UNIVERSIDAD AUTONOMA DE MADRID

Quantifying the mixing due to bars

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And the CALIFA collaboration

Project: Systematic study of the stellar populations and ionised gas properties along the bar, the bulge and the disk of spiral galaxies

Aims:

Determine the importance of **bars in building the central bulge** and the time-scales in the processes involved - stellar bars are very common (**70% of all disc galaxies are barred** to some degree (Erwin 2005; Eskridge et al. 2000)

Determine the **amount of radial mixing** due to the presence of a bar.

Determine whether **bars are long-lasting** or not and detemine when they formed – their own fate may depend on the shape of the DM halo.

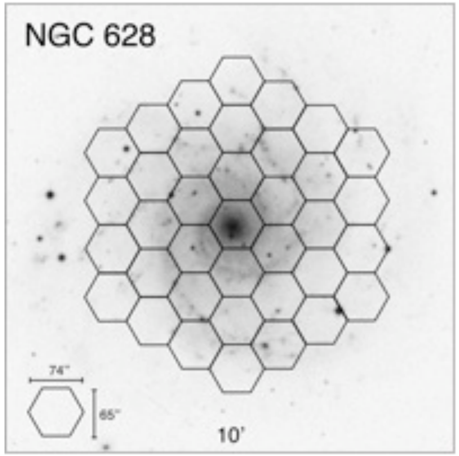
The sample (face-on spiral galaxies with types from S0 to Sd)

1) **Long slit spectroscopy along the bar of 20 barred early-type galaxies** **(Pérez, PSB, Zurita 2007 Pérez; PSB, Zurita 2009; Pérez, PSB, 2011).**

2) 4 galaxies with long-slit GMOS @ GEMINI **along the major axis of the disk** (4 h integration)

PSB et al. (2011)

3) 3D spectroscopy of 4 weakly barred late-type (Sc) galaxies form the **PINGS** survey (Rosales-Ortega et al. 2010)



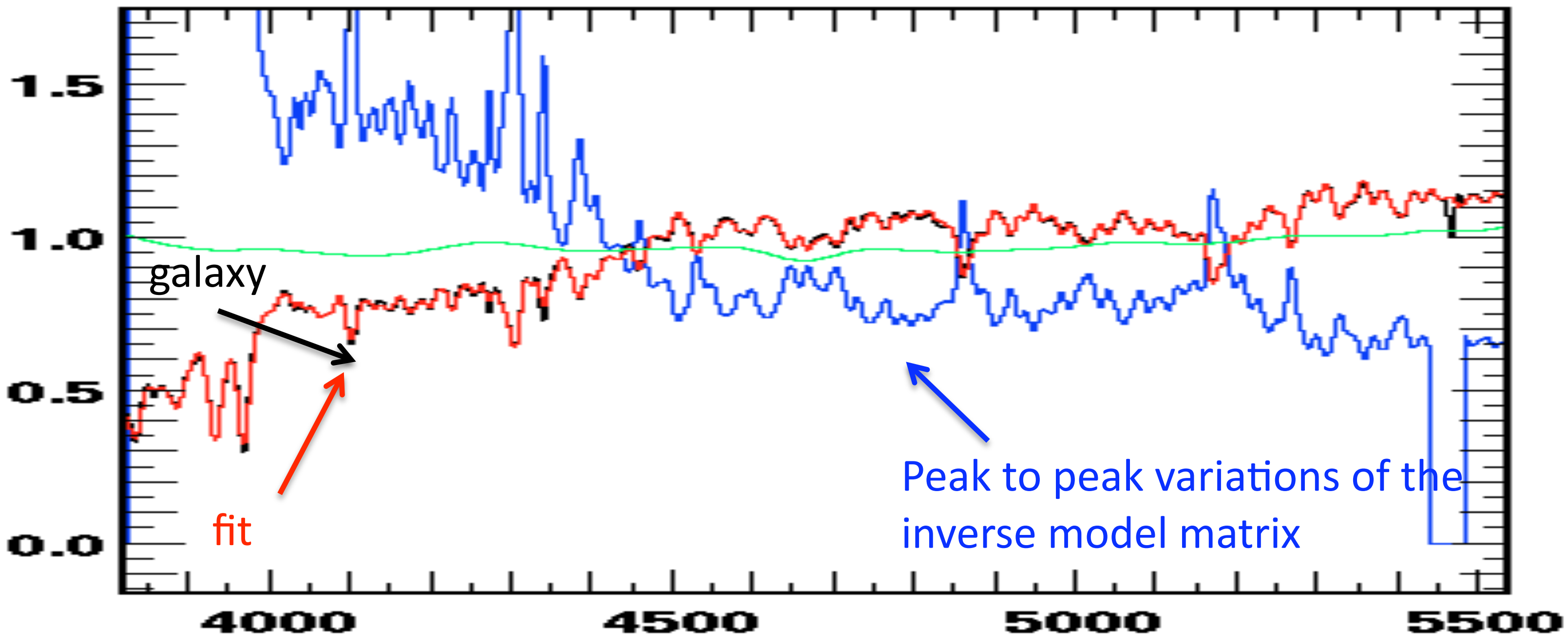
4) 3D spectroscopy of 29 galaxies: 4 E
3 S0 (1 barred)
5 Sa (4 barred)
8 SB (4 barred)
9 Sc (4 barred)

Sánchez et al. (2011)
http://www.caha.es/CALIFA/

See poster **4.23** by Sebastian Sánchez

Derivation of stellar population properties

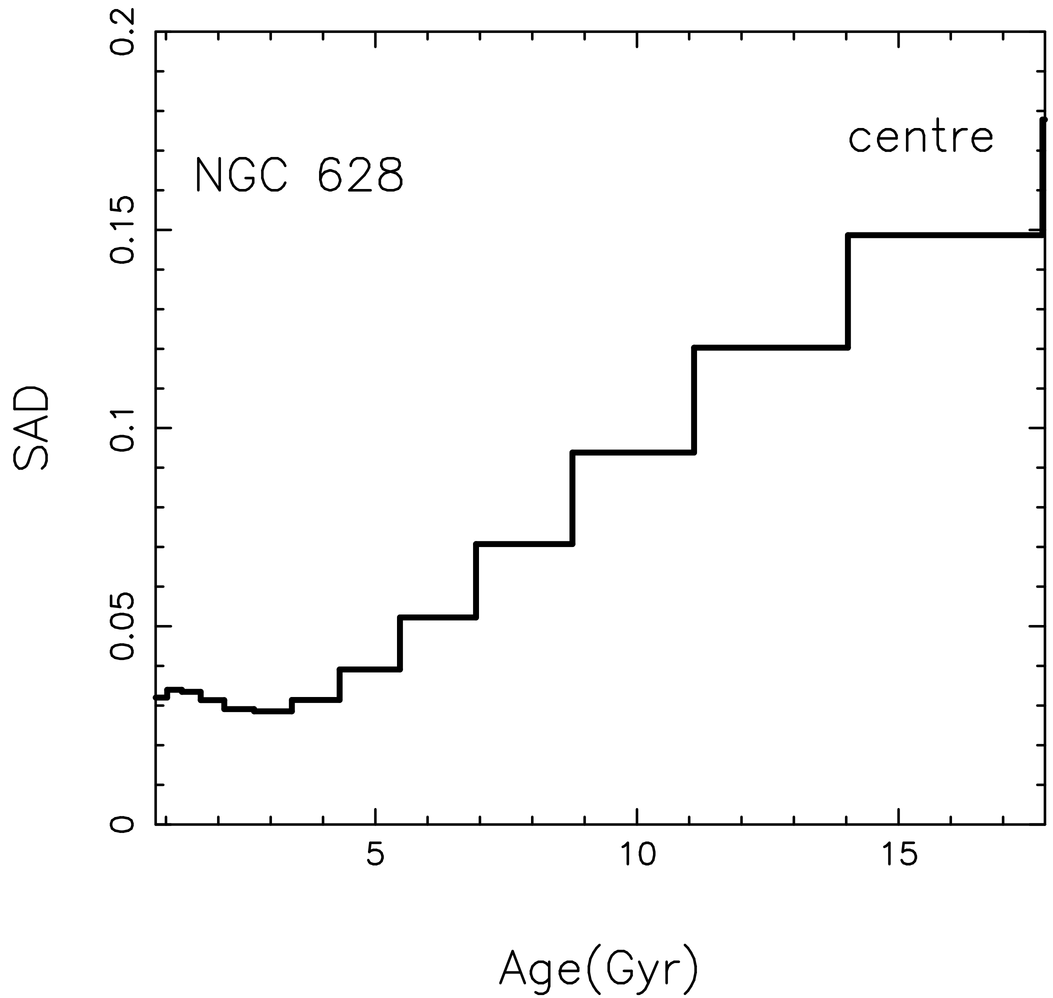
- **STECKMAP** (STEllar Content via Maximum A Posteriori, Ocvirk et al. 2006ab)
- **It is non parametric**, and thus provides properties such as the stellar age distribution with minimal constraints on their shape
- The ill-conditioning of the problem is taken into account through **explicit regularization.**



http://astro.u-strasbg.fr/~ocvirk/STECKMAP

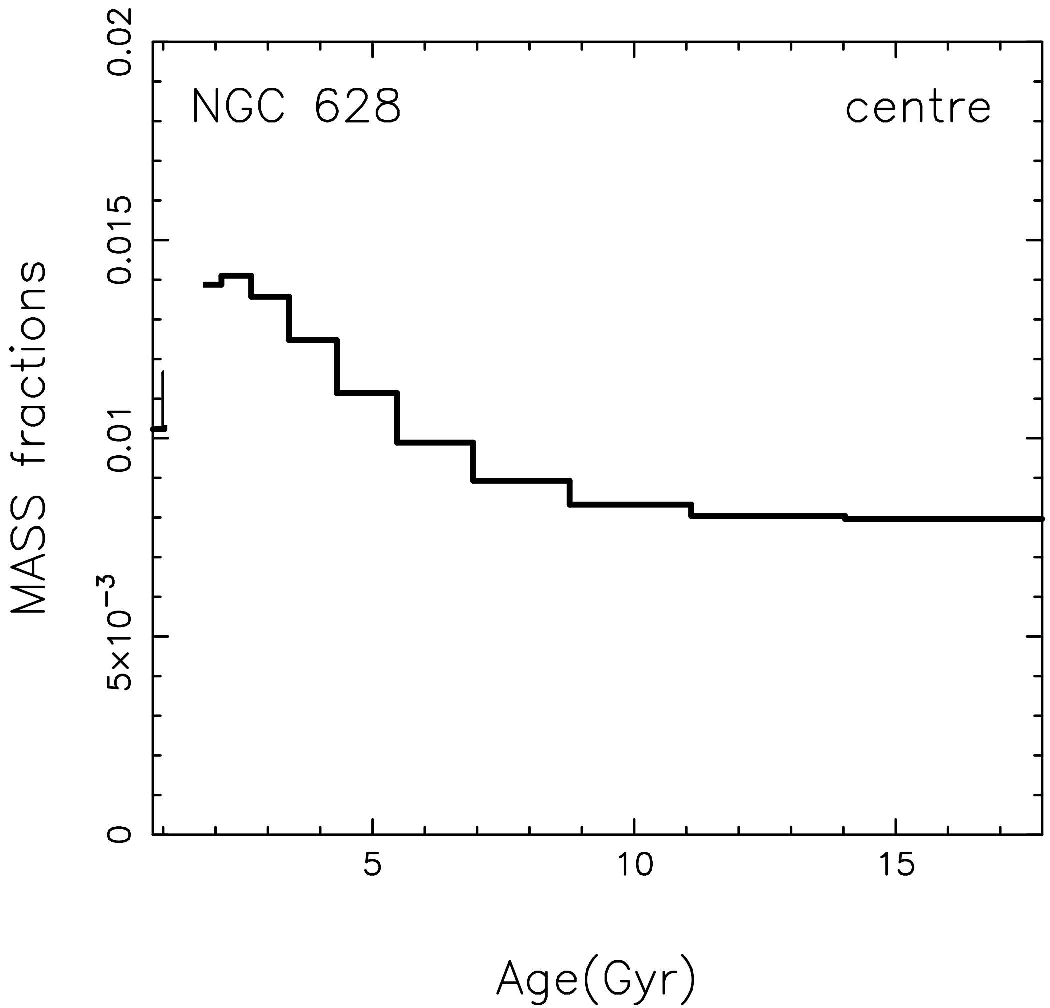
Steckmap outputs

Star Formation Histories

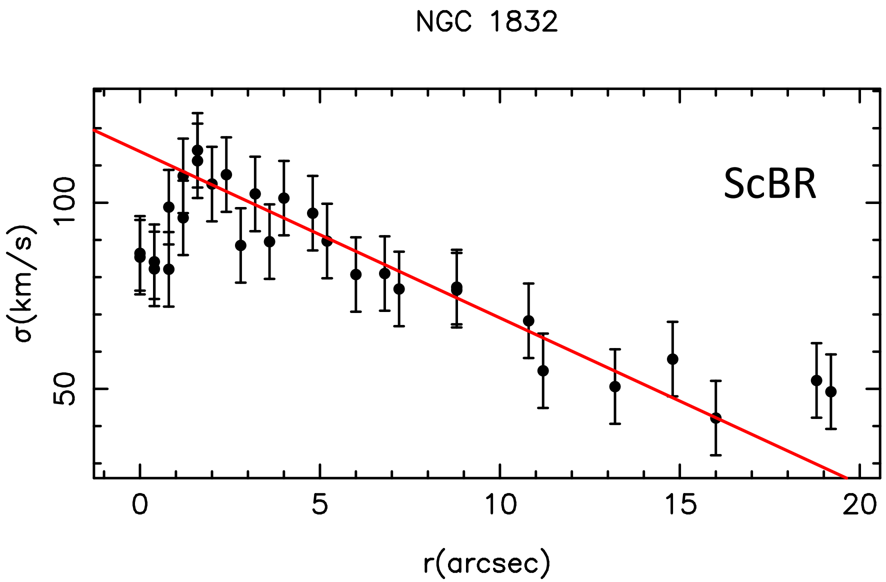


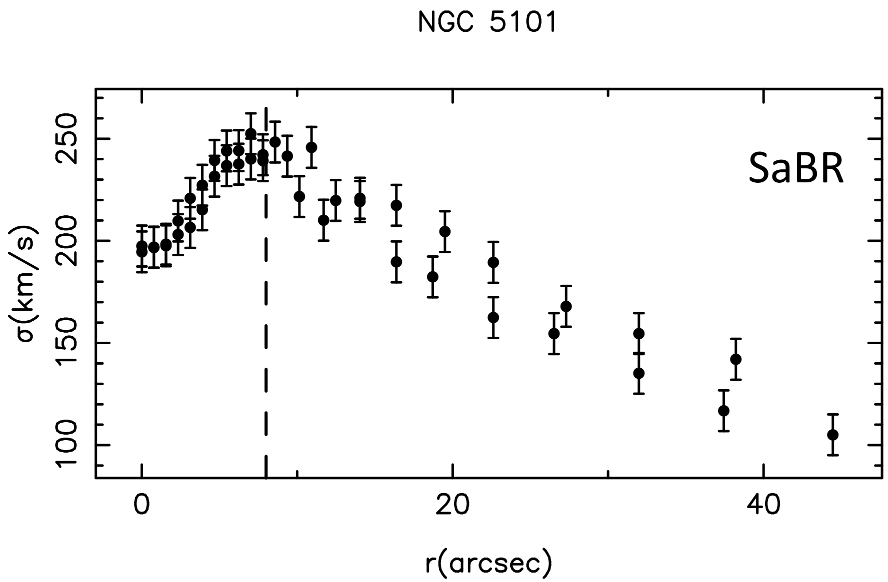
Steckmap outputs

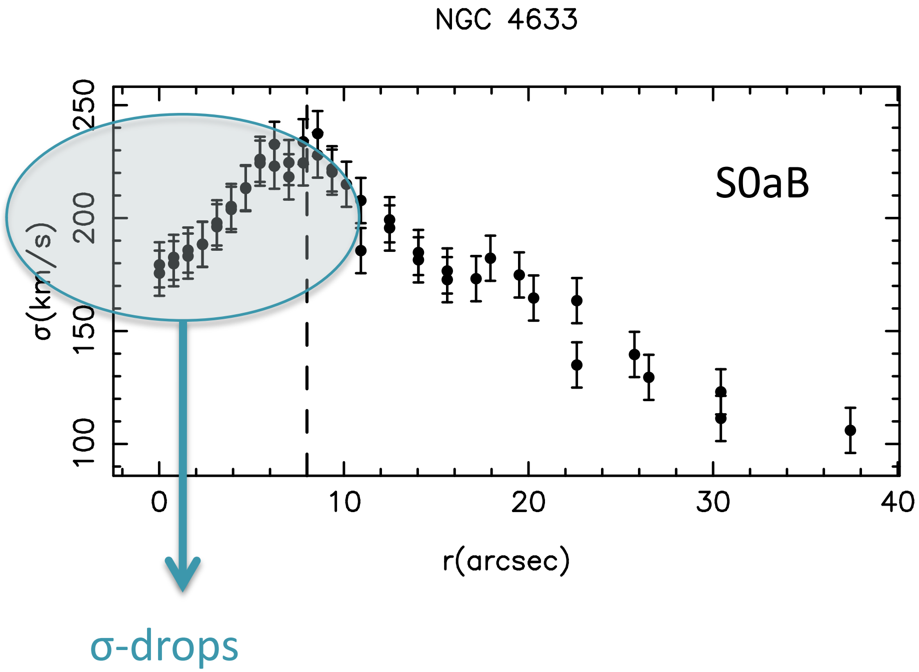
Chemical enrichment

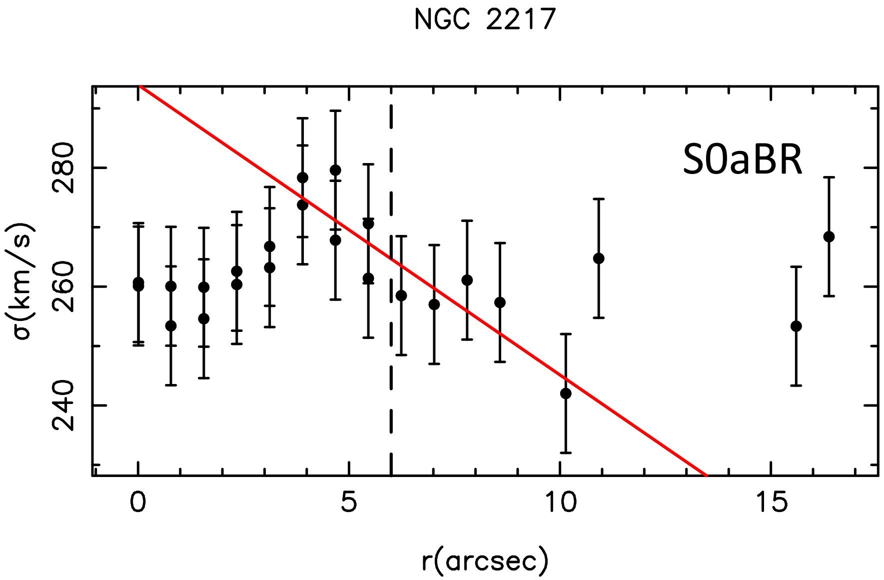


Velocity dispersion profiles: σ-drops

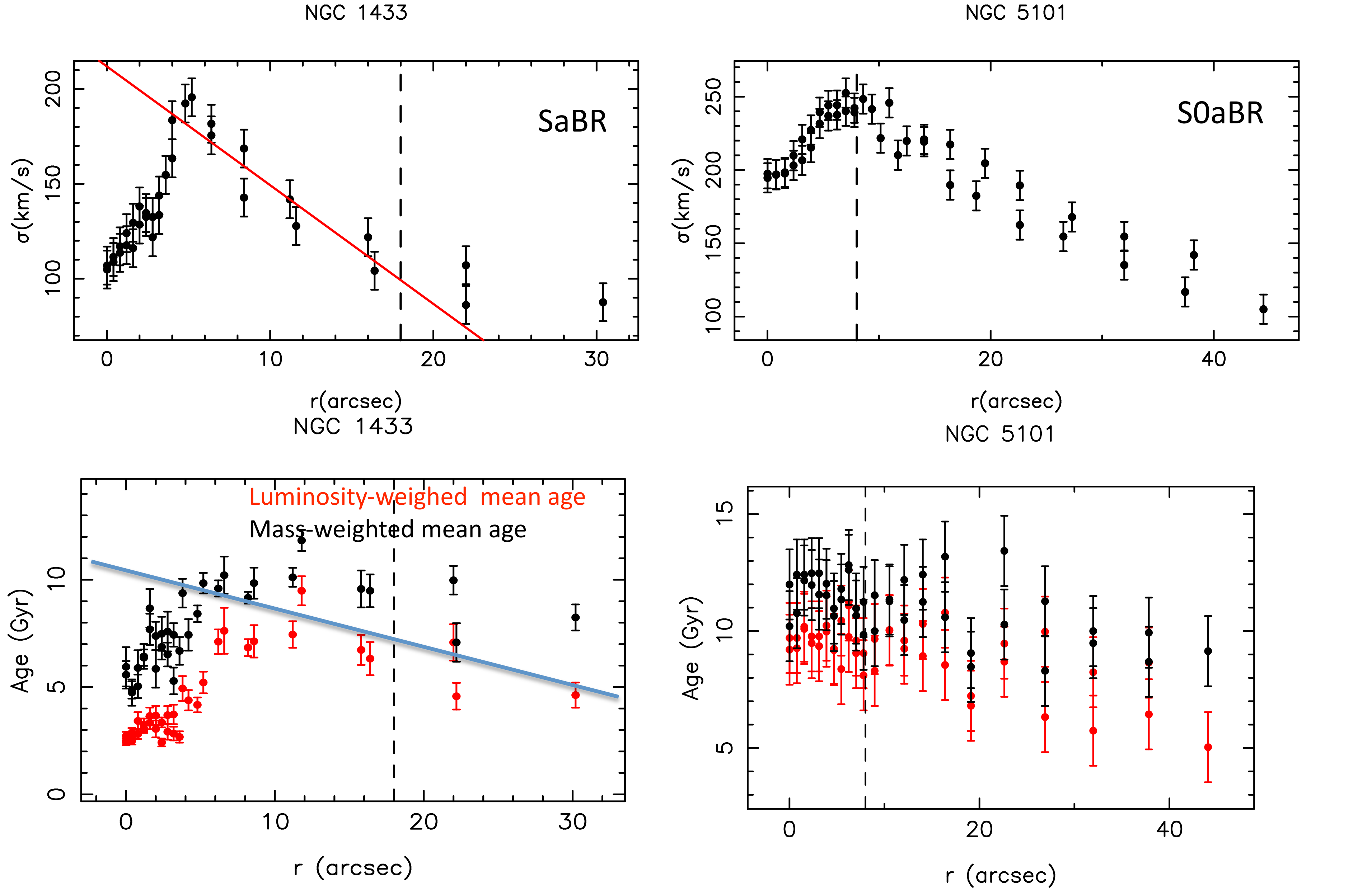








Stellar ages of σ-drops



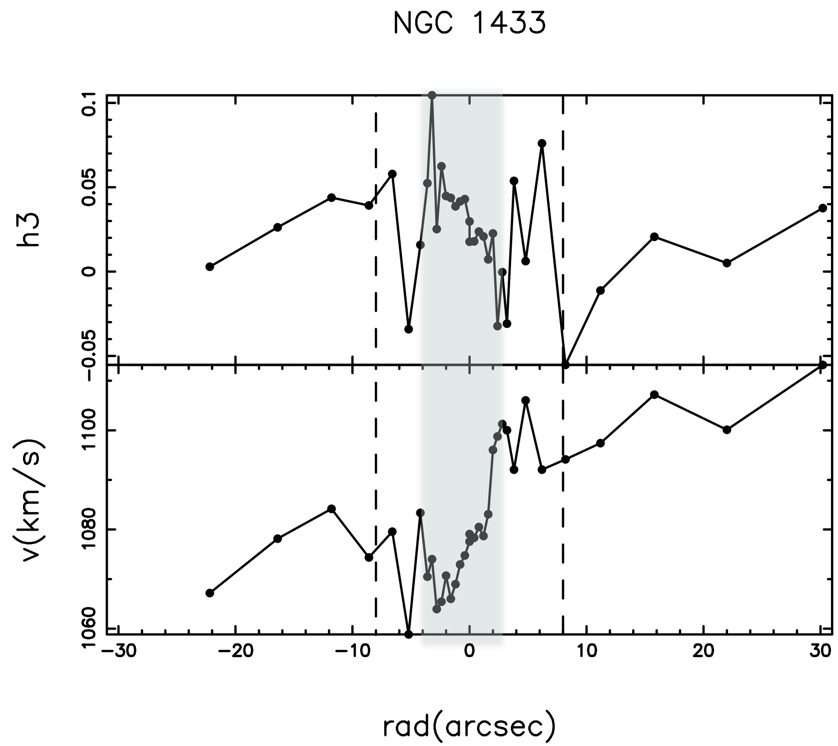
Other possibilities:

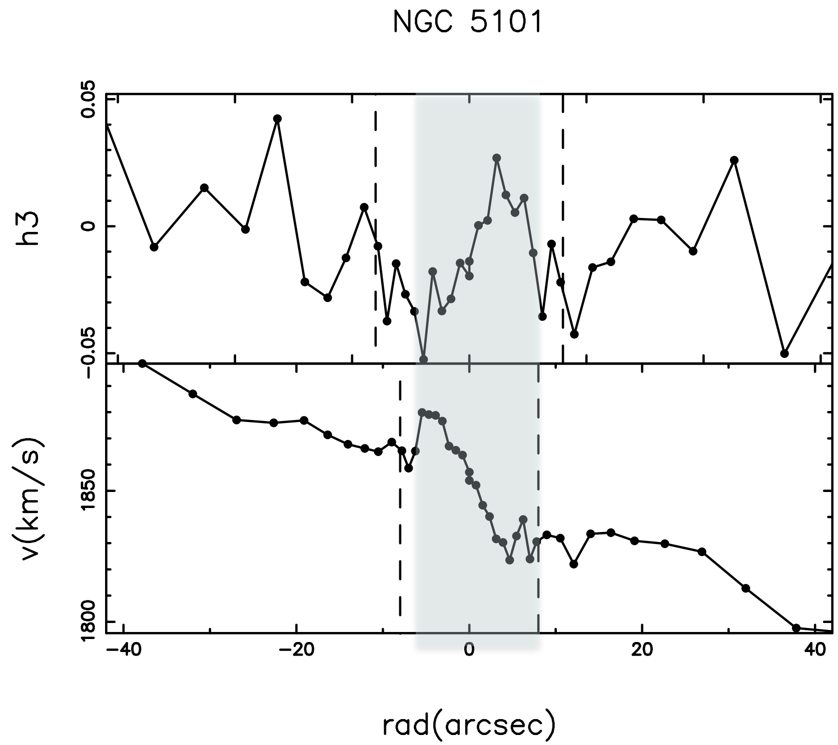
(1) A massive, concentrated dark matter halo could remove kinetic energy from the stellar component (Athanassoula & Misioritis 2002)

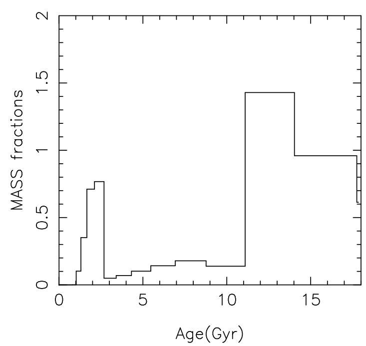
(2) They arise from the orbital structure of (strongly) barred disks (Bureau & Athanassoula 2004);

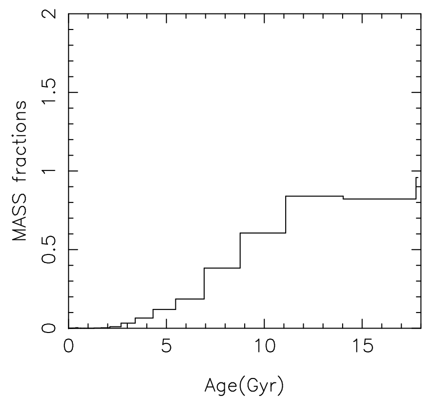
(2) Accretion of satellites (Eliche-Moral et al. 2010)

h3-V Anticorrelation



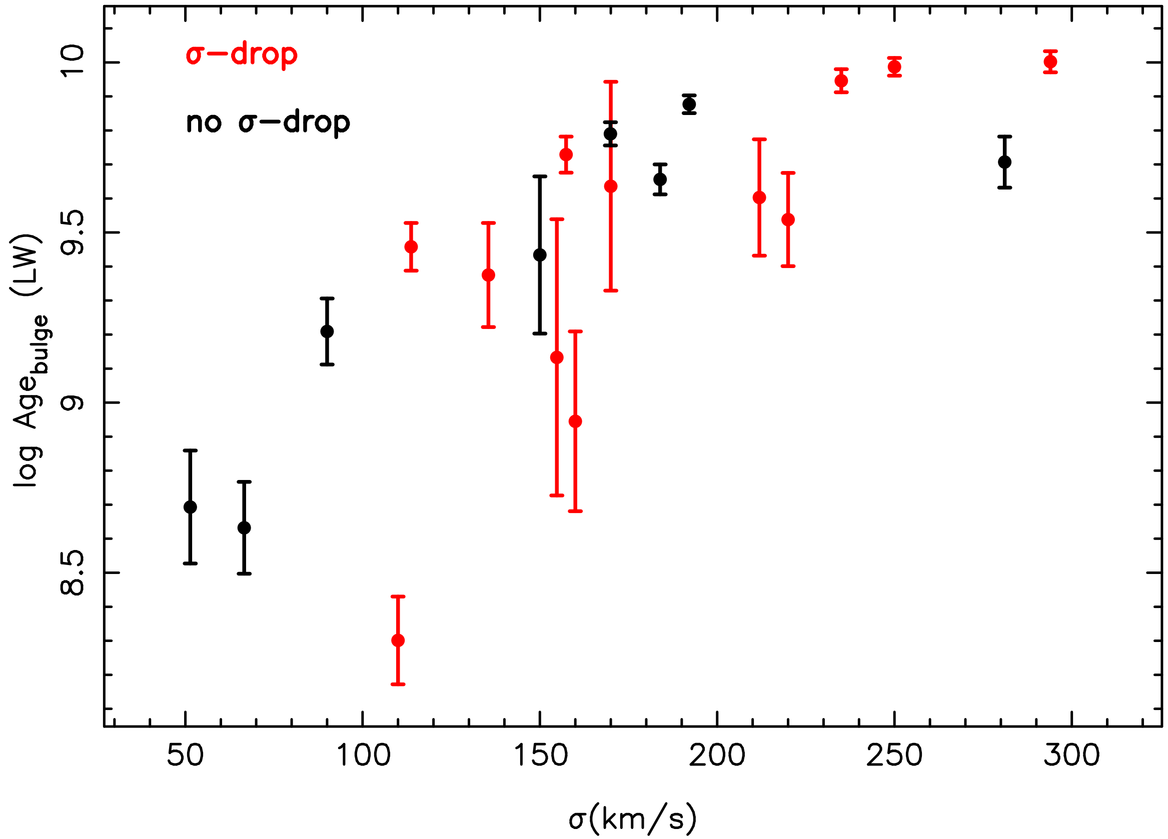






Up to 50% of the mass in the “young” component

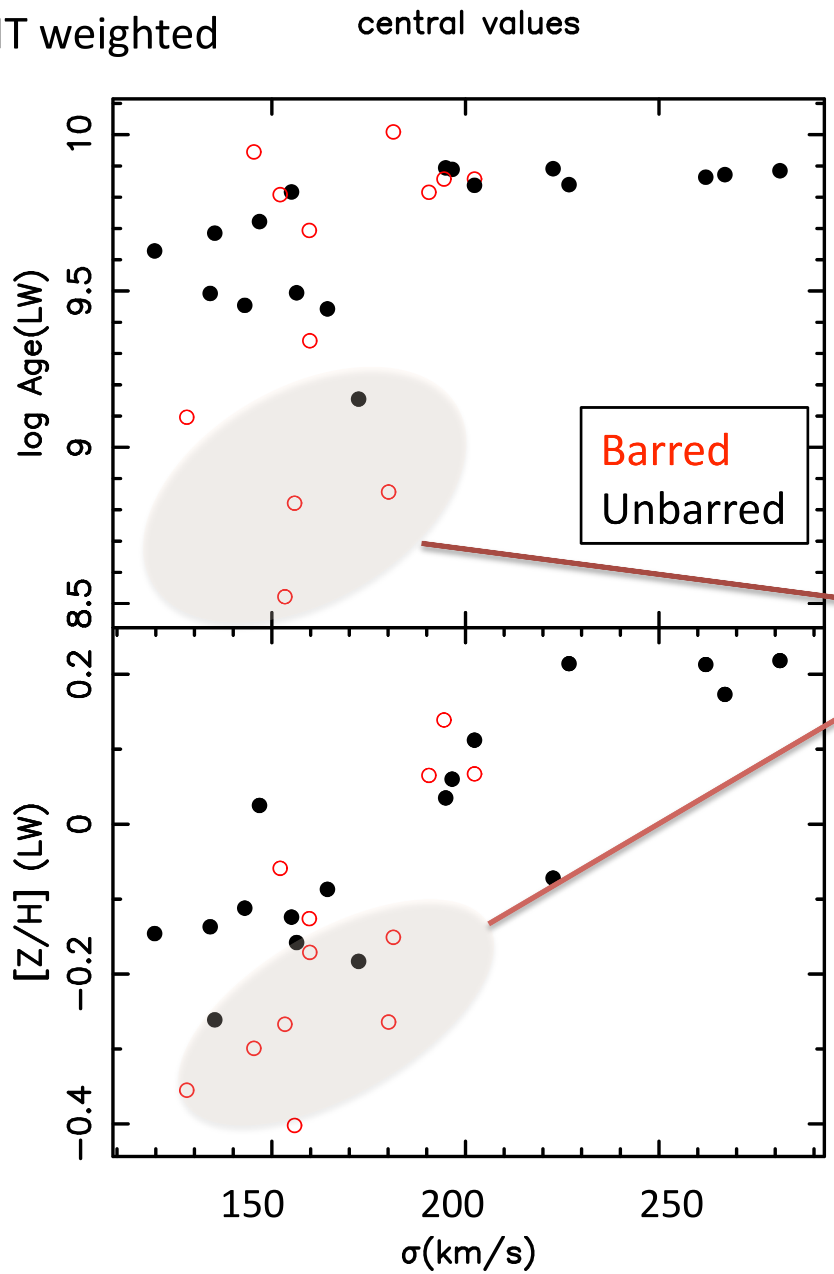
Luminosity-weighted age of the bulge vs. central velocity dispersion



Sigma-drops are *not always* associated with a younger component
(see also Peletier et al. 2007)
The presence of young population is not correlated with the presence of a double bar or the strength of the bar.

Comparison of Stellar Population in barred and unbarred galaxies

LIGHT weighted



Barred galaxies tend to have lower ages and metallicities than galaxies without bars

Preliminary results indicate that:

The bulges of **unbarred** galaxies are **more metal rich** than those of the barred galaxies

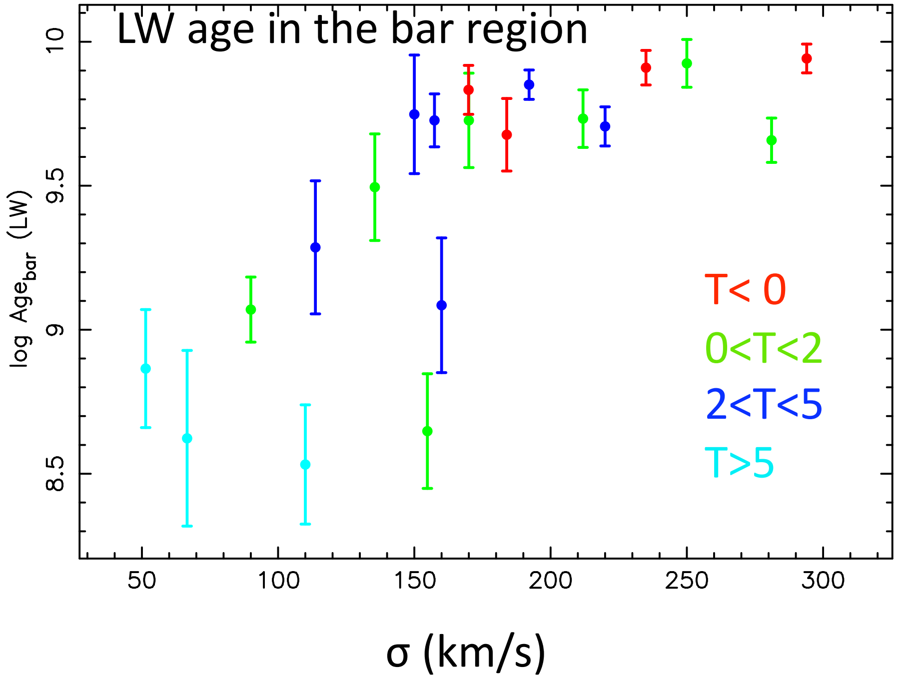
However, maybe the trend reverses for more massive bulges

Can this explain the contradictory results in the gas phase metallicity of barred and unbarred galaxies

2. Are bars long lasting structures?

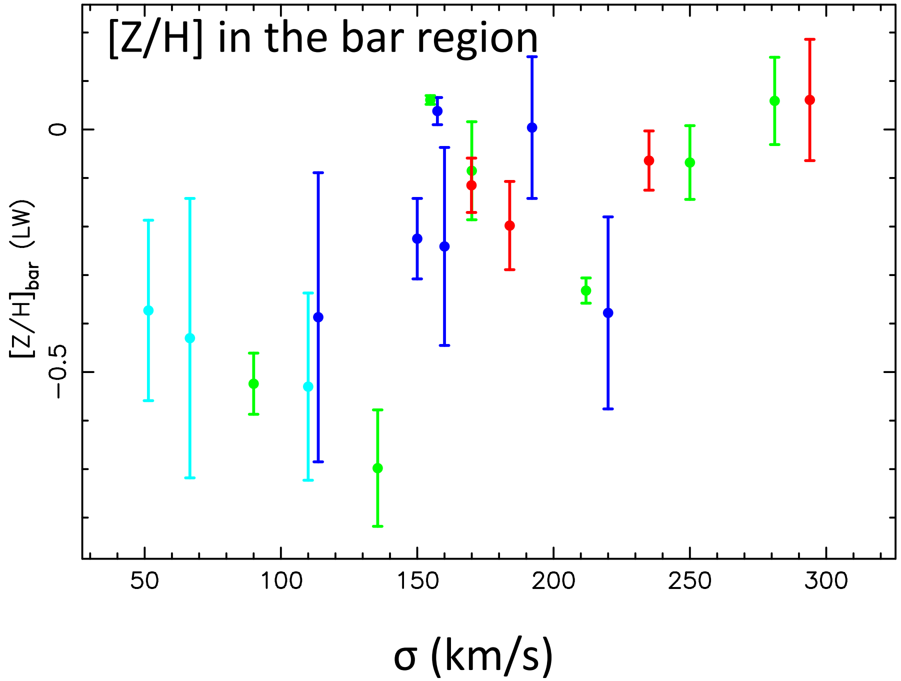
Numerical simulations make **widely different predictions** (Friedli & Benz 1993; Shlosman & Noguchi 1993; El-Zant & Shlosman 2002; Athanassoula 2002; Bournaud & Combes 2002; Shen & Sellwood 2004) while **observational** results on the evolution of the bar fraction with redshifts are **conflicting** (Abraham et al. 1999; van den Bergh et al. 2000; Elmegreen et al. 2004; Jogee et al. 2004ab, Zheng et al. 2005; Sheth et al. (2008); Barazza et al. 2009).

Mean (luminosity-weighted) stellar populations parameters in the bar region

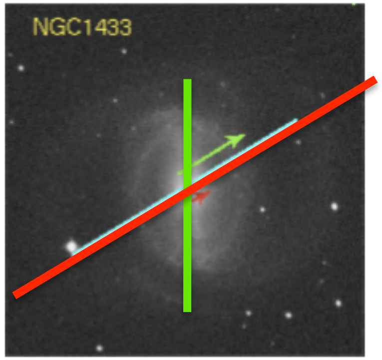


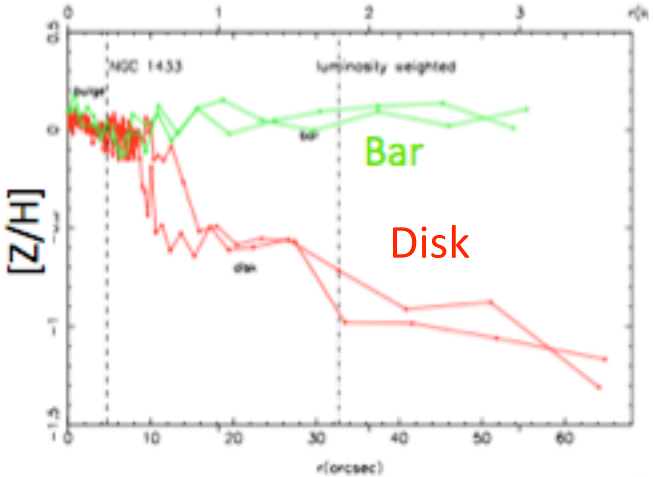
The stellar ages in the bar regions follow a similar trend than in the bulge.

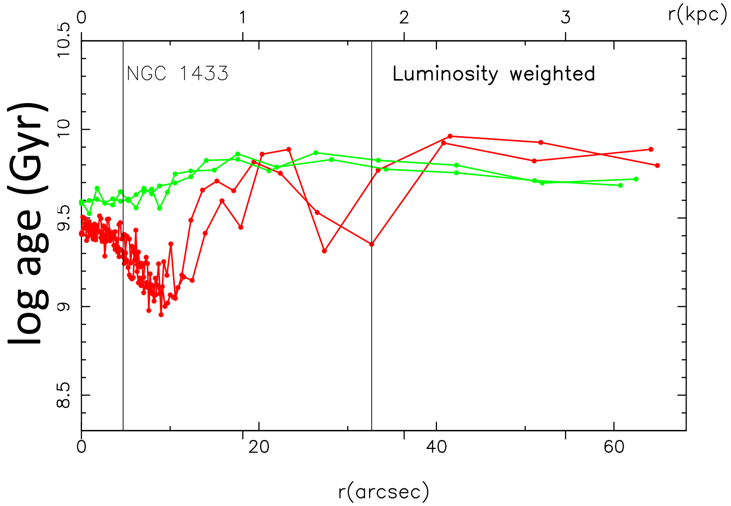
Bars in galaxies with massive bulges have old stars



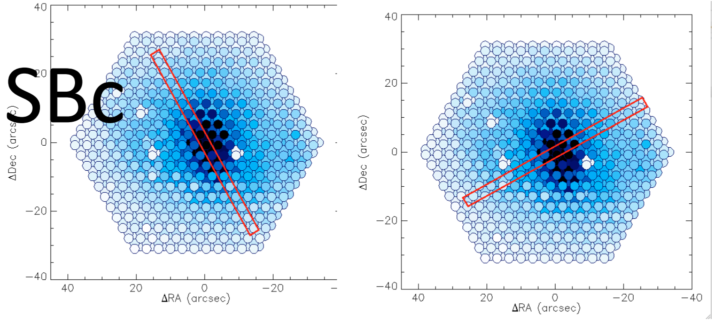
Are bars long-lasting structures?
Comparison of bar and disk populations



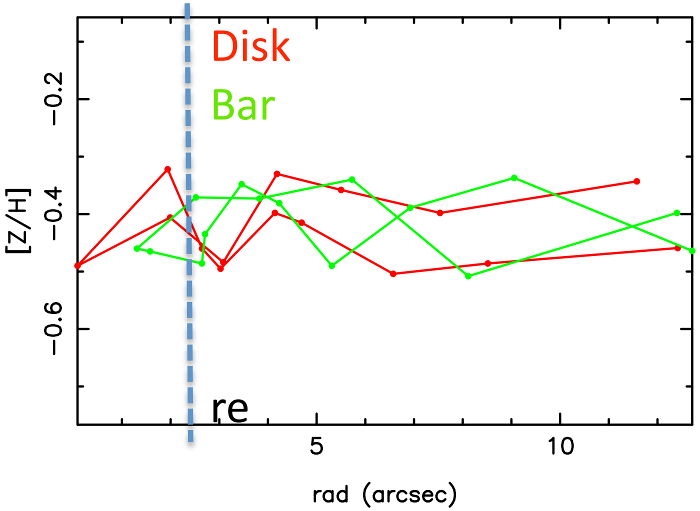


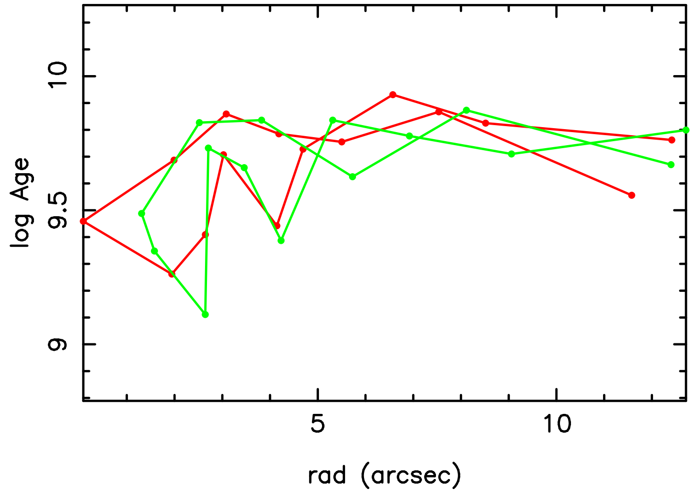


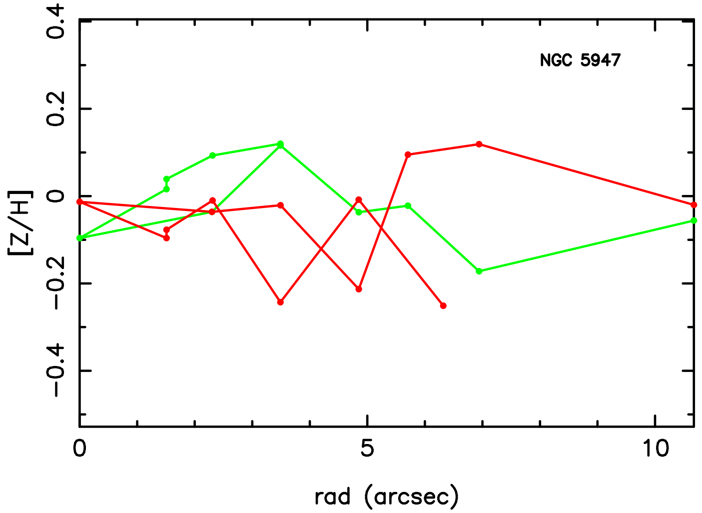
PSB et al. 2011

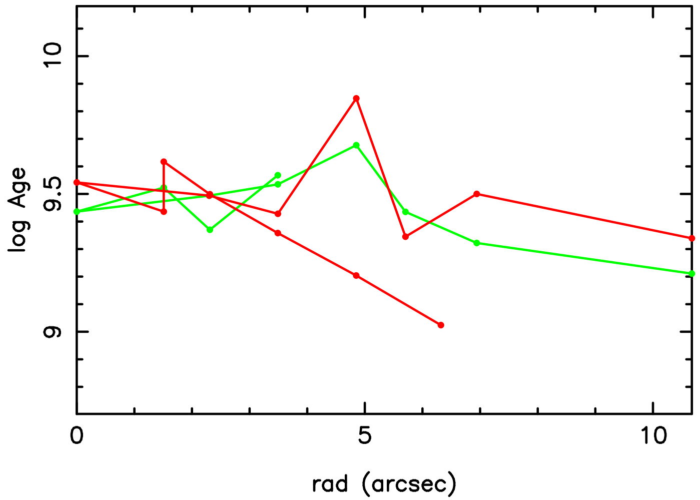


Comparison of bar and disk: SBc Galaxies









Preliminary results in the bar region indicates:

Bars in ***early-type*** galaxies are long-lasting **structures**

Bars in **late-type** spirals *might be* **recently formed**

(also suggested by other authors; see Gadotti & de Souza (2005, 2006) ; Martin & Friedli (1997) , Laurikainen et al. (2007)).

This could also explain the correlation between bar length and disk scale-length found in early type (S0-Sb) and lack of it in late-type (Sc-Sd) galaxies (Erwin 2005).

Quantifying radial mixing

Comparison of stellar population gradients in the disks of barred and unbarred galaxies and studying their evolution with time

Pilot study in PSB et al. (2011)

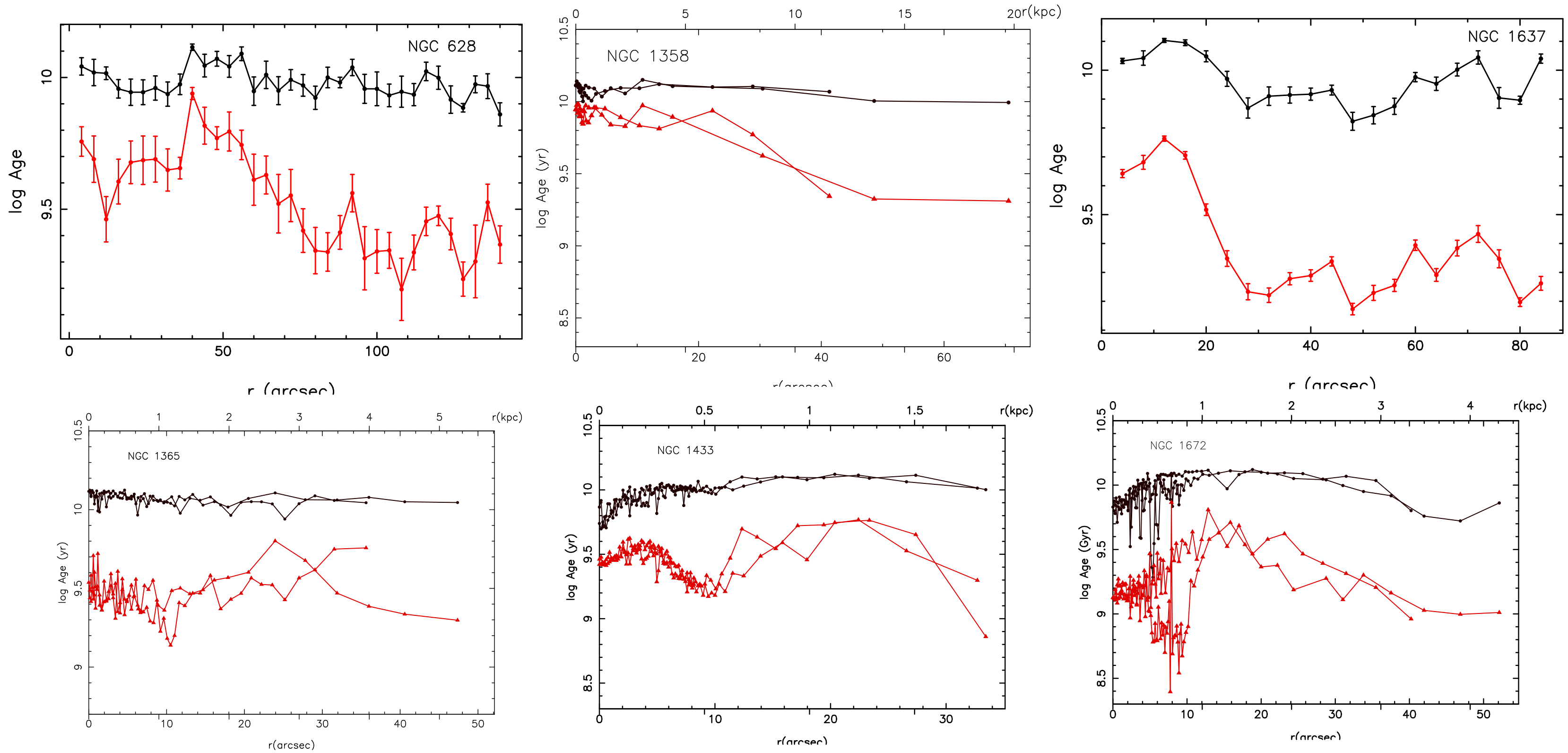
Previous studies:

Very little has been done up to now using spectroscopoy: preliminary studies with TF (Beauchamp & Hardy 1997; Molla, Hardy & Beauchamp 1999; Ryder et al. 2005).

Line-strength indices by Yoachim & Dalcanton (2008) and full spectral fitting by MacArthur et al. (2009) (see talk by Lauren MacArthur on Thursday!).

Age gradients. First results

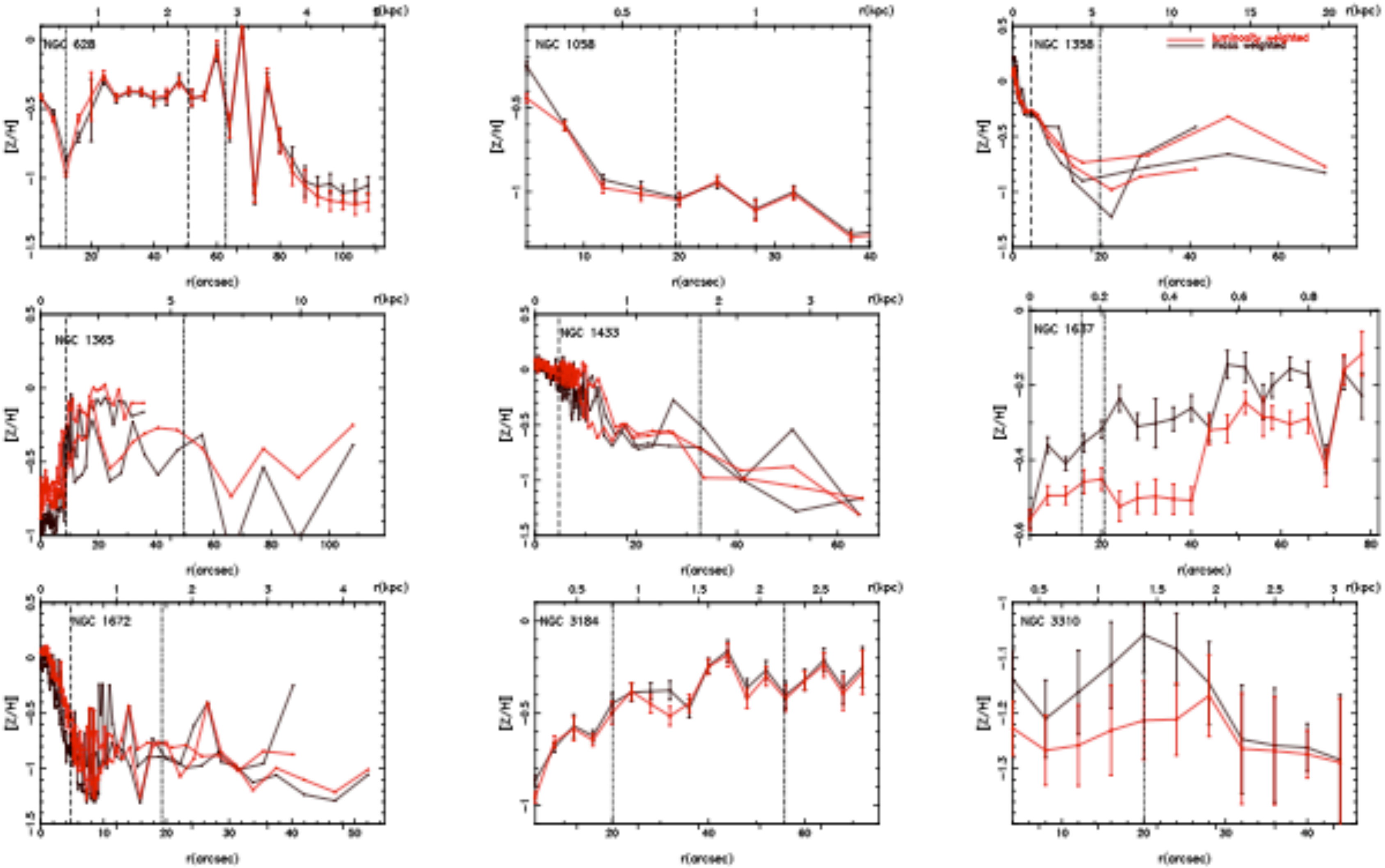
Luminosity weighted
Mass weighted



Mass-weighted age gradient: very flat. Most stars are old even at 2-3 scale-length
Luminosity-weighted age gradient: compatible with an inside-out formation

[Z/H] gradients. First results

Luminosity weighted
Mass weighted



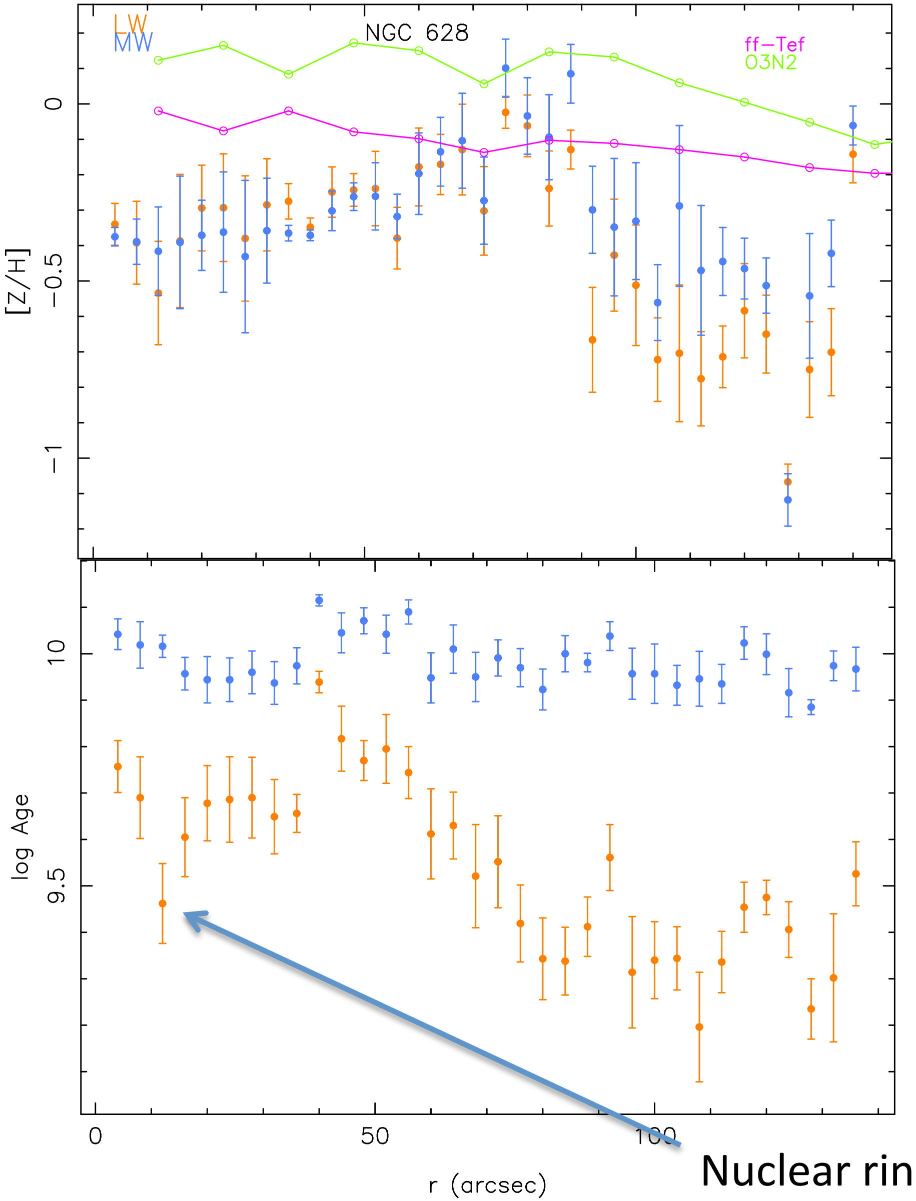
Large variety of metallicity gradients but very mild in the disk region

Stellar populations in disk galaxies:

We found that the majority of the stellar mass in all the components is in old (~10 Gyr) stars.
This is true in the bulge and the disc region, even beyond two disc scale-lengths (See talk of Lauren MacArthur on Thursday)

The disc growth is compatible with a "moderate" inside-out formation scenario, where the luminosity-weighted age changes from ~10 Gyrs in the centre, to ~4 Gyrs at two disc scale-lengths, depending upon the galaxy-> The disk has not grow very much in the last 8 Gyr or there has been radial mixing (in agreement with Munoz-Mateos et al. 2007 & MacArthur et al. 2009).

Variety of metallicity gradients although, in general, very mild. Are inverse metallicity gradients in the bulge a sign of recent interactions?



Gas phase metallicity

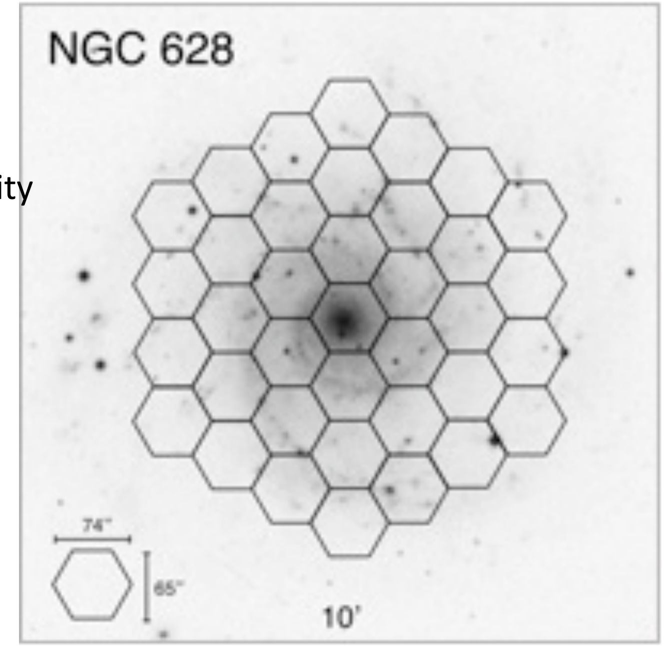
O3N2

ff-Tef

Mass weighted values

Luminosity weighted values

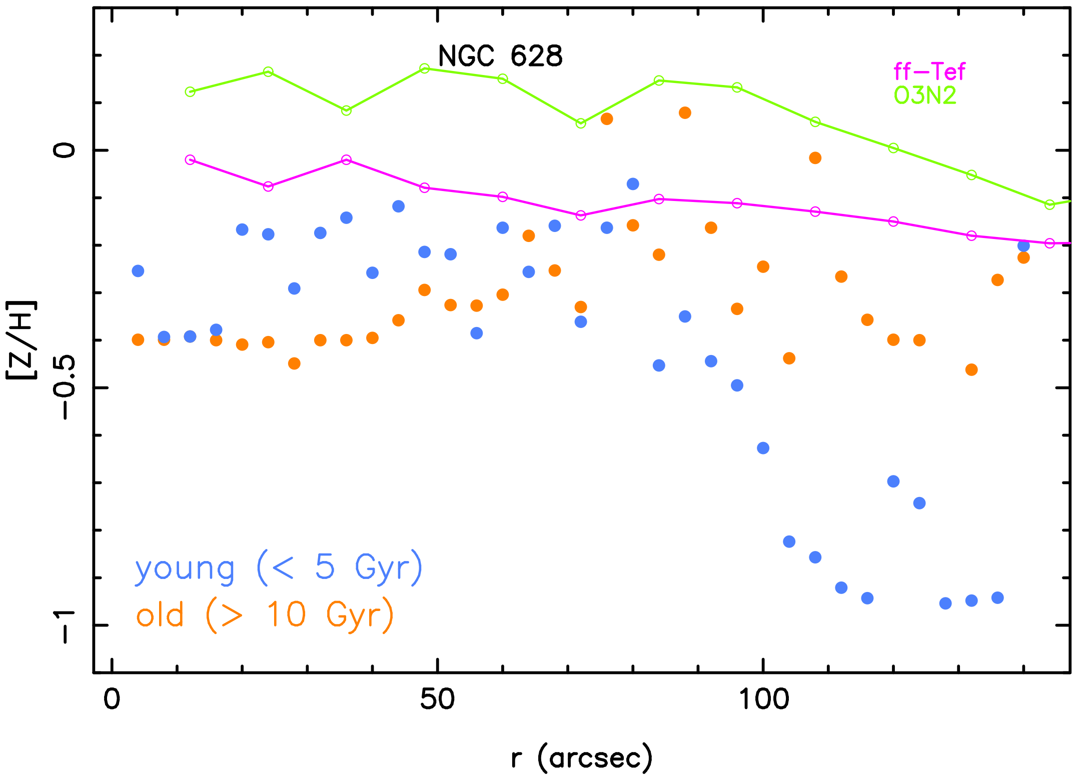
Nuclear ring (Wakker & Adler 1995)

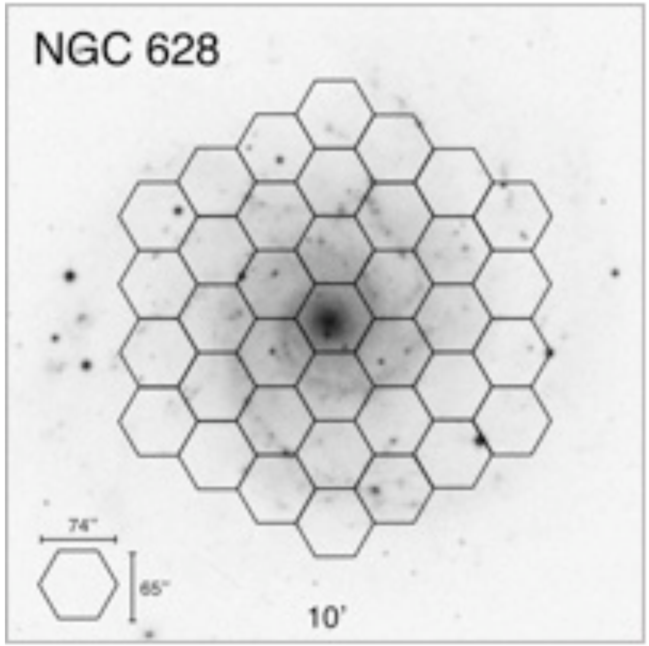


See also Sanchez et al. (2010)

Preliminary!!!!

Evolution of the metallicity gradient with time





See also Sanchez et al. (2010)

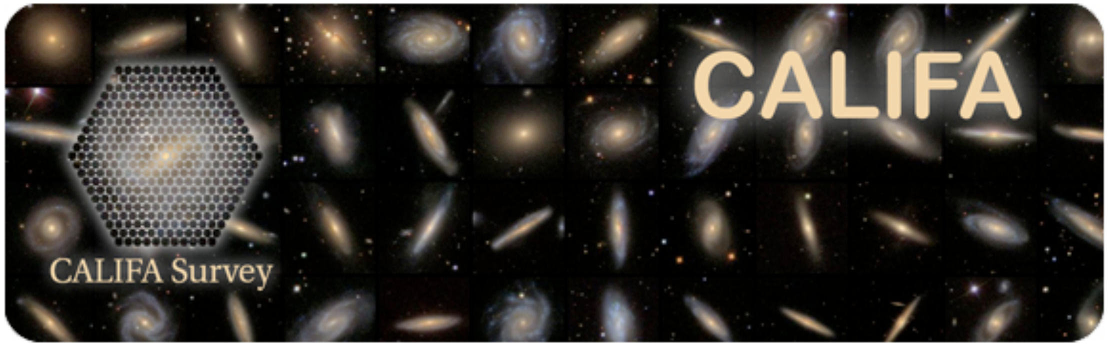
Summary and future work

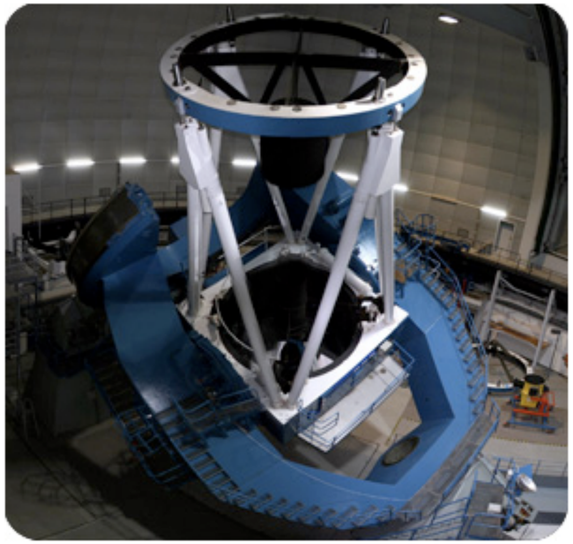
Bulges in galaxies with bars are younger and more metal poor than those in galaxies without a bar. Maybe this trend change wiht the mass or velocity dipsersion of the bulge.

- Bars may have a different evolutionary history in early and late type galaxies. Bars seem to be long-lasting structures at least in early-type spirals.
- Most of the stars in disk galaxies are old (~10 Gyr). This is true even at three scale-lengths, but there is a larger fraction of young stars at larger radius (inside-out disk growing)
- There is a large variety in the behaviour of the metallicity gradients (not clearly related with the presence of a bar).

Future work:

-A systematic study of this evolution for a sample of galaxies with different B/T ratios, luminosity, velocity dispersion is fundamental for this purpose (CALIFA survey, expected to be finished in 2 years)





CALIFA Survey (Sánchez et al. 2011)
600 galaxies in the Local Universe (D< 120 Mpc)
during 250 dark nights (3 years)
IFS using PPAK@3.5 m Calar Alto (FOV 33"x41")
Mid-resolution (R~1000/2000) between 3700-7000A
http://www.caha.es/CALIFA/

For details about the CALIFA survey see Poster by Sebastian Sánchez