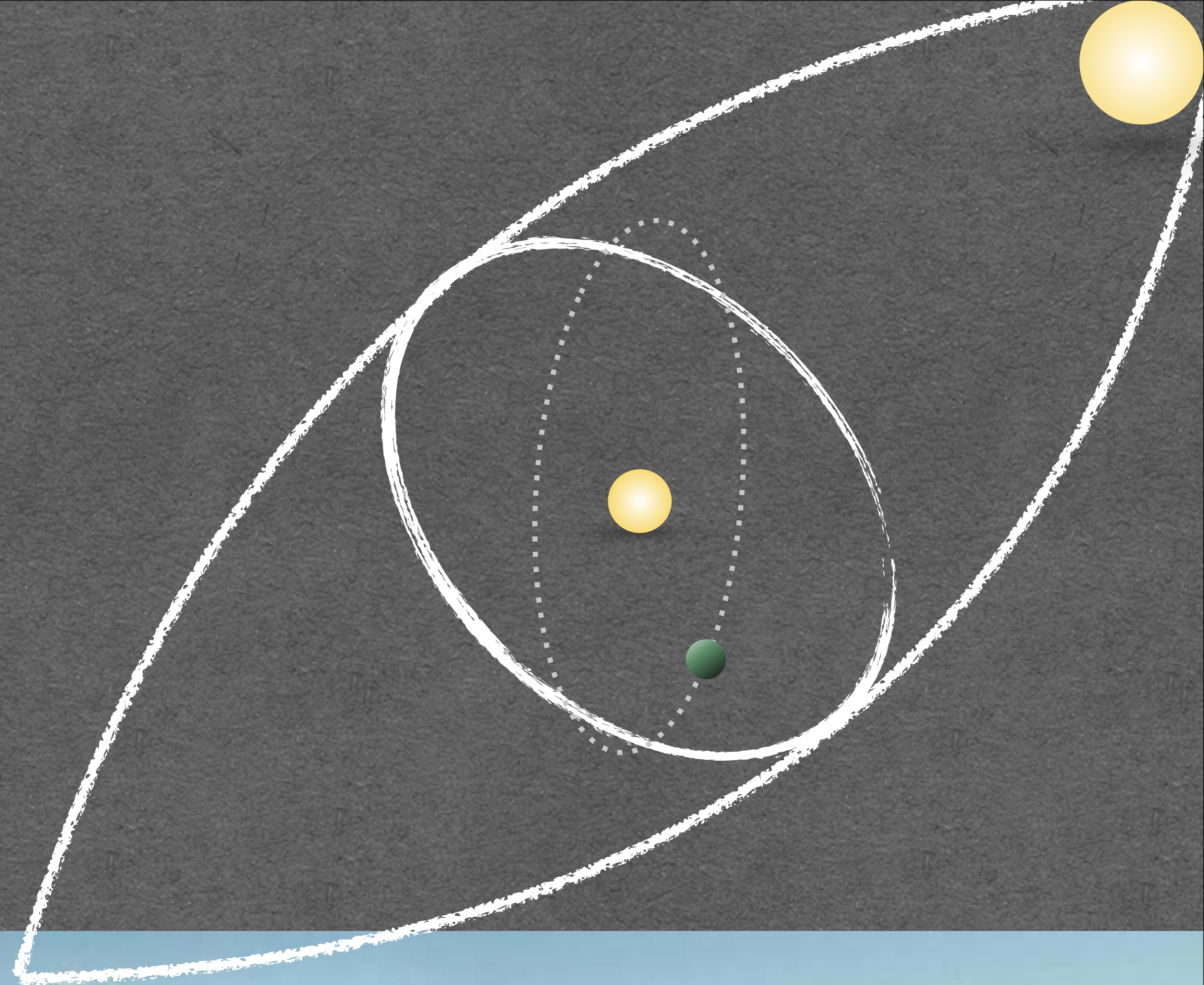
Microlensing observations via interferometry



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CHARA science week — Wednesday March 26th

UPMC SORBONNE UNIVERSITÉS

Overview

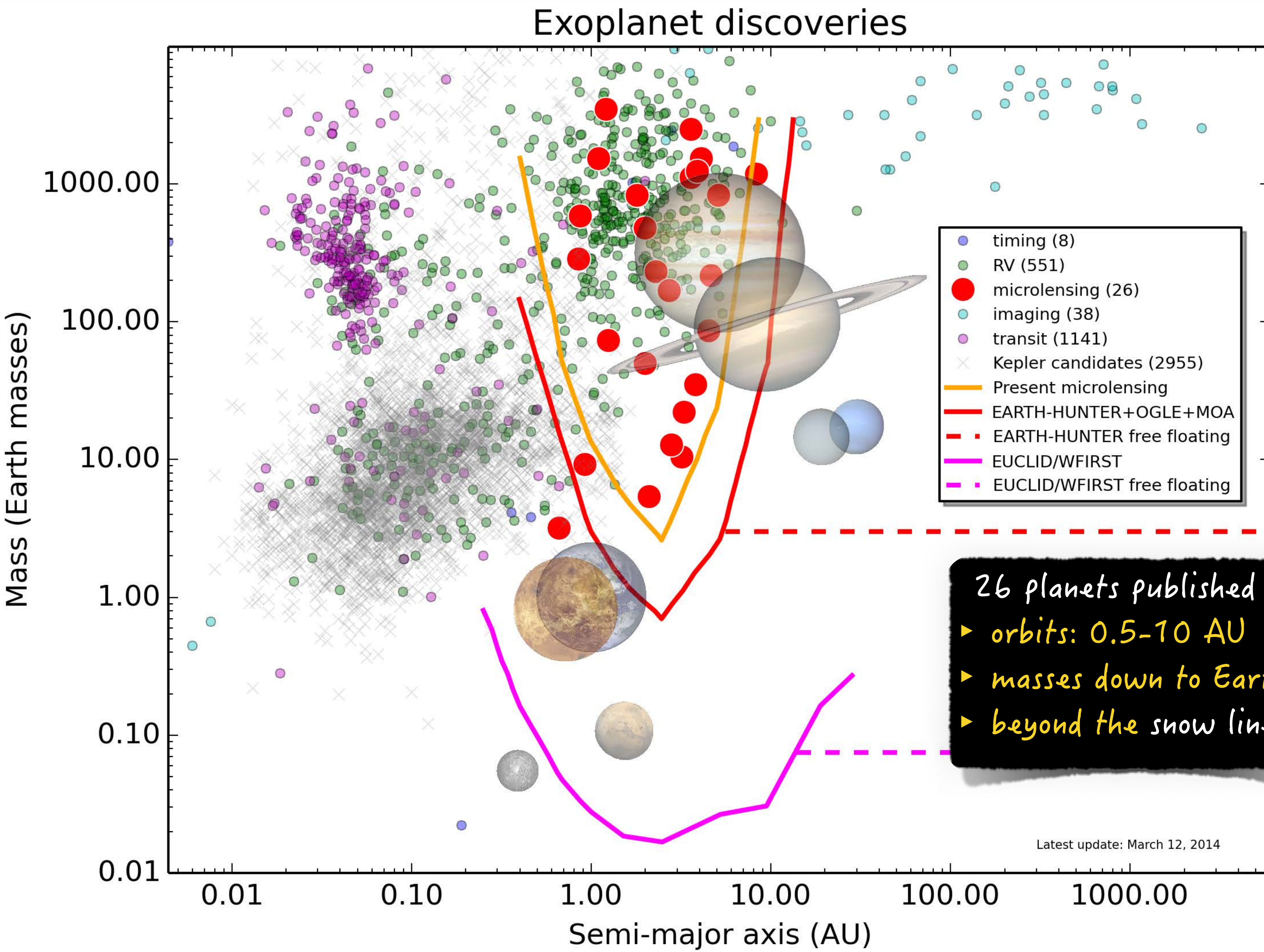
1. On gravitational microlensing

- This method among exoplanets detection techniques
- What's gravitational microlensing?
- Gravitational microlensing events
- Breaking the degeneracies

2. Microlensing observations with an interferometer

- How many events could be observed every year?
- Visibility: when interferometry joins microlensing
- Simulations
- Observational strategy

Microlensing among exoplanets detection techniques



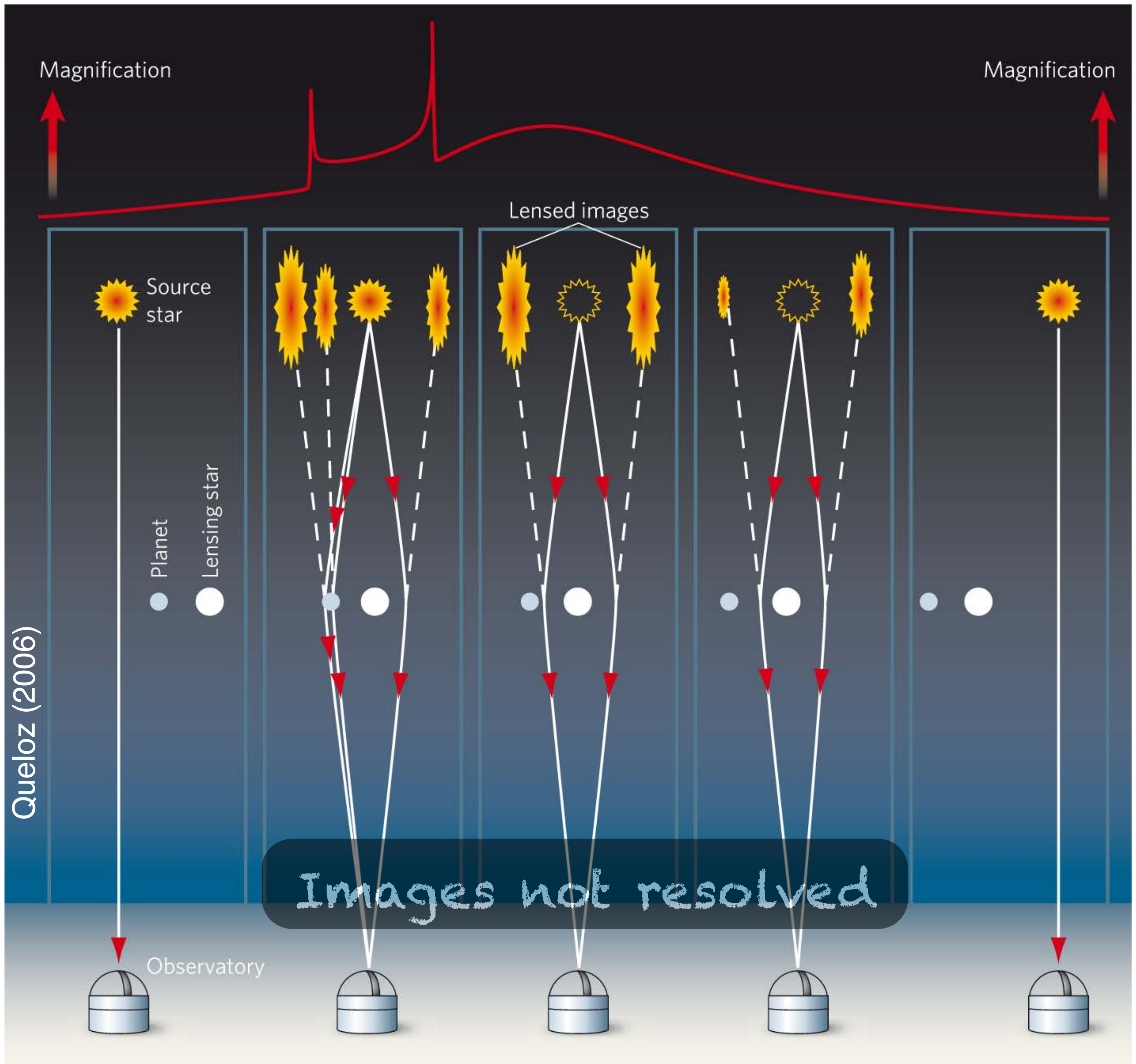
26 planets published

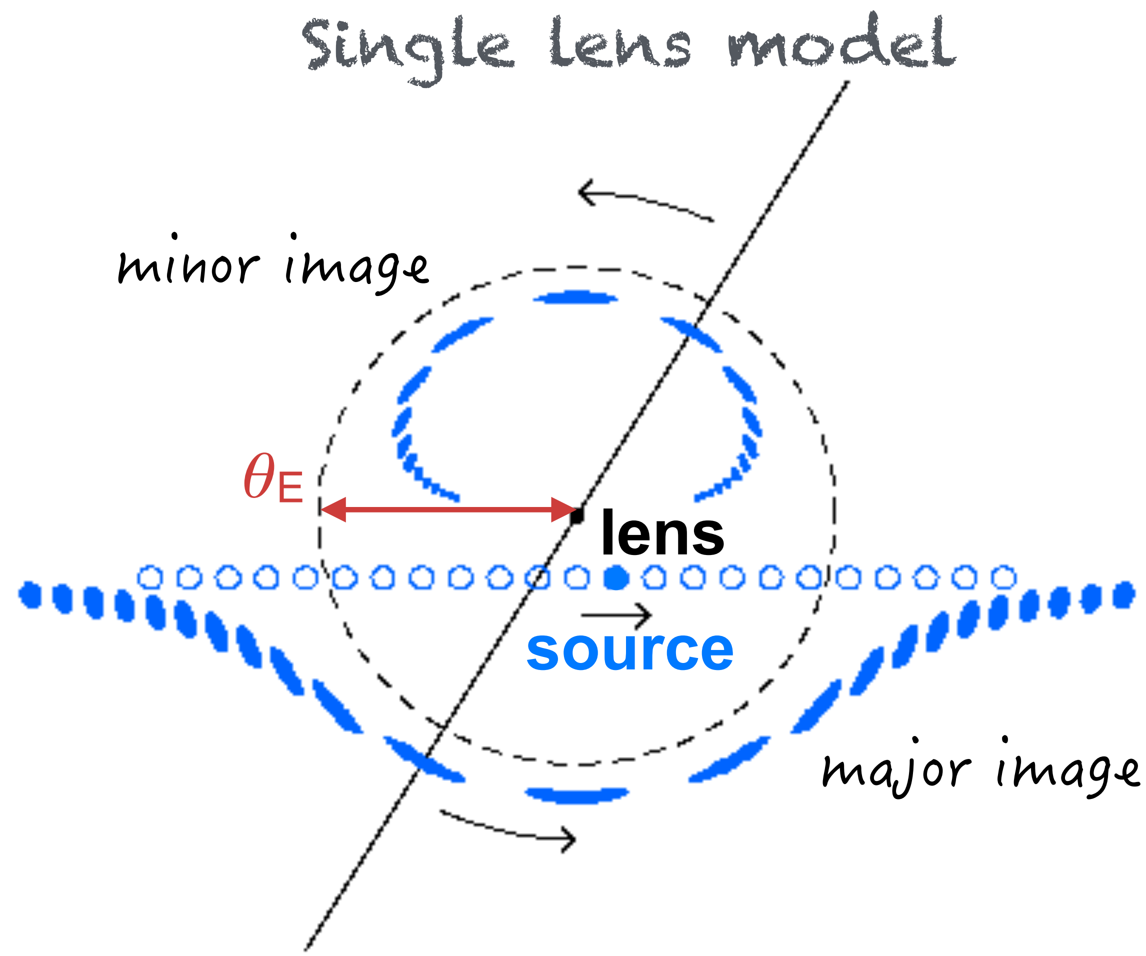
- orbits: 0.5-10 AU
- masses down to Earth
- beyond the snow line

What's gravitational microlensing?

Deflexion due to a star. microlens

High sensitivity to the mass distribution in the microlens plane.





Angular scale: **Einstein radius θ_E**

Typical values:

$\theta_E \leq 1$ mas

$D_l \sim 8$ kpc

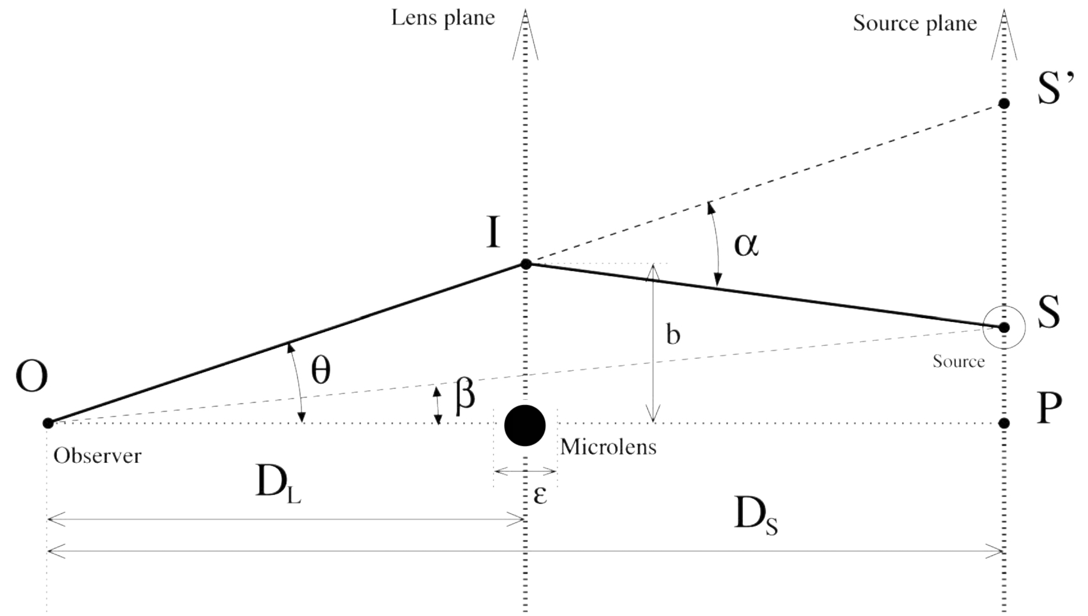
$D_s \sim 0.5 - 8$ kpc

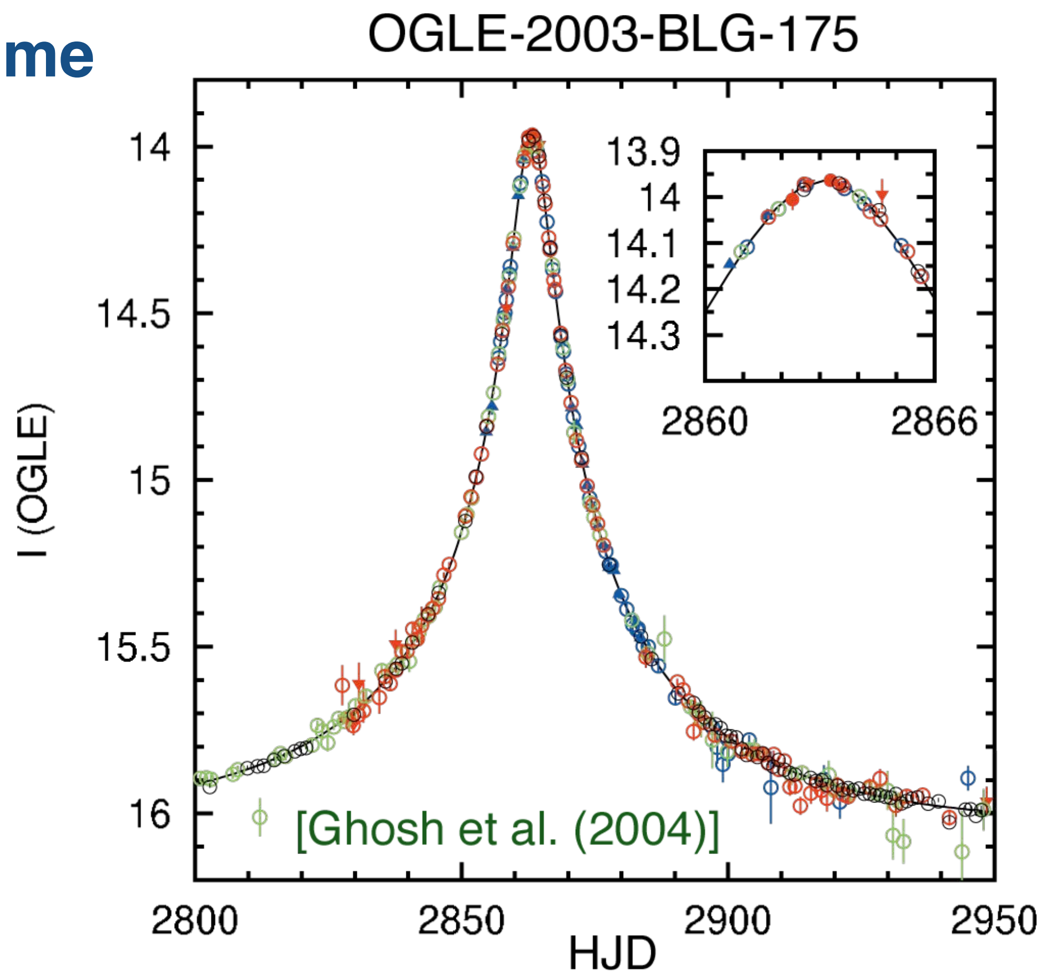
Images can be resolved by a 200m baseline in K band.

Gravitational microlensing events

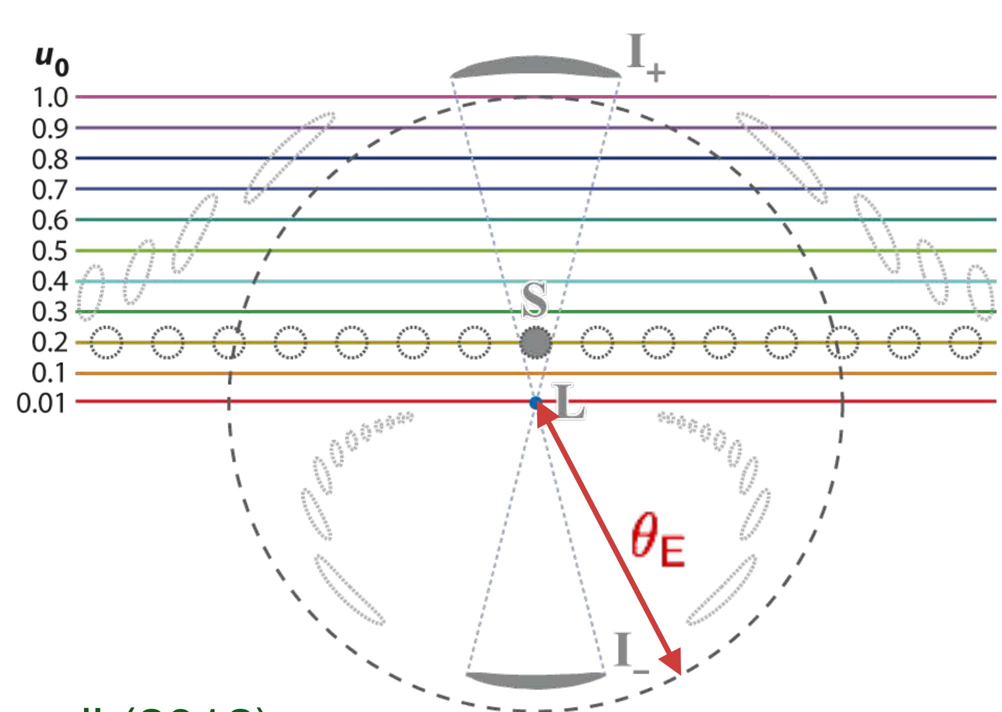
- **Light curve: source magnification as a function of time**

Follow up by international collaborations such as OGLE, MOA, PLANET, RoboNet, μFUN…

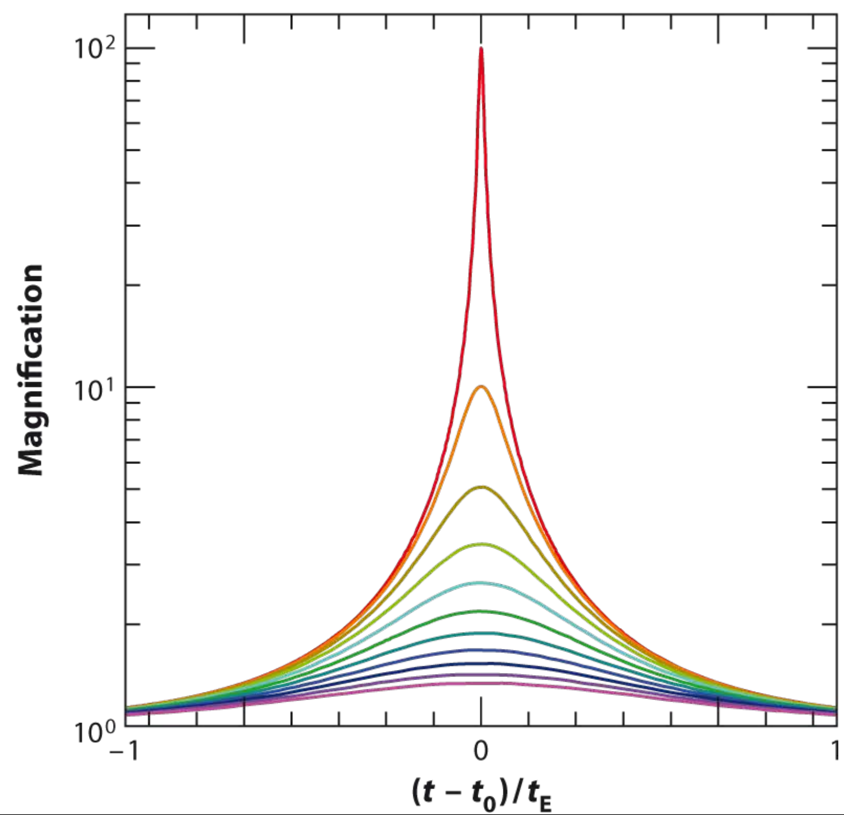




- **Characteristic length parameter: Einstein radius θ_E**



Gaudi (2012)



Typical values:

$\theta_E \leq 1$ mas

$D_l \sim 8$ kpc

$D_s \sim 0.5 - 8$ kpc

Breaking degeneracies

- A light curve gives the Einstein timescale but not the Einstein radius

degeneracies between parameters

$$t_E = \frac{D_L \theta_E}{v} \quad \text{with} \quad \theta_E = \sqrt{\frac{4\,G\,\mathcal{M}}{c^2}\left(\frac{1}{D_L} - \frac{1}{D_S}\right)}$$

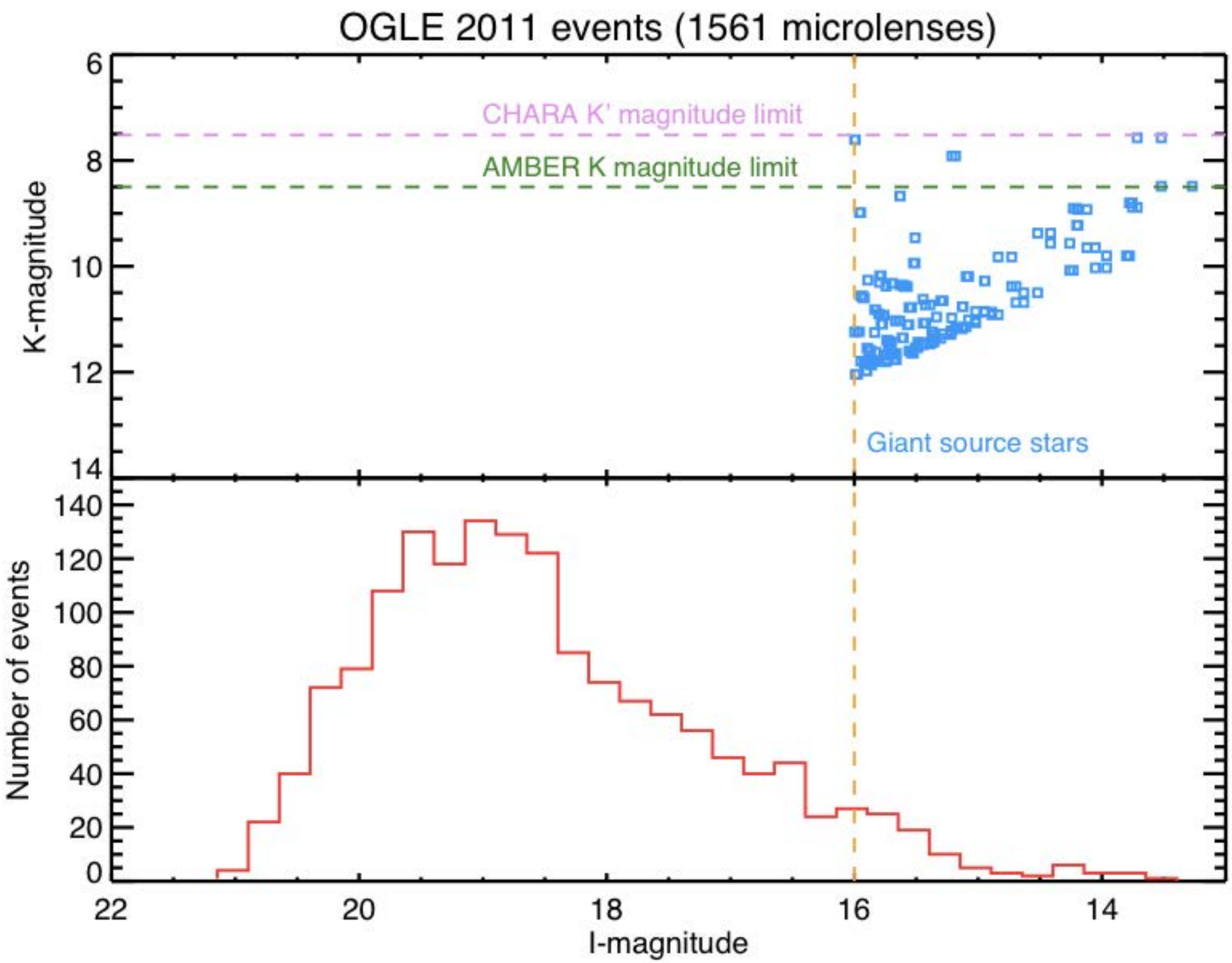
- How can we break the parameters degeneracy?
  - ✓ Measuring the source size
  - ✓ Measuring parallax effects
  - ✓ Using high-resolution AO images

… Measuring the Einstein radius θ_E resolving the images with an interferometer

Typical values:
$\theta_E \lesssim 1$ mas
$t_E \sim 50$ days
$D_l \sim 8$ kpc
$D_s \sim 0.5 - 8$ kpc

Einstein radius → mass of the lens → full characterisation of the potential exoplanet

How many events could be observed every year?



Criteria

- High magnitication events
- Bright events

… Answer: a few!

Visibility: when interferometry joins microlensing

- Microlensing point of view

If parallax constrained:

$$\pi_{\rm rel} = 1\ {\rm mas}\left(\frac{1\ {\rm kpc}}{D_{\rm L}} - \frac{1\ {\rm kpc}}{D_{\rm S}}\right)$$

$$\pi_{\rm E} = \frac{\pi_{\rm rel}}{\theta_{\rm E}}$$

If source size constrained:

$$\rho = \frac{\theta_{\rm S}}{\theta_{\rm E}}$$

… assumptions on the source location/type often necessary

- Interferometry point of view: **visibility** is related to the **Einstein angular radius**

$$\mathcal{V} = |\gamma(\mathrm{T}_1, \mathrm{T}_2)| = \left|\frac{\mathcal{F}_{[\mathcal{L}(x\,\theta_E,\, y\,\theta_E)]}(u,v)}{\mathcal{F}_{[\mathcal{L}(x\,\theta_E,\, y\,\theta_E)]}(0,0)}\right|$$

N multiple images located at $\vec{r}_i$

$$\mathcal{V}(\vec{k}) = \frac{\left[\sum\limits_{1\leq i\leq N} A_i^2 + \sum\limits_{1\leq i<j\leq N} 2A_iA_j\cos\left(\vec{k}\cdot\vec{r_{ij}}\right)\right]^{1/2}}{\sum\limits_{1\leq i\leq N} A_i}$$

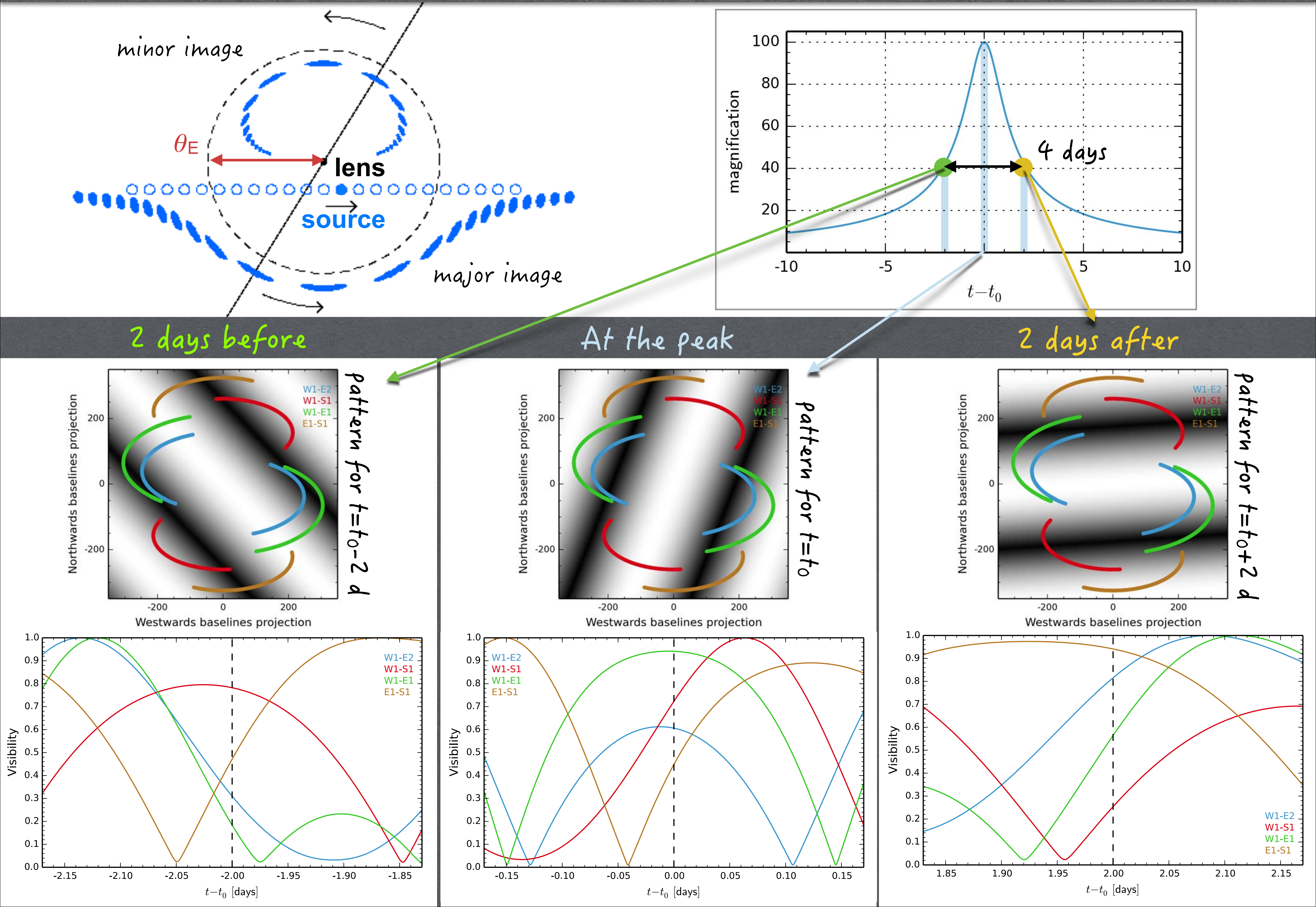
$$\vec{r}_{ij} = \vec{r}_i - \vec{r}_j$$

$$\vec{k} = \frac{2\pi\theta_E}{\lambda_0}\begin{vmatrix}\Delta X\\ \Delta Y\\ \Delta Z\end{vmatrix}$$

Independent measurement of θ_E

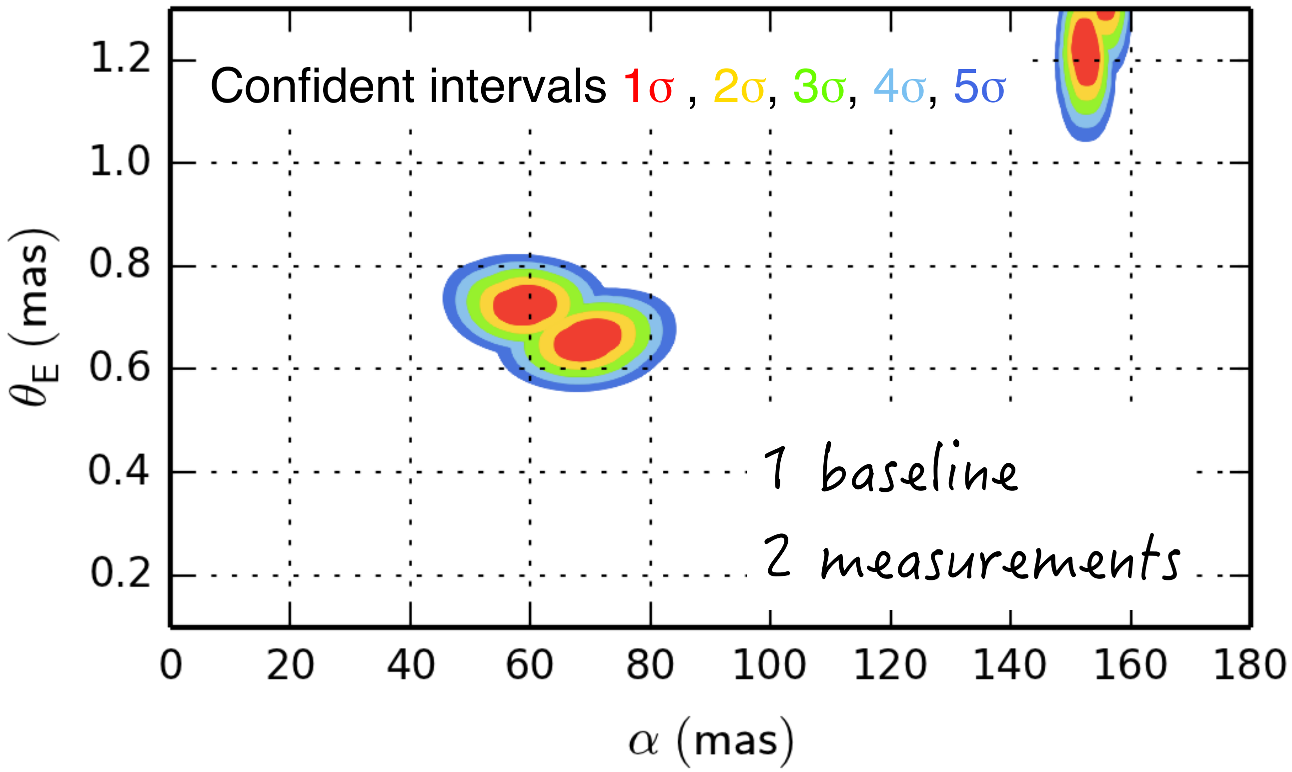
- Visibility as a function of time due to the rotation of images as well as the Earth motion

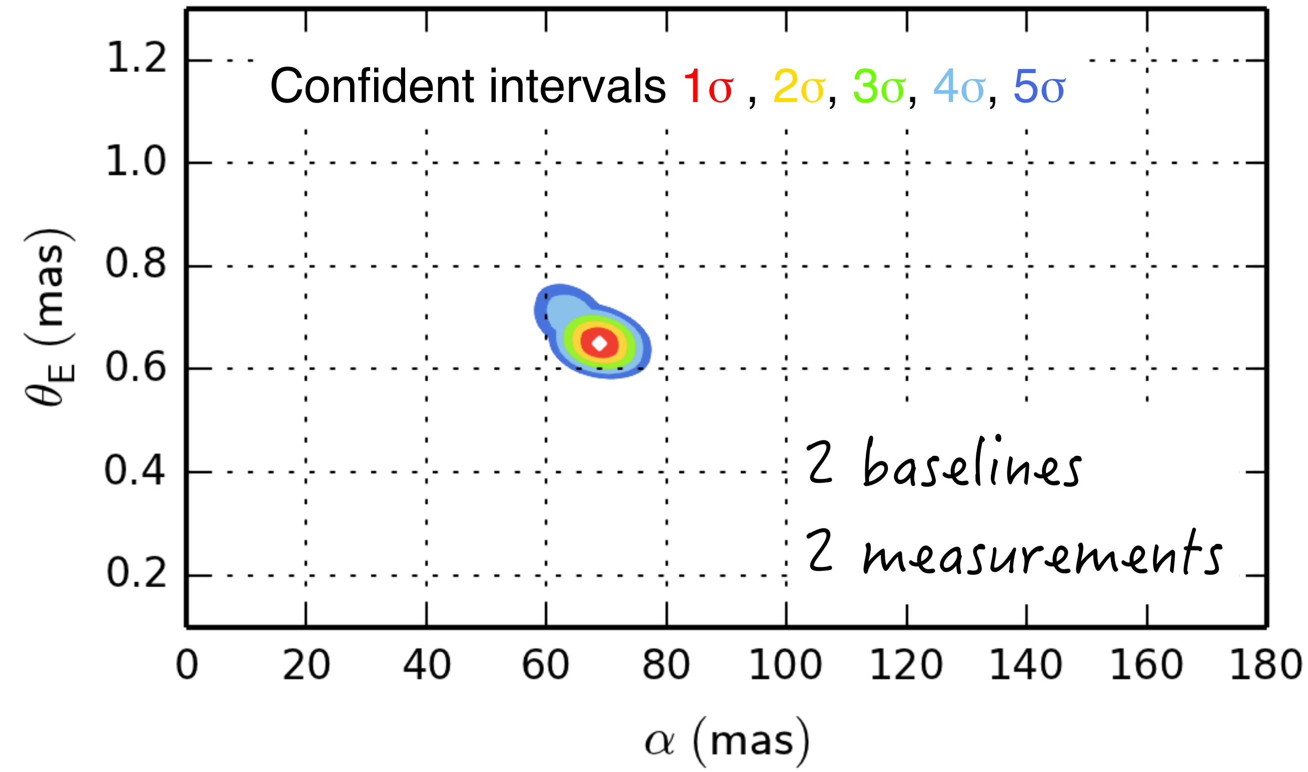
Simulations



Simulations

- Both **prediction** AND **parameters determining** after observations.





- Possibility to use prior from Galactic models for both α and θ_E

- Strategy based on **high-magnification events** alert/follow-up
  - for microlensing network, it is a **usual strategy** (although very demanding)
  - new for CHARA

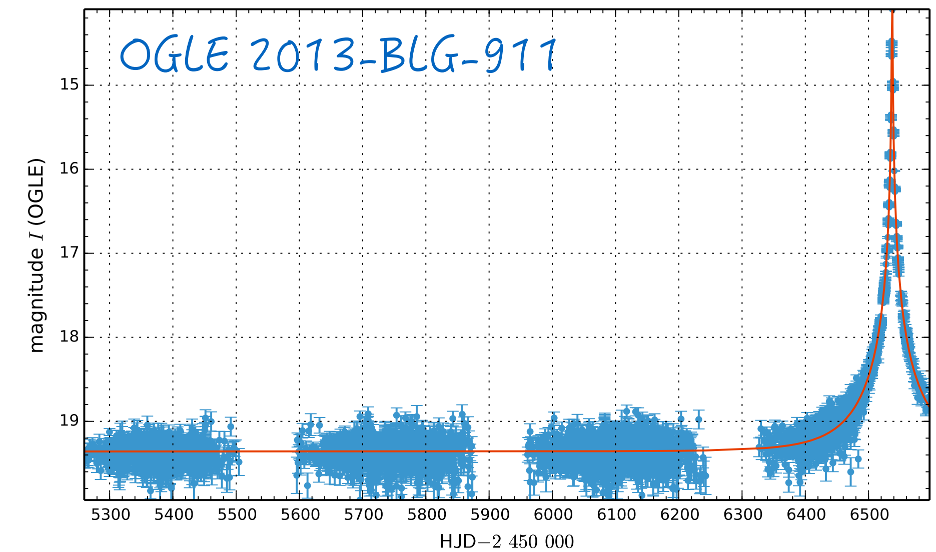
  ⟶ Experimental observation runs will be necessary to test the full strategy

- Interpretation of interferometric observations rely on the **photometric light curve.**

Observational strategy

Stage 1: follow-up & real time analysis

Follow up by OGLE, MOA, PLANET, RoboNet, μFUN…



Stage 2: alert

Real-time analysis for anomaly alert

↓

Probability distribution function on
- date of peak t_0
- amplification at t_0
- magnitude at t_0

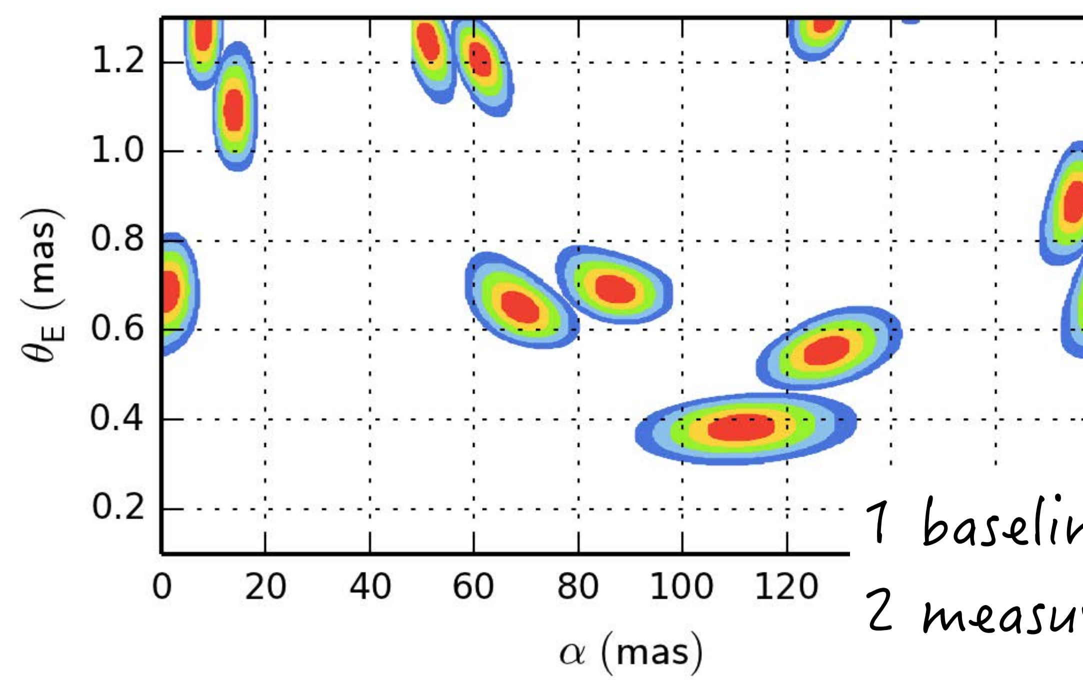
↓

As soon as optimal night is known:

ALERT

Stage 3: back-and-forth

Available telescopes / expectations from simulations

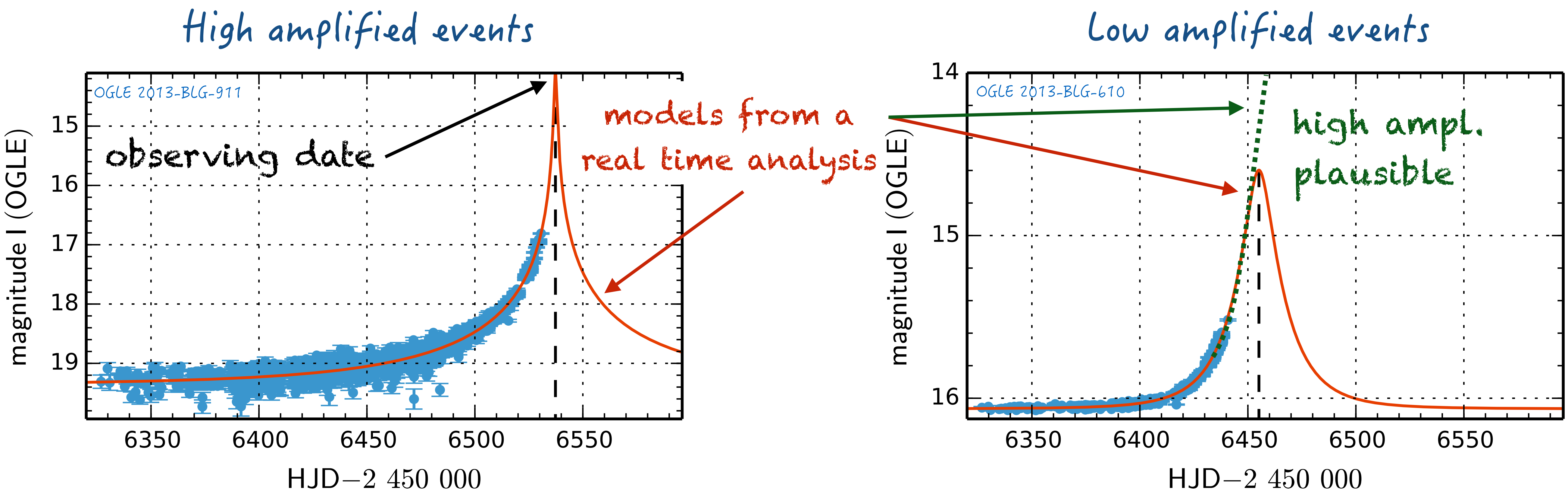


1 baseline
2 measurements

Stage 4: observations

Warning delay

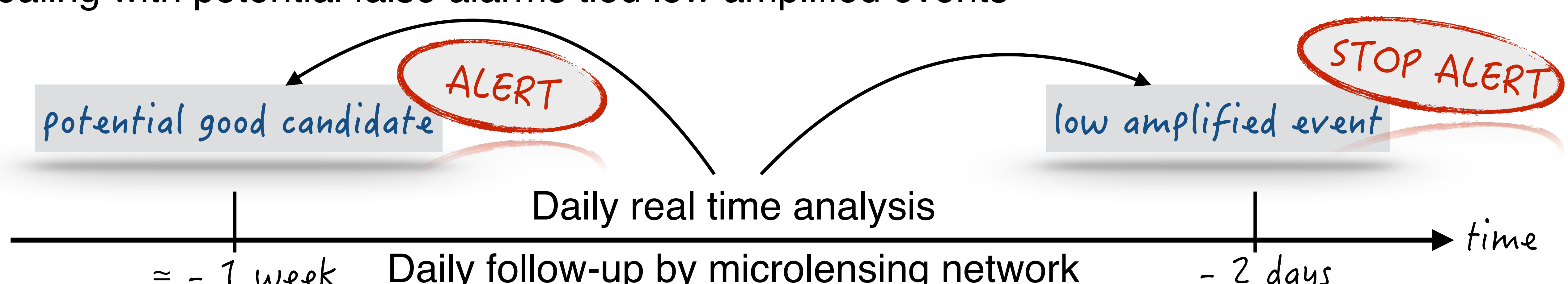
- Prediction of the **observing date = peak**



known up to a week before

known 2 days before

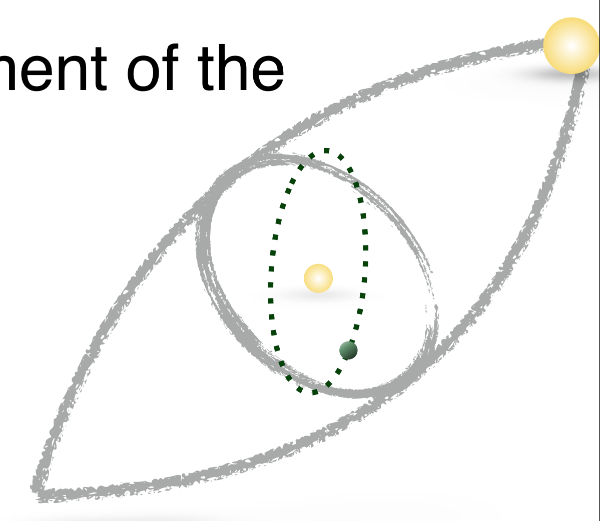
- Dealing with potential false alarms tied low amplified events



Conclusion

Why interferometry?

- Characterizing a microlens demands a constraint on mass.
- Microlensing multiple images can be in principle resolved by 200m-baseline interferometers in K band
- Interferometric observations would yield to an **independent** measurement of the **Einstein angular radius**



Why observe now?

- Many observational challenges: limiting magnitudes, short-notice alert…

… but interferometers have improved in sensitivity: there is a hope for microlensing observations

- Experience is currently almost inexistant…
- Microlensing **real time analysis is experienced**
- Strategic tools coupling photometry to interferometric predictions in a bayesian framework to alert for **observations with CHARA** are under development