ICRAR

International Centre for Radio Astronomy Research

What scintillation can tell us about the physics of the Universe

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The early years

Stanley & Slee (1950): on scintillation in Cygnus

V. Fluctuations

Since their discovery by Hey, Parsons, and Phillips(1) the fluctuations in the received intensity of the source in Cygnus have remained one of the puzzling features of this phenomenon. It was at first thought that the radiation from the source consisted of two distinct components(2) as in the case of thermal and enhanced radiation from the sun. However, a longer period of observations

(i) & (ii) fluctuations decrease with frequency and cut out at ~160 MHz

(iii) variations faster with decreasing frequency

(iv) degree of fluctuation similar for simultaneous observations at a range of *v*'s

(v) no correlation between lightcurves between 85 & 100 MHz

(vi) annual variation in the occurrence of the fluctuations

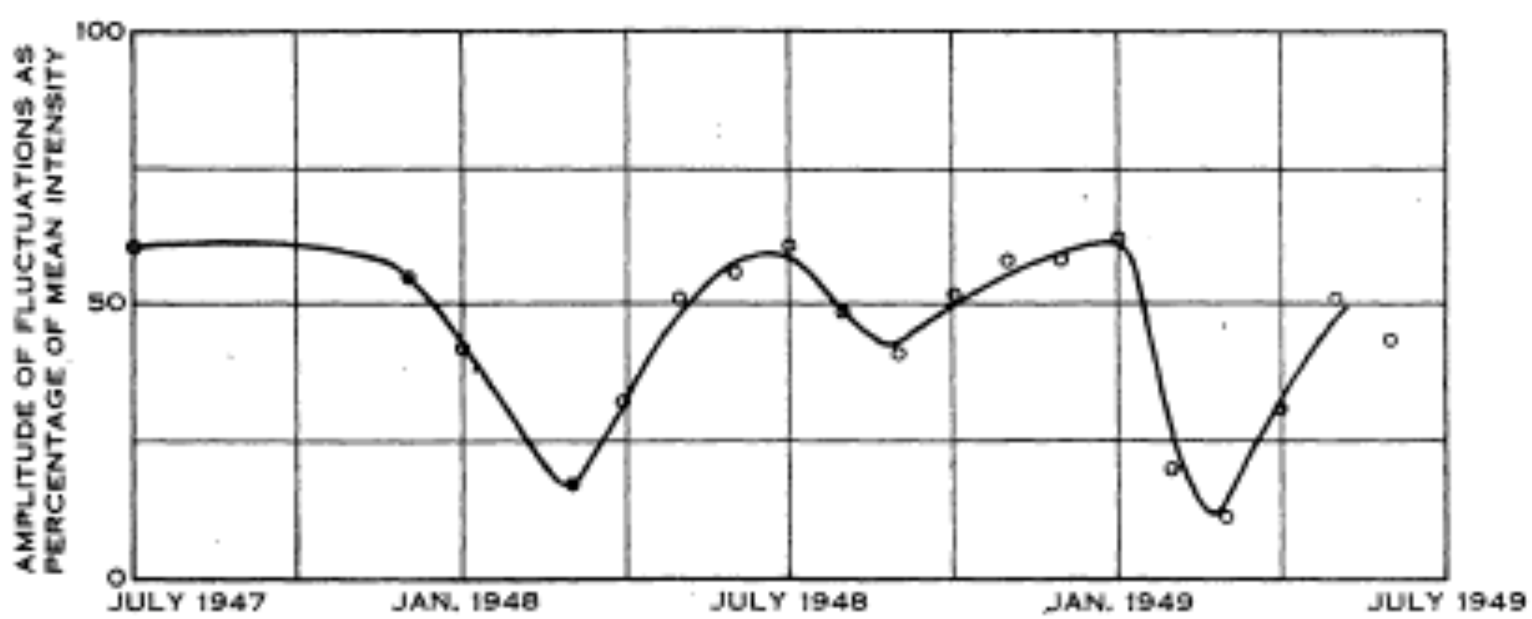


Fig. 6.—Degree of fluctuation of the intensity of the source in Cygnus. Individual points are monthly means.

What can scintillation do for you?

What is scintillation?

Three themes:

increasing level of speculation

(i) Active Galaxies

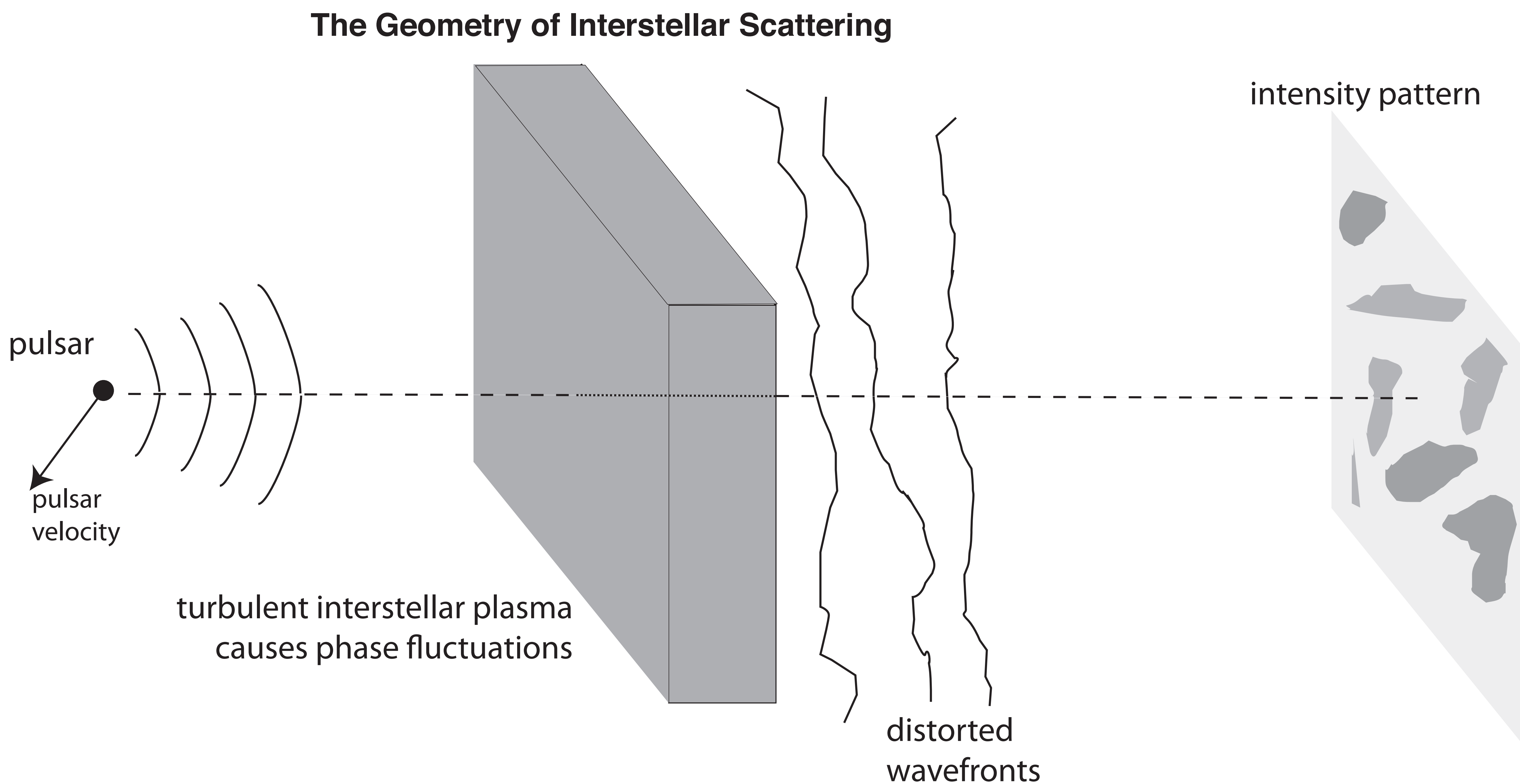
(ii) Pulsar emission and ISM turbulence

(iii) FRB scattering and the physics of the Inter-Galactic medium

or

“Plus ça change, plus c'est la même chose”

Ionospheric/Interplanetary/Interstellar Scintillation



Scintillation as an interferometer

There is a characteristic size to the pattern

This relates to the range of angles from which radiation is received θ_{scatt}

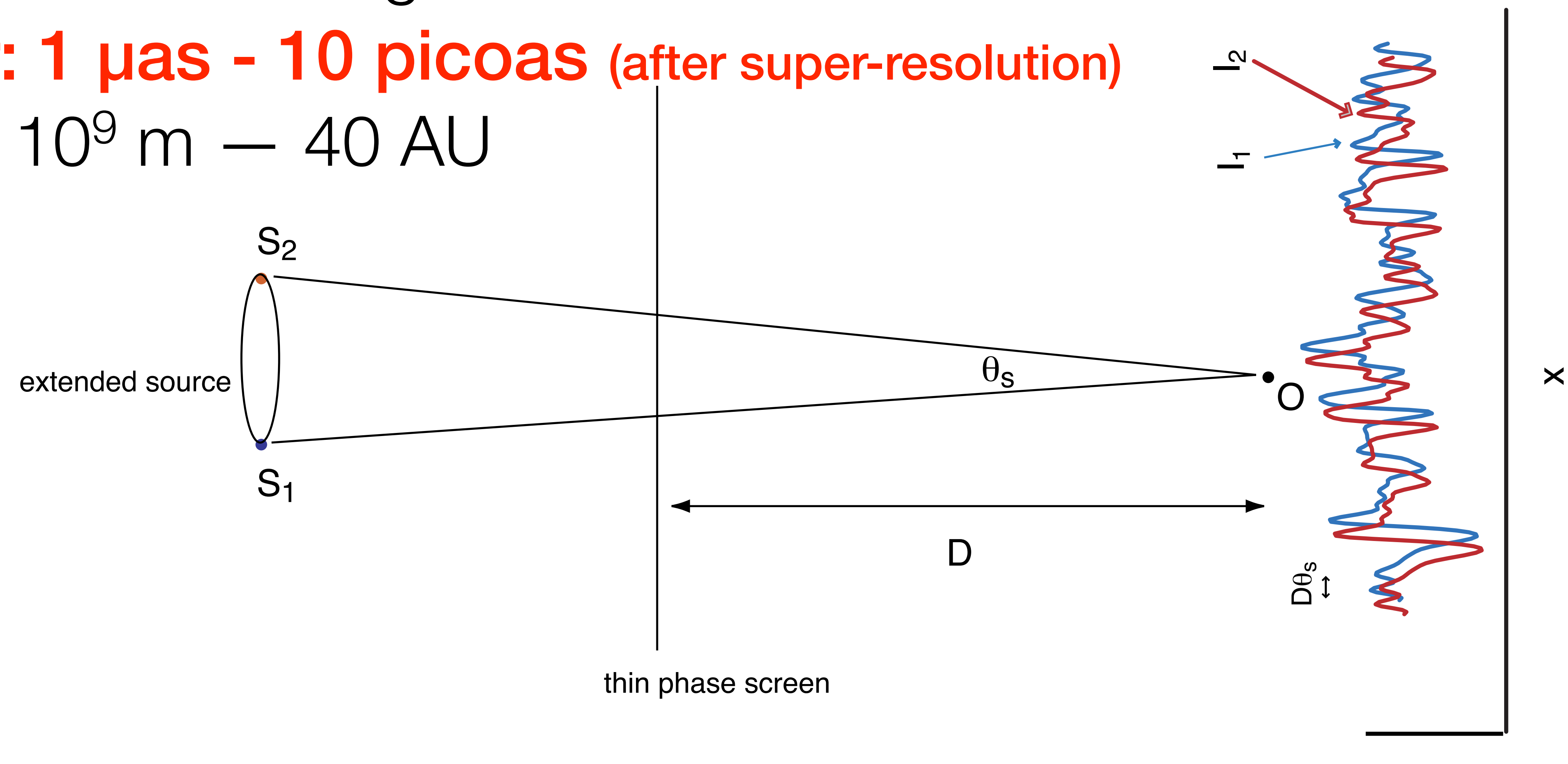
Resolution depends on the baseline $D\theta_{scatt}$

Interplanetary: Typically ~1”

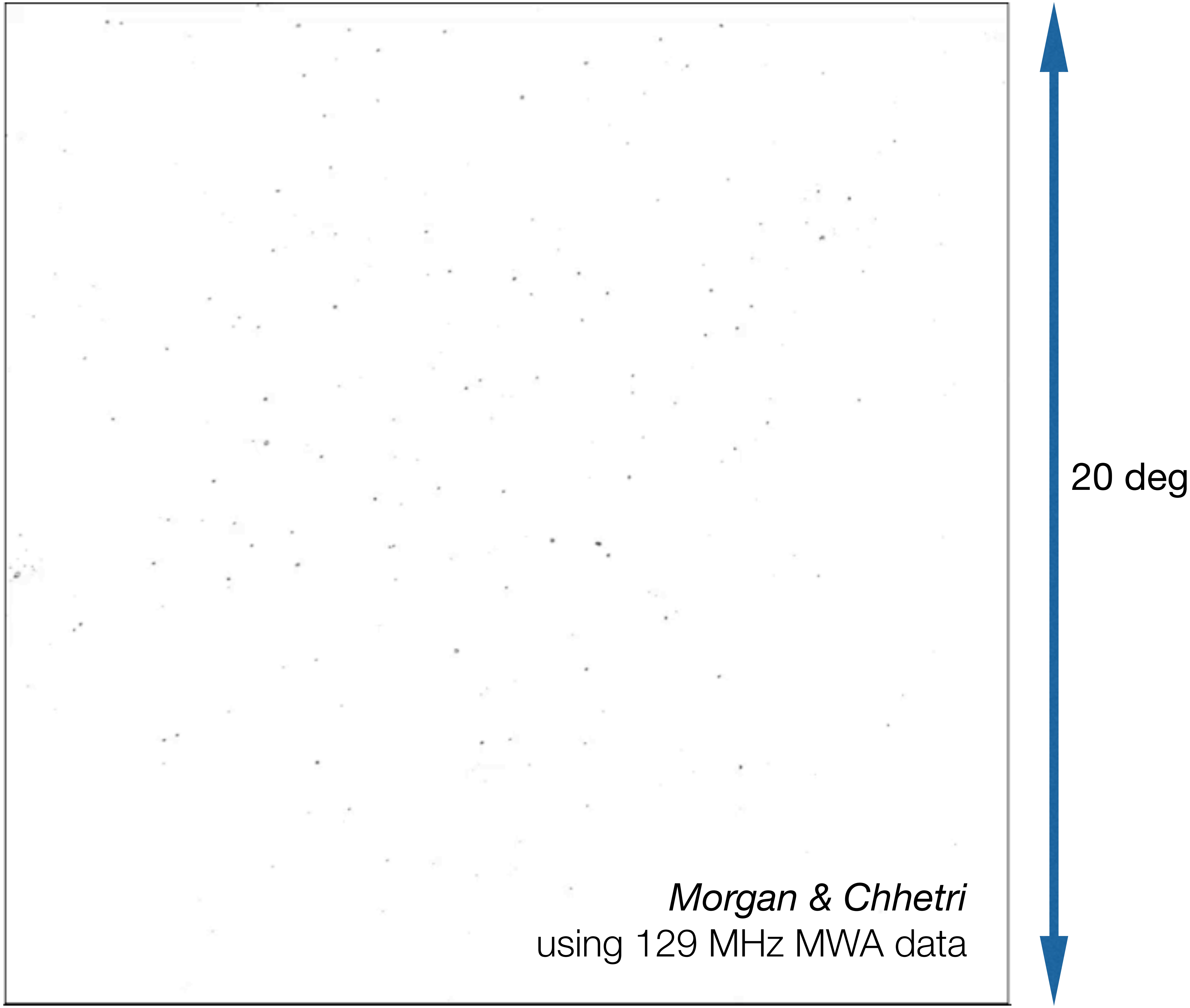
depends on solar elongation

Interstellar: 1 µas - 10 picoas (after super-resolution)

baselines 10^9 m — 40 AU

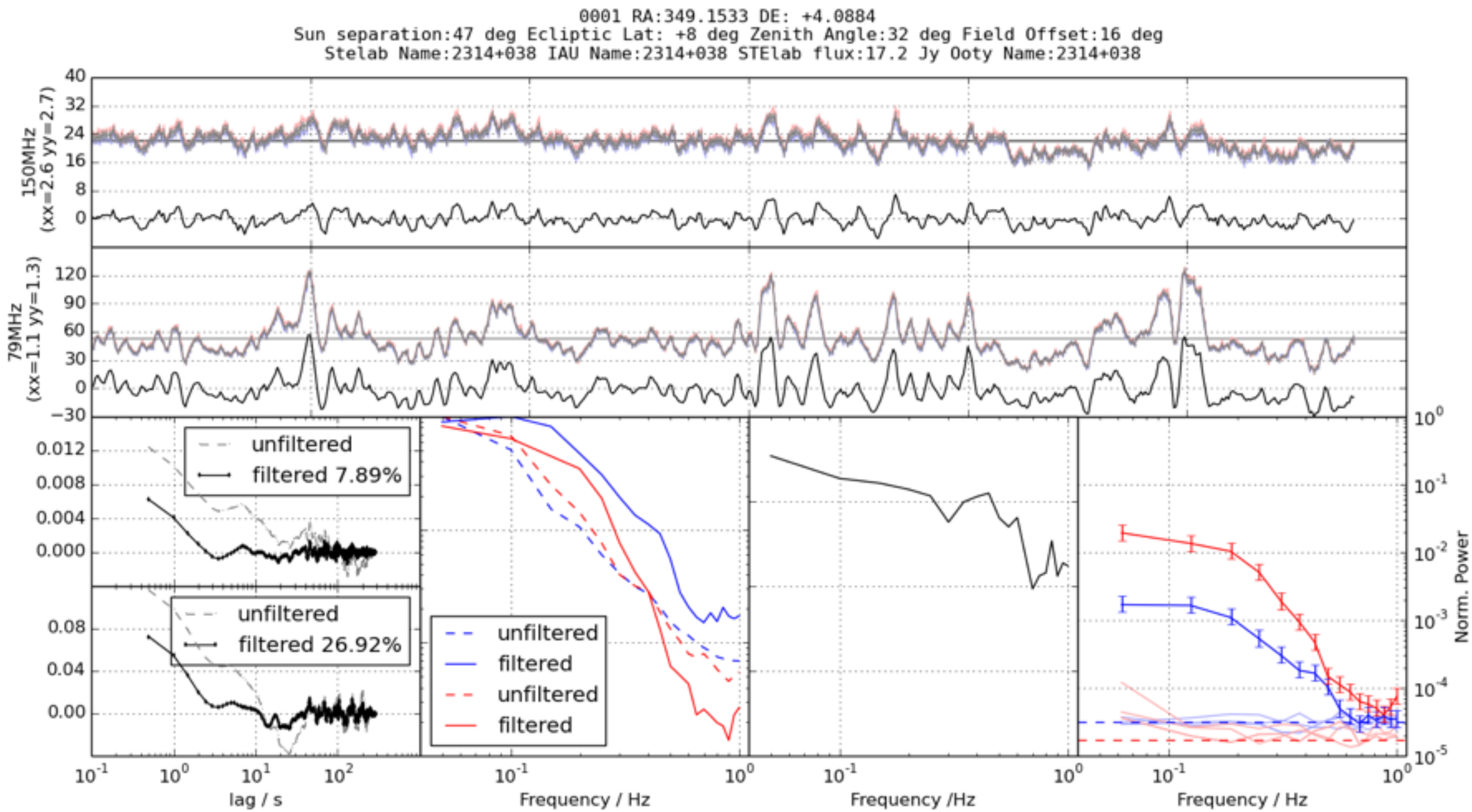


Interplanetary scintillation as seen by the MWA



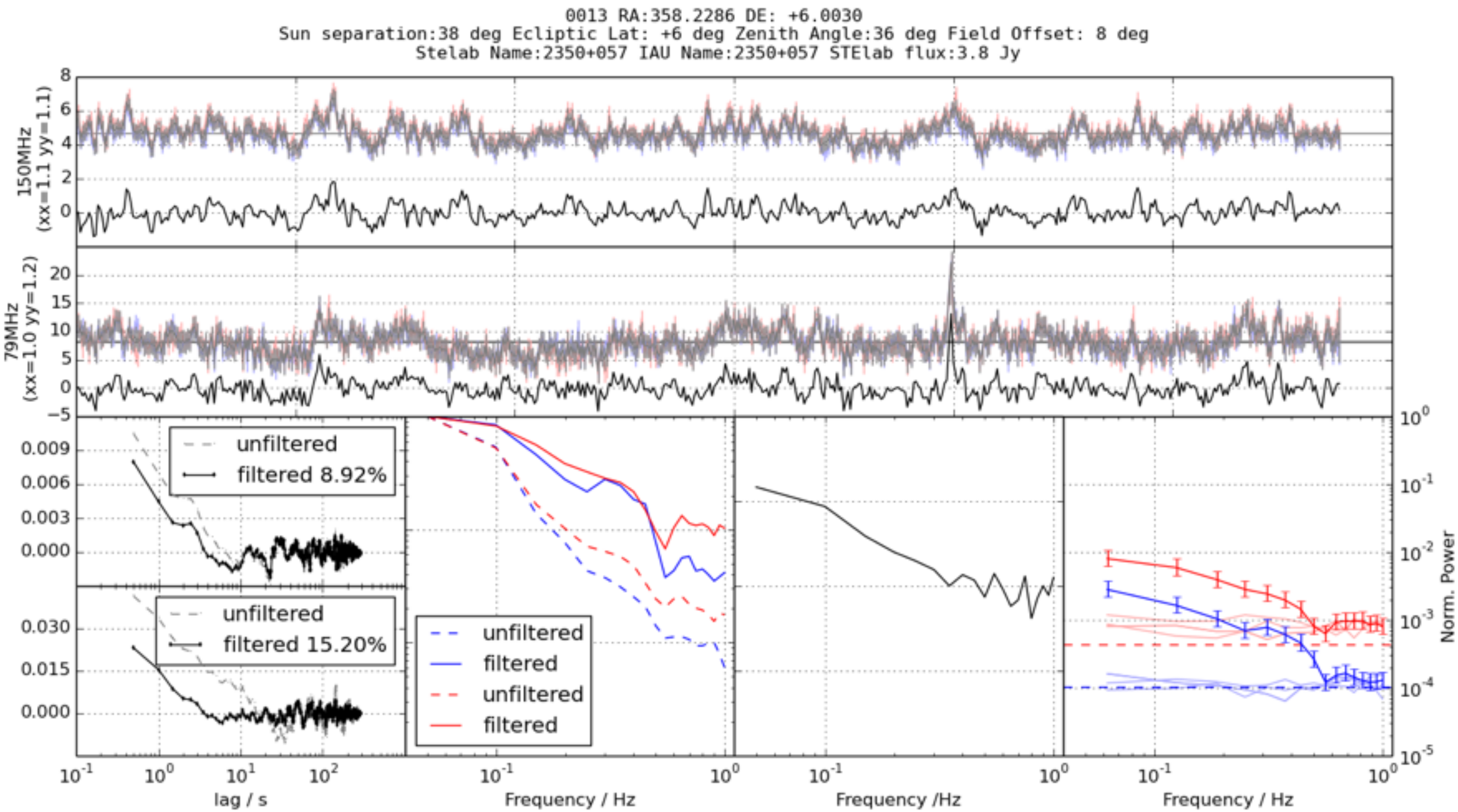
Interplanetary scintillation as seen by the MWA

How to get ~400km baselines from a 3km baseline telescope

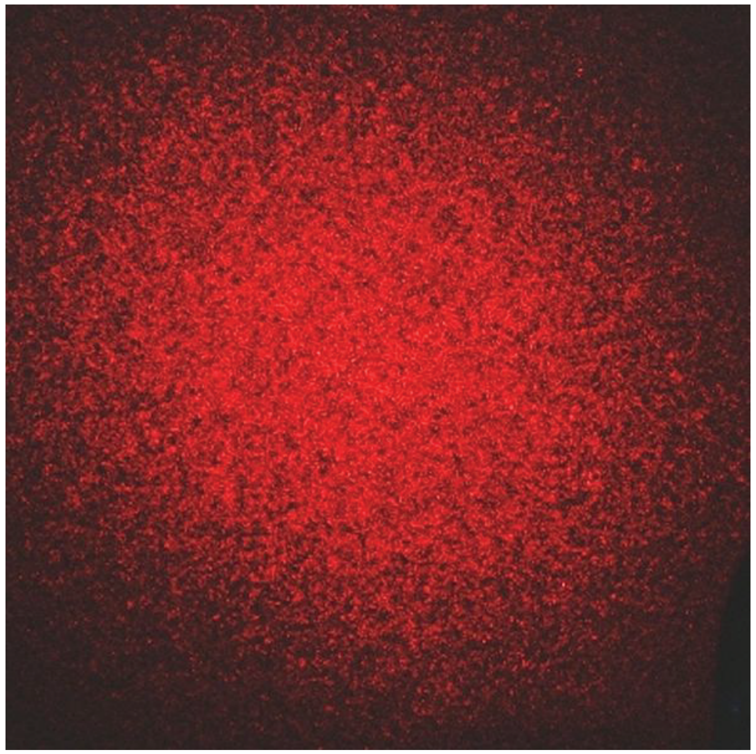


Interplanetary scintillation as seen by the MWA

A double source: 1” ~ 1 second

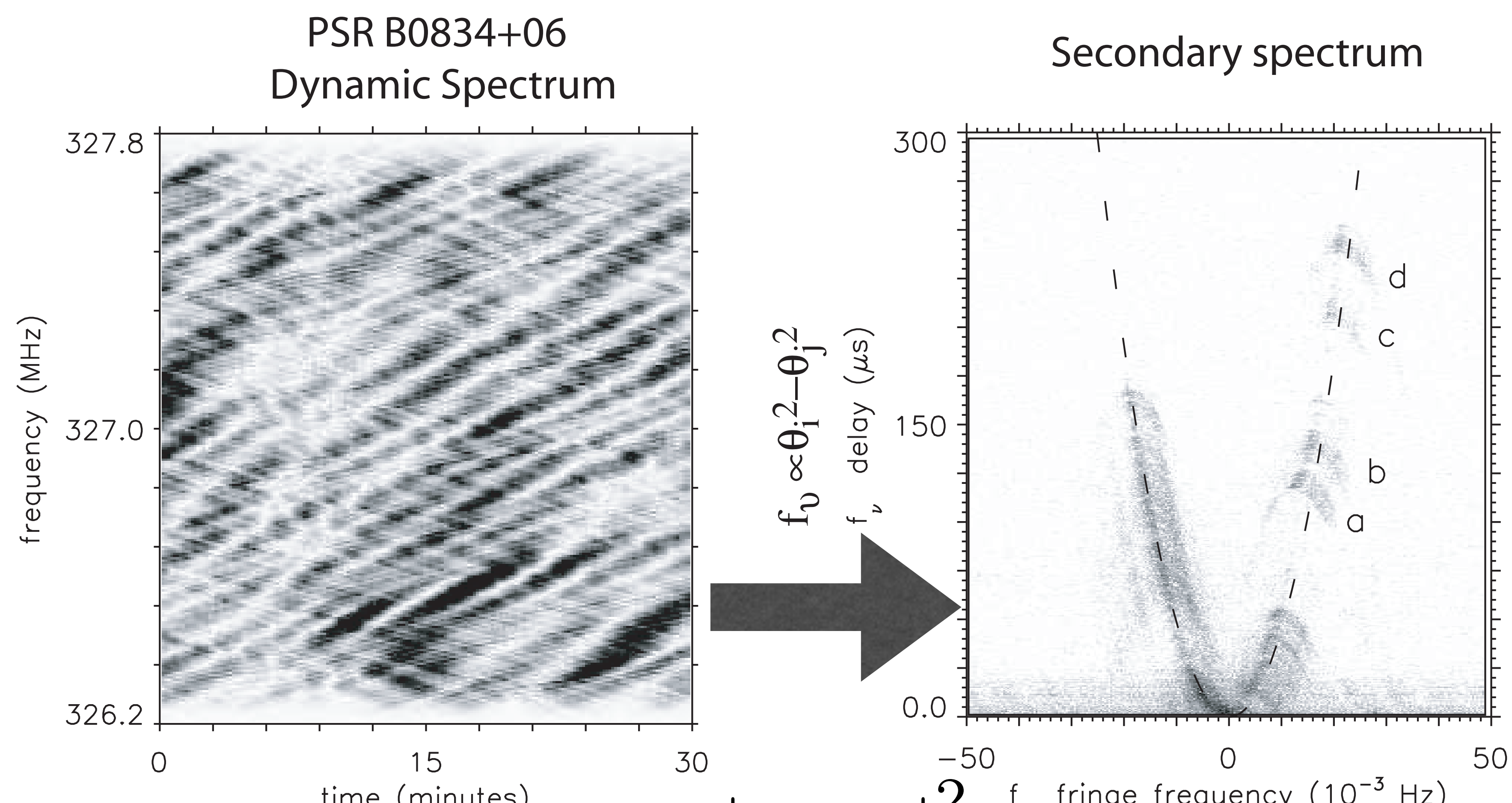


Pulsar scintellometry



Laser speckle pattern on a rough wall

Speckle patterns abound in interstellar space from Nature's own interferometer



$|\mathrm{FFT}|^2$

$f_t \propto (\theta_i - \theta_j) \cdot \mathbf{v}_{scint}$

Harnessing nature's interferometer

Secondary Spectrum shape determined by **speckle** geometry

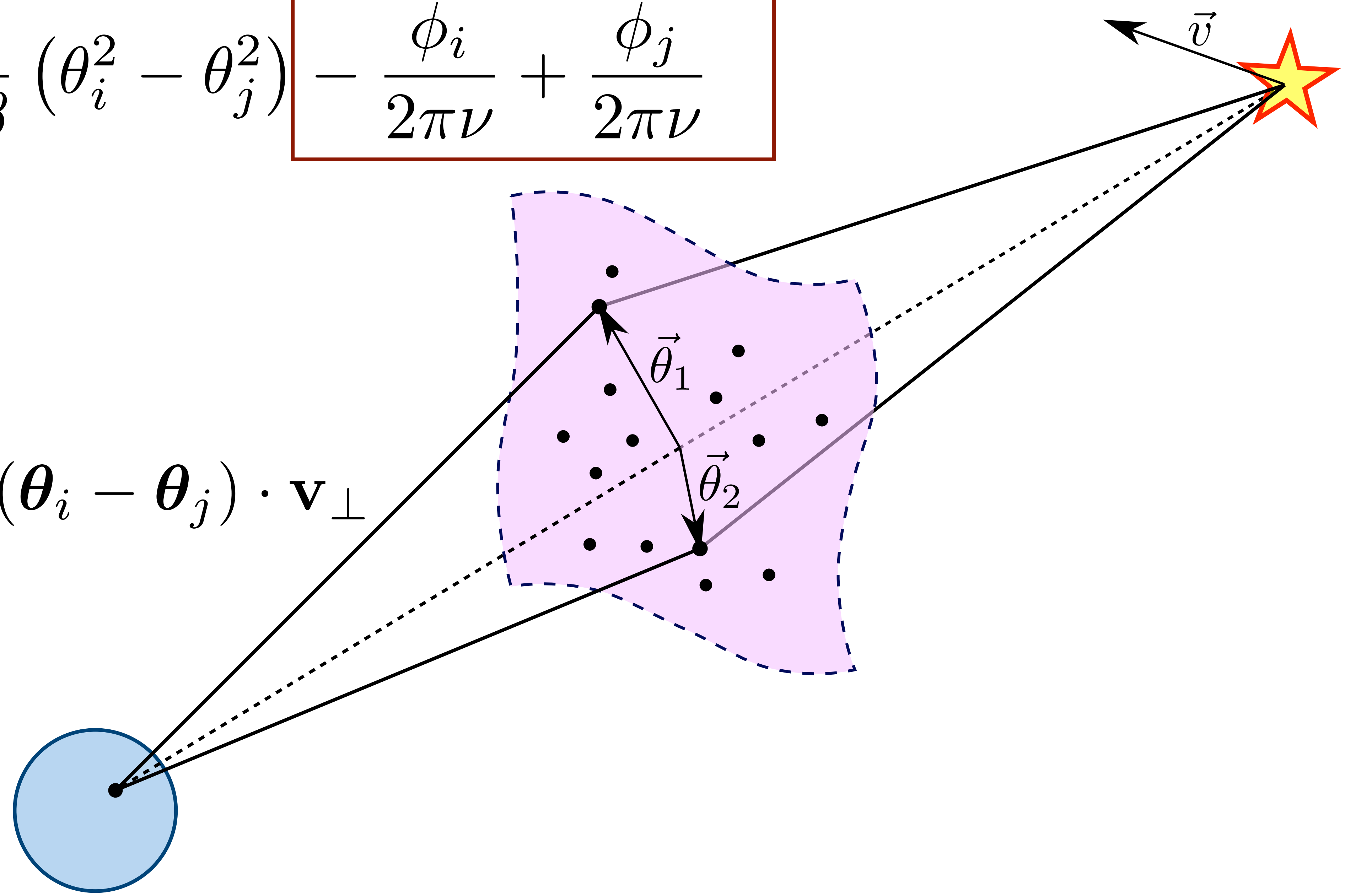
this term usually unimportant

delay (conjugate to frequency axis)

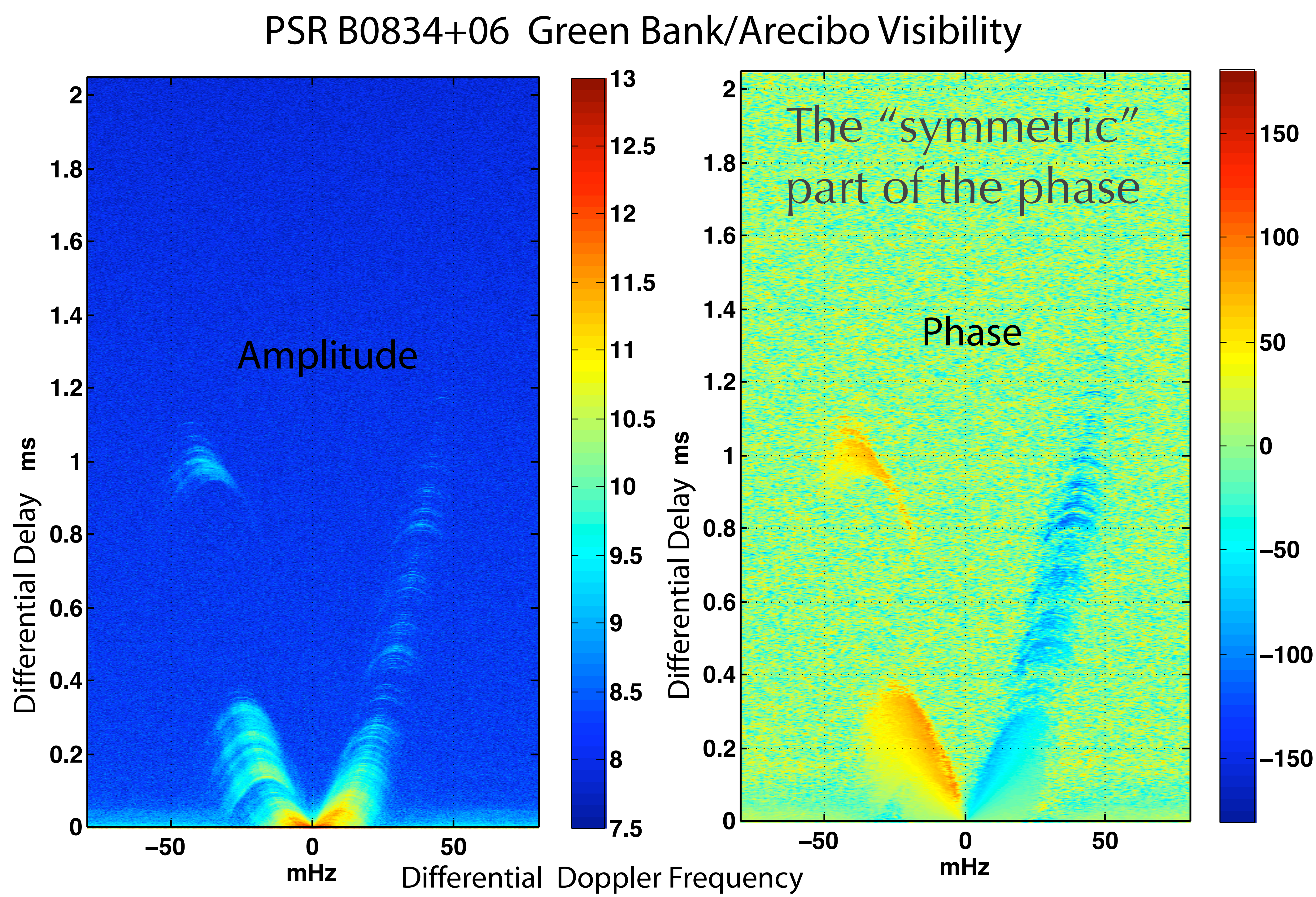
$$\tau = \frac{D_s}{2c\beta}\left(\theta_i^2 - \theta_j^2\right) - \frac{\phi_i}{2\pi\nu} + \frac{\phi_j}{2\pi\nu}$$

Doppler shift (conjugate to time axis)

$$\omega = \frac{1}{\lambda\beta}\left(\boldsymbol{\theta}_i - \boldsymbol{\theta}_j\right)\cdot \mathbf{v}_\perp$$

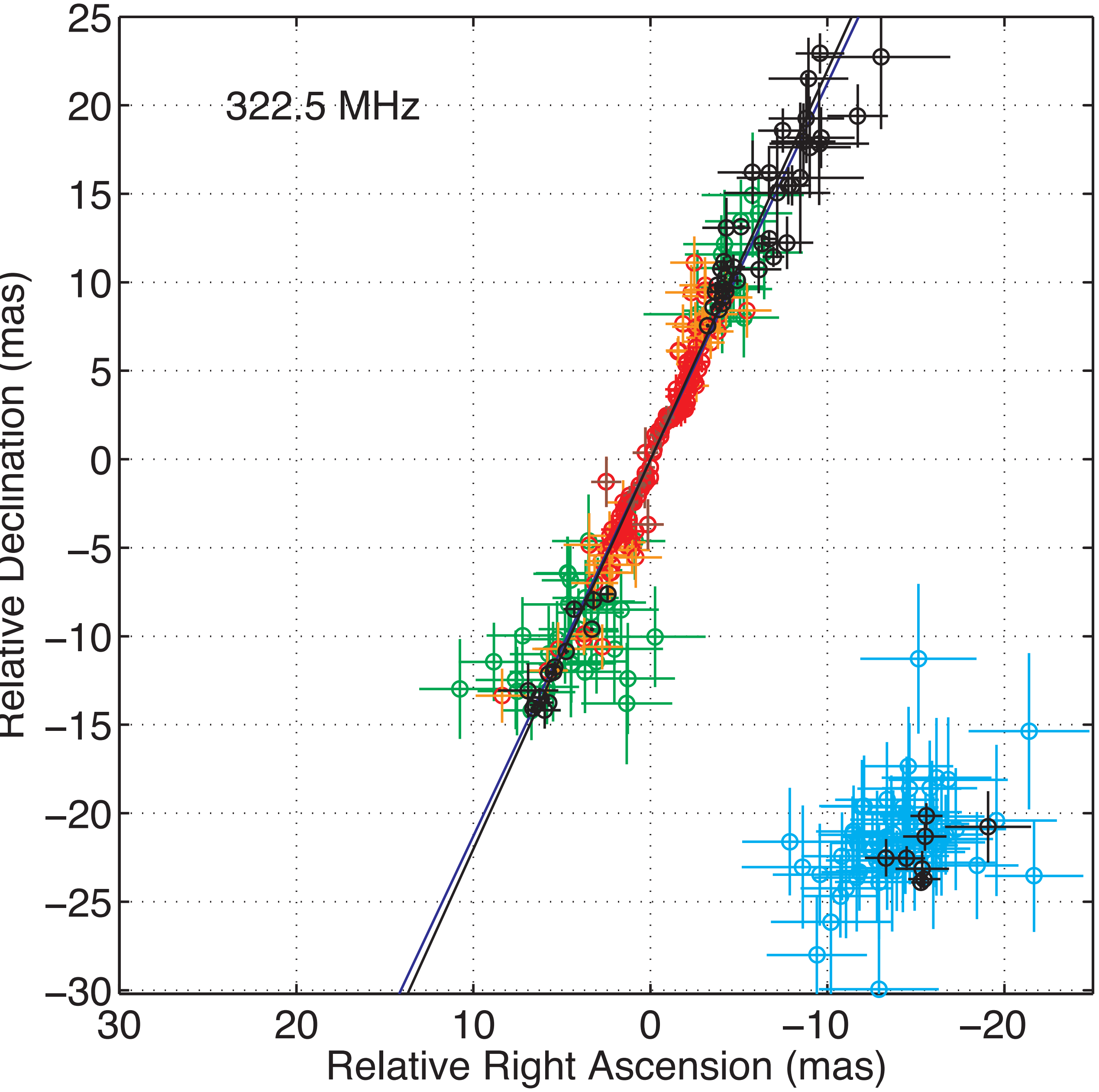


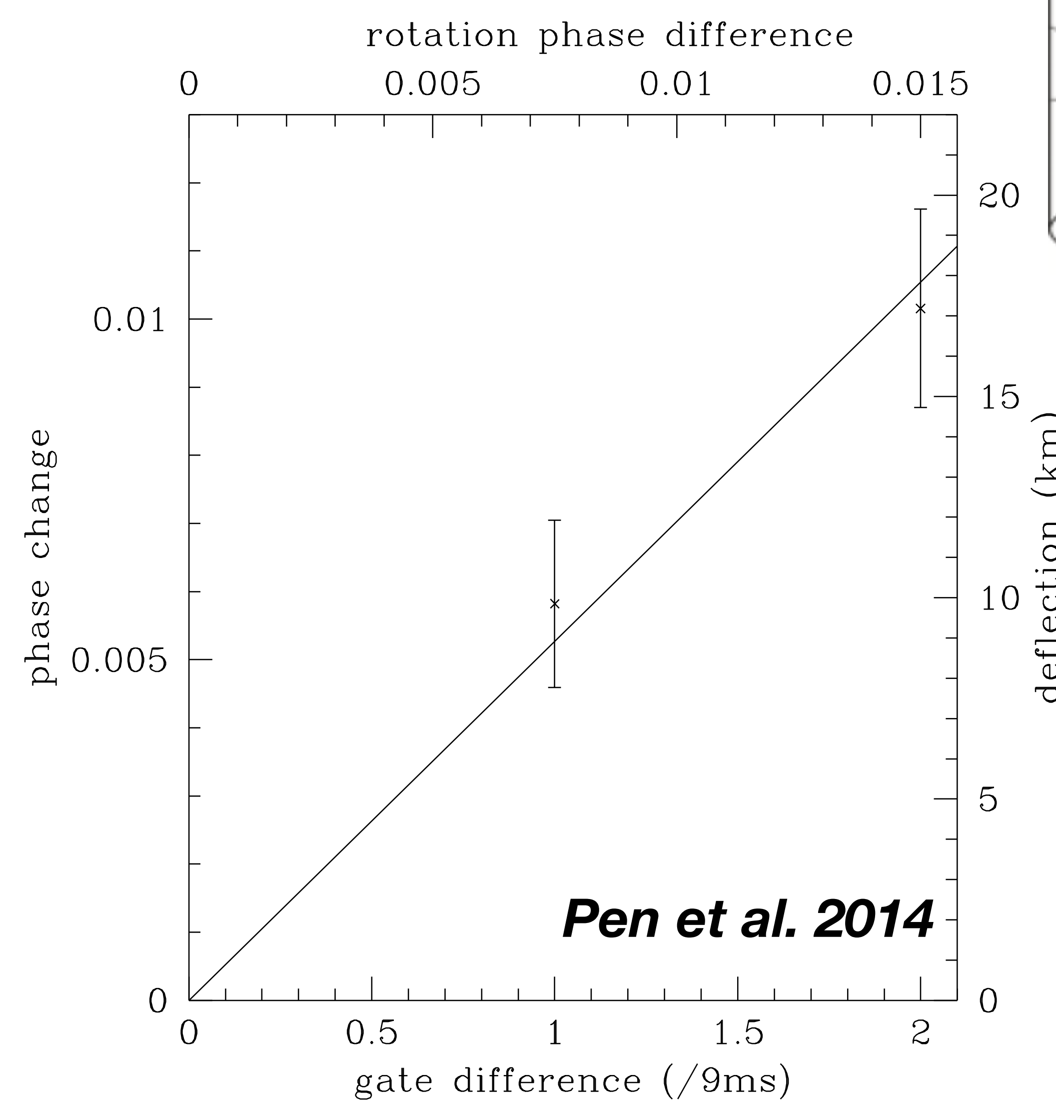
Resolving pulsar emission regions

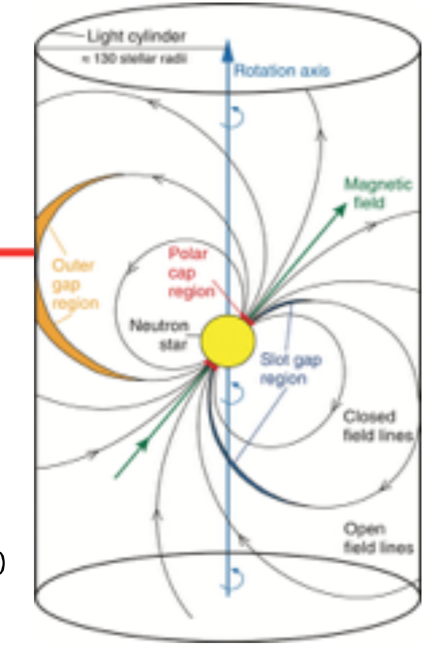


Brisken, Macquart et al. 2010

Resolving pulsar emission regions

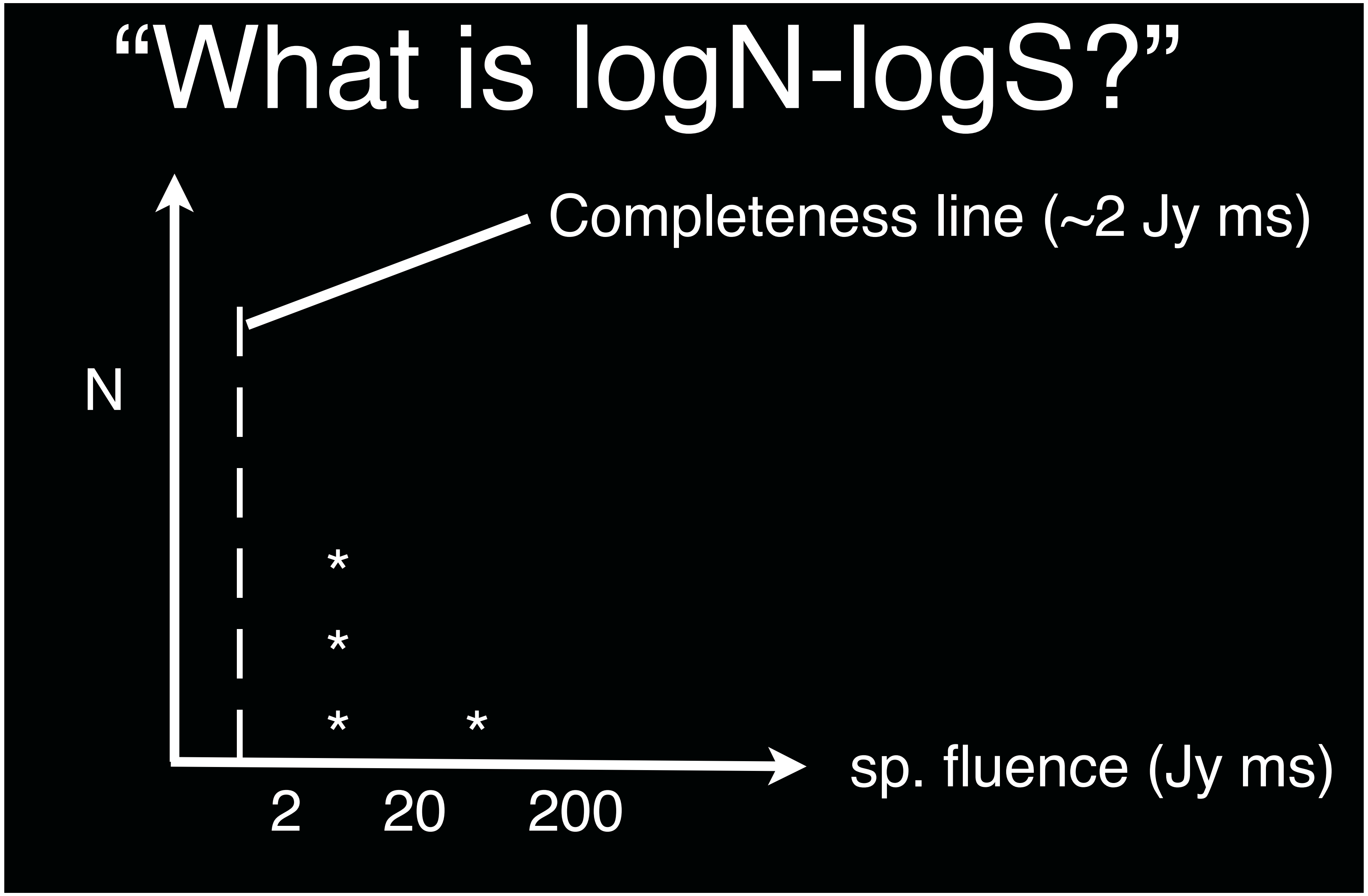






The phase difference in the scintillation pattern as a function of pulse phase, measured to 1mrad precision in PSR B0834+06, corresponding to a systematic deflection in the emission site as a function of pulse gate of 18 ± 2 km.

How do we find out FRBs are?



FRB source counts!

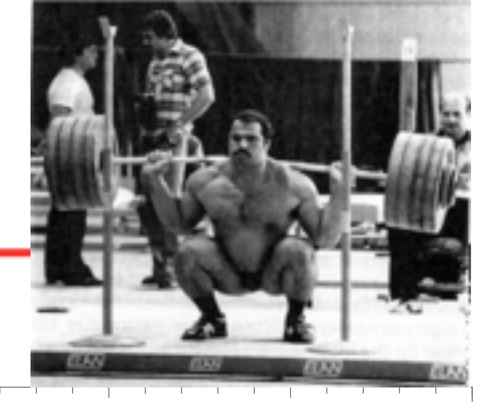
Observations show there is a ~4:1 difference in the detection rate between high (>30 deg) and low latitude
(*Petroff et al. 2014*)

How can this be if the population is extragalactic?

- Bayesian analysis shows the event rate disparity is significant at the 99% confidence level
- Even a Galactic population will show more detections at low latitude than high
  - even if the objects are confined to the Galaxy's halo

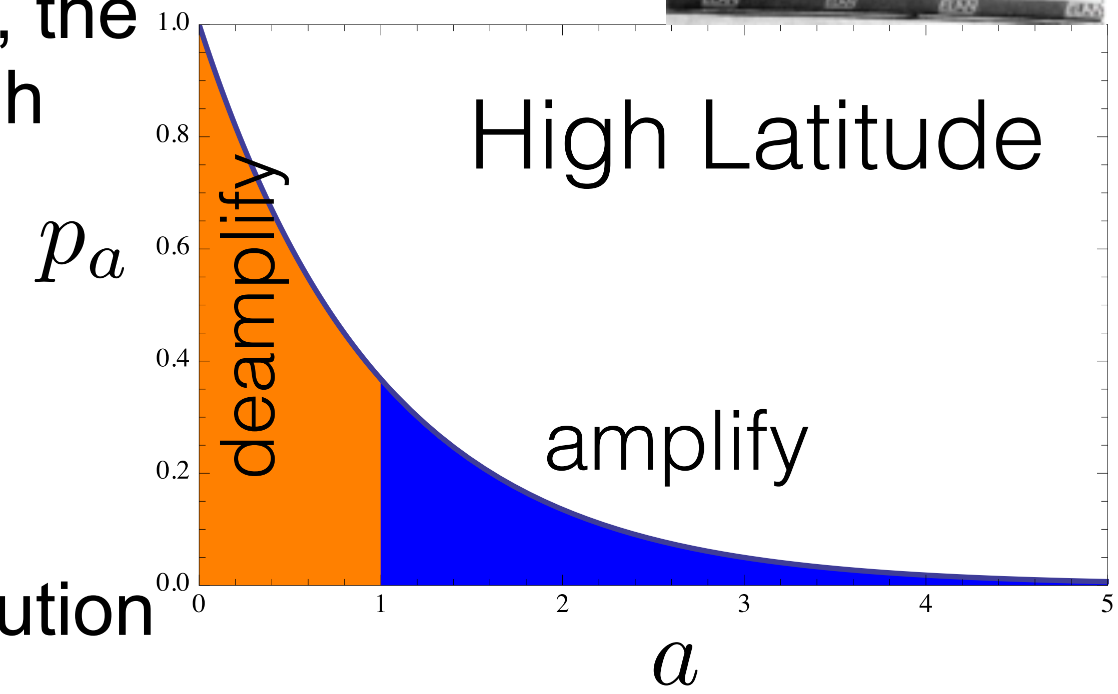
latitude	Hours on sky	Events	Rate (h/event)
$\|b\|<15$	1927.7	2	960
$30<\|b\|<45$	2128.85	7	300
$\|b\|>45$	1030.0	6	170

How does it work?



In the regime of strong diffractive scintillation, the probability distribution of amplifications at high latitude is

$$p_a(a) = e^{-a}$$

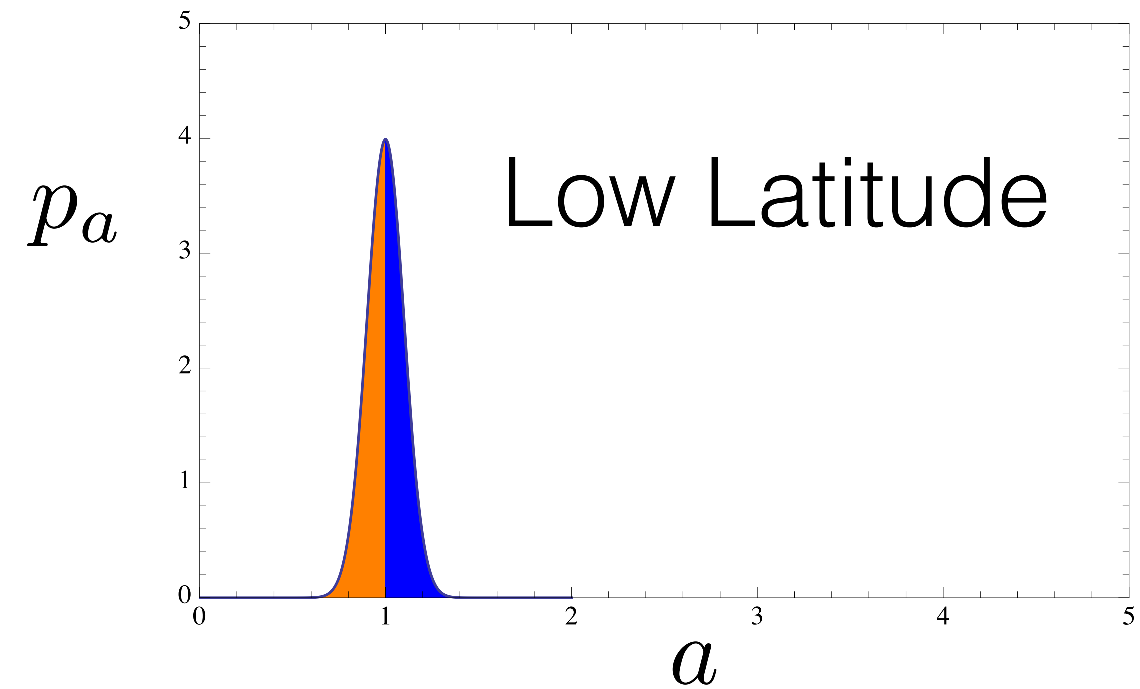


The differential source counts follow a distribution

$$p(S_\nu) \propto S_\nu^{-5/2+\delta}$$

vs

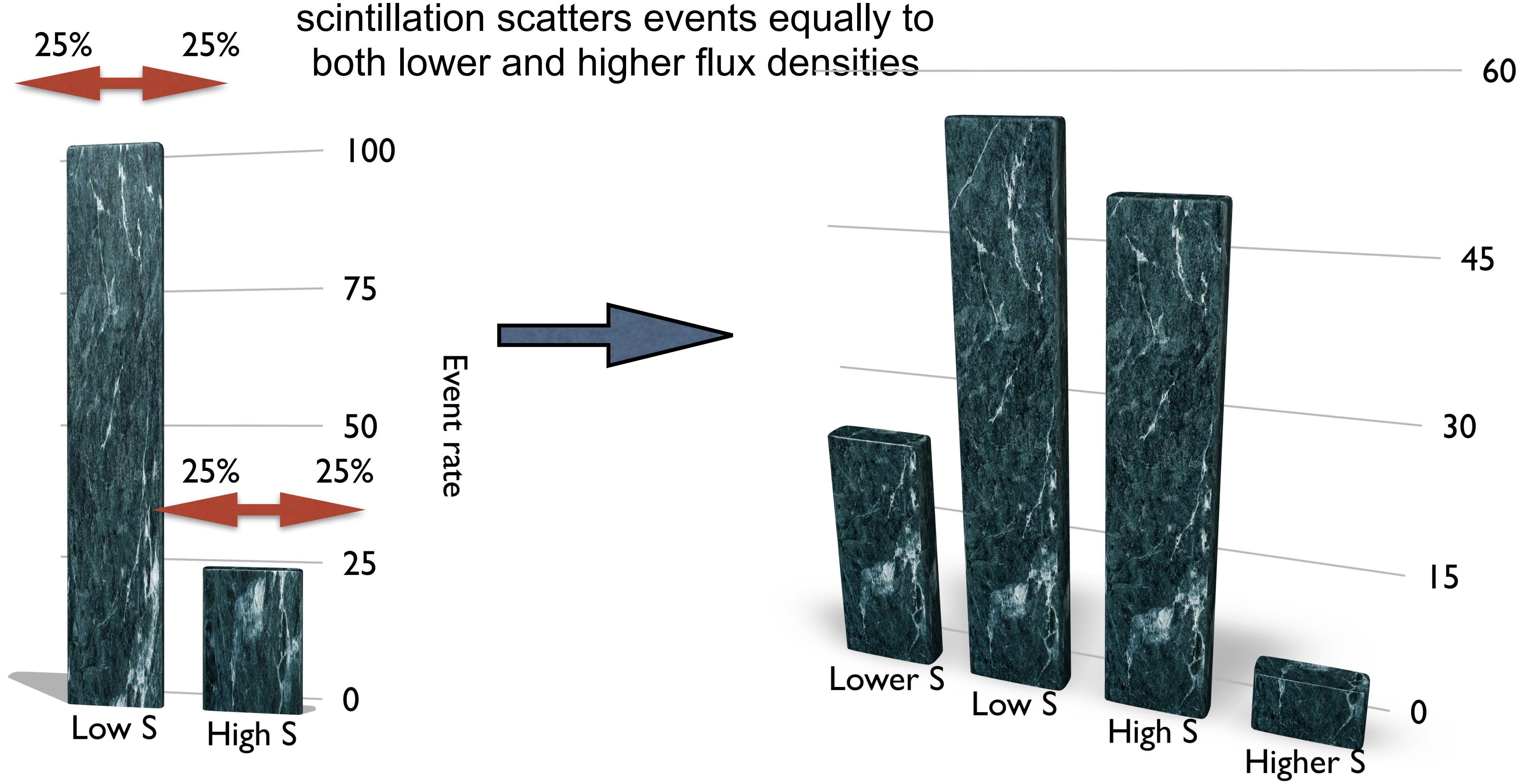
where δ=0 for a Euclidean universe that is homogeneously populated with transients



Physical origin

Eddington Bias

scintillation scatters events equally to both lower and higher flux densities



Scintillation equalizes the two distributions:
enhance the low event rate bin at the expense of high event rate bins

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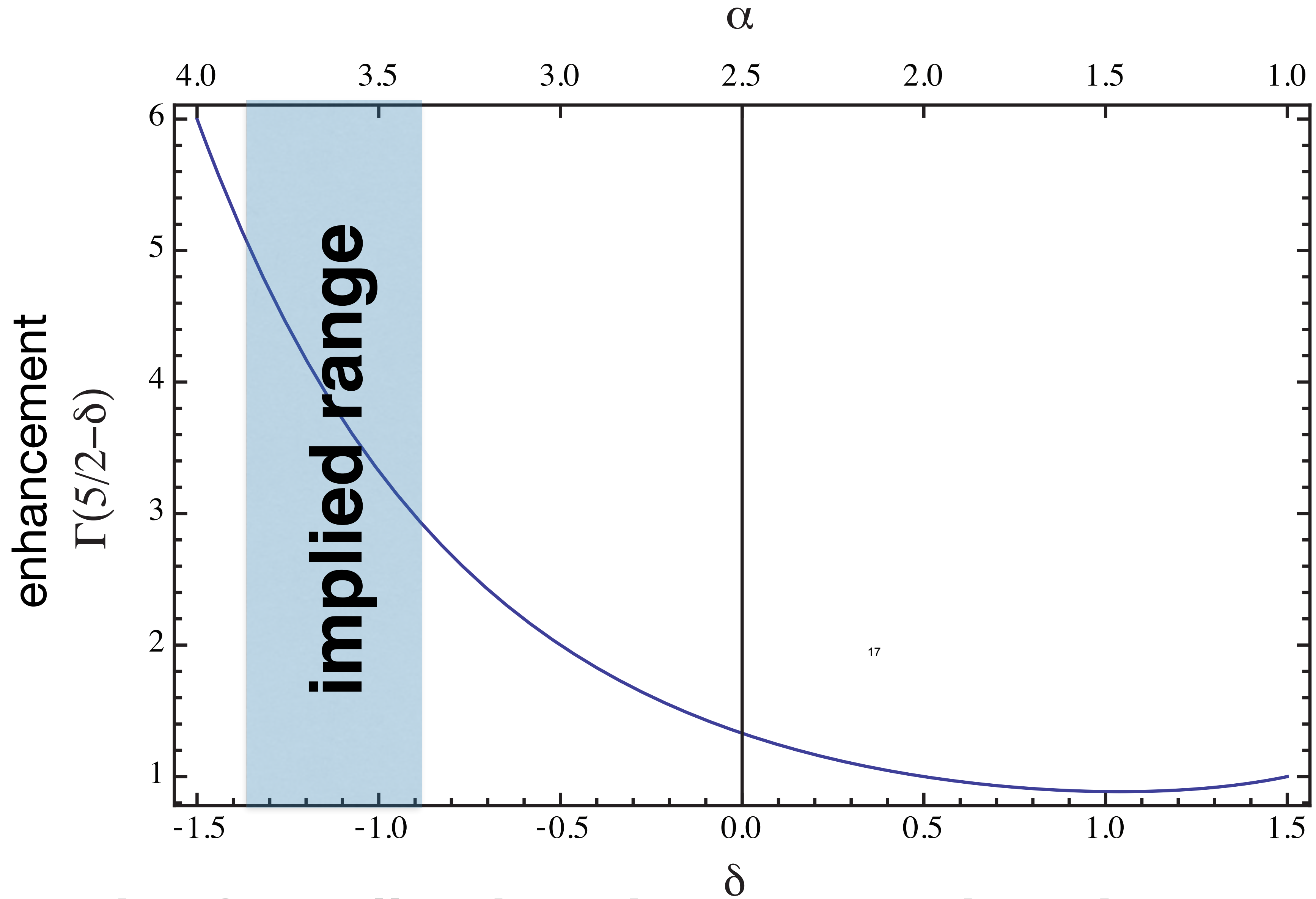
Consequences

An indirect measurement of the source count distribution!

steepness of the source count distribution $N(S_\nu) \propto S_\nu^{-\alpha}$

disparity	α
2:1	3
3:1	3.4
4:1	3.67
5:1	3.85

likely range { (3:1 – 5:1)



Actual FRB event rate is >3 smaller than the measured rate!

Scintillation selectively enhances the rate at high Galactic latitudes, where most FRBs have been found

Implications

The latitude dependence of the FRB event rate directly constrains their source count distribution, *without even needing enough sources to measure the distribution directly!*

The source counts has profound implications for the origins of FRBs: they do not follow the Euclidean/homogeneous distribution

The only way: population must be strongly evolving over time

FRBs ***must* be cosmological!**

This rules out a class of FRB theories because there has not been enough time for the population to evolve

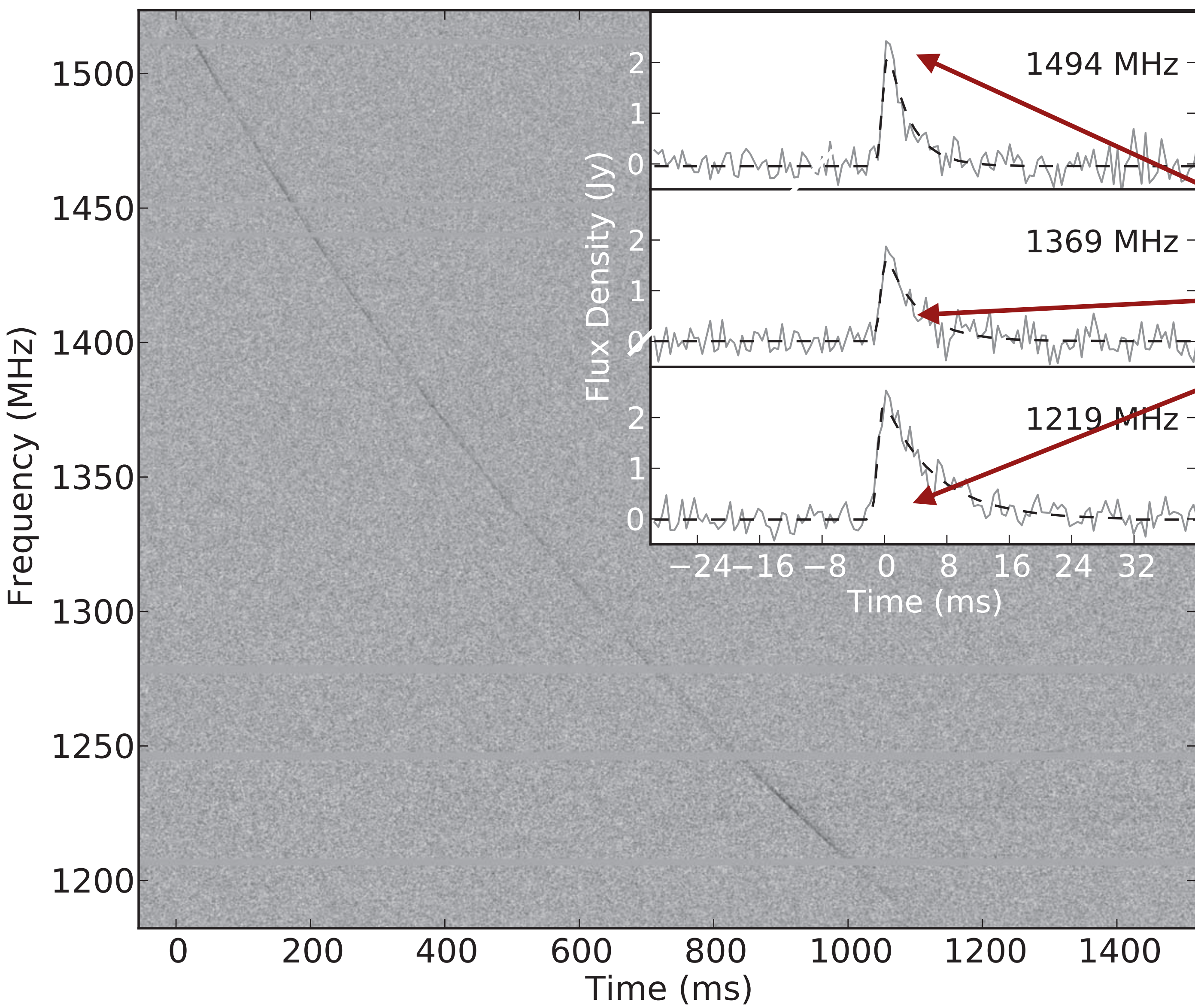
- ~~Magnetar flares~~
- ~~Giant pulses from extragalactic pulsars~~
- ~~Galactic flare stars~~

Macquart & Johnston, MNRAS 2015

An unsolved mystery: IGM or host galaxy?

What is the origin of the temporal smearing in FRBs?

When observed, it is > 10^3 times greater than the contribution due to our Galaxy



Pulse width increases as $\nu^{-4.0}$, consistent with scattering in a turbulent plasma

Probes turbulence on scales down to ~10,000km at distances from >3 Gpc!

Conclusions

Scintillation studies have entered a new era:

A cheap way of doing ultra-widefield VLBI at low frequencies

Achieving incredible angular resolution of pulsars:

- 20 pico-arcseconds!
- Challenges views of the nature of interstellar turbulence

Yielding unique insights into the nature of a new radio population

- Fascinating parallels between early quasar discovery era and present FRB discoveries