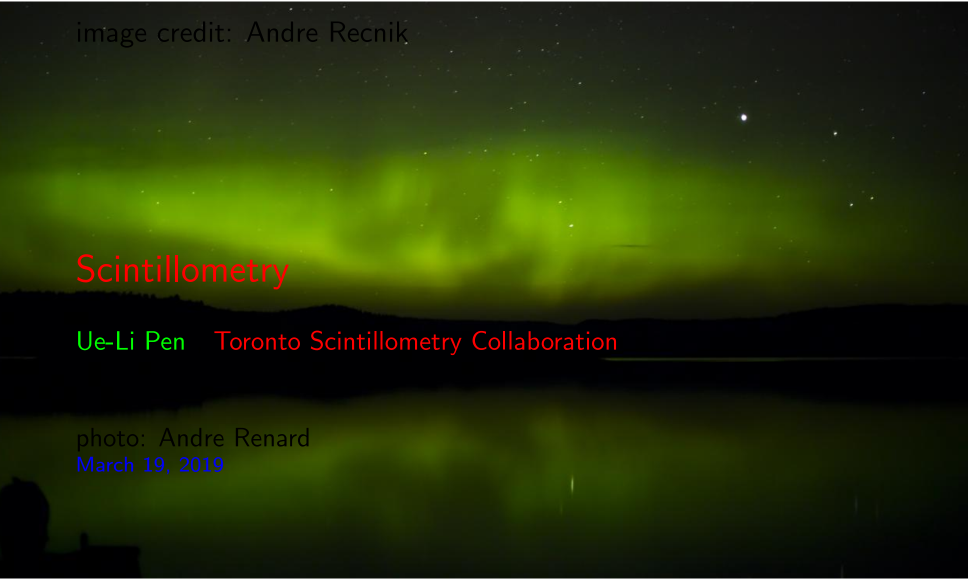


image credit: Andre Recnik

Scintillometry

Ue-Li Pen   Toronto Scintillometry Collaboration

photo: Andre Renard

March 19, 2019

Overview

- Exploiting natural lenses
- potentially precision pulsar distances, precise PTA GW localization
- pico-arcsecond astrometry
- FRB/pulsar emission
- nature of lenses
- baseband data, VLBI
- unique opportunity for GMRT

Natural Lenses

676 LETTERS TO NATURE NATURE VOL. 326 16 APRIL 1987

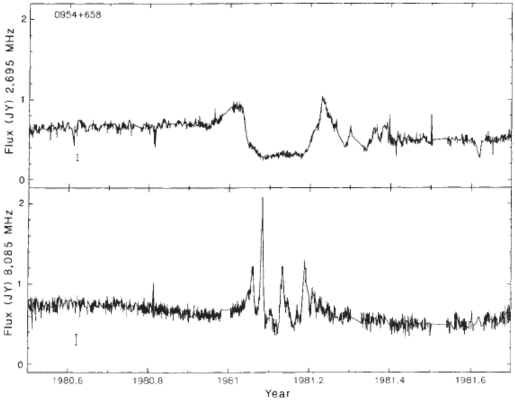


Fig. 1 The 2.7- and 8.1-GHz radio light curves for a 1.2-yr interval surrounding the unusual minimum in 0954+658. Although the individual data points are connected by line segments, none of the peaks shown here, or in Figs 2 and 3, contain fewer than 20 points. The error bars are 2σ in height and were obtained from ref.1.

Fiedler et al 1987

Natural Lenses

- Fiedler 1987++: chromatic radio flux variations
- evidence for localized ISM lenses: not volume filling
- AU transverse scale: if isotropic, requires $n_e \sim 10^3 \mathrm{cm}^{-3}$
- ISM explosions, or exotically confined
- exploding dark matter, quark nuggets, superconducting cosmic strings
- hints from pulsar inverted parabolic arclets
- lenses elongated, perhaps also along line of sight!

Sheets

Figure 10. Simulated scattering image of the pulsar. A typical scale for this image would be 100 mas end-to-end. The pulsar is modelled as a unit disc, with a much exaggerated diameter of 2 mas. The actual size of the pulsar emission spot would be ~100 picoarcsec. Flux conservation requires that the sum of the image areas equals the original disc. Thus, each pixel is either white or black in this figure. This compares favourably with the VLBI reconstructed positions of Brisken et al. (2010), where fig. 5 also shows images closely aligned along a straight line.

Pen and Levin 2014

Secondar

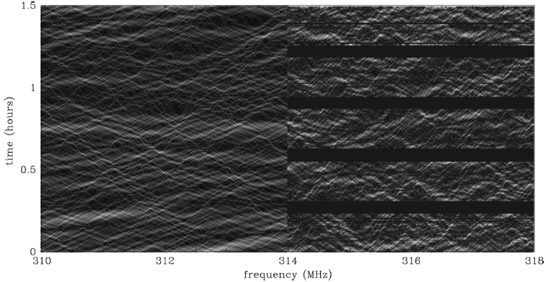


Figure 8. Dynamic pulsar spectrum. The left panel is the simulated spectrum and the right panel is the dynamic spectrum of PSR B0834+06 from the Brisken et al (2010) data set. The horizontal axis is time and the vertical axis is frequency. For B0834, the horizontal axis is 4 MHz of bandwidth and the vertical axis is 1.5 h of time. We reproduce the characteristic criss-cross pattern observed in real scintillation spectra.

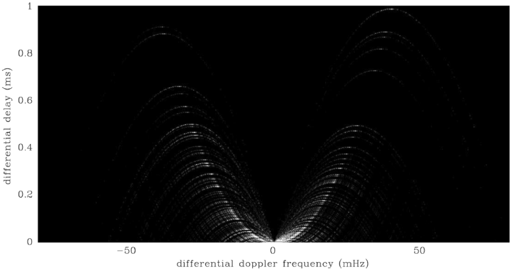


Figure 9. Simulated model secondary pulsar spectrum. The inverted parabolic arcs at large delay arise naturally in this model from the interference of the distant lensed images at the apparent sheet fold singularity with the brighter images closer to the unlensed position. The axis scales are meant to be illustrative, and depend on distance, pulsar velocity, etc.

Scintillometry

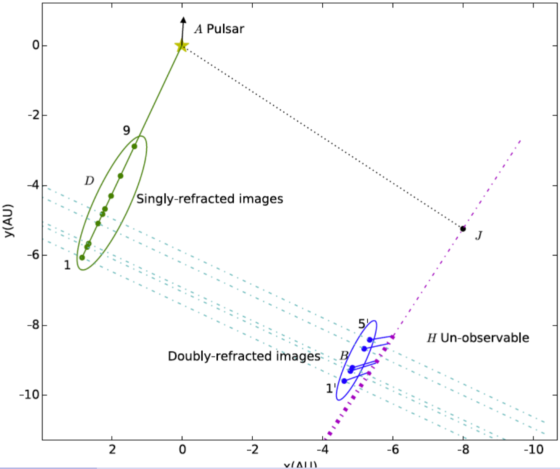
PSR B0834+06:

$D_S = 620\text{pc}$,

$D_L = 389/415\text{pc}$

Sheet cusp caustic?

Brisken+2010, Liu+2016, Simard+2018



Grazing incidence

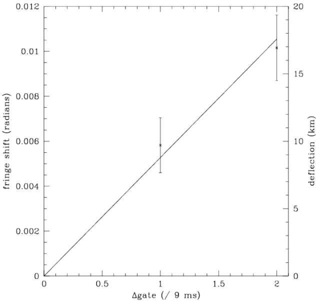
Figure 1. Reflection of lights on surface waves. At grazing angle, each wave crest results in an apparent image, causing a linear streak of images centred on the unperturbed image location. For example, the red light streak would consist of a single image at its centre in the absence of waves. The inclined sheet model for pulsar scintillation is analogous, with reflection replaced by refraction. Image copyright Kaitlyn McLachlan, licensed through shutterstock.com image ID 45186139.

Applications

- cosmic telescope: picoarcsecond astrometry of magnetospheres
- measured 1km motion of PSR B0834+06 emission, initial results for crab
- potential for precision distances to pulsars, increased PTA sensitivity, accurate GW localization.
- Masui+ 2015, FRB110523: lensing of scattering tail by milky way localizes scattering screen to host galaxy, rules out IGM scattering
- repeating FRB: potential to discriminate AGN from nebula

Pulsars

- plasma microscopes: B1957+20 (see talk by Dongzi)
- map distances to invididual screens (see talk by Viswesh)
- distances and inclinations to binary pulars: masses, sizes (inertia), distances



Pen+ 2014 .

Discussion

- ISM lenses: probed by compact radio sources at high frequencies
- pulsars are low frequencies
- ISM contains localized, 1-D, strong lensing screens
- Pulsars/FRB: unique source of coherent radiation
- Use ISM to map source structure

Conclusion

- new picture of ISM lensing by small number of inclined sheets
- VLBI for screen distances, initial results (incl uGMRT, see Viswesh talk)
- new analysis techniques needed: coherent imaging, phase retrieval.
- unique window on ISM
- potential to use scintillometry for precision pulsar distances, orbits, masses, improved PTA, emission structures, FRB, magnetic fields