The Role of Mergers vs Internal Processes in Disk Formation (Destruction?)

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- Mergers do NOT:
  - Bring most mass into *disks*:
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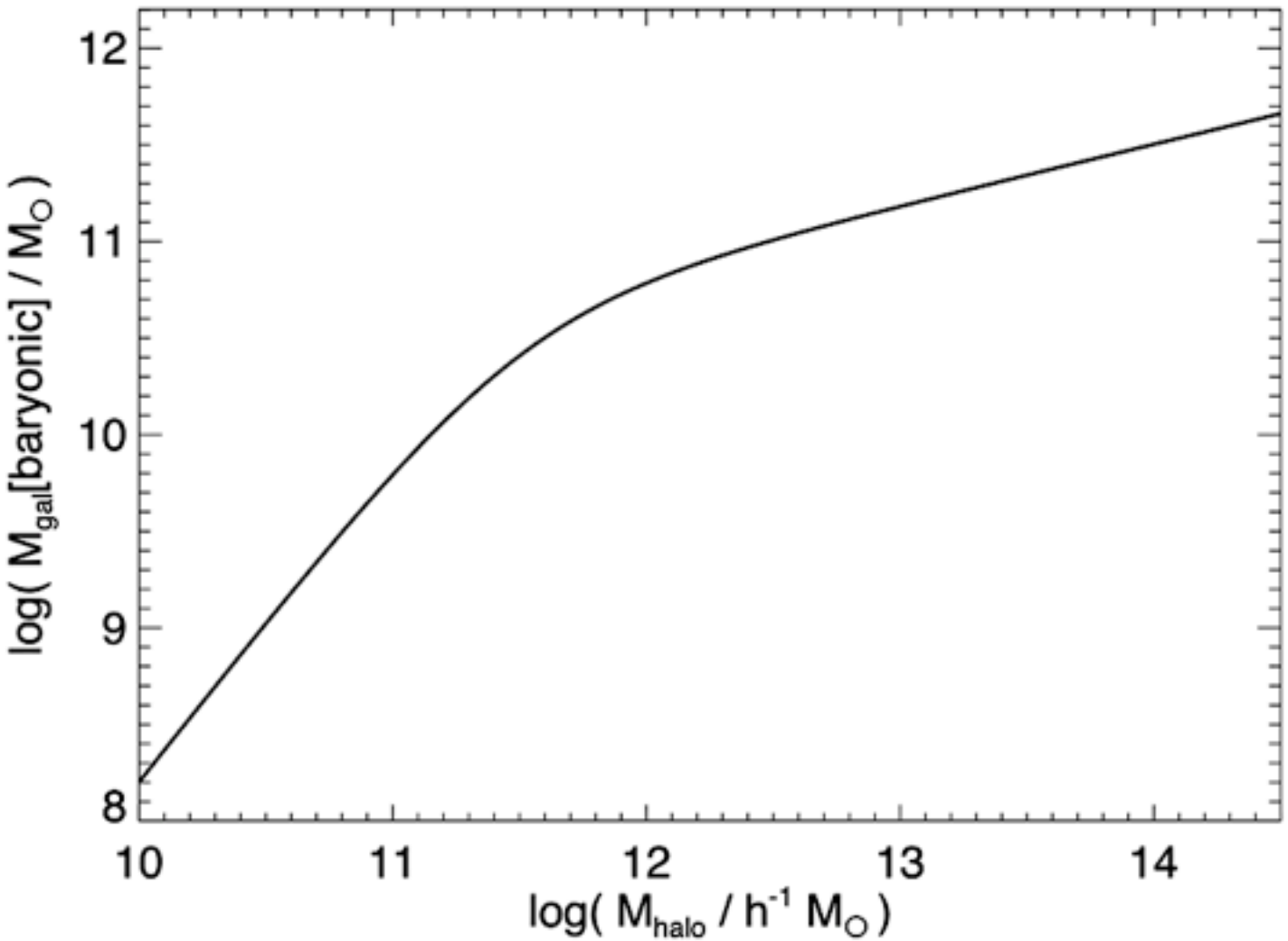

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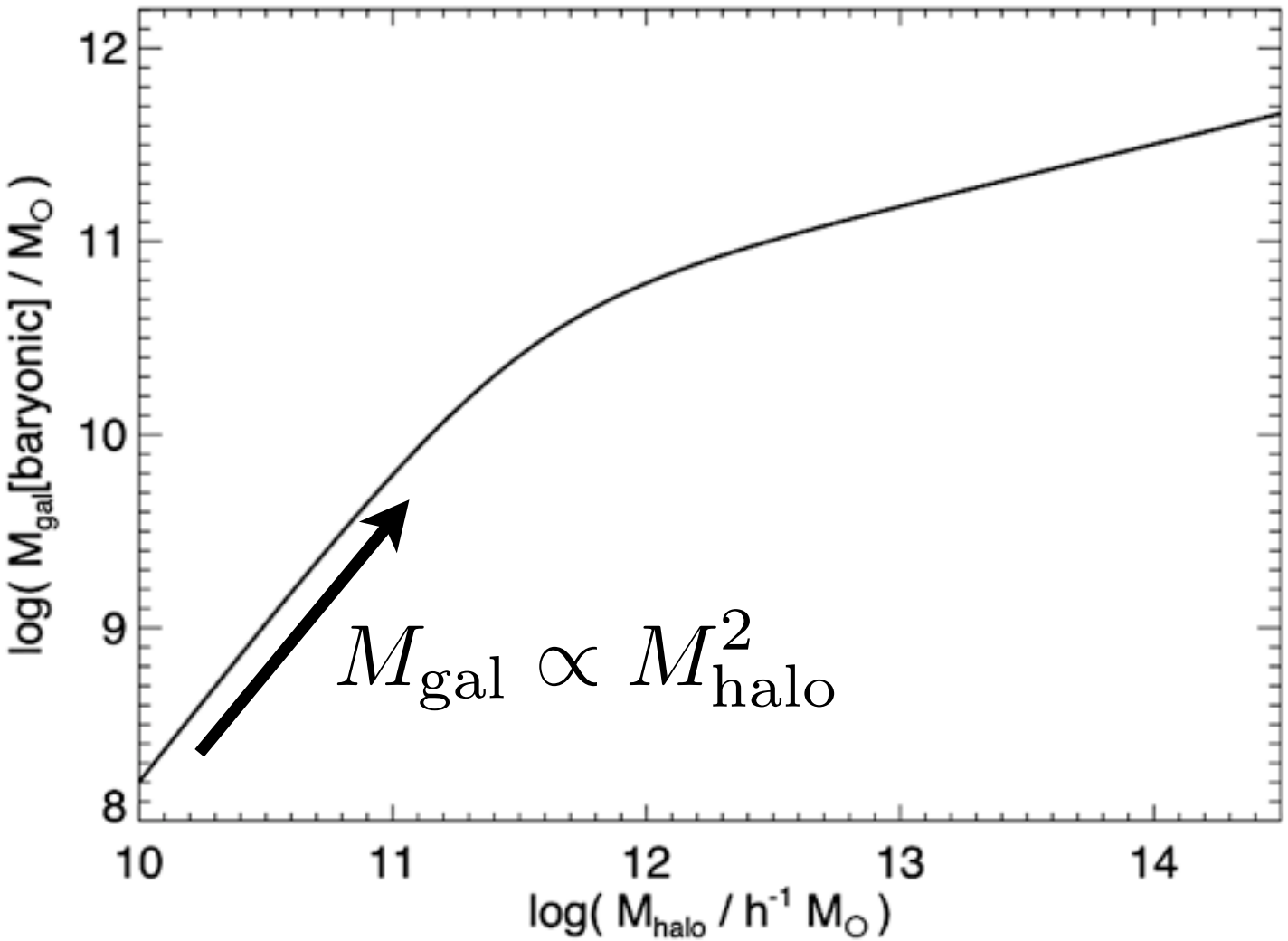

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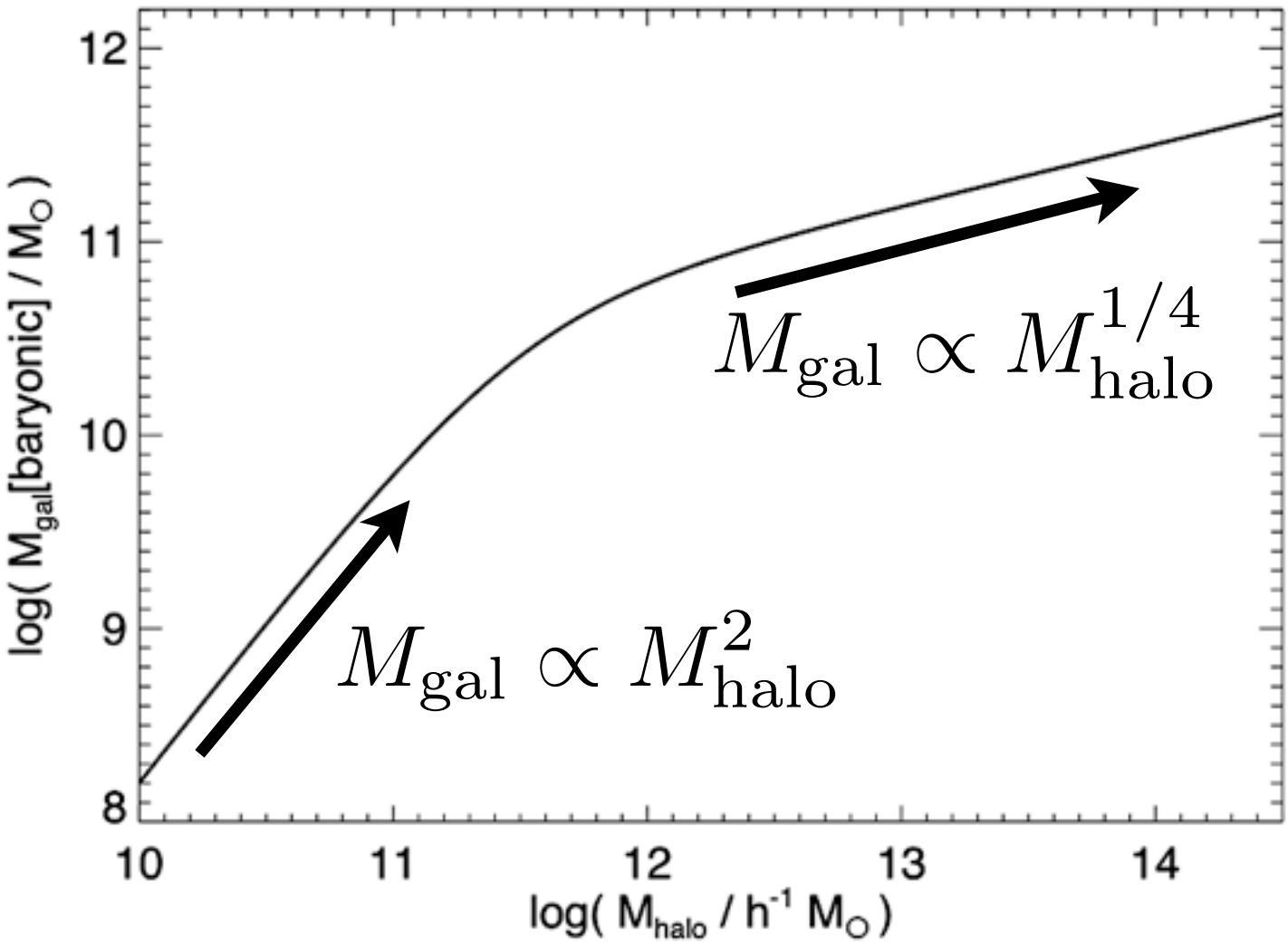

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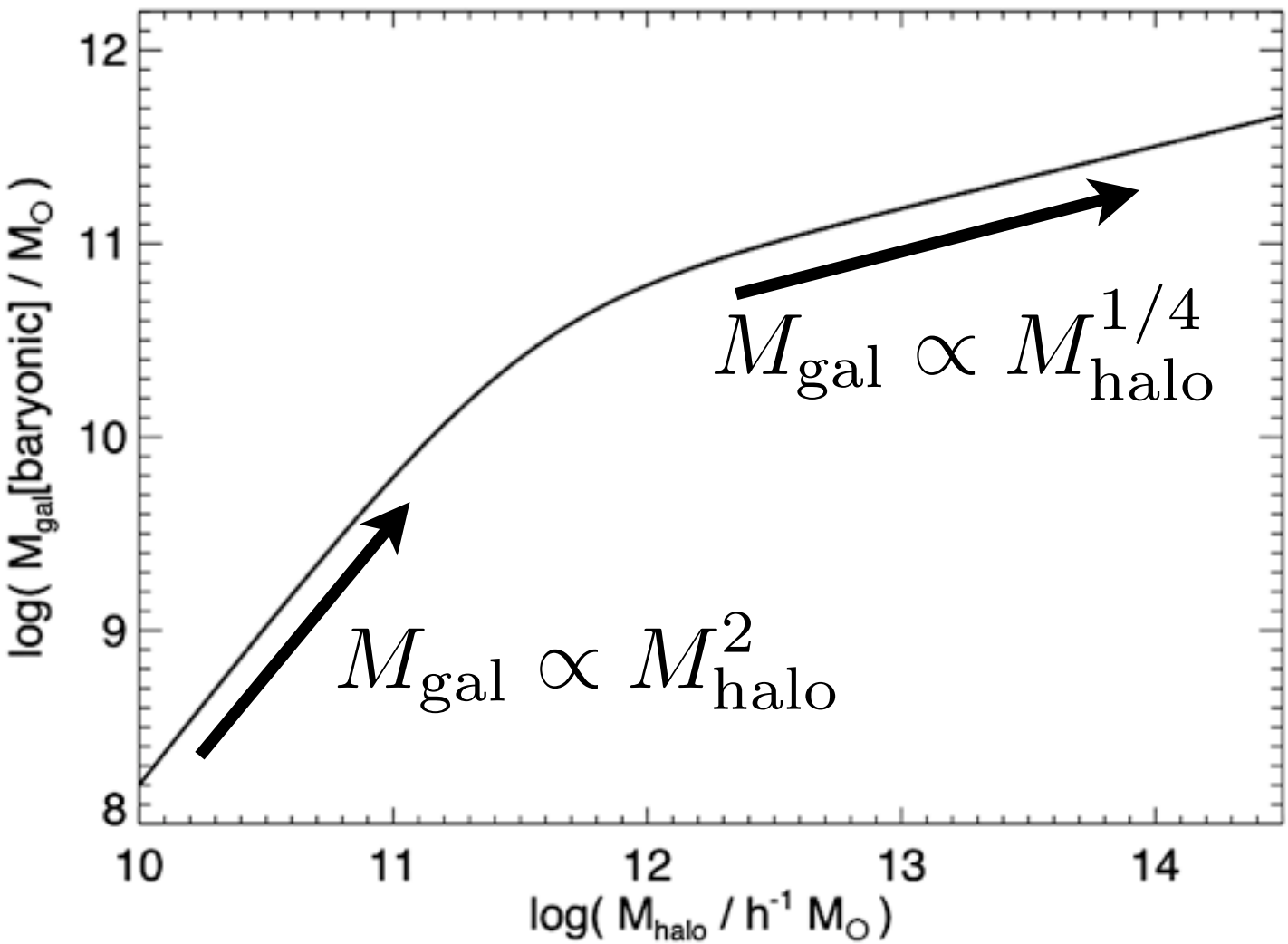
- Mergers do become critical above L* !



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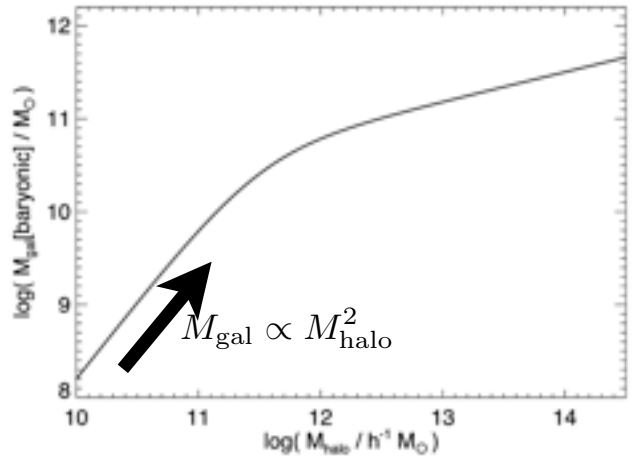

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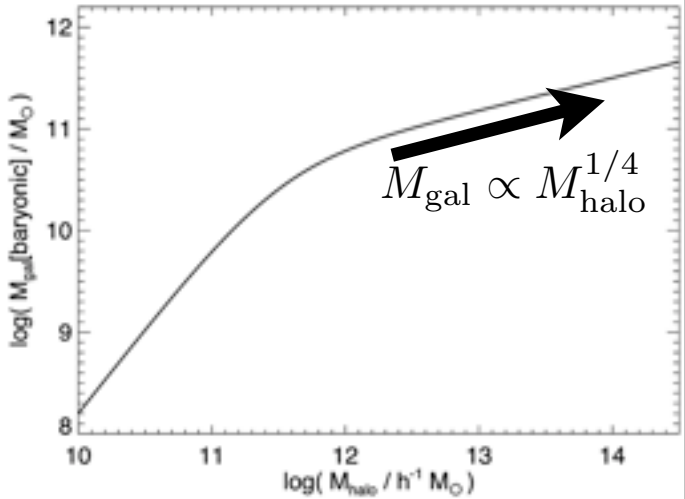

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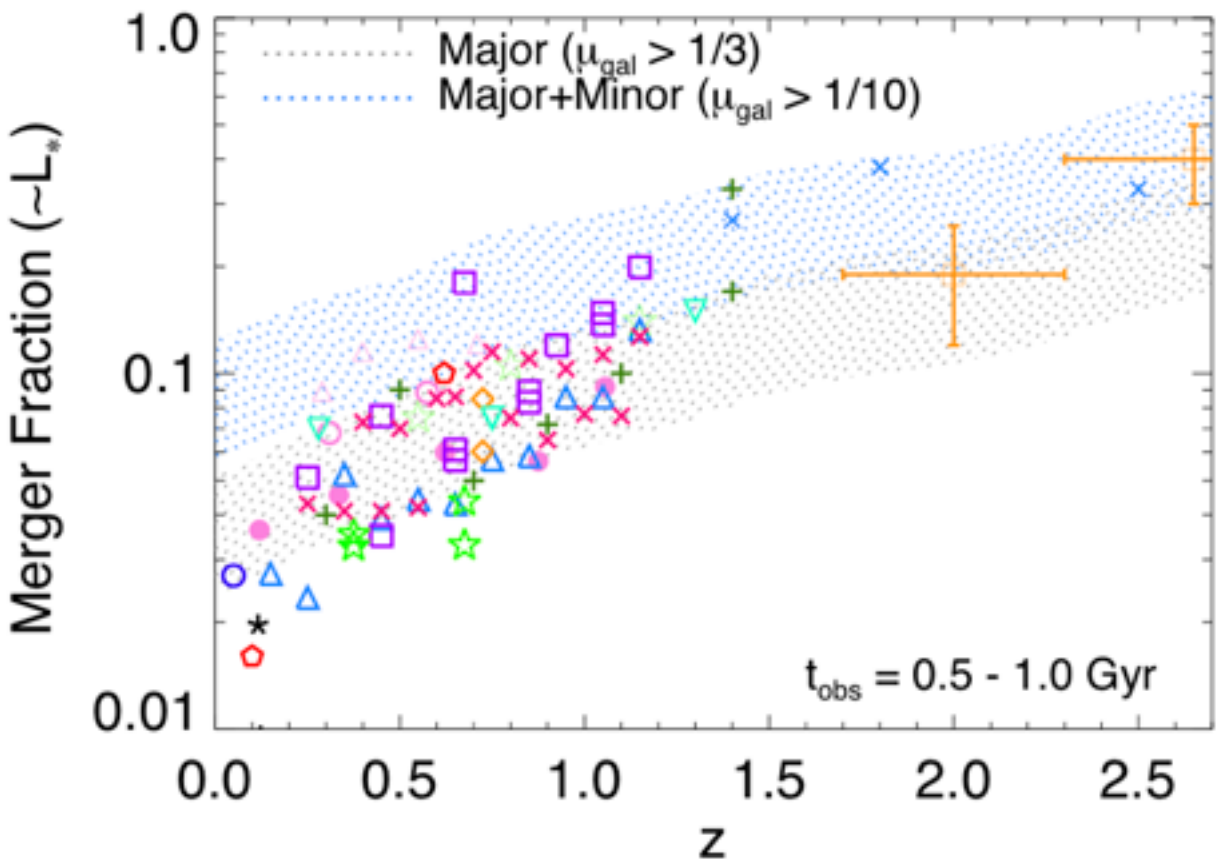

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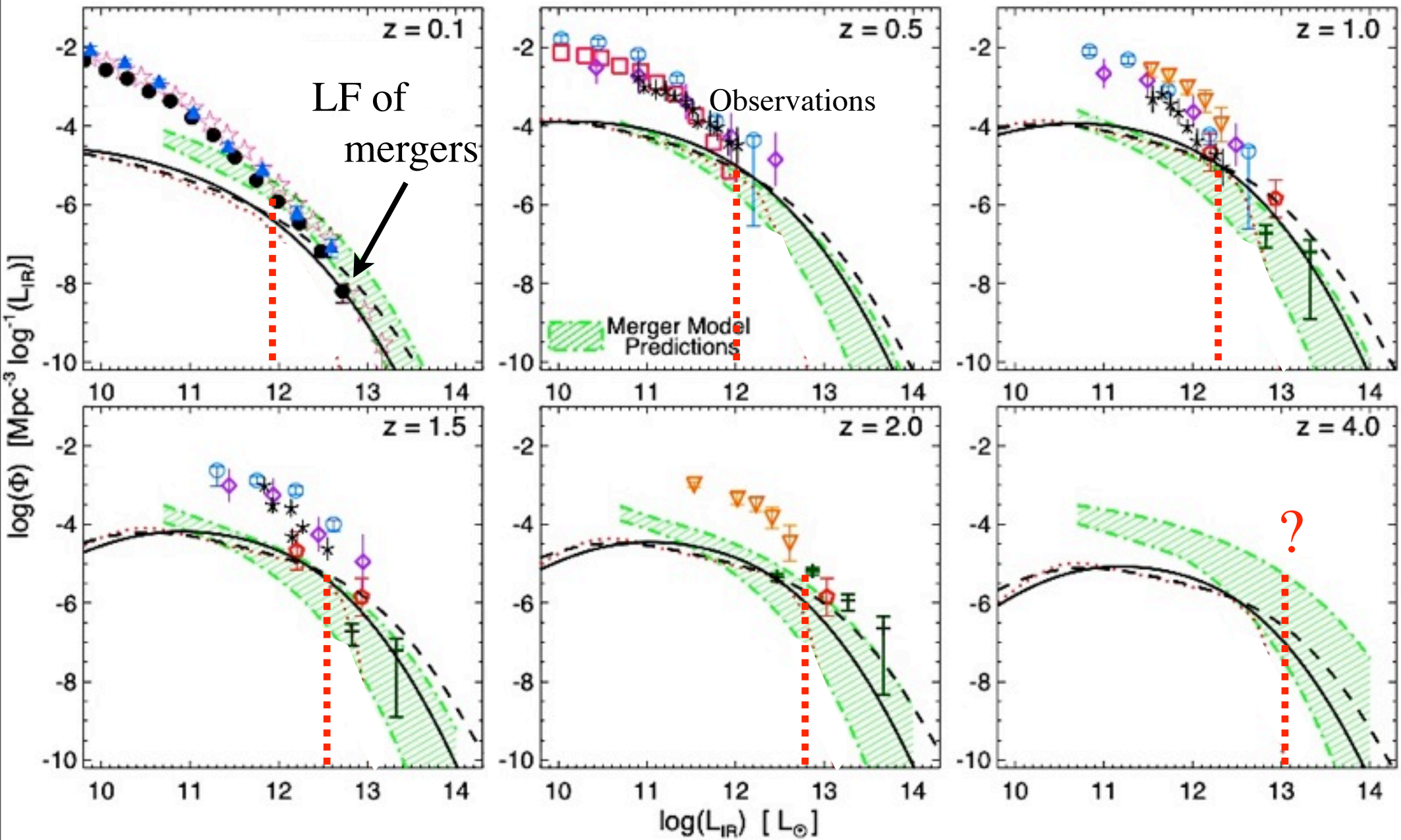

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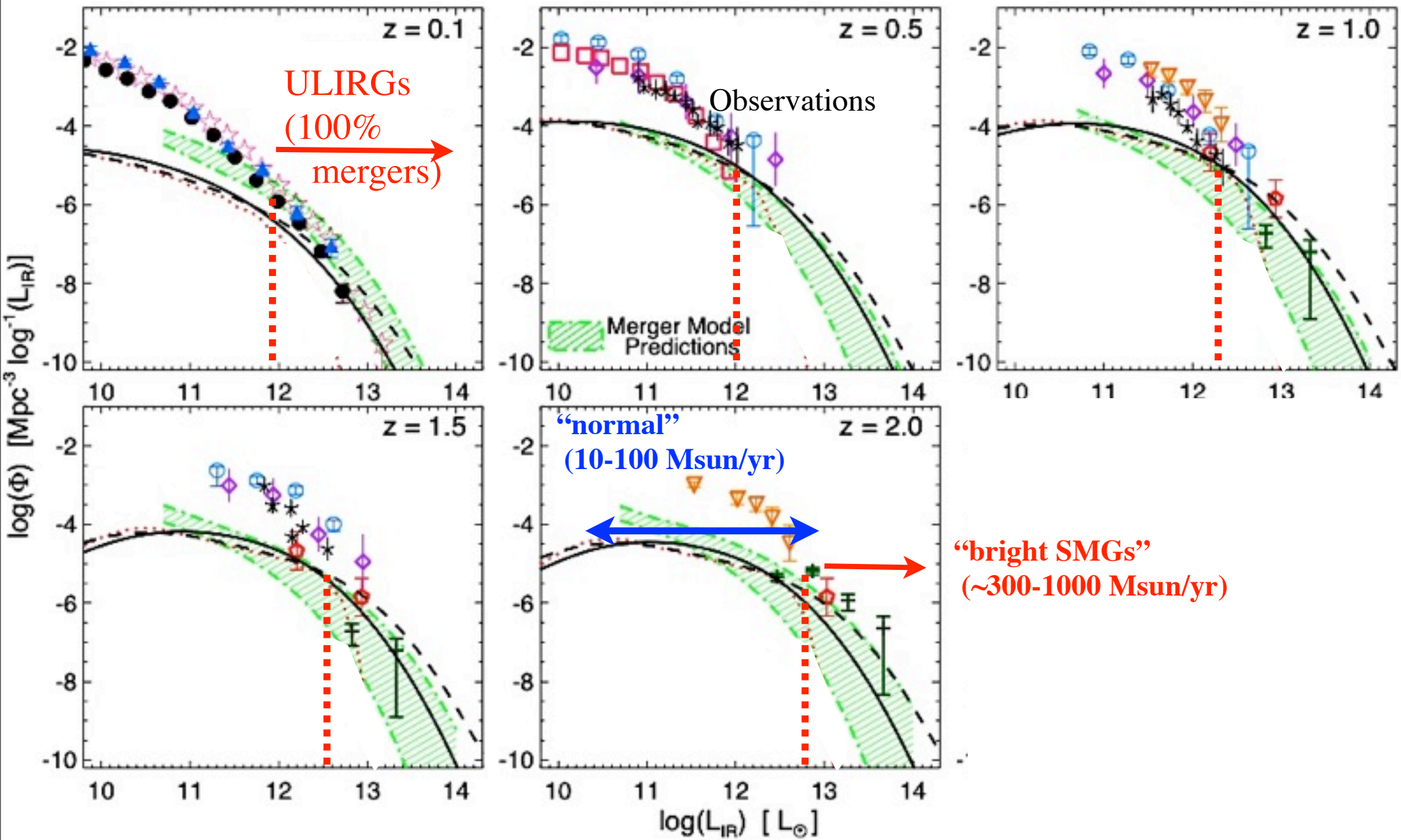
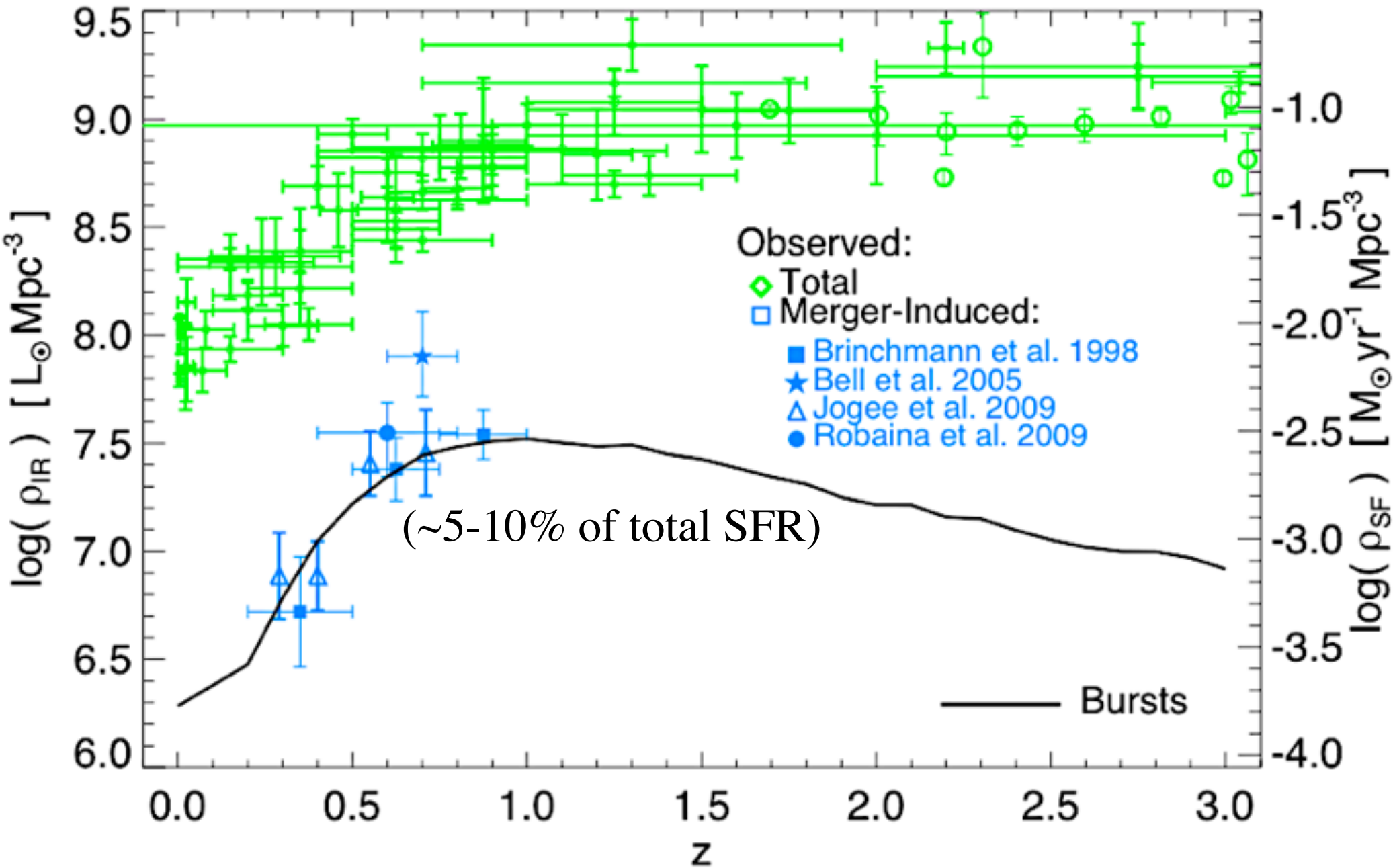


Merger-induced star formation does not dominate SFR density



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  - BUT, such disks also have $M_{\rm gas} \gtrsim M_{\rm disk}$

High gas fractions ⟶ *non-destructive* mergers

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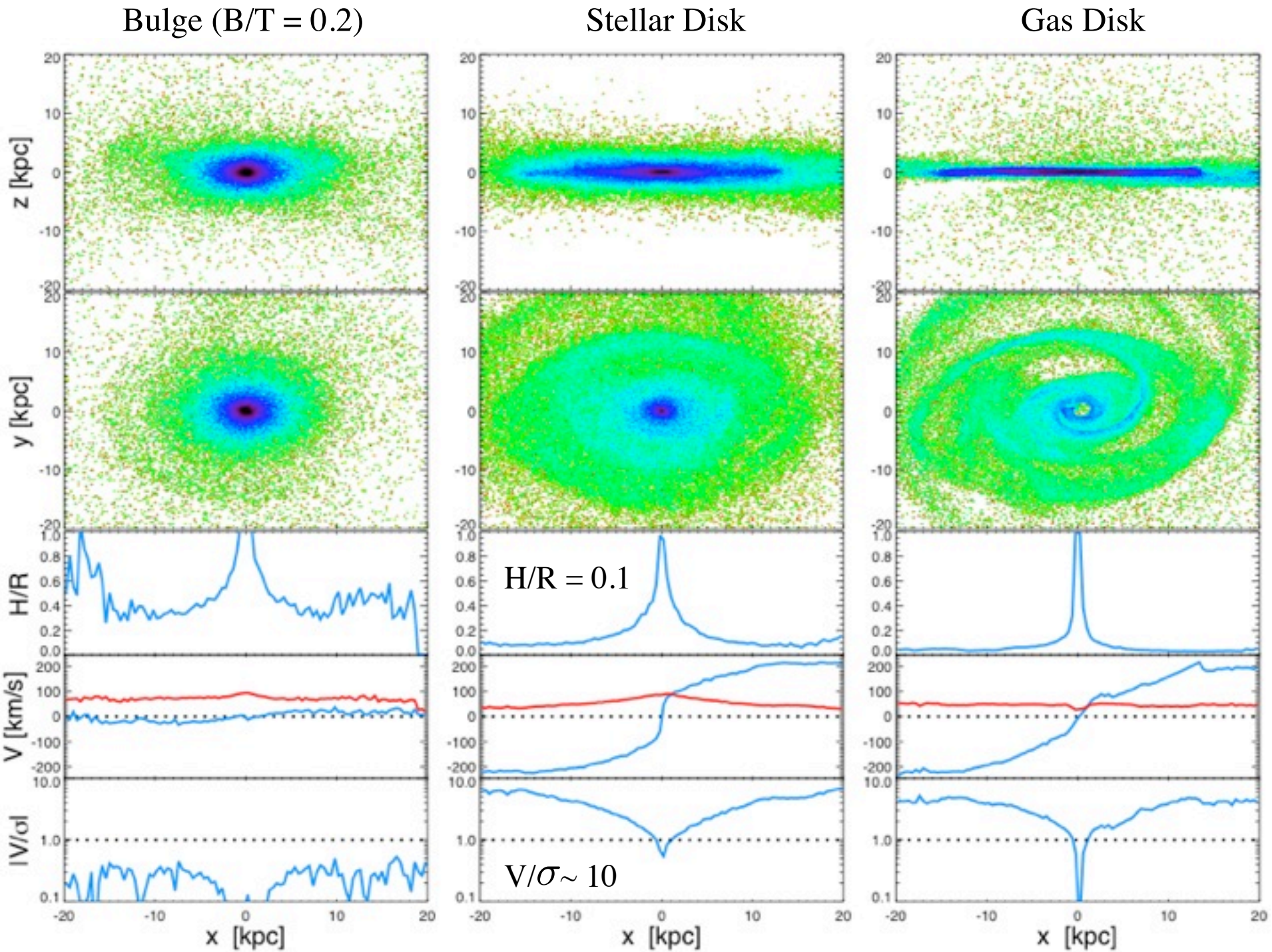

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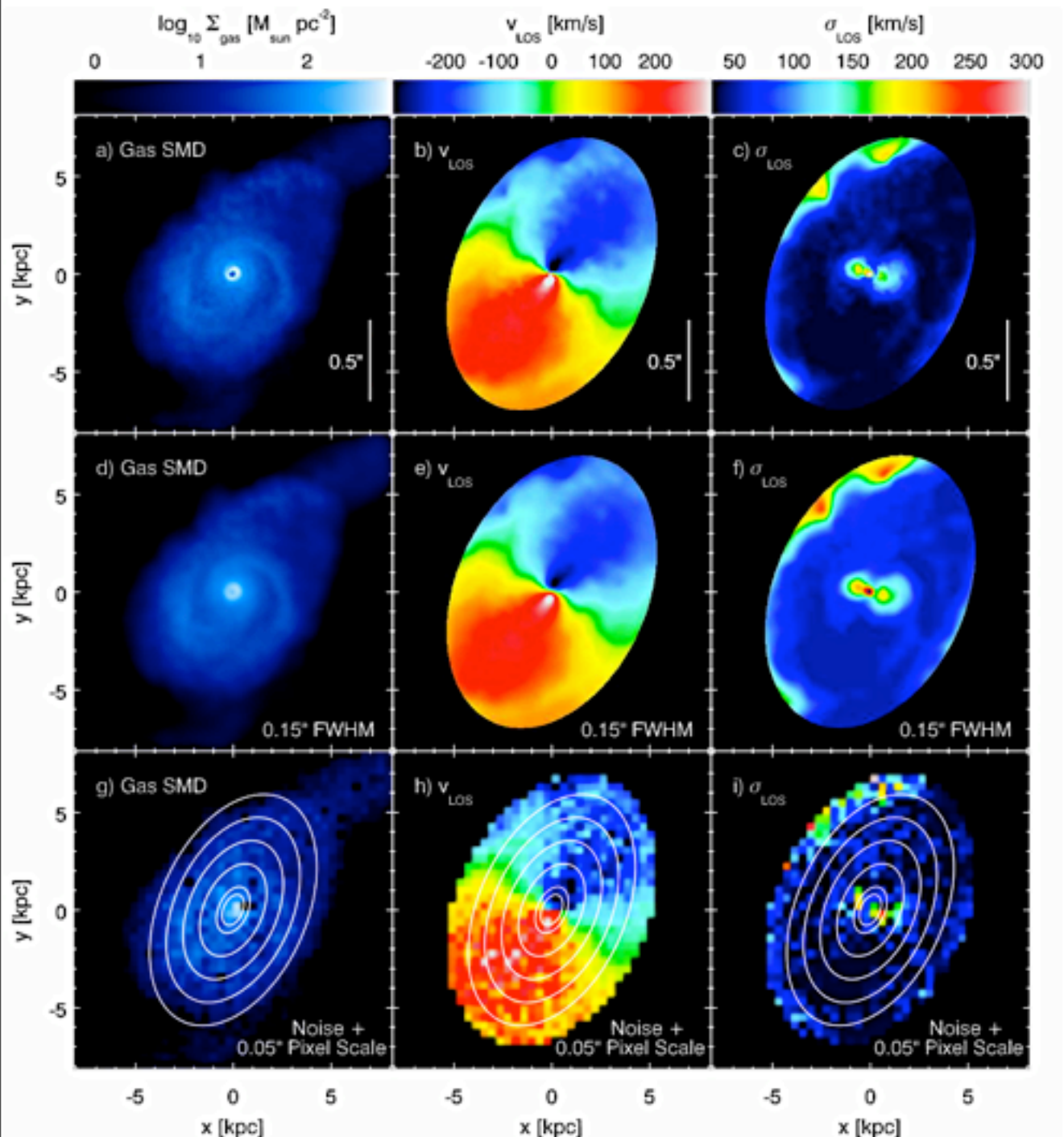

- Just gravity!
- Remnants are true disks:
  properties (clumps, V/s,
  scale length, shape)
  no different from any disk
  not in a merger
- Important for
  "why *no* bulge",
  not for
  "why a disk?"

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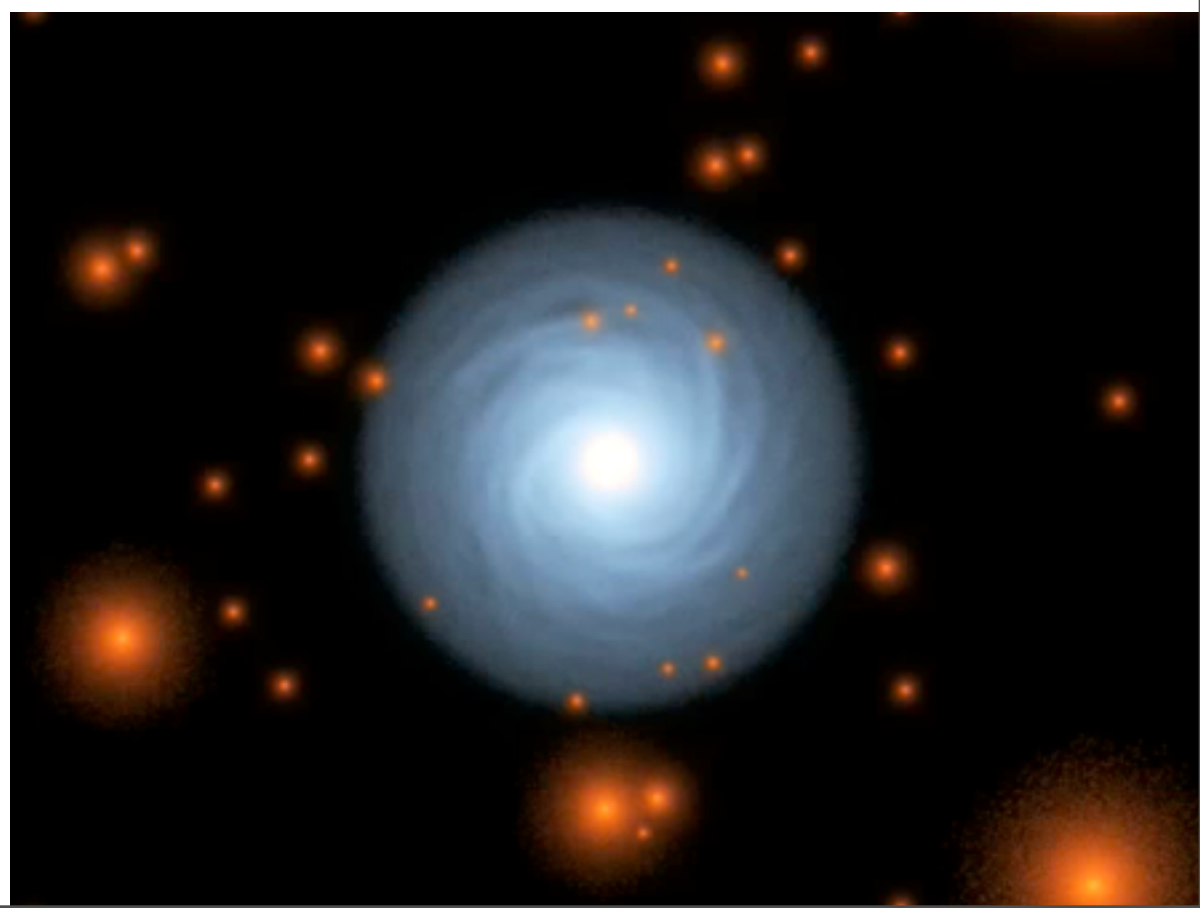
  - BUT, such disks also have $M_{\rm gas} \gtrsim M_{\rm disk}$
  - By definition, non-destructive mergers do *not* dominate changes in disks

The Role of Mergers

- Mergers DO:
  - Drive the most extreme events (hard to be more extreme!)
    - Brightest starburst/SMG/QSO(?) populations
    - Confirmed at all redshifts where possible
      - CAUTION: These are driven by resonances:
        resolution must be very high (<~ 100 pc) [recall Lucio's talk]
  - Perturbations to disks:
    triggering secular activity,
    disk heating, etc.
    (Francoise's talk)
  - Build massive bulges...

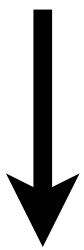


Is Bulge formation Dominated by Mergers or Internal Processes?

- What we know:

Mergers

Major Minor



Tidal torques, inflow,
starburst (build inner)
Violent relaxation
of disk stars (outer)

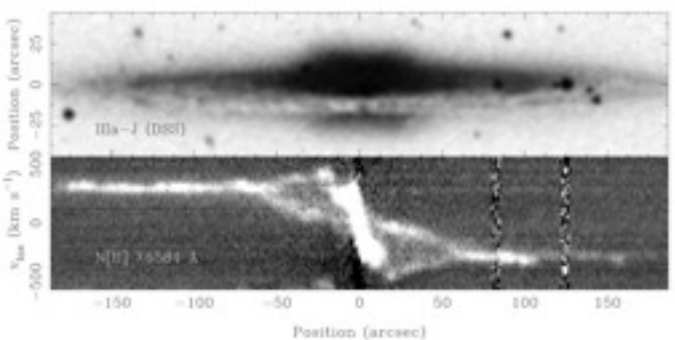
‘Classical’ Bulges

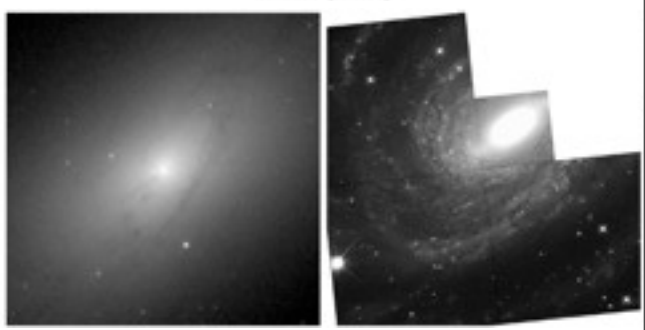
High-density, s, mini-Es

Is Bulge formation Dominated by Mergers or Internal Processes?

- What we know:

Mergers		Secular	
Major	Minor	Bars	Spirals
↓		↓	
Tidal torques, inflow, starburst (build inner) Violent relaxation of disk stars (outer)		Tidal torques, inflow, starburst (but only to ILR!) Second-order (weak) exchange in stars Conserve angular momentum	
↓		↓	
‘Classical’ Bulges		‘Pseudo’ Bulges	
High-density, s, mini-Es		Low-density, V, disk-like	





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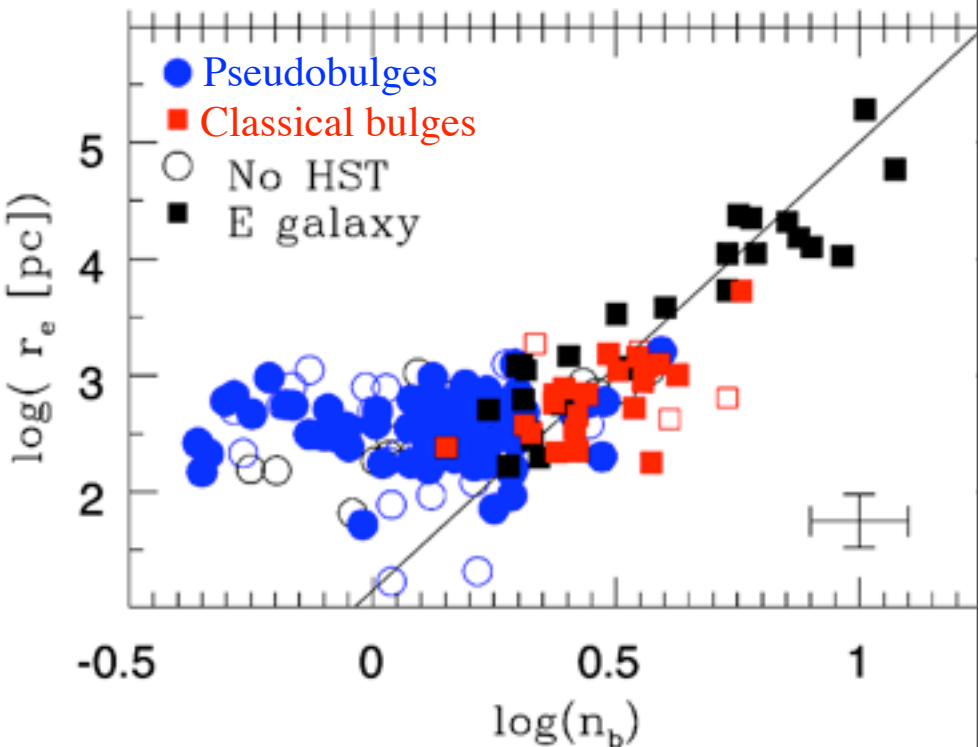
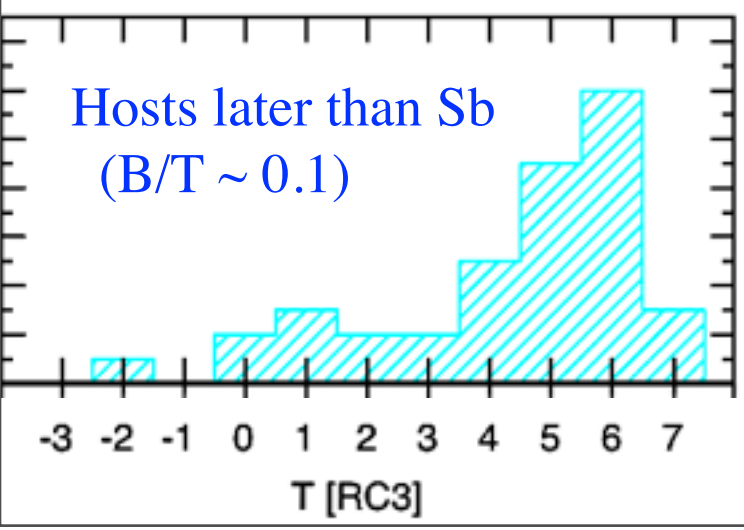
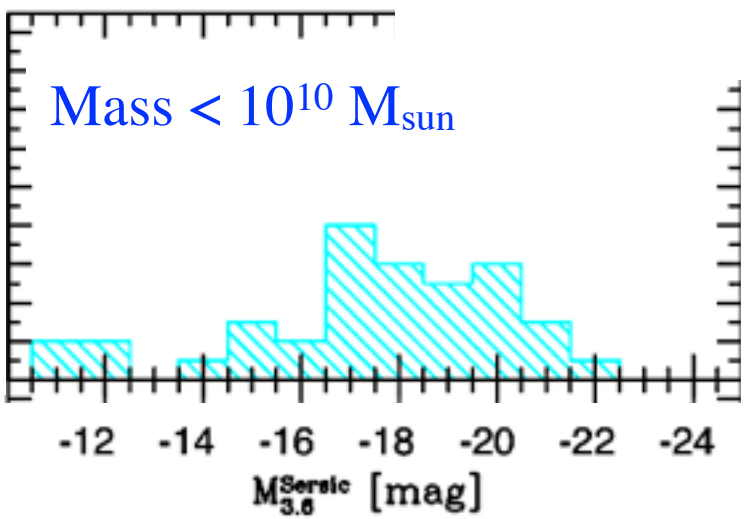
- Pseudobulges dominate at *low* masses, in late-type systems







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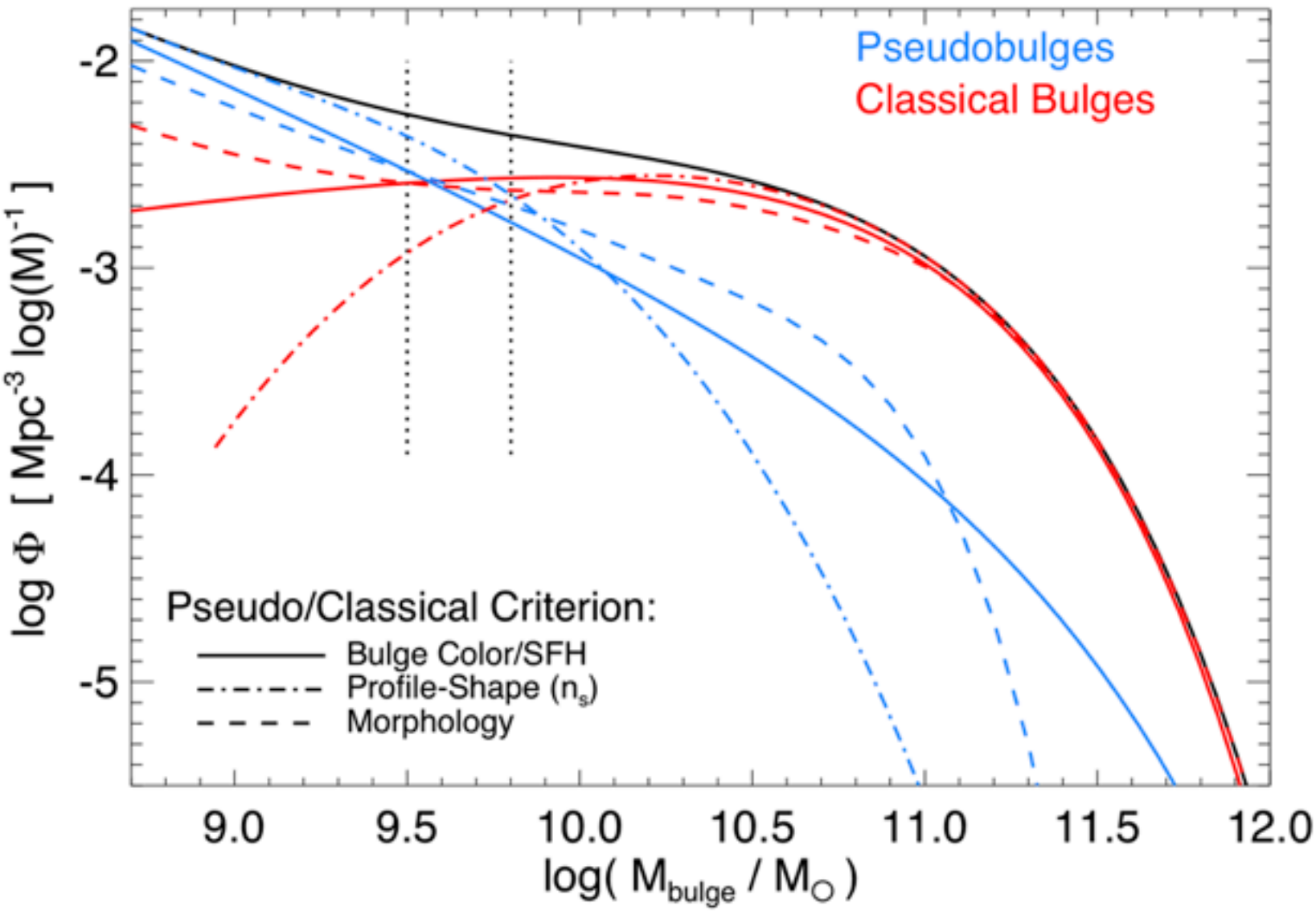

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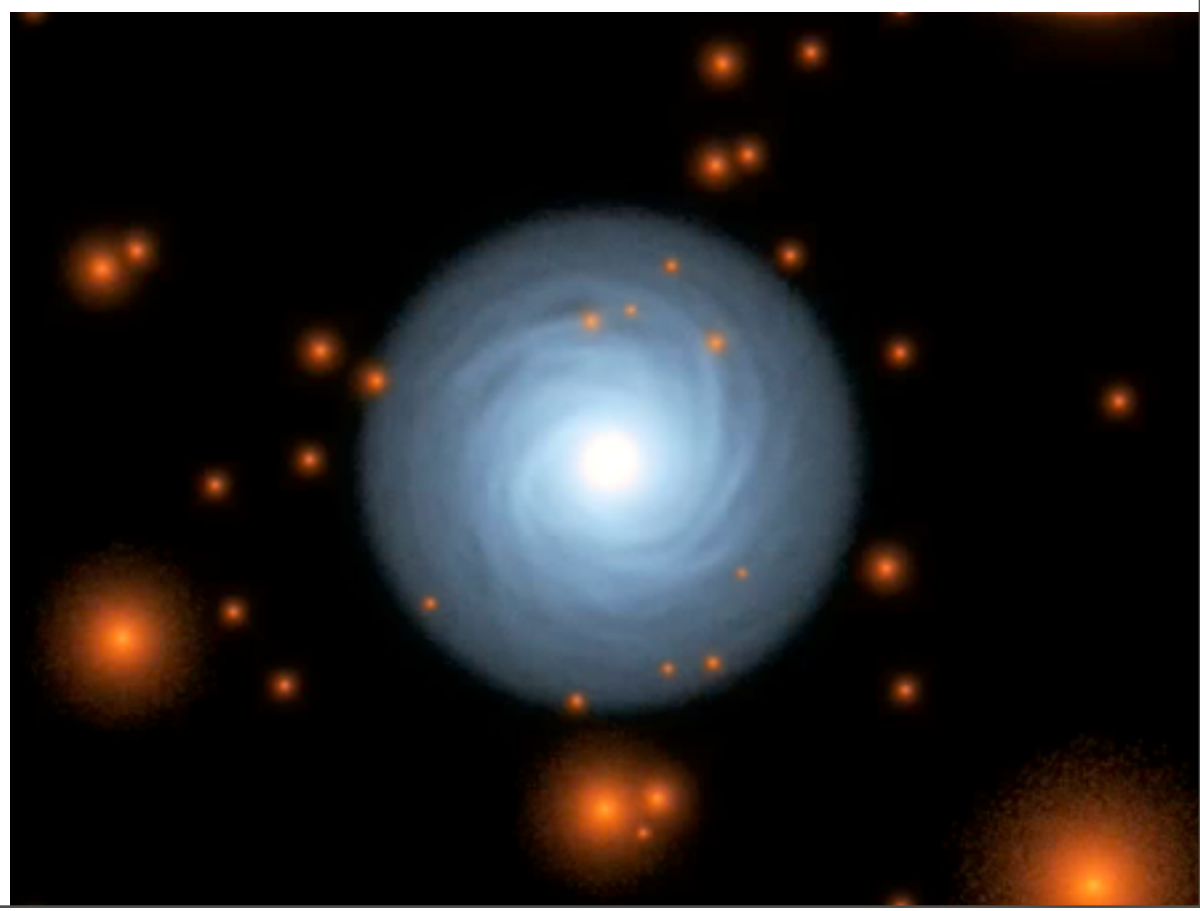

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This is a well-established picture....

What seems to be the real debate here is, where do the clumps come in?

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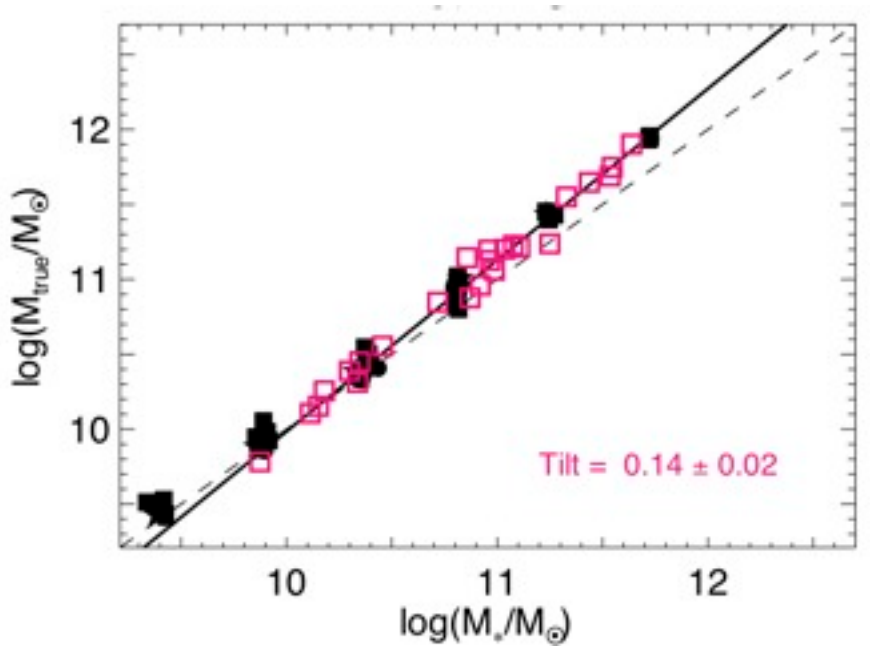

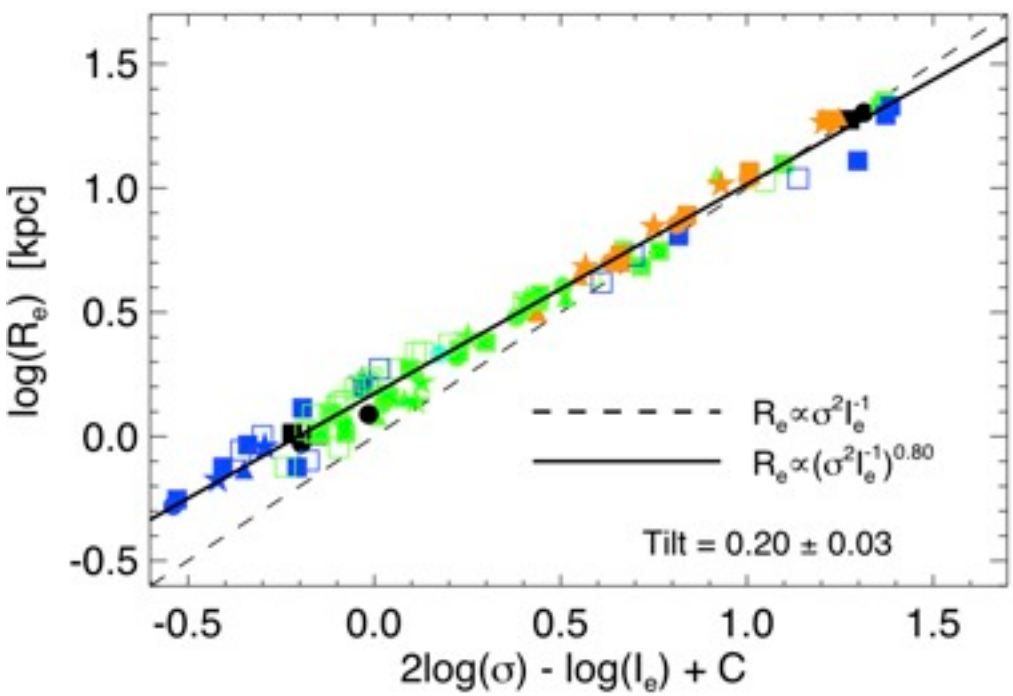

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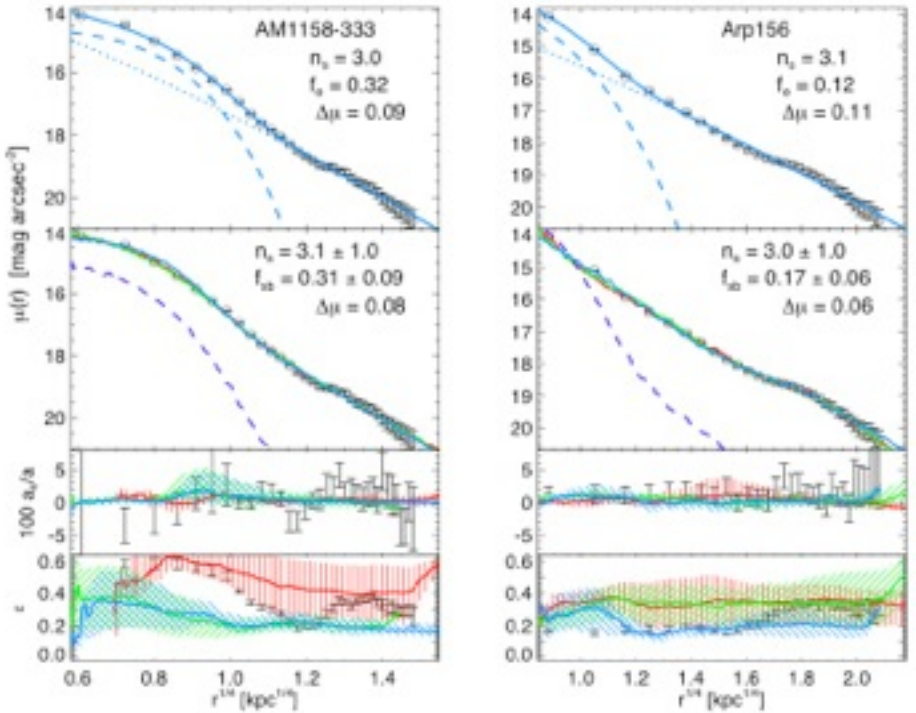
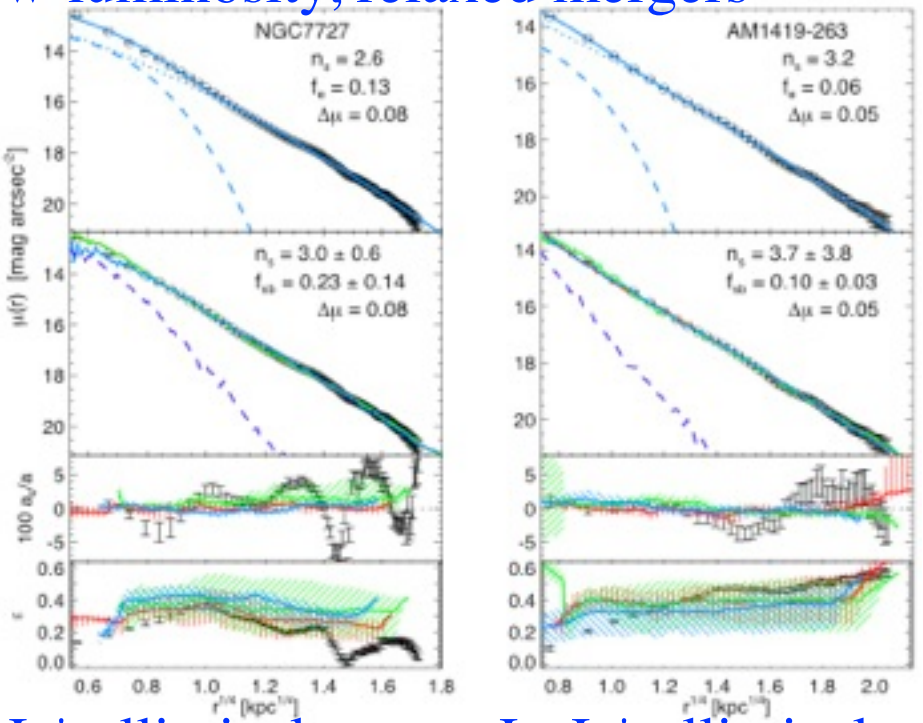
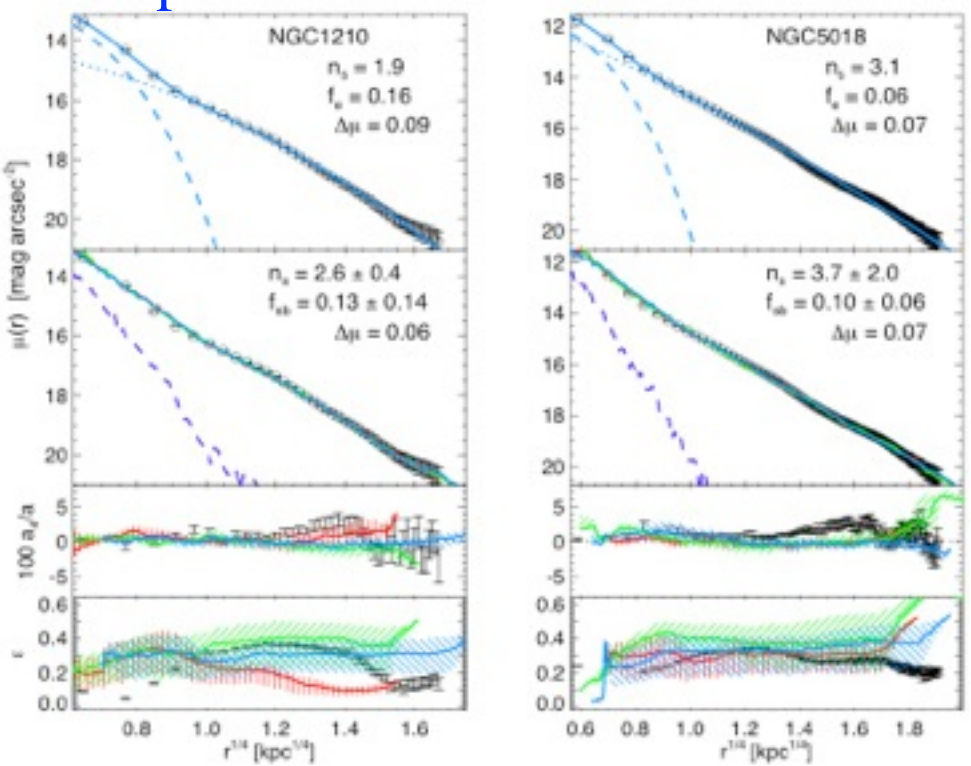
bright, young merger remnants



low-luminosity, relaxed mergers



old ellipticals with outer shells/tails



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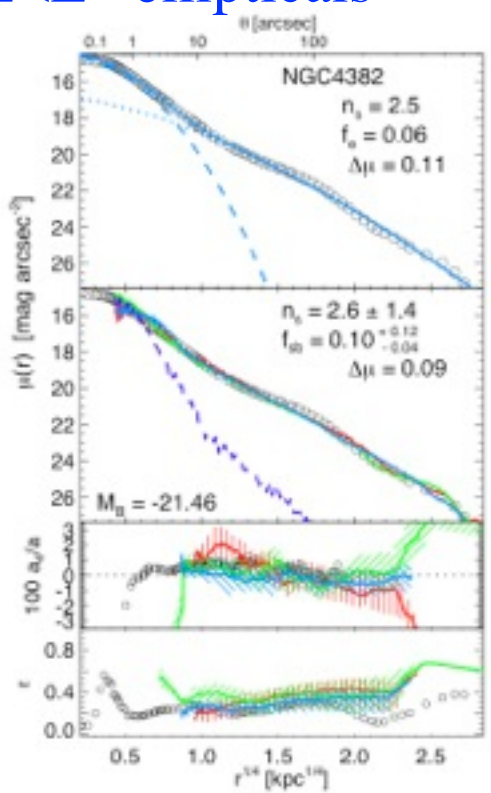

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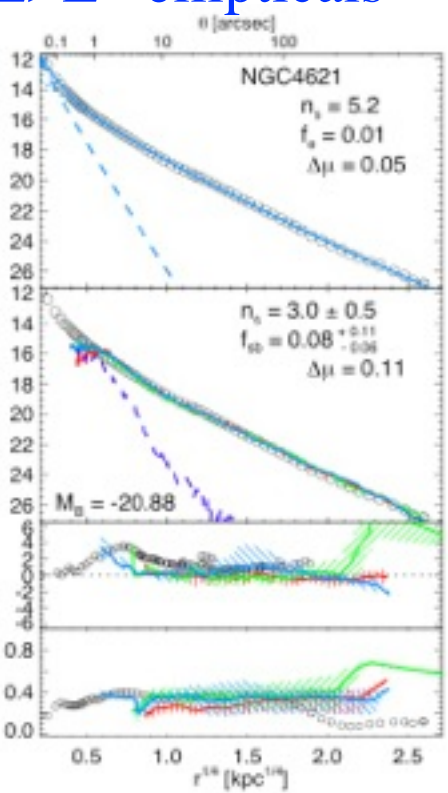

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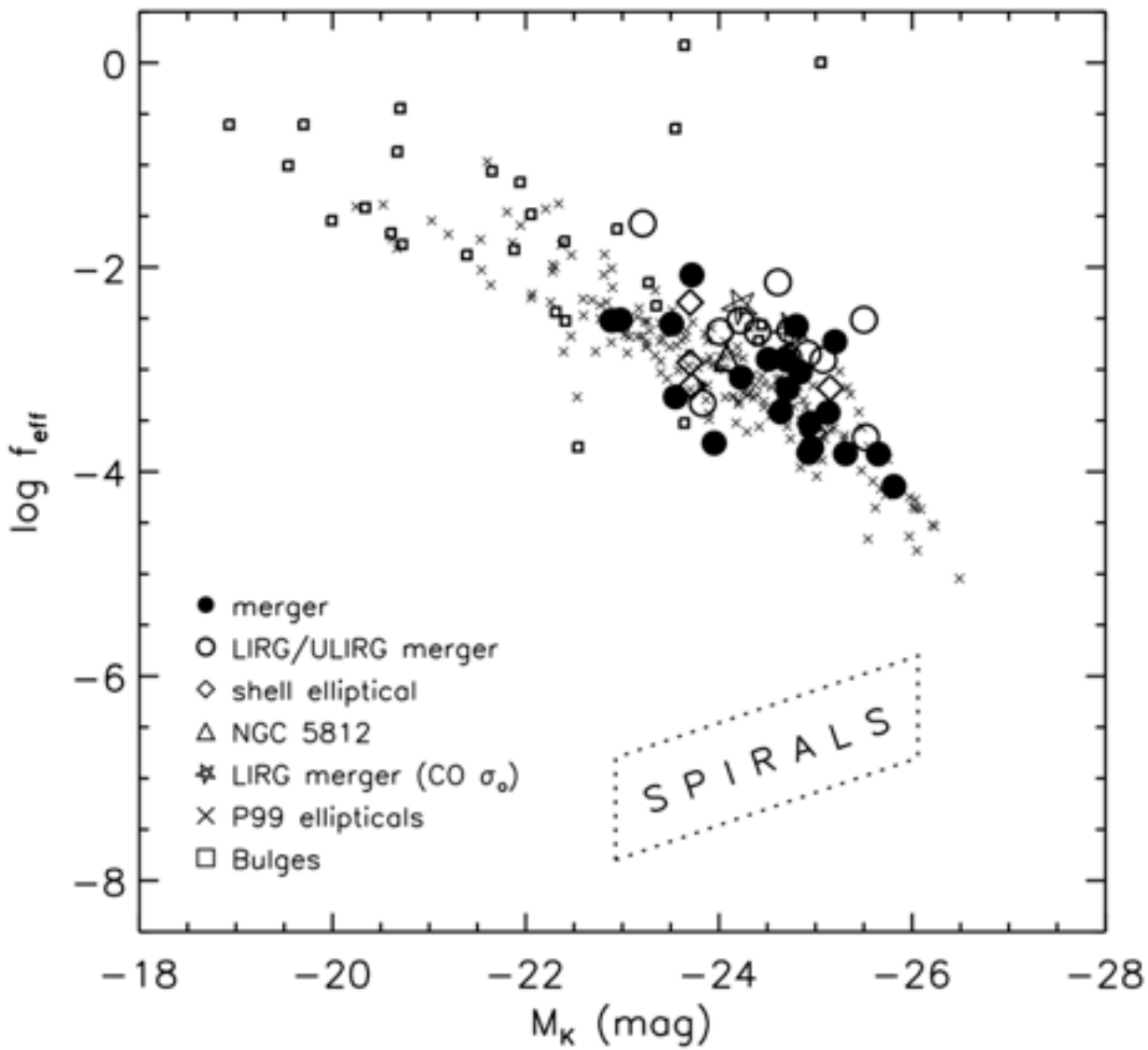

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- Cusp/core bimodality/dichotomy
- Substructures: kinematically decouple nuclear disks, streams

- Kinematics:
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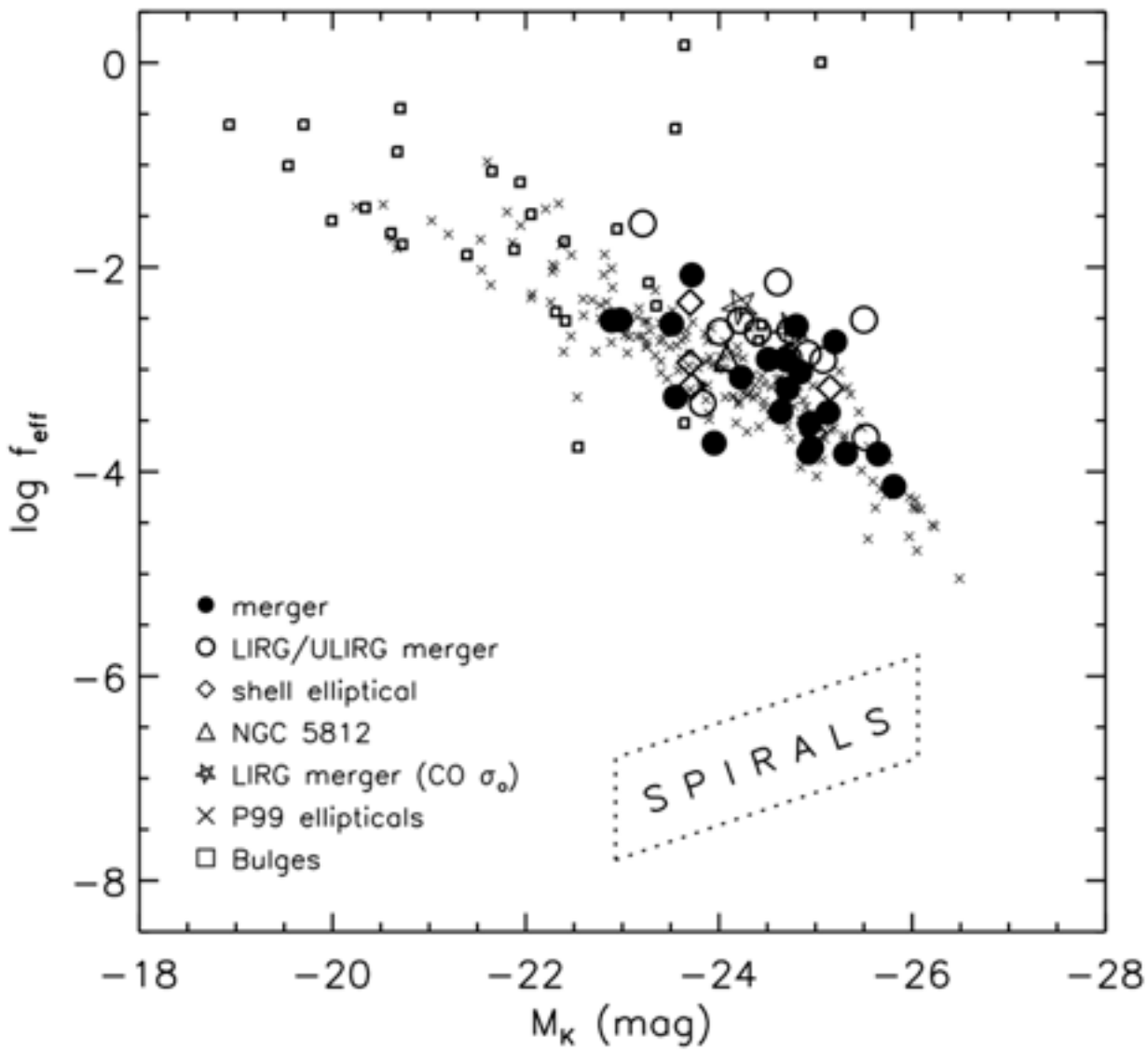
  - (V/s)*
  - anisotropy d



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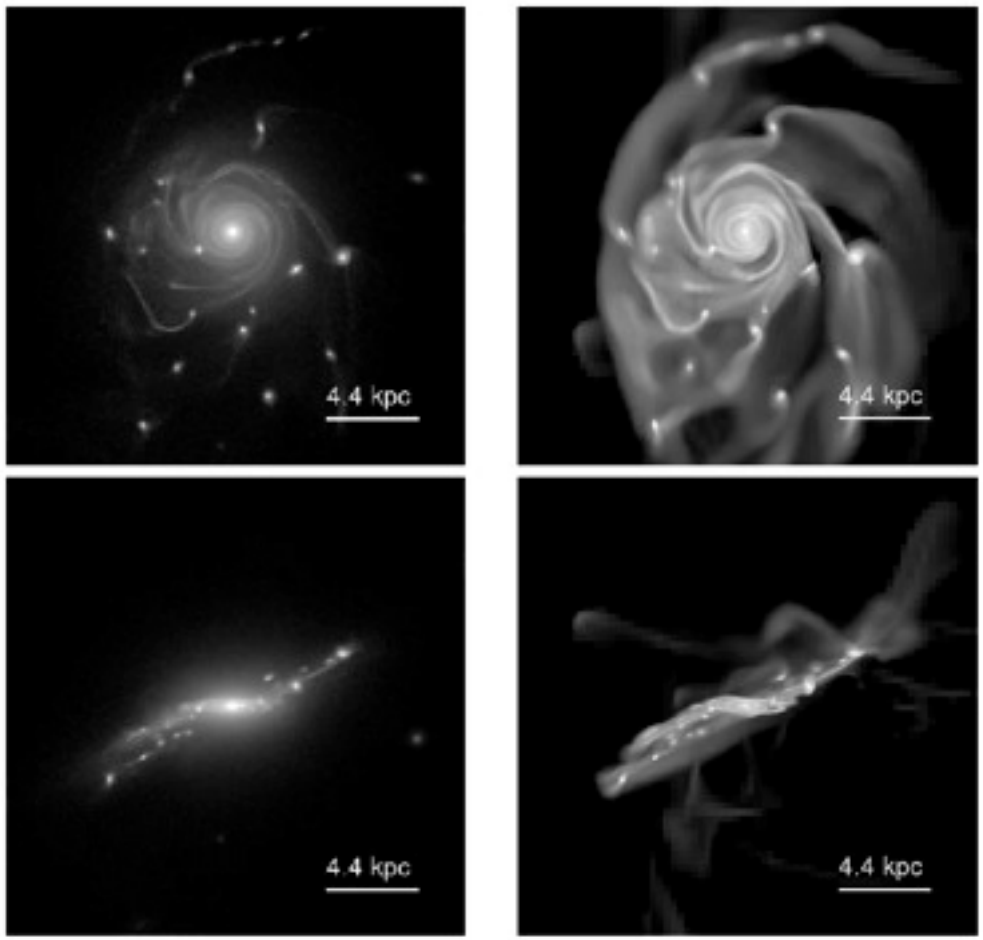
  - h_3 & h_4
  - misalignments γ
- Morphologies: faint tidal tails, shells
- Dark-matter fraction vs mass & radius
- # of merger-induced starbursts (ULIRGs)
- Post-starburst spheroid populations
- Mass function evolution
- Dry merger populations
- Size evolution with redshift

Clump-Coalescence:
"The New Monolithic Collapse"



- Most massive high-z disks appear clumpy:

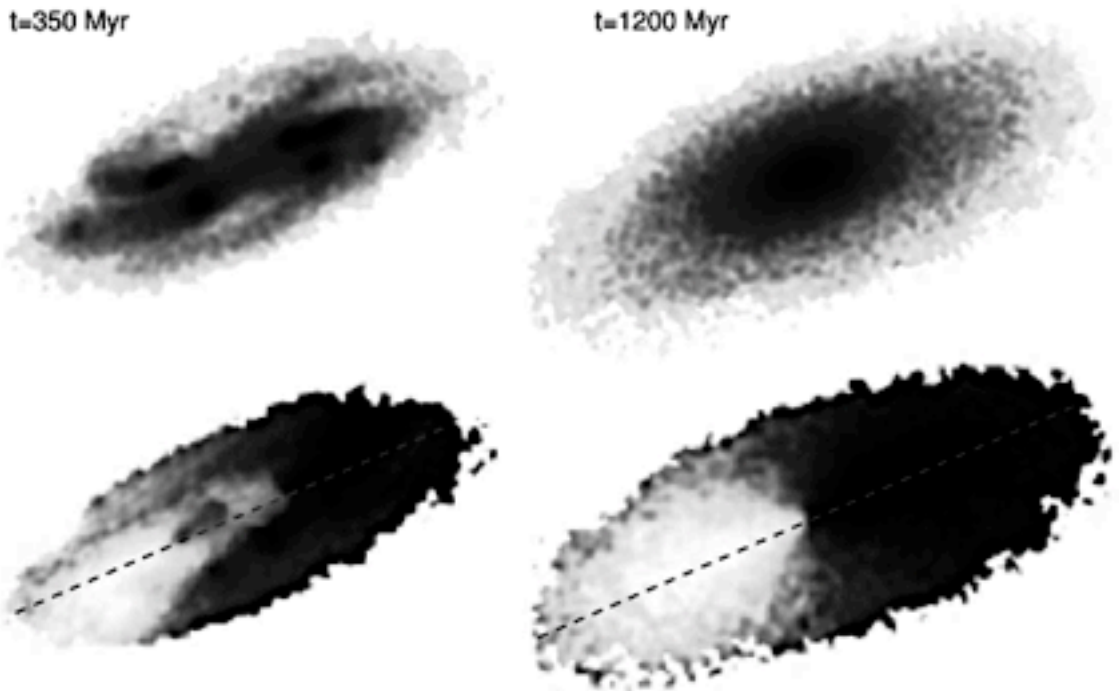
  The Idea:

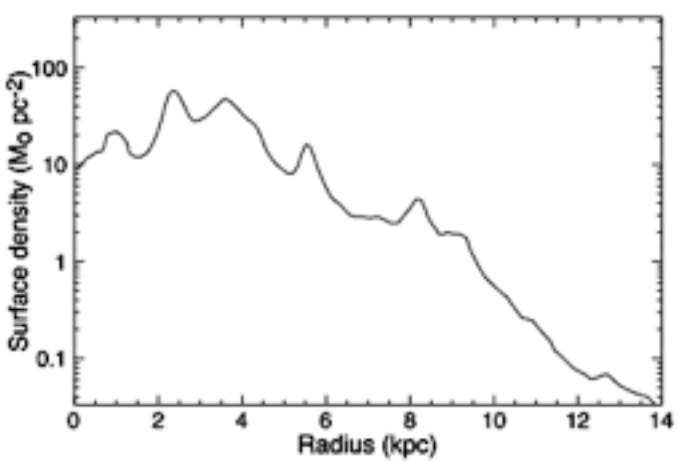
  Clumps form, live a long time, sink by dynamical friction to center, form bulges

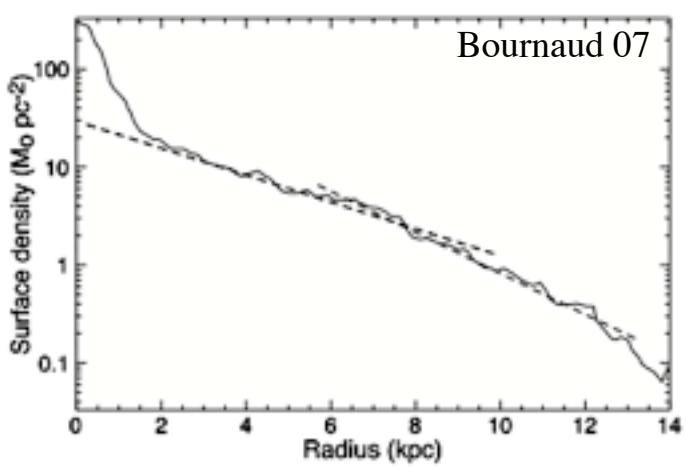
- Can we make bulges this way? Do we?

Successes of the Clump-to-Bulge Hypothesis:

- The remnant looks kind of bulge-y....





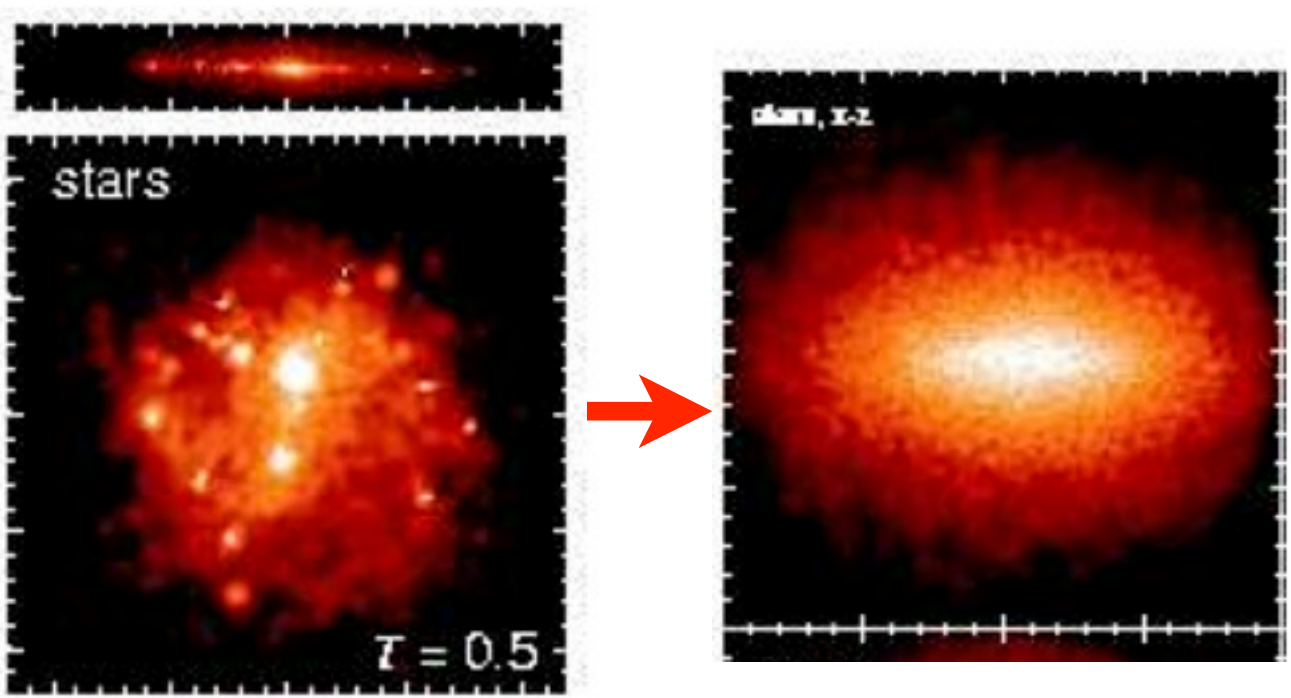


Why Clumps Don't Dominate Disk Evolution

- [1] Clumps are an old, big, PROBLEM
  - Cosmological sims: *always* saw your disks catastrophically fragment without strong feedback

"However, cosmological simulations of galaxy formation have not yet been able to form realistic disk galaxies: dynamical friction suffered by dense gaseous lumps and subsequent catastrophic angular momentum loss caused typical disk scale lengths to come short of those observed (Navarro & White 1994)."

-Governato 2004



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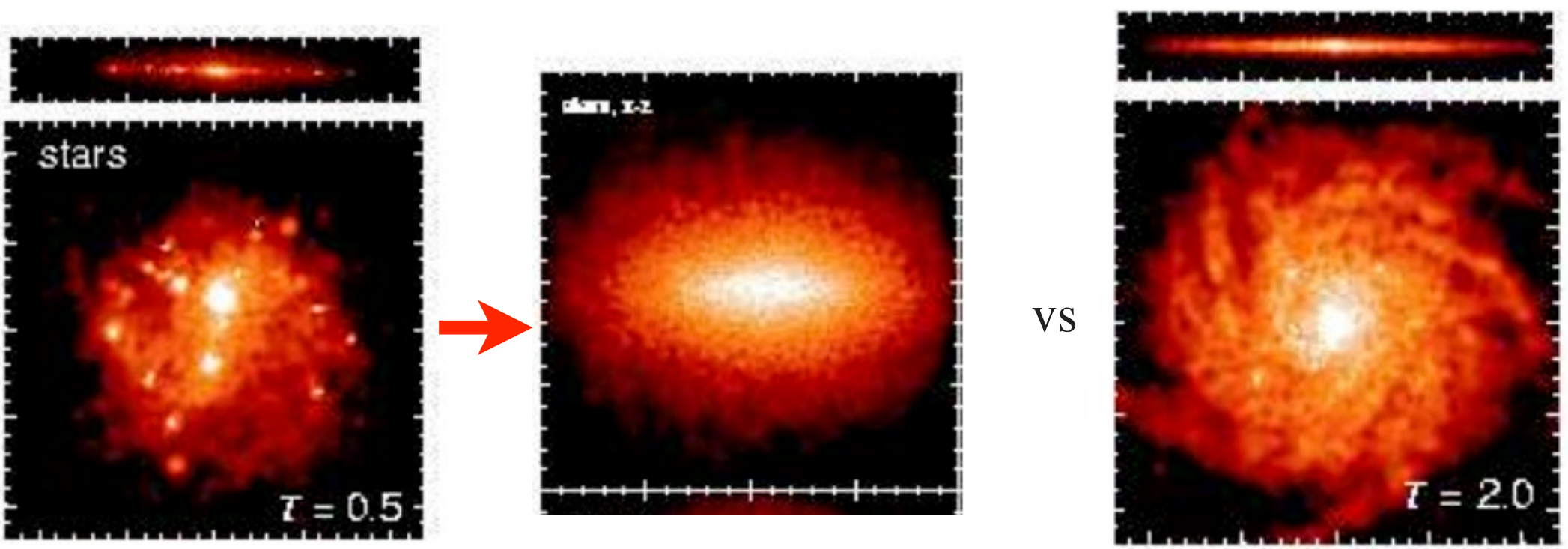
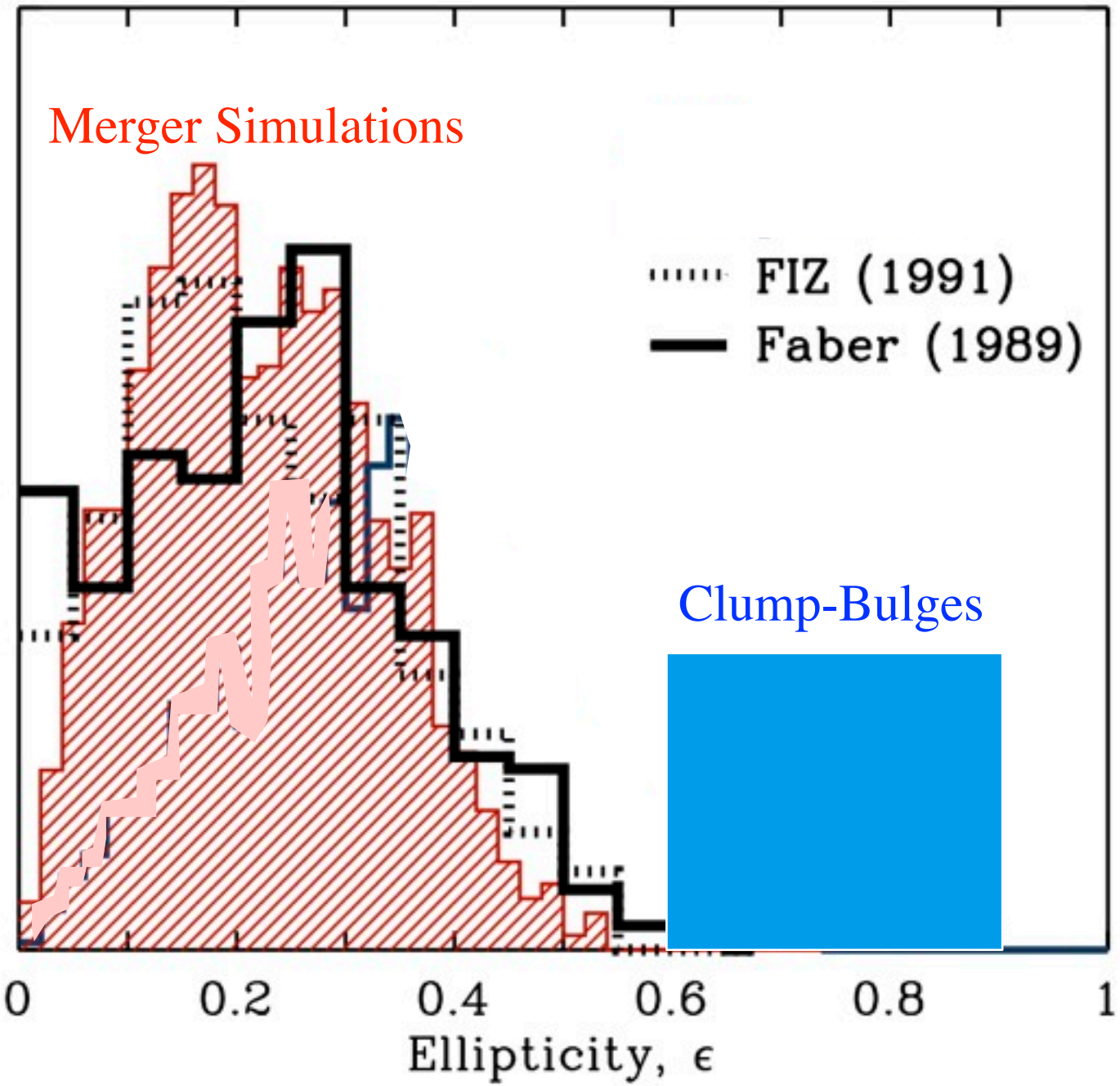
  - Even ~20% B/T from clumps is too much, prevents us from reaching z=0 late-type disks



[2] Clump-Bulges don't look like Bulges....



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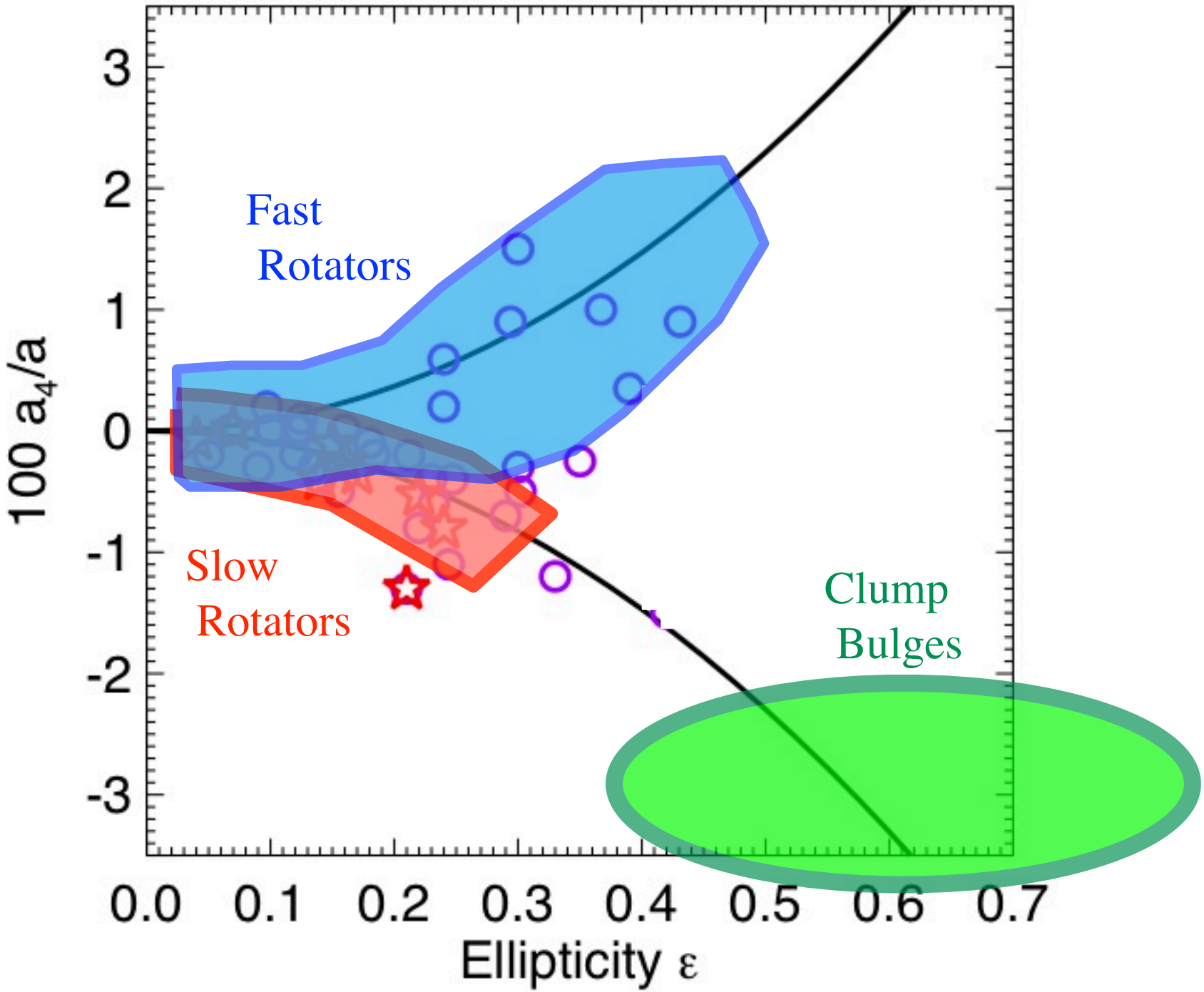

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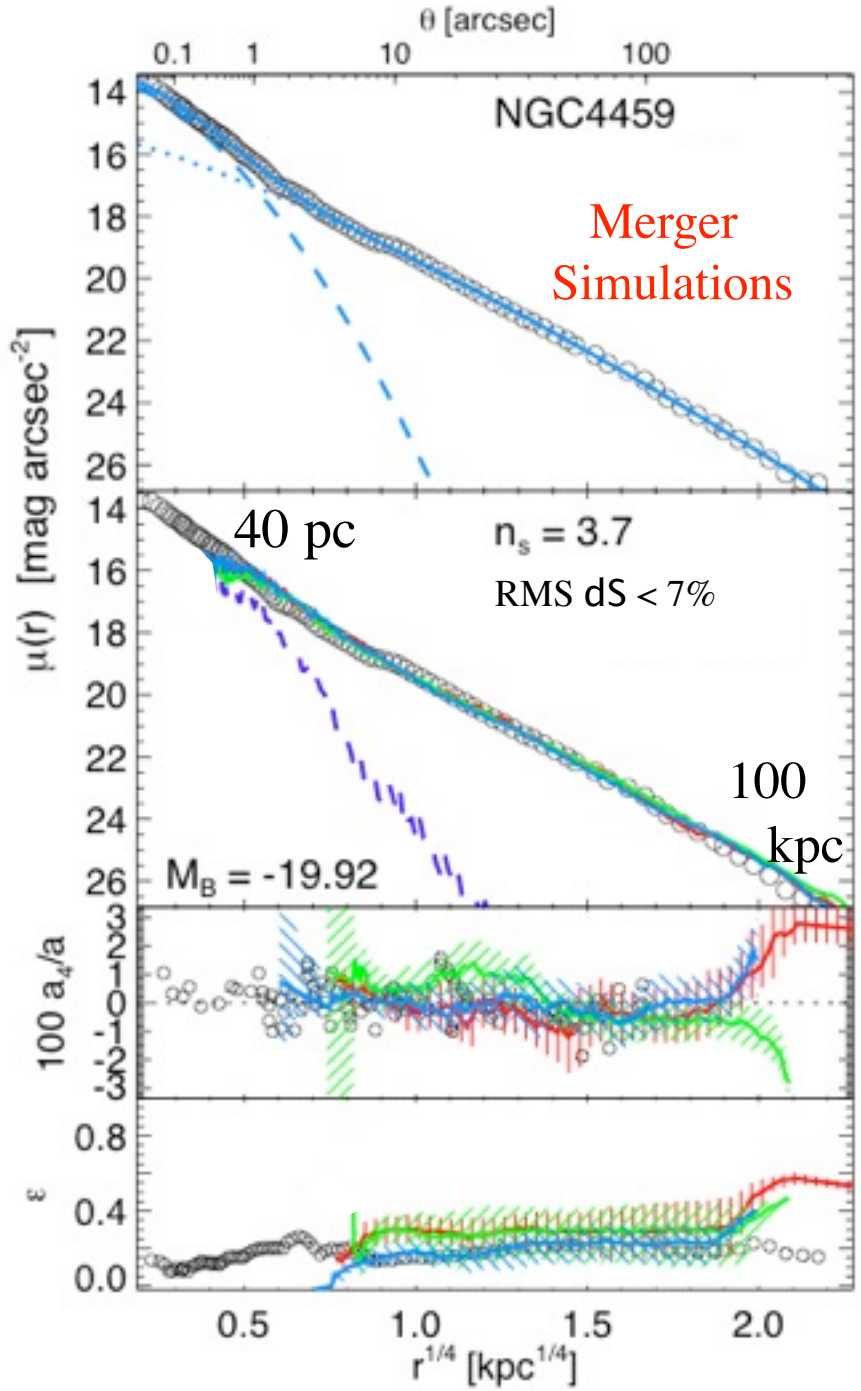

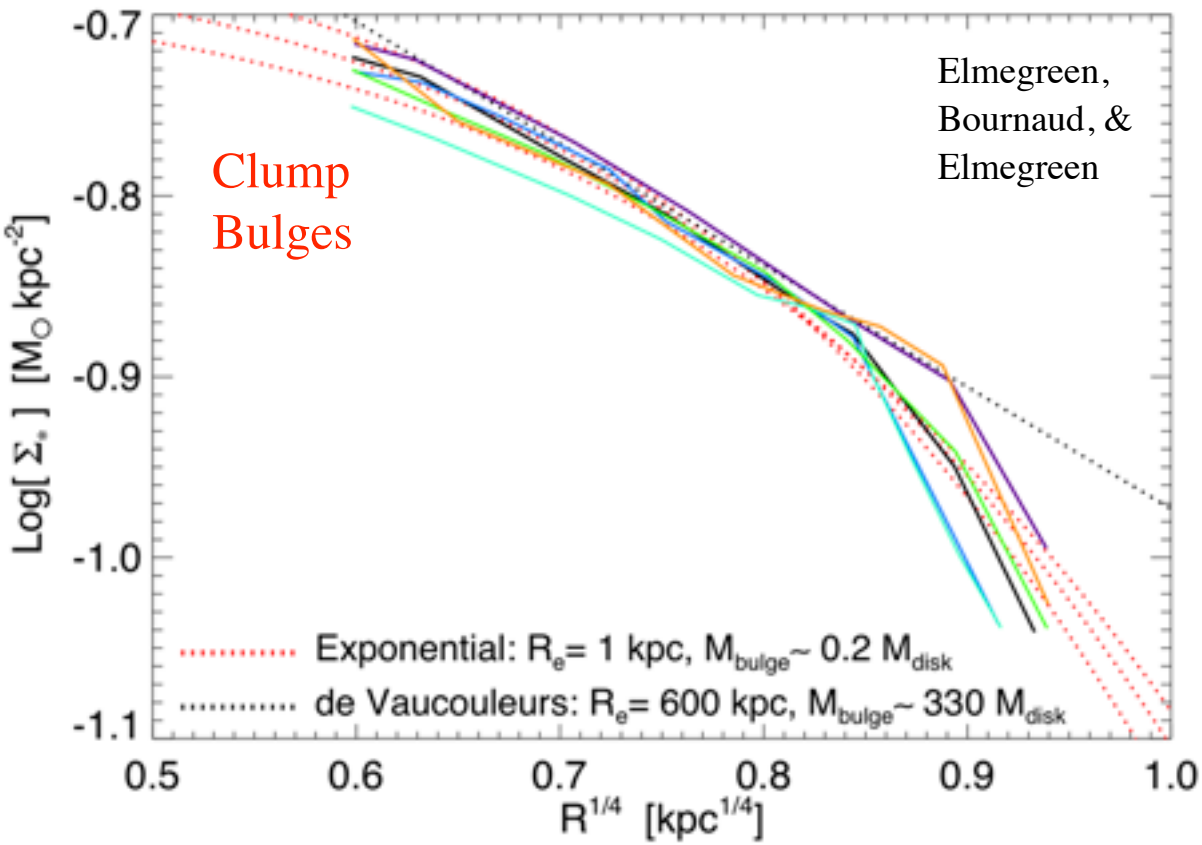

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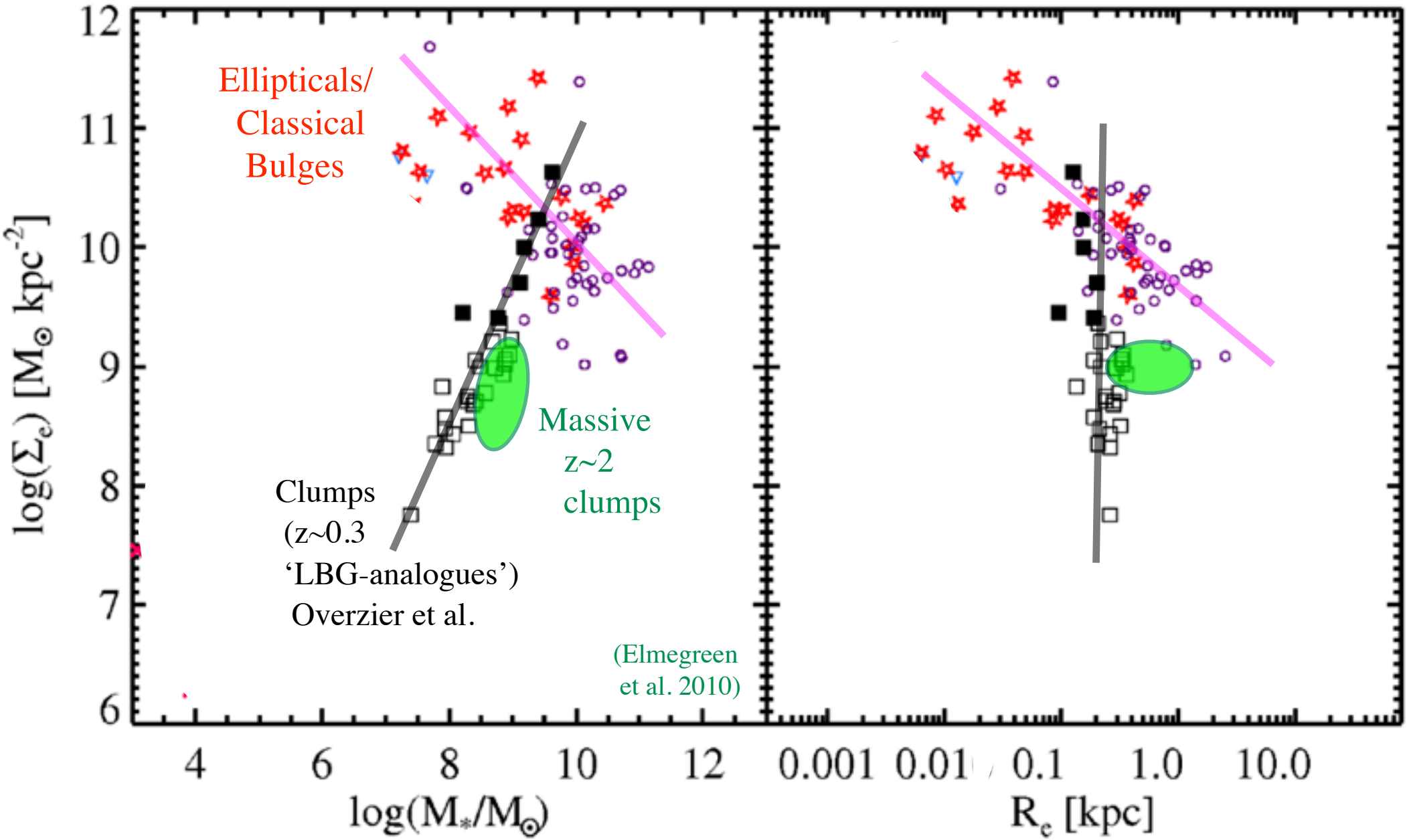

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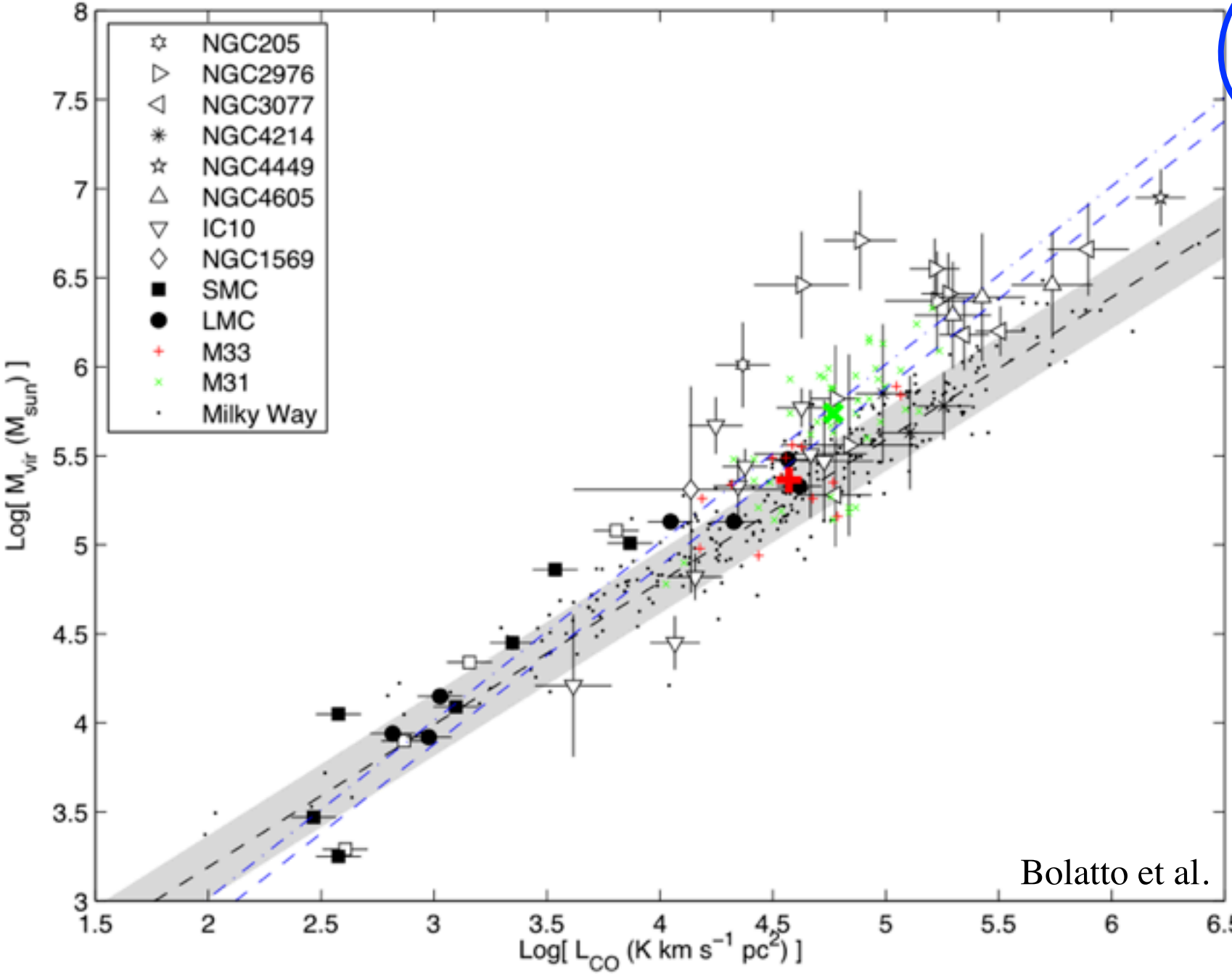
Clumps form, turn a few % into stars, dissolve, mix, re-form.....
.... just like star-forming clumps we see today

Why Are We Excited?



"clumps"

Bolatto et al.

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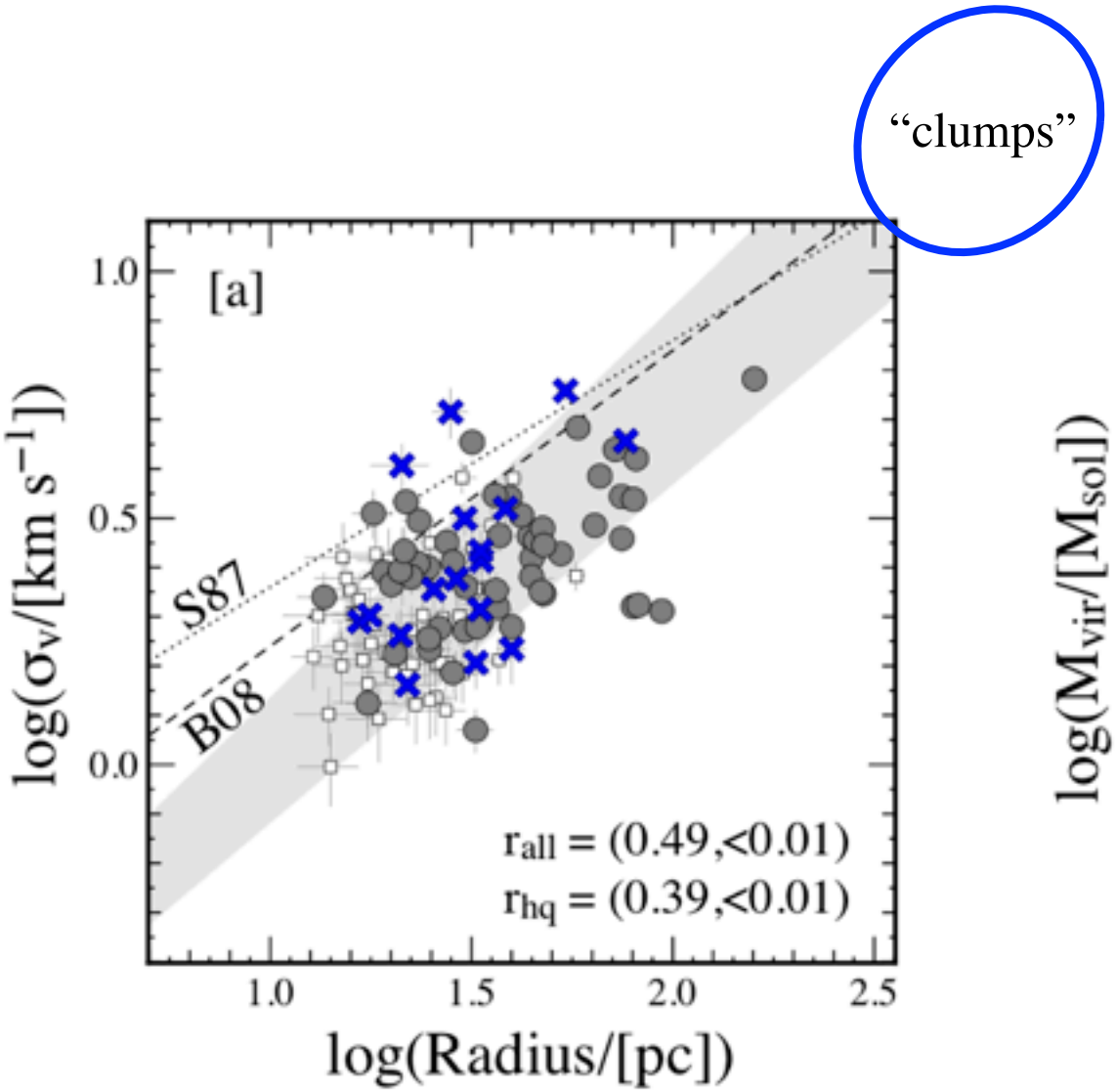

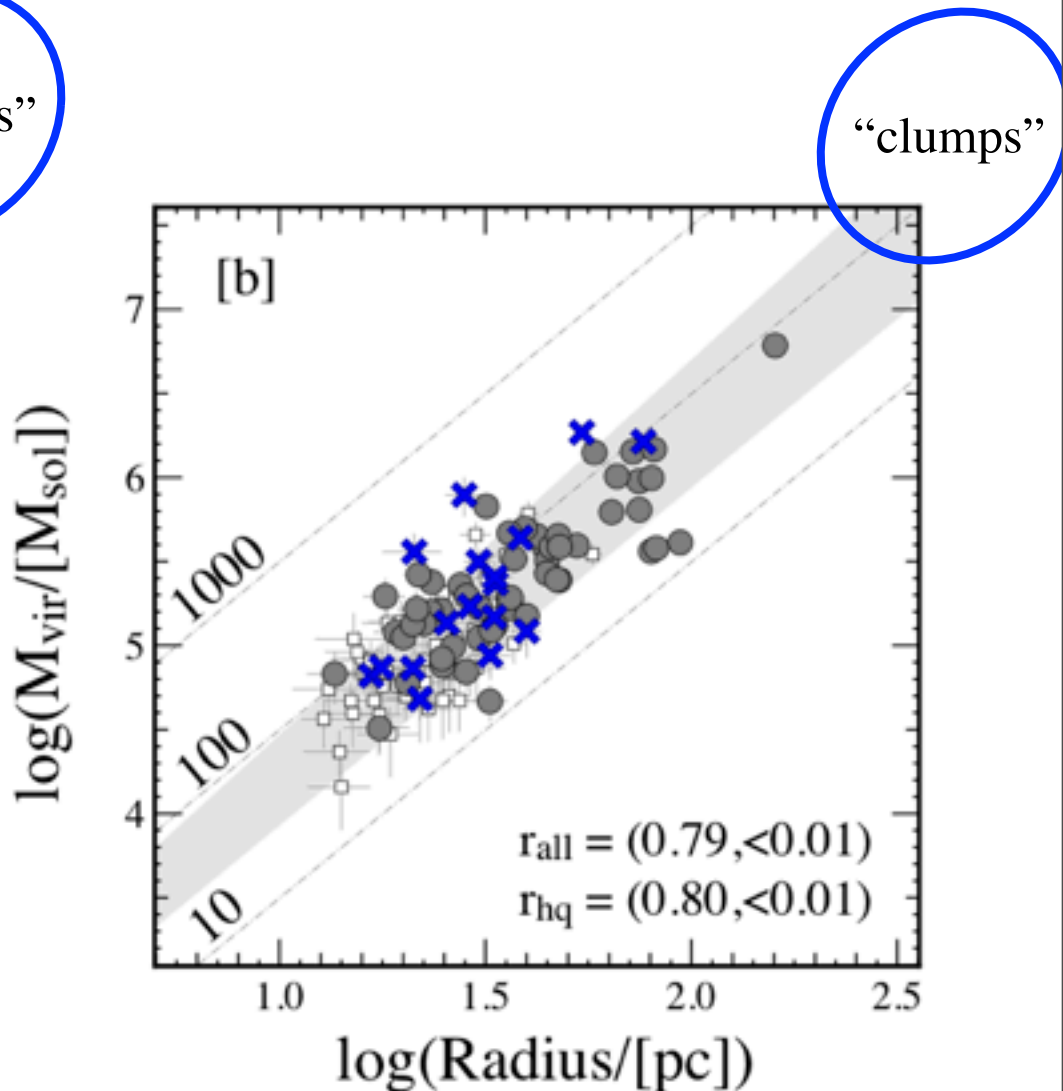

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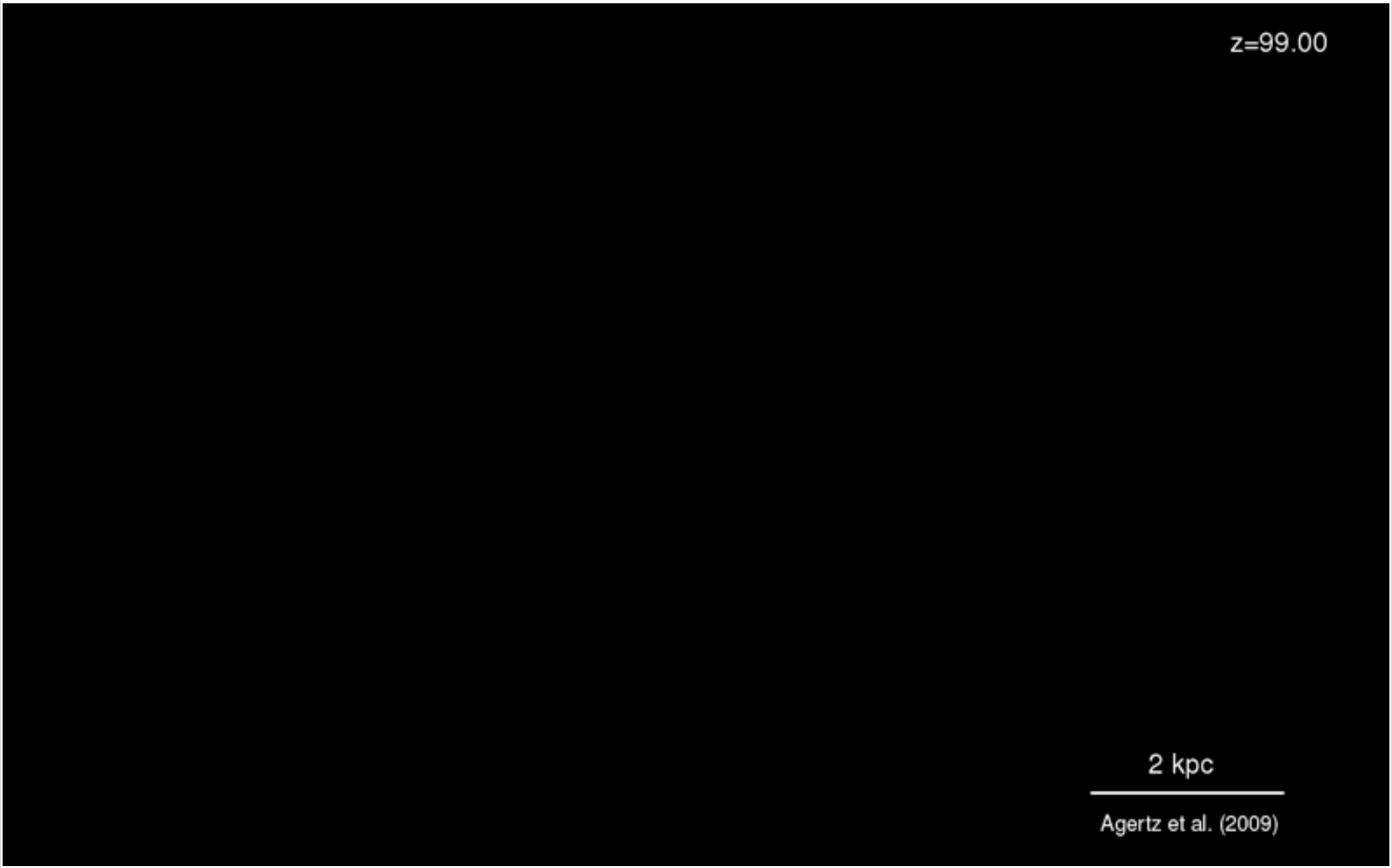

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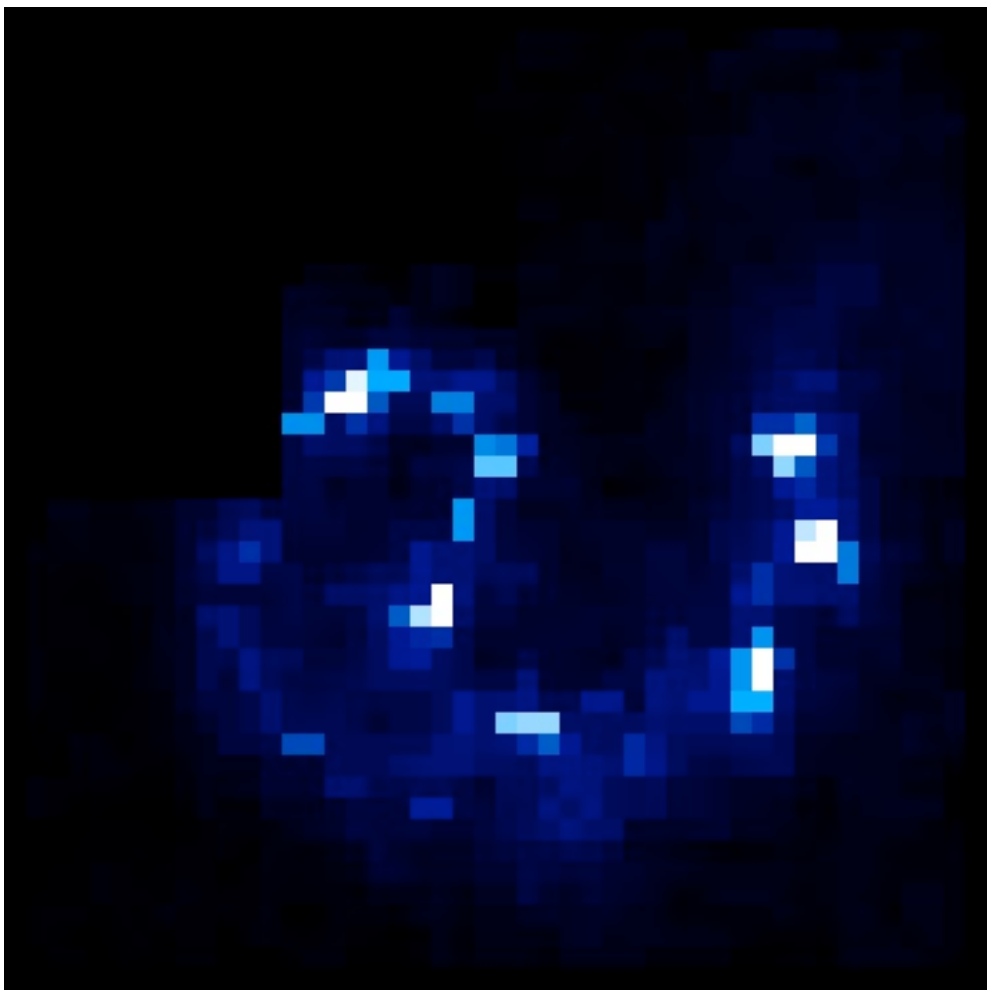

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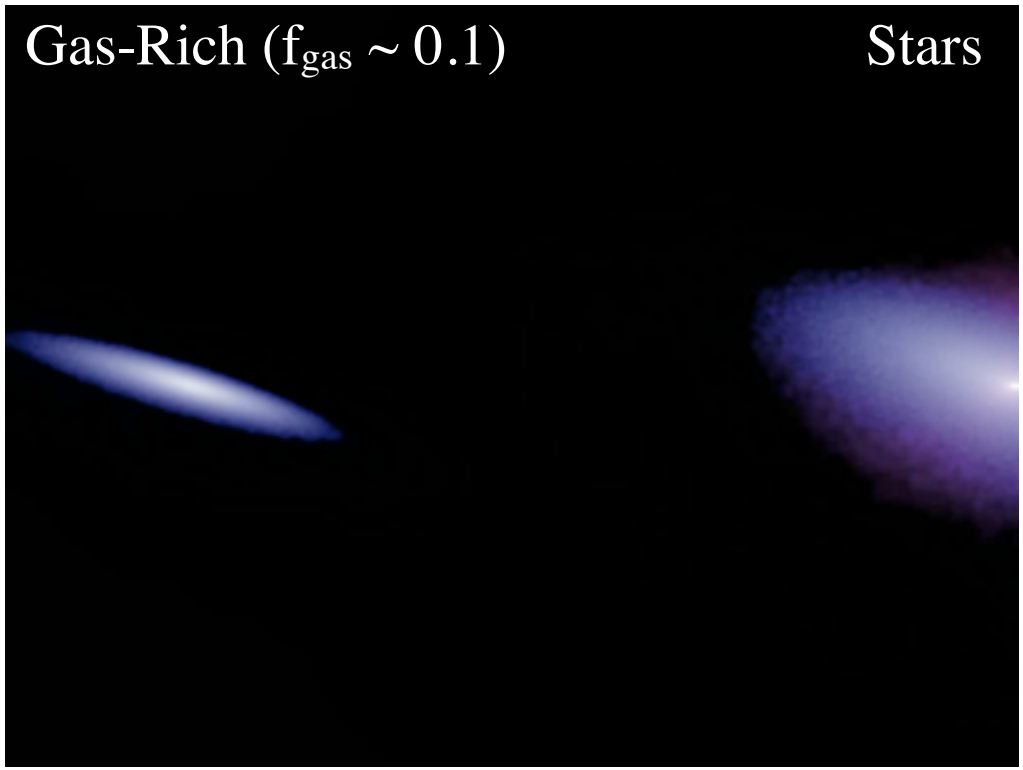
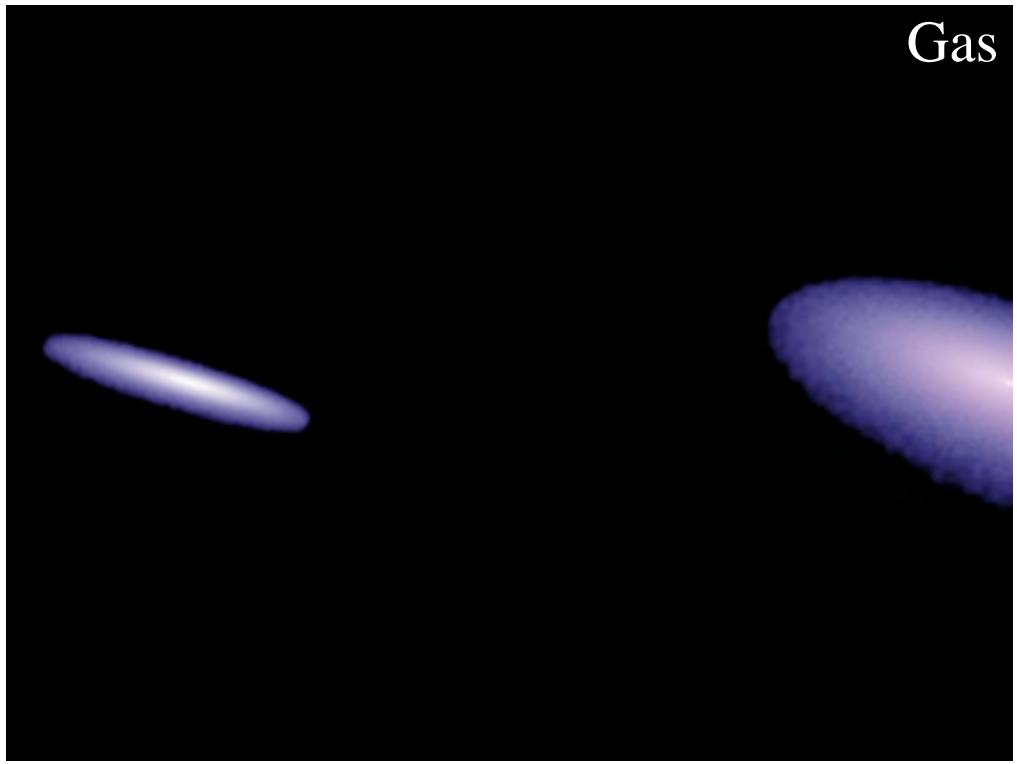
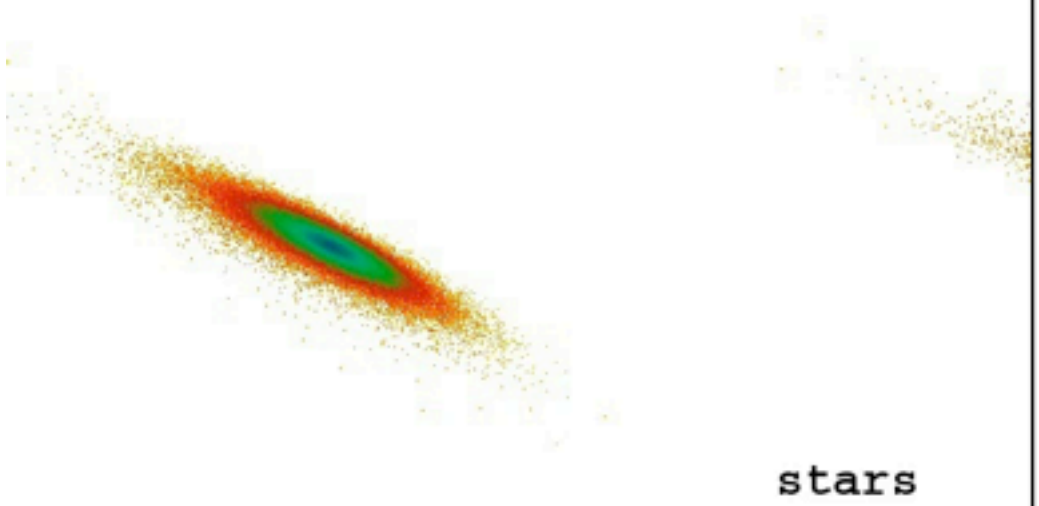
- Separating clumps and lots of minor merging is hard
- Formation induced? (akin to tidal-dwarf galaxies)
- Simple Toomre instability of a massive “progenitor” disk is misleading

How Good Is Our Conventional Wisdom?





Gas-Richer ($f_{gas} \sim 0.4$)



Robertson et al. 2006