Two Growing Modes and the Morphology-Quiescence Relation in Isolated Galaxies

Joanna Woo, Sara L. Ellison (2019) MNRAS

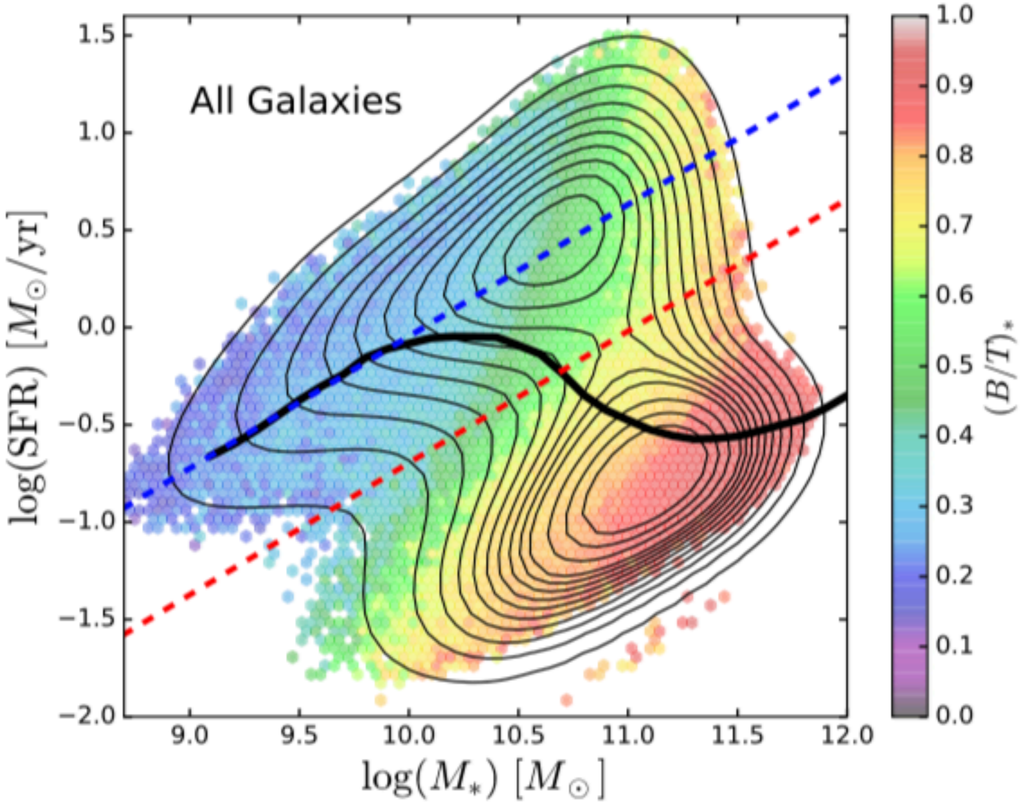
Reporter: Chen Guangwen (USTC) 2019.06.05

1. Introduction

- Galaxies (bimodality) (e.g. Strateva et al. 2001; Bell et al. 2004; Faber et al. 2007)
  - Star-forming galaxies (SFGs): blue, disk-like…
  - Quiescent galaxies (QGs): red, spheroid-like…

SFG **QG**

From Hubble/Galaxy Zoo



Asa F. L. Bluck et al. 2018, MNRAS

- SFG->QG under debate

Morphology-Quiescence Relation

- Morphology: B/T, bulge mass, concentration, Sersic index, line-of-sight velocity dispersion, Σ_{1kpc}, Σ_{Re} ...
- Argue: **building of the core/bulge** vs **quenching** (Bell et al. 2012)
- **Compaction - AGN hypothesis** (Sanchez et al. 2018):
  - Merger/disk instability -> inflows of gas -> **feed a central starburst** -> builds the density of a galaxy's inner core (Σ_{1kpc})
  - Merger/disk instability -> inflows of gas -> **feed an AGN** -> heats/expels cold gas -> **preventing SF**

‘Inside-out’ disk growth

- Lilly & Carollo (2016) presented a simple **‘Inside-out’ model of disk growth**, growing galaxies by successively adding exponential disks of star-forming gas.
  - It requires no bulge formation events -> older centers and younger outskirts, also confirmed by hydrodynamical simulations (Tissera et al. 2016)
  - Quenching probability depended only on its **stellar mass M_***
- Morphology-quiescence relation can be derived **without explicit morphological transformation.**

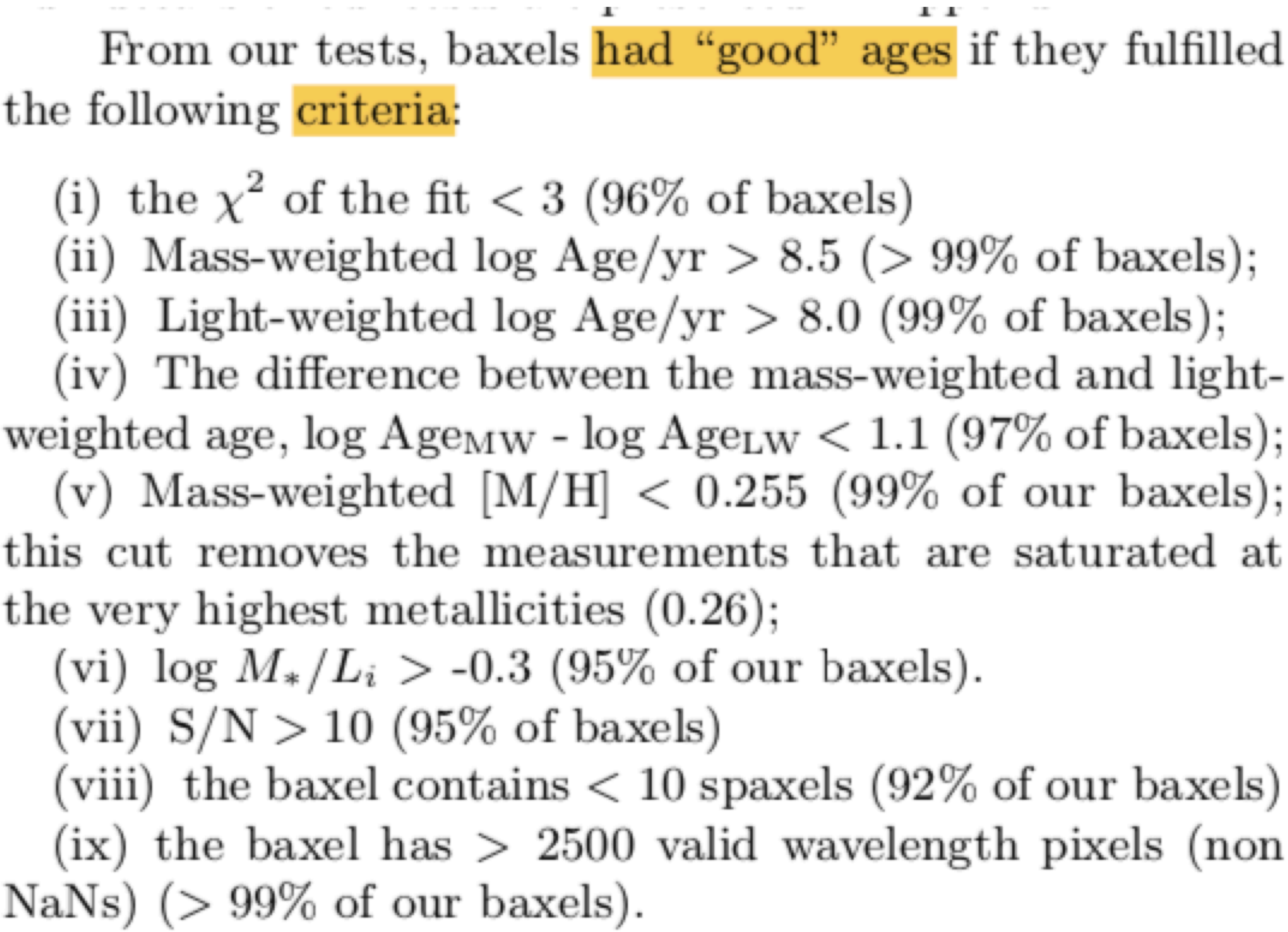
Motivation

- **Distinguishing** (where is the new star formation?)
    - **Core-building compaction-like scenarios — new stars to the centres — flatten age gradients**
    - **Progenitor effects of inside-out growth — new stars in the outskirts — negative age gradients**
- Explore whether **compaction-like core-building events** contribute to the **build-up of the central density of galaxies** and whether this is related to **quenching**.

Data

- **Sample**: MaNGA DR14, 2780 galaxies
- Global criteria: **616** galaxies
    - $\log M_*/M_\odot > 9$, SFR (MPA-JHU, $< 3''$),
    - Redshift<0.07, PSF (r-band) < 1 kpc, b/a>0.4,
    - Isolated (Yang et al. group 1 member)
- Spaxels: Voronoi bins of spaxels as baxels
    - pPXF (Penalized Pixel Fitting) : mean mass-weighted log age, metallicities and i-band mass-to-light ratio, $\log M_*/L_i$, for each baxel.

Stellar age: 610 galaxies



From our tests, baxels had “good” ages if they fulfilled the following criteria:

(i) the χ^2 of the fit < 3 (96% of baxels)

(ii) Mass-weighted log Age/yr > 8.5 ($>$ 99% of baxels);

(iii) Light-weighted log Age/yr > 8.0 (99% of baxels);

(iv) The difference between the mass-weighted and light-weighted age, log $\mathrm{Age_{MW}}$ - log $\mathrm{Age_{LW}} < 1.1$ (97% of baxels);

(v) Mass-weighted [M/H] < 0.255 (99% of our baxels); this cut removes the measurements that are saturated at the very highest metallicities (0.26);

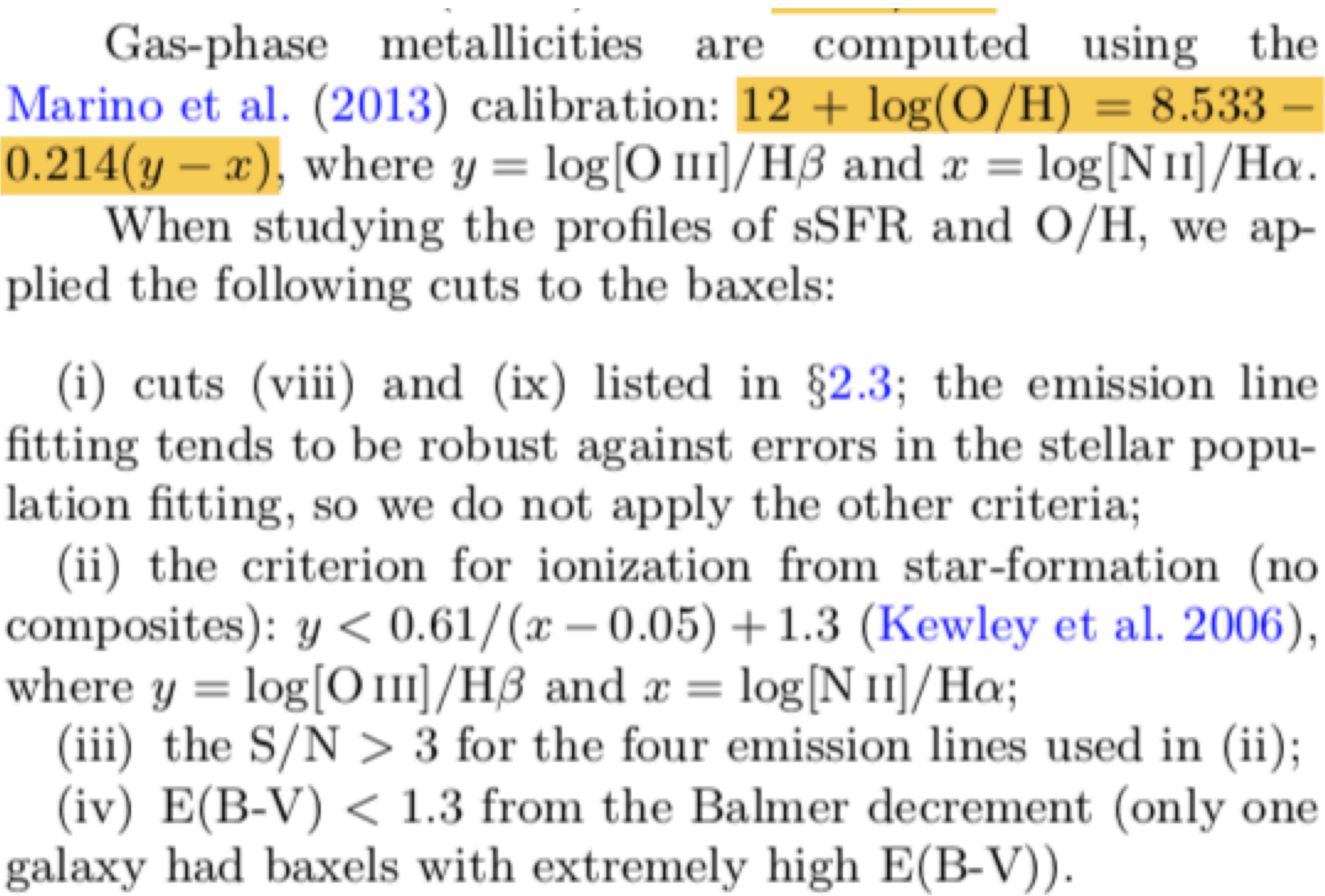
(vi) log $M_*/L_i >$ -0.3 (95% of our baxels).

(vii) S/N > 10 (95% of baxels)

(viii) the baxel contains < 10 spaxels (92% of our baxels)

(ix) the baxel has > 2500 valid wavelength pixels (non NaNs) ($>$ 99% of our baxels).

sSFR、O/H: 482 galaxies



Gas-phase metallicities are computed using the Marino et al. (2013) calibration: $12 + \log(\mathrm{O/H}) = 8.533 - 0.214(y - x)$, where $y = \log[\mathrm{O\,III}]/\mathrm{H}\beta$ and $x = \log[\mathrm{N\,II}]/\mathrm{H}\alpha$.

When studying the profiles of sSFR and O/H, we applied the following cuts to the baxels:

(i) cuts (viii) and (ix) listed in §2.3; the emission line fitting tends to be robust against errors in the stellar population fitting, so we do not apply the other criteria;

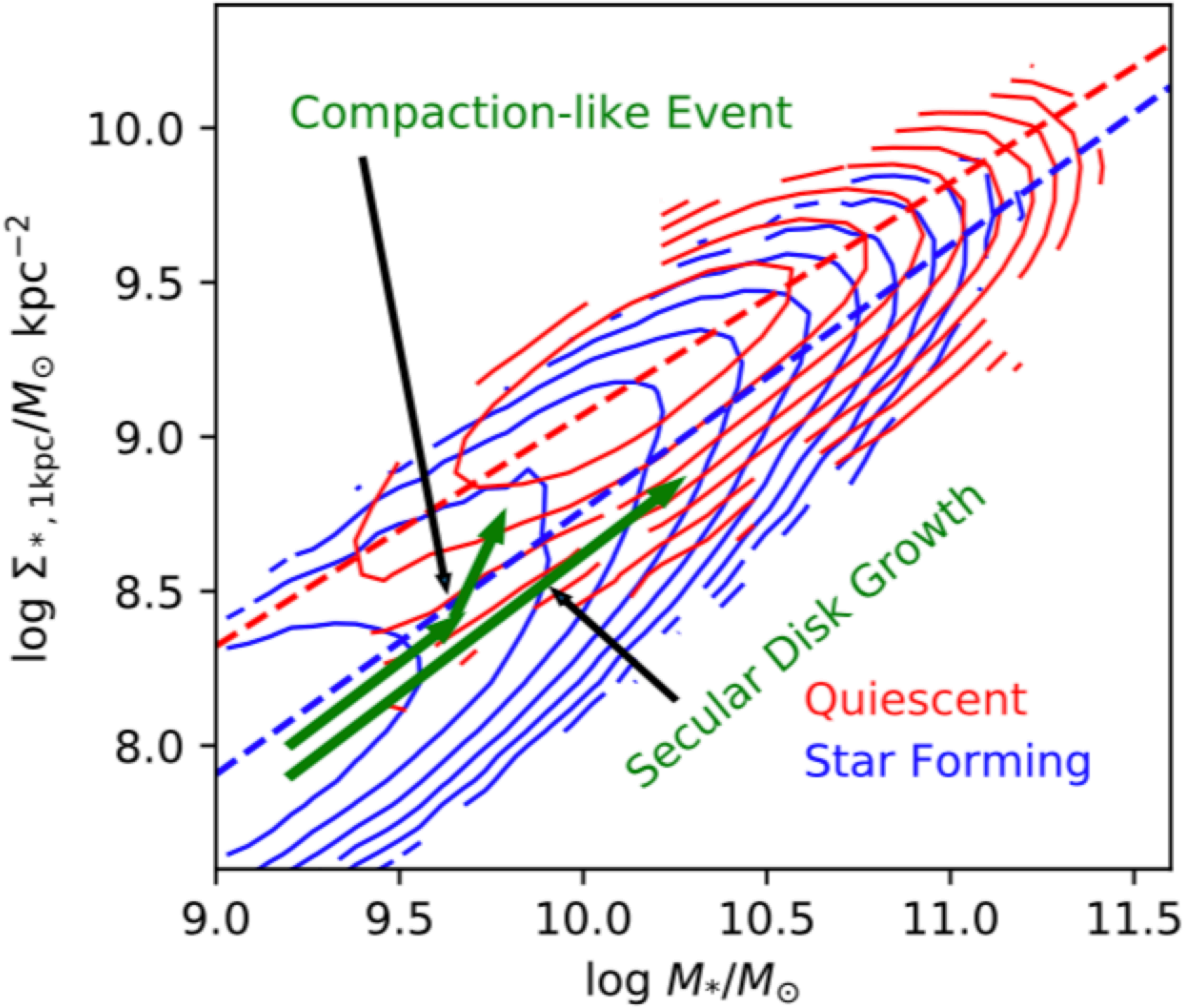
(ii) the criterion for ionization from star-formation (no composites): $y < 0.61/(x - 0.05) + 1.3$ (Kewley et al. 2006), where $y = \log[\mathrm{O\,III}]/\mathrm{H}\beta$ and $x = \log[\mathrm{N\,II}]/\mathrm{H}\alpha$;

(iii) the S/N > 3 for the four emission lines used in (ii);

(iv) E(B-V) < 1.3 from the Balmer decrement (only one galaxy had baxels with extremely high E(B-V)).

Results: Σ_{1kpc} - M_* diagram

Σ_{1kpc} : $\log M_*/L_i = 1.13+0.83(g-i)$ (Fang et al. 2013)



log sSFR > -11: **SFGs**

log sSFR < -11: **QGs**

Upper: compaction-like

Lower: secular disk growth

Age Gradients

- **Gradients** for each galaxy: the **slope** of the **linear fit** of the quantity of interest vs. the galactocentric distance of the baxels in units of the **half-mass radius Re,**$_*$.

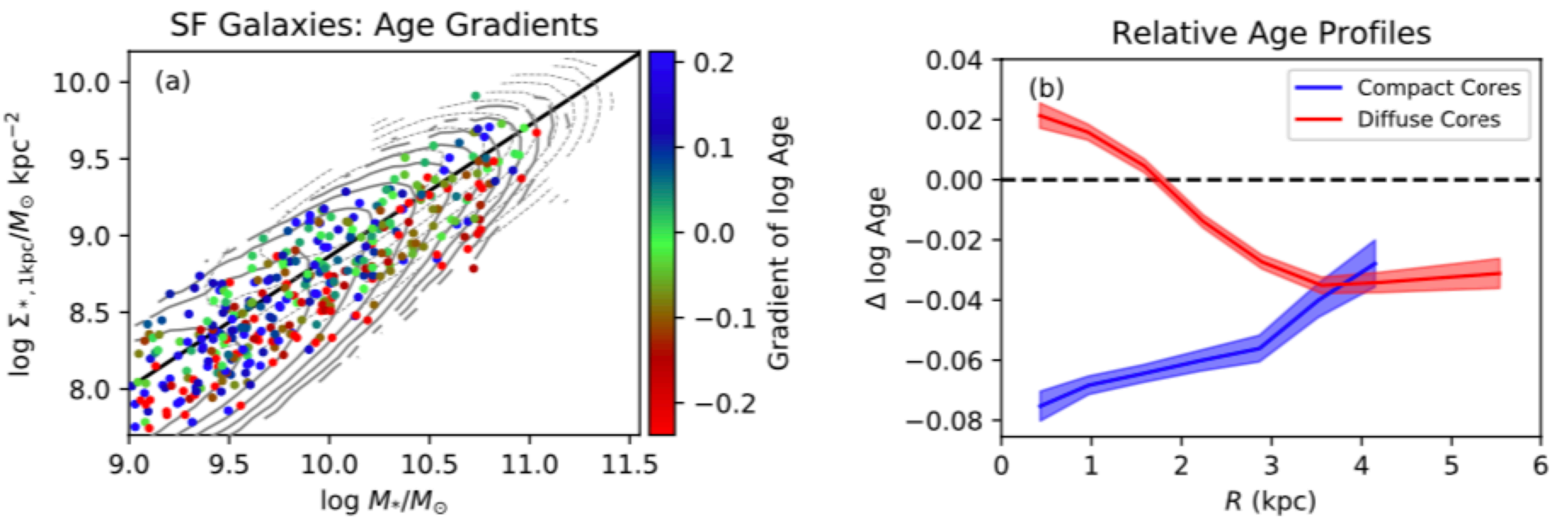


Figure 3. (a) The age gradient as a function of $\Sigma_{*,1\mathrm{kpc}}$ and M_* for SF galaxis in MaNGA (points). The grey contours mark the SF and Q populations in the SDSS DR7 sample. The black line divides "compact" from "diffuse" cores. (b) The smoothed median relative age profiles for galaxies with compact (blue) and diffuse (red) cores. The thickness of the curves is the error on the median. Galaxies with compact cores have relatively younger centres compared to their outskirts while galaxies with lower $\Sigma_{*,1\mathrm{kpc}}$ have older centres.

Age vs. stellar mass density

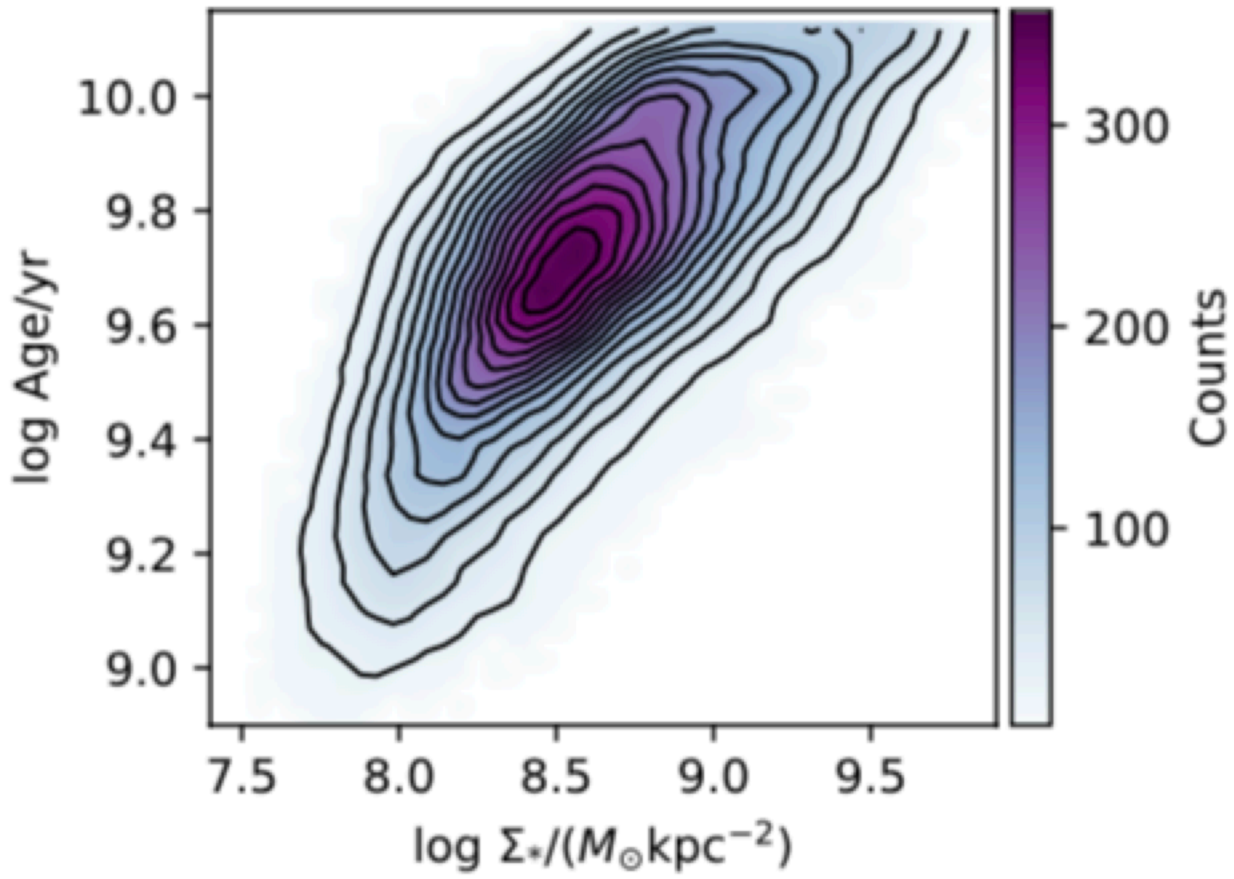


Figure 1. Mass-weighted stellar age vs. stellar mass density in MaNGA baxels.

- Stellar age correlates strongly with Σ_*, we can remove this correlation by defining Δ log age as the difference in log age of a baxel from the mean log age of all baxels within a 0.1 dex window of the test baxel's Σ_*.

Relative Age Profiles

- Control for Σ∗, total stellar mass (M∗) and radial position (R) within the galaxies using windows of 0.1 logΣ∗, 0.1 logM∗ and 0.2 R/kpc.

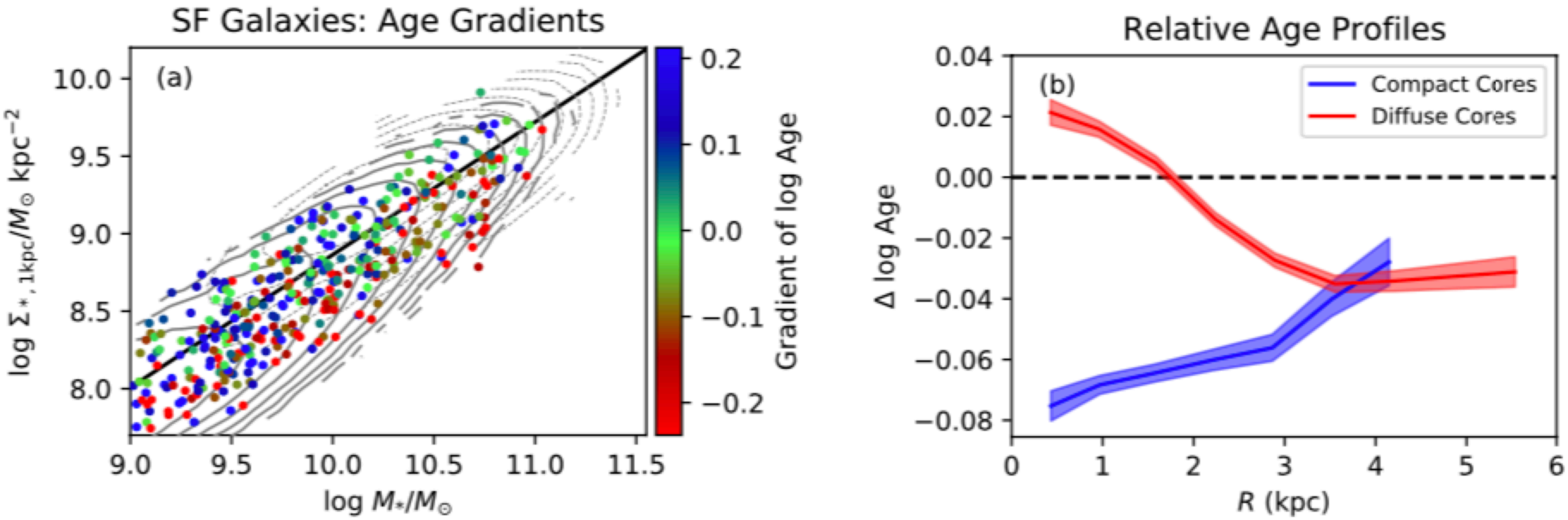


Figure 3. (a) The age gradient as a function of $\Sigma_{*,1\mathrm{kpc}}$ and M_* for SF galaxis in MaNGA (points). The grey contours mark the SF and Q populations in the SDSS DR7 sample. The black line divides "compact" from "diffuse" cores. (b) The smoothed median relative age profiles for galaxies with compact (blue) and diffuse (red) cores. The thickness of the curves is the error on the median. Galaxies with compact cores have relatively younger centres compared to their outskirts while galaxies with lower $\Sigma_{*,1\mathrm{kpc}}$ have older centres.

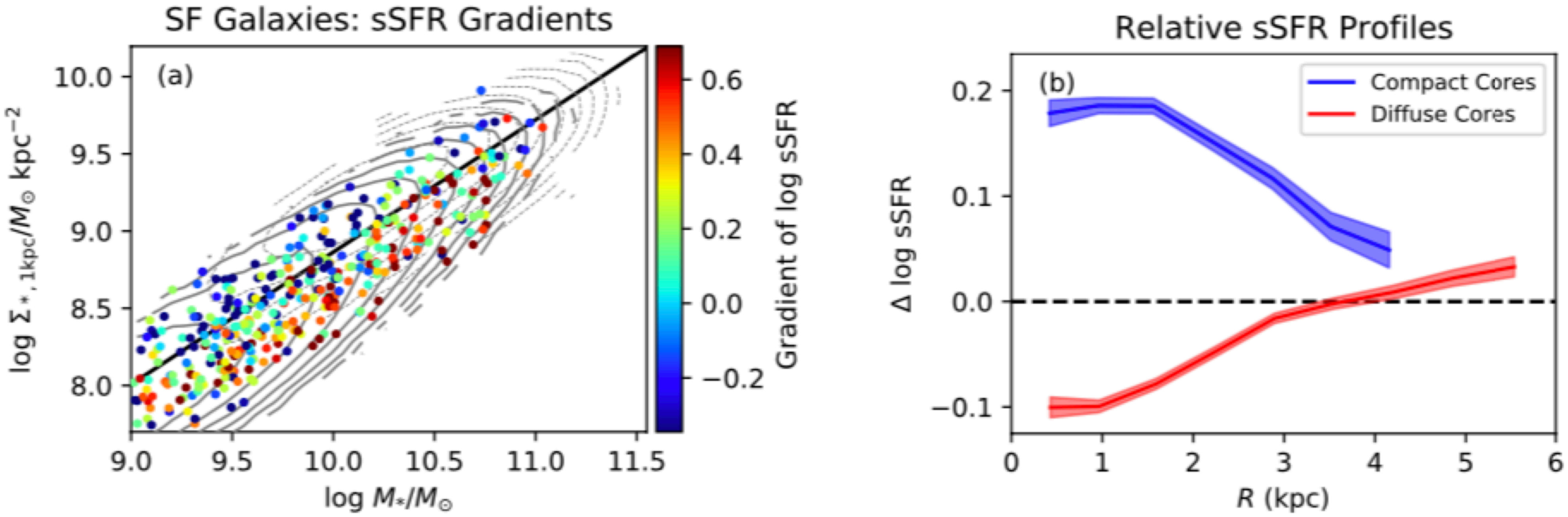


Figure 4. (a) The sSFR gradient as a function of $\Sigma_{*,1\mathrm{kpc}}$ and M_* for SF galaxies in MaNGA (points). The grey contours mark the SF and Q populations in the SDSS DR7 sample. The black line divides "compact" from "diffuse" cores. (b) The smoothed median relative sSFR profiles for galaxies with compact (blue) and diffuse (red) cores. The thickness of the curves is the error on the median. Galaxies with compact cores have centrally peaked sSFR while galaxies with lower $\Sigma_{*,1\mathrm{kpc}}$ form stars in their outskirts.

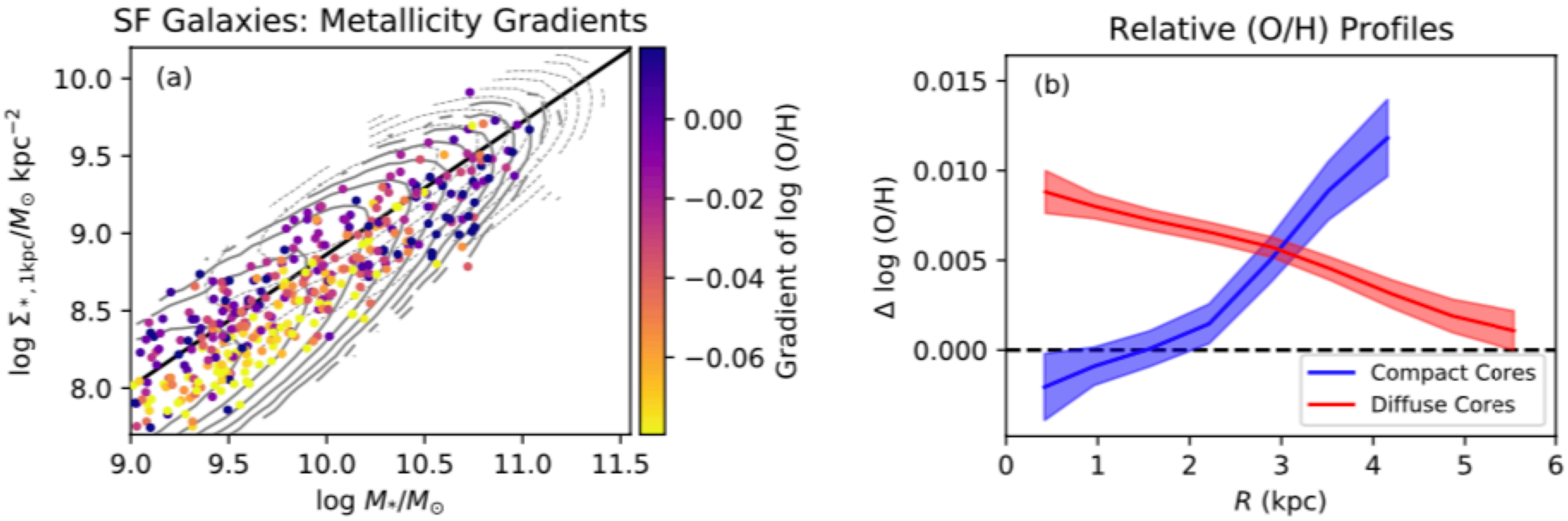


Figure 5. (a) The gradient of 12 + log(O/H) as a function of $\Sigma_{*,1\mathrm{kpc}}$ and M_* for SF galaxies in MaNGA (points). The grey contours mark the SF and Q populations in the SDSS DR7 sample. The black line divides "compact" from "diffuse" cores. (b) The smoothed median relative log(O/H) profiles for galaxies with compact (blue) and diffuse (red) cores. The thickness of the curves is the error on the median. Galaxies with compact cores have relatively metal-poor gas in their centres while galaxies with lower $\Sigma_{*,1\mathrm{kpc}}$ have O/H profiles that mildly decrease with radius.

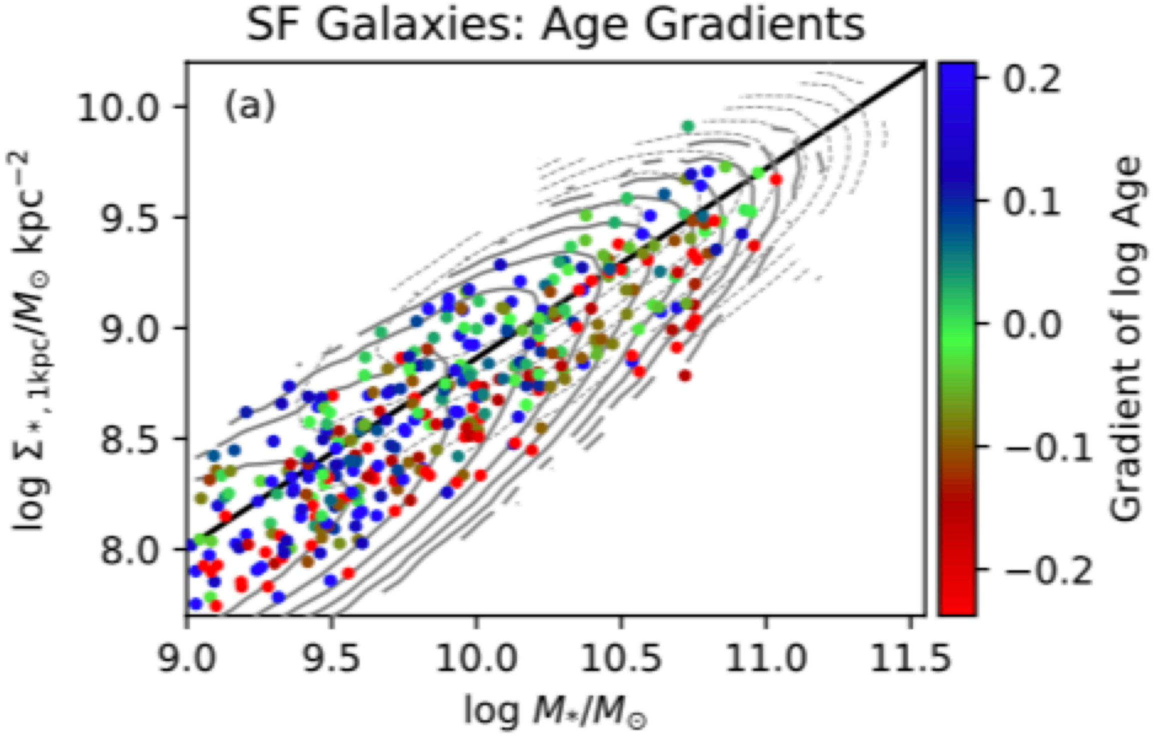
Discussion: Growth and quenching

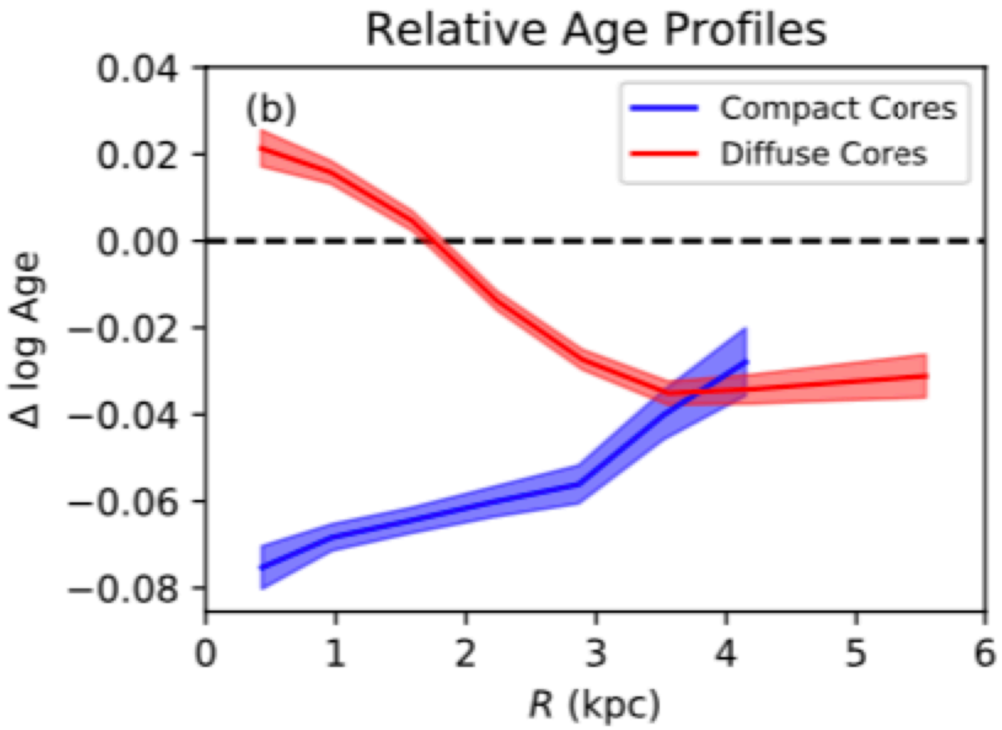
- **Compaction-like events (high $\Sigma_{*,\mathrm{1kpc}}$ at given M_*)**
    - **Compact cores: relatively young, high sSFR, low O/H.**
- **Secular inside-out growth (low $\Sigma_{*,\mathrm{1kpc}}$ at given M_*)**
    - **Diffuse cores: relatively old, lower sSFR, high O/H.**
- **Both** modes contribute to the **quiescent population** and that the **morphology-quiescence relation** results from both modes.
- Consistent with previous studies

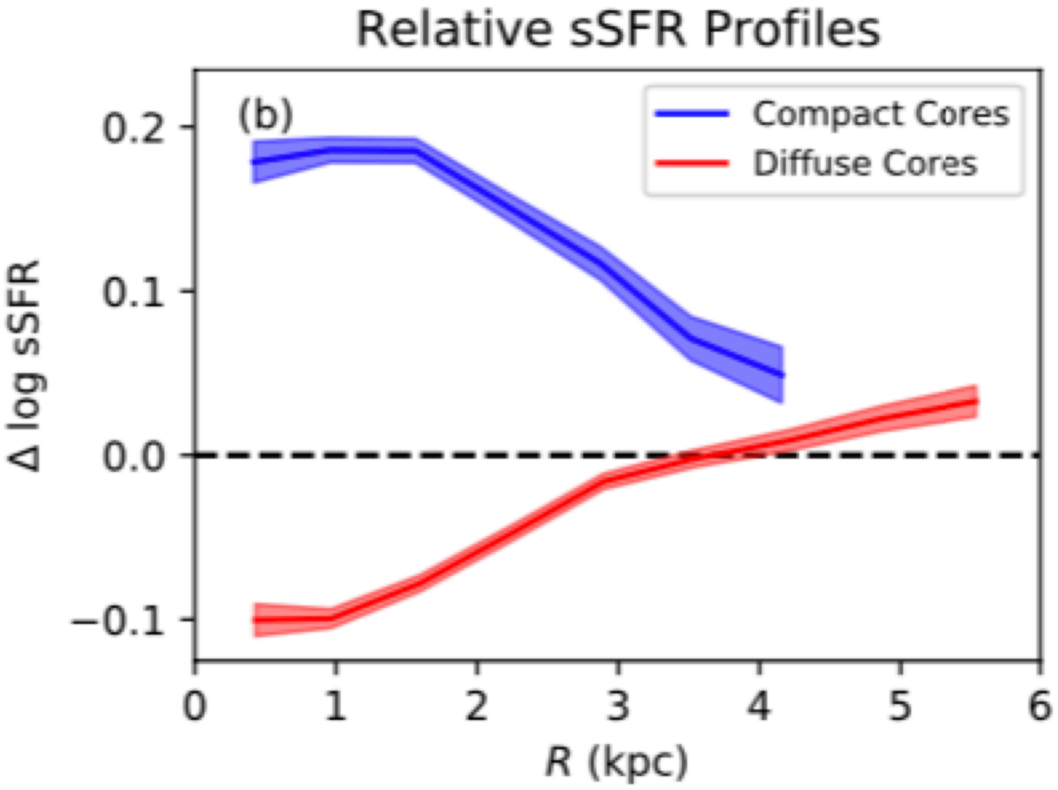
Compaction-like Evolutionary Track

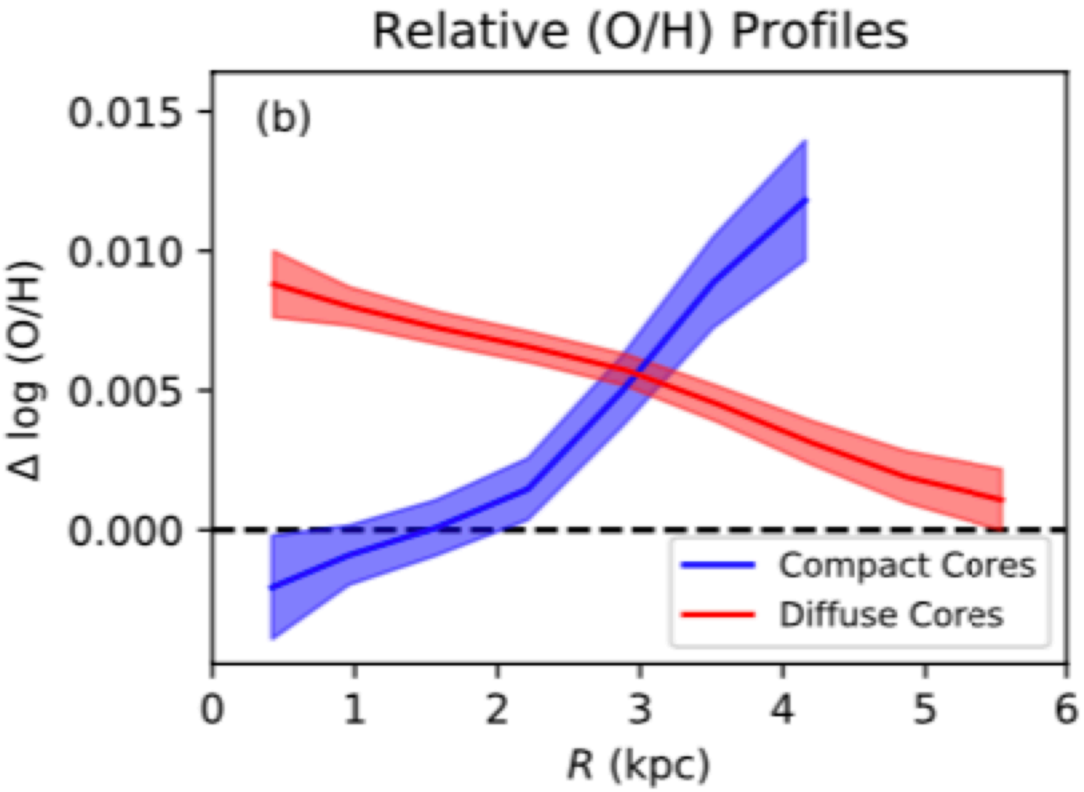
- What is the **nature** of this low-z phenomenon characterized by the gradients and profiles of stellar age, sSFR and gas metallicity?
- Possible mechanisms:
  - **Galaxy mergers**
  - **Bar instability**

Galaxy mergers: rare in the local universe

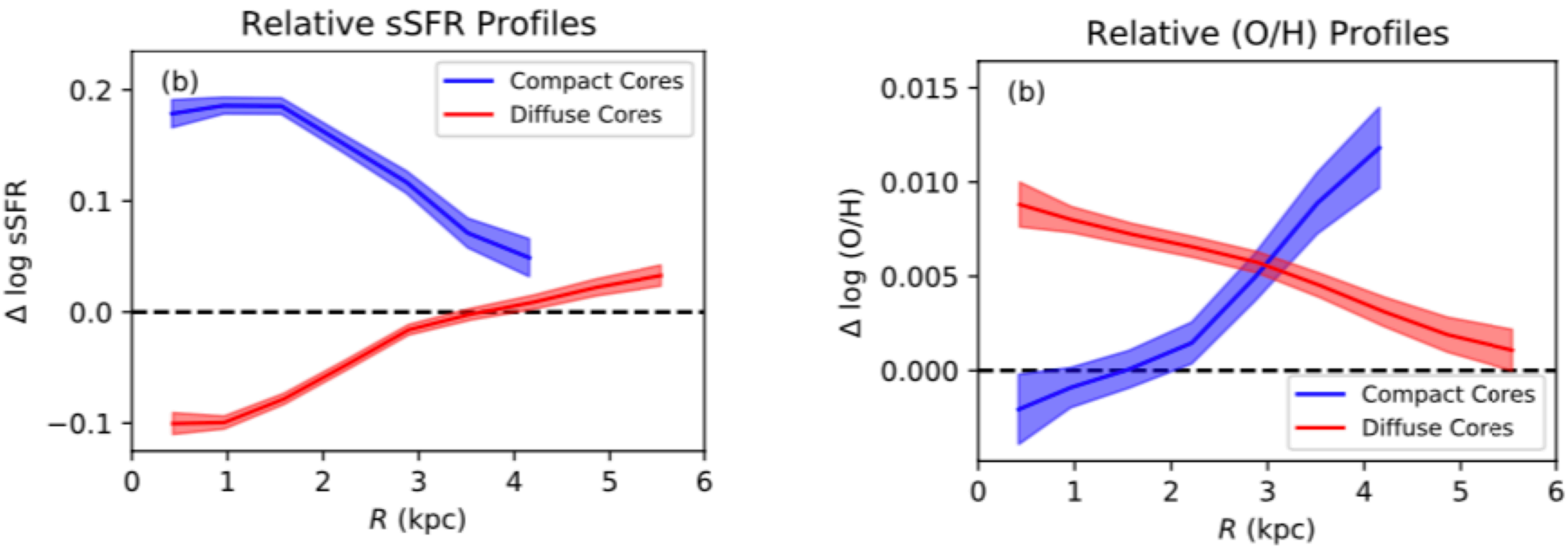






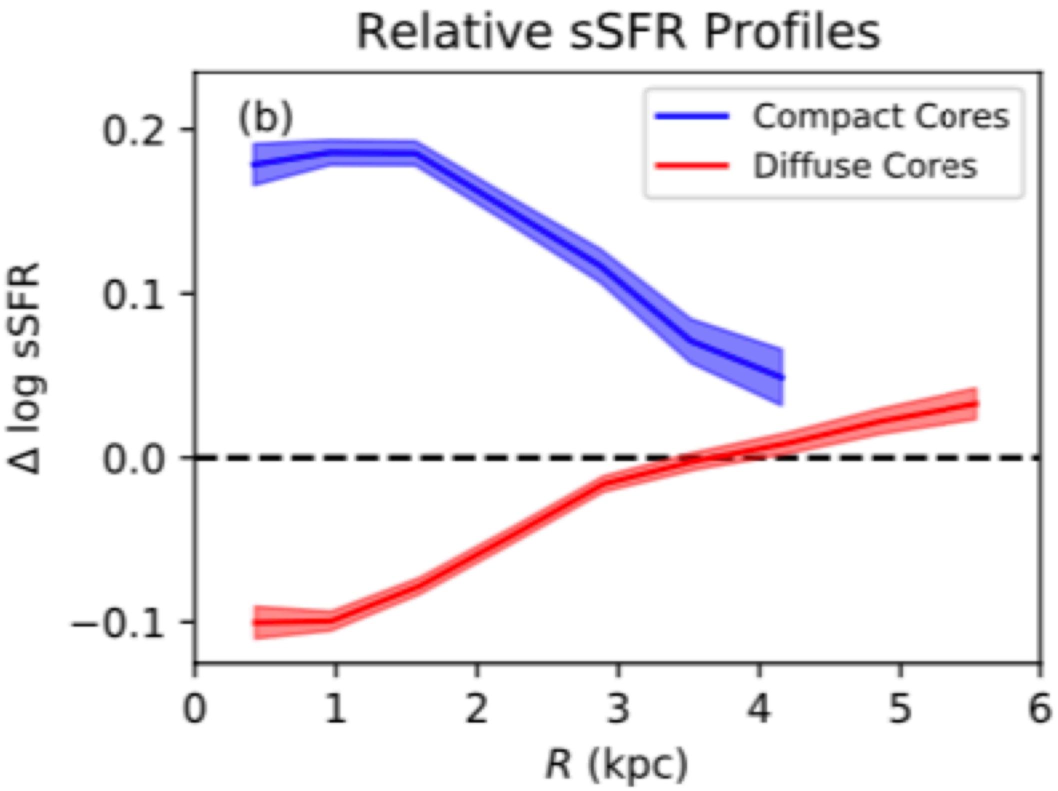


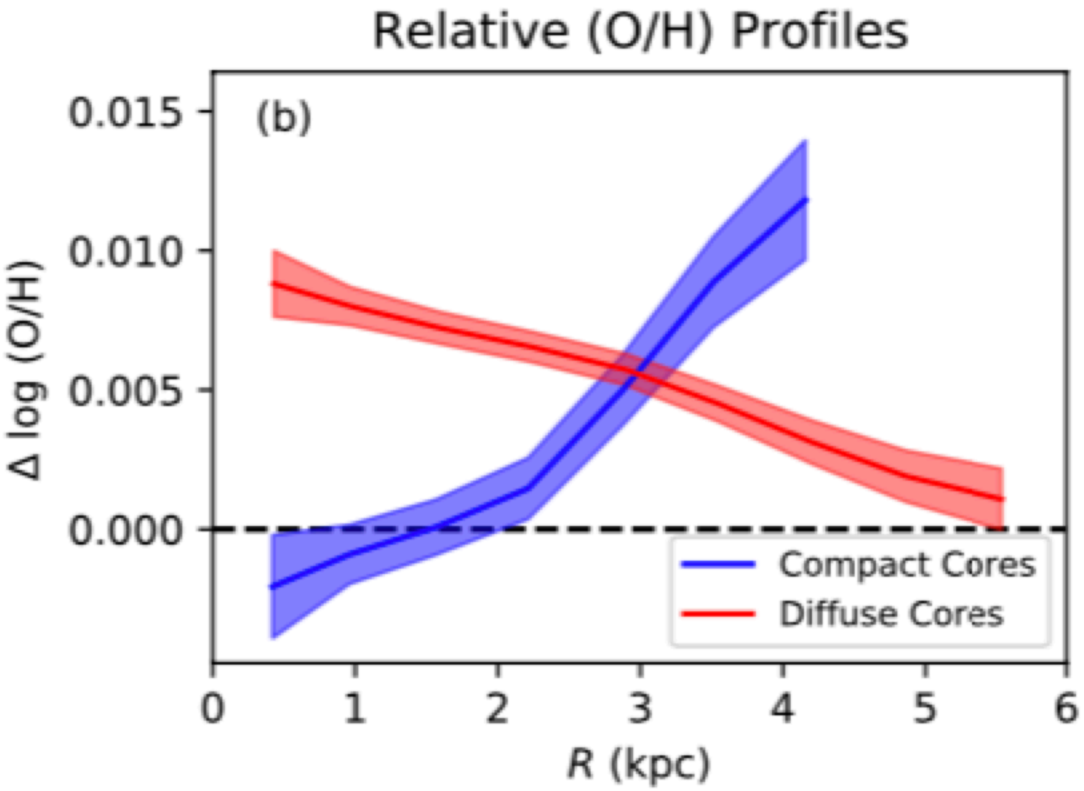
Bar instability: in contrast to Ellison et al. (2011)



- Although barred galaxies in the SDSS have elevated SFR in their centres, their gas metallicities are higher than unbarred galaxies.

Bar instability: in contrast to Ellison et al. (2011)


Relative sSFR Profiles


Relative (O/H) Profiles

- Although barred galaxies in the SDSS have elevated SFR in their centres, their gas metallicities are higher than unbarred galaxies.

- Bars are a long-lived phenomenon, maybe a completely different population from compaction-like galaxies.

Compaction-like Evolutionary Track

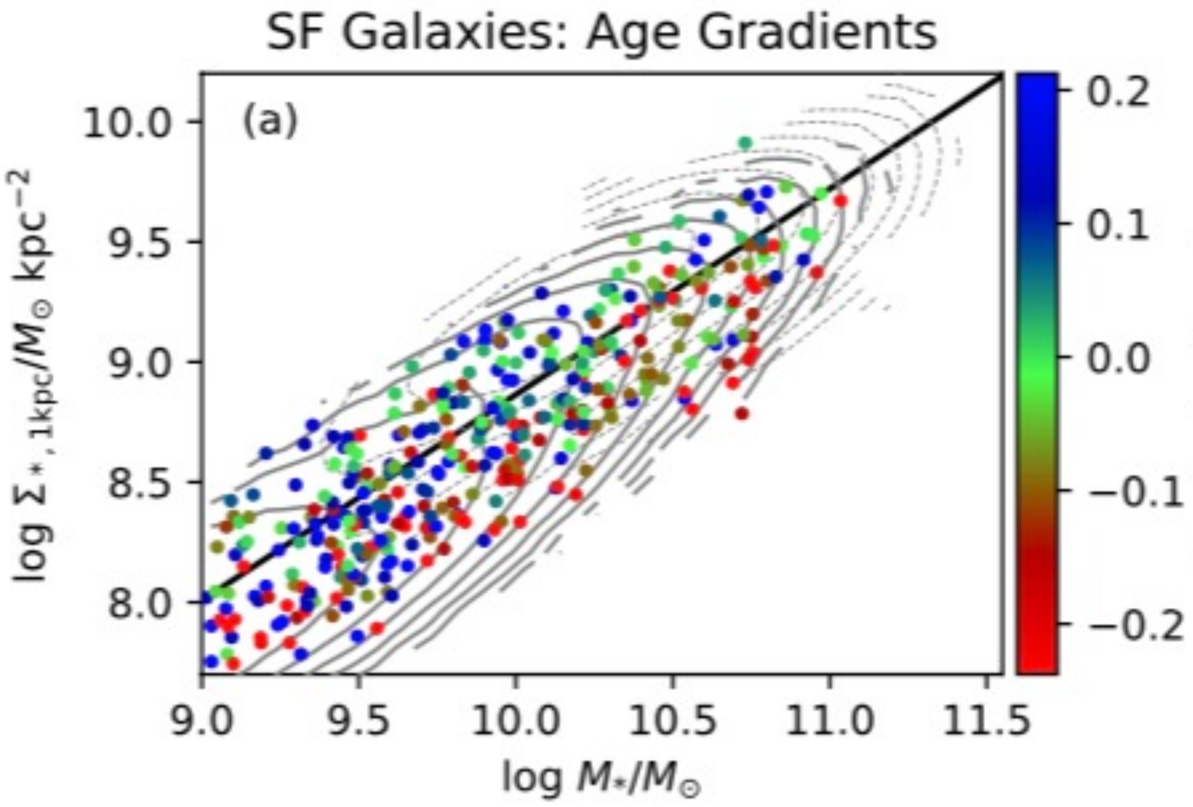
- What is the **nature** of this low-z phenomenon characterized by the gradients and profiles of stellar age, sSFR and gas metallicity?

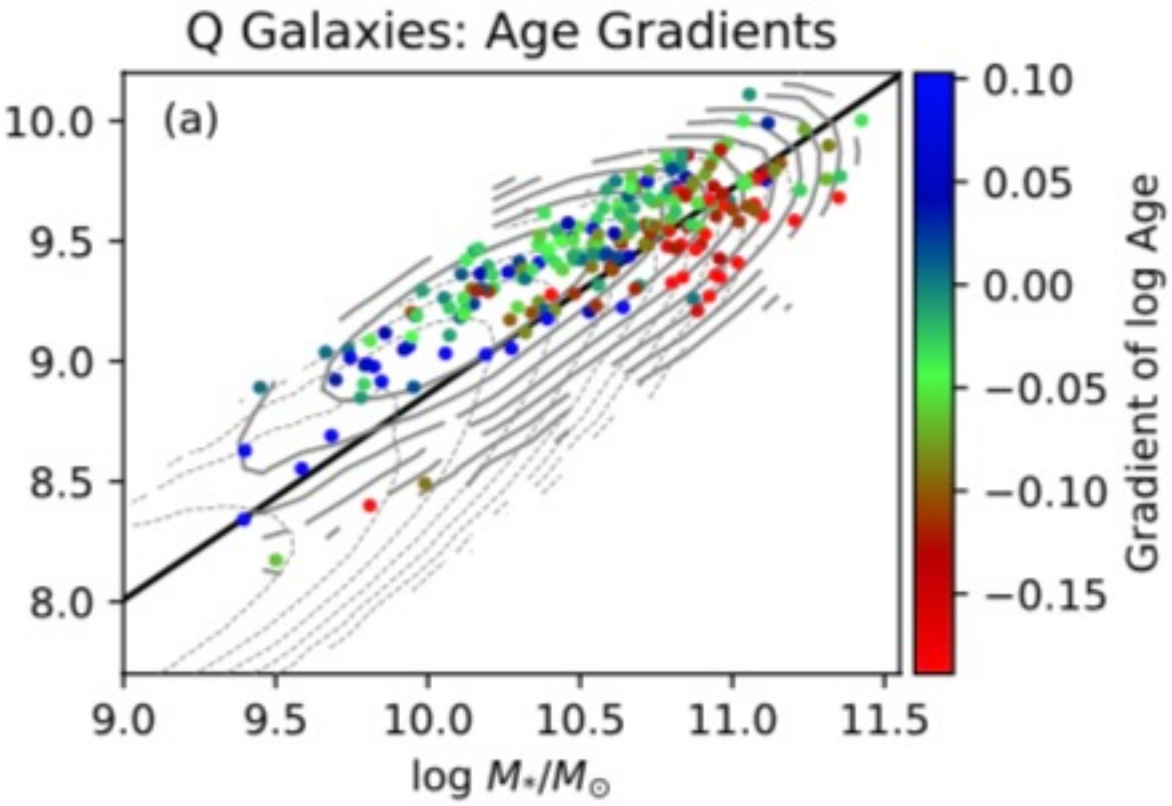
- **Further study is required about the nature of low-z phenomenon.**

- Possible mechanisms:
  - Galaxy mergers: **rare** in the local universe
  - Bar instability: in contrast to Ellison et al. (2011)

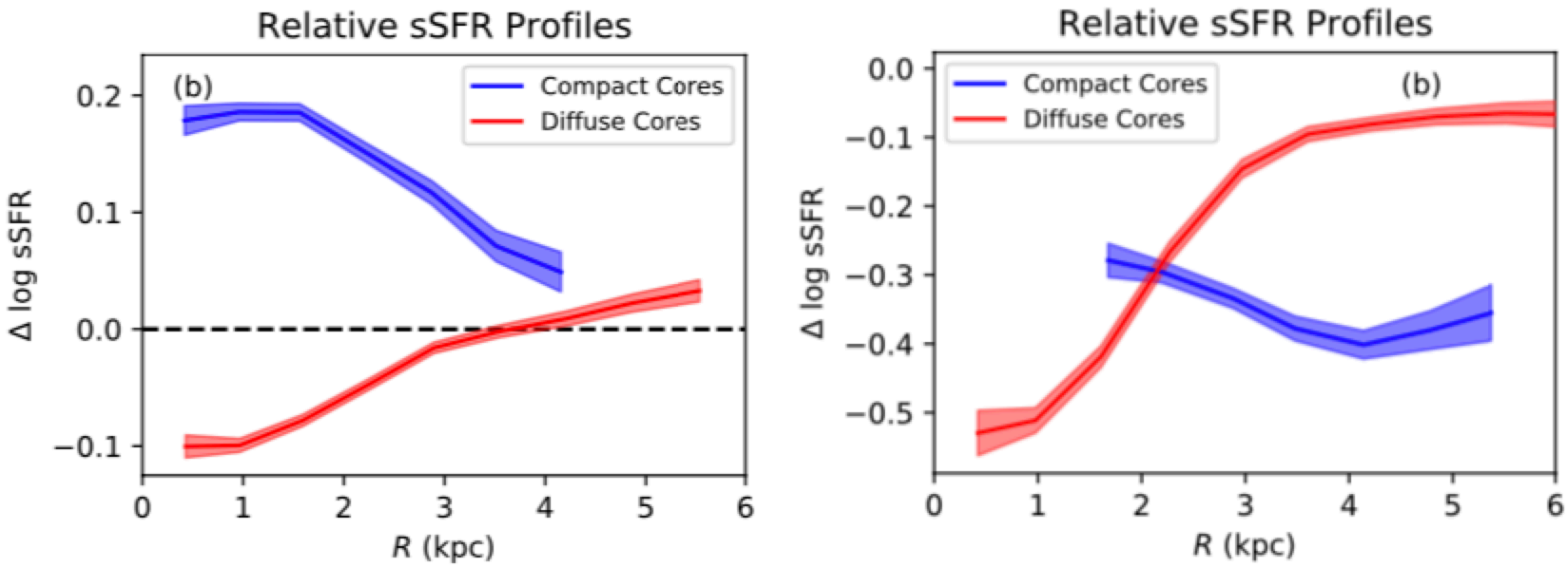
Growth and quenching

- Assume that the position on the $\Sigma_{*,1\mathrm{kpc}}$-M_* diagram for the Q galaxies is the end point of the two growing pathways.





Compaction-like growing mode related to quenching



- Declining shape of the sSFR profiles, is roughly preserved.
- Quench uniformly across most of the galaxy.

AGN feedback

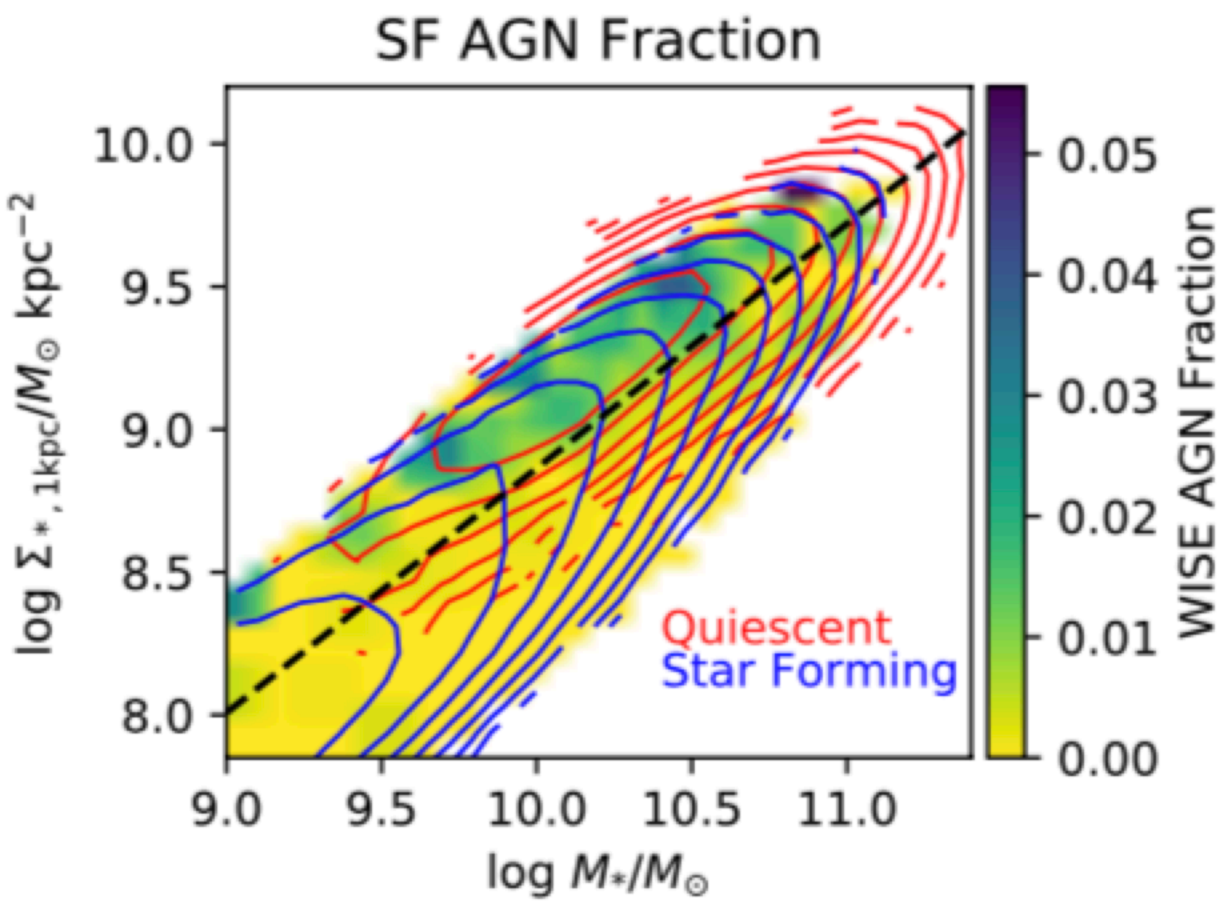
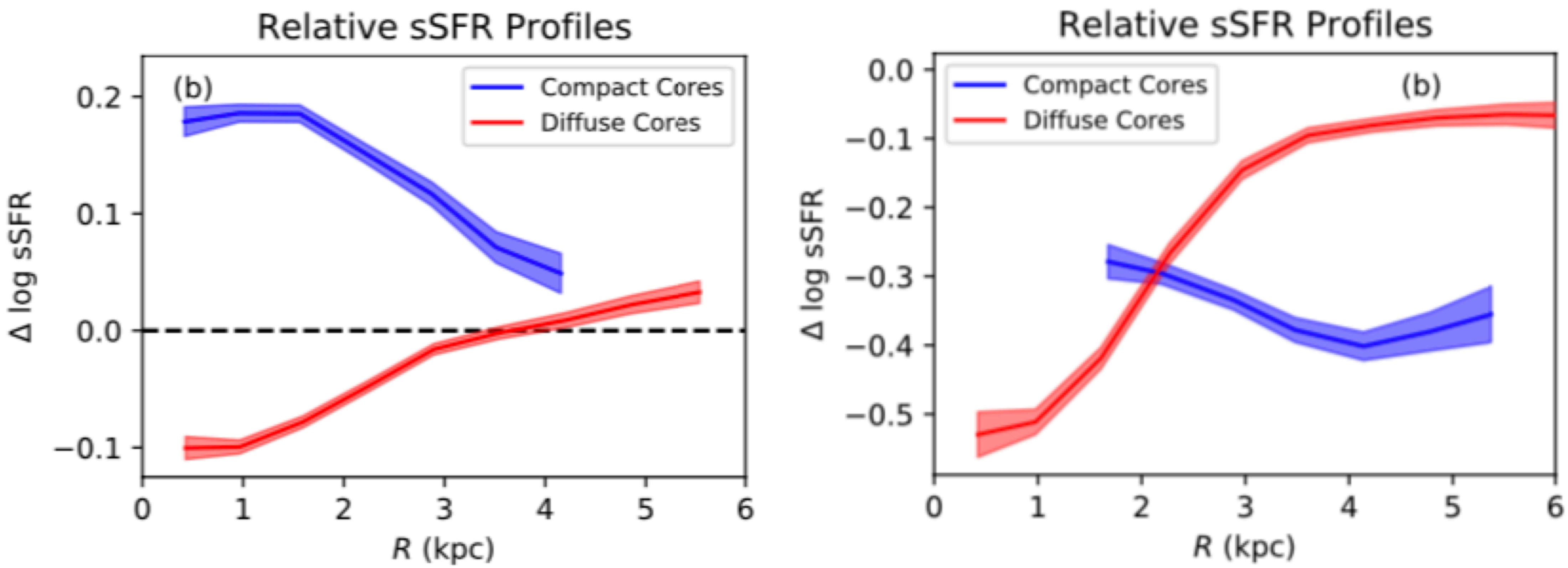


Figure 10. The $\Sigma_{*,1\mathrm{kpc}}$-M_* diagram colour-coded with the WISE-detected AGN fraction for SF galaxies. WISE detections are matched to SDSS DR7 objects if the angular separation is less than 6". The AGN fraction is then computed from the fraction of WISE detections with $W1$-$W2$ colour greater than 0.77, which is the 75% completeness criterion of Assef et al. (2018). The black dashed line indicates our division between "compact" and "diffuse" cores. The WISE-detected AGN fraction peaks in the upper region of the $\Sigma_{*,1\mathrm{kpc}}$-M_* diagram (galaxies with compact cores), where the profiles of stellar age, sSFR and gas metallicity are characteristic of compaction-like events.

- the WISE-selected AGN fraction for SF galaxies **peaks** in the upper regions
- Possible connection between AGN and compaction-like evolution
- Compaction-like events leading to the triggering of AGN

Secular Disk-Growing Mode



- sSFR is suppressed most strongly in the centres.

- With previous study: quench gradually and longer-lived mode than the compaction-like track.

Caveats/Limitation

- Assumption: local QGs from local SFGs.
  - Local QGs evolutionary pathways will not in general be the same as galaxies evolve (local SFGs->local QGs) today.
- Age gradients, including their sign, are disturbingly inconsistent between fitting codes and different SSP templates.-> Choose relative values.

Summary

They studied the behaviour of the gradients and average profiles of stellar age, sSFR and O/H as a function of total mass M_* and the stellar surface density within 1 kpc.

(1) The gradients of stellar age, sSFR and O/H for SFGs depend on position in the $\Sigma_{*,1\mathrm{kpc}}$-M_* diagram. Galaxies with “diffuse” cores have centres that are **old, depressed in sSFR and enriched in metals**, while galaxies with “compact” cores have **centres that are young, elevated in sSFR and metal-deficient**. This is consistent with an evolutionary picture that includes both **“inside-out” secular disk growth** and **dissipative “compaction”-like core-building processes**.

(2) **Both** the inside-out growth and compaction-like growing modes **contribute** to the quiescent population, and the morphology-quiescence relation results from at least both these modes.

(3) Galaxies that quench after the compaction-like track **quench uniformly,** while galaxies that quench after secular disk growth seem to **suppress the SFR with a strong radial dependence**, suggesting a more gradual outward moving quenching.

(4) Compaction-like events leading to the triggering of AGN