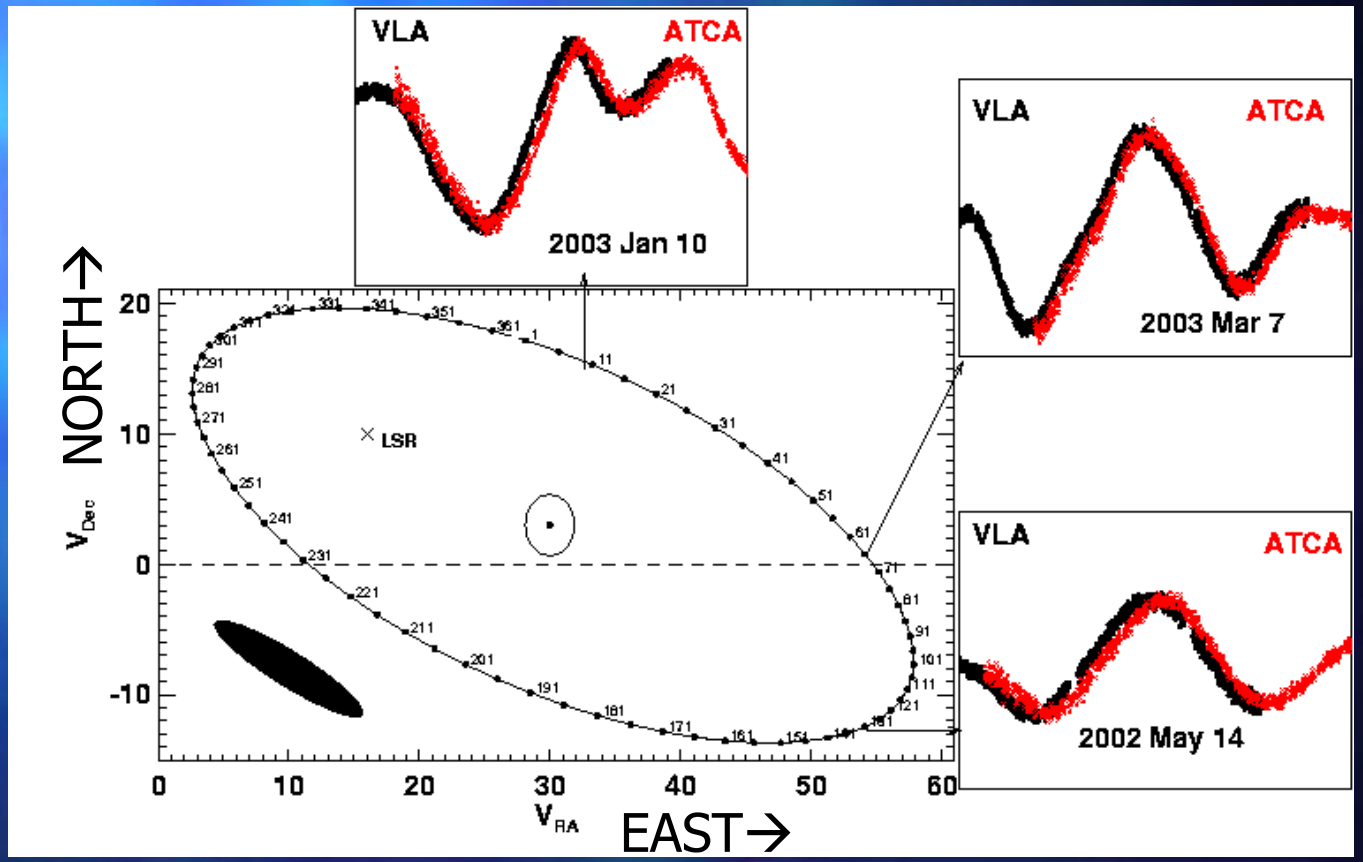
- Fit for scintillation velocity, pattern scale, axial ratio and angle:

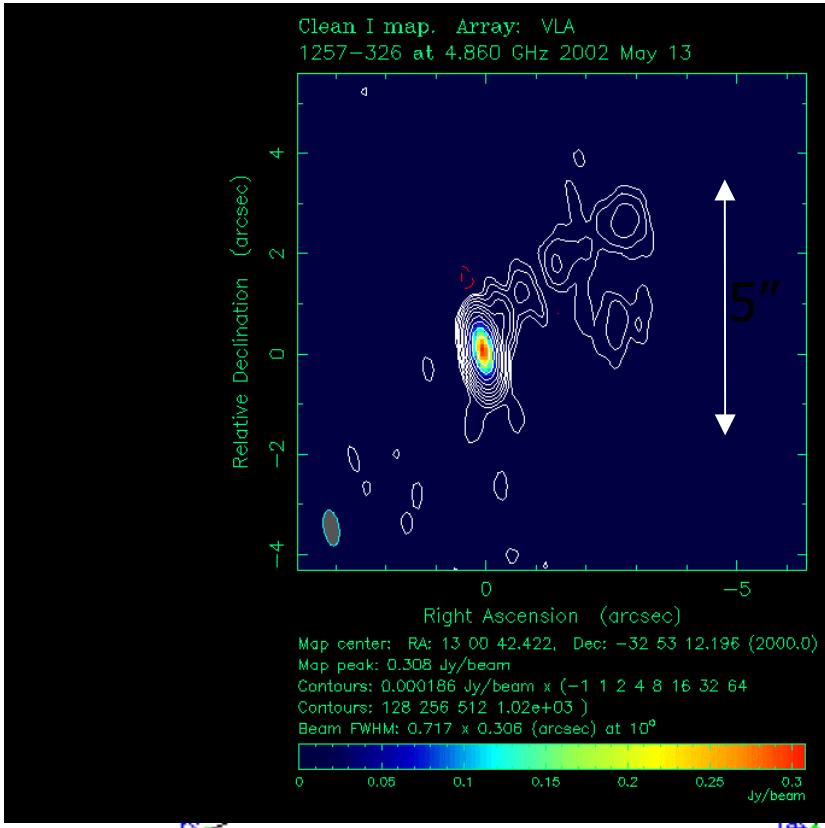
At 5 GHz,

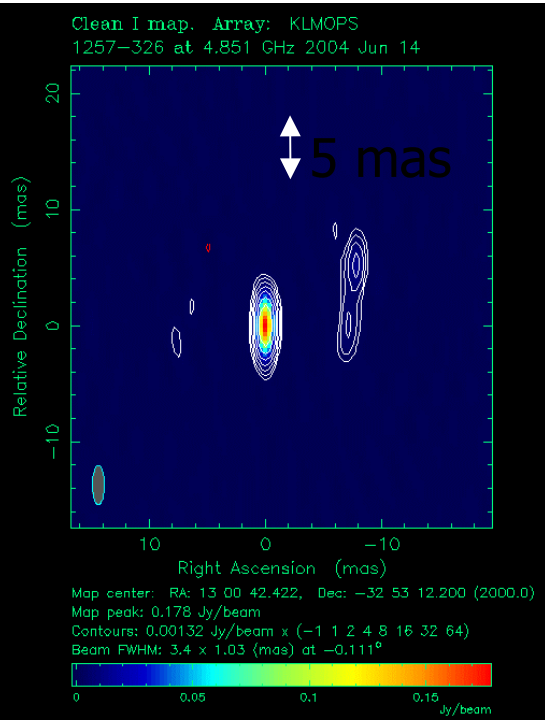
- $s_0 \approx 10^5$ km
- $R \geq 5$

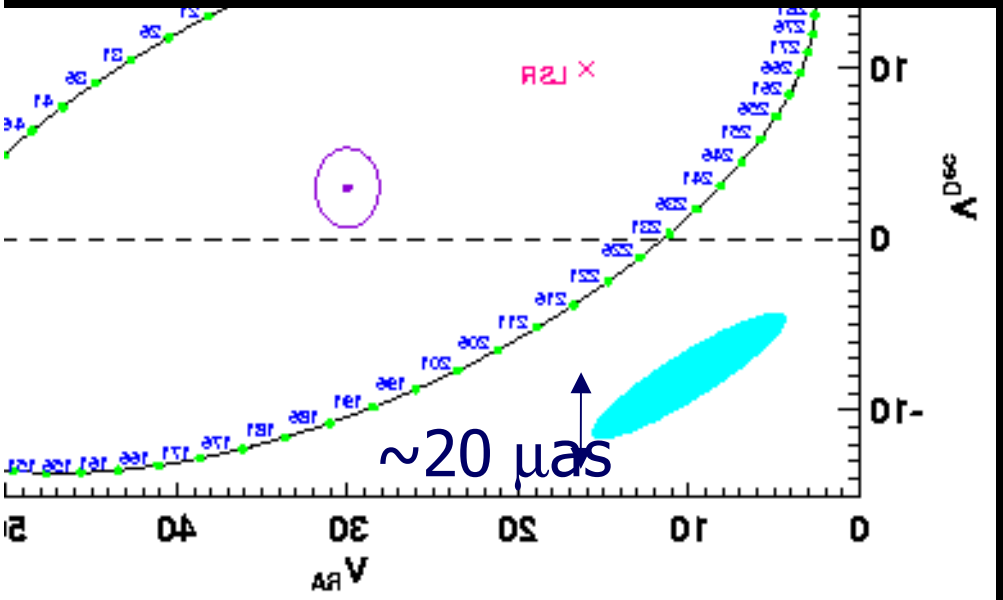
If $r_F \approx s_0$: (smaller if source resolved)

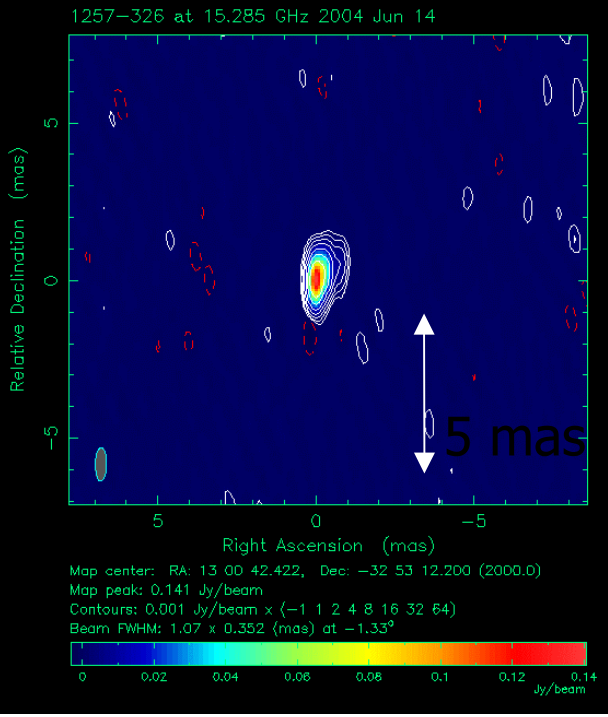
→ $L \approx 30$ pc and $\theta_F \approx 20\mu$as

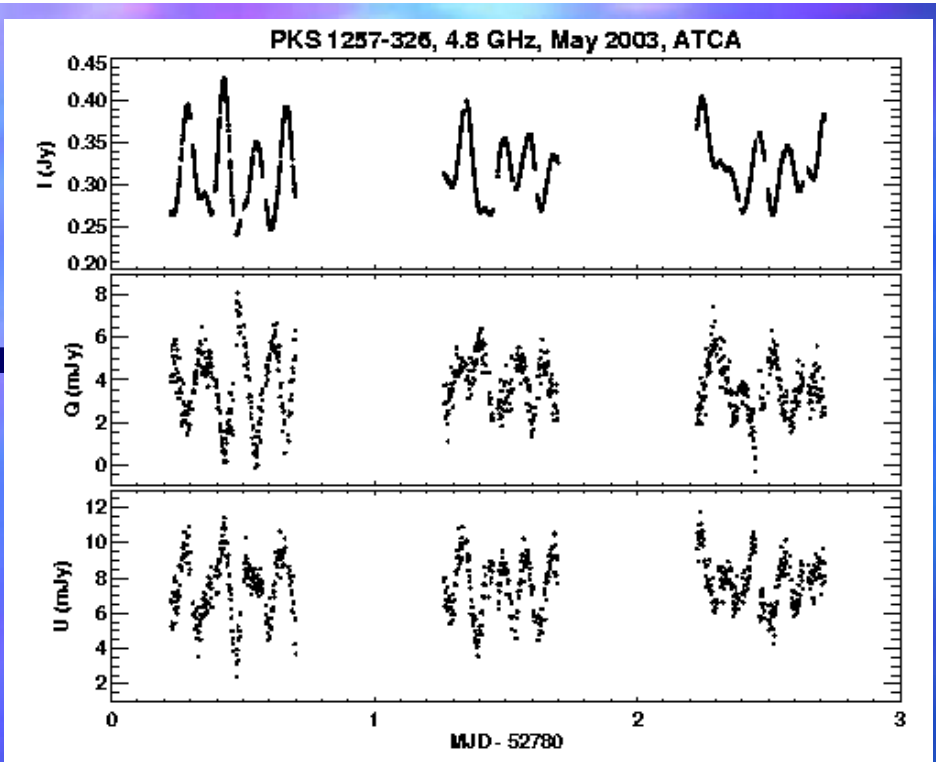


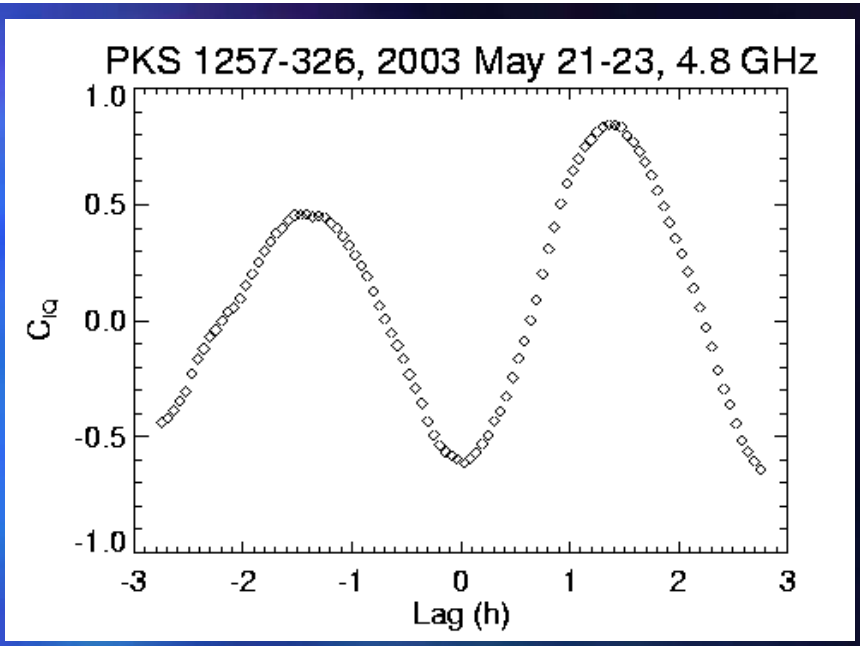

Clean I map. Array: VLA
1257−326 at 4.860 GHz 2002 May 13
Relative Declination (arcsec)
Right Ascension (arcsec)
5″
Map center: RA: 13 00 42.422, Dec: −32 53 12.196 (2000.0)
Map peak: 0.308 Jy/beam
Contours: 0.000186 Jy/beam x (−1 1 2 4 8 16 32 64
Contours: 128 256 512 1.02e+03)
Beam FWHM: 0.717 x 0.306 (arcsec) at 10°
Jy/beam

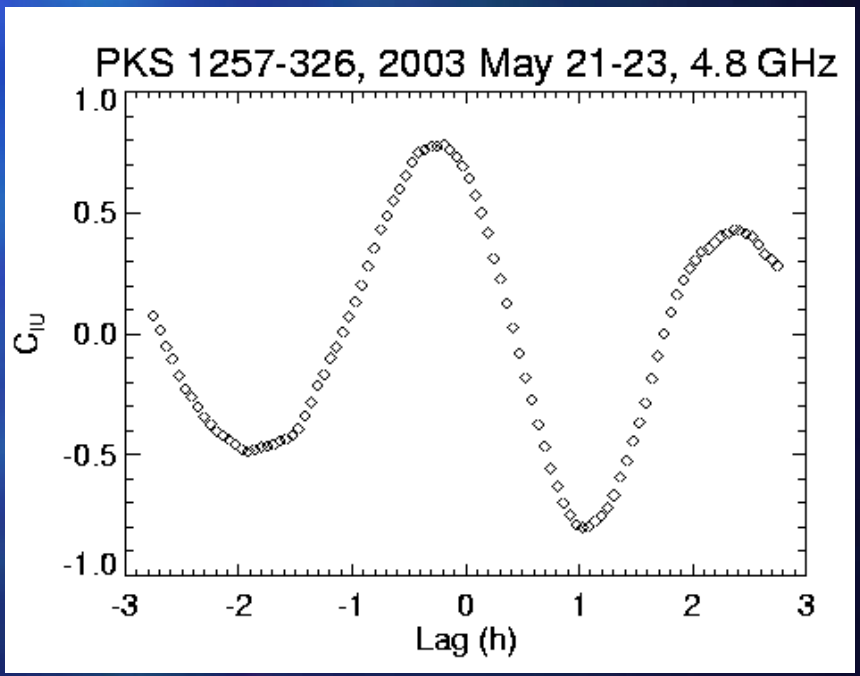

Clean I map. Array: KLMOPS
1257−326 at 4.851 GHz 2004 Jun 14
Relative Declination (mas)
Right Ascension (mas)
5 mas
Map center: RA: 13 00 42.422, Dec: −32 53 12.200 (2000.0)
Map peak: 0.178 Jy/beam
Contours: 0.00132 Jy/beam x (−1 1 2 4 8 16 32 64)
Beam FWHM: 3.4 x 1.03 (mas) at −0.111°
Jy/beam


~20 μas


1257−326 at 15.285 GHz 2004 Jun 14
Relative Declination (mas)
Right Ascension (mas)
5 mas
Map center: RA: 13 00 42.422, Dec: −32 53 12.200 (2000.0)
Map peak: 0.141 Jy/beam
Contours: 0.001 Jy/beam x (−1 1 2 4 8 16 32 64)
Beam FWHM: 1.07 x 0.352 (mas) at −1.33°
Jy/beam



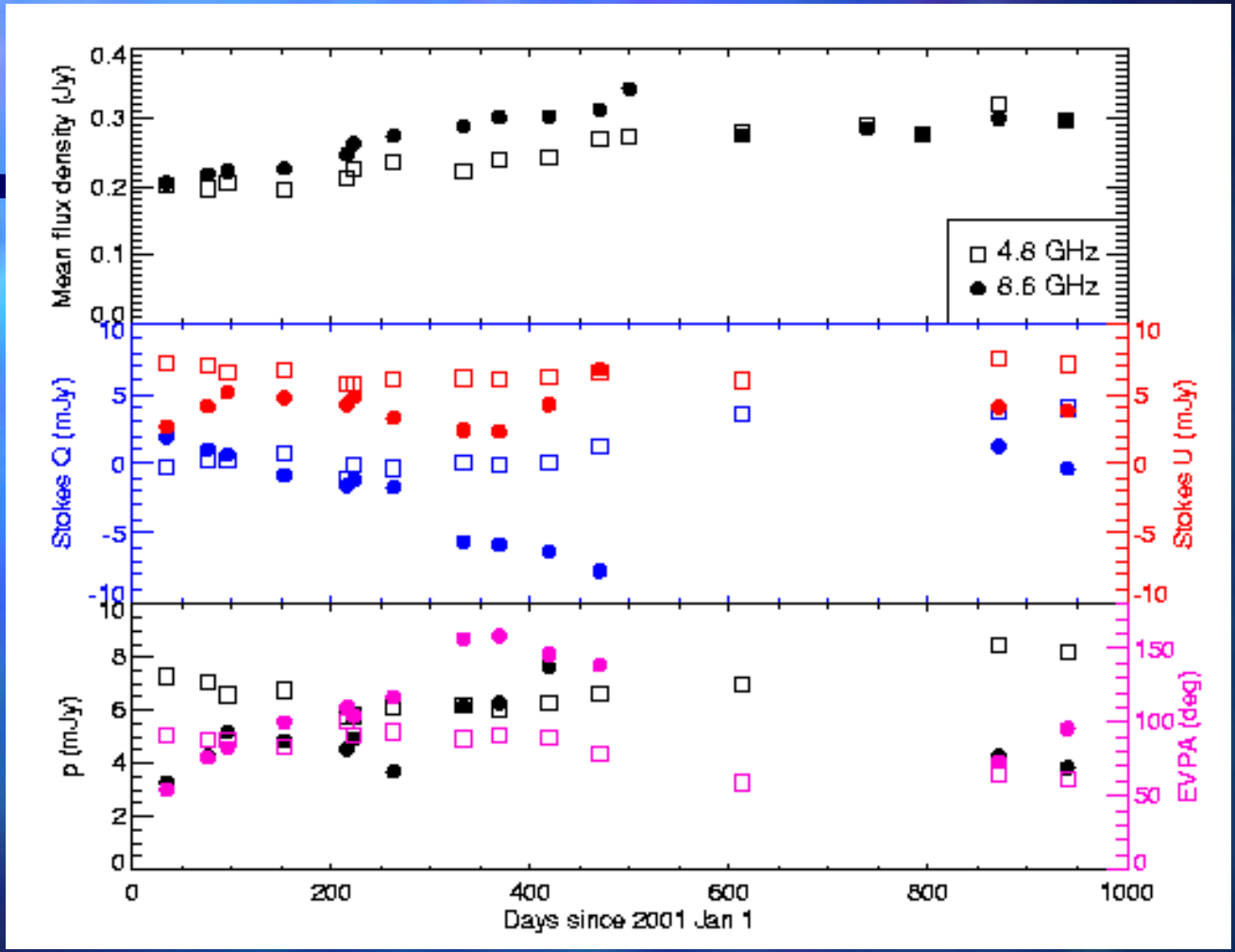




Work in progress:

- Modelling of μas-scale polarization based on various Stokes cross-correlations (cf 0405)
- Frequency offsets (see Bignall et al. 2003)

PKS 1257-326: long term changes



PKS 1257-326 and J1819+3845 show remarkably similar behaviour

The MASIV Survey

- Micro-Arcsecond Scintillation Induced Variability
- Observations:
  - VLA at 5 GHz, 5 subarrays
  - 525 unresolved, flat-spectrum sources observed in 4 epochs, each 72 h
- Results:
  - 28% of sources varied in at least one epoch (rms > 2σ)
  - In any given epoch, 11-15% varied
  - *Fast scintillators (intra-hour variations, nearby screens) are extremely rare*

1st results: Lovell et al. 2003. See also Ojha et al. 2004 (Oct 20 ApJ)

The COSMIC program…

COntinous
Single dish
Monitoring of
Intraday variability at
Ceduna

16 Nov 2004

The COSMIC program…

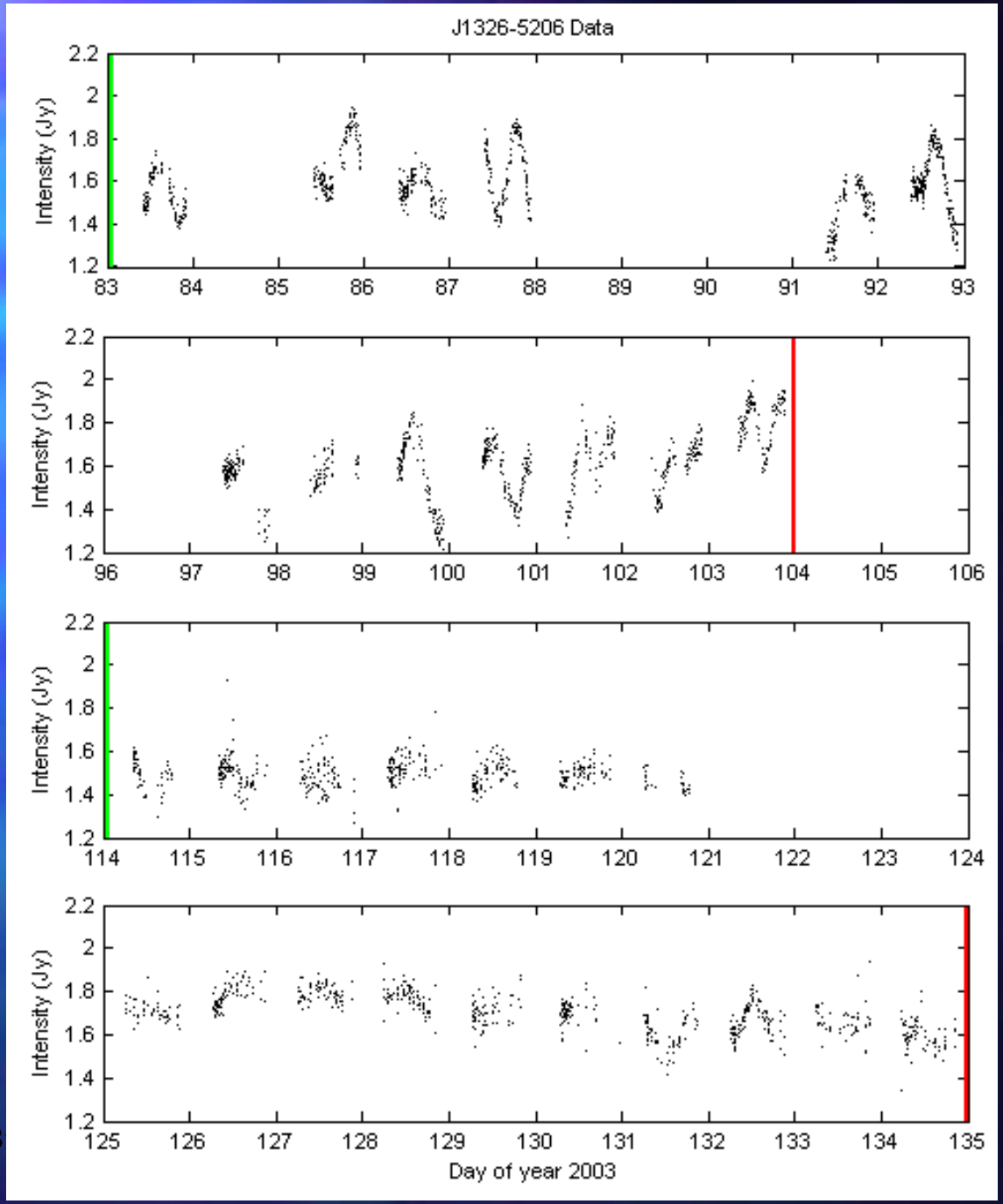
- University of Tasmania's 30m telescope at Ceduna, operated remotely from Hobart
- 4 strong southern IDVs + calibrators observed at 6.7 GHz
- Can measure variations >2% (in ~1 Jy sources)
- Now have data over 1 year

PMN J1326-5256

(Carter et al. in prep.)

Under investigation:

- Power spectra of fluctuations → scattering "screen" properties, source size
- Changes in IDV behaviour – due to source or screen?

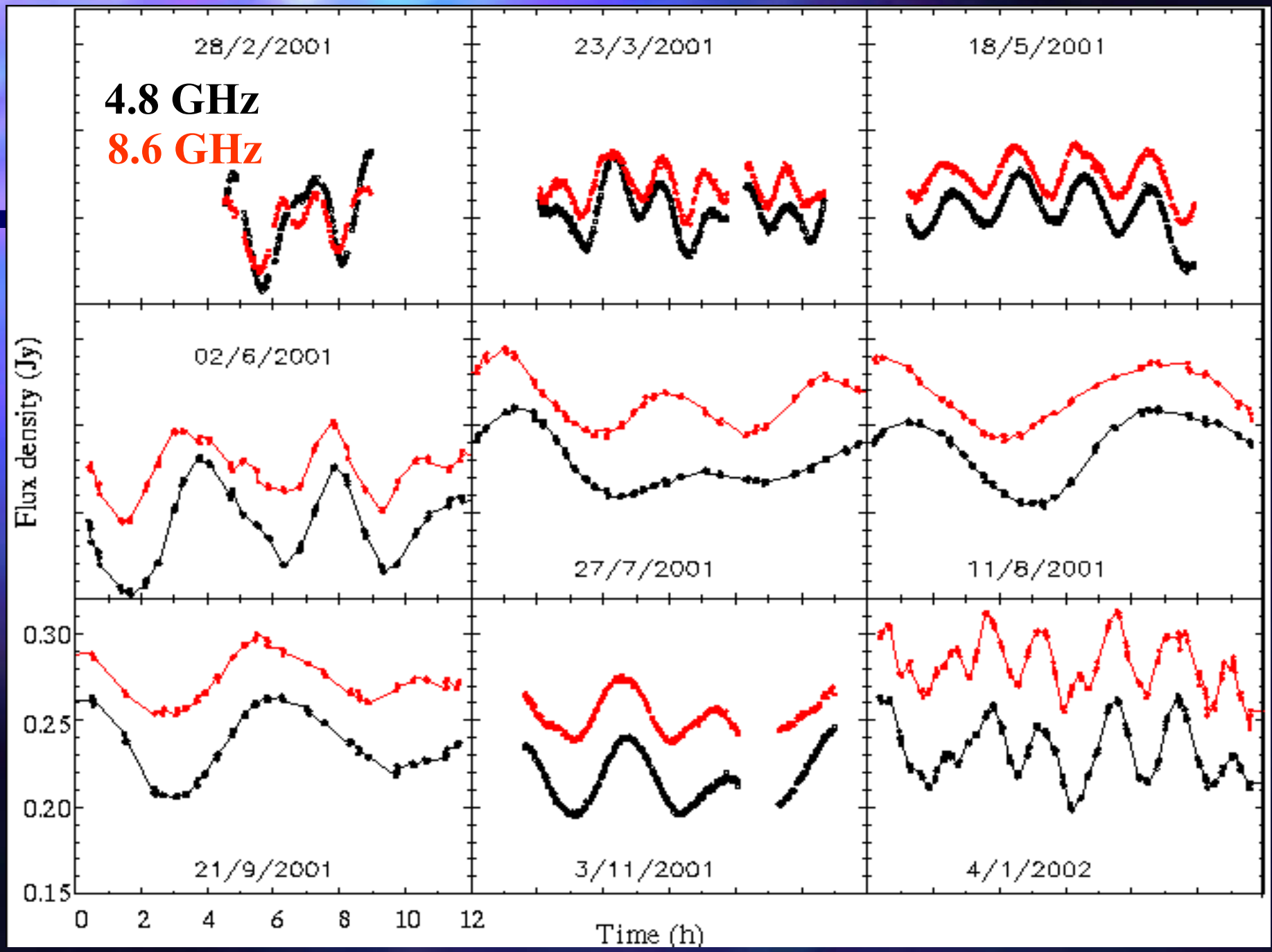


Summary

- For AGN, interstellar scintillation is influenced by source structure
- ISS not subject to T_b limit of Earth-based VLBI ($\sim 10^{12}$ K)
  - However, preliminary analysis of MASIV data indicates peak $T_b \sim 10^{12}$ K
- ISS is a unique tool for μas-scale "reference mapping": polarization and multi-frequency

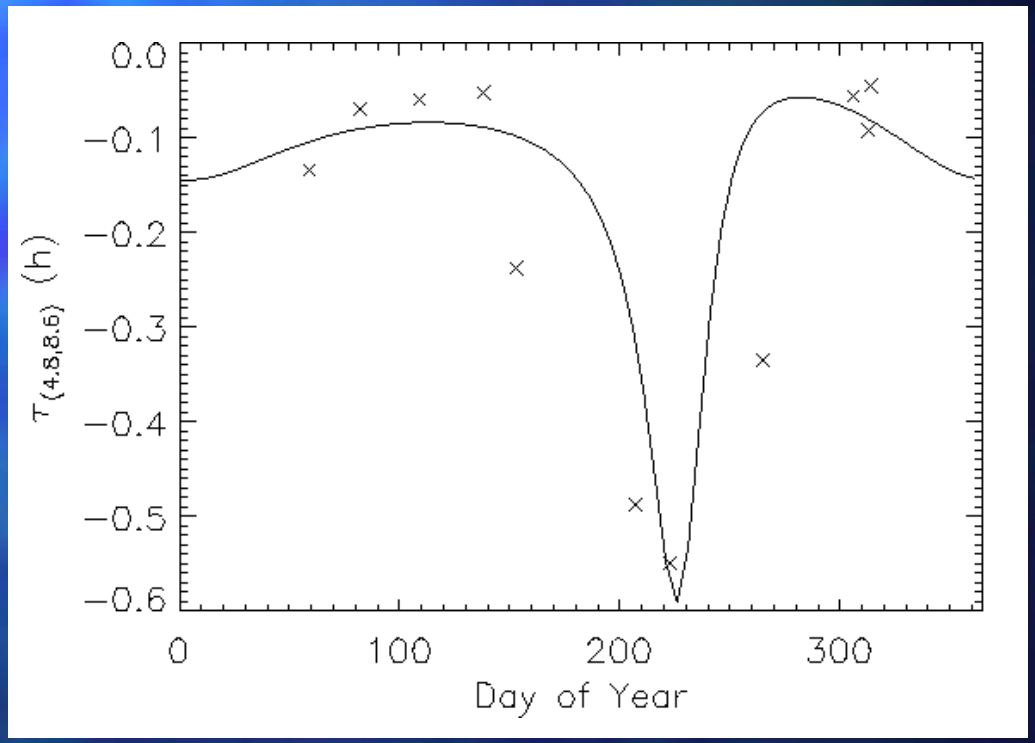
Summary

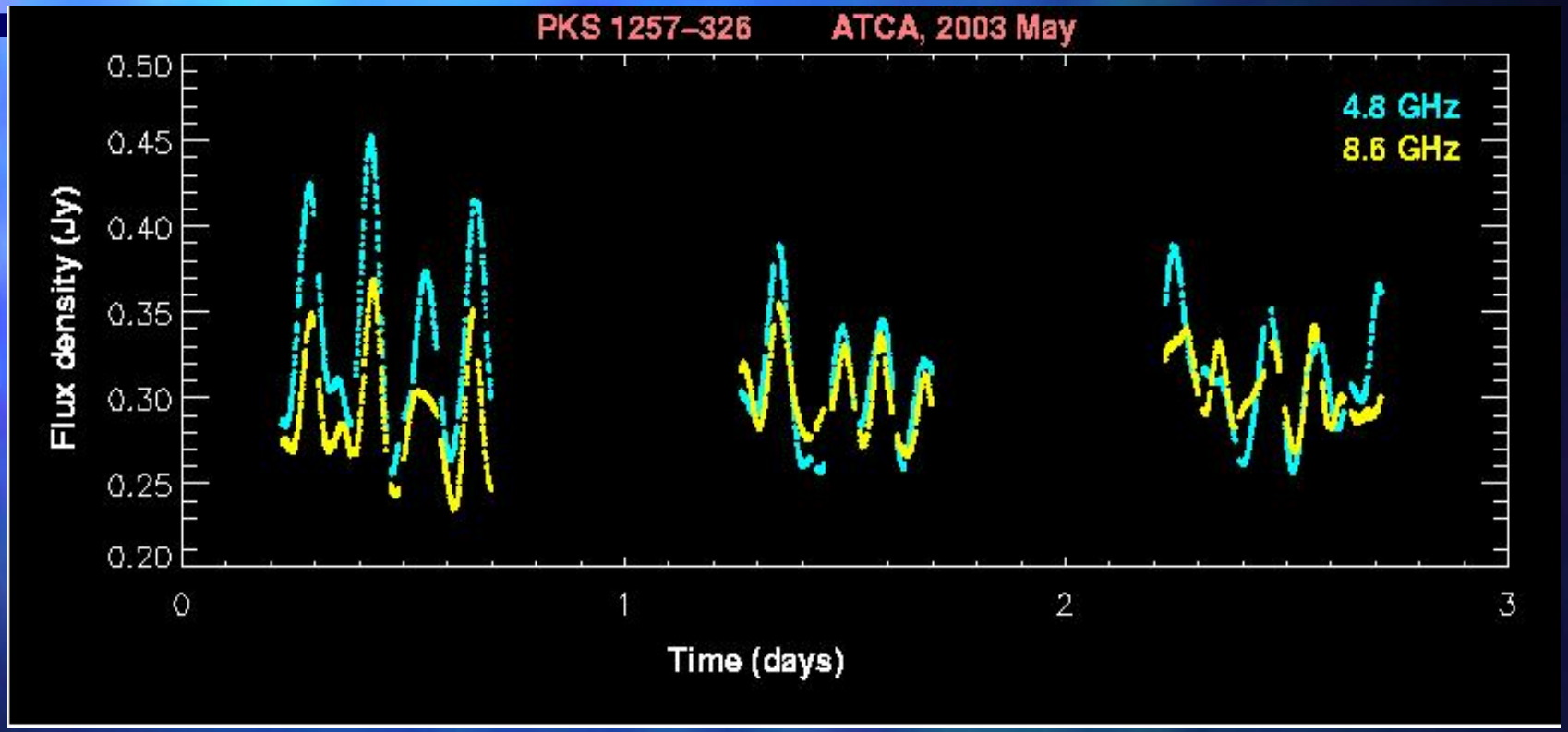
- Currently, monitoring with interferometers only feasible for few fast scintillators
- For slower, bright scintillators, dedicated monitoring possible with single dish telescopes
  - educational facilities (PARTNeR, GAVRT)

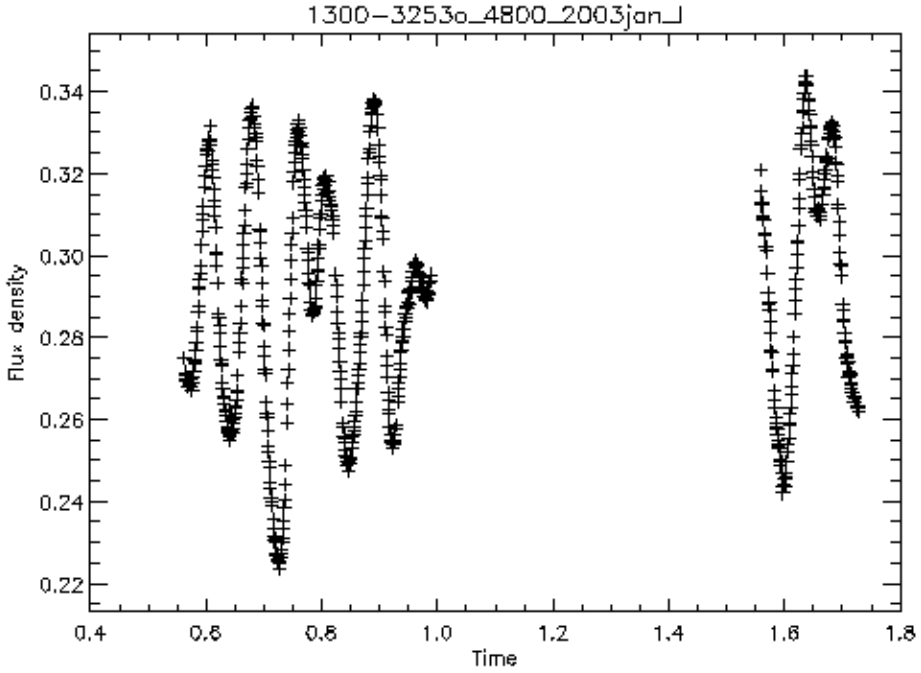

28/2/2001
23/3/2001
18/5/2001
4.8 GHz
8.6 GHz
02/6/2001
27/7/2001
11/8/2001
21/9/2001
3/11/2001
4/1/2002
Flux density (Jy)
0.30
0.25
0.20
0.15
0
2
4
6
8
10
12
Time (h)

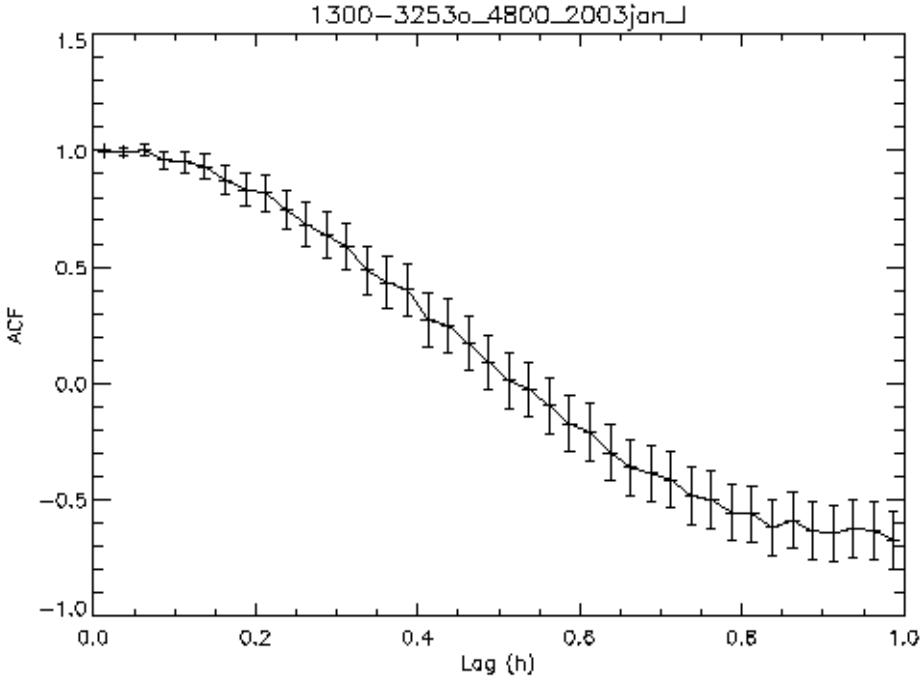
PKS 1257-326: Offset between 4.8 & 8.6 GHz components

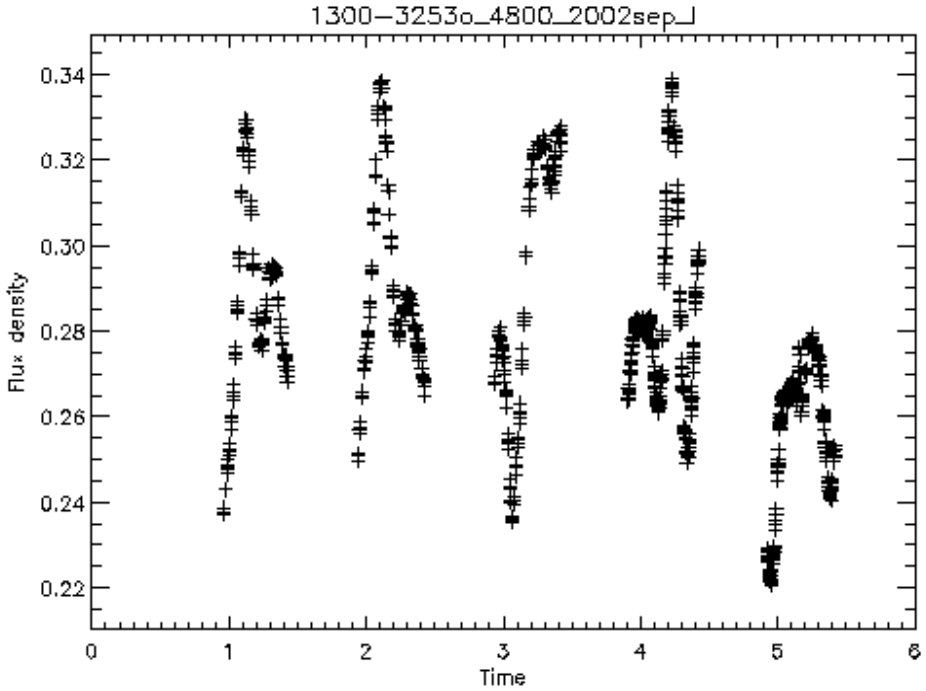
- May be due to opacity effects (SSA): μas-scale "core-shift"
  - At source, separation is <0.1 pc
  - Possible evolution?




PKS 1257–326
ATCA, 2003 May
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)


1300−3253o_4800_2003jan_J
Flux density
Time


1300−3253o_4800_2003jan_J
ACF
Lag (h)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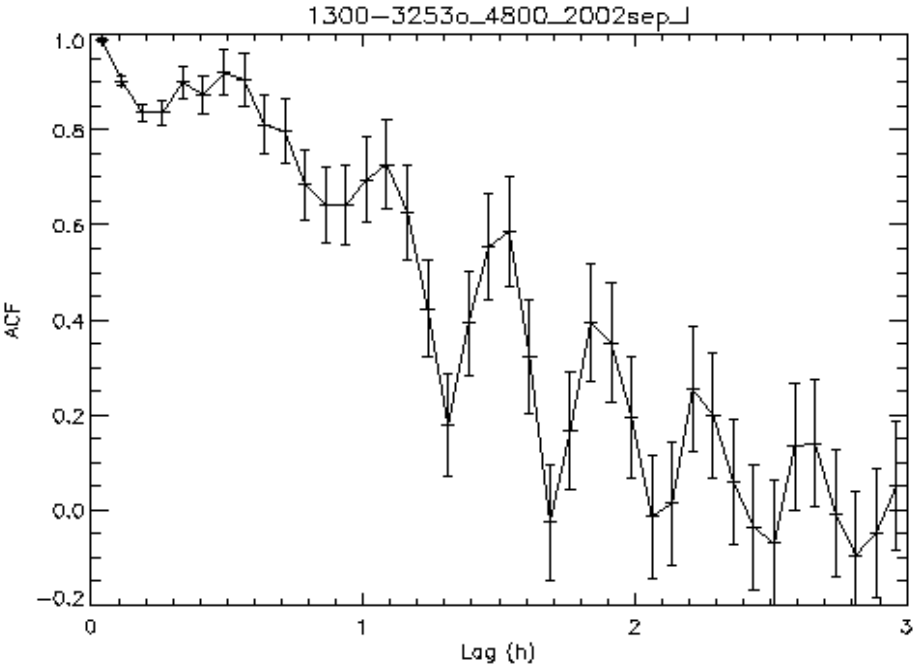
Flux density
Time


1300−3253o_4800_2002sep_J
ACF
Lag (h)