Integrated spectra of bright galaxies: successes and problems

Daniel Thomas

University of Portsmouth

Problem or success?

Problem or success?

There are far more successes than problems!

Problem or success?

There are far more successes than problems!

Two problems:

Problem or success?

There are far more successes than problems!

Two problems:

- Age/metallicity/dust/IMF/HB/etc degeneracy

Problem or success?

There are far more successes than problems!

Two problems:

- Age/metallicity/dust/IMF/HB/etc degeneracy
- Stars unresolved in most galaxies

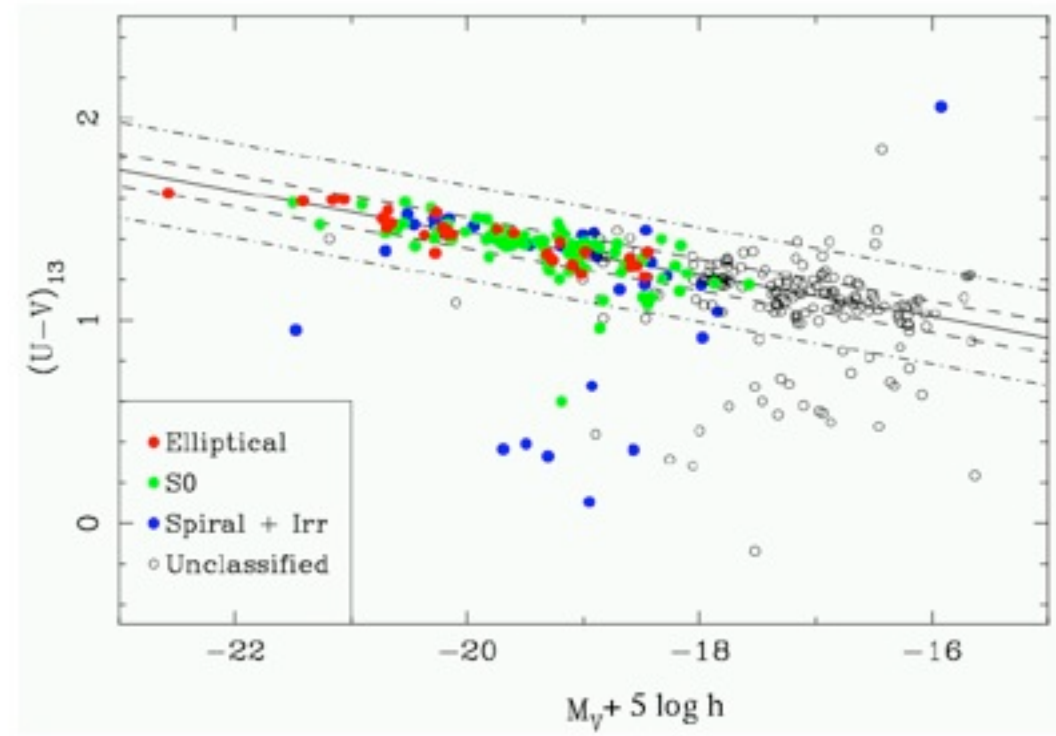
Outline

- Tapping into the fossil record of galaxies
- Stellar population models
    - Stellar libraries
    - Absorption-line indices
- Chemical abundance ratios of SDSS galaxies
- Large galaxy surveys (z-surveys and IFU)
- Moving on to higher redshifts (SDSS-III/BOSS)
- Summary

Ellipticals - the dinosaurs of the Universe

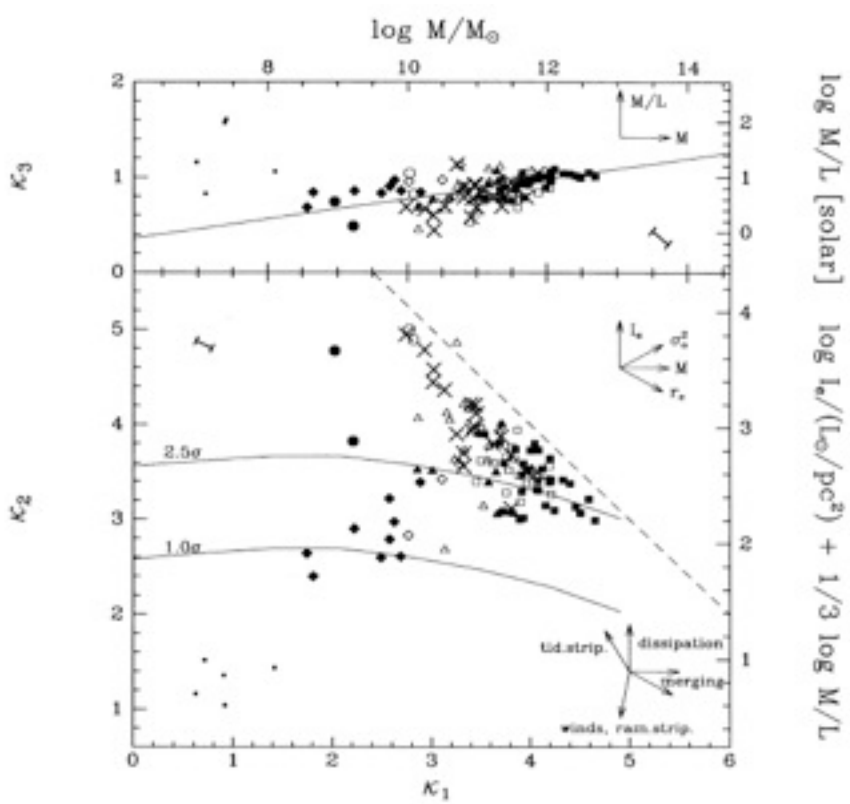
Colour-magnitude relation

Visvanathan & Sandange 1977
Bower, Lucey, Ellis 1992

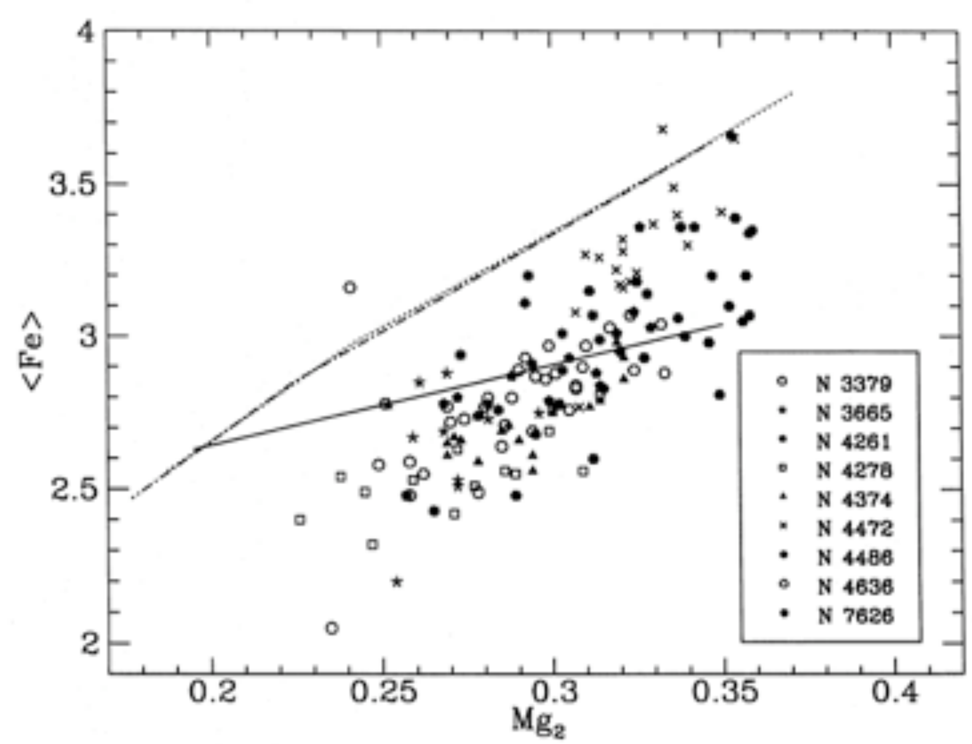


Bower et al 2008

Fundamental plane Dressler et al 1987; Djorgovski & Davis 1987; Bender et al 1992; Renzini & Ciotti 1993; Jørgensen et al 1995



Bender et al 1992



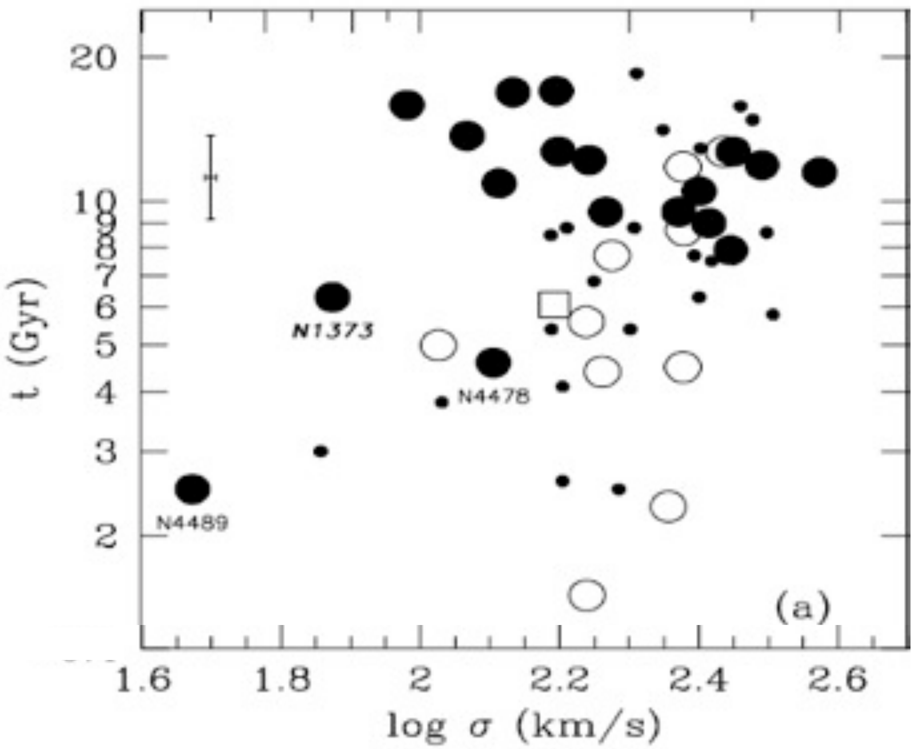
Davies et al 1993

Mg/Fe ratios

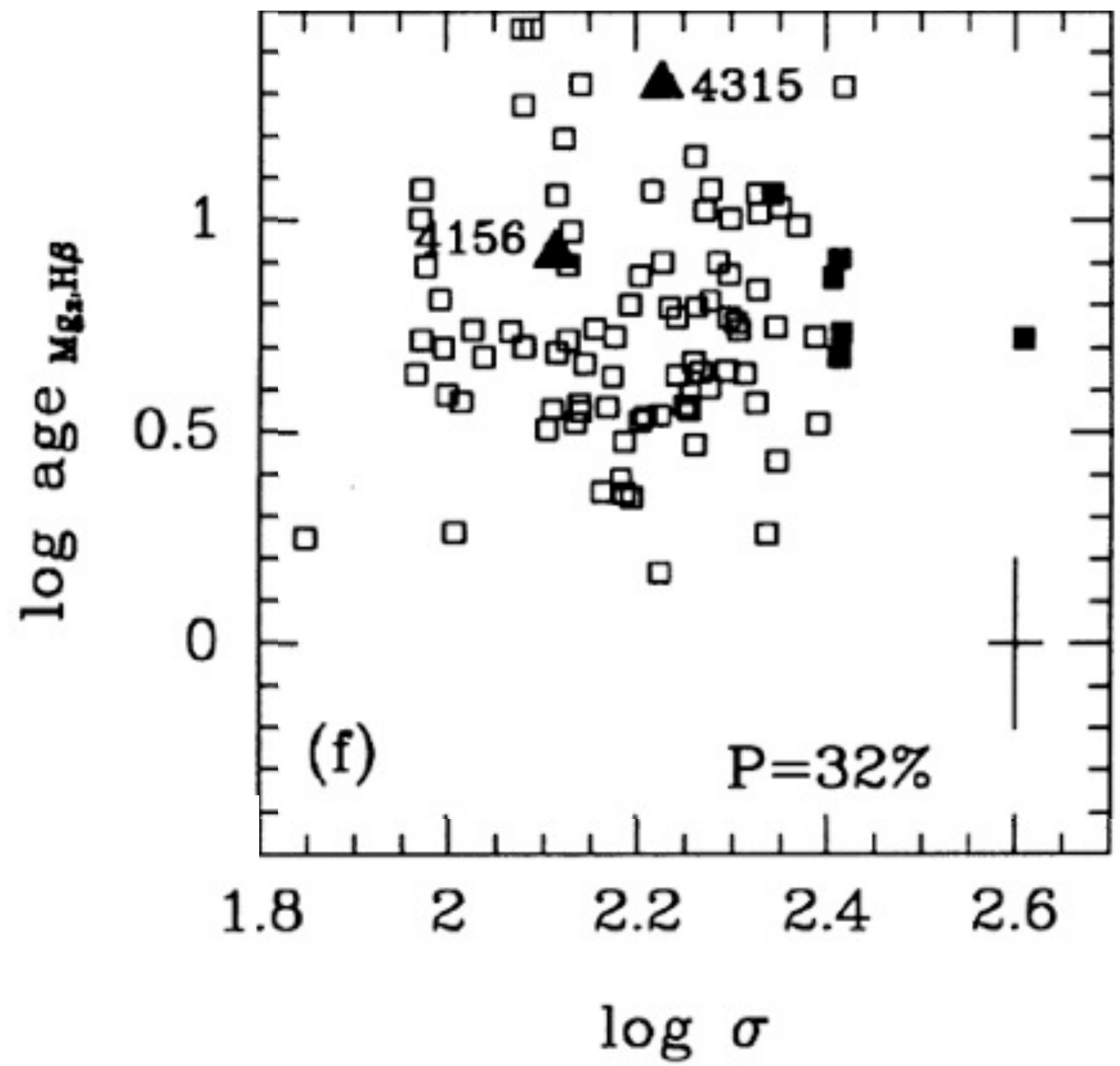
Gorgas et al 1990; Worthey et al 1992; Davies et al 1993; Fisher et al 1995; Surma & Bender 1995

Renzini 2006

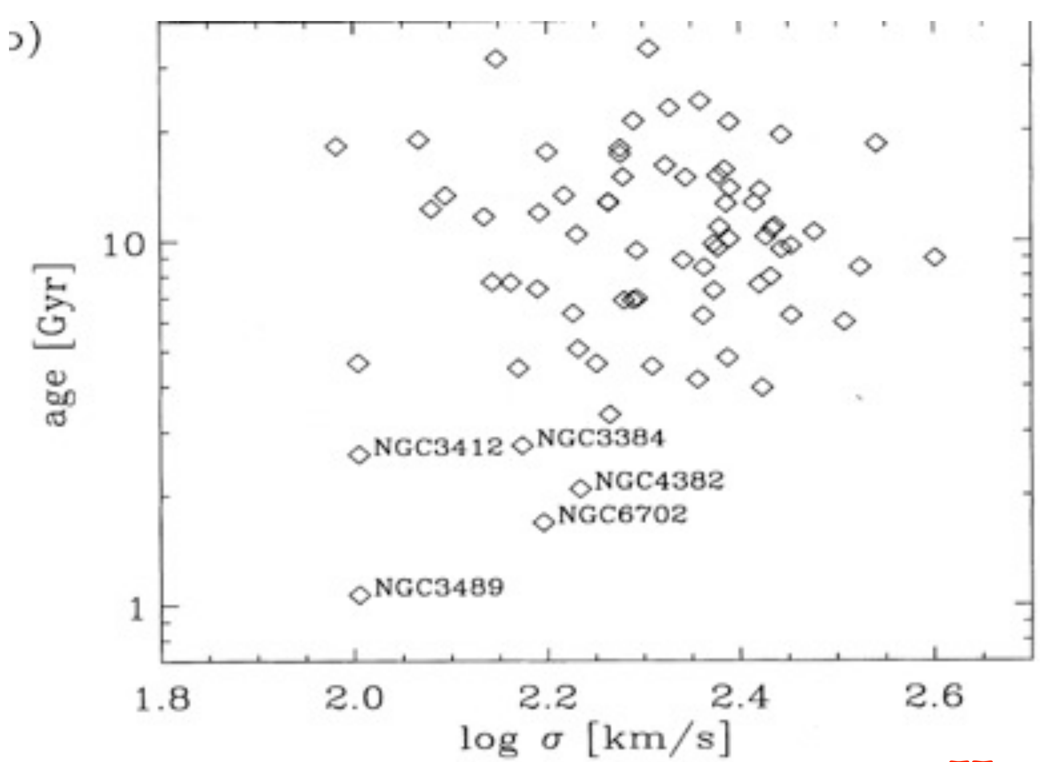
Yet ages are poorly constrained



Trager et al 2000

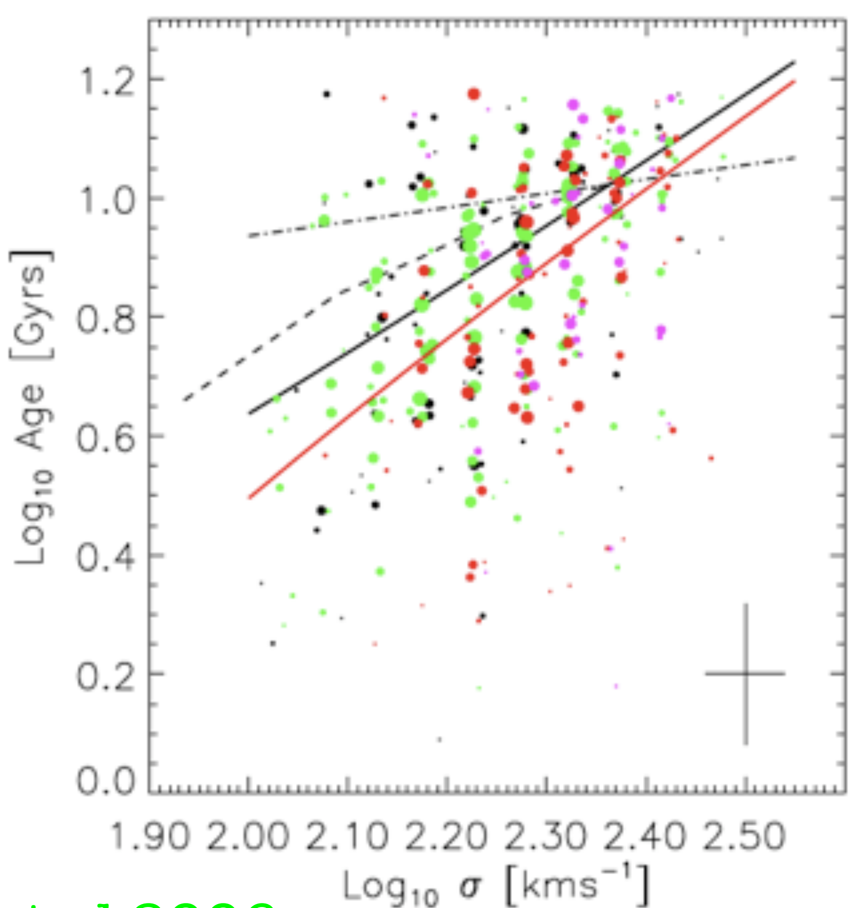


Jørgensen 1999



Kuntschner et al 2001

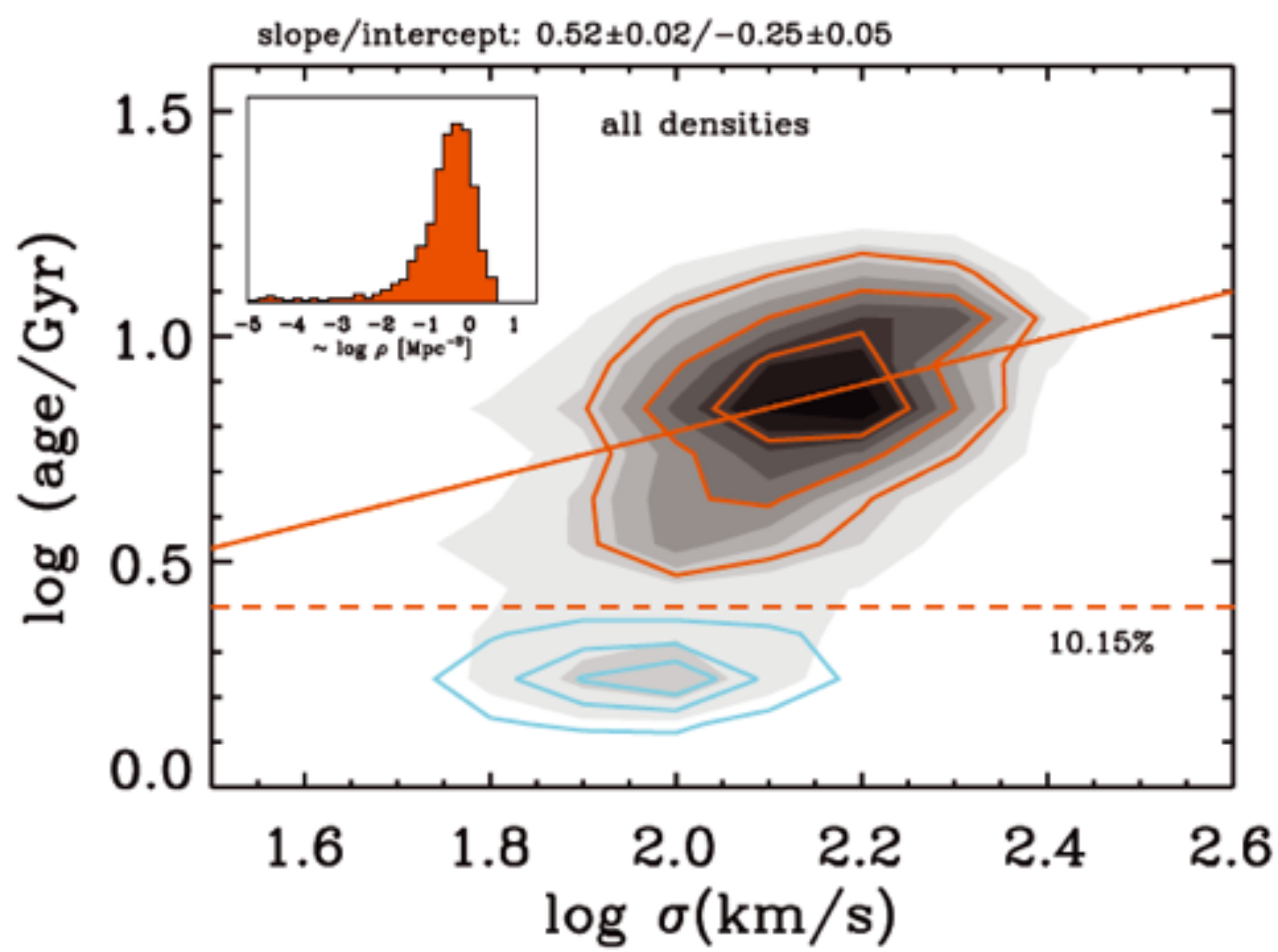
Archaeological downsizing

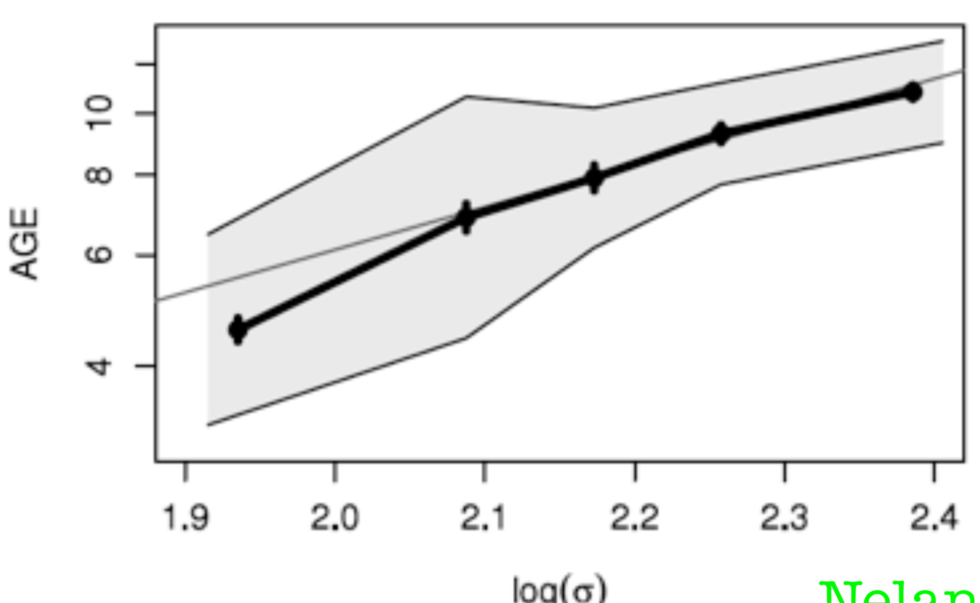


Bernardi et al 2006

New SSP models + Statistical approaches

Thomas et al 2010



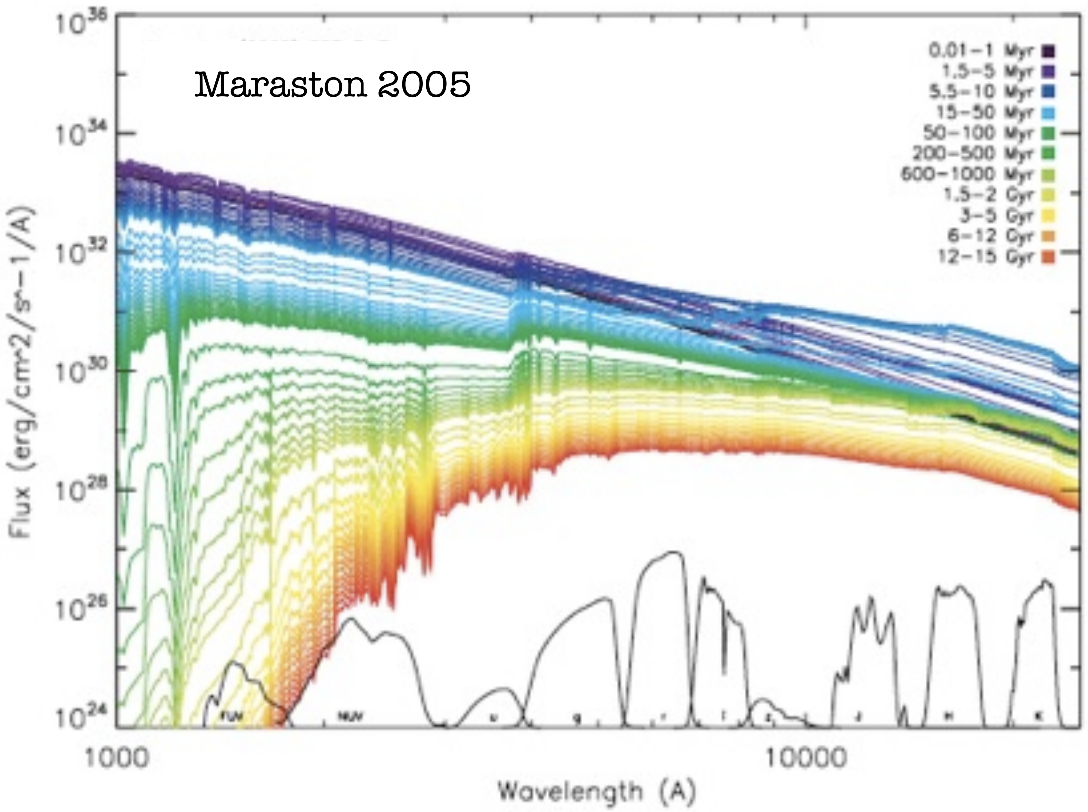


Nelan et al 2005

Integrated spectra of bright galaxies

Probing baryon physics in galaxies

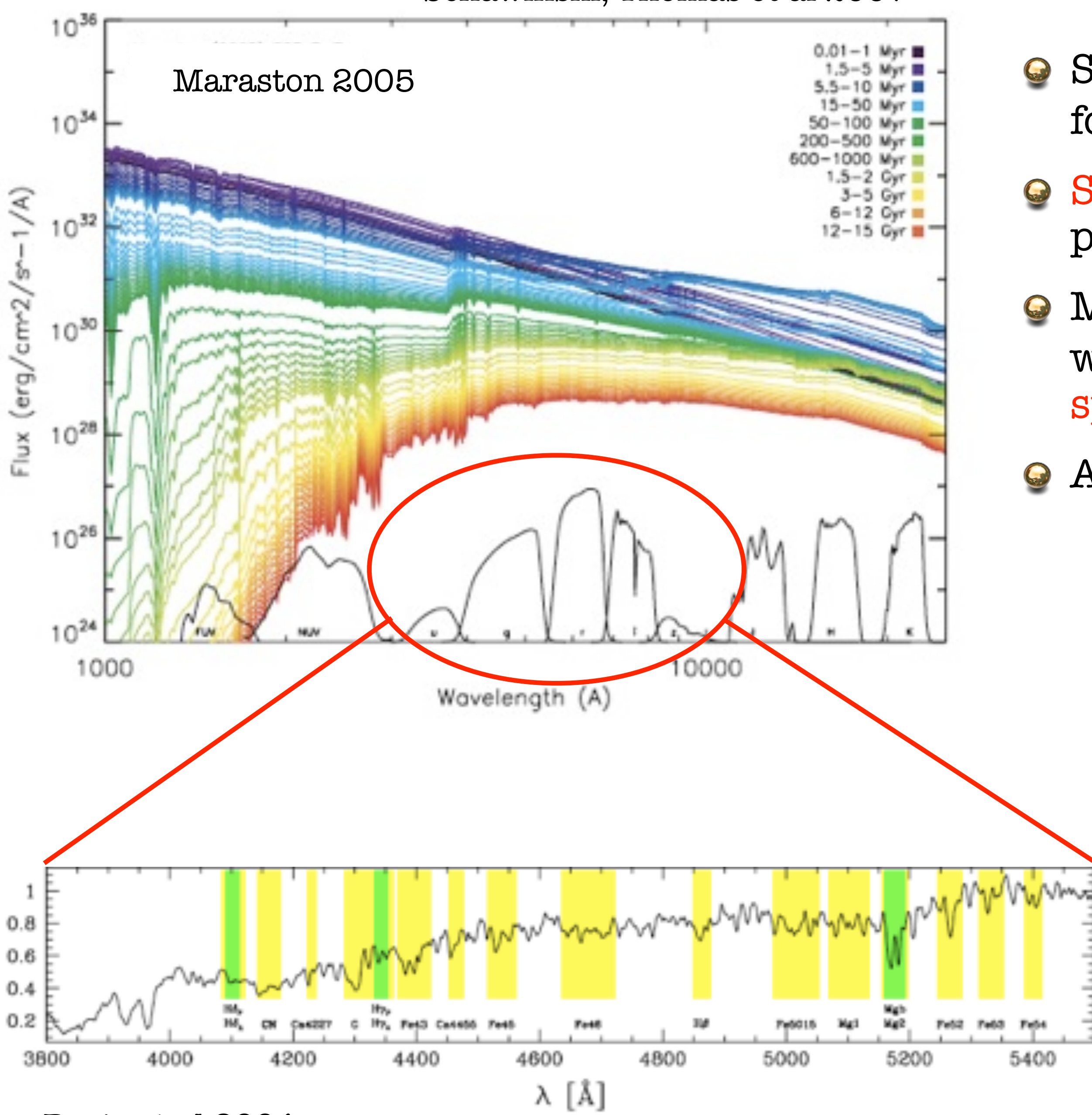
Schawinski, Thomas et al 2007



- 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

Probing baryon physics in galaxies

Schawinski, Thomas et al 2007

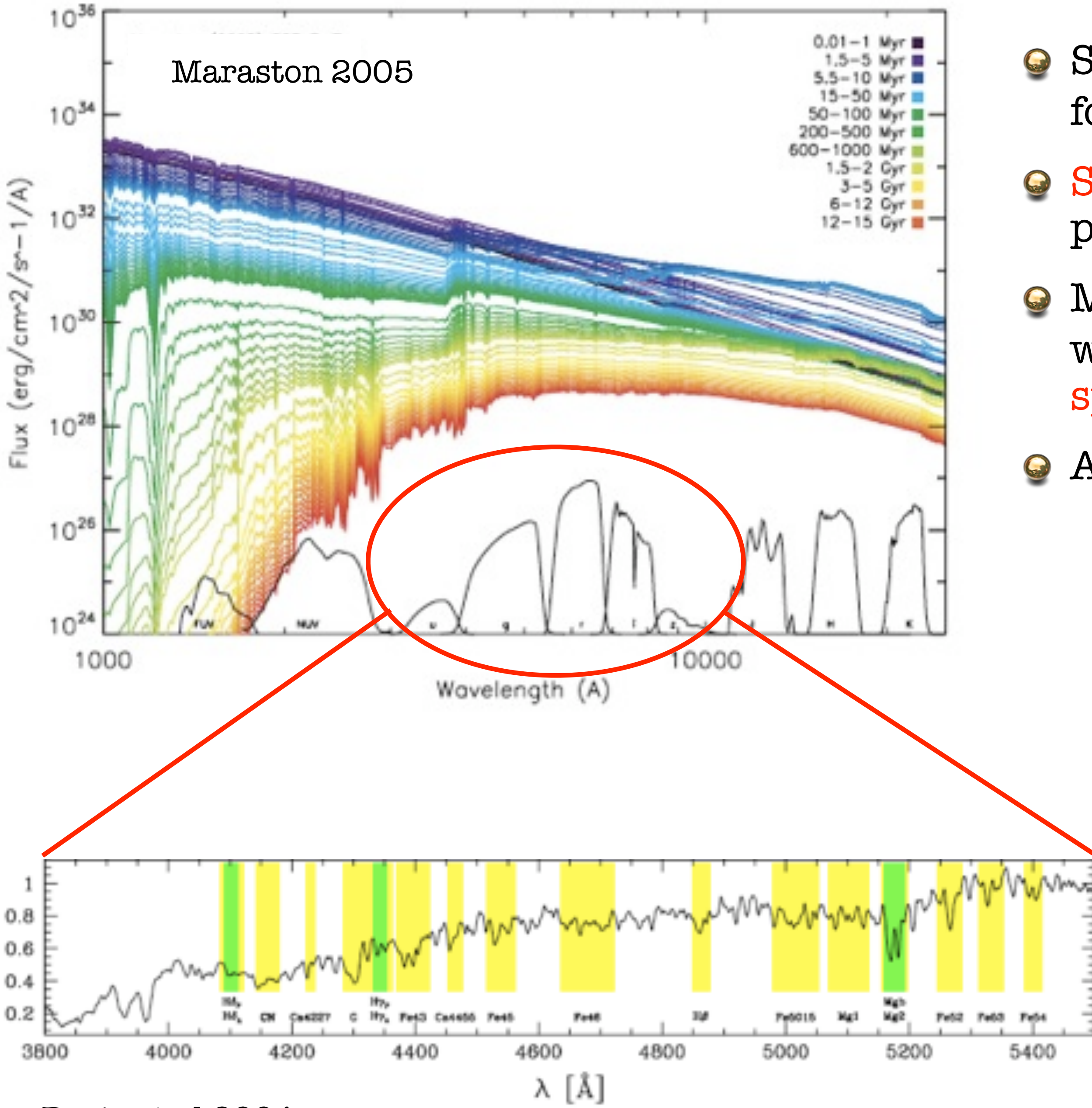


Puzia et al 2004

- 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

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

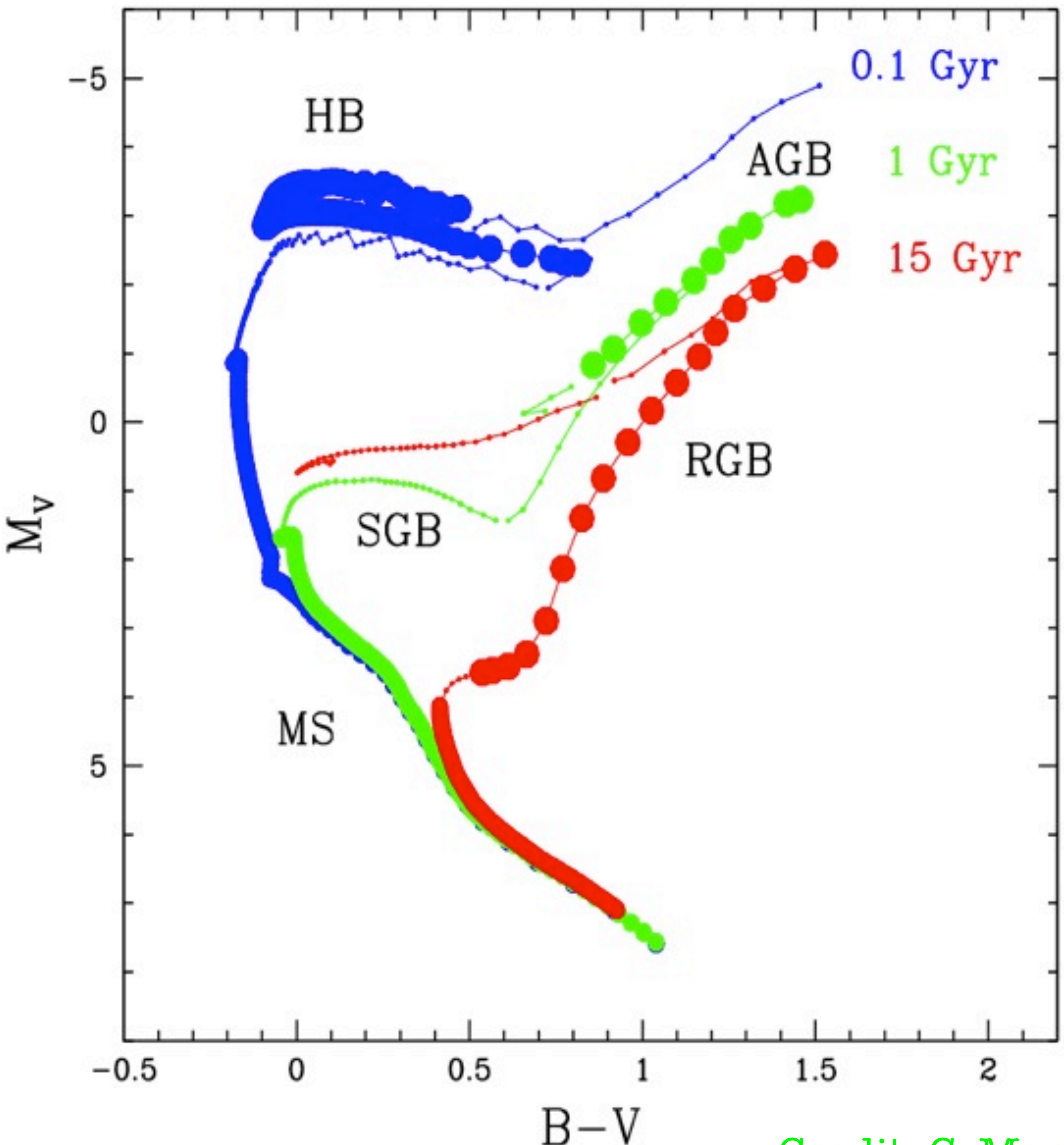
Emission line spectrum

Gas ionisation stage, star formation/black hole activity, gas kinematics, galactic outflows, gas accretion, gas metallicities

Absorption line spectrum

stellar kinematics, dynamical stellar masses, dark matter, stellar populations, star formation histories, metal content, element abundance ratios

Stellar population models



Credit: C. Maraston

Needs

- Stellar evolutionary tracks
- Stellar libraries or model atmospheres

Predicts

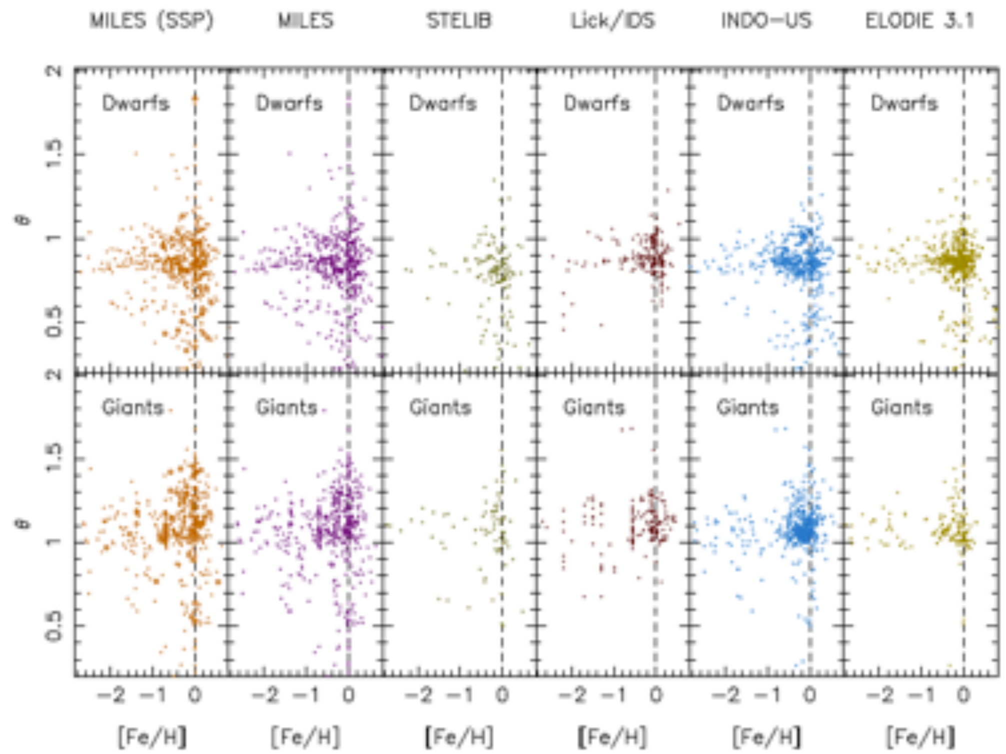
- Spectra, colours
- Luminosity evolution, k-corrections

Assumes (derives)

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

Stellar libraries

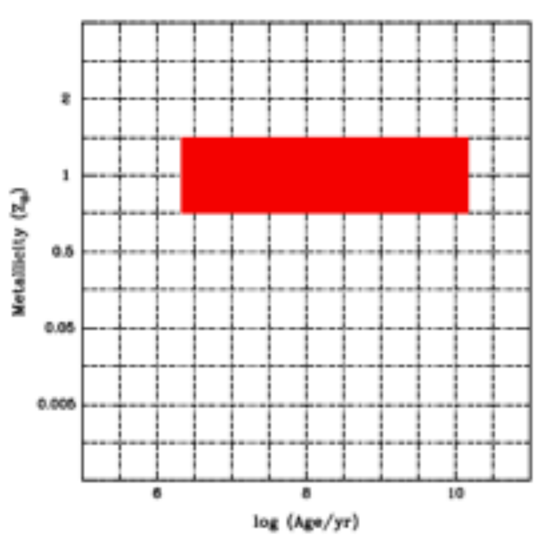
- Stellar parameter coverage
- Spectral resolution
- Wavelength range
- Flux-calibration



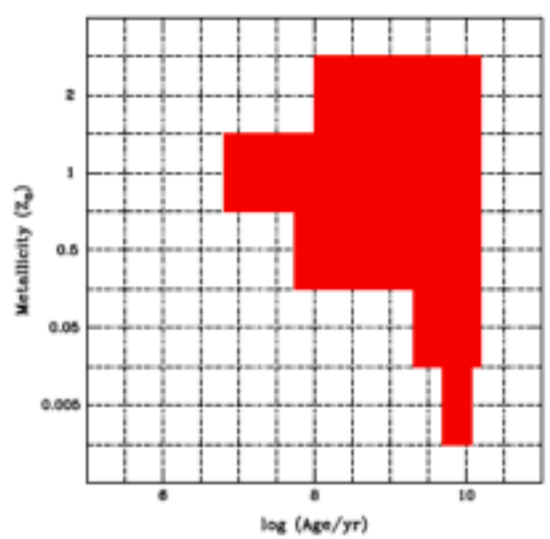
Vazdekis et al 2010

Maraston & Strömbäck 2011

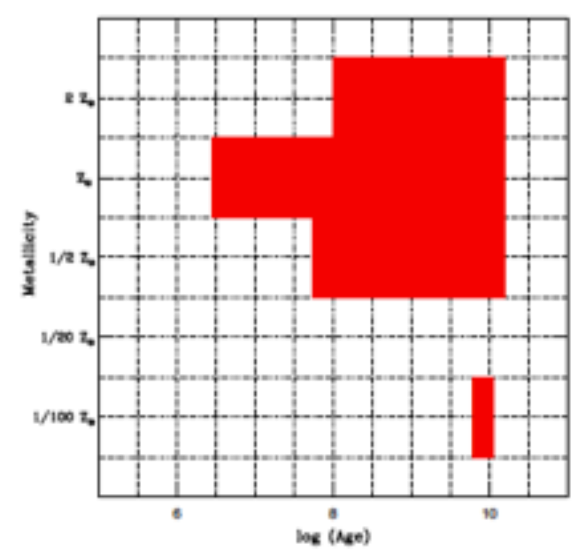
Pickles



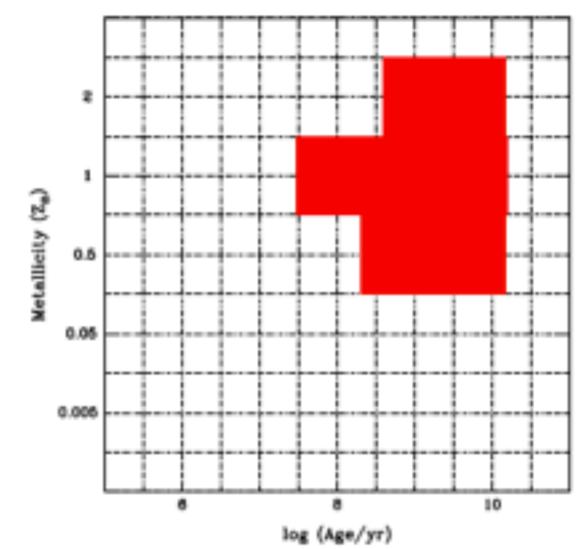
STELIB



MILES



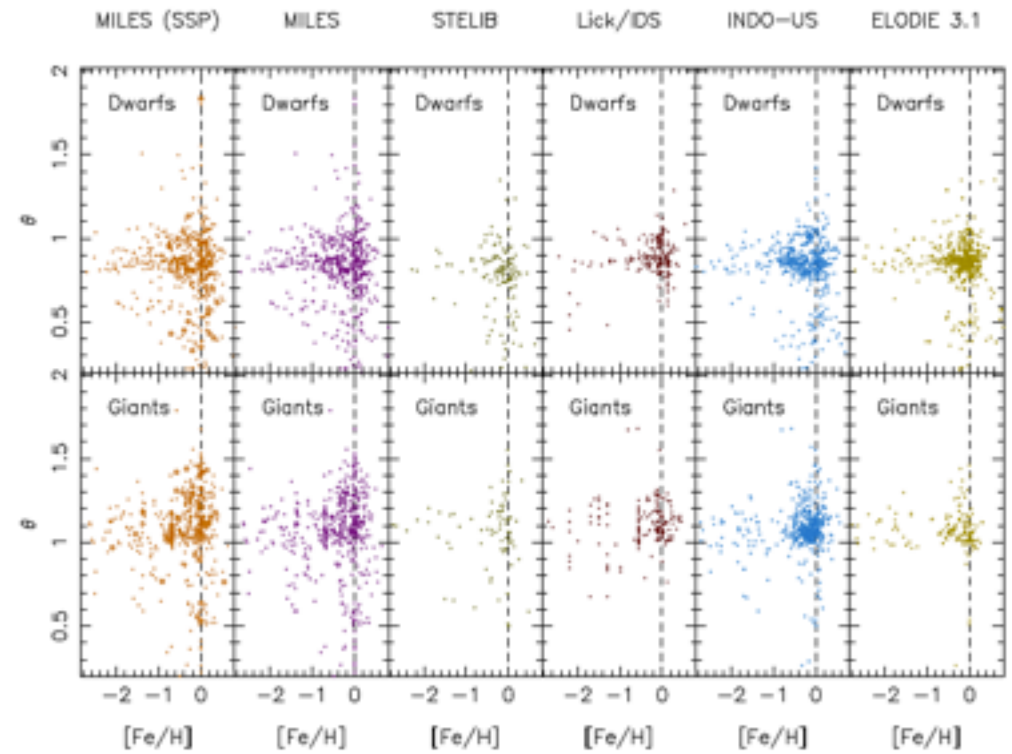
ELODIE



	Pickles	STELIB	MILES	ELODIE
N_{stars}	131	249	985	1388
λ	1,150-25,000	3,200-9,300	3,500-7,430	3,900-6,800
$\Delta\lambda$	11.0	3.0	2.3	0.55

Stellar libraries

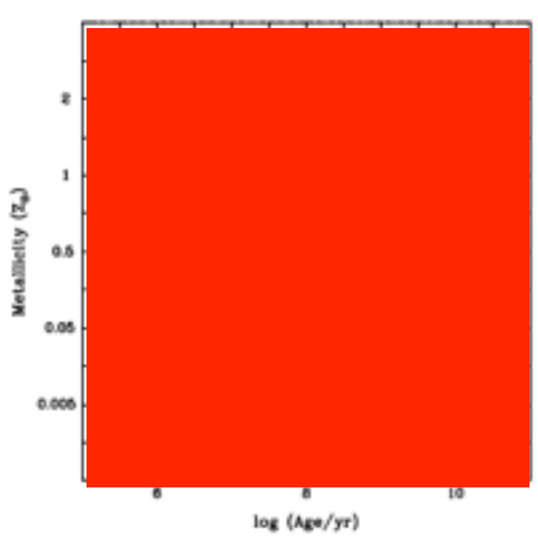
- Stellar parameter coverage
- Spectral resolution
- Wavelength range
- Flux-calibration



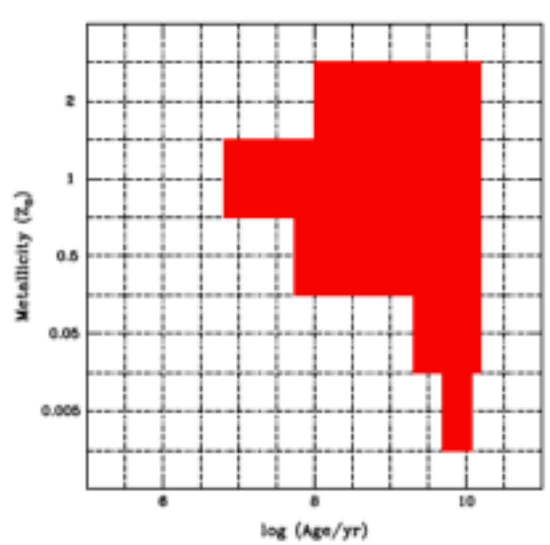
Vazdekis et al 2010

Maraston & Strömbäck 2011

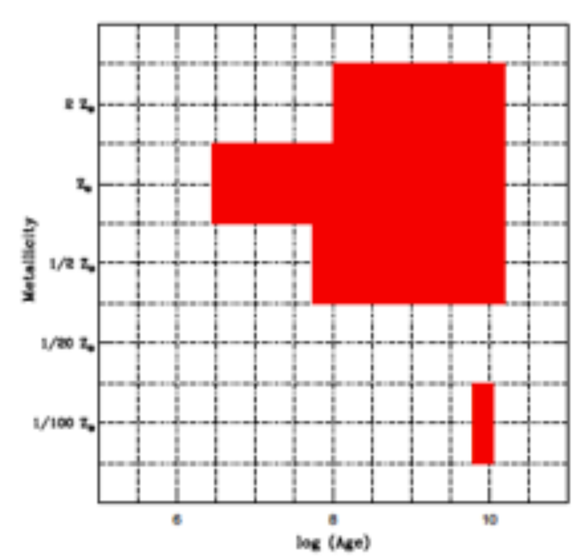
Theoretical



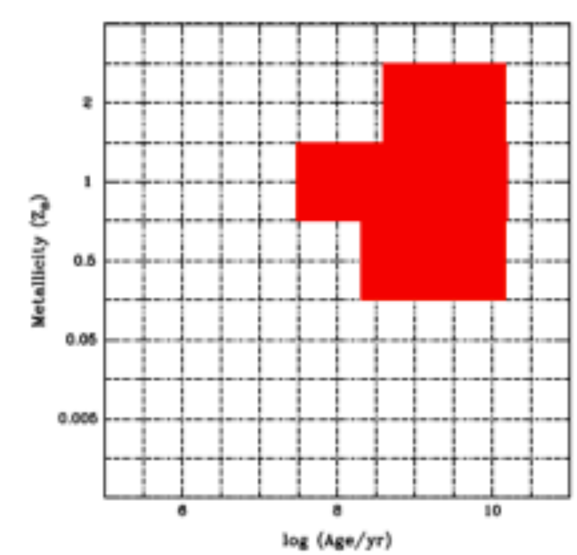
STELIB



MILES



ELODIE



	Theoretical	STELIB	MILES	ELODIE
N_{stars}	131	249	985	1388
λ	1,150-25,000	3,200-9,300	3,500-7,430	3,900-6,800
$\Delta\lambda$	11.0	3.0	2.3	0.55

MILES spectral resolution

Beifiori et al 2011

Assess spectral resolution of library with other library as template

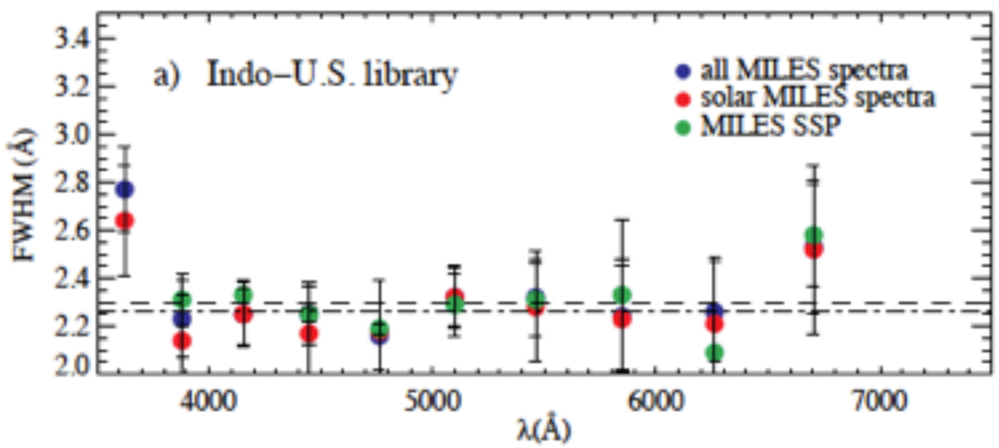
using pPXF (Cappellari & Emsellem 2004)

MILES spectral resolution

Beifiori et al 2011

Assess spectral resolution of library with other library as template

using pPXF (Cappellari & Emsellem 2004)



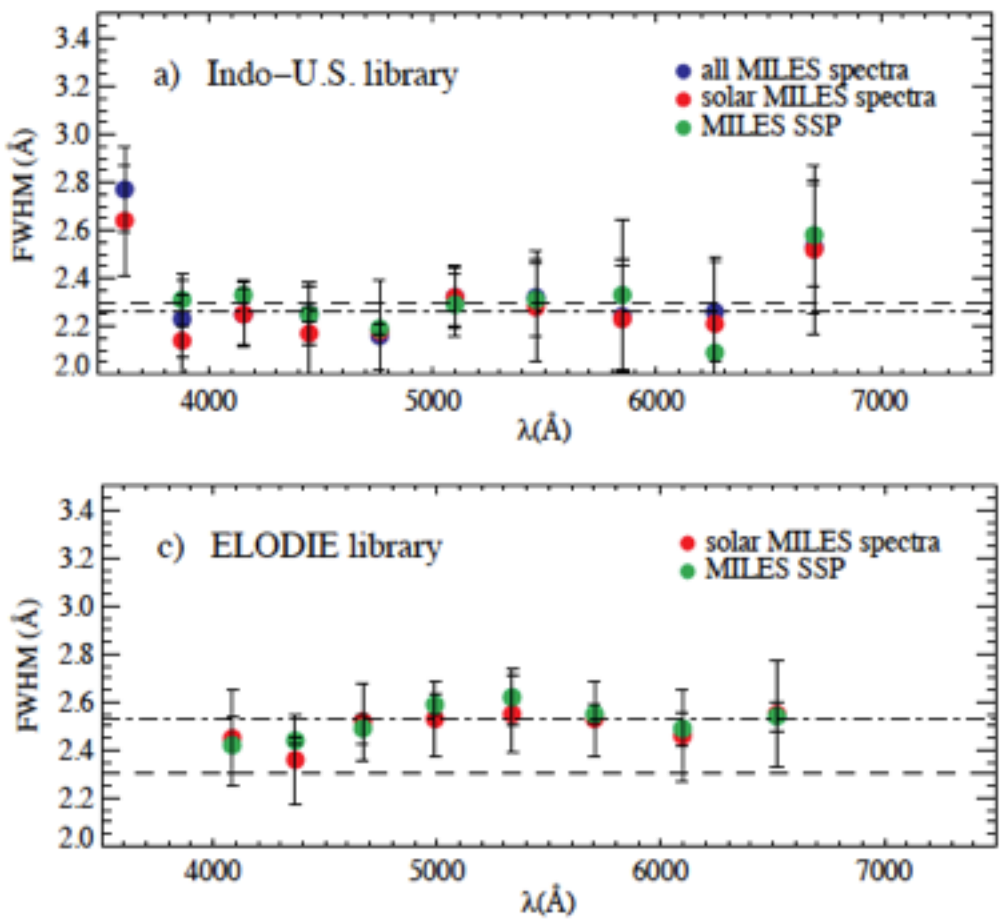
- Nominal MILES resolution of $\Delta\lambda = 2.3$ reproduced with Indo-US as template

MILES spectral resolution

Beifiori et al 2011

Assess spectral resolution of library with other library as template

using pPXF (Cappellari & Emsellem 2004)



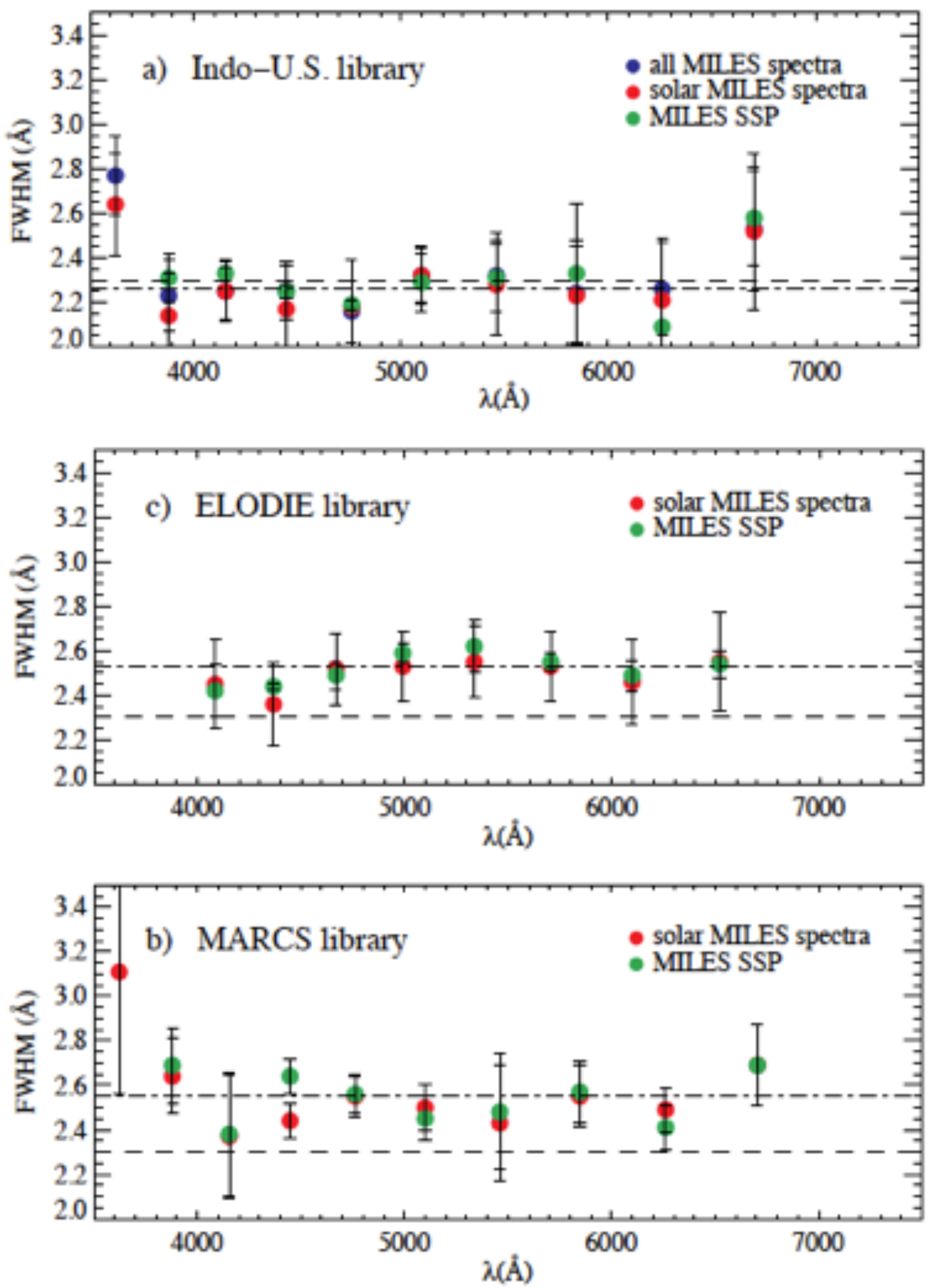
- Nominal MILES resolution of Δλ = 2.3 reproduced with Indo-US as template
- Lower resolution of Δλ = 2.54 obtained with ELODIE as template

MILES spectral resolution

Beifiori et al 2011

Assess spectral resolution of library with other library as template

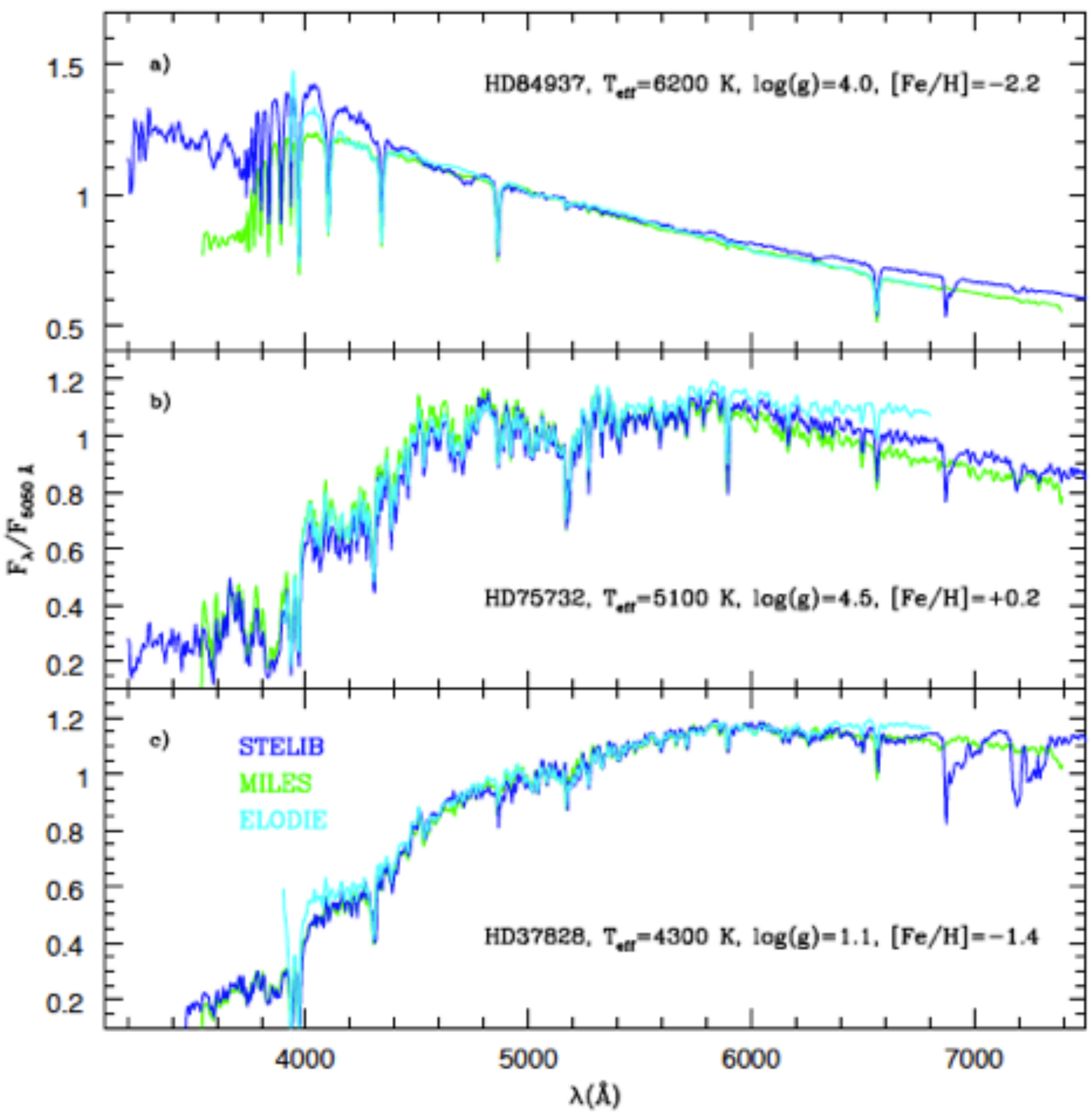
using pPXF (Cappellari & Emsellem 2004)



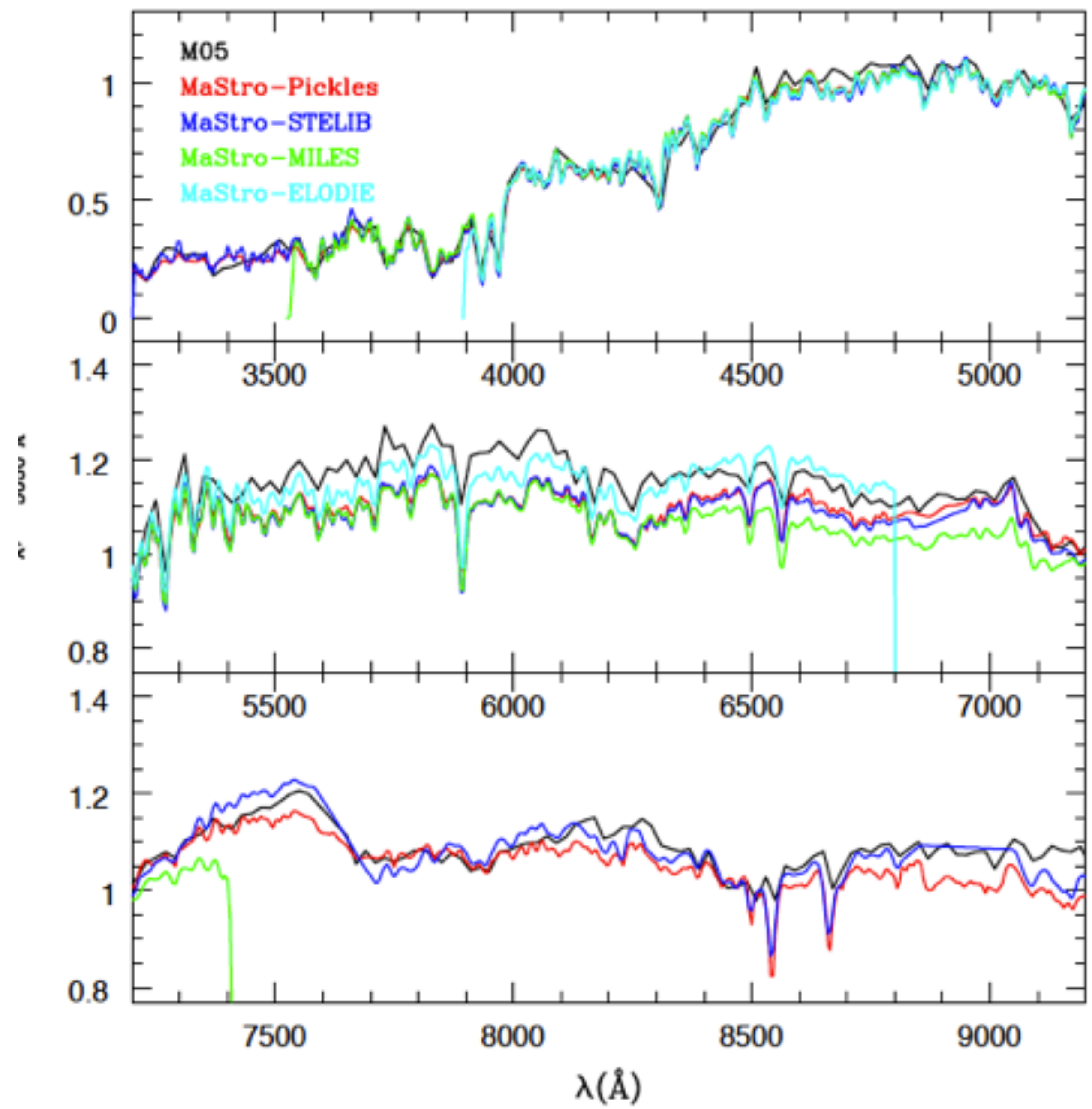
- Nominal MILES resolution of Δλ = 2.3 reproduced with Indo-US as template
- Lower resolution of Δλ = 2.54 obtained with ELODIE as template
- New resolution confirmed using theoretical MARCS library as template

Stellar libraries in comparison

Stars



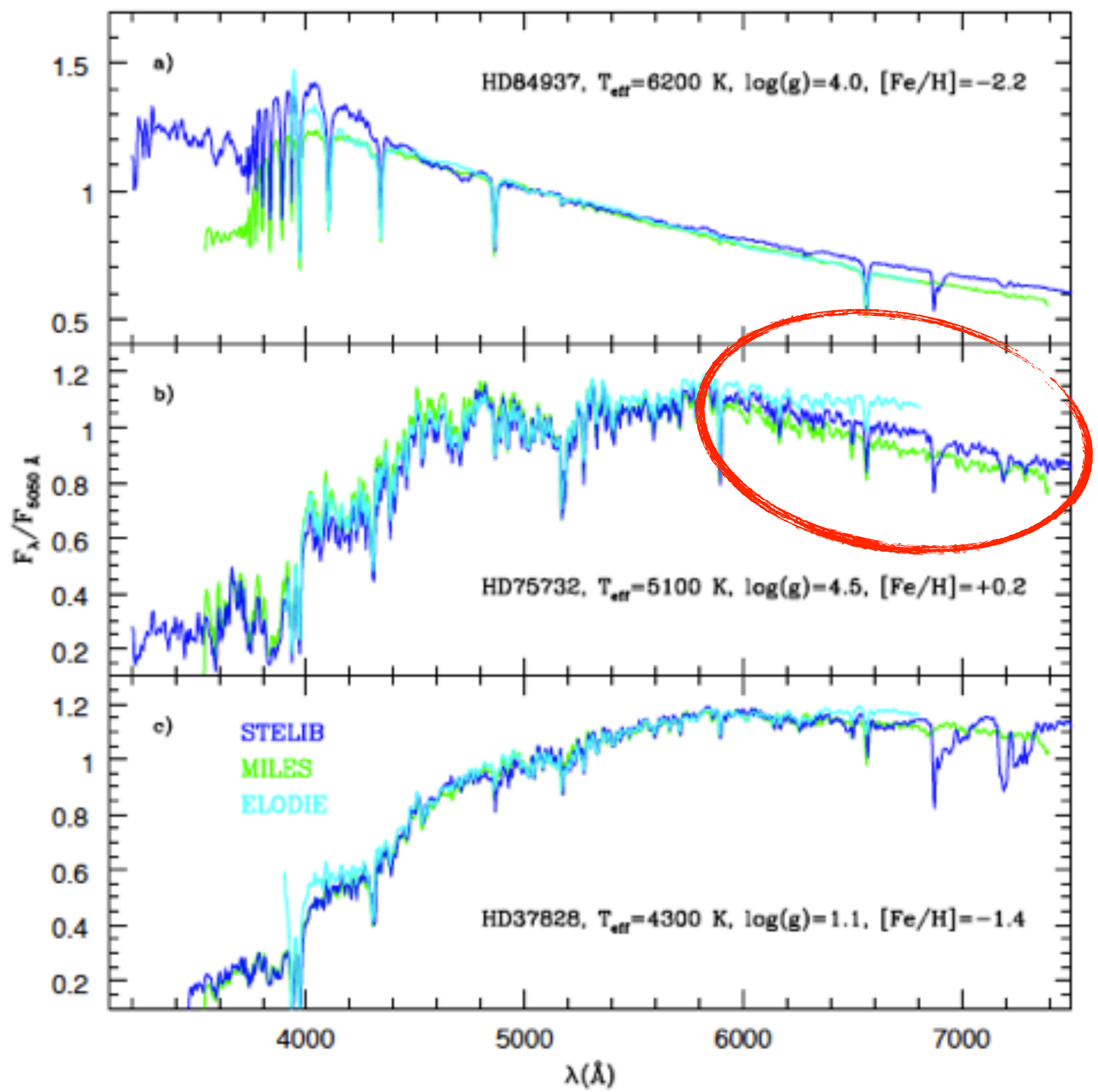
Stellar population models



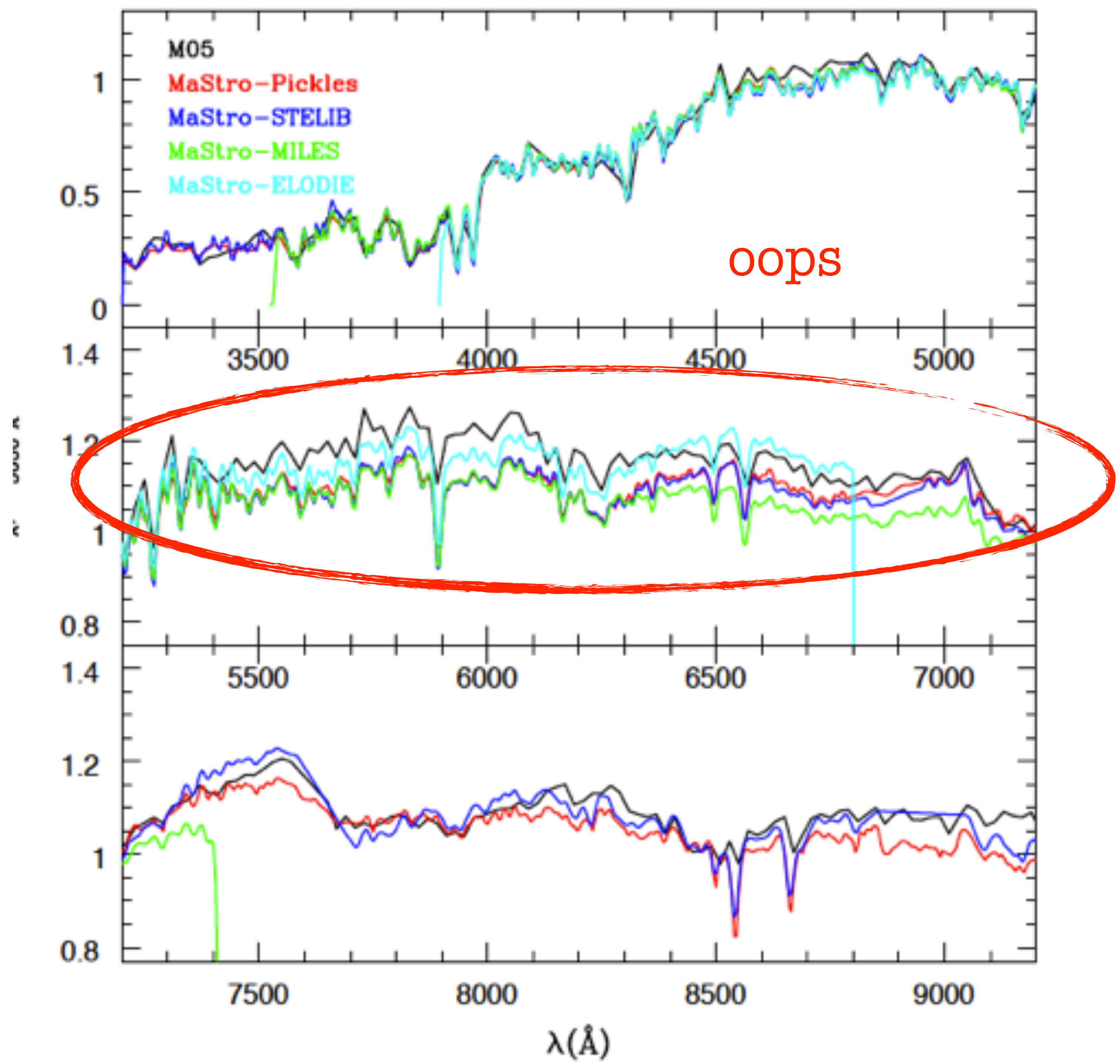
Maraston & Strömbäck 2011

Stellar libraries in comparison

Stars



Stellar population models

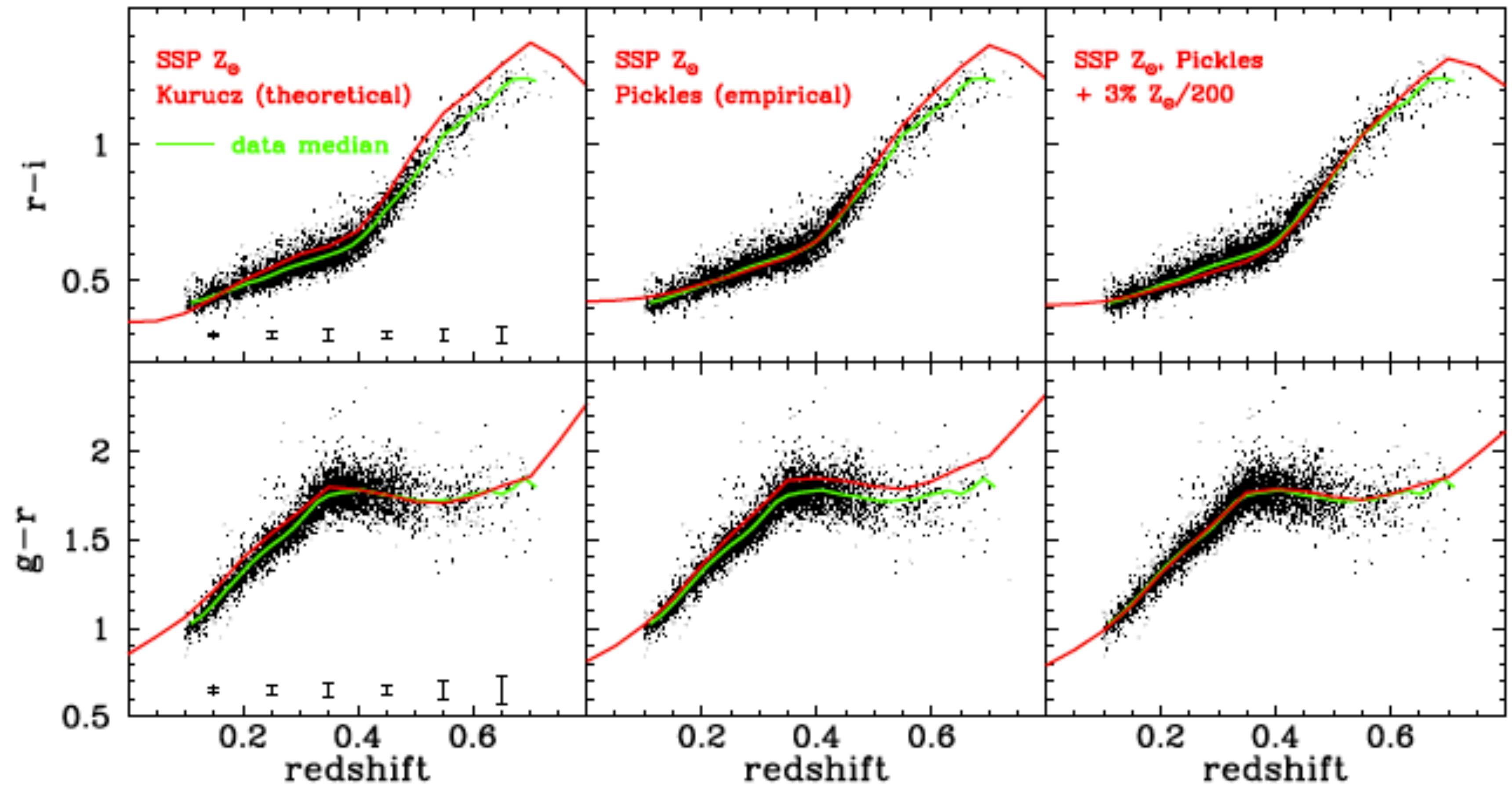


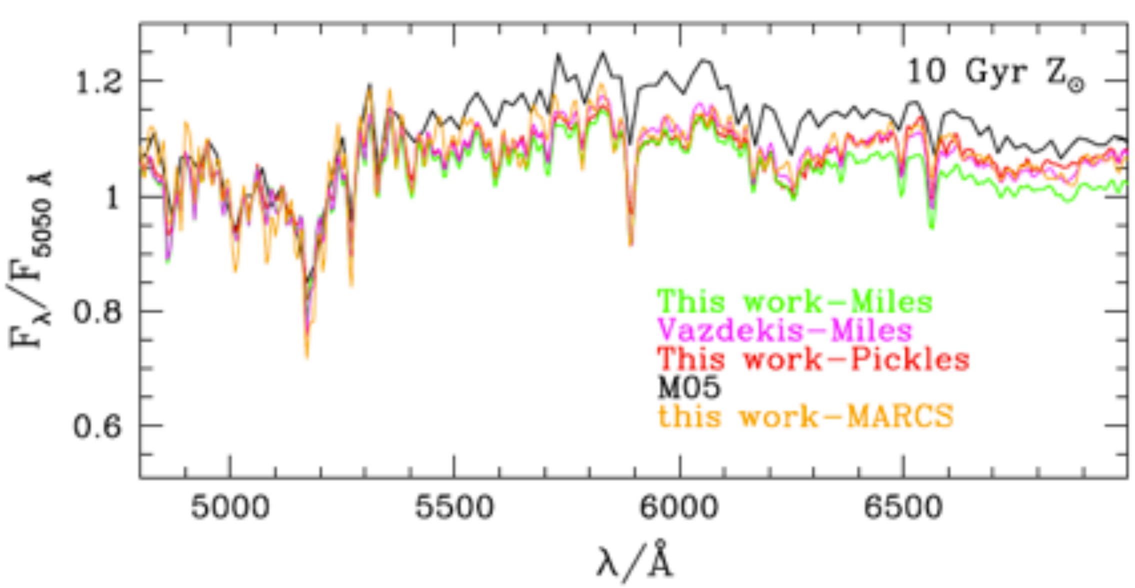
Maraston & Strömbäck 2011

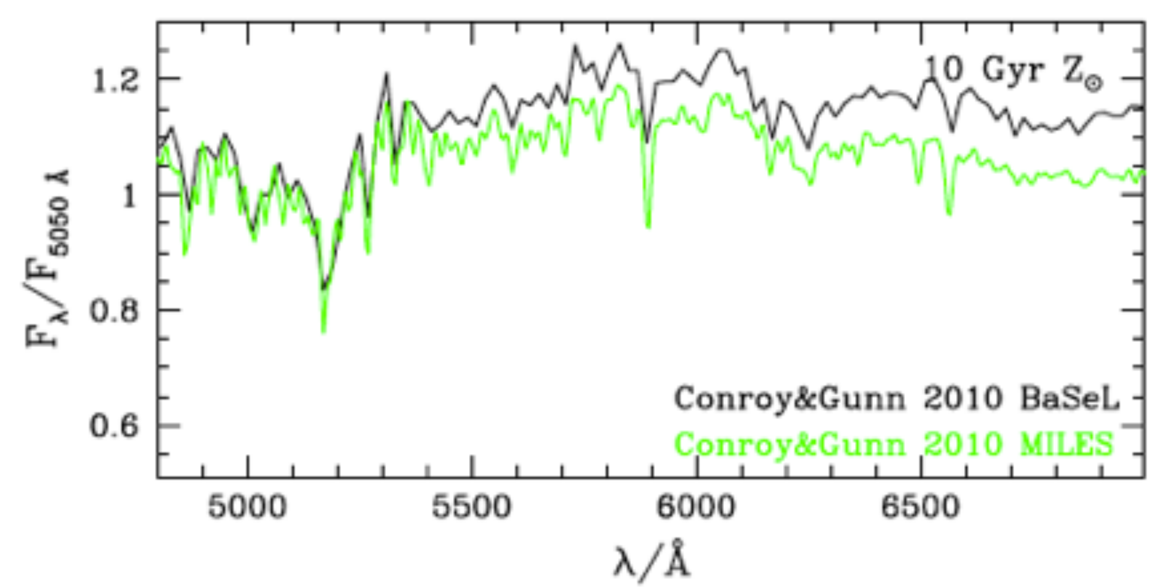
Bright galaxies as calibrators

- Redshift evolution of LRG colours
- Models too blue in g-r
- Empirical libraries improve match

Maraston et al 2009

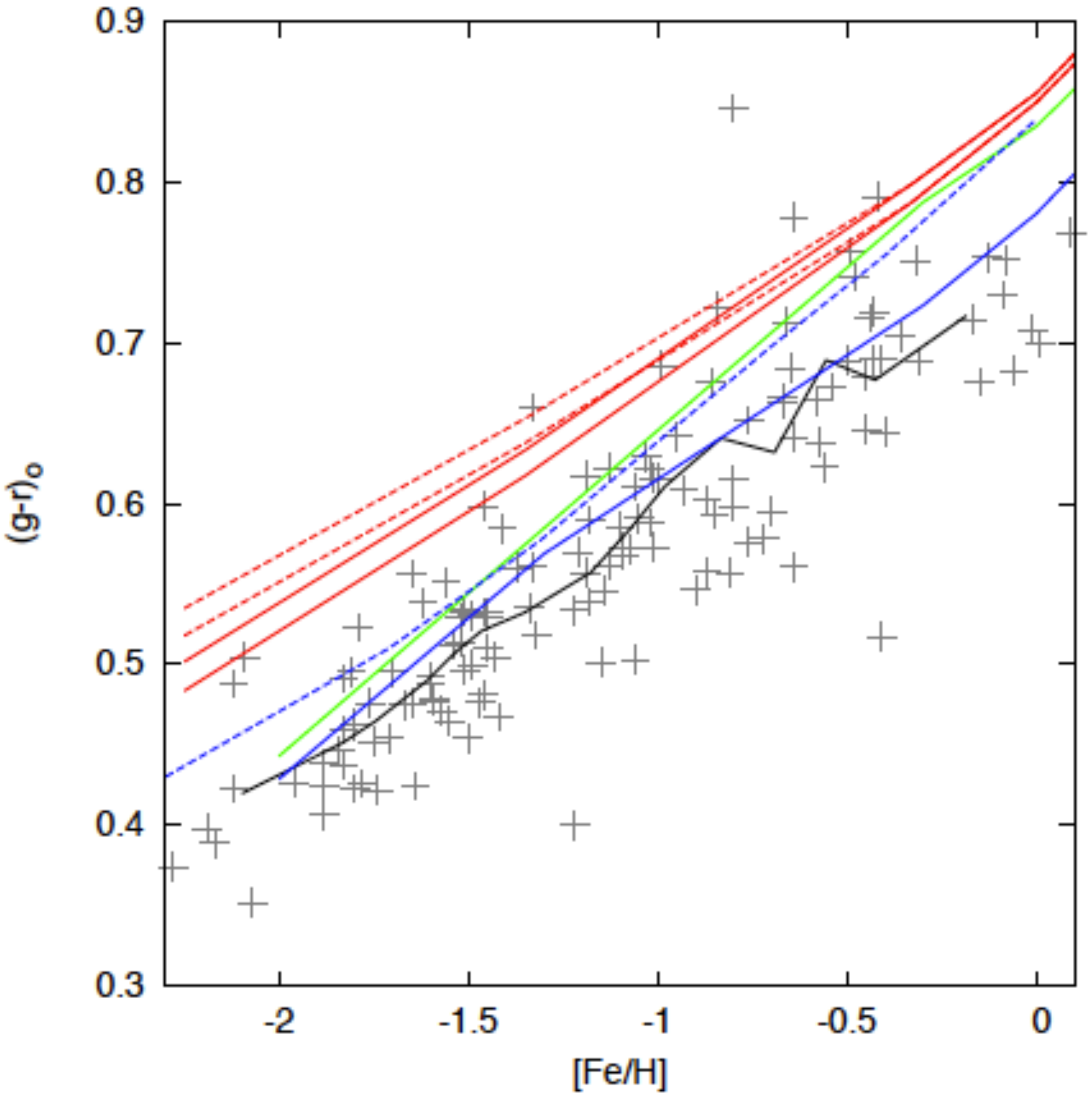






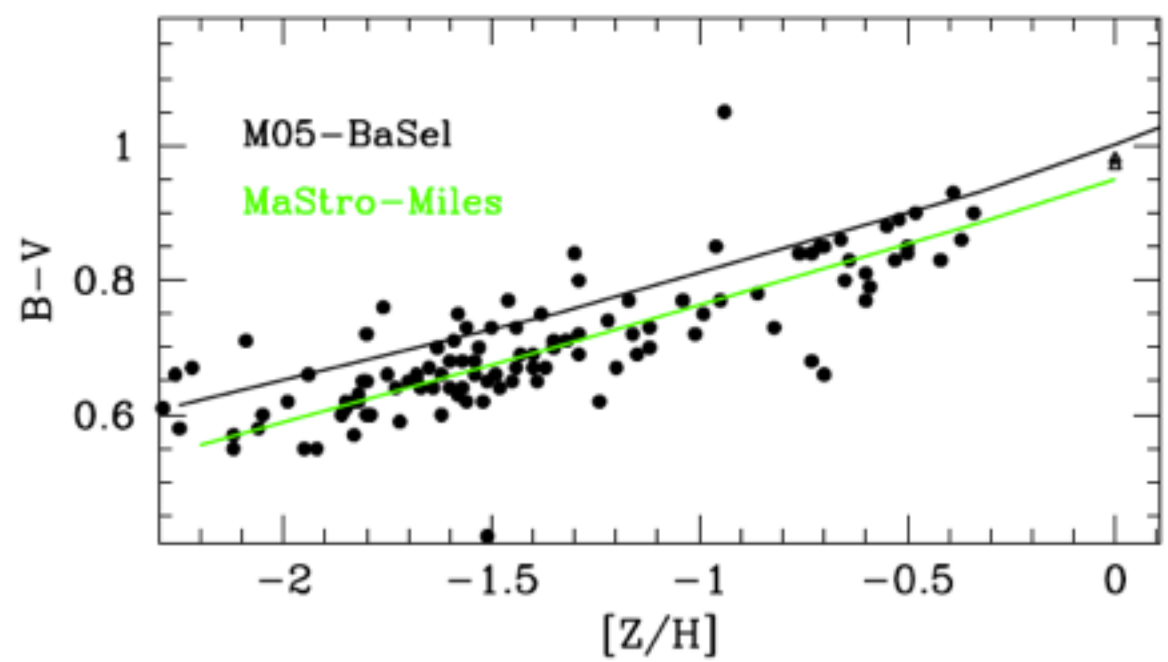
Consistent with globular clusters

GC's from SDSS



Peacock et al 2011

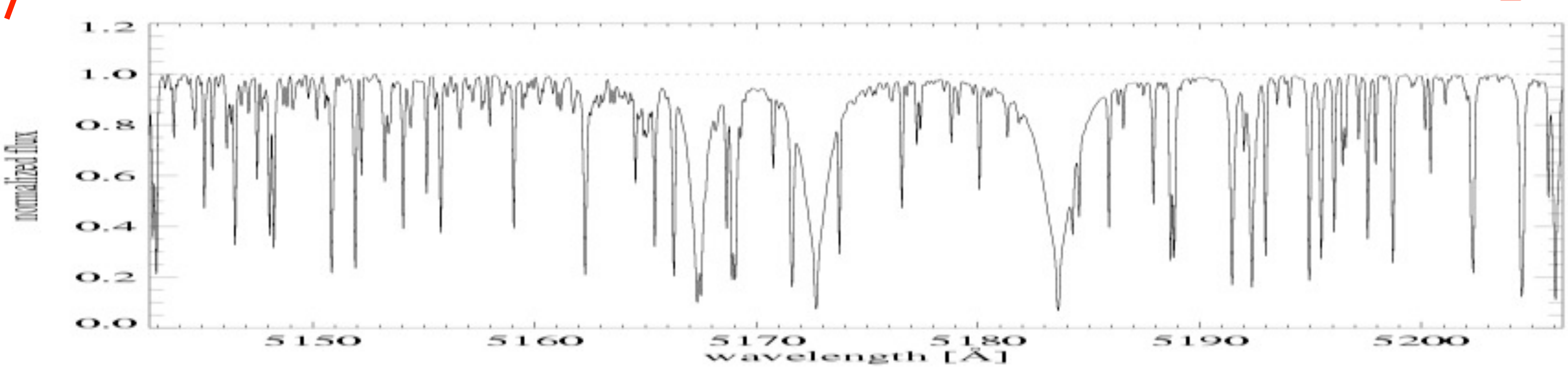
- Also globular clusters too blue in g-r
- Empirical library MILES fixes the problem



Maraston & Strömbäck 2011

Absorption features in galaxies

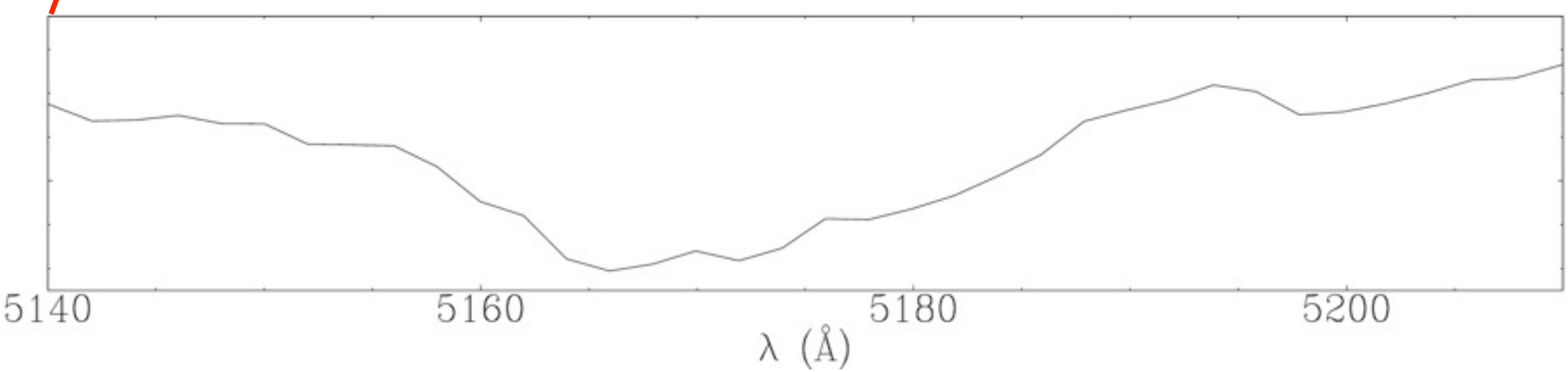
Key for the derivation of chemical element abundance ratios



Absorption features in galaxies

Key for the derivation of chemical element abundance ratios

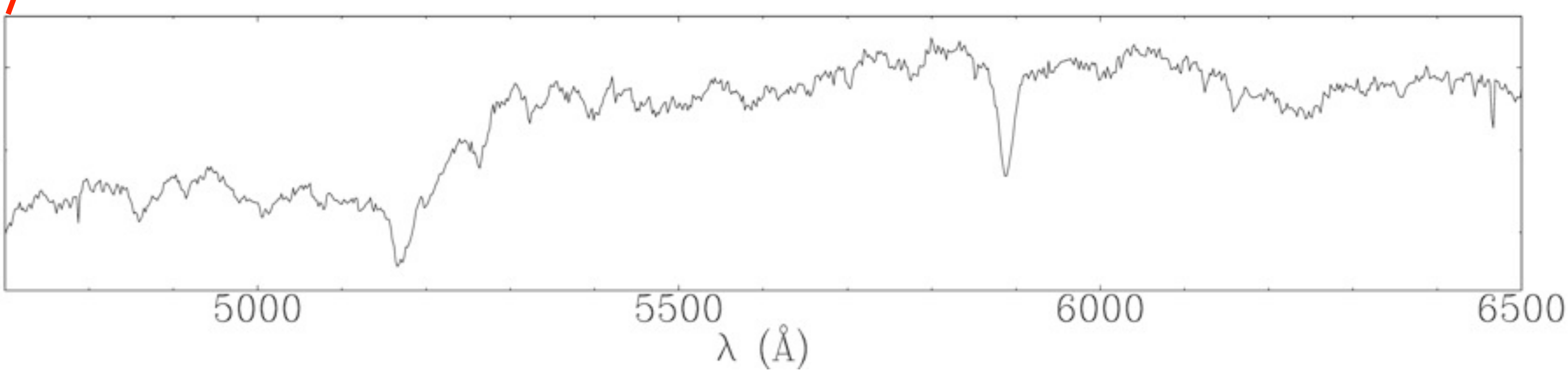
- Stars not resolved in most galaxies
- Spectral resolution reduced by stellar velocities in bright galaxies



Absorption features in galaxies

Key for the derivation of chemical element abundance ratios

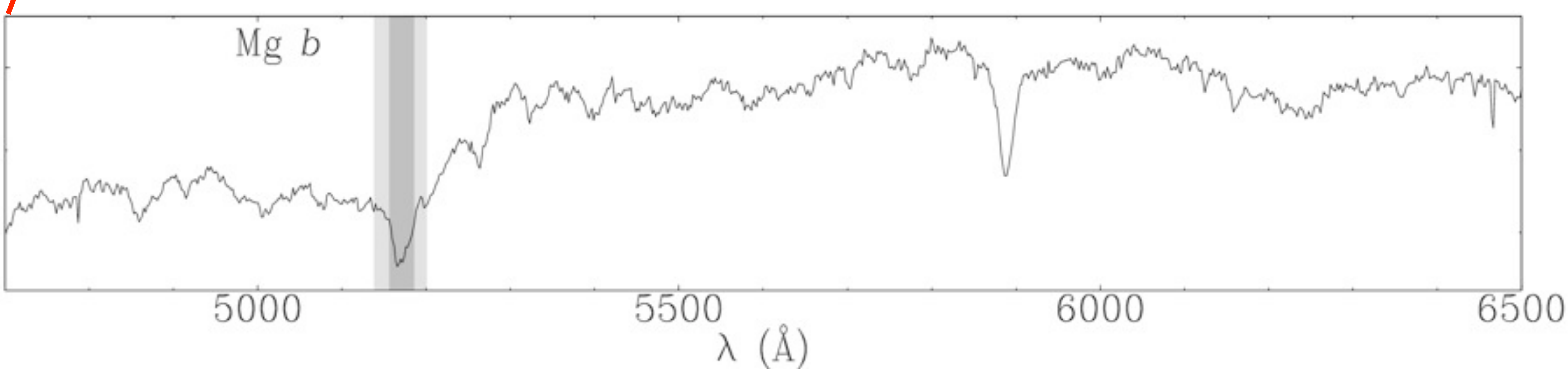
- Stars not resolved in most galaxies
- Spectral resolution reduced by stellar velocities in bright galaxies



Absorption features in galaxies

Key for the derivation of chemical element abundance ratios

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



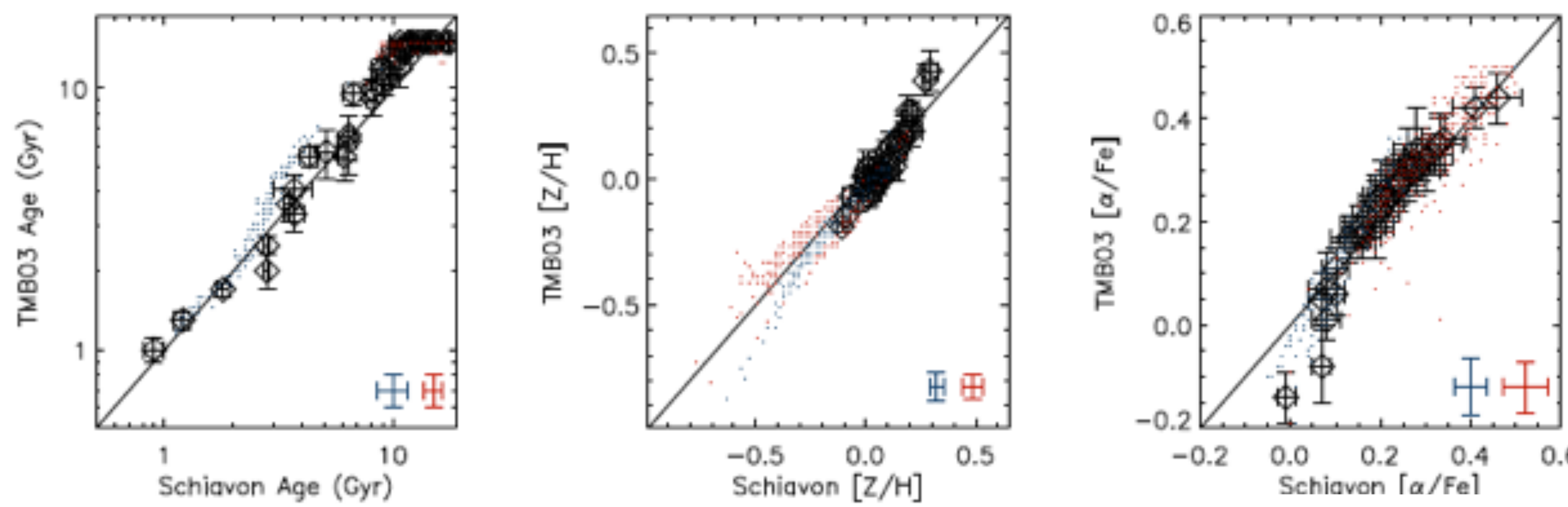
ICG Portsmouth

Absorption features in galaxies

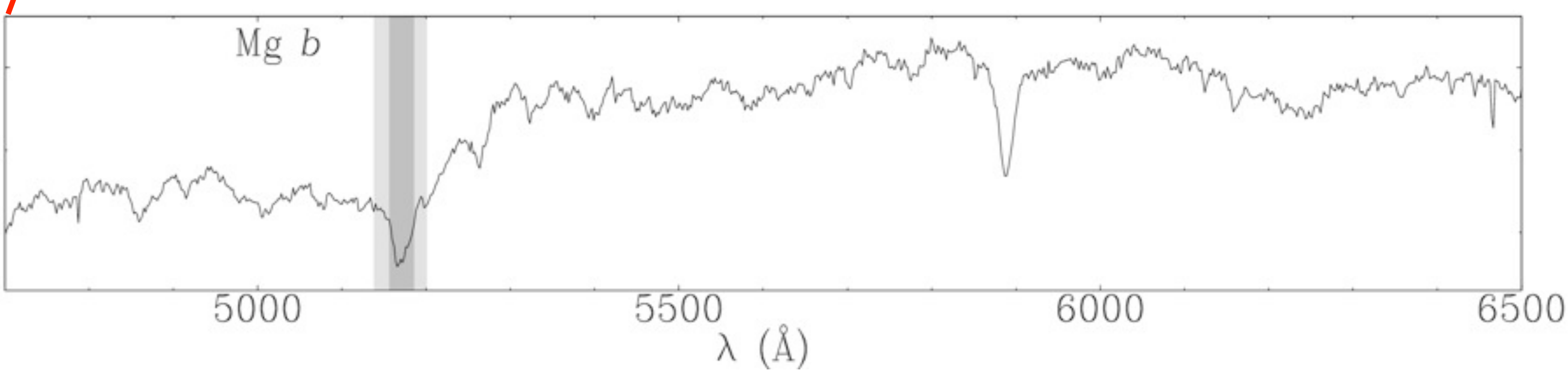
University of Portsmouth

Key for the derivation of chemical element abundance ratios

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



Kuntschner et al 2010

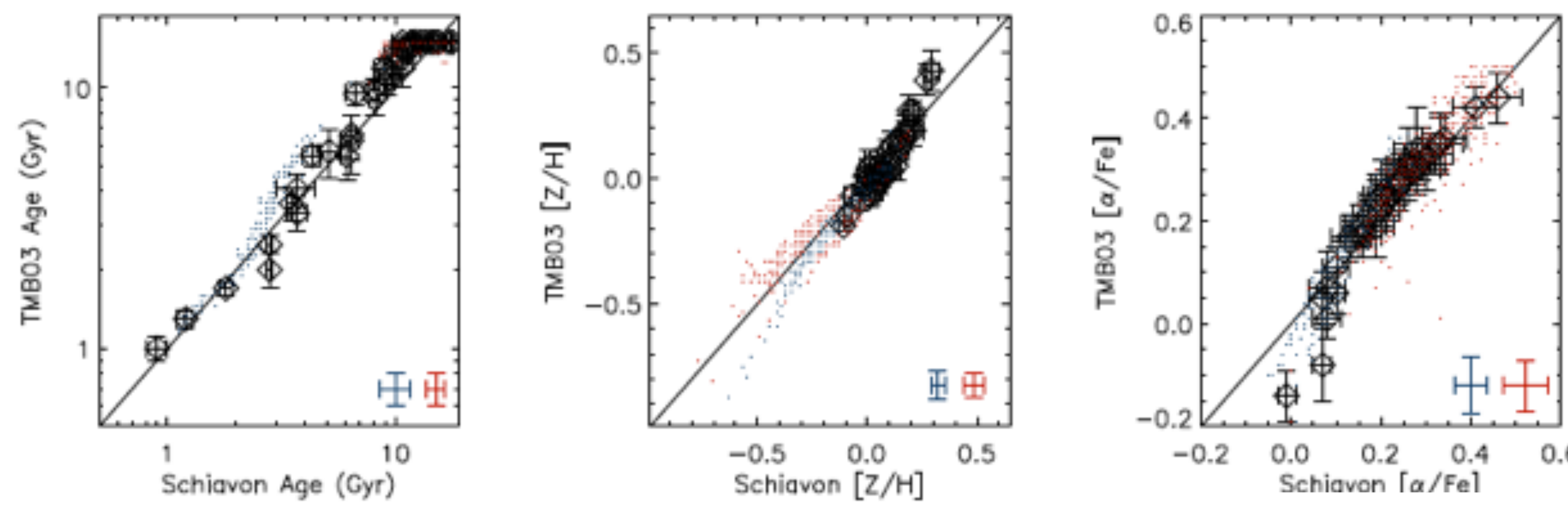


Absorption features in galaxies

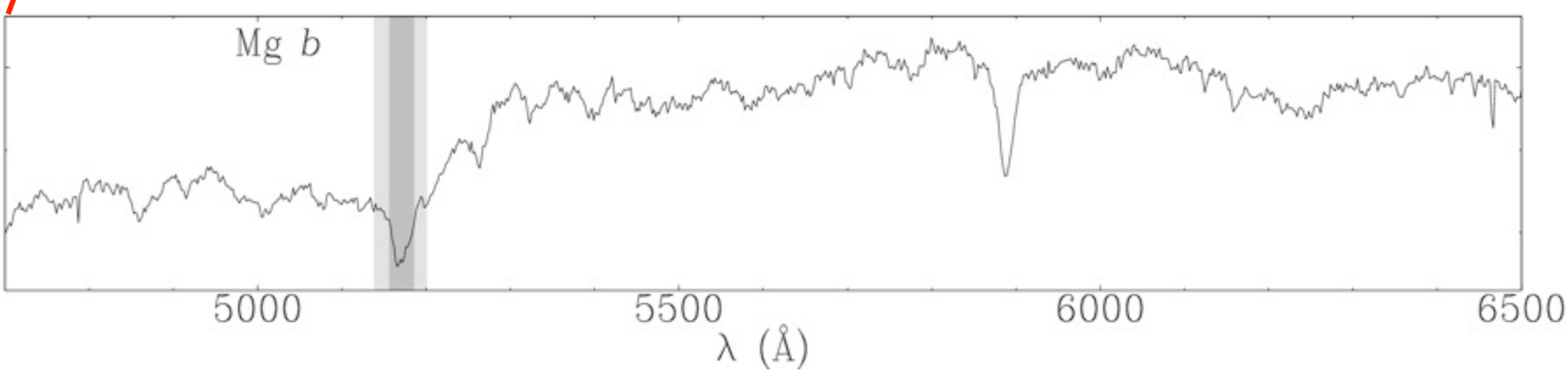
Key for the derivation of chemical element abundance ratios

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

Good agreement between different models



Kuntschner et al 2010



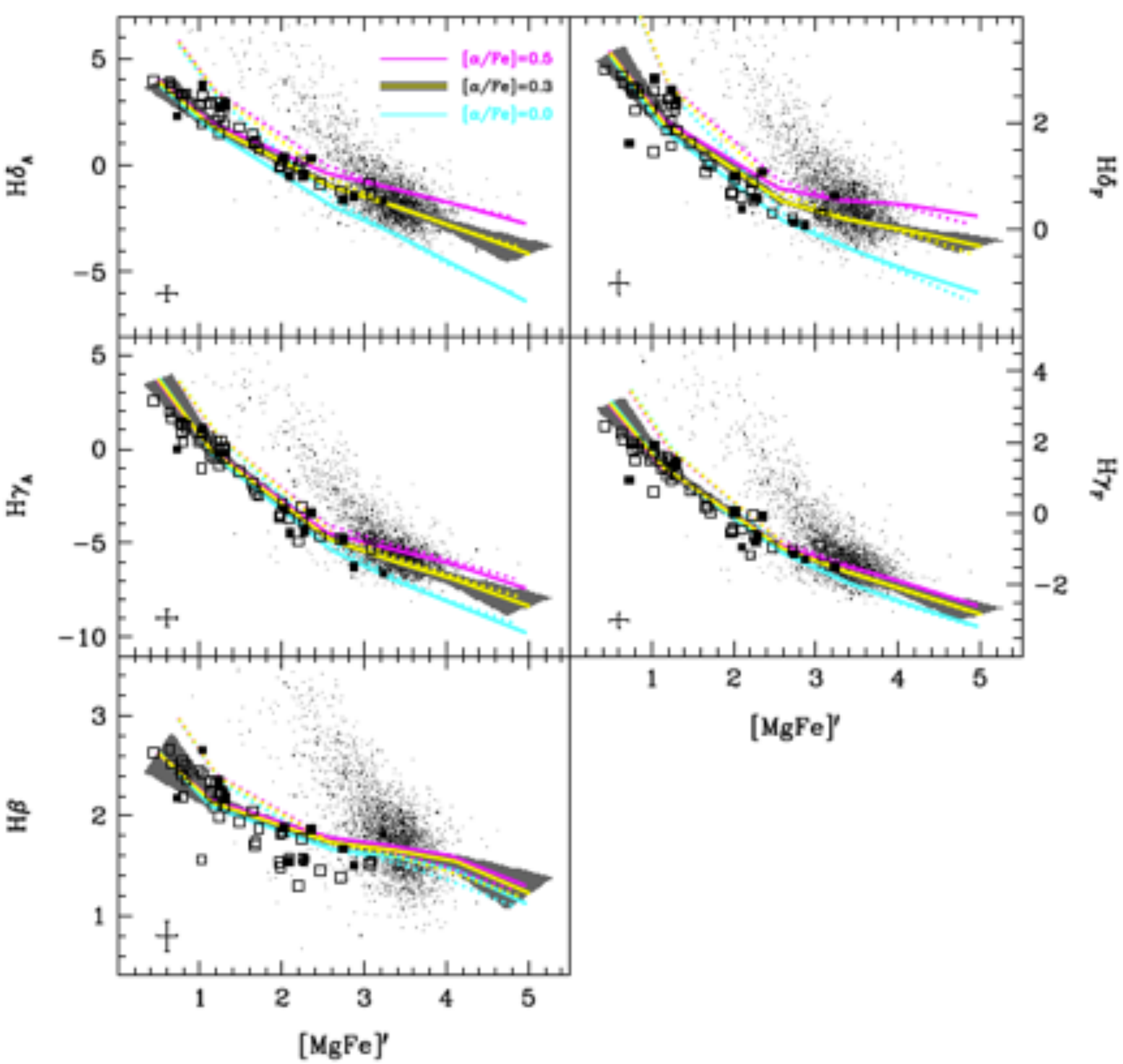
ICG Portsmouth

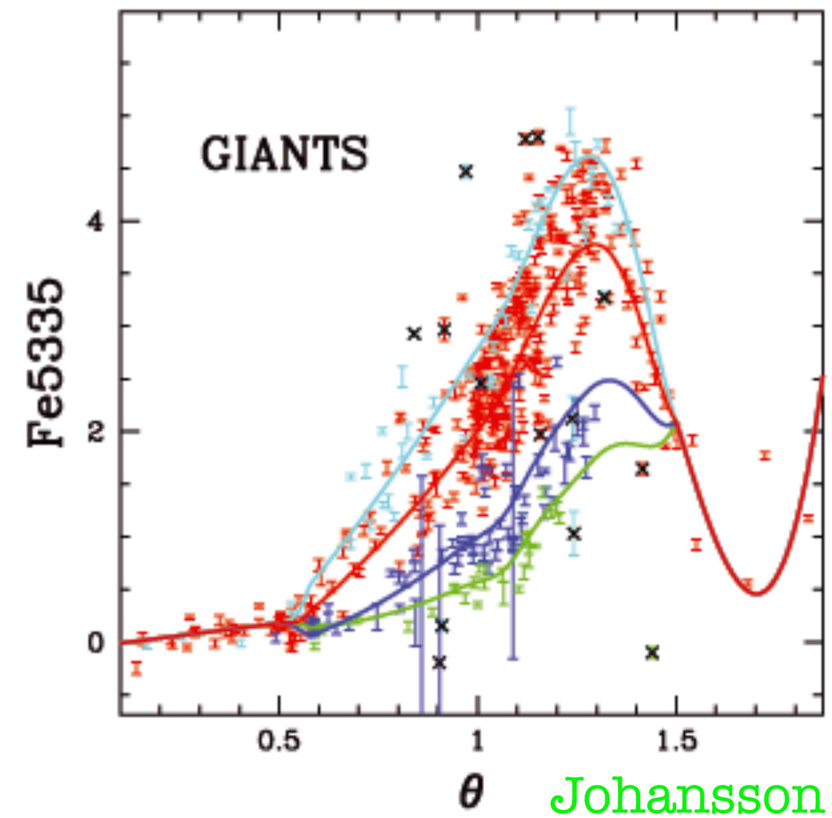
New models for variable element ratios

University of Portsmouth

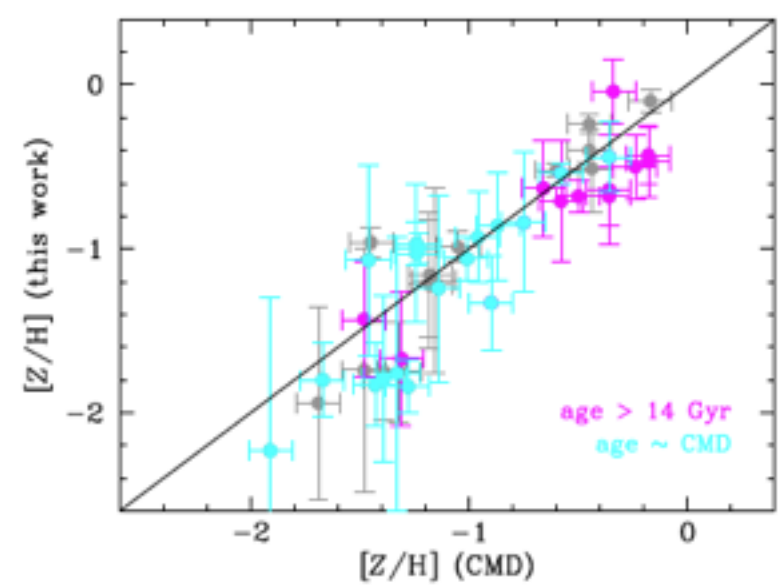
Thomas et al 2011a

- Based on new fitting functions for MILES
- Flux-calibrated hence no ‘Lick offsets’
- Well calibrated with globular clusters
- Model errors



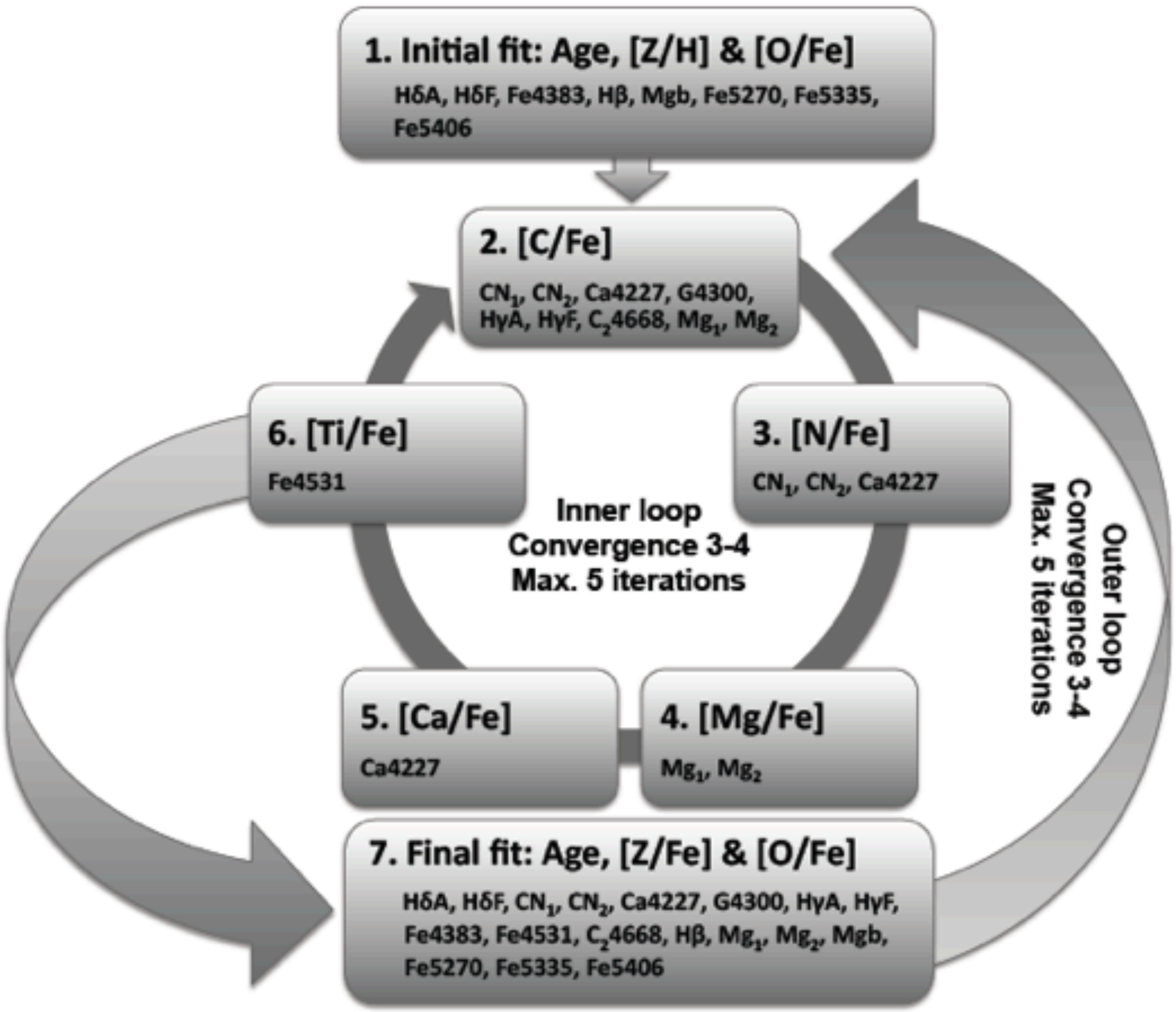


Johansson et al 2010



Thomas et al 2011b

Deriving element abundance ratios

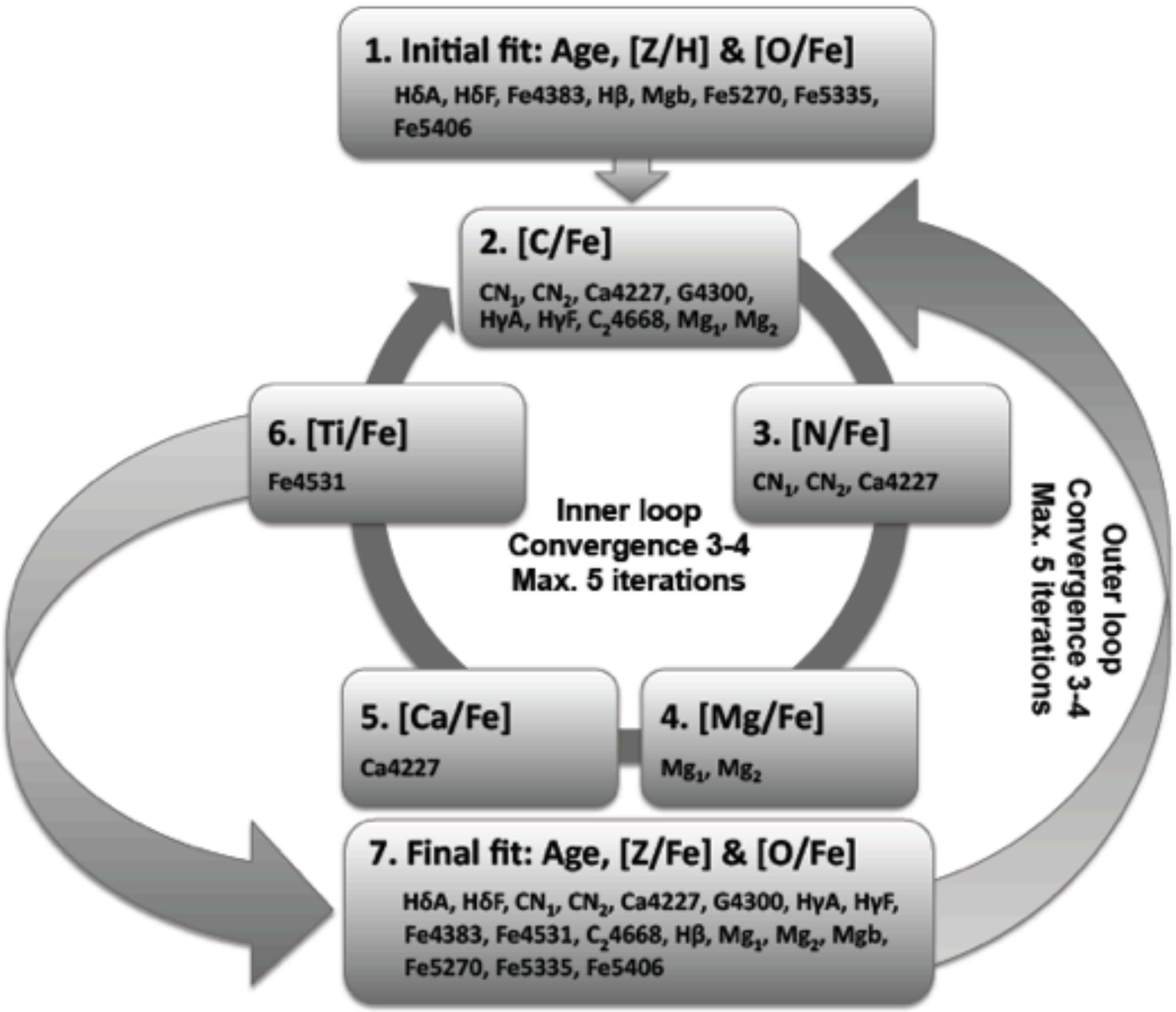


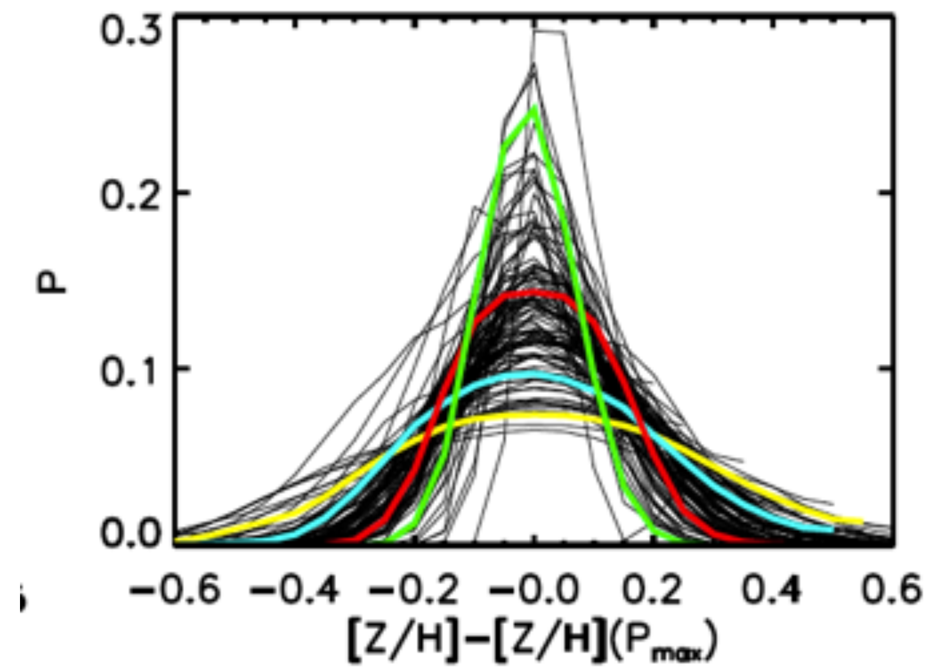
Johansson et al 2011

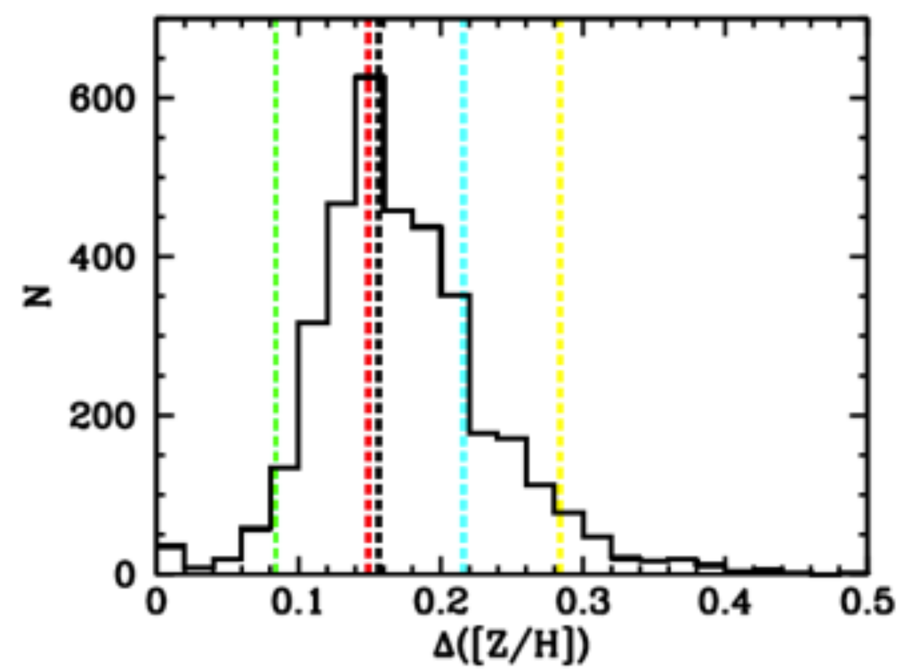
ICG Portsmouth

Deriving element abundance ratios

University of Portsmouth





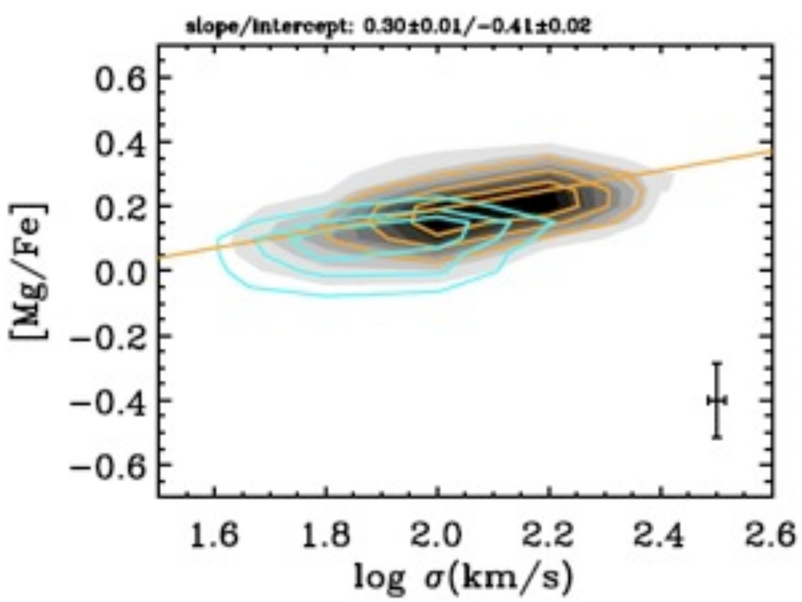


Johansson et al 2011

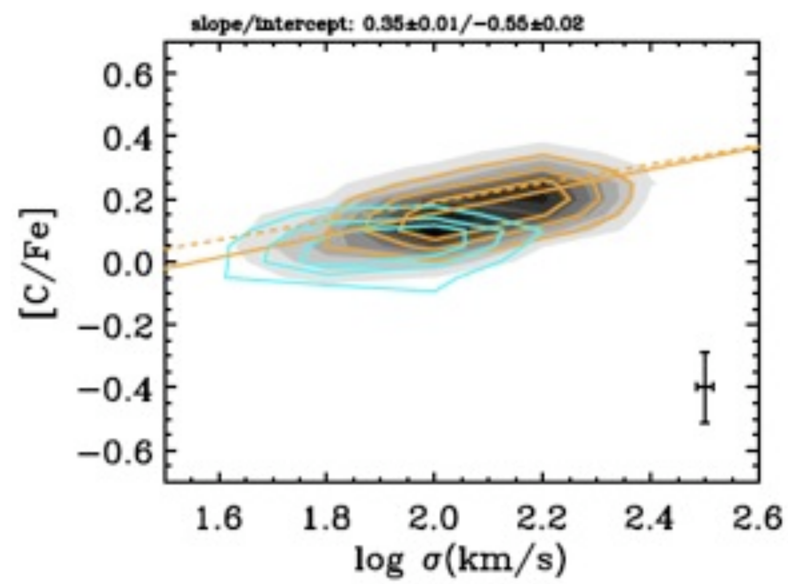
Full chemical enrichment

Johansson et al 2011

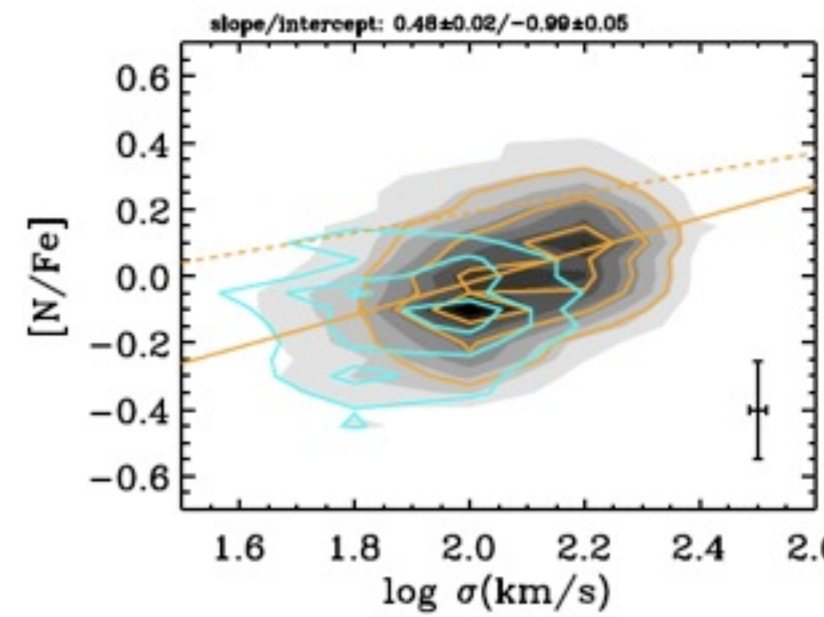
Magnesium



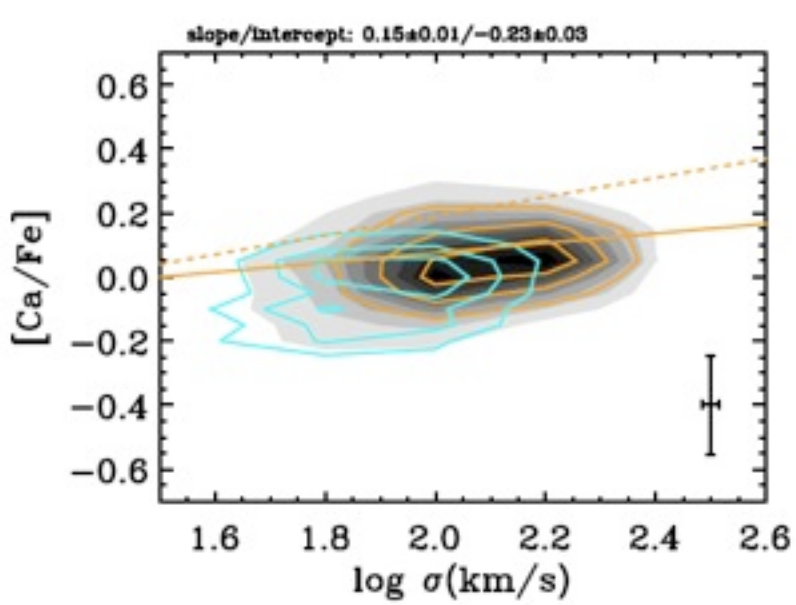
Carbon



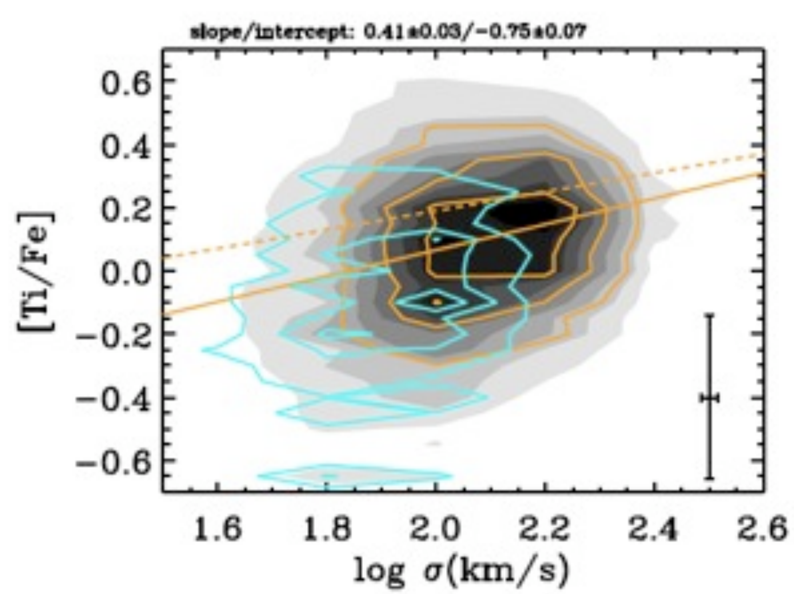
Nitrogen



Calcium



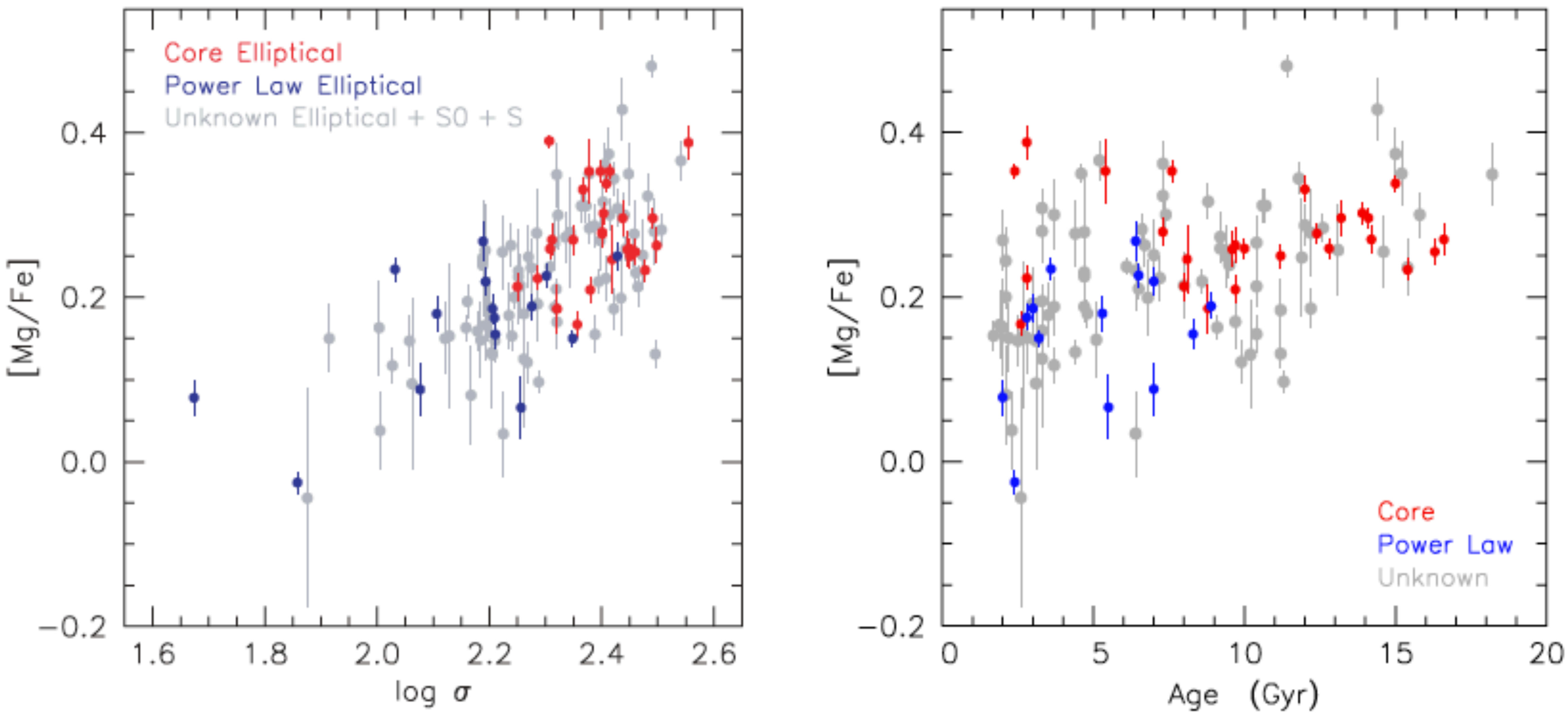
Titanium



- Carbon follows magnesium
- Nitrogen suppressed
- Calcium and titanium follow iron

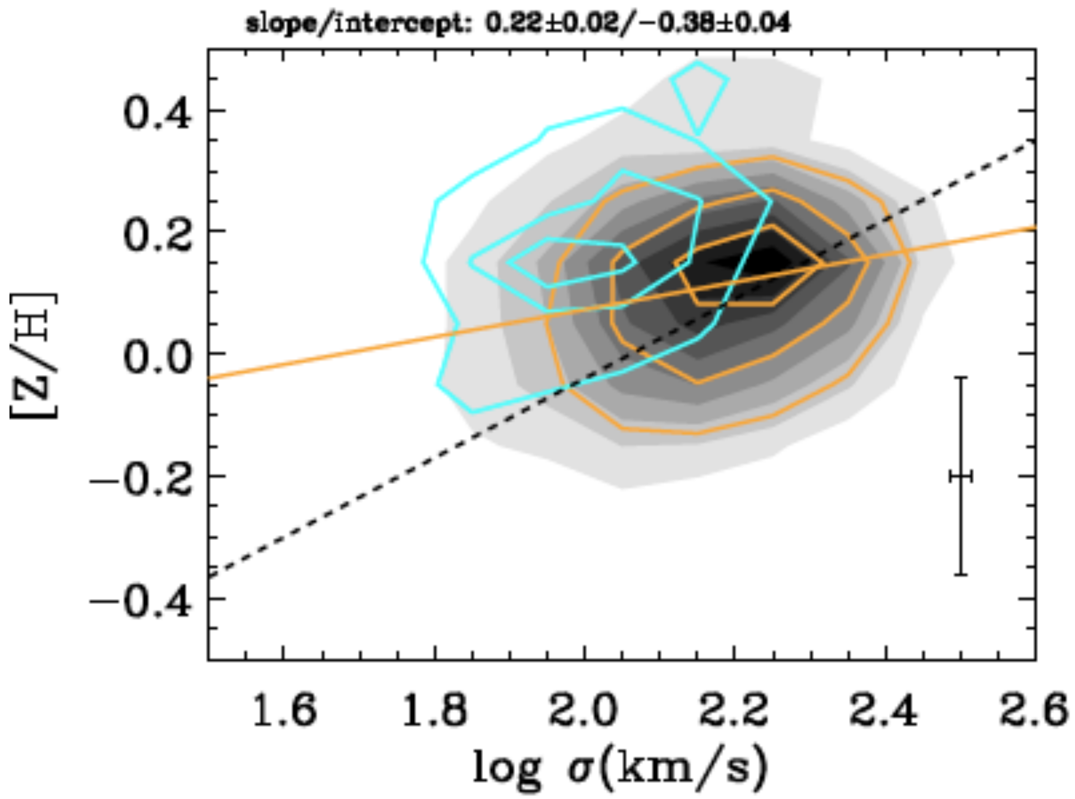
Structural parameters and Mg/Fe

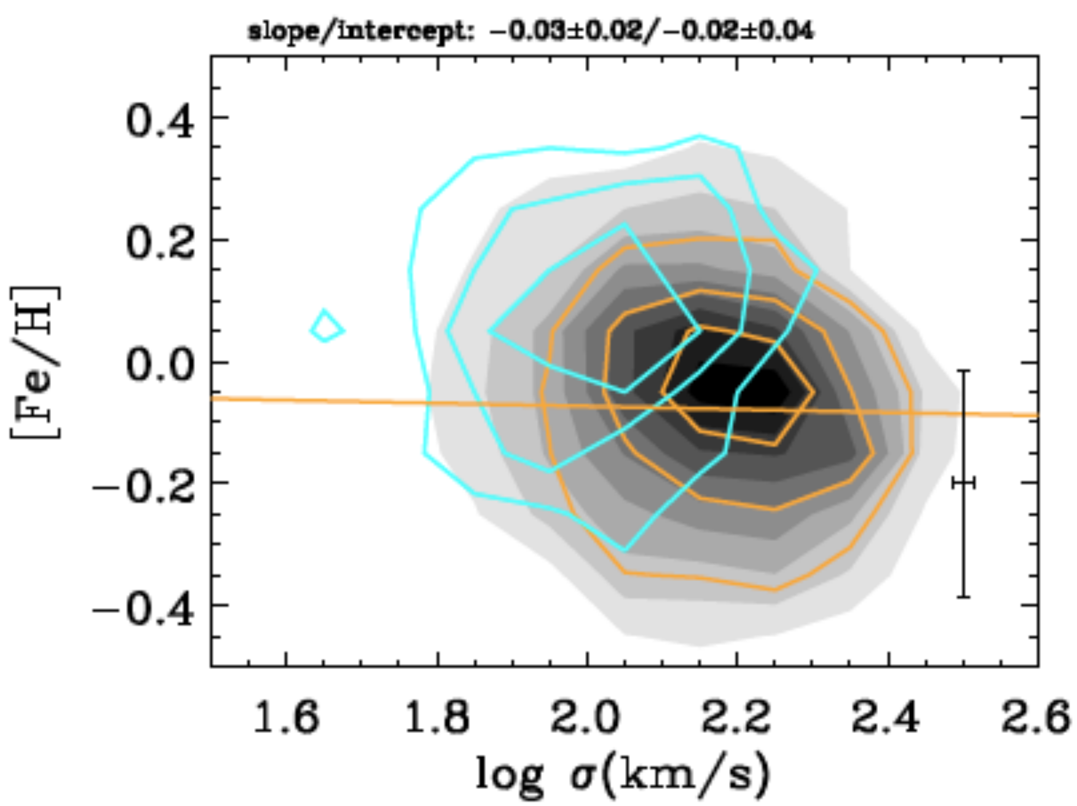
Mg/Fe ratio participates in the E-E dichotomy



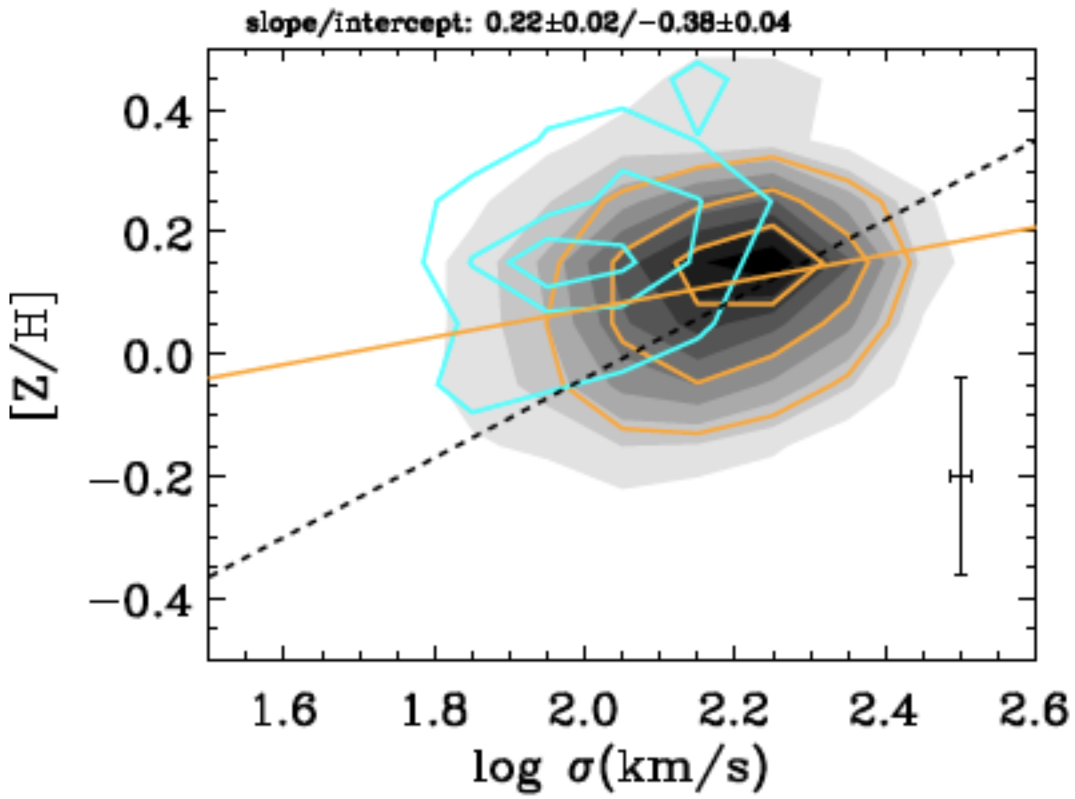
Kormendy et al 2009

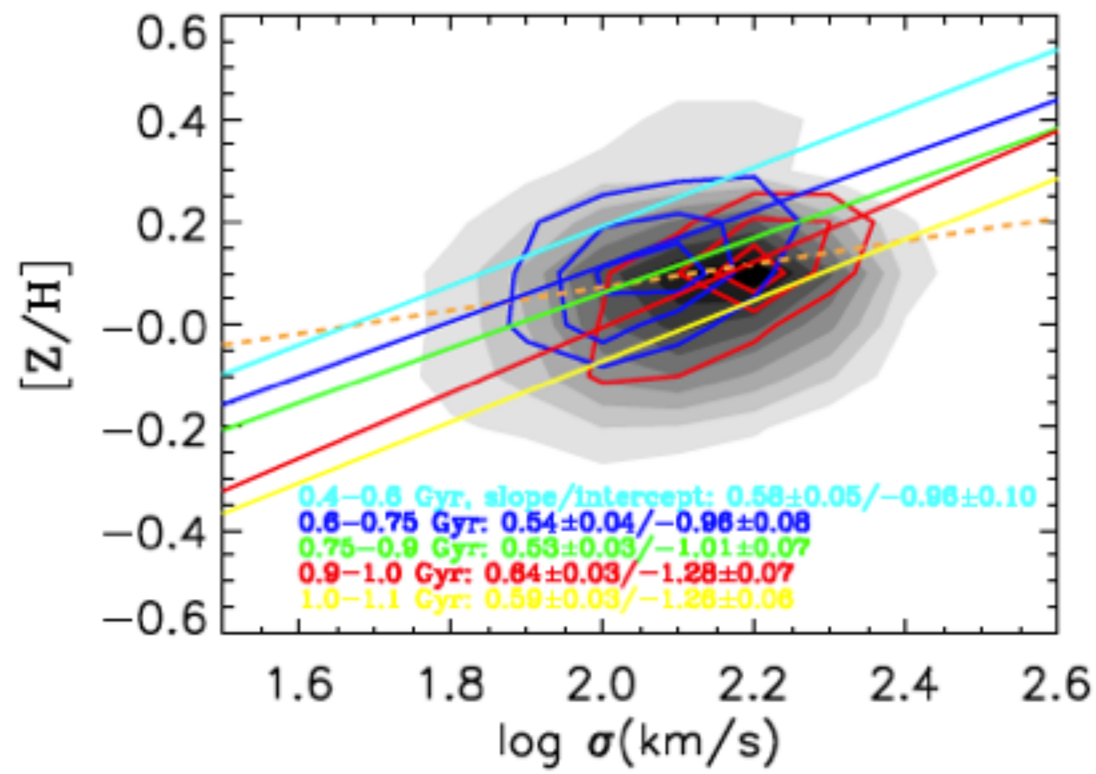
Metal enrichment

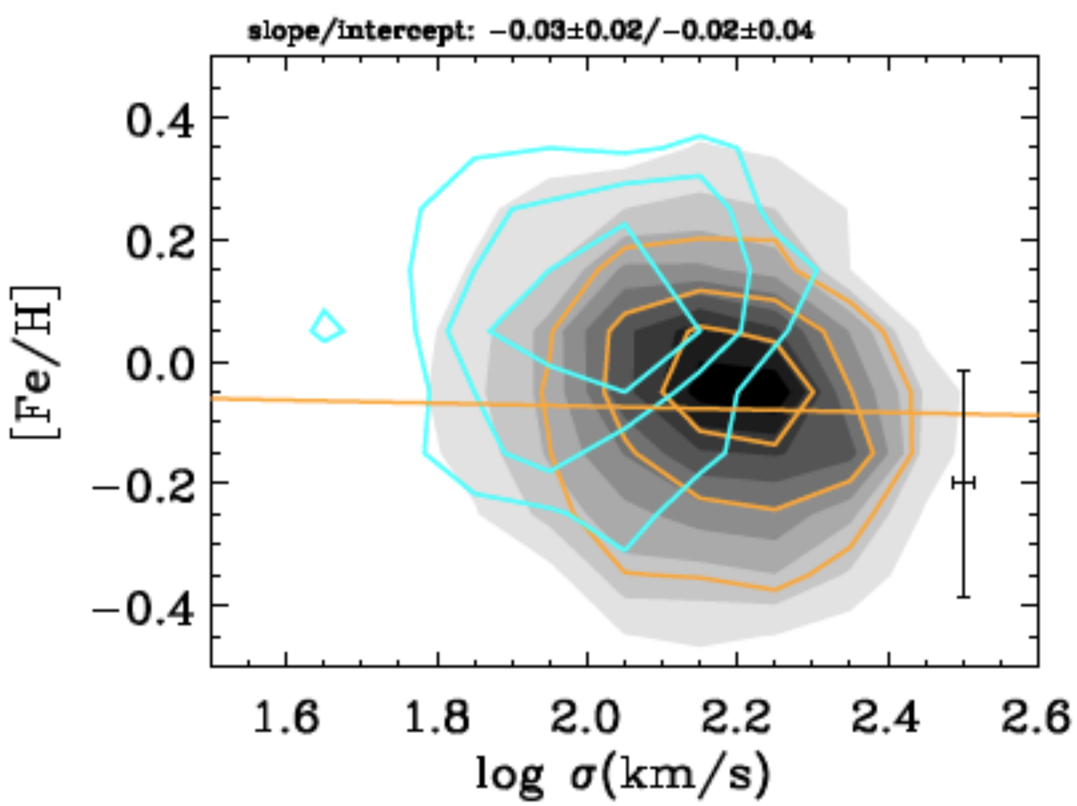




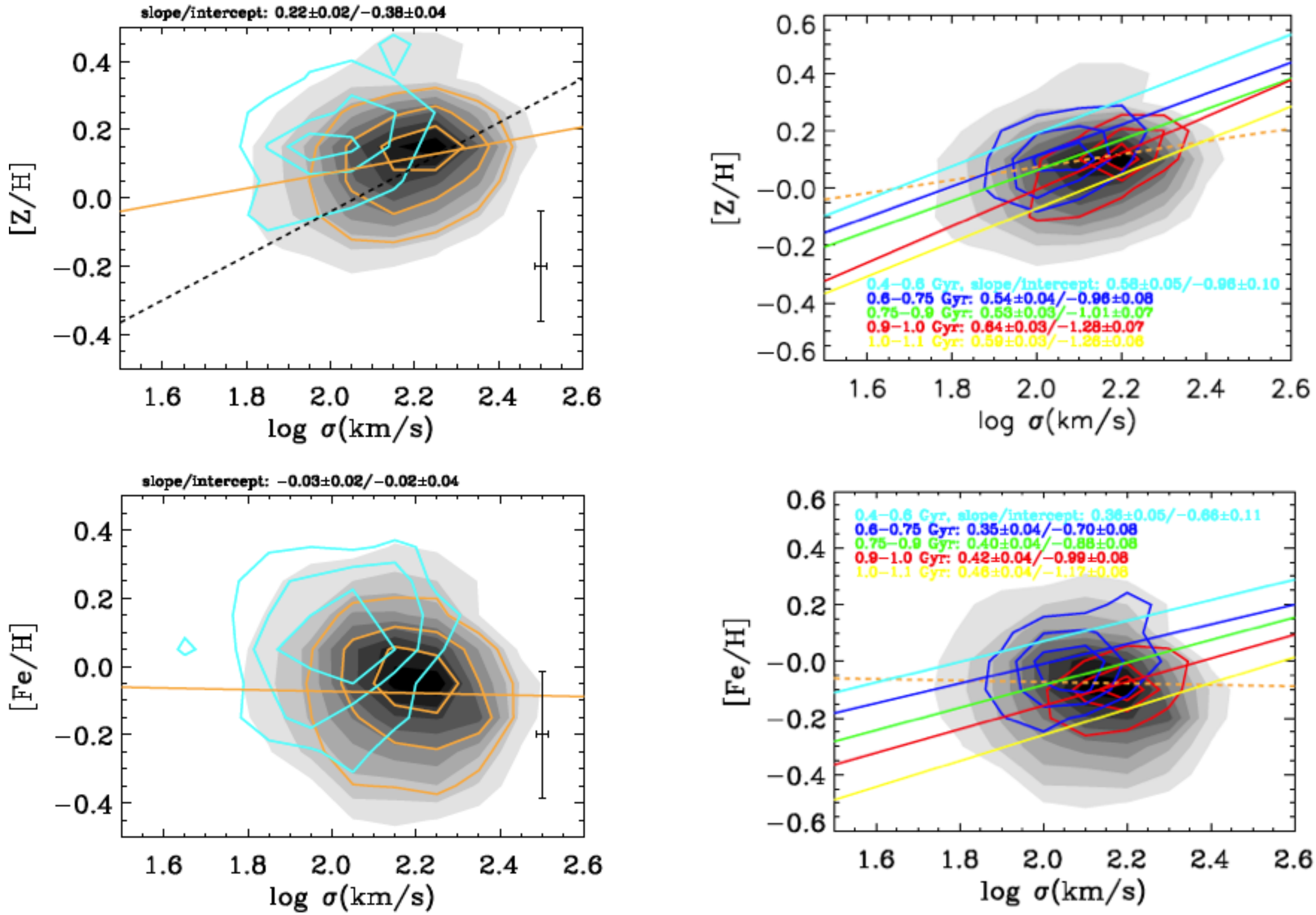
Metal enrichment





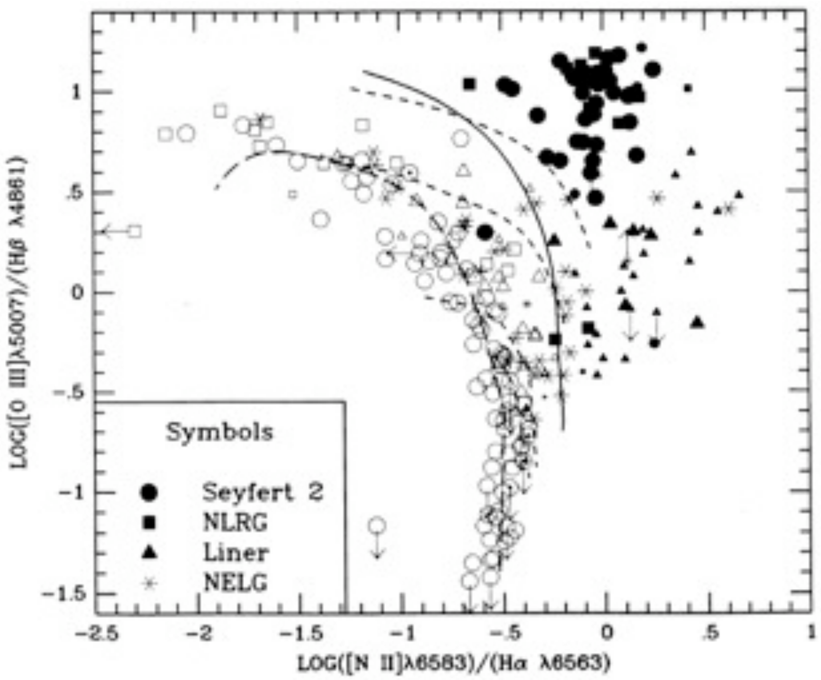


Metal enrichment



Large galaxy surveys

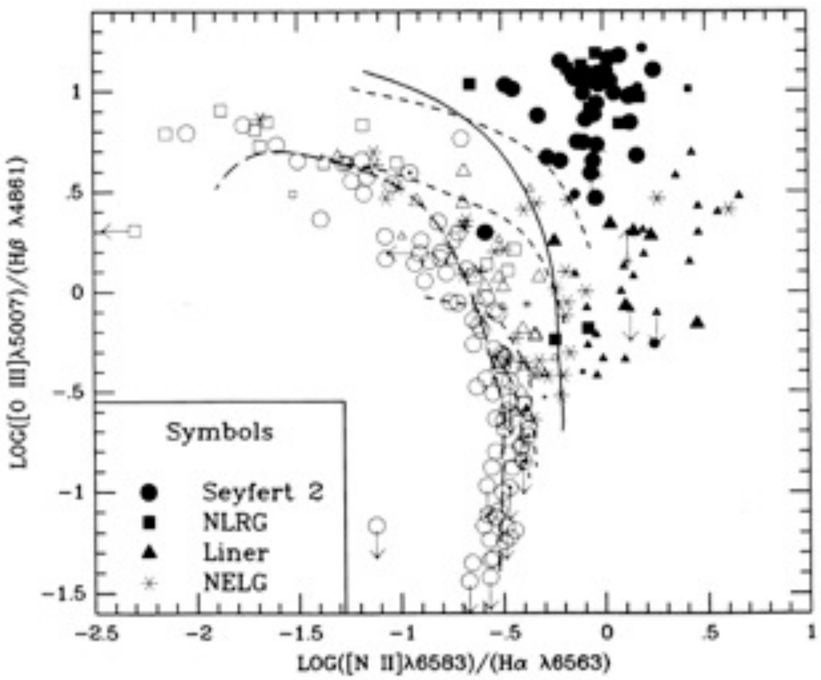
1990's



Veilleux & Osterbrock 1989

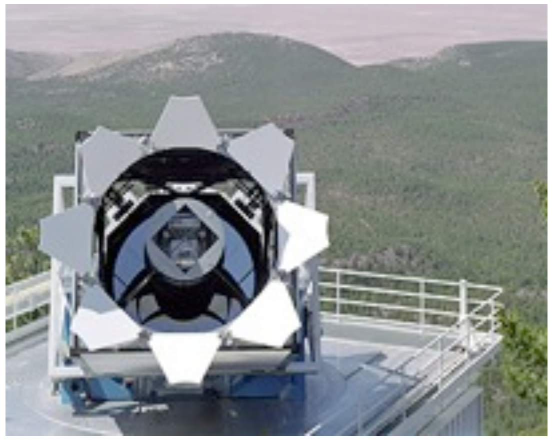
Large galaxy surveys

1990's

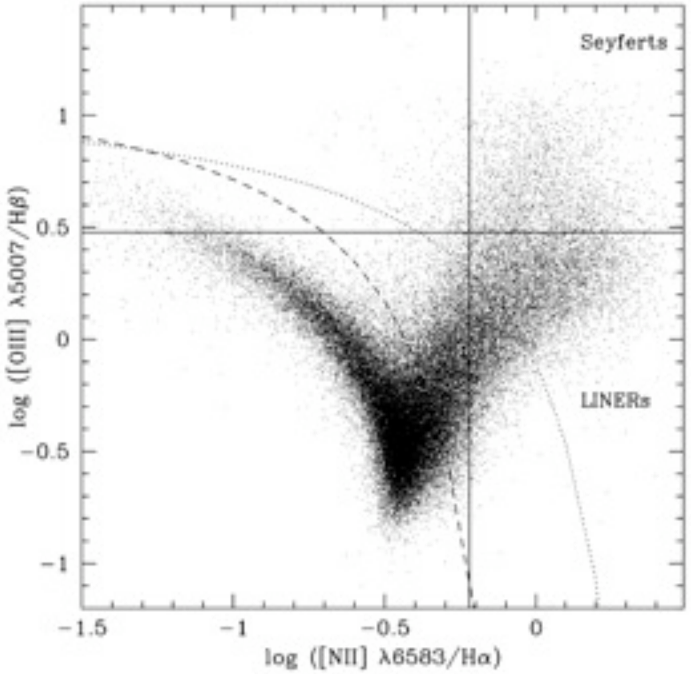


Veilleux & Osterbrock 1989

SDSS-I/II



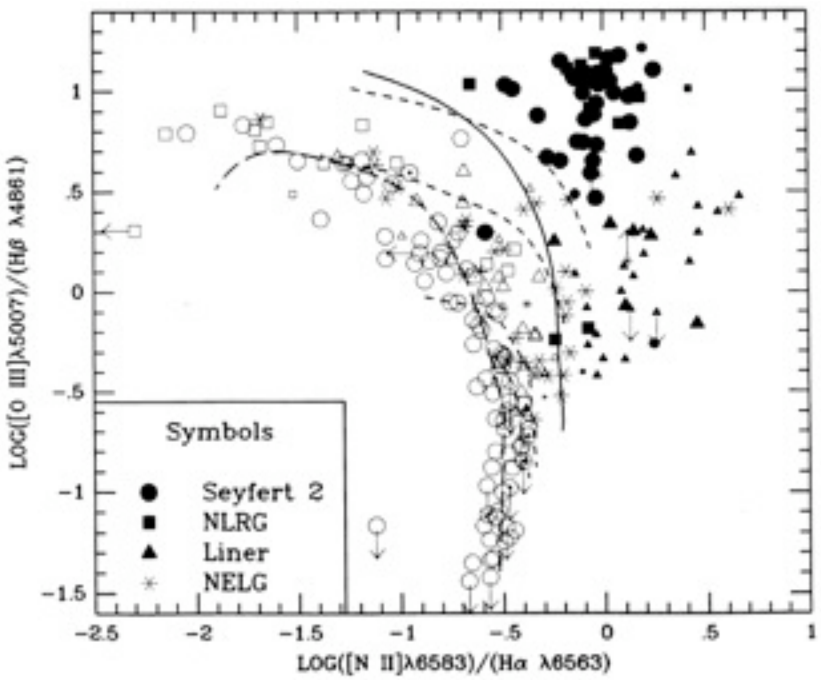
2000's



Kauffmann et al 2003

Large galaxy surveys

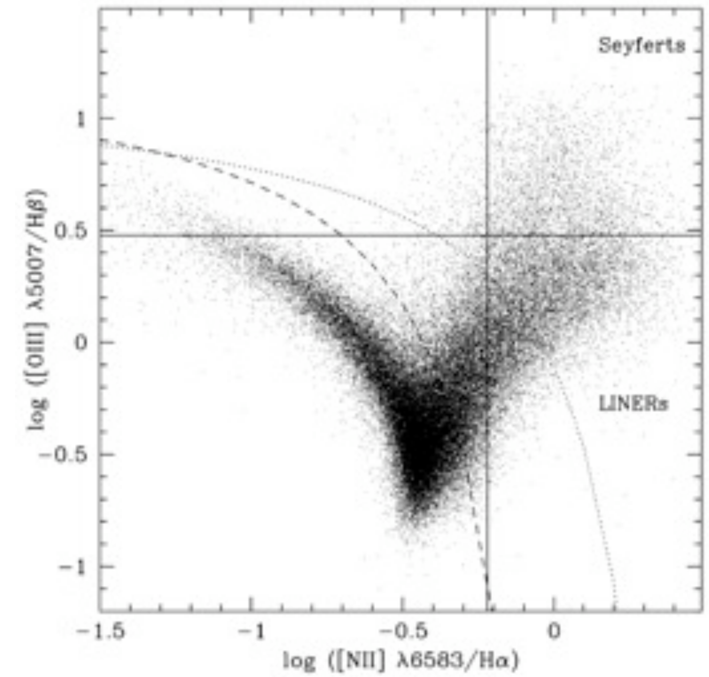
1990's



Veilleux & Osterbrock 1989

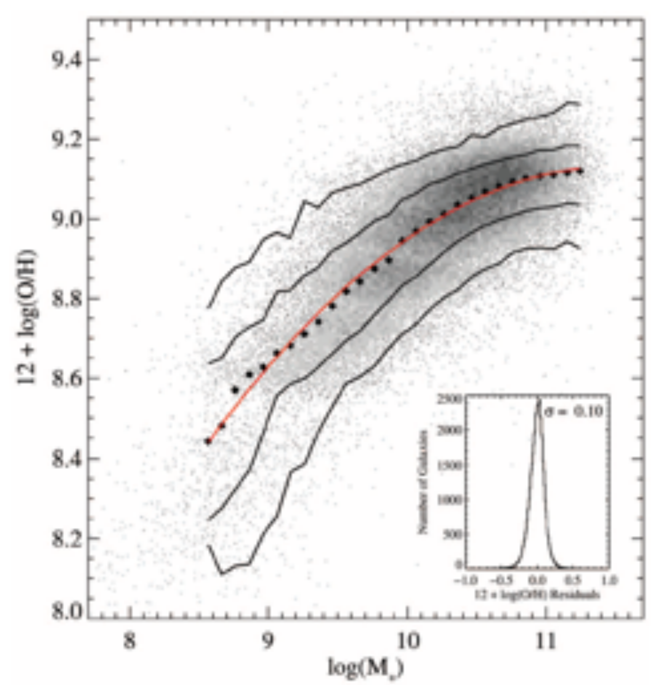
SDSS-I/II

2000's

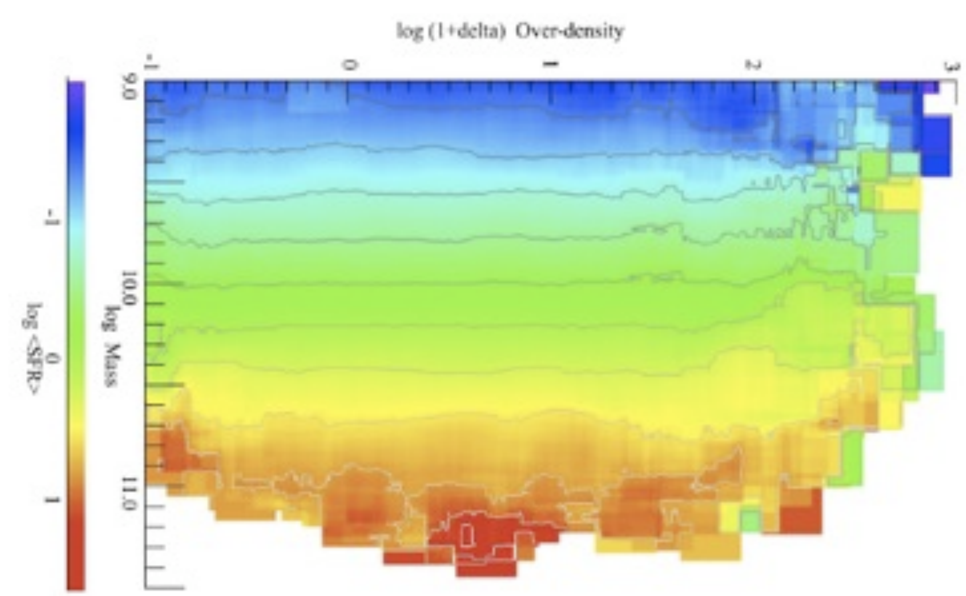


Kauffmann et al 2003

- Statistical approach to galaxy evolution
- 'Precision astronomy'
- Significant progress in understanding of local galaxy population

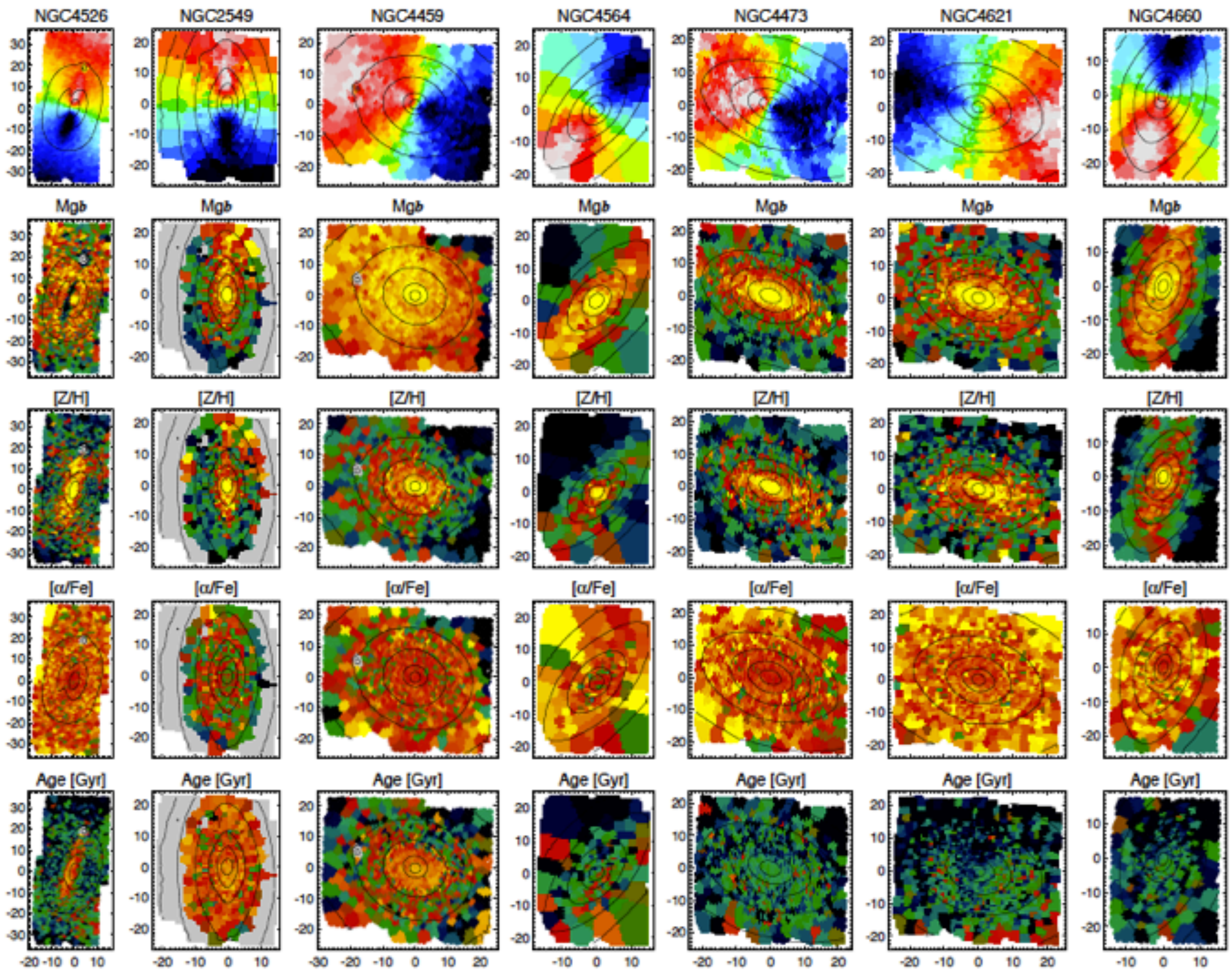


Tremonti et al 2004



Peng et al 2010

The inside of galaxies



Kuntschner et al 2010

- Mapping stellar populations and gas physics
- Wealth of information on kinematics and stellar population gradients

SDSS-III (BOSS)

PI: David Schlegel

- Fall 2009 - Spring 2014
- 10,000 square degrees on the sky
- 1,000-fiber spectrograph, resolution R = 2000
- Wavelengths 360-1000 nm
- Spectra of 1.5 million luminous galaxies to z = 0.7 (6 billion years into the past)
- Lyman-α forest spectra of 160,000 quasars at redshifts 2.2 < z < 3
- Eisenstein et al 2011

Probe a million massive galaxies half way back to the Big Bang

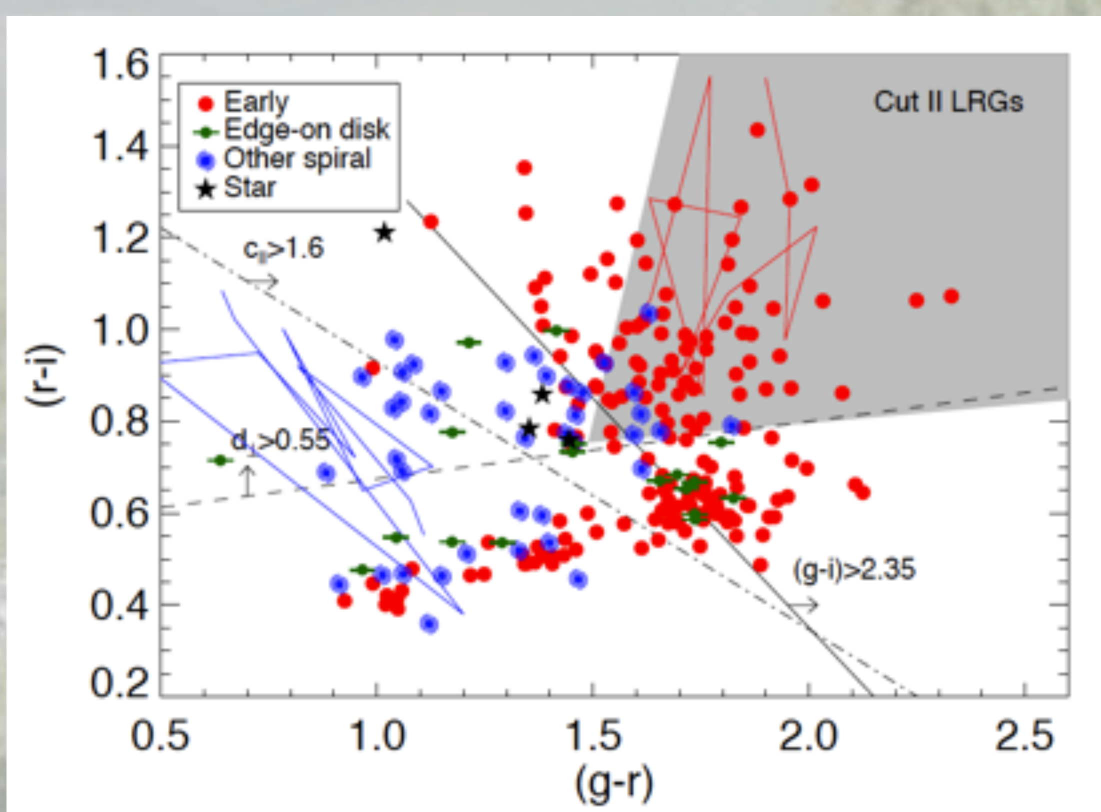
- Kinematics and stellar masses
- Ages and chemical abundance ratios
- Black hole activity
- Star formation and gas physics

SDSS-III (BOSS)

PI: David Schlegel

- Fall 2009 - Spring 2014
- 10,000 square degrees on the sky
- 1,000-fiber spectrograph, resolution R = 2000
- Wavelengths 360-1000 nm
- Spectra of 1.5 million luminous galaxies to z = 0.7 (6 billion years into the past)
- Lyman-α forest spectra of 160,000 quasars at redshifts 2.2 < z < 3
- Eisenstein et al 2011

Probe a million massive galaxies half way back to the Big Bang



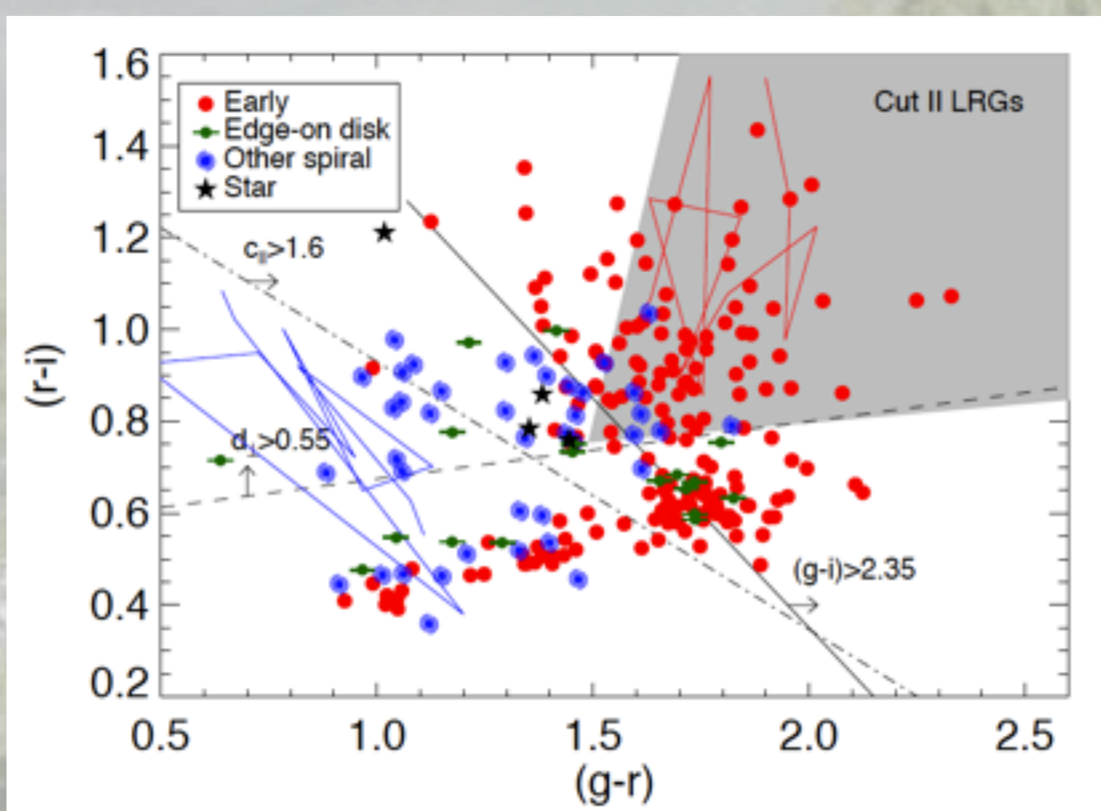
Masters et al 2011

SDSS-III (BOSS)

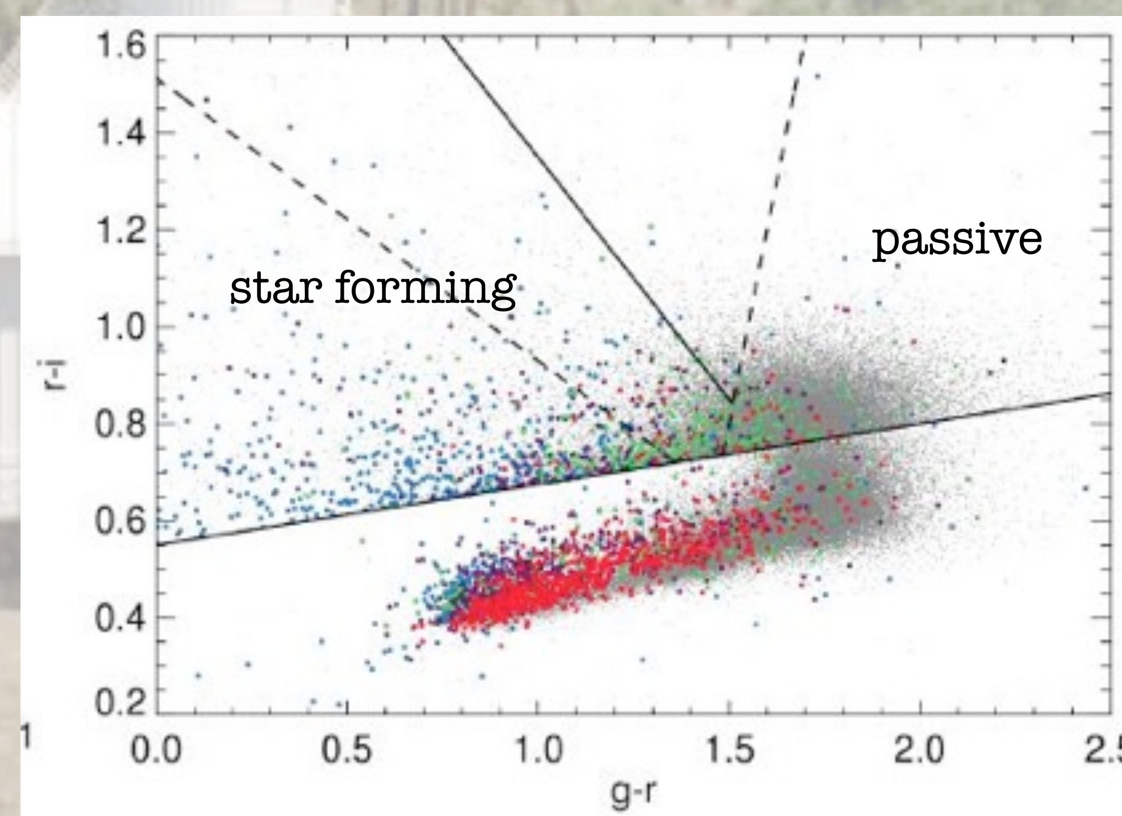
PI: David Schlegel

- Fall 2009 - Spring 2014
- 10,000 square degrees on the sky
- 1,000-fiber spectrograph, resolution R = 2000
- Wavelengths 360-1000 nm
- Spectra of 1.5 million luminous galaxies to z = 0.7 (6 billion years into the past)
- Lyman-α forest spectra of 160,000 quasars at redshifts 2.2 < z < 3
- Eisenstein et al 2011

Probe a million massive galaxies half way back to the Big Bang

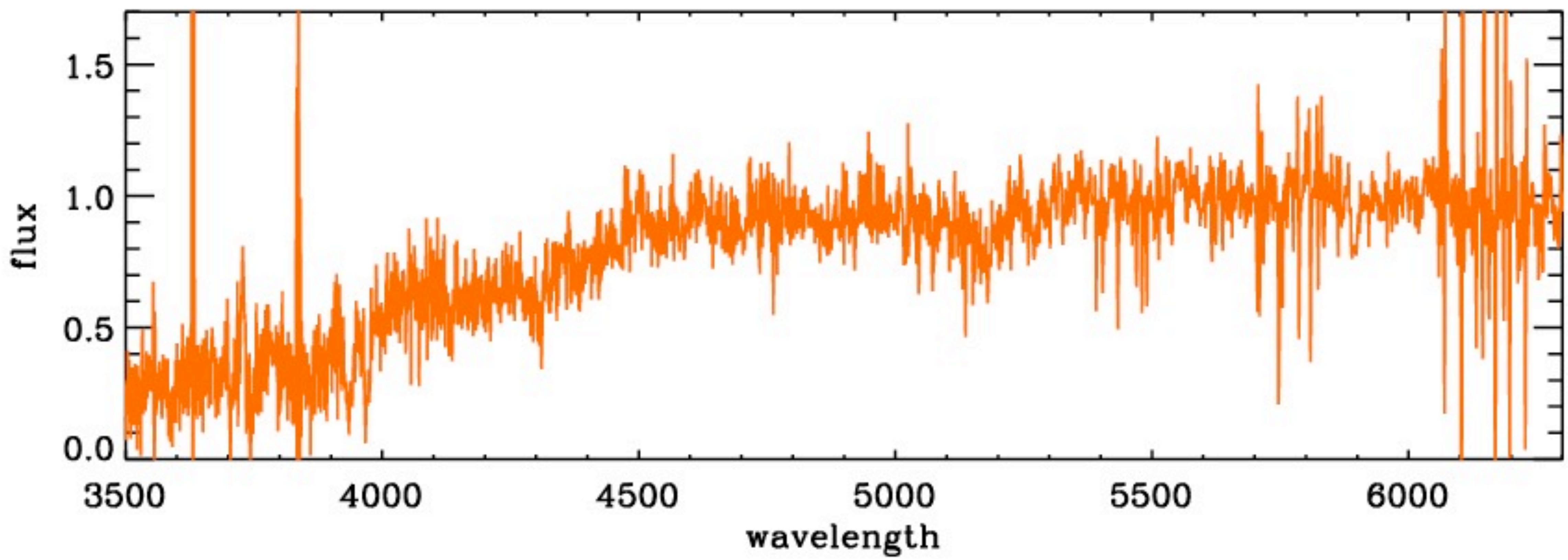


Masters et al 2011

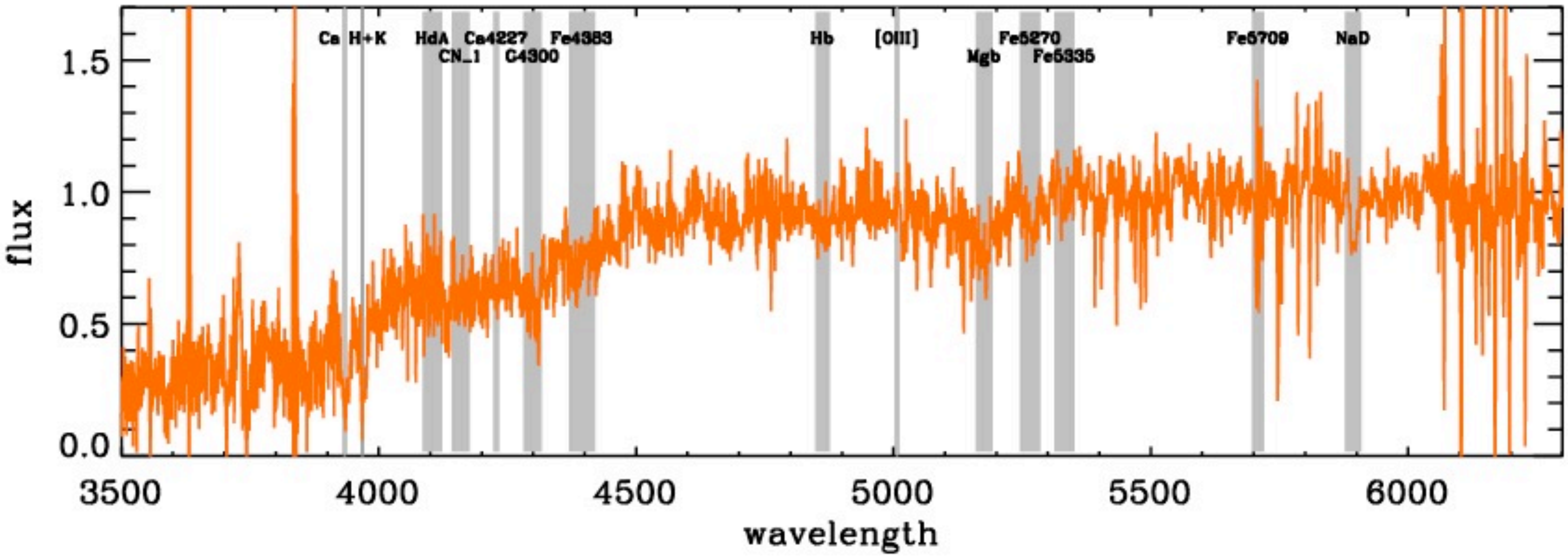


Thomas et al 2011

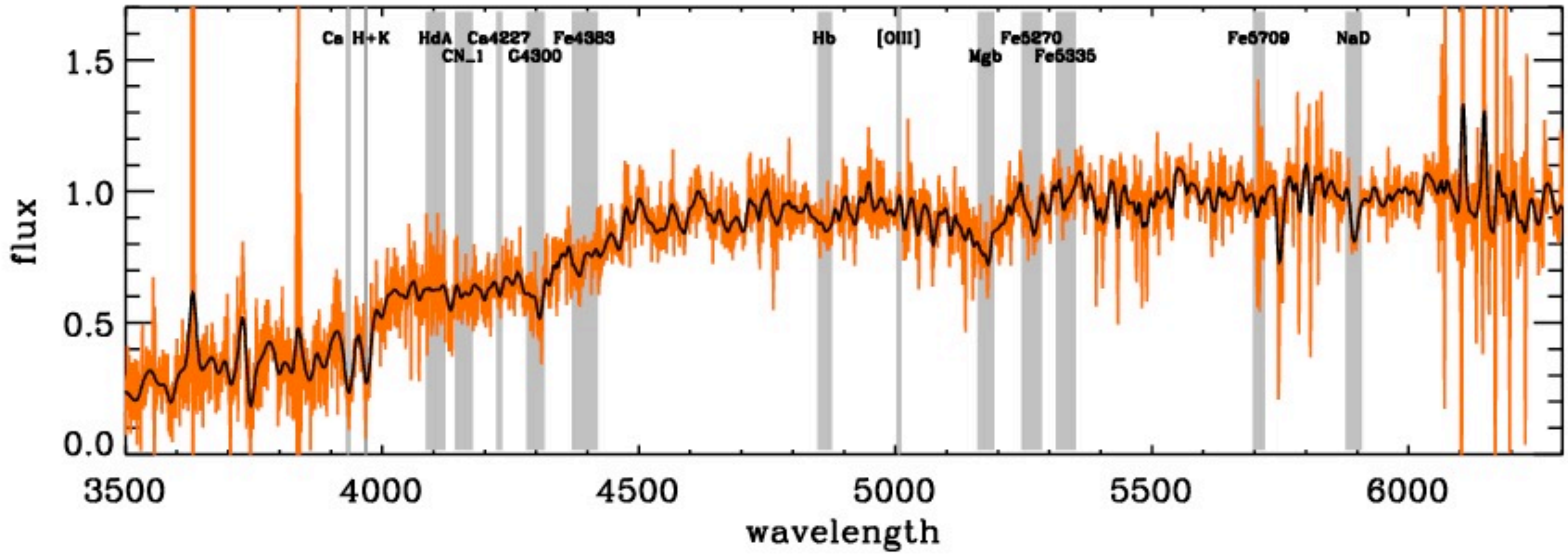
The BOSS LRG@z>0.5



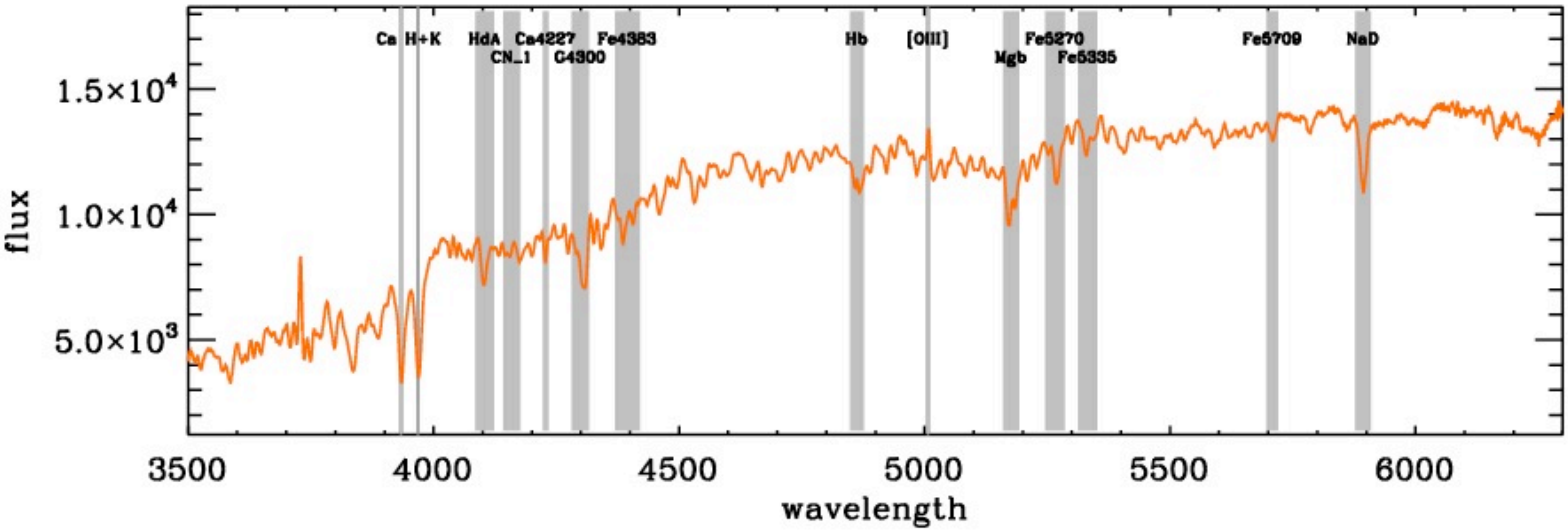
The BOSS LRG@z>0.5



The BOSS LRG@z>0.5

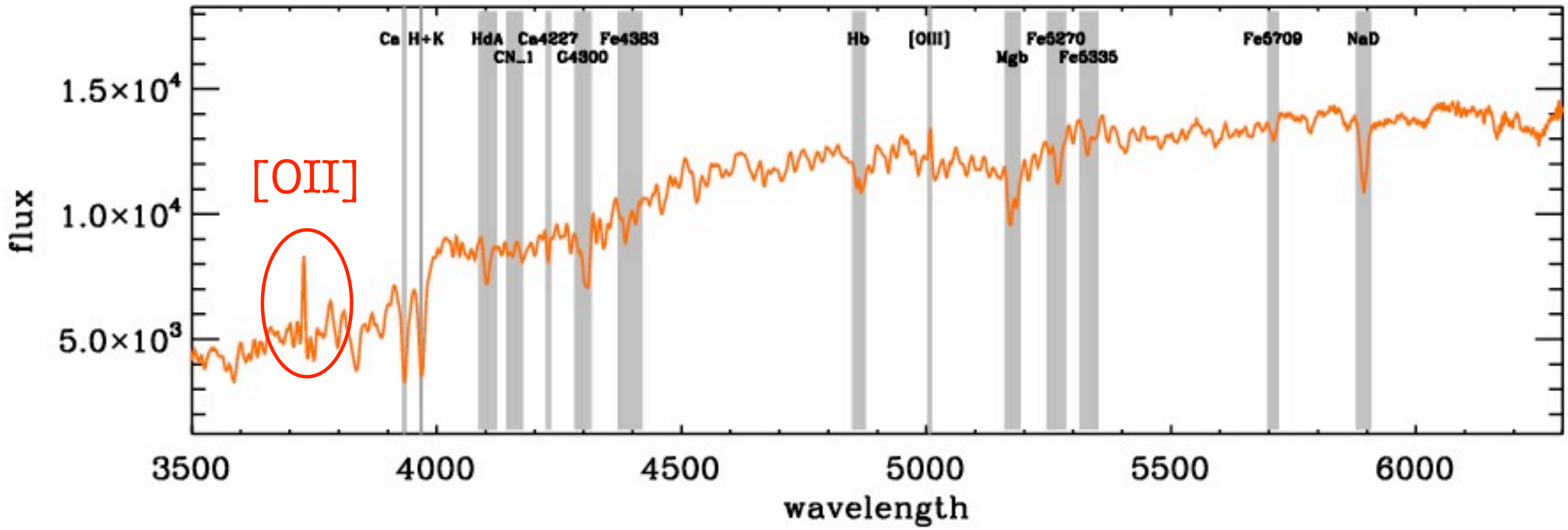


The BOSS LRG@z>0.5



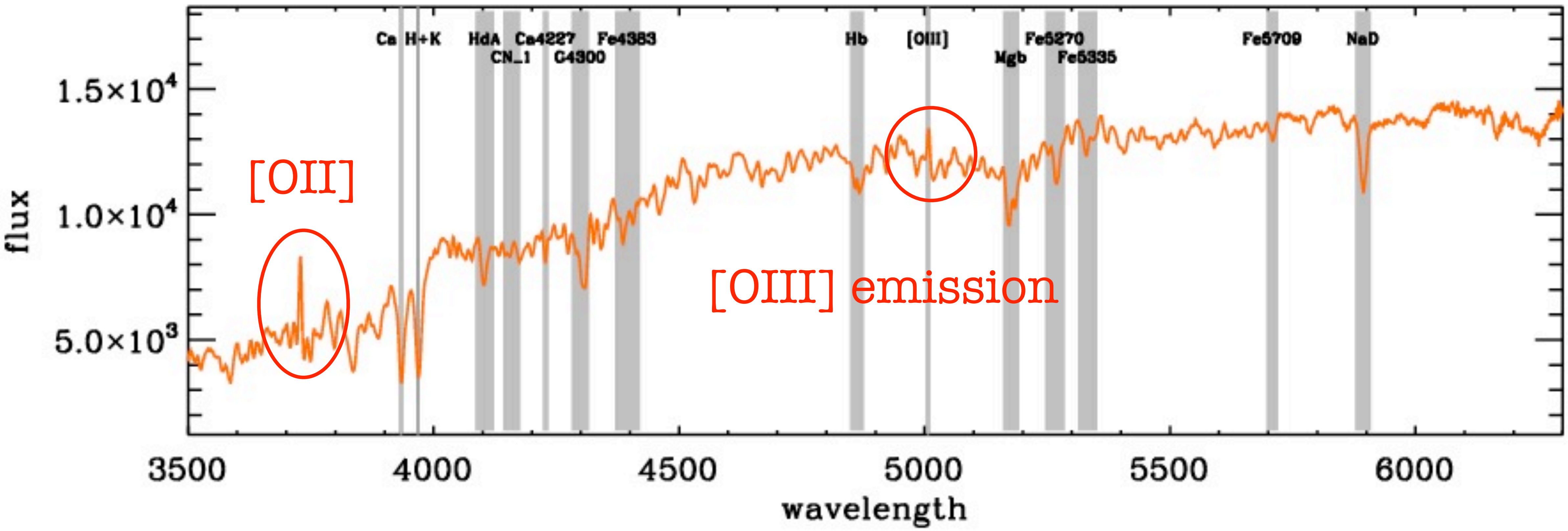
69 plates, 18663 galaxies, S/N>1000

The BOSS LRG@z>0.5



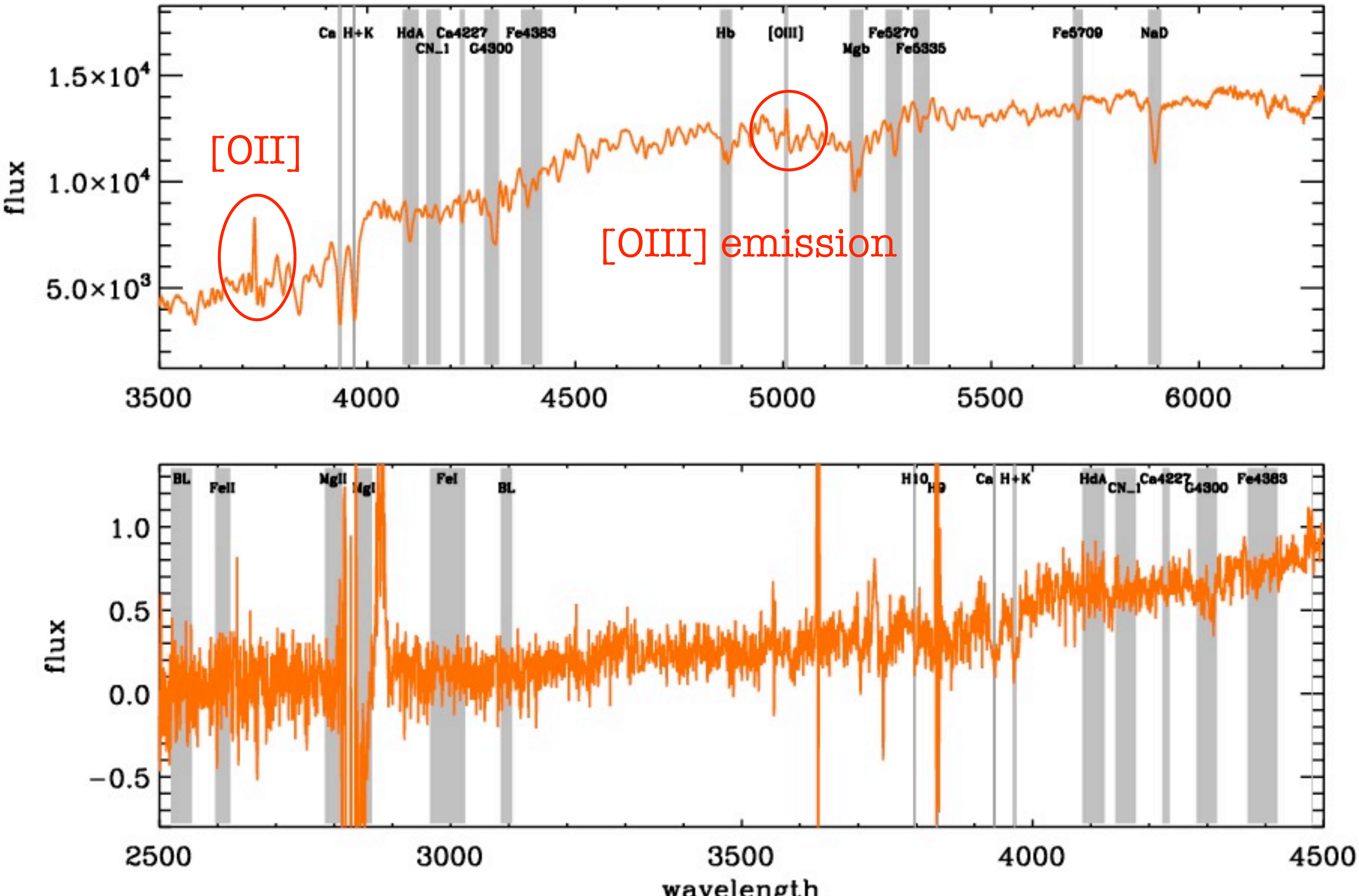
69 plates, 18663 galaxies, S/N>1000

The BOSS LRG@z>0.5

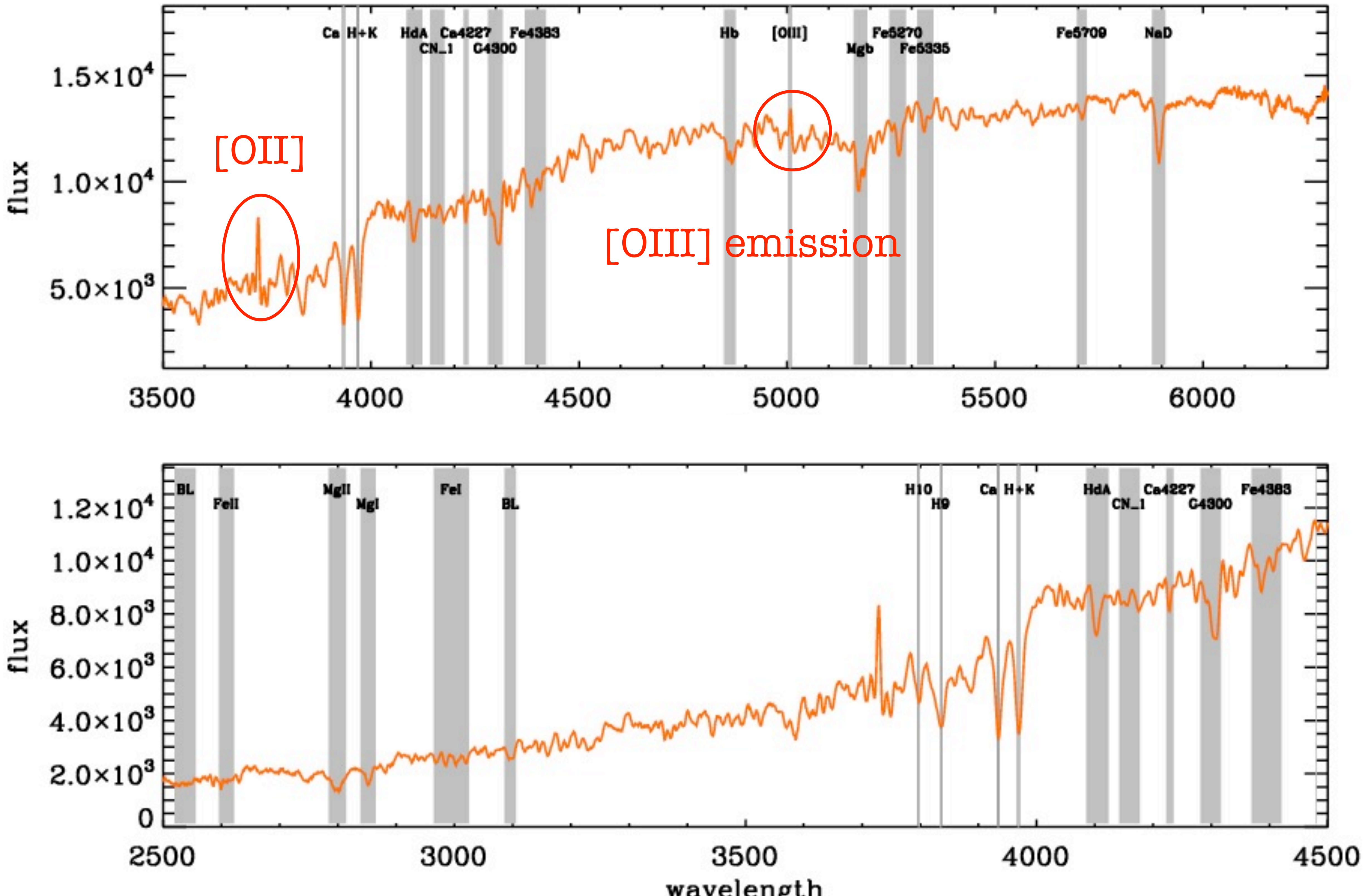


69 plates, 18663 galaxies, S/N>1000

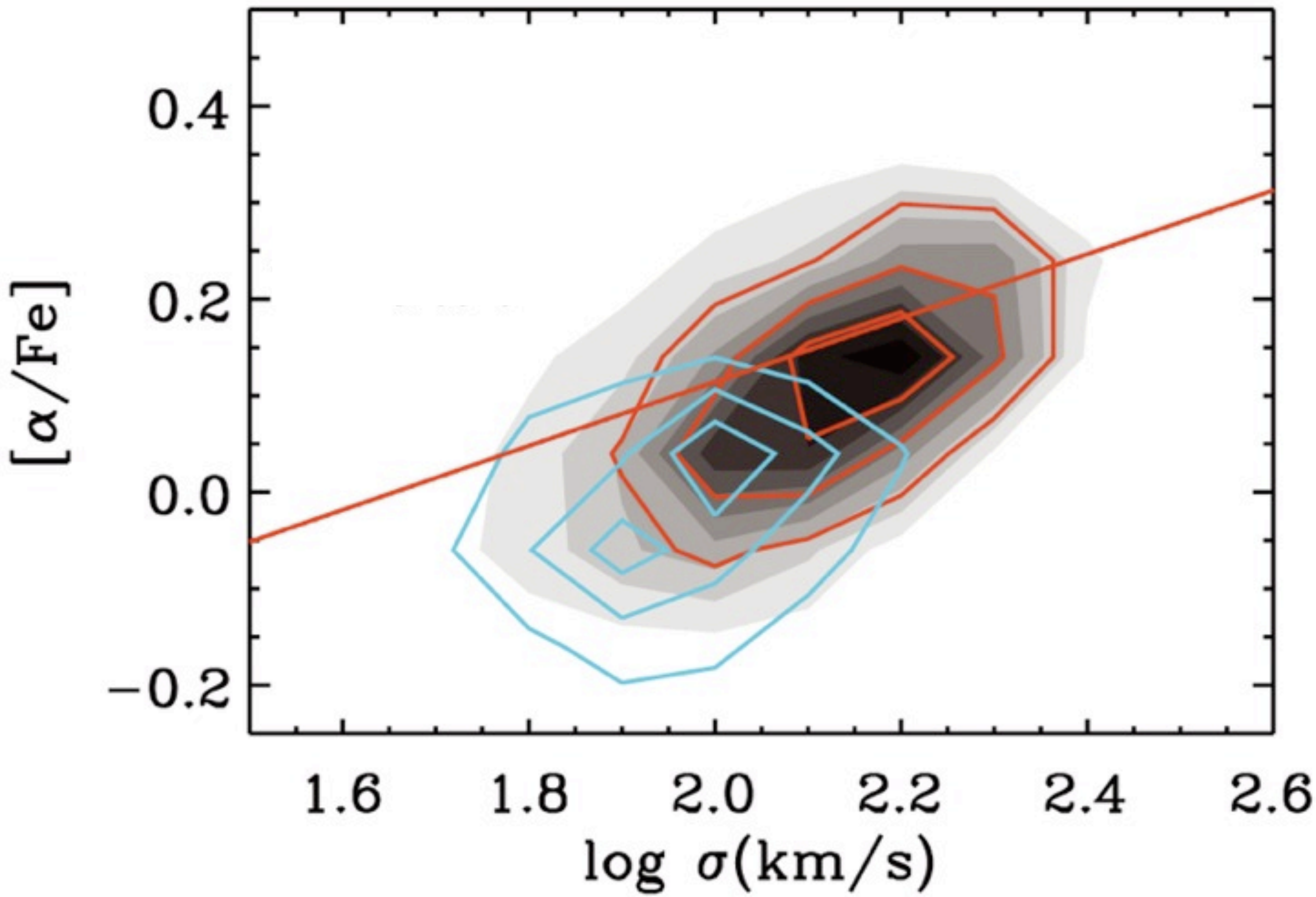
The BOSS LRG@z>0.5



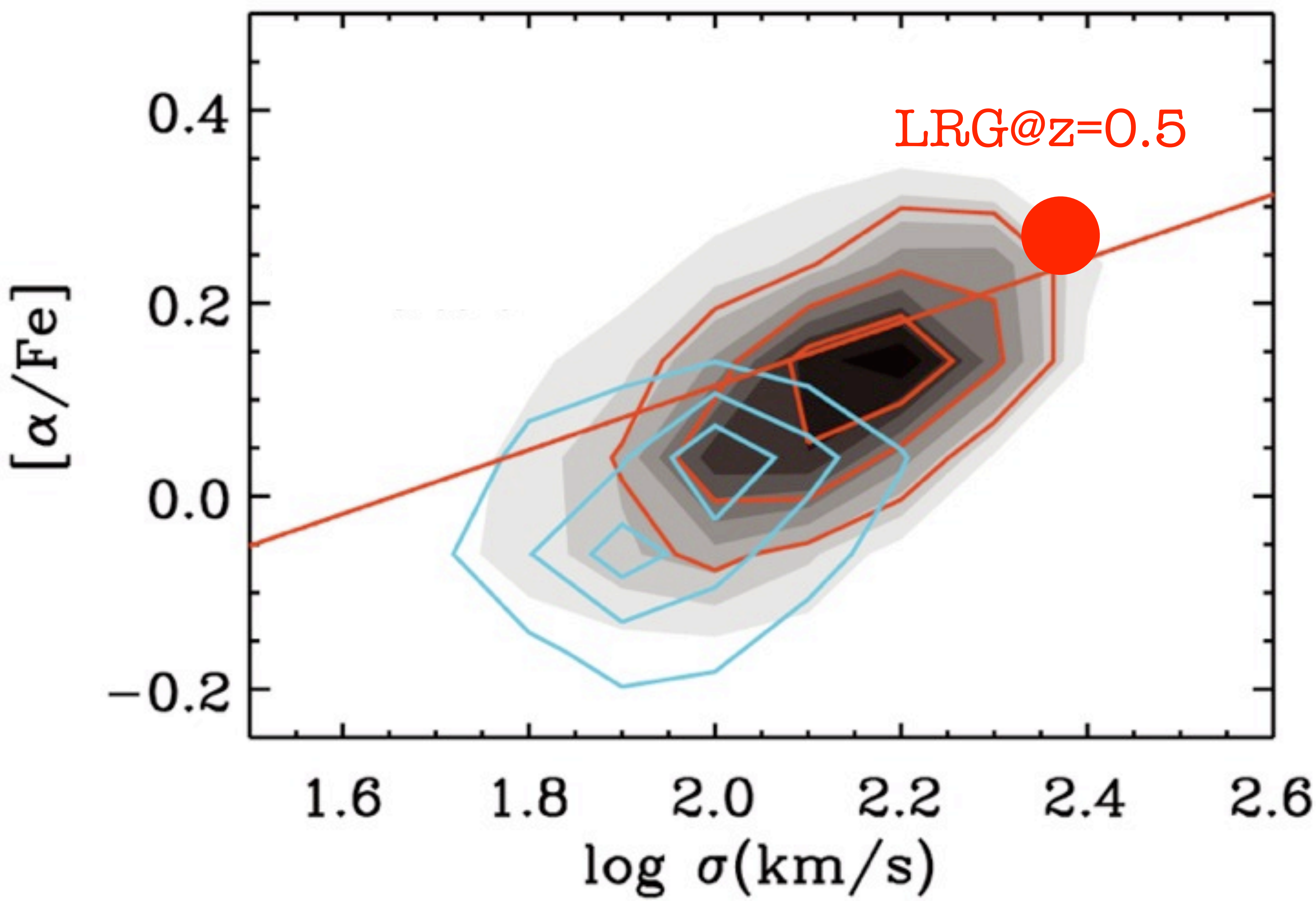
The BOSS LRG@z>0.5



Mg/Fe-σ relation



Mg/Fe-σ relation



Summary

- Fossil record in galaxies
  - Ages from integrated galaxy spectra was (still is) hard
  - Great improvements over past 10 years through models and data
- Stellar population modelling
  - New empirical stellar libraries with good parameter coverage
  - Still some discrepancies in flux calibration/stellar parameters
- Galaxy surveys (IFU and z-surveys)
  - Impressive progress in understanding of local galaxy population
  - Statistical approach to galaxy evolution studies
  - Chemical evolution and element abundance ratios
- Outlook
  - Evolution with morphology, redshift, environment
    Galaxy Zoo, GAMA, SDSS-III/BOSS, CALIFA, ATLAS3D