Galactic Pulsar Scintillation: evidence for glints from grazing-incidence sheets

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Galactic Pulsar Scintillation: evidence for glints from grazing-incidence sheets

and how that might relate to FRBs …

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References & Collaborators

Observation

- Stinebring et al. 2001, ApJ, 549, L97
- Hill et al. 2003, ApJ, 599, 457
- Hill et al. 2005, ApJ, 619, L17
- Brisken et al. 2010, ApJ, 708, 232

…

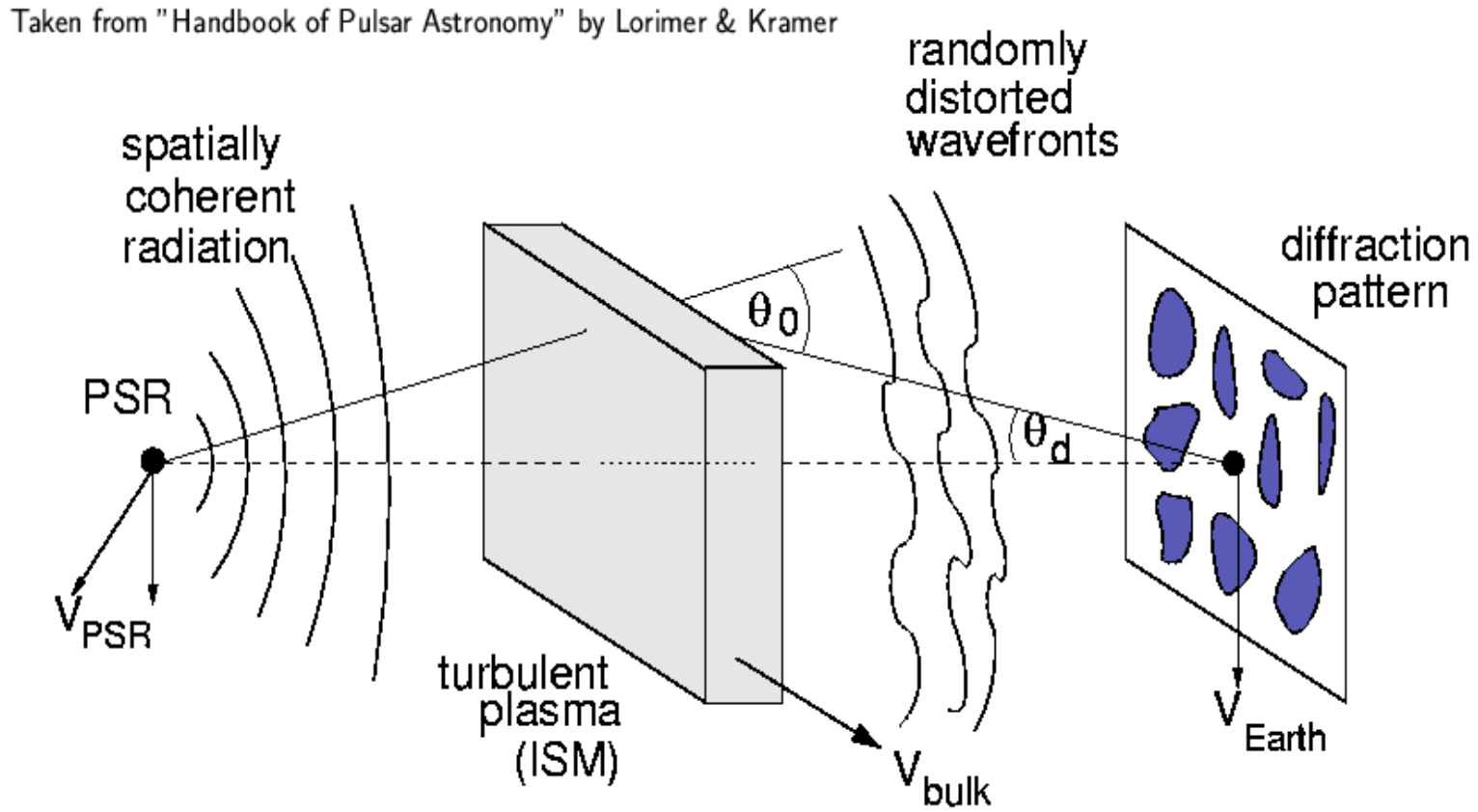
Theory

- Walker et al. 2004, MNRAS, 354, 43
- Walker & Stinebring 2005, MNRAS, 362, 1279
- Cordes et al. 2006, ApJ, 637, 346
- Pen and Levin 2014, MNRAS, 442, 3338

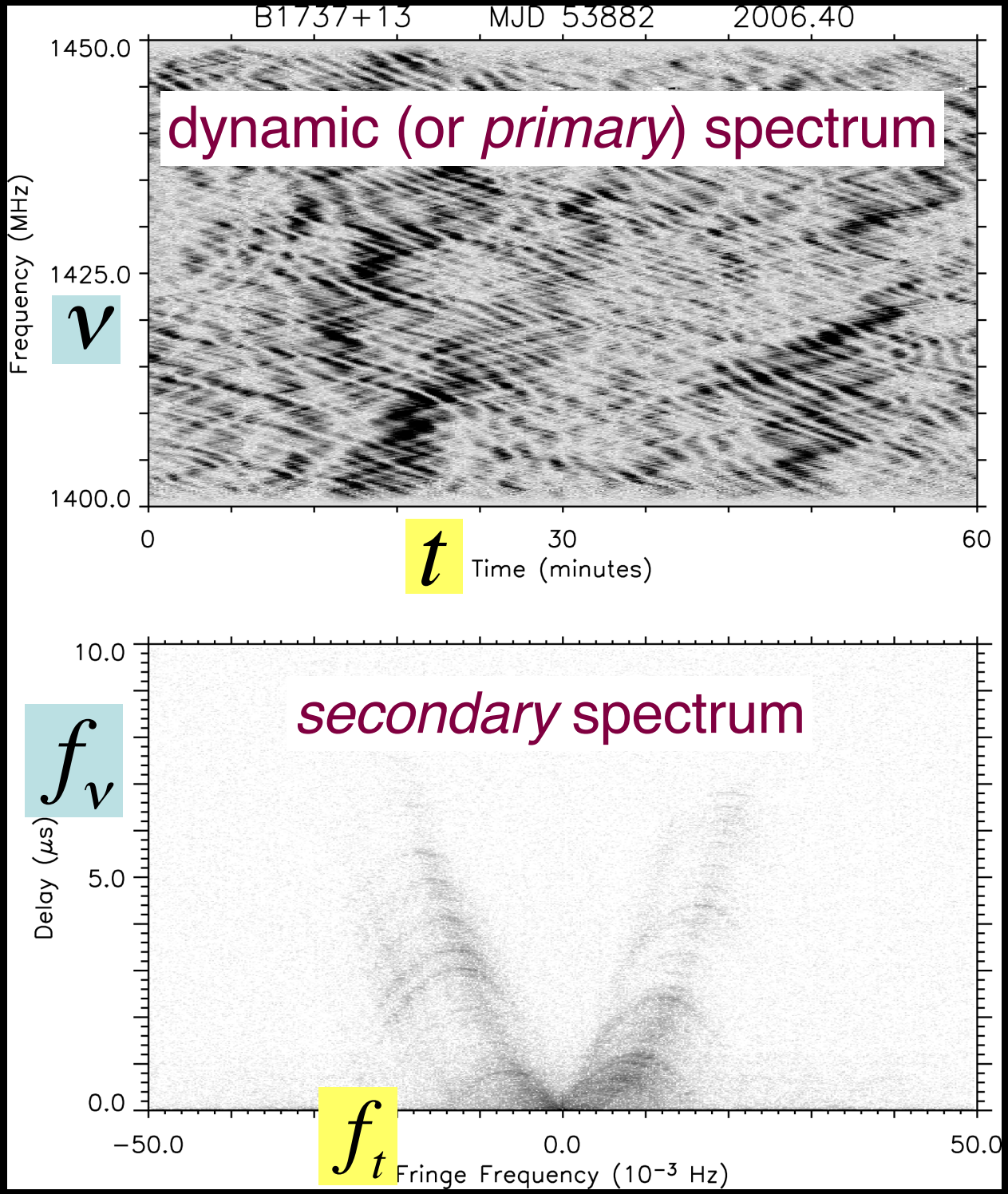
Jim Cordes
Barney Rickett
Bill Coles
Maura McLaughlin
Mark Walker
Oberlin students
Stella Ocker

Ue-Li Pen
Yuri Levin

…

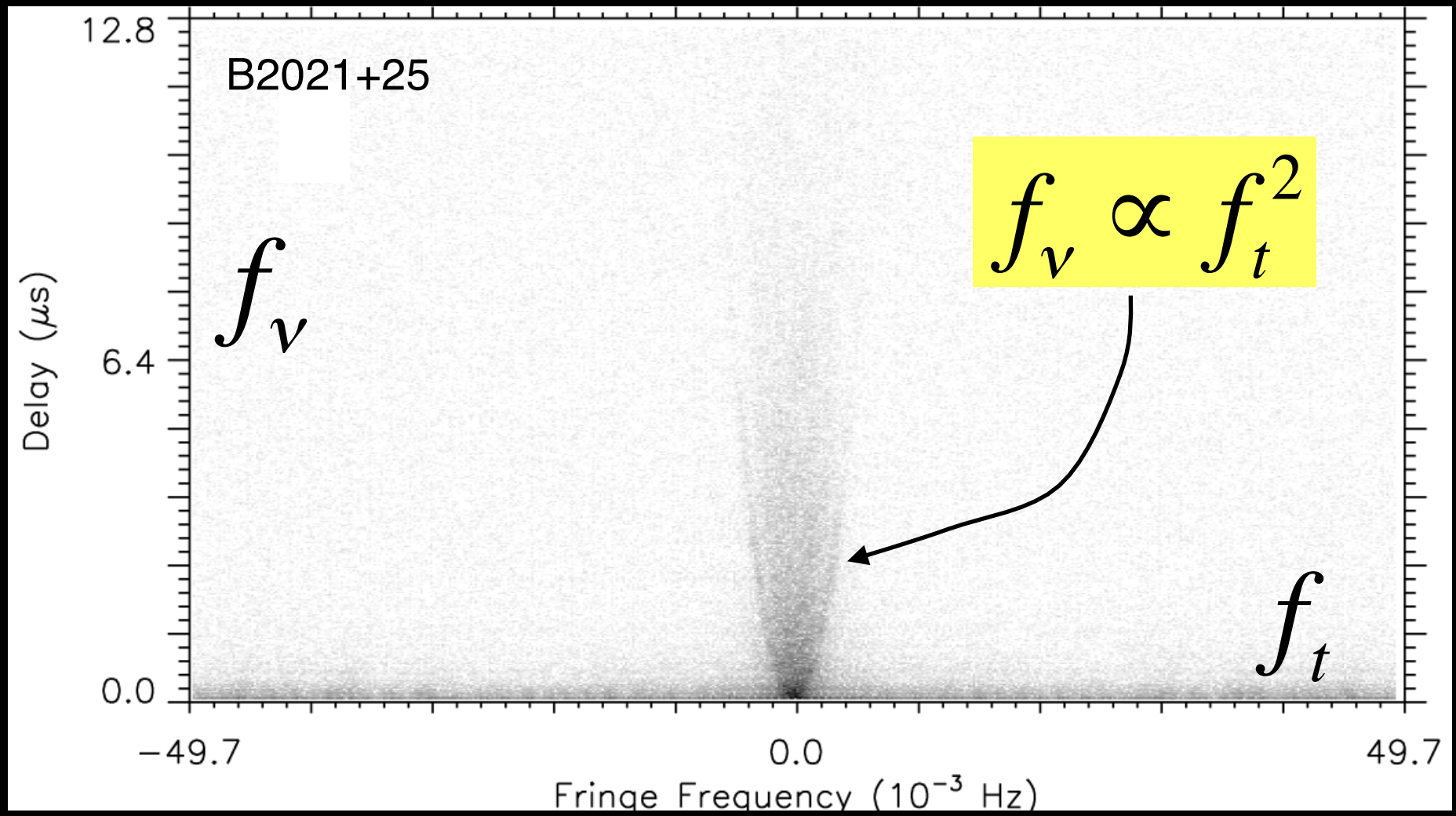


Lorimer&Kramer (LK) Fig. 4.2 Sketch showing inhomogeneities in the ISM that result in observed scattering and scintillation effects.



linear grayscale

logarithmic grayscale


B2021+25
$f_\nu \propto f_t^2$
f_ν
f_t
12.8
6.4
0.0
Delay (μs)
−49.7
0.0
49.7
Fringe Frequency (10^{-3} Hz)

Where do the parabolas come from?

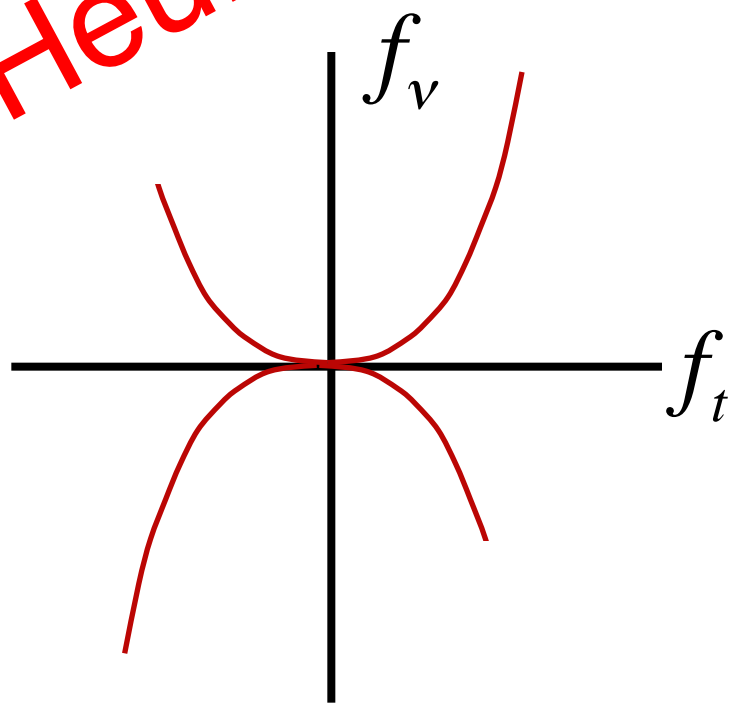
$$f_t = \frac{V_x \theta_x}{\lambda}$$

$$f_\nu = \frac{\pi D \theta^2}{c}$$

(pulsar motion is in the x-direction)

Heuristic

$$f_\nu = \pm \left(\frac{\pi D \lambda^2}{c V^2} \right) f_t^2$$

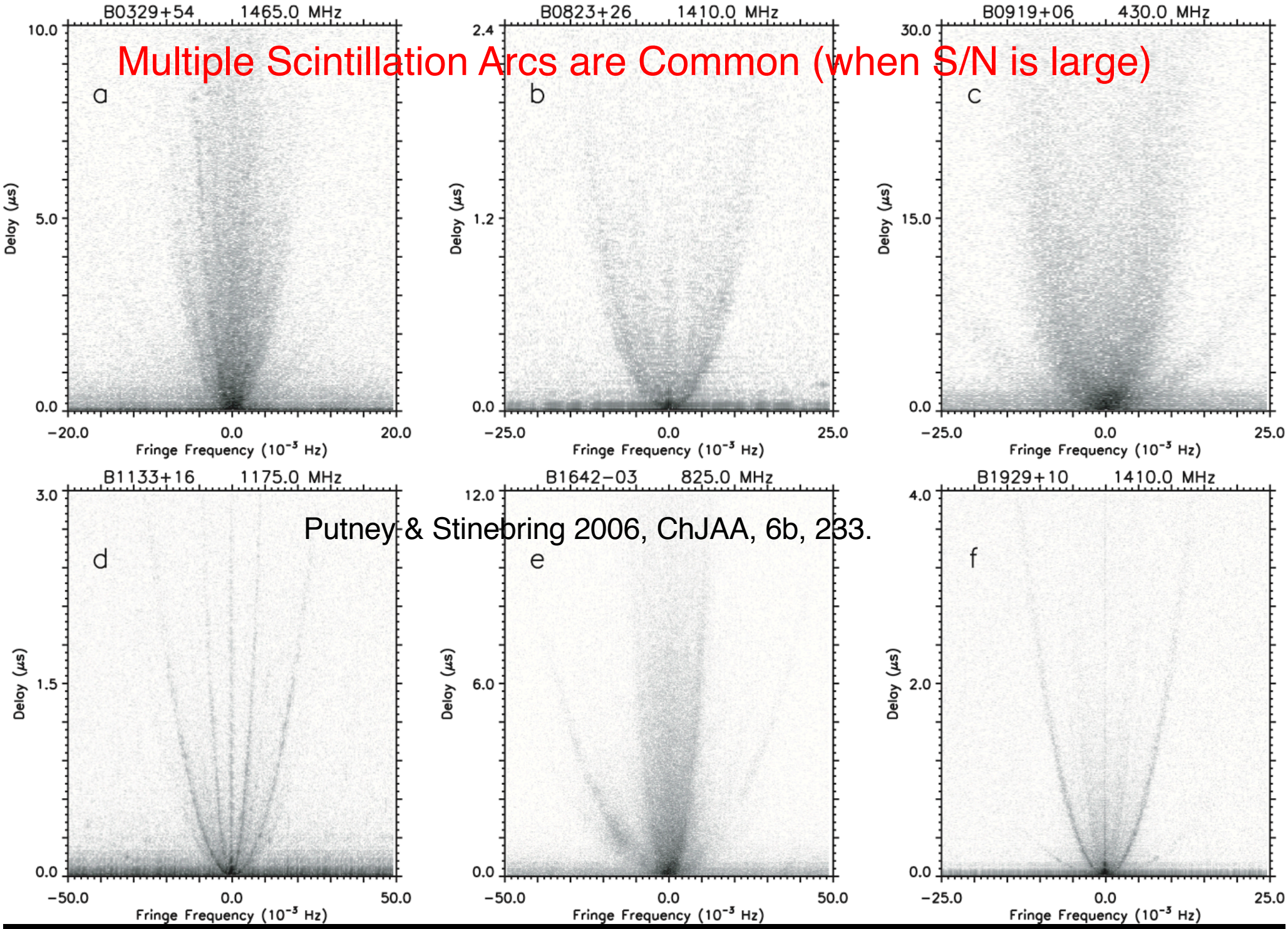


Sharply defined scintillation arcs are common in relatively nearby pulsars (DM < 50 pc cm^{-3})

(a linear feature on the sky – at a fixed location along the LOS – will

give rise to a sharply defined scintillation arc)

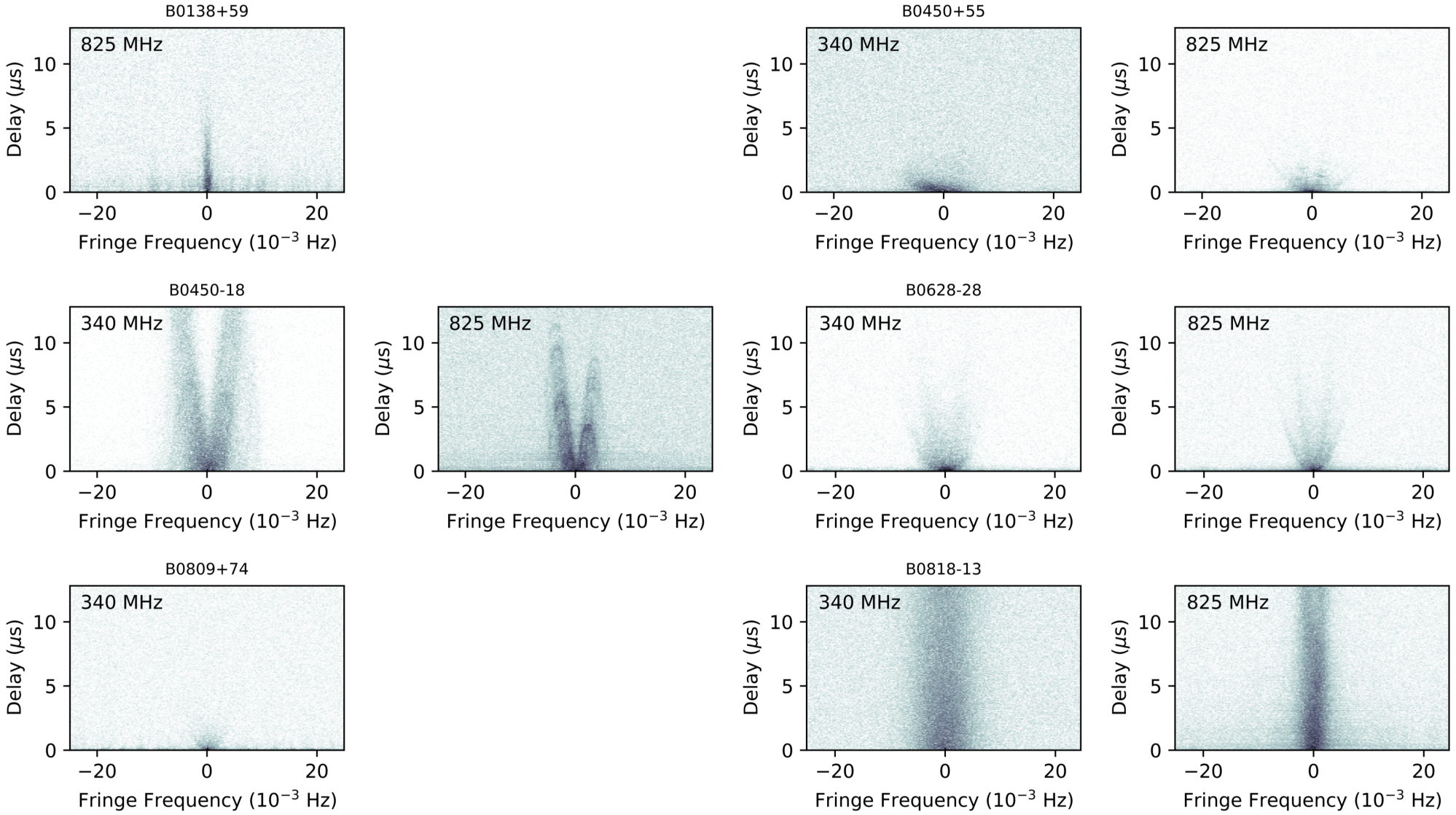
Multiple Scintillation Arcs are Common (when S/N is large)

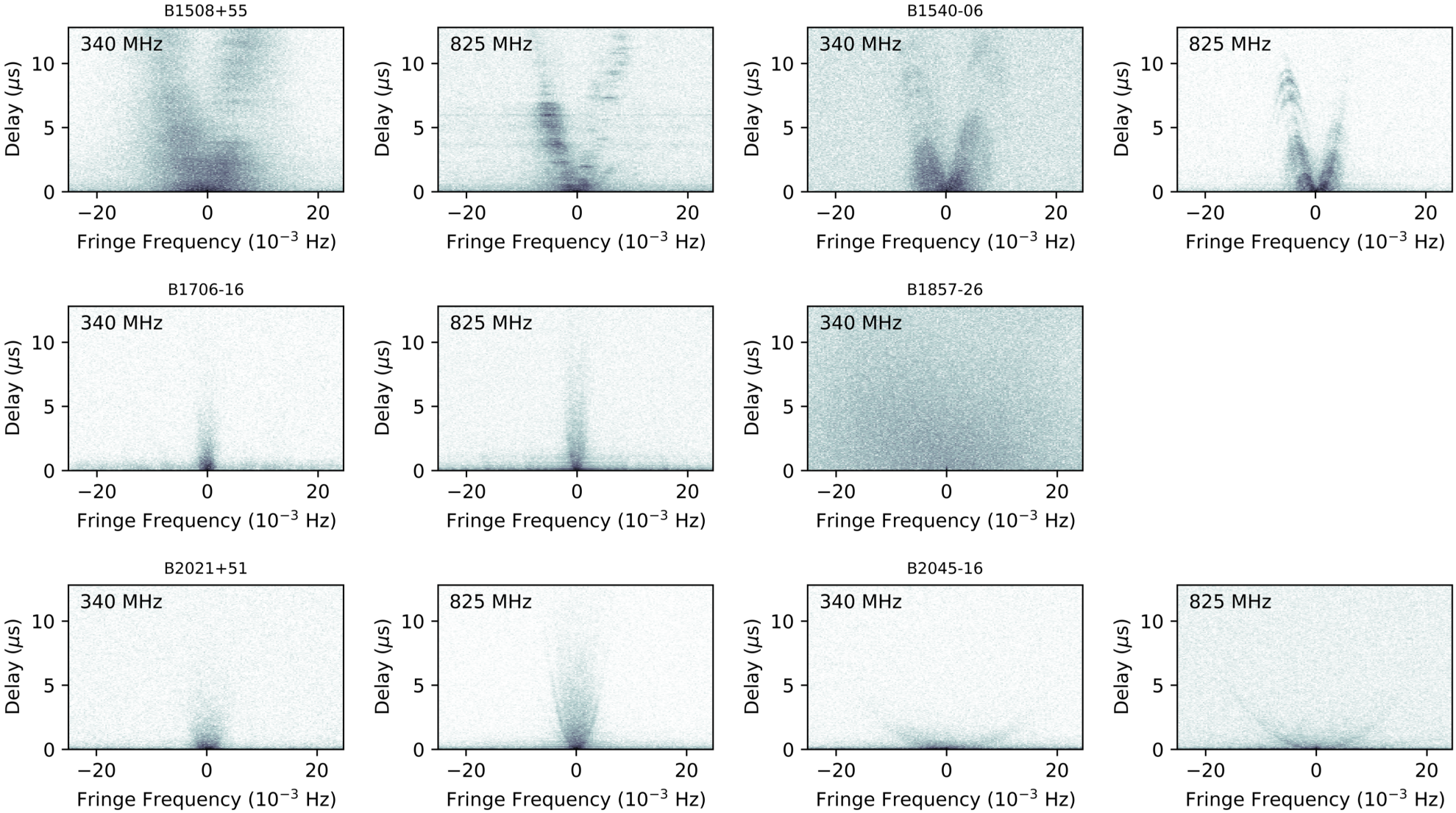


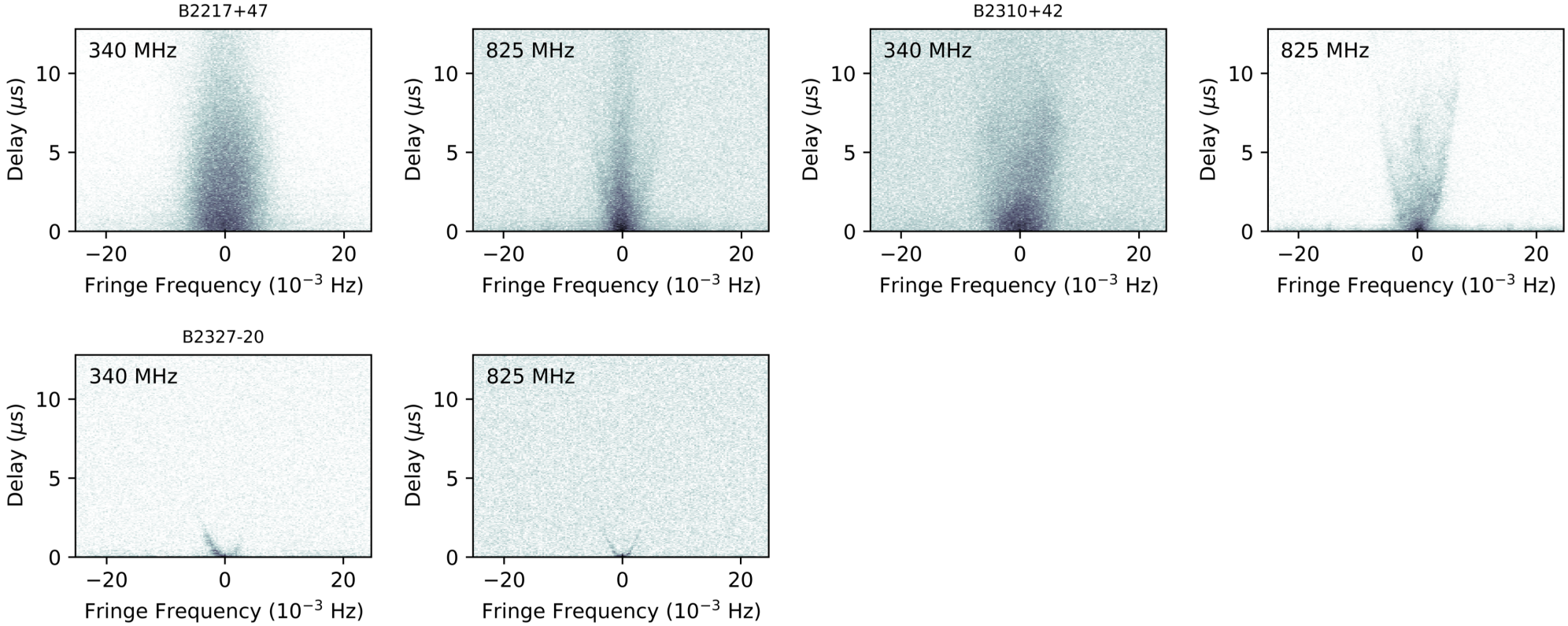
Putney & Stinebring 2006, ChJAA, 6b, 233.

Green Bank Telescope Scintarc Survey
Stinebring et al. 2017 (in prep)

- 18 pulsars selected with DM < 50 pc cm^{-3} and $S_{400} > 25$ mJy
- 340 MHz and 825 MHz observations
- 15 pulsars with adequate S/N ratio
- 13 of 15 have a detectable scintillation arc
- many of these are sharply defined and/or multiple, particularly at the higher frequency


B0138+59
825 MHz
B0450+55
340 MHz
825 MHz
B0450-18
340 MHz
825 MHz
B0628-28
340 MHz
825 MHz
B0809+74
340 MHz
B0818-13
340 MHz
825 MHz
Delay (μs)
Fringe Frequency (10^−3 Hz)
0
5
10
−20
0
20


B1508+55
340 MHz
825 MHz
B1540-06
340 MHz
825 MHz
B1706-16
340 MHz
825 MHz
B1857-26
340 MHz
B2021+51
340 MHz
825 MHz
B2045-16
340 MHz
825 MHz
Delay (μs)
Fringe Frequency (10^{-3} Hz)
0
5
10
−20
0
20


B2217+47
340 MHz
825 MHz
B2310+42
340 MHz
825 MHz
B2327-20
340 MHz
825 MHz
Delay (μs)
Fringe Frequency (10^{-3} Hz)
0
5
10
−20
0
20

"Screen" Locations

$$f_\nu = \eta f_t^2$$

$$\eta = \frac{\lambda^2 D\, s\,(1-s)}{2cV_{eff}^2}$$

s = 0 (at pulsar) s = 1 (at observer)

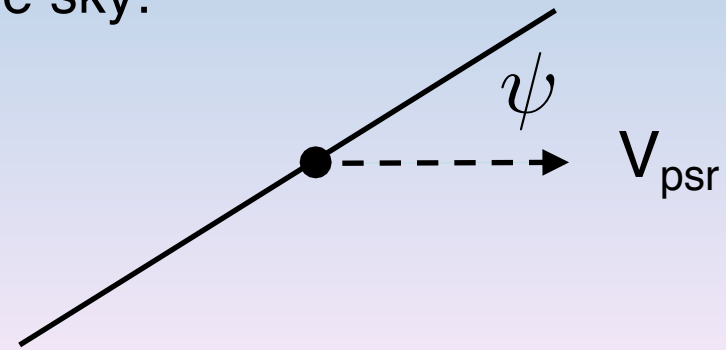
$$\mathbf{V}_{eff\perp} = (1-s)\mathbf{V}_{p\perp} + s\mathbf{V}_{obs\perp} - \mathbf{V}_{scr\perp}$$

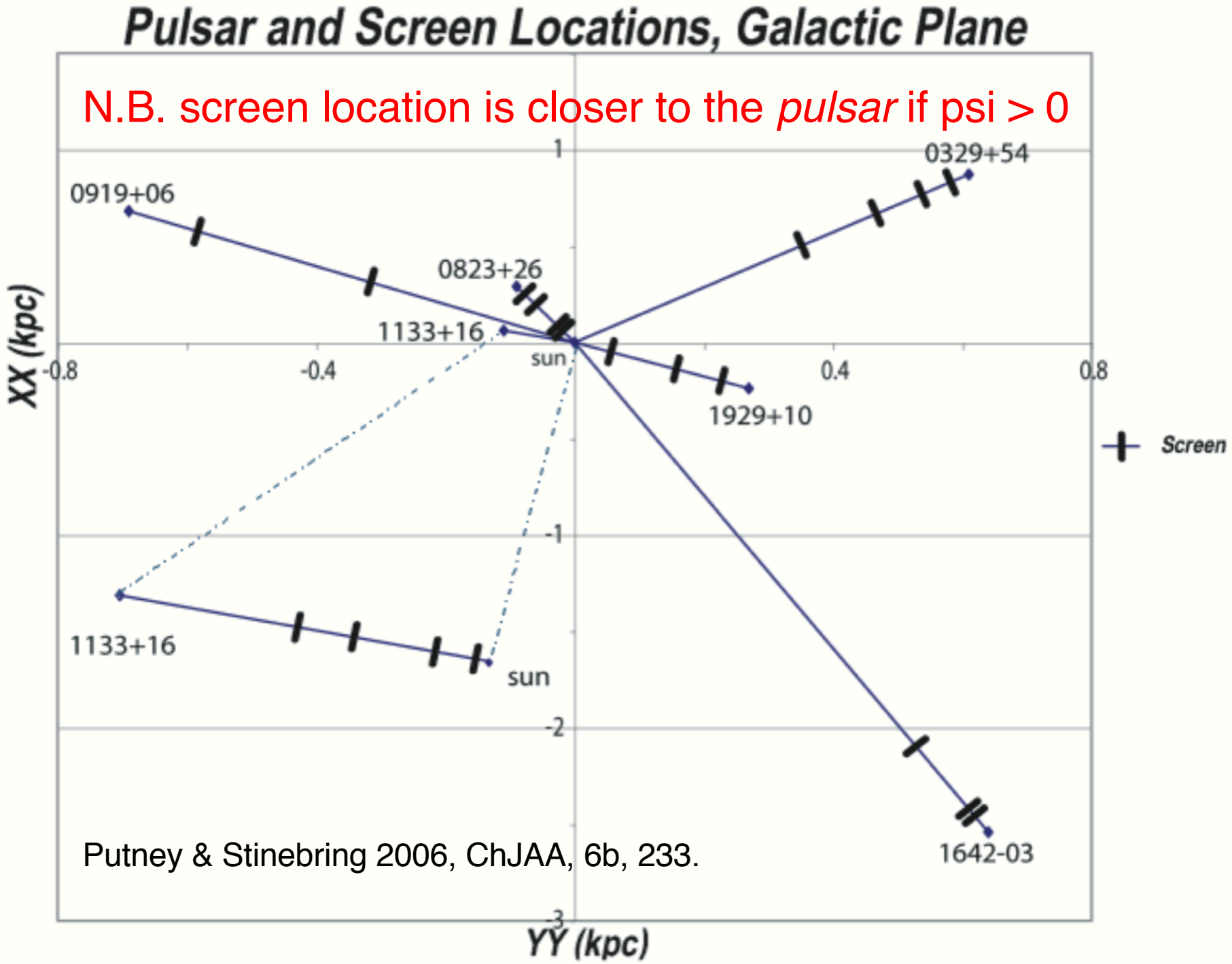
"Screen" Locations

$$f_\nu = \eta f_t^2$$

$$\eta = \frac{\lambda^2 D}{2c V_{psr}^2} \frac{s}{(1-s)} \sec^2 \psi$$

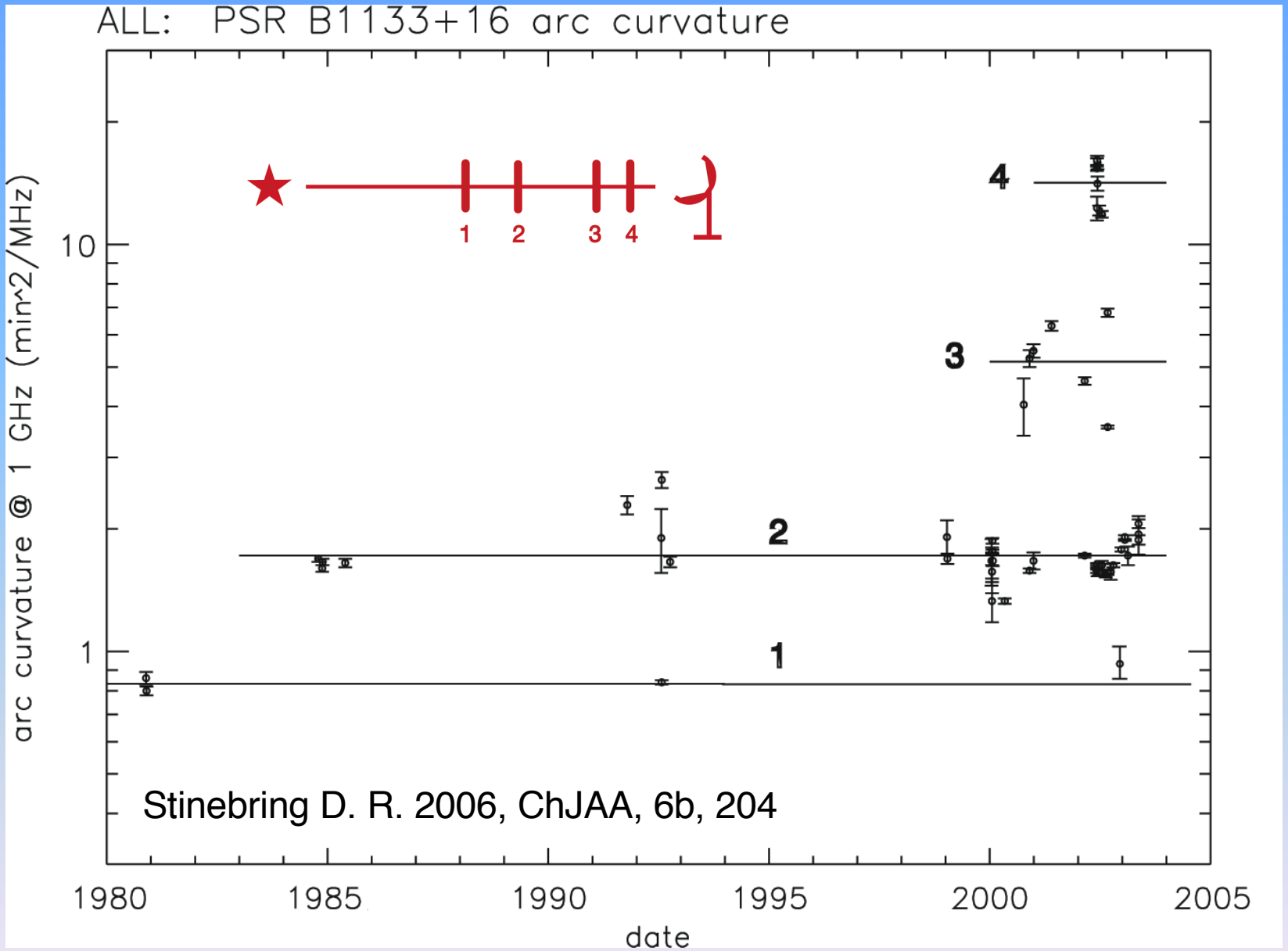
… if the pulsar velocity dominates and if the "image" can be described as a point source plus a line inclined by an angle ψ to the pulsar motion across the sky:

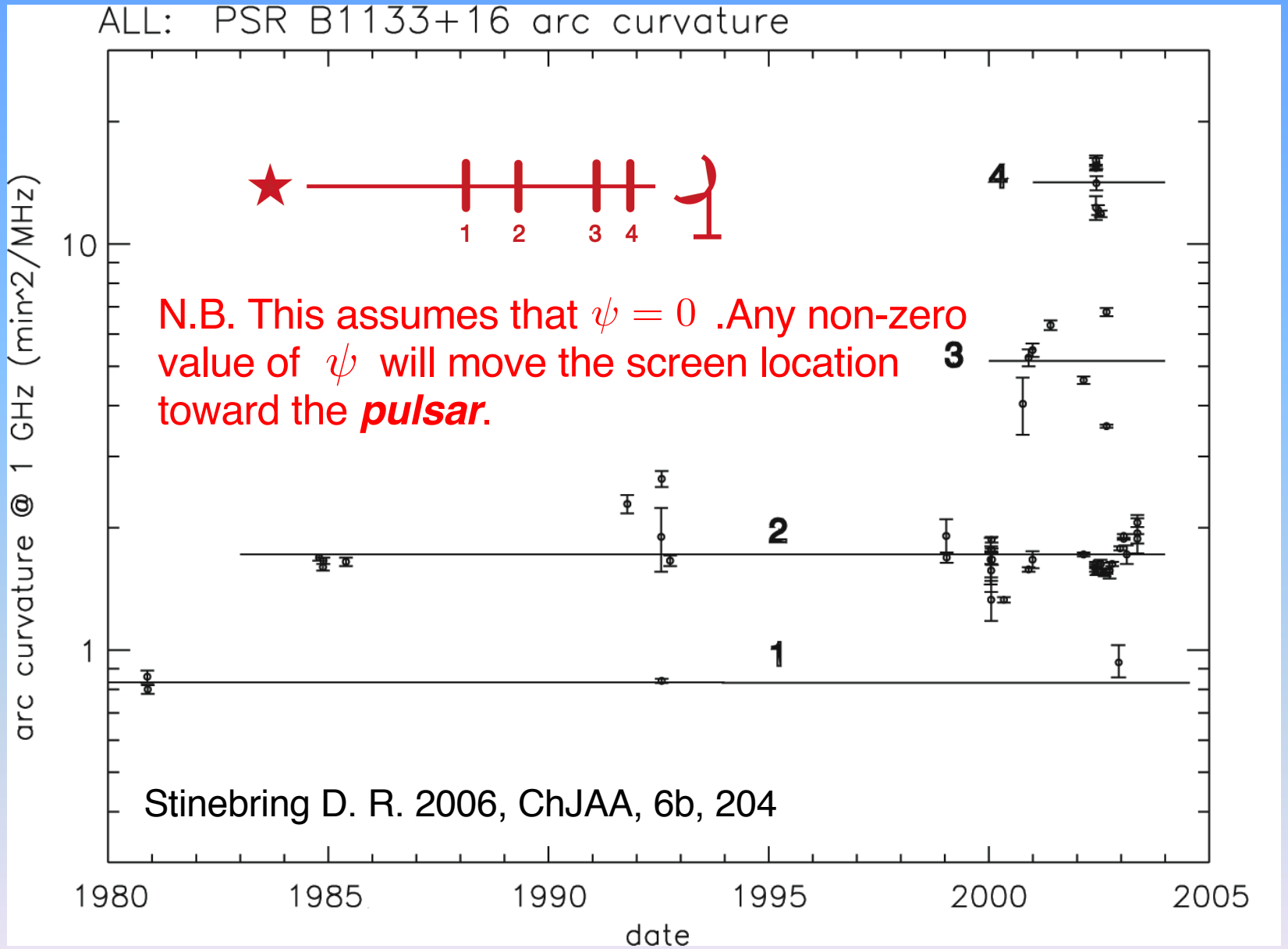



Pulsar and Screen Locations, Galactic Plane
N.B. screen location is closer to the *pulsar* if psi > 0
0919+06
0823+26
1133+16
sun
0329+54
1929+10
1133+16
sun
1642-03
Screen
XX (kpc)
YY (kpc)
1
-1
-2
-3
-0.8
-0.4
0.4
0.8
Putney & Stinebring 2006, ChJAA, 6b, 233.

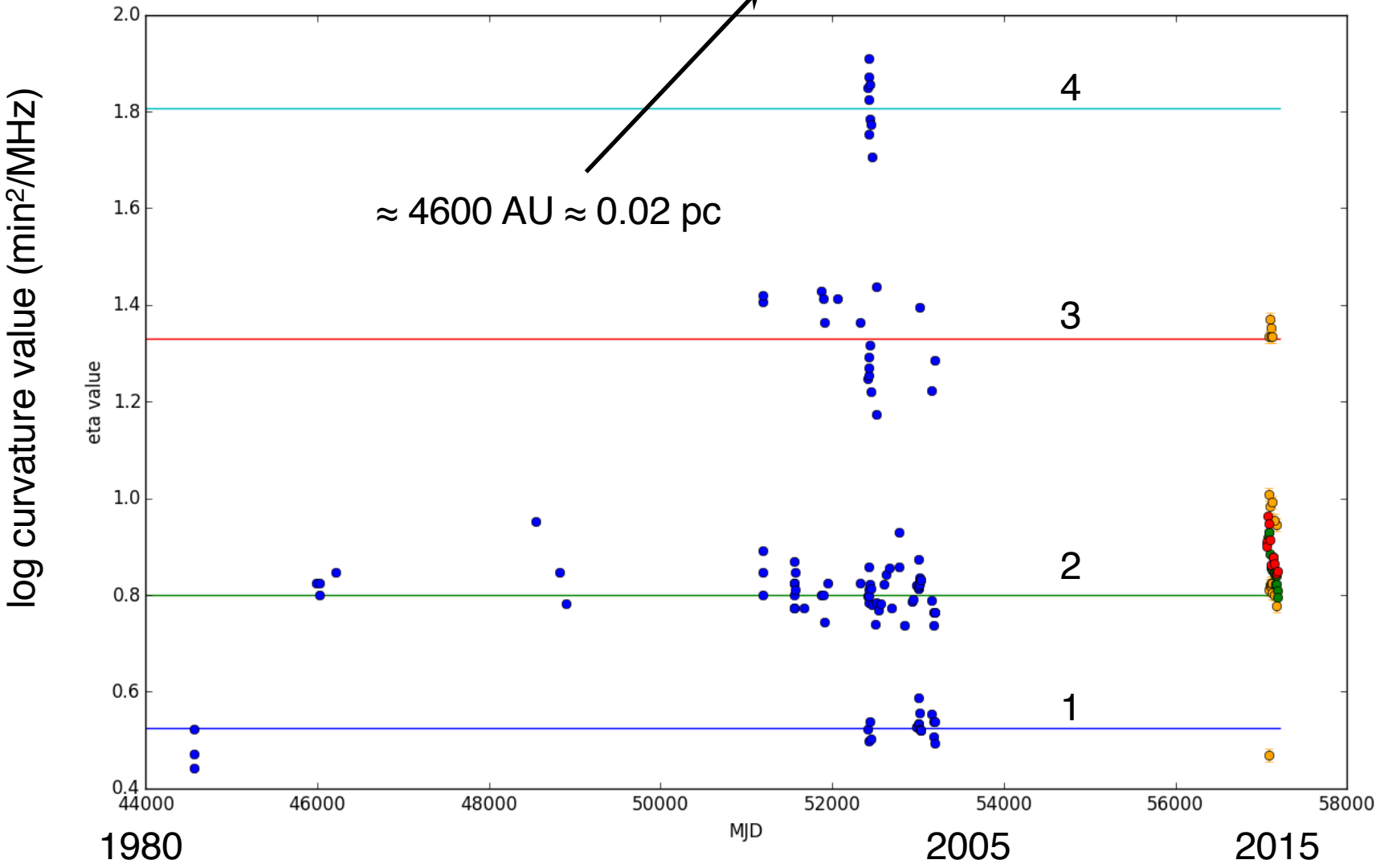
an interesting (nearby) pulsar: B1133+16

- D = 350 pc nearby
- V_{trans} = 620 km/s fast
- S400 = 260 mJy bright
- b = 69° high Galactic latitude


ALL: PSR B1133+16 arc curvature
arc curvature @ 1 GHz (min^2/MHz)
10
1
1
2
3
4
1980
1985
1990
1995
2000
2005
date
Stinebring D. R. 2006, ChJAA, 6b, 204


ALL: PSR B1133+16 arc curvature
1
2
3
4
N.B. This assumes that $\psi = 0$ .Any non-zero value of ψ will move the screen location toward the ***pulsar***.
Stinebring D. R. 2006, ChJAA, 6b, 204
arc curvature @ 1 GHz (min^2/MHz)
10
1
1980
1985
1990
1995
2000
2005
date

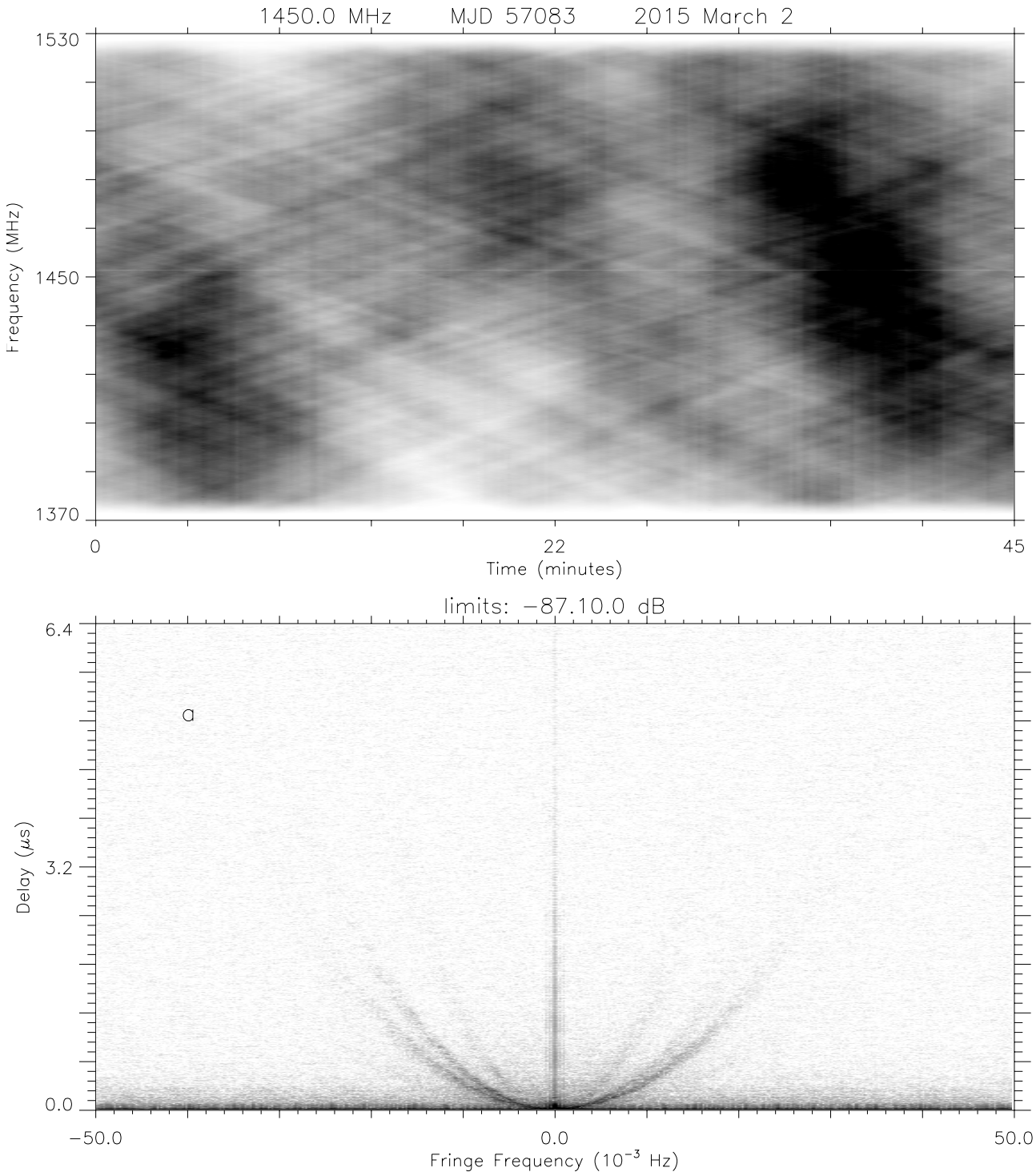
Four arcs constant in curvature over 35 years! (Stinebring et al. 2017, in prep)



1450 MHz

Arecibo observations 21 ~ weekly epochs (2015) at 327 MHz, 430 MHz, 1450 MHz

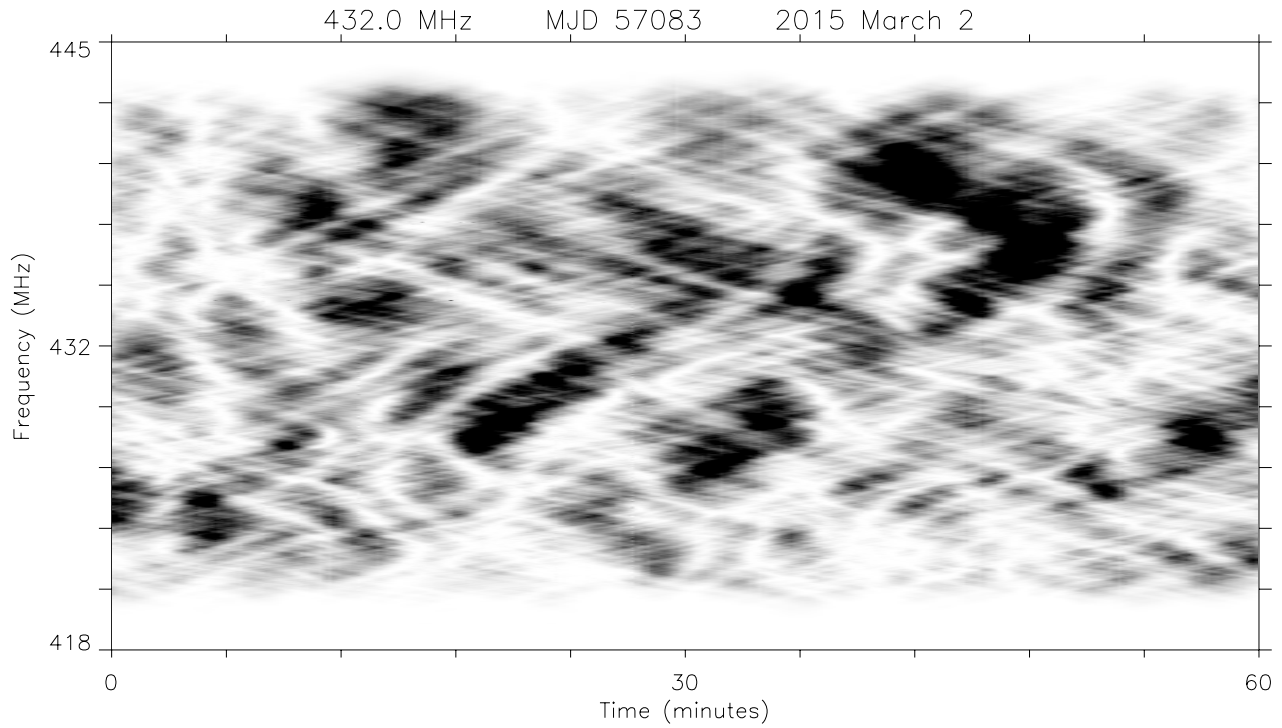
Stinebring et al. 2017, in prep

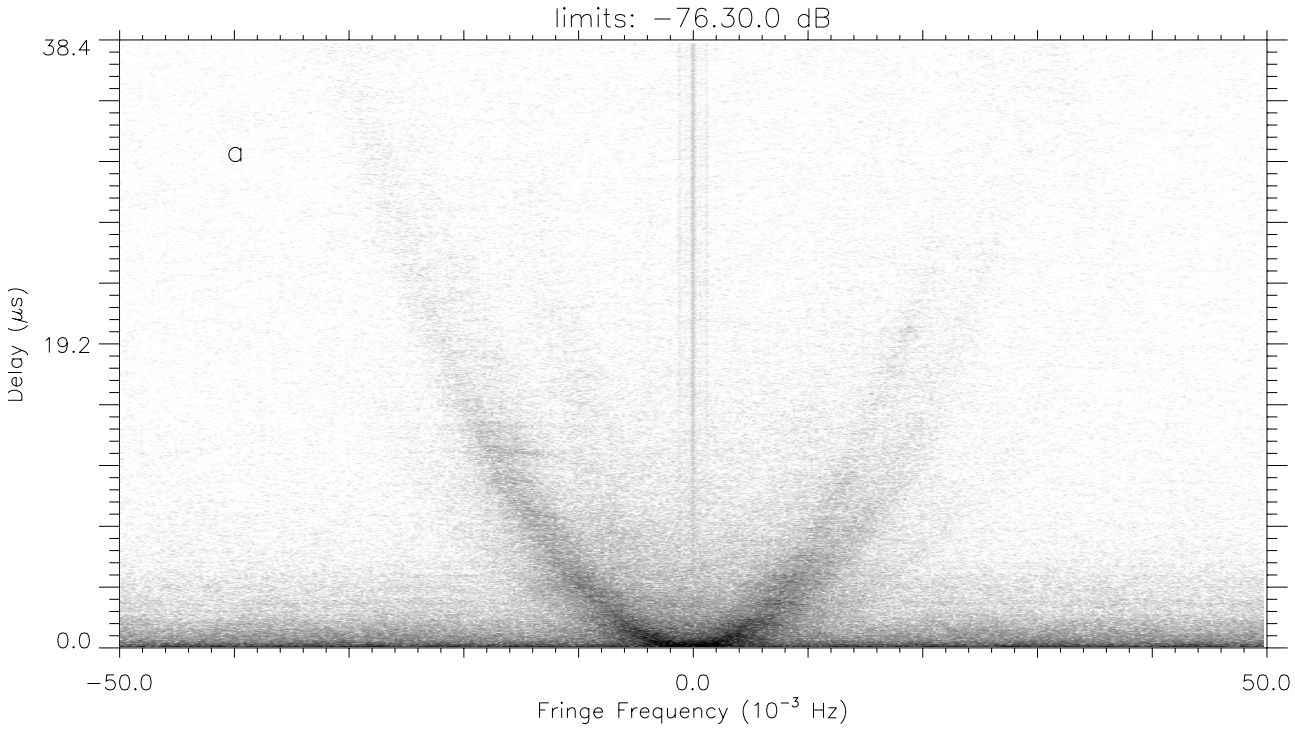


432 MHz

Arecibo observations 21 ~ weekly epochs (2015) at 327 MHz, 430 MHz, 1450 MHz

Stinebring et al. 2017, in prep

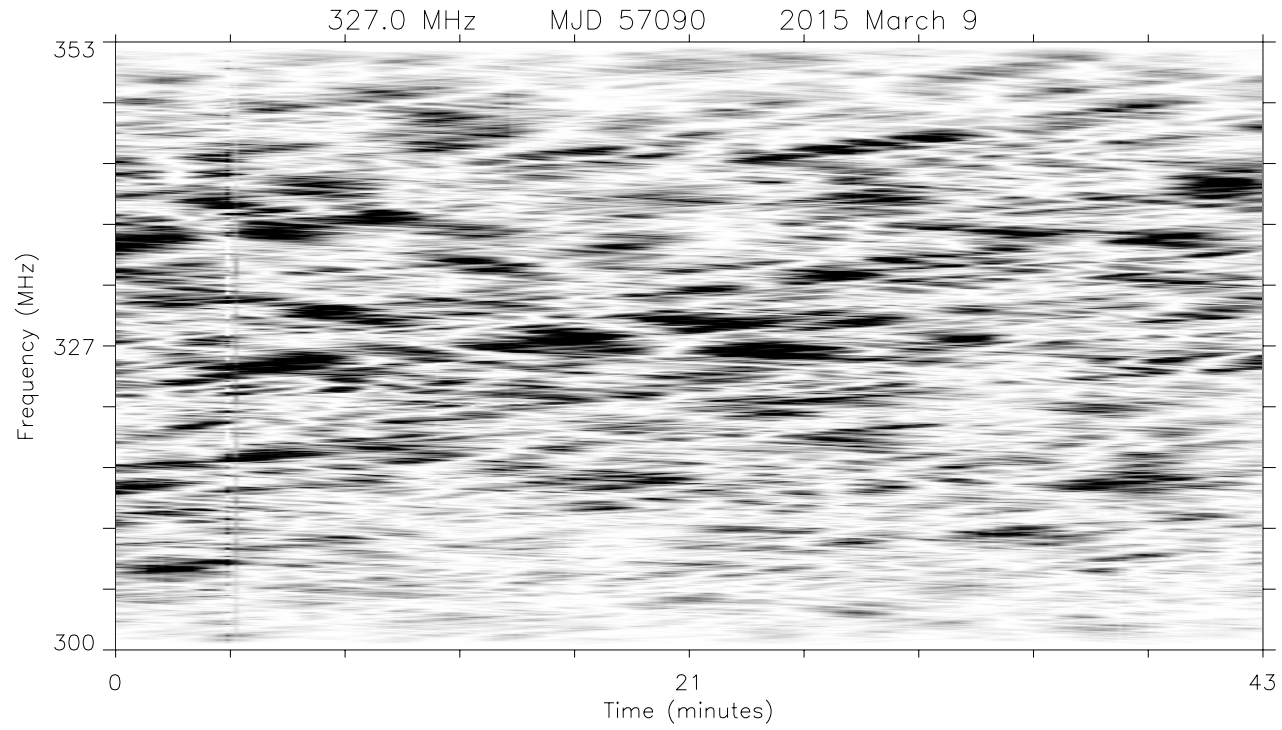


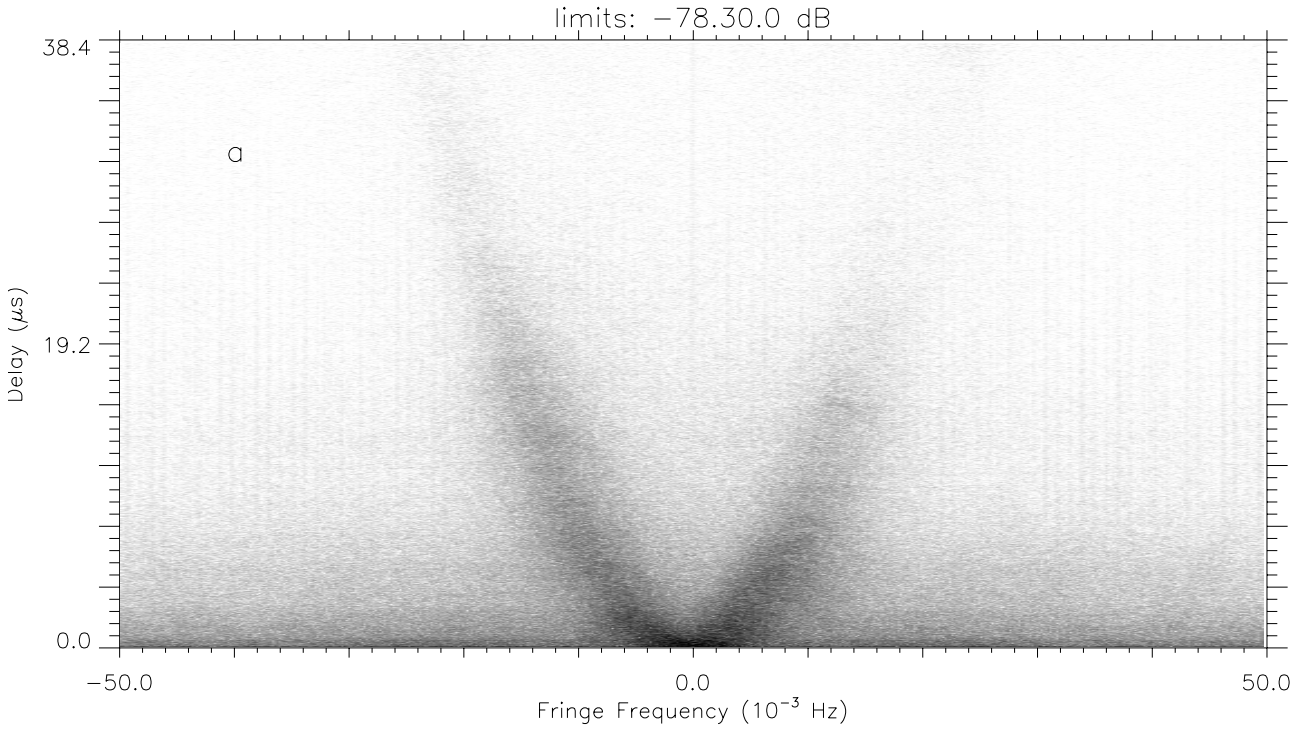


327 MHz

Arecibo observations 21 ~ weekly epochs (2015) at 327 MHz, 430 MHz, 1450 MHz

Stinebring et al. 2017, in prep

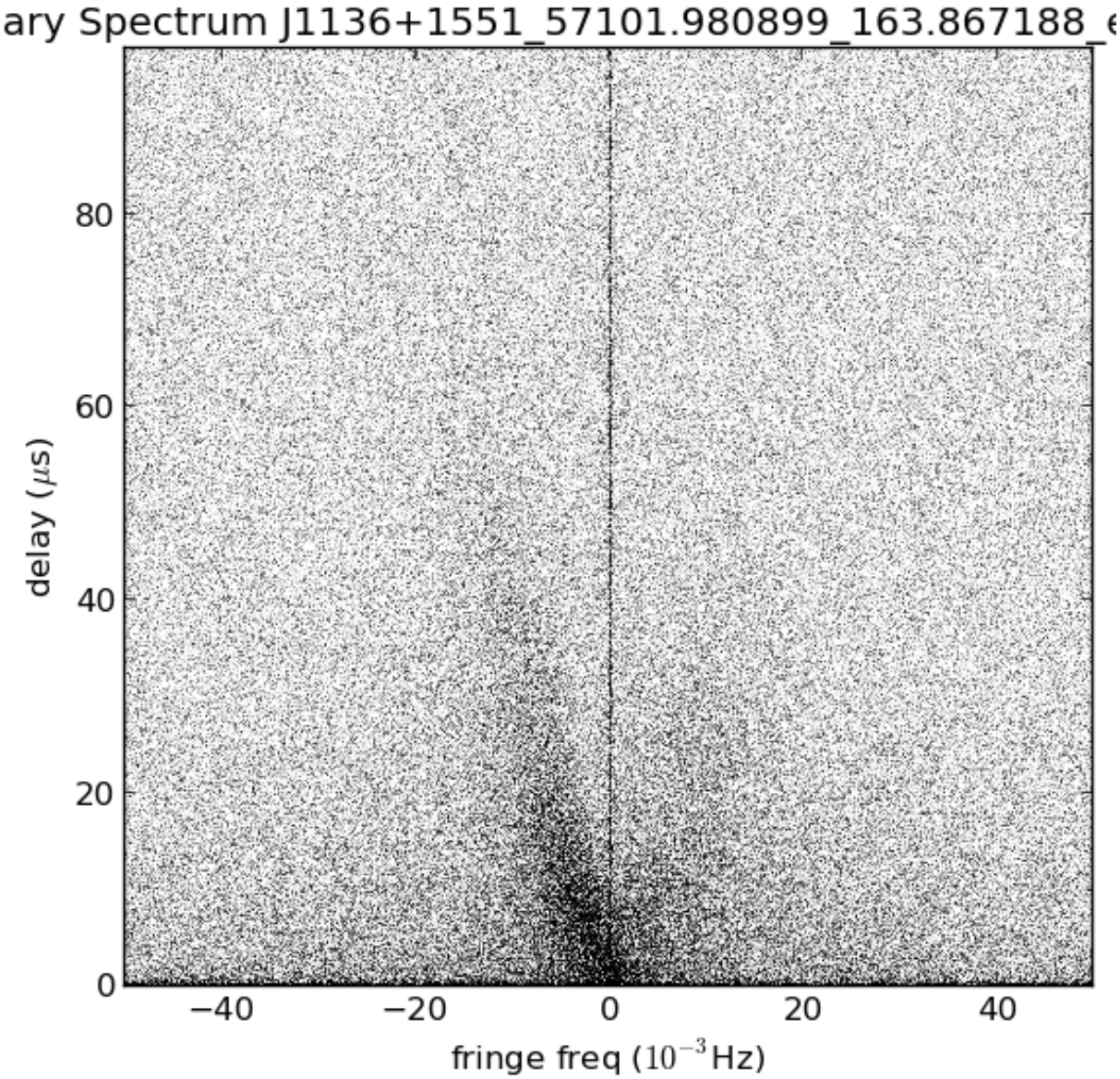




163 MHz

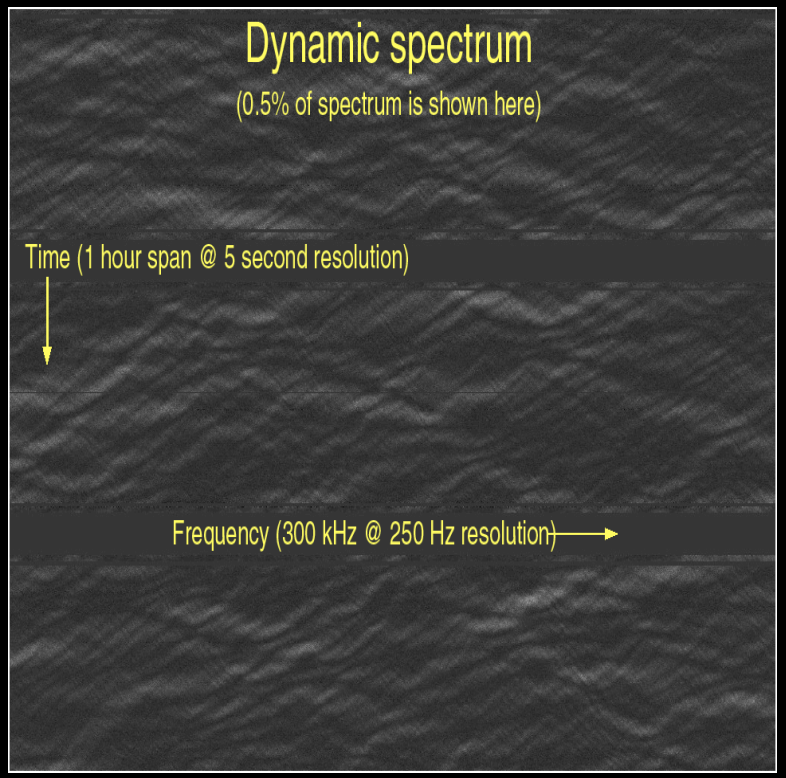
LOFAR single-station observation

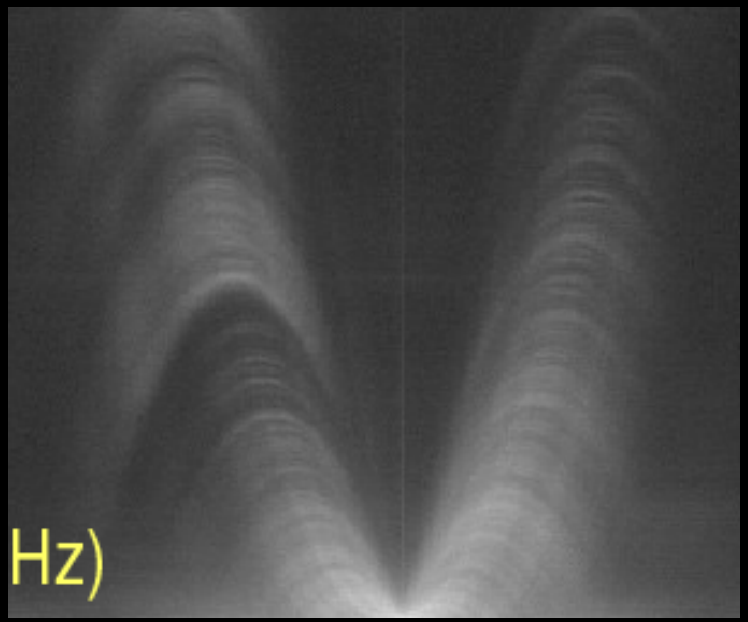
Joris Verbiest
Stefan Oslowski
& Oberlin students



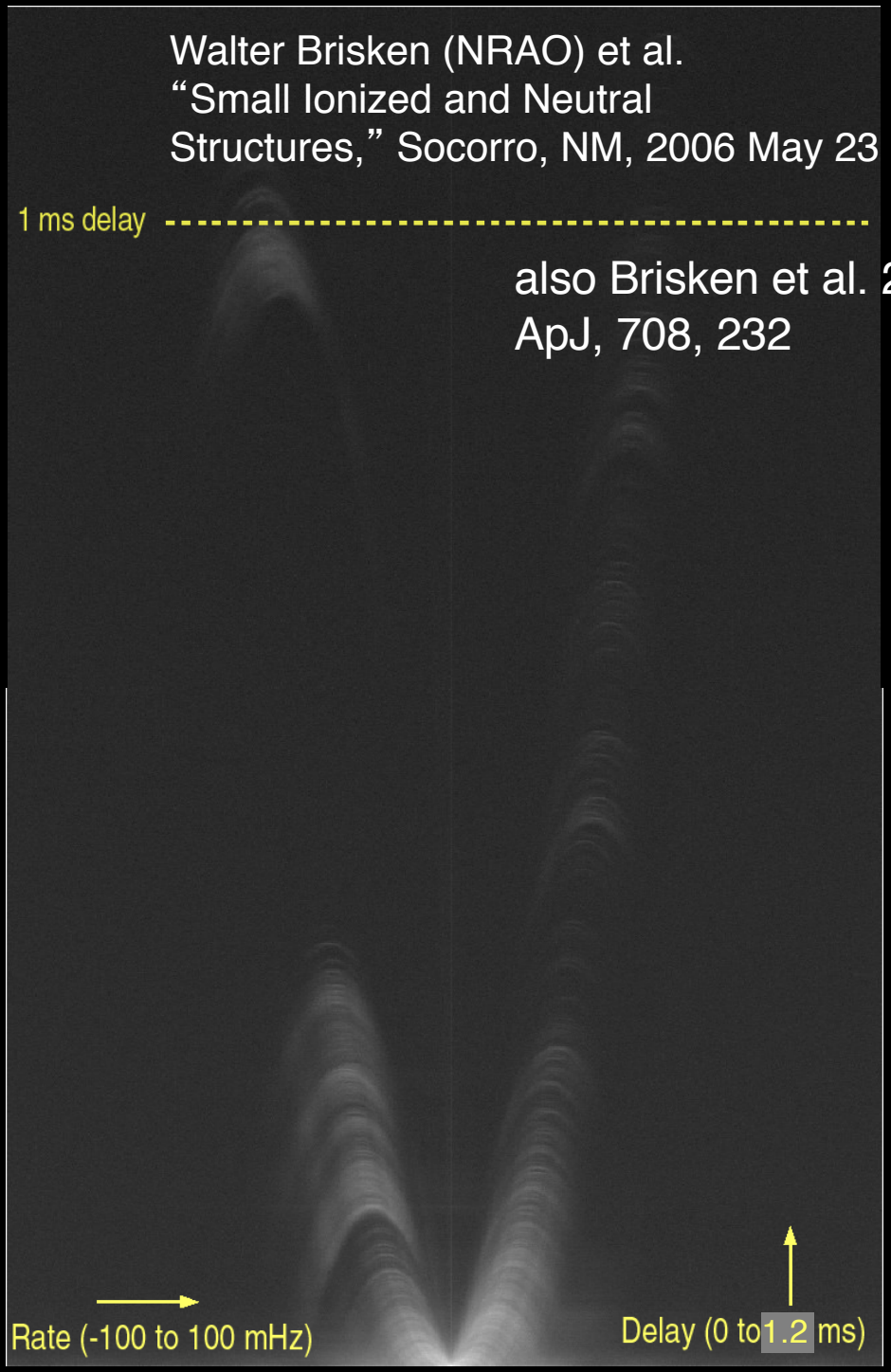
another interesting (nearby) pulsar: B0834+06

- D = 190 pc nearby
- V_{trans} = 46 km/s slow
- S400 = 90 mJy fairly bright
- b = 26° modest Galactic latitude

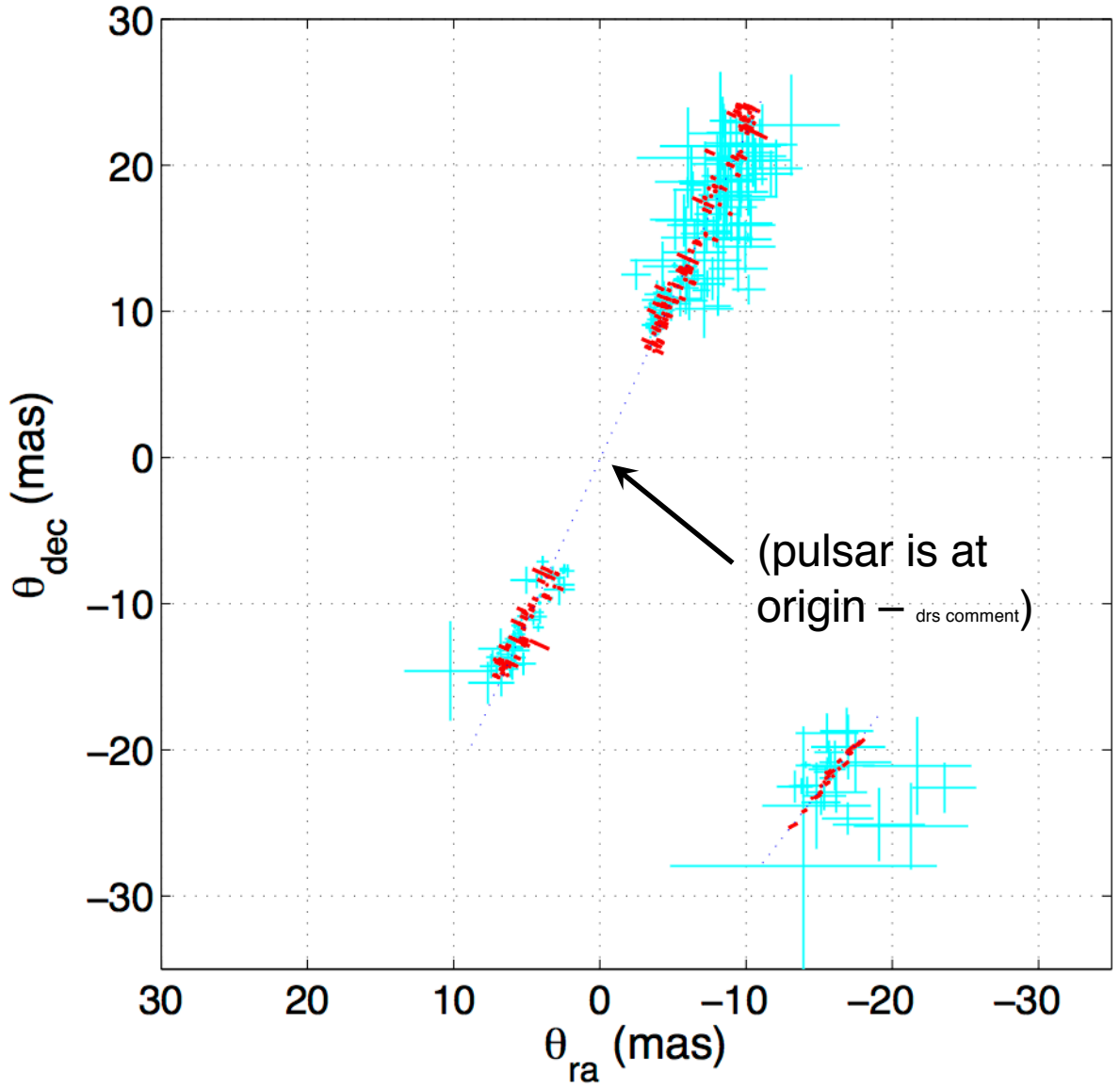




Walter Brisken (NRAO) et al.
"Small Ionized and Neutral Structures," Socorro, NM, 2006 May 23



also Brisken et al. 2010
ApJ, 708, 232



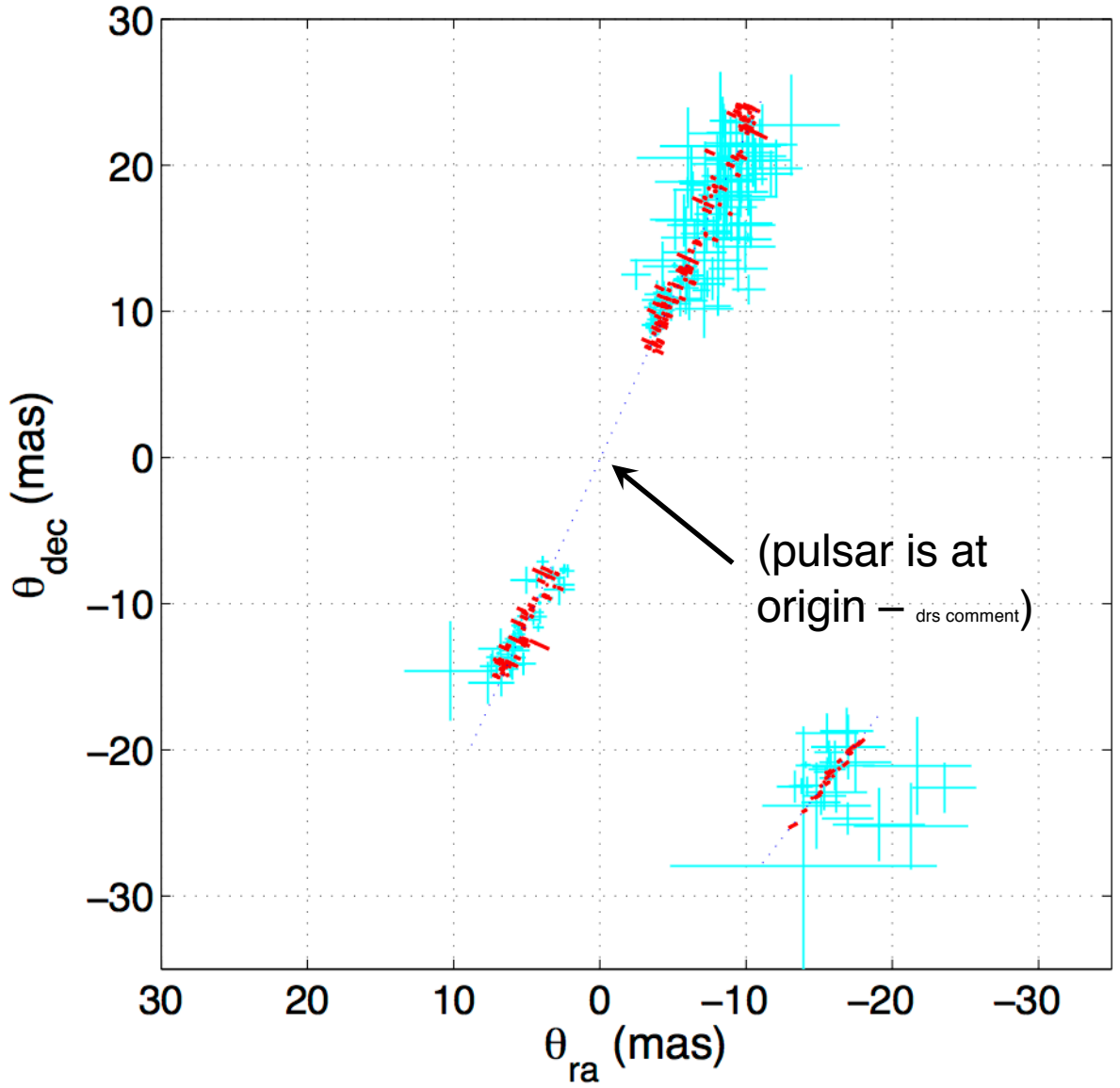
100 μas RESOLUTION VLBI IMAGING OF ANISOTROPIC INTERSTELLAR SCATTERING TOWARD PULSAR B0834+06

Brisken et al. 2010, ApJ, 708, 232

What produces the highly linear features in the scattered image?

- Pen and Levin 2014, MNRAS, 442, 3338 (and references therein)

from Ue-Li Pen ”Galt talk”



100 μas RESOLUTION VLBI IMAGING OF ANISOTROPIC INTERSTELLAR SCATTERING TOWARD PULSAR B0834+06

Brisken et al. 2010, ApJ, 708, 232

Hulburt, E.O. 1934, JOSA, 34, 24

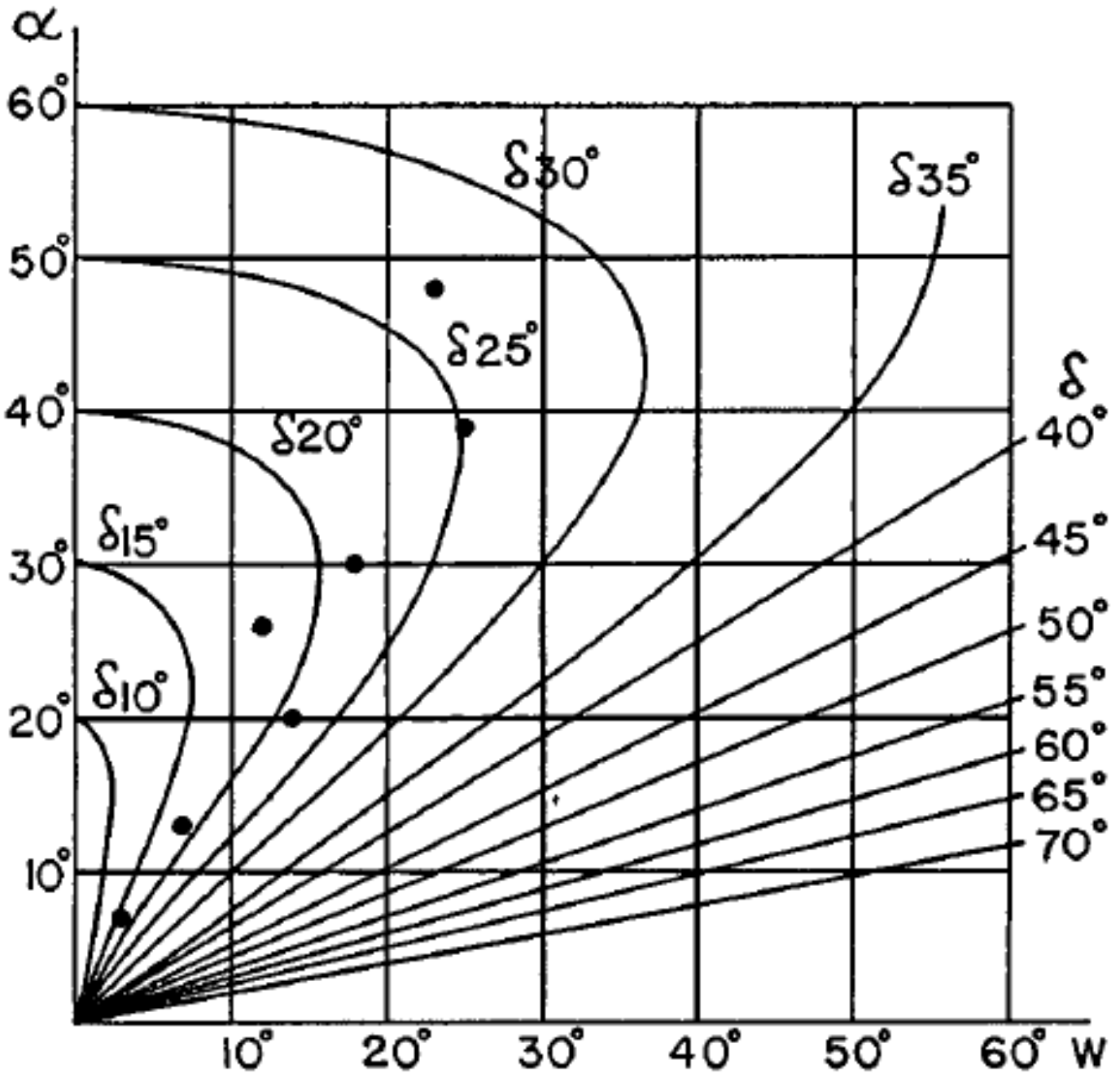
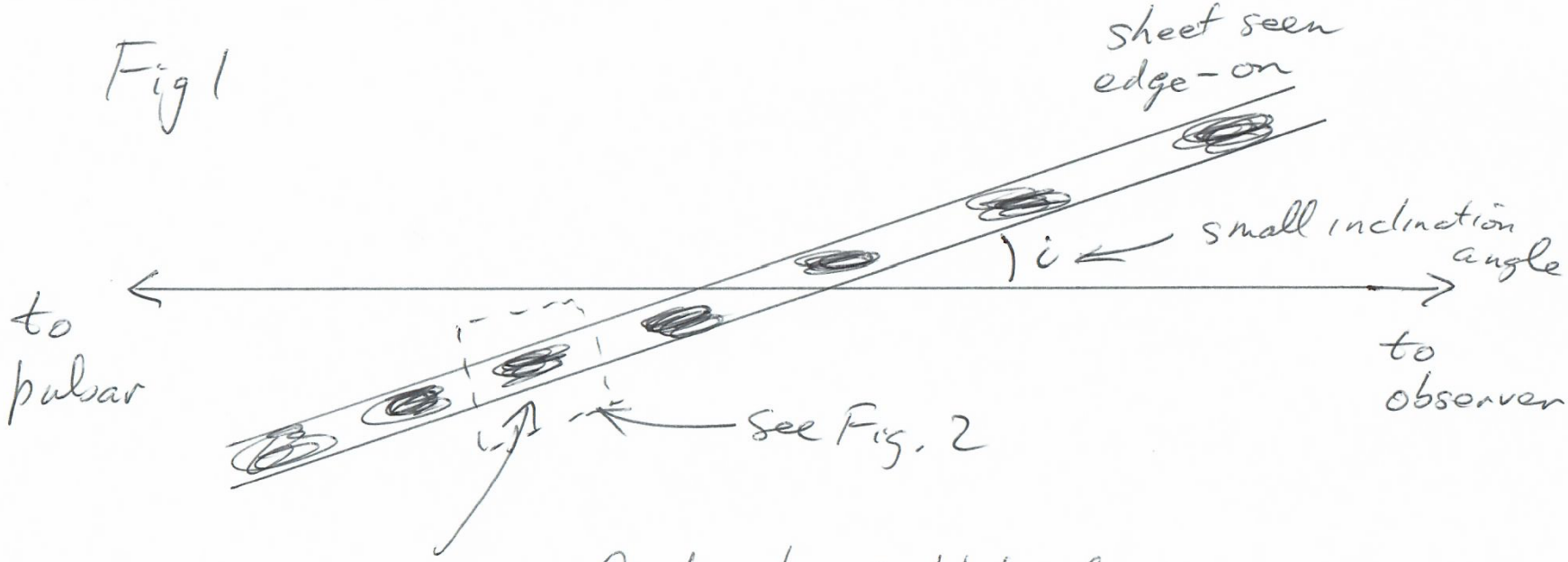


FIG. 6. Width of sun path; curves, theoretical, and dots, experimental.

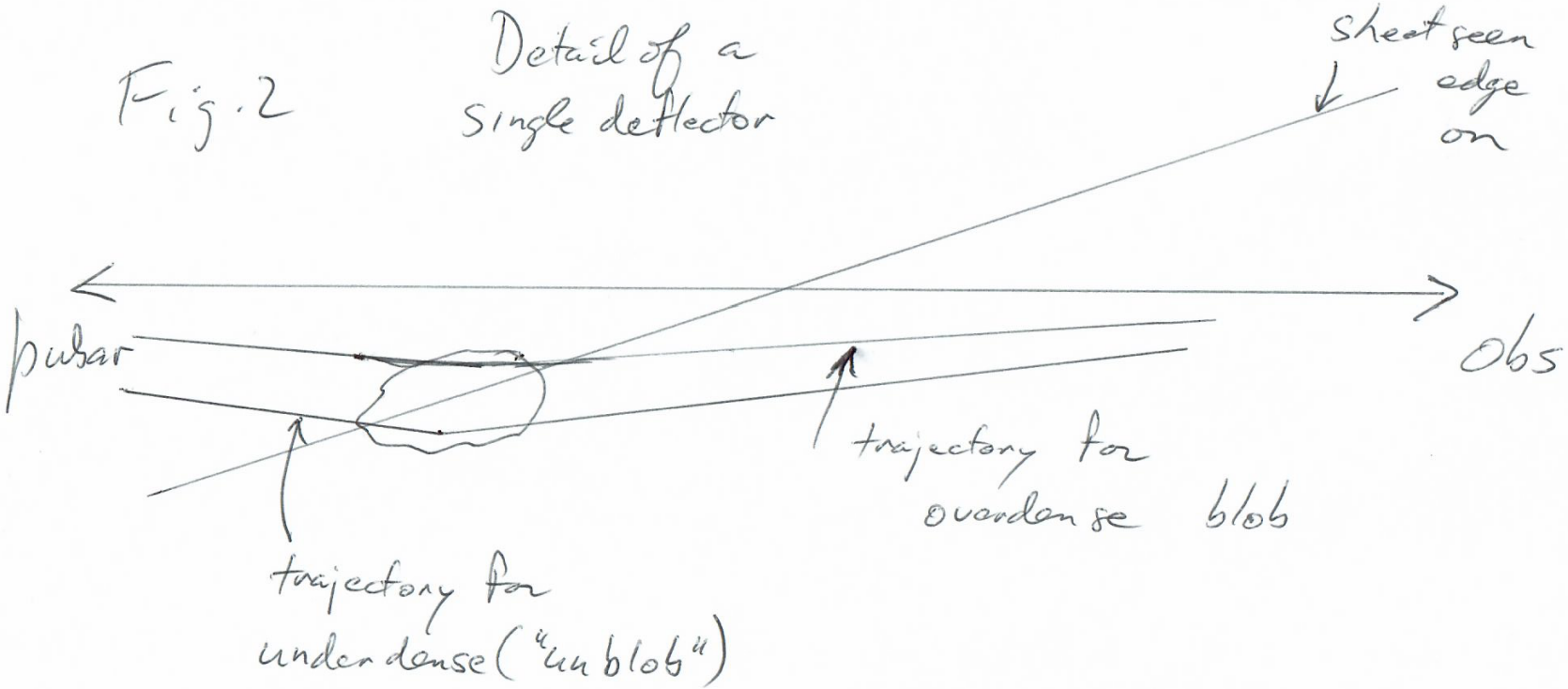
Fig 1



- grazing sheet geometry produces the linear scattering features a la Hulburt i.e. no need for regular corrugation
- rays are refracted at the edges of the blobs allowing either overdense or underdense blobs to work

3/29/17

Fig. 2 Detail of a single deflector



3/29/17

How does this relate to FRBs? (if at all)

- these 2D(?) structures appear to be common along the LOS to even nearby pulsars
- particularly fortuitous alignments could give rise to large lensing magnifications (cf. talks by Jim Cordes & Dana Simard)
- if so – and if scintillation arcs could be seen toward (repeating) FRBs – this is a powerful tool for analyzing the location of the scattering material