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International Centre for Radio Astronomy Research

The latest from MASIV

and

Resolving the milli-parsec-scale structure of AGN jets

Hayley Bignall

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What are the strongest factors influencing the interstellar scintillation (ISS) of AGN?

ISS of AGN depends on:

- The line-of-sight Galactic electron column density, traced by the Hα emission measure
- Scattering properties of the intervening medium, e.g. fast ISS caused by nearby "screens" ($t \sim \sqrt{D}$)

Extrinsic

- Flux density
- Radio spectral index
- Optical type
- VLBI core dominance and angular extent

Source intrinsic

- Redshift – Intrinsic and/or extrinsic effects?

Some of these parameters are interdependent.

Amplitude of ISS vs optical spectral type & radio flux density

Pursimo et al., submitted to ApJ

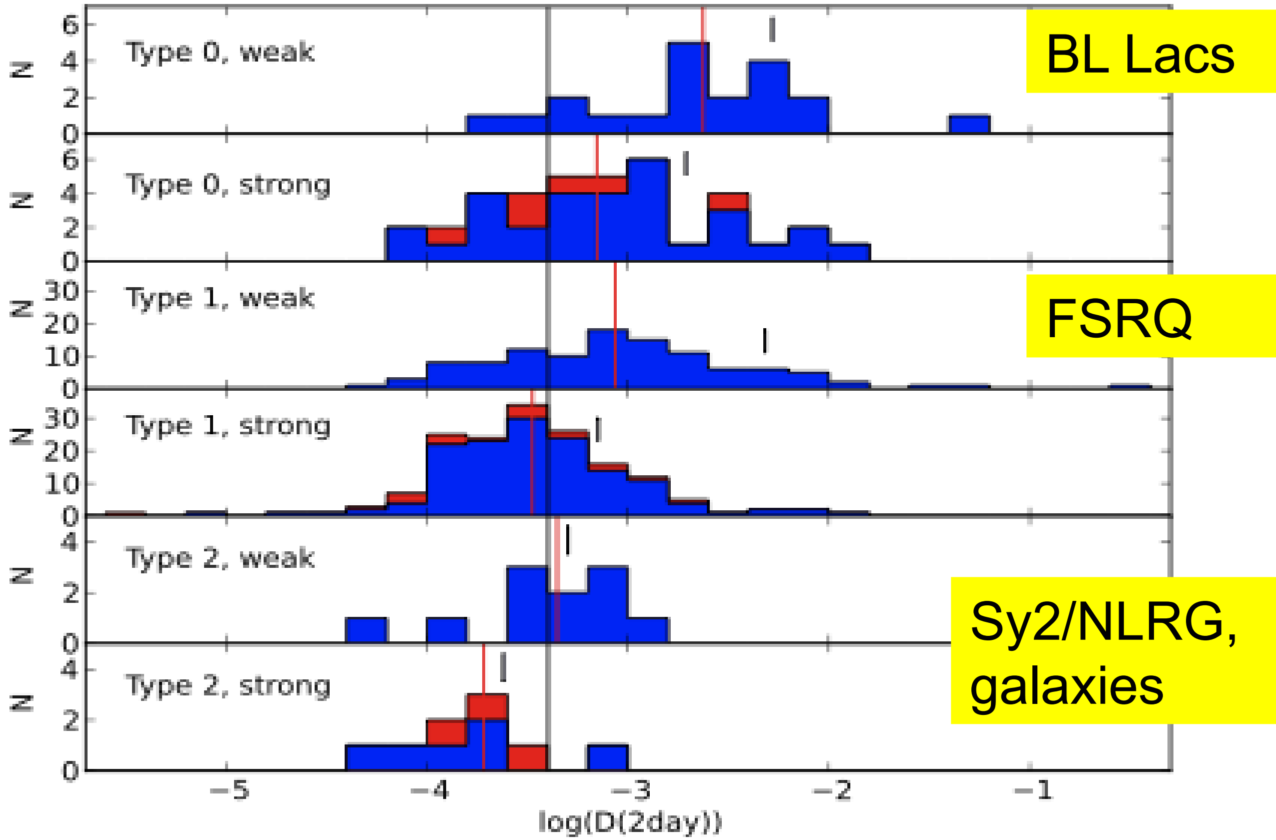


Fig. 4.— D(2days) histograms of MASIV subsamples selected by 5 GHz flux density and optical spectral type. The secondary calibrators are marked with red colour. The black vertical line at −3.4 indicates the limit where SF-analysis suggests variability. In each subplot the red vertical line indicates the median value and the black line the mean value.

Amplitude of ISS vs redshift (Type 1 sources)

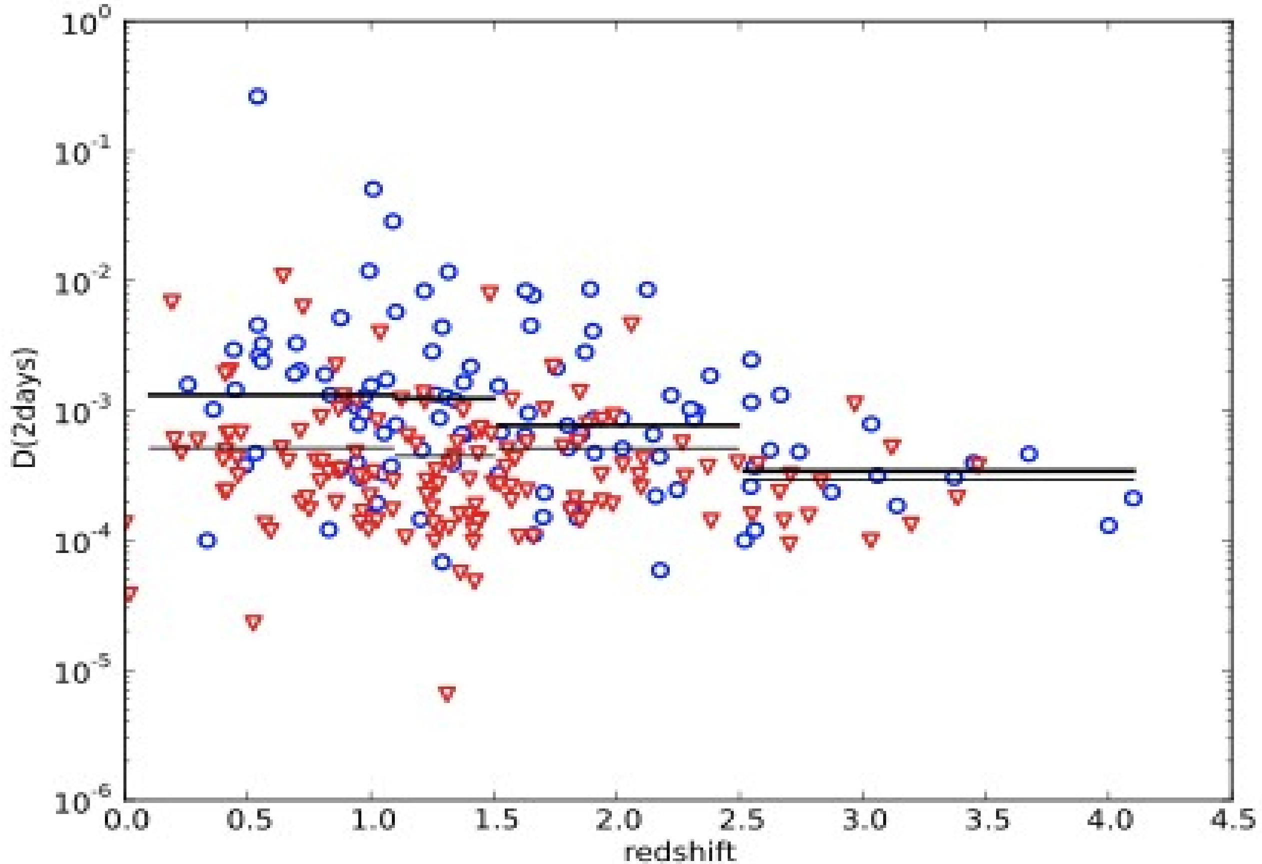


Fig. 5.— D(2days) against redshift for the Type 1 sources. Red triangles indicate radio strong sources and blue circles radio weak. The horizontal thin and thick lines indicate the median D(2days) for the given redshift interval for radio strong and weak samples, respectively. Type 0 objects are not shown as most of them do not have redshifts.

Pursimo et al., submitted to ApJ

Amplitude of ISS vs redshift

$$T_{b,obs} = \frac{T_{b,em}}{(1+z)} = \frac{\delta T_{b,\iota\nu\tau}}{(1+z)}$$

$$\Rightarrow \theta_{src} \propto (1+z)^{0.5}$$

Assuming:
- Flux-limited sample
- Intrinsic brightness temperature has a fixed cutoff (between 10^{11} and 10^{12} K) (independent of rest-frame emission frequency)
- No evolution of Doppler factor or compact fraction with redshift

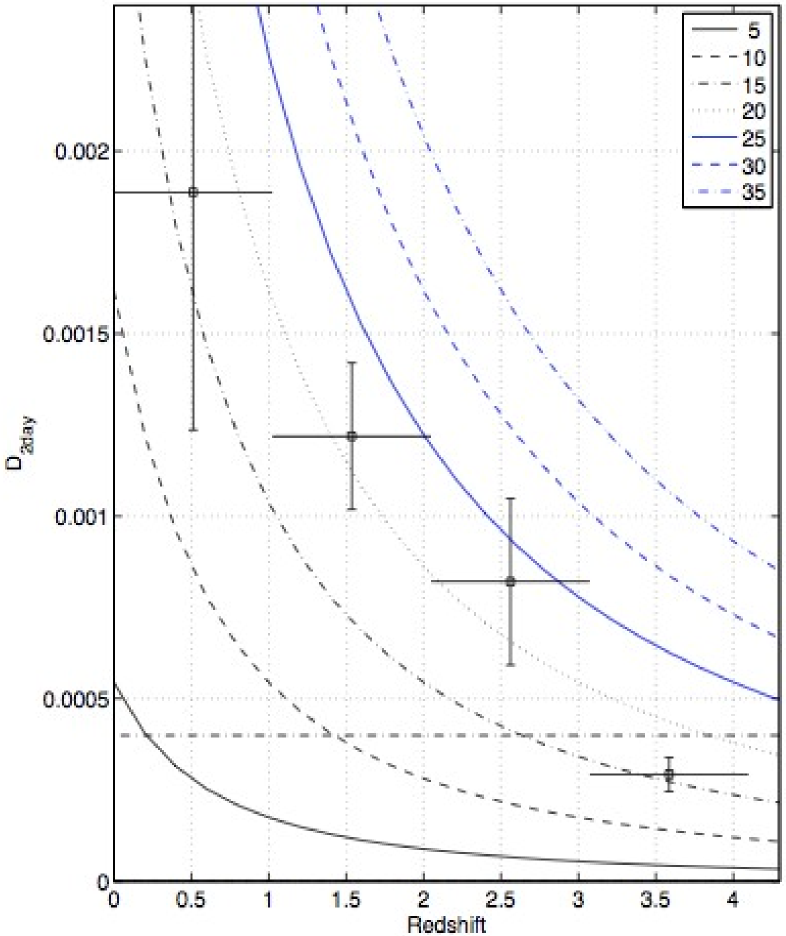


Fig. 7.— The data for all FSRQs averaged into 4 redshift bins. Overplotted are theoretical curves for a simple ISS model, discussed in the text, with Doppler factors as indicated in the legend. The horizontal dotted line represents D(2day) $= 1 \times 10^{-4}$.

Is there any evidence for scatter broadening of the high redshift sources in the IGM? MASIV follow-up observations

- Scatter-broadening is expected to have a different frequency dependence from source-intrinsic effects.
- Selected 140 MASIV sources: ~70 with redshift $z > 2$, 70 with $z < 2$.
- Observed over 11 days with VLA in January 2009, at 4.9 and 8.5 GHz.
- Analysis and modelling a major part of Jun Yi (Kevin) Koay's PhD thesis:
  - Koay et al. 2011, AJ, 142: 108
  - Koay et al. 2012, in prep.

MASIV follow-up example data

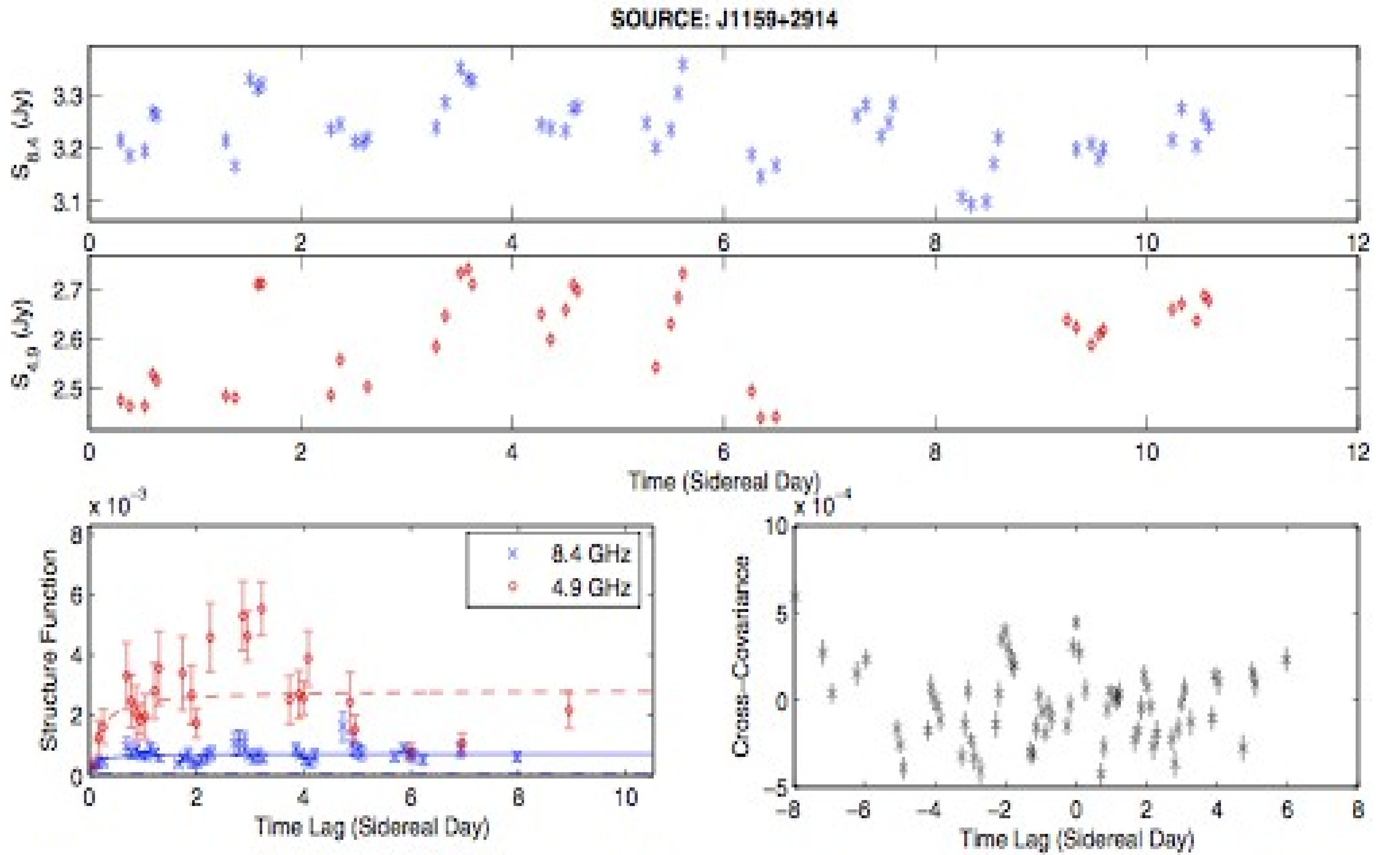


Figure 1. Light curves for the source J1159+2914 at 8.4 GHz (top) and 4.9 GHz (middle), with their corresponding structure functions (bottom left, where the solid curve and dashed curve represent the model fits at 8.4 GHz and 4.9 GHz respectively, the dash-dotted line represents D_{noise} at 4.9 GHz, and the dotted line represents D_{noise} at 8.4 GHz) and cross-covariance function (bottom right).

ISS vs spectral index

THE ASTRONOMICAL JOURNAL, 142:108 (21pp), 2011 October

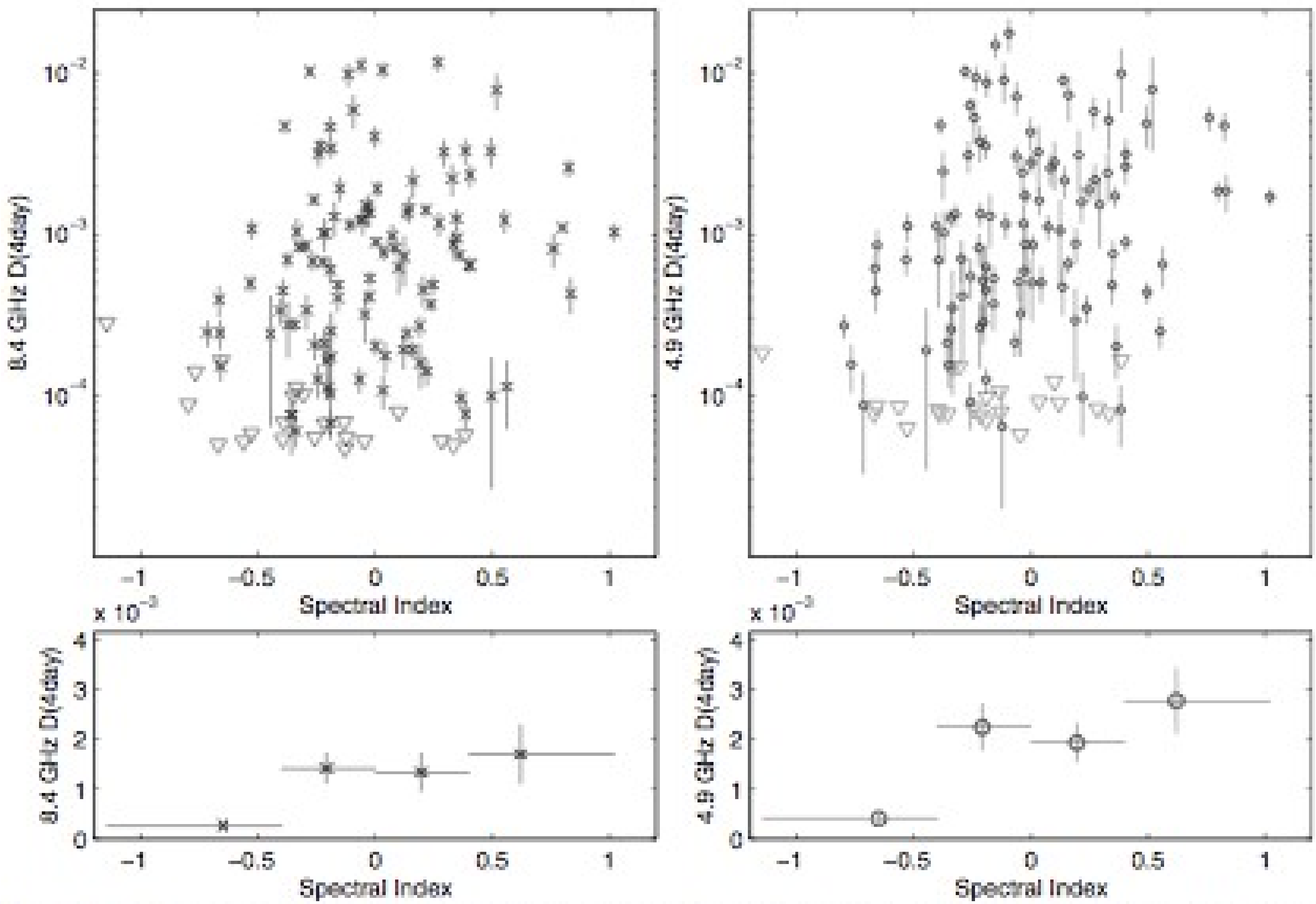


Figure 12. D(4 day) at 8.4 GHz (scatter plot at top left and binned plots at bottom left) and 4.9 GHz (scatter plot at top right and binned plots at bottom right) plotted against source spectral index. The triangles represent upper limits of D(4 day) for sources where D(4 day) < D_{noise}.

Spectral index vs redshift

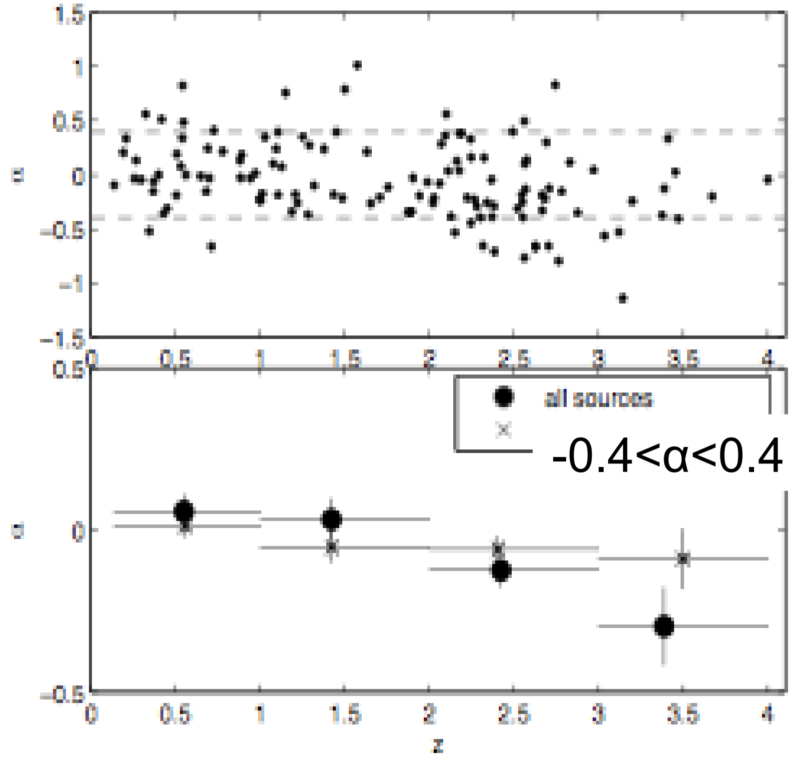
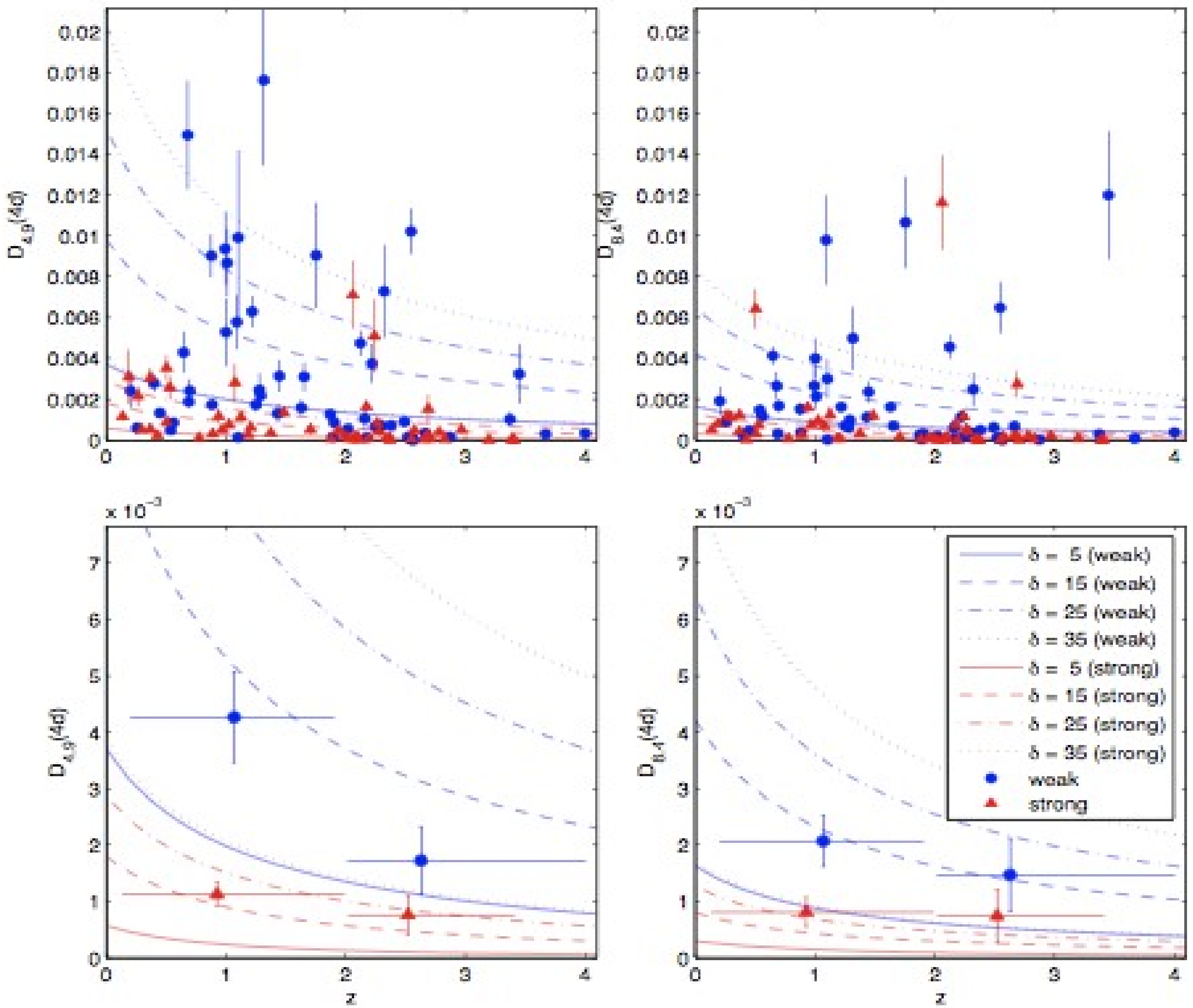


Fig. 1.— The top panel shows a scatter plot of source spectral indices against source redshift for all 128 sources. The horizontal dashed lines indicate $\alpha_{8.4}^{4.9} < -0.4$ and $\alpha_{8.4}^{4.9} < -0.4$, in between which the sources are considered as flat-spectrum sources. The bottom panel shows the mean spectral indices in four redshift bins before and after the removal of the inverted and steep-spectrum sources. The error bars in the binned plots indicate 1σ errors in the mean.

ISS vs redshift, frequency dependence

No evidence for scatter-broadening in IGM.
Upper limits derived from ratio of structure functions at 2 frequencies.



On the redshift dependence of ISS

- Given a compact, flat-spectrum source sample, the strongest dependence of ISS is on source flux density
- Most trends indicate sources limited to a fixed* rest-frame brightness temperature
- Upper limits on IGM scatter-broadening (Koay et al., 2012, in prep.)

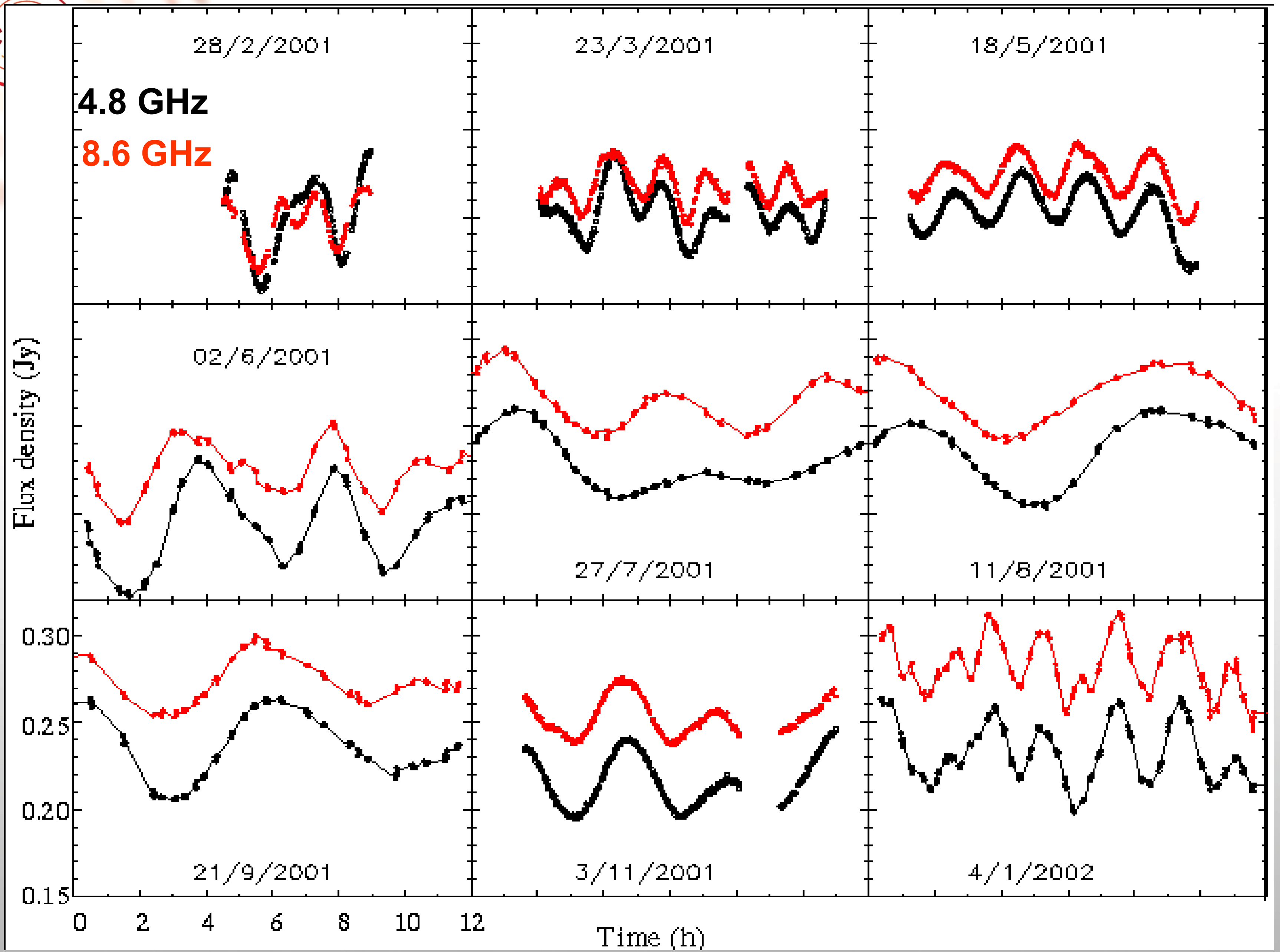
  θ_{scatt} < 120 μas at 4.9 GHz for all sources

  θ_{scatt} < 10 μas for the most compact sources

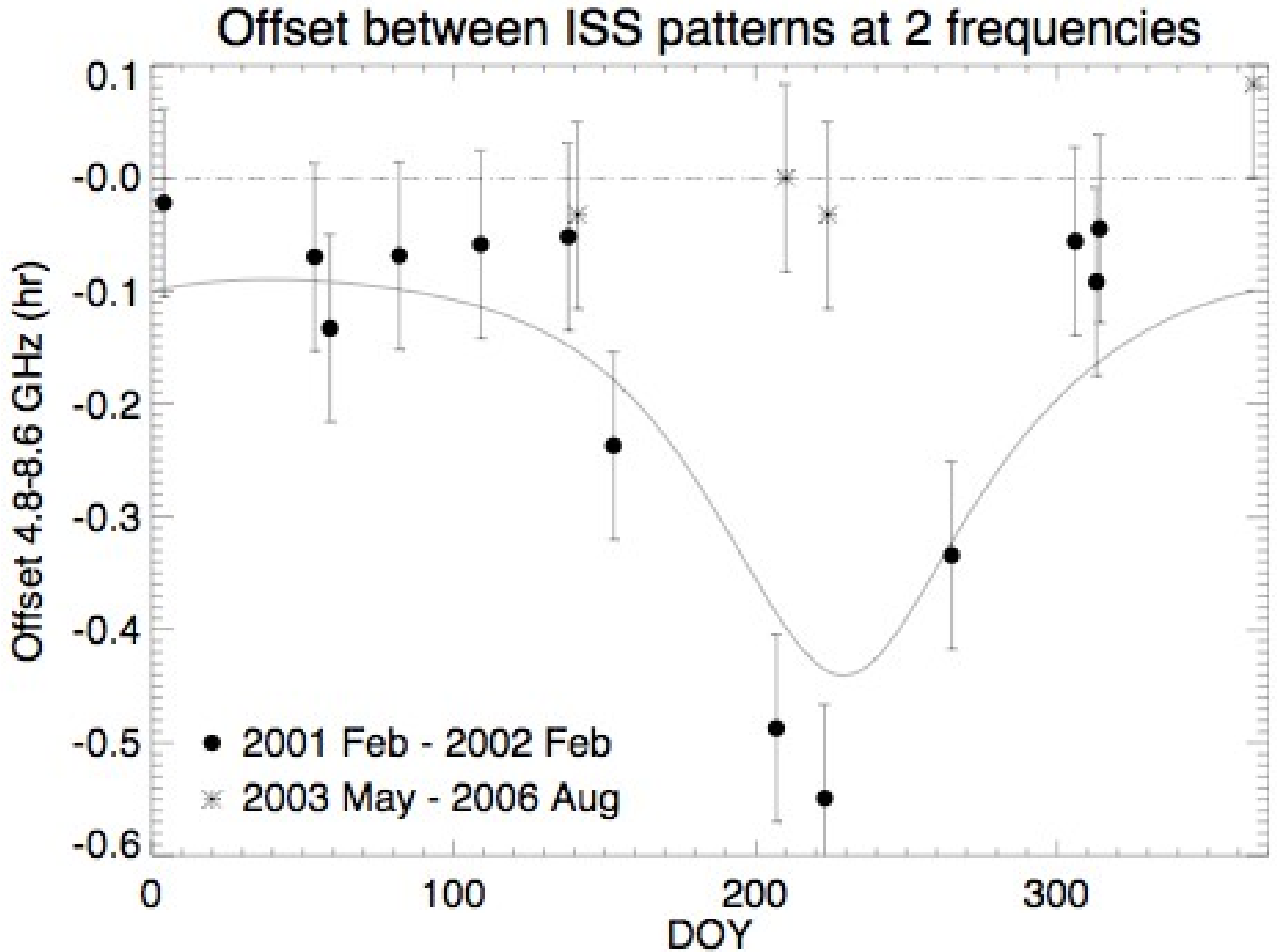
  [Space VLBI..?]
- BL Lacs in MASIV may be viewed at smaller angle to l-o-s compared with FSRQ → increased Doppler boosting; intrinsically smaller angular sizes
- Spectral index-redshift correlation: rest-frame turnover frequency? Lower core fraction for high redshift sources? ✓
- More detailed jet model under investigation (Godfrey, Macquart, Bignall, Koay et al.)

Milliparsec-scale structure of an AGN jet: PKS 1257-326

H. Bignall, L. Godfrey, J-P. Macquart

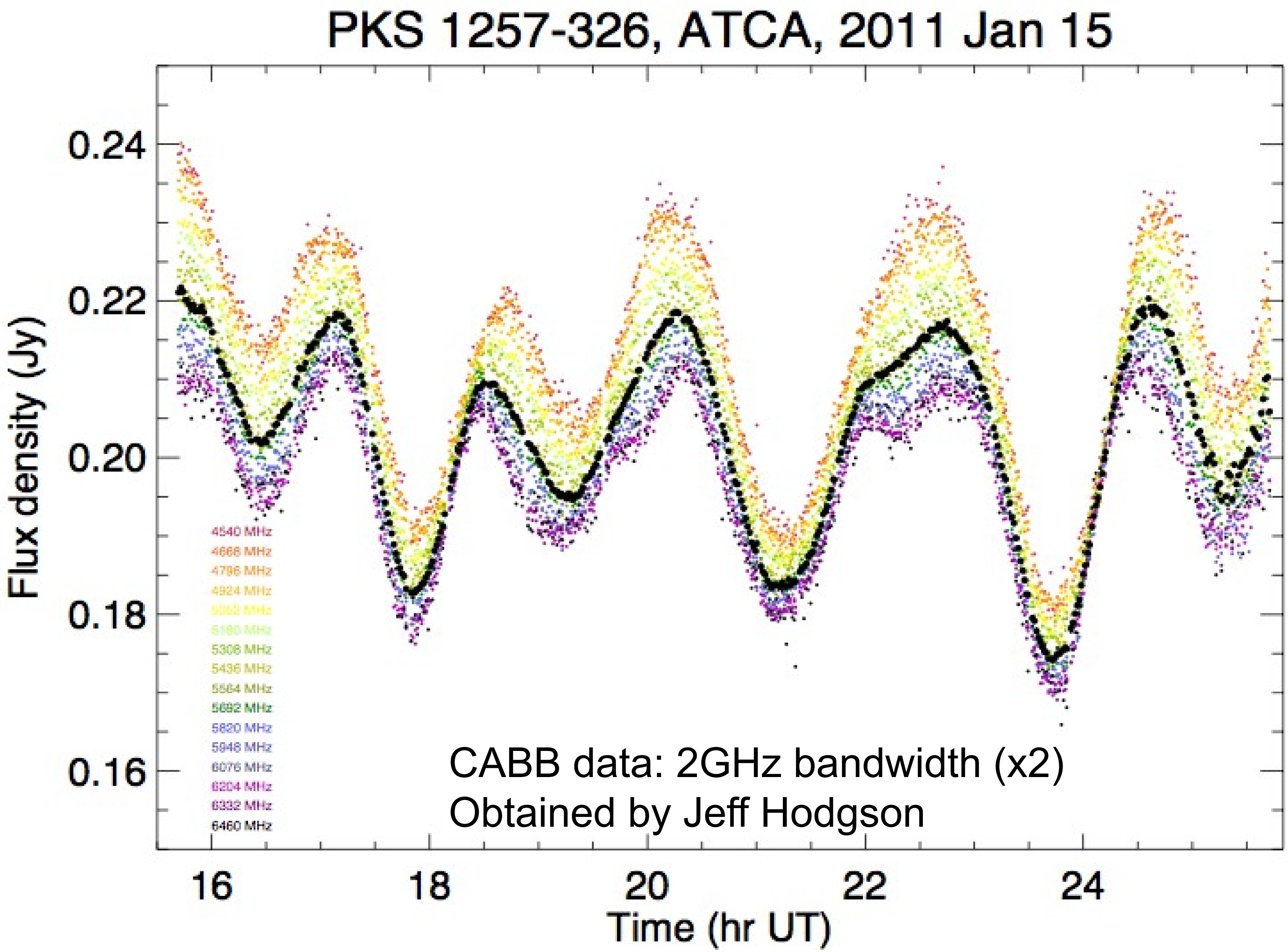


28/2/2001
4.8 GHz
8.6 GHz
23/3/2001
18/5/2001
02/6/2001
27/7/2001
11/8/2001
21/9/2001
3/11/2001
4/1/2002
Flux density (Jy)
0.30
0.25
0.20
0.15
0
2
4
6
8
10
12
Time (h)



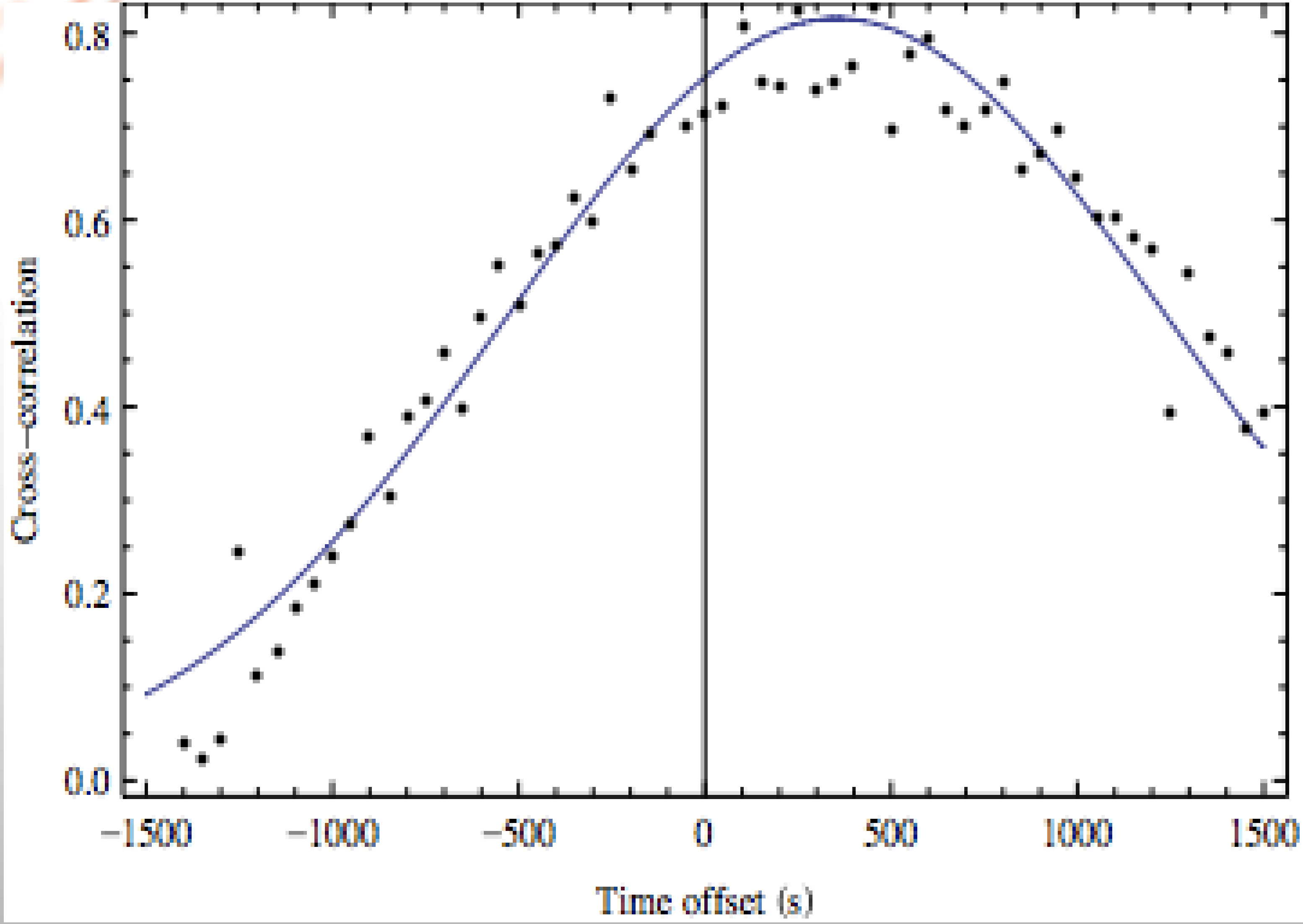
Fitted displacement ~15μas, or <0.1 pc at source z=1.256

Bignall & Hodgson, in Proceedings of IAU S285

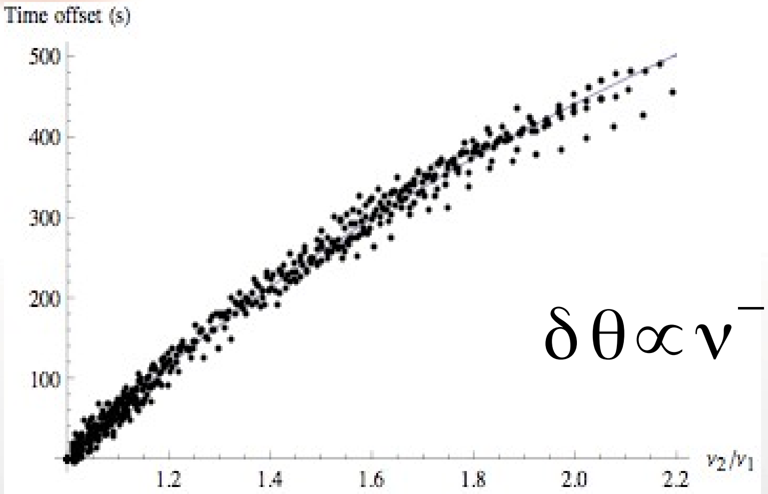


CABB data: 2GHz bandwidth (x2)
Obtained by Jeff Hodgson

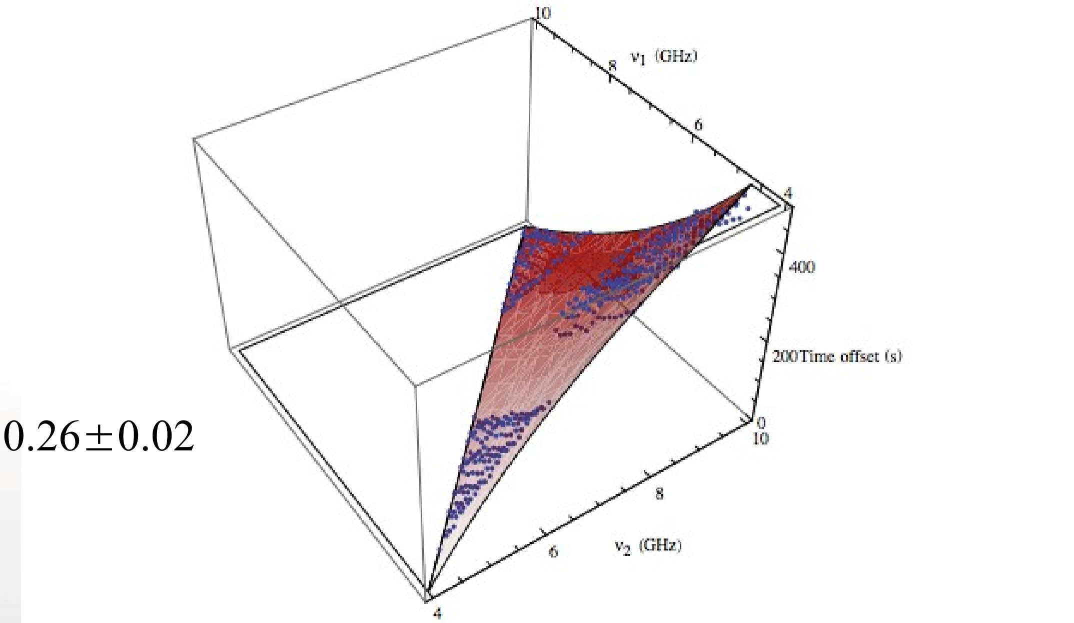
Sample cross-correlation & fit (J-P Macquart)

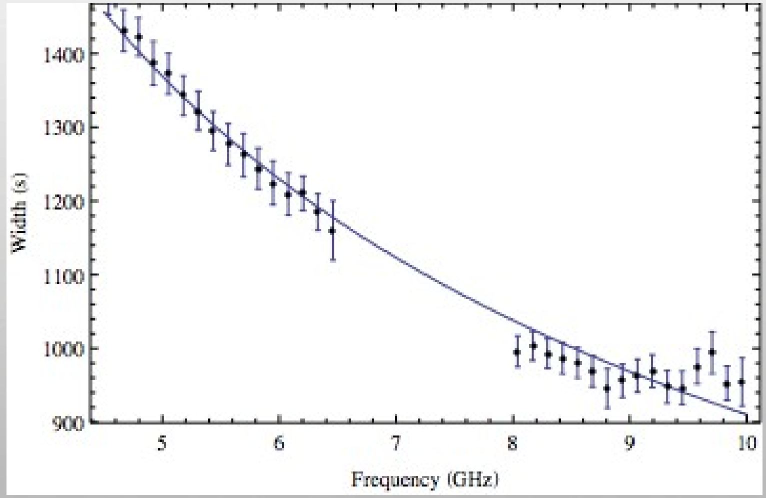


Frequency scaling of time (spatial) offset



$$\delta\theta \propto \nu^{-0.26\pm0.02}$$





Frequency scaling of angular size from light-curve autocorrelations:

$$\theta \propto \nu^{-0.57}$$

Interpretation of microarcsecond jet structure & implications

(Godfrey, Macquart, Bignall, in prep.)

- Frequency dependence of core-shift observed in PKS 1257-326 is <u>not</u> consistent with synchrotron self-absorption
- Appears to be consistent with free-free absorption at jet base
- Also, offset is <u>not</u> in same direction as mas-scale jet
- Frequency dependence of source size may indicate flared jet structure
- The new broad-band instruments (CABB at ATCA, EVLA) are vital for this work
- Applicable to other sources; higher resolution than VLBI.
- Requires sufficiently long sample of scintillation pattern – initially target fast scintillators (nearby scattering screens)

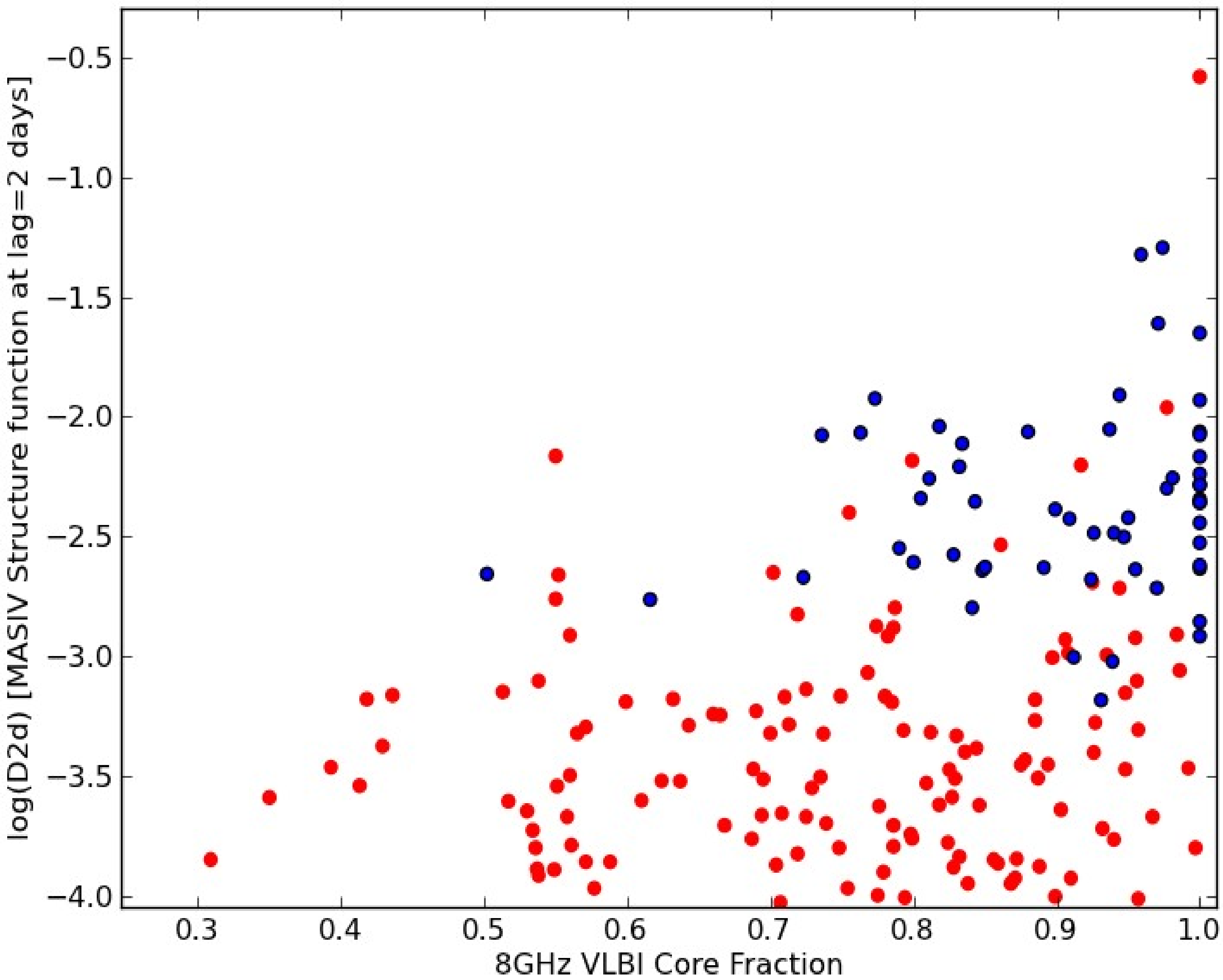
  e.g. Koay et al. 2011, A&A 534, L1 "Detection of six rapidly scintillating active galactic nuclei and the diminished variability of J1819+3845"

Ideally, combine with simultaneous astrometric VLBI at 2 frequencies to determine <u>direction</u> and <u>magnitude</u> of core-shift (e.g. Sokolovsky, Kovalev et al., 2011, A&A, 532, 38)

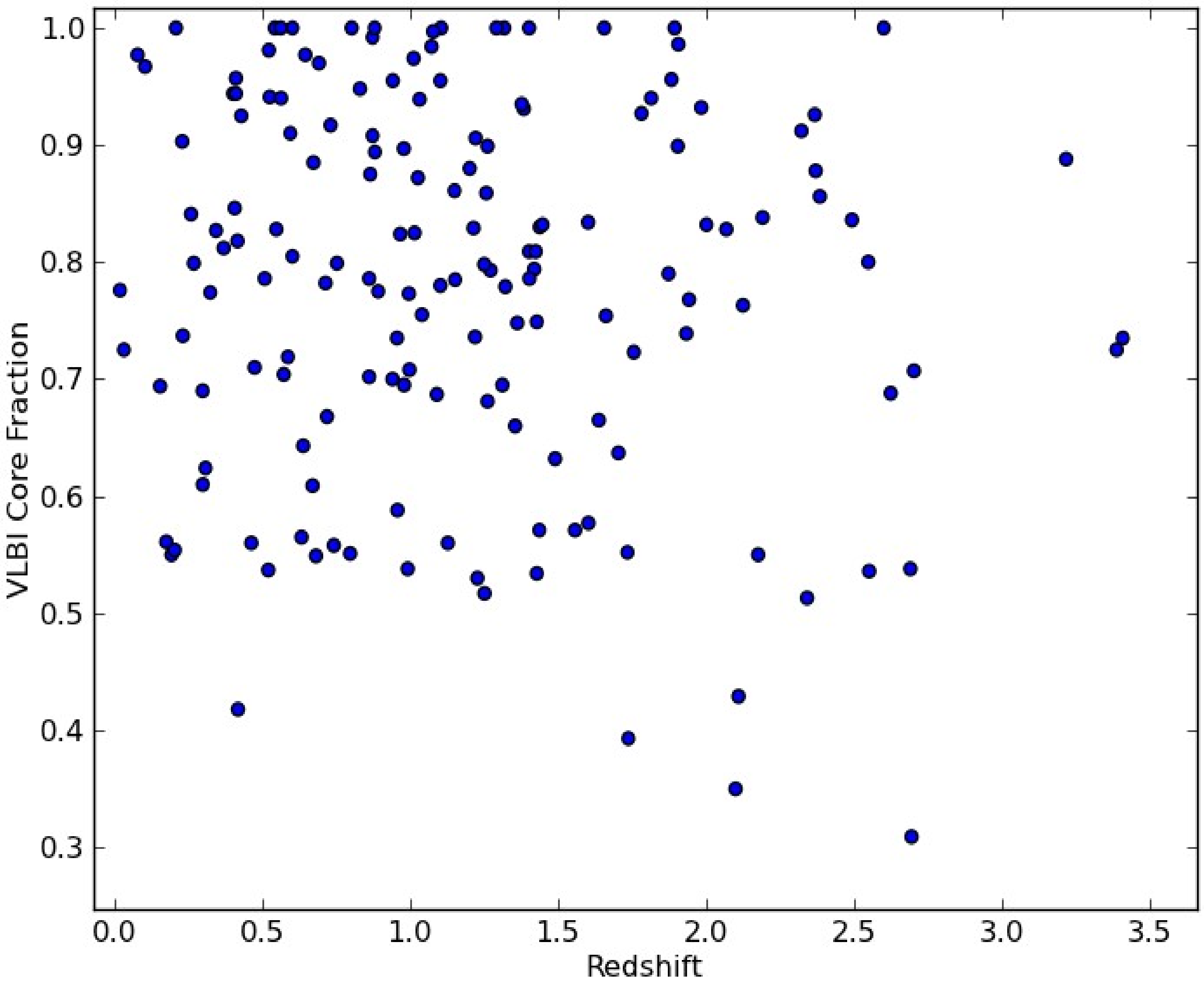
Conclusions

Interpretation of interstellar scintillation of the MASIV sample is complicated by various effects that we don't yet fully understand, but...

ISS is a very powerful probe of the smallest structure in AGN “cores”



log(D2d) [MASIV Structure function at lag=2 days]
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
8GHz VLBI Core Fraction


VLBI Core Fraction
Redshift
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5