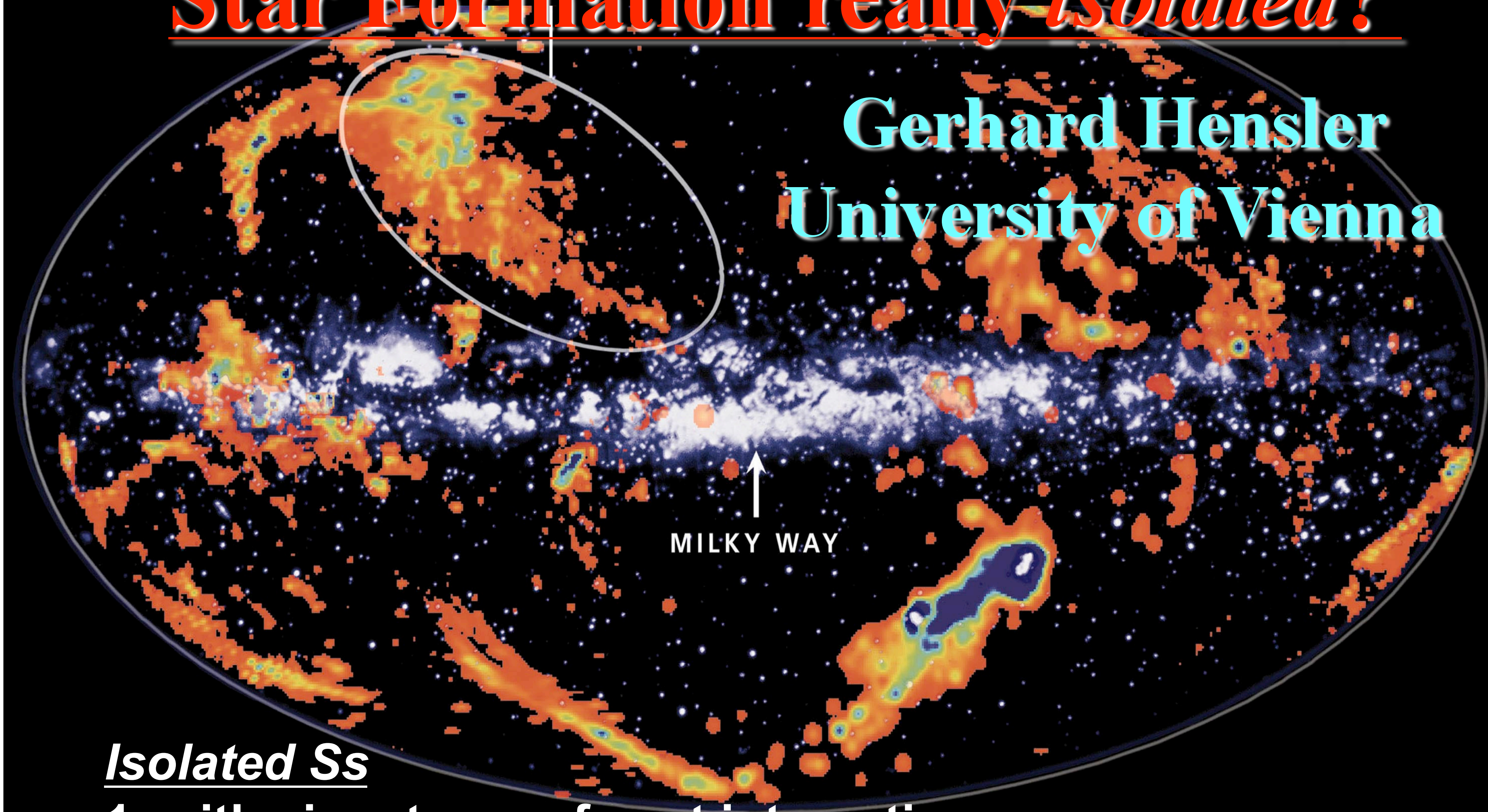
Are Galaxies with ongoing Star Formation really *isolated*?

Gerhard Hensler
University of Vienna

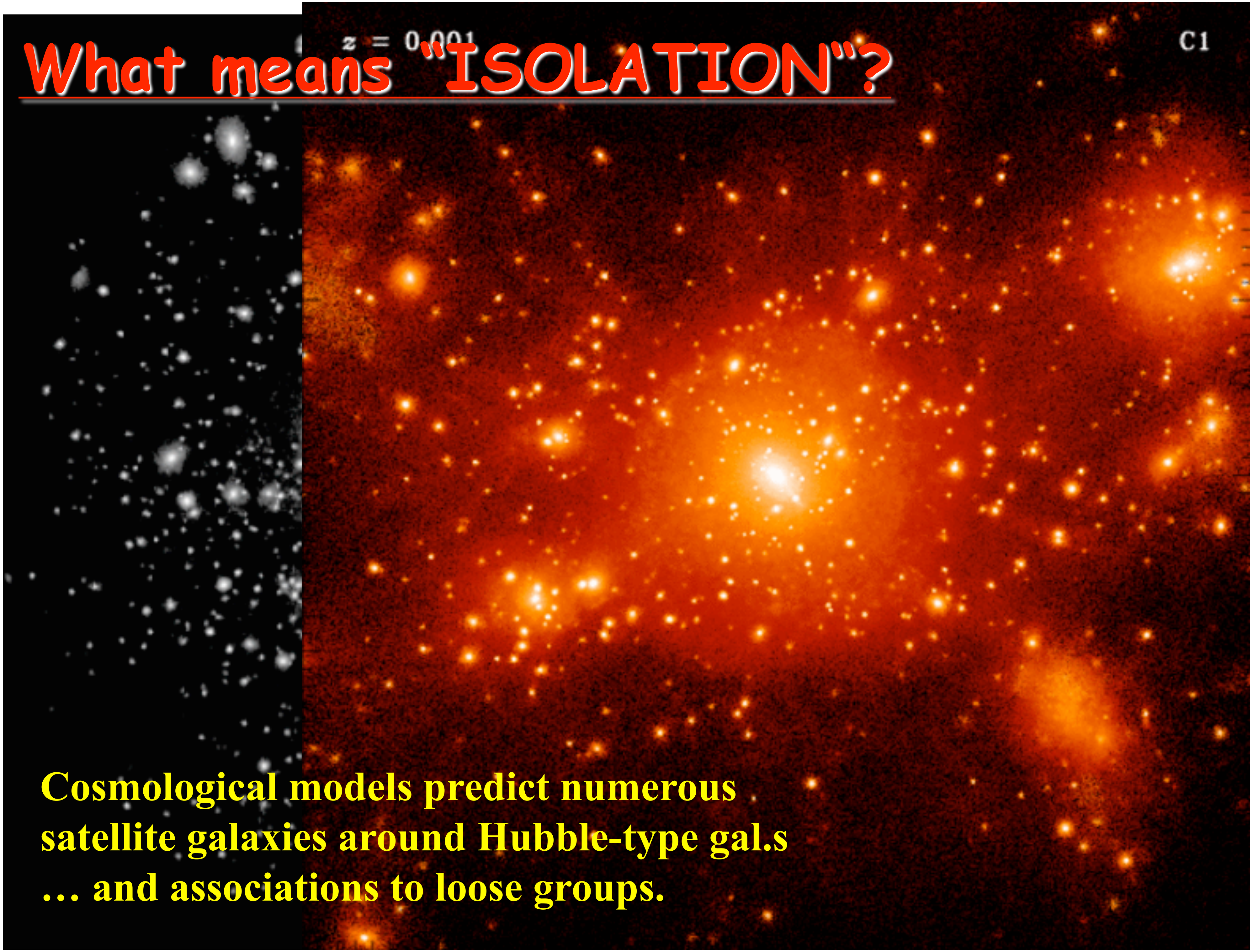


Isolated Ss

1. with signatures of past interactions
2. determined, but surrounding gas

NASA and B. Wakker (University of Wisconsin-Madison) • STScI-PRC99-46

What means "ISOLATION"?



Cosmological models predict numerous satellite galaxies around Hubble-type gal.s … and associations to loose groups.

Ram-pressure stripping galaxies are NOT ISOLATED!

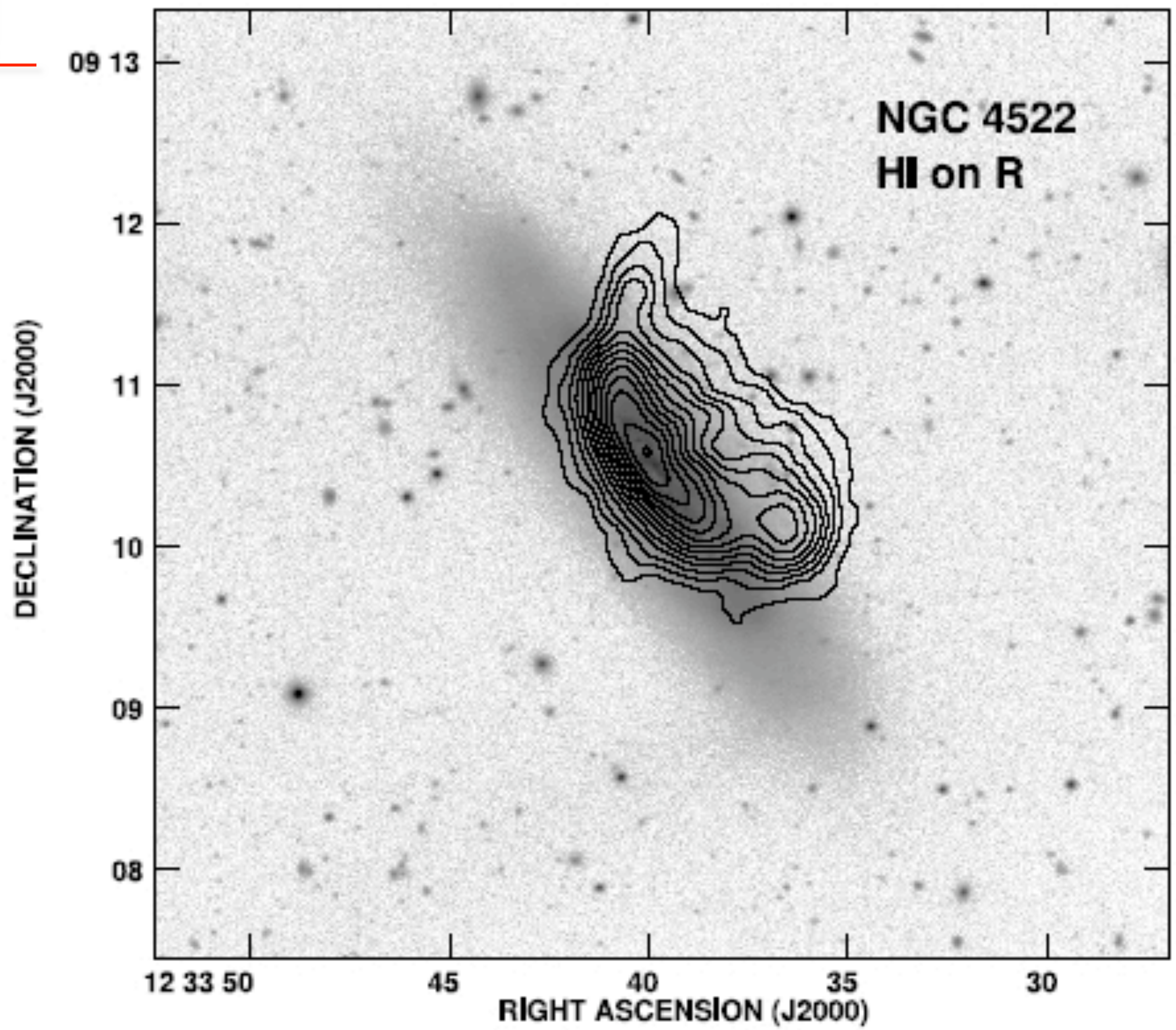


FIG. 3.—H I moment 0 contour map of NGC 4522 on *R*-band gray-scale image from the WIYN telescope from Kenney & Koopmann (1999). The lowest H I contour level and contour increments are 50 mJy beam^{-1} km s^{-1}. The optical image is shown with logarithmic stretch. Note the undisturbed outer stellar disk.

Gas Deficiency

definition with resp. to the gas content of „normal" field galaxies.

Virgo Cluster Spirals

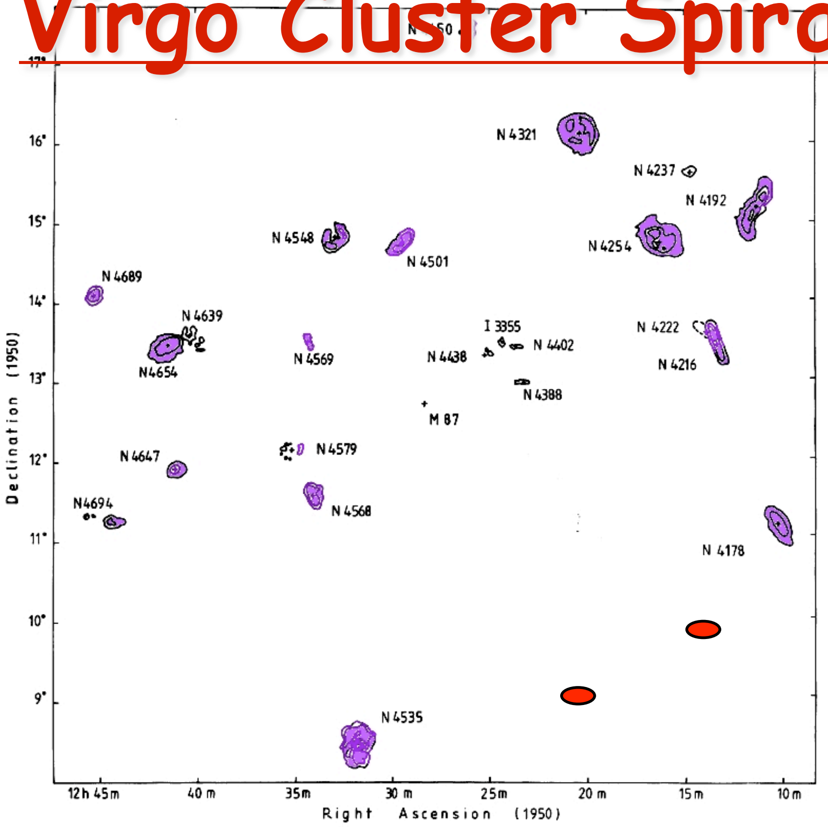
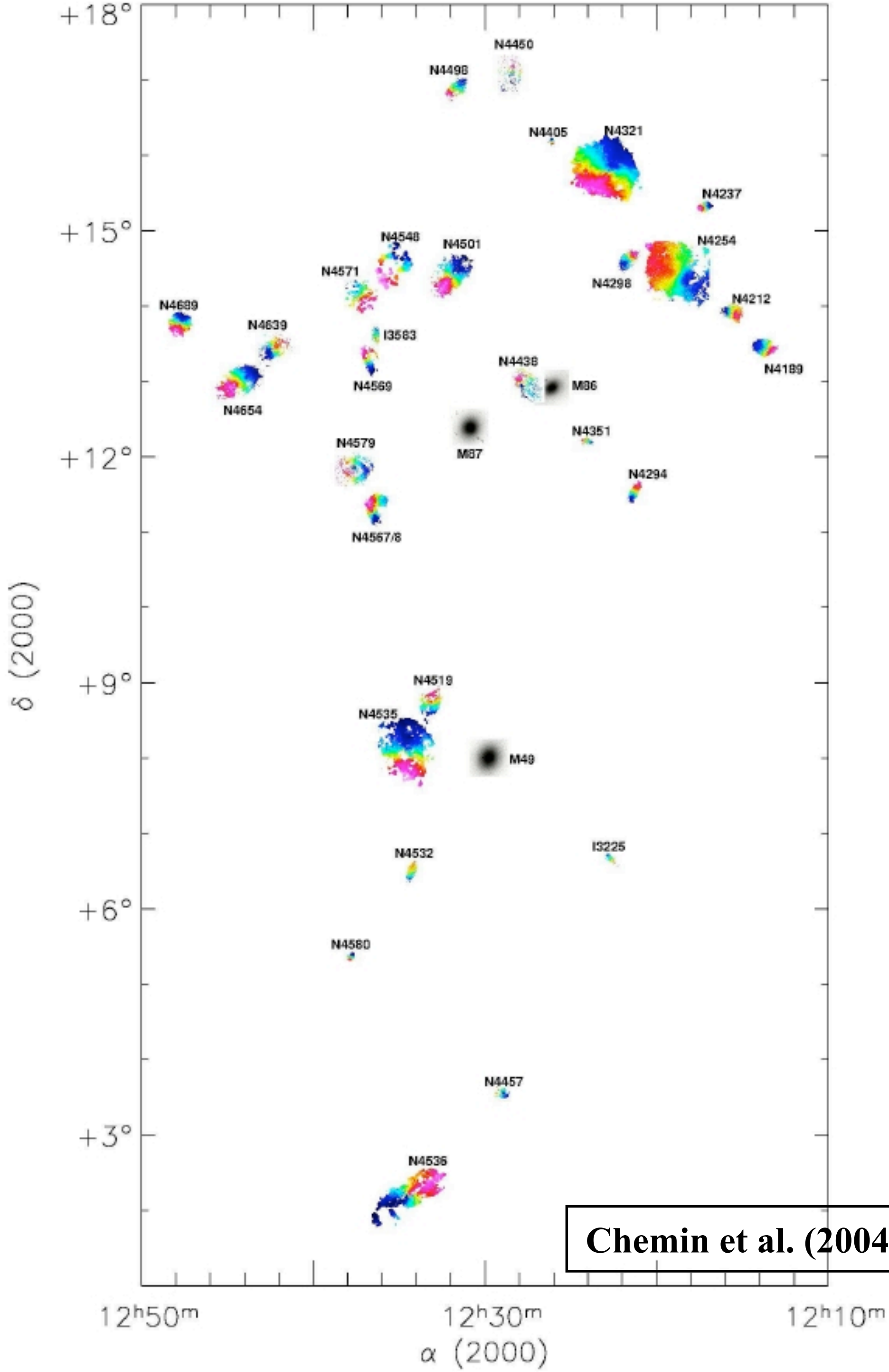


FIG. 23. Integrated neutral hydrogen maps of the brightest spirals in the Virgo Cluster center. Each map has been drawn at the galaxy position indicated by a cross and magnified by a factor of 5 compared with the scale in right ascension and declination. The first contour in each map corresponds approximately to a column density of 10^{20} atoms cm^{-2} (even if it is not the case in the maps published in Figs. 1–22 especially for NGC 4388, 4450, 4569, 4694).

Cayatte et al. (1984)



Chemin et al. (2004)

HI distribution of spirals in the Virgo Cluster:

Gas def. is higher the closer gal.s to cluster center!

Where are the PRS survivors and how do they look like?

We expect to observe galaxies with truncated gaseous disks in the outskirst of clusters with higher probability because of their longer periode at pericentric orbit.

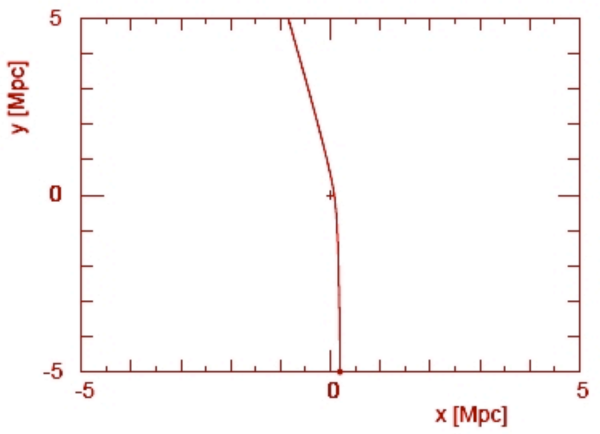


Figure 1. Orbit of the galaxy through the cluster

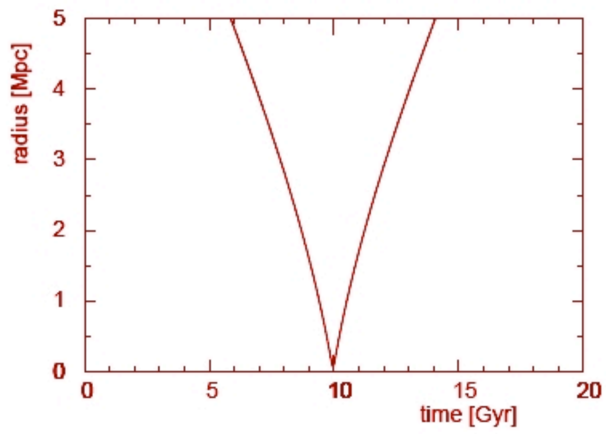
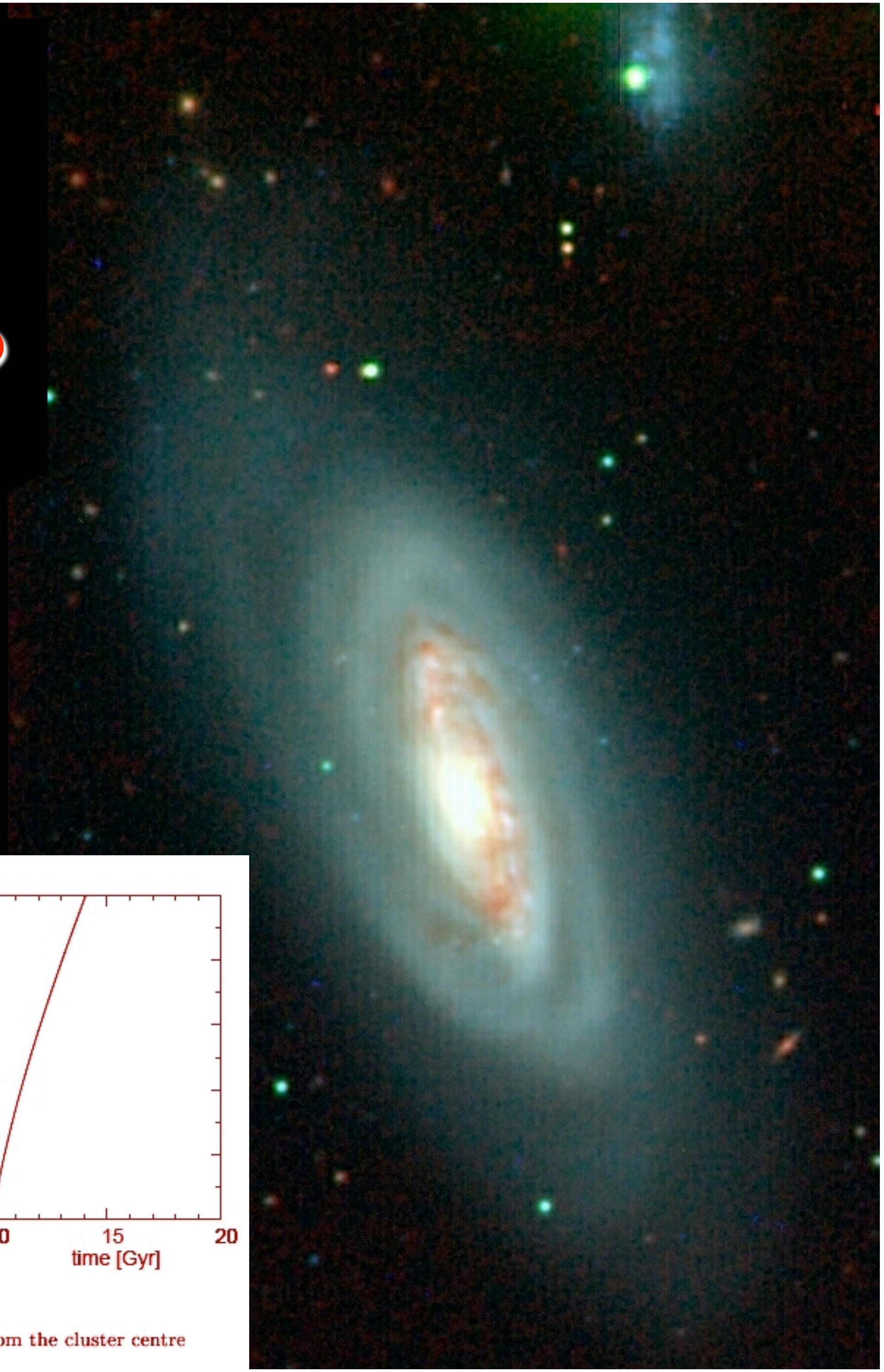
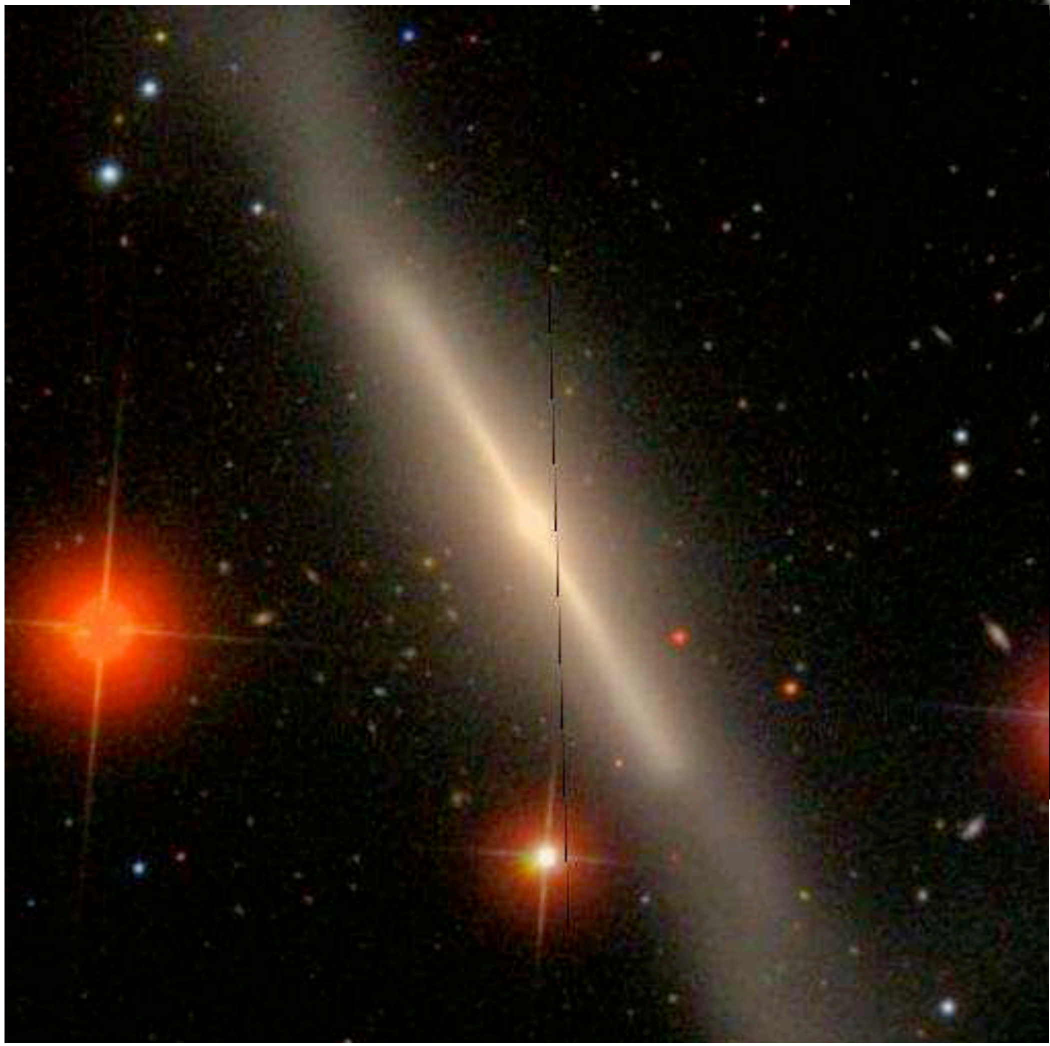


Figure 2. Distance of the galaxy from the cluster centre



Disk-dominated S0's as candidates of RP-stripped galaxies?

Why are those S0s gas free?



VCC1125

VCC2095

Deficiency definitions

Giovanelli & Haynes (1985):

$$def = \langle \log X \rangle_{T,D} - \log X_{obs}$$

X : e.g. HI mass

$\langle \log X \rangle_{T,D}$: value averaged over field galaxies of morph. type T and opt. diameter D

Gavazzi (1987):

$$M_{HI} = 2.36 \cdot 10^5 \cdot D^2 \cdot S_{HI}$$

S_{HI} : HI flux

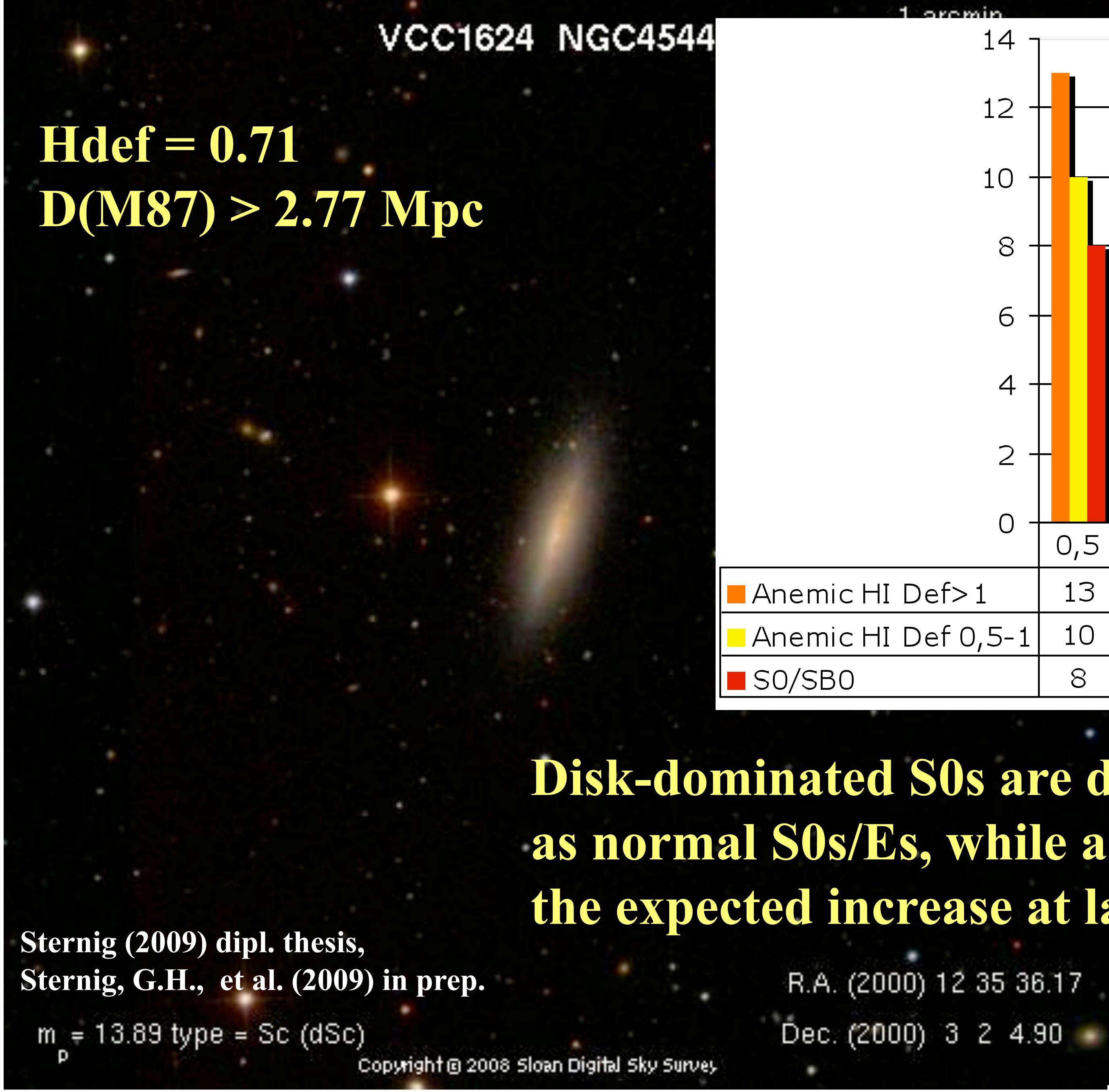
$$Def_{HI} = \langle C_1 + C_2 \log d_l^2 \rangle - \log M_{HI,obs}$$

d_l : linear diameter

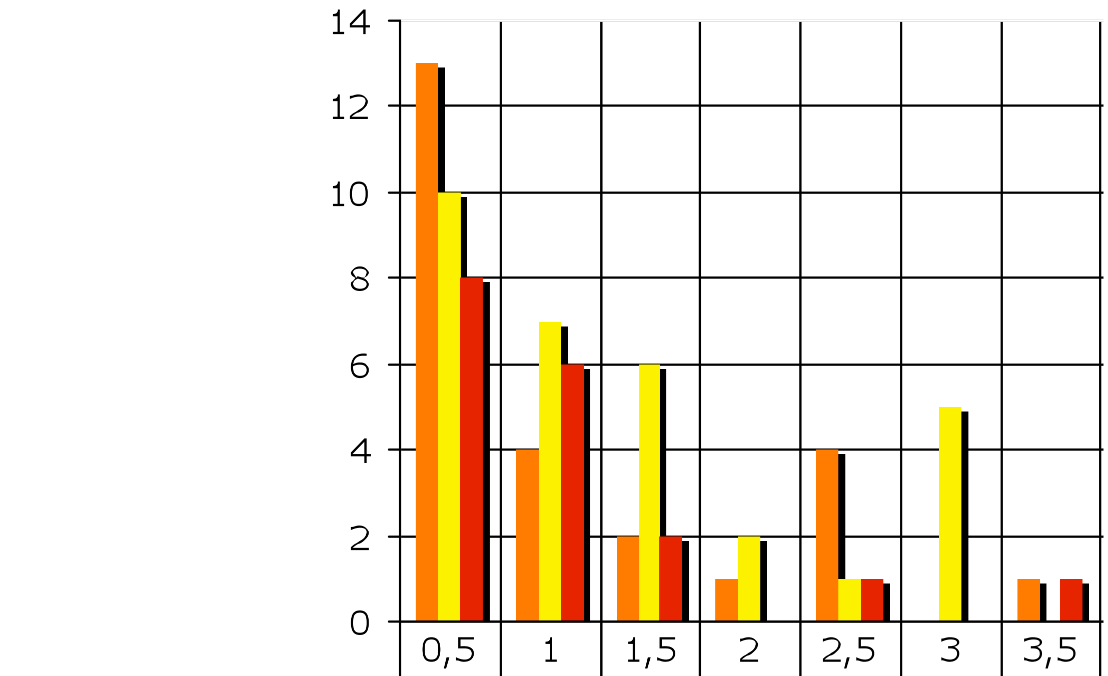
numerical models:

$$def \equiv \log\left(M_{HI}^{in} \big/ M_{HI}^{fin} \right)$$

Are anemic S's the survivors?



Hdef = 0.71
D(M87) > 2.77 Mpc



	0,5	1	1,5	2	2,5	3	3,5
Anemic HI Def>1	13	4	2	1	4	0	1
Anemic HI Def 0,5-1	10	7	6	2	1	5	0
S0/SB0	8	6	2	0	1	0	1

Disk-dominated S0s are distributed in clusters as normal S0s/Es, while anemic galaxies show the expected increase at large r!

Sternig (2009) dipl. thesis,
Sternig, G.H., et al. (2009) in prep.

Solanes et al. (2002)

HI deficiency exists even in the *outskirts* of clusters!

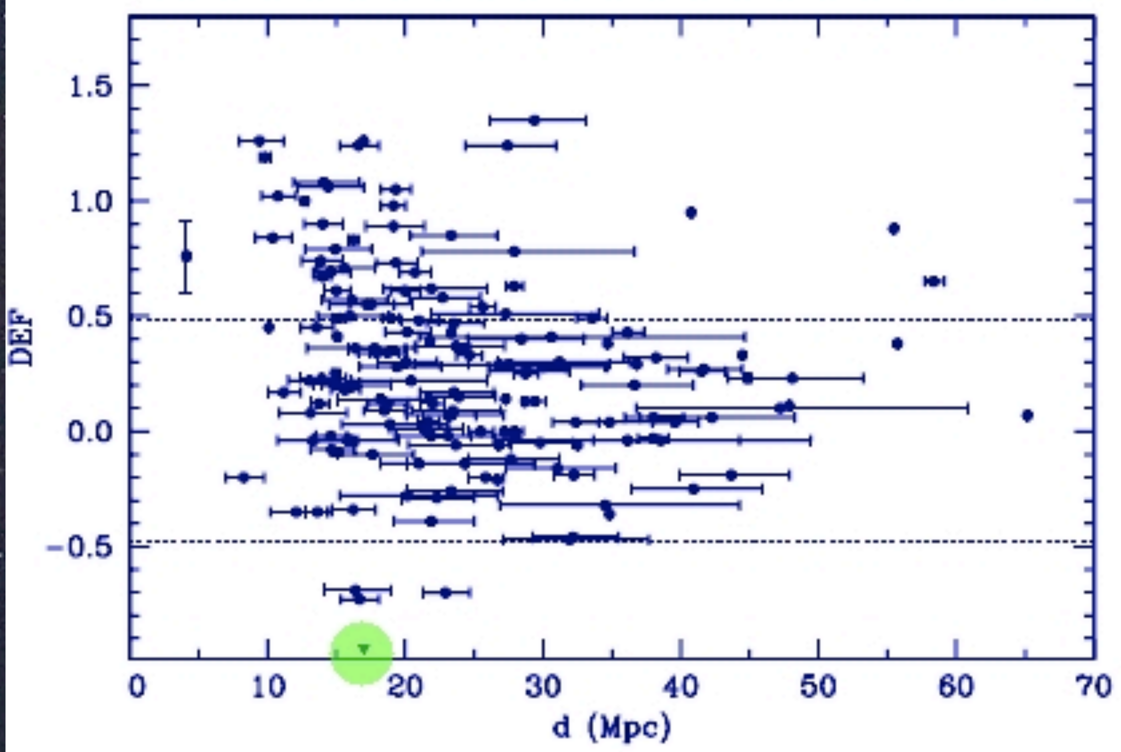


FIG. 2.—Individual values of DEF for the 161 members of the 21 cm sample as a function of the LOS distance. Dotted lines show 2 times the standard deviation shown by the values of this parameter in field galaxies. Horizontal error bars represent the 1 σ uncertainties of the distances quoted in the literature with respect to the calculated mean values. The triangle marks the distance to M87 quoted in LEDA. The vertical error bar in the point closest to us shows an estimate of the typical uncertainty of the individual values of DEF expected from random errors in the determination of the observables a^2_{opt}, F^c_{DEF}, and T that enter in the calculation of this parameter.

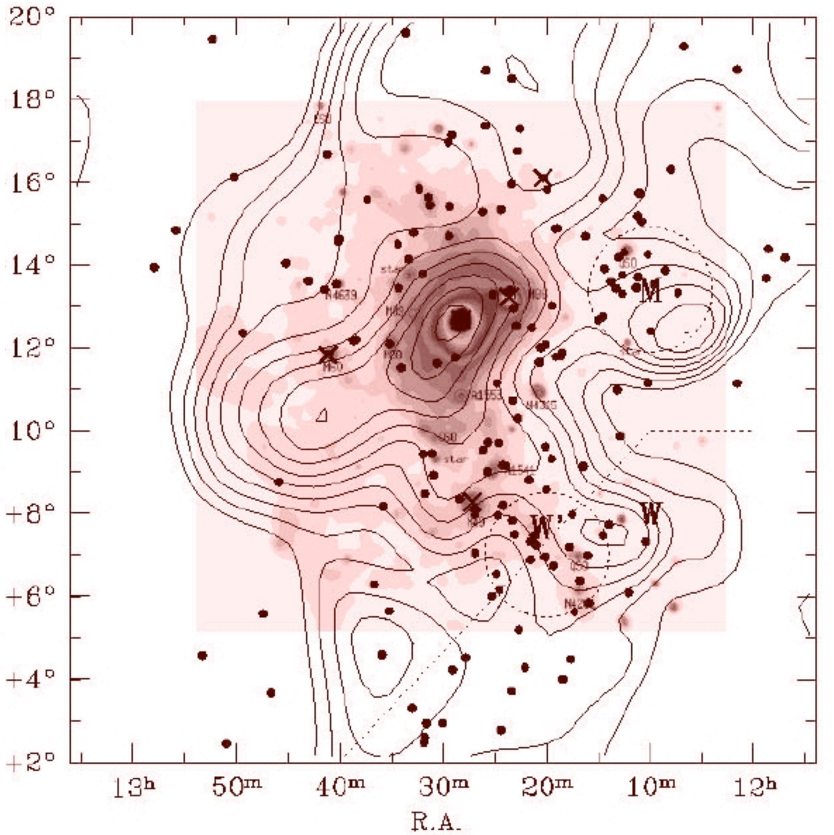


TABLE 2

POPULATIONS OF STAR FORMATION CLASSES FOR CLUSTER AND ISOLATED ENVIRONMENTS

	Isolated Galaxies		Virgo Galaxies	
Star Formation Class	Percent	Number of Galaxies	Percent	Number of Galaxies
Normal	83	20	37	19
Enhanced	0	0	6	3
Anemic	4	1	6	3
Truncated/normal	8	2	37	19
Truncated/compact	4	1	6	3
Truncated/anemic	0	0	8	4
Truncated/enhanced	0	0	2	1
Truncated (all)	12	3	52	27
Anemic (all)	4	1	13	7
Enhanced (all)	0	0	8	4

NOTES.—Percentages and numbers of isolated and Virgo Cluster galaxies in the star formation classes described in § 2. The last three rows sum the total numbers of truncated galaxies and the total numbers of galaxies with anemia or enhancement over at least part of the star-forming disk.

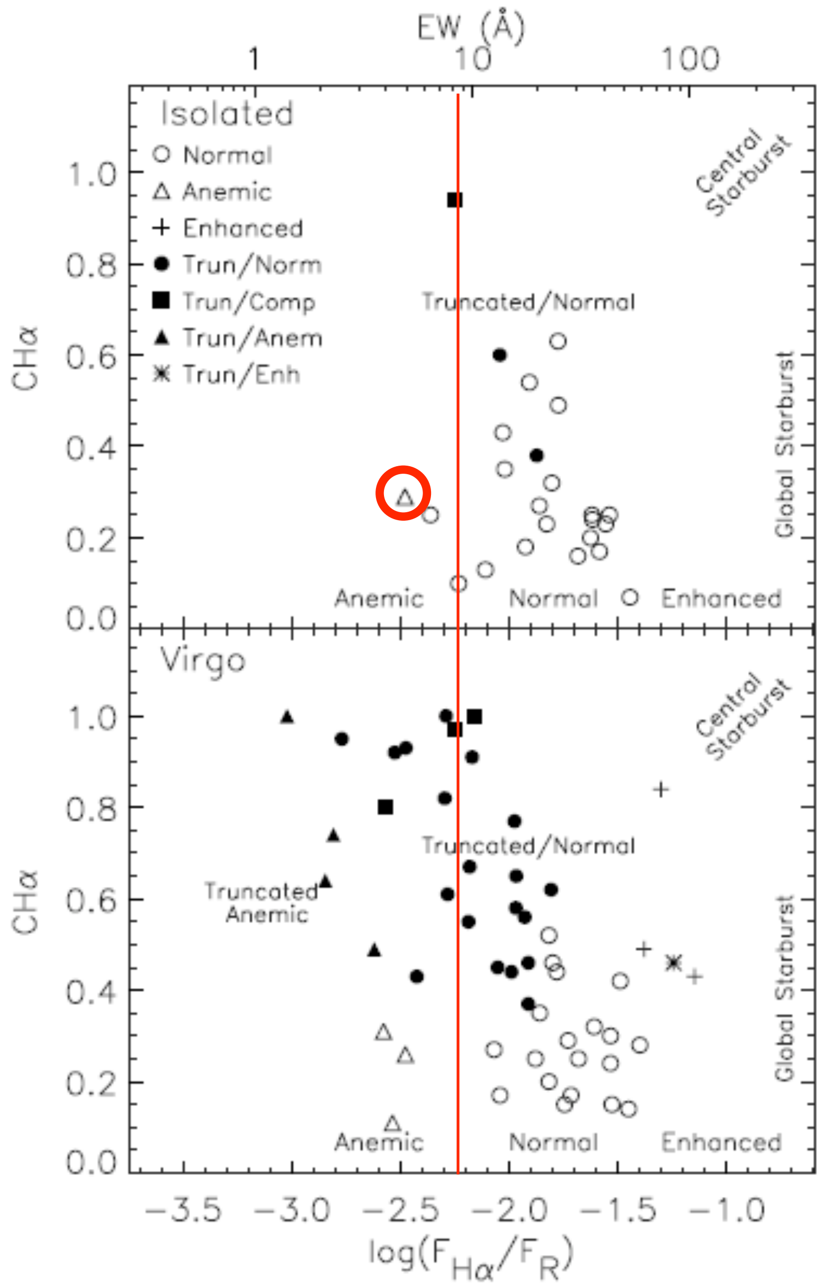


Fig. 1.—Hα concentration vs. the global NMSFR for the Virgo sample. The symbols indicate the Hα morphology class, which is defined by the radial distribution of star formation (§ 2). The upper x-axis provides the equivalent-width scale. The Hα morphology classes can be well discriminated using these two parameters.

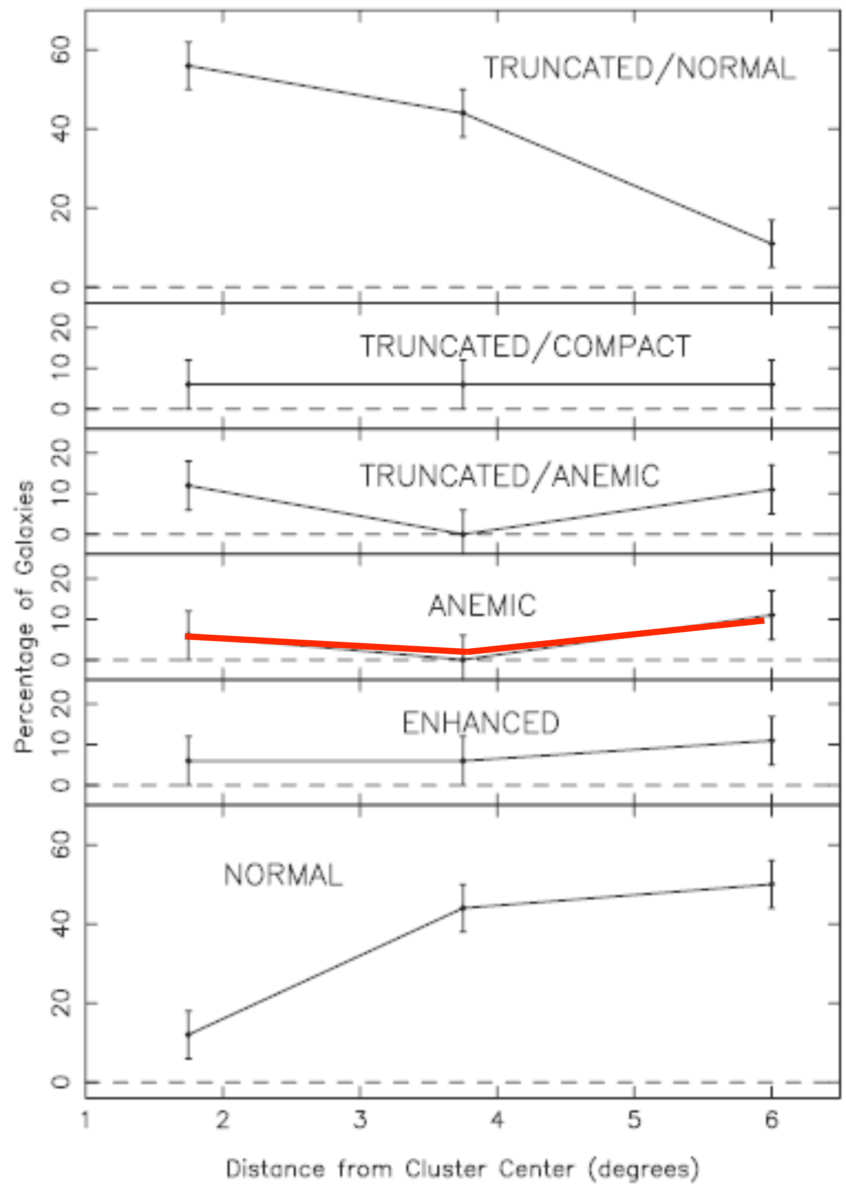


Fig. 13.—Cluster radial distributions of each Hα class, plotted as percentages of all the galaxies in that radial bin. Bins are ≤3°, 3°–4°.5, and ≥4°.5. Error bars correspond to 1 galaxy, comparable to the uncertainty in our Hα classification. There is a clear radial dependence for the normal and truncated/normal classes, with fewer normal and more truncated/normal galaxies closer to the cluster center. Other Hα classes have a flatter distribution (but contain fewer sample galaxies).

Questions:

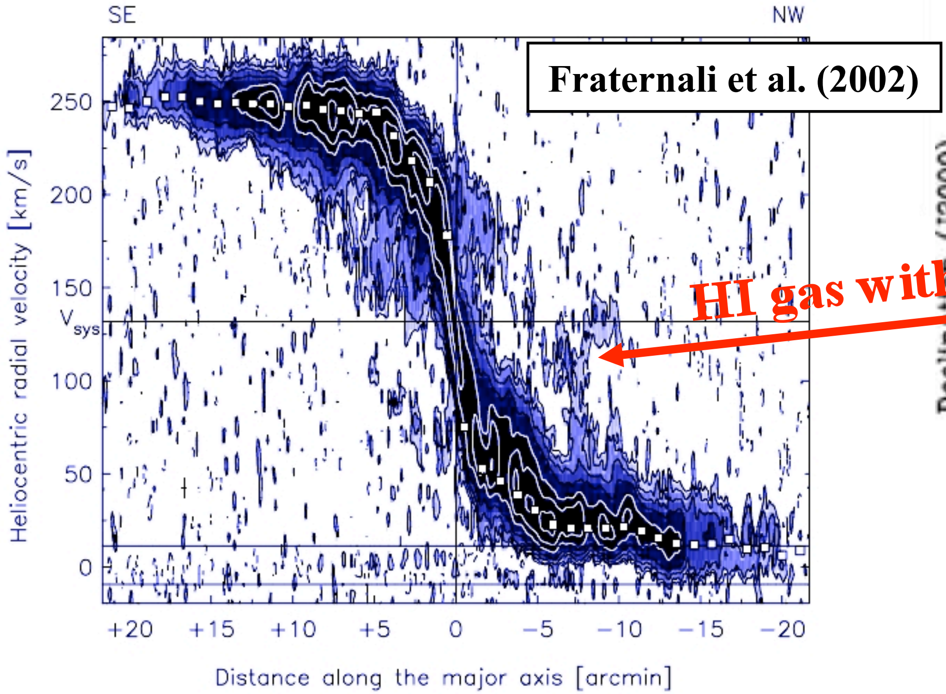
- HI deficient/anemic galaxies populate the *outskirts* of clusters:

  Who would attribute the HI def. at separation of >10 Mpc to cluster effects?

- Star formation “strangulation“ of anemic galaxies.
  SF correlates with the HI reservoir?! Infall!

  How does infall determine the SF rate?

Gas Infall everywhere? The case of NGC 2403



HI gas with different velocity

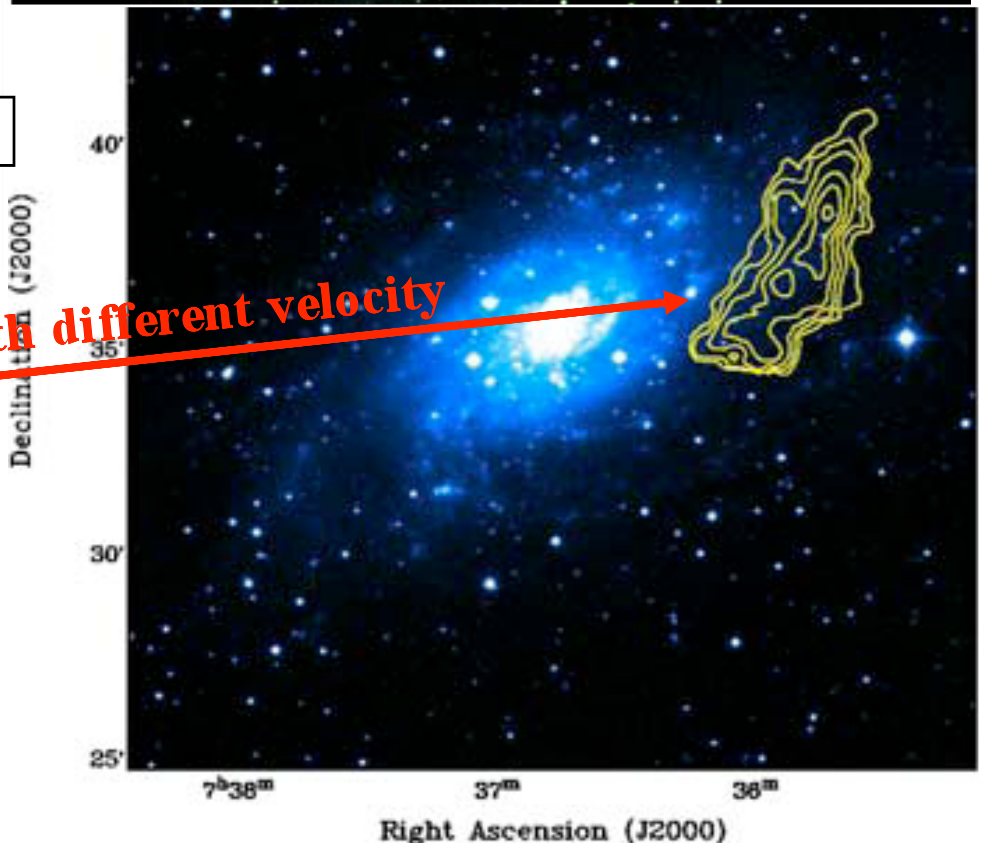
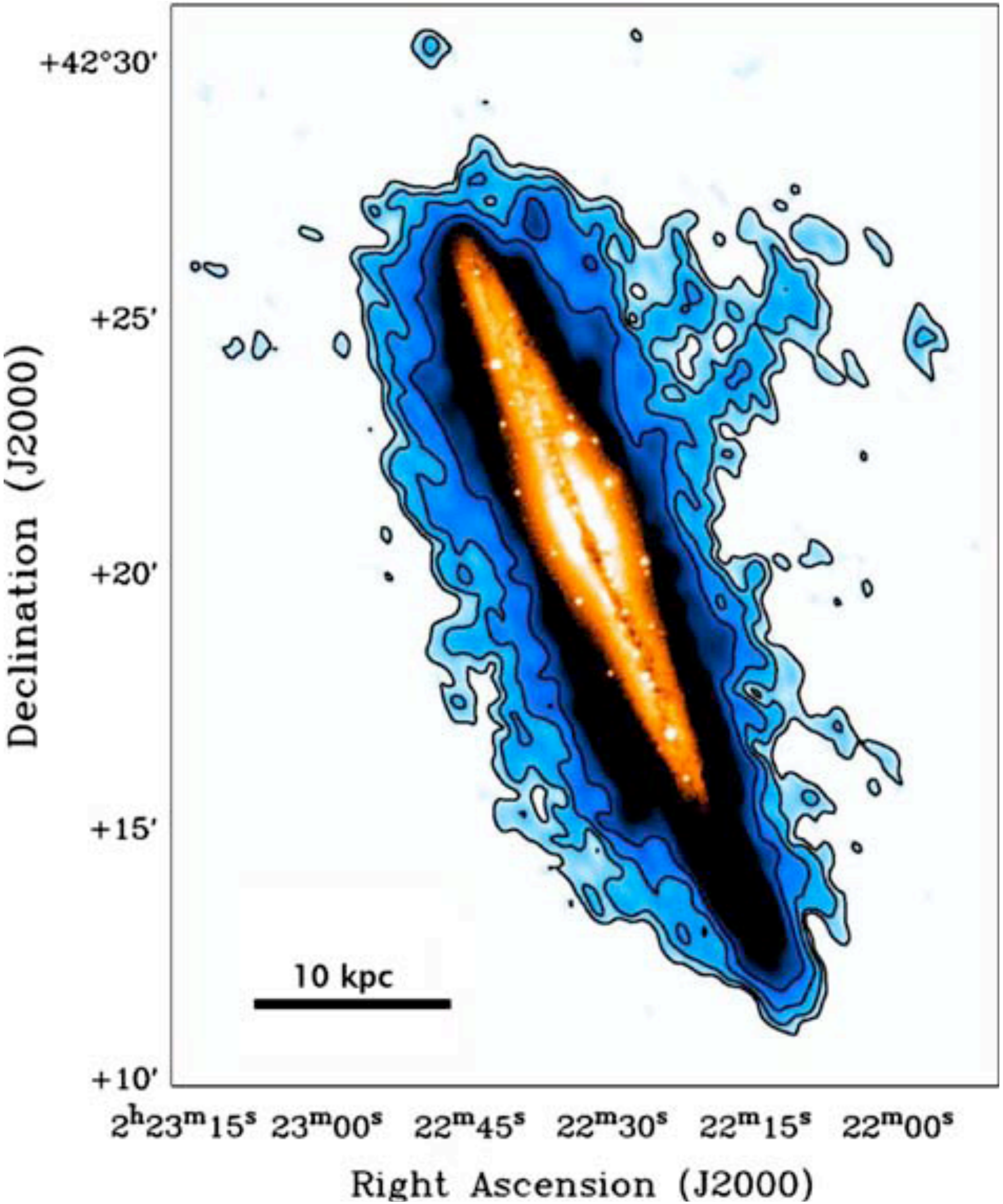


Fig. 7.—Position-velocity diagram (slice ~1′ wide) along the major axis (P.A. = 124°5) of NGC 2403. The spatial resolution is 15″, and the velocity resolution 10.3 km s^{-1}. The central horizontal line shows the systemic velocity; the other two horizontal lines mark the channels contaminated by H I emission from the Milky Way. Contours are −0.26, 0.26, 0.5, 1, 2, 5, 10, 20 mJy beam^{-1}. The rms noise is 0.17 mJy beam^{-1}. White squares mark the rotation curves for the two sides of the galaxy.

NGC 891

huge HI envelops
- exist;
- raise problems to ΛCDM!



Oosterloo et al. (2007)

Gas Infall to a multi-phase ISM with SF

Analytical approach as in Koeppen, Theis, G.H. (1995, 1998)

Limitation: not closed box, but no ISM disk stratification

hot gas	$\dot{g} = \frac{\eta}{\tau} s + E_c - K_g$
warm clouds	$\dot{c} = -\Psi - E_c + K_g + A_c$
stars	$\dot{s} = \xi \Psi - \frac{1}{\tau} s$
remnants	$\dot{r} = (1 - \xi) \Psi + \frac{(1-\eta)}{\tau} s$
gas energy	$\dot{e}_g = h_{SN} s - g^2 \Lambda_0(T_g) + E_c b \tilde{T}_c - K_g b T_g$
cloud energy	$\dot{e}_c = h_\gamma s - c^2 \Lambda_0(T_c) - E_c b T_c + K_g b \tilde{T}_g - \Psi b T_c + b T_{A_c} A_c + \frac{1}{2} v^2 A_c$

Star-formation rate $\Psi(c, T_c) = C_n c^n \exp\{-T_c / 10^3 K\}$

ξ : mass star fraction
τ : SF timescale
η : mass return fraction
Ec : evaporation
Kg : condensation
Ti : temprature

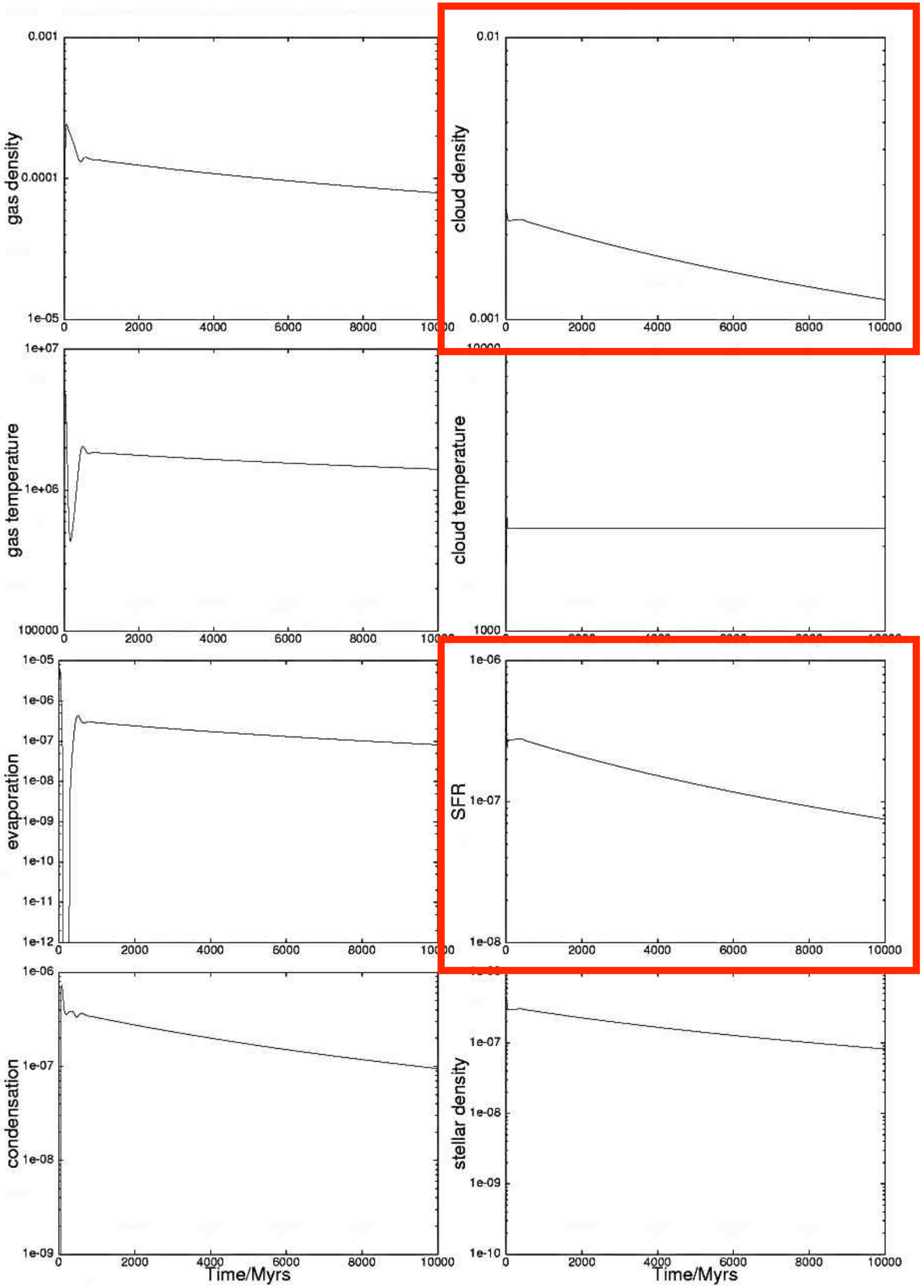
Pflamm dipl. thesis
Pflamm, G.H., Köppen (2009) in subm.

Self-regulated evolution without gas infall

solar vicinity;
units in Myrs, $M_\odot$, pc

star formation self-regulation: due to collisionally excited line cooling ~ n^2

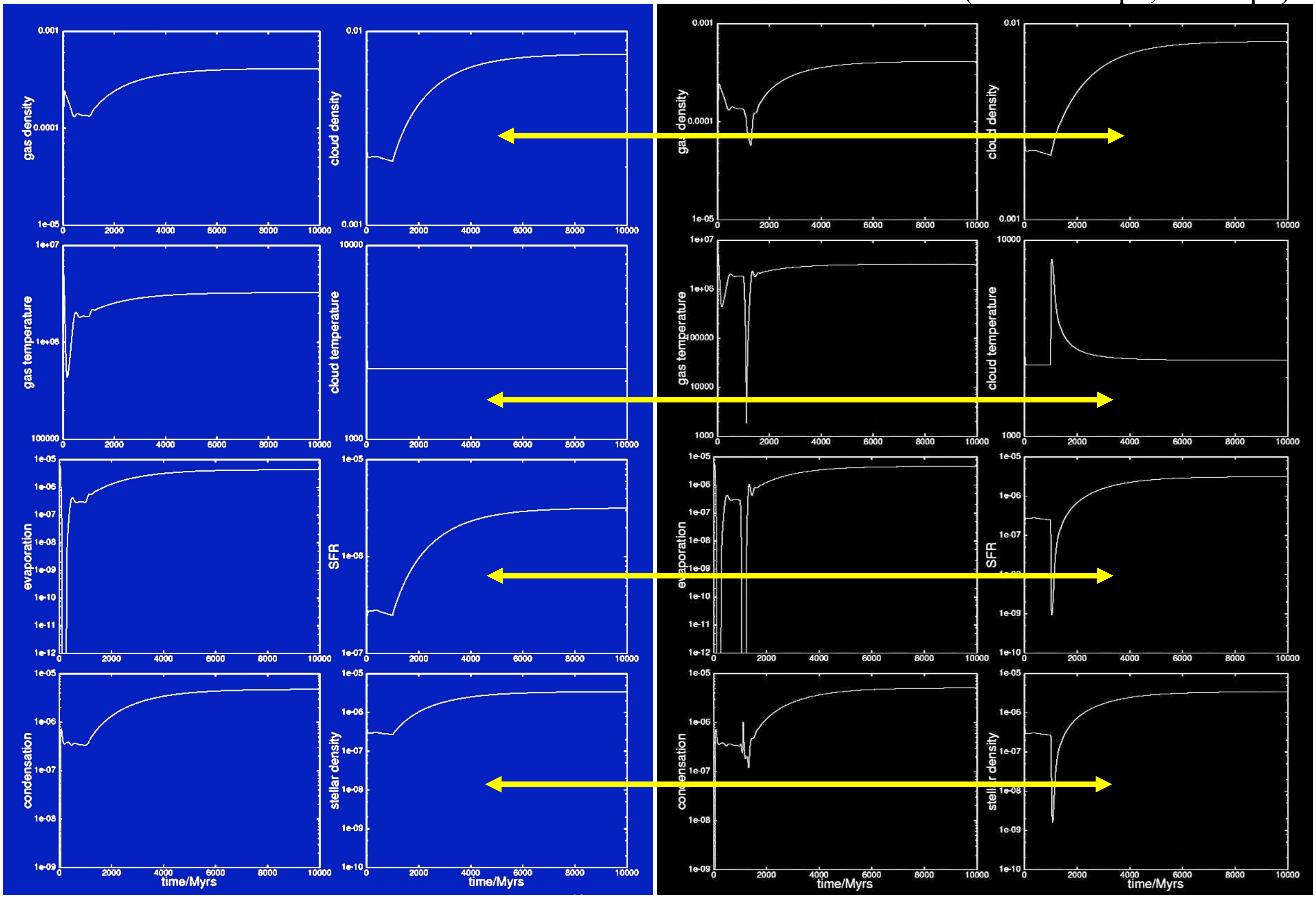
but: SFR low



continuous gas infall

$A_c = 2.83\ 10^{-6}\ M_\odot/(pc^3\ Myr) = 2\ M_\odot/yr$

10 km/s   100km/s   (for R=15 kpc, H=1 kpc)



continuous gas infall

- different accretion rates A_c

  at 10 km/s (upper curve to lower):

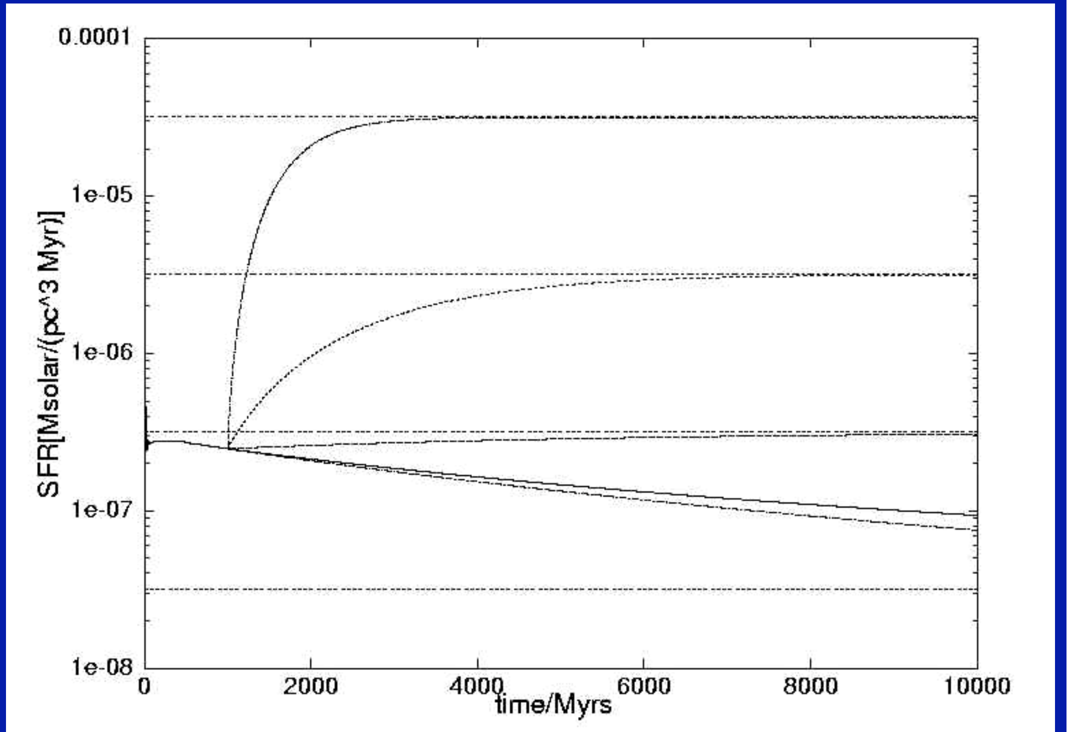
  $2.83 \cdot 10^{-5}$ $M_\odot/(pc^3$ Myr)

  $2.83 \cdot 10^{-6}$ $M_\odot/(pc^3$ Myr)

  $2.83 \cdot 10^{-7}$ $M_\odot/(pc^3$ Myr)

  $2.83 \cdot 10^{-8}$ $M_\odot/(pc^3$ Myr)

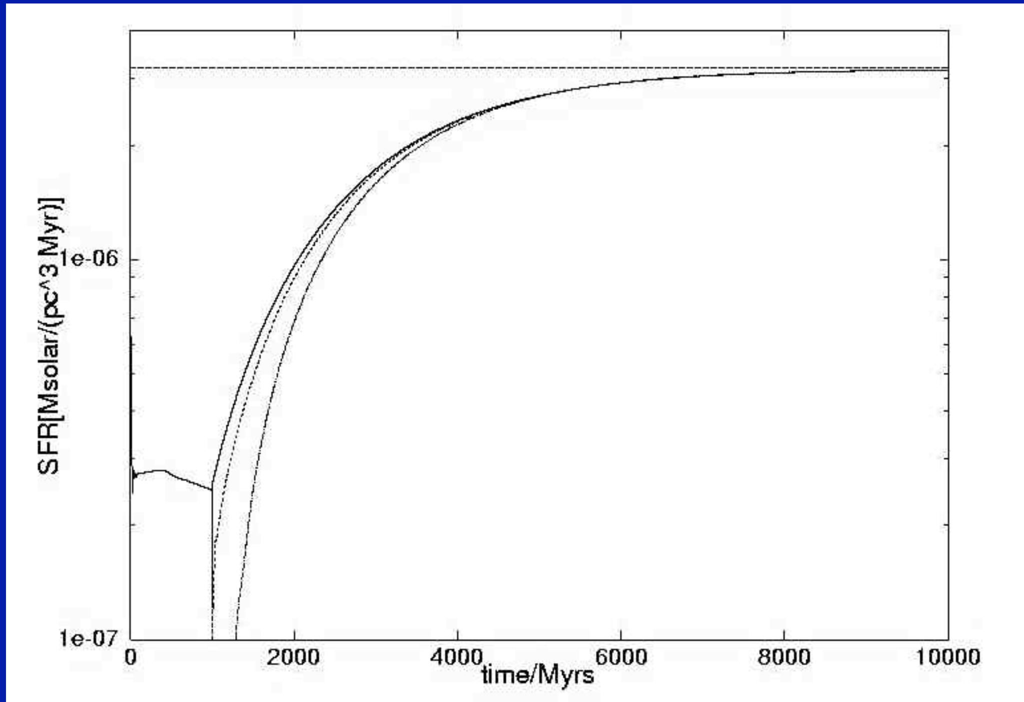
  Self-regulation



- velocity studies

  at $2.83 \cdot 10^{-6}$ $M_\odot/(pc^3$ Myr):

  10 km/s, 50 km/s, 100 km/s



- issues:

  SFR increases and approaches a constant value

$$r(t) = r_0 + \int_0^t \left[(1-\xi)\cdot\Psi(x) + \frac{1-\eta}{\tau} s(x) \right] dx$$

starting from:

$$\dot{g} = \frac{\eta}{\tau} s + E_c - K_g$$

$$\dot{c} = -\Psi - E_c + K_g + A_c$$

$$\dot{s} = \xi\,\Psi - \frac{1}{\tau} s$$

$$\dot{r} = (1-\xi)\,\Psi + \frac{(1-\eta)}{\tau} s$$

$r(t)$ is monotonicly increasing!

assumption : $g = const. \quad c = const. \quad s = const.$

$$\dot{s} = 0 = \xi\cdot\Psi - \frac{1}{\tau} s \quad \Rightarrow \quad s = \xi\cdot\tau\cdot\Psi$$

with $\alpha := K\cdot g - E\cdot c$

$$\dot{g} = 0 = E\cdot c - K\cdot g + \frac{\eta}{\tau} s \qquad \Rightarrow \quad \tau\cdot\alpha = \eta\cdot s \Rightarrow \alpha = \frac{\eta}{\tau} s$$

$\Rightarrow$ condensation > evaporation, i.e. overcompensation of c reduction by SF

$$\dot{c} = 0 = -\Psi + K\cdot g - E\cdot c + A_c \quad \Rightarrow \Psi = \alpha + A_c = \frac{\eta}{\tau} s + A_c$$

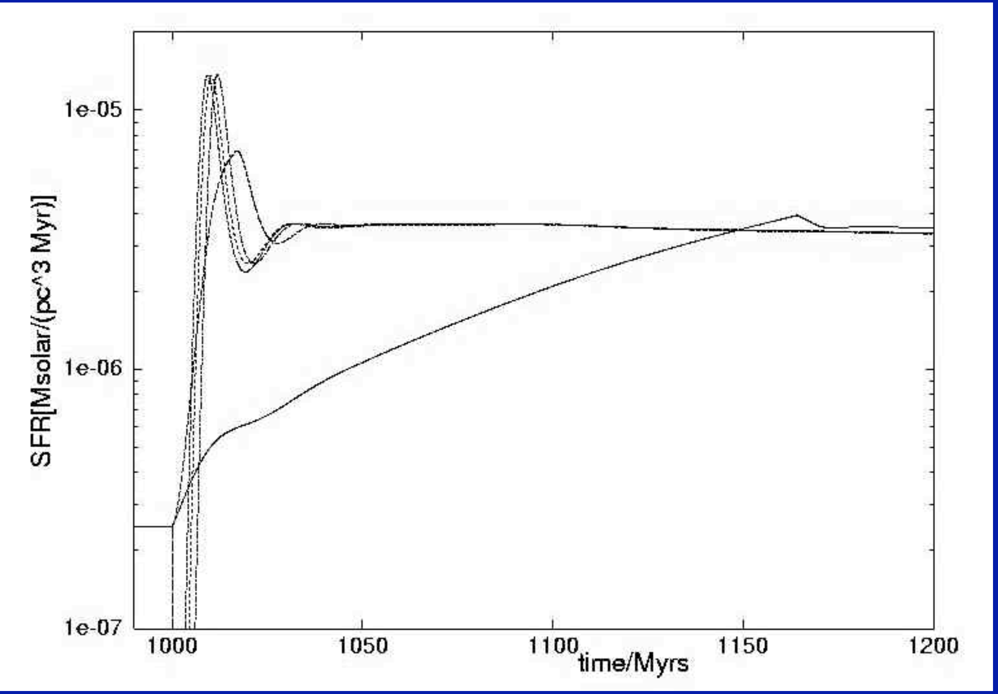
$$\Psi = \alpha + A_c = \eta\cdot\xi\cdot\Psi + A_c \quad \Rightarrow \boxed{\Psi = \frac{1}{(1-\eta\cdot\xi)} A_c}$$

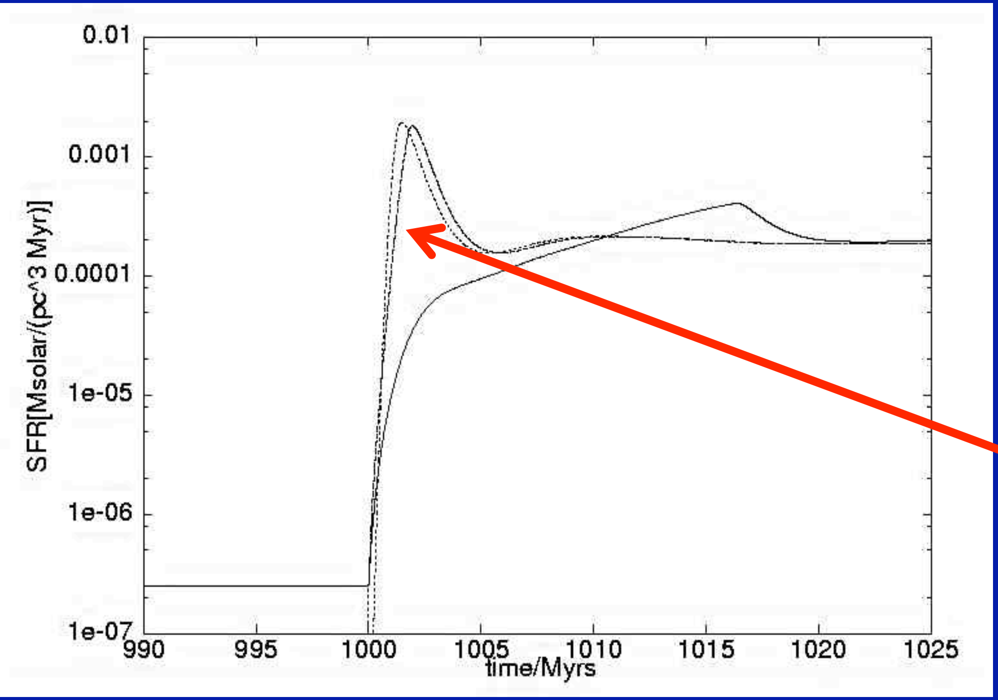
$$0 < (1-\eta\cdot\xi) < 1 \;, \quad \eta\cdot\xi \approx 0.11$$

$$\Rightarrow \quad \Psi \approx 1.12 A_c$$

Ψ : SF rate
ξ : mass star fraction ≈ 0.12
τ : SF timescale = 4-8 Gyrs
η : mass return fraction ≈ 0.9

Star formation





Infall of a cloud with Jeans mass of

- $10^5\ M_\odot$
(curves from left to right):
400, 100, 50,10, 1 km/s

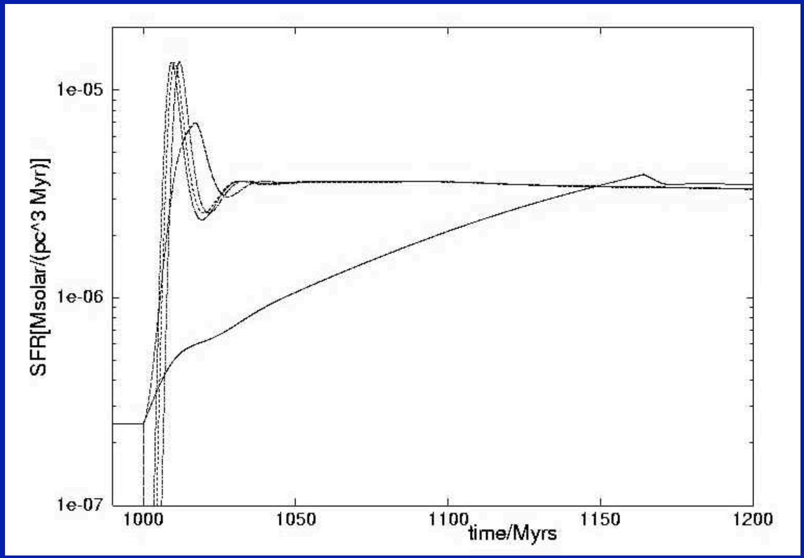
- $10^4\ M_\odot$
(curves from left to right):
100,10, 1 km/s

Starbursts occur

Pflamm, G.H., Köppen (2009) in prep.

Pflamm, G.H., Köppen
(2004) in prep.

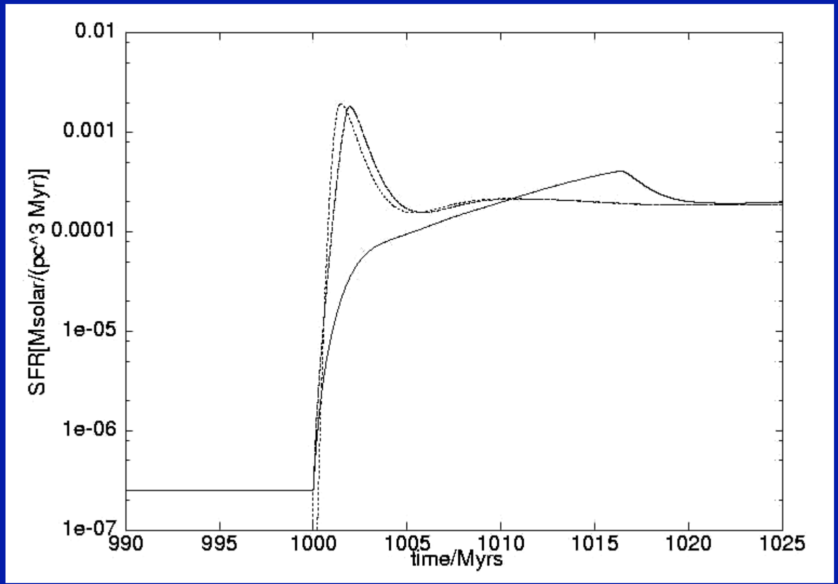
Analytical Approach to Cloud infall

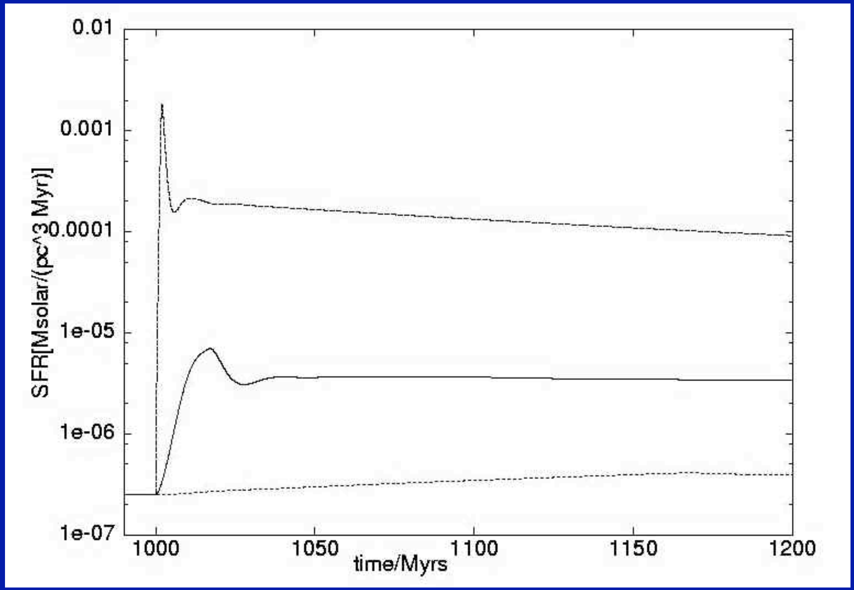


- cloud mass 10^5 $M_\odot$
  (curves from left to right): 400, 100, 50,10, 1 km/s
  ←

- cloud mass 10^4 $M_\odot$
  (curves from left to right): 100,10, 1 km/s

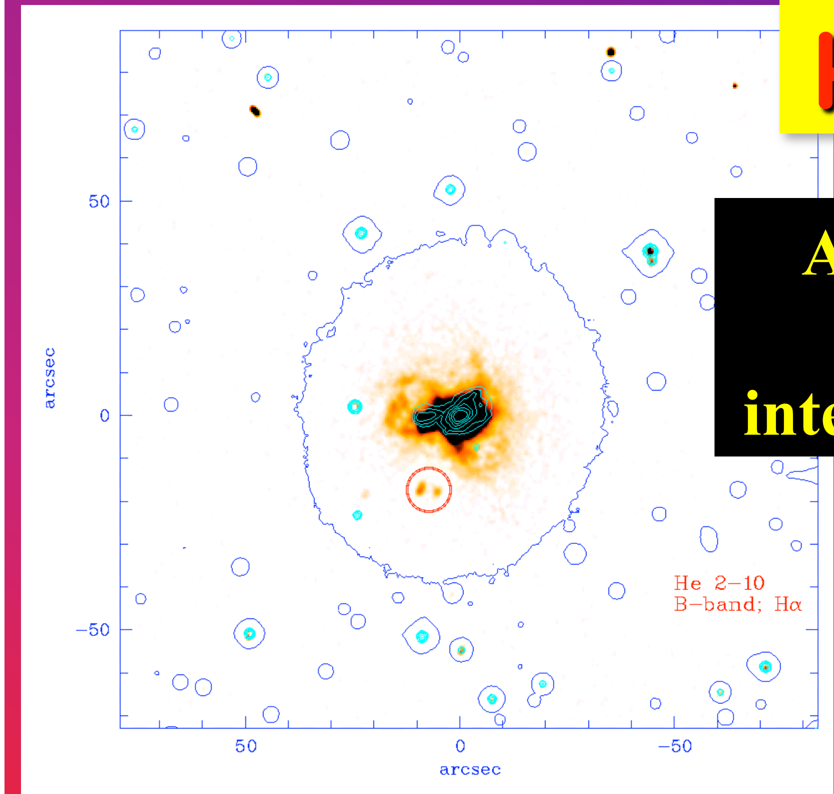
- mass studies (curves from upper down):
  10^4 $M_\odot$, 10^5 $M_\odot$, 10^6 $M_\odot$ ↓





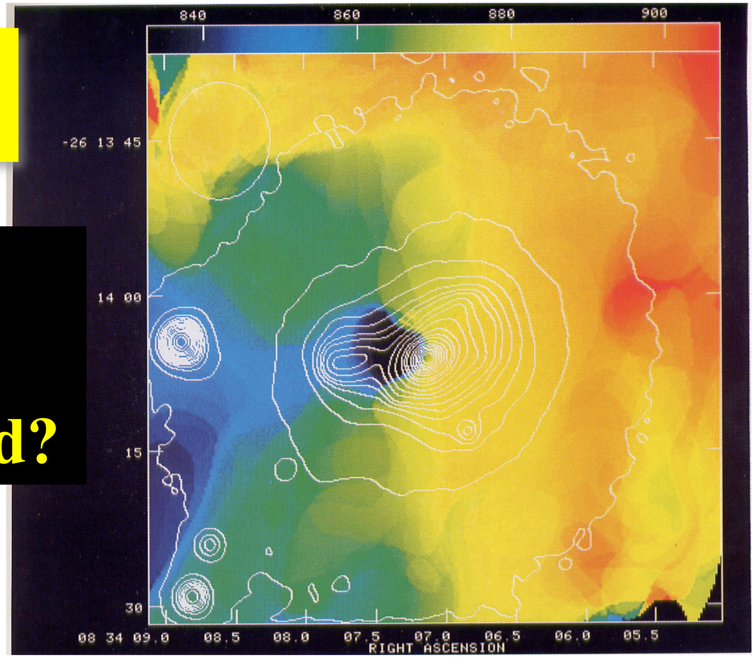
He 2-10

A dIrr colliding with an intergalactic cloud?



Papaderos et al. (1998)

←



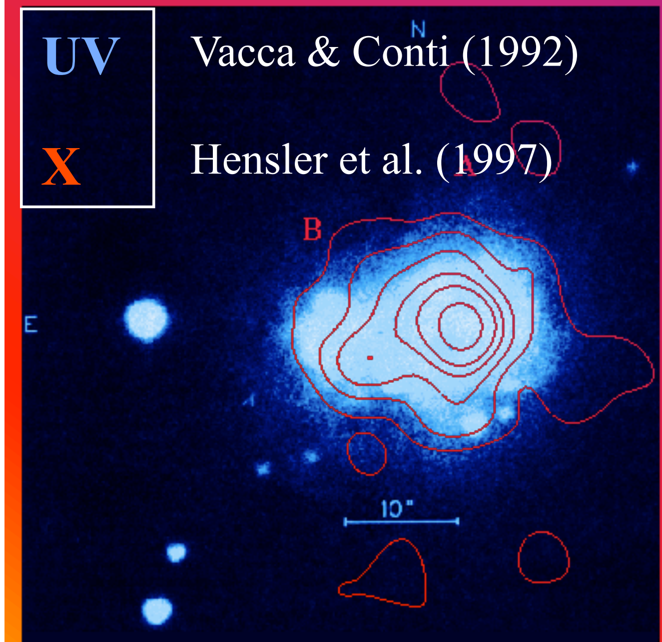
Kobulnicky et al. (1995)

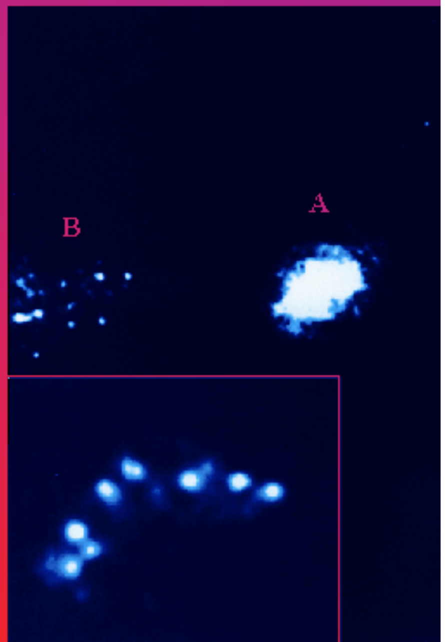
UV

X

Vacca & Conti (1992)

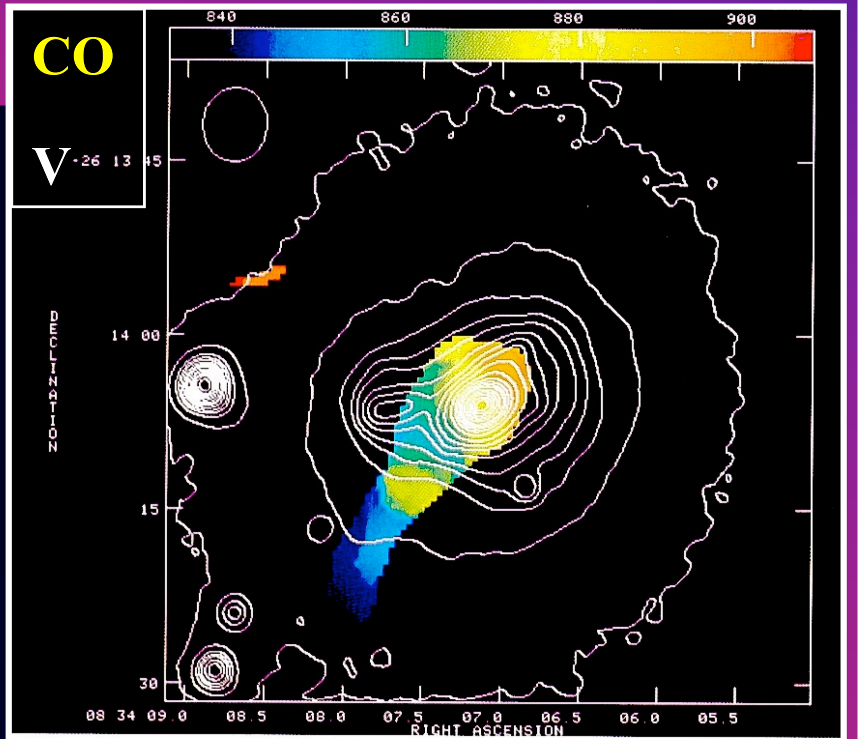
Hensler et al. (1997)





CO

V

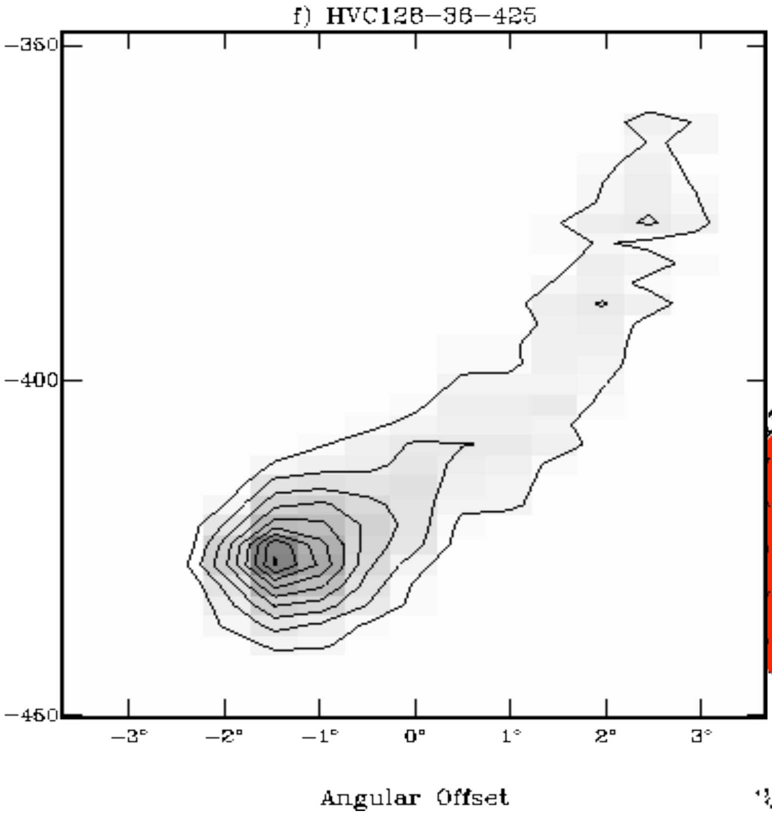


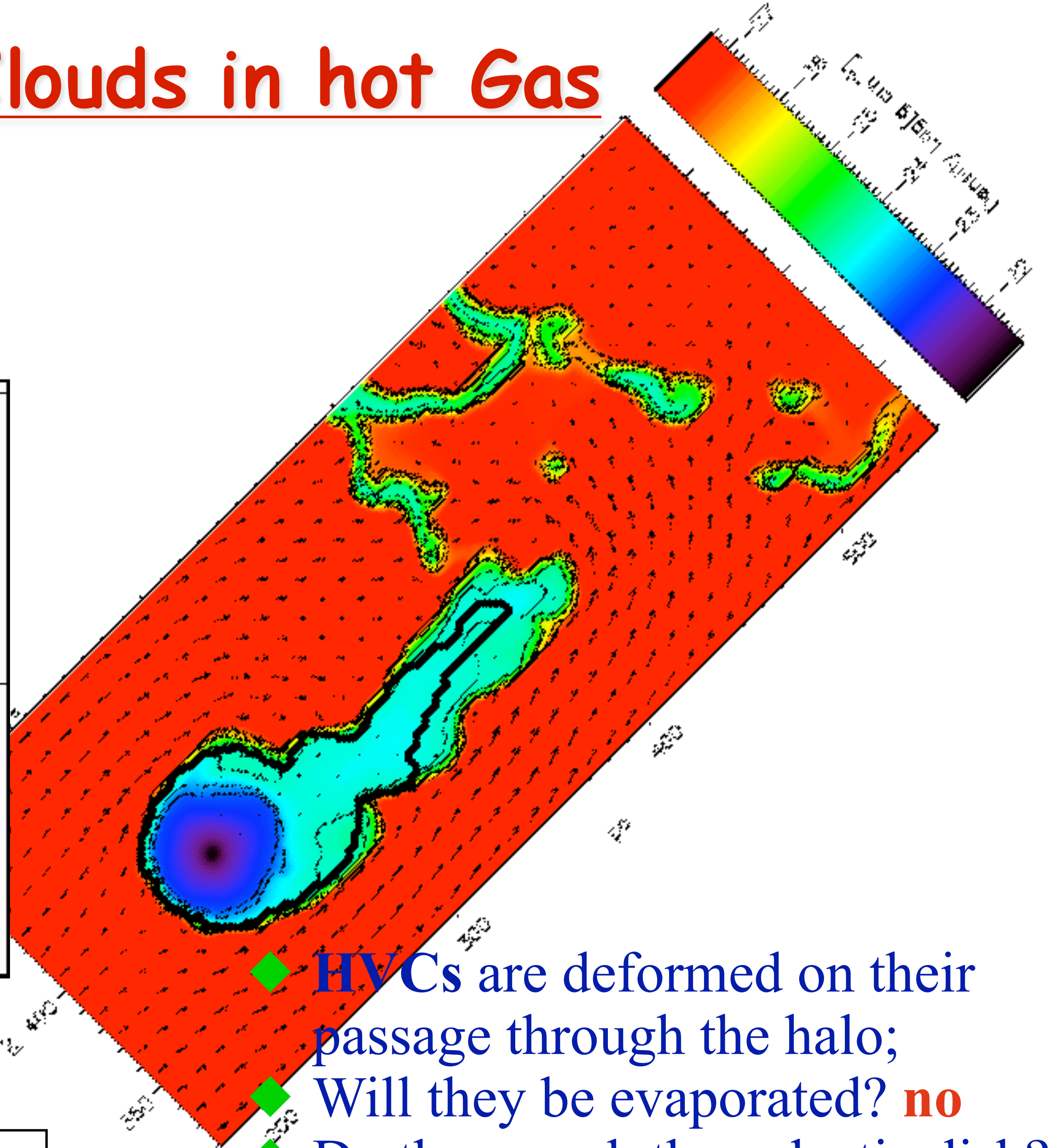
Conclusions:

If *Isolations* means ”void of neighbours = empty field“, distant galaxies with “cluster history” are misinterpreted!

Isolation is mismatched from optical observations: Environments of gas envelopes and satellite galaxies effect galaxy evolution

Survival of HI Clouds in hot Gas



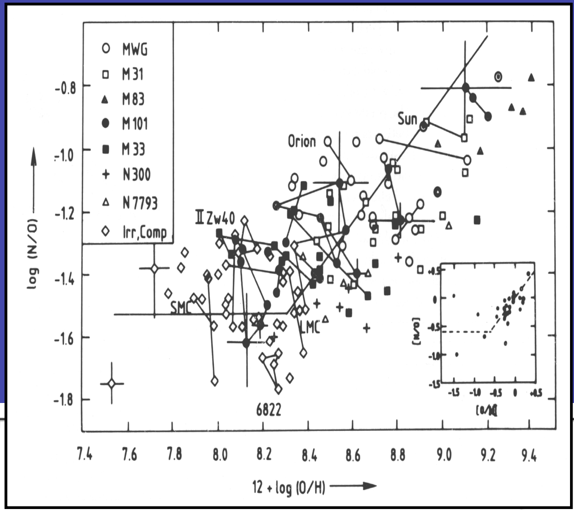


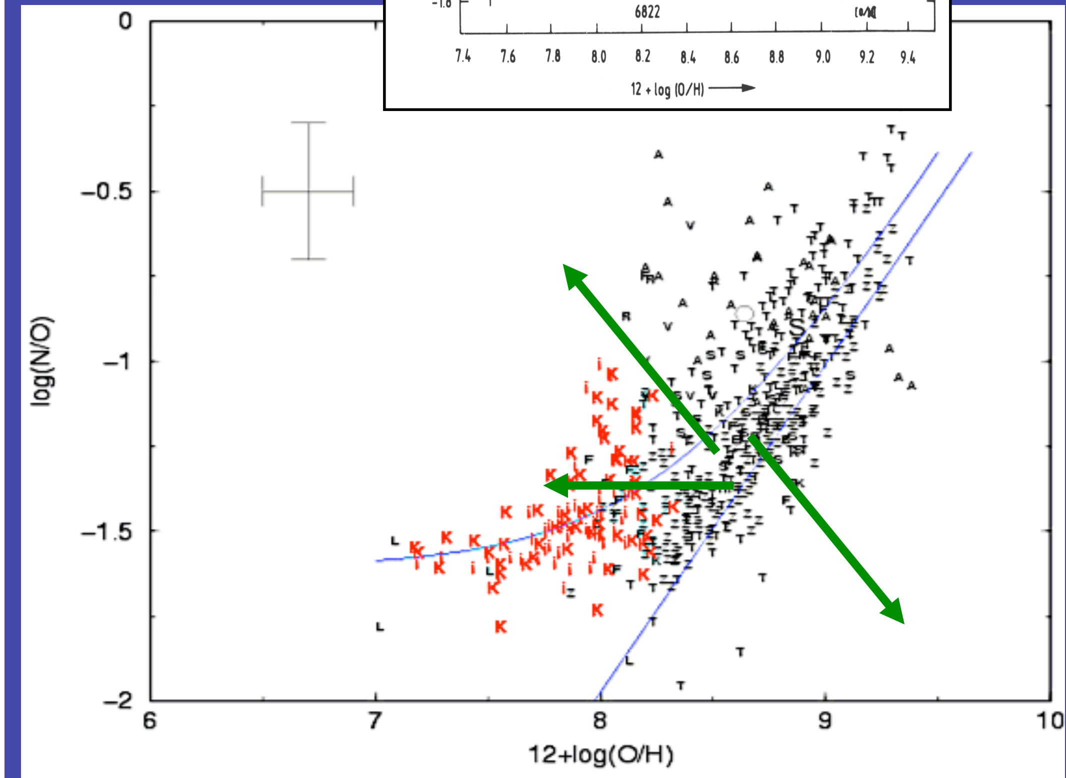
- HVCs are deformed on their passage through the halo;
- Will they be evaporated? **no**
- Do they reach the galactic disk?
- Do they grow?

left panel: HI head-tail HVC (Brüns et al., 2000)
right panel: 2d Model with Heat Conduction
(Vieser & G.H., 2007)

the N/O problem of dIrrs/BCDs

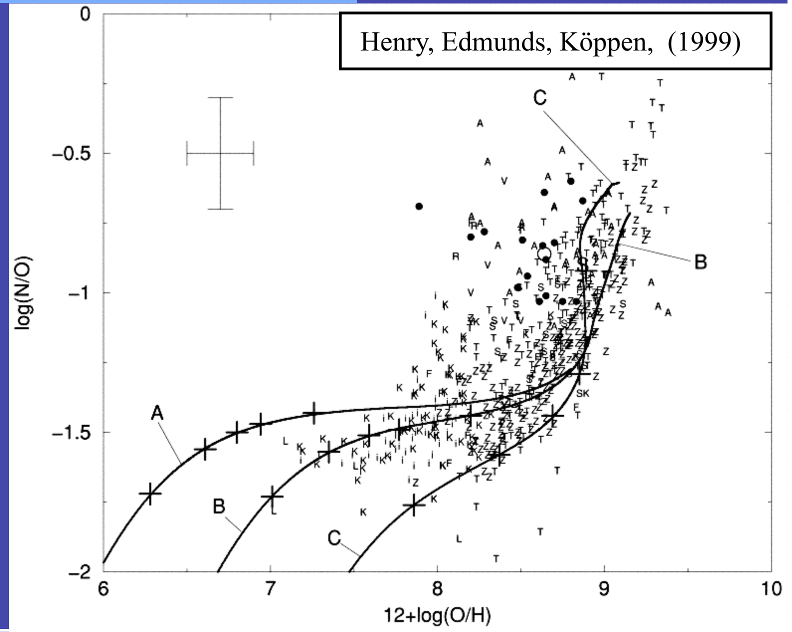
Pagel, B.N.P. (1985)
ESO Workshop
"… *C,N,O Elements*"





Henry, R.B.C. & Worthey, G. (1999)

Henry, Edmunds, Köppen, (1999)



early evolution only: track through DLA regime

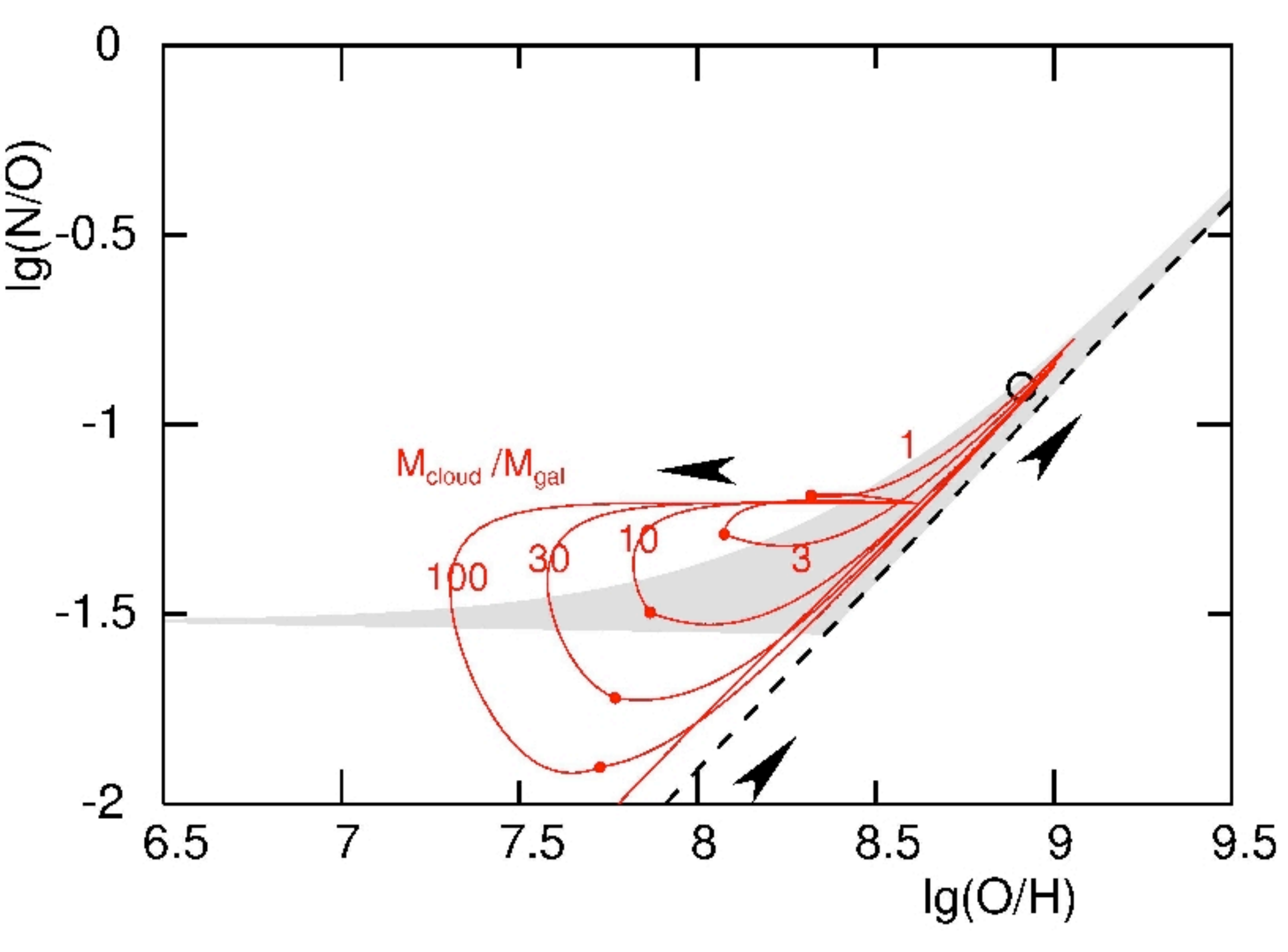
at later epochs: models settle at secondary N-line,

But: **no return to dIrr regime !**

solutions:

- **dIrrs are very young like DLAs: no!**
- **O loss by galactic winds: O/H-N/O ↖**
- **Starbursts produce fresh O: O/H-N/O ↘**
- **Infall of pristine gas: O/H-N/O ←**

10.3. Gas Infall and its Effect on Abundances

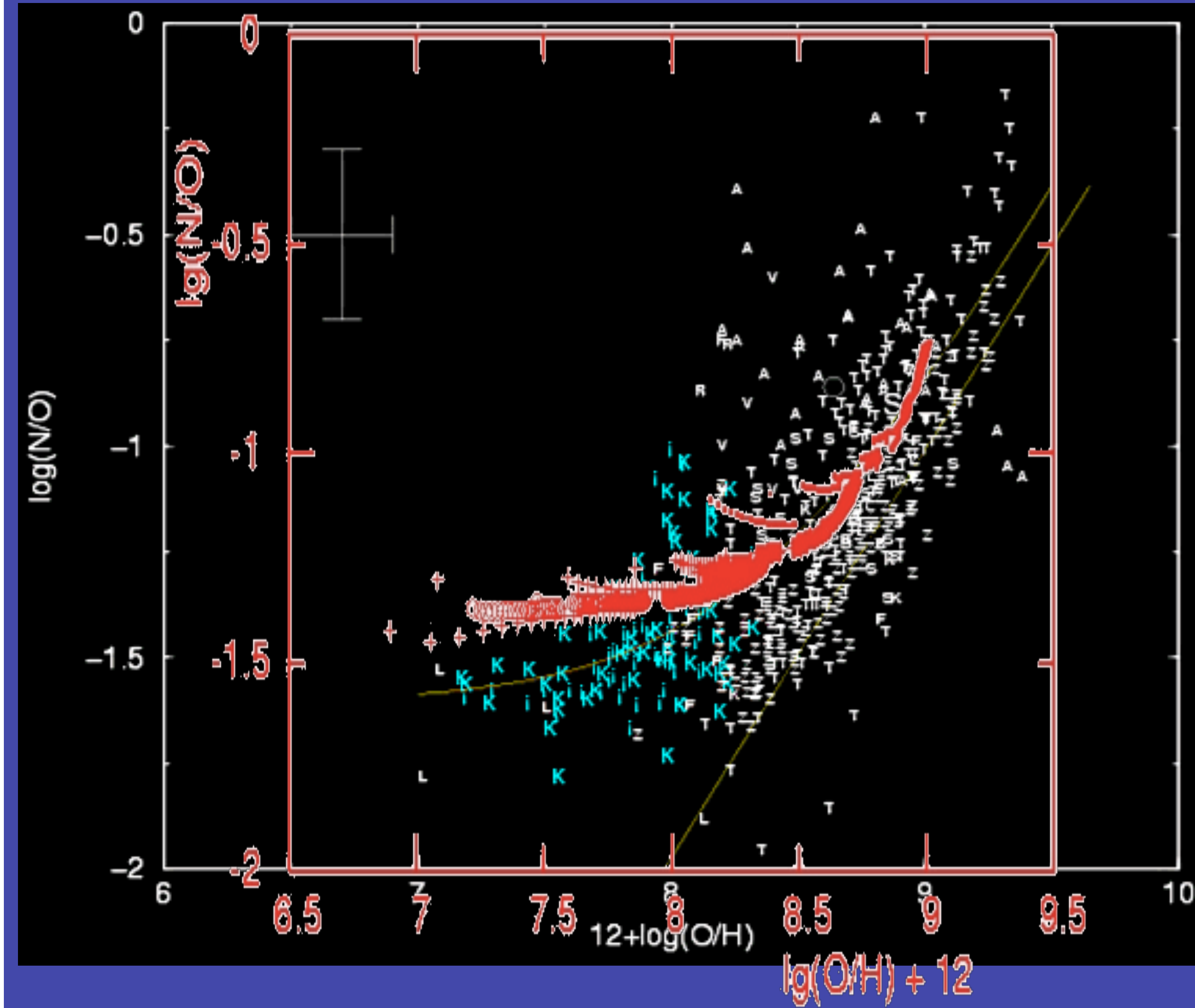


Köppen, G.H. (2005) A&A, 434

Model assumptions:

- Yields same as in Henry, Edmunds, Köppen (2000): van der Hoek & Groenewegen (1997), Maeder (1992)
- Galaxy models evolve for 13 Gyrs with different y_{eff} of 0.1 ... 1

  ⇒ different locations in (N/O)-(O/H) diagram
- Infall of clouds with primordial abund. and masses of $10^6 ... 10^8$ $M_\odot$.



Results:

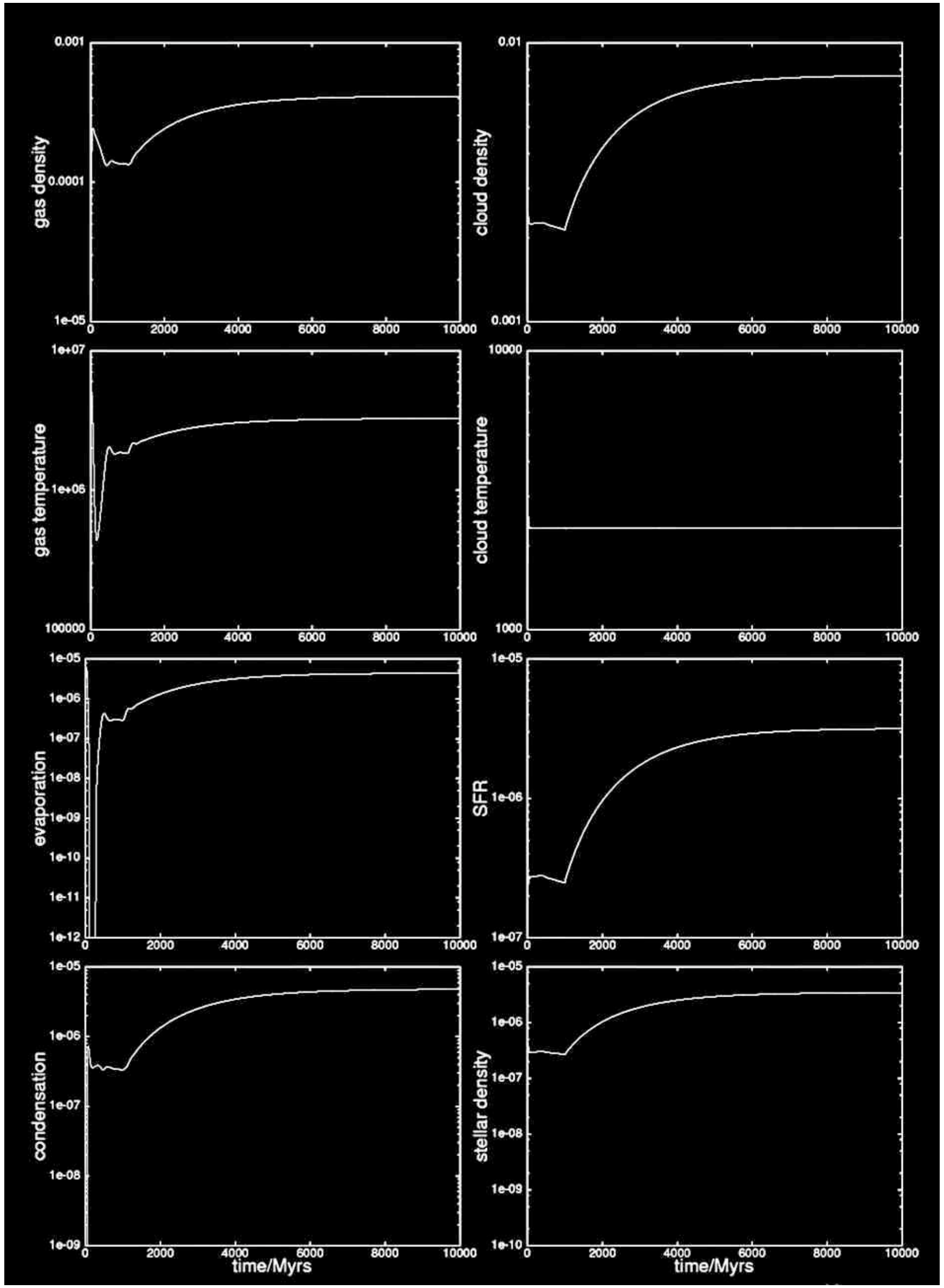
- Extension of tracks depends on y_{eff}
- (N/O) scatter reproducible by age differences of start models

Köppen, G.H. (2005) A&A

continuous gas infall

$A_c = 2.83\ 10^{-6}\ M_\odot/(pc^3\ Myr) = 2\ M_\odot/yr$ (R=15 kpc, H=1 kpc)

10 km/s



100km/s