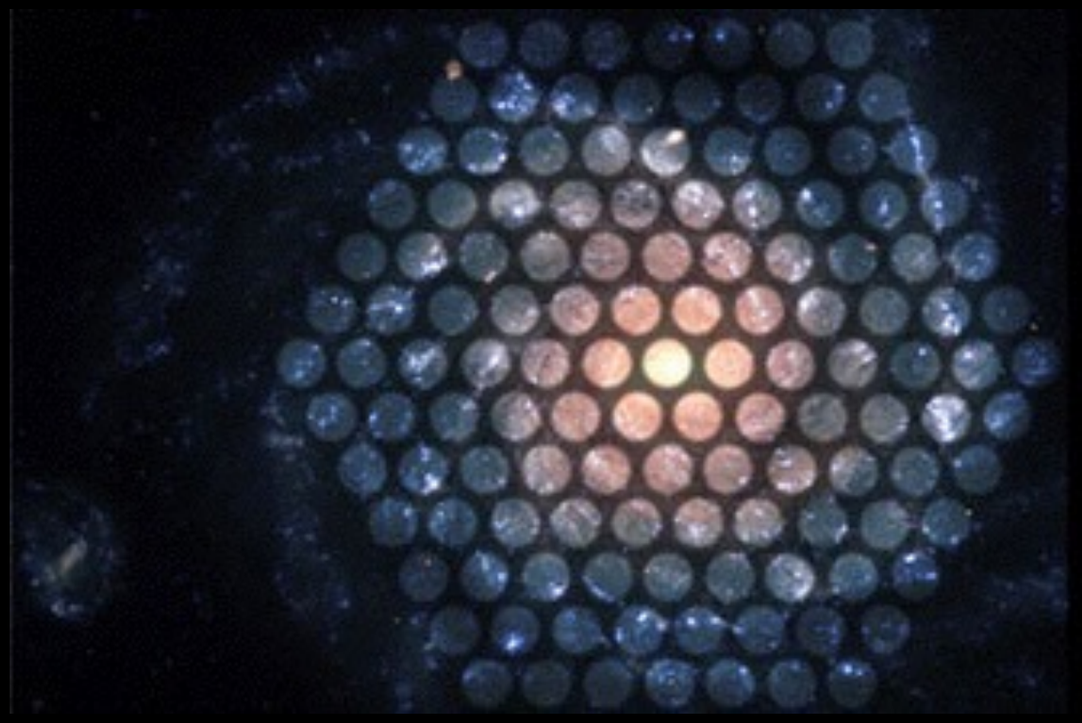
Stellar population synthesis and galactic archaeology of unresolved populations

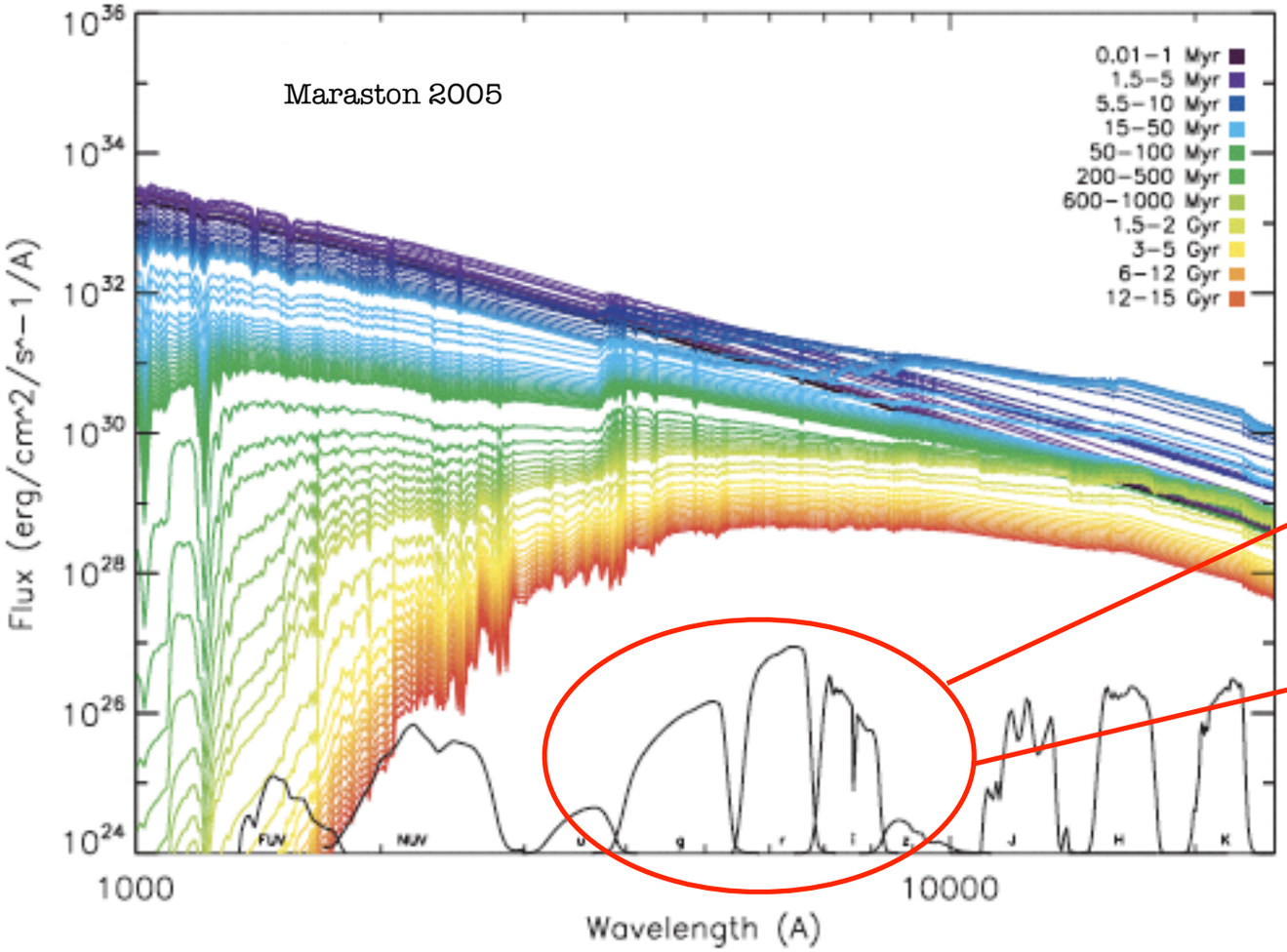


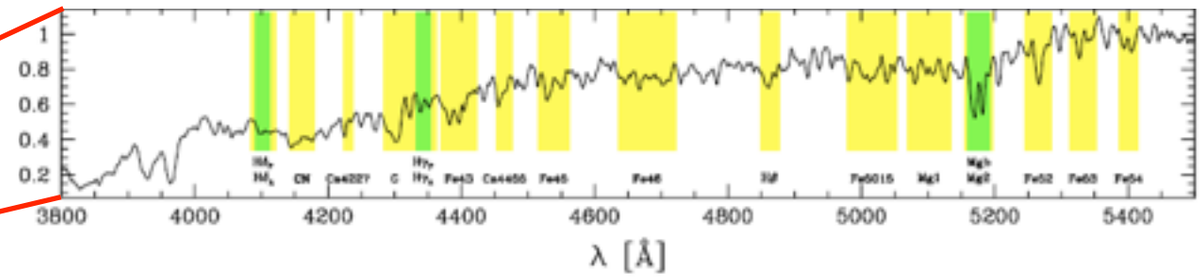
Daniel Thomas

University of Portsmouth

Probing baryon physics in galaxies

Schawinski, Thomas et al 2007

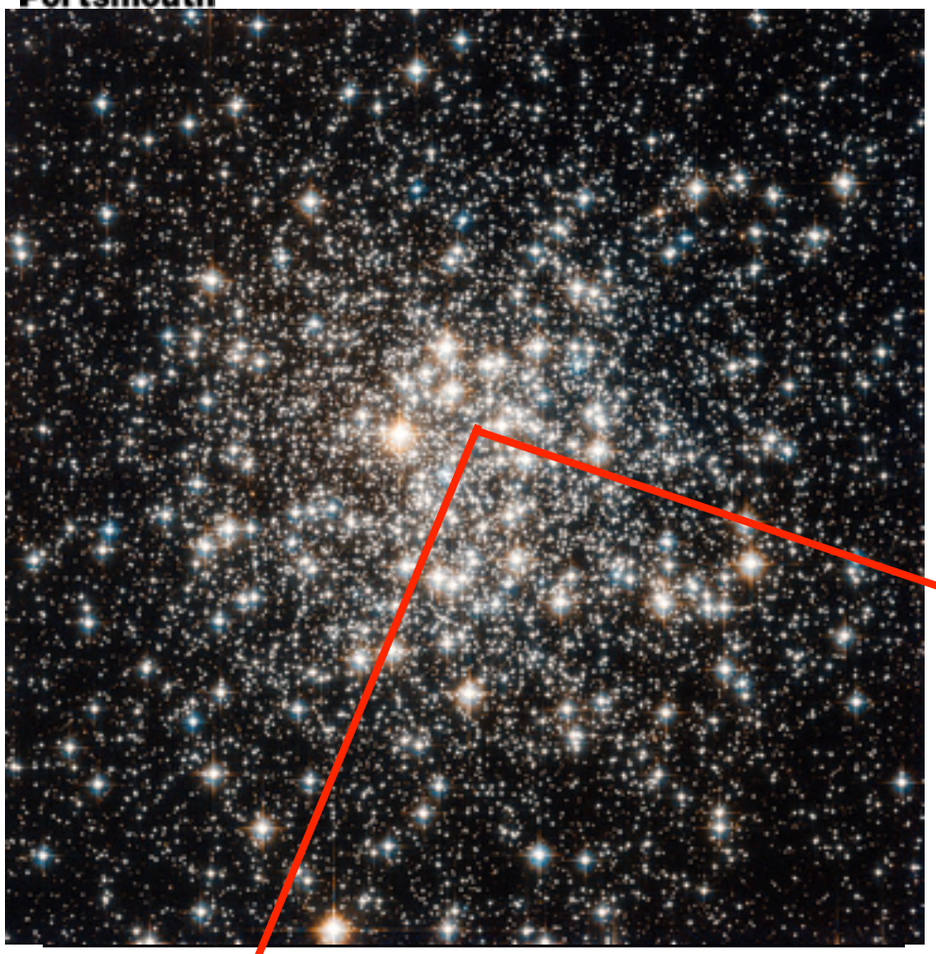




Puzia et al 2004

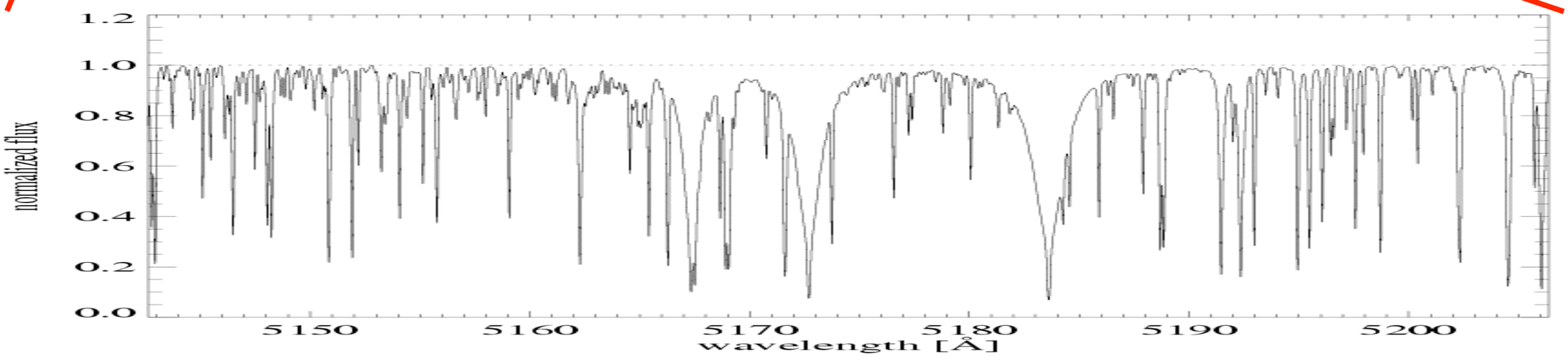
- Stars in galaxies keep the fossil record over formation history
- Stellar population models to derive parameters
- Multi-band photometry over large wavelength base or medium-resolution spectroscopy
- Ages and chemical enrichment history

Dissecting unresolved populations

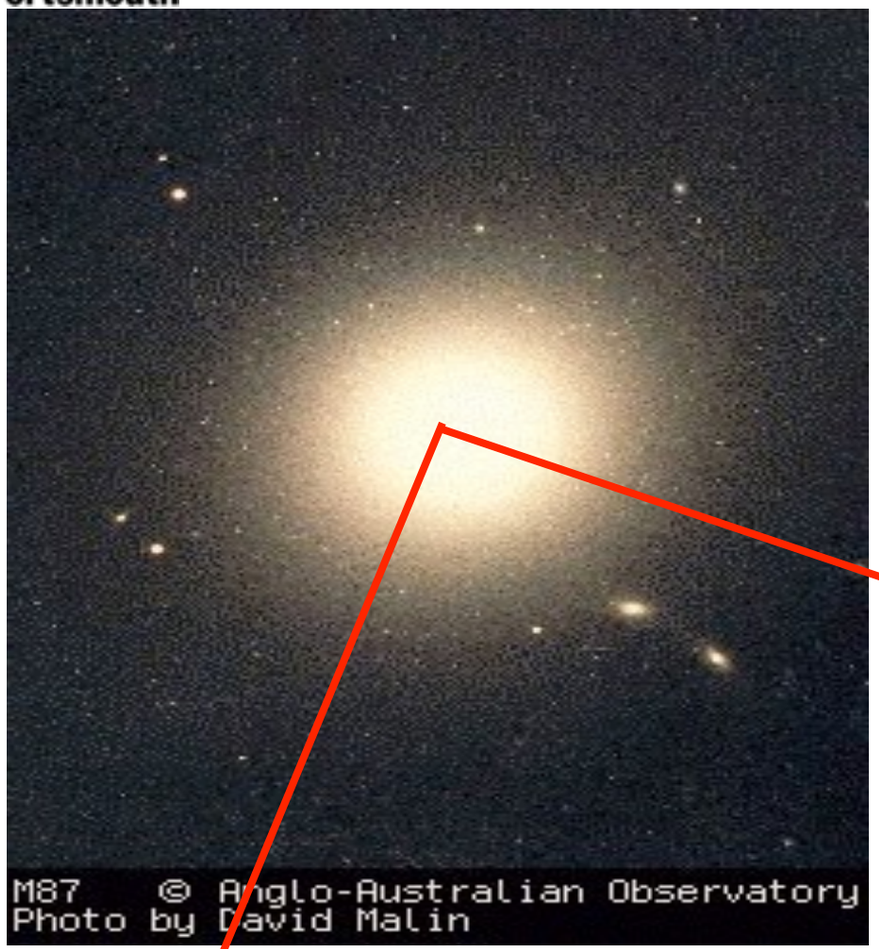


Key for the derivation of chemical element abundance ratios

- Stars not resolved in most galaxies
- Spectral resolution reduced by stellar velocities in bright galaxies



Dissecting unresolved populations



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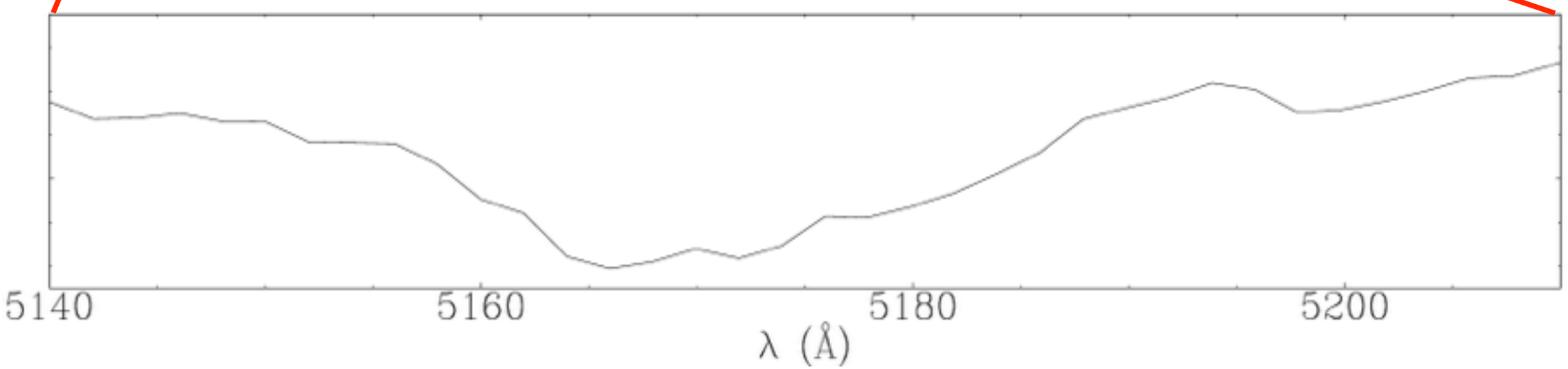
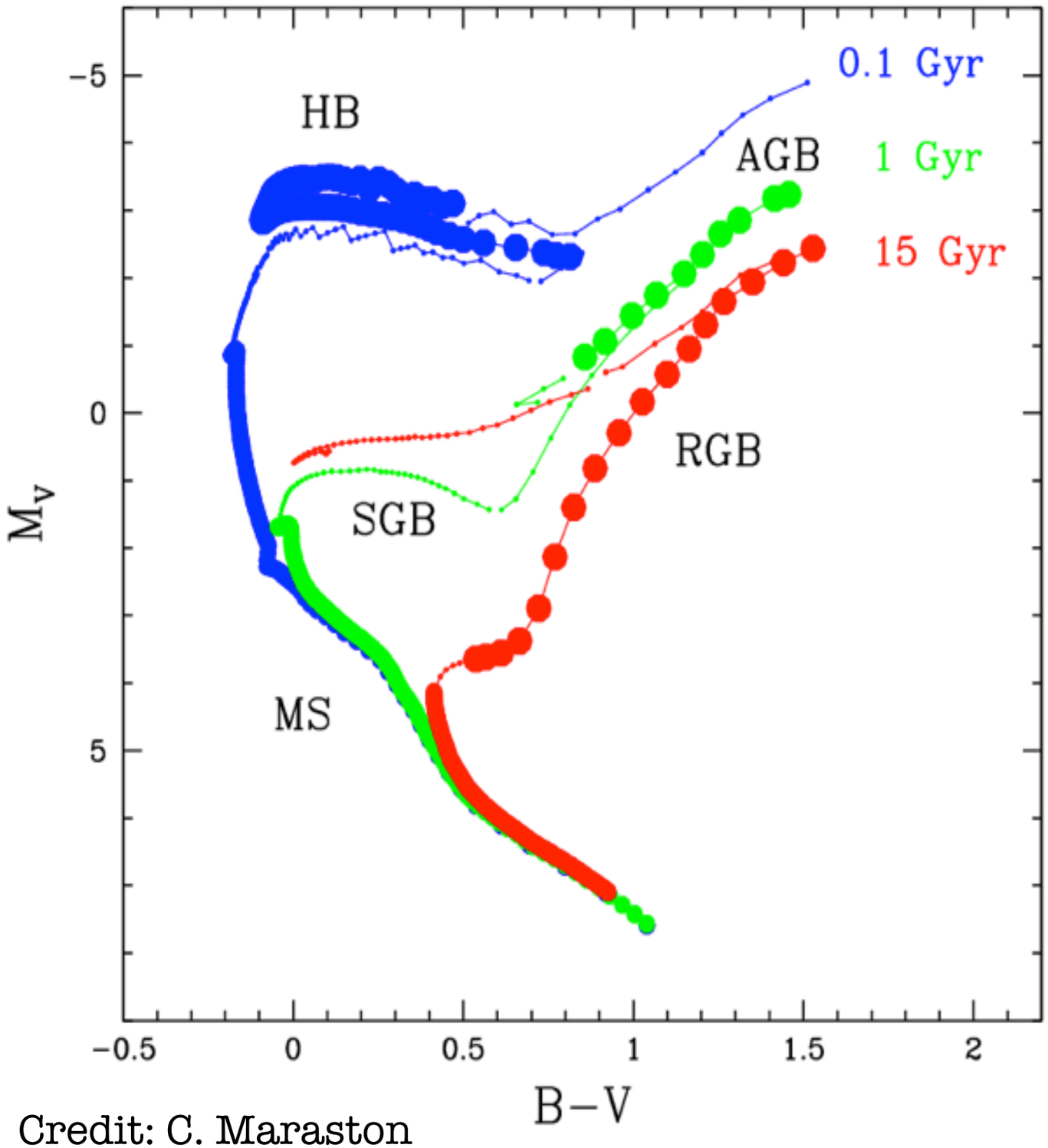


Stellar population models



Credit: C. Maraston

Needs

- Stellar evolutionary tracks
- Stellar libraries or model atmospheres

Predicts

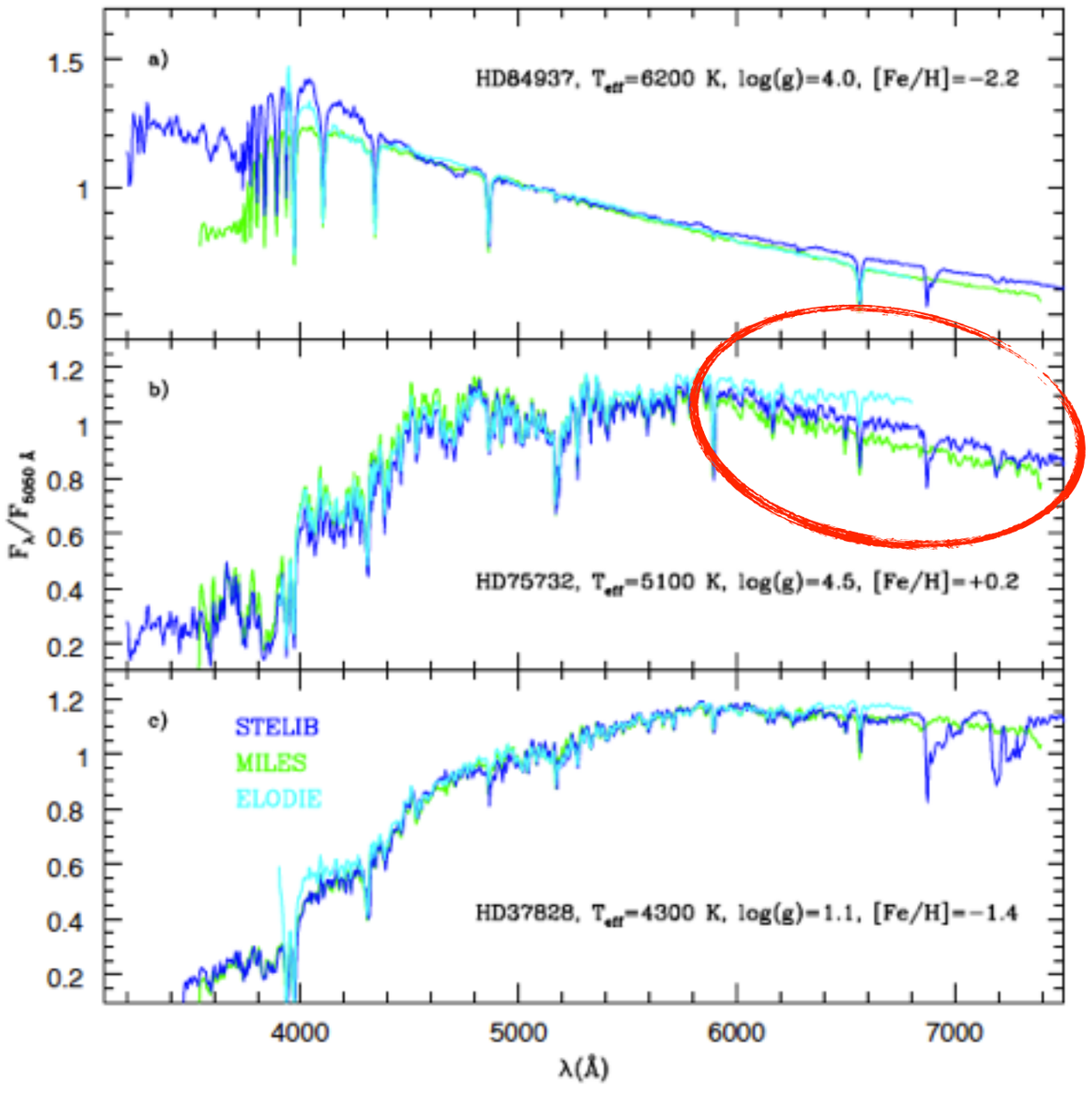
- Spectra, colours
- Luminosity evolution, k-corrections

Assumes (derives)

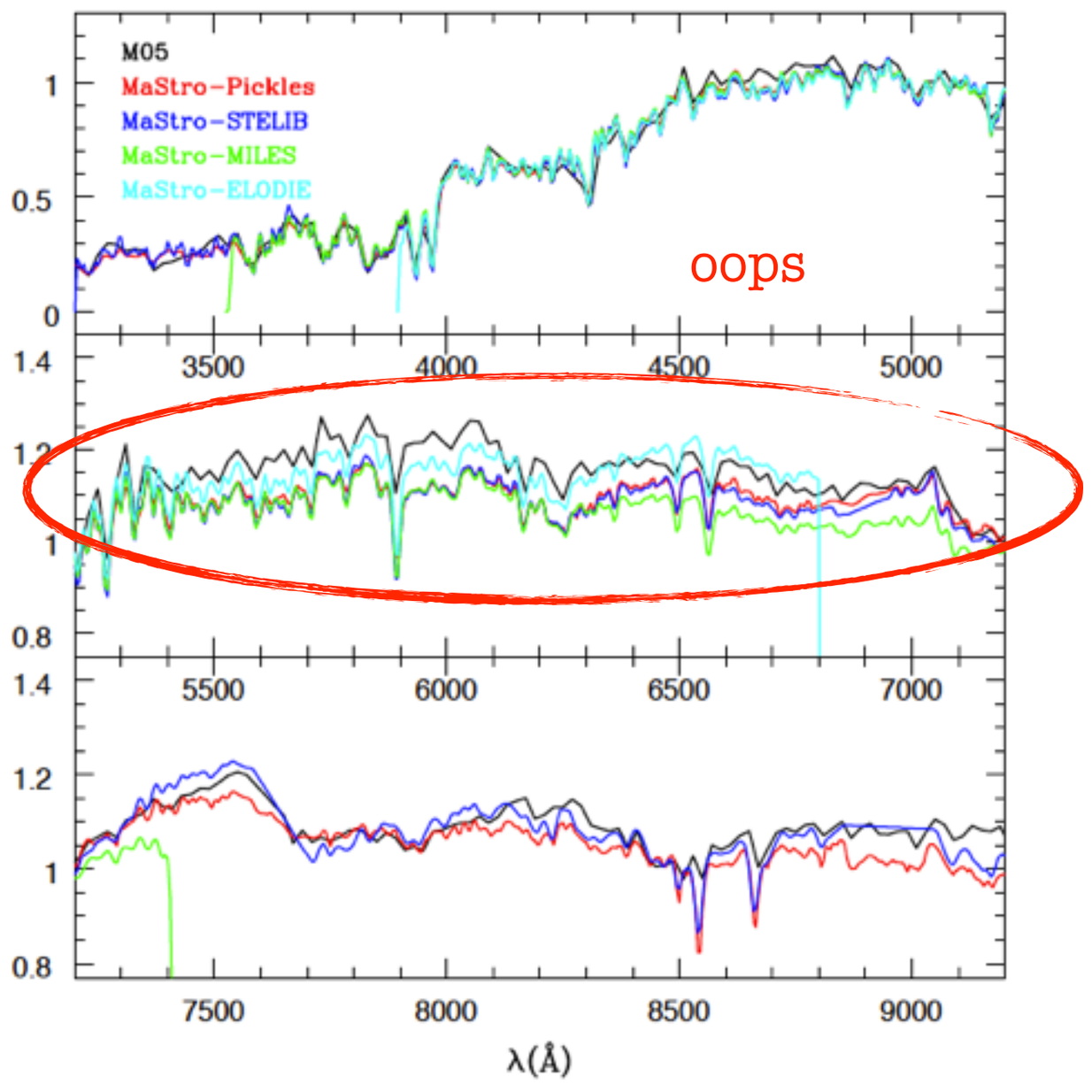
- Star formation histories
- IMF
- Ages and element abundances
- Horizontal branch stars

Stellar libraries in comparison

Stars

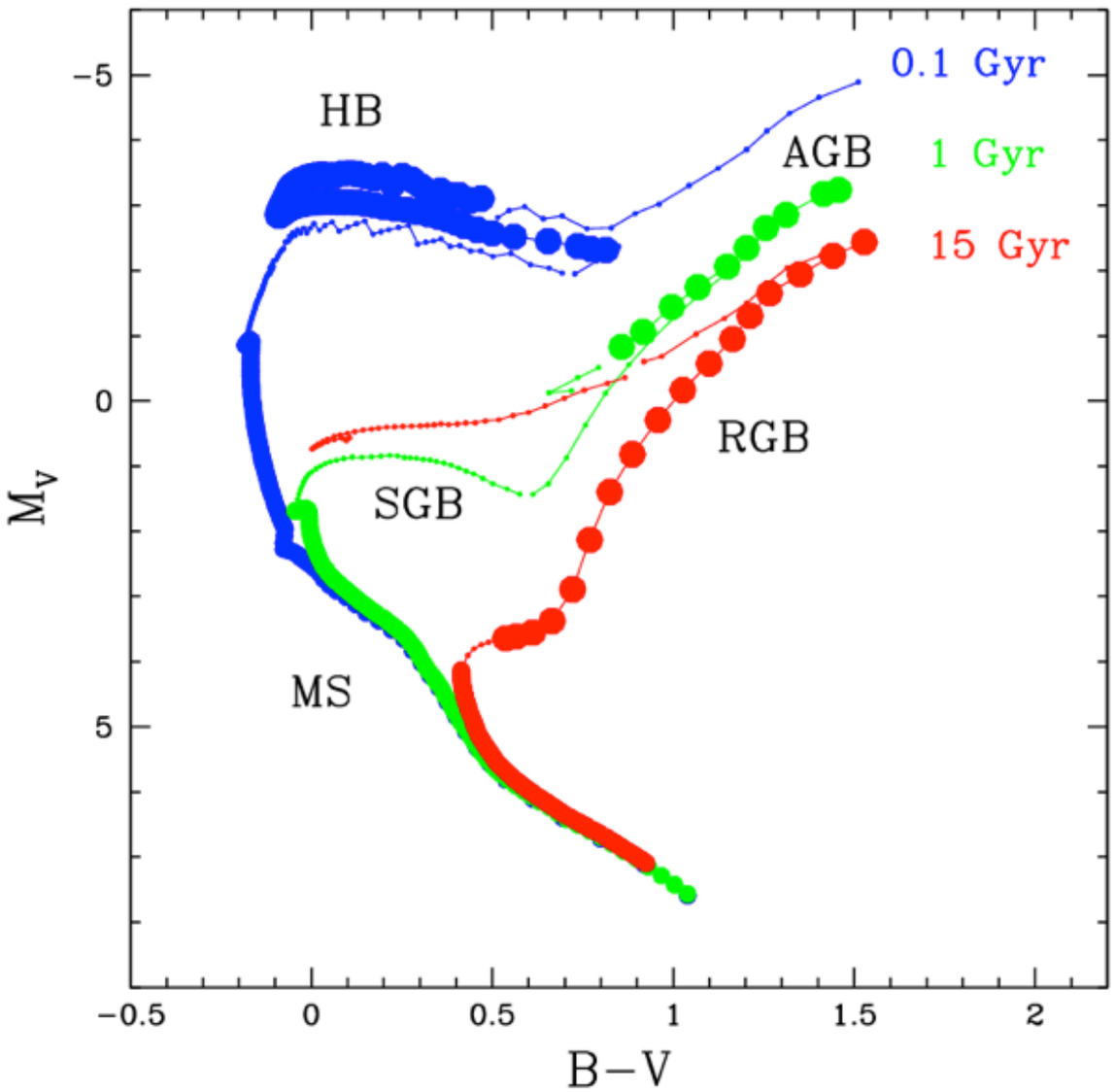


Stellar population models



Maraston & Strömbäck 2011

Element ratios through semi-theoretical



C. Maraston

$$I^{SSP} = \sum_j I_j^* \cdot f_{c,j}^*$$

$$f(T_{\rm eff}, \log g, [Z/{\rm H}])$$

response functions

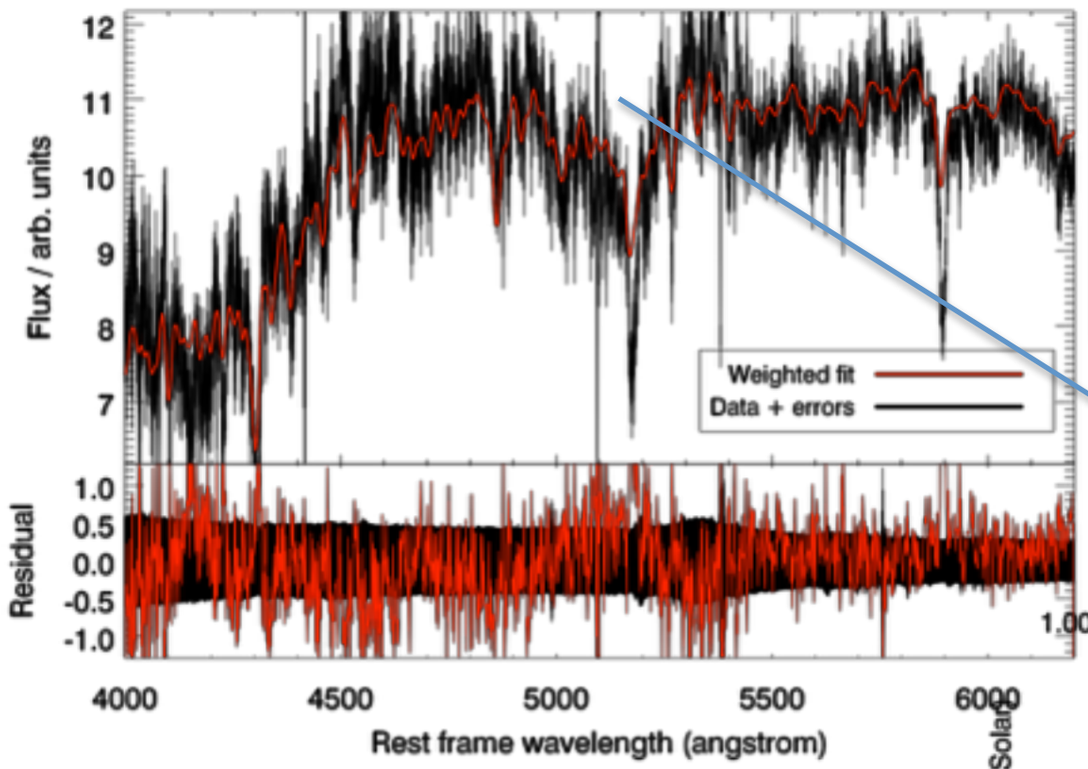
$$\partial I / \partial [X_i]$$

stellar atmospheres

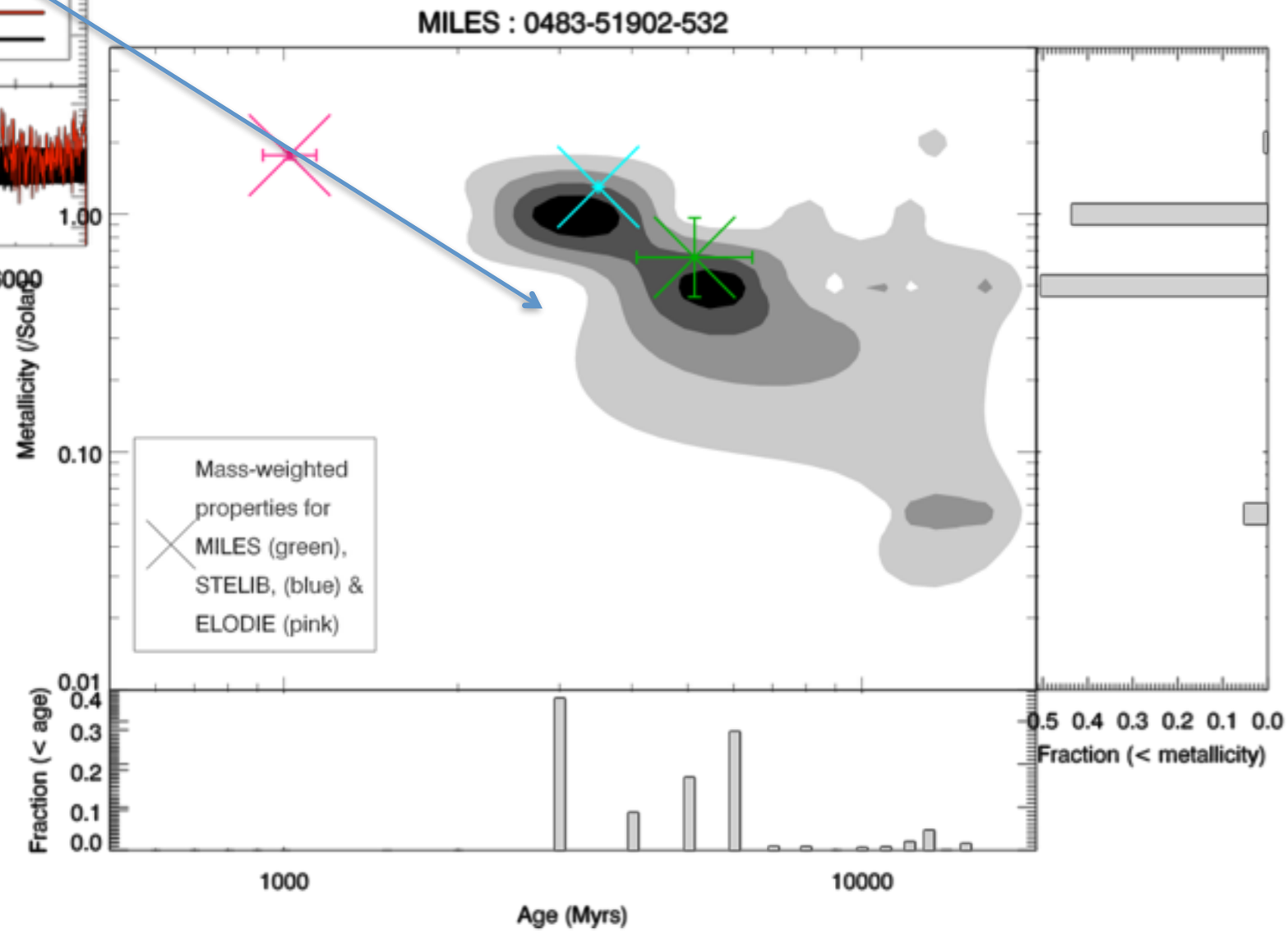
Korn, Maraston, Thomas 2005
Tripicco & Bell 1995; Trager et al 2000

Full Spectral Fitting Code FIREFLY

Wilkinson & Maraston 2015



Gives an array of fits, each as a combination of single-burst modes (SSPs), to get SFH, metallicity, age distribution, etc.



Fast computation of **likelihood surfaces** of properties

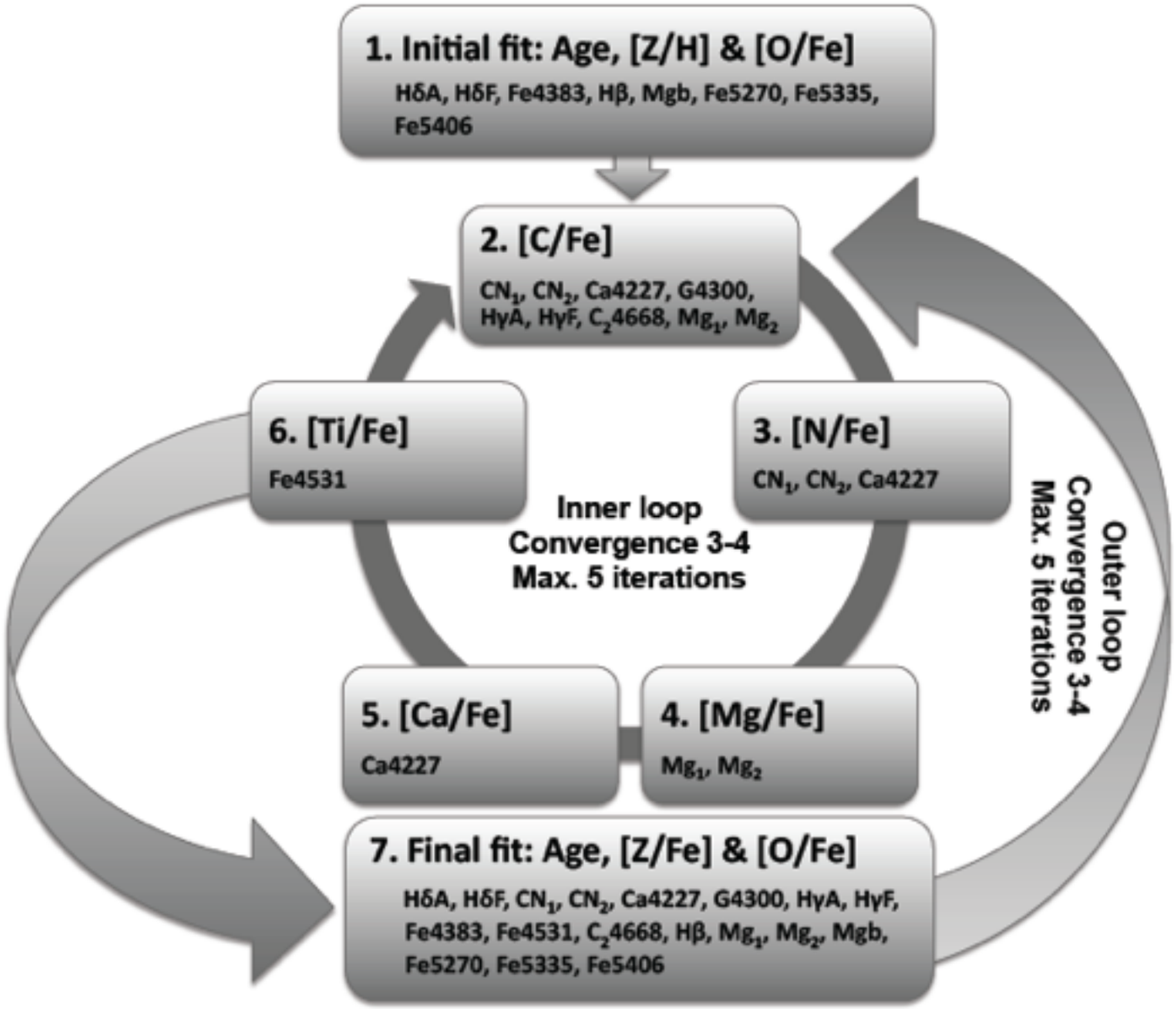
Ability to change and **compare input stellar population** model ingredients

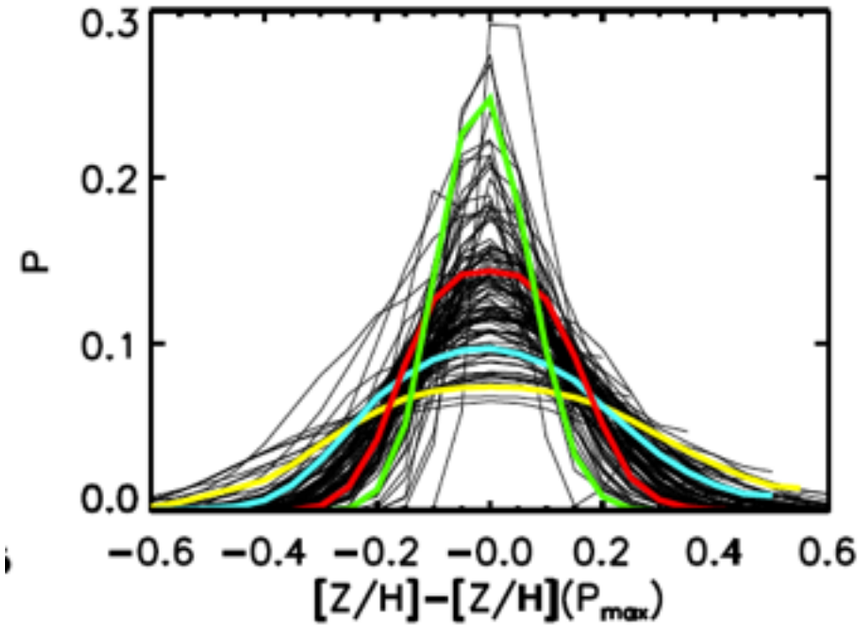
Reconstructs SFHs from combinations of bursts

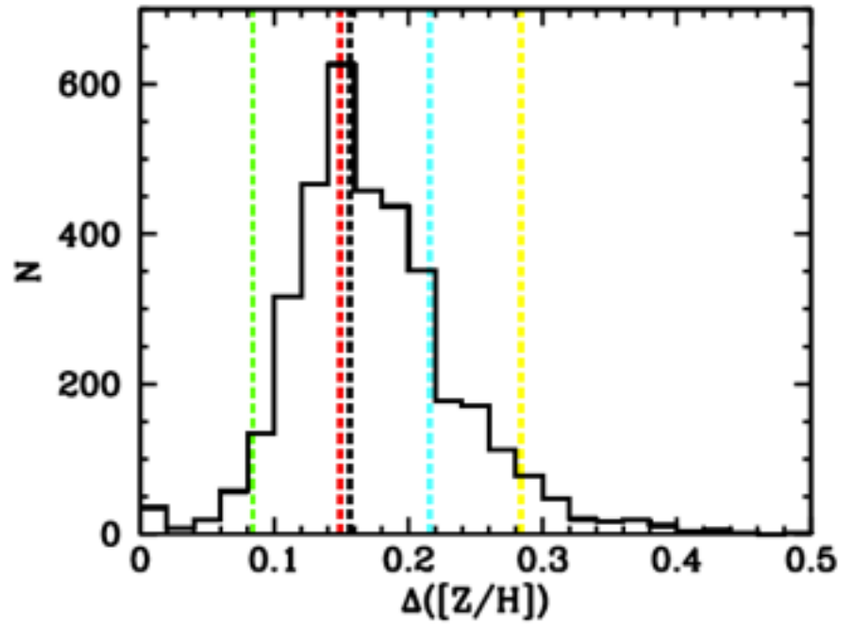
pPXF (Cappellari & Emsellem 2004)
STARLIGHT (Cid-Fernandes et al)
FSPS (Conroy et al 2014)
...

SP models of Maraston & Strömbäck 2011

Deriving element abundance ratios





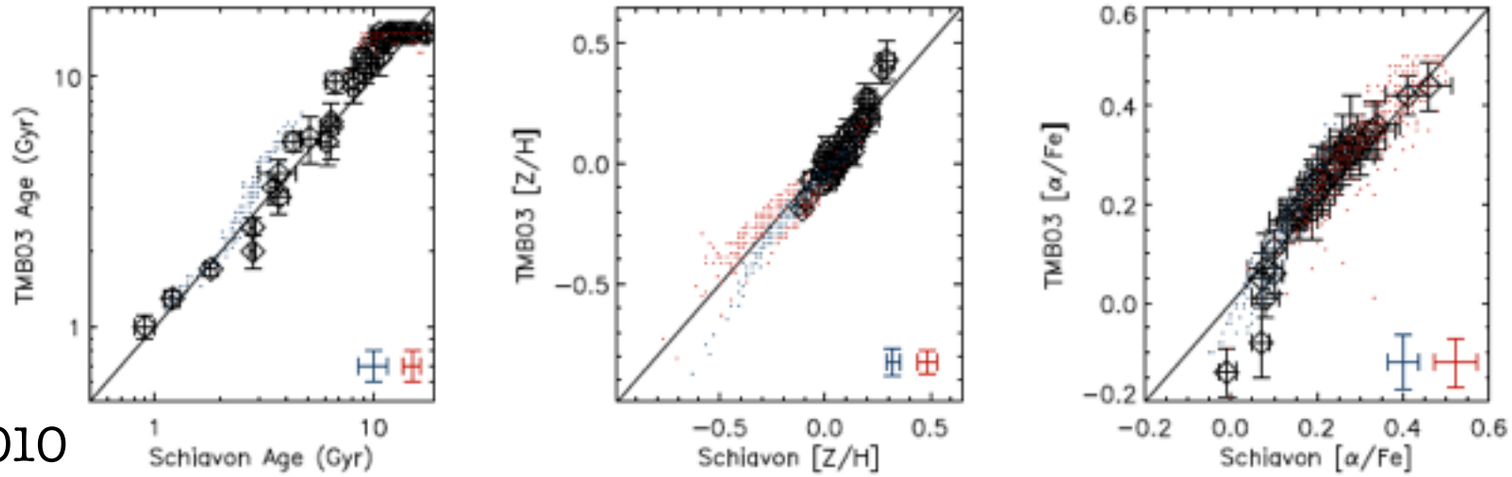


Thomas et al 2011; Johansson et al 2012;
Graves & Schiavon 2008; Proctor & Sansom 2002

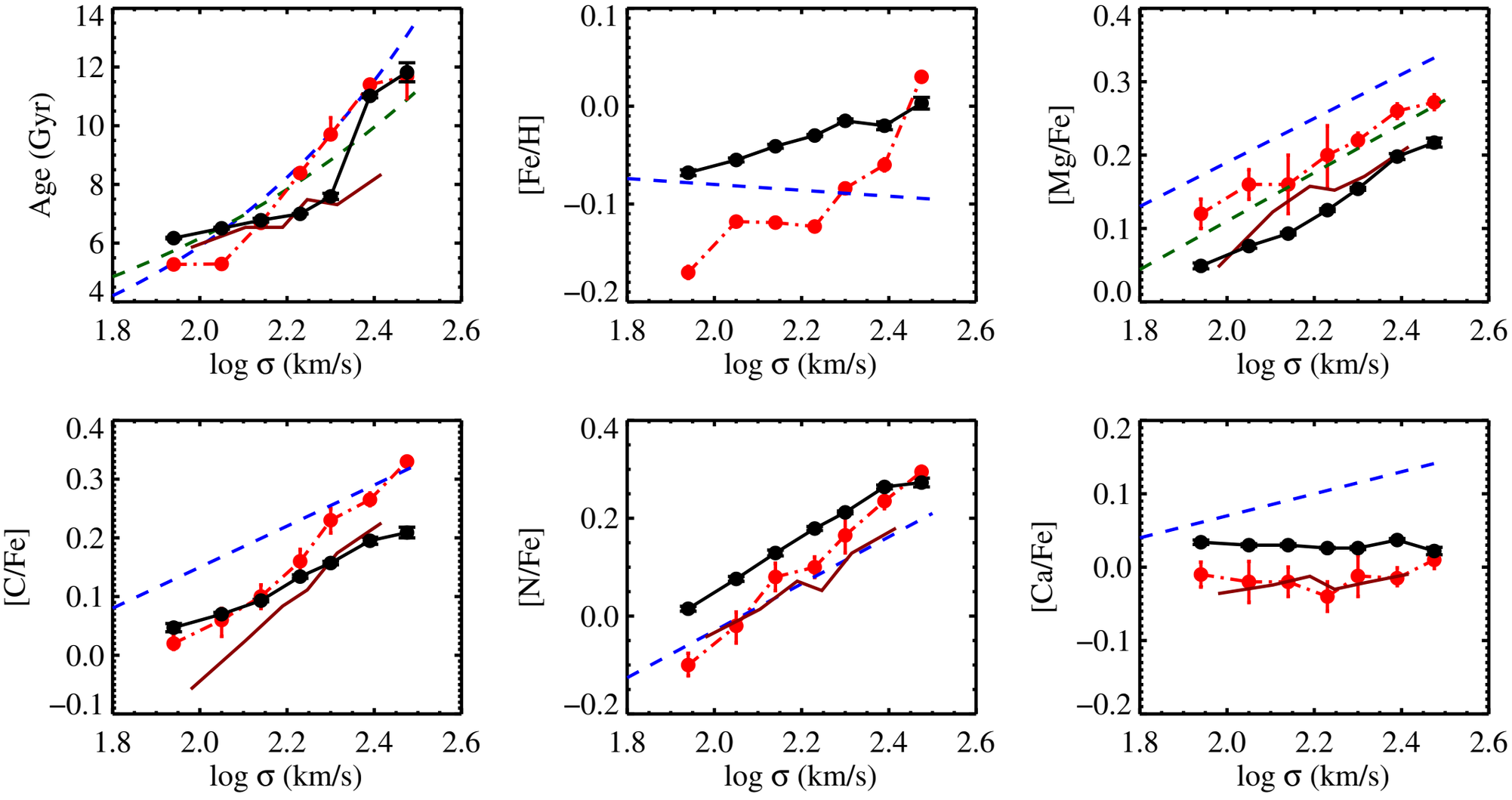
University of Portsmouth

Model comparison

Good (dis)agreement!



Kuntschner et al 2010

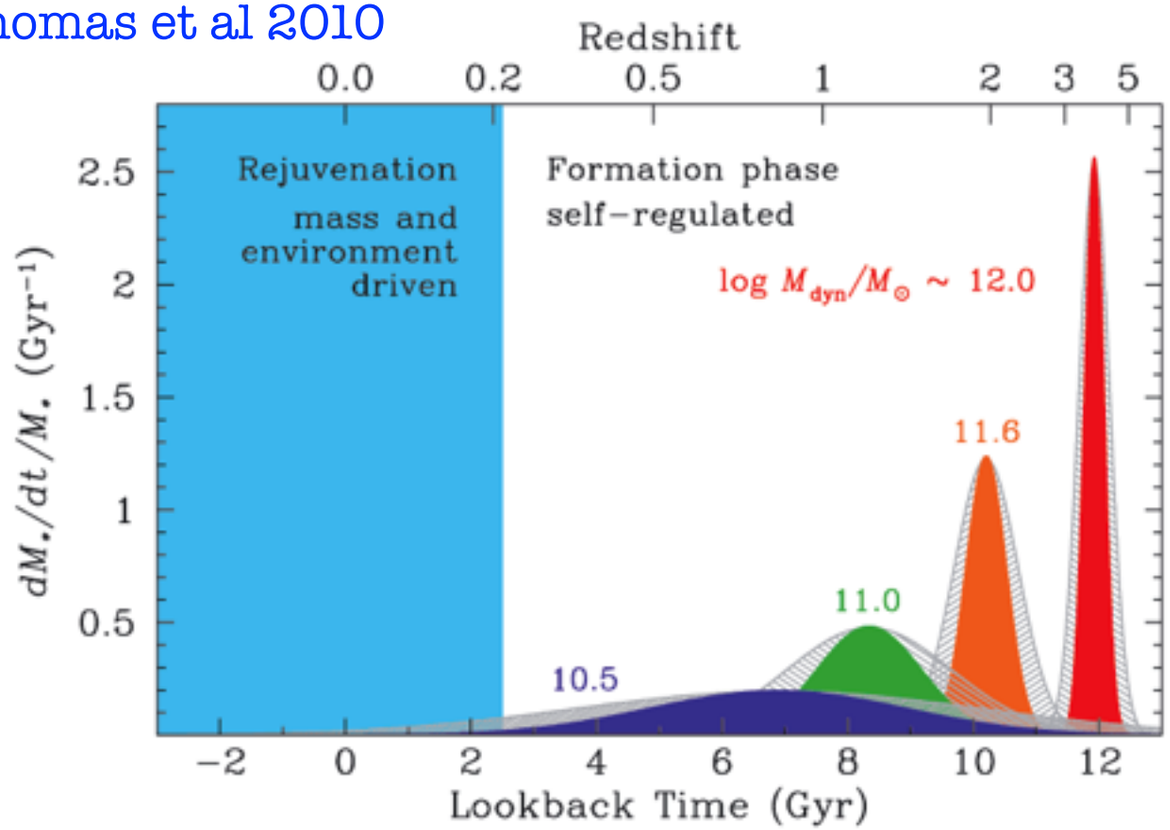


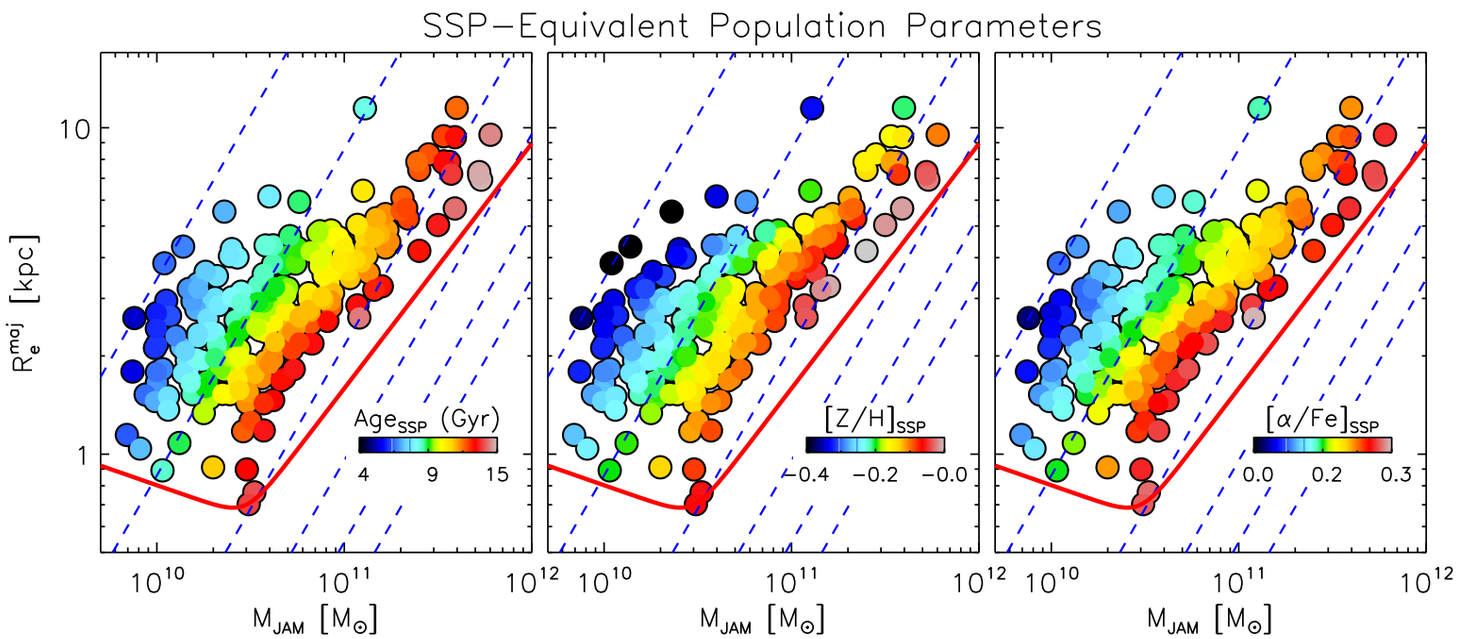
Johansson et al
Graves&Schiavon
Thomas et al
Worthey et al
Conroy et al

Conroy et al 2014

Formation timescales and downsizing

Thomas et al 2010



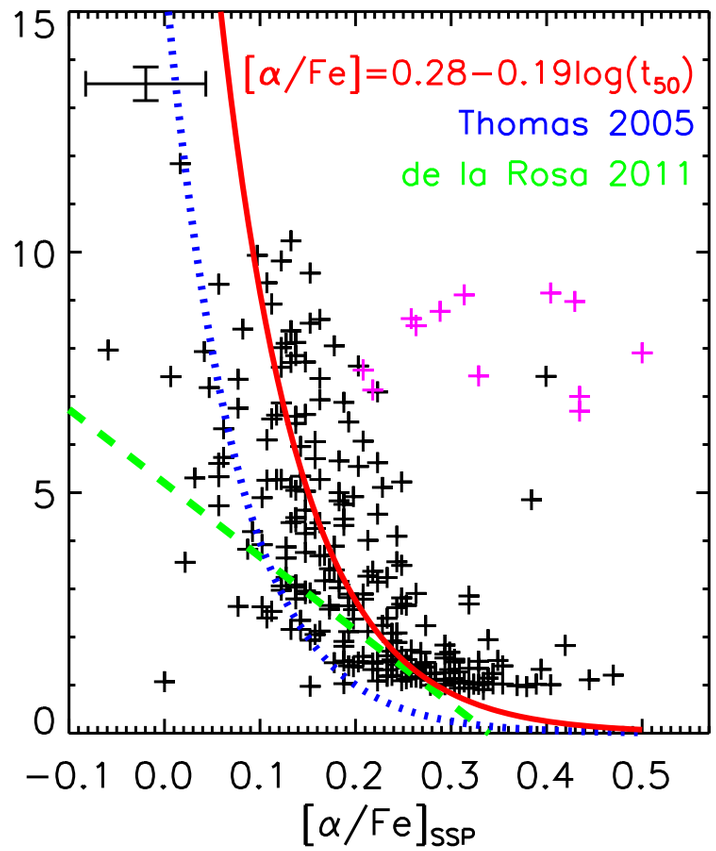


$$[\alpha/\mathrm{Fe}] \approx \frac{1}{5} - \frac{1}{6}\log \Delta t.$$

Thomas et al 2005

- Formation time-scales from α/Fe ratio
- With ages: downsizing
- Strongest correlation with velocity dispersion

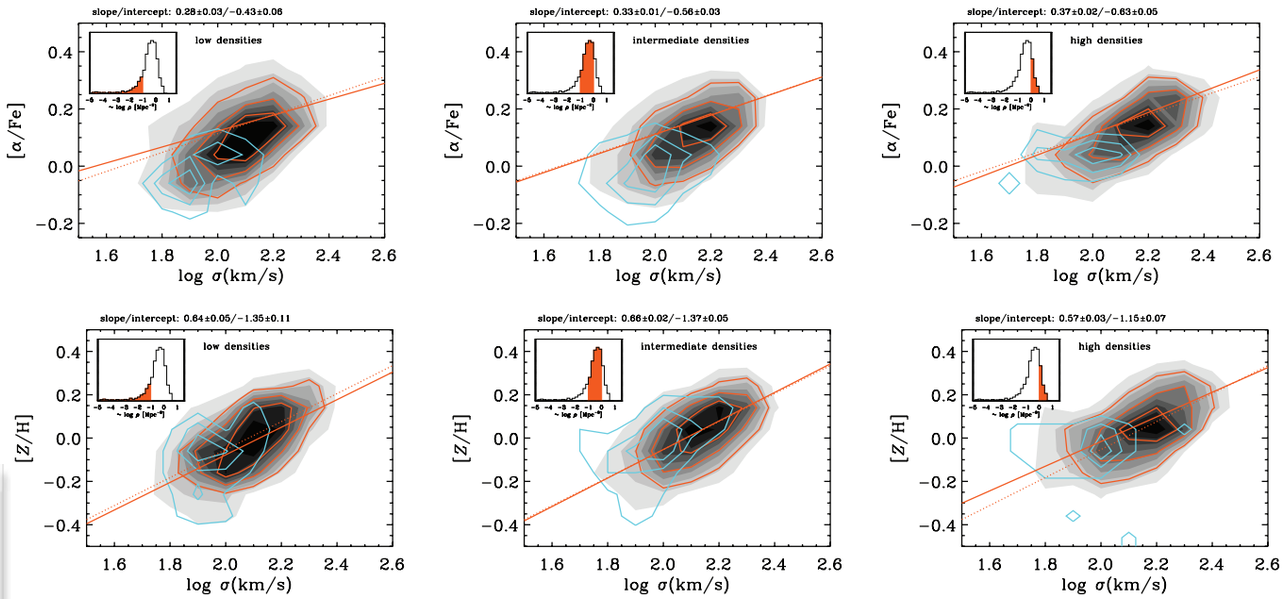
McDermid et al 2015

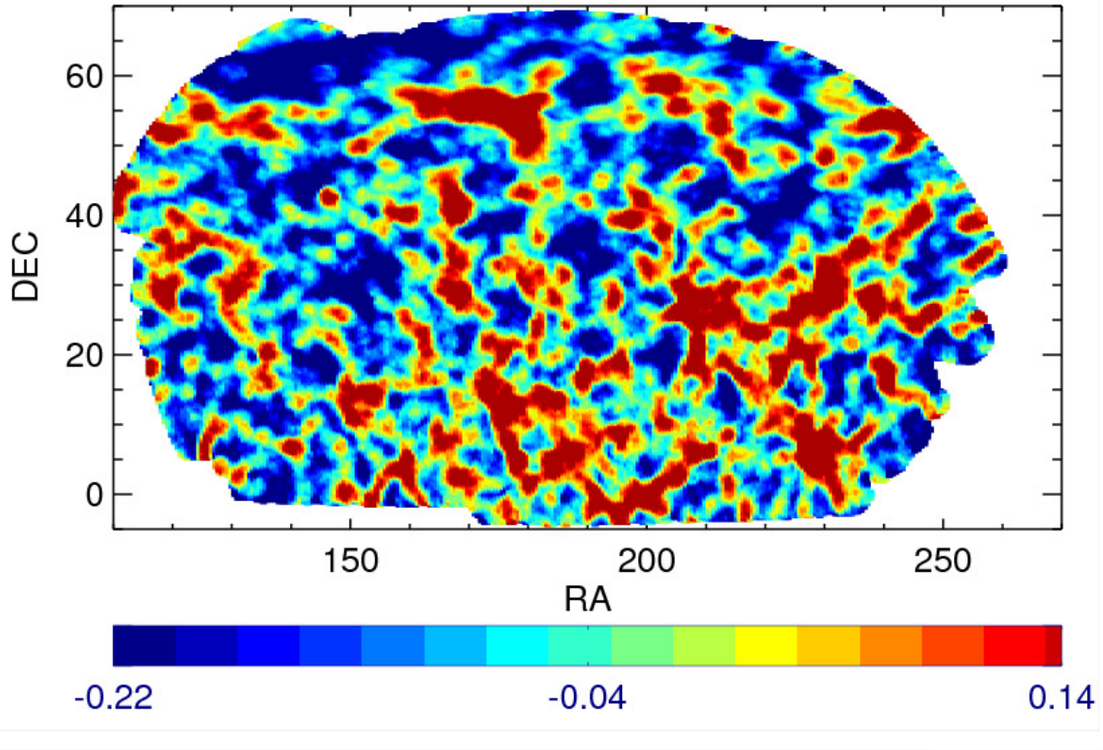


Galaxy populations with SDSS

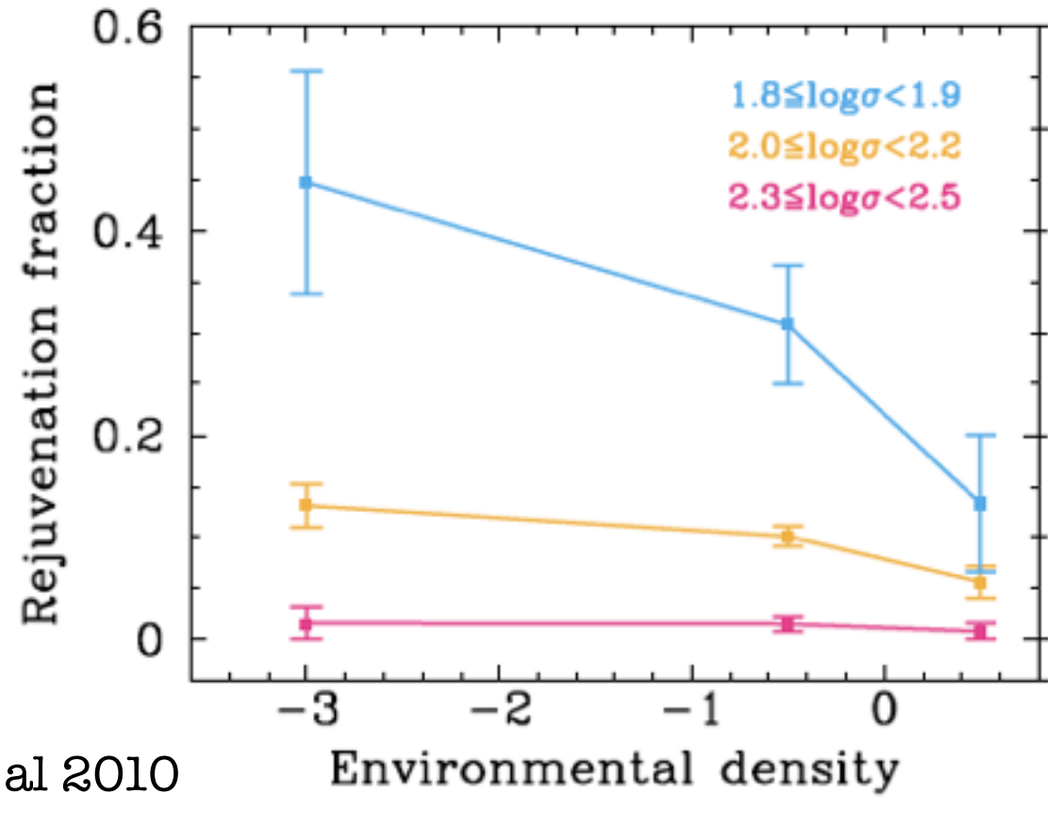
Environmental density

Large survey area allows precise mapping of large scale structure and galaxy environment with statistical analysis of galaxy populations





Etherington & Thomas 2015



Thomas et al 2010

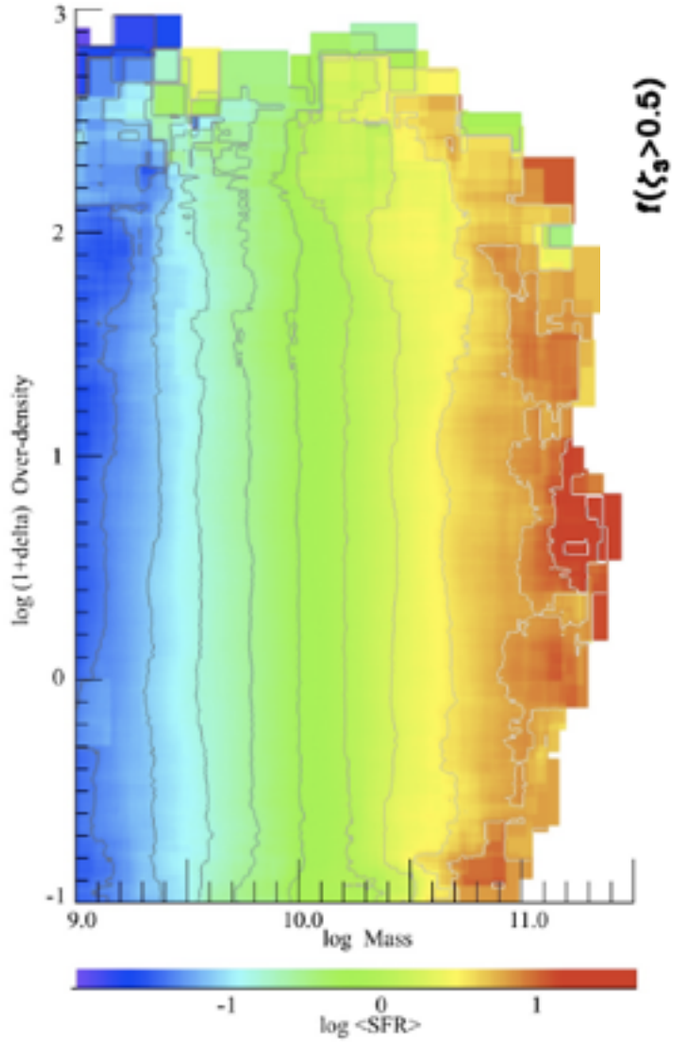
“Mass is the fundamental parameter, not local density”

Anna Gallazzi’s talk

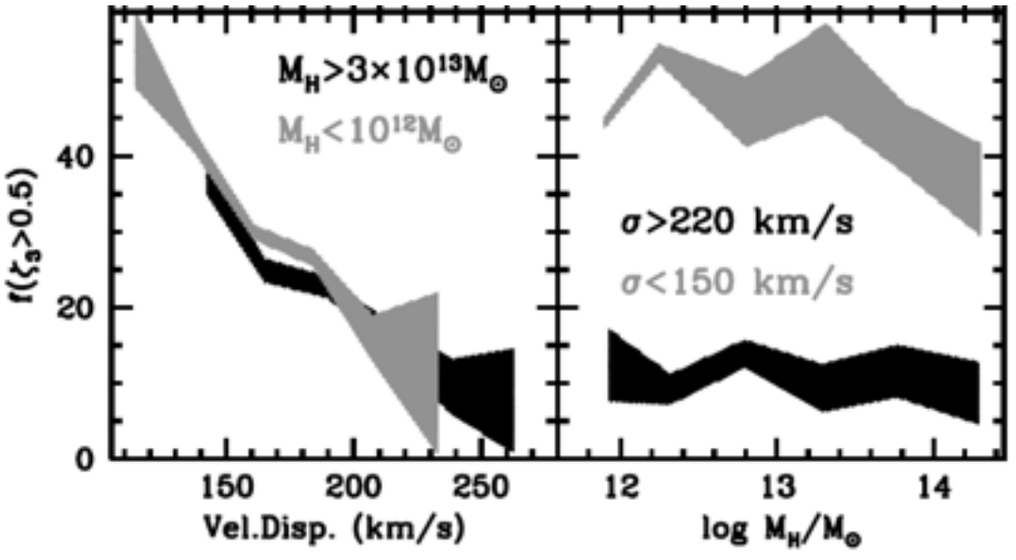
- Environment drives galaxy evolution at low redshifts and low masses
- Fraction of star forming galaxies is independent of environment
- Star formation rate scales with mass

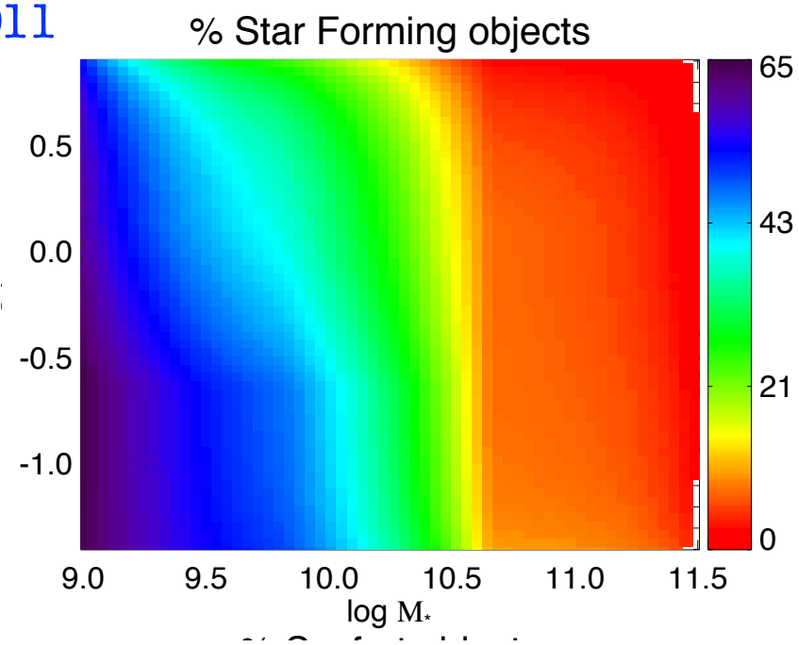
Steele et al 2015

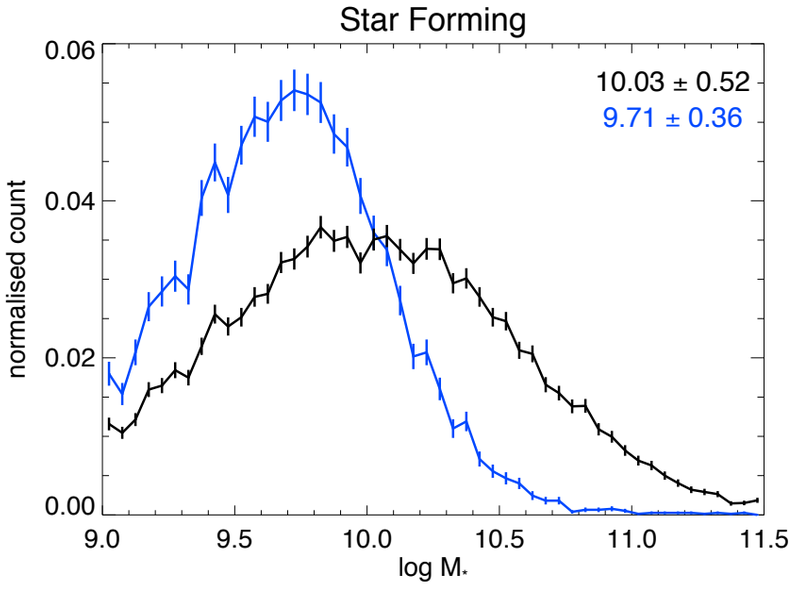
Peng et al 2010

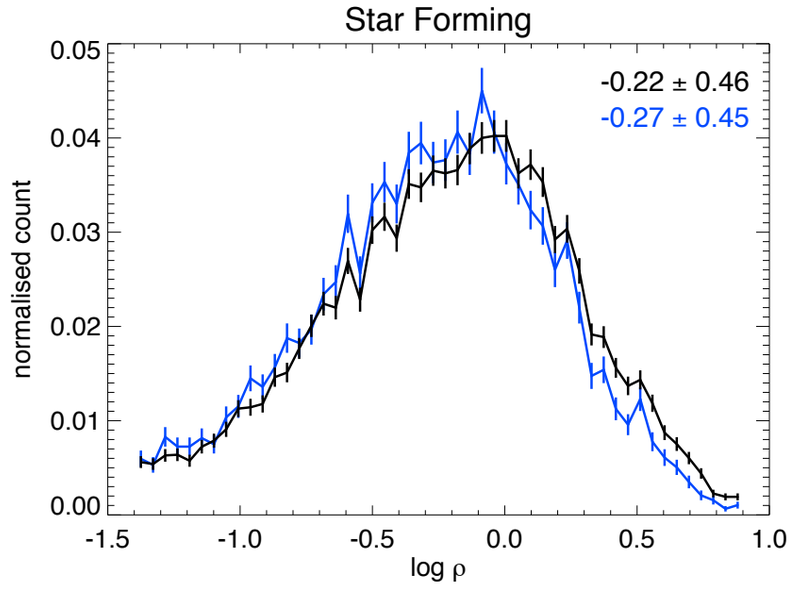


Ferreras et al 2011



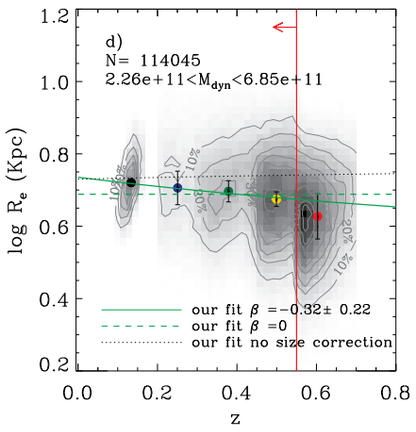




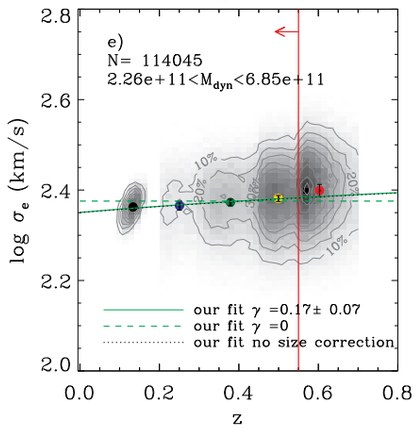


Redshift evolution of dark matter fraction

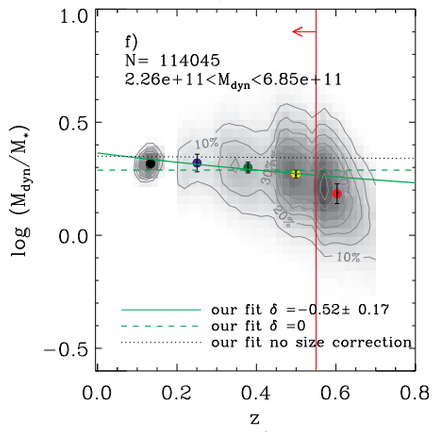
radius



sigma



M_{dyn}/M_{star}

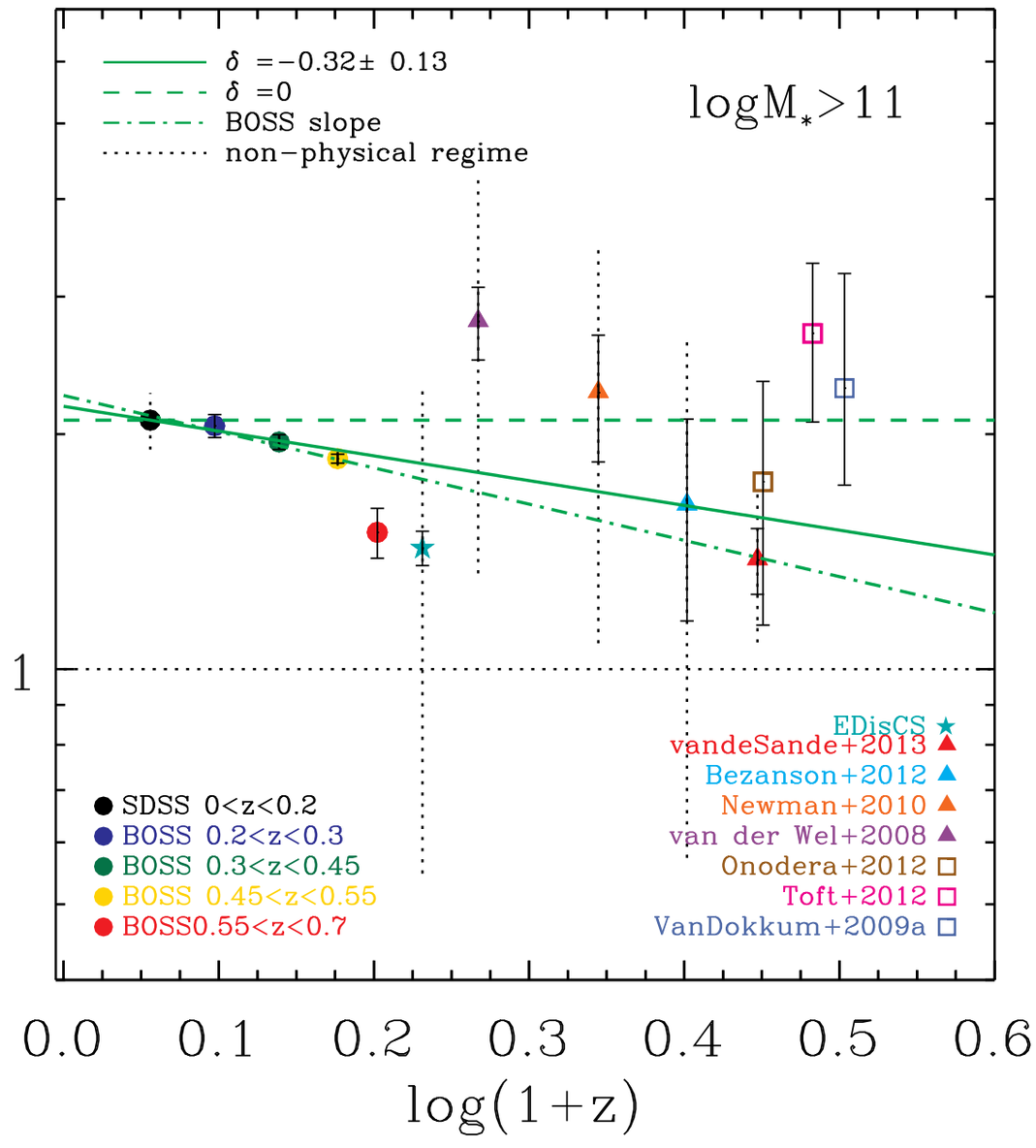


- SDSS-III/BOSS
- M_{dyn}/M^* evolution at >2σ significance
- Dark matter fraction within R_e has been lower in the past

$$M_{\rm dyn}/M_\star \sim (1+z)^{-0.30\pm0.12}$$

Dark matter fraction in centres of massive galaxies grows with cosmic time

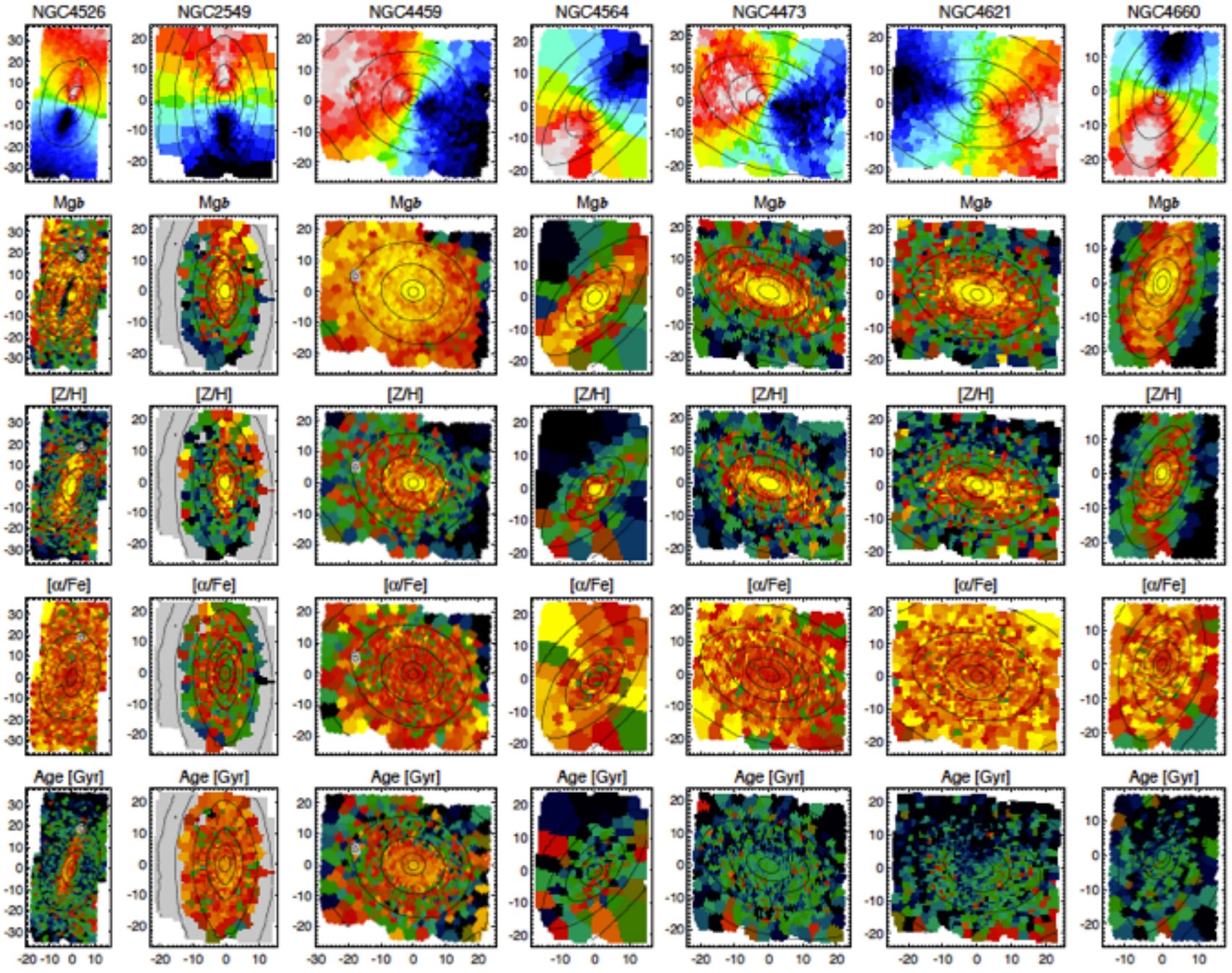
Beifiori et al 2014



Dark Matter Fraction

Cosmic Time

Unresolved populations resolved

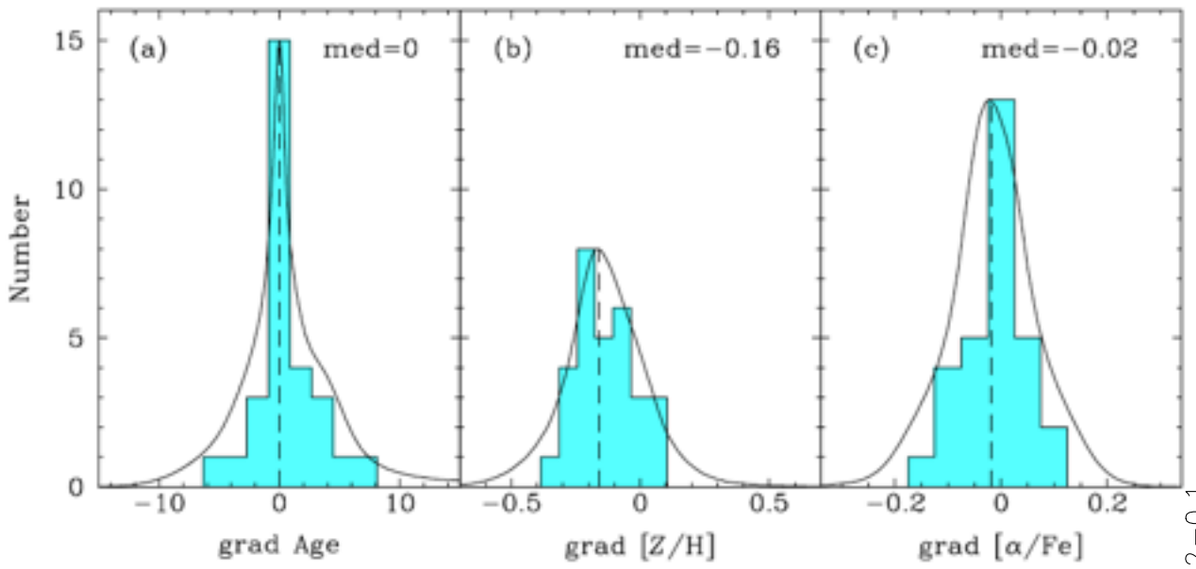


- IFU surveys (SAURON, ATLAS3D, CALIFA)
- Mapping stellar populations and gas physics
- Wealth of information on kinematics and stellar population gradients

Kuntschner et al 2010

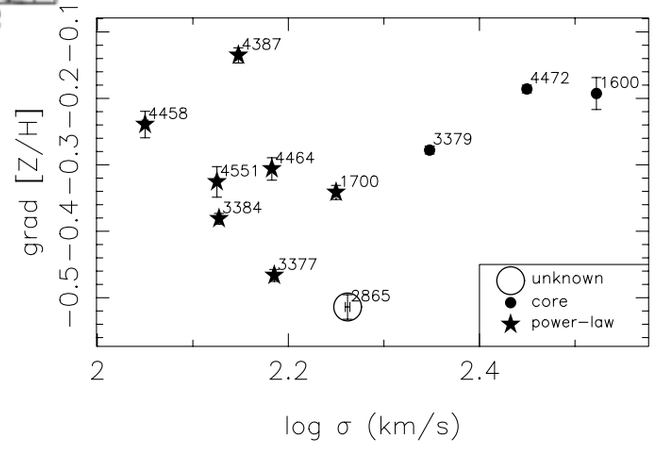
Stellar population gradients

Mehlert et al 2003

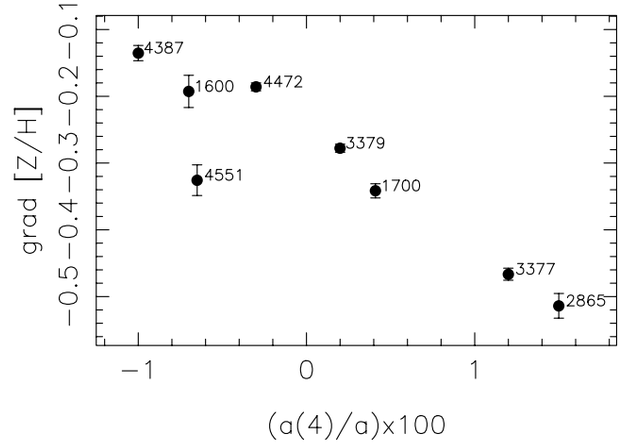


- Flat gradients in age and α/Fe
- Weak correlations with velocity dispersion
- Clear trends with isophotal shape

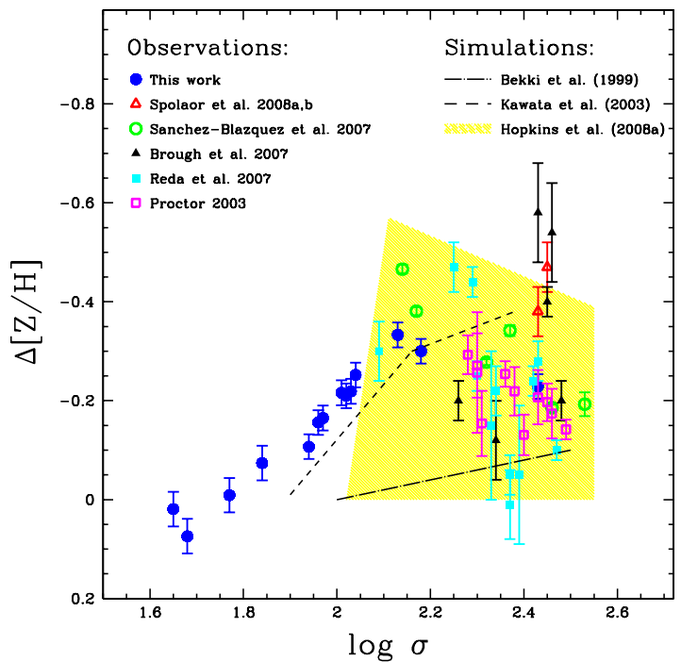
velocity dispersion

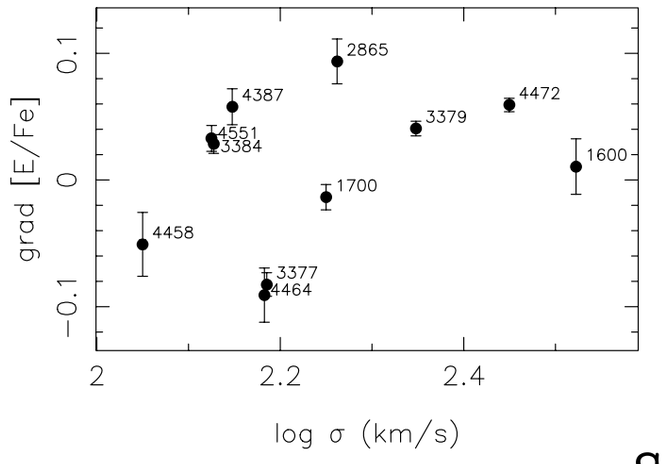


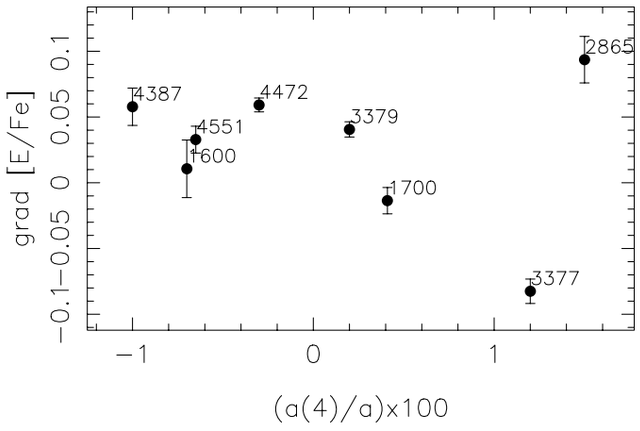
isophotal shape



Spolaor et al 2009



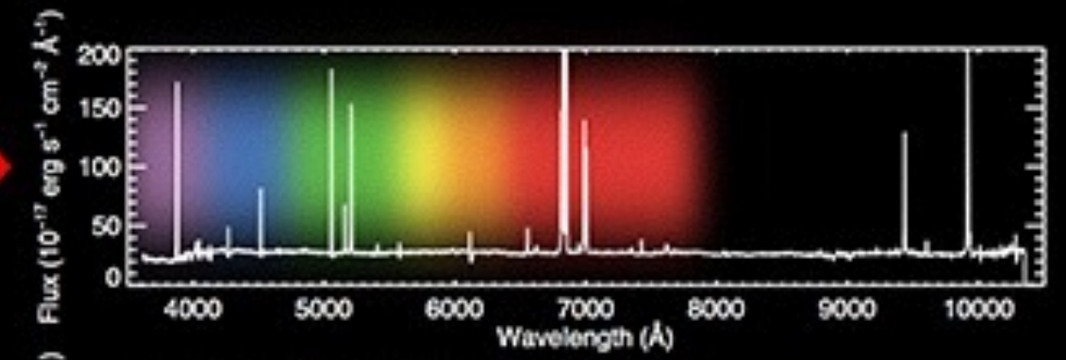




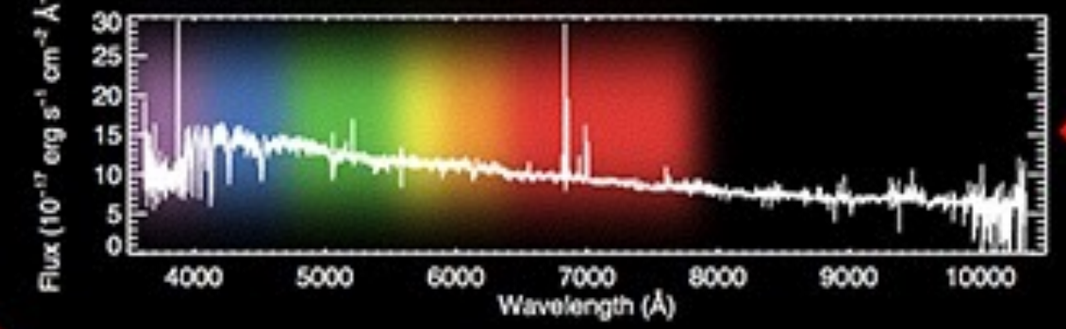
Sánchez-Blázquez et al 2007

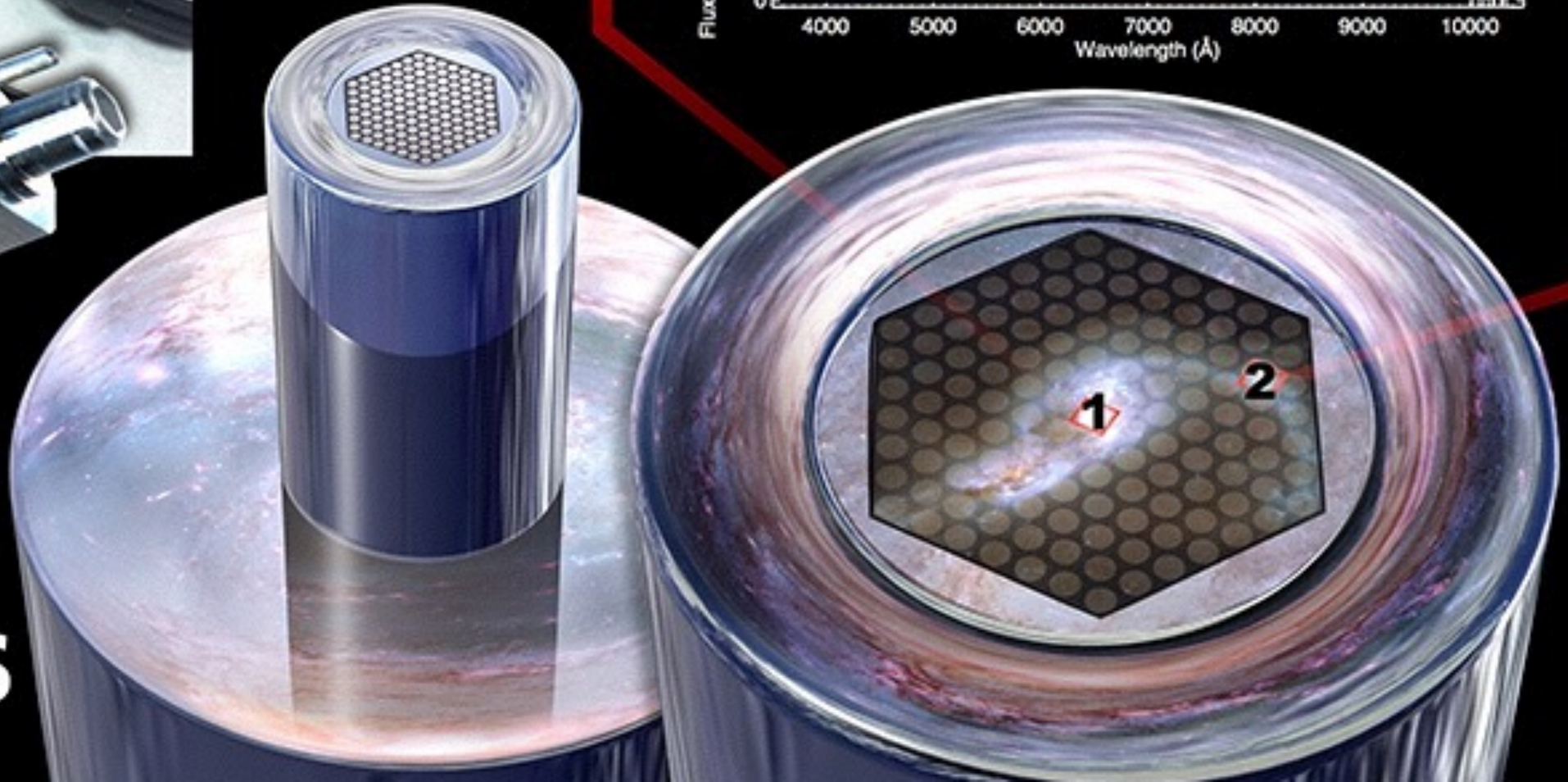
SDSS-IV Dissects 10,000 Galaxies in Nearby Universe

1



2



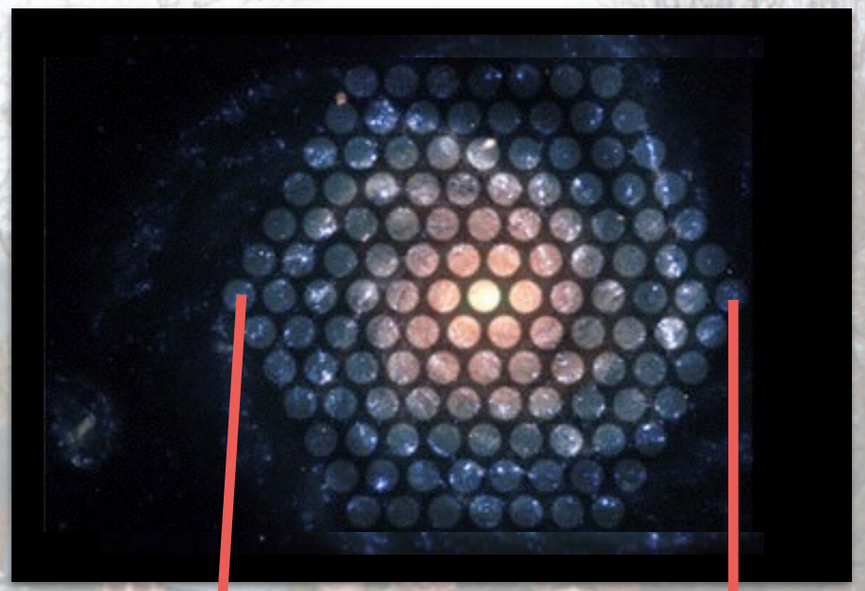


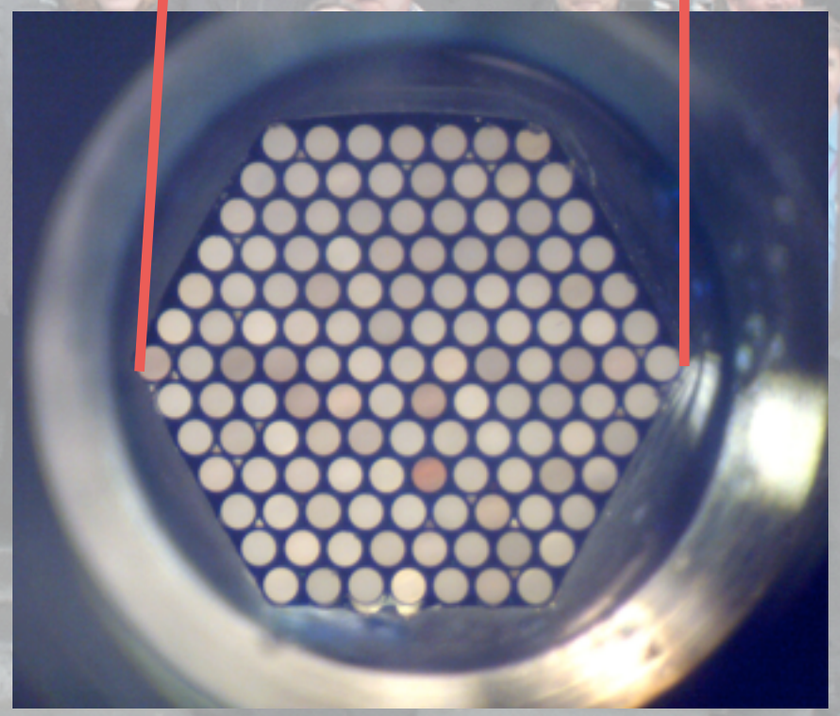
SDSS

MaNGA - galaxies in 3D

Mapping Galaxies at APO (part of SDSS-IV)

- Bundy et al (2015); Drory et al (2015)
- Bundles of 1300 fibres to create Integral Field Units
- 3D view of 10,000 galaxies across the cosmic web
- Resolution = 1- 4 kpc (2"); 50-70 km/s (σ)
- S/N ~ 5-10 at 1.5 Re
- First since papers published (Wilkinson et al 2015; Beifiori et al 2015; Li et al 2015)





Principal Investigator	Kevin Bundy (Kavli IPMU)
Chief Engineer/Project Manager:	Nick MacDonald (Washington)
Survey Scientist:	Renbin Yan (Kentucky)
Instrument Scientist	Niv Drory (UT Austin)
Lead Data Scientist	David Law (Dunlap Institute, Toronto)
Sample Design Lead	David Wake (Open University, Wisconsin)
Lead Observer	Anne-Marie Weijmans (St Andrews)
Science Team Chair	Daniel Thomas (Portsmouth)

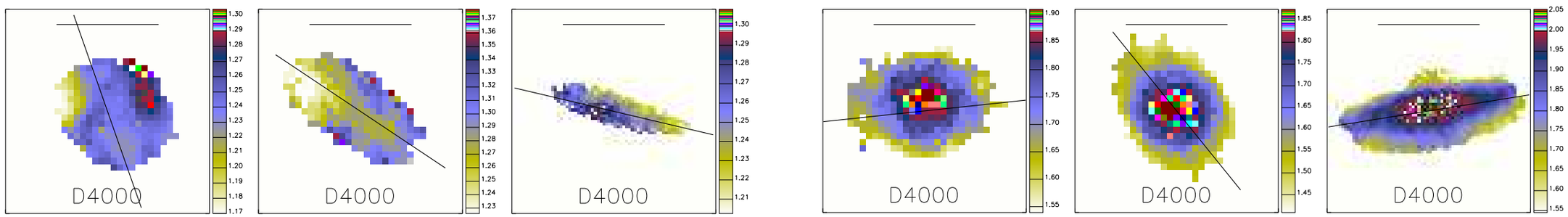
University of Portsmouth

ICG Portsmouth

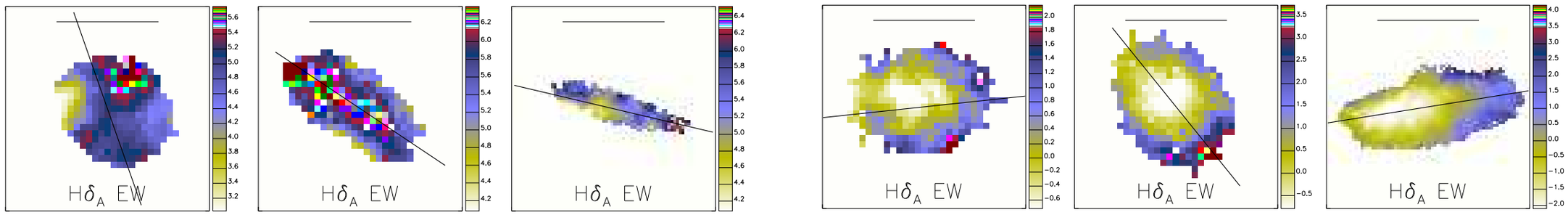
Star forming

Quiescent

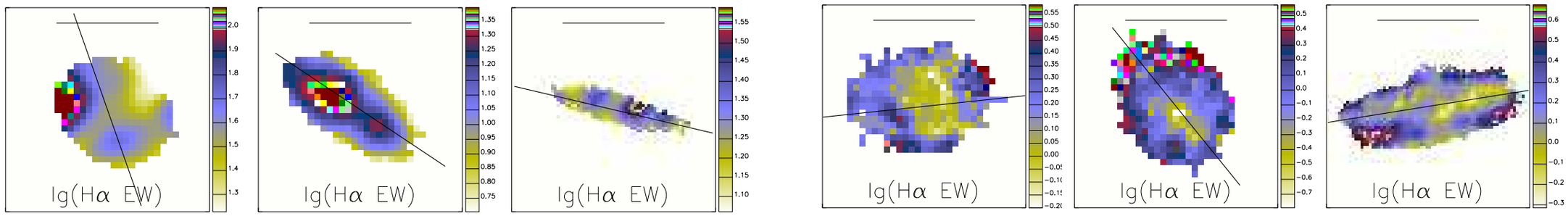
D4000



Hδ

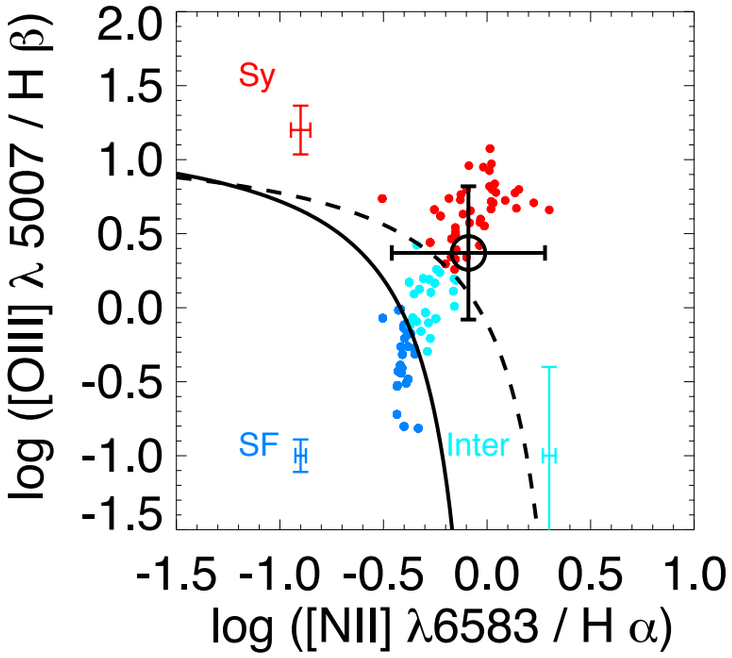


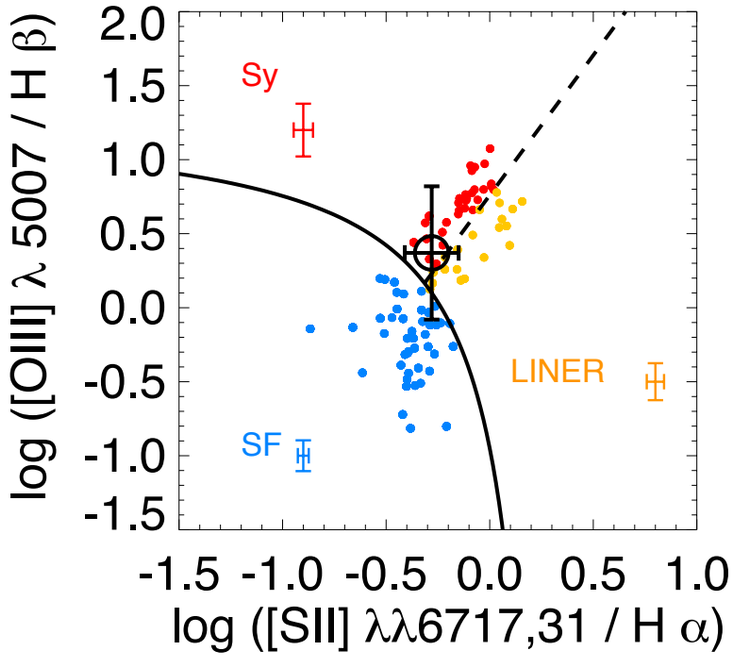
Hα

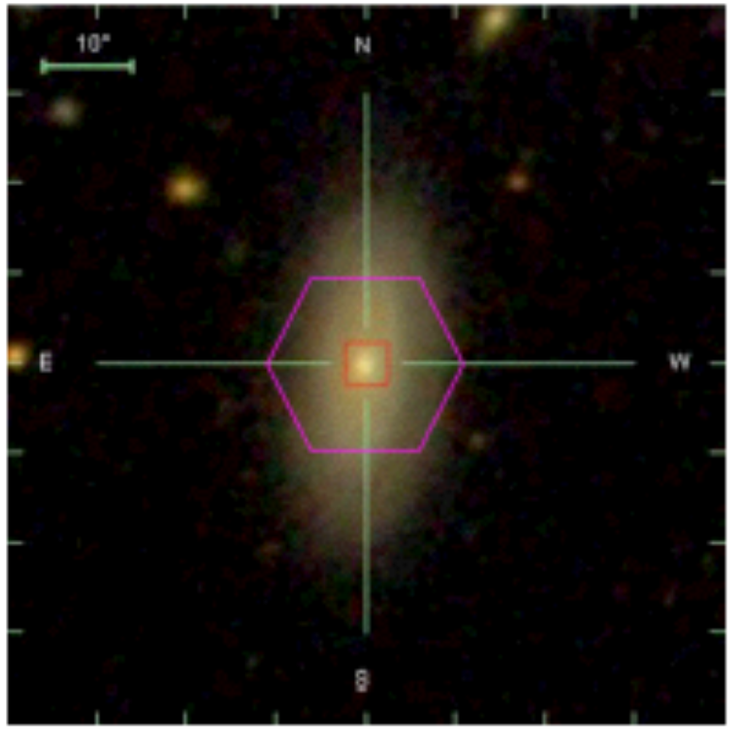


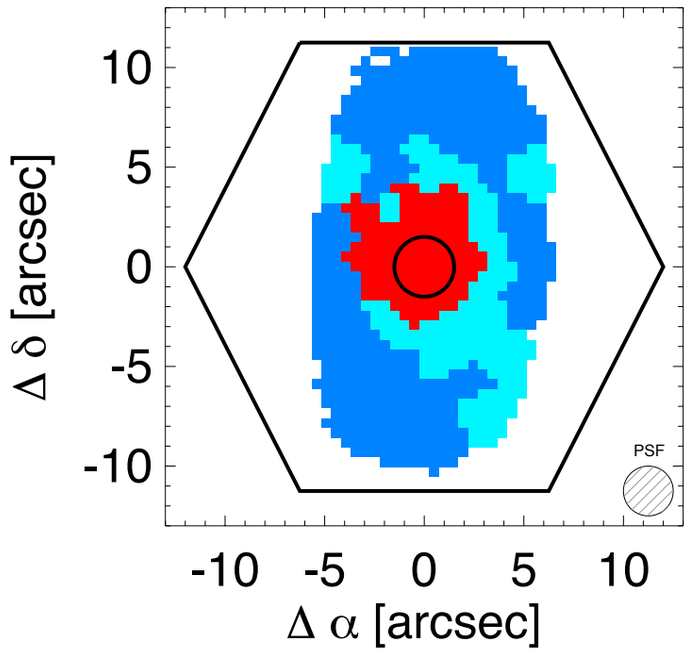
Li et al 2015

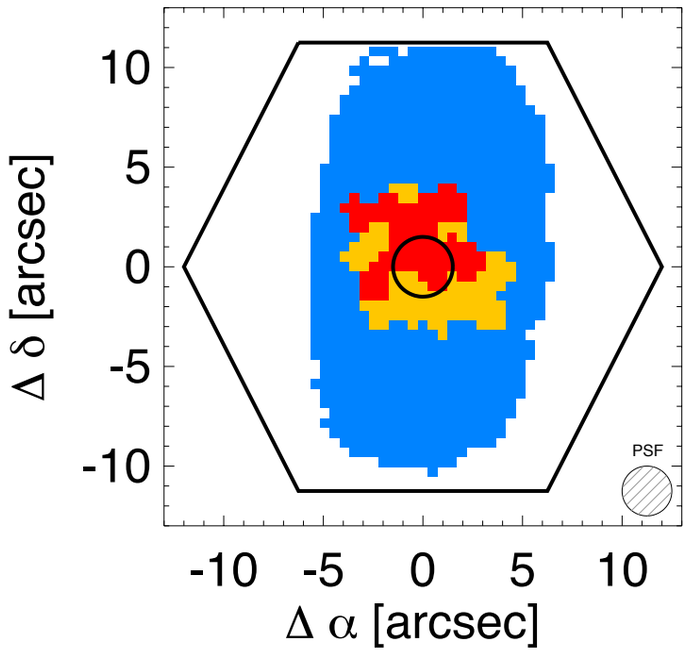
Spatially resolved BPT: disentangling AGN from SF





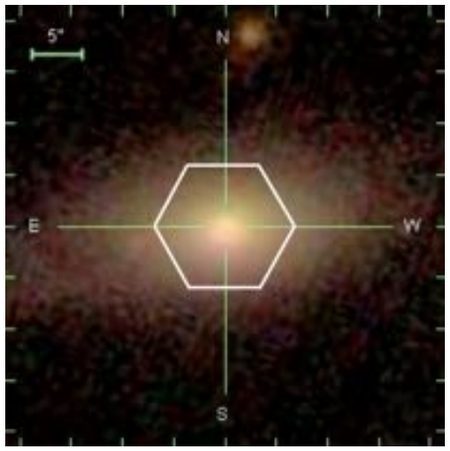




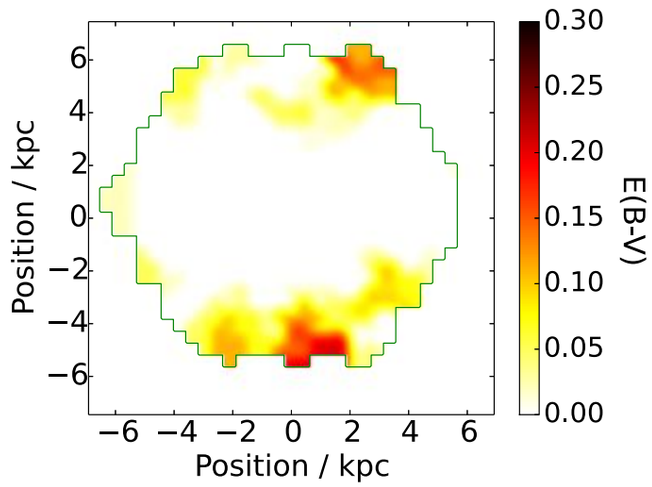


- SDSS: AGN
- MaNGA: Seyfert/ LINER in centre with extended star formation in outskirts

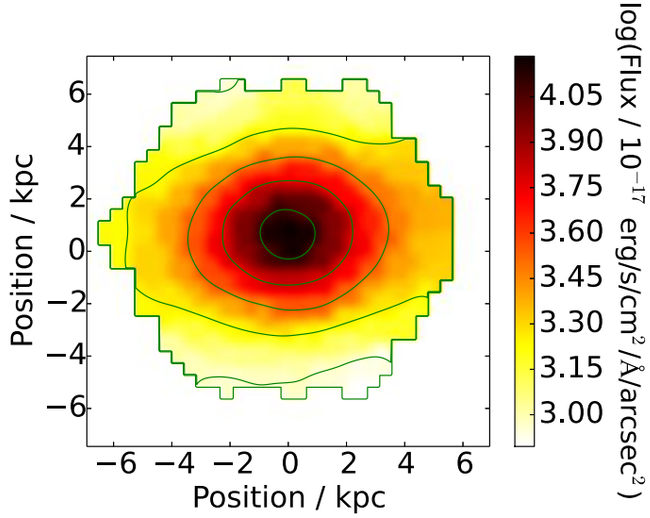
Belfiore et al 2015



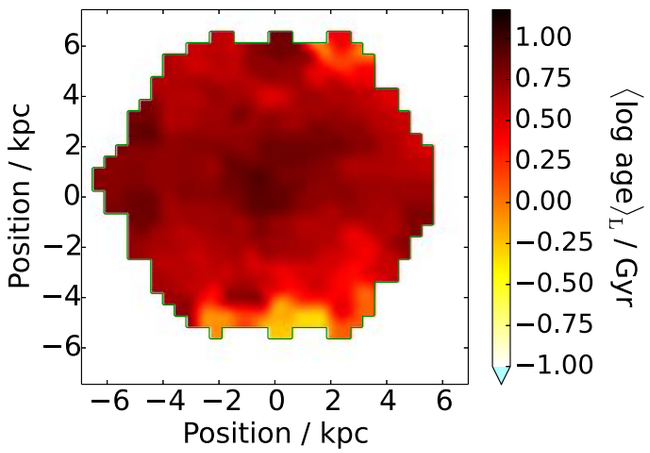
(a) SDSS image with the P-MaNGA footprint.



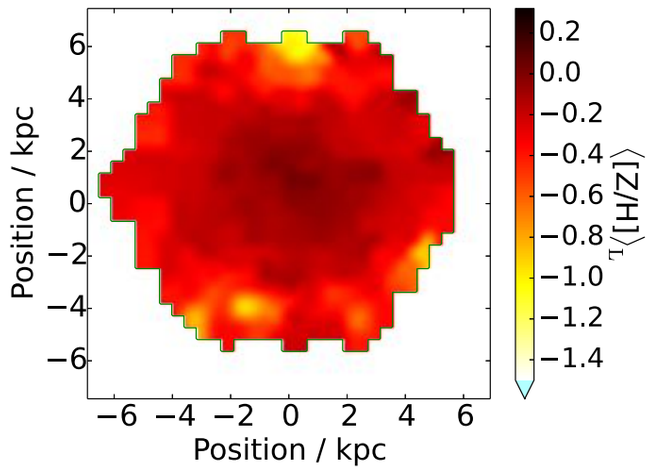
(b) Dust extinction, E(B-V).



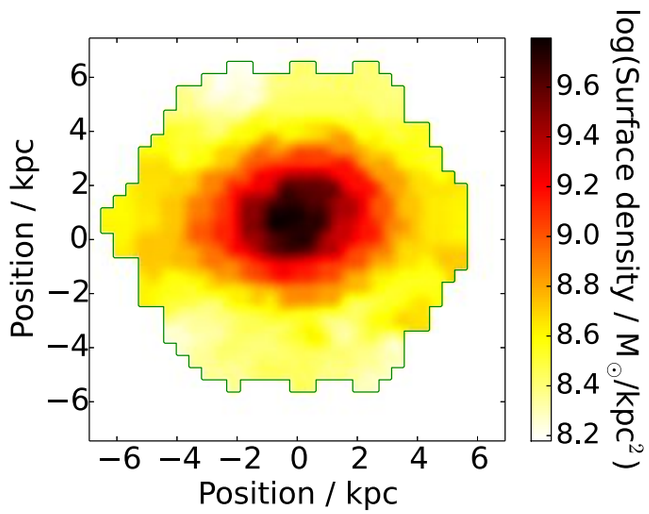
(c) Flux map with isoflux contours (green).



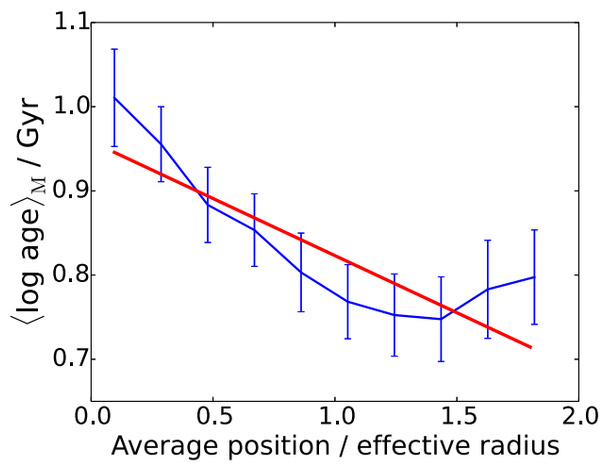
(d) Luminosity-weighted stellar age.



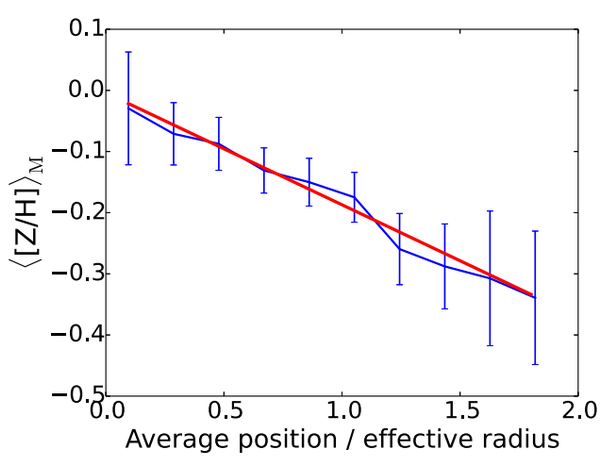
(e) Luminosity-weighted metallicity.



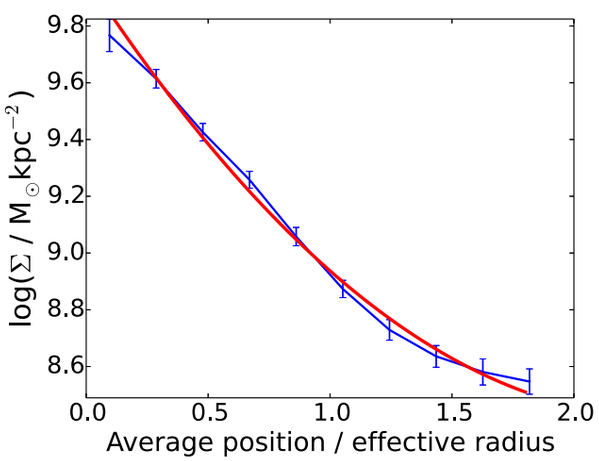
(f) Stellar mass.



(j) Radial age profile.



(k) Radial metallicity profile.

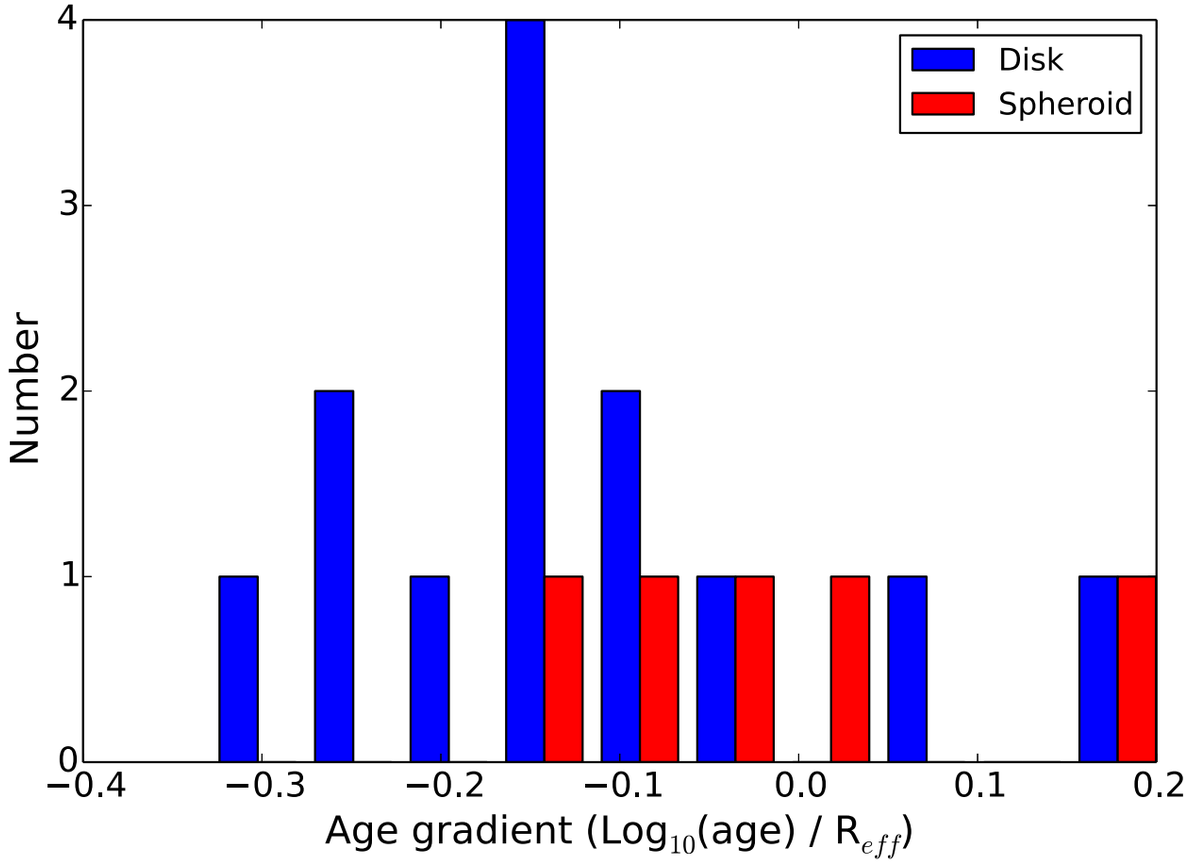


(l) Stellar mass surface density gradient profile.

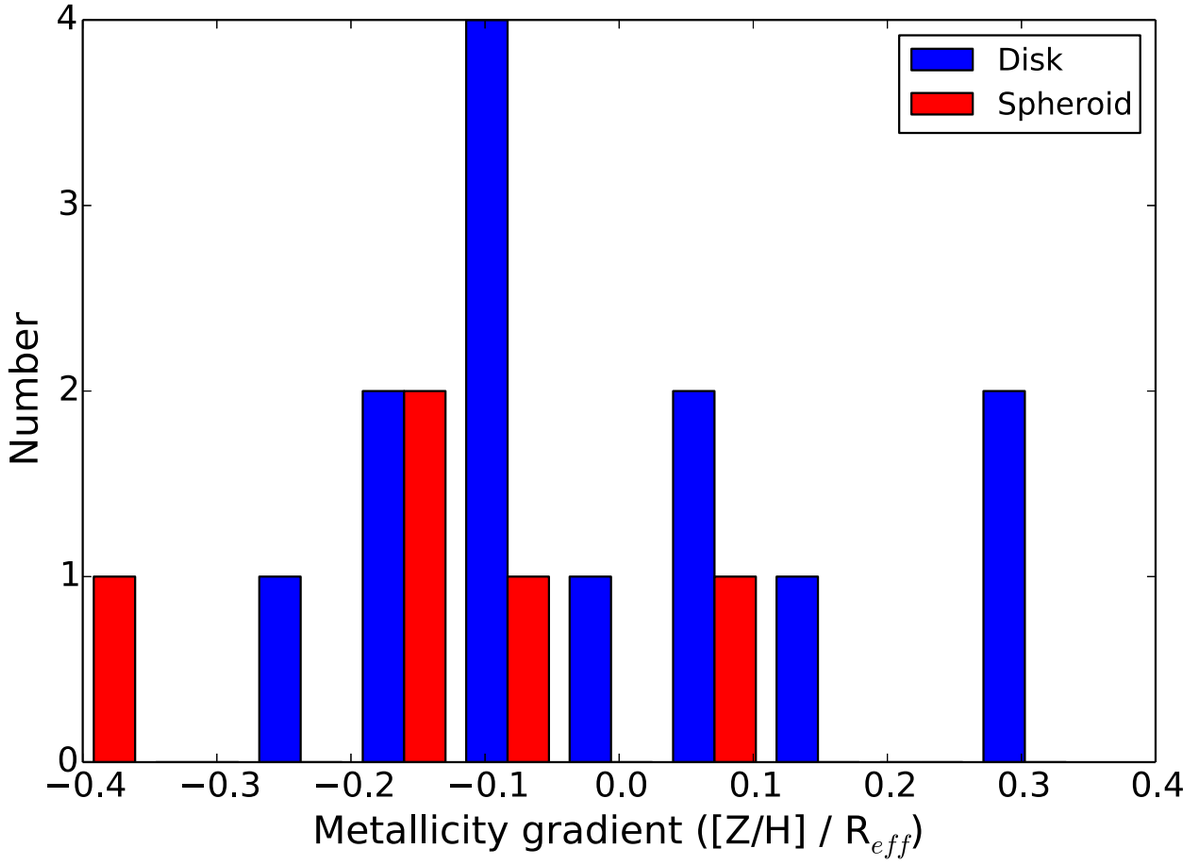
Wilkinson, Maraston, Thomas et al 2015

Stellar population gradients

Age



Metallicity



Age gradients: Negative for discs, flat for spheroids

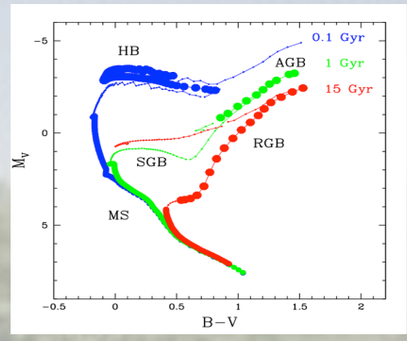
Metallicity gradients: Flat for discs, negative for spheroids

(Mehlert et al 2003; Kuntschner et al 2010; González Delgado et al 2014)

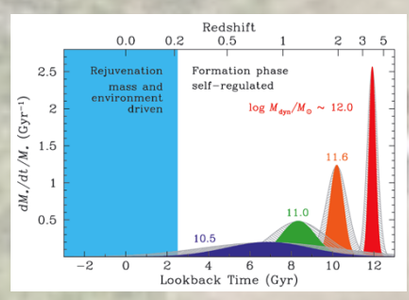
Wilkinson et al 2015

Summary

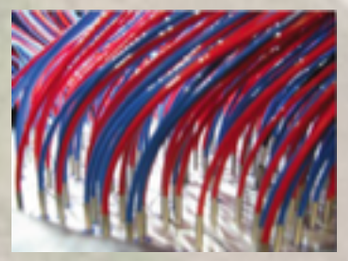
- Unresolved populations
  - Fossil record from stellar population modelling
  - Stellar libraries: discrepancies between state-of-the art libraries
  - Variable element ratios remain challenging



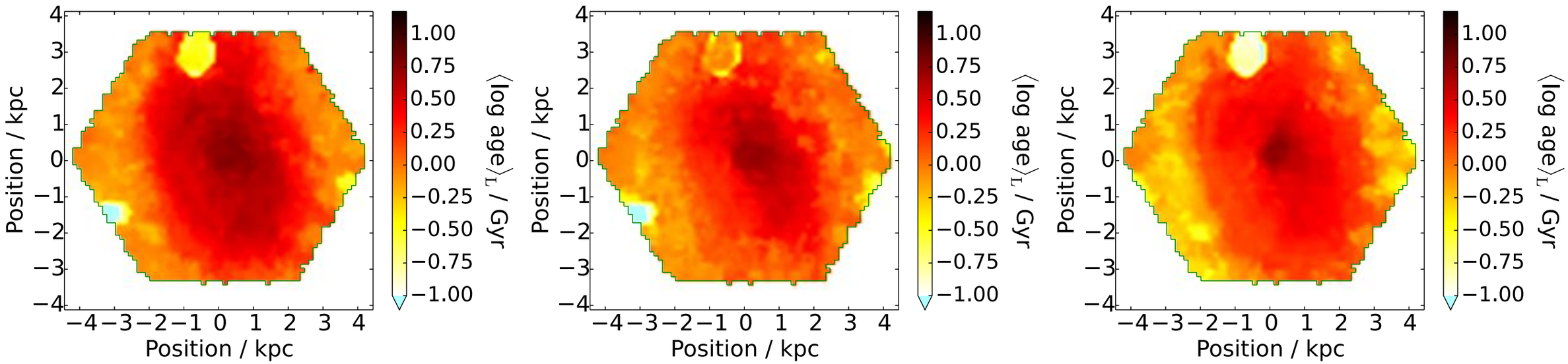
- Progress from large galaxy surveys
  - Statistical analysis of galaxy populations: downsizing
  - Robust measurement of environment: mass is driving parameter
  - Redshift evolution of galaxy properties becomes accessible



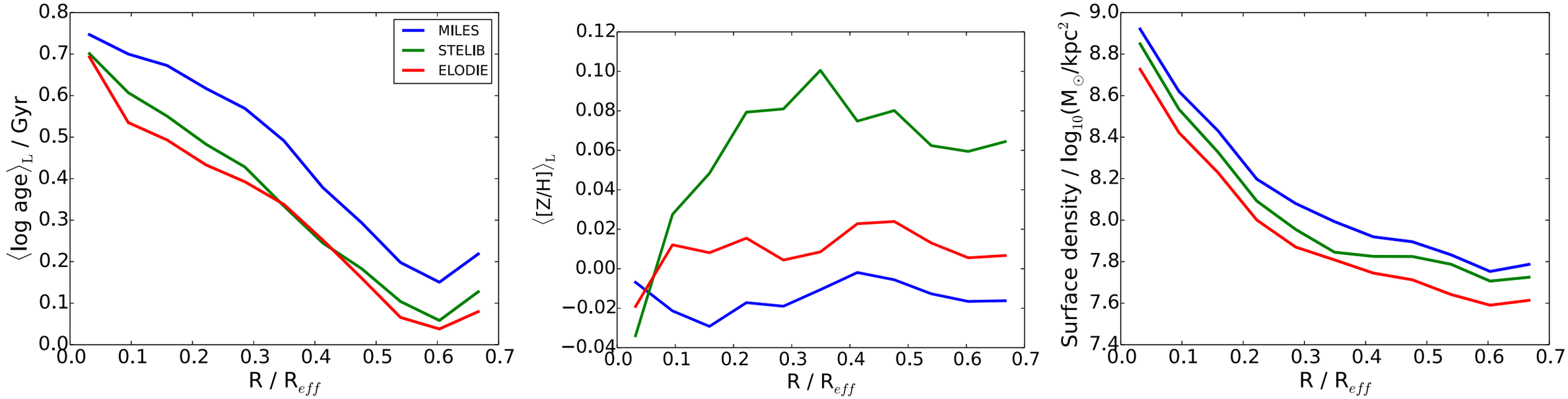
- Spatially resolved stellar populations
  - Flat gradient in age and alpha/Fe challenge formation models
  - Correlations between stellar pop gradients and galaxy properties uncertain
  - Major progress through IFU surveys
  - New large-scale IFU surveys are major step forward
  - SDSS-IV/MaNGA: large sample size and spectral range



Effect of stellar libraries



(a) Light-weighted age maps of p9-127A as a function of stellar library; MILES, STELIB, and ELODIE are shown in the left, middle, and right panels respectively.



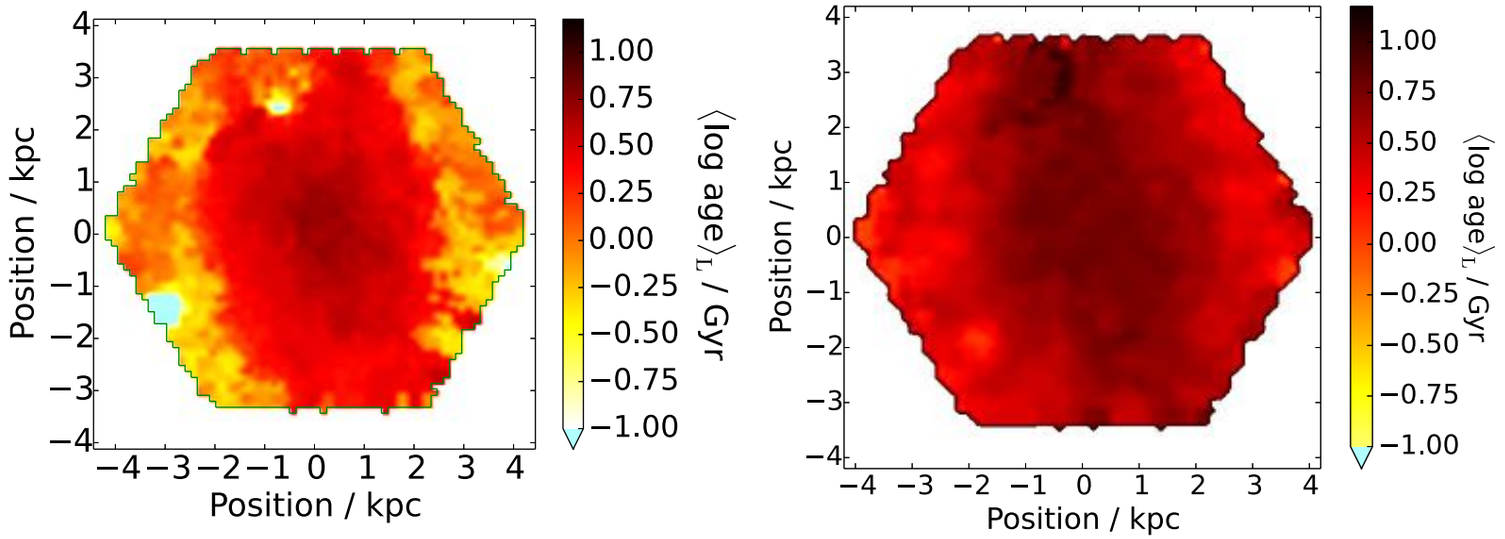
Wilkinson et al 2015

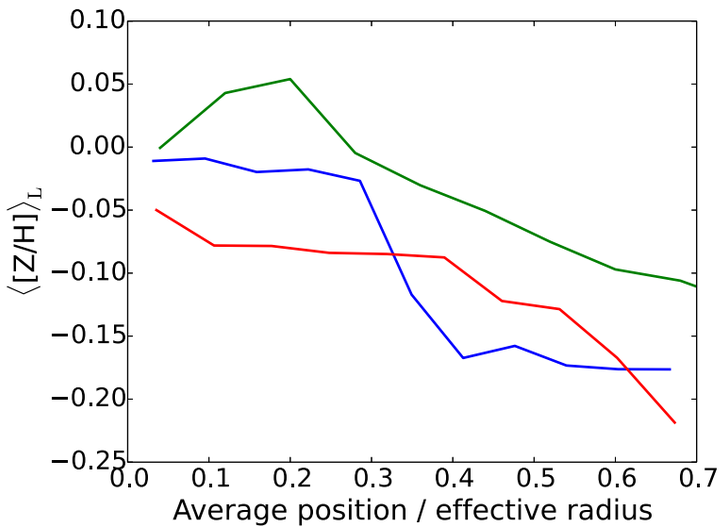
Impact of fitting algorithms/models

FIREFLY

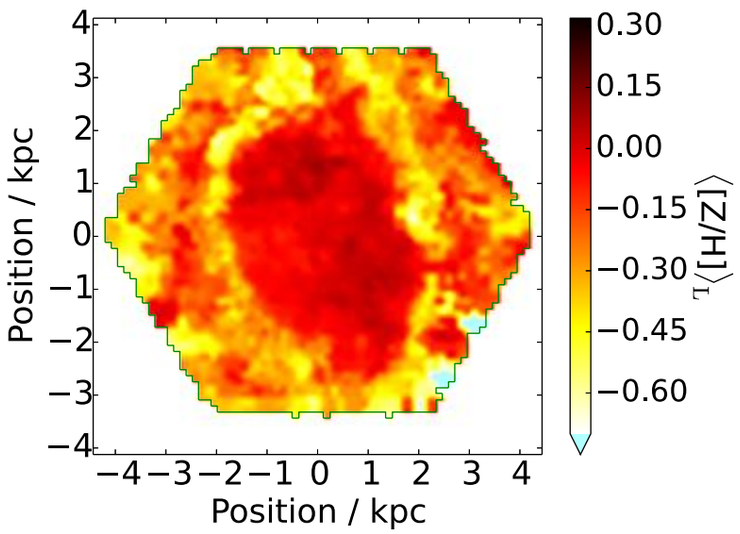
pPXF

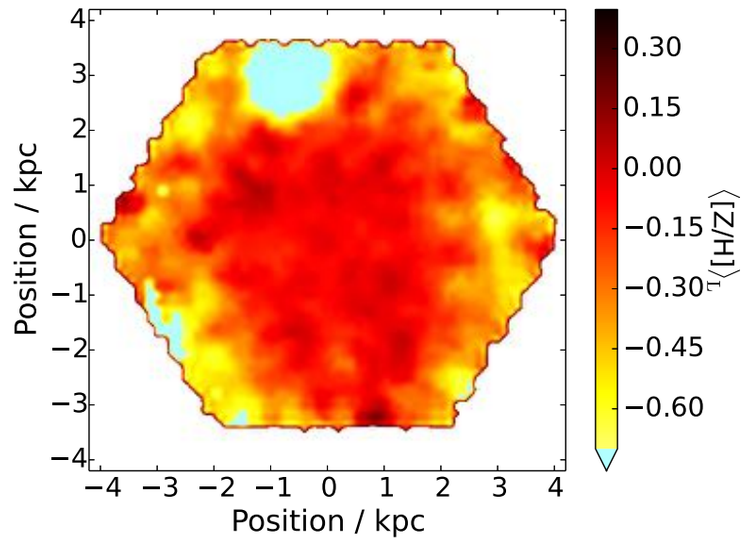
age

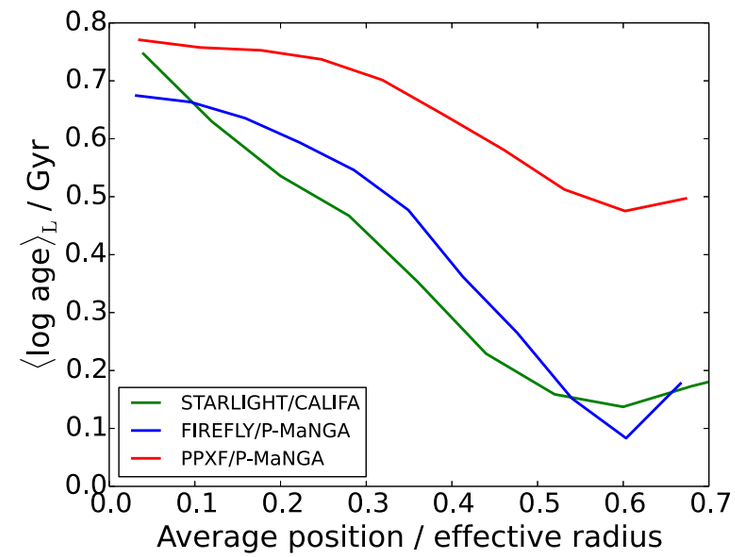




[Z/H]



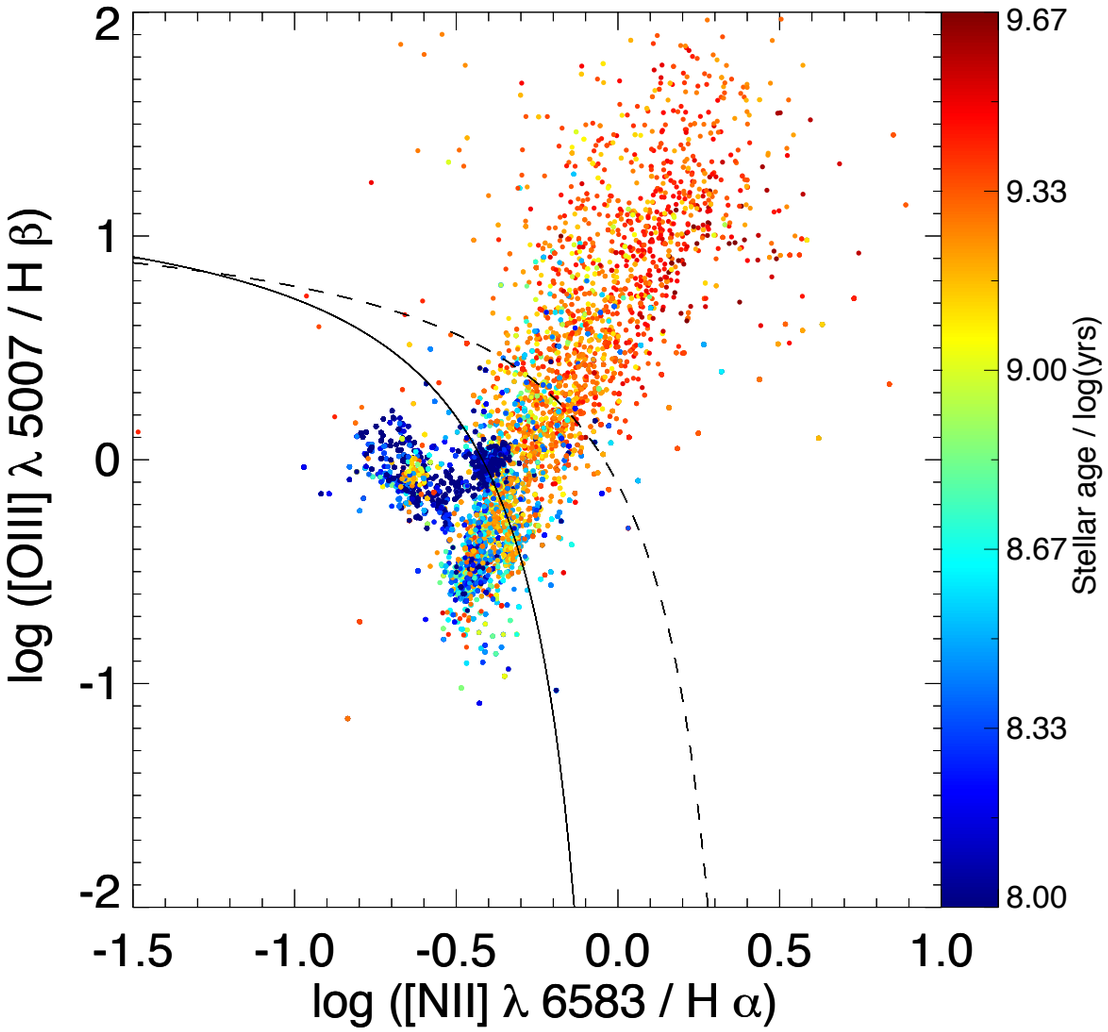


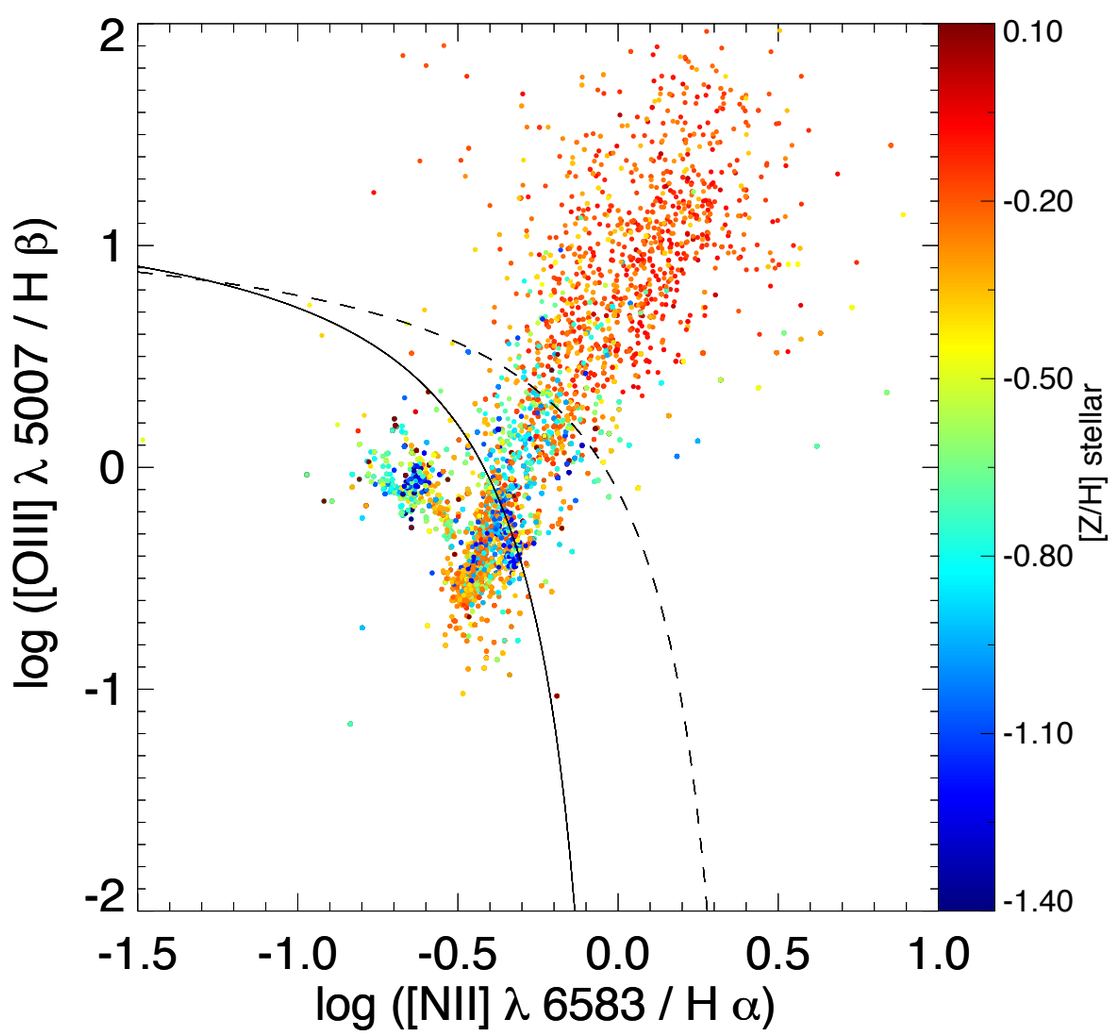


Wilkinson et al 2015

Stellar populations vs gas physics

Age and metallicity pattern on emission line classification resolved





Belfiore et al 2015

Wilkinson et al 2015

Bundle size distribution

16 bundles per cartridge
(1017 bundled fibers)
5 cartridges ➙ 80 bundles total

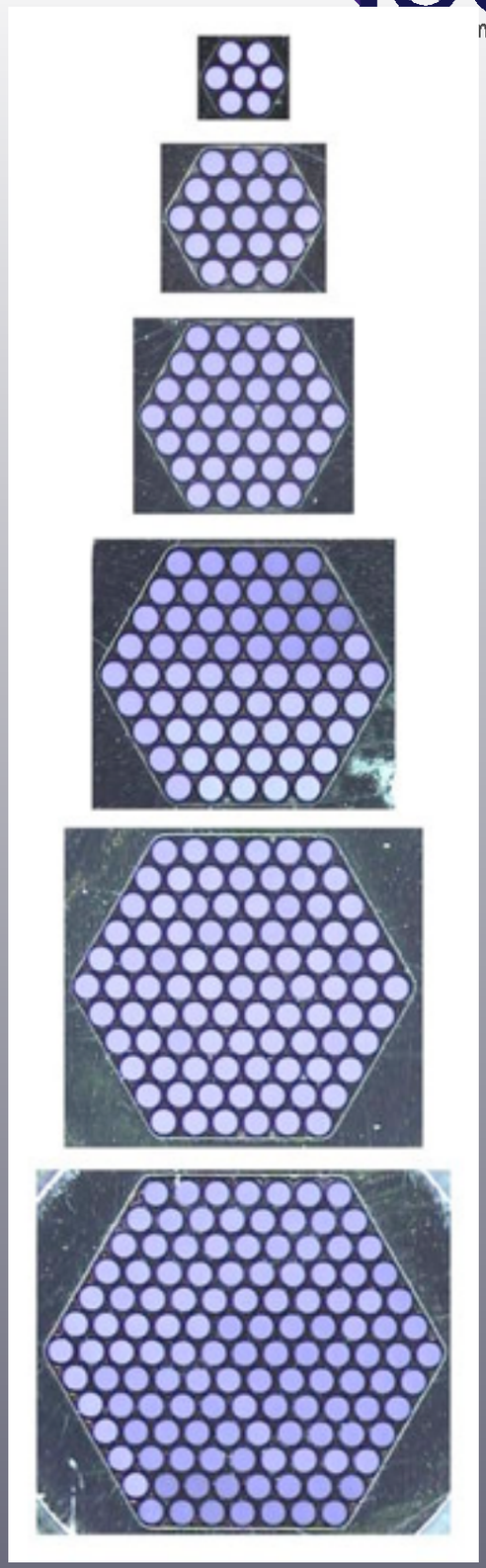
3 bundles x 19 fibers

4 bundles x 37 fibers

3 bundles x 61 fibers

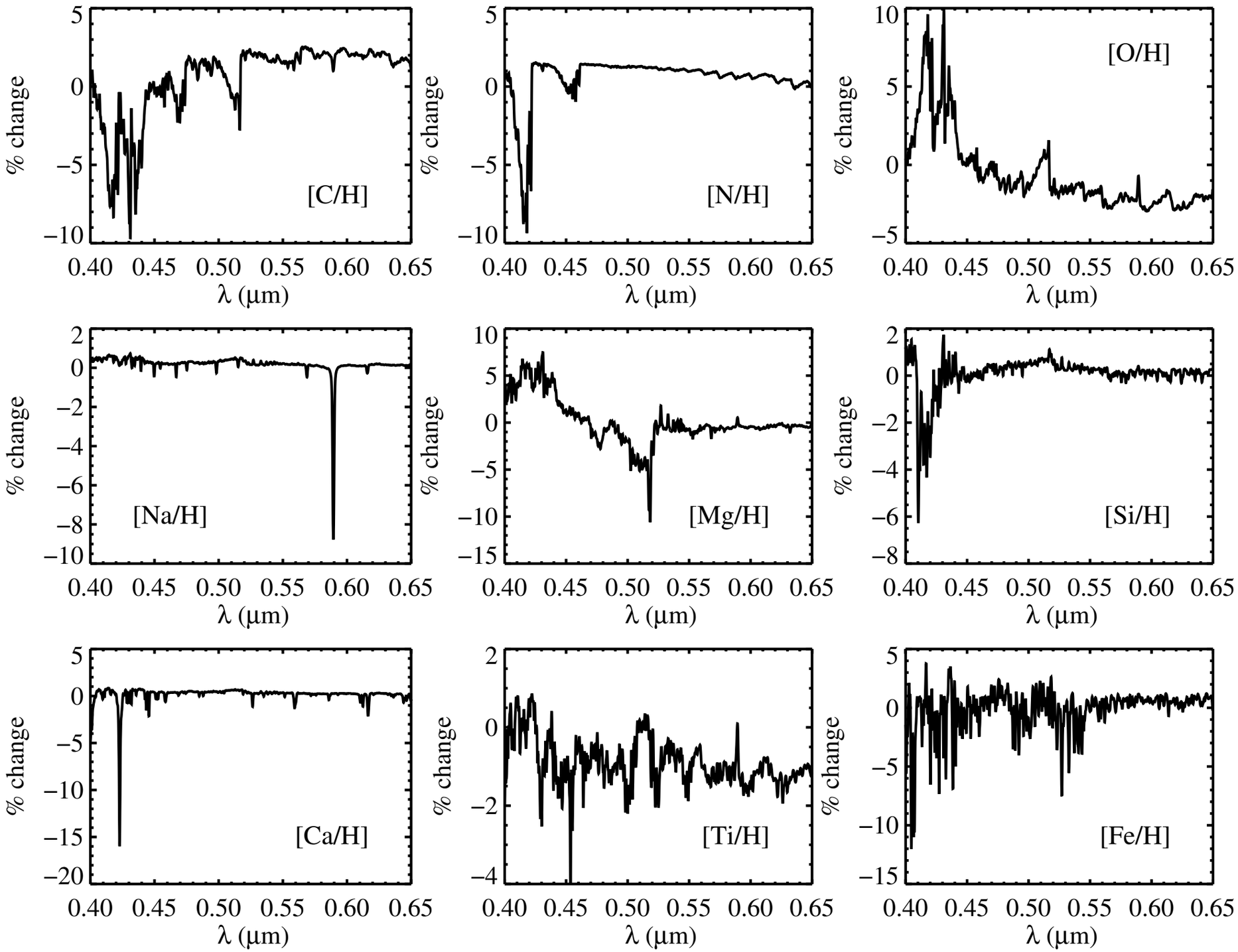
3 bundles x 91 fibers

3 bundles x 127 fibers



fresh from the production line

Full spectral responses

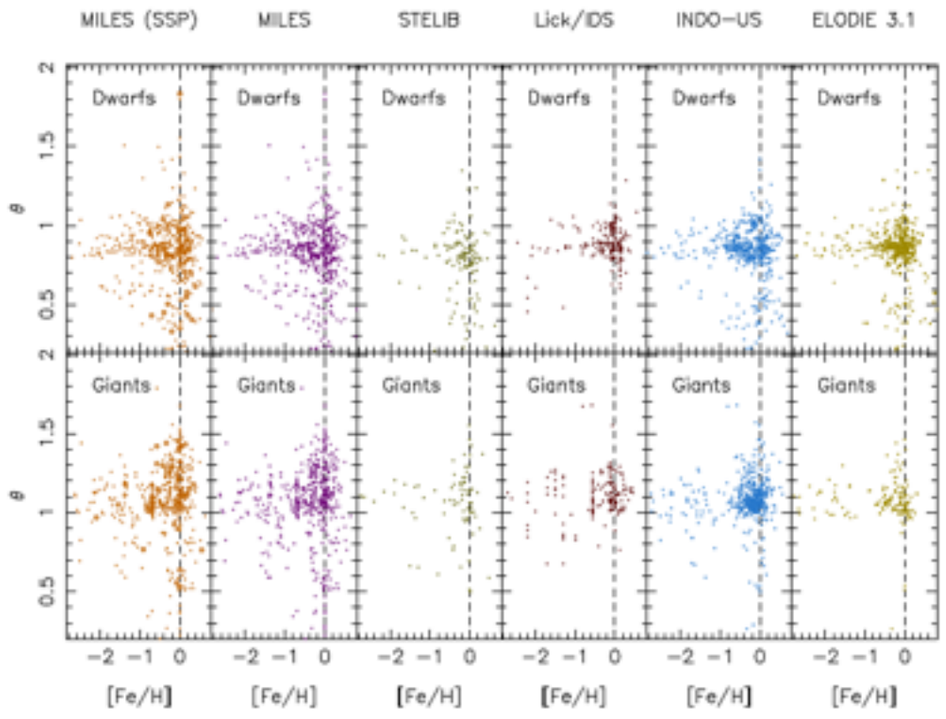


- Based on empirical stellar libraries
- Differential effect from theoretical model atmospheres by Kurucz

Conroy et al 2014

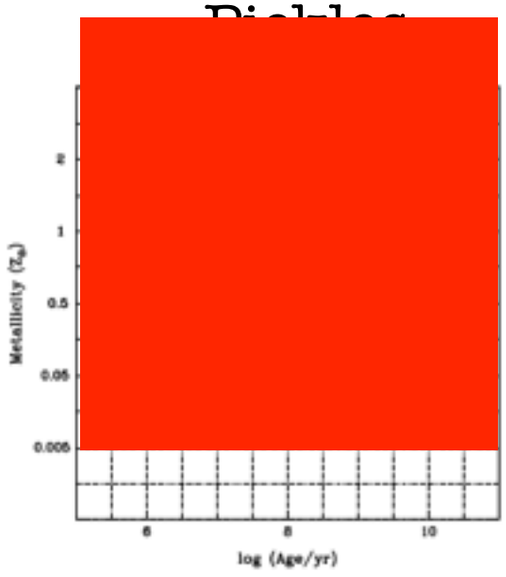
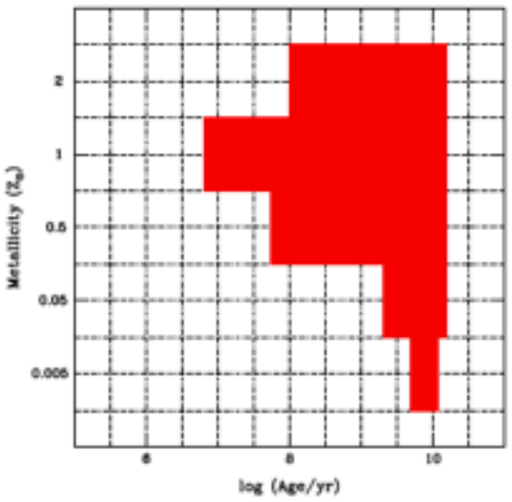
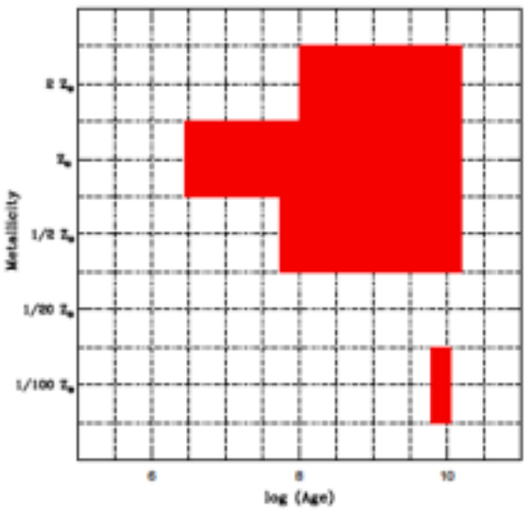
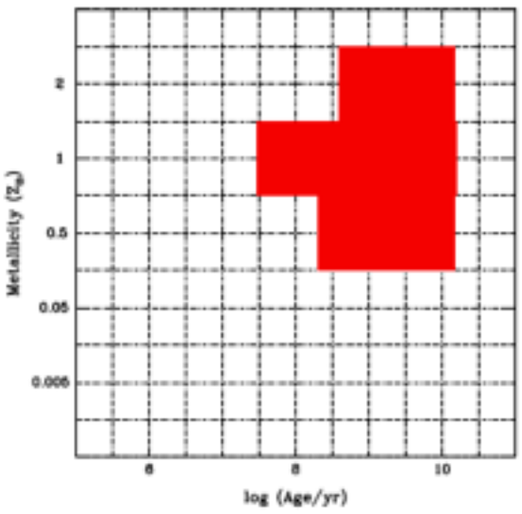
Stellar libraries

- Stellar parameter coverage
- Spectral resolution
- Wavelength range
- Flux-calibration



Vazdekis et al 2010

Maraston & Strömbäck 2011

	Theoretical	STELIB	MILES	ELODIE
				
N_{stars}	-	249	985	1388
λ	-	3,200-9,300	3,500-7,430	3,900-6,800
$\Delta\lambda$	-	3.0	2.3	0.55