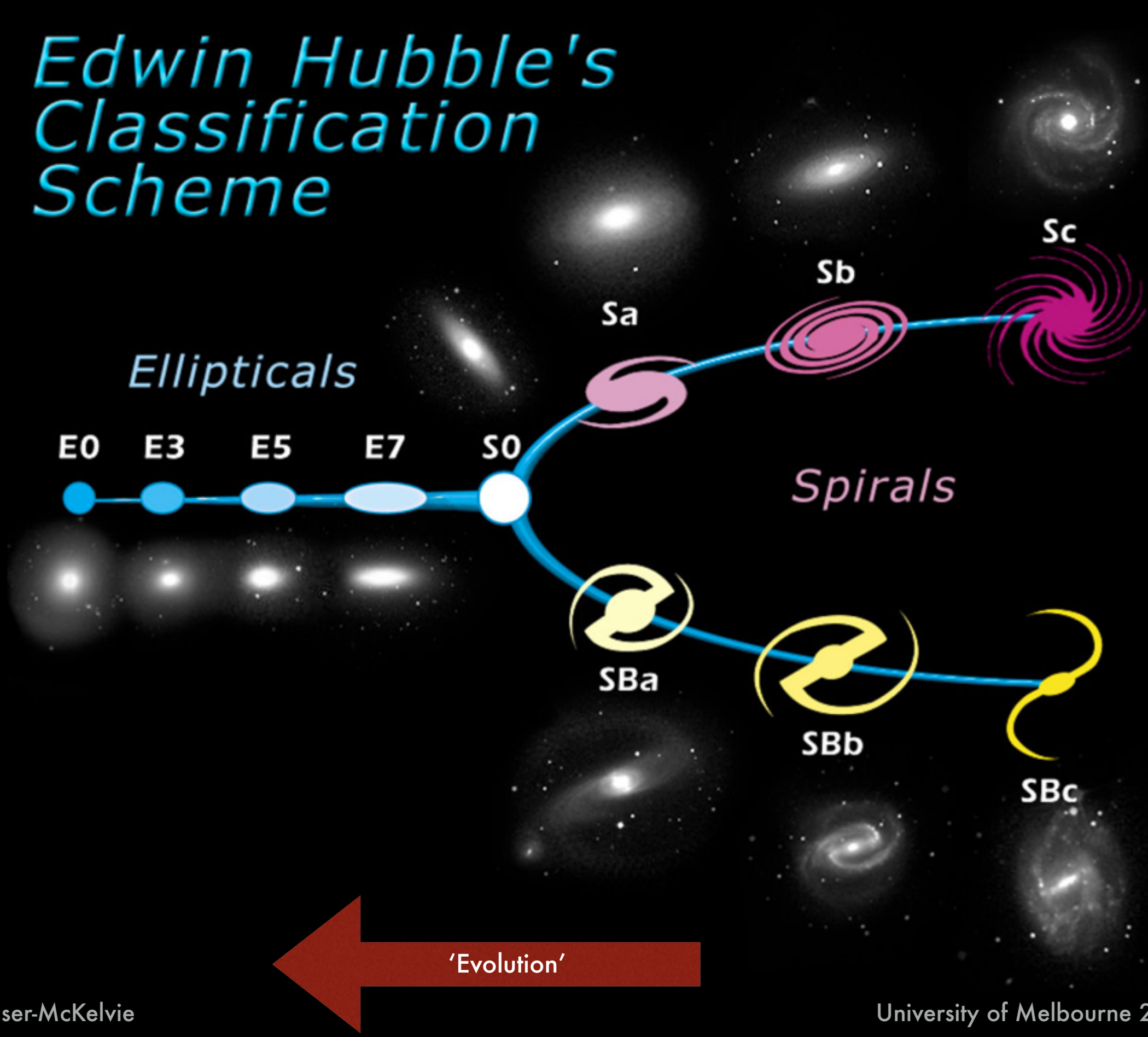
AMELIA FRASER-MCKELVIE

AND THE NOTTINGHAM MANGA TEAM: ALFONSO ARAGÓN-SALAMANCA, MIKE MERRIFIELD, MARTHA TABOR, TOM PETERKEN.

DISENTANGLING THE COMPLICATED LIVES OF DISK GALAXIES

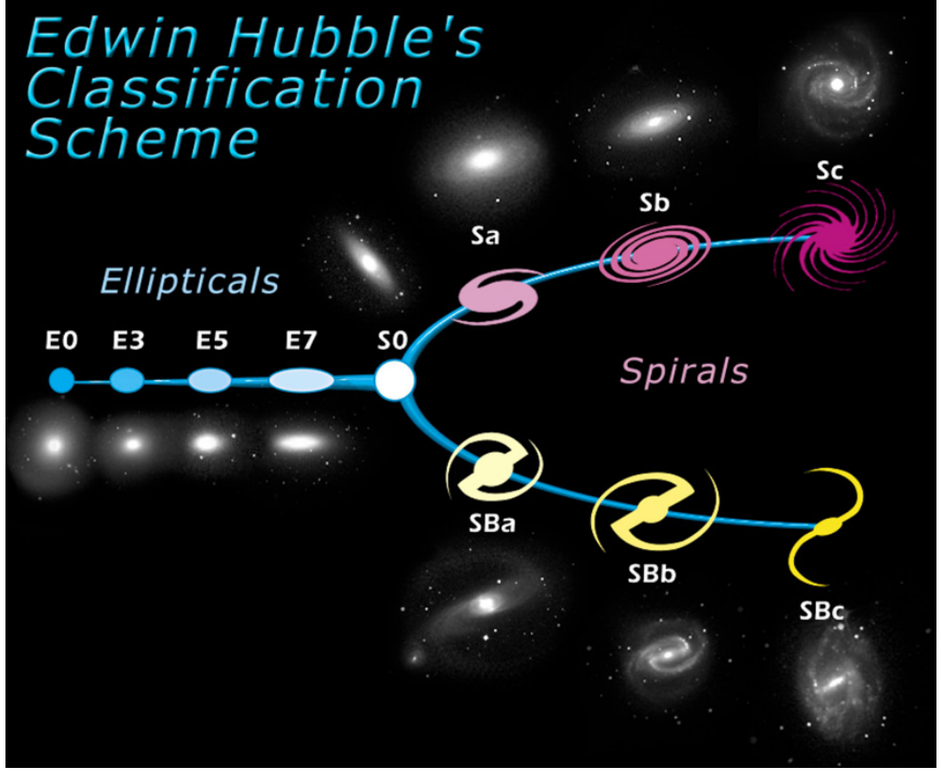
Image: Dane Kleiner

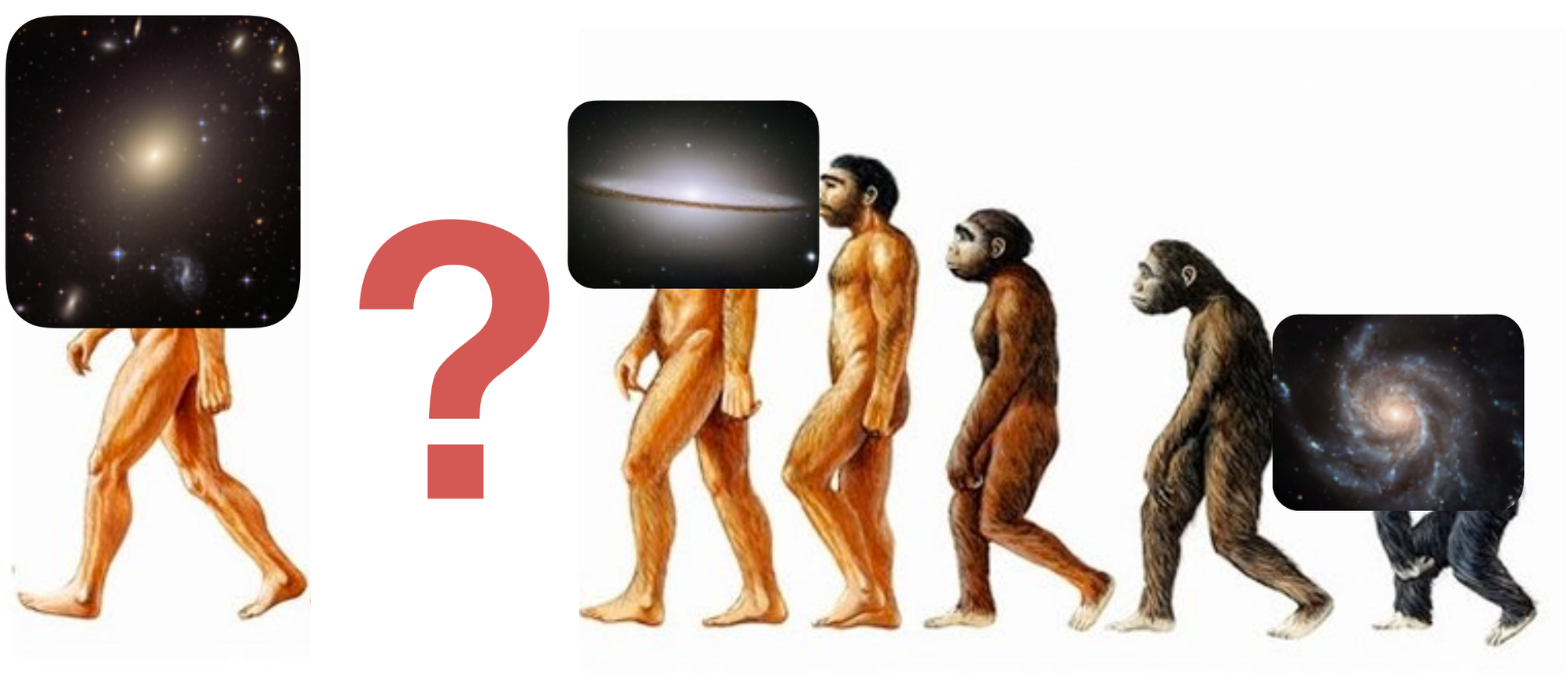
Edwin Hubble's Classification Scheme

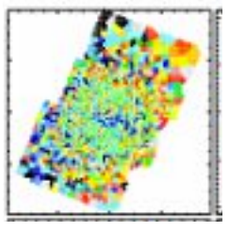


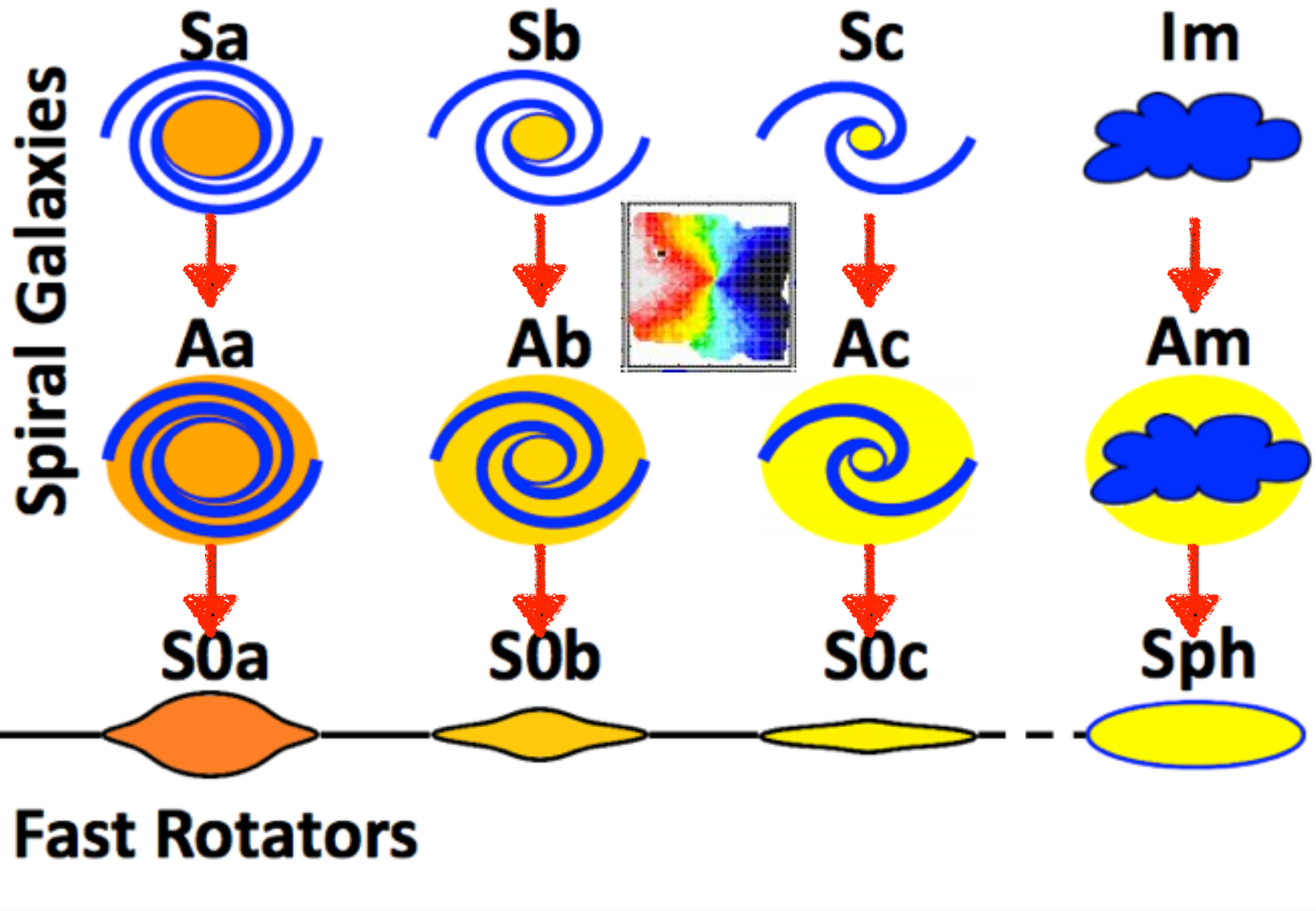
'Evolution'

Galaxy ‘Evolution’– are S0s the ‘missing link’?





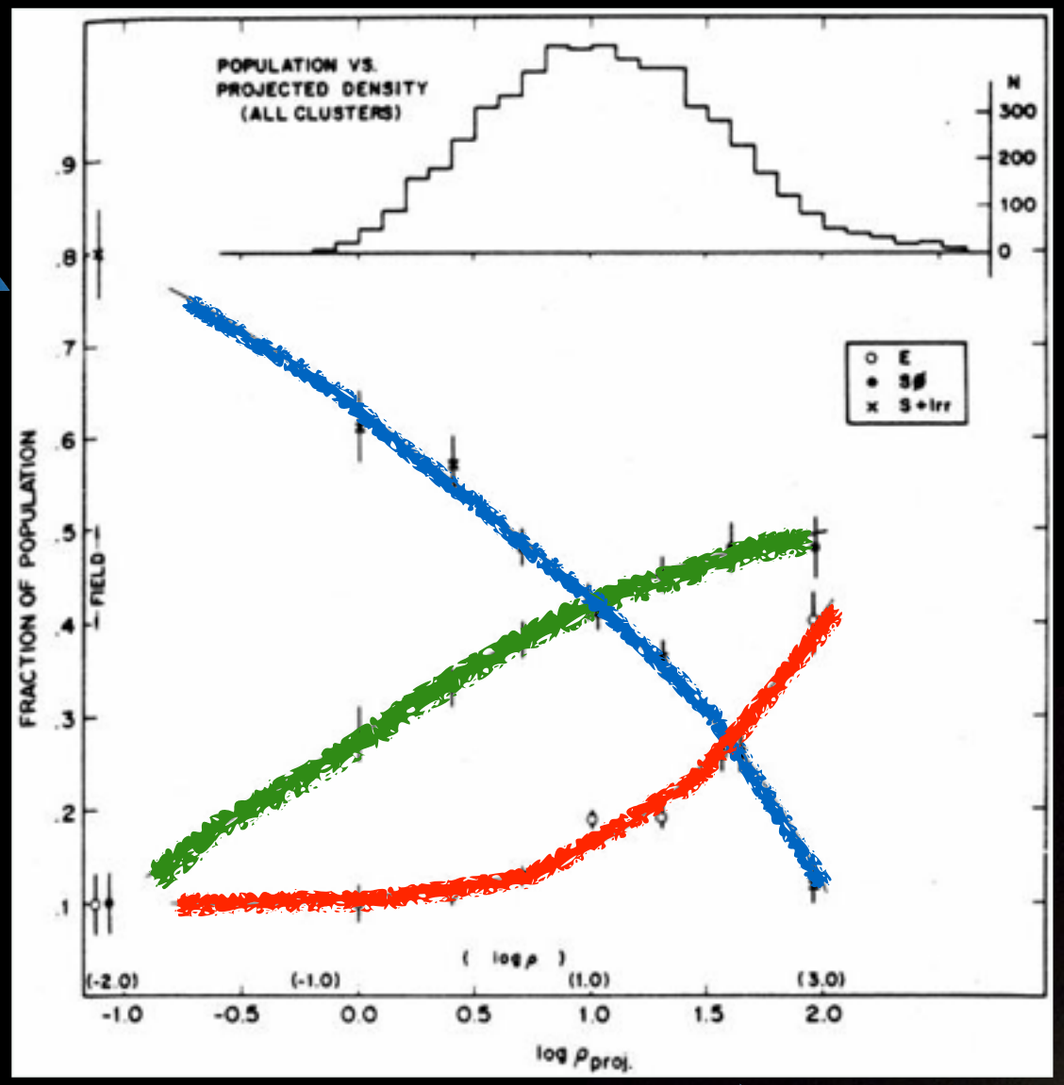




The ATLAS^{3D} 'comb'

van den Bergh 76, Emsellem+07, Cappellari+07, Cappellari+16

Lenticular Galaxies



Dressler 1980

Higher fraction of galaxies

Denser environment

-Galaxy with a bulge and a disk, but no spiral arms

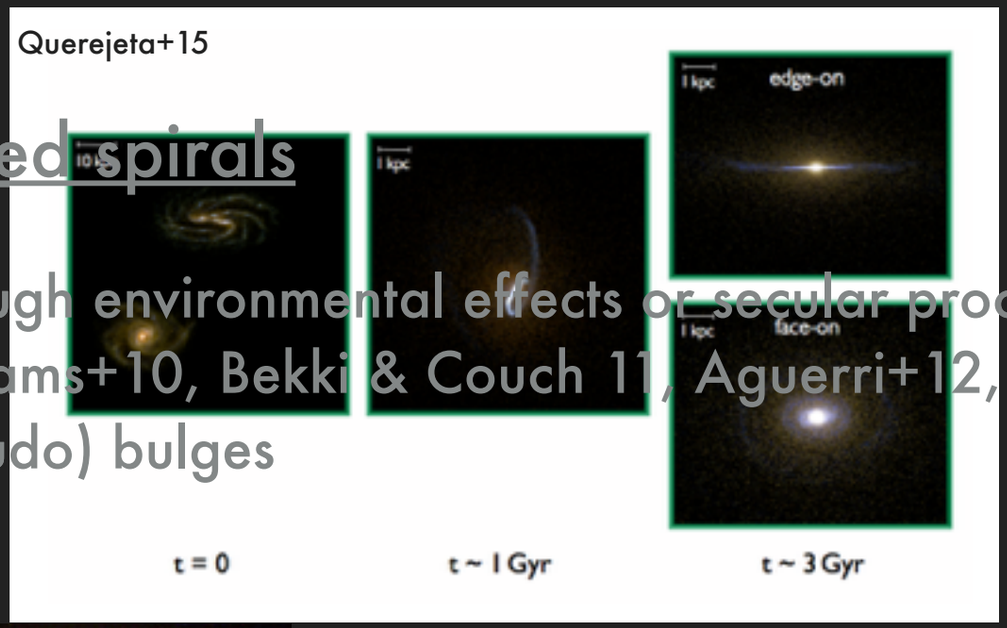
-Large mass range

-Can host pseudo or classical bulges

-Can host star formation

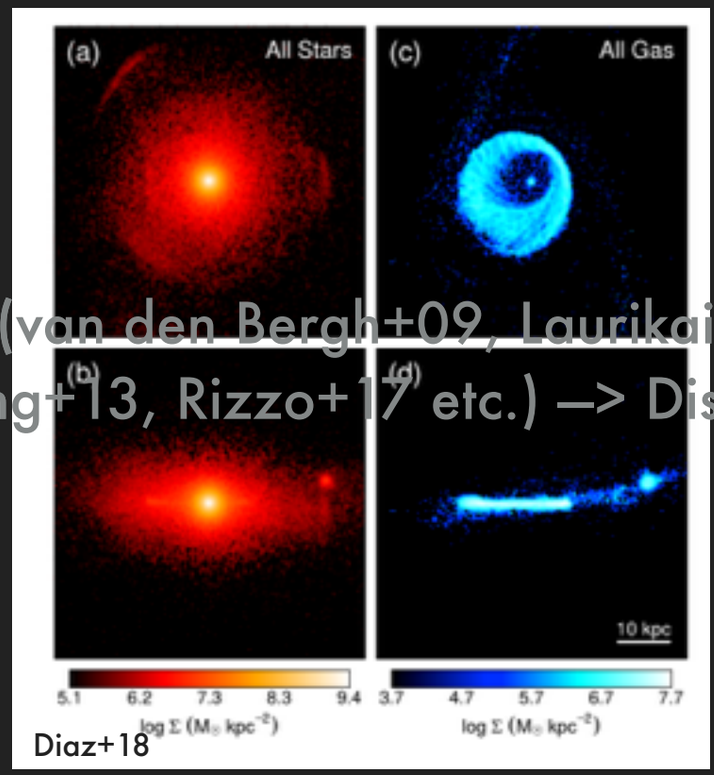
–More prevalent in clusters

FORMATION SCENARIOS FOR SO GALAXIES

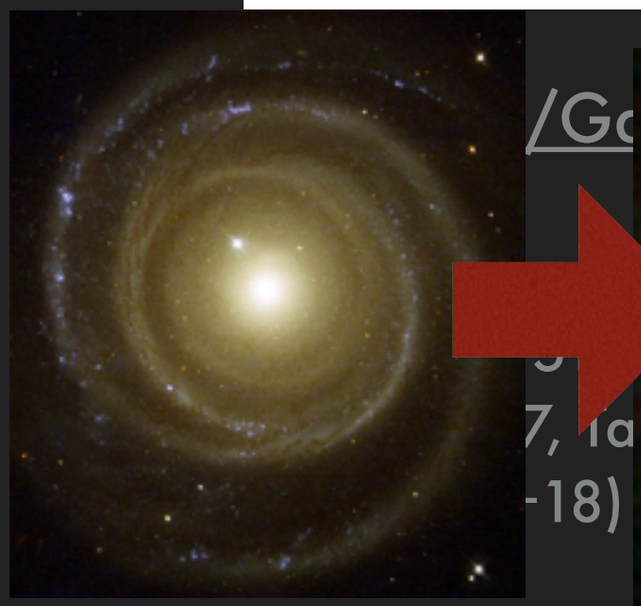


Faded spirals

Through environmental effects or secular processes (van den Bergh+09, Laurikainen+10, Williams+10, Bekki & Couch 11, Aguerri+12, Cheung+13, Rizzo+17 etc.) –> Disk-like (pseudo) bulges



Diaz+18



/Ga

7, Ia

-18)

WHERE DID I COME FROM??

When/Where/Why does each scenario dominate?

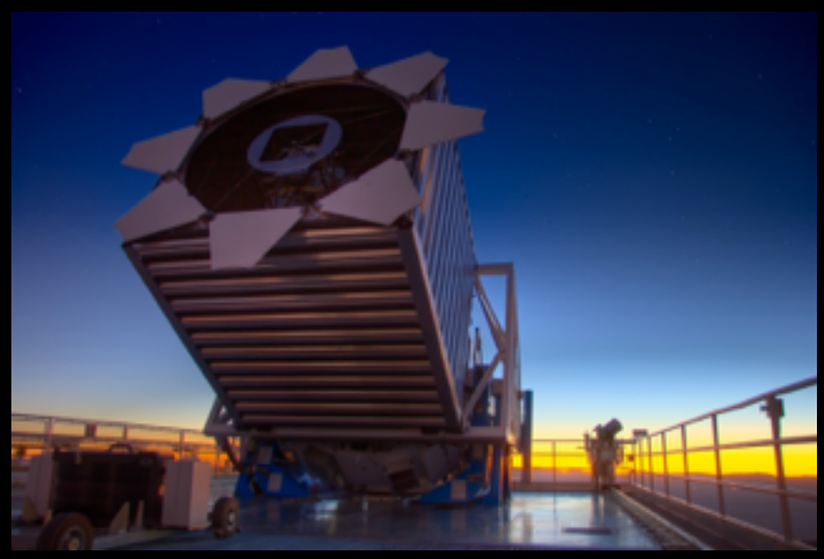
The MaNGA Galaxy Survey

Mapping Nearby Galaxies at APO (MaNGA)

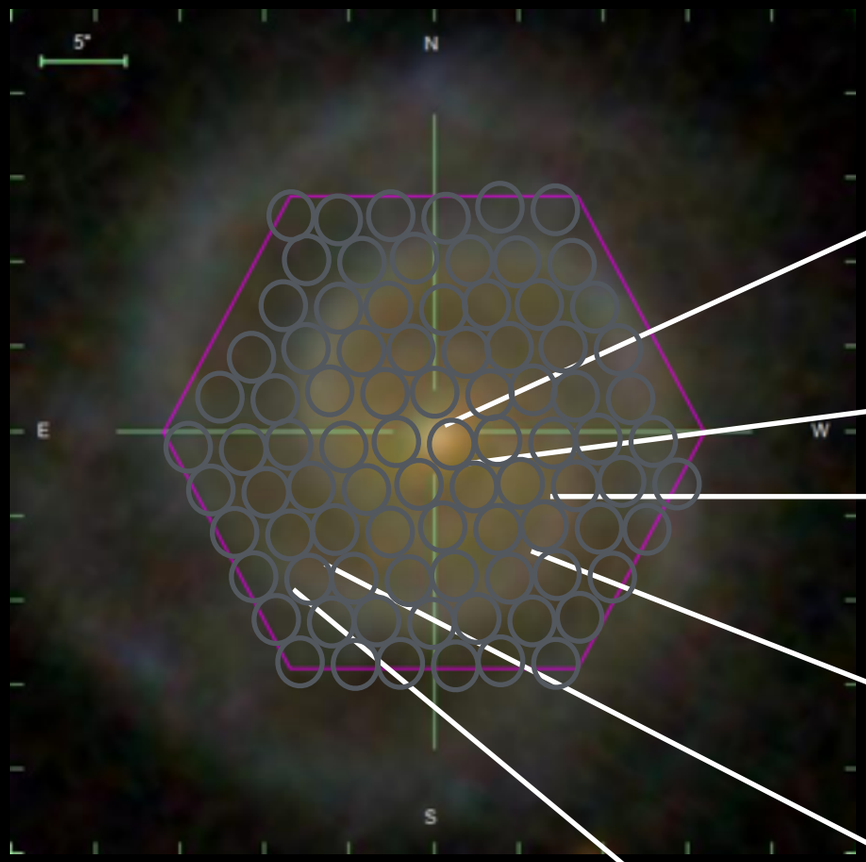
-IFS observations of 10,000 galaxies by 2020

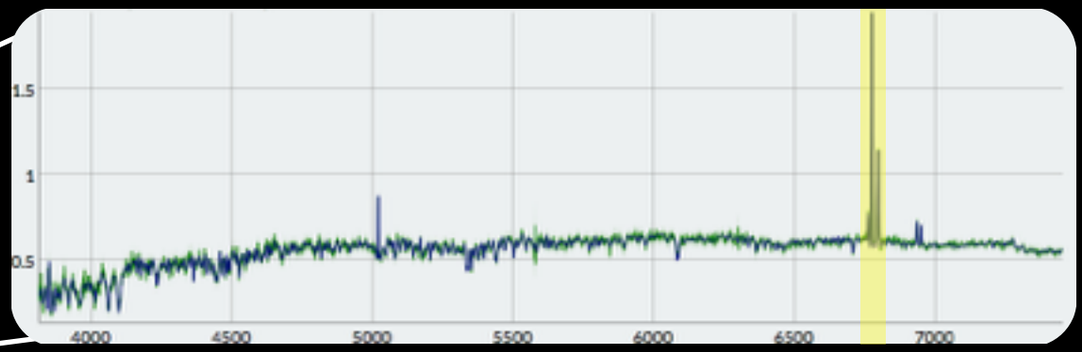
-~3000 galaxies already available as data cubes for public use

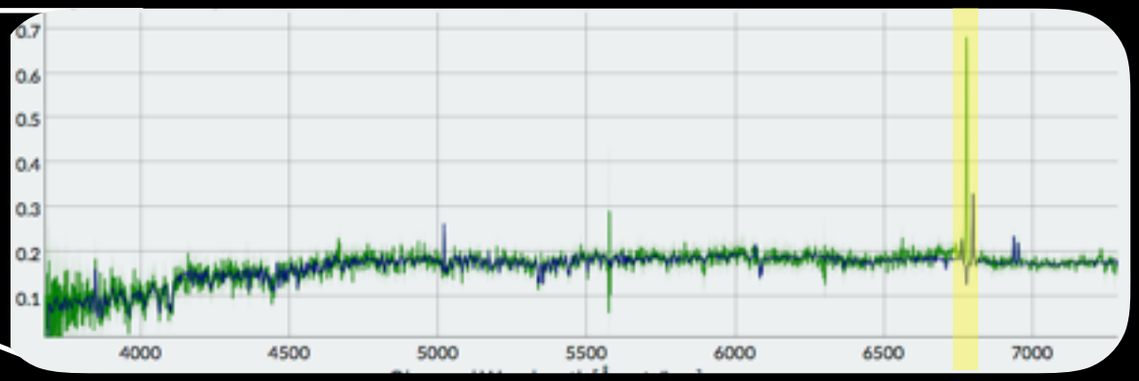
-Data products include emission and absorption line maps, kinematics, and various derived quantities



The MaNGA Galaxy Survey

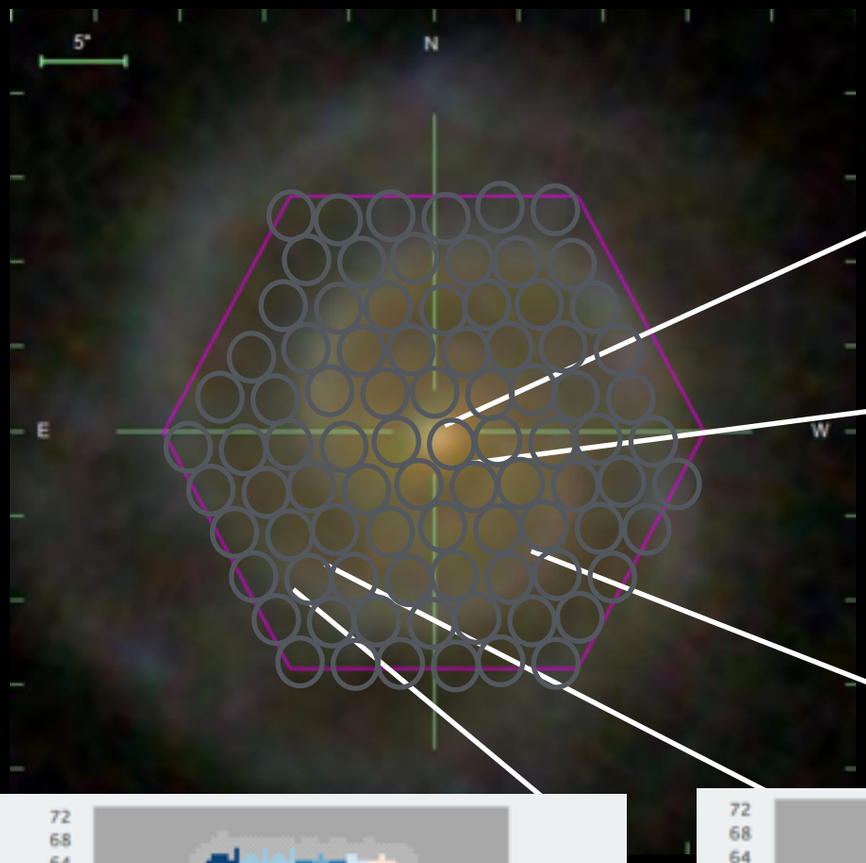


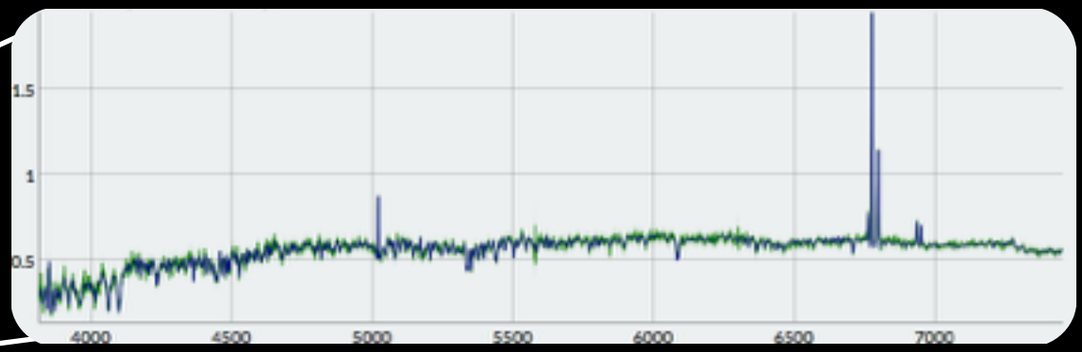


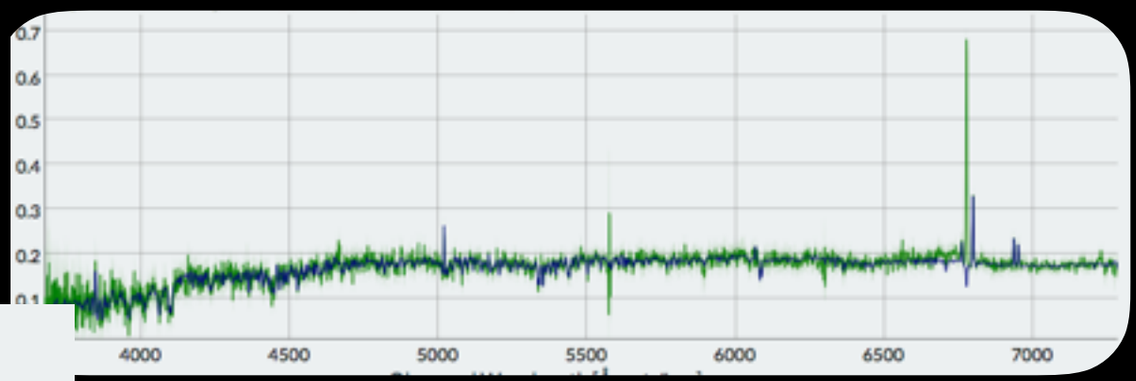


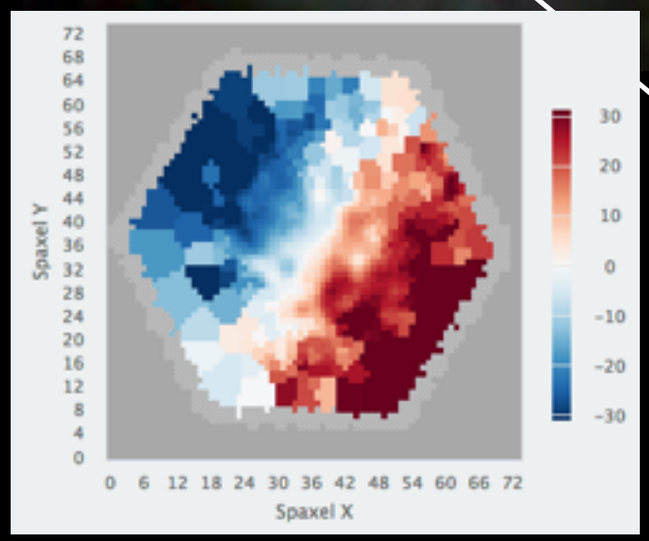
MCG+07-34-138

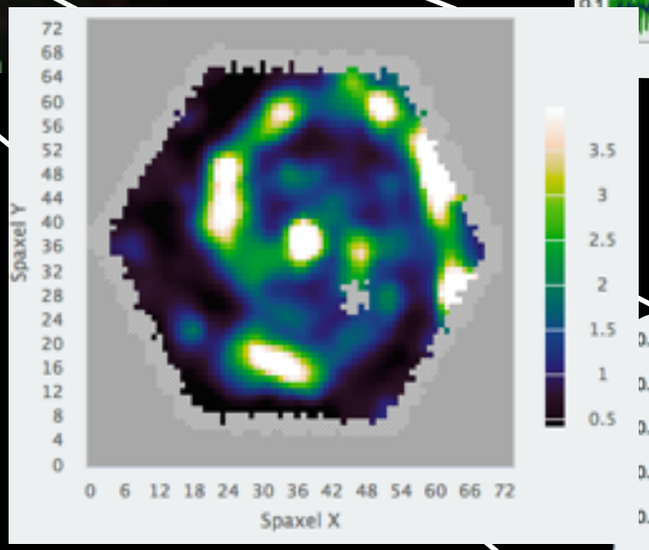
A Motivating Example: MCG+07-34-138

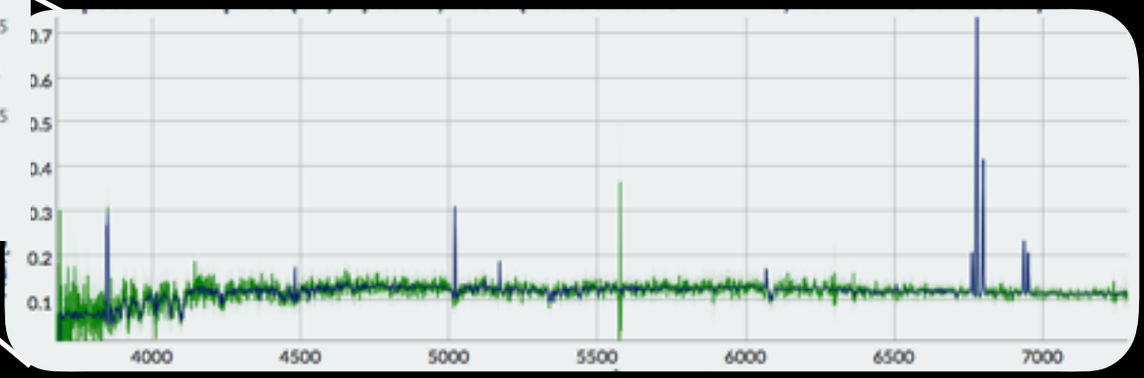




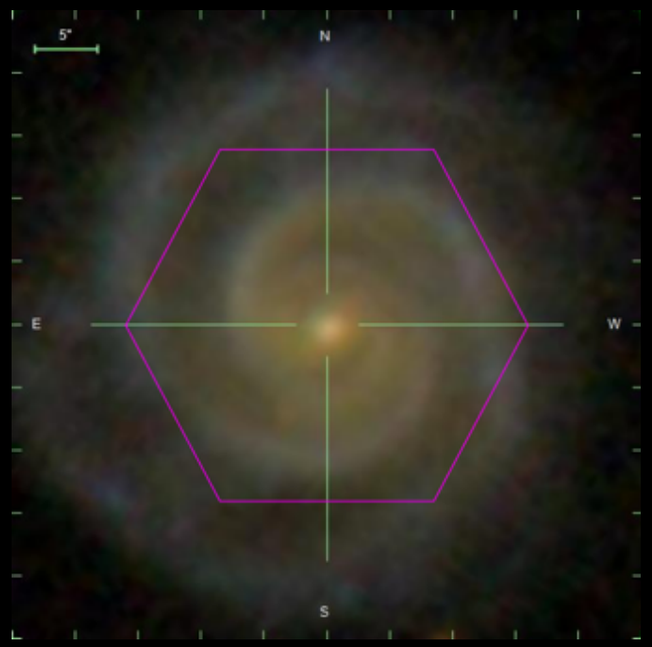


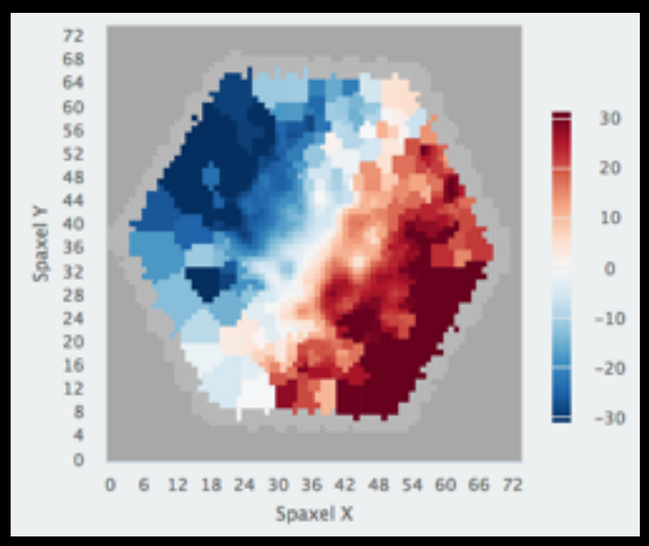


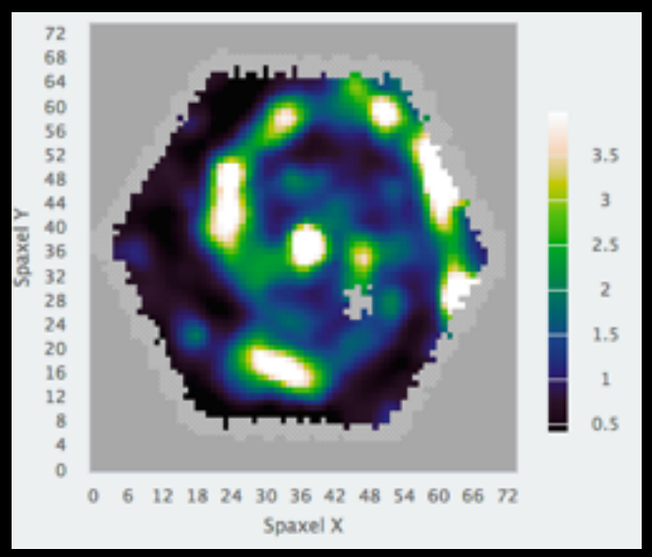


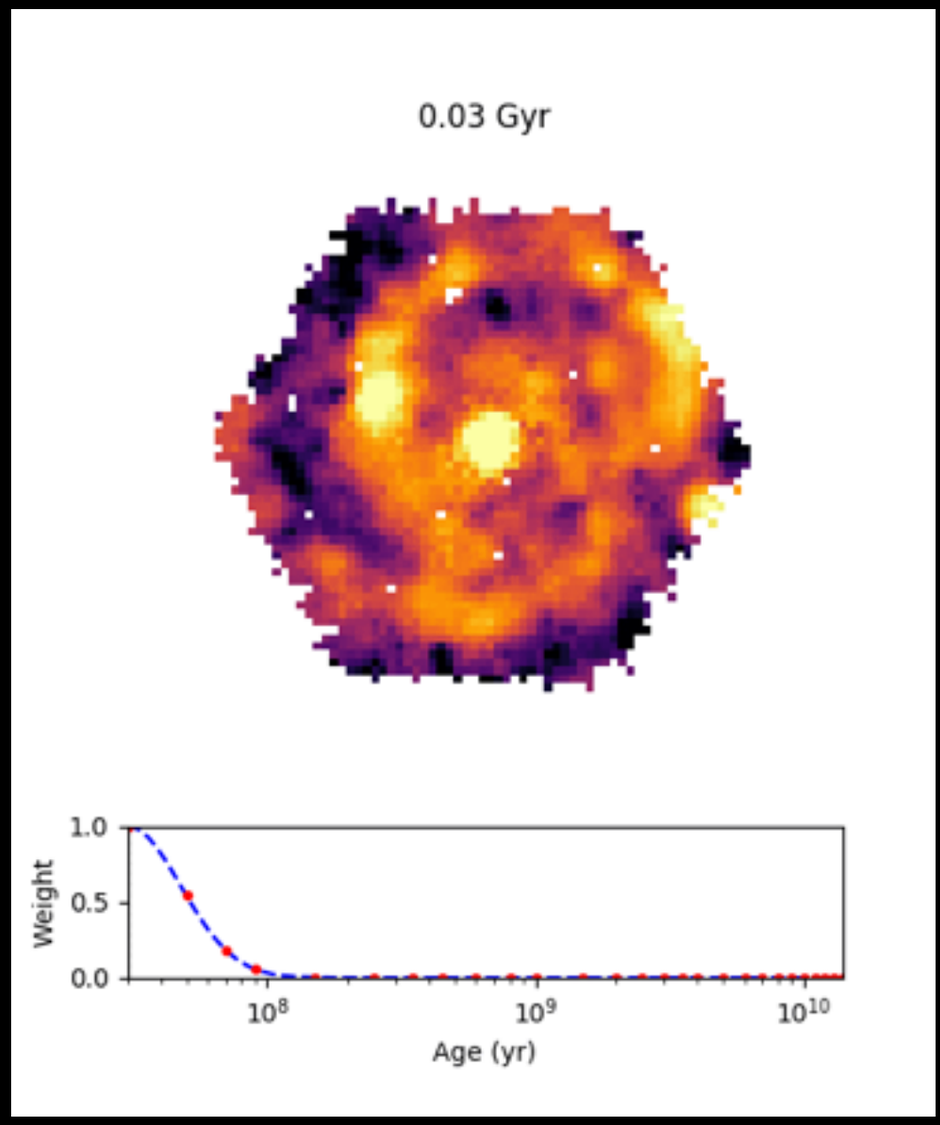


A Motivating Example: MCG+07-34-138









gif: Tom Peterken

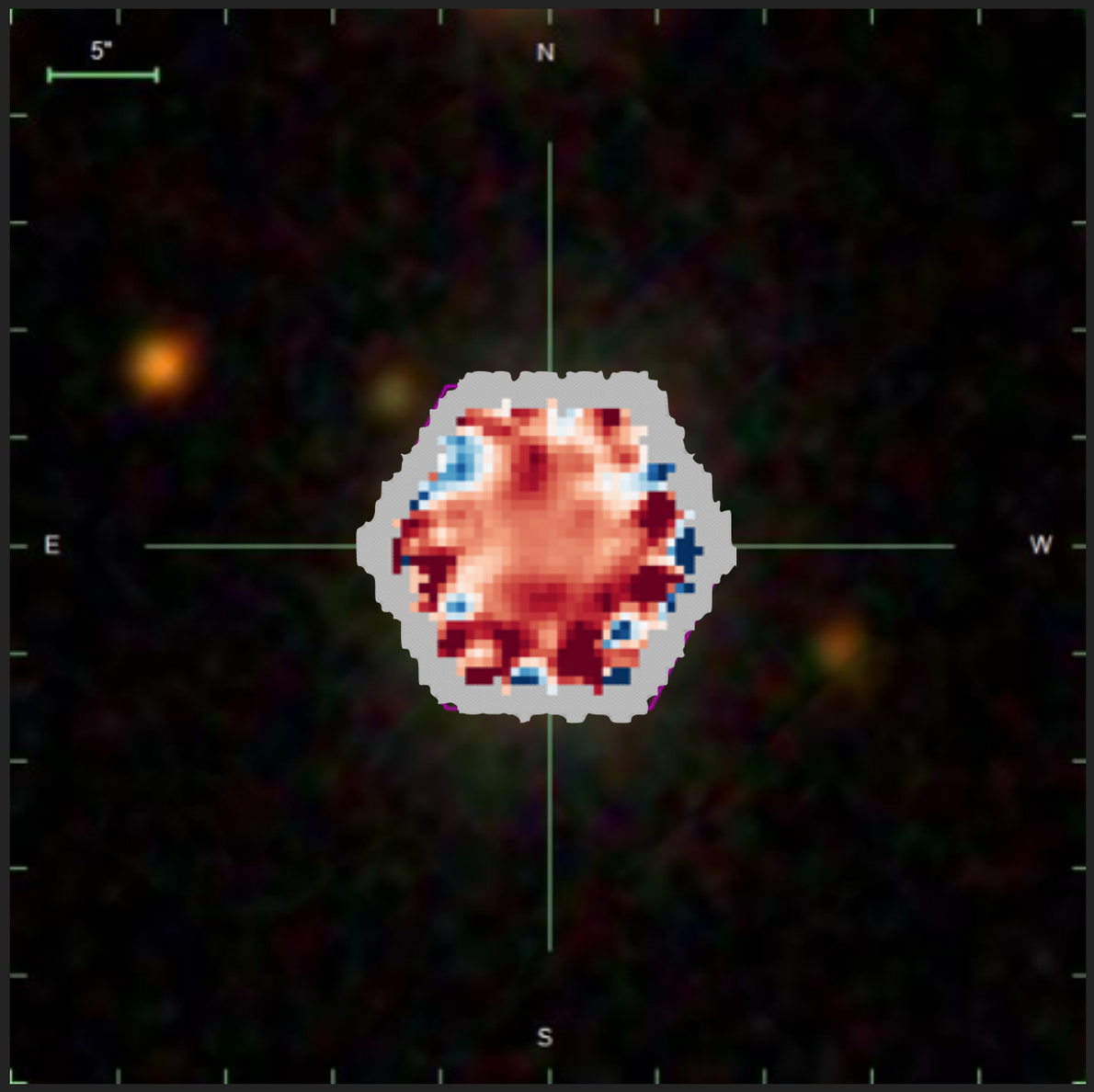
My Science Questions

1. How do S0 galaxies form/quench?

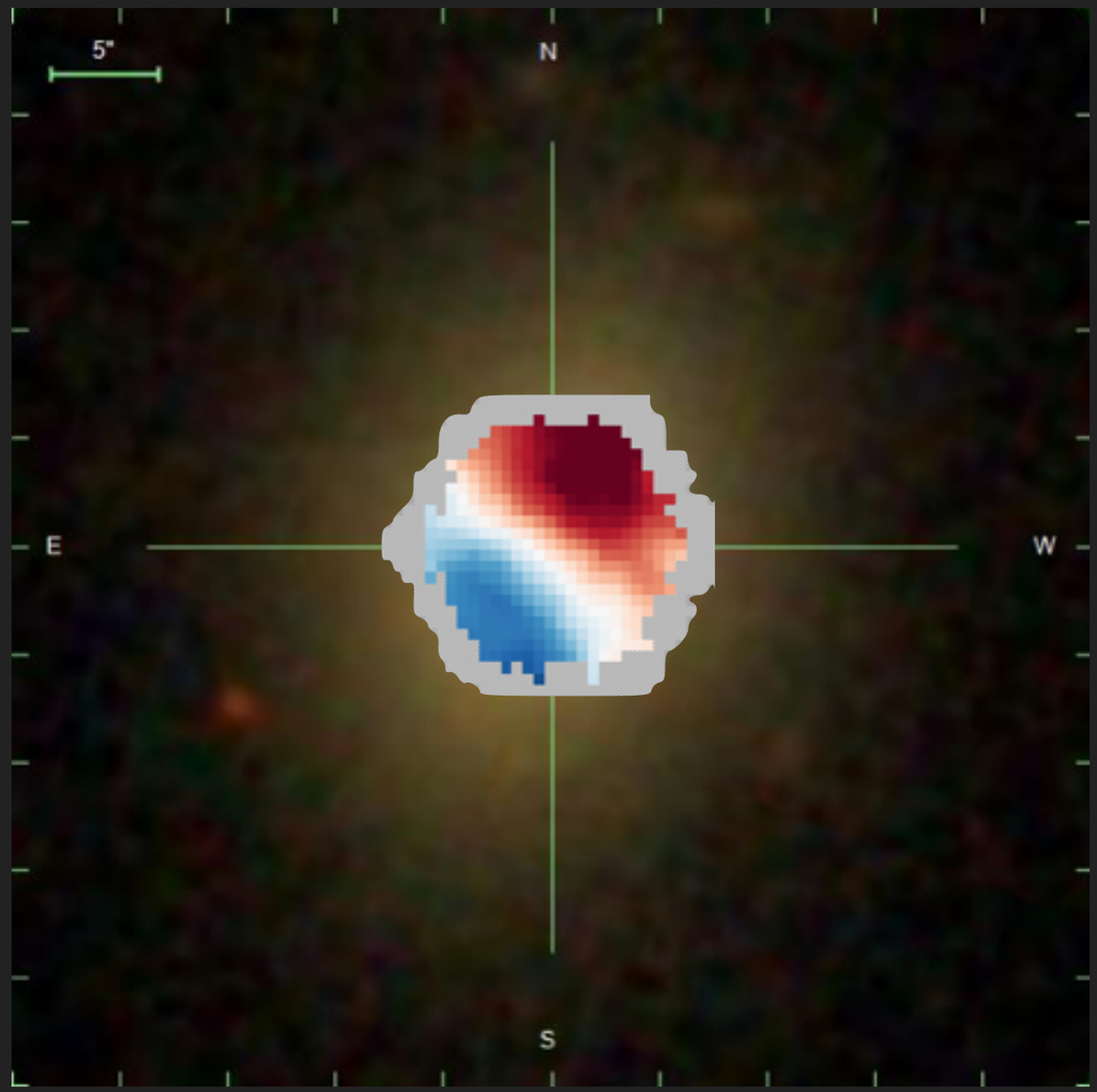
2. Are bulge and disk components in lenticulars linked?

NEED: SAMPLES OF LENTICULAR GALAXIES!

SO IDENTIFICATION

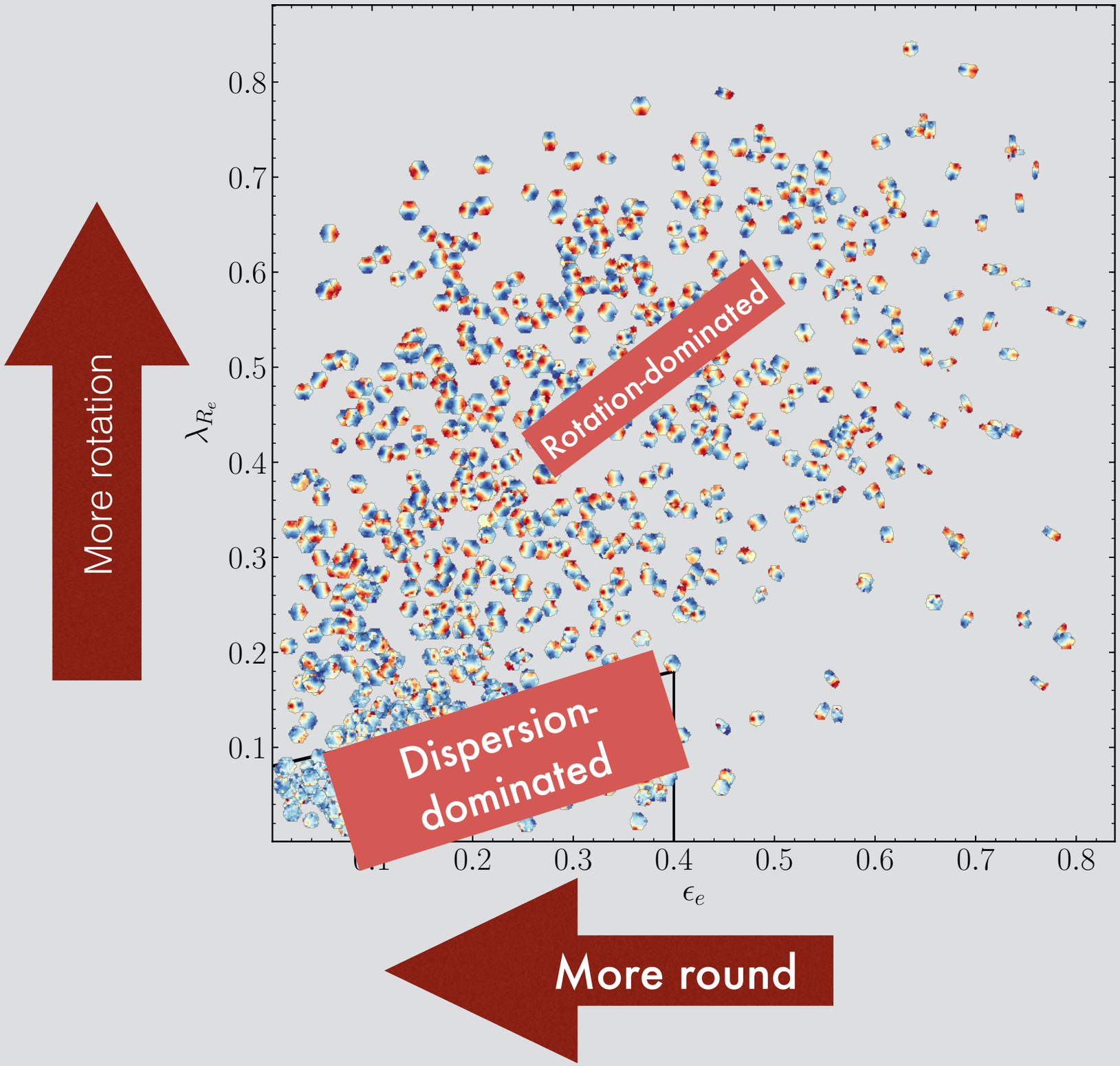


Galaxy A



Galaxy B

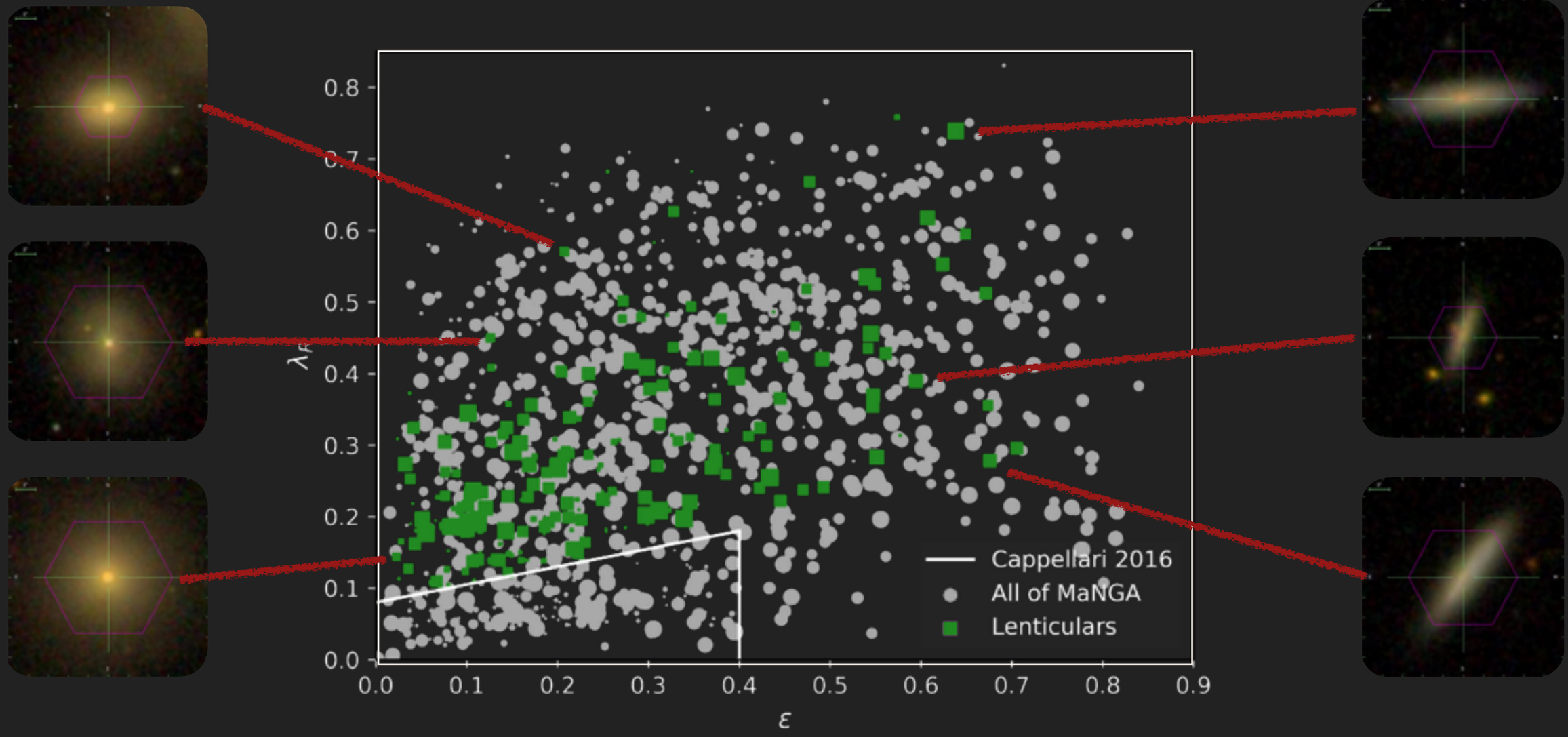
SO IDENTIFICATION



$$\lambda_{R_e} \approx \frac{k\,(V/\sigma)_e}{\sqrt{1+k^2(V/\sigma)_e^2}} \qquad \text{with} \qquad k = 1.1$$

Smethurst+18

SO IDENTIFICATION



-Galaxy Zoo2 classifications ‘Smooth’ weighted fraction of votes >0.7

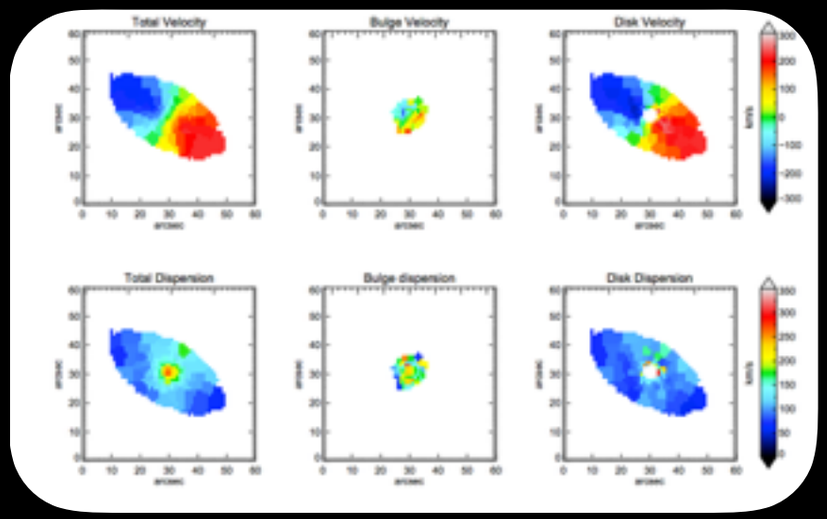
-Fast Rotator cut: $\lambda R > 0.04 + \varepsilon/4$ with $\varepsilon>0.4$

GALAXY ZOO

279 lenticulars satisfying these criteria in Primary+ sample

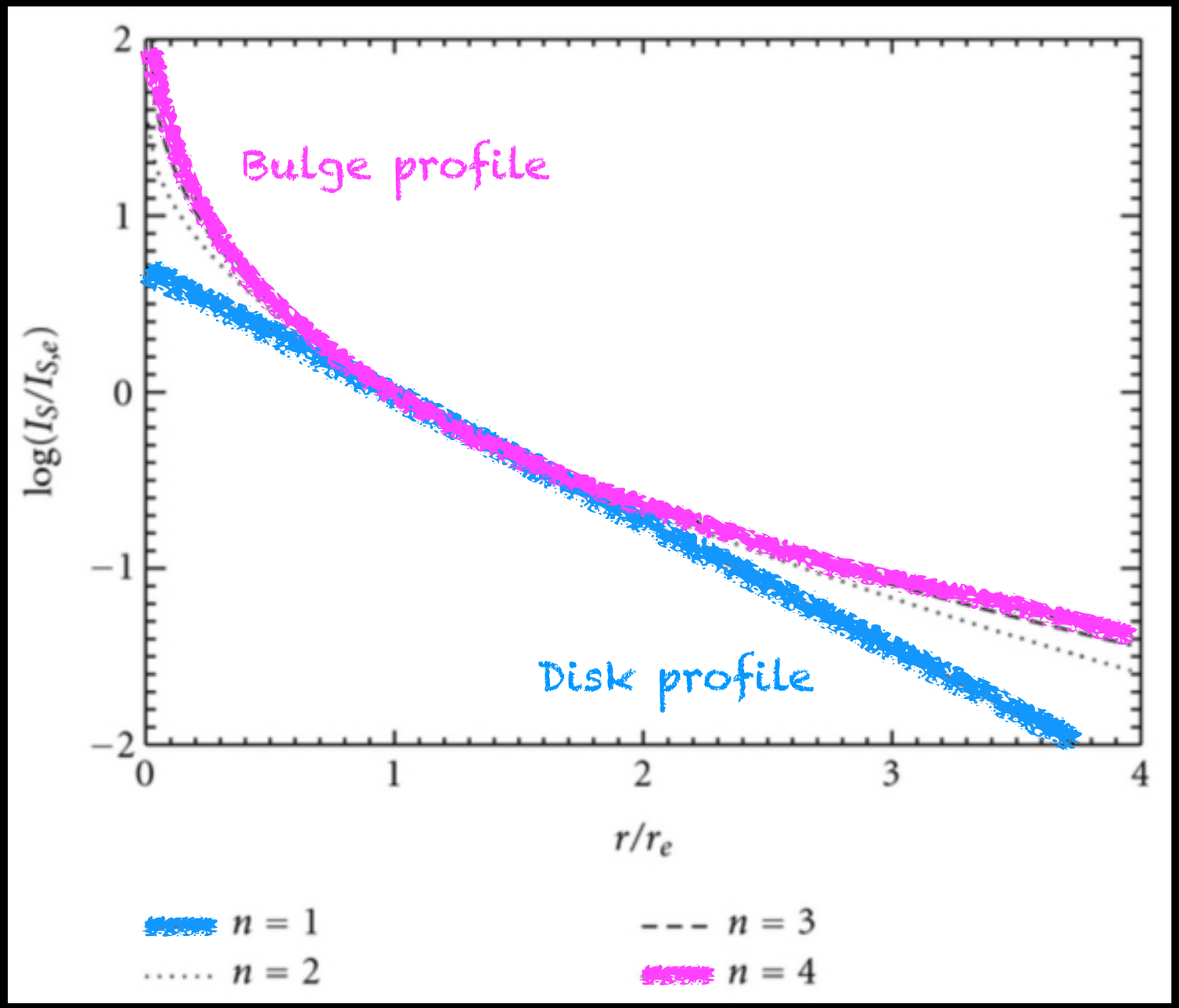
Separating Galaxies into their Components

NGC 528



Tabor et al., 2017

Photometric bulge–disk decompositions



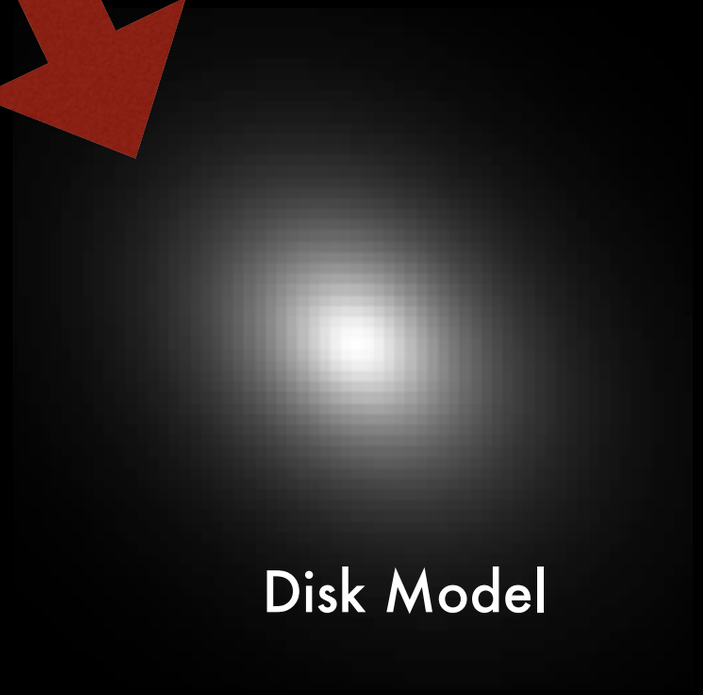
$$I_S(r) = I_{S,e} e^{-b_n((r/r_e)^{1/n}-1)}$$

Sérsic radial profiles

Photometric bulge–disk decompositions

Original galaxy white light image

Bulge Model



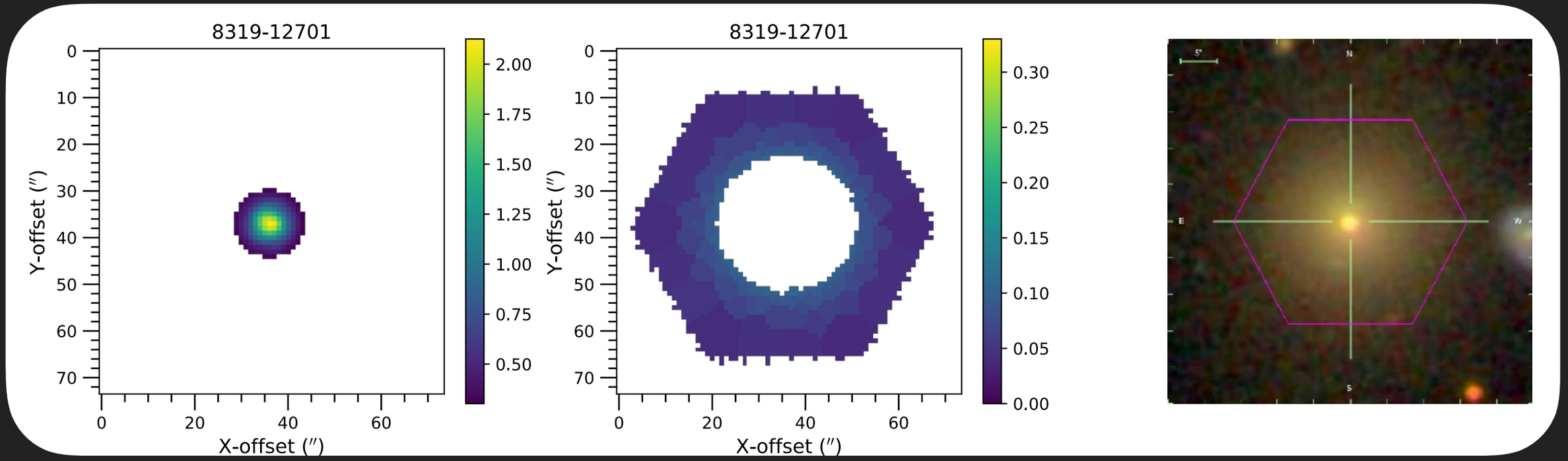
Disk Model

BULGE AND DISK MEASUREMENT

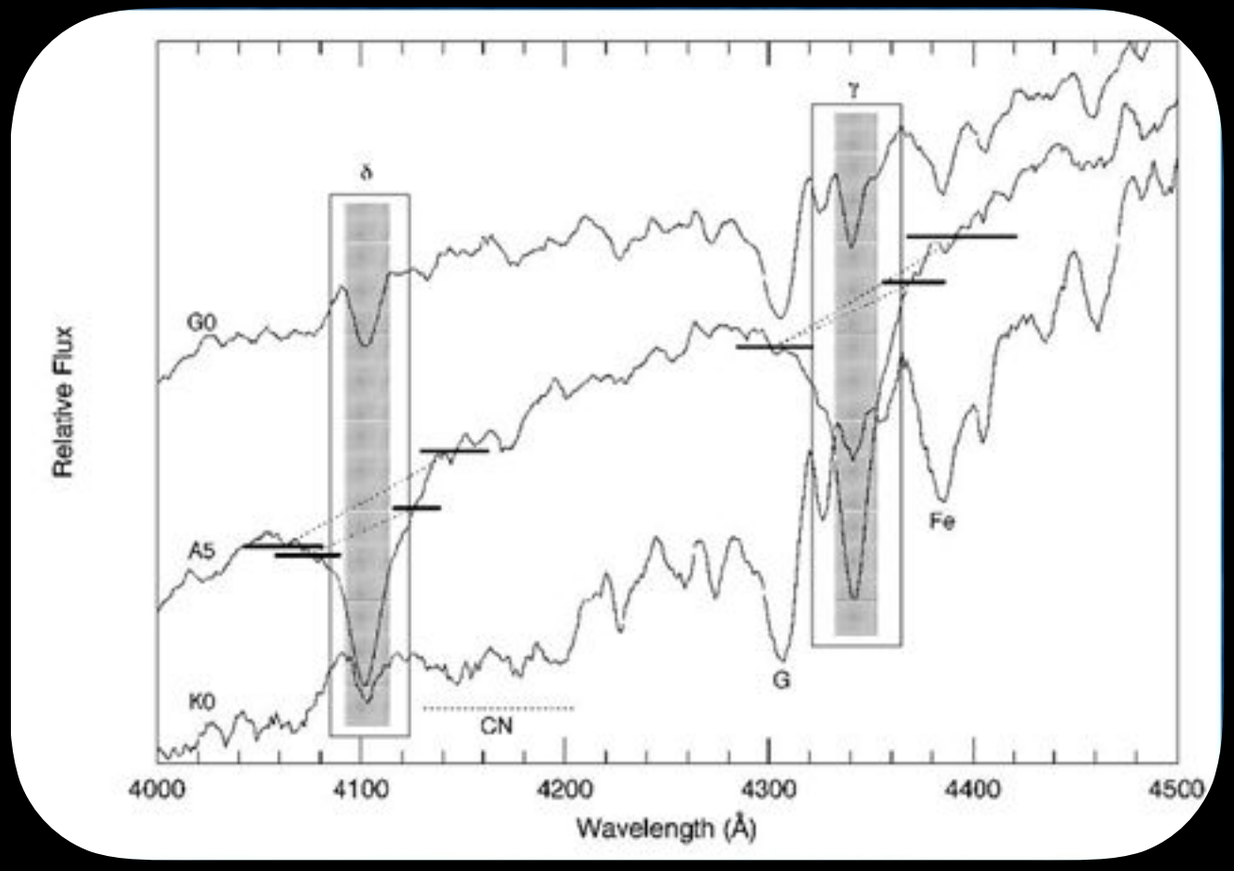
-Simard+11 catalogue of SDSS bulge and disk measurements

-Firefly Hβ, Mgb, Fe5270Å and Fe5335Å Lick indices measured

-Flux measured for each Voronoi bin and a light-weighted average taken for each spectral index for the bulge and disk regions



Stellar populations from line index measurements



-Hβ = Stellar ages

-Mgb, Fe5270, Fe5335 = Stellar metallicities

Worthey et al., 1994

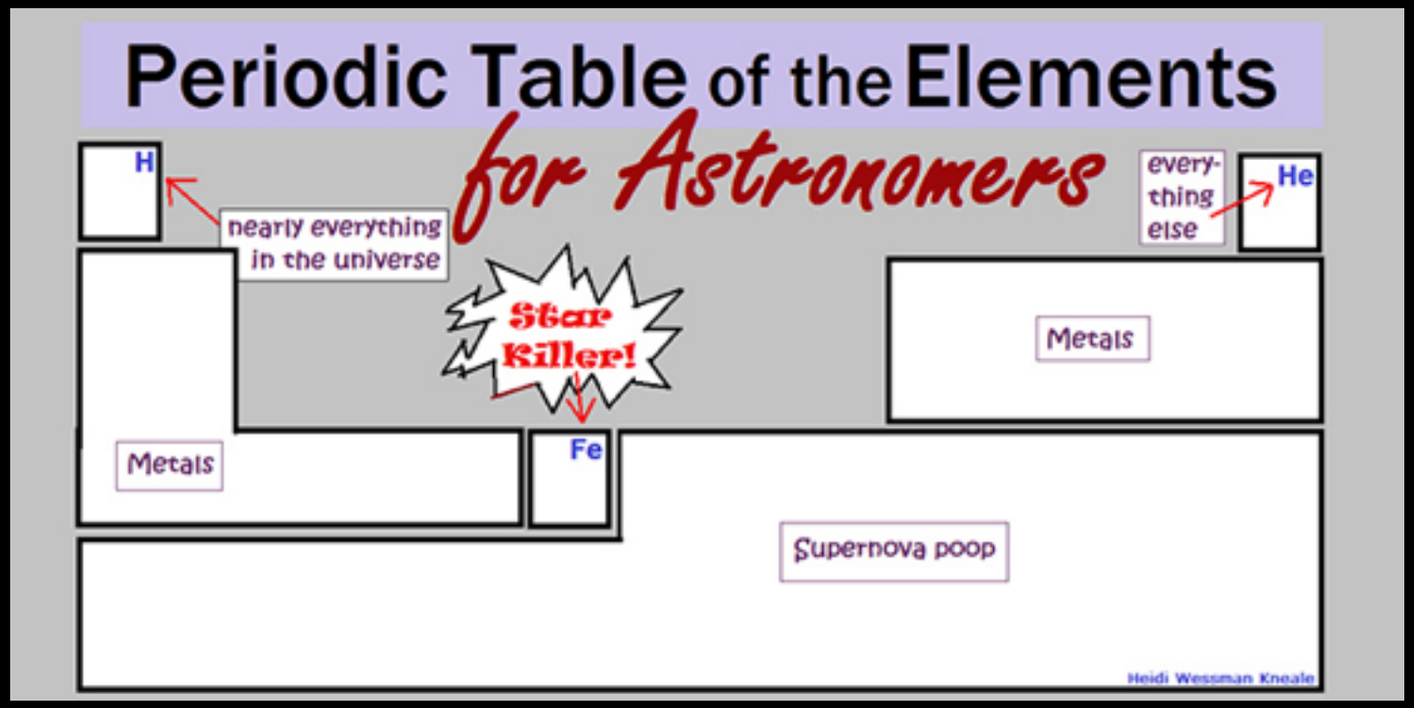
Stellar metallicities

Stellar Metallicity

-Galaxies build up their metallicity via stellar enrichment.

-The more 'evolved' a galaxy is, the more generations of stars have lived.

-Metallicity correlates with galaxy luminosity, mass, and colour.



$$[Z/H] = \frac{H+He}{Everything\ else}$$

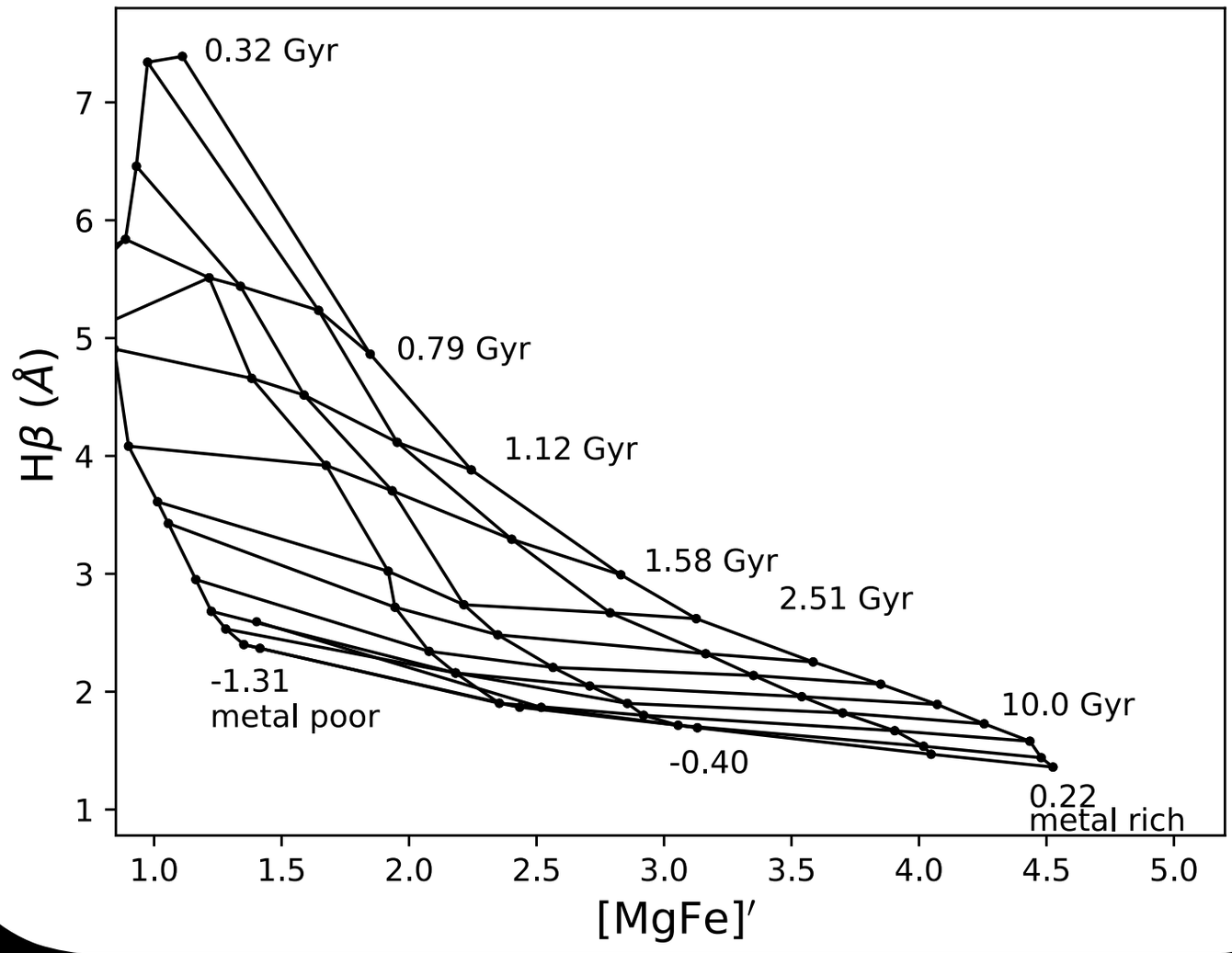
$$[Z/H]_{\odot} = 0$$

$$[Z/H] > 0 = metal\text{-}rich$$

$$[Z/H] < 0 = metal\text{-}poor$$

Stellar populations from line index measurements

Older



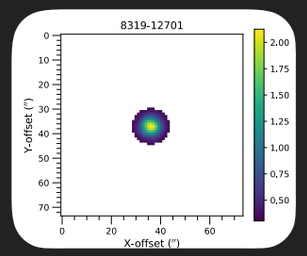
Model lines: Vazdekis+10

$$[\mathrm{MgFe}]' = \sqrt{\mathrm{Mg}b\ (0.72 \times \mathrm{Fe5270} + 0.28 \times \mathrm{Fe5335})},$$

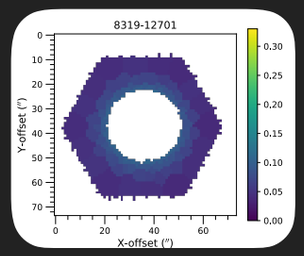
More metal rich

RESULTS: INDEX–INDEX DIAGRAMS

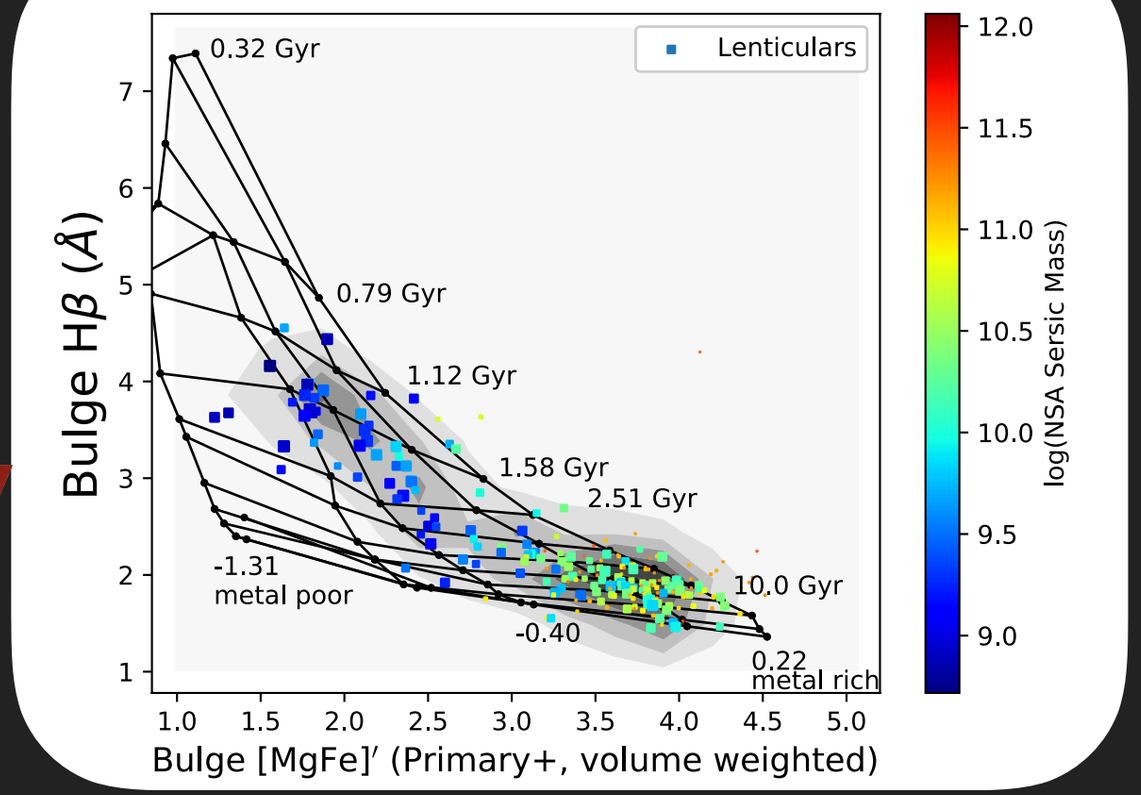
Bulge region

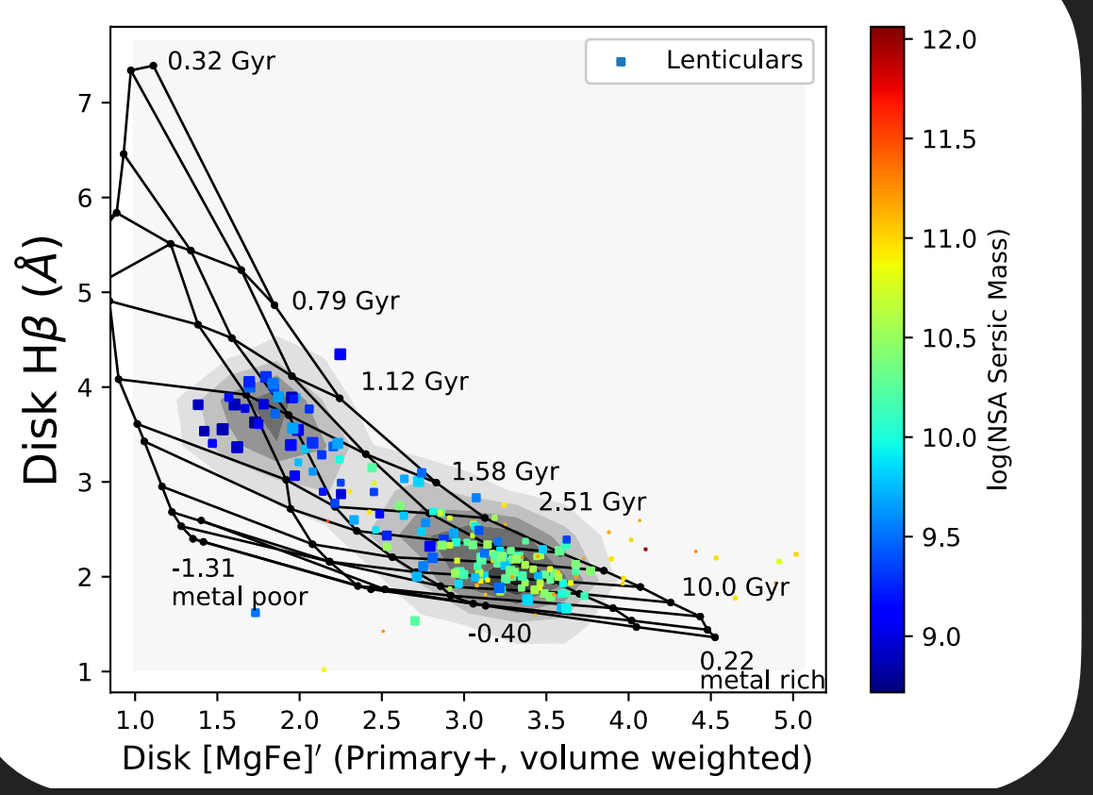


Disk region



Older



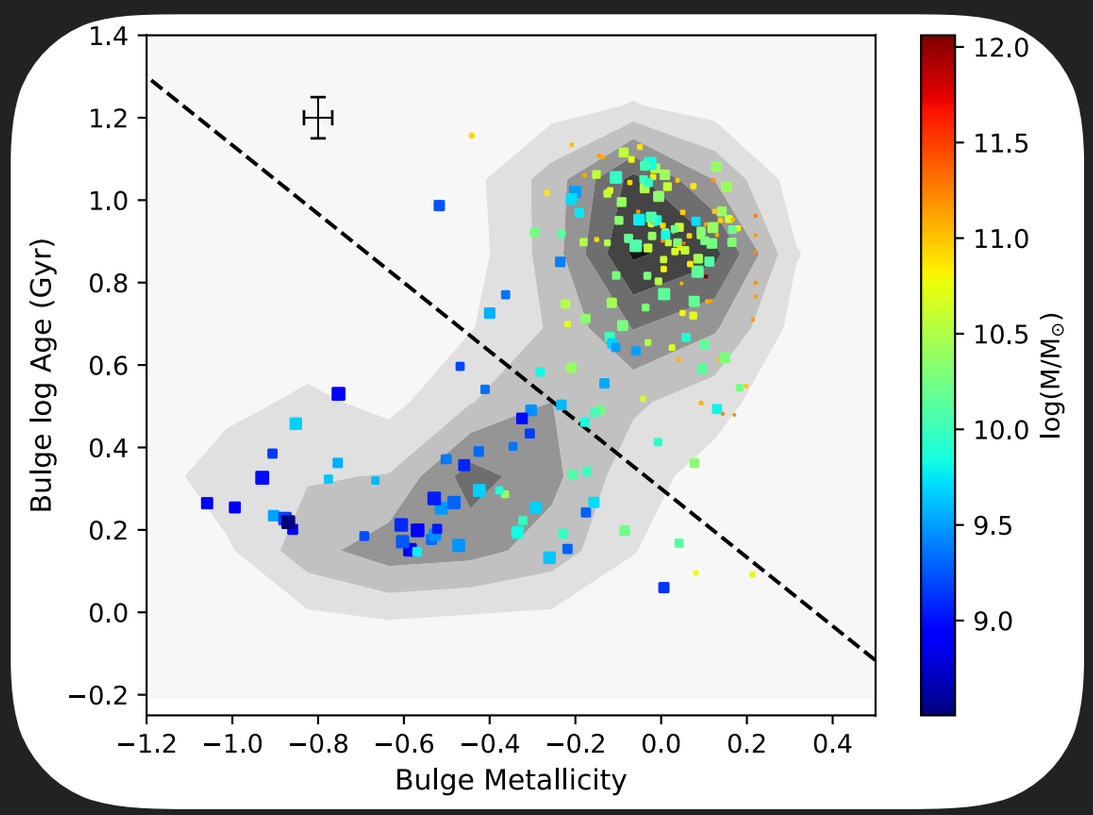


Fraser-McKelvie et al., 2018

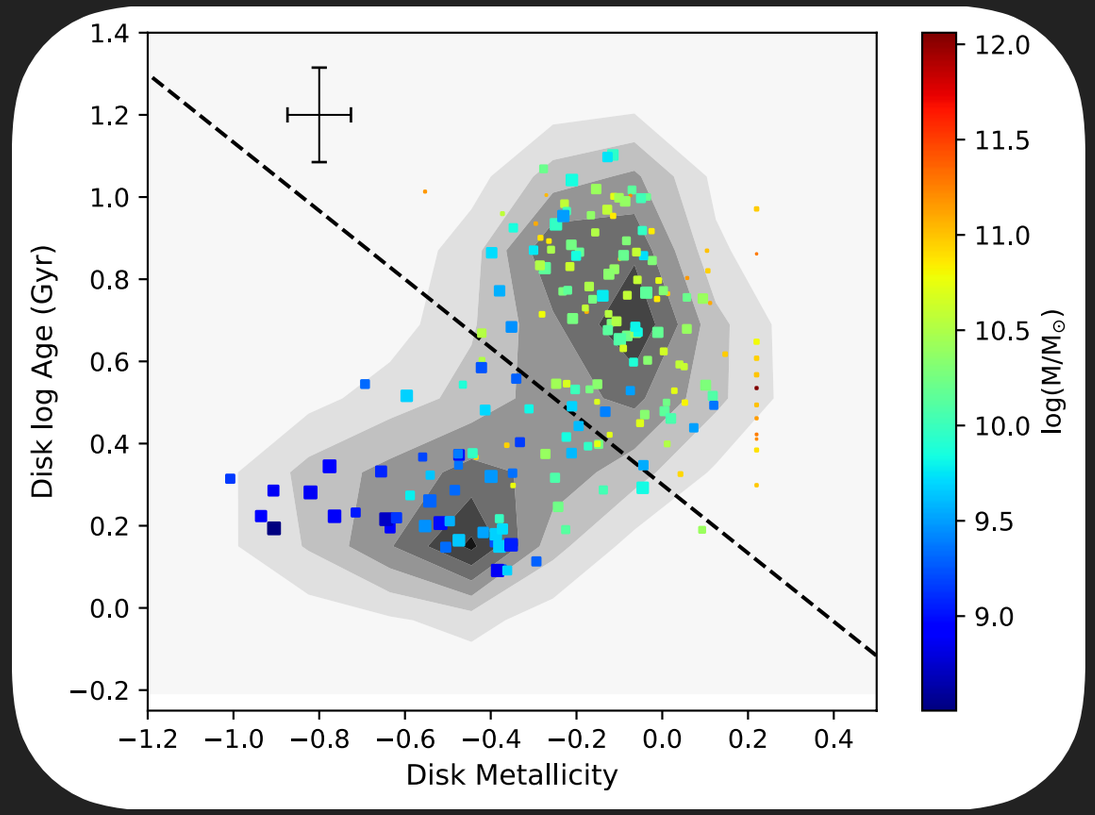
More metal rich

RESULTS: AGE/METALLICITY PLOTS

Model lines: Vazdekis+10



Bulge region



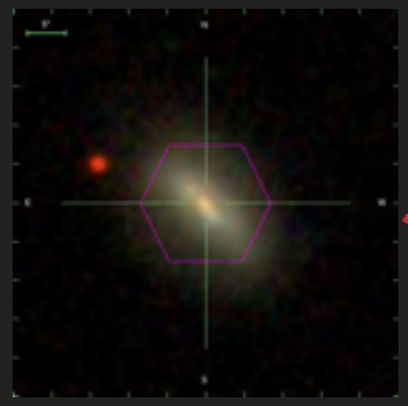
Disk region

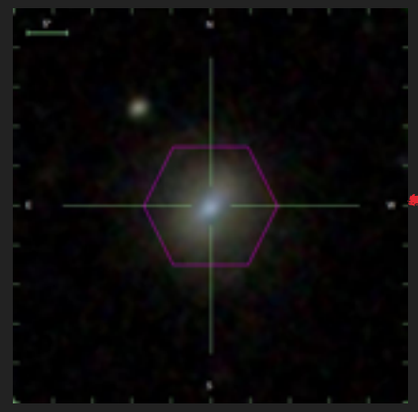
Low/high mass dichotomy in stellar population parameters = two separate populations?

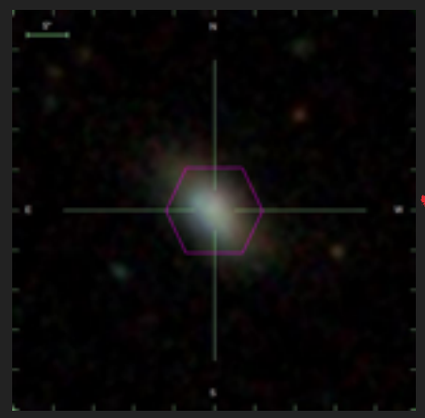
Bulge-disk co-evolution?

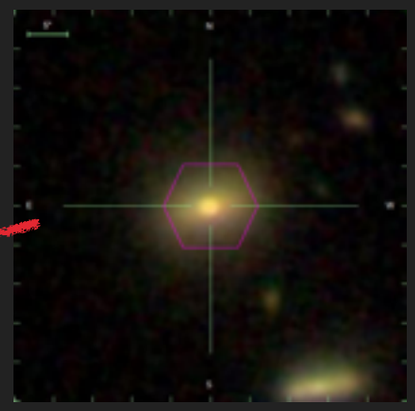
Fraser-McKelvie et al., 2018

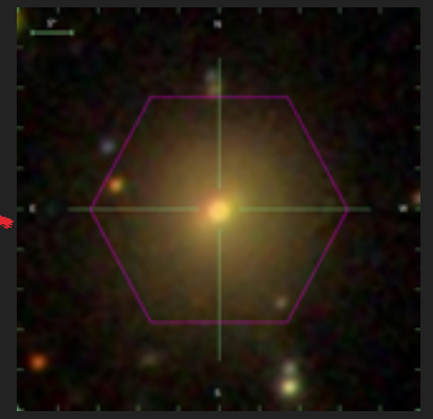
RESULTS: AGE/METALLICITY PLOTS

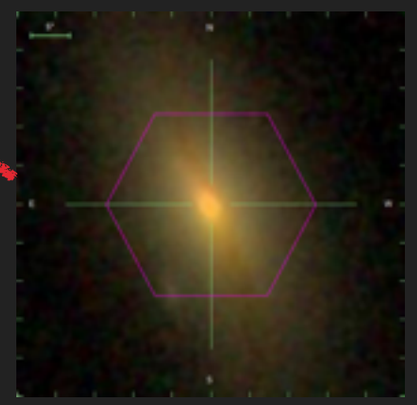


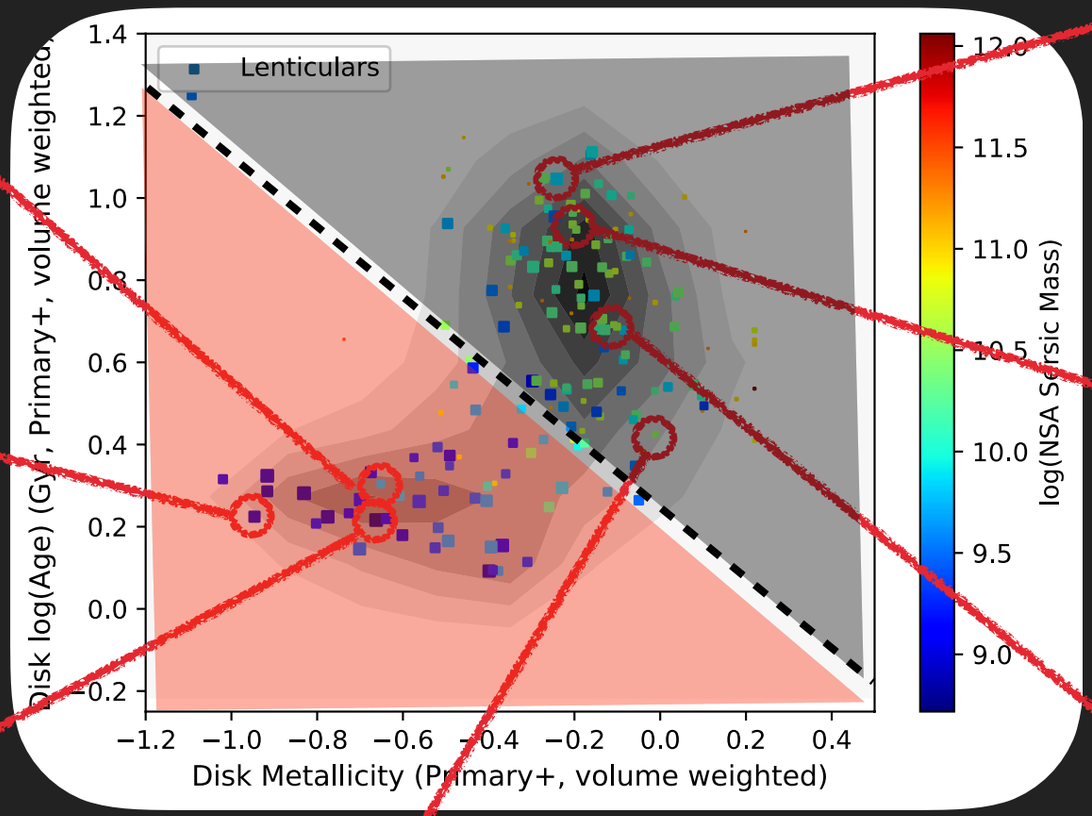


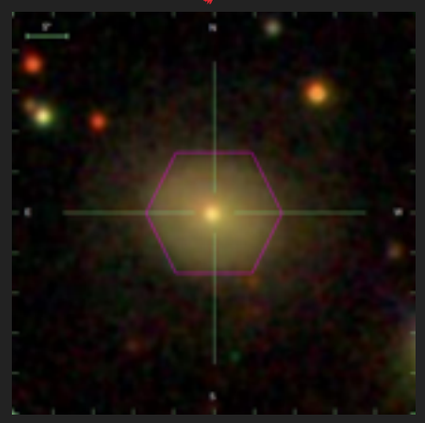




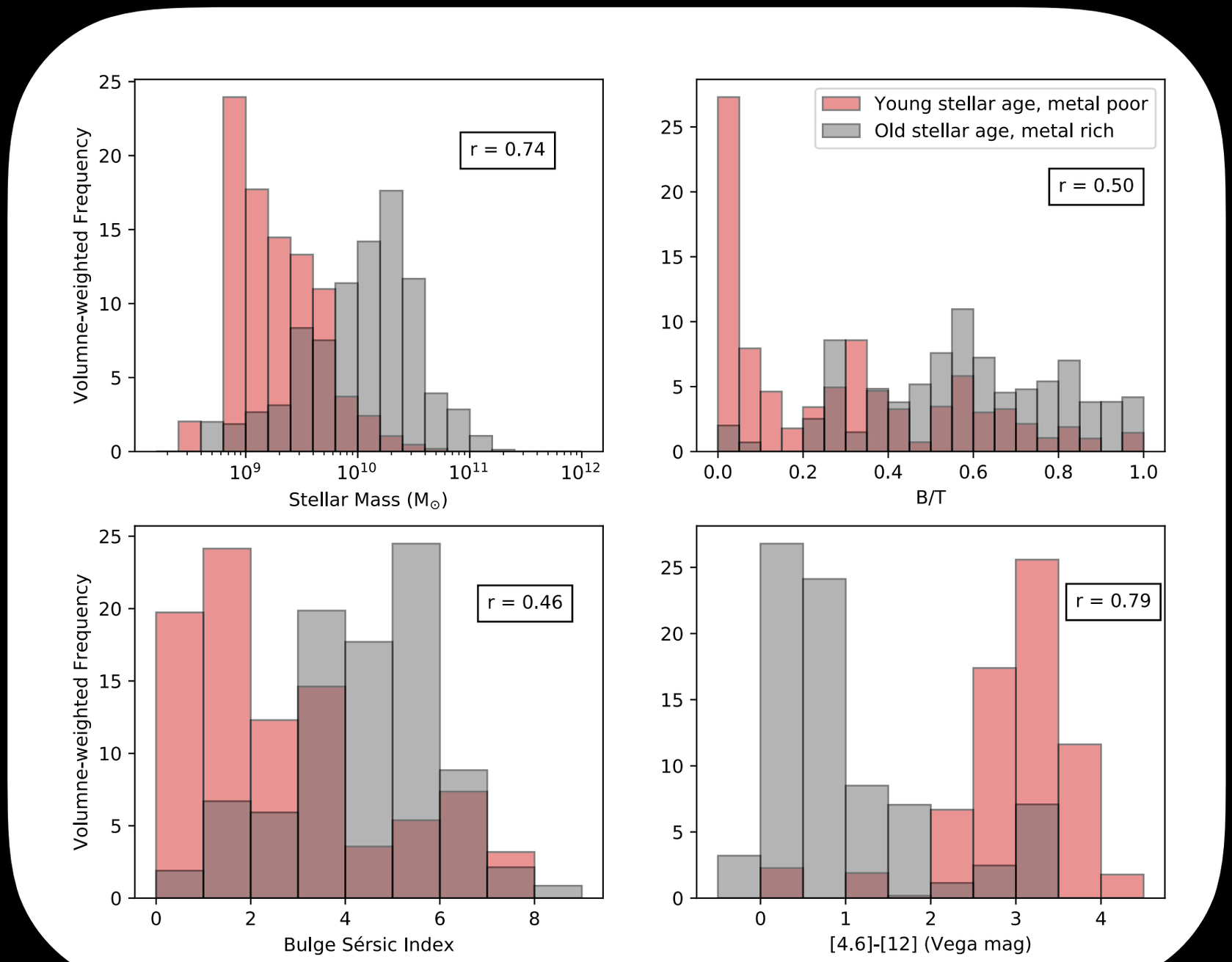




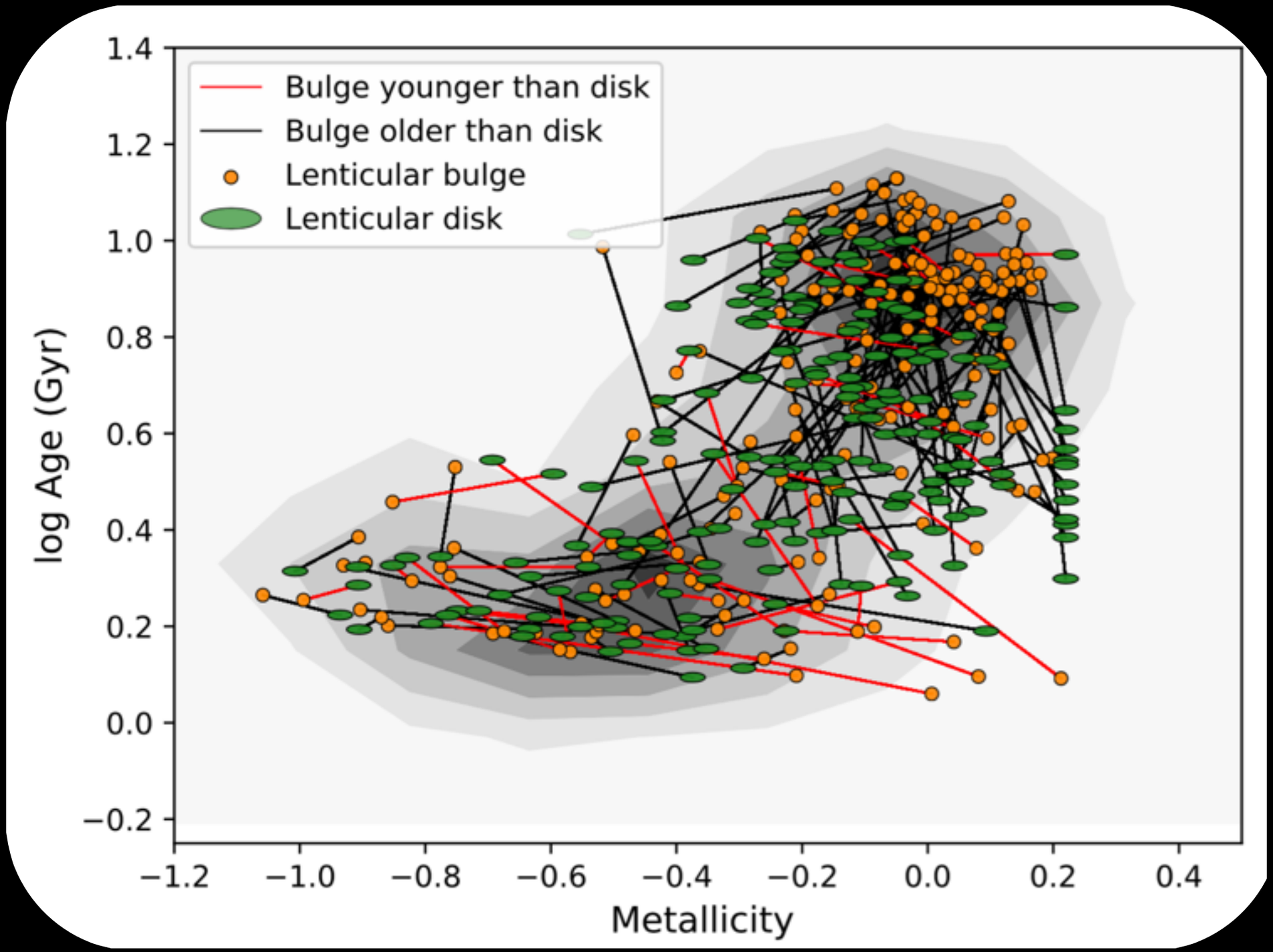




What do SO populations correlate with?



Amelia Fraser-McKelvie



Fraser-McKelvie et al., 2018

So, What's Going On?

HIGH MASS, OLD, METAL-RICH POPULATION:

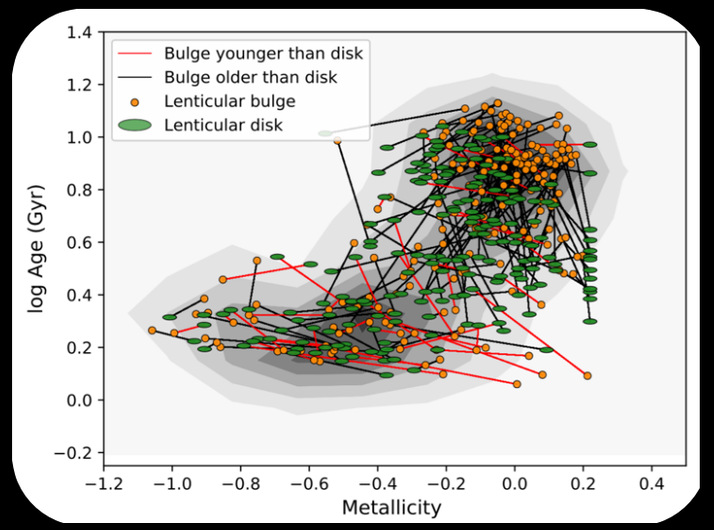
Bulge older than disk, inside out quenching.
Morphological quenching?

High Sérsic index, Merger-driven formation?

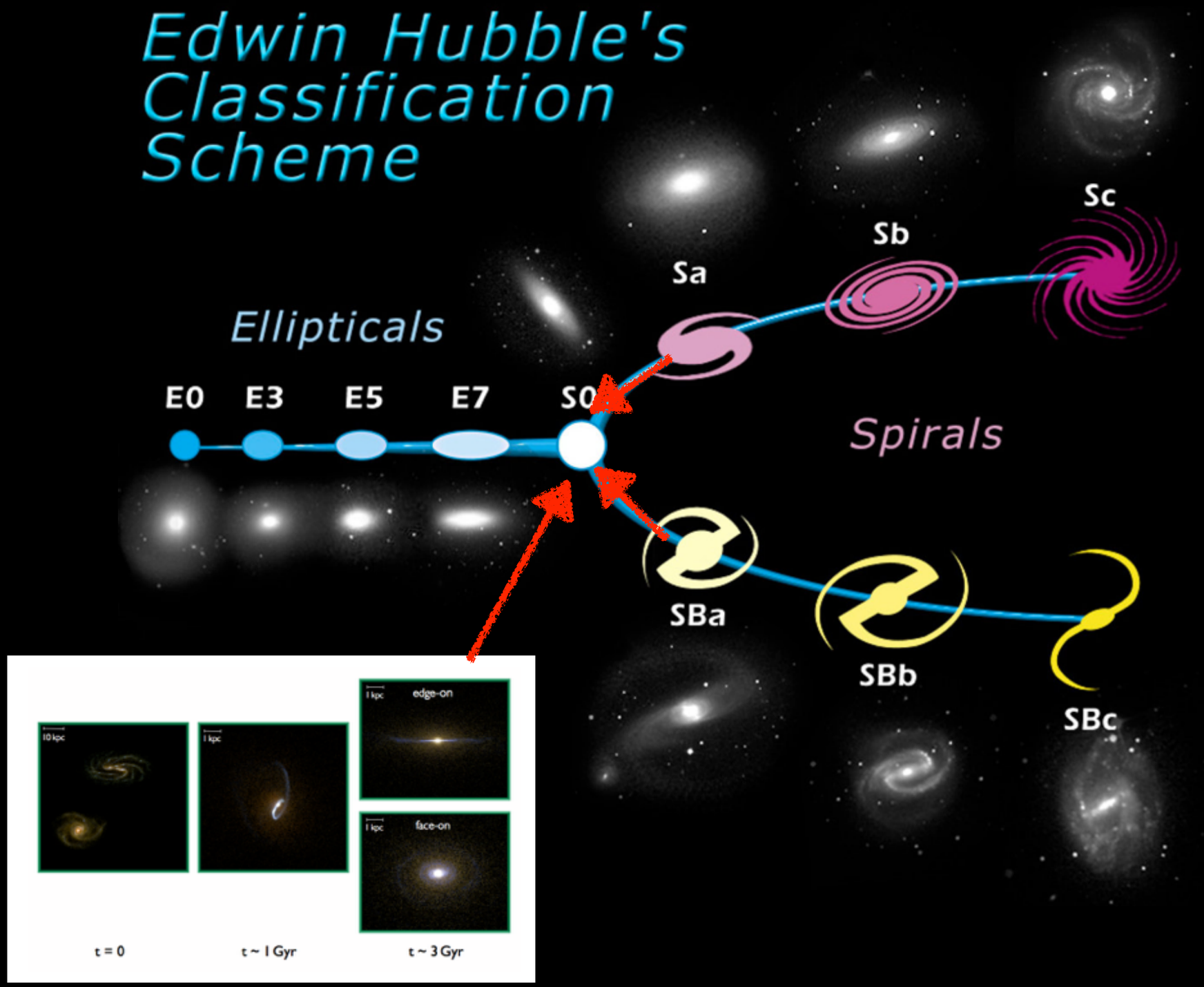
LOW MASS, YOUNG, METAL-POOR POPULATION:

Bulge younger than the disk, gas inflows,
bulge rejuvenation or compaction?

Low Sérsic index, faded disk scenario?



The Hubble Sequence & Galaxy Evolution



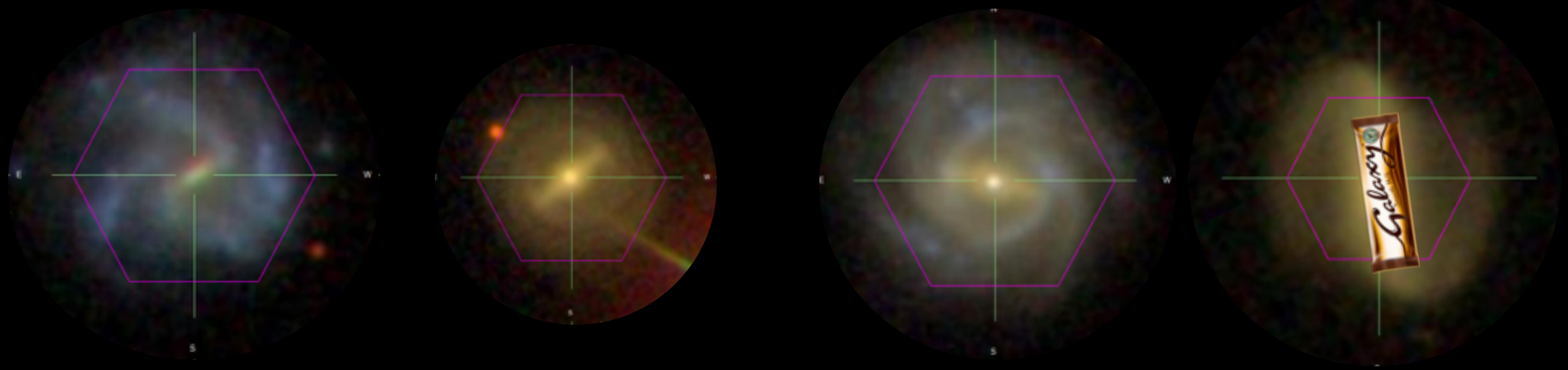
A Brief Foray into Bars

Bars Redistribute Material

-Bars can act to redistribute stellar material in galaxies in simulations (e.g. Minchev & Famaey 2010, Kubryk+13, Di Matteo+13).

-This effect has been seen observationally in small samples (e.g. Sánchez-Blázquez+11, Seidel+16), but also not seen in larger samples (e.g. Sánchez-Blázquez+14).

-Can we see evidence of this in the MaNGA galaxy sample?



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Stellar Orbits– what do we expect?

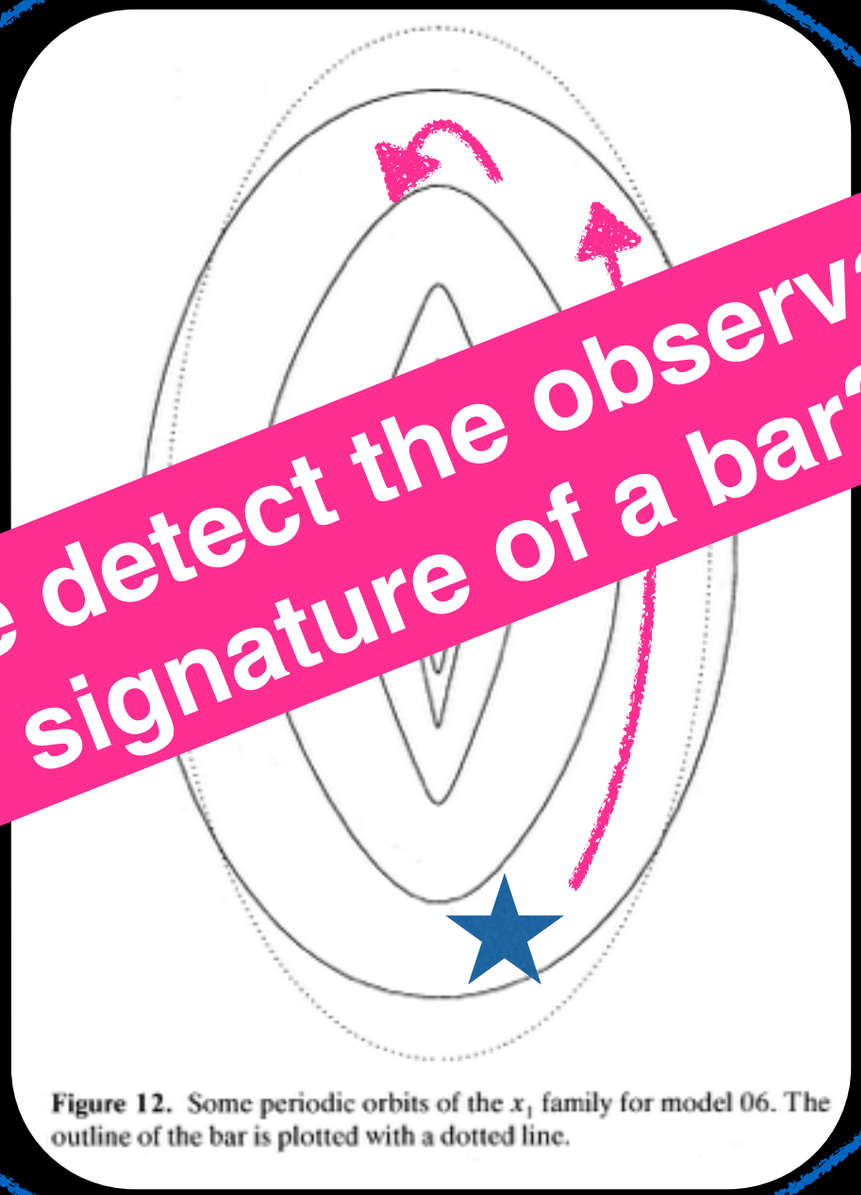


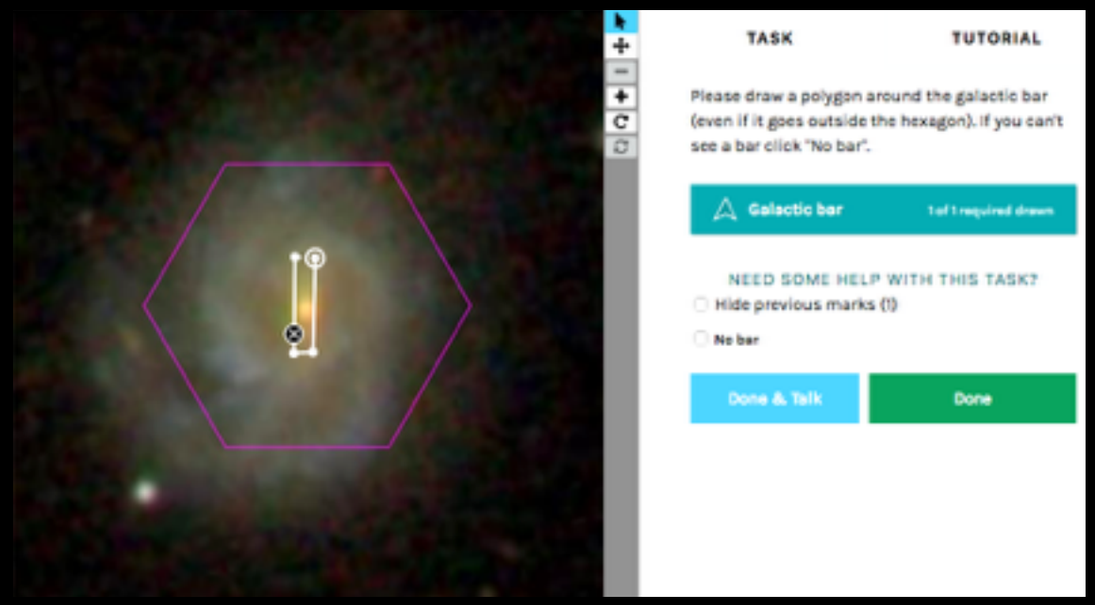
Figure 12. Some periodic orbits of the x_1 family for model 06. The outline of the bar is plotted with a dotted line.

Athanassoula 1992

Can we detect the observational signature of a bar?

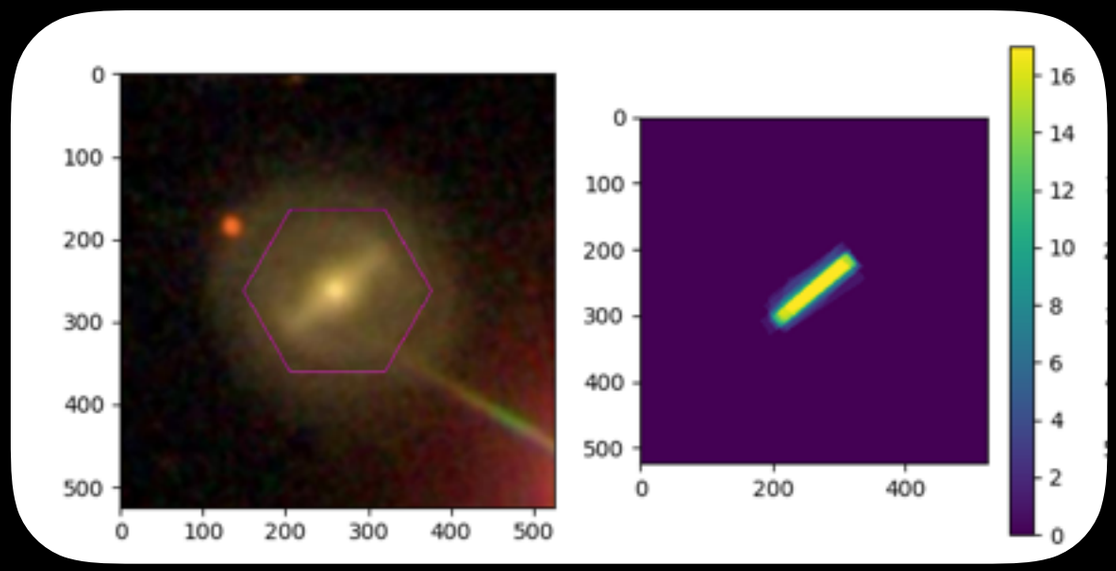
MaNGA Sample of Barred Galaxies

-Galaxy Zoo 2, vote fraction for a bar feature >70%.



-Employ Galaxy Zoo: 3D bar masks.

-316 galaxies



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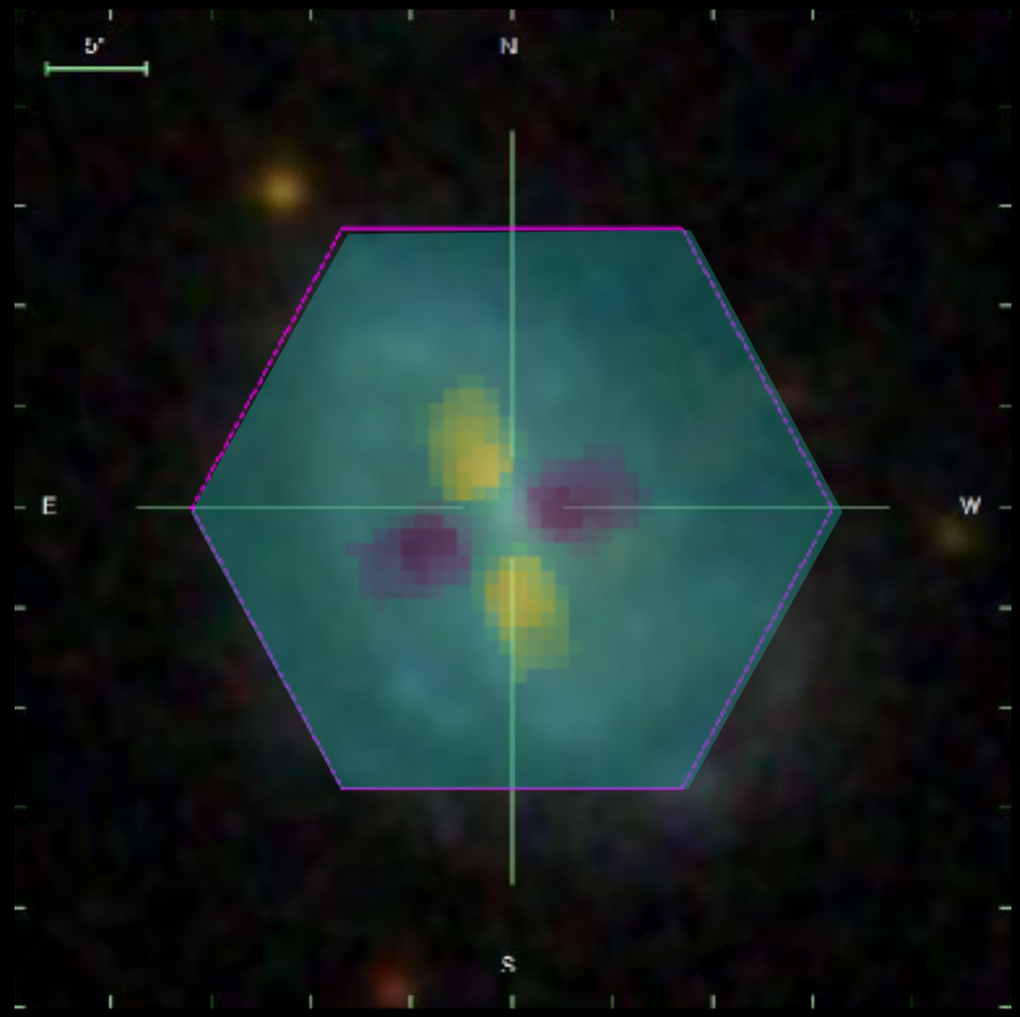
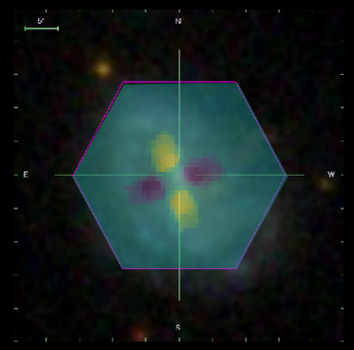
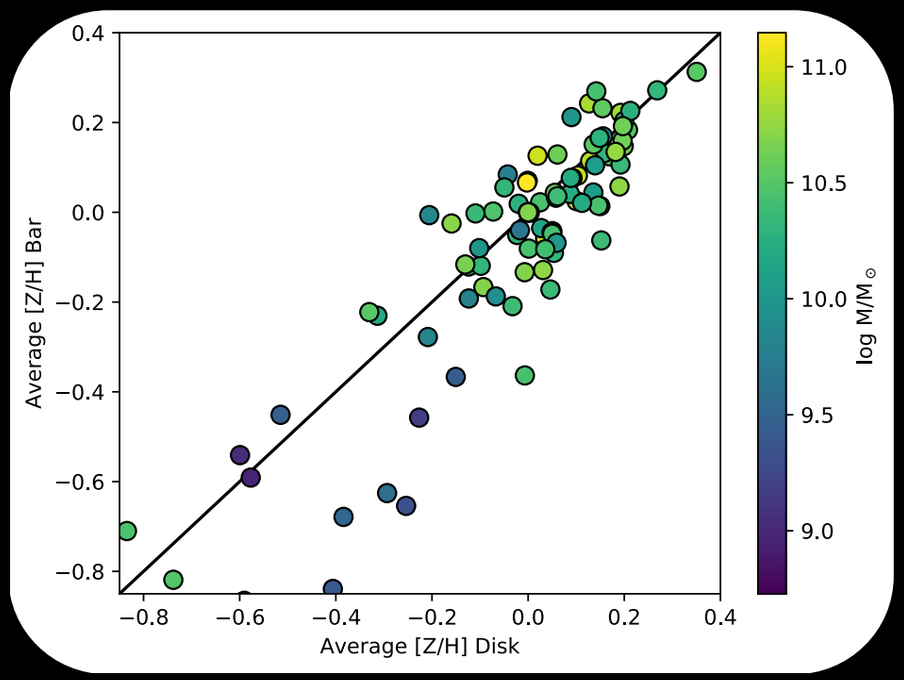
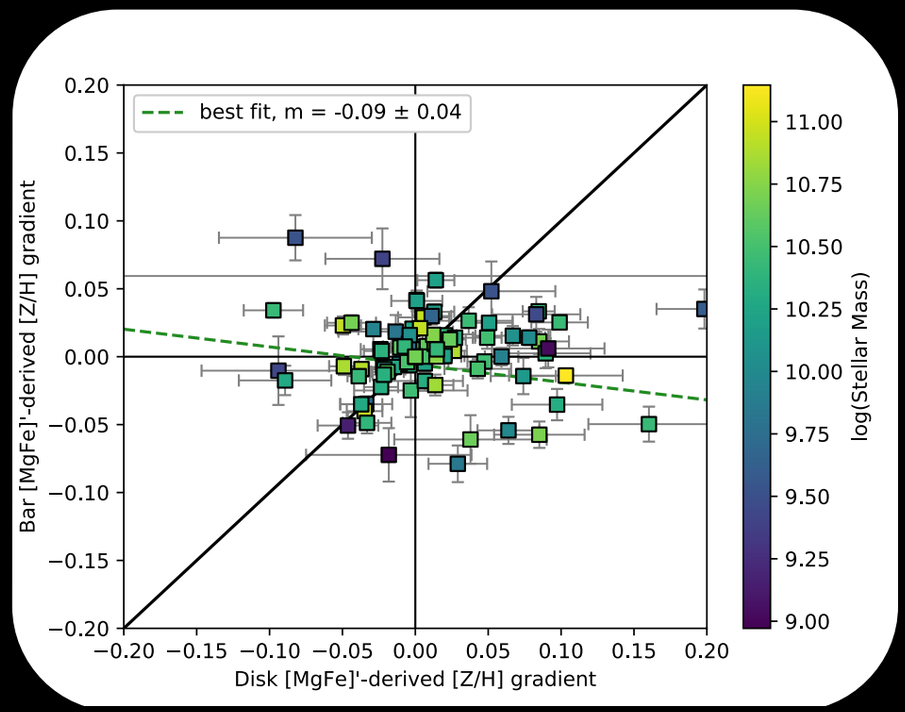


8332-12701

Metallicity effects with age slices







Total/average metallicity doesn't change throughout the galaxy, but the gradient does!

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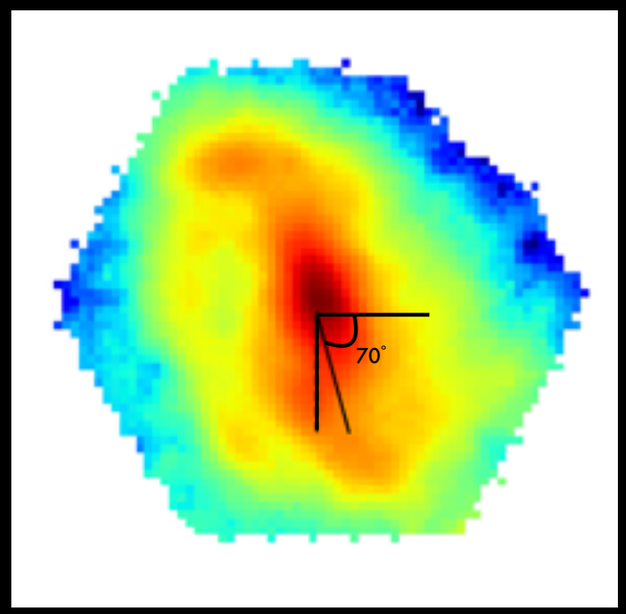
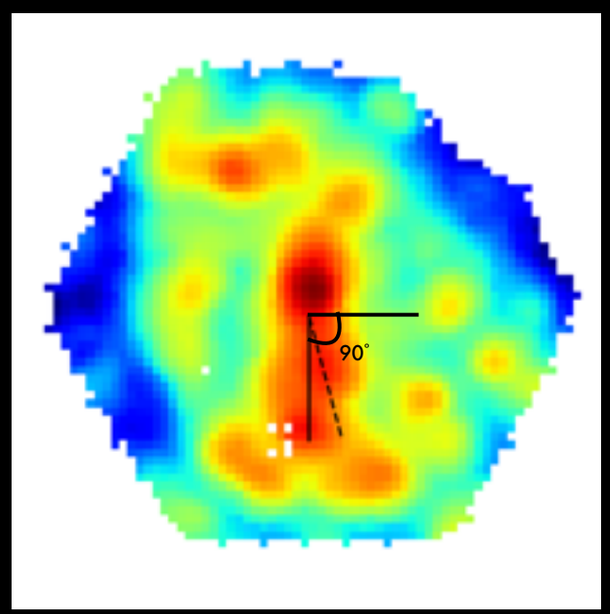
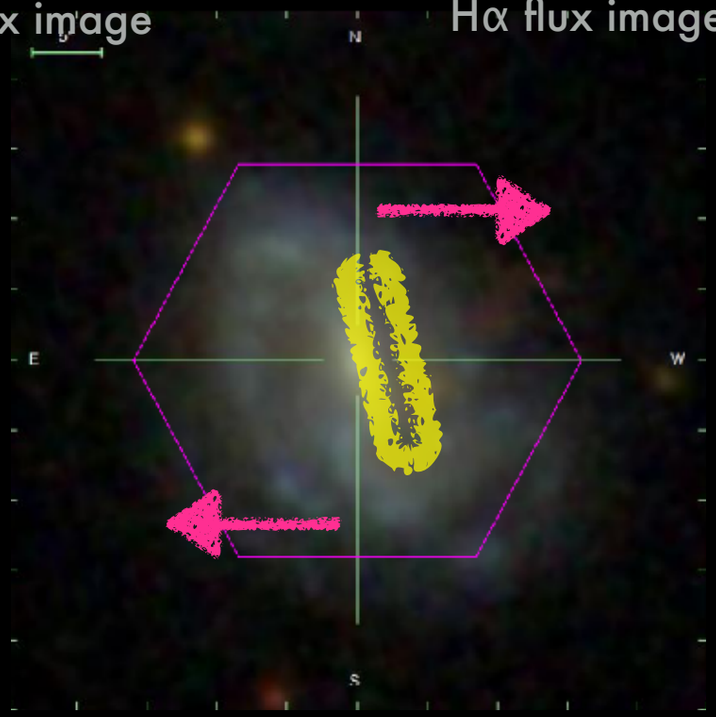
Slicing the bars out of galaxies





‘White light’ total flux image

Hα flux image



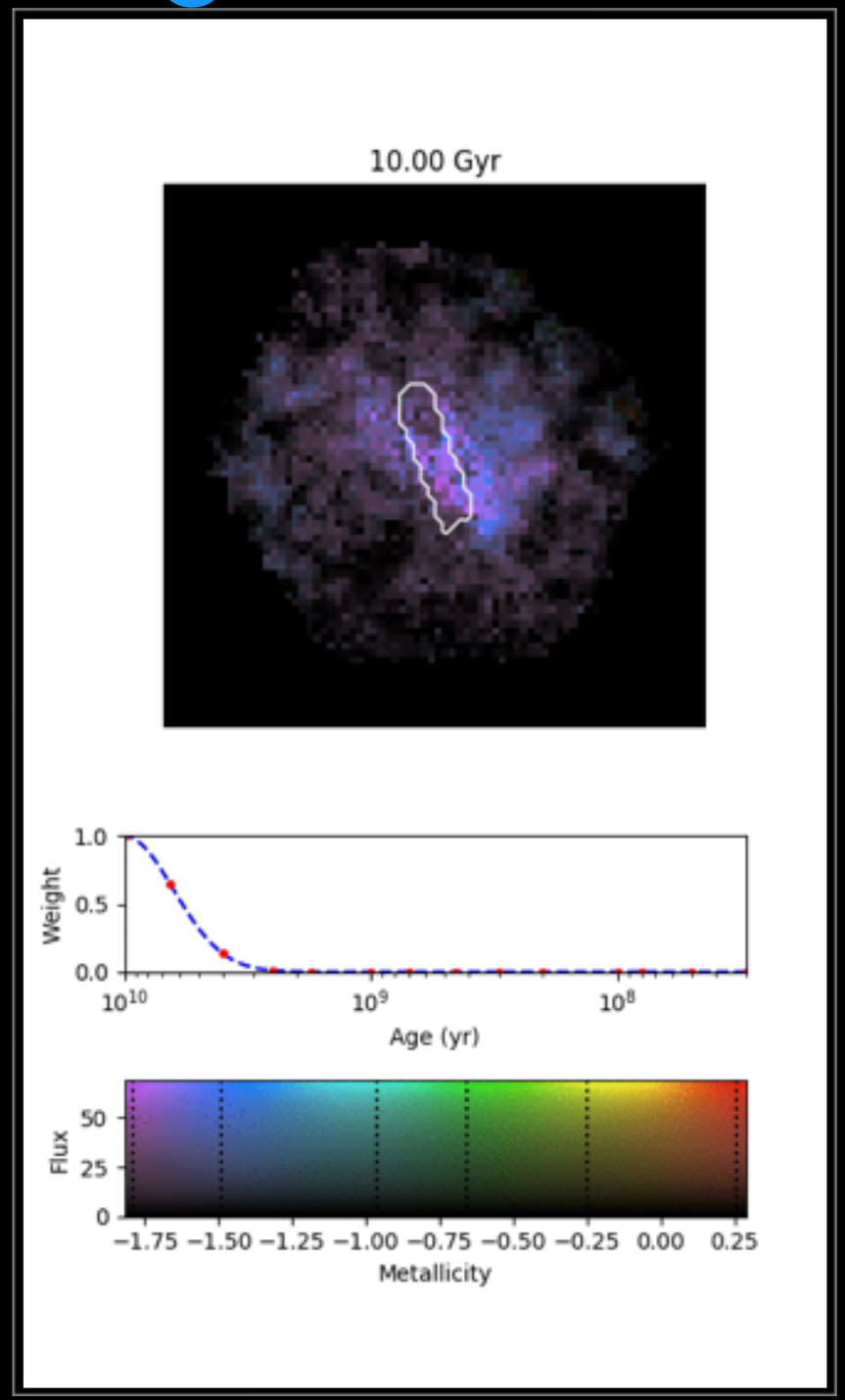
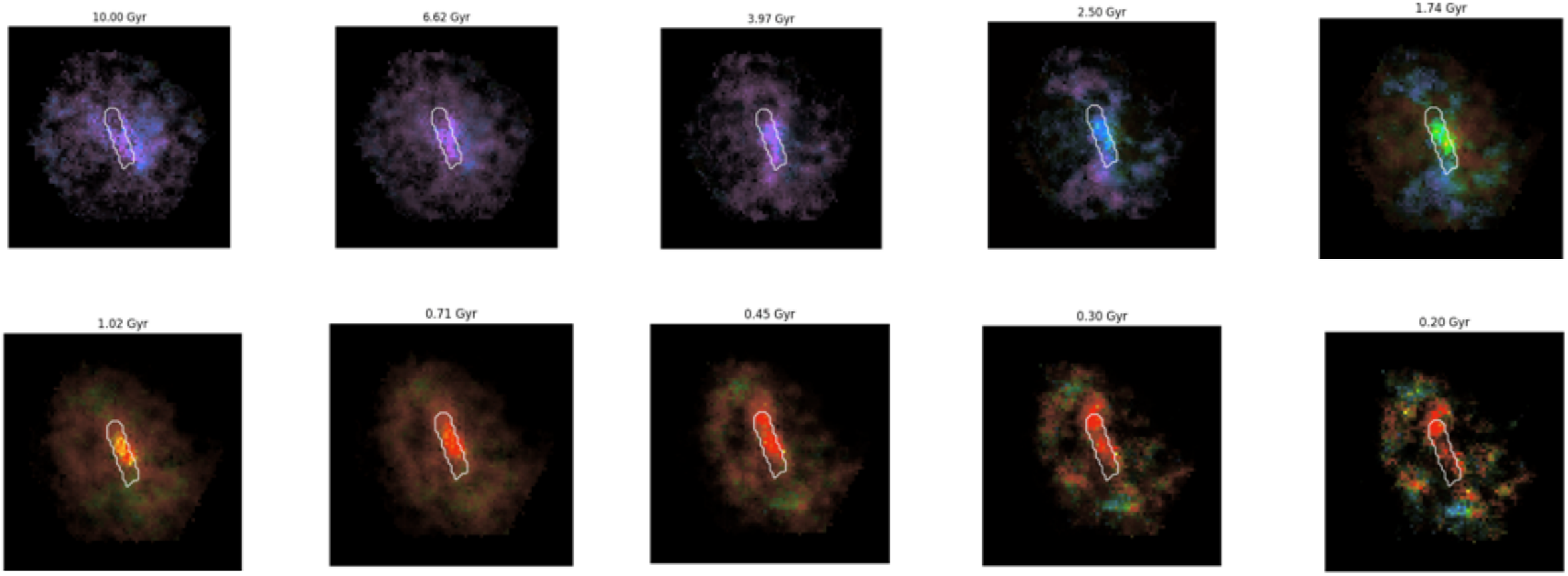
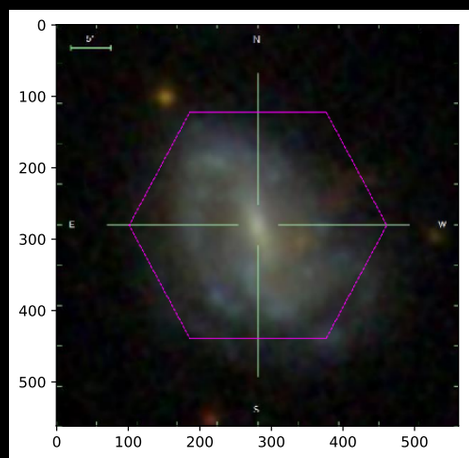
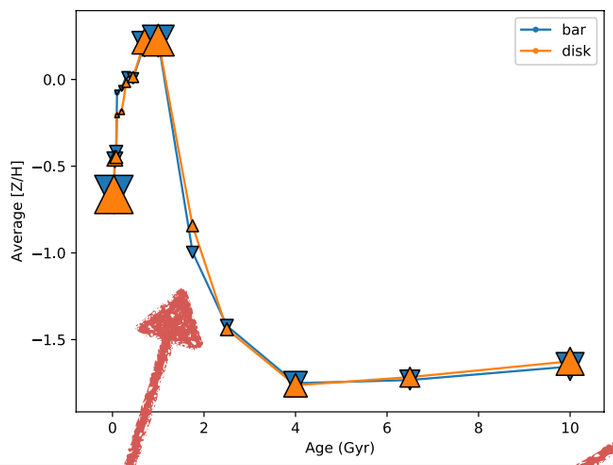


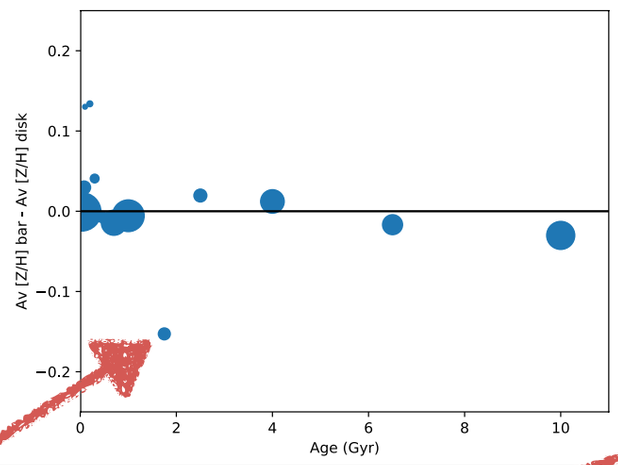
Image credit: Tom Peterken

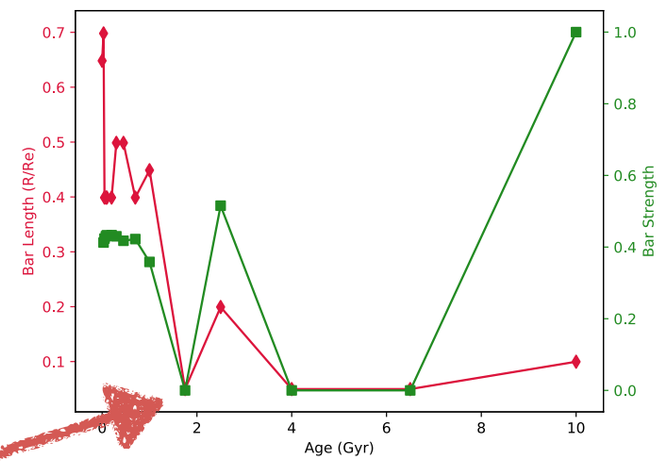

10.00 Gyr
6.62 Gyr
3.97 Gyr
2.50 Gyr
1.74 Gyr
1.02 Gyr
0.71 Gyr
0.45 Gyr
0.30 Gyr
0.20 Gyr
0.10 Gyr
0.08 Gyr
0.05 Gyr
0.03 Gyr
Weight
Age (yr)
Flux
Metallicity
N
E
W
S
5"

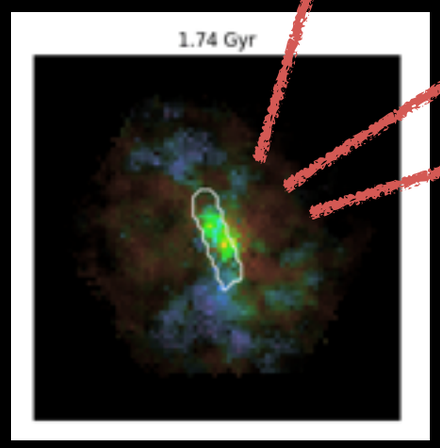
Other fun things you can do with bars











Bar and disk metallicity is very similar for most time slices, but for short periods this varies.

Does this correspond to bar formation timescales?

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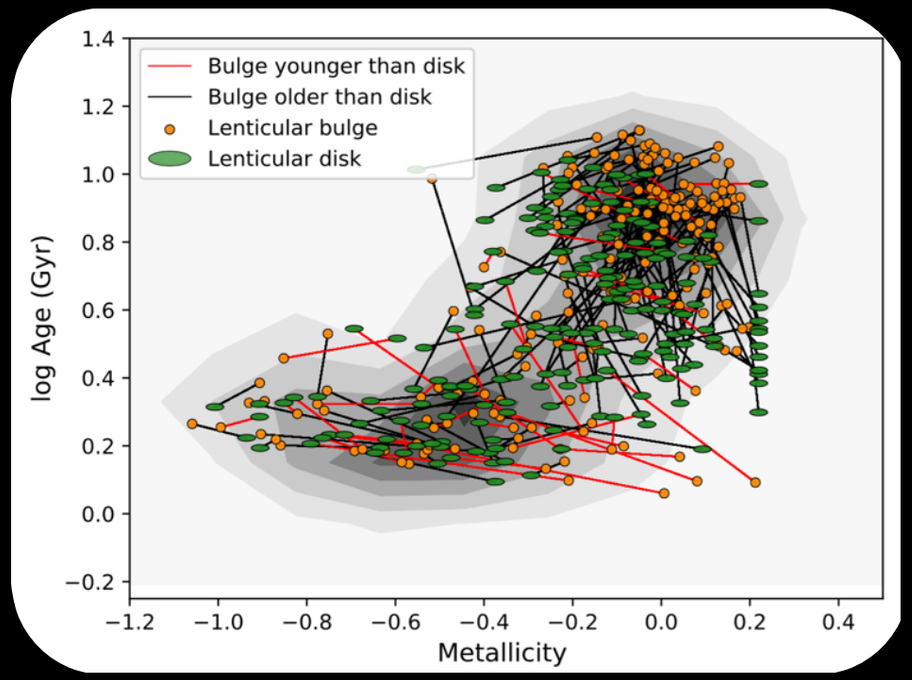
Conclusions & Take-Homes



Bar age and metallicity gradients are flatter than corresponding disk regions —>Bars are efficient mixers of stars

Galaxies can be split both spatially AND temporally using full spectral fitting

Two populations of S0s, best separated by STELLAR MASS

<u>Old, metal-rich, massive population</u>:
Possibly formed by high-z mergers, quenched by inside-out means or morphological quenching

<u>Young, metal-poor, low-mass population</u>:
Faded spiral scenario, undergoing bulge rejuvenation.