Backward Evolutionary models: Stellar Mass and Velocity Functions of Galaxies

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Context: Nearby and far far away galaxies

Nearby galaxies: Fossils of their evolution

Deep surveys: Seeing galaxies at various epochs

Backward Models
Context: distant galaxies

Deep surveys tell us about the “cosmic” evolution of the Stellar Mass, the SFR (e.g. Kajisawa 2010)...

... and their distributions (e.g. Mass Functions of Ilbert el al. 2010, by type)
Integrating the SFR and M* Functions, we obtain the “Cosmic” evolution (e.g. Wilkins et al. 2008, Hopkins & Beacom 2006)
Fossil records in the Milky Way and nearby galaxies

Recovery of Star Formation Histories from CMD diagrams (e.g. LMC by Harris & Zaritsky 2009)
Fossil records in the Milky Way and nearby spirals: use of “backwards” models to “guess” their SFR History (e.g. Matteucci 2007).

Abundance ratios in the Milky Way (Francois et al. 2004).
Other example: fossil records in E type galaxies (abs. Lines indices, also linked to variable abundance ratios)

Stars in more massive galaxies “formed” at higher redshift, density effect

(Thomas et al. 2010)
Use “backward” models + statistical approach + Data at “high/intermediate” redshift to address some issues:

1) “ Typical” histories of star forming-galaxies derived from local constraints: consistent with the “cosmic” picture?

2) Number evolution of star forming galaxies: do some disappear? When? What do they become?
I- MODELS OF DISK-GALAXY EVOLUTION IN THE NEARBY UNIVERSE, AND APPLICATION TO HIGH $z$ ("individualist" approach)

II- FROM MASS TO VELOCITY FUNCTIONS AND APPLICATIONS (statistic approach)

III- ENVIRONMENTAL EFFECTS ON THE EVOLUTION OF GALAXIES
I - A grid of models for star forming galaxies

BASED ON Boissier & Prantzos 2000 + New component

- Scaling relationships

- A universal SFR LAW
  (Boissier et al. 2003: observed in nearby spirals)

- Accretion History

  - The more massive, the earlier (downsizing)
  - The denser, the earlier (inside out formation)

- Note on the IMF:
  Kroupa et al. 1993

  -> Kroupa 2001 “universal IMF”

  2 parameters: $V$, spin
  Mass $\alpha V^{**3}$ (~ Tully Fisher)
  Scale-length $\alpha spin \times V$

  (e.g. Mo Mao and White 98)
I-A grid of models for star forming galaxies

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\[ \text{SFR} = a \text{GAS}^{**1.48} \frac{V(R)}{R} \]
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Sandage 1986
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- Note on the IMF:
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The IMF affects the full grid, however switching from KTG93 to K01 leaves most of the evolution changed by less than 20% (except UV emission and metals)

-> Kroupa 2001 “universal IMF”
(spin, V) = one unique model (SFR History, profiles, ...)

Comparison with observations:
- calibration in "old" papers
- recently checked with SINGS galaxies:
  Thesis of Juan Carlos Muños Mateos.

Muños Mateos et al., submitted
I-The Grid of Models vs the SINGS sample

Velocity distribution: not representative but covers the range from dwarfs to big spirals

Spin distribution: representative. Only a typical value adopted in what follows

Muños Mateos et al., submitted
SFR Histories for typical spin for various Velocity

\[ SFR(t) = A t^b \exp(-t/\tau)^{0.5} \]

or

\[ \log(SFR(t)) = a + b \log(t) + c t^{0.5} \]

with \( a = \log A \) \( c = -0.43 \tau^{-0.5} \).

Buat et al. 2008
I–The Grid of Models vs the high z galaxies

Evolution of the Mass-Metallicity relationship

Evolution of the Mass-Specific Star Formation Rate relationship

See also e.g. Calura et al. 2009
IR-selected and UV-selected samples at \( z=0 \) and \( z=0.7 \)

Evolution of the Specific Star Formation Rate (SSFR) vs \( M^* \) relationship.

Buat et al. 2008
Trend confirmed in other studies
(3.6 microns selection. Star forming based on color)
Evolution of the SFR-M* relationship up to redshift 2

(black : model, color: data)

Boissier, Buat, Ilbert 2010
I–The Grid of Models vs the high z galaxies

Overplotting
Kajisawa et al. 2010
(stellar mass limited)

Boissier, Buat, Ilbert 2010
Stellar Mass Function $F(M^*)$ of star-forming galaxies is “constant”. $M^*$ evolves but $F(M^*)$ is constant: $M^*$ not a good parameter to follow star forming galaxies (e.g. Noeske, 2007)

Boissier, Buat, Ilbert 2010
The models provide the relation $M^*$-Velocity at various redshift.

“V” tags a galaxy (does not evolve).
At each redshift, we can compute a Velocity Function $F(V)$

$F(M^*)$ (cst)

$(M^* - V)(f(z))$
Evolution of $F(V)$ necessary?

Assuming $F(V) = \text{cst}$, we predict an evolution of $F(M^*)$ that should be detected in the various studies.
II- Stastisical evolution

$F(V)$

$F(SFR)$

Cosmic SFR per $M^*$

Cosmic SFR per SFR
II- Staticial evolution

We found that $F(V)$ evolves:

at each $V$, in each redshift bin, a fraction of star-forming galaxies disappear:

We can compute a “Quenching Flux Function” : $F_q$
II- Statisclial evolution

If $F_q = \text{quenched star-forming galaxies}$, it should be equal to the increase in quiescent galaxies mass functions in the same redshift bins!
Quenching at “intermediate” mass: Quiescent galaxies are forming from the quenching of Star-forming ones. At high masses: they were already in place at $z \sim 1$. 
Evolution of the Cosmic SFR: slightly too weak...

Largely due to our z=0 point
Evolution of SFR functions

- High z: absence of the most active galaxies...

- Low z: too many low / intermediate mass galaxies?
II- Back to redshift 0: what is happening?

This excess results from the combination of the stellar mass function and the SFR-M* relationship, both directly observed at z~0! Something is not consistent in the observations themselves!
Implementing **environmental effects**, reducing the SFR in the models (e.g; Boselli et al. 2006, 2008).

- Starvation
- Ram-Pressure

We can reproduce many properties of dwarfs and anemic spirals in **Virgo** with models incorporating Ram Pressure.

On-going surveys of Virgo: **GUViCS** (UV), NGVS (optical), HRS/HeViCS (FIR), Alfalfa (HI)
What happened to the Milky Way sibling?

50% are not any more star forming galaxies.

Massive clusters like Virgo are not enough to explain these numbers!

It has to be groups (e.g. tidal interactions).
Conclusions & Perspectives

Backward models + simple “statistical” prescriptions allow us to put all the observables of the “cosmic” evolution of galaxies in an educational framework.

NEXT:

- Predict Luminosity Functions, to be compared with observations up to the highest redshifts (in collaboration with Tresse, Ilbert, Cucciati) to constrain the evolution of the star-forming velocity function and study consequences (role of quenching, mergers)

- Track the possible physical causes of quenching, and develop models incorporating them.