A predictive & physical model of scintillation

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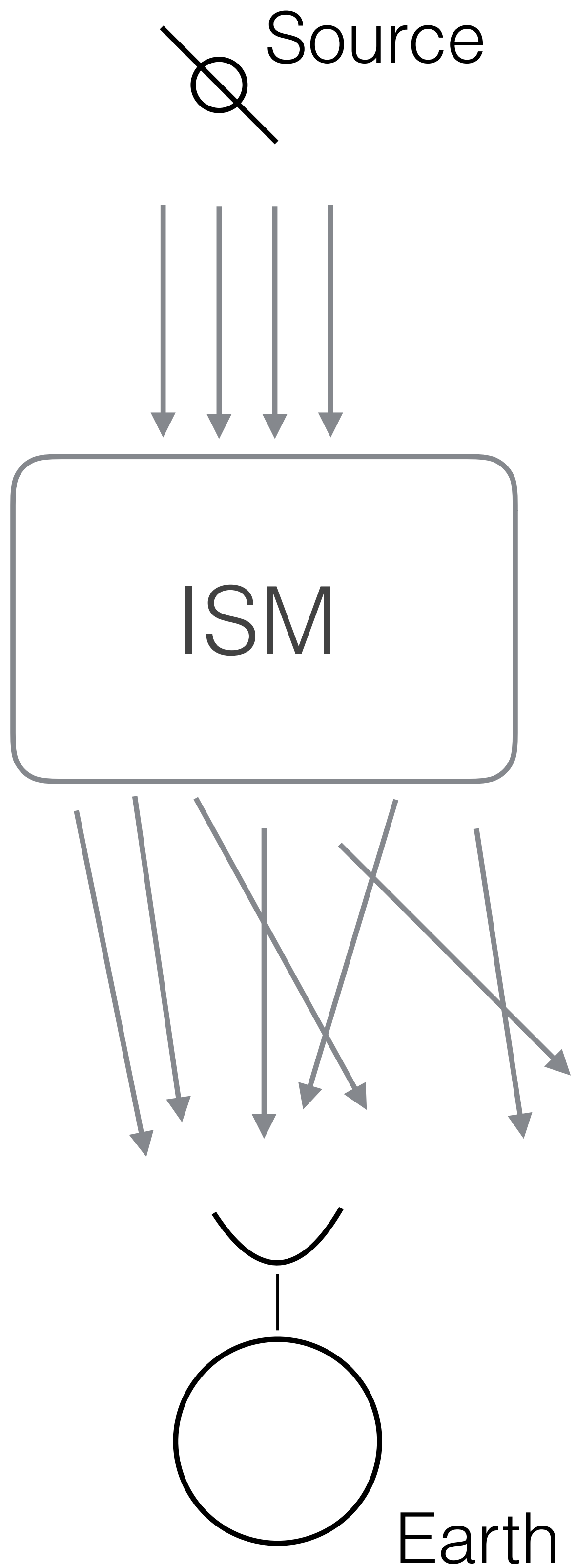
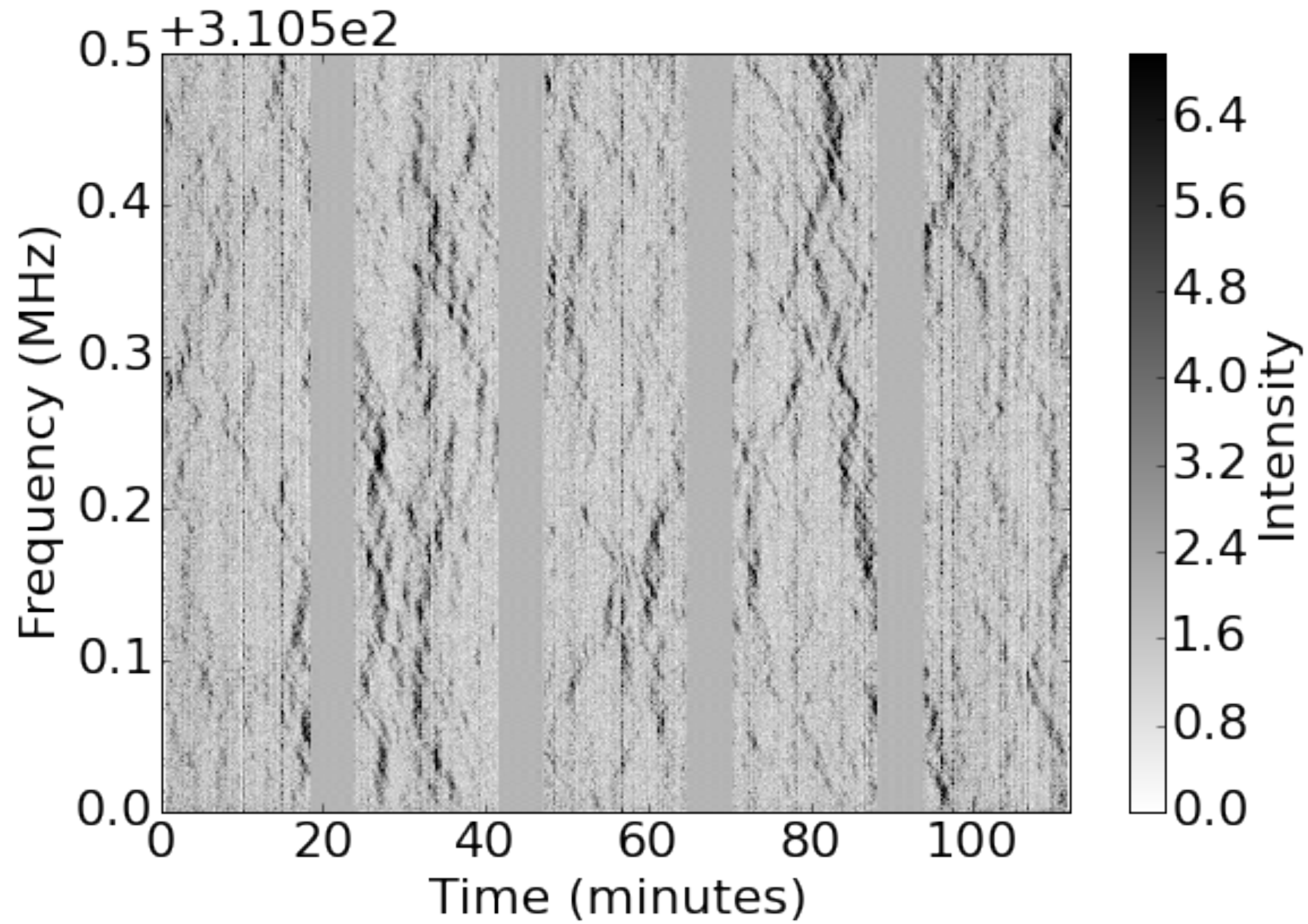
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

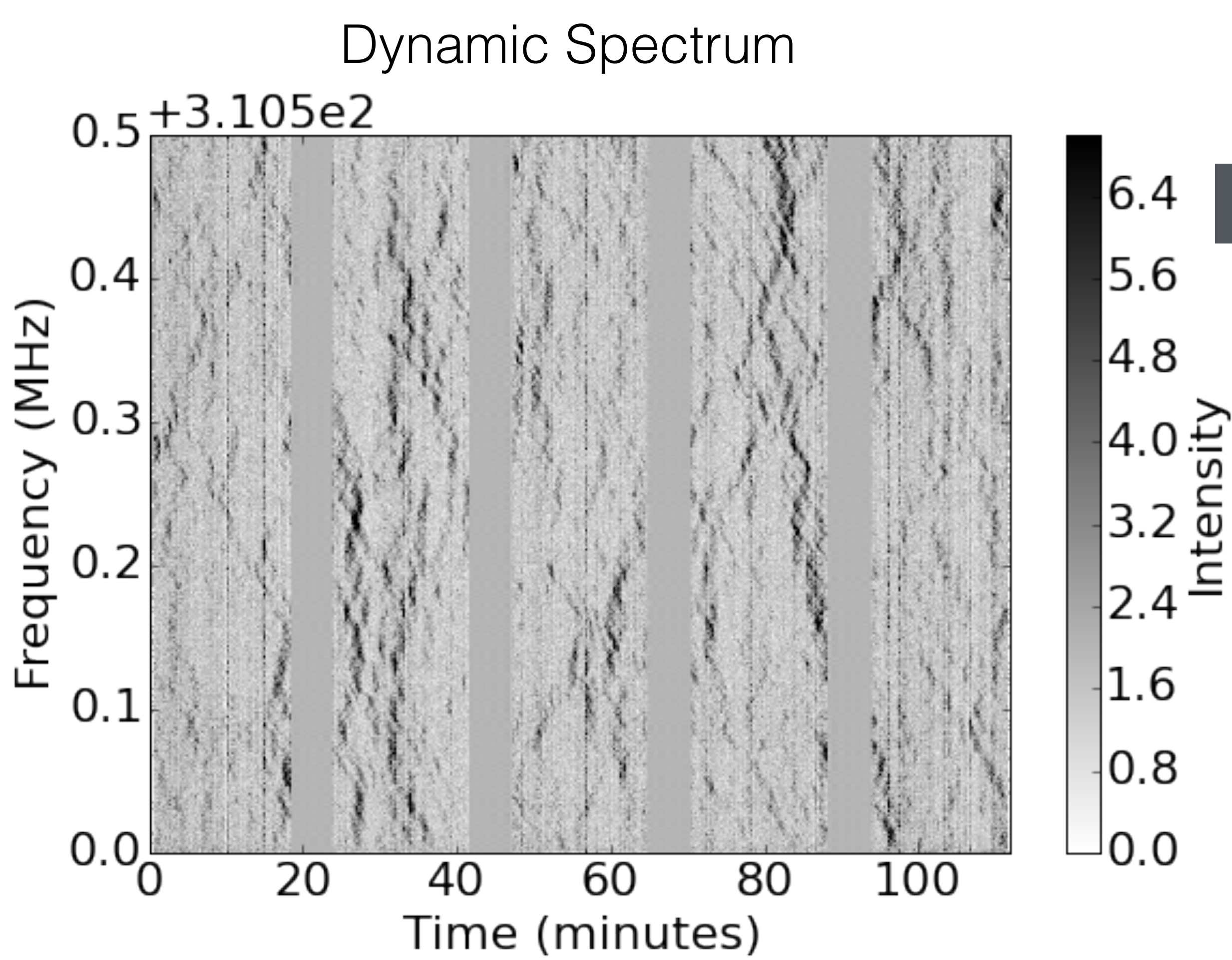
Scintillation



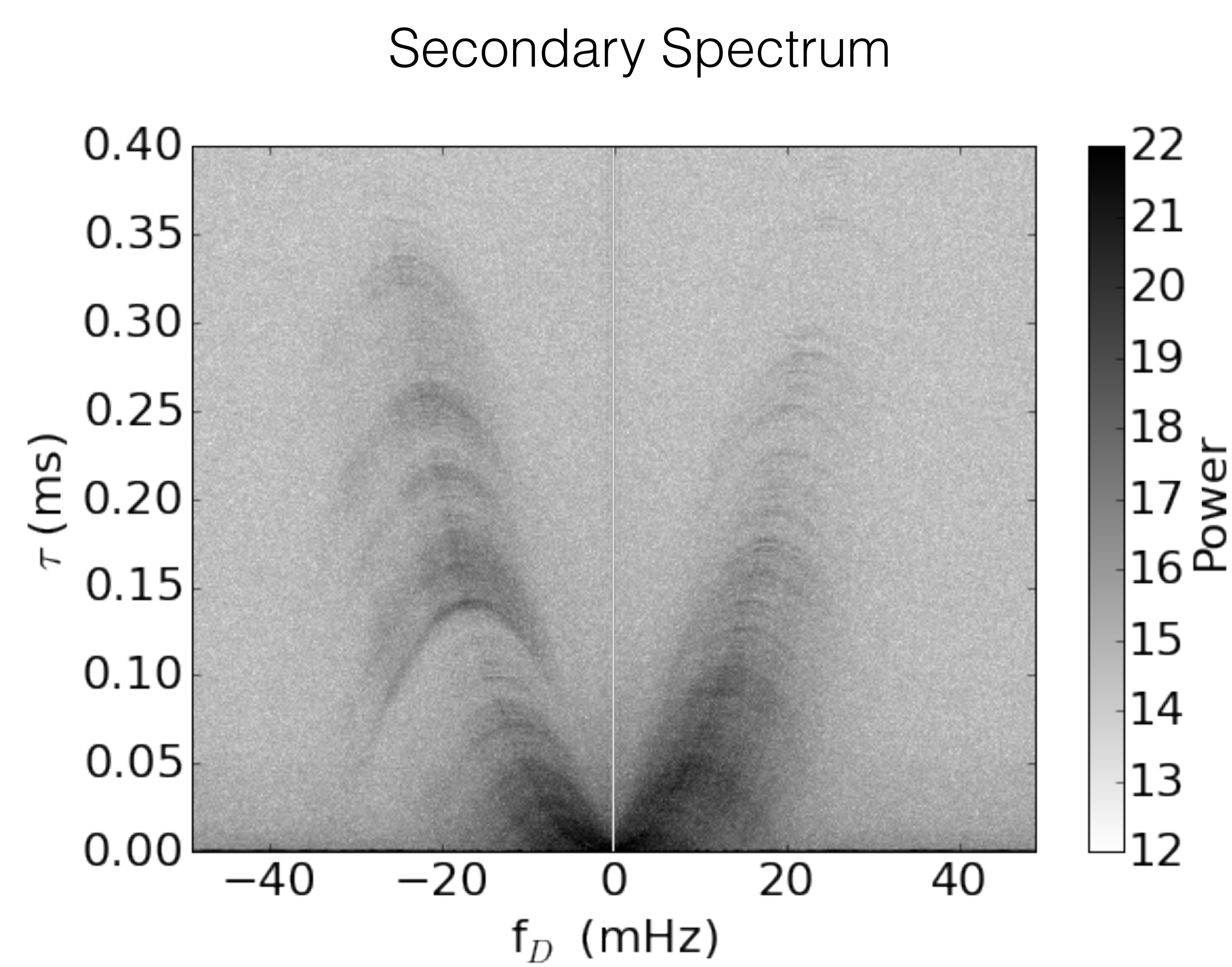


B0834+06,
published in
Brisken et al. 2010,
observed at
Arecibo

When we look at the Fourier transform, structure becomes apparent



2-D FT

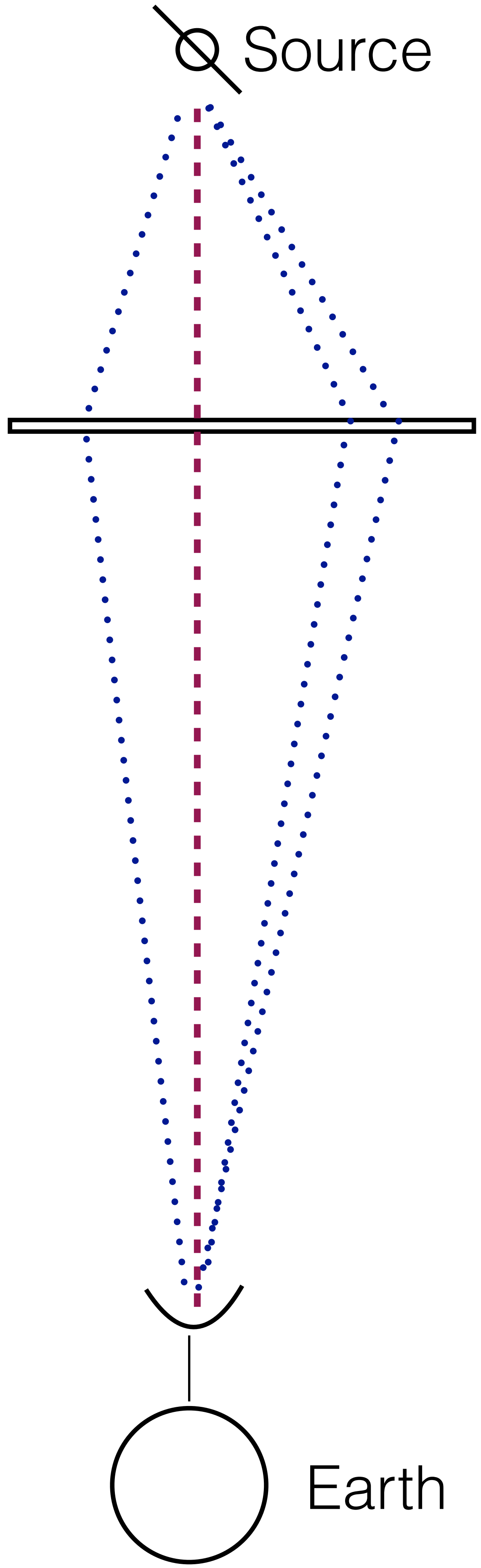


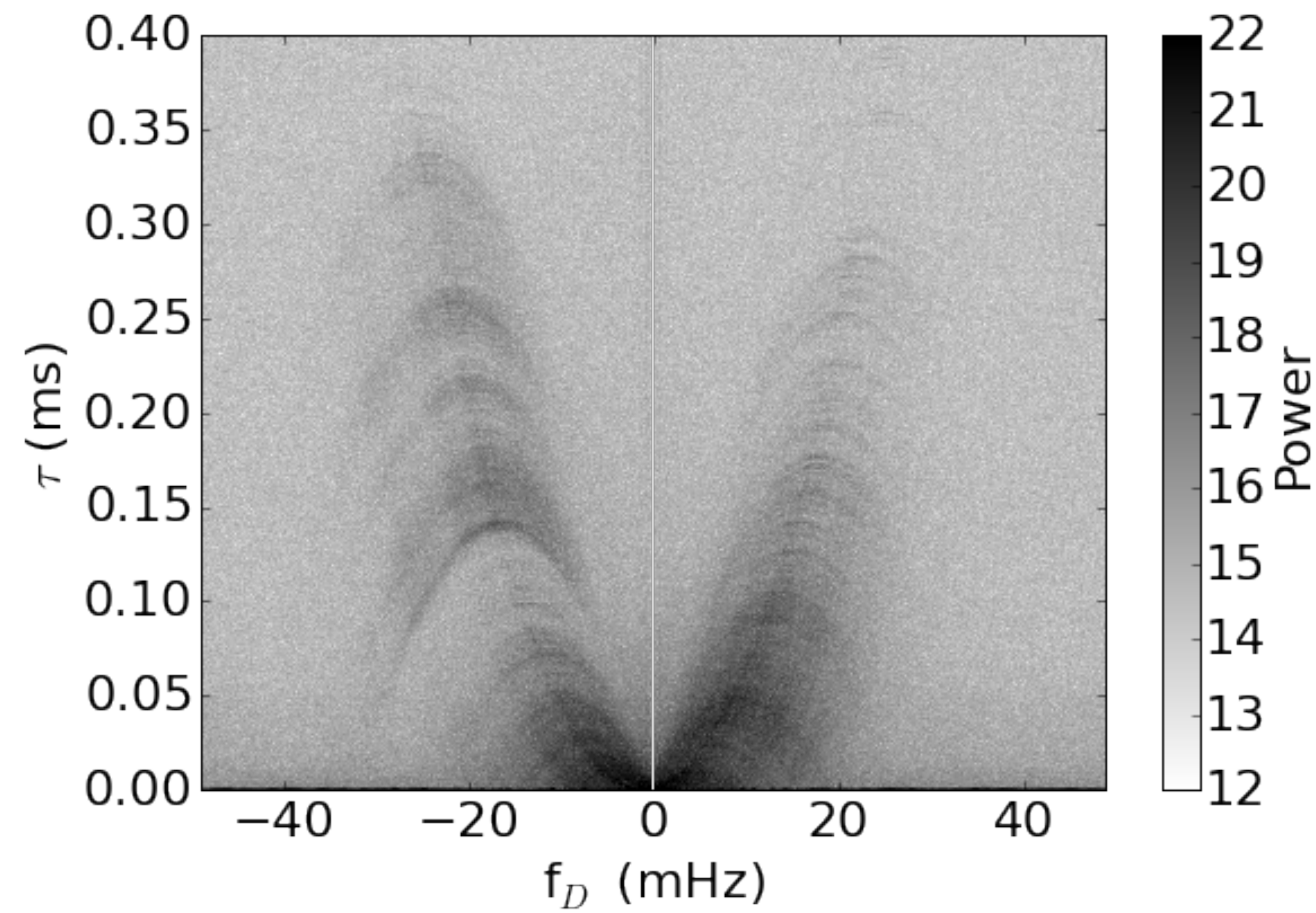
Parabolic arcs very common:

Stinebring et al. 2001, Putney et al. 2005

Thin Screen Model

eg. Walker et al. 2004,
Cordes et al. 2006





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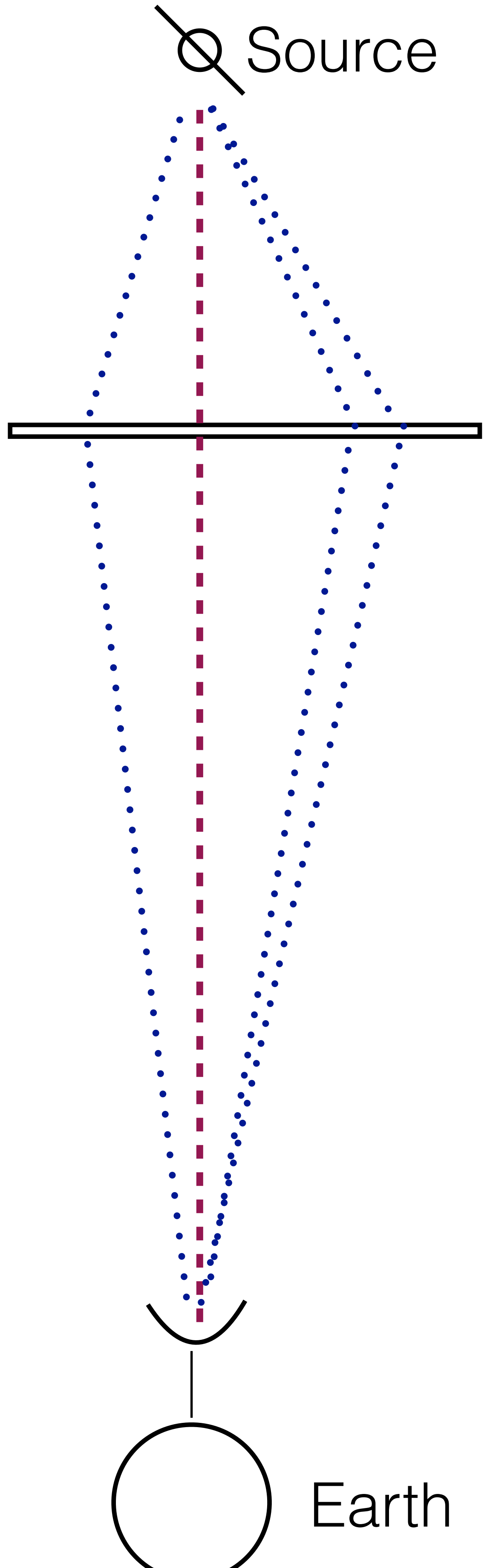
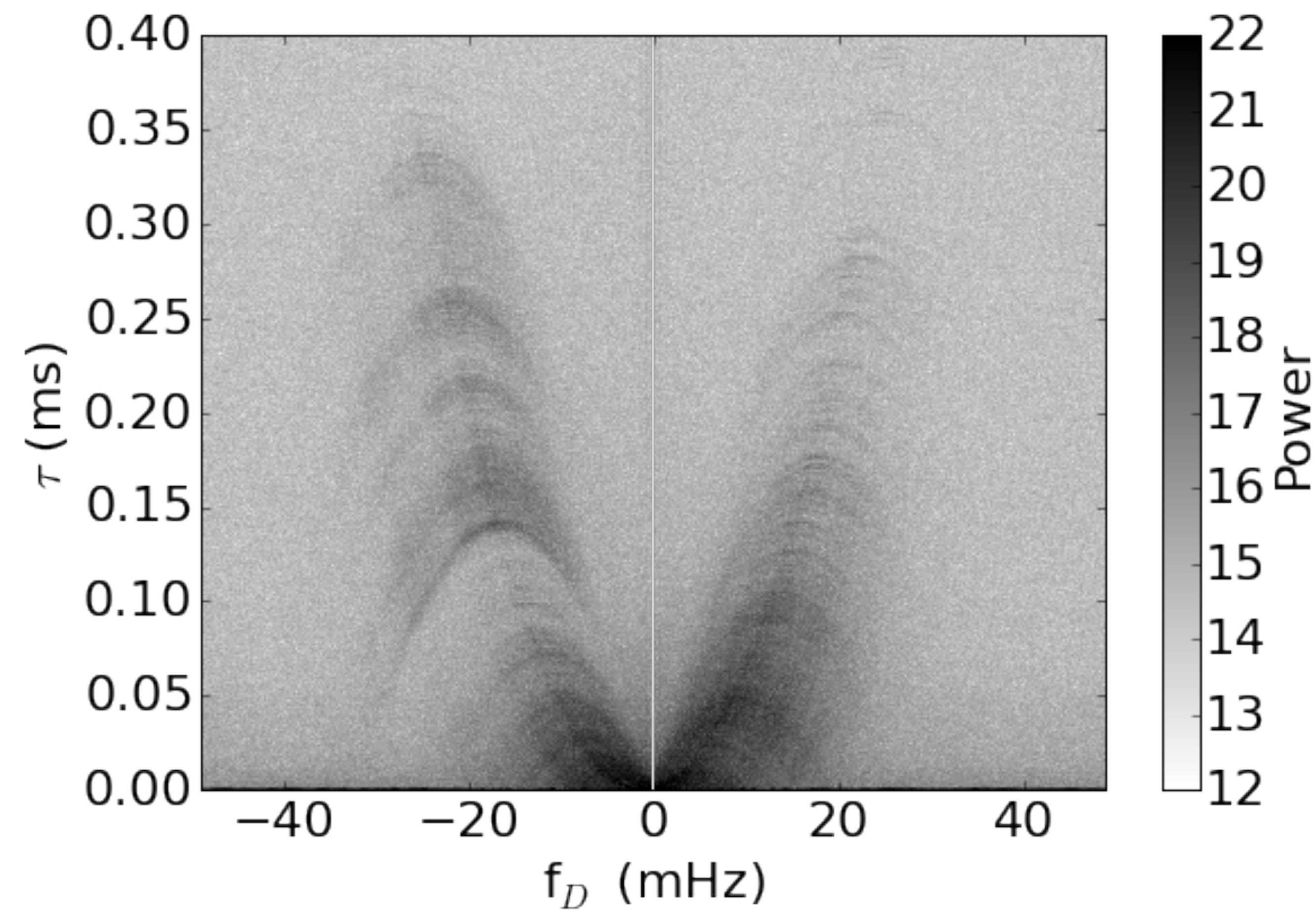
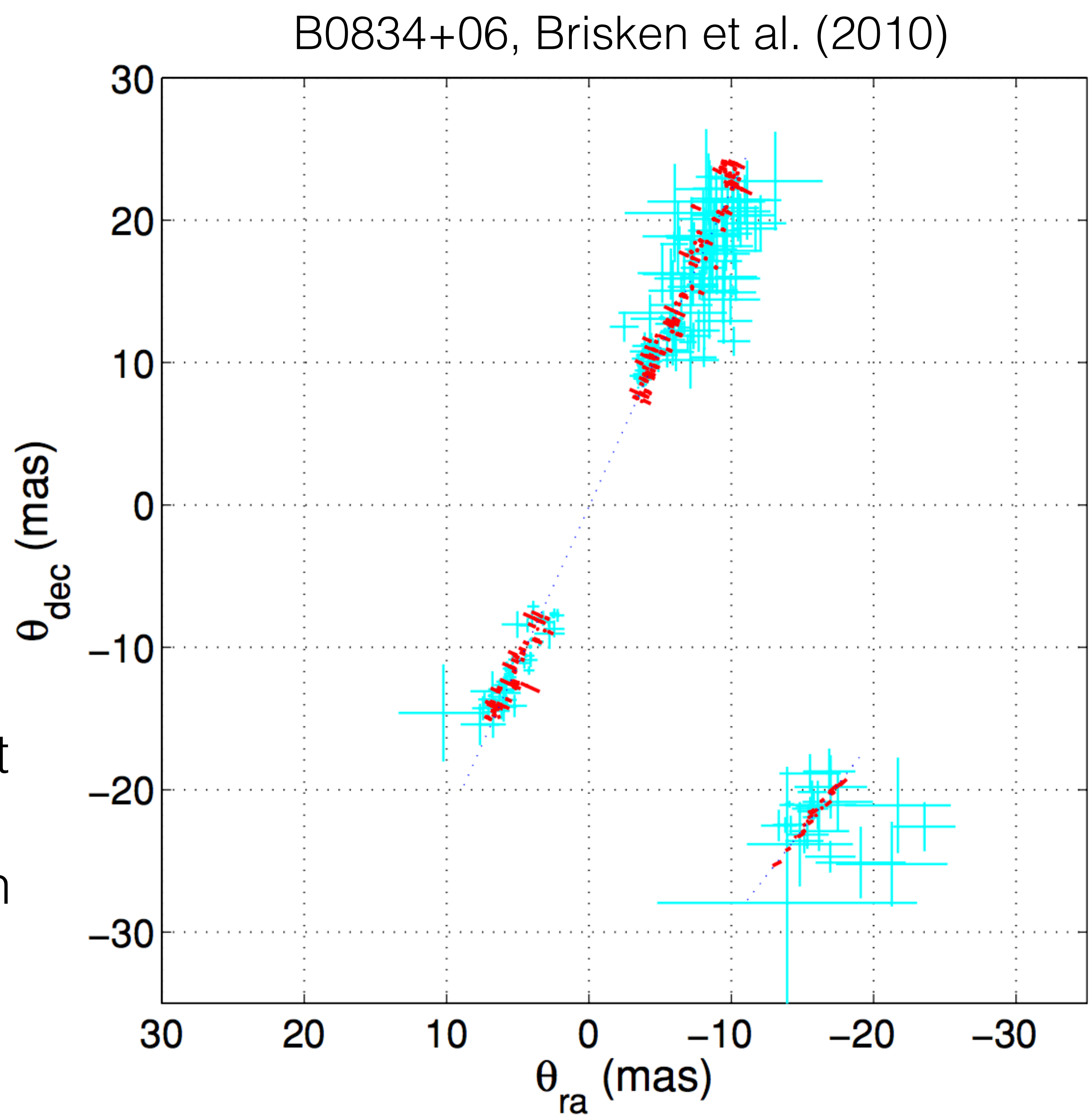




B0834+06,
Brisken et al. 2010

$$\tau = \frac{D_{\rm eff}\ \Delta\theta^2}{2c} \qquad f_D = \frac{\boldsymbol{\Delta}\theta \cdot \mathbf{V}_{\rm eff}}{\lambda}$$

- Using VLBI, we can "image" the scattering screen to 100 microarcsecond resolution (Brisken et al. 2010)
- These images are ~stationary on the scattering screen over hour-long timescales, but move as the pulsar moves behind the screen (eg. B0834+06, Hill et al. 2005)



Scattering Screens as Interferometers

- Since the images on the scattering screen are stationary over the timescale of a typical observation, we can use the scattering screen itself as an interferometer (eg. Pen et al. 2012)
    - Nanoarcsecond resolution of the source at 300 MHz

FRB Scintillation

- Propagation effects from both local and host galaxies
- Two-screen model for scintillation & scattering
  - Galactic screen - 1D screen like that seen for PSR B0834+06 and other pulsars
  - Host galaxy screen

FRB Scintillation

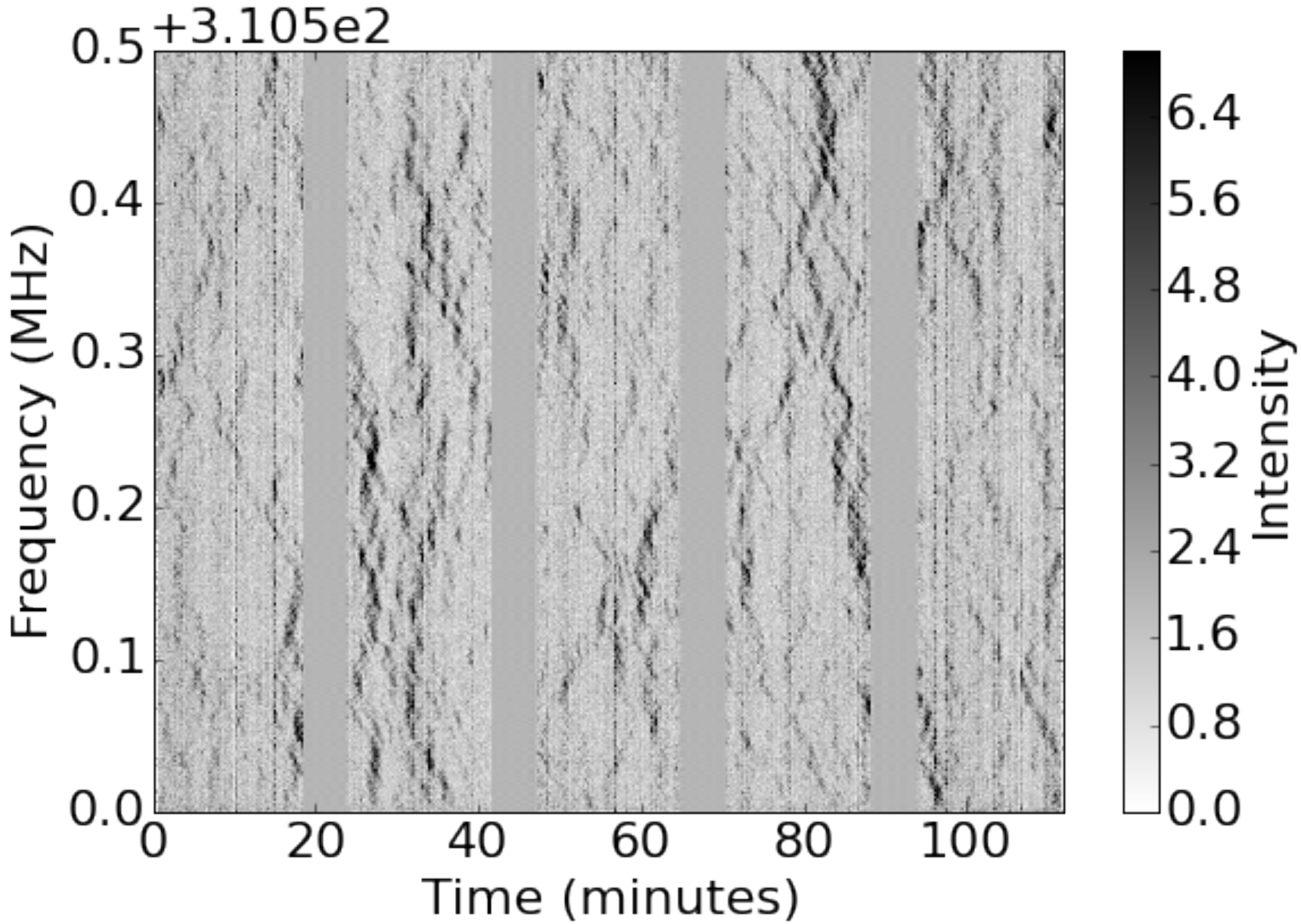
- Simple constraints can be placed on the location of the host screen if scintillation from the Galactic screen is observed
  - Requires that the host-scattered image is not resolved by the Galactic screen
  - Allows distance between source and host screen to be constrained (eg. Masui et al. 2015)

- To better use the Galactic screens to understand the local environment of FRBs, need a model to interpret what we are seeing.

What can we gain from a model of scintillation?

- Models can make predictions about the scintillation based on our understanding of the Galactic ISM
    - Allows us to test and develop our understanding & model
- Remove scintillation from observations
- Using scintillation to study sources, including pulsars and FRBs

How much information do we need to predict pulsar scintillation?



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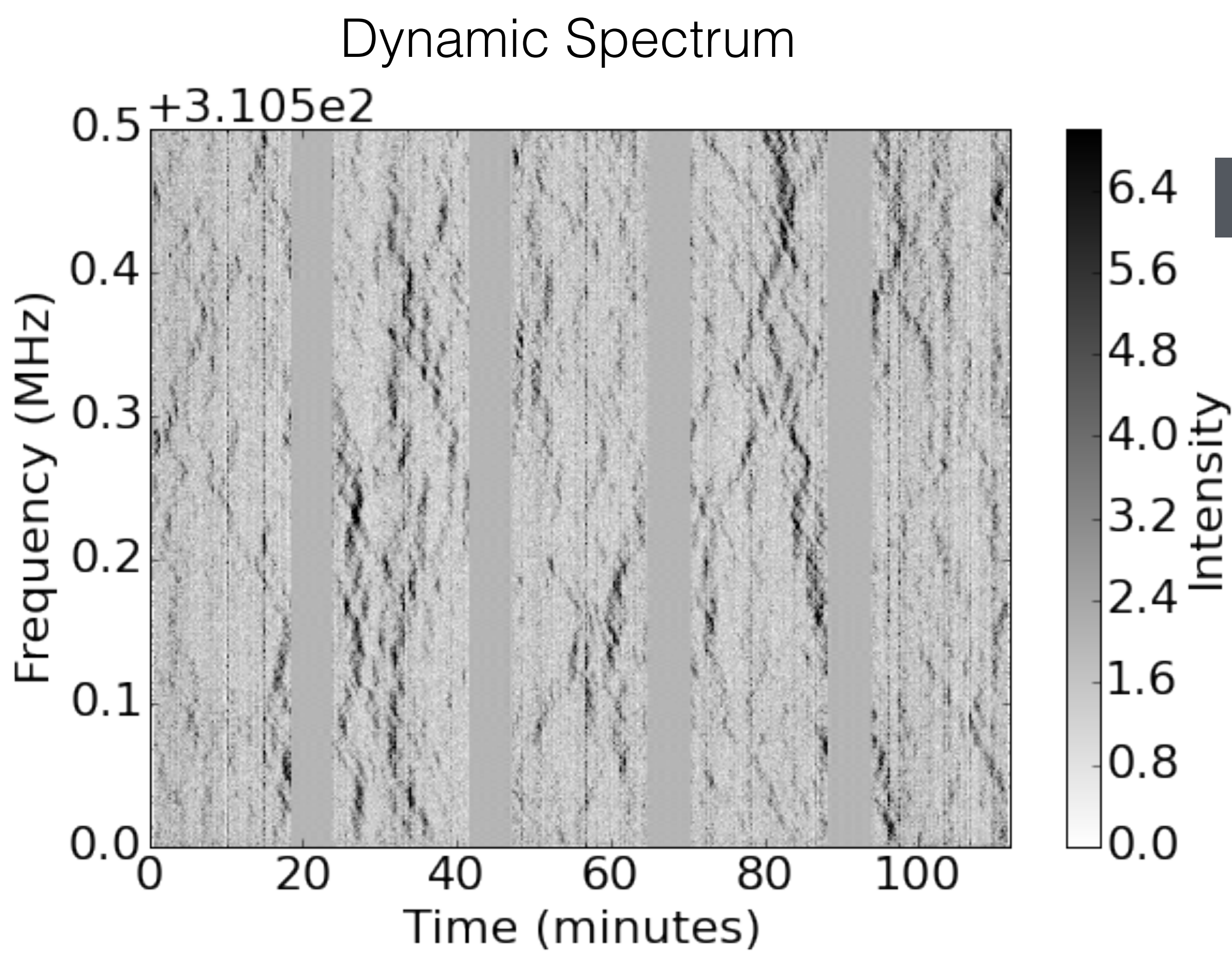

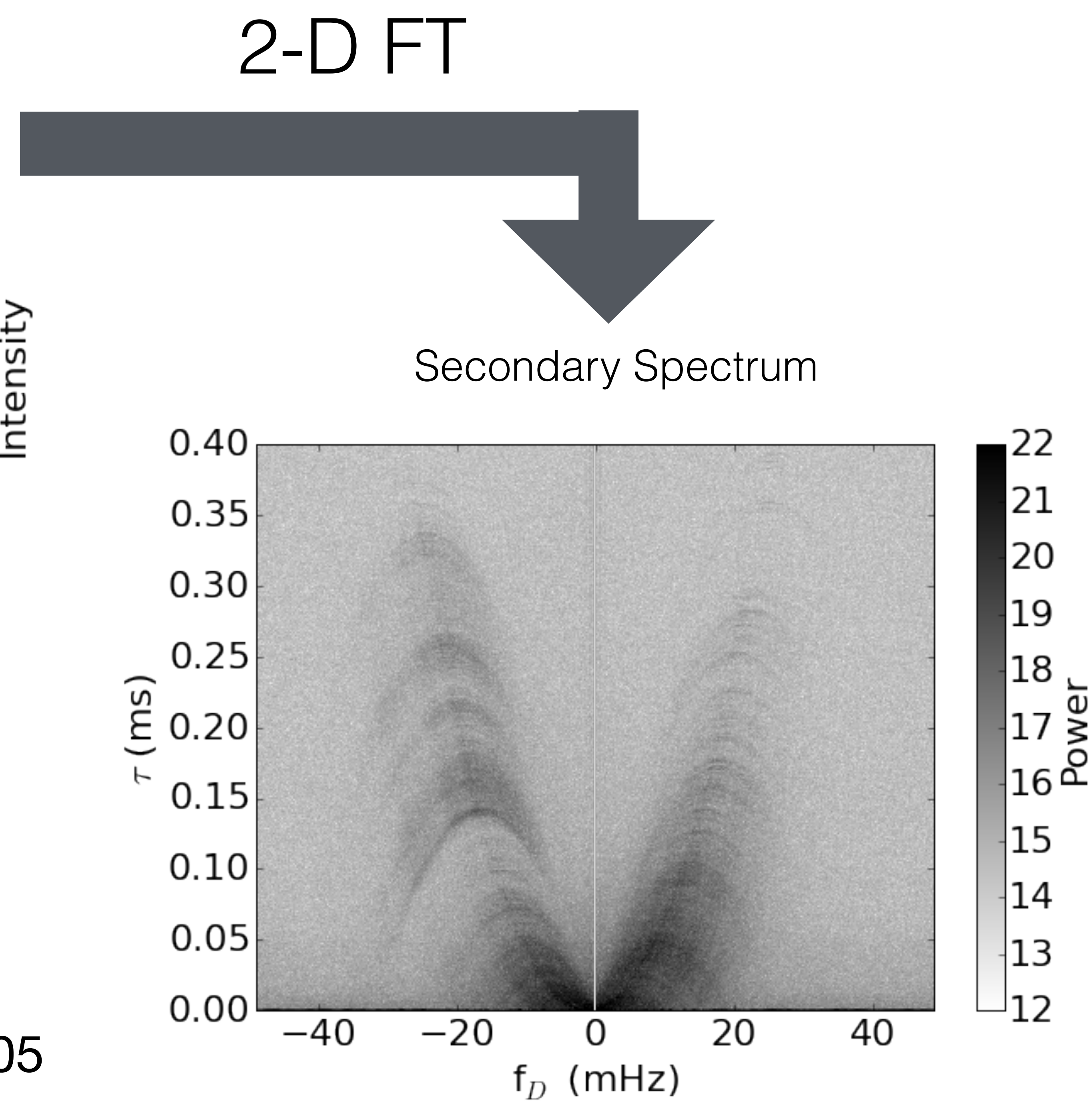

Parabolic arcs very common:

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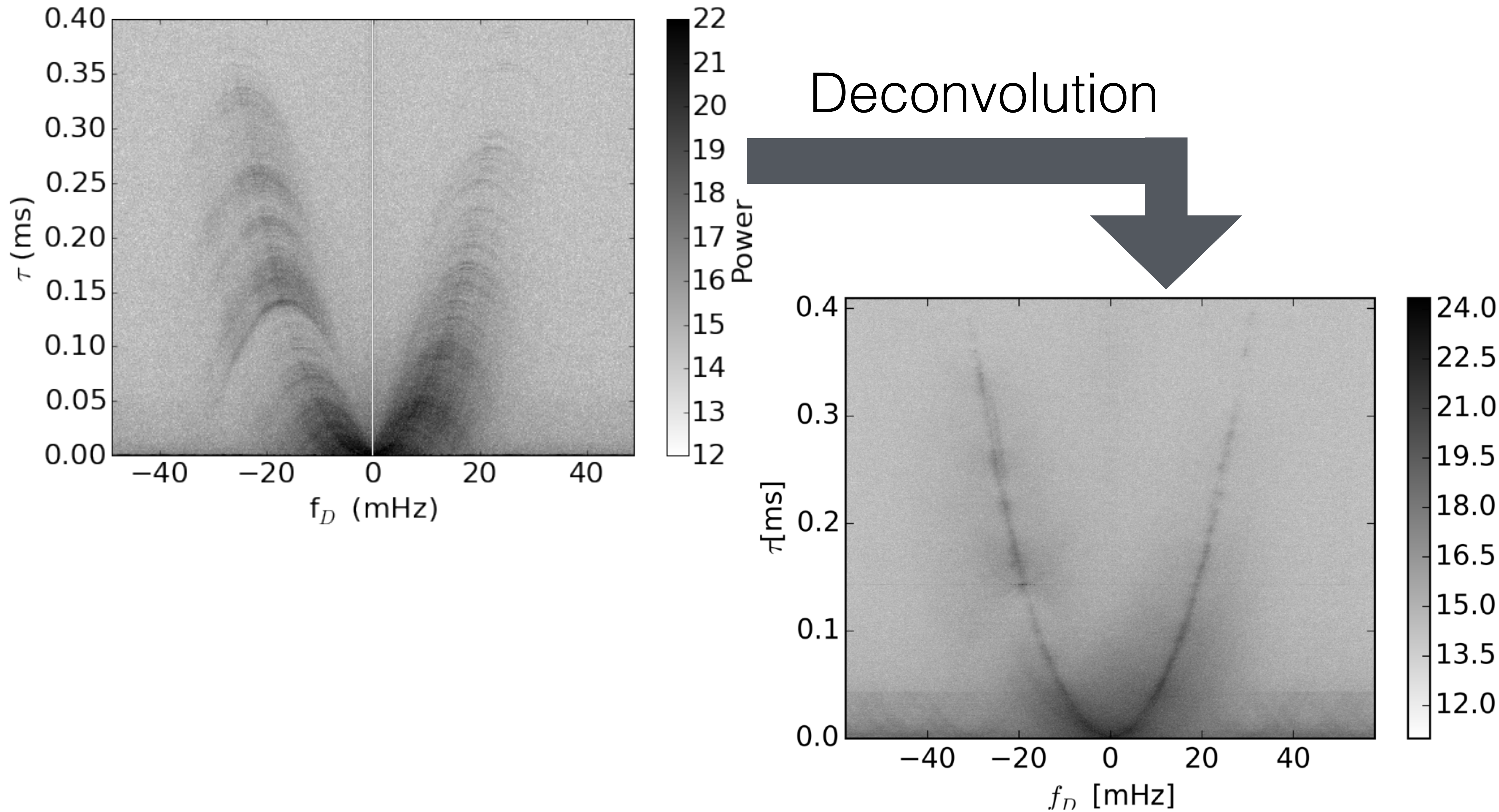
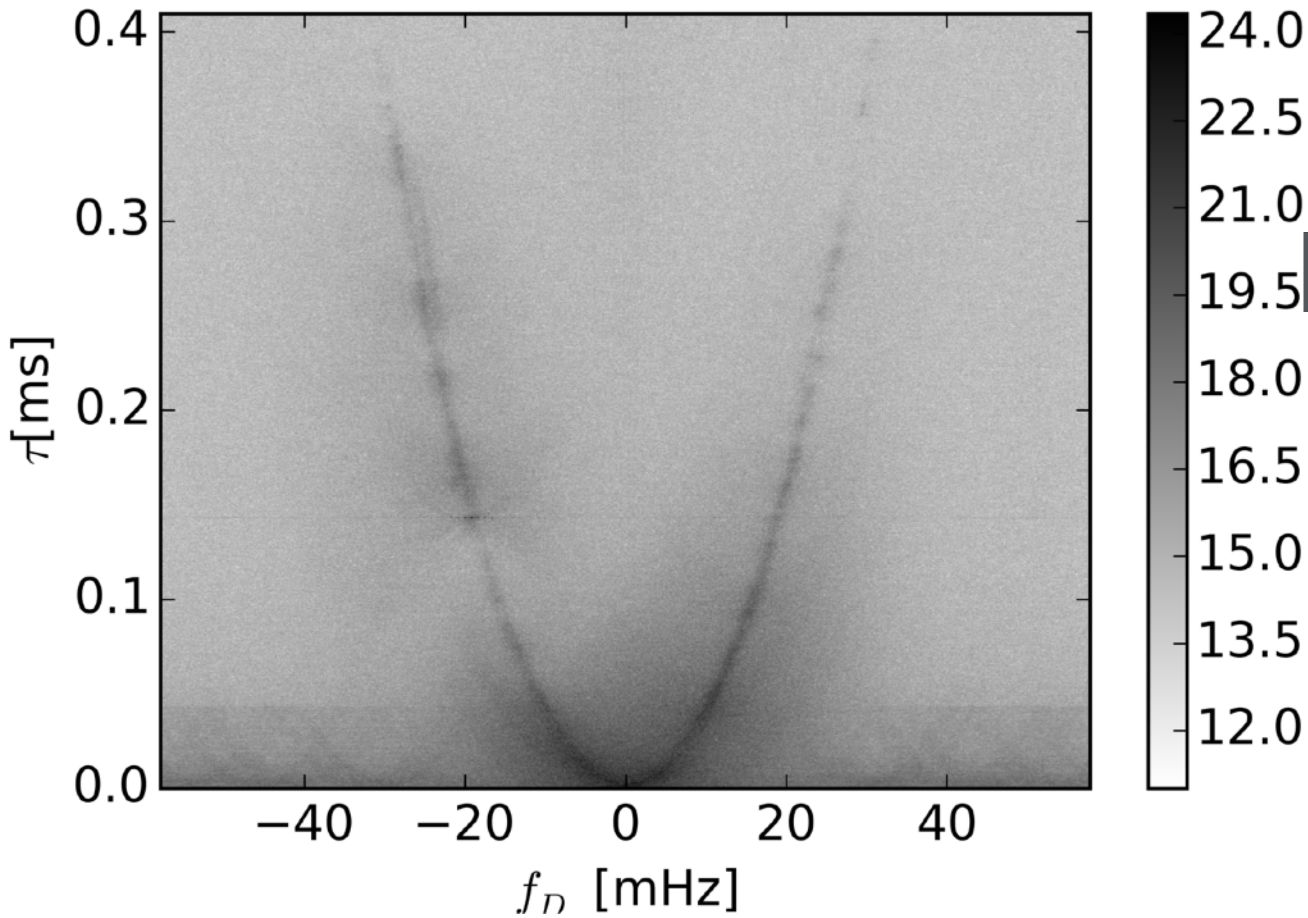
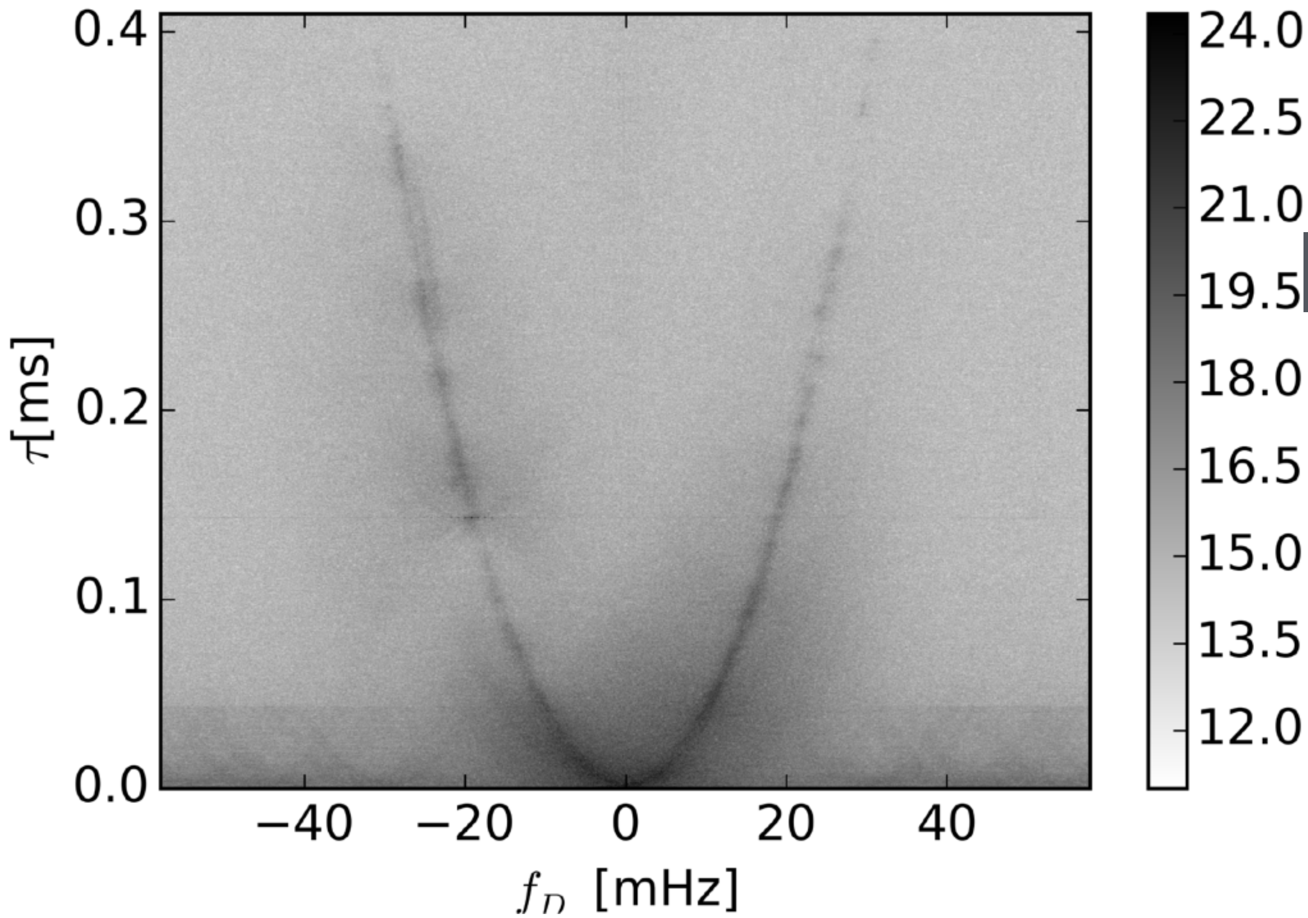
We can deconvolve with a single arclet to reduce the information even further (eg.Walker et al. 2008; Pen et al. 2014)





Scattering screen model

- Fluxes + angular separations of the images for all times and frequencies
- Properties of the system:
  - Effective distance
  - Velocity of the scintillation pattern



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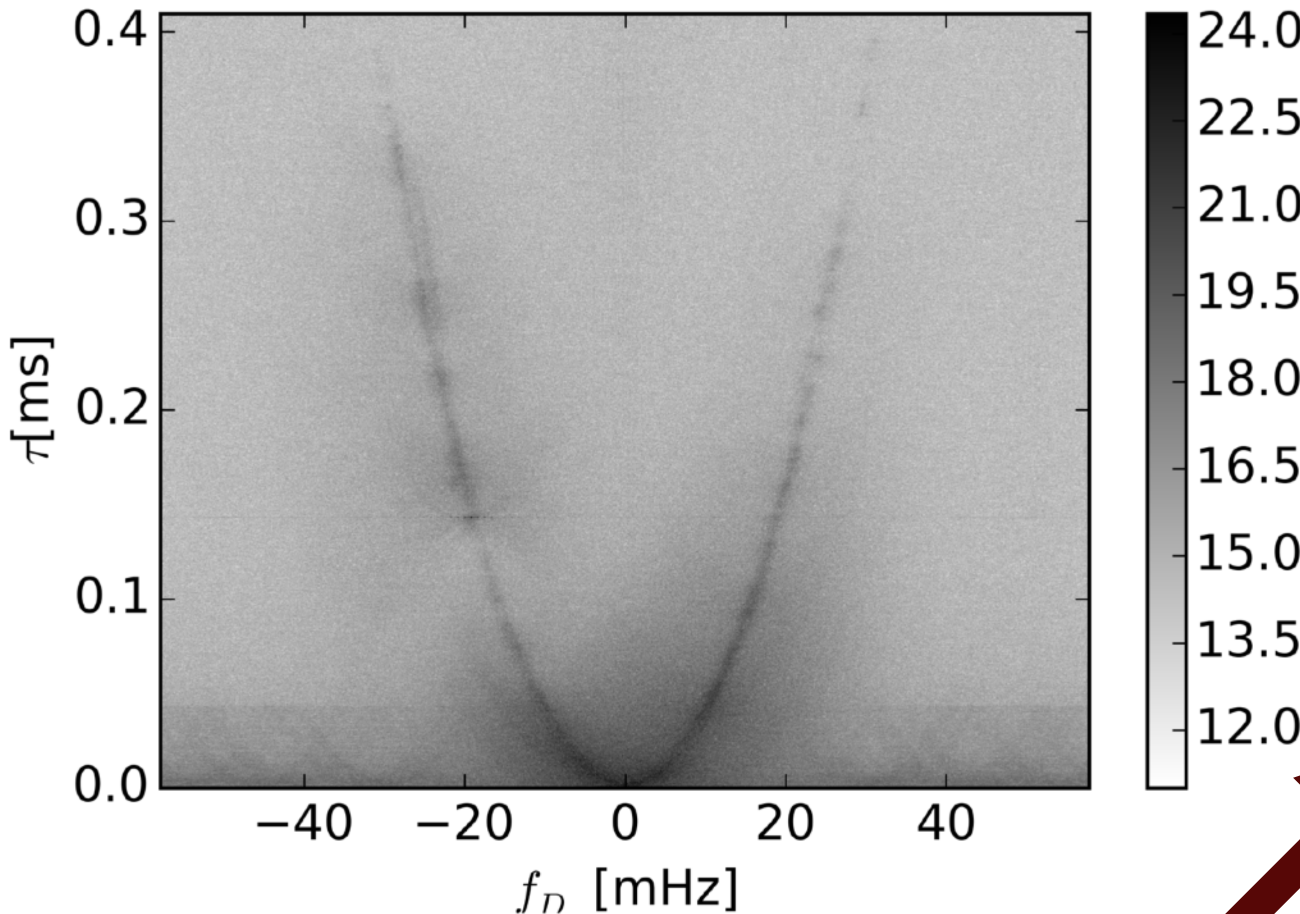
From VLBI observations
Brisken et al. 2010



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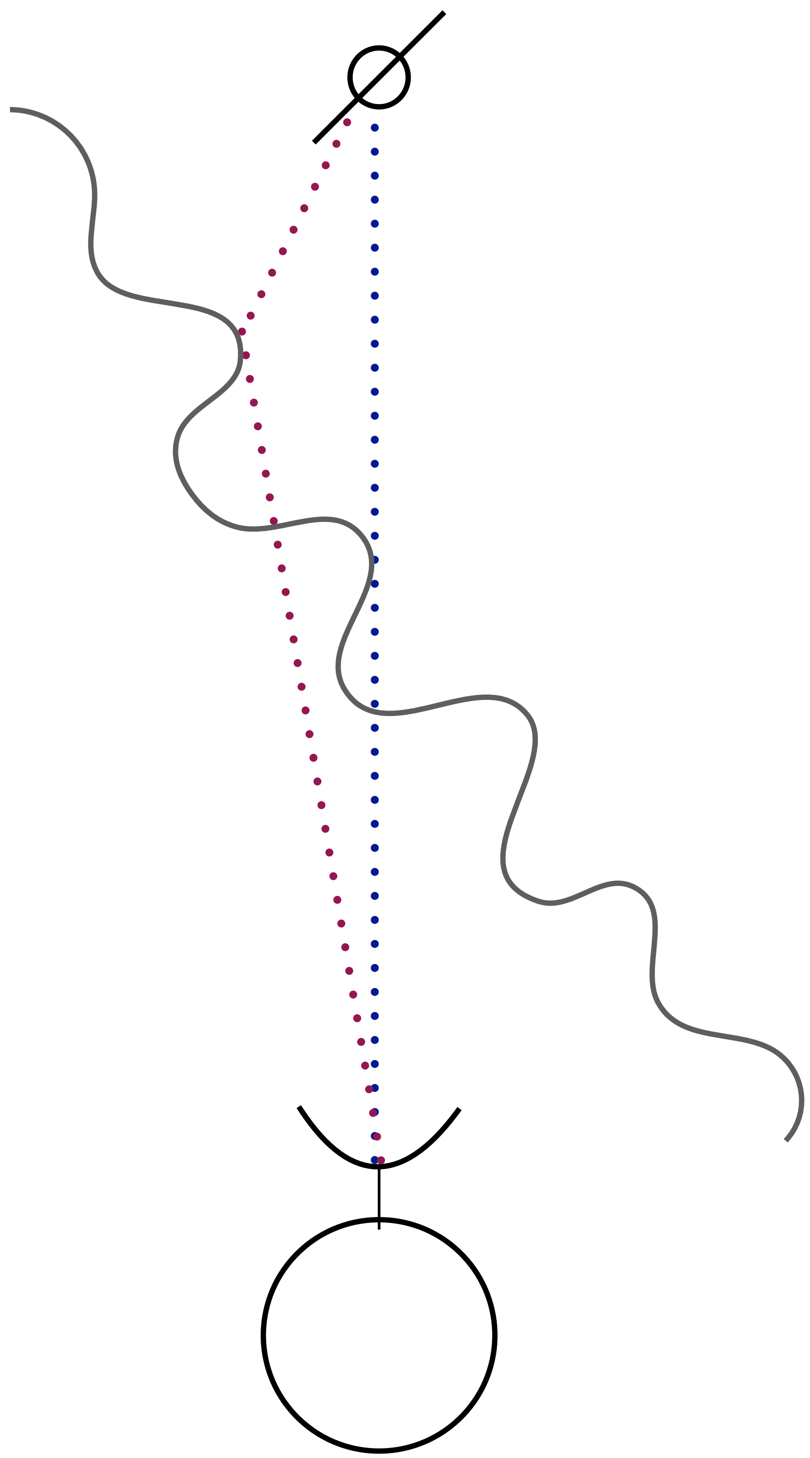
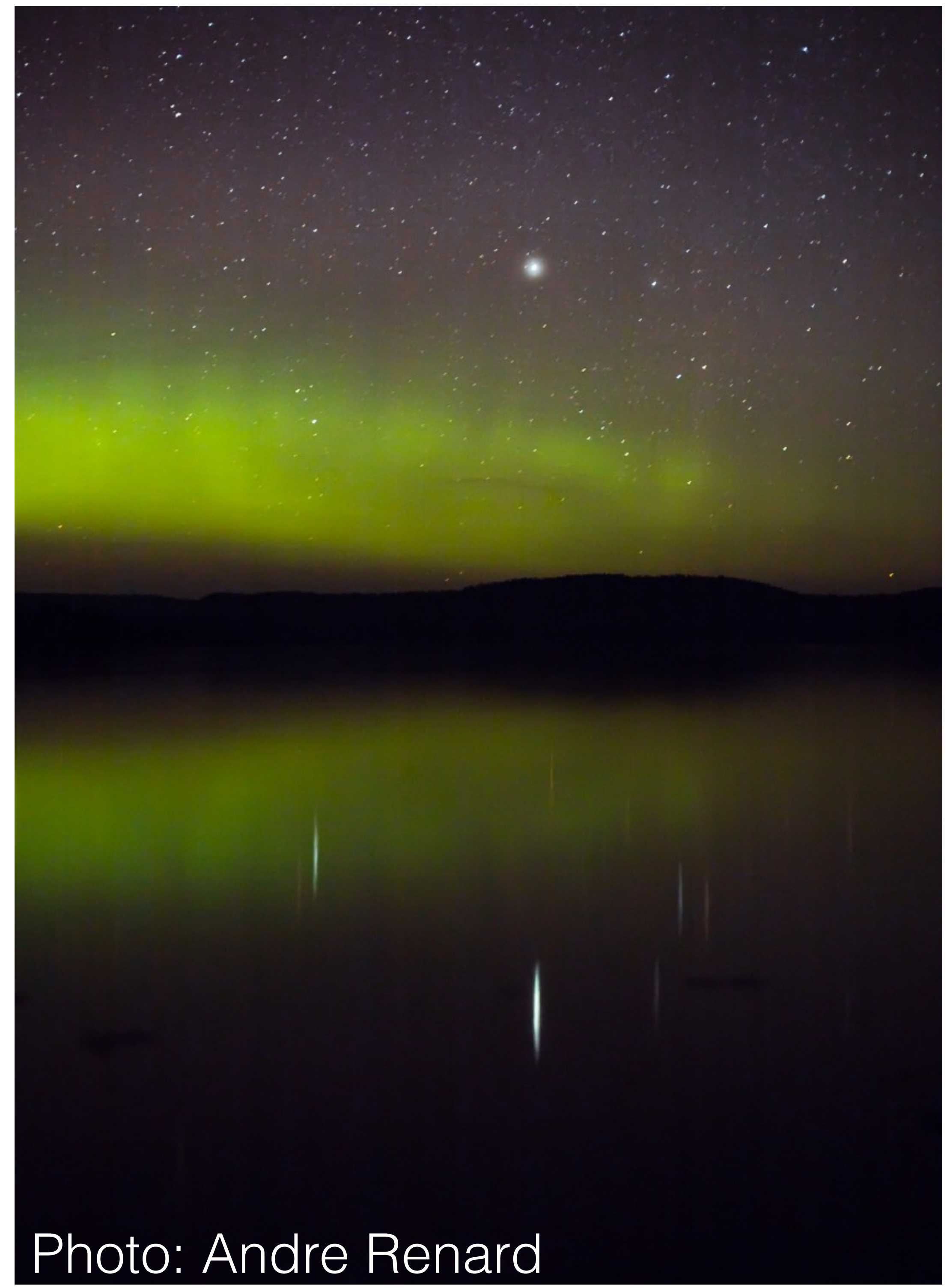
Can we get these from a model of the scattering screen?

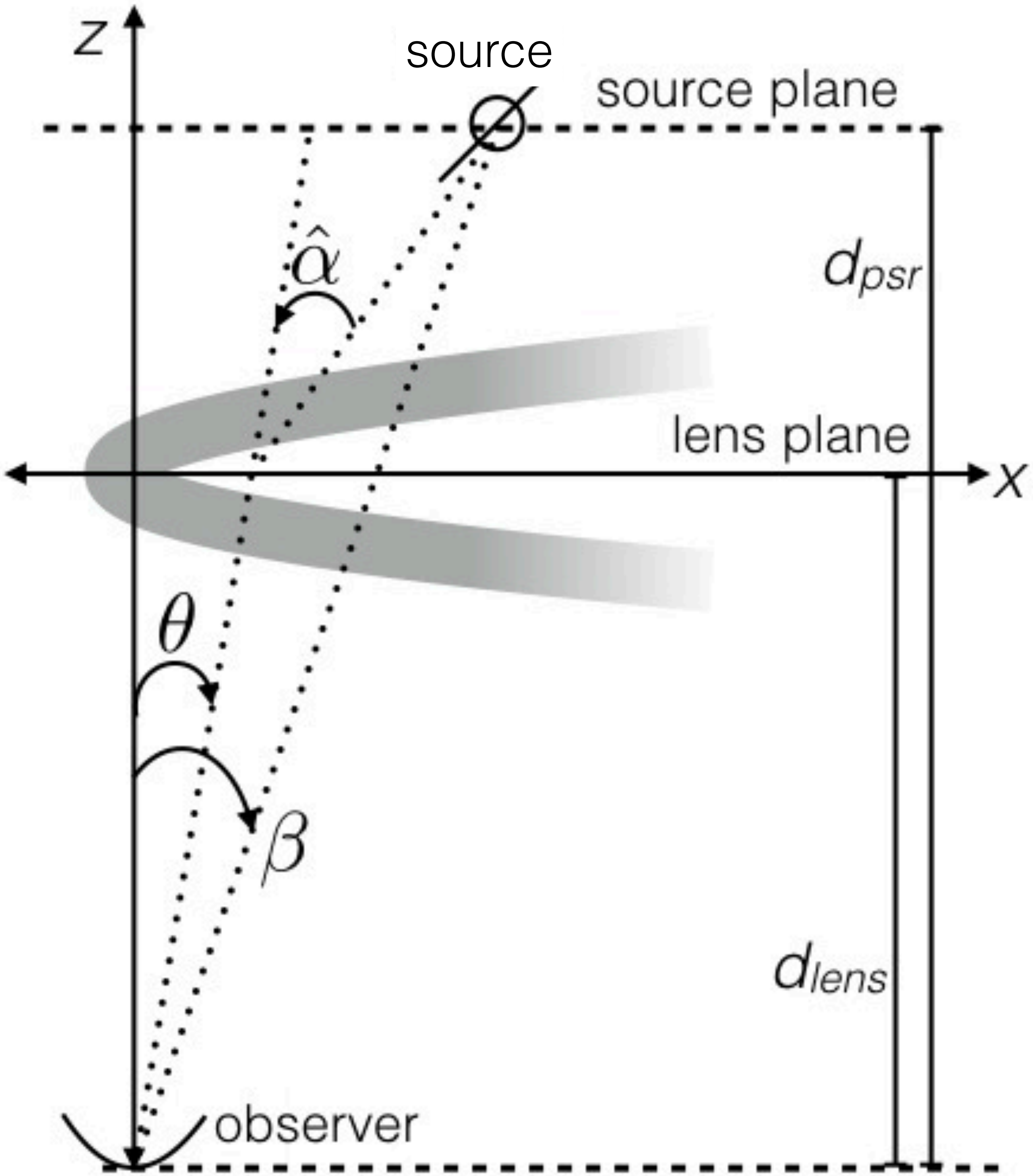
Pen & Levin (2014) propose that scintillation is due to grazing refraction off of corrugated current sheets





Refraction from a single fold

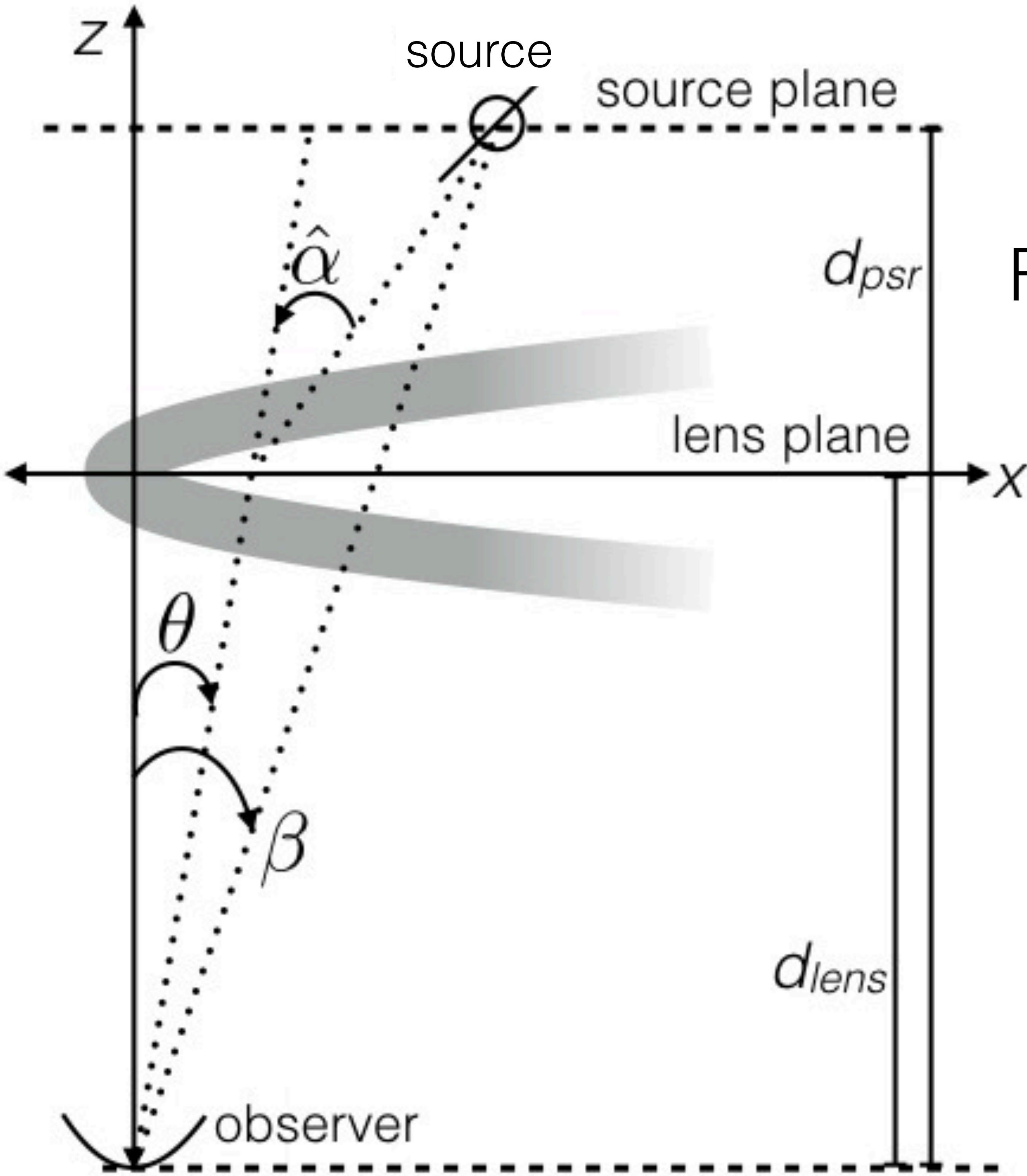
Simard & Pen, arXiv: 703.06855



$$\theta = \beta + s\ \hat{\alpha}$$

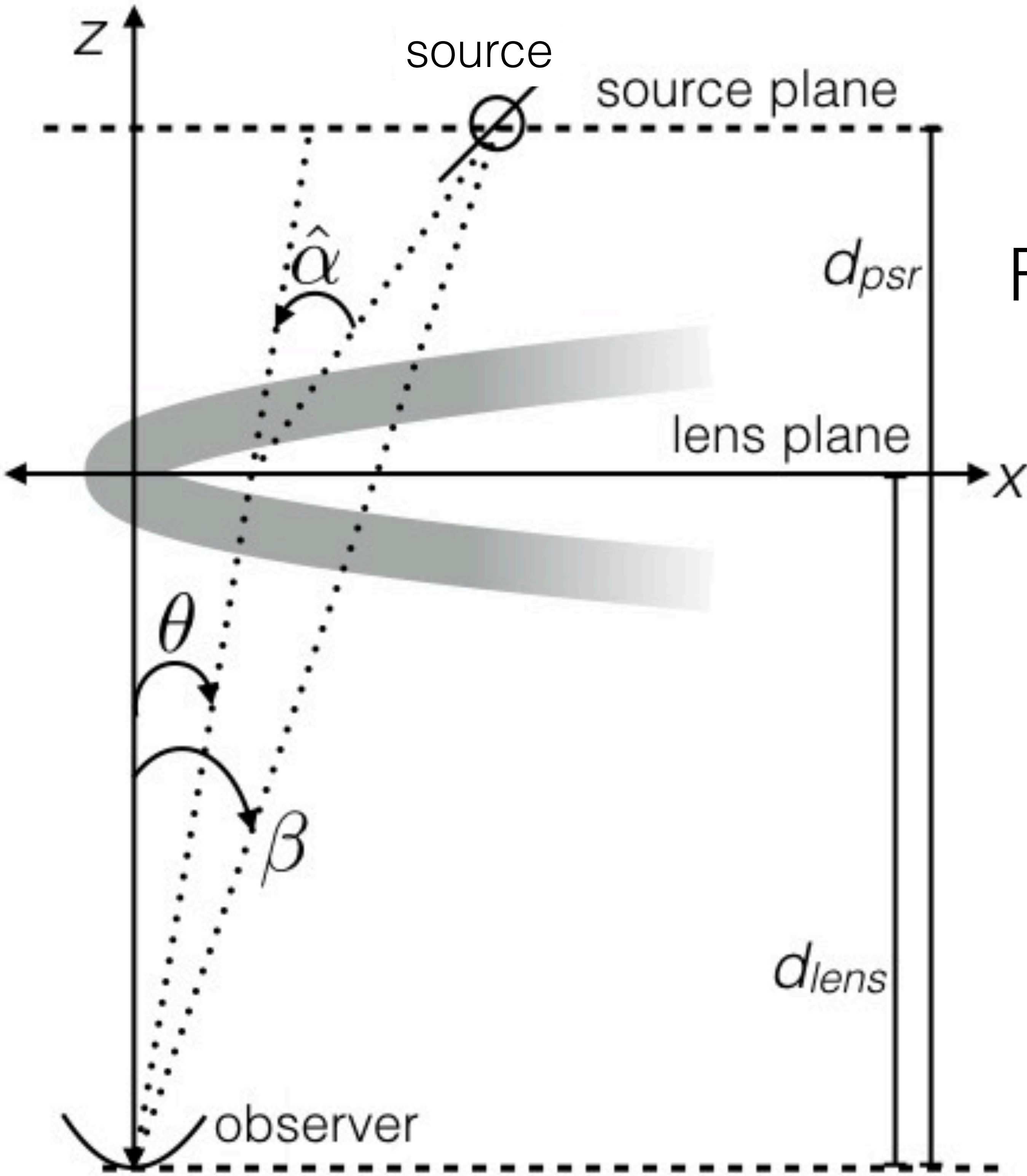
$$s = 1 - \frac{d_{\rm lens}}{d_{\rm psr}}$$

$$\mu = \frac{{\rm d}\theta}{{\rm d}\beta}$$



For large separations between the source and the fold:

$$\hat{\alpha} \simeq \frac{\sqrt{2}}{2} \frac{\Delta n \, \theta_T \, \sqrt{\theta_R}}{\theta^{3/2}}$$



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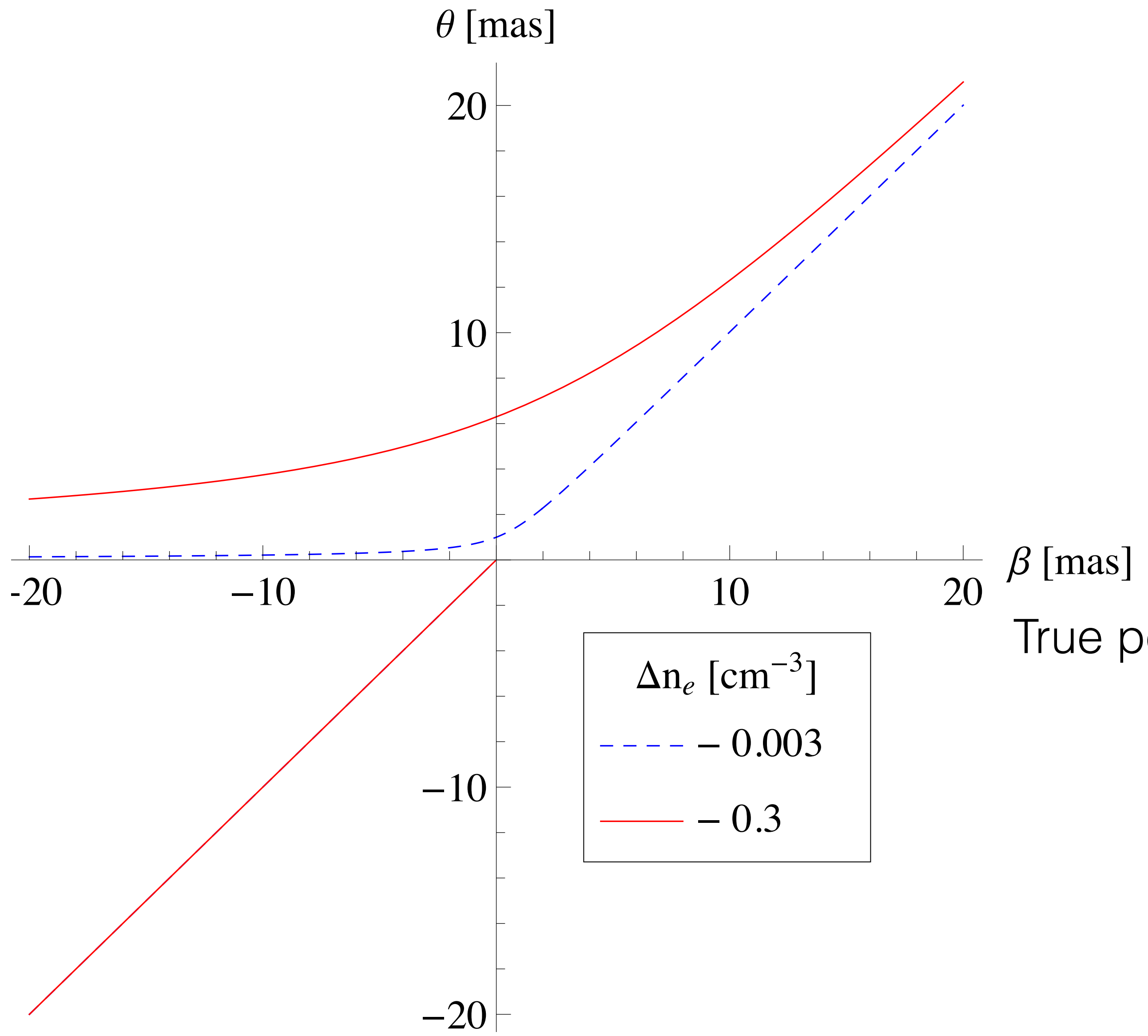
Single parameter describes the lens

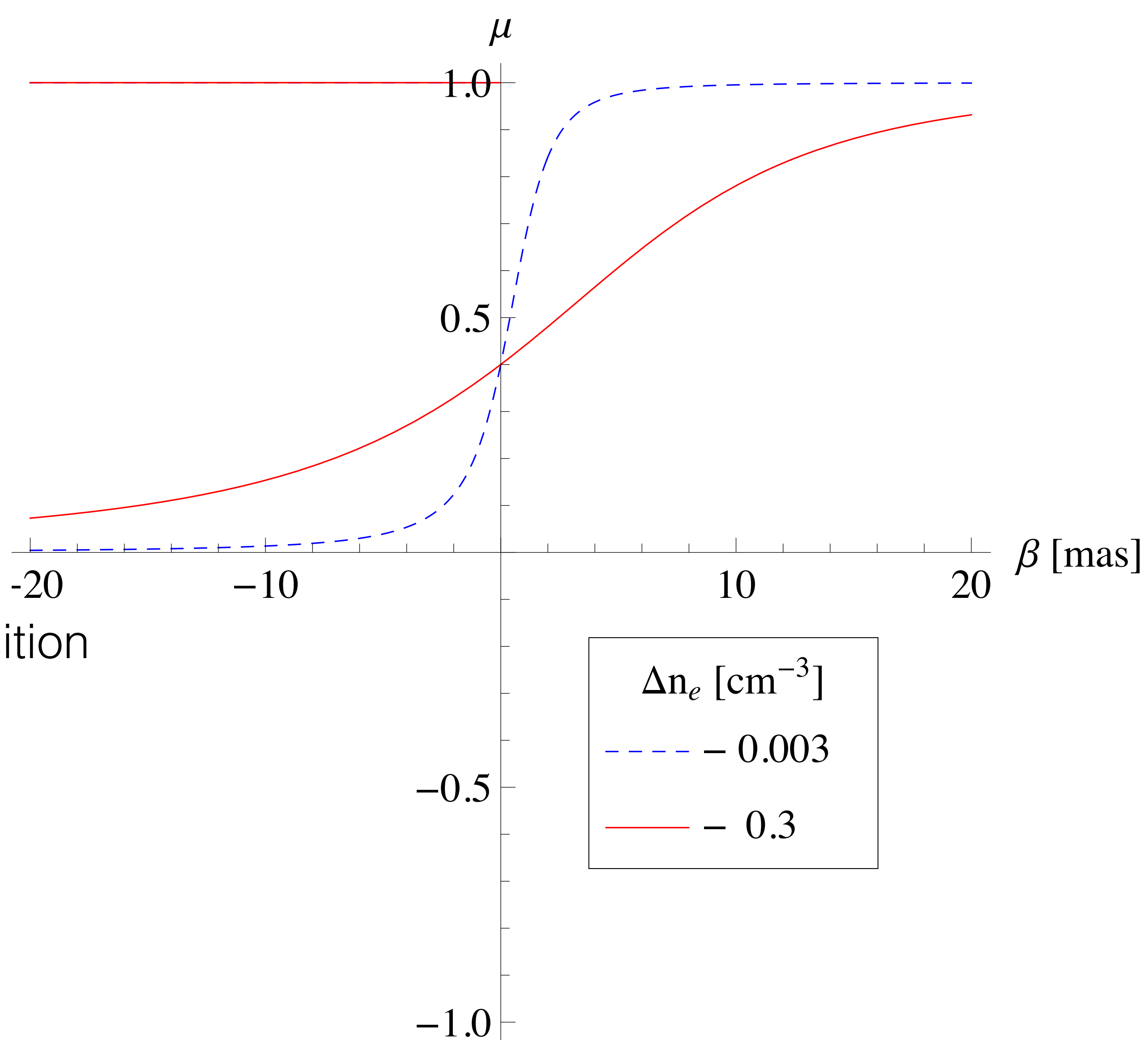
Underdense sheet

Observed position



True position

Magnification



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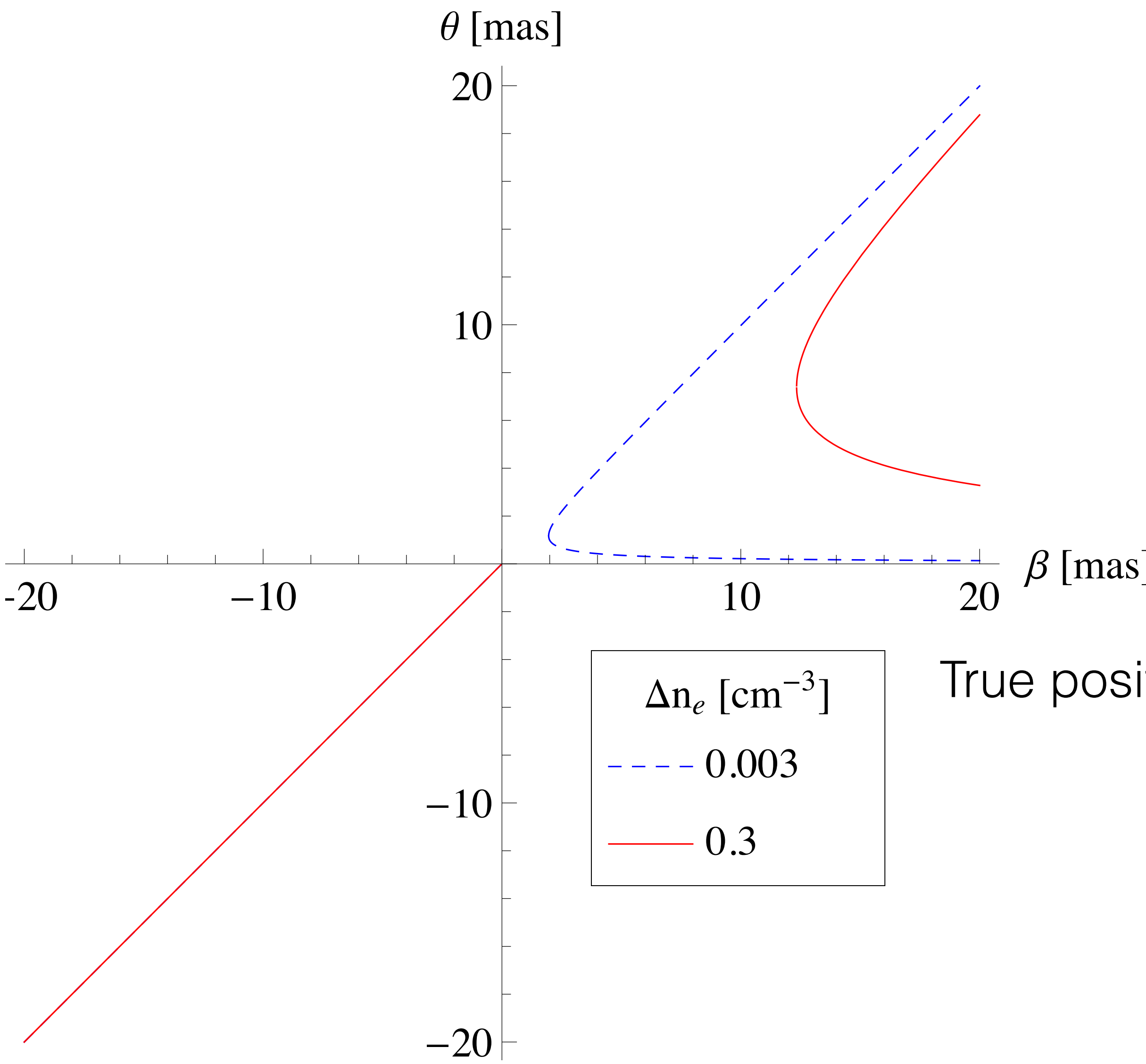
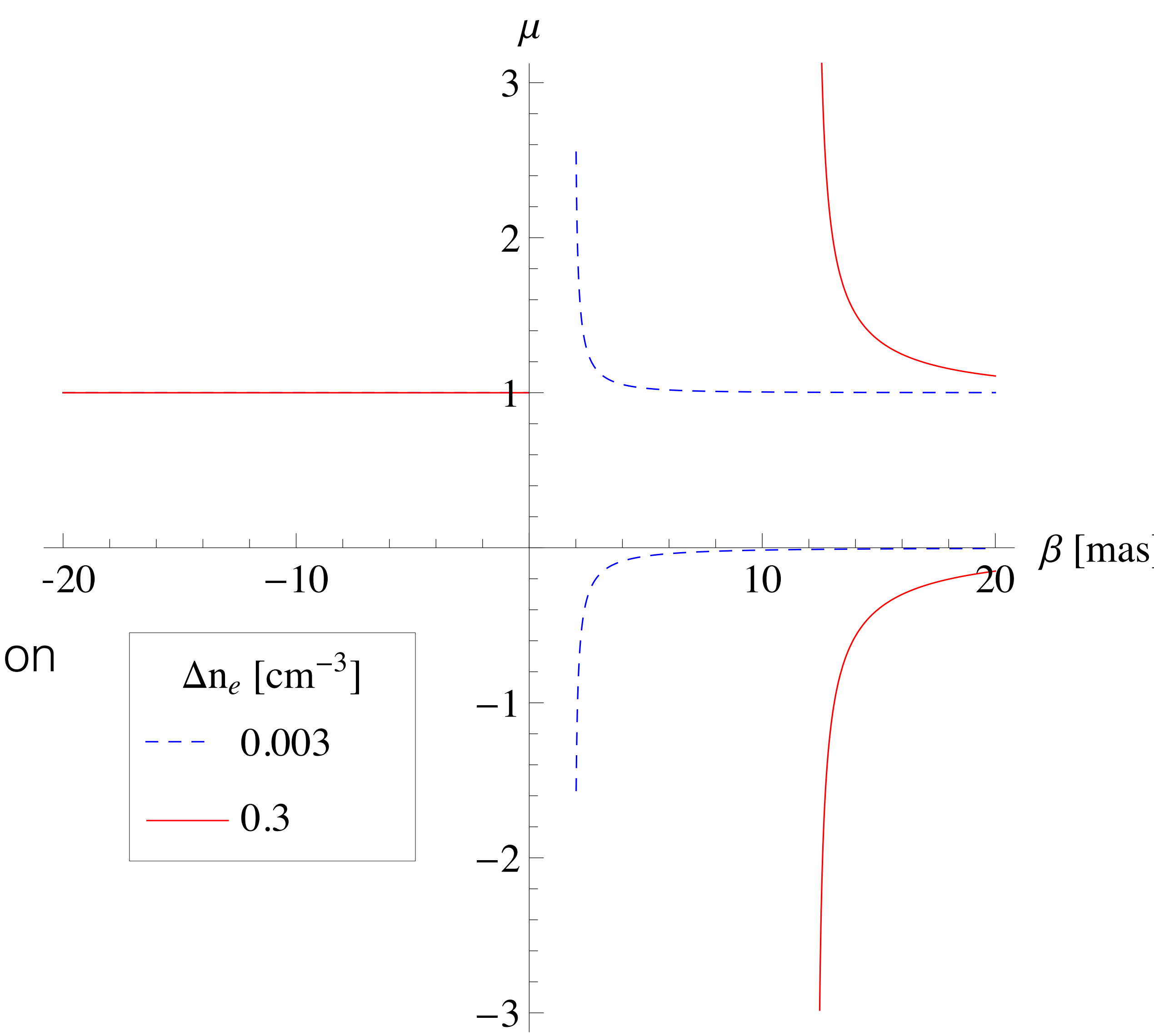


True position

Magnification



For large separations:

$$\left|\frac{\mu}{\mu_0}\right| \simeq \frac{2}{3}\left|\frac{\Delta\theta_{\mathrm{ref}}}{\Delta\theta}\right|^{5/3}$$

$$\Delta\theta_{\mathrm{ref}} = \left(\frac{\sqrt{2}}{2} s\ \Delta n\ \theta_T \sqrt{\theta_R}\right)^{2/5}$$

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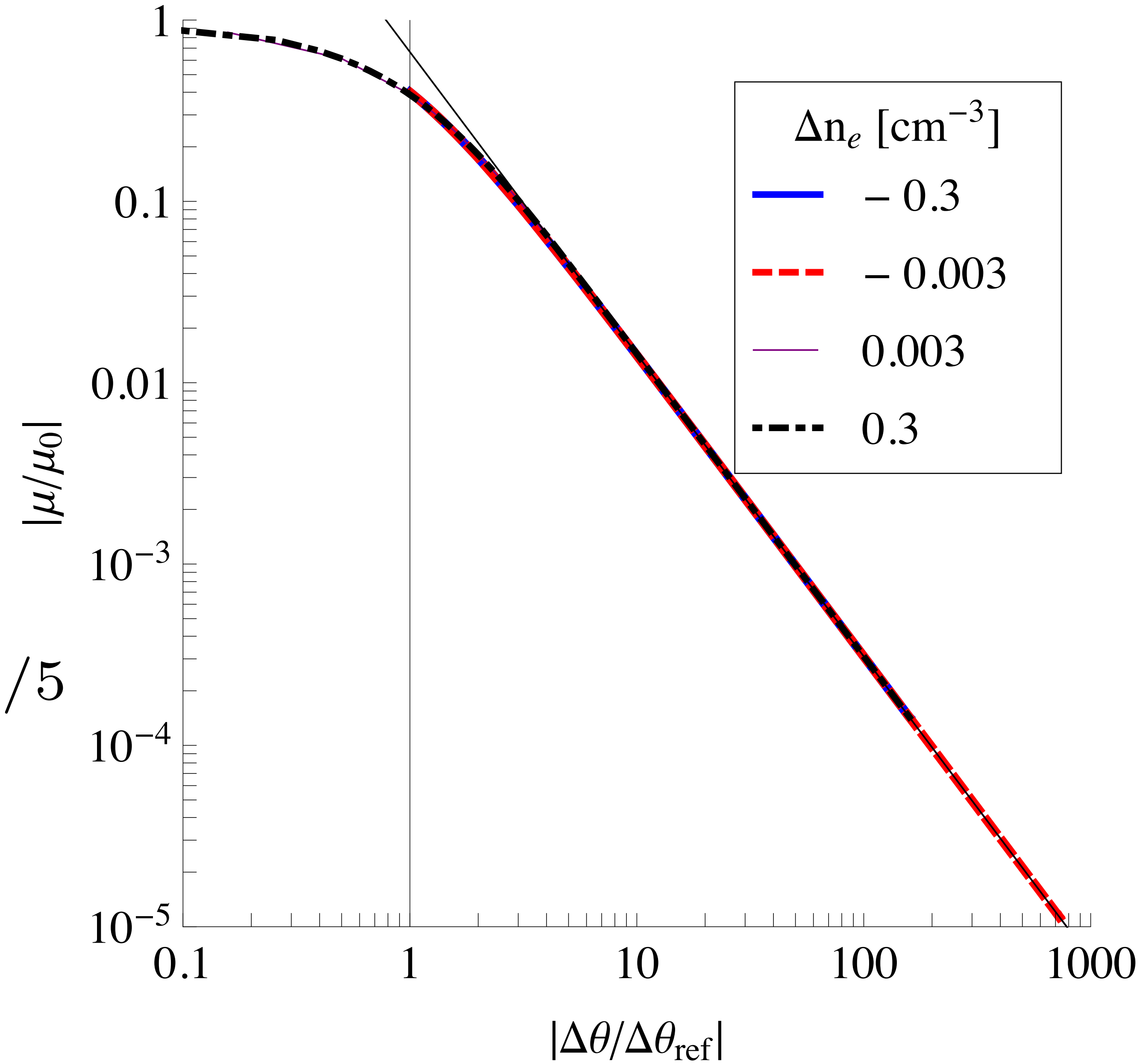

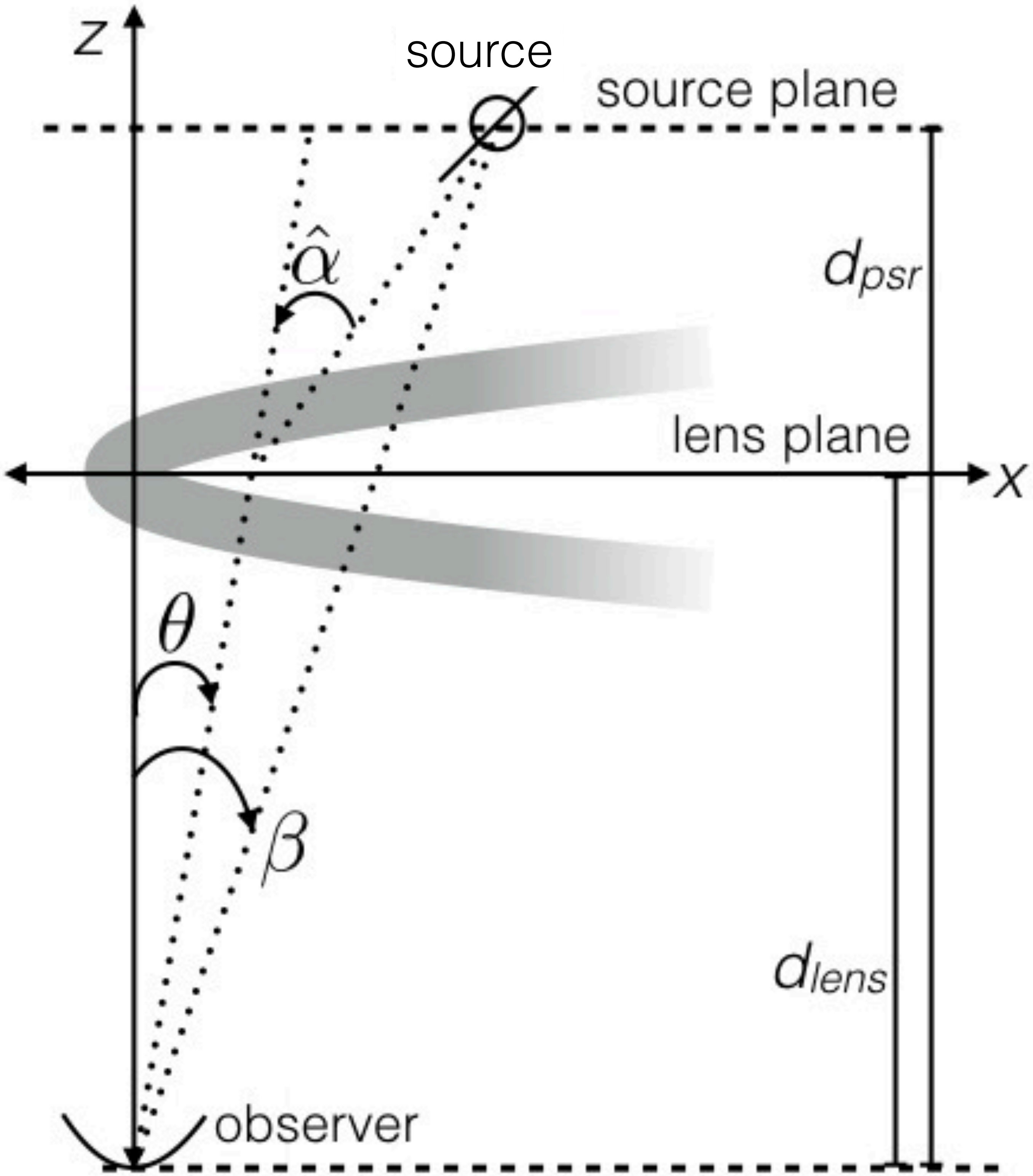

$$\theta = \beta + s\ \hat{\alpha}$$

$$\mu = \frac{\mathrm{d}\theta}{\mathrm{d}\beta}$$

$$\hat{\alpha} \simeq \frac{\sqrt{2}}{2} \frac{\Delta n\ \theta_T\ \sqrt{\theta_R}}{\theta^{3/2}}$$

Calculate $\Delta\theta(\lambda)$

and fit a power law of the form

$\Delta\theta \propto \lambda^{\gamma}$

	γ
Underdense sheet	0.01910(3)
Overdense sheet	-0.02239(4)

For a lensed image with magnification 0.01 and angular separation 10 mas at 314.5 MHz:

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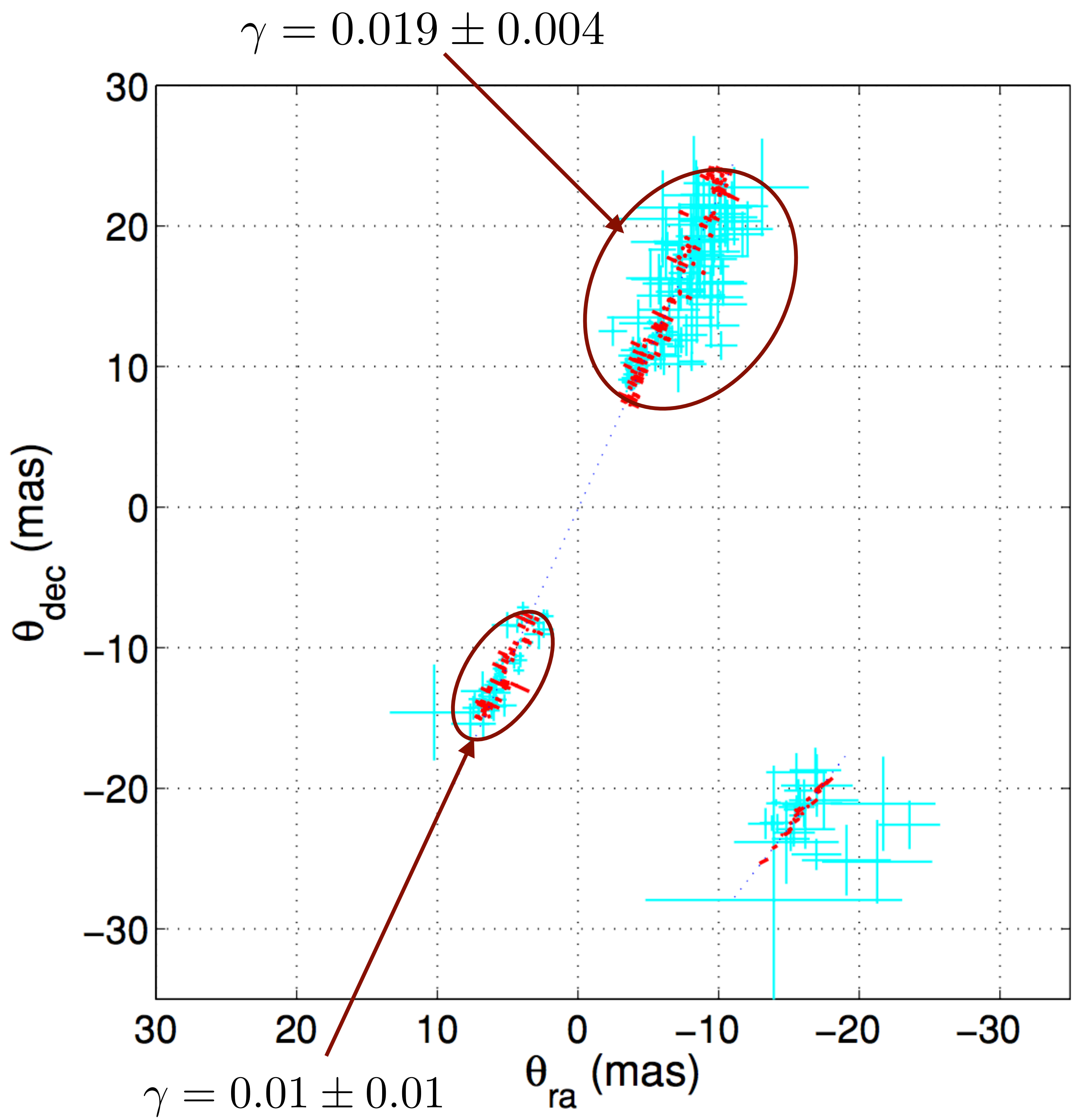
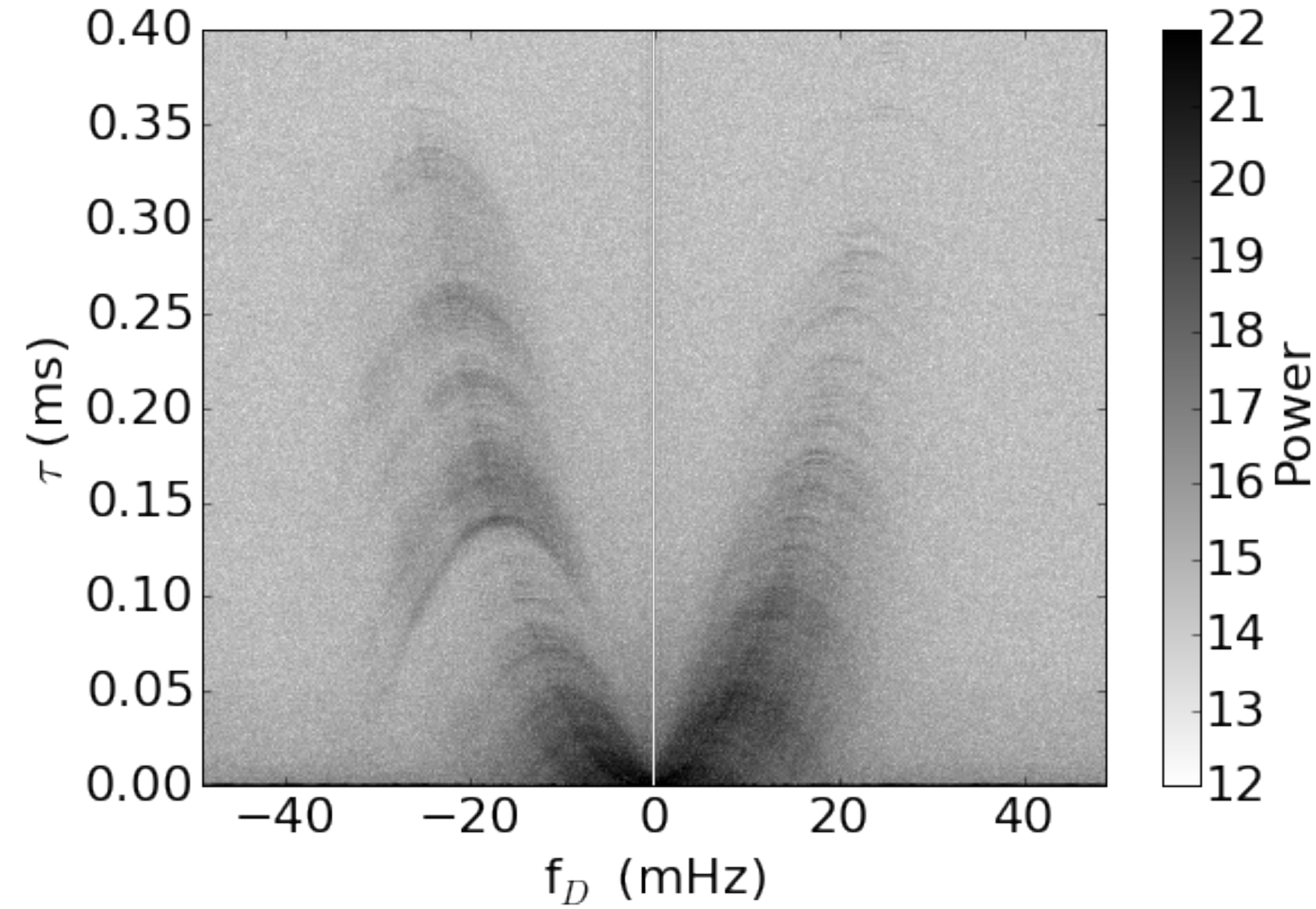


Brisken et al. 2010

Reality: many images



- In general, each fold is characterized by a different value of the parameter $\Delta n \, \theta_T \sqrt{\theta_R}$

- Simulations of this phenomenon can predict statistical behaviour

Summary

- Using pulsars, we can improve our understanding of the Galactic ISM, and create predictive models of Galactic scintillation
- Scattering screens themselves can be used as interferometers to study sources with nano-arcsecond precision

What do we need to learn more?

- *Low-frequency global VLBI and wide-band, multi-epoch observations*
  - of pulsars to study the scattering screens and better understand Galactic scintillation
  - of FRBs to better understand the local scattering environment

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