Dispersal and mixing of metals in blue LSB galaxies

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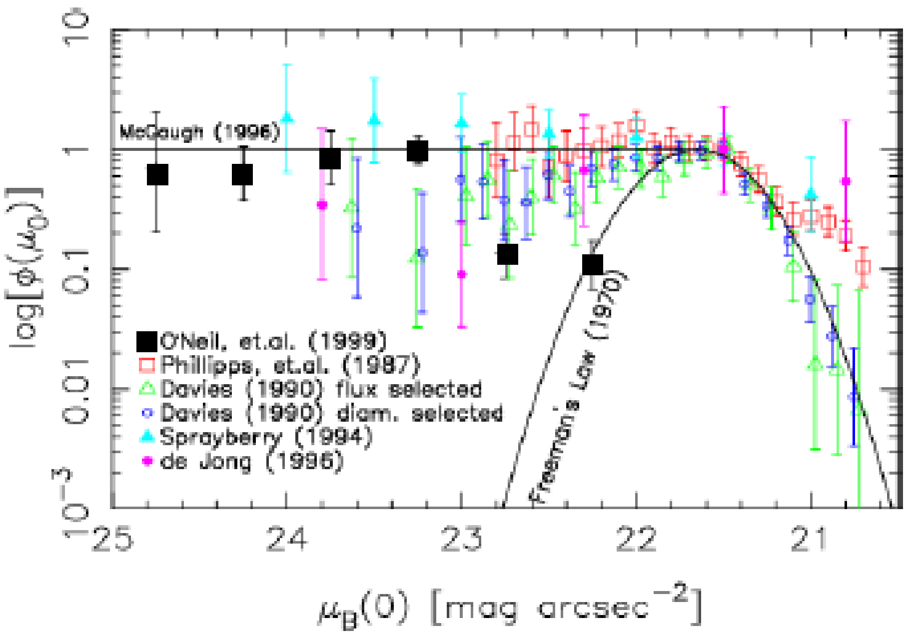
- Luminosity function

Fainter than the Freeman limit: μ(B) ~23 > 21.65+/- 0.30 mag/arcsec^2

Cheshire cat glxs **Salpeter**



O'Neil 2000

- Baryon content in LSB

Ω(LSB)~10Ω(HSB)

Hayward et al 2005

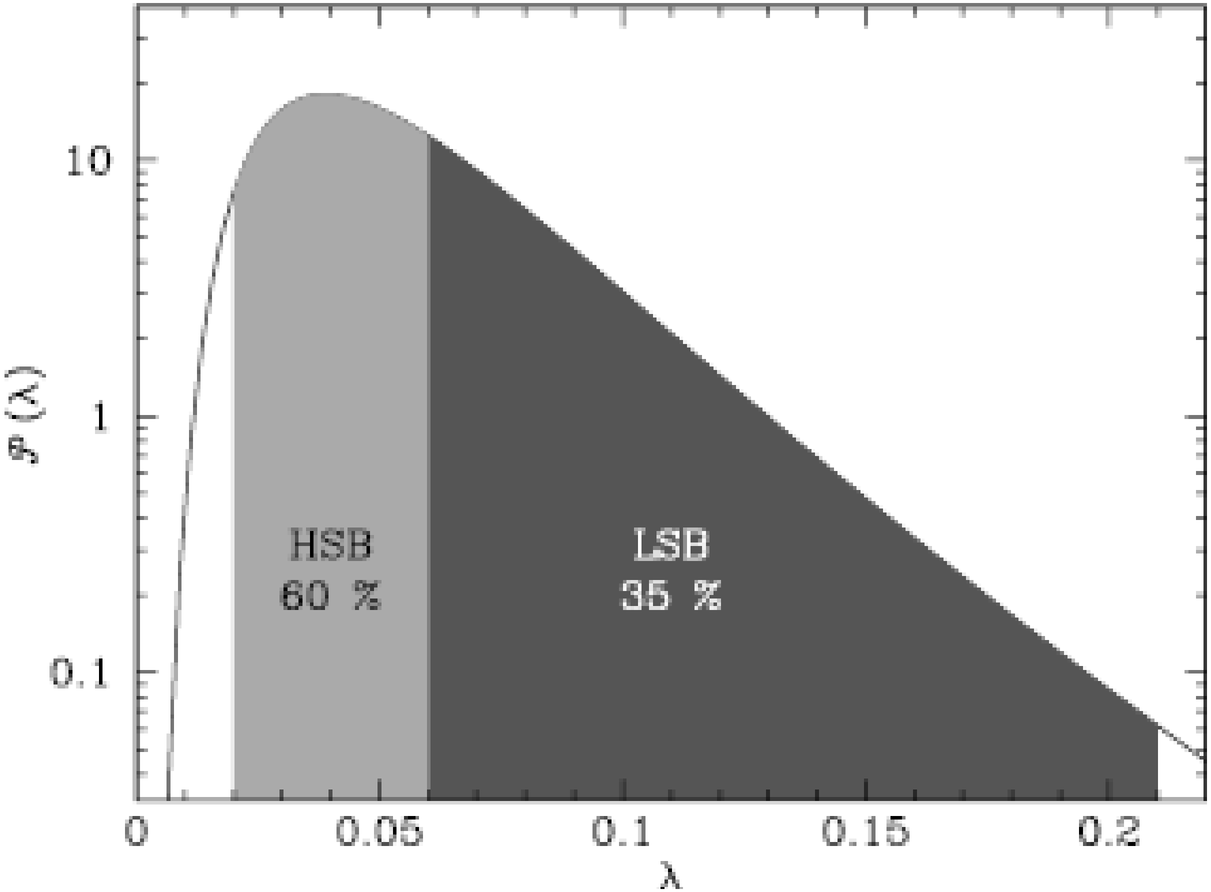
- from SNe Ia counts

Ω(LSB) ≤ Ω(HSB)

Comprise up to half of galaxy population **McGaugh 1995**

- Spin

Boissier et al 2002



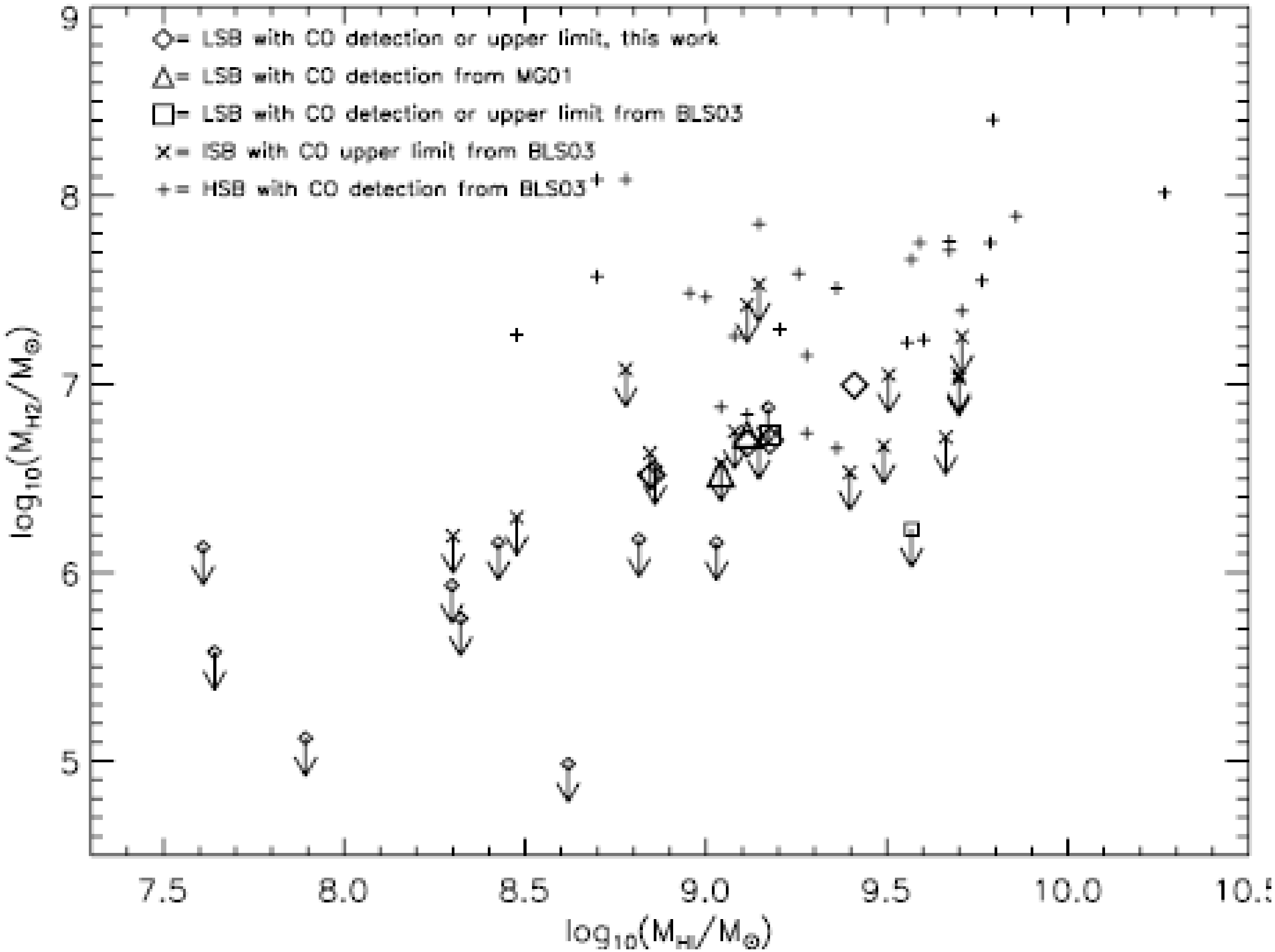
$$R_d = R_{d,MW} \times \frac{V_C}{V_{C,MW}} \times \frac{\lambda}{\lambda_{MW}}$$

- Location

Rosenbaum & Bomans 2006

On the periphery of the large scale web

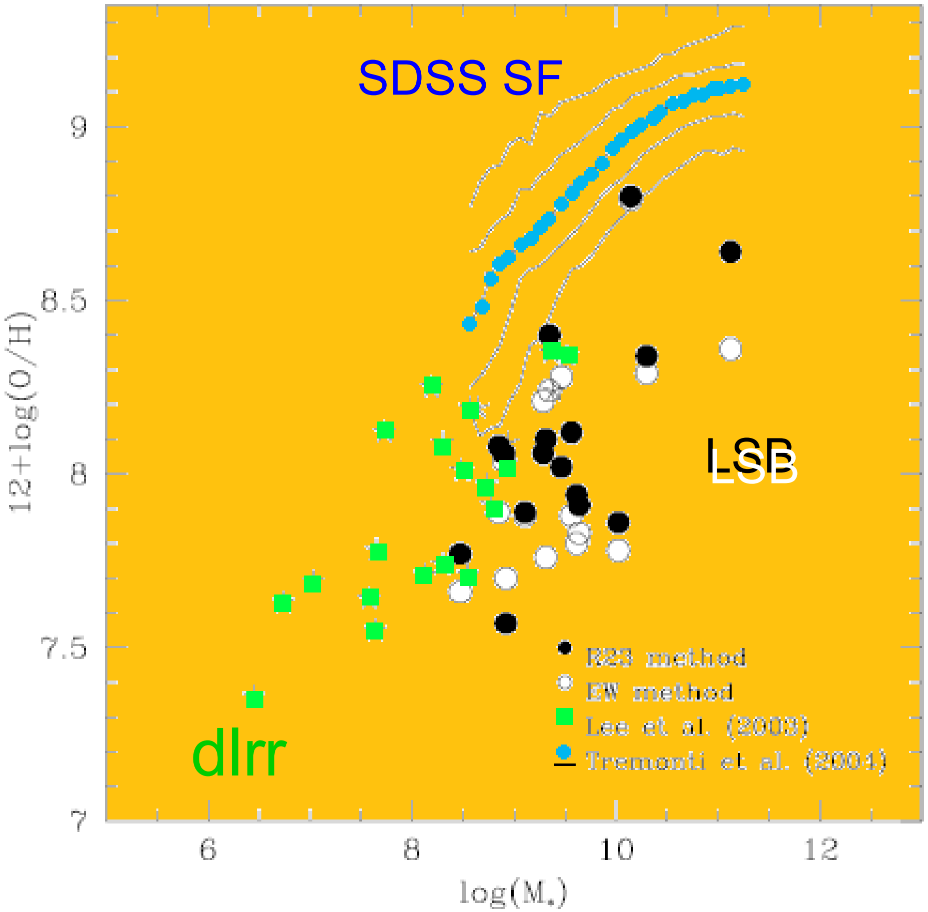
- no H2

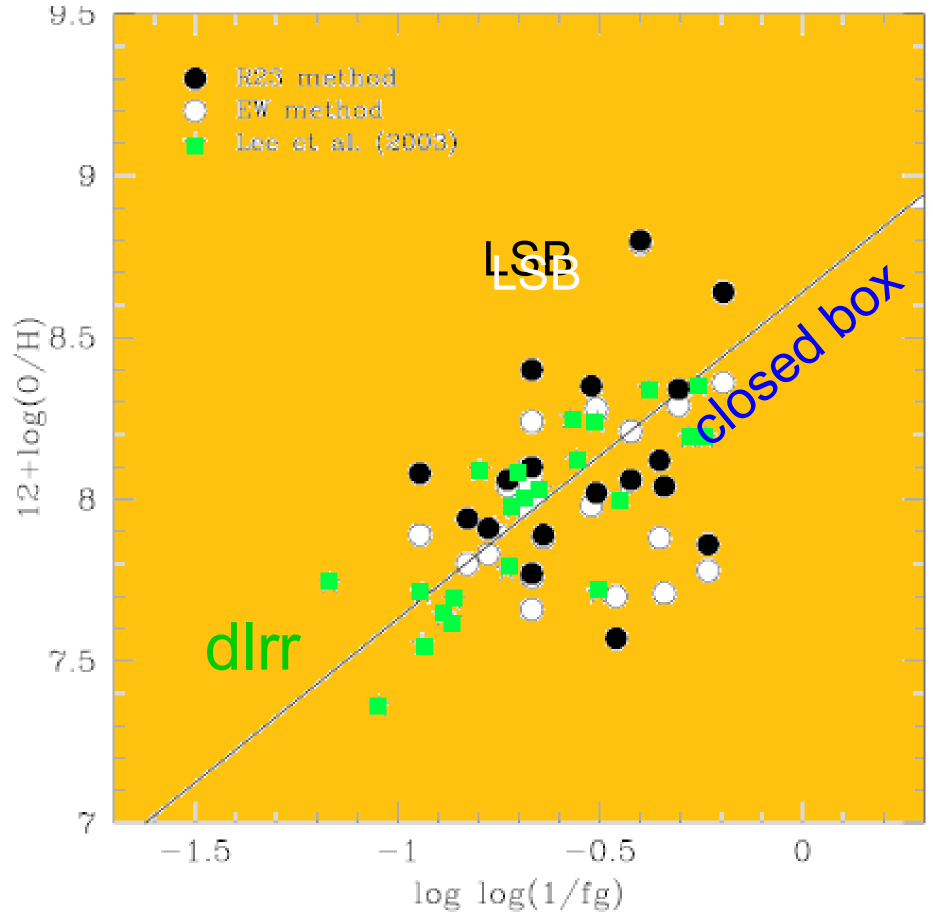


Matthews et al 2005

Metallicity

HII zones





High spread in metallicity...

de Naray, McGaugh & de Blok 2004

LSBs vs hierarchical structure formation

- colors $B-V \sim 1.2-0.2$ mag
- gas mass $f_{gas} > 50\ \%$
- metallicities $Z = 5-20\ \%\ Z_{\odot}$

LSBs may have formed recently !

Confronts hierarchical scenario ?

Aging

Padoan etal 1997, Jimenez etal 1998:

U-B, B-V, B-R, V-I photometry → t≥7-9 Gyr

Schombert etal 2001:

HI content, V-I photometry → LSB dwarfs t≤5 Gyr

Haberzettl etal 2005:

Spectral energy distribution → t=2-5 Gyr

Zackrisson etal 2005:

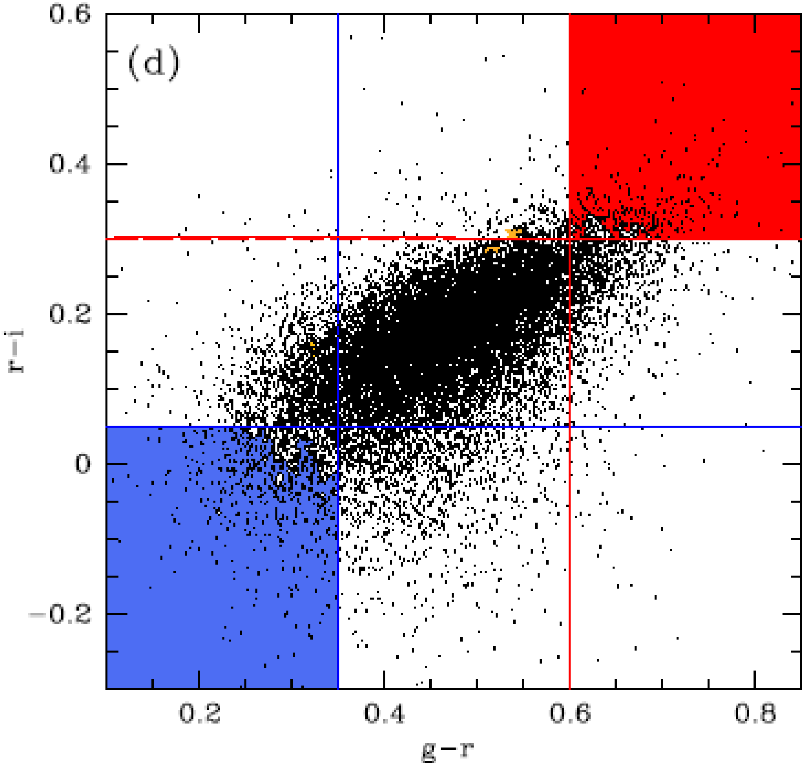
optical/NIR photometry + H-alpha EW → t=1-2 Gyr (though 10-14 Gyr equally well reproduce the data)

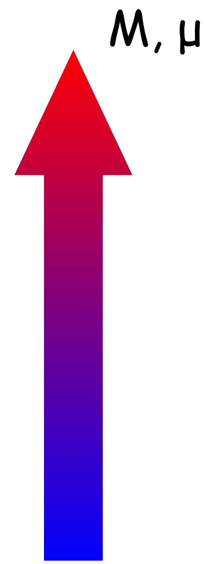
Vorobyov , YuS, Bomans, Dettmar & Bizyaev 2009:

aging through chemical inhomogeneity

Z~ Z_sun

33.3% older than 5 Gyr





Only 5.9% older than 5 Gyr

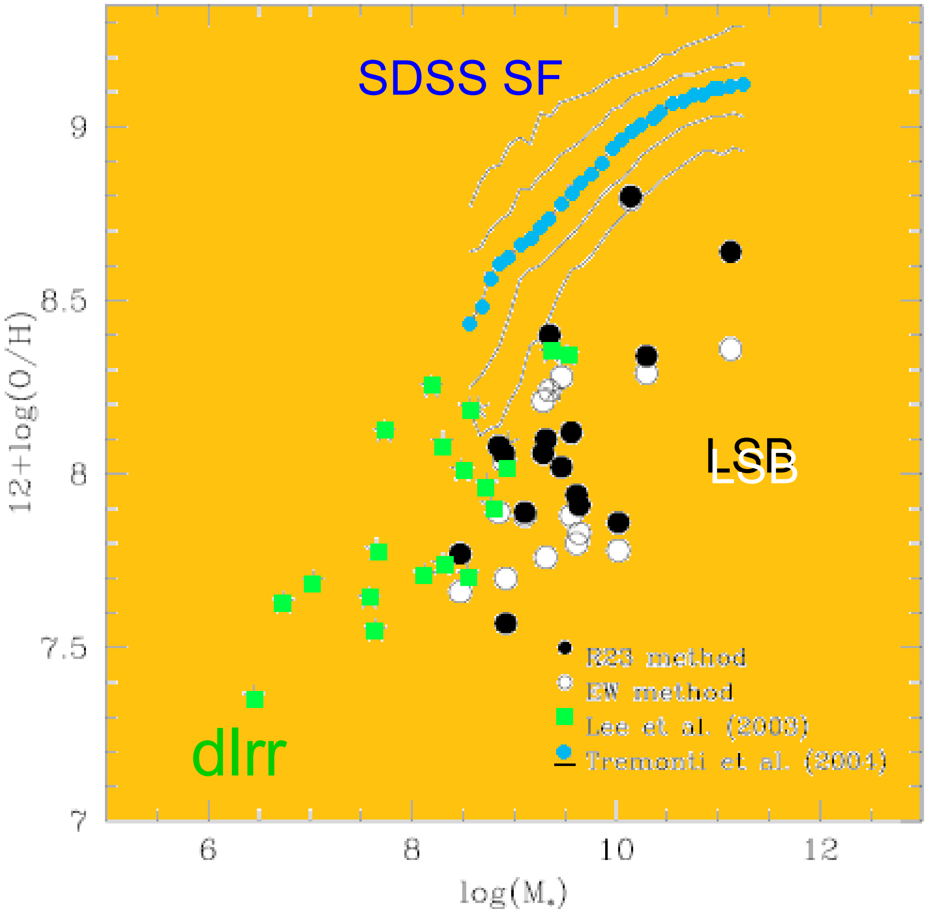
Z~0.2 Z_sun

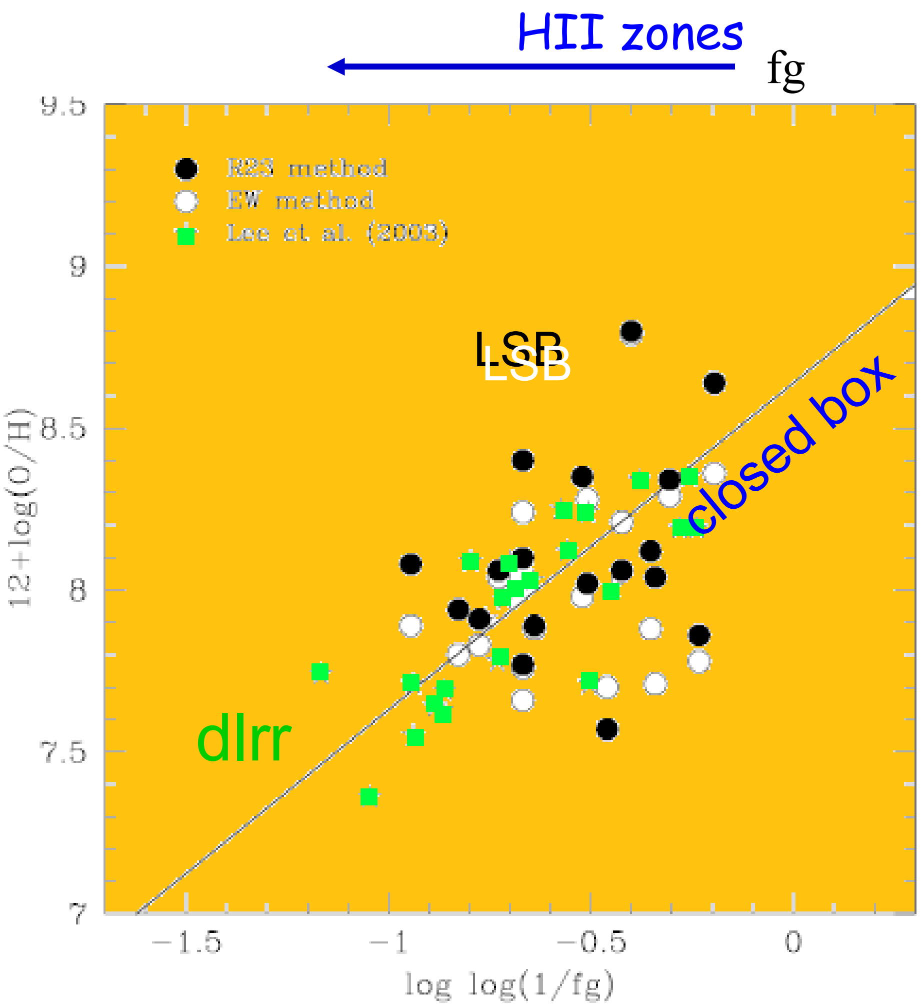
Zhong, Liang et al 2010

LSBs may have formed recently !

Confronts hierarchical scenario ?

Metallicity





High spread in metallicity for LSBs reflects highly inhomogeneous distribution of metals in their ISM ?

de Naray, McGaugh & de Blok 2004

Metal transport in disk galaxies

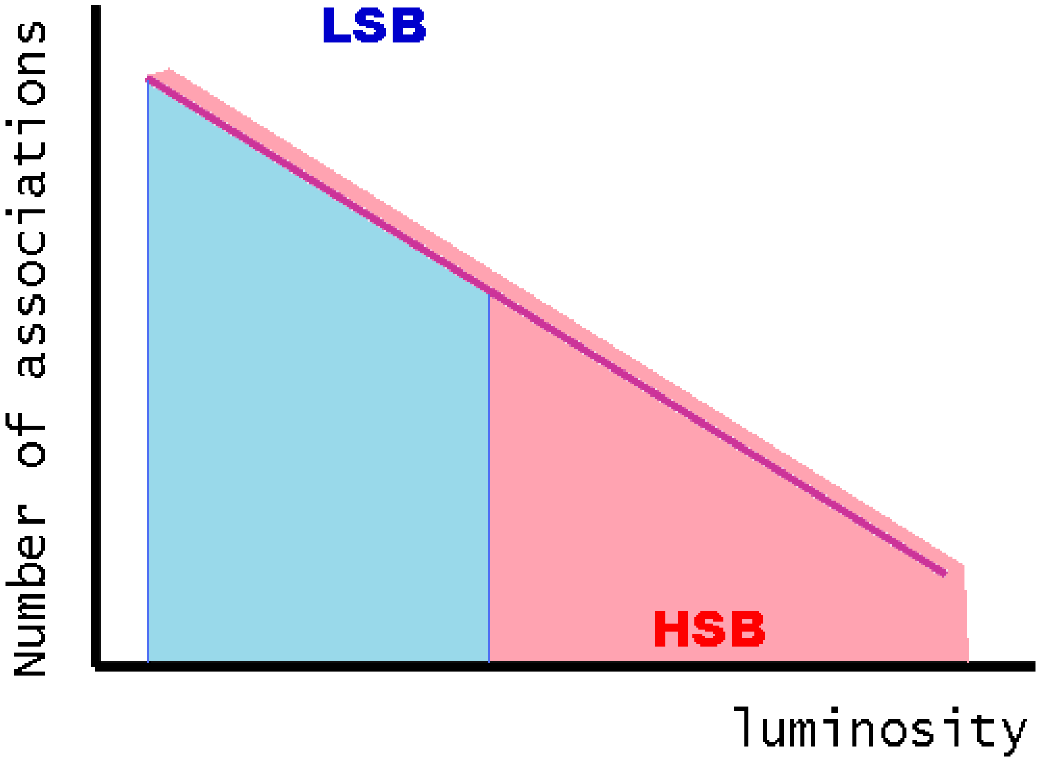
• Ejection by breakthrough from SNe into the halo and radial dispersal by ballistic fragments **(Tenorio-Tagle 1996)**

• Multiple SNe activity in nuclear regions and following spread through the halo **(Tenorio-Tagle 1996)**

• Random motions of interstellar clouds **Acharova, Mishurov & Lipine last 5 years**

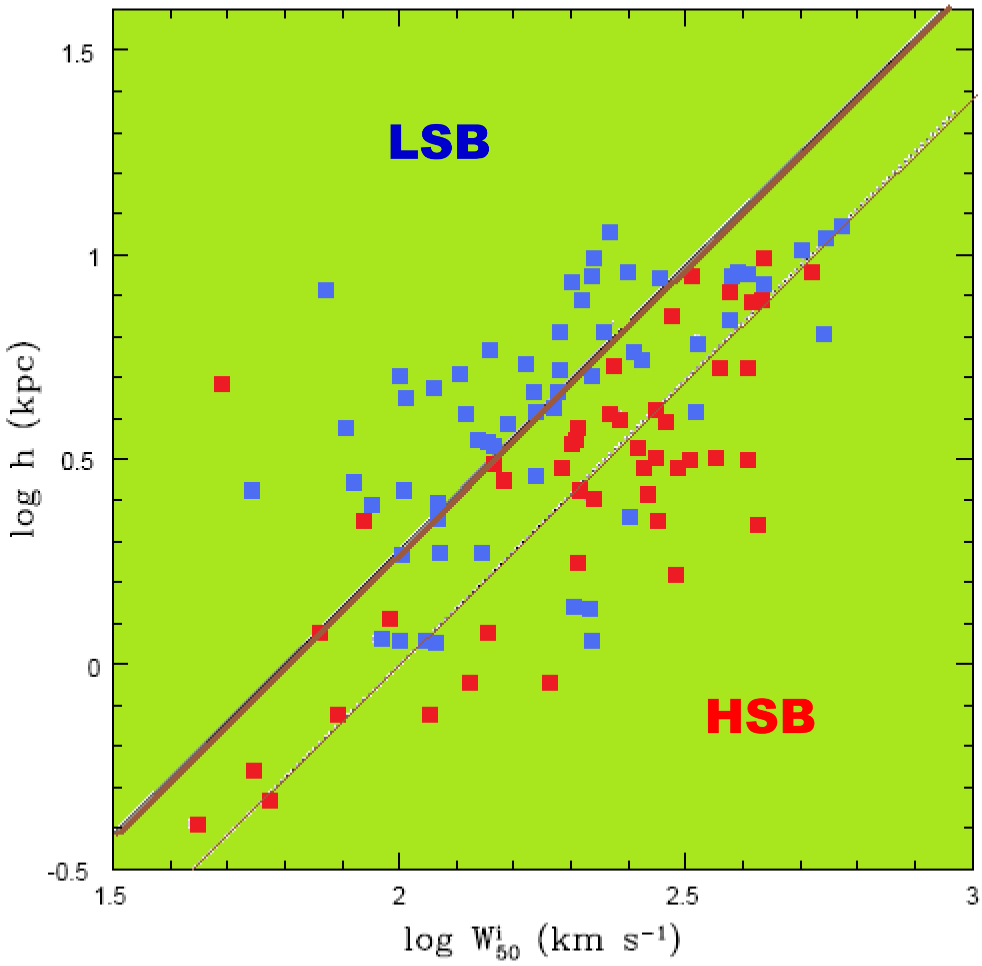
• Convectively driven radial mixing supported by the large scale spiral wave motion **Vorobyov, YuS, Bizyaev, Bomans & Dettmar 2009**

Breakthrough



SFR(LSB) < 0.1 SFR(HSB)

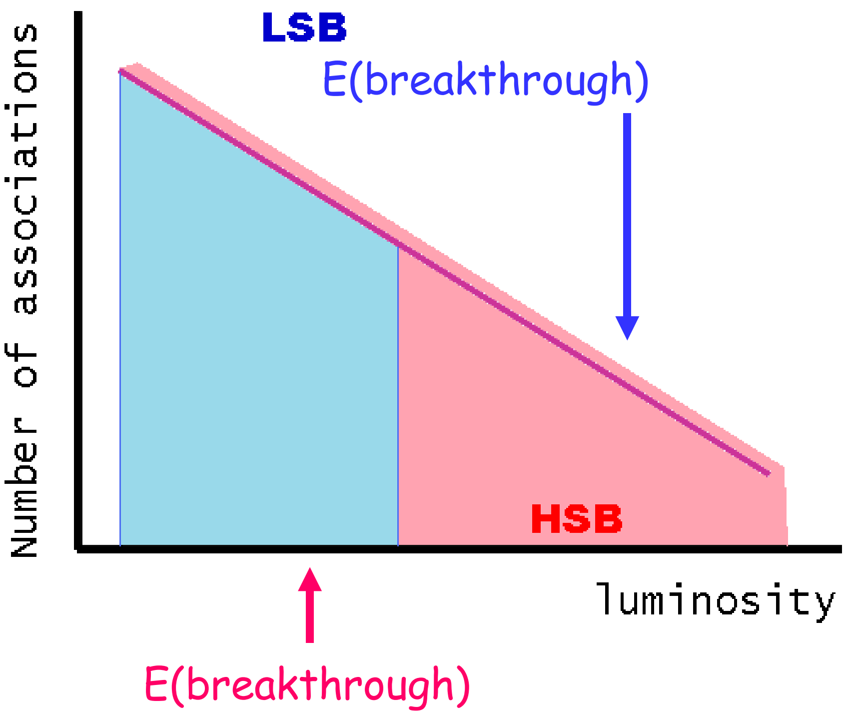
Breakthrough



Burkholder et al 2001

E(breakthrough) ~ h^3

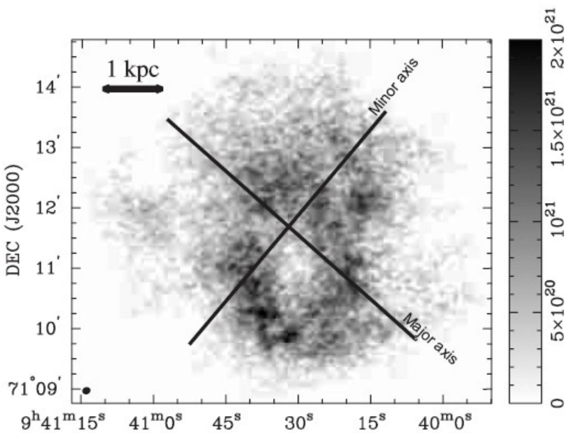
h(LSB) ~ 2 h(HSB)

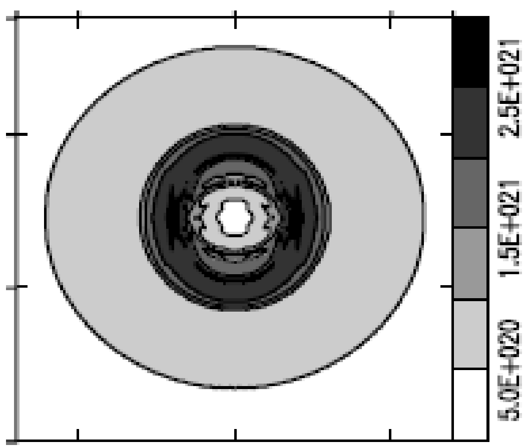


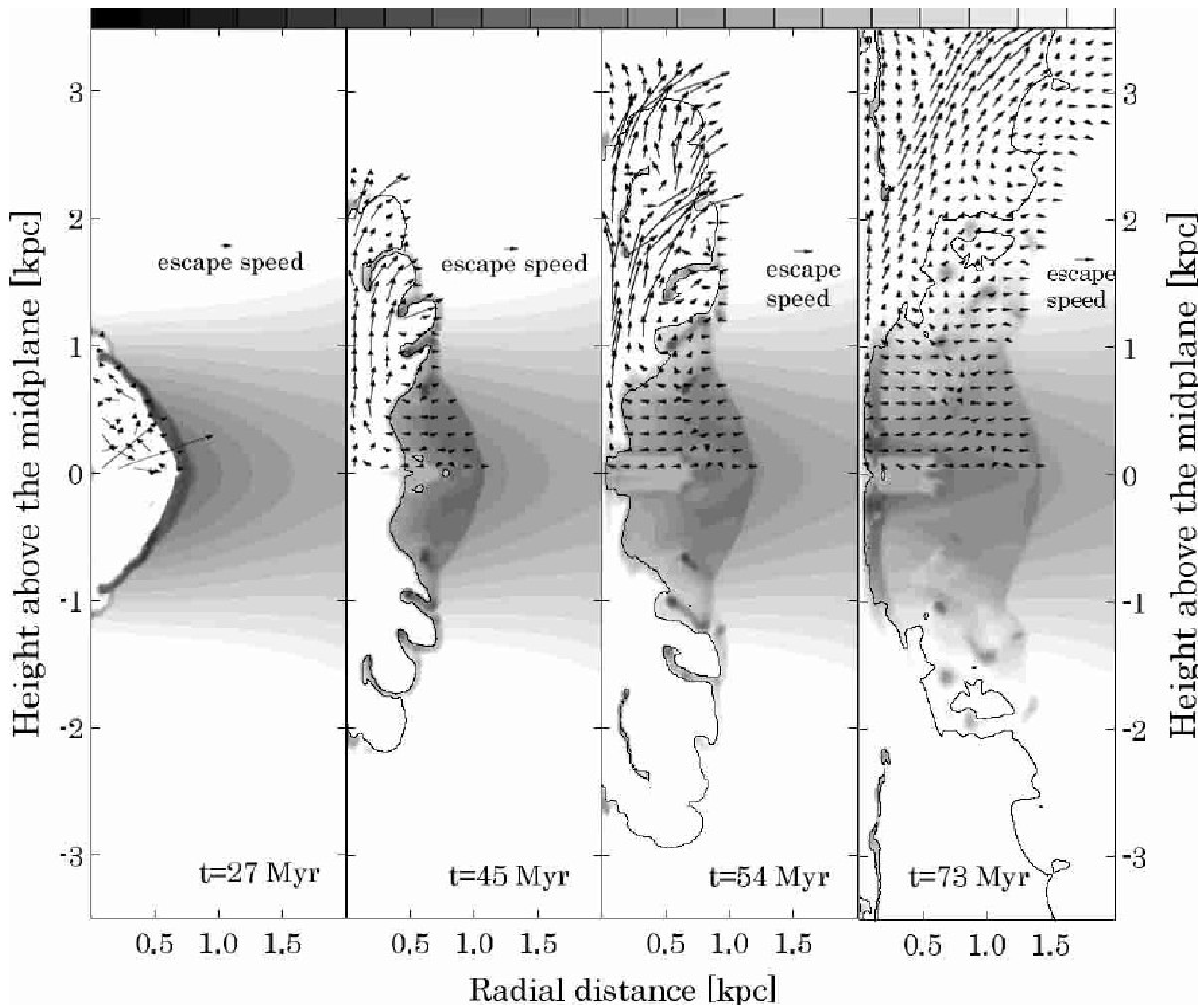
Nuclear SNe activity

Vorobyov, YuS, Klein, Ott 2004

- central HI holes





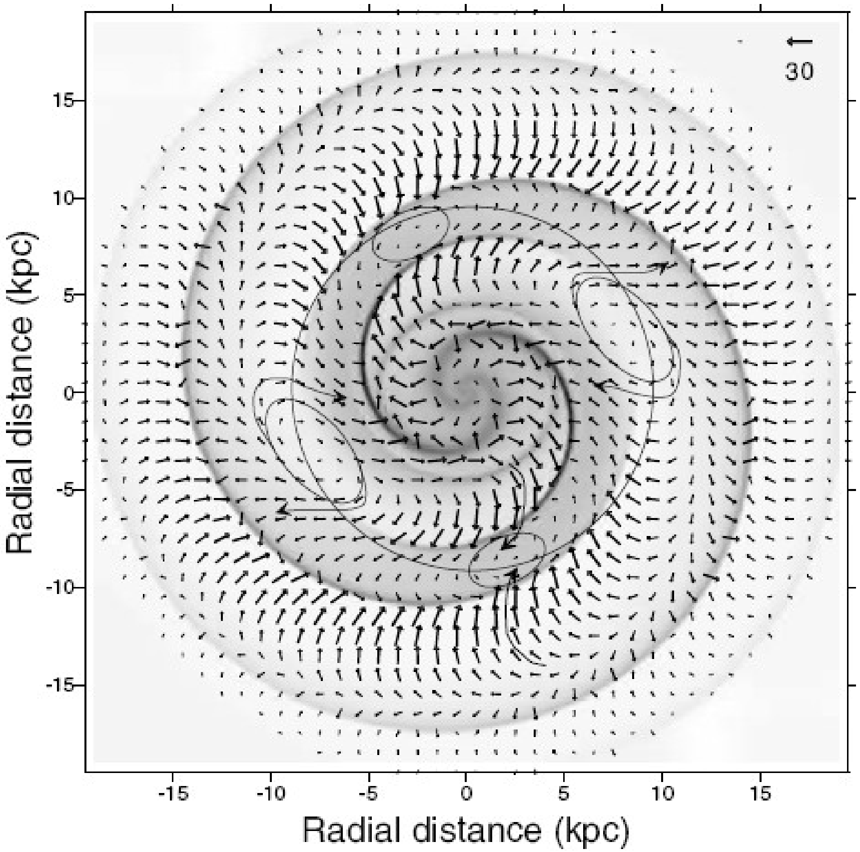


Convection

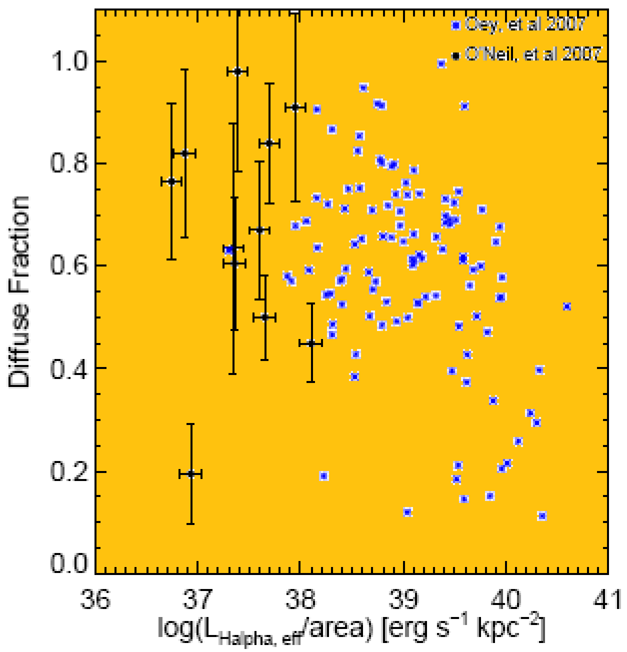
Korchagin, Petviashvili, Ryabtsev 1989

Fridman, Afanasiev, Dodonov, Zasov, Silchenko 2003

Vorobyov 2006



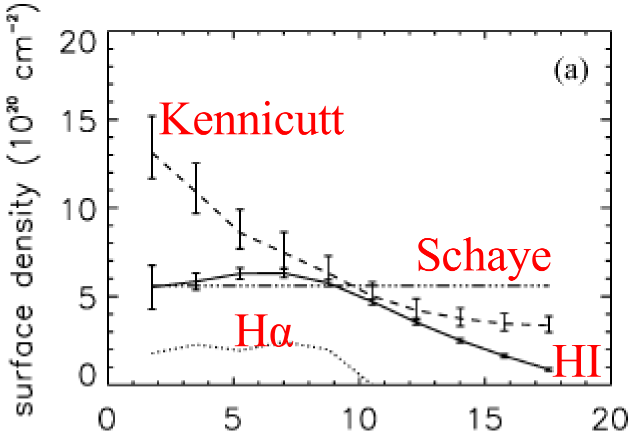
SF in LSBs



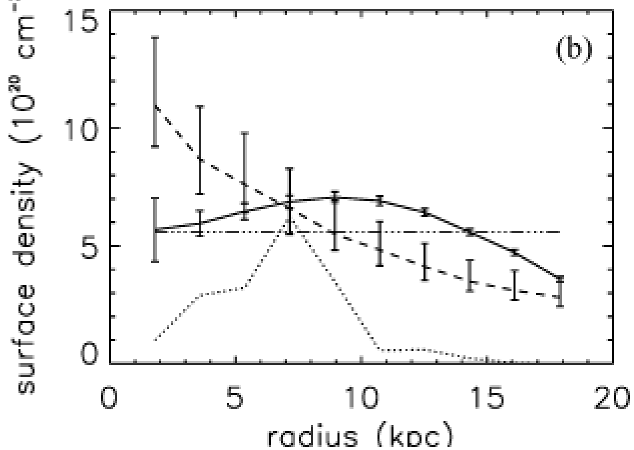
O'Neil 2007

- Considerable fraction of SF occurs outside the HII regions – as if in small mass atomic clouds dispersed over the disk?
- HII regions represent SF in giant (molecular/atomic) clouds, while the diffuse SF component holds in diffuse HI clouds?

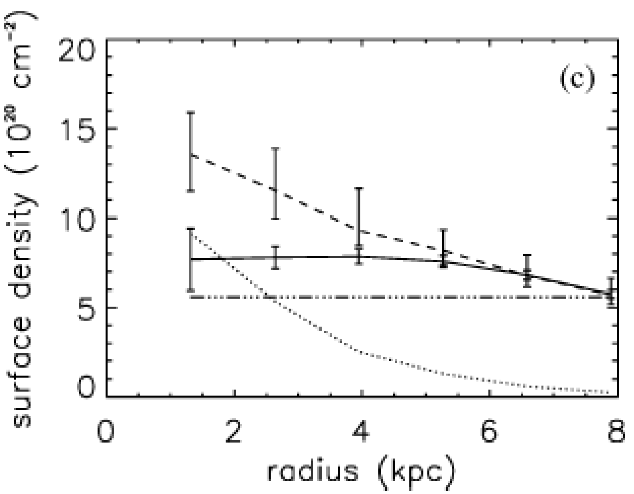
The weaker the galaxy, the rarer single localized SF events, the higher the diffuse fraction ?



ESO-LV 0280140

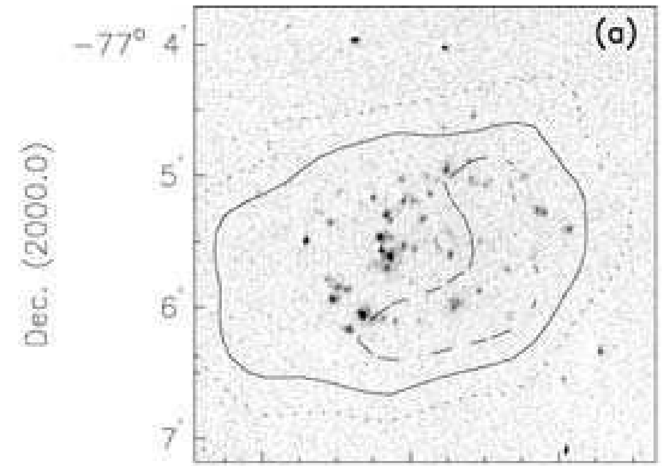


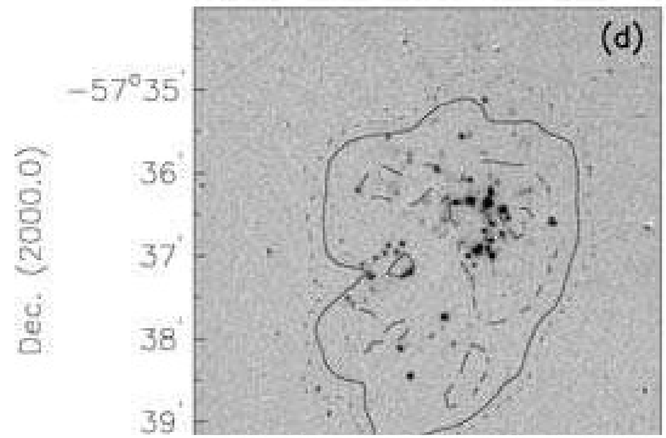
ESO-LV 1450250

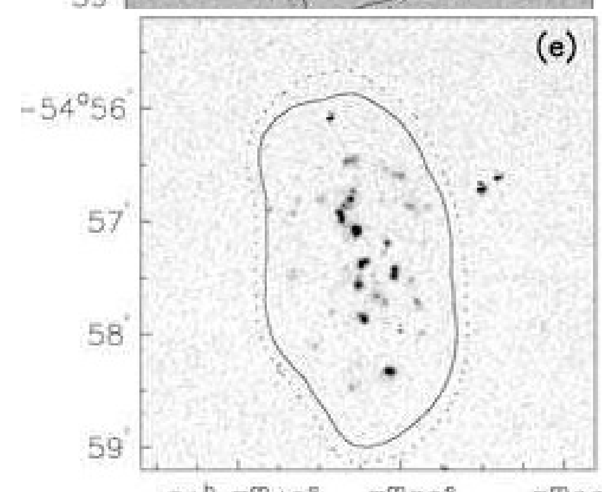


ESO-LV 1870510

Auld et al 2006



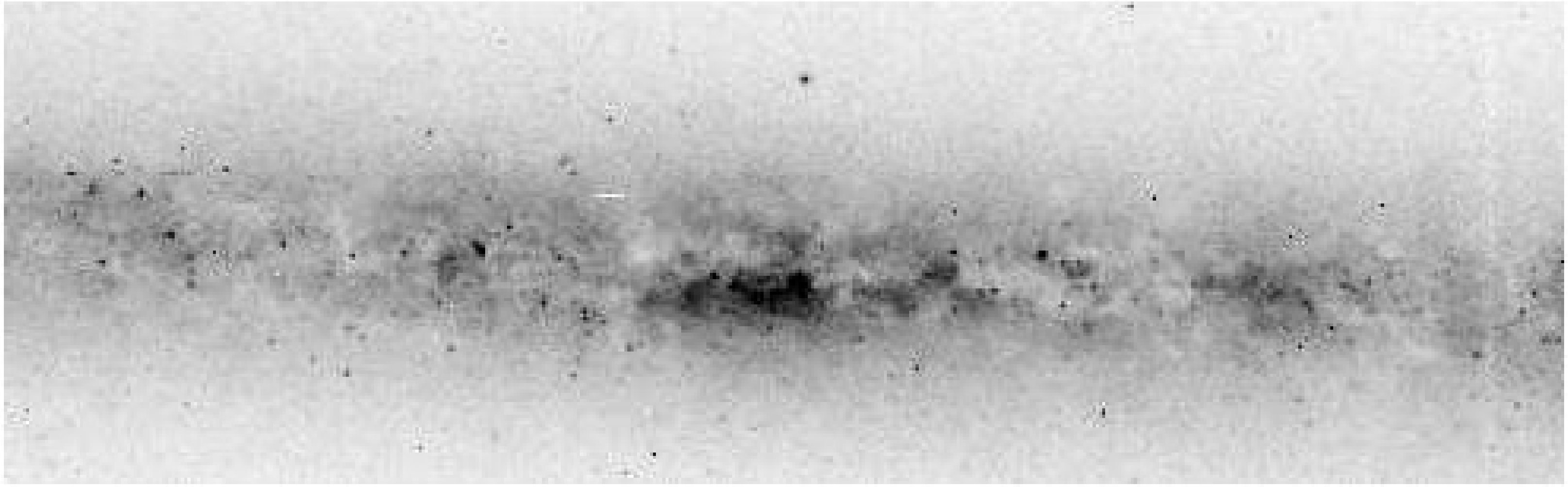




SF in LSBs

Matthews et al 2000

UGC 7321



Dusty clumps of 30-40 pc

- SF in LSBs

Thermal instability Elmegreen & Parravano 2000

t~10/n Myr at low metallicity [Z]=-2

Mock gravity Field 2000

t~1/n Myr under extragalactic background UV

- Mixing in the MW

2D hydrodynamic simulations: $\int ..dz$

+ chemistry (instantaneous recycling)

+ photometry

- Mixing in the MW

- Shock frequency

Draine & Salpeter 1979

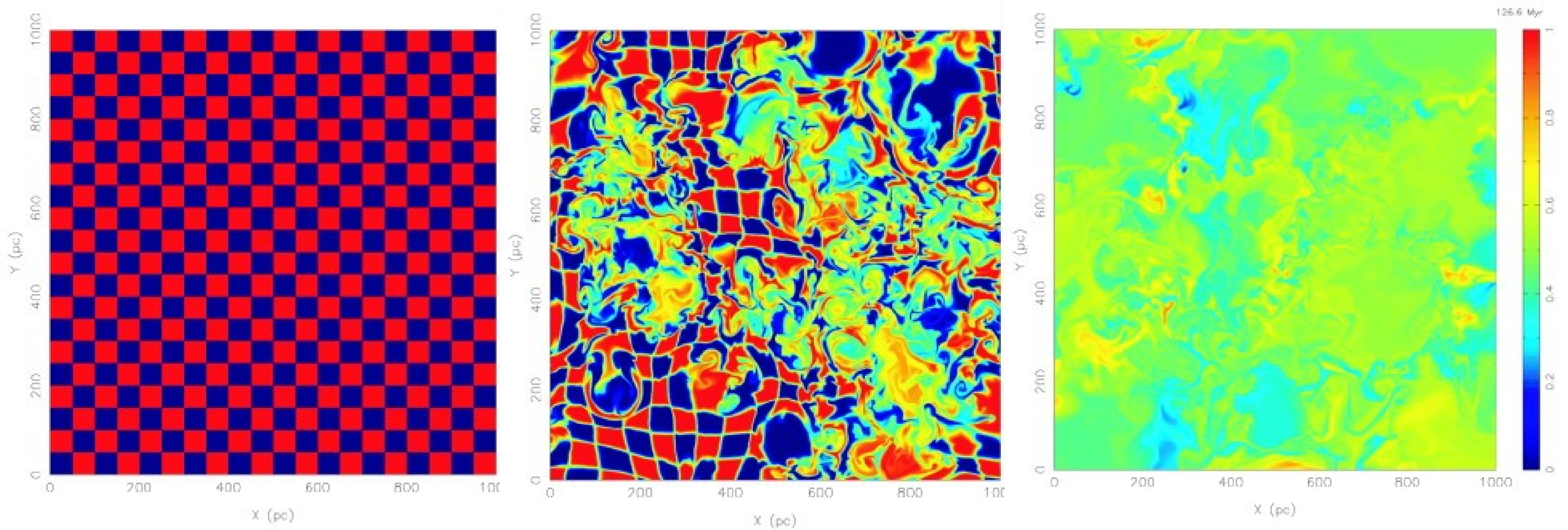
probability of a SN shock of $v_s \geq 10 \text{ km s}^{-1}$

$$\Psi_s \leq \frac{\text{one shock}}{5 \text{ Myr}}$$

Mixing in the MW

- Numerical examples **Avillez & MacLow 2002**

t=0 t=50 Myr t=126.6 Myr



- Mixing in LSBs

- Shock frequency with a 0.1 SFR

Boissier etal 2008

probability of a SN shock of $v_s \geq 10 \text{ km s}^{-1}$

$$\Psi_s \leq \frac{\text{one shock}}{50 \text{ Myr}}$$

t=126.6 Myr in the MW → t=1.266 Gyr in LSB

SF in LSBs = 0.1 SF in MW

- SNR filling factor

$$2z_0 \times R = 2 \times 150 \text{ pc} \times 10 \text{ kpc}$$

assume linear proportionality

Milky Way

$$R_{\rm sn} \sim 10^{-13} \text{ yr}^{-1} \text{ pc}^{-3}$$

$$f_{\rm sn} \lesssim 0.2$$

(de Avillez & Breitschwerdt 2004)

an LSB

$$R_{\rm sn} \sim 10^{-14} \text{ yr}^{-1} \text{ pc}^{-3}$$

$$f_{\rm sn} \lesssim 0.02$$

- Mixing in LSBs

no mixing! unless differential rotation & spiral waves help

- Dynamical model of an LSB

Table 1. Main structural properties of our model galaxy

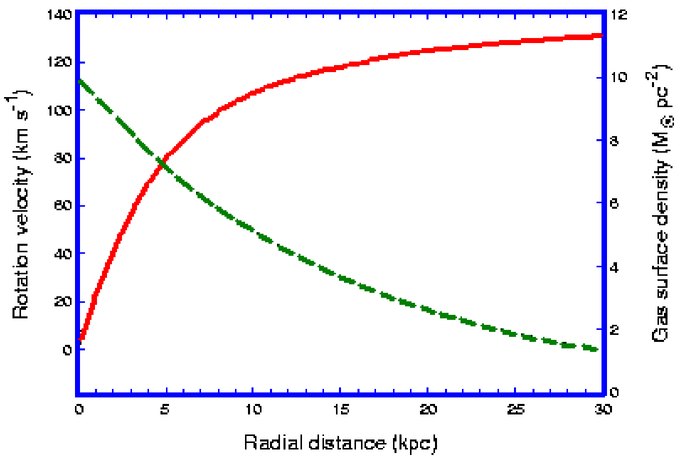
	mass	scale length	central density
Stellar disk	2.6×10^9	4	30
gas disk	3.3×10^9	30	6.5
halo	2.0×10^{10}	5.7	6.0×10^{-3}

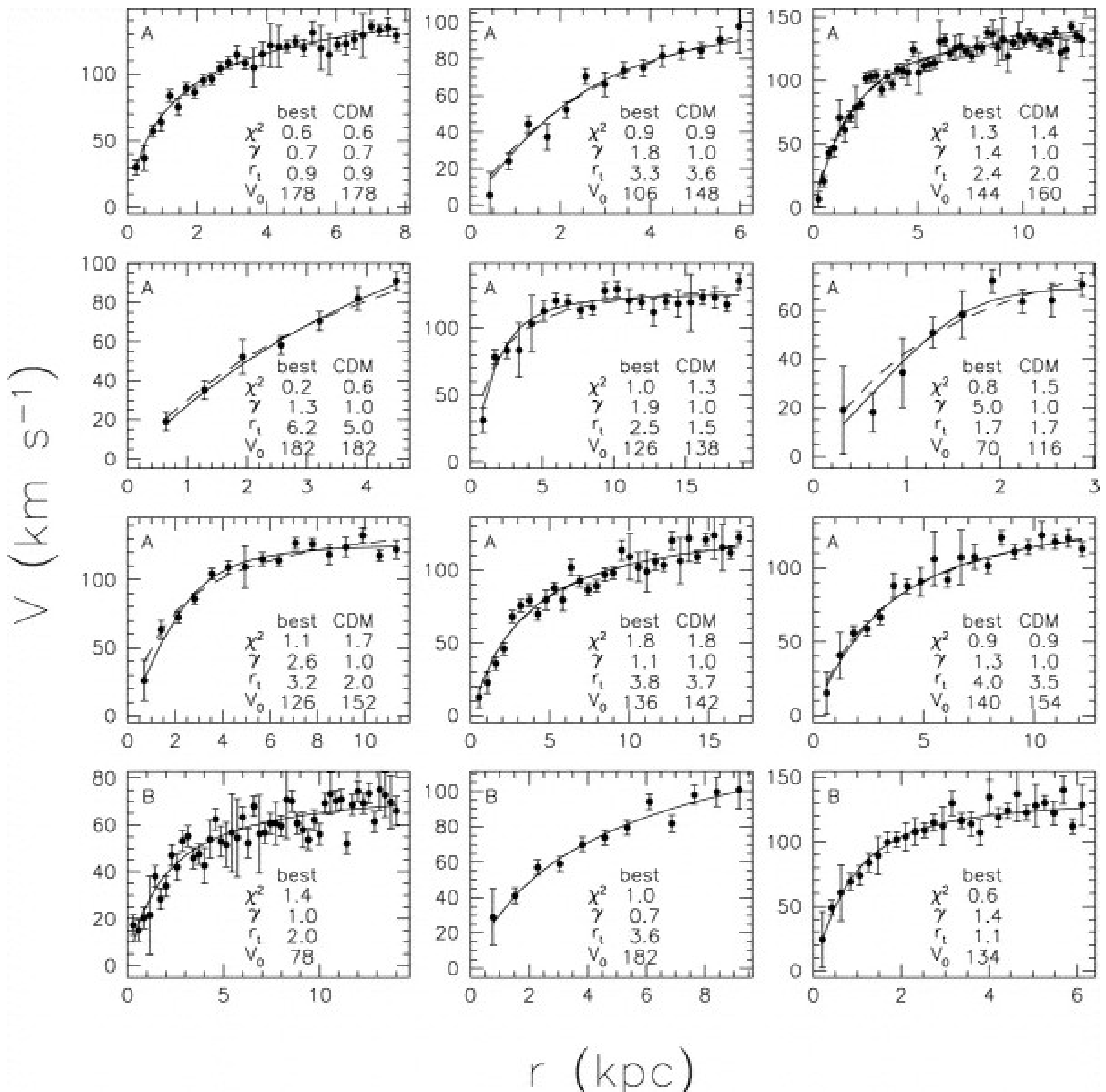
All masses are in $M_\odot$, scale lengths in kpc, and densities in $M_\odot$ pc^{-2} (gas and stellar disks) and $M_\odot$ pc^{-3} (halo). All masses are calculated inside 15 kpc radius.

Dynamical model of a LSB

de Blok 05

- V(R)





- Dynamical model of a LSB

- Equations: 2D hydro+instantaneous recycling

$$\frac{\partial \Sigma_{\rm g}}{\partial t} + \boldsymbol{\nabla} \cdot (\boldsymbol{v} \Sigma_{\rm g}) = -\beta \, \Sigma_{\rm SF} + A$$

$$\frac{\partial \Sigma_{\rm ox}}{\partial t} + \boldsymbol{\nabla} \cdot (\boldsymbol{v} \Sigma_{\rm ox}) = R_{\rm ox} - \beta \, \Sigma_{\rm SF} \frac{\Sigma_{\rm ox}}{\Sigma_{\rm g}} + A \, \zeta_{\rm ox}^{\rm igm}$$

$$\begin{aligned} \frac{\partial}{\partial t}(\Sigma_{\rm g} \boldsymbol{v}) \; + \; \boldsymbol{\nabla} \cdot (\Sigma_{\rm g} \boldsymbol{v} \cdot \boldsymbol{v}) \\ = -\boldsymbol{\nabla} P - \Sigma_{\rm g} \boldsymbol{\nabla} (\Phi_{\rm h} + \Phi_{\rm s}) \\ + \boldsymbol{v} (A - \beta \, \Sigma_{\rm SF}) \end{aligned}$$

- Dynamical model of a LSB

- SF scenario: sporadic SF

Schmidt law SF sites randomly distributed through the disk

$$\Sigma_{\rm SF,i} = \epsilon \, \Sigma_{\rm g,i}^{1.5}$$

if $T < T_{cr} = 10^4$ K

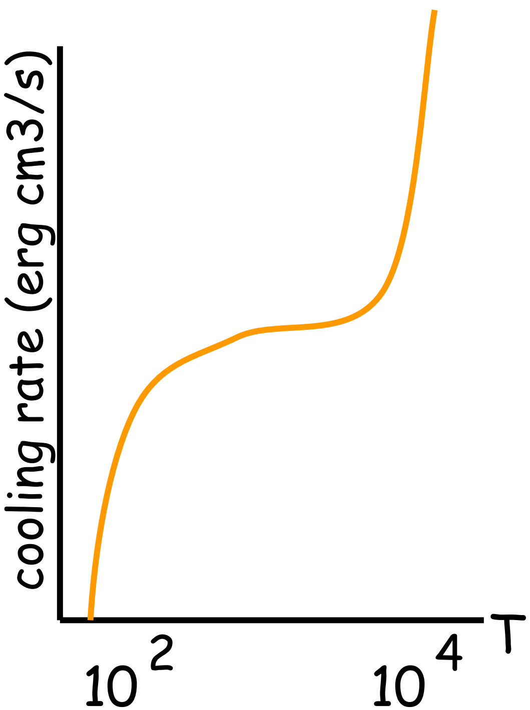
$$\rightarrow \mathcal{SFR} = \sum_i S_{\rm i} \, \Sigma_{\rm SF,i}$$

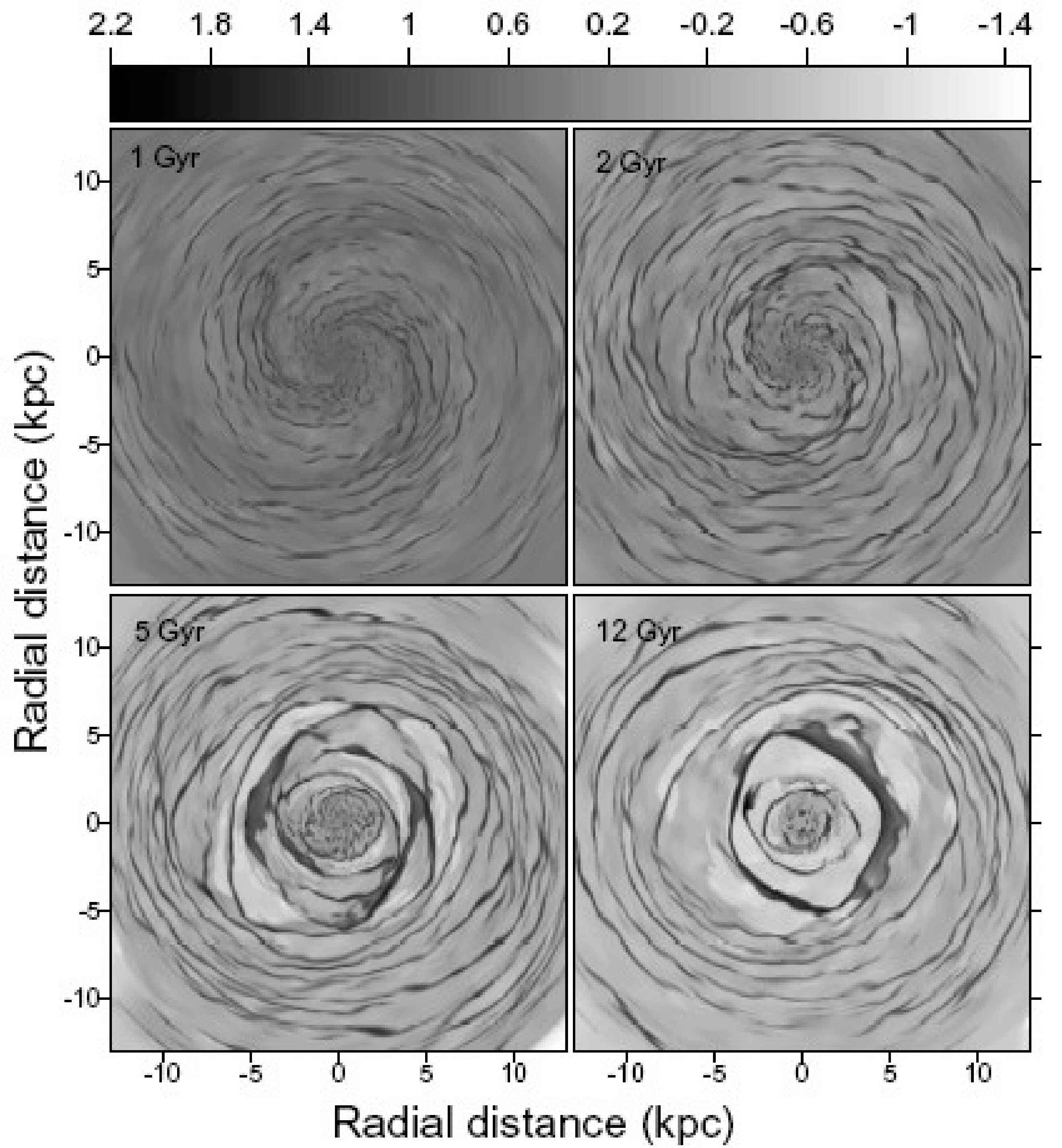
$$\mathcal{SFR} \sim 0.1 M_\odot \, {\rm yr}^{-1}$$

Δt_{SF} = 20 Myr

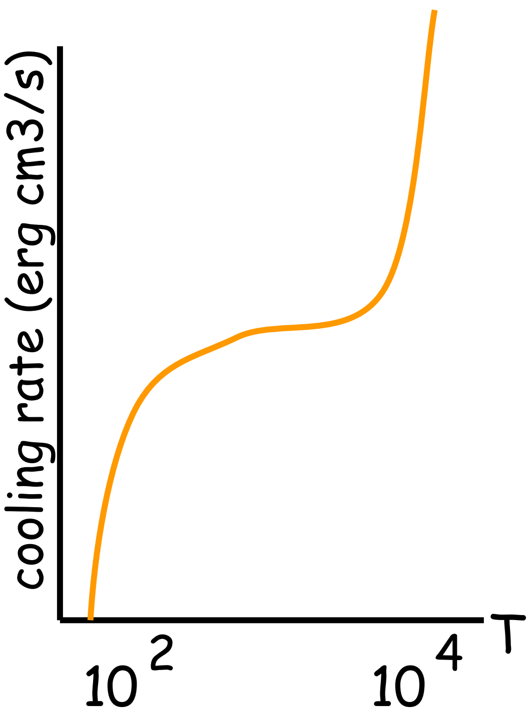
$$S_i = 0.2 - 0.4 \ {\rm kpc}^2$$

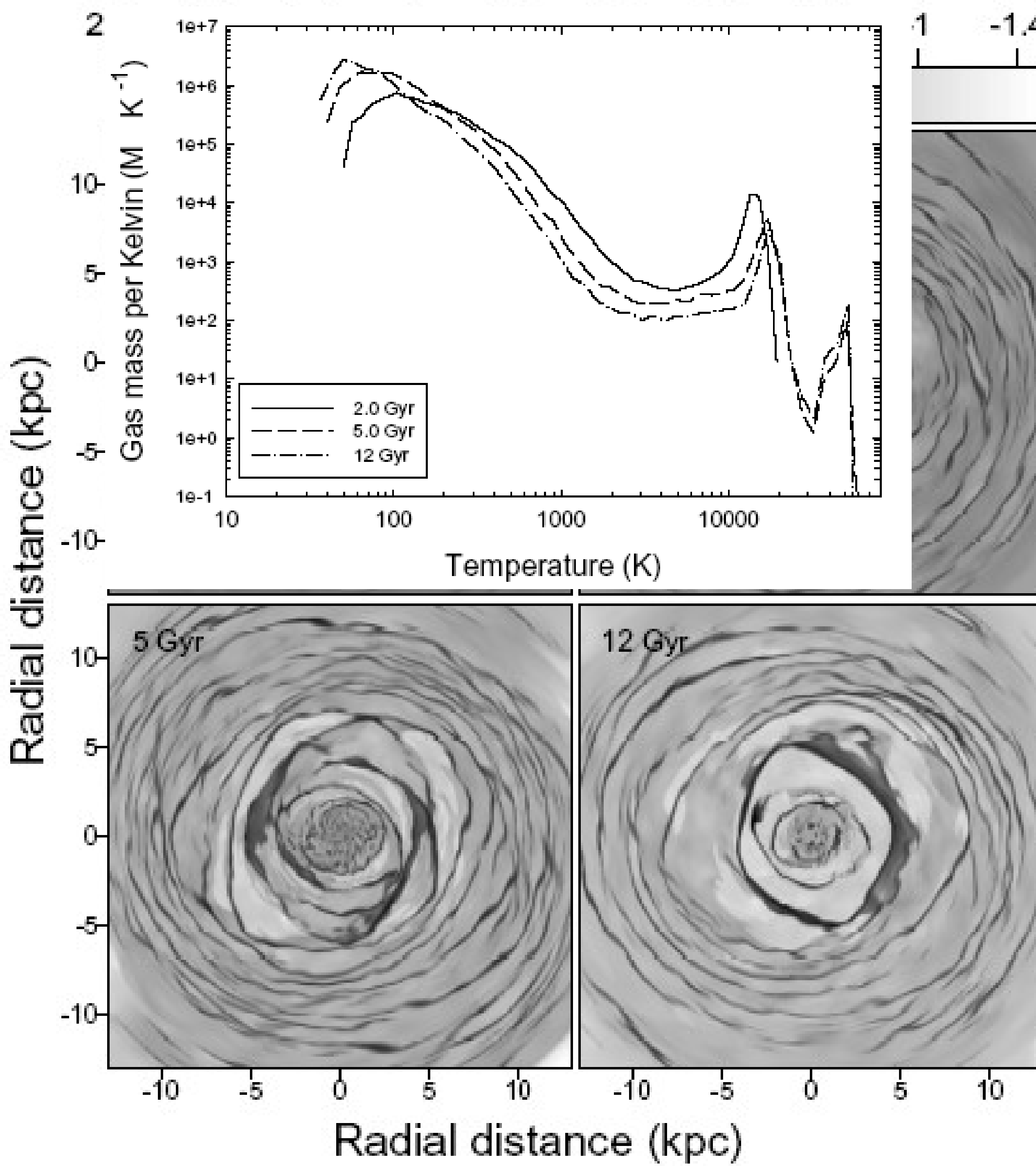
Radiative gas





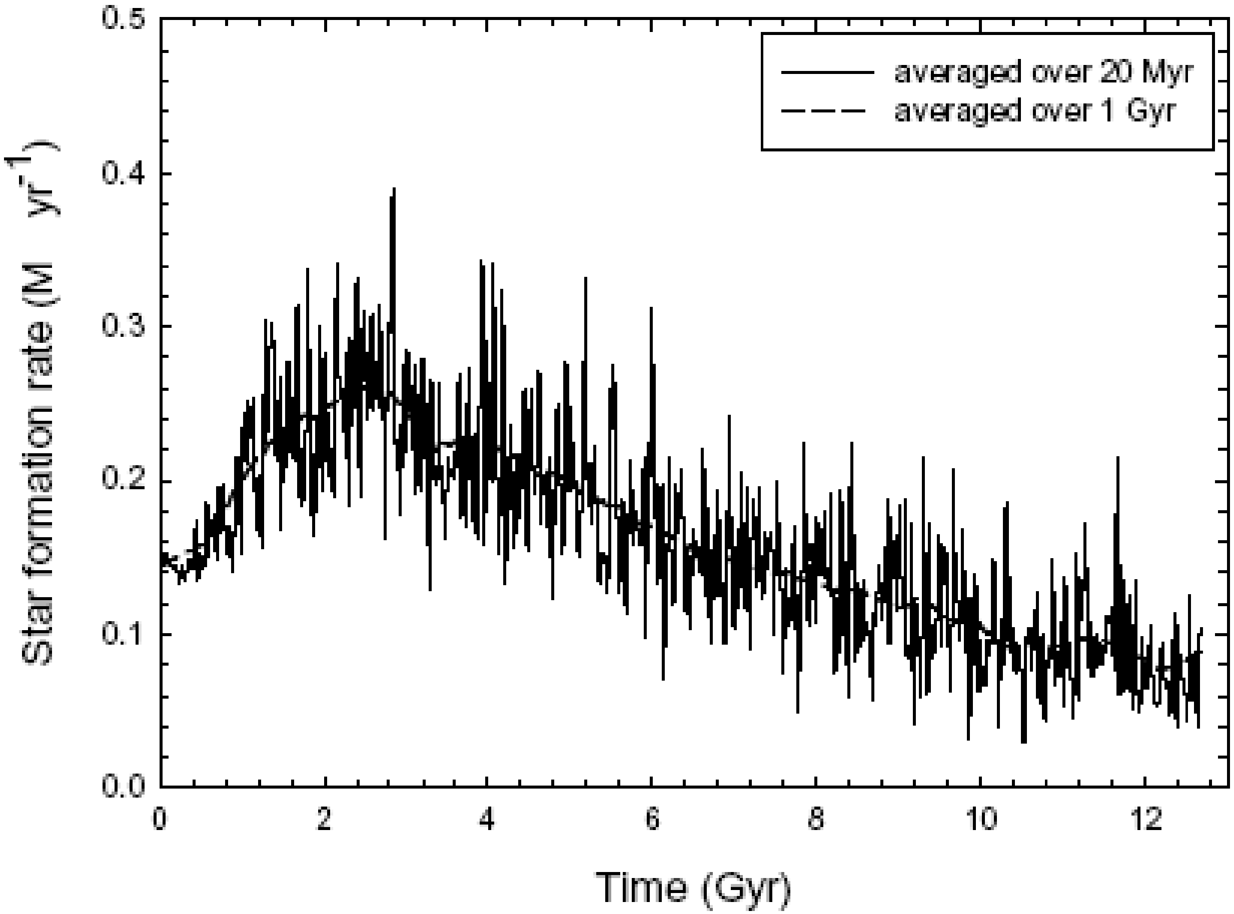
Radiative gas



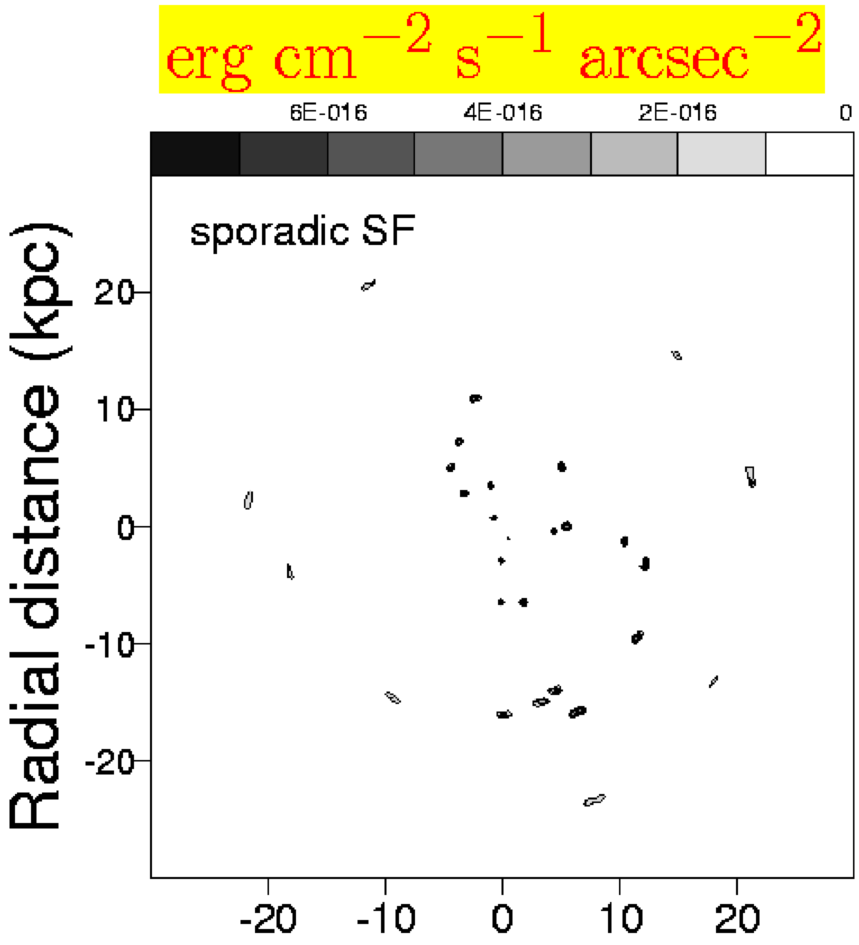


Dynamical model of a LSB

- SF scenario: sporadic SF

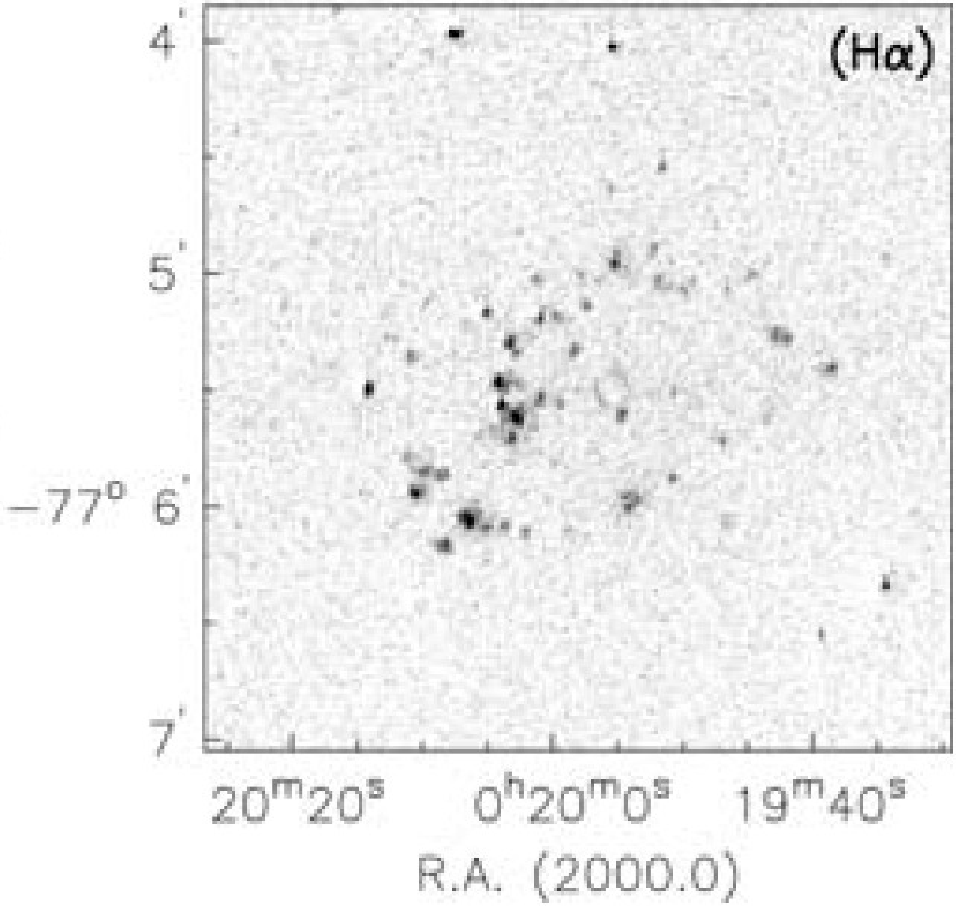


H-alpha emission: sporadic SF



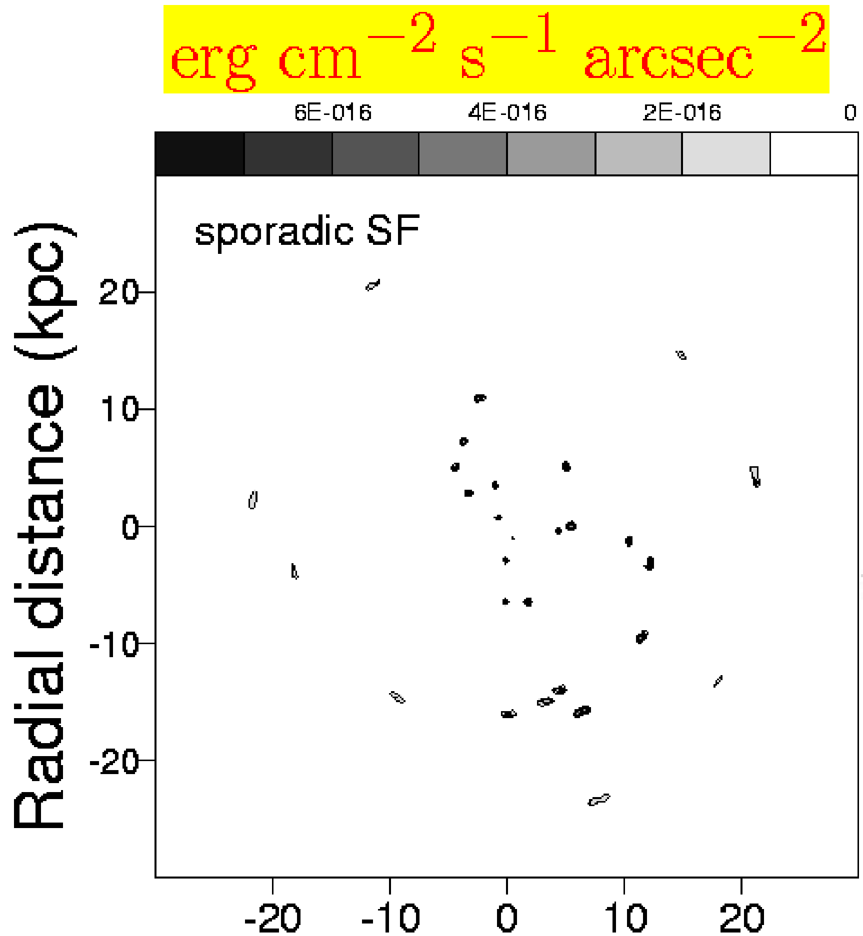
model

ESO-LV 0280140



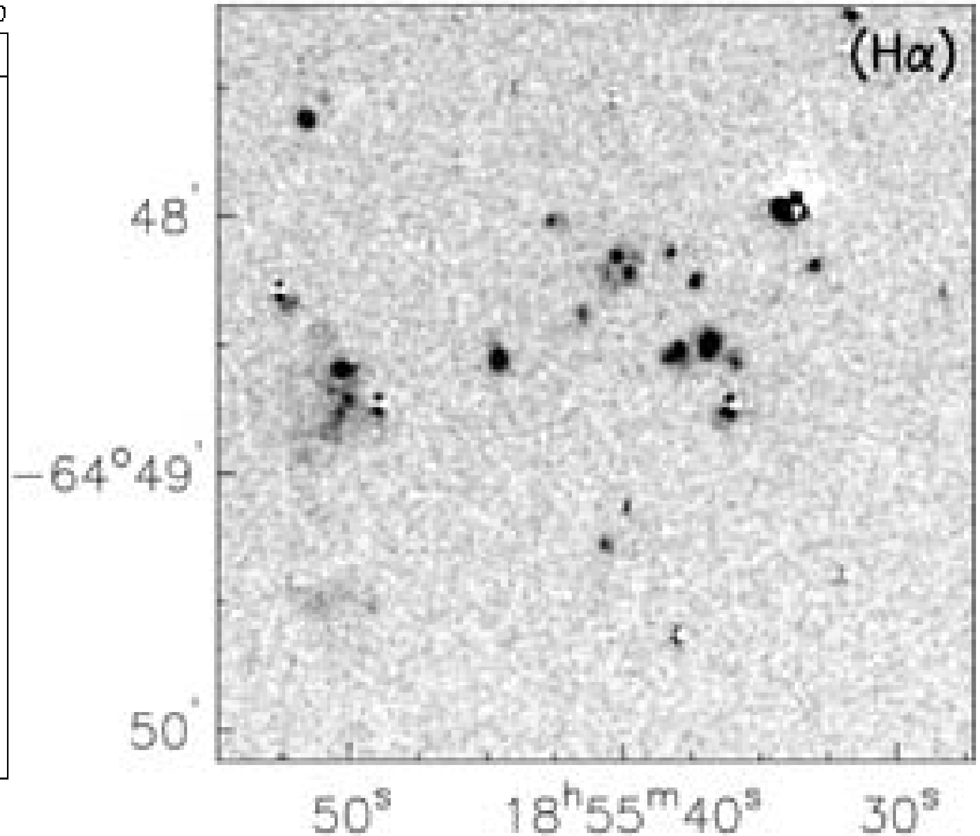
Auld et al 2006

H-alpha emission: sporadic SF



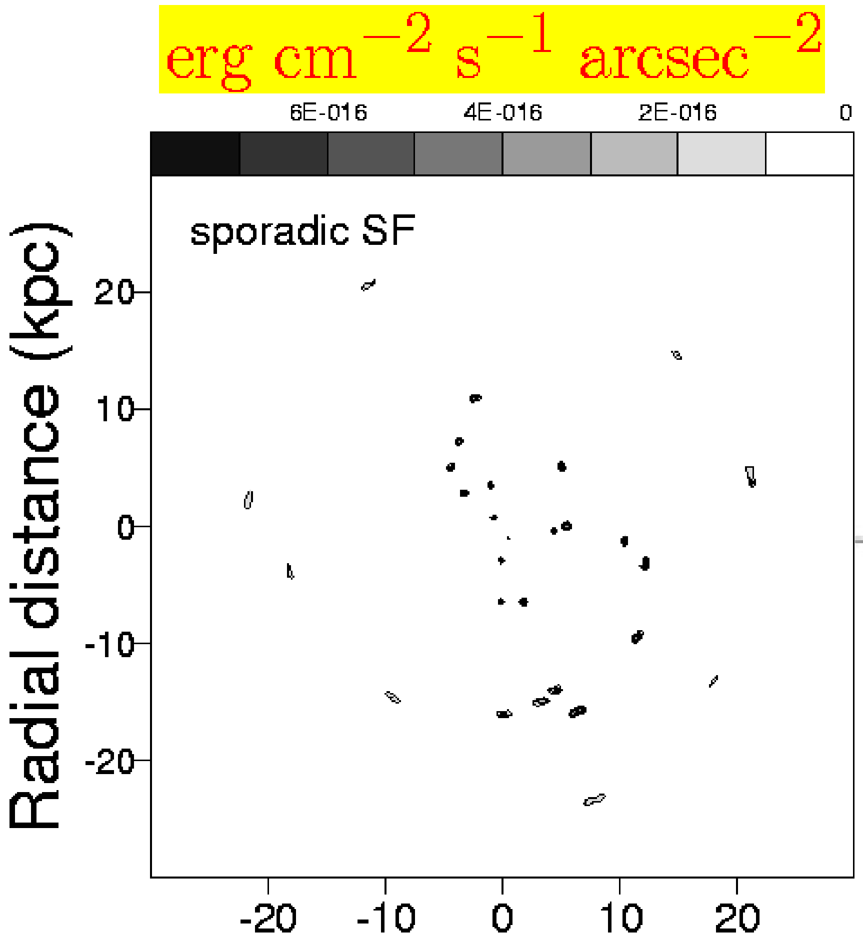
model

ESO-LV 1040220



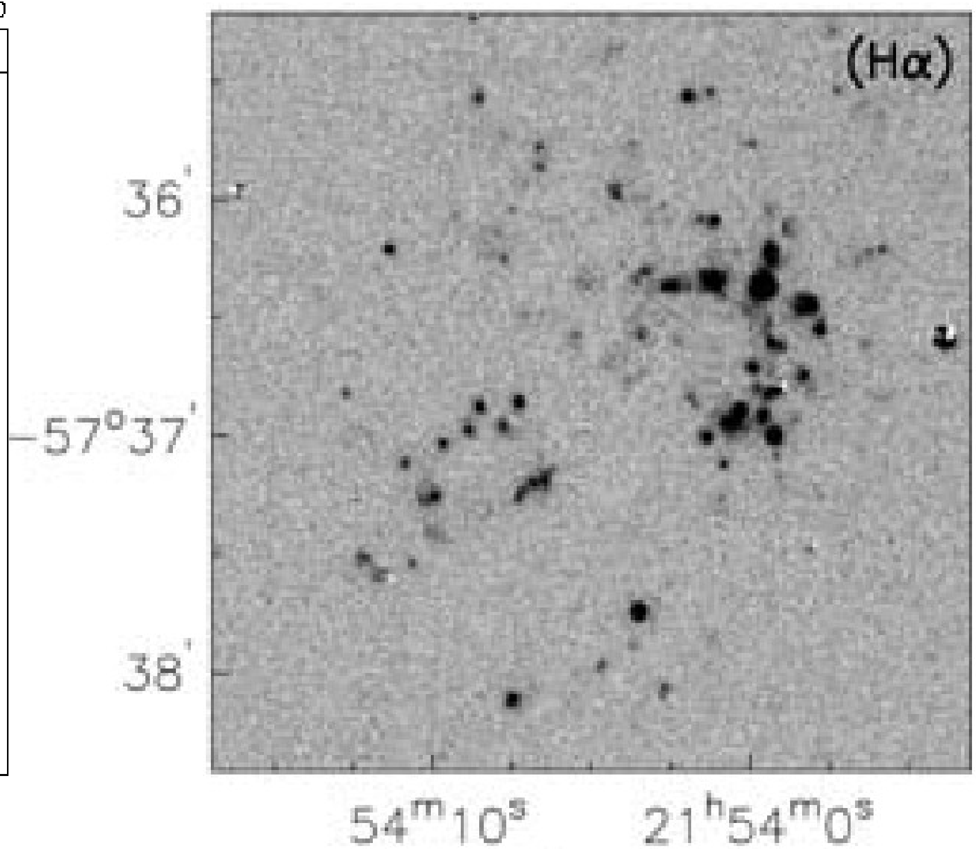
Auld et al 2006

H-alpha emission: sporadic SF



model

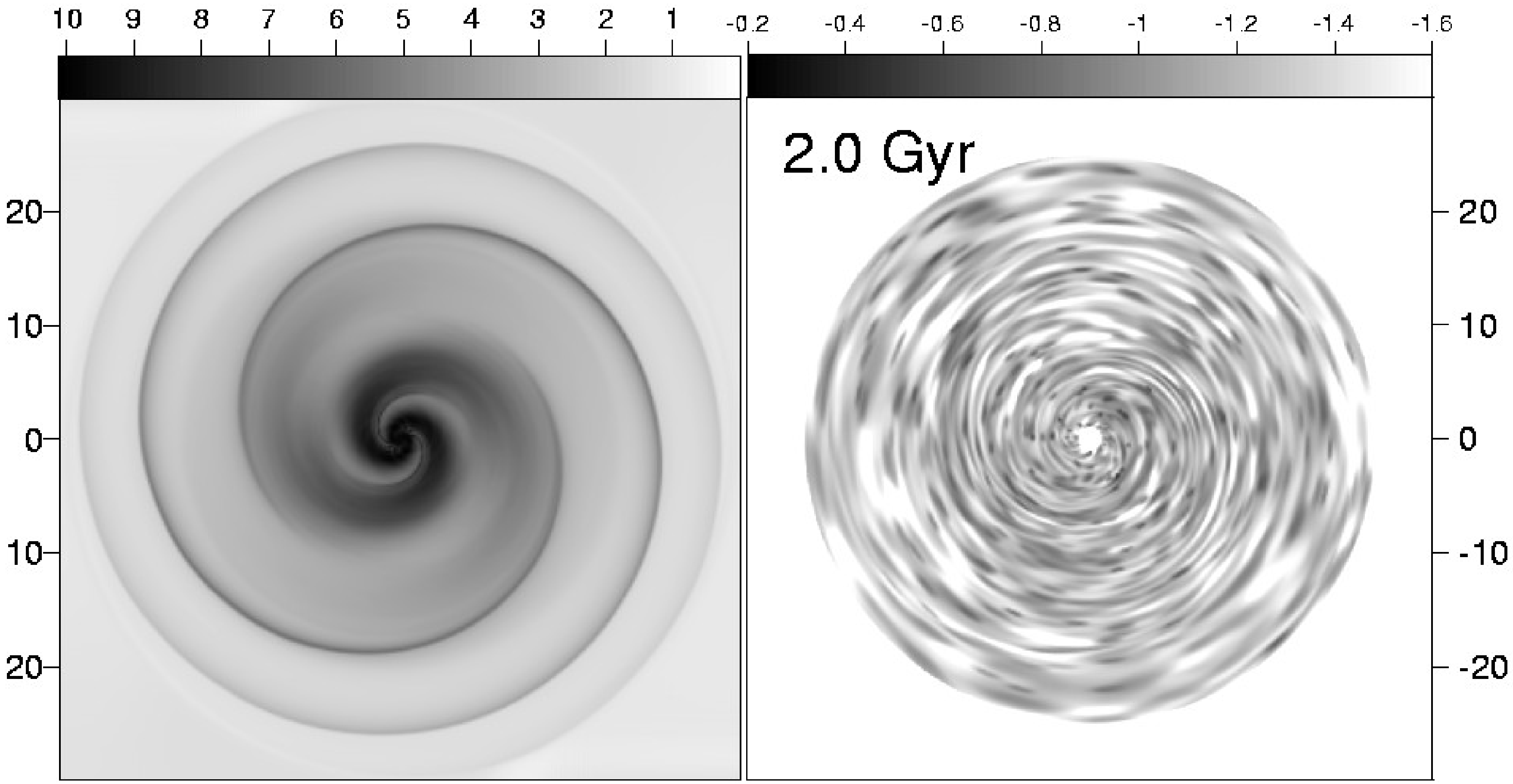
ESO-LV 1450250



Auld et al 2006

- Dynamical model of a LSB

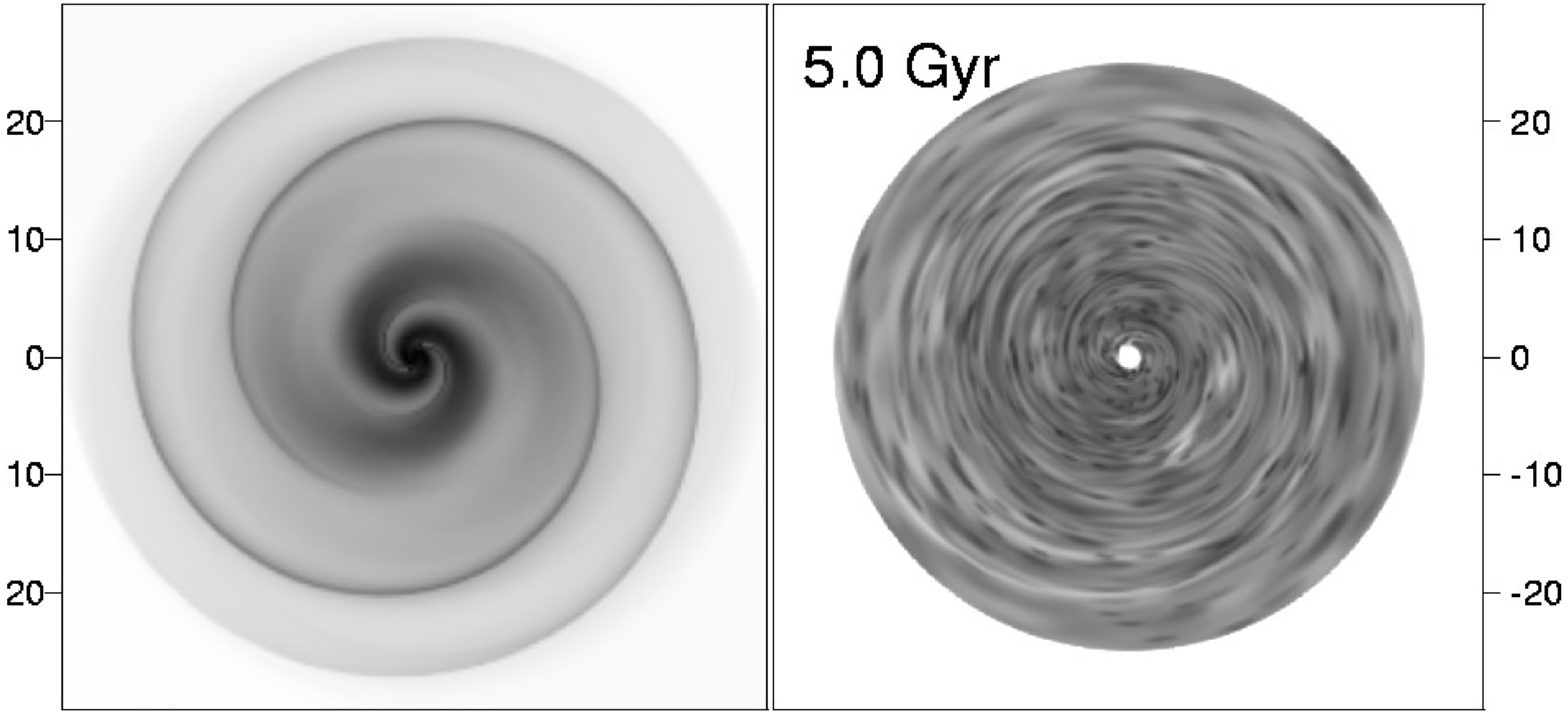
Metal mixing



$$SFR \simeq 0.15 M_{\odot}\ \mathrm{yr}^{-1}$$

Dynamical model of a LSB

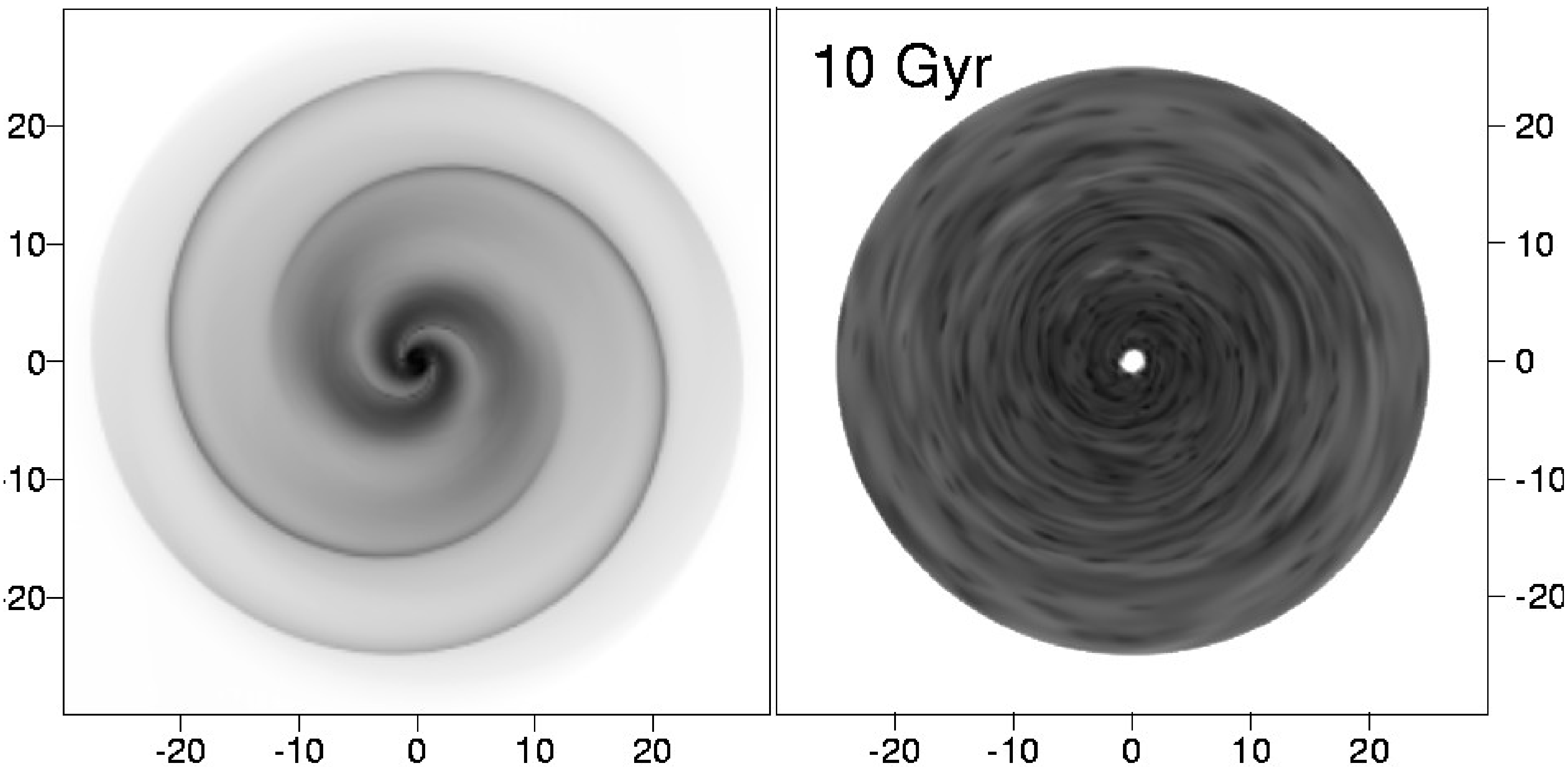
Metal mixing



$$\mathcal{SFR} \simeq 0.15 M_{\odot}\ \mathrm{yr}^{-1}$$

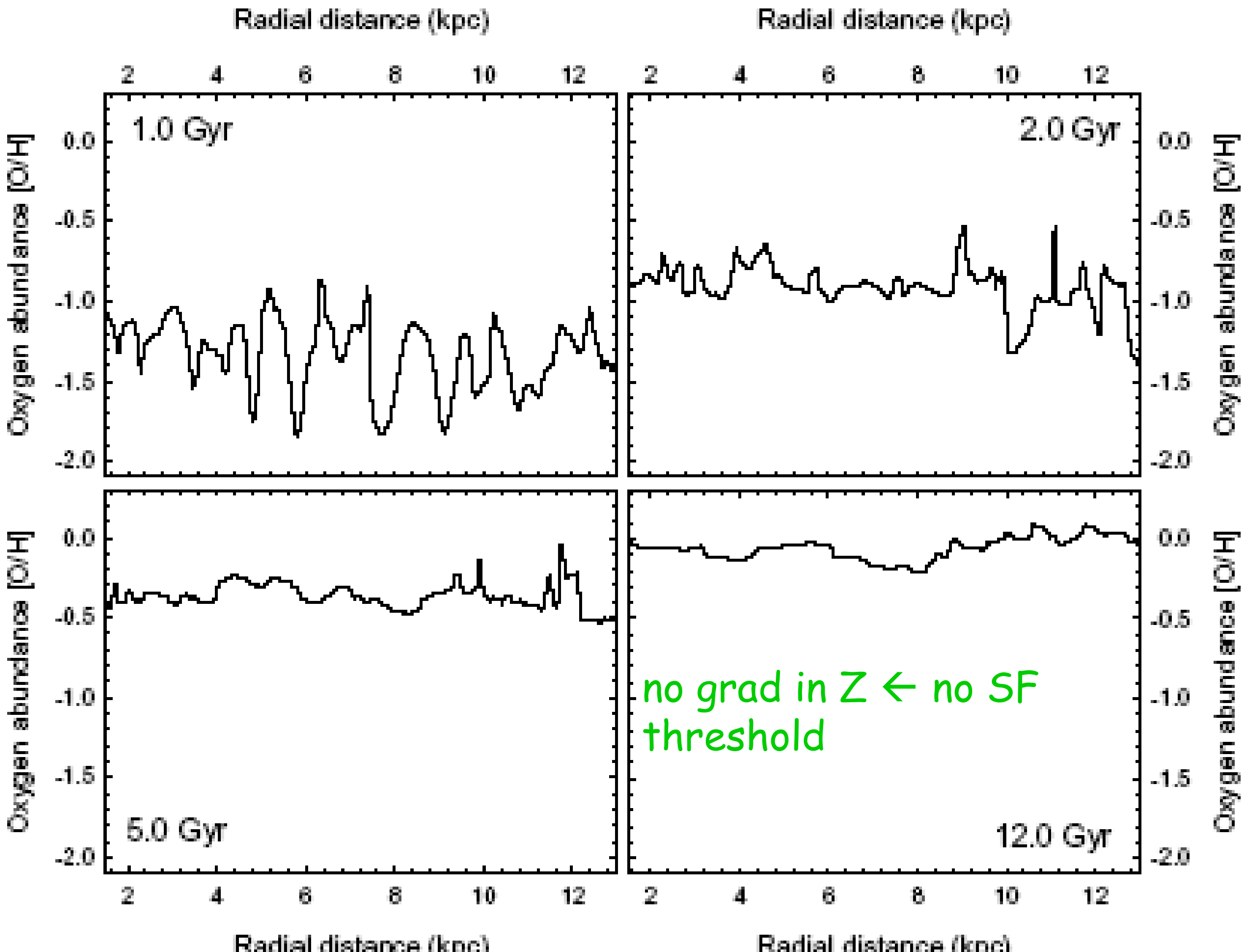
- Dynamical model of a LSB

Metal mixing

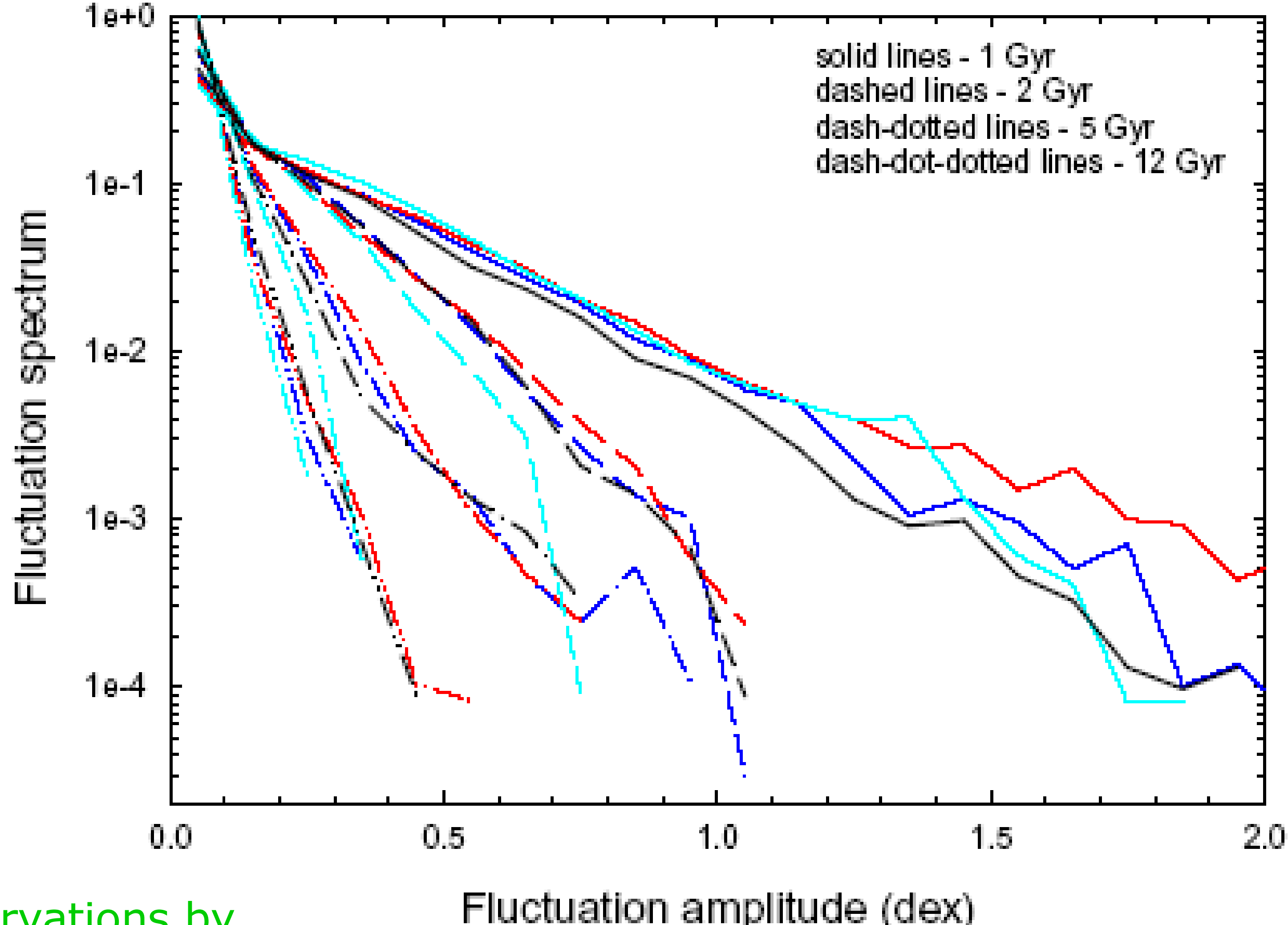


$SFR \simeq 0.15 M_{\odot}\ \mathrm{yr}^{-1}$

Radial distribution of oxygen

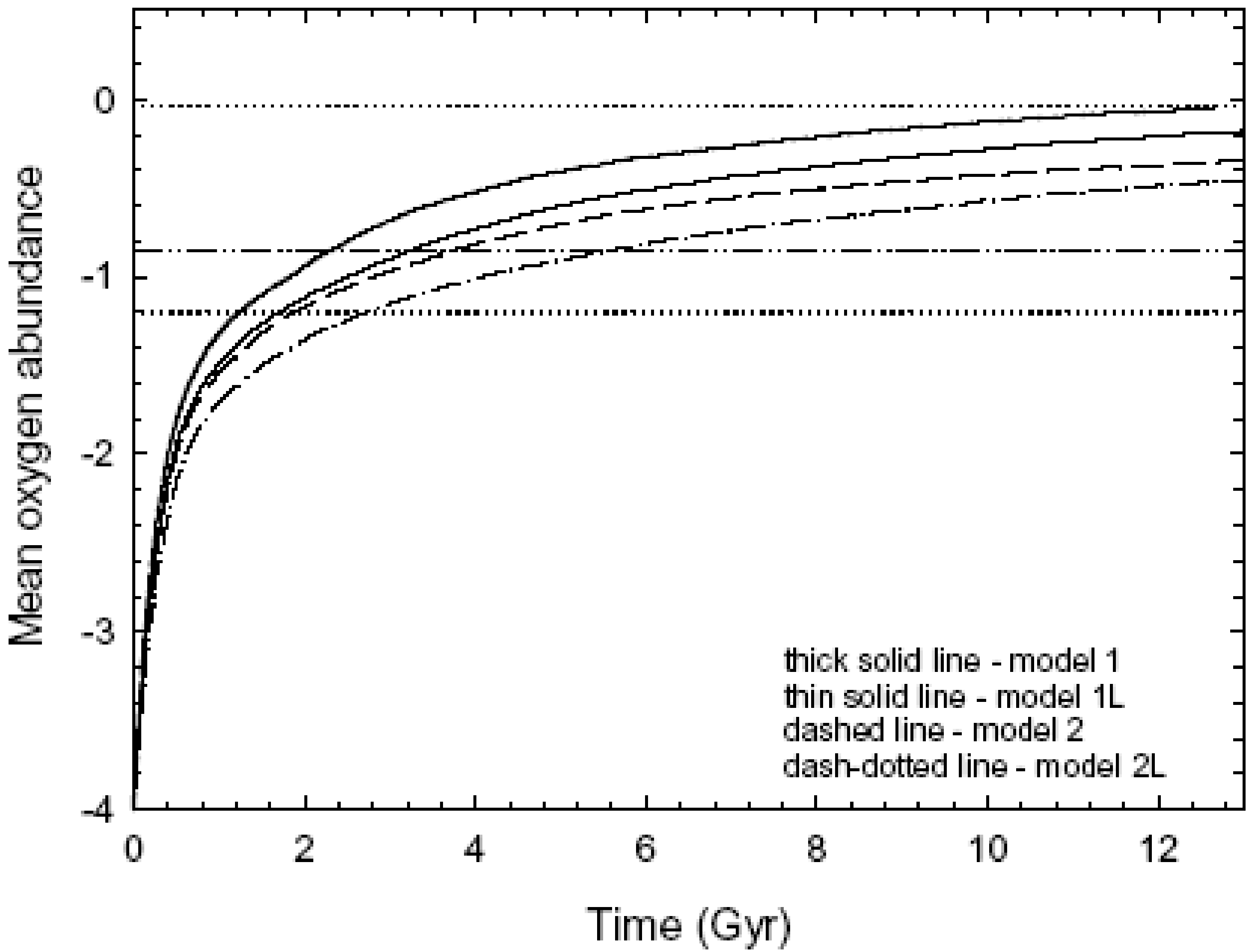


Radial distribution of oxygen

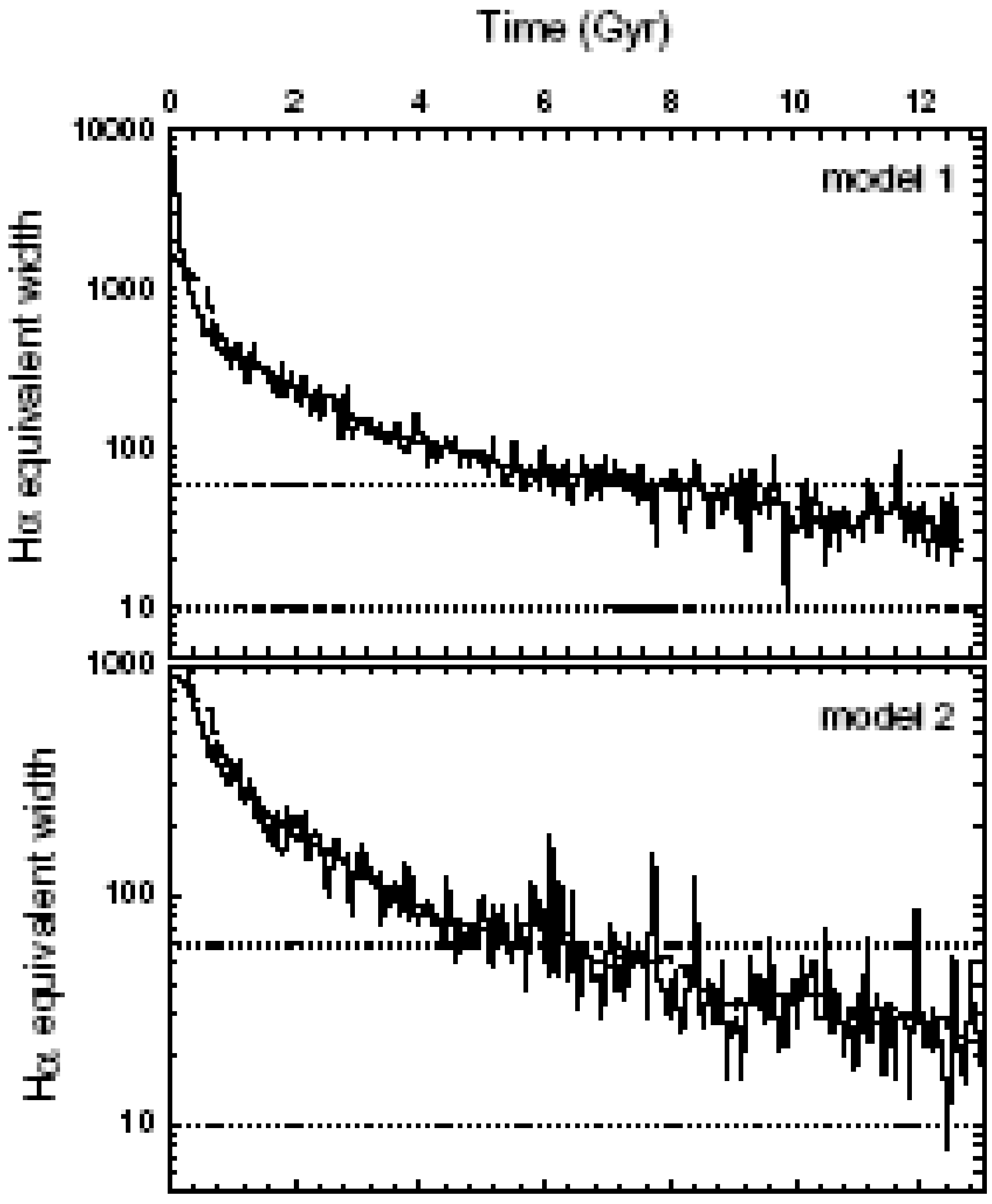


! Observations by
de Block & van der Hulst 1998

Oxygen abundance

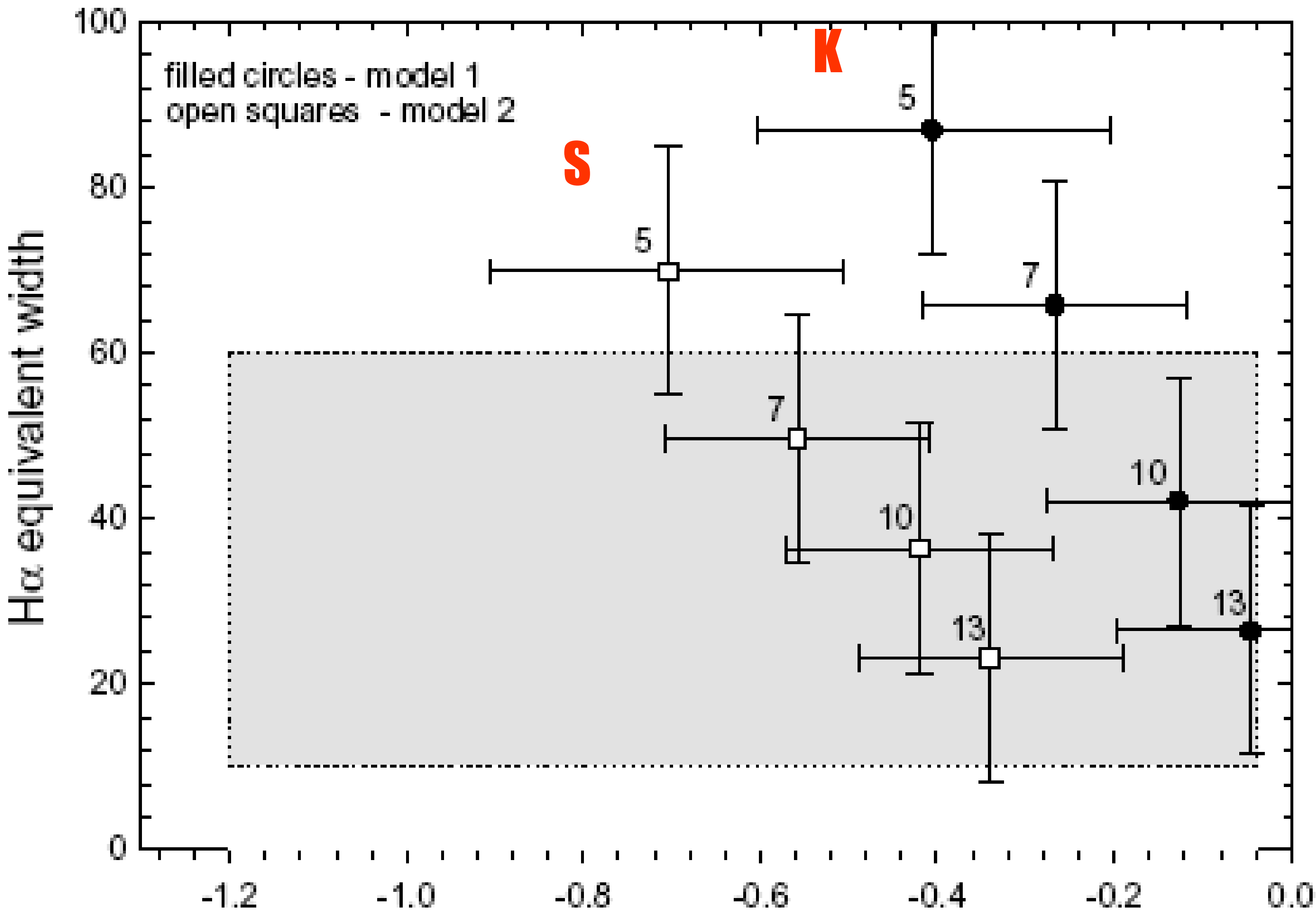


H-alpha EW



Time (Gyr)
0
2
4
6
8
10
12
10000
1000
100
10
model 1
Hα equivalent width
1000
100
10
model 2
Hα equivalent width

Oxygen & H-alpha EW



Conclusions

- Most likely metals are redistributed by differential rotation and in-plane convection driven by spiral motions
- Patchy distribution of metals (1-2 kpc) remains distinguishable (0.5-1.0 dex) on 1-2 Gyr
- The abundance fluctuation spectrum is age-dependent
- [O/H] vs Ha EW seems good for constraining the age provided a preliminary information of the IMF is available
- Combined [O/H] and Ha EW data constrain LSB ages between 7 and 13 Gyr
- It looks reasonable to assume that the observed highly spread metallicity in LSBs reflects their youth