The chemical evolution of elliptical galaxies:
Insights from semi-analytic modelling

Rob Yates

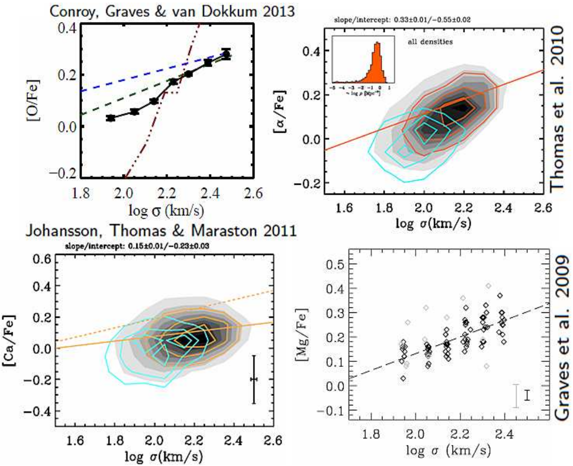
with Bruno Henriques, Peter Thomas, Guinevere Kauffmann, Jonas Johansson & Simon White

EWASS 2013: Symposium 4

9th July 2013

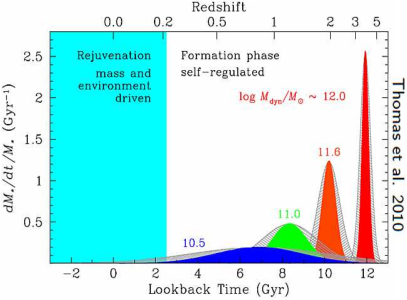
Observations

Observed M_*-[α/Fe] relations

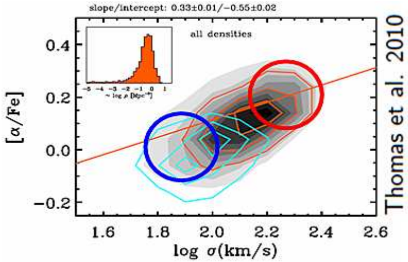


A **positive correlation** between σ (i.e. M_*) and α enhancement is found in local ellipticals.

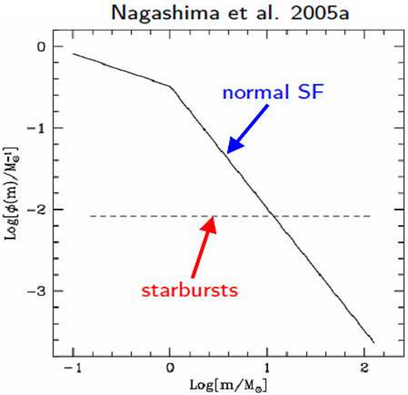
1) Shorter τ_{SF} in massive ellipticals



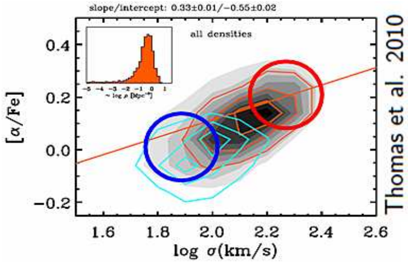
- **Massive ellipticals:**
  Form stars over shorter timescales
  $\Rightarrow$ high $[\alpha/\mathrm{Fe}]$
- **Low-mass ellipticals:**
  Form stars over longer timescales
  $\Rightarrow$ low $[\alpha/\mathrm{Fe}]$



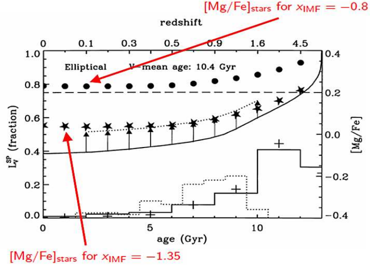
2) Top-heavy IMF in massive ellipticals

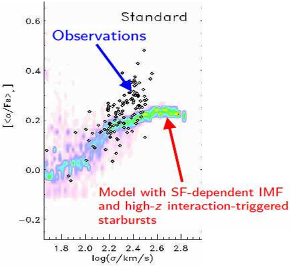


- **Massive ellipticals:**
  Form more massive stars per SSP
  ⇒ high [α/Fe]
- **Low-mass ellipticals:**
  Form fewer massive stars per SSP
  ⇒ low [α/Fe]



Top-heavy IMF in massive ellipticals?





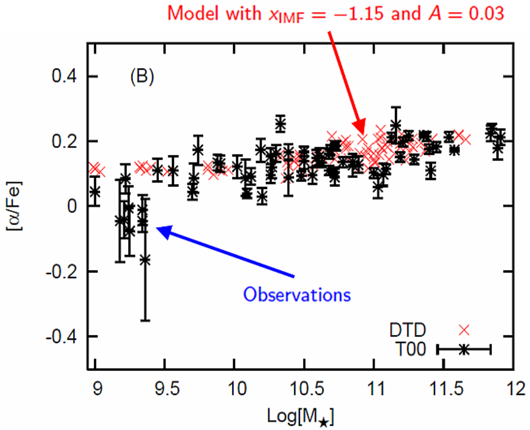
Thomas (1999)

"Only under the assumption that **the IMF is significantly flattened** with respect to the Salpeter value during the [major-merger-induced] starburst, can a Mg/Fe overabundant population be obtained."

Calura & Menci (2009)

"By **assuming a SF-dependent IMF**,. . . the observed correlation between [α/Fe] and σ can be accounted for."

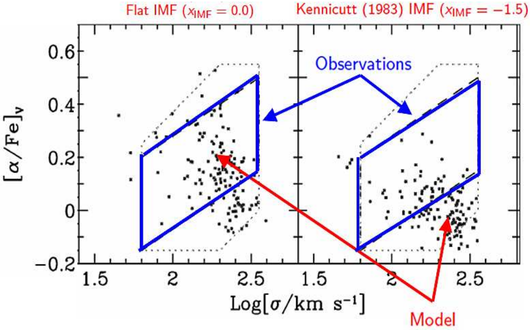
Top-heavy IMF in massive ellipticals?



Arrigoni et al. (2010a)

"We reproduce the observed positive slope of the M_*-$[\alpha/\mathrm{Fe}]$ relation... [when using] **a very mildly top-heavy IMF** ($x = -1.15$)."

Top-heavy IMF in massive ellipticals?



Nagashima et al. (2005b)

"The α element abundance in ellipticals is consistent with observed values **only if the top-heavy IMF is used**."

"...**none of the models reproduces the observed increase of α/Fe with σ**."

(see also Pipino et al. 2009b)

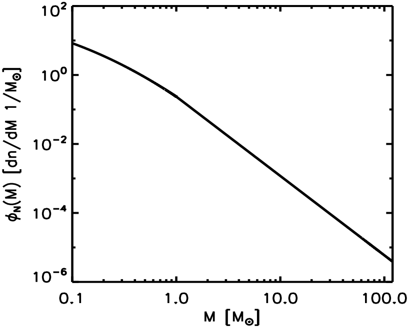
Chemical evolution modelling

Inputs to the GCE model

$$e_{\mathrm{Z}}(t) = \int_{M_L}^{M_U} M_{\mathrm{Z}}(M, Z_0)\ \psi(t - \tau_{\mathrm{M}})\ \phi(M)\ \mathrm{dM}$$

1) Initial mass function (IMF)

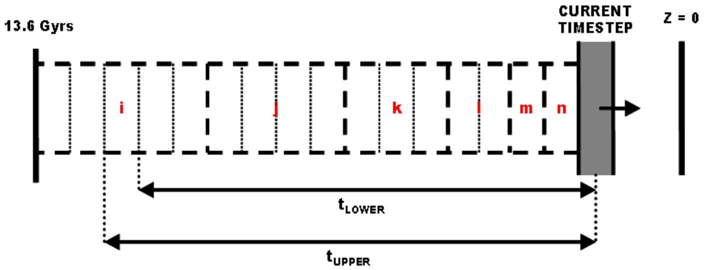
$$e_Z(t) = \int_{M_L}^{M_U} M_Z(M, Z_0)\, \psi(t - \tau_M)\, \phi(M)\, \mathrm{dM}$$



Standard *Chabrier (2003)* IMF, fixed across time and space

2) Star formation histories (SFHs)

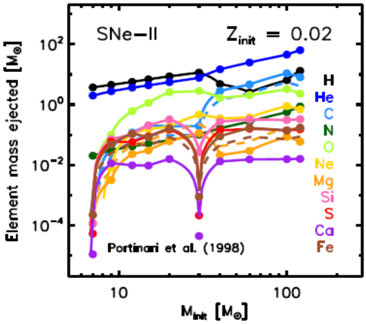
$$e_Z(t) = \int_{M_L}^{M_U} M_Z(M, Z_0)\ \psi(t - \tau_M)\ \phi(M)\ \mathrm{dM}$$



3) Metal yields

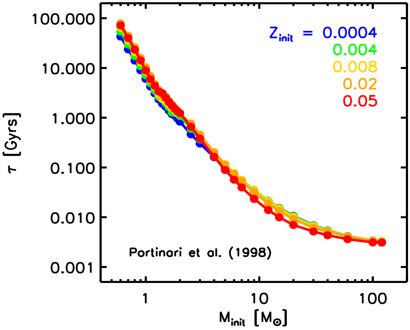
$$e_Z(t) = \int_{M_L}^{M_U} M_Z(M, Z_0)\ \psi(t - \tau_M)\ \phi(M)\ dM$$

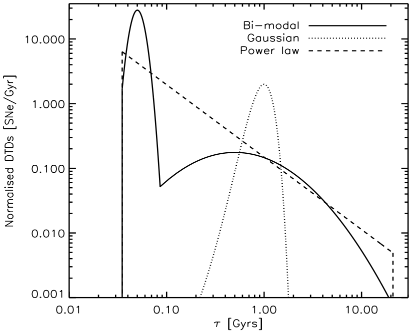
- **AGB:** *Marigo (2001)*
- **SN-Ia:** *Thielemann et al. (2003) (W7 model)*
- **SN-II:** *Portinari et al. (1998)*



4) Stellar lifetimes

$$e_Z(t) = \int_{M_L}^{M_U} M_Z(M, Z_0)\, \psi(t - \tau_M)\, \phi(M)\, \mathrm{dM}$$

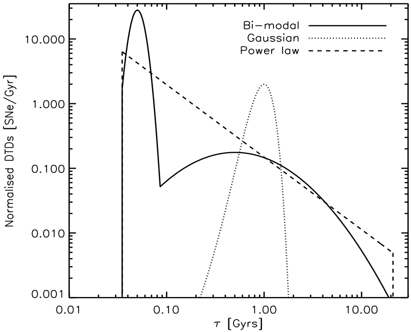




4) Stellar lifetimes

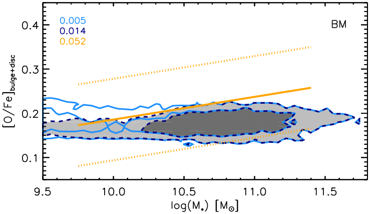
$$e_Z(t) = \int_{M_L}^{M_U} M_Z(M, Z_0)\, \psi(t - \tau_M)\, \phi(M)\, \mathrm{dM}$$

- **BM:** *Mannucci et al. (2006)*
- **PL:** *Maoz et al. (2012)*
- **NG:** *Strolger et al. (2004)*

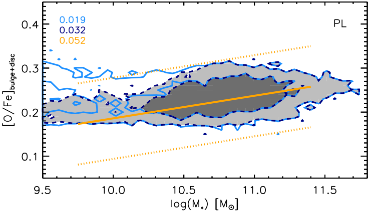


Model elliptical galaxies

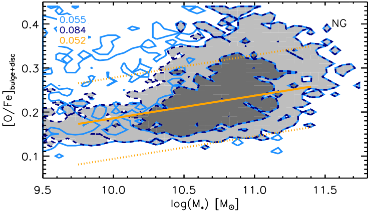
Model M_*-[O/Fe] relation



58 % prompt SNe-Ia



48 % prompt SNe-Ia

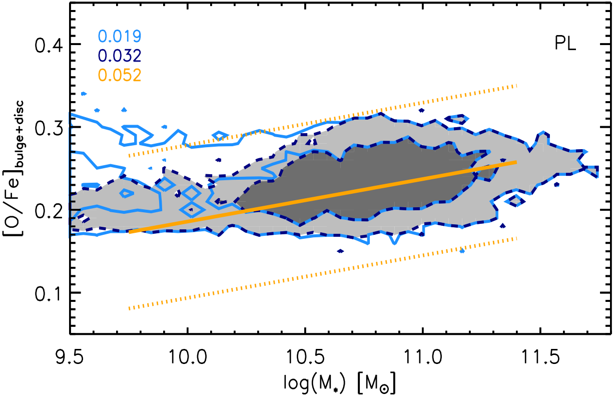


$\sim$ 0 % prompt SNe-Ia

(where ‘prompt’ means $\lesssim$ 400 Myrs)

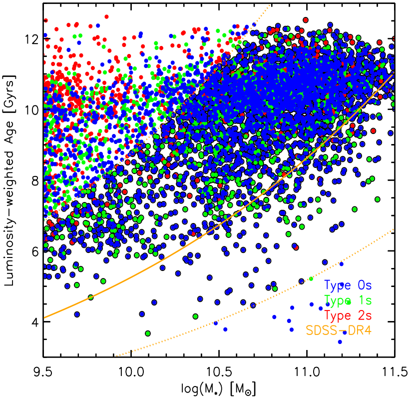
Slope of the M_*-[O/Fe] relation increases with decreasing SN-Ia prompt fraction

Improving the slope. . .



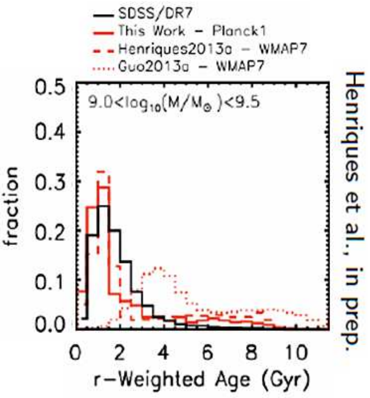
For full elliptical sample (light blue contours), some low-M_* galaxies are too α enhanced. . .

1) Model ages



Some very old, low-mass ellipticals in the model

1) Model ages

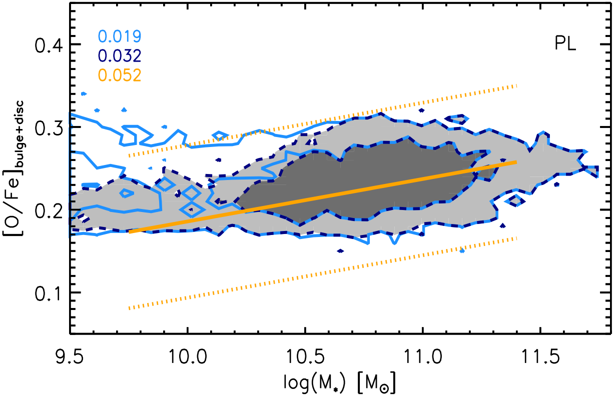


Ongoing improvements:

- Reincorporation of gas onto galaxies over longer timescales *(Henriques et al. 2013)*
- SFR proportional to H_2 density *(Fu et al. 2013)*
- Reduction in ram pressure stripping efficiency in galaxy groups *(Henriques et al. in prep.)*

Some very old, low-mass ellipticals in the model

PL: Model M_*-[O/Fe] relation

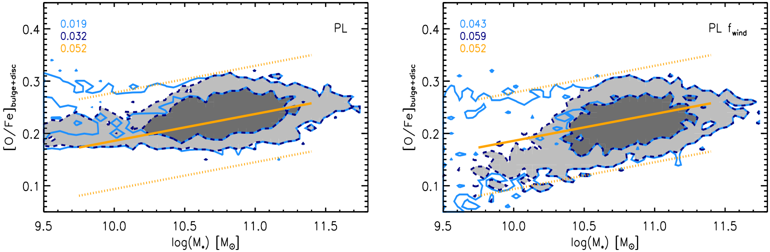


Steeper slopes for the mass-age-selected sample (dark blue, dashed contours)

2) Metal-rich winds from SNe-II

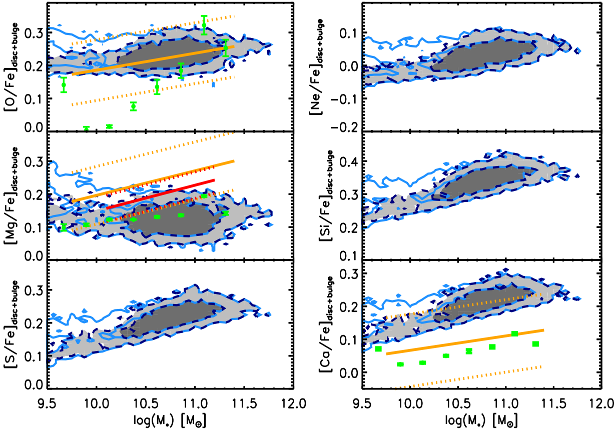
$$f_{\text{wind}} = \min\left[1.0, \left(\frac{\Sigma_{\text{cold}}}{10\ \text{M}_{\odot}\text{pc}^{-2}}\right)^{-1}\right]$$

Oxygen rich, α enhanced, and shortly after SF. *(e.g. Martin et al. 2002; Tumlinson et al. 2011)*



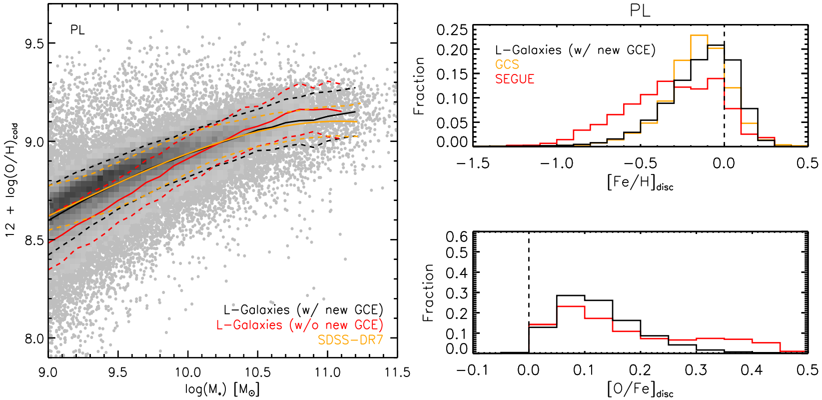
Including SN-II-driven galactic winds increases slopes

PL: [α/Fe] relations



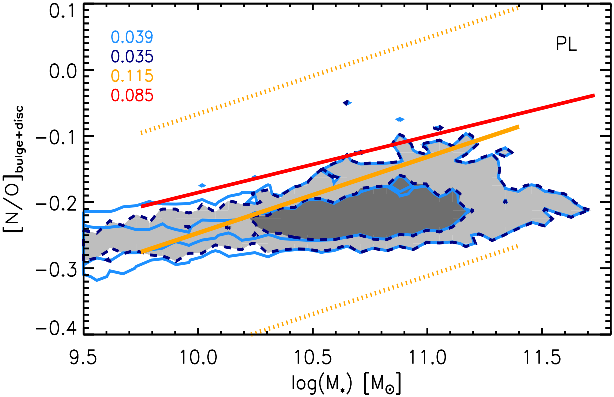
Positive slopes are obtained (when using a ‘small’ fraction of prompt SN-Ia) for all α elements, except Mg

Other types of galaxy



Our SAM+GCE also provides a good match to the $z = 0$ gas-phase MZR and chemical composition of the MW disc

Nitrogen



Additional production of N in high-metallicity, *massive* stars required to obtain strong M_*-[N/Fe] and M_*-[N/O] relations

Conclusions

- Positive slopes in the M_*-[α/Fe] relations of local ellipticals can be obtained in a hierarchical clustering model (without requiring a variable IMF).
- This is best achieved when using a SN-Ia DTD with small ‘prompt’ component, and SN-II yields that account for prior stellar mass loss
- The $z = 0$ gas-phase MZR, as well as the chemical properties of G dwarfs in the MW disc, can also be reproduced *with the same model*.
- Galactic winds, driven by SNe-II, strengthen positive slopes in M_*-[α/Fe] relations.
- Reproduction of e.g. M_*-[N/O] in ellipticals and [Fe/H] in the ICM requires further work. . .