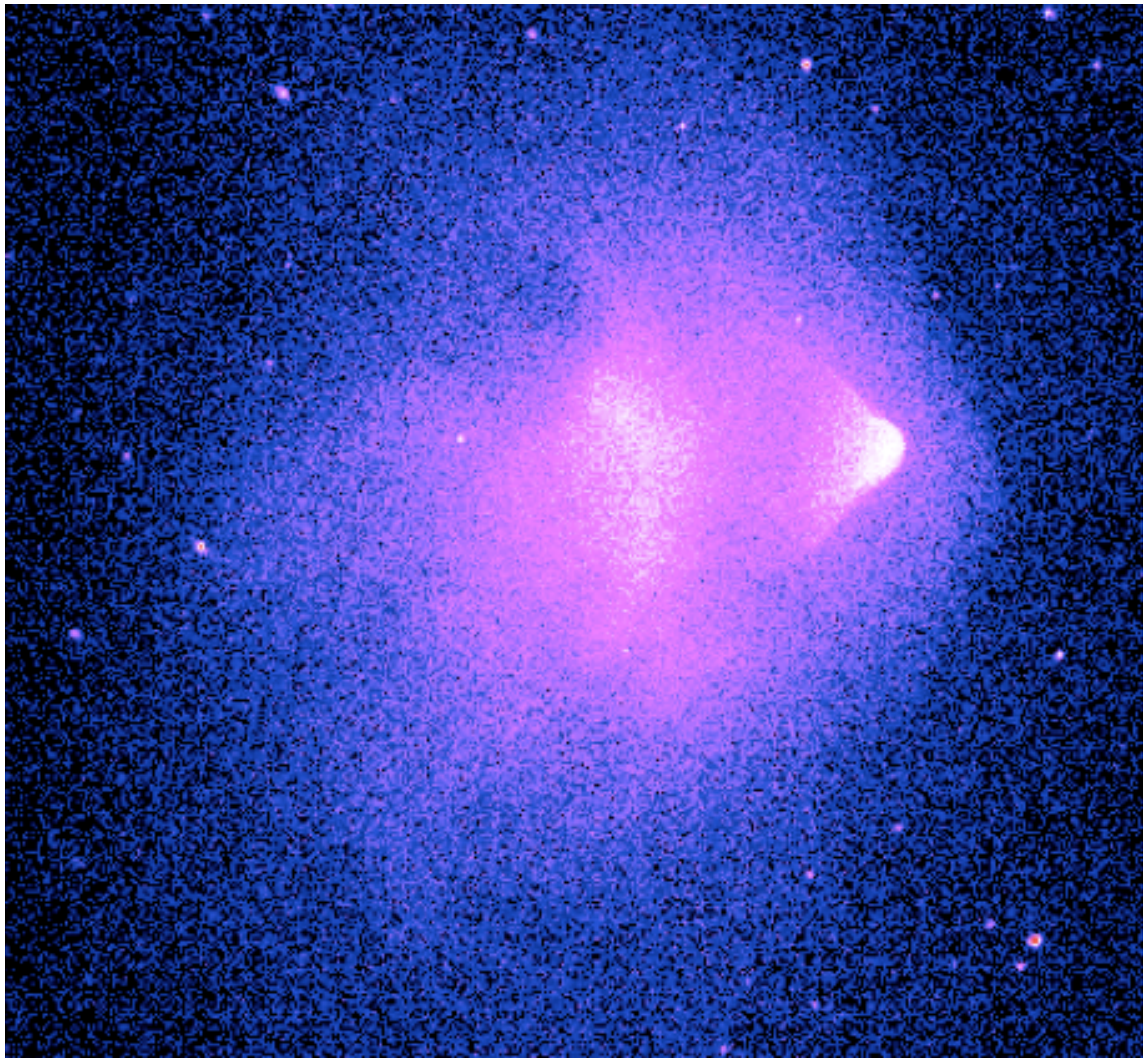
Simulating galaxy populations within clusters



(Image: M. Markevitch)

Brian O'Shea
Michigan State University

With: Brian Crosby, Mark Voit (MSU)

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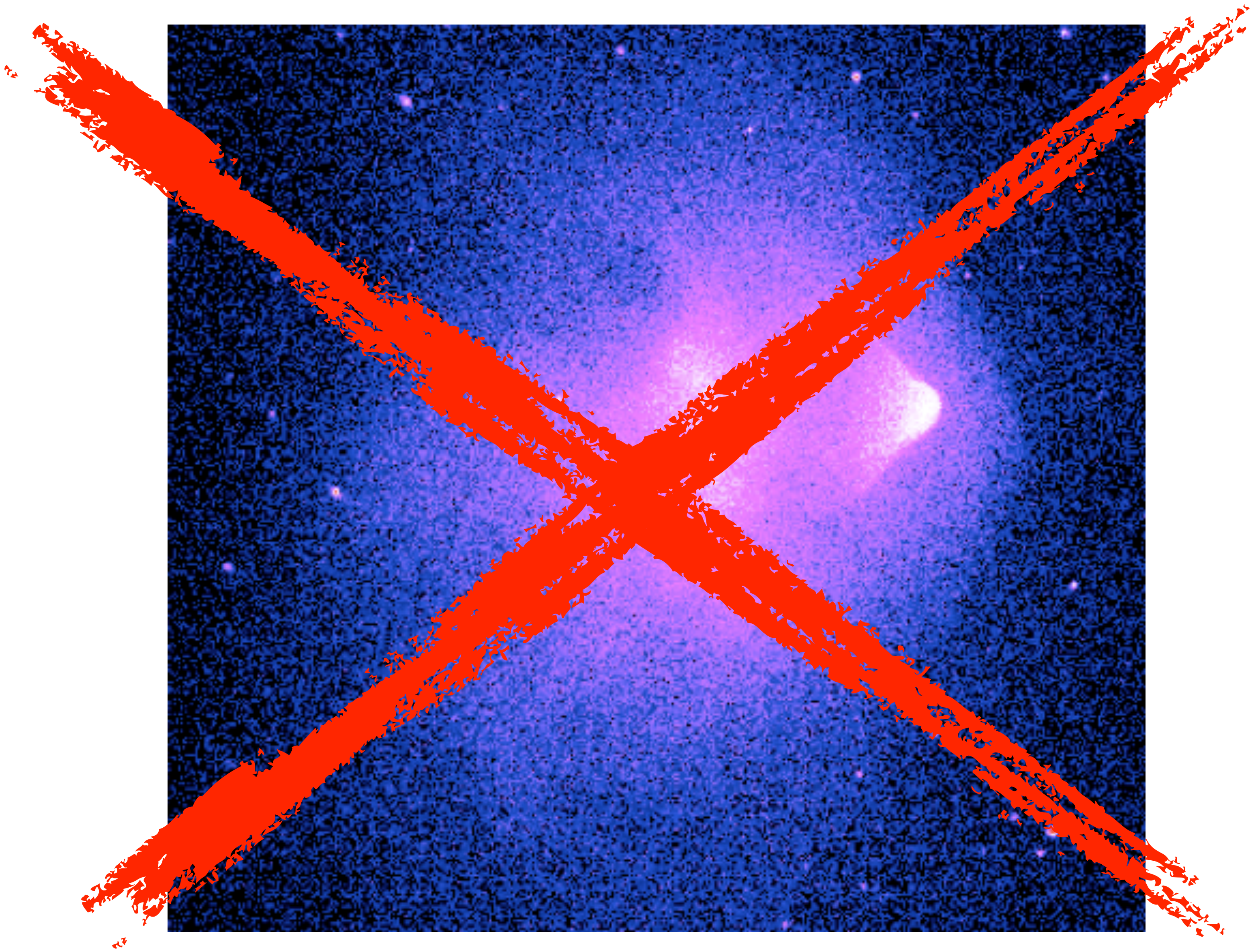

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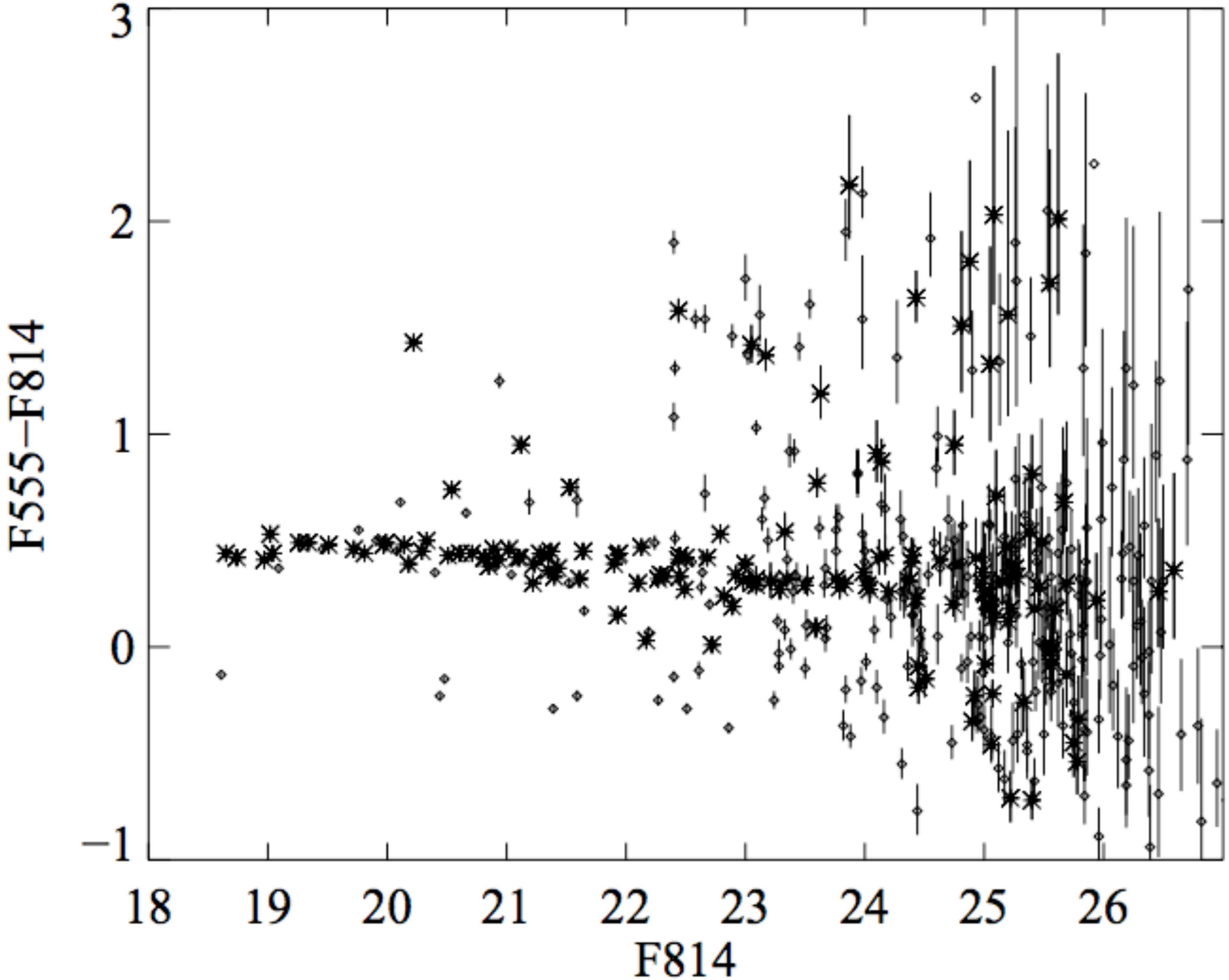
MACS 1206 (Image c/o CLASH collaboration)

Cluster red sequence (Abell 2390)

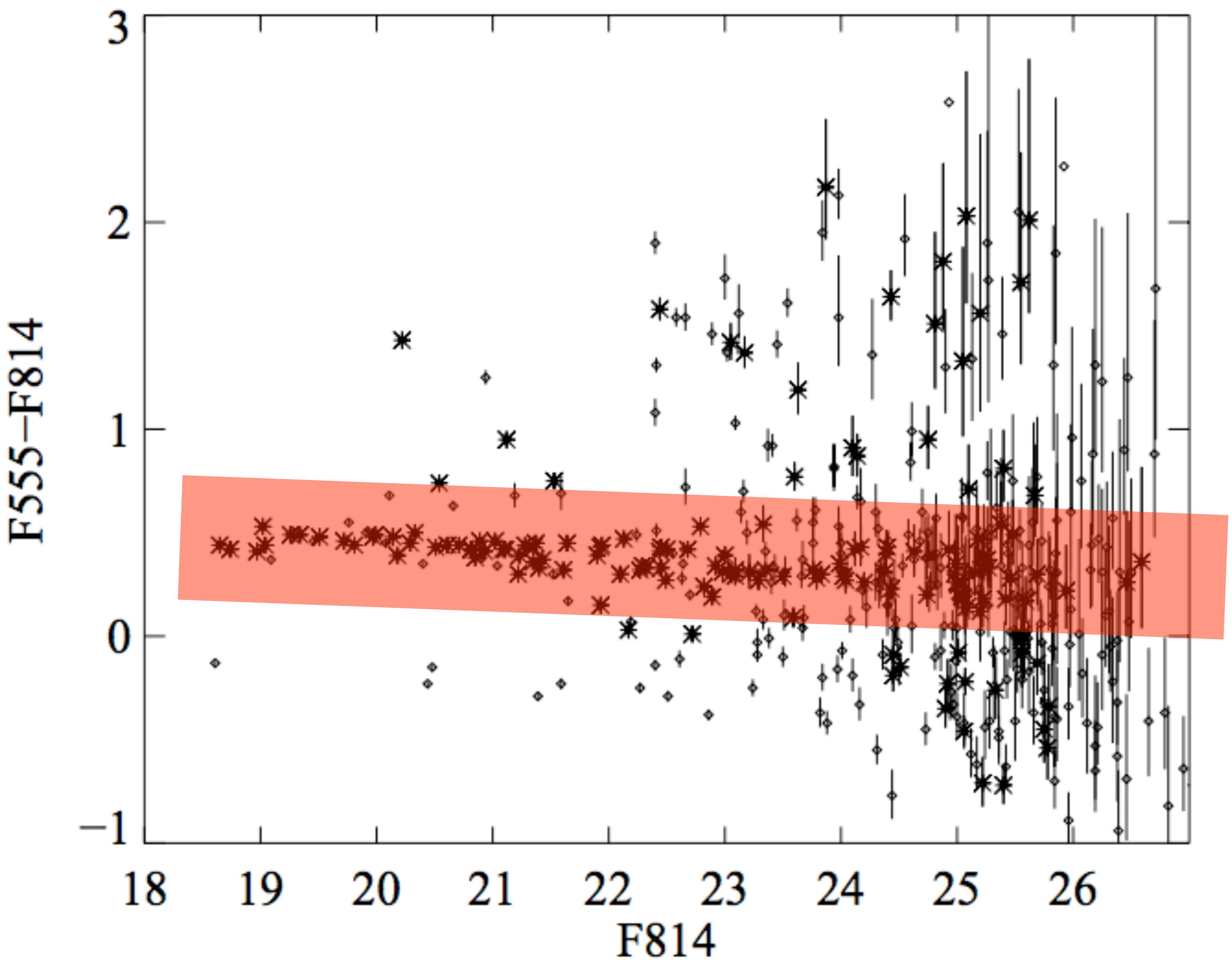


Redder

Brighter

Gladders & Yee 2000

Cluster red sequence (Abell 2390)



Redder

Brighter

Gladders & Yee 2000

Who cares about the galaxies?

- Source of energy, magnetic fields, metals, AGN jets
- Clusters are an extreme environment for galaxy formation + evolution: useful as an edge case!
- Some questions one can ask about cluster galaxies:
  - Why does the red sequence evolve?
  - Why do all BCGs have basically the same stellar mass?
  - Can we explain radial dependence of galaxy colors?
  - Why do more massive clusters have (proportionally) fewer stars?

Simulating MW-like field galaxies has become "easy"

- Key ingredients:
  - good enough mass resolution ($M_{dm} \sim 10^6$ $M_{\odot}$) and spatial resolution ($\Delta x \sim 100$ pc)
  - metal-dependent radiative cooling
  - sensible star formation + feedback prescriptions
  - AGN feedback*

Simulating MW-like field galaxies has become "easy"

- Examples:
  - OWLS, EAGLE (Schaye et al. - Gadget)
  - FIRE (Hopkins et al. - Gadget)
  - Illustris (Vogelsberger et al. - AREPO)
  - No cool name #1 (Agertz et al. - RAMSES)
  - No cool name #2 (Hummels & Bryan - Enzo)
  - No cool name #3 (O'Shea+, in prep. - Enzo)

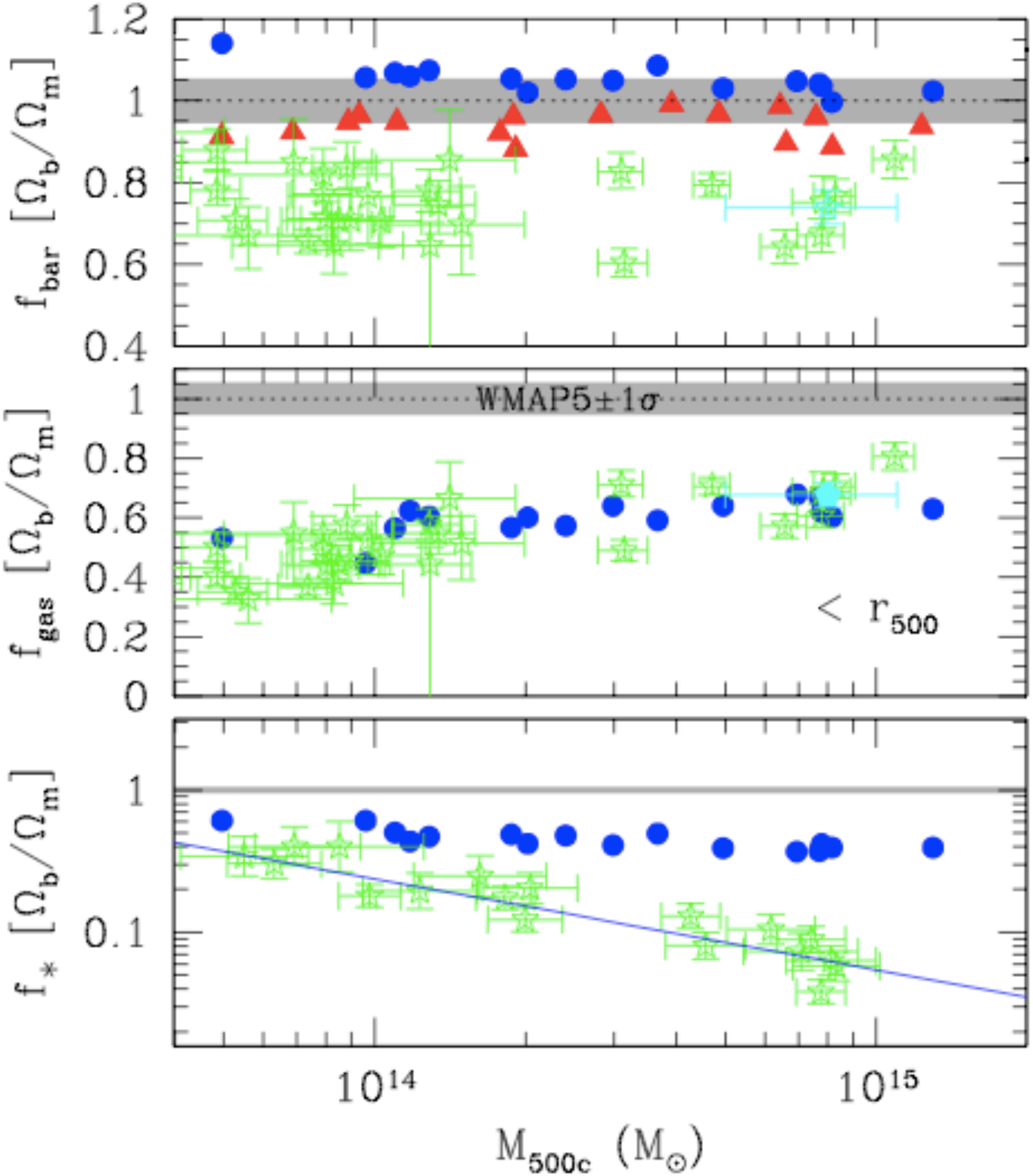
Simulating cluster galaxies is still very hard

- Clusters are much bigger! For 10^{15} $M_\odot$ cluster at z=0 (R_{vir} ~ 2 Mpc), need:
  - O(10^9) dm particles
  - $2R_{vir}/\Delta x \sim 4 \times 10^6$ spatial dynamic range
  - Plus all of the same physics! (And maybe more: cosmic rays, MHD, ...)

Simulating cluster galaxies is still very hard

- Cluste … M$_\odot$ clust… eed:
  - O(…
  - 2R… amic ran…
  - Plu… (And may… HD, …)

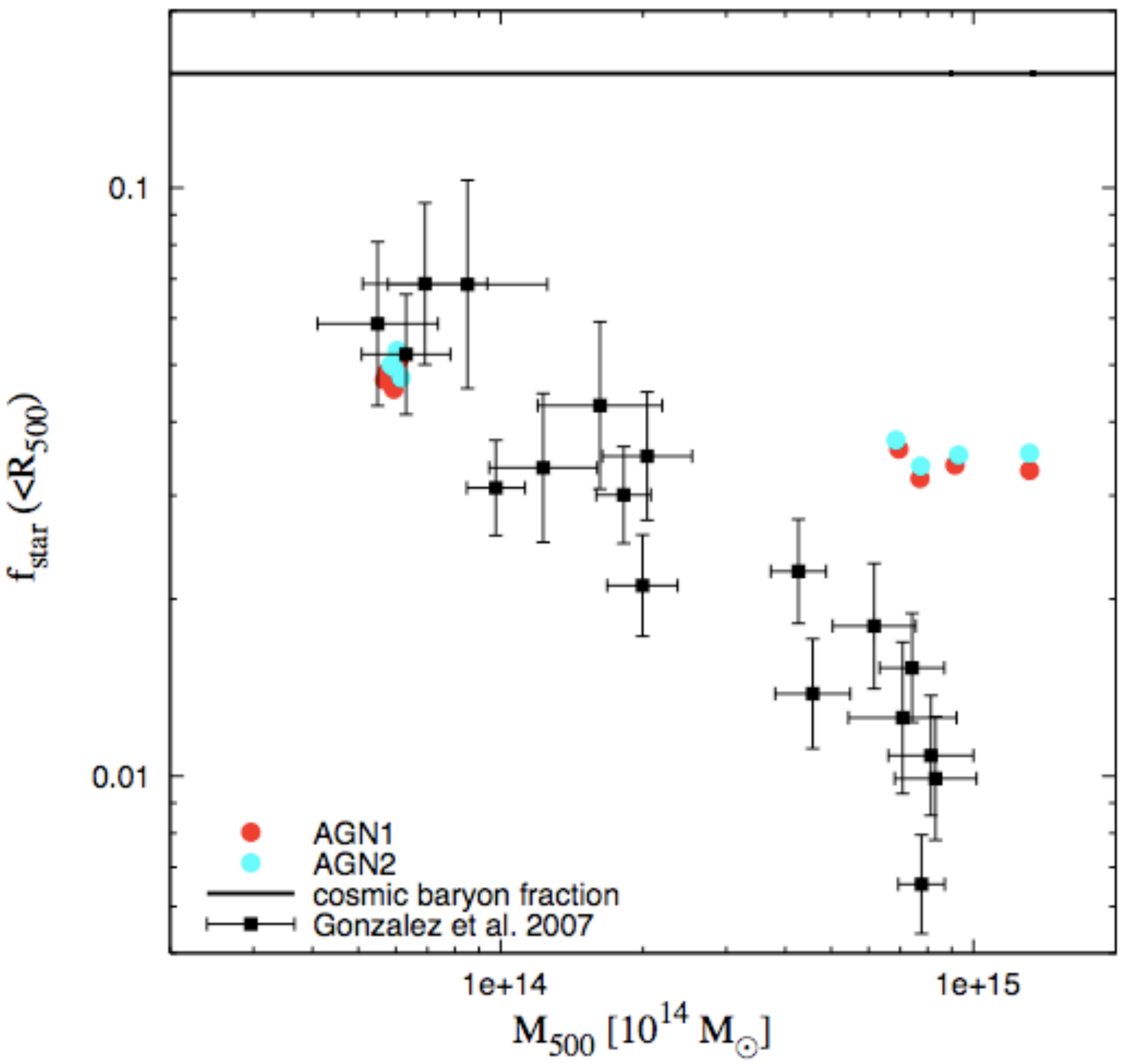
Kravtsov et al. 2009



Observations

Simulations:
Star formation + feedback
Non-radiative

Fabjan et al. 2010



Fundamental problem:

We currently can't both resolve the galaxies' ISM and also finish our simulations in a graduate student lifetime

Proposed solution #1:
Wait for Moore's Law to bail us out!

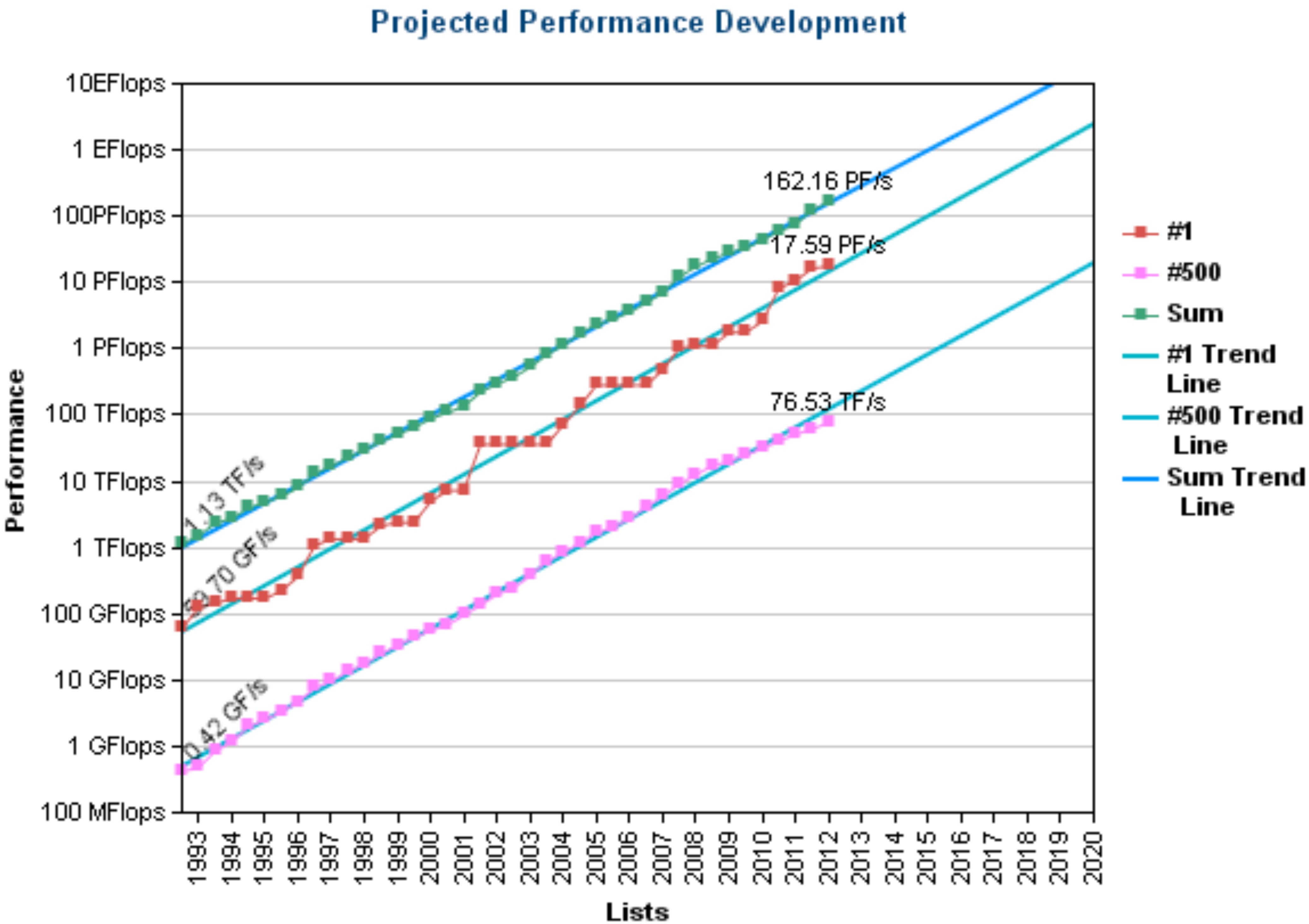


Image: top500.org

(Hey, it worked for N-body simulations...)

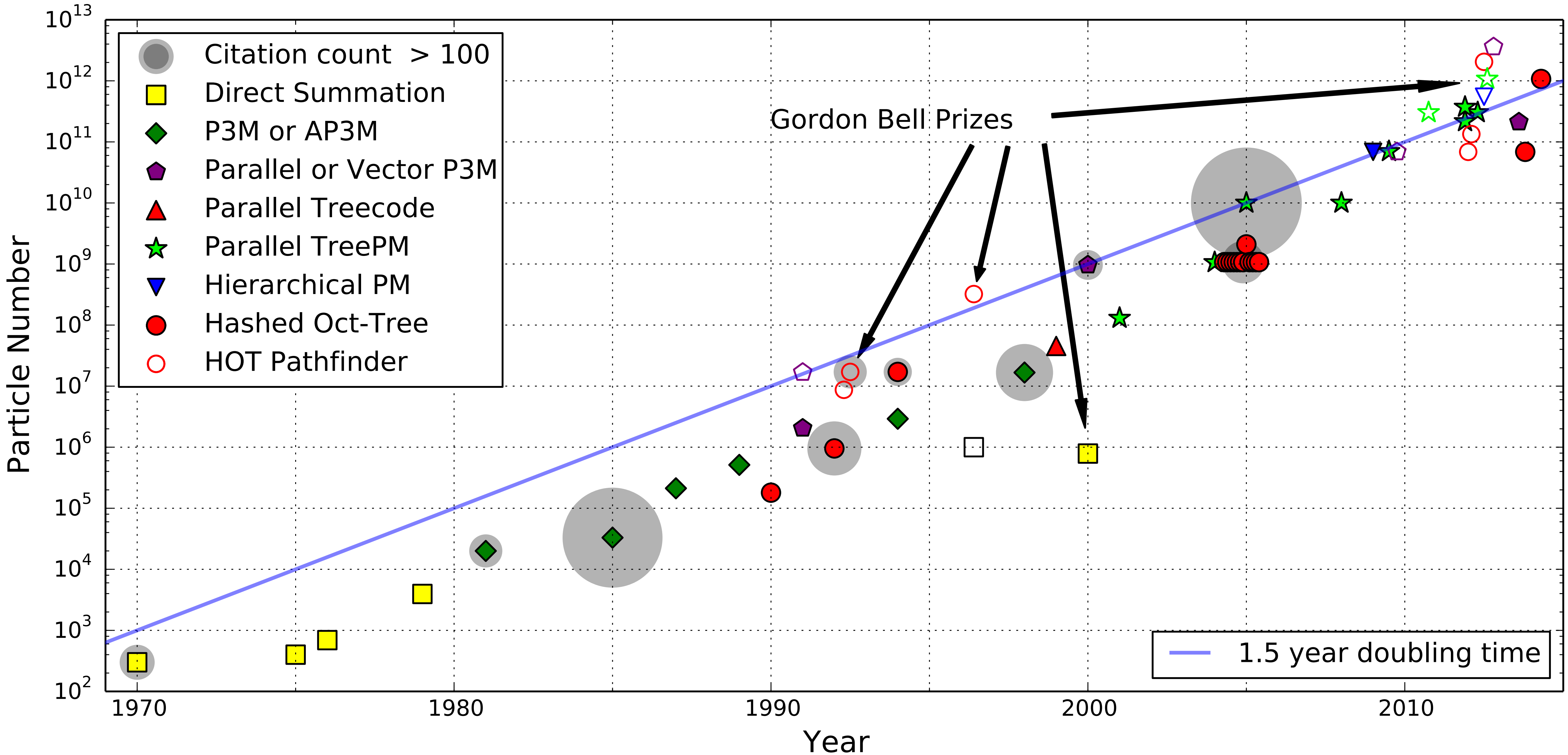
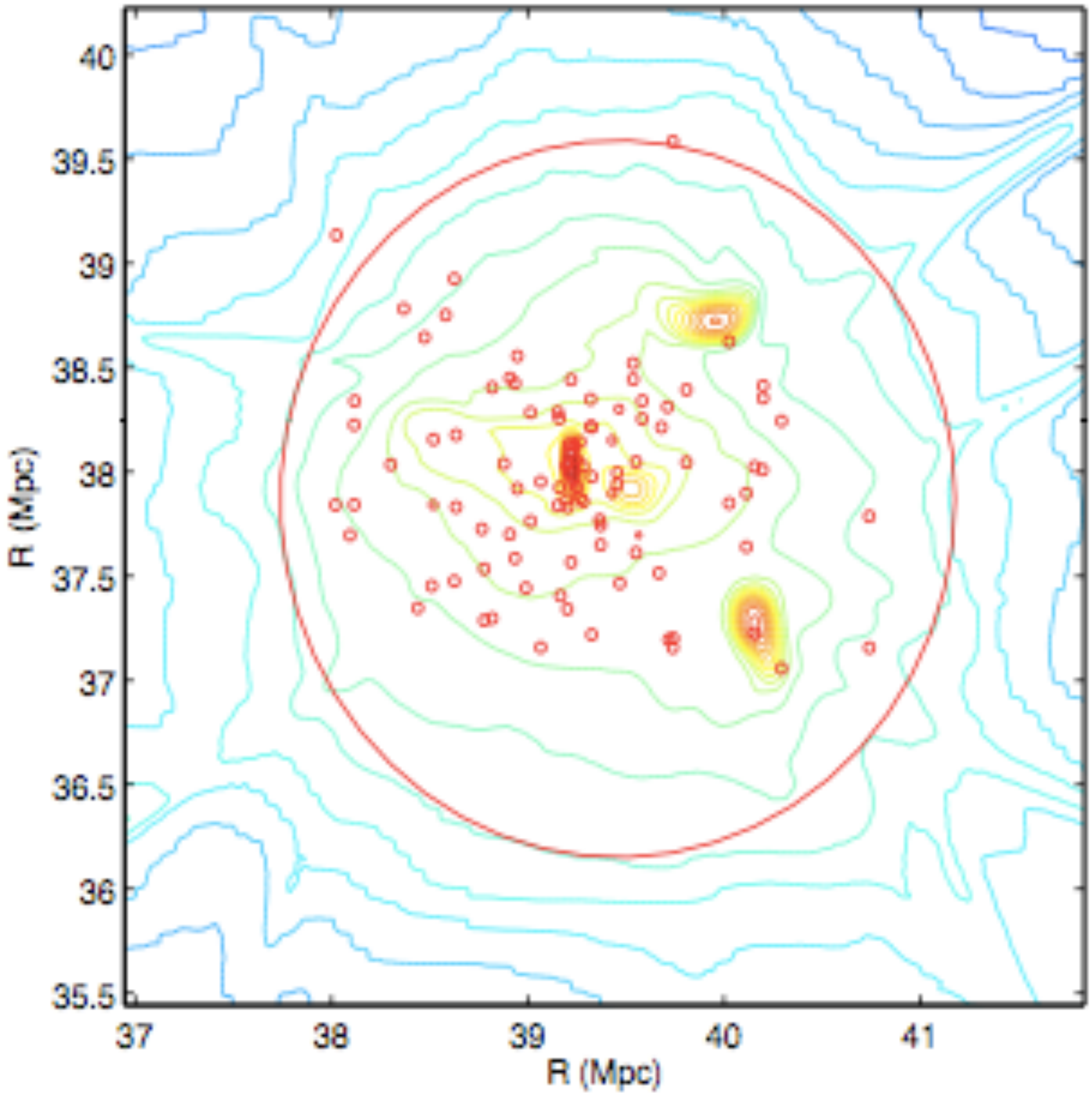


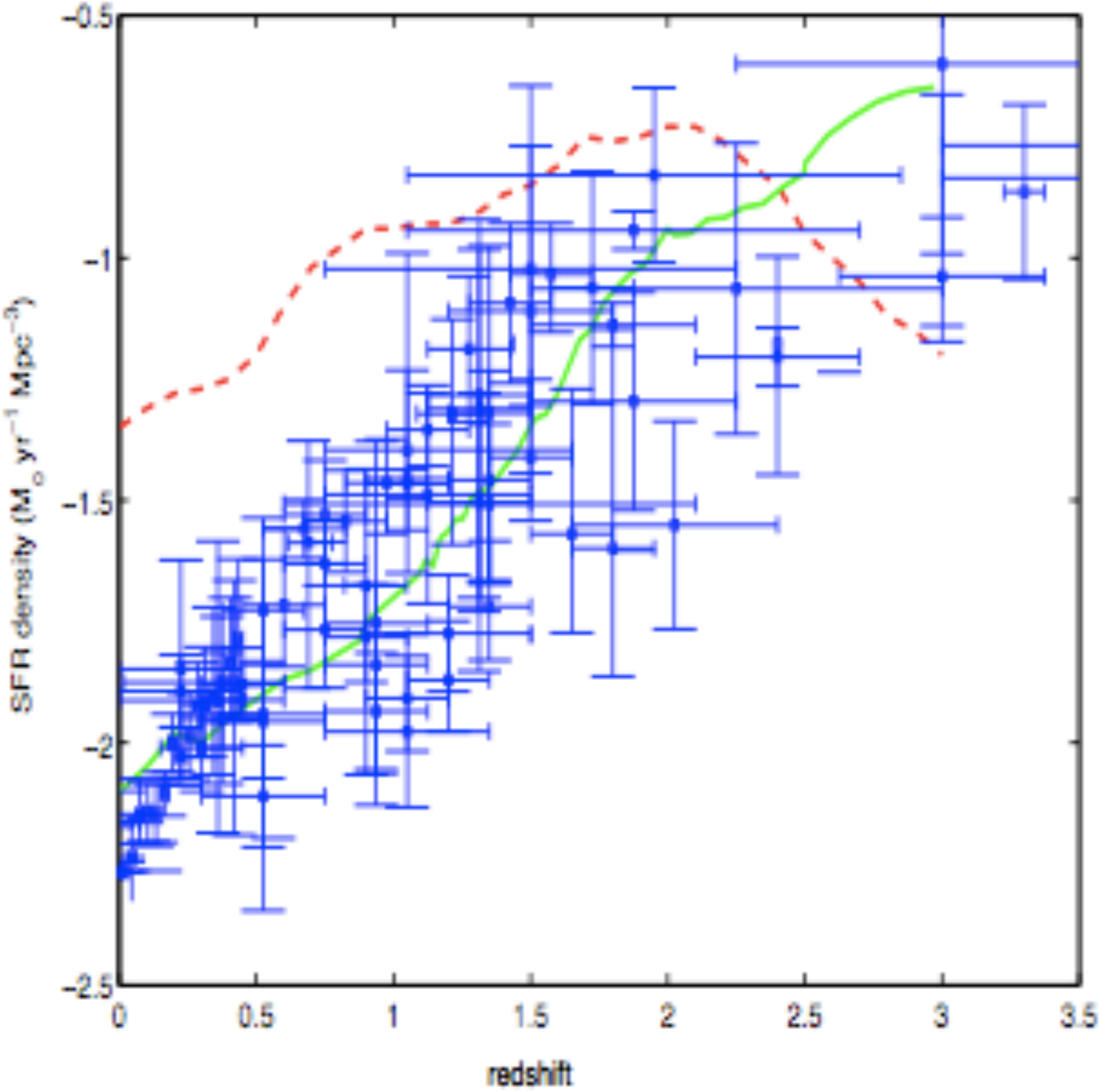
Image: Mike Warren (LANL)

Proposed solution #2: try something (somewhat) new - "galaxy particles" instead of "star particles" in hydrodynamic simulations

- Move abstraction up a level: stars→galaxies
- Use semi-analytic models for galaxy internal behavior and interaction with ICM (c.f. Galform - Bower et al., Galacticus - Benson et al.)



Arieli et al.
2010



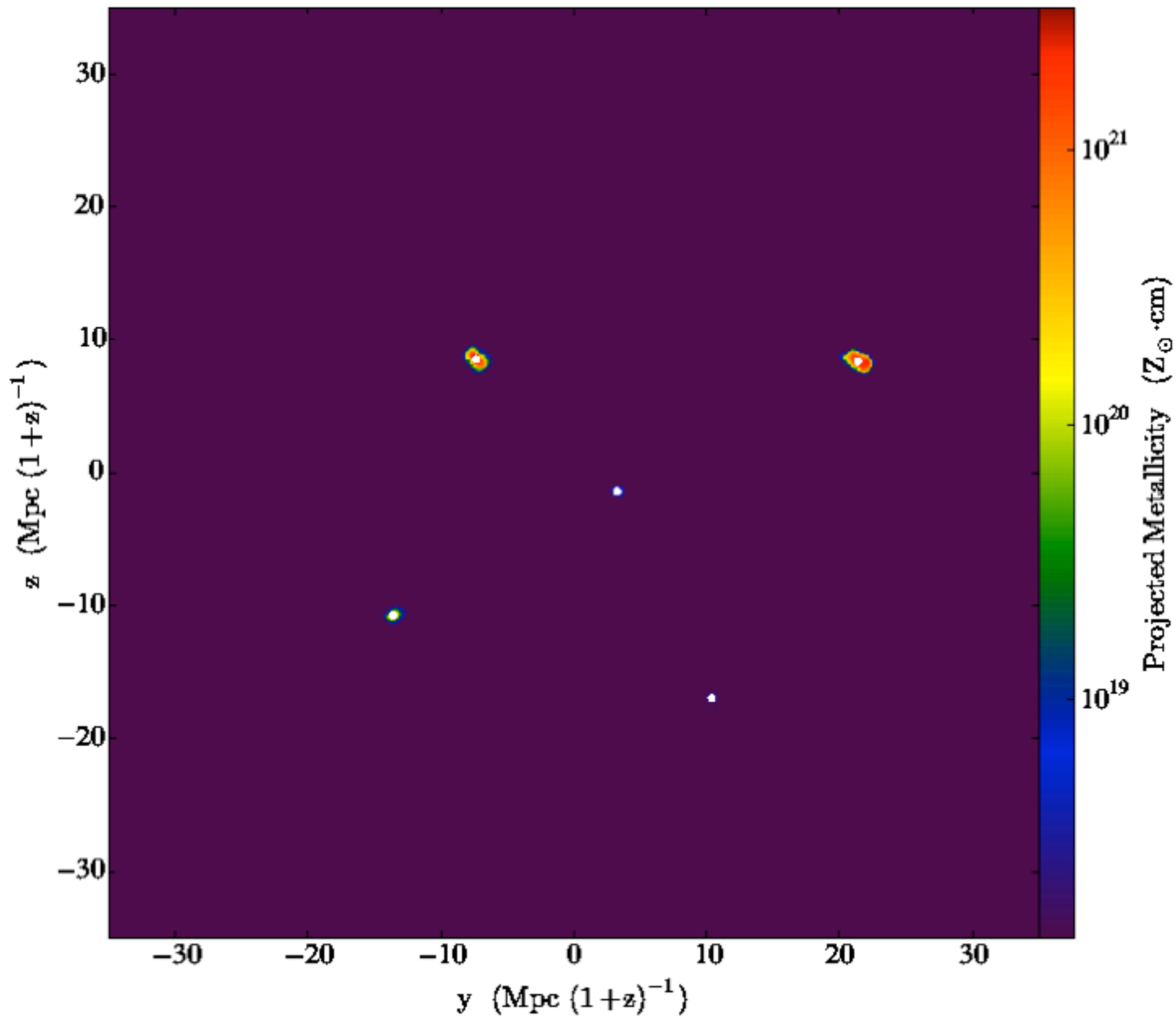
Arieli et al. 2010

Hopkins & Beacom (2006)

Galaxy particles

Standard star formation + feedback

Test simulation (low resolution)



Upsides

- Needs less resolution: less costly or larger calculations! (More clusters for your CPU-hour)
- Greater control over internal galaxy behavior, galaxy/galaxy, galaxy/IGM interactions
- Can trace galaxy histories within clusters and re-simulate just the galaxies (within limits) - useful for exploring model parameter space for galaxy color variations, etc.

Downsides(?)

- Higher-level abstraction than the standard "star particle" method (i.e., more prescription-based)
- Some things cannot be studied with this method: intracluster light, galaxy morphology, galaxy 'tails' (i.e. Roediger et al.)

Some observations to target

- Red sequence appears at z ~ 1.5: star formation also dies down here.
- Cluster galaxy star formation turns off “inside-out” from z~ 1.5-1
- velocity bias depends on galaxy color, projected distance from cluster center
- BCG stellar age and metallicity distributions
- ICM metallicity distribution and evolution

Summary

- Cluster galaxies deserve our attention too!
- While simulations of field galaxies produce reasonable results, cluster galaxies are still challenging.
- “Galaxy particles” offer a possible new avenue for modeling clusters within galaxies
- Stay tuned!