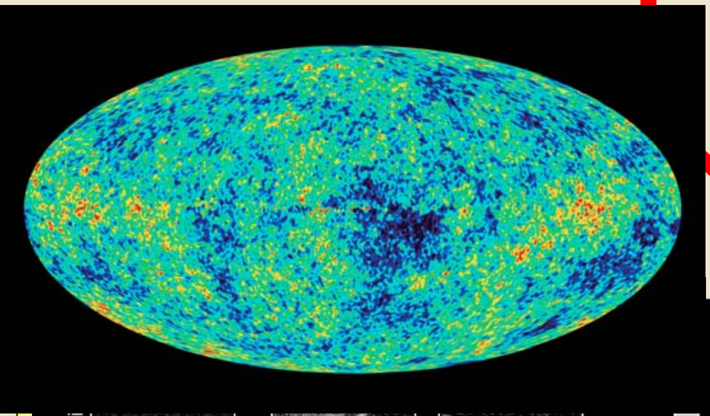
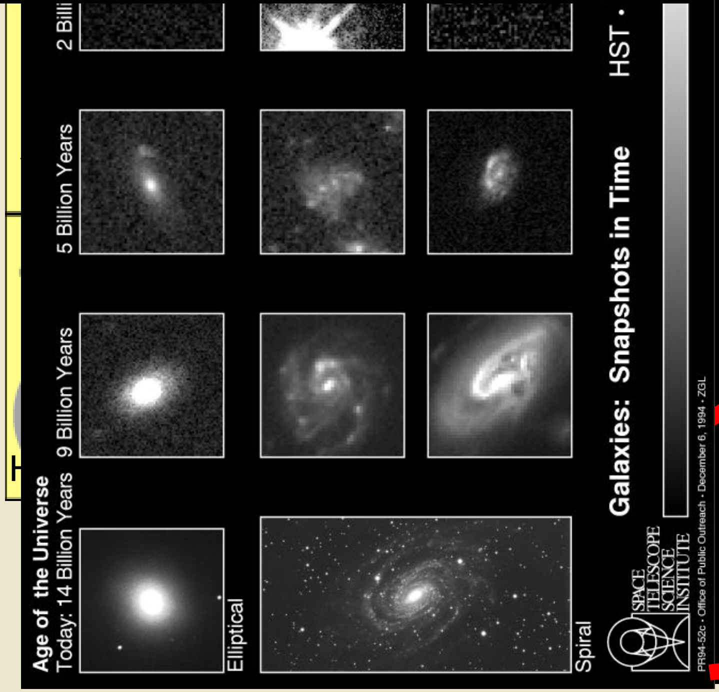
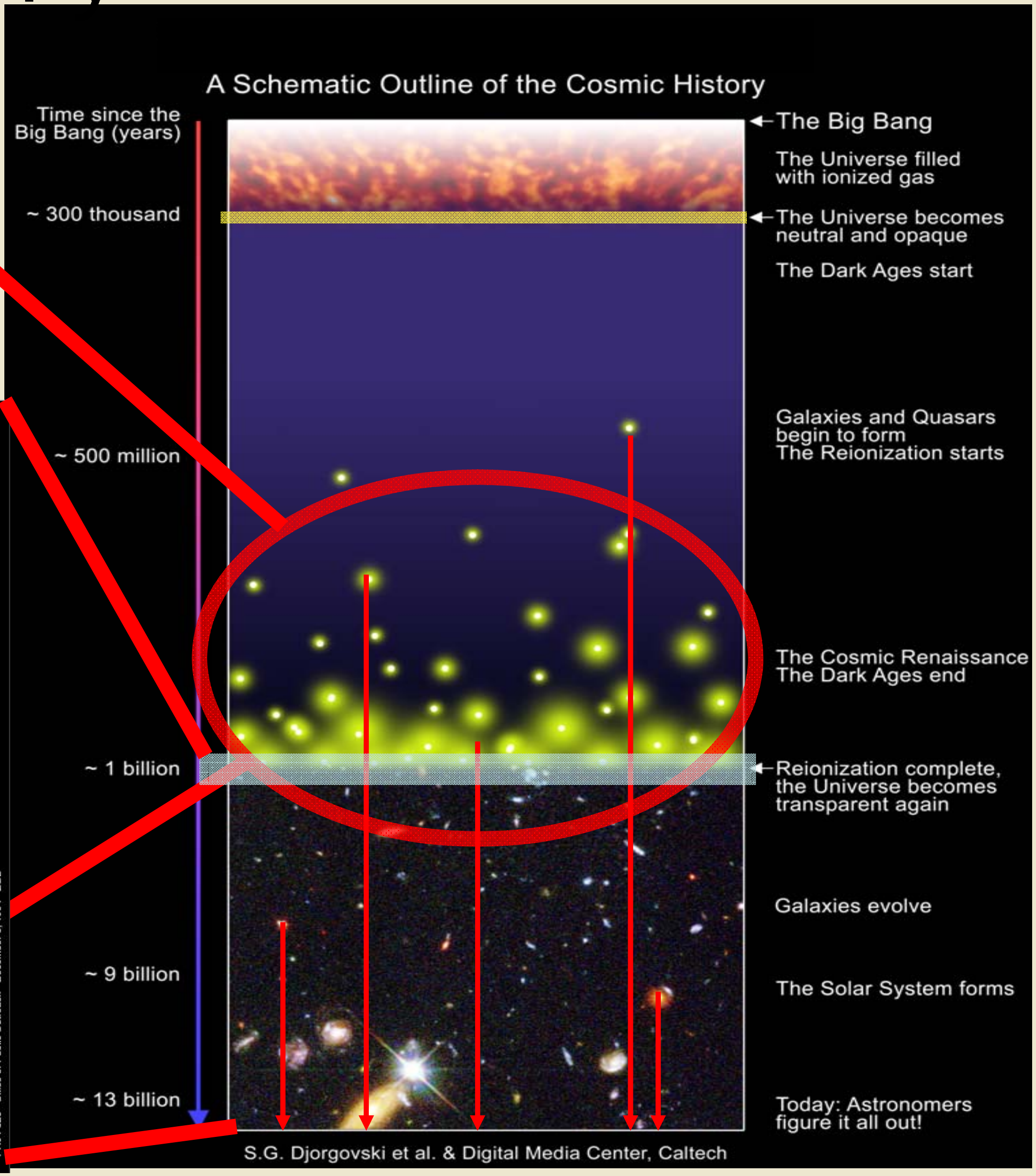
# Cosmic History

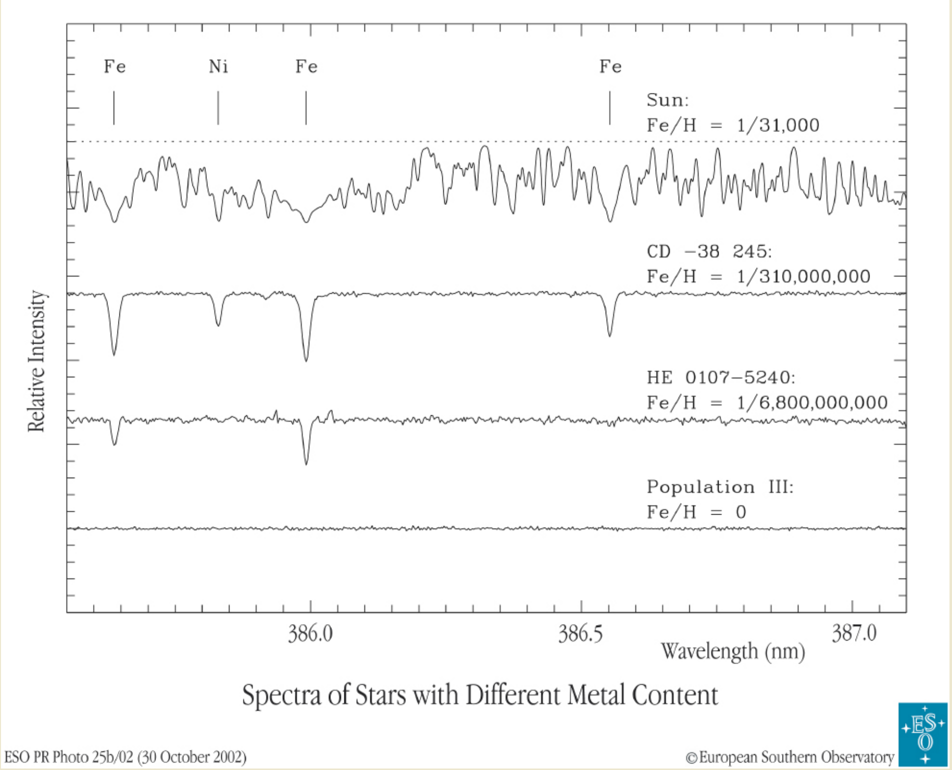
## Big Bang





# Studying Galaxy Formation and Evolution with High Resolution Stellar Spectroscopy




Let's look in detail at the stellar populations of the Milky Way and it's satellites

# Chemical Tagging

- Light Elements – e.g., O Na Mg Al
tracers of deep mixing abundances pa
(globular clusters versus field star

- $\alpha$- Elements – e.g., O Mg Si Ca Ti
dominated by products of Supernovae II

- Iron-peak Elements e.g., V Cr Mn Co Ni Cu Zn
explosive nucleosynthesis (supernovae I)

- Heavy Elements ( Z > 30 )
mix of r- and s- process elements
e.g., s-process e.g., Ba, La (stell
r-process e.g., Eu

e.g., McWilliam 1997

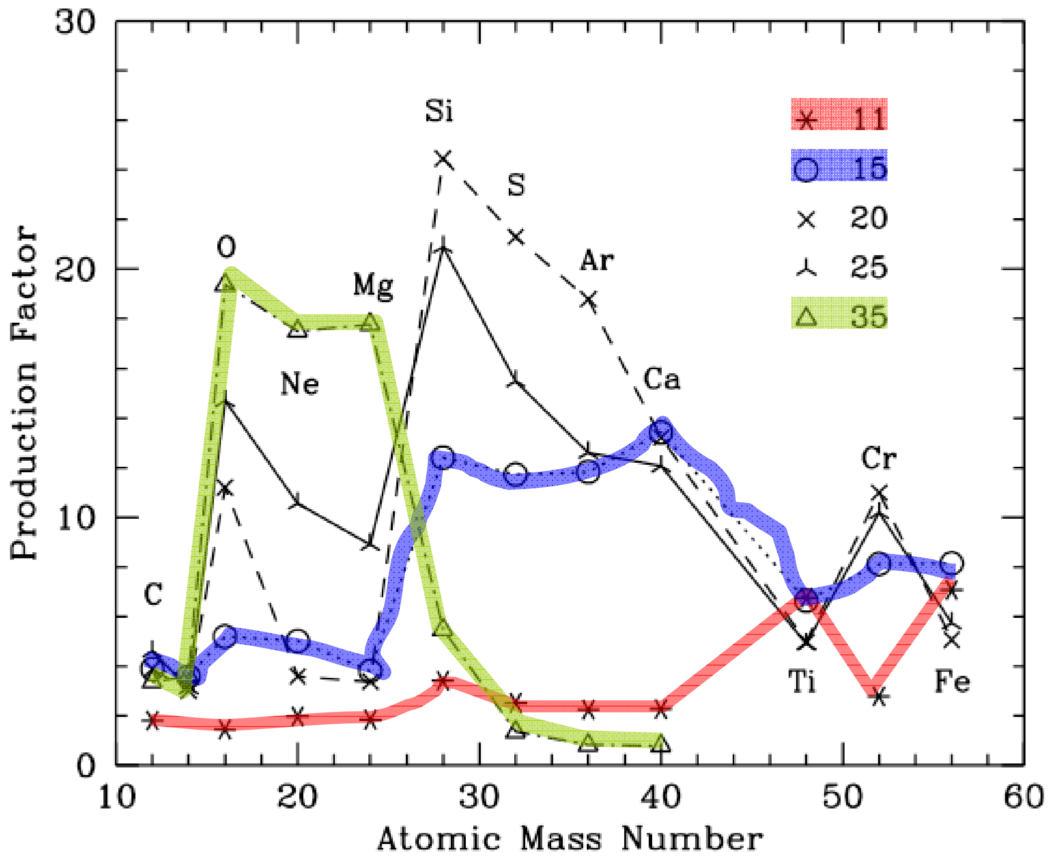
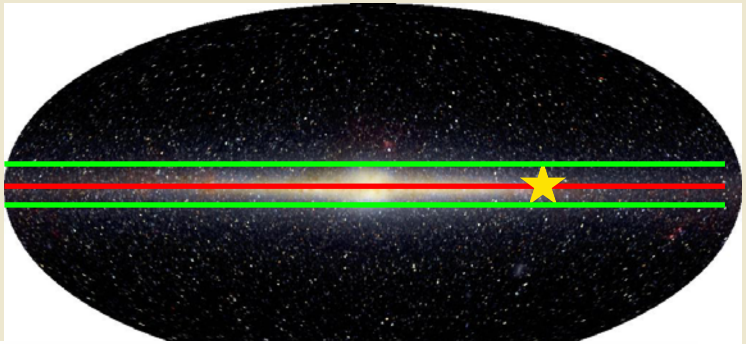
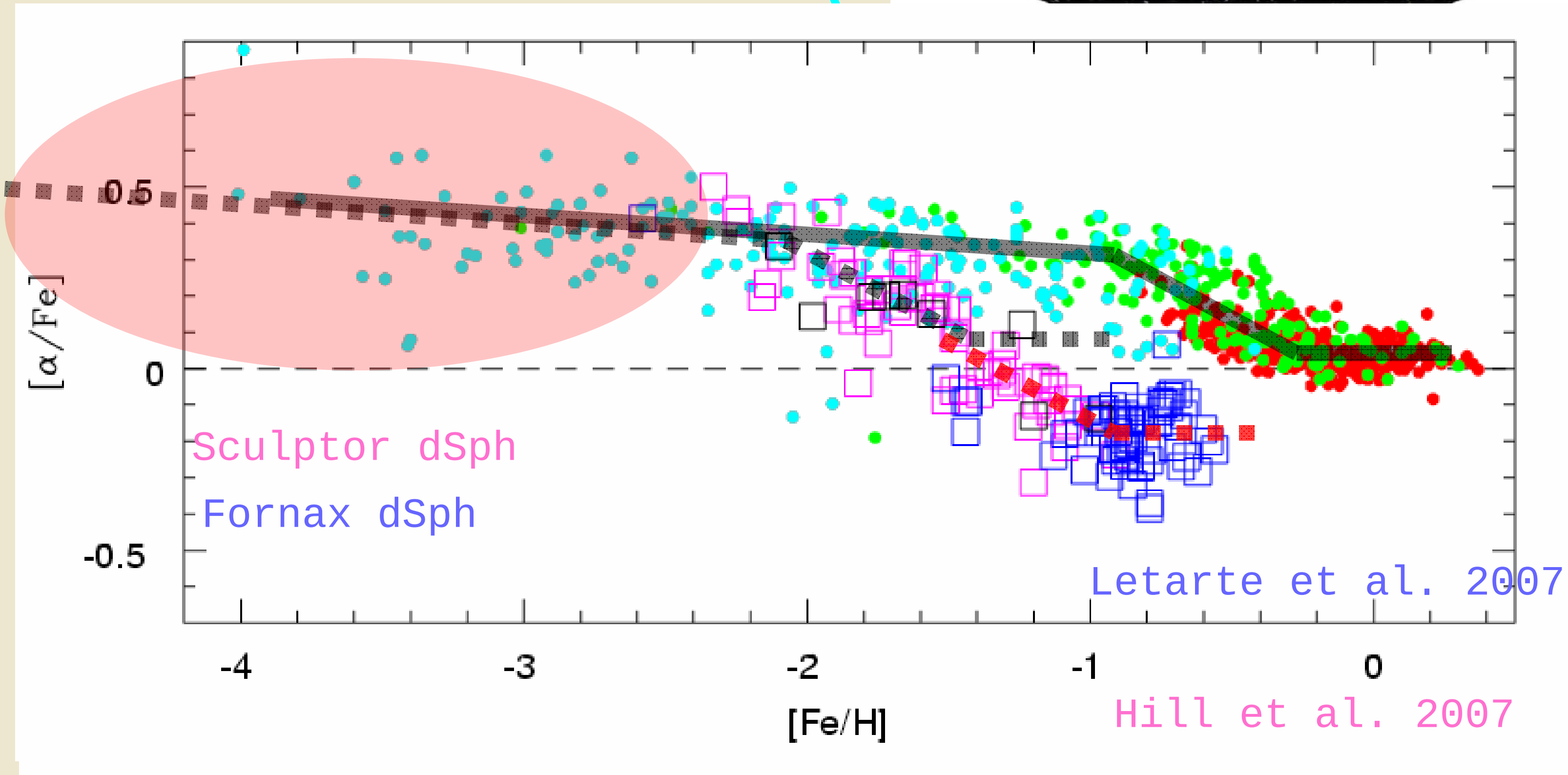



*Figure 6* Production factors from models of SN II by Woosley & Weaver (1995). Ejected element abundances for various progenitor masses are indicated by *connected symbols*; O and Mg are produced in large quantitiesat high mass (~35 $M_{\odot}$) but not in the lower mass (15–25 $M_{\odot}$) SN, which are responsible for most of the Si and Ca production. None of the models give significant enhancements of Ti relative to Fe, contrary to observations of stars in the Galactic bulge and halo. Note that production factor is defined as the ratio of the mass fraction of an isotope in the SN ejecta, divided by its corresponding mass fraction in the Sun. The mass of the progenitor making the indicated elements is given in the key in the upper right.

# Comparing the Milky Way to dSph






compilation by Venn et al. 2004

## 1.1 Surveys for metal-poor stars

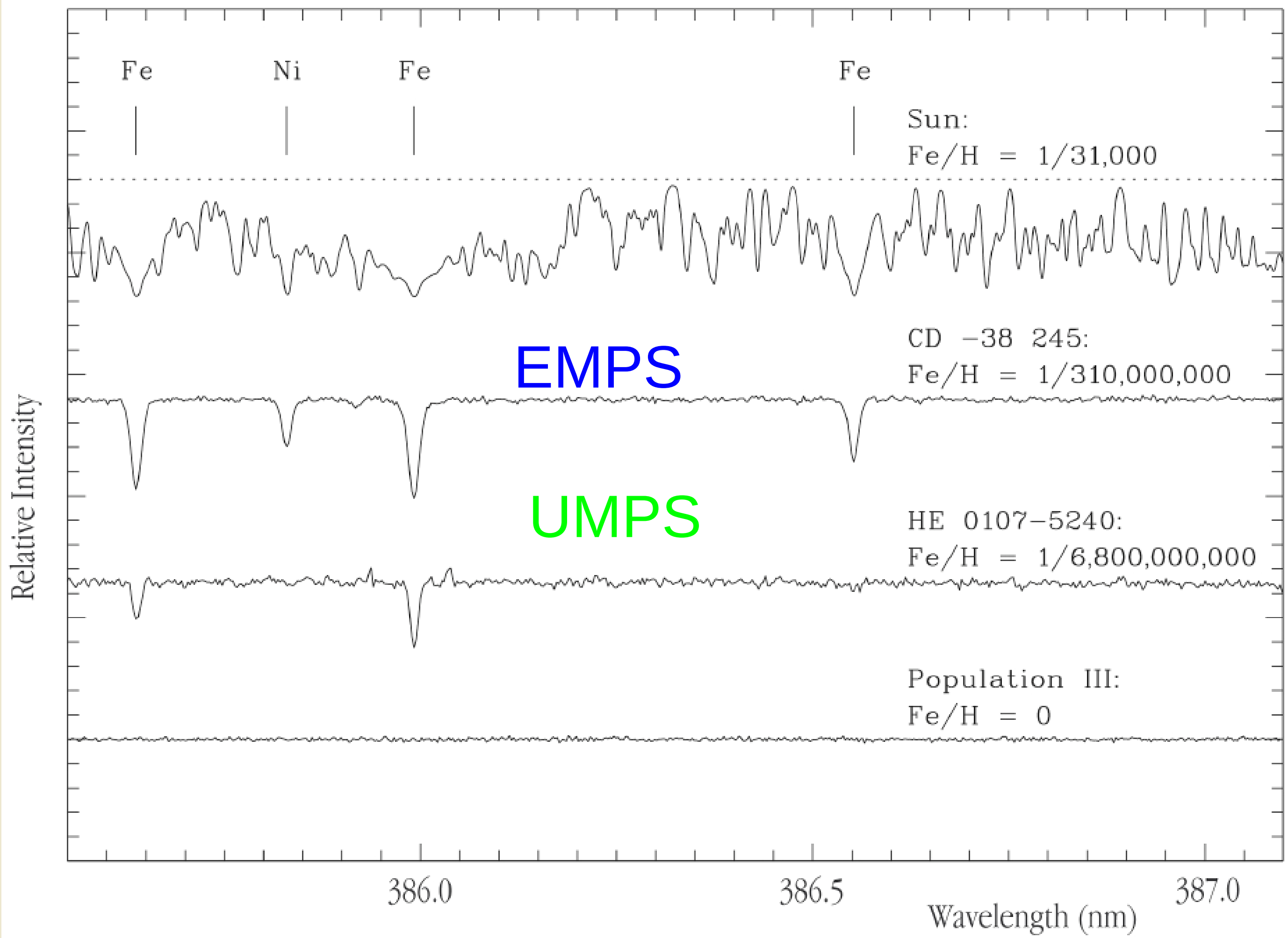
| Survey | Hemisph. | Start | Eff. sky coverage | Eff. mag limit | $N < -3.0$ (EMP) | $N < -5.0$ (HMP) |
|---|---|---|---|---|---|---|
| HES | South | 1989 | 6400 $\deg^2$ | $B < 17.0$ | 400 | 4 |
| SEGUE | North | 2005 | 1000 $\deg^2$ | $B < 19.0$ | 1000 | 10 |
| SSHS | South | 2006 | 500 $\deg^2$ | $B < 17.0$ | 30 | 0 |
| LAMOST | North | 2007 | 10,000 $\deg^2$ | $B < 19.0$ | 10,000 | 100 |
| SSS | South | 2007 | 20,000 $\deg^2$ | $B < 18.0$ | 5000 | 50 |

Basic requirements:

V~20 R~40000 S/N>100

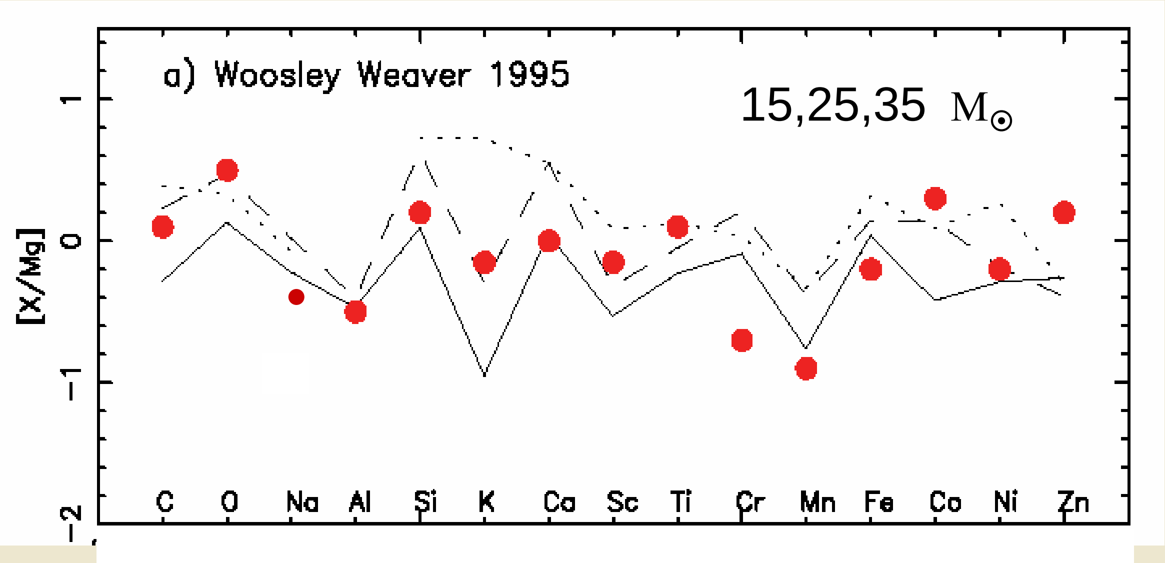
λ as blue as possible Δλ>1000Å

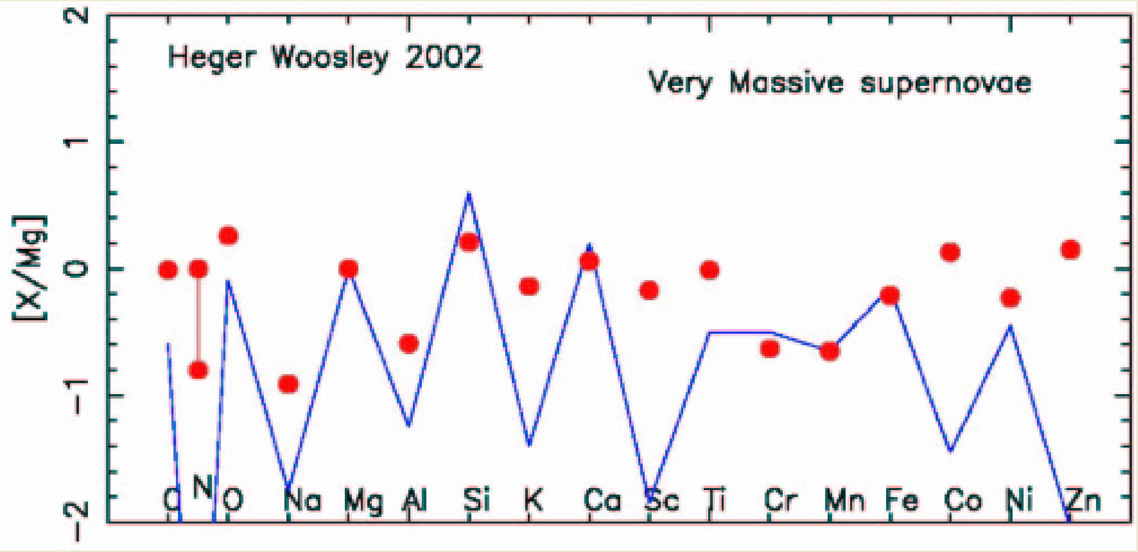
No specific spatial resolution

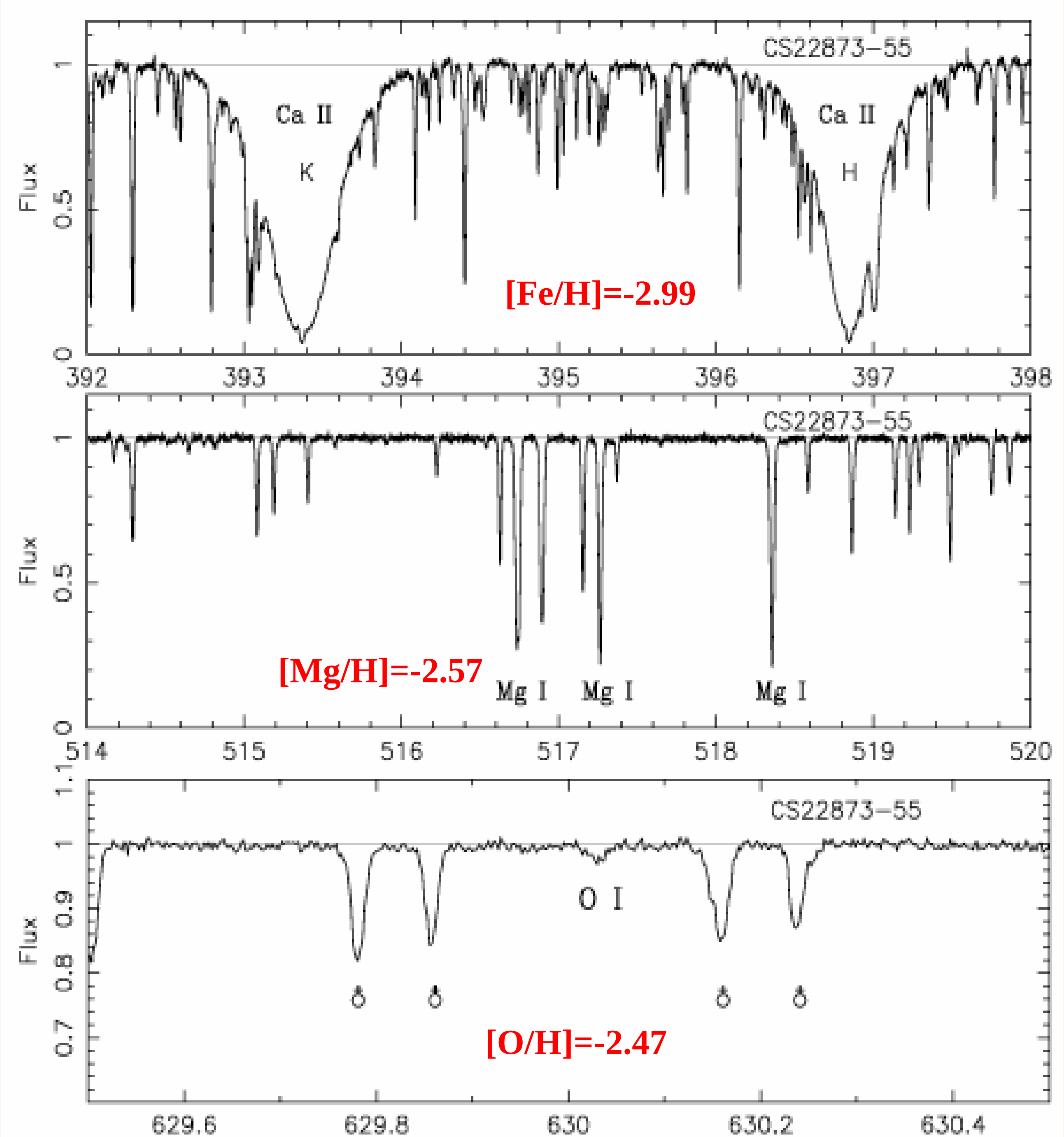



Spectra of Stars with Different Metal Content

# Constraining early chemical enrichement: EMPS



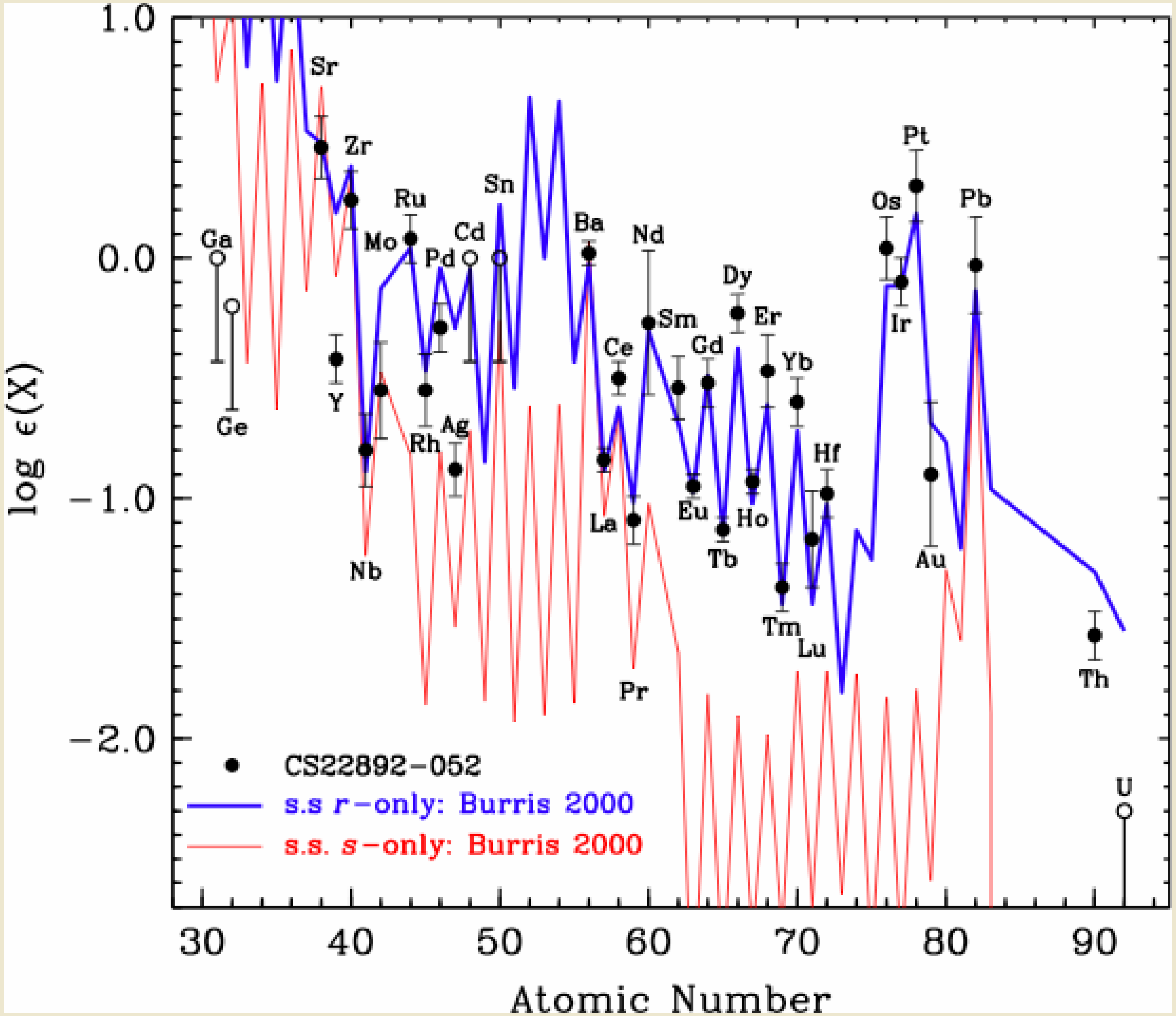





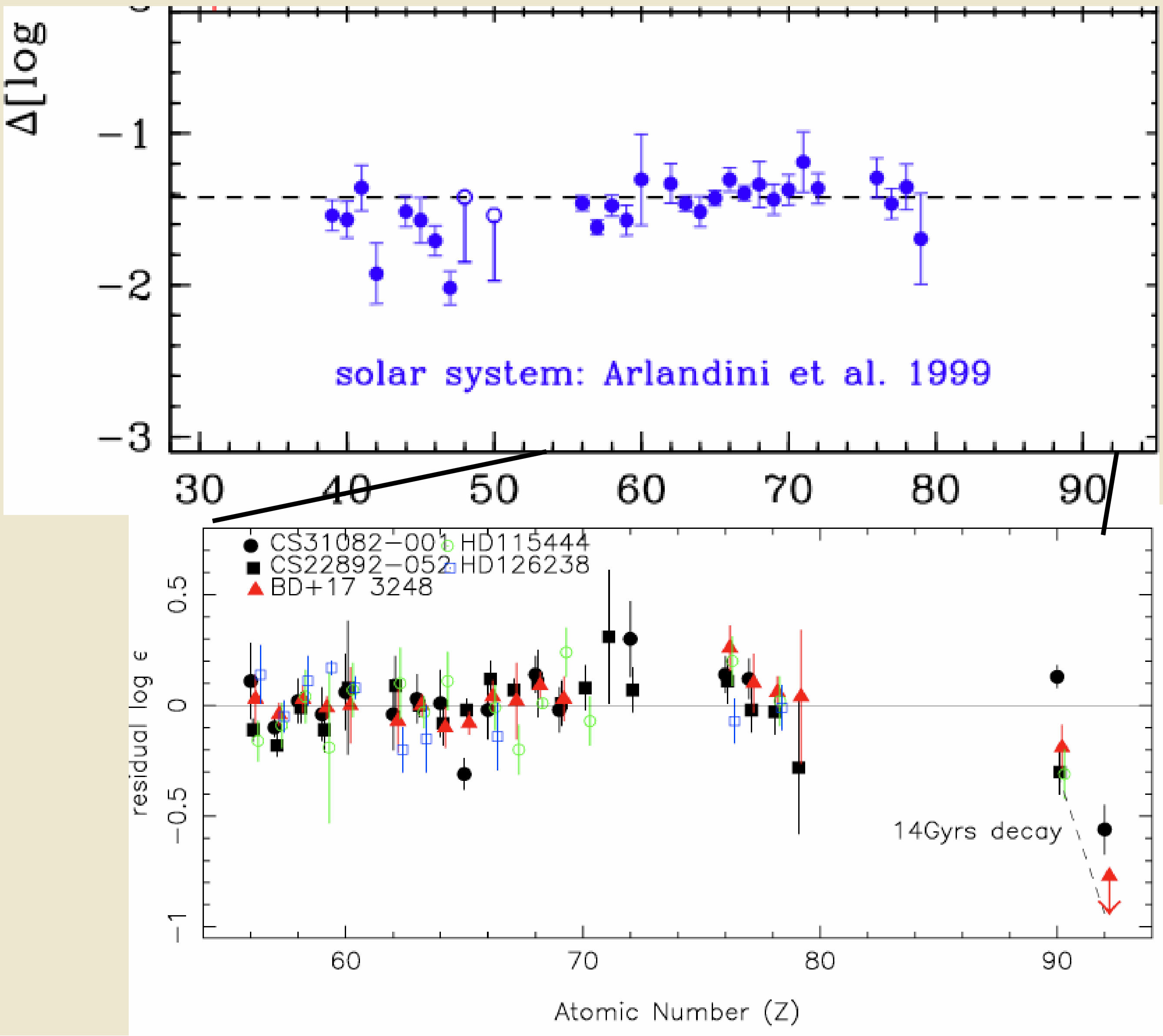
CS22873-55
Ca II
K
Ca II
H
[Fe/H]=-2.99
Flux
CS22873-55
[Mg/H]=-2.57
Mg I
Mg I
Mg I
Flux
CS22873-55
O I
[O/H]=-2.47
Flux

# Constraining the origin of the r-process

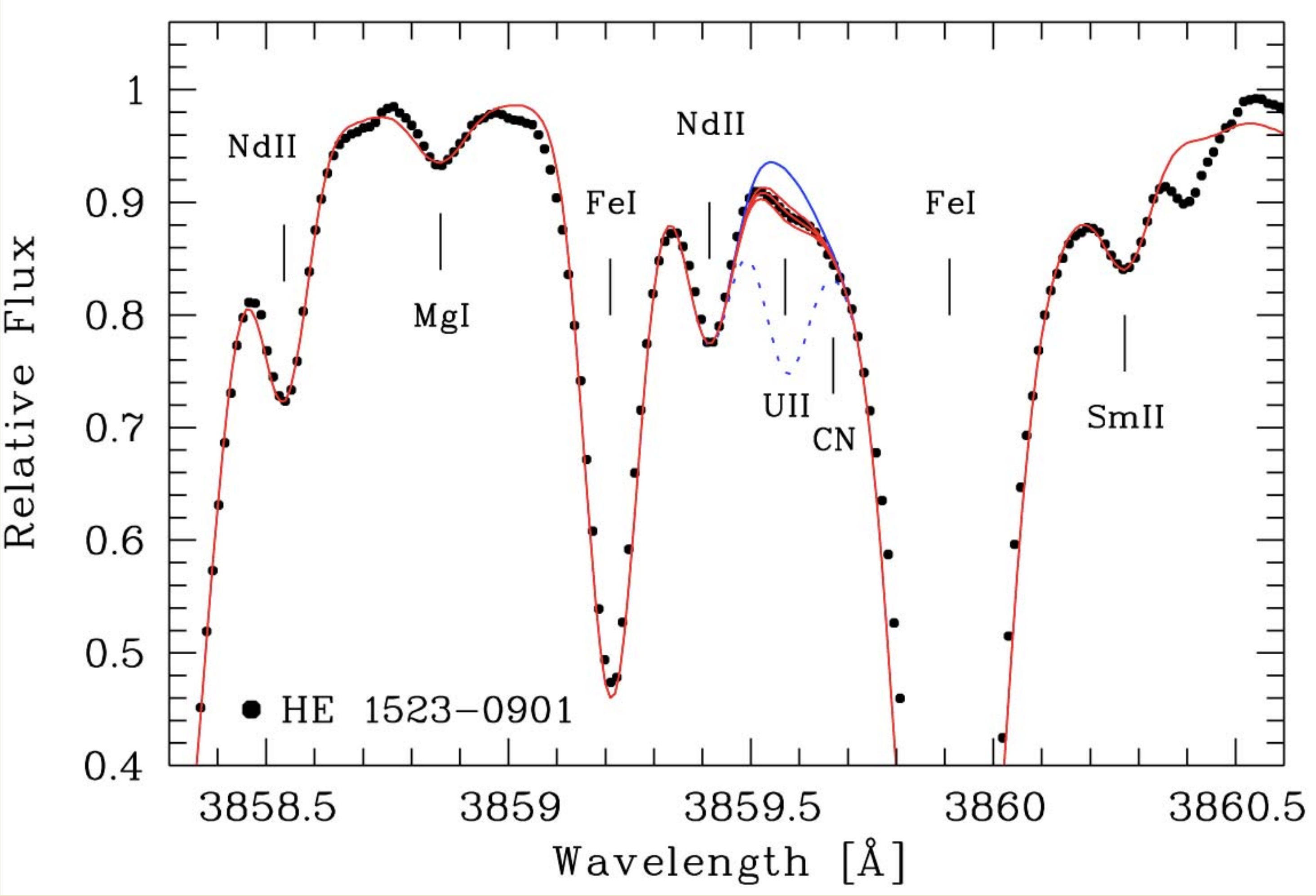
r-process enhanced EMPS



# How universal is the r- process ?



# Radioactive dating



Stell param

[Fe/H]<-5.

R-process

| Quantity | Indicator | Minium $R = \lambda/\Delta\lambda$ G/−5.2 | Minium $R = \lambda/\Delta\lambda$ SG/−5.4 | Minium $R = \lambda/\Delta\lambda$ r-II giant | Minium $S/N$ per pixel G/−5.2 | Minium $S/N$ per pixel SG/−5.4 | Minium $S/N$ per pixel r-II giant | Notes |
|---|---|---|---|---|---|---|---|---|
| $T_{\rm eff}$ | H$\alpha$ | 40,000 | 40,000 | 40,000 | 150 | 150 | 150 | |
| $\log g$ | Fe I/Fe II | 20,000 | 20,000 | 20,000 | | | | 1 |
| $\log g$ | Ca I/Ca II | 20,000 | 20,000 | 20,000 | | | | |
| $\xi_{\rm micr}$ | Fe I | 40,000 | 60,000 | 20,000 | 50 | 200 | 30 | 2 |
| $\log\epsilon\,(^7{\rm Li})$ | $^7$Li 6707.76 Å | – | 40,000 | – | – | 120 | – | 3 |
| $\log\epsilon\,({\rm C})$ | CH | 20,000 | 20,000 | 20,000 | | | | |
| $\log\epsilon\,({\rm N})$ | CN | 20,000 | 20,000 | 20,000 | | | | |
| $\log\epsilon\,({\rm N})$ | NH 3360 Å | 40,000 | 20,000 | | 70 | 50 | | |
| $\log\epsilon\,({\rm O})$ | OH 3100 Å | 40,000 | 40,000 | 40,000 | 30 | 40 | | |
| $^{12}{\rm C}/^{13}{\rm C}$ | $^{12}$CH, $^{13}$CH | 40,000 | – | 40,000 | 100 | | | |
| $\log\epsilon\,({\rm Mg})$ | Mg I 3838.29 Å | 40,000 | 40,000 | 20,000 | 40 | 40 | 50 | |
| $\log\epsilon\,({\rm Mg})$ | Mg I 5183.60 Å | 40,000 | 40,000 | 20,000 | 100 | 60 | 50 | |
| $\log\epsilon\,({\rm Ca})$ | Ca I 4226.73 Å | 40,000 | 60,000 | 20,000 | 60 | 370 | 50 | |
| $\log\epsilon\,({\rm Ca})$ | Ca II | | | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Ti})$ | | | | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Mn})$ | | | | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Fe})$ | Fe I 3859.91 Å | 40,000 | 40,000 | 20,000 | 20 | 200 | 50 | |
| $\log\epsilon\,({\rm Fe})$ | Fe II 3227.74 Å | 40,000 | – | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Co})$ | Co I | | | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Ni})$ | | | | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Zn})$ | | | | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Sr})$ | Sr II4077.72 Å | – | 40,000 | 20,000 | – | 200 | 30 | |
| $\log\epsilon\,({\rm Y})$ | | – | – | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Zr})$ | | – | – | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Ba})$ | Ba II 4554.03 Å | – | – | 20,000 | | | 30 | |
| $\log\epsilon\,({\rm La})$ | | – | – | 20,000 | | | 50 | |
| $\log\epsilon\,({\rm Eu})$ | Eu II 4129.73 Å | – | – | 20,000 | | | 30 | |
| $\log\epsilon\,({\rm Os})$ | | – | – | | | | | |
| $\log\epsilon\,({\rm Ir})$ | | – | – | | | | | |
| $\log\epsilon\,({\rm Pb})$ | | – | – | | | | | |
| $\log\epsilon\,({\rm Th})$ | | – | – | 40,000 | – | – | 50 | |
| $\log\epsilon\,({\rm U})$ | | – | – | 75,000 | – | – | 150 | |

Notes:

1 – Detection of at least one Fe II line required.

2 – Detection of at least a couple of Fe I lines required.

3 – Assuming an abundance of $\log\epsilon\,(^7{\rm Li}) = 2.2$.

Table 3: Data quality requirements for spectroscopic analyses of metal-poor stars.

# HR spectroscopy

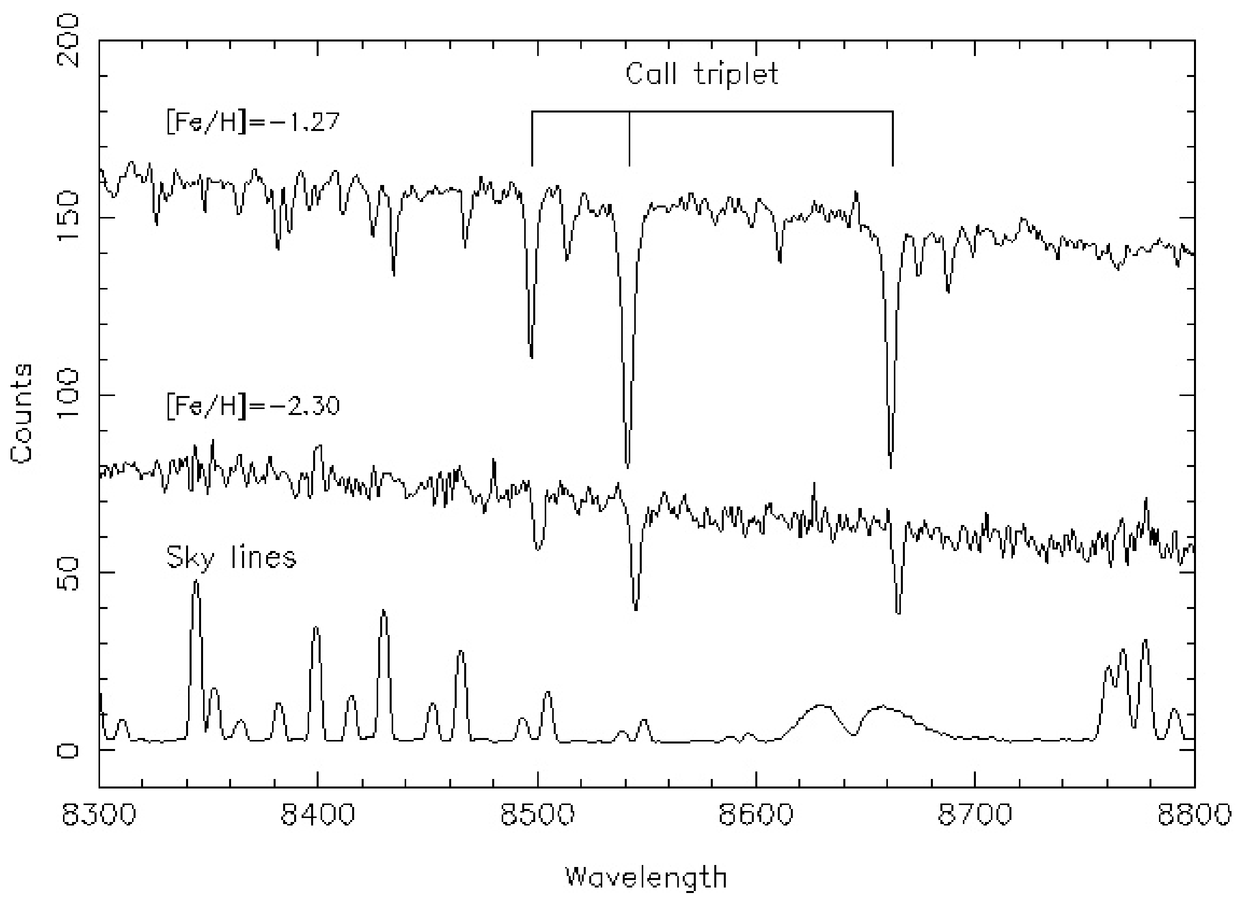
**MOS - 100 stars per local galaxy (min); 500-800nm; R~20000 (min);**

**fov: 2 arcmin (?), $M_I$ > -3**

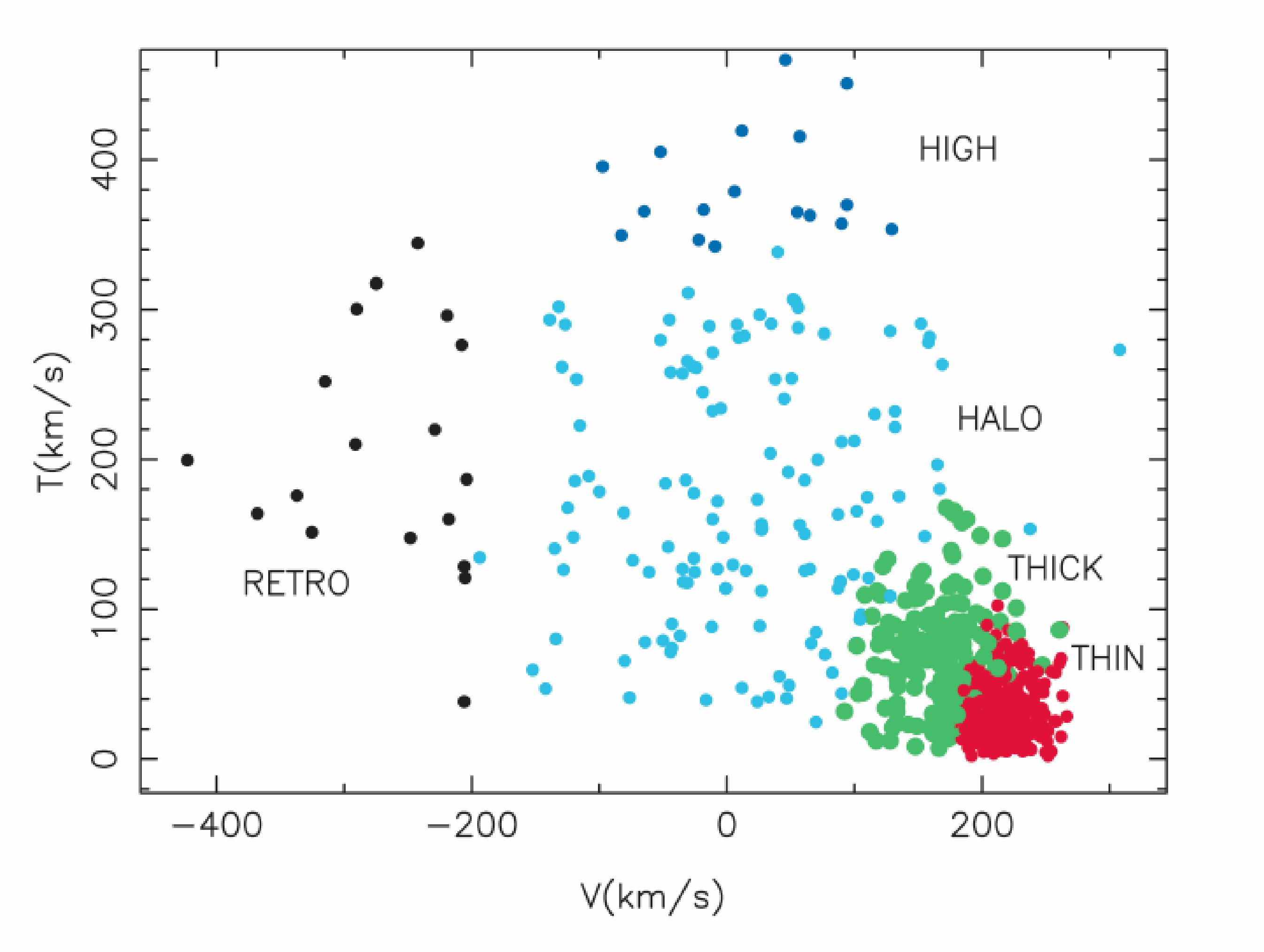
**SOS - 10s stars per local galaxy (min); 300-500nm; R~40000 (min);**

**$M_I$ > -3**

# Low Resolution Stellar Spectroscopy: the Ca II Triplet



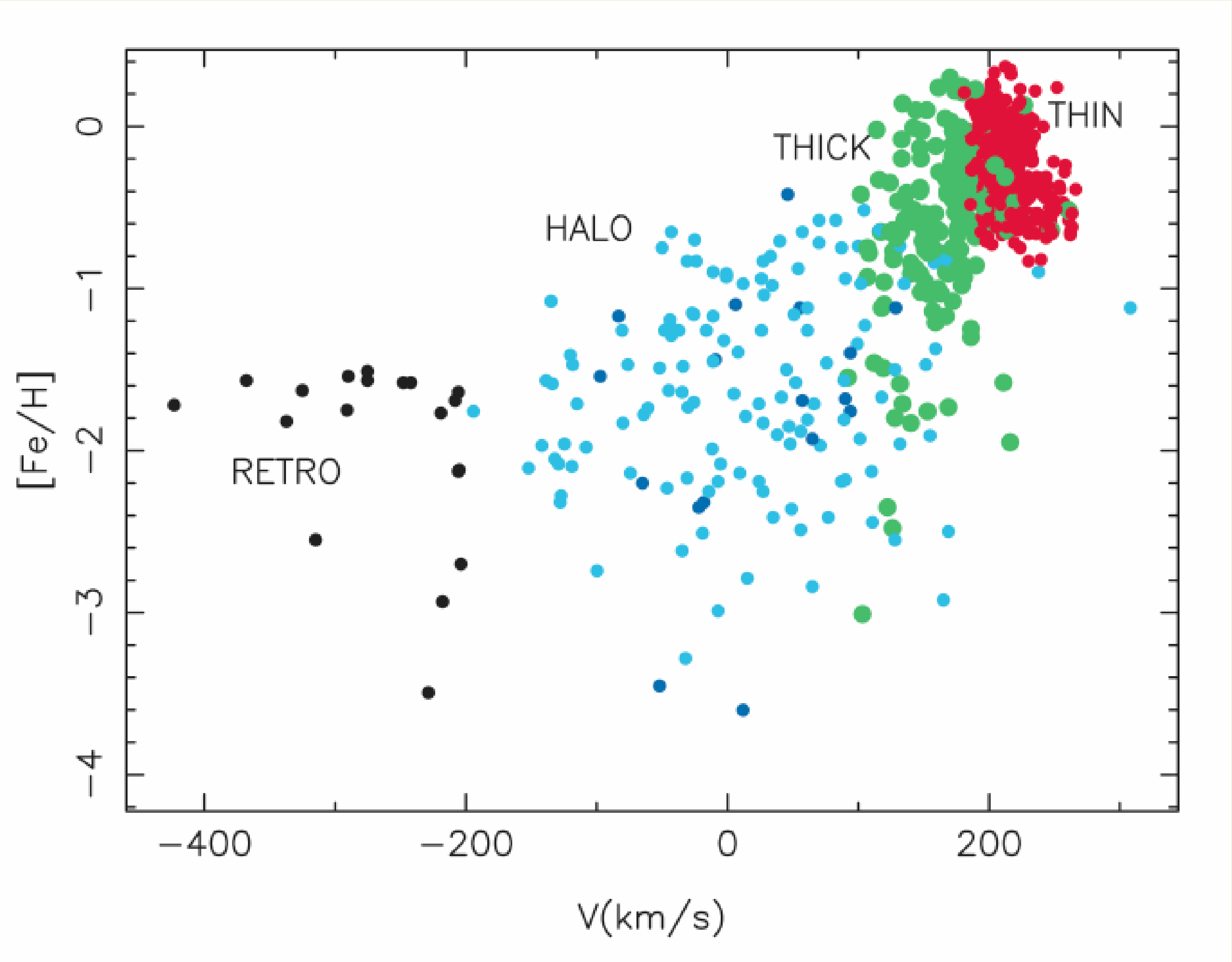
# Kinematic Classification




$T = (U^2 + W^2)^{1/2}$

Venn et al. 2004

# Metallicty of different components

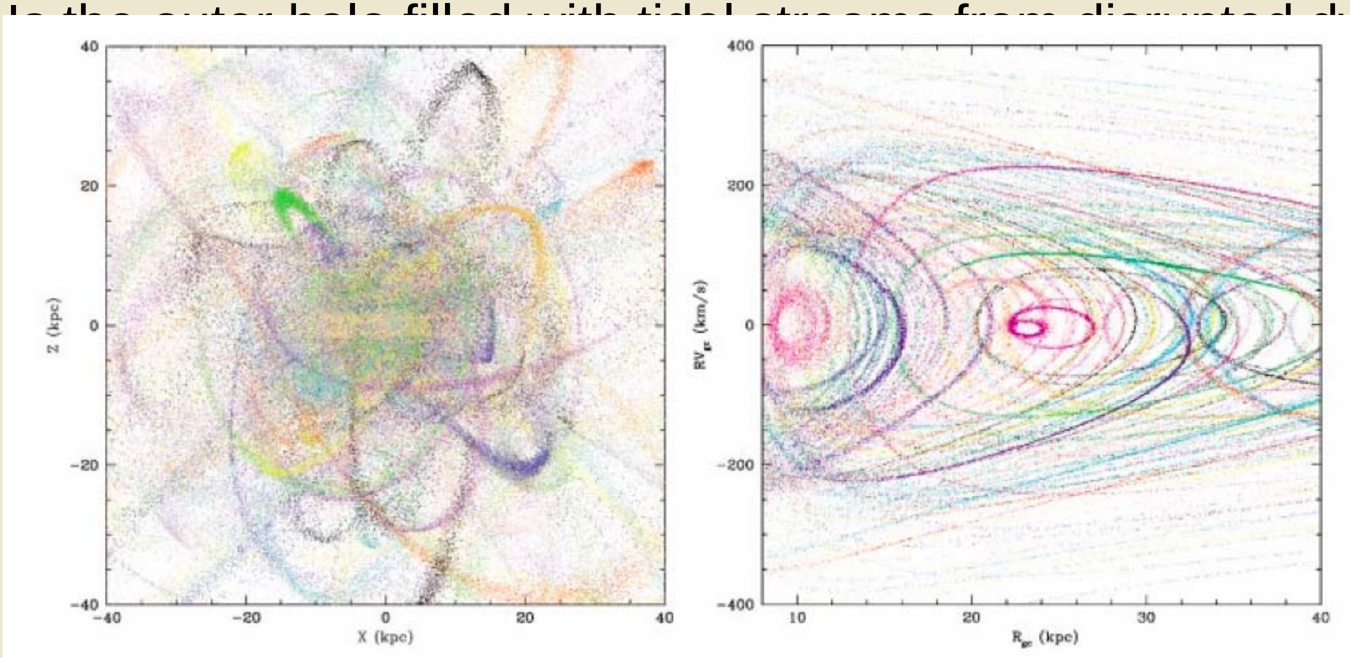


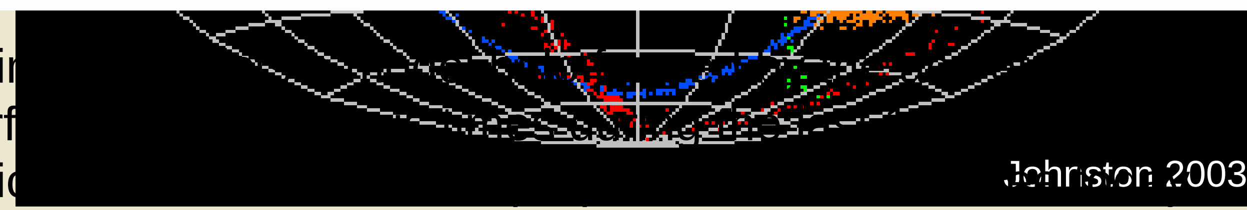

Venn et al. 2004

# Looking for Evidence on small scales...

warf

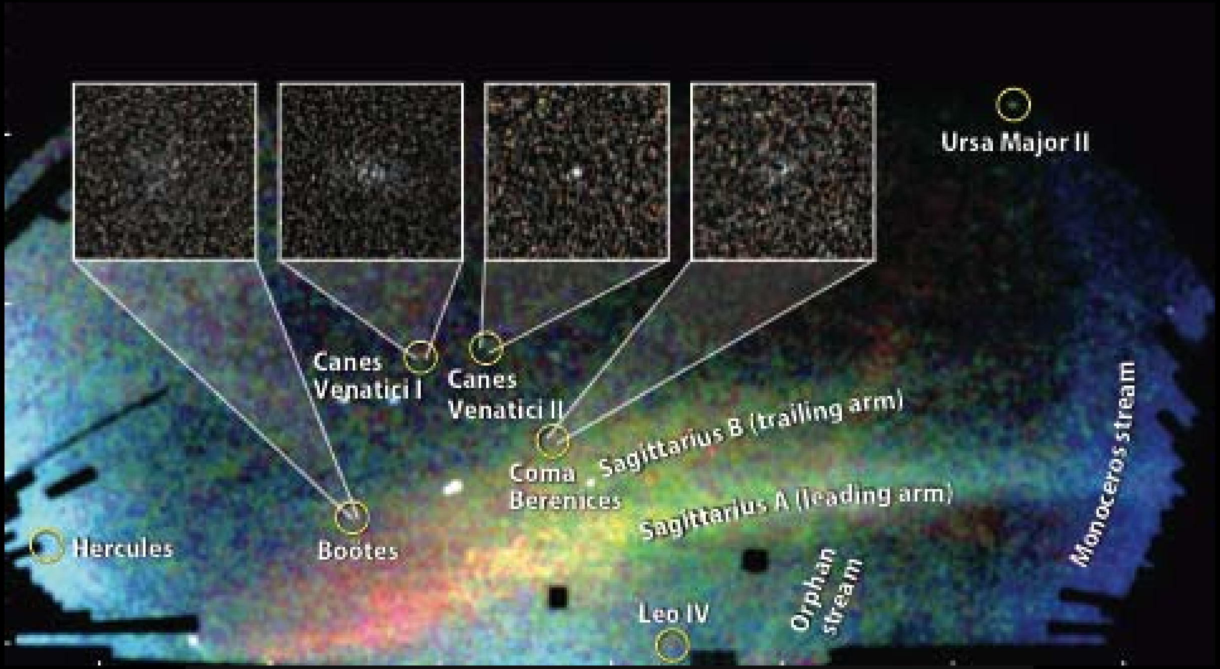
99 etc...)

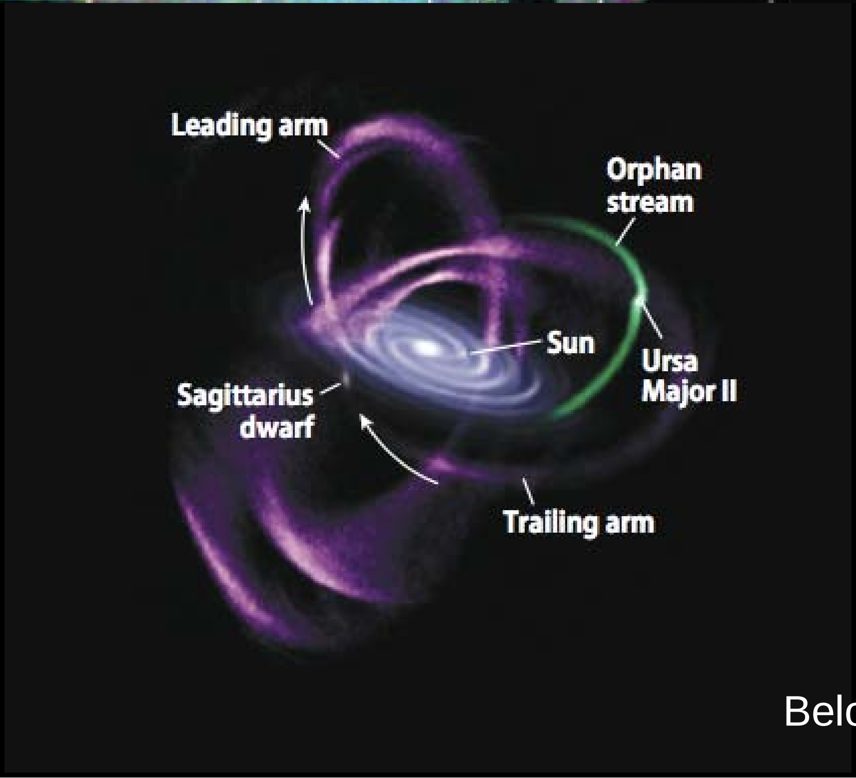



The i
dwarf es
predic

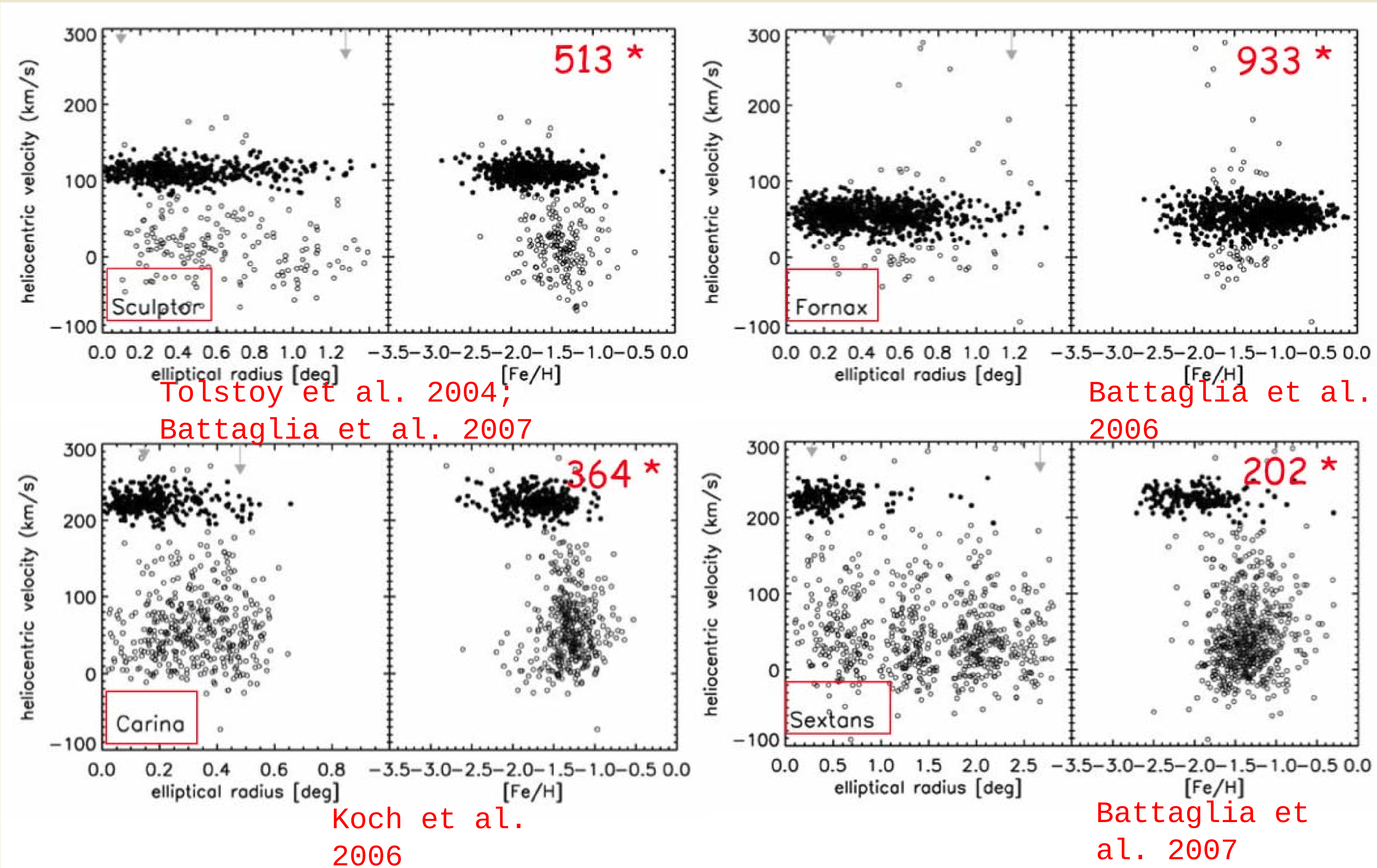
Paul Harding




Belokurov, Zucker, Irwin et al.

# VLT/FLAMES results



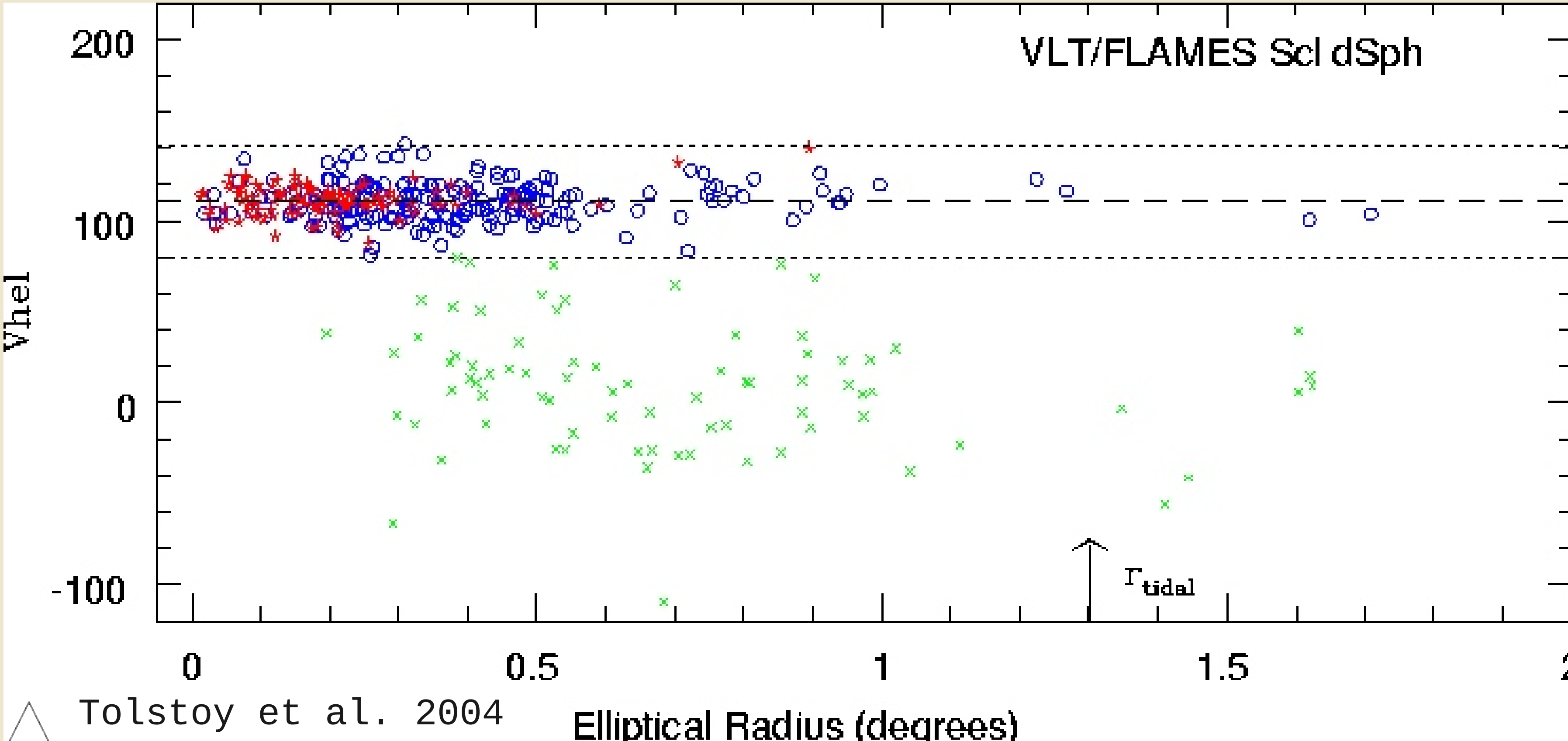

Tolstoy et al. 2004; Battaglia et al. 2007

Battaglia et al. 2006

Koch et al. 2006

Battaglia et al. 2007

# Kinematics & Metallicity




Tolstoy et al. 2004

# LR spectroscopy

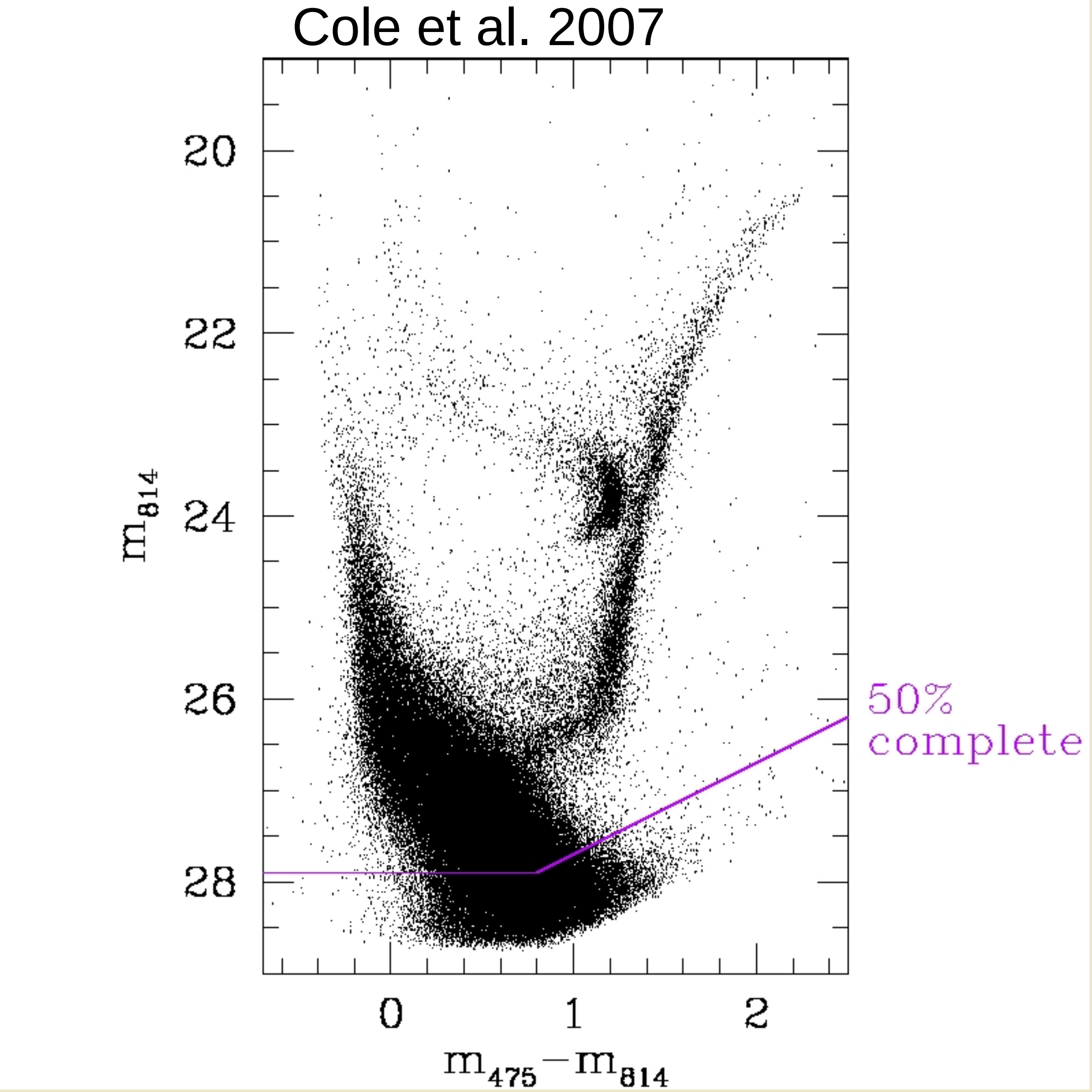
**MOS - 1000 stars per local galaxy (min); 800-900nm; R~6000 (min);**

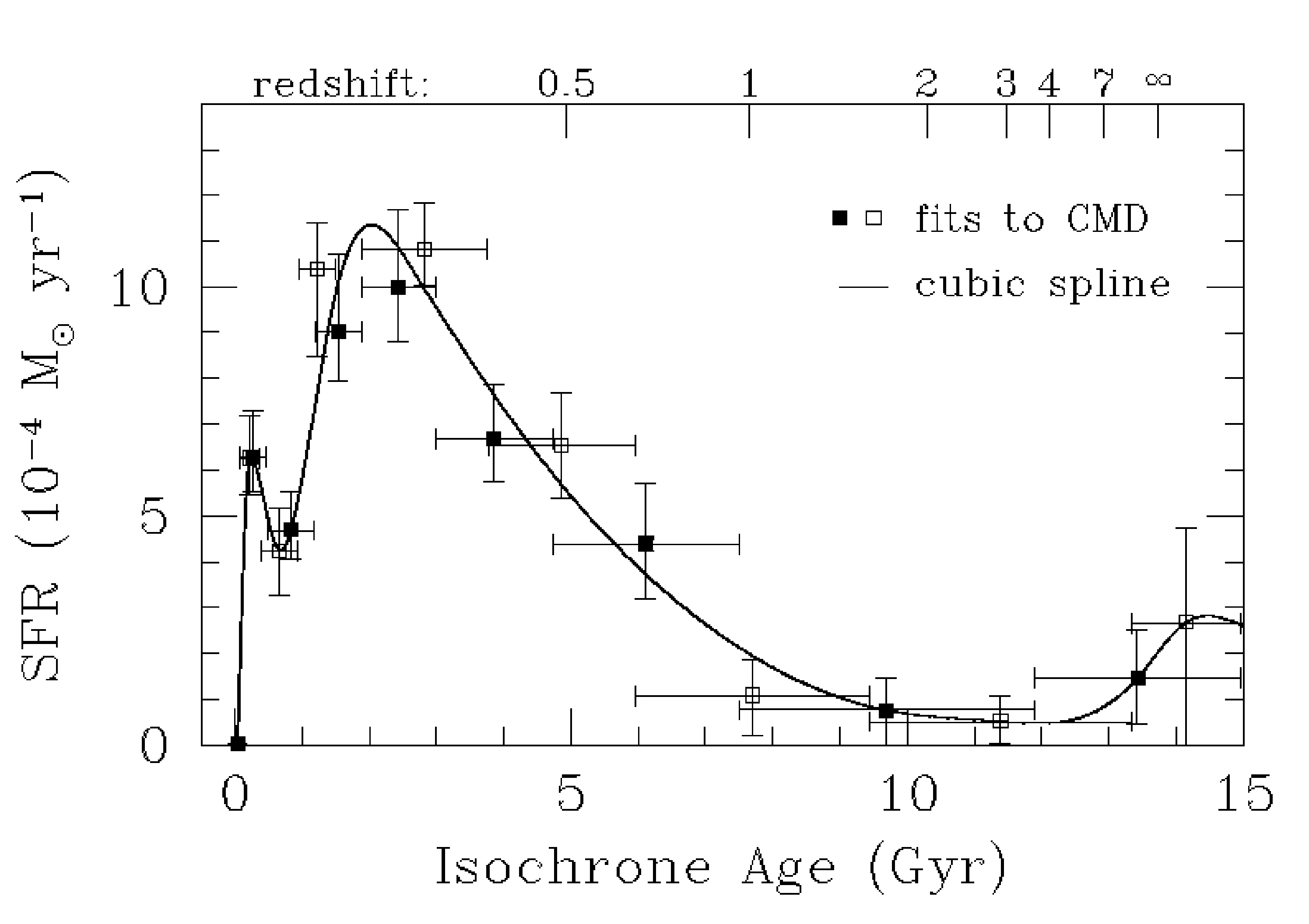
**fov: 2 arcmin (?), $M_I$ > -3**

# Leo A

Deepest ever CMD (in absolute mag) for an isolated dwarf irregular.

$M_{814} \approx +3.4$
$M_{475} \approx +4.2$






Results for 2 age binnings, with 1σ random errors on SFR

Cole et al. 2007, ApJL, in press (astro-ph/0702646)