

MACS J1423 : Mass modelling with gravitational lensing

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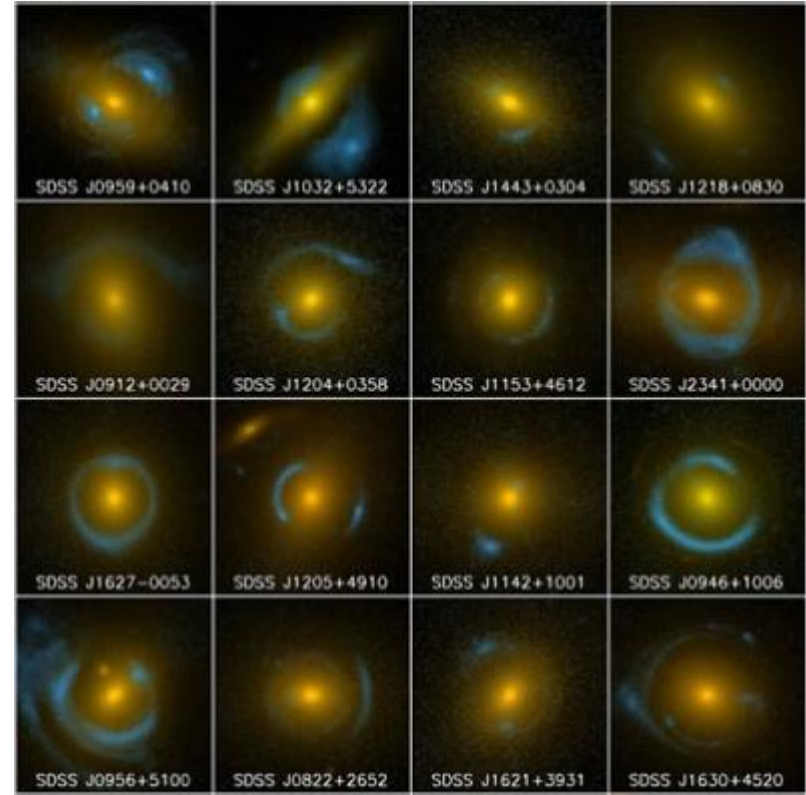
Supervisors : Mathilde Jauzac & Anna Niemiec

German Conference of Women in Physics : 26th November 2022



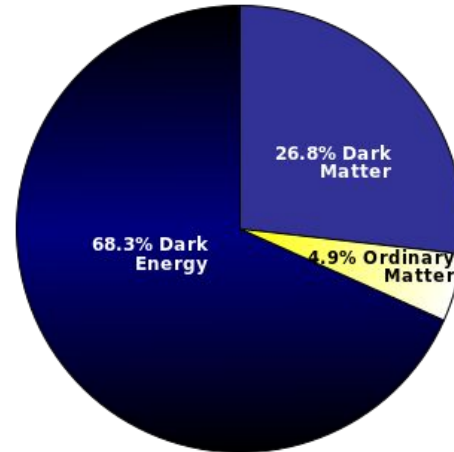
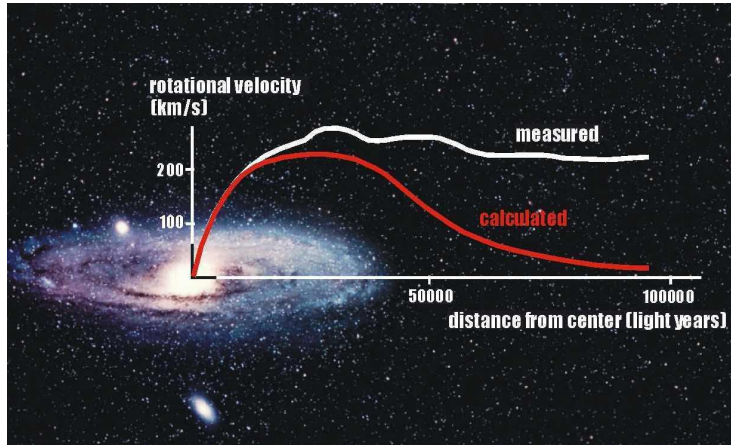
Outline

- Galaxy Clusters
- Gravitational lensing
- Clusters as lenses
- Mass modelling of MACSJ1423
 - Strong lensing analysis
 - Weak lensing analysis



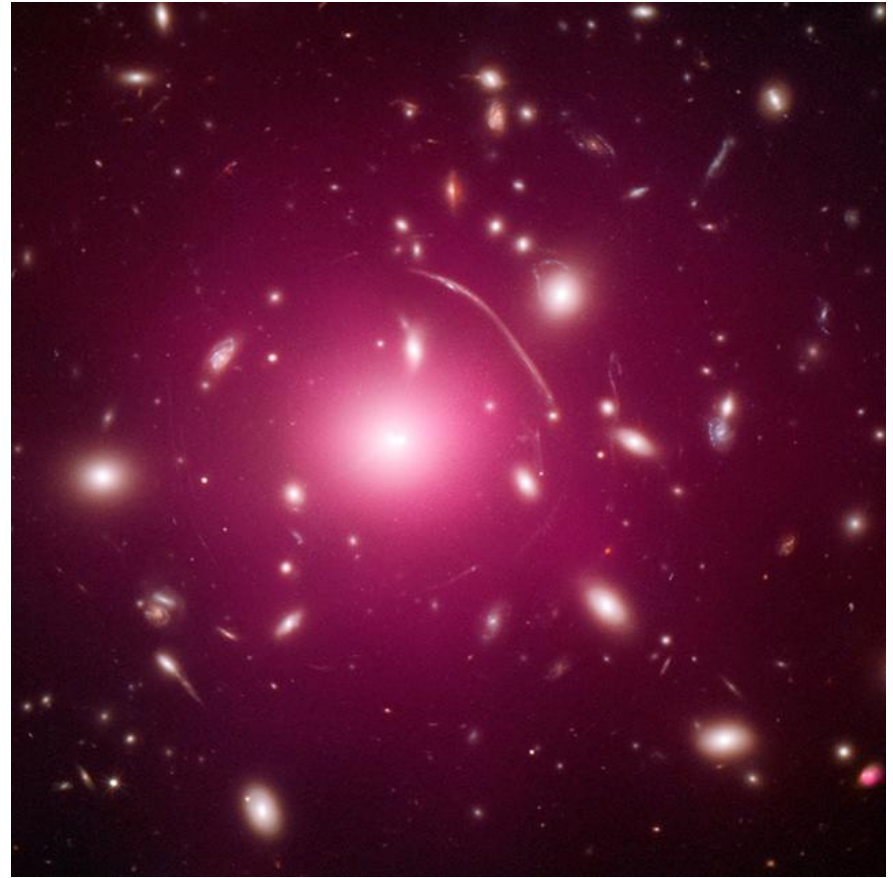
Dark Matter

- Predicted by Fritz Zwicky in 1933
- Not confirmed until 1970 by Vera Rubin : velocity rotation curves
- Λ Cold Dark Matter (Λ CDM) model : Dark matter dominated Universe



Galaxy Clusters

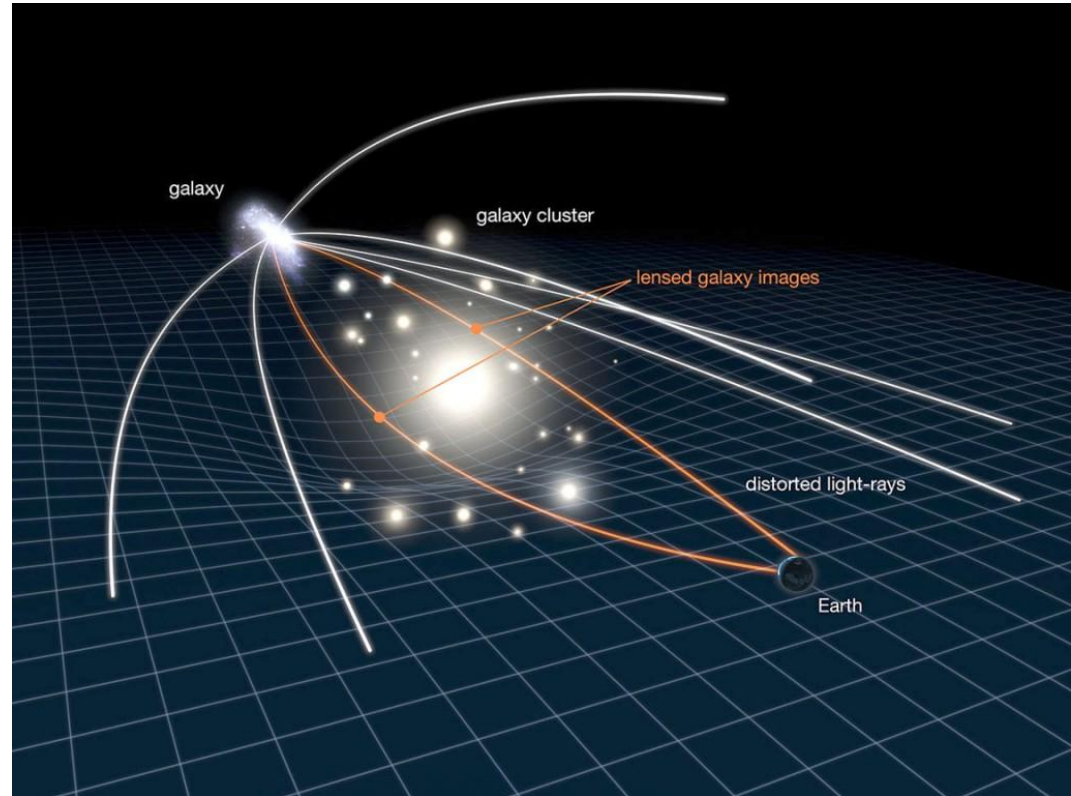
- Largest gravitationally bound objects in the Universe
- Dark matter + X-ray emitting gas (ICM) + tens to hundreds of galaxies
- Mass budget : 85% of dark matter + 15% of gas + 5% of stars (Gonzalez et al. 2007)
- Perfect laboratories to study dark matter



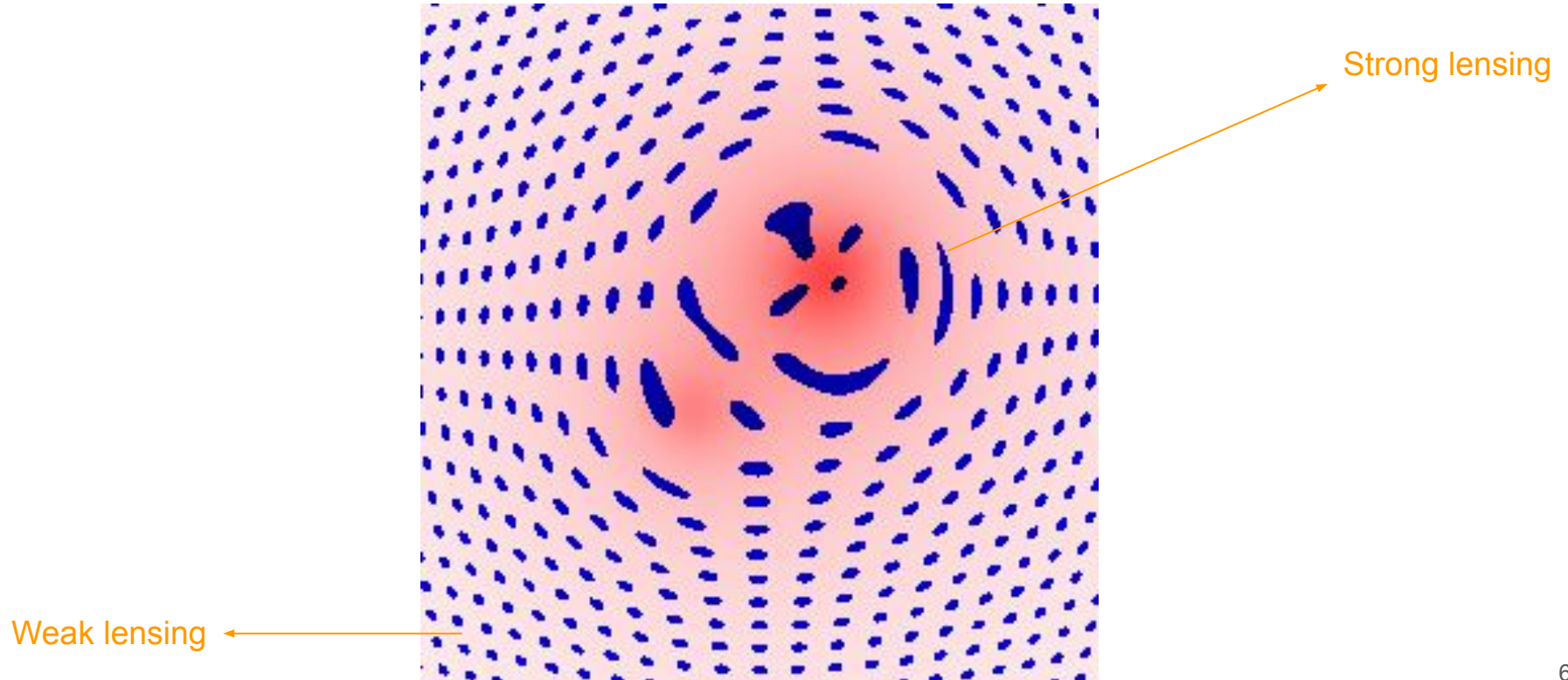
Abell 383 : X-ray + optical (Credit : Chandra, NASA)

Gravitational lensing

- Deflection of light due to the distortion of space-time by an intervening mass concentration (called lens)
- Distorted, magnified and sometimes multiple images of background source (Kneib and Natarajan, 2011)

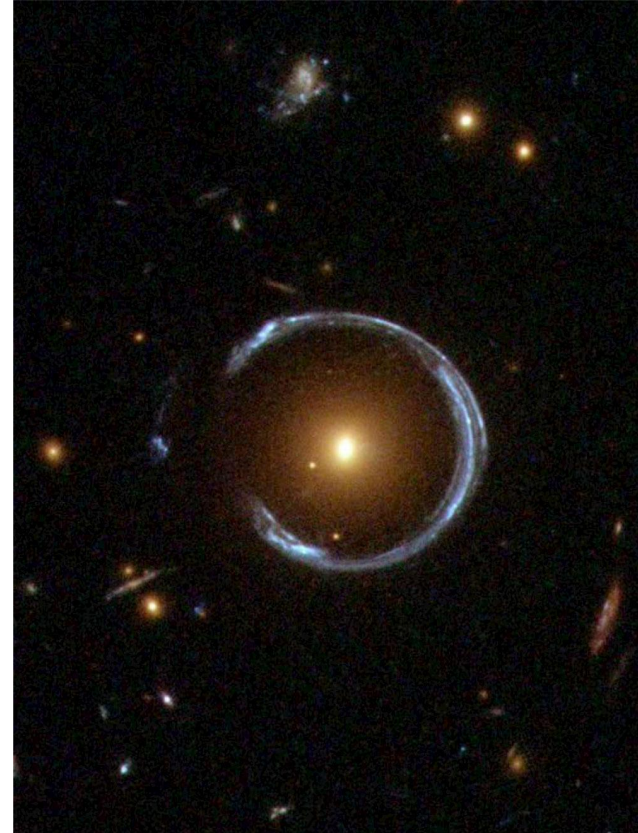


Gravitational lensing



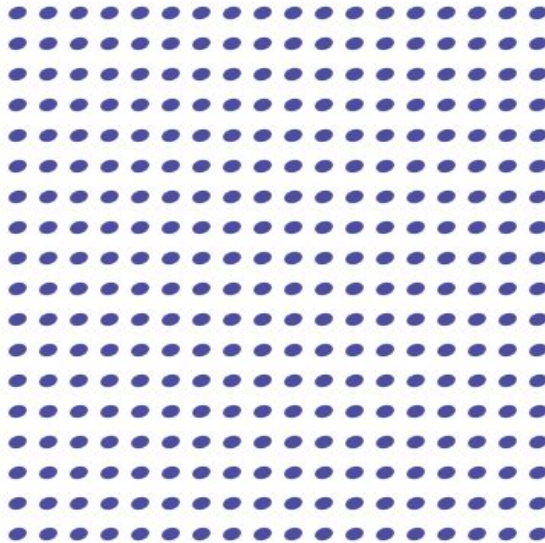
Gravitational lensing : Strong lensing

- High density region
- Large distortions
- Magnified giant arcs, multiple images

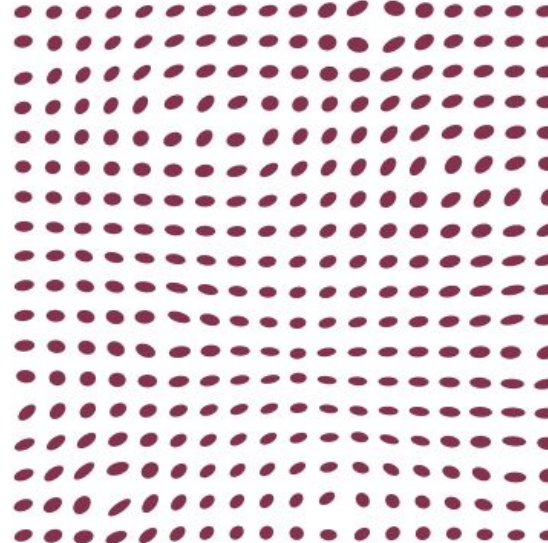


Gravitational lensing : Weak lensing

- Low density region
- Minor distortions (shear) : Quantified statistically



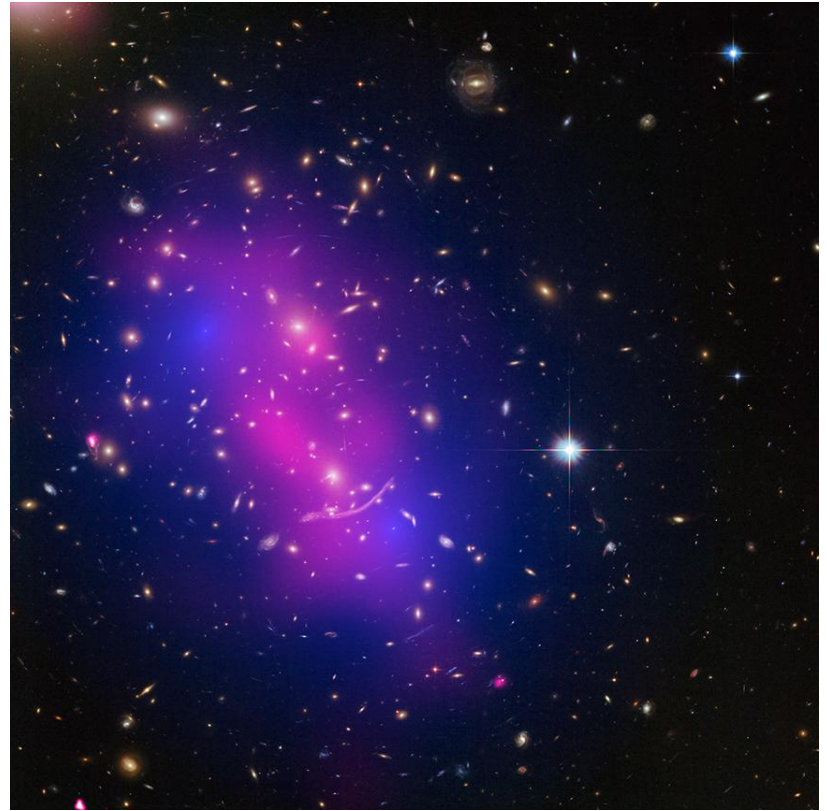
Unlensed sources



Weak lensing

Clusters as gravitational lenses

- Most powerful lenses
- Highly distorts space-time
- Clusters + lensing
 - **Map dark matter distribution** in clusters
 - Study background sources
 - Understanding geometry of the Universe



Abell 370 : X-rays + optical + lensing map
(Credit : Chandra, NASA)

The MAssive Cluster Survey (MACS)

- 124 X-ray luminous clusters
- $0.3 < z < 0.7$

MACS J1423.8+2404 (MACS J1423)

- Massive, relaxed cluster
- $z = 0.54$
- ~7 Gyr after the Big Bang

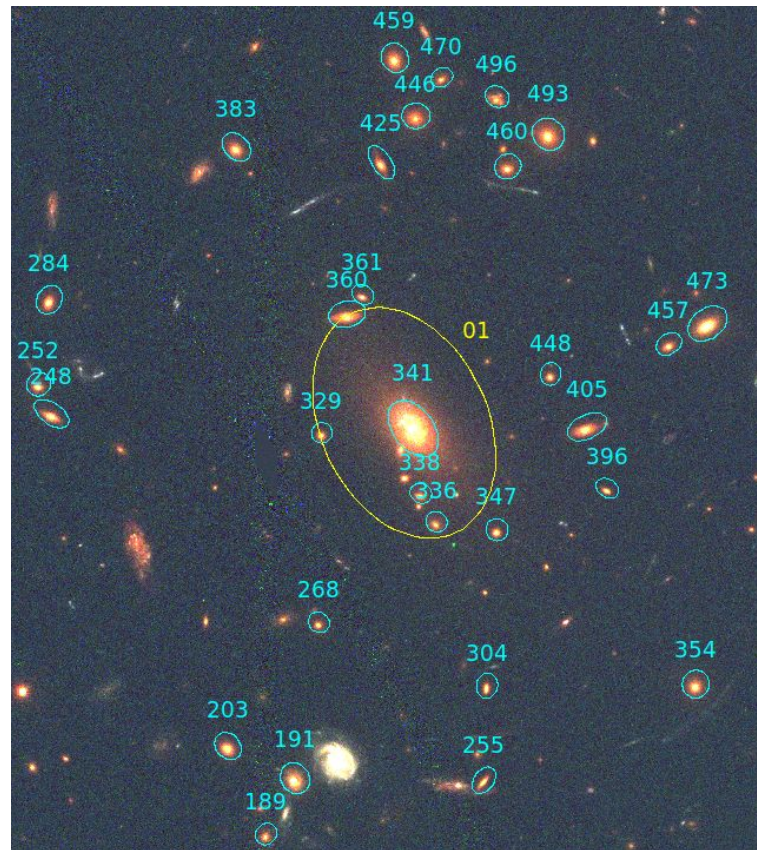


Mass modelling : Strong lensing

Parametric mass distribution with two mass components

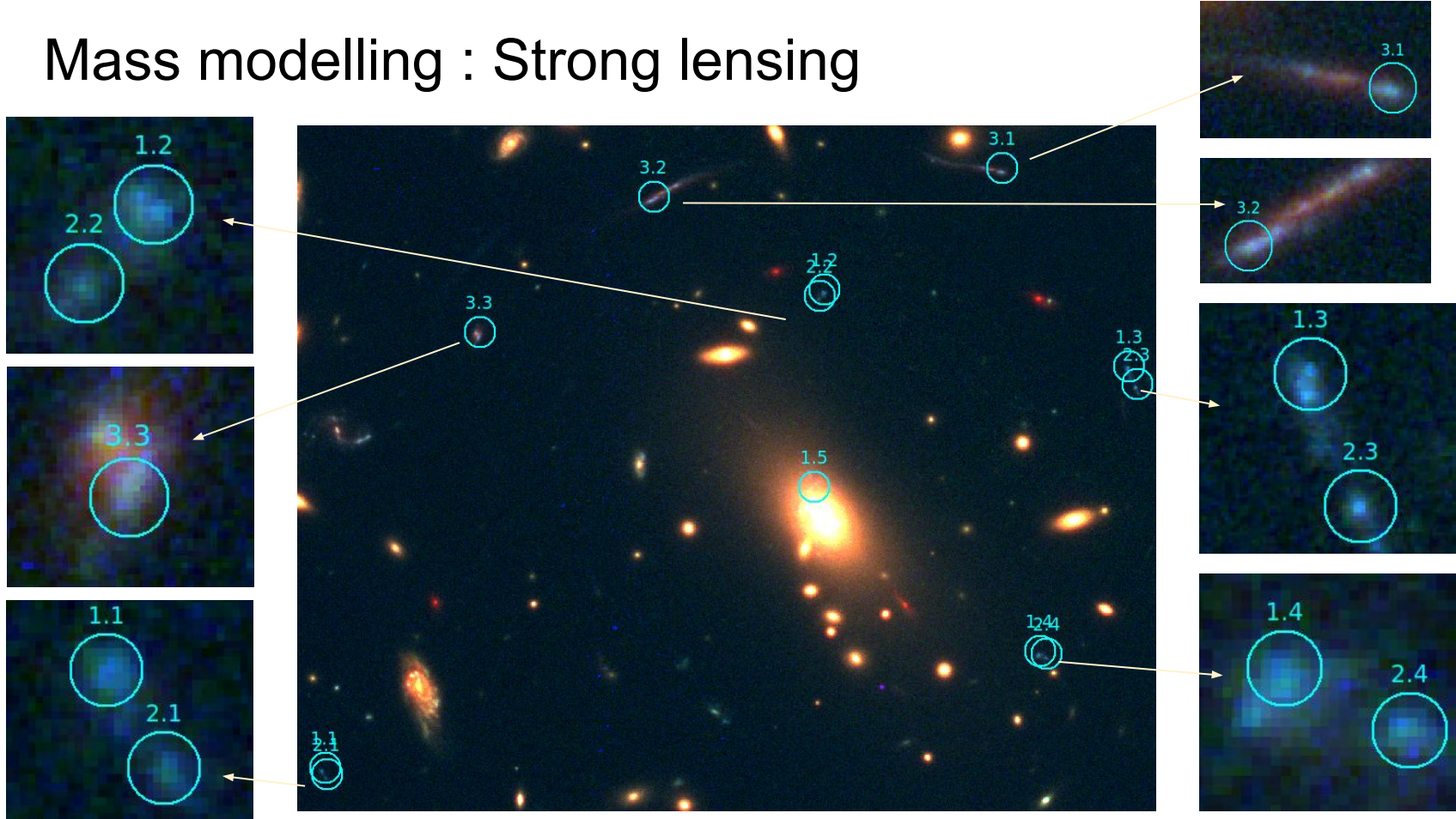
- **large-scale**
 - cluster dark matter halo
- **small-scale**
 - cluster galaxies

Density profile : dual Pseudo Isothermal
Elliptical (dPIE) Mass Distribution



Large-scale (yellow) & small-scale (cyan)
potentials

Mass modelling : Strong lensing

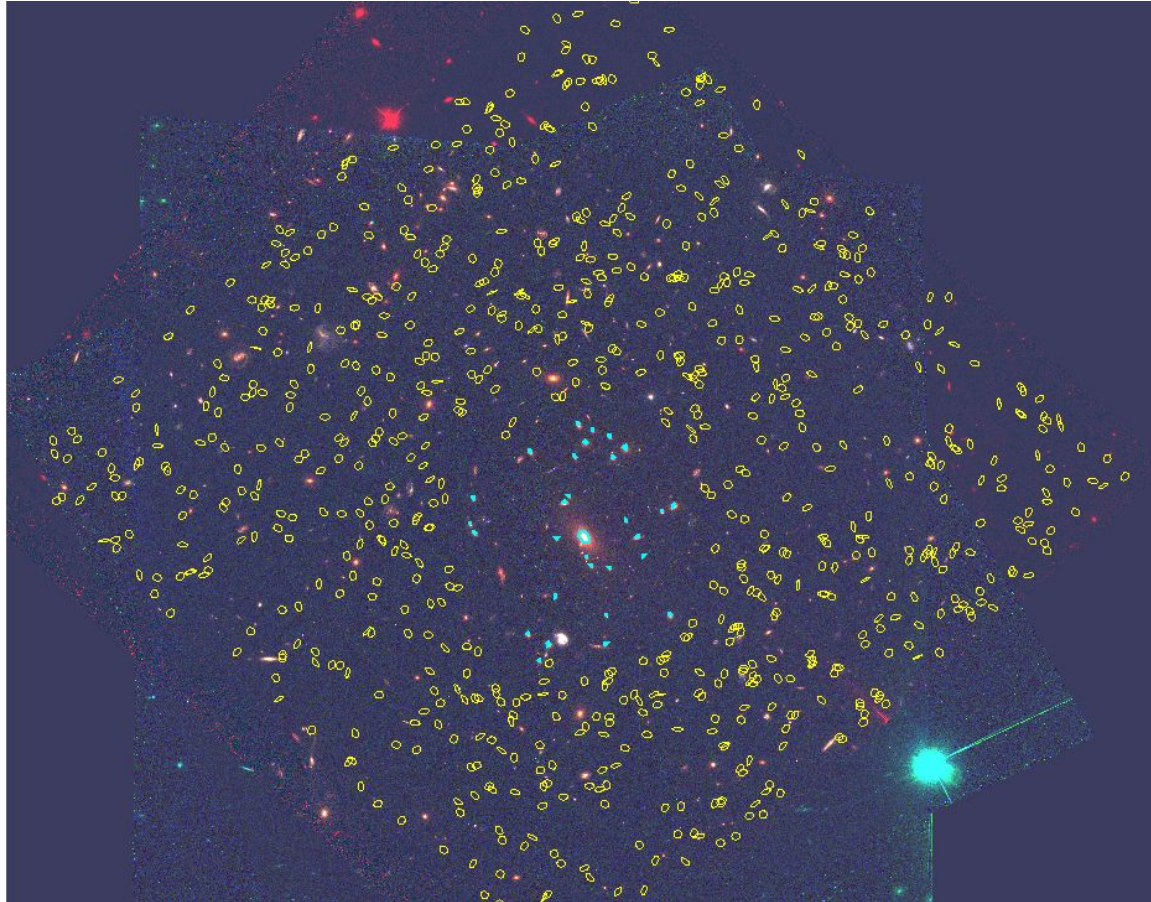


Mass modelling : Strong lensing

The LENSTOOL software (Jullo et al. 2007; publicly available) is used to model the mass distribution.

- Mass within 65 arcsec :
 - LENSTOOL : $M [< 65'' (415 \text{ kpc})] = (4.15 \pm 0.15) \times 10^{14} M_{\odot}$
 - Limousin et al. 2010 (L10) : $M [< 65'' (415 \text{ kpc})] = (4.3 \pm 0.6) \times 10^{14} M_{\odot}$
- Mass enclosed for source redshift of $z \sim 2$ at an effective Einstein radius of 20''
 - LENSTOOL : $M = (0.97 \pm 0.006) \times 10^{14} M_{\odot}$
 - Zitrin et al. 2011 (Z11) : $M = (1.3 \pm 0.40) \times 10^{14} M_{\odot}$
- Mass measurement from LENSTOOL and Z11 accounts for strong lensing only while L10 is a combination of strong and weak lensing.

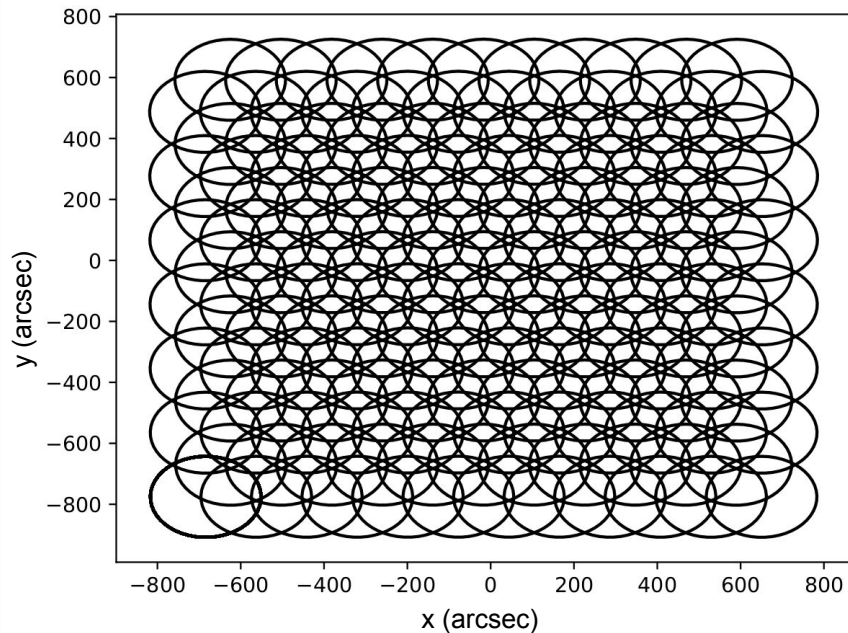
Mass modelling : strong lensing $\rightarrow$ weak lensing



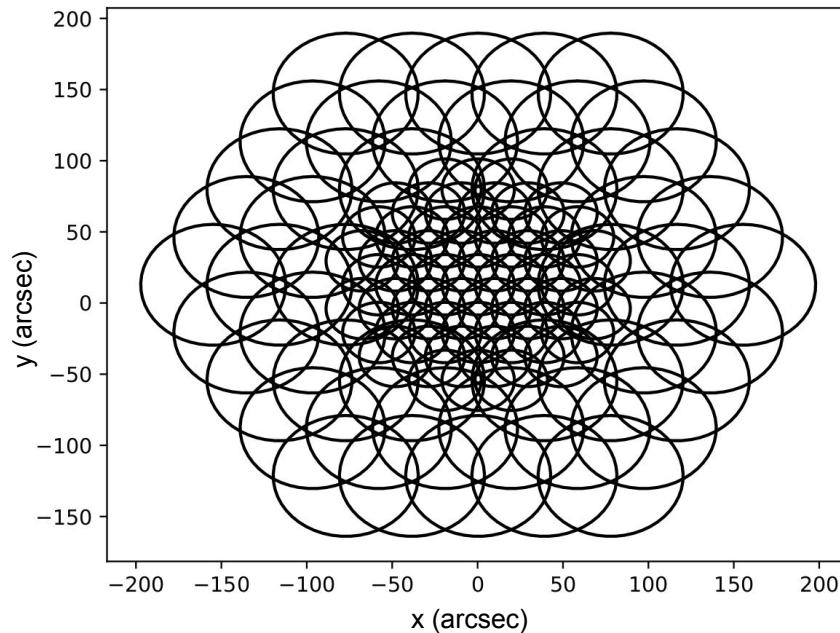
Mass modelling : Weak lensing

Non-parametric grid

Regular grid

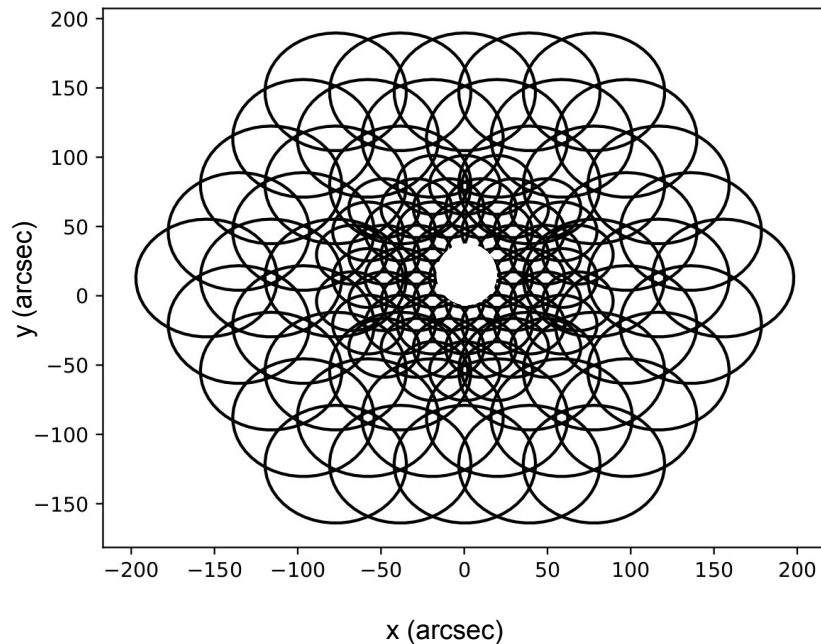


Multiscale Irregular grid



Mass modelling : Weak lensing

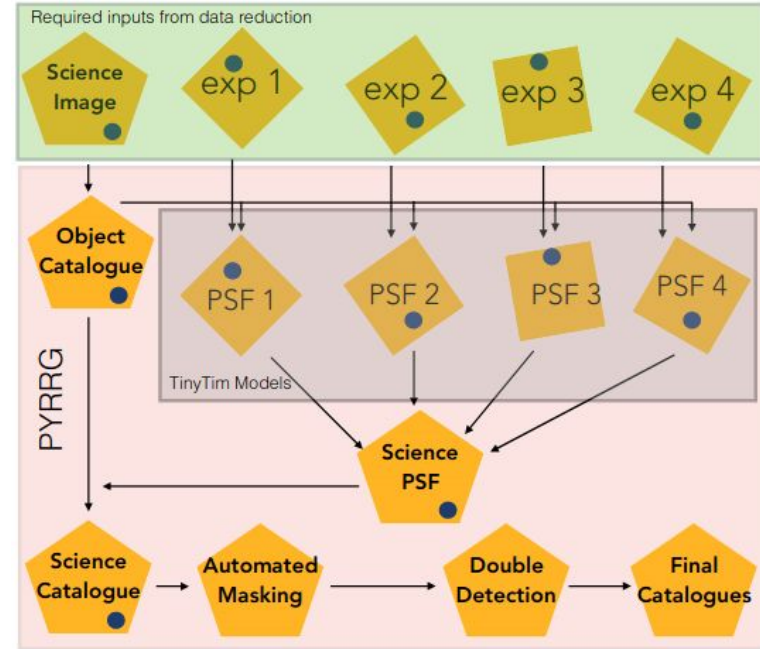
- Grid : weak lensing region
- Density profile
 - Truncated Isothermal Mass Distribution (TIMD)
- Optimization using LENSTOOL
 - Needs constraints



Mass modelling : Weak lensing

Weak lensing shape measurement : pyRRG

- Detect sources
- Star-Galaxy Classification
- Shape Estimation
- Clean the catalogue



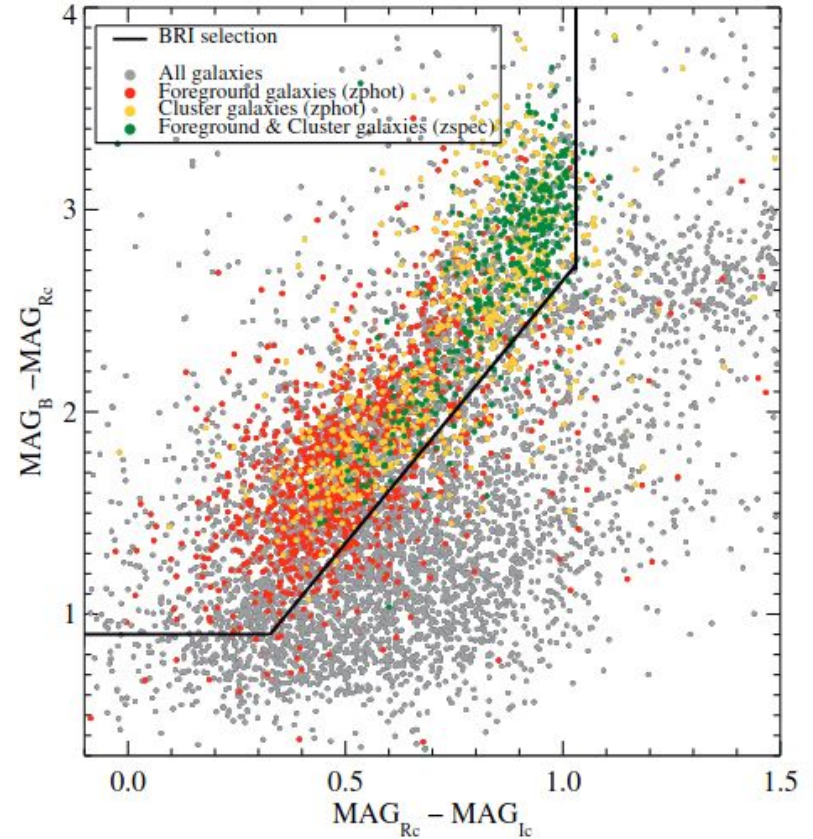
An overview of the pyRRG algorithm.

Harvey, D et al. 2019

Mass modelling : Weak lensing

Weak lensing Catalogue

- Background galaxies : lensing signal
- Remove
 - Cluster galaxies
 - Foreground galaxies
 - stars

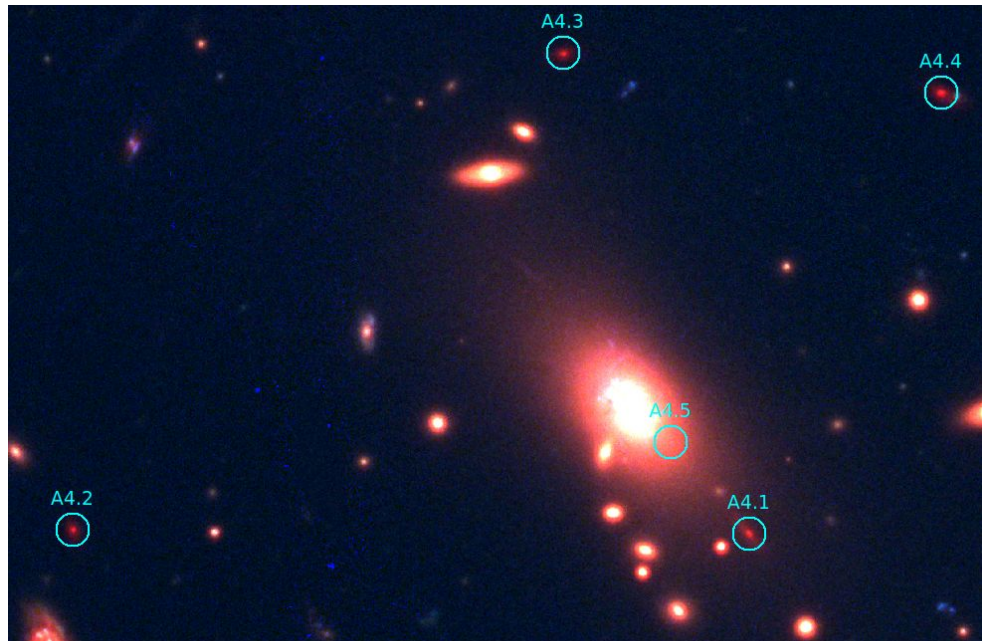


Colour-colour diagram for MACS J0717.

Jauzac, M et al. 2012

Future Work

- MACS J1423
 - More strong lensing constraints
 - Combine strong & weak lensing



Fourth multiple image system in MACS J1423

Summary

- Clusters + lensing → natural telescope
 - Study of dark matter
 - Observe distant Universe
 - Cosmology
- Mass distribution in clusters
- Mass modelling of MACS J1423
 - Strong Lensing
 - Weak Lensing



Credit : Hubble, NASA