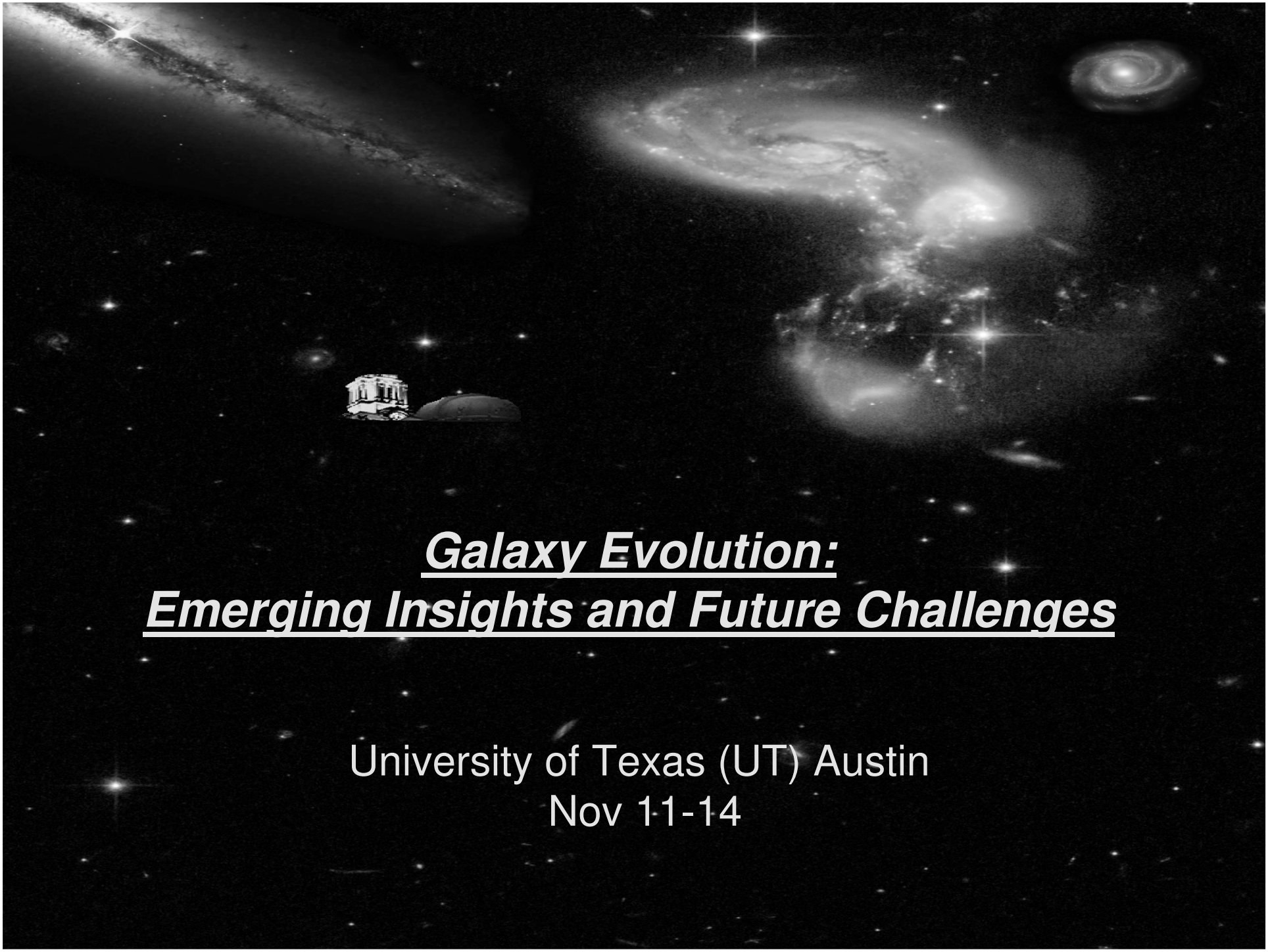


Galaxy Evolution:
Emerging Insights and Future Challenges

University of Texas (UT) Austin
Nov 11-14

Thank You !

- Department of Astronomy & Mc Donald Observatory Board of Visitors
- Scientific Organizing Committee (SOC)

Andreas Burkert (U. Observatory Munich, Germany)
Francoise Combes (Observatoire de Paris, France)
Avishai Dekel (Hebrew University, Israel)
Mark Dickinson (NOAO, USA)
Shardha Jogee (UT Austin, USA)
Robert Kennicutt (IoA, Cambridge, England)
John Kormendy (UT Austin, USA)
Julio Navarro (U. of Victoria, Canada)
Hans-Walter Rix (MPIA, Germany)
Isaac Shlosman (U. of Kentucky, USA)
Rachel Somerville (STScI, USA)

Thank You !

- Local Organizing Committee (LOC)

Monica Kidd, Jim Umbarger, Debbie Winegarten

Lara Eakins

Joel Barna

Lei Hao

Irina Marinova, Amanda Heiderman

Tim Weinzirl, Guillermo Blanc, Jeremy Murphy

Chris Wilkinson, Gordon Orris

- Graduate Student Drivers

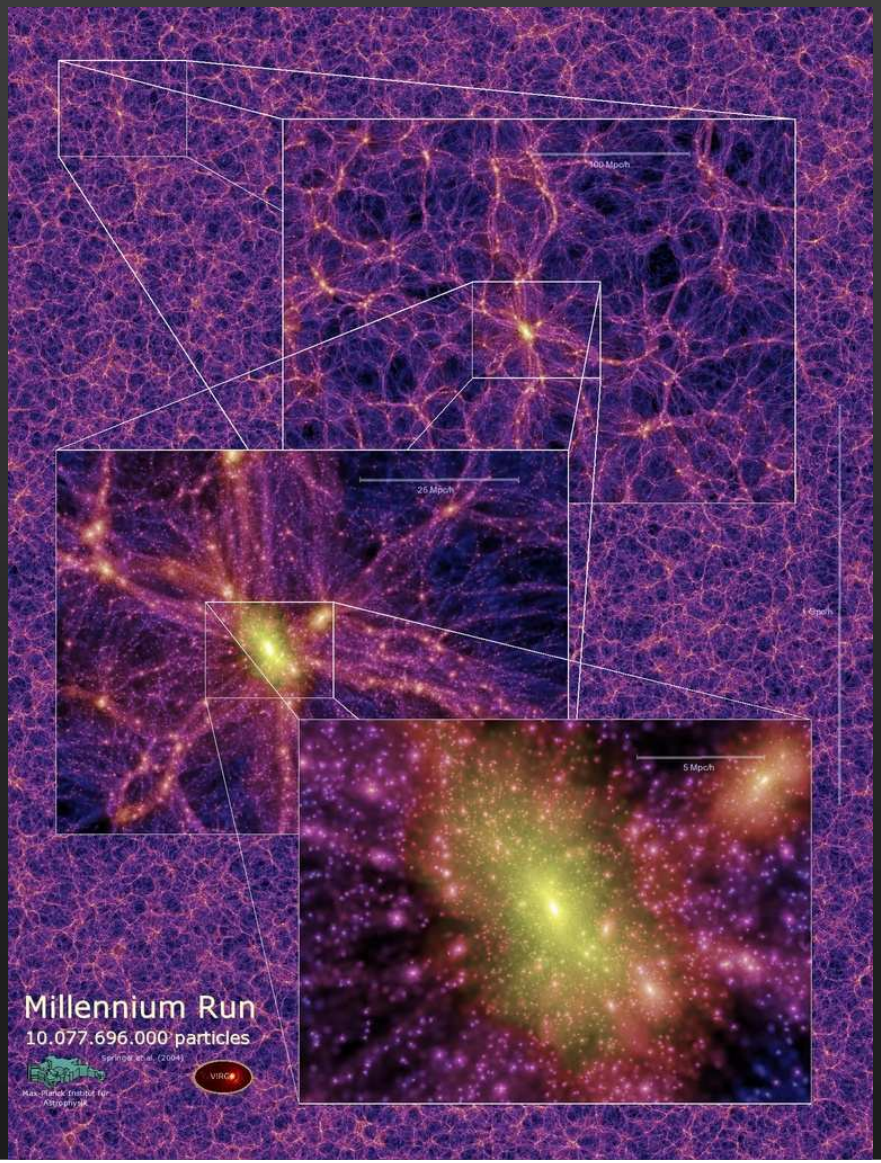
Guillermo Blanc, Jeremy Murphy

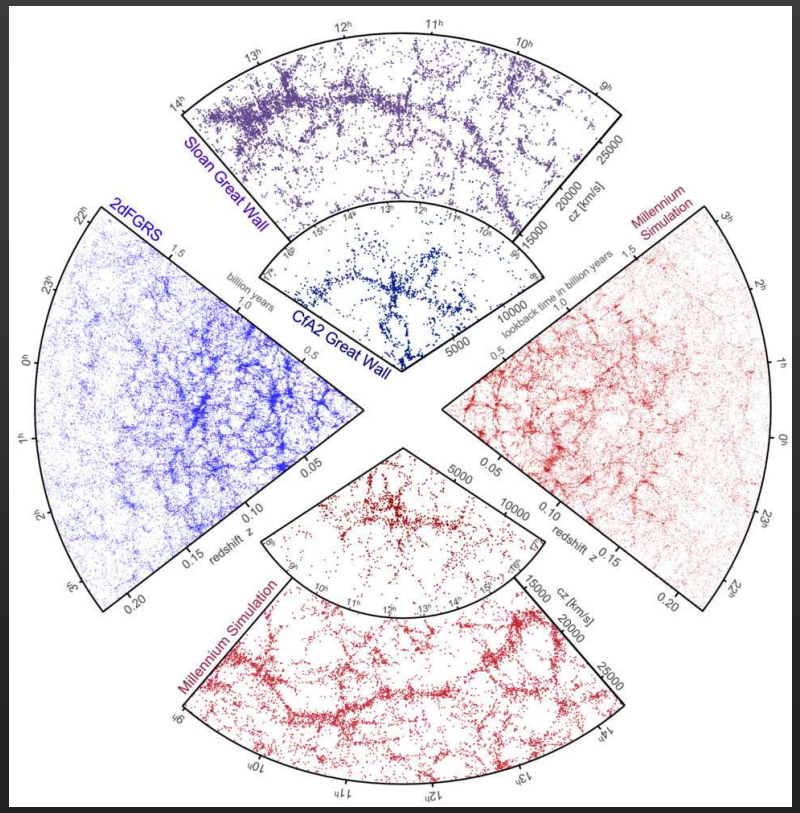
Tim Weinzirl, Josh Adams , Chalence Safranek-Shrader

Megan Agarwal Irina Marinova, James Hermes, John Barentine

Challenges for ΛCDM models of galaxy evolution

ΛCDM models = good paradigm for how structure and DM evolves on large scales





(Springel et al. 2005)

Millenium Run : 10^{10} particles
Follows DM in region D=15 Mpc/h
Resolution = 5 kpc/h

Challenges for predicting how galaxies evolve

à Model predictions not unique/robust

1) Limited dynamic range + spatial resolution

Cannot simultaneously model large-scale environment and resolve galaxy components (bulge, bar, disk)

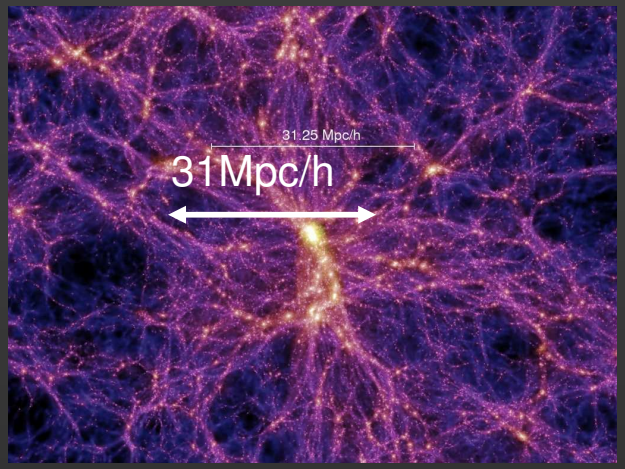
[N=$10^{10,}$ D=500Mpc/h, Resolution~5kpc/h]

2) Halo occupation statistics

3) DM halo merger à galaxy merger history

4) Assumed baryonic physics

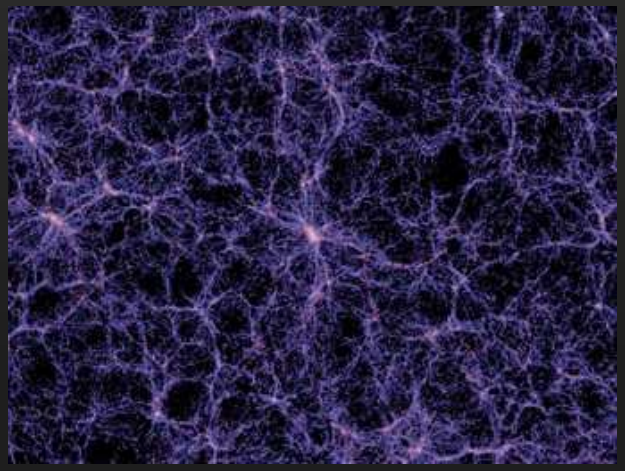
Model of ISM, recipes for star formation and feedback, mechanisms to redistribute angular momentum (mergers, bars, dynamical friction)



DM

↓

Light



Broad Questions For This Workshop

1) Status of challenges to LCDM models of galaxy evolution?
- Angular momentum problem
- Challenge of galaxies with no bulges or bulges of (low B/T, n)
- Substructure or missing satellite problem
- Cusp–core controversy

à Latest empirical constraints on the history of (mergers, SF, and structural assembly)

à Are problems alleviated by improvement in resolution + baryonic physics (feedback)

2. New challenges ?
- massive disks at z~1.5 to 3 with high SFR/bulges but no signs of major mergers
- mass function of very massive galaxies

3. Relative importance of different galaxy assembly modes as f(z)
major mergers, minor mergers, cold gas accretion, secular modes

4. SF and AGN activity: triggers and feedback

(A) Challenge of galaxies with no bulge or low (B/T, n) bulges

(A) Challenge of galaxies with no bulge or low (B/T, n) bulges

1) Major mergers build classical bulges

- Violent relaxation of stars à spheroid of low v/σ, n=4 (or 2<n <6)
- B/T at z~0 depends on epoch of last major merger & subsequent disk buildup

Every galaxy that had a major merger at an epoch when its mass was a significant fraction of its present-day mass should harbor a classical bulge with a significant bulge-to-total (B/T) ratio.

2) Secular processes build disky pseudobulges and boxy bulges

- Gas inflow driven by a bar in non-interacting galaxy à SF builds disky, high v/σ, low n<2.5 stellar component = disky/pseudobulge (Kormendy 93)
- Buckling instability + vertical ILRs make edge-on bars look peanut/boxy (Combes, Shlosman)

3) Minor mergers build …. bulges

- Gas inflow driven by induced bar and tidal torques à SF builds disky component?
- Satellite accretion in central region builds/enhances bulge. Structure?

(A) Challenge of galaxies with no bulge or low (B/T n) bulges

1) In low mass/late type galaxies: bulgeless galaxies are frequent

- late type galaxies are often bulgeless (Boker et al. 2002)
- 15% of edge-on SDSS galaxies are thin bulgeless disks (Kautsch et al. 2006)
- 20% of i<60 SDSS galaxies at z<0.03 appear bulgeless (Barazza, Jogee, Marinova 08)

(Kautsch et al. 2006)

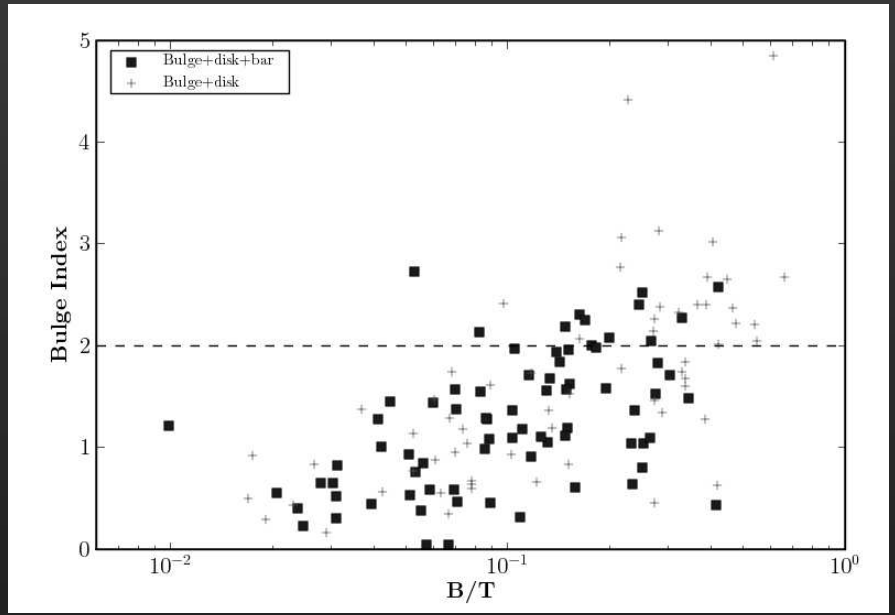
(Barazza, Jogee, Marinova 08)

(A) Challenge of galaxies with no bulge or low (B/T n) bulges

2) Even high mass spirals show a high frequency of low (B/T, n) bulges

- Most S0 -S0/Sa have bulges with Sersic n < 2 (Balcells et al 03; Laurikainen et al 07)
- 11/19 galaxies with D<8 Mpc& Vc>150 km/s have pseudobulges (Kormendy & Fisher 08)

- For a sample of 140 M*>1e10 spirals:
66% have B/T < 0.2 & 77% have n< 2.
SAM models predict that galaxies with a past major merger can only account for 3% of spirals with such low B/T.
à Are remaining bulges built via minor mergers and secular modes?
(Weinzirl et al. 08; See talks by Khochfar, Weinzirl, Balcells)



(Weinzirl et al. 08)

- Most of 400 spirals along Hubble sequence have B/T<0.25 (Graham & Worley 2008)

QUESTIONS/OPEN ISSUES

Theory

1) Can cosmological simulations produce enough bulgeless/low B/T galaxies ?
2) Do main processes for removing low J gas differ in high vs low mass systems?
3) Models have focused primarily on major mergers. How do we better incorporate bulge building via secular evolution, minor mergers, and cold gas accretion?

[Talks: Burkert, Navarro, Governato, Dekel, Khochfar, Combes,,Shlosman, Cox, Stewart, Hopkins]

Observations

4) Fold in Ages + Kinematics+ Metallicity w/ structure of (B/T, n) of bulges
5) How do bulge, bar, disks vary in field vs cluster enviroments ?

[e.g.,Talks by Barroso, Juric, Brown, Balcells, Fisher, Weinzirl, Marinova, Graves]

6) Direct empirical constraints on minor and merger history out to z~2

[see talks by Balcells, Sanjuan, Robaina, Sketlon, Stewart, Conselice, Jogee]

(B) Kinematics of massive, star-forming galaxies at z~1.5-3

(B) Kinematics of massive, star-forming galaxies at z~1.5-3

For UV/optically selected, massive star forming galaxies at z~1.5 to 3.0

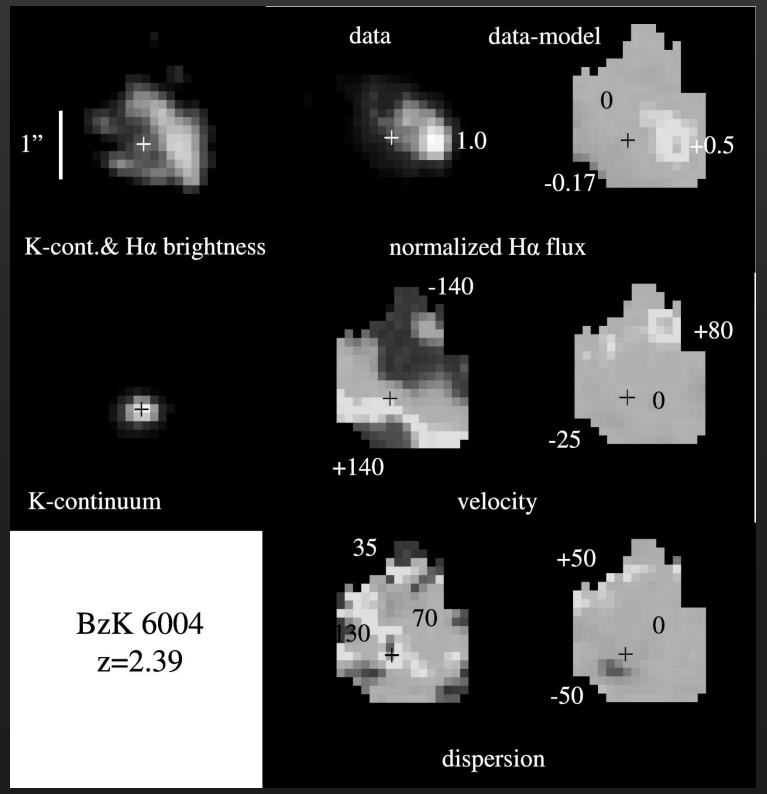
- ionized gas show high % of large rotating disks with no signs of major mergers
  (Shapiro et al. 2008; Forster Schreiber et al 2006; Genzel et al. 2006; Wright et al 2007; etc)

- Hα IFS of sub-sample of 8 galaxies show turbulent outer disks + bulge/inner disks whose dynamical mass fraction scale with [NII]/Ha and SF age (Genzel et al. 08).

Authors suggest

à inner components assemble through rapid secular evolution (DF + viscous)

à turbulence in outer disk is stirred up by cold accretion flows



(B) Massive, star-forming galaxies at z~1.5-3

QUESTIONS/OPEN ISSUES

1) Small sample
   Selection bias of UV/optically selected vs submm selected systems

2) Detectability of merger signatures at z~2?
   Alternative interpretation of kinematics ?

3) What are observational prospects for
   - increasing sample size for ionized gas kinematics
   - tracing cold gas with future radio/submm facilities in such systems?

   [Talks by Shapiro, Elmegreen, Dekel, Daddi, Blain, Reddi, Noeske]

(C) Direct constraints on galaxy merger history

QUESTIONS/OPEN ISSUES

- Merger rates from morphological distortions & pair counts in ACS surveys
  - out to z~1 in rest-frame optical
  - at z~1.5 to 3.0 in rest-frame UV : how reliable?

- How well do observed merger rates agree w/ predictions from hierarchical models?

- Since z=1 over the last 8 Gyr: mounting evidence that major mergers only have a small impact on SFR density à Is decline in SFR density driven by smooth accretion of gas and/or minor mergers ?

  (see talks by Balcells, Sanjuan, Robaina, Conselice, Jogee)