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Oxford Physics

Extreme refractive lensing in the interstellar medium

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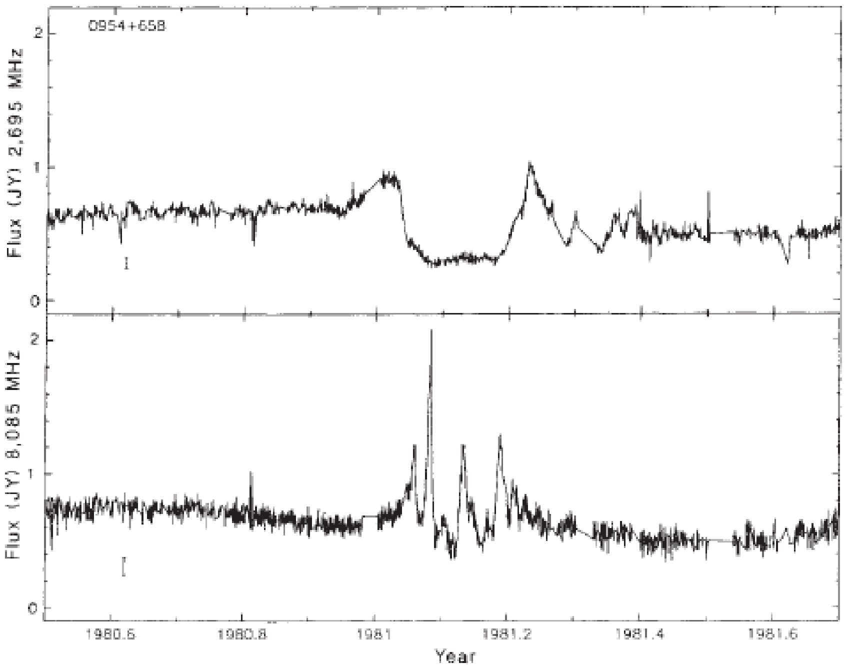
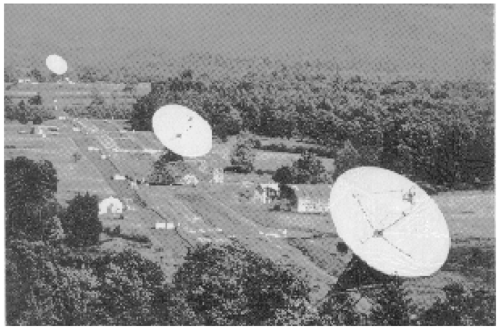
Extreme Scattering Events (ESEs) 1





Green Bank Interferometer (GBI)

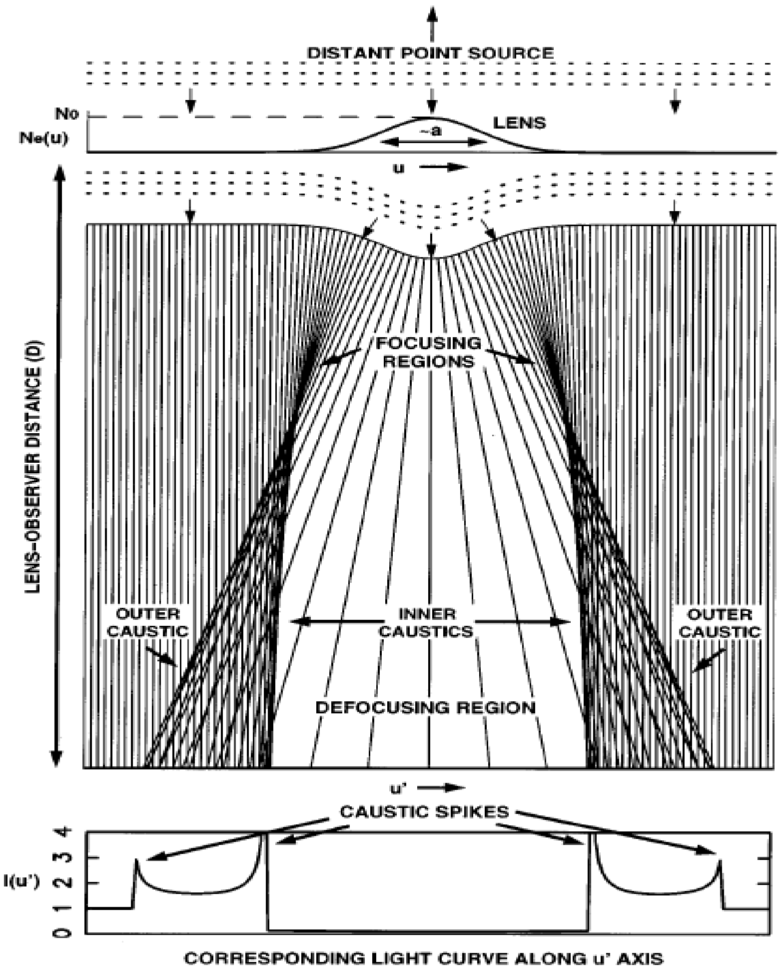
- First time observed by Fiedler et al. 1987
- sudden changes in the flux density of radio sources
- decreases up to 50% in the flux density
- periods of several weeks
- preceded and followed by substantial increases in the flux density
- also observed for pulsars PSR B1937+21 (Cognard et al. 1993; Lestrade, Rickett, & Cognard 1998) and PSR J1643-1224 (Maitia, Lestrade, & Cognard 1998)

Extreme Scattering Events (ESEs) 2

- synchronized events at different wavelengths
- time scales of the events
- arguments about light travel time

- Dense and ionized clouds have been proposed to cause ESEs acting as refractive lenses (Romani, Blandford, & Cordes 1987; Walker & Wardle 1998)

Extreme Scattering Events (ESEs) 3



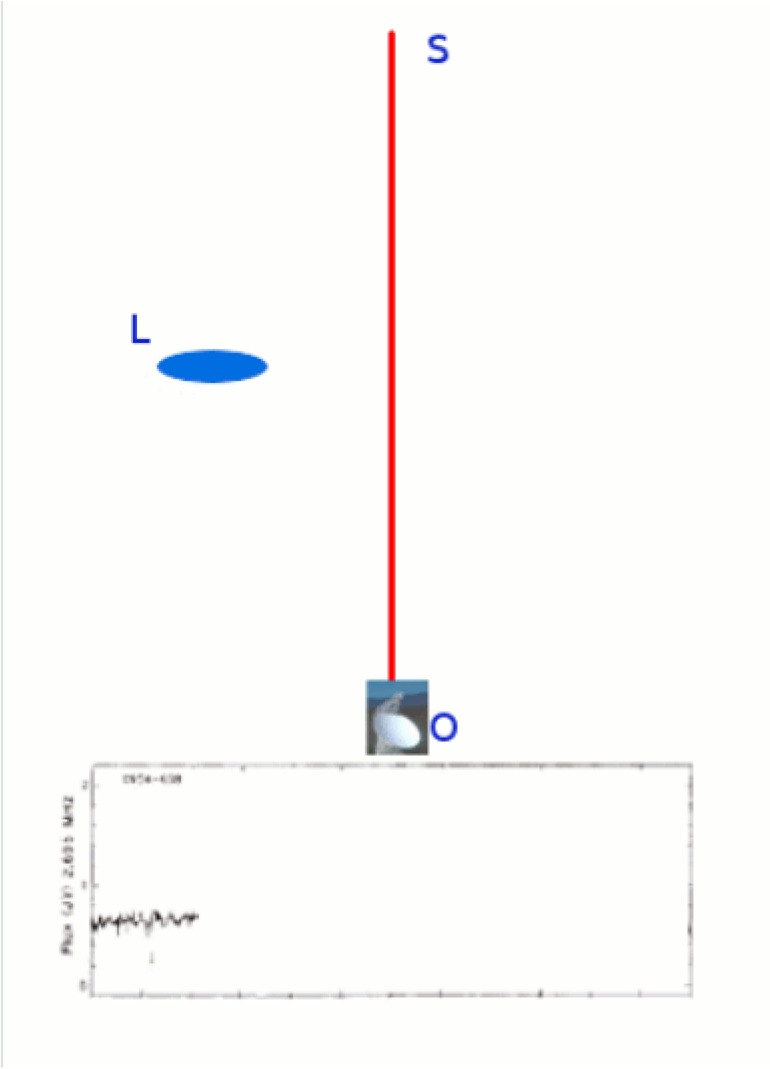
Clegg, Fey, & Lazio 1998

- Dense, ionized clouds
- "Divergent" plasma type lens
- Radius (~1-3 AU)
- Electron column density ~10^{15} cm^{-2}
- Mass up to 10^{-3} $M_\odot$
- Number density up to 600 pc^{-3} (more than the star number density in the Galaxy ~ 0.12 pc^{-3}

$$\varphi(b) = r_e \lambda n_e(b)$$

$$a(b) = \frac{\lambda}{2\pi} \varphi'(b)$$

Extreme Scattering Events (ESEs) 4



Approaching the line-of-sight(los)

- Extra rays deflected to the observer
- Increased flux density

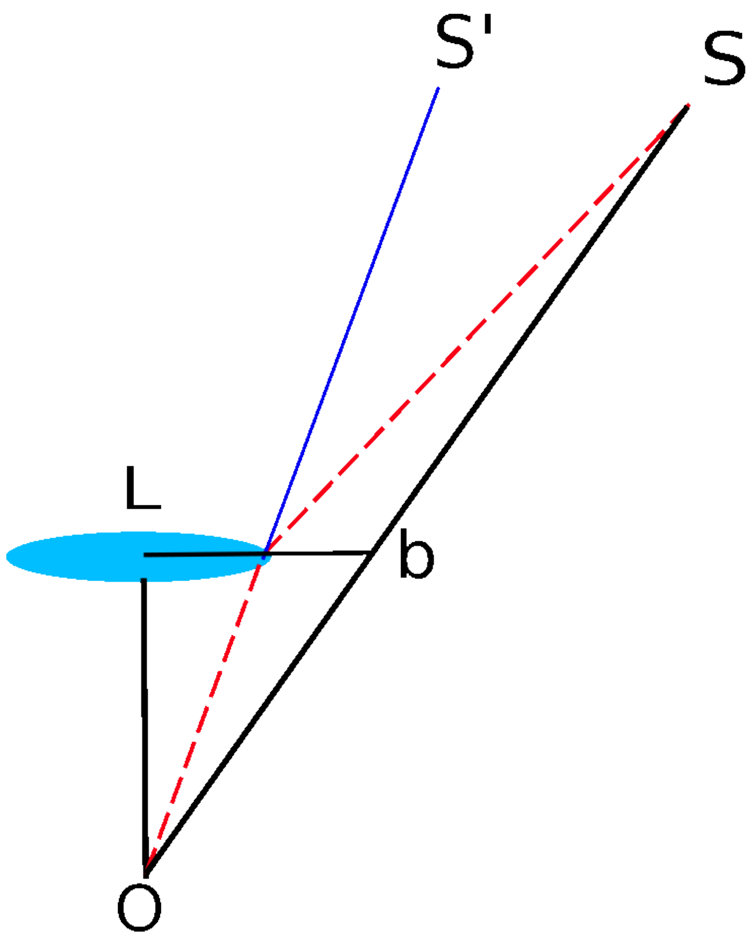
Centring with the los

- Deflects rays away from the observer
- Decreased flux density

ESE requires strict alignment with los

ESE probability $\sim 10^{-5}$

Large angle scattering



Depending on the:

- Real and apparent distances of the source(S), the lens(L) and the observer(O)
- Observing wavelength
- Lens size
- Lens electron density

There are parameter regions that allow:

- Large angle (~ 10^{-8} radians) scattering,

  Formation of extra images (S'),

  Lens interaction from greater distance to the los

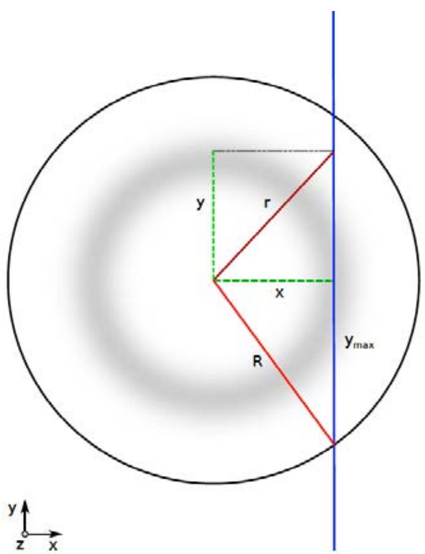
Lens models

- Two models are used:
- A Gaussian free-electron column density profile
- A lens model by Walker & Wardle 1998

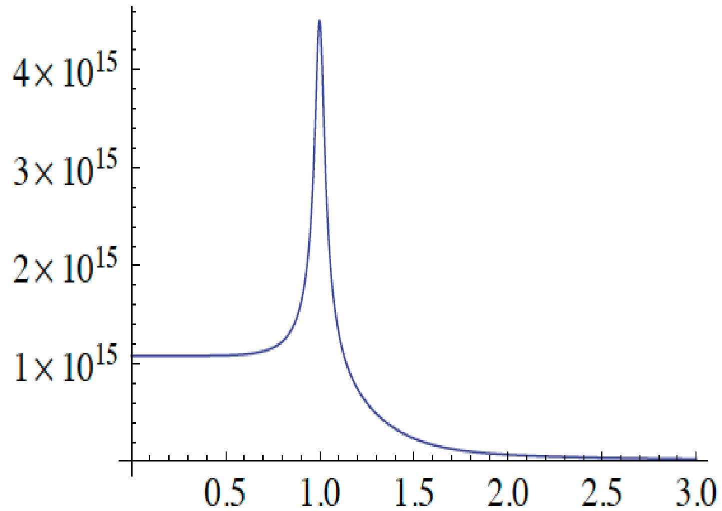
  Both have a maximum electron column density of ~10^{15} cm^{-2}

  A diameter of ~2 AU

  Both are spherical

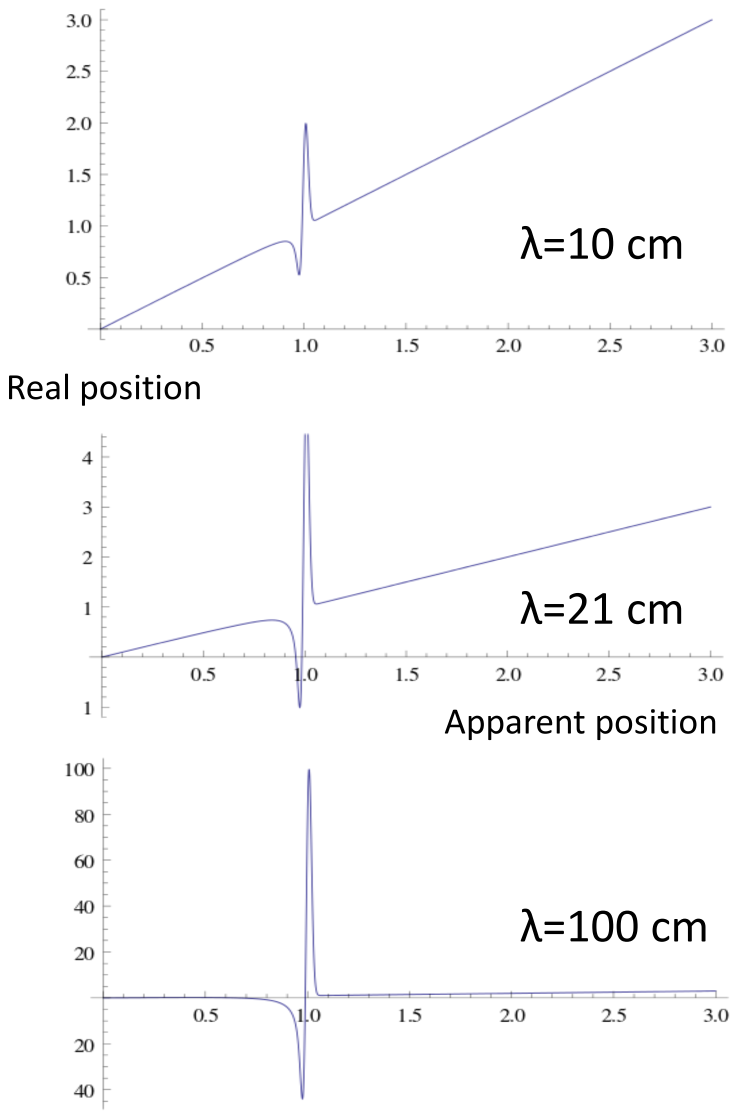


Electron density cm^{-2}



Radius (lens units)

Extra Images



Extra images are produced when the lens and the line of sight are not aligned

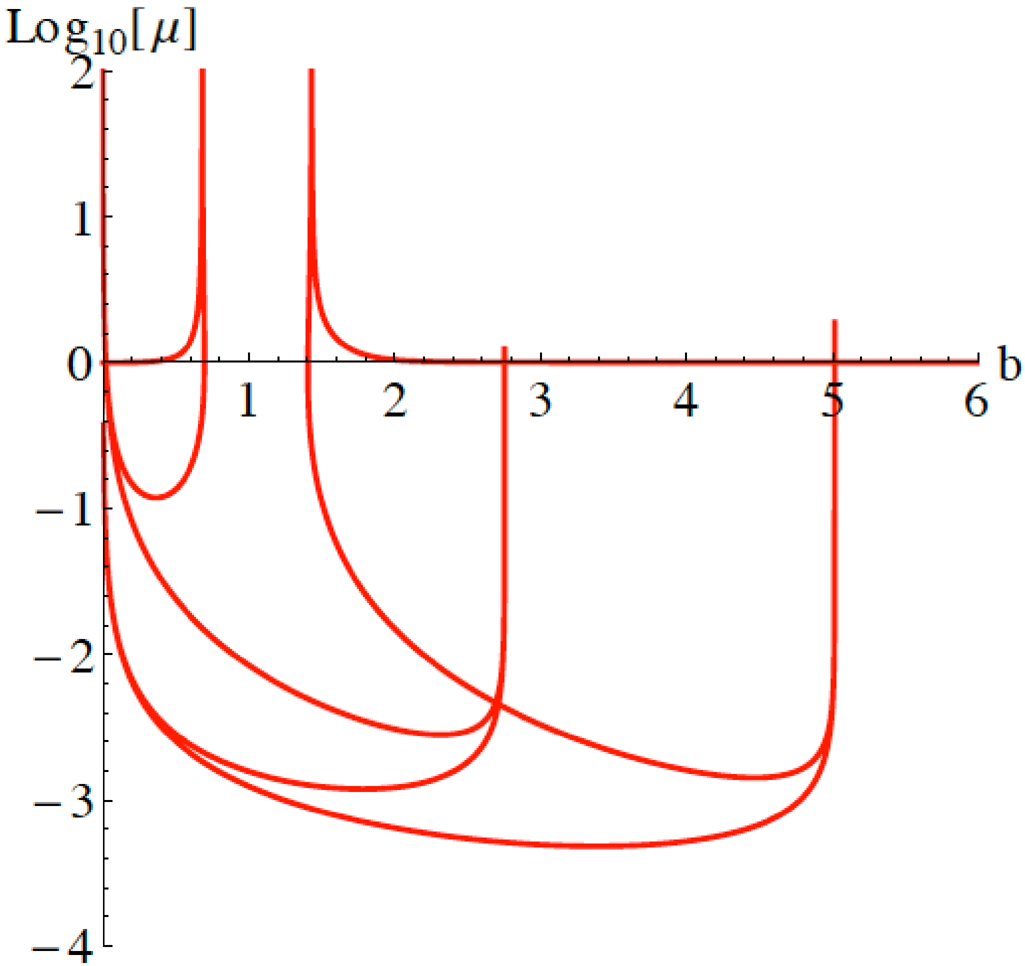
The angular distance of the lens to the source can be 3-10 times bigger than the one required to have an ESE.

This significantly increases the cross-section

$$\sigma \propto \pi b^2$$

The cross-section can be up to two orders of magnitude greater than for an ESE

Magnification and cross-section of extra images

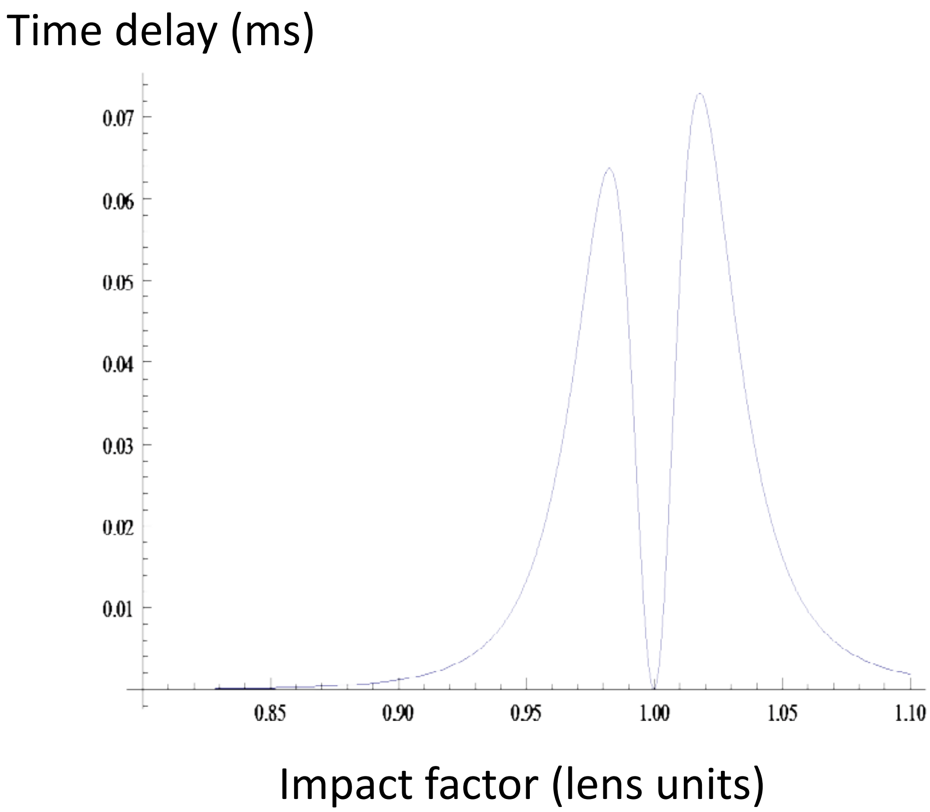


The extra images produced are fainter by ~3 orders of magnitude

They remain at this level for high relative positions (b)

Can be detected using high s/n data (GBT)

Time delay of the extra images

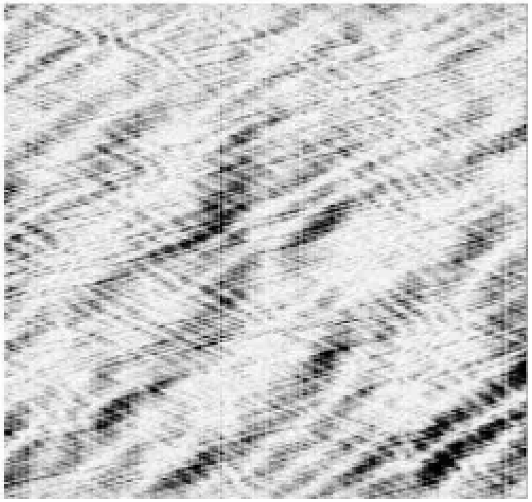


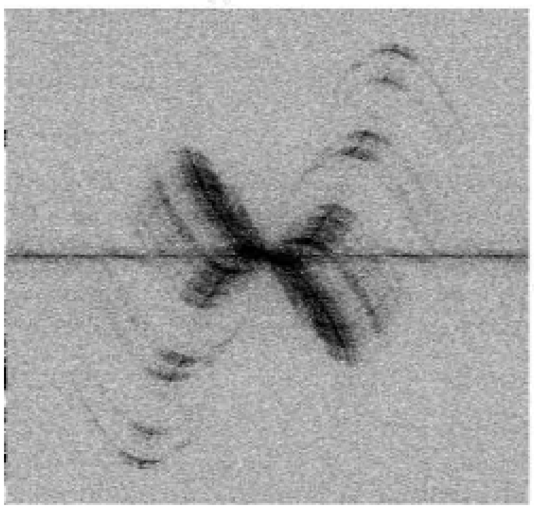
- Extra images follow different paths to reach the observer
- A time delay with respect to the direct image
- The time delay can be up to 50 μs
- The delayed rays are coherent with the direct ones

Large angle scattering probabilities

Name	Probability	Gb (º)	Distance (kpc)
B1937+21	9.738	-0.29	8.33
B2020+28	0.267	-4.67	2.7
B2021+51	0.101	8.38	2
B1642-03	0.078	26.06	2.91
B0818-13	0.077	12.59	1.96
B0355+54	0.029	0.81	1.1
B0450+55	0.028	7.55	1.19
B0329+54	0.026	-1.22	1.06
B1822-09	0.022	1.32	1
B2016+28	0.019	-3.98	0.97
B1944+17	0.014	-3.5	0.85
B1919+21	0.007	3.5	0.66

Cyclic Spectra Analysis Method





Walker et al. 2008

- First introduced to pulsar astronomy by P. Demorest 2011
- The method is applied to baseband data to extract the incident electric field (algorithm by Walker, Demorest and Van Straten)
- Plotting the electric field amplitude versus Doppler-shift and group delay we can search for faint images from large angles

Summary

With this study we expect:

- To increase the probability to detect a plasma lens.
- To constrain the model parameters that describe the physical parameters of these clouds (electron density, mass, size).
- To better estimate the number density of the lenses and their total contribution in the Interstellar medium (ISM) mass.

Understanding the nature and population of these lenses will help:

- In correctly accounting for ISM propagation effects in pulsar timing experiments.
- Prepare for ISM related phenomena seen in current and future slow transient surveys(e.g. the Australian SKA Pathfinder VAST project).

Thank you !