TESTING CDM WITH STRONG GRAVITATIONAL LENSING OF AGN

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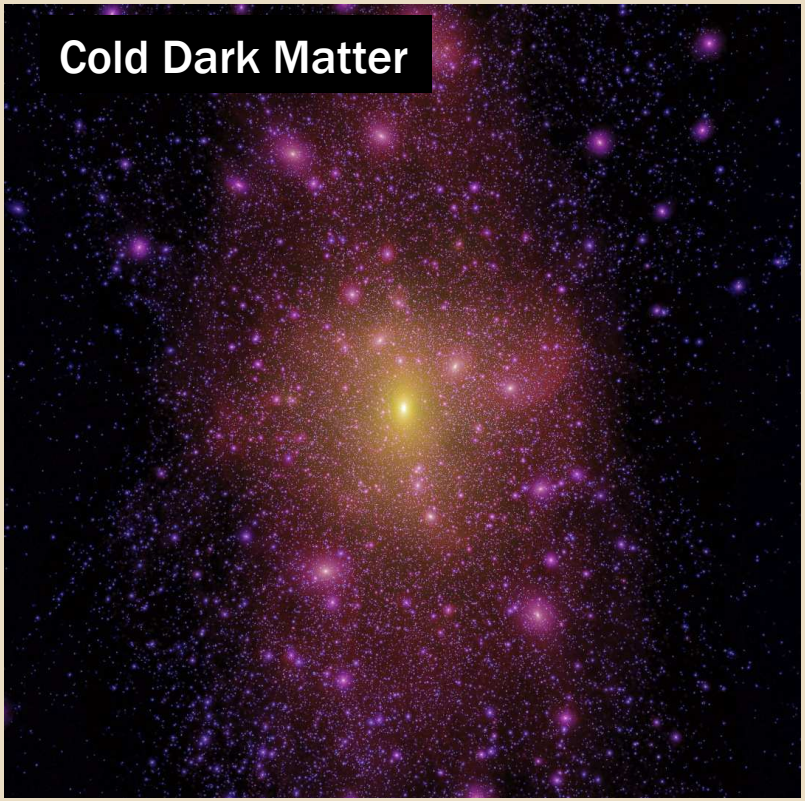
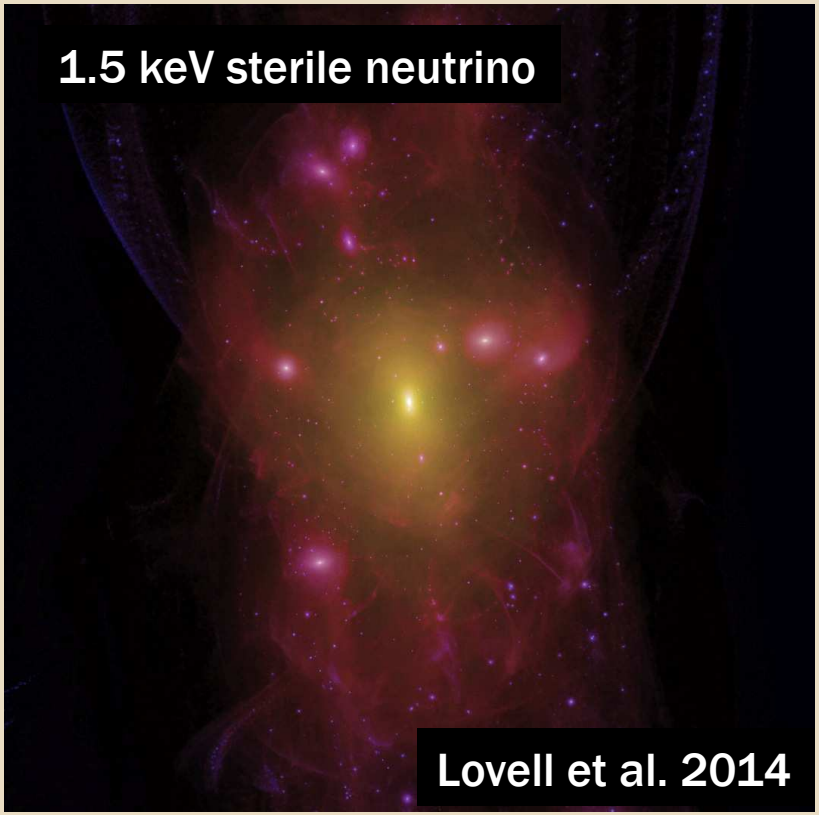
OUTLINE

- Dark matter and the matter power spectrum
- Measuring the small scale matter power spectrum with strong gravitational lensing
- Many new lenses with AGN narrow-line lensing
- Future prospects

THE MICROSCOPIC PROPERTIES OF DARK MATTER AFFECT THE POWER SPECTRUM

E.g. Warm Dark Matter has a large free streaming length at early times which erases structure on small scales.

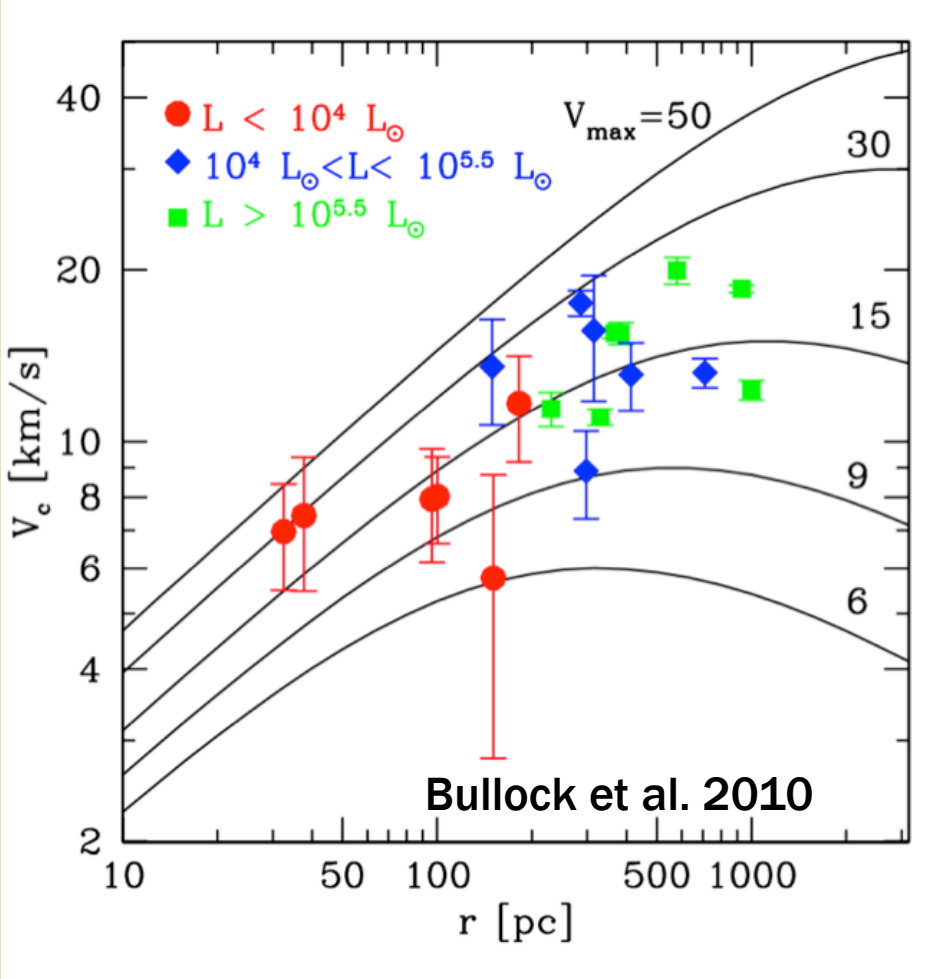




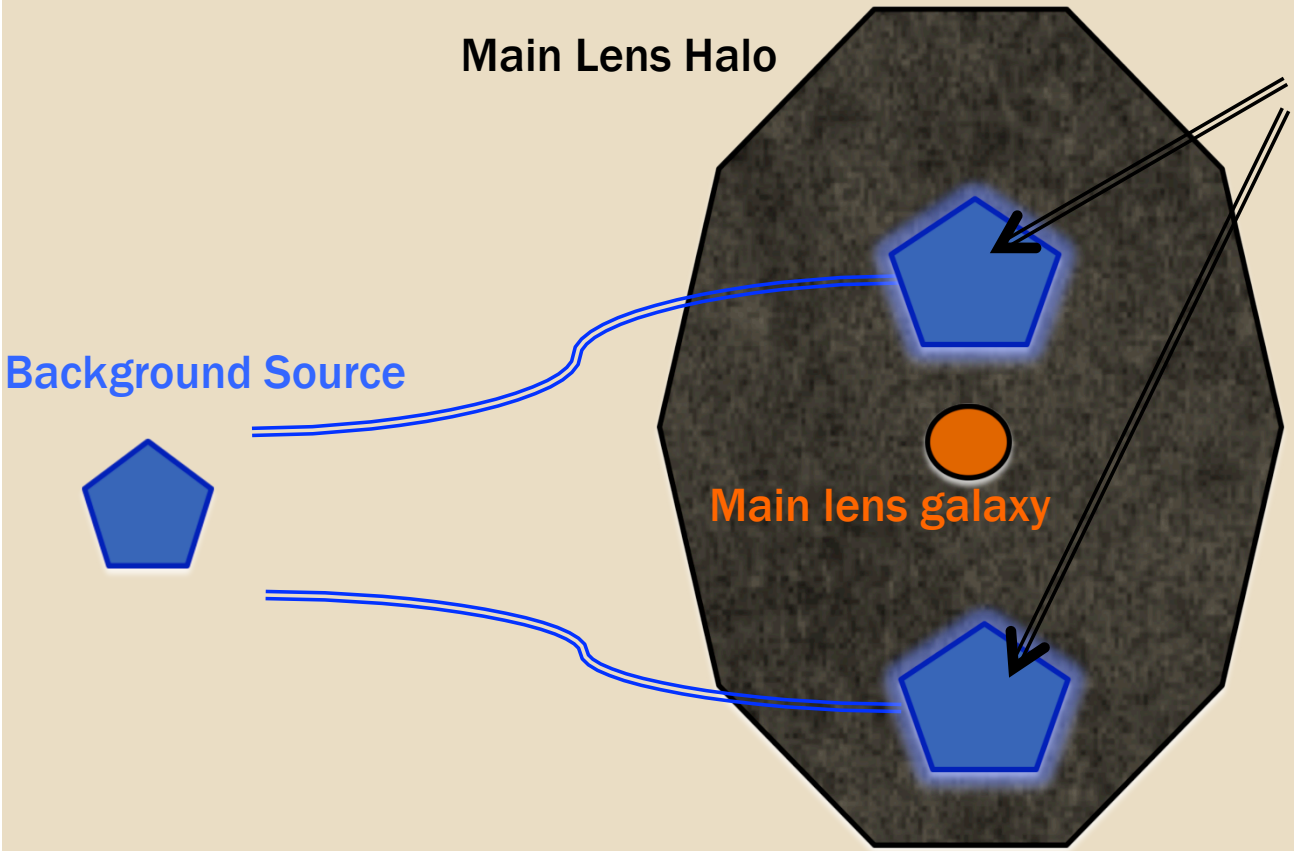
Simulated Milky Way mass dark matter halos

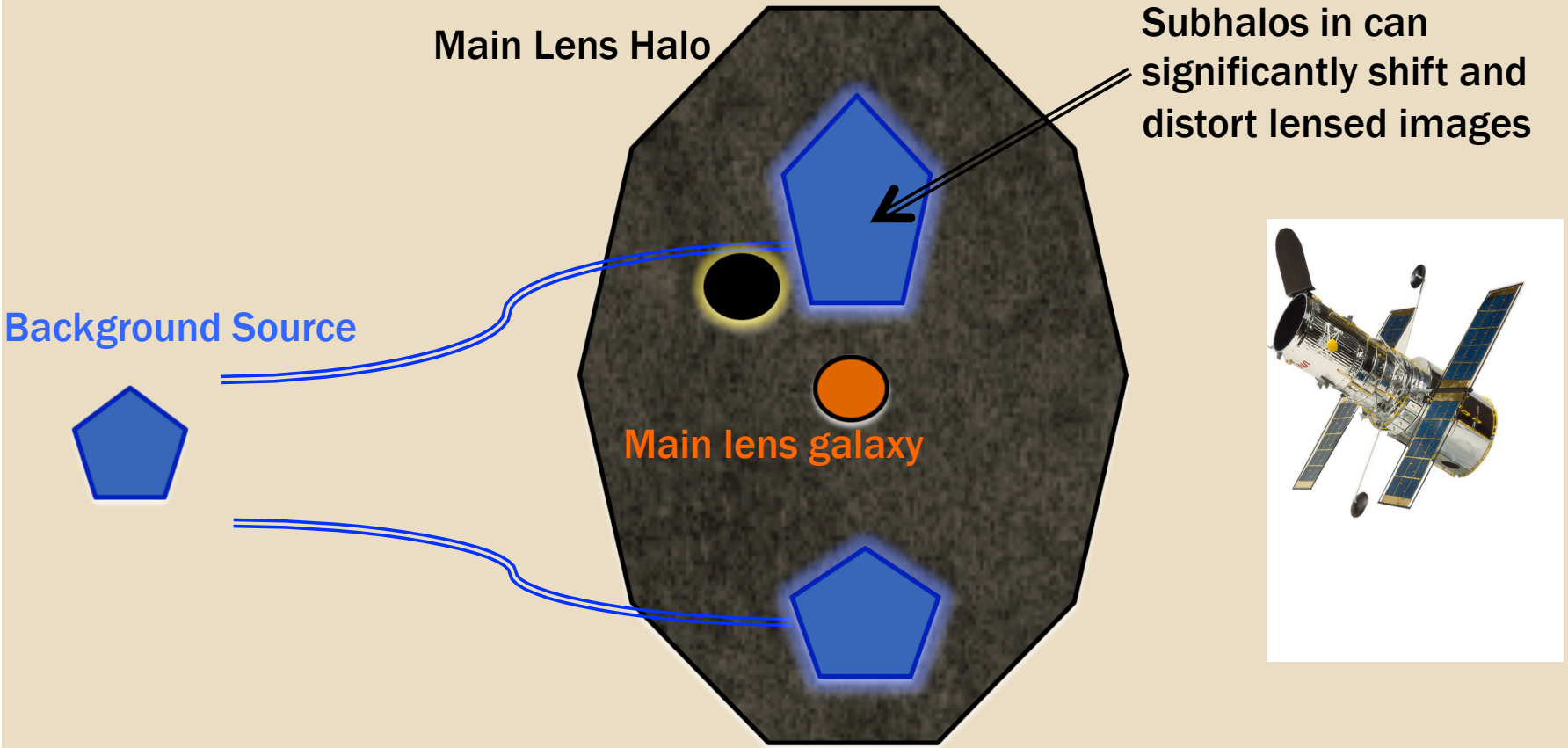
MEASURING THE SMALL SCALE POWER SPECTRUM IS DIFFICULT WITH STAR TRACERS

- Kinematic measurements rely on bright stars, of which there are very few in small halos
- Stars occupy <100 pc of their DM halo which is believed to extend out ~kpc even for small halos
- Some fraction of halos may contain no stars at all.



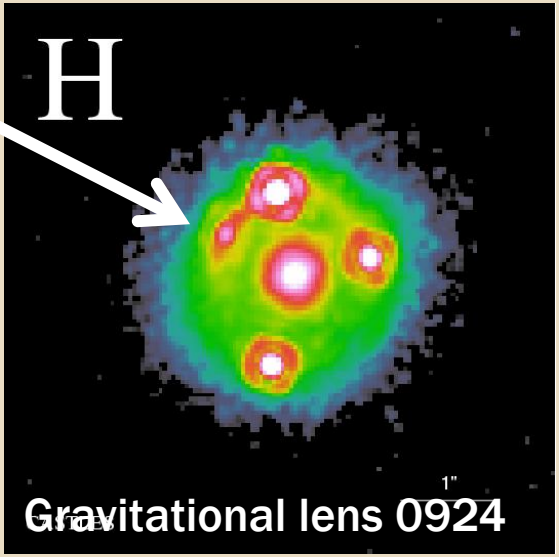
STRONG GRAVITATIONAL LENSING; THE NEXT BEST THING TO DARK MATTER GOGGLES



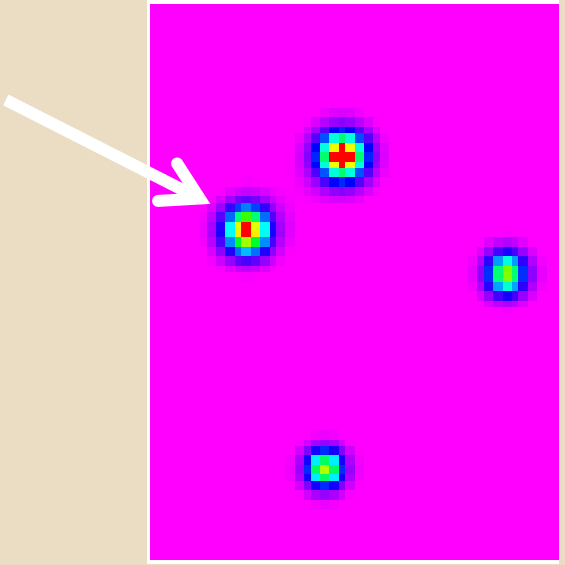

Main Lens Halo
Subhalos in can significantly shift and distort lensed images
Background Source
Main lens galaxy

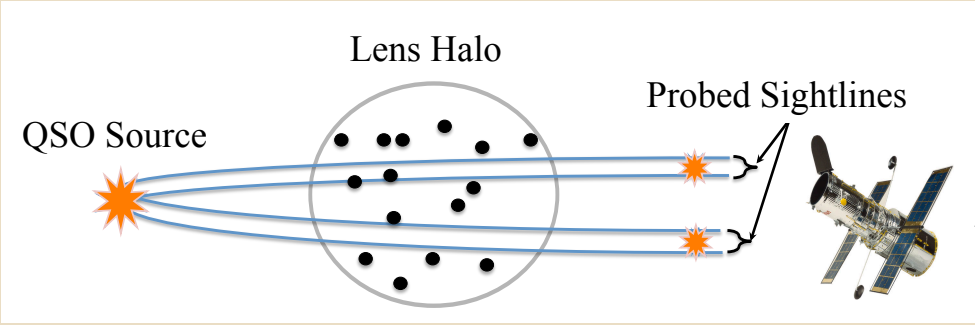
STRONG GRAVITATIONAL LENSING IN REAL LIFE

Observed quad lens

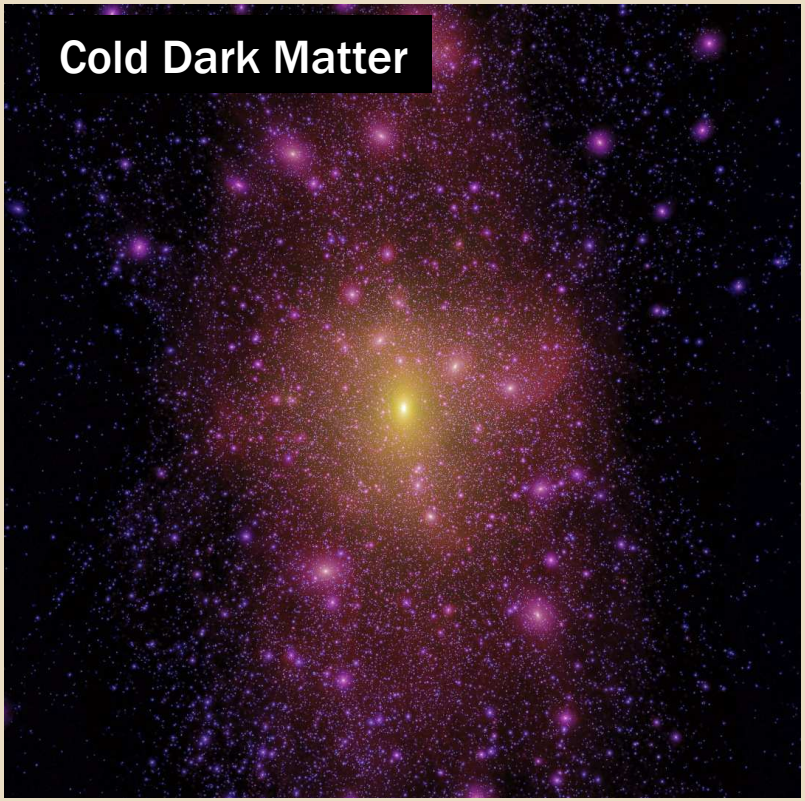


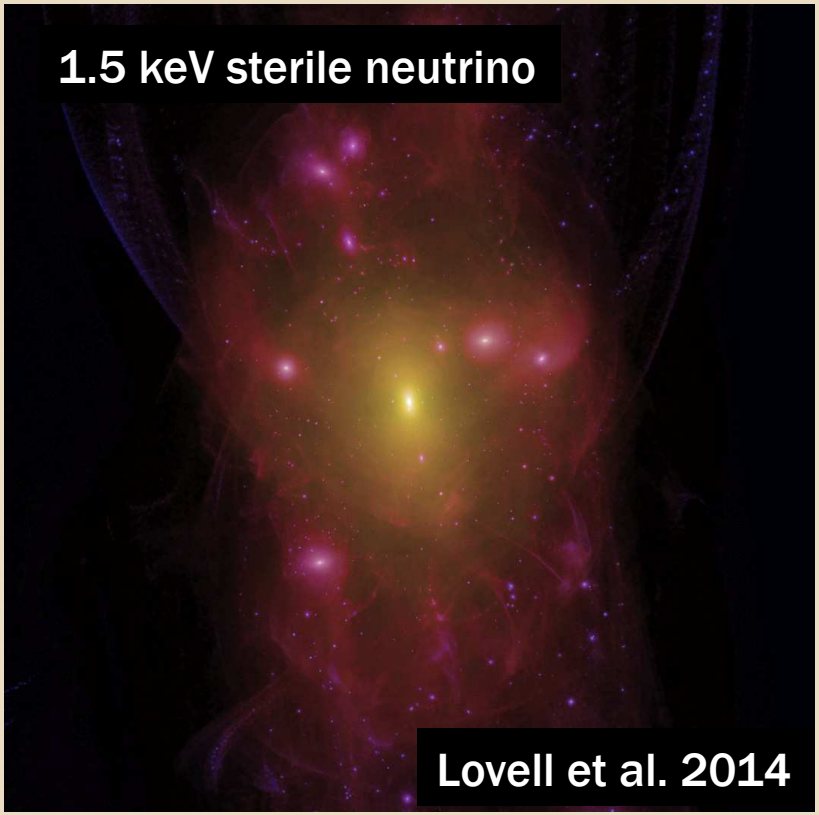
Smooth halo model prediction





WITH ENOUGH LENSES IT IS POSSIBLE TO DISTINGUISH BETWEEN THESE SCENARIOS

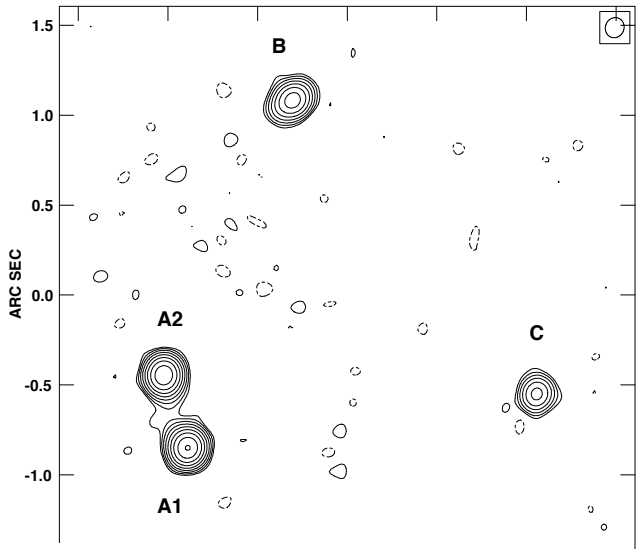




Simulated Milky Way- mass dark matter halos

THE LENS MASS SENSITIVITY DEPENDS ON THE SIZE OF THE *SOURCE*

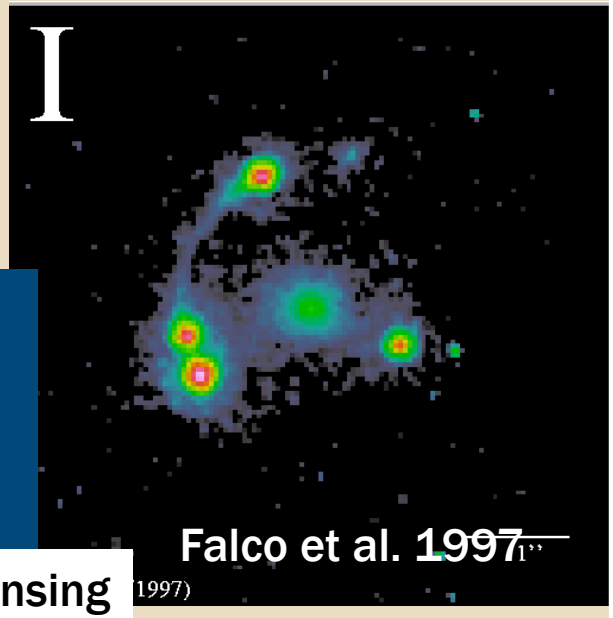
Lensed Radio Jet

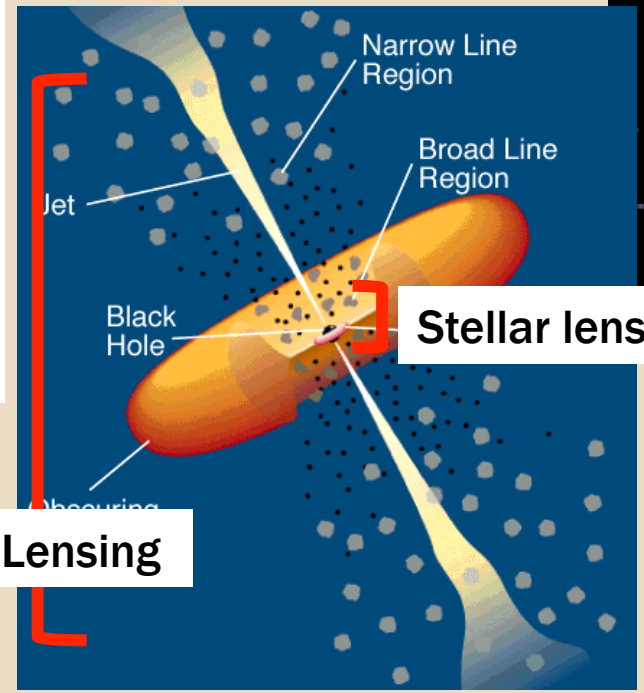


15 GHz, Katz et al. 1997

Gravitational lens MG 0414

Lensed Accretion Disk

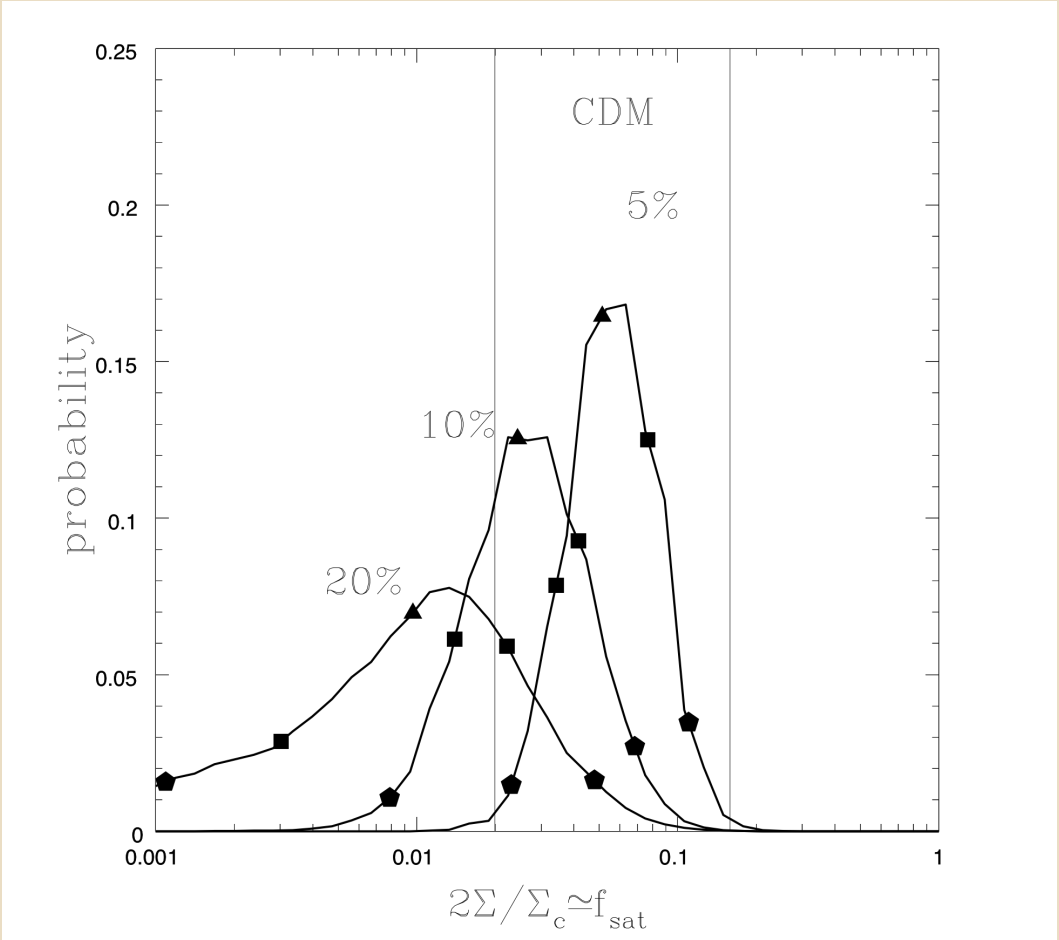




Stellar lensing

Subhalo Lensing

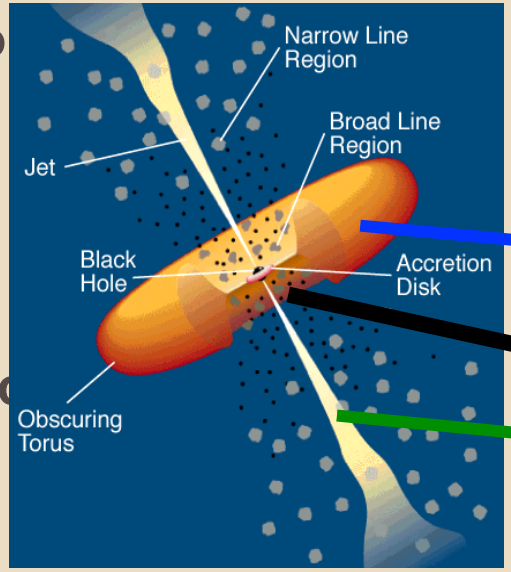
THERE ARE ONLY 7 RADIO LOUD QUAD LENSES KNOWN

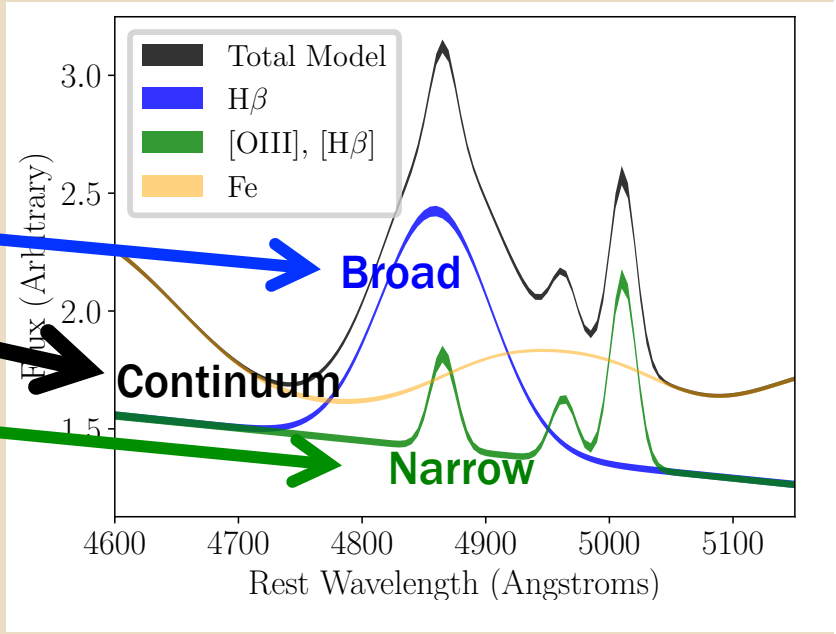


Dalal and Kochanek 2002, 7 radio-loud lens systems

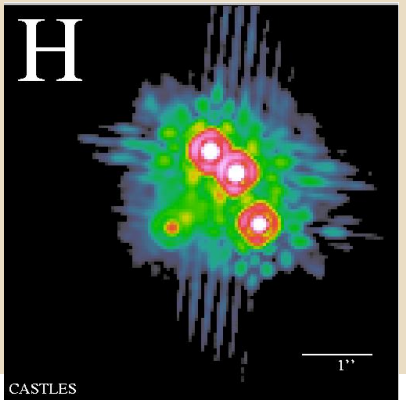
INCREASE THE SAMPLE OF LENSES USING AGN NARROW LINE EMISSION

- All quasars sho significant narrow line emission - can double the number of systems used t detect substructure





- Narrow-line is not variable and not microlensed

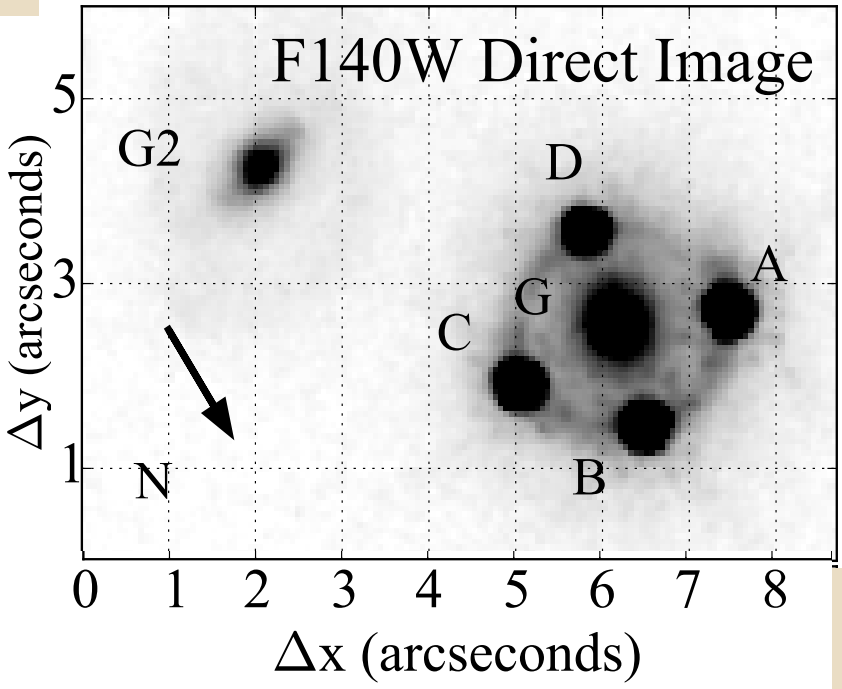


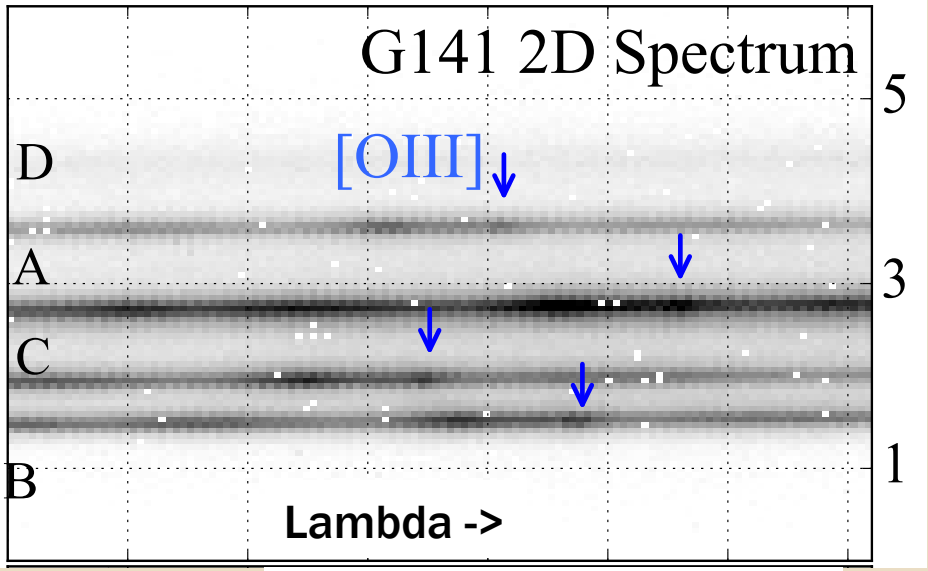
Need high res, spatially resolved spectroscopy

WFC3 GRISM HAS HIGH ENOUGH SPATIAL AND SPECTRAL RESOLUTION FOR THIS

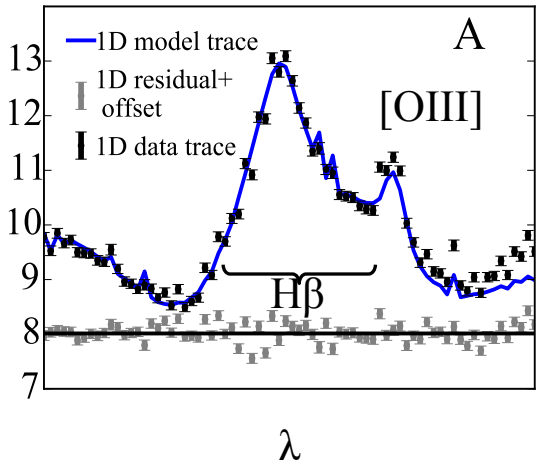
HST GO-13732 (PI Nierenberg) 6 NL quad lenses

PROOF OF METHOD: GRAVITATIONAL LENS HE0435-1223



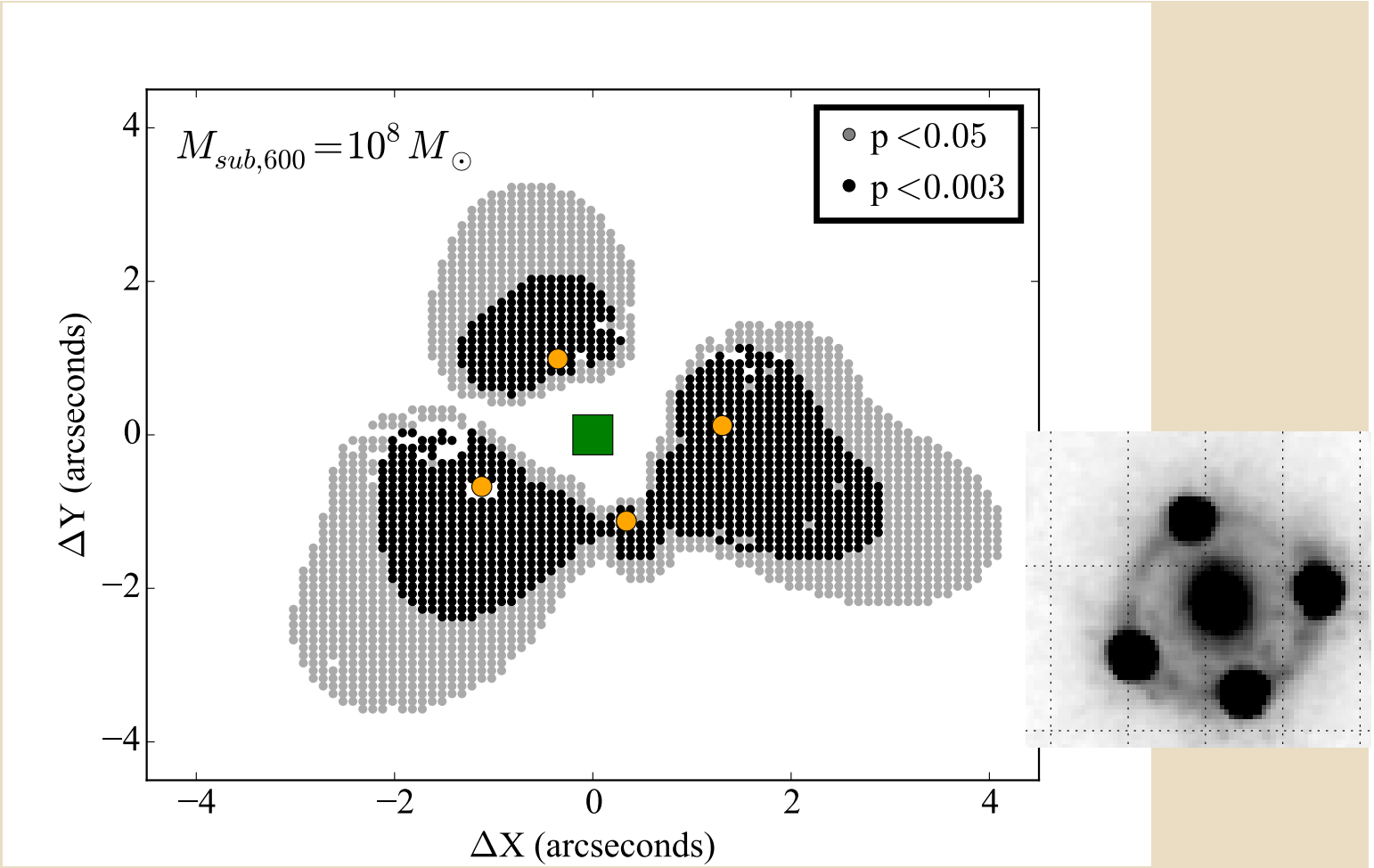


HST-GO 13732 PI: Nierenberg



1D, PSF-weighted grism trace, Nierenberg et al. 2017

LIMITS ON THE PRESENCE OF AN NFW PERTURBER

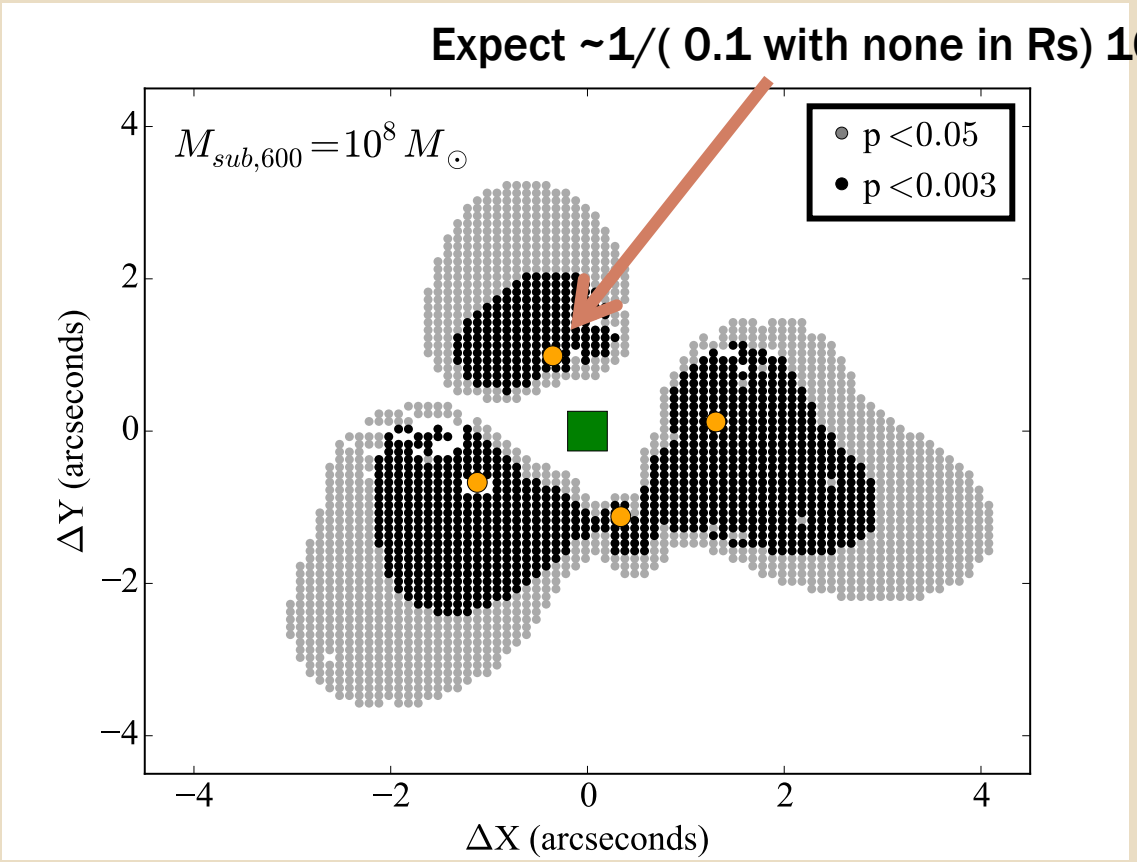


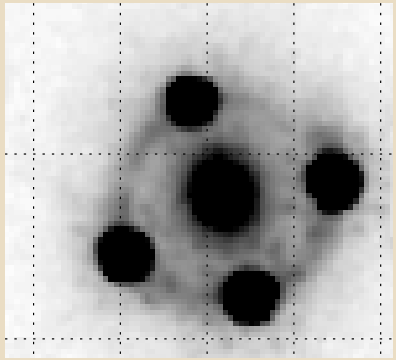
~1” radius excluded around each image (~5.5 kpc)

APPROXIMATE CDM EXPECTATIONS

Ignoring the effects of tidal stripping, DM only sims (Han et al. 2016) give optimistic order of magnitude for the two scenarios:

Expect ~1/(0.1 with none in Rs) 10^8 M 600 satellites





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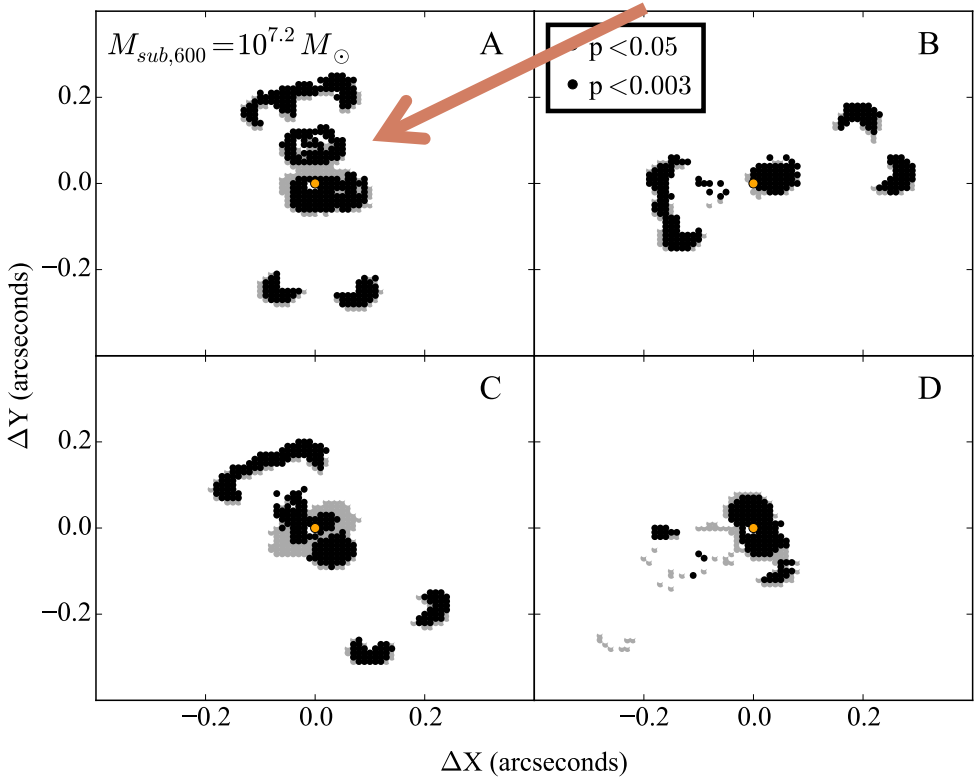
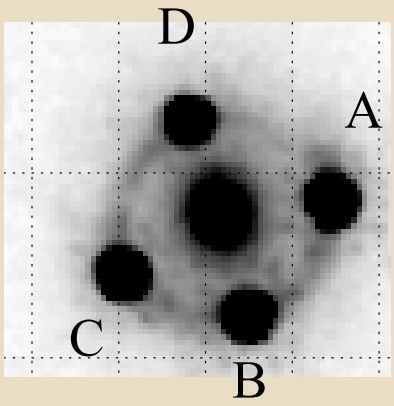
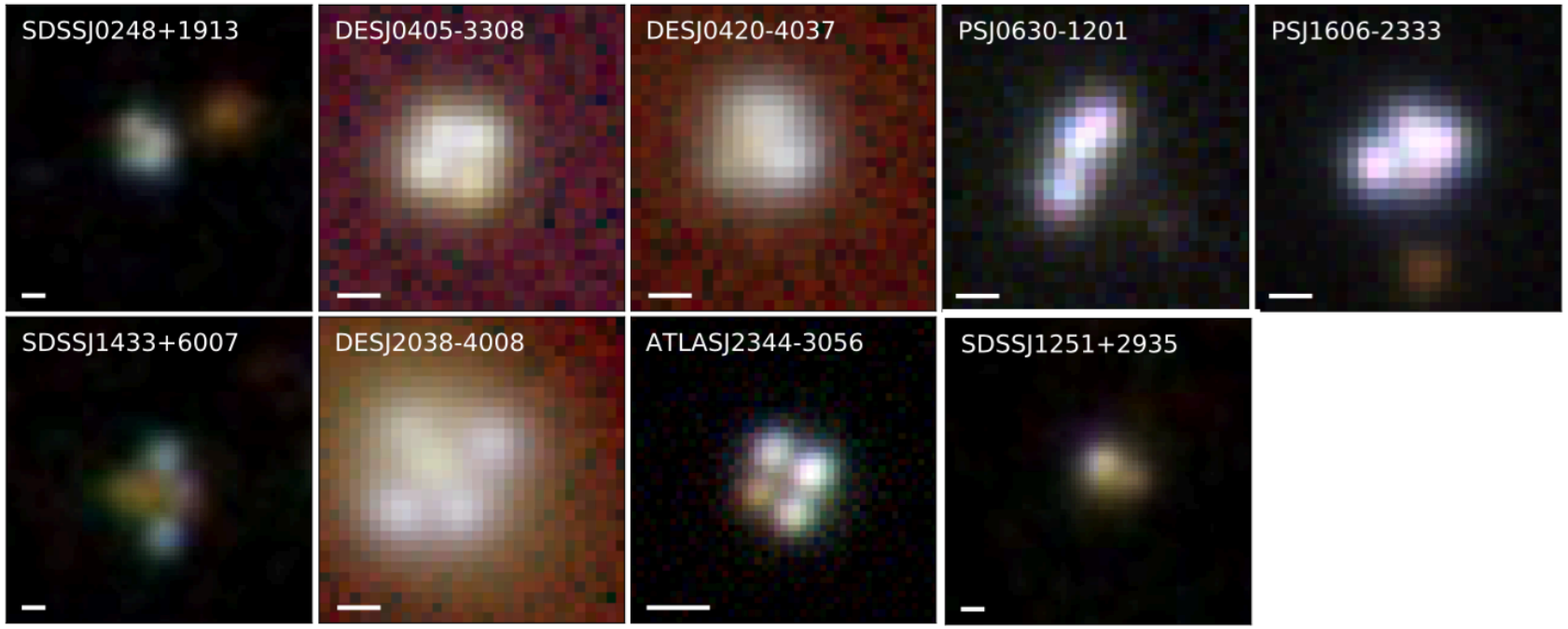


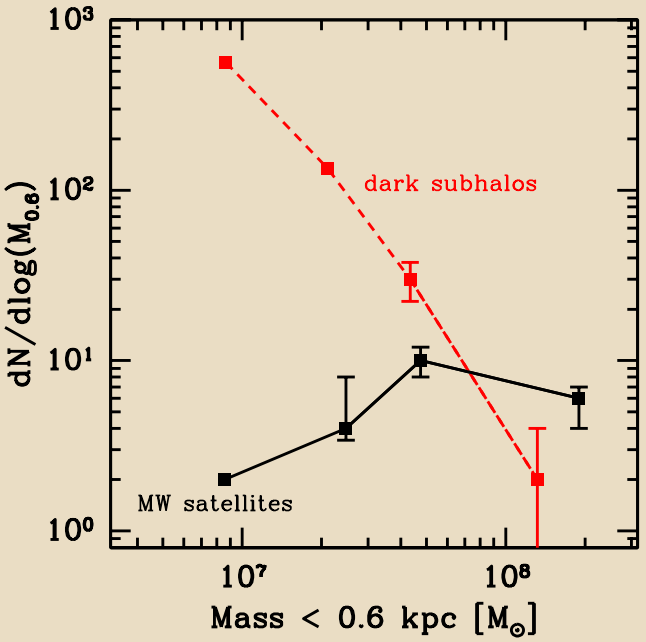


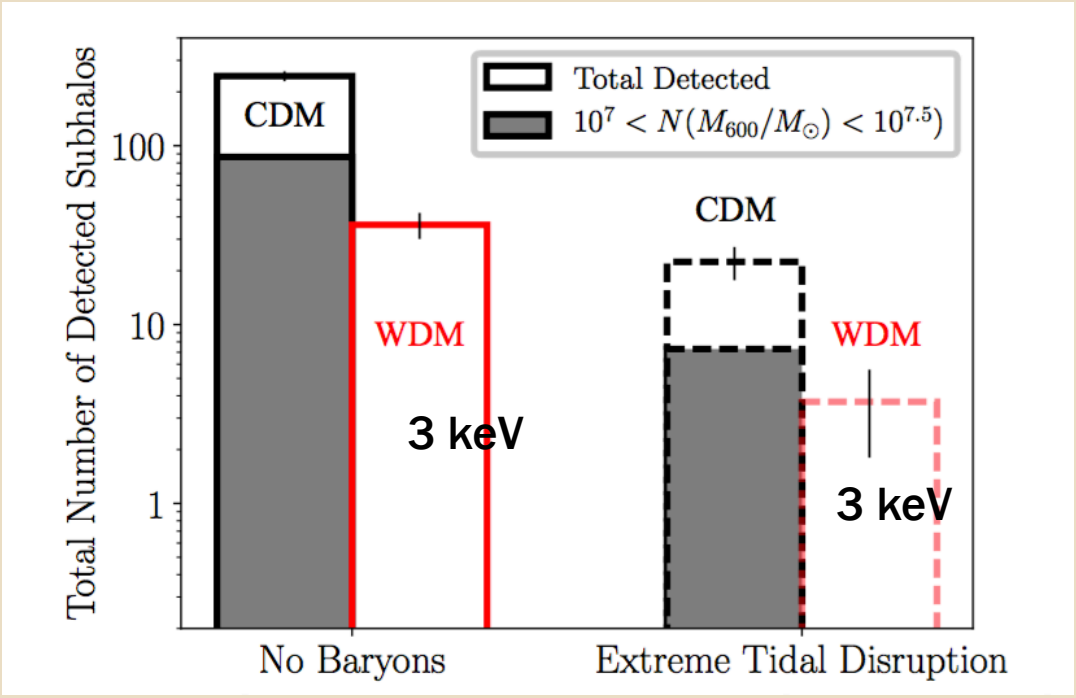
9 NEW NL LENSES FROM PANSTARRS AND DES: HST-GO-15177



PI Nierenberg

EXPECTED NUMBER OF DETECTIONS FOR 18 QUAD LENSES

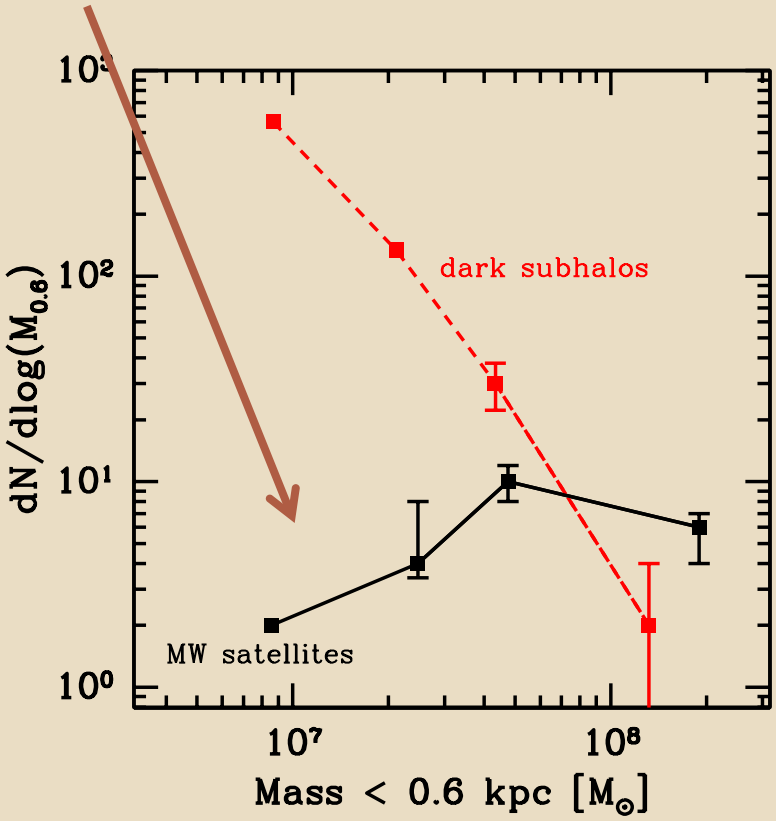




A sample of ~20 systems will contain a significant number of subhalo detections and can place more stringent constraints on WDM than current ly-alpha forest limits

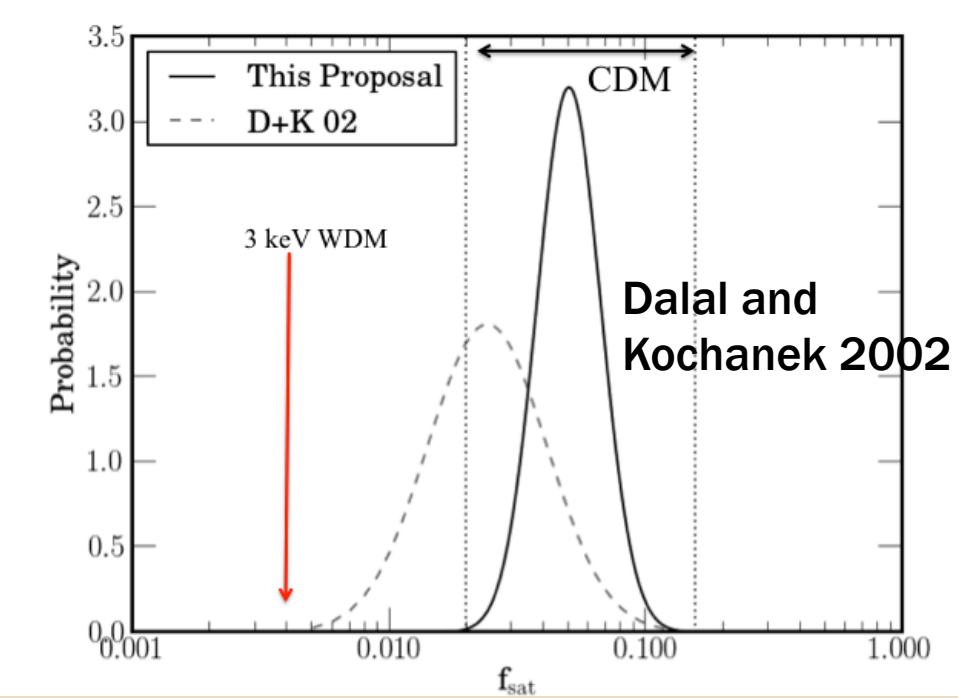
MORE THAN DOUBLE THE PREVIOUS SAMPLE

We are sensitive to these masses!



Strigari et al. 2008.

Tentative constraint forecast



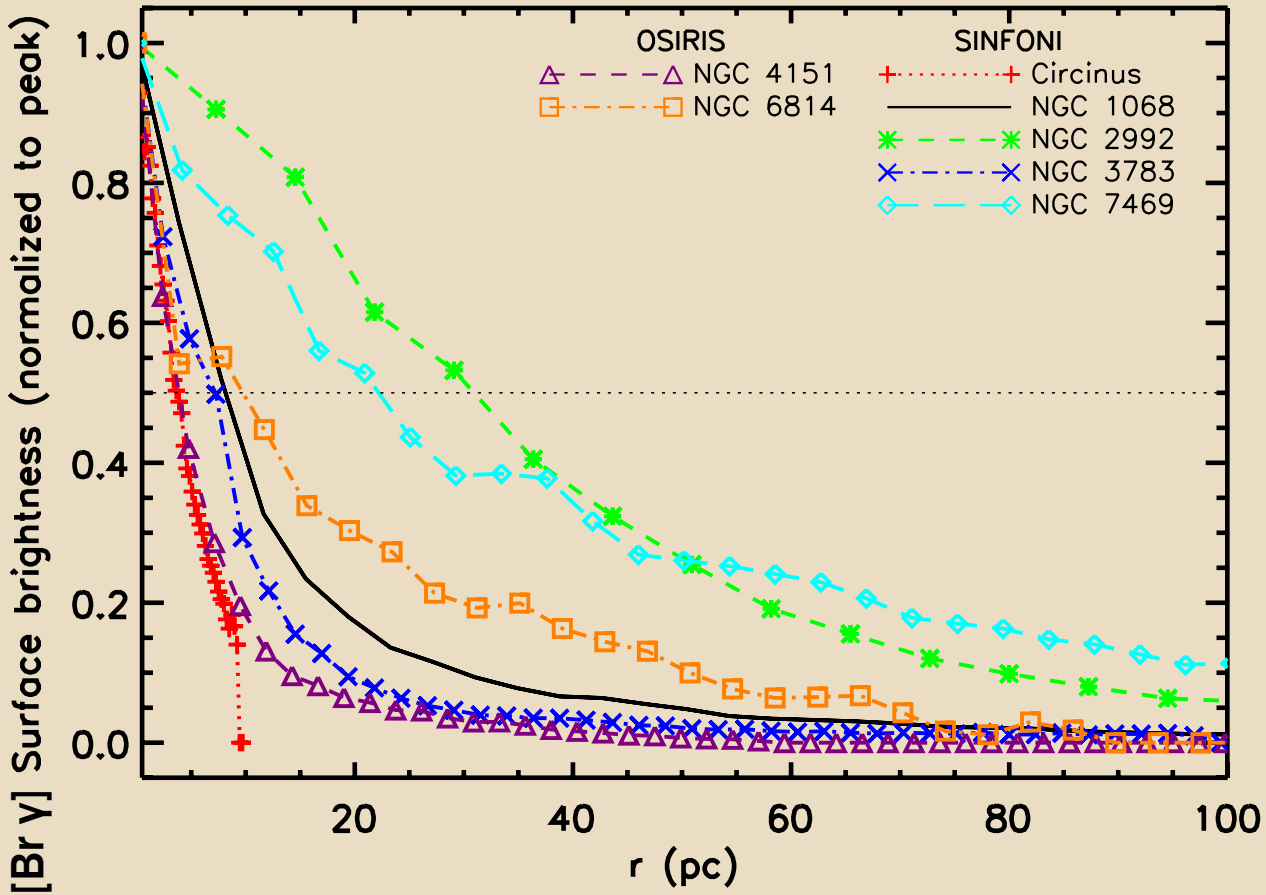
EVEN MORE SYSTEMS

- Combine these results with gravitational lensing results from lensed background galaxies and radio jets (Vegetti, Hezaveh…)
- Extend analysis to hundreds of quad quasar lenses to be discovered in DES, PAN-STARRS and LSST.
- JWST and next generation of ground based telescopes will enable rapid follow up and allow us to push to lower luminosities.

CONCLUSIONS (THANKS FOR LISTENING!)

- Strong gravitational lensing is a powerful tool for constraining the properties of dark matter on small scales
- Narrow-line lensing is a promising new way to expand the sample of gravitational lenses with can be used to probe dark matter substructure
- The WFC3 grism provides sufficient spatial and spectral resolution to detect low mass subhalos, well below the regime where stars become unreliable tracers of dark matter.
- With the current sample of narrow-line lenses we expect to be able to place new constraints on WDM/CDM.
- Thousands of new lenses will be discovered in LSST and can be followed up with this method with JWST/next generation of telescopes.

NARROW LINE LIGHT PROFILE



Müller-Sanchez et al. 2011

FINITE SOURCE EFFECTS FOR HE0435