Poblaciones estelares

(I, II,…,III)

Poblaciones estelares

(I, II,…,III)

- Composición química
- Abundancia y metalicidad

Population I, II, and III Stars

The universe began with the Big Bang 13.7 billion years ago. At that time hydrogen and helium were essentially the only elements produced by the nucleosynthesis that occurred during the initial fireball. Consequently, the first stars to form did so with virtually no metal content; $\boxed{Z = 0.}$ The next generation of stars that formed were extremely **metal-poor**, having very low but non-zero values of Z. Each succeeding generation of star production resulted in higher and higher proportions of heavier elements, leading to metal-rich stars for which Z may reach values as high as 0.03. The (thus far hypothetical) original stars that formed immediately after the Big Bang are referred to as **Population III** stars, metal-poor stars with $Z \gtrsim 0$ are referred to as **Population II**, and metal-rich stars are called **Population I**.

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Composition of outer layers (original composition)

Fractional mass	X (H)	$= 0.71$
	Y (He)	$= 0.265$
	Z (other elements)	$= 0.025$

One way to quantify the **metallicity** is by comparing the ratios of iron to hydrogen in stars relative to our Sun, defining the metallicity to be

$$\boxed{[\mathrm{Fe/H}] \equiv \log_{10}\left[\frac{(N_{\mathrm{Fe}}/N_{\mathrm{H}})_{\mathrm{star}}}{(N_{\mathrm{Fe}}/N_{\mathrm{H}})_{\odot}}\right],} \tag{23.2}$$

where N_{Fe} and N_{H} represent the *number* of iron and hydrogen atoms, respectively. Stars with [Fe/H] < 0 are metal-poor relative to the Sun, and stars with [Fe/H] > 0 are relatively metal-rich.

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	Z	[Fe/H]	Z/Z_{sol}
Sol	0.02	0	1
LMC	0.008	-0.4	0.4
SMC	0.004	-0.7	0.2

Table 16.3. *The solar chemical composition.*

Element	A	$\log A$	$\log A + 12$	Element	A	$\log A$	$\log A + 12$
1 H	1.00×10^{0}	0.00	12.00	42 Mo	8.32×10^{-11}	−10.08	1.92
2 He	8.51×10^{-2}	−1.07	10.93	44 Ru	6.92×10^{-11}	−10.16	1.84
3 Li	1.26×10^{-11}	−10.90	1.10	45 Rh	1.32×10^{-11}	−10.88	1.12
4 Be	2.51×10^{-11}	−10.60	1.40	46 Pd	4.90×10^{-11}	−10.31	1.69
5 B	3.55×10^{-10}	−9.45	2.55	47 Ag	8.71×10^{-12}	−11.06	0.94
6 C	3.31×10^{-4}	−3.48	8.52	48 Cd	5.89×10^{-11}	−10.23	1.77
7 N	8.32×10^{-5}	−4.08	7.92	49 In	4.57×10^{-11}	−10.34	1.66
8 O	6.76×10^{-4}	−3.34	8.66	50 Sn	1.0×10^{-10}	−10.0	2.0
9 F	4.0×10^{-8}	−7.44	4.56	51 Sb	1.0×10^{-11}	−11.0	1.0
10 Ne	1.20×10^{-4}	−4.16	7.84	55 Cs	$<6.2 \times 10^{-11}$	<−10.2	<1.8
11 Na	2.14×10^{-6}	−5.67	6.33	56 Ba	1.35×10^{-10}	−9.87	2.13
12 Mg	3.80×10^{-5}	−4.42	7.58	57 La	1.35×10^{-11}	−10.87	1.13
13 Al	2.95×10^{-6}	−5.53	6.47	58 Ce	3.80×10^{-11}	−10.42	1.58
14 Si	3.55×10^{-5}	−4.45	7.55	59 Pr	5.13×10^{-12}	−11.29	0.71
15 P	2.81×10^{-7}	−6.55	5.45	60 Nd	3.16×10^{-11}	−10.50	1.50
16 S	2.14×10^{-5}	−4.67	7.33	62 Sm	1.02×10^{-11}	−10.99	1.01
17 Cl	3.2×10^{-7}	−6.5	5.5	63 Eu	3.31×10^{-12}	−11.48	0.52
18 Ar	2.51×10^{-6}	−5.82	6.18	64 Gd	1.32×10^{-11}	−10.88	1.12
19 K	1.32×10^{-7}	−6.88	5.12	65 Tb	1.0×10^{-12}	−12.0	0.0
20 Ca	2.29×10^{-6}	−5.64	6.36	66 Dy	1.38×10^{-11}	−10.86	1.14
21 Sc	1.48×10^{-9}	−8.83	3.17	67 Ho	3.39×10^{-12}	−11.47	0.53
22 Ti	1.05×10^{-7}	−6.98	5.02	68 Er	8.51×10^{-12}	−11.07	0.93
23 V	1.00×10^{-8}	−8.00	4.00	69 Tm	1.00×10^{-12}	−12.00	0.00
24 Cr	4.68×10^{-7}	−6.33	5.67	70 Yb	1.20×10^{-11}	−10.92	1.08
25 Mn	2.45×10^{-7}	−6.61	5.39	71 Lu	1.15×10^{-12}	−11.94	0.06
26 Fe	2.75×10^{-5}	−4.56	7.44	72 Hf	7.59×10^{-12}	−11.12	0.88
27 Co	8.32×10^{-8}	−7.08	4.92	74 W	1.29×10^{-11}	−10.89	1.11
28 Ni	1.78×10^{-6}	−5.75	6.25	76 Os	2.82×10^{-11}	−10.55	1.45
29 Cu	1.62×10^{-8}	−7.79	4.21	77 Ir	2.24×10^{-11}	−10.65	1.35
30 Zn	3.98×10^{-8}	−7.40	4.60	78 Pt	6.3×10^{-11}	−10.2	1.8
31 Ga	7.59×10^{-10}	−9.12	2.88	79 Au	1.02×10^{-11}	−10.99	1.01
32 Ge	2.57×10^{-9}	−8.59	3.41	80 Hg	$<1.0 \times 10^{-9}$	<−9.0	<3.0
37 Rb	3.98×10^{-10}	−9.40	2.60	81 Tl	7.9×10^{-12}	−11.1	0.9
38 Sr	9.33×10^{-10}	−9.03	2.97	82 Pb	8.91×10^{-11}	−10.05	1.95
39 Y	1.74×10^{-10}	−9.76	2.24	83 Bi	$<6.3 \times 10^{-12}$	<−11.2	<0.8
40 Zr	3.98×10^{-10}	−9.40	2.60	90 Th	1.32×10^{-12}	−11.88	0.12
41 Nb	2.63×10^{-11}	−10.58	1.42	92 U	$<3.4 \times 10^{-13}$	<−12.47	<−0.47

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1 H	1.00×10^{0}	0.00	12.00	42 Mo	8.32×10^{-11}	−1	
2 He	8.51×10^{-2}	−1.07	10.93	44 Ru	6.92×10^{-11}	−1	
3 Li	1.26×10^{-11}	−10.90	1.10	45 Rh	1.32×10^{-11}	−1	
4 Be	2.51×10^{-11}	−10.60	1.40	46 Pd	4.90×10^{-11}	−1	
5 B	3.55×10^{-10}	−9.45	2.55	47 Ag	8.71×10^{-12}	−1	
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9 F	4.0×10^{-8}	−7.44	4.56	51 Sb			
10 Ne	1.20×10^{-4}	−4.16	7.84	55 C			
11 Na	2.14×10^{-6}	−5.67	6.33	56 B			
12 Mg	3.80×10^{-5}	−4.42	7.58	57 L			
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18 Ar	2.51×10^{-6}	−5.82	6.18	64 G			
19 K	1.32×10^{-7}	−6.88	5.12	65 T			
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21 Sc	1.48×10^{-9}	−8.83	3.17	67 H			
22 Ti	1.05×10^{-7}	−6.98	5.02	68 E			
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24 Cr	4.68×10^{-7}	−6.33	5.67	70 Y			
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41 Nb	2.63×10^{-11}	−10.58	1.42	92 U	$<3.4\times10^{-13}$	<-12.47	<-0.47

The Chemical Composition of the Sun

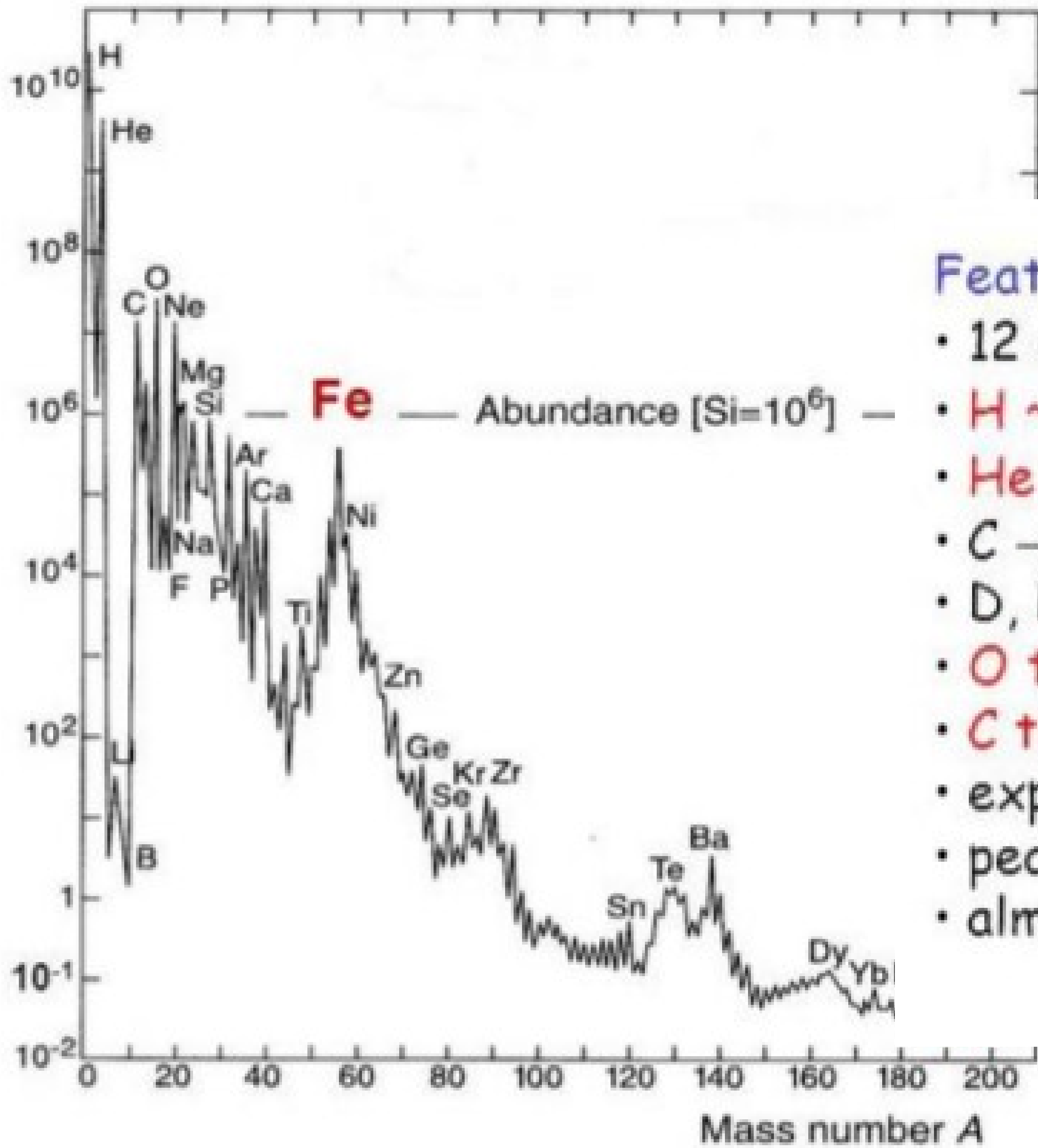
Annu. Rev. Astron. Astrophys. 2009. 47:481–522

Martin Asplund,[1] Nicolas Grevesse,[2] A. Jacques Sauval,[3] and Pat Scott[4]

Table 1 Element abundances in the present-day solar photosphere. Also given are the corresponding values for CI carbonaceous chondrites (Lodders, Palme & Gail 2009). Indirect photospheric estimates have been used for the noble gases (Section 3.9)

Z	Element	Photosphere	Meteorites	Z	Element	Photosphere	Meteorites
1	H	12.00	8.22 ± 0.04	44	Ru	1.75 ± 0.08	1.76 ± 0.03
2	He	[10.93 ± 0.01]	1.29	45	Rh	0.91 ± 0.10	1.06 ± 0.04
3	Li	1.05 ± 0.10	3.26 ± 0.05	46	Pd	1.57 ± 0.10	1.65 ± 0.02
4	Be	1.38 ± 0.09	1.30 ± 0.03	47	Ag	0.94 ± 0.10	1.20 ± 0.02
5	B	2.70 ± 0.20	2.79 ± 0.04	48	Cd		1.71 ± 0.03
6	C	8.43 ± 0.05	7.39 ± 0.04	49	In	0.80 ± 0.20	0.76 ± 0.03
7	N	7.83 ± 0.05	6.26 ± 0.06	50	Sn	2.04 ± 0.10	2.07 ± 0.06
8	O	8.69 ± 0.05	8.40 ± 0.04	51	Sb		1.01 ± 0.06
9	F	4.56 ± 0.30	4.42 ± 0.06	52	Te		2.18 ± 0.03
10	Ne	[7.93 ± 0.10]	−1.12	53	I		1.55 ± 0.08
11	Na	6.24 ± 0.04	6.27 ± 0.02	54	Xe	[2.24 ± 0.06]	−1.95
12	Mg	7.60 ± 0.04	7.53 ± 0.01	55	Cs		1.08 ± 0.02
13	Al	6.45 ± 0.03	6.43 ± 0.01	56	Ba	2.18 ± 0.09	2.18 ± 0.03
14	Si	7.51 ± 0.03	7.51 ± 0.01	57	La	1.10 ± 0.04	1.17 ± 0.02
15	P	5.41 ± 0.03	5.43 ± 0.04	58	Ce	1.58 ± 0.04	1.58 ± 0.02
16	S	7.12 ± 0.03	7.15 ± 0.02	59	Pr	0.72 ± 0.04	0.76 ± 0.03
17	Cl	5.50 ± 0.30	5.23 ± 0.06	60	Nd	1.42 ± 0.04	1.45 ± 0.02
18	Ar	[6.40 ± 0.13]	−0.50	62	Sm	0.96 ± 0.04	0.94 ± 0.02
19	K	5.03 ± 0.09	5.08 ± 0.02	63	Eu	0.52 ± 0.04	0.51 ± 0.02
20	Ca	6.34 ± 0.04	6.29 ± 0.02	64	Gd	1.07 ± 0.04	1.05 ± 0.02

Table 16.3. *The solar chemical composition.*



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Features:

- 12 orders-of-magnitude span
- H ~ 75%
- He ~ 23%
- C → U ~ 2% ("metals")
- D, Li, Be, B under-abundant
- O the third most abundant
- C the fourth most abundant
- exponential decrease up to Fe
- peak near Fe
- almost flat distribution beyond Fe

Element	Percentage by Number of Atoms	Percentage by Mass
Hydrogen	91.0	70.9
Helium	8.9	27.4
Carbon	0.03	0.3
Nitrogen	0.008	0.1
Oxygen	0.07	0.8
Neon	0.01	0.2
Magnesium	0.003	0.06
Silicon	0.003	0.07
Sulfur	0.002	0.04
Iron	0.003	0.1

164 SUN

Composition of outer layers (original composition)

Fractional mass	X (H)	$= 0.71$
	Y (He)	$= 0.265$
	Z (other elements)	$= 0.025$

Las atmósferas de las estrellas no están constituidas por H puro. Además He y los metales (todo elemento que no sea H o He).

~ por cada átomo de He hay 10 de H.

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164 SUN

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Pequeña cantidad de elementos pesados mezclados con el H y el He. En número de átomos la fracción de elementos pesados es ~ 10^{-3} por lo que su fracción en masa ~ 2% (Z = 0.02).

El resto corresponde al Y(He) = 0.28 y al X(H) = 0.70.

Population I, II, and III Stars

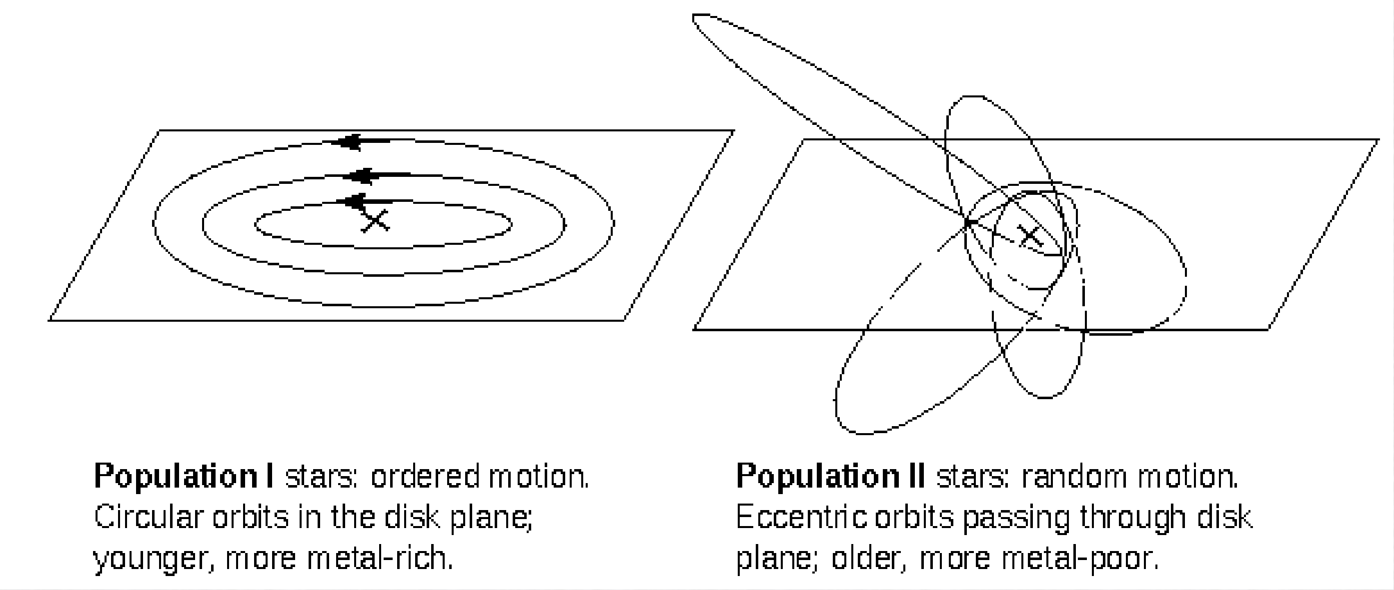
The universe began with the Big Bang 13.7 billion years ago. At that time hydrogen and helium were essentially the only elements produced by the nucleosynthesis that occurred during the initial fireball. Consequently, the first stars to form did so with virtually no metal content; $Z = 0$. The next generation of stars that formed were extremely **metal-poor**, having very low but non-zero values of Z. Each succeeding generation of star production resulted in higher and higher proportions of heavier elements, leading to metal-rich stars for which Z may reach values as high as 0.03. The (thus far hypothetical) original stars that formed immediately after the Big Bang are referred to as **Population III** stars, metal-poor stars with $Z \gtrsim 0$ are referred to as **Population II**, and metal-rich stars are called **Population I**.

The classifications of Population II and Population I are due originally to their identifications with kinematically distinct groups of stars within our Galaxy. Population I stars have velocities relative to the Sun that are low compared to Population II stars. Furthermore, Population I stars are found predominantly in the disk of the Milky Way, while Population II stars can be found well above or below the disk. It was only later that astronomers realized that these two groups of stars differed chemically as well. Not only do populations tell us something about evolution, but the kinematic characteristics, positions, and compositions of Population I and Population II stars also provide us with a great deal of information about the formation and evolution of the Milky Way Galaxy.

Poblaciones estelares (MW)

W. Baade (1944; Oort 1926) – "**Poblaciones Estelares**":

- **Población I:** movimientos orbitales ‘’organizados’’ es decir, órbitas circulares en el plano de la **Galaxia,** son jóvenes y ricas en metales.
- **Población II:** movimientos *random*, órbitas excéntricas que pasan por el plano de la **Galaxia**, son viejas y pobres en metales.

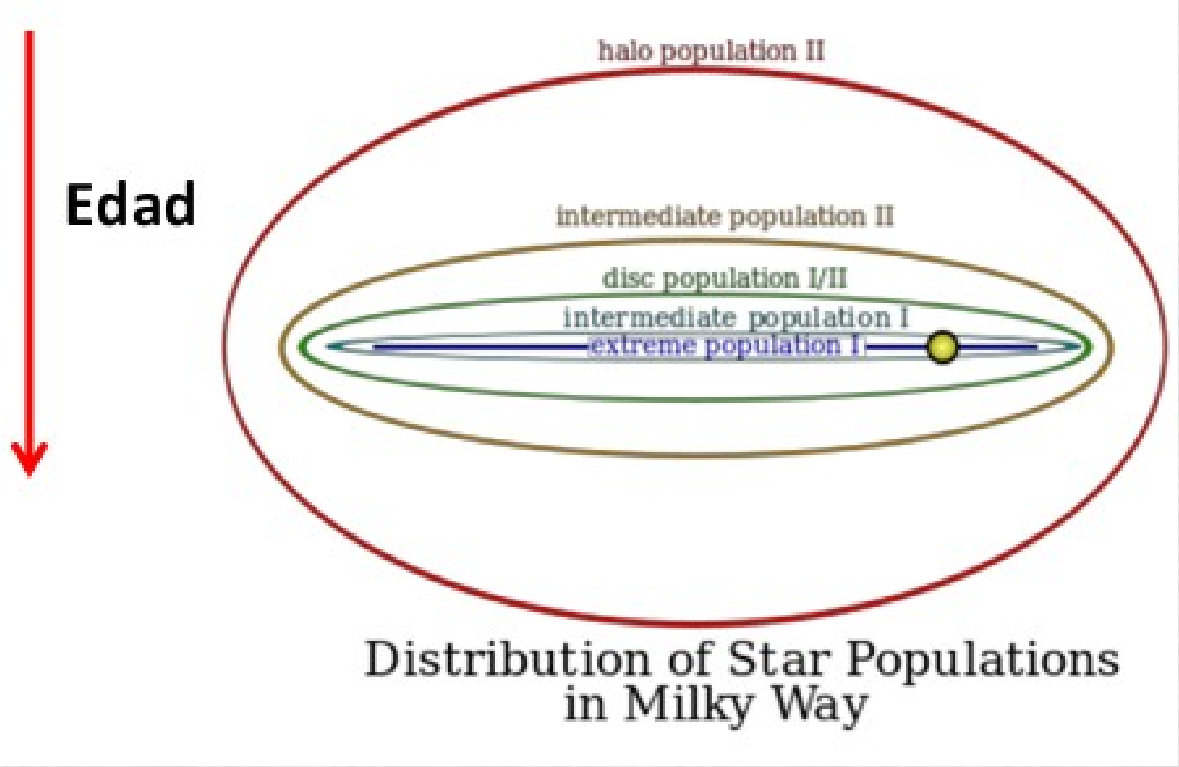


Propiedades	Población I	Población II
Diagrama HR	Cúmulos Galácticos	Cúmulos Globulares
Localización	Disco	Halo
Velocidades	Bajas	Altas
Órbitas	Planas y circulares	Inclinadas y excéntricas
Material Interestelar	Asociada	No asociada
Edad	Joven	Vieja
Metalicidad	Alta	Baja

Poblaciones estelares (MW)

- Oort (1958): otras poblaciones estelares:

Poblaciones
Población I Extrema
Población I Intermedia
Población I/II del Disco
Población II Intermedia
Población II del Halo



The Age–Metallicity Relation

The thin and thick disks not only are identifiable by separate scale heights and stellar number densities but are further distinguished by the chemical compositions and kinematic properties of their members. We will discuss composition effects now but will delay our discussion of kinematics until the next section.

As we noted in Section 13.3, stars are generally classified according to the relative abundance of heavier elements; Population I stars are metal-rich, with $Z \sim 0.02$, Population II stars are metal-poor, with $Z \sim 0.001$, and Population III stars are essentially devoid of metals, with $Z \sim 0$. In reality, a wide range of metallicities exists in stars. At one end are the extreme Population I stars, and on the other, the hypothetical Population III stars (if they still exist). Between Population I and Population II stars are the **intermediate** (or, alternatively and suggestively, **disk**) population stars.

Stars with abundances identical to the Sun's have [Fe/H] $= 0.0$, less-metal-rich stars have negative values, and more-metal-rich stars have positive values. Values ranging from -5.4 for old, extremely metal-poor stars to about 0.6 for young, extremely metal-rich stars have been measured in our Galaxy. According to studies of the main-sequence turn-off points in clusters (both globular and galactic), metal-rich stars tend to be younger than metal-poor ones of similar spectral type. The apparent correlation between age and composition is referred to as the **age–metallicity relation**.

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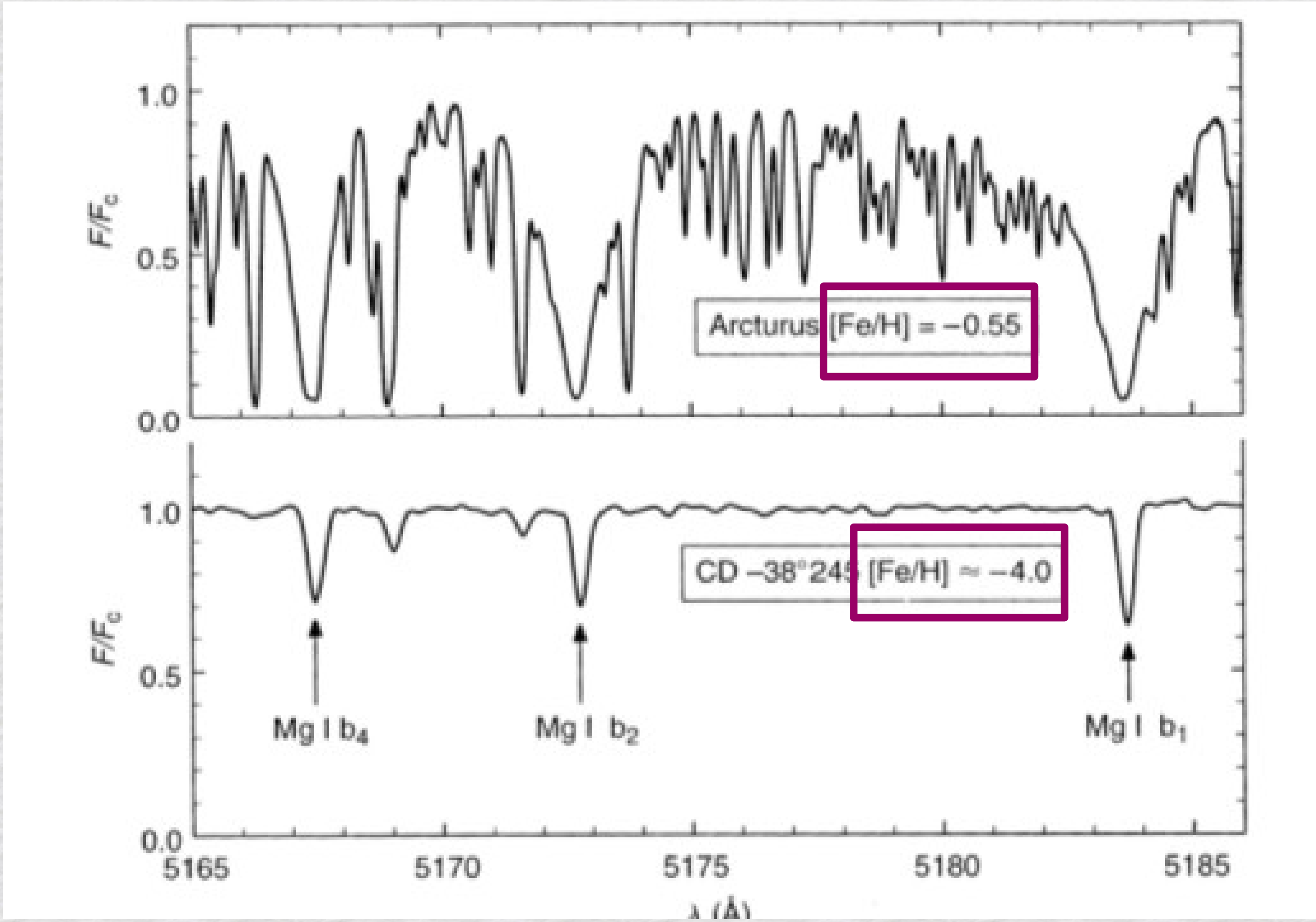

$$[\mathrm{Fe/H}] \equiv \log_{10}\left[\frac{(N_{\mathrm{Fe}}/N_{\mathrm{H}})_{\mathrm{star}}}{(N_{\mathrm{Fe}}/N_{\mathrm{H}})_{\odot}}\right],$$

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Metal-poor Stars

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Abstract. The abundance patterns of metal-poor stars provide a wealth of chemical information about various stages of the chemical evolution of the Galaxy. In particular, these stars allow us to study the formation and evolution of the elements and the involved nucleosynthetic processes. This knowledge is invaluable for our understanding of cosmic chemical evolution and the onset of star- and galaxy formation. Metal-poor stars are the local equivalent of the high-redshift Universe, and offer crucial observational constraints on the nature of the first stars. This review presents the history of the first discoveries of metal-poor stars that laid the foundation to this field. Observed abundance trends at the lowest metallicities are described, as well as particular classes of metal-poor stars such as r-process and C-rich stars. Scenarios on the origins of the abundances of metal-poor stars and the application of large samples of metal-poor stars to cosmological questions are discussed.

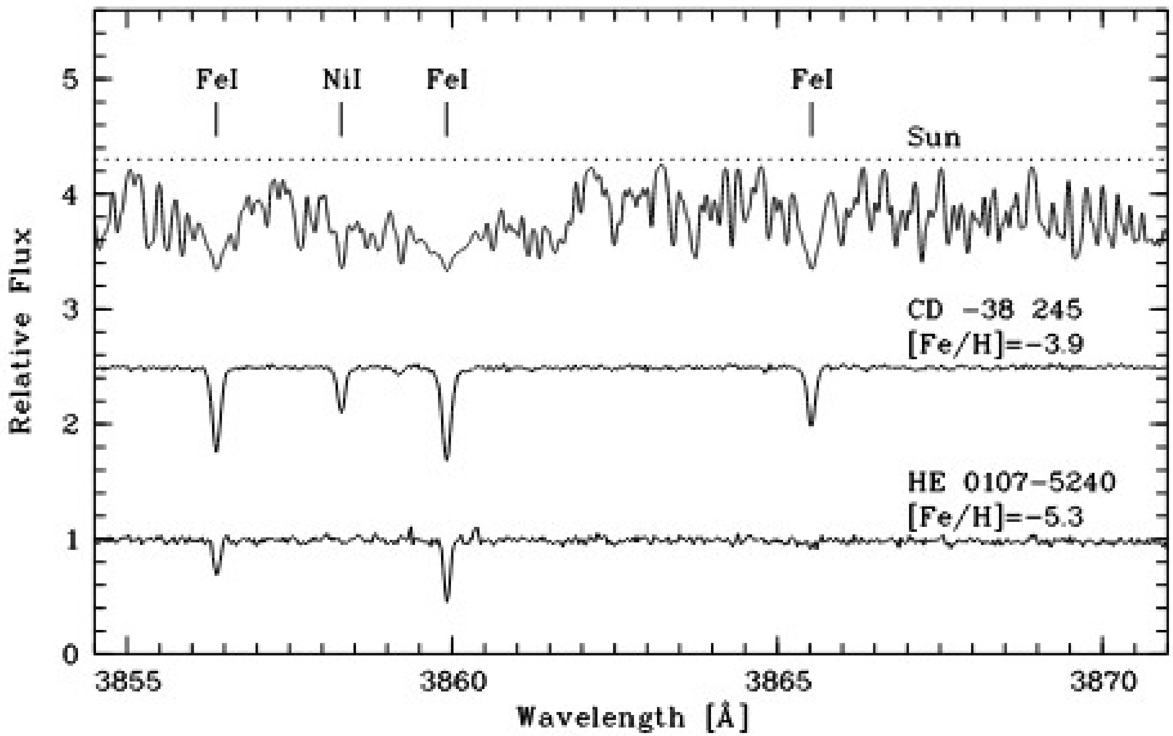

Figure 1. Spectral comparison of the Sun with the metal-poor stars CD −38° 245 and HE 0107−5240. Figure taken from Christlieb et al. (2004).

$$\boxed{[\mathrm{Fe/H}] \equiv \log_{10}\left[\frac{(N_{\mathrm{Fe}}/N_{\mathrm{H}})_{\mathrm{star}}}{(N_{\mathrm{Fe}}/N_{\mathrm{H}})_{\odot}}\right],}$$

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The lowest detected stellar Fe abundance: the halo star SMSS J160540.18−144323.1

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ABSTRACT
We report the discovery of SMSS J160540.18−144323.1, a new ultra-metal poor halo star discovered with the SkyMapper telescope. We measure [Fe/H] = −6.2 ± 0.2 (1D LTE), the lowest ever detected abundance of iron in a star. The star is strongly carbon-enhanced, [C/Fe] = 3.9 ± 0.2, while other abundances are compatible with an α-enhanced solar-like pattern with [Ca/Fe] = 0.4 ± 0.2, [Mg/Fe] = 0.6 ± 0.2, [Ti/Fe] = 0.8 ± 0.2, and no significant s- or r-process enrichment, [Sr/Fe] < 0.2 and [Ba/Fe] < 1.0 (3σ limits). Population III stars exploding as fallback supernovae may explain both the strong carbon enhancement and the apparent lack of enhancement of odd-Z and neutron-capture element abundances. Grids of supernova models computed for metal-free progenitor stars yield good matches for stars of about 10 $M_\odot$ imparting a low kinetic energy on the supernova ejecta, while models for stars more massive than roughly 20 $M_\odot$ are incompatible with the observed abundance pattern.

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The lowest detected stellar Fe abundance: the halo star SMSS J160540.18−144323.1

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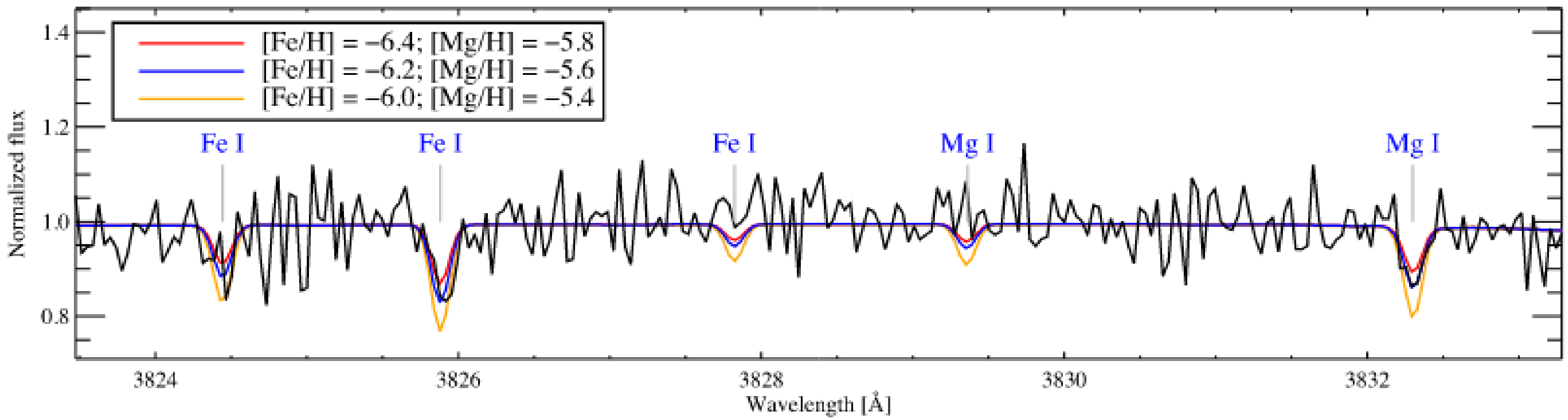

Figure 1. *Upper panel*: Fit of the effective temperature to the first three Balmer lines (labelled) in the MIKE high-resolution spectrum, compared to models at the preferred $T_{\rm eff} = 4850$ K. The lines are shown on a velocity scale centred on each line, and have been offset vertically. The grey shaded blocks represent the wavelength ranges used in the χ^2 minimization. *Middle panel*: Fit of the surface gravity to the WiFeS medium-resolution spectrophotometry, with a zoomed inset showing the Balmer jump region, at the preferred $\log g = 2.0$. *Lower panel*: Example fits to lines of Fe and Mg in the MIKE high-resolution spectrum. In all panels additional models illustrate the sensitivity, and the legend lists the models as shown from top to bottom.

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EVIDENCE FOR PopIII-LIKE STELLAR POPULATIONS IN THE MOST LUMINOUS Lyα EMITTERS AT THE EPOCH OF REIONIZATION: SPECTROSCOPIC CONFIRMATION*

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ABSTRACT

Faint Lyα emitters become increasingly rarer toward the reionization epoch ($z \sim 6$–7). However, observations from a very large ($\sim$5 deg^2) Lyα narrow-band survey at $z = 6.6$ show that this is not the case for the most luminous emitters, capable of ionizing their own local bubbles. Here we present follow-up observations of the two most luminous Lyα candidates in the COSMOS field: "MASOSA" and "CR7." We used X-SHOOTER, SINFONI, and FORS2 on the Very Large Telescope, and DEIMOS on Keck, to confirm both candidates beyond any doubt. We find redshifts of $z = 6.541$ and $z = 6.604$ for "MASOSA" and "CR7," respectively. MASOSA has a strong detection in Lyα with a line width of 386 ± 30 km s^{-1} (FWHM) and with very high EW$_0$ (>200 Å), but undetected in the continuum, implying very low stellar mass and a likely young, metal-poor stellar population. "CR7," with an observed Lyα luminosity of $10^{43.92\pm0.05}$ erg s^{-1} is the most luminous Lyα emitter ever found at $z > 6$ and is spatially extended ($\sim$16 kpc). "CR7" reveals a narrow Lyα line with 266 ± 15 km s^{-1} FWHM, being detected in the near-infrared (NIR) (rest-frame UV; $\beta = -2.3 \pm 0.1$) and in IRAC/*Spitzer*. We detect a narrow He II 1640 Å emission line (6σ, FWHM $= 130 \pm 30$ km s^{-1}) in CR7 which can explain the clear excess seen in the *J*-band photometry (EW$_0 \sim 80$ Å). We find no other emission lines from the UV to the NIR in our X-SHOOTER spectra (He II/O III] 1663 Å > 3 and He II/C III] 1908 Å > 2.5). We conclude that CR7 is best explained by a combination of a PopIII-like population, which dominates the rest-frame UV and the nebular emission, and a more normal stellar population, which presumably dominates the mass. *Hubble Space Telescope*/WFC3 observations show that the light is indeed spatially separated between a very blue component, coincident with Lyα and He II emission, and two red components ($\sim$5 kpc away), which dominate the mass. Our findings are consistent with theoretical predictions of a PopIII wave, with PopIII star formation migrating away from the original sites of star formation.

Poblaciones estelares

- Las estrellas de Población I: “metalicidades” entre 0.5 y 2 veces la Solar.
- Las estrellas de Población II: “metalicidades” entre 0.1 y 0.001 de la Solar.

Poblaciones estelares

- Las estrellas de Población I: “metalicidades” entre 0.5 y 2 veces la Solar.
- Los elementos pesados de las estrellas de Población I → creados por anteriores generaciones de estrellas y diseminados en el medio interestelar por SN.
- El Sol es de Población I.
- Son comunes en los brazos espirales de la VL y de cualquier otra galaxia espiral.

Poblaciones estelares

- Las estrellas de Población II: “metalicidades” entre 0.1 y 0.001 de la Solar.
- Las estrellas de Población II pertenecen a las primeras generaciones de estrellas → la mayoría con poca abundancia de metales.
- Las estrellas de población II se encuentran en cúmulos globulares y en el núcleo de la VL.

Poblaciones estelares

- Población III (?). Después del Big Bang, el Universo era completamente de H y He (tal vez alguna traza de Li y Be). No contienen material ‘’reciclado’’ (es decir elementos pesados) en el interior de las estrellas.
- PIII: estrellas muy masivas (60-300 M_Sol) → evolucionan muy rápido (~ 1 Myr).
- Las estrellas de Población III → probablemente se transformaron en remanentes estelares muy difíciles de detectar.