Galaxy Evolution Workshop
Austin, TX, Nov 2008

- LCDM is a well-specified theory which makes definite predictions about the way structures in the Universe form and evolve.
  - most (all?) of the mass of the Universe is in collapsed clumps of some mass at all times
  - more massive structure assemble later through merging of smaller subunits
- This is *not* the way most stars/baryons have formed and assembled into galaxies
  - non-gravitational, baryonic processes is needed to overturn the “natural” predictions and to explain the properties of observed galaxies
  - messy astrophysics will dominate the evolution of galaxy systems

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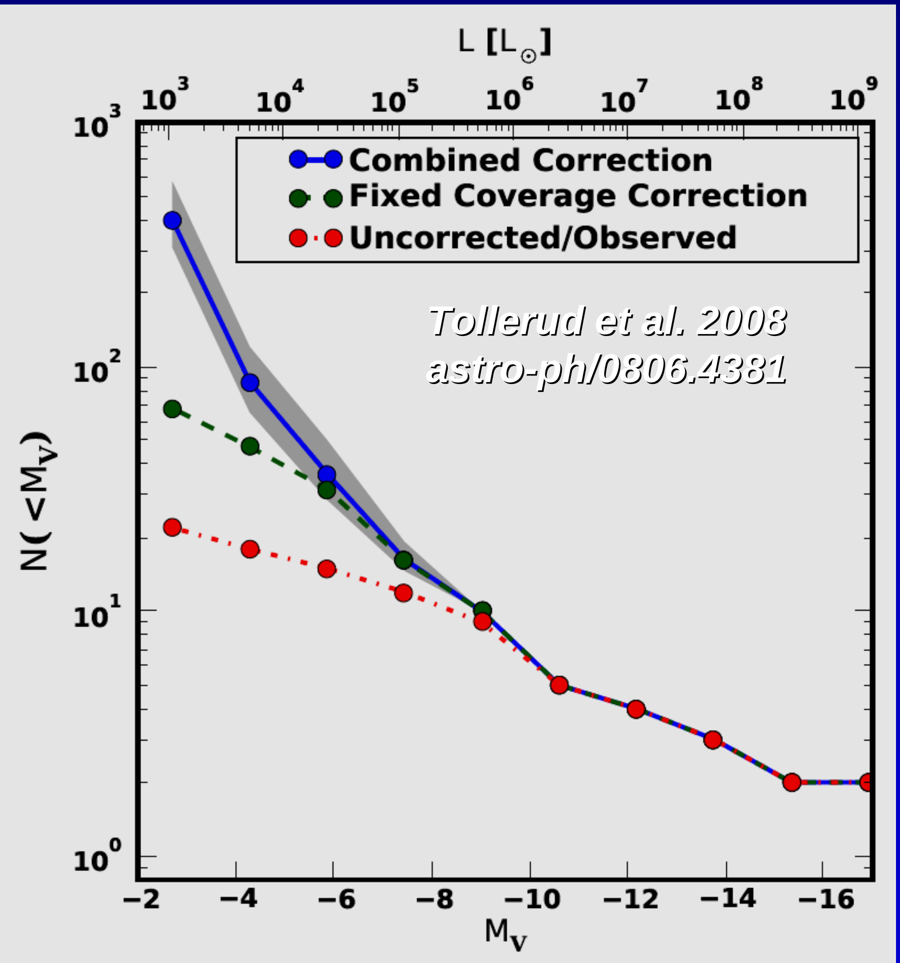
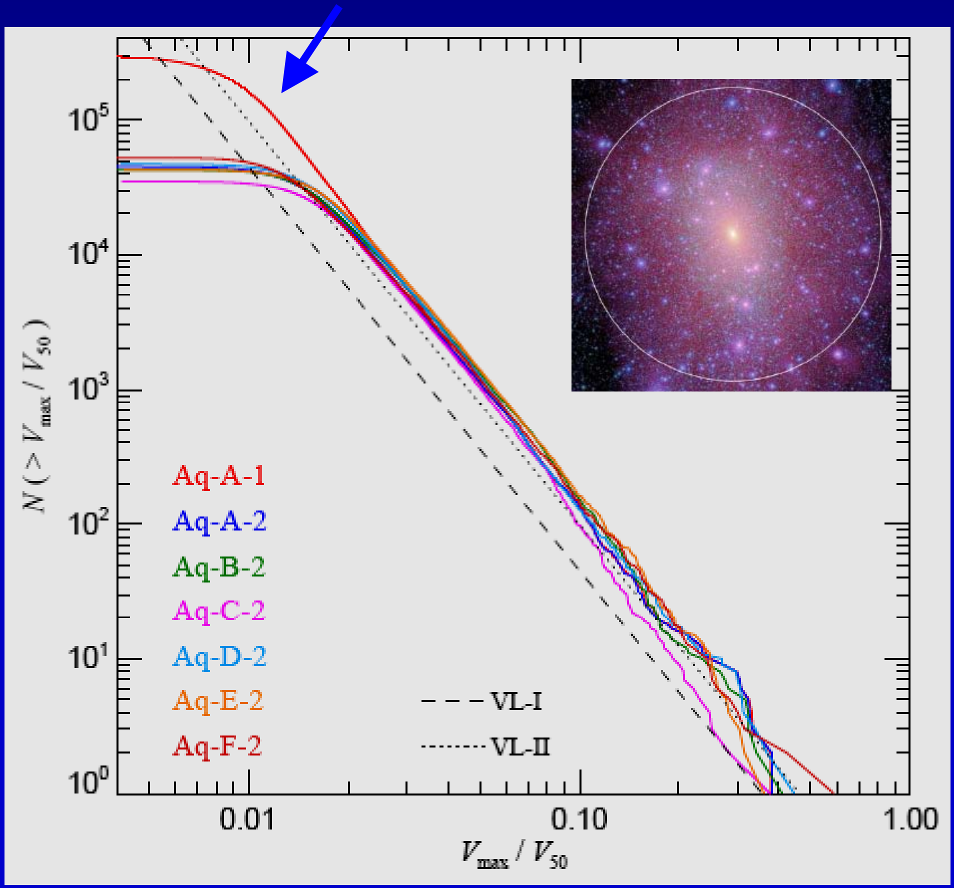
- Will try to review some of the results presented sorted by scale and distance:
  - CDM substructure/Faint galaxies in the Local Group
  - The Milky Way as seen from the Sun
  - Present-day Galaxies
    - Early types
    - Late types/Bulges
  - Evolution
    - Moderate-z galaxies/Merger rates
    - High-z galaxies/Cold Flows
    - Black Holes/AGN

CDM substructure/Faint galaxies in the Local Group (Kravtsov, Madau, Brown)

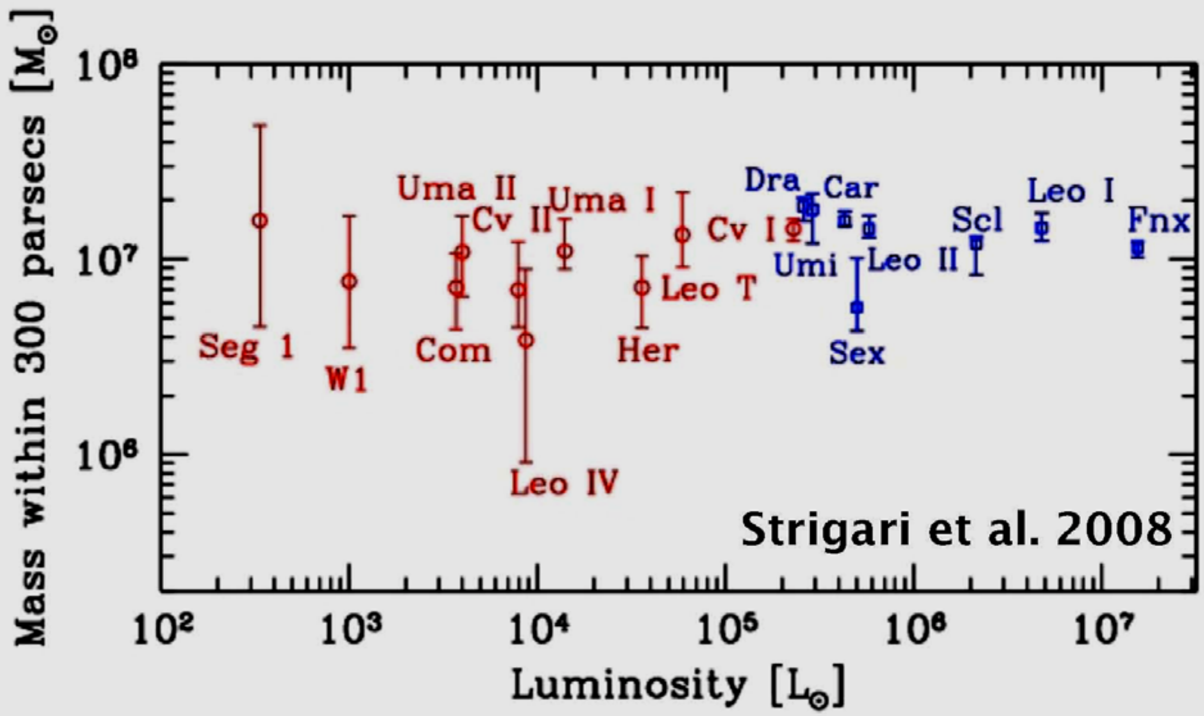


100000 subhalos within MW-sized halo

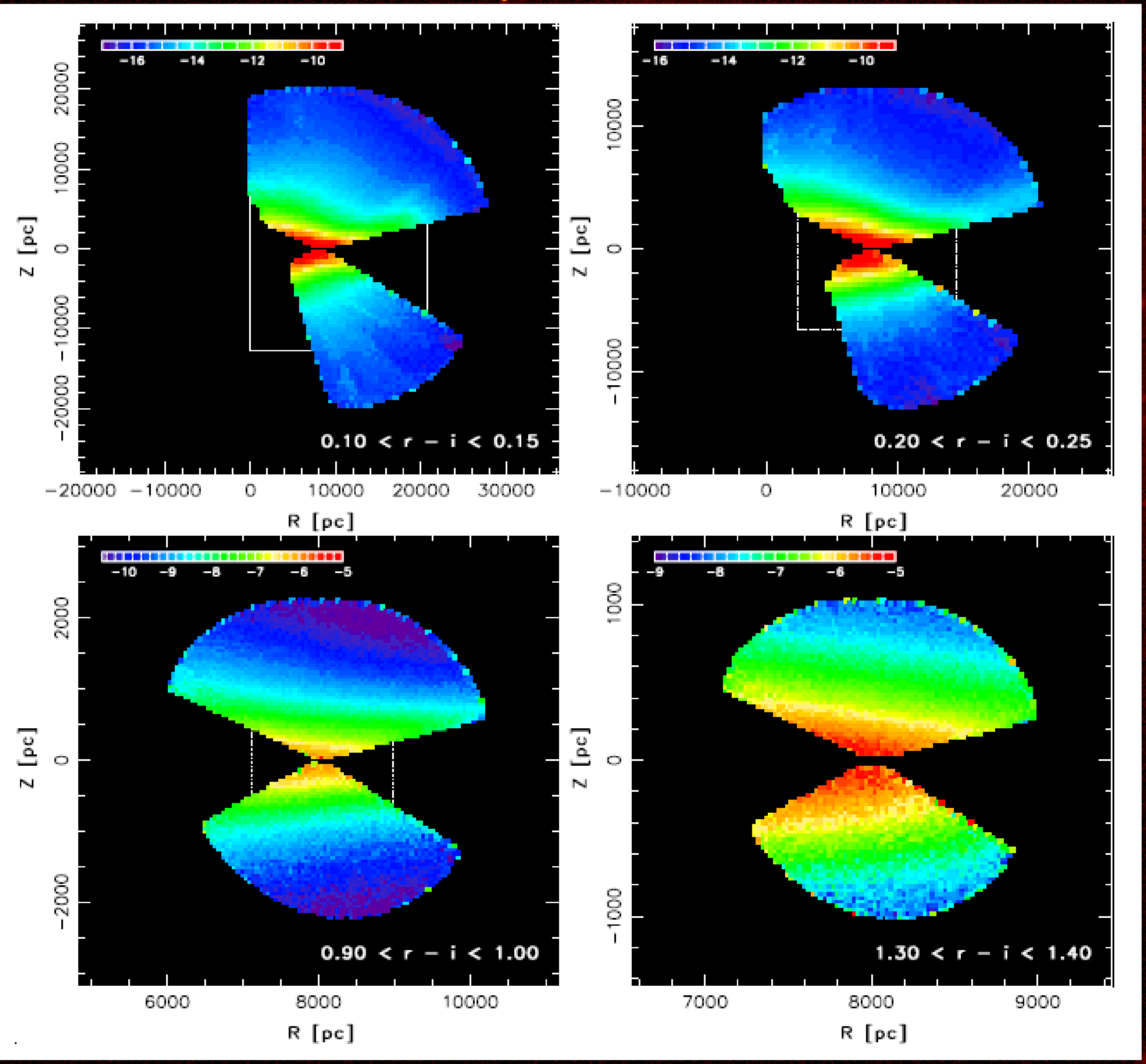


CDM substructure/Faint galaxies in the Local Group

Low-mass stars did not form in significant numbers in halos below the atomic cooling mass threshold even before the EoR. Star formation at first light occurred either with an IMF lacking stars below $0.9 M_\odot$, or was intrinsically very inefficient in hosts with $M_{sub} < 10^8 M_\odot$.



The Milky Way Tomography (Juric)

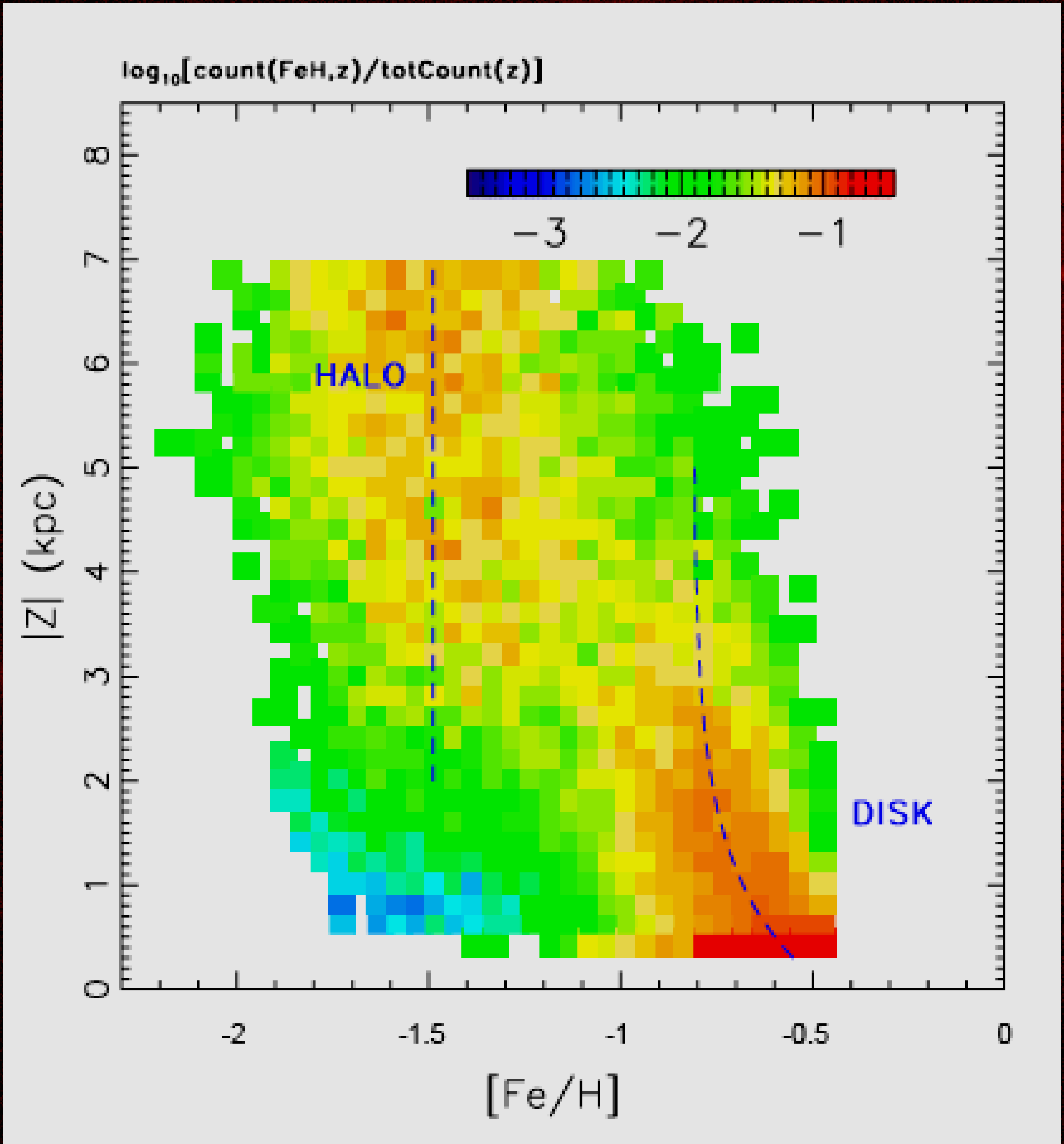


Milky Way is a galaxy with complex structures

Plenty of recognizable sub-structures

Thick disk may be 6 times more massive than previously thought?

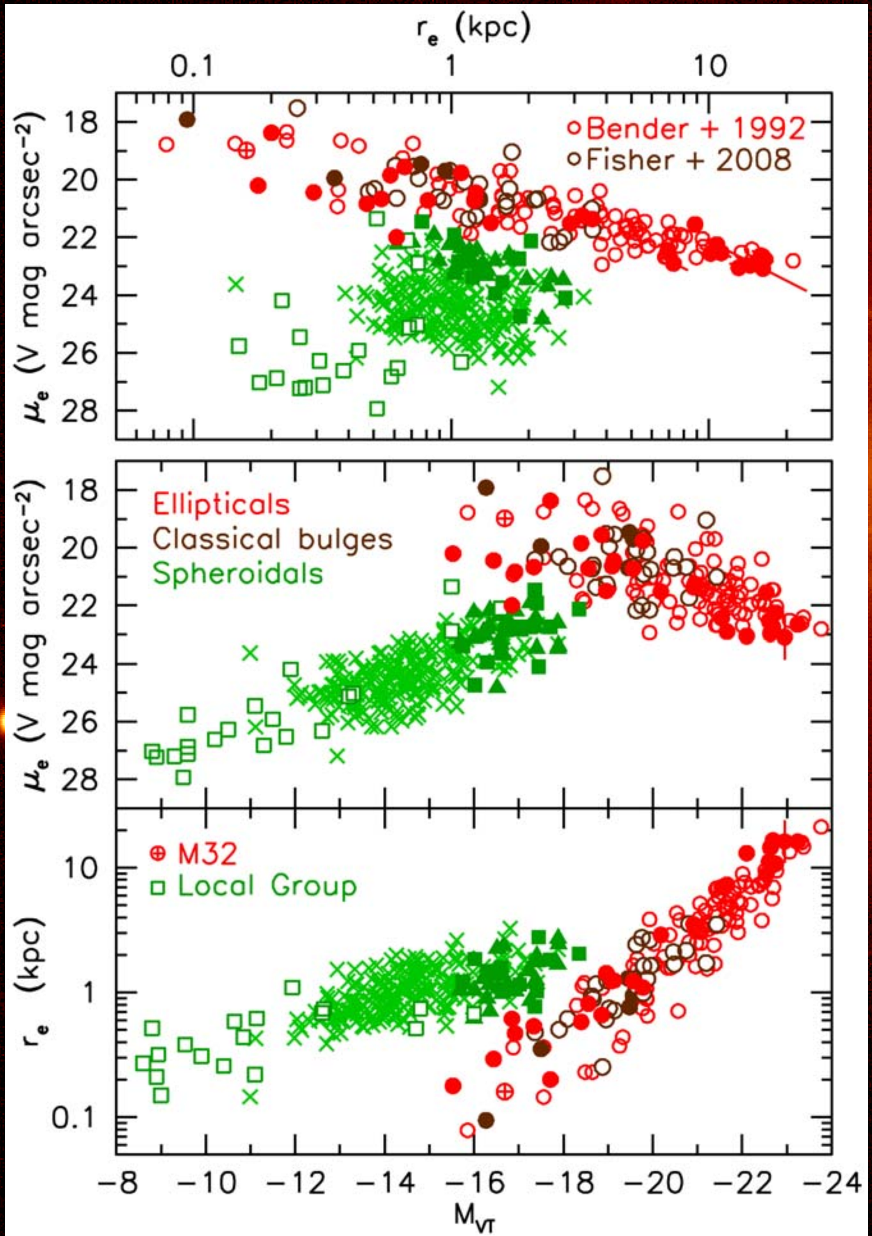
The Milky Way Tomography (Juric)



No obvious distinction between thin and thick disk

Is the Milky Way the poster child of a bulgeless galaxy with a thin disk and a quiet accretion history?

Present day Galaxies: Early types (Kormendy, Graves, Skelton, Schiminovich)



- Non rotationally-supported galaxies come at least in two types

- Mergers cannot be the only answer, although they may play a role in dictating details within the Fundamental Plane and the Red Sequence.

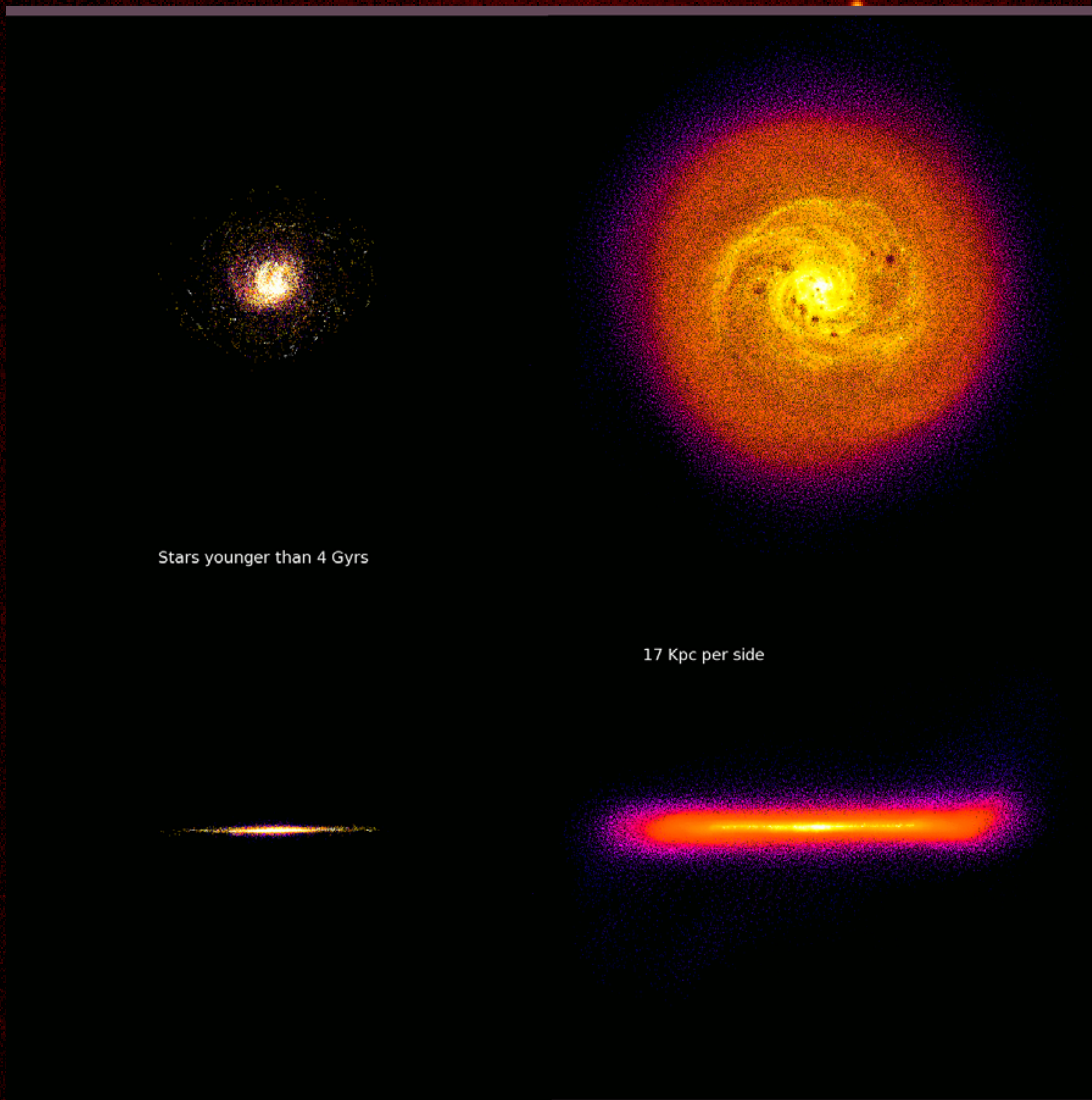
- Origin of Spheroidals. Defunct Irregulars? Not obvious that one can explain the huge range in properties and the common halo mass at the faint end.

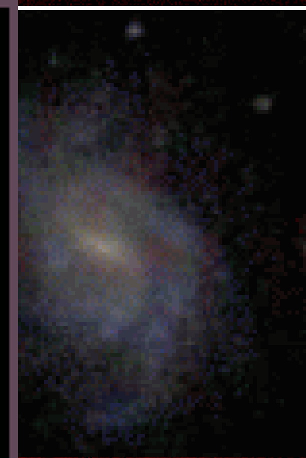
- UV properties? Need to sort out contribution of various populations.

Present day Galaxies: Late types (Burkert, Dutton, Governato, Marinova, Rhee, Balcells, Weinzirl)

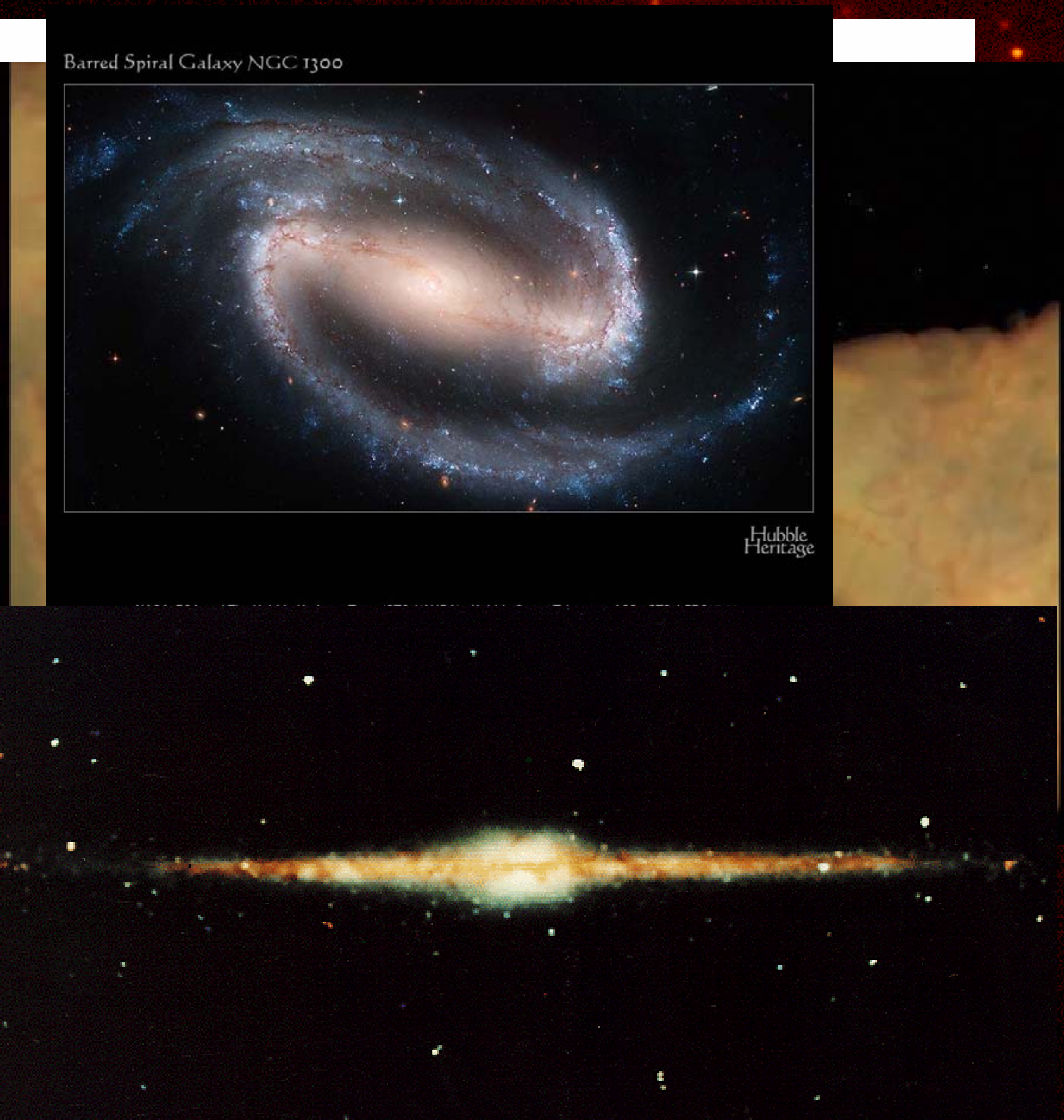
- Angular Momentum problem: need outflows to solve it?
- Cusp-Core problem: uncertainty principle?
- Bulgeless Galaxies:
    - Accounting problem?
    - Definition? ➔ Counterrotating stars
    - Can one make n<2 bulges through minor mergers?
    - How does the abundance of bulgeless galaxies depend on stellar mass?

Present day Galaxies: Late types (Burkert, Dutton, Governato, Marinova, Rhee, Balcells, Weinzirl, Shlosman)



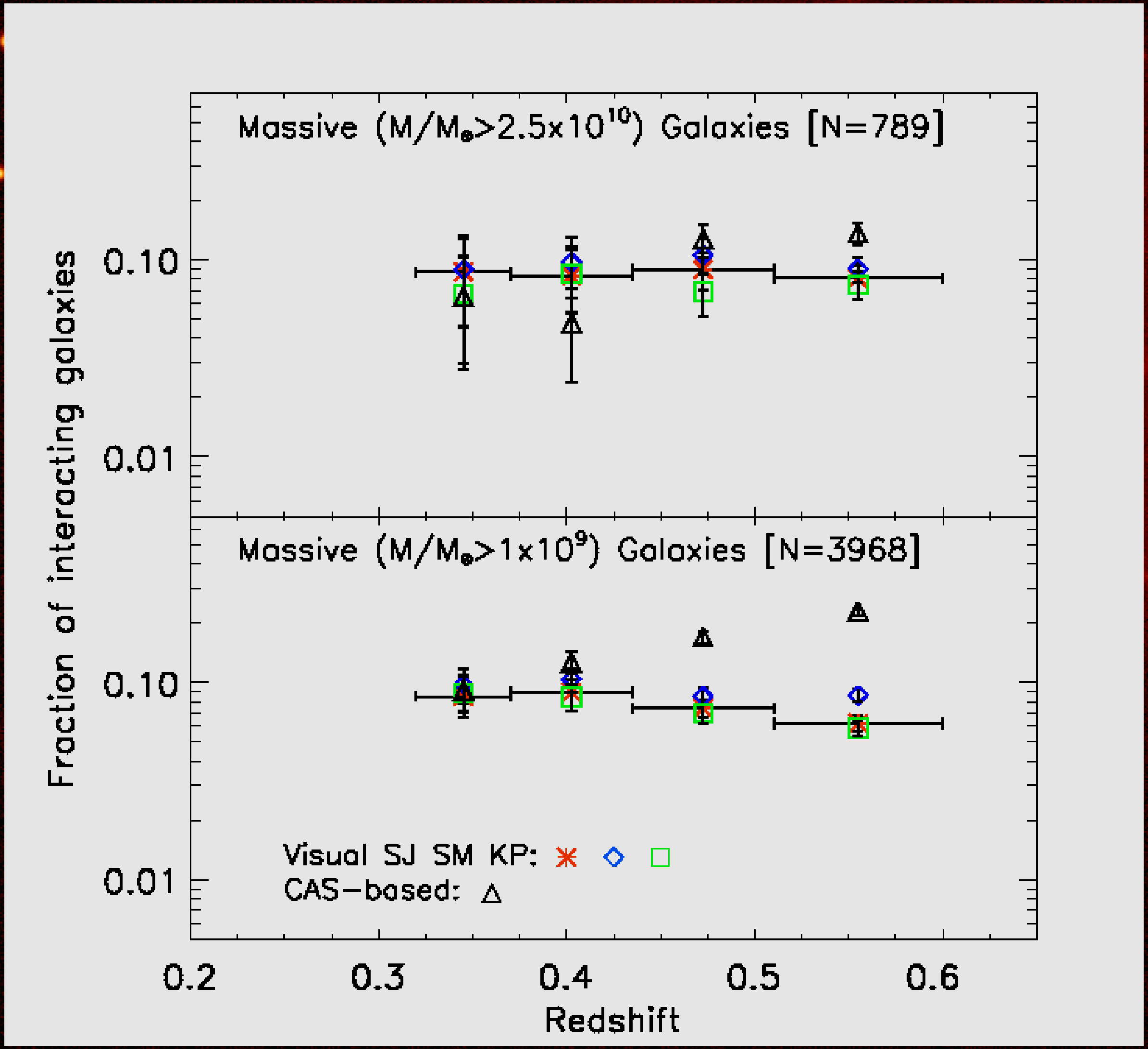


Present day Galaxies: Late types (Burkert, Dutton, Governato, Marinova, Rhee, Balcells, Weinzirl, Falcon-Barroso, Ceverino)



- Scaling laws: need for feedback and outflows
- Bulges/Disks: siamese twins? Definition of a bulge? Look at edge-on galaxies?
- Bars: ubiquitous
  - strength an important issue not yet fully taken into account?

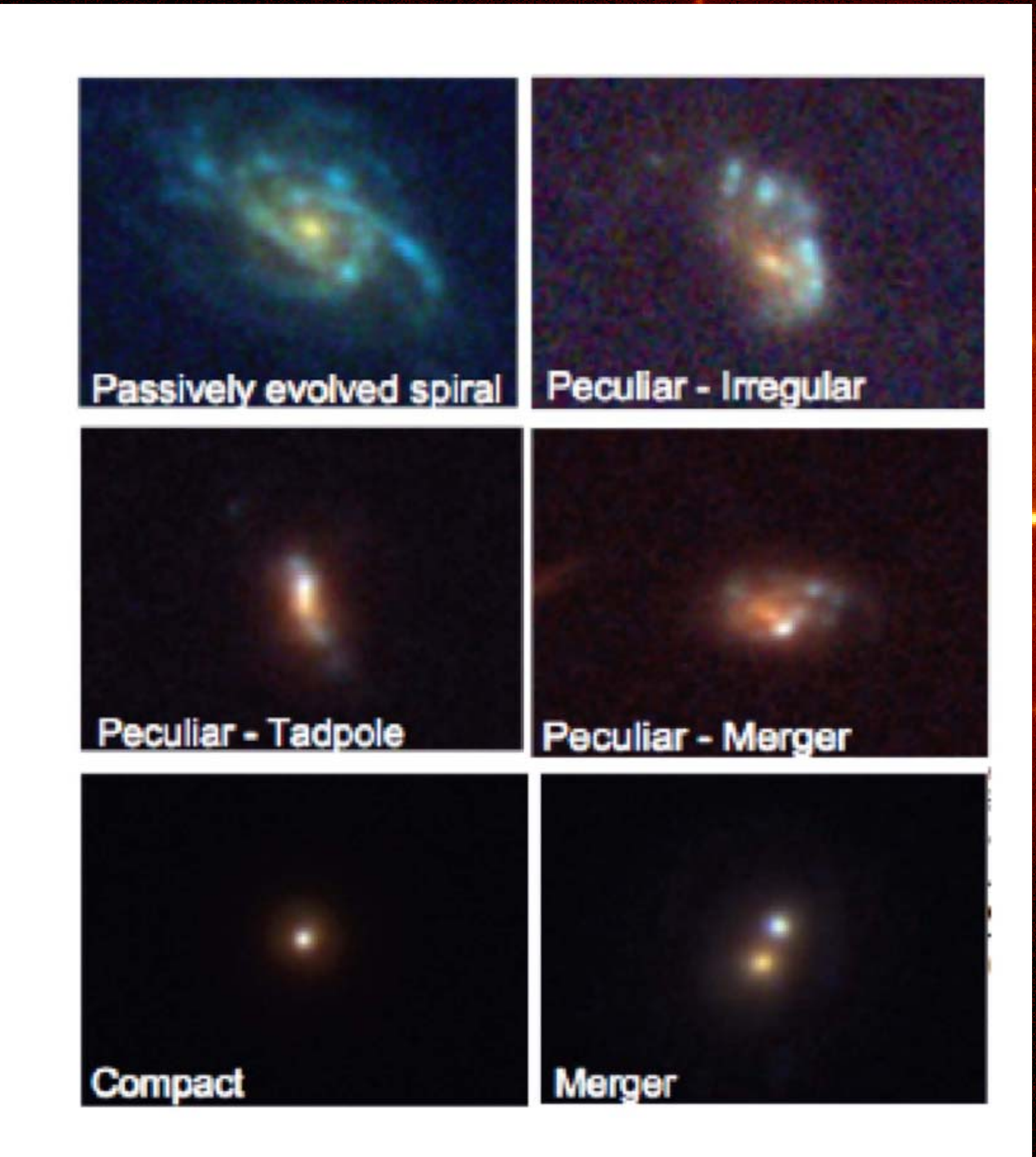
Evolutionary Processes at moderate redshift: mergers (Jogee,Robaina,Lopez-Sanjuan,Khochfar,Cox,Stewart)



- Abundance of interacting pairs/ongoing mergers seems consistent with what is expected from LCDM.

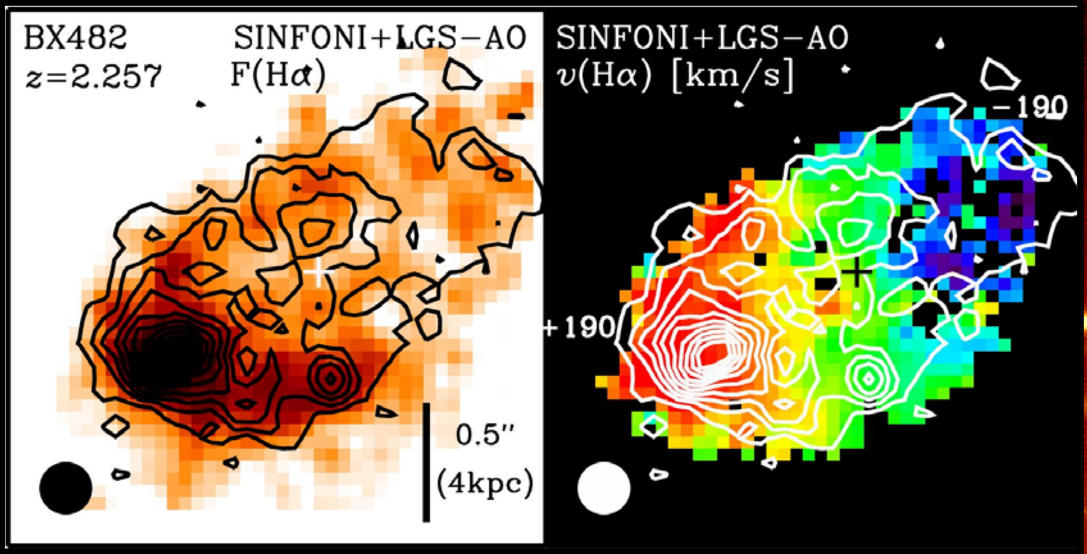
- Surprisingly small effect on star formation rates. Have mergers been overrated?

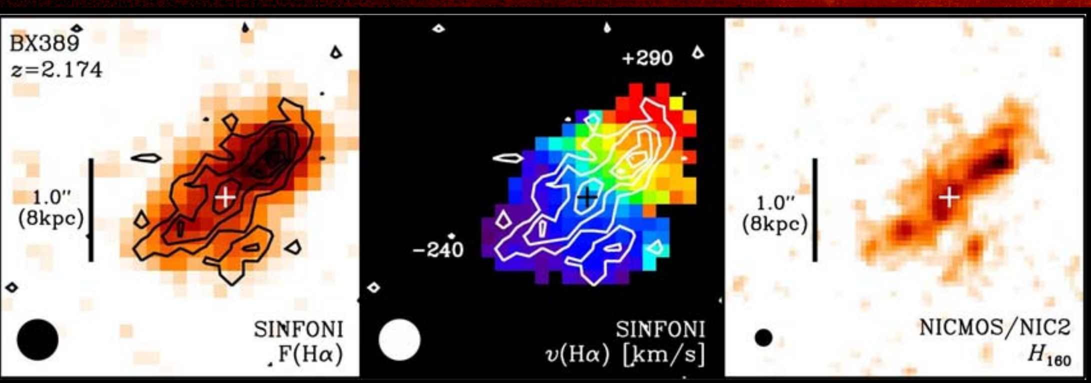
Evolutionary Processes at moderate redshift: z~0.6 galaxies (Hammer, Noeske)



- A minority (~30%) of z=0.6 galaxies are thin centrifugally supported disks in dynamical equilibrium (Hammer).
- Does this imply that mergers are important?
- How does this relate to the fairly high abundance of bulgeless galaxies?
- How does one define a galaxy in equilibrium?

Evolutionary Processes at high redshift: z~2 galaxies
(Shapiro, Dekel, Elmegreen,Dave, Reddy, Blain)





A fair fraction of star forming galaxies at z=2 are extended thick disks.

Very high star formation rates/densities.

Large sizes (problem for angular momentum?)

Clumpy, similar to “chain galaxies”. Massive, gravitationally unstable disks?

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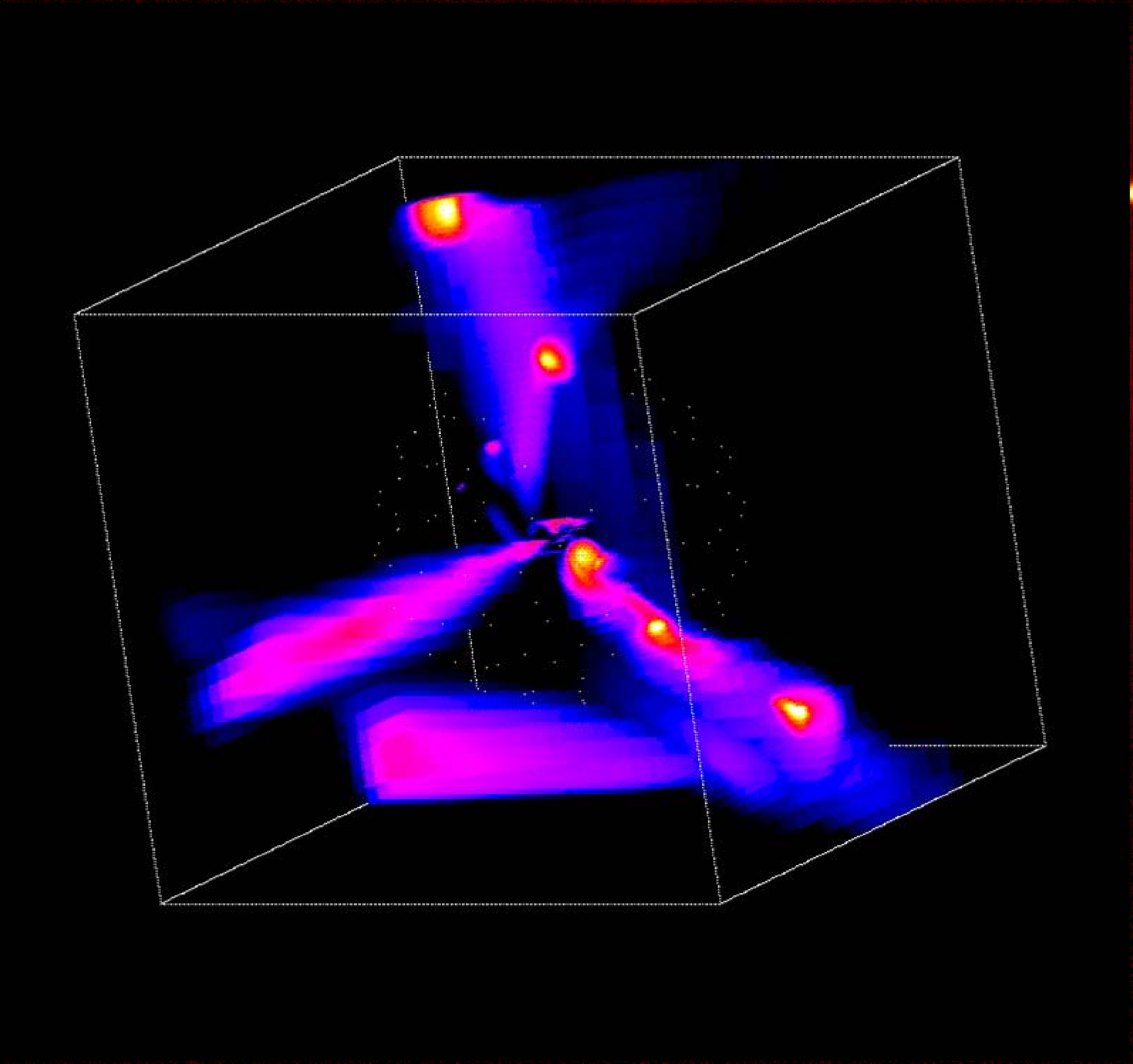
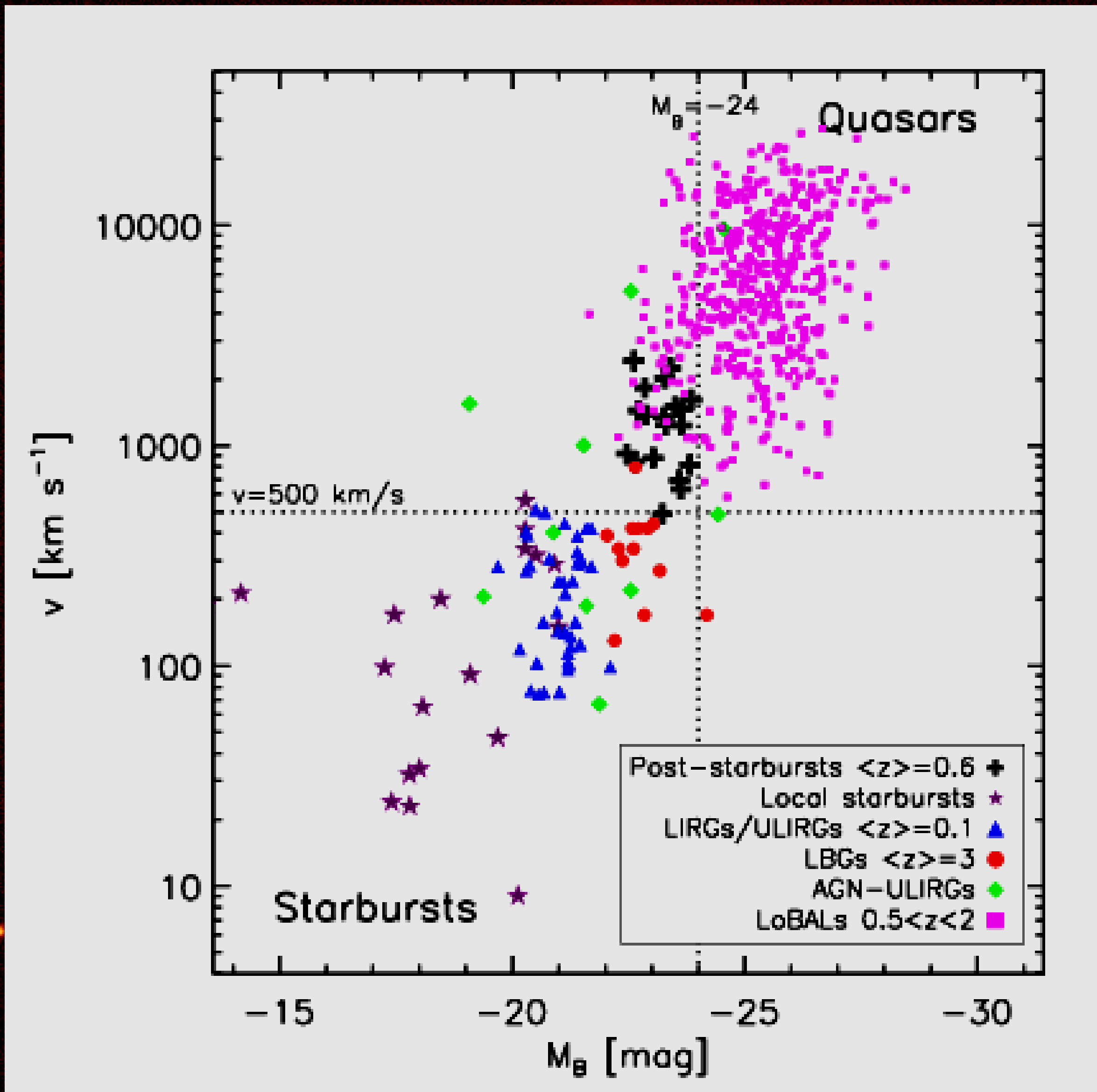


- Gravitationally unstable disks fed by "cold flows" or by mergers?
- Do we need cold flows? Are flows clumpy?
- How frequent are these massive large disks?
- How do cold flows relate to submillimeter galaxies and to star forming galaxies at high-z?
- Where are the outflows that we need? Should they be obvious in high-z gx?

Black Holes and AGN Feedback (Gebhardt, Tremonti, Hopkins)



Some mass is being lost due to feedback-driven outflows, but it is still unclear how much.

Is it worrying that this should be a ubiquitous phenomenon if one is to explain the properties of galaxies in LCDM?

The TOP TEN Questions

1. What shuts off/regulates star formation in very low-mass halos and substructures?
2. Can the scaling laws of spirals like the Milky Way be accounted for while simultaneously matching the galaxy luminosity function?
3. What determines the (small) fraction of baryons in a halo that end up in the central galaxy? How does this bias their formation times/angular momentum?
4. How do winds/outflows remove substantial amounts of baryons from early galactic potential wells and low-mass galaxies?
5. What is the physical origin of the Schmidt-Kennicutt law? Does it hold at high redshift? Do thresholds really exist? If so, what is their origin?

The TOP TEN Questions

6. Is the merging history of LCDM halos consistent with the presence of pure-disk, bulgeless galaxies? Do disks form in gas-rich mergers?
7. What feeds the high star-formation rates seen at high-z? Mergers? Cold Flows? Cooling flows?
8. How is star formation regulated in galaxies of different types and at different redshifts? Outflows should be ubiquitous, where are they?
9. What determines the mass of a central supermassive black hole? Why does it scale with bulge properties? Why don’t bulgeless galaxies develop substantial black holes?
10. Is feedback from evolving stars needed/sufficient? Do AGN play a substantial role in the formation of disk/early type galaxies?