Galaxies: Structure, formation and evolution

Lecture 14

Yogesh Wadadekar

Mar-Apr 2022

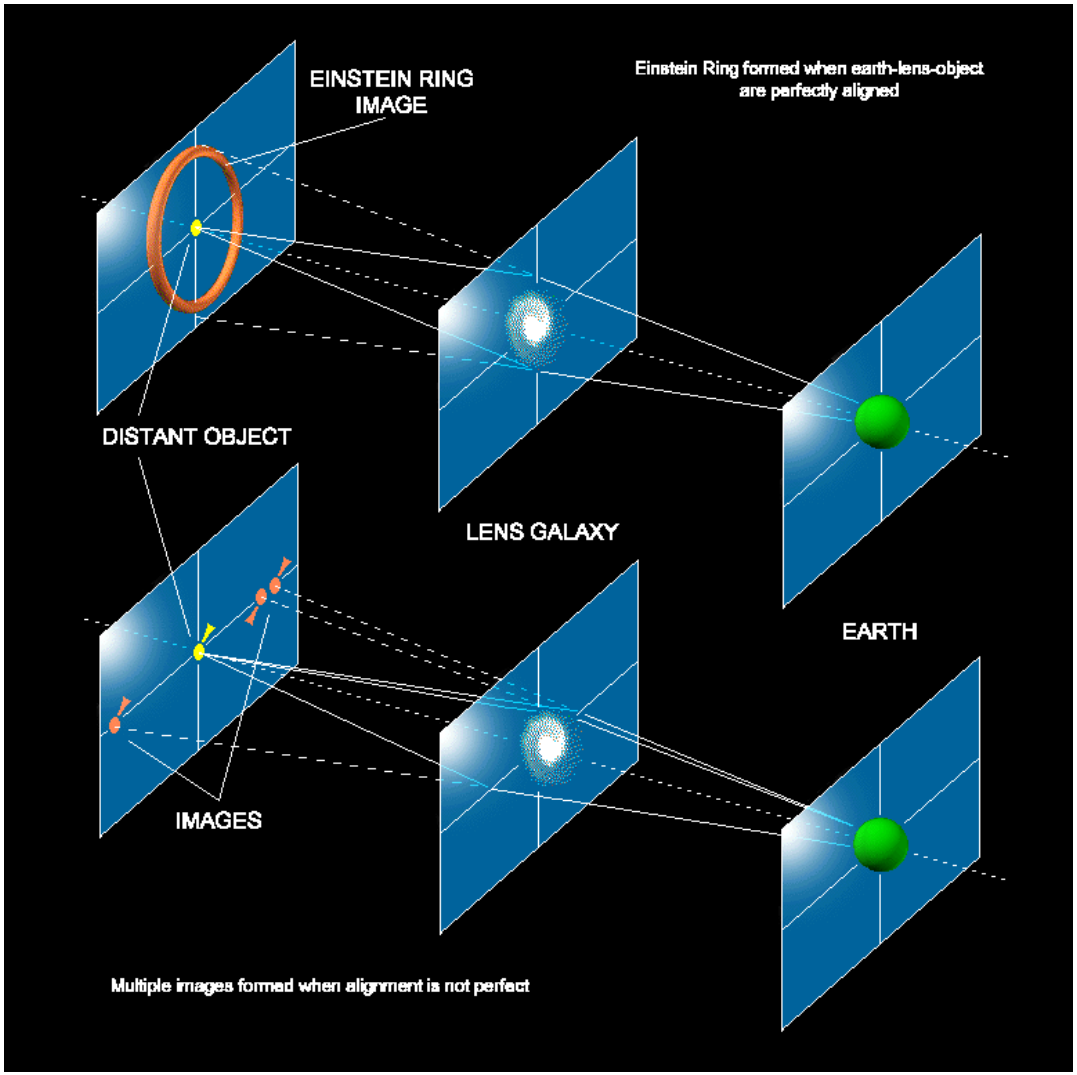
Gravitational lensing

Bending of light is similar to deflection of massive particles, except that GR predicts that for photons the bending is exactly twice the Newtonian value:

$$\alpha = \frac{4GM}{bc^2} = \frac{2R_S}{b}$$

where R_s is the Schwarzschild radius of a body of mass M, and b is the impact parameter. This formula is valid if $b >> R_s$: The deflection angle α will be small e.g., for the stars near the Solar limb, $\sim$ 2 arcsec

Lensing Geometry



Question

What does lensing tell us that photons and kinematic modeling/virial theorem doesn't?

Question

What does lensing tell us that photons and kinematic modeling/virial theorem doesn't?

- photons only provide information about objects that emit/absorb/reflect light - what about dark matter?

Question

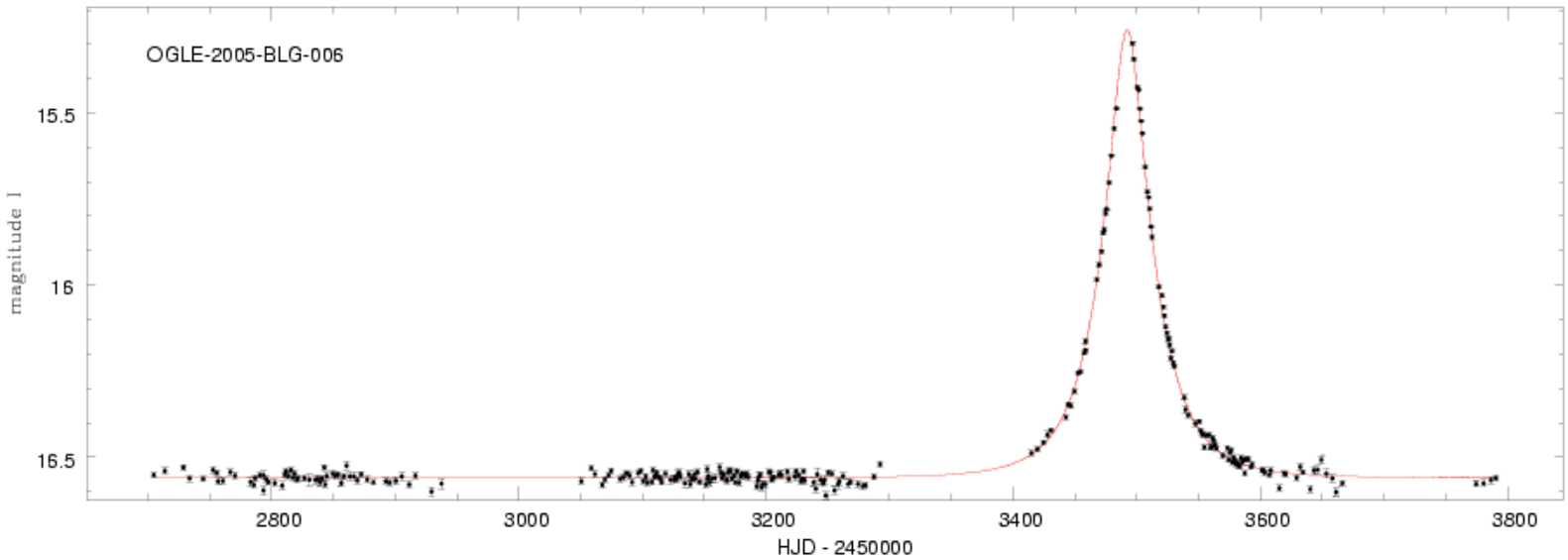
What does lensing tell us that photons and kinematic modeling/virial theorem doesn't?

- photons only provide information about objects that emit/absorb/reflect light - what about dark matter?
- probing dark matter requires additional assumptions - with lensing no need for knowledge of orbits (spiral galaxies or stars around a supermassive black hole) or of virialised state (ellipticals) to convert velocity (dispersion) measurements to mass measurements.

Microlensing

There are ongoing searches to use lensing to find a type of dark matter called MACHOs (massive compact halo objects). Although MACHOs, as dark matter, cannot be seen themselves, if they pass in front of a source (e.g. a star nearby), they can cause the star to become brighter for a while, e.g. days or weeks. This effect has been observed but determinations of the dark matter are not yet conclusive. Microlensing observations are underway by many groups.

Gravitational microlensing

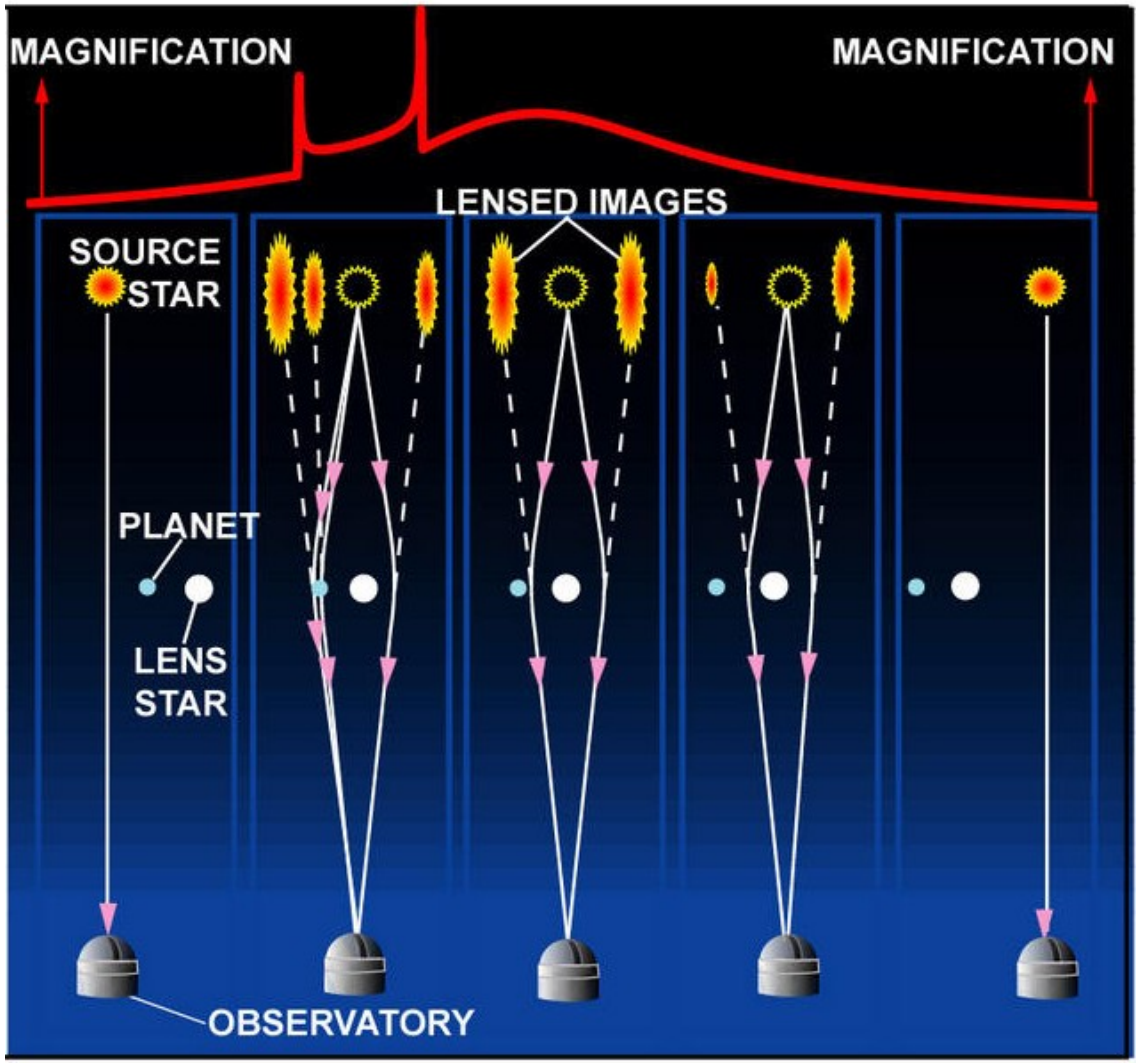


Paczynski (1986)

Question

How can we distinguish a microlensing event from a variable star?

Planet star binary lens geometry



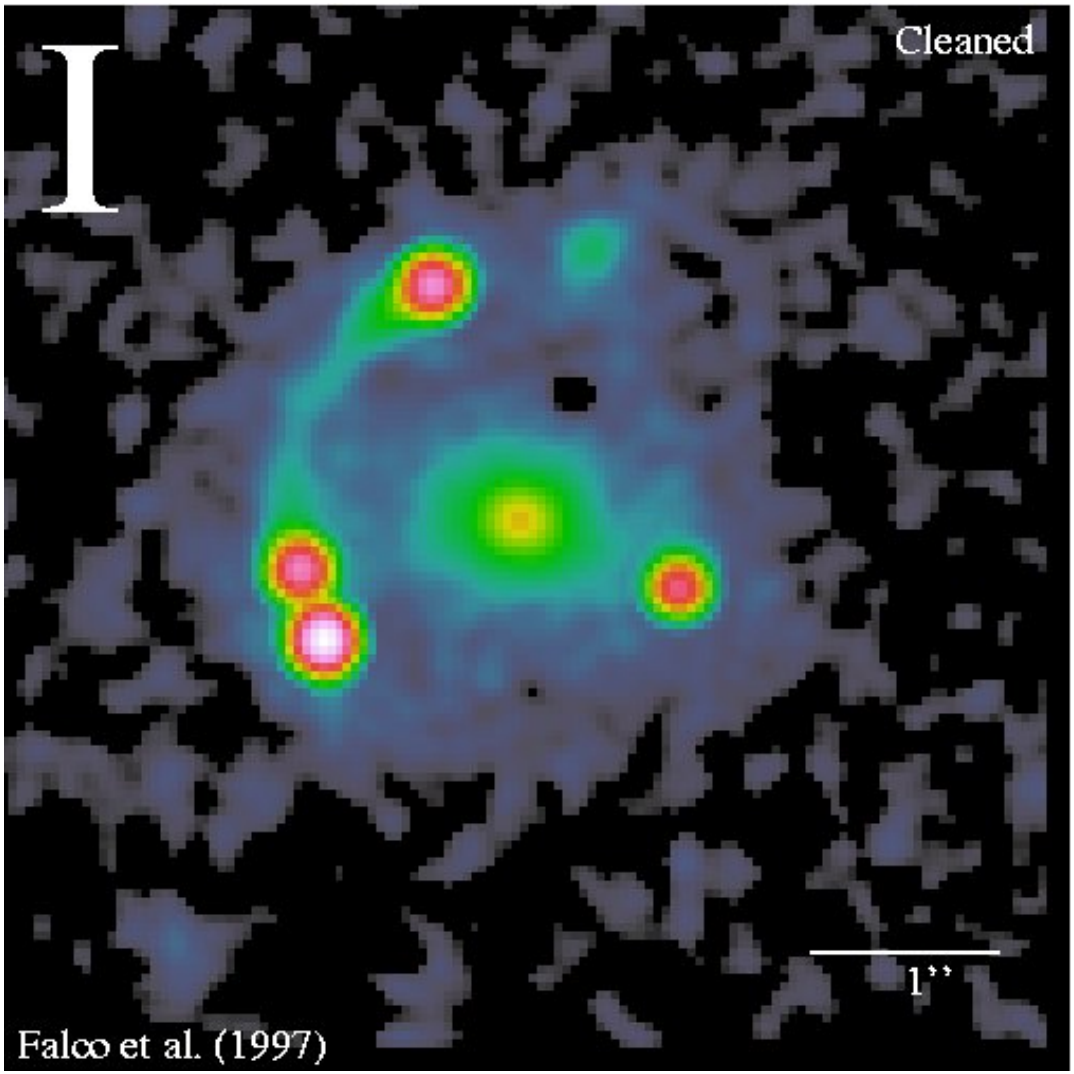
Microlensing in the synoptic era

Rubin/LSST: An optical/near-IR survey of half the sky in *ugrizy* bands to $r \sim 27.5$ based on ~ 1000 visits over a 10-year period

LSST Observing strategy

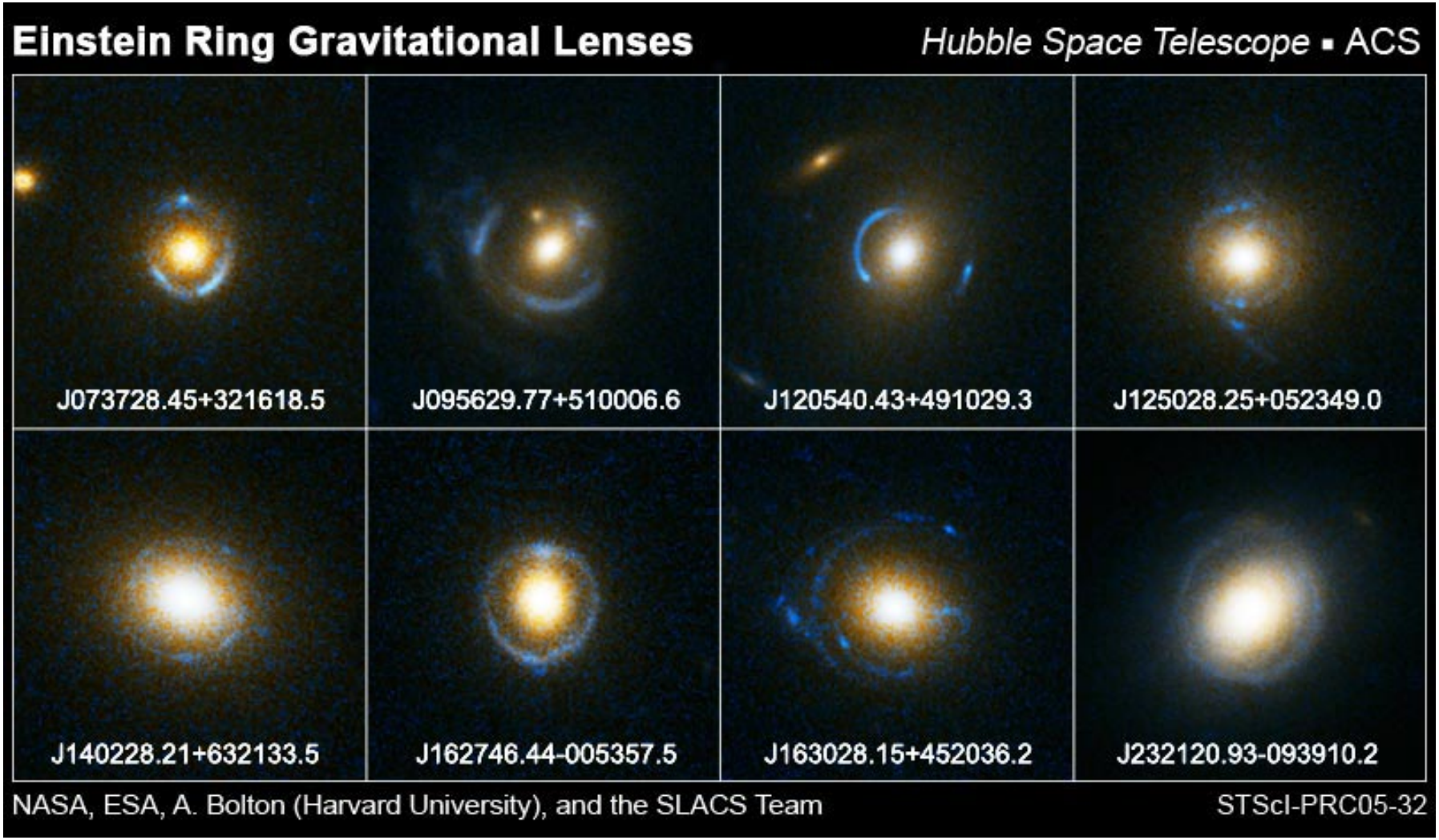
- The main wide-fast-deep survey will use about 90% of the observing time and will be simultaneously optimized for the homogeneity of depth and number of visits, and for time- domain science (e.g., asteroids, supernovae, variable stars).
- The remaining observing time will be used to obtain improved coverage of parameter space such as very deep observations, observations with very short revisit times, and observations of "special" regions (e.g., the Ecliptic, the Large and Small Magellanic Clouds).

quasar lensed by galaxies

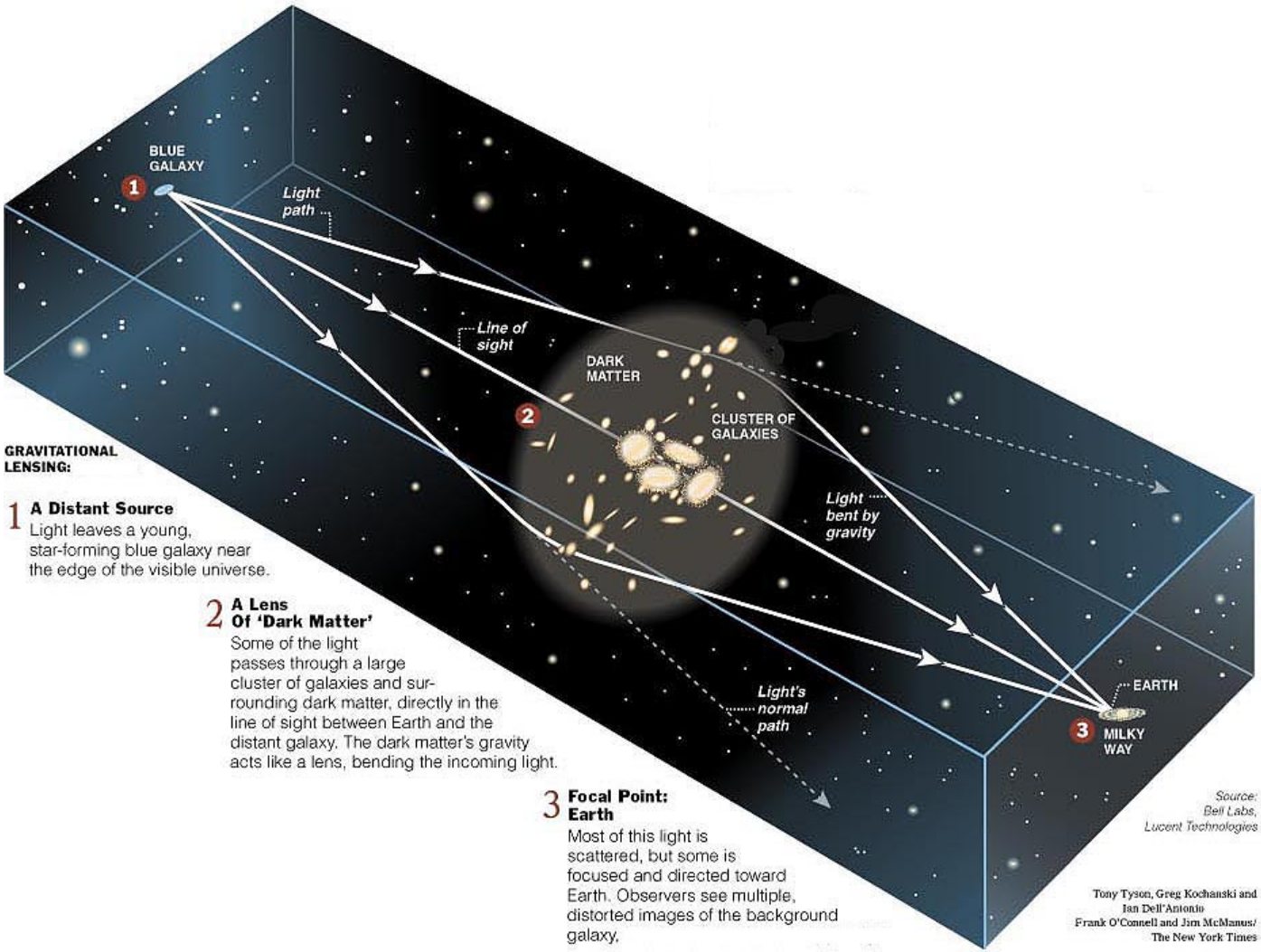


first lens discovered in 1979. Why was it not discovered sooner?

Galaxies lensed by single galaxies



Gravitational Lensing by a cluster



many galaxies lensing one or more galaxies

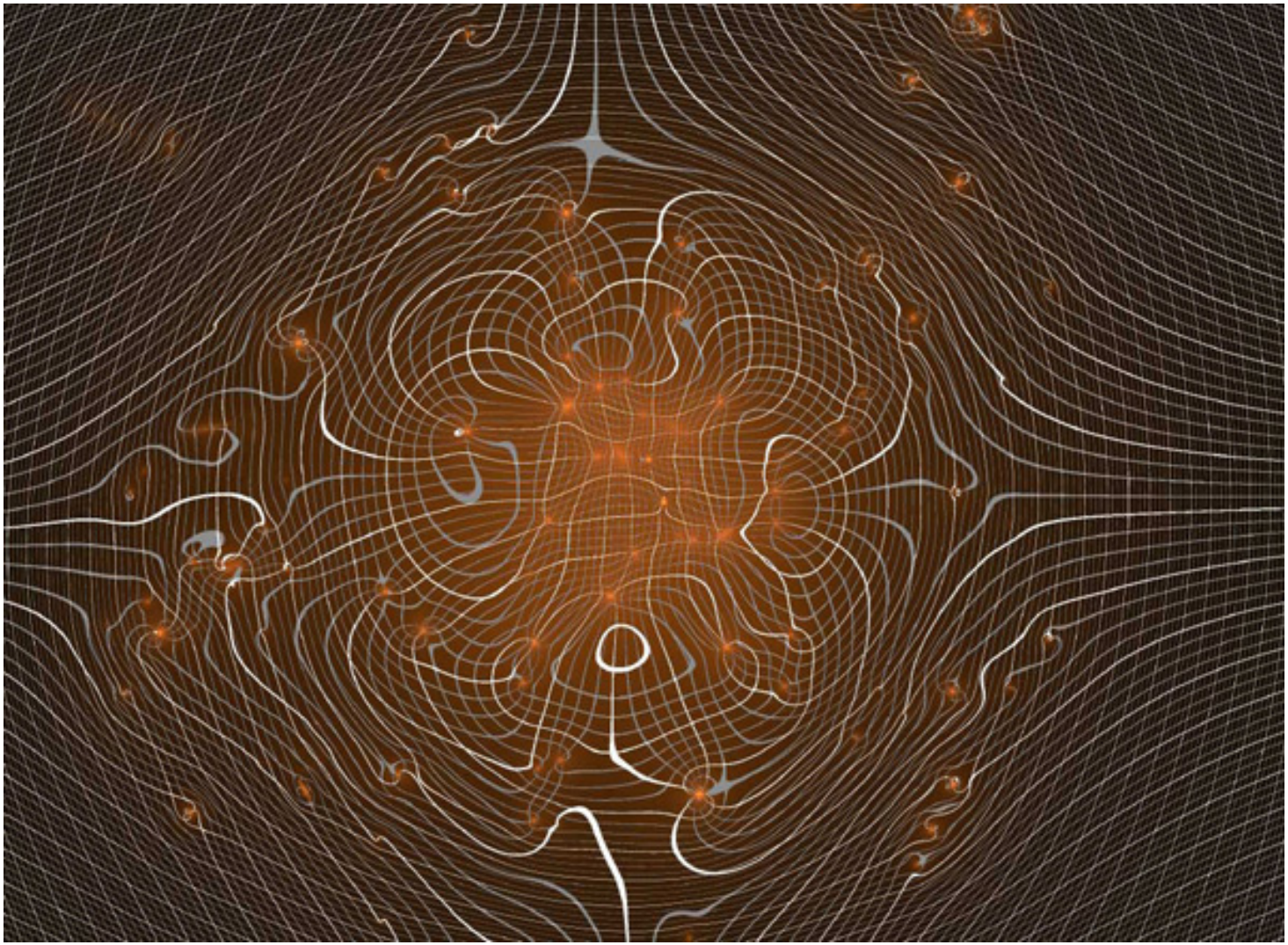
Abell 2218

arcs - single galaxy may form multiple images.

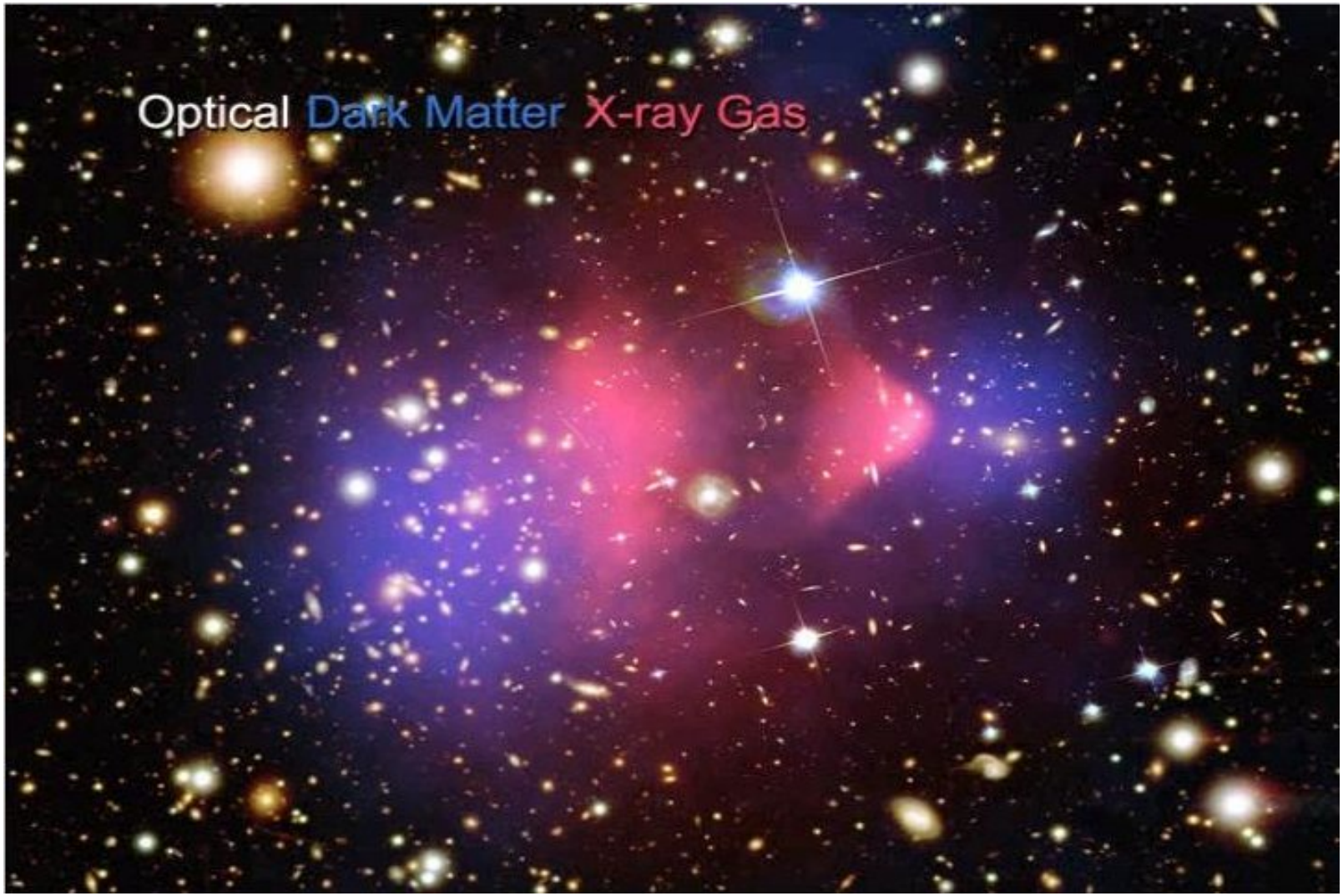
Main characteristics of lensing

- sensitive to matter of all kinds - dark matter + baryonic matter in any form - molecular, atomic, ionized
- bending of light in GR is wavelength independent - can be observed from optical to radio.

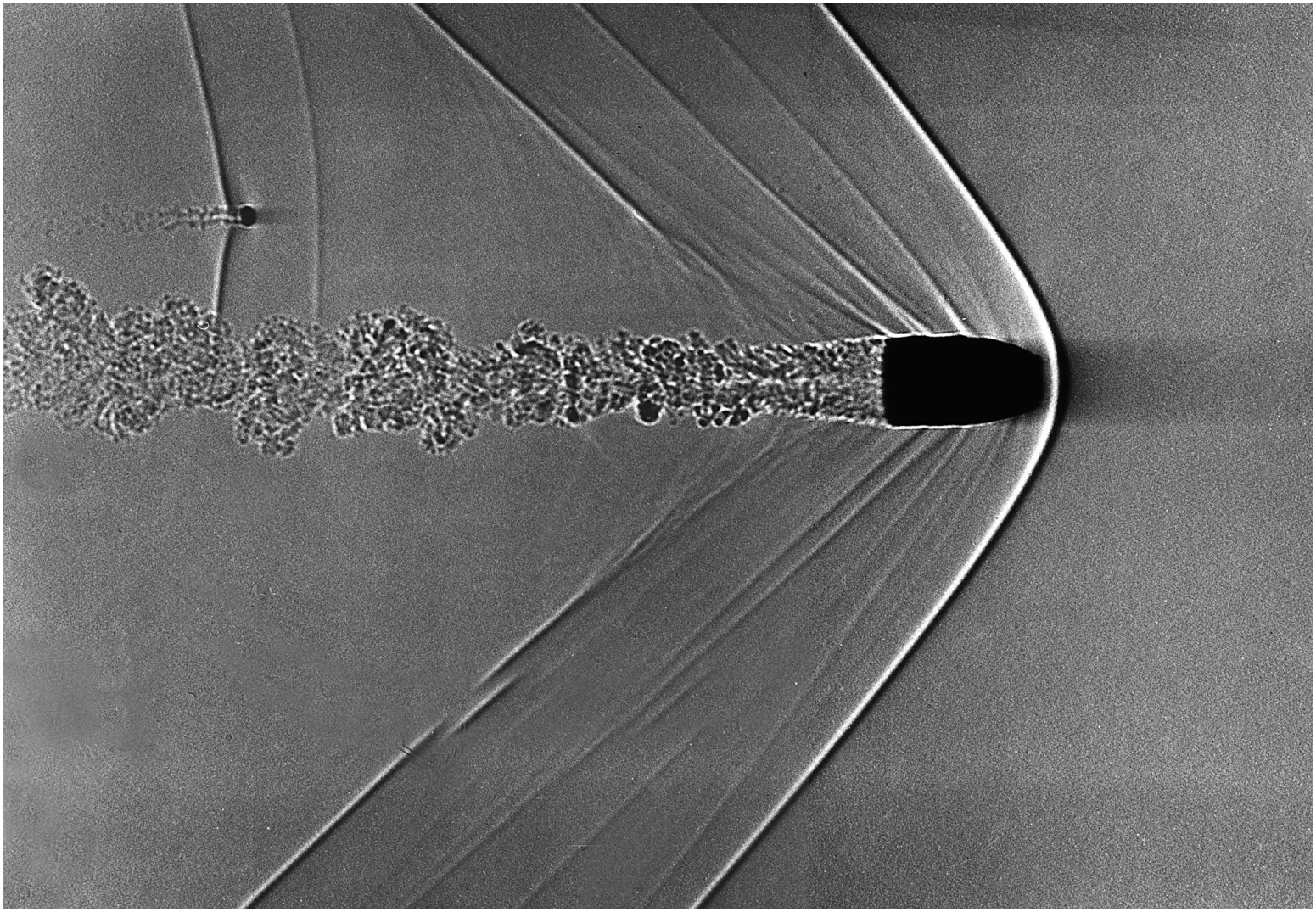
Mass model for a cluster



The bullet cluster



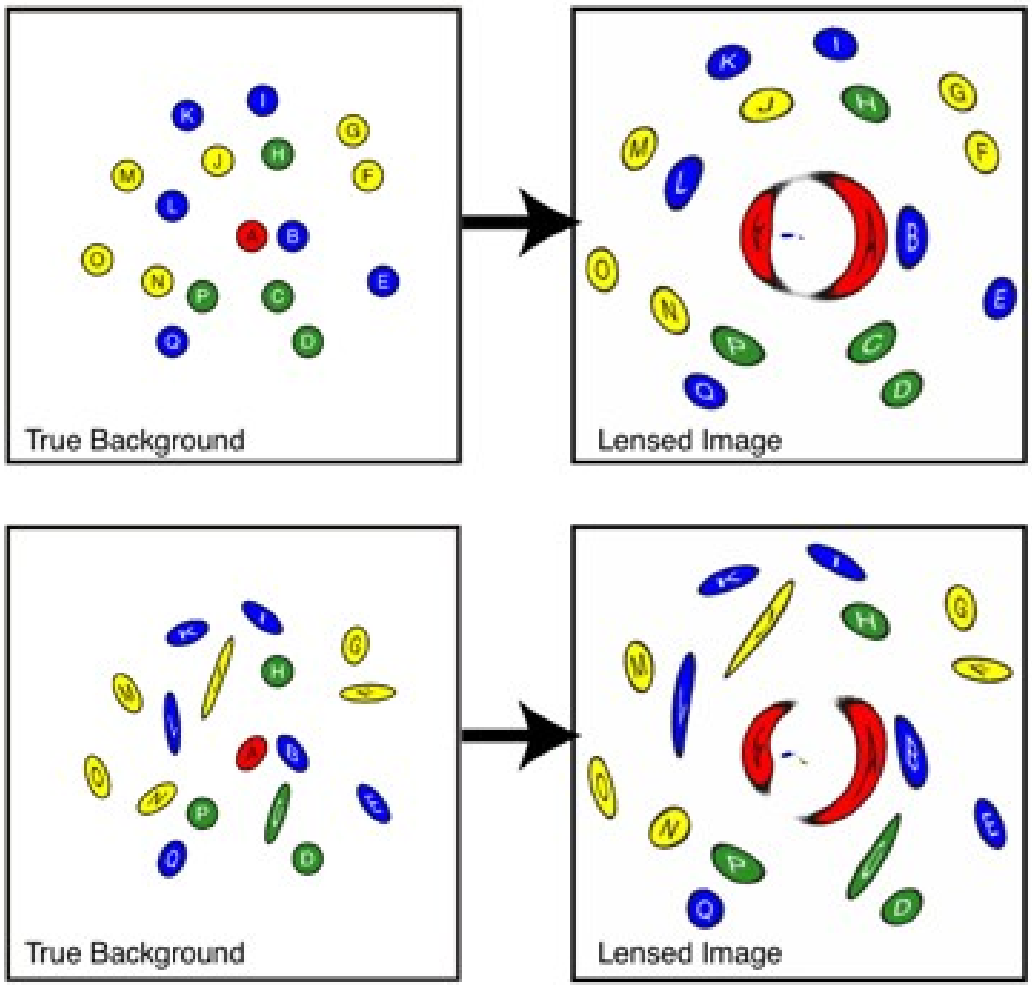
Bullet shock



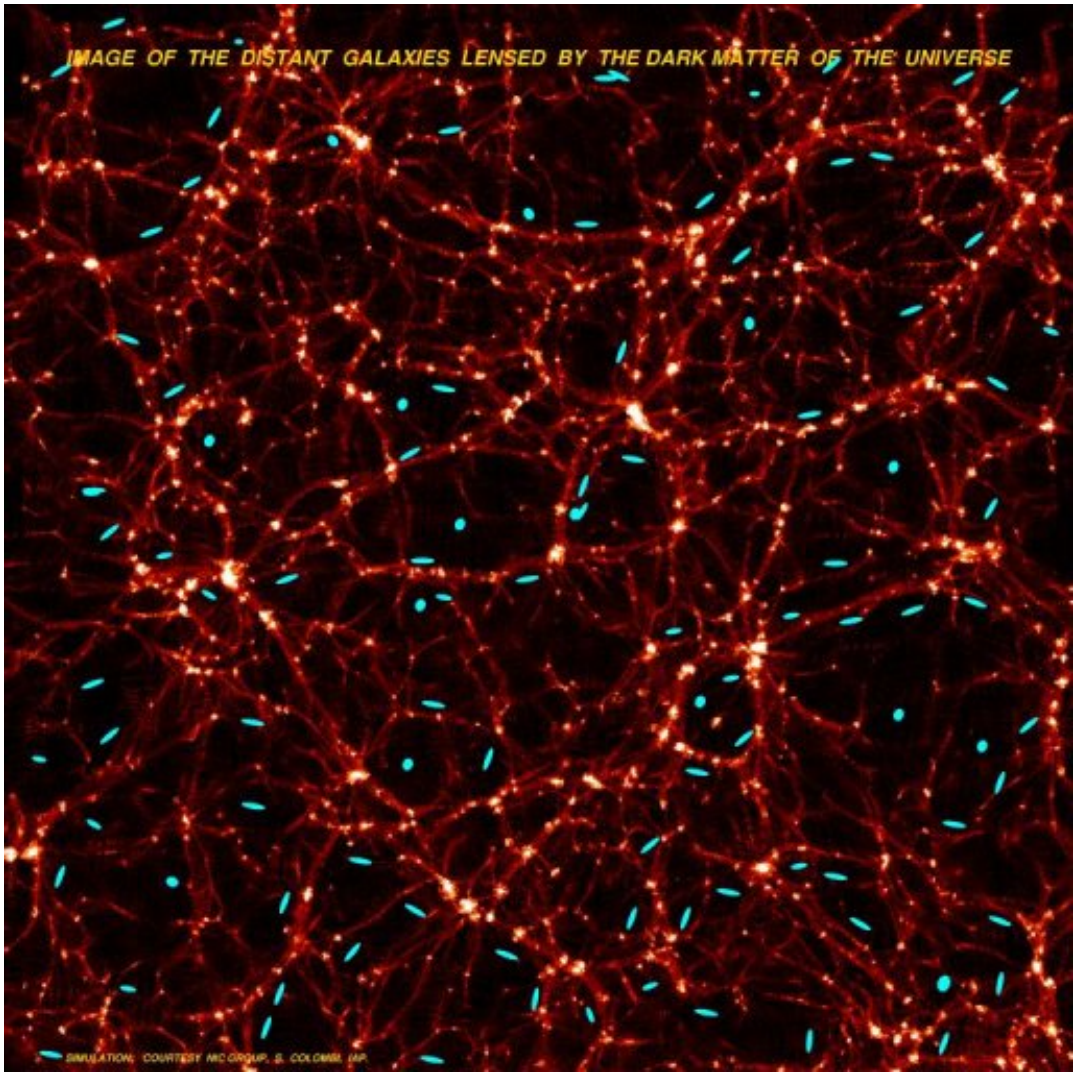
difference between weak and strong lensing

- weak lensing statistical in nature - we look for distortions in shape that affect the average shape of galaxies. Probe large scale structure of very large scales - 0.1 - 10 GPc.

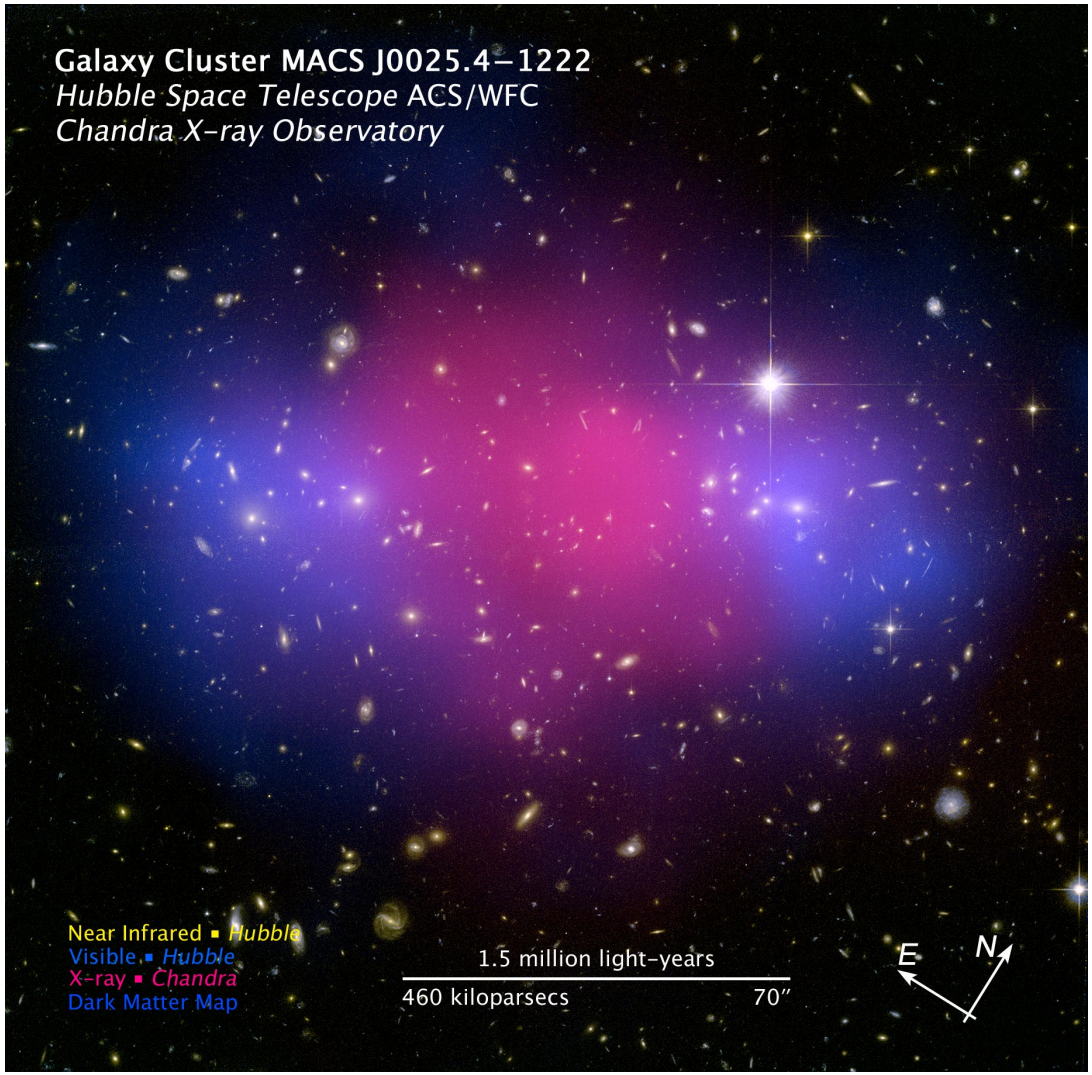
Why is weak lensing statistical?



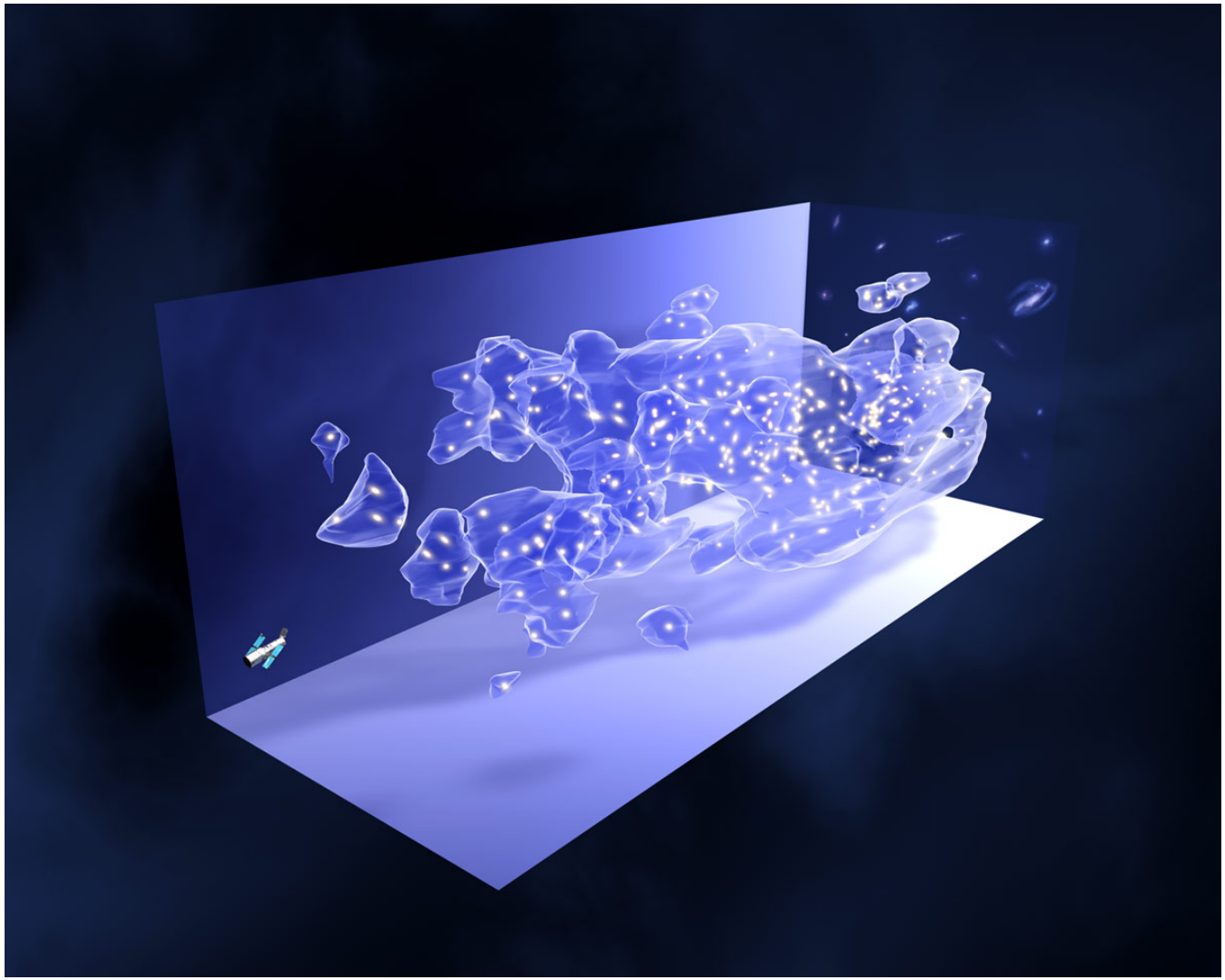
Weak lensing by large scale structure



Does weak lensing really work?



COSMOS survey mass model



Weak lensing for cosmology

- Systematics, eg. PSF measurement

Weak lensing for cosmology

- Systematics, eg. PSF measurement
- 3D lensing - tomography

Weak lensing for cosmology

- Systematics, eg. PSF measurement
- 3D lensing - tomography
- lensing of diffuse radiation - CMB, 21 cm

Weak lensing for cosmology

- Systematics, eg. PSF measurement
- 3D lensing - tomography
- lensing of diffuse radiation - CMB, 21 cm
- lensing so far has mostly been done in optical. Why? Can also be done in done in radio (with SKA).

How does starlight from 10^{11} stars add up to form galaxy light?

If you want to construct a galaxy spectrum by summing up the spectra of stars what do you need to know?

How does starlight from 10^{11} stars add up to form galaxy light?

- IMF - mass distribution of stars e.g. Salpeter

How does starlight from 10^{11} stars add up to form galaxy light?

- IMF - mass distribution of stars e.g. Salpeter
- stellar evolution - How do stars evolve *in time* on the main sequence and outside it?

How does starlight from 10^{11} stars add up to form galaxy light?

- IMF - mass distribution of stars e.g. Salpeter
- stellar evolution - How do stars evolve *in time* on the main sequence and outside it?
- spectral library (metallicity) - What is spectrum of any particular type of star as a function of age, mass, metallicity? All of the above are very uncertain at high masses and low metallicities. Why?

How does starlight from 10^{11} stars add up to form galaxy light?

- IMF - mass distribution of stars e.g. Salpeter
- stellar evolution - How do stars evolve *in time* on the main sequence and outside it?
- spectral library (metallicity) - What is spectrum of any particular type of star as a function of age, mass, metallicity? All of the above are very uncertain at high masses and low metallicities. Why?
- Star formation history (SFH) - When did stars form and at what rate?

How does starlight from 10^{11} stars add up to form galaxy light?

- IMF - mass distribution of stars e.g. Salpeter
- stellar evolution - How do stars evolve *in time* on the main sequence and outside it?
- spectral library (metallicity) - What is spectrum of any particular type of star as a function of age, mass, metallicity? All of the above are very uncertain at high masses and low metallicities. Why?
- Star formation history (SFH) - When did stars form and at what rate?
- dust - attenuation needs to be modeled.

After that, it is just arithmetic to get the galaxy spectrum