Testing the LCDM cosmology with an 8m space telescope

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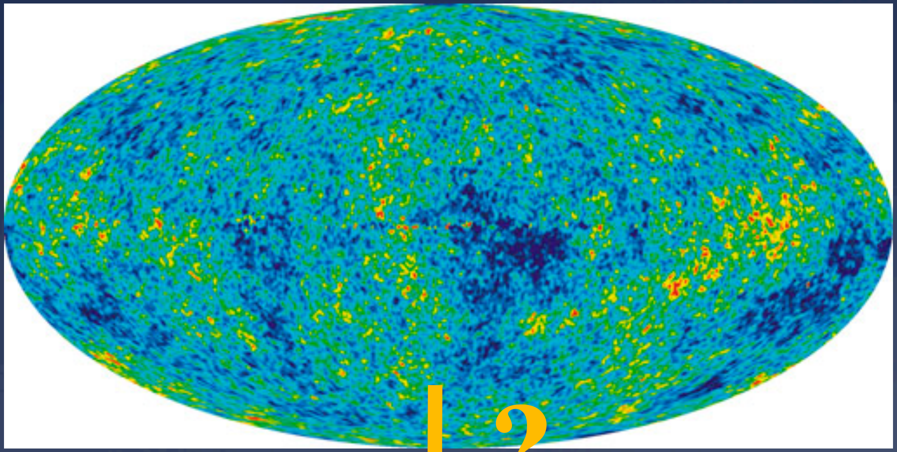
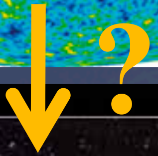
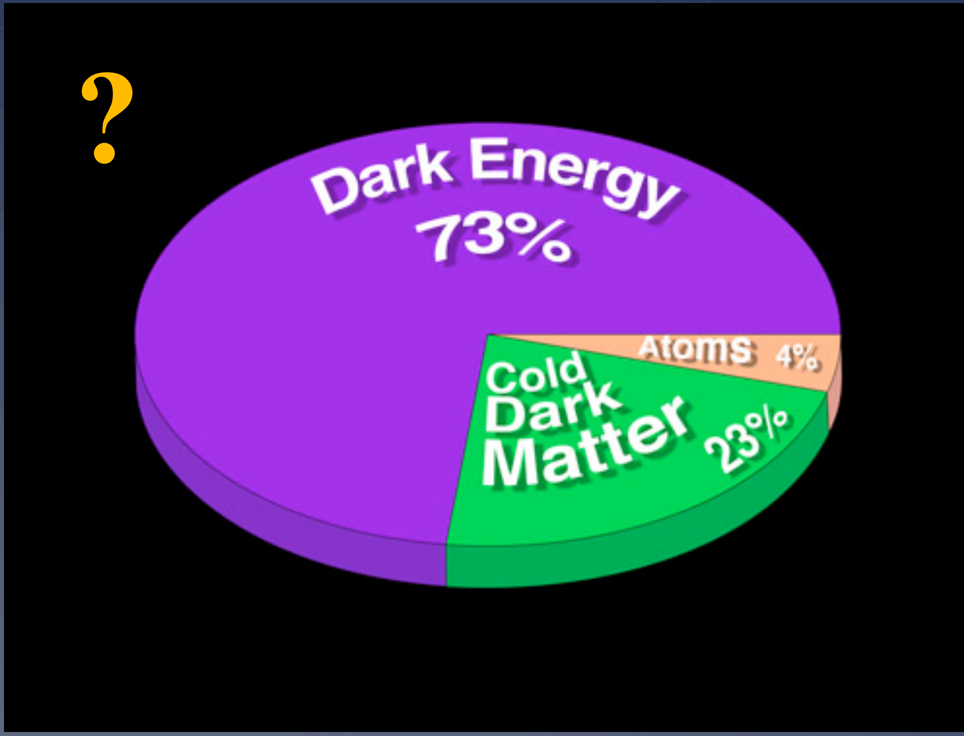
Outline

- Introduction:
  - Cosmology after JWST
  - the missing satellite problem
- Dark substructure
  - Gravitational imaging
- Luminous substructure
- Future prospects

The two key questions







Cosmology after JWST++

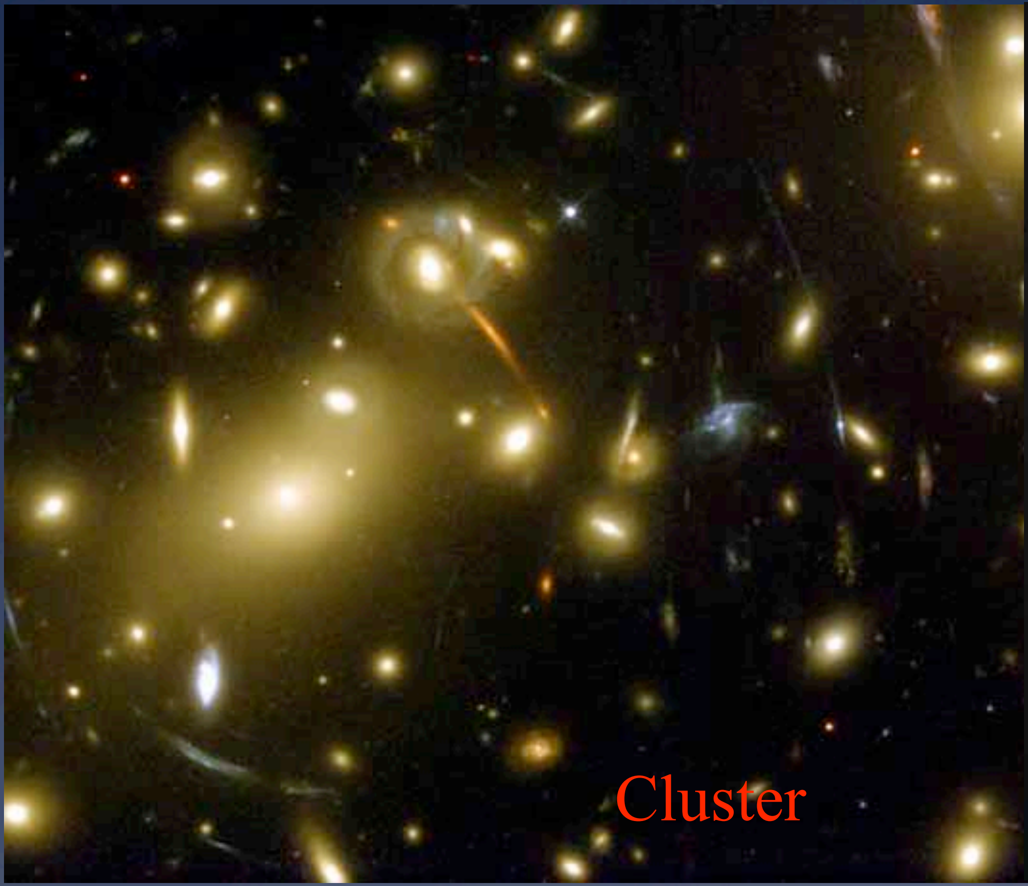
- Assumptions:
  - Cosmography has been pinned down to exquisite accuracy (1% on H0, w to a few %, etc)
    - Consistent with inflation and LCDM
  - Dark matter particle not detected by LHC and other ground based experiments
- Goals:
  - Understand nature of dark matter
  - Understand physics of galaxy formation and evolution

Substructure: a probe of dark matter and galaxy formation

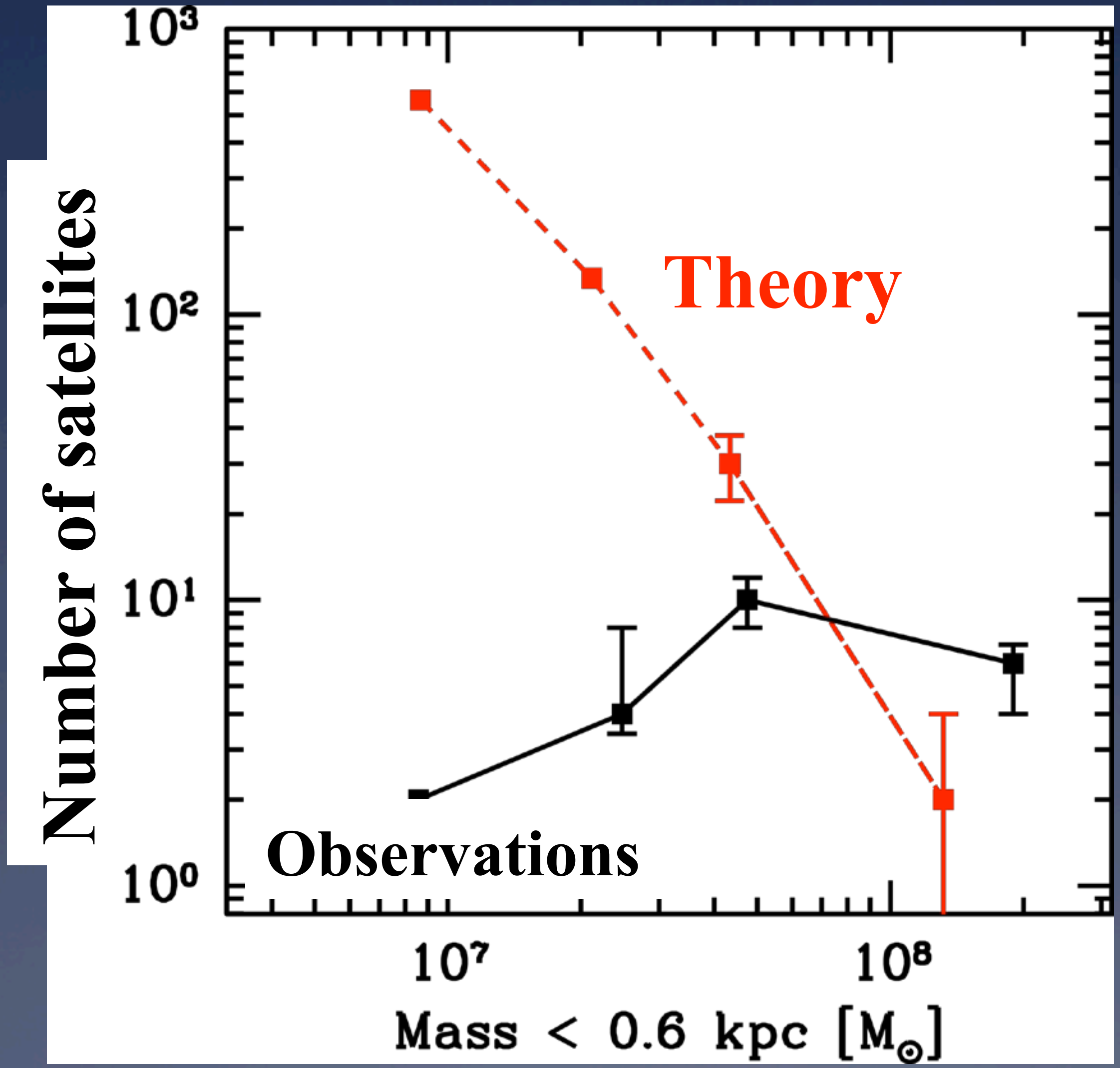
Substucture: Theory

Kravtsov 2010

Substructure: Observations



Milky Way Satellites



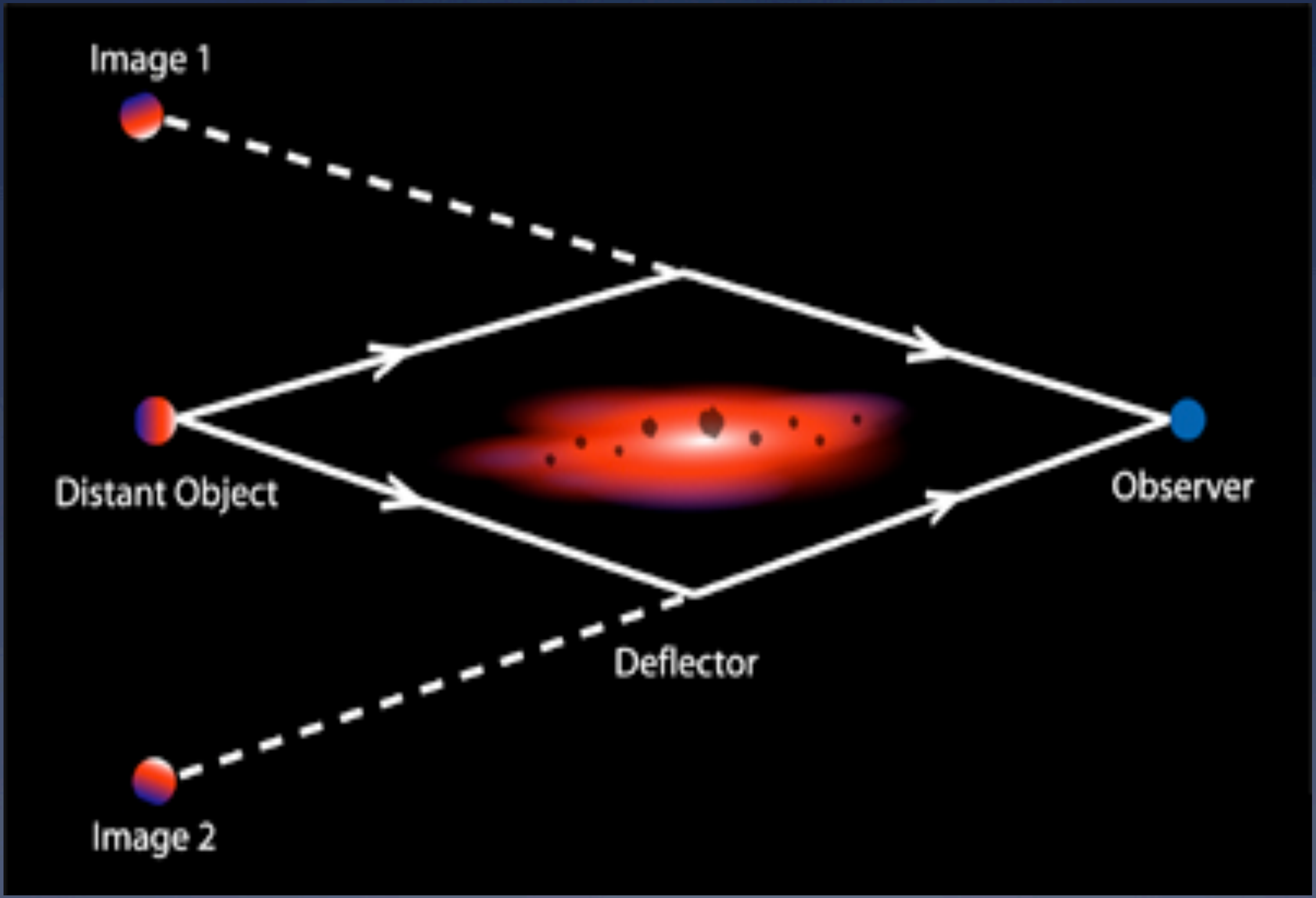
Strigari et al. 2007

The missing satellites problem: big questions

- Are the satellites predicted by theory non-existent or just dark?
- If they don't exist, what's wrong with the standard cosmological model?
- If they exist and are dark, why are they not forming stars?

Dark substructure

Strong gravitational Lensing



Light ray deflection is a direct measurement of mass, luminous or dark!

“Missing satellites” and lensing

- Strong lensing can detect satellites based solely on mass!
- Satellites are detected as “anomalies” in the gravitational potential ψ and its derivatives
  - ψ'' = Flux anomalies
  - ψ' = Astrometric anomalies
- **Natural scale is a few milliarcseconds. Astrometric perturbations of 10mas are expected (within reach with 8-m)**

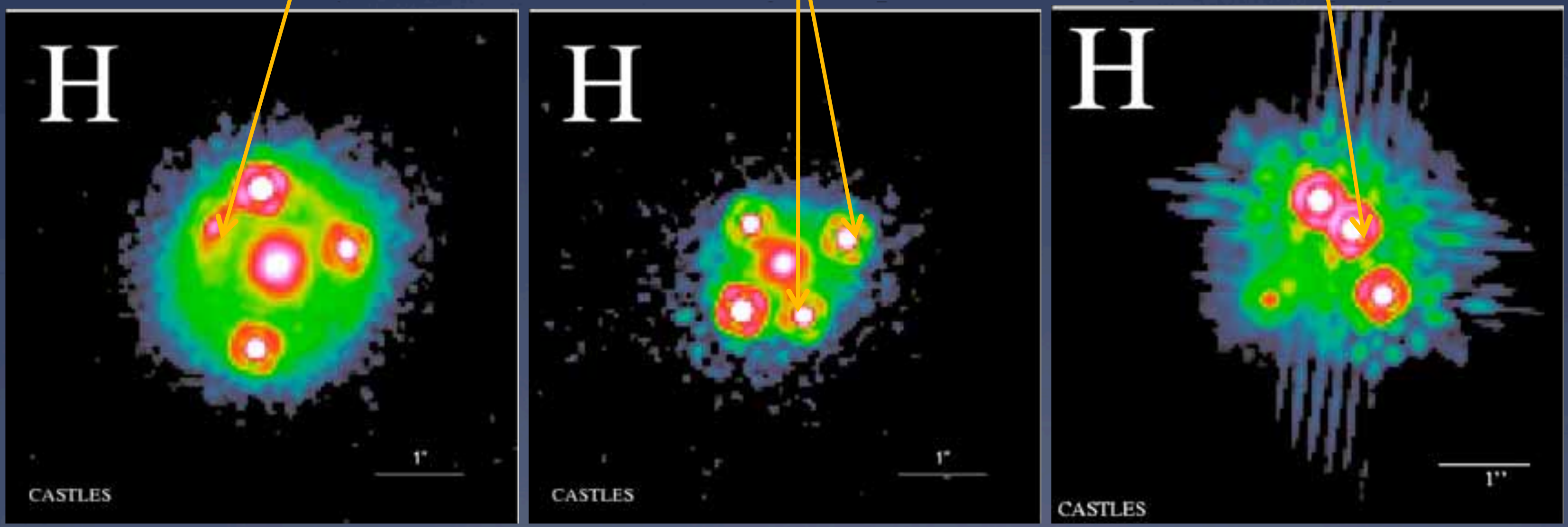
Flux Ratio Anomalies

A smooth mass distribution would predict:

This to be 100x brighter

These to be 2x brighter

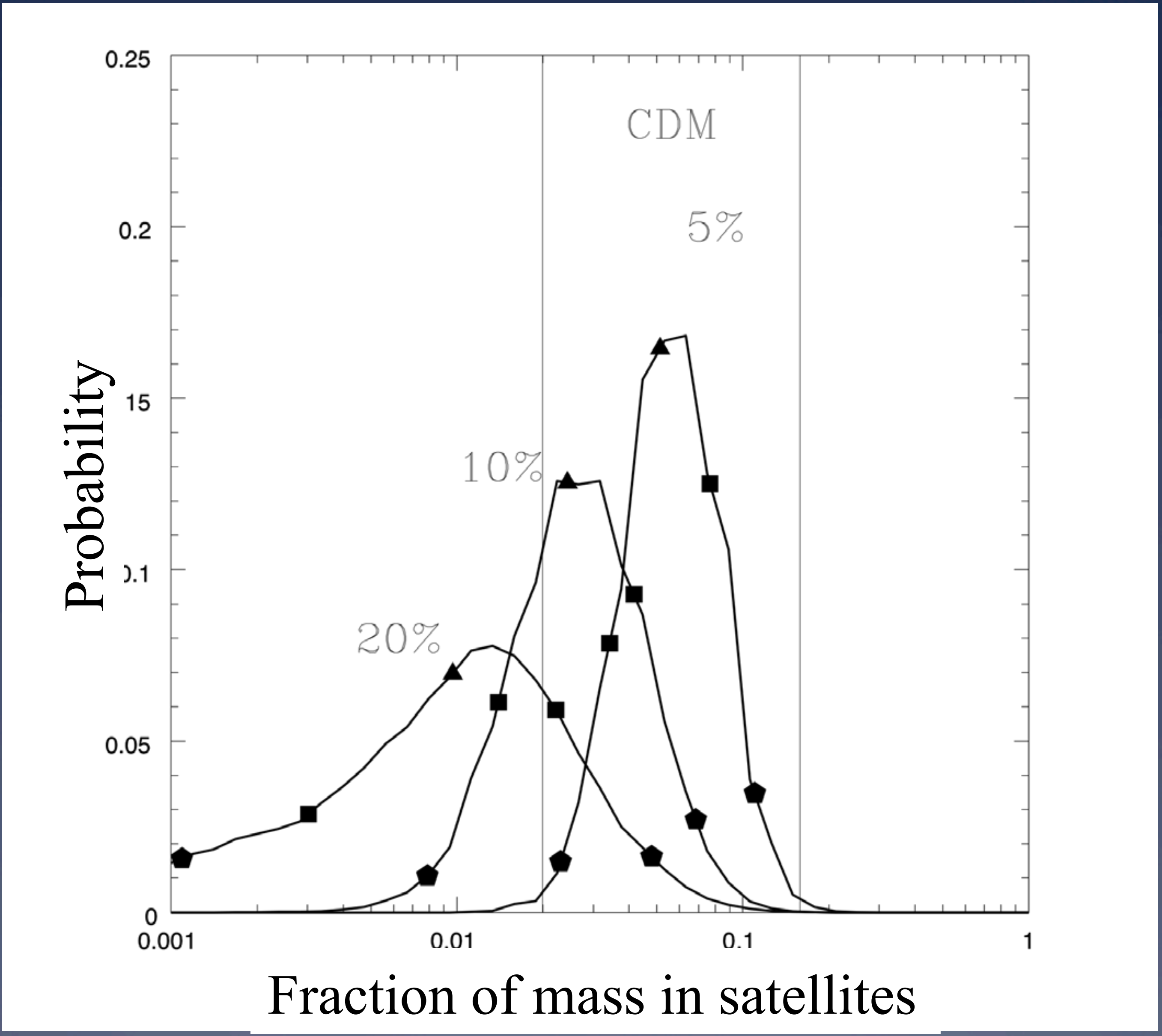
This to be 10% brighter



What causes this the anomaly?

1. Dark satellites?
2. Astrophysical noise (i.e. microlensing and dust)?

Are anomalies enough?



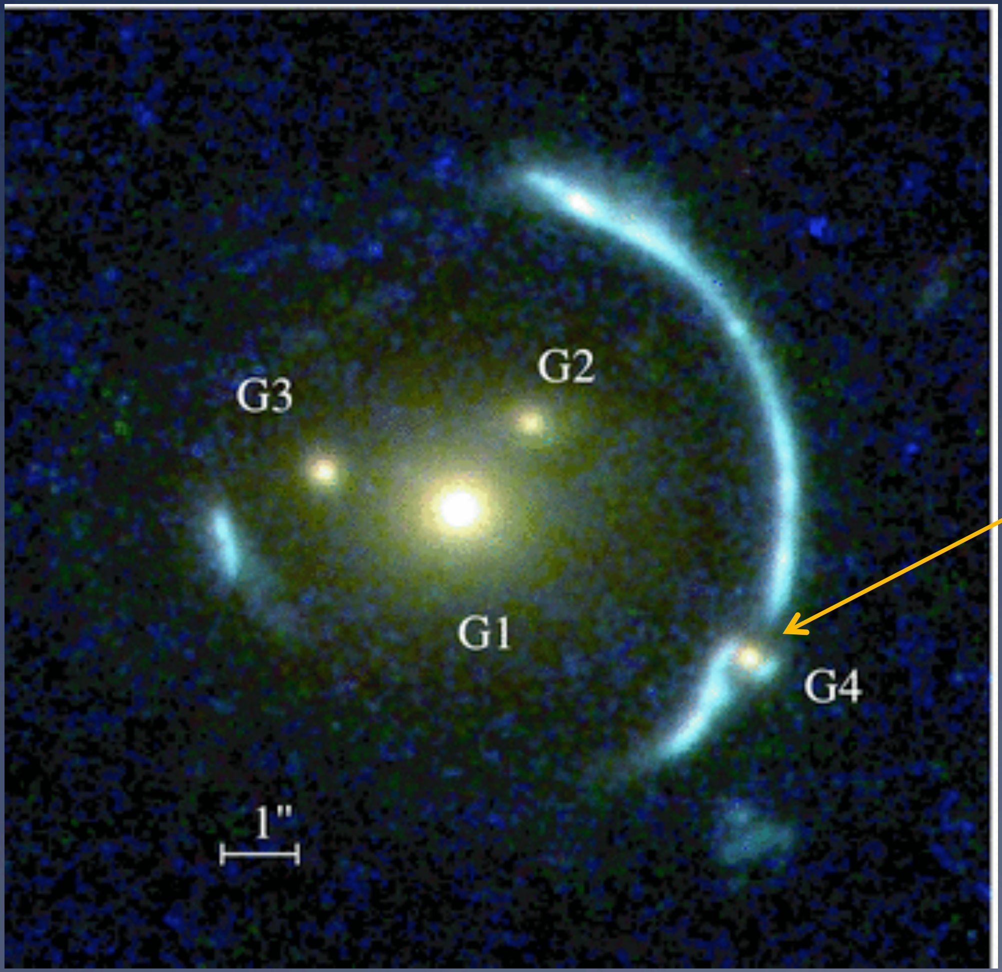
Dalal and Kochanek 2002

How do we make progress?

1. Direct detection a.k.a. "gravitational imaging"
2. Larger samples (Dalal & Kochanek used only 7 lenses)
3. High precision photometry and astrometry
4. Avoid microlensing

Gravitational imaging

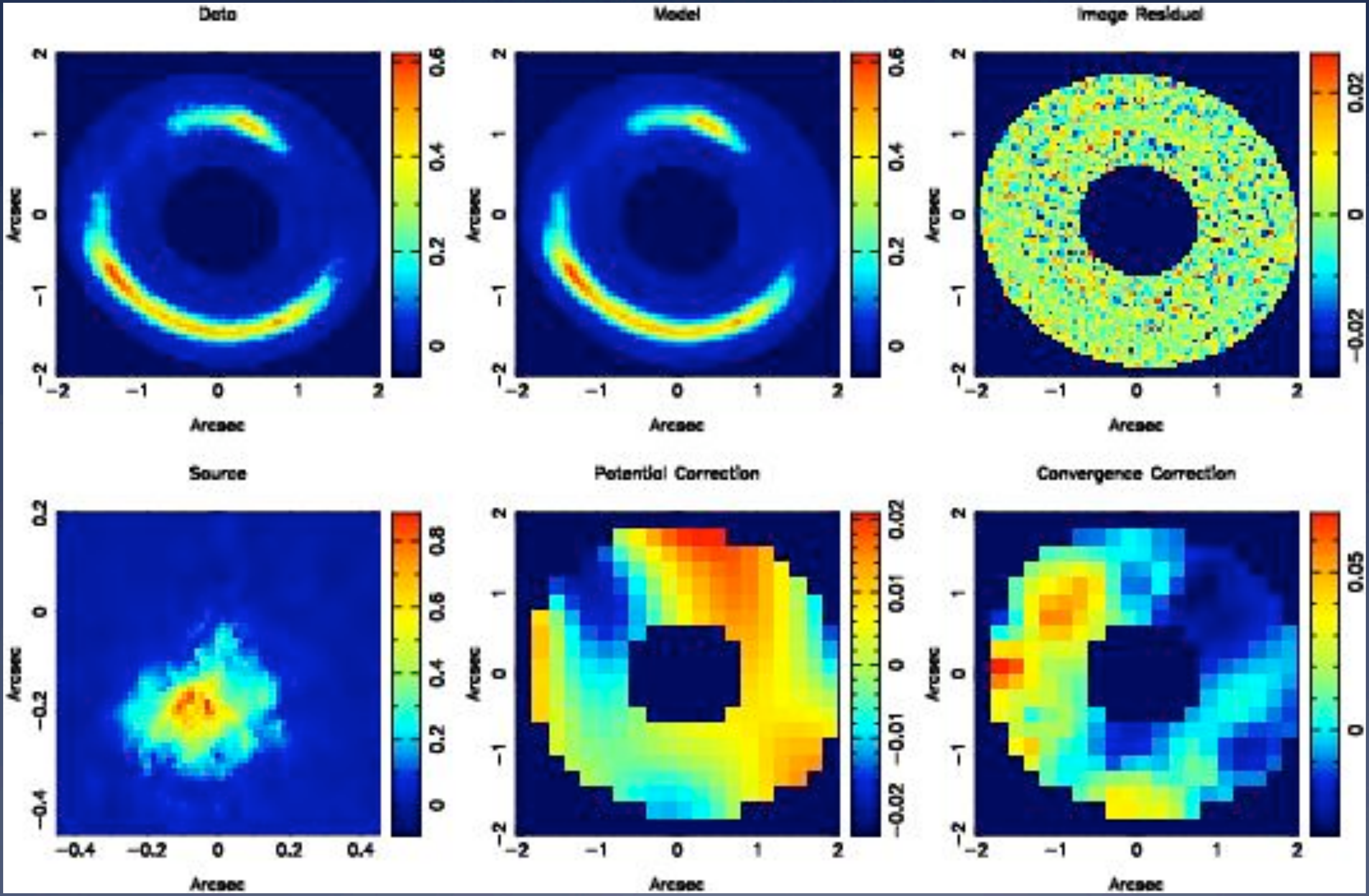
Gravitational mass imaging: idea



Mass substructure distorts
extended lensed sources

Vegetti et al. 2010

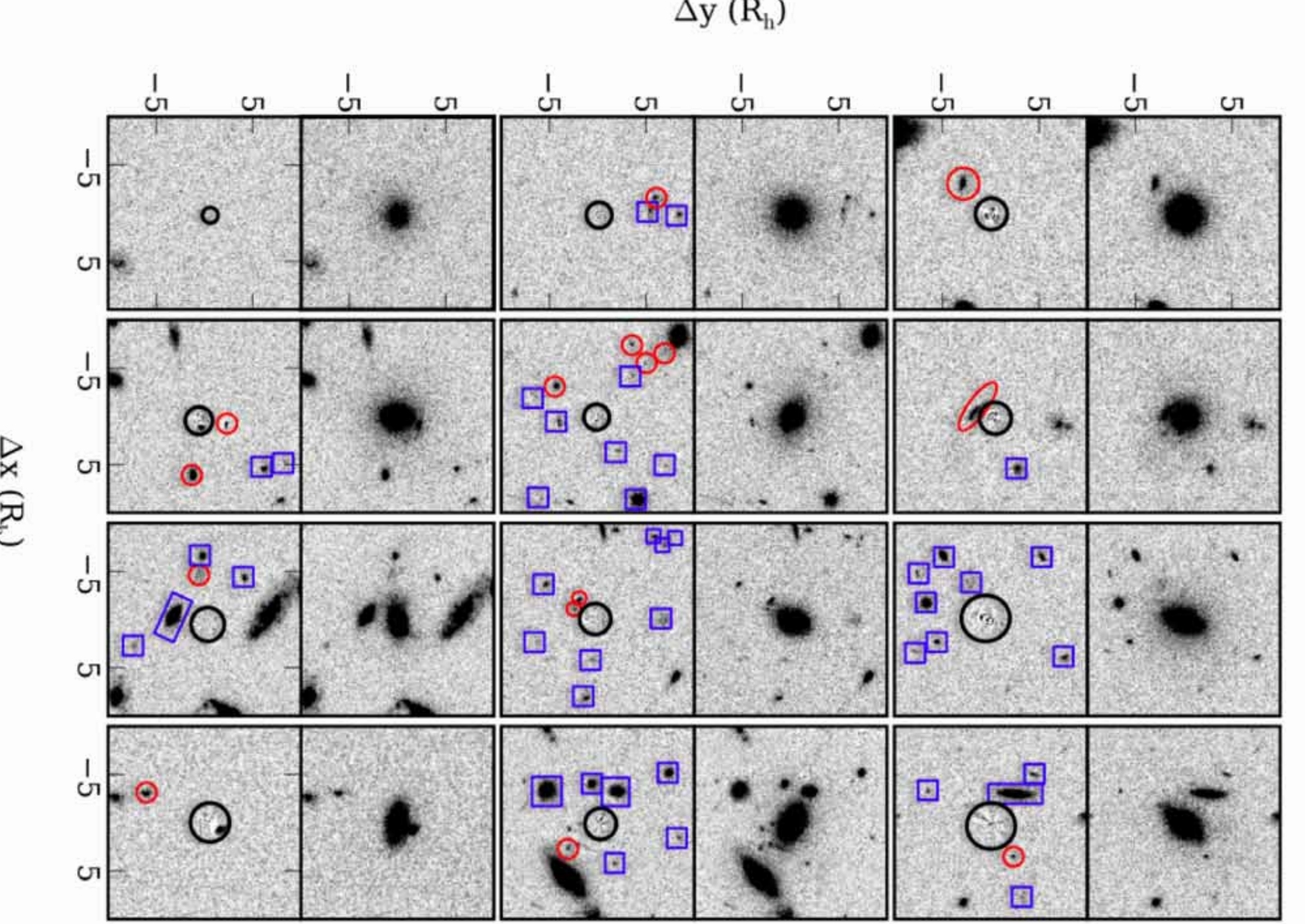
Direct detection of a dark substructure



HST can detect down to 5e8 Msun

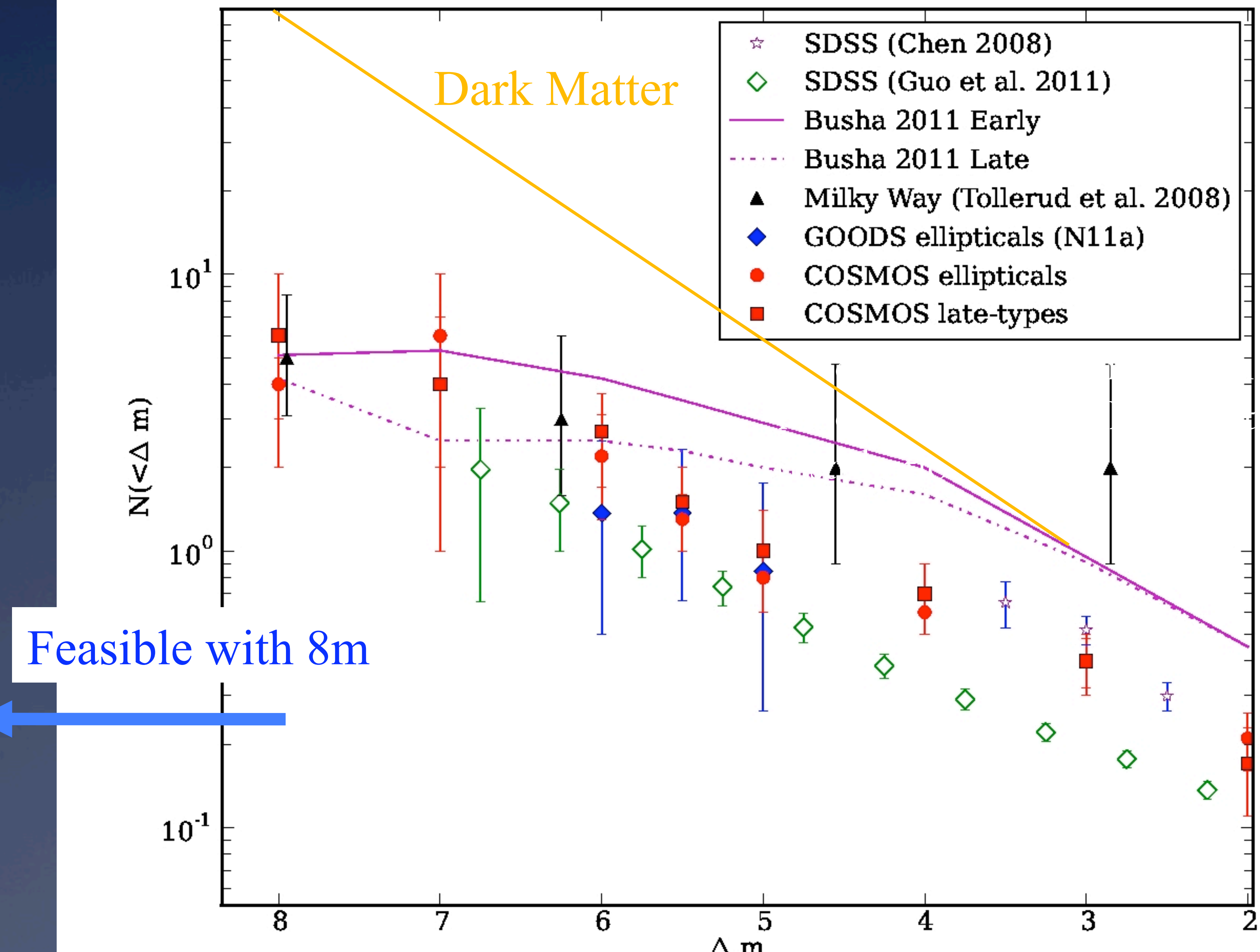
Vegetti et al 2010

Luminous substructure



Nierenberg et al. 2011

Satellite cumulative luminosity function



Nierenberg et al. 2011

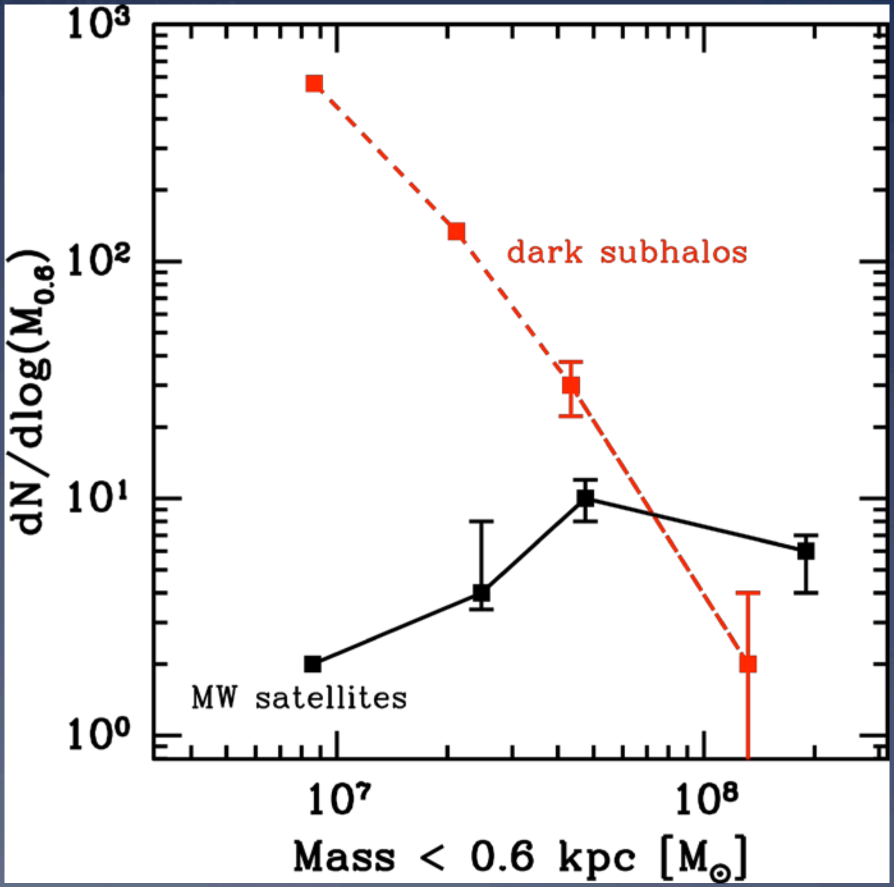
The missing satellites problem: some answers

- Are the satellites predicted by theory non-existent or just dark?
  - There are indeed some "Dark" satellites. It is not clear (yet) if they are as many as predicted by theory
- If they don't exist, what's wrong with the standard cosmological model?
  - If they don't exist at smaller masses, it may be that dark matter is "warm" or self-interacting
- If they exist and are dark, why are they not forming stars?
  - Probably because the gas inside them was blown away or photo-evaporated early on

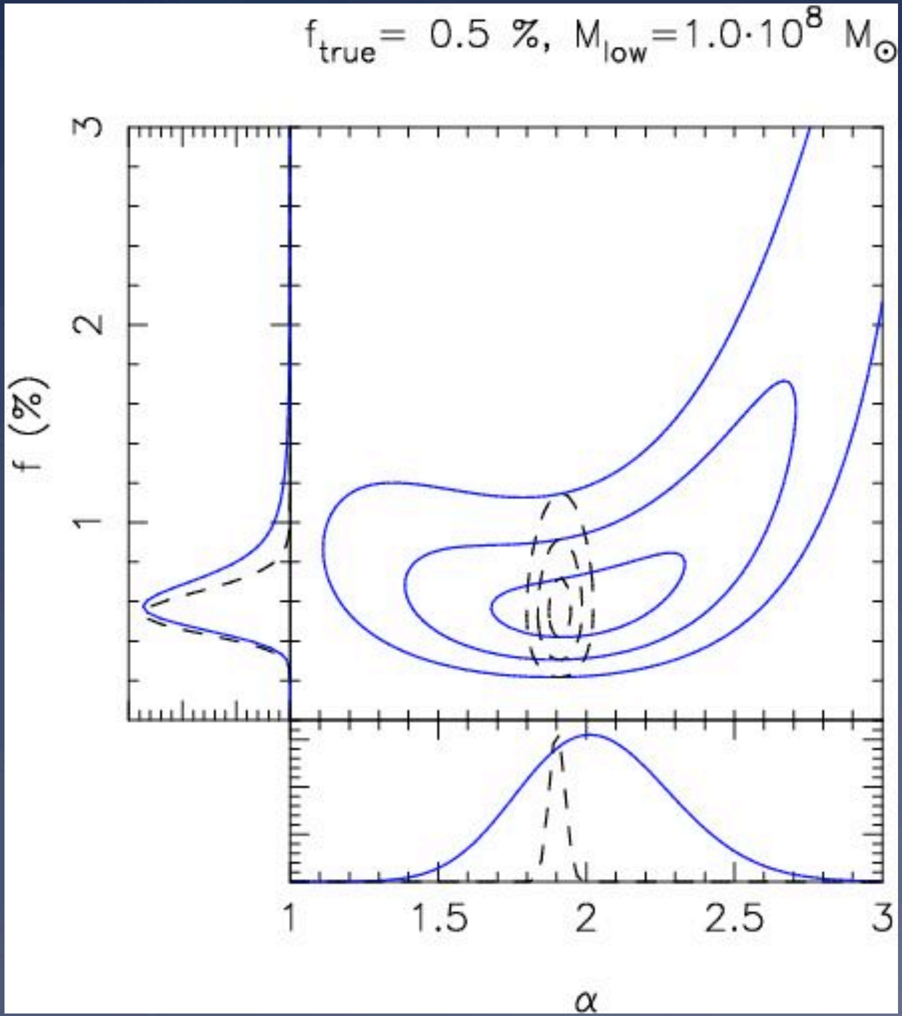
Prospects for and 8-m in space

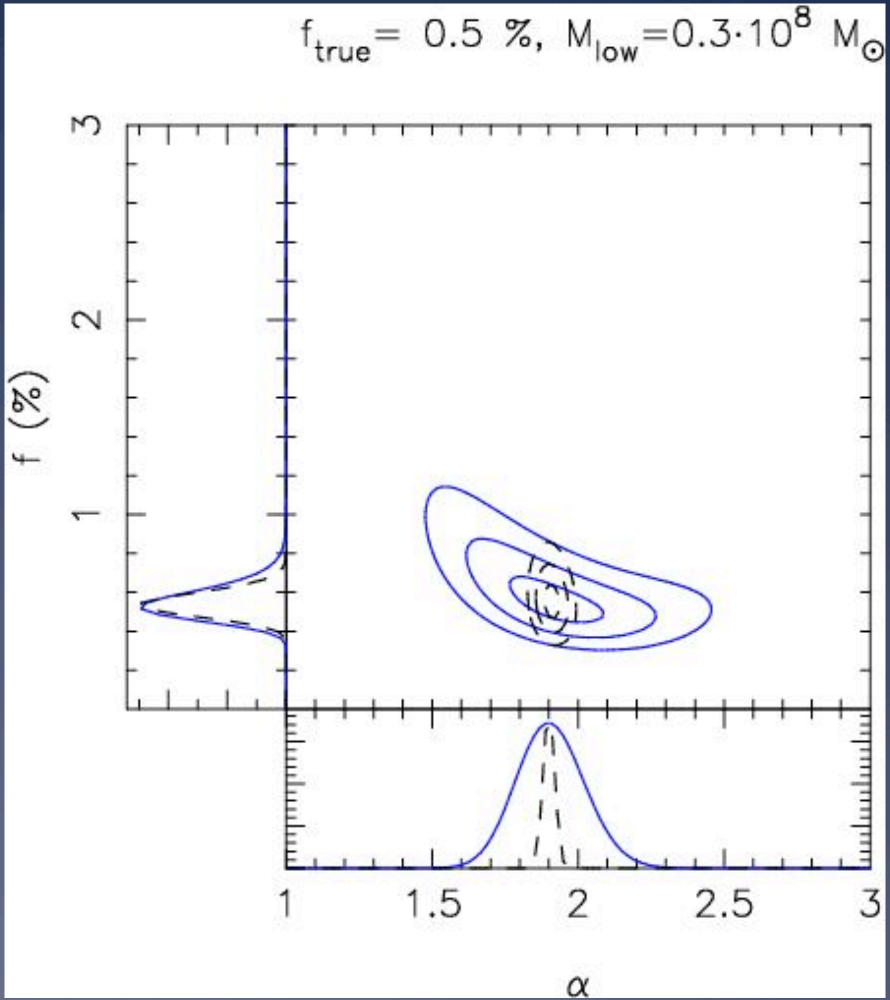
Gravitational imaging: Future Prospects

- Gravitational imaging can now reach a few 10^8 solar mass sensitivity, limited by resolution and S/N
- With 8m in space we should reach 10^7 solar masses, that is where the discrepancy with theory is strongest
- PSF stability and Optical/rest UV coverage are strengths



Gravitational mass imaging prospects
Sample of ~30 lenses





Vegetti & Koopmans 2009

Luminous substructure

- High redshift satellites are compact and likely blue
- Sensitivity gain w.r.t. HST/JWST of order x10-100
- With HST we can now reach satellites 1000x fainter than host. With 8m we could go down to 1e4-1e5, starting to probe the more interesting regime
- Measure UVOIR colors and optical spectra lines of the brighter ones and infer star formation history and chemical composition

The end