Formation and evolution of isolated massive HI clouds.

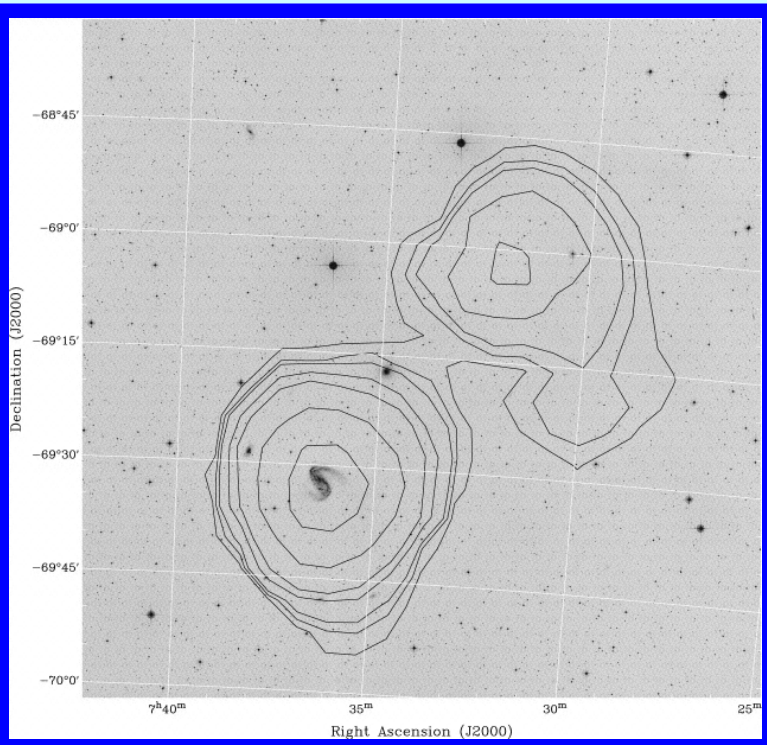
Dark galaxies ? Or Tidal debris ? Or something else ?

Kenji Bekki (UNSW, Australia)

Physical properties of isolated, massive HI clouds.

- Masses larger than 10^8 M_{sun} .
- Apparently no (nearby) optical counterparts.
- Extremely rare objects (e.g., Koribalski et al. 2004).

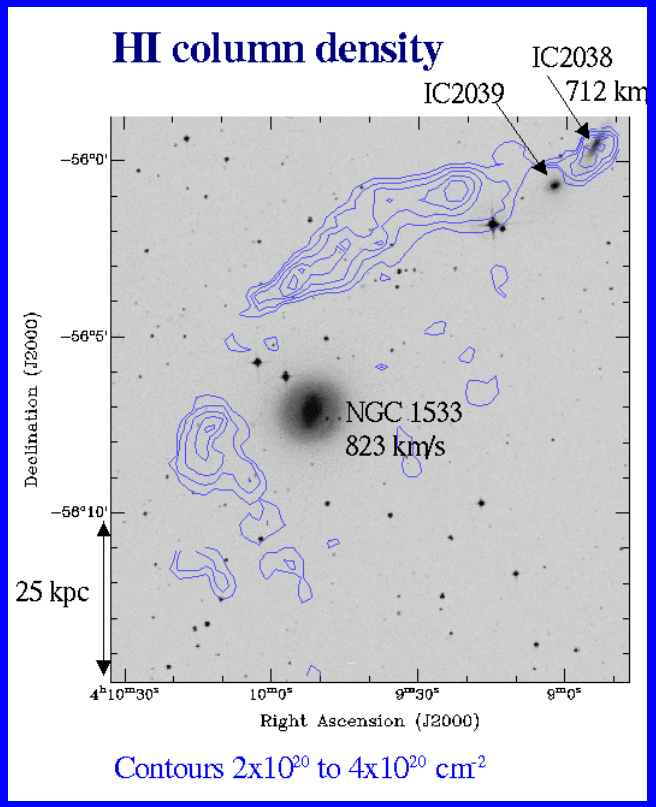
Intragroup HI cloud (NGC 2442)
M(HI)~10^9 M_{sun}.



Ryder et al. (2002)

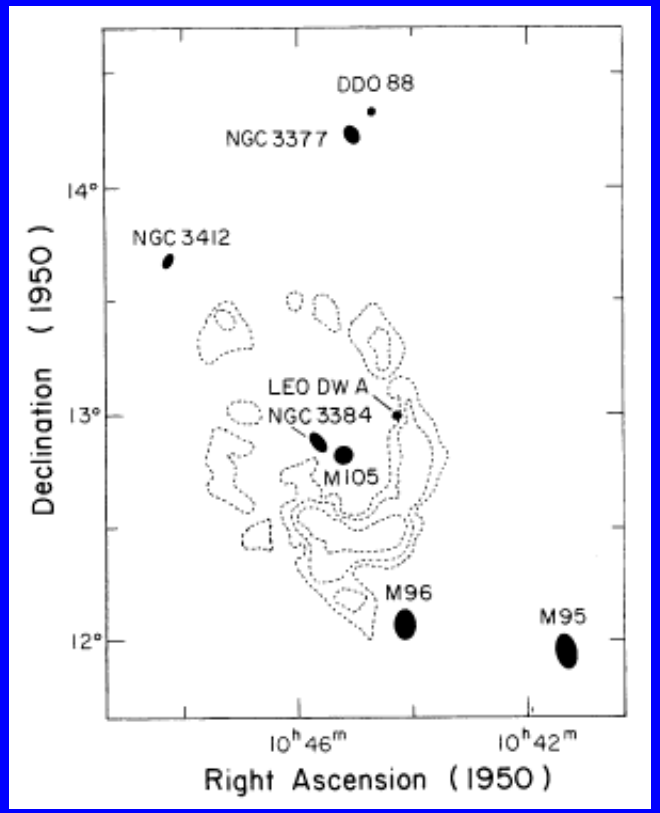
Isolated ring-like HI clouds (intragroup HI gas).

The Dorado group
(M(HI)~5*10^9 M_{sun})



Ryan-Weber et al. (2002)

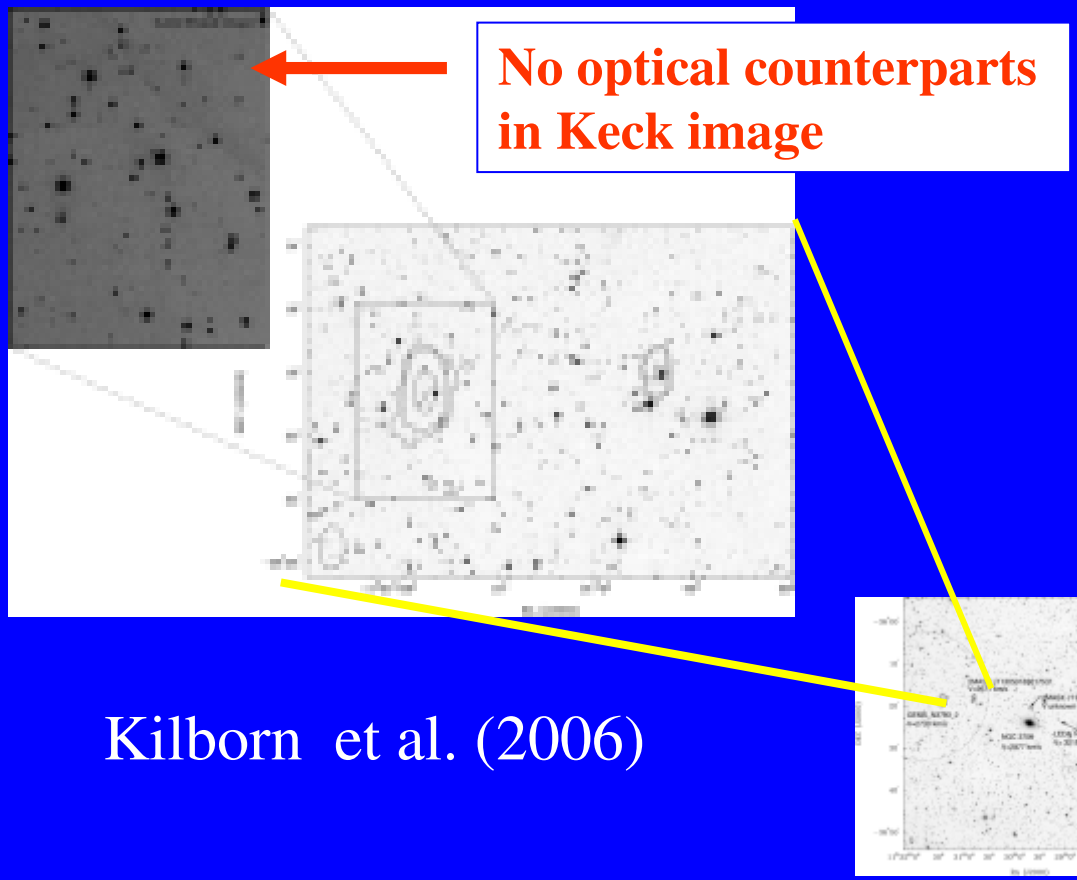
M96 group
(M(HI)~10^9 M_{sun})



Schneider et al. (1989)

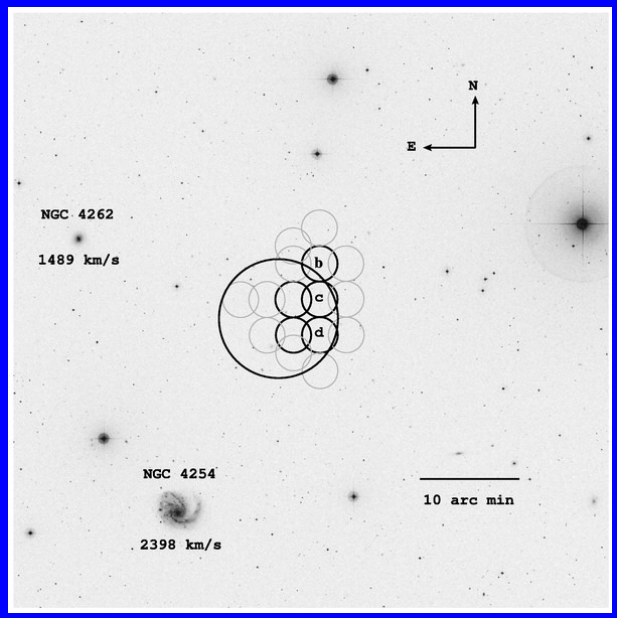
Isolated, massive HI clouds (intragroup HI gas).

NGC 3783 group
(M(HI)~4*10^8 M_{sun})



Kilborn et al. (2006)

The Virgo cluster
(M(HI)~2*10^8 M_{sun})



Minchin et al. (2005)

Three topics

- Formation mechanisms ?
- Evolution into intergalactic stars and ``new galaxies'' ?
- ``Dark impact'' on outer HI disks of galaxies?

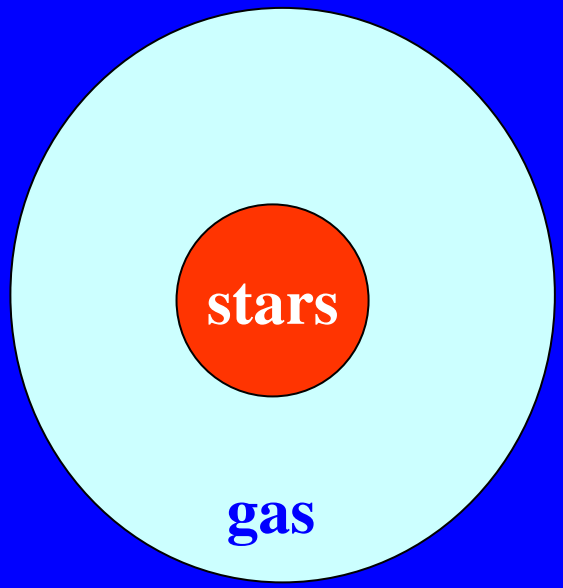
(I) Possible origins of massive HI clouds.

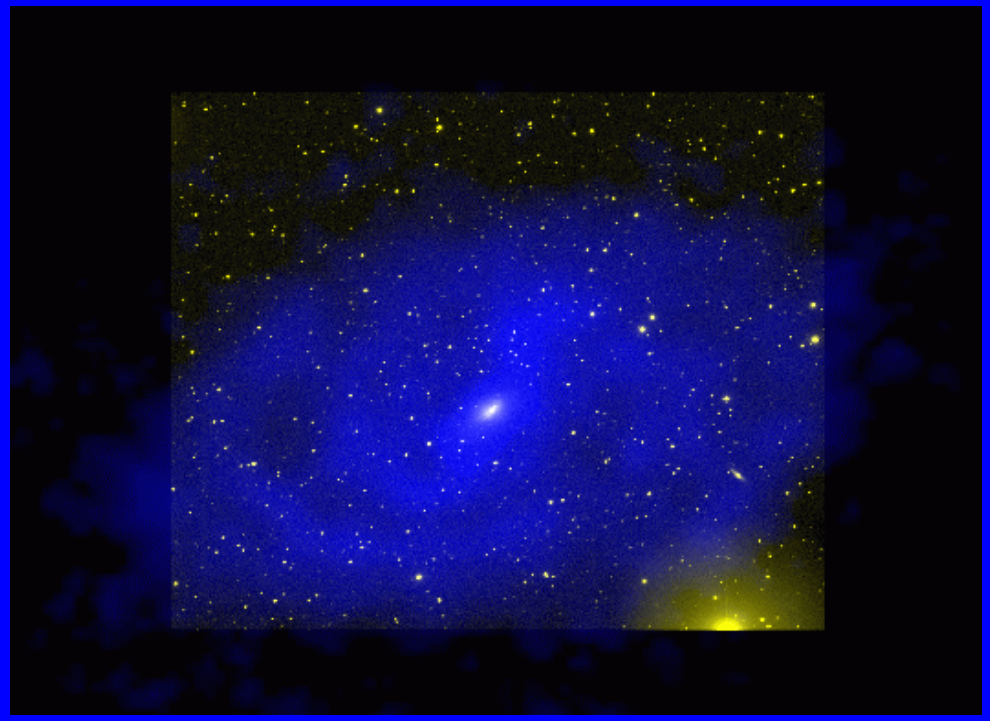
- ``Dark galaxies'' , i.e., truly isolated HI embedded in dark matter halos (Minchin et al. 2005).
- Tidal debris (Bekki et al. 2005).
- Other origins ? Leftovers in galaxy formation (like HVCs) ??

Numerical simulations on the formation of isolated HI clouds from galaxy-group (cluster) interaction.

- Formation of isolated HI gas around NGC 2442 (Bekki, Koribalski, Ryder, & Couch 2005)
- ``Dark galaxy formation'' (Bekki, Kilborn, & Koribalski 2005).
- Intragroup HII regions from tidal compression of HI clouds (Bekki & Ryan-Weber 2007).

Evolution of extended gas disks in high M/L galaxies.





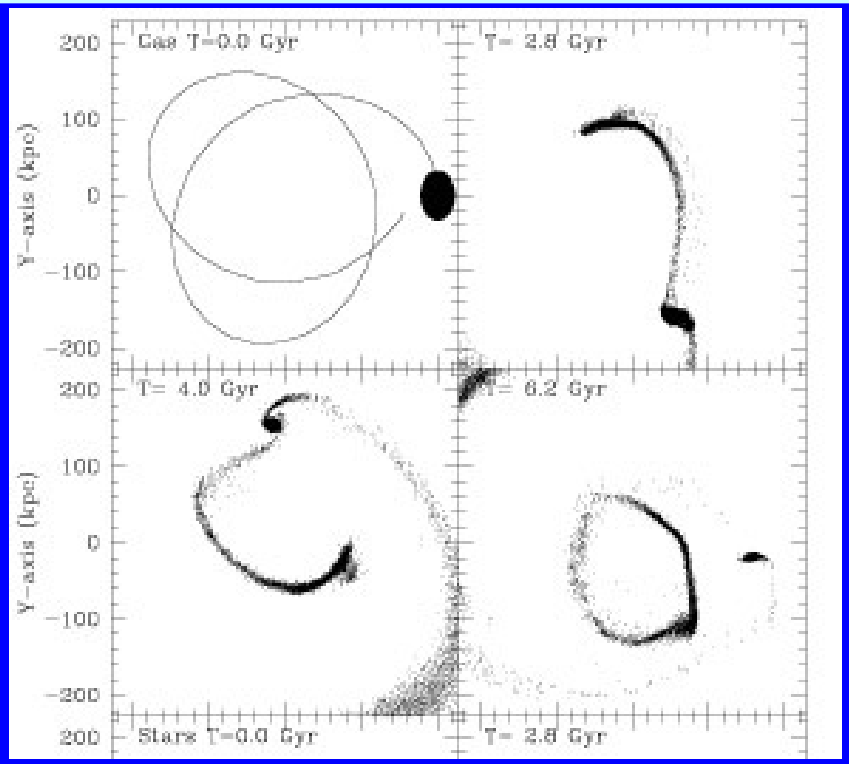
R_{HI}/R_{OPT}~ 2.0

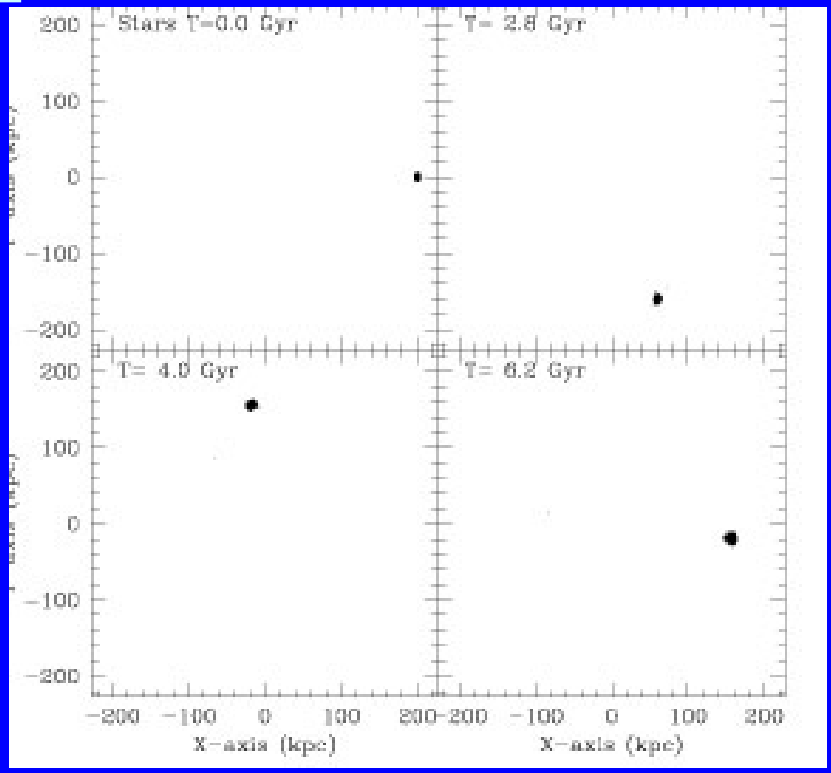
(e.g., Broeils et al. 1994, 1997)

NGC 2915 (Meurer et al. 1996)

Formation of intragroup HI rings for R_{HI}/R_s=5 (Bekki et al. 2005)

An example of rare interaction….



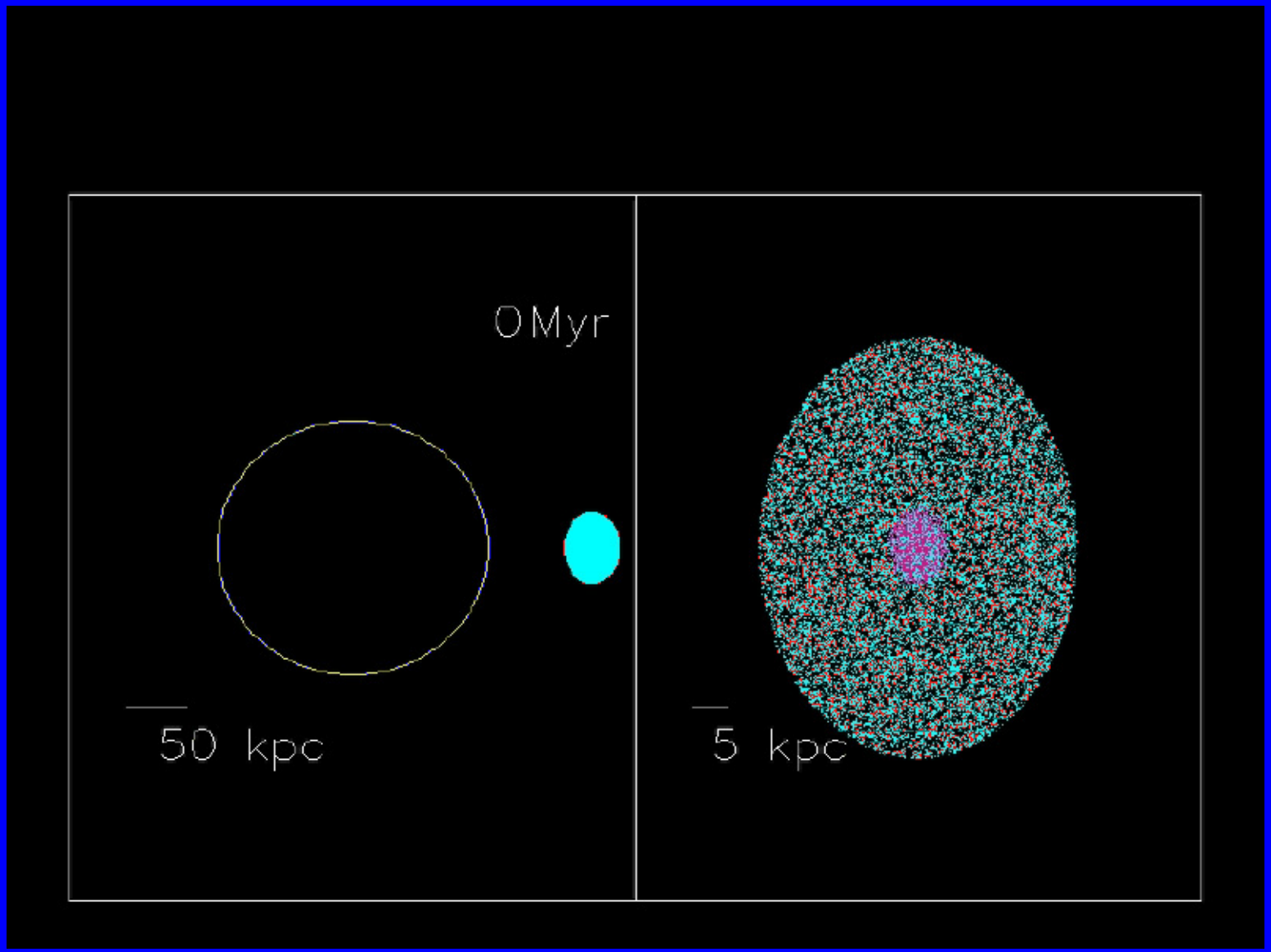


Gas

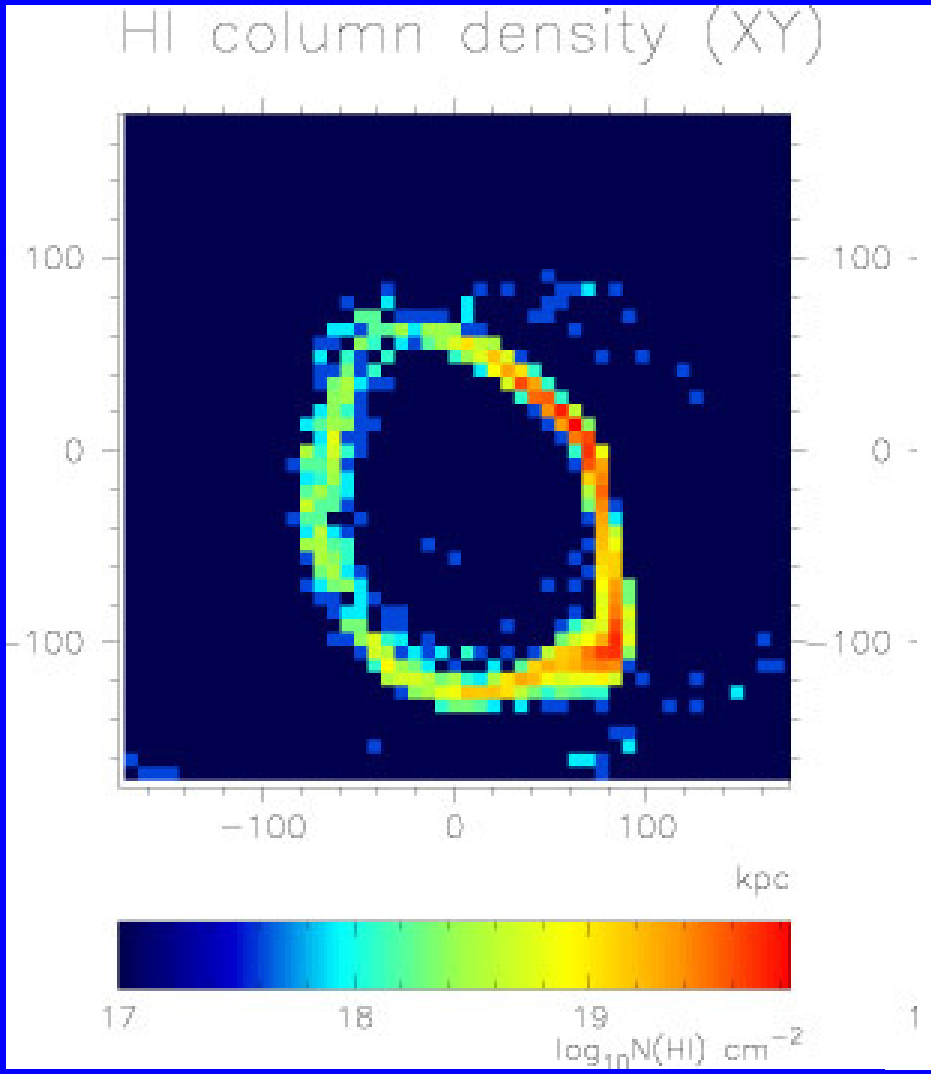
Stars

(M_s=8*10^8 M_{sun} , M_g/M_s=4,R_s=4kpc)

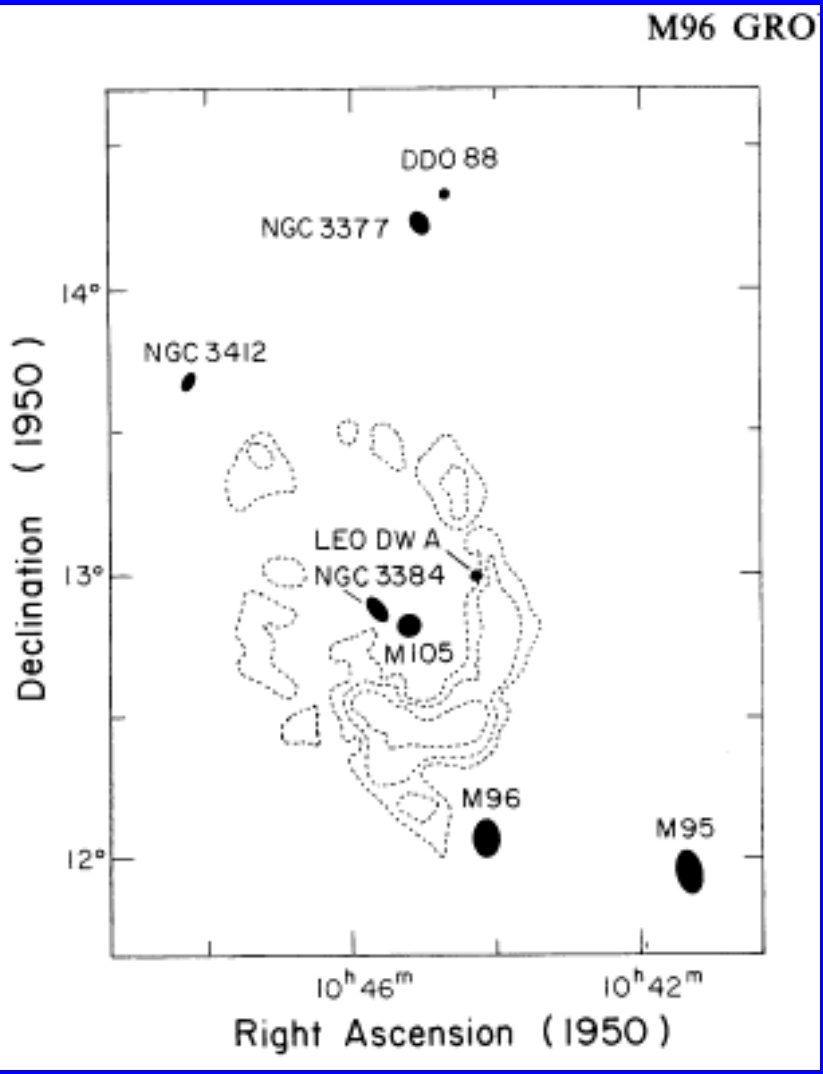
HI ring formation from a LSB



(A) Simulation.

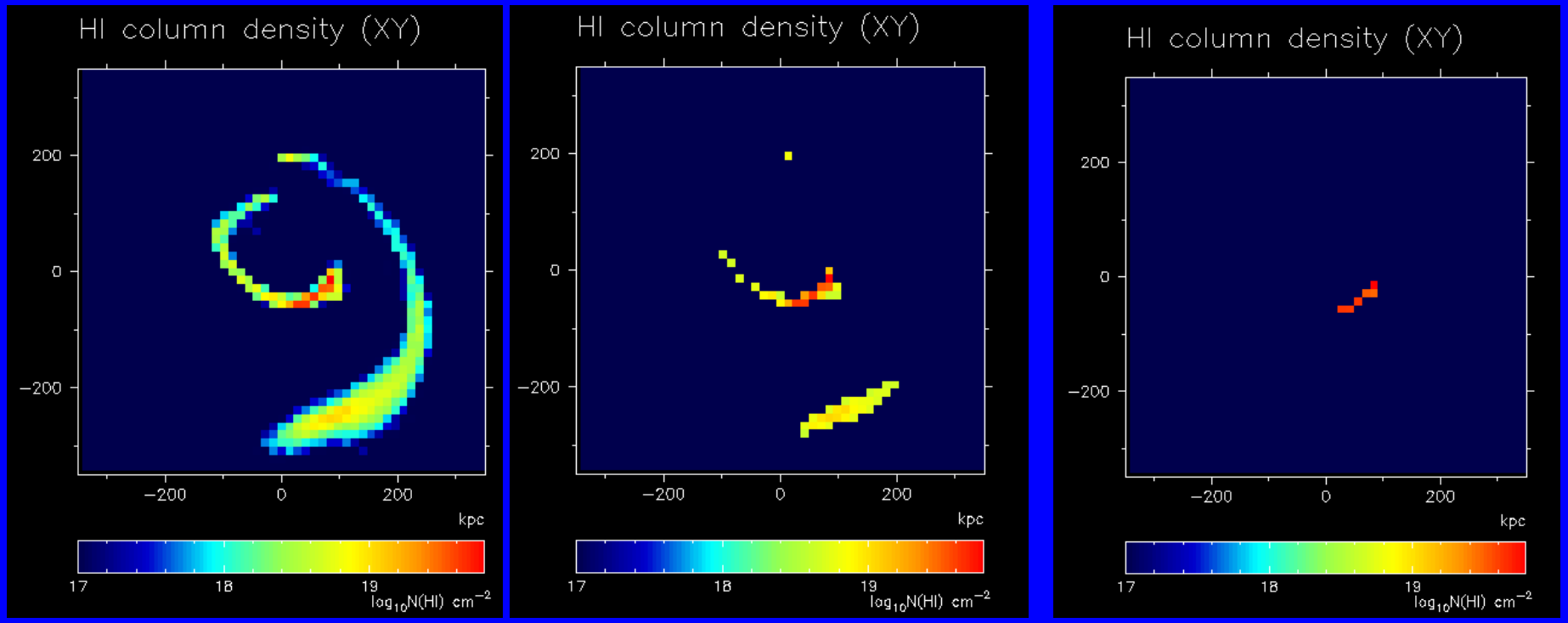


(B) Observation

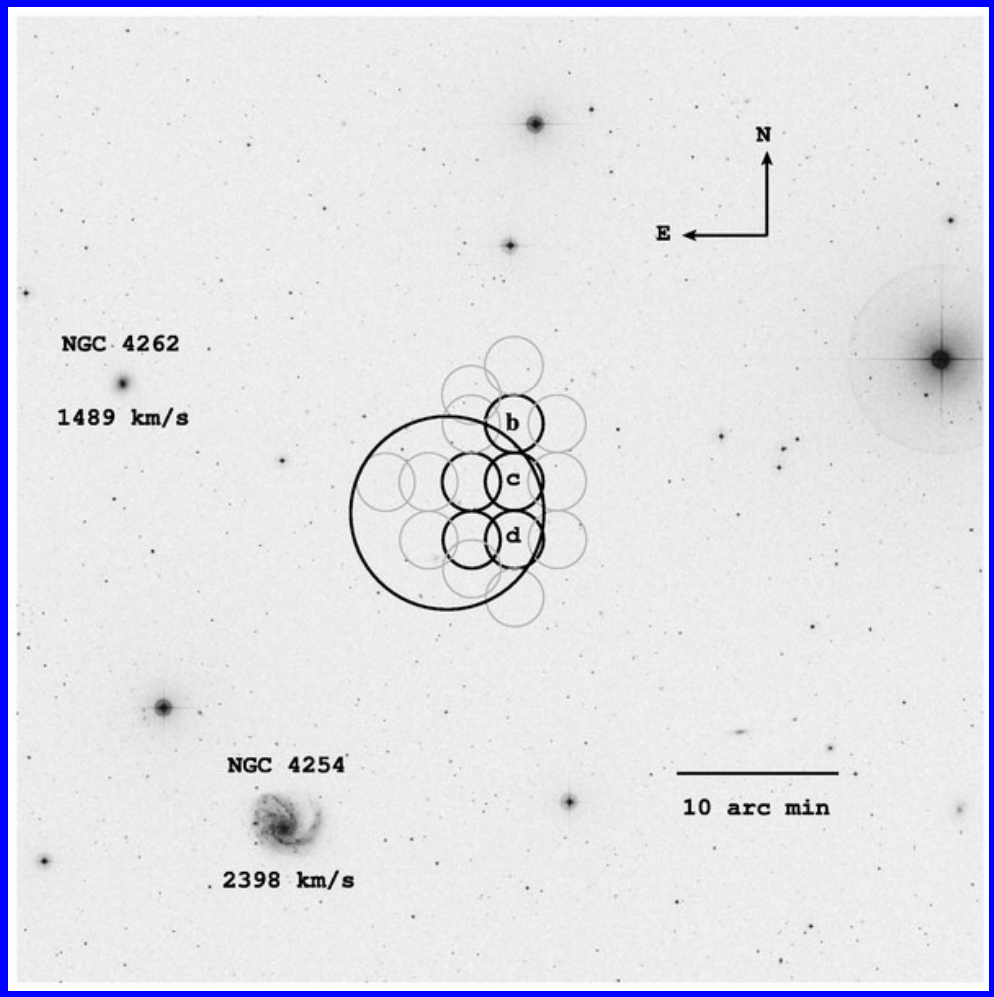


Dependence of HI morphology on detection limit

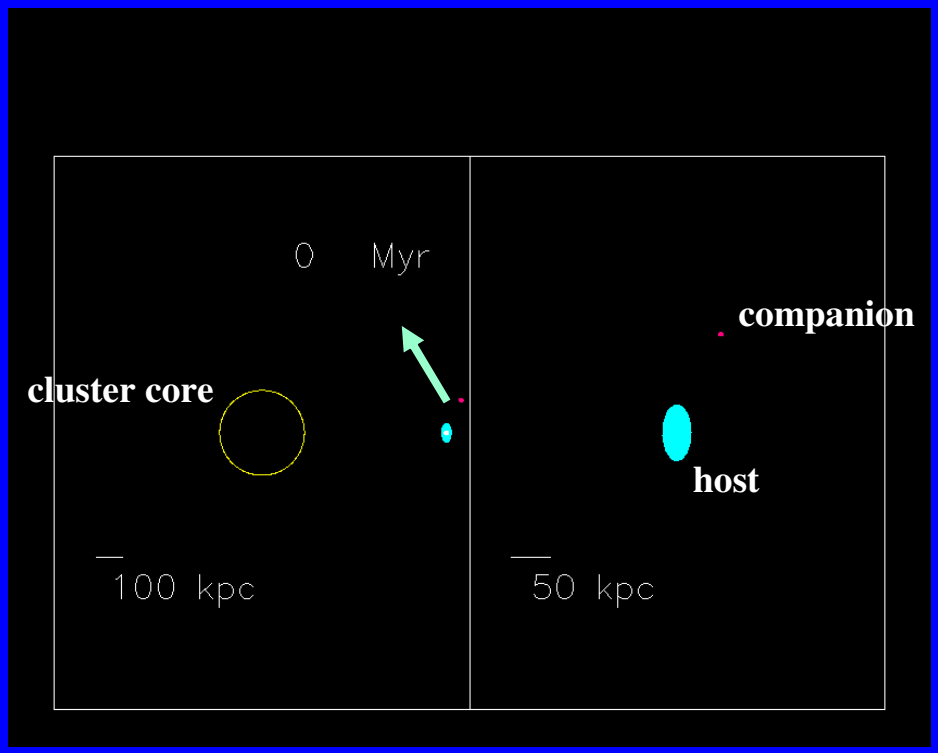
$N(HI)_{thres}$ $=10^{17}$ cm^{-2} $4*10^{18}$ cm^{-2} $2*10^{19}$ cm^{-2}

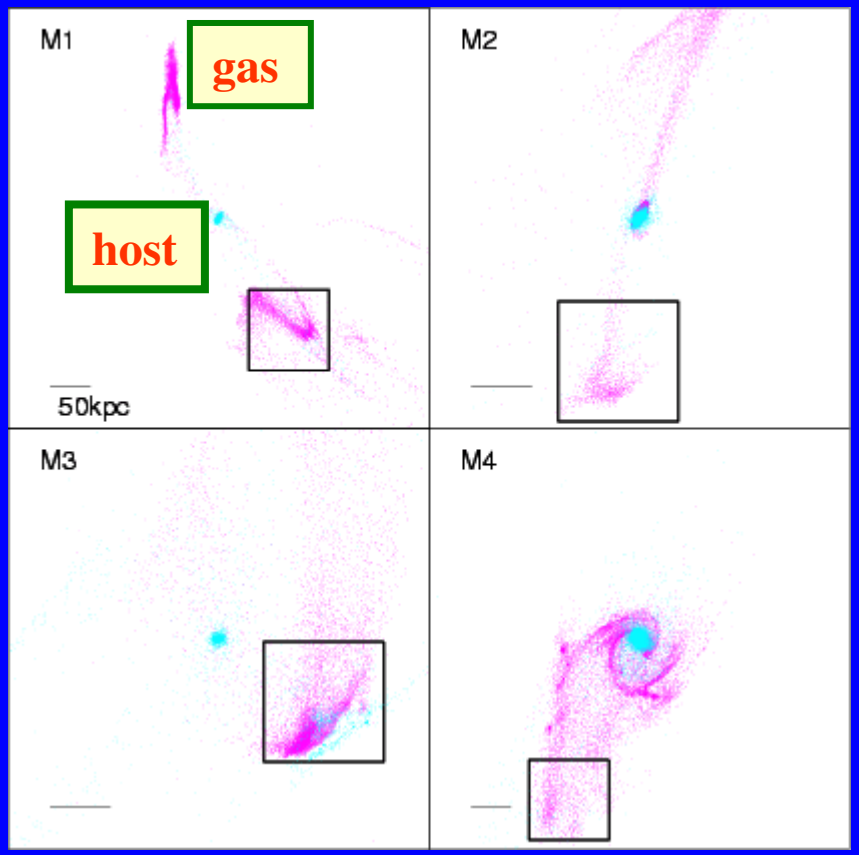


``Dark HI galaxy" in the Virgo cluster (Minchin et al. 2005)

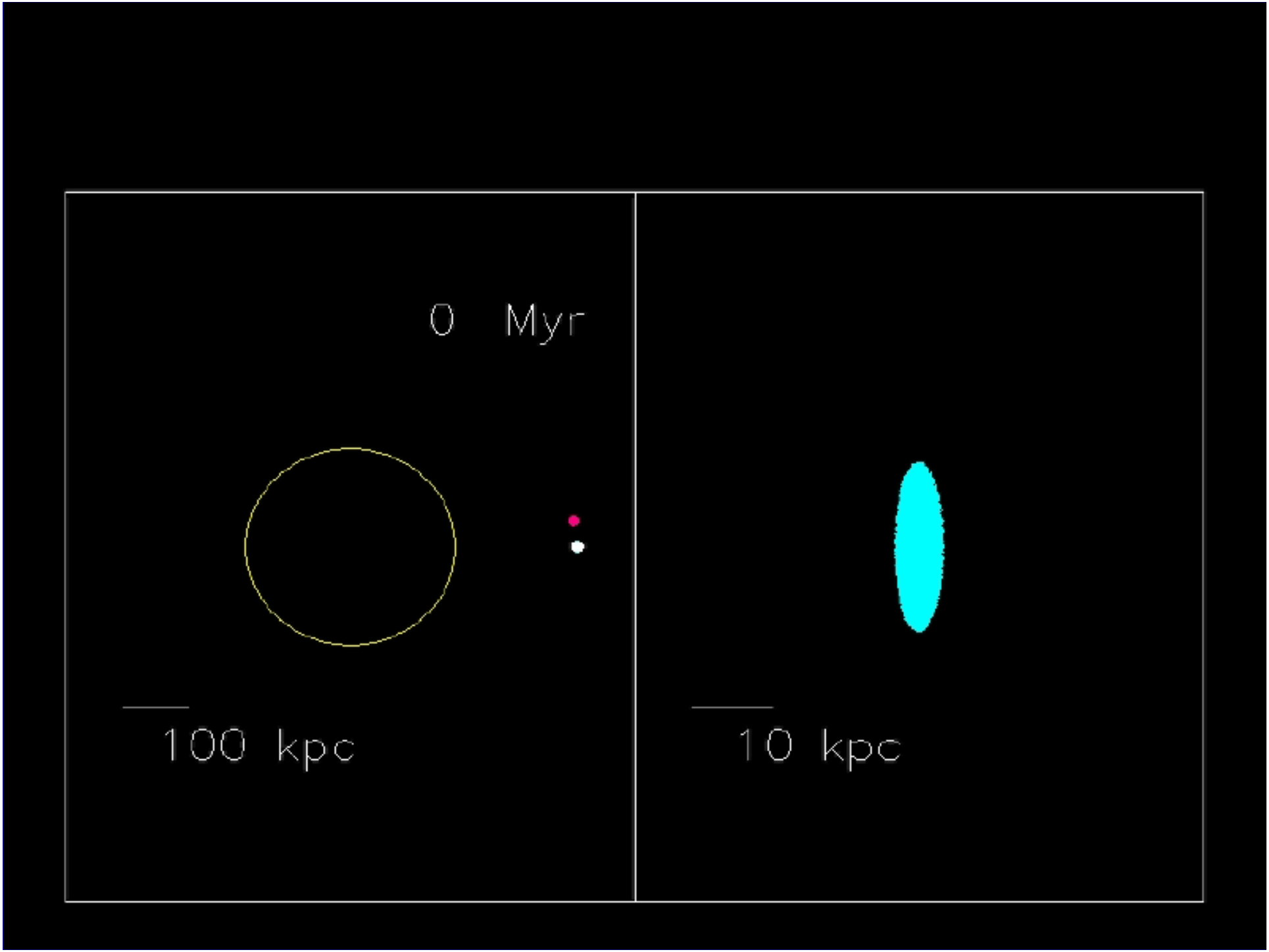


``Dark HI galaxy" as tidal debris (Bekki et al. 2005)

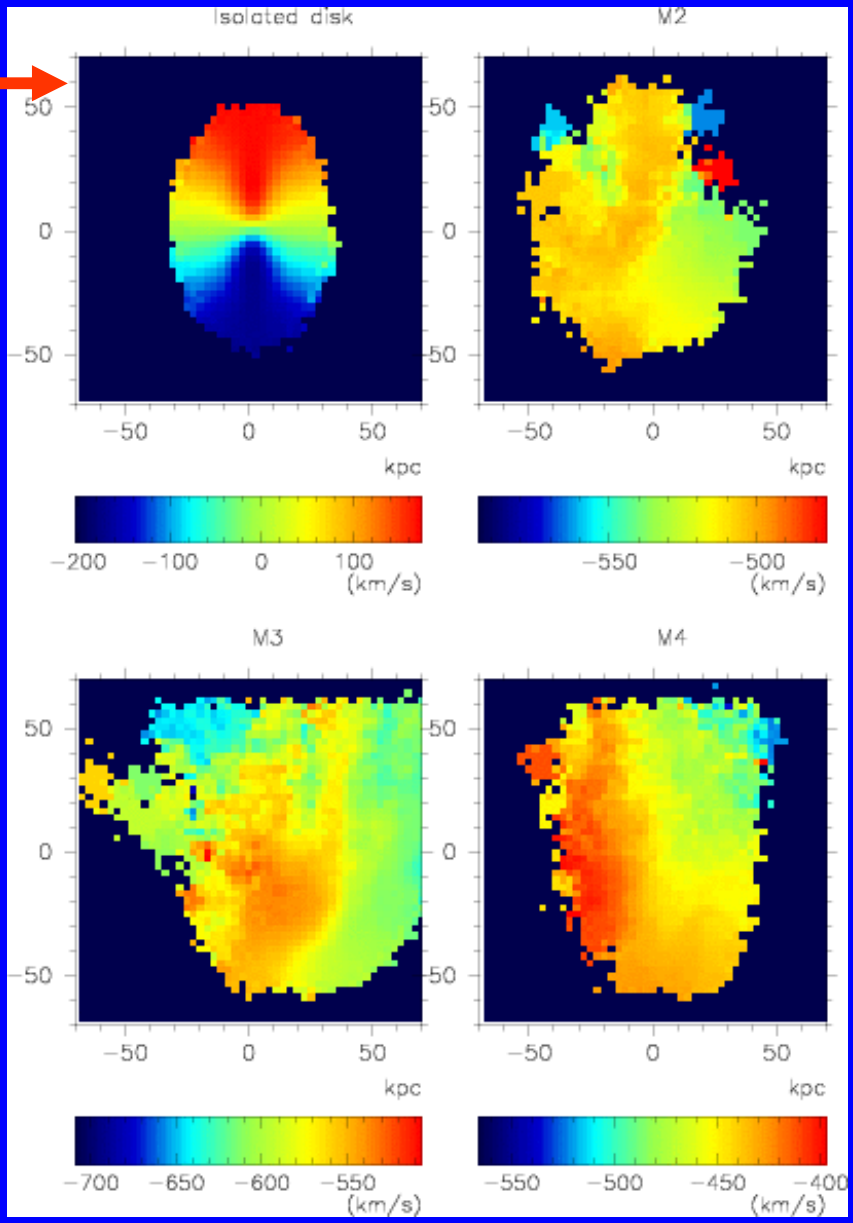




$M_d=6.0*10^9\,M_{sun}$, $m_2=3.$


0 Myr
100 kpc
10 kpc

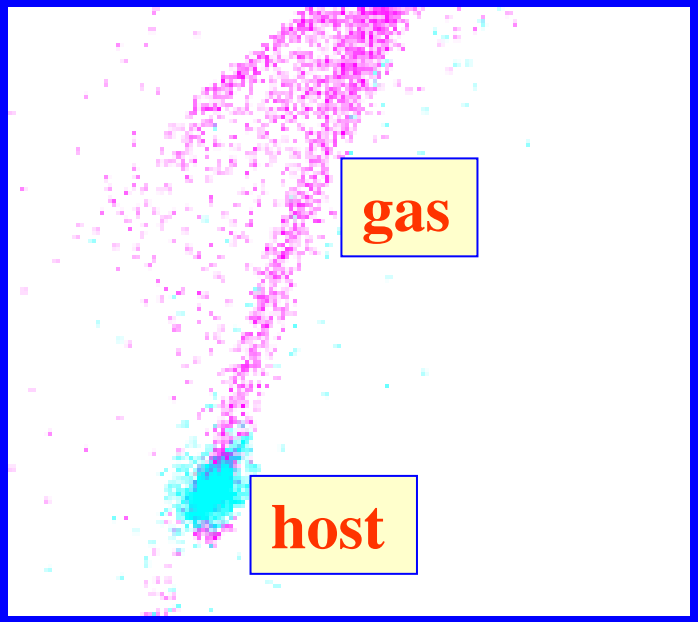
Isolated disk



2D velocity fields of simulated ``dark HI clouds''.

(II) Evolution of isolated HI clouds/tails : Photoionized ?

Simulation (HI)



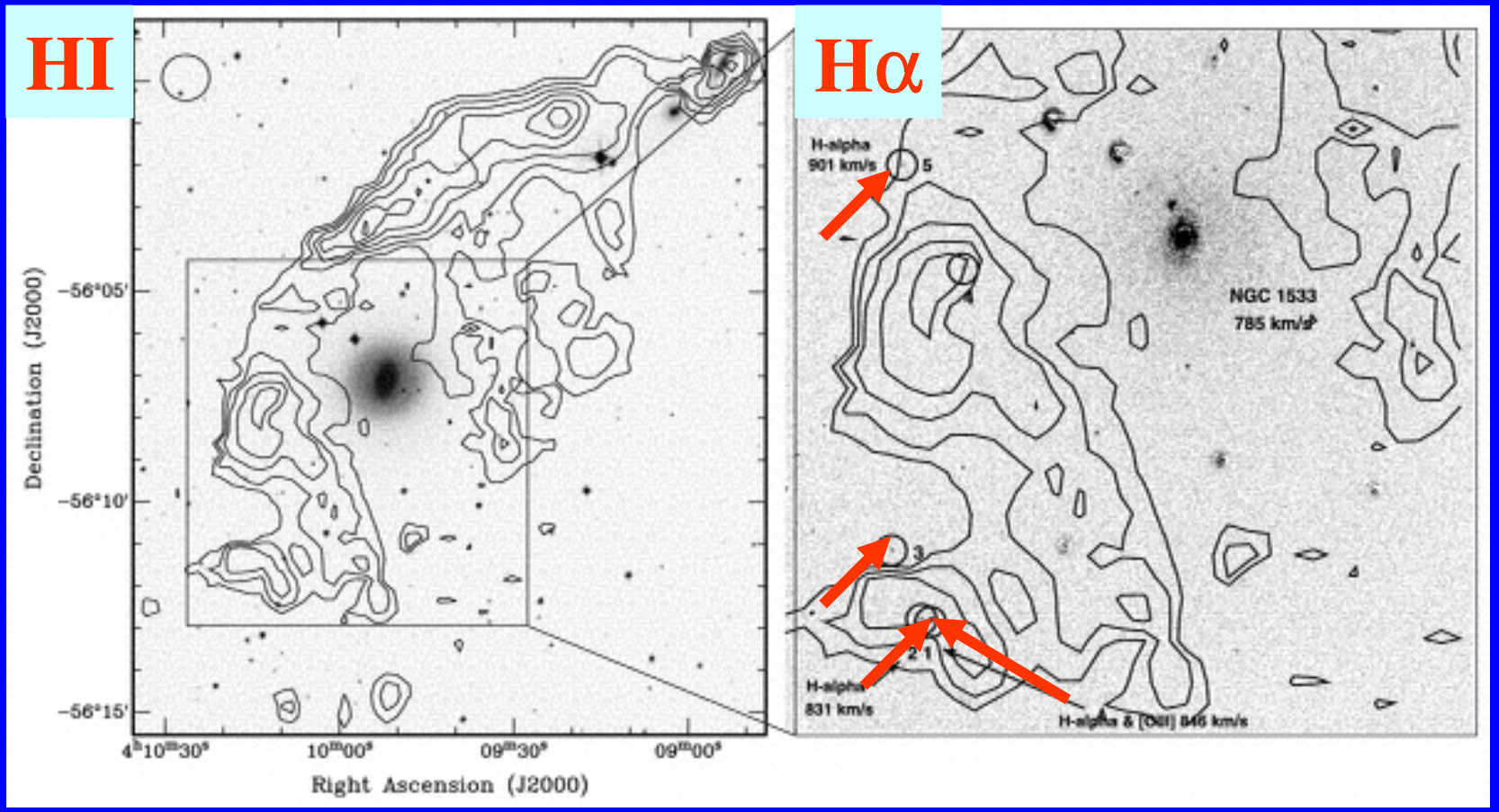
Tidal tail (Bekki et al. 2005)

Evolution ?

Observation (Hα)

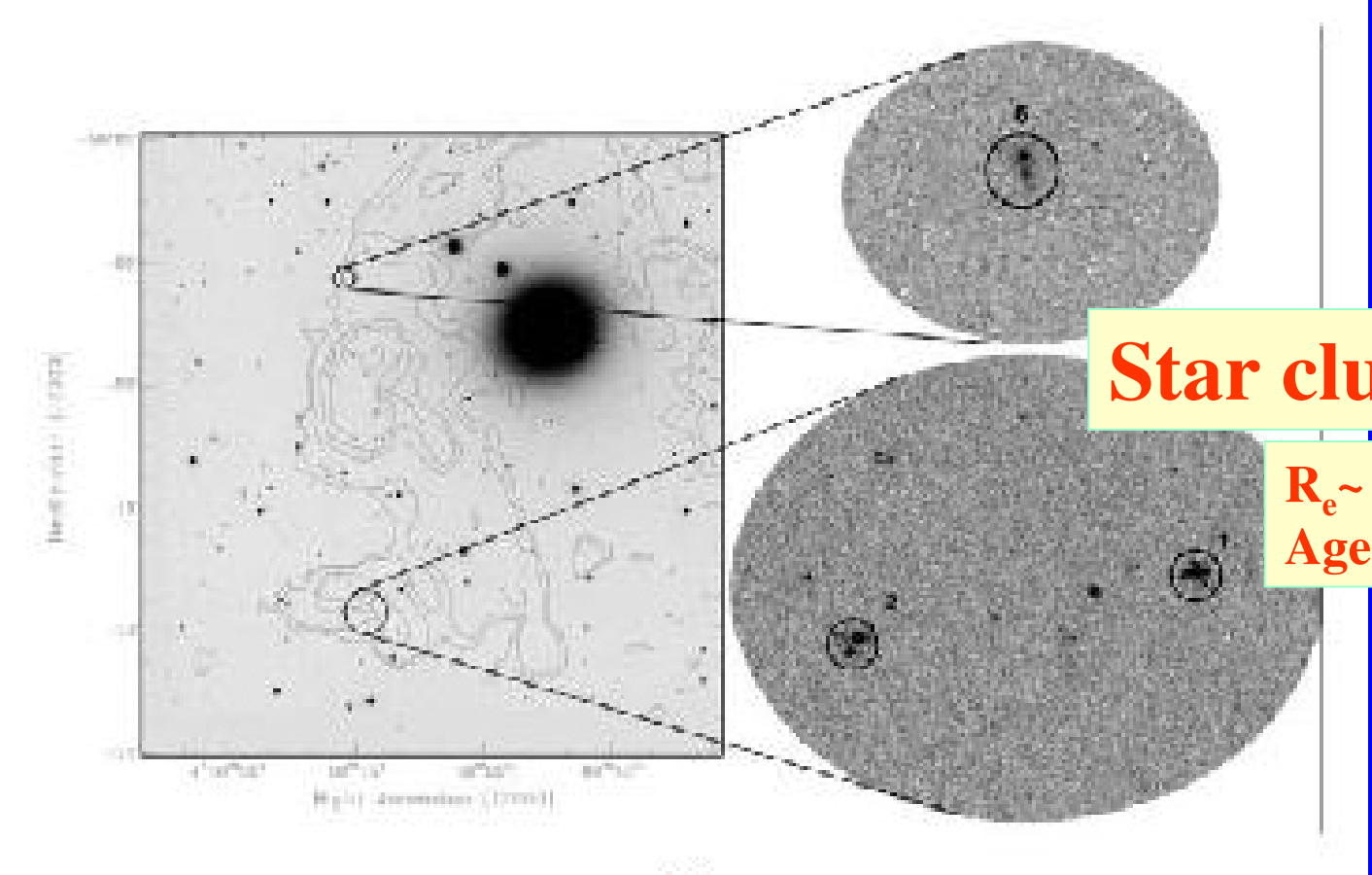
60kpc x 2kpc Hα emitting gas
in D100 by Subaru Suprime-cam
(Yagi et al. 2007)

Evolution of isolated HI gas into intergalactic young stars/star clusters ?



Ryan-Weber et al. (2004) for NGC 1533 in the Dorado group

Evolution of isolated HI gas into intergalactic young stars/star clusters ?

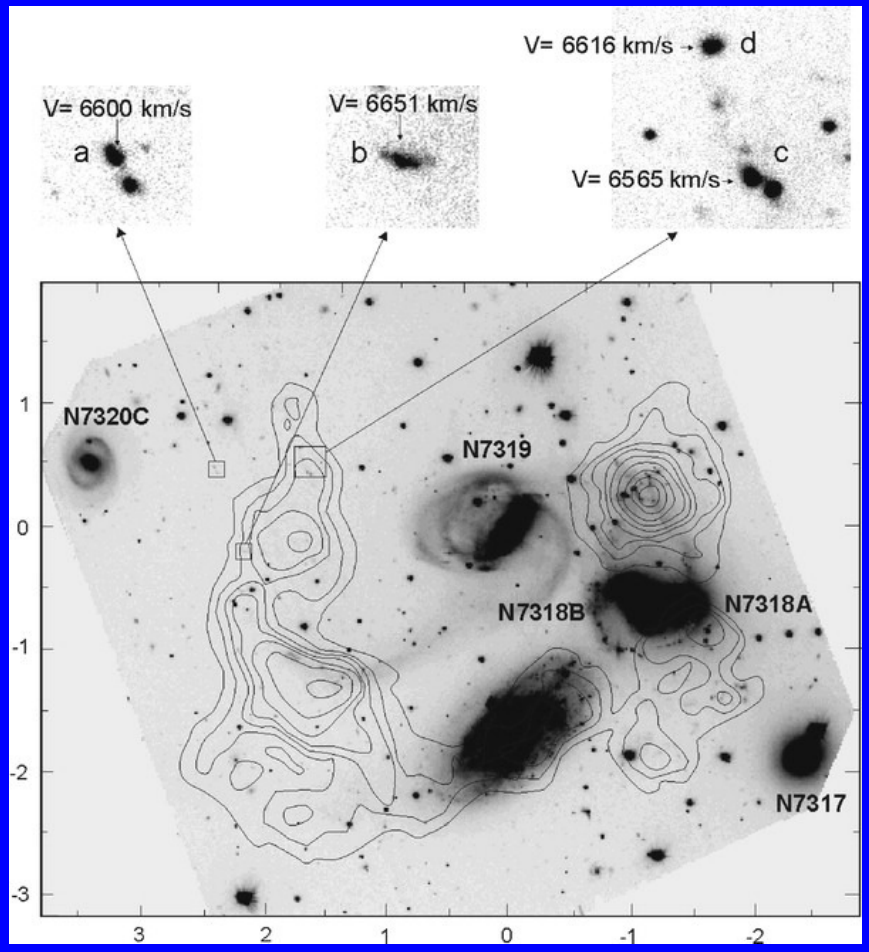


Star clusters

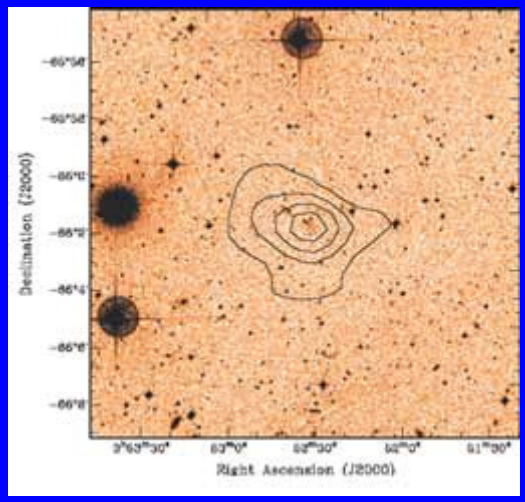
R_e~ 17-25pc,
Age ~ 4-6 Myr

HST ACS/HRC imaging by Werk et al. (2007) for NGC 1533

Two other cases….



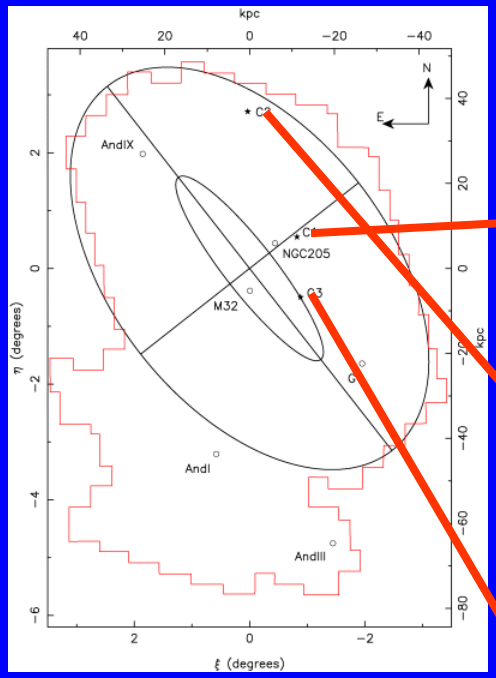
Gemini GMOS observations by de Oliveira et al. (2004)

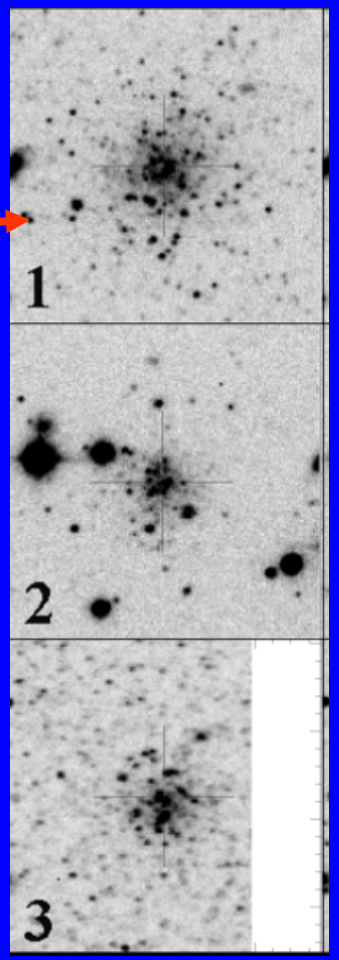


NGC 1490
(Oosterloo et al. 2004)

Further evolution into star clusters (SCs) and dwarf galaxies ?

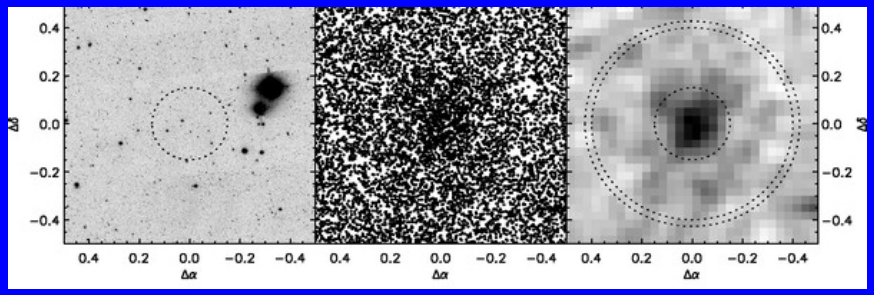
(1) Diffuse SCs in M31





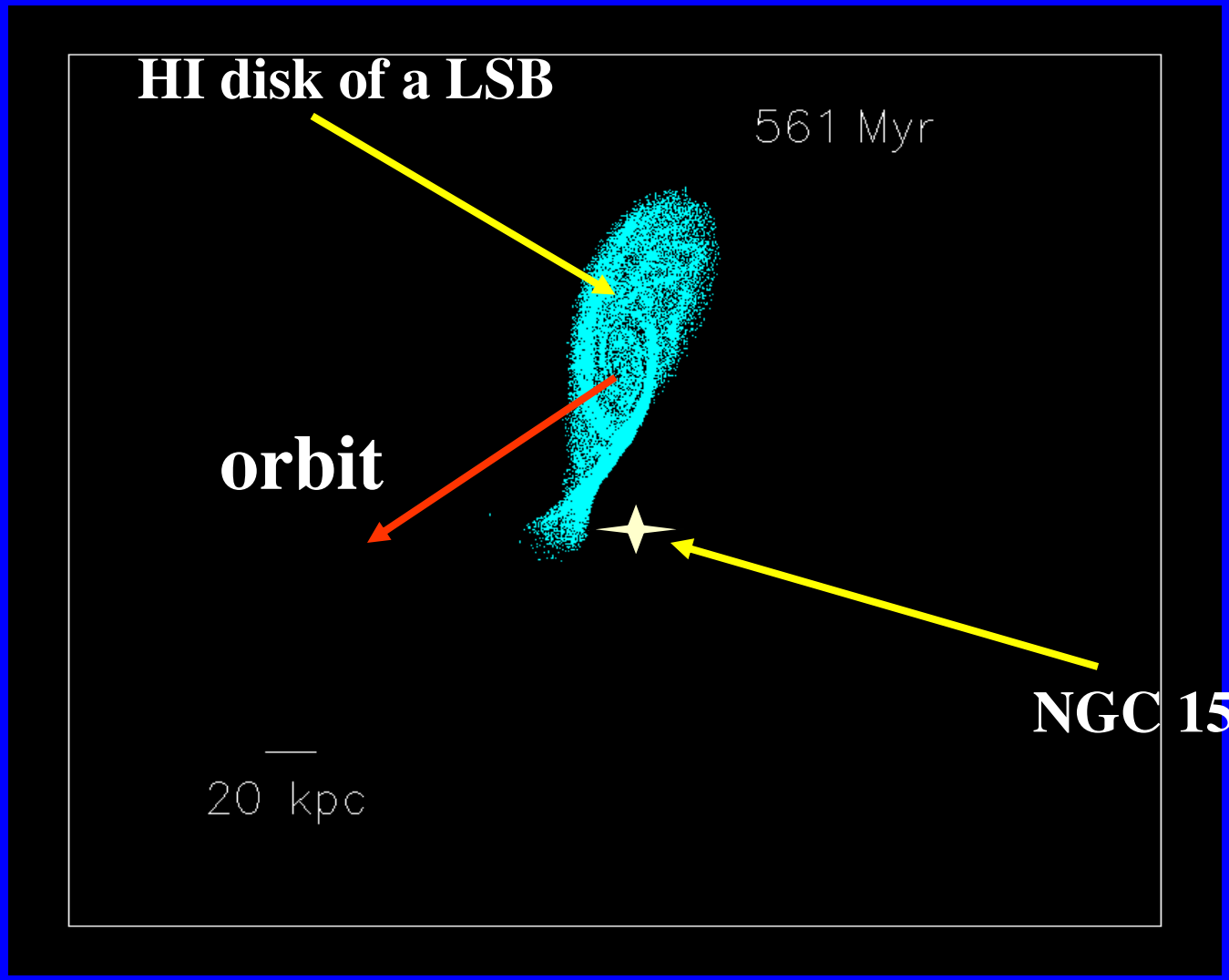
M_V~-7 mag, R_e~ 30pc
(Huxor et al. 2005)

(2) Very faint dwarfs in the Galaxy



A new ``dwarf'' in the Bootes by SDSS: M_V~-6 mag, R_e~ 220 pc (Belolurov et al. 2006)

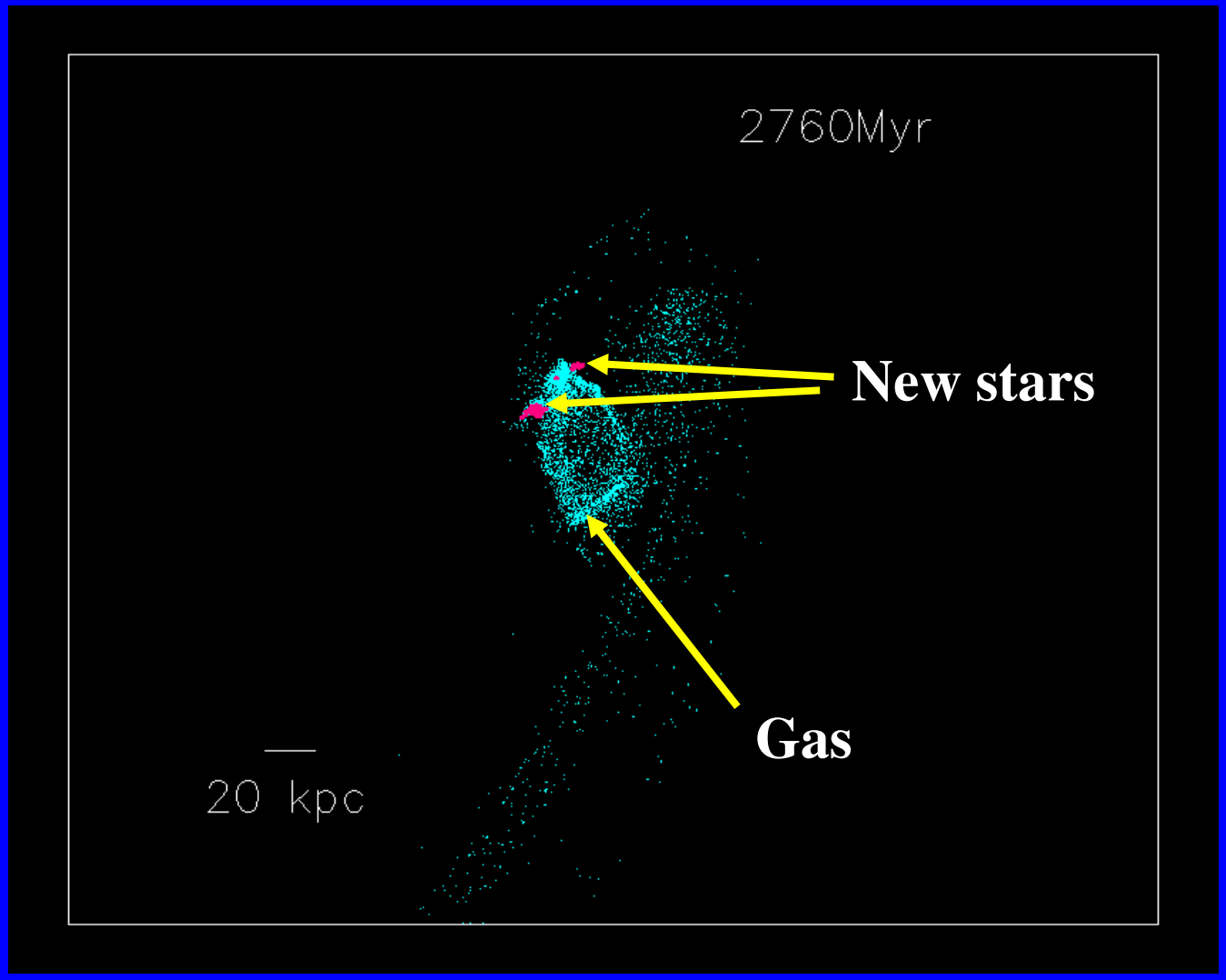
Formation of intragroup HII region from tidal compression.



M_d =4*10^9 M_{sun}, f_g=4

$\rho_{thres} = 3\ M_{sun}/pc^2$

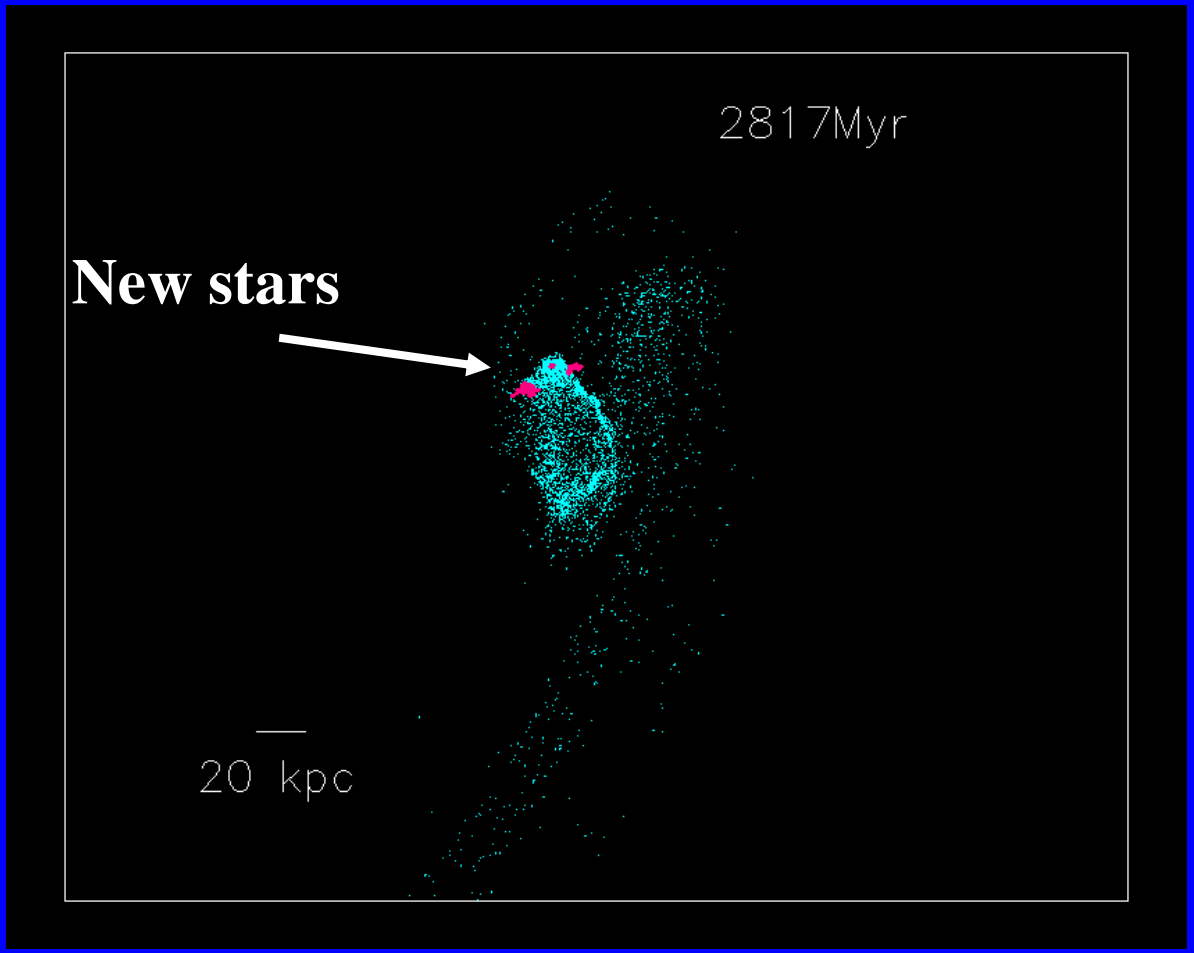
Formation of stars within stripped HI.



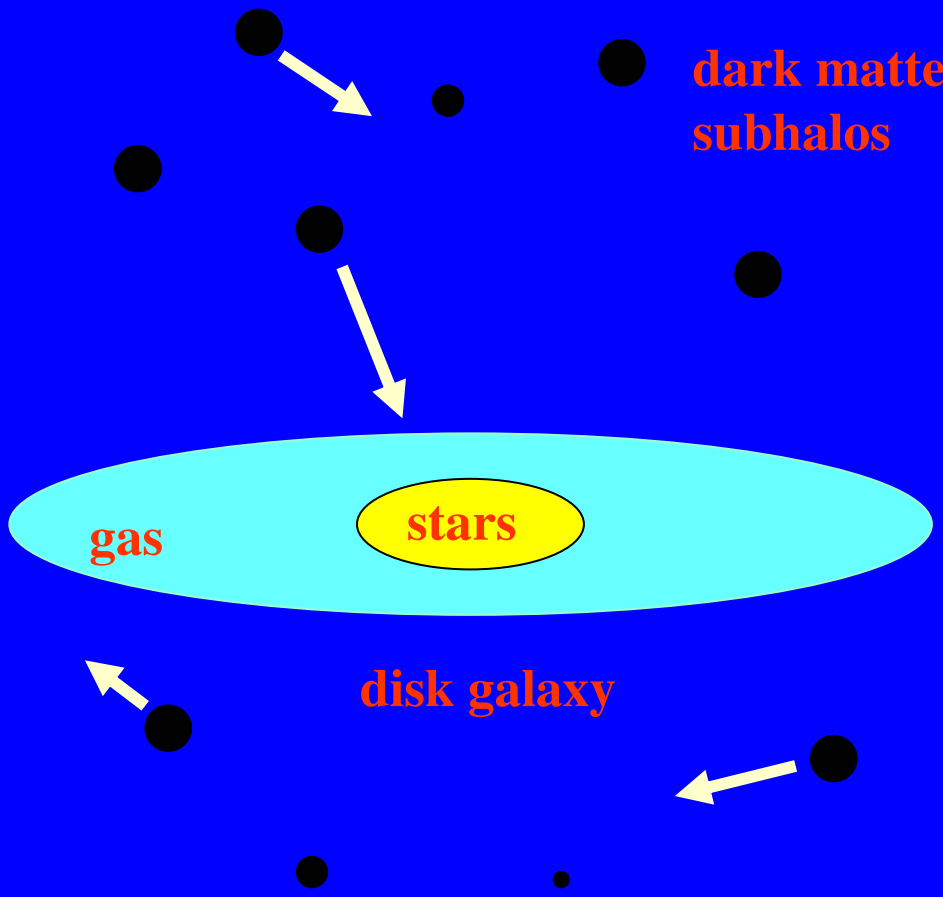
Bekki & Ryan-Weber (2007)

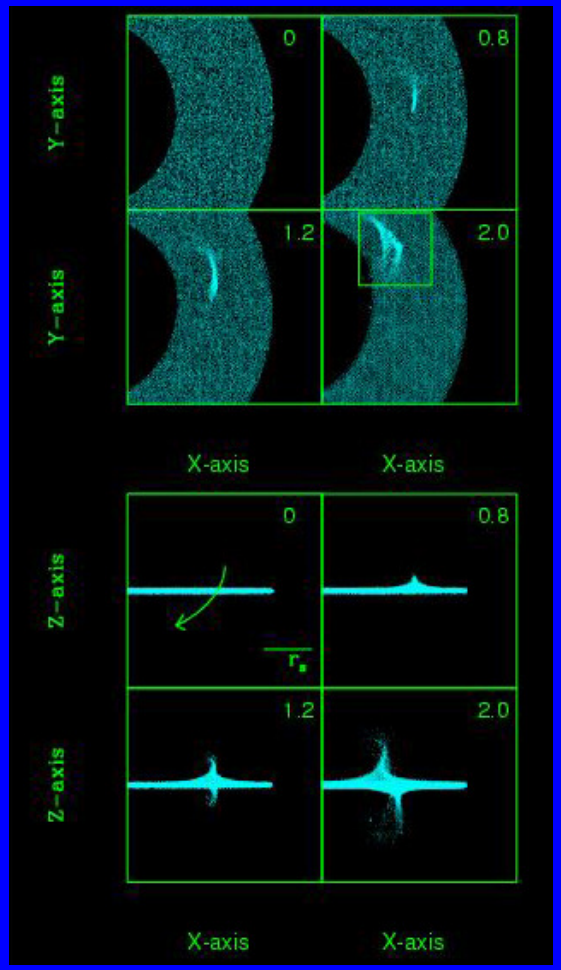
Formation of intragroup HII regions (The case for NGC 1533)

Formation of ``intergalactic stars'' or ``a new galaxy'' (i.e., at most only a few % of gas can be converted into stars).



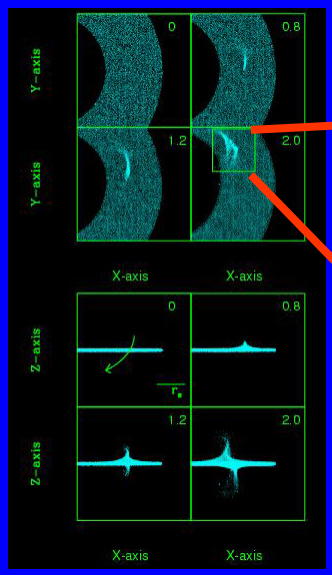
(III) Interaction of the outer HI gas disks and dark matter subhalos (``Dark Impact").

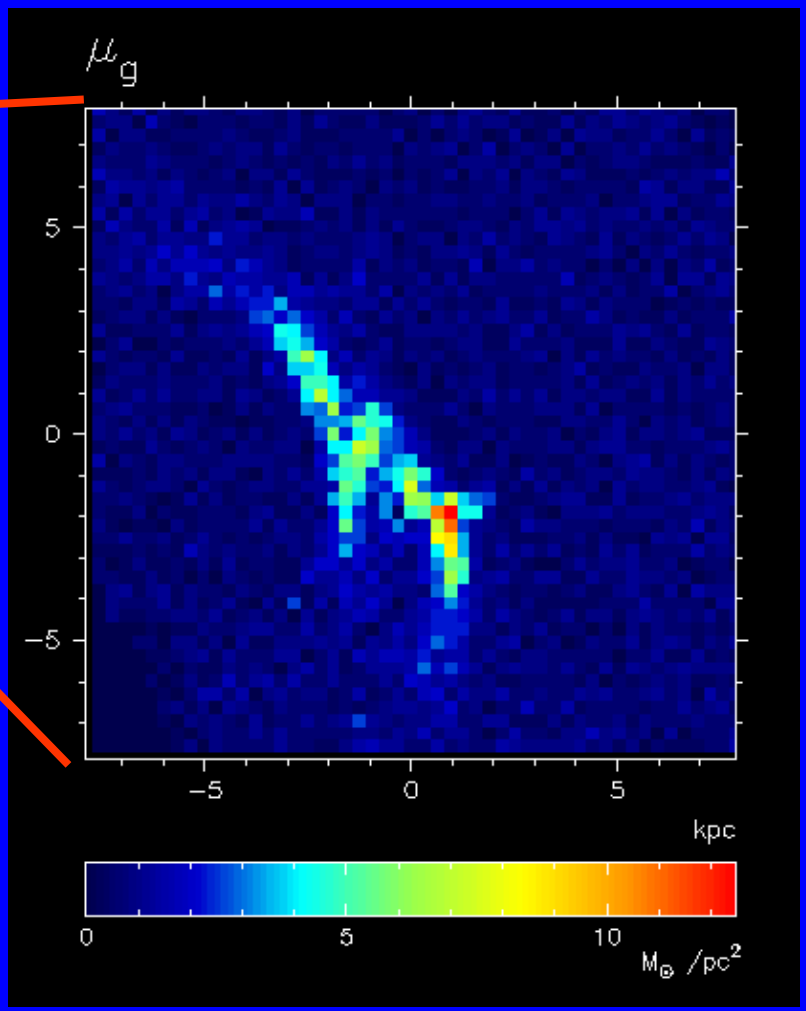




Bekki & Chiba (2006)

Formation of (locally) high-density regions for SF.



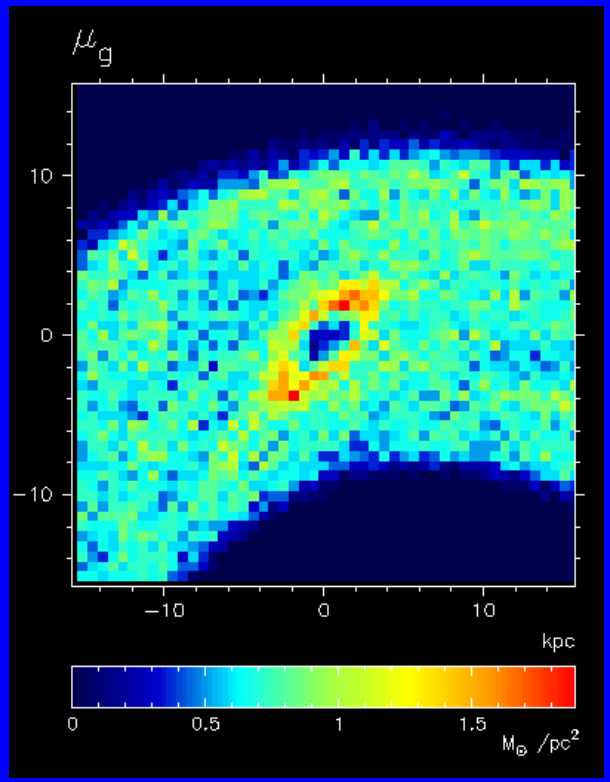


Σ_g>10 M_{sun}/pc^2
→Over threshold gas density for SF ?

(Bekki & Chiba 2006)

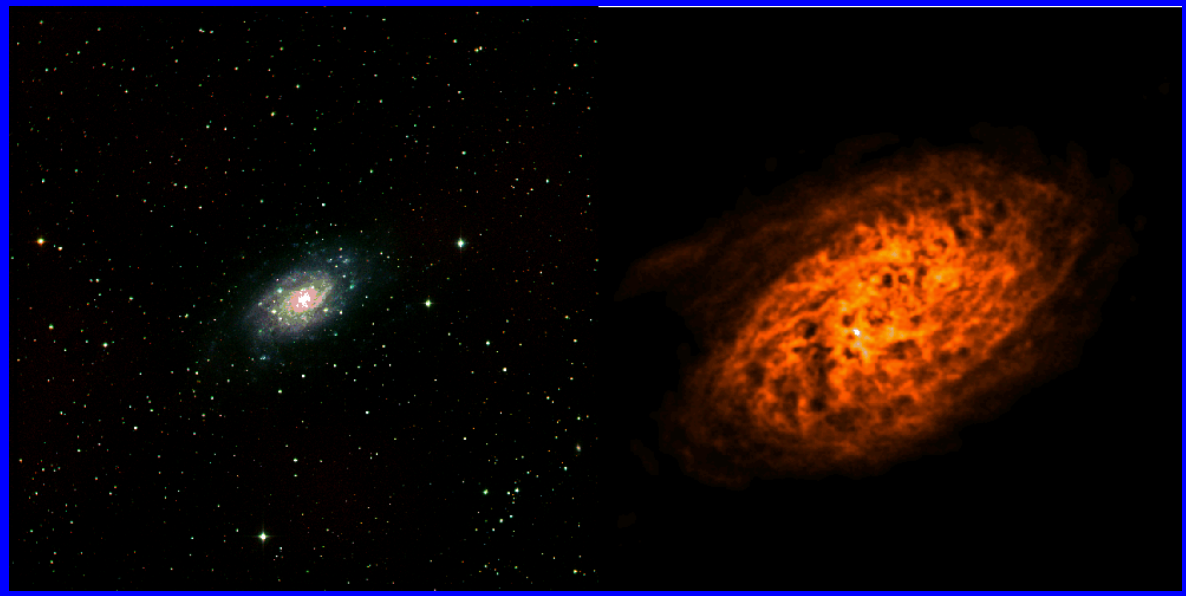
Formation of HI holes: ``HI Kamiokande'' for the indirect detection of dark matter subhalos.

Simulation



(Bekki & Chiba 2006)

Observation



stars HI

NGC 2403

(Oosterloo et al. 2005)

Summary

(1) Isolated, massive HI clouds as tidal debris of gas-rich galaxies.

(2) Possible evolution from HI clouds into intergalactic stars and star clusters.

(3) Formation of high-density HI regions and holes by ``dark impact'' .