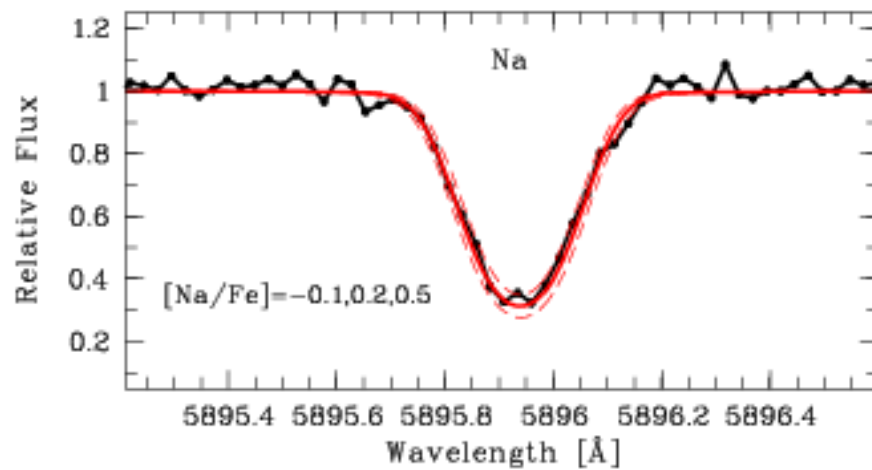
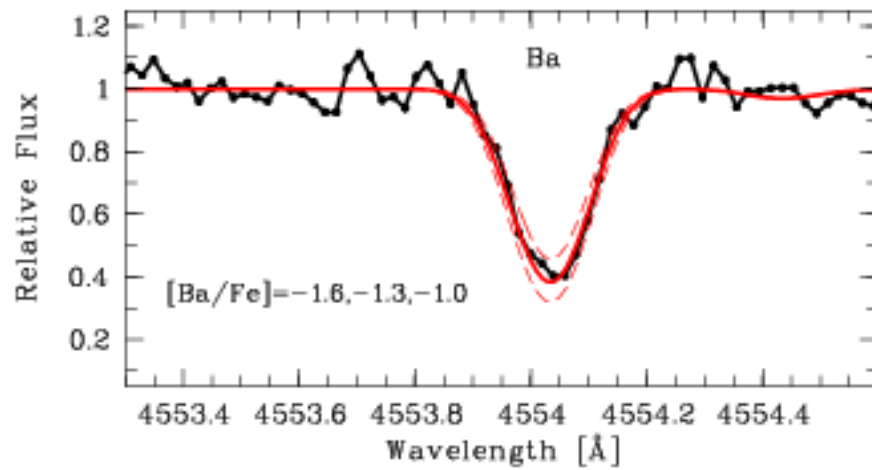
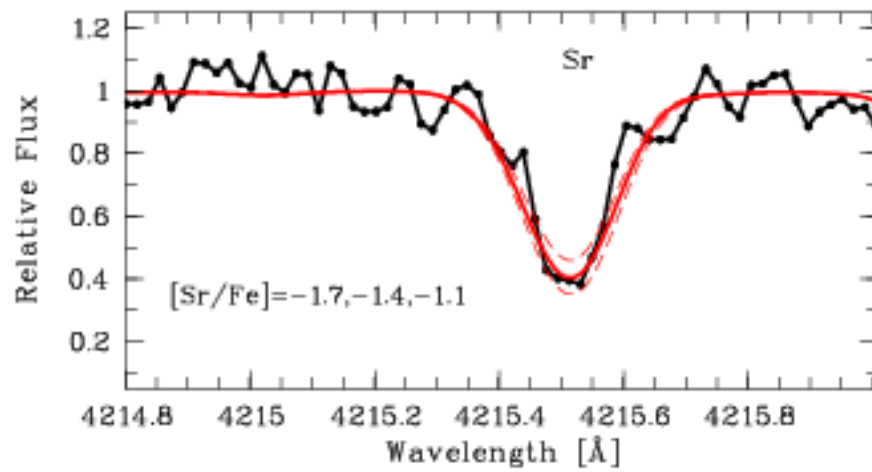
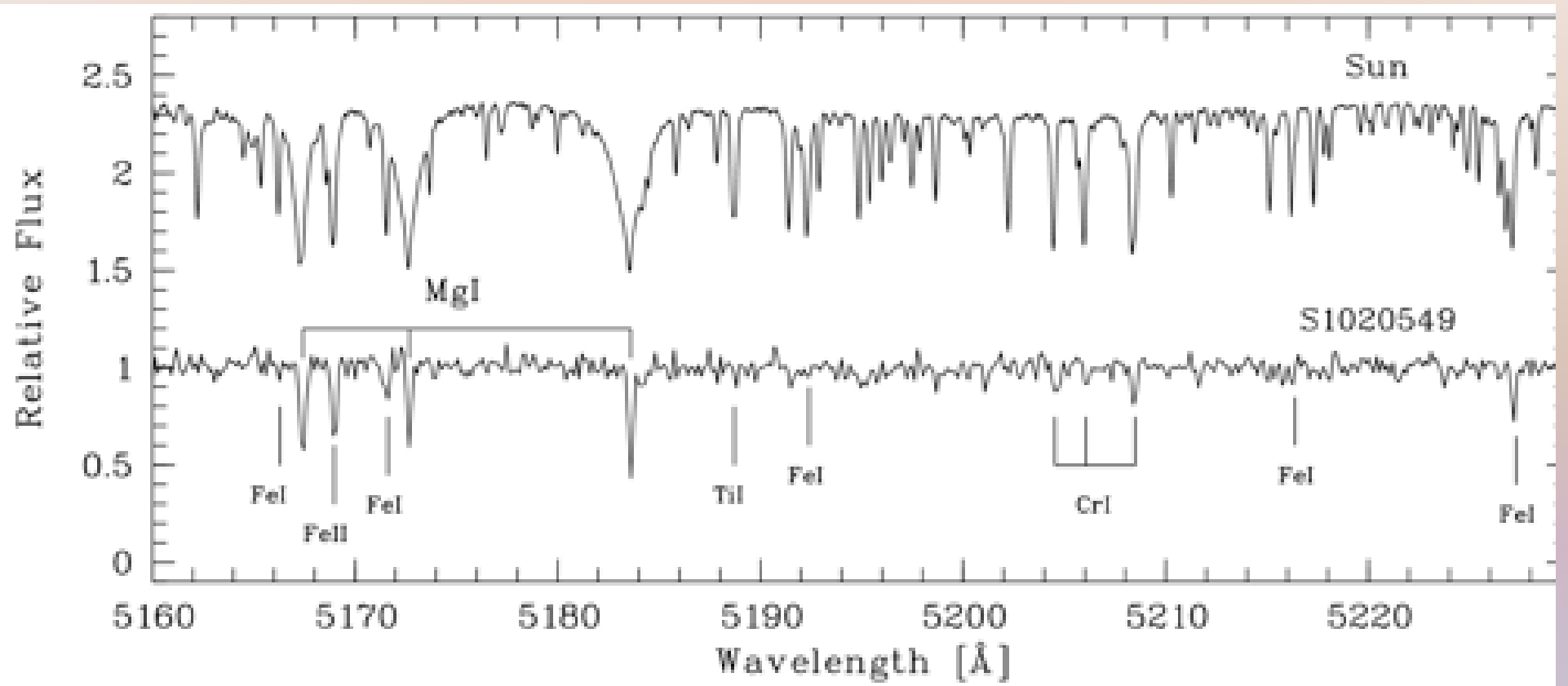


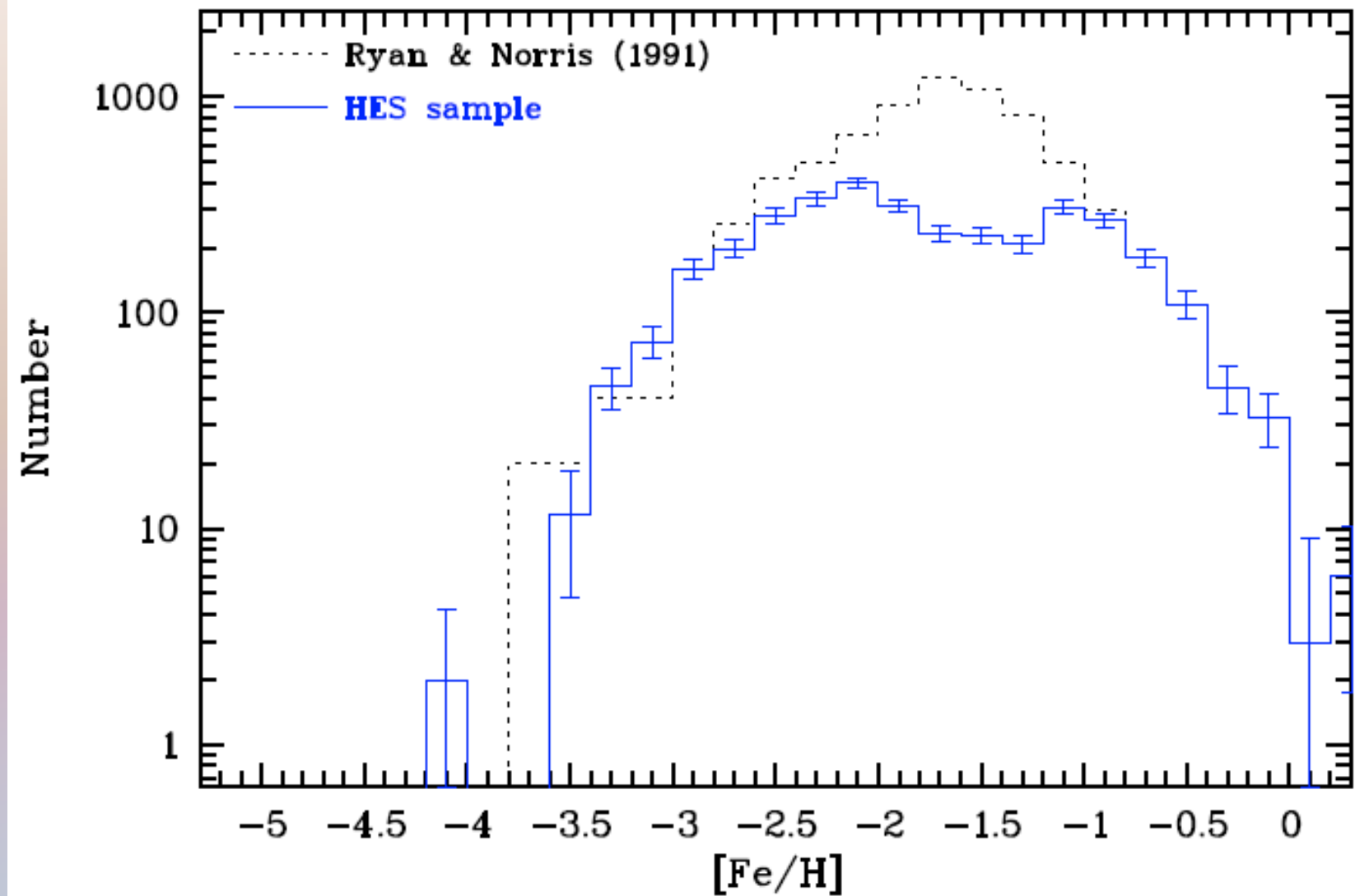
# Chemical Evolution: Measurements in the Galaxy and Beyond

- Measuring abundances in
  - Stars
  - Galaxies (integrated light spectroscopy)
  - HII regions
  - DLAs



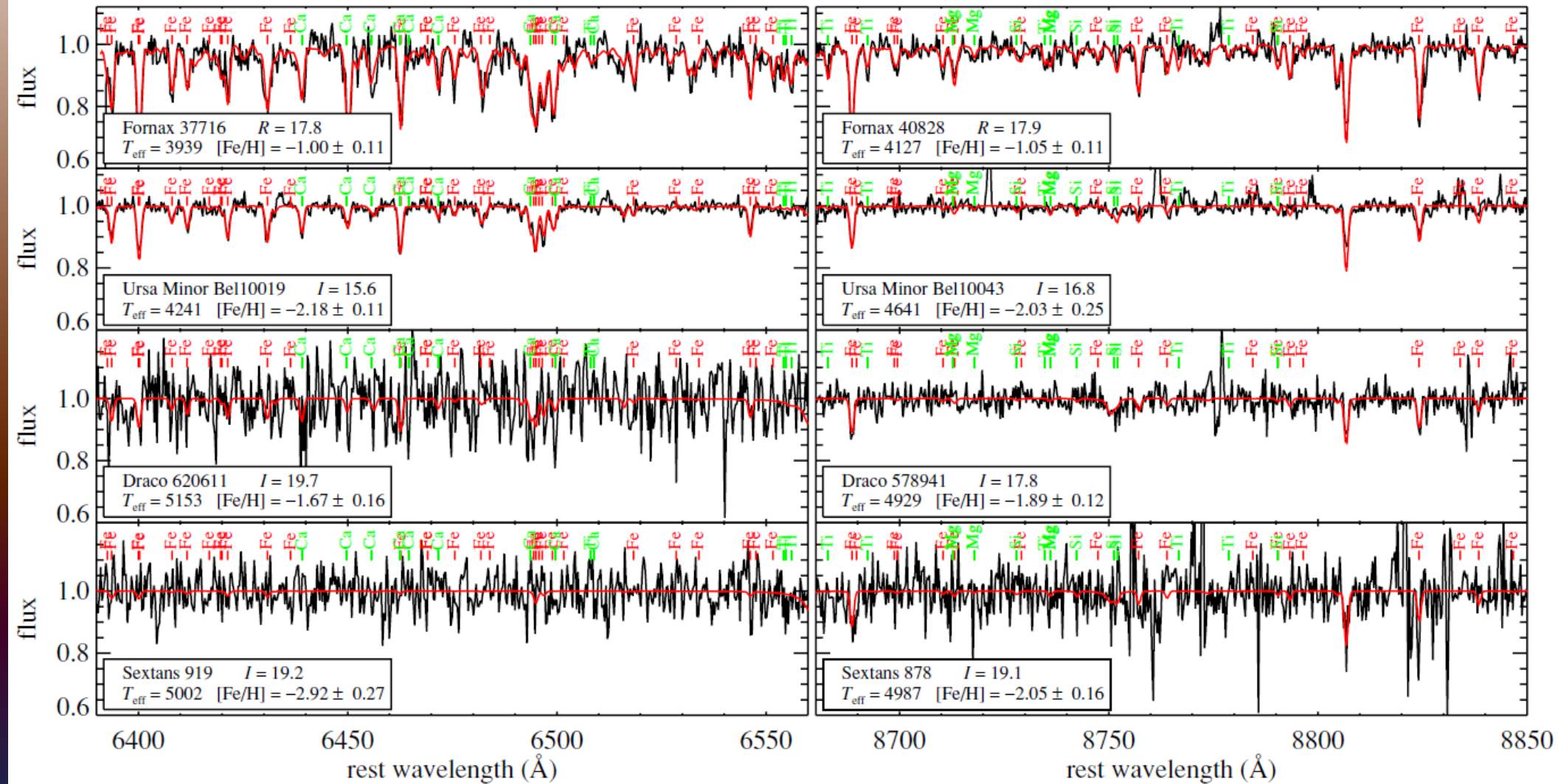


# Metallicity distribution function



Schörck et al. 2009, A&A, 507, 817

# Medium-resolution spectroscopy



# THE OBSERVED PROPERTIES OF DWARF GALAXIES IN AND AROUND THE LOCAL GROUP

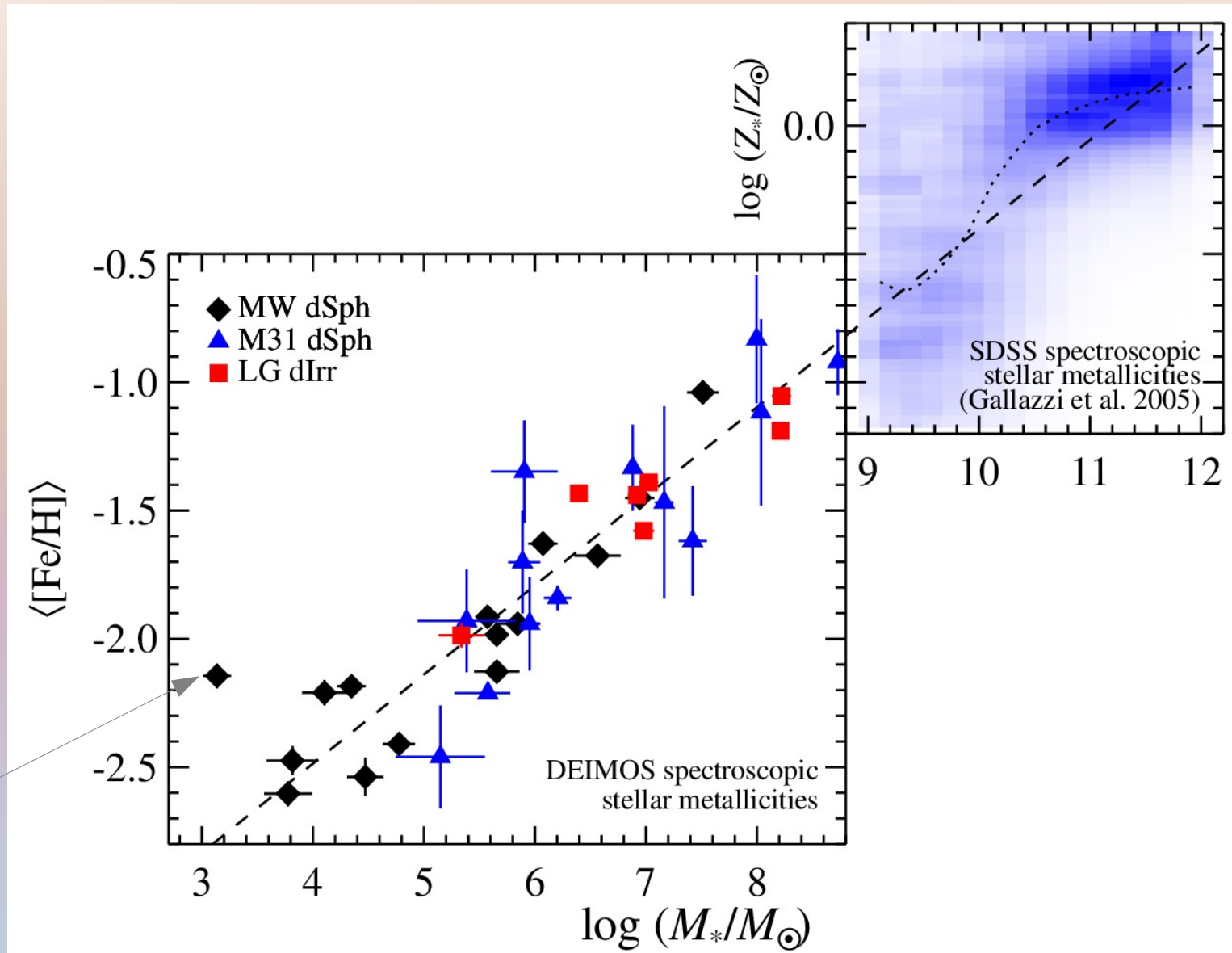
ALAN W. McCONNACHIE

NRC Herzberg Institute of Astrophysics, 5071 West Saanich Road, Victoria, BC, V9E 2E7, Canada; [alan.mcconnachie@nrc-cnrc.gc.ca](mailto:alan.mcconnachie@nrc-cnrc.gc.ca)

“classic” reference: Mateo 1998 ARA&A 36 435

Table 1					
Basic Information					
(1)	(2)	(3)	(4)	(5)	(6)
Galaxy	Other Names			R.A. J2000	Decl. J2000
The MW sub-group (in order of distance from the MW)					
The Galaxy	The MW	G	S(B)bc	17 <sup>h</sup> 45 <sup>m</sup> 40 <sup>s</sup> .0	−29 <sup>d</sup> 00 <sup>m</sup> 28 <sup>s</sup>
Canis Major		G	????	07 <sup>h</sup> 12 <sup>m</sup> 35 <sup>s</sup> .0	−27 <sup>d</sup> 40 <sup>m</sup> 00 <sup>s</sup>
Sagittarius dSph		G	dSph	18 <sup>h</sup> 55 <sup>m</sup> 19 <sup>s</sup> .5	−30 <sup>d</sup> 32 <sup>m</sup> 43 <sup>s</sup>
Segue (I)		G	dSph	10 <sup>h</sup> 07 <sup>m</sup> 04 <sup>s</sup> .0	+16 <sup>d</sup> 04 <sup>m</sup> 55 <sup>s</sup>
Ursa Major II		G	dSph	08 <sup>h</sup> 51 <sup>m</sup> 30 <sup>s</sup> .0	+63 <sup>d</sup> 07 <sup>m</sup> 48 <sup>s</sup>
Bootes II		G	dSph	13 <sup>h</sup> 58 <sup>m</sup> 00 <sup>s</sup> .0	+12 <sup>d</sup> 51 <sup>m</sup> 00 <sup>s</sup>
Segue II		G	dSph	02 <sup>h</sup> 19 <sup>m</sup> 16 <sup>s</sup> .0	+20 <sup>d</sup> 10 <sup>m</sup> 31 <sup>s</sup>
Willman I	SDSS J1049+5103	G	dSph	10 <sup>h</sup> 49 <sup>m</sup> 21 <sup>s</sup> .0	+51 <sup>d</sup> 03 <sup>m</sup> 00 <sup>s</sup>
Coma Berenices		G	dSph	12 <sup>h</sup> 26 <sup>m</sup> 59 <sup>s</sup> .0	+23 <sup>d</sup> 54 <sup>m</sup> 15 <sup>s</sup>
Bootes III		G	dSph?	13 <sup>h</sup> 57 <sup>m</sup> 12 <sup>s</sup> .0	+26 <sup>d</sup> 48 <sup>m</sup> 00 <sup>s</sup>
LMC	Nubecula Major	G	Irr	05 <sup>h</sup> 23 <sup>m</sup> 34 <sup>s</sup> .5	−69 <sup>d</sup> 45 <sup>m</sup> 22 <sup>s</sup>
SMC	Nubecula Minor	G	dIrr	00 <sup>h</sup> 52 <sup>m</sup> 44 <sup>s</sup> .8	−72 <sup>d</sup> 49 <sup>m</sup> 43 <sup>s</sup>
	NGC 292				
Bootes (I)		G	dSph	14 <sup>h</sup> 00 <sup>m</sup> 06 <sup>s</sup> .0	+14 <sup>d</sup> 30 <sup>m</sup> 00 <sup>s</sup>
Draco	UGC 10822	G	dSph	17 <sup>h</sup> 20 <sup>m</sup> 12 <sup>s</sup> .4	+57 <sup>d</sup> 54 <sup>m</sup> 55 <sup>s</sup>
	DDO 208				
Ursa Minor	UGC 9749	G	dSph	15 <sup>h</sup> 09 <sup>m</sup> 08 <sup>s</sup> .5	+67 <sup>d</sup> 13 <sup>m</sup> 21 <sup>s</sup>
	DDO 199				
Sculptor		G	dSph	01 <sup>h</sup> 00 <sup>m</sup> 09 <sup>s</sup> .4	−33 <sup>d</sup> 42 <sup>m</sup> 33 <sup>s</sup>
Sextans (I)		G	dSph	10 <sup>h</sup> 13 <sup>m</sup> 03 <sup>s</sup> .0	−01 <sup>d</sup> 36 <sup>m</sup> 53 <sup>s</sup>
Ursa Major (I)		G	dSph	10 <sup>h</sup> 34 <sup>m</sup> 52 <sup>s</sup> .8	+51 <sup>d</sup> 55 <sup>m</sup> 12 <sup>s</sup>
Carina		G	dSph	06 <sup>h</sup> 41 <sup>m</sup> 36 <sup>s</sup> .7	−50 <sup>d</sup> 57 <sup>m</sup> 58 <sup>s</sup>
Hercules		G	dSph	16 <sup>h</sup> 31 <sup>m</sup> 02 <sup>s</sup> .0	+12 <sup>d</sup> 47 <sup>m</sup> 30 <sup>s</sup>
Formax		G	dSph	02 <sup>h</sup> 39 <sup>m</sup> 59 <sup>s</sup> .3	−34 <sup>d</sup> 26 <sup>m</sup> 57 <sup>s</sup>
Leo IV		G	dSph	11 <sup>h</sup> 32 <sup>m</sup> 57 <sup>s</sup> .0	−00 <sup>d</sup> 32 <sup>m</sup> 00 <sup>s</sup>
Canes Venatici II	SDSS J1257+3419	G	dSph	12 <sup>h</sup> 57 <sup>m</sup> 10 <sup>s</sup> .0	+34 <sup>d</sup> 19 <sup>m</sup> 15 <sup>s</sup>
Leo V		G	dSph	11 <sup>h</sup> 31 <sup>m</sup> 09 <sup>s</sup> .6	+02 <sup>d</sup> 13 <sup>m</sup> 12 <sup>s</sup>
Pisces II		G	dSph	22 <sup>h</sup> 58 <sup>m</sup> 31 <sup>s</sup> .0	+05 <sup>d</sup> 57 <sup>m</sup> 09 <sup>s</sup>
Canes Venatici (I)		G	dSph	13 <sup>h</sup> 28 <sup>m</sup> 03 <sup>s</sup> .5	+33 <sup>d</sup> 33 <sup>m</sup> 21 <sup>s</sup>
Leo II	Leo B	G	dSph	11 <sup>h</sup> 13 <sup>m</sup> 28 <sup>s</sup> .8	+22 <sup>d</sup> 09 <sup>m</sup> 06 <sup>s</sup>
	UGC 6253				
	DDO 93				
Leo I	UGC 5470	G/L	dSph	10 <sup>h</sup> 08 <sup>m</sup> 28 <sup>s</sup> .1	+12 <sup>d</sup> 18 <sup>m</sup> 23 <sup>s</sup>
	DDO 74				
	Regulus Dwarf				

# Mass-metallicity relation (in stars)



Segue 2  
Kirby et al.  
2013, ApJ,  
770, 16

# Applying GCE models to data

Closed/Leaky Box (“Pristine”) Model:

$$\frac{dN}{d[\text{Fe}/\text{H}]} \propto (10^{[\text{Fe}/\text{H}]}) \exp\left(-\frac{10^{[\text{Fe}/\text{H}]}}{p}\right). \quad (2)$$

Pre-Enriched Model:

$$\frac{dN}{d[\text{Fe}/\text{H}]} \propto (10^{[\text{Fe}/\text{H}]} - 10^{[\text{Fe}/\text{H}]_0}) \exp\left(-\frac{10^{[\text{Fe}/\text{H}]}}{p}\right), \quad (1)$$

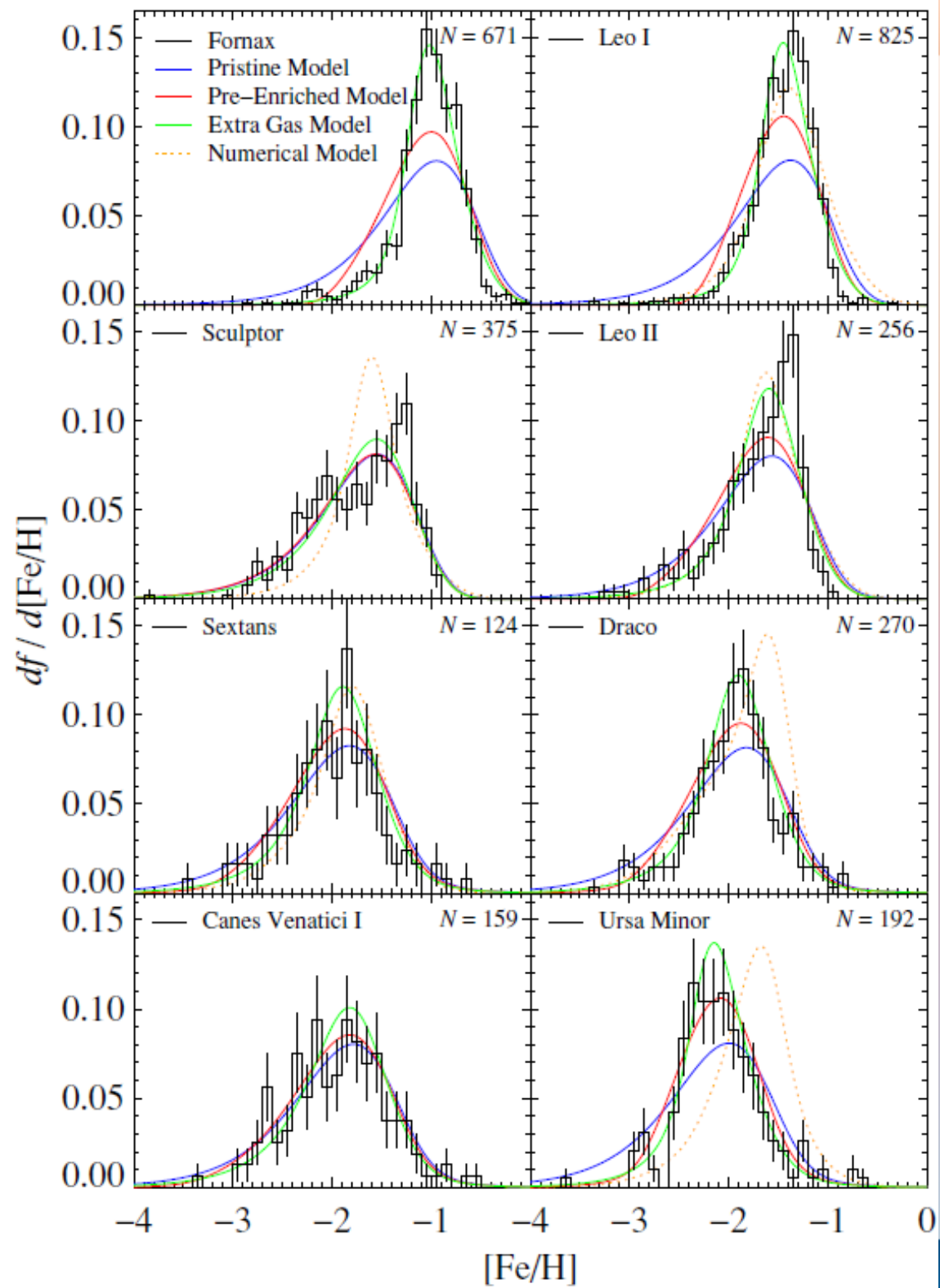
“Extra Gas” or “Infall” Model:

$$g(s) = \left(1 - \frac{s}{M}\right) \left(1 + s - \frac{s}{M}\right), \quad (3)$$

$$[\text{Fe}/\text{H}](s) = \log \left\{ p \left( \frac{M}{1 + s - \frac{s}{M}} \right)^2 \times \left[ \ln \frac{1}{1 - \frac{s}{M}} - \frac{s}{M} \left( 1 - \frac{1}{M} \right) \right] \right\} \quad (4)$$

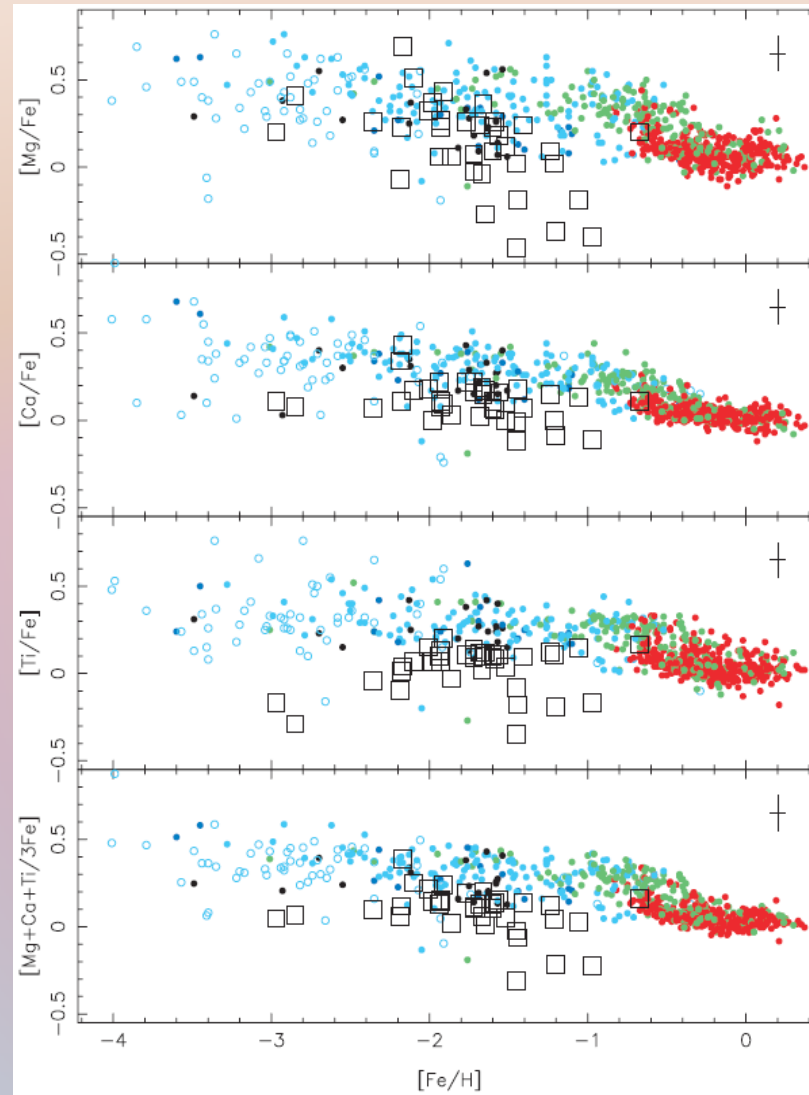
$$\frac{dN}{d[\text{Fe}/\text{H}]} \propto \frac{10^{[\text{Fe}/\text{H}]}}{p} \frac{1 + s \left(1 - \frac{1}{M}\right)}{\left(1 - \frac{s}{M}\right)^{-1} - 2 \left(1 - \frac{1}{M}\right) \times 10^{[\text{Fe}/\text{H}]/p}}. \quad (5)$$





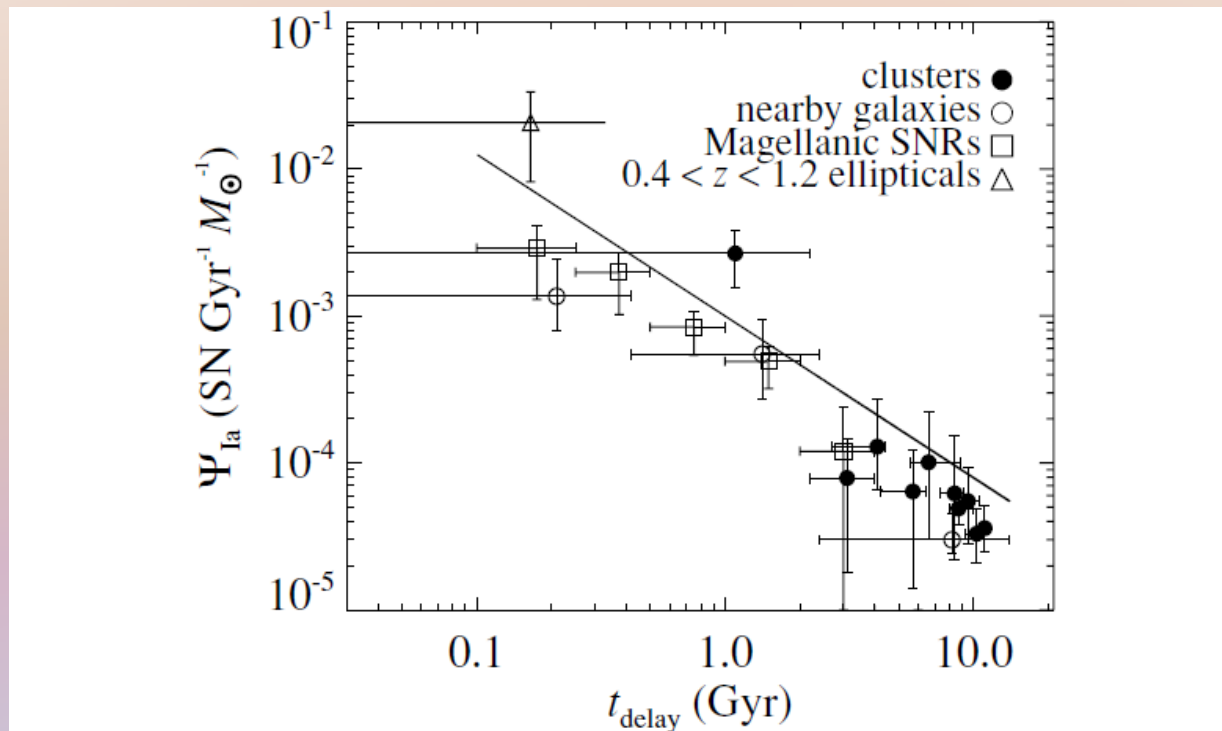
Kirby et al. 2011, ApJ, 727, 78

# Galactic archaeology in dwarf galaxy



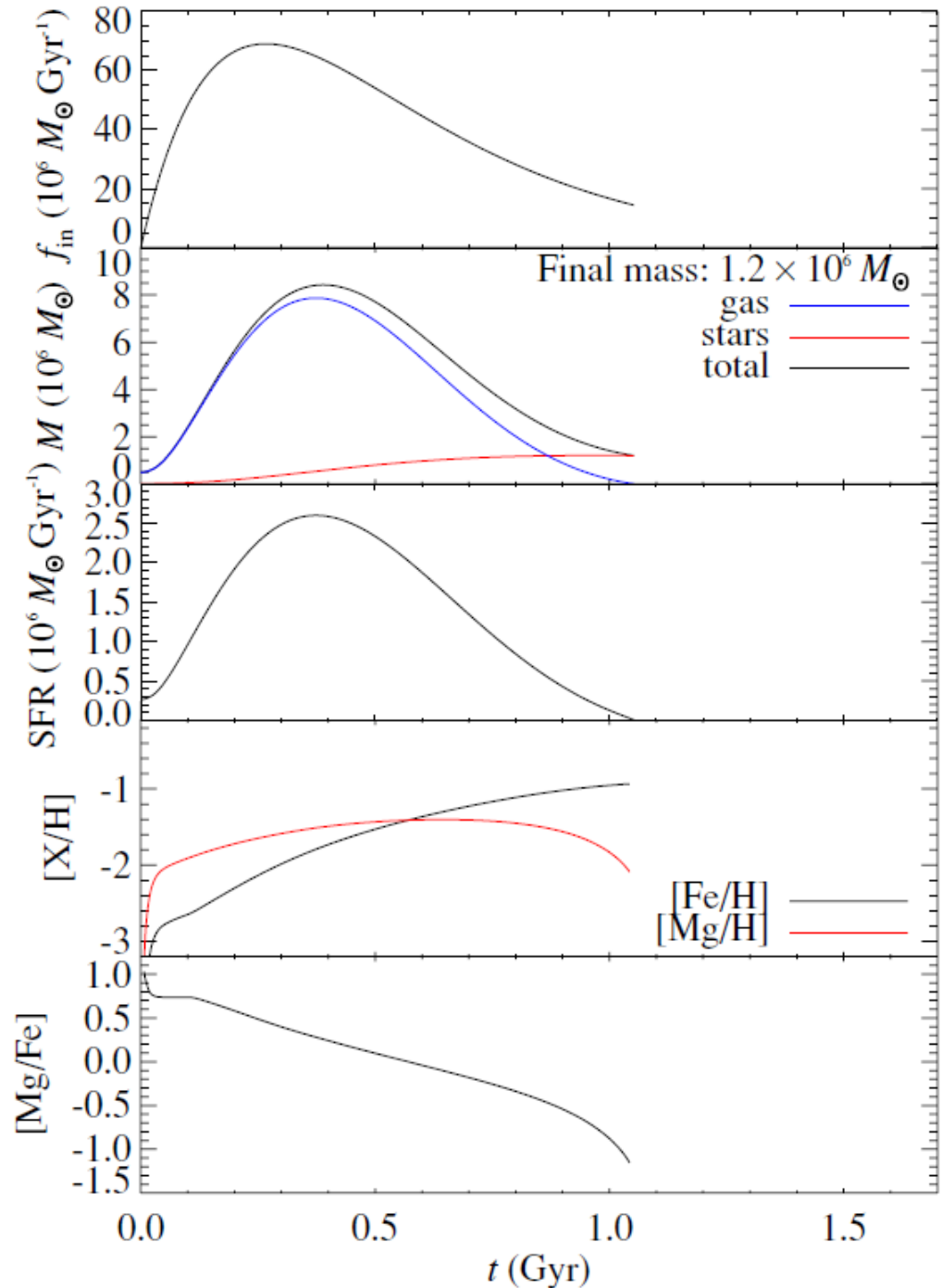
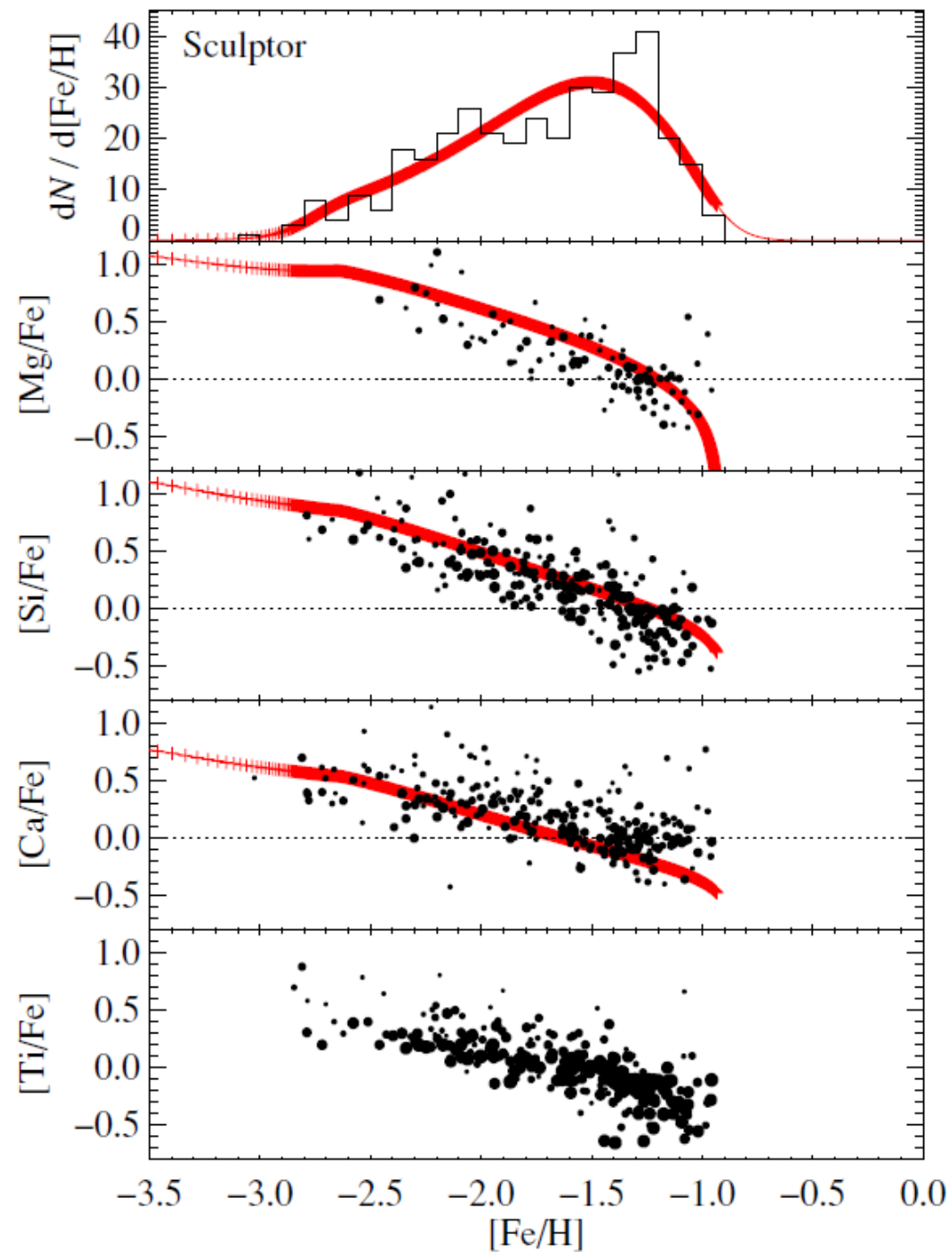
Venn et al. 2004, AJ, 128, 1177 (360+ citations)

# Numerical models for dwarf galaxies

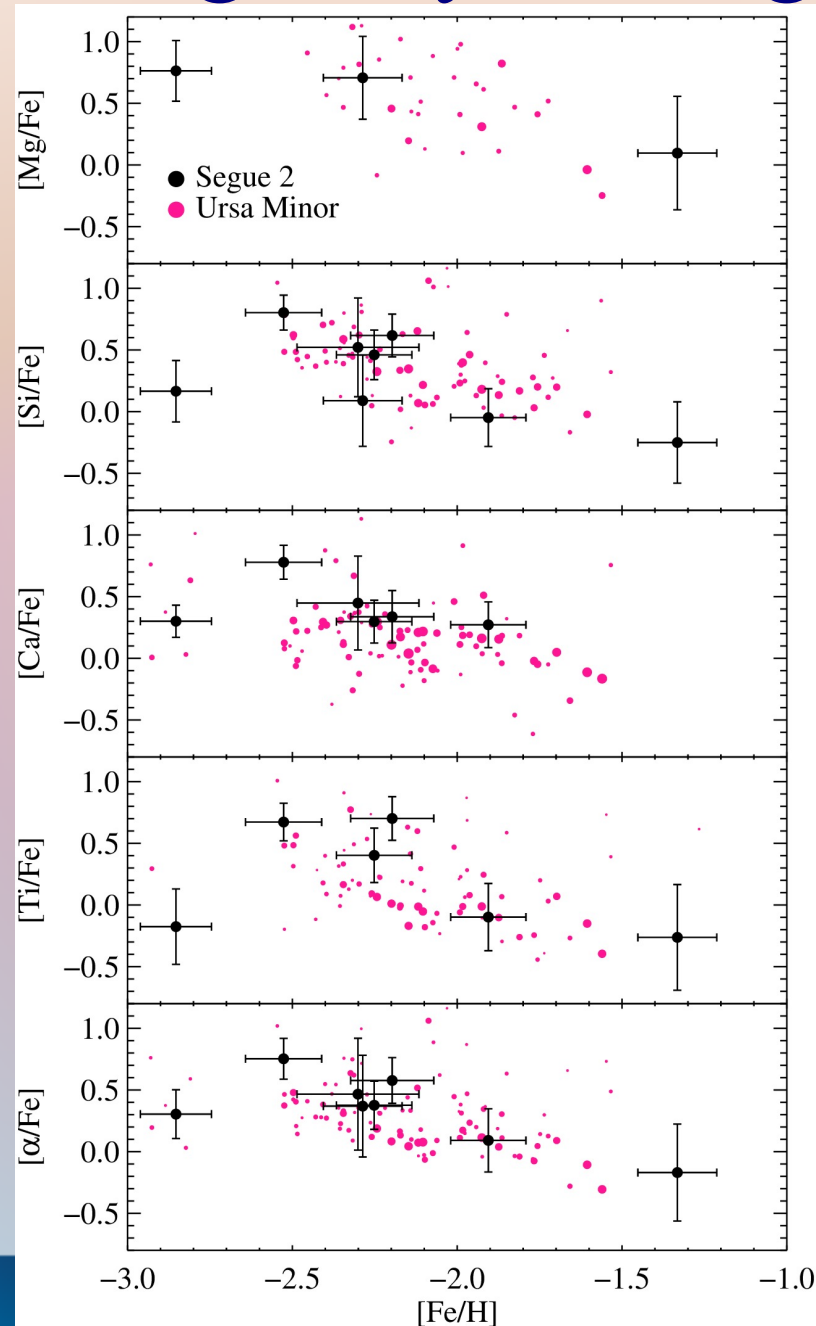


**Figure 1.** Type Ia SN DTD, as measured by Maoz et al. (2010). The data come from a variety of star formation environments, given in the figure legend. Equation (9) gives the expression for this function. Compare this figure to Maoz et al.'s Figure 2.

Maoz et al. 2010, ApJ, 722, 1879



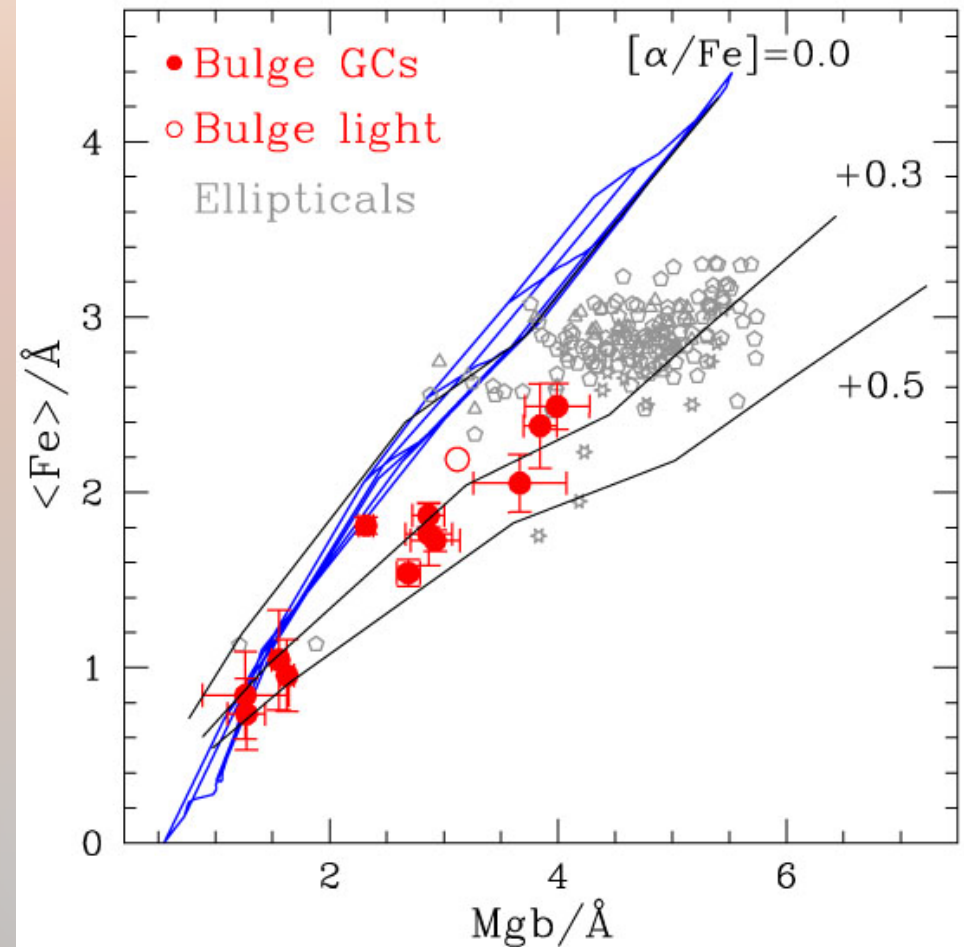
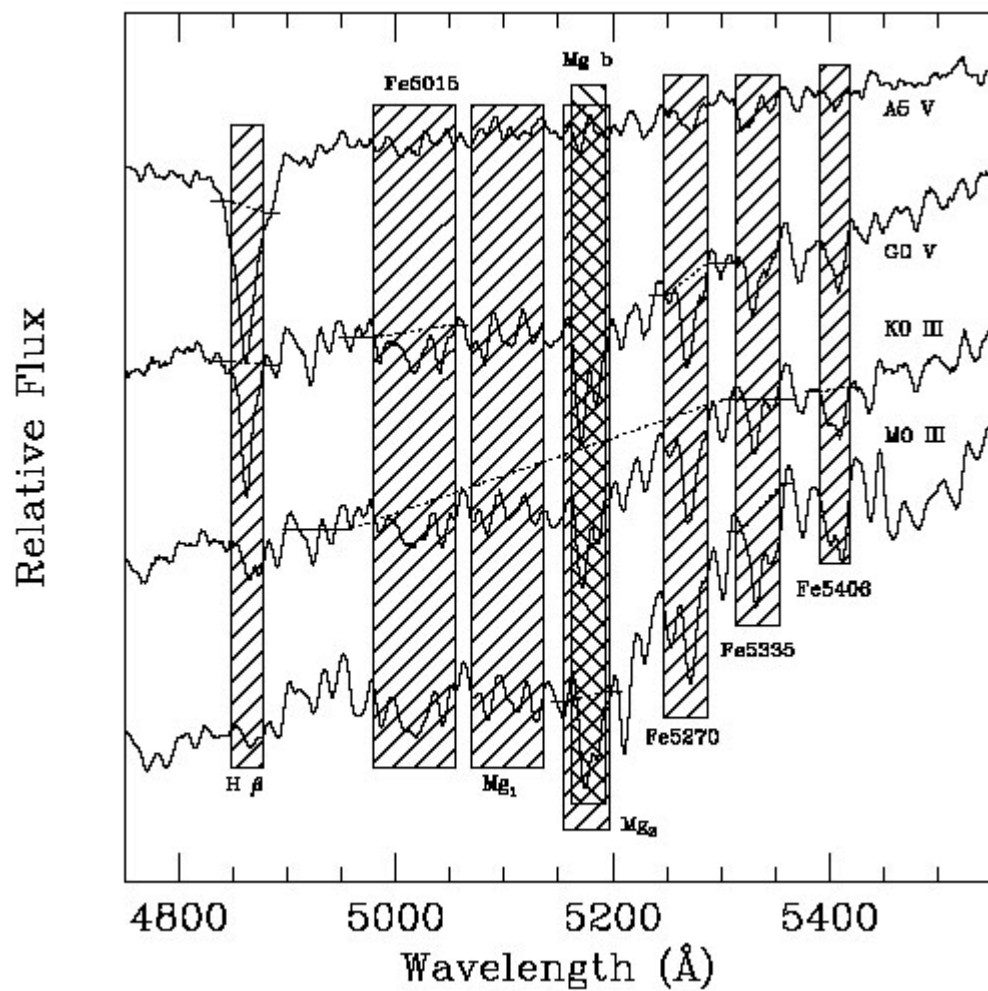
# When is a galaxy not a galaxy?



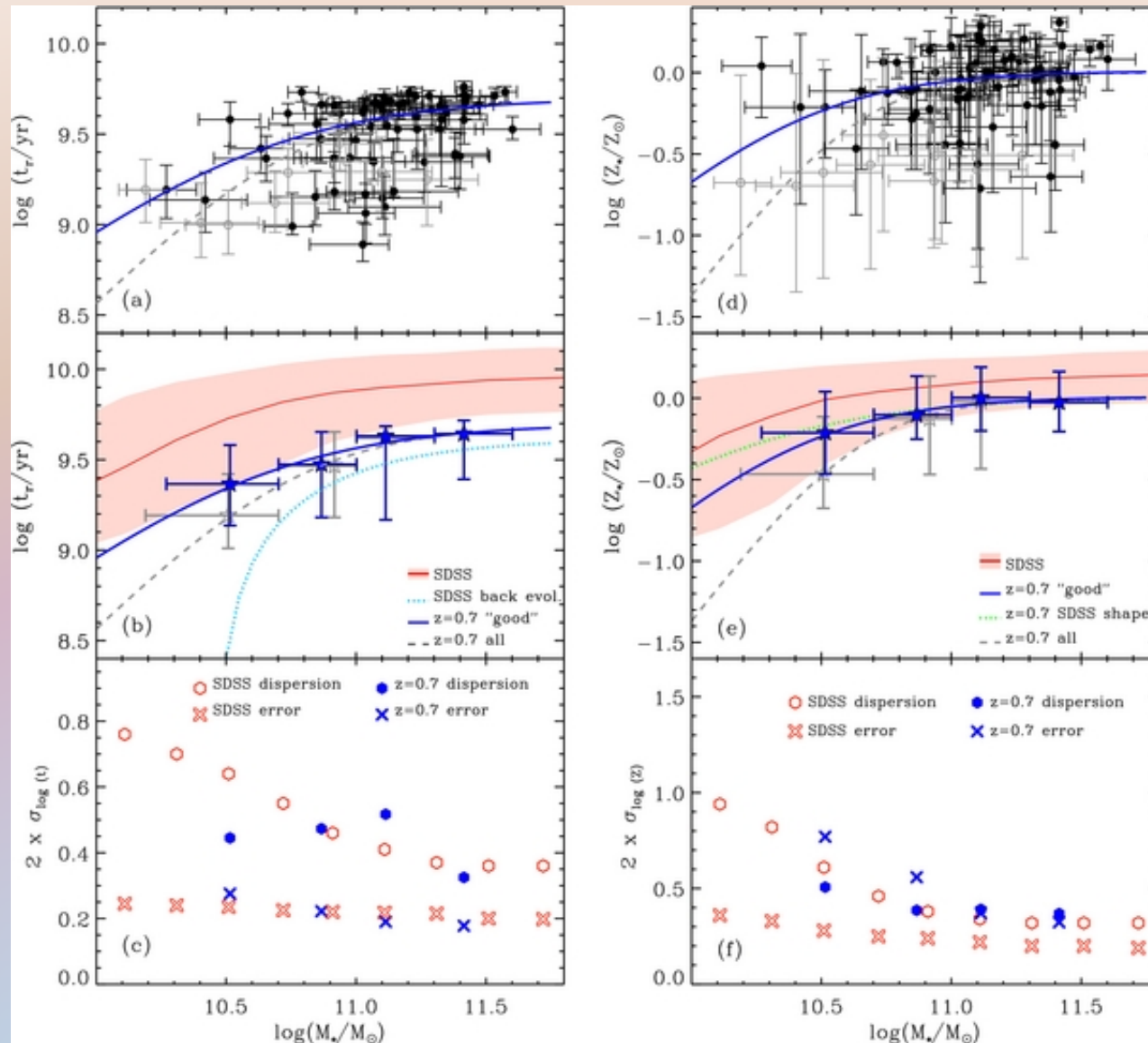
Kirby et al. 2011, ApJ, 770, 16

# Whole galaxies: Integrated light spectroscopy

## Lick Indices

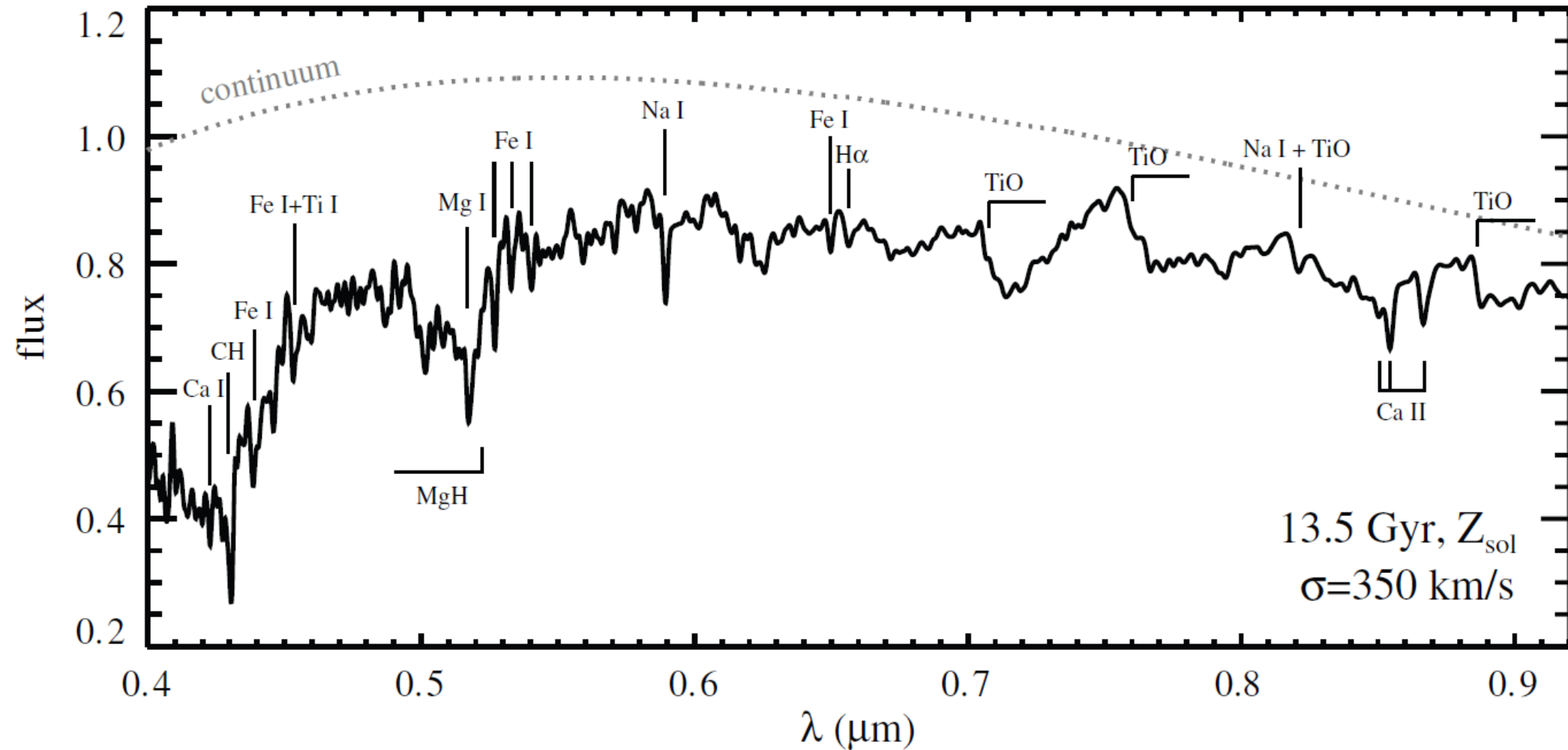


# Mass-metallicity relation (still in stars)

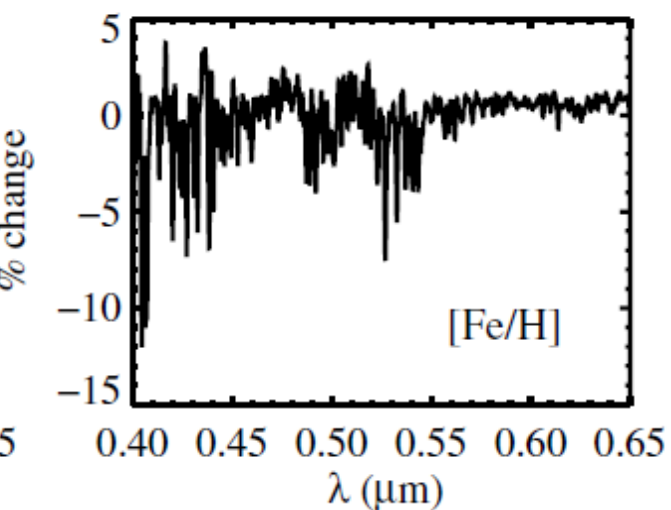
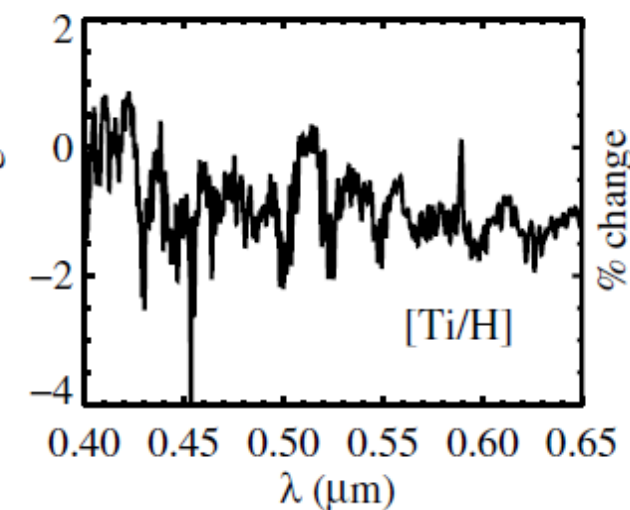
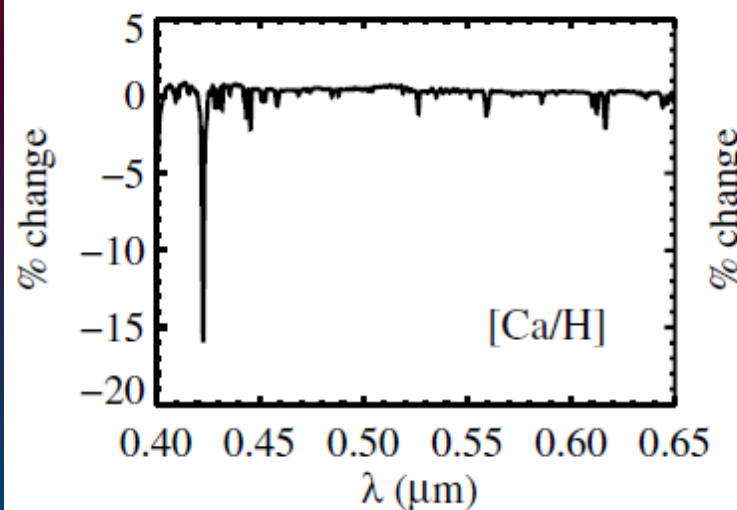
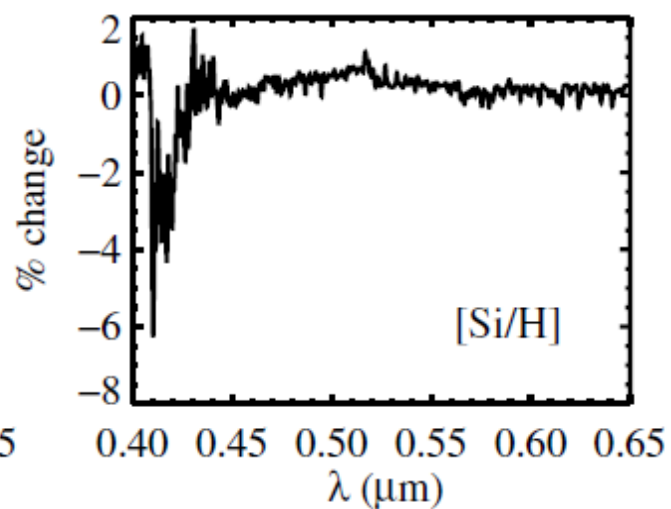
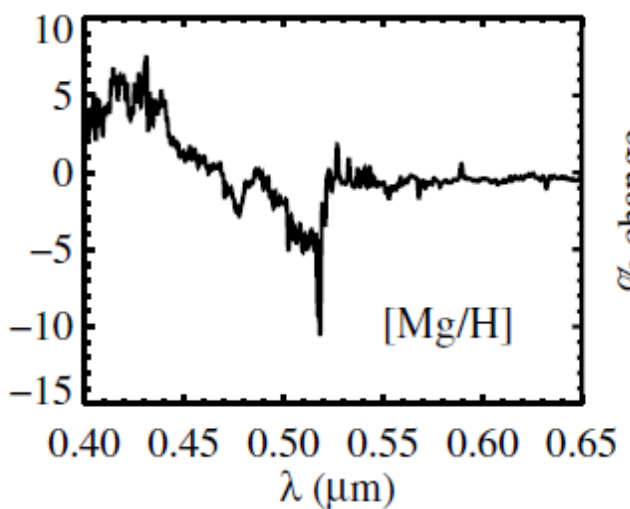
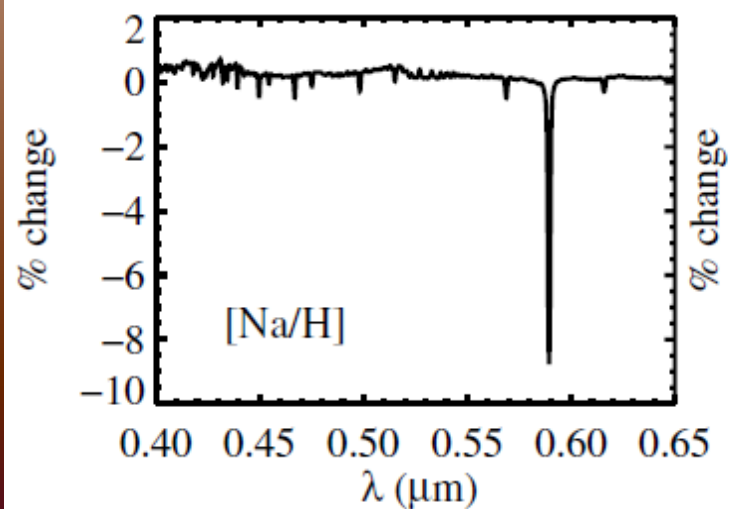
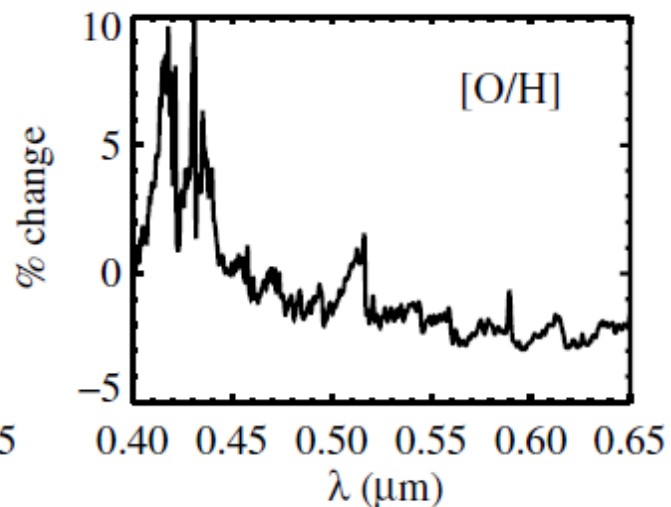
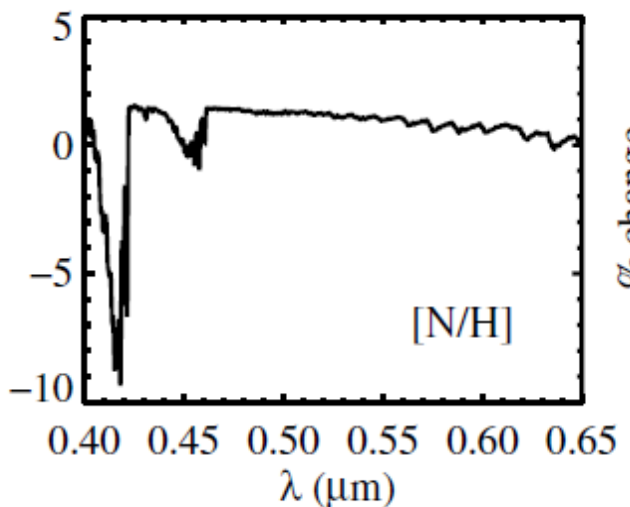
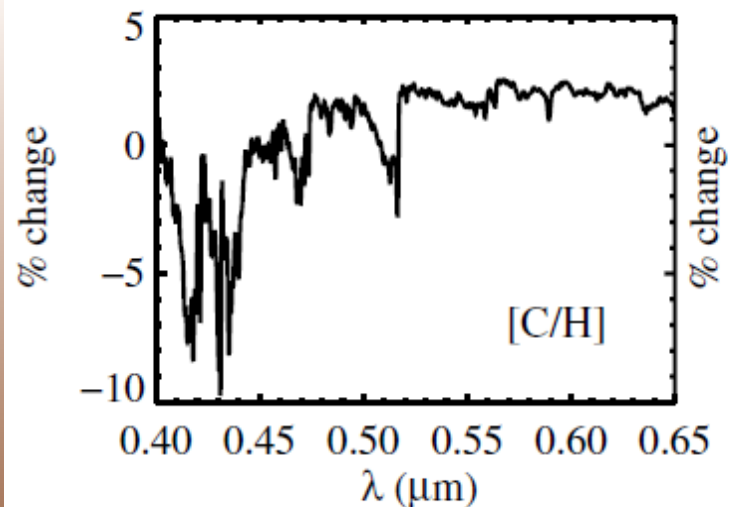


Gallazzi et al. 2014, ApJ, 788, 1

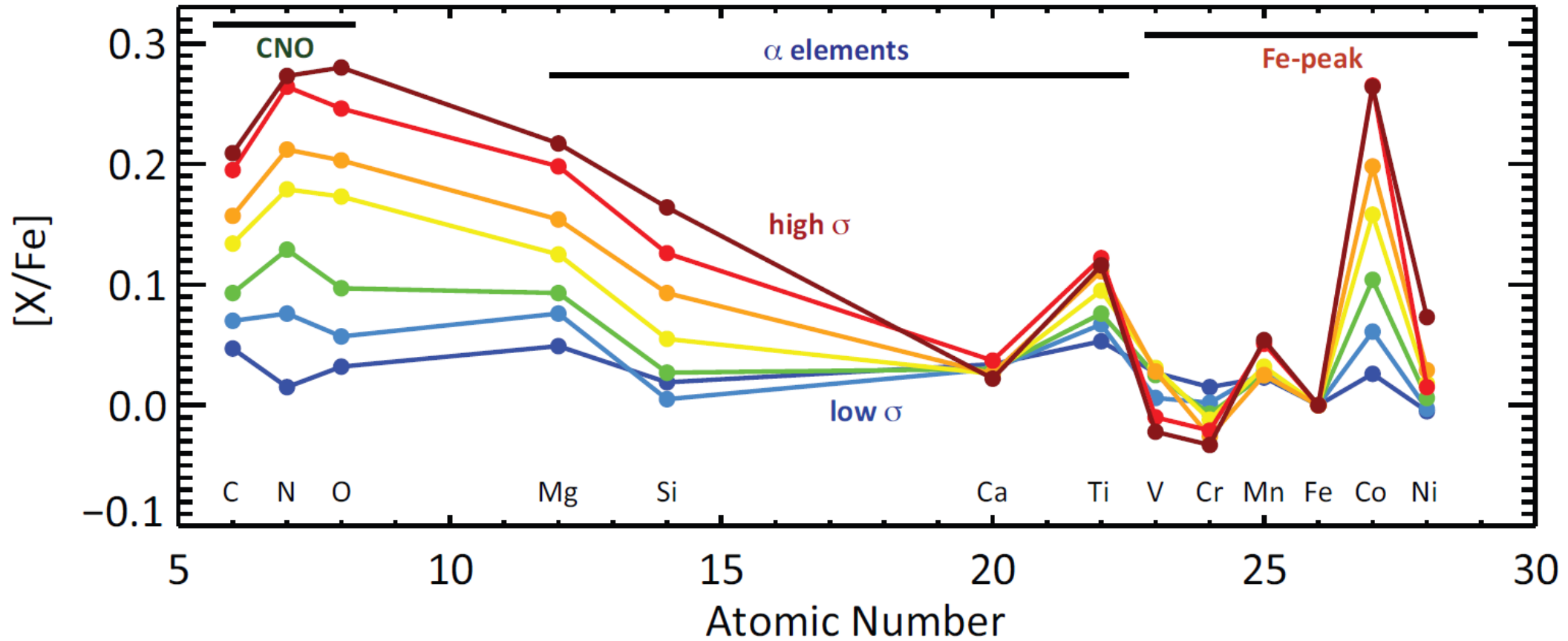
# Full spectrum synthesis + fitting





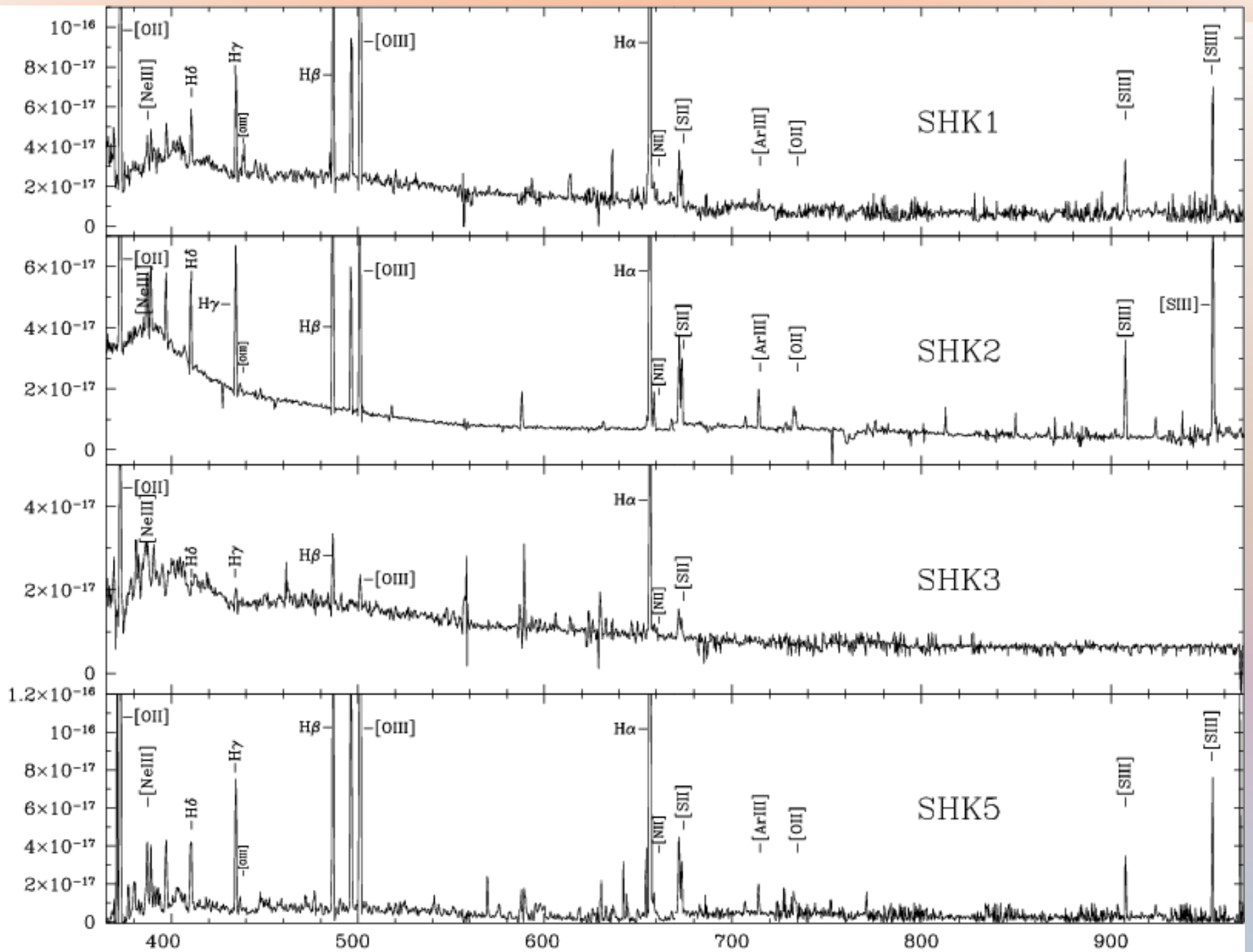


### SDSS Early-Type Galaxies



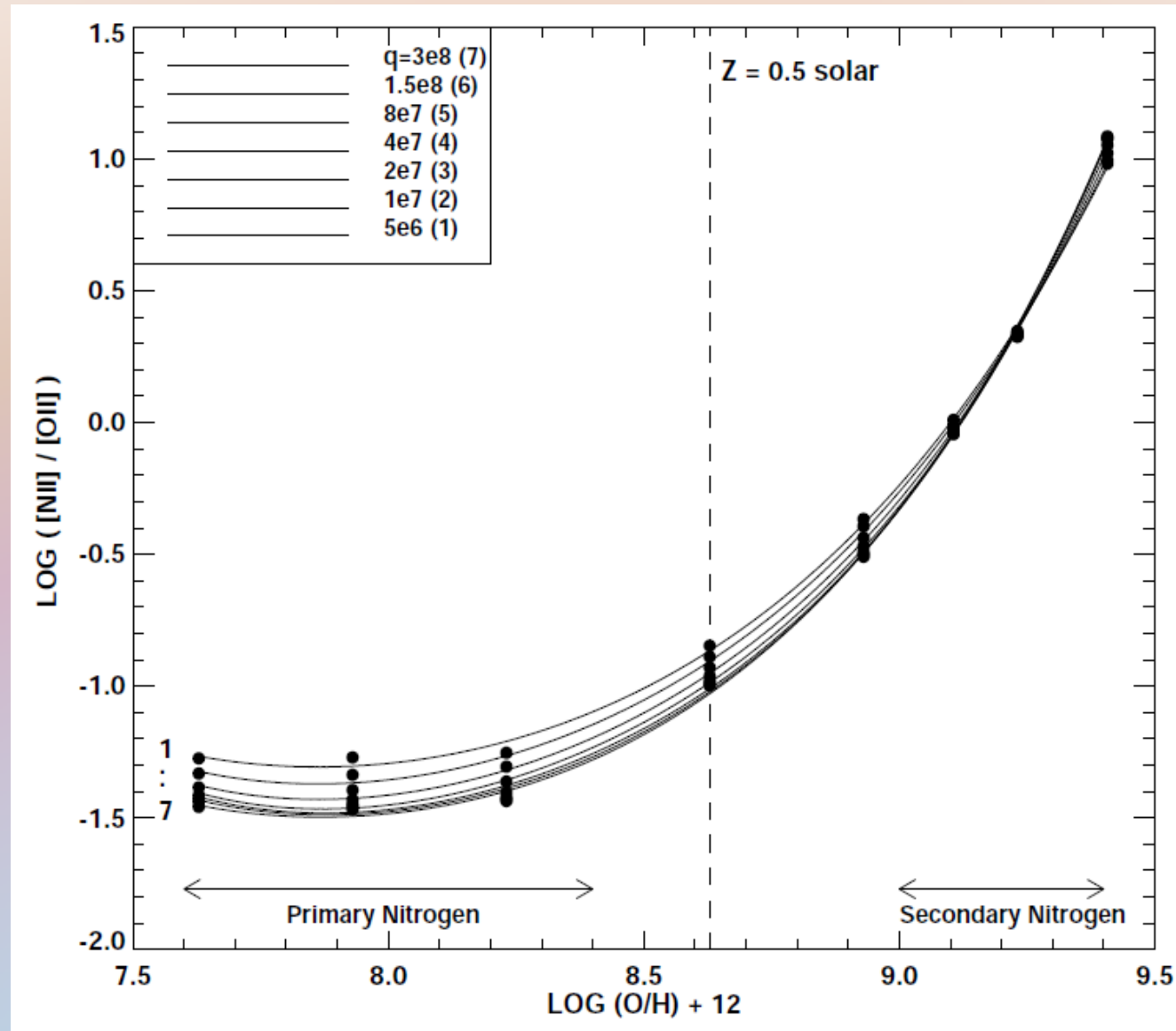


Flux ( $\text{erg cm}^{-2} \text{s}^{-1}$ )



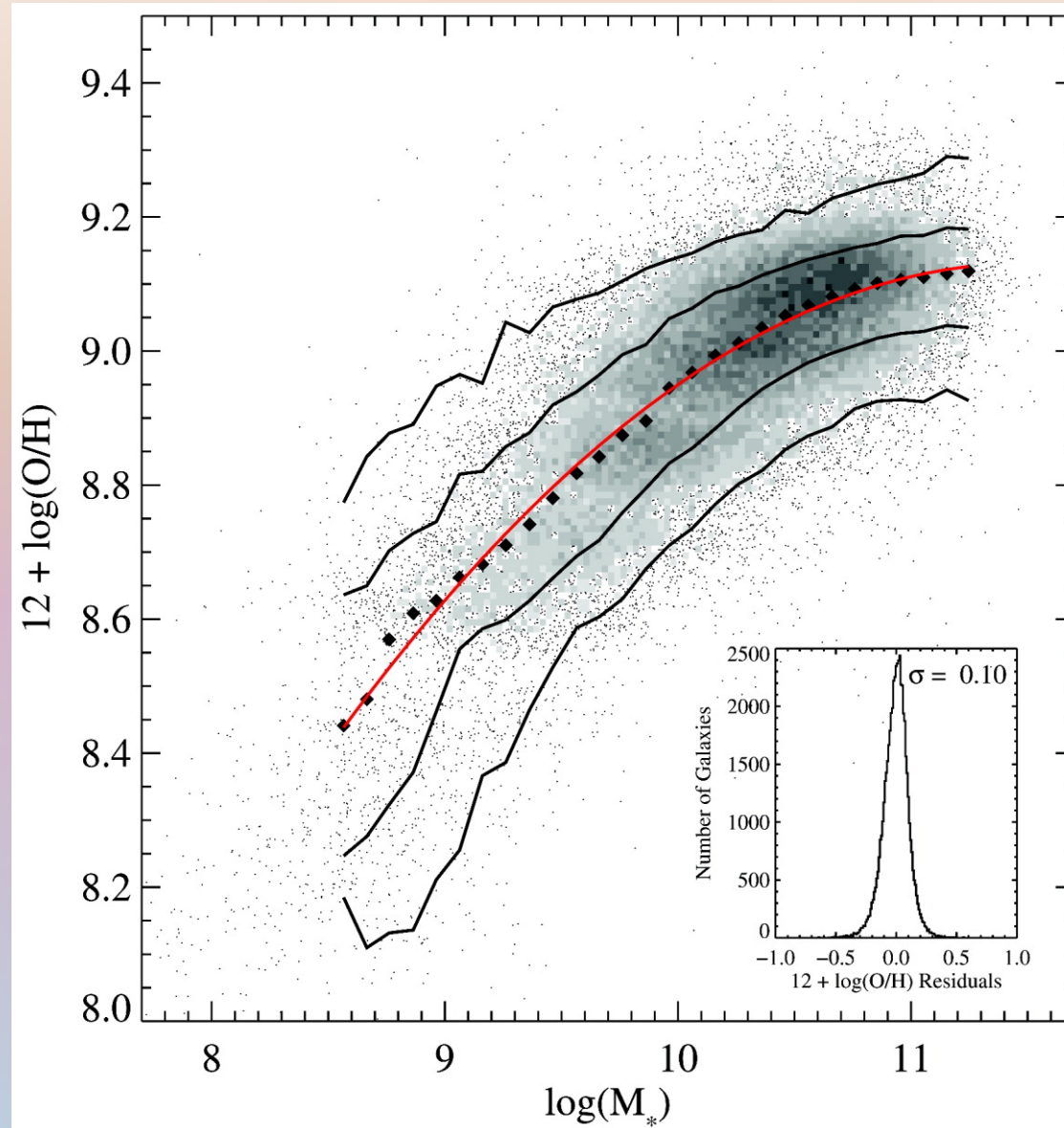
Wavelength (nm)

# Emission lines in HII regions



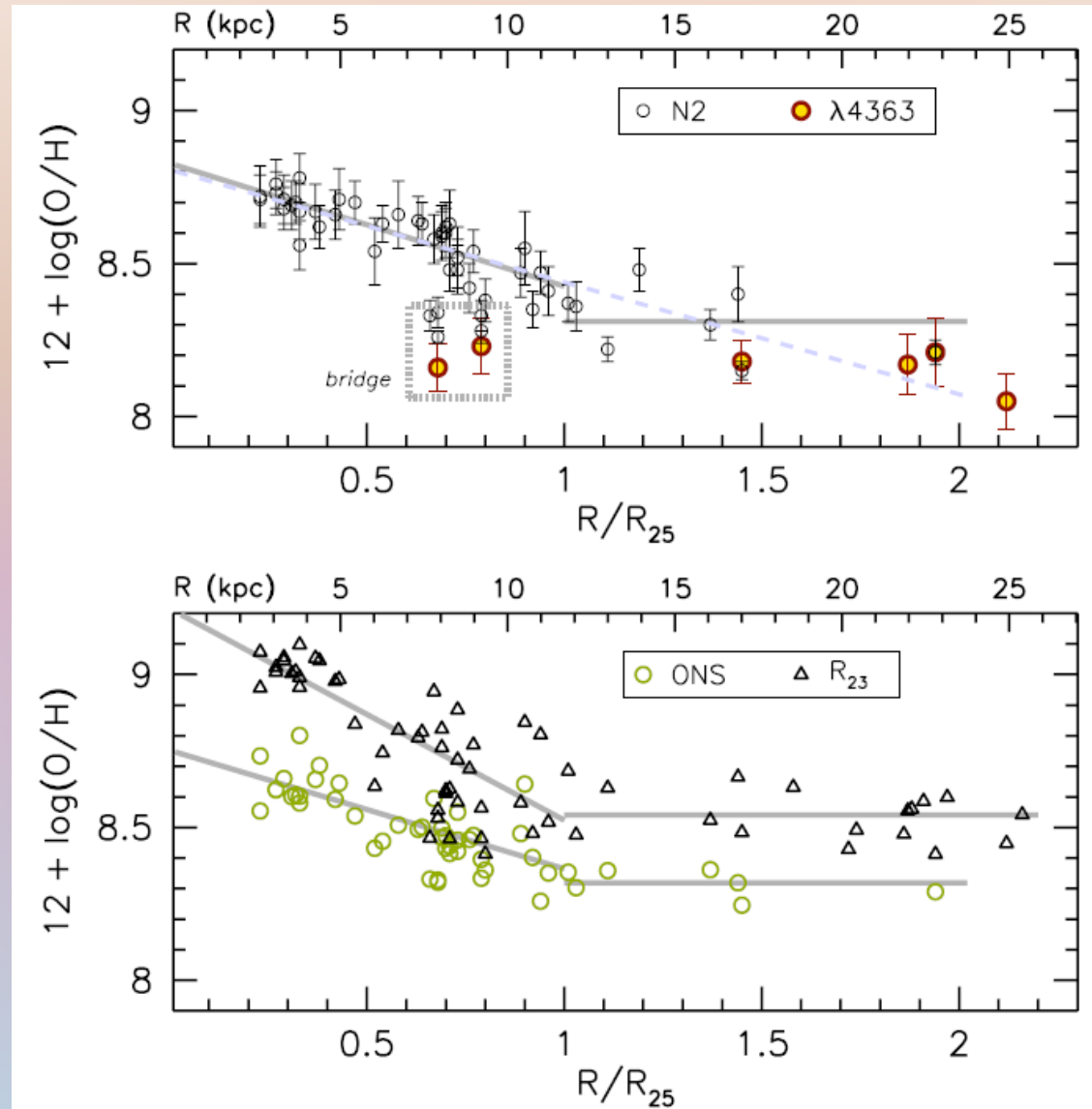
Kewley & Dopita 2002, ApJS, 142, 35 (~500 citations)

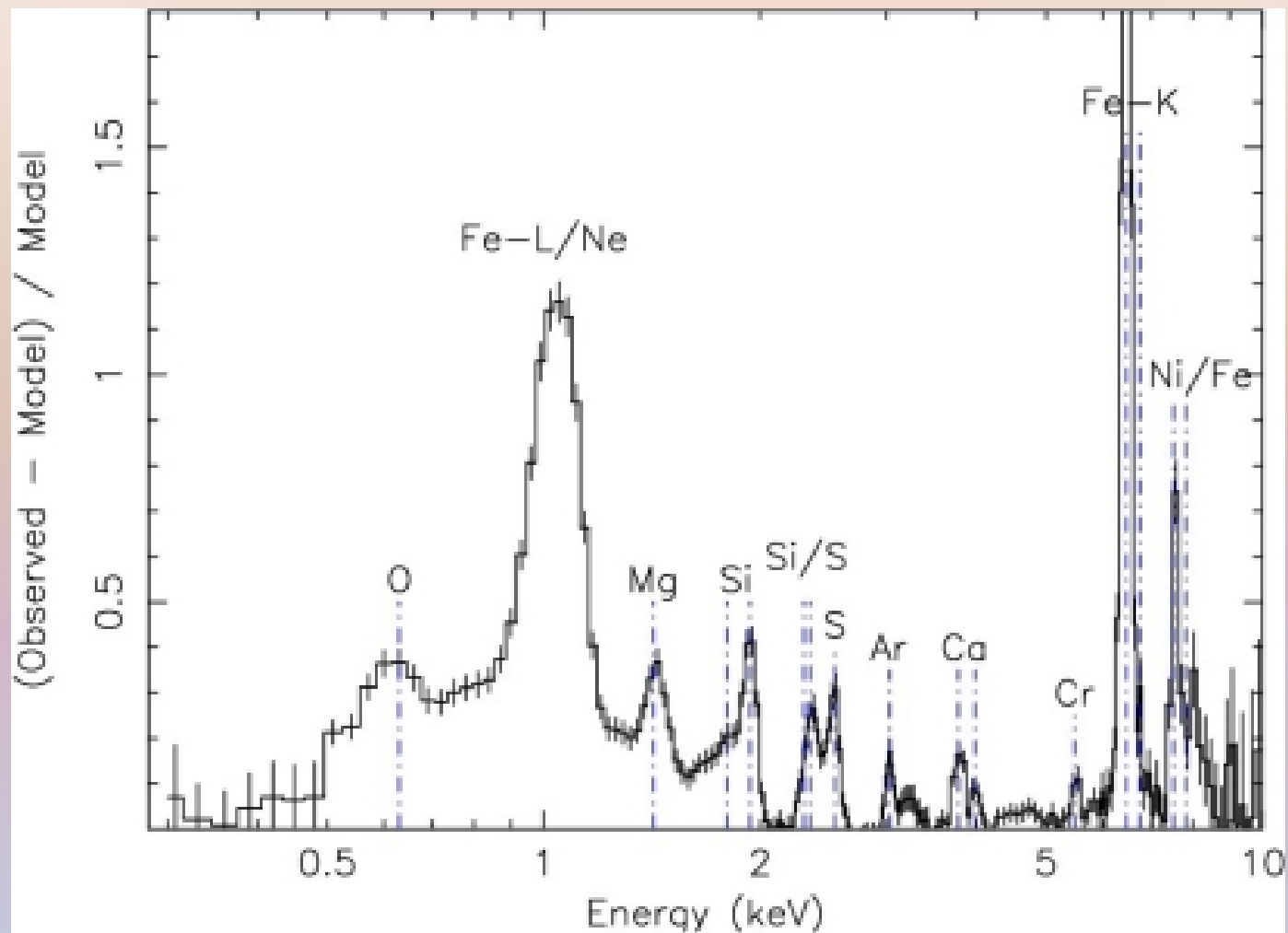
# Mass-metallicity relation (in gas)



Tremonti et al. 2004, ApJ, 613, 898 (1300+ citations)

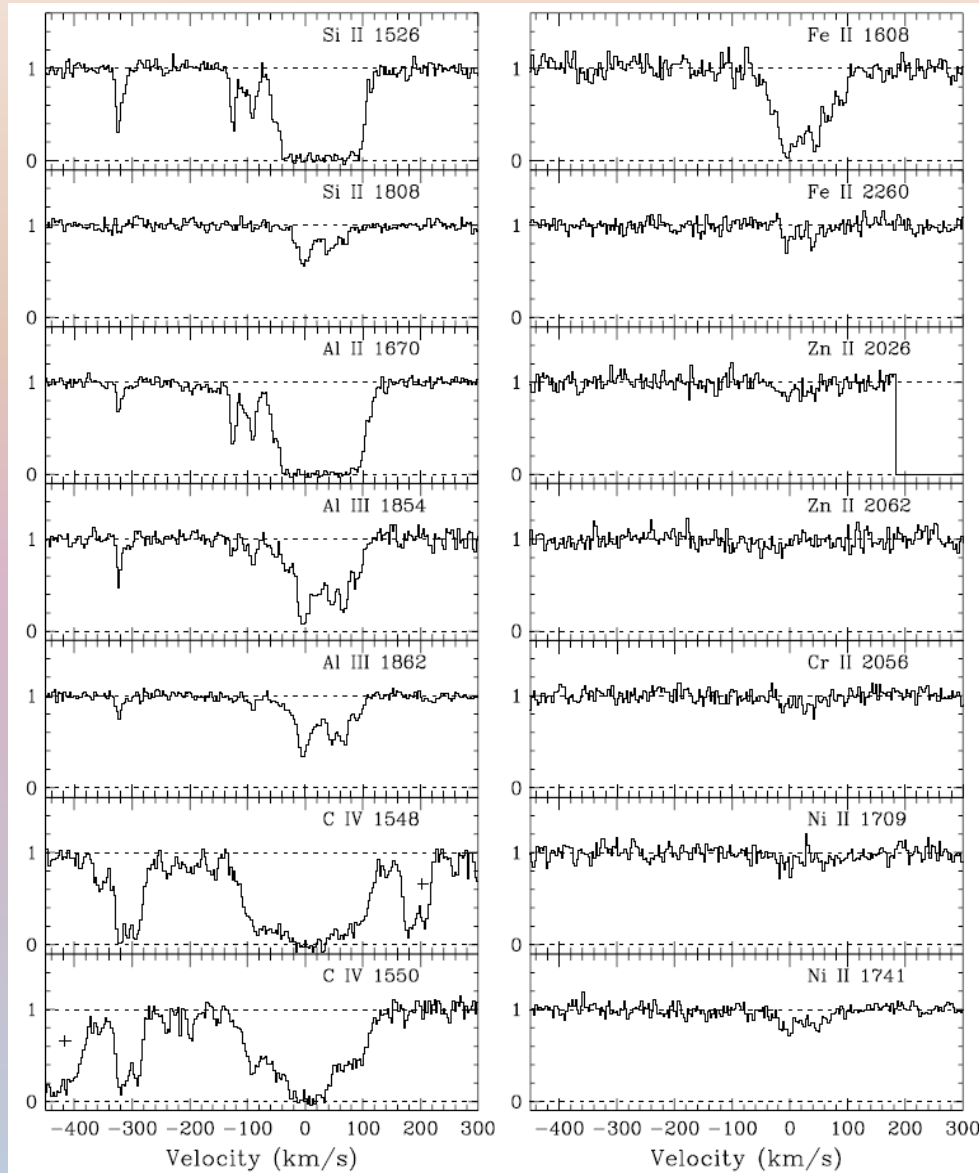
# HII region abundance gradients in disks



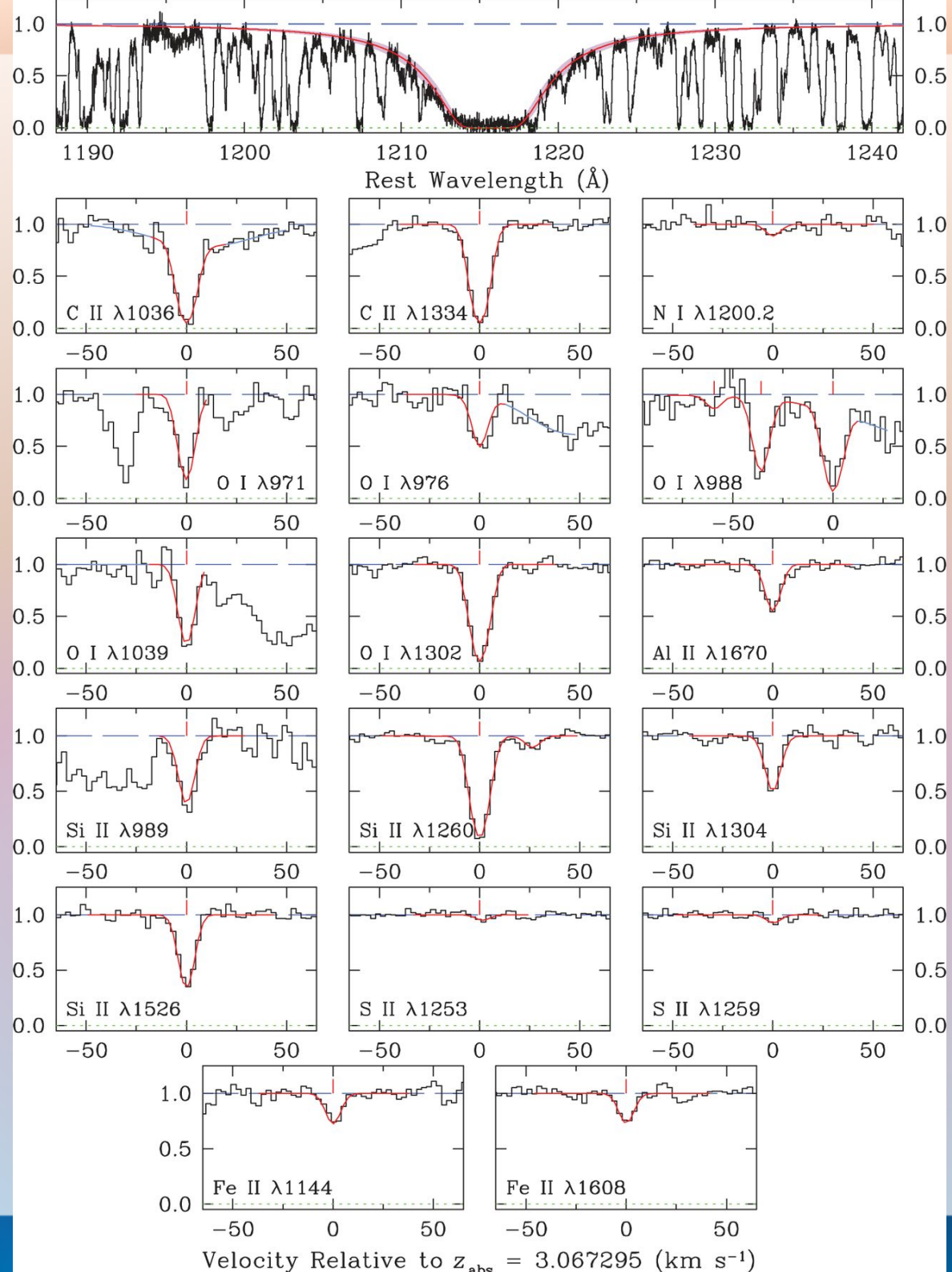




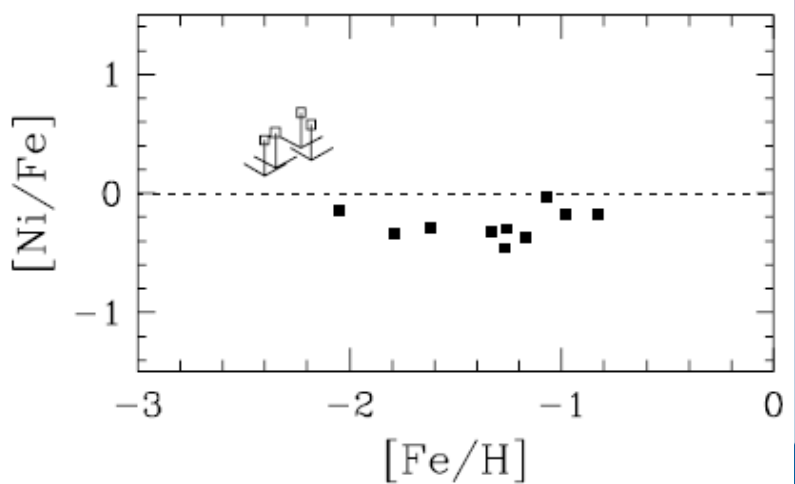
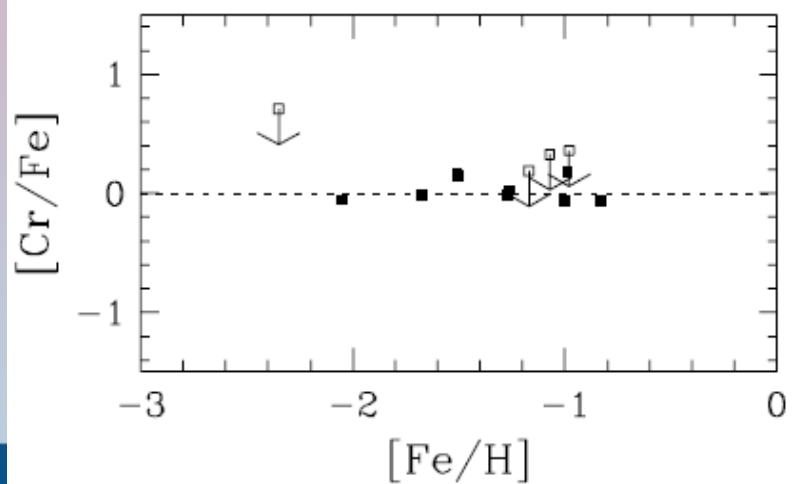
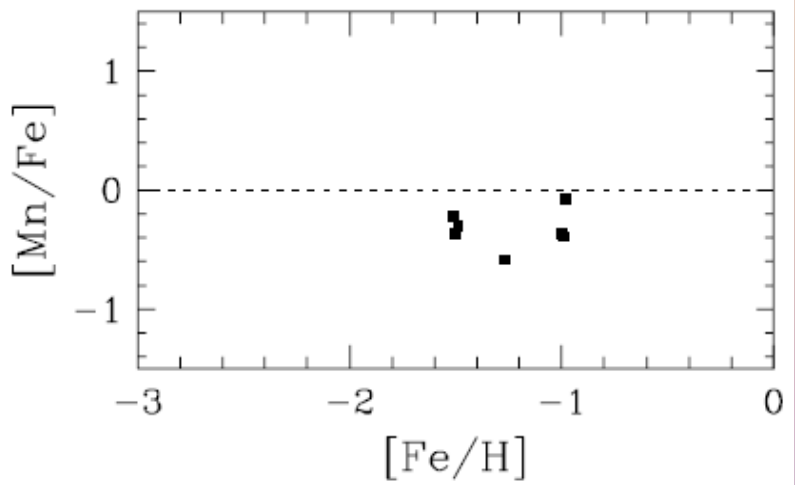
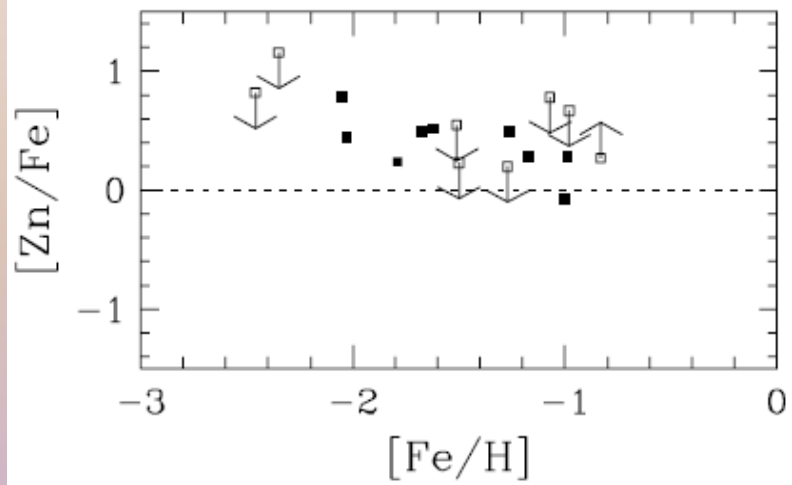
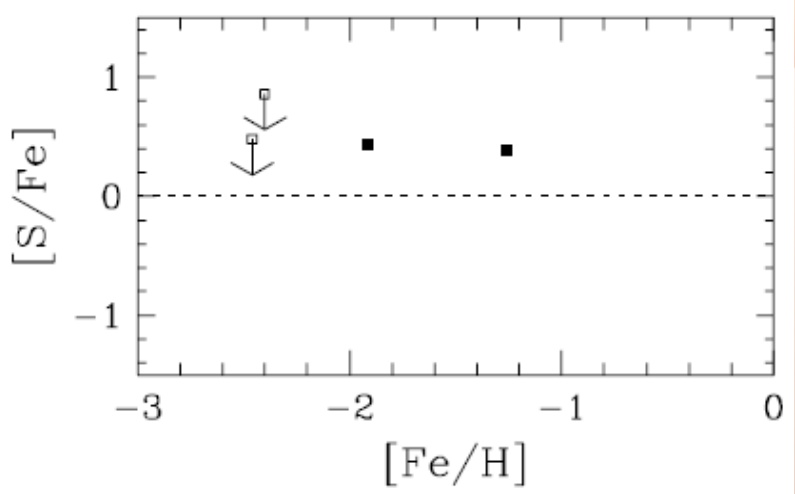
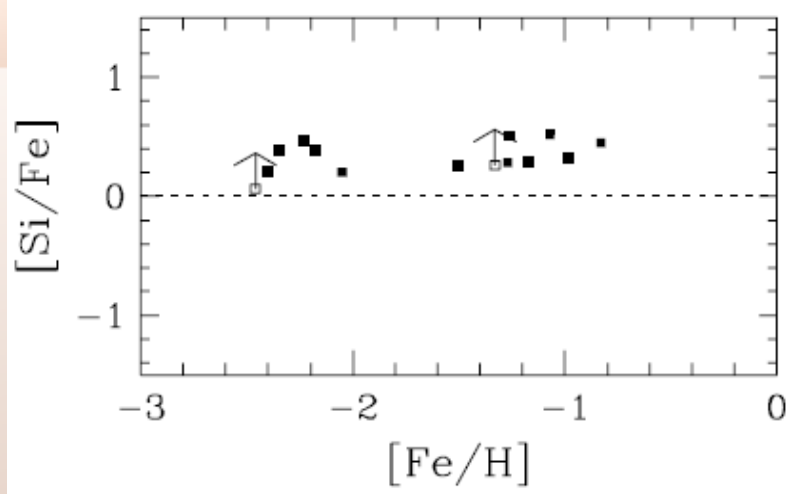
# Abundances in DLAs



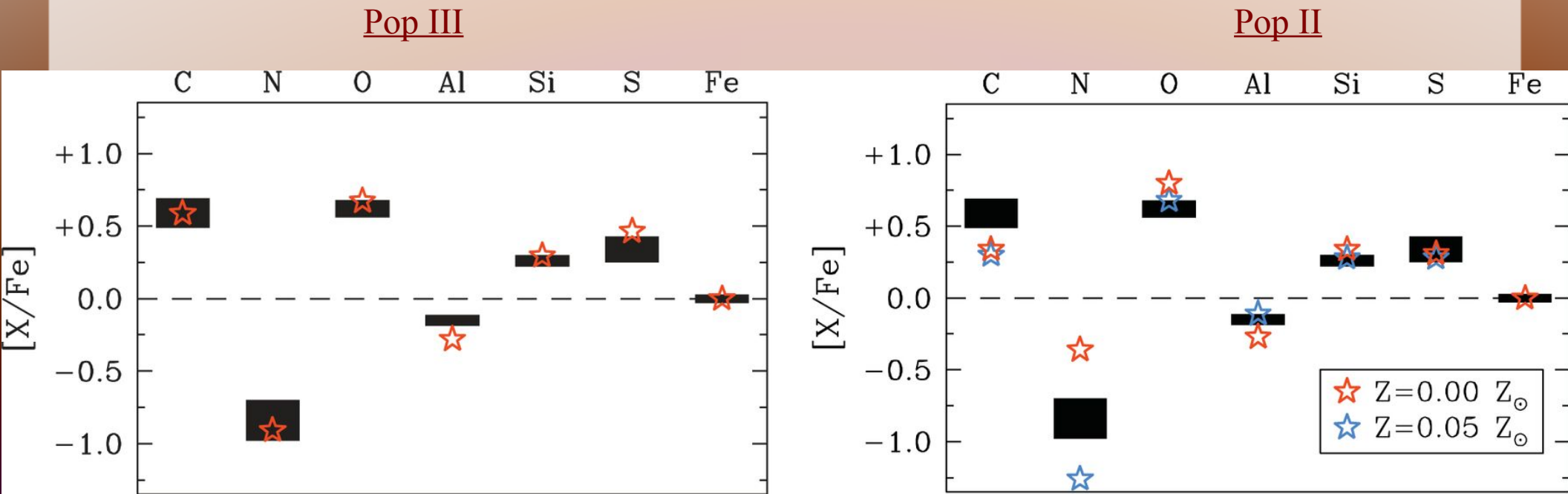
Lu et al. 1996, ApJS, 107, 475 (~400 citations)



Cooke, Pettini, & Murphy 2012, MNRAS, 425, 327

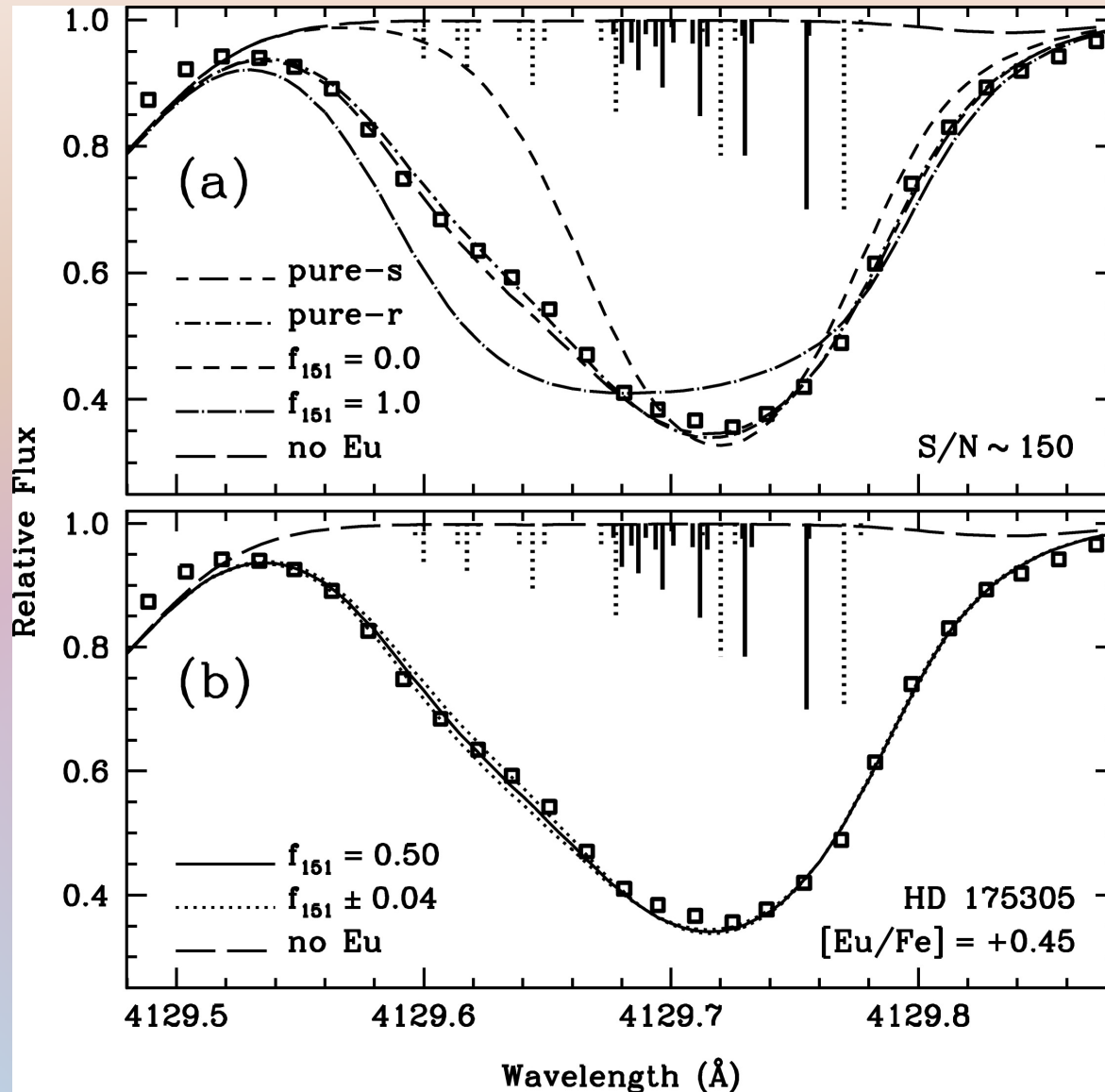


# Pop III nucleosynthesis and DLAs



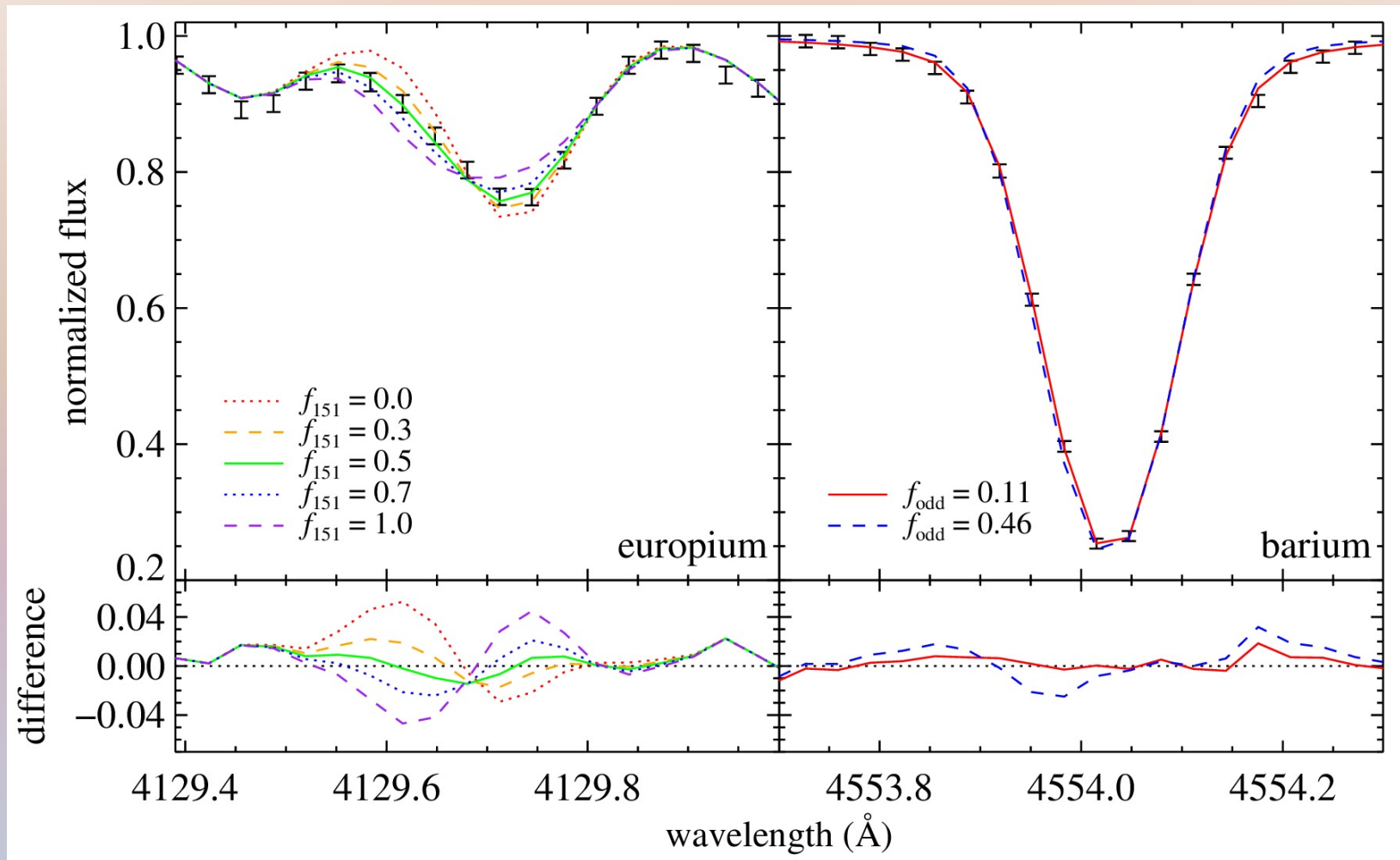
Cooke, Pettini, & Murphy 2012, MNRAS, 425, 327

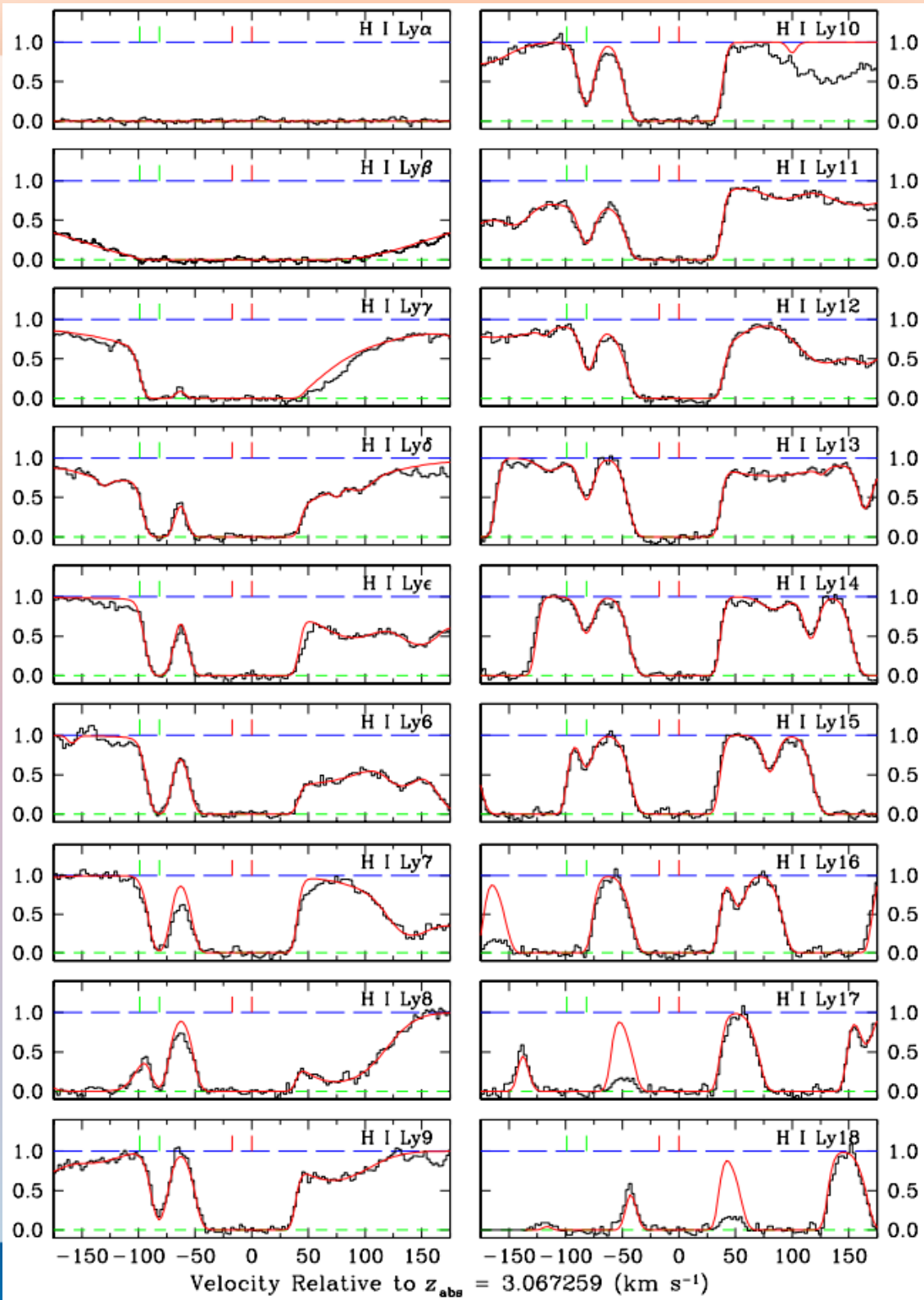
# Stellar isotopes



Roederer et al. 2008, ApJ, 675, 723

# Stellar isotopes





Cooke et al. 2014, ApJ, 781, 31