Modelling of μ–arcsecond Components in AGN Jets by using Interstellar Scintillations

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Overview

Interstellar Scintillation (ISS) - the origin of Intraday Variability in AGN

Properties of Scintillating Sources

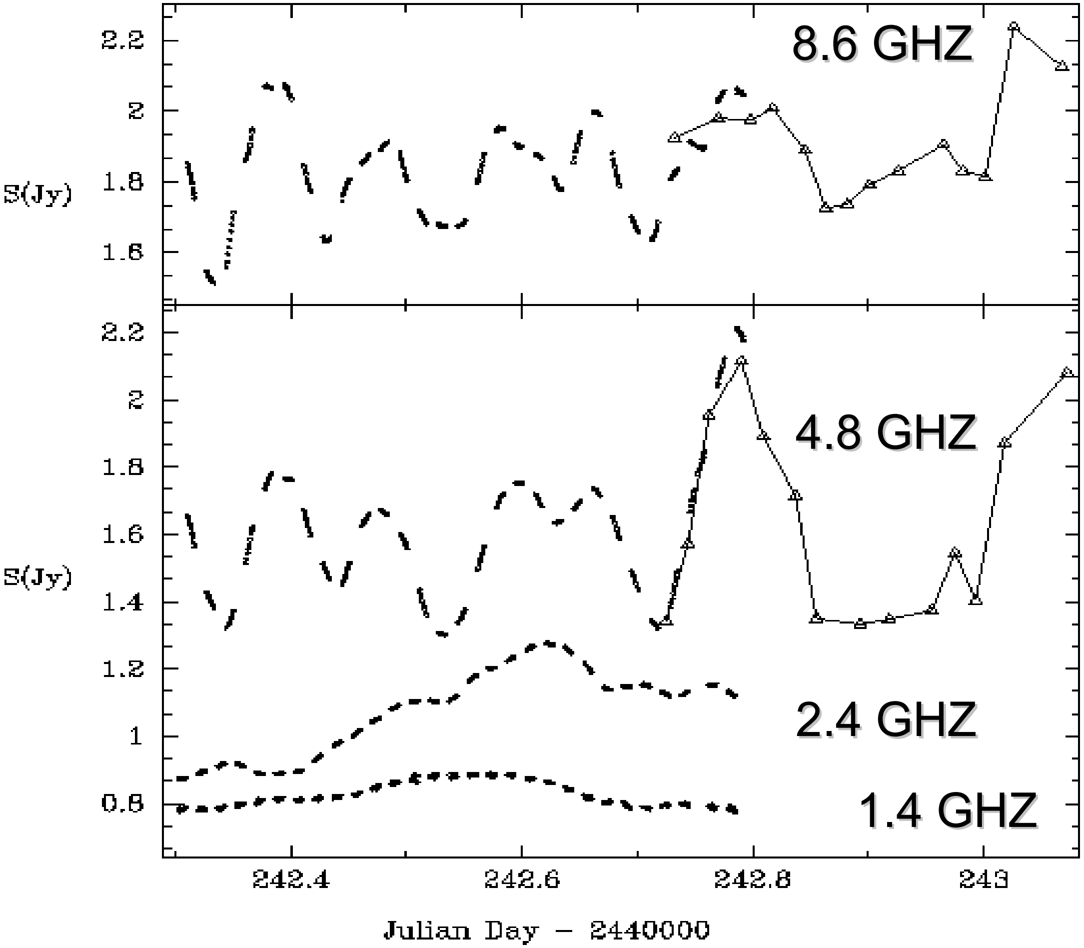
Gathering information about the μ–arcsecond structure

Imaging of polarized scintillating components

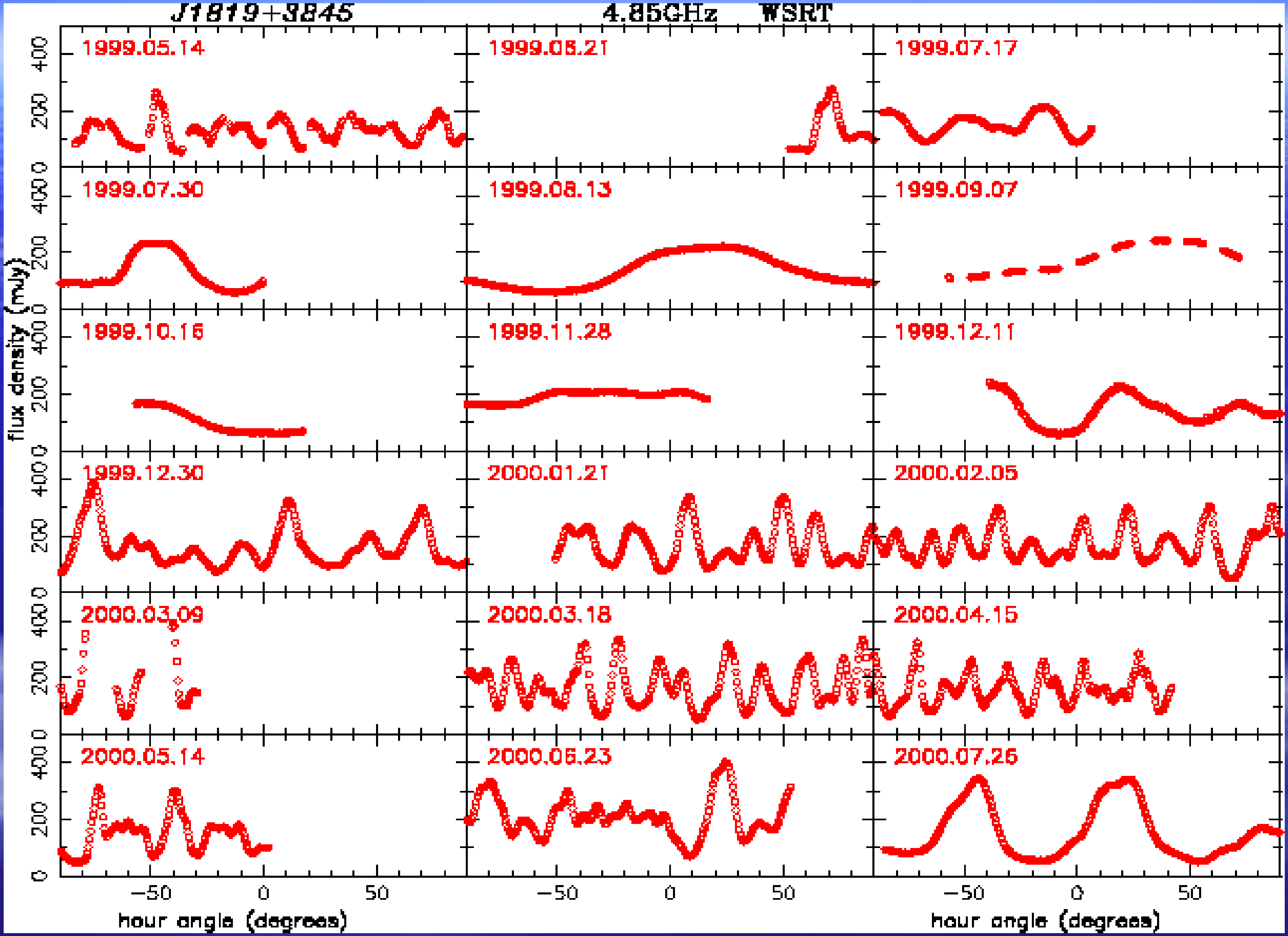
Moving towards the Earth-Orbit Synthesis

The role of elusive, local Interstellar Medium

Four-frequency light curve of the extreme scintillating quasar, PKS 0405-385



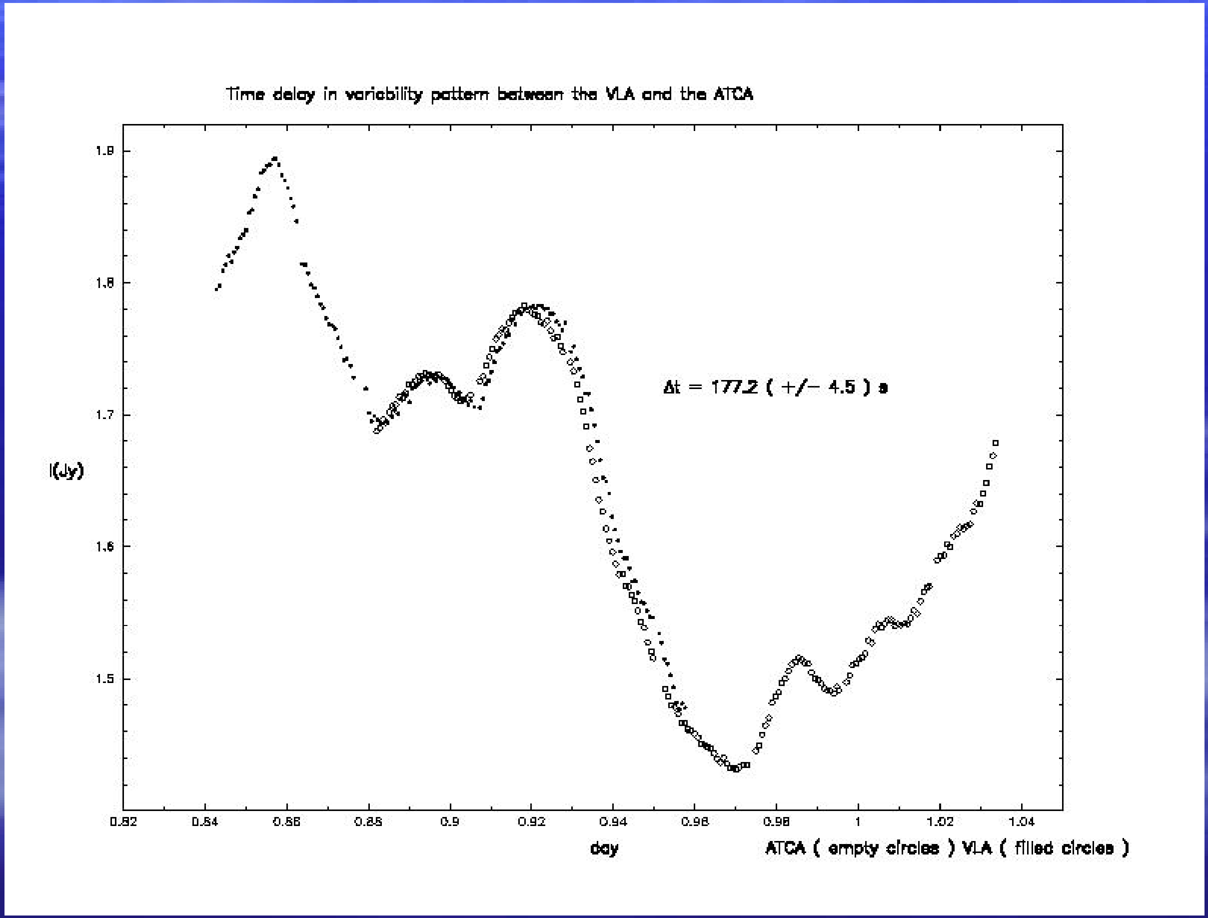
Scintillating quasar, J1819+3845

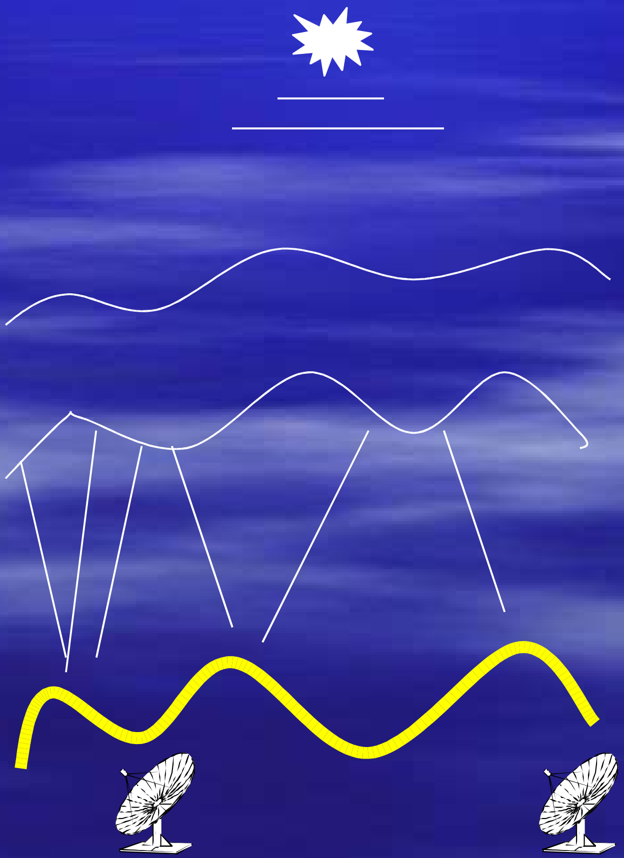


Courtesy: J.Dennett-Thorpe

Evidence for ISS

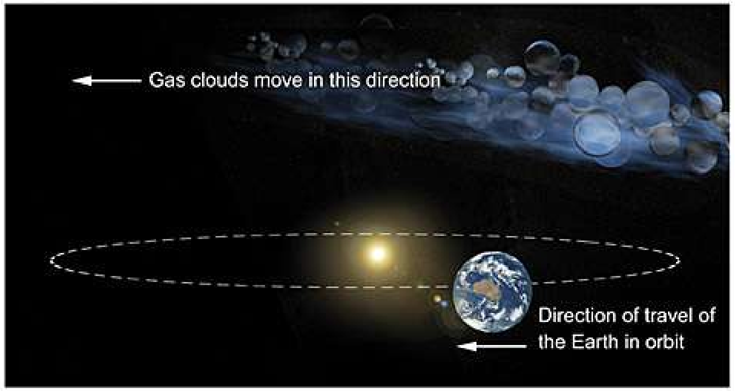
(1) Every intra-hour quasar shows time delay in variability pattern when observed by widely separated telescopes



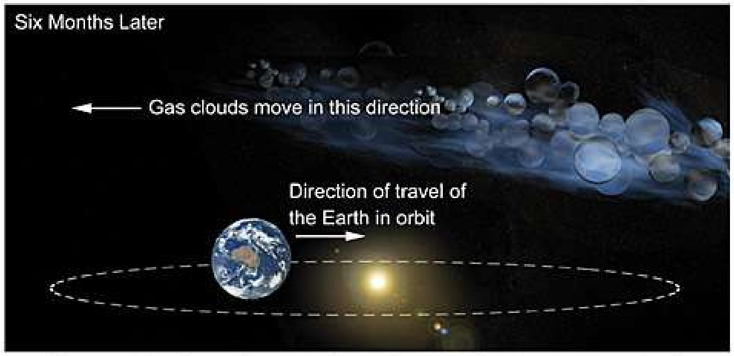


Evidence for ISS:

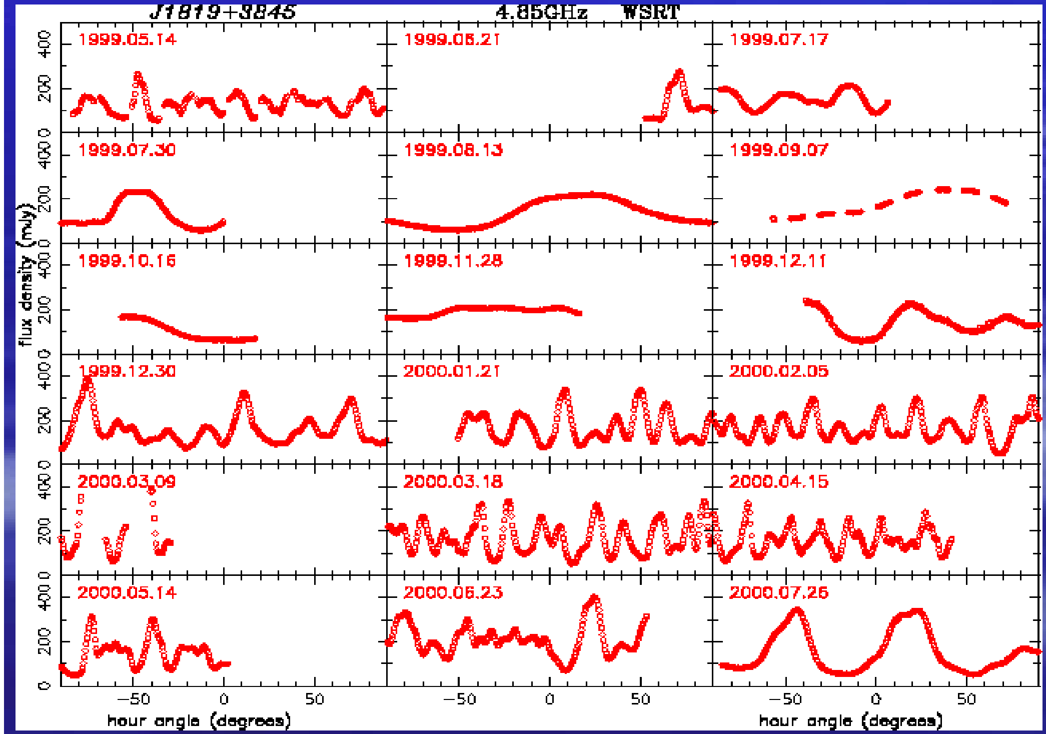
(2) The annual change in variability timescale is observed for ALMOST all Intraday Variables



At some times of the year, the Earth and gas clouds are moving in the same direction.



Six months later, the Earth and gas clouds are moving in opposite directions.



Properties of scintillating AGN

- Scintillating AGN are statistically more compact than non-scintillating compact radio sources imaged with the VLBI resolution (Ojha et al.)

- Scintillating AGN have the highest measured and highest inferred T_b (blazars and BL Lacs)

- Extremely strong and fast scintillating sources are RARE(!) – result from the dedicated IDV surveys (ATCA IDV and MASIV).

- AGN which show moderate and low level of ISS are relatively common (60%).
- Most scintillating sources show episodic ISS (80%)

- The transition frequency ν_0 between weak and strong scattering, where the strongest flux density modulations are expected and observed, is located between $\nu \sim 1$ GHz and 22 GHz

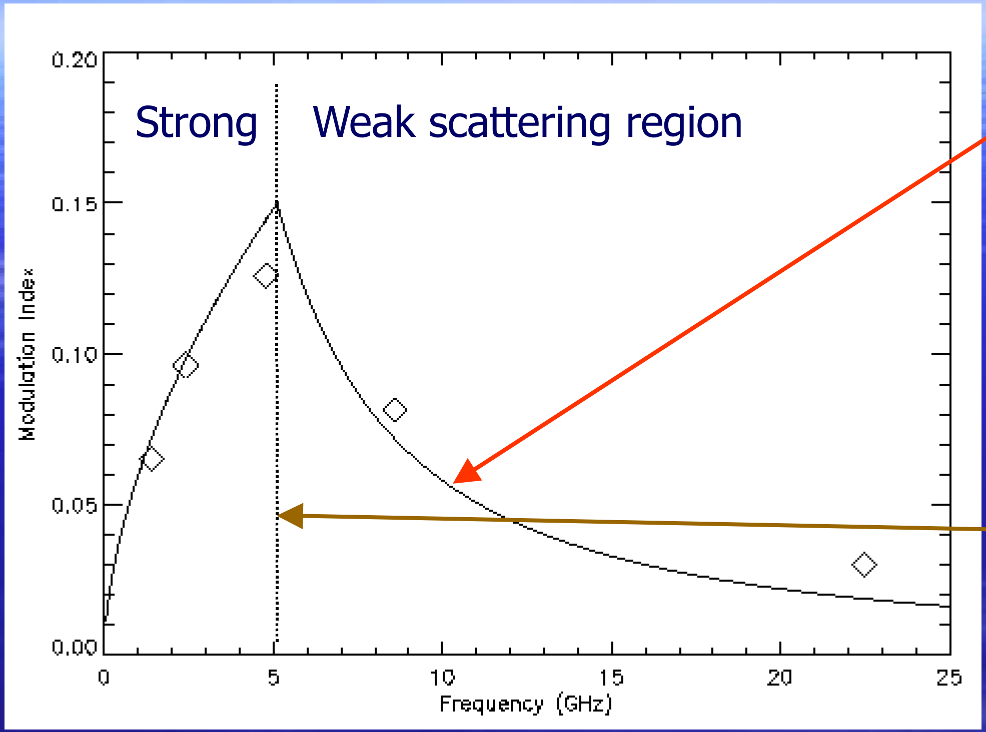
So what can we learn from scintillations?

- Probe the structure of AGN
  with μ–ARCSECOND resolution

and

- Probe the properties of Interstellar Medium
  which causes scintillations

Multifrequency information about variability strength



The one-parameter (flux density in the scintillating component) fit for the expected modulation index spectrum.

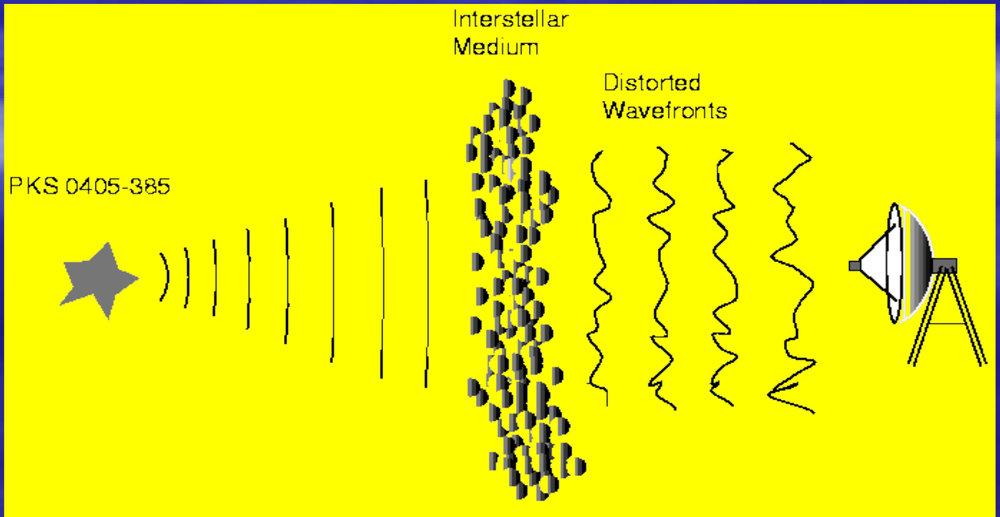
Transition frequency between the strong and weak scattering determines the size of the scintillating component ~ a few MICROARCSEC.

$$\theta_F=(\lambda/2\pi L)^{0.5}$$

L –the distance to the scattering screen

Modulation index spectrum

for PKS 0405-385.



Multifrequency information - time offset between light curves due to displacement of components at both frequencies

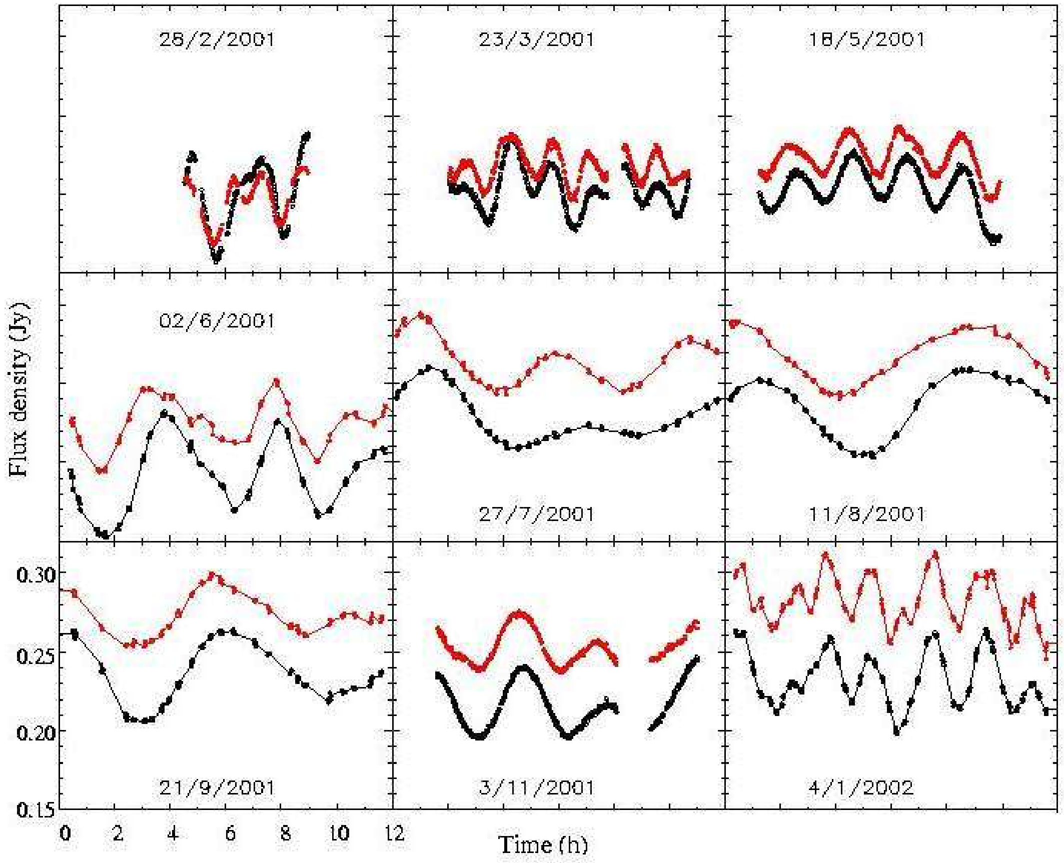
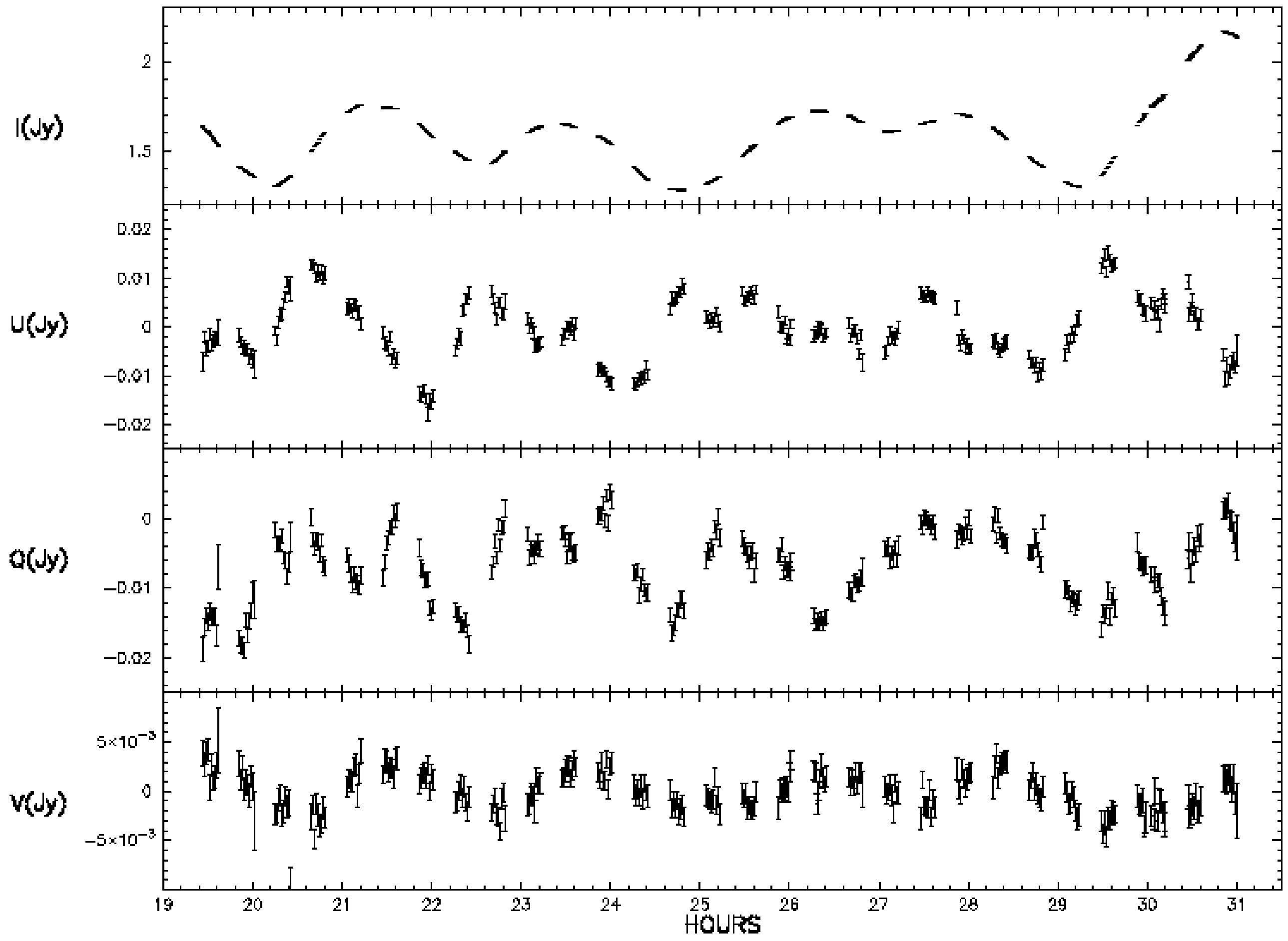


Figure 1: PKS 1257-326. 4.8 GHz (black symbols) and 8.6 GHz (red symbols). Bignall et al. 2002, ApJ, submitted.

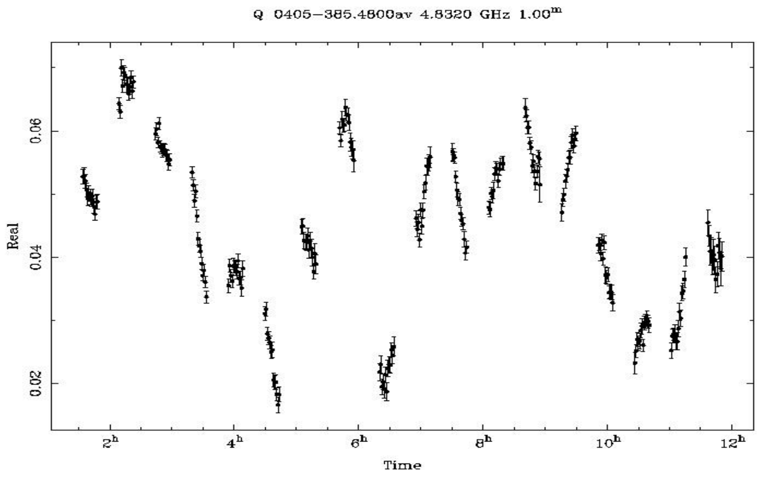
The offset due to possible opacity effects translates to 12 μ−arcseconds (0.08 pc).

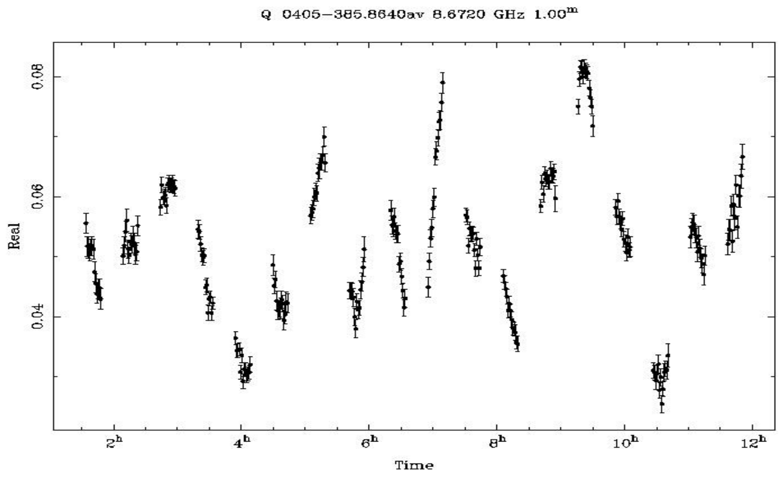
Polarization variability at 4.8 GHz (I,Q,U,V Stokes)

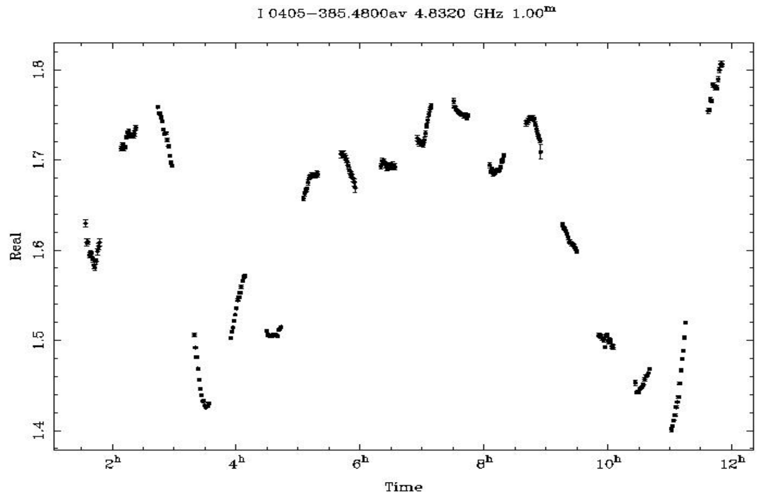


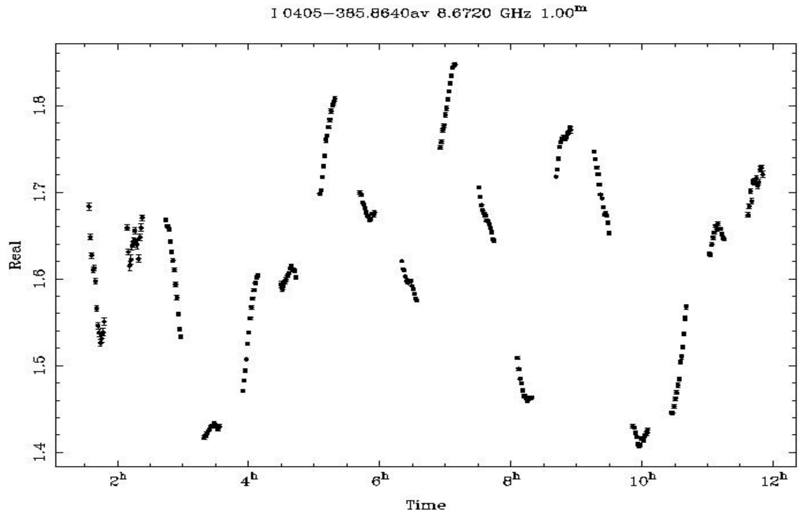
PKS 0405-385

Polarization variability in PKS 0405-385

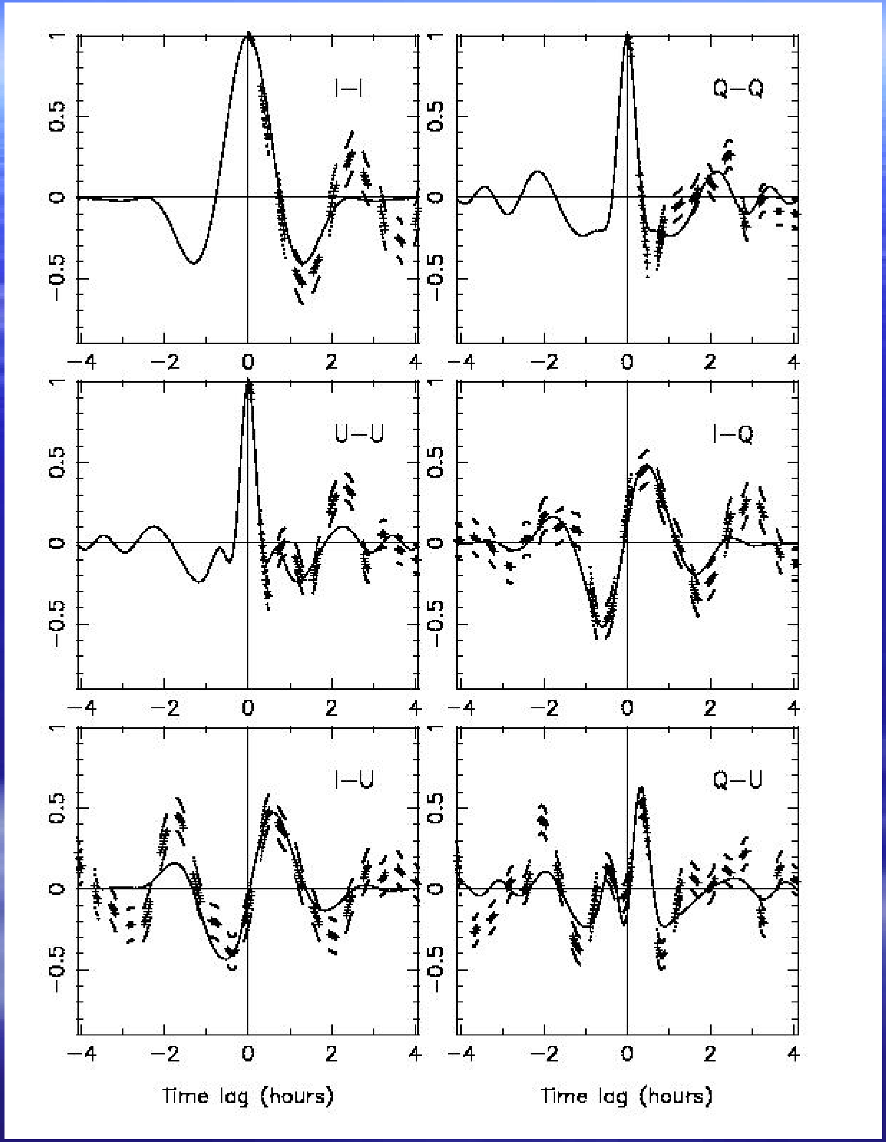








MICROarcsecond imaging of polarized source components for PKS 0405-385



Nonlinear least-squares optimization scheme to search for source parameters which best fit the six observed auto- and cross-correlations

$$C_{IQ}(\tau)=<\Delta I(t)\Delta Q(t+\tau)>$$

$$C_{IQ}(\xi,\eta)=<\Delta I(x,y)\Delta Q(x+\xi,y+\eta)>$$

Rickett et al. 2002

MICROarcsecond imaging of polarized source components for PKS 0405-385

Spacial correlation functions are computed as a Fourier transform of a product of the point-source scintillation power spectrum by a complex source filter

$$C_{IQ}(\xi,\eta)=\iint P_{IQ}(\kappa_x,\kappa_y)\exp[i(\kappa_x\xi+\kappa_y\eta)]d\kappa_x d\kappa_y$$

Cohen-Salpeter equation for the weak scattering (power spectrum of intensity fluctuations):

$$P_{IQ}(\kappa_x,\kappa_y) = 8\pi r_e^2\lambda C_N^2\delta L(R\kappa_x^2+\kappa_y^2/R)^{-\alpha-2}\sin^2(L\kappa^2\lambda/4\pi)$$

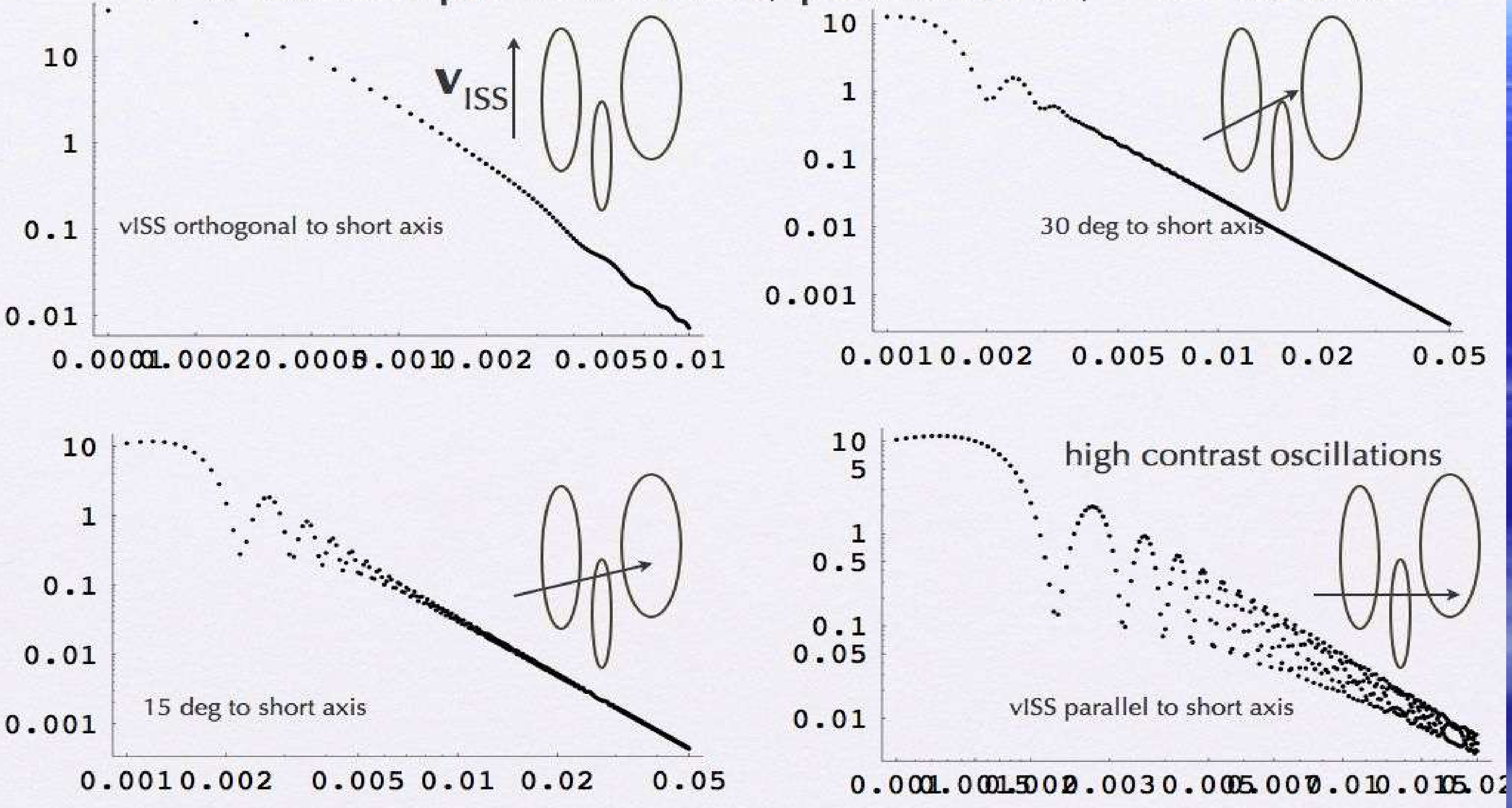
$$\times V_I(\kappa_x L/2\pi,\kappa_y L/2\pi)V_Q^*(\kappa_x L/2\pi,\kappa_y L/2\pi)$$

Modelling is done in temporal domain
(spacial lags mapped to temporal by the given V_{ISS} model)

$$C_{IQ}(\tau)=\langle\Delta I(t)\Delta Q(t+\tau)\rangle \qquad C_{IQ}(\tau)=C_{IQ}(\xi=V_{ISS,x}\tau,\eta=V_{ISS,y}\tau)$$

Theoretical spectra

R=5 anisotropic turbulence, point source, vISS=50km/s



vISS orthogonal to short axis

30 deg to short axis

15 deg to short axis

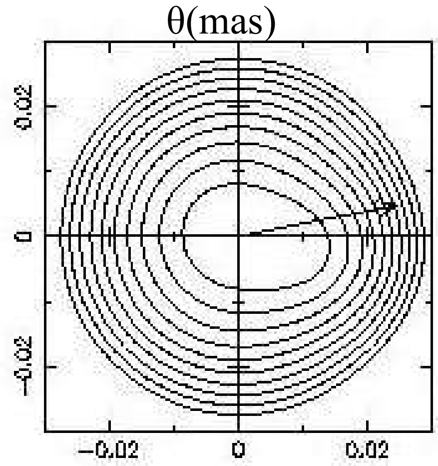
high contrast oscillations

vISS parallel to short axis

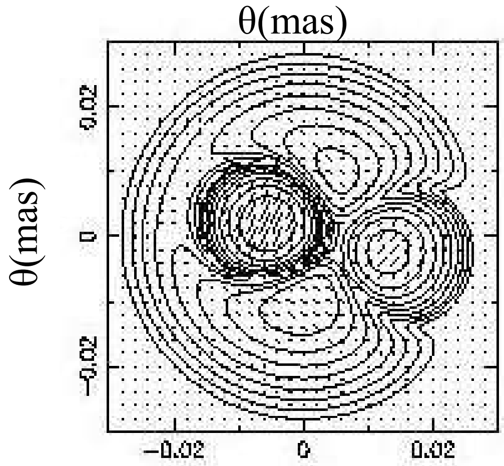
by J-P. Macquart

Three-component model of the linearly polarized structure in PKS 0405-385

21-parameter fit:
5 parameters describe the ISM properties,
for each of 3 Gausian components - sizes of components, total and polarized flux density, and position angle of polarization
4 parameters describing positions of 2 components relative to the first component



Brightness distribution
in the total flux density
with a peak T_b at 2×10^{13}K.

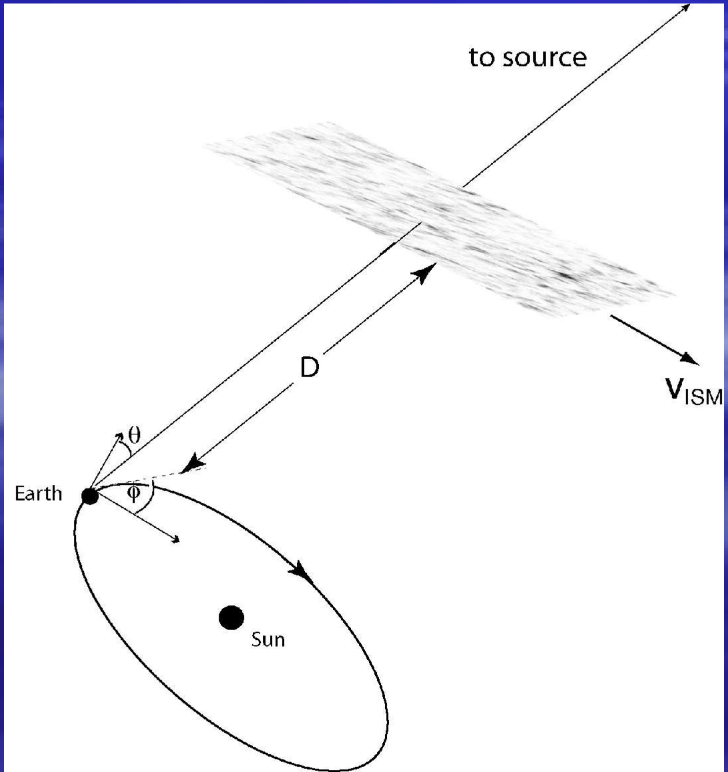


Polarized brightness distribution
with maximum ~70% of the total brightness

Microarcsecond imaging using Earth-Orbit Synthesis

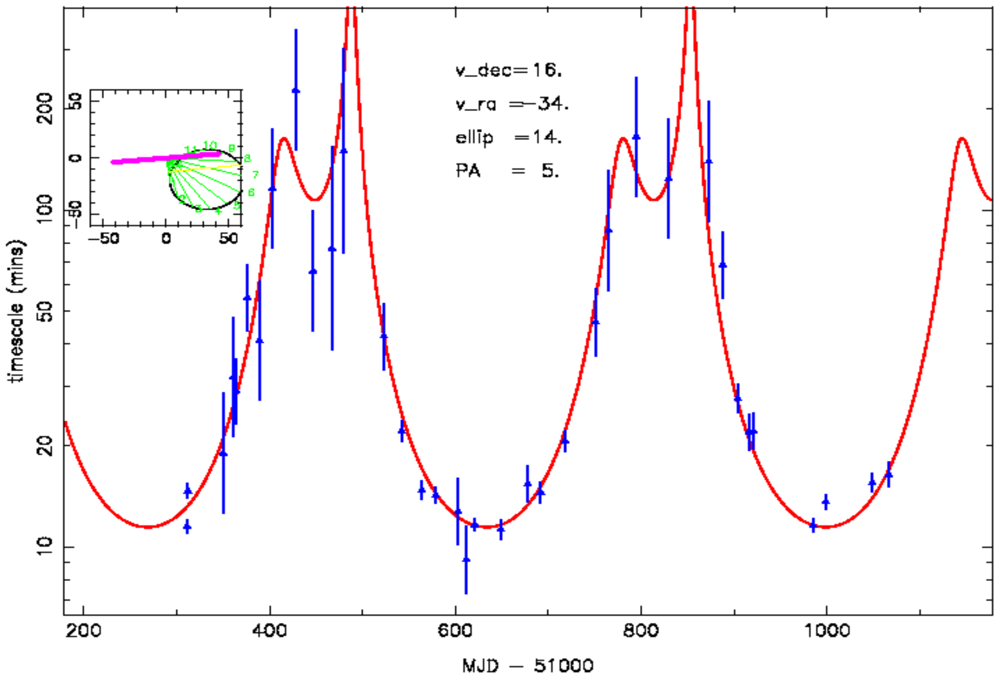
$$C_{IQ}(\tau)=C_{IQ}(\xi=V_{ISS,x}\tau,\eta=V_{ISS,y}\tau)$$

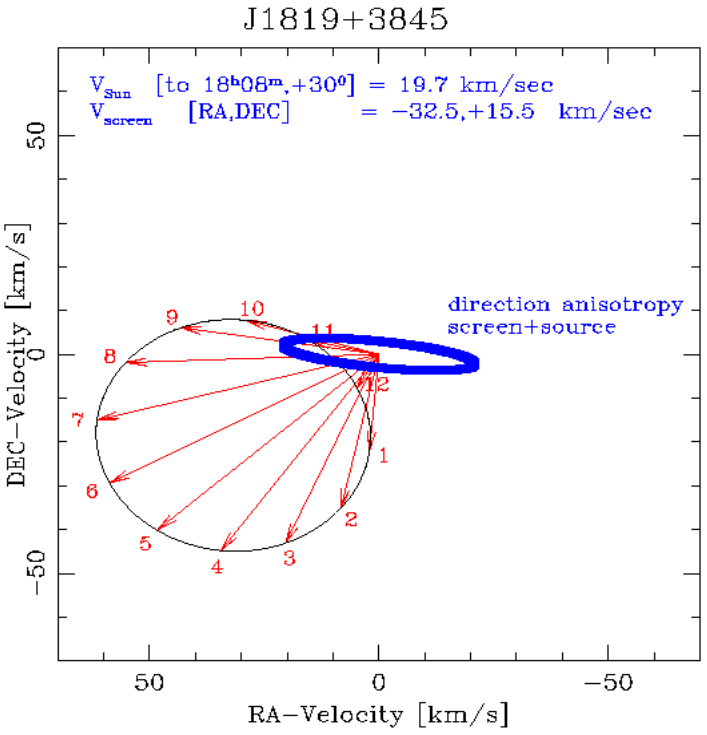
- The two-dimensional structure in the scintillation pattern recovered by using changes in the magnitude and direction of relative velocity between ISM and observer over the course of a year.
- The imaging can be achieved for any Stokes parameters fluctuations
- The effect of source structure is visible in the timescale of variability, although anisotropy of the medium can mimic this effect too



Macquart and Jauncey, 2002, ApJ 572, 786

Source structure or anisotropy of ISM effect in the annual cycle of variability timescale of quasar J1918+3845

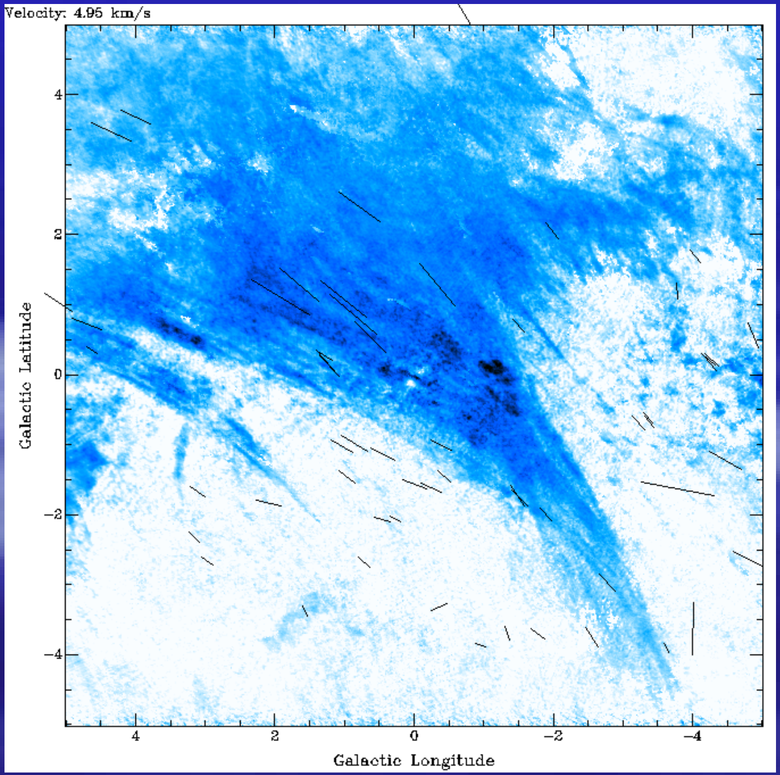




Courtesy of J. Dennett-Thorpe

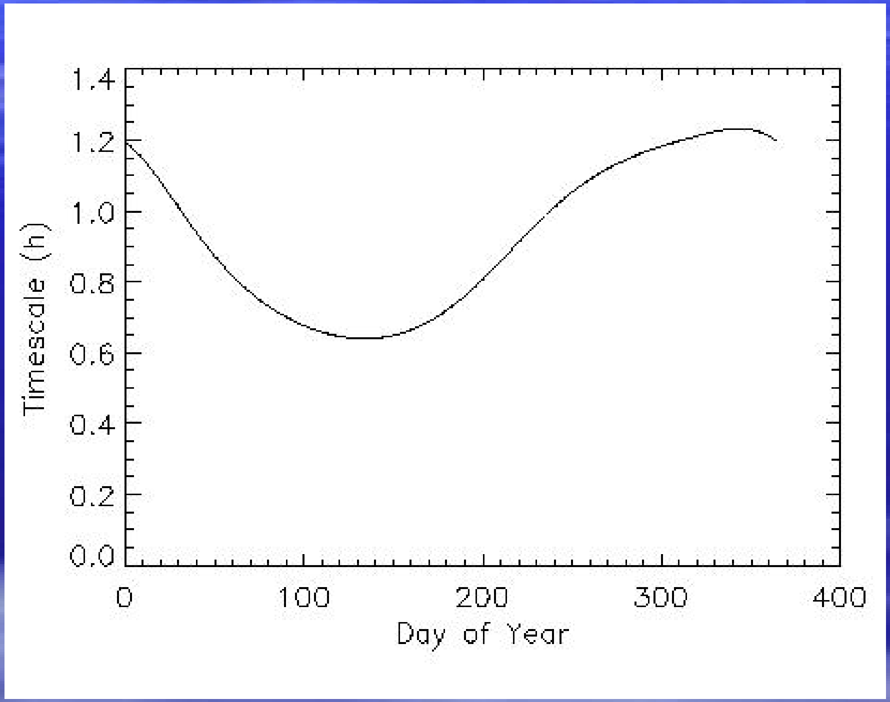
Interstellar medium - scattering screen:

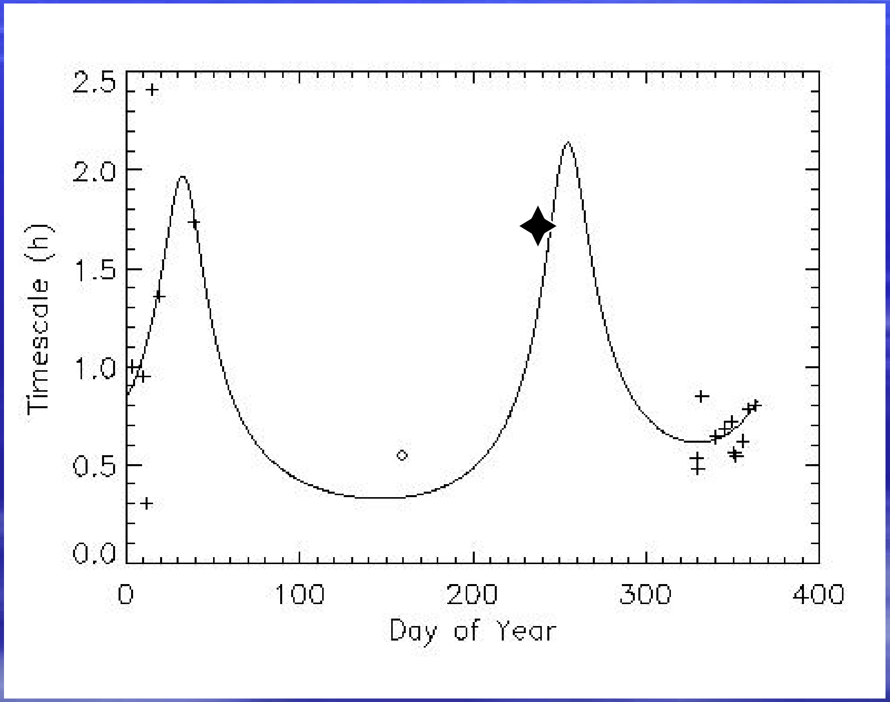
- Ionized
- Nearby (3-30 pc) – for the fastest variables (Cetus Arc, edge of the Local bubble?)
- ISM velocity of the order of the V_{LSR} (from observations of annual cycles of variability timescales)
- Thin screen
- Anisotropic (from obsevations of annual cycles and the shape of the ACF)
- Intermittent turbulence localized in AU-size regions



Distribution of HI in the local ISM (150 pc away)
Thanks to Naomi McClure-Griffiths (ATNF)

The example of annual timescale difference in isotropic and anisotropic turbulence model





What is needed to improve μ-arcsec modelling

- Better understanding of structure, turbulence and velocity of local ISM
- Frequent monitoring of the four-Stokes intensities to use the orbital motion of the Earth and the changes in the direction of scintillation velocity
- Location of the scintillating component
- Relationship of the miliarcsecond and μ-arcsecond structure
- Explanation why some IDV sources are episodic and other long-lived
- Connection of high circular polarization and IDV
- Exploring even smaller angular diameters and higher brightness temperatures in search for diffractive scintillations