Integral field spectroscopy and unresolved stellar populations

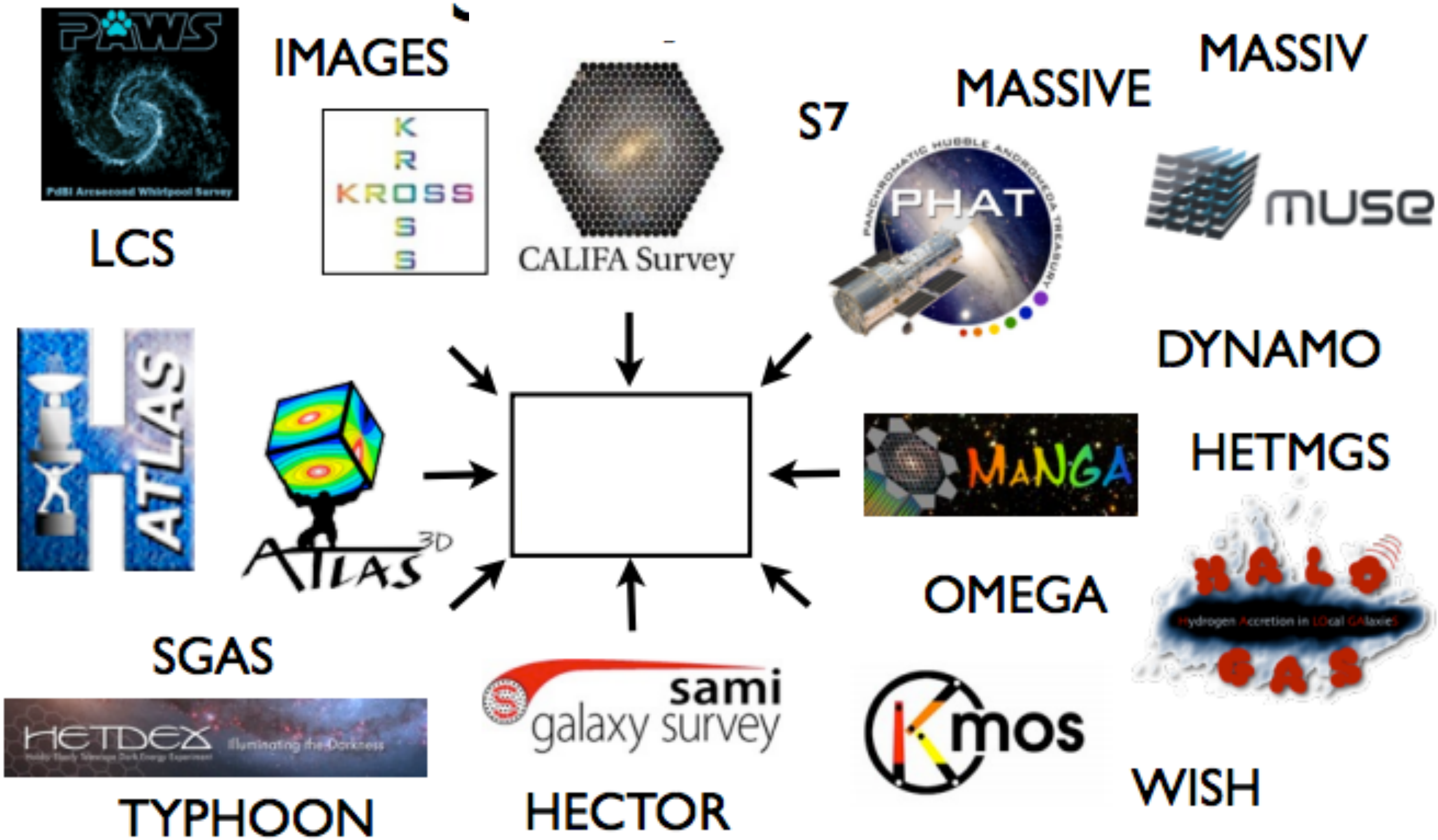
UNIVERSIDAD AUTONOMA DE MADRID

Patricia Sánchez-Blázquez (UAM)

Why IFS?

- Gives a unique view of the stellar population properties allowing spatial structures in the population to be unambigously associated to other features, such as kinematic components, dust lanes, gas disks, etc.
- Allows to remove foreground stars, AGN regions, etc…
- Allows binning schemes to improve the S/N

Surveys with IFS



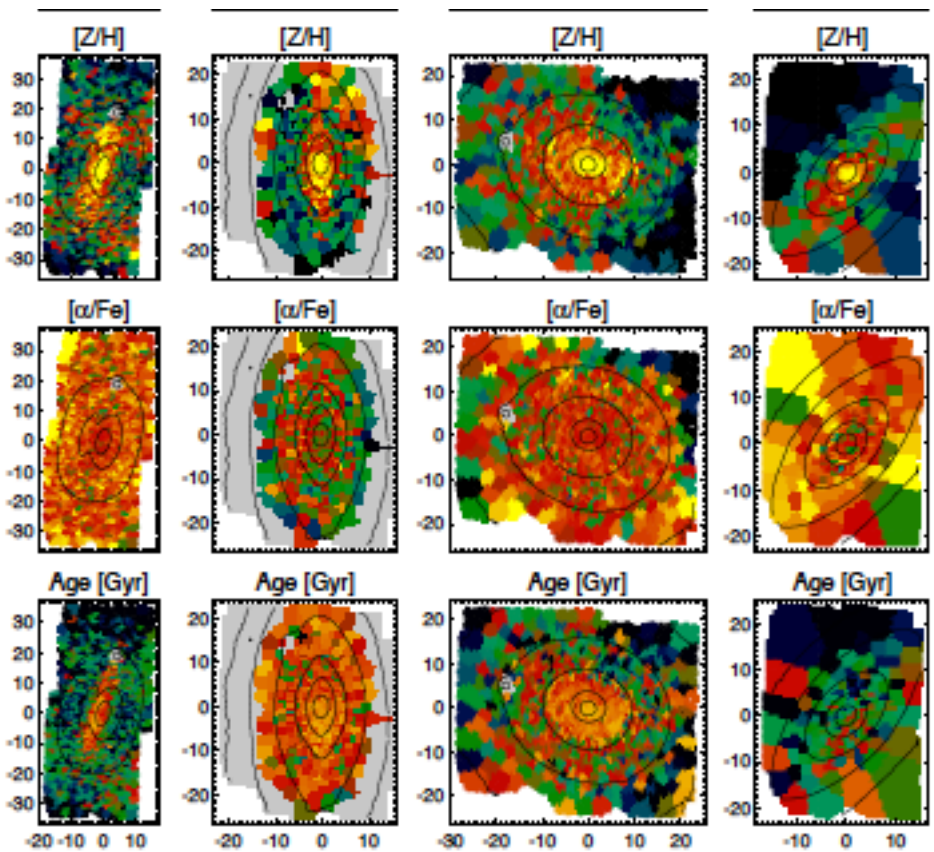
Unresolved stellar populations with IFS

Other individual efforts: Rawle et al. 2008, 2010; Pracy et al. 2009; Sil'chenko et al 2009,2011, 2013.; PSB et al. 2013; Chillingarian (2009); Coccatto et al. (2011), etc…

SAURON

- de Zeeuw et al. (2002)
- Representative sample of 72 early-type galaxies E/S0 and Sa

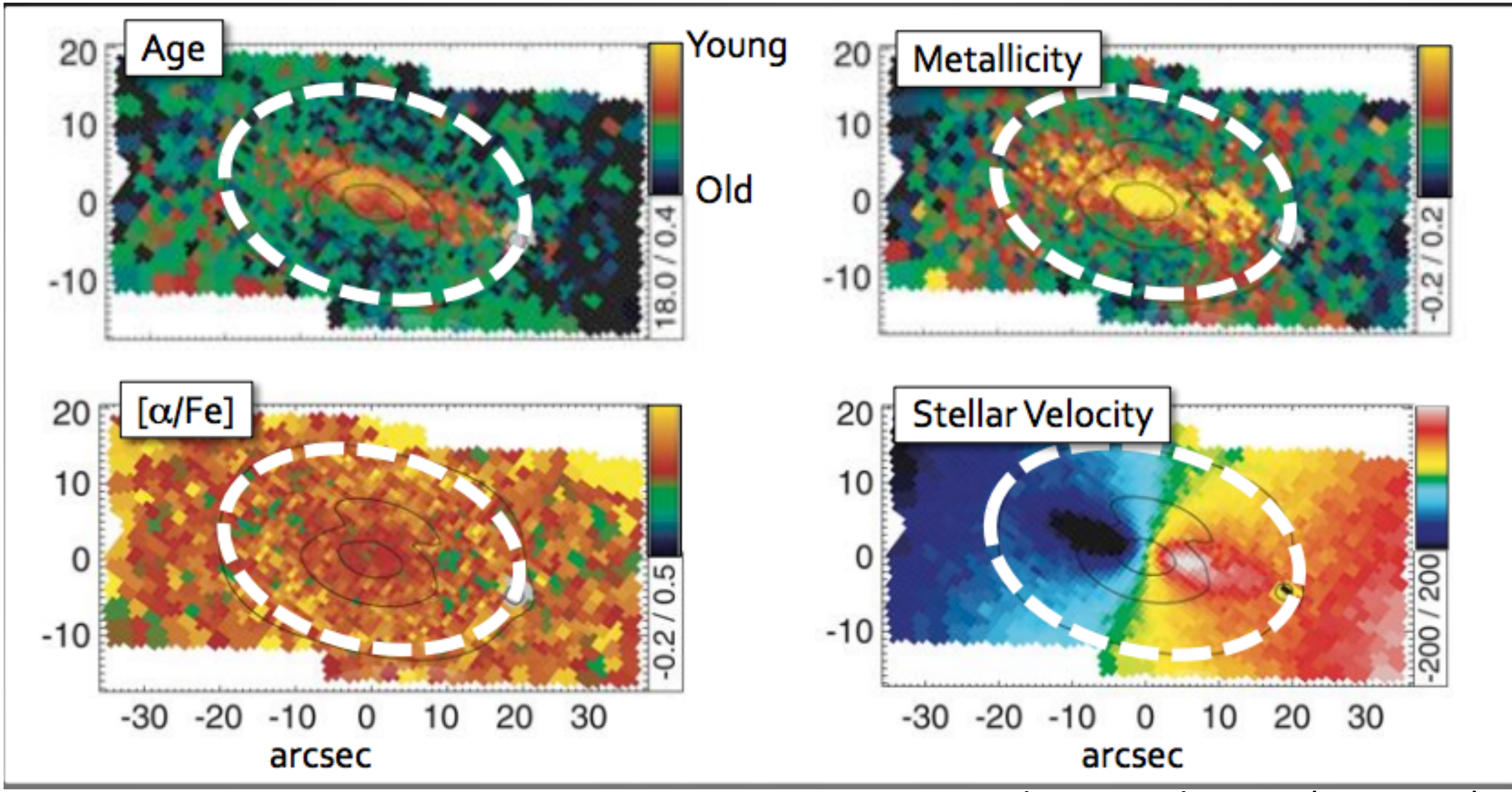
SAURON IFU @ WHT (4.2m)
FOV:
33”x41”
Lenset :
0.94”
Spectral range: 4800-5400 Å
Spectral resolution:
3Å (75 km/s)



Kuntschner et al. 2010

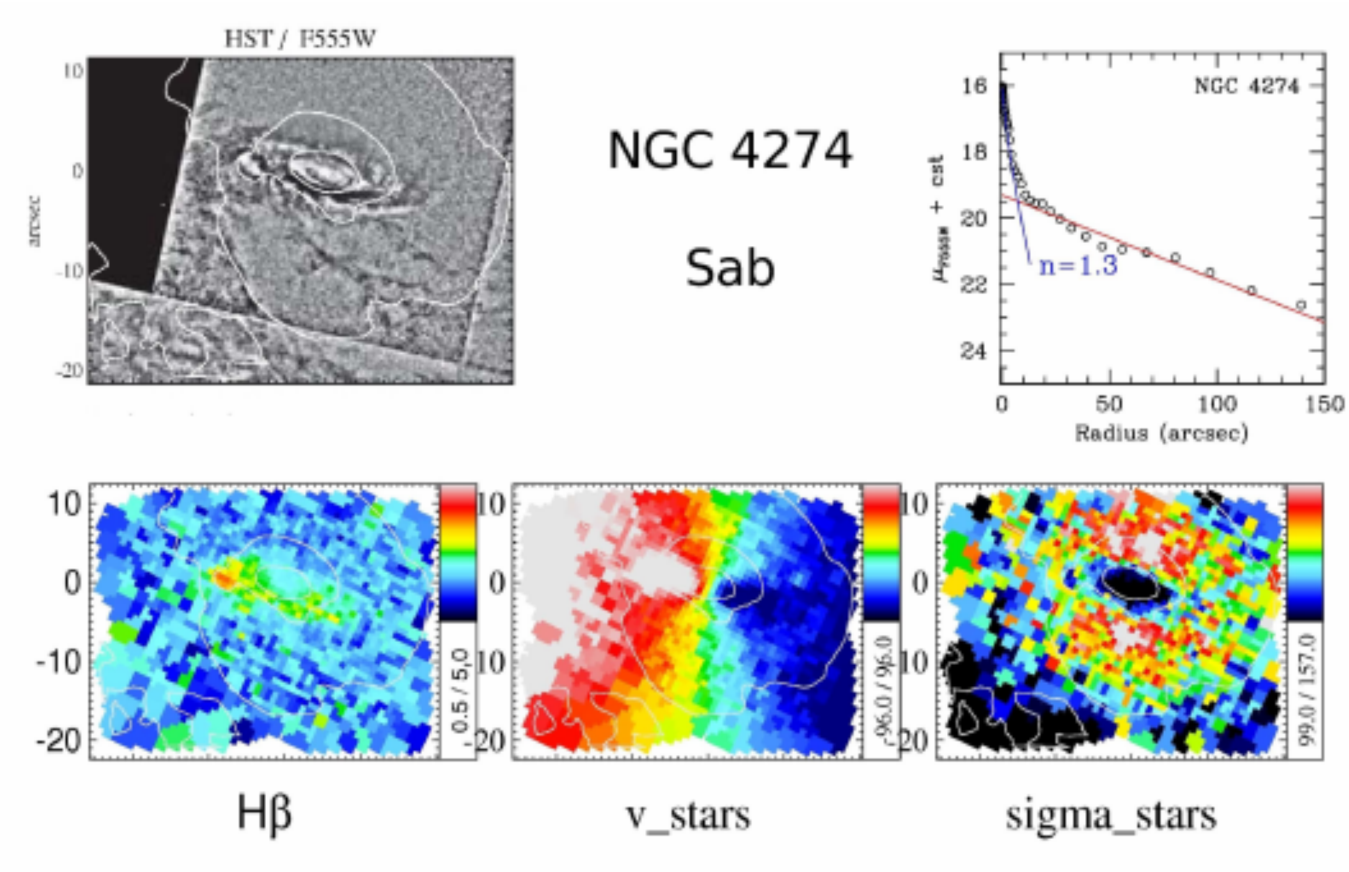
Stellar Populations with IFS: examples

40% of the galaxies show signs of contributions from young stellar populations
Many early-type galaxies contain kinematically defined central disks.



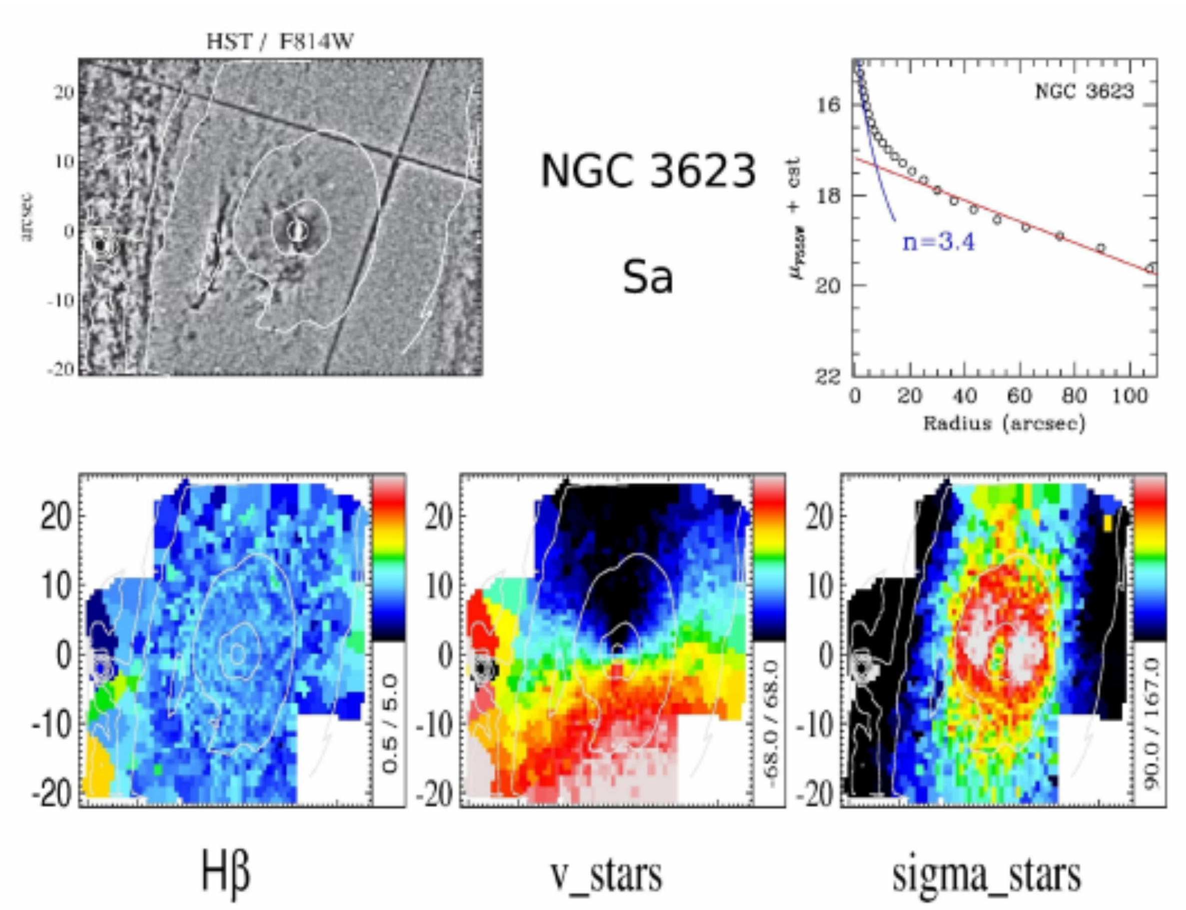
Kuntschner et al. 2010 (SAURON)

Bulges of Sa



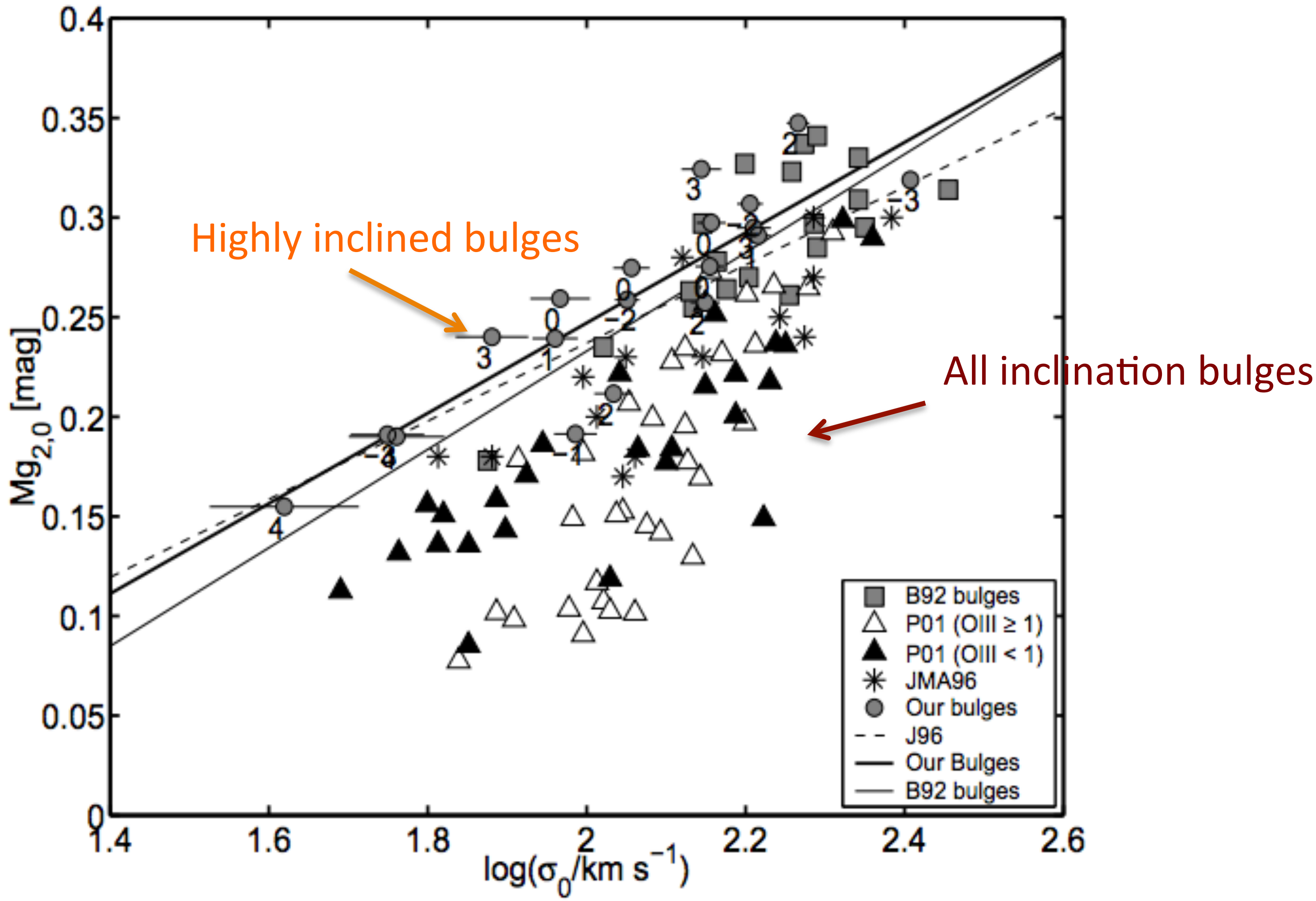
Falcon-Barroso et al. (2006)
Peletier et al. (2007)

Bulges of Sa



Falcon-Barroso et al. (2006)
Peletier et al. (2007)

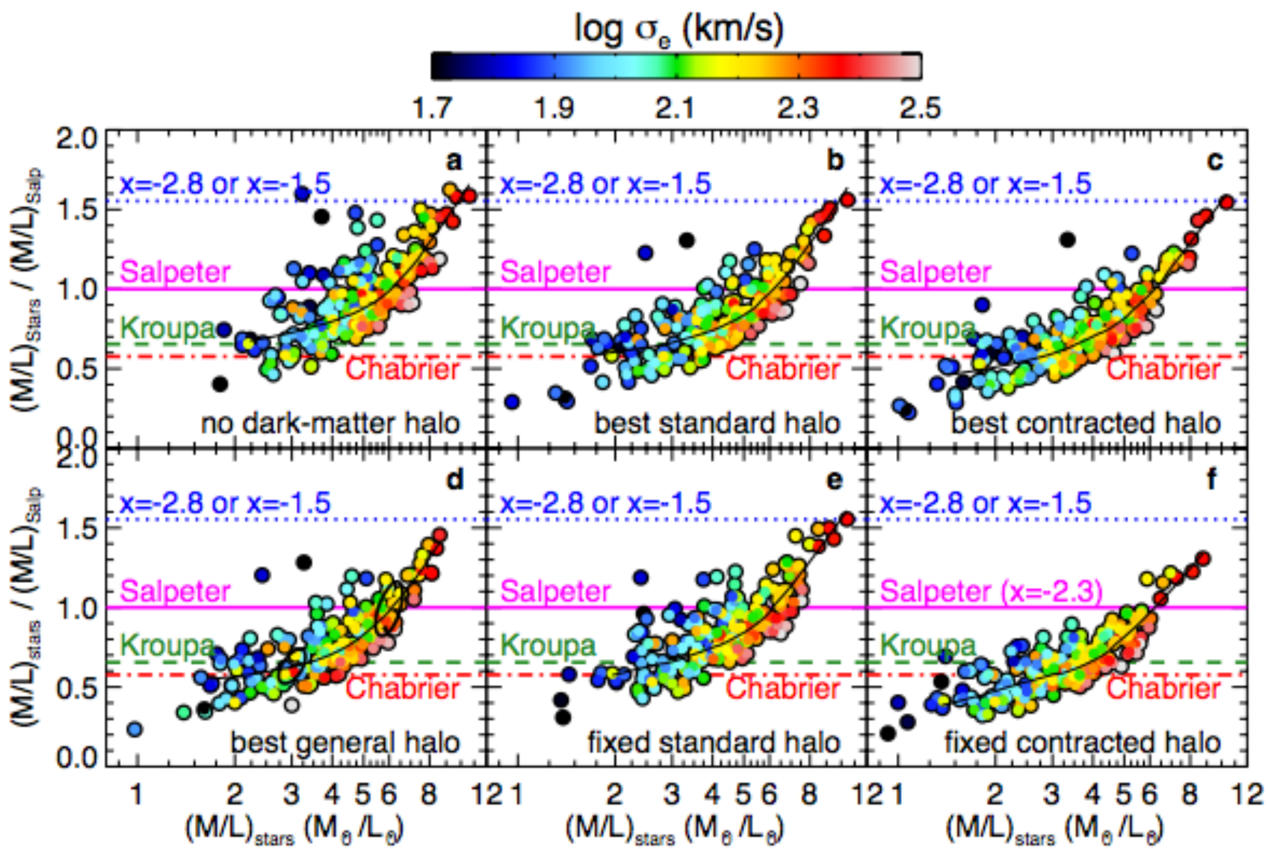
Bulges as composite systems



Falcon-Barroso et al. (2002)

Variations of IMF with mass

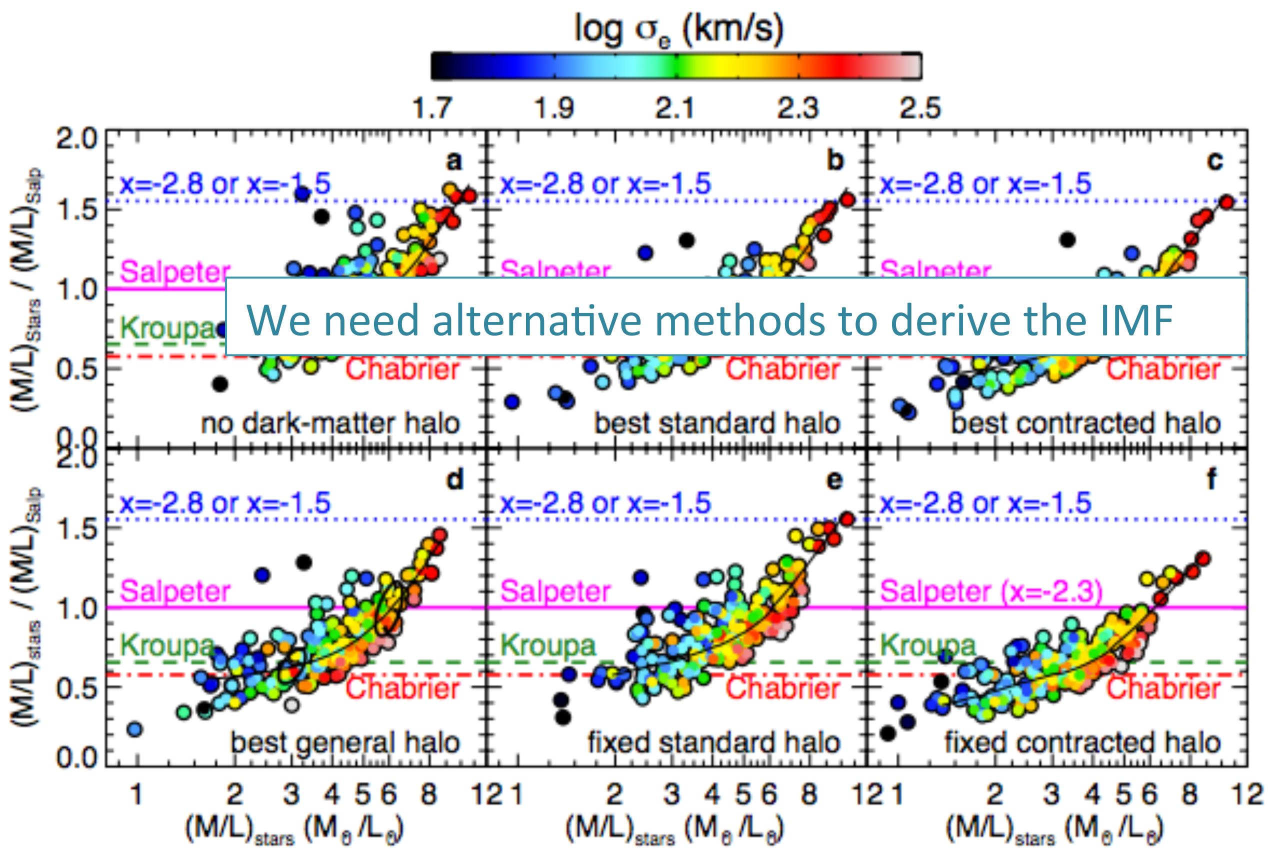
Sample: volume limited sample of 260 early-type galaxies



Cappellari et al. (2012)

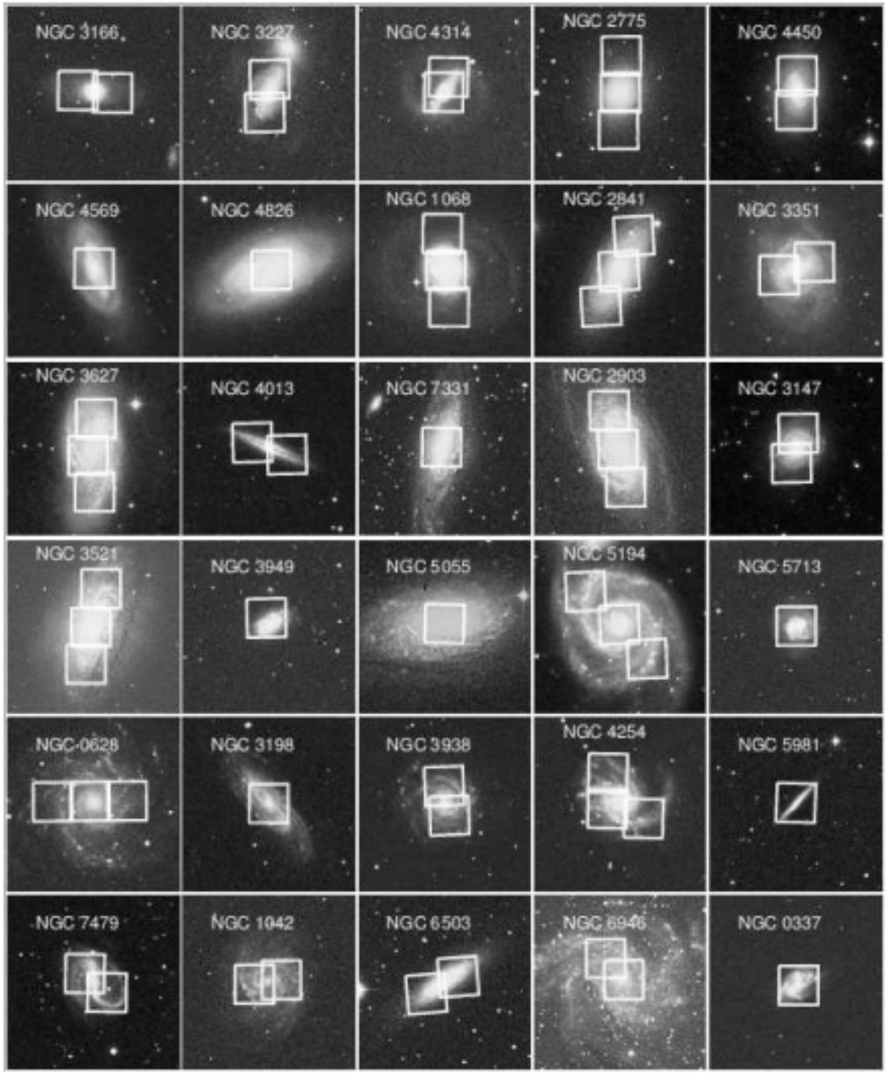
Variations of IMF with mass

Cappellari et al. (2012)



We need alternative methods to derive the IMF

VENGA



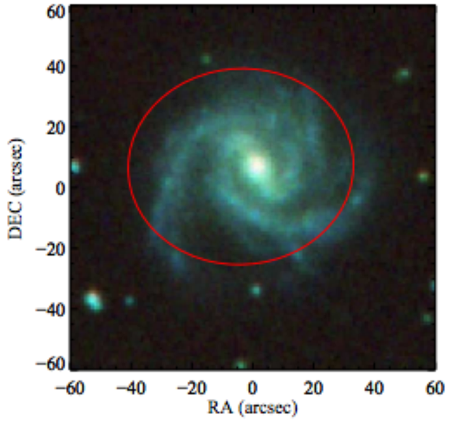
Blanc et al. (2013)

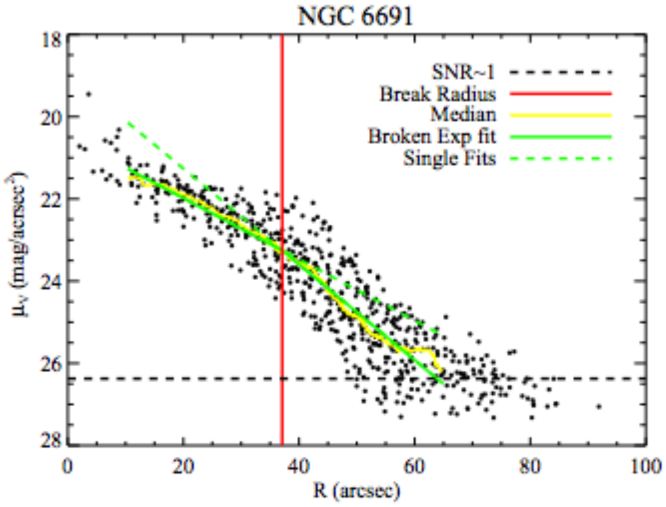
The VENGA sample 32 nearby spiral galaxies using VIRUS-P and IFU bundle of 246 optical fibers.

2.7m Harlan J. Smith (McDonald)
4.3” fiber diameter
5.6” FWHM spatial resolution
5A FWHM spectral resolution
3600-6800 A spectral range
~0.7 R25
FOV: 1.9’x1.9’ with 1/3 filling factor

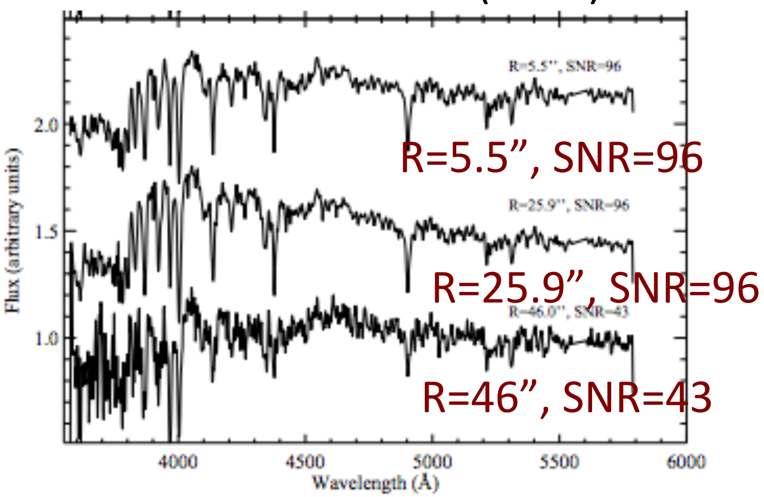
Stellar populations in the outer disks

- 12 nearby disk galaxies to the outer disk
- They sample the population in the outskirts to look for signatures of 'stellar migration' due to resonant interactions with disk structures.



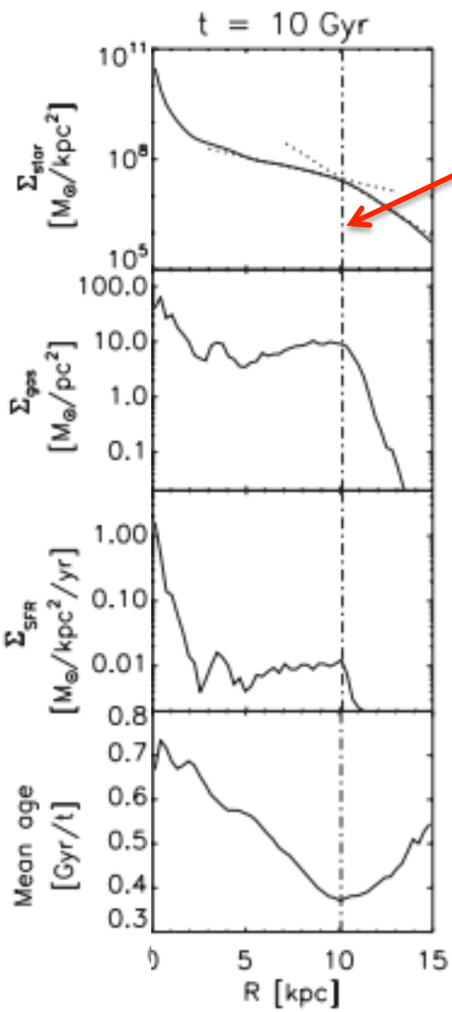


Yoachim et al. (2012)



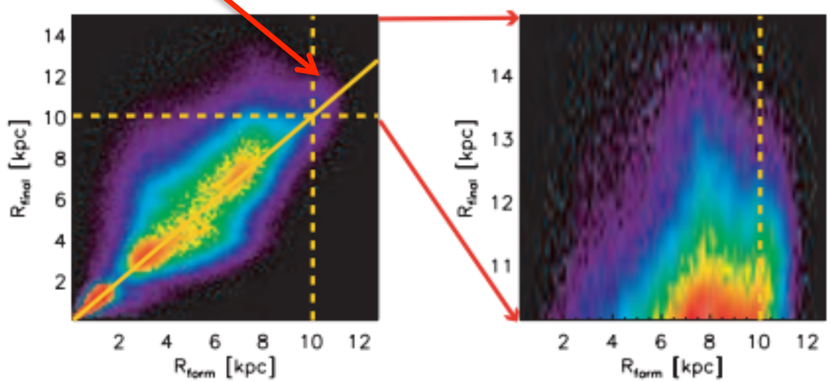
Stellar migrations in disk galaxies

- 60% spiral galaxies have truncated profiles



truncation radius

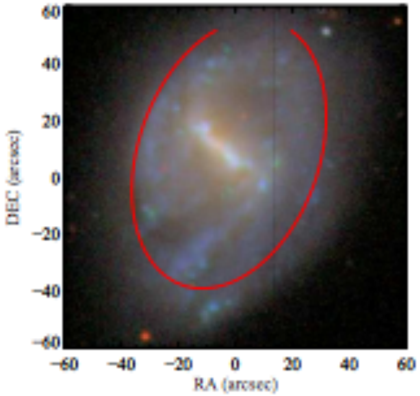
Roskar et al. (2008)

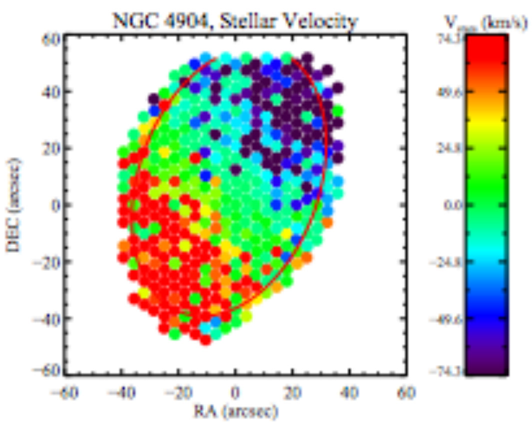


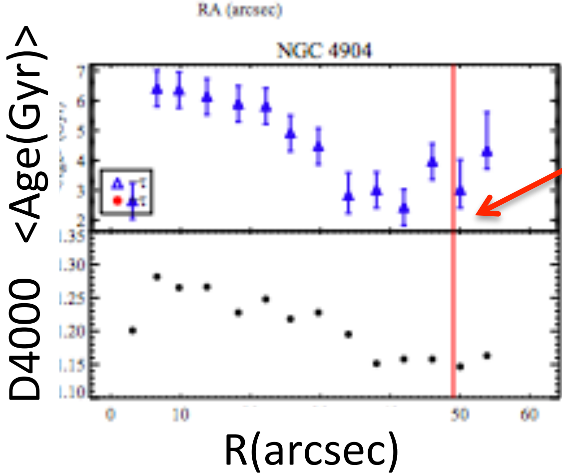
Understand the stellar migration is very important for:
- Stellar archaeology
- Chemical evolution models (age-metallicity relation, MDF)

Stellar Populations in the outer disks

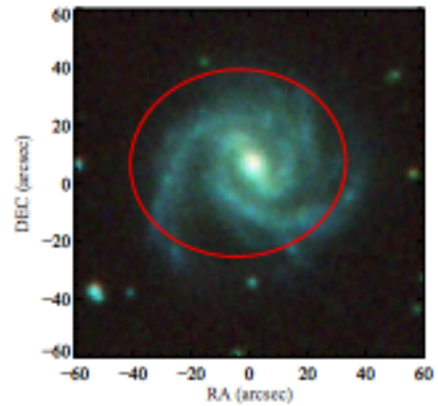
Yoachim et al. (2012)

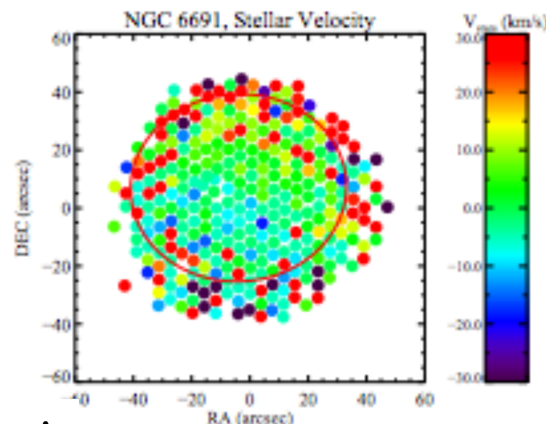


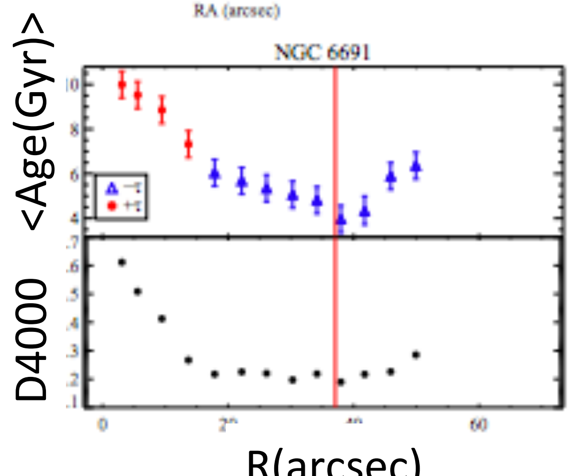




Break radius







Results from Yoachim et al. (2012)

They were able to measure ages in the outskirts of 6 galaxies:

- **3 cases they found an increase in the age beyond the break**
- **3 cases they do not observe a change in the age beyond the break**

→ Model of stellar migration for formation of type II profile are not clear.

Results from Yoachim et al. (2012)

They were able to measure ages in the outskirts of 6 galaxies:

- **3 cases they found an increase in the age beyond the break**
- **3 cases they do not observe a change in the age beyond the break**

→ Model of stellar migration for formation of type II profile are not clear.

U-shape age profiles can be created by other means (PSB et al. 2009) → need of other methods to quantify radial migration

Sanchez et al. (2012)

600 galaxies of all types at z=0.005 to 0.03 diameter selected from SDSS to fit in the PPAK FOV (45”<D25<80”)

Covered out to isophotal radius at 25 mag/arcsec^2 with spatial sampling of 2”~0.5-1kpc (although with dithering the *spatial resolution* is better ~1 arcsec)

Spectroscopic coverage of full wavelength range from *3700 to 7000 Å* at two spectral resolutions R=850 and R=1600

Legacy survey: reduced data public once quality verified (the second DR has been in Oct. 1st (200 galaxies) – see http://califa.caha.es/ --).

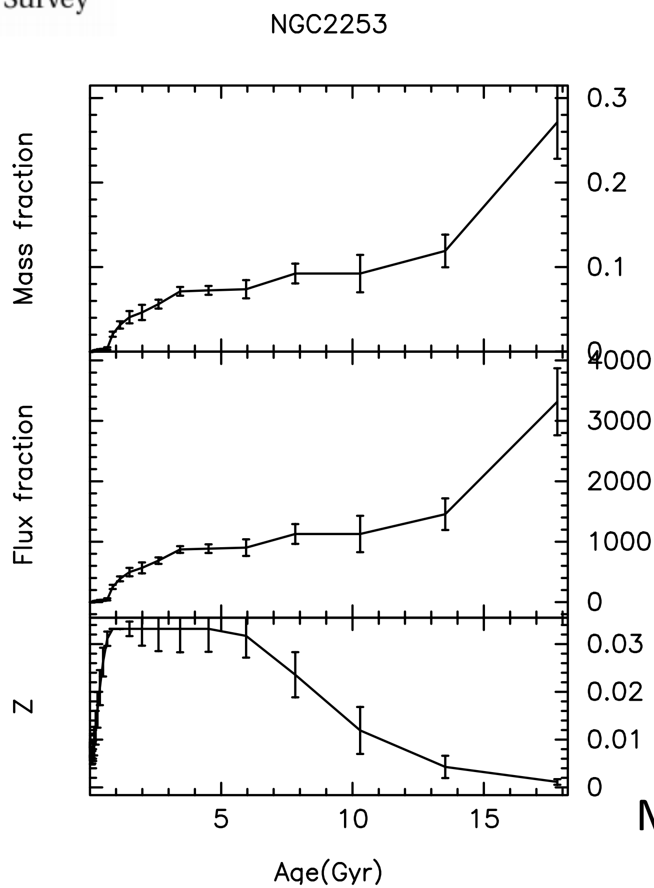
Non-parametric SFH

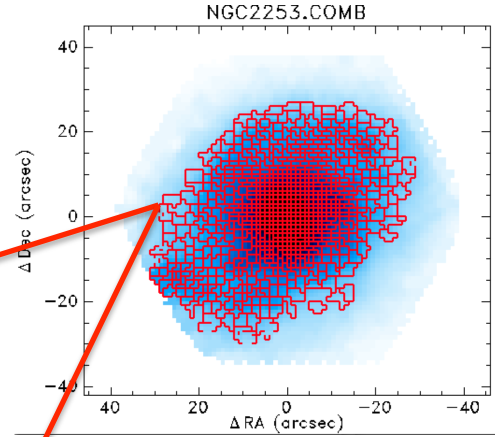
- In the simplest implementation one specifies a fixed set of age bins and fits for the fraction of mass formed within each bin.

- MOPED (Heavens et al. 2000); STARLIGHT (Cid Fernandes et al. 2005; STECKMAP (Ocvirk et al. 2006); VESPA (Tojeiro et al. 2007); ULySS (Koleva et al. 2009); MacArthur et al. (2009)

- Perez et al. (2013); Cid Fernandes et al. (2014ab); Gonzalez Delgado et al. (2014ab); Sanchez-Blazquez et al. (2013, 2014), McDermid et al. (in preparation)

S/N~40 per Å (@ 5800Å)



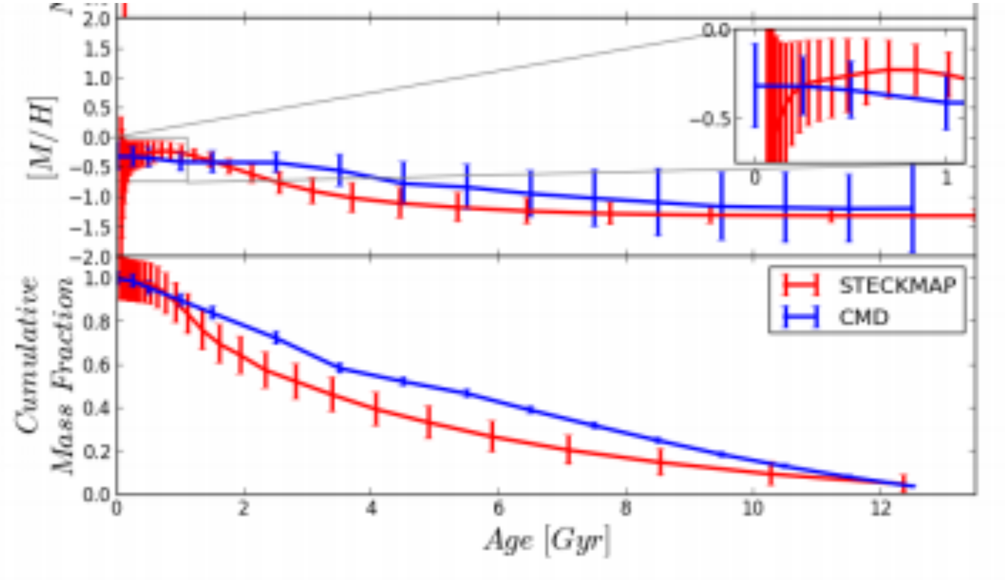


Mean values

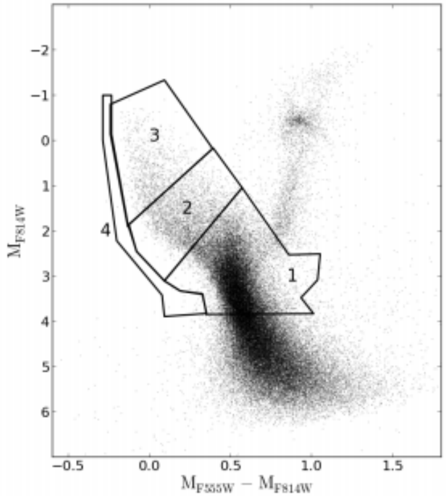
$$< \log age >_{MW} = \frac{\sum_i mass(i) \log age_i}{\sum_i mass(i)}$$

$$< \log age >_{LW} = \frac{\sum_i flux(i) \log age_i}{\sum_i flux(i)}$$

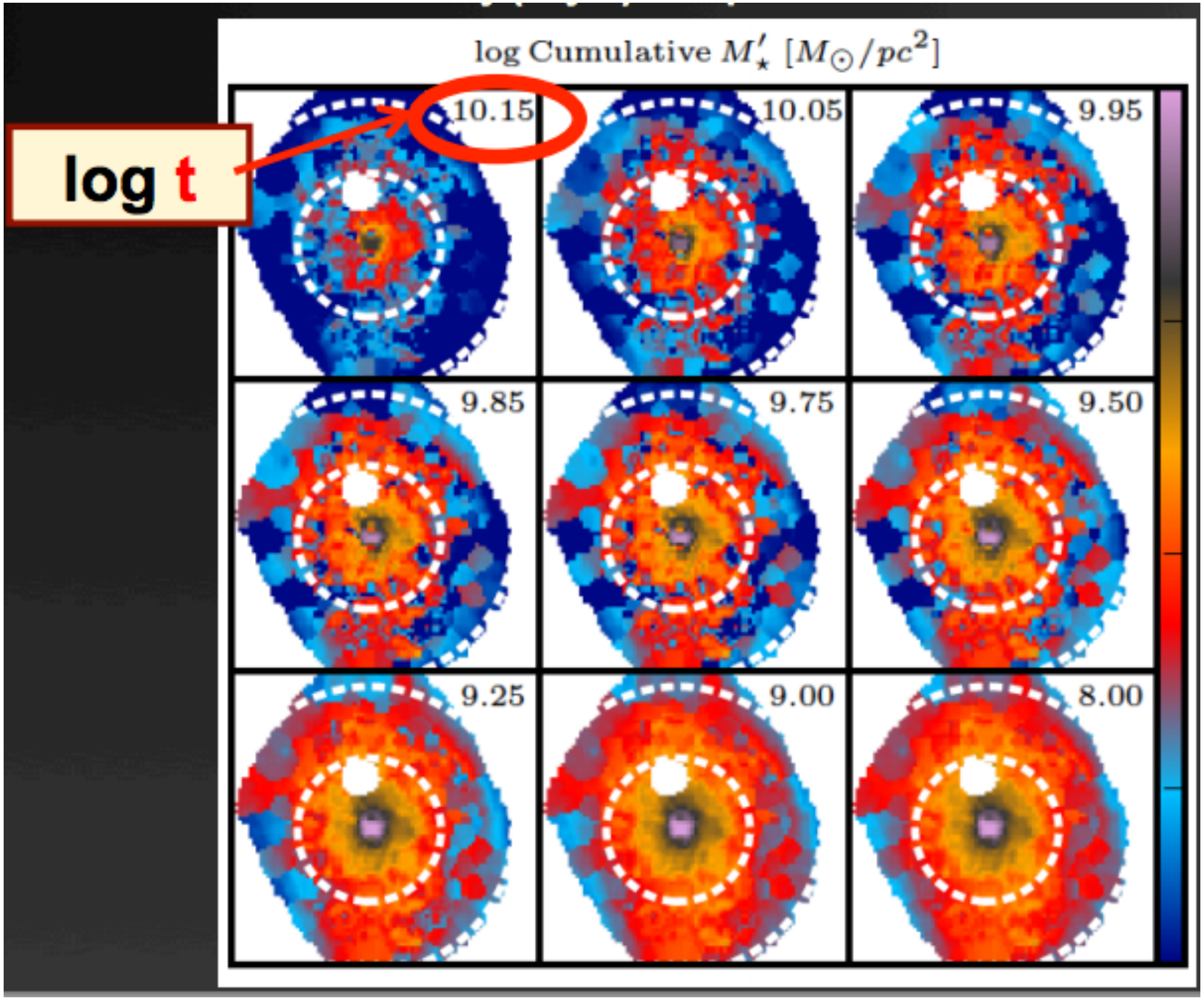
Comparison of resolved and unresolved SP
Test case: LMC



Ruiz-Lara (in preparation)

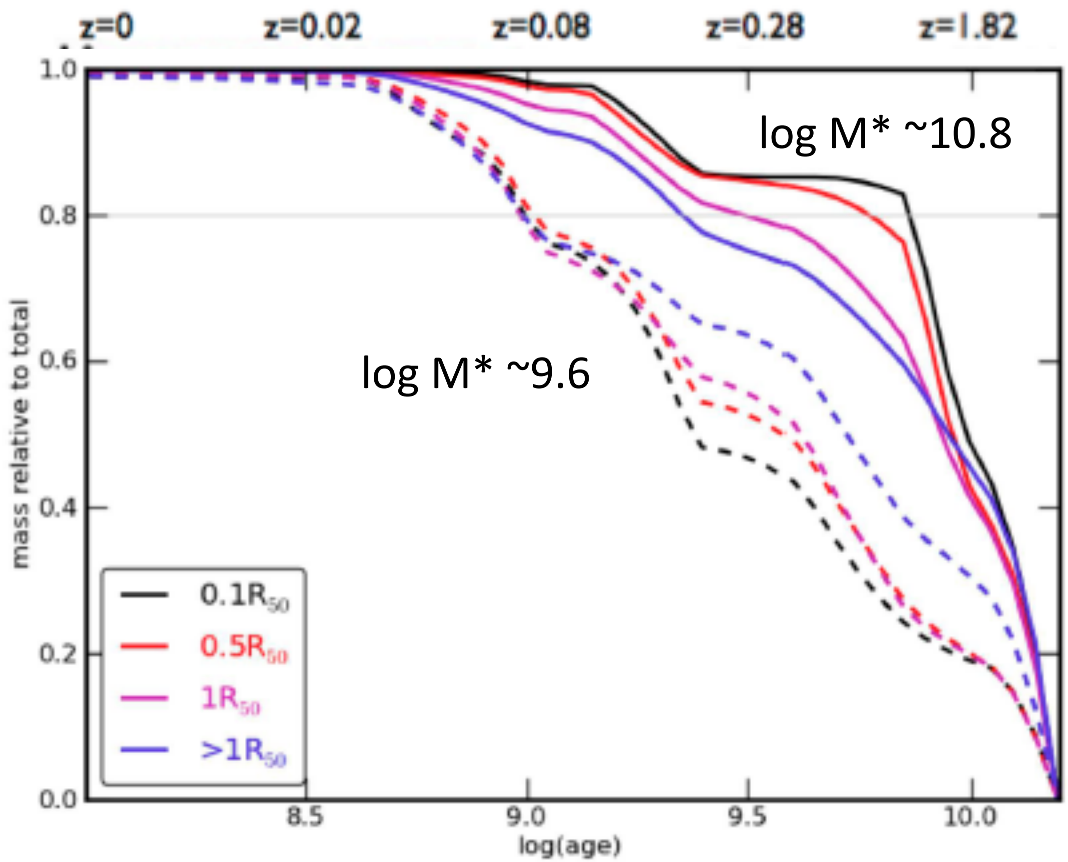


The inside-out growing of galaxies



Cid Fernandes et al. (2013) [CALIFA]

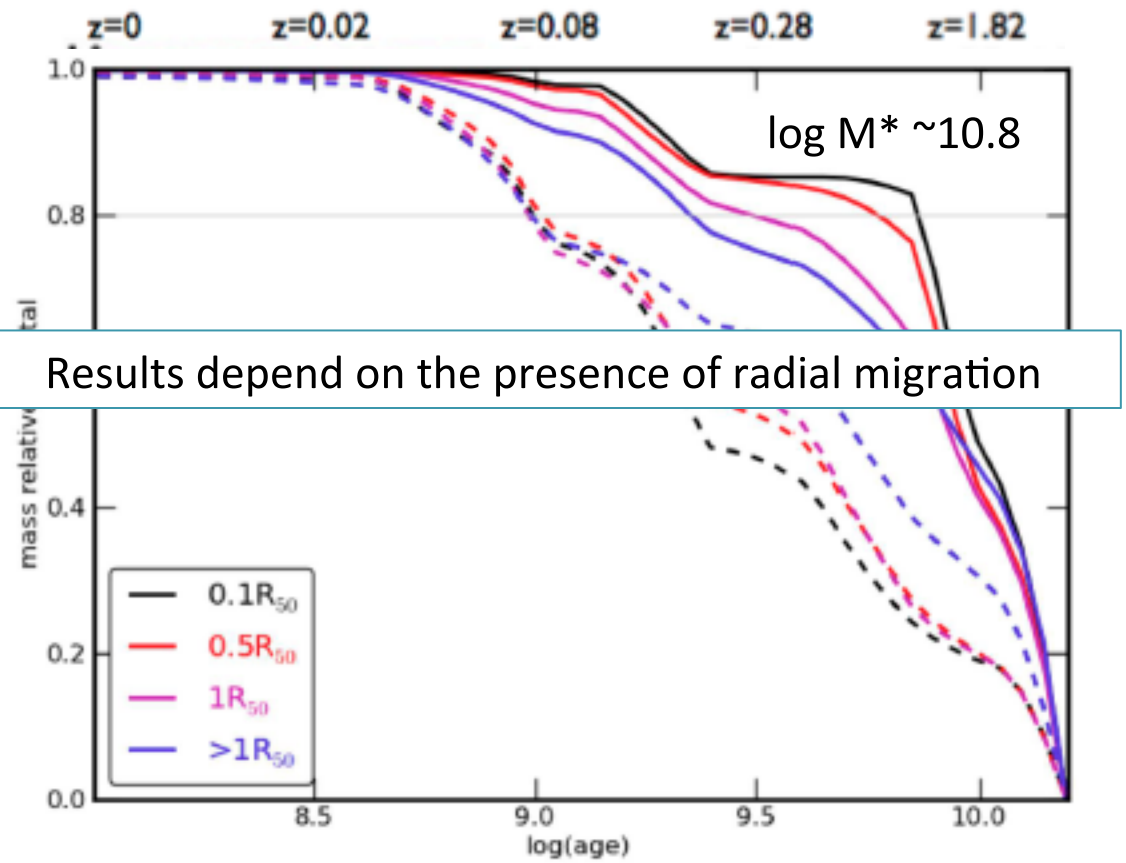
The Inside out growing of galaxies



Perez et al. (2013)

CALIFA Survey

The Inside out growing of galaxies

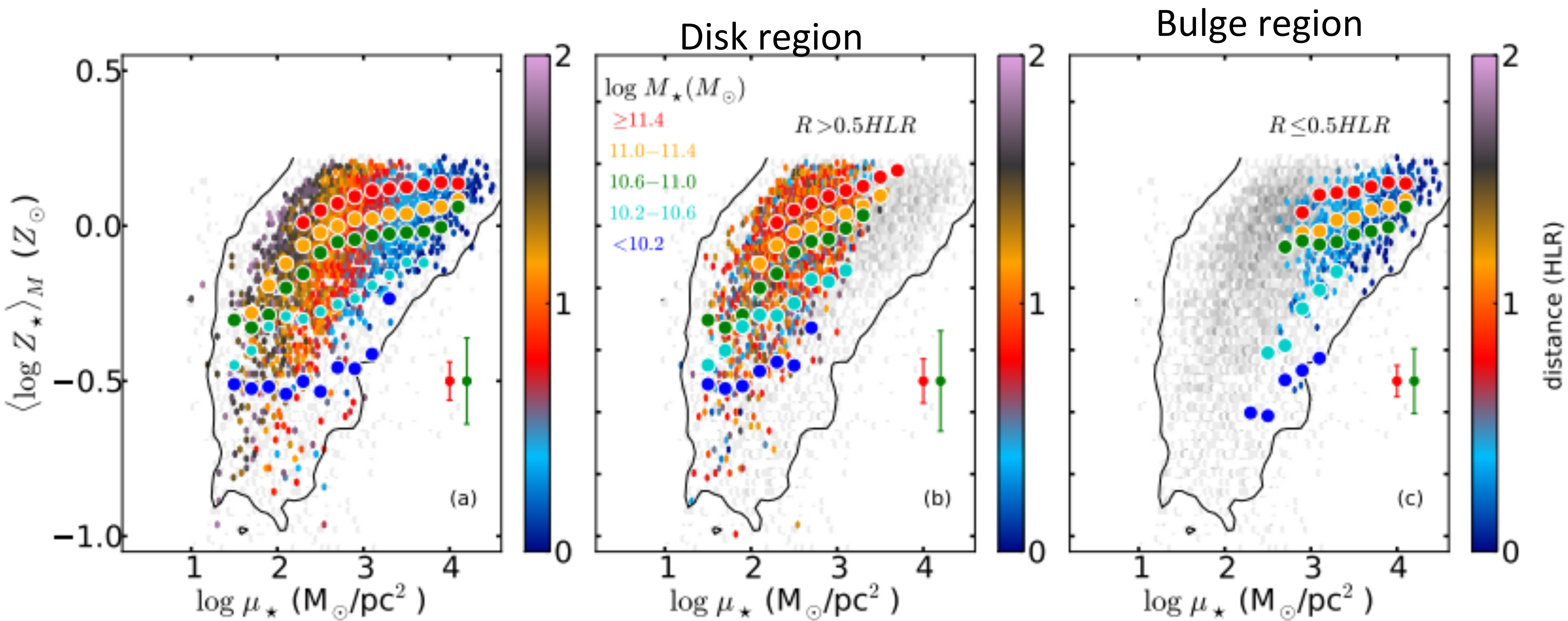


Results depend on the presence of radial migration

Perez et al. (2013)

CALIFA Survey

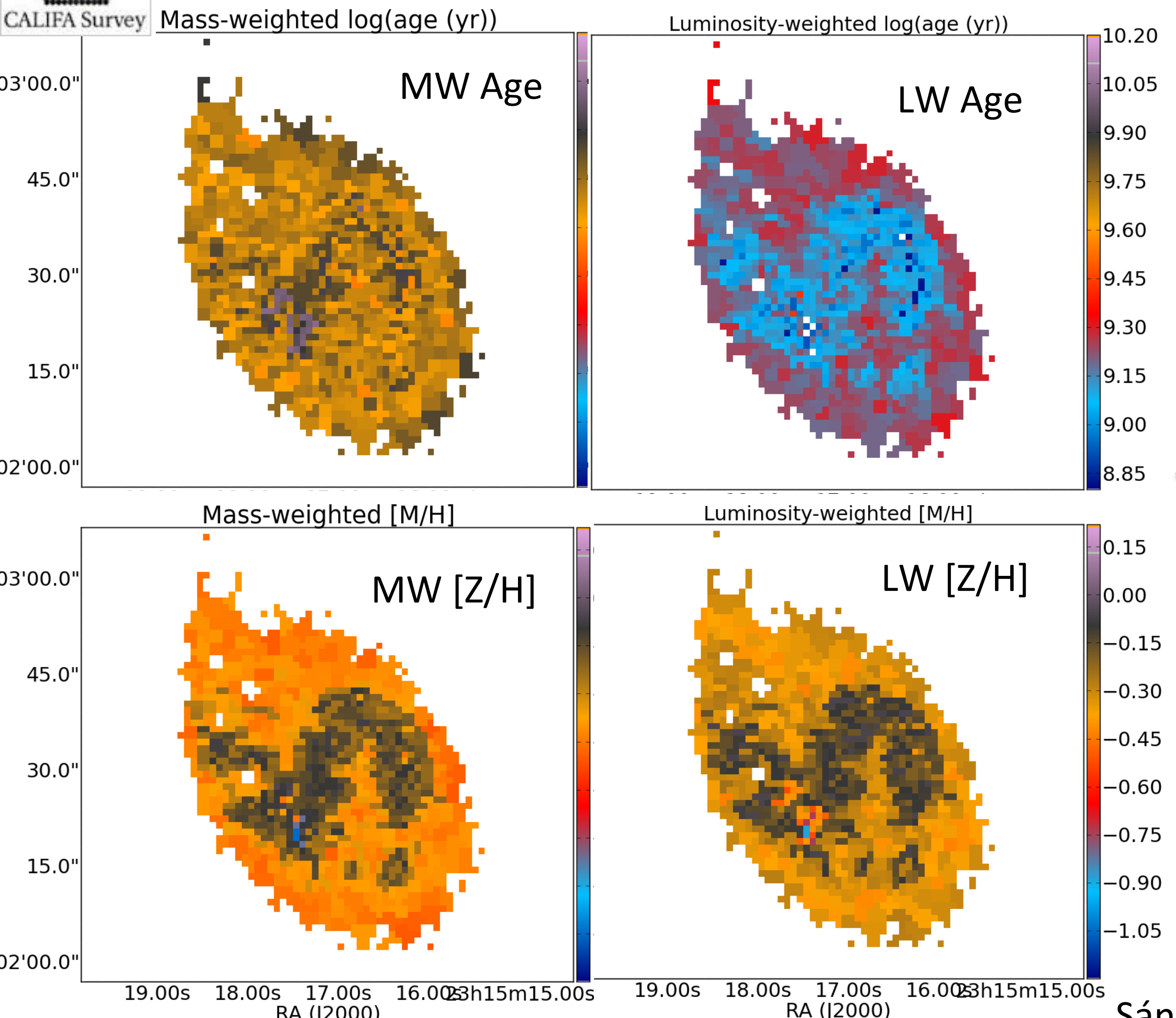
Correlations between local metallicity and local stellar surface density



Gonzalez Delgado et al. (2014)

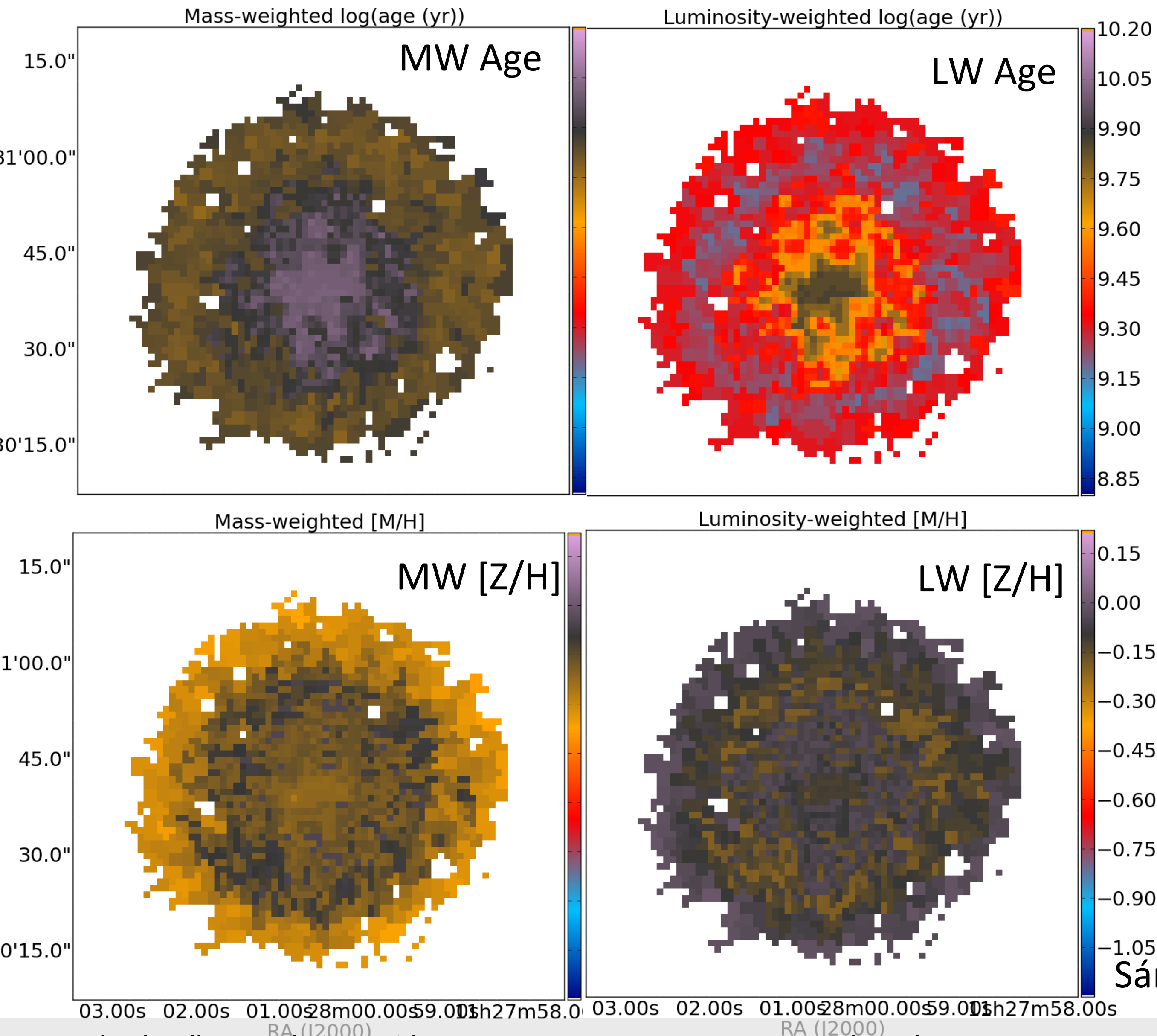
The mean stellar metallicity (and age) is more closely related to M_* in spheroids
The mean stellar metallicity (and age) is more closely related to μ_* en disks.

The Stellar populations in disk galaxies



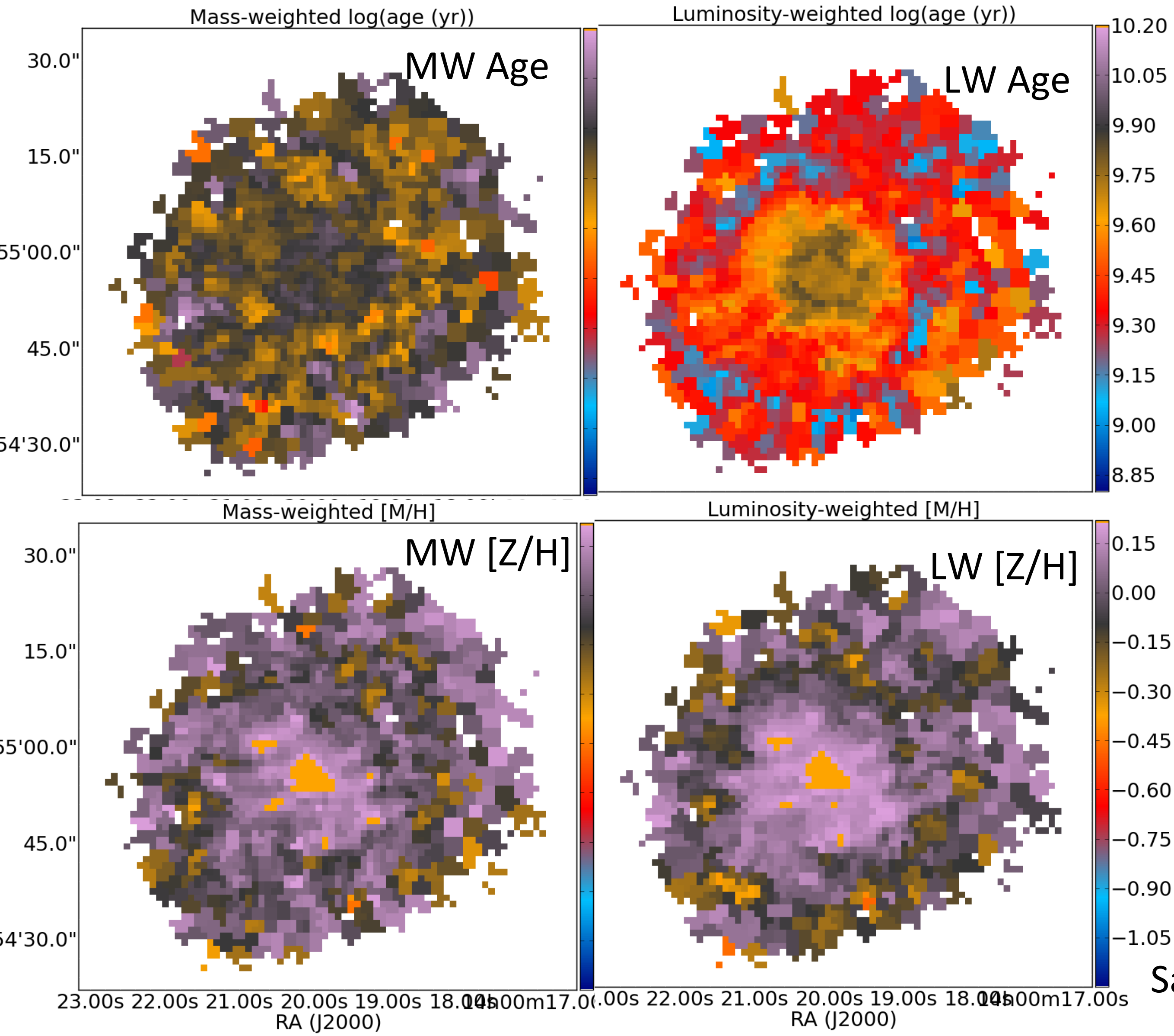
Sánchez-Blázquez et al. (2014)

The Stellar populations in disk galaxies



Sánchez-Blázquez et al. (2014)

The Stellar populations in disk galaxies



Sánchez-Blázquez et al. (2014)

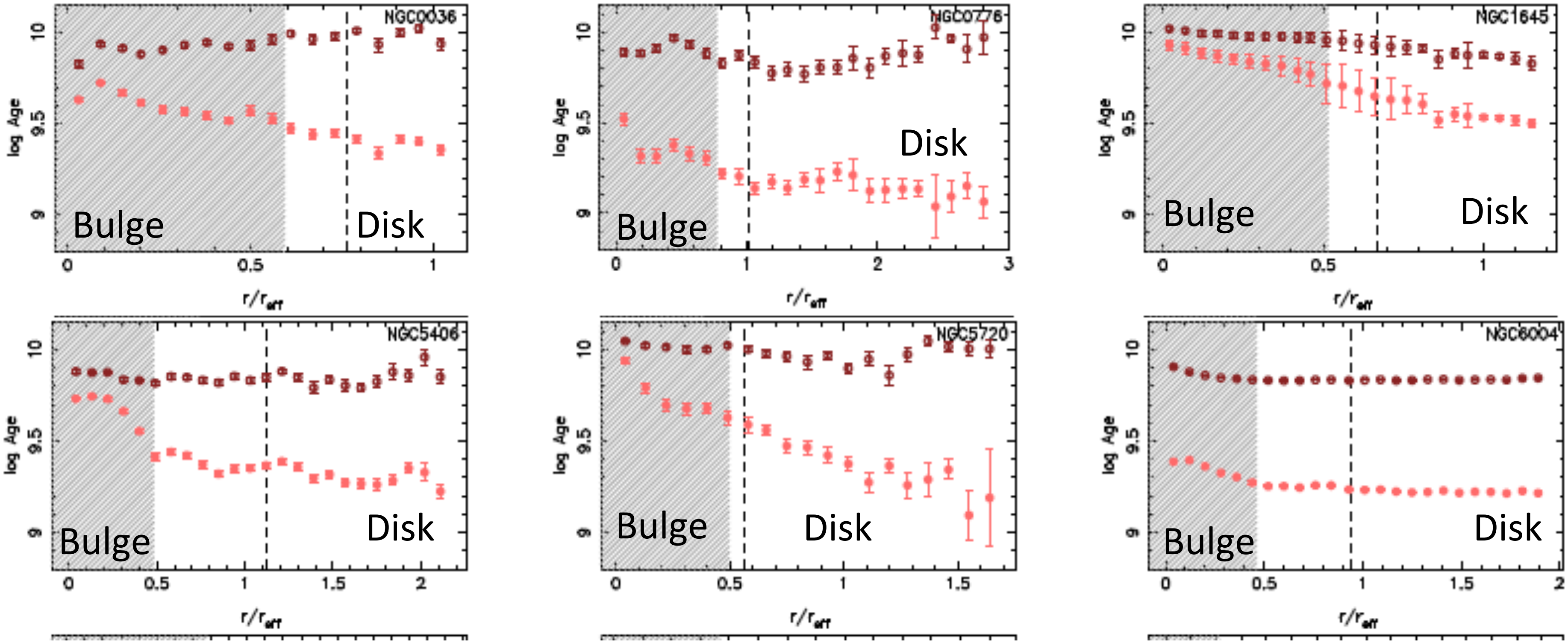
Luminosity weighted values

Mass weighted values

Age gradients

reff = 1.67835rd

Sánchez-Blázquez et al. (2014)

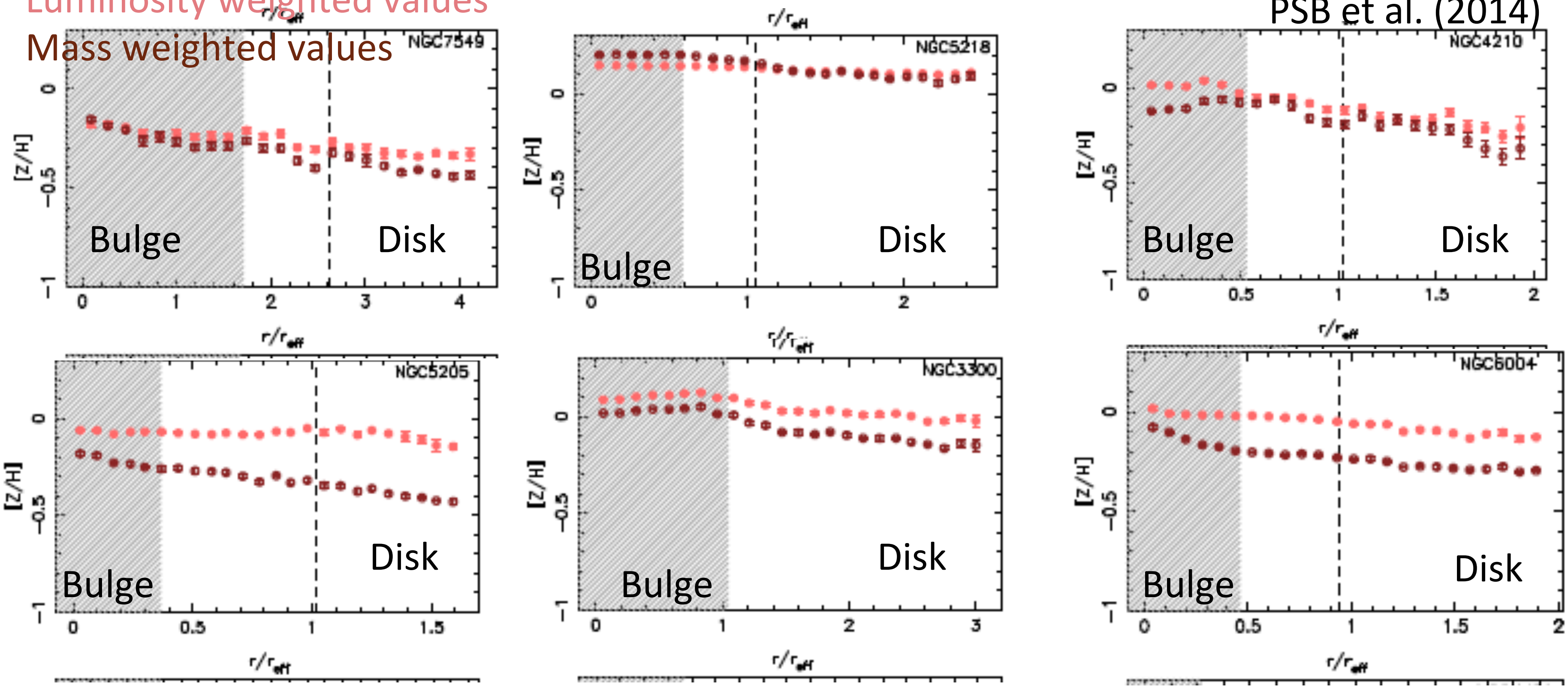


- Results:
- Mass-weighted age gradient reflect **old stellar populations** at all sampled radii
- Lum-weighted age gradient is always negative in the disk region (although very mild)

Metallicity gradients

Luminosity weighted values
Mass weighted values

PSB et al. (2014)



Results:
- •In general, metallicities are very high in the disk region
- •The slopes of the MW and LW metallicities are very similar

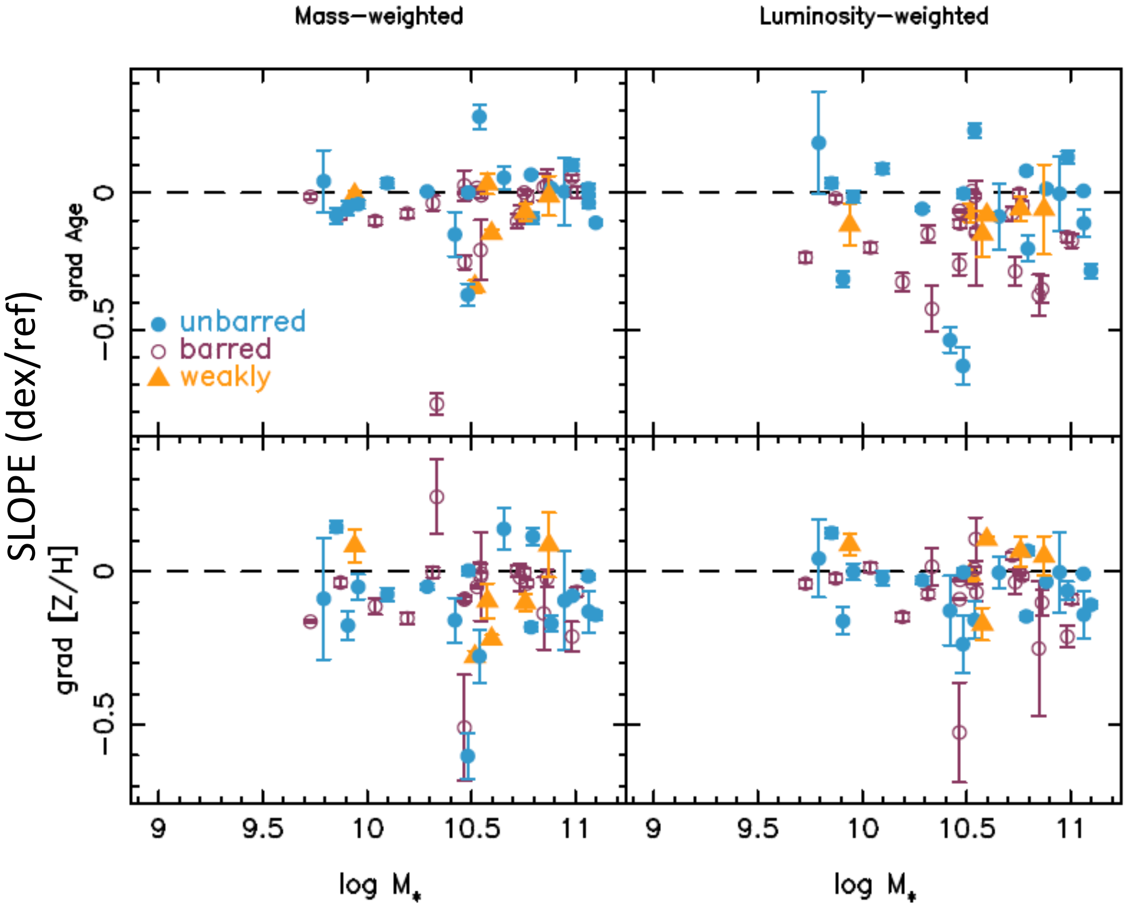
Summary: disk galaxies (in the disk region)

→The flat mass-weighted age gradient and the high metallicity values suggest an early and rapid formation of the disk (similarly to what is seen in resolved stellar population studies (e.g., Gorgarten 2010; William et al. 2009).

→Alternatively, radial migration can bring old and metal rich stars from the internal parts.

Differences in the Stellar population gradients of barred and unbarred galaxies

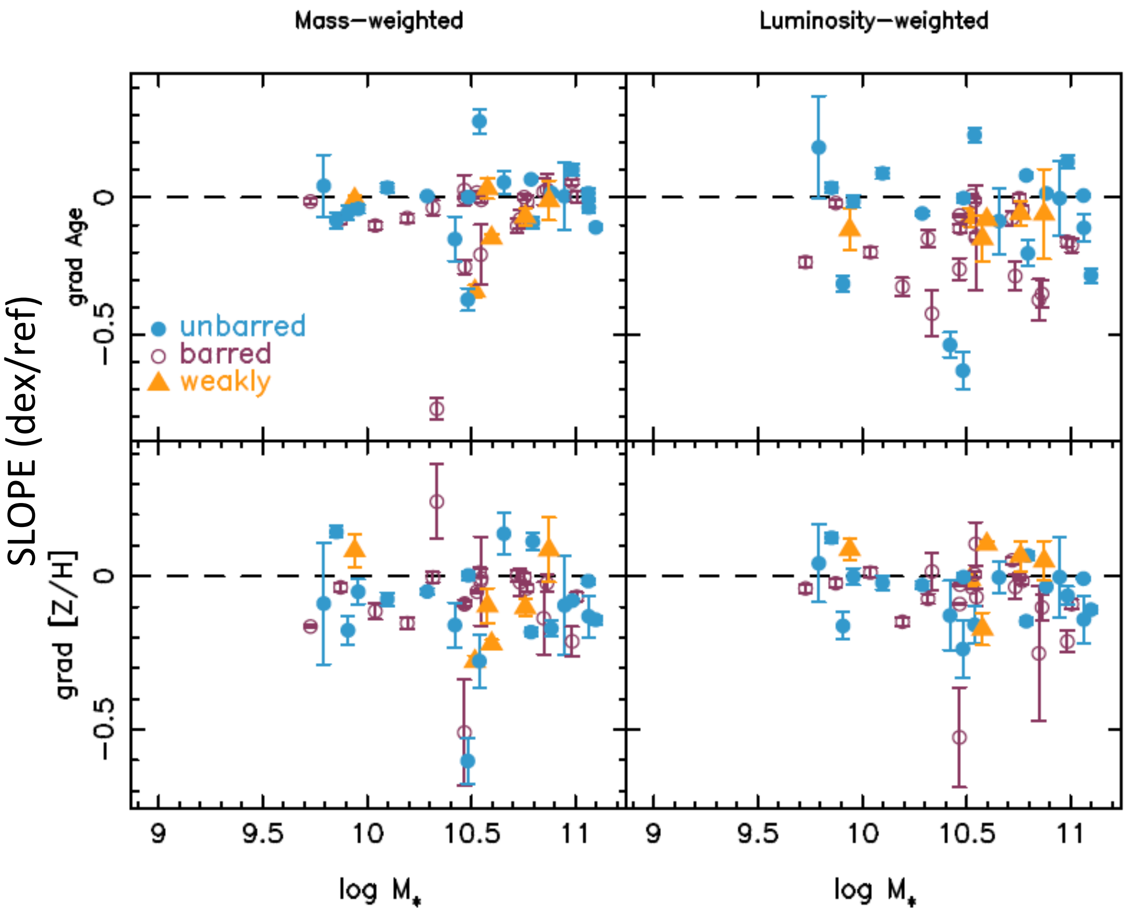
CALIFA Survey



Sánchez-Blázquez et al. (2014)

•There **is no difference** in the SP gradient of barred and unbarred galaxies.

Differences in the Stellar population gradients of barred and unbarred galaxies



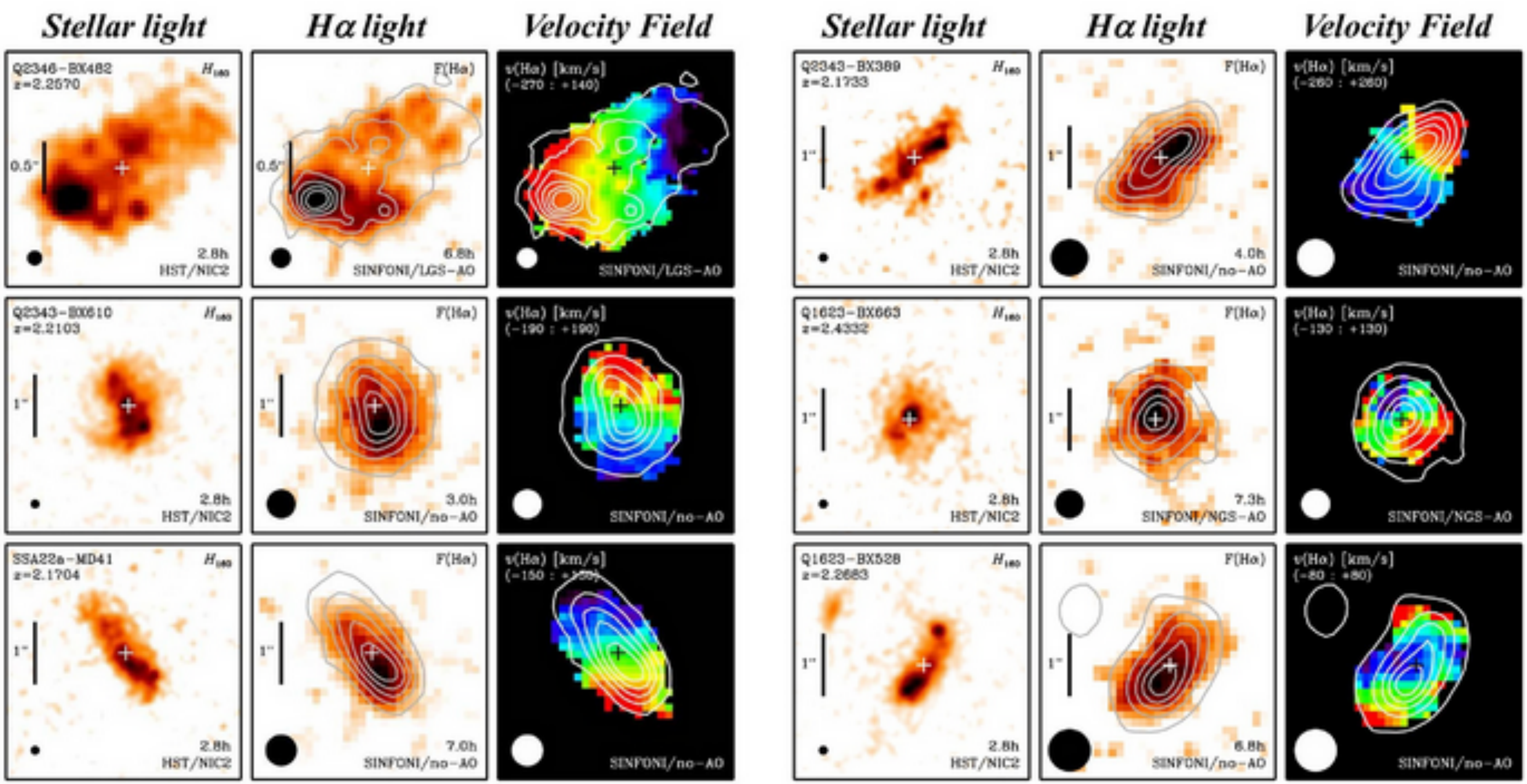
Sánchez-Blázquez et al. (2014)

•There **is no difference** in the SP gradient of barred and unbarred galaxies.

No radial migration due to bar?
Not necessarily. Result depends on
→ Metallicity gradient in the past
→ Epoch of bar formation

What's next?

- We can now derive spatially resolved kinematics (from the ionized gas) of distant galaxies at redshifts of up to z~3 (e.g., Forster-Schreiber et al. 2006, 2009; Yang et al. 2008; Law et al. 2009; Lemoine-Busserolle et al. 2010; Contini et al. 2012; Puech et al. 2012).



Stellar populations at high redshift

- For resolved stellar populations maybe at z~1.5, but we will be able to obtain representative samples

(1) **In situ vs. migration**: What is the age of the extended disk? What is the metallicity gradient?

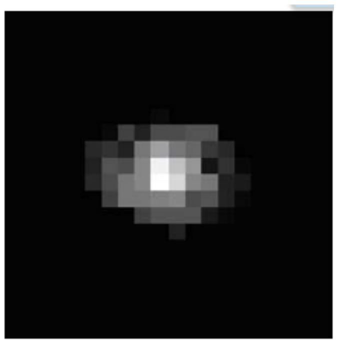
(2) Evolution of the metallicity gradient.

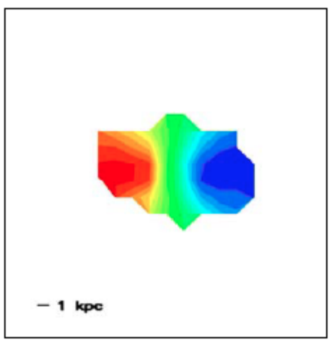
(3) **The formation of bars**: Are the stellar disk that we observe at high redshift stable? (we need kinematics and sigma)

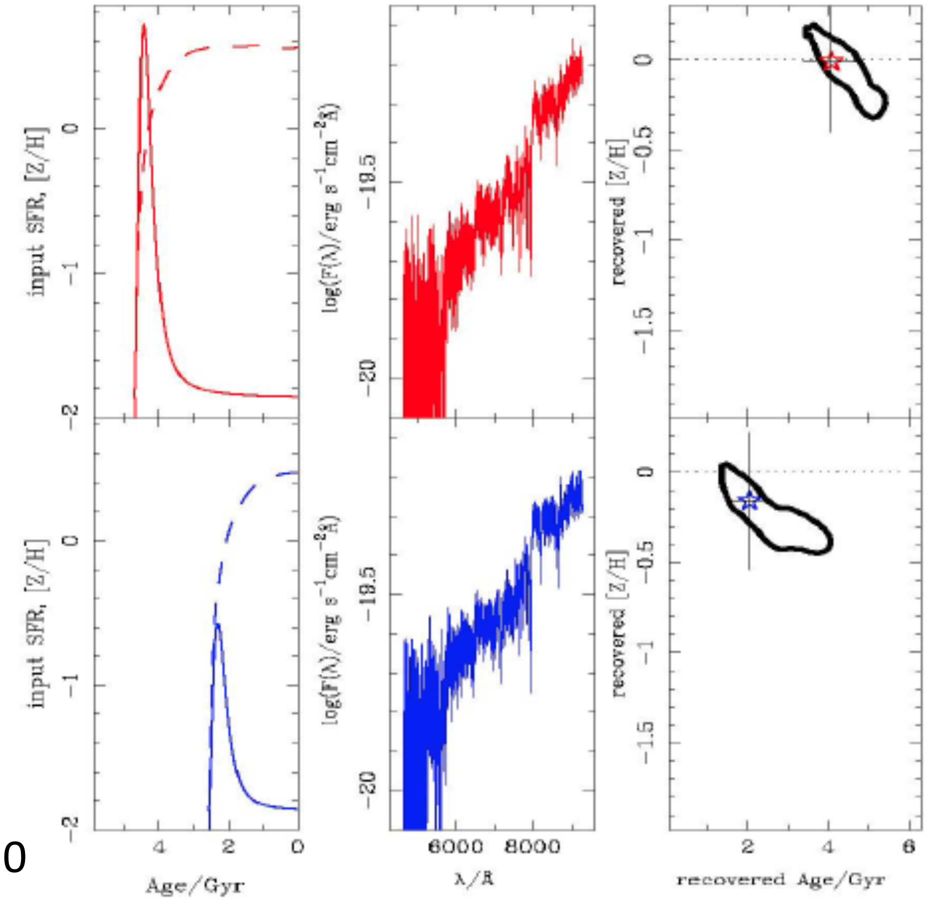
(4) **Testing the growing mechanism** of early-type galaxies via accretion of smaller galaxies

(5) At high redshift **better separation of age** (age gradients)

What can we get with current facilities



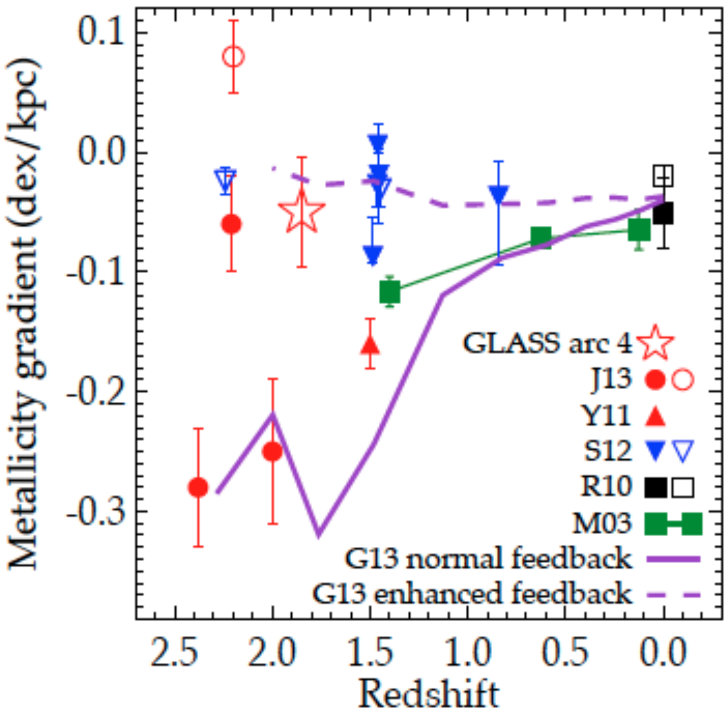




Simulations of a disk galaxy at z=1.0
With a disk scale-length of 0.4”.
80h with MUSE

Difficult to obtain a statistical sample of galaxies

Feedback processes: Temporal evolution of the metallicity gradient

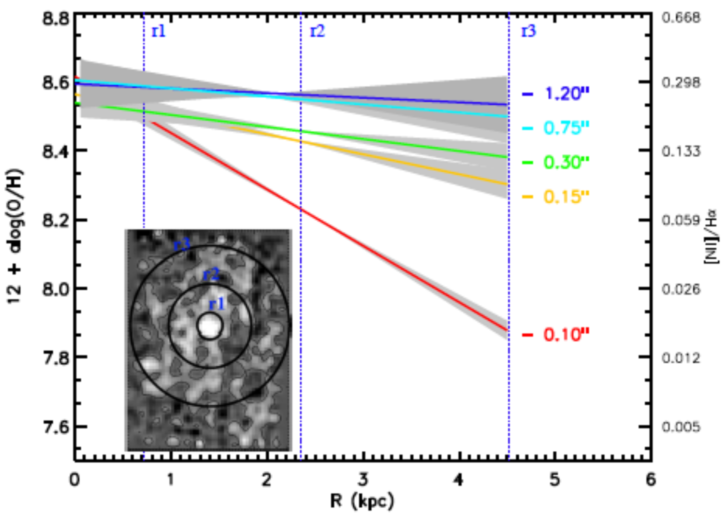


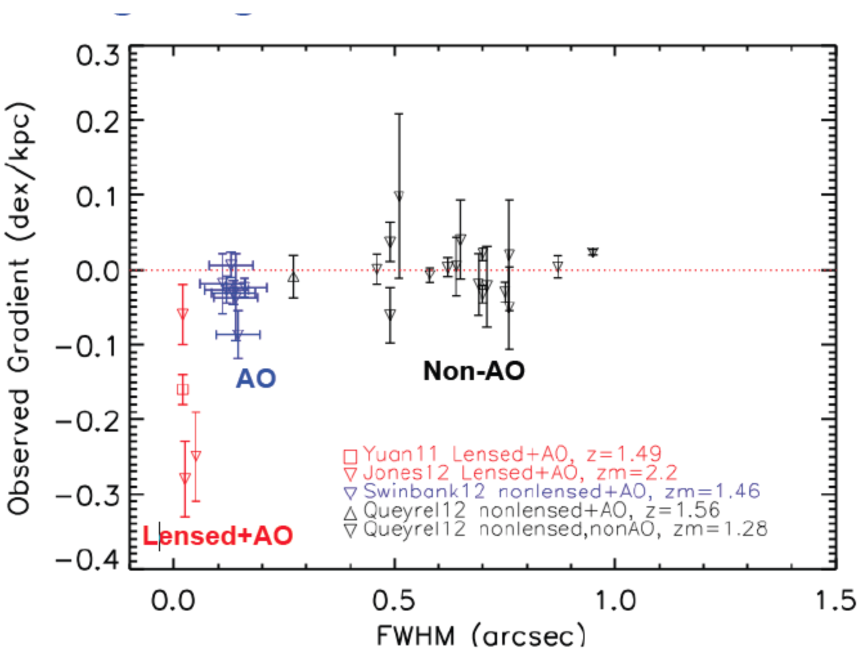
- Evolution of the metallicity gradient with time give us information about the feedback processes
- Empirical evidence remains highly contradictory.

Jones et al. (2014)

High-angular resolution is essential for high-z gradient gradients

Resolution better than 1 kpc is needed
With MUSE, 0.2”→ 1.6 kpc at 0.5 < z < 1 (in concordance cosmology
→ Difficult to obtain representative samples

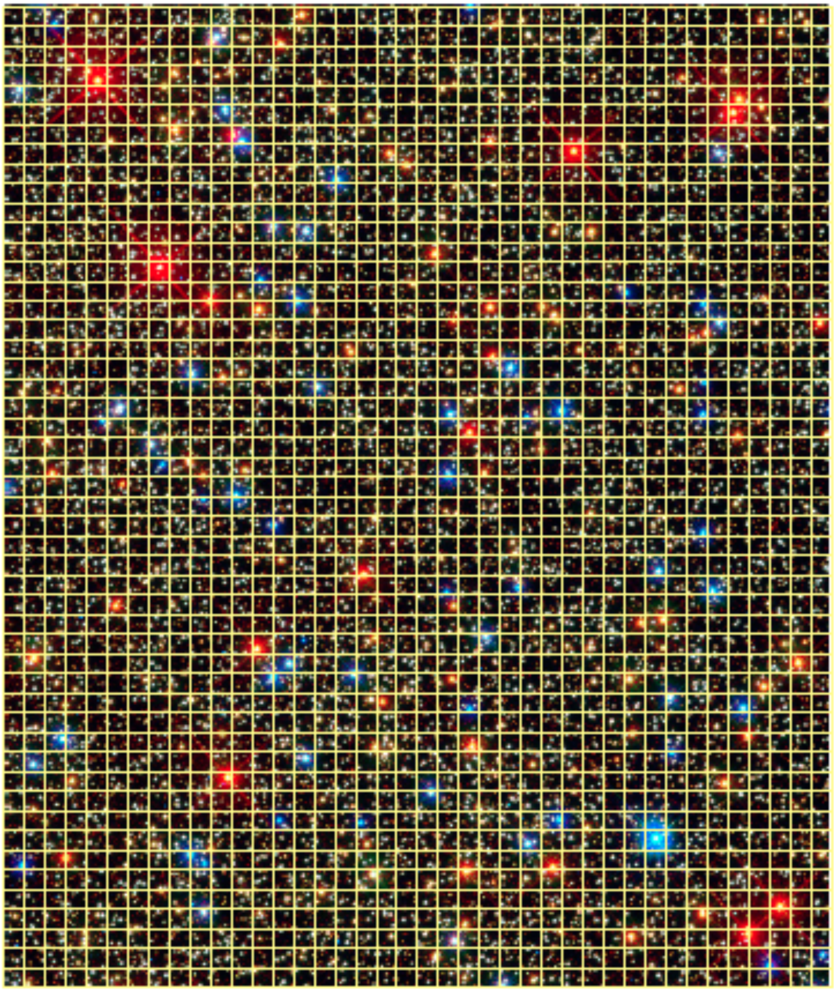


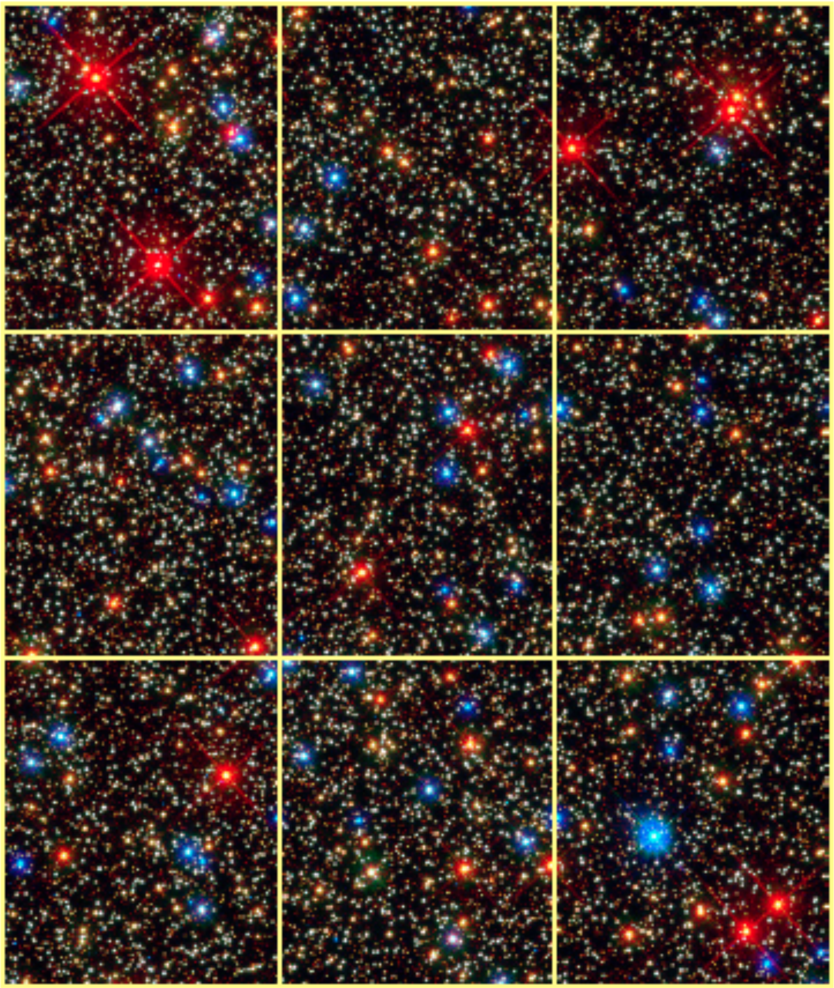


Yuan, Kewley, & Rich 2013

R. Smith

Spectroscopic SBF





Resolved spectroscopy:

Each bright star dominates its spatial element

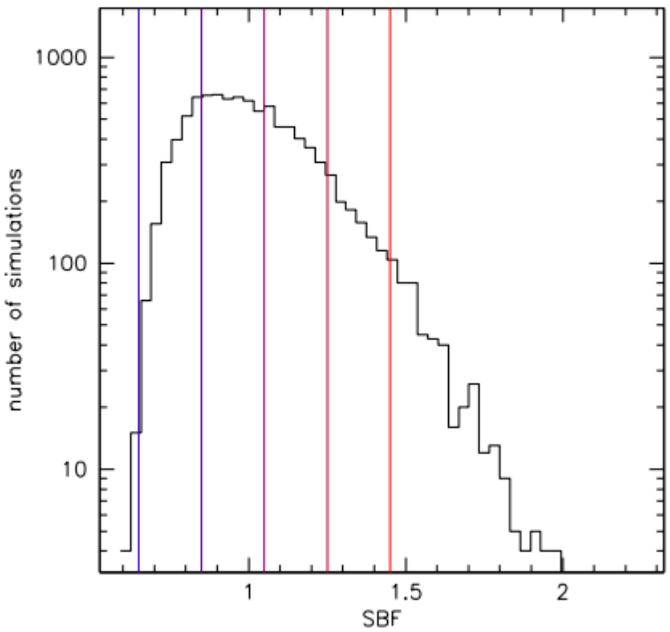
Nearly-resolved spectroscopy:

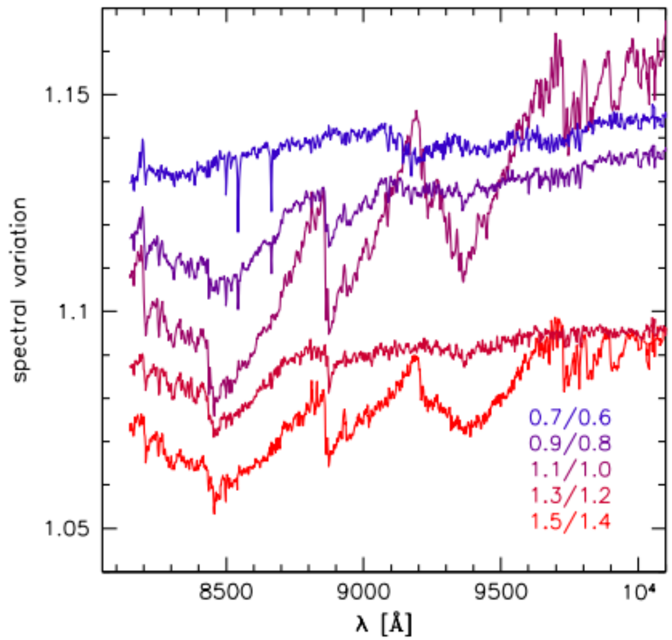
Single stars don't dominate any element

Large poisson fluctuations in bright stars per element

Spectroscopic SBF in the near-IR

Assuming <Nstars>=10^5 per pixel



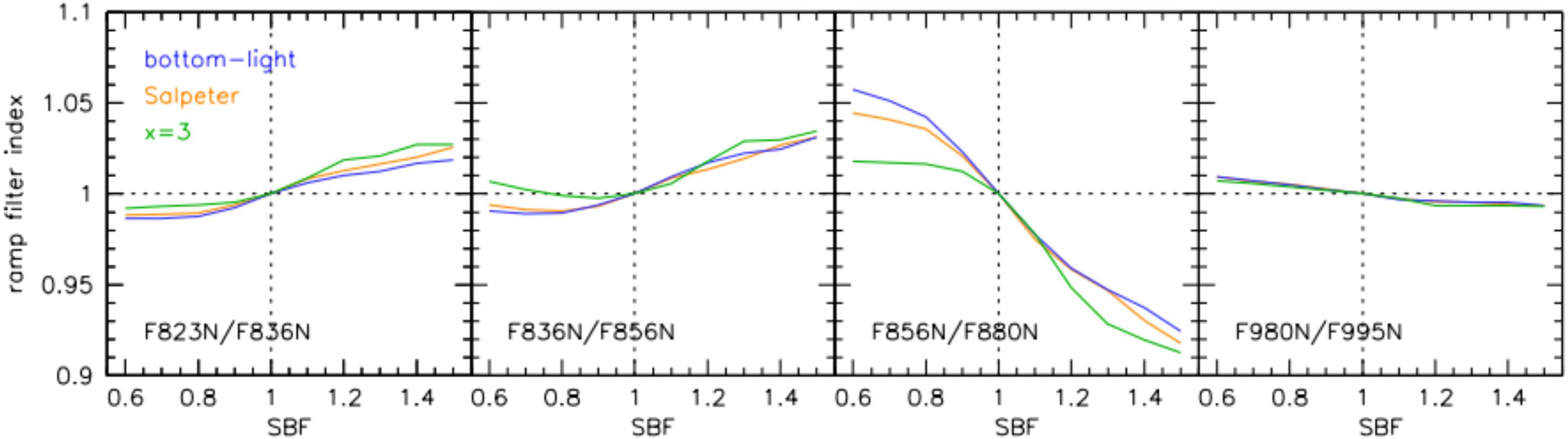


Variation of low luminosity giants and subgiants with temperature

Variation of the spectra of very luminous giants with temperature

Van Dokkum & Conroy (2014)

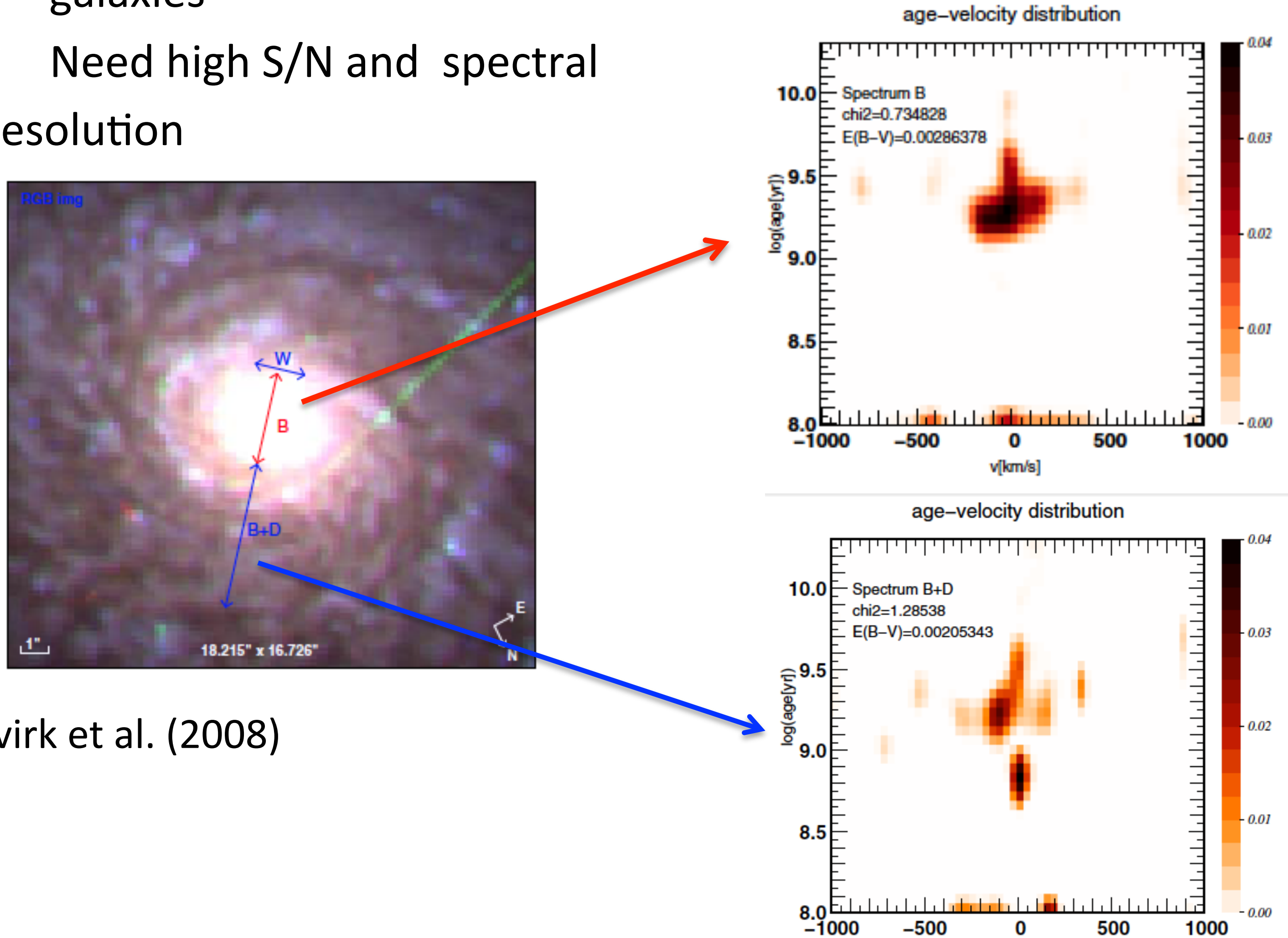
Constraining the IMF with SBF



Van Dokkum & Conroy (2014)
(see also Liu et al. 2000)

New challenges with the ELT: New techniques

- Separation of kinematically distinct components in bulges of nearby galaxies
- Need high S/N and spectral resolution



Ocvirk et al. (2008)

Summary

- IFS are unique tools to understand the complexity of of galaxies and to unequivocally relate the stellar populations with the different morphological and kinematical subcomponents.

IFS at the ELT

- Will allow us to explore the **high redshift universe** and resolve structures (at least up to z~1.5).

→ Extended disks. Stellar pop and stability (how disk, bars, form)
→ Stellar pop of clumps (how bulges form)
→ Separation of migration vs evolution of metallicity gradient (efficiency of migration)
→ Disks in early-type galaxies
→ Evolution of gradients with time.
→ Growing mechanism of early-type galaxies

- We should star thinking **of other techniques** to make the best use of the data (spectroscopic SBF, decompositions in the optical-kinematical plane, IMF, other abundance ratios, etc…)