Galactic winds: a link between Ellipticals and the chemical enrichment of the ICM

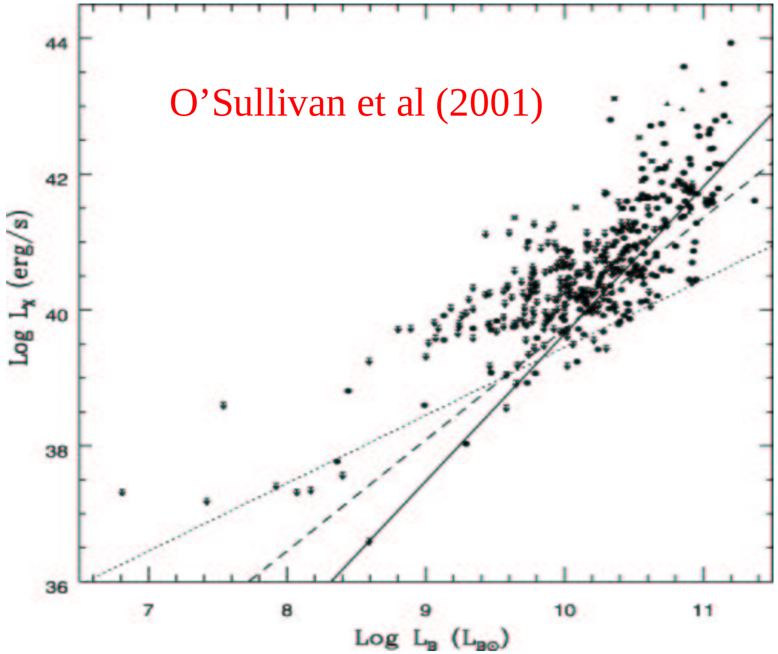
A.Pipino (Dip.Astronomia, Univ. Trieste, Italy)
F.Matteucci (Dip.Astronomia, Univ. Trieste, Italy)
D.Kawata(Swinburne)
B.Gibson(Swinburne)

ABSTRACT

We present preliminary results from a new chemical evolution model meant to be a first step in the self−consistent study of both optical and X−ray properties of elliptical galaxies in cluster of galaxies.
Detailed cooling and heating processes in the interstellar medium are taken into account using a mono−phase one−zone treatment which allows a more reliable modelling of the galactic wind regime with respect to previous work.
The model successfully reproduces simultaneously the mass−metallicity, colour−magnitude and the $L_X - L_B$ *relations, as well as the observed trend of the [Mg/Fe] ratio as a function of* σ*, by assuming that the gas infall and star formation timescales are shorter for brighter objects.*
We found that a late secondary accretion of gas from the environment plays a fundamental role in driving the $L_X - L_B$ *and* $L_X - T$ *relations and can explain their large observational scatter. The iron discrepancy, namely the too high predicted iron abundance in X−ray haloes of ellipticals compared to observations, still persists. On the other hand, we predict [O/Fe] in the ISM which is in good agreement with the most recent observations.*
New predictions for the amounts of iron, oxygen and energy ejected into the intracluster medium are presented and we conclude that Type Ia supernovae play a fundamental role in the ICM enrichment.
SNe Ia activity, in fact, may power a galactic wind lasting for a considerable amount of the galactic lifetime, even in the case for which the efficiency of energy transfer into the ISM per SN Ia event is much less than unity.

X−Raying ellipticals...

- **ISM in EGs first detected in the '70:**
  - X−ray halo extending out to 50−100 kpc
  - ISM mass ≈ 1% luminous
  - $T_X \approx T_{Vir} \approx 1$ keV
  - In massive EGs: $L_X \approx L_B^2$



Chemical abundances in the hot ISM

- ASCA: $X_{Fe,ISM} << X_{Fe,Stars} << X_{Fe,Model}$: Fe−discrepancy (Arimoto et al. 1997)
- XMM, Chandra: $X_{Fe,ISM} \approx X_{Fe,Star}$ (solar) $<< X_{Fe,Model}$
- O, Ca underabundant w.r.t. Fe (i.e. −0.5 dex within 50 kpc) + positive radial gradient
- Si, Mg ≈ solar
- At large radii (100 kpc), the ISM chemical properties reach the values typical of the ICM

Chemical evolution model

- Chemical code + prescriptions by Pipino & Matteucci (2004, PM04) on IMF (Salpeter), yields, star−formation and infall timescales
- 1−zone model extending out to 10 effective radii
- New formulation for the ISM energetics (cooling functions by Sutherland & Dopita, detailed treatment of SNIa and SNII)
- Possibility for secondary accretion (inflow) episodes
- Self−consistent mass flow rate during galactic winds
- Self−consistent prediction of both optical and X−ray properties of EGs
- Modelling of the ICM/IGM enrichment

Equation of the chemical evolution for an element *i*

$$
\begin{aligned}
\frac{dG_i(t)}{dt} &= -\psi(t)X_i(t) + \\
&+ \int_{M_L}^{M_{Bm}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm + \\
&+ A\int_{M_{Bm}}^{M_{BM}} \phi(m)\left[\int_{\mu_{min}}^{0.5} f(\mu)\psi(t-\tau_{m_2})d\mu\right] dm + \\
&+ (1-A)\int_{M_{Bm}}^{M_{BM}} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm + \\
&+ \int_{M_{BM}}^{M_U} \psi(t-\tau_m)Q_{mi}(t-\tau_m)\phi(m)dm + \\
&+ \left(\frac{dG_i(t)}{dt}\right)_{infall} - W(t)X_i(t) + \left(\frac{dG_i(t)}{dt}\right)_{acc},
\end{aligned}
$$

Mass returned from dying stars:

detailed computation of SNIa, SNII explosion rates. Stellar lifetimes are taken into account.

NOVELTIES:

$$
\left(\frac{dG_i(t)}{dt}\right)_{infall} = X_{i,infall} C e^{-\frac{t}{\tau}},
$$

Main (fast) infall

The creation of the spheroid: primordial lumps of gas are assumed to fall on the galactic potential well.

Mass flow rate (galactic wind)

Energy feedback from stars, SNIa and SNII. The galaxies undergo a strong wind when the gas thermal energy becomes greater than its potential energy. The mass flow rate is consistently evaluated from the available energy.

$$
\left(\frac{dG_i(t)}{dt}\right)_{acc} = X_{i,acc}\frac{M_{acc}}{M_{lum} t_0},
$$

Secondary infall

The secular mild accretion of gas of primordial composition is assumed to be constant in time.

Chemical code

Virialized system

SN explosion rate,
$\varepsilon_{SNIa,SNII}=0.1$, $E_0=10^{51}$ erg

M_{gas} , ρ_{gas}, Z

$$\Gamma_{SN} = \epsilon_{SNIa} E_0 R_{SNIa} + \epsilon_{SNII} E_0 R_{SNII} \,,$$

Cooling term

(cooling functions: MappingsIII, Sutherland & Dopita)

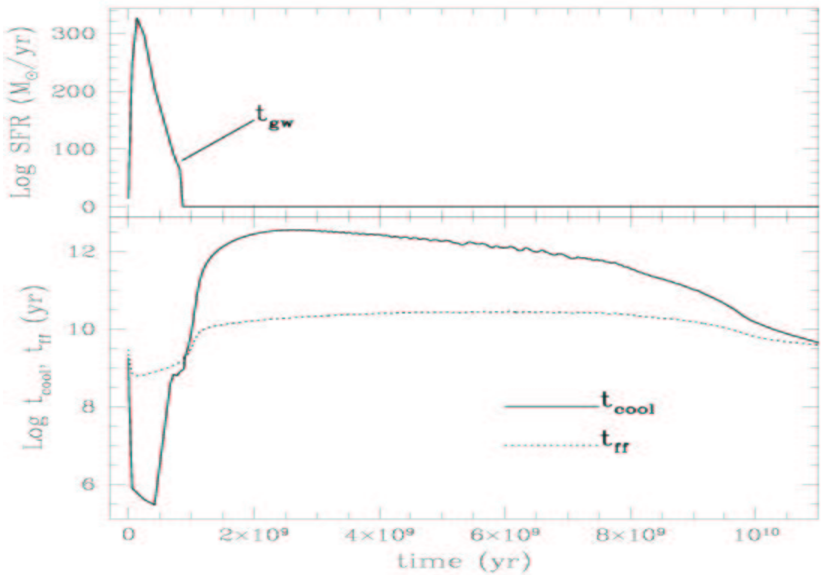
Heating

$$\frac{du_{th}}{dt} = \frac{\Gamma_{SN}}{M_{gas}} - \frac{n_H^2 \Lambda(Z,T)}{\rho_{gas}} + \frac{1}{M_{gas}} \frac{dM_*}{dt} \cdot (u_{vir} - u_{th})$$

X−ray emission

Feedback

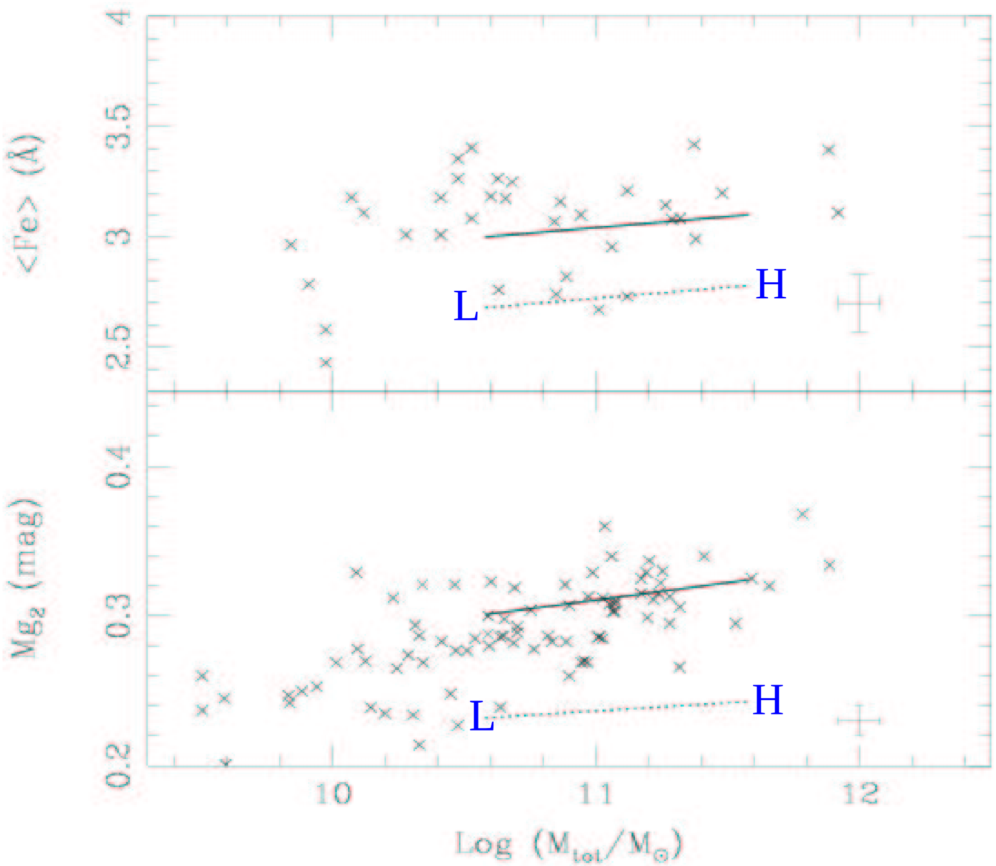
(galactic wind if $E_{th} > E_{bin}$)



Star formation history for a typical galactic model:
SF stops when $t_{cool} > t_{dyn}$

Results: the stellar component

- Test independent from the 2nd infall
- Simultaneous match of:
- Mass−Metallicity rel.
- Mg/Fe − σ rel.
- Color−Magnitude rel.
- Predictions from PM04 are confirmed. In order to satisfy the above relations:
- ν (star formation efficiency) increases with galactic mass
- τ (infall timescale) decreases with galactic mass
- Redshift of formation of 3
- Typical $\varepsilon_{SNIa,\,SNII}$ = 10% is enough for teh wind to develop



Crosses: data from Kuntschner 2000, Kuntschner et al 2001

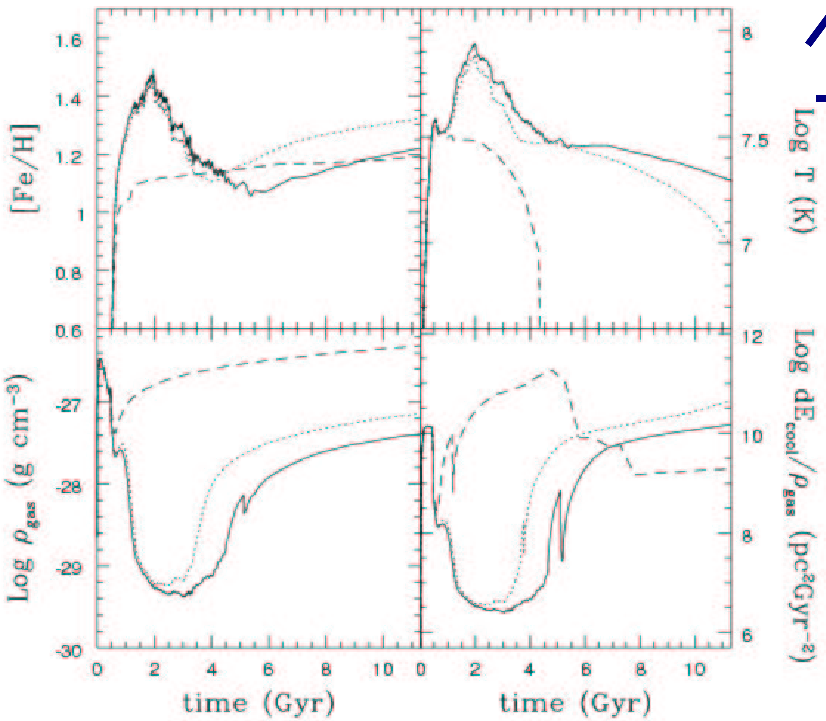
- L: Low mass = 10^{11} M_{sun}
- H: High mass = 10^{12} M_{sun}

Results: ISM energetics

We varied the amount of primordial gas accreted during the secondary infall.
We produced a fake spectrum starting from the ISM temperature and metallicity. Then we derived the X−ray luminosity and compared model results with observations.

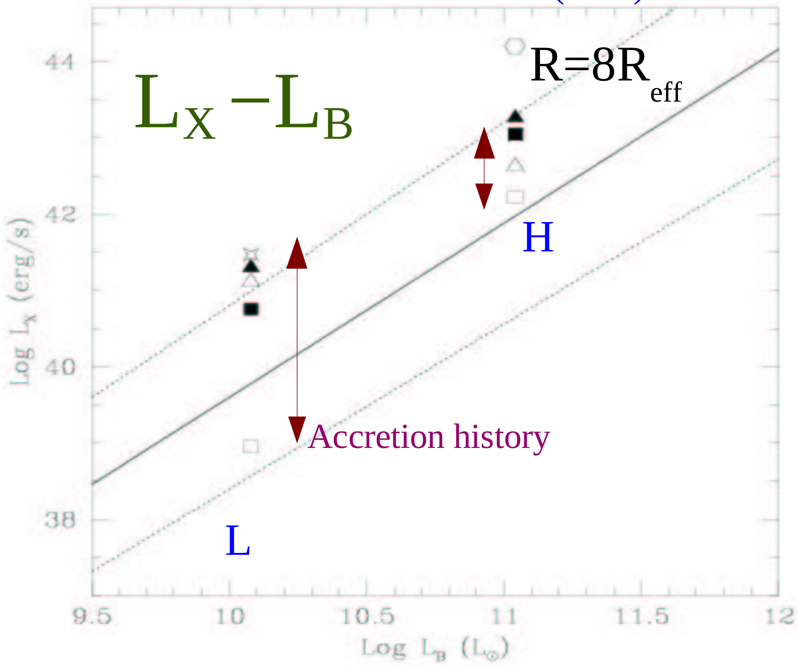
ISM of model H

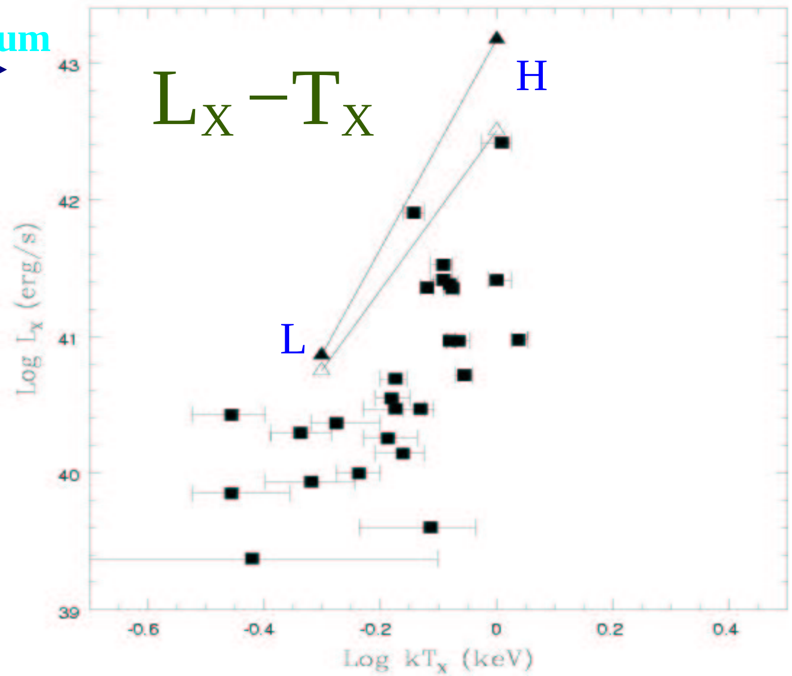
- No accretion (solid)
- High accretion (dashed)
- Mild accretion (dotted)



XSPEC fake spectrum

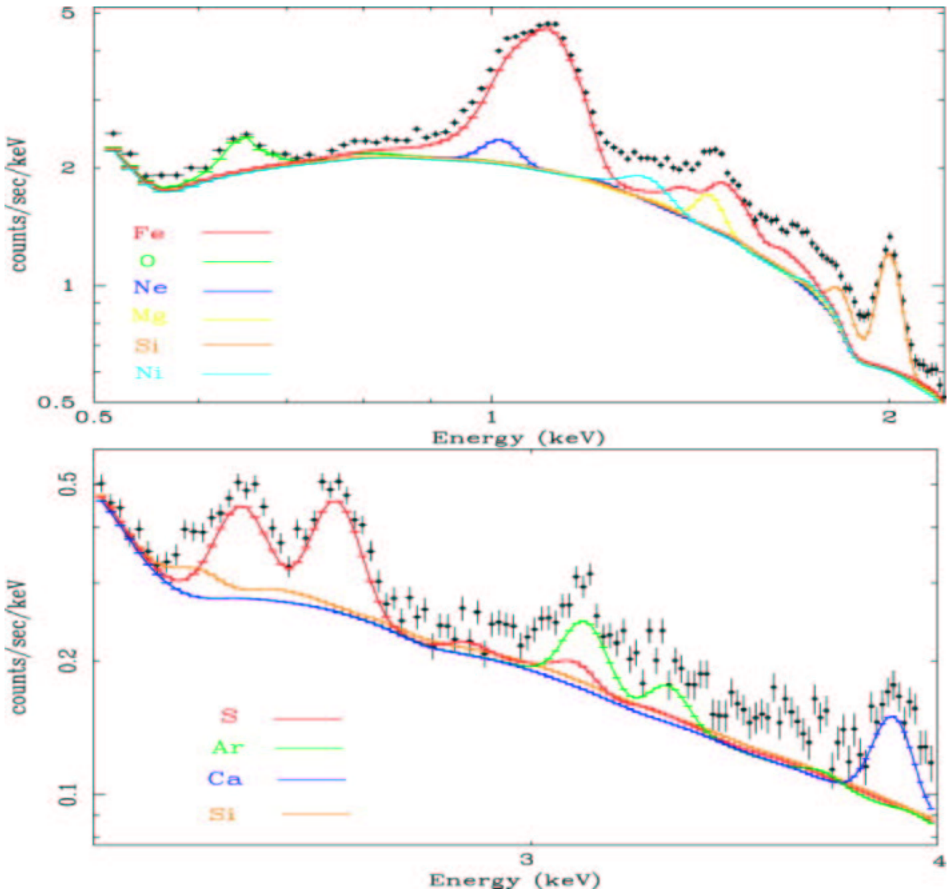
Solid:fit to O'Sullivan et al's (2001) data





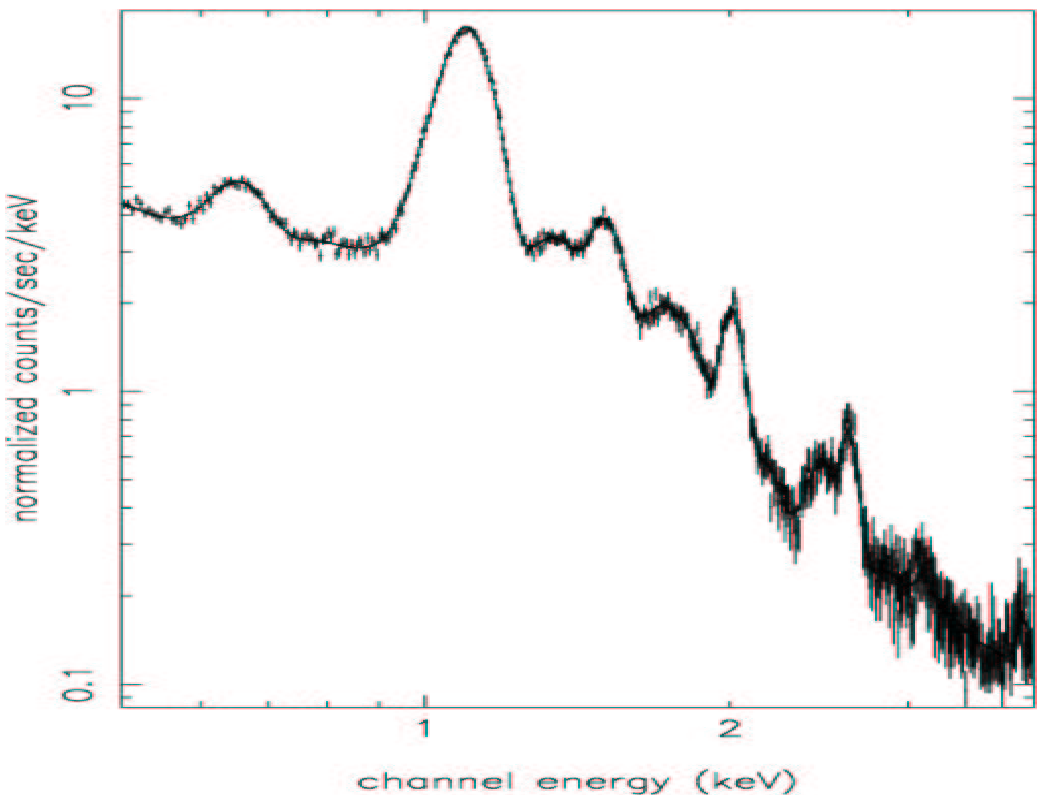
Boxes:data from Matsushita et al (2000)

Results: comparing the spectra



M87 (Gastaldello & Molendi 2002)

Predicted spectrum for the best model (this work)

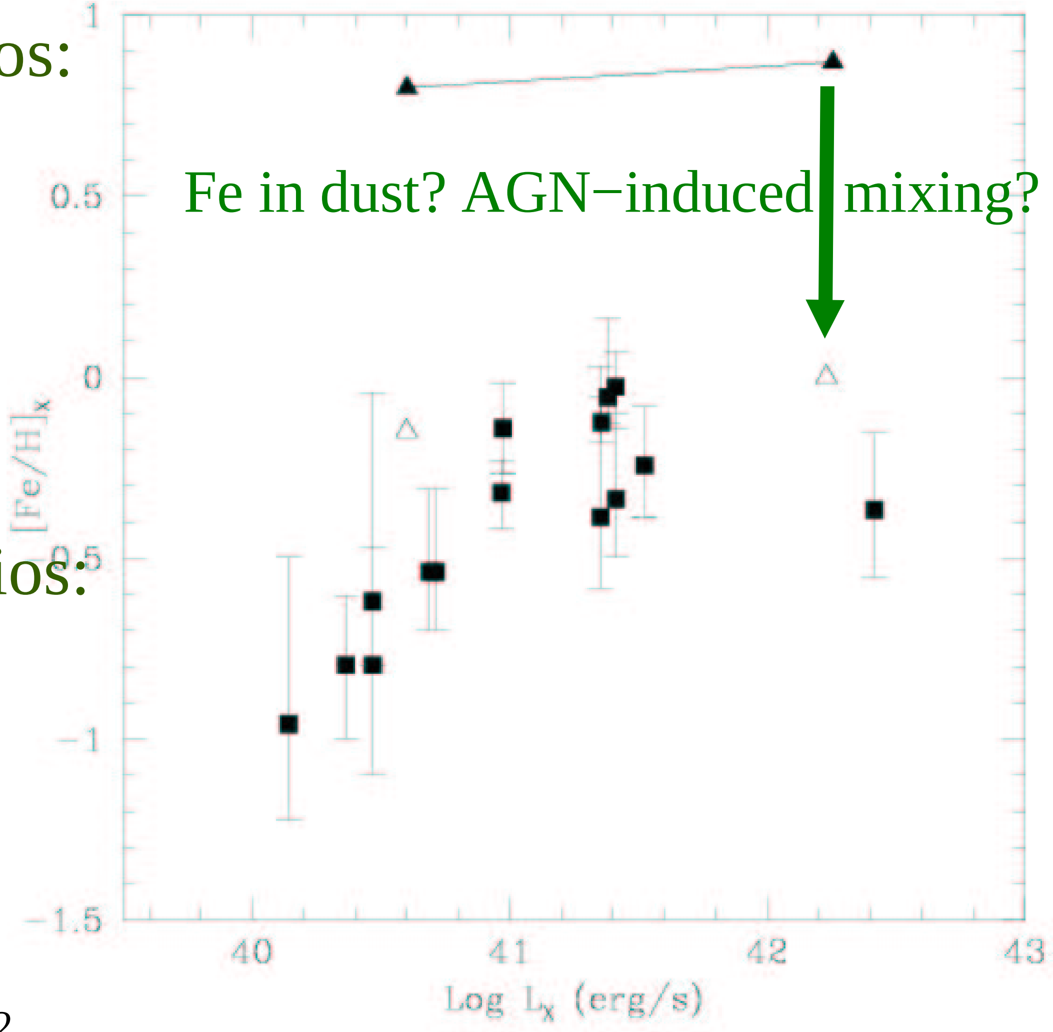


Results: the chemistry of the ISM

Predicted Fe abundance in the ISM ≈ 8 times the solar value
How to reconcile it with observations?

Predicted abundance ratios:
[O,Mg/Fe]=−0.6 dex
[Ca,Si/Fe]=−0.3 dex

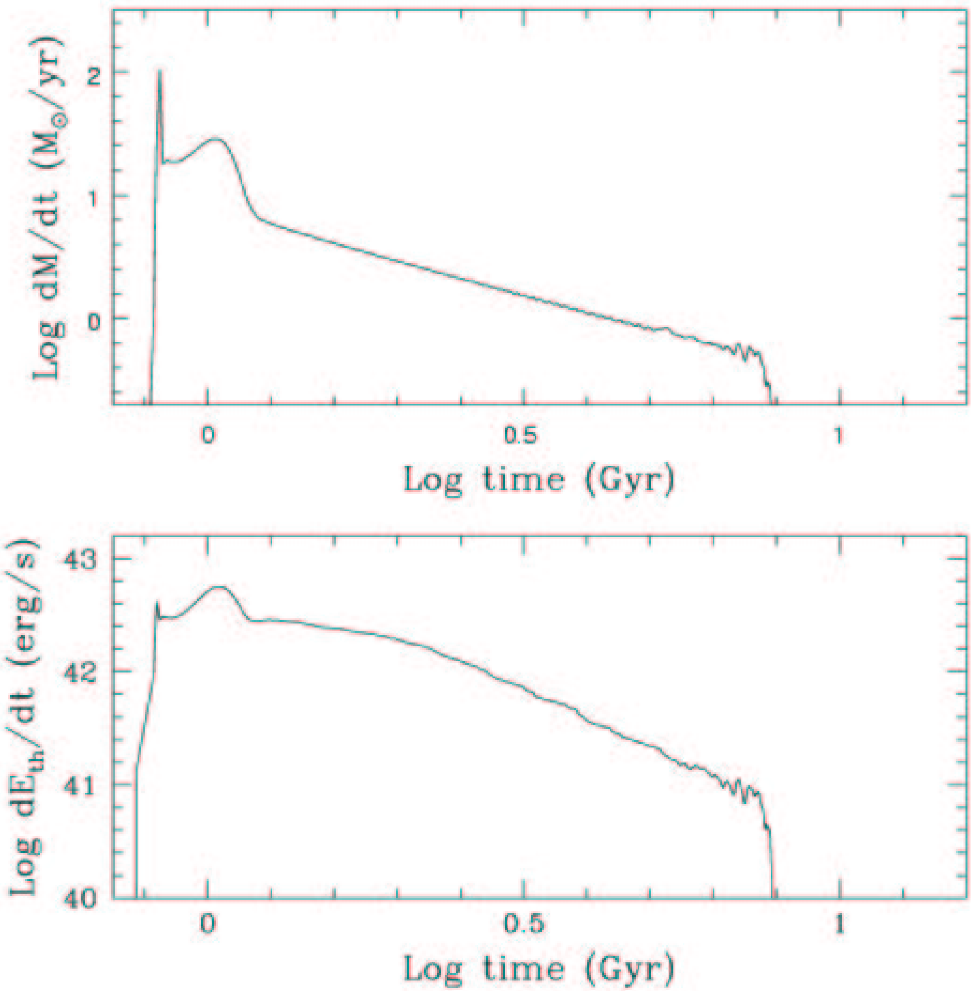
Observed abundance ratios:
[O/Fe]= −0.5 dex
[Ca/Fe]= −0.3 dex
[Mg/Fe]= −0.1/0 dex
[Si/Fe]= 0 dex



(e.g. Buote et al 2003, Sakelliou et al. 2002, Gastaldello & Molendi 2002, Xu et al. 2002)

Boxes:data from Matsushita et al (2000)

Predicted mass and energy flow rate for a typical galaxy:



$(dM/dt)_{wind} \sim \psi$

$V_{wind} = (2\, dE/dM)^{1/2} = 200$ Km/s

In agreement with observations of local starburst galaxies

Galaxies pollute the ICM/IGM in metals and energy well before redshift 1.

Conclusions − Ellipticals formation:

- The simultaneous fitting of the Colour − Magnitude, Mass −Metallicity and Mg/Fe −σ relations in ellipticals, implies that the star formation and the infall timescales should decrease with galactic mass (see PM04).

- Therefore the more massive galaxies undergo a stronger and faster assembly history than the less massive ones.

Conclusions –Hot haloes:

- At the same time secondary secular inflow might drive the $L_X - L_B$ relation. The observed scatter being possibly related to the different accretion histories.
- The iron discrepancy still persists. Fe could be hidden in dust grains or removed by a mixing process induced by AGN activity.
- [O/Fe], [Ca/Fe] in the ISM are in good agreement with new XMM and Chandra observations in the cores of the galactic haloes.

Conclusions − ICM enrichment:

- ICM: ellipticals undergo galactic wind for a long phase of their life (even if $\varepsilon_{SNIa} << 1$). The Fe mass in the ICM is recovered with a Salpeter IMF.
- Predicted energy injected into the ICM: 0.4 keV per particle (in line with our earlier estimates, Pipino et al 2002)
- Predicted [O/Fe] < −0.5 in better agreement with new observations of cluster cores (i.e. −0.2 dex on average).
- Other elemental abundances still too uncertain to represent reliable constraints.

References:

Arimoto, N., Matsushita, K., Ishimaru, Y., Ohashi, T., Renzini, A. 1997, ApJ, 477, 128

Buote, D.A., Lewis, A.D., Brighenti, F., Mathews, W.G. 2003, ApJ, 595, 151

Gastaldello, F., Molendi, S. 2002, ApJ, 572, 160

Kuntschner, H. 2000, MNRAS, 315, 184

Kuntschner, H., Lucey, J.R., Smith, R.J., Hudson, M.J., Davies, R.L. 2001, MNRAS, 323, 615

Matsushita, K., Ohashi, T., Makishima, K. 2000, PASJ, 52, 685

O'Sullivan, E., Forbes, D.A., Ponman, T.J. 2001, MNRAS, 328, 461

Pipino, A., Matteucci, F. 2004, MNRAS, 347, 968 (PM04)

Pipino, A., Matteucci, F., Borgani, S., Biviano, A. 2002, NewA, 7, 227

Sakelliou, I., Peterson, J.R., Tamura, T., Paerels, F.B.S., Kaastra, J.S., et al. 2002, A&A, 391, 903

Salpeter, E.E. 1955, ApJ, 121, 161

Sutherland, R.S., Dopita, M.A. 1993, ApJS, 88, 253

Xu, H., Kahn, S.M., Peterson, J.R., Behar, E., Paerels, F.B.S., Mushotzky, R.F. et al. 2002, ApJ, 579, 600