Interstellar Scintillation and Scattering of Micro-arc-second AGN

The MASIV Collaboration:

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The beginning of radio variability where a clear pattern emerged:

strong variability at high frequency, but very weak at low frequency.

Such variability was seen as intrinsic to the sources

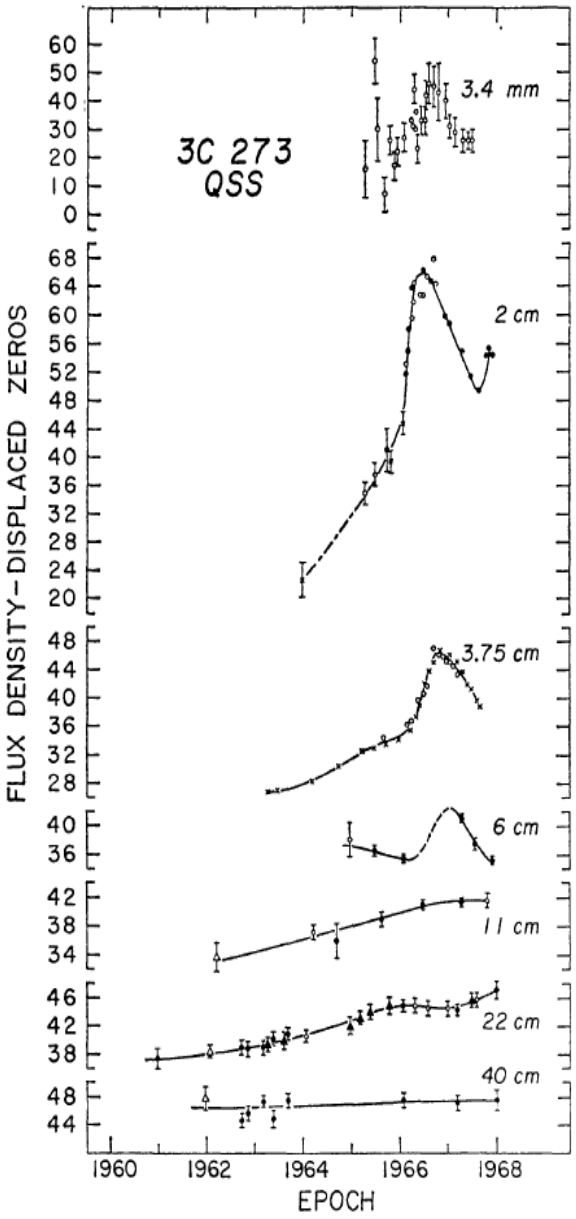


FIG. 2. Radio variations of 3C 273.

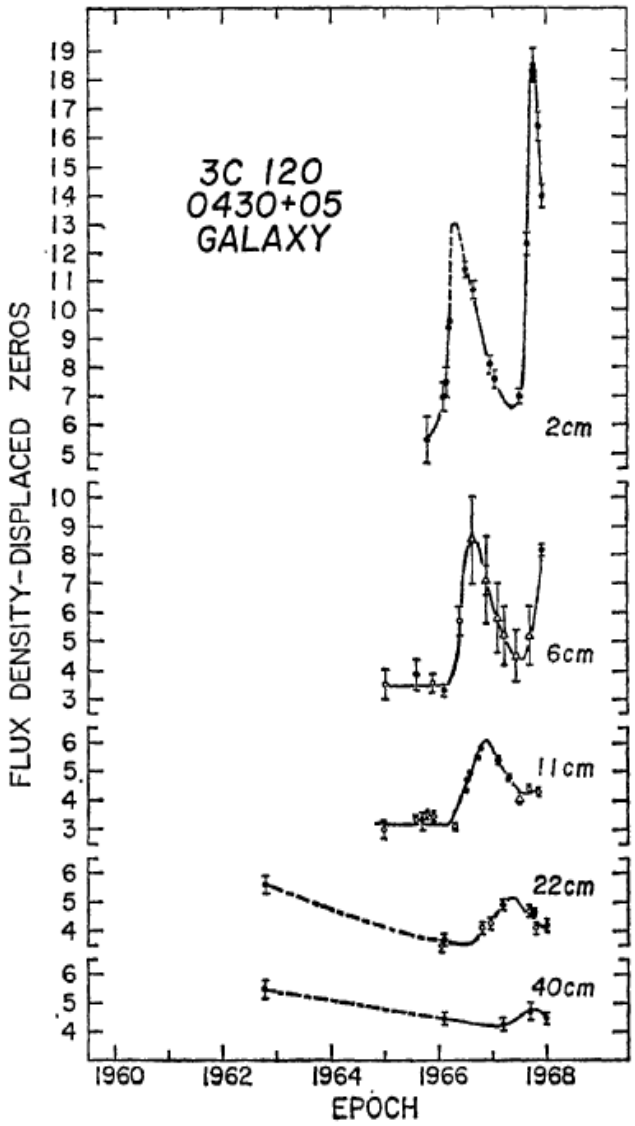


FIG. 1. Radio variations of 3C 120.

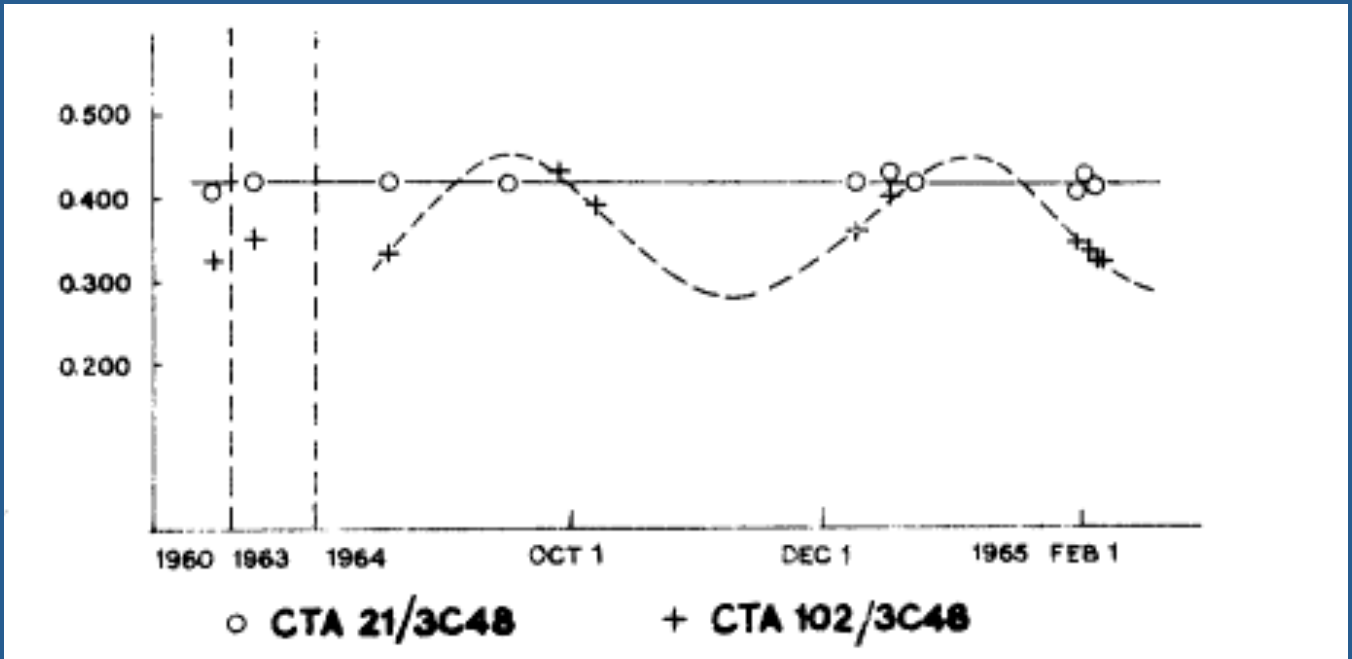
From Kellermann & Pauliny-Toth ARA&A article

But at lower frequencies things were quite different.

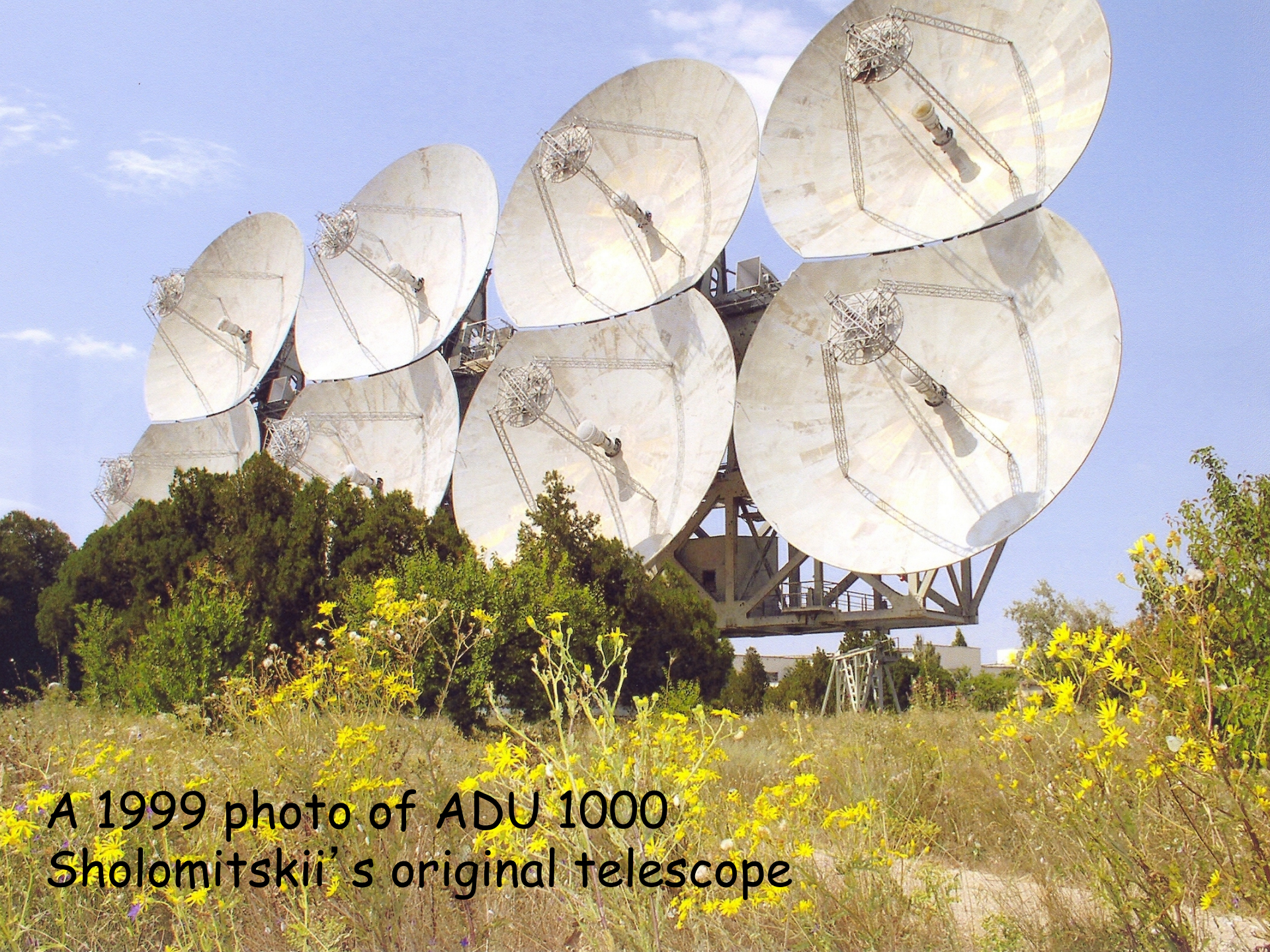
Sholomitskii's 1964-65 Soviet telescope data. He claimed detection of rapid variability at a wavelength of 32.5 cm, on a time-scale of months or less.

Compared with the higher frequency observations the implied brightness temperature in excess of 10^{16} K, was unacceptably high.

These observations, and their interpretation were not taken seriously in the West as knowledge of the telescope and its performance were unavailable.



But CTA102 became the only quasar with a popular song!

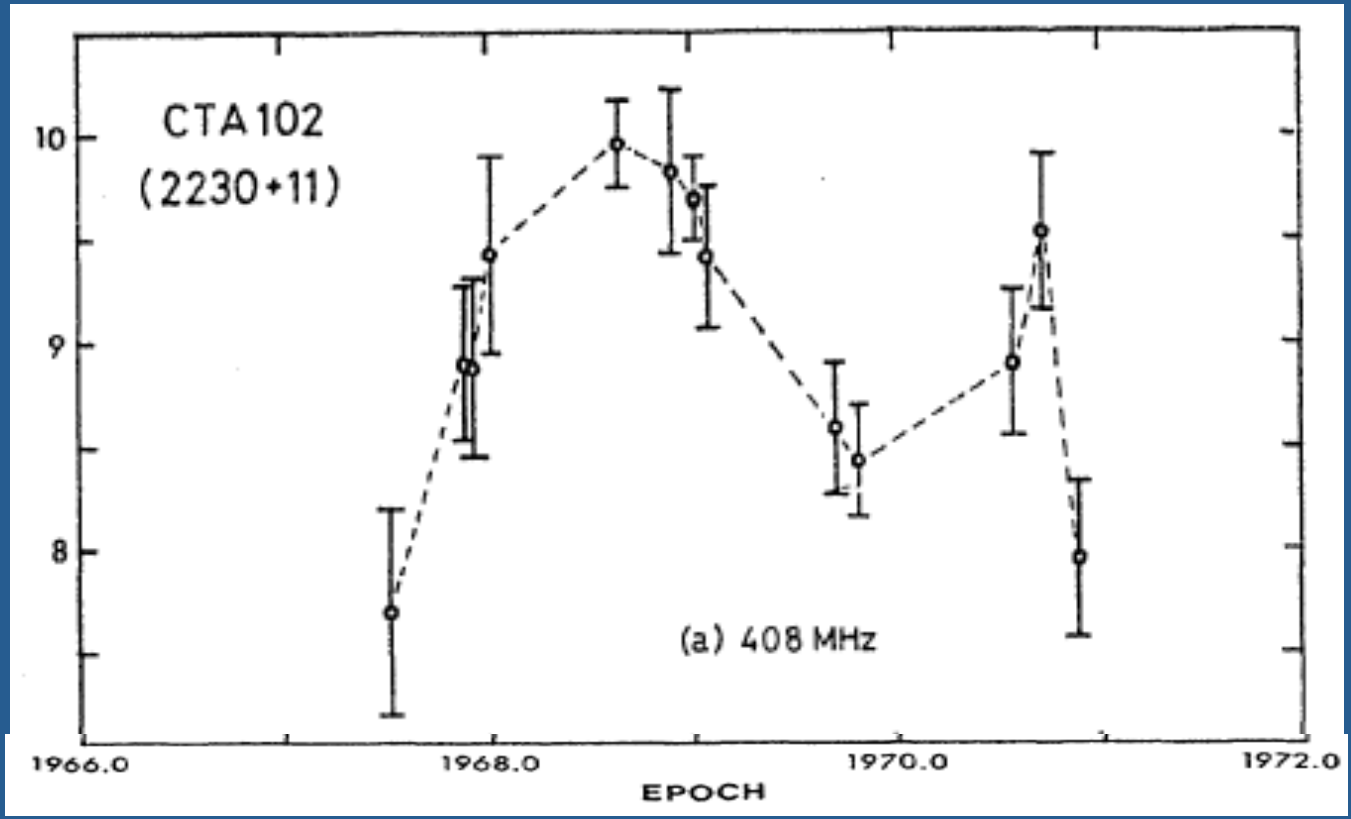


A 1999 photo of ADU 1000
Sholomitskii's original telescope

Hunstead (1972) published his 5 year Mills Cross 408 MHz study of four sources, including CTA102. These dramatically confirmed the variability seen earlier by Sholomitskii.

Hunstead also observed variability at 408 MHz in 3 other sources, including 3C 454.3

The implied brightness temperatures are so high that such variability clearly could not be intrinsic. So they were again generally dismissed.



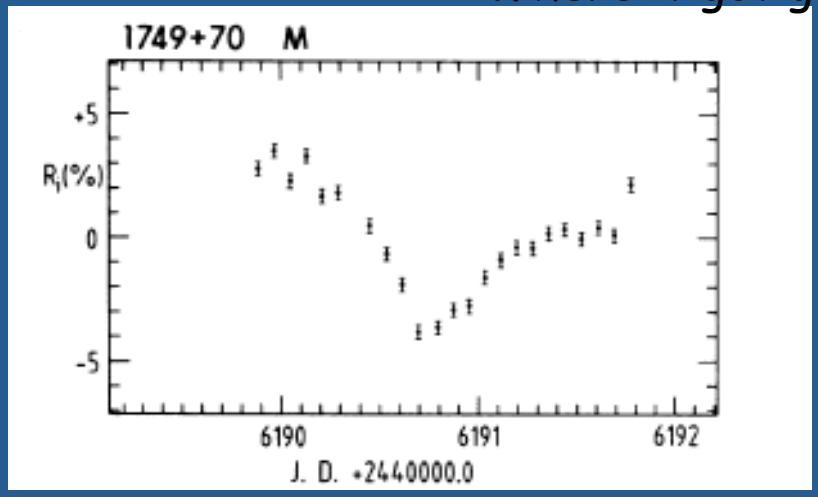
Hunstead suggested several possible explanations, one of which was that the observed were not intrinsic, but rather caused by slow scintillation in the inter-stellar or inter-Galactic medium.

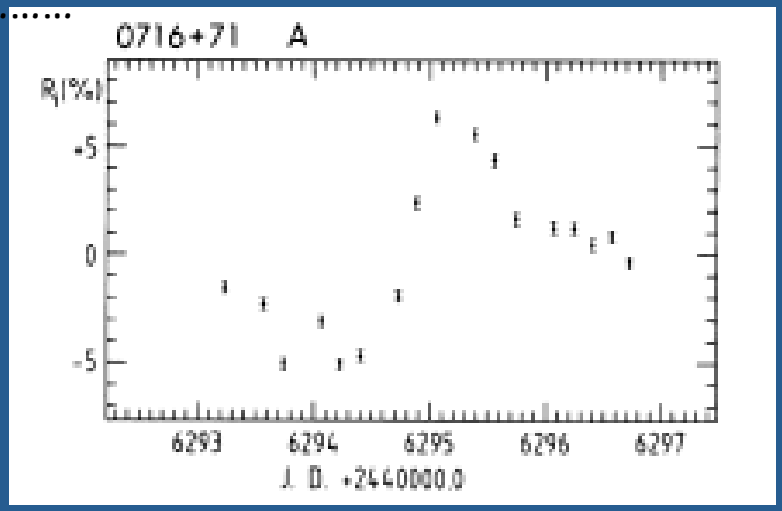
Some time later Rickett et al., (1984) proposed;

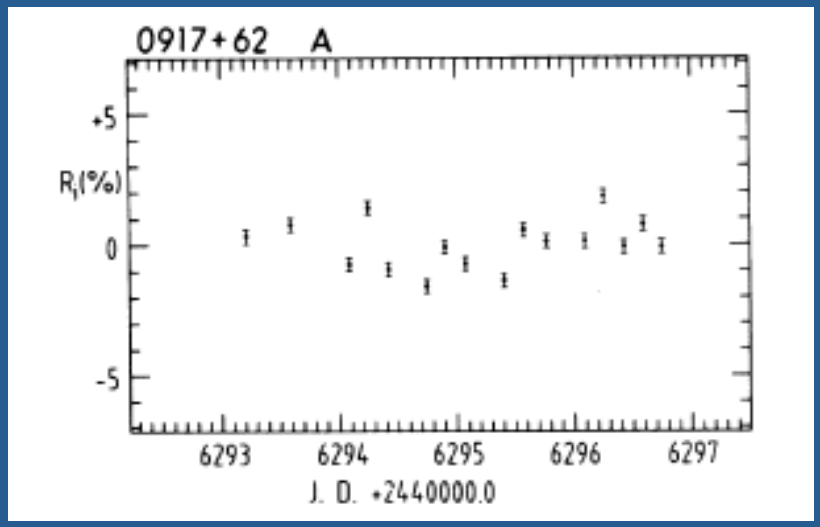
..thus we speculate that other slow variations in source intensity, particularly those of “low frequency variables” may also be caused by the interstellar medium.

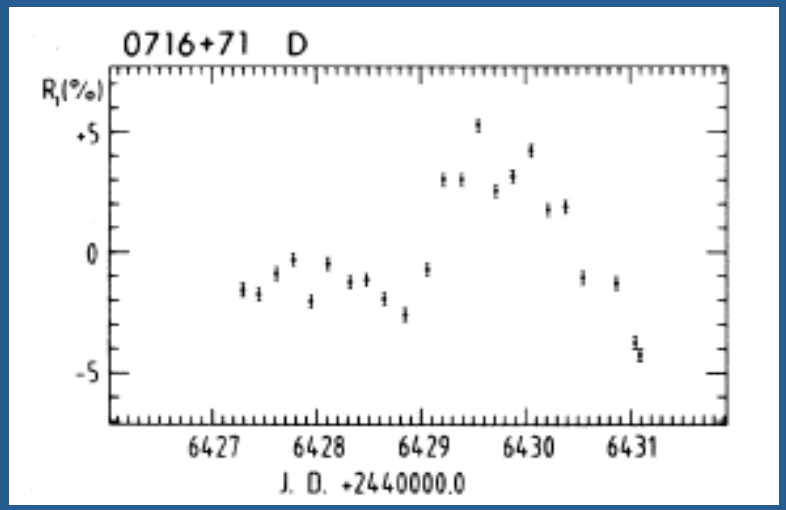
the extra-galactic sources were scintillating just like pulsars

Where it got going……









Dave Heeschen and the discovery of intra-day variables (IDV) with the beautiful Effelsberg 100 m

But is it intrinsic or extrinsic?

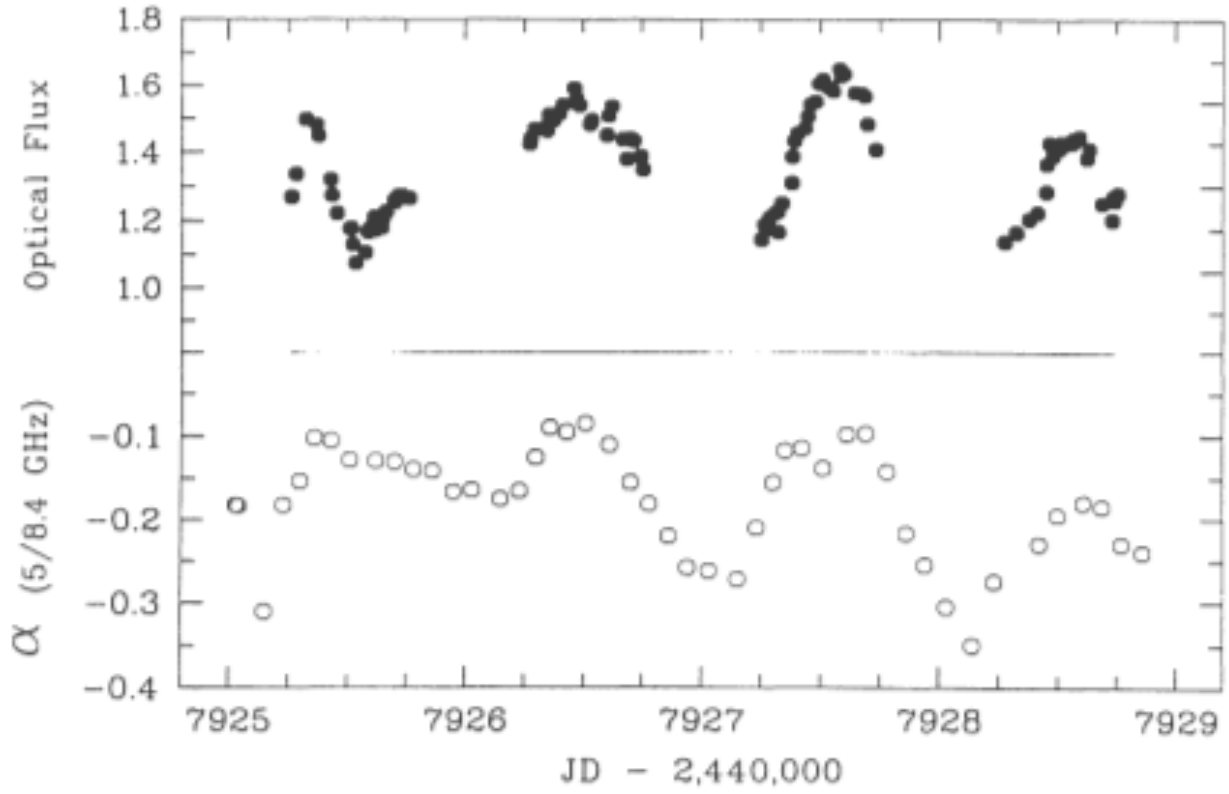


Figure 4 Correlations of the radio spectral-index $\alpha_{3.6\,\mathrm{cm}}^{6\,\mathrm{cm}}$ (*open circles*) with optical flux (650 nm; *filled circles*) in 0716 + 714. The variations are in phase without any measurable lag (see Wagner et al 1995c).

The argument for intrinsic IDV was based on the radio-optical "correlation" in 0716+714.

Wagner & Witzel, ARA&A, 33, 163, 1995

Then came the three most rapidly variable sources that have revolutionized the study of intra-day variability:

PKS 0405-385

Lucyna Kedziora-Chudczer

J 1819+3845

Jane Dennett-Thorpe

PKS 1257-326.

Hayley Bignall

All three were discovered serendipitously!

In 1996 at the ATCA, as part of her IDV Survey, Lucyna Kedziora-Chudczer found

PKS0405-385

the first of the 3 rapid variables

But if intrinsic $T_B \sim 10^{21}$K !!

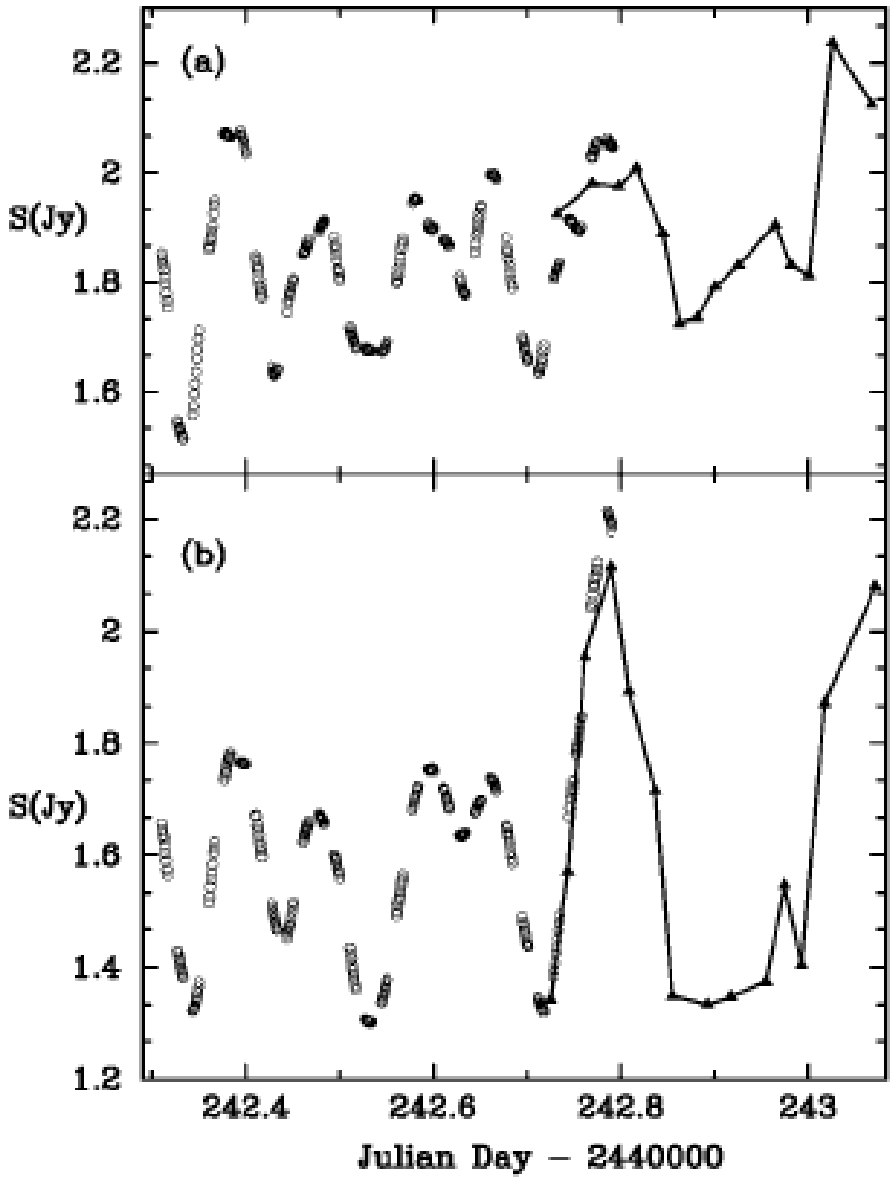
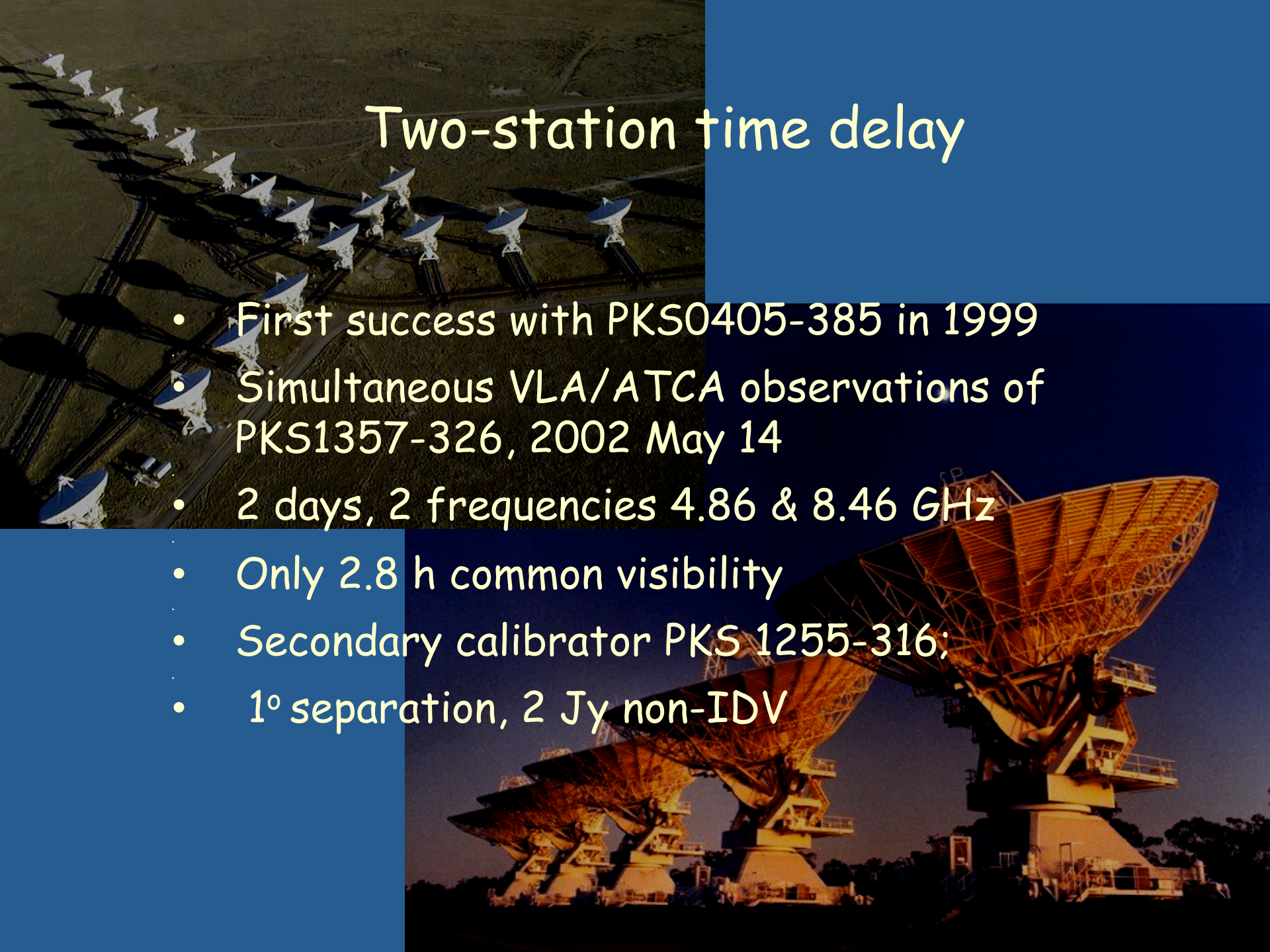


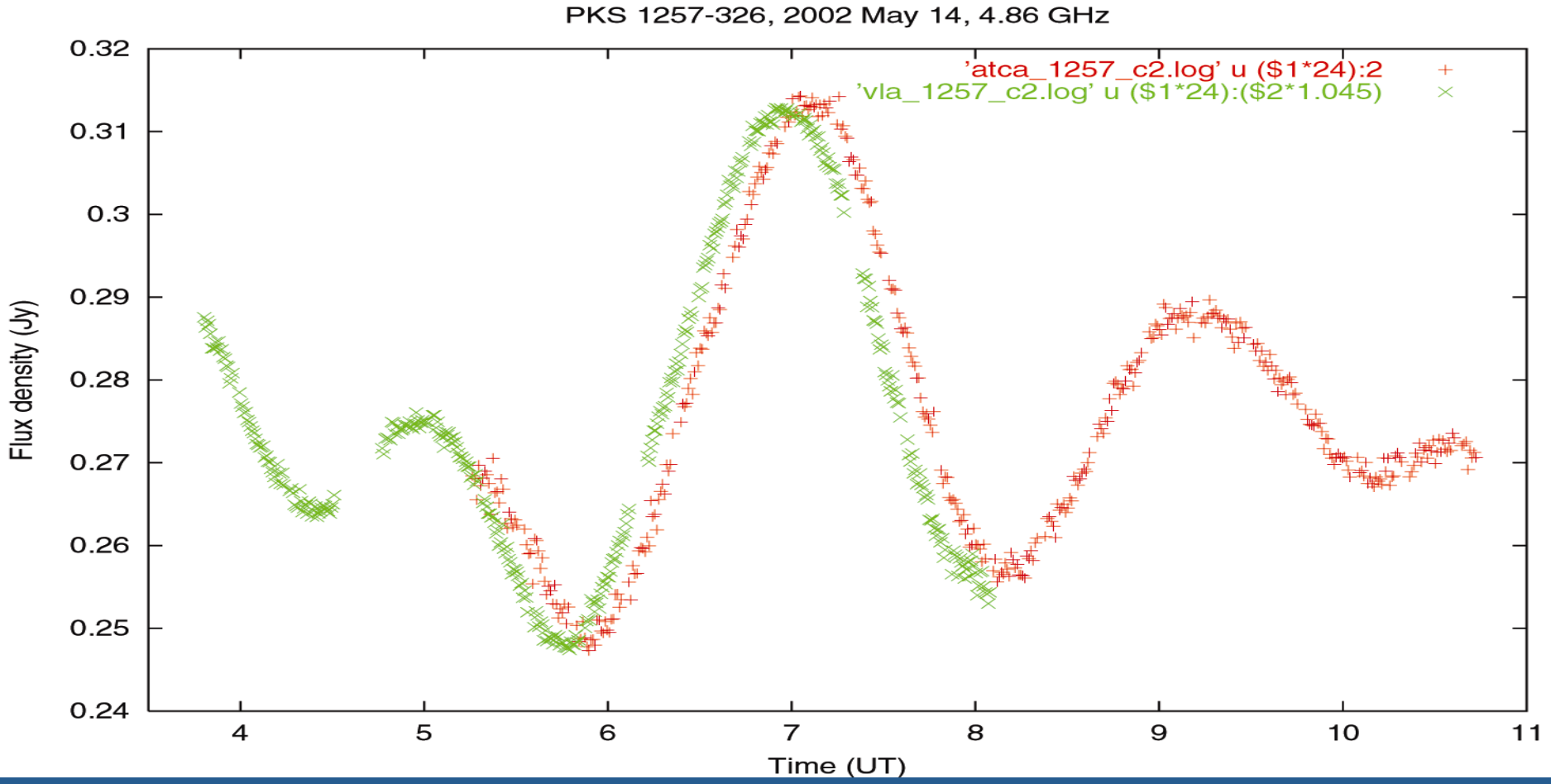
FIG. 2.—Combined ATCA and HARTRAO light curve measured on the 996 June 8 at (*a*) 8.6/8.4 GHz (ATCA/HARTRAO) and (*b*) 4.8/5.0 GHz ATCA/HARTRAO); ATCA data are plotted as circles ($\sigma = 0.01$ Jy), HARTRAO data as triangles ($\sigma = 0.05$ Jy).

Two-station time delay

- First success with PKS0405-385 in 1999
- Simultaneous VLA/ATCA observations of PKS1357-326, 2002 May 14
- 2 days, 2 frequencies 4.86 & 8.46 GHz
- Only 2.8 h common visibility
- Secondary calibrator PKS 1255-316;
- 1^{o} separation, 2 Jy non-IDV



Pattern Time Delay Observed between the ATCA and the VLA.



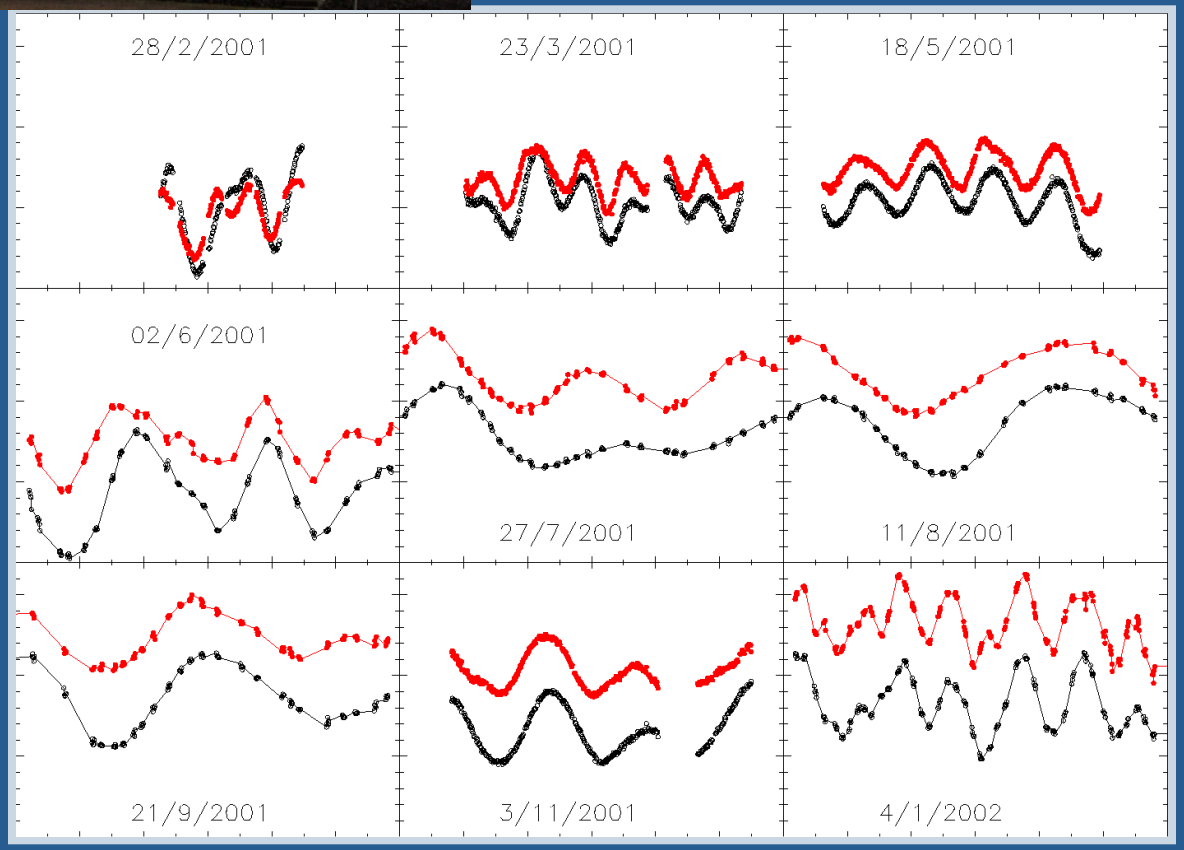
An unequivocal result!

PKS 1257-326

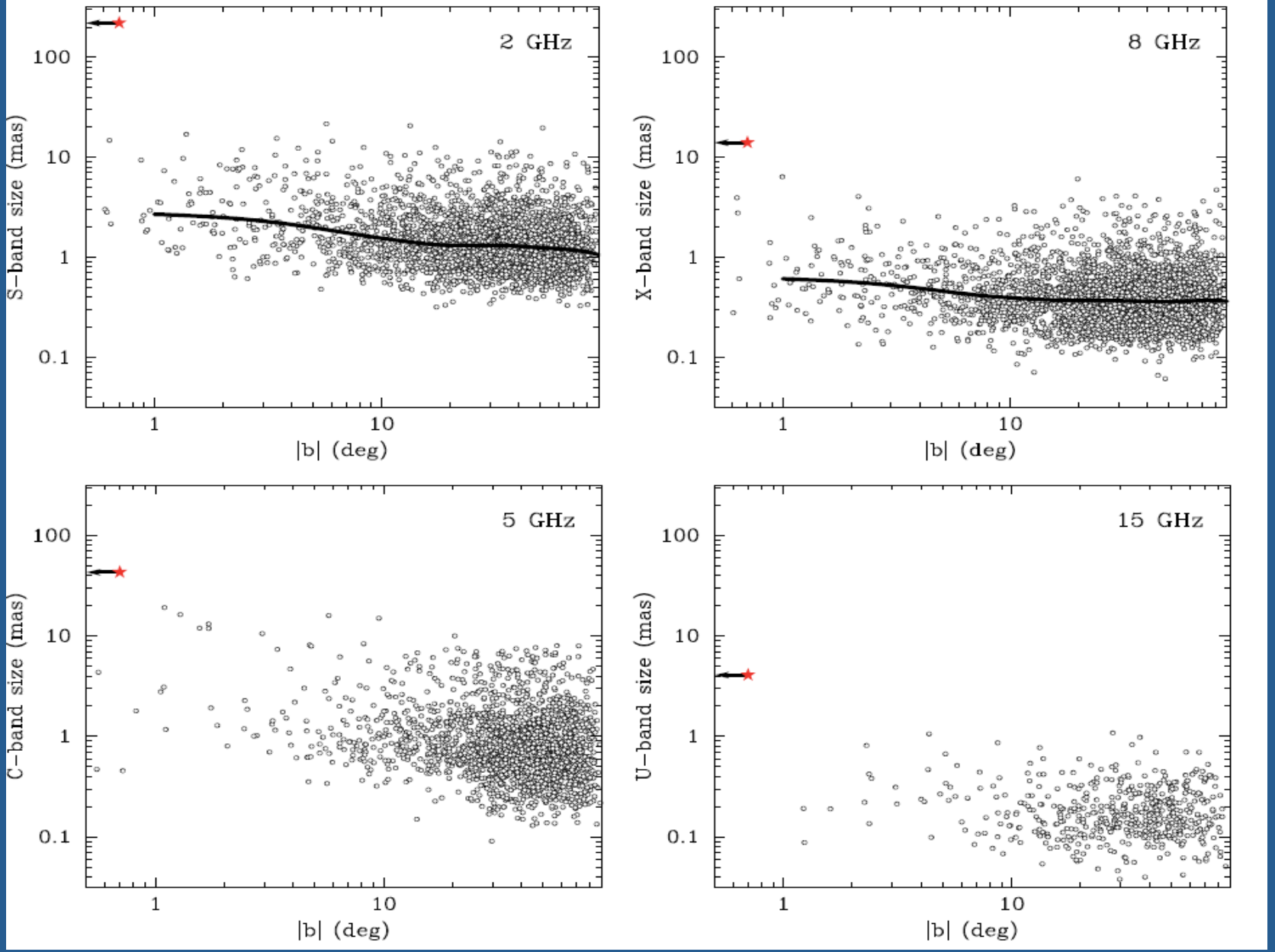
(Bignall et al. 2002, 2006)

Quasar, z = 1.256.

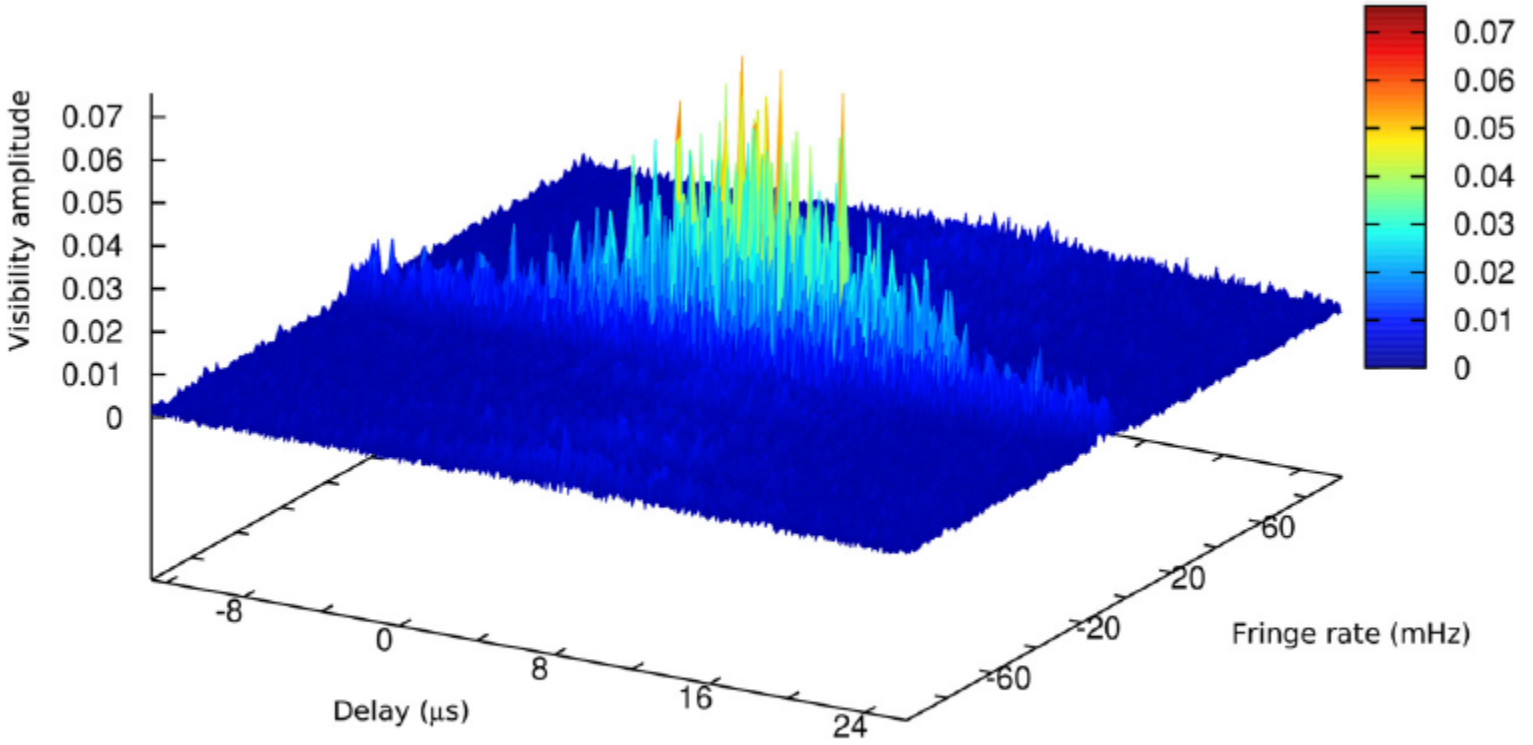
1 year of ATCA monitoring.



● = 4.8 GHz ● = 8.6 GHz



Angular size vs absolute value of Galactic latitude (Pushkarev & Kovalev 2015)



Magnitude of the visibility in the delay/fringe rate domain for a 500 s span of the pulsar PSR B0329+54 at 324 MHz on November 29 2012 on the GB-RadioAstron baseline of 235,000 km.
The scattering disc is fully resolved.

But there is still much to learn about inter-stellar scattering……

Summary:

Interstellar scintillation is a common phenomenon.

MASIV Survey shows 60% of flat-spectrum exhibit inter-stellar scintillation

ISS provides micro-arc-second resolution

Significant effects for VLBI and for SVLBI

Still much to learn about scattering in the ISM