Galaxy cluster masses from magnification and the effects of intracluster dust

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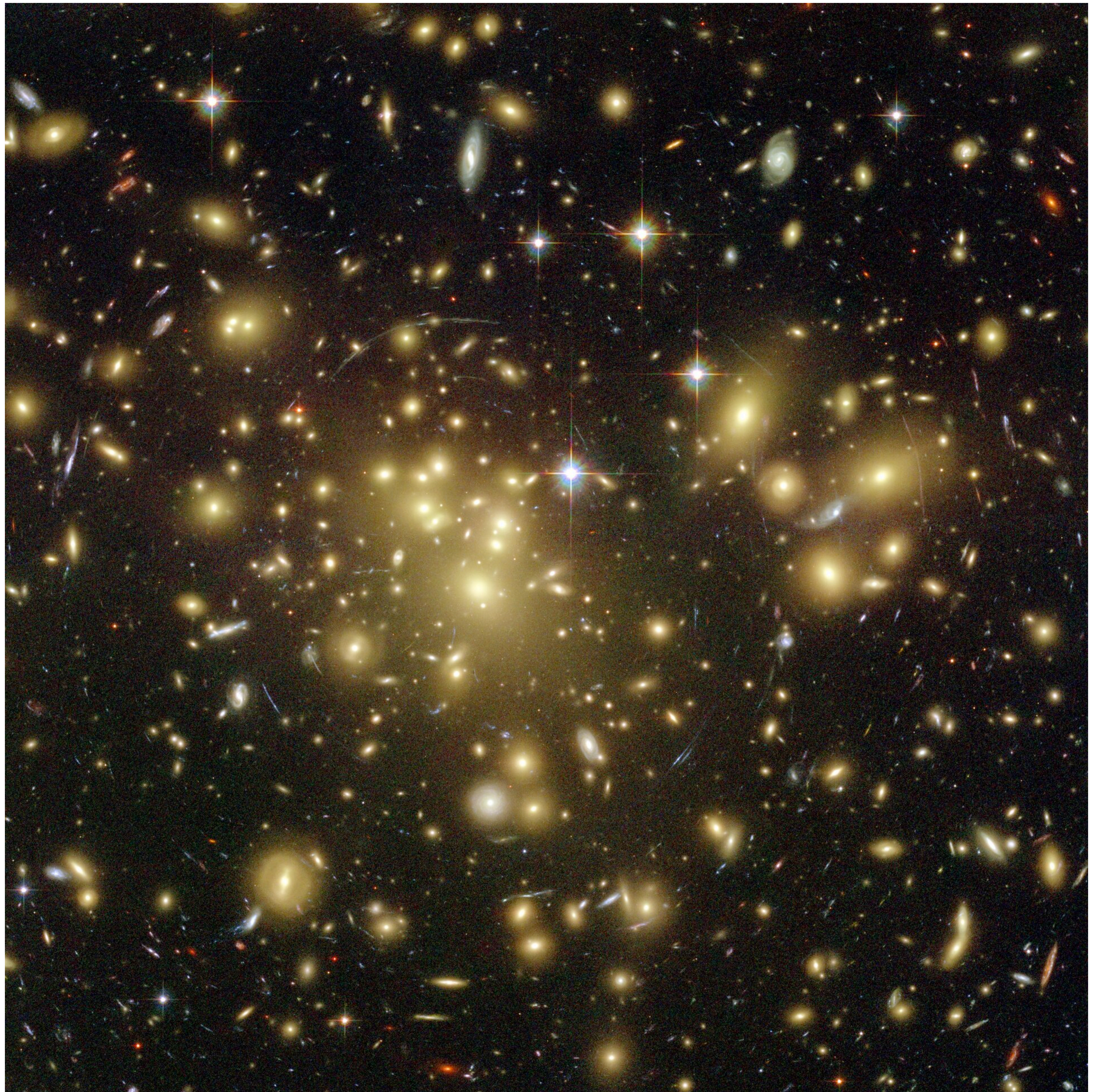
Galaxy clusters

- Largest bound objects in the universe $> 10^{14}\,M_{\odot}$
- Composition
  - 85% dark matter
  - 12% hot gas
  - 3 % stellar mass
- Provided early evidence for dark matter through observations of galaxy velocities (Zwicky 1933)
- They provide strong constraints on the matter content, geometry, the nature of gravity and the formation of structure in the universe and **gravitational lensing gives information on all of this!**



Galaxy cluster Abell 1689 observed by Hubble

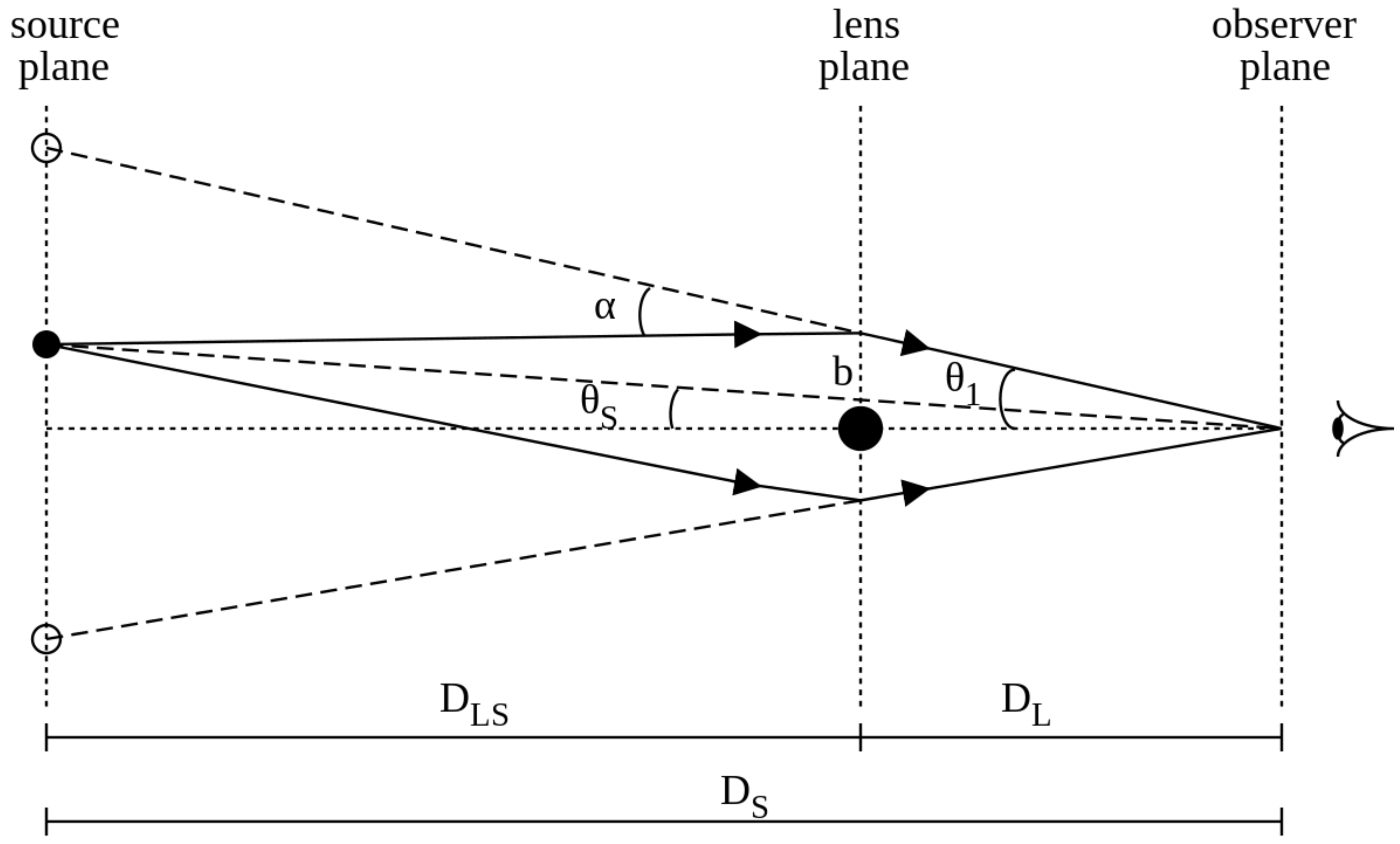
Intracluster dust

- Dust may be thrown into the intracluster medium by
  - Supernova explosions
  - Ram pressure stripping
  - Tidal interactions
  - Super massive blackholes!
- However once in the medium they will be heated by the intracluster X-ray gas
- Dust can cool the intracluster medium but also inform us of the phenomena that may send dust into the medium

NGC 4402 falling towards the Virgo supercluster - HST

Cluster Lensing

- Shears galaxy images (primary probe)
- Increases galaxy magnitudes
- Galaxy surveys are magnitude limited, magnification **introduces faint galaxies** into the sample which we would not normally see
- Deflects galaxy images away from the cluster centre, which **reduces the number of galaxies** in radial annuli from the centre
- Magnification has different systematics than shear!

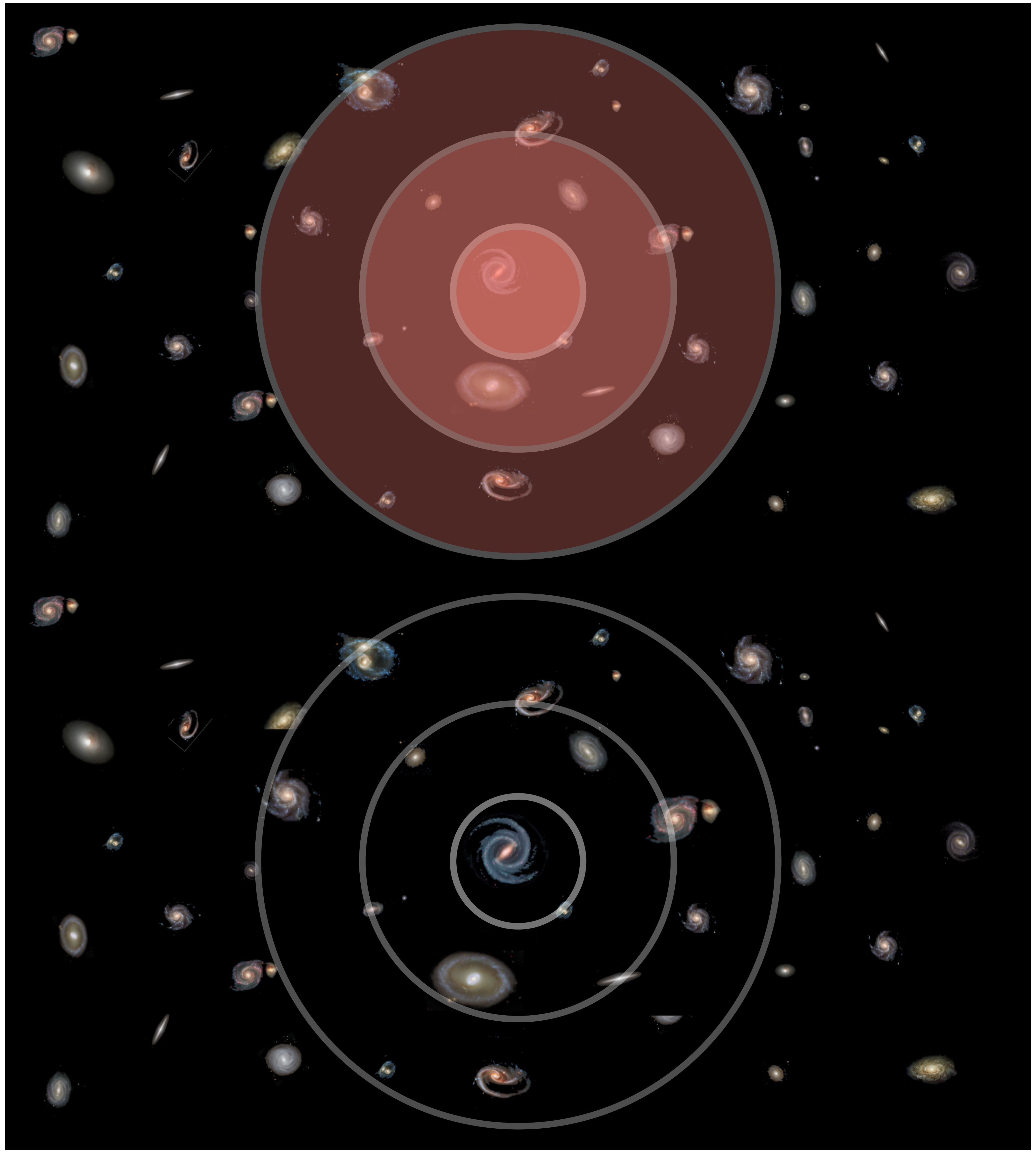


Dust and magnification

- Dust
  - Reduces background galaxy magnitude
- Lensing
  - Galaxies appear further from the cluster centre
  - Increase galaxy magnitudes
- However the dust effects are wavelength dependent!
- Galaxy magnitude is m, κ is the lensing convergence, τ_λ is the optical dust depth at a given wavelength, $\vec{\theta}$ is the position of a background galaxy and $\vec{\alpha}$ is the lensing angle

$$m_{obs} \approx m_{int} - \frac{5}{2ln10}(2\kappa - \tau_\lambda)$$

$$\vec{\theta}_{obs} = \vec{\theta}_{int} + \vec{\alpha}_{lens}$$



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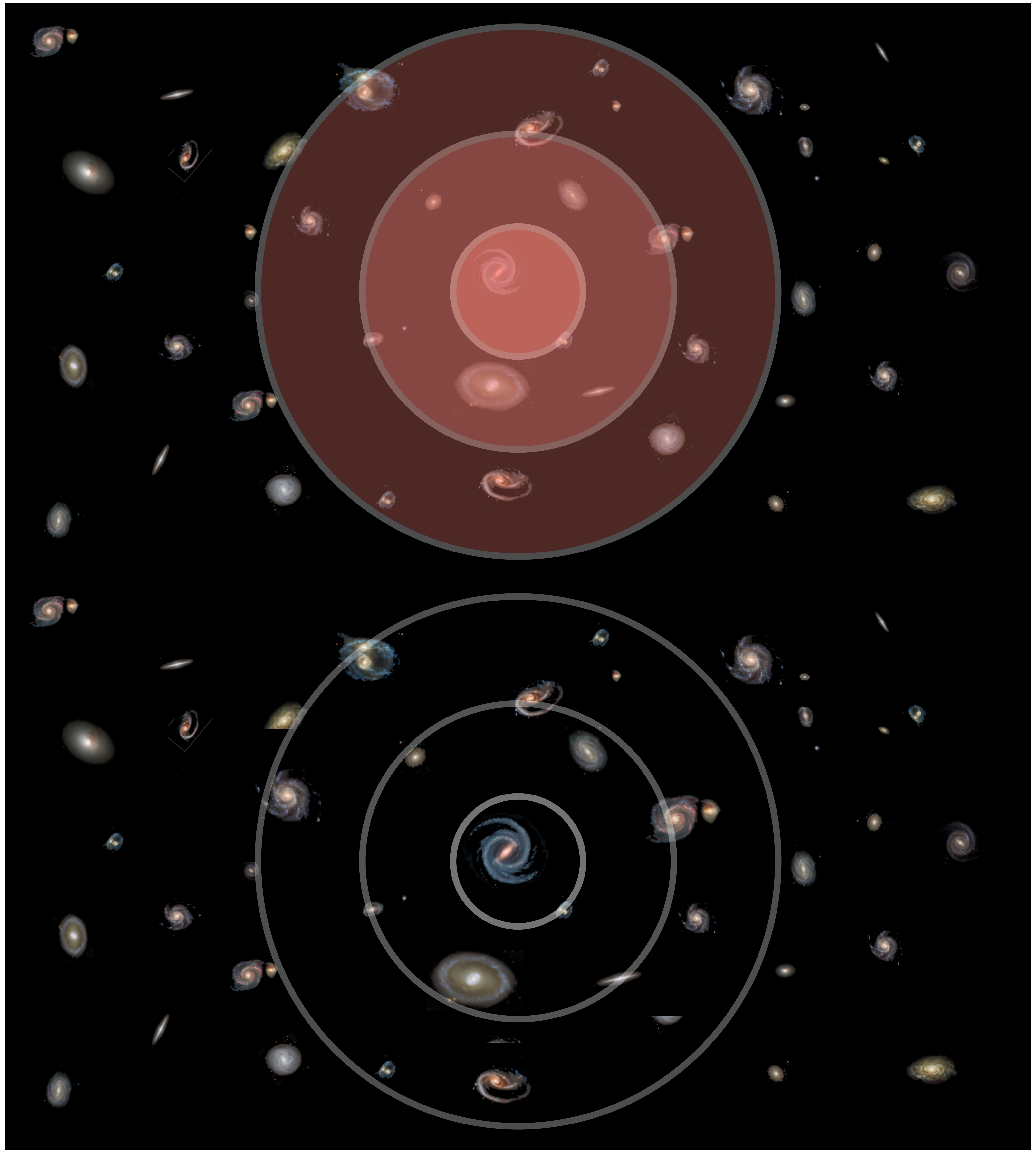
$$\delta m_{lens} \approx 0.1$$

Towards the centre of a cluster we expect

$$\delta m_{dust} \approx 0.01$$

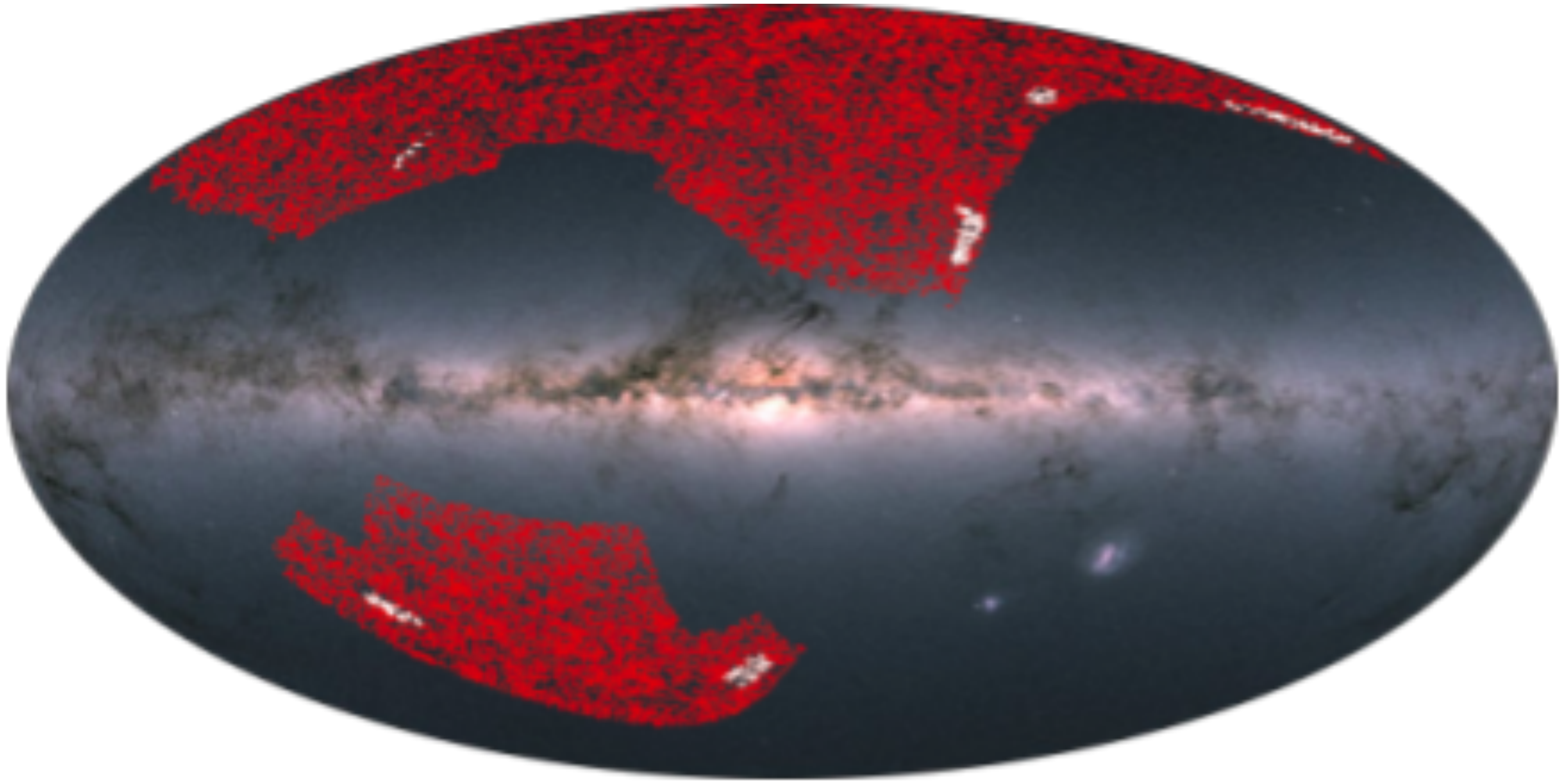


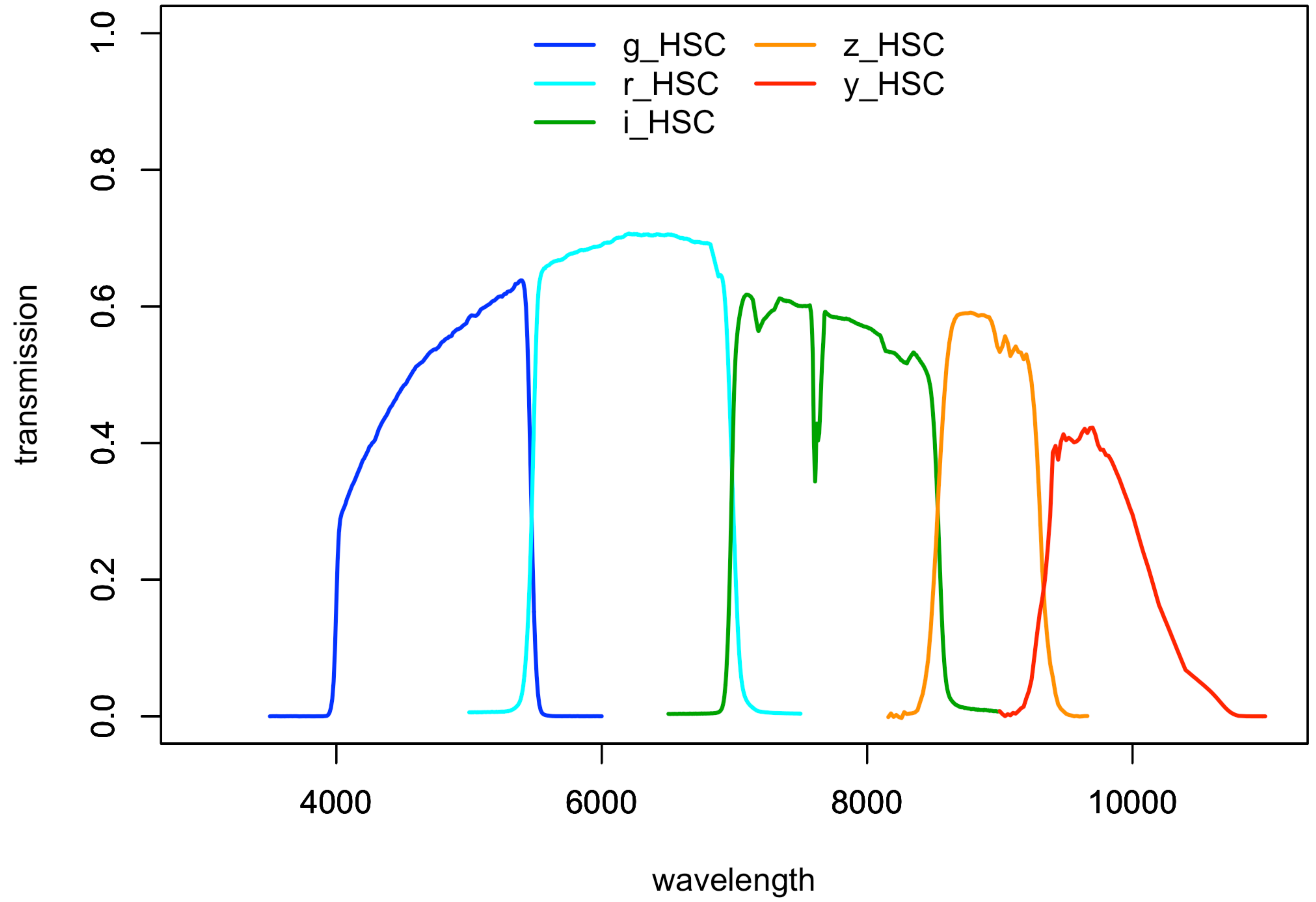
Objectives

- Joint measure of cluster dust content and cluster masses with **magnification**
- Introduce a **new** (and hopefully improved) likelihood which incorporates galaxy clustering, magnitude and redshift information

Redmapper clusters and Hyper Suprime Cam

- 458 SDSS Redmapper clusters are found in the HSC field
- Red dots are SDSS Redmapper clusters
- White dots are Redmapper clusters within the HSC field
- HSC has a high galaxy density $n_{gal} \approx 20\,[arcmin^2]$
- 5 magnitude bands (grizy) important for dust searches
- HSC is a good testing ground for Rubin LSST (weak lensing)



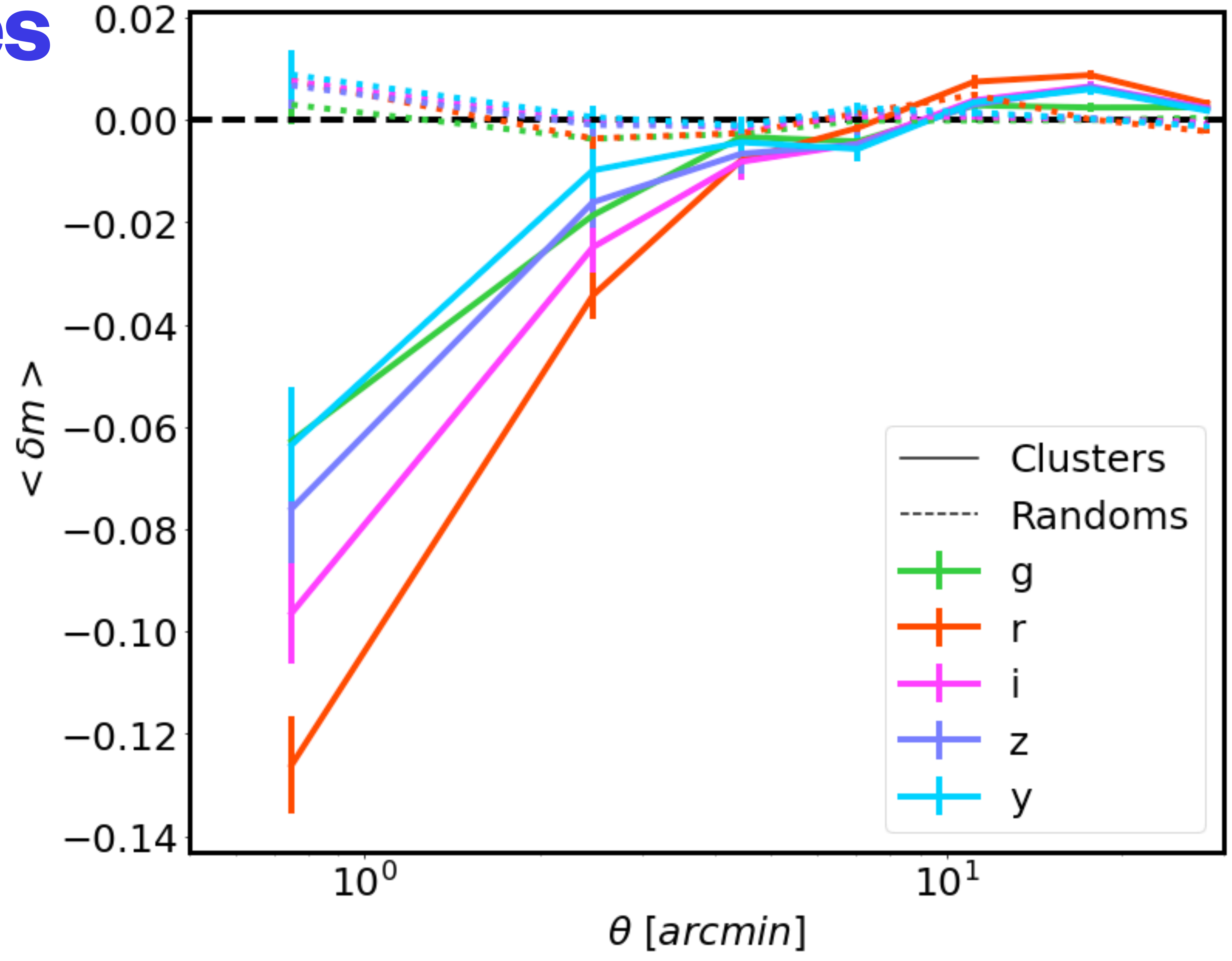


Stacked magnitude profiles

- Using a subsample of 90 clusters in the redshift interval $0.2 < z_{cluster} < 0.3$
- We measure the average magnitude for a stack of clusters in annuli from the cluster centre
- Clear chromatic signal
- **Attention!** Lensing introduces colour changes, faint galaxies which are introduced to the sample have different colours to bright galaxies
- These profiles have been used to measure dust, not strictly true (Menard et al. 2009)

$$\langle \delta m \rangle = \langle m(\theta) \rangle - \left\langle m_{field} \right\rangle$$

$$m_{obs} \approx m_{int} - \frac{5}{2ln10}\left(2\kappa - \tau_\lambda\right)$$



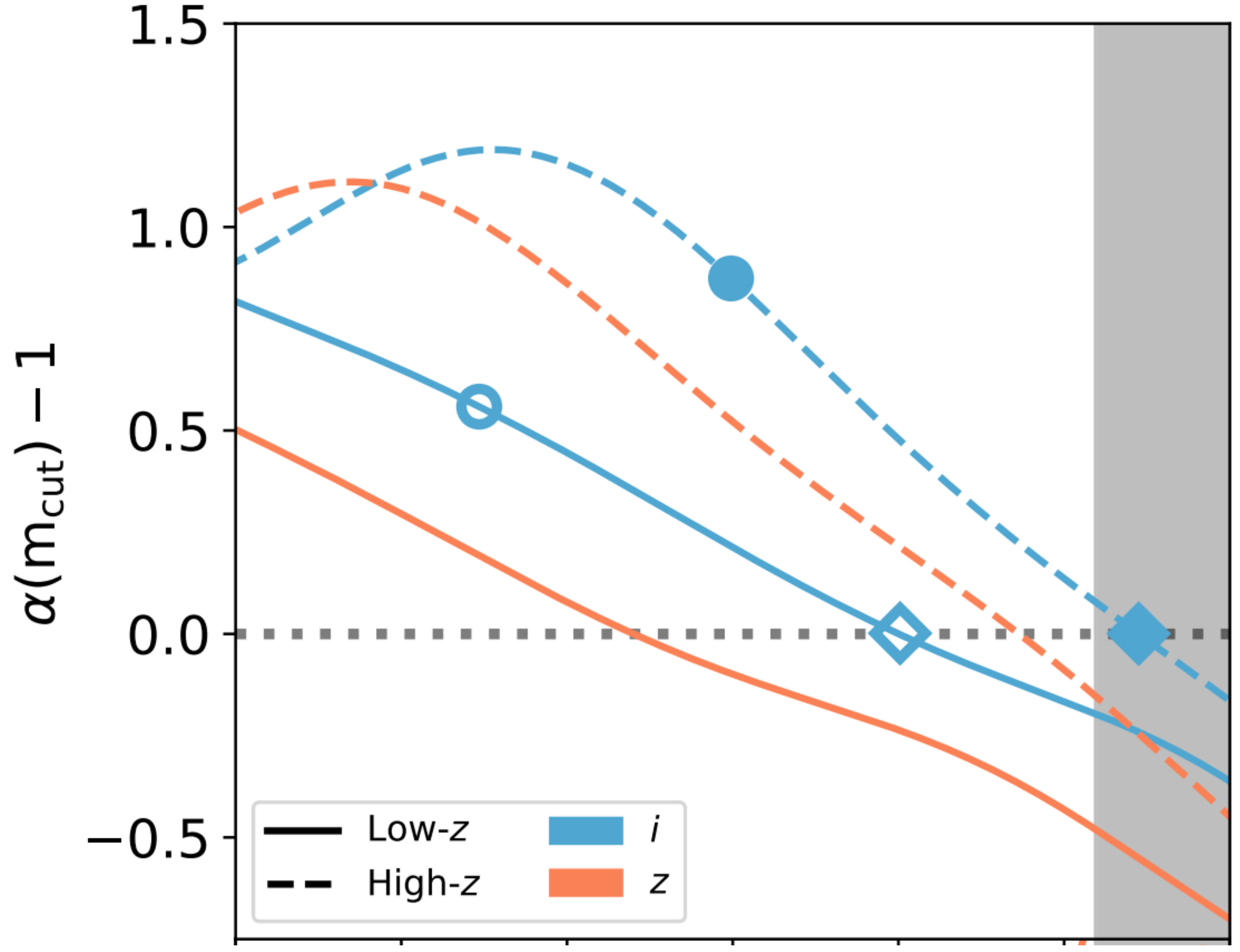
The usual method - single magnitude cut

- Galaxies are **magnified** which **introduces** galaxies into the sample
- **Solid angles** on the sky are magnified which **reduces** galaxies per solid angle

$$n_{obs}(\overrightarrow{\theta}) \approx n_{int}(\overrightarrow{\theta})\left[1 + 2\kappa(\alpha - 1)\right] \qquad \alpha = 2.5\frac{dlog_{10}n}{dm}|_{m_{cut}}$$

- Choose **one magnitude cut** which gives a α which maximises the signal
  - This is a game between the best value of α and keeping as many galaxies as possible
  - Does not make much use of galaxy magnitude or redshift information
- Chiu, Umetsu et al. 2020, Schmidt et al. 2010, Broadhurst, Taylor and Peacock 1994

Chiu, Umetsu et al. 2020



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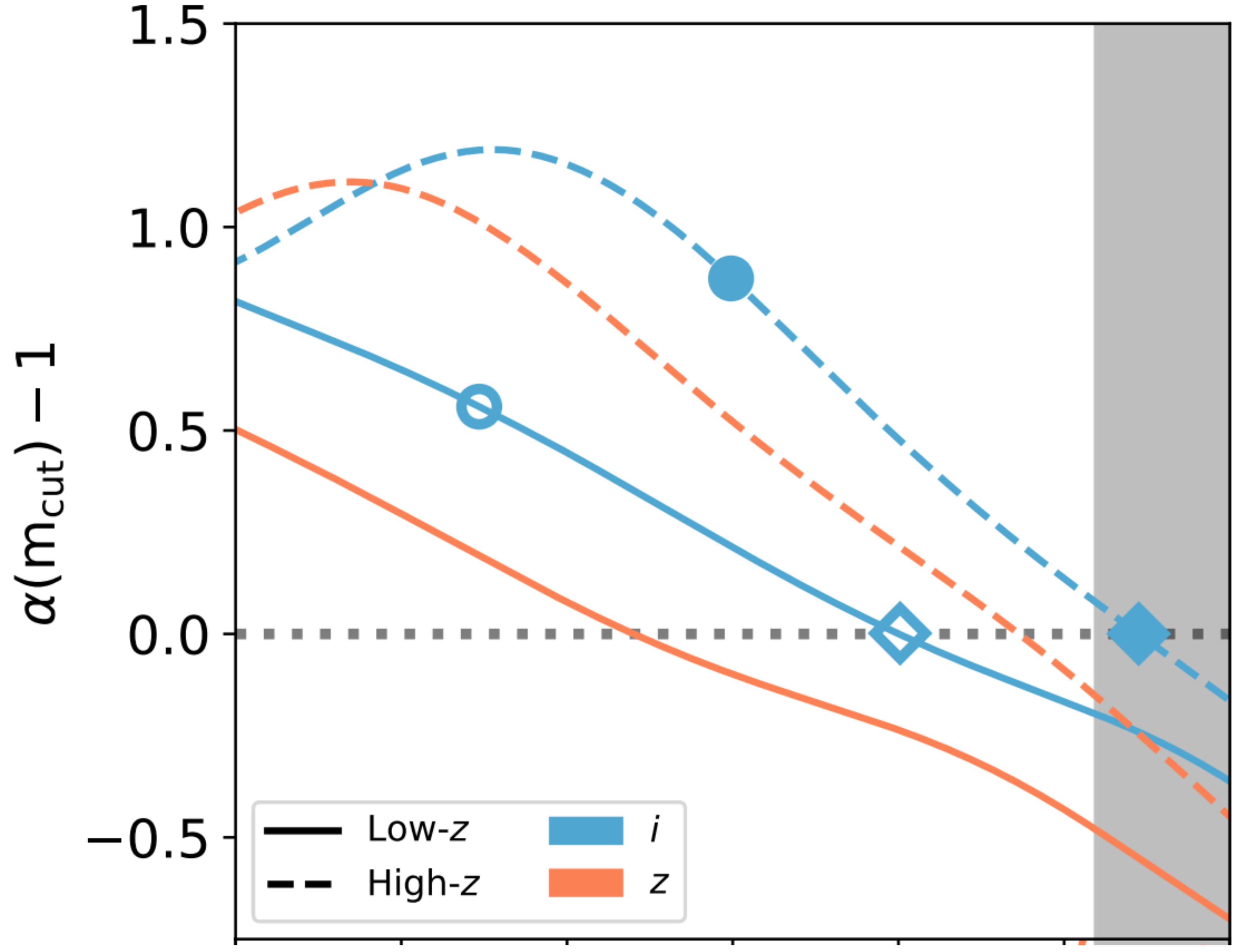
- **Clearly these two effects compete/cancel with one another**
- Pros
  - Simple
- Cons
  - Doesn't use all the available information
  - Relies heavily on the **weak lensing approximation**

$$n_o(m + \delta m) \approx n_o[1 + \frac{dn}{dm}\delta m]$$

Chiu, Umetsu et al. 2020

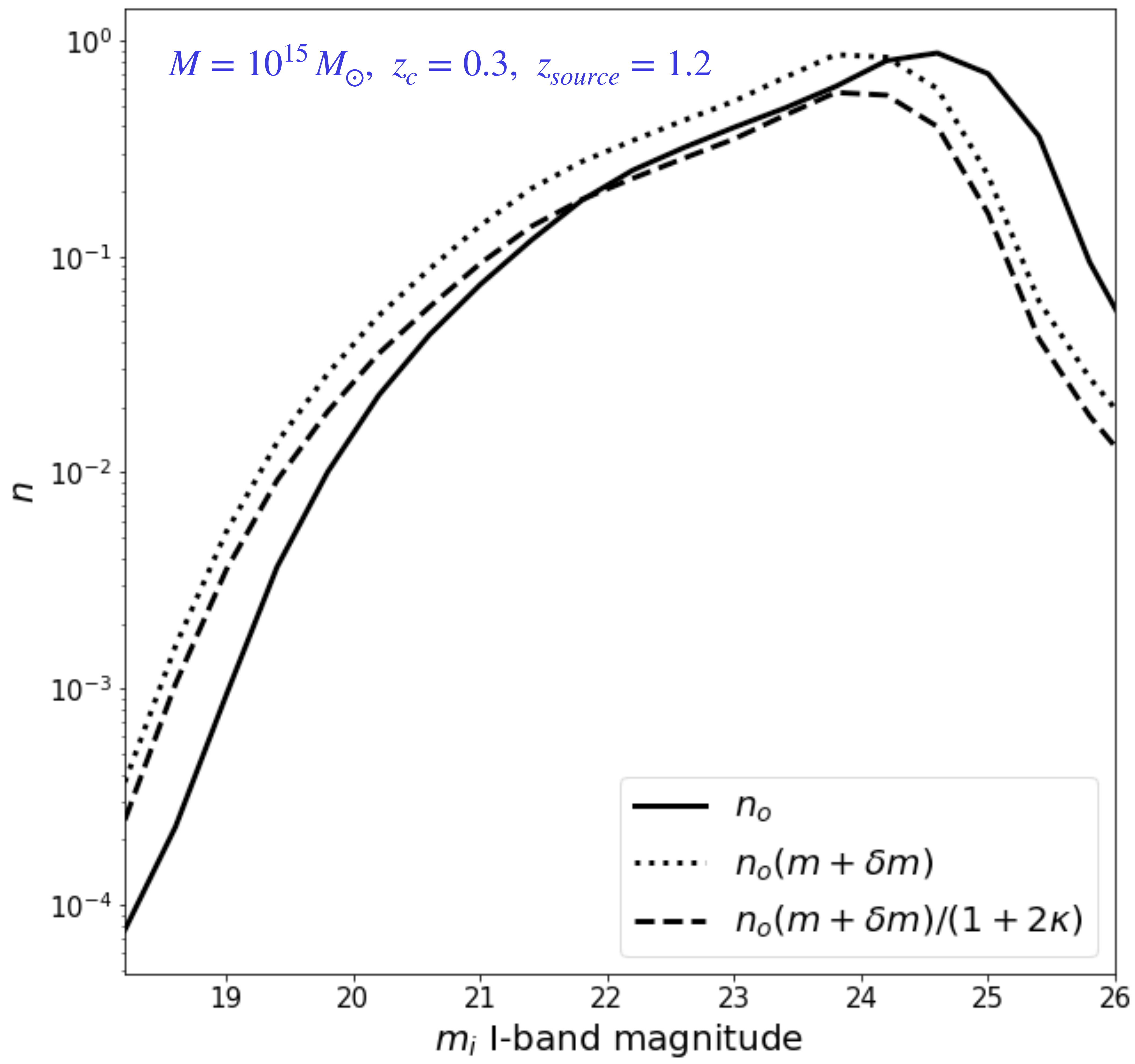


New approach - full magnitude distribution

- Resolution: use the full galaxy magnitude distribution
- Two effects
    - Change in magnitude δm -> shifts distribution
    - Change in **solid angle on the sky** A -> changes normalisation
- Pros
    - More info
- Cons
    - More difficult

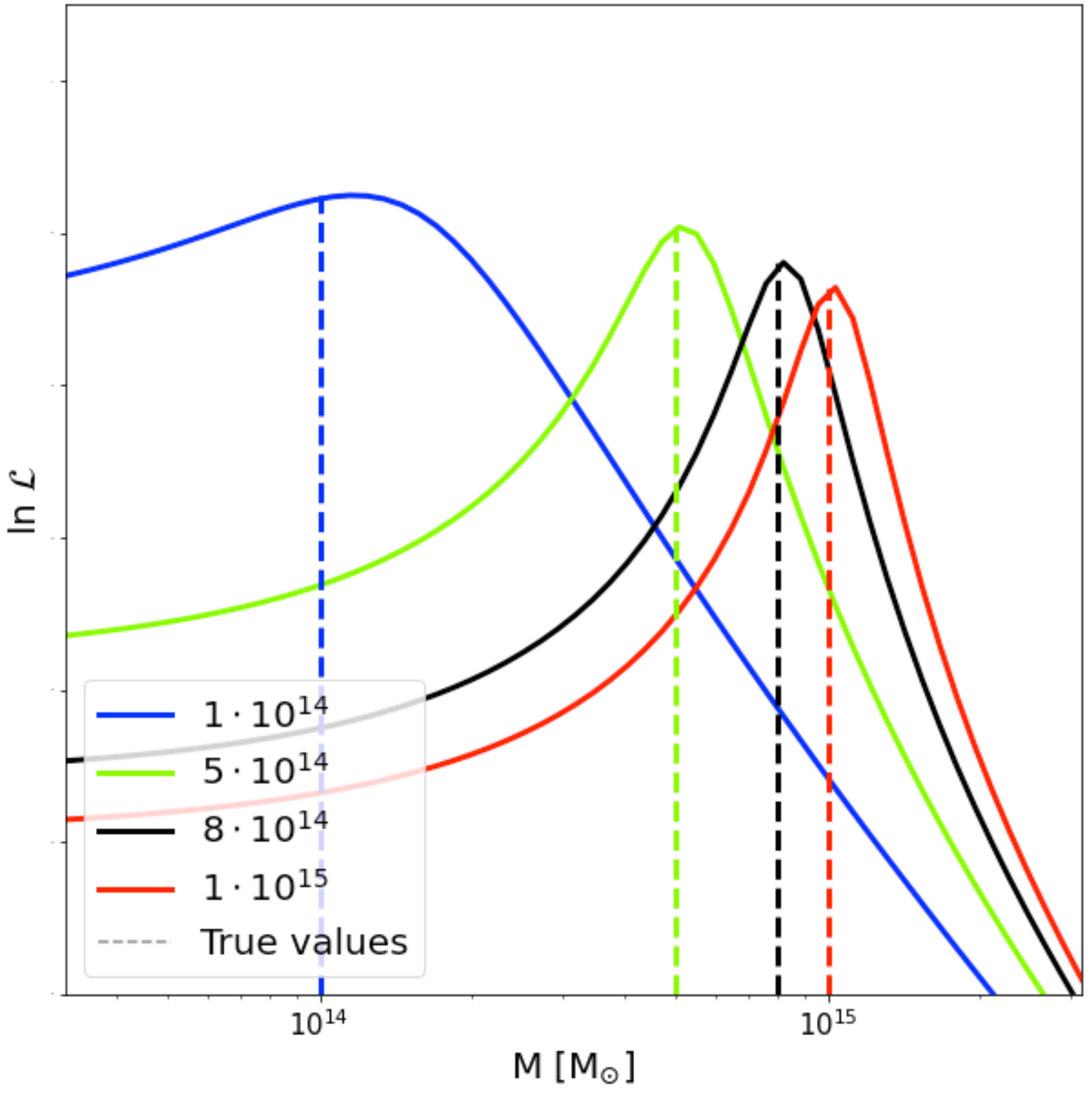
$$\delta m \approx -\frac{5}{2ln10}\left(2\kappa - \tau_\lambda\right) \quad A_{obs} = \frac{A_o}{(1-\kappa)^2 - |\gamma|^2}$$

$$n_{obs} = n_o(m + \delta m, \overrightarrow{\theta}_{int} + \overrightarrow{\alpha}_{lens}) = n_o(m+\delta m)\left[(1-\kappa)^2 - |\gamma|^2\right]$$



Mock results

- n_o **is calculated from the global galaxy distribution**
- We generate random positions within the HSC footprint and inject a fake cluster signal
    - Lensed galaxy positions
    - Lensed/~~dusted~~ galaxy magnitudes
    - Estimate the mass with our model
- It works!



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Future work

- ~~Estimate stacked cluster masses on mocks~~
- Incorporate dust models into the mock and our likelihood
- Estimate dust content and cluster masses with redMaPPer clusters and HSC galaxies