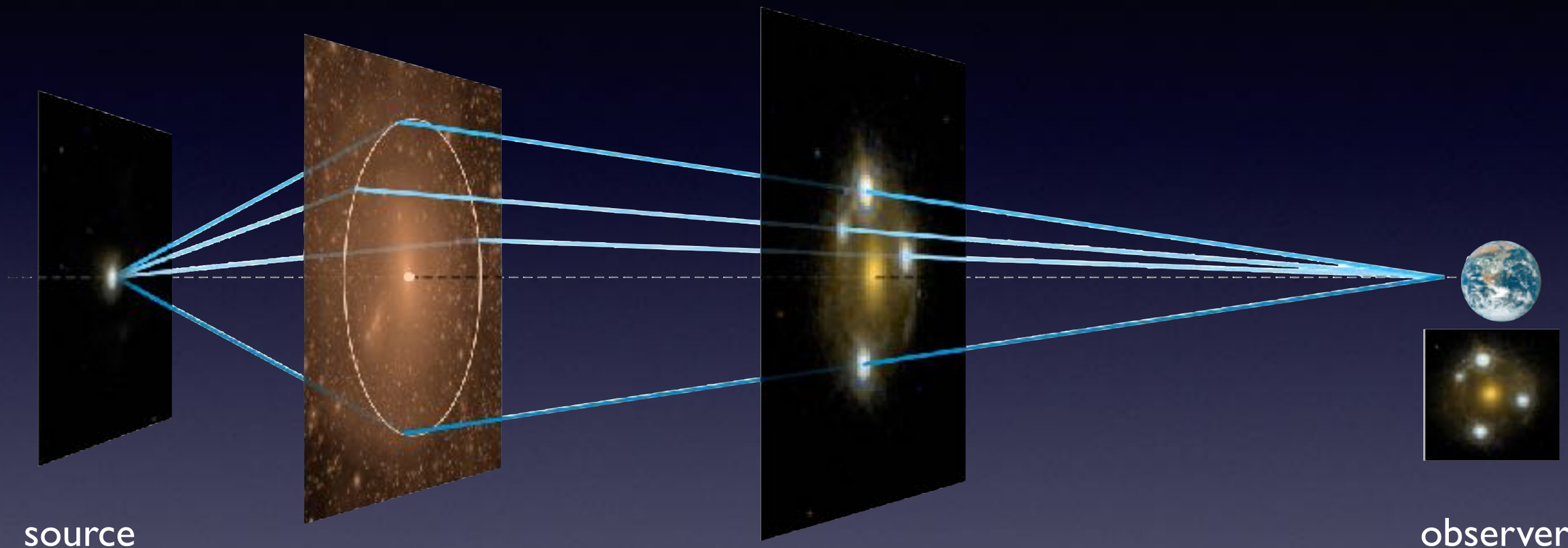
Gravitational Lensing

Prof. R. Ben Metcalf

Autumn 2024



source

Galaxy and/or
Quasar

lens galaxy

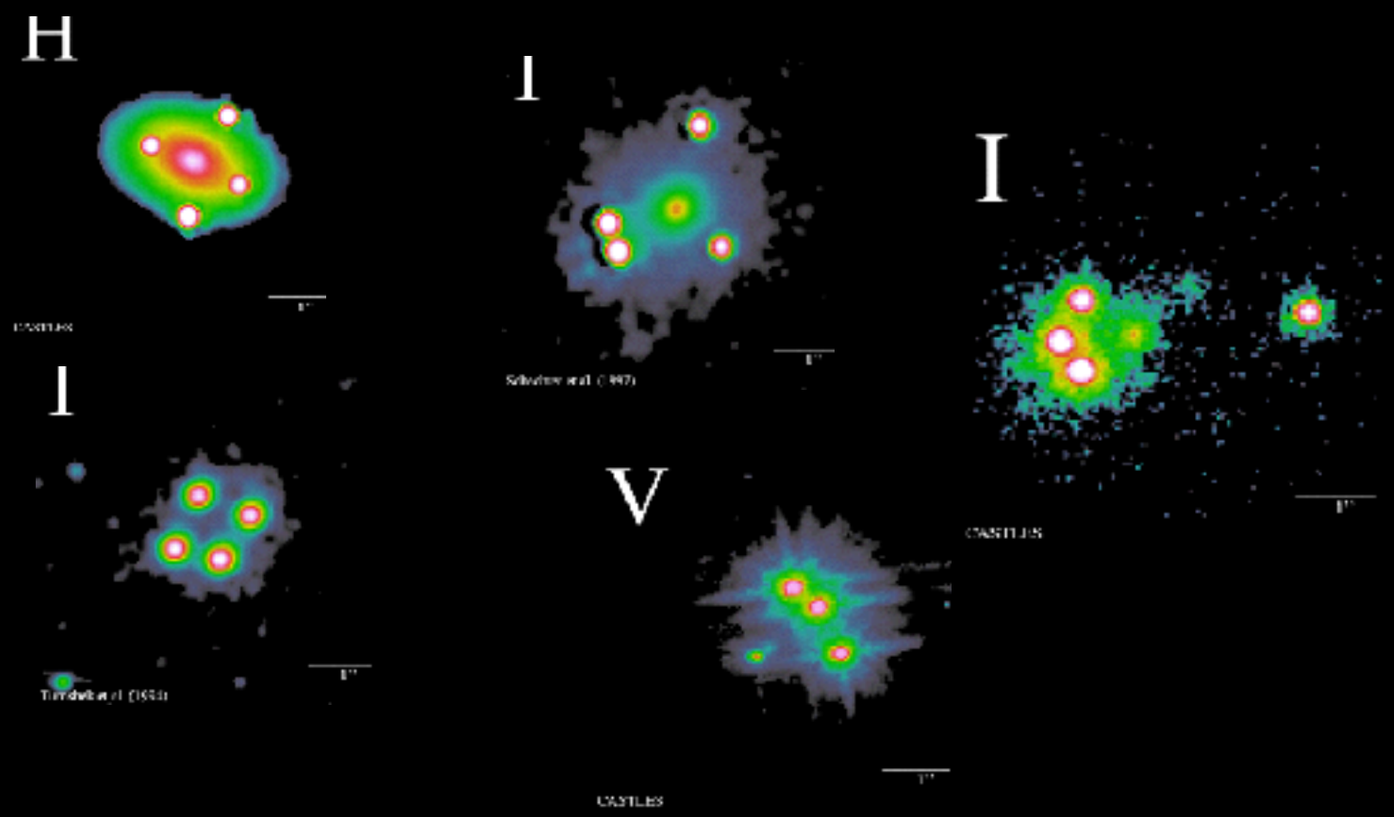
Galaxy or Cluster
of Galaxies

images

observer

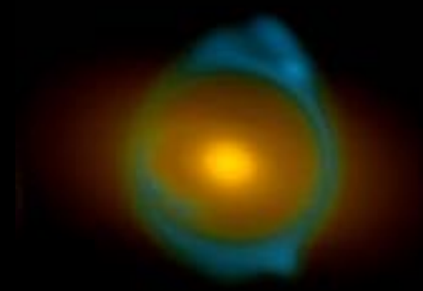
Strong Gravitational Lenses

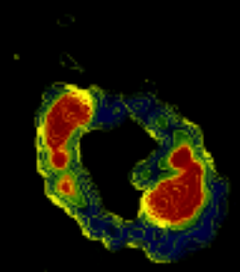
Galaxy - QSO Lenses

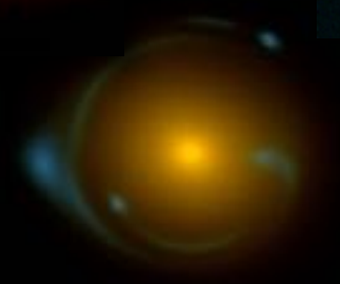


Galaxy - Cluster Lenses

Galaxy - Galaxy Lenses







Gravitational Microlensing

Gravitational lensing of stars in the Milky Way, Large Magellanic Clouds and M31 by stars and planets

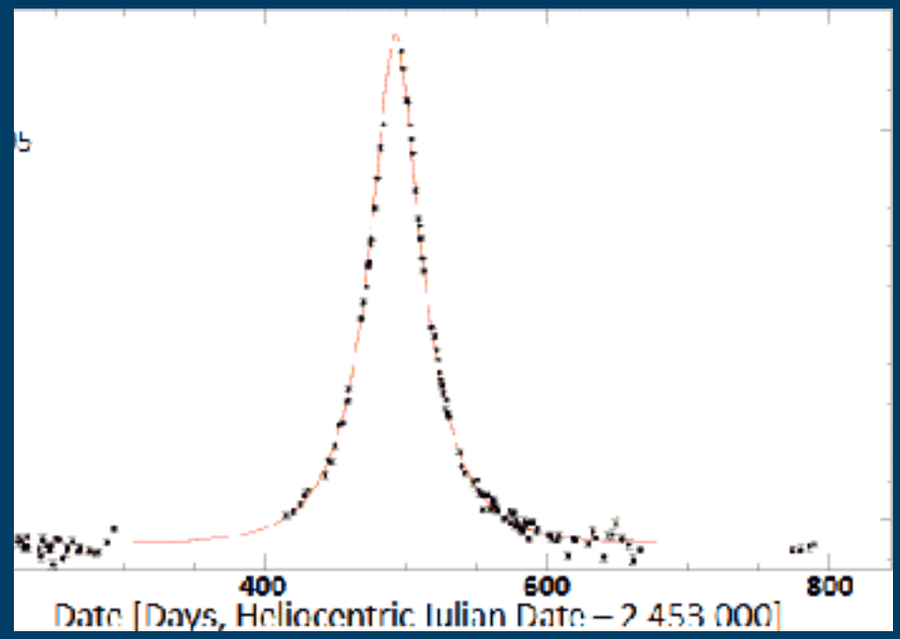
- *determine if dark matter consisting of massive compact objects (MACHOs)*

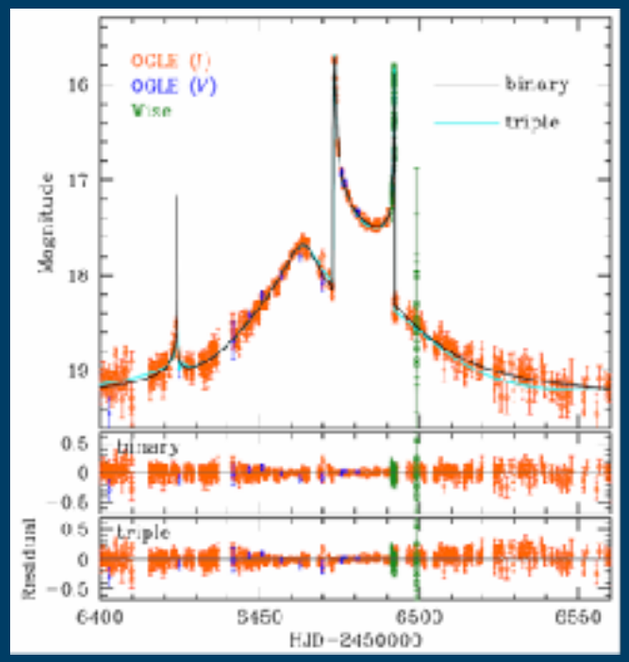
- *distribution of faint stars in the galaxy*

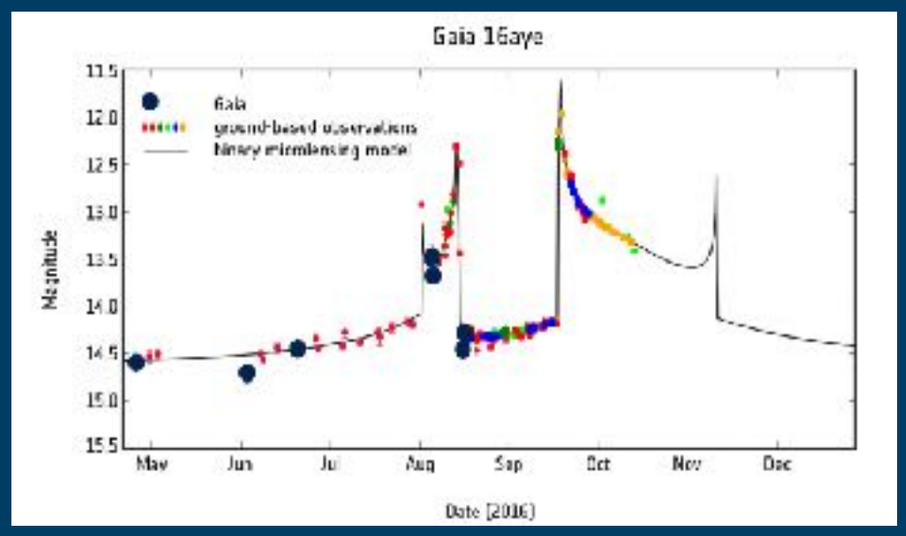
- *extrasolar planets*

- *binary stars*

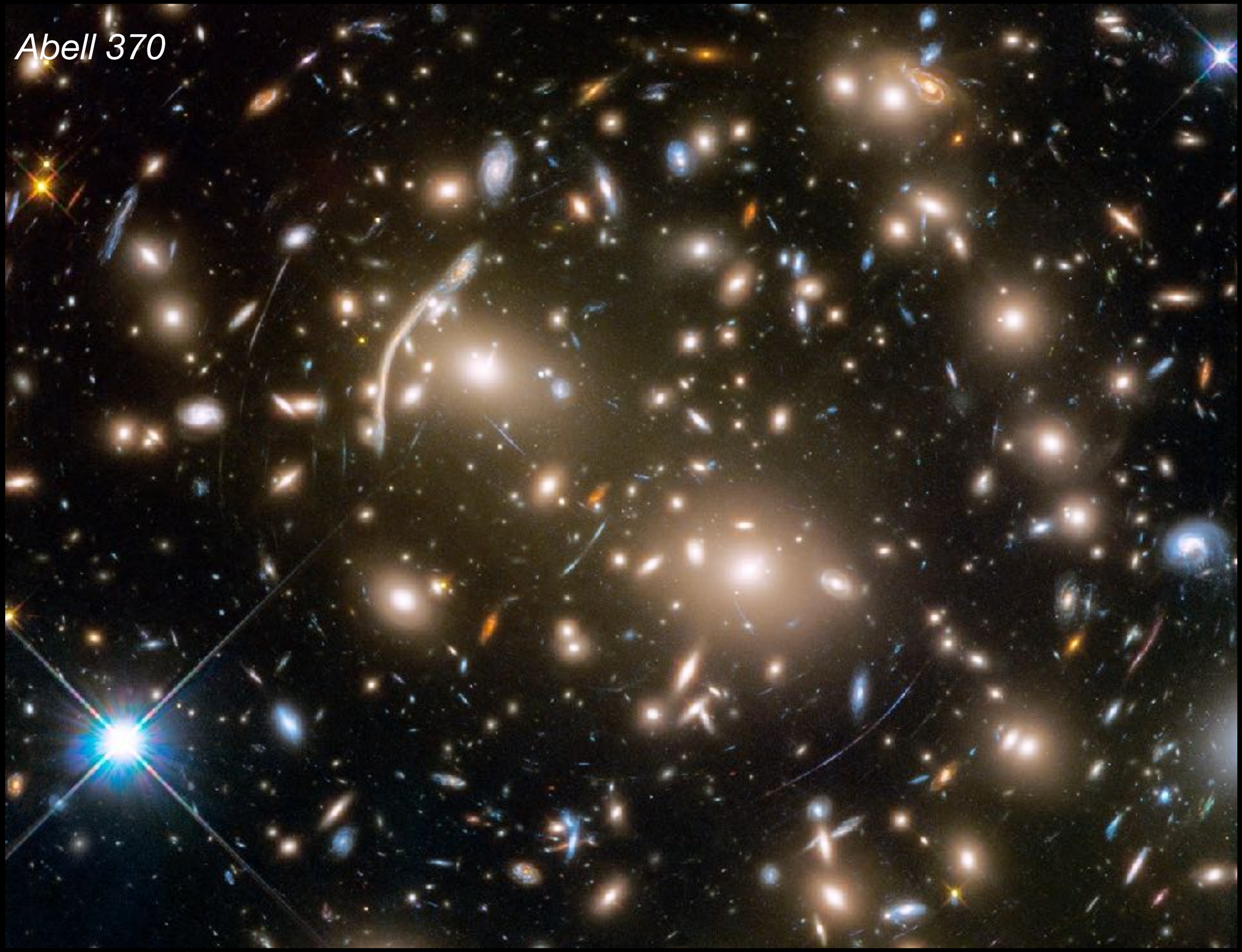
light curves during lensing events







Abell 370



Lensing Density Reconstruction

- *determine the dark matter content of galaxies and clusters*

- *map the distribution of matter within clusters*

- *studying very high redshift and faint sources : gravitational telescope*

- *measure the self-interaction of dark matter*

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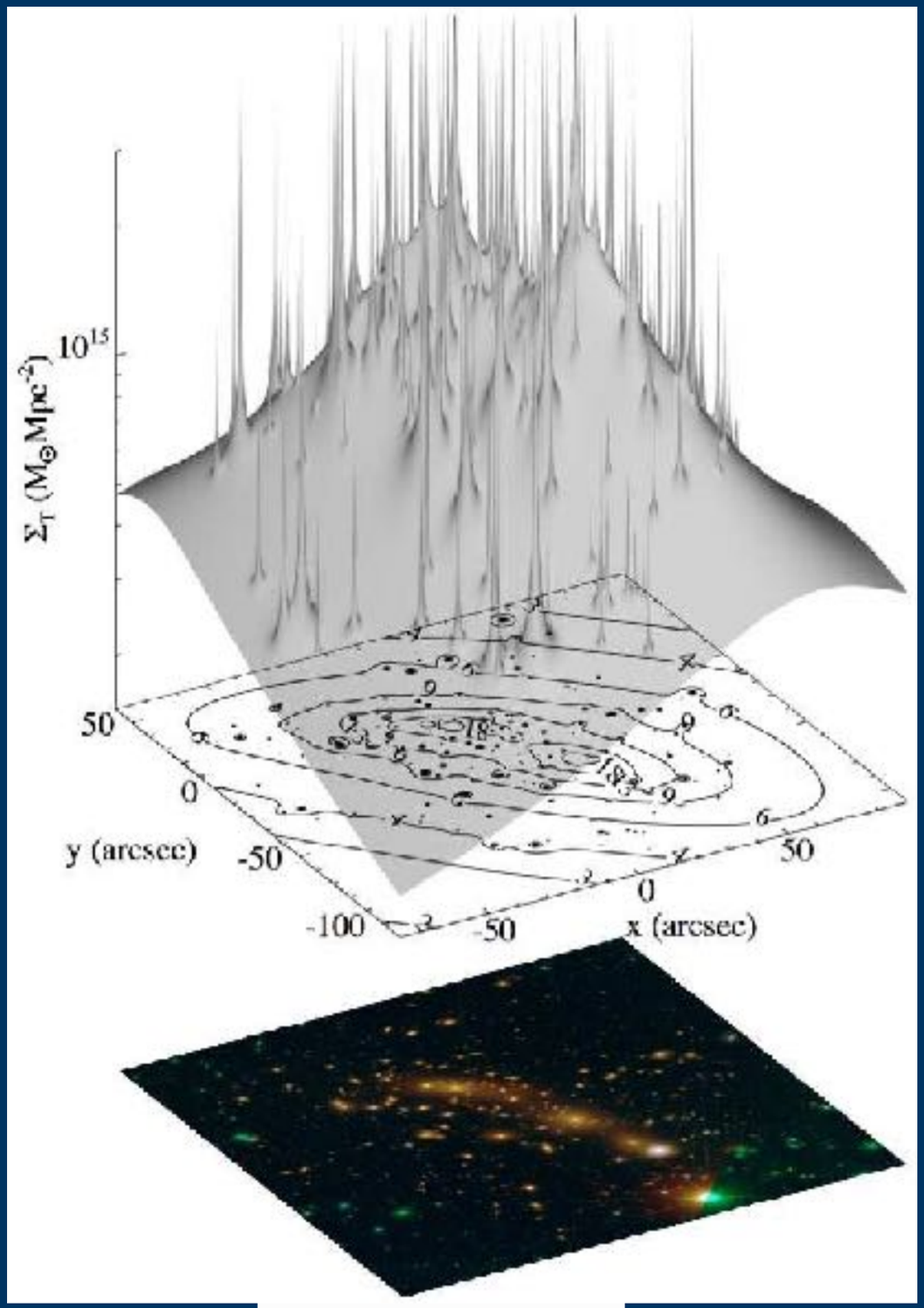
Grillo et al. 2014



MACS J0416.1-2403

Weak Gravitational Lensing

The apparent alignment of galaxy caused by the coherent stretching (or shearing) of their images by gravitational fields.

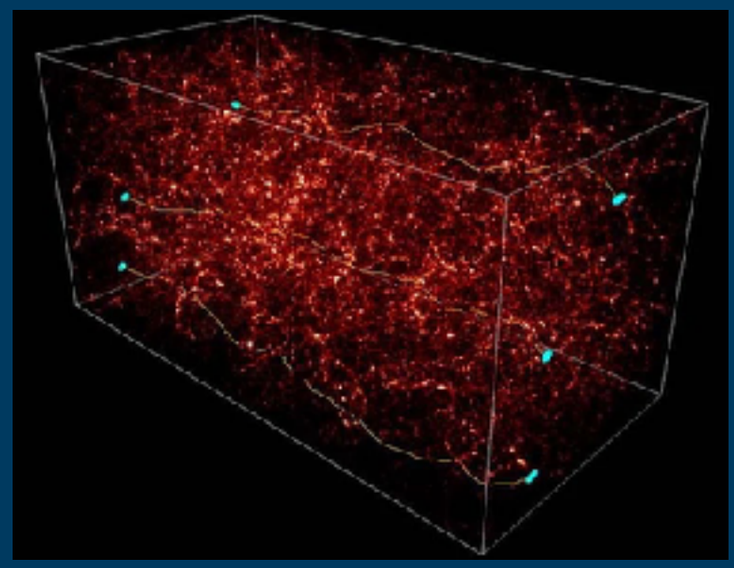
Detected statistically in large samples of galaxies

- *mapping of the density in the outskirts of galaxy clusters*
- *cosmic shear*

Evolution in the shear correlation with redshift can be used to measure the evolution of structure formation in the Universe.

cosmological parameters

probe of dark energy



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The Bullet Cluster

Colliding components have passed through one another.

In blue is the mass and in red is the gas.

Shows that dark matter has minimal self interaction.

Topics in Gravitational Lensing

Many hands-on computational examples in python notebooks.

- *light in a gravitational field*
- *theory of gravitational lenses - multiple images, caustics & critical curves*
- *micro-lensing*
  - *limits of dark matter in compact objects*
  - *binary stars & exoplanets*
- *strong lensing of quasars*
  - *time-delays and measuring the Hubble constant and other cosmological parameters*
- *strong lensing by galaxy cluster*
  - *density reconstruction from strong lensing*
- *Weak lensing of galaxies*
  - *density reconstruction*
  - *weak lensing in cosmological*
- *Weak lensing of the Cosmic Microwave Background*

COURSE MATERIALS

PRIMARY TEXT : “INTRODUCTION TO GRAVITATIONAL LENSING WITH PYTHON EXAMPLES”, by Massimo Meneghetti, Springer

AVAILABLE COURSE MATERIALS : https://virtuale.unibo.it

- LECTURE SLIDES
- PYTHON NOTEBOOKS

OTHER SUGGESTED TEXTS :

- “GRAVITATIONAL LENSING: STRONG, WEAK & MICRO”, Schneider, Kochaneck & Wamsganss
- “PRINCIPLES OF GRAVITATIONAL LENSING”, Congdon & Keeton
- “GRAVIATATIONAL LENSING”, Dodelson