Disentangling pulsar scattering screens through global VLBI

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Ue-Li Pen, Viswesh Marthi, Walter Brisken

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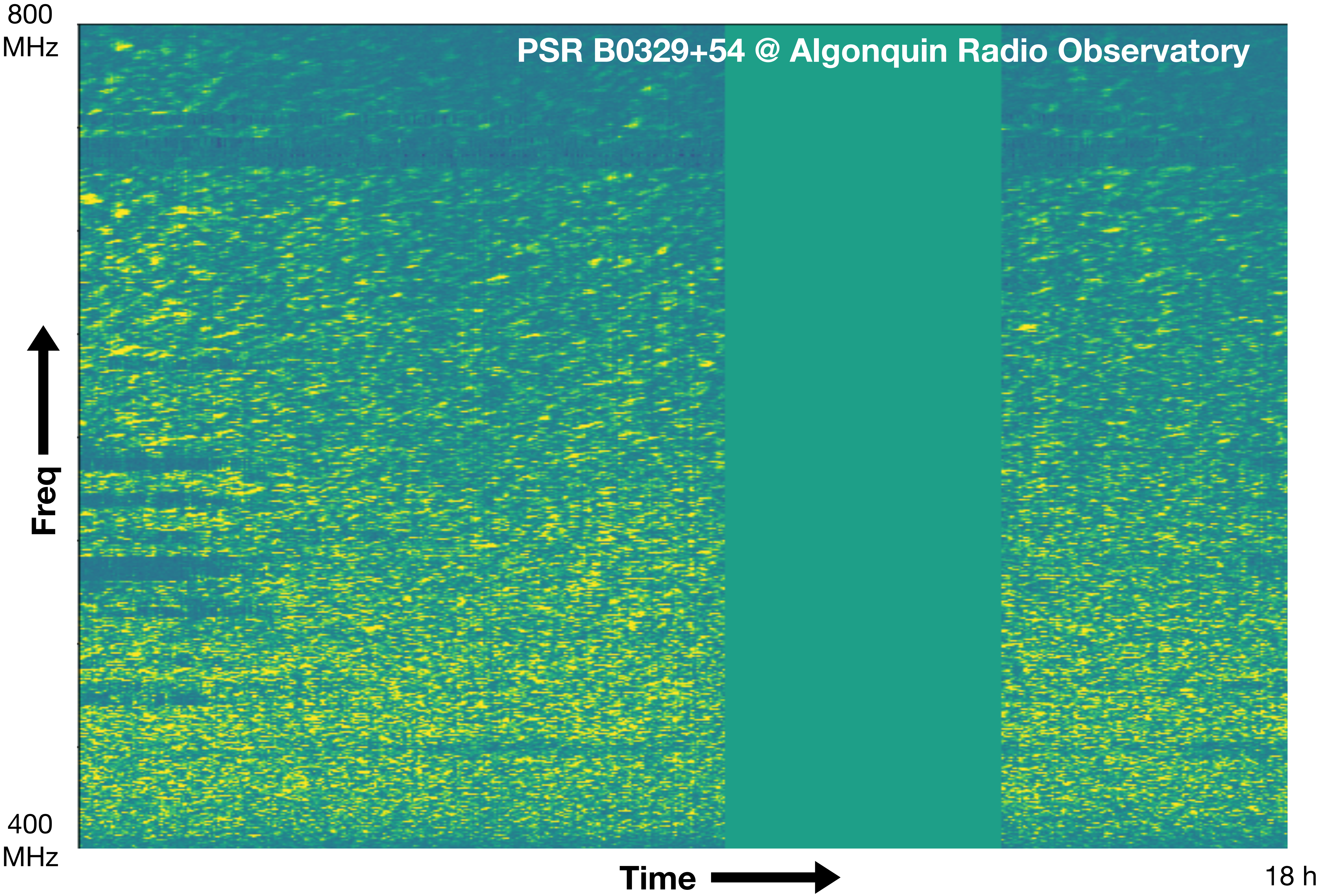
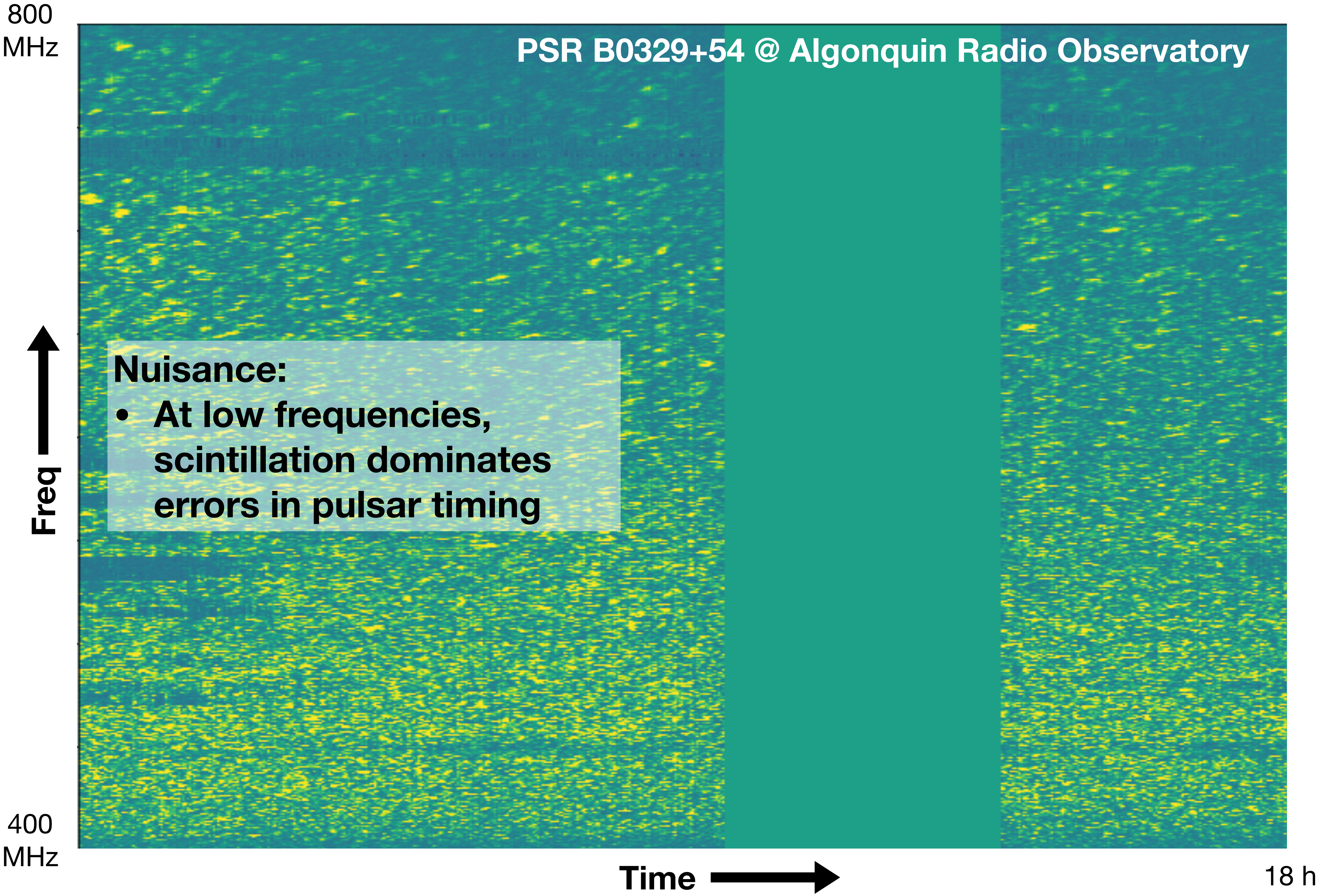
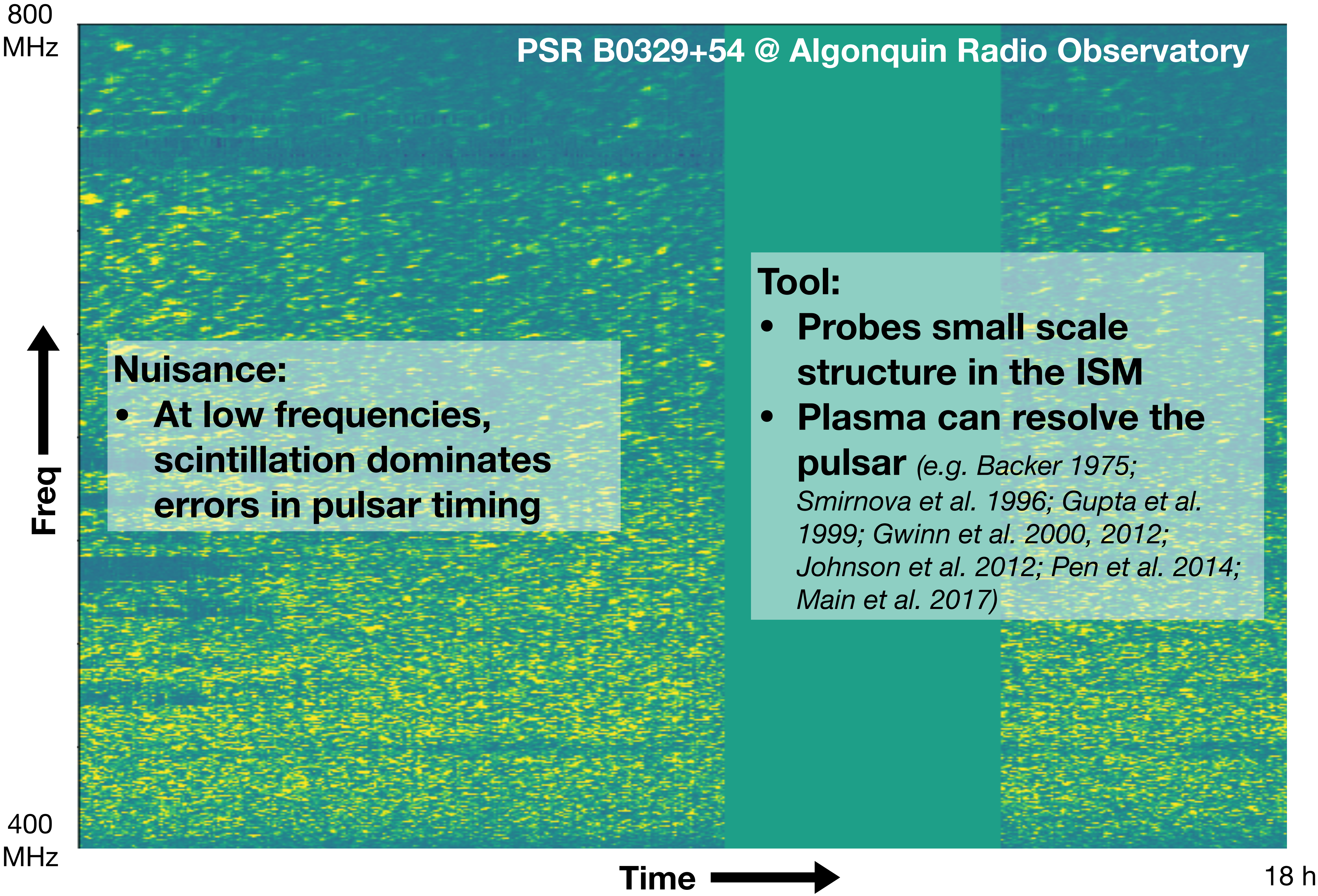
October 8th, 2018


800
MHz
PSR B0329+54 @ Algonquin Radio Observatory
Freq
400
MHz
Time
18 h



Nuisance:

- **At low frequencies, scintillation dominates errors in pulsar timing**

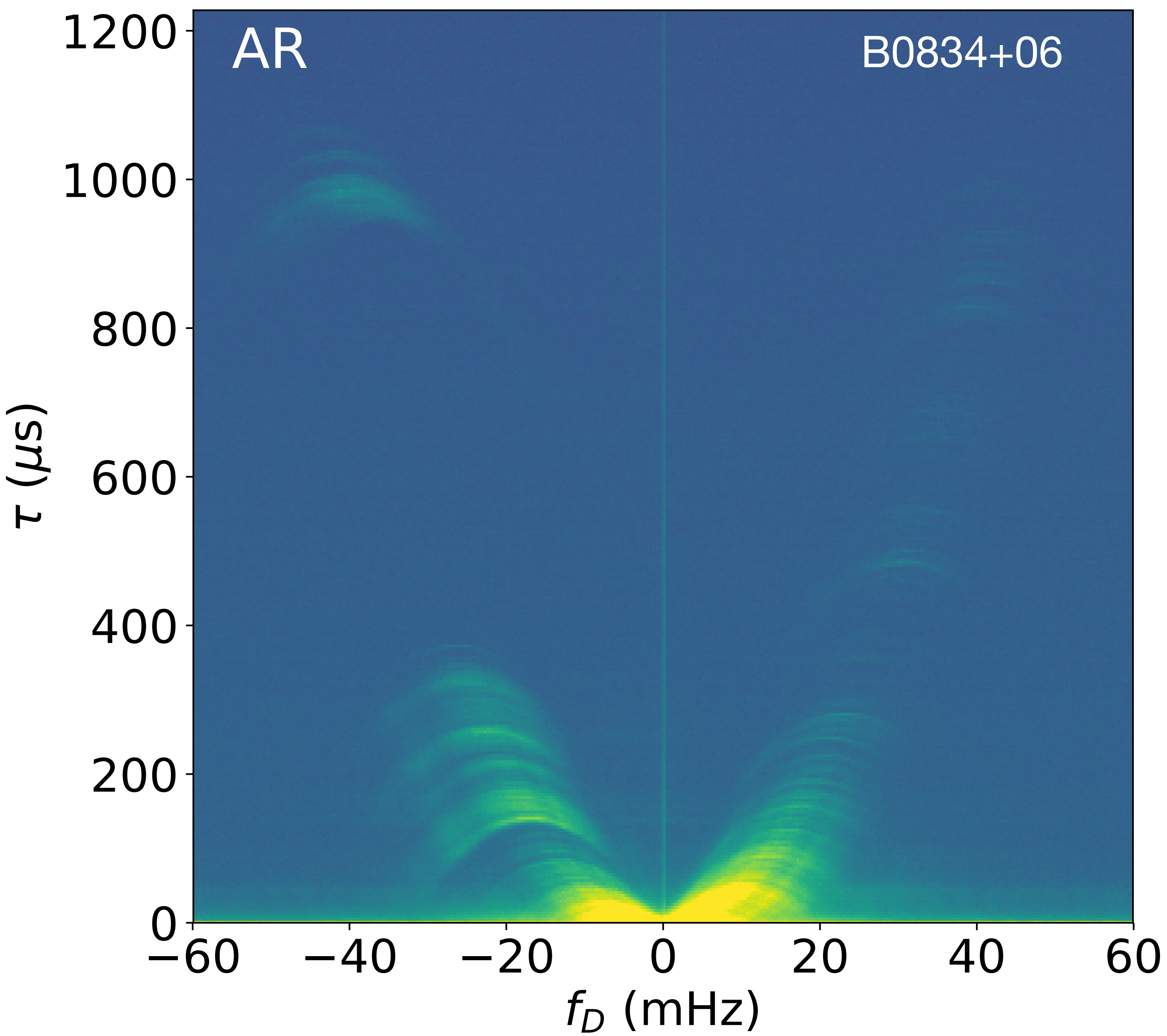


Nuisance:

- **At low frequencies, scintillation dominates errors in pulsar timing**

Tool:

- **Probes small scale structure in the ISM**
- **Plasma can resolve the pulsar** *(e.g. Backer 1975; Smirnova et al. 1996; Gupta et al. 1999; Gwinn et al. 2000, 2012; Johnson et al. 2012; Pen et al. 2014; Main et al. 2017)*



AR
B0834+06
1200
1000
800
600
400
200
0
−60
−40
−20
0
20
40
60
f_D (mHz)
τ (μs)

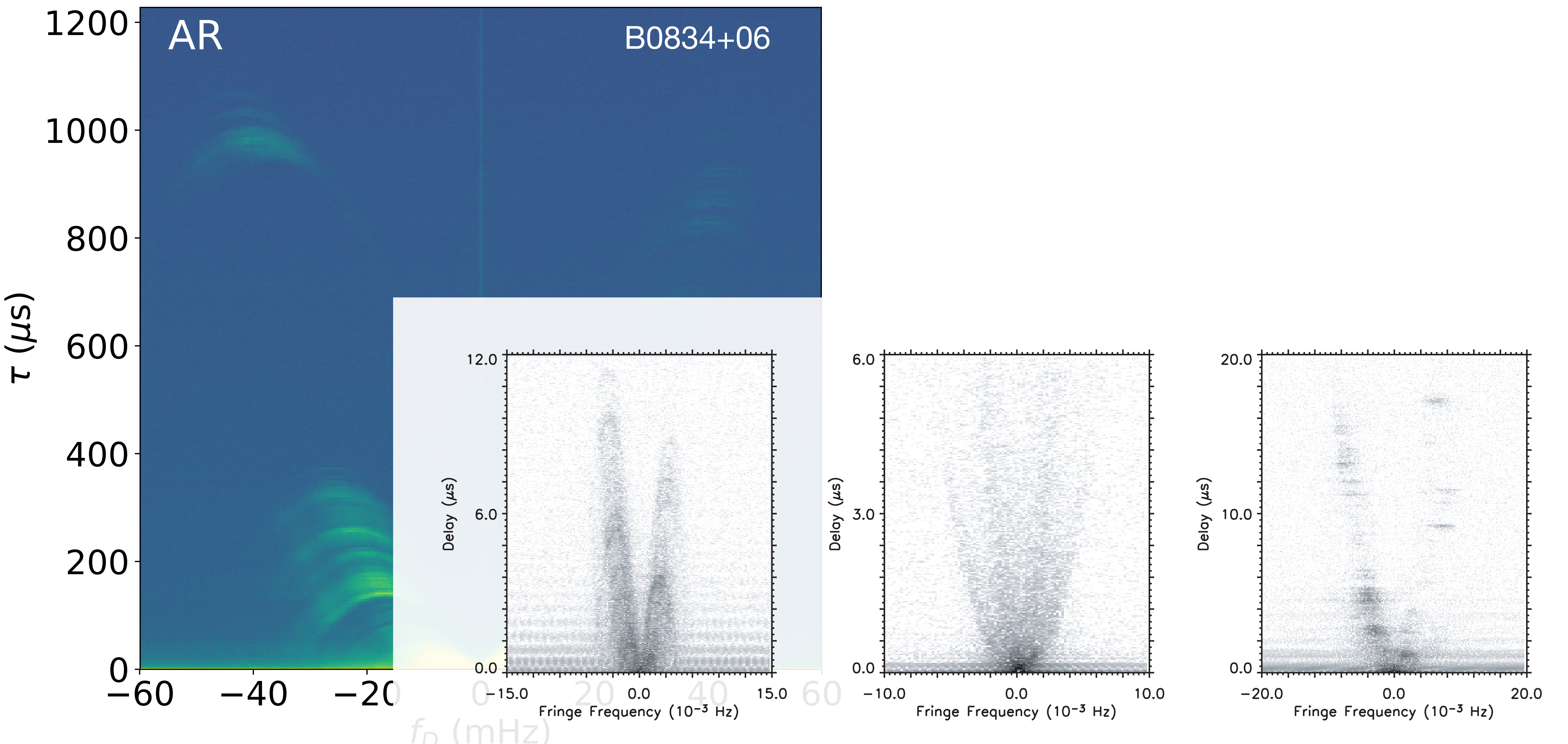


Figure 1. Dynamic (top row) and secondary spectra (bottom row) observed with the NRAO GBT (T. Minter and S. Ransom, collaborators). The gray scales in the dynamic spectra are linear in power with darker being stronger power. The gray scales in the secondary spectra are logarithmic in power with darker being stronger power.

Stinebring 2007, SINS proceedings

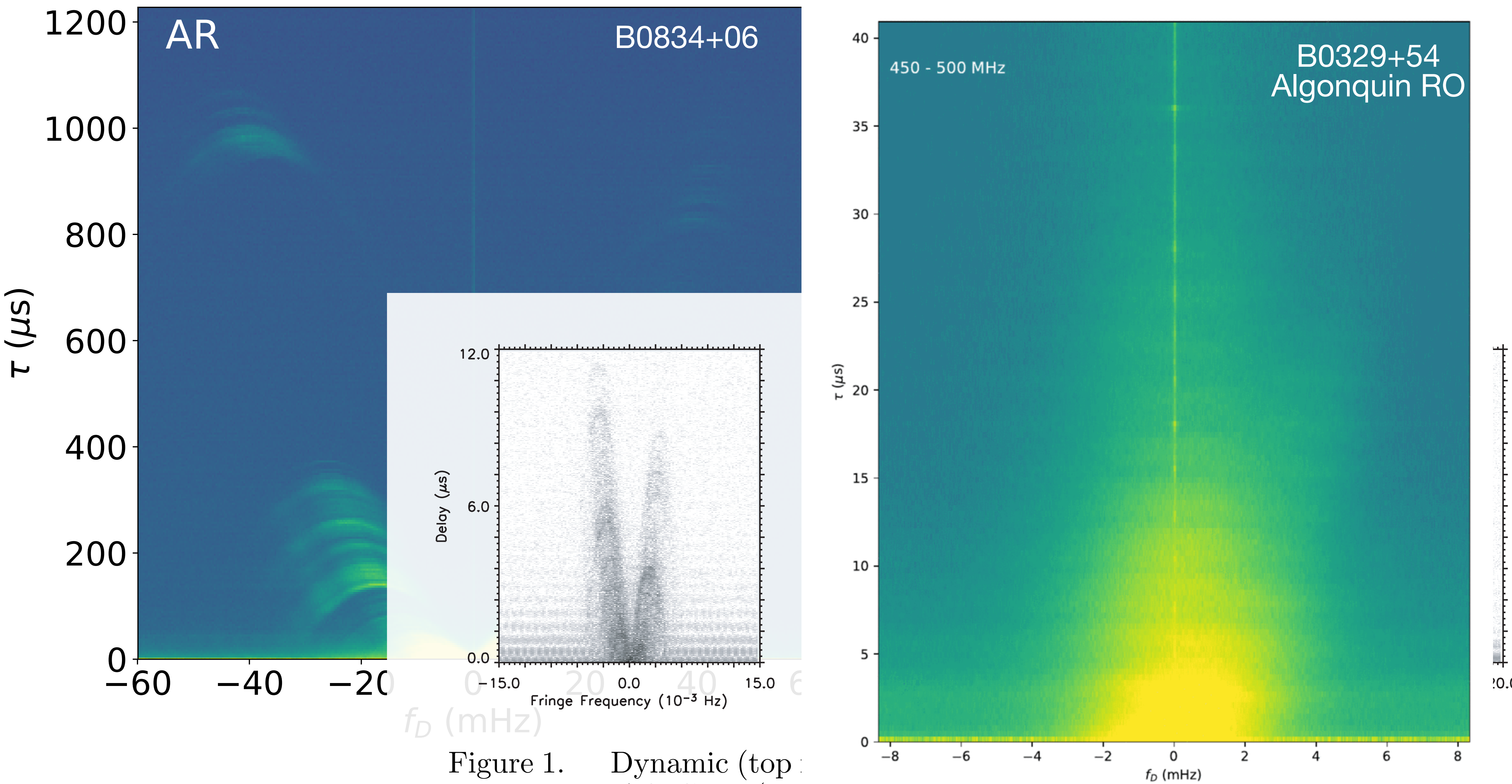


Figure 1. Dynamic (top
with the NRAO GBT (T. Minter and S. Ransom, collaborators). The gray scales in the dynamic spectra are linear in power with darker being stronger power. The gray scales in the secondary spectra are logarithmic in power with darker being stronger power.

Stinebring 2007, SINS proceedings

How can we explain this structure?

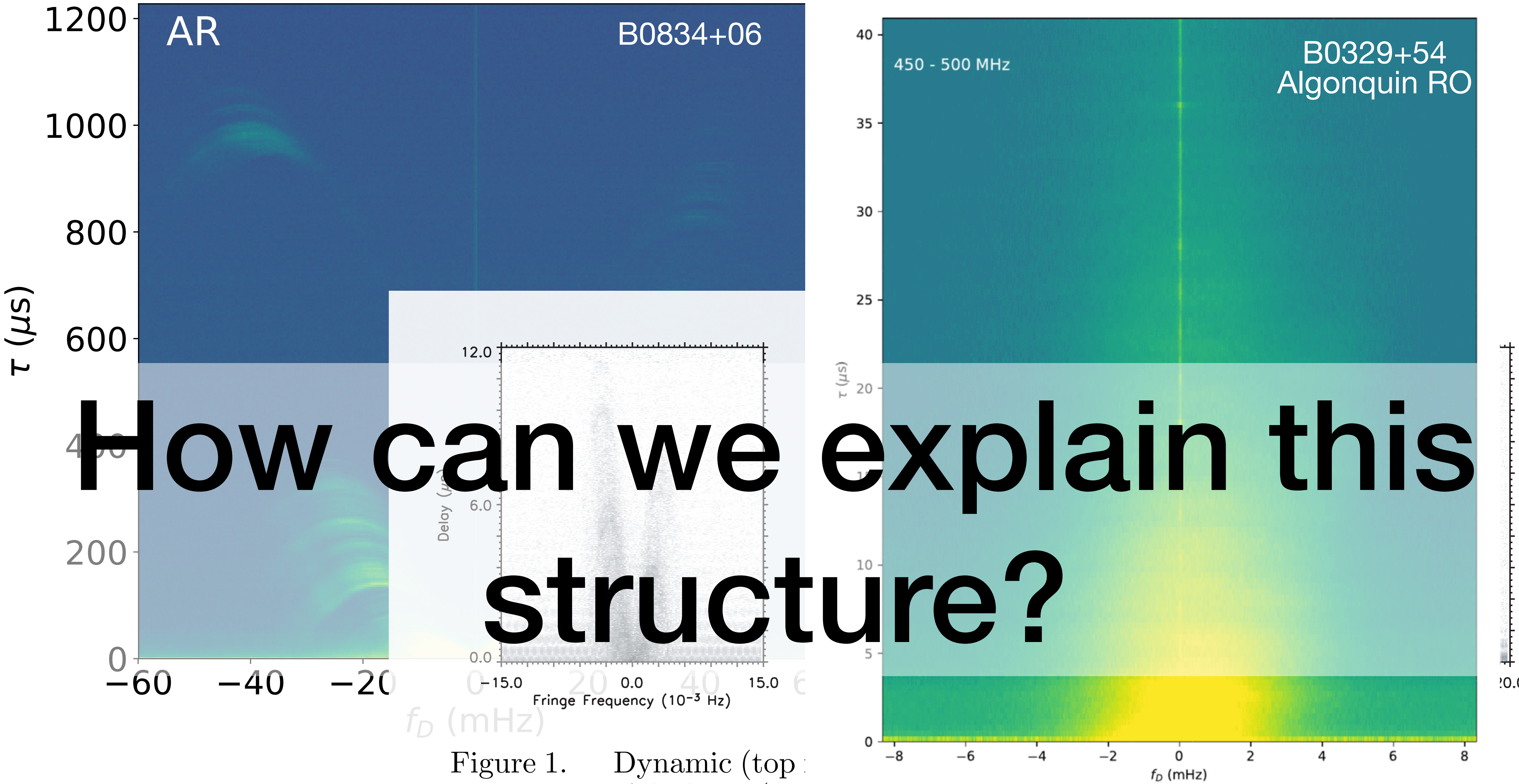


Figure 1. Dynamic (top ... with the NRAO GBT (T. Minter and S. Ransom, collaborators). The gray scales in the dynamic spectra are linear in power with darker being stronger power. The gray scales in the secondary spectra are logarithmic in power with darker being stronger power.

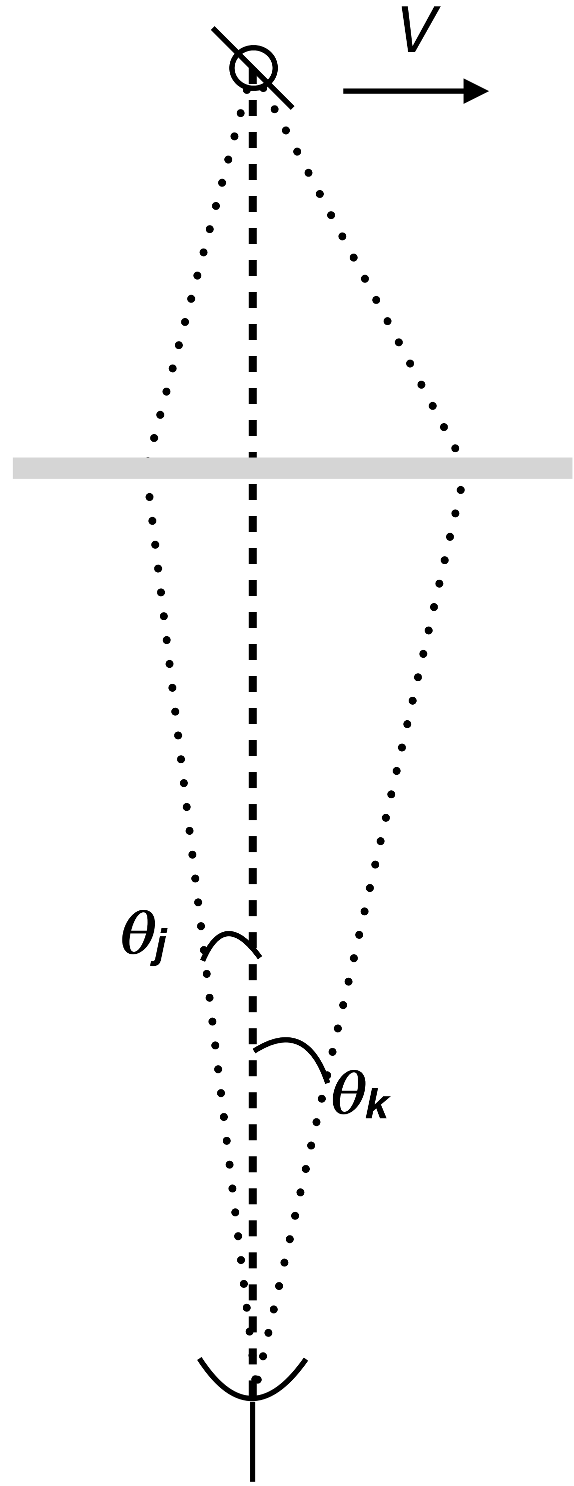
Stinebring 2007, SINS proceedings

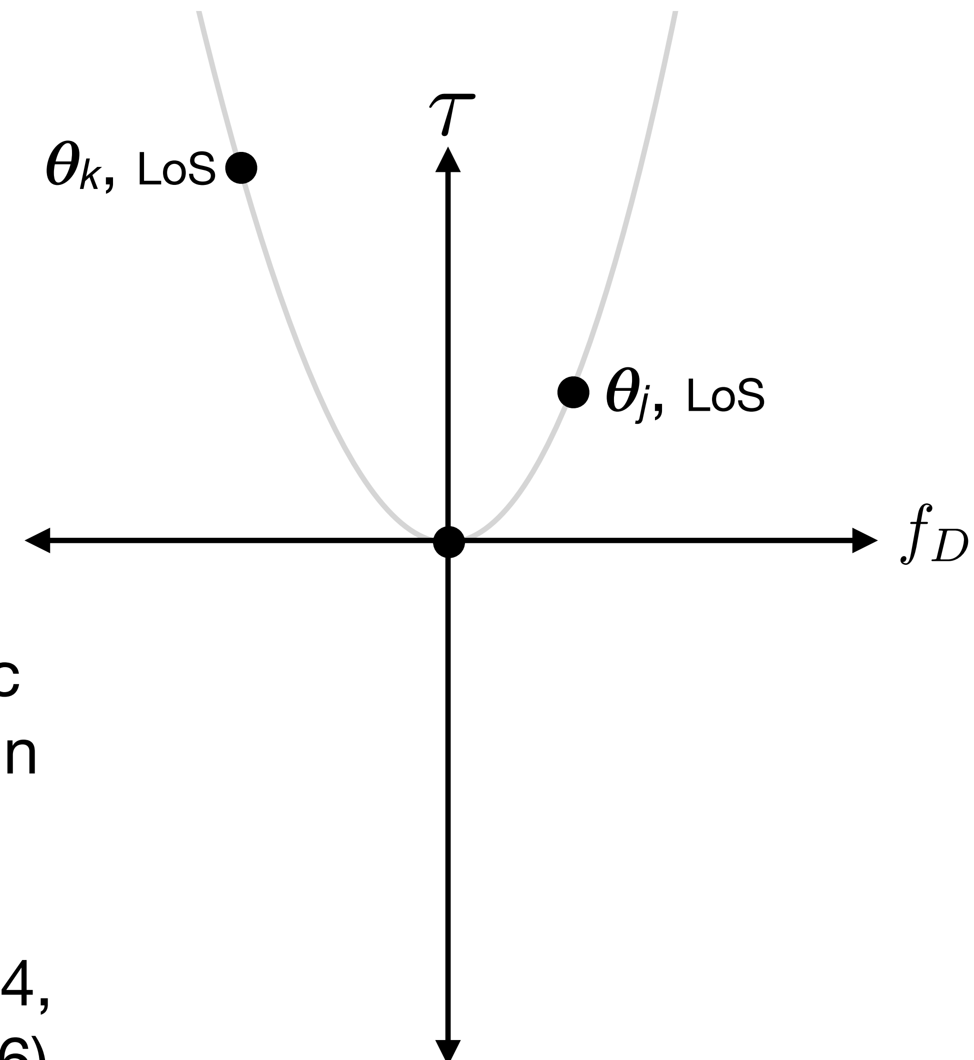
- How do we investigate the cause of pulsar scintillation?
- How do we reconcile parabolic spectra with messier secondary spectra?
  - Is this a pile up of screens? An isotropic component of the scattering?

- How do we investigate the cause of pulsar scintillation?
- How do we reconcile parabolic spectra with messier secondary spectra?
  - Is this a pile up of screens? An isotropic component of the scattering?
- We need:
  - To reconstruct the scattered flux and measure the distances to the screens *even when the scattering environment is complex*

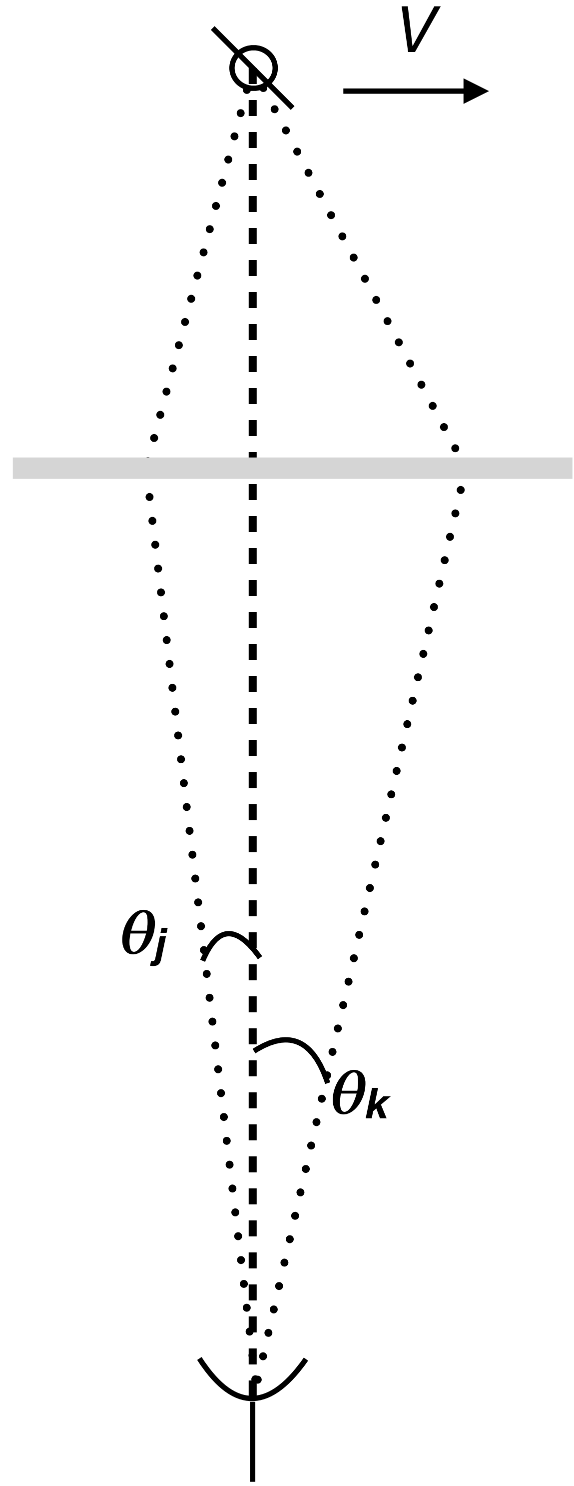
$$f_t = f_D = \frac{\mathbf{V}_{\text{eff}} \cdot (\boldsymbol{\theta}_k - \boldsymbol{\theta}_j)}{\lambda}$$

$$f_\nu = \tau = \frac{D_{\text{eff}}(\theta_j^2 - \theta_k^2)}{2c}$$





Highly anisotropic scattering at a thin screen explains parabolic arcs (Walker et al. 2004, Cordes et al. 2006)



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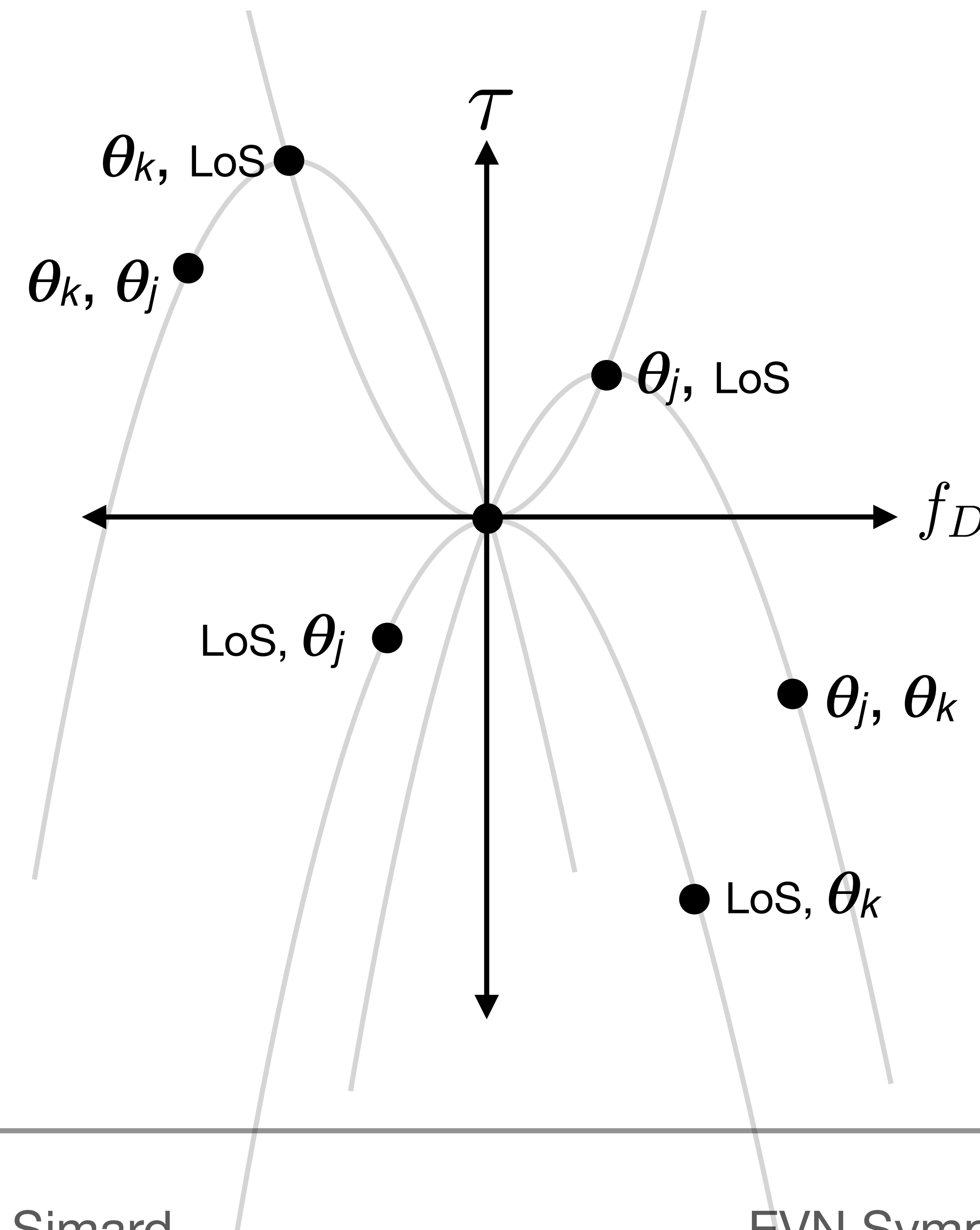
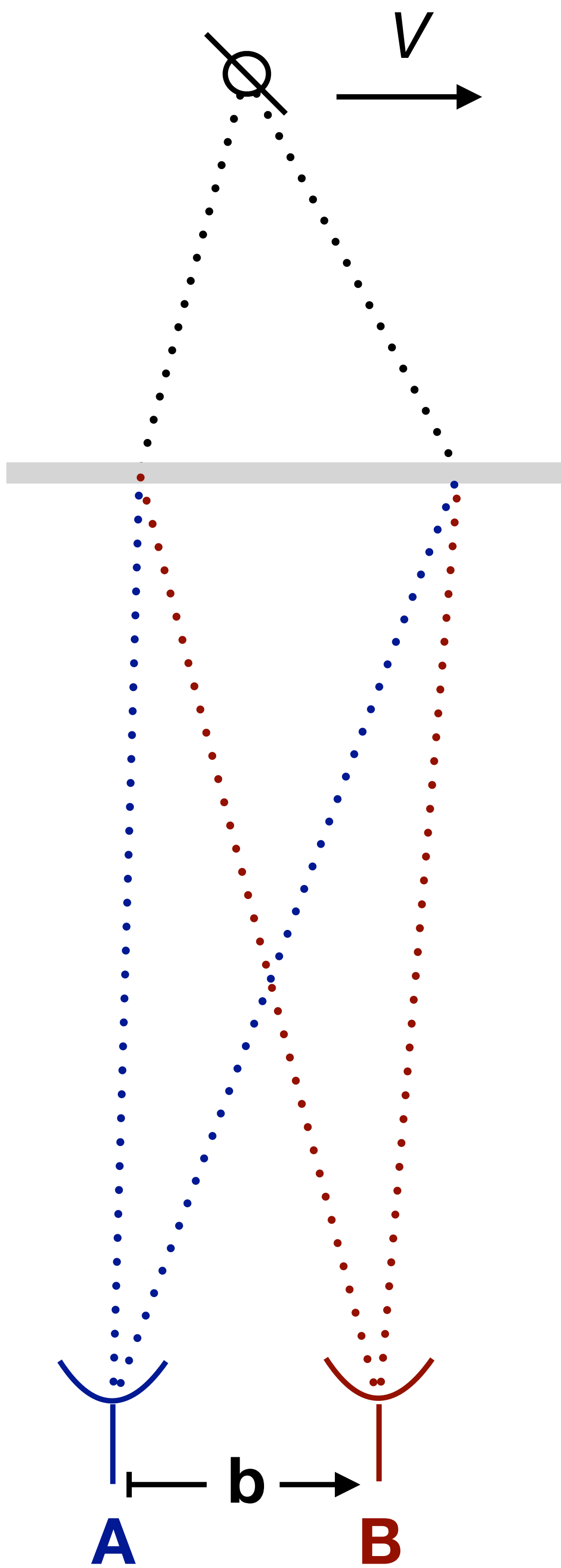
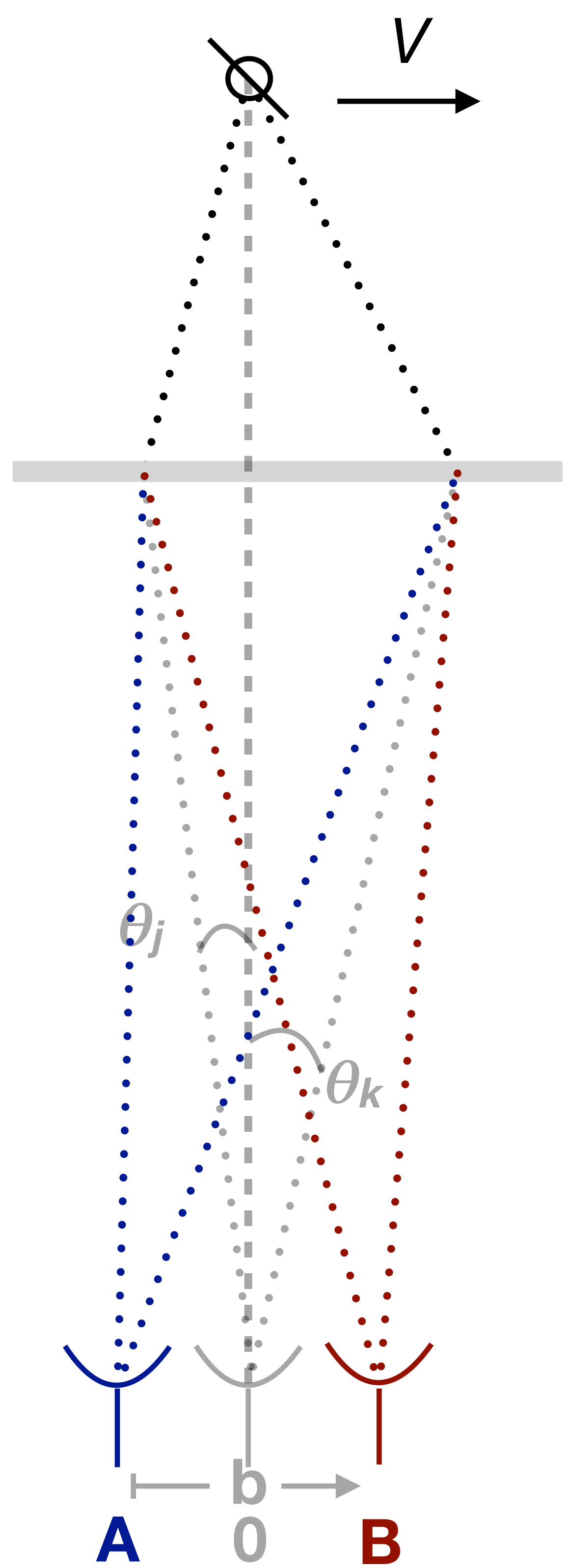



V
b
A
B

The visibilities:

(Brisken et al. 2010, ApJ, 708, 232)



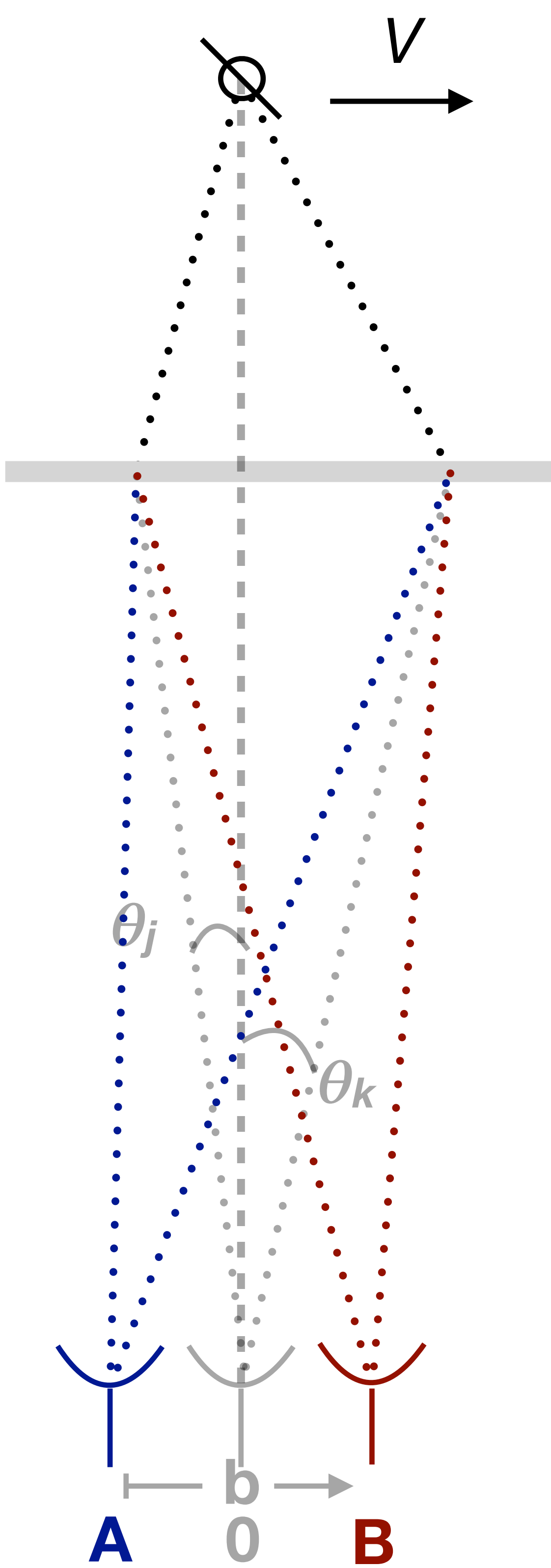
$$\Phi_{jk,AB^*} = \Phi_{jk,00^*} + \frac{2\pi}{\lambda}\frac{1}{2}(\theta_j + \theta_k)\cdot b$$

$$\Phi_{kj,AB^*} = \Phi_{kj,00^*} + \frac{2\pi}{\lambda}\frac{1}{2}(\theta_j + \theta_k)\cdot b$$

equal but opposite

The visibilities:

(Brisken et al. 2010, ApJ, 708, 232)



$$\Phi_{jk,AB^*} = \Phi_{jk,00^*} + \frac{2\pi}{\lambda}\frac{1}{2}(\theta_j + \theta_k) \cdot b$$

$$\Phi_{kj,AB^*} = \Phi_{kj,00^*} + \frac{2\pi}{\lambda}\frac{1}{2}(\theta_j + \theta_k) \cdot b$$

$$\Phi[\tilde{V}_{AB^*}(\tau, f_D)\tilde{V}_{AB^*}(-\tau, -f_D)]$$

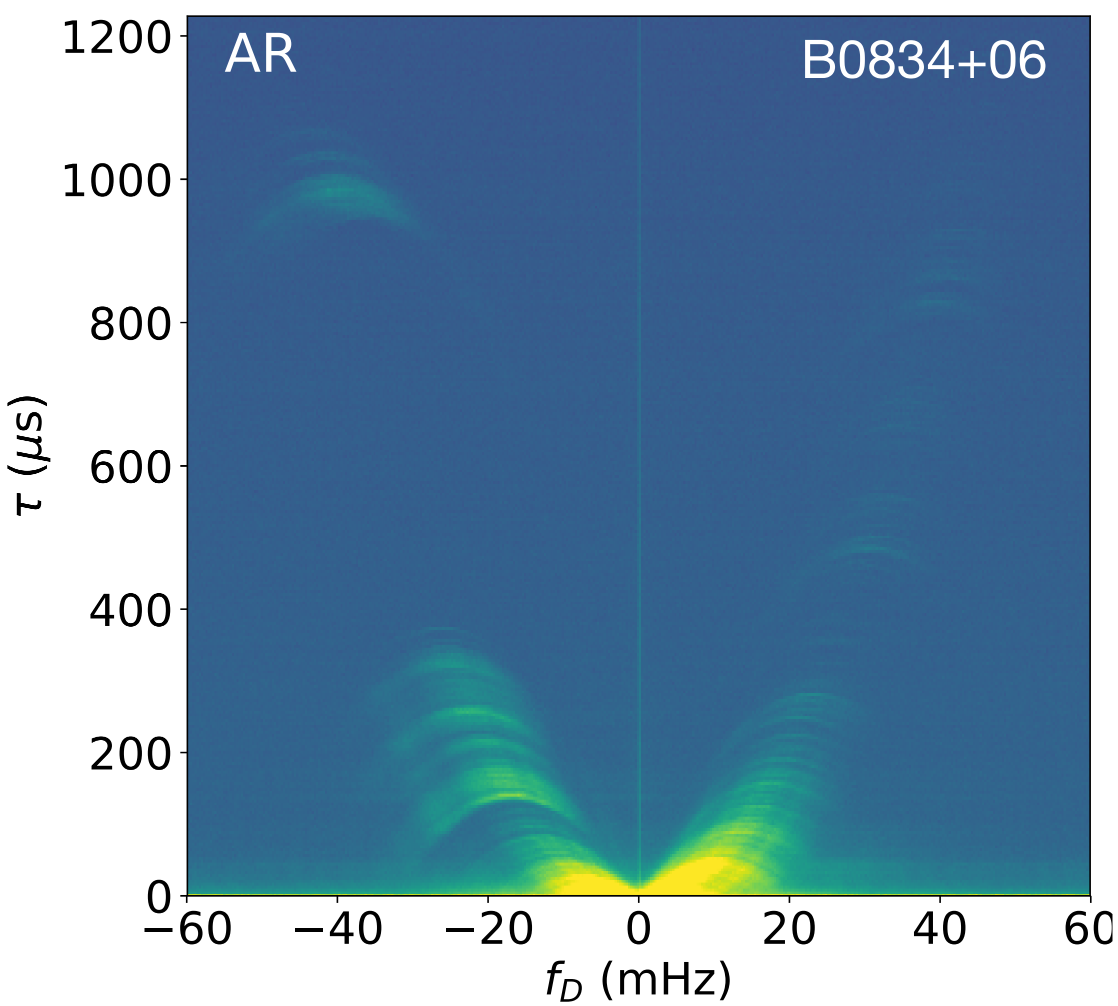
$$= \Phi_{jk,AB^*} + \Phi_{kj,AB^*}$$

$$= \frac{2\pi}{\lambda}(\theta_j + \theta_k) \cdot b$$

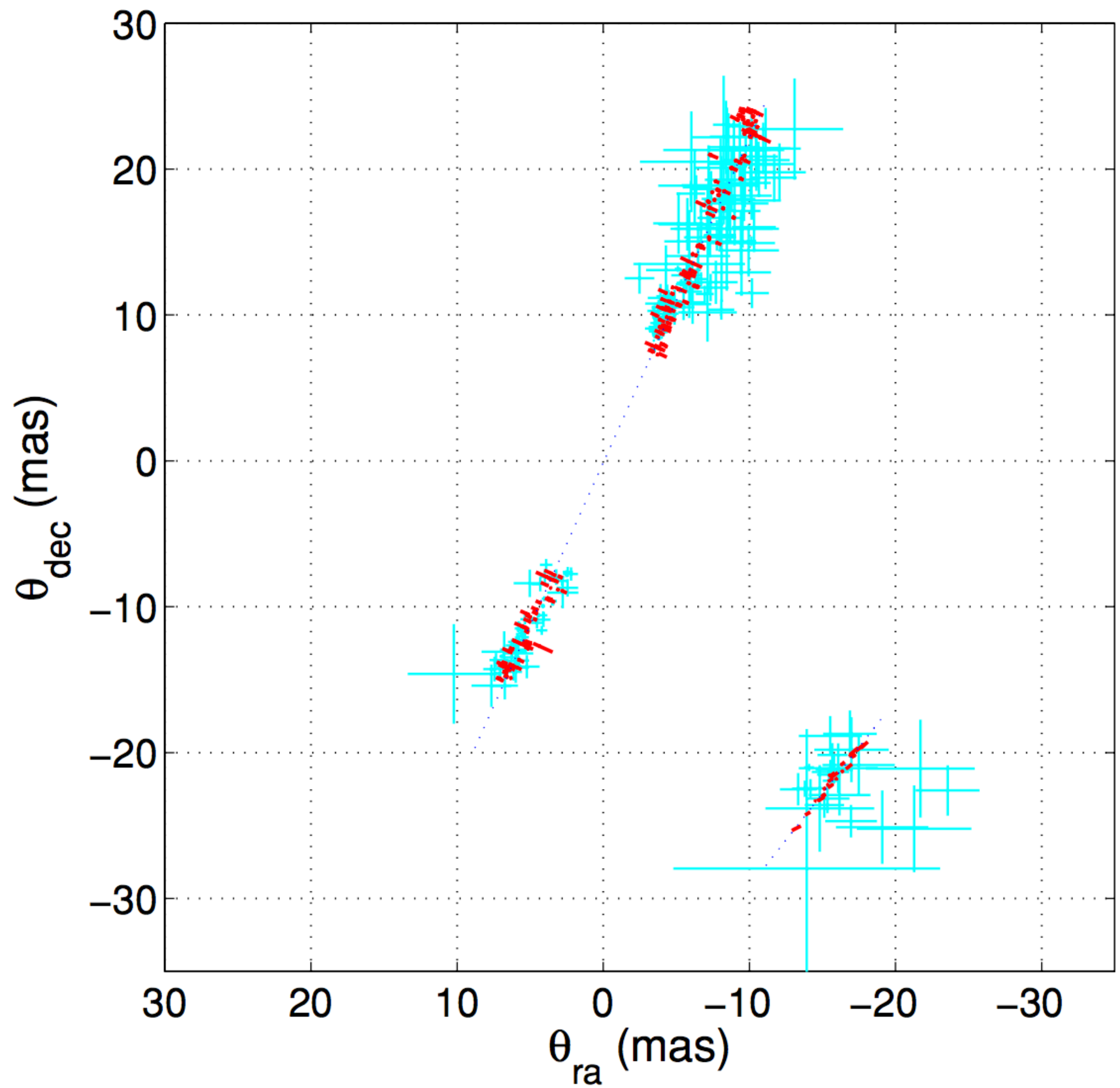
The visibilities:

(Brisken et al. 2010, ApJ, 708, 232)

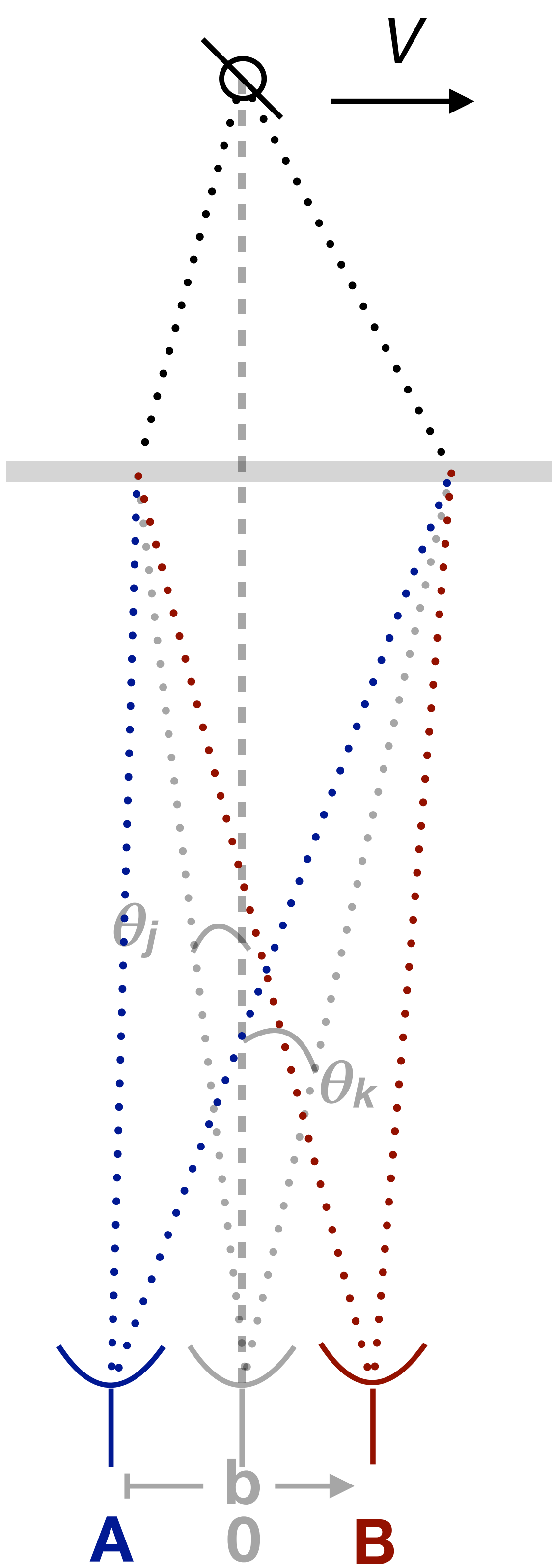
- **To use, you must have a way of finding the points where $\theta_k = 0$**



PSR B0834+06



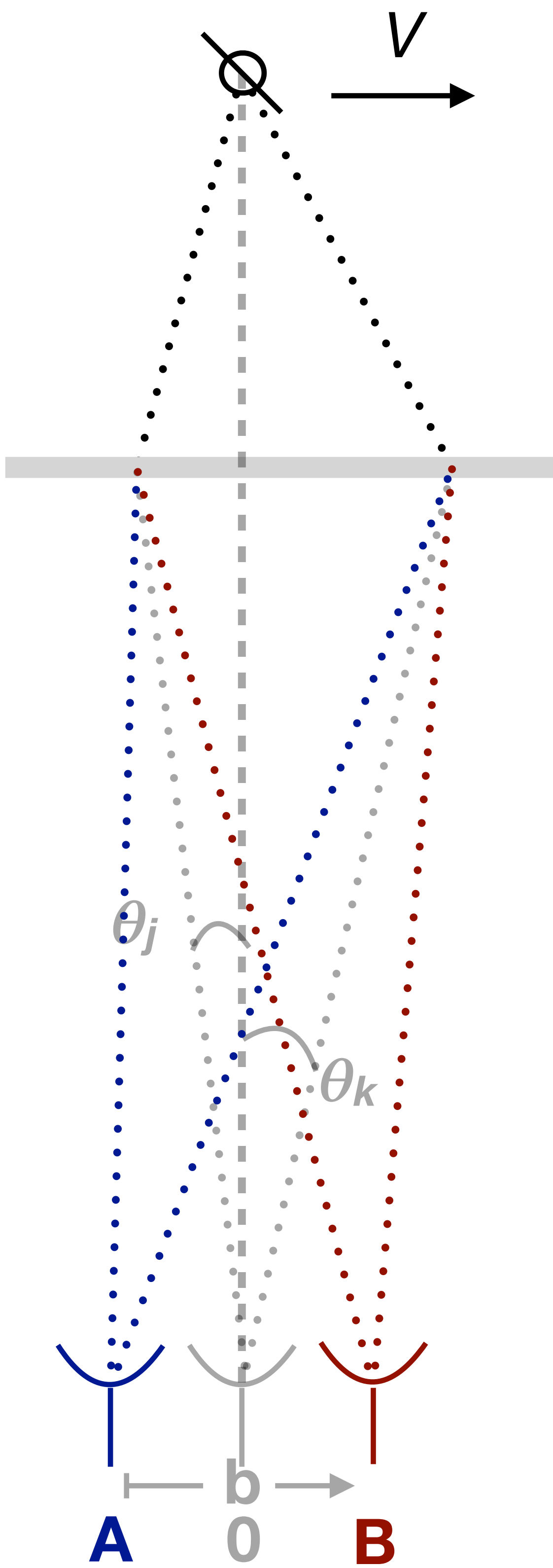
The intensities:



$$\Phi_{jk,AA^*} = \Phi_{jk,00^*} + \frac{2\pi}{\lambda}\frac{1}{2}(\theta_j - \theta_k) \cdot b$$

$$\Phi_{kj,BB^*} = \Phi_{kj,00^*} + \frac{2\pi}{\lambda}\frac{1}{2}(\theta_j - \theta_k) \cdot b$$

$$\Phi[\tilde{I}_{AA^*}(\tau, f_D)\tilde{I}_{BB^*}(-\tau, -f_D)]$$
$$= \Phi_{jk,AA^*} + \Phi_{kj,BB^*}$$
$$= \frac{2\pi}{\lambda}(\theta_j - \theta_k) \cdot b$$

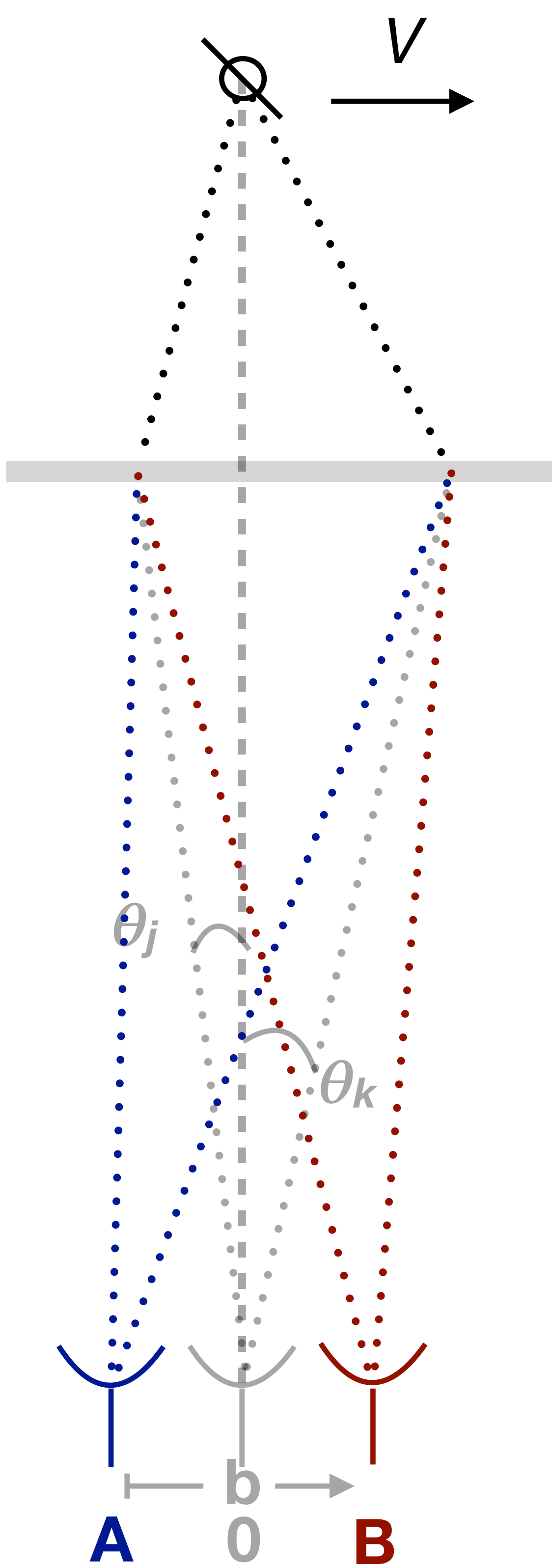


From the intensities:

$$\Phi[\tilde{I}_{AA^*}(\tau, f_D)\tilde{I}_{BB^*}(-\tau, -f_D)]$$
$$= \frac{2\pi}{\lambda}(\theta_j - \theta_k) \cdot b$$

From the visibilities:

$$\Phi[\tilde{V}_{AB^*}(\tau, f_D)\tilde{V}_{AB^*}(-\tau, -f_D)]$$
$$= \frac{2\pi}{\lambda}(\theta_j + \theta_k) \cdot b$$



From the intensities:

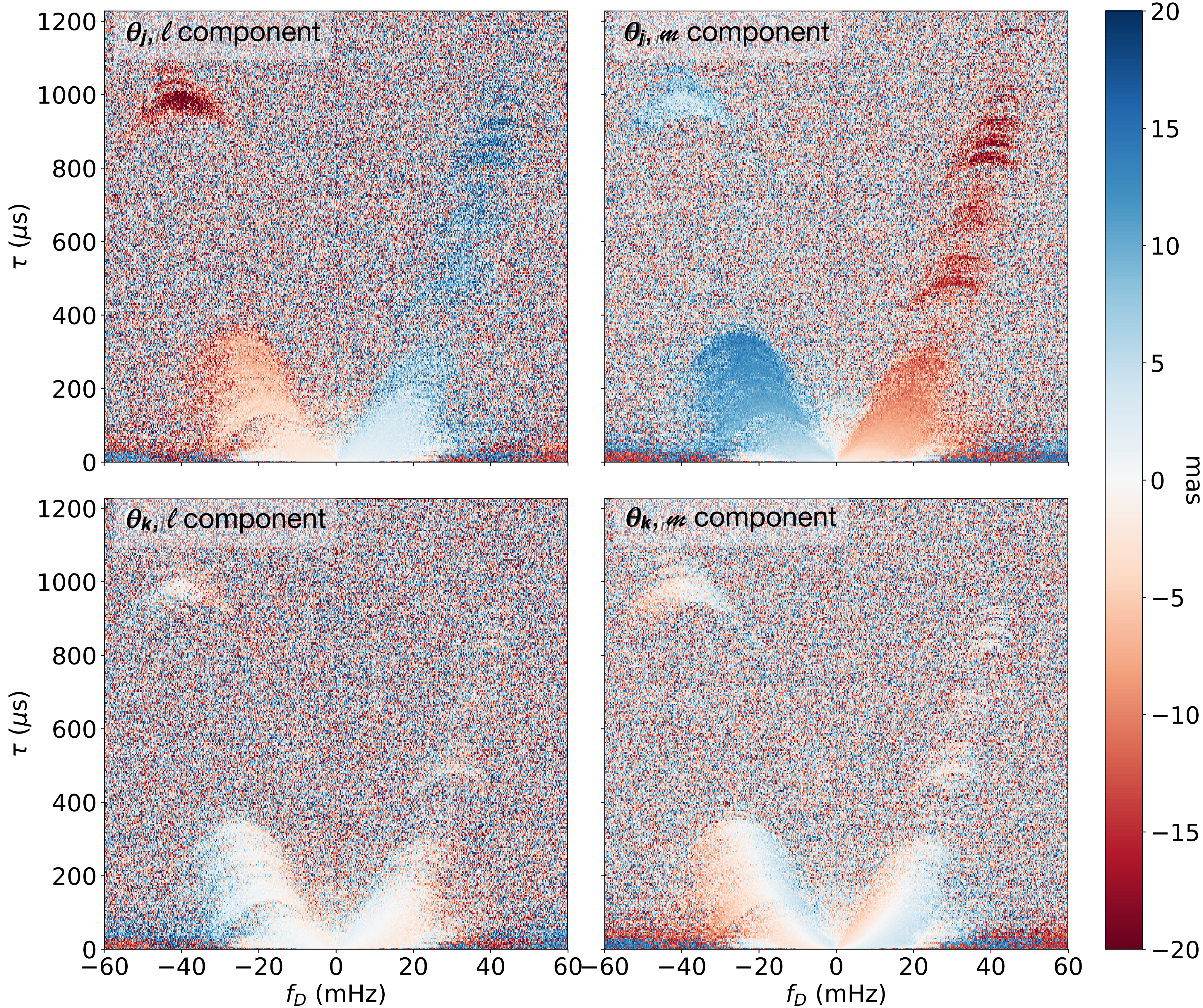
$$\Phi[\tilde{I}_{AA^*}(\tau, f_D)\tilde{I}_{BB^*}(-\tau, -f_D)] = \frac{2\pi}{\lambda}(\theta_j - \theta_k) \cdot b$$

From the visibilities:

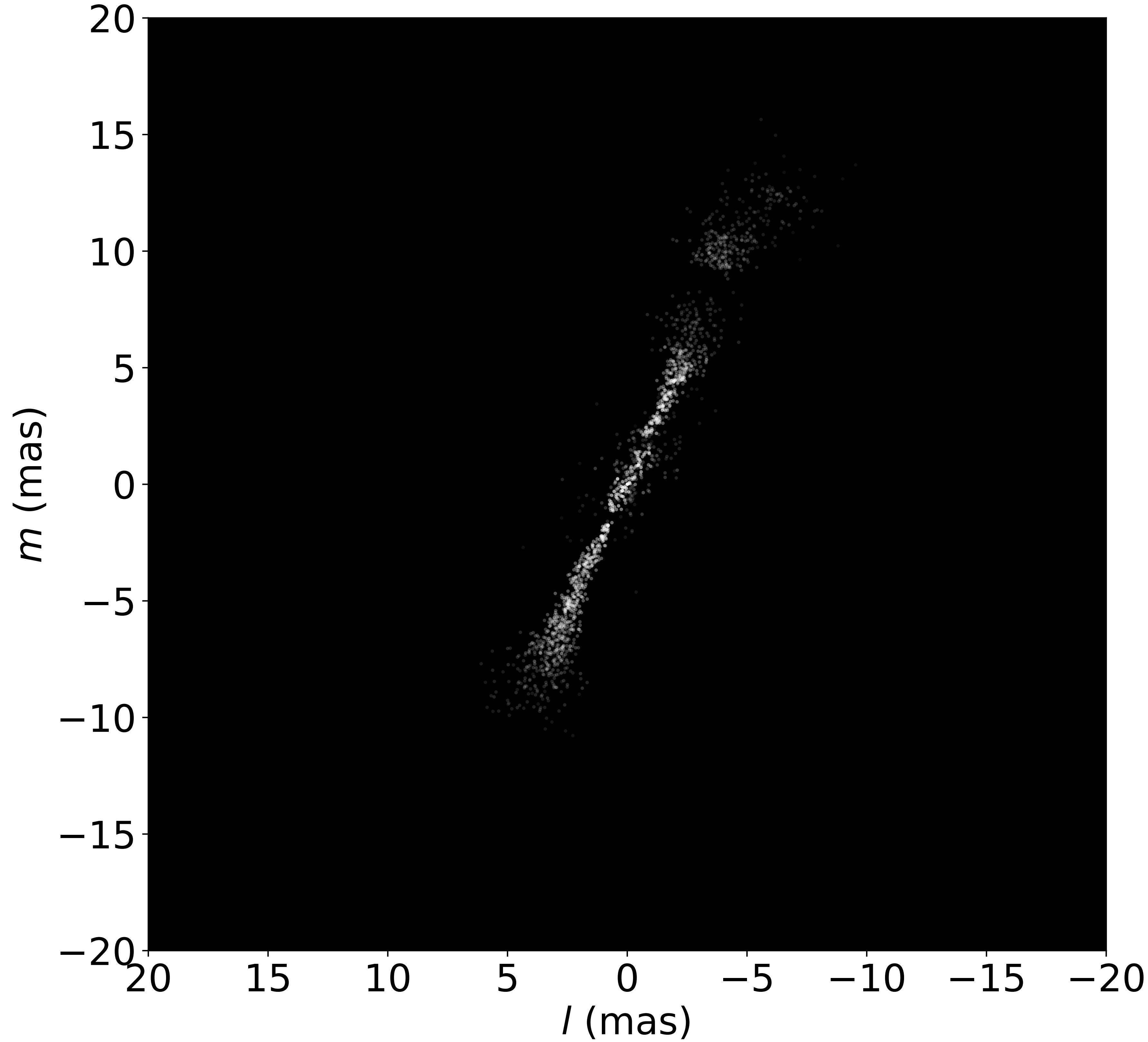
$$\Phi[\tilde{V}_{AB^*}(\tau, f_D)\tilde{V}_{AB^*}(-\tau, -f_D)] = \frac{2\pi}{\lambda}(\theta_j + \theta_k) \cdot b$$

So by adding and differencing these, we can recover both θ_j *and* θ_k

(without relying on the picture of anisotropic scattering at a thin screen)

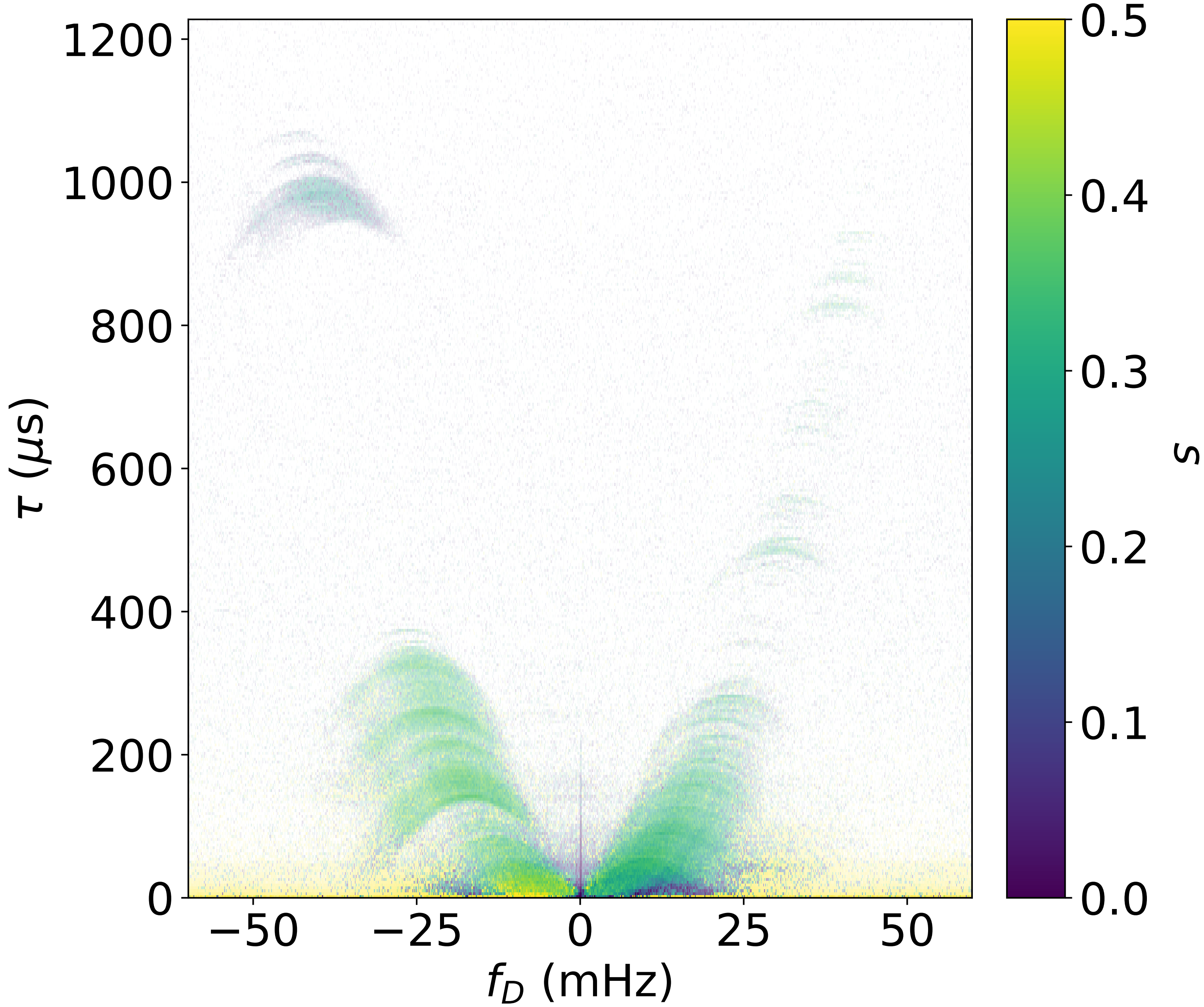


θ_j, ℓ component
θ_j, m component
θ_k, ℓ component
θ_k, m component
τ (μs)
f_D (mHz)
mas


20
15
10
5
0
−5
−10
−15
−20
m (mas)
20
15
10
5
0
−5
−10
−15
−20
l (mas)

$$s = 1 - \frac{d_{\rm lens}}{d_{\rm psr}}$$

$$\tau = \frac{d_{\rm psr}}{2c} \frac{1-s}{s} (\theta_j^2 - \theta_k^2)$$



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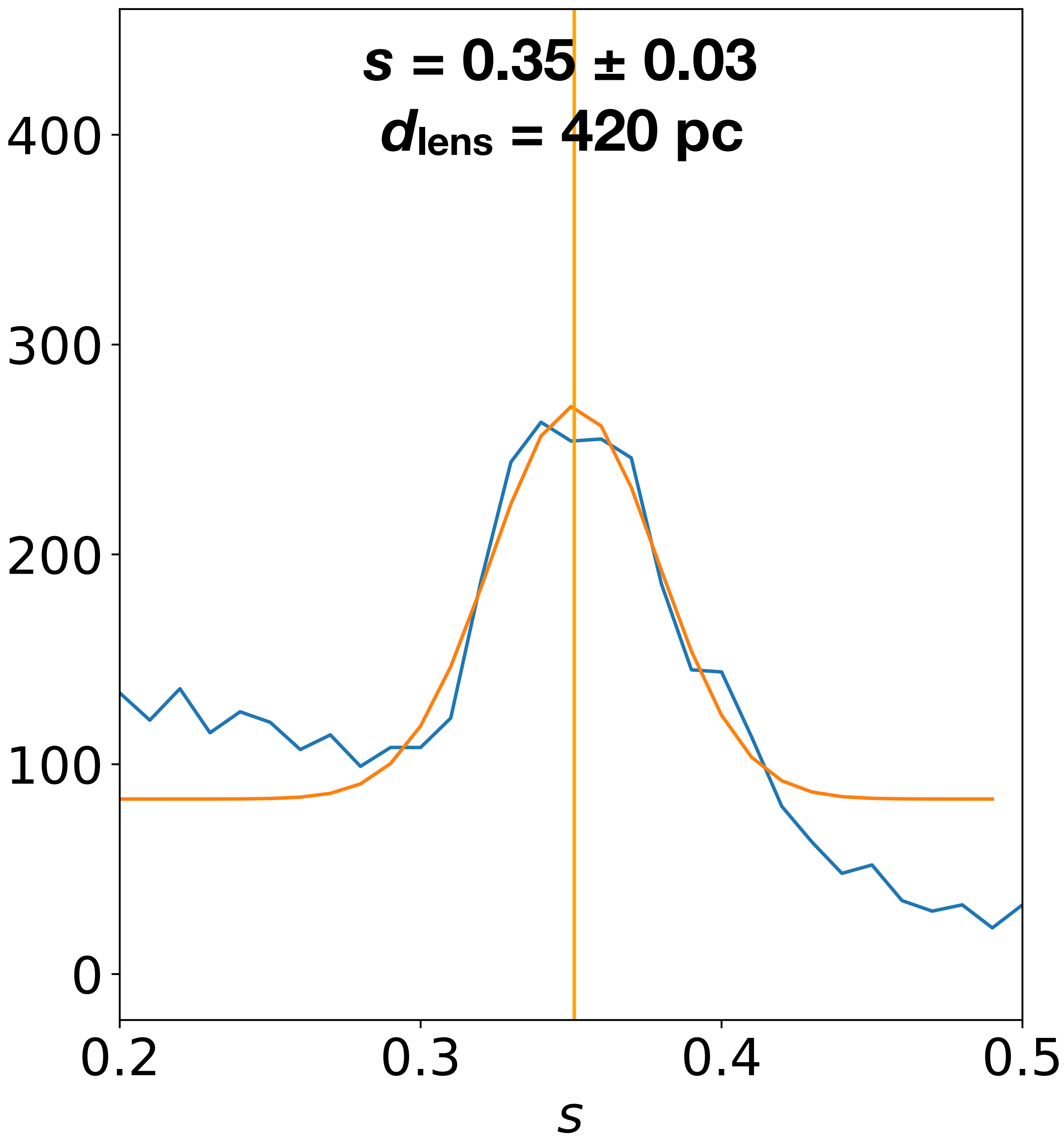
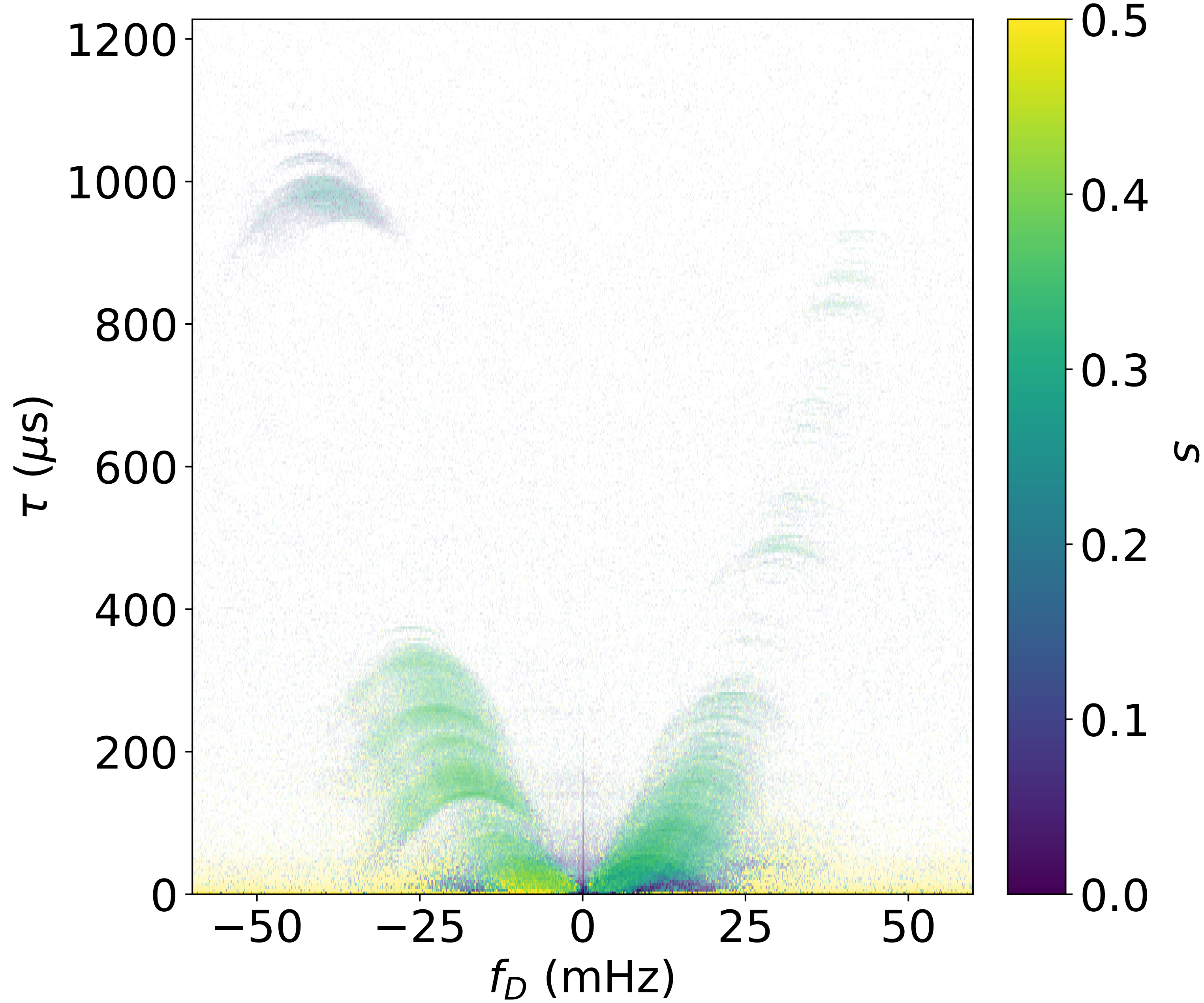
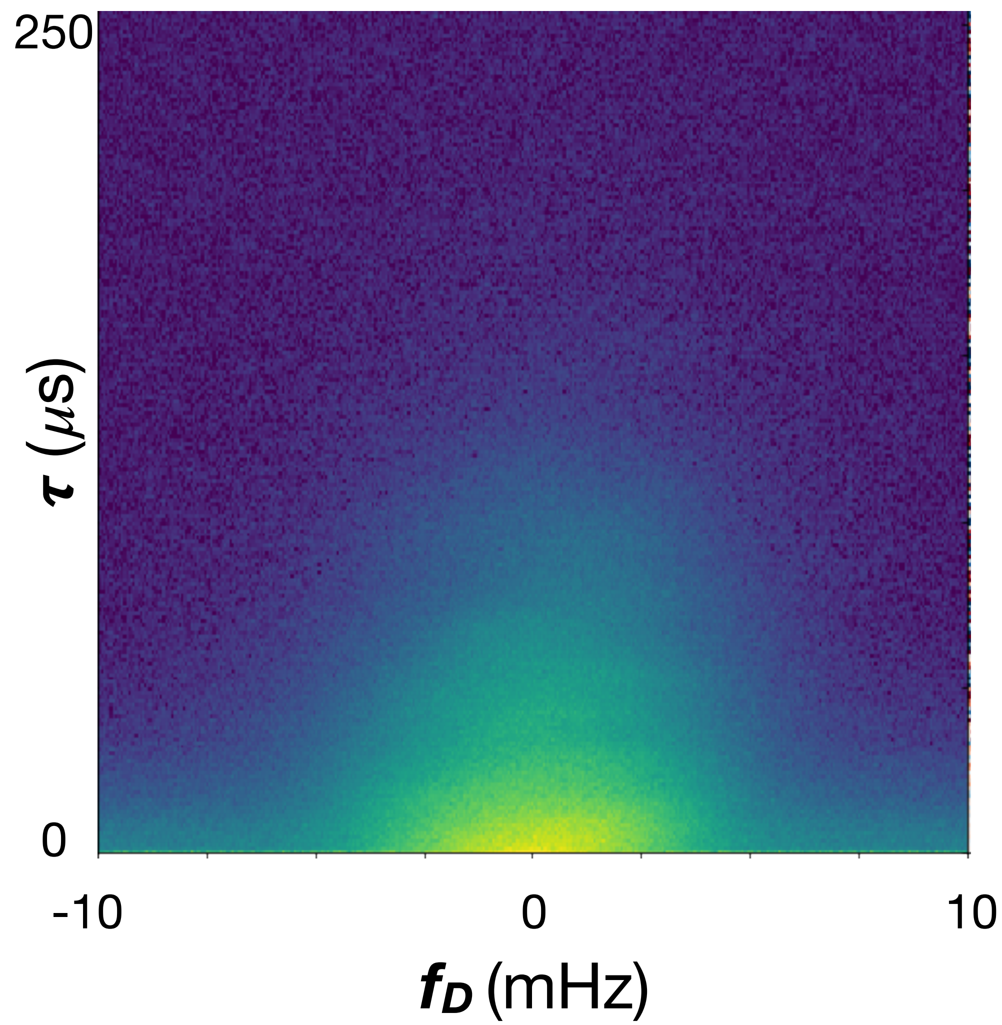




Consistent w/ original analysis by Brisken et al. (2010)

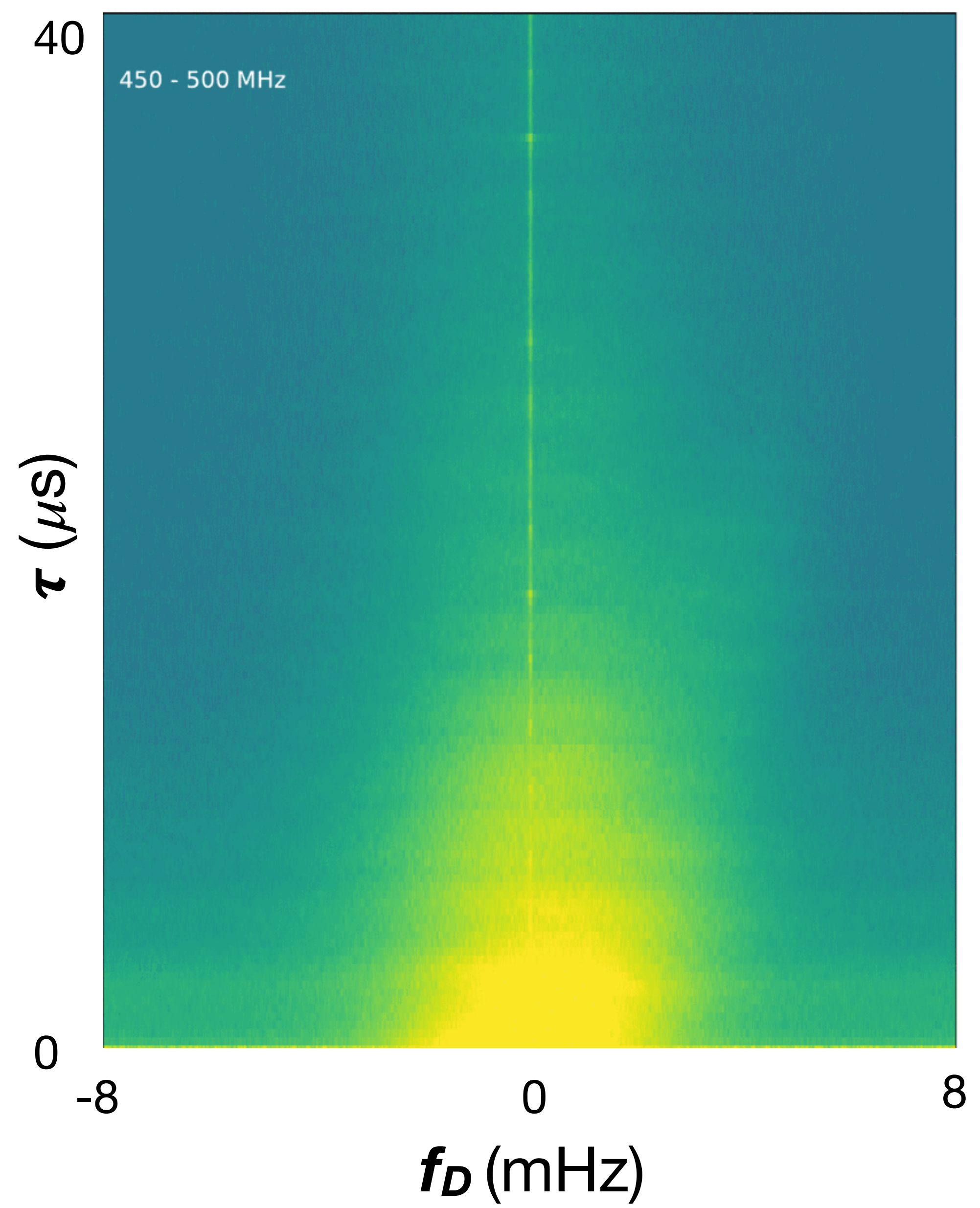
B0329+54 - A complex story

327 MHz



WB, KL, RadioAstron SRT
Gwinn et al. 2016; Popov et al. 2017

475 MHz



Canadian VLBI
DRAO to ARO

1465 MHz

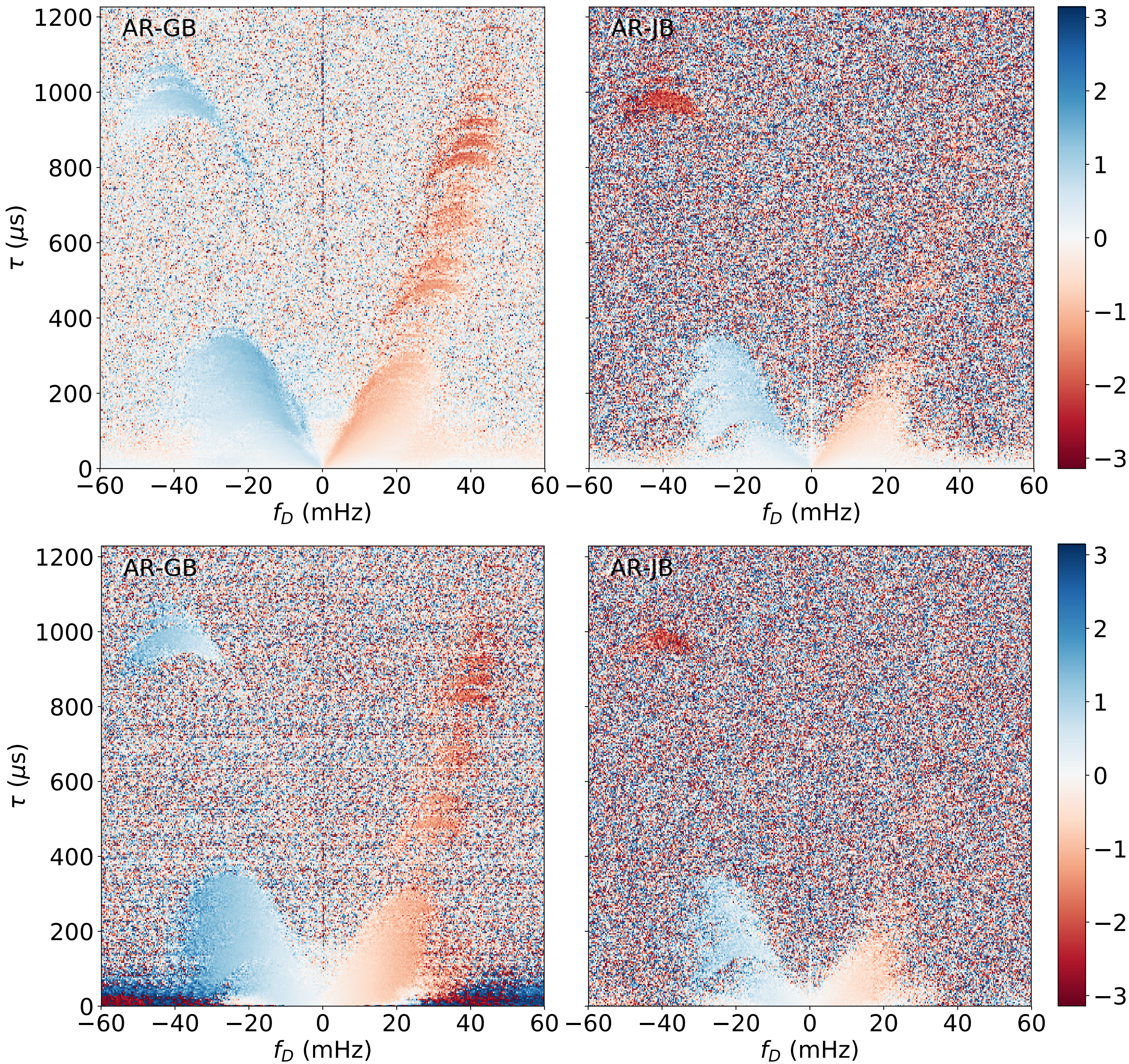
4 screens
(Putney & Stinebring, 2005)

- Large-bandwidth, multi-epoch VLBI observations can test models of scintillation
- Intensities + visibilities from global VLBI experiments can be combined to reconstruct scattering environments, even if there aren't distinguishable parabolic in the power spectrum
- This will allow us to apply our study of scintillation, and of pulsars using scintillation, to many more sources, and to understand the relationship between highly complex scattering environments and those with a single screen

This presentation has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet]

Visibilities:

Intensities:



Simulation of a 2-screen system