Microlensing with CCDs

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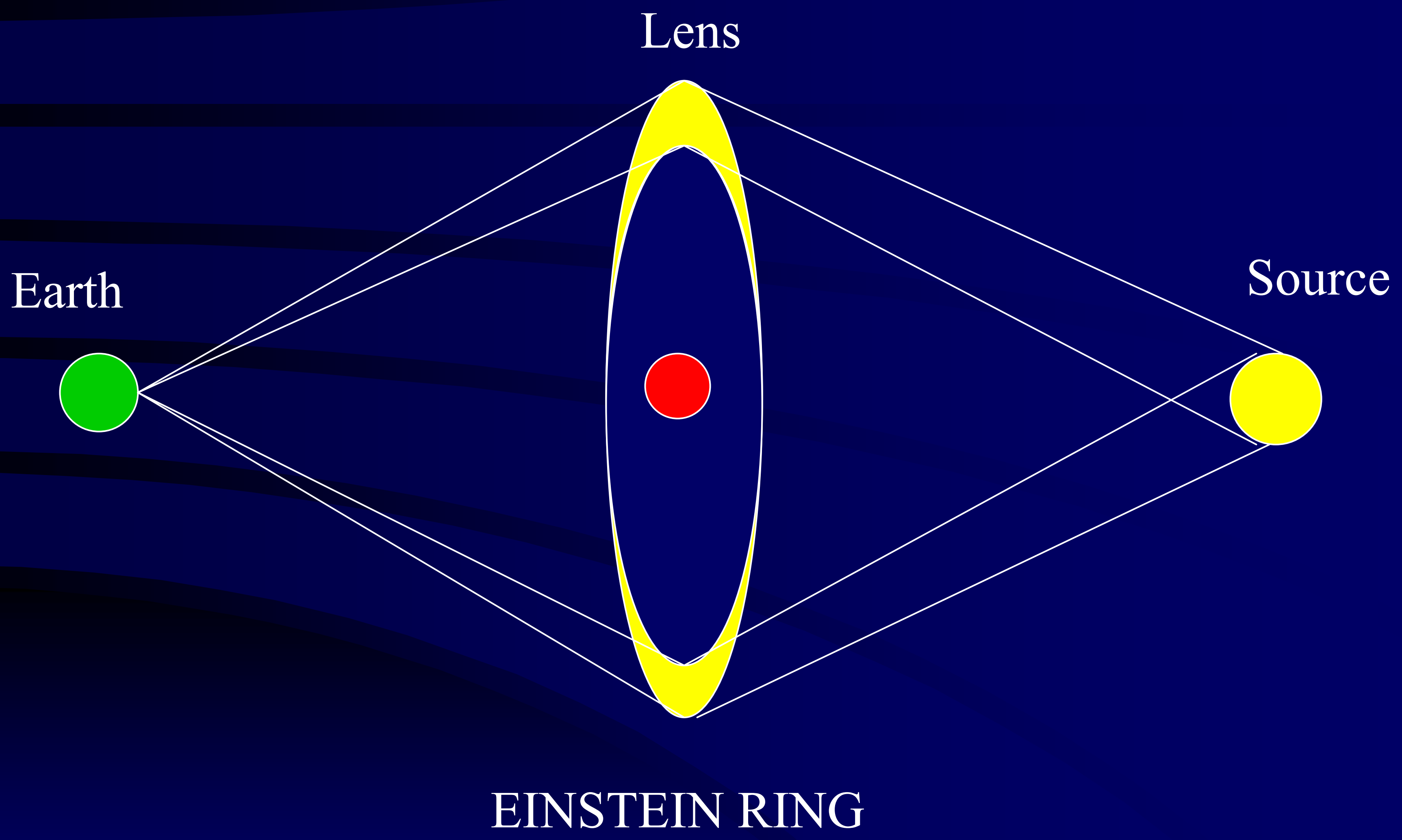
Why microlensing? – Why CCDs?

- Precision measurements can be made on stars
- Highest precision measurements on planets
- Many stars must be monitored – CCDs essential

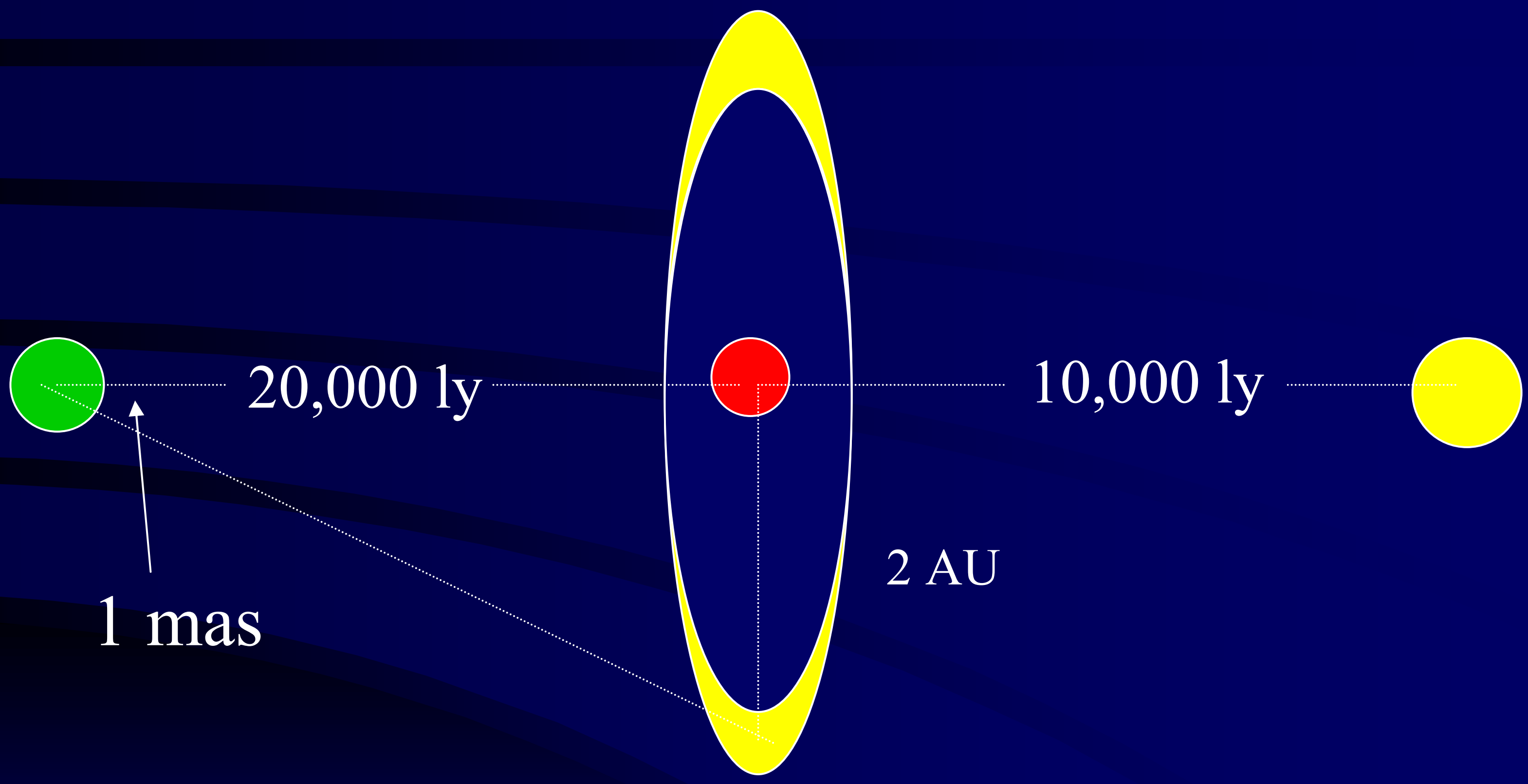
Basics of microlensing



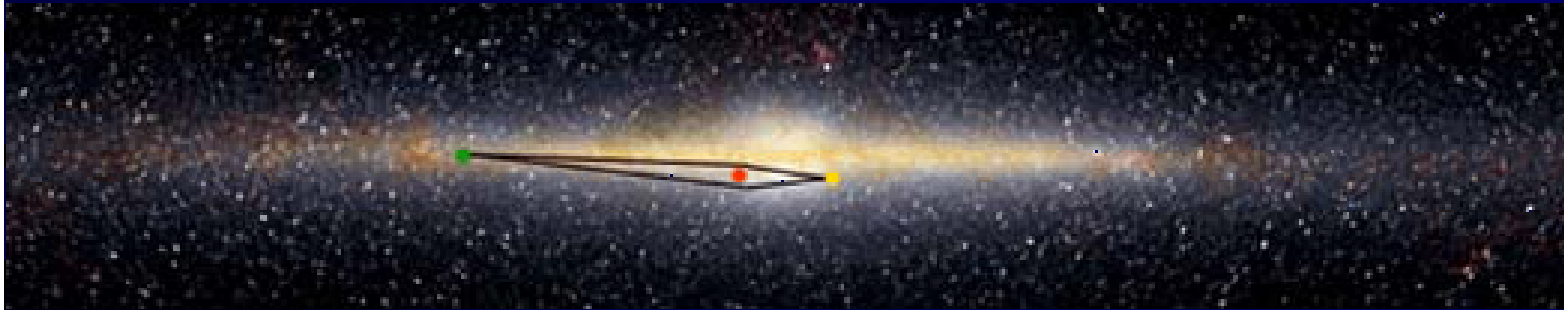
Demonstration with a glass lens

- Courtesy Sidney Liebes, Princeton

Typical astronomical dimensions

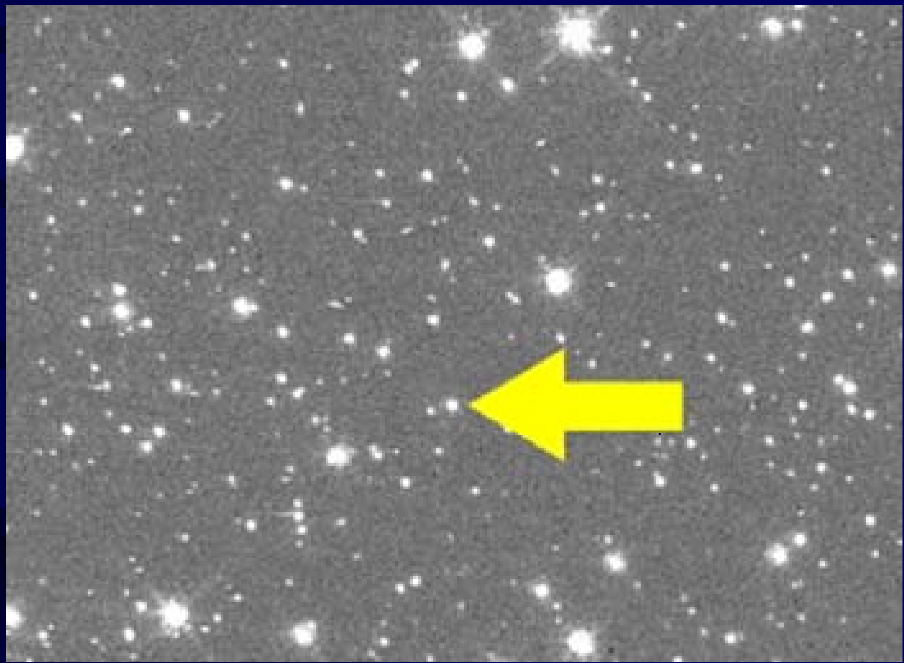


Detectable in the Galactic Bulge



The need for CCDs

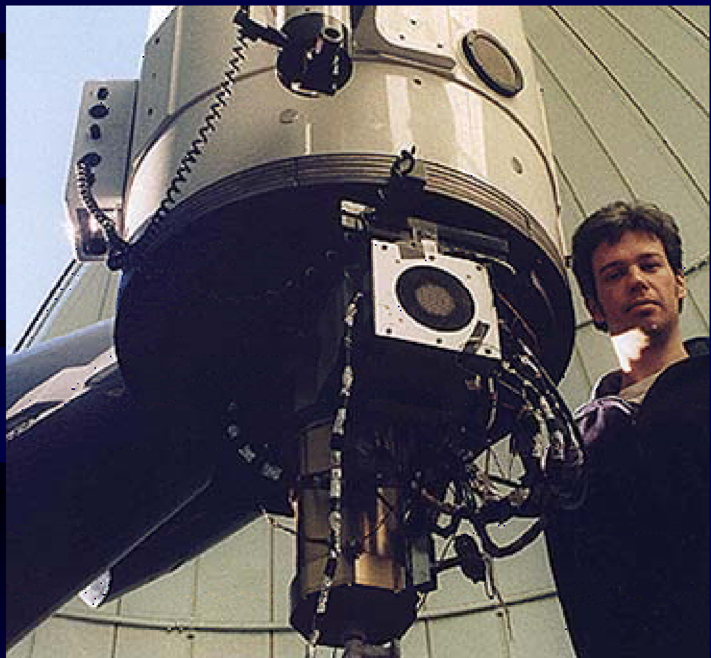
Required separation ~ 1mas, but typical separation ~1as



“No chance of observing this phenomenon” - Einstein (1936)

Typical CCD arrays

MOA-I



MOA-II

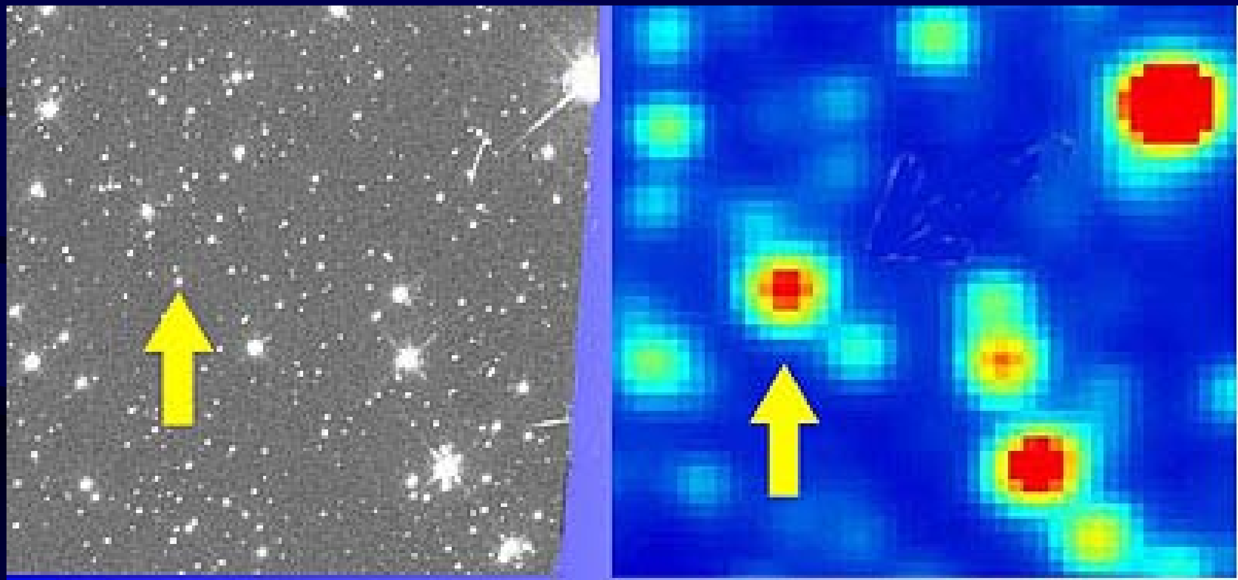
24 million pixels

80 million pixels

Ground versus space

MACHO 98-BLG-35

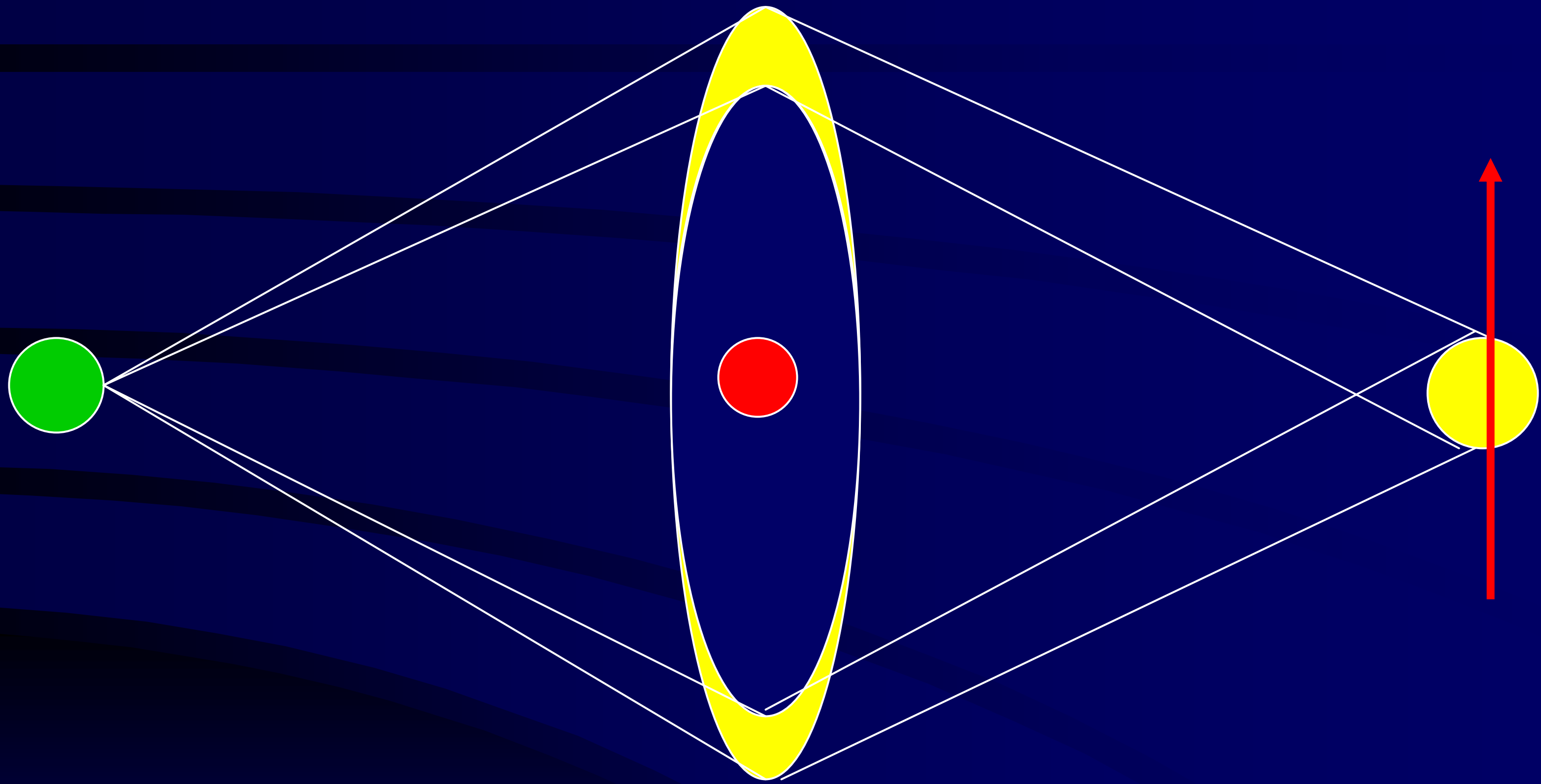
HST



MOA

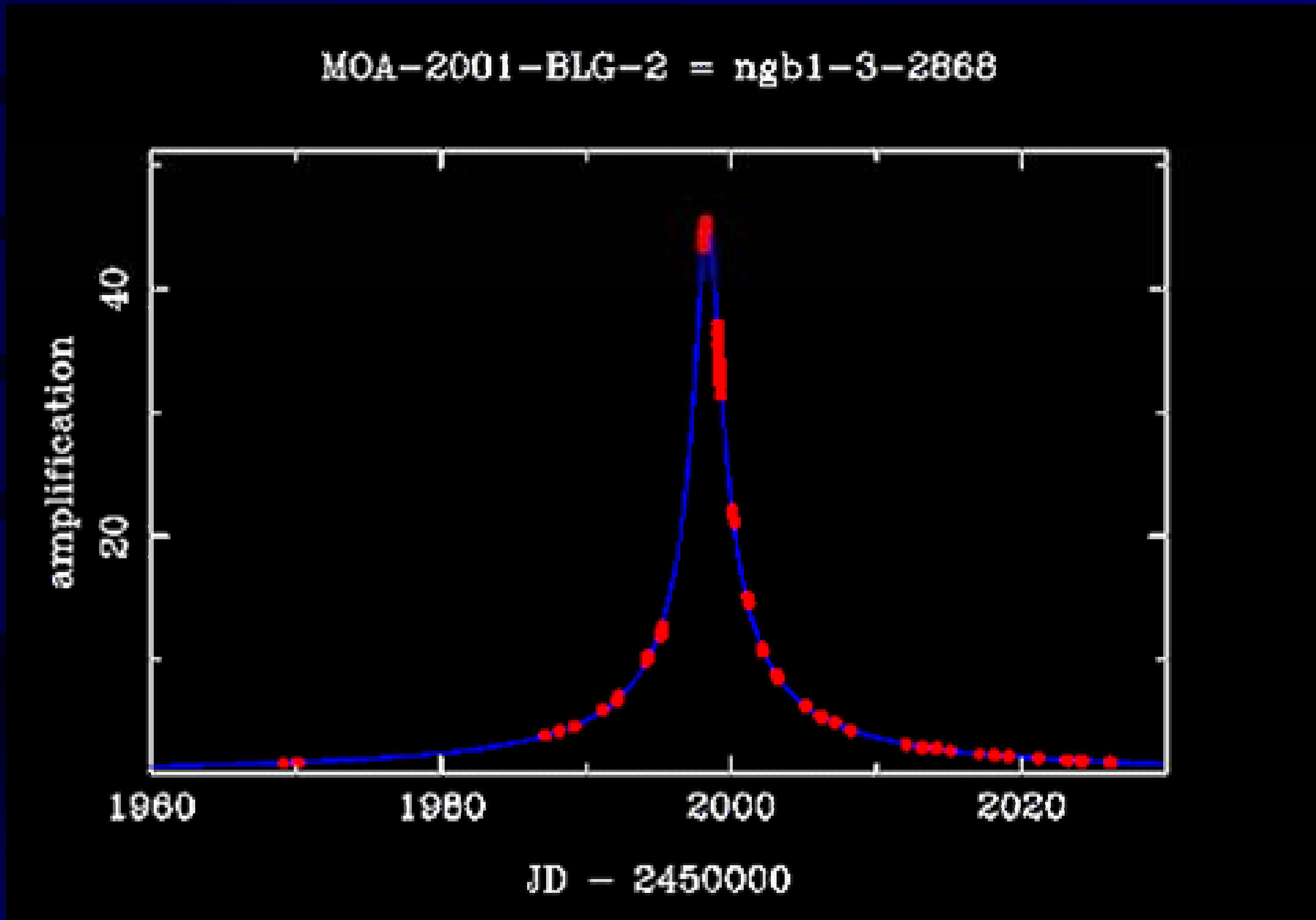
Difference imaging essential from the ground

Light curve



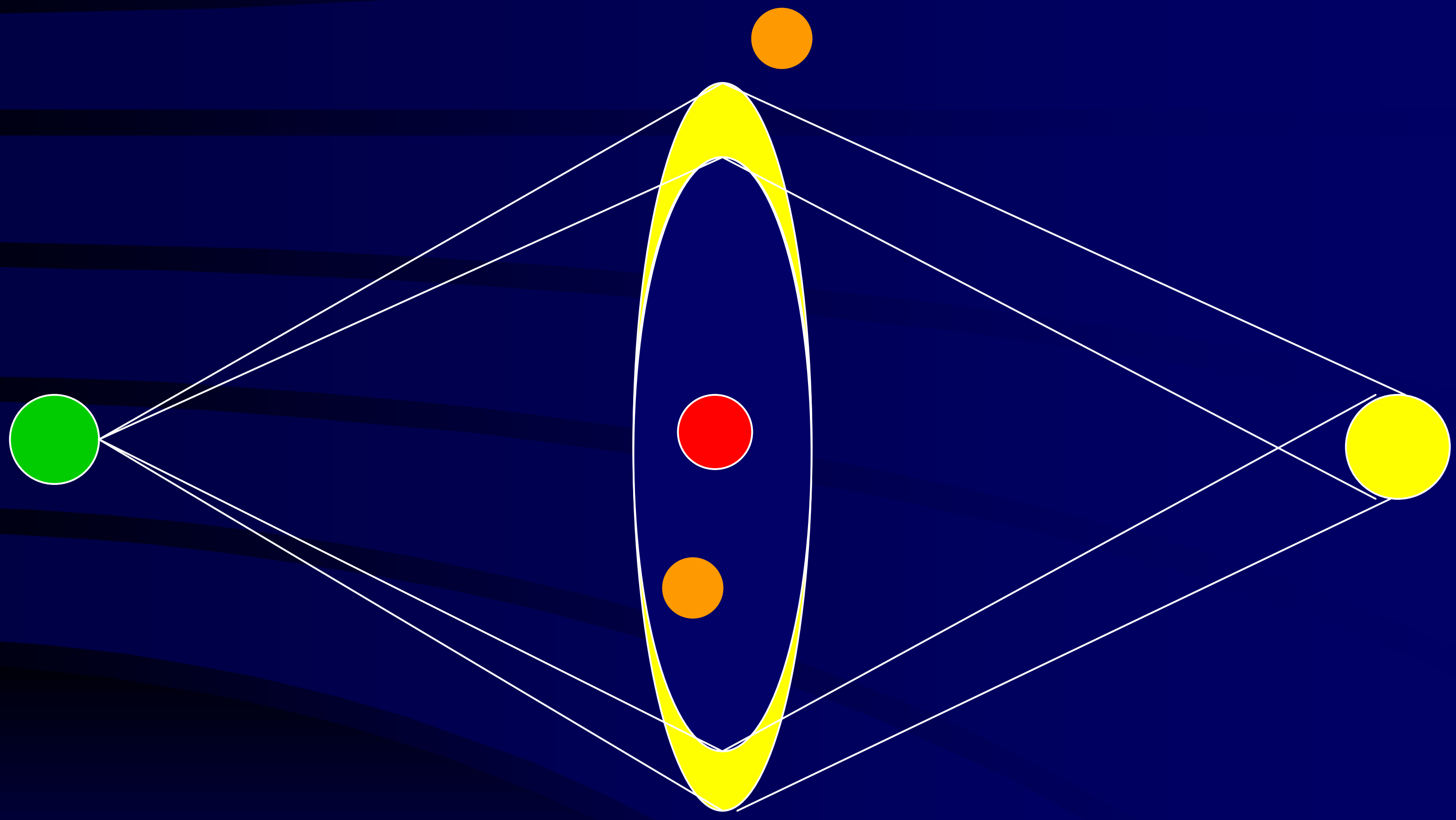
Typical transverse velocity ~ 200 km/sec

Light curve



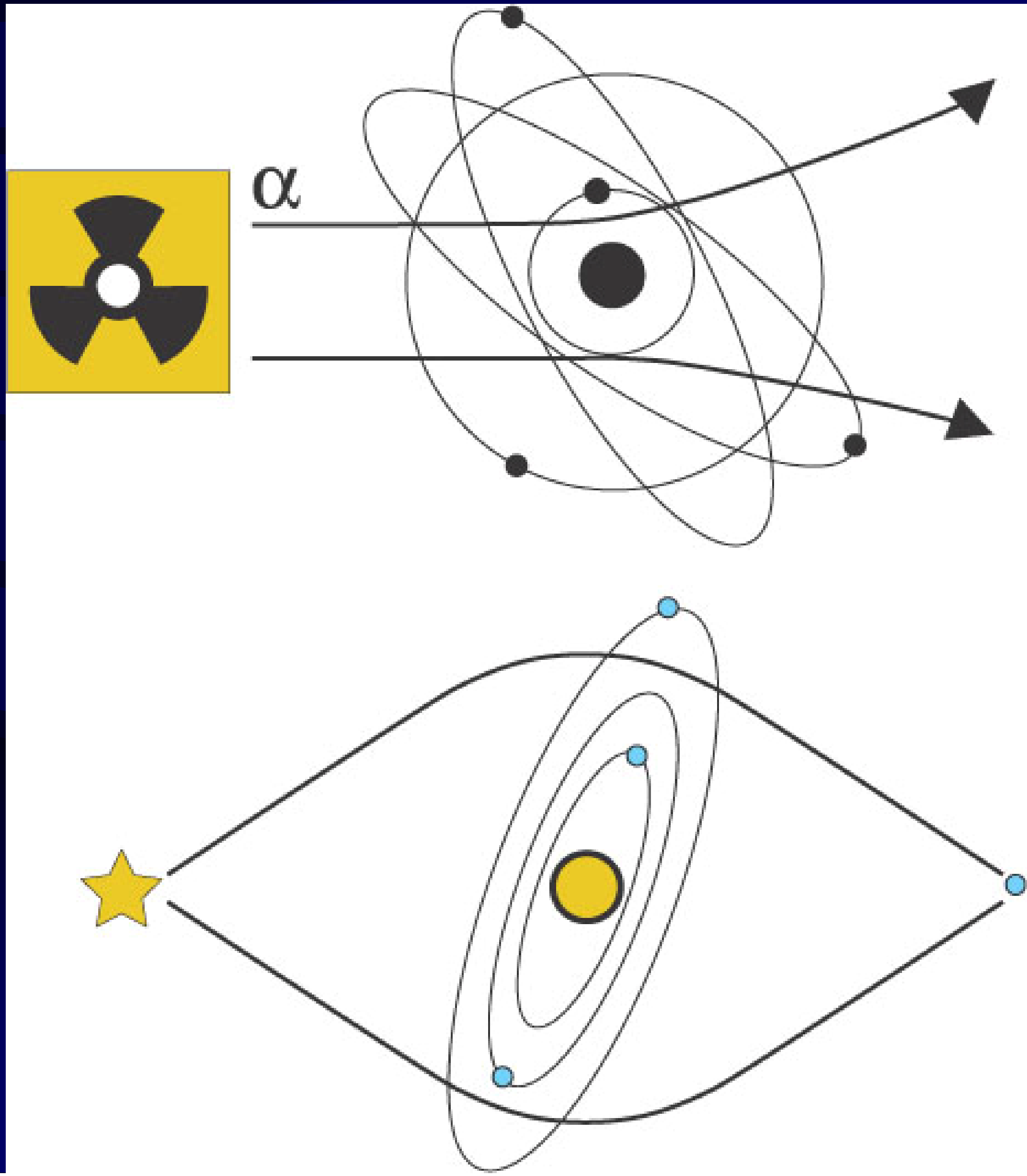
Liebes-Paczynski light curve versus data

Planetary microlensing



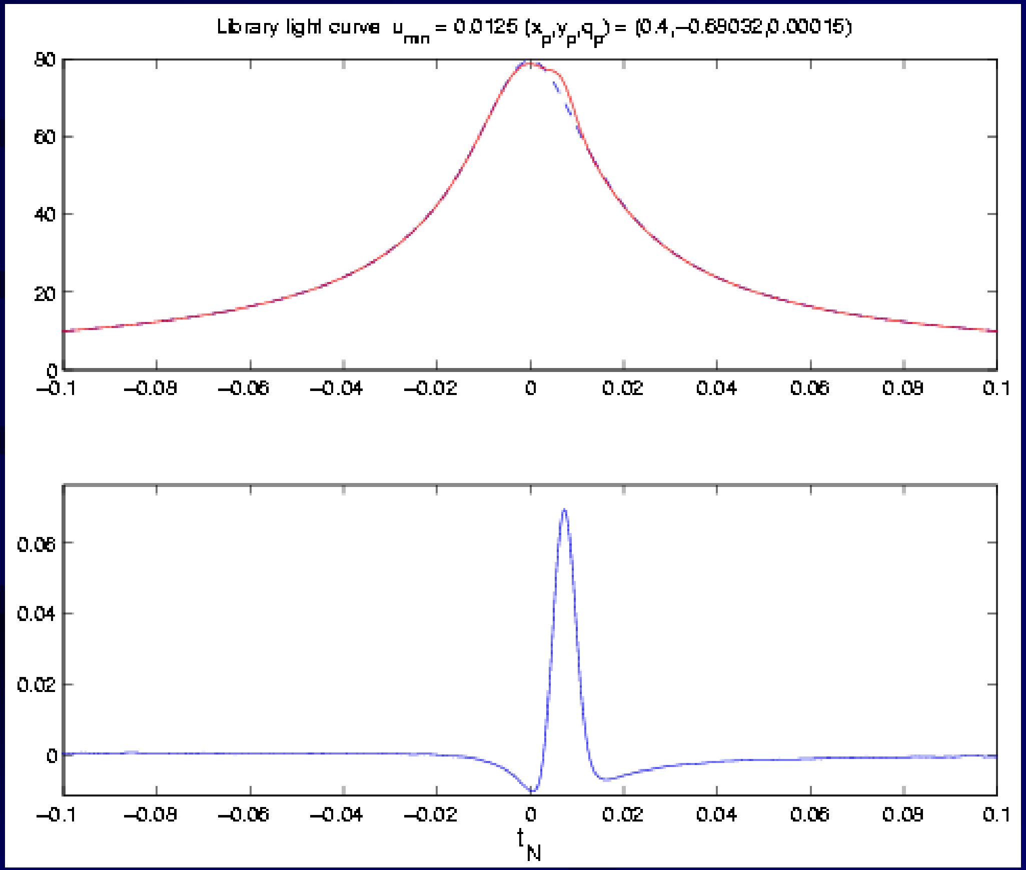
Planets perturb the Einstein ring

Comparison with Rutherford scattering



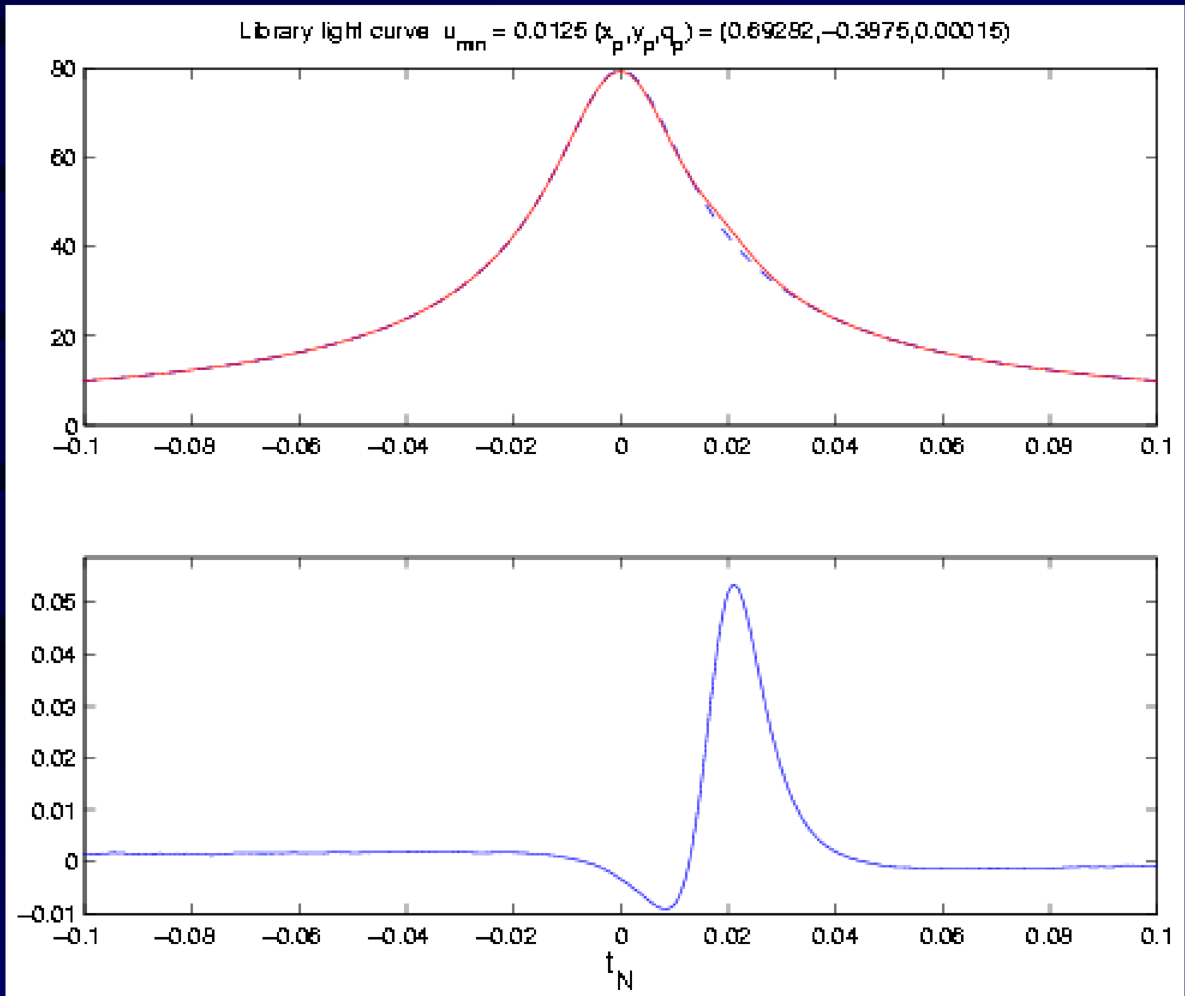
Planetary perturbations

Neptune at 2 AU

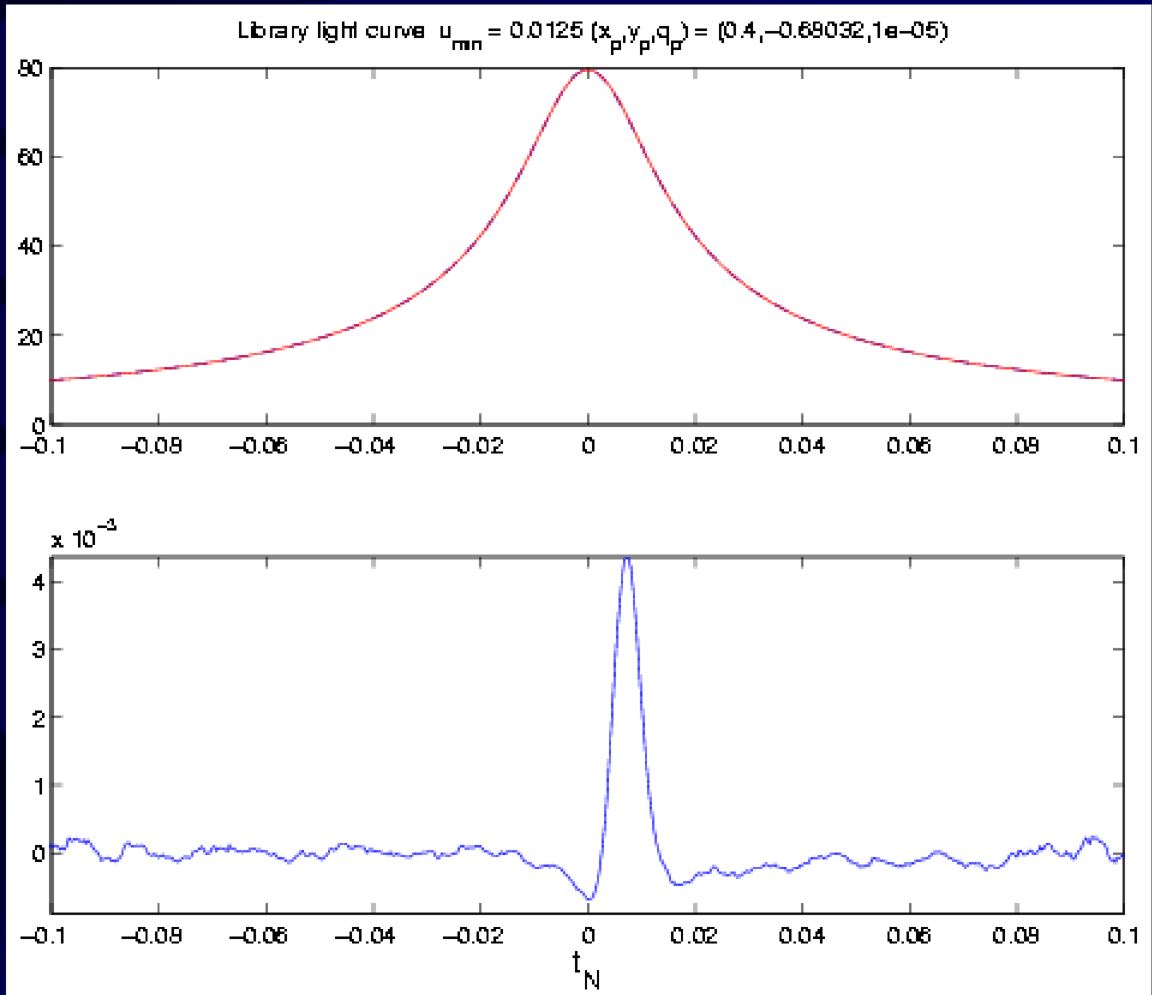


Perturbation ~ 5%

Neptune at ~ 2AU at different θ

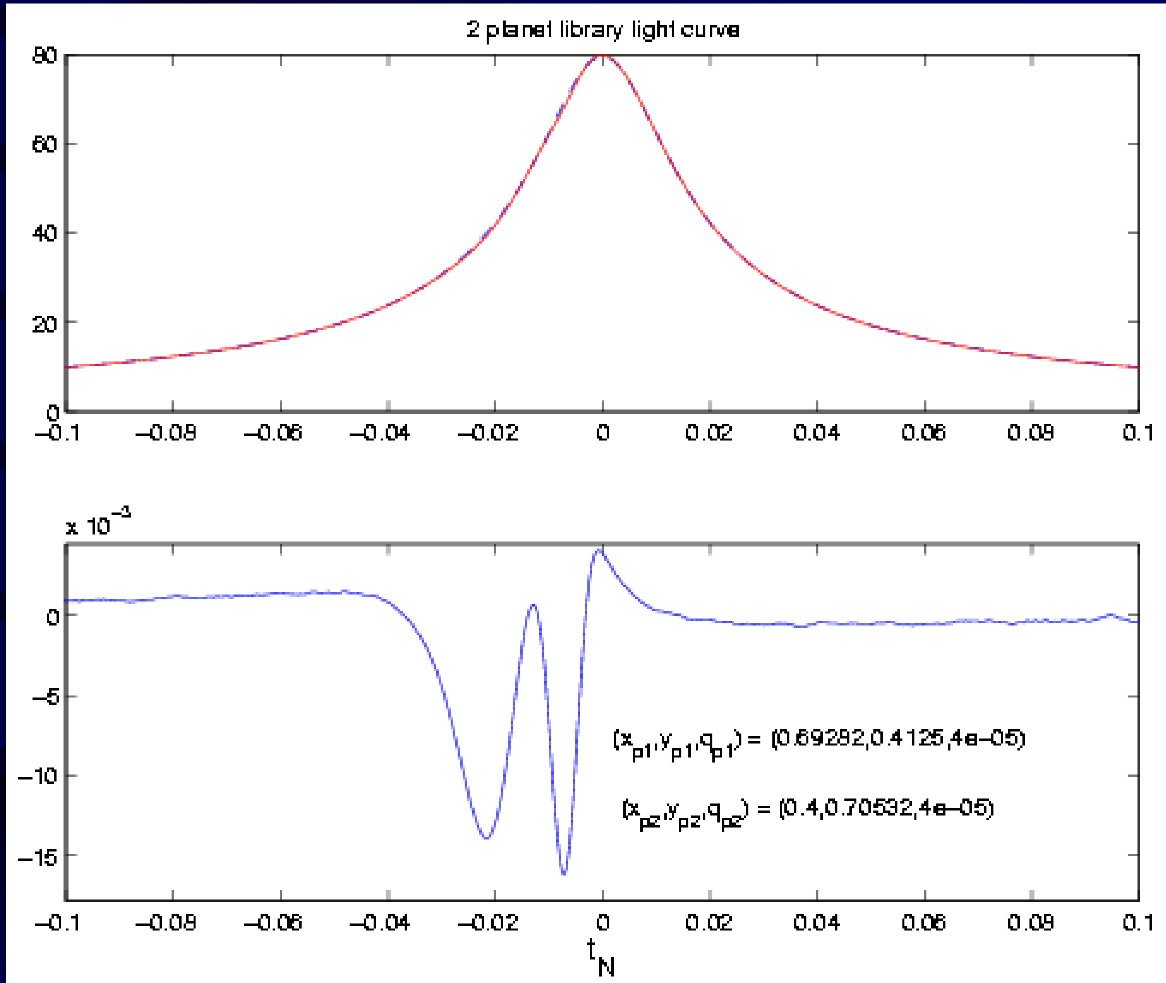


Earth at ~ 2 AU



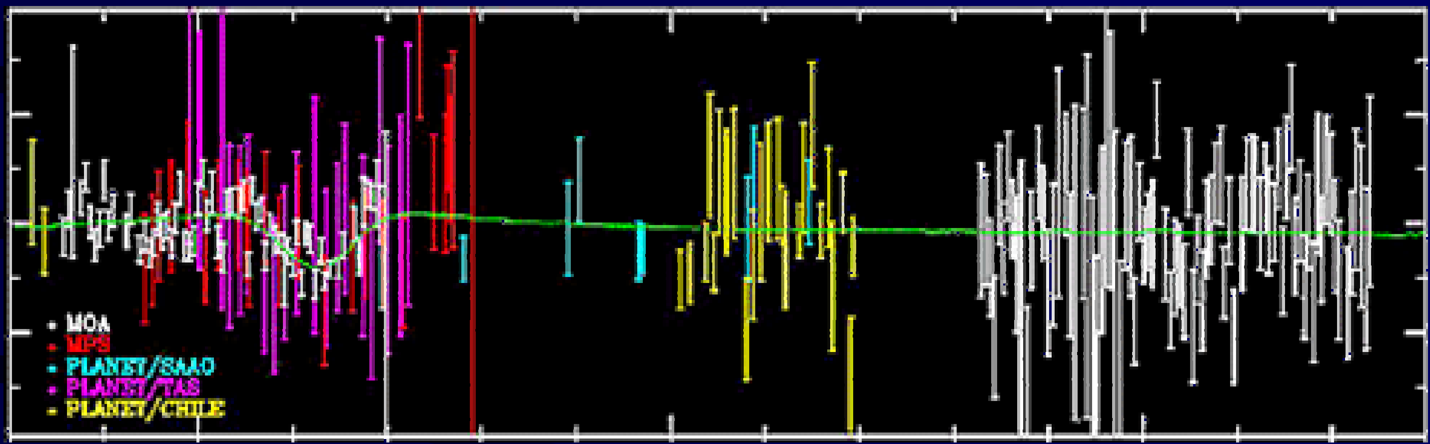
Perturbation ~ 0.5%

Two planets



Detectable if $\Delta\theta > 20°$

MACHO 98-BLG-35



- Magnification = 80
- Possible Earth-mass planet

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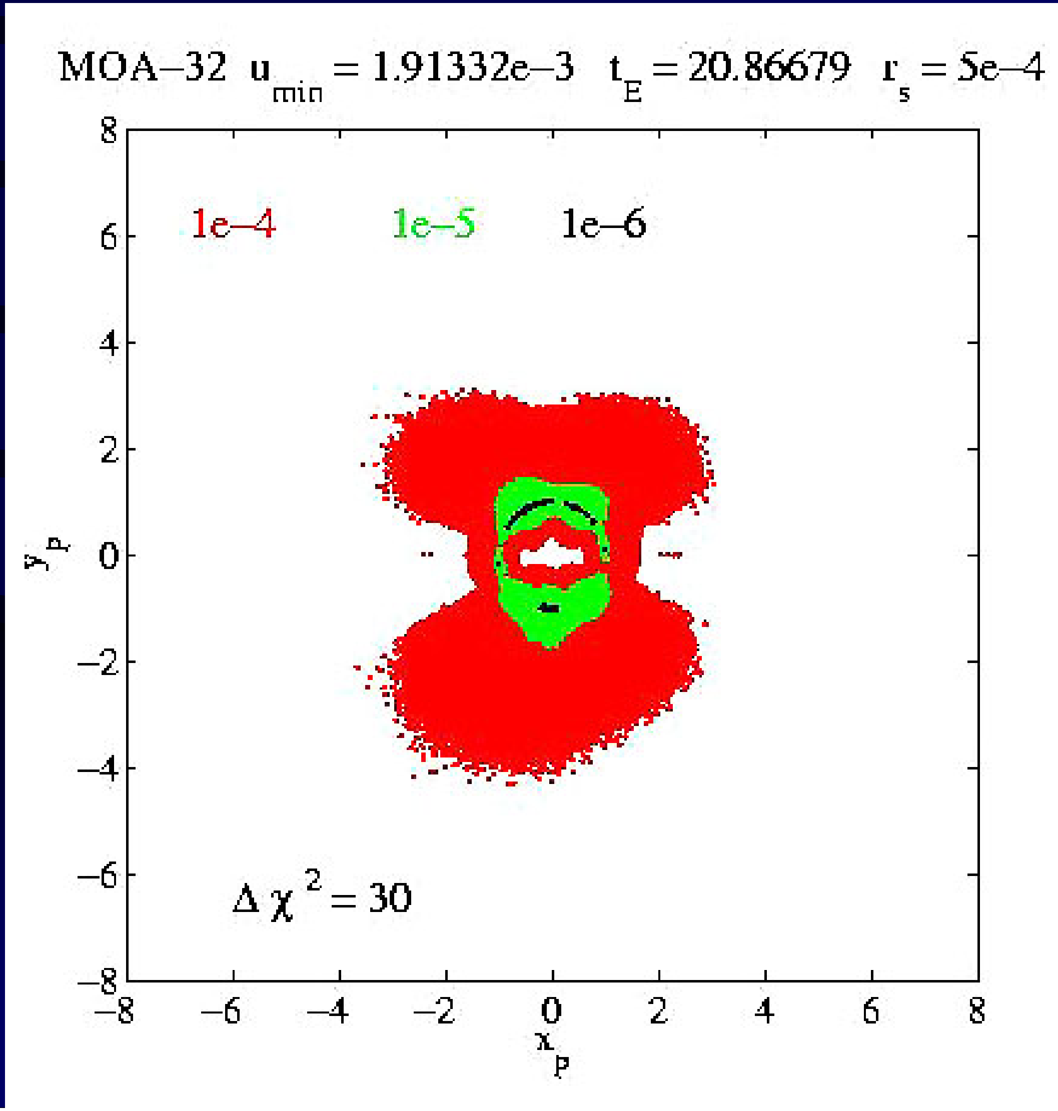
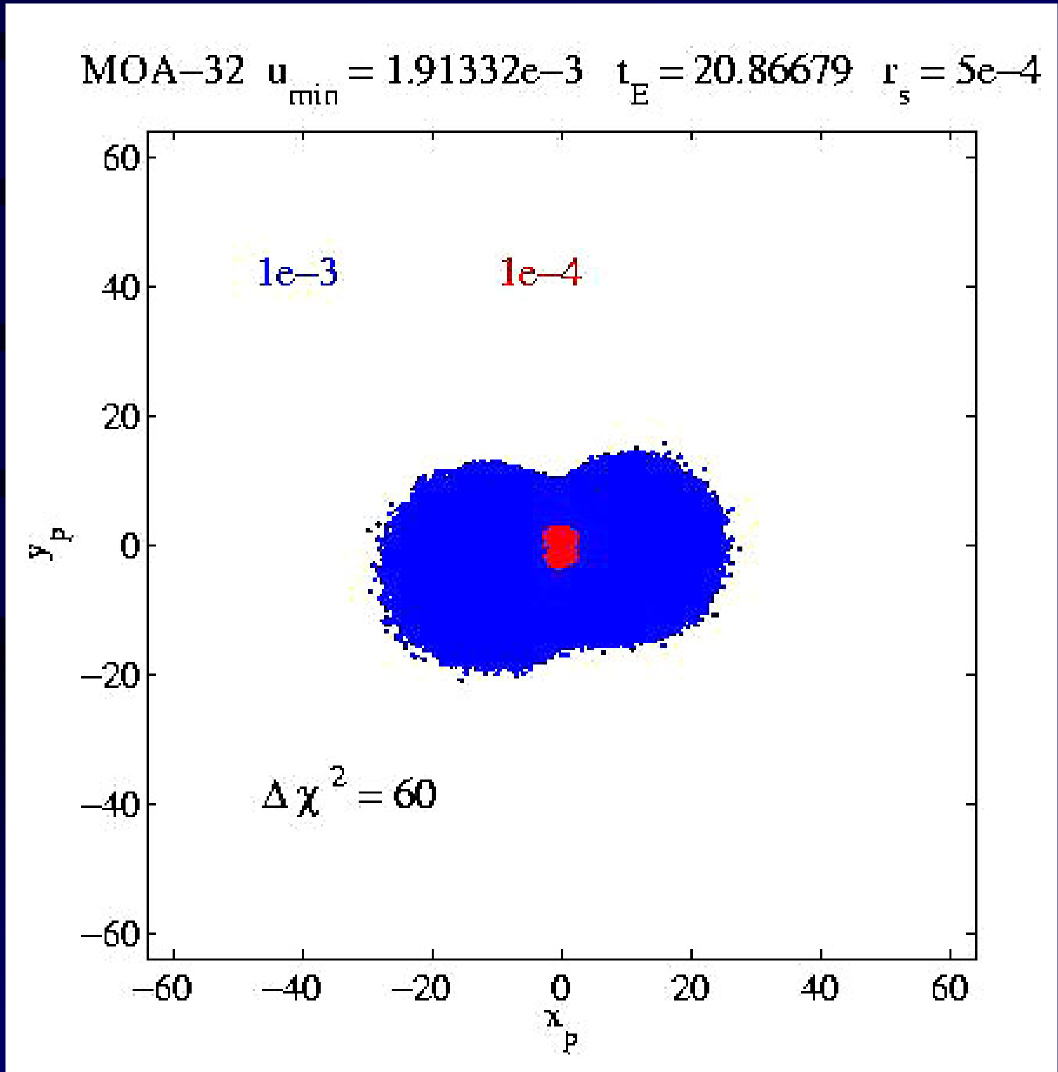
Magnification = 520



e-4 = Neptune
e-5 = Earth
e-6 = Mars

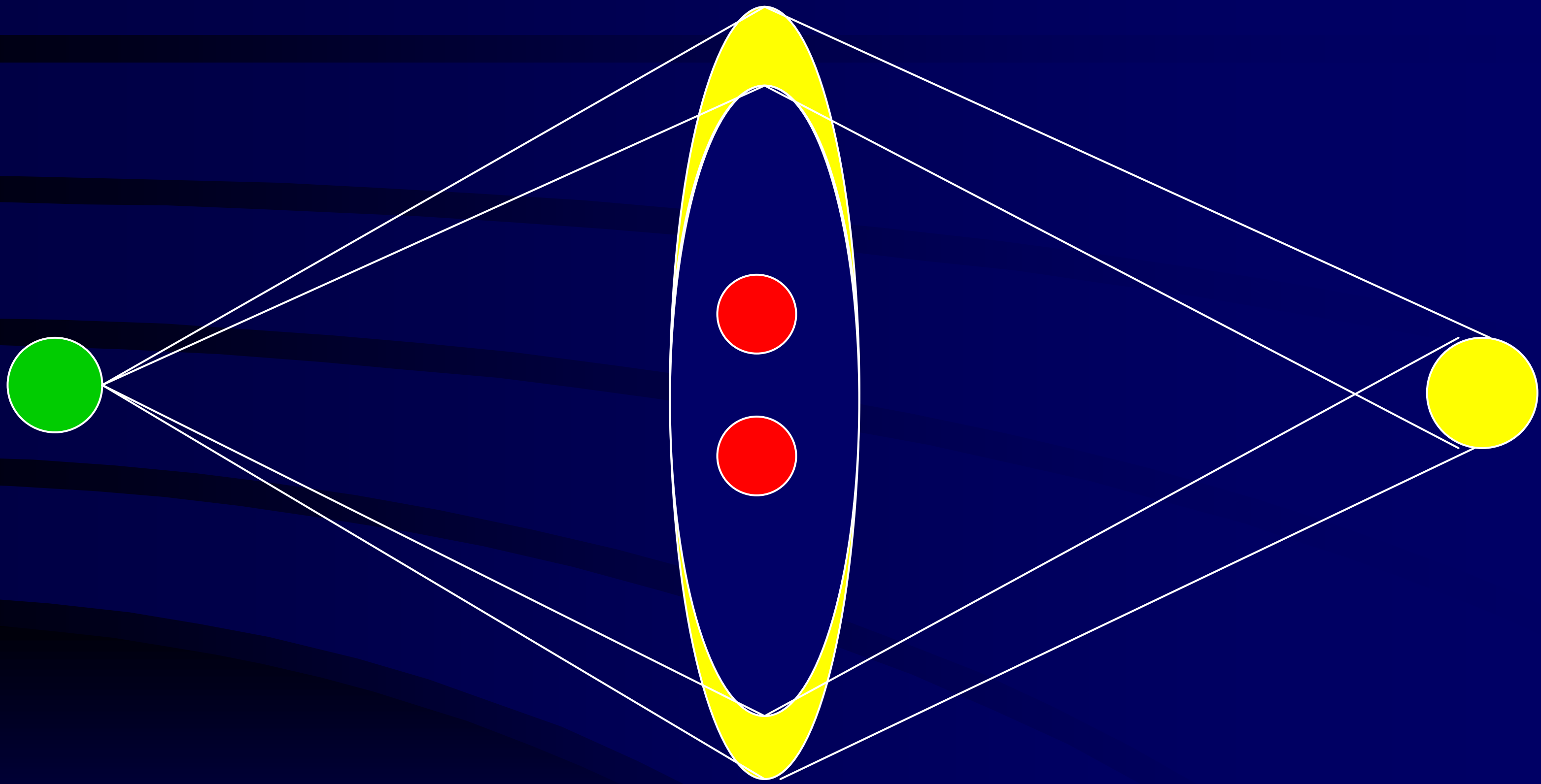
(preliminary)

MOA 2003-BLG-32/OGLE 2003-BLG-219



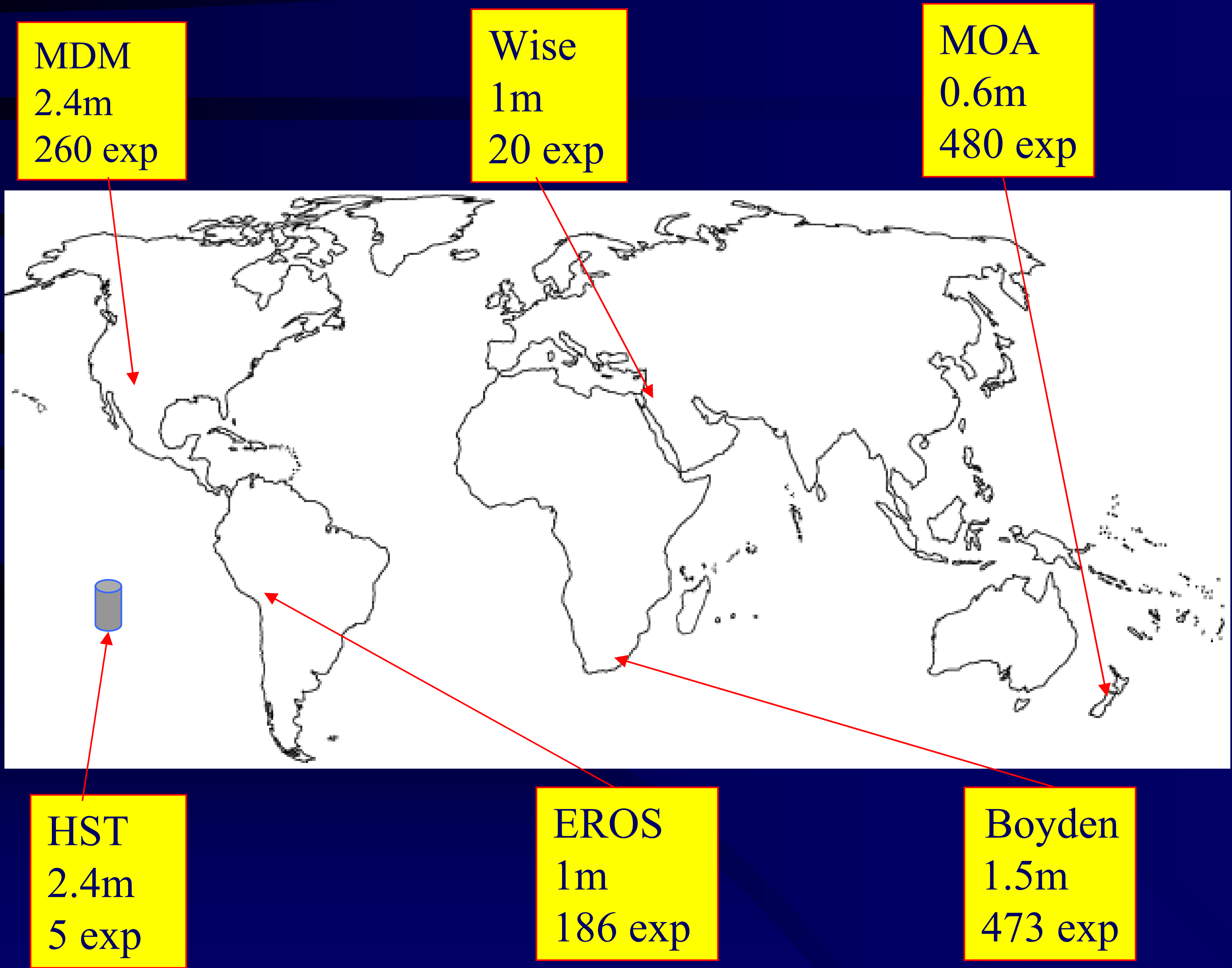
e-4 = Neptune
e-3 = Saturn

Binary lens

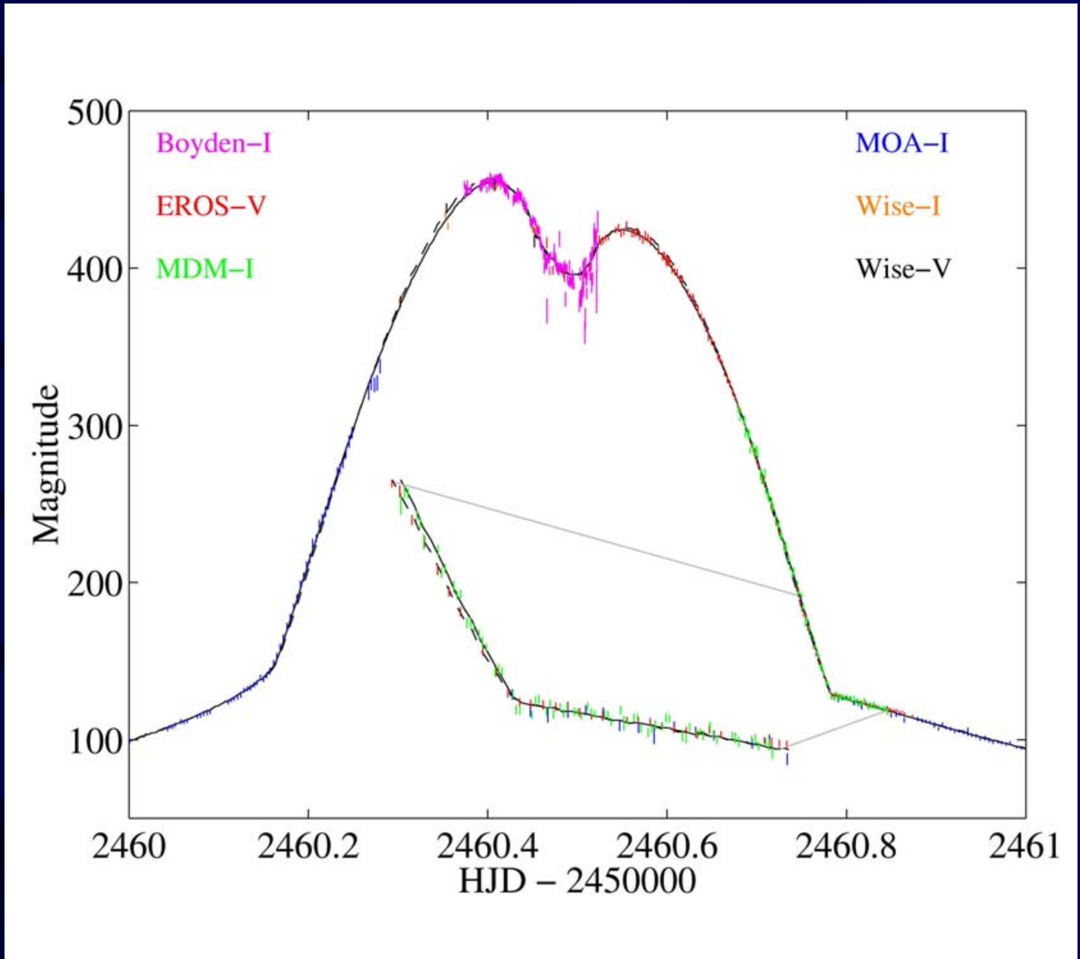


A “caustic” is formed

MOA 2002-BLG-33

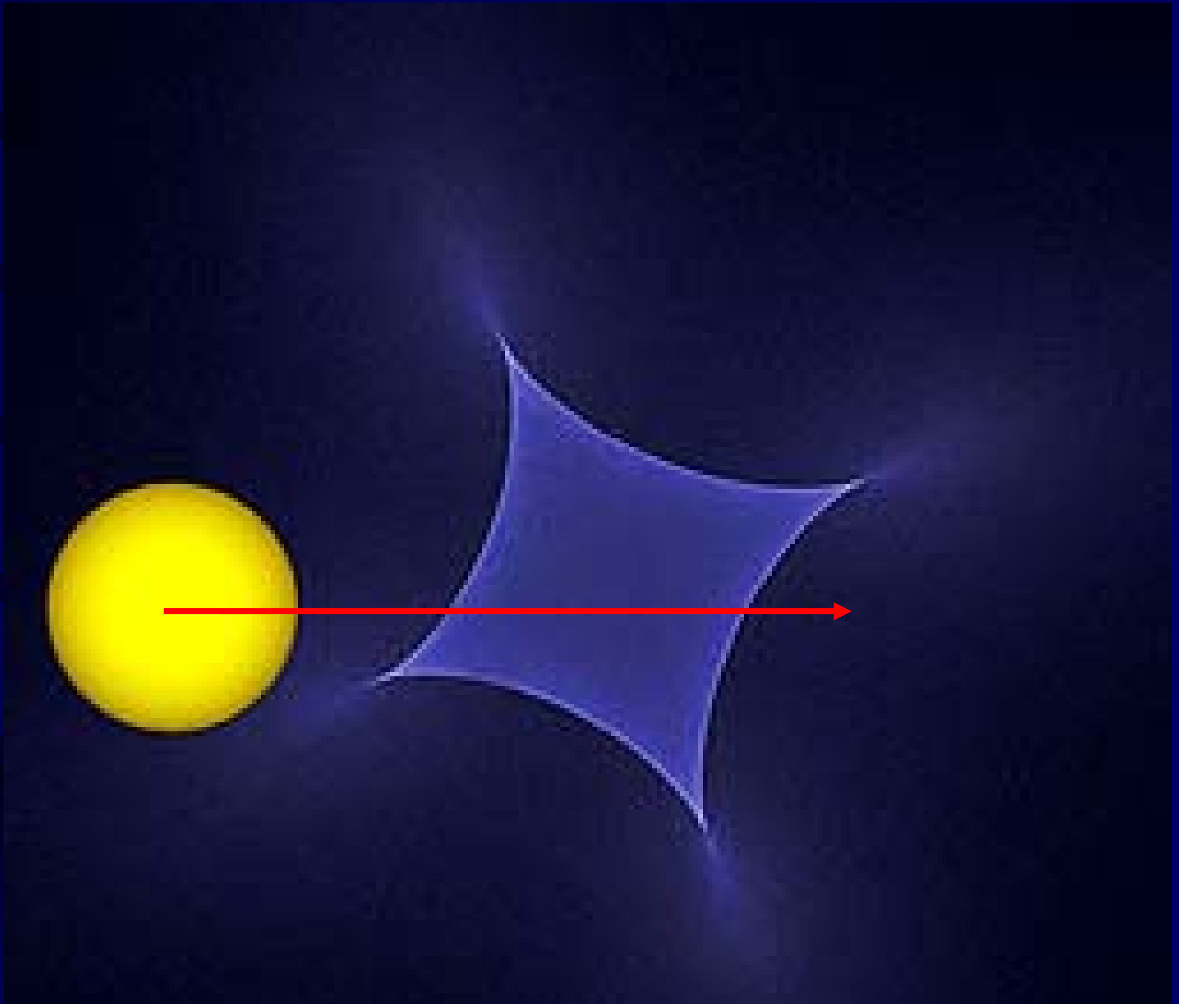


MOA 2002-BLG-33



- The light curve determines the lens geometry
- The lens profiles the source

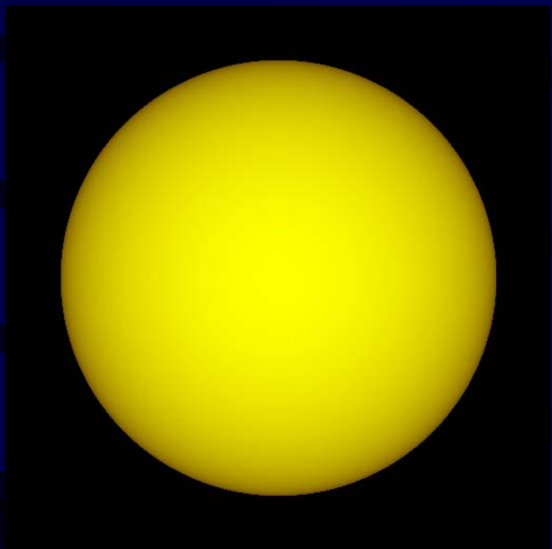
MOA 2002-BLG-33



- Caustic crossed in 15.6 hours
- Profiles obtained, on entry and on exit

Stellar profile

MOA 2002-BLG33



Another star

- Stellar atmosphere theory confirmed
- Precision comparable to that of the VLTI - Very Large Telescope Interferometer at ESO

Conclusions

- Stellar gravitational lenses exist
- Extra-solar planets detectable
- Stars resolvable
- Nature helpful!

64 million dollar question

Is $SU(3)\times SU(2)\times U(1)$ being studied on other planets?

Acknowledgements

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