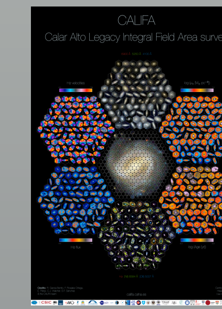
The interplay between local and global processes in galaxies
Cozumel, 11-15 April 2016

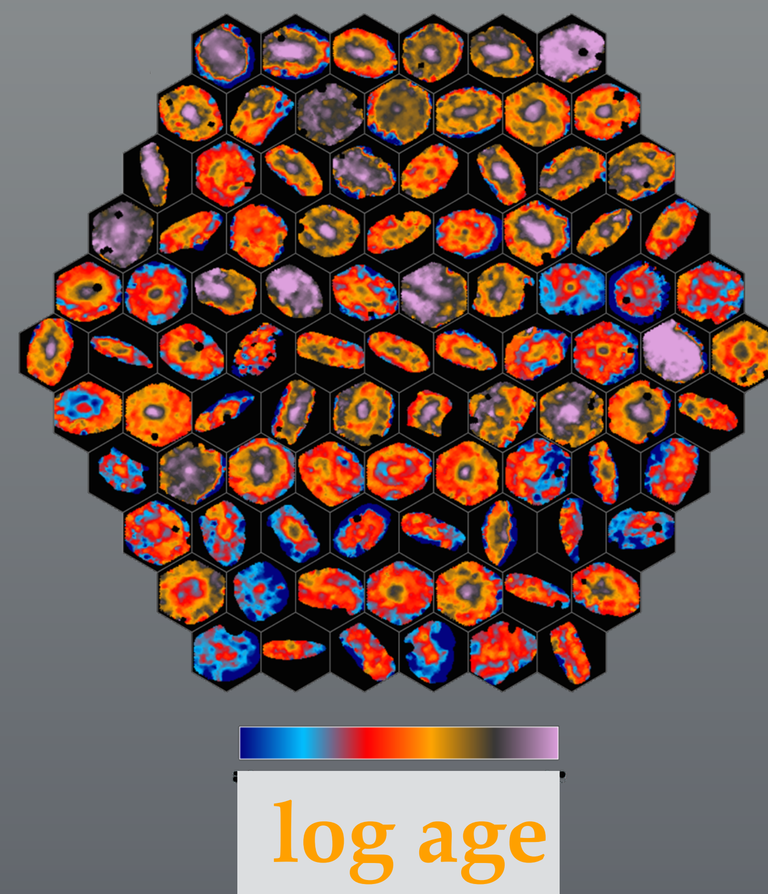


The Stellar Population of Local Galaxies

Rosa González Delgado

Instituto de Astrofísica de Andalucía (CSIC), Spain

Enrique Pérez
Ruben García Benito
Clara Cortijo Ferrero
Rafael López Fernández
Roberto Cid Fernandes
Eduardo Lacerda
André Amorim



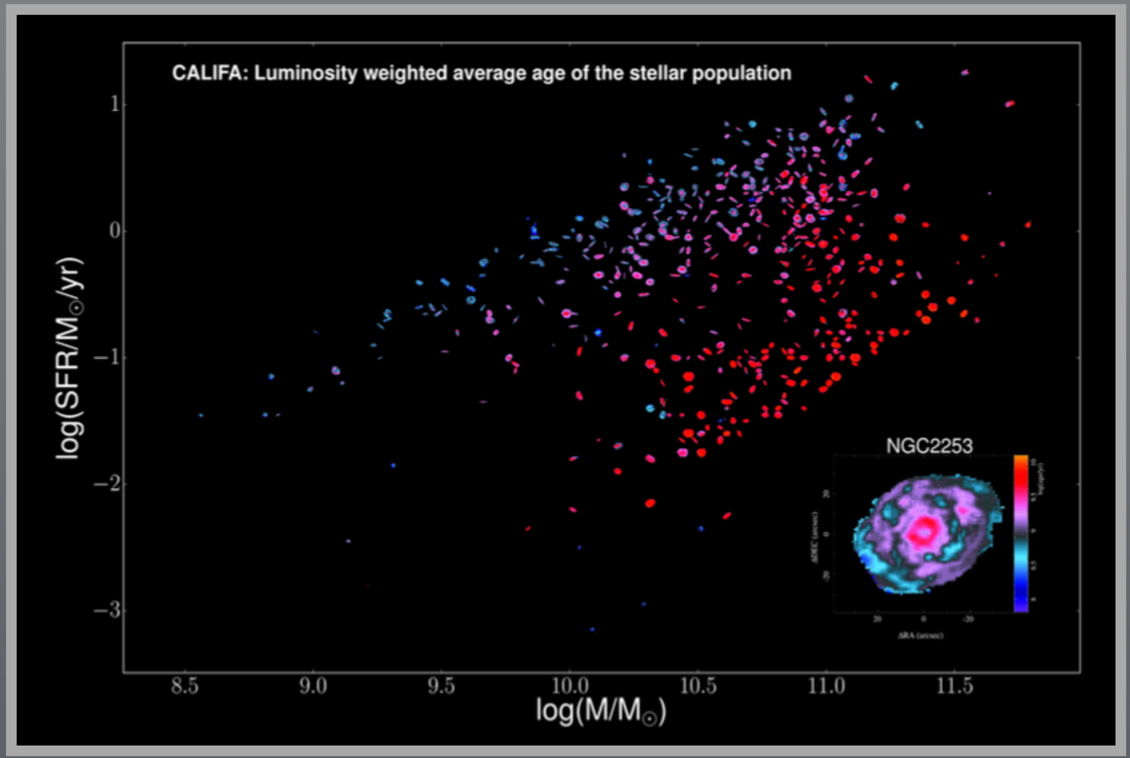
and Sebastian Sanchez (IP) of the CALIFA collaboration

Are global and/or local processes responsible of driving the evolution of galaxies?

Global relations	Local relations
* Mass-Metallicity	* μ✶- local Z
* Mass-SFR	* μ✶- Σ_{SFR}
* Mass-age	* μ✶- local age

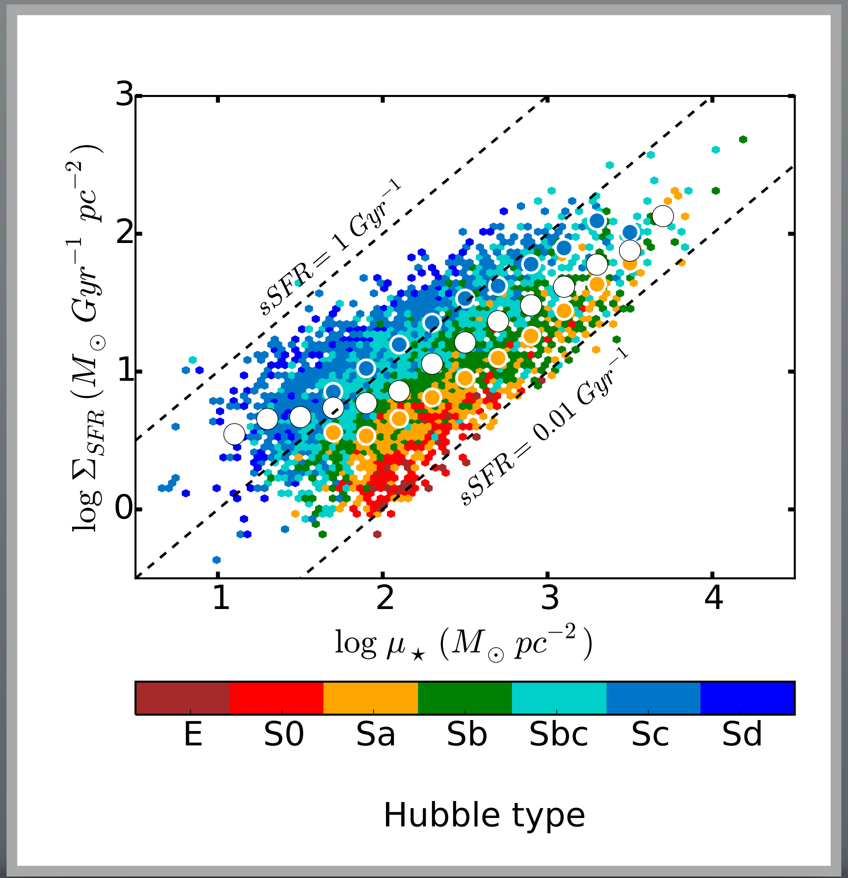
Main sequence of Star Formation (MSSF)

Global MSSF



Sánchez & CALIFA DR3, 2016

Local MSSF

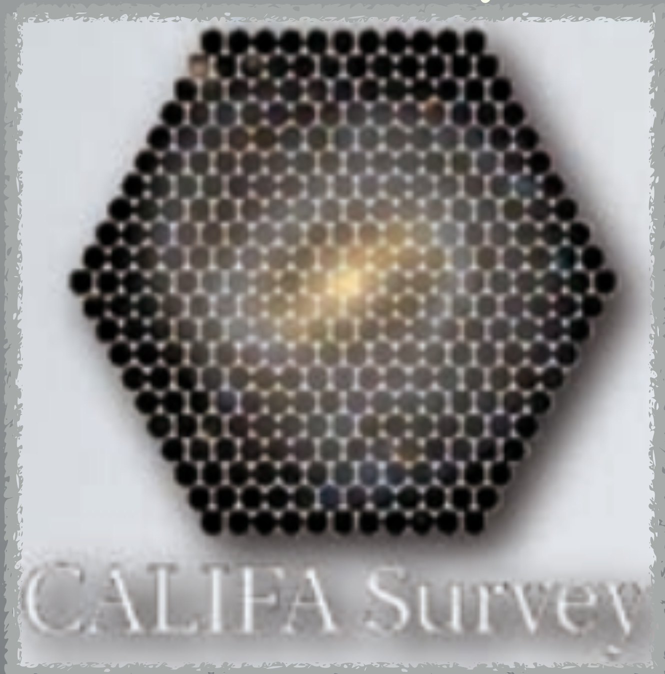


González Delgado +, 2016

Galaxies in 3D

To dissect galaxies in space and time: 2D spatial and lookback time

IFS surveys



Fossil record method

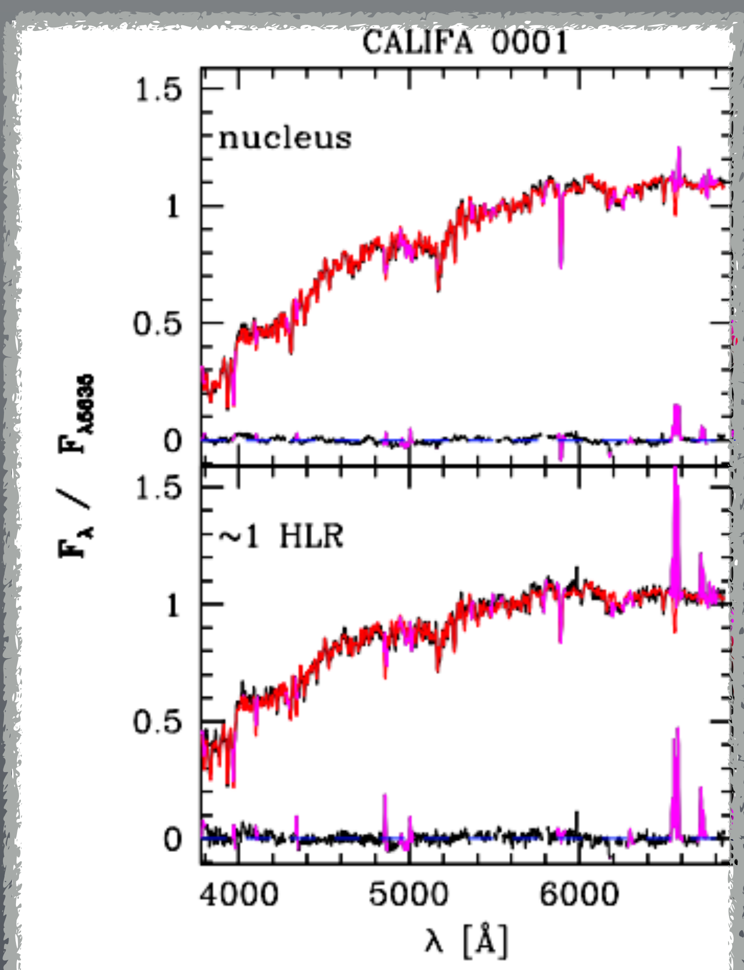
$$L_{gal}(\lambda) = \sum_{t,Z} M_{SSP}(t,Z) \times SSP(\lambda;t,Z) \times e^{-\tau(\lambda)}$$

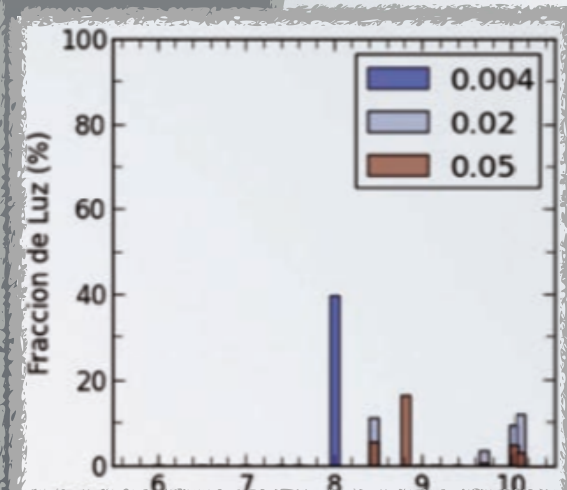
Observables: *Full spectrum*

SFH: *Mass or light fractions*

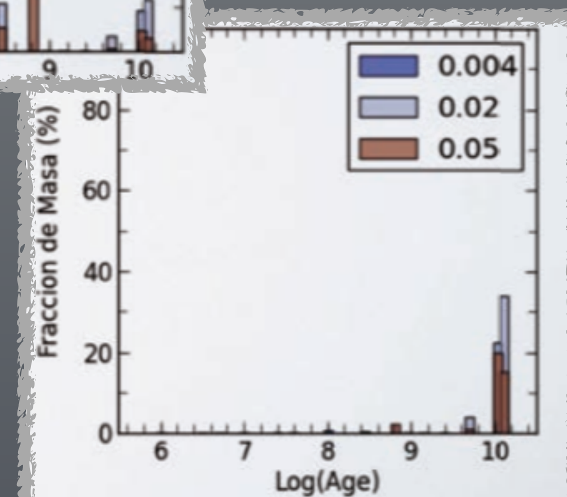
Spectral Base

Dust

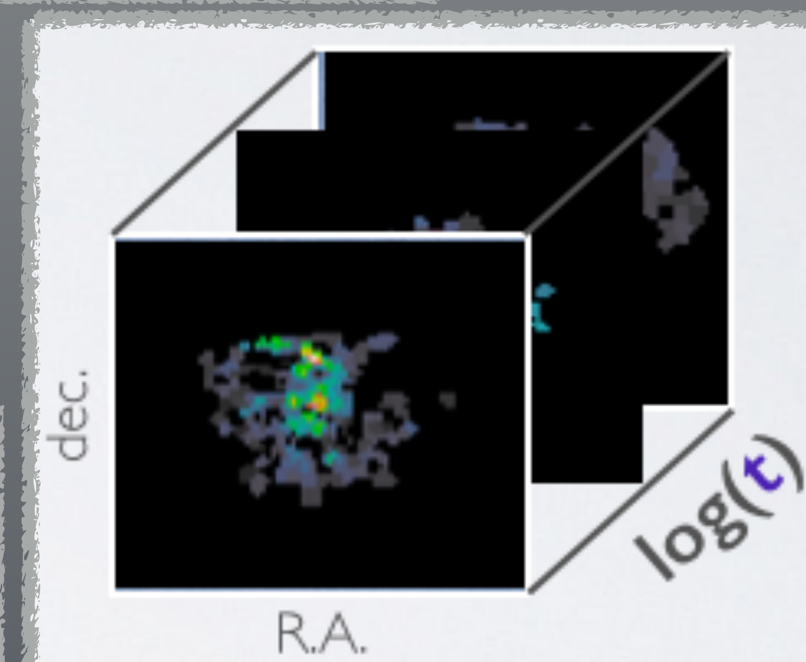




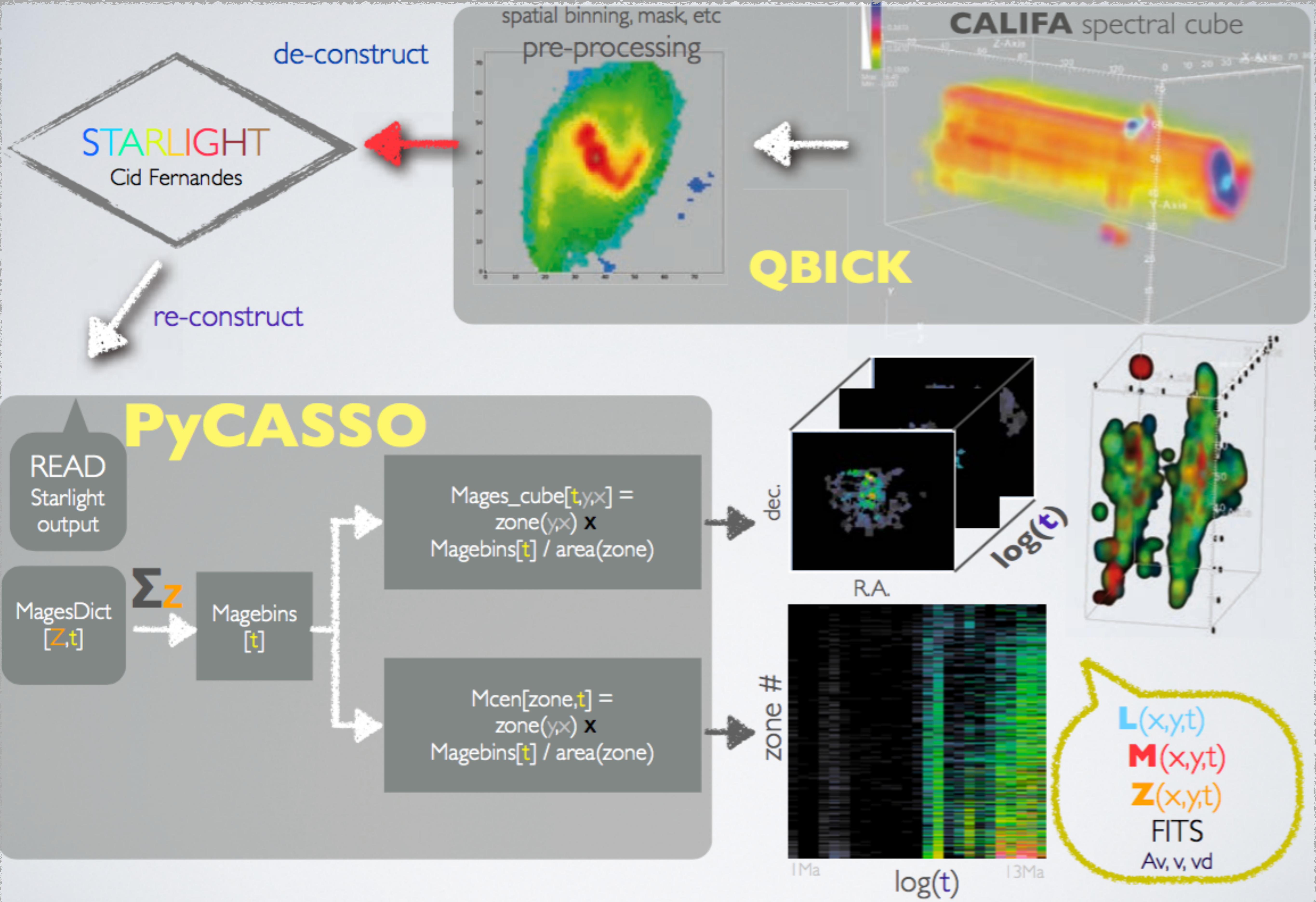
Light and Mass fraction



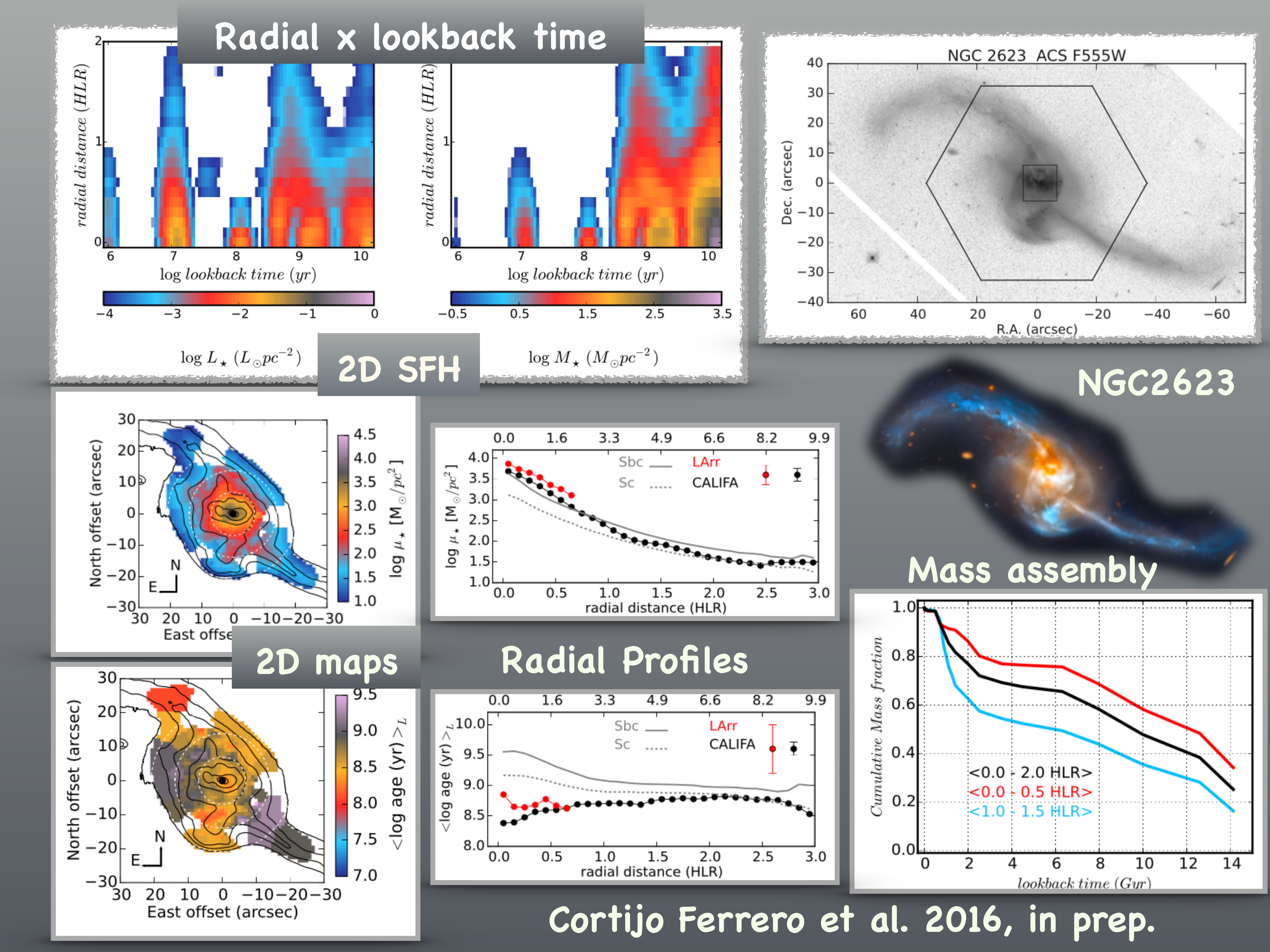
space-time cube



$\mu_\star$, $M_\star$, ages, Z, Av, SFR



Processing & Analysis pipelines


Radial x lookback time
radial distance (HLR)
log lookback time (yr)
log $L_\star$ ($L_\odot pc^{-2}$)
log $M_\star$ ($M_\odot pc^{-2}$)
2D SFH
NGC 2623 ACS F555W
Dec. (arcsec)
R.A. (arcsec)
NGC2623
Mass assembly
North offset (arcsec)
East offset (arcsec)
log $\mu_\star$ [$M_\odot/pc^2$]
2D maps
<log age (yr)>$_L$
Sbc
Sc
LArr
CALIFA
radial distance (HLR)
Radial Profiles
Cumulative Mass fraction
lookback time (Gyr)
<0.0 - 2.0 HLR>
<0.0 - 0.5 HLR>
<1.0 - 1.5 HLR>
Cortijo Ferrero et al. 2016, in prep.

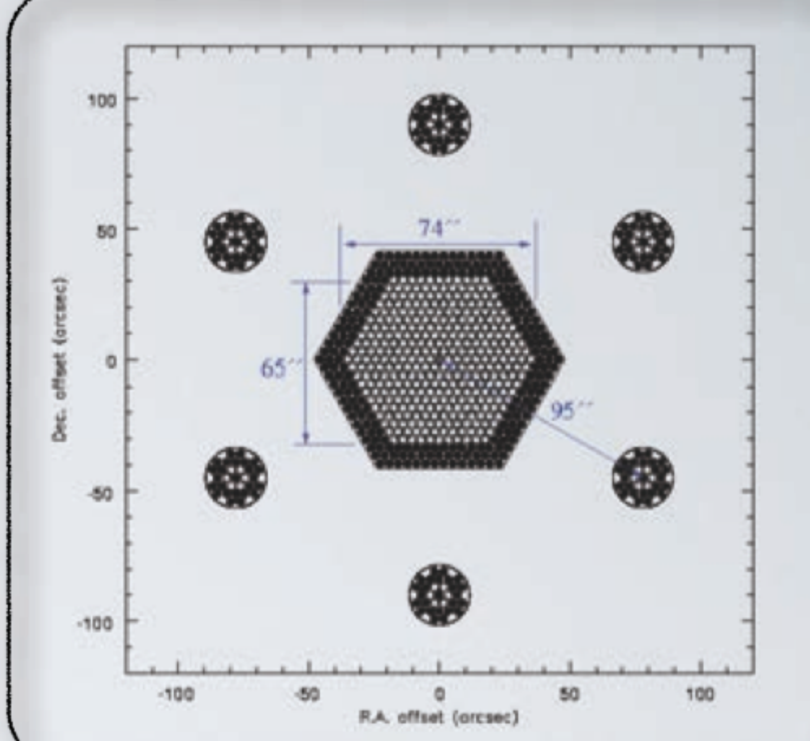
600 galaxies

0.005 < redshift < 0.03

★ Large homogeneous sample

937 galaxies
Mother sample

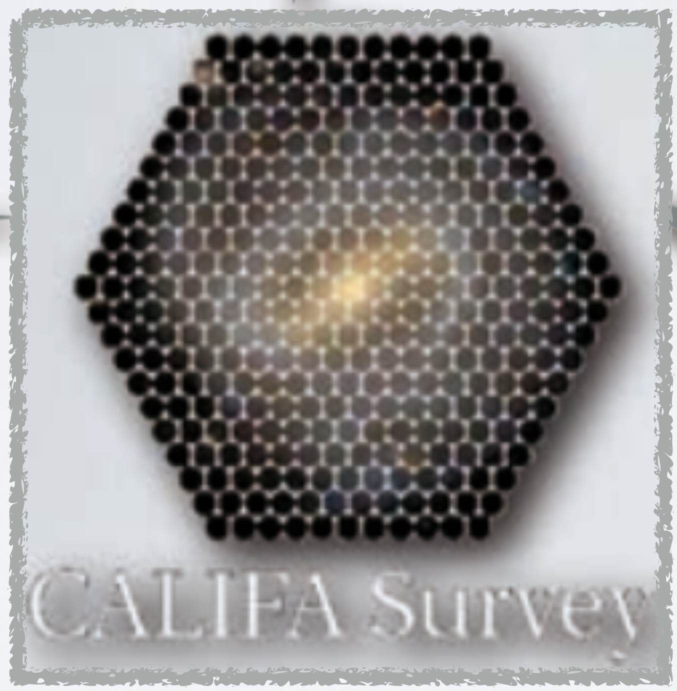
E, S0, Sa to Sd



★ Large FoV (1'x1')

FoV (2-5 HLR)

λ range:
3700-7000 Å



Fibers 2.7 arsec
~ 0.5 - 1 kpc

★ Cover optical λ

Calar Alto Legacy Integral Field Area

PPAK at 3.5m CAHA

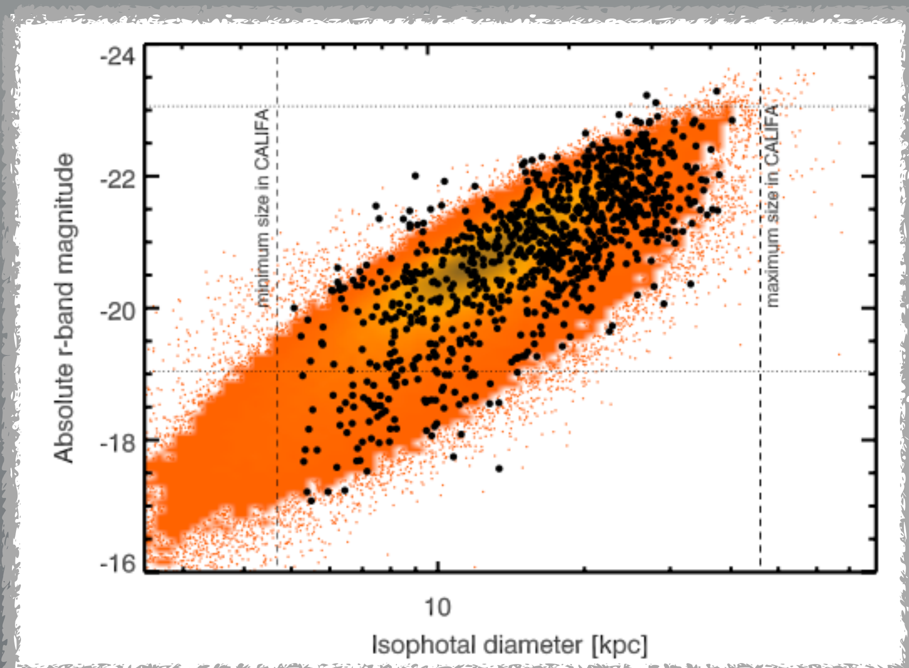
V1200@R = 1650
V500@R = 850

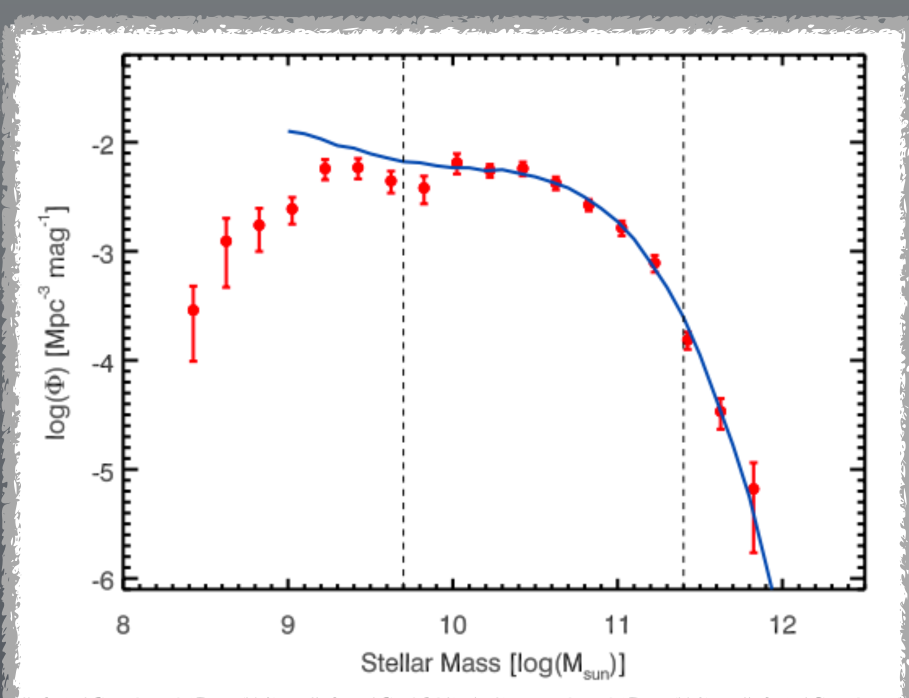
3 dithering:
final 1 arsec
sampling

Properties of CALIFA sample

Mother sample

- 937 galx SDSS DR7
- 0.005 < z <0.03
- 45" < isoAr < 79.2"

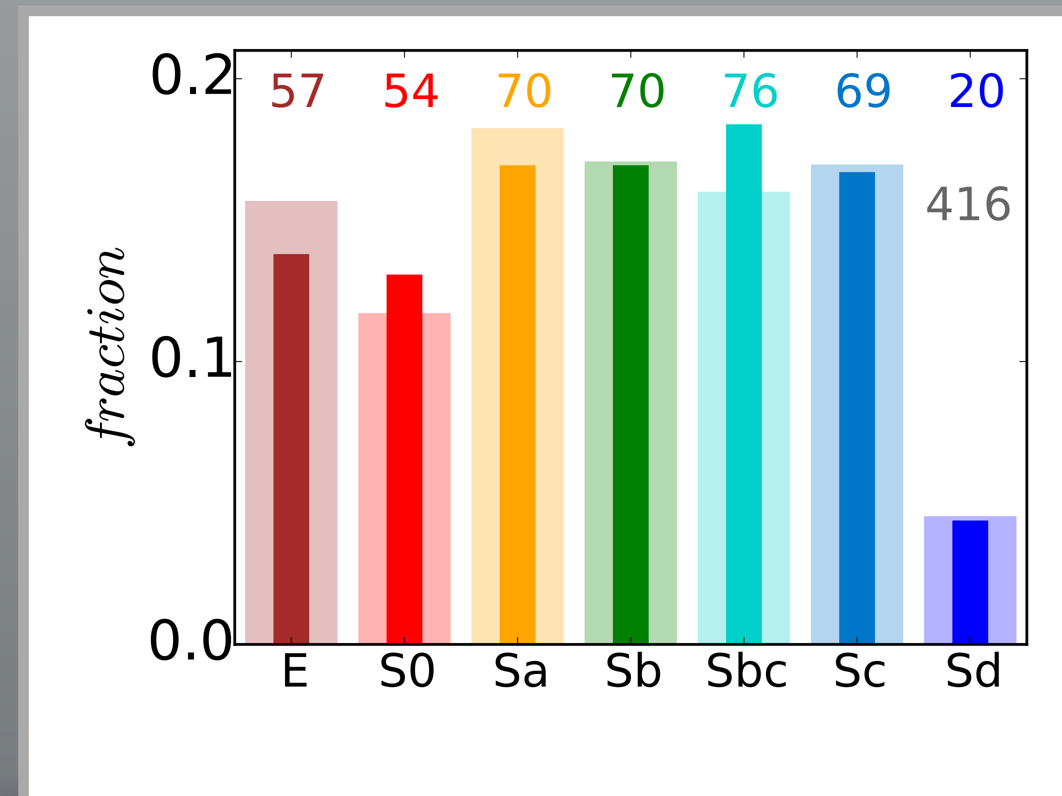


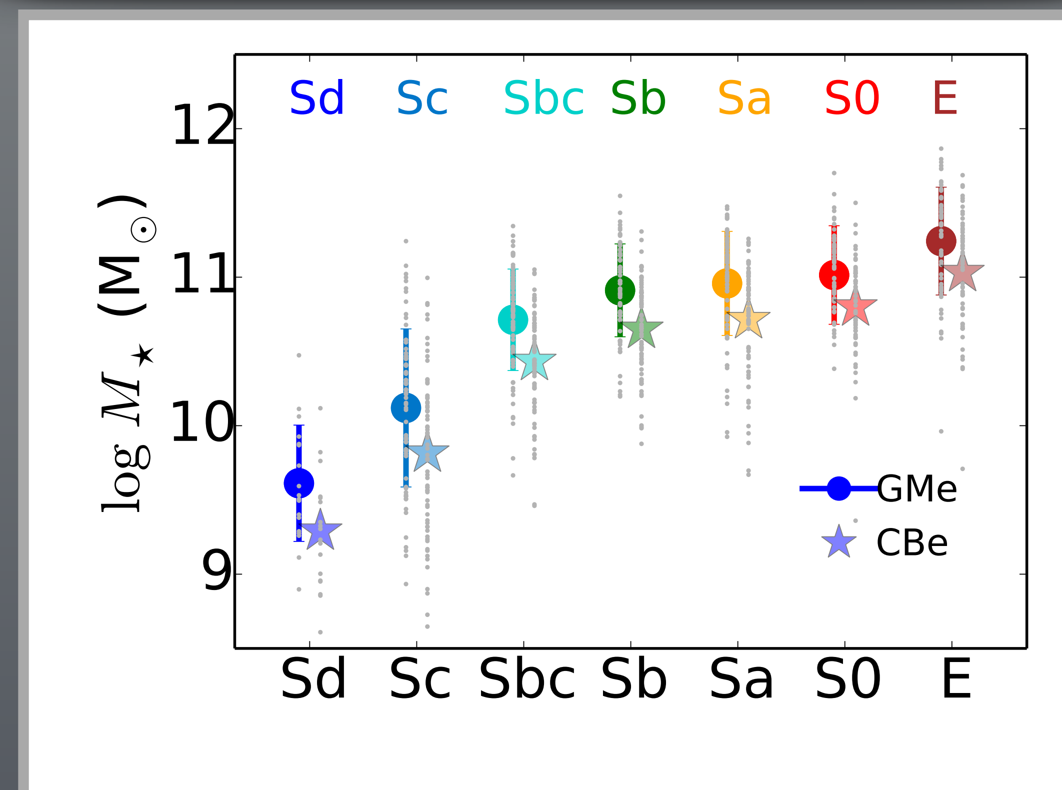


Walcher +, 2014, A&A, 569, A1

sub-sample in SP studies

- ~430 galx with V500+V1200

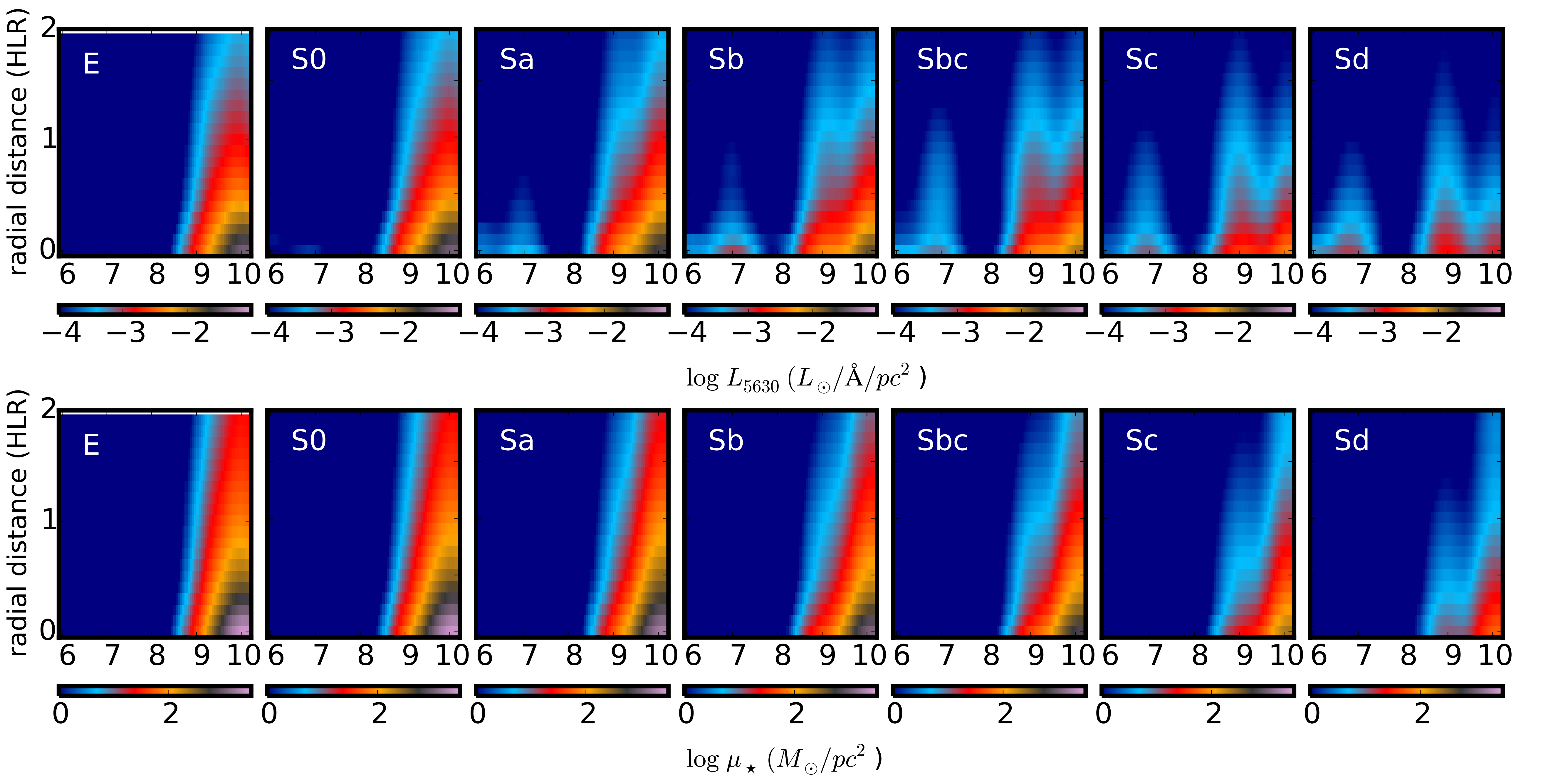




2D maps of SFH: Radial x lookback time

Mass formed at each epoch per pc²

and Luminosity per pc²

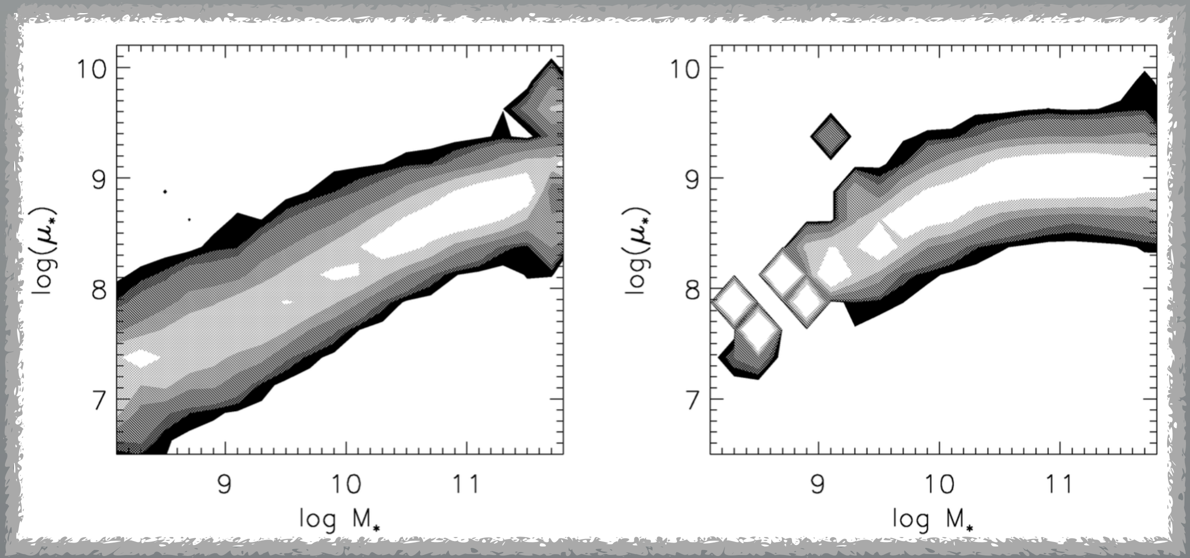


Stellar mass surface density (μ✶)- age

Global relation

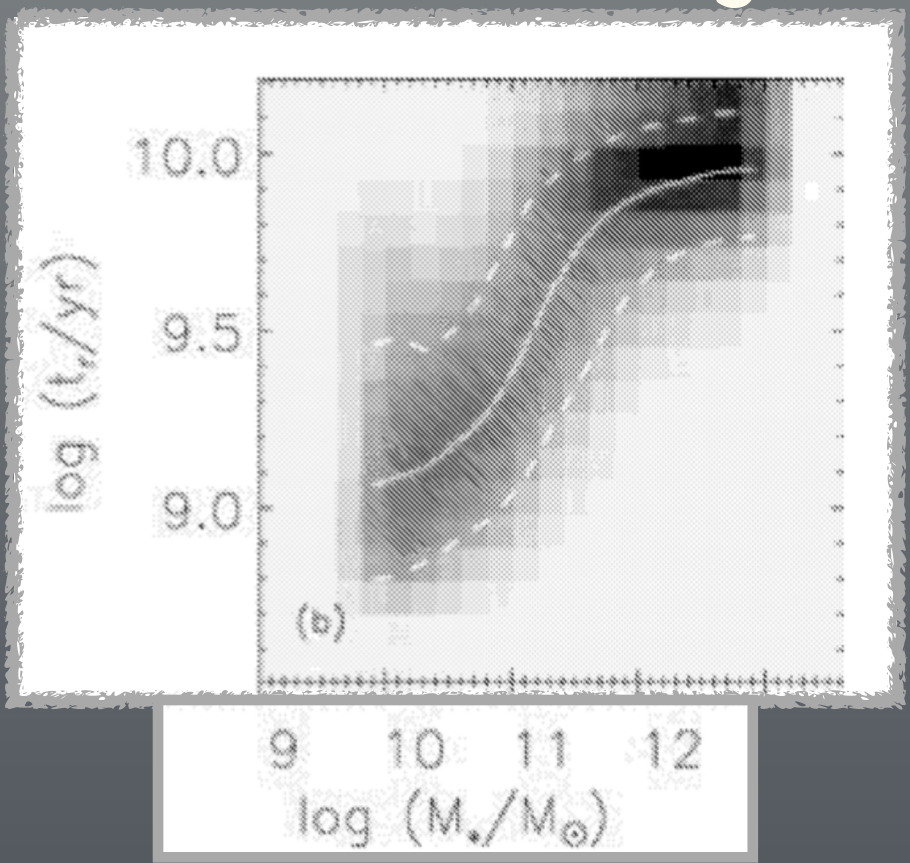
Kauffmann +, 2003

* SDSS: μ✶ - M✶



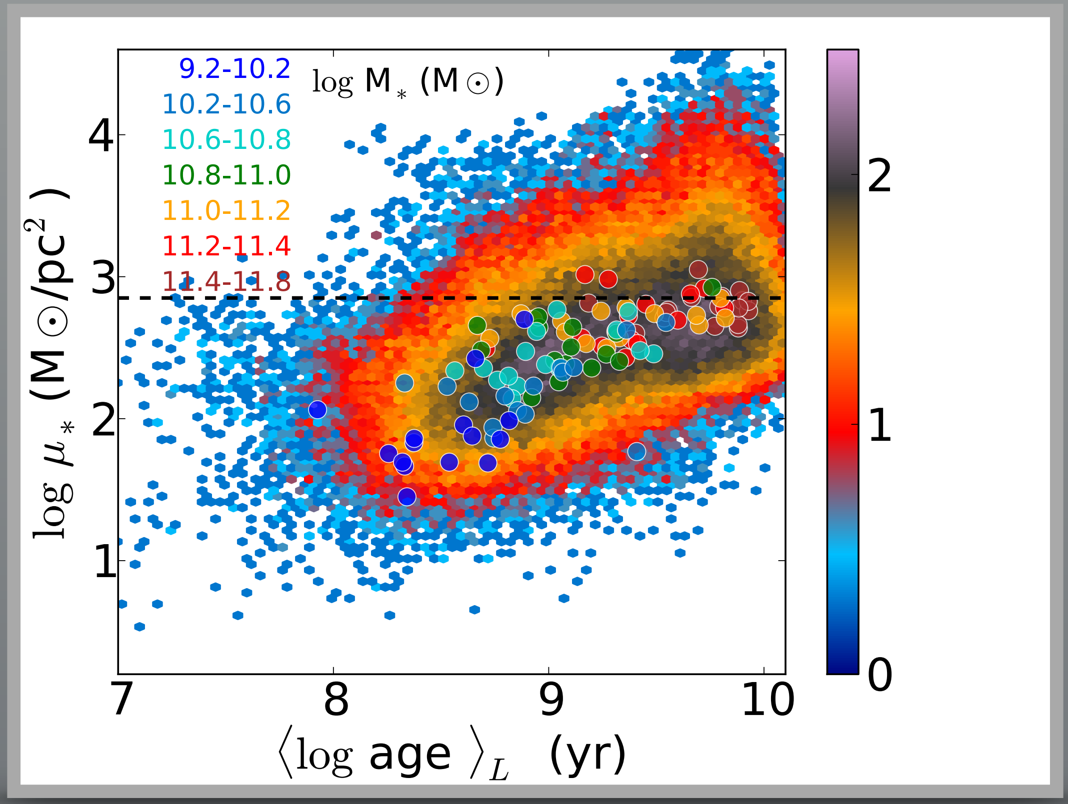
* SDSS: M✶ - age

Gallazzi +, 2005



Local relation

* CALIFA: μ✶ - age



González Delgado +, 2014, A&A, 562, 47

SFH in disks and spheroids

- Disks: μ✶ drives the ages (SFH) of galaxies
- Spheroids: M✶

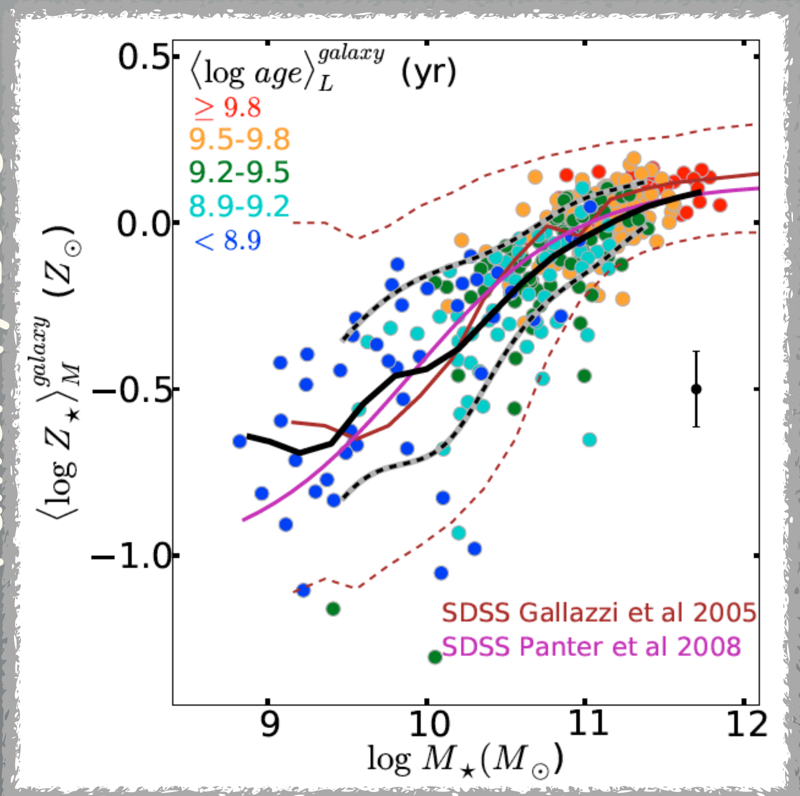
Stellar mass surface density (μ★)- Metallicity (Z★)

Global relation (SDSS)

SDSS: global M★ - Z★

Gallazzi +, 2005

Panter +, 2008



Local relation

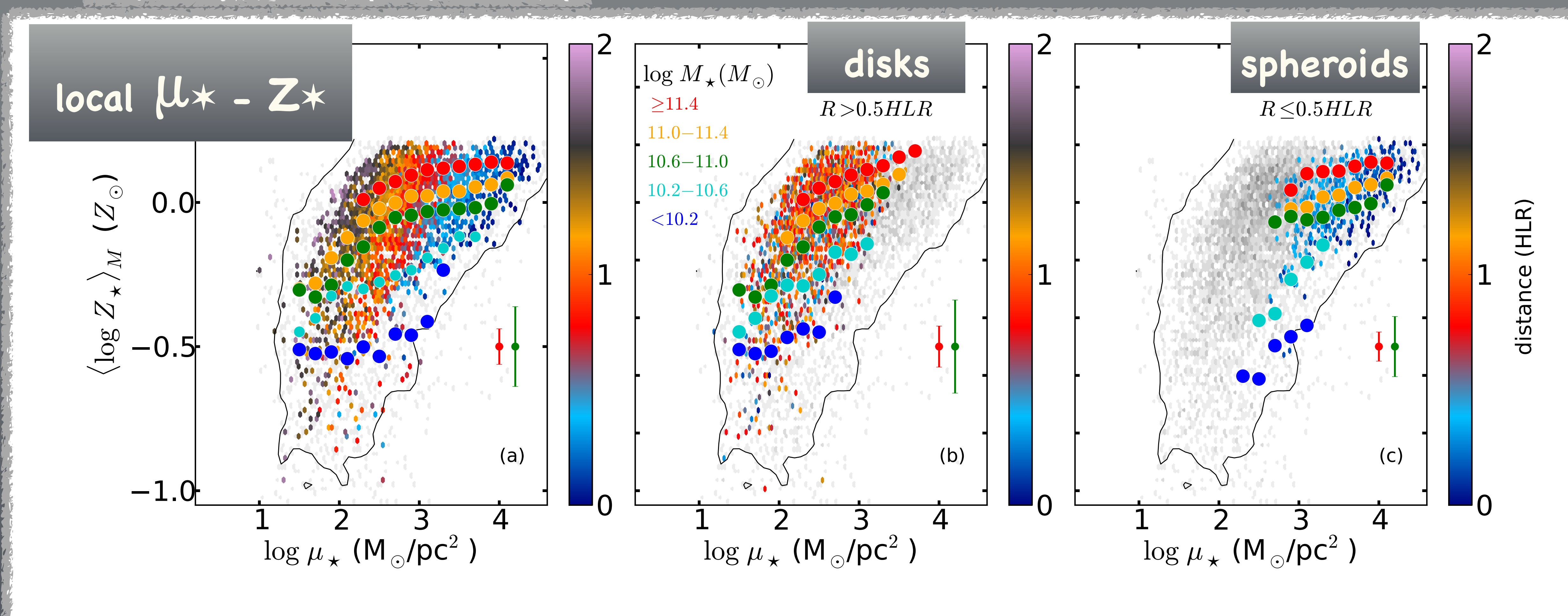
* CALIFA: μ★ -Z★

Chemical enrichment

✳Disks: μ★ regulates the metallicity, galaxy Mass modulates the amplitude

✳ Spheroids: galaxy Mass dominates the physics of chemical enrichment (except for low mass galaxies)

González Delgado et al. 2014b, ApJ, 791, L16

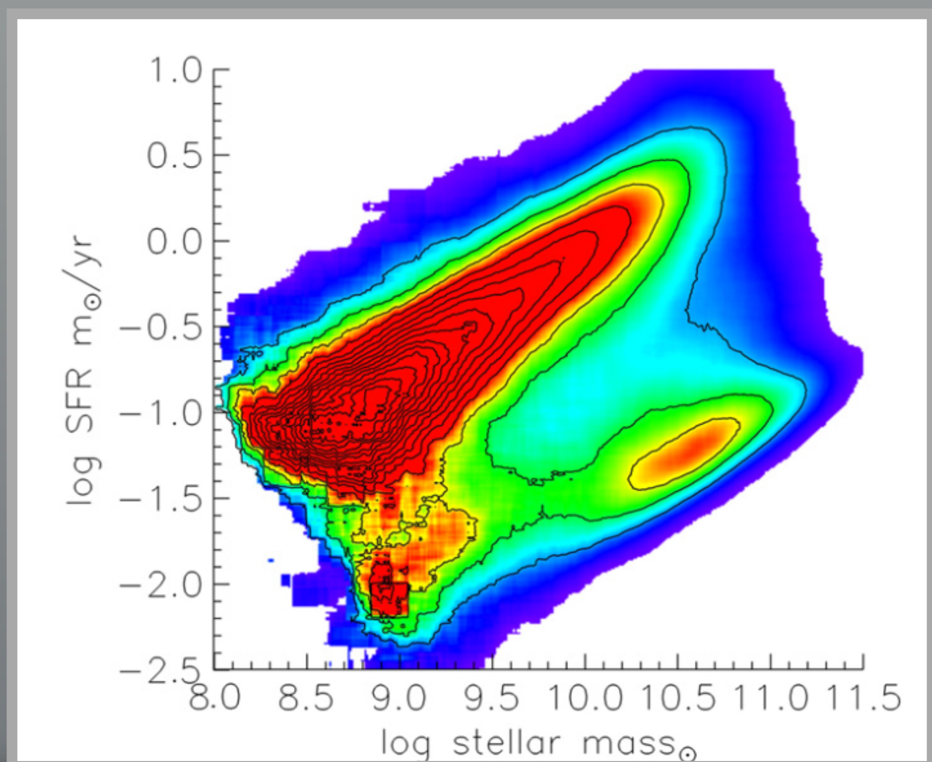


$\mu_\star$-intensity of the SFR: $\mu_\star$ - Σ_{SFR}

Global relation

* SDSS: $M_\star$ - SFR (MSSF)

Renzini & Peng, 2015

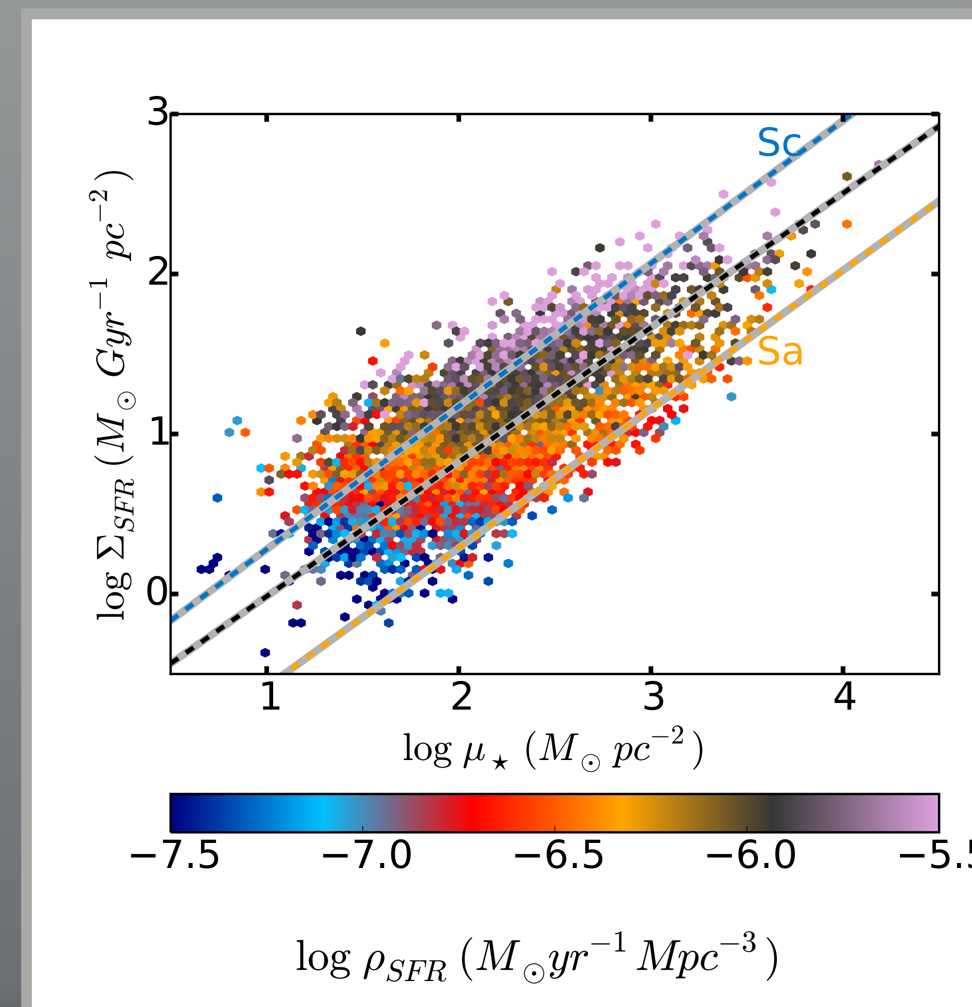


SFR = cte $M_\star^{\beta}$ with β < 1 (0.75 in RP2015)

* SFR = cte $\Sigma_{SFR}(HLR)/\mu_\star(HLR)\ M_\star$
* Σ_{SFR} = cte $\mu_\star^{\propto}$
* $\mu_\star$ = cte $M_\star^{\gamma}$
* SFR = cte $M_\star^{1-\gamma(1-\propto)}$
* with $\propto$ = 0.8; γ = 0.5; β < 1

Local relation

* CALIFA: $\mu_\star$ - Σ_{SFR}



González Delgado +, 2016, A&A, arXiv1603008074

Σ_{SFR} = cte $\mu_\star^{\propto}$ with $\propto$ = 0.8

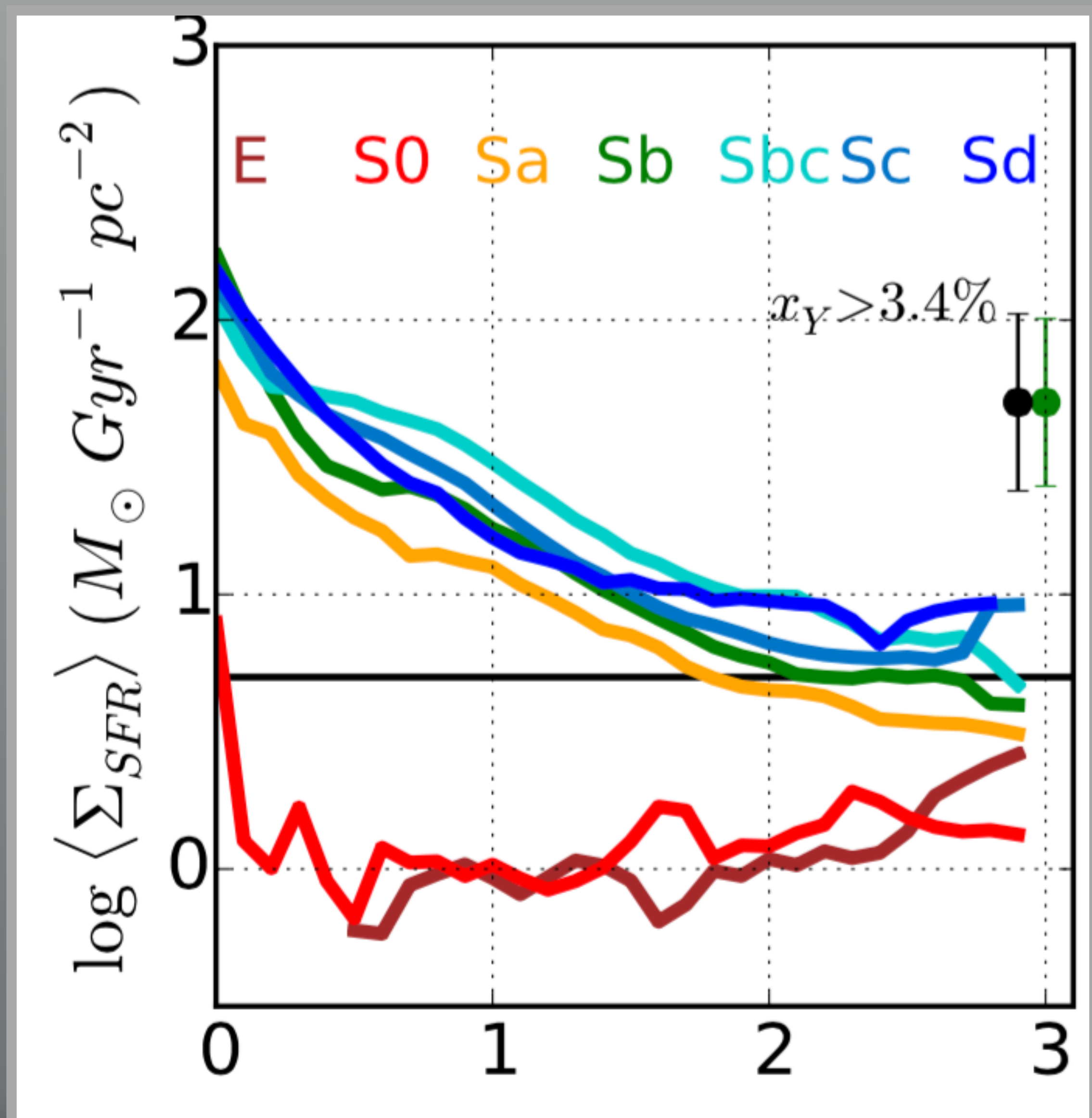
cte = local sSFR= $\Sigma_{SFR}/\mu_\star$

increases for early to late type spirals

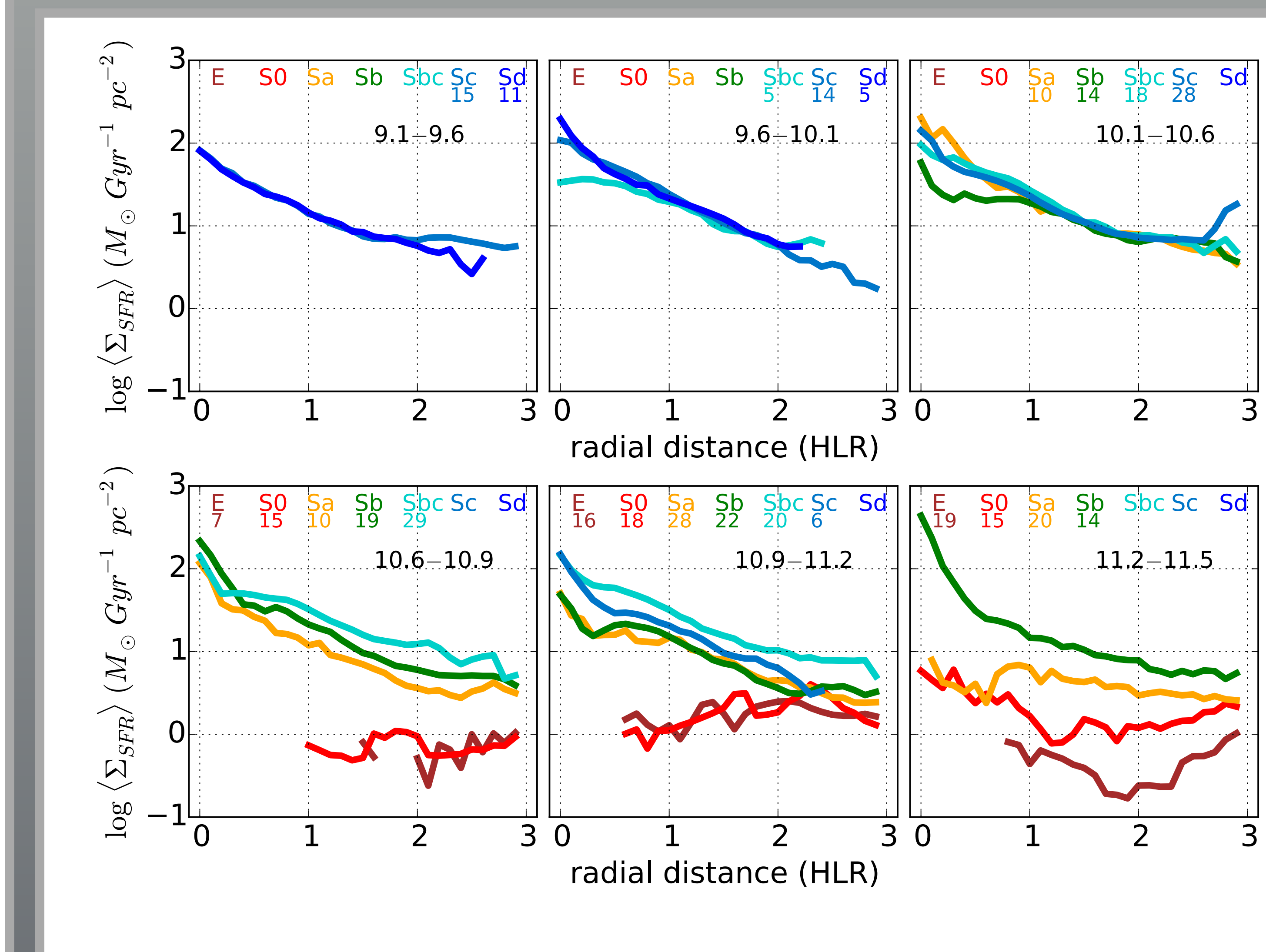
Global relation is sub-linear (< 1)
because the sub-linearity of the local relation

Star formation along the Hubble sequence

Radial profiles: Σ_{SFR}

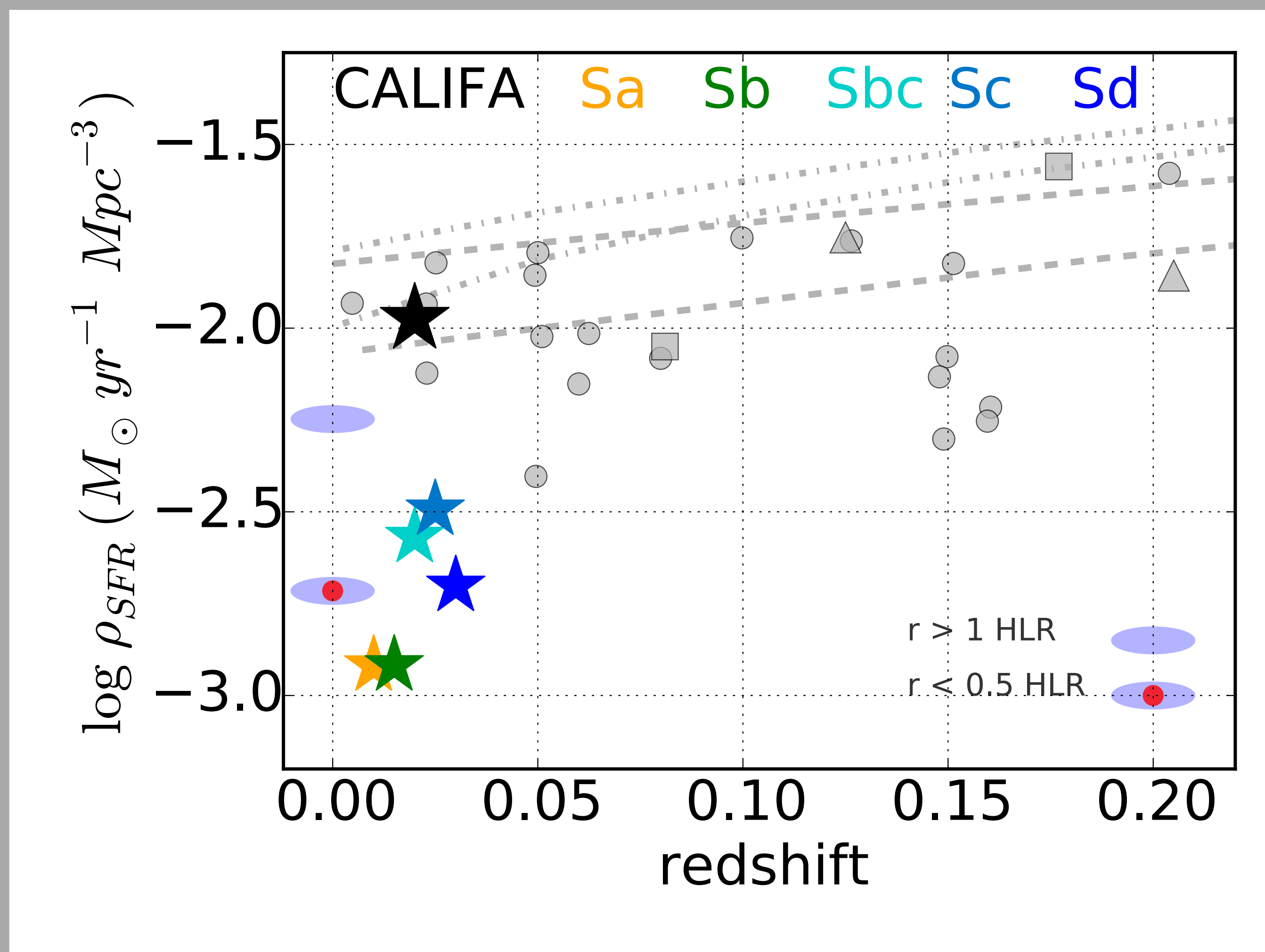


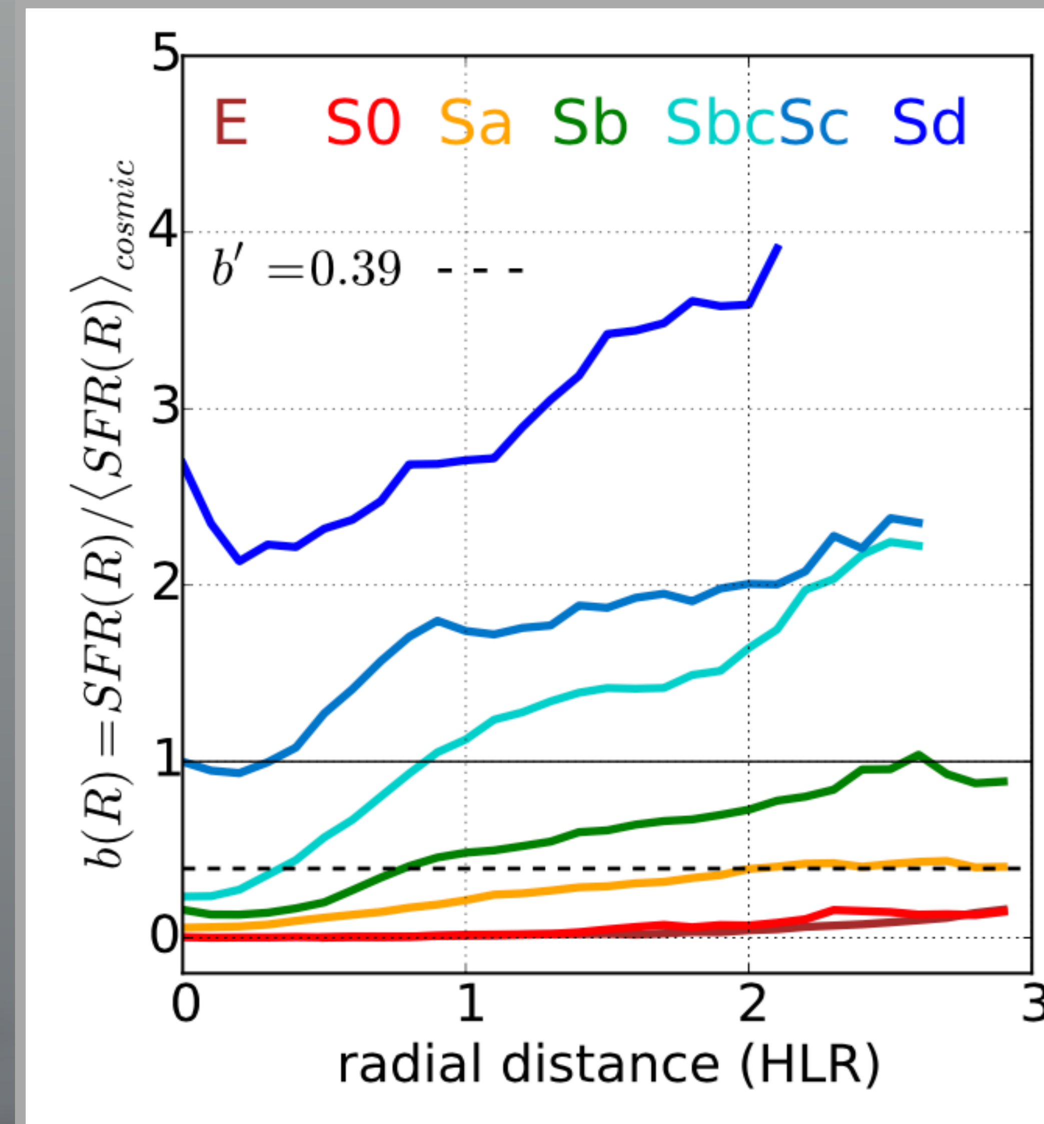
radial distance (HLR)



- ★ Spirals: Σ_{SFR}(1 HLR) ~20 Msun Gyr^{-1} pc^{-2}
- ★ Spirals: the dispersion in Σ_{SFR}(R) is small
- ★ MSSF is a sequence with Σ_{SFR} ~ constant

Star formation rate density and the Scalo b birthrate parameter

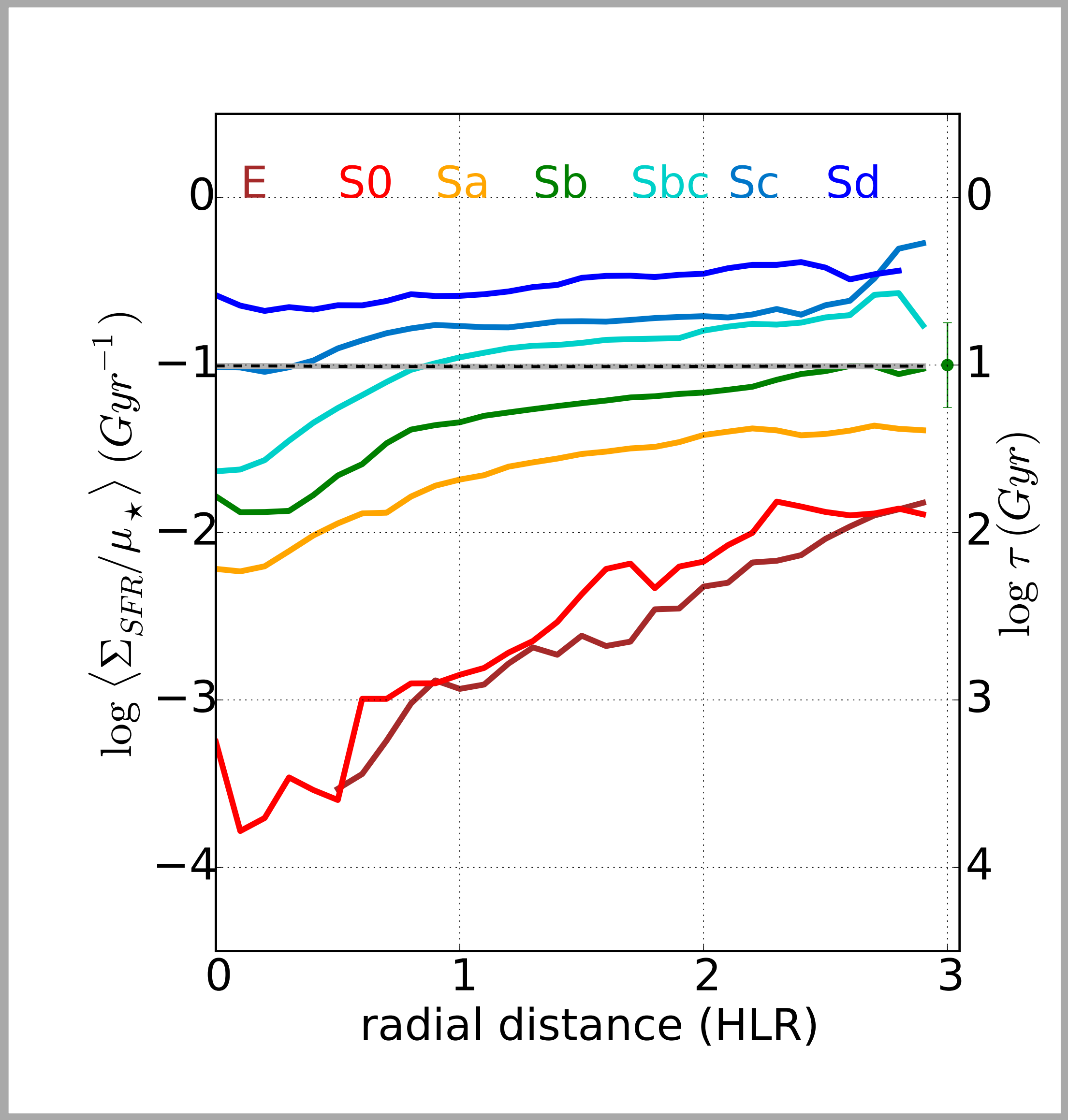




- ρ_{SFR} = (0.0105 ± 0.0008) $M_\odot\ yr^{-1}\ Mpc^{-3}$
- Most of the star formation is occurring in the disks of spirals (R> 1 HLR)
- The volume averaged birthrate parameter, b' = 0.39 ± 0.03,
- present day Universe is forming stars at ~ 1/3 of its past average rate.
- E, S0, and the bulge of Sa and Sb contribute little to the recent SFR of the Universe, which is dominated by the disks of Sbc, Sc, and Sd spirals.

Star formation along the Hubble sequence

Radial profiles: local sSFR = $\Sigma_{SFR}/\mu_\star = \tau^{-1}$



Galaxies are quenched inside-out

✳sSFR(R) values scale with Hubble type

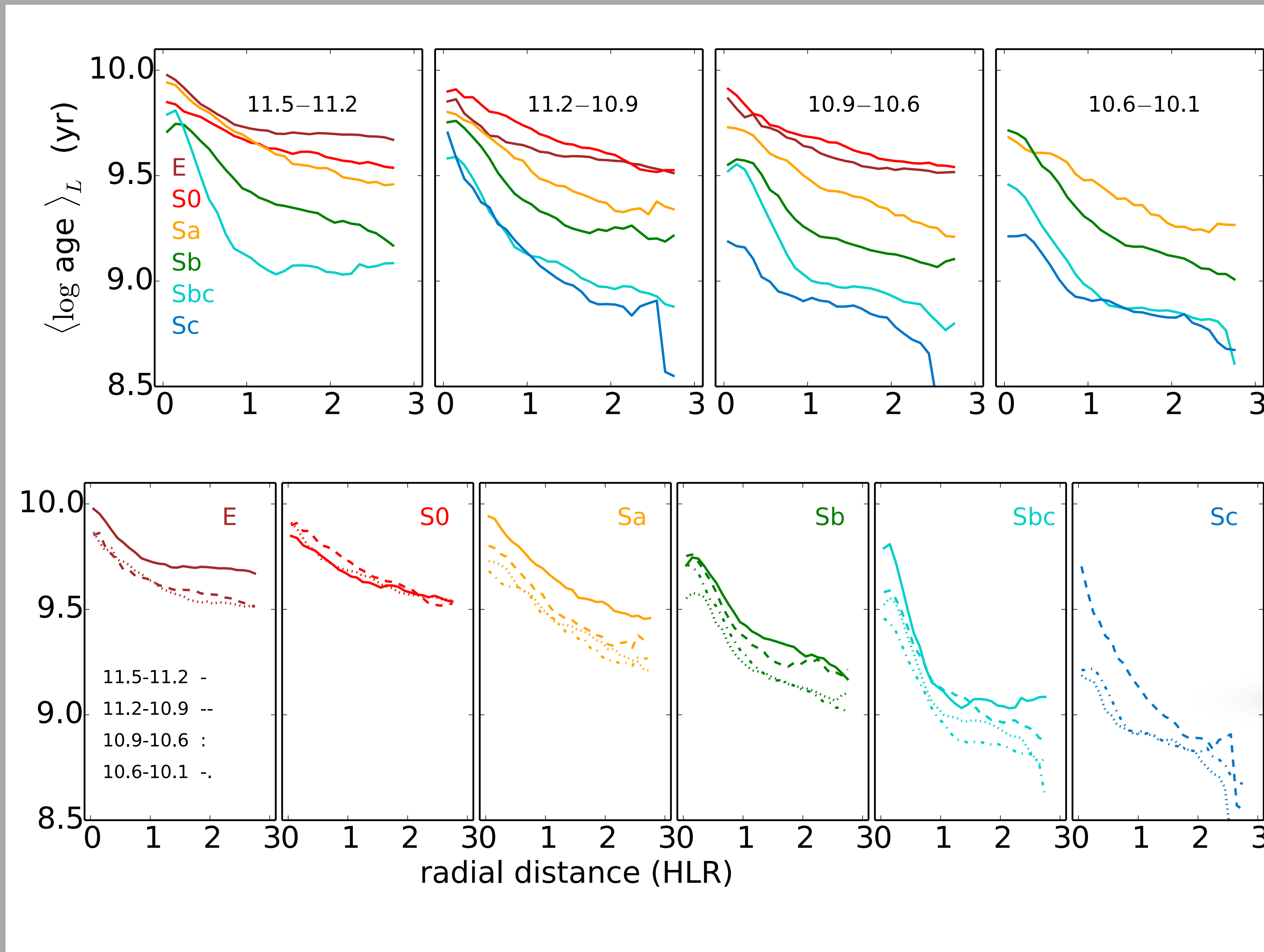
✳sSFR(R) increases radially outwards, with a steeper slope in the inner 1 HLR.

✳galaxies are quenched inside-out, and this process is faster in the central, bulge-dominated part than in the disks.

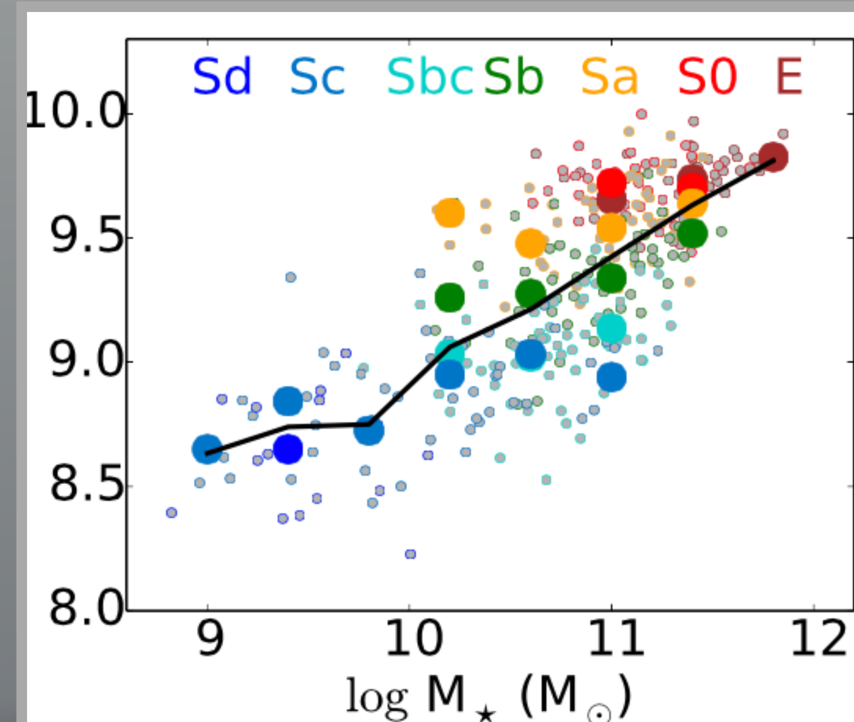
González Delgado +, 2016, A&A, arXiv160300874

Quenching related with the morphology

Radial profiles of age



Mass-age relation

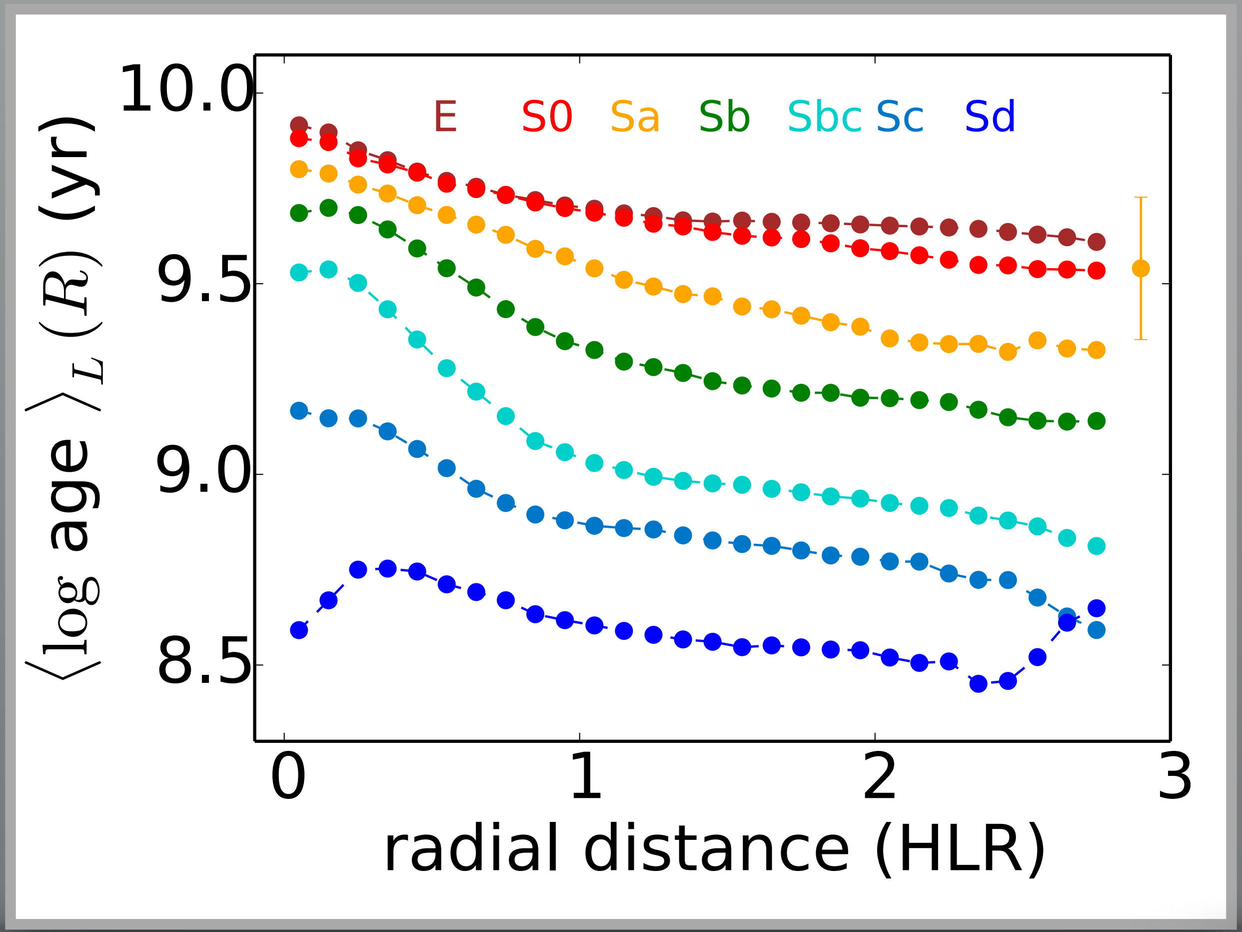


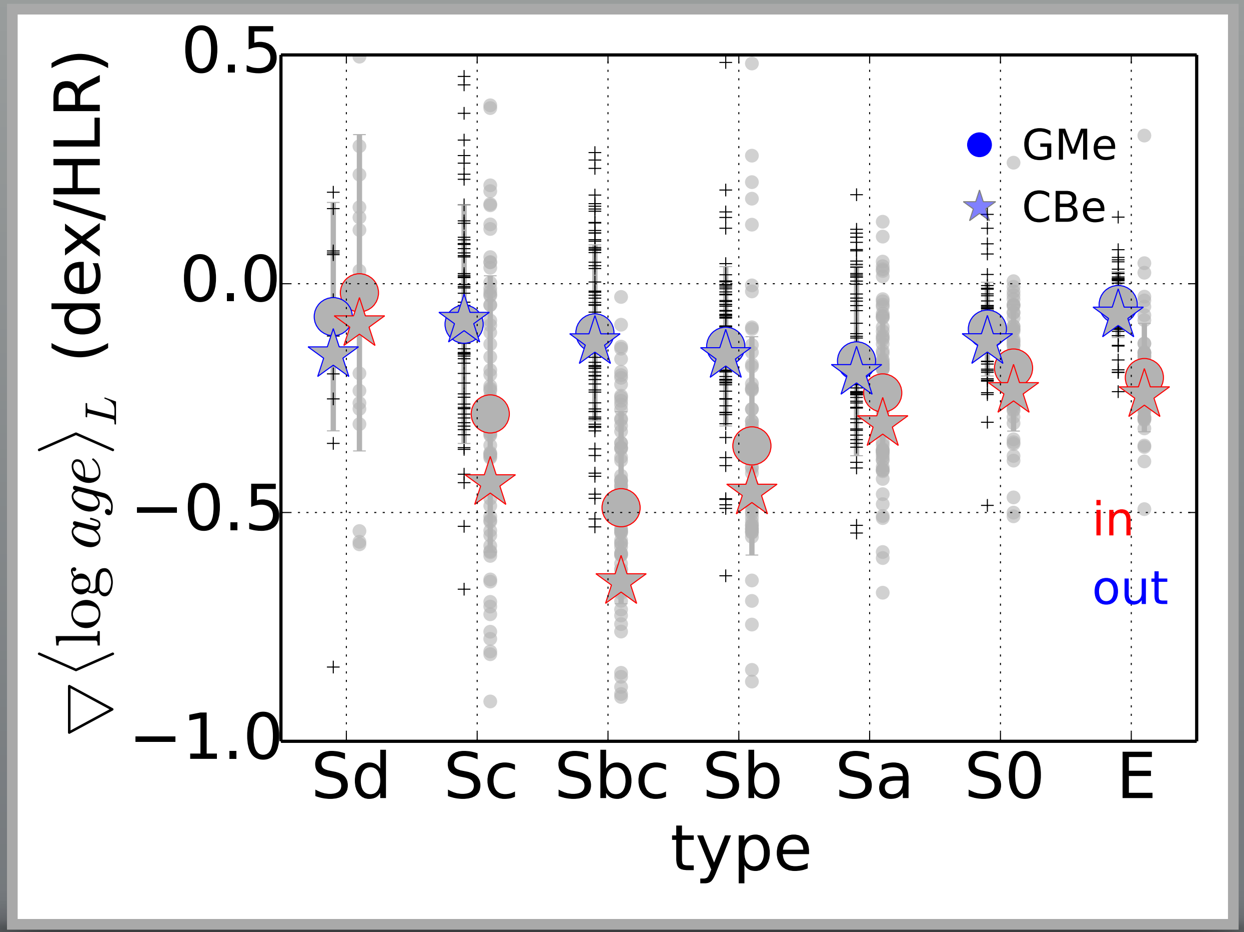
M✶ - age:
dispersion links to the morphology

- Galaxies of equal M✶: have different galaxy averaged age, and radial age gradients.
- SFH and their radial variations are modulated primarily by galaxy morphology, and only secondarily M*.
- Galaxies are morphologically quenched, and the shutdown of star formation occurs outwards and earlier in galaxies with a large spheroid than in galaxies of later Hubble type.

Stellar Population properties along the Hubble sequence

Radial profiles: ages



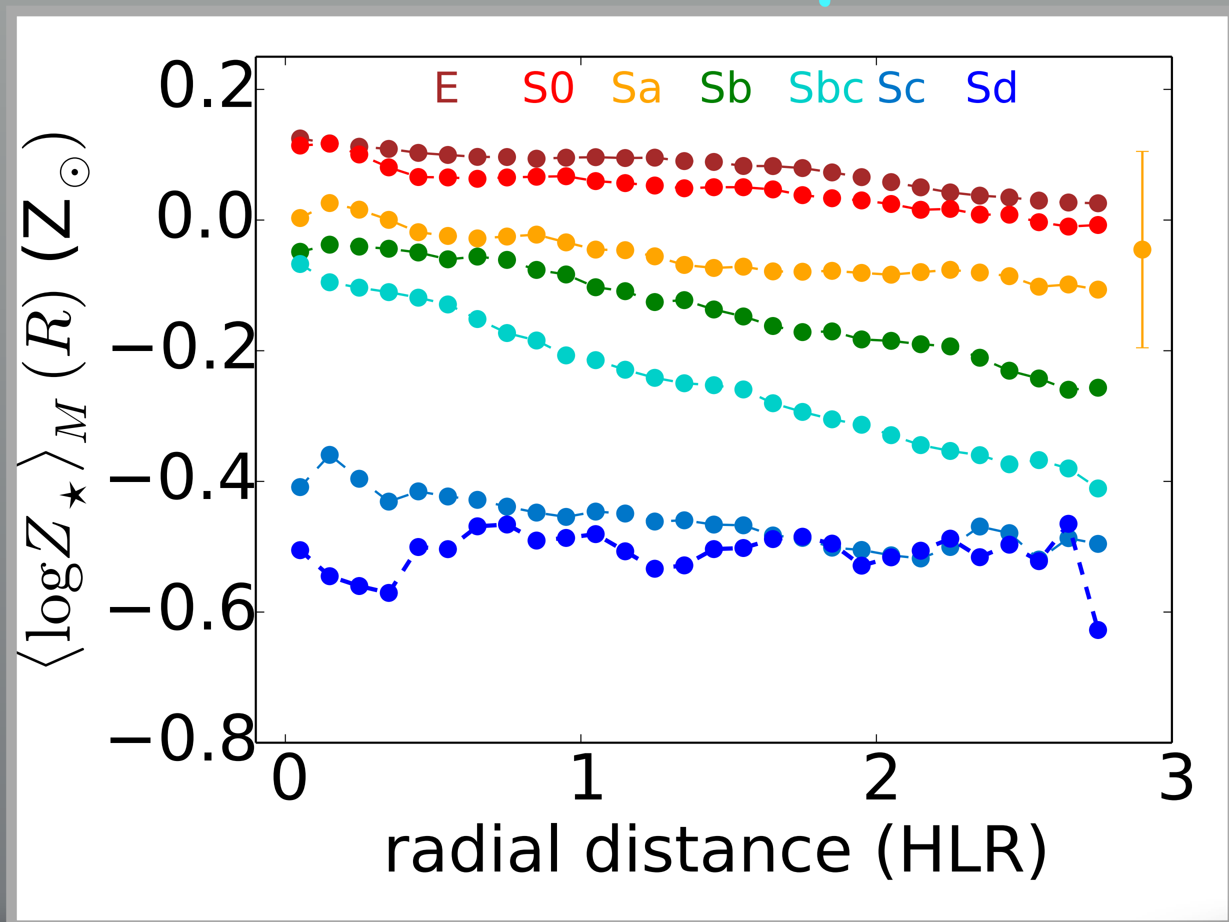


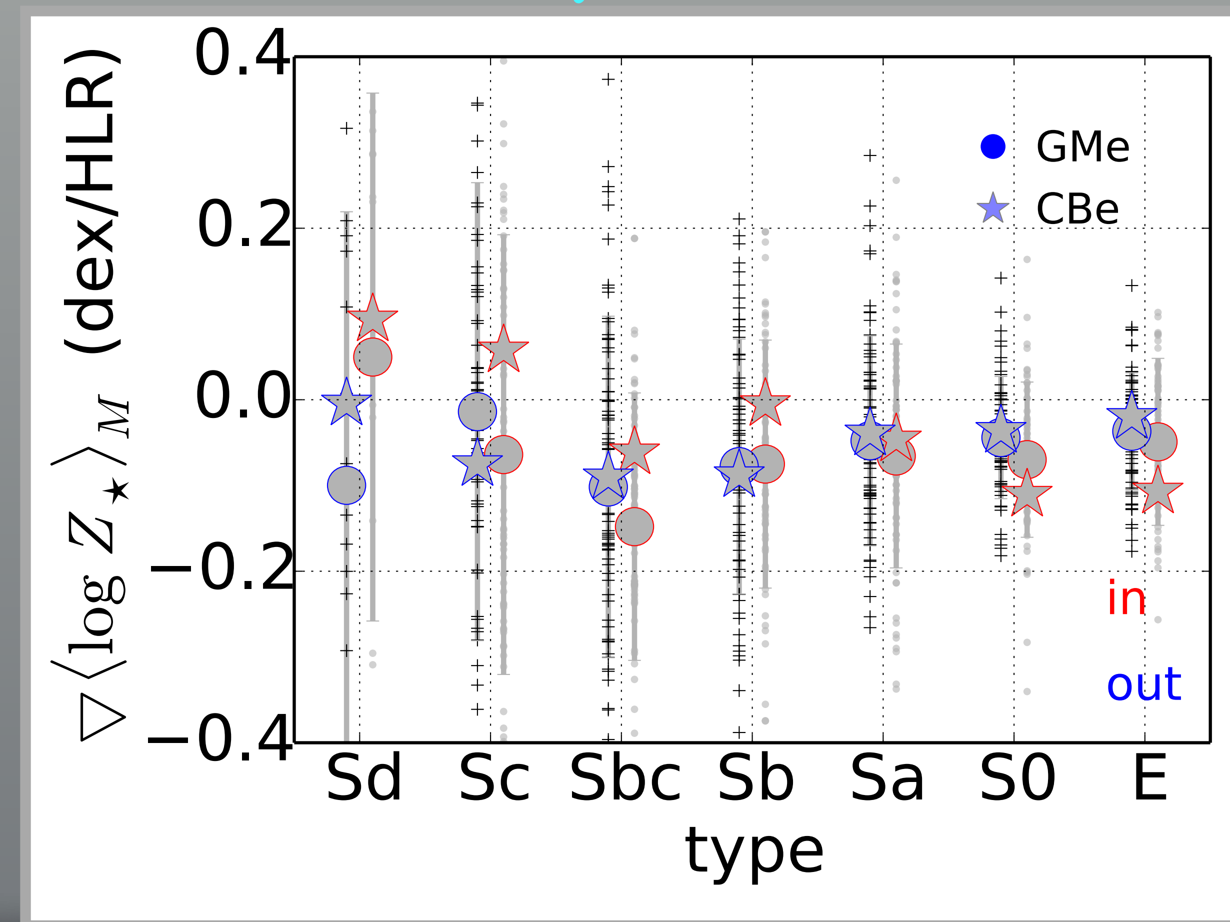
- declining profiles: galaxies are growing inside-out
- largest age gradient in MW type galaxies (Sbc)
- downsizing behavior is preserved with radial distance
- E and S0: no evidence of growing through minor dry mergers, no inversion of the ⟨log age⟩ toward older ages beyond 1–2 HLR

González Delgado et al. 2015, A&A, 581, 103

Stellar Population properties along the Hubble sequence

Radial profiles: stellar metallicity





- declining profiles, evidence of disks growing inside-out
- largest gradient in MW type galaxies (Sbc), as predicted by chemical evolution models (e.g. Molla & Díaz 2005)
- Sbc galaxies have a $\nabla\langle \log Z_\star \rangle \sim -0.1$ [dex/HLR] similar to the predictions by RaDES simulations (Few et al. 2012; Pilkington et al. 2012a).
- later type: very flat, small ∇in$\langle$log Z$\rangle$M L
- dispersion in the ∇in$\langle$log Z$\rangle$M–M$\star_\star$ relation is related with morphology
- E and S0: no evidence of a steepening of $\langle$log Z$\rangle$M L beyond 1-2 HLR if they were growing through minor dry mergers

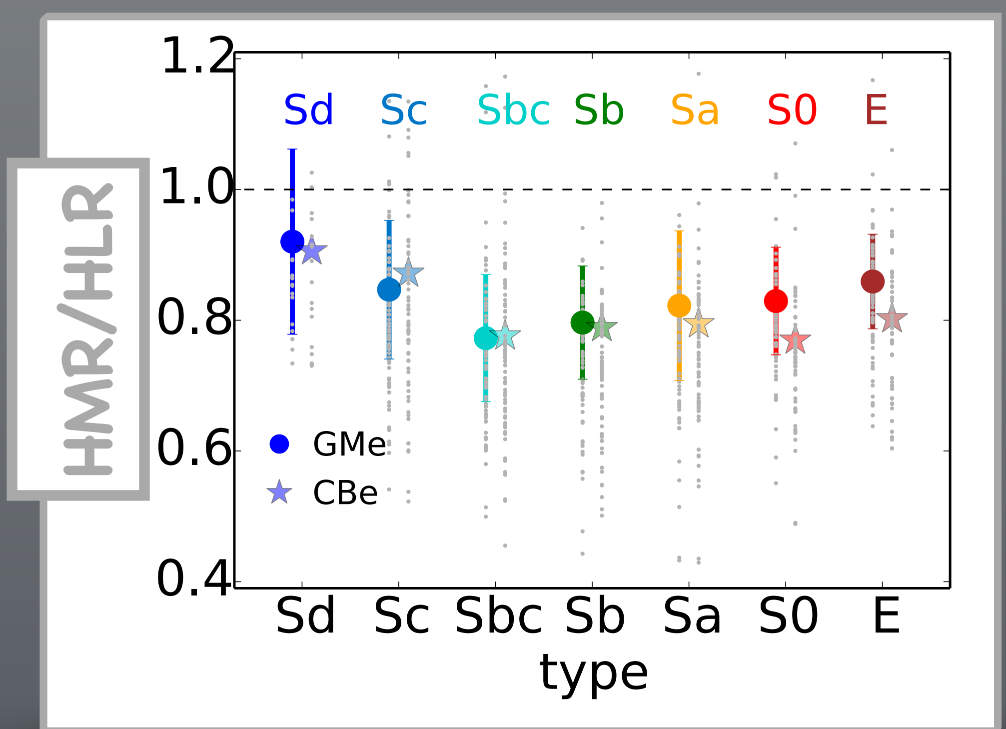
Mass assembly

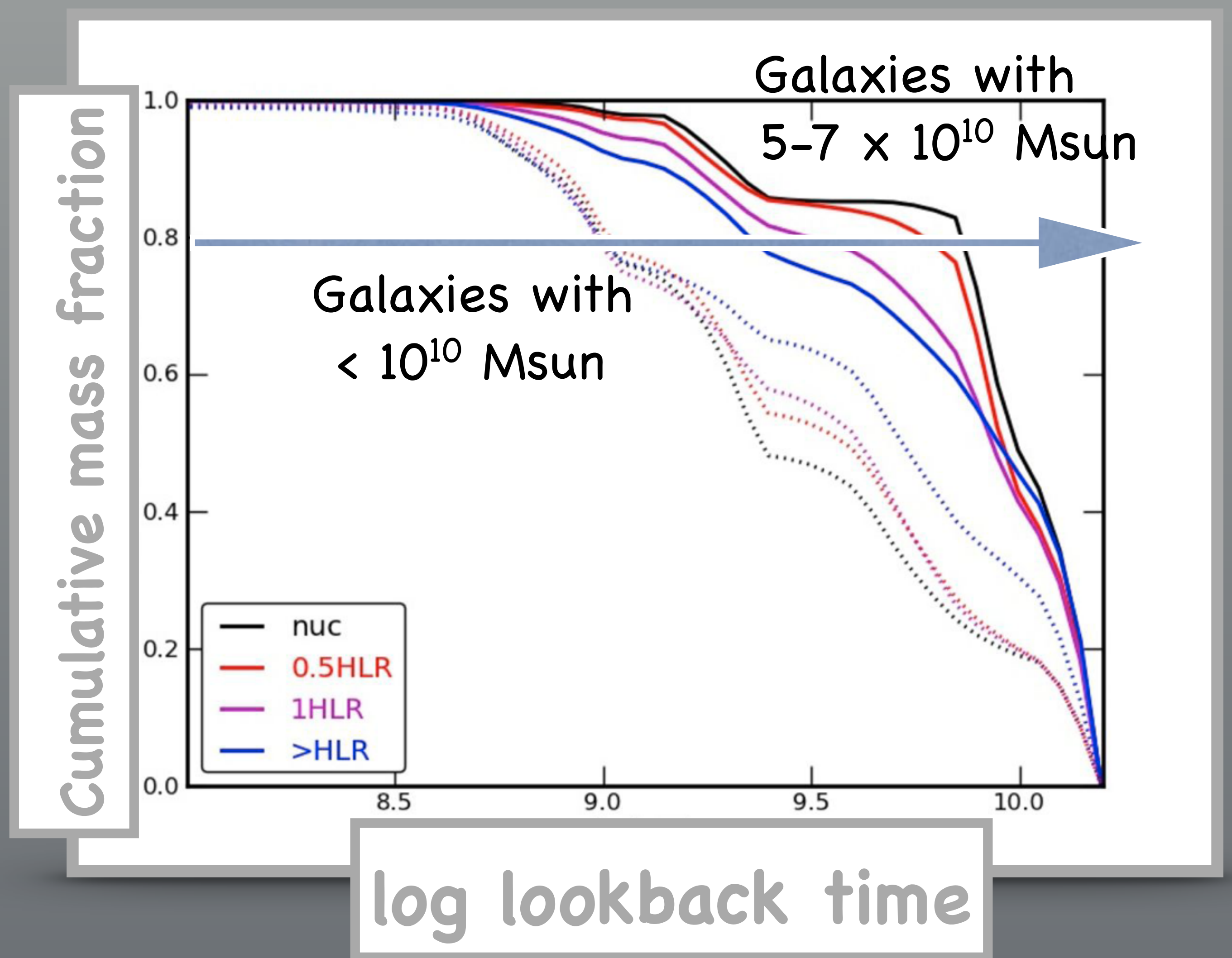
Galaxies grow inside-out

Other evidence:

- Negative radial stellar age gradients.
- Negative metallicity gradients
- Galaxies are more compact in mass than in light

HMR/HLR = Half Mass Radius / Half Light Radius

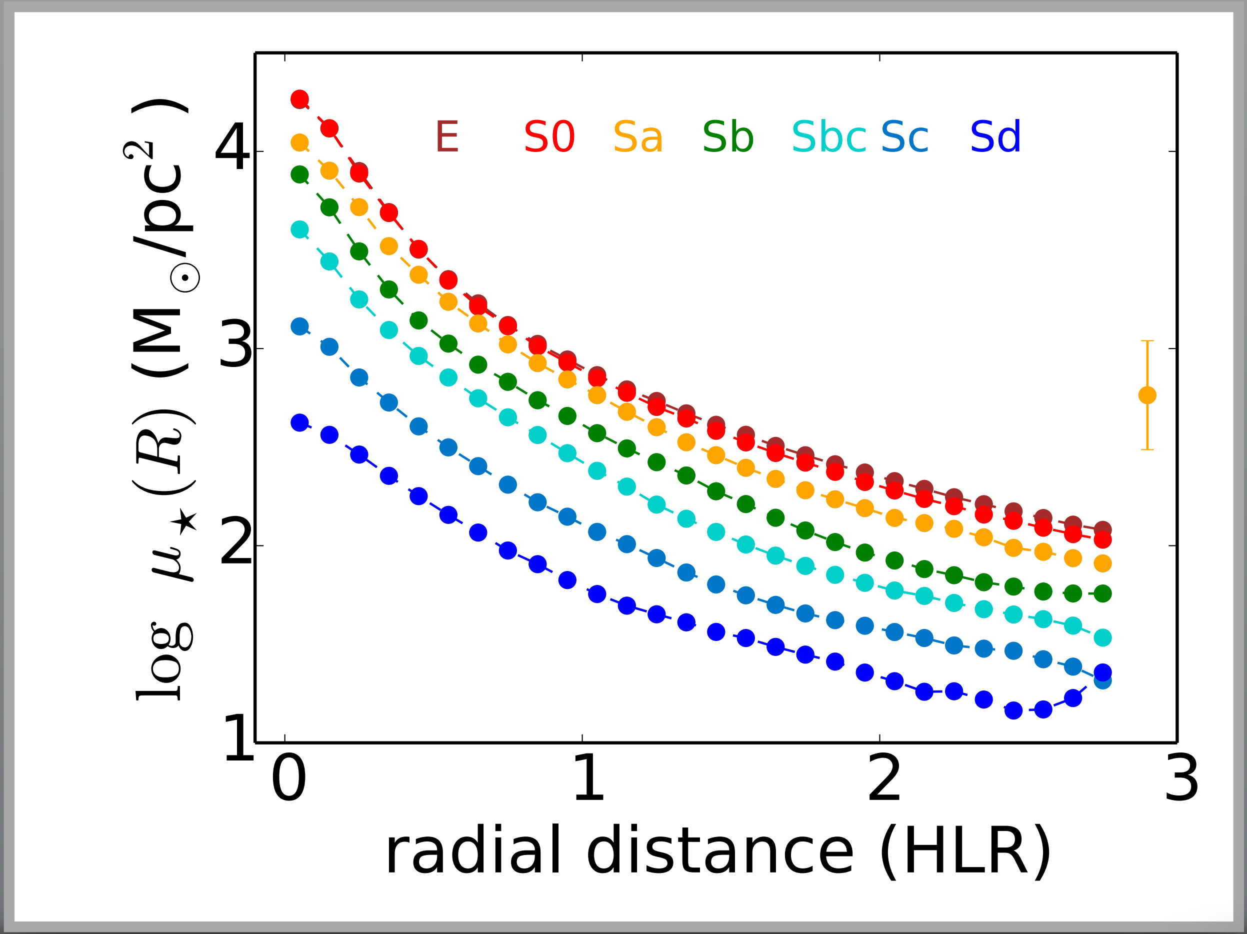


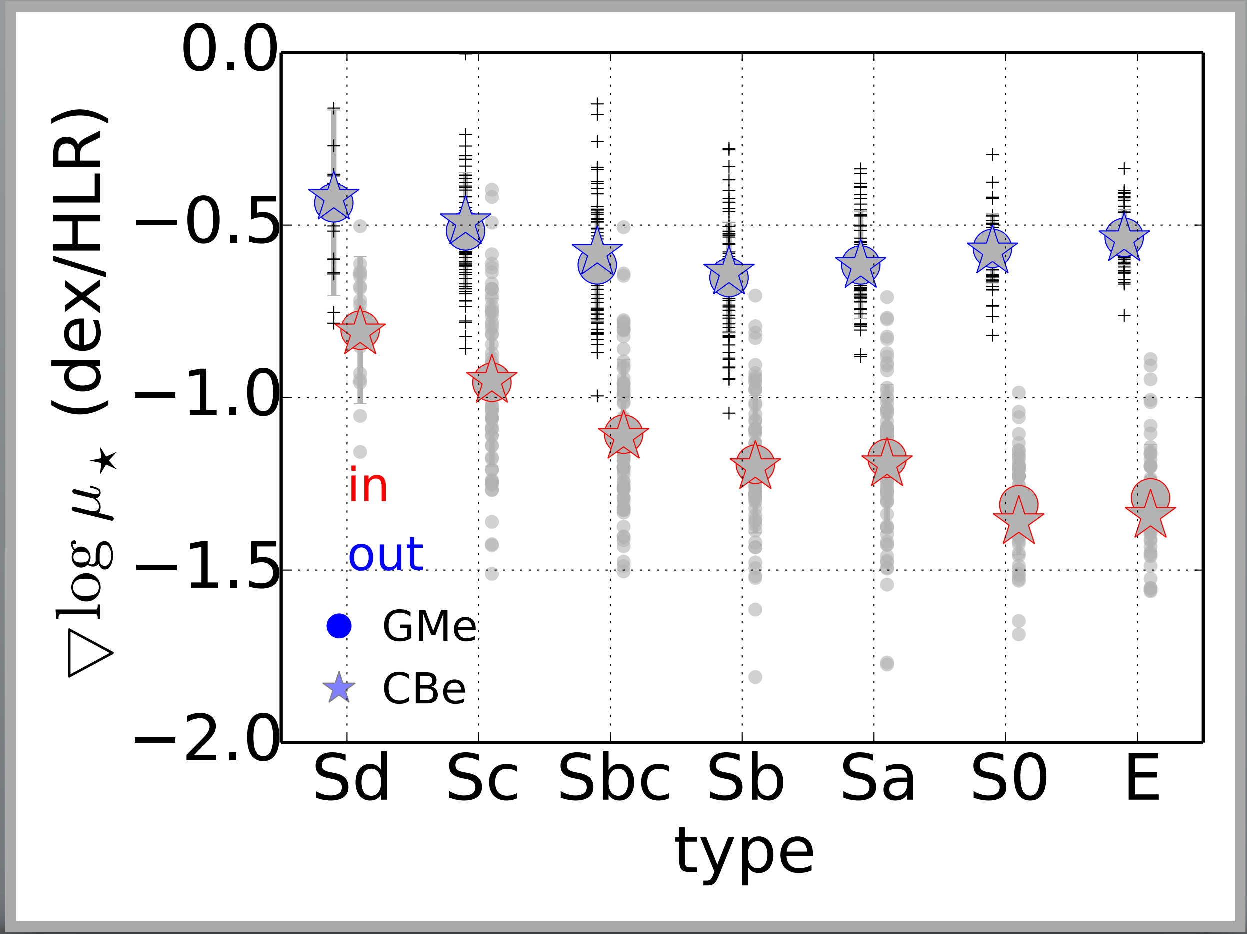


Pérez et al. 2013, ApJL, 764, L1

Stellar Population properties along the Hubble sequence

Radial profiles: stellar mass surface density ($\mu\star$)

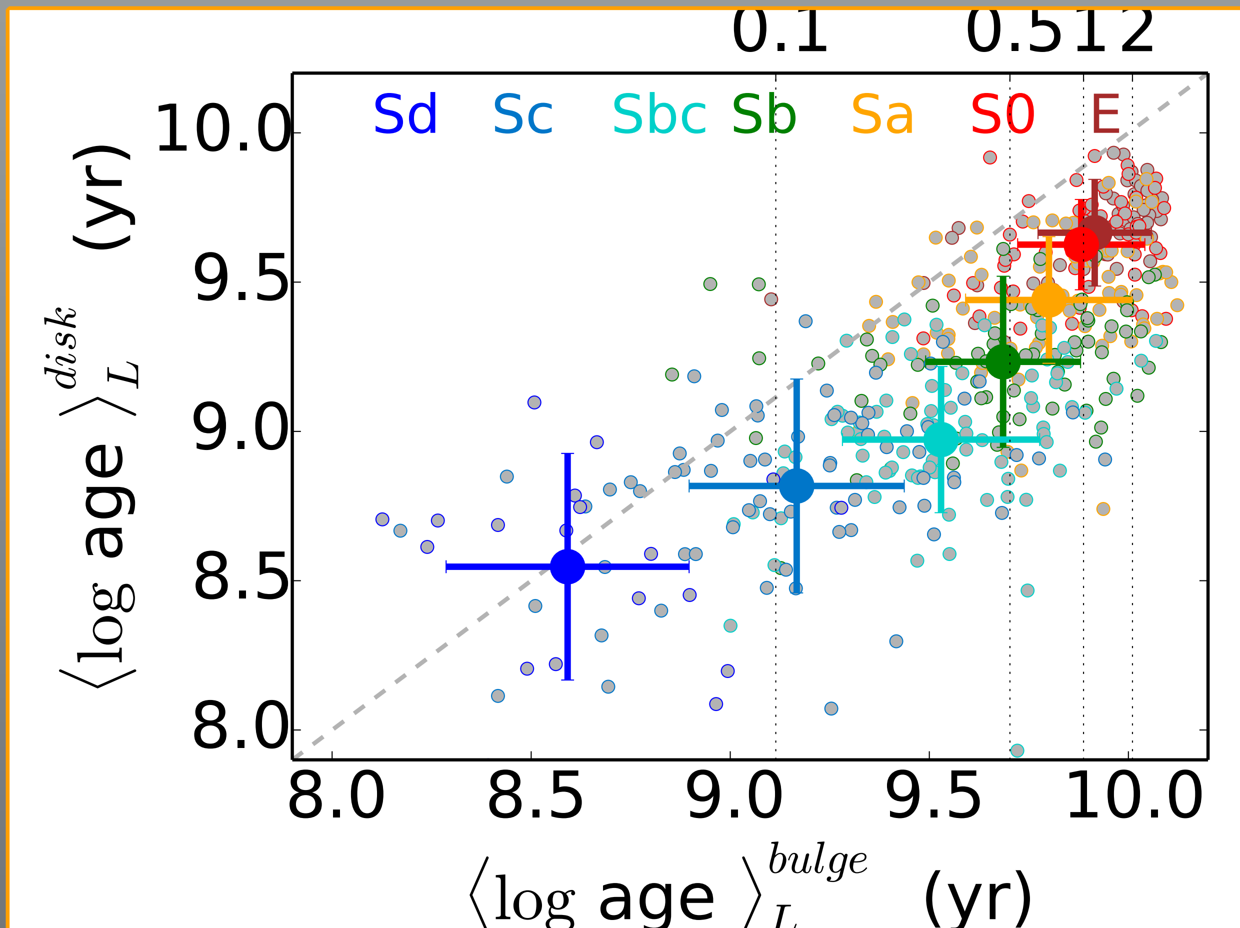


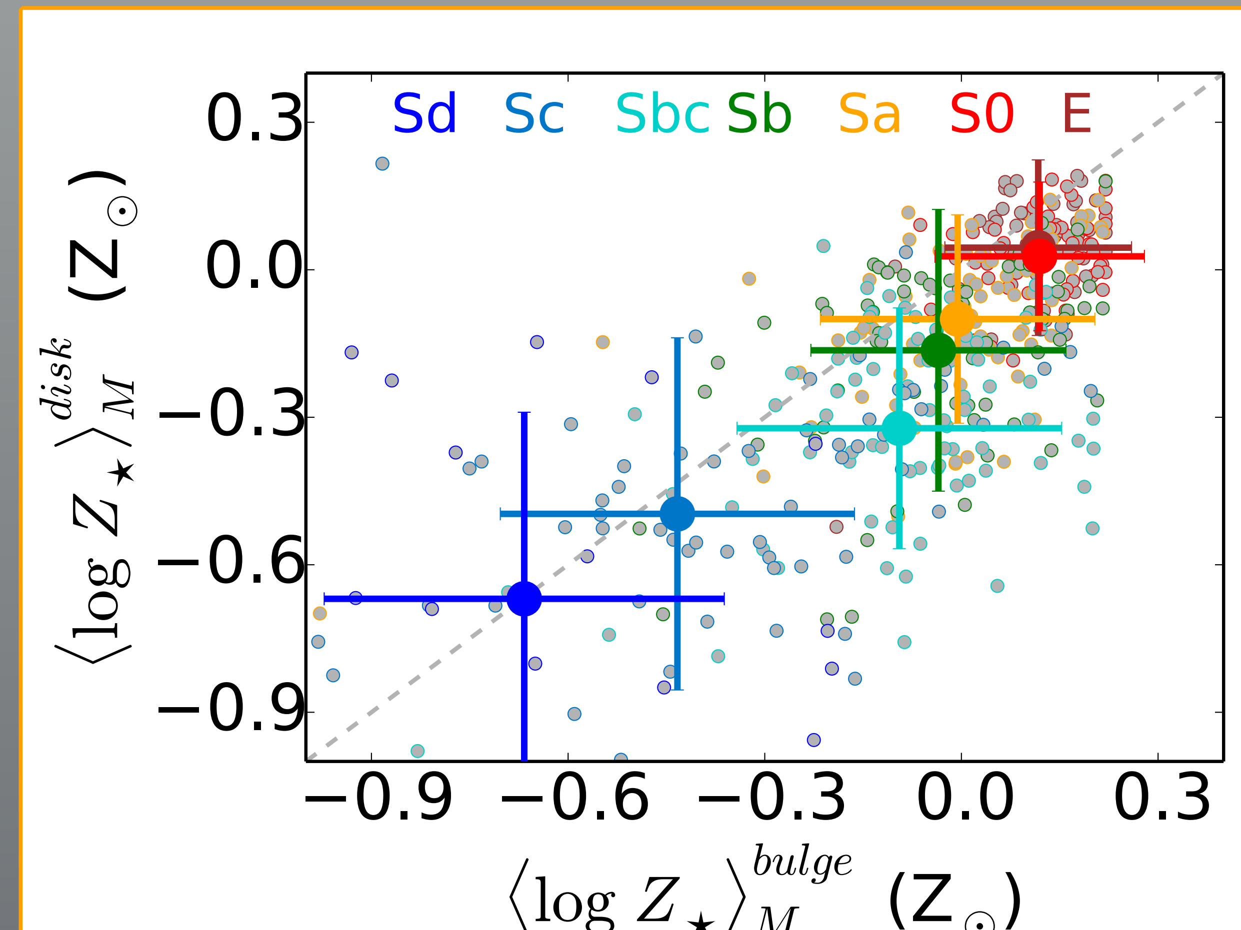


- declining profiles that scale with Hubble type
- largest inner gradient in spheroidals
- CALIFA E and SO galaxies have similar formation scenario: similar $\mu\star(R)$ and gradient

Stellar Population properties along the Hubble sequence

Bulges and disks





- The mean stellar ages of disks and bulges are correlated; late spirals host younger disks.
- Bulges of S0 and early type spirals are old and metal rich as the core of E's. They formed by similar processes, through mergers
- Late type spirals have younger bulges, and have larger contribution from secular evolution
- Disks are younger and more metal poor than bulges; evidence of the inside-out formation

Conclusions

✳ Hubble sequence is a useful scheme to organize galaxies by their spatially resolved stellar density, age, and metallicity.

✳ Spirals form a galaxy sequence with constant intensity of the SFR.

✳ Local processes are relevant in setting the SF in the disks of galaxies probably through a density dependence SFR law.

✳ Stellar mass sets the average properties of the stellar population in galaxies, but have little impact on quenching.

✳ Morphology plays the main role in the shut down of the star formation activity in galaxies.

✳Pérez et al. 2013, ApJL, 764, L1
✳Cid Fernandes et al. 2013, A&A, 557, 86
✳Cid Fernandes et al. 2014, A&A, 561, 130
✳González Delgado et al. 2014, A&A, 562, 47
✳González Delgado et al. 2014, ApJL, 791, L16
✳González Delgado et al. 2015, A&A, 581, 103.
✳López Fernández et al. 2016, MNRAS, 458, 184
✳González Delgado et al. 2016, A&A, arXiv:160300874