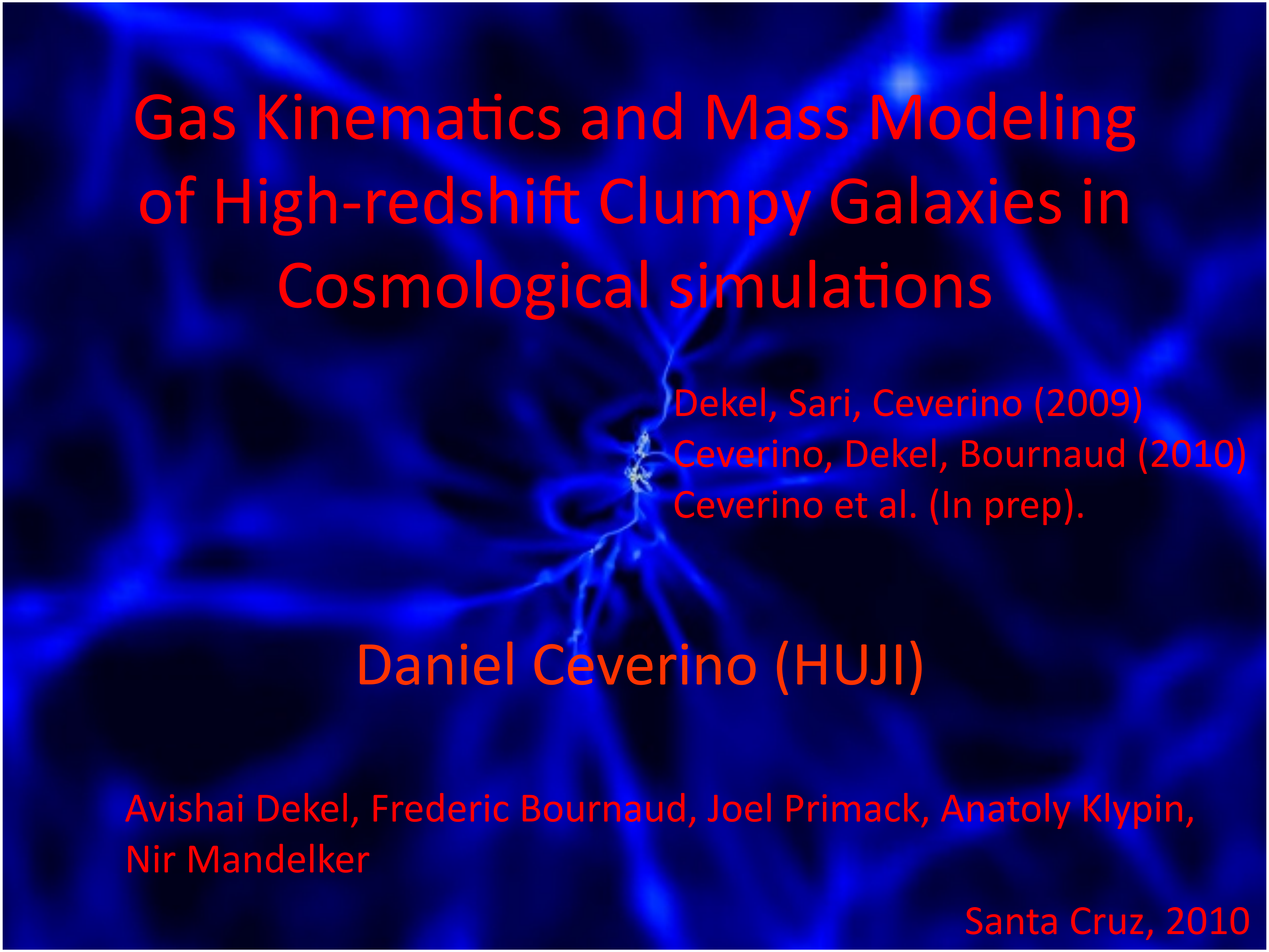


Gas Kinematics and Mass Modeling of High-redshift Clumpy Galaxies in Cosmological simulations

Dekel, Sari, Ceverino (2009)
Ceverino, Dekel, Bournaud (2010)
Ceverino et al. (In prep).

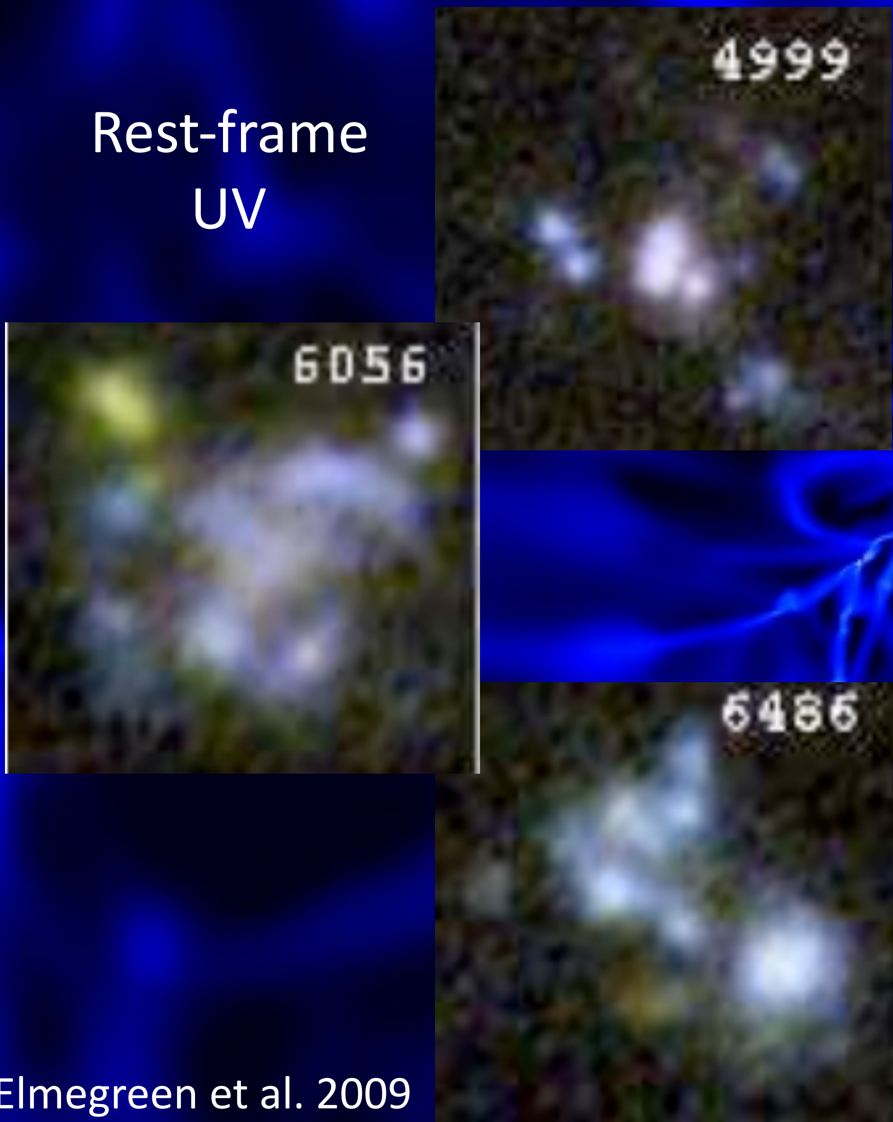
Daniel Ceverino (HUJI)

Avishai Dekel, Frederic Bournaud, Joel Primack, Anatoly Klypin, Nir Mandelker

Santa Cruz, 2010

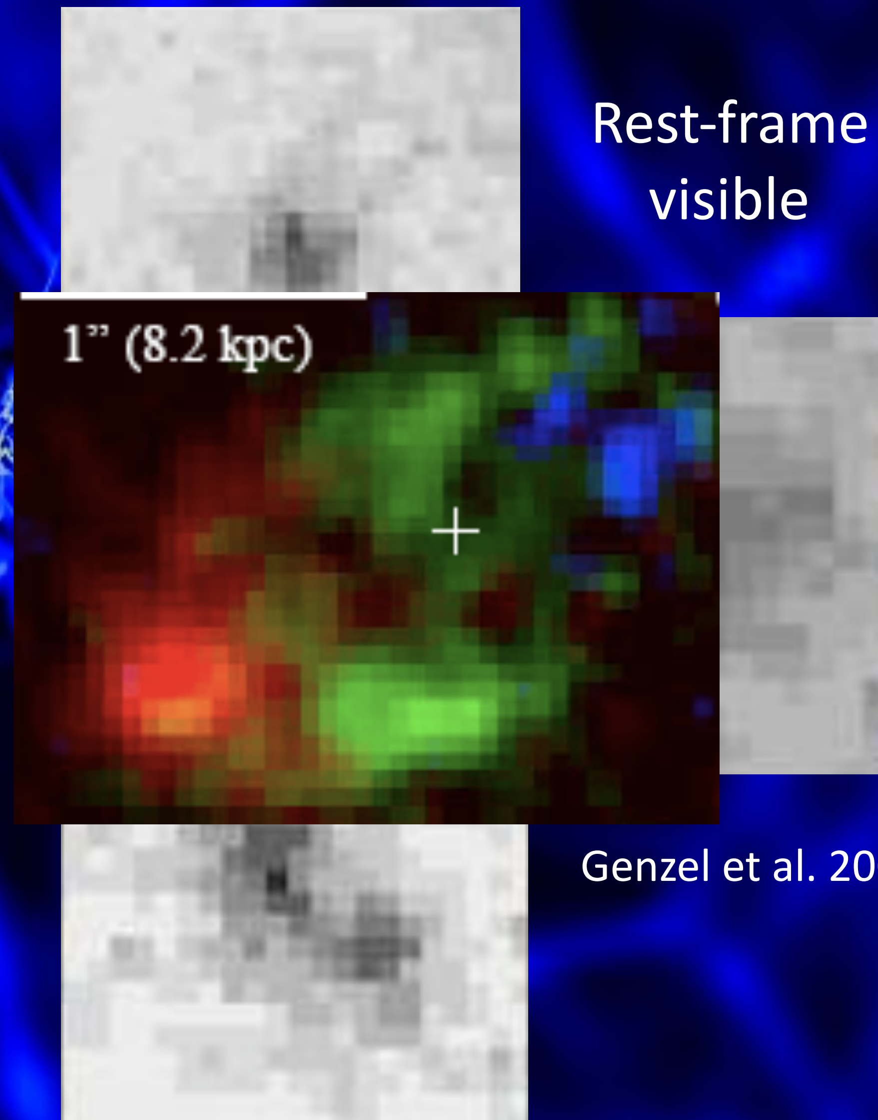
From Disks to Bulges

Rest-frame UV



Elmegreen et al. 2009

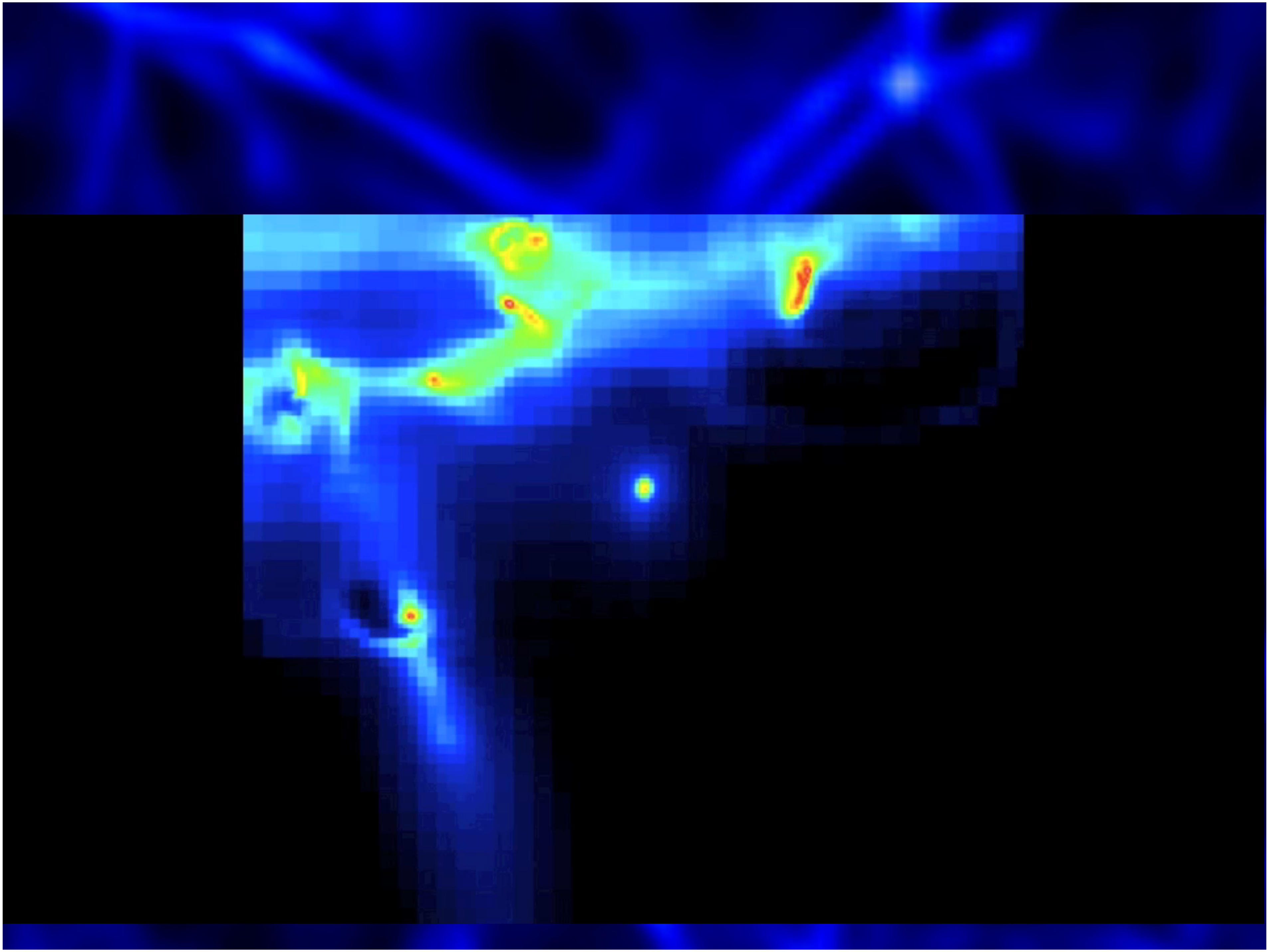
Rest-frame visible



Genzel et al. 2006

Galaxy formation simulations done with ART

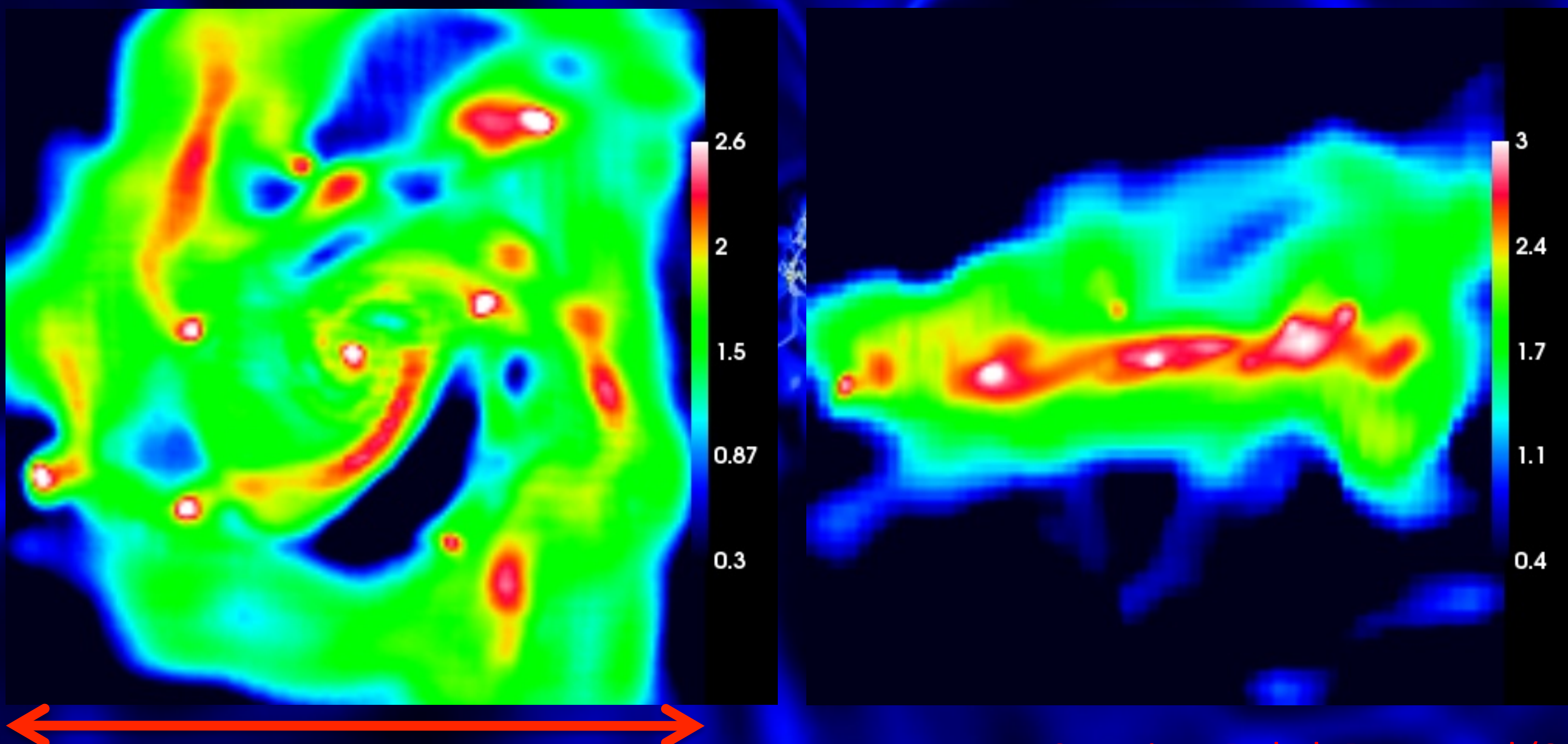
- AMR code: HYDRO-ART (Kravtsov et al 1997, Kravtsov 2003)
- Gas Cooling, Star Formation, Stellar Feedback (Ceverino & Klypin 2009; Ceverino, Dekel and Bournaud 2010)
  - Cooling below 10^4 K (minimum temperature of 300 K).
  - Thermal feedback + runaway stars.
  - Things that we are NOT doing (although it is tempting): Shutdown cooling, shutdown of hydrodynamical forces.
- Sample of halos with a virial mass between $5\ 10^{11} - 10^{12}\ M_\odot$ at z=2
- Maximum resolution of 30-70 pc



Gravitationally unstable disks

Max. resolution of 70 pc

Gas Surface Density in log ($M_{\odot}/pc^2$)



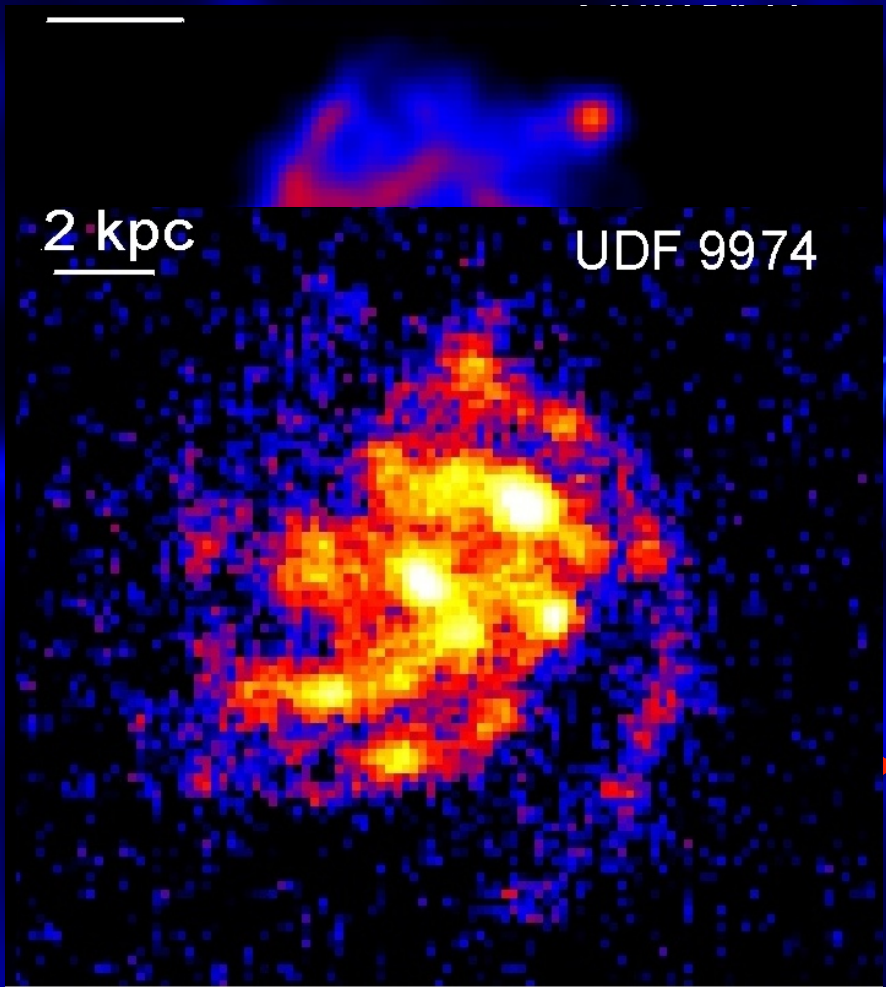
10 kpc

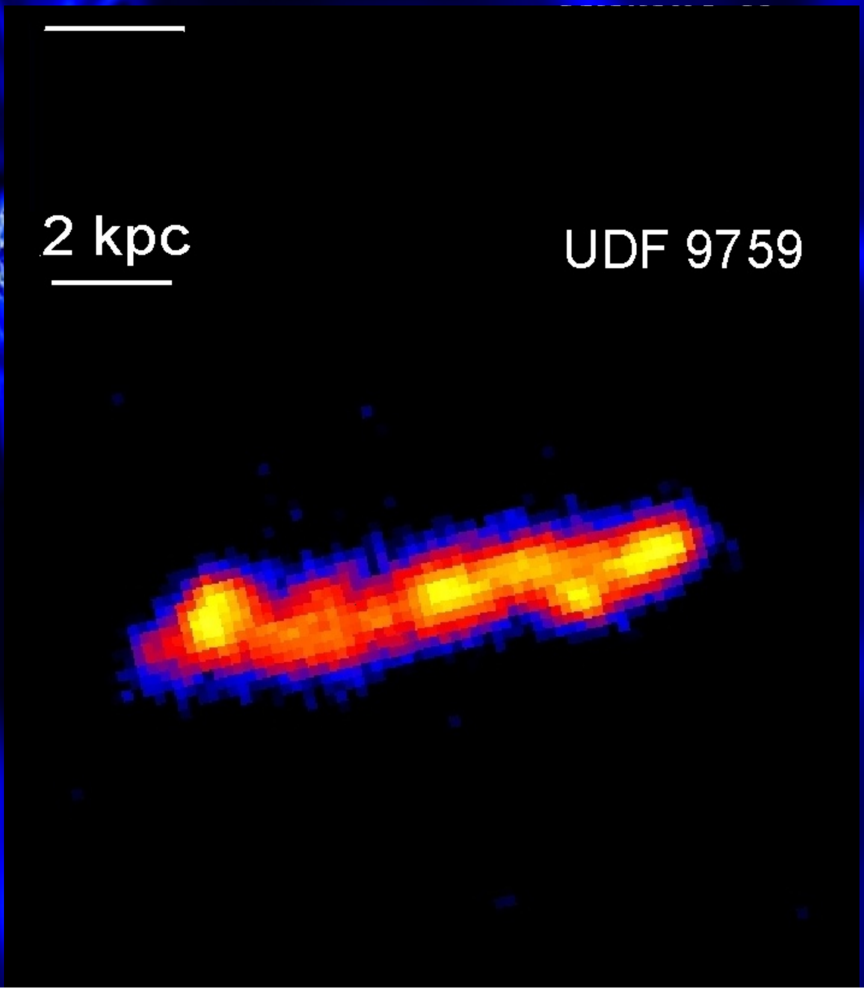
Ceverino, Dekel, Bournaud (2010)

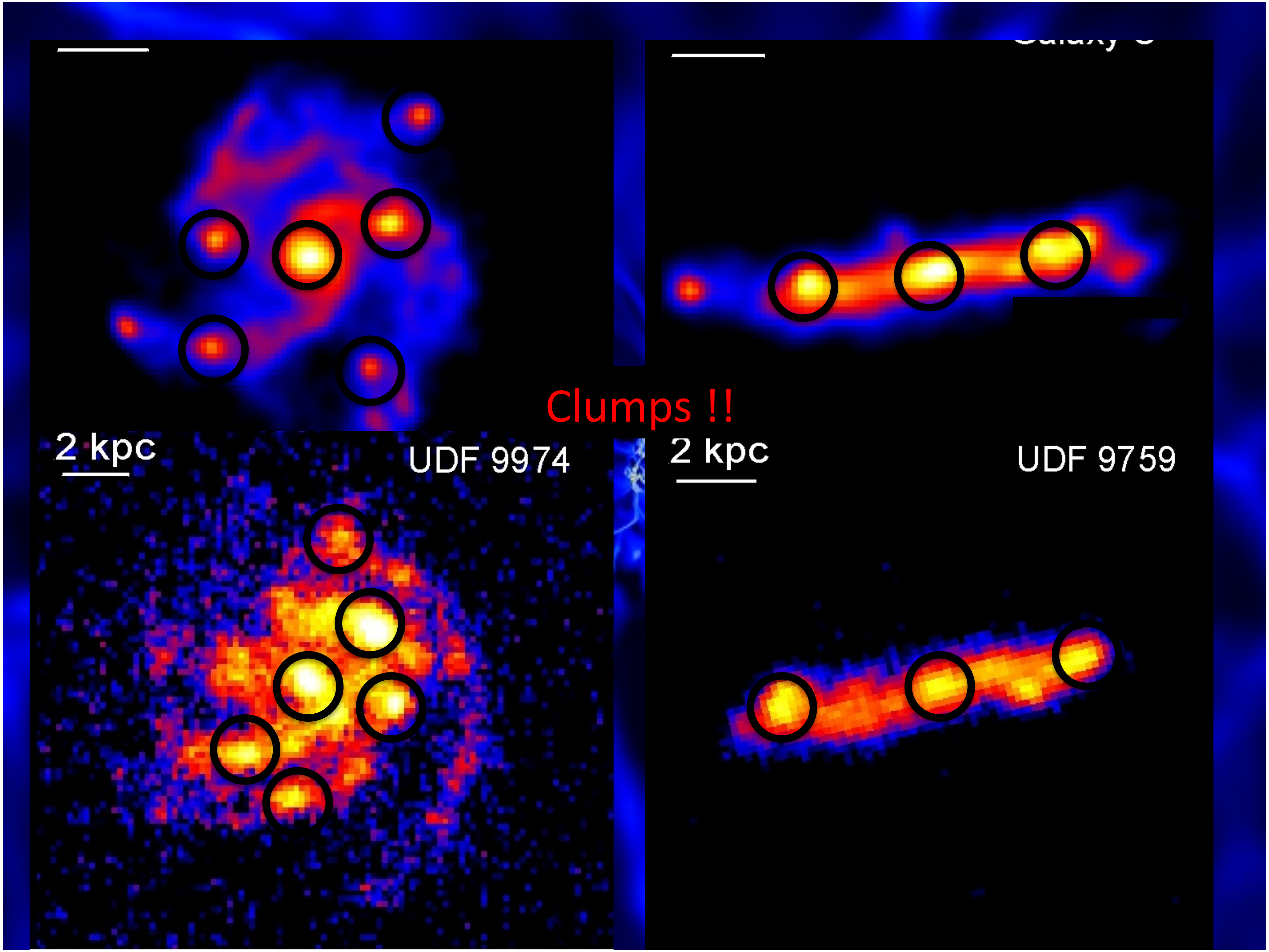
Face-on view

Edge-on view

Young Stars

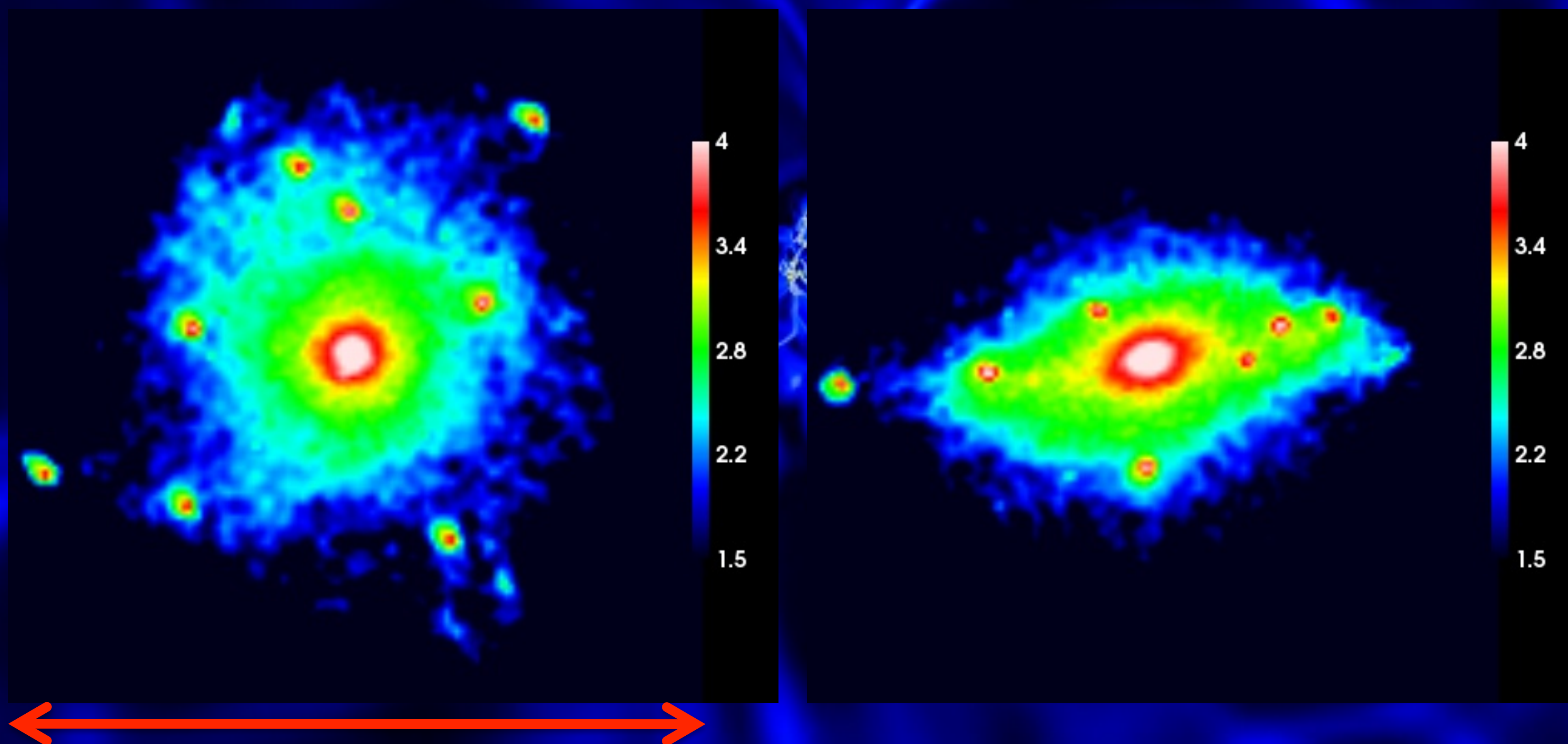





Clumps !!
2 kpc
UDF 9974
2 kpc
UDF 9759

A Massive Bulge

Stellar Surface Density



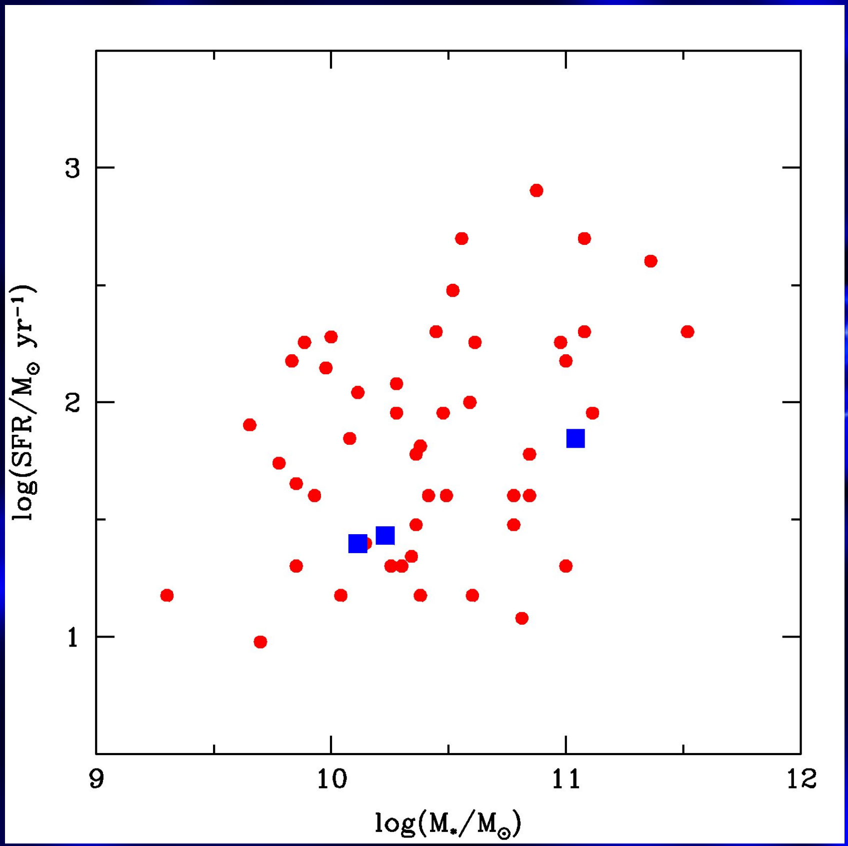
10 kpc

Face-on view

Edge-on view

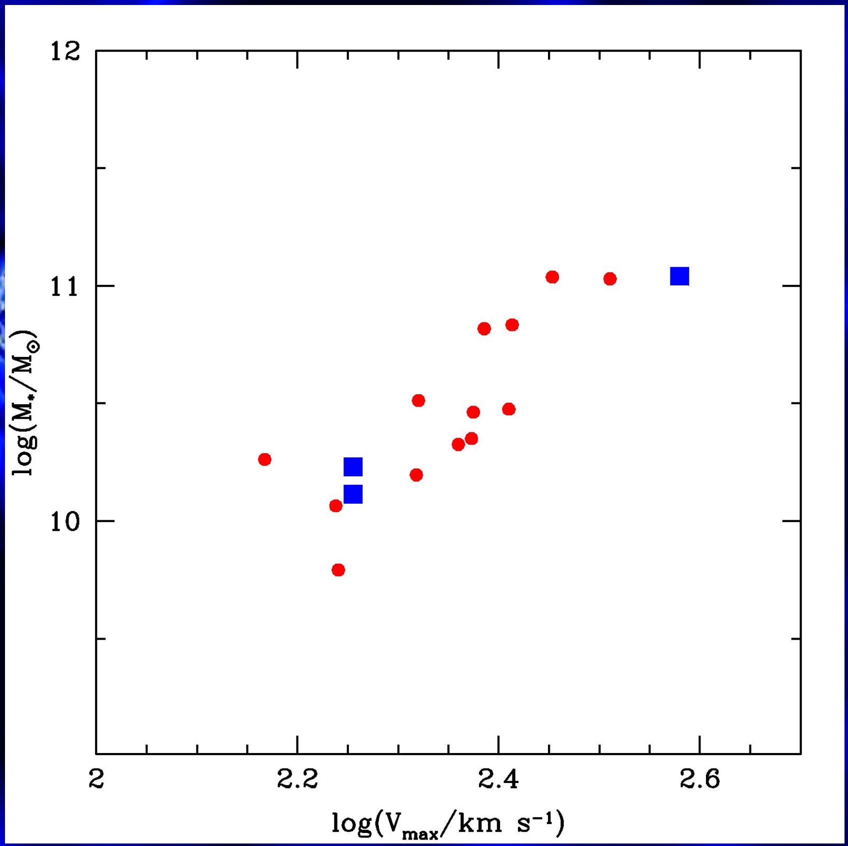
SINS and Simulations

SFR vs Stellar Mass



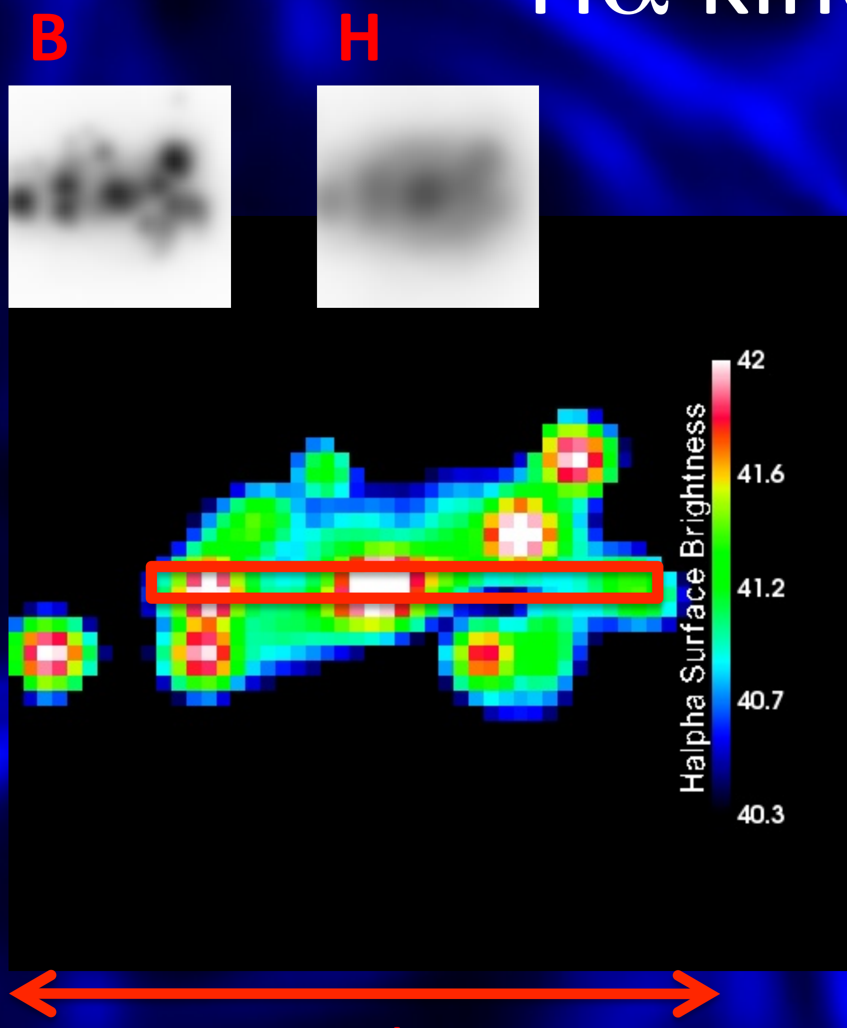
Data (Red circles) from
Forster Schreiber et al. 2009

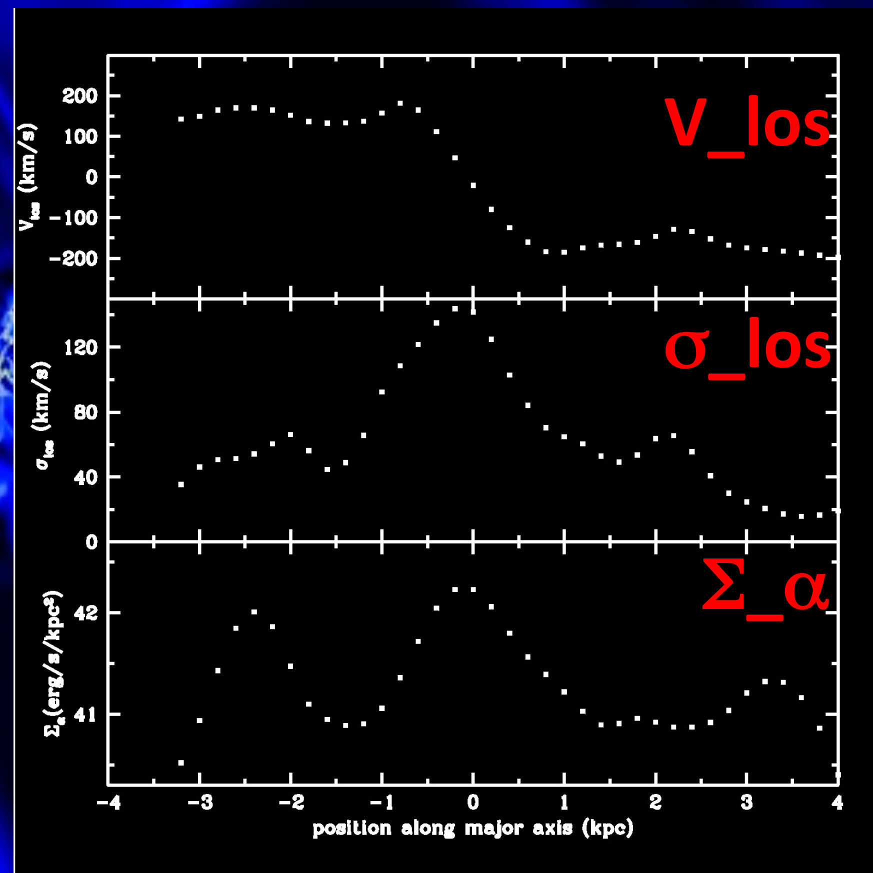
Stellar Mass vs Max. Velocity



Data (Red circles) from
Cresci et al. 2009

Hα kinematics

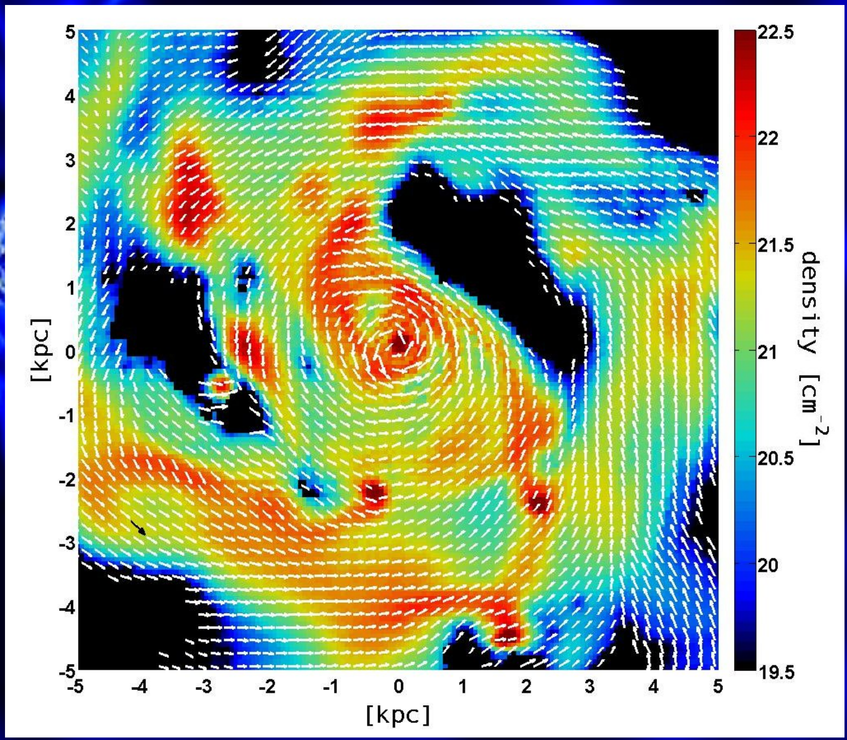




Ceverino et al. (In prep).

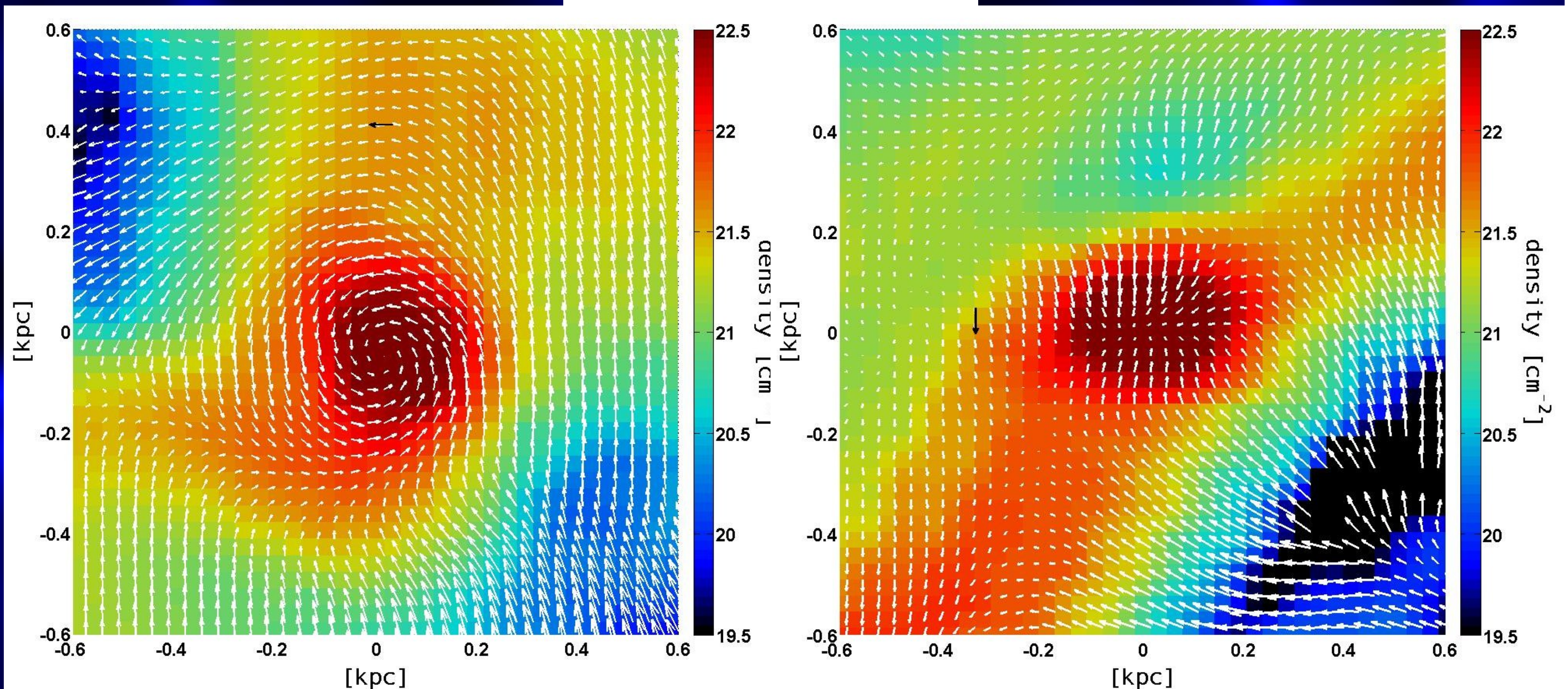
Clumps support

- Are the clumps supported by…
  - Rotation
  - Random motions/ pressure
  - Artifacts ?



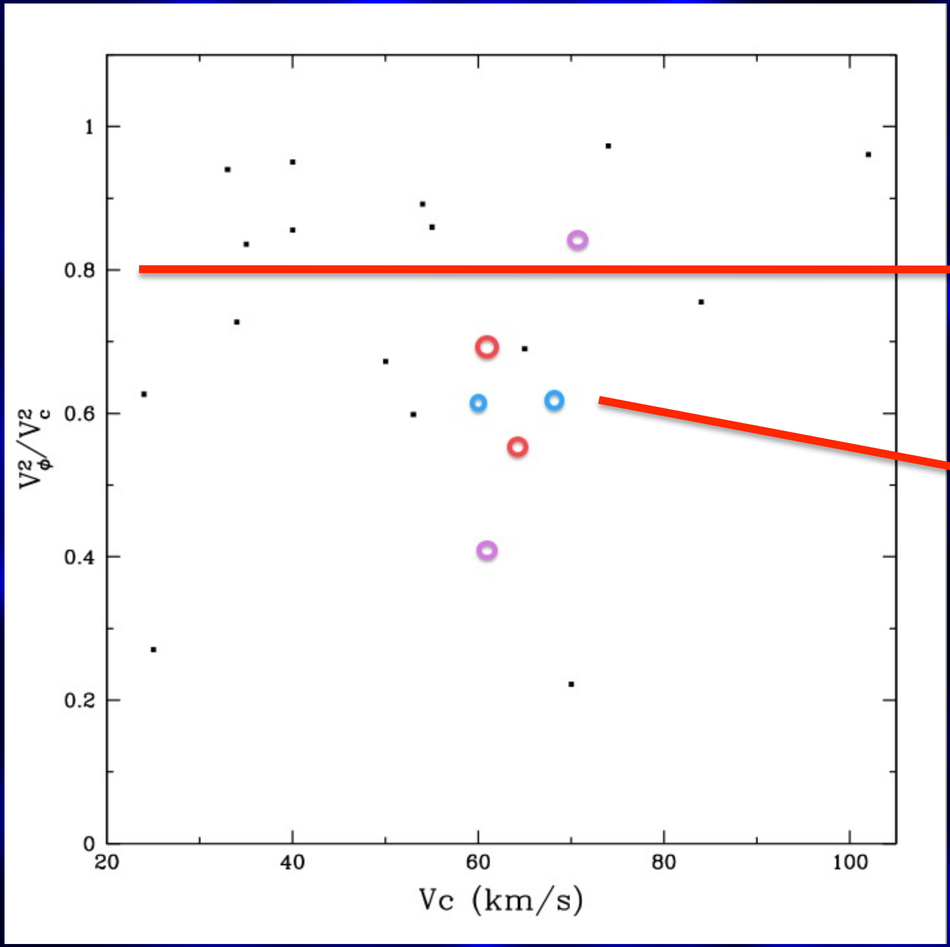
Clumps kinematics

Face-on view V_ϕ=70 km/s Edge-on view



1.2 kpc

Rotationally-supported clumps



V_ϕ^2 / Vc^2

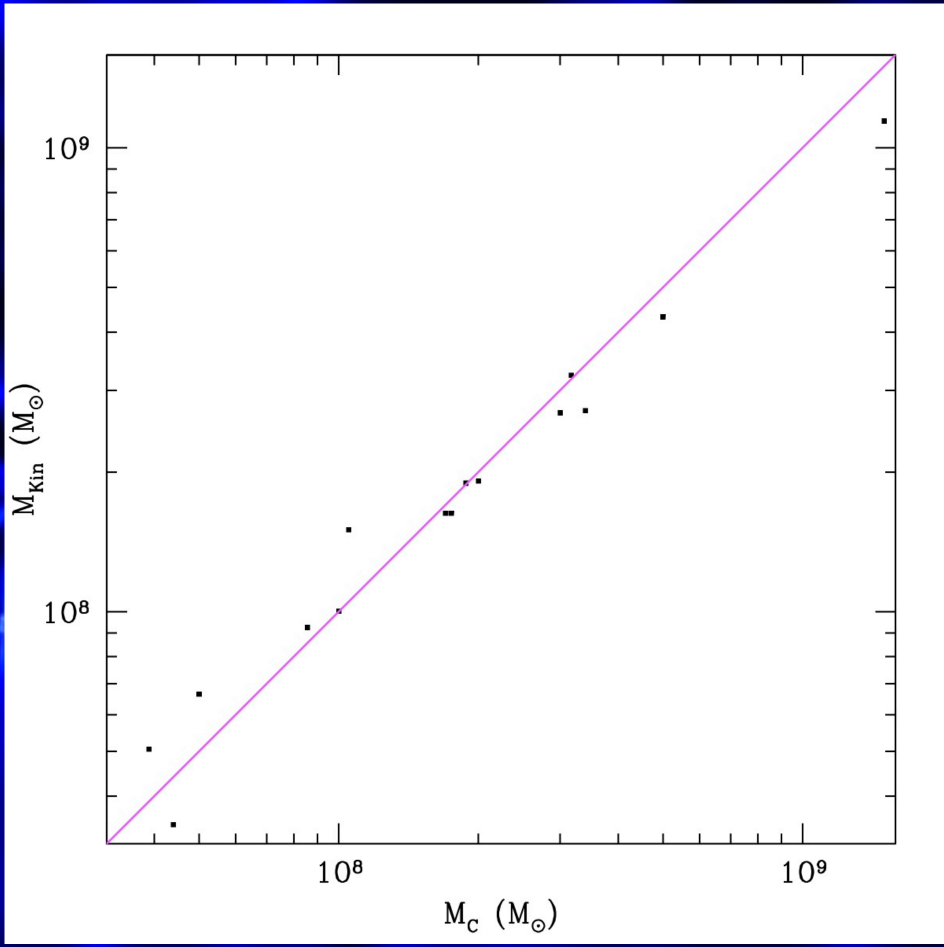
Around %80 of rotational support

Clumps from isolated disc simulations (Bournaud's) with 2-70 pc resolution. Around %60 of rotational support

Vc

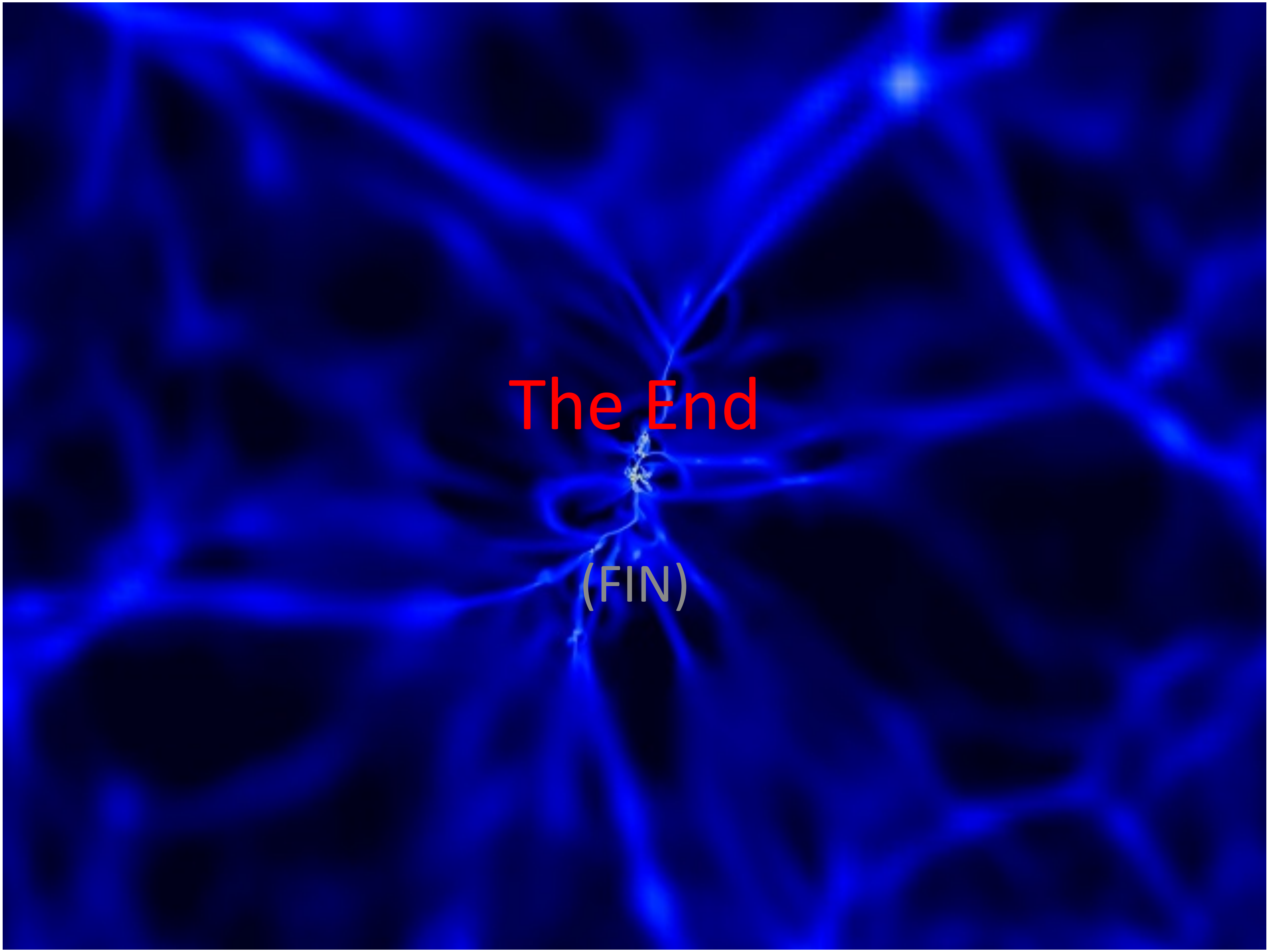
Mass Modeling of Clumps

$$V_c^2 = V_\phi^2 + 2\sigma^2 = \frac{GM_{kin}}{R_c}$$



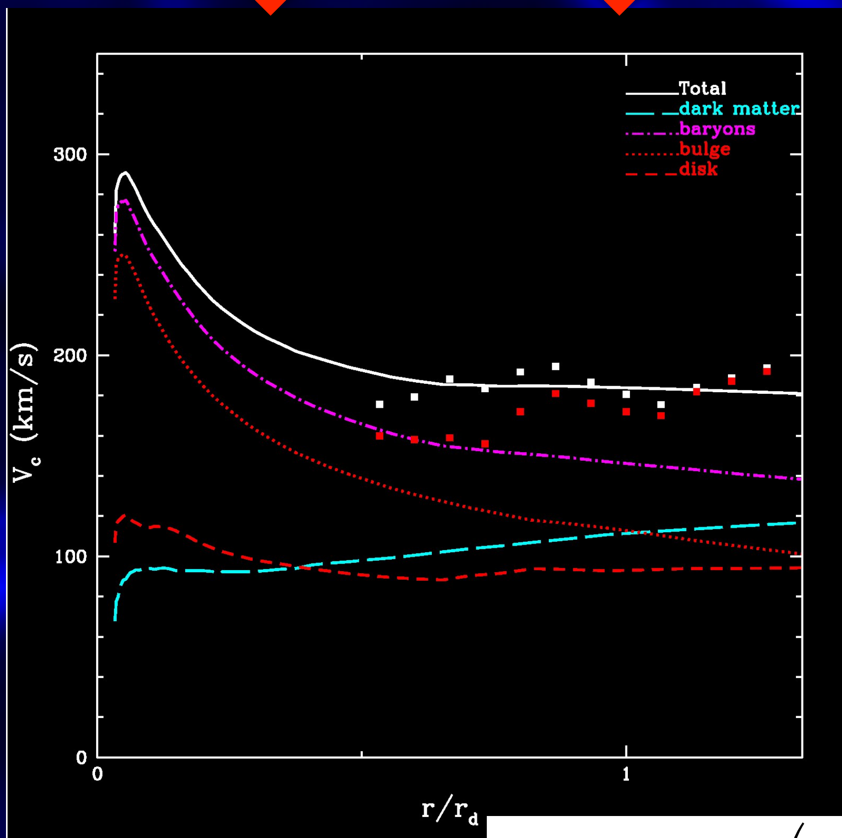
Summary

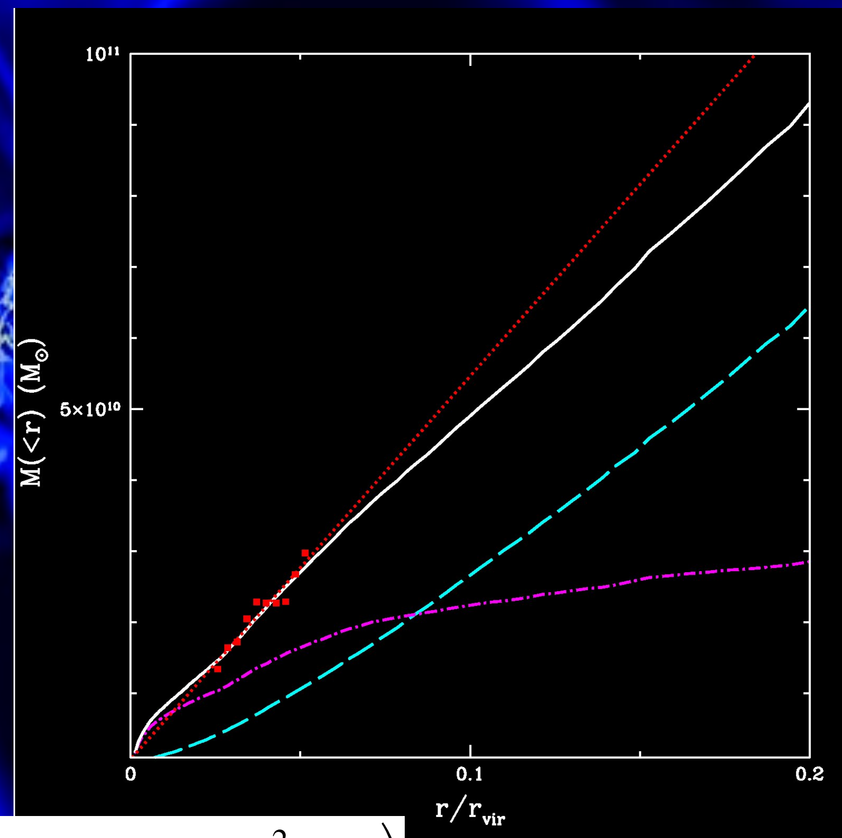
- Cosmological simulations of massive galaxies at high redshift.
- They host marginally gravitationally-unstable disks, supported by rotation (V_{rot}=180-200 km/s).
- Giant clumps (10^7-10^9 $M_{\odot}$) form by disk instabilities.
- Giant clumps are mainly supported by rotation (V_{rot}=40-100 km/s).
- They survive for several orbital periods as they migrate to the center and contribute to the growth of a bulge/spheroid.


The End
(FIN)

Mass Modeling

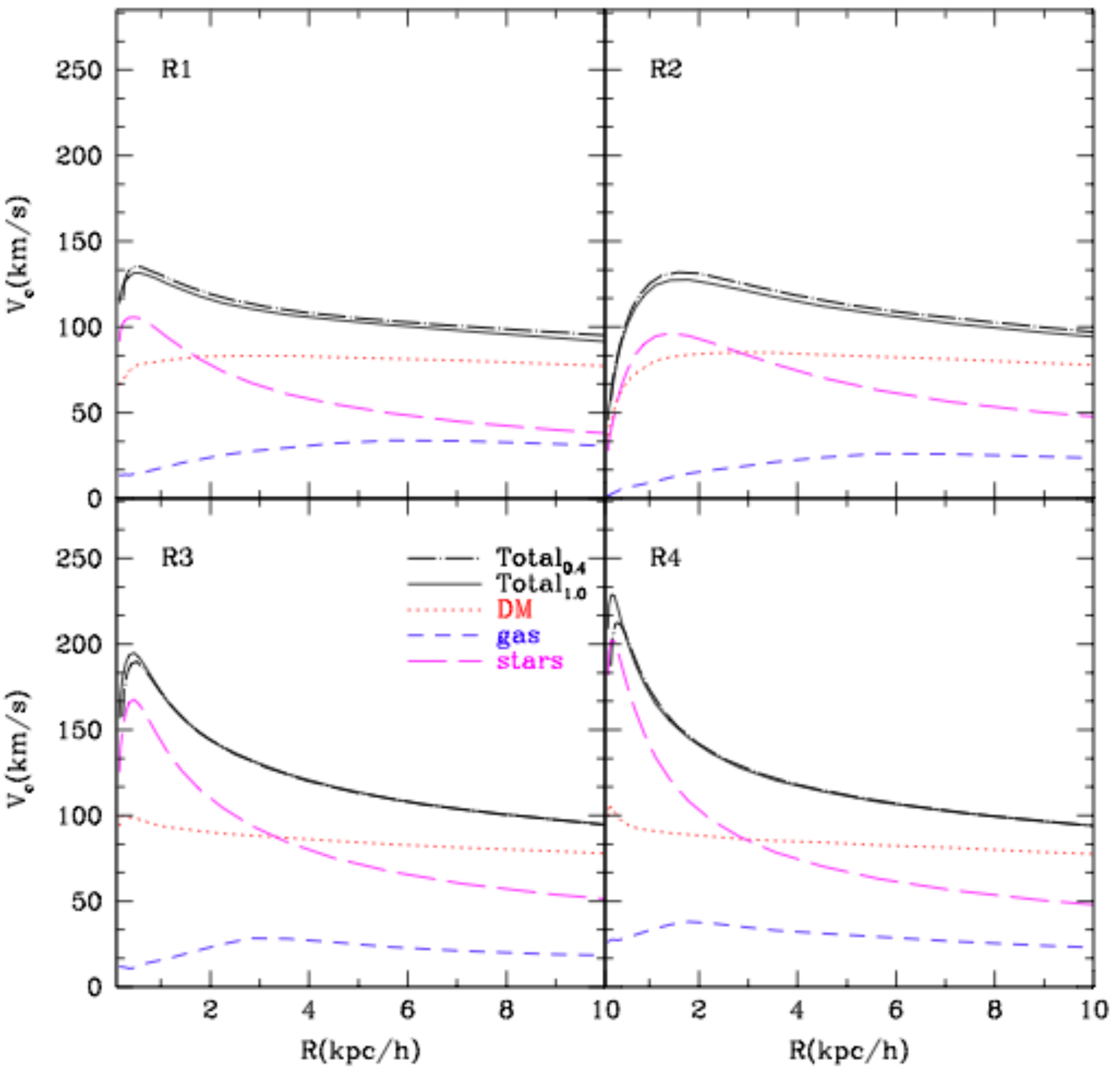
1 kpc **3 kpc**



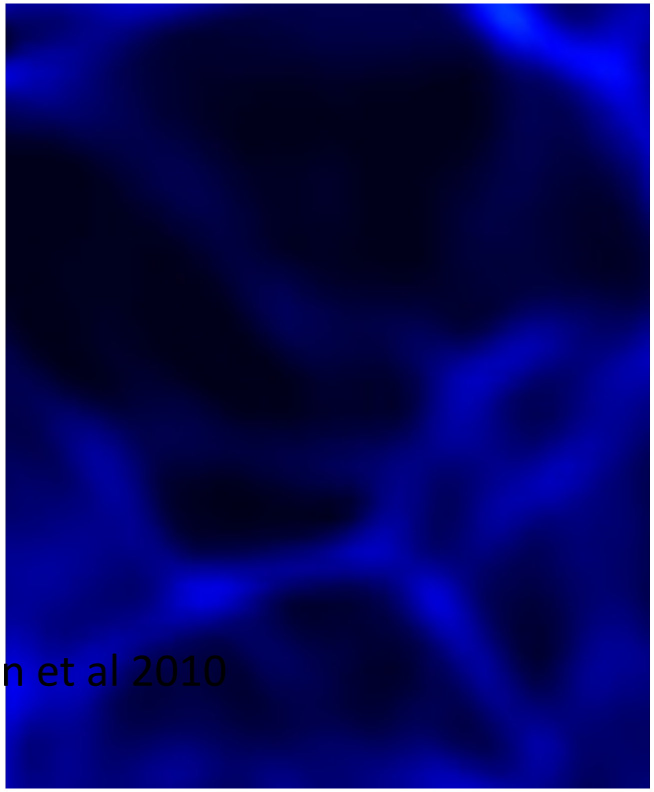


$$V_c^2 = V_\phi^2 - \sigma_r^2\left(\frac{\partial \ln \Sigma_D}{\partial \ln r} + \frac{\partial \ln \sigma^2}{\partial \ln r} - \beta\right)$$

Parameter study



Model	$m_{\star,lim}$ (10^4 M$_\odot$)	n_{SF} (cm^{-3})	$C_\star$ (2.5×10^{-10} yr^{-1})	Cooling	β (10^6 yr)
D1	1.0	50.0	1.0	on	off
D2	8.0	6.25	1.0	on	off
D3	8.0	6.25	1.0	40	off
D4	∞	6.25	none	40	off
R1	1.0	1.0	667.0	on	100.0
R2	1.0	0.1	500.0	40	20.0
R3	1.0	1.0	500.0	40	20.0
R4	1.0	6.25	500.0	40	20.0
Ad	off	off	off	off	off



Colin et al 2010

Mass Modeling of Clumps

$$V_c^2 = V_\phi^2 + 2\sigma^2 = \frac{GM_{kin}}{R_c}$$