Stellar populations of dwarf galaxies

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Dwarfs as cosmological probes

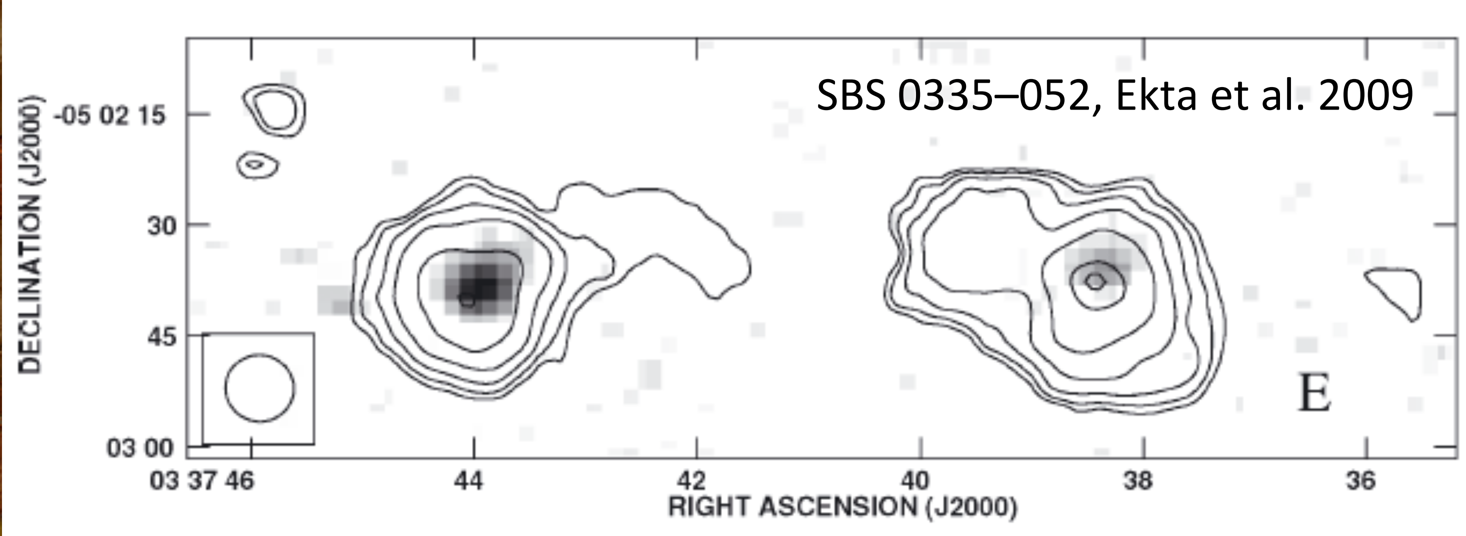
Ingredients:

- Gadget2 (Springel 2005) – N-body/SPH

    +

- Star formation
    - → density threshold n_H=100 cm^{-3}
    - → thermal feedback (SNII, SNIa, stellar winds)
    - → nucleosynthesis

- Heating & ionization by Faucher-Giguère et al. 2009 UVB
    - → ionization equilibrium
    - → self-shielding by HI
    - → radiative cooling (De Rijcke et al. 2013)



feedback

to core

50% of halos @ $2\times10^9 M_\odot$ contain

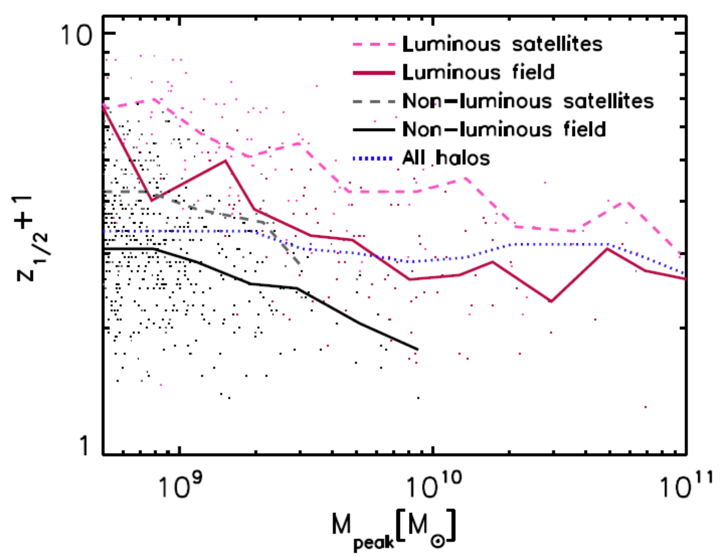
luminous dwarf halos are specia

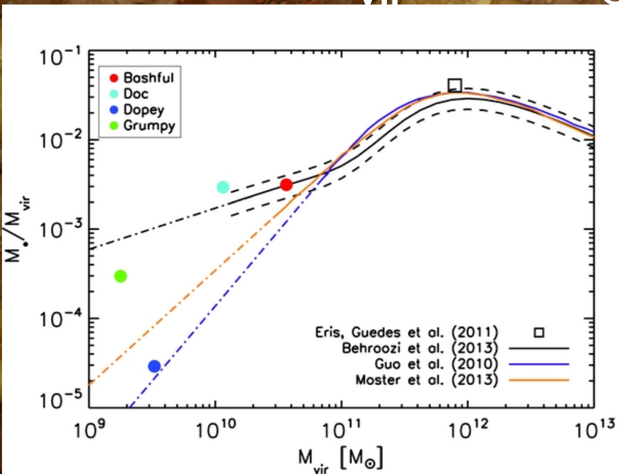
→ sensitive to details!

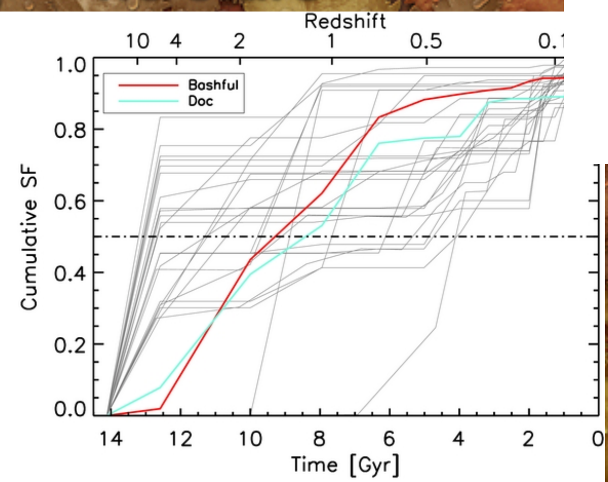
- **Shen et al. (2014):**

$M_{vir} \sim 10^{10} M_\odot \leftrightarrow \sim 10^{7\text{-}8} M_\odot$ stars

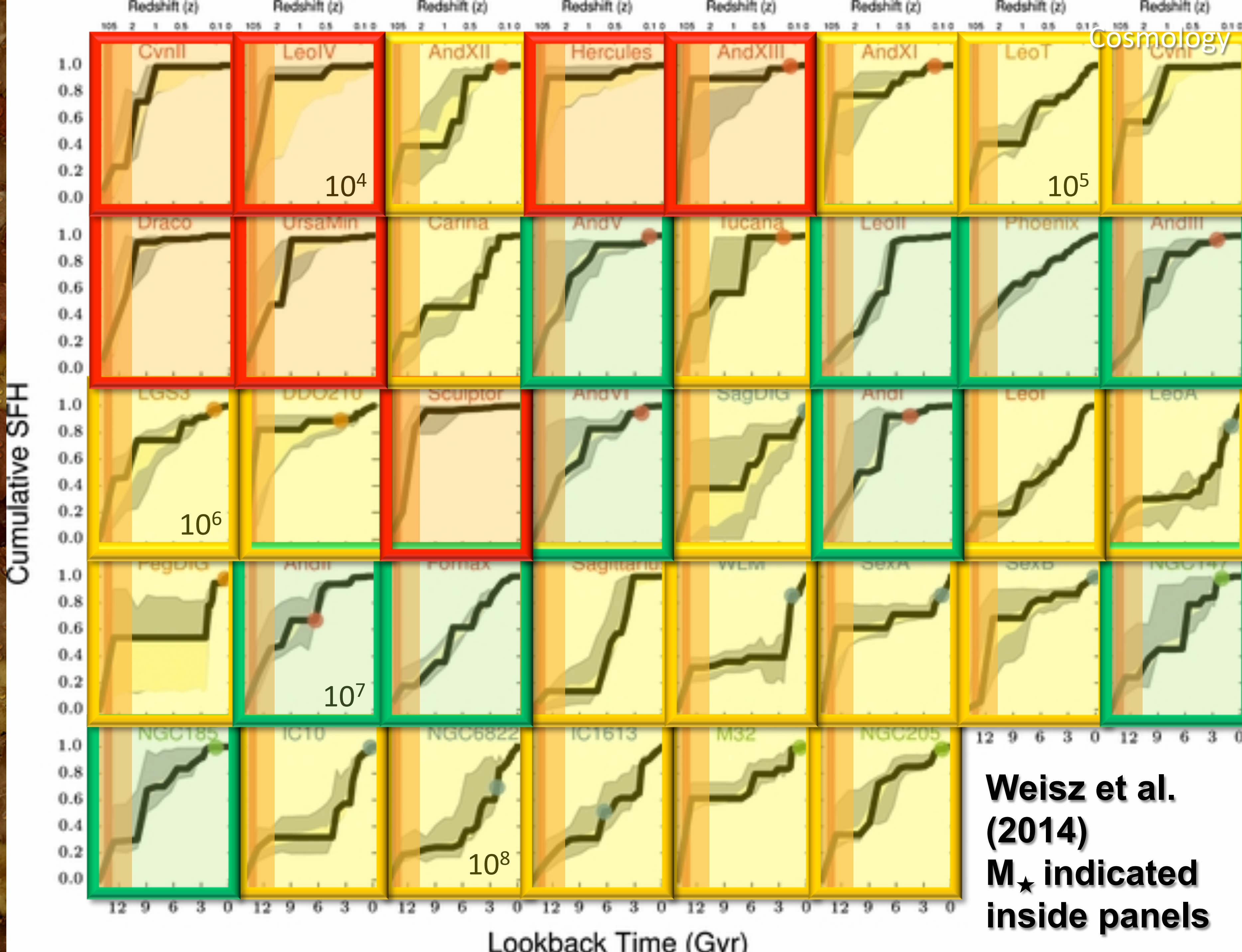
$M_{vir} < 10^{<9} M_\odot \leftrightarrow$ no stars







Cosmology

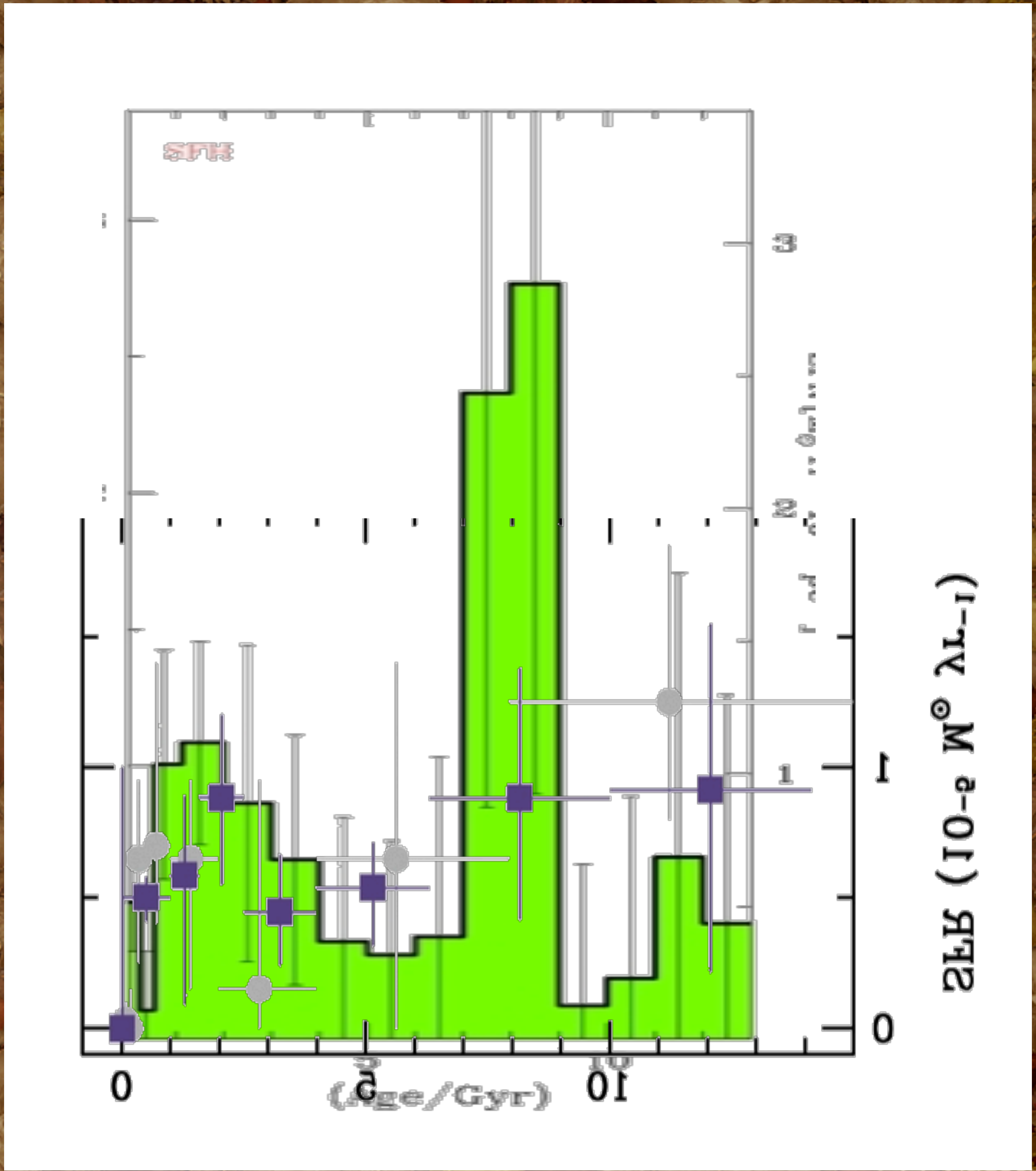


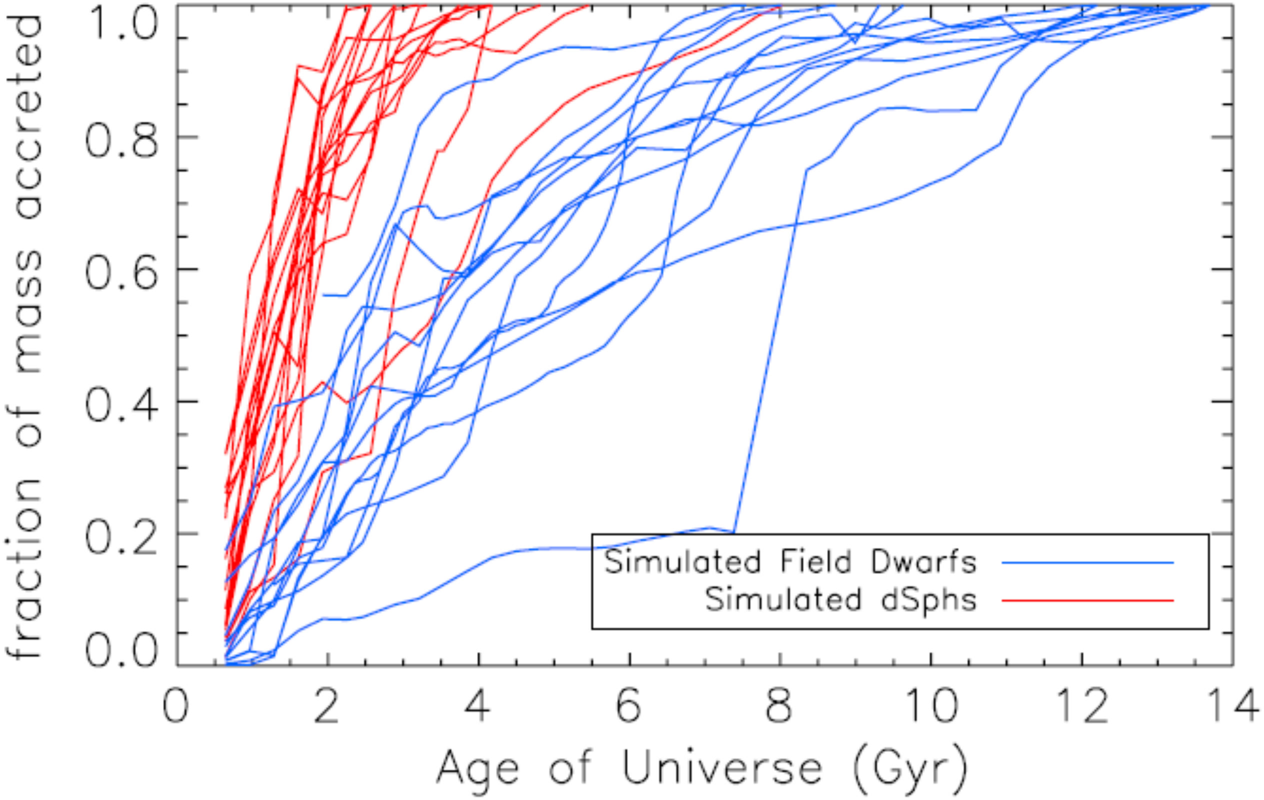
Weisz et al. (2014)
$M_\star$ indicated inside panels

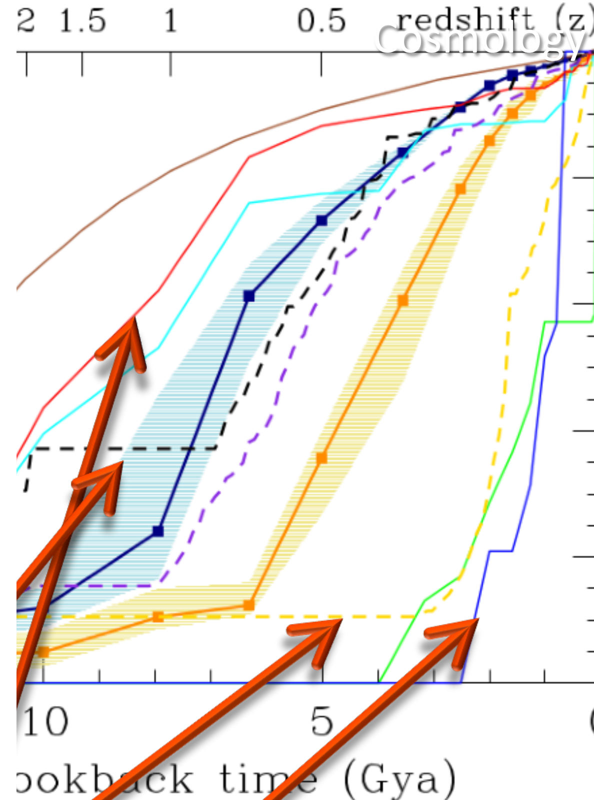
Leo T: same HST data!

Weisz et al. 2012 (MATCH, Kroupa IMF, Padova stellar evolution)

Clementini et al. 2012 (Salpeter IMF, Pisa Evolutionary Library)



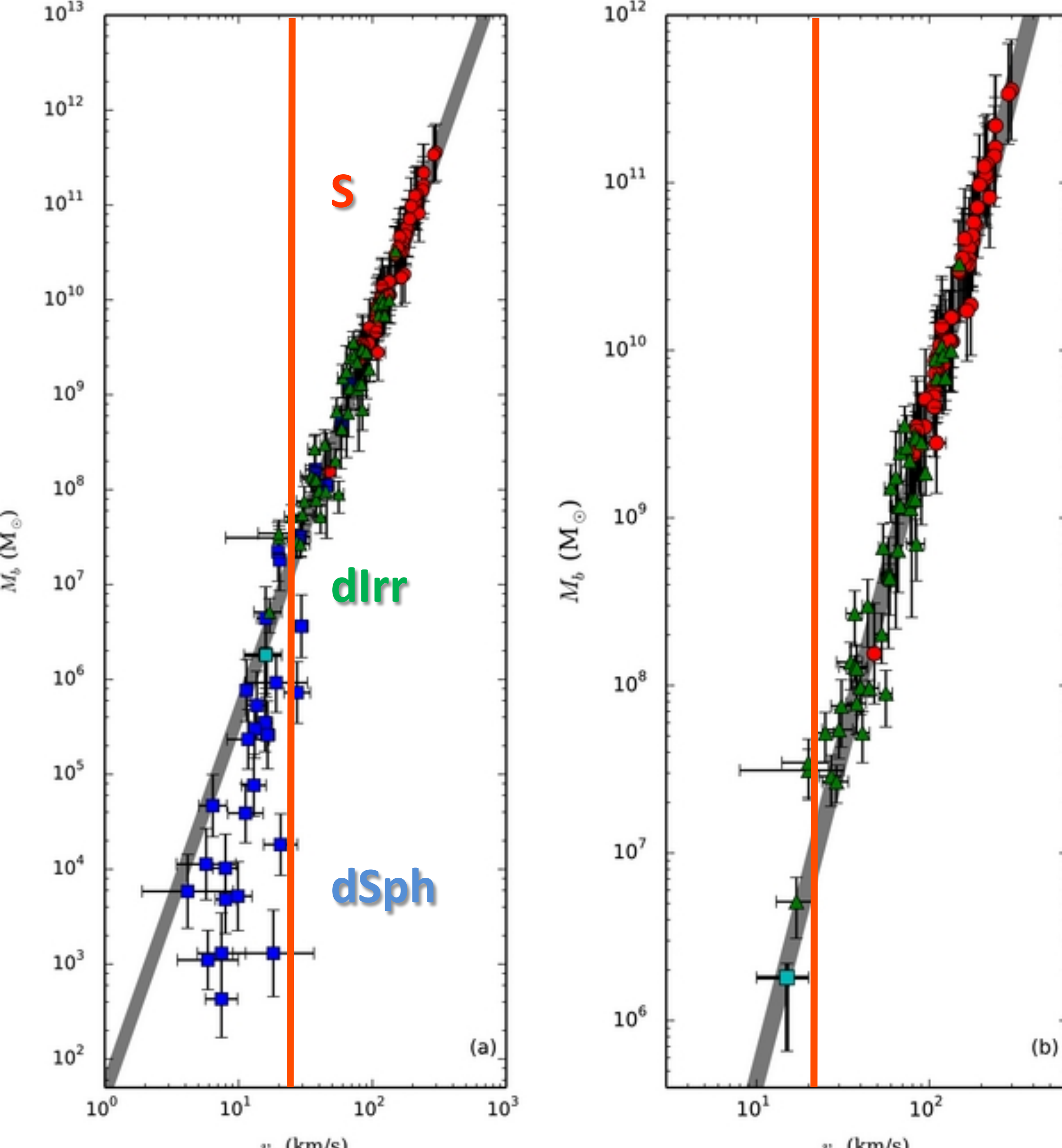




Cole et al. (2014), Aquarius, Leo A: $M_\star \sim 10^{6-7} M_\odot$ → delayed star formation

Late mass accretion?
Gas was there but unavailable for SF?

Comparison with Sawala et al. (2011) & Shen et al. (2014) sims with $M_{vir} \sim 10^{10} M_\odot$
Comparison with Brooks & Zolotov (2014) → delayed mass

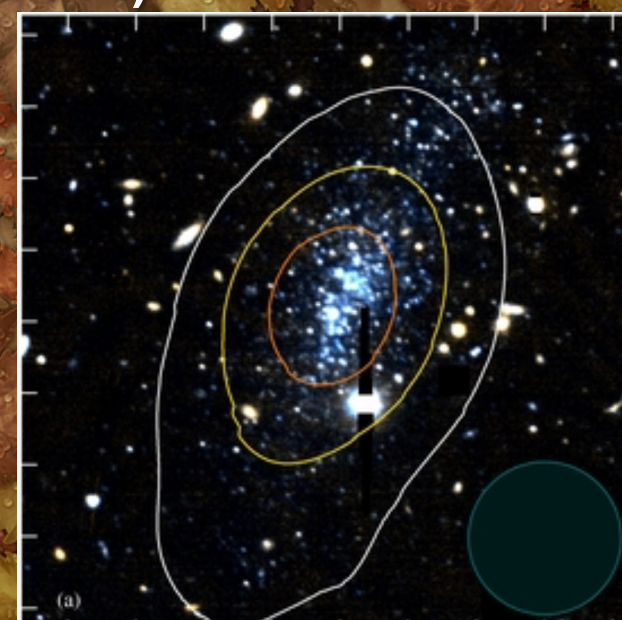


Leo P:

Cosmology

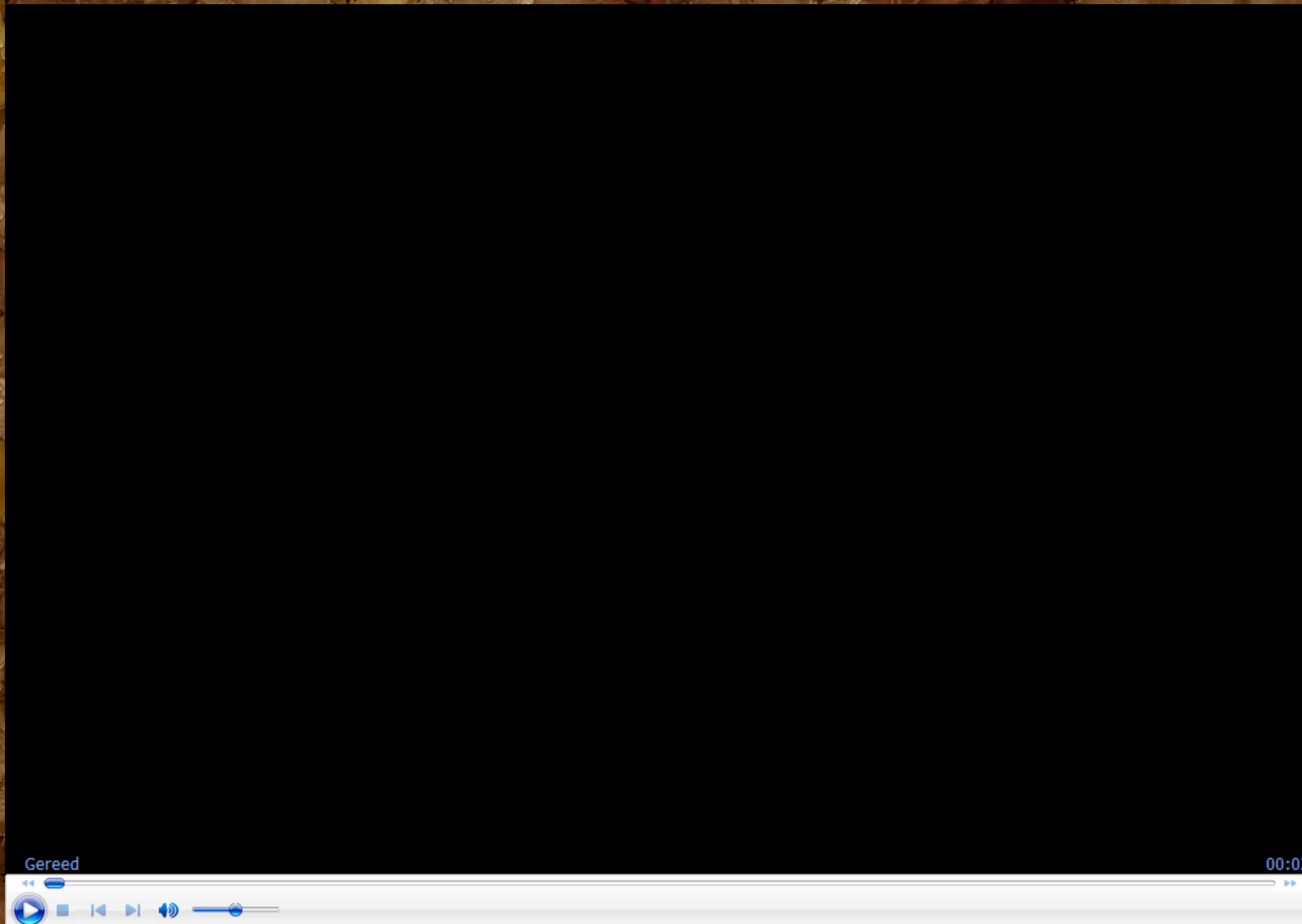
Isolated dIrr (D~1.7 Mpc, Sextans B @ 0.5 Mpc)

ALFALFA:
V_{circ}~15 km/s
M_{HI}~9×10^5 $M_\odot$
$M_\star$~6×10^5 $M_\odot$
(Bernstein-Cooper et al. 2014)



Stellar populations & Internal dynamics

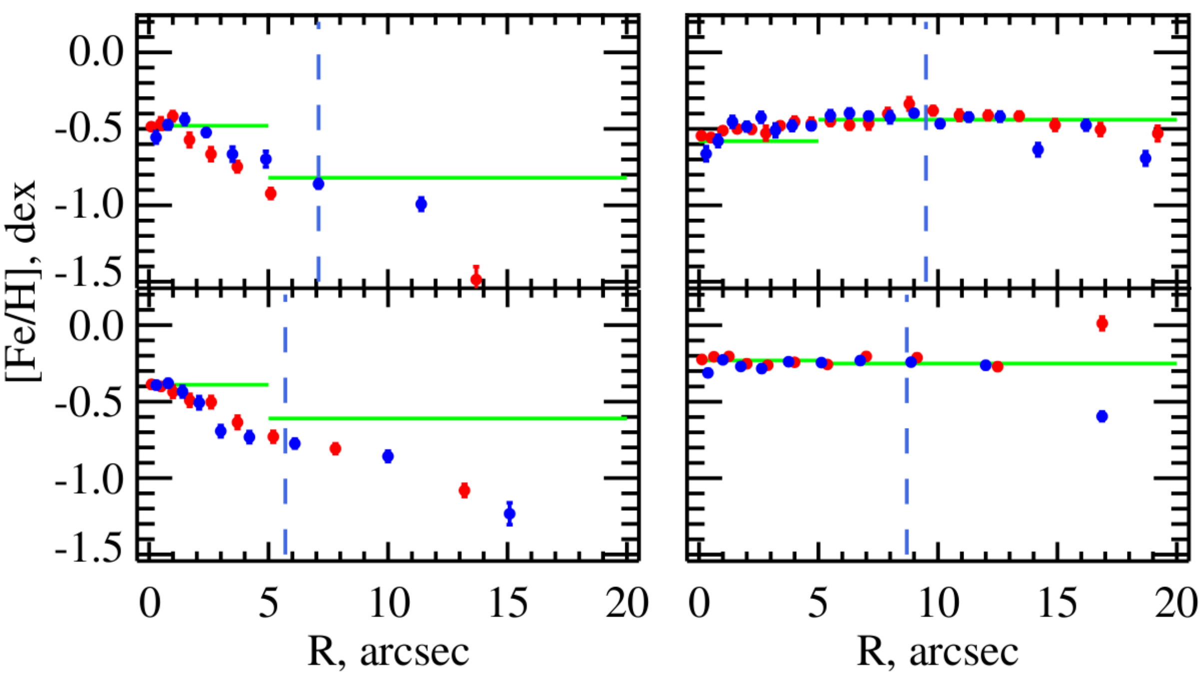
Non-rotating

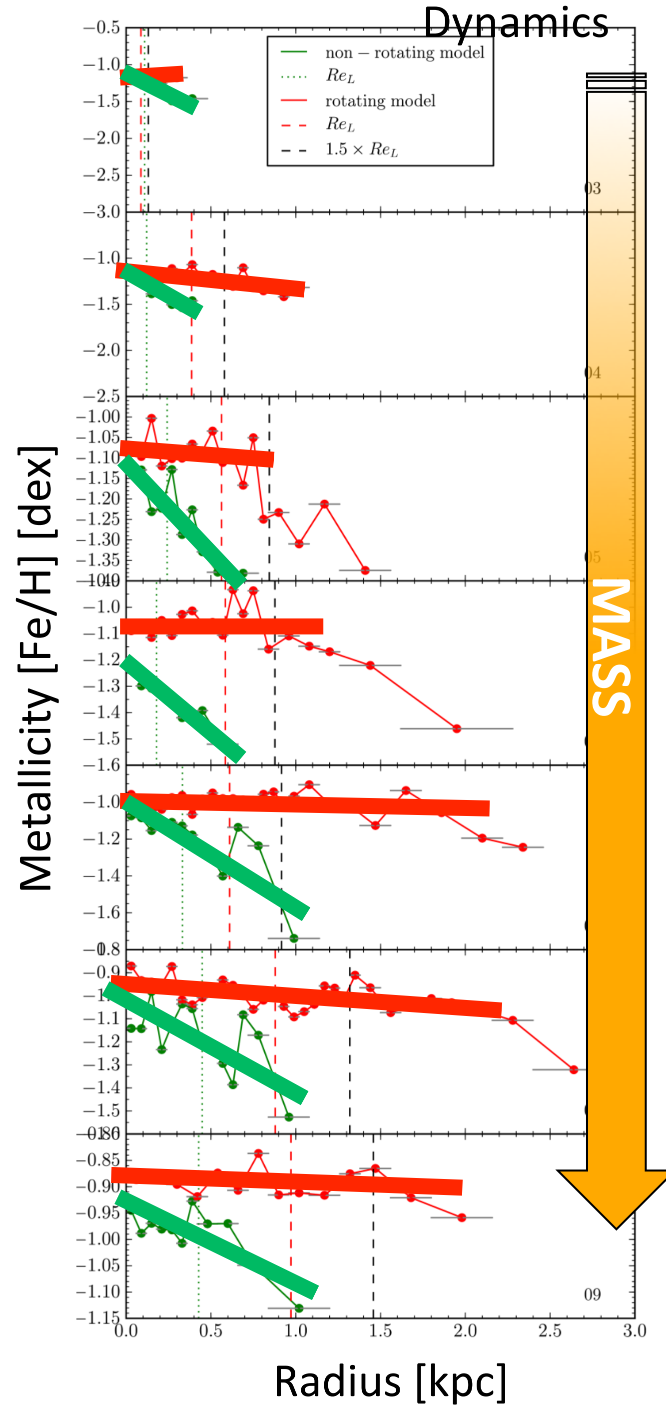


Rotating

Metallicity gradient: rotating vs. non-rotating

- Angular momentum barrier causes
  more spatially uniform star formation
  less bursty star formation
- Observational consequence:
  flatter metallicity profiles inside $1R_e$ in rotating dwarfs (Schroyen et al. 2011)
- Borne out by observations of dEs
  (Koleva et al. 2009)

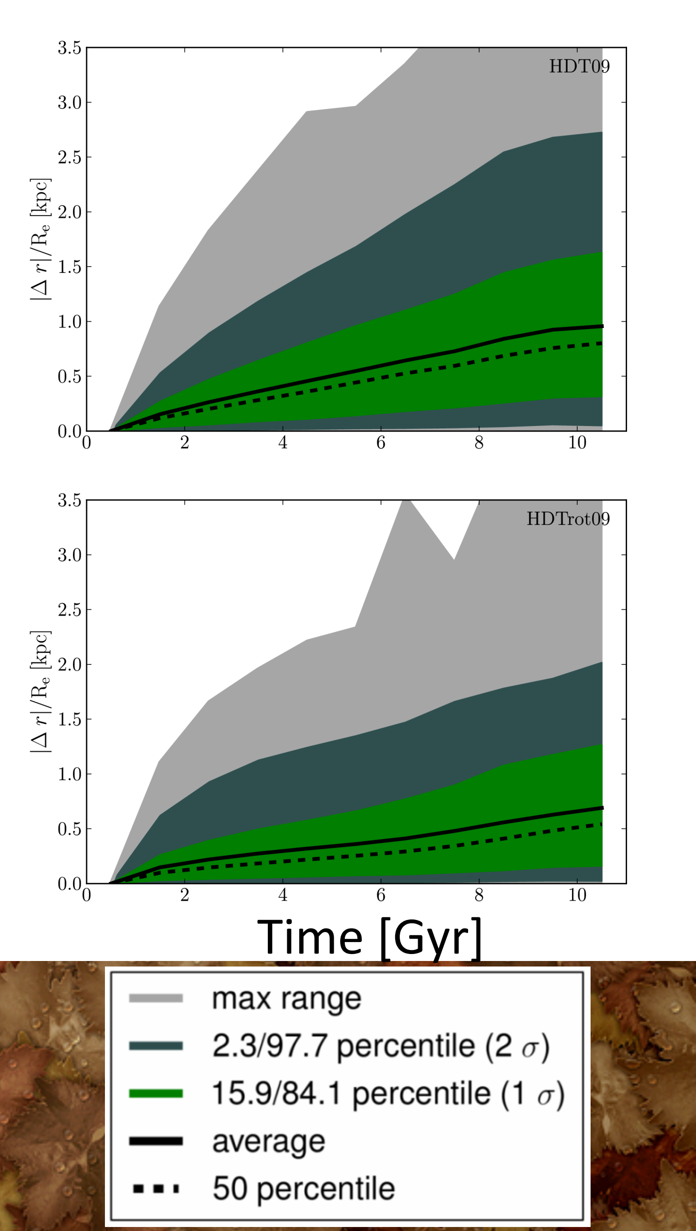


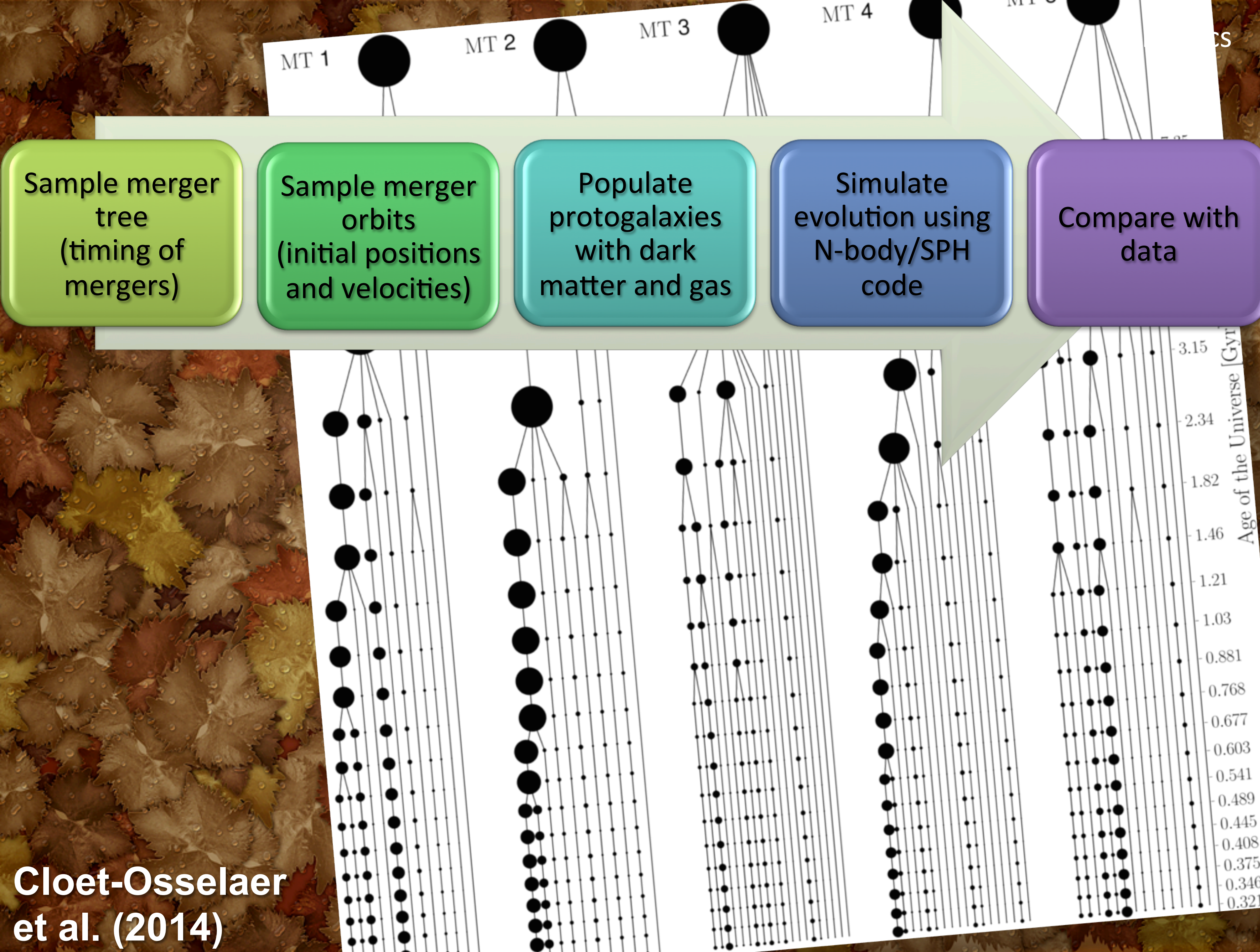


- **Longevity of gradients** (schroyen et al. 201
- In massive disc galaxies:
  stellar migration driven by
  spiral structure
- dIrrs lack strong spiral structure
  → orbital deviations are limited
  (fractions of R_e over 5-10 Gyr)
  → stellar population gradients can survive
  for many Gyrs
- SF density threshold has influence
  → higher threshold:
  - more turbulent ISM
  - more scattering clouds

  ↓

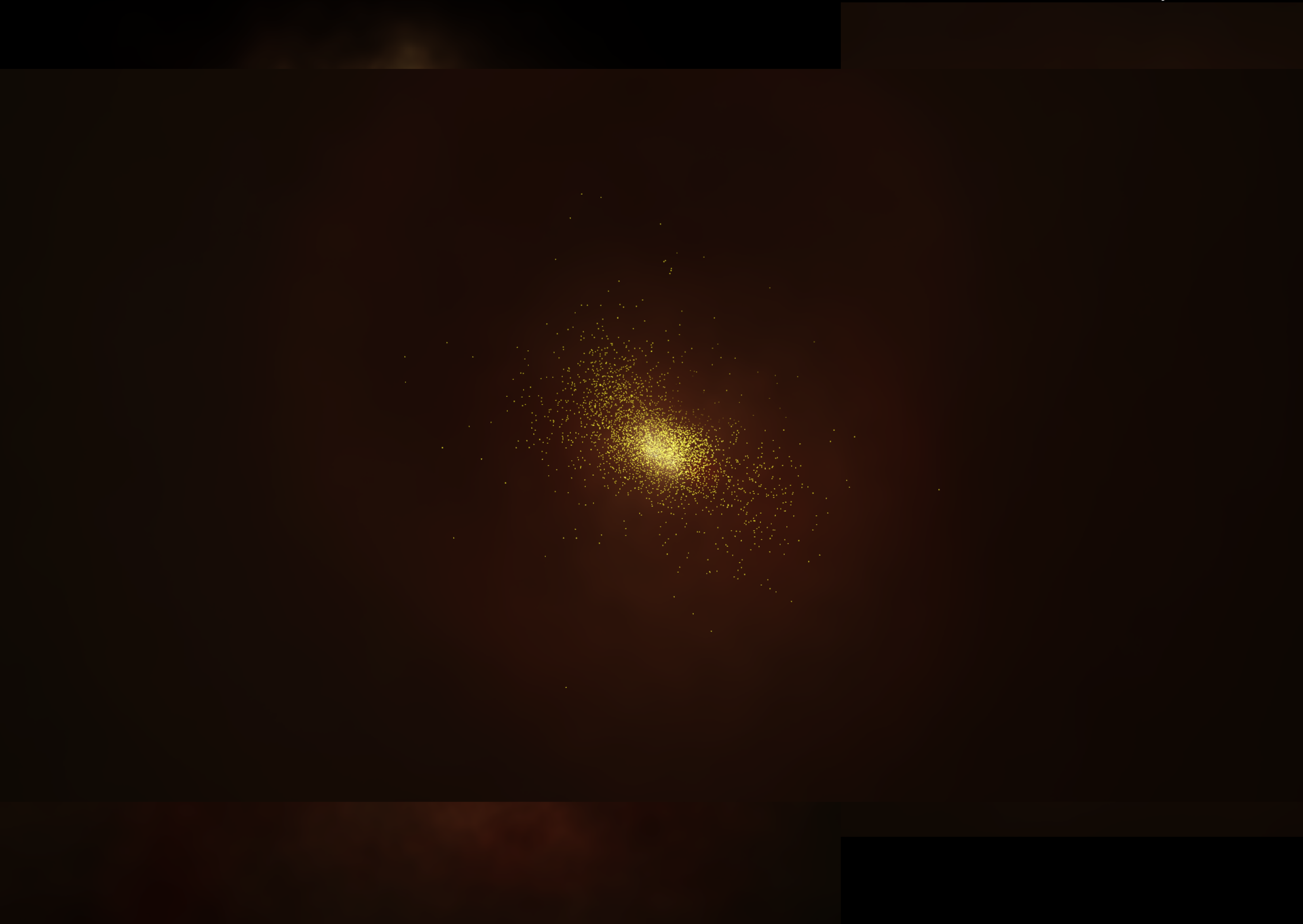
  0.3-0.5 Re / 5 Gyr



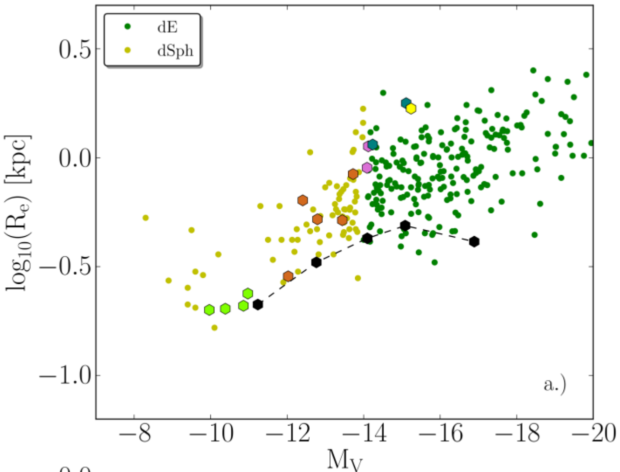


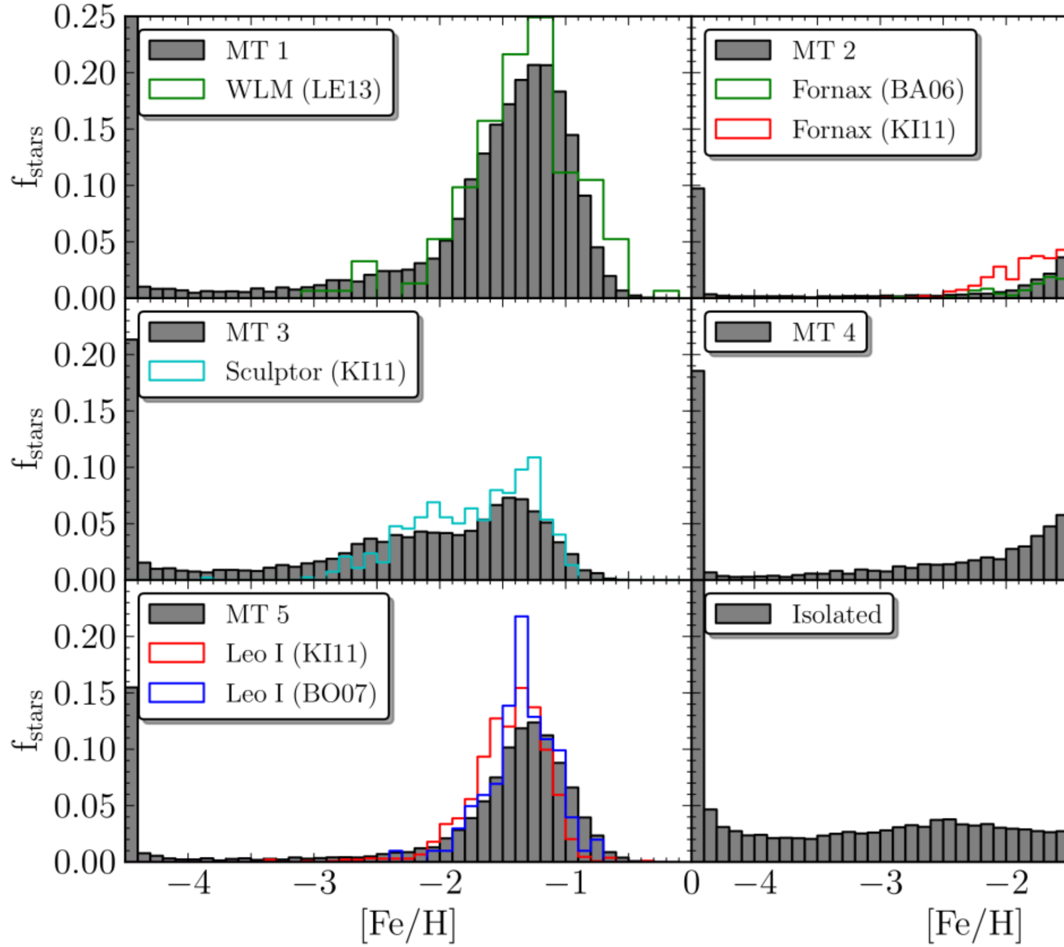
Cloet-Osselaer et al. (2014)

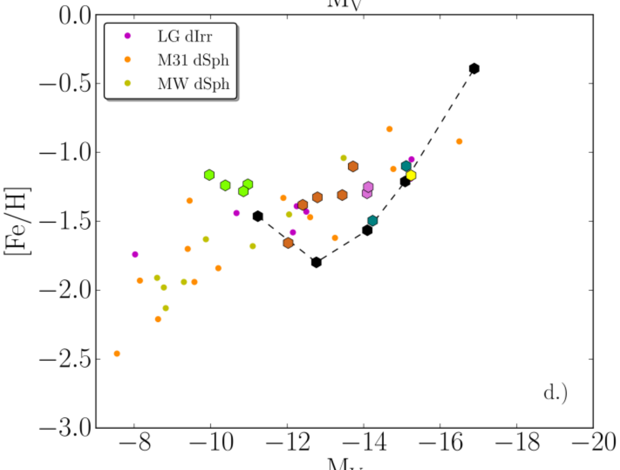
Dynamics

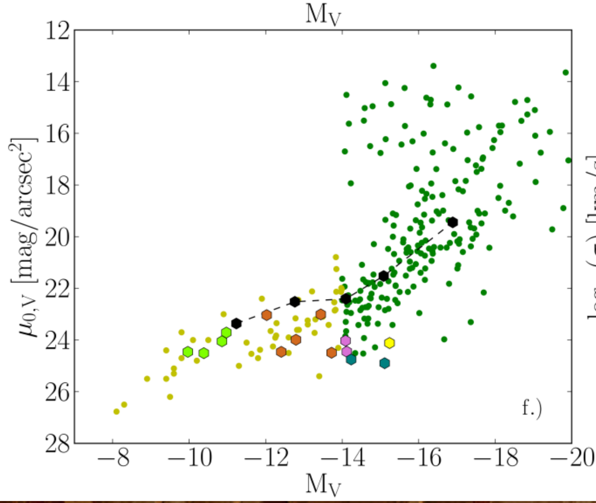


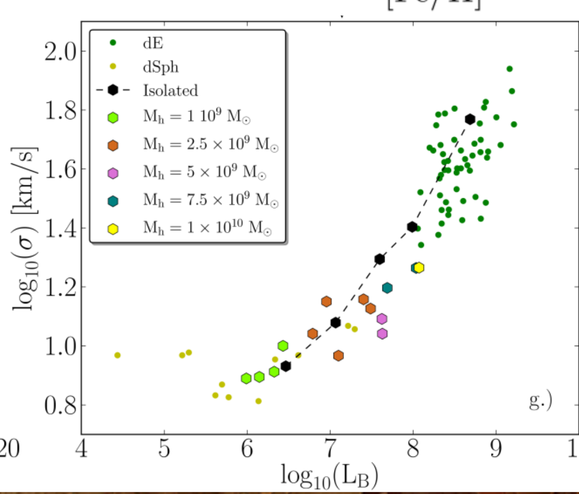
Dynamics


dE
dSph
log10(Re) [kpc]
MV
a.)

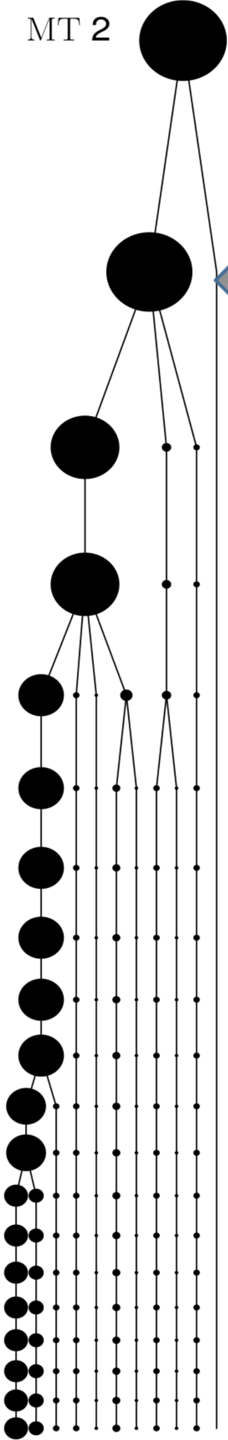

MT 1
WLM (LE13)
MT 2
Fornax (BA06)
Fornax (KI11)
MT 3
Sculptor (KI11)
MT 4
MT 5
Leo I (KI11)
Leo I (BO07)
Isolated
fstars
[Fe/H]


LG dIrr
M31 dSph
MW dSph
[Fe/H]
MV
d.)


μ0,V [mag/arcsec2]
MV
f.)


dE
dSph
Isolated
Mh = 1 10^9 M⊙
Mh = 2.5 × 10^9 M⊙
Mh = 5 × 10^9 M⊙
Mh = 7.5 × 10^9 M⊙
Mh = 1 × 10^10 M⊙
log10(σ) [km/s]
log10(LB)
g.)


Vladstudio



Two extreme types of merger tree:

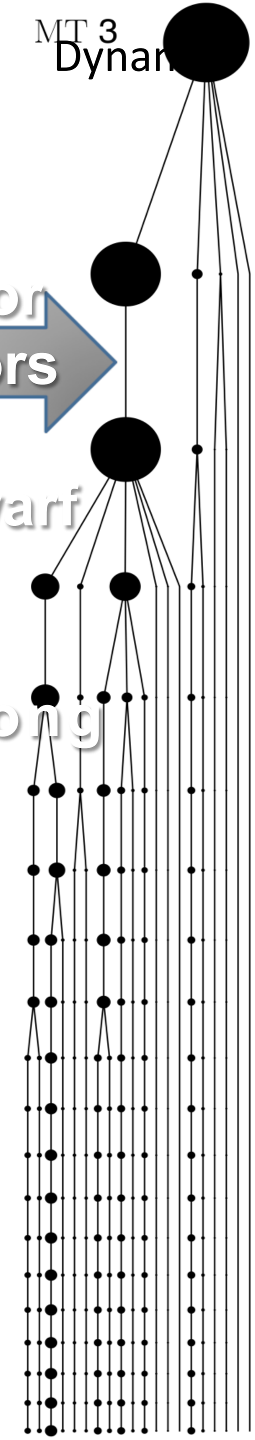
(i) merger trees with one massive progenitor
(ii) merger trees with many small progenitors

At fixed halo mass, a type (i) tree produces dwarf galaxies with

- larger stellar masses (star formation not halted by strong starbursts),
- larger half-light radii (repeated feedback flattens gravitational potential),
- lower central surface brightness (idem),
- higher specific angular momentum (fewer rotation cancelling mergers),

compared with a type (ii) tree.

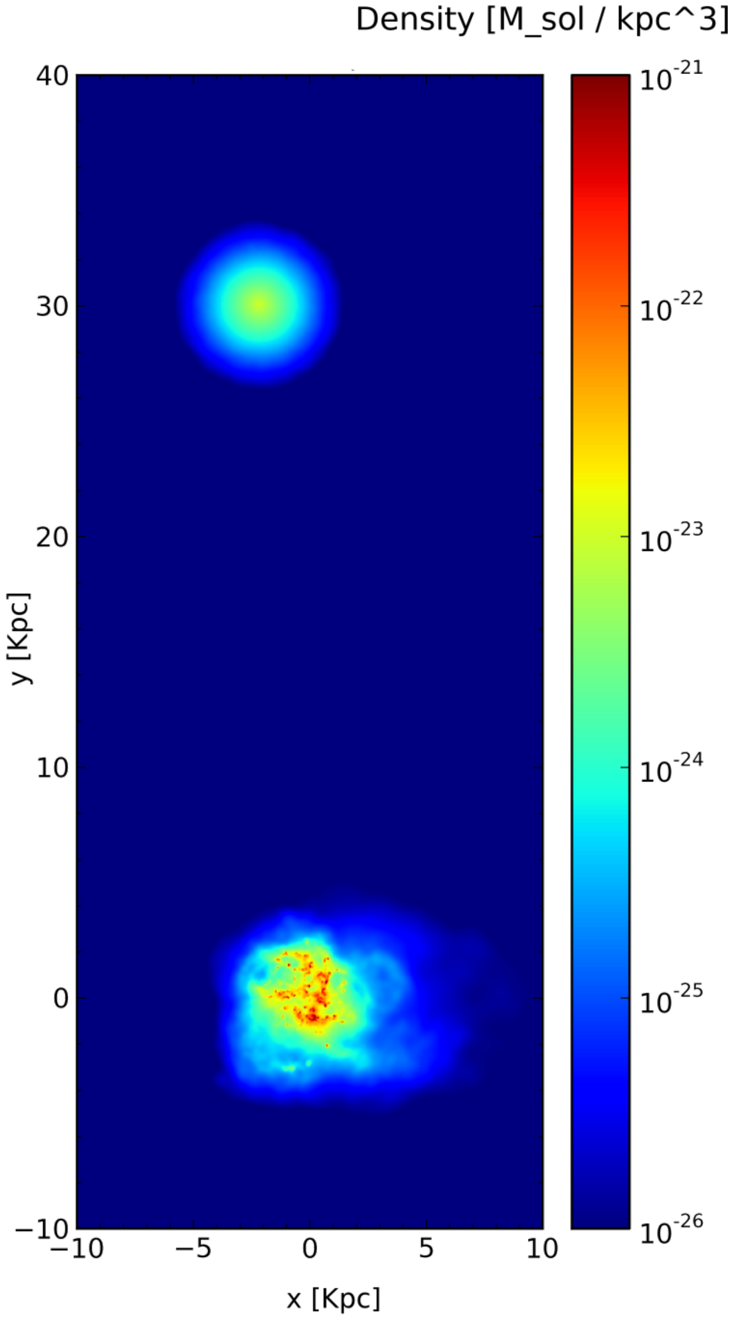
Cloet-Osselaer et al.



Environment

-

BCDs

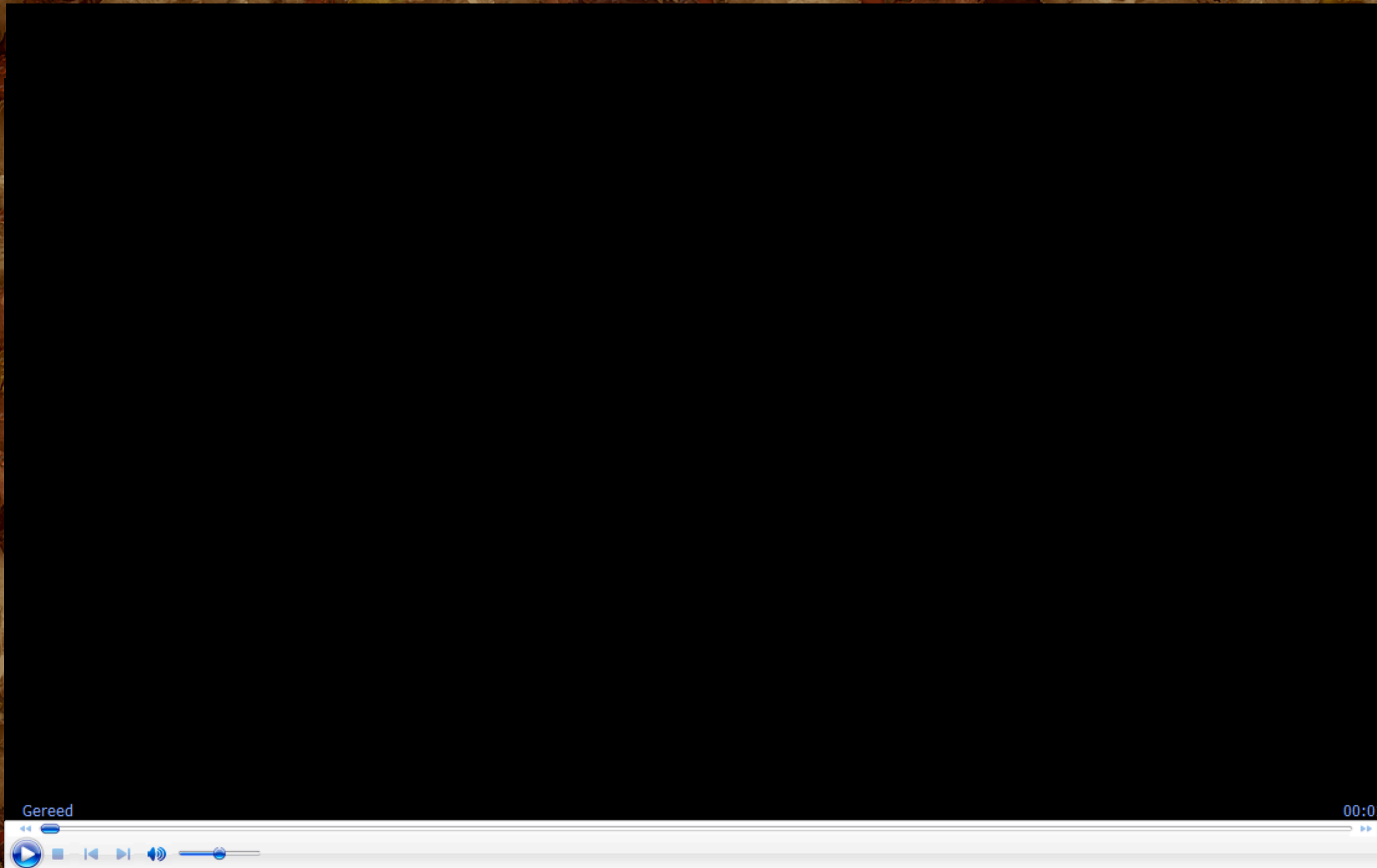


Starbursts triggered by infall of gas cloud

(Verbeke et al. 2014)

- Simulate dwarf in isolation
- Introduce gas cloud
  Inspired by HI clouds around BCDs and HVC around Milky Way
  - Zero metallicity
  - $1/r$ density profile
  - $v \approx$ escape velocity
- Variables
  - Orbits
  - Size
  - Mass

BCDs



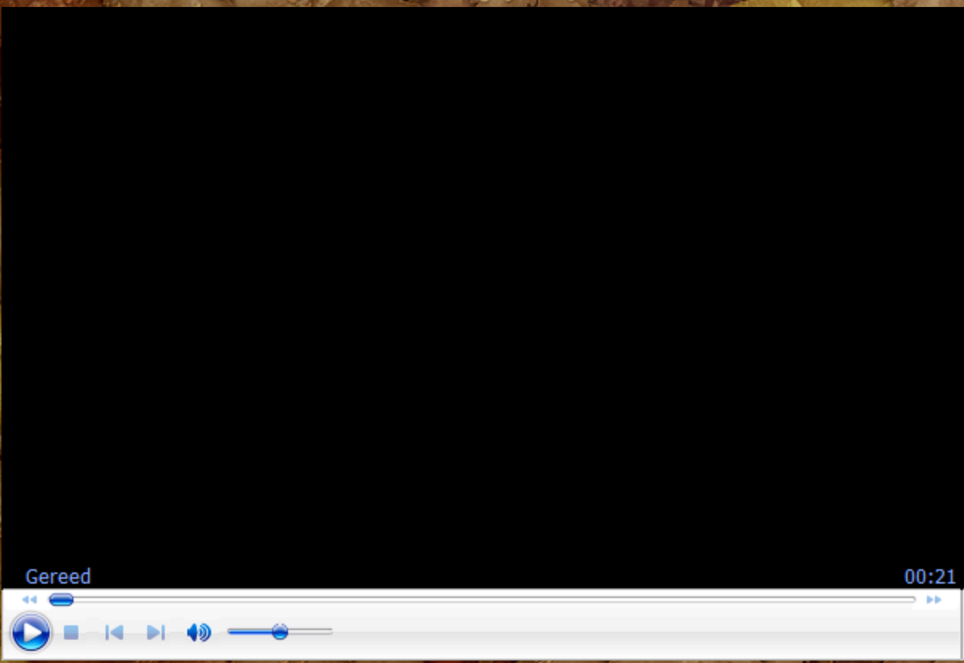
Verbeke et al. 2014

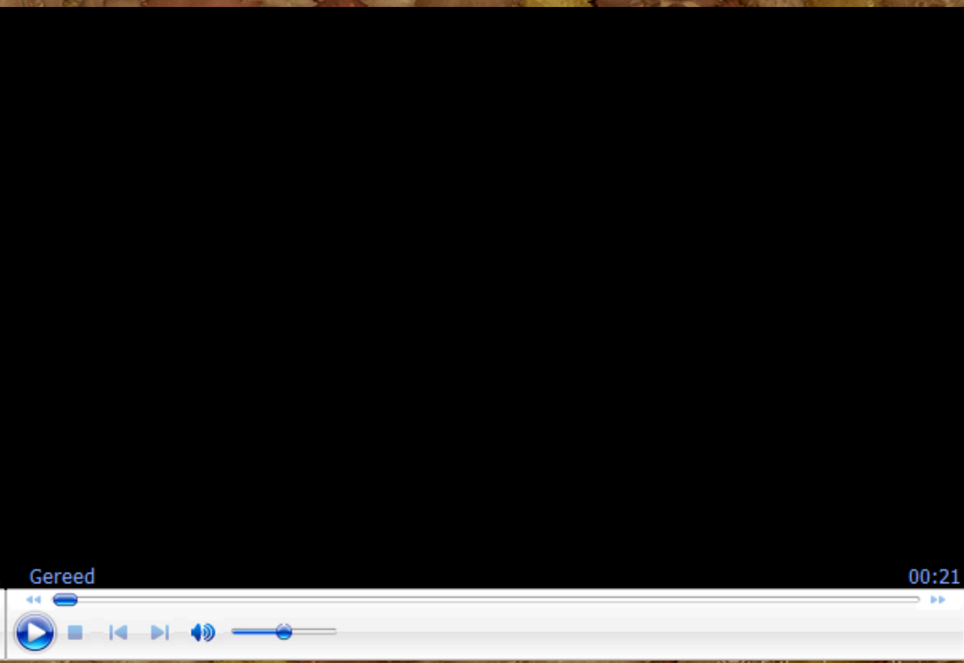
General results:

SFR can go up by a factor of ~ 15,

but it needs special conditions:

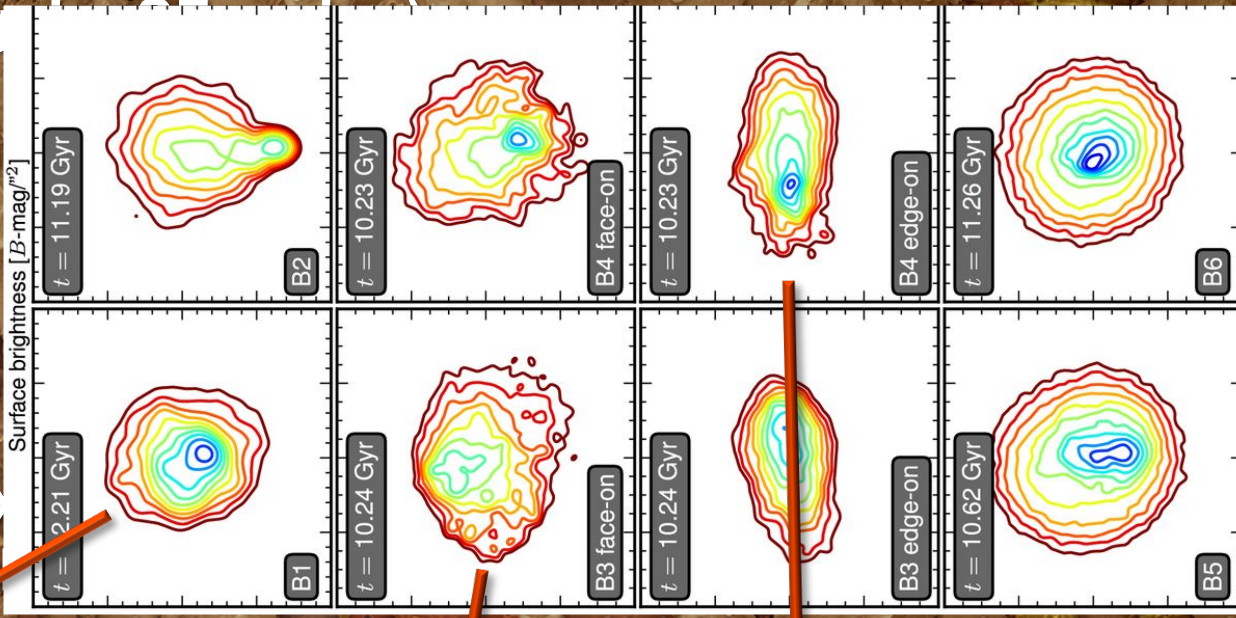
- $M_{gas\ cloud} / M_{gal}$ must be large enough
- Retrograde orbits are favourable. Prograde orbits do not produce a

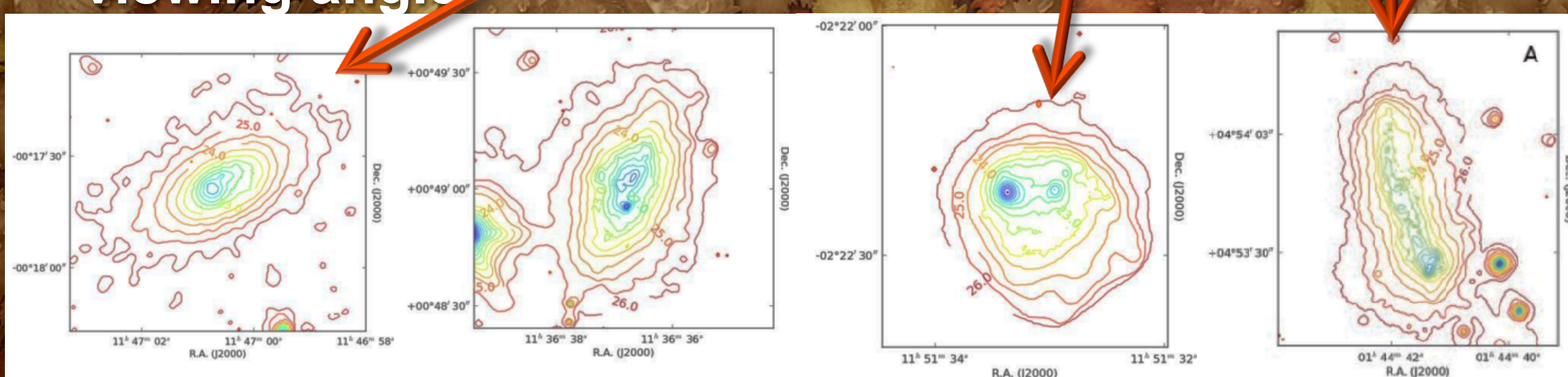




BCD subclasses (Loose & Thuan, 1986):

- nE BCD: elliptical outer isophotes, smooth SF region
- Feedback can induce further star formation → evolution from nE to iE (irreg
- iI: irregular outer isophotes
- cometary shape → iI,C
- Depends on cloud compactness, galax dynamics, cloud or viewing angle



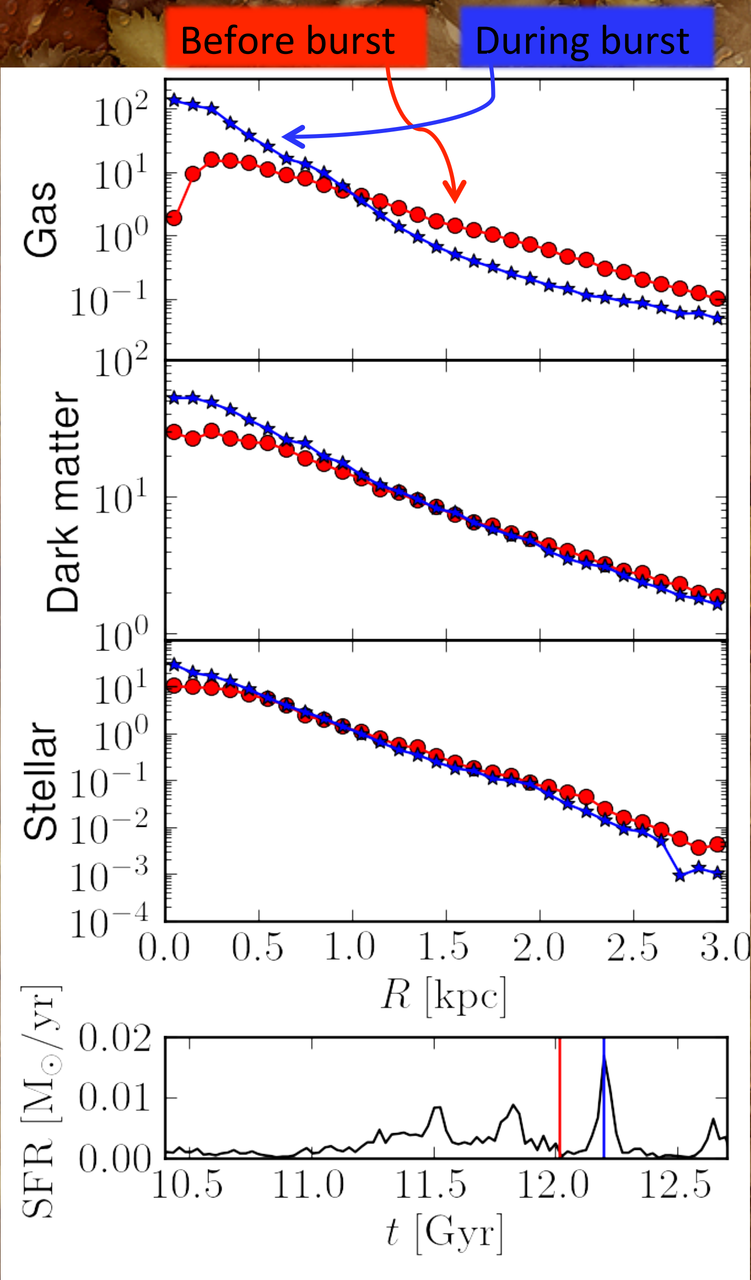


nE/iE

iI

iI,C

Micheva+ 2013a,b

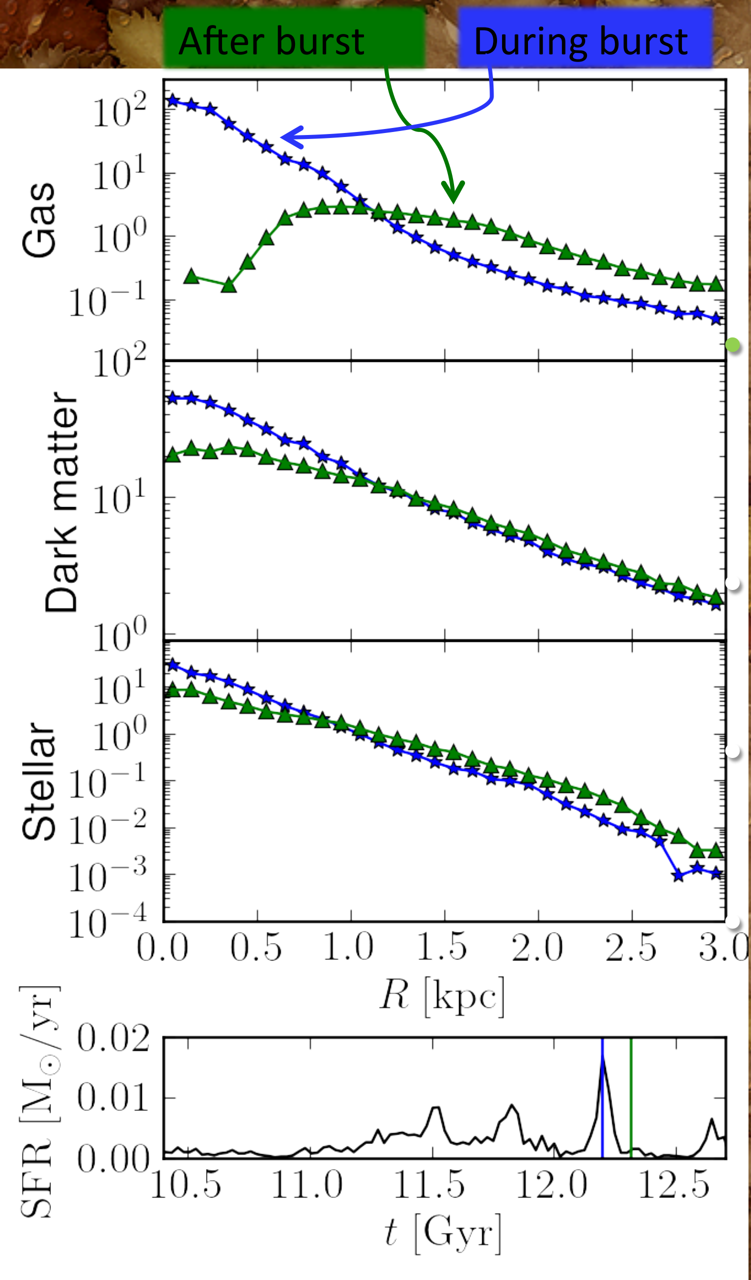


Density profiles

During burst: large central gas concentration that fuels the burst

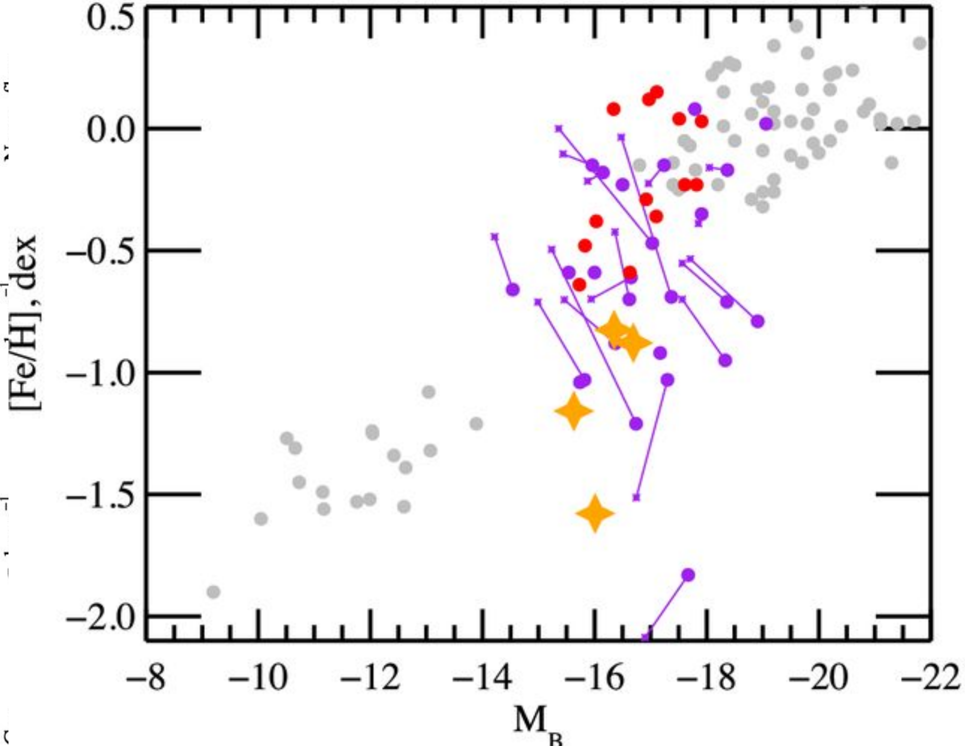
Gravitational potential deepens

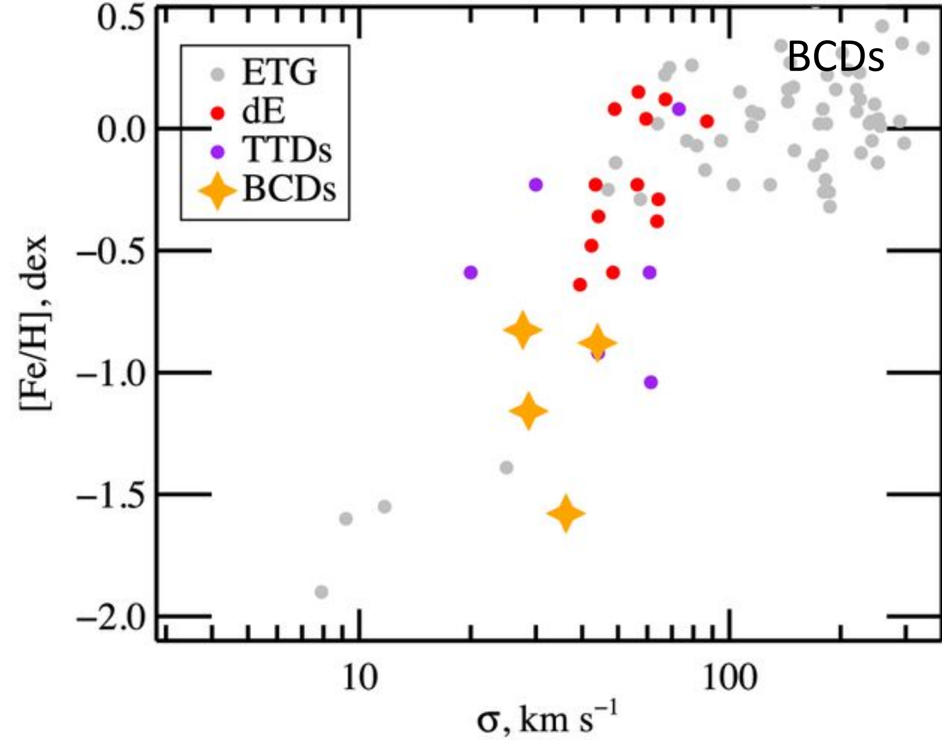
Dark matter and stellar concentration increase as well



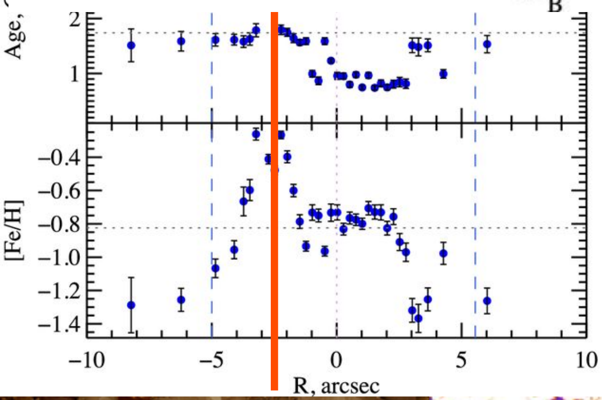
Density profiles

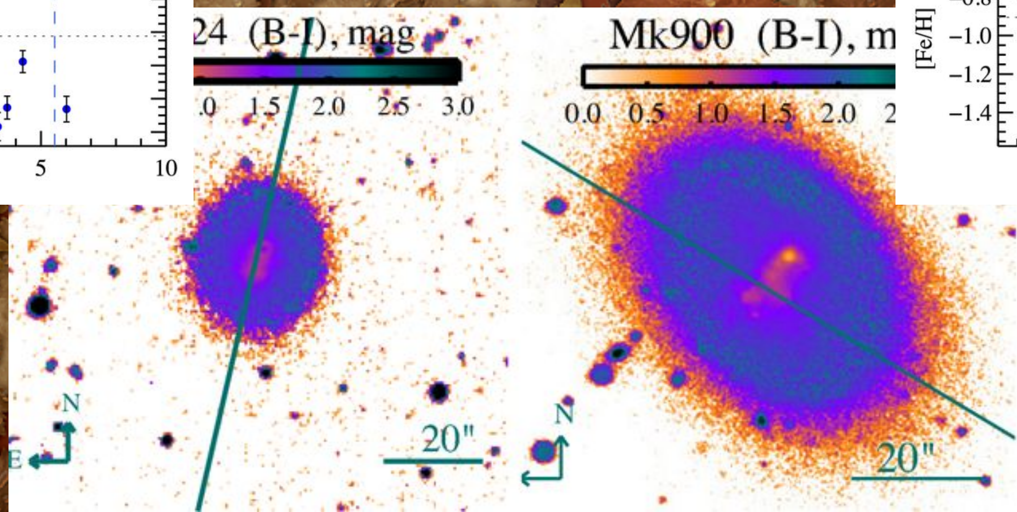
- After burst: gas is rapidly removed from center by SN feedback
- Shallower gravitational potential
- Dark matter and stars expand
- Postburst dwarfs are more diffuse

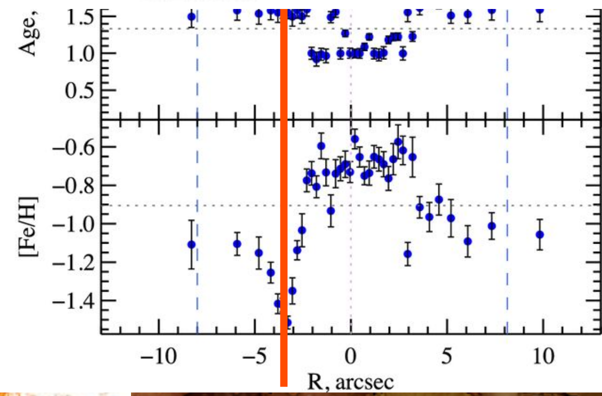




density cloud): stellar Z high

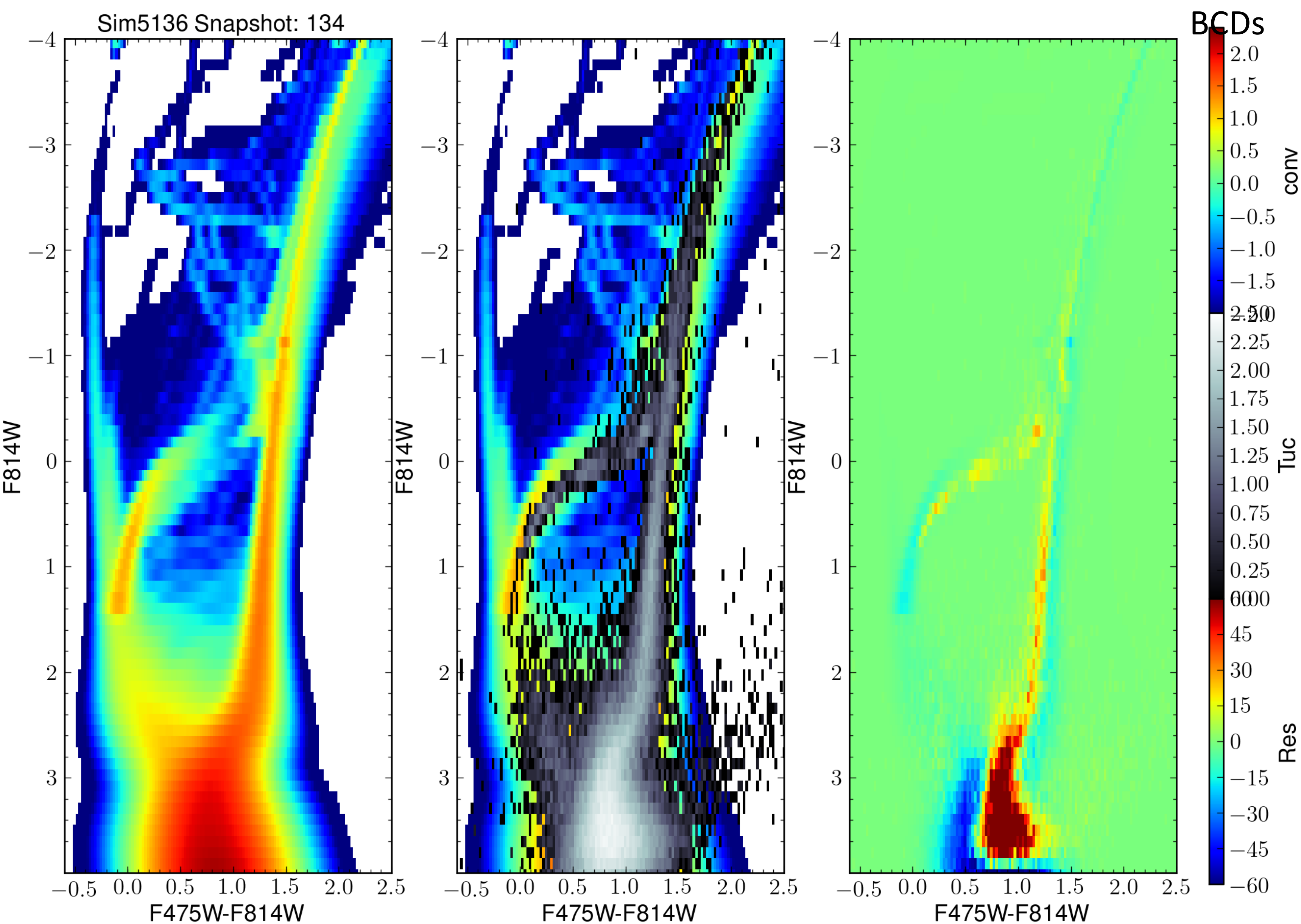




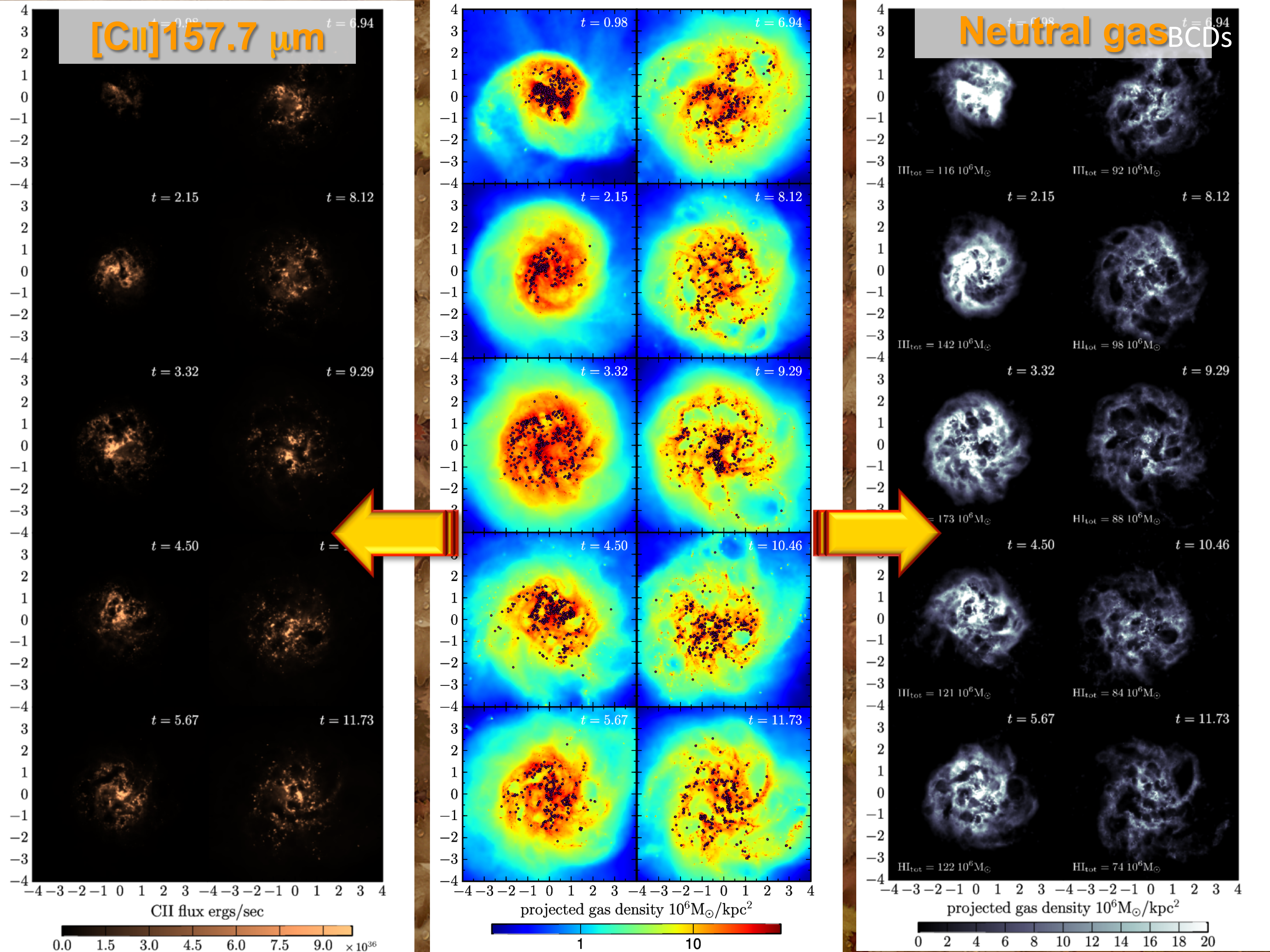


Koleva et al. 2014

Observations of simulations



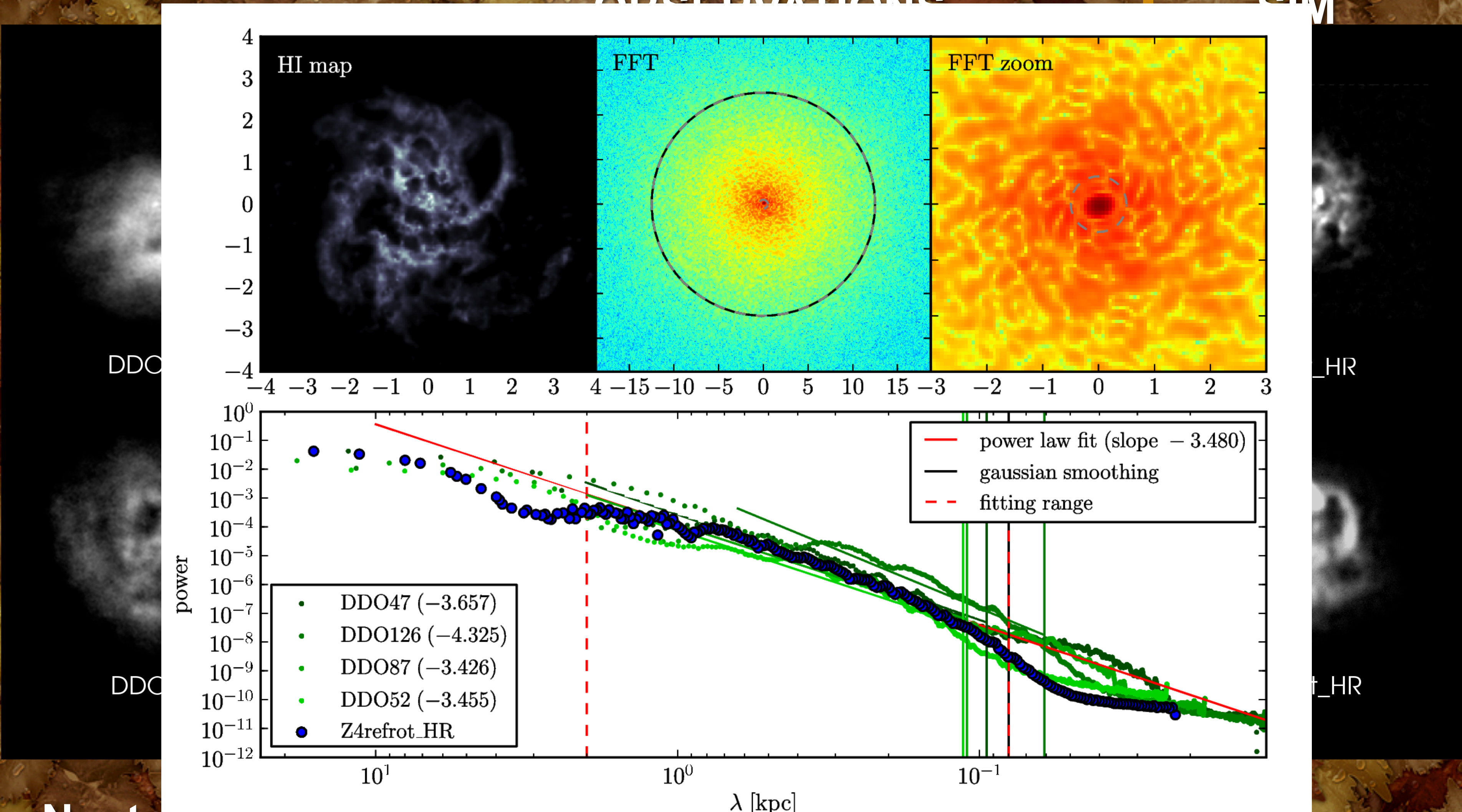
Cloet-Osselaer, in prep., http://basti.oa-teramo.inaf.it/index.html



[CII]157.7 μm
Neutral gas
BCDs
t = 0.98
t = 6.94
t = 2.15
t = 8.12
t = 3.32
t = 9.29
t = 4.50
t = 10.46
t = 5.67
t = 11.73
HItot = 116 10^6 M⊙
HItot = 92 10^6 M⊙
HItot = 142 10^6 M⊙
HItot = 98 10^6 M⊙
173 10^6 M⊙
HItot = 88 10^6 M⊙
HItot = 121 10^6 M⊙
HItot = 84 10^6 M⊙
HItot = 122 10^6 M⊙
HItot = 74 10^6 M⊙
CII flux ergs/sec
0.0 1.5 3.0 4.5 6.0 7.5 9.0 ×10^36
projected gas density 10^6 M⊙/kpc^2
1 10
projected gas density 10^6 M⊙/kpc^2
0 2 4 6 8 10 12 14 16 18 20

LITTLE THINGS survey

OBSERVATIONS | SIM



Neutral gas images are quantitatively similar to observations

E-ELT$^{>2020}$ & future facilities (JWST^{2018}, SKA$^{2018/23}$)

- SFHs of dwarfs in different environments, higher z (z~2)
- gas content, baryonic TF < 10^5 $M_\odot$
  - Statistically significant sample of observations & sims
  - Constrain impact of reionization
  - Study evolutionary links between different dwarf types