Simulating Disk Galaxies:
current status and implications for Milky Way formation

N-body Shop™

makers of quality galaxies

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Image processing: Sunrise by P. Jonsson

Outline

Next generation simulations

- resolving star forming regions
- gas blowout
- bulgeless disks, linear rising rotation curves

Implictions for the Milky Way:

Accreted vs Insitu Stars

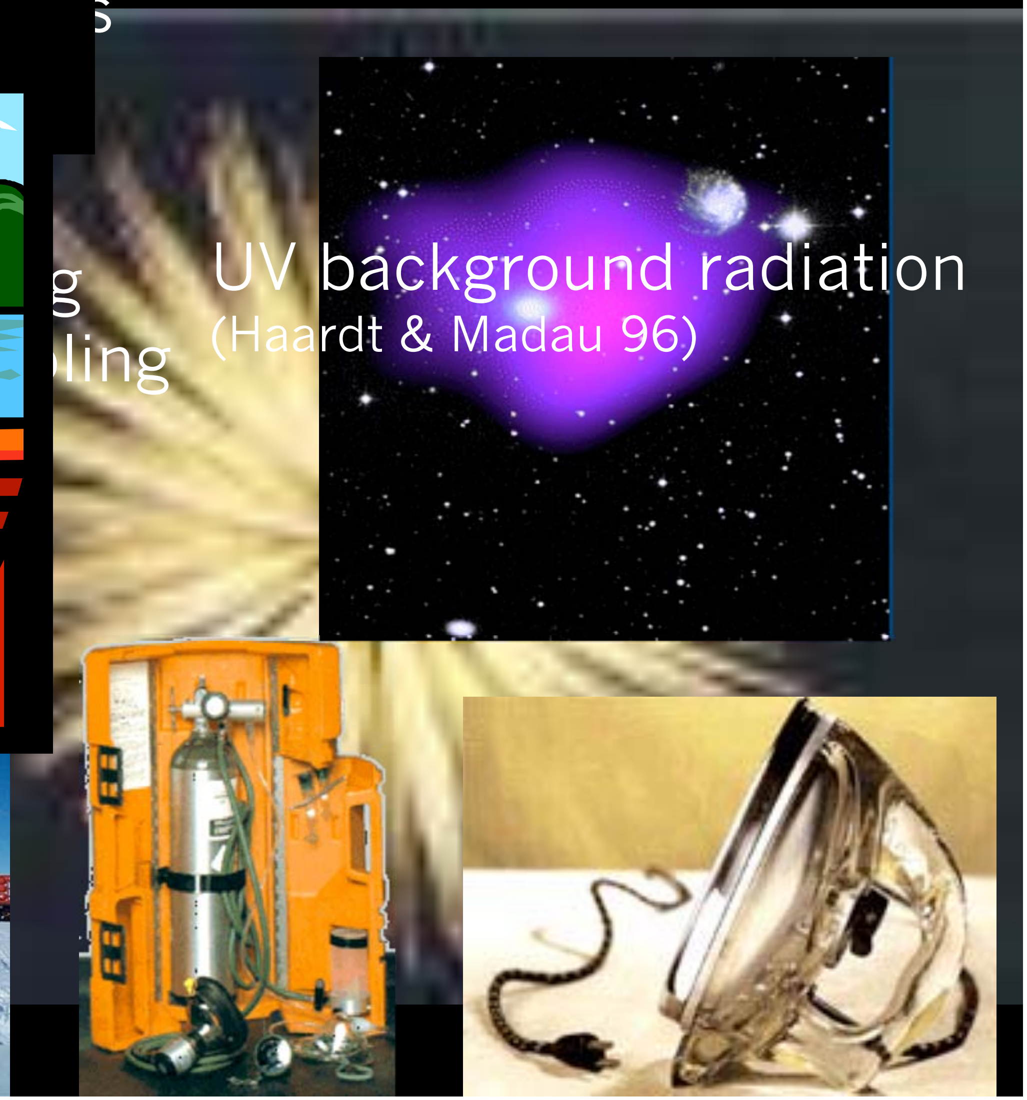
- characteristics of the two populations
- relation to components:
  bulge, disks, (thin & thick), halo
- feedback recipe dependence
- mass dependence

Details of the simulations

parallel chemo-dynamical galaxy evolution code

metal enrichment:

s



g

ling

UV background radiation

(Haardt & Madau 96)

Where to next with the simulations?

So far, star formation regions are not resolved

Star formation “averaged” over large regions

Star formation: density threshold and efficiency are low

Parameters set to match Milky Way star formation rate

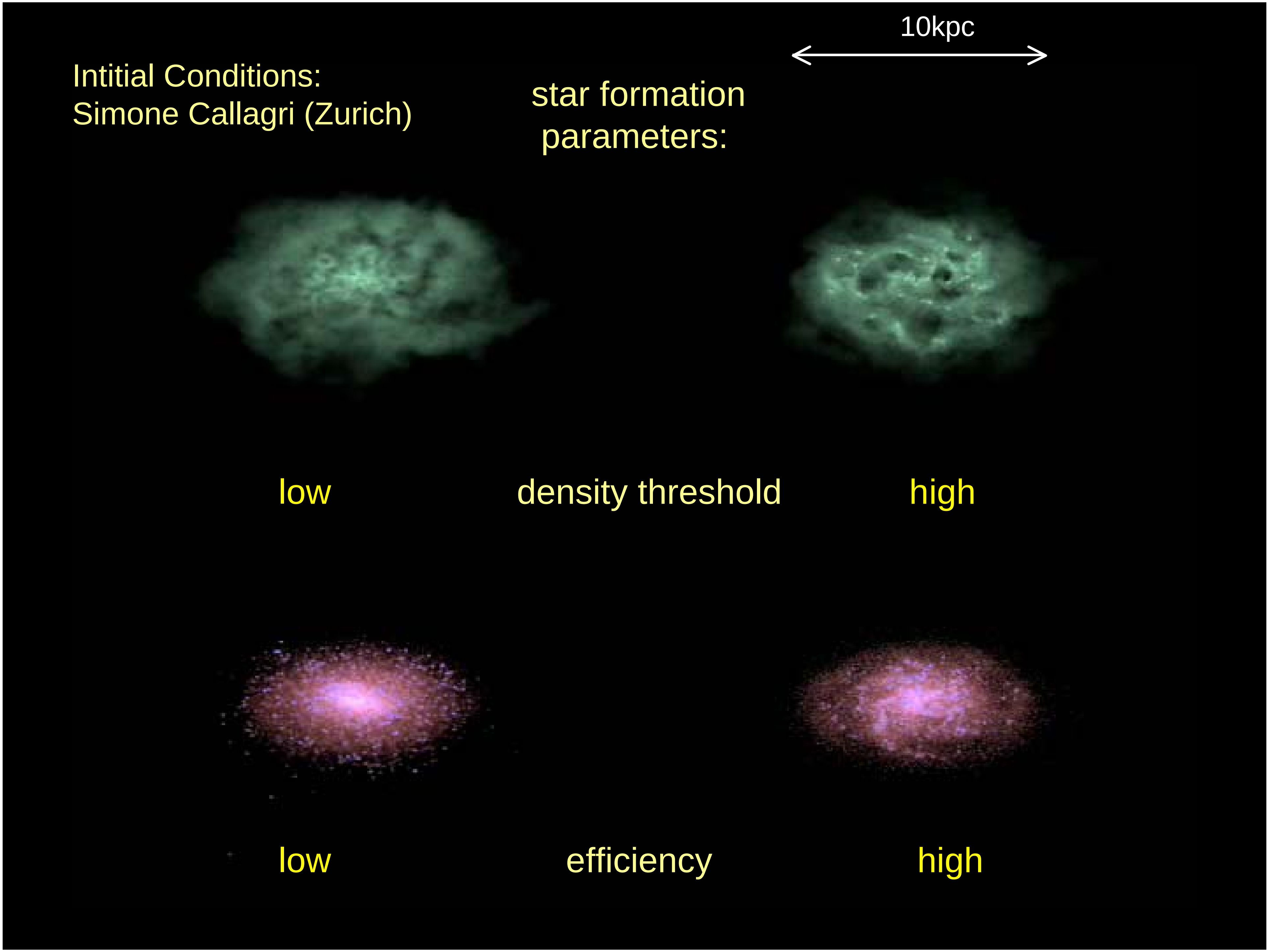
We now have ability to resolve star forming regions in dwarf galaxy simulations

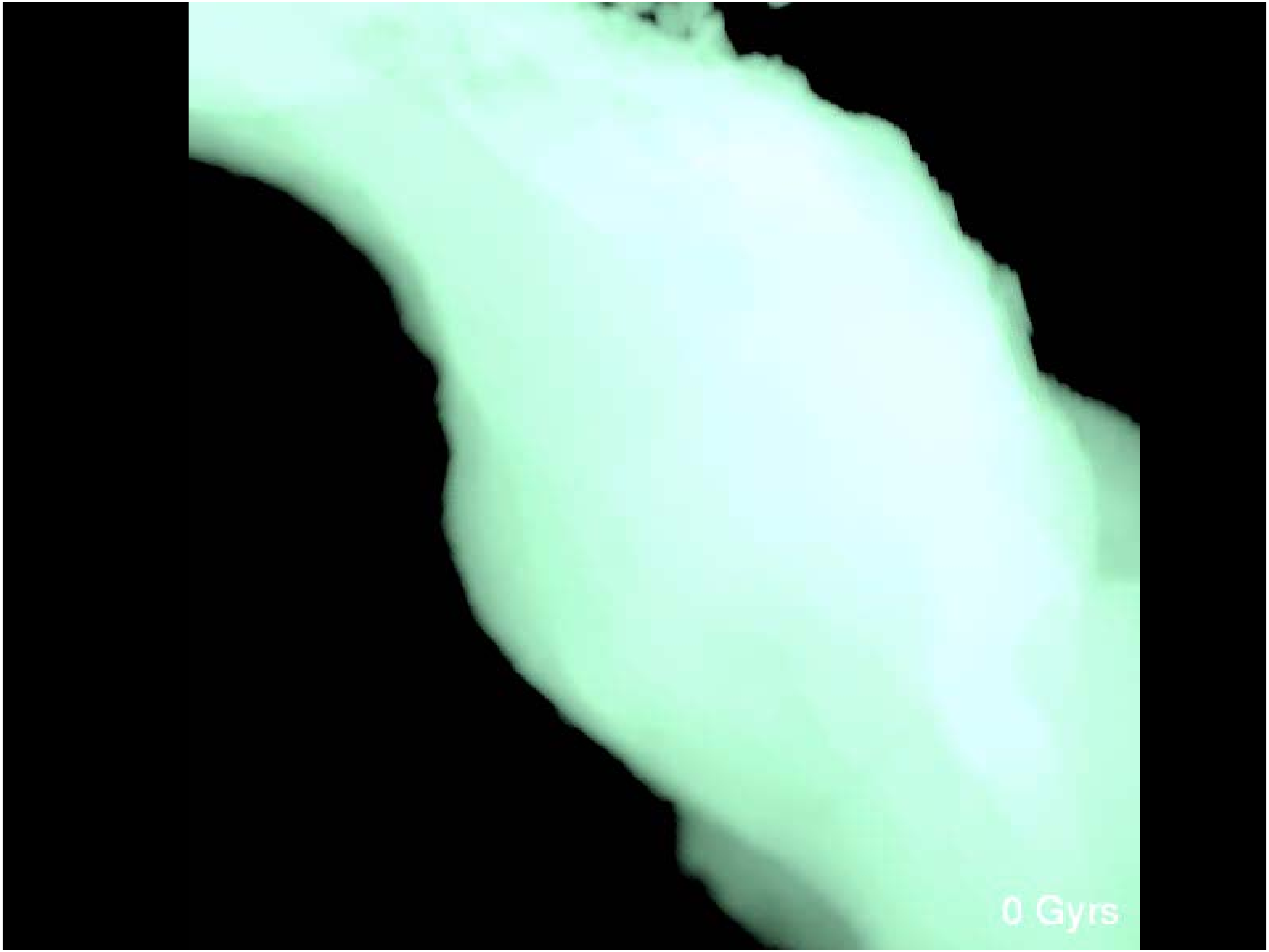
High density threshold and star formation efficiency

Particle mass resolution ~ a few 10^3 $M_\odot$

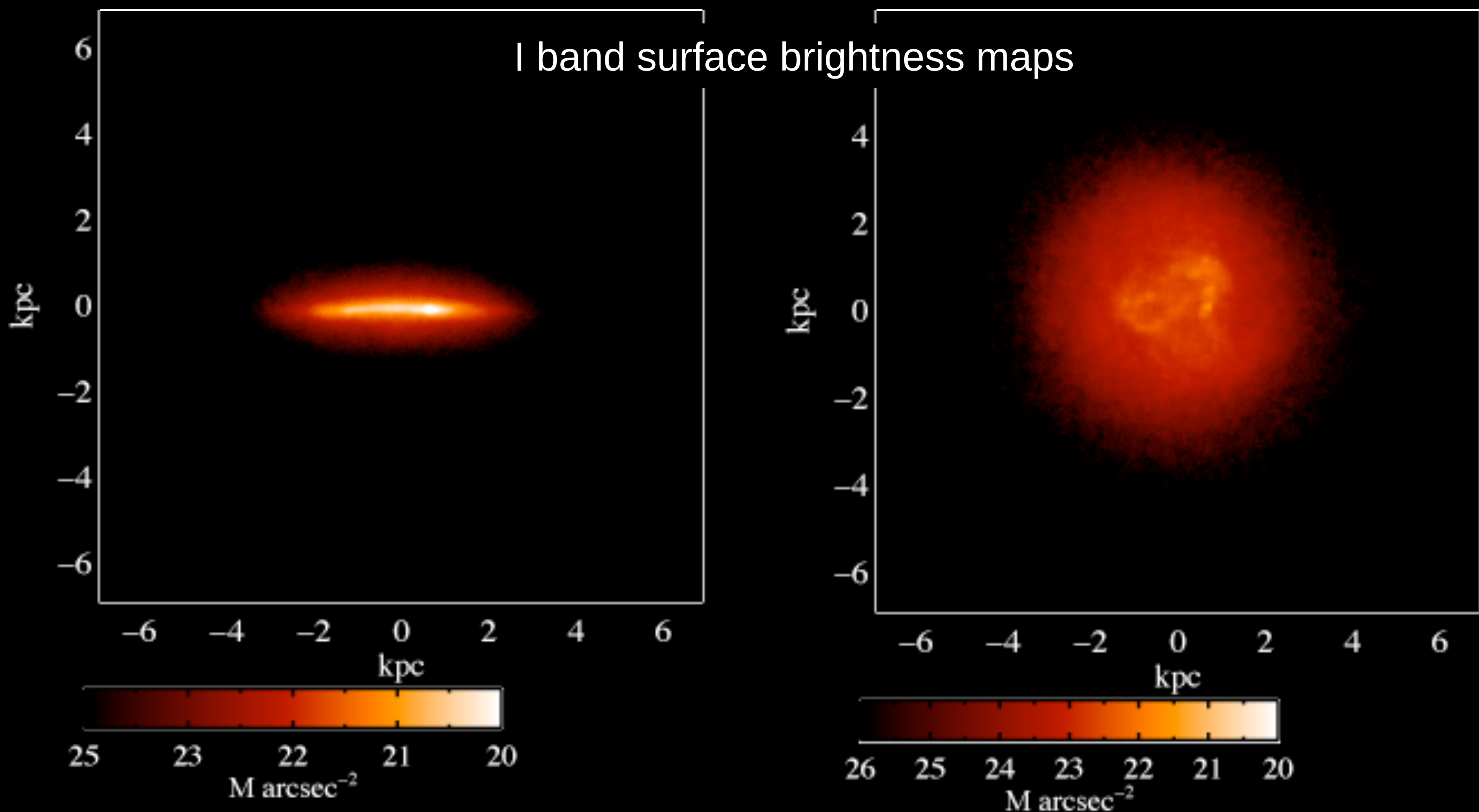
Gravitational Softening ~10pc

See also: Robertson talk tomorrow


10kpc
Intitial Conditions:
Simone Callagri (Zurich)
star formation
parameters:
low
density threshold
high
low
efficiency
high


0 Gyrs

I band surface brightness maps



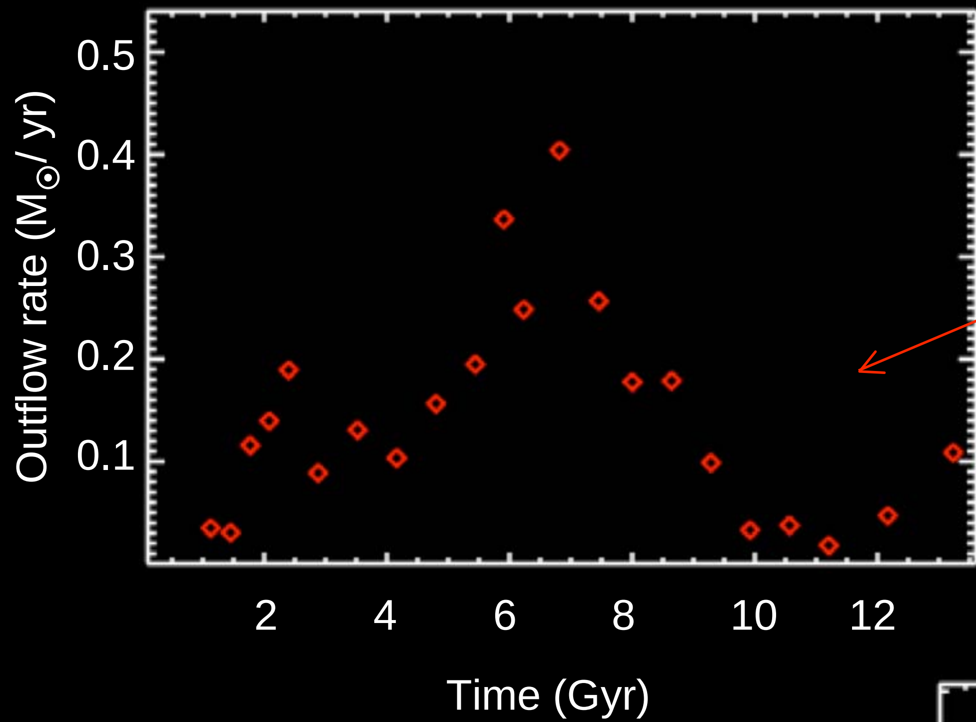
M_I= -17.4

MHI/L_B=1.1

Vrot~50km/s

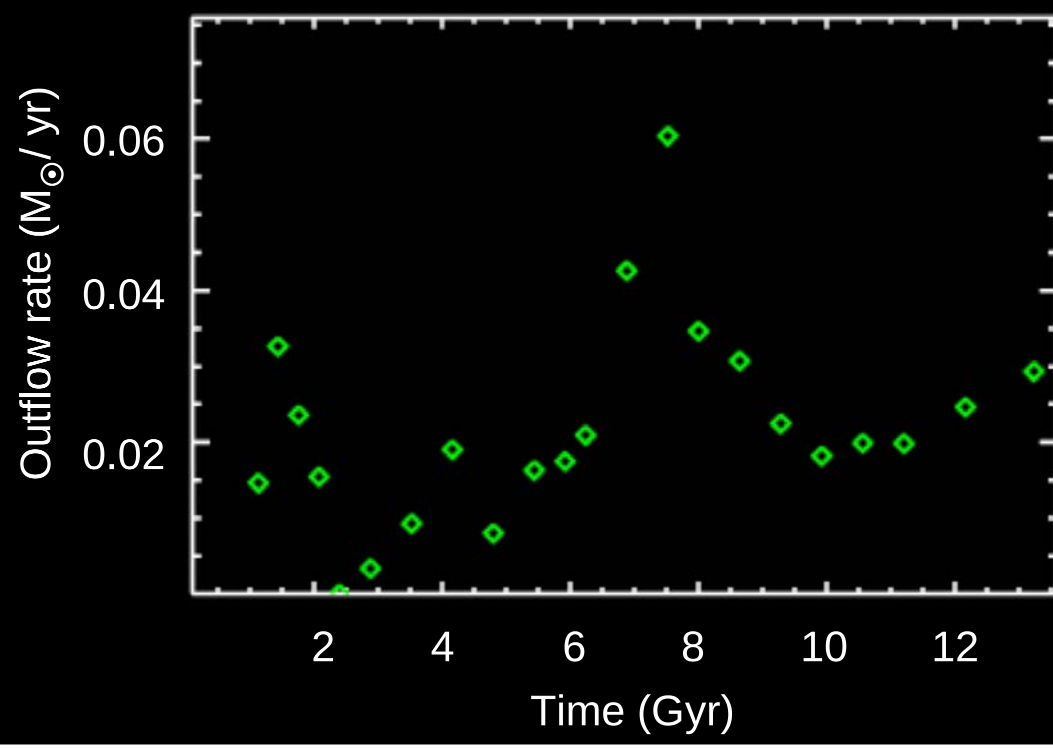
u-r = 1.5

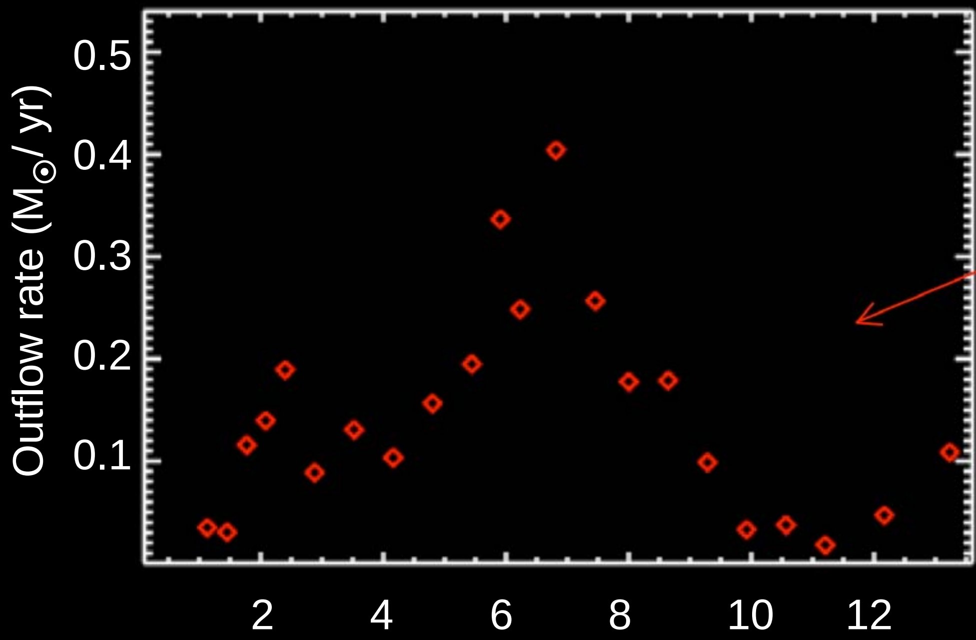
Baryon Fraction ~0.067



significant gas outflow
from central galaxy
when star forming
regions resolved

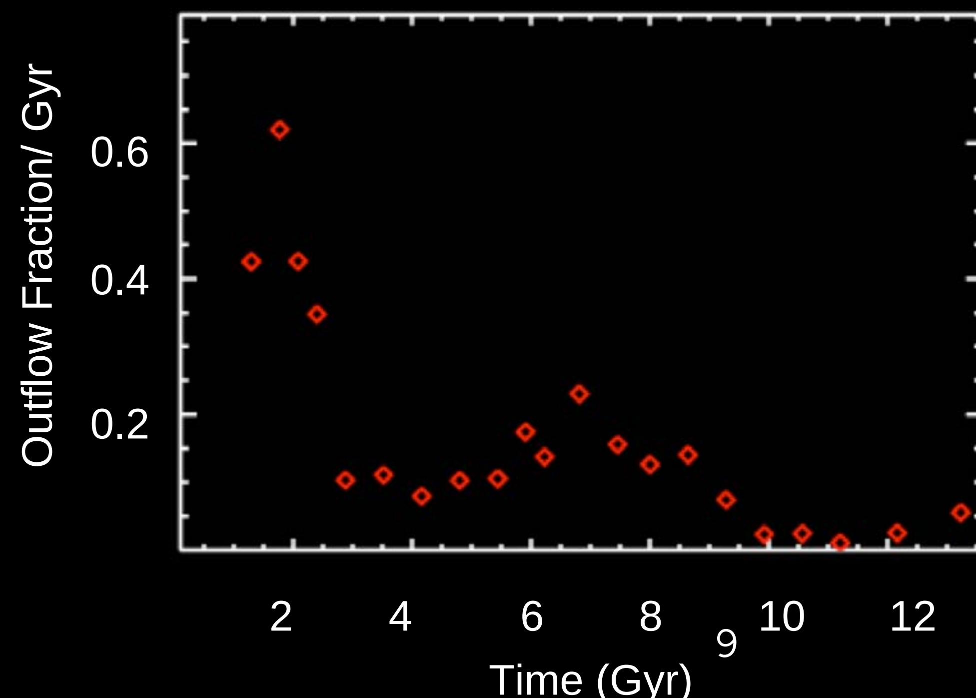
unresolved star formation:
insignificant outflows

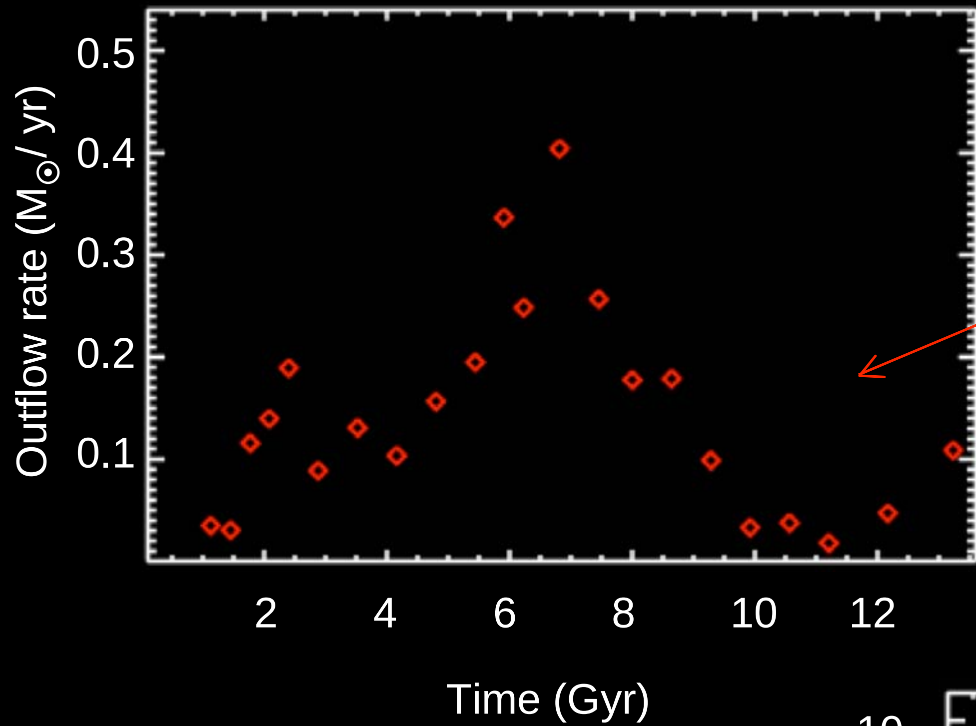




significant gas outflow from central galaxy when star forming regions resolved

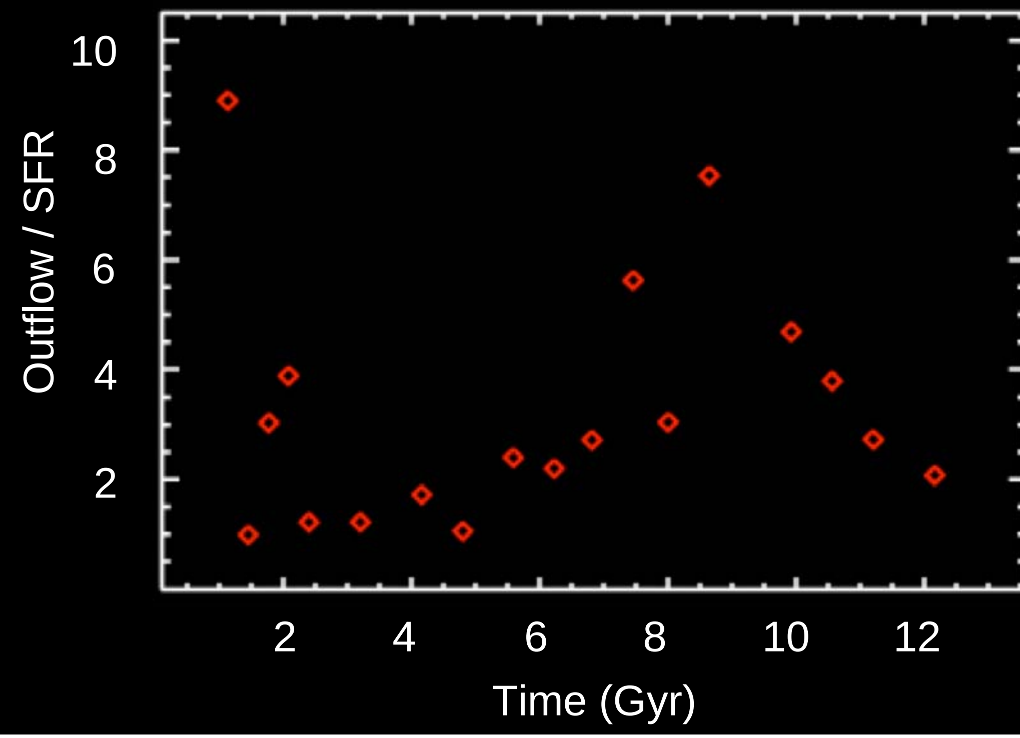
Fraction of mass lost to outflows is highest at high z ie in low mass progenitors

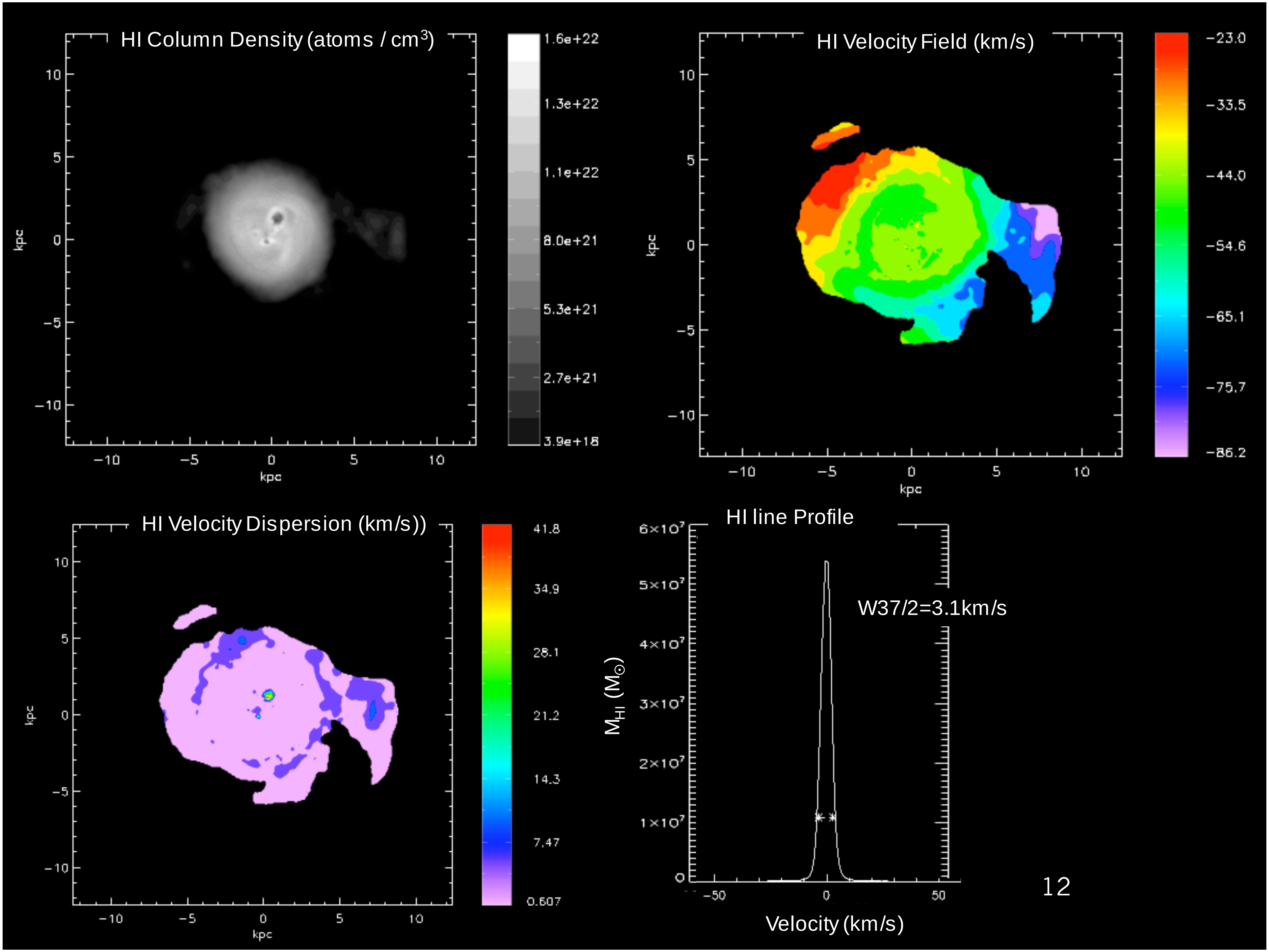




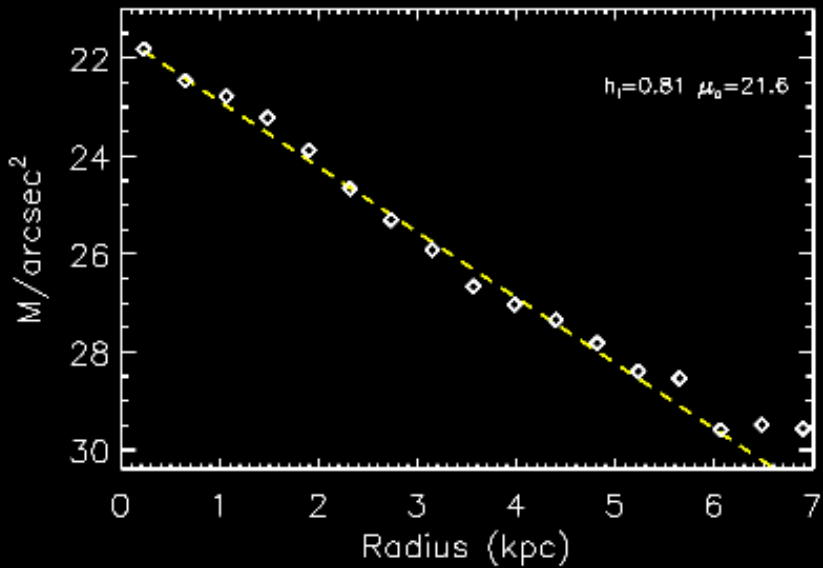
significant gas outflow from central galaxy when star forming regions resolved

mass loading

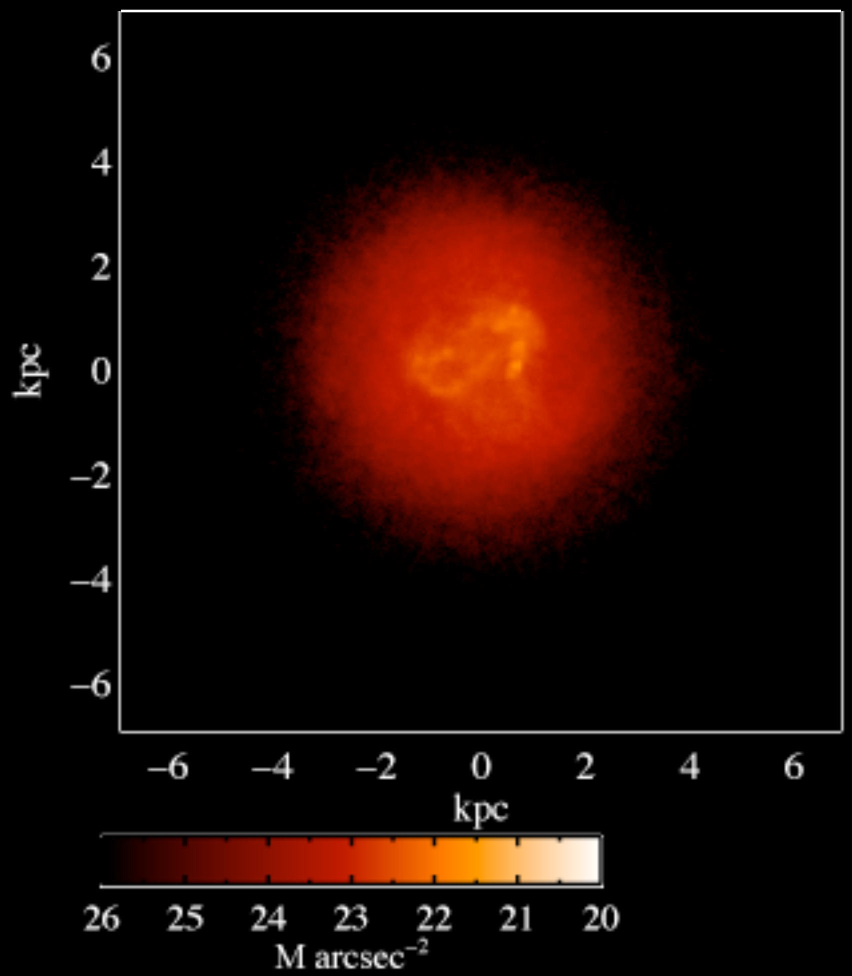




HI Column Density (atoms / cm^3)
1.6e+22
1.3e+22
1.1e+22
8.0e+21
5.3e+21
2.7e+21
3.9e+18
kpc
HI Velocity Field (km/s)
−23.0
−33.5
−44.0
−54.6
−65.1
−75.7
−86.2
HI Velocity Dispersion (km/s))
41.8
34.9
28.1
21.2
14.3
7.47
0.607
HI line Profile
W37/2=3.1km/s
M_{HI} ($M_\odot$)
Velocity (km/s)

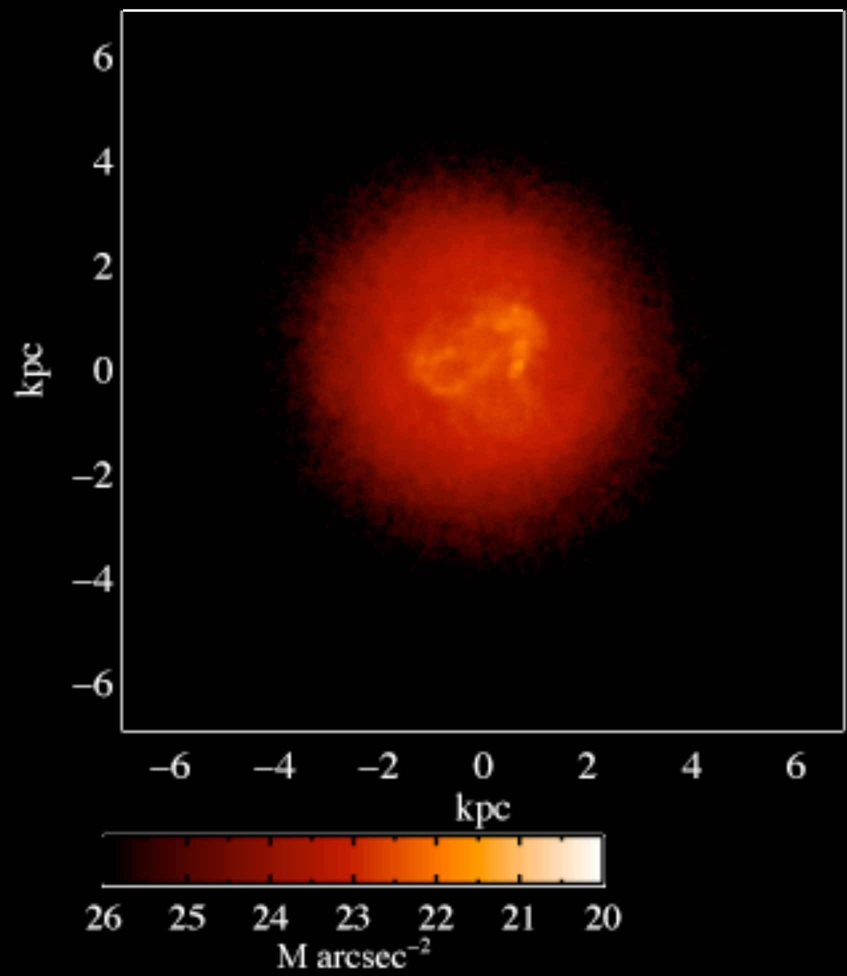


22
24
26
28
30
M/arcsec^2
h_i=0.81 μ_0=21.6
0
1
2
3
4
5
6
7
Radius (kpc)

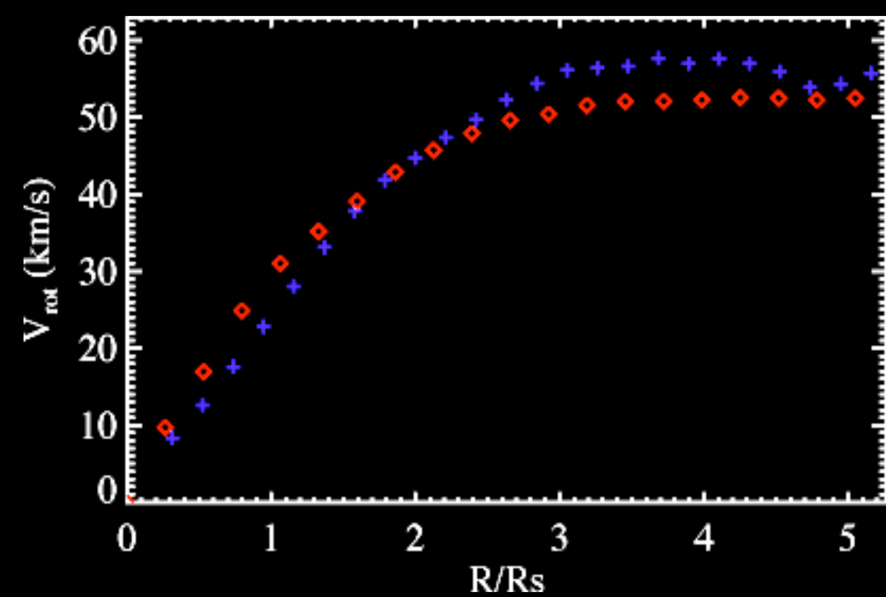


6
4
2
0
−2
−4
−6
kpc
−6
−4
−2
0
2
4
6
kpc
26
25
24
23
22
21
20
M arcsec^{-2}

No bulge!

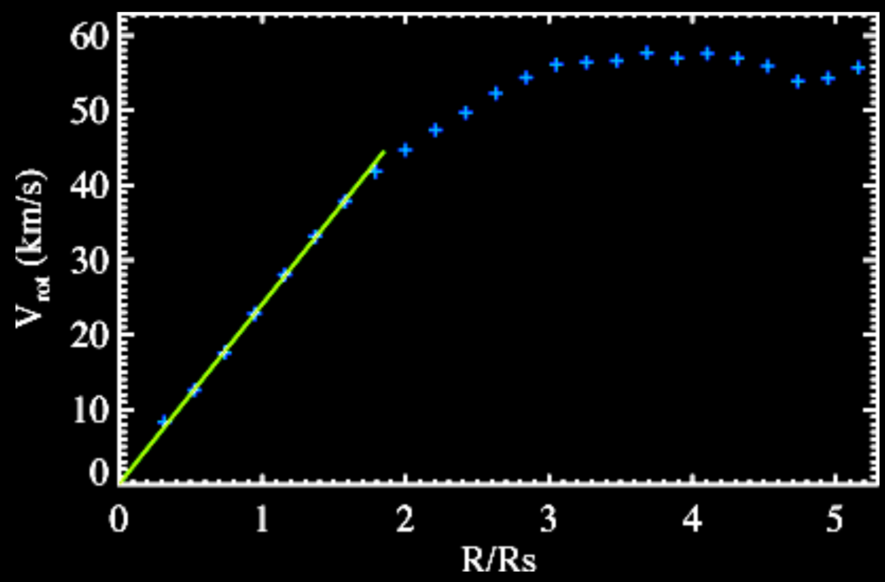


rotation curve

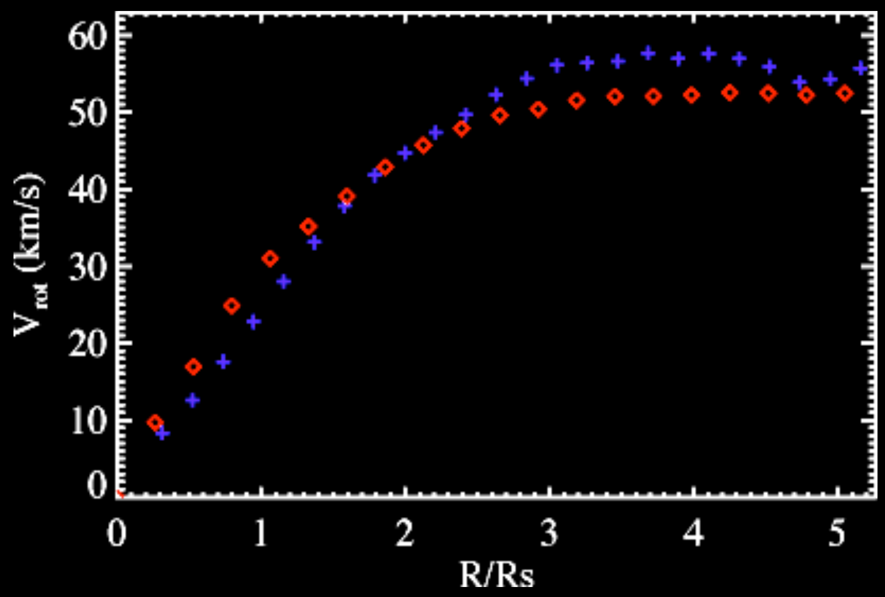


◇ theoretical

+ Tilted ring model
(using cold gas: George Rhee)



rotation curve



◇ theoretical

+ Tilted ring model
(using cold gas: George Rhee)

Conclusions (so far)

Resolving star forming regions is the next step

Gas blowout arises naturally with our supernova recipes

Eject low angular momentum gas from high redshift cold flows

Promising results on two outstanding problems:

- bulgeless disk galaxies
- linearly rising rotation curves

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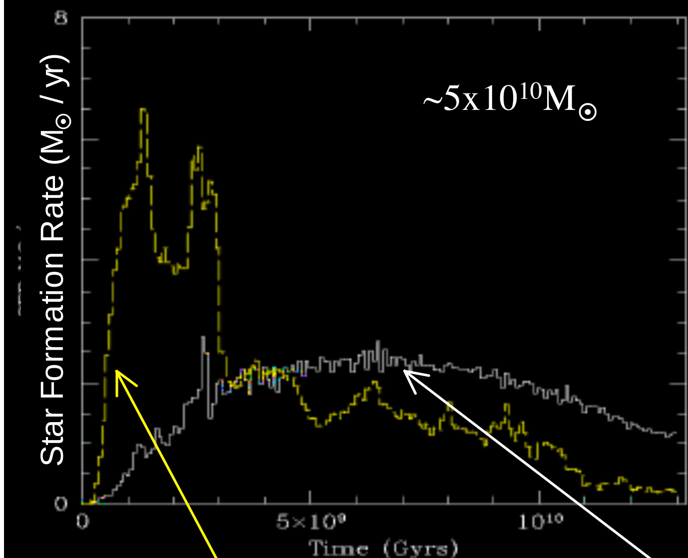
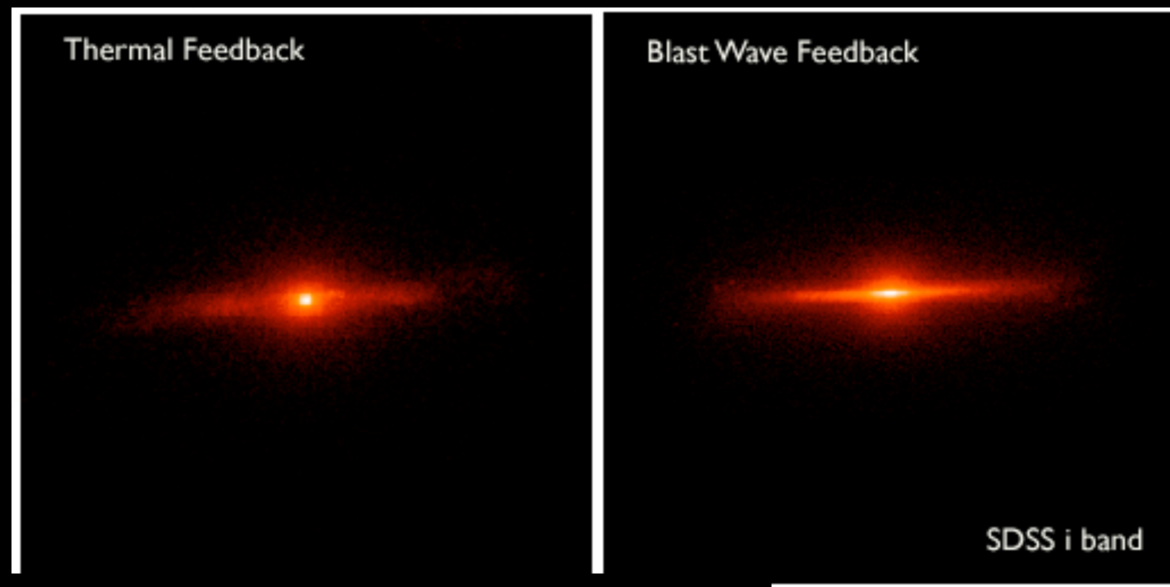
Regulation of star formation has important consequences

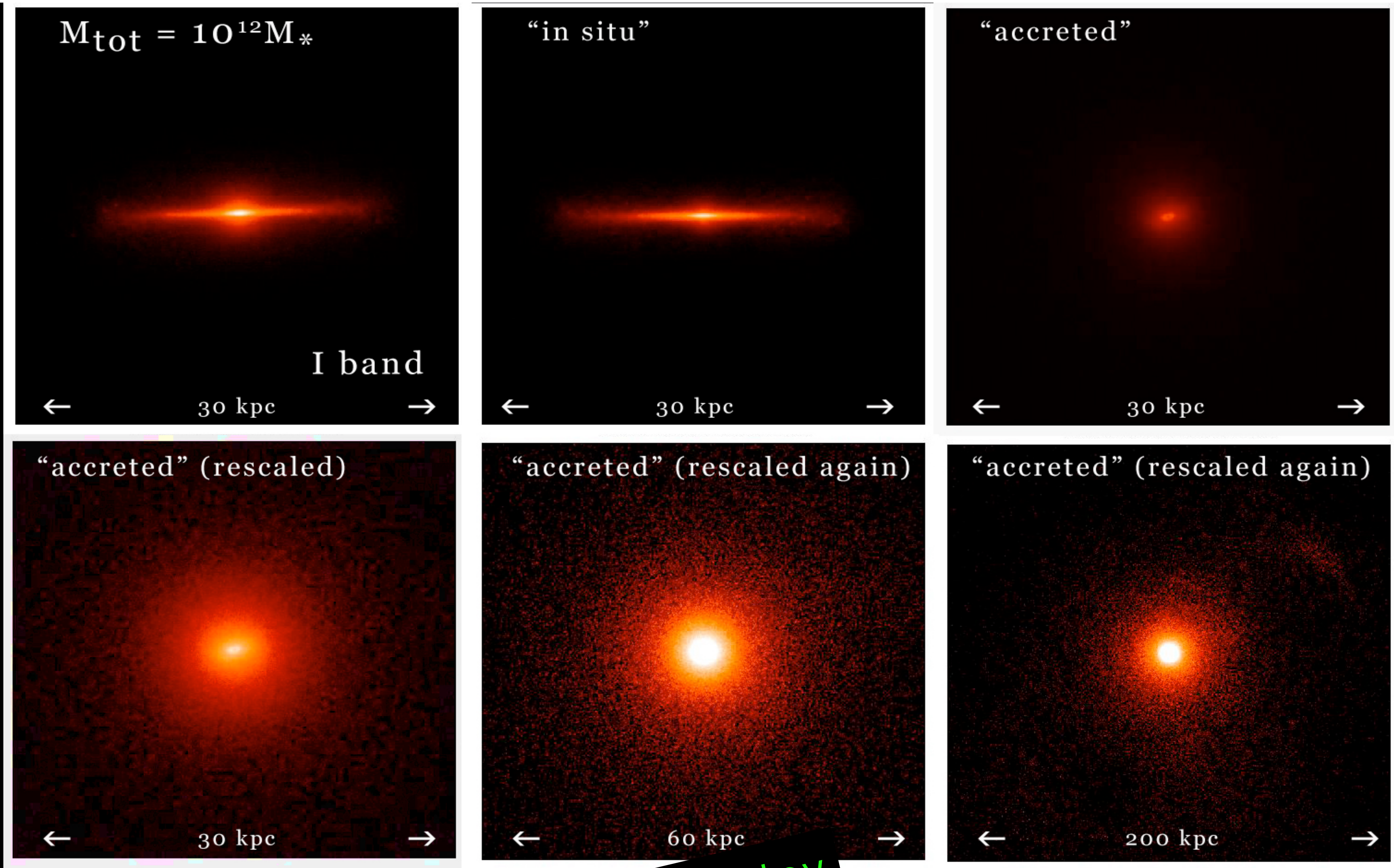




thermal feedback

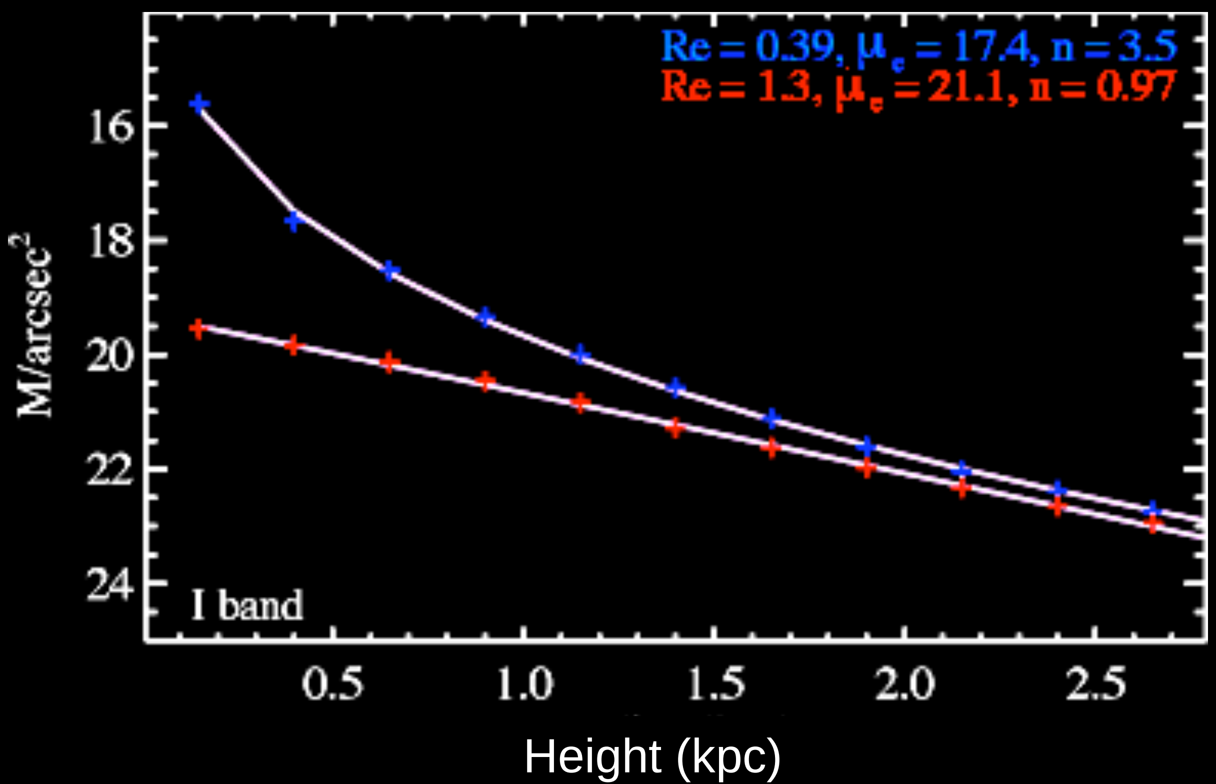
“blast wave” feedback (Stinson et al. 2006)

- angular momentum retention : less dynamical friction
  Thacker & Couchman 2000, Governato et al. 2007
- essential to forming low mass, low metallicity stellar halo
  Brook, Kawata, Gibson, Flynn 2004
  Bullock et al. 2005, Font et al. 2005, Moore et al. 2005
- early mergers are gas rich: implications for thick disk & bulge formation
  Brook, Kawata, Gibson, Freeman 2004, Robertson et al. 2006, Hopkins et al. 2008
- results in a galactic mass metallicity relation
  Brooks et al . 2007



in situ stars do… thick disk and bulge
accret… …ate the halo

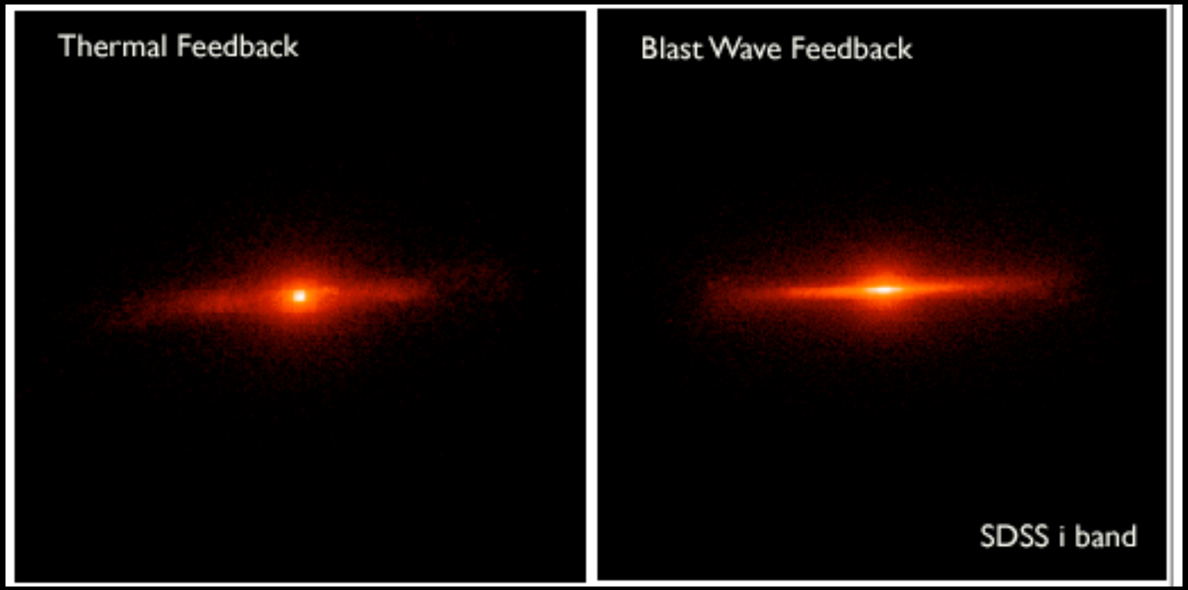
See poster by Adi Zolotov



$1.1x10^{12}M_{\odot}$

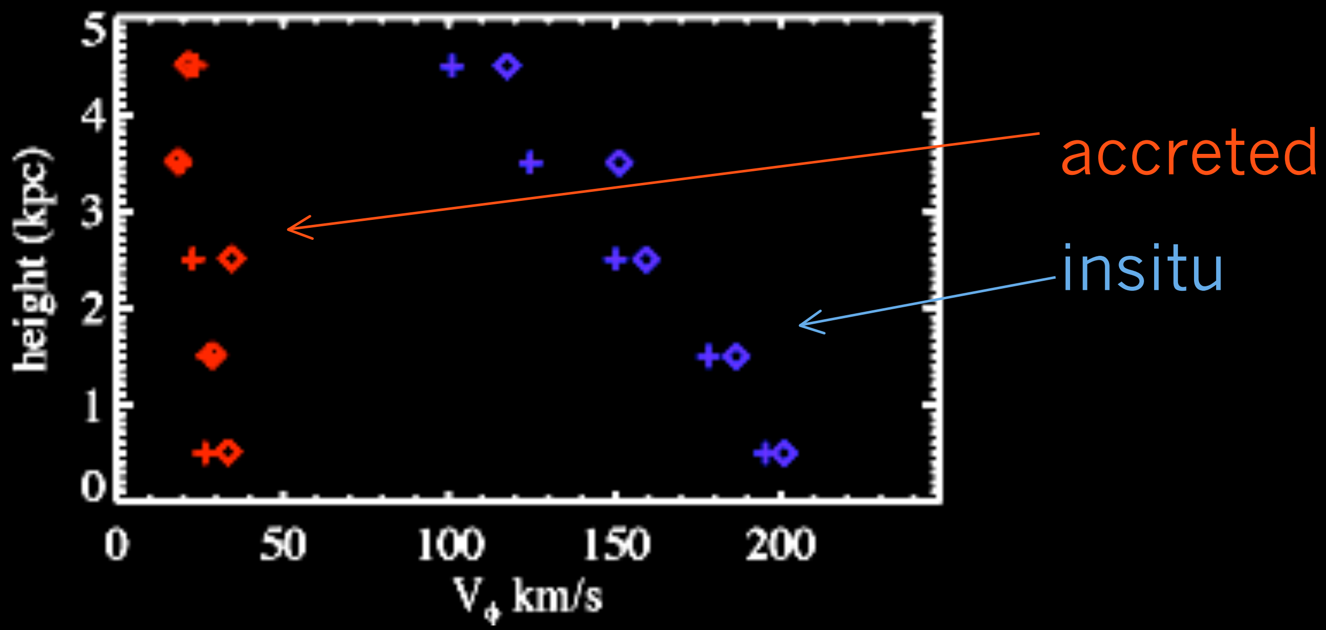
accreted & insitu profiles

Feedback Effects



thermal feedback: 20% of solar neighbourhood stars “accreted”
angular momentum problem, massive spheroid

“blast wave” feedback: 5% solar n’hood stars “accreted”
sits on Tully-Fisher relation, dominant disk

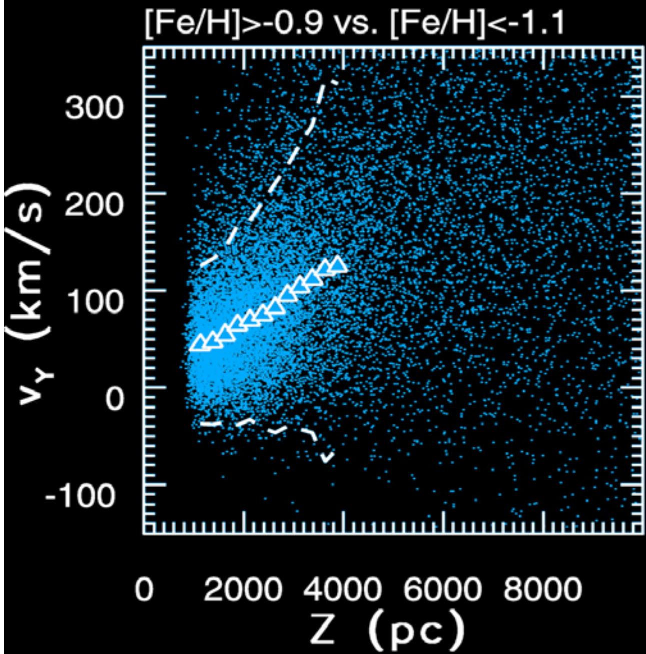


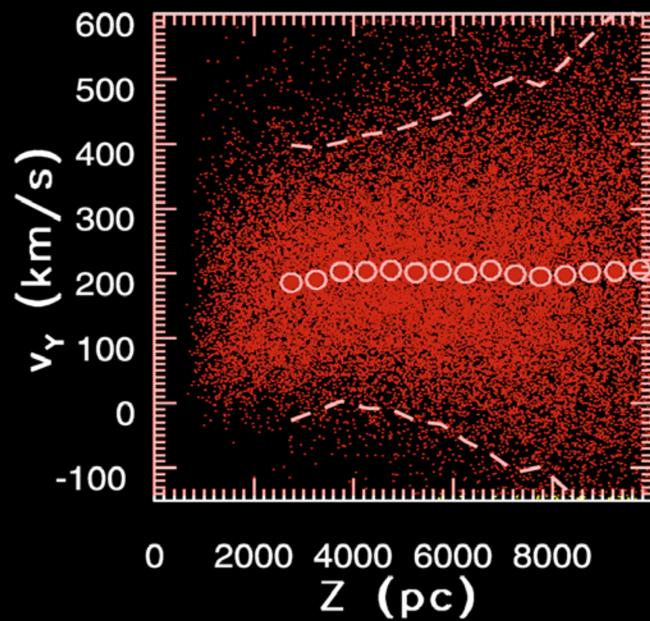
rotational velocity gradients

height= from the disk plane

+ thermal feedback: 20% of solar neighbourhood stars “accreted”

◇ “blast wave” feedback: 5% solar n’hood stars “accreted” rotational velocity gradients





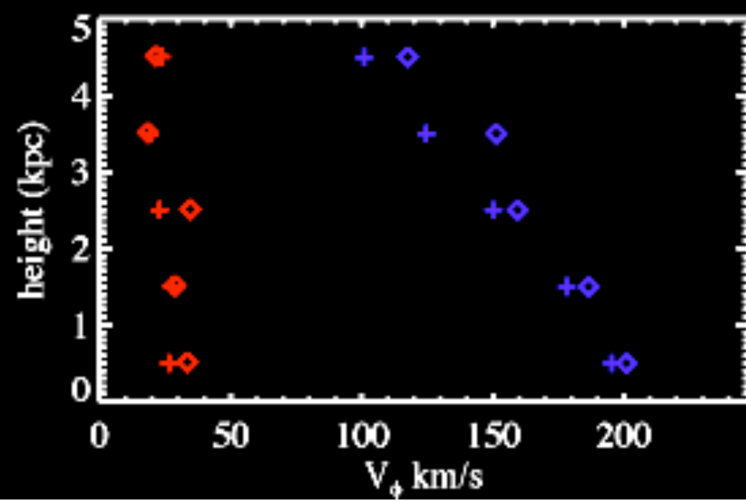
Low metallicity

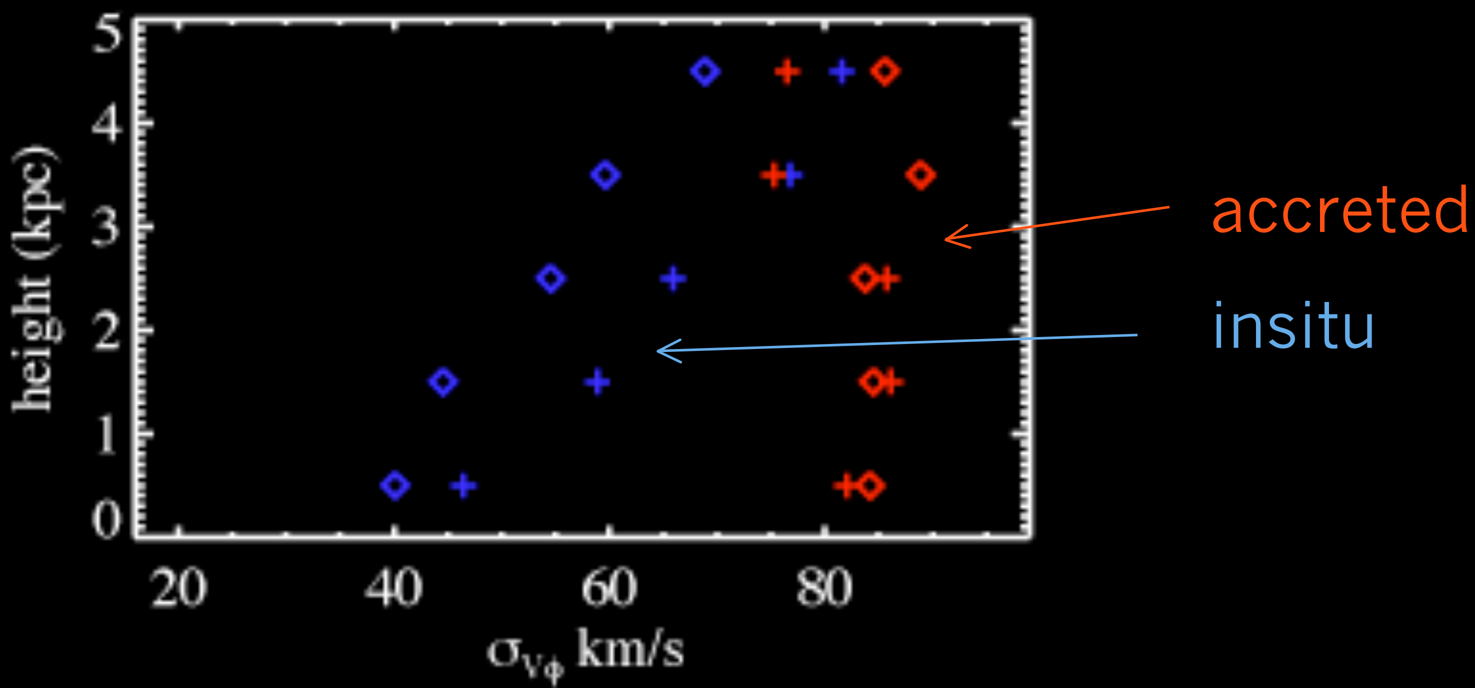
High metallicity

Ivezic et al. 2008

accreted

insitu





velocity dispersion gradients

+ thermal feedback: 20% of solar neighbourhood stars "accreted"

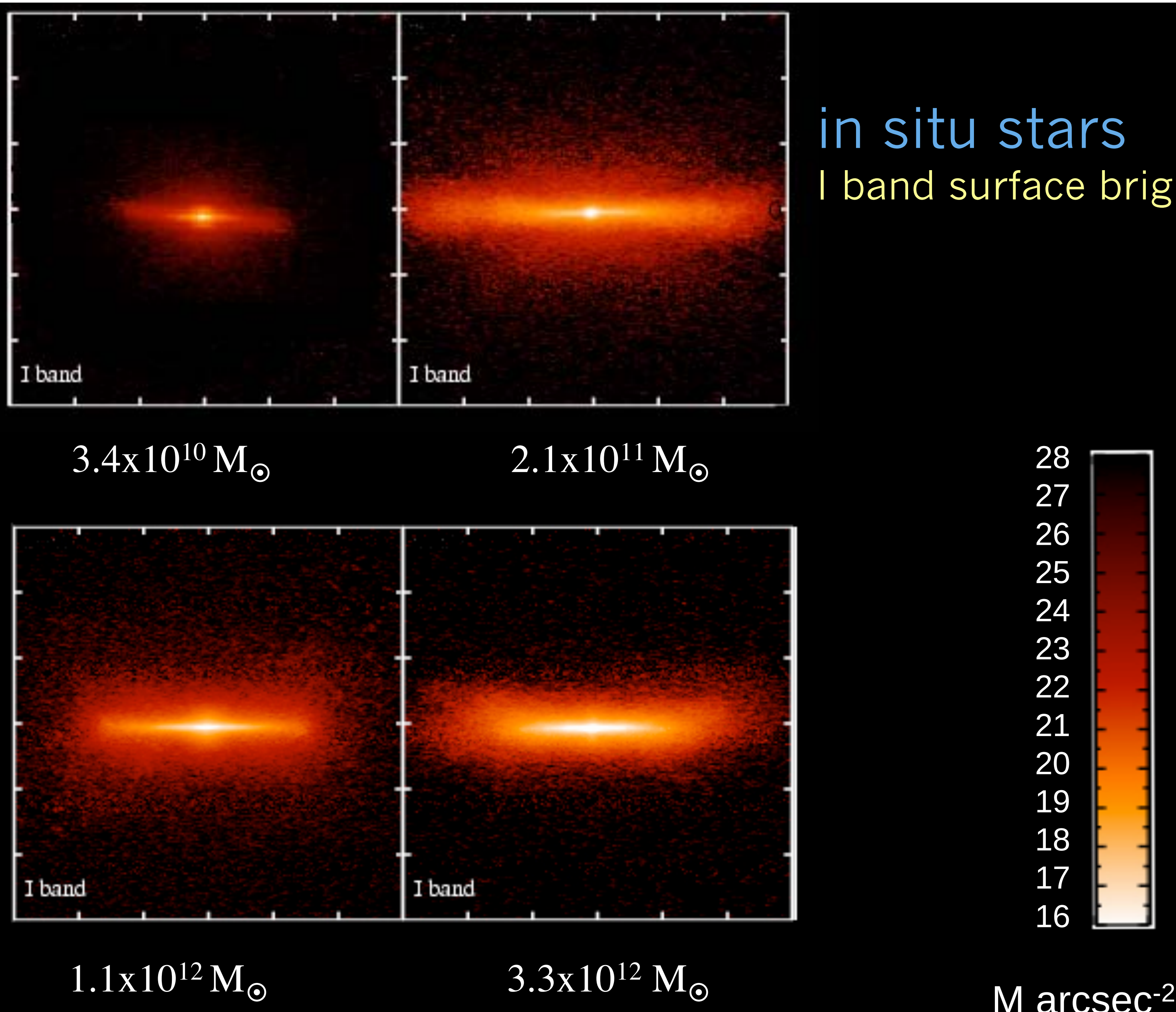
◇ "blast wave" feedback: 5% solar n'hood stars "accreted"

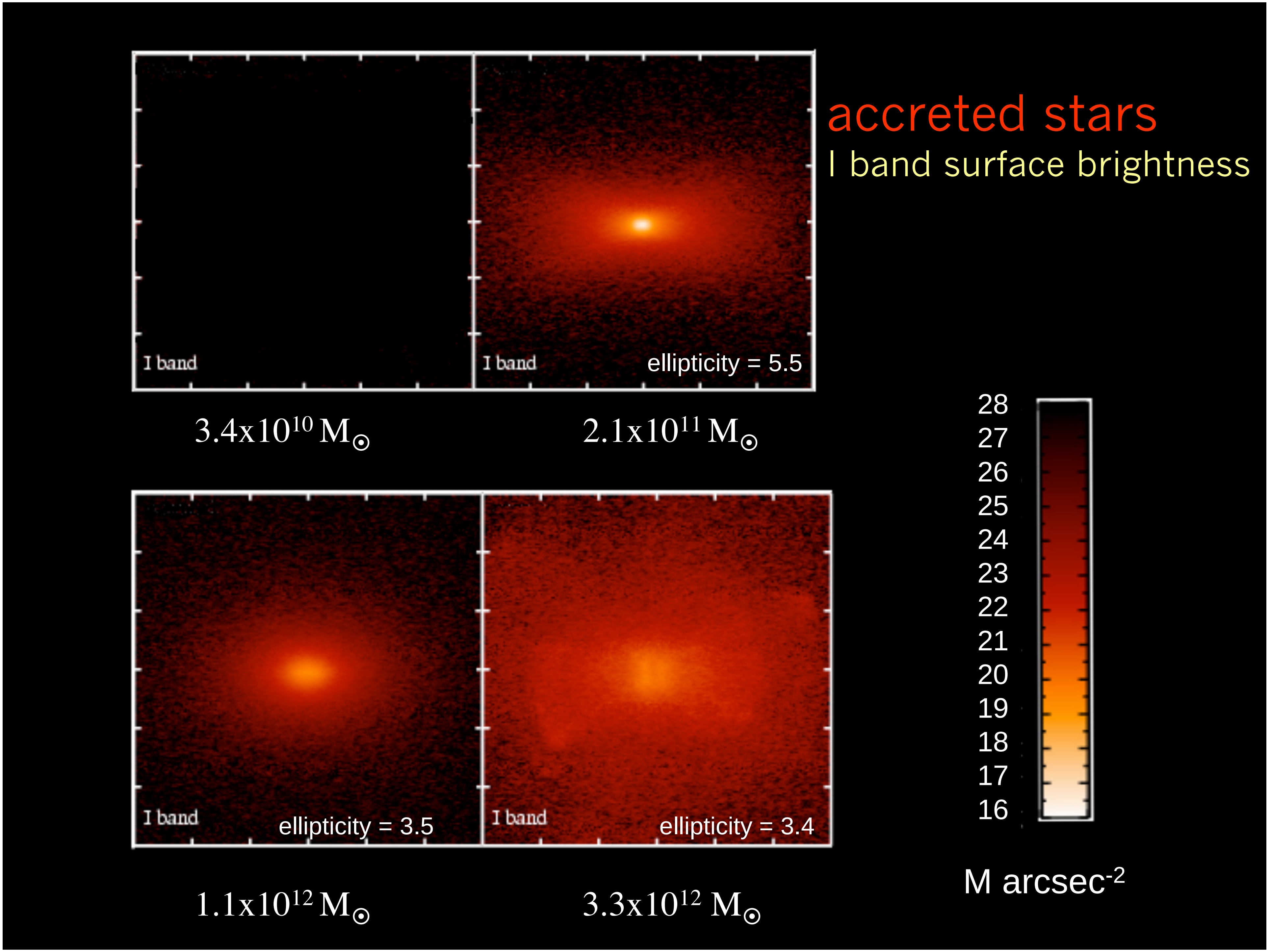
Mass dependence of satellite accretion

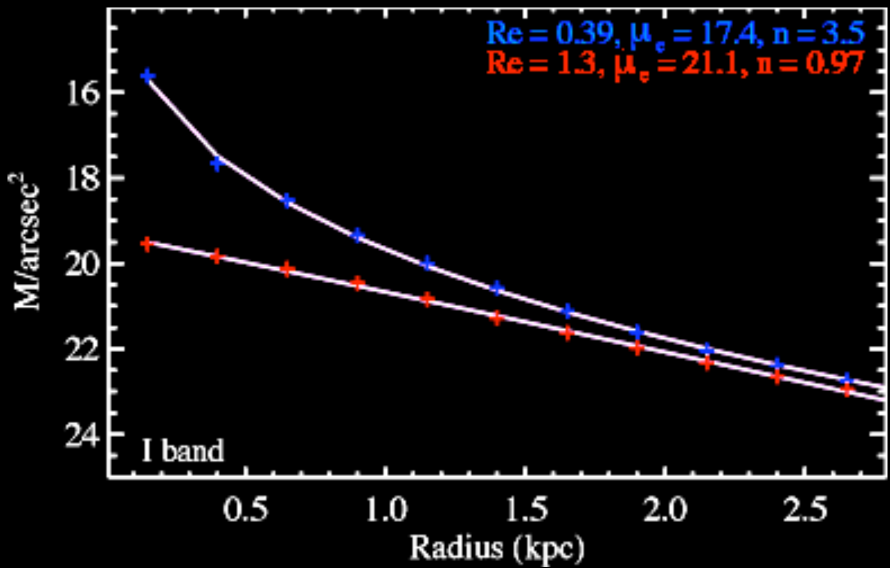
$3.4 \times 10^{10}\ M_\odot$ $3.3 \times 10^{12}\ M_\odot$

in situ stars

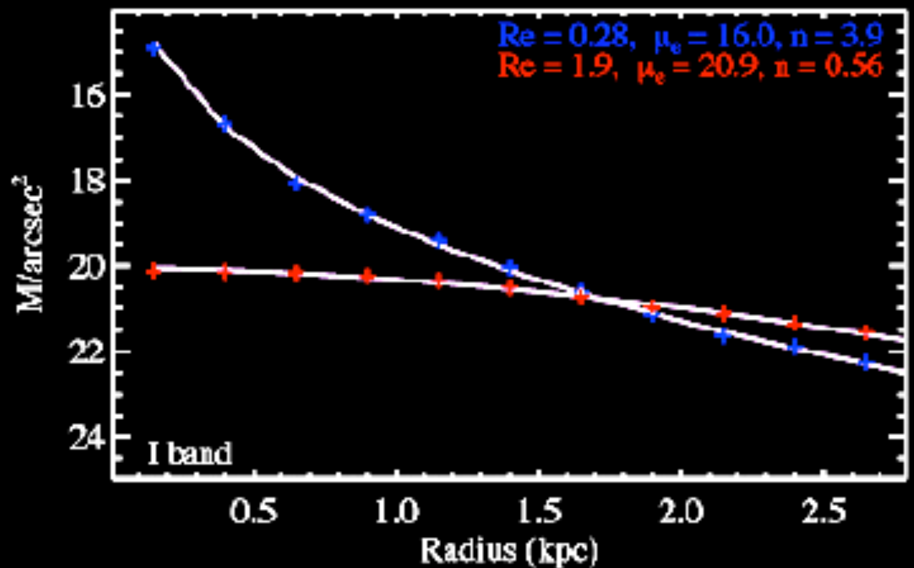
I band surface brightness




accreted stars
I band surface brightness
I band
I band
ellipticity = 5.5
3.4x10^10 M⊙
2.1x10^11 M⊙
I band
ellipticity = 3.5
I band
ellipticity = 3.4
1.1x10^12 M⊙
3.3x10^12 M⊙
28
27
26
25
24
23
22
21
20
19
18
17
16
M arcsec^-2

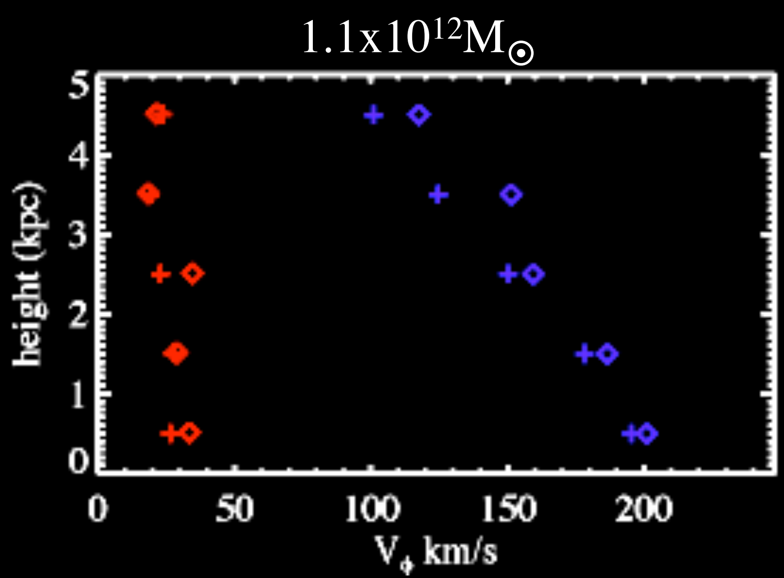


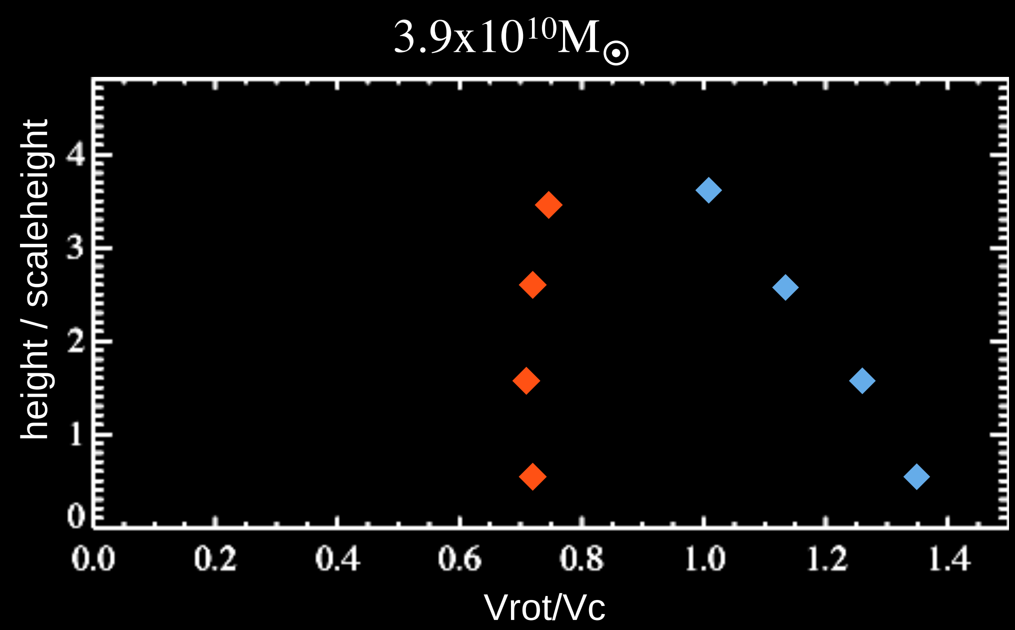
$1.1x10^{12}M_\odot$



$3.3x10^{12}M_\odot$

accreted & insitu profiles





rotational velocity gradients

height= from the disk plane

accreted

insitu

Left Panel: Milky Way thermal and blastwave feedbacks
Right Panel : low mass disk galaxy with late major merger, rotating spheroid

Conclusions II

- Galaxies largely acquire baryons as gas
- Accreted stars make extended ellipsoids
- in situ stars dominate disks, thick disks and bulges
- The relative size of these components is determined by the accretion: insitu ratio
- The ratio of accreted vs insitu depends on

  -galaxy mass

  -accretion history

SDSS low z galaxies.