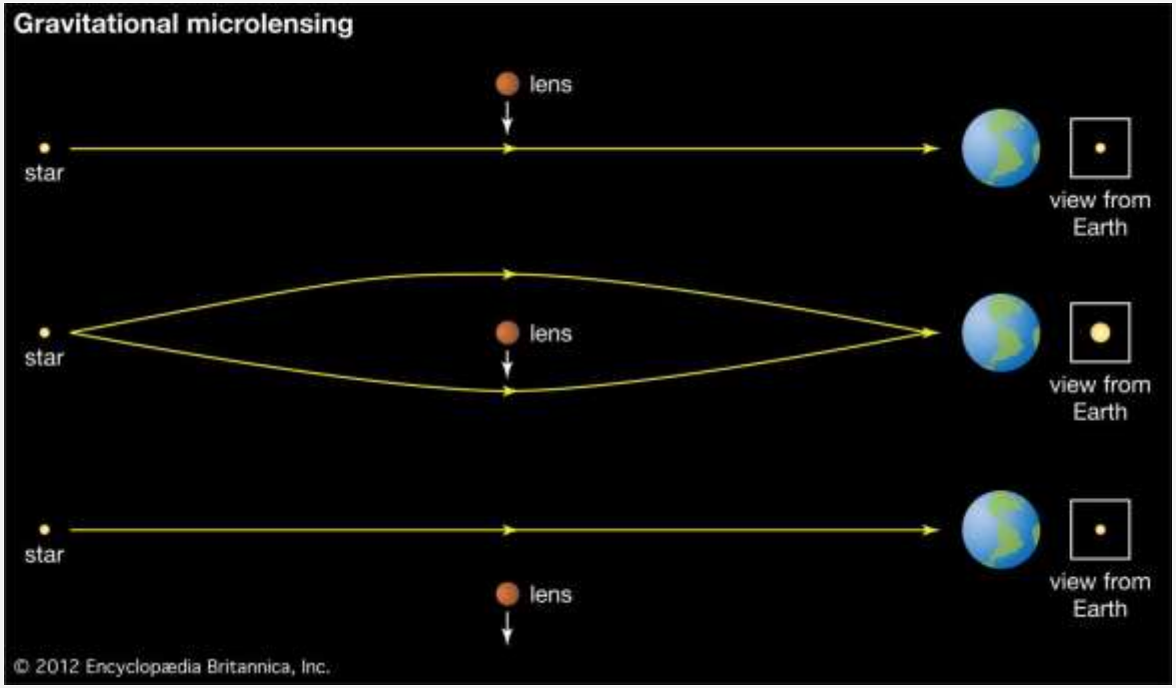
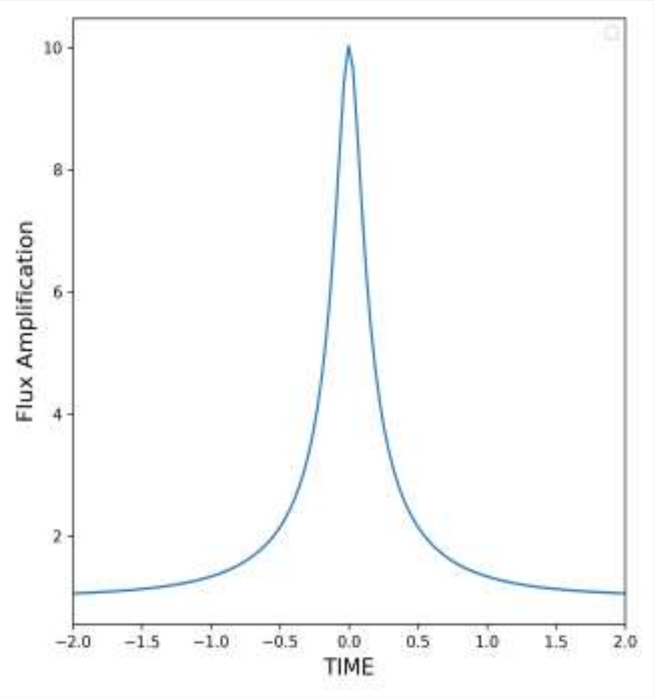
POLARIMETRIC MICROLENSING AS A TOOL FOR BREAKING DEGENERACIES IN COMPACT OBJECT LENSING TOWARD THE GALACTIC BULGE

Marsida Laze[1], Lindita Hamolli[2], Mimoza Hafizi[2]

[1]University of Elbasan “Aleksandër Xhuvani”, Elbasan, Albania
[2]University of Tirana, Tirana, Albania

WHAT IS GRAVITATIONAL MICROLENSING?





- *Light from a background source is bent by a foreground lensing object, reaching the observer.*

- *Observed brightness increases as alignment improves, peaking at closest approach.*

PARAMETER DEGENERACY

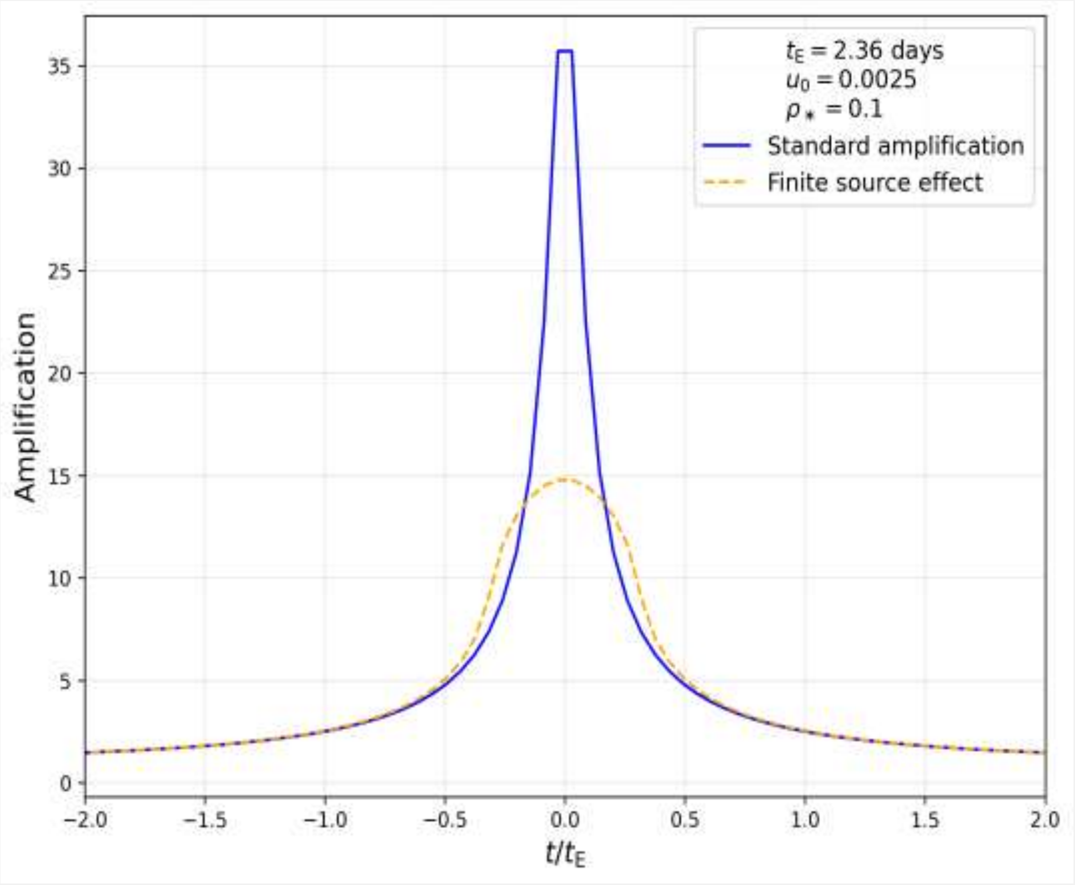
A microlensing event is described by three parameters:

- **Time of maximum amplification - t_0**
- **Einstein time T_E**
- **impact parameter u_0**

- $T_E = R_E/V_T$
- $R_E = \sqrt{\frac{4GM_L}{c^2}\left(\frac{1}{D_L} - \frac{1}{D_S}\right)}$

MICROLENSING LIGHT CURVE

- **1. Standard Amplification (Paczynsky)**
  - **2. Finite source size effects**
  - **3. Paralax**
  - **4. Astrometric shift**
  - **5. *Polarization signal***



➢ ***Figure 1**. Comparison of standard point-source light curve (blue) and finite-source model (red), showing peak suppression and broadening.*

POLARIZATION EFFECTS

- Assumes:
  - **Spherically symmetric, optically thin** envelope
  - **Single scattering**
  - **Central cavity** possible
  - **Radial density profile** of the envelope: $n = n_0(\frac{R_h}{r})^\beta$

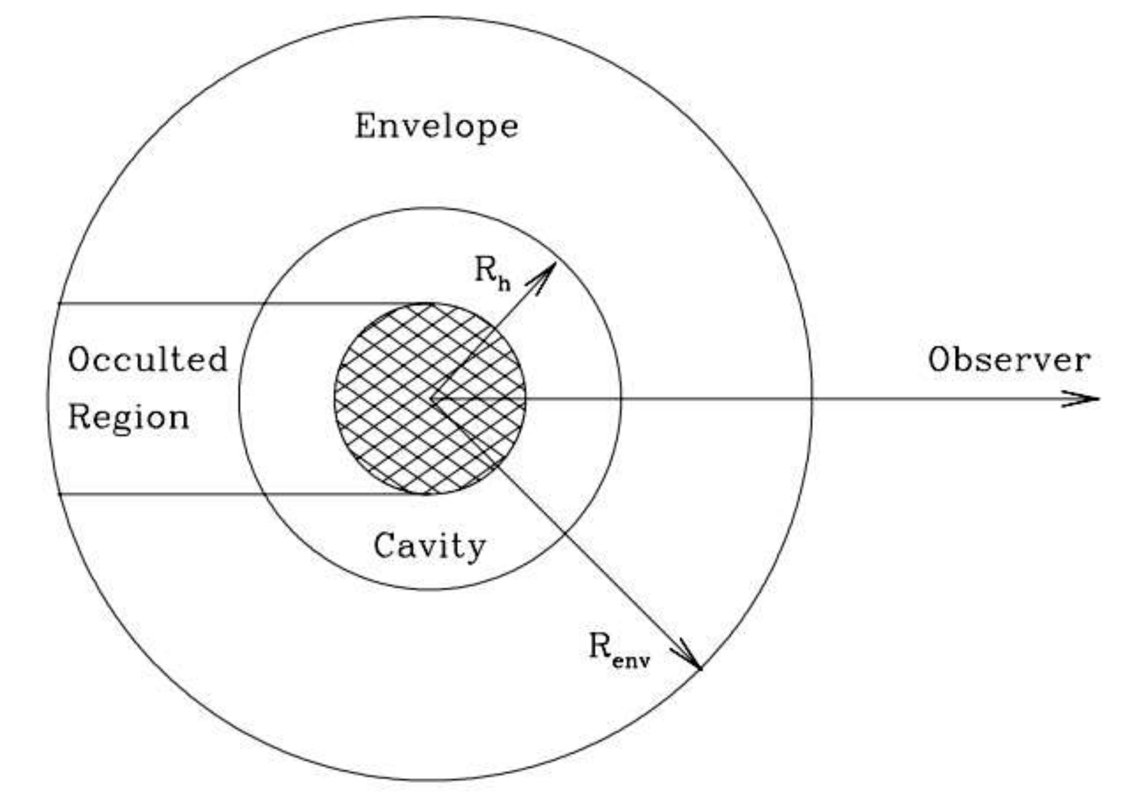


Figure 2: *Geometry of the circumstellar envelope model adopted from Simmons et al. (2002). The central source has radius R_* and the scattering envelope extends from R_h to R_{env}. A cavity exists between the stellar surface and the inner edge of the envelope.*

POLARIZATION SIGNAL

- $P(p_l) = \frac{\tau_{sc} H_p(p_l)}{H_*(p_l)+\tau_{sc} H_I(p_l)}$

➢ Where τ_{sc} is the optical depth of the envelope

➢ $H_P(p_L) = \frac{3(\beta-1)}{16\pi} R_h^{\beta-1} \int_0^{2\pi} \cos 2\alpha' \, d\alpha' \int_0^{\infty} g_0(p)\, p^{\beta+1} A(p,\alpha')\, G_P\, p\, dp$

➢ $H_*(p_L) = \frac{1}{\pi R_*^2} \int_0^{2\pi} d\alpha' \int_0^{R_*} A(p,\alpha')\, p\, dp$

➢ $H_I(p_L) = \frac{3(\beta-1)}{16\pi} R_h^{\beta-1} \int_0^{2\pi} d\alpha' \int_0^{\infty} A(p,\alpha')\, g_0(p)\, p^{\beta+1}\, G_I\, p\, dp$

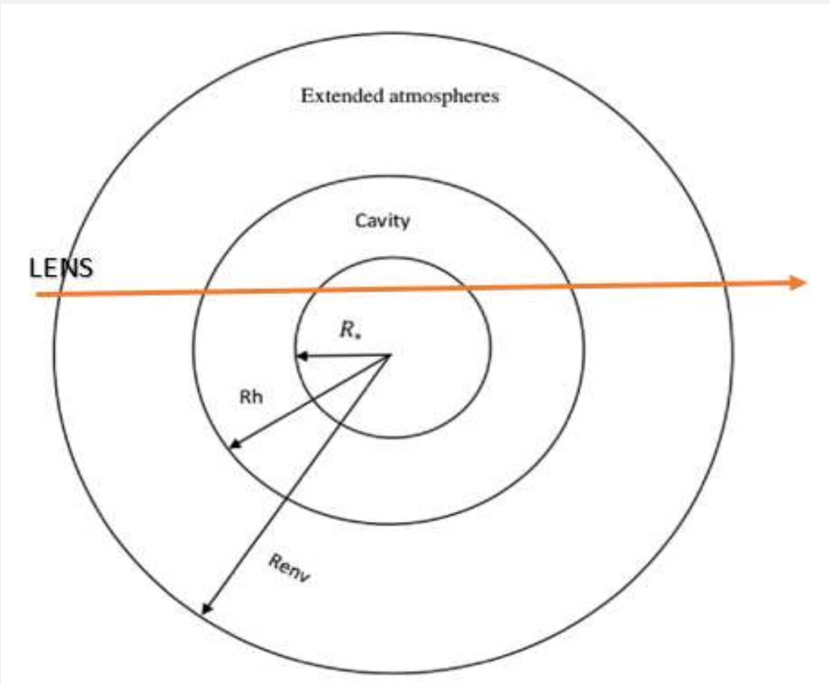
➢ $M(p_l) = H_*(p_l) + \tau_{sc} H_I(p_l)$ is the total flux amplification.

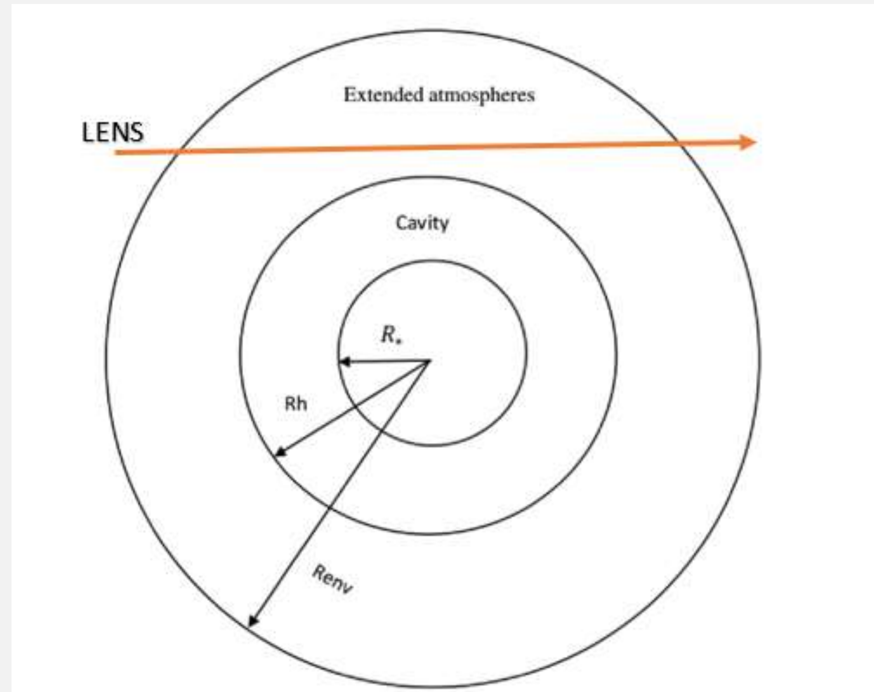
Polarization angle:

- $\Psi = \pi - \tan^{-1}[\frac{\theta_0}{\mu_{rel}(t-t_0)}]$

Changes from 0^o to 180^o and at closest approach the direction of polarization is parallel to the lens direction of travel

TRANSIT AND BYPASS POLARIZATION REGIMES





- TRANSIT

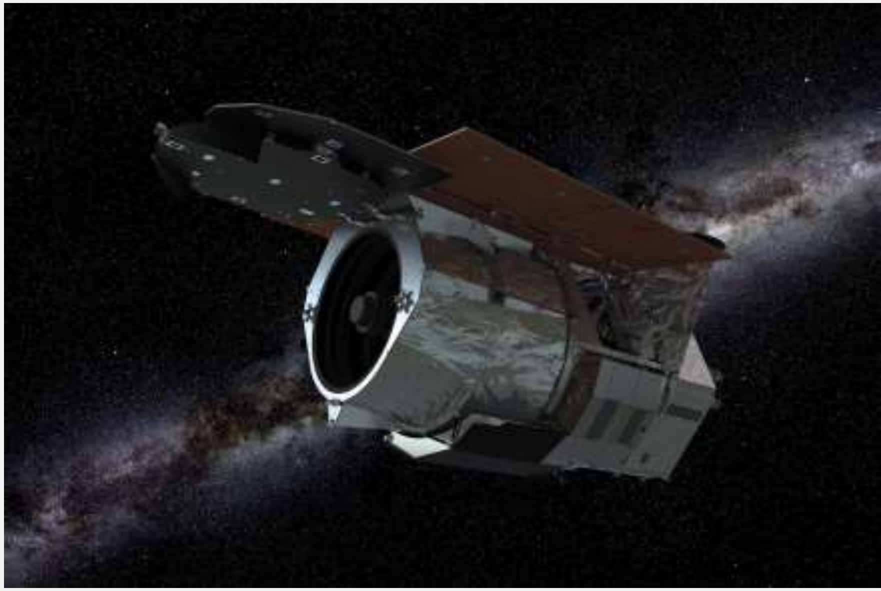
- BYPASS

ROMAN SPACE TELESCOPE

- ***It is scheduled to launch in 2027, at L2 point of the Earth-Sun system.***
- ***It will observe in optic and NIR (from 0.48 to 2.3 µm)***
- **7 fields in Galactic Bulge**

(~2 square degree centered on *l*=*0.8°*, *b*=*-1.4°*)

- **6 seasons during 5 year, 62 days per season**
- ***Cadence 15 min***



FORS2 POLARIMETER AT VLT

The **Very Large Telescope (VLT)** is located at **Paranal Observatory**, in the **Atacama Desert, Chile**. It is operated by the **European Southern Observatory (ESO)** and is one of the most advanced optical telescopes in the world.

- **wavelength range from 330 nm to 1100 nm**
- **Each measurement takes 18 minutes (Exposure time+ Readout time)**
- **The FORS2 precision is 0.1%**

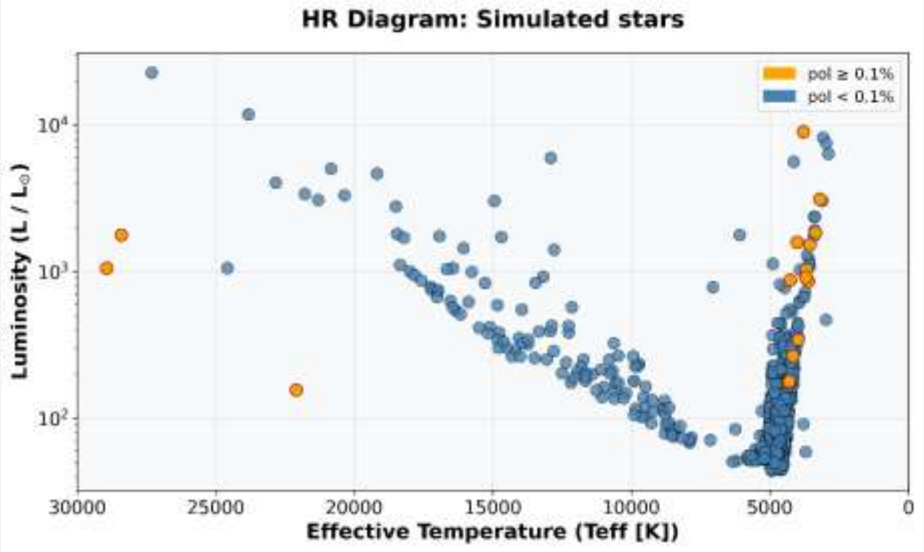
SYNTHETIC RGB POPULATION

- **Simulation Tool:** IAC-STAR online synthetic stellar population generator
- **Sample:** 1,000 bulge stars (L, Teff, g, Z)
- **Purpose:** Identify stars with envelope optical depth τ >0.01

$$\tau_{sc} = 2 \times 10^{-3} \eta \kappa \left(\frac{\dot{M}}{10^{-9} M_\odot yr^{-1}}\right)\left(\frac{30 kms^{-1}}{v_\infty}\right)\left(\frac{24 R_\odot}{R_h}\right)$$

$$v_\infty = 14 \left(\frac{L_*}{1000 L_\odot}\right)^{0.3} \left(\frac{\varrho}{200}\right)^{-0.5} \left(\frac{km}{s}\right)$$

$$\dot{M} = 4\xi \times 10^{-13} \frac{(L_*/L_\odot)}{\left(\frac{g_*}{g_\odot}\right)\left(\frac{R_*}{R_\odot}\right)} (M_\odot yr^{-1})$$



➢ ***Figure 3.*** *Simulated H-R diagram for 1000 bulge stars.*

➢ 1.6% produce a polarization signal above the 0.1% threshold and are therefore deemed detectable with the FORS2 instrument

➢ *56.25% of which were classified as transit and 43.75% as bypass.*

MAGNIFICATION AND POLARIZATION SIGNAL (M_L)

- Stellar radius fixed at R_*= 20 $R_\odot$
- Inner radius R_h= 9 R_*
- optical depth $\tau = 0.1$
- Lens mass range $10^{-5} - 10\ M_\odot$

Key results:

- For lens masses < $10^{-3} M_\odot$ polarization signal is negligible.
- Between $10^{-3} - 10\ M_\odot$ polarization increases with mass
- For lens masses > 10 $M_\odot$ polarization reaches a plateau and remains constant

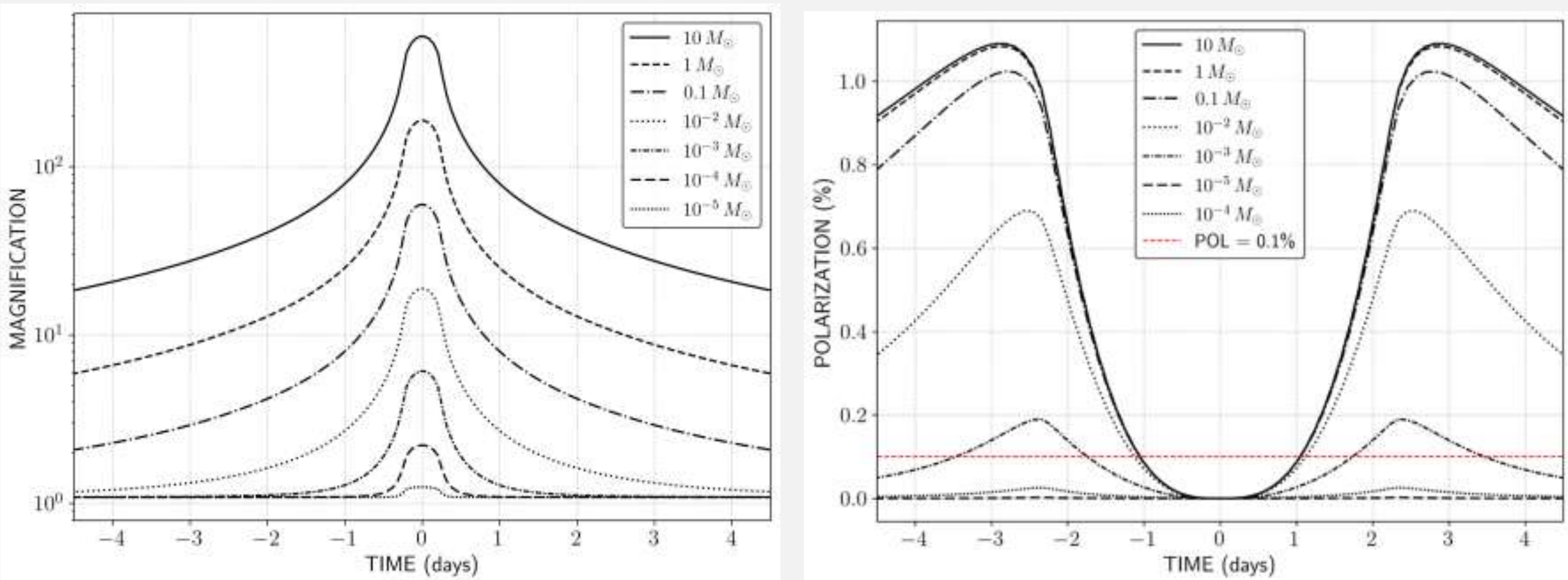
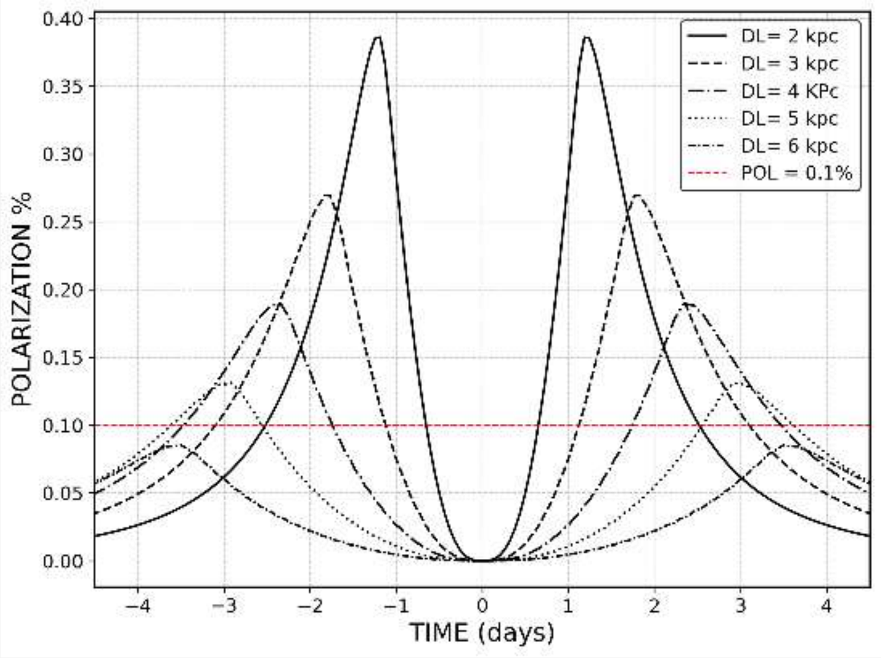


***Figure 4**. Left: Flux magnification over time for different lens masses at distance DL= 4 kpc from the observer. Right: The corresponding polarization curves for each mass. Red line shows the polarization scale sensitivity threshold of FORS2 polarimeter at the VLT*

TRANSIT EVENT (DL)



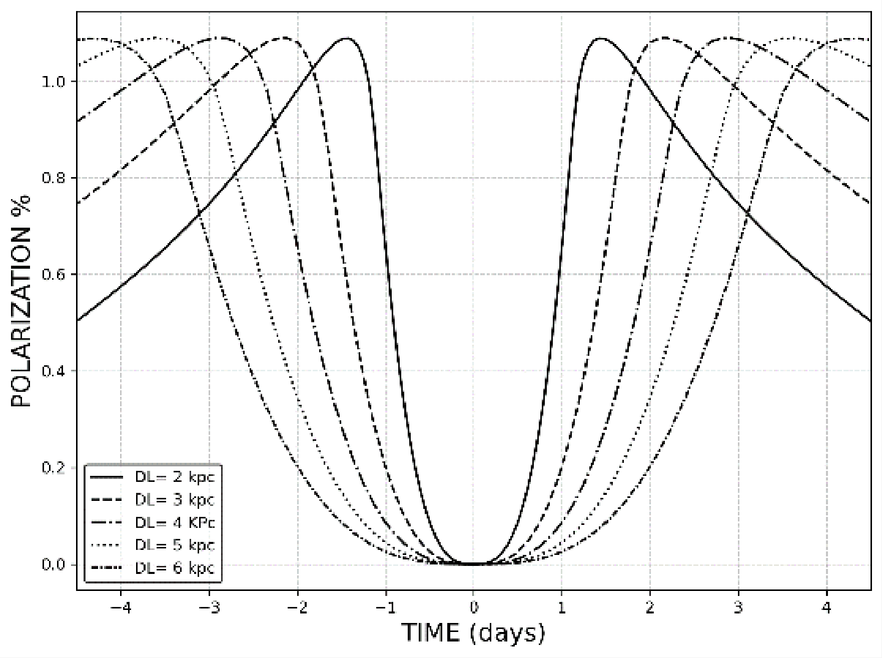


Figure. Polarization curves for fixed lens mass at 0.001 $M_\odot$ (left) and 10 $M_\odot$ (right) at D_L= 2, 3, 4, 5, 6 kpc.

BYPASS EVENTS (M_L)

- When increasing the impact parameter events shift from **transit** to **bypass**
- For lens masses < $0.01 M_\odot$ polarization signal is negligible.
- Between $0.01 - 10\ M_\odot$ polarization increases with mass
- For lens masses > 10 $M_\odot$ polarization saturates and shows little change

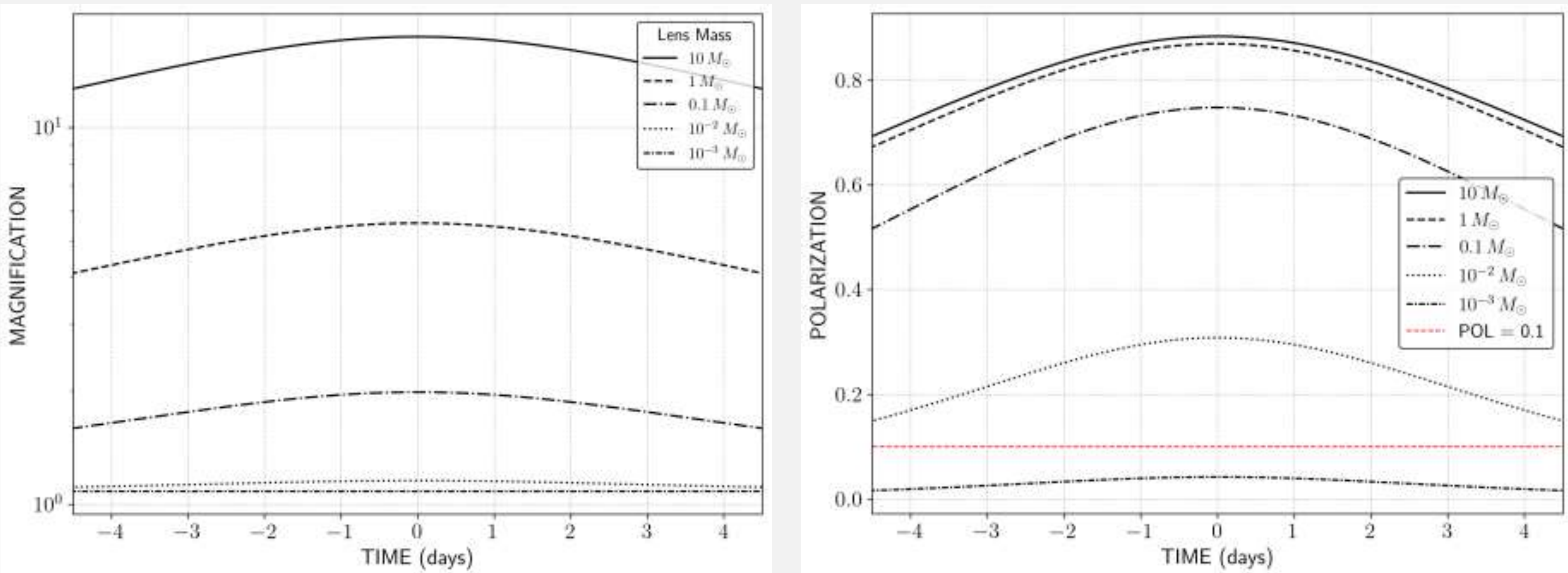


Figure 8. *Left: Flux magnification curves for fixed lenss distance DL=4 kpc and different masses in bypass events. Right: Corresponding polarization curves. Red line: polarization threshold of 0.1%*

BYPASS EVENTS (DL)

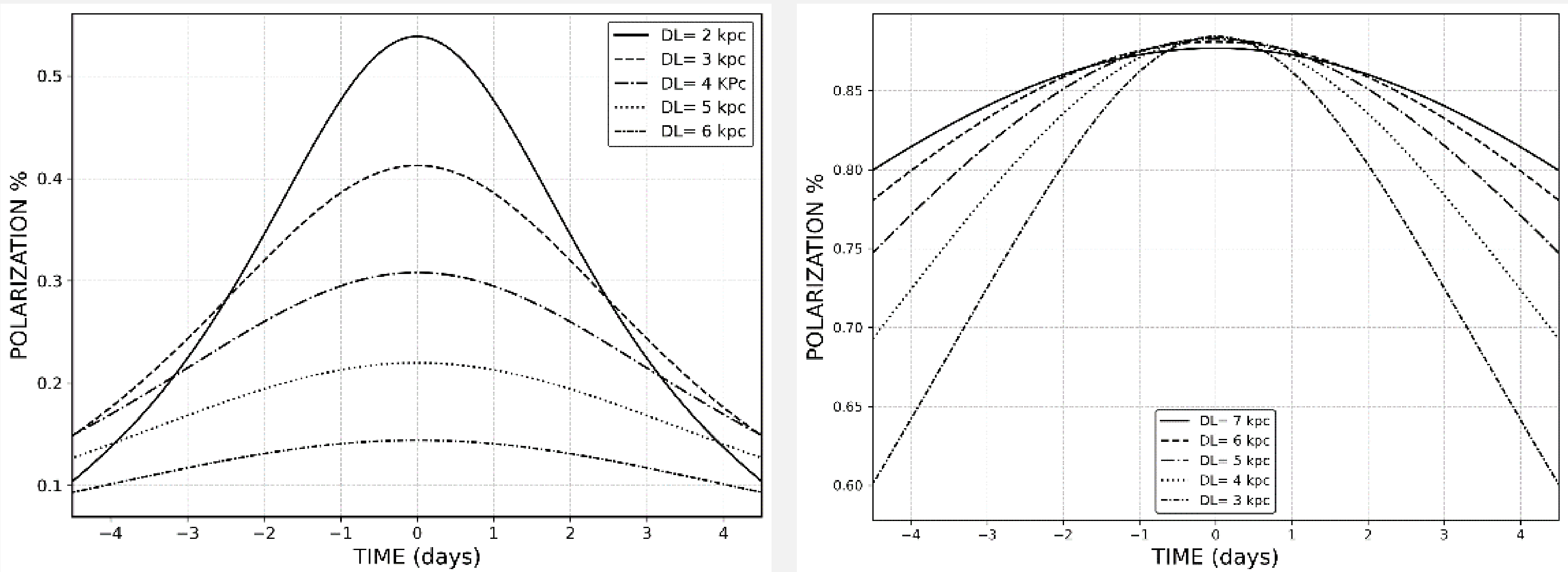


Figure 10. Bypass events polarization curves for fixed lens mass at 0.01 $M_\odot$ (left) and 10 $M_\odot$ (right) at D_L= 2, 3, 4, 5, 6 kpc

CONCLUSIONS

- *For subsolar lens masses, the polarization signal weakens with increasing lens distance, whereas for lens masses* $\geq 10\ M_\odot$ *it is maximized and remains roughly constant with distance.*
- *The best range for a detectable signal is between* 10^{-3} *to* $10^2\ M_\odot$ *at a distance* ≥ 5 *kpc, with the highest signal appearing in transit events.*
- *For bypass events, polarization signal follows the same trend as in transit but at a lower peak. It is negliable for lens mass* $< 10^{-2} M_\odot$ *and becomes constant for lens mass* $>10\ M_\odot$
- *From our simulations we find that 1.6% of events produce a measurable signal. 56.25% of these events were classified as transit and 43.75% as bypass.*

THANK YOU FOR YOUR ATTENTION!