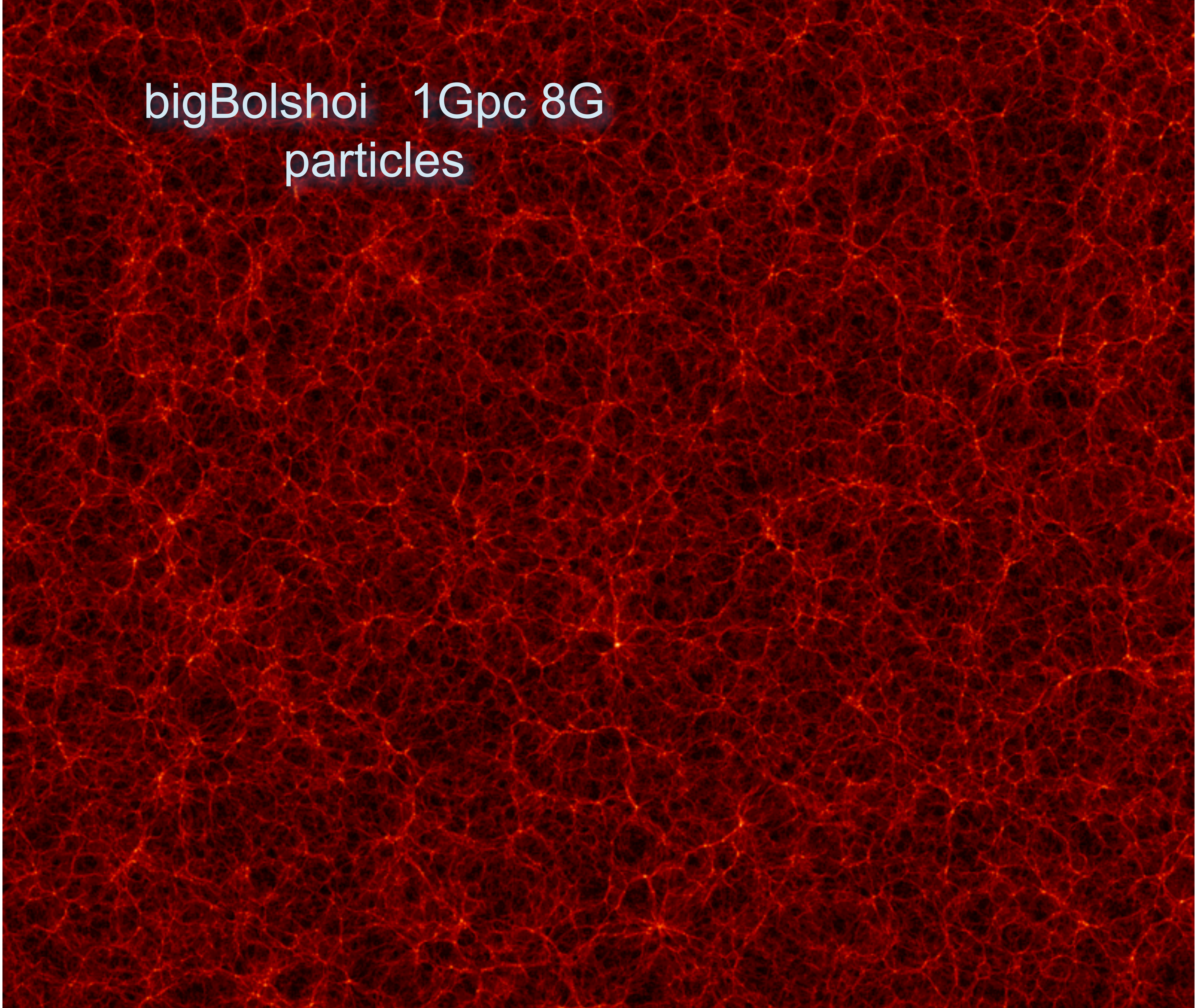
Early formation of compact spheroids by disc instabilities, compaction and quenching

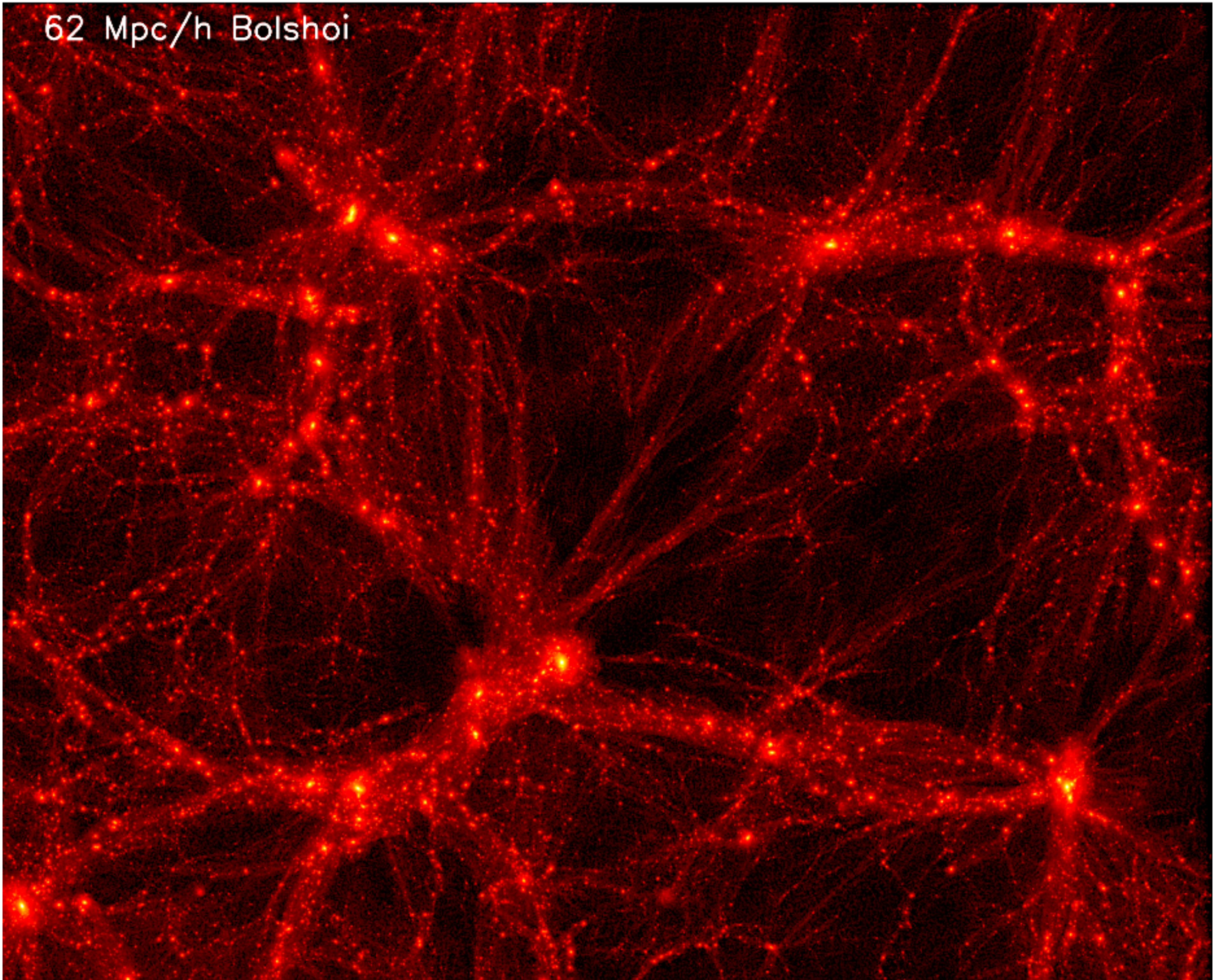
Daniel Ceverino (CAB, Madrid)

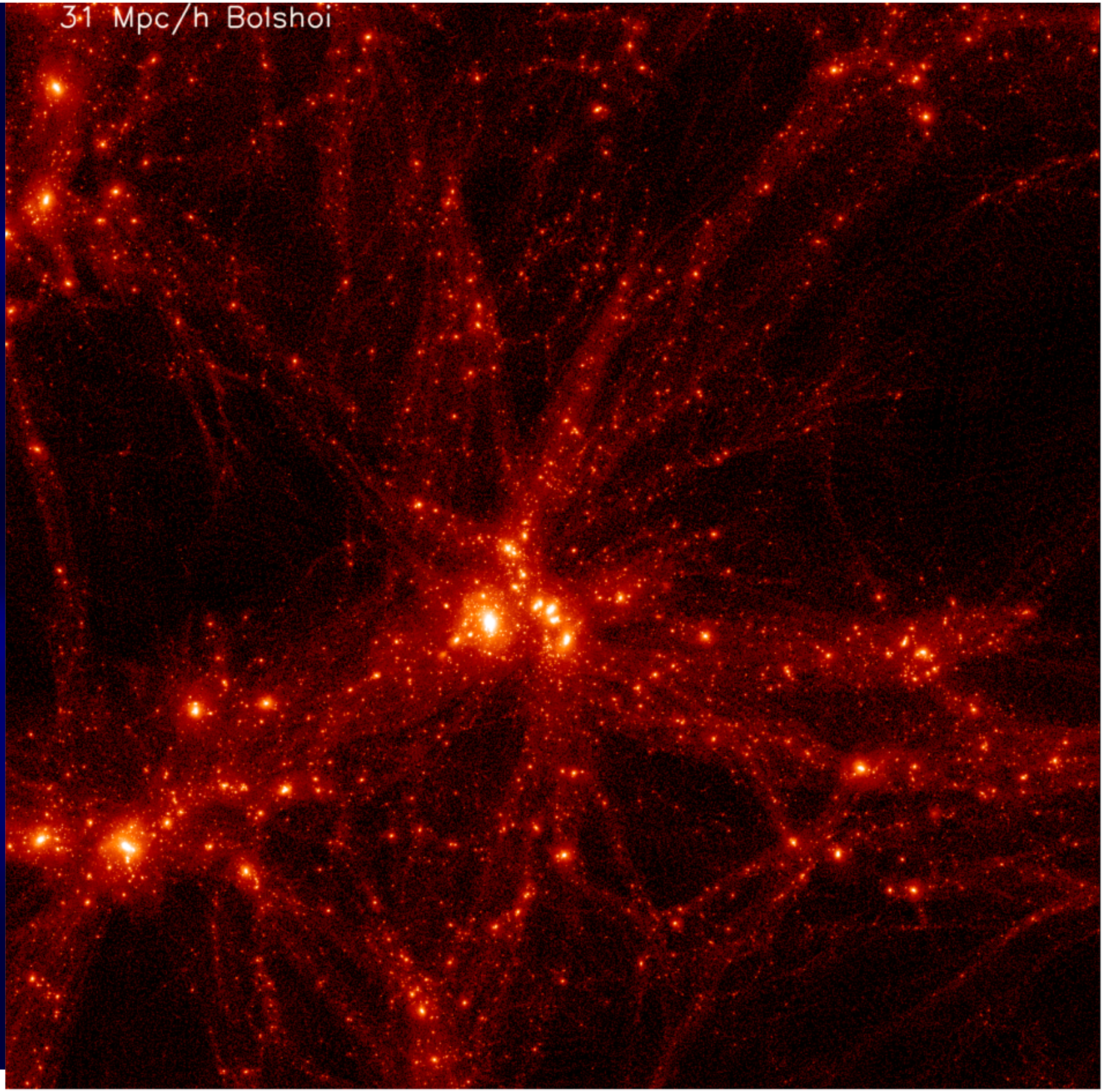
CENTRO DE ASTROBIOLOGÍA
Asociado al NASA Astrobiology Institute

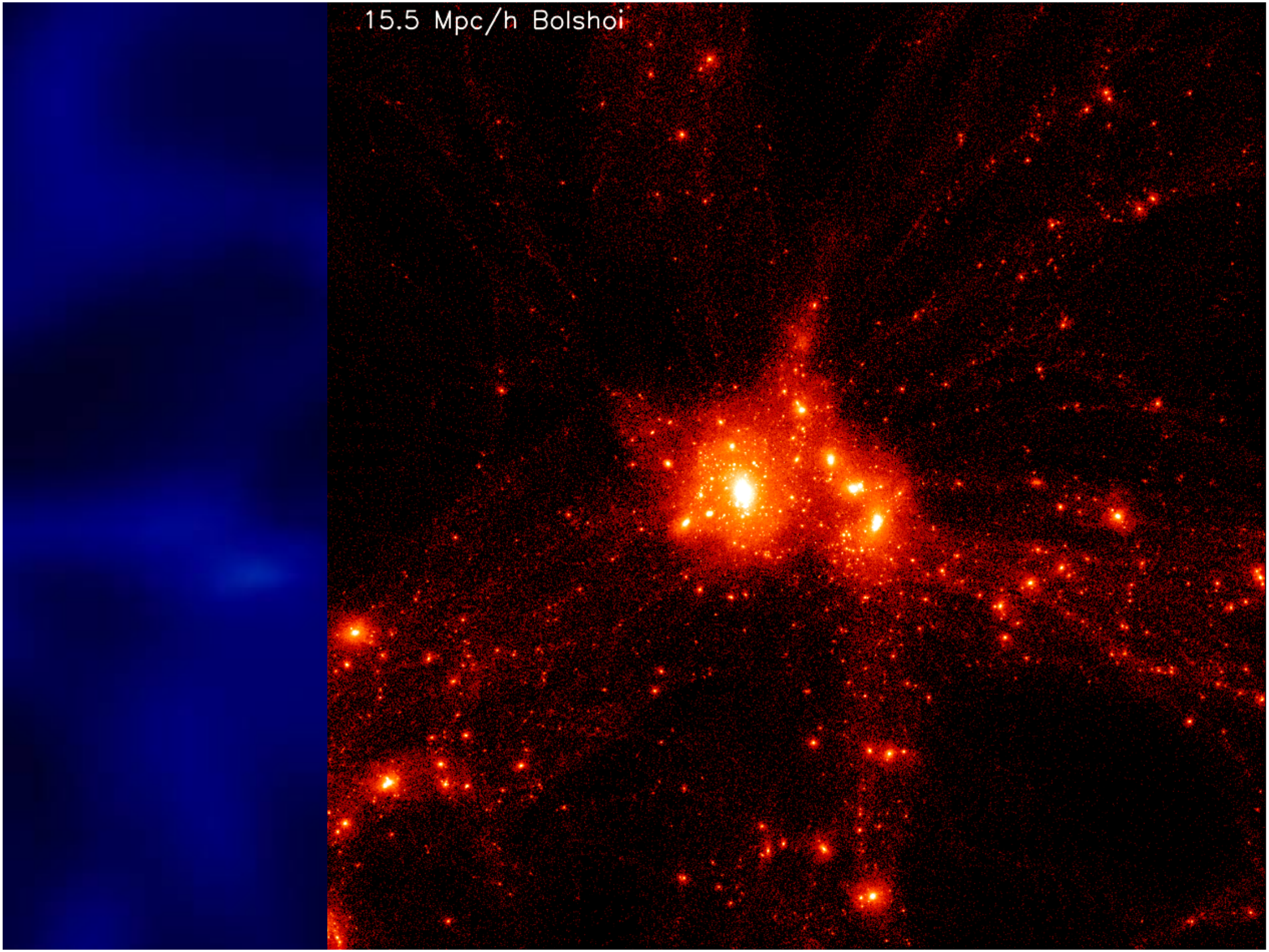
Anatoly Klypin, Avishai Dekel, Frederic Bournaud, Andreas Burkert, Reinhard Genzel, Joel Primack, Adi Zolotov

SHARDS, 2015


bigBolshoi 1Gpc 8G
particles


62 Mpc/h Bolshoi



31 Mpc/h Bolshoi


15.5 Mpc/h Bolshoi

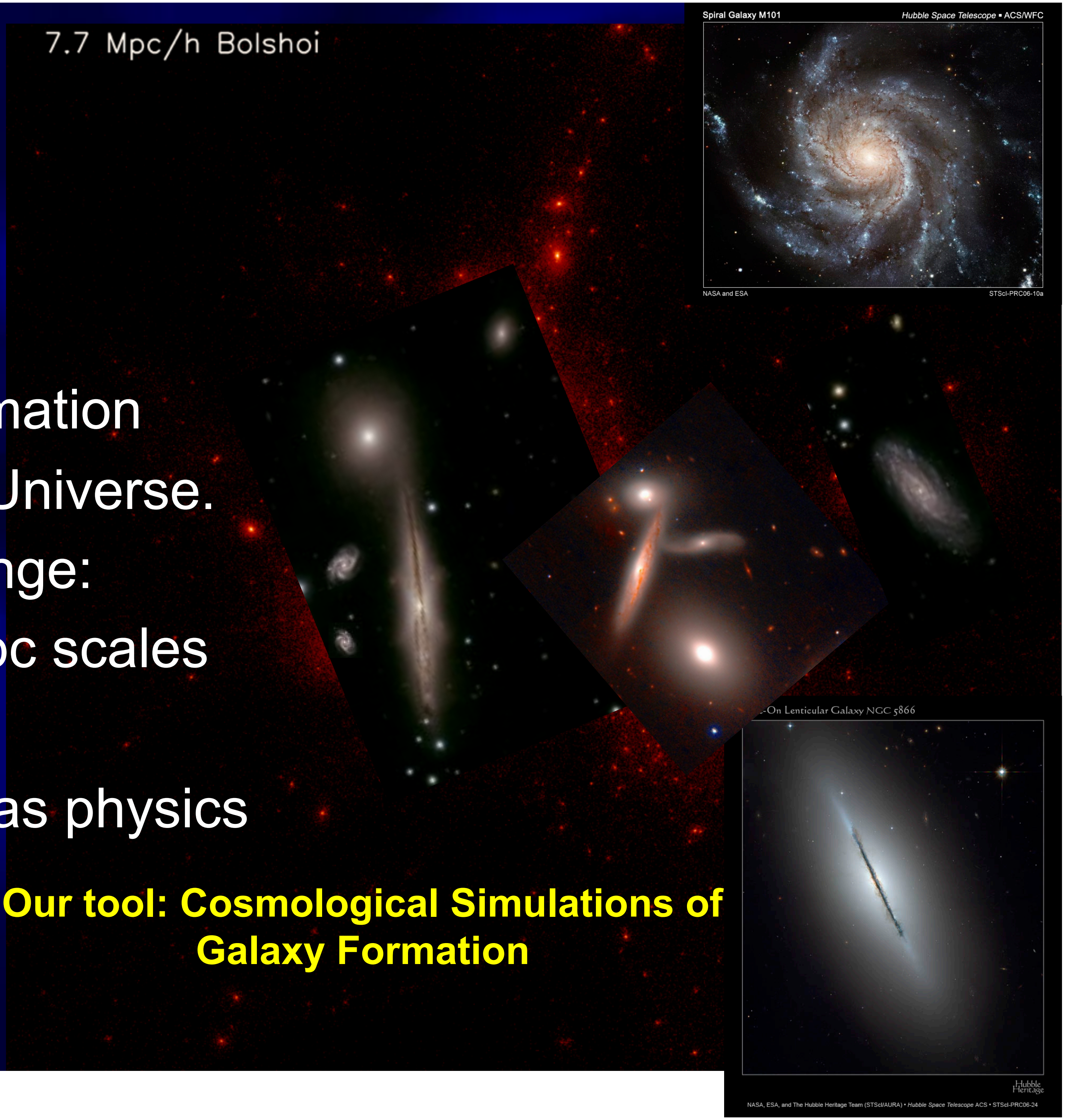
Small Galaxy Group

- Galaxy Formation in a ΛCDM Universe.
- Dynamic range:

From Mpc to pc scales

- Physics:

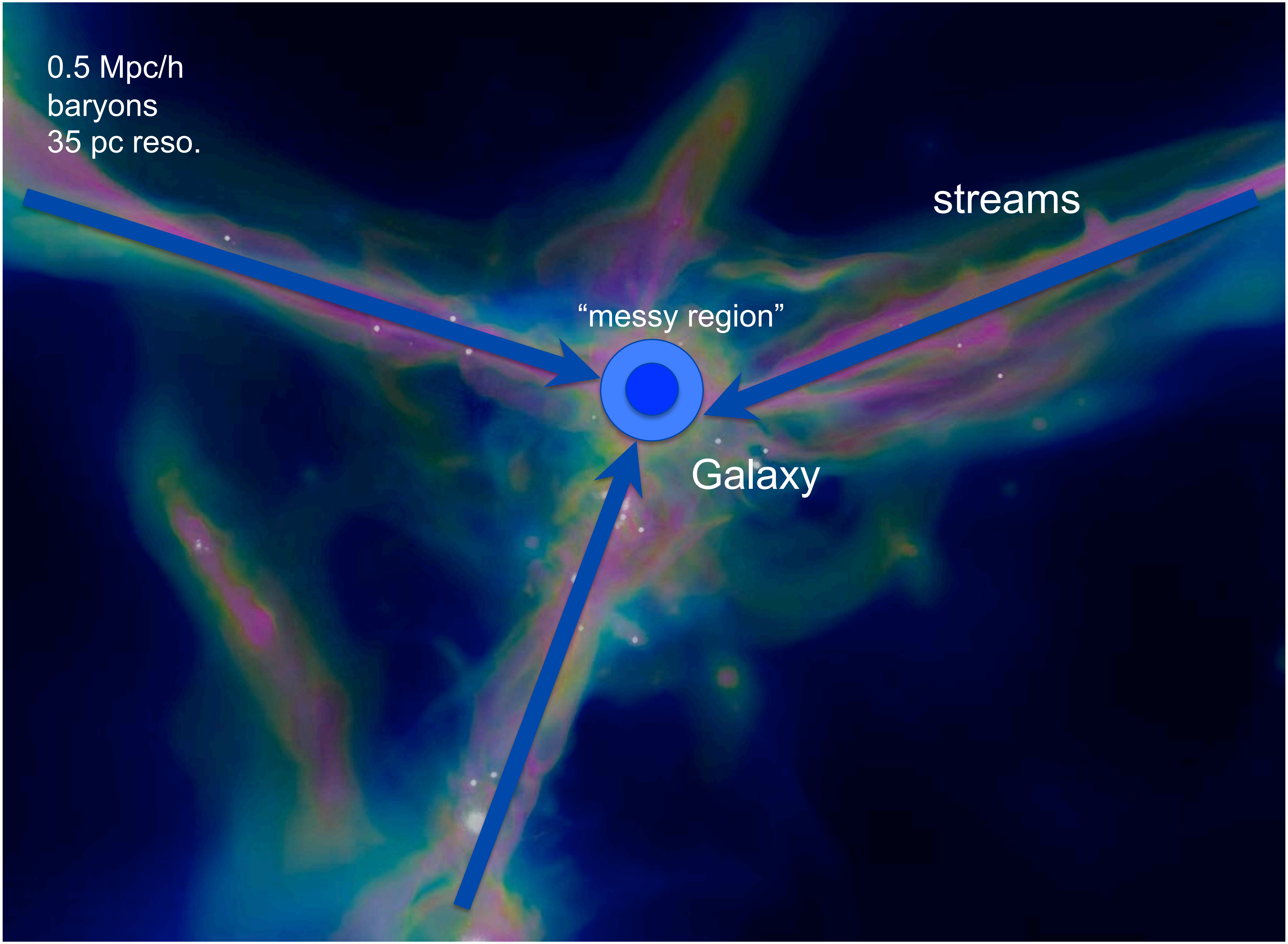
Gravity plus gas physics



Our tool: Cosmological Simulations of Galaxy Formation

.1
85
5
2
ensity

0.5 Mpc/h
baryons
35 pc reso.


0.5 Mpc/h
baryons
35 pc reso.
streams
"messy region"
Galaxy

“Early formation of massive, compact, spheroidal galaxies with classical profiles by violent disc instability or mergers”

Ceverino, Daniel; Dekel, Avishai; Tweed, Dylan; Primack, Joel, MNRAS, 447, 3291 (2015)

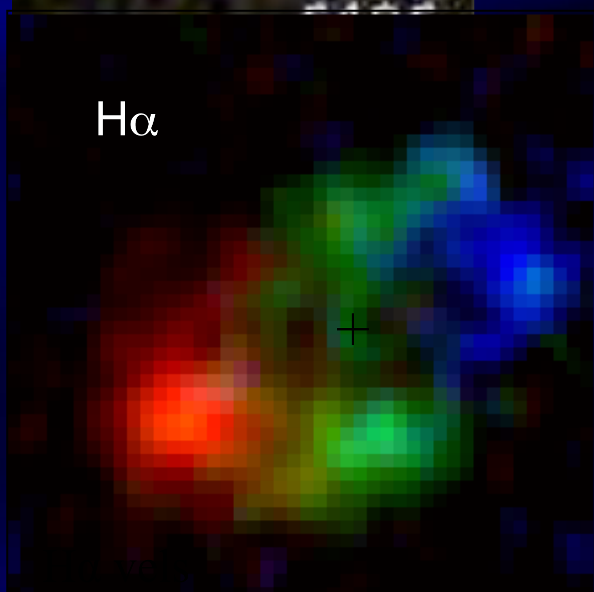
“Compaction and quenching of high-z galaxies in cosmological simulations: blue and red nuggets”

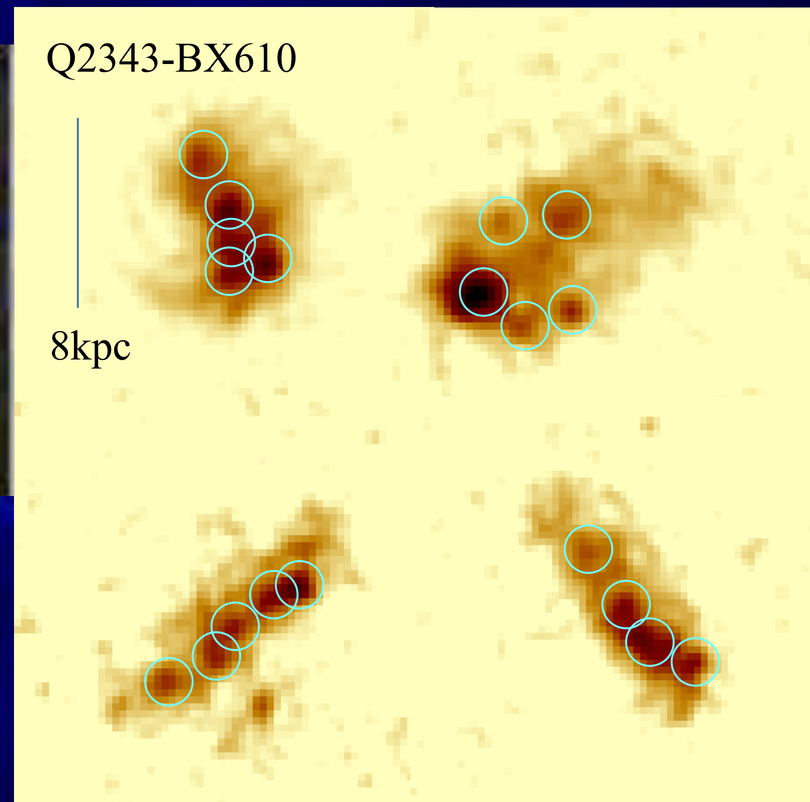
Zolotov, Adi; Dekel, Avishai; Mandelker, Nir; Tweed, Dylan; Inoue, Shigeki; DeGraf, Colin; Ceverino, Daniel; Primack, Joel R.; Barro, Guillermo; Faber, Sandra M., MNRAS, 450, 2327 (2015)

Cluster/Chain Galaxies: Fragmented Disks

Rest-frame UV

SINS collaboration



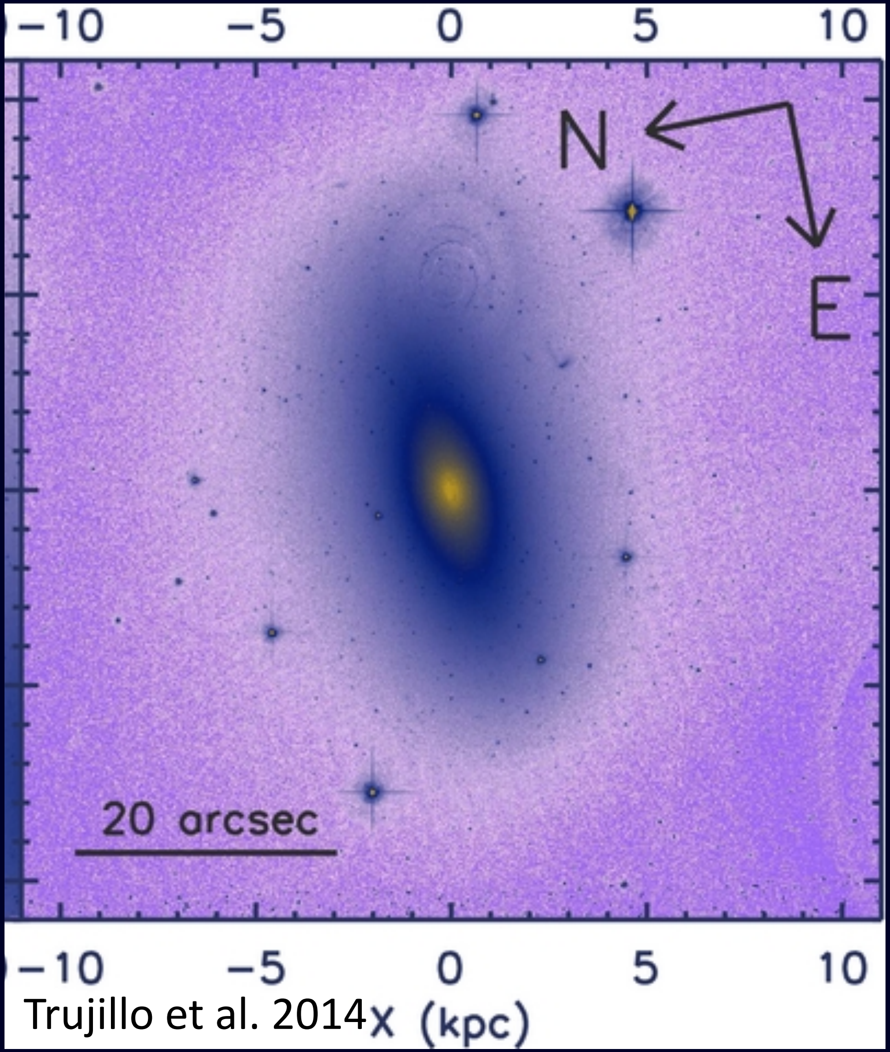


NICMOS H_{160}
Foerster Schreiber, Shapley et al. 2008

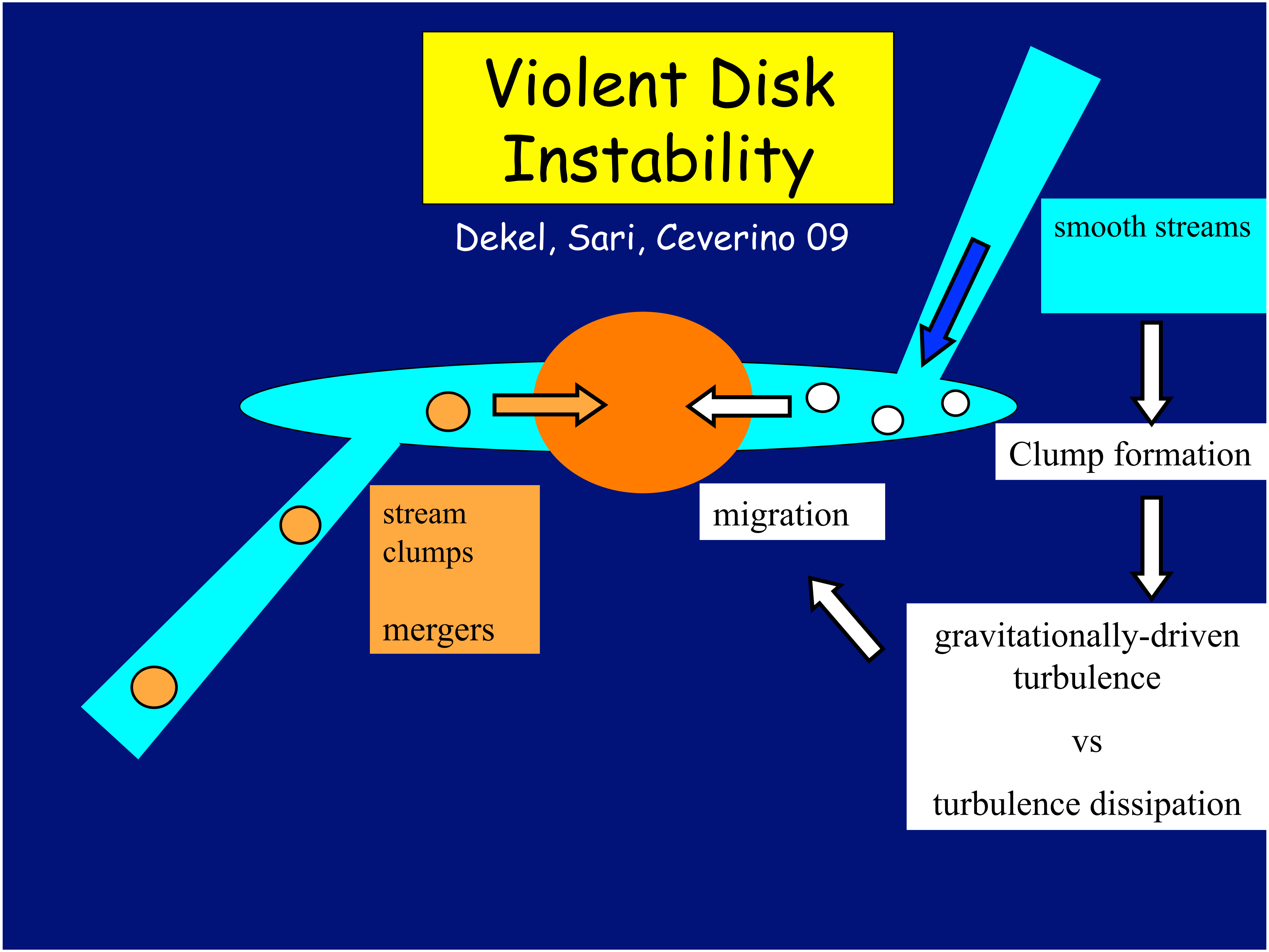
Genzel et al. 2008, Foerster Schreiber et al. 2008b,
Elmegreen & Elmegreen 2005, Elmegreen et al. 2007,2009

A relic from a violent past?

- NGC 1277: M=10^11 Msun, Re=1 kpc
- Which is the main formation scenario?
- internal vs external processes?
- alternative scenario to the merger picture



Trujillo et al. 2014


Violent Disk Instability
Dekel, Sari, Ceverino 09
smooth streams
Clump formation
gravitationally-driven turbulence
vs
turbulence dissipation
migration
stream clumps
mergers

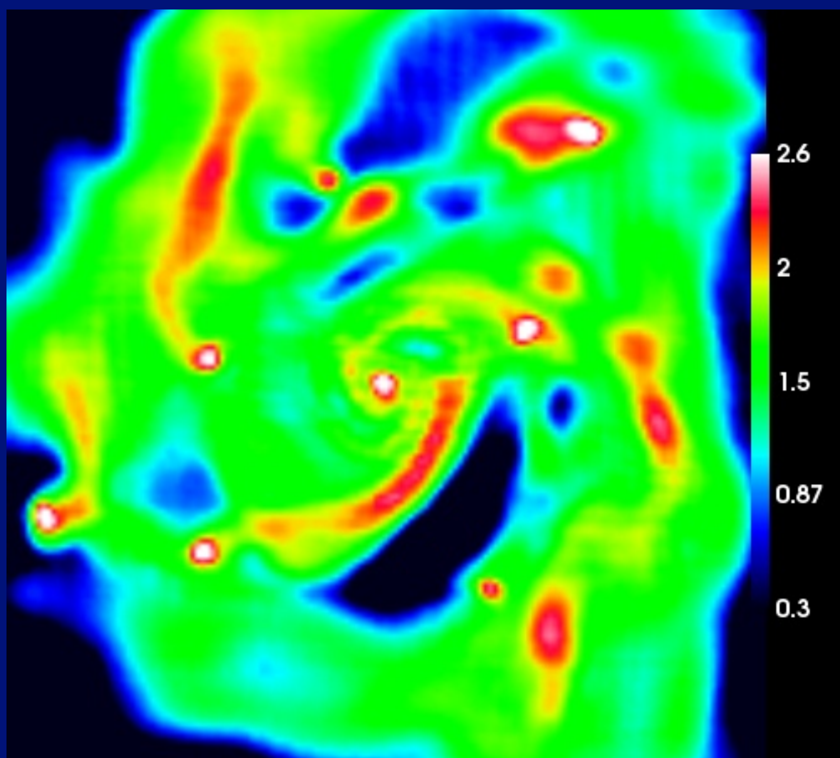
Galaxy formation simulations done with ART

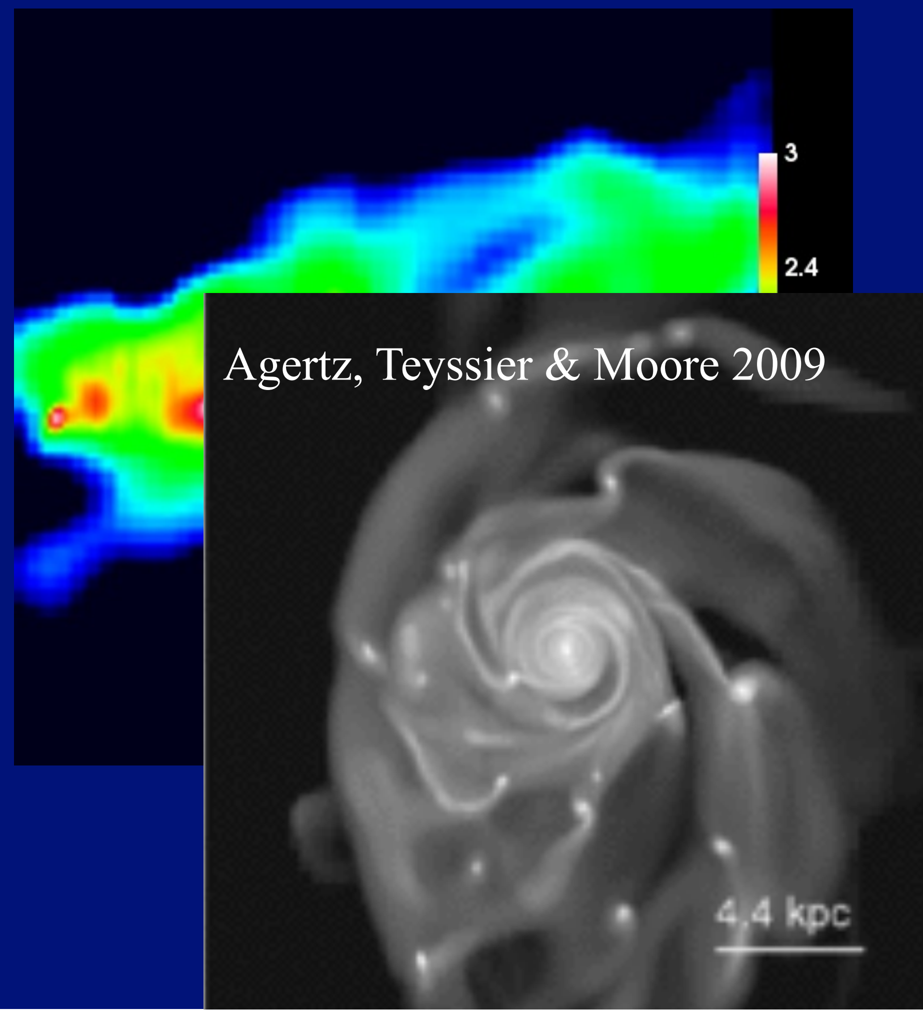
- AMR code: ART (Kravtsov et al 1997, Kravtsov 2003)
- Gas Cooling, Star Formation, Stellar Feedback (Ceverino & Klypin 2009; Ceverino, Dekel and Bournaud 2010)
  - Cooling below 10^4 K (minimum temperature of 300 K).
  - Thermal feedback + runaway stars.
  - Things that we are NOT doing (although it is tempting): Shutdown cooling, shutdown of hydrodynamical forces.
- Sample of **100** halos with a virial mass between $10^{11}\ M_\odot$ - $5 \times 10^{12}\ M_\odot$ at $z \approx 1$
- Maximum resolution of 15-70 pc

Clumpy Discs in Galaxy Formation Simulations of z~2 galaxies

Dekel, Sari & Ceverino 2009
Ceverino, Dekel & Bournaud 2010

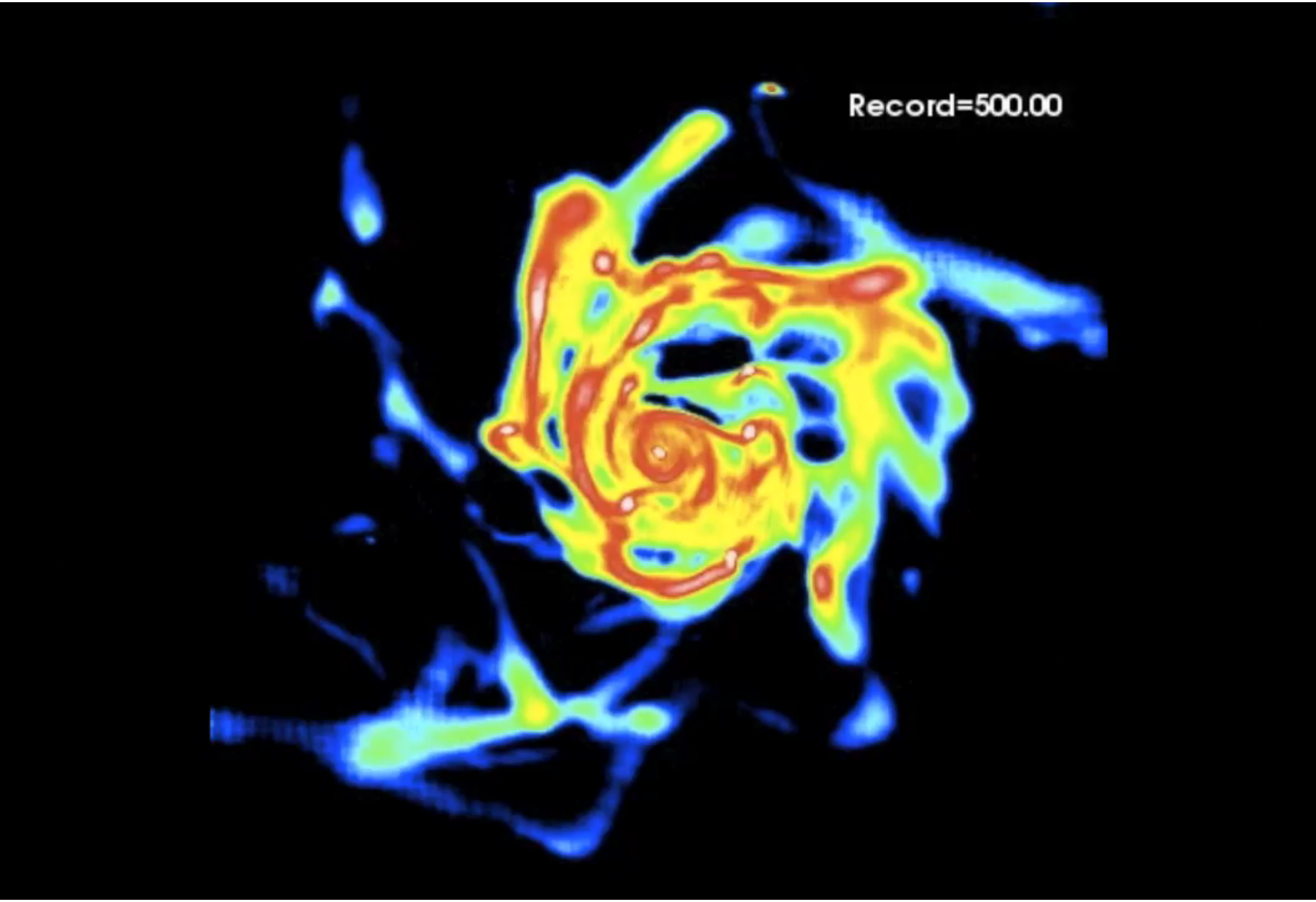
Gas Surface Density





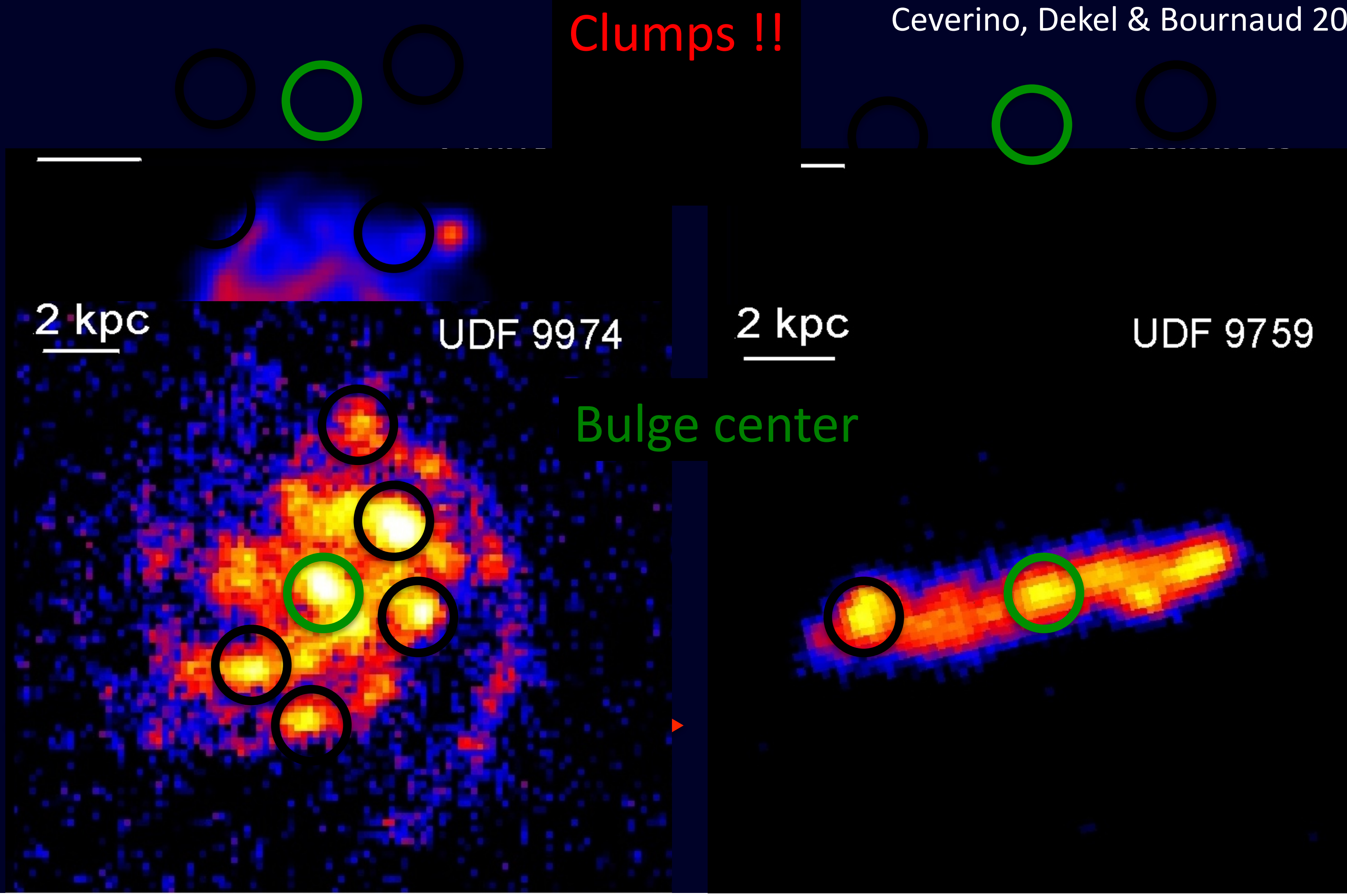
10 kpc

Face-on view


Record=500.00

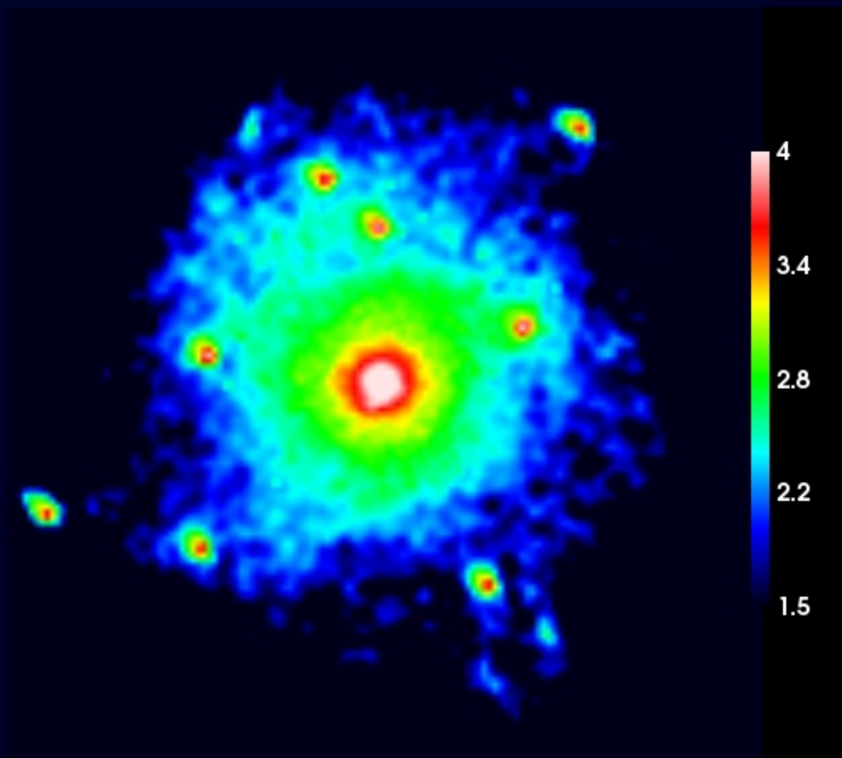
Young Stars

Ceverino, Dekel & Bournaud 2010



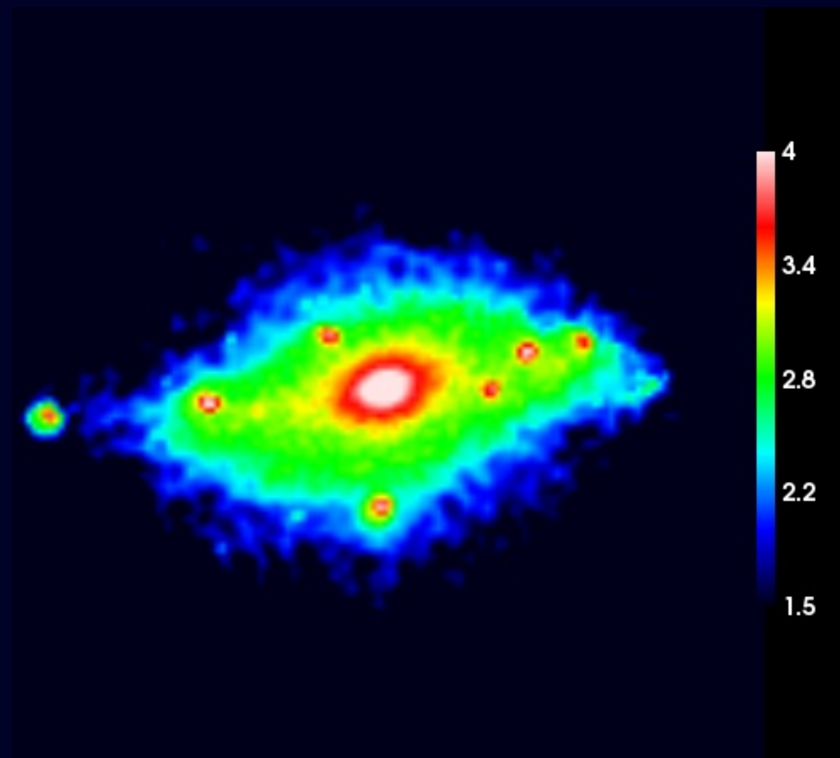
A Massive Bulge

Stellar Surface Density



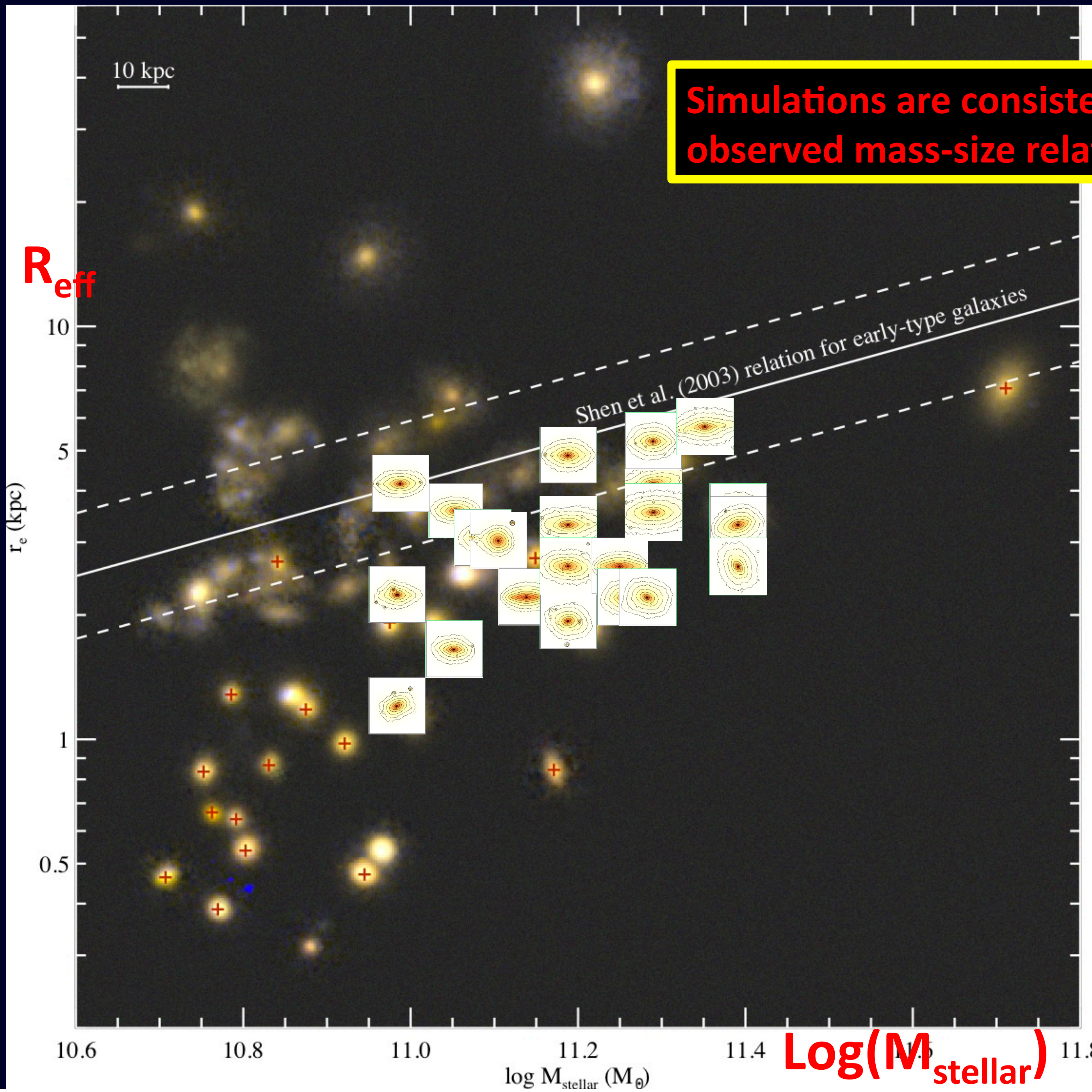
10 kpc

Face-on view



Edge-on view

Simulations are consistent with the observed mass-size relation at z=1.5



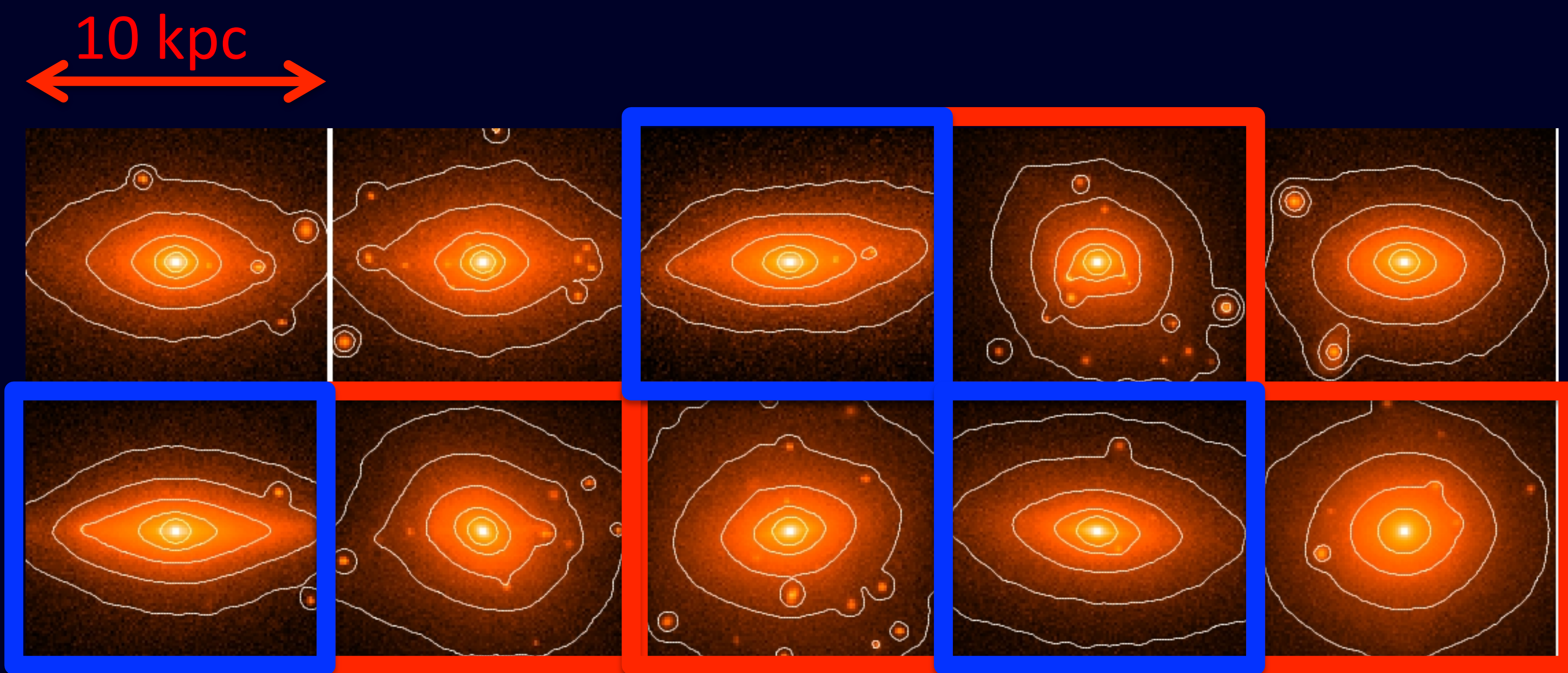
R_{eff}

$Log(M_{stellar})$

z=1.5

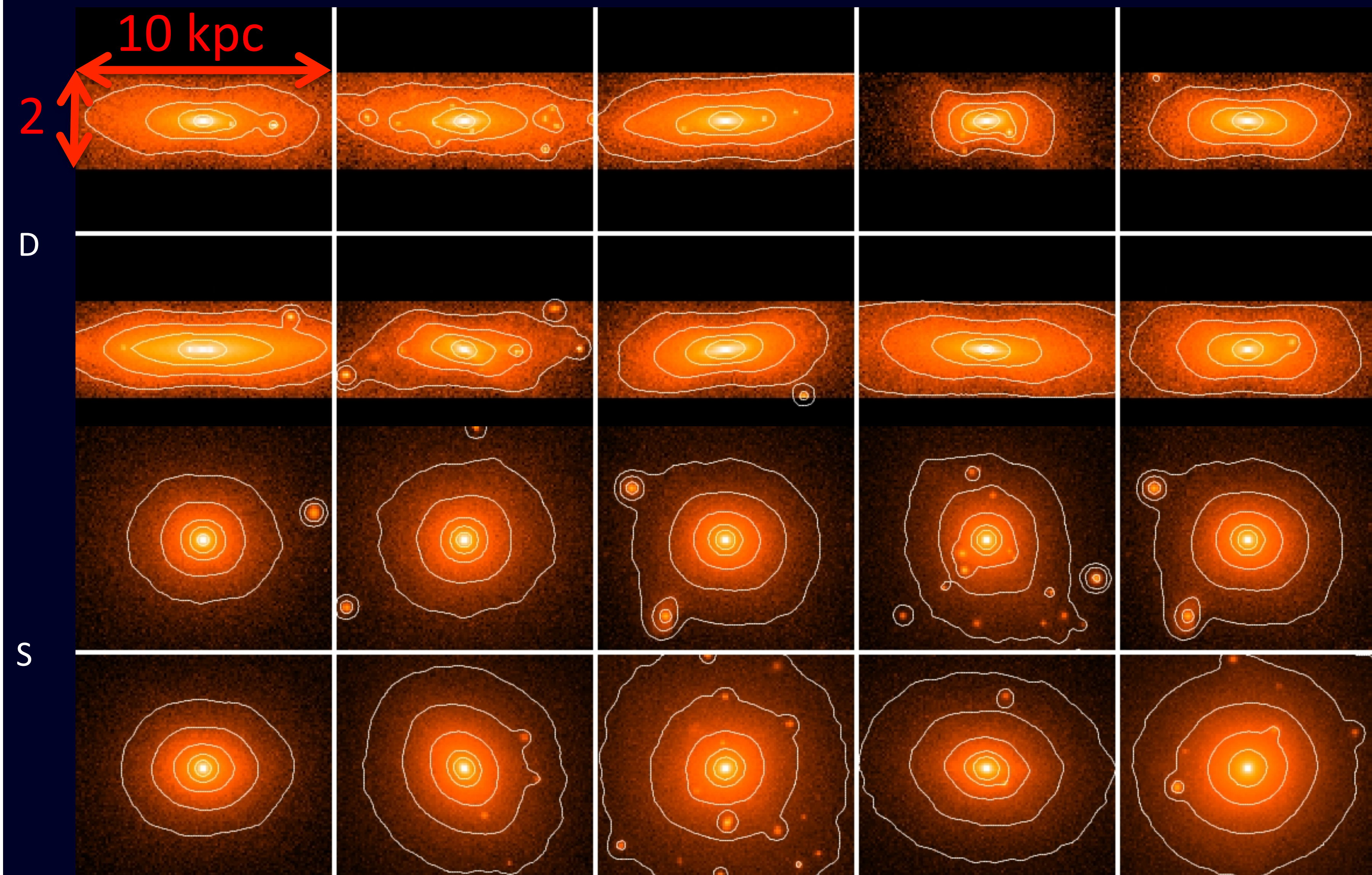
Szomoru, Franx, van Dokkum 2011

The sample at z=1



A large variety of shapes: from compact spheroids to discs as well as merger remnants

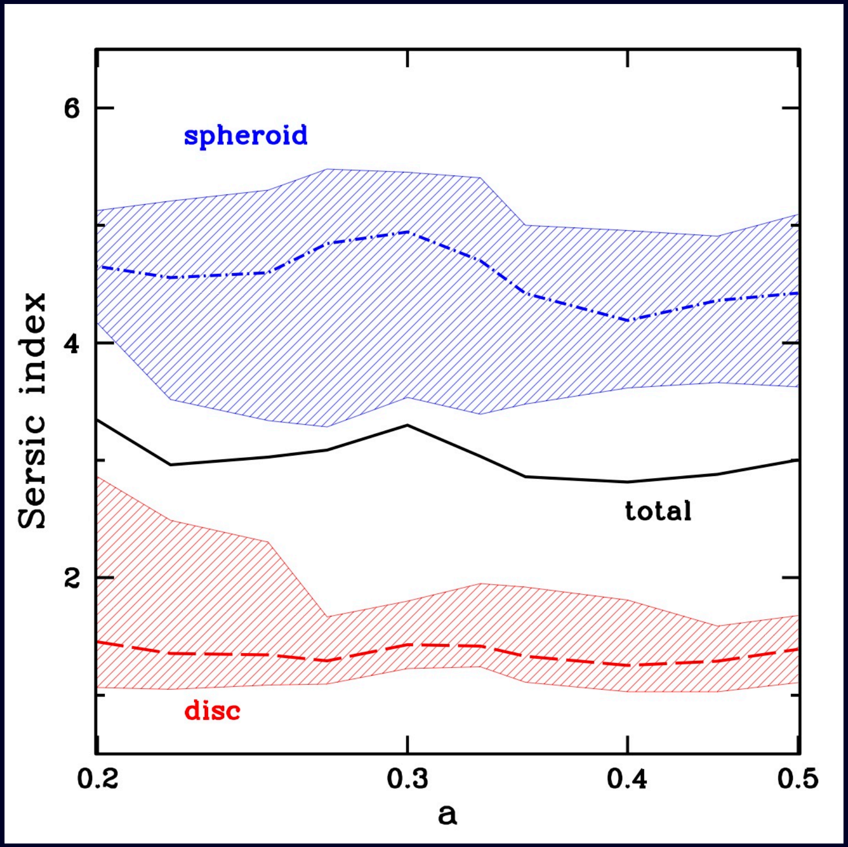
Spheroid and disk components



Sersic fitting for different components

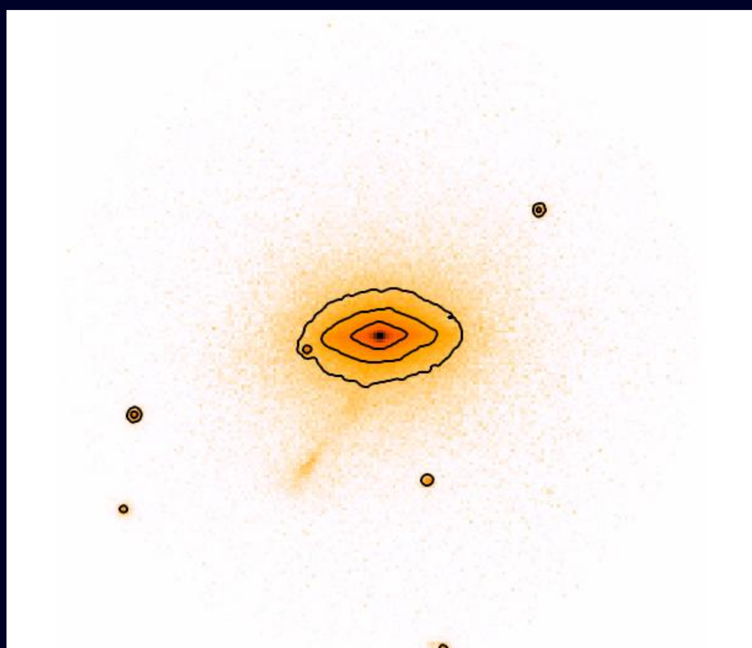
- Classical spheroids: <n>=4.3 ±1.4
- Exponential Discs: <n>=1.5 ± 0.6
- No redshift evolution

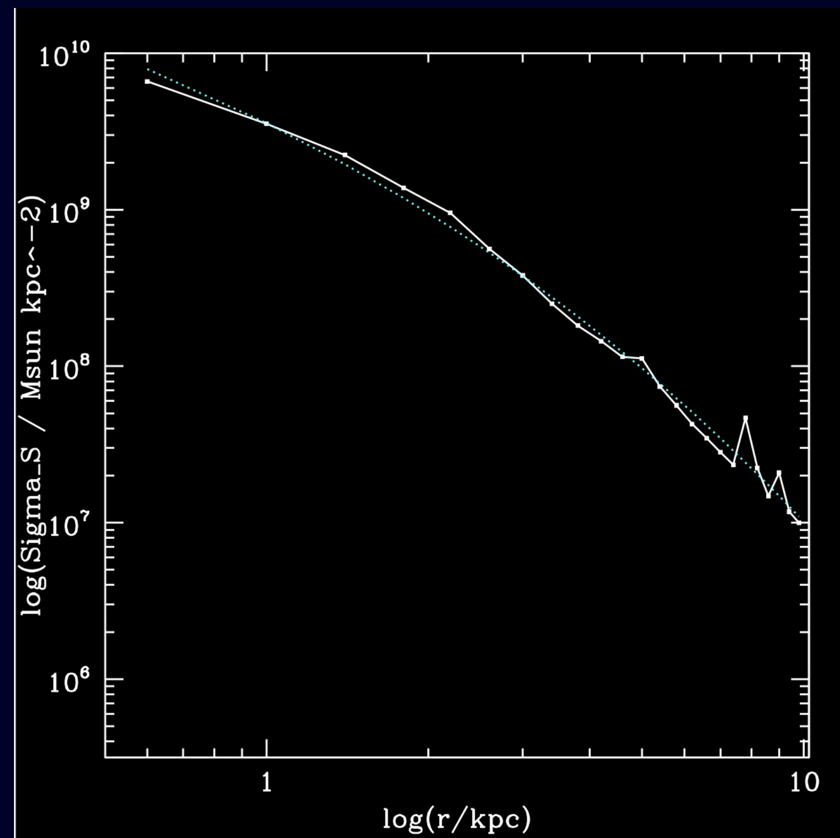
Violent disk instability leads to compact and classical, spheroids



Comparison with NGC 1277

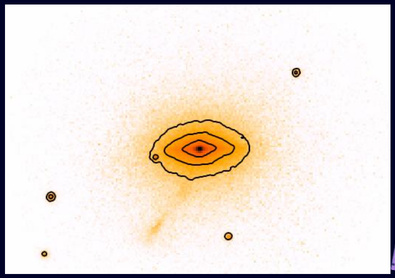
- stellar mass of Ms=0.9 10^11 Msun at z=2
- Re=1.4 kpc , n=2.9

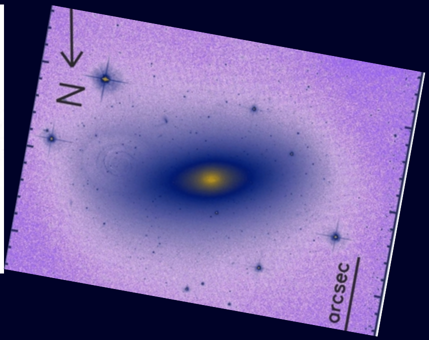


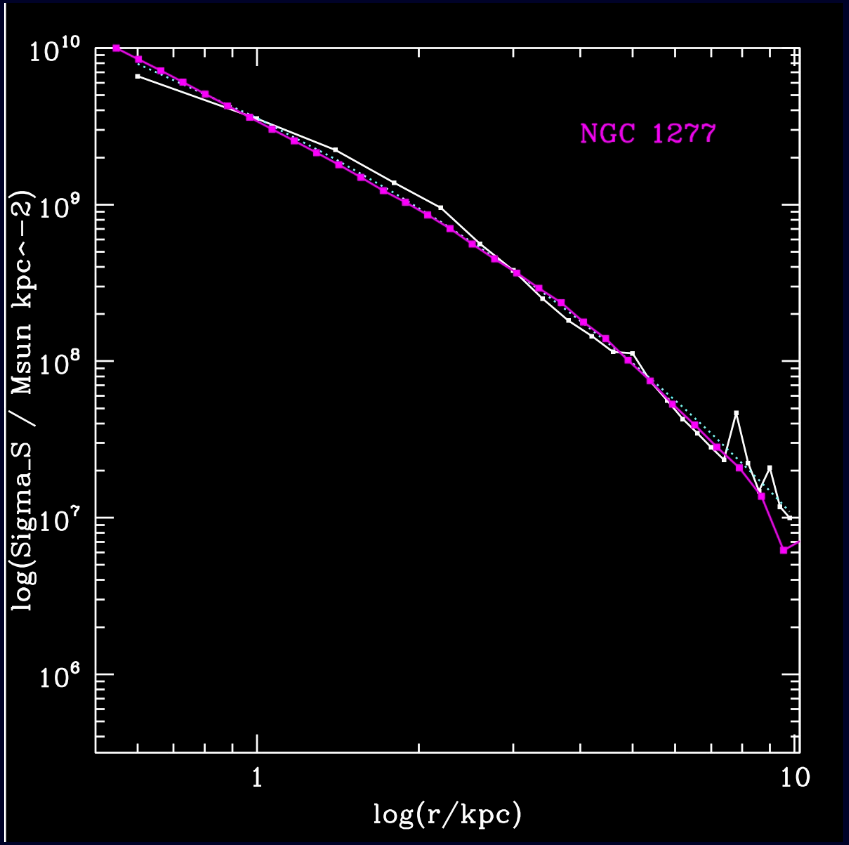


Comparison with NGC 1277

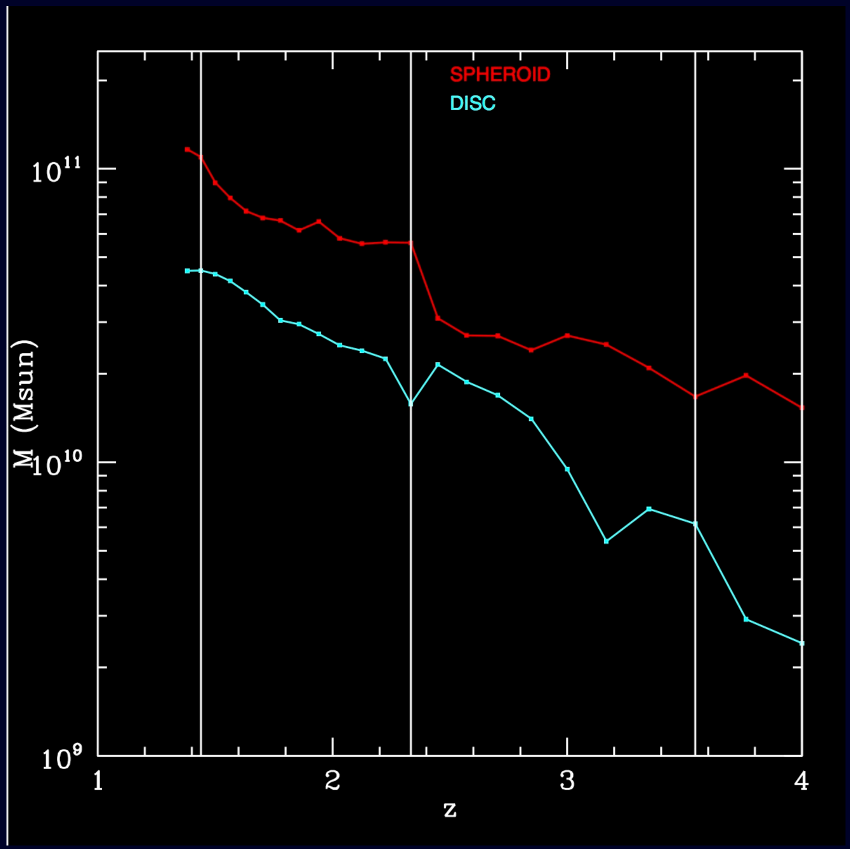
- S/T=0.7
- Spheroid: n=4 Re=1.4 kpc
- Disc: n=1.5, Re=1.3 kpc
- 80% stars formed in-situ







Continuous spheroid and disc growth

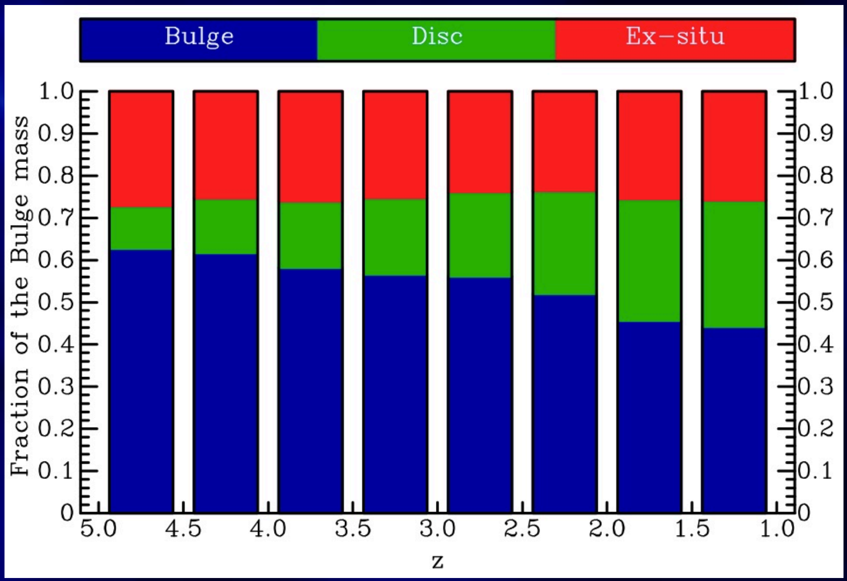


- Continuous disc growth fueled by gas accretion
- Continuous spheroid growth due to VDI
- Major mergers only produces discrete and rare jumps in the spheroid growth.
- This galaxy double its mass between z=2.8 and z=2.1, a 0.8 Gyr period

Compaction: wet origin of the bulge

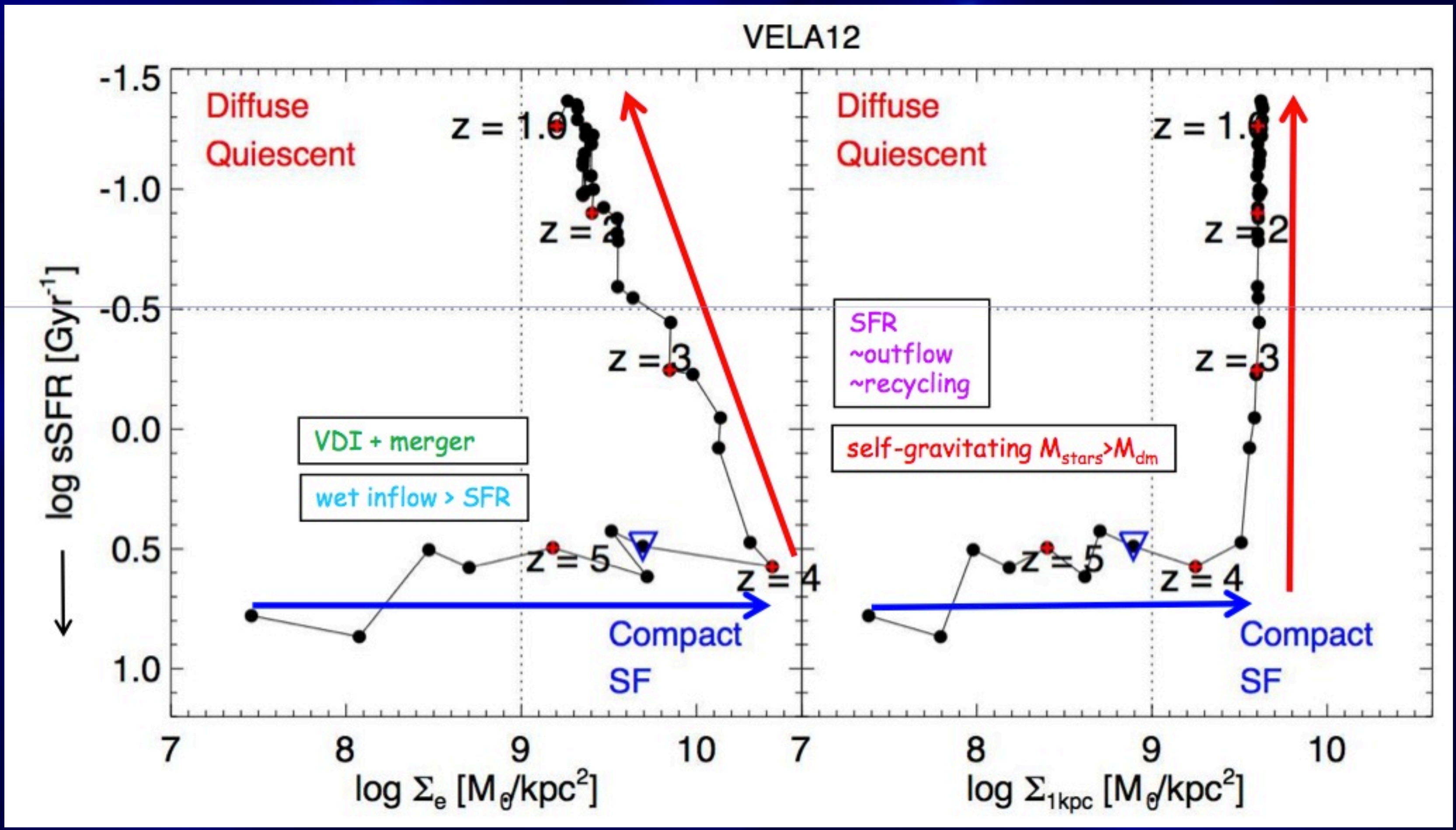
- Compact spheroid is the result of a dissipative “wet” inflow: $t_{inflow} << t_{SFR}$ (Dekel & Burkert 2014)
- 60-30% of the bulge stars form in the bulge → wet inflow
- driven by VDI or mergers

Fraction of bulge stars born in different components



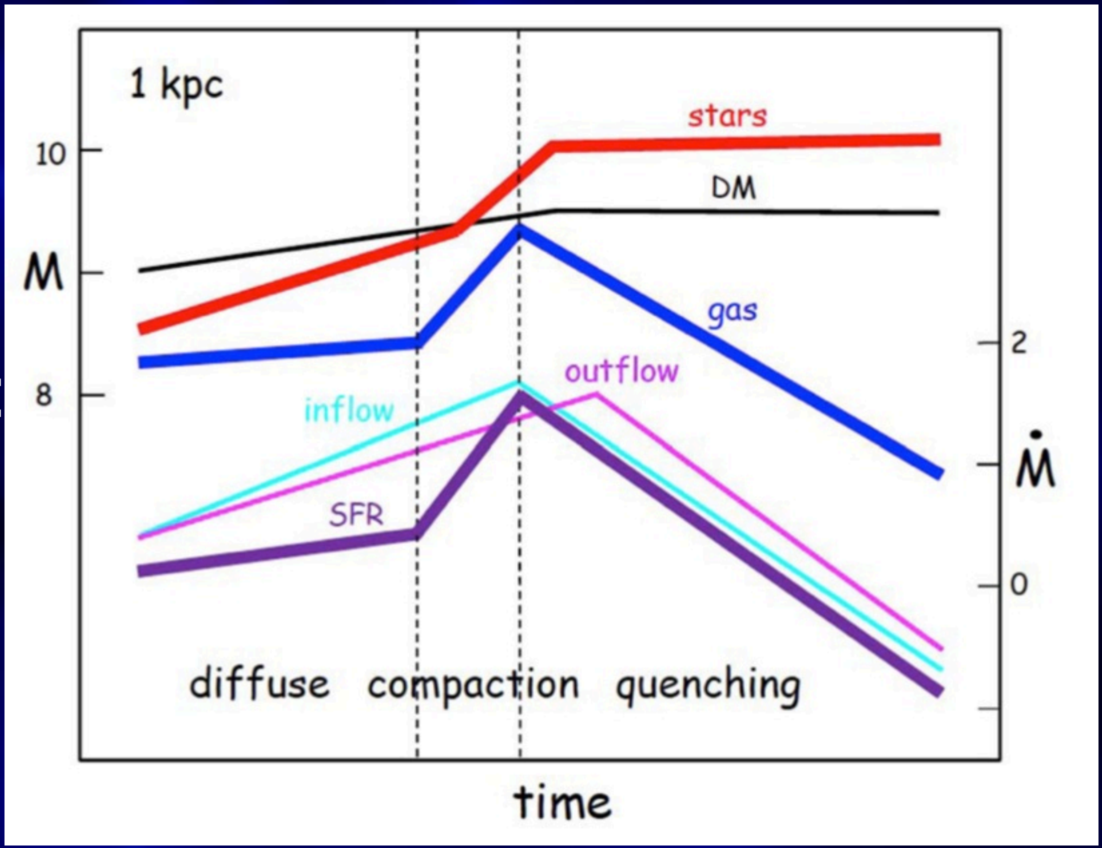
Zolotov et al. (2015)

Compaction & Quenching



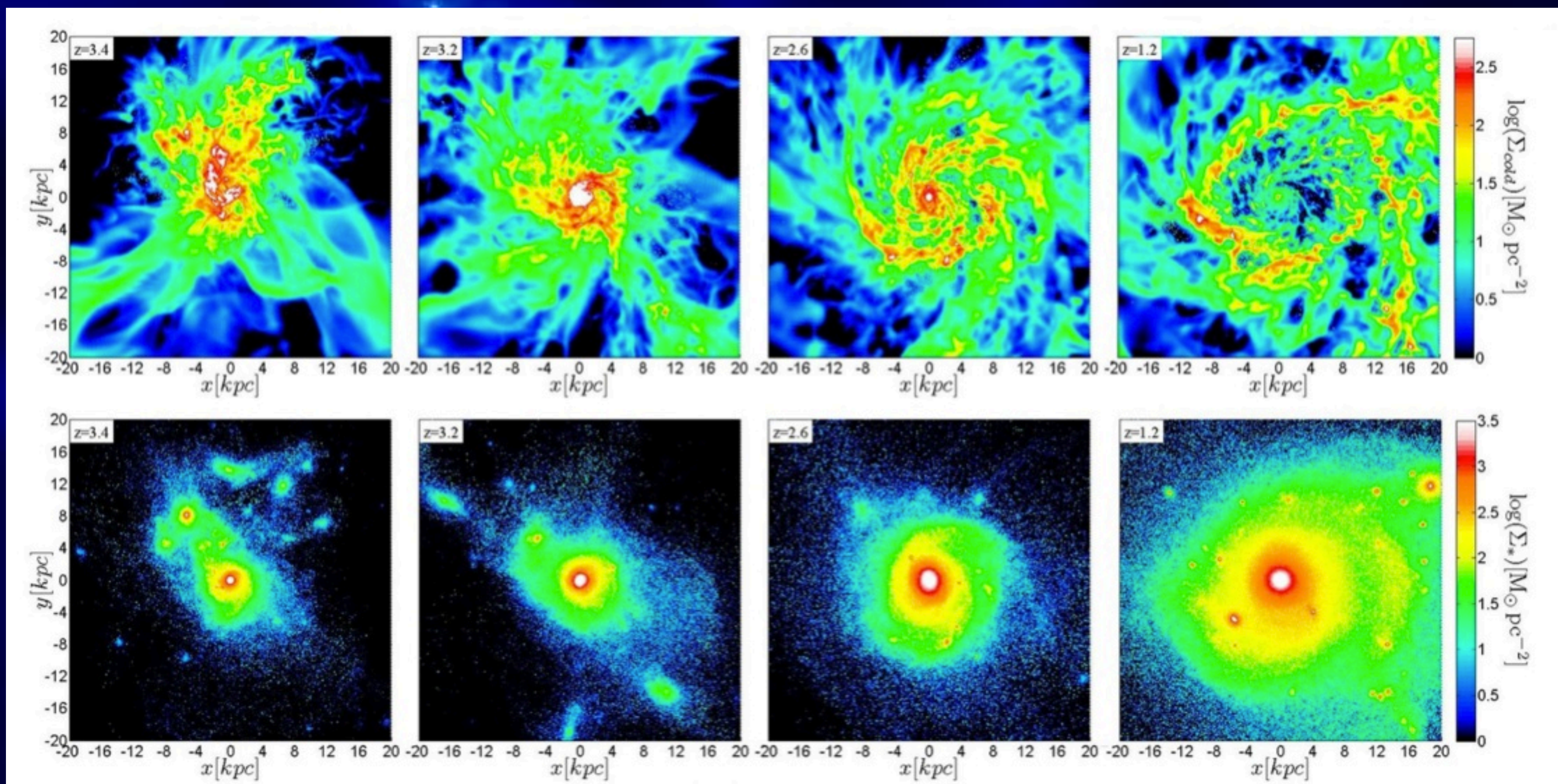
Compaction & Quenching

- Diffuse phase
- compact phase: blue nugget
- quiescent phase: red nugget



Compaction & Quenching

wet compaction | blue nugget | VDI disc | red nugget



Conclusions

- High-z, gravitationally-unstable discs break into Giant Clumps that migrate to the center.
- Final products of violent disk instability are compact, classical spheroids or S0s.
- Compaction is produced by dissipative “wet” inflow: blue nuggets
- Quenching proceeds inside-out by the decrease of wet inflow to the center


THE END