# The shape of cluster-scale dark matter halos

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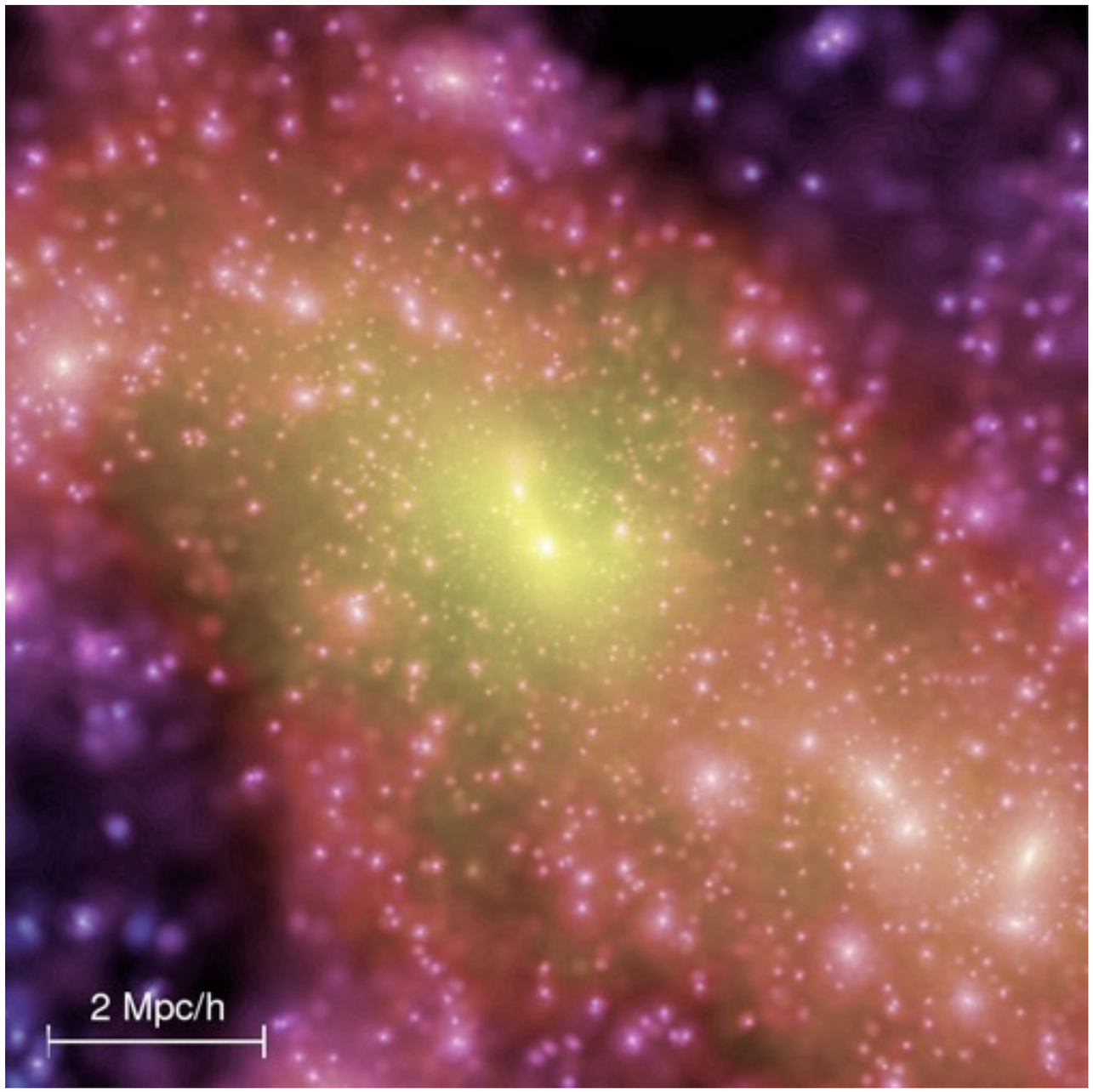
# Expected halo shape in ΛCDM

- Cuspy
  NFW radial profile
- Concentration
  more massive halos
  less concentrated
- Triaxial
  highly non-spherical
  with axis ratio ~1:2

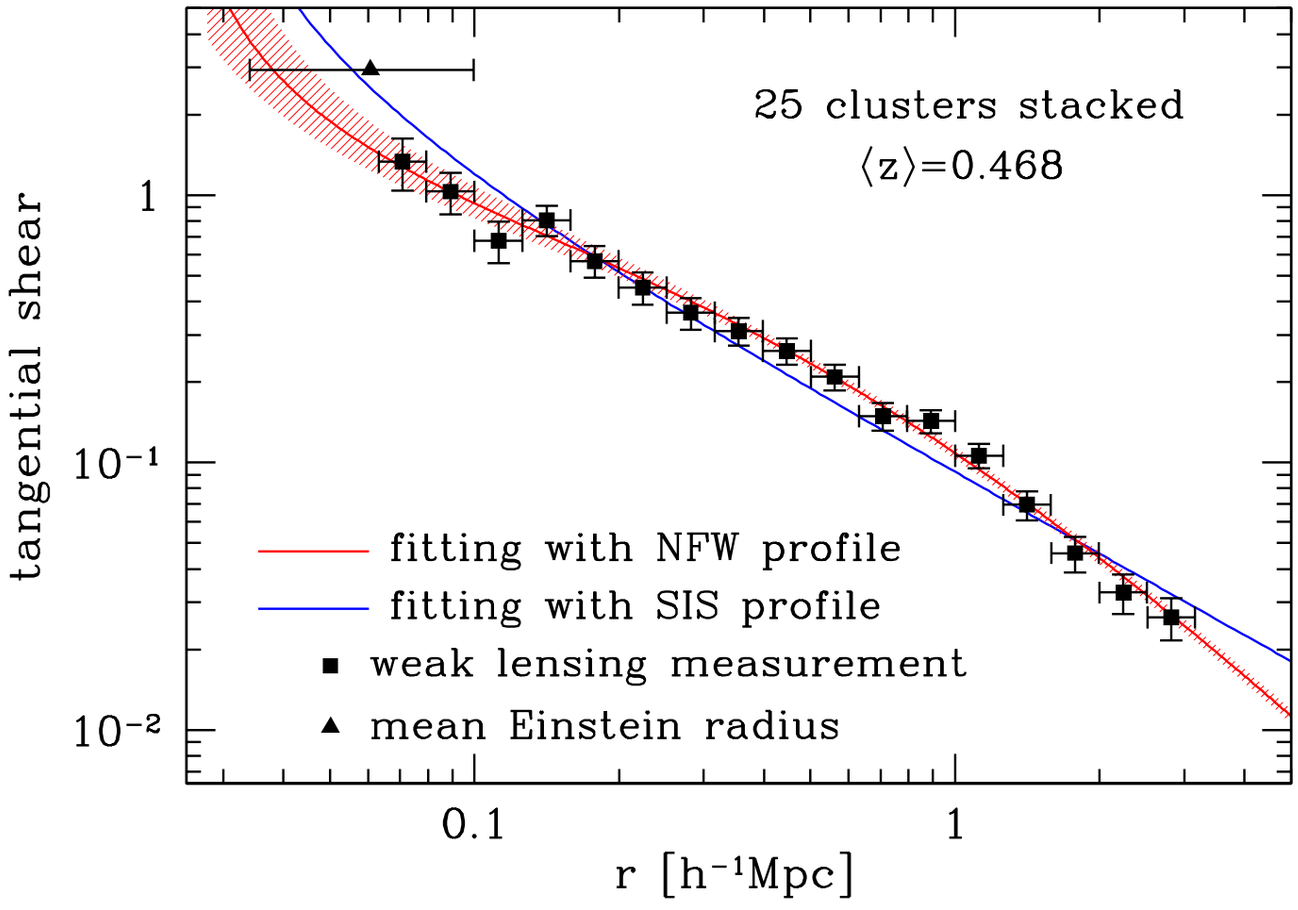



http://www.mpa-garching.mpg.de/galform/millennium/

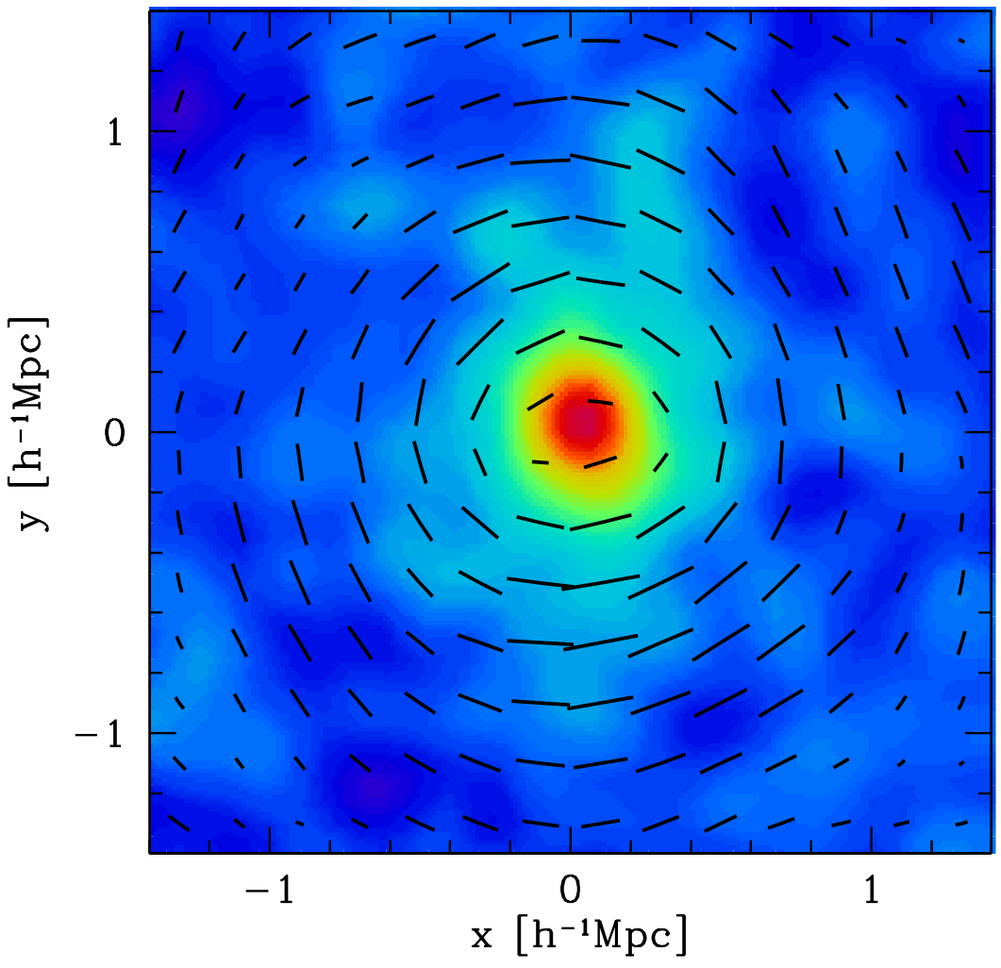
Oguri, Bayliss, Dahle, et al. MNRAS **420**(2012)3213

# Strong+weak lensing with SGAS

- Subaru/S-cam weak lensing analysis of 28 strong lensing clusters from Sloan Giant Arcs Survey
  [also talks by Keren Sharon, Matt Bayliss, Mike Gladders]




- stacked radial profile consistent with NFW
  (also Umetsu+11, Newman+13, Okabe+13)




- stacked 2D shape
  $\langle e \rangle = 0.47 \pm 0.06$

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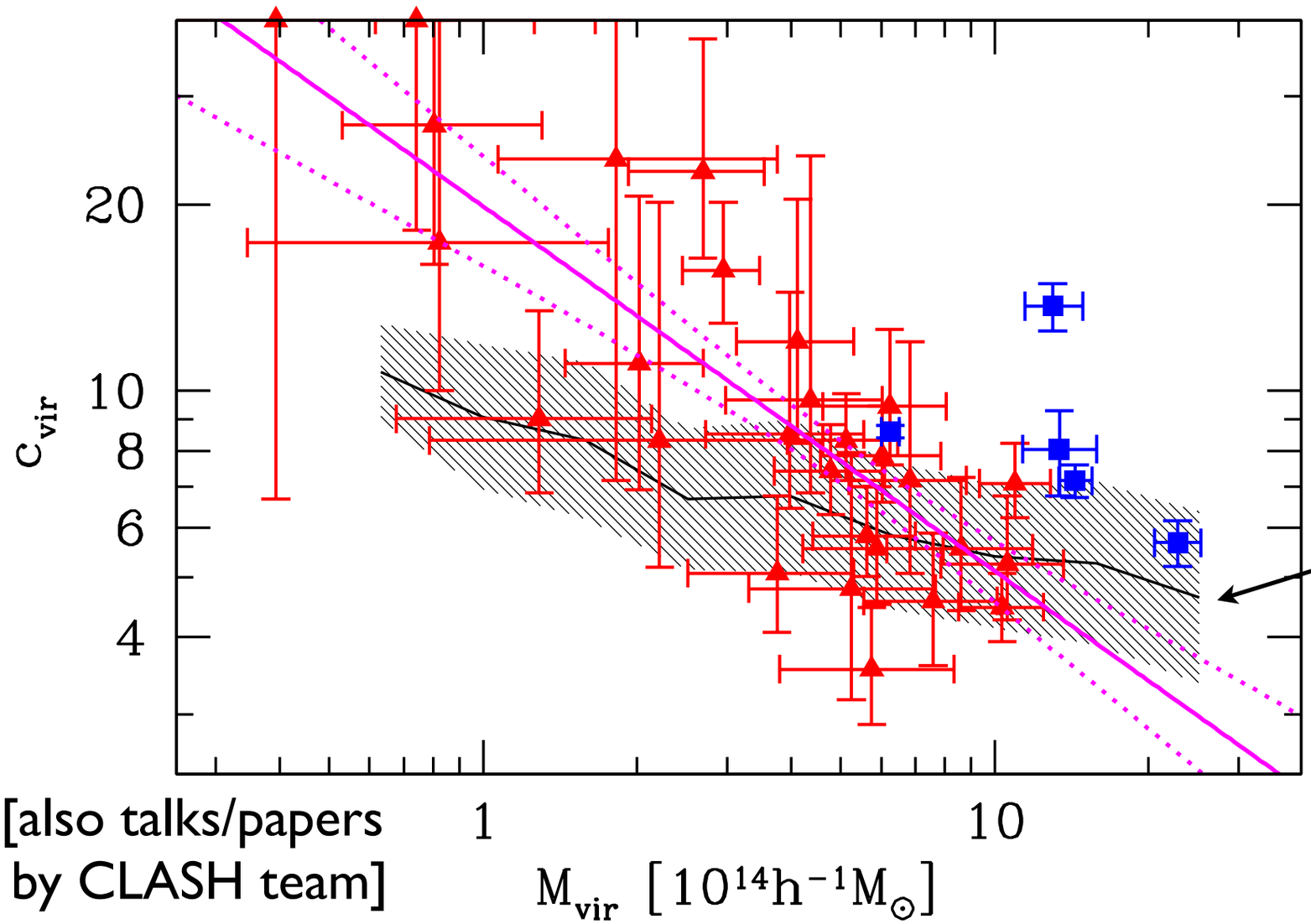
# Mass-concentration relation




our sample

from literature
(Umetsu+11; Zitrin+11)

ΛCDM prediction w/ triaxiality and lensing ~~bias~~
selection effect

[also talks/papers by CLASH team]

- consistent with ΛCDM for high-mass clusters
- excess at low-mass due to baryon cooling and central galaxy (e.g., Fedeli 2012)

# Measured halo shape

- shape of cluster-scale halos measured with gravitational lensing on average agrees very well with ΛCDM model prediction
- however, sometimes the structure of clusters is much more complicated than this simple picture

# SDSS J1029+2623 ("the Hidden Fortress")

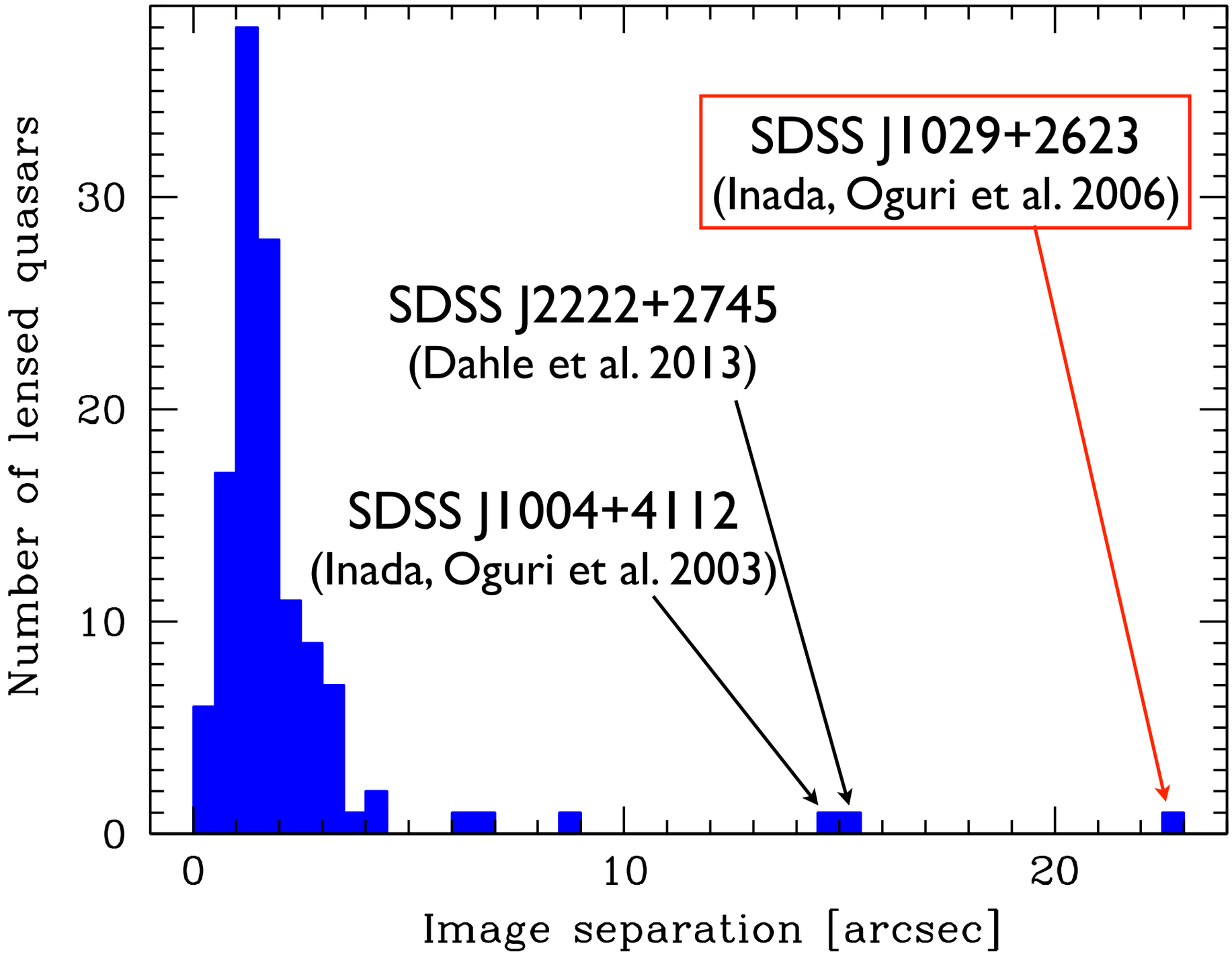
- largest-separation ($\theta$=22.5″) lensed quasar among ~150 lensed quasars known

  (Inada+2006; Oguri+2008)

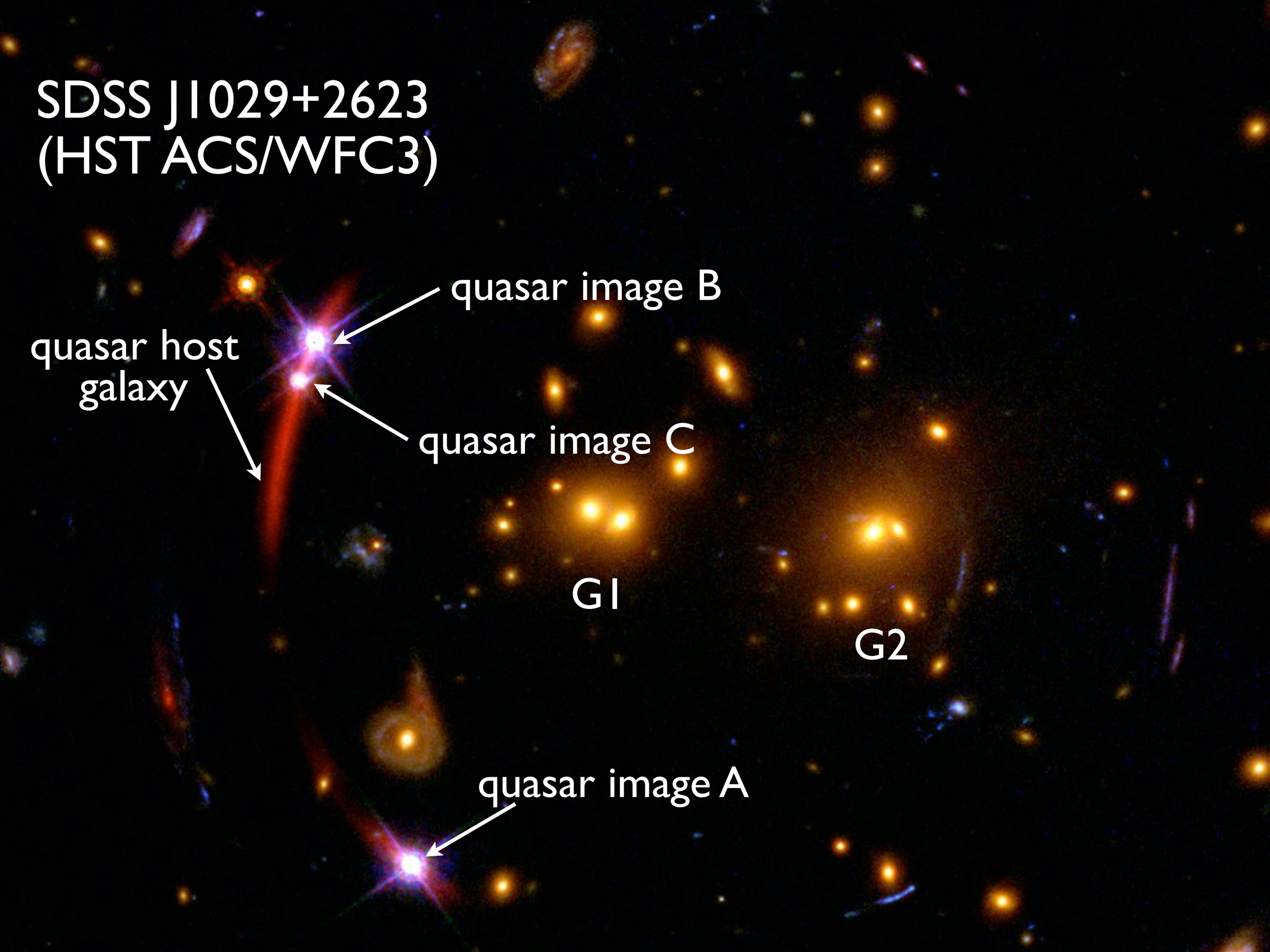
- rare example of three images "naked cusp" configuration, which has been predicted to be common among large-separation lenses

  (Oguri & Keeton 2004)

# Image separations of quasar lenses

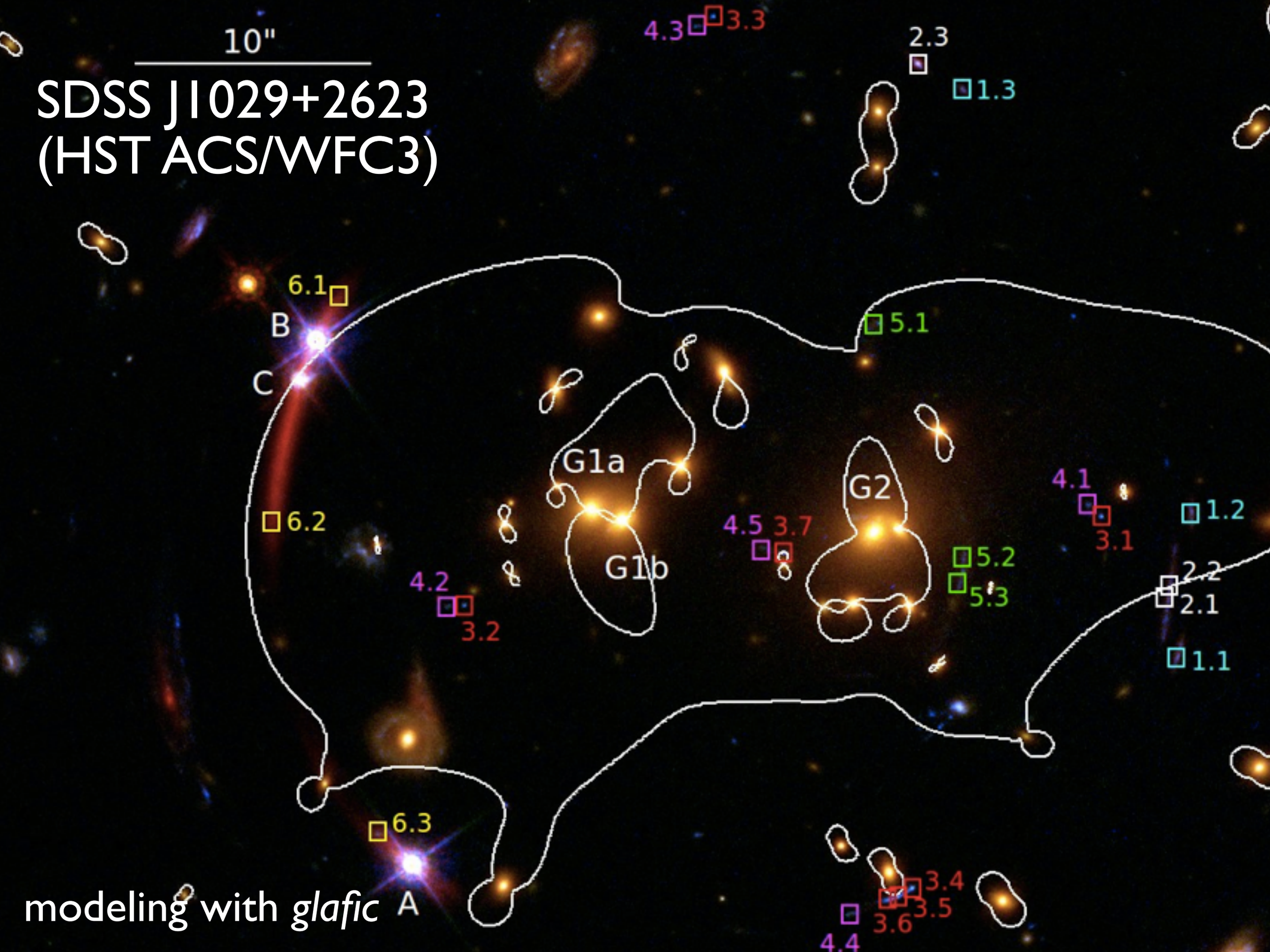


SDSS J1029+2623
(HST ACS/WFC3)


SDSS J1029+2623
(HST ACS/WFC3)
quasar image B
quasar host
galaxy
quasar image C
G1
G2
quasar image A

10"

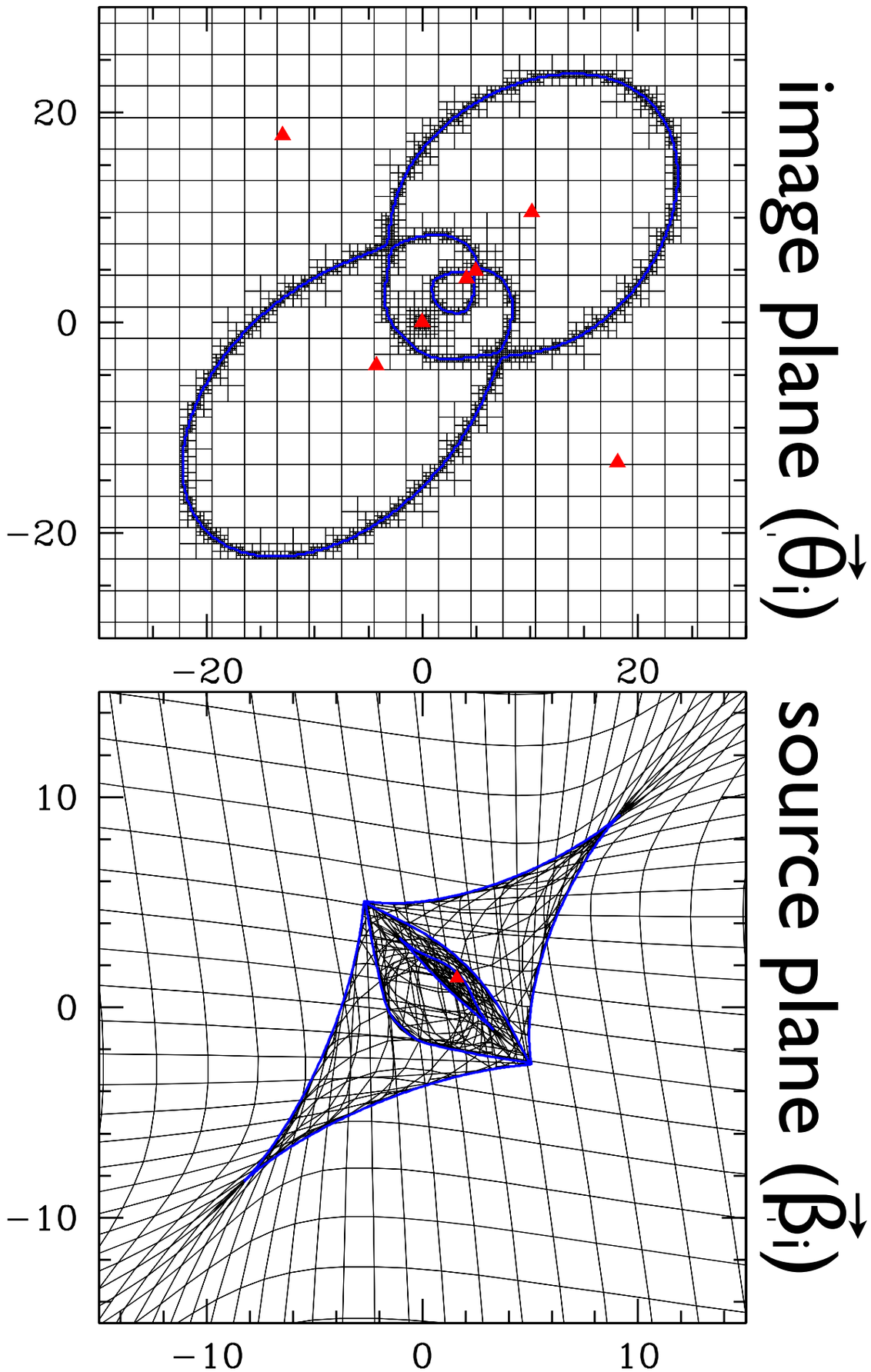
# SDSS J1029+2623 (HST ACS/WFC3)




modeling with *glafic*

http://www.slac.stanford.edu/~oguri/glafic/

# *glafic*

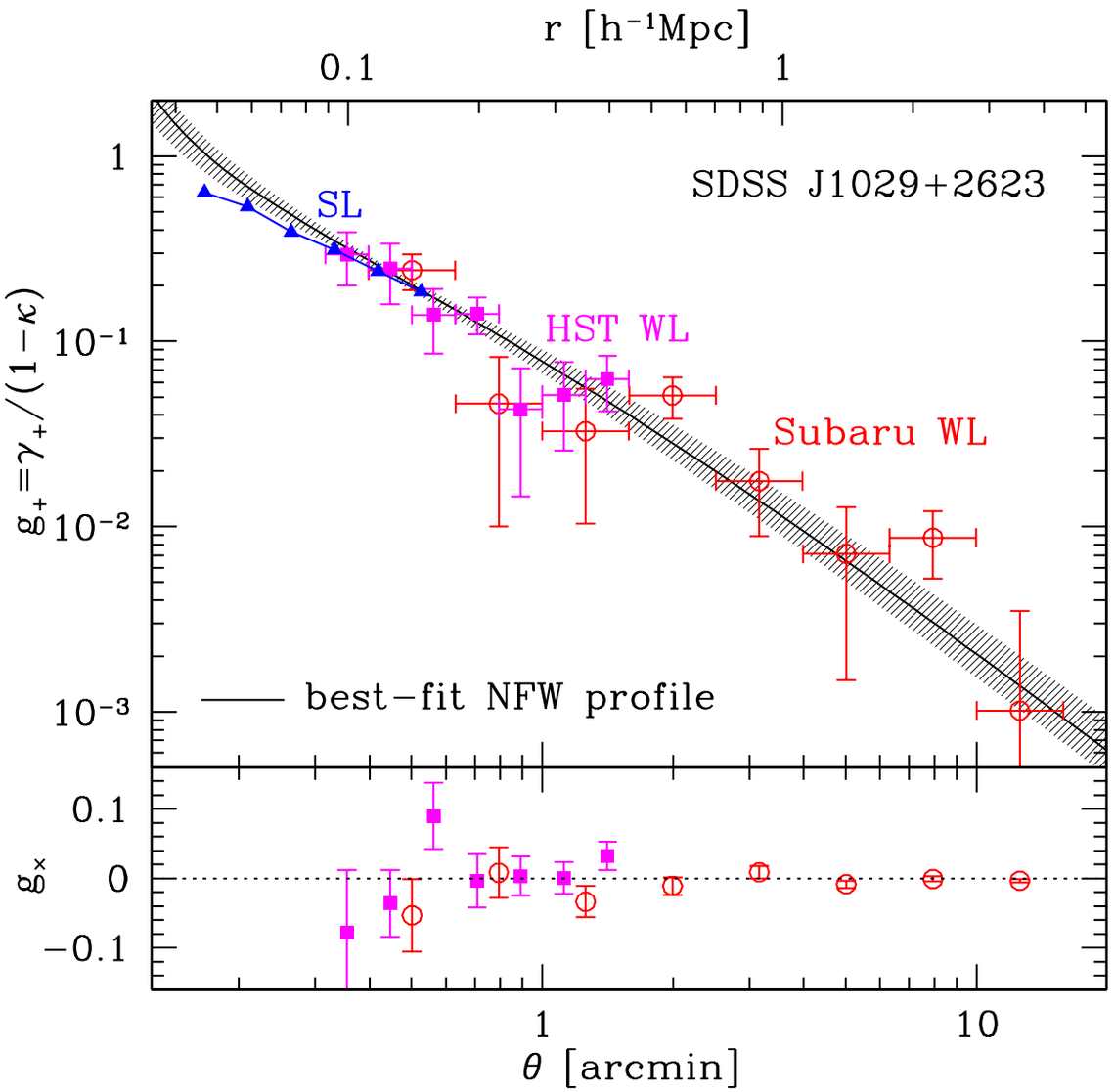


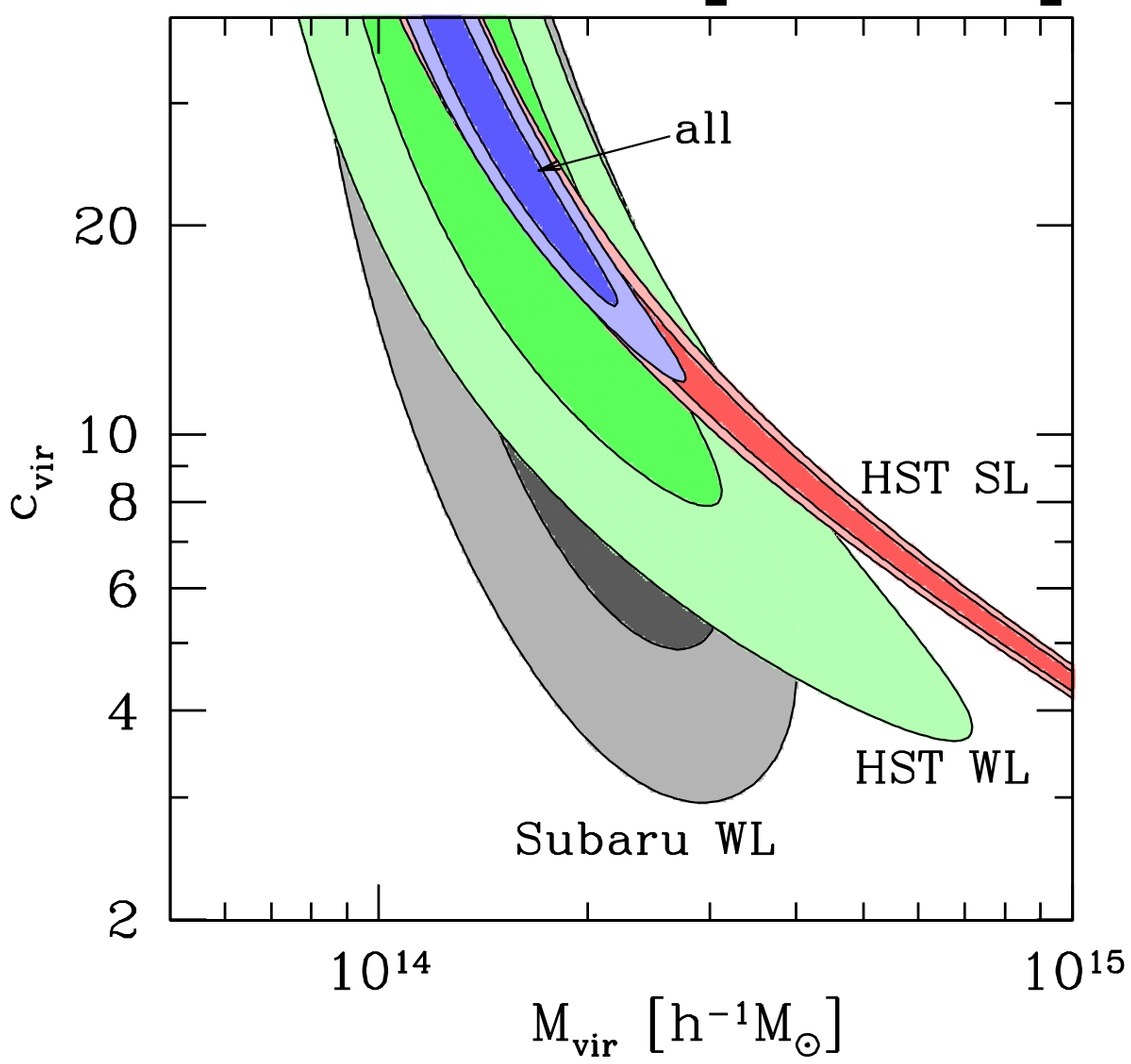

- public software for lensing analysis
- adaptive grid for efficient lens equation solving
- efficient mass modeling for observed strong lens systems
- feel free to contact me if you are interested!

Oguri, Schrabback, Jullo, et al. MNRAS **429**(2013)482

# Combined lensing analysis

[$z_{cl}$= 0.58]




- accurate and robust mass profile from three lensing observations, revealing its steep profile ($c_{vir}$~20)

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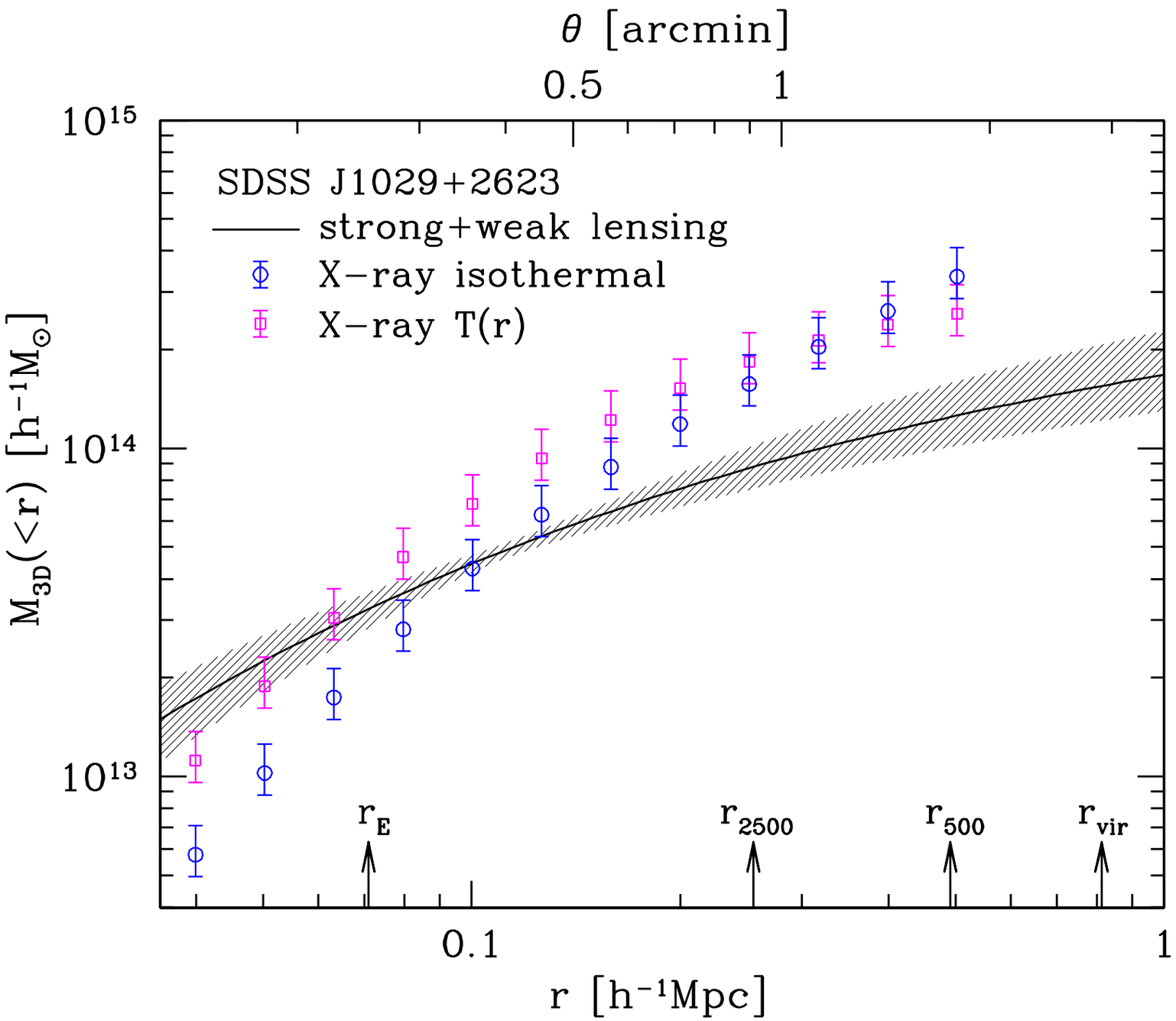
# Lensing/X-ray mass discrepancy

- Compare with X-ray mass from Chandra

- $M_X/M_{lens}$~2-3

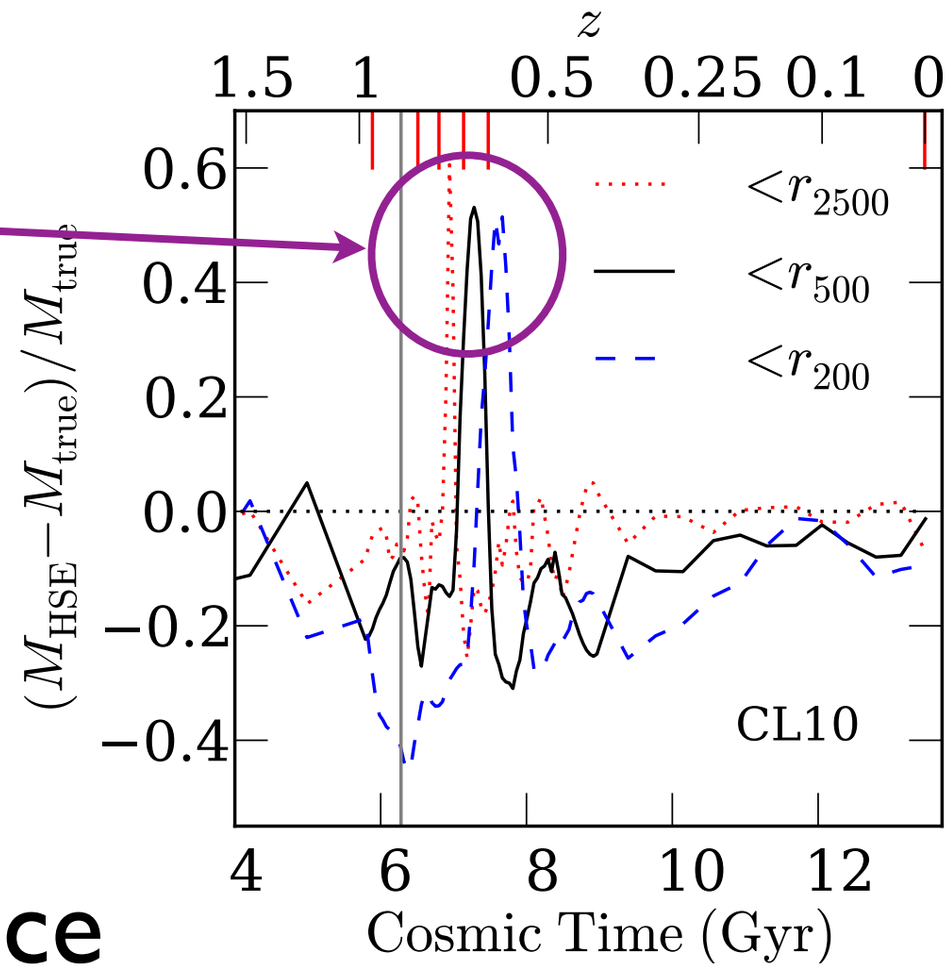
- hard to explain by non-thermal pressure, halo triaxiality, ...

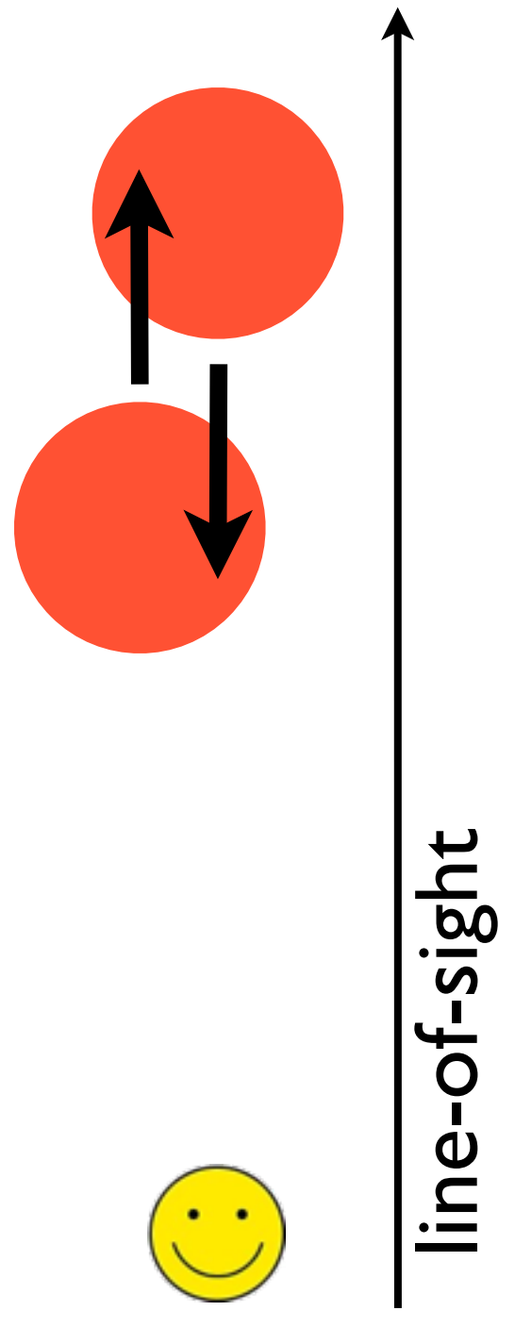


# Suggested solution: Merger

boost of X-ray signals
~1Gyr after merger

Simulation by
Nelson et al. (2012)




- merger can enhance X-ray temperature and luminosity, as a result X-ray derived mass is biased high



- line-of-sight merger can also explain the high $c_{vir}$ (King & Corless 2007)

# Summary

- average dark matter distribution in a large sample of galaxy clusters measured with gravitational lensing is in excellent agreement with ΛCDM prediction

- on the other hand, sometimes the structure of clusters is highly complicated, showing a huge (a factor of 2-3) discrepancy between X-ray and lensing mass measurements, presumably caused by merger

- understanding these peculiar "outliers" will be important for cosmology