Probing Dark Matter with strong gravitational lensing

Simon Birrer, UCLA

Collaborators:
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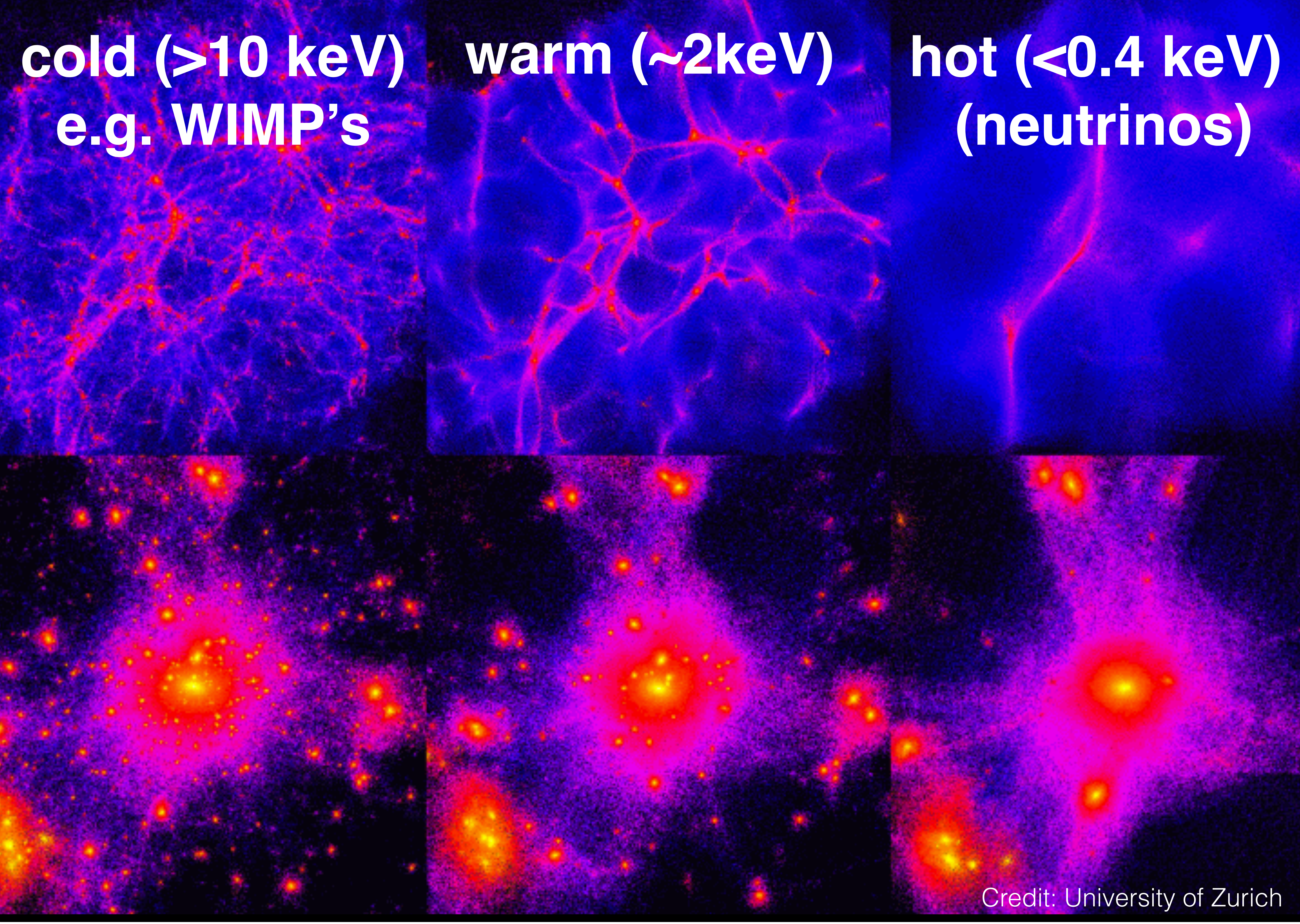
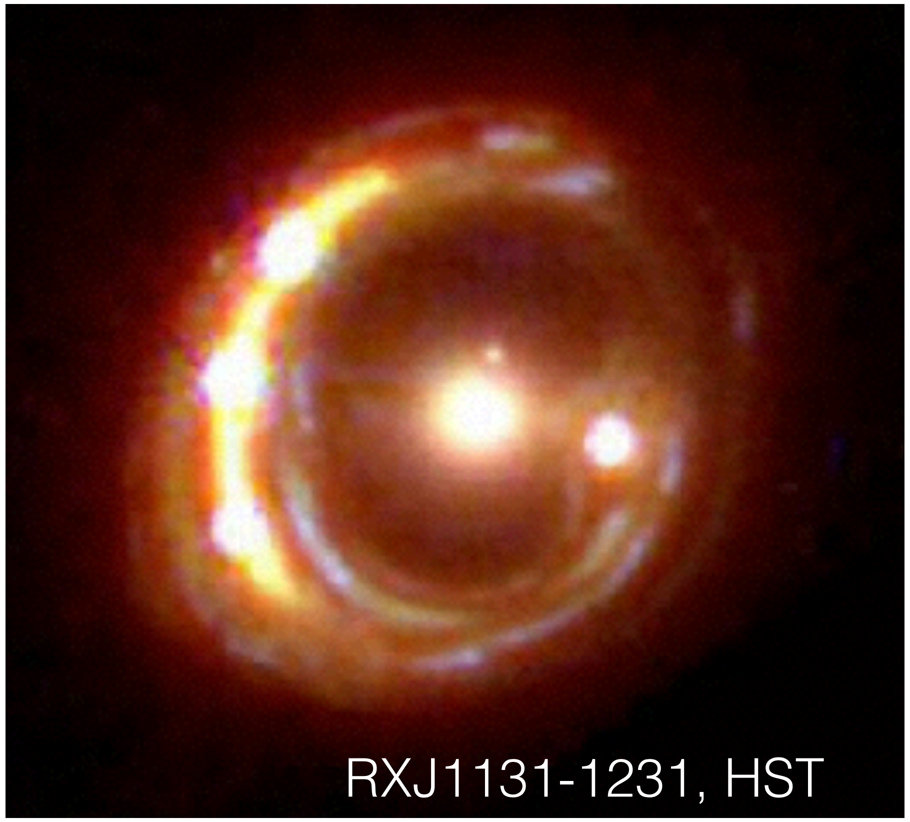
Adam Amara, Alexandre Refregier (ETHZ)

DaMaSC IV, Caltech 8.30.17


cold (>10 keV)
e.g. WIMP's
warm (~2keV)
hot (<0.4 keV)
(neutrinos)
Credit: University of Zurich

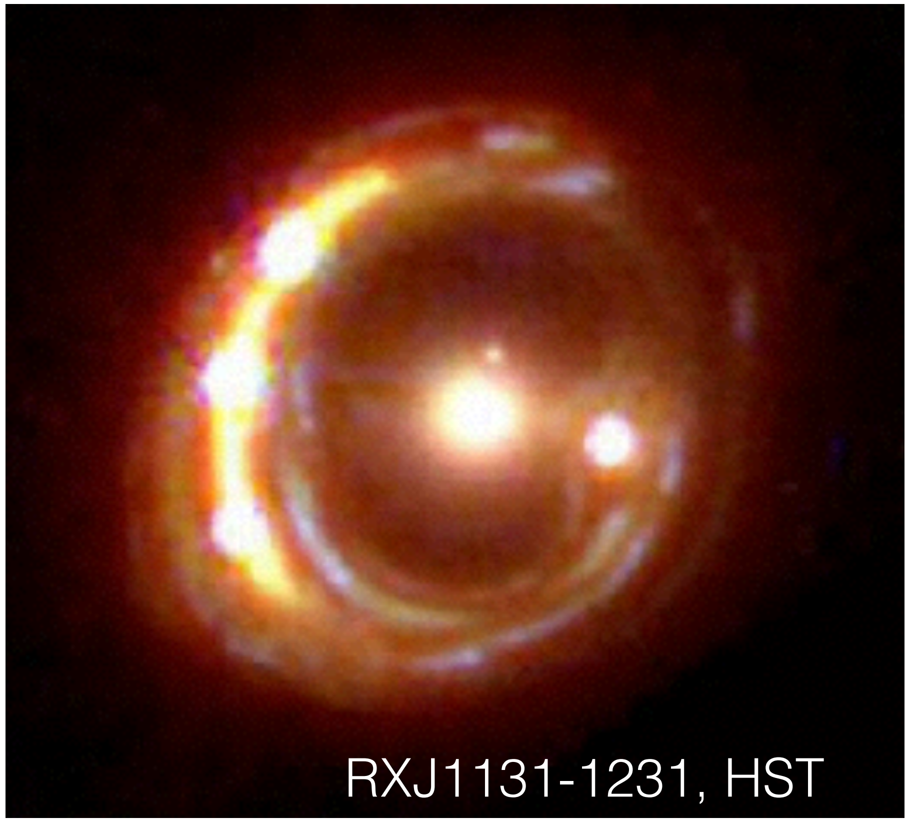
Strong gravitational lensing

Sluse+ 2003, Suyu+ 2013, Birrer+ 2016, …



Strong gravitational lensing

Observables:
image positions + time delays



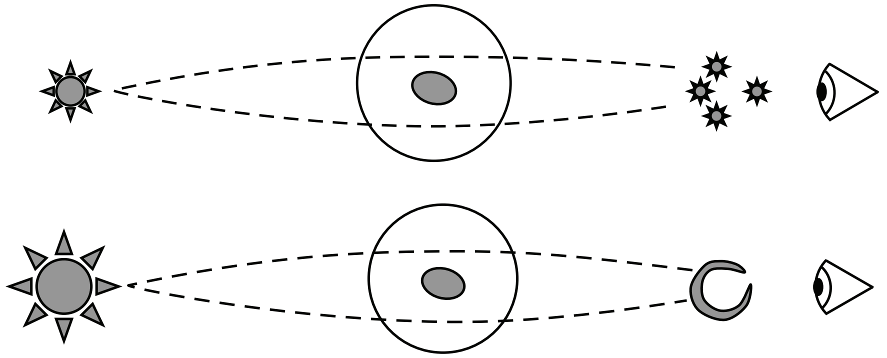
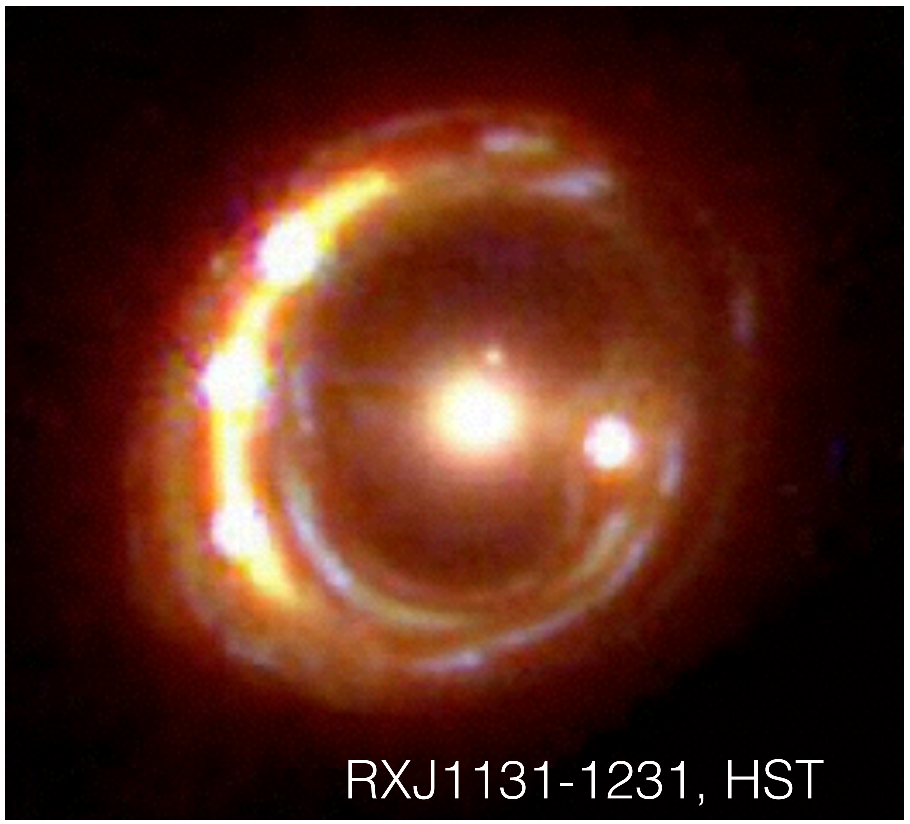
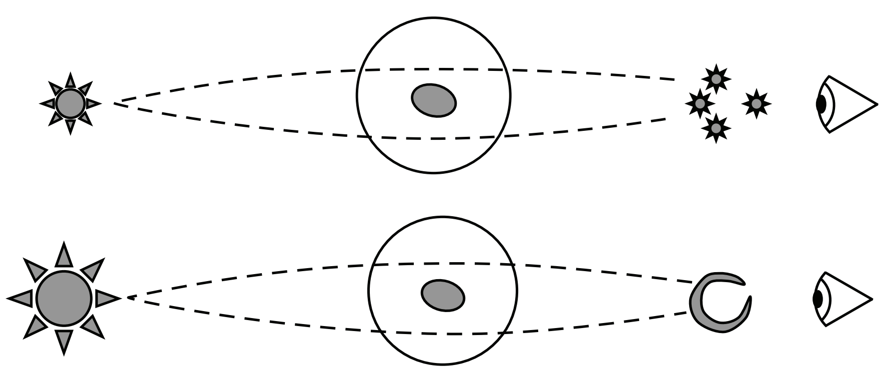


Illustration: Zachrisson & Riehe 2009

Strong gravitational lensing





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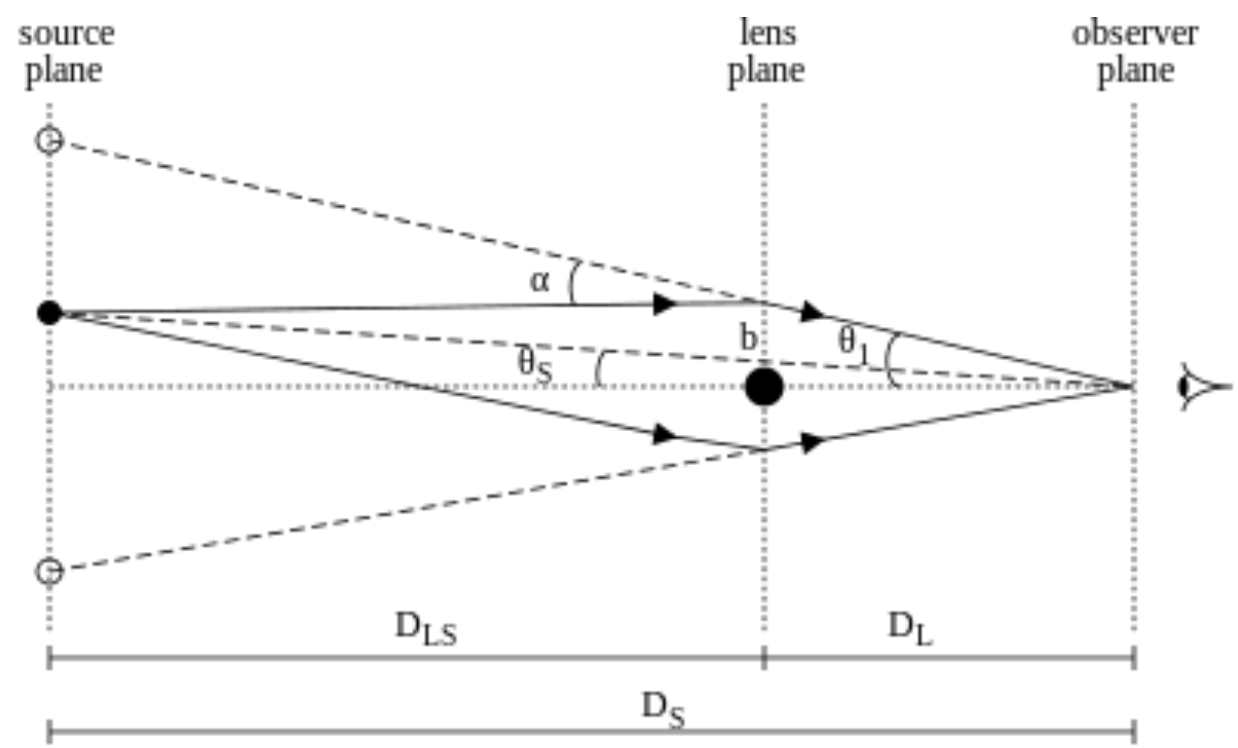
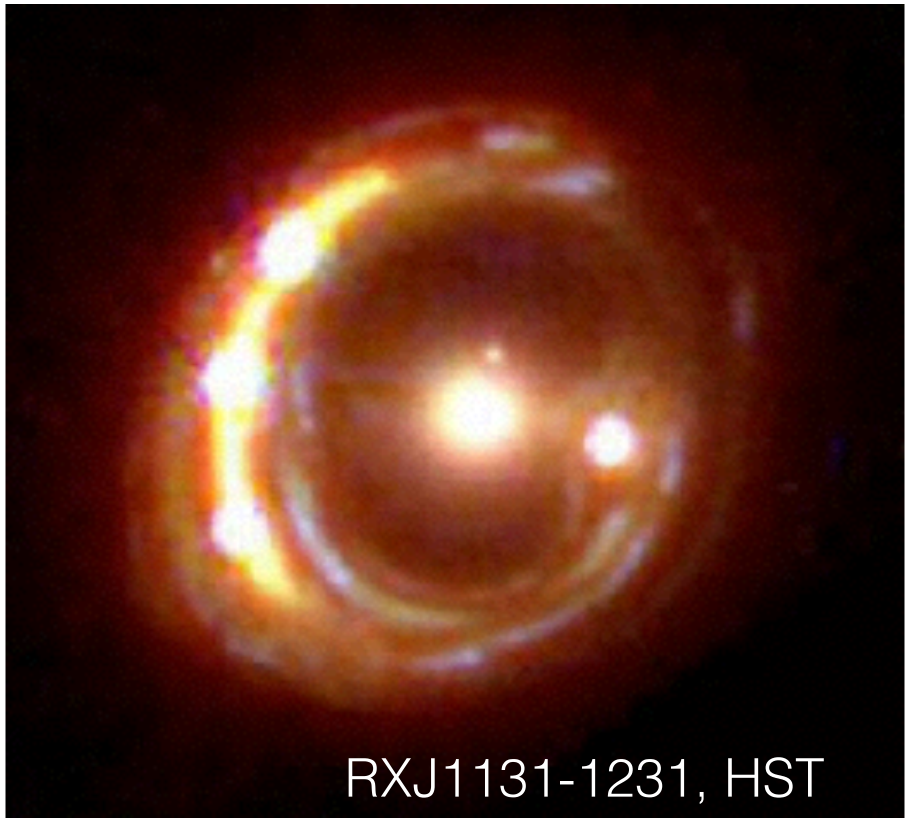


Strong gravitational lensing



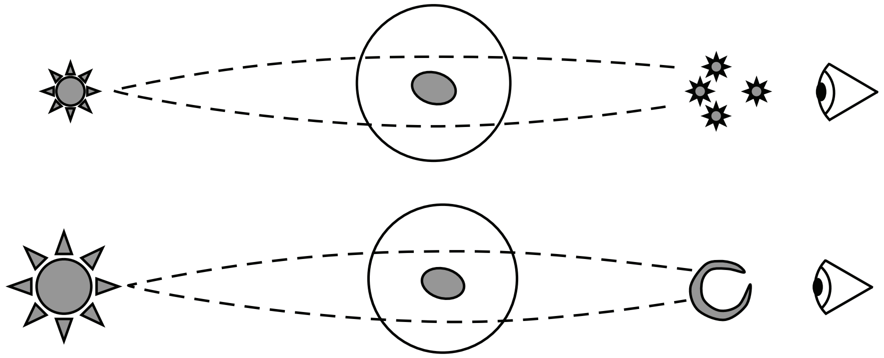


Illustration: Zachrisson & Riehe 2009

Observables:
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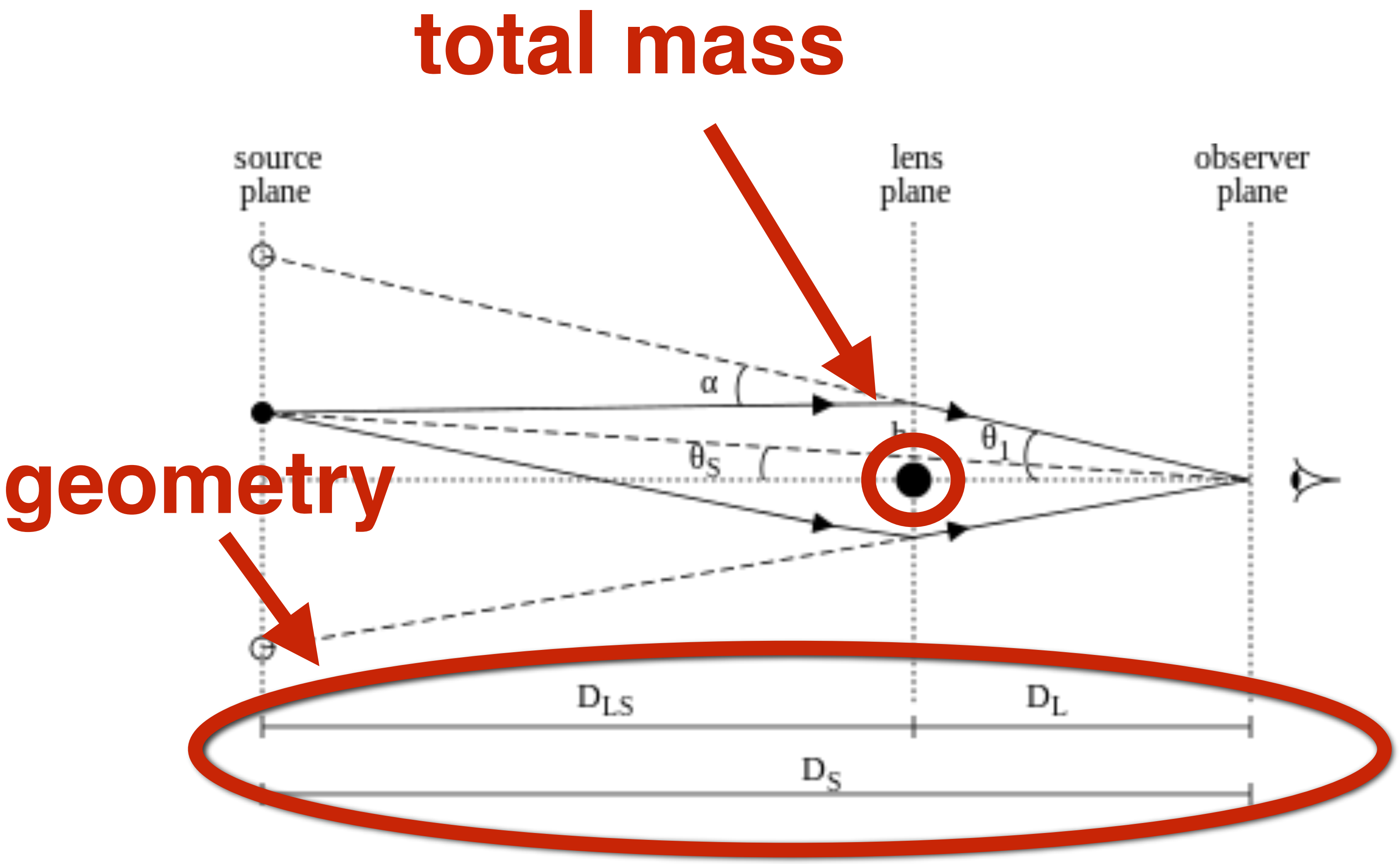


Strong gravitational lensing

Source
unknown

Lens
unknown

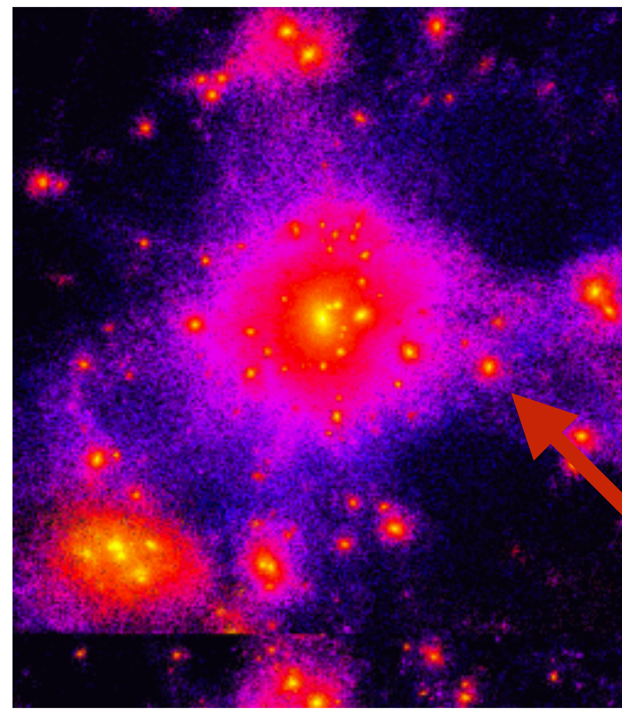
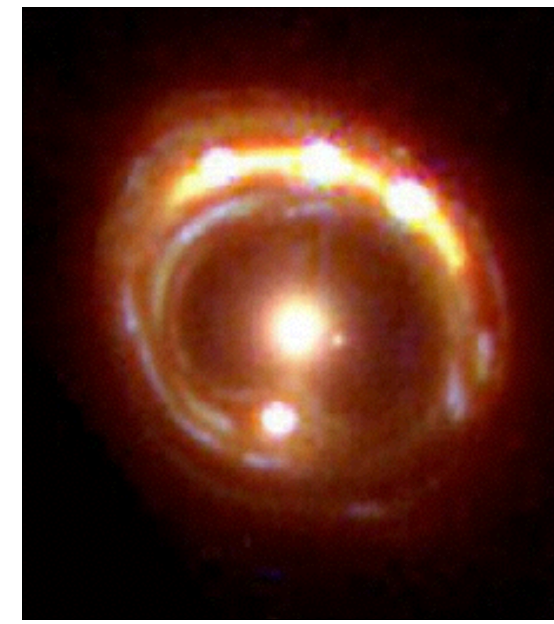
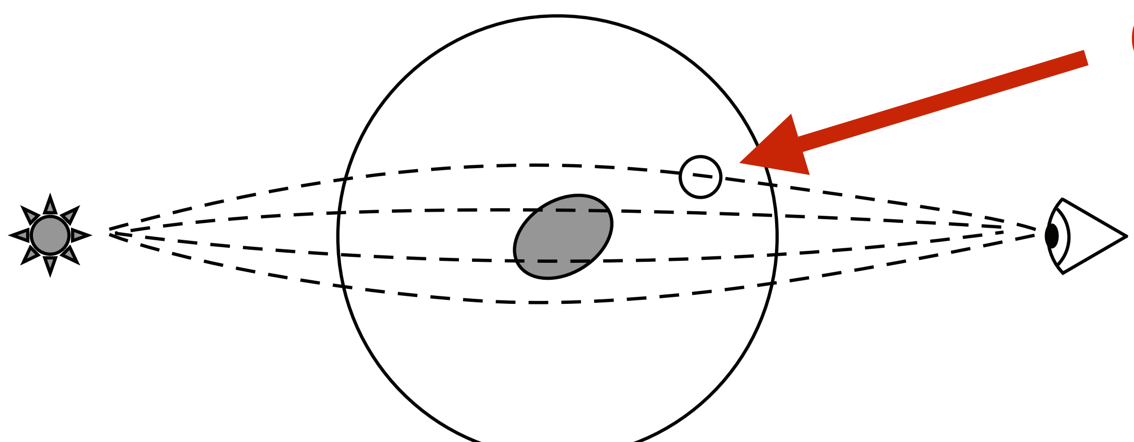


Image
data



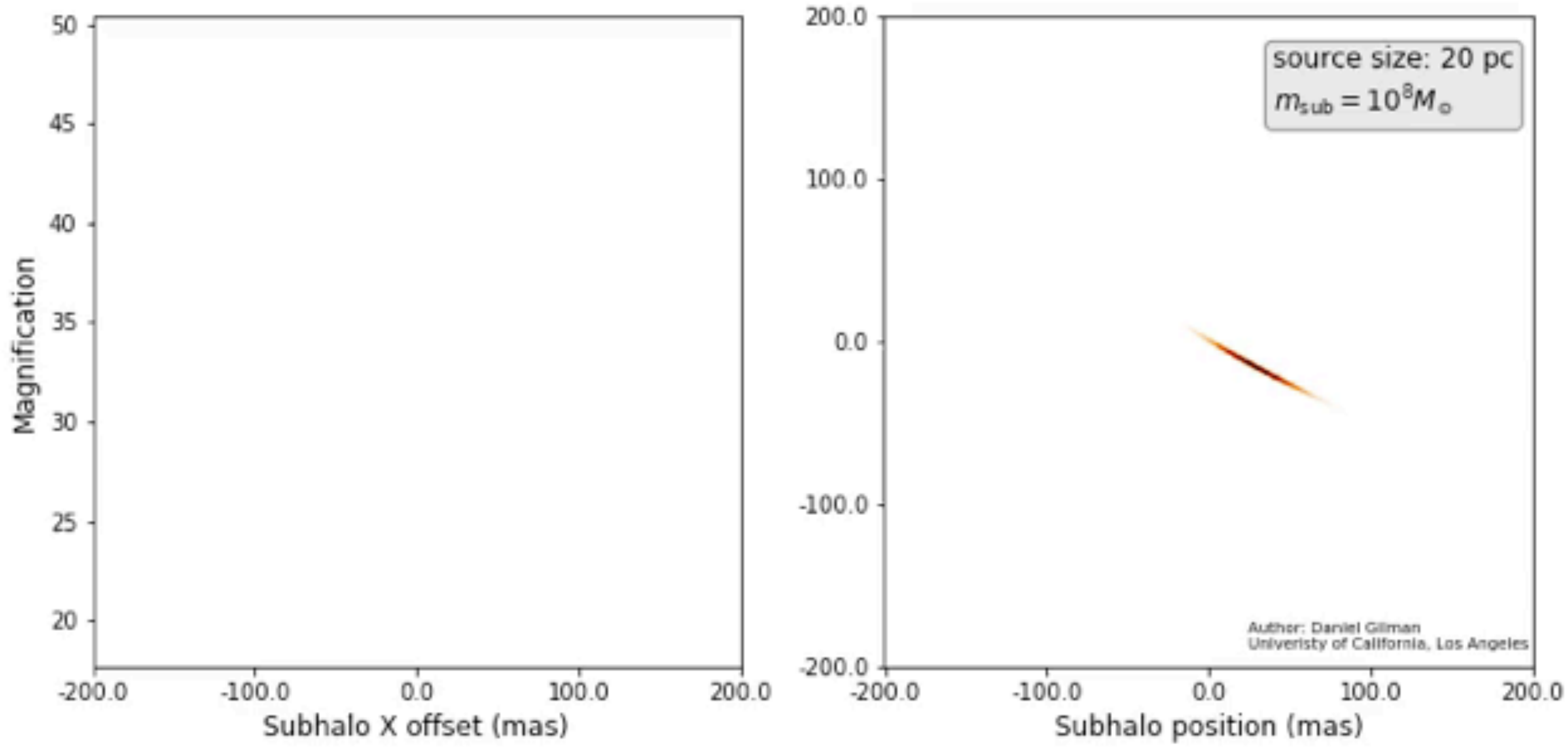
can be dark!



Metcalf & Madau 2001
Dalal & Kochanek 2002
Moustakas & Metcalf (2003)
Koopmans 2005

Vegetti+ 2010, 2012
Hezaveh+ 2016
Nierenberg+ 2014, 2017
Birrer+ 2017

Strong gravitational lensing - an illustration

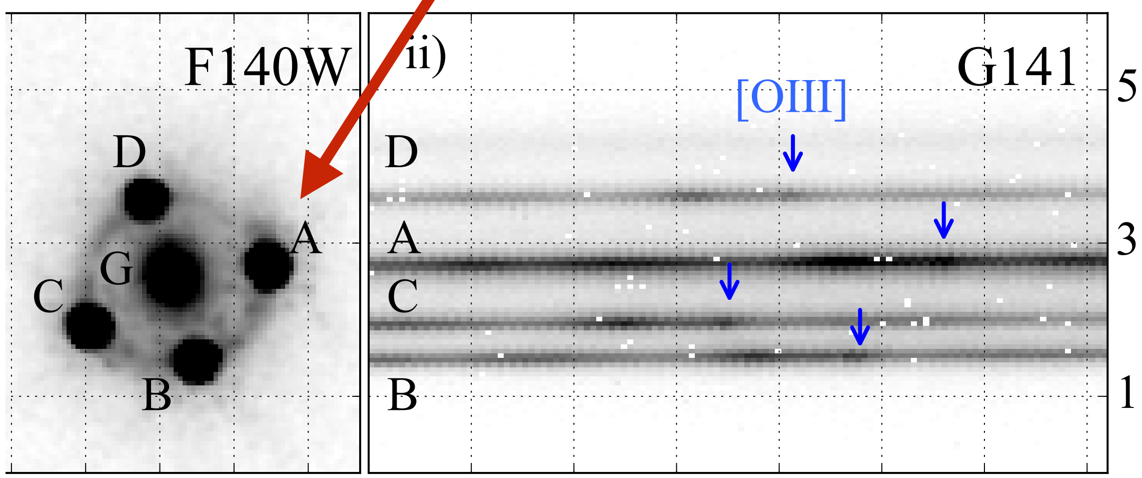


by Daniel Gilman (UCLA)

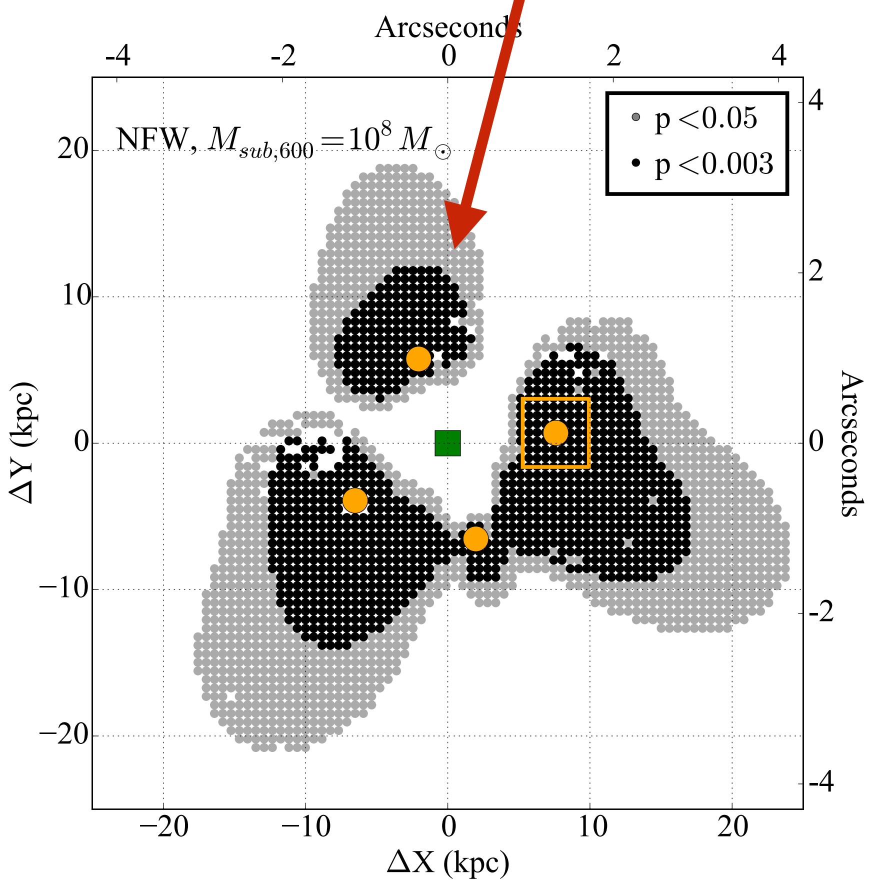
Observables change with:
- source size
- clump mass
- clump profile

Method 1: Quasar flux ratio anomalies

unresolved strong lensing from quasar narrow line emission region



exclusion regions for a certain type of sub-clump



small physical source size allows for sensitivity to very **low masses**

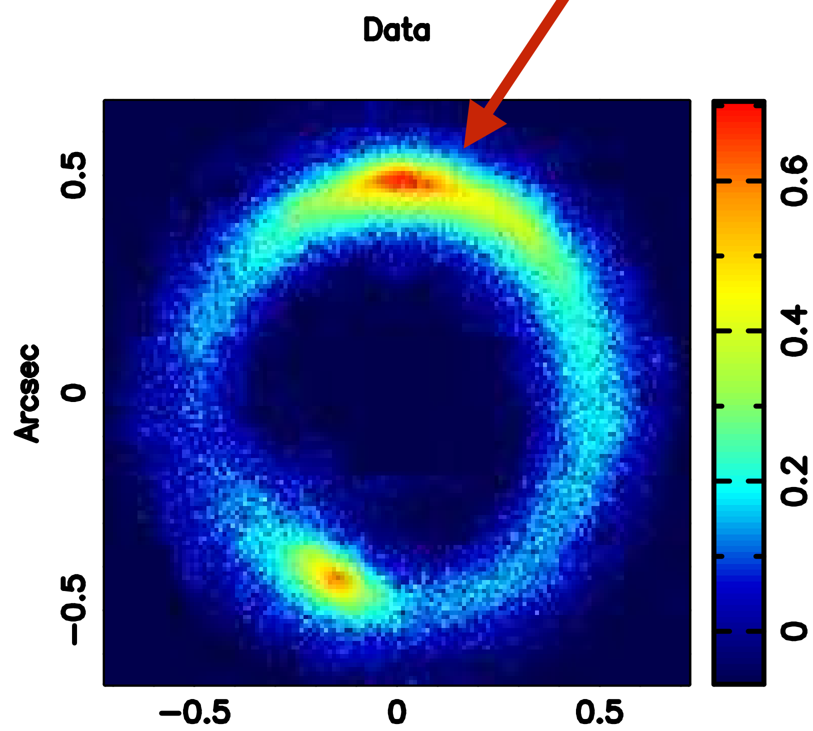
Statistical statement requires a significant sample size of strong lenses

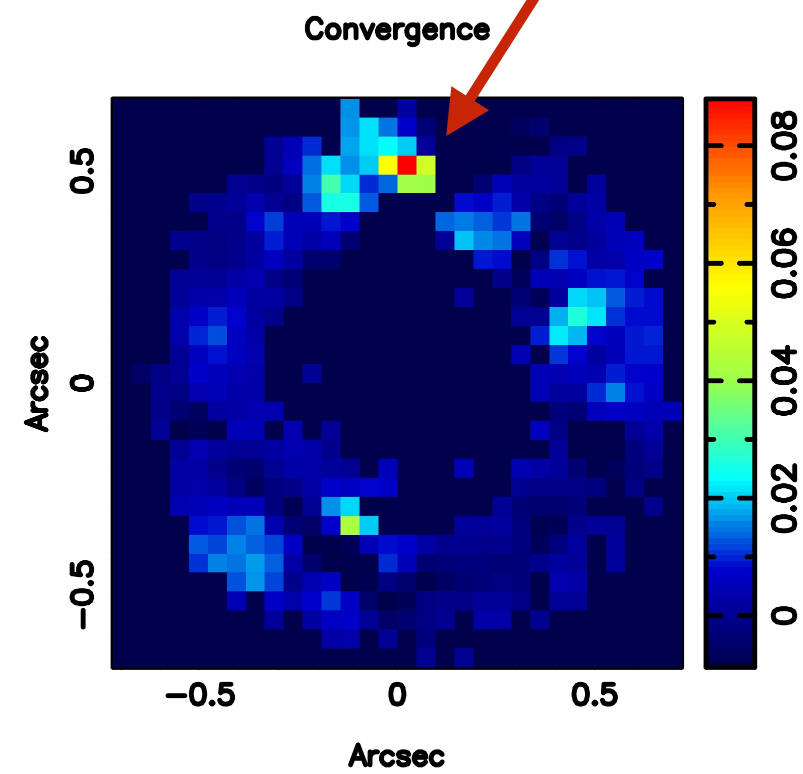
Moustakas & Metcalf (2003)
Nierenberg+2014, 2017

Method 2: gravitational imaging

resolved strong lensing from galaxy surface brightness

direct detection through lens modelling of $2 \times 10^8 M_\odot$





sensitive to **individual** clumps near the Einstein ring

sensitivity depends on **spatial resolution** and **source** structure

quantifying a detection challenging and high S/N required

Koopmans 2005
Vegetti+2010, 2012
Hezaveh+ 2016

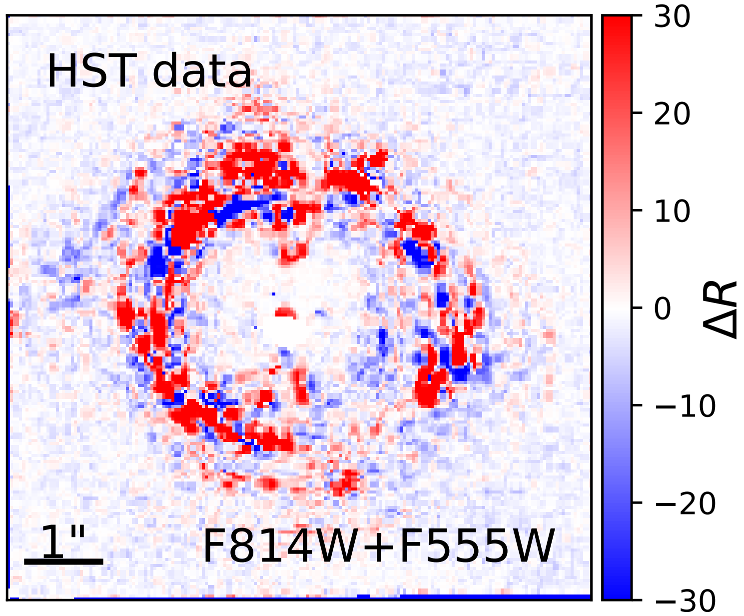
Method 2+: statistical analysis of gravitational imaging

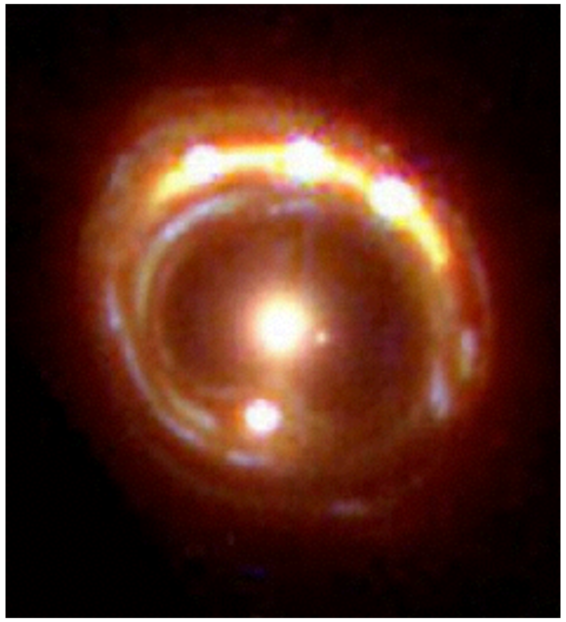
Extract **features** attributed to substructure by a scanning process

Can probe substructure at the **sensitivity limit**

smooth preferred

clump preferred





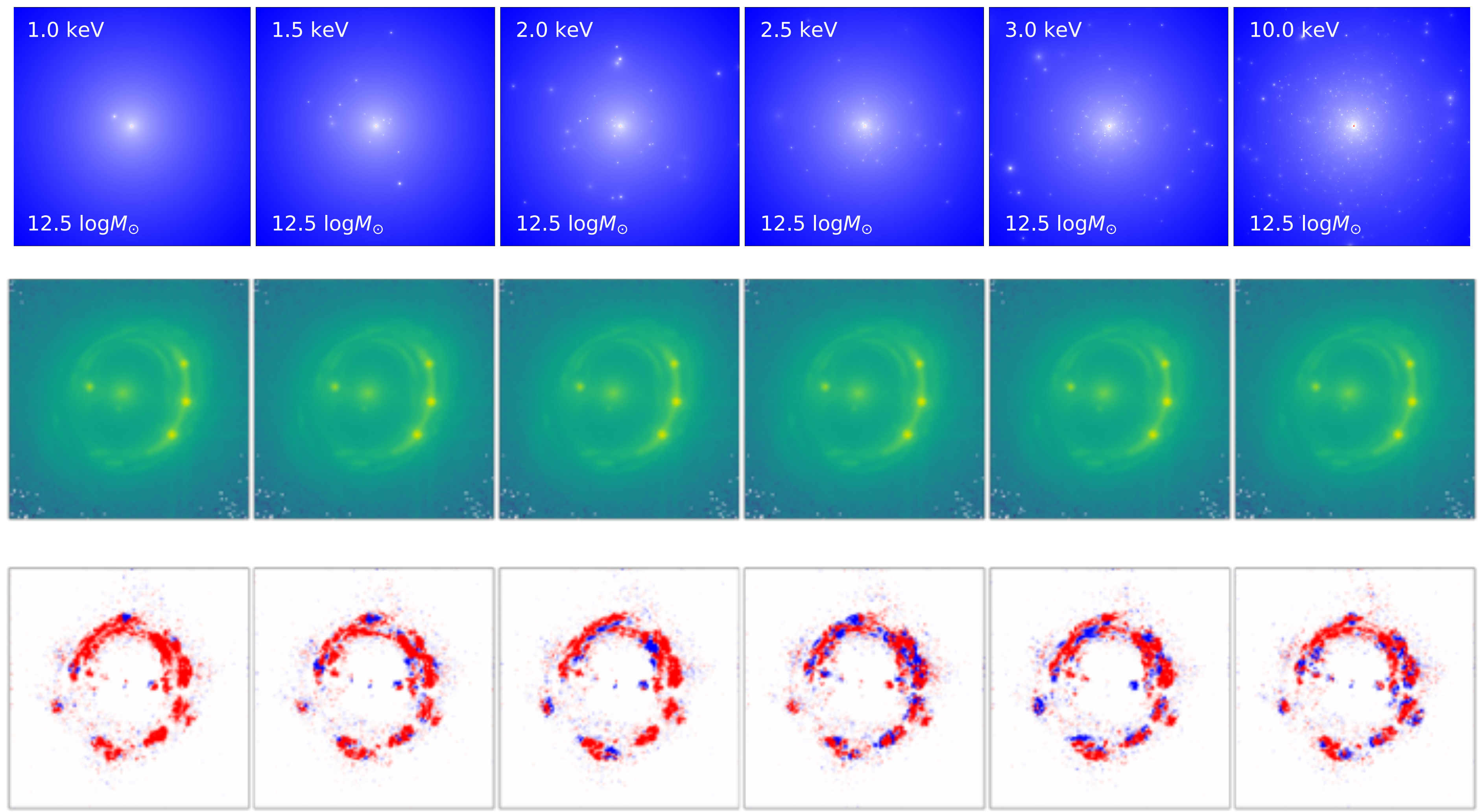
Interpretation of features relies on **simulations**

does **not rely** on assumption on **number** and **shape** of sub-clumps

Birrer+ 2017

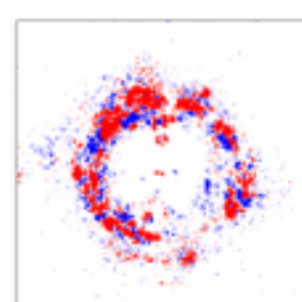
Dark Matter thermal relic mass constraints from lensing substructure

Turn a physical model stochastically into **simulated data**



look for the **same features** in your simulated data

Accept/reject simulations based on **summary statistics**



Approximate Bayesian Computing (ABC)

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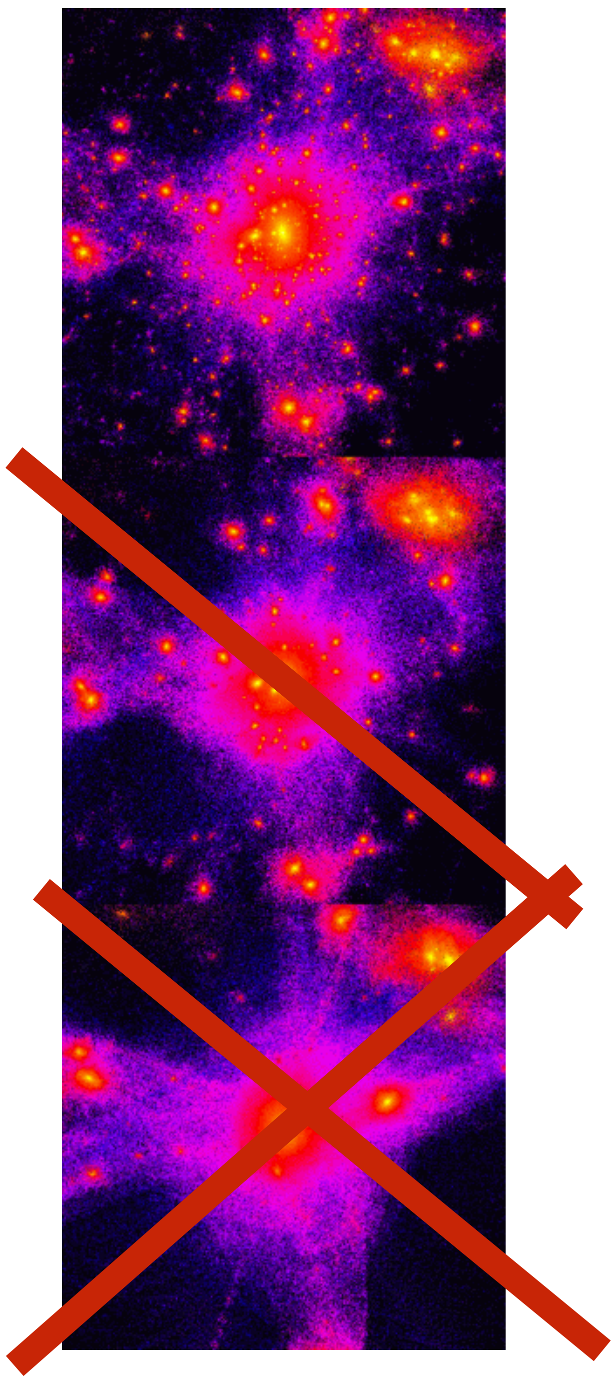
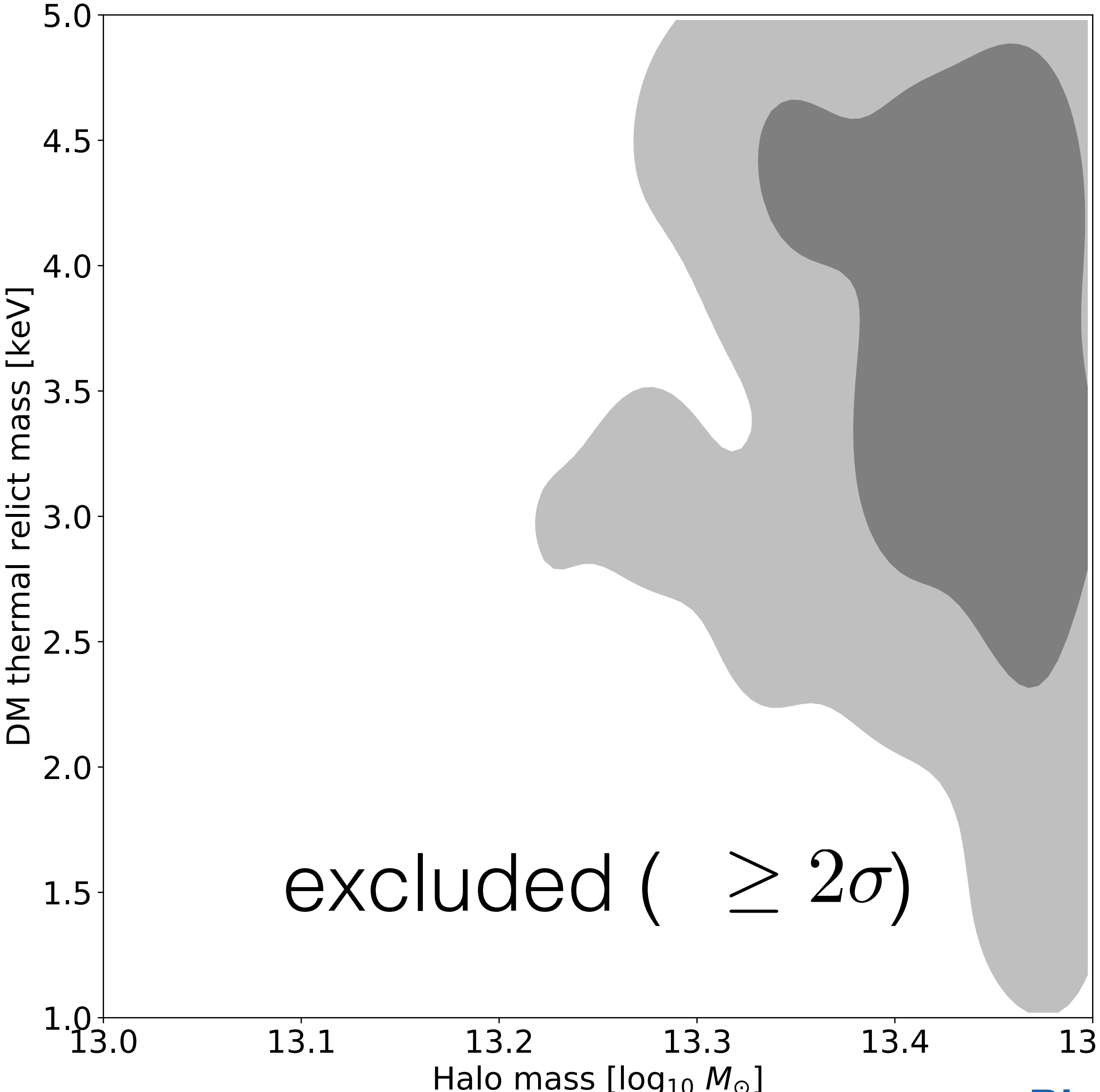
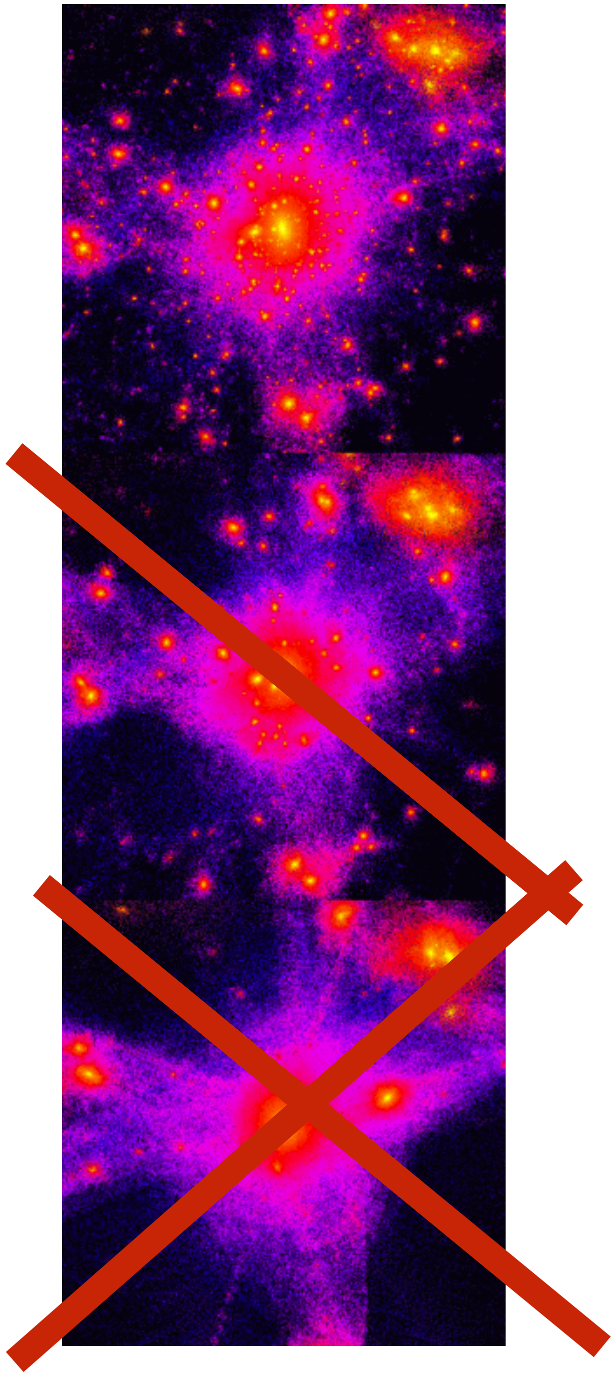
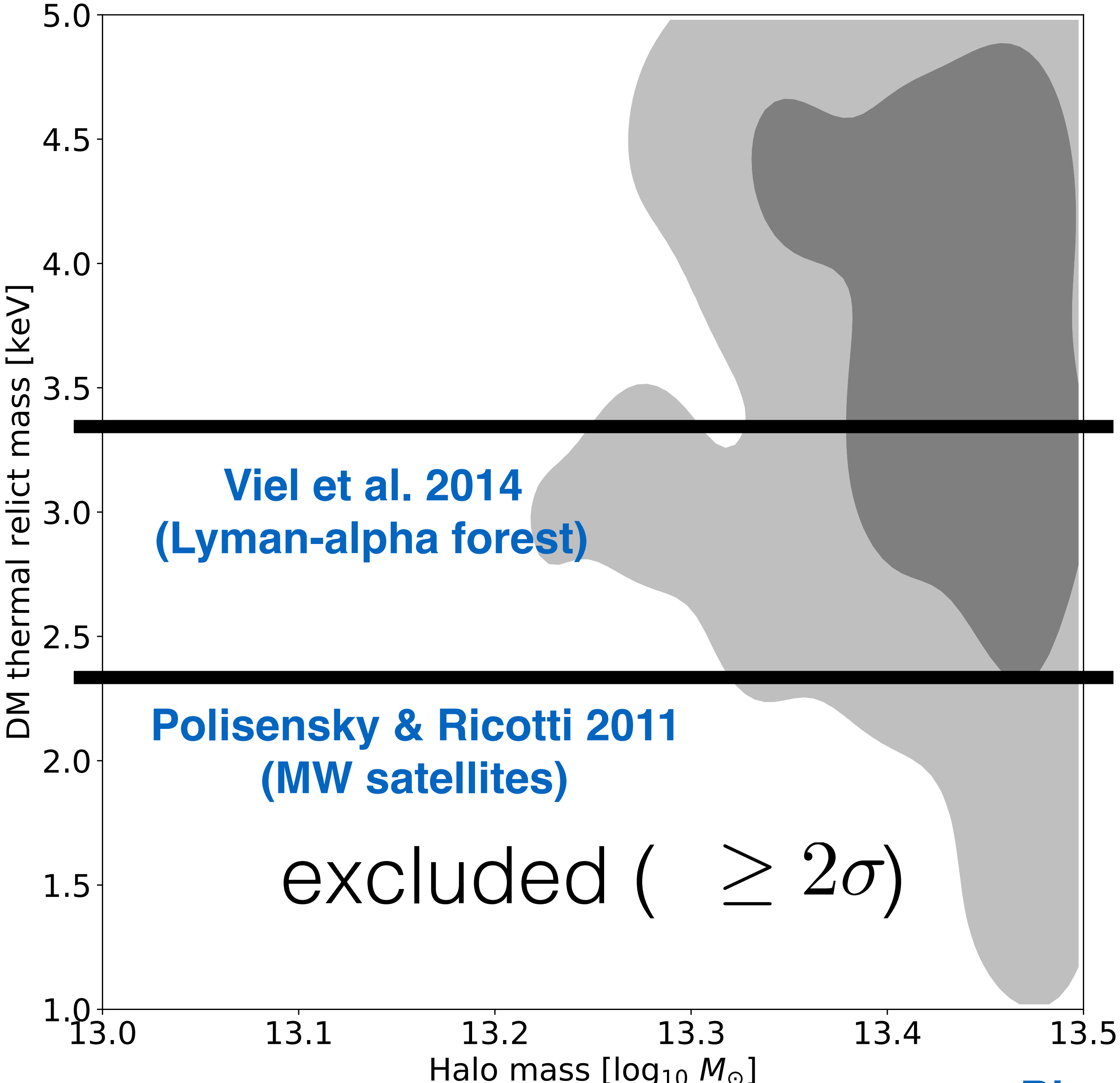




Birrer+ 2017

Dark Matter thermal relic mass constraints from lensing substructure

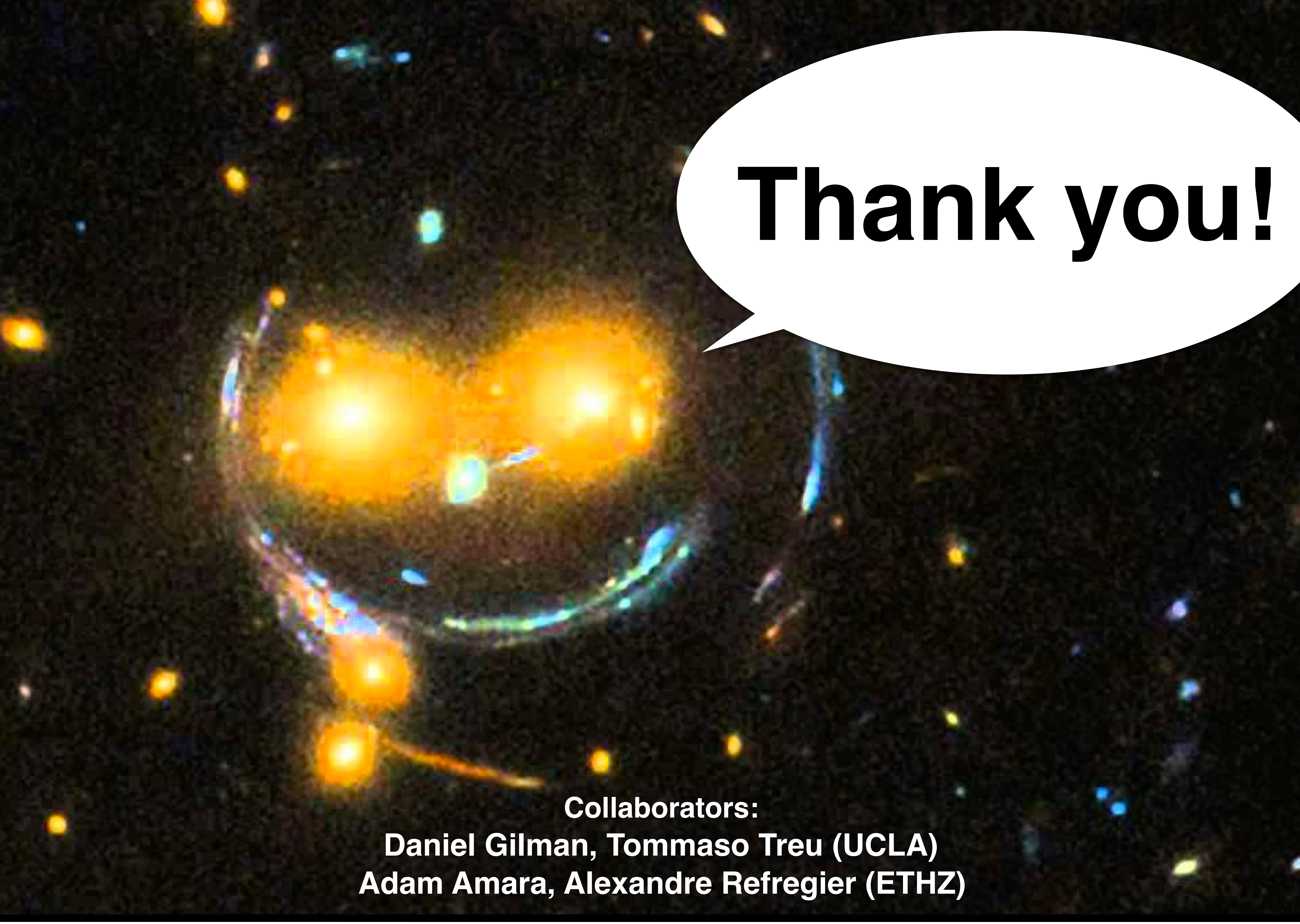




Birrer+ 2017

Summary

- Strong lensing is an unique probe to test different dark matter scenarios in the cosmological context
- Dark substructure has been directly detected down to 10^8-9 M_sol, statistical signal goes down to 10^6-7 M_sol (mass definition dependent)
- Statistical constraints based on one single lens excludes a thermal relic mass < 2 keV to 2 sigma confidence level
- Modelling and inference methods are in place. Extensions to other dark matter models in progress. Combined method 1+2 in progress.
- Sample of high quality HST data is vastly increasing, right now!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