FROM GRAVITATIONAL TO PLASMA LENSING

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In collaboration with
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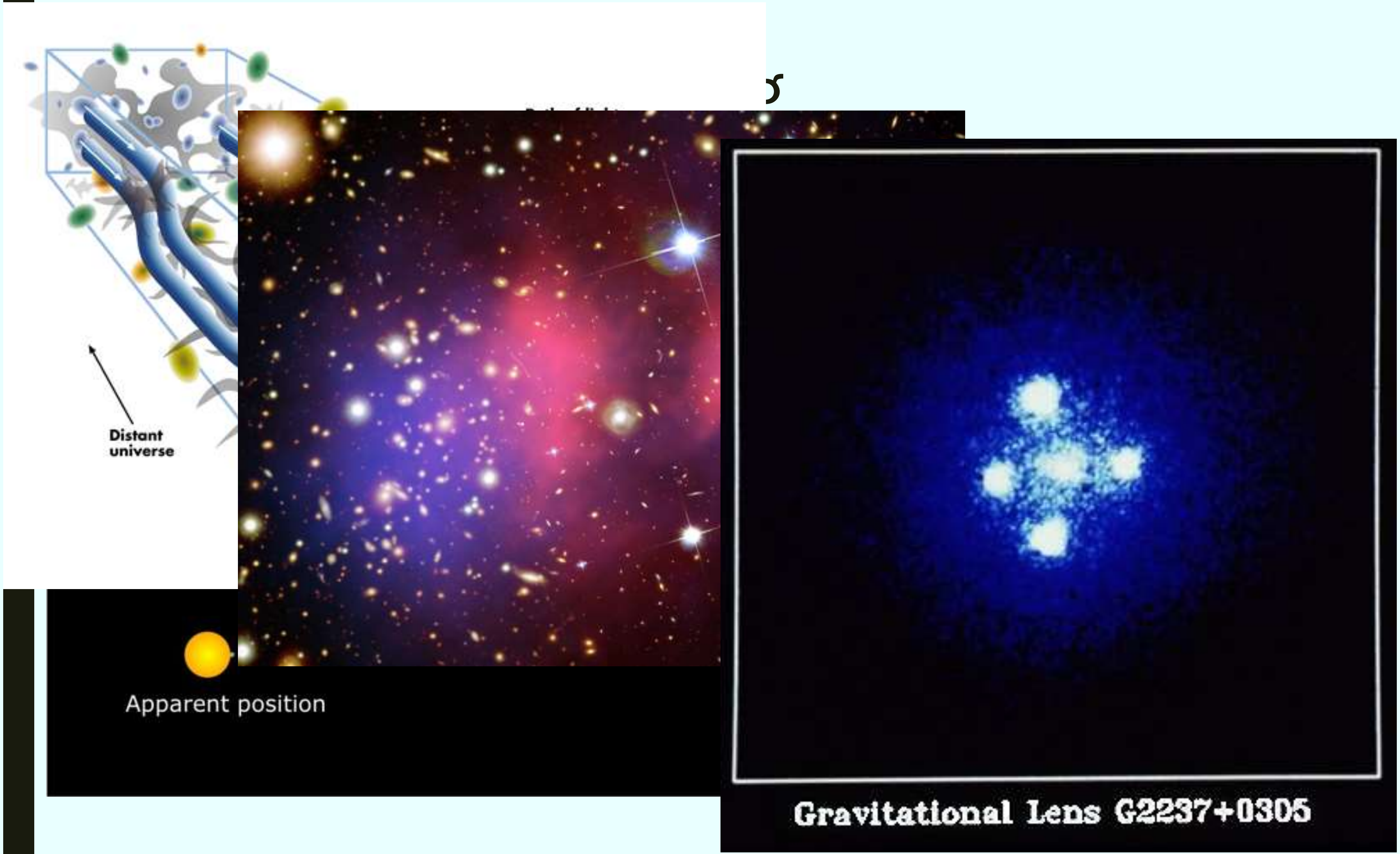
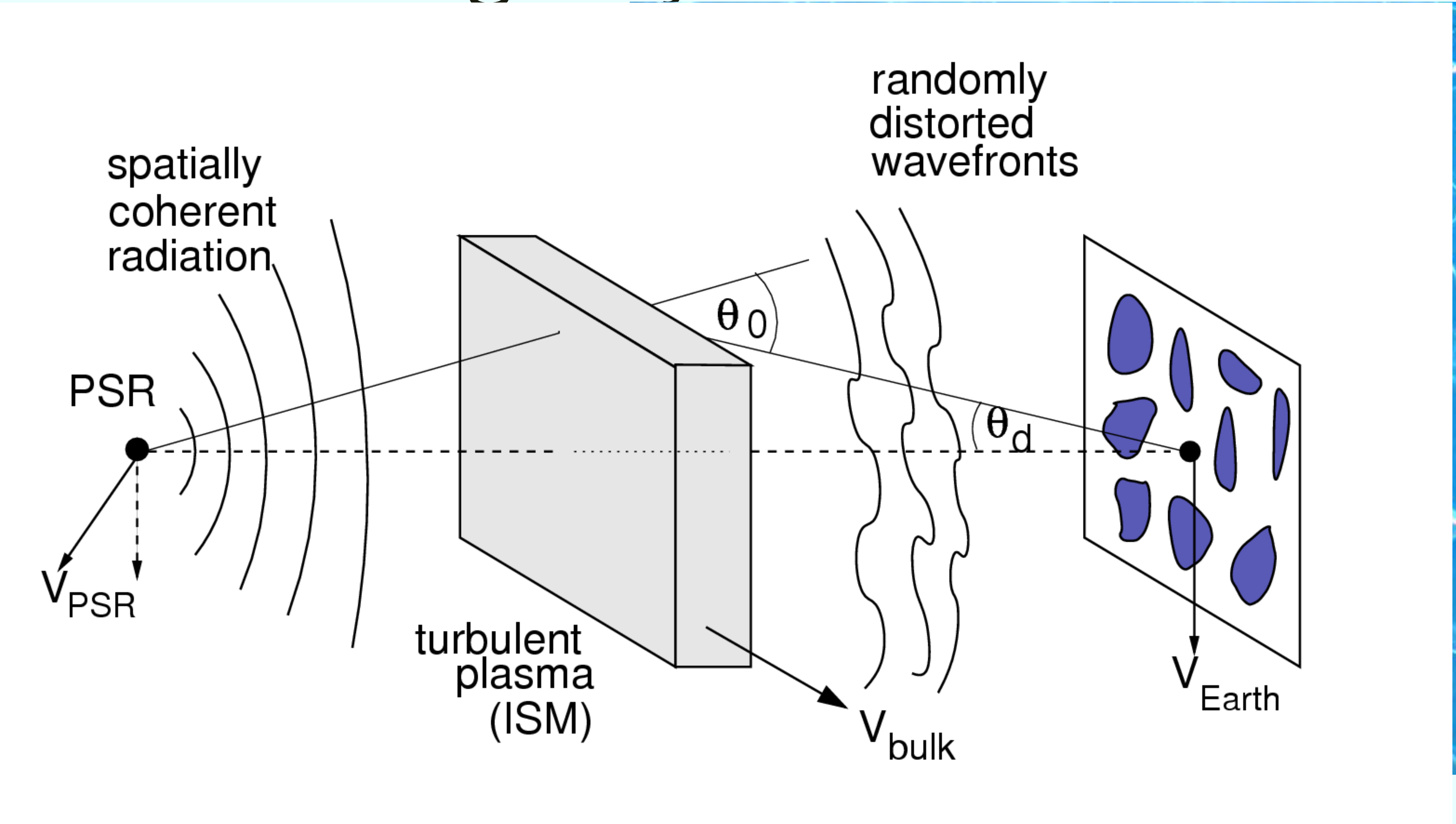
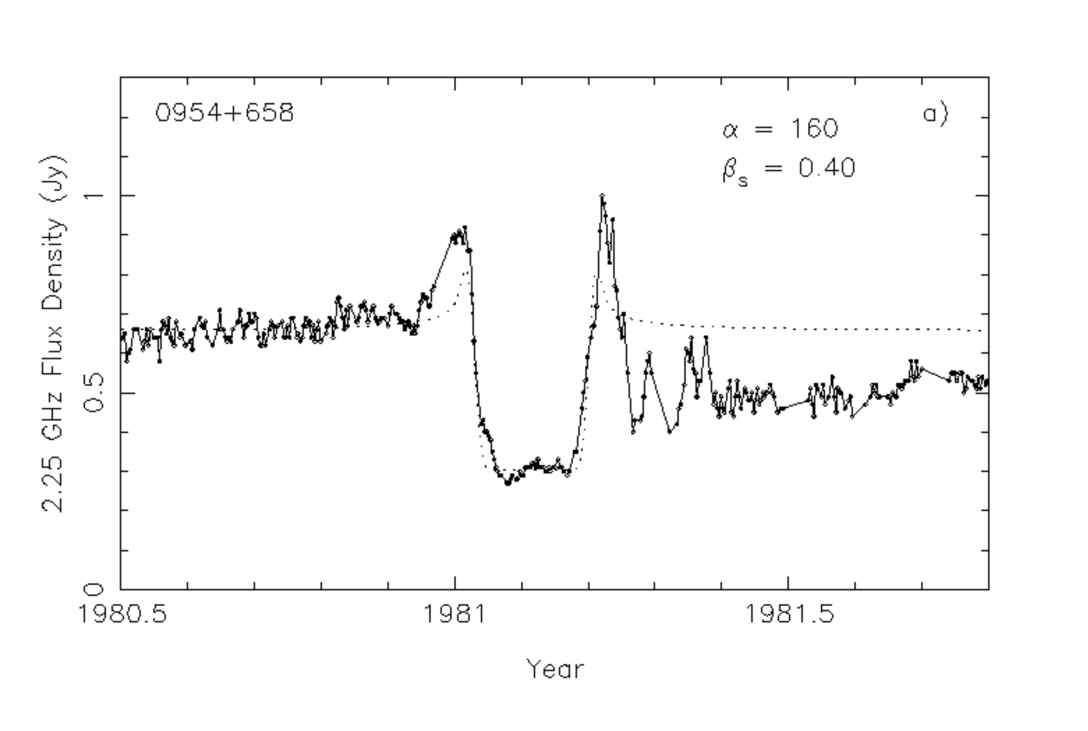
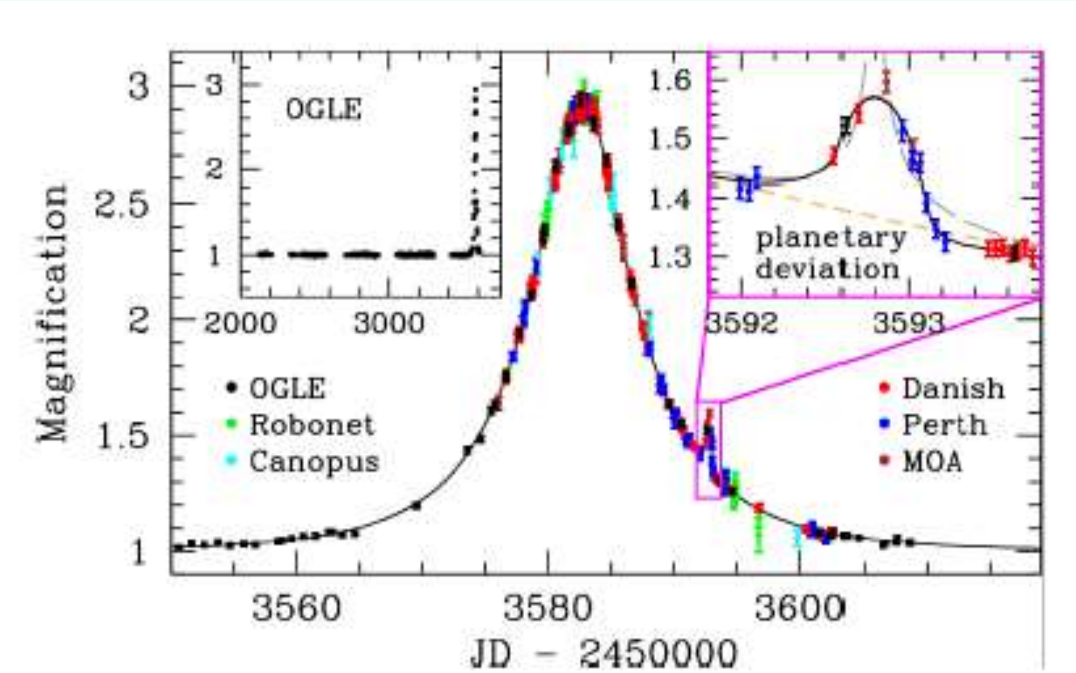

Distant
universe
Apparent position
Gravitational Lens G2237+0305

Other than gravity?



Radio scatter Events





A radio microlensing event?
(Clegg, Fey & Lazio 1998)

Micro-lensing, image credit: OGLE

Same, but different

Gravitational lens

- Inhom. Projected mass density
- converge
- Non-dispersive
- Image distortions
- Source unobservable

Plasma lens

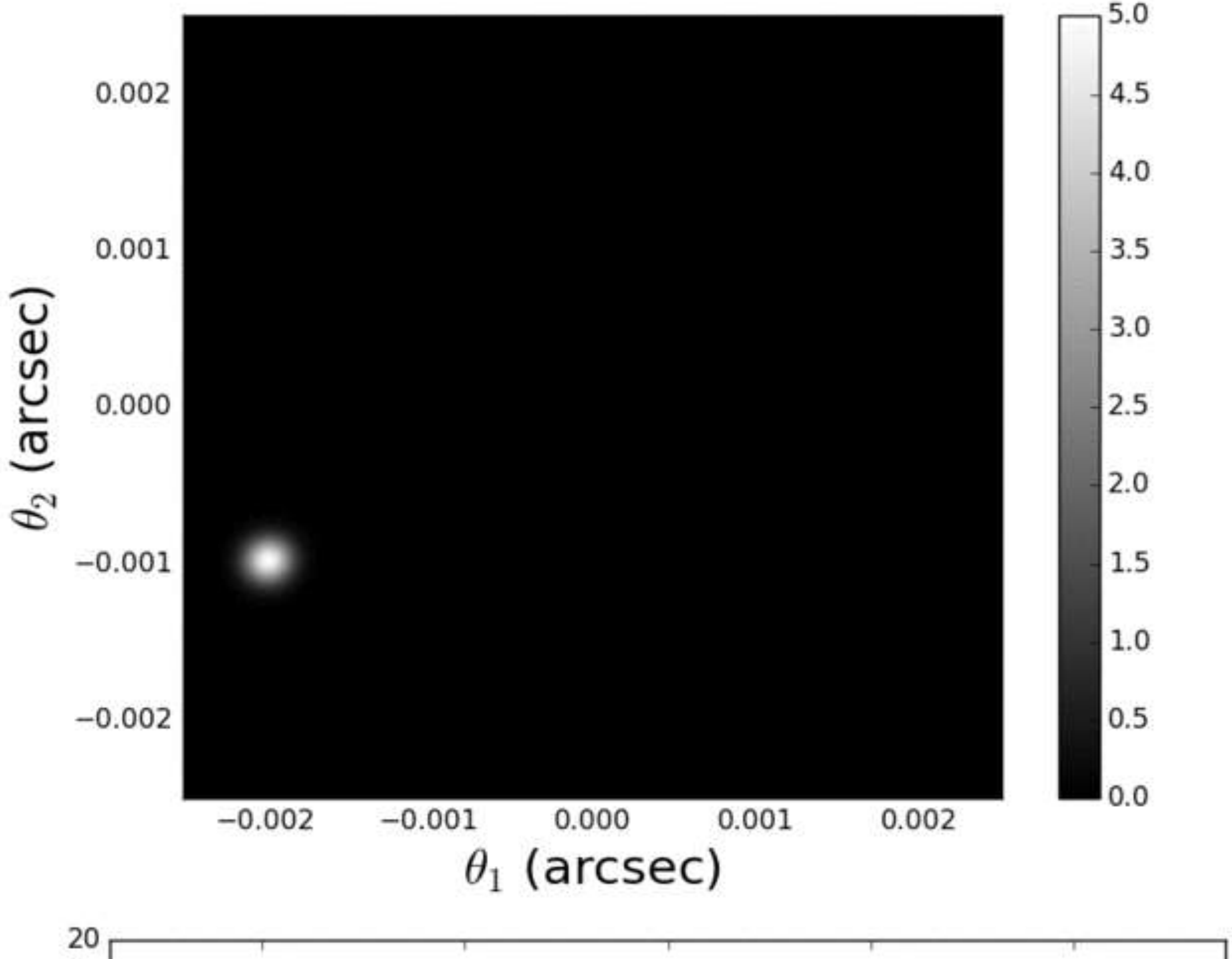
- Inhom. Projected electrons
- diverge
- Dispersive
- Magnification curve,
  - *Time-delay*
- Source observable

Let’s borrow some math from GL

- Lens eq. $\boldsymbol{\beta} = \boldsymbol{\theta} - \boldsymbol{\alpha}(\boldsymbol{\theta})$
  - *But,* $\boldsymbol{\alpha} \propto \nabla \mathbf{N_e}(\boldsymbol{\theta})$
- The effective plasma ‘lens potential’
  - $\boldsymbol{\psi}(\boldsymbol{\theta}) = \frac{D_{ds}}{D_s D_d} \frac{r_e}{2\pi} \lambda^2 N_e(\boldsymbol{\theta})$
  - *λ-wavelength, -N_e electron projected density*
  - *No Poisson eq.*

Plasma lensing

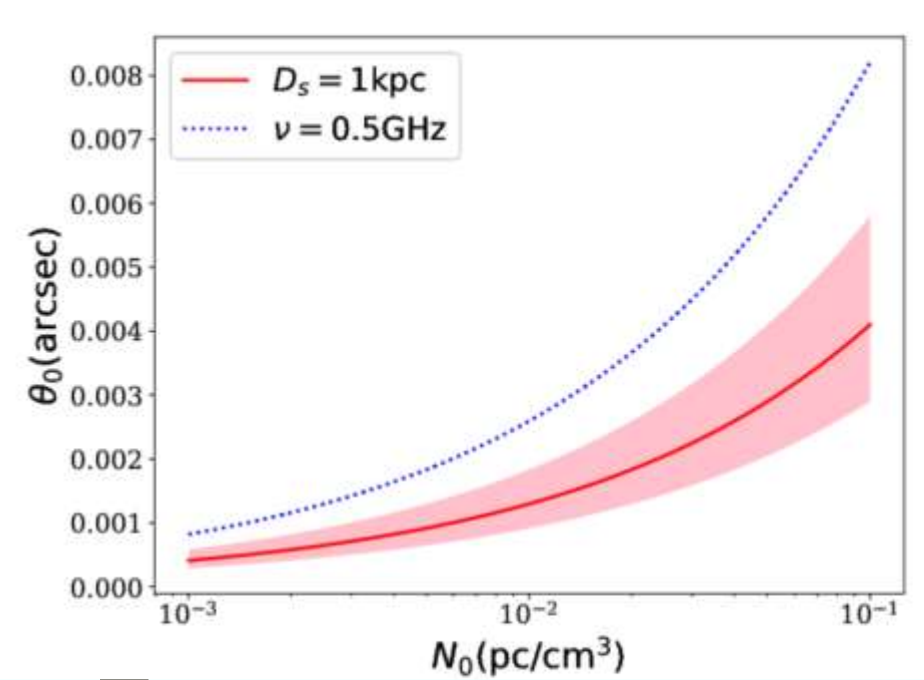
- Astrophysical properties:
  - *Lens:*
    - small scale ~10^3 AU to large scale (maybe)
    - Density profiles?
    - Typical density?
    - B-field?
  - *Source:*
    - Point source, pulsar, QSO, FRB
- Observations:
  - *Image distortions, multiple images?*
  - *Light curve(s), frequency-delay*

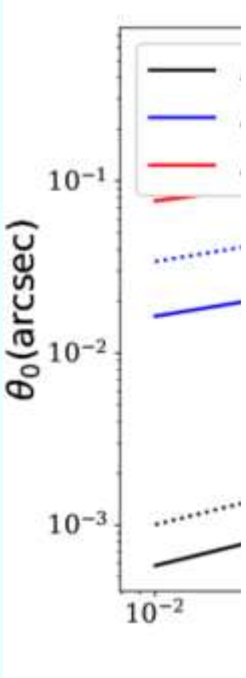


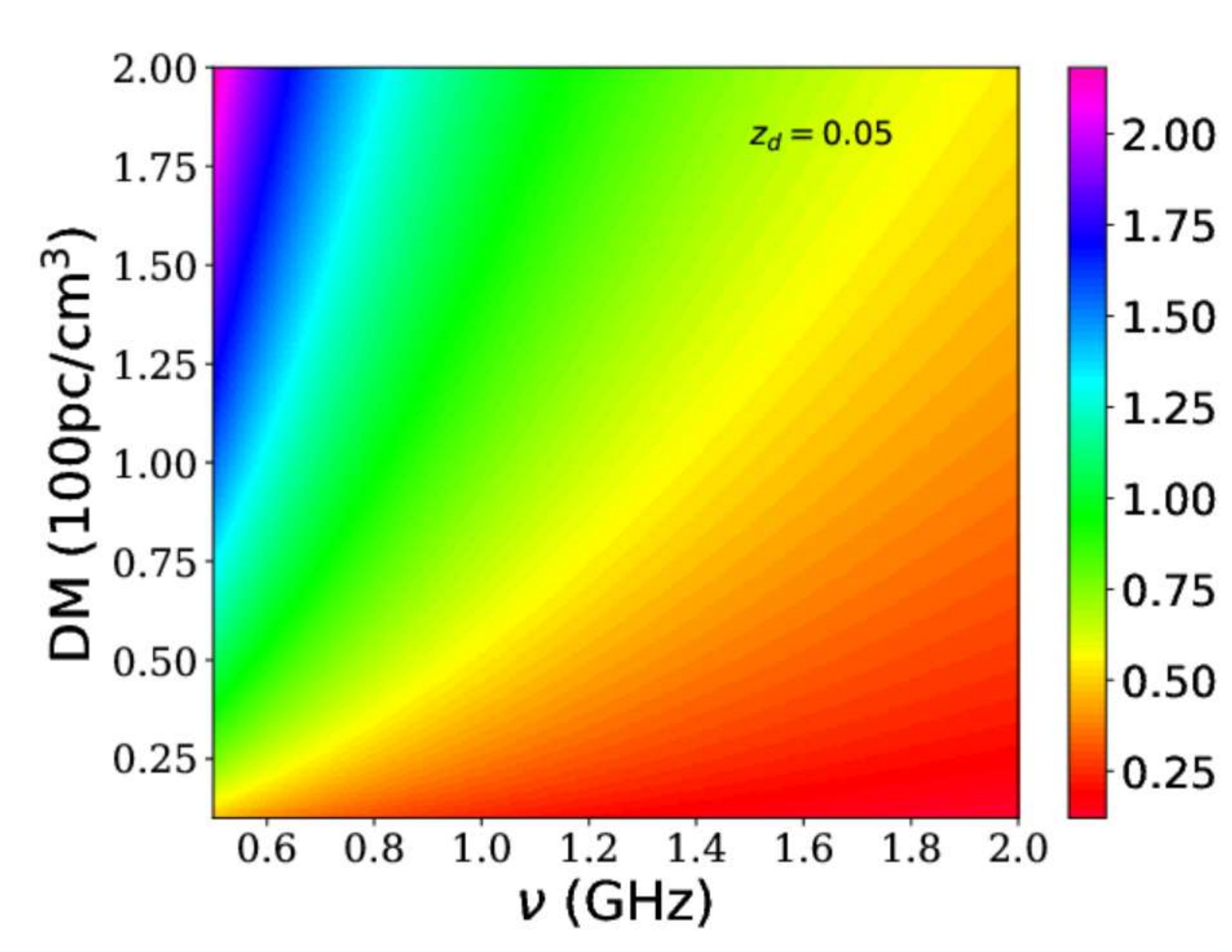
plasma lensing

Spatial scale and density

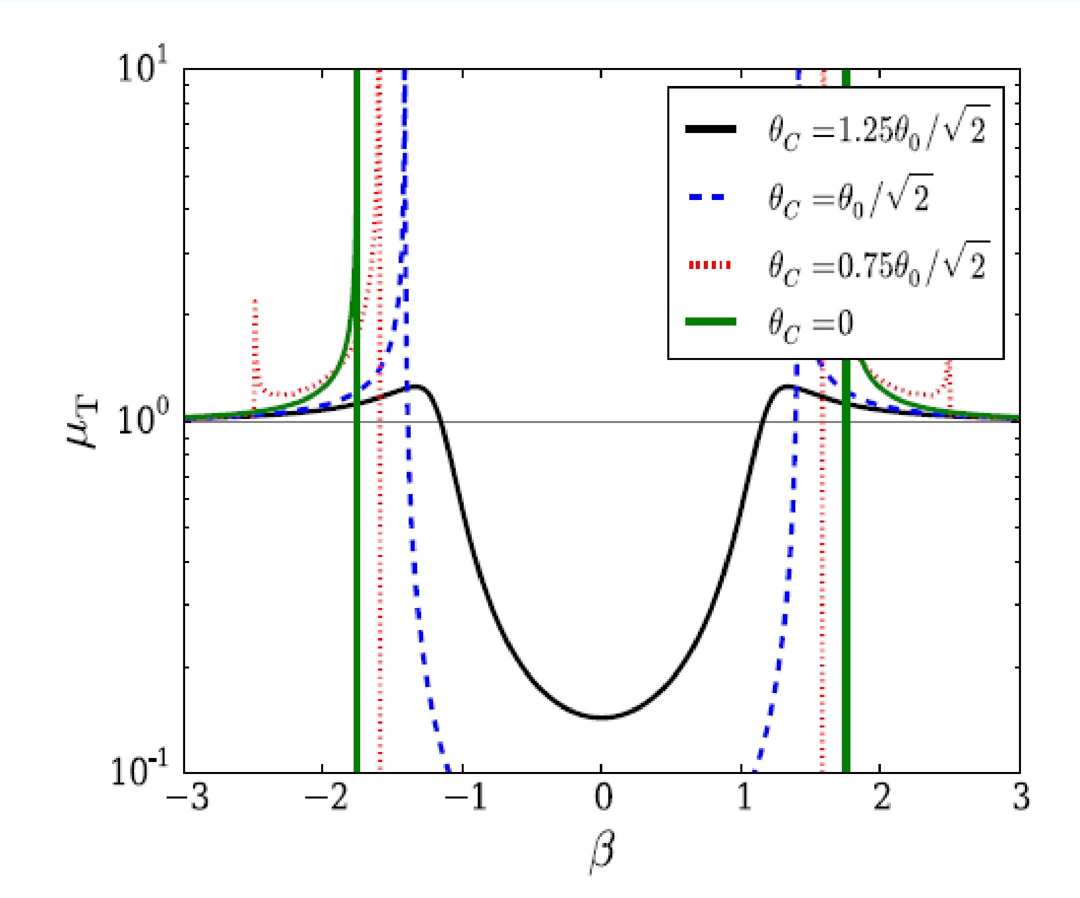
- 'Einstein radius' in plasma lensing θ_0-- the strength of lens
- Density or gradient?

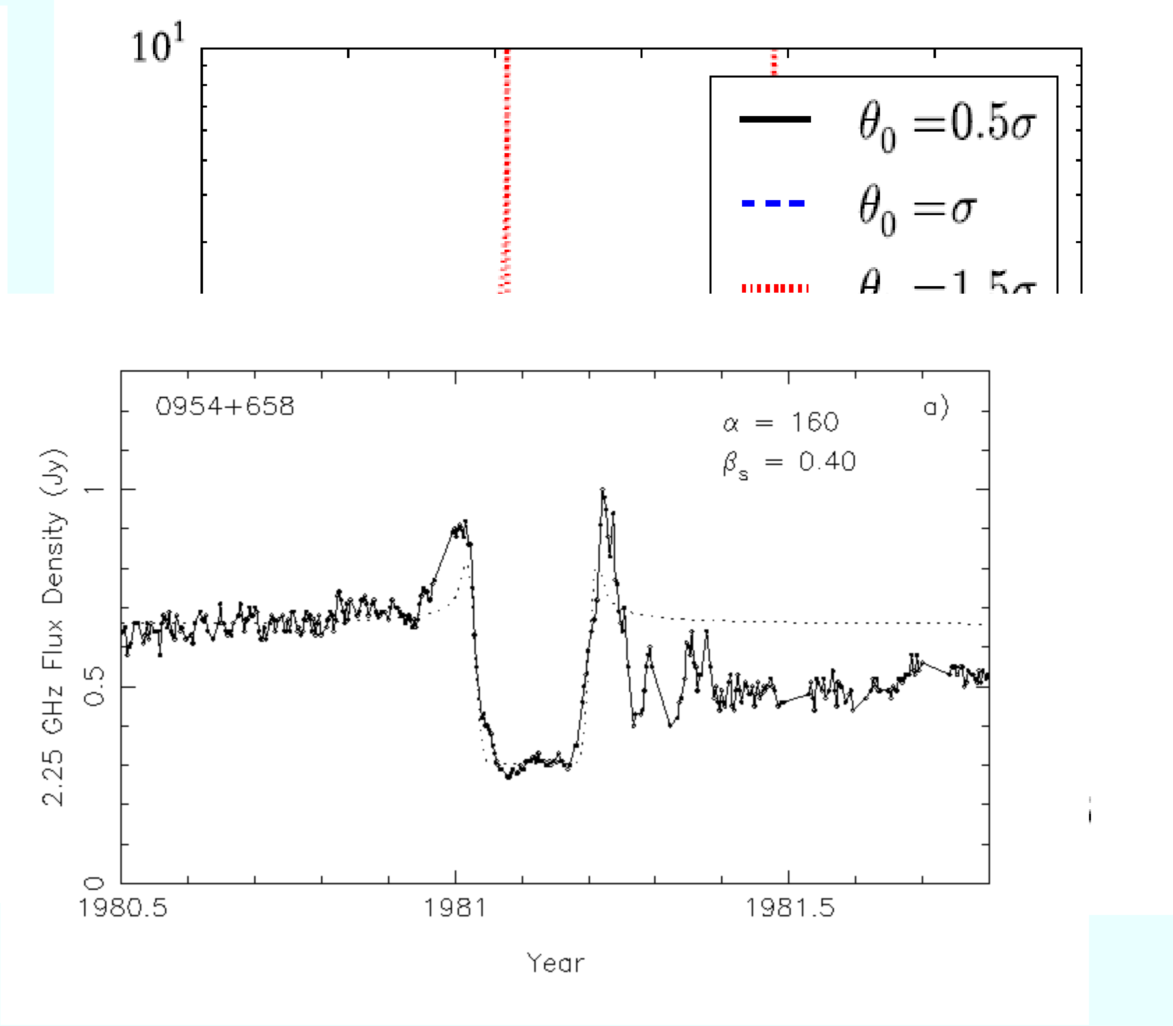






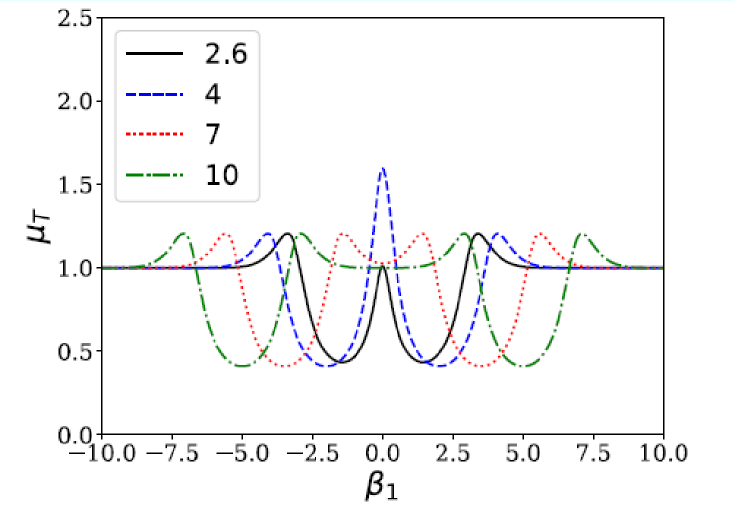
Magnification curves

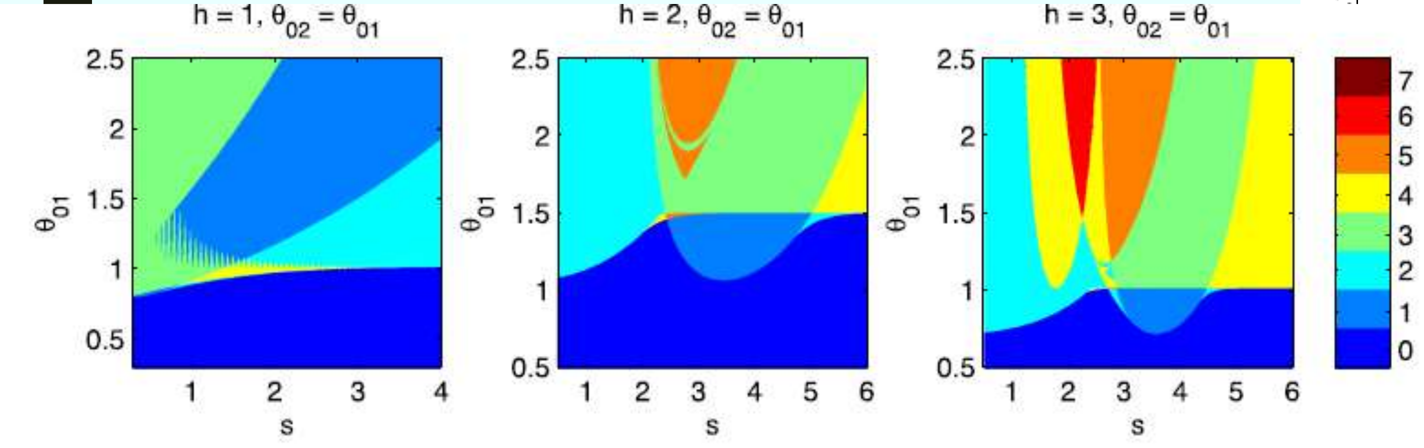


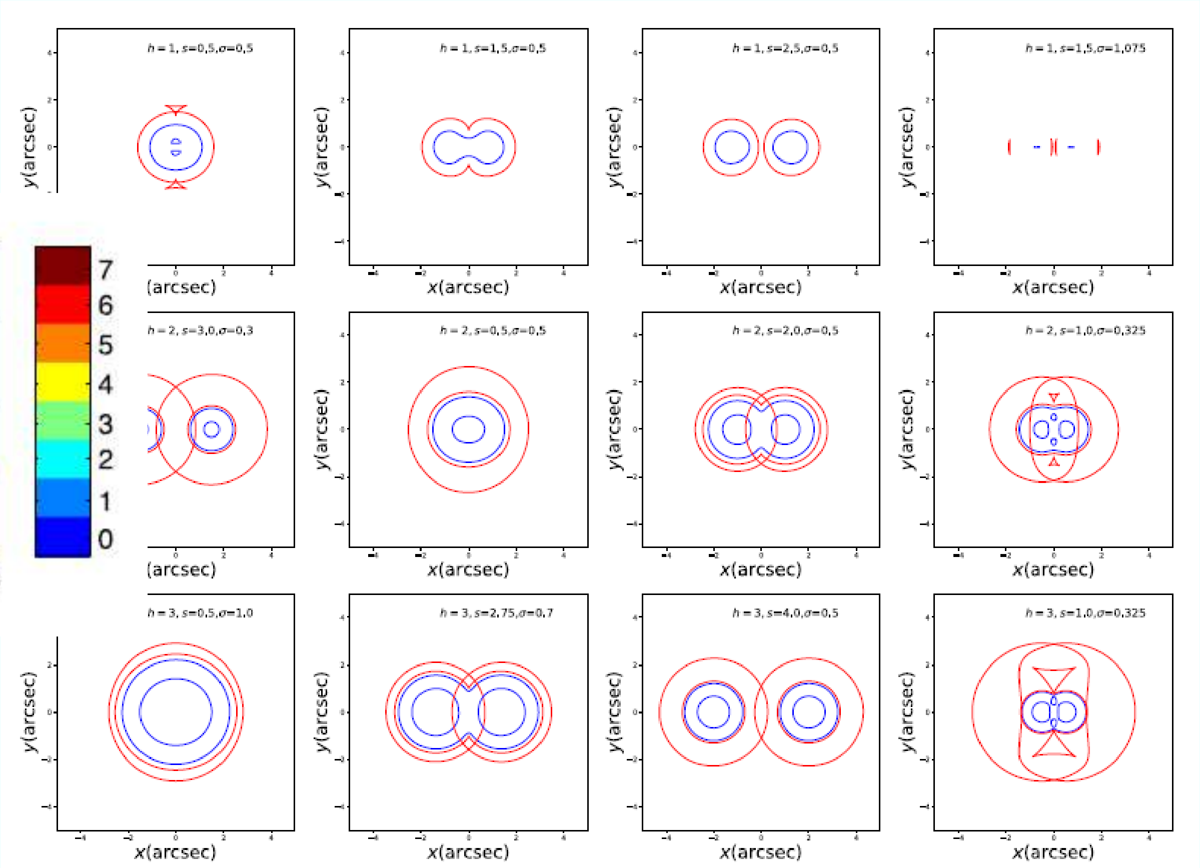


Clumpy distributions

- E.g. binary cases,
  - *very large parameter space*
  - *Various critical curves (caustics)*

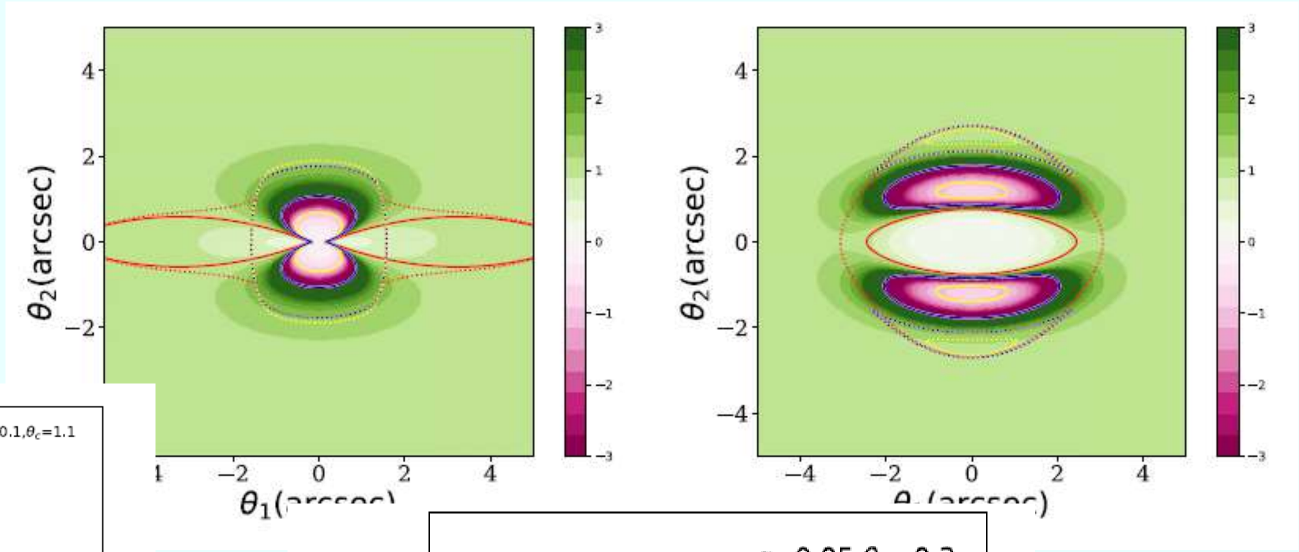


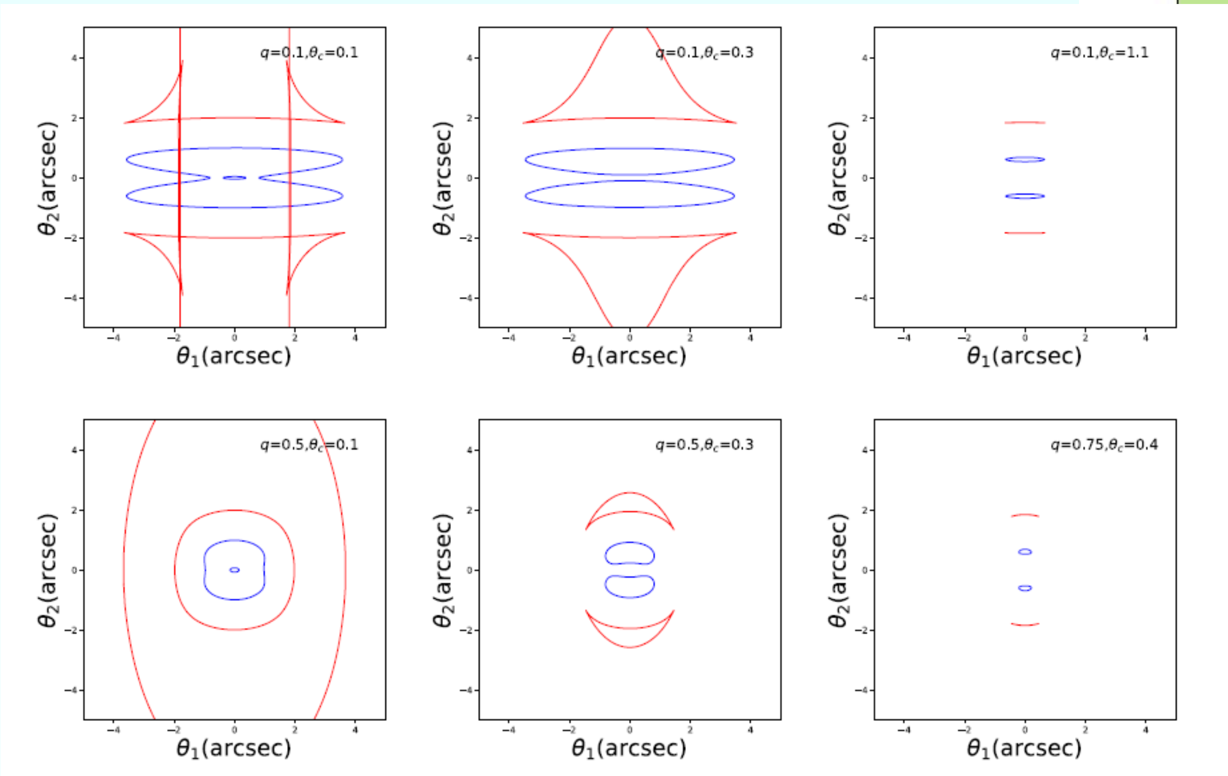


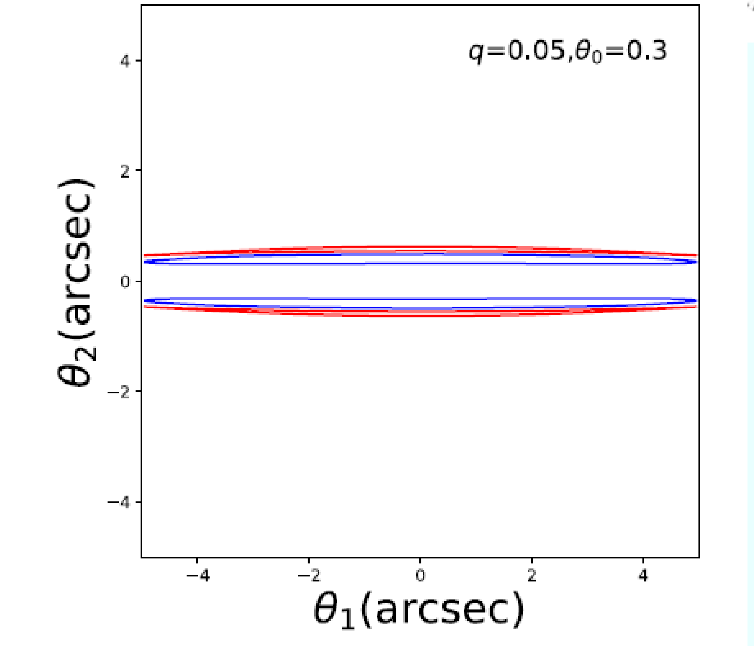


The elliptical distribution

- Highly elongate
- Asymmetric distribution increases lensing efficiency





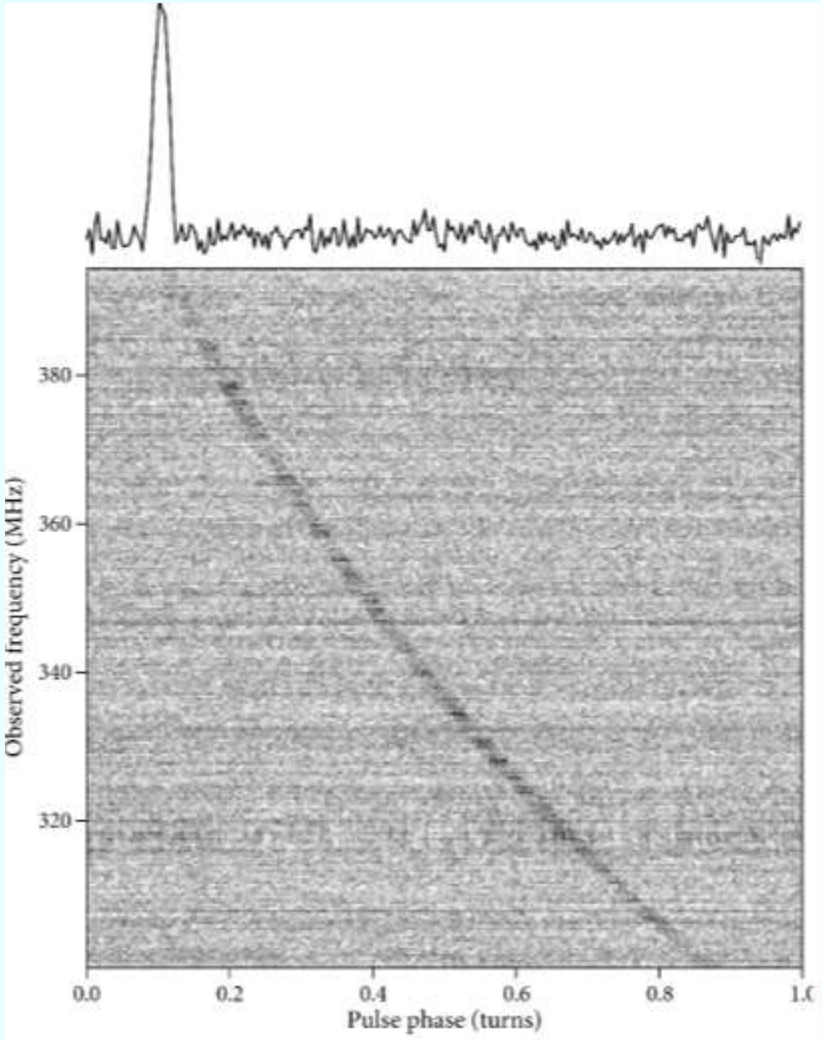


Dispersion Measure

- In pulsar study, the radio signal is delayed by plasma, i.e.

$$V_\nu = c\left(1 - \frac{e^2 n_e}{\pi m_e \nu^2}\right)^2$$

Usually we see,



$$DM = \int n_e \, dl$$

The time delay

In Gravitational Lensing

$$\Delta t \propto \frac{1}{2}(\theta - \beta)^2 \ - \psi$$

-- geometric delay

-- Shapiro delay

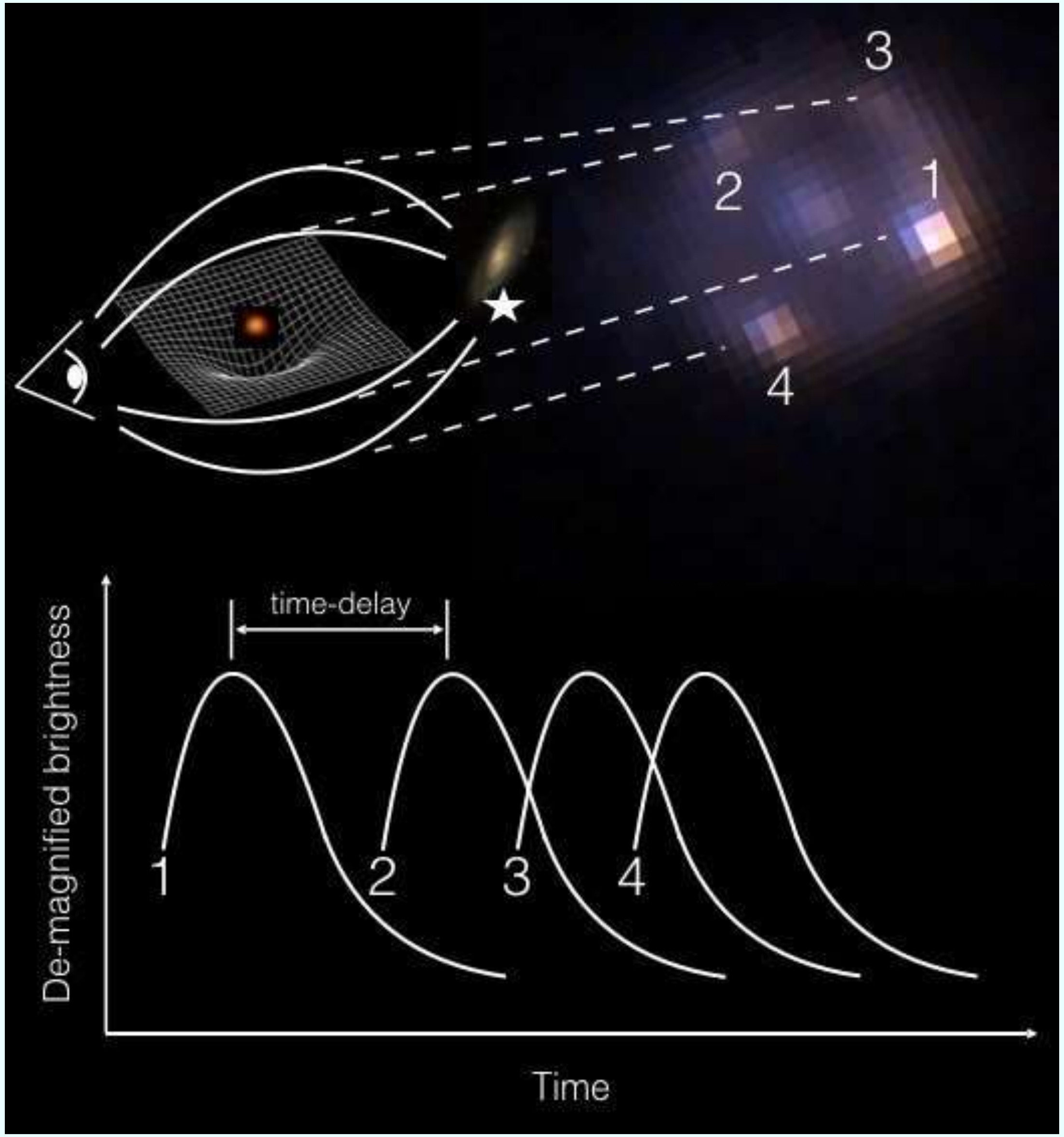
In Plasma lensing

$$\Delta t \propto \frac{1}{2}\ (\theta - \beta)^2 \ - N_e$$

-- geometric delay

-- dispersion delay (DM)

How significant are the two terms?



The geometric delay

- In Shapiro's origin paper:
- In the community of Strong lensing
  - $\theta, \beta \ vs \ \theta_E$
- In plasma lensing?

FOURTH TEST OF GENERAL RELATIVITY

Irwin I. Shapiro
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(Received 13 November 1964)

Recent advances in radar astronomy have made possible a fourth test of Einstein's theory of general relativity. The test involves measuring the time delays between transmission of radar pulses towards either of the inner planets (Venus or Mercury) and detection of the echoes. Because, according to the general theory, the speed of a light wave depends on the strength of the gravitational potential along its path, these time delays should thereby be increased by almost 2×10^{-4} sec when the radar pulses pass near the sun.[1] Such a change, equivalent to 60 km in distance, could now be measured over the required path length to within about 5 to 10% with presently obtainable equipment.[2]

An analytical representation of this predicted increase in delay, useful for discussion, can be obtained by calculating the difference Δt...

tance of closest approach of the radar wave to the center of the sun, x_e is the distance along the line of flight from the earth-based antenna to the point of closest approach to the sun, and x_p represents the distance along the path from this point to the planet. Both x_e and x_p are measured positively in a direction away from the earth. The gravitational radius r_0 for the sun is $GM_S/c^2 \approx 1.5$ km, where G is the gravitational constant, M_S the mass of the sun, and c the speed of light. The right-hand side of Eq. (1) is due primarily to the variable speed of the light ray; the contribution from the change in path, being of second order in (r_0/c), is negligible. (This type of result is a general one for refraction phenomena in which the change in index is small.)

At superior conjunction, when the target planet is by definition on the opposite side of the...

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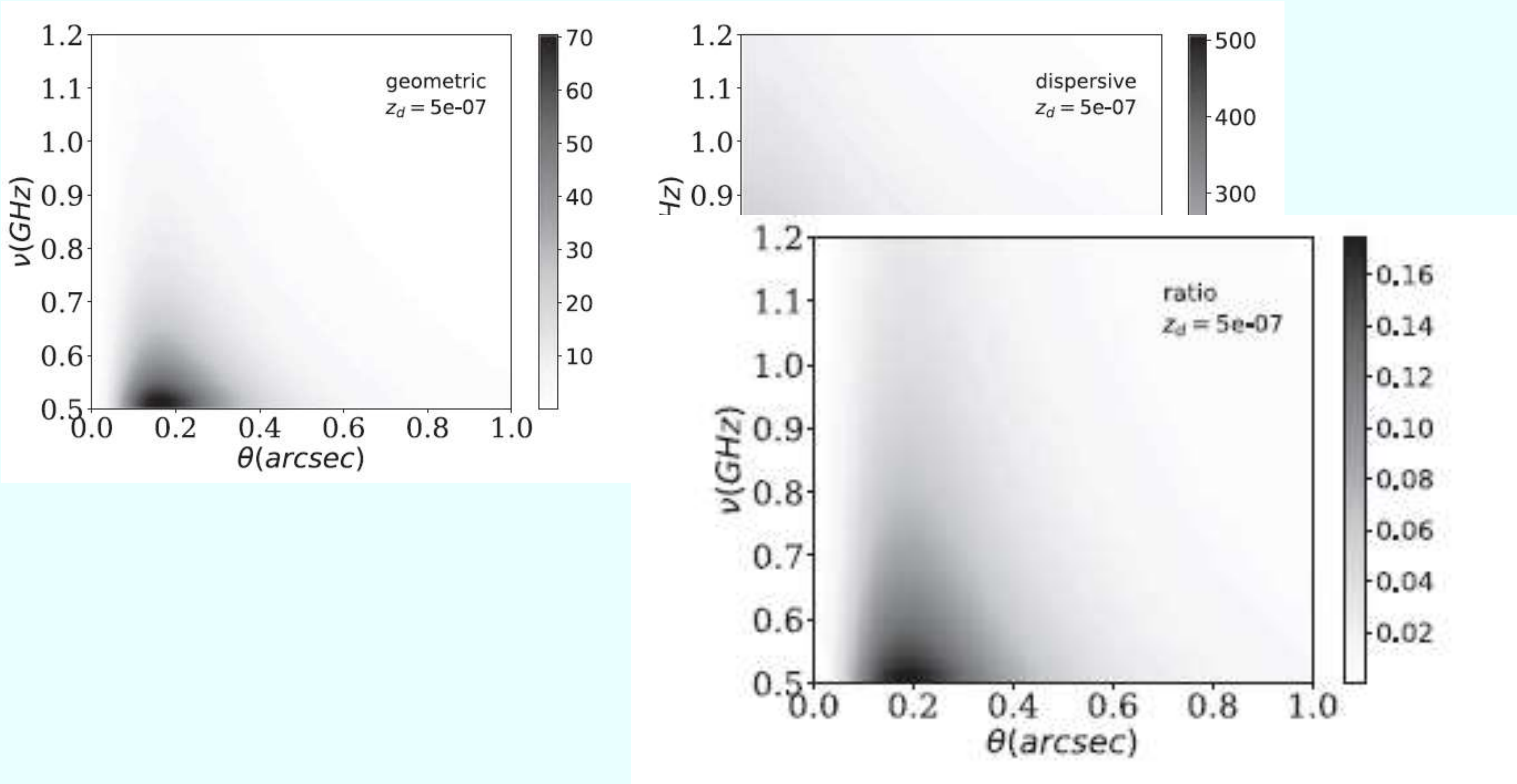
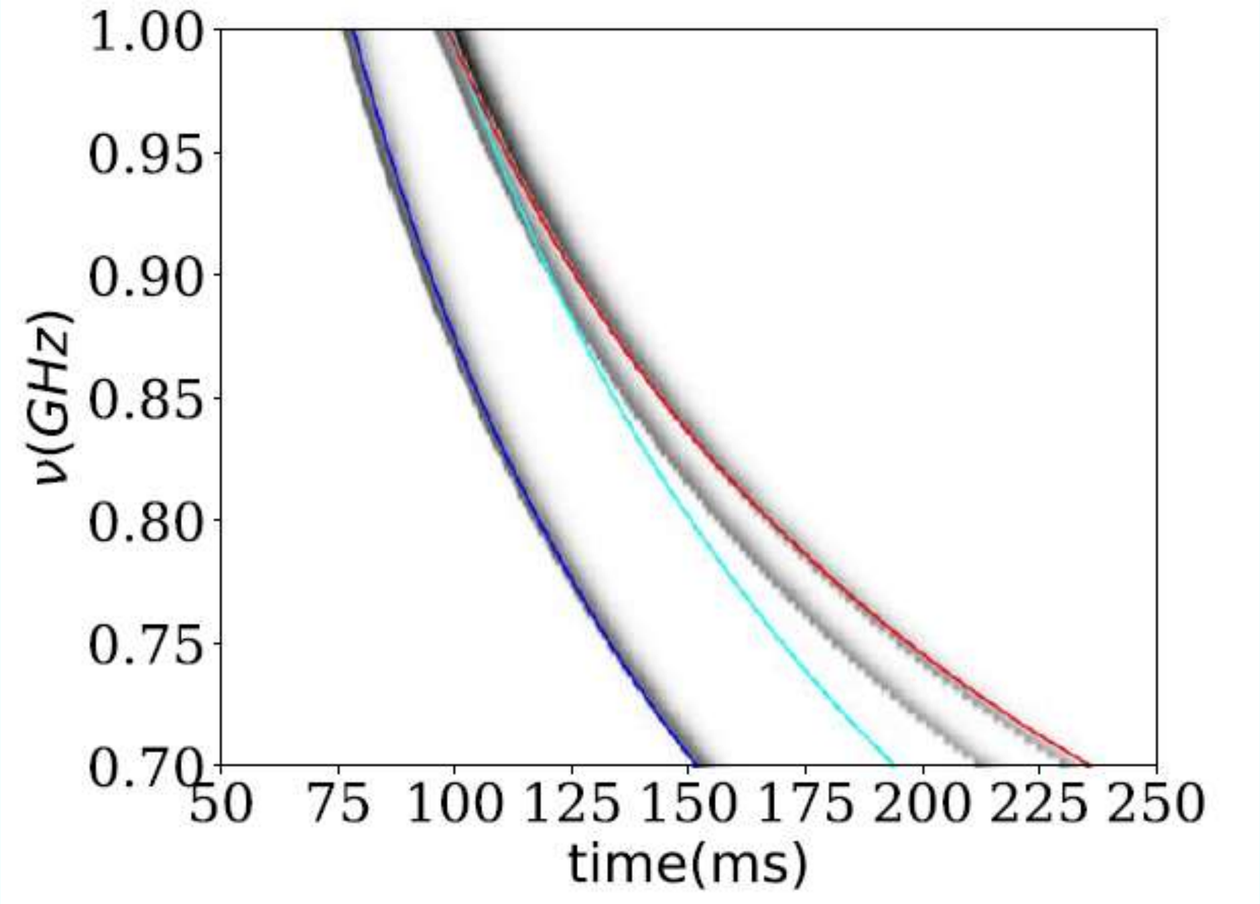
Time delay in plasma lens



Dispersion delay and geometric delay

- The frequency-delay relation (DM delay) $t(\nu) \sim 4.15\ ms\ (\frac{DM}{\nu^2})$
- The geometric delay: $(\theta - \beta)^2 \propto \nu^{-4}$



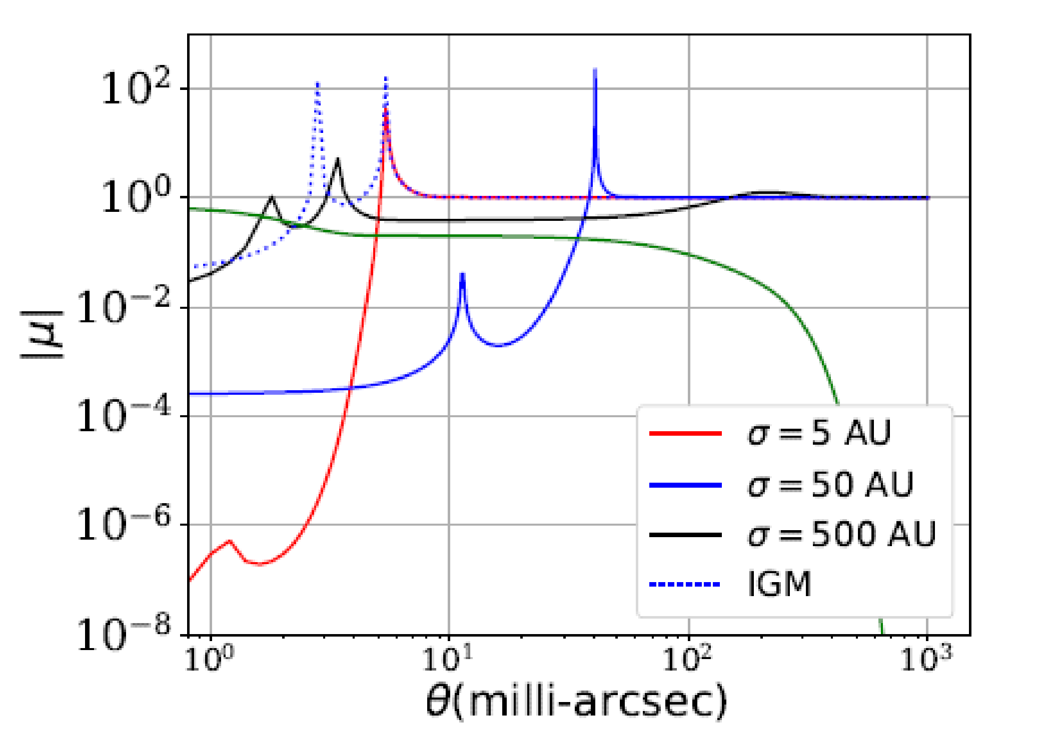
Multiple- planes?

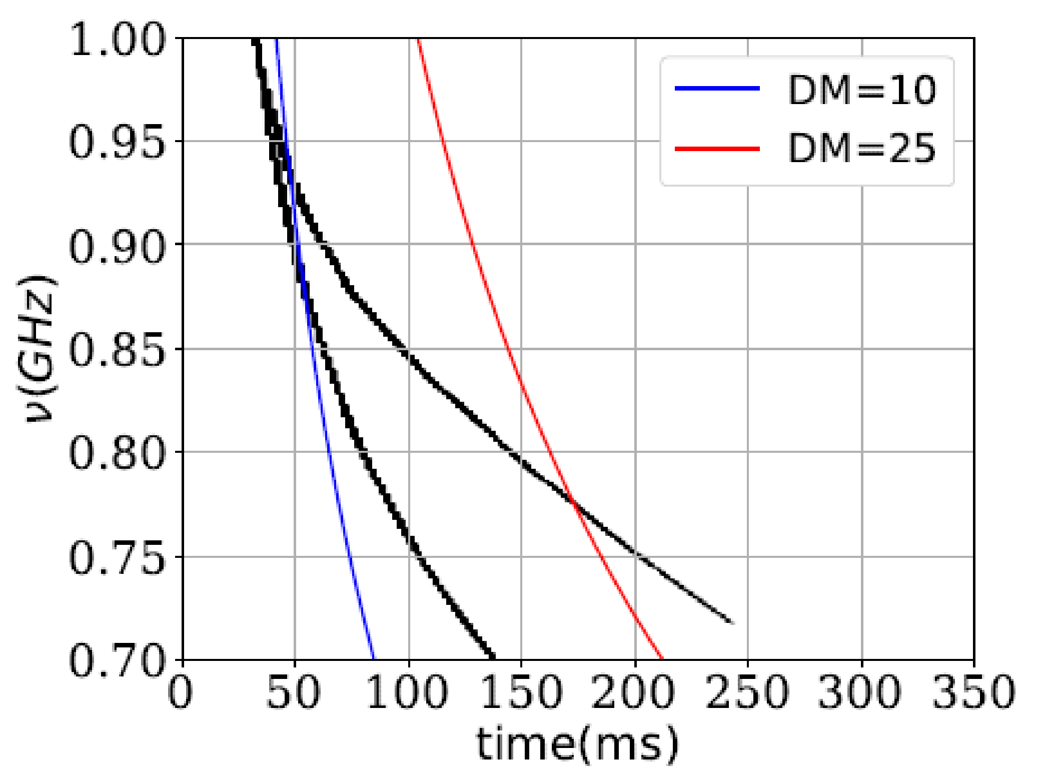
- In GL, the structures alone the line of sight: perturbators

- In plasma lensing, not so.
  - *E.g. the cosmological sources FRB, DM*~$\mathbf{10^2 - 10^3}$
  - $\boldsymbol{DM_{tot} = DM_{MW} + DM_{IGM} + DM_{host}}$ …
  - $\boldsymbol{\psi(\theta) = \frac{D_{ds}}{D_s D_d} \frac{r_e}{2\pi} \lambda^2 N_e(\theta)}$, *distances differ huge*
  - $\boldsymbol{D_{MW} \sim 10\ kpc,\ \ D_{IGM} \sim 10 - 1000\ Mpc}$

Multiple-planes

- An effective single plane? Yes and no
- Then



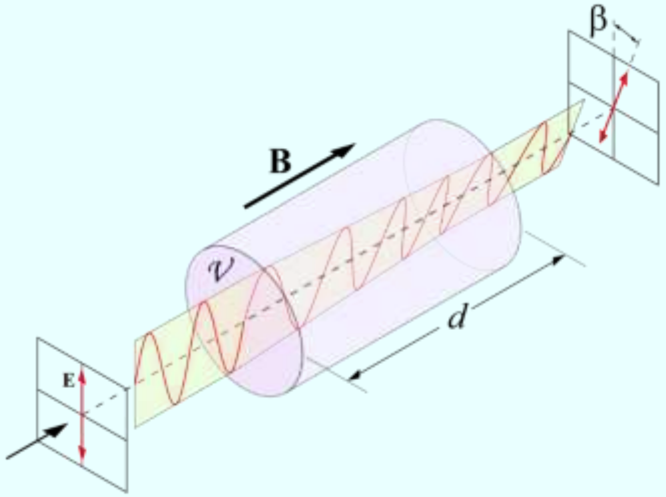


The magnetic field B

- The effective potential with B
  - $\psi(\theta) = \frac{D_{ds}}{D_s D_d} \frac{r_e}{2\pi} [\lambda^2 N_e(\theta) \pm \frac{\lambda^3 r_e}{e} RM(\theta)]$

$$RM = \int n_e B_{\parallel} \, dz$$

- α- depends on the helicity of circular polarization
- Faraday rotation
  - *Linear polarization*



Summary and outlook

- There are scatters by plasma of radio sources
- The DM-frequency relation can be biased
- Multiple-planes are necessary

- More realistic structure, magnetic field
- Multiple-planes and thin lens?
- Can we study IGM using distance source (FRB)?