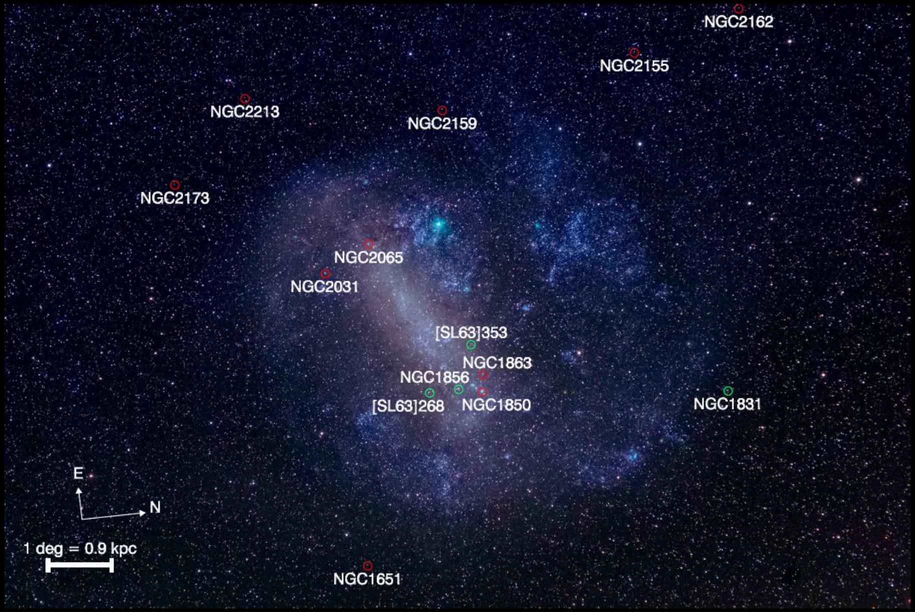
Chemical History of Galaxies



Dr. Randa Asa'd
American University of Sharjah

Before we start professionally .. I will share a personal secret:

Randa Asa'd is at **Cetatea Fagarasului.**

Aug 27, 2021 · Fagaras, Romania ·

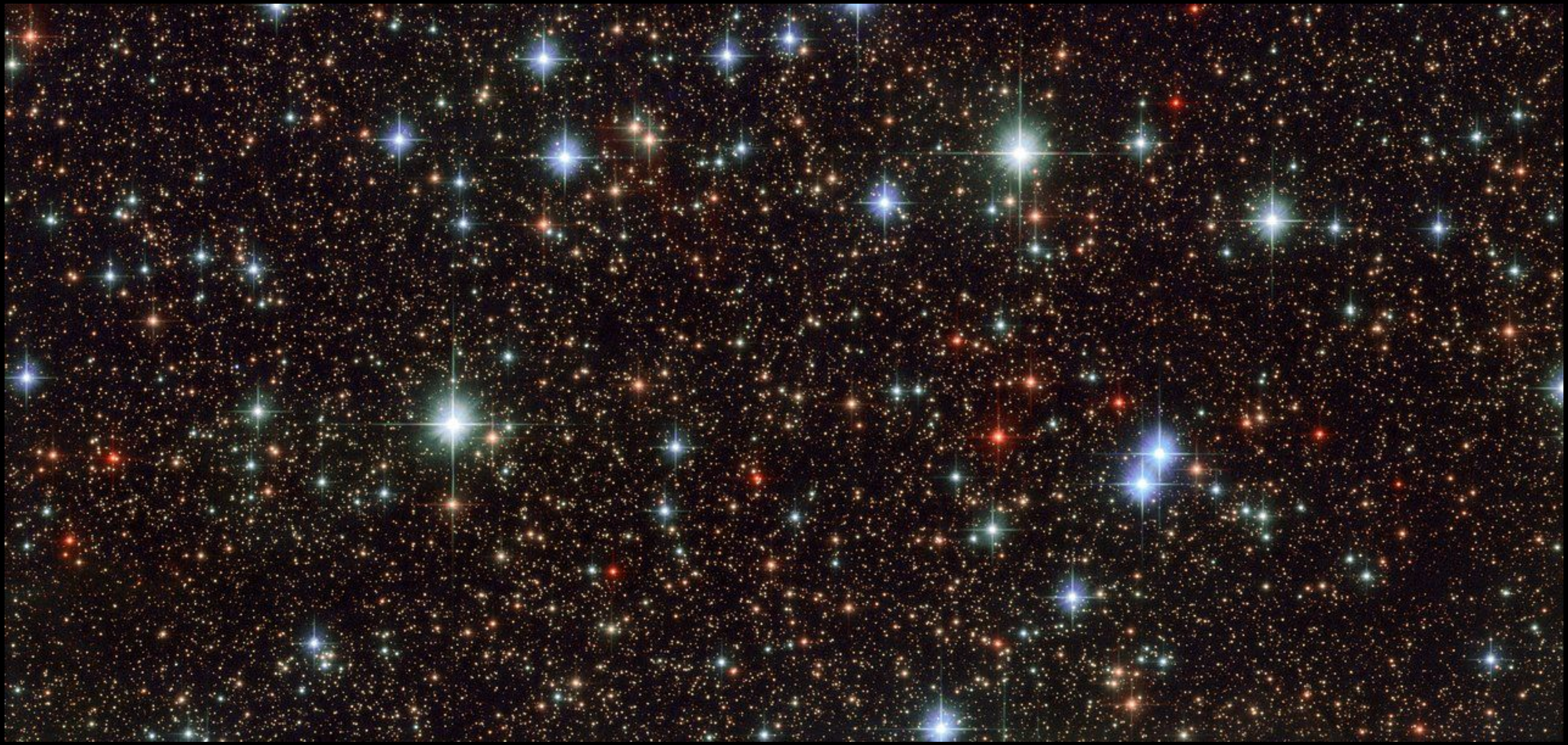
Am călătorit in 6 continente, dar orașul copilăriei (Făgăraș) va rămâne întodeauna orașul meu cel mai drag.

What do we know about the chemical composition of the universe?

- It all started with the Big Bang …
- The first generation of stars had a composition of 75% H, 25% He and $< 10^{-8}$ Li, Be, B
- The current composition of the galaxies is 75% H, 23% He and 2% for all the remaining elements.

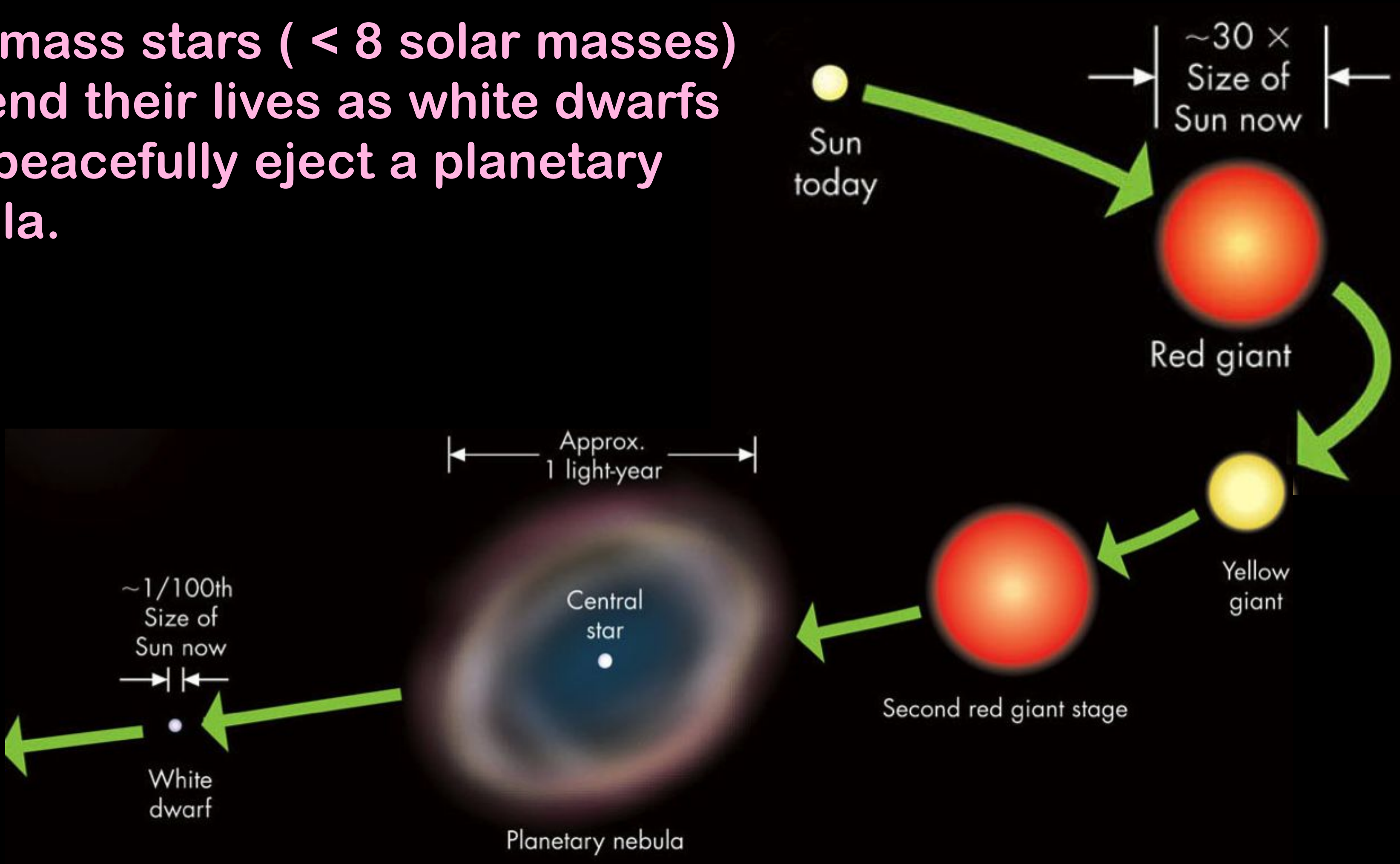
- What caused this change in the chemical composition?
- Where did the new elements come from?

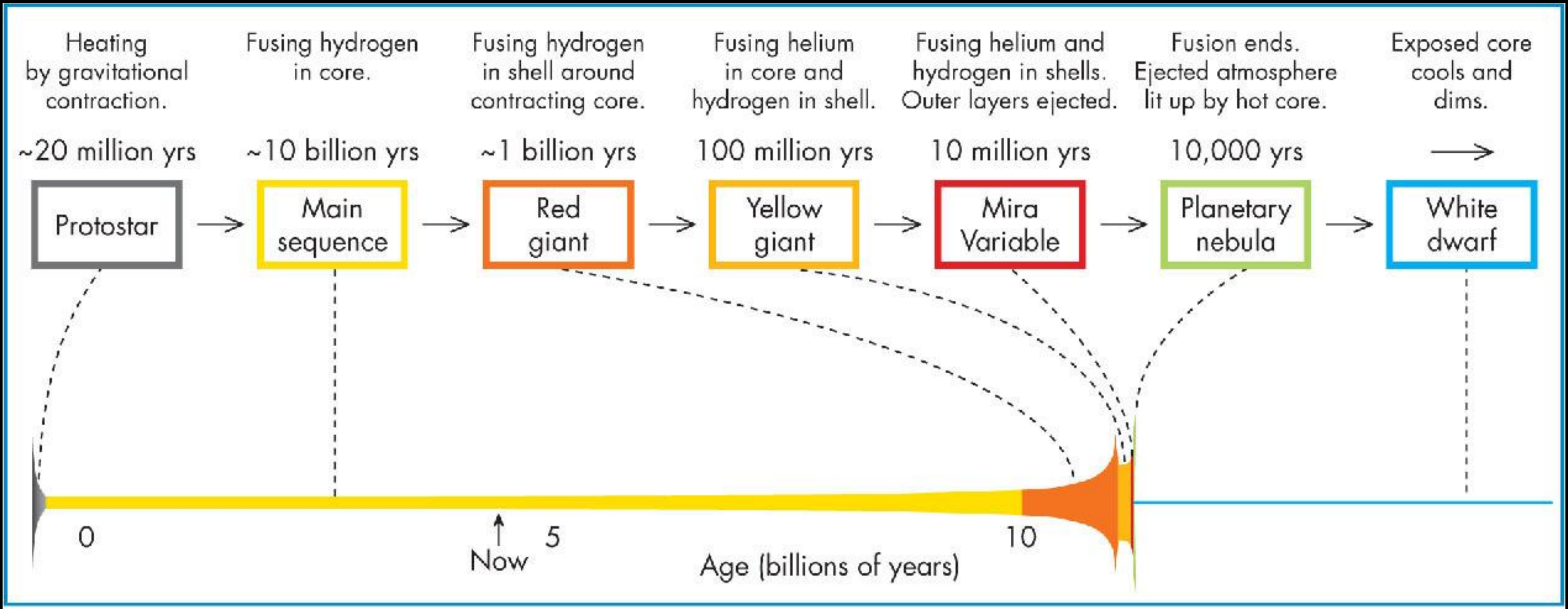
Answer: Stars



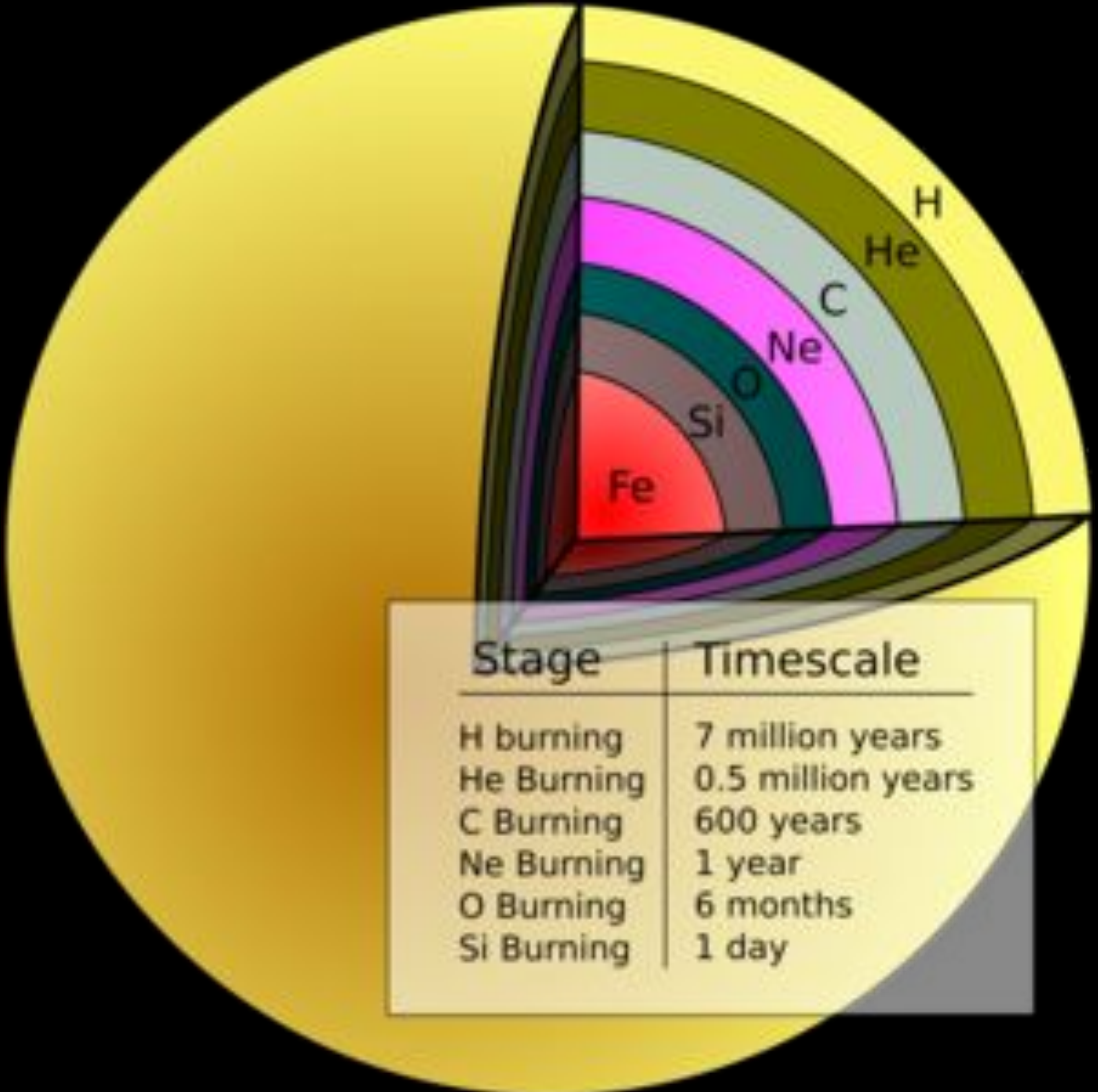
Stars of different masses will enrich the interstellar medium with different elements:

- Low mass stars (< 8 solar masses) will end their lives as white dwarfs and peacefully eject a planetary nebula.

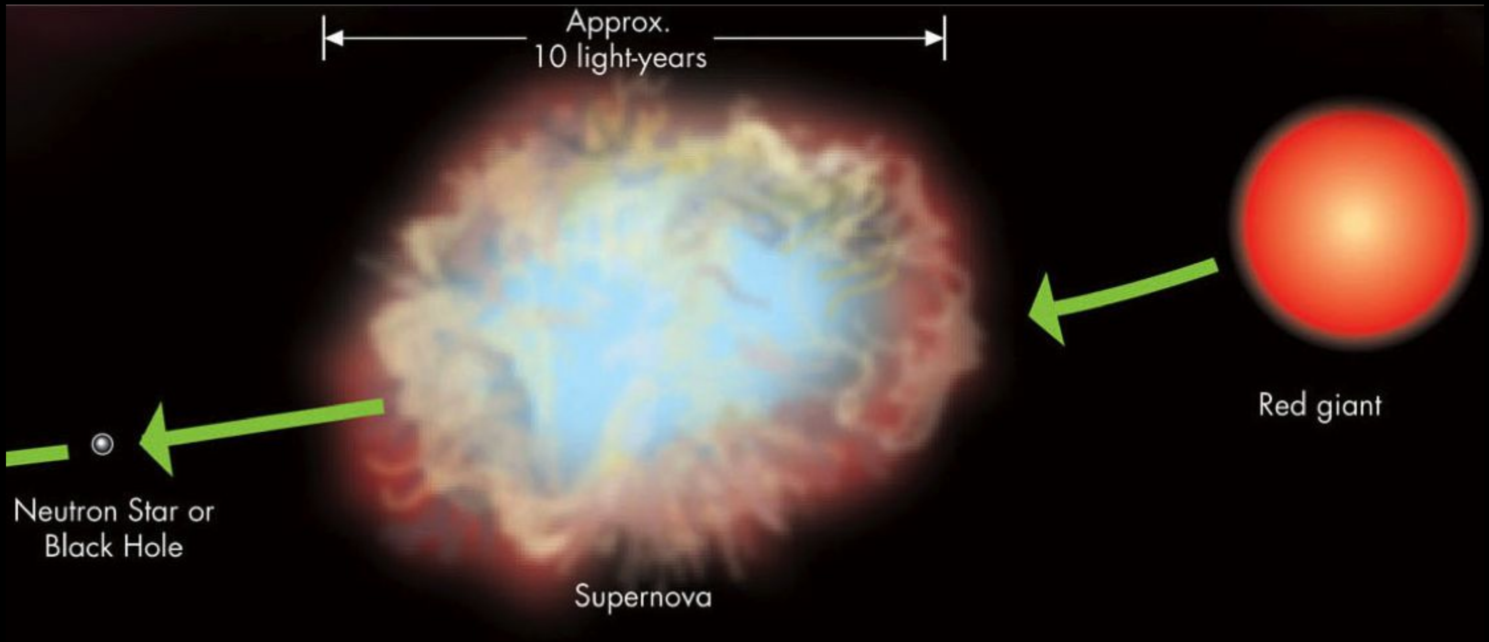



Heating by gravitational contraction.
~20 million yrs
Protostar
Fusing hydrogen in core.
~10 billion yrs
Main sequence
Fusing hydrogen in shell around contracting core.
~1 billion yrs
Red giant
Fusing helium in core and hydrogen in shell.
100 million yrs
Yellow giant
Fusing helium and hydrogen in shells. Outer layers ejected.
10 million yrs
Mira Variable
Fusion ends. Ejected atmosphere lit up by hot core.
10,000 yrs
Planetary nebula
Exposed core cools and dims.
White dwarf
0
5
10
Now
Age (billions of years)

High mass stars:



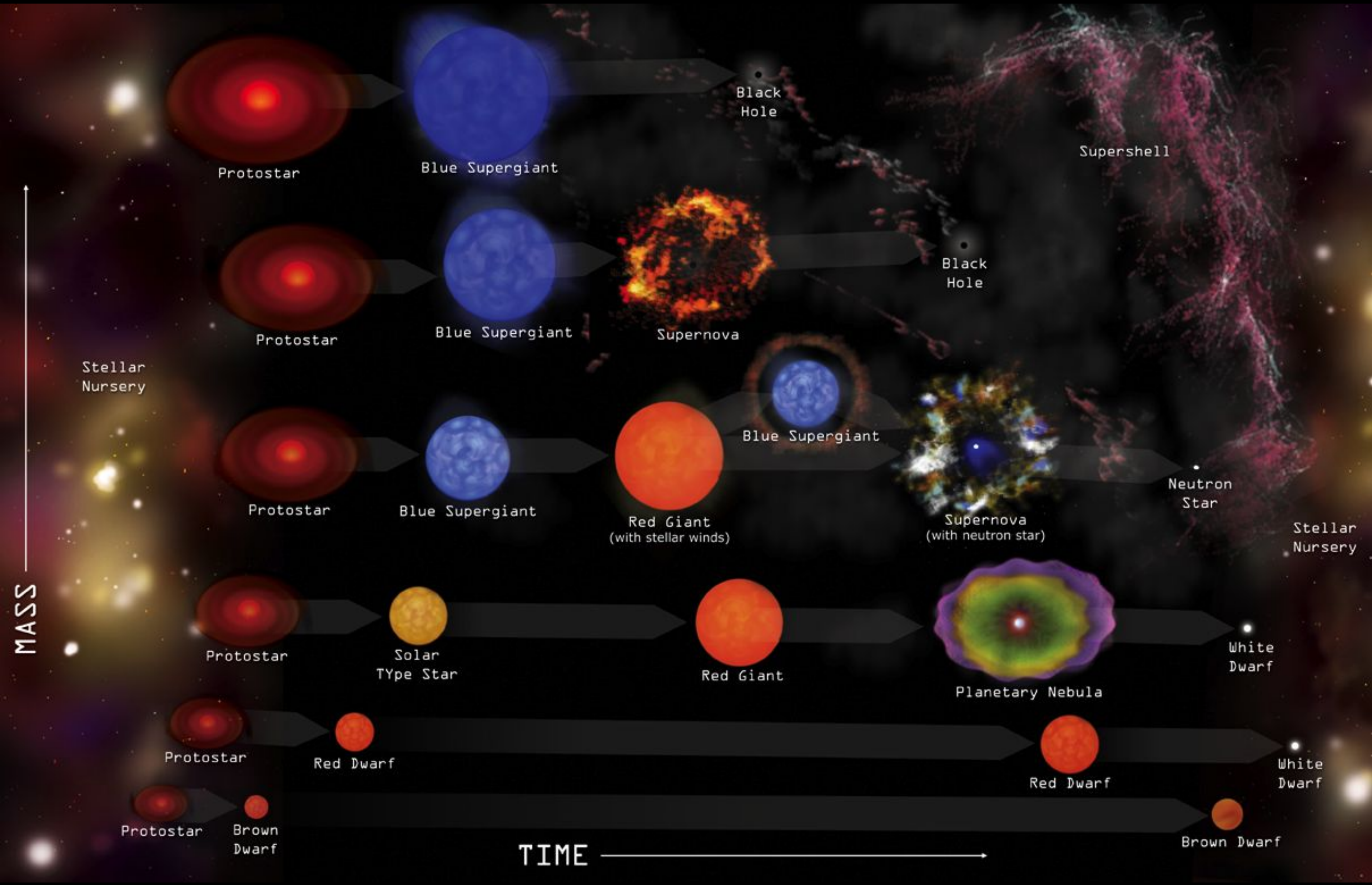
Stage	Timescale
H burning	7 million years
He Burning	0.5 million years
C Burning	600 years
Ne Burning	1 year
O Burning	6 months
Si Burning	1 day



- High mass stars (> 8 solar masses) will explode in supernovae leaving behind a neutron star or black hole.

$8 < M_o < 20$ becomes a neutron star

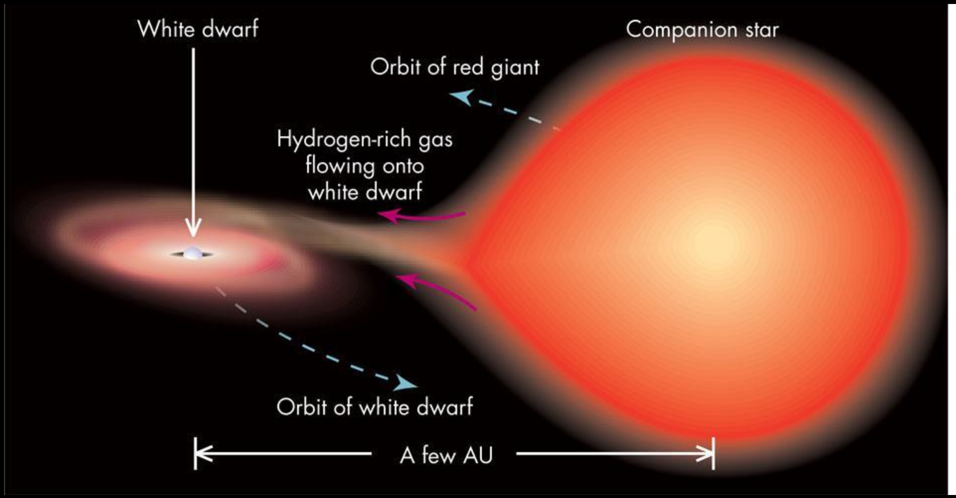
$M_o > 20$ becomes a black hole.



As a result, the new stars are chemically enriched.

Another type of supernovae - white dwarfs in Binary Systems

- Type Ia supernova
- The white dwarf collapses, igniting carbon and oxygen.

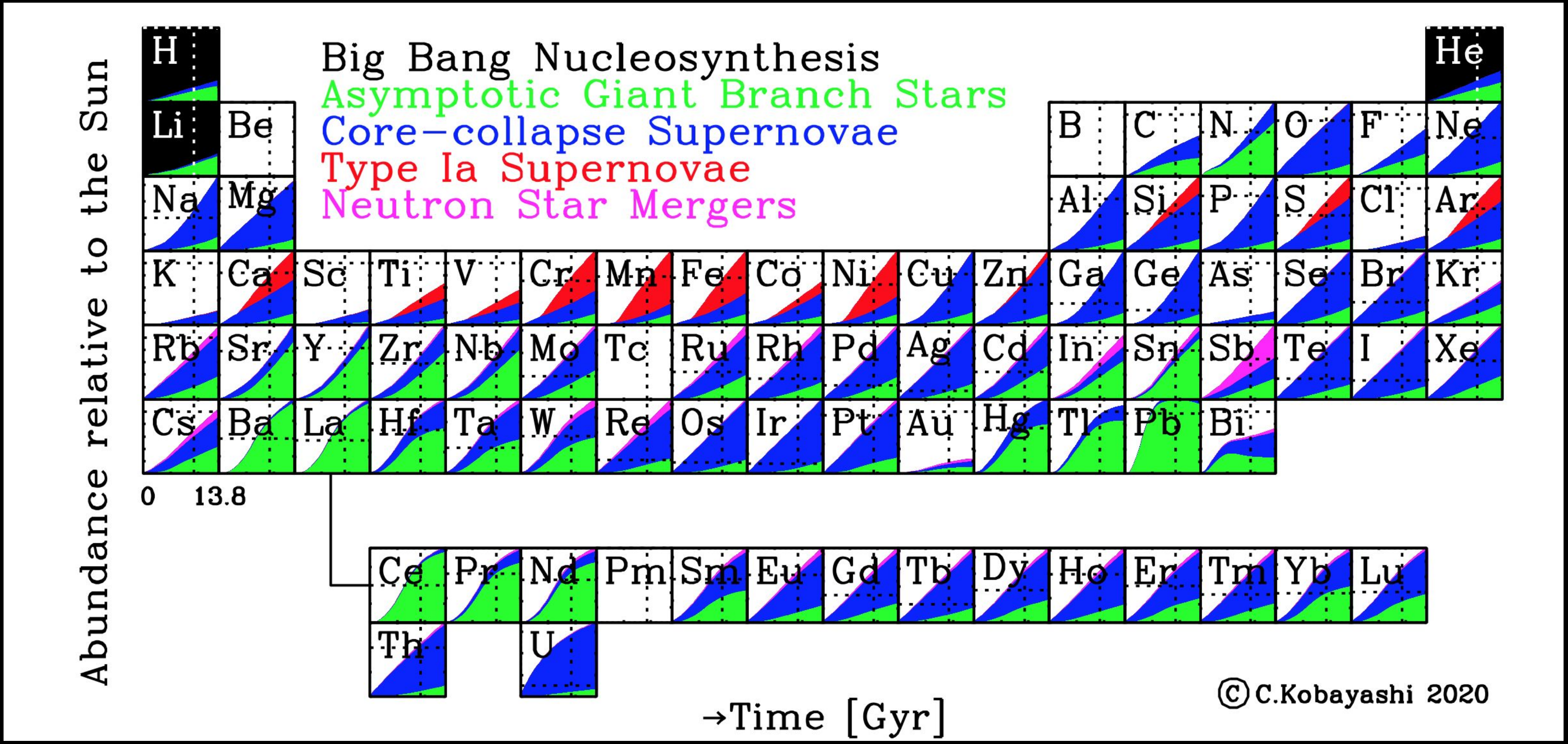


Stellar Lifetimes

- A core collapse supernova would occur one billion years before the type Ia supernova.

This means that the chemical enrichment with α- elements (like Ne, Mg, Si, S, Ar, Ca.. etc) is not at the same time as iron.

What the models tell us:



Metallicity:

- x = mass fraction of H
- y = mass fraction of He
- z = mass fraction of all remaining elements (metallicity)

x + y + z =1

- The abundance ratio is defined as the logarithm of the ratio of a star's iron abundance compared to that of the Sun.

$$[\mathrm{Fe/H}] = \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\mathrm{star}} - \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\mathrm{sun}}$$

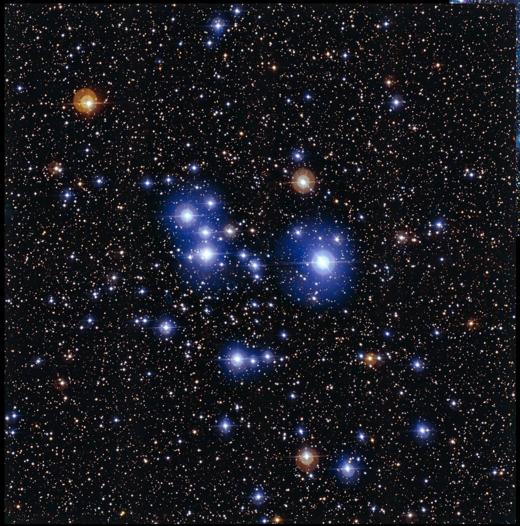
- Stars with a higher metallicity than the Sun have a positive logarithmic value, whereas those with a lower metallicity than the Sun have a negative value

Chemical history requires knowing :

Chemical Composition + Age

This is done by studying Star Cluster






There are two ways:

A. Using resolved data
B. Using Integrated Spectra

A. Analyzing individual stars in the cluster
B. Integrated light

ESO headquarters -Germany

The Astrophysical Journal, 900:138 (7pp), 2020 September 10
https://doi.org/10.3847/1538-4357/aba439

CrossMark

Analysis of Red Supergiants in VDBH 222

Randa Asa'd[1], M. Kovalev[2], B. Davies[3], V. D. Ivanov[4], M. Rejkuba[4], A. Gonneau[5], S. Hernandez[6], C. Lardo[7], and M. Bergemann[2]
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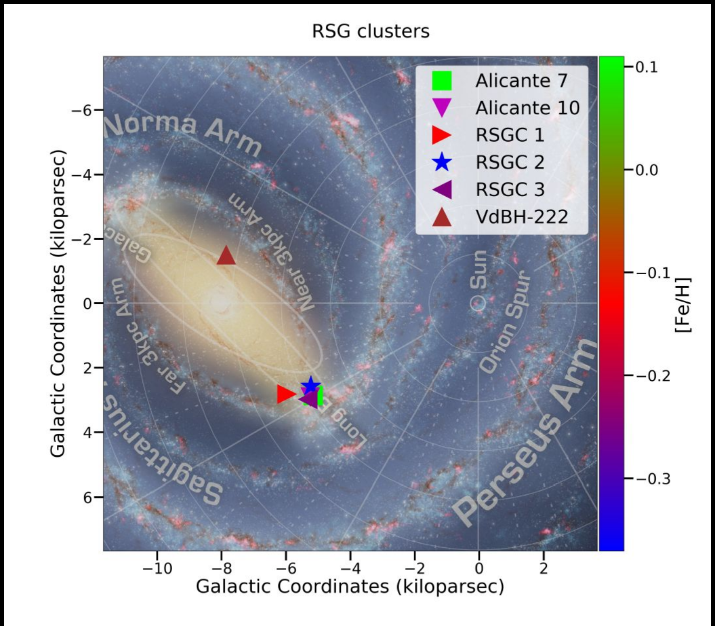
Received 2020 May 12; revised 2020 June 25; accepted 2020 June 26; published 2020 September 9

The space between stars is not empty: it contains interstellar matter composed of gas and dust.

Because of high distance and the dust, clusters near the center of the galaxy can only be identified by the presence of very bright red supergiants.

RSGs as metallicity indicators

- They are evolved stars (left the main sequence).
- With Masses between 10 to 30 $M_{\odot}$.
- The largest stars in the universe (size).
- Young < 50 Myr - short lifetime

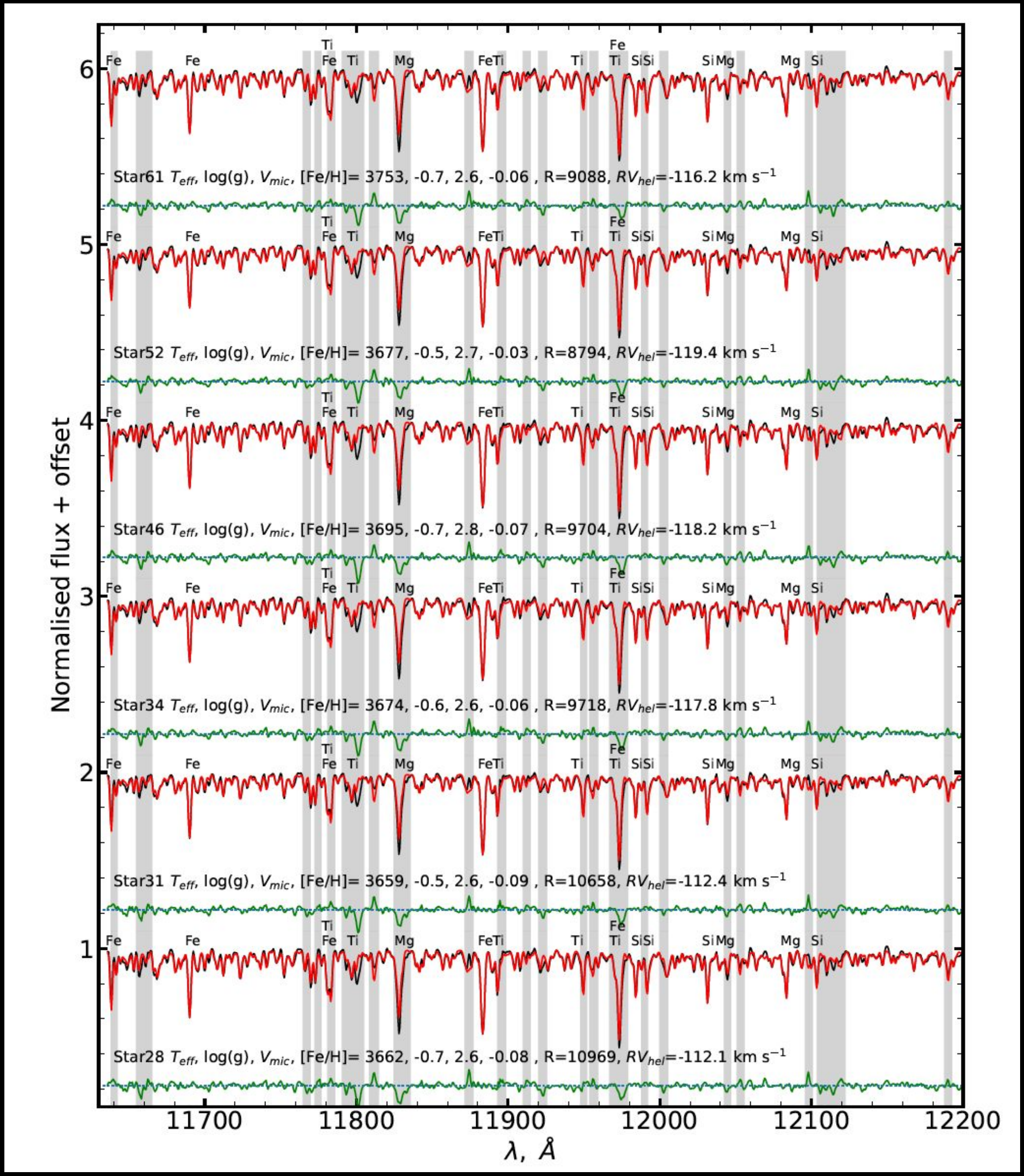


Based on our
VLT-Xshooter data
(PI: R. Asa'd)

We present the first
[Fe/H] measurement
for VdBH 222

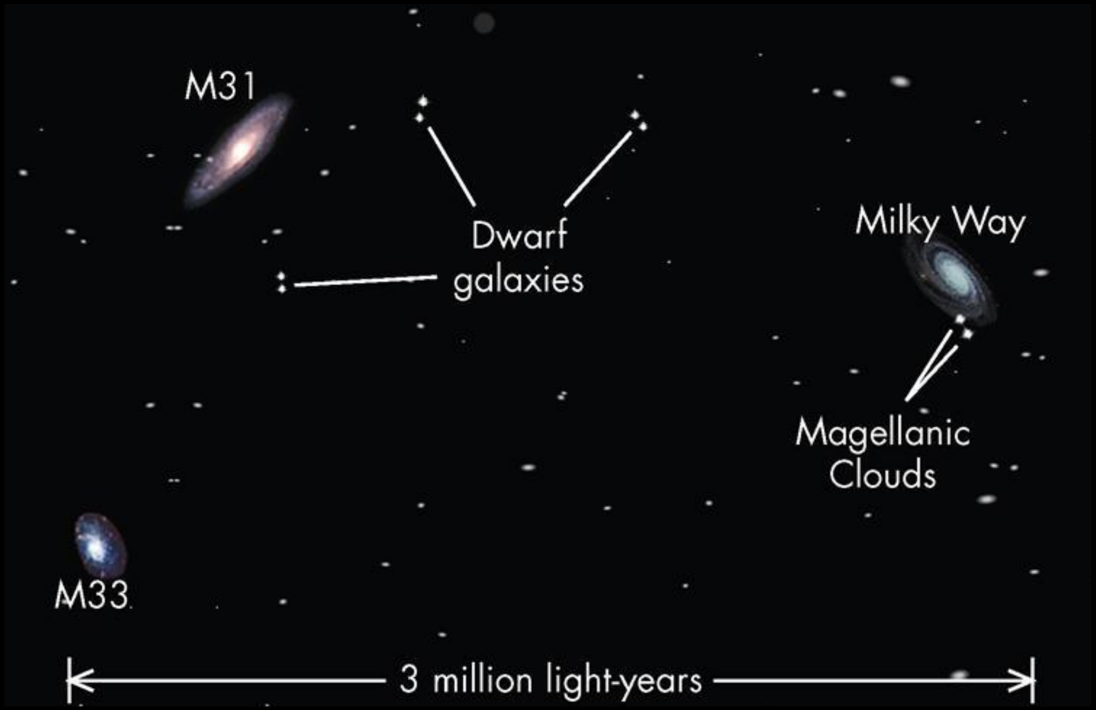
[Fe/H] = -0.07+/-0.02
Age = 16 Myr

Asa'd et al. (2020)



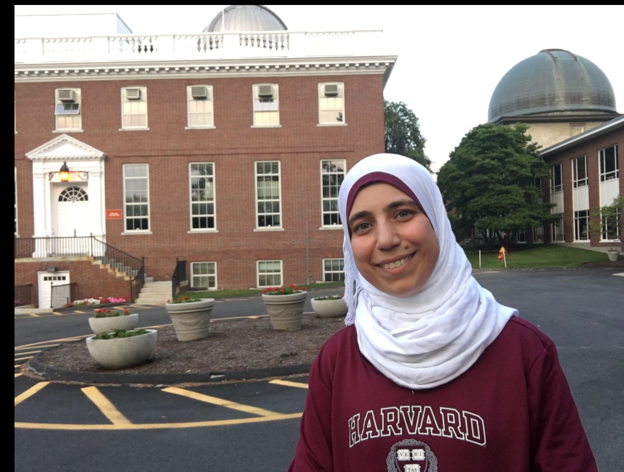
But how about galaxies for which we can't get the resolved data?

We need to rely on integrated light..



A. Analyzing individual stars in the cluster
B. Integrated light

Harvard-Smithsonian Center for Astrophysics (CfA)



The Astrophysical Journal, 858:63 (9pp), 2018 May 1 https://doi.org/10.3847/1538-4357/aaba77

CrossMark

Using Star Clusters as Tracers of Star Formation and Chemical Evolution: The Chemical Enrichment History of the Large Magellanic Cloud*

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Received 2017 August 19; revised 2018 March 10; accepted 2018 March 14; published 2018 May 4

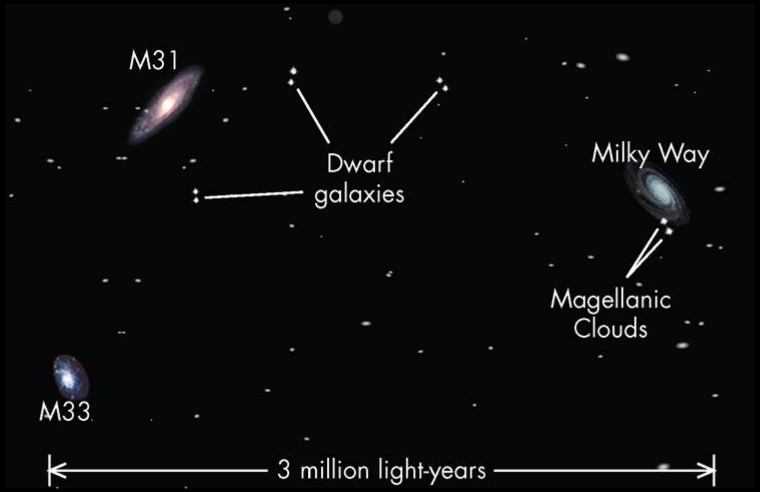
Abstract

The star formation (SFH) and chemical enrichment (CEH) histories of Local Group galaxies are traditionally studied by analyzing their resolved stellar populations in a form of color–magnitude diagrams obtained with the *Hubble Space Telescope*. Star clusters can be studied in integrated light using ground-based telescopes to much larger distances. They represent snapshots of the chemical evolution of their host galaxy at different ages. Here we

Large Magellanic Cloud Galaxy

- It is a good laboratory to get resolved clusters as well as integrated spectra and photometry.

- Has about 1200 clusters – with a well-mixed stellar populations unlike our Galaxy.



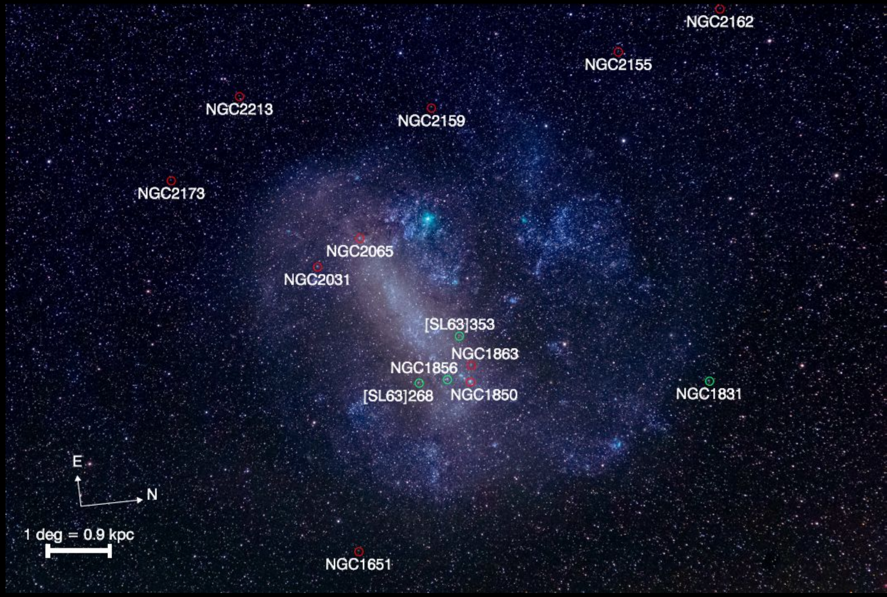
Data: Our Observed Sample

- 11 clusters observed with the 4 m SOAR telescope (Goodman Spectrograph).

P.I: Asa'd

- 4 clusters observed with the 6.5 m Magellan Baade telescope (MagE spectrograph)

P.I: Chilingarian

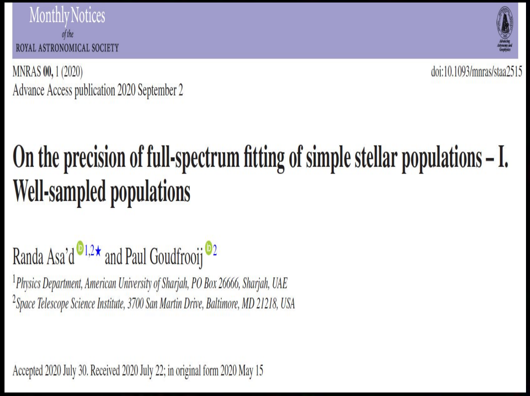


ASTRONOMER

What my friends think I do

What my mom thinks I do

What society thinks I do



Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS 00, 1 (2020) doi:10.1093/mnras/staa2515
Advance Access publication 2020 September 2

On the precision of full-spectrum fitting of simple stellar populations – I. Well-sampled populations

Randa Asa'd[1,2★] and Paul Goudfrooij[2]

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Accepted 2020 July 30. Received 2020 July 22; in original form 2020 May 15

What the university thinks I do

What I think I do

```
cl_names=['eso121_3','lindsay1','ngc0256','ngc0290','ngc0299',$
          'ngc0330','ngc0376','ngc0411','ngc0416','ngc0643',$
          'ngc1696','ngc1718','ngc1755','ngc1805','ngc1806',$
          'ngc1810','ngc1818','ngc1831','ngc1834','ngc1844',$
          'ngc1846','ngc1847','ngc1872','ngc1978','ngc2058',$
           'ngc2121','ngc2155','ngc2157','ngc2160','ngc2164',$
          'ngc2203','ngc2209','ngc2213','ngc2214','sl385',$
           'sl387','sl495','sl505']


; vsys_all = radial velocity (shift by 200 km/s (similar to LMC radial velocity))
; fltarr means array of floats.
; (n_elements(cl_names)) is an empty array (all zeros)
vsys_all=200.0+fltarr(n_elements(cl_names))

; age estimation from CMD
ages_all=[3162.,1259.,126.,32.,32.,$
          6.,32.,1000.,1585.,794.,$
          794., 1259.,32.,8.,1259.,$
          32., 6., 398., 40.,126.,$
          1259., 32.,158.,1259.,126.,$
          3162., 1259., 126., 32.,32.,$
          1259., 794., 1585.,32.,215.,$
          794., 32., 1585.$
          ]

ages_cmd_new=ages_all

; Note: in the below there are boolean sets of 5 to look organized, as per the list of clusters above.

; emission lines:
; Those are identified by looking at the residual spectra one by one. For obtaining the residual spectra, we first run this code using 1 in the emission
eml_all=[0,0,0,0,1,   1,1,0,0,0,   0,1,0,1,0,   1,1,0,1,0,   0,0,1,0,0,   0,0,0,0,0,   0,0,0,0,0,   0,1,0]

; This means ages should not be fixed (0 means varying, 1 means fixed).
fix_age=[0,0,0,0,0,   0,0,0,0,0,   0,0,0,0,0,   0,0,0,0,0,   0,0,0,0,0,   0,0,0,0,0,   0,0,0,0,0,   0,0,0]


; This means some sigma should be fixed (sigma is the internal velocity dispersion)
; We can't measure velocity dispersion with these spectra, the line broadening in young clusters is likely due to stellar rotation.
```

What I really do

Using Nburst* to obtain the age and metallicity:

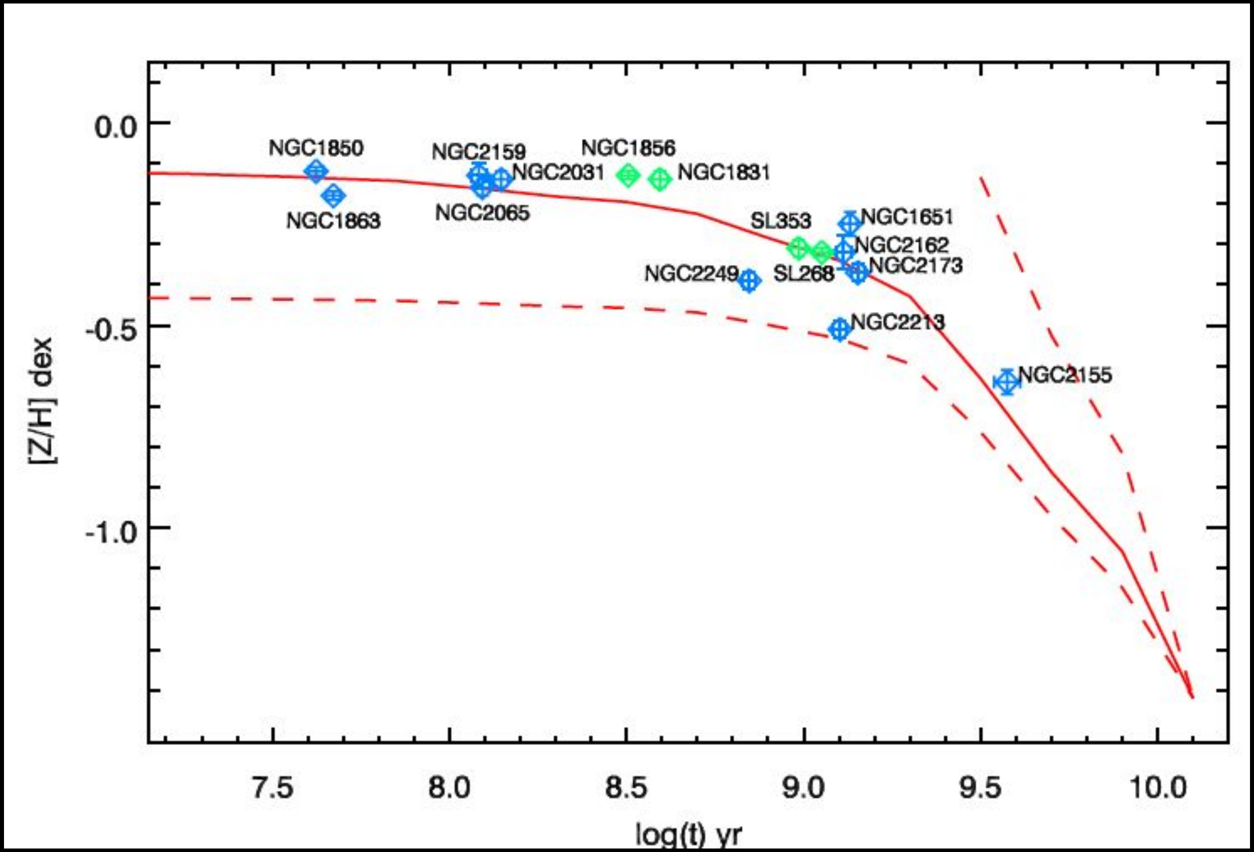
Table 1
Ages and Metallicities of the LMC Cluster Obtained with the NBURSTS Full Spectrum Fitting

Object	t, Myr	[Fe/H], dex	Data Set
NGC1651	1353 ± 70	−0.25 ± 0.03	SOAR
NGC1831	393 ± 20	−0.14 ± 0.02	*Magellan*
NGC1850	42 ± 2	−0.12 ± 0.01	SOAR
NGC1856	320 ± 16	−0.13 ± 0.01	*Magellan*
NGC1863	47 ± 3	−0.18 ± 0.01	SOAR
NGC2031	140 ± 7	−0.14 ± 0.02	SOAR
NGC2065	124 ± 6	−0.16 ± 0.02	SOAR
NGC2155	3757 ± 190	−0.64 ± 0.03	SOAR
NGC2159	121 ± 6	−0.13 ± 0.03	SOAR
NGC2162	1298 ± 60	−0.32 ± 0.04	SOAR
NGC2173	1423 ± 70	−0.37 ± 0.02	SOAR
NGC2213	1267 ± 60	−0.51 ± 0.02	SOAR
NGC2249	703 ± 35	−0.39 ± 0.02	SOAR
[SL63]268	1125 ± 60	−0.32 ± 0.01	*Magellan*
[SL63]353	969 ± 50	−0.31 ± 0.02	*Magellan*

*Full spectrum fitting technique.

Chilingarian & Asa’d (2018)

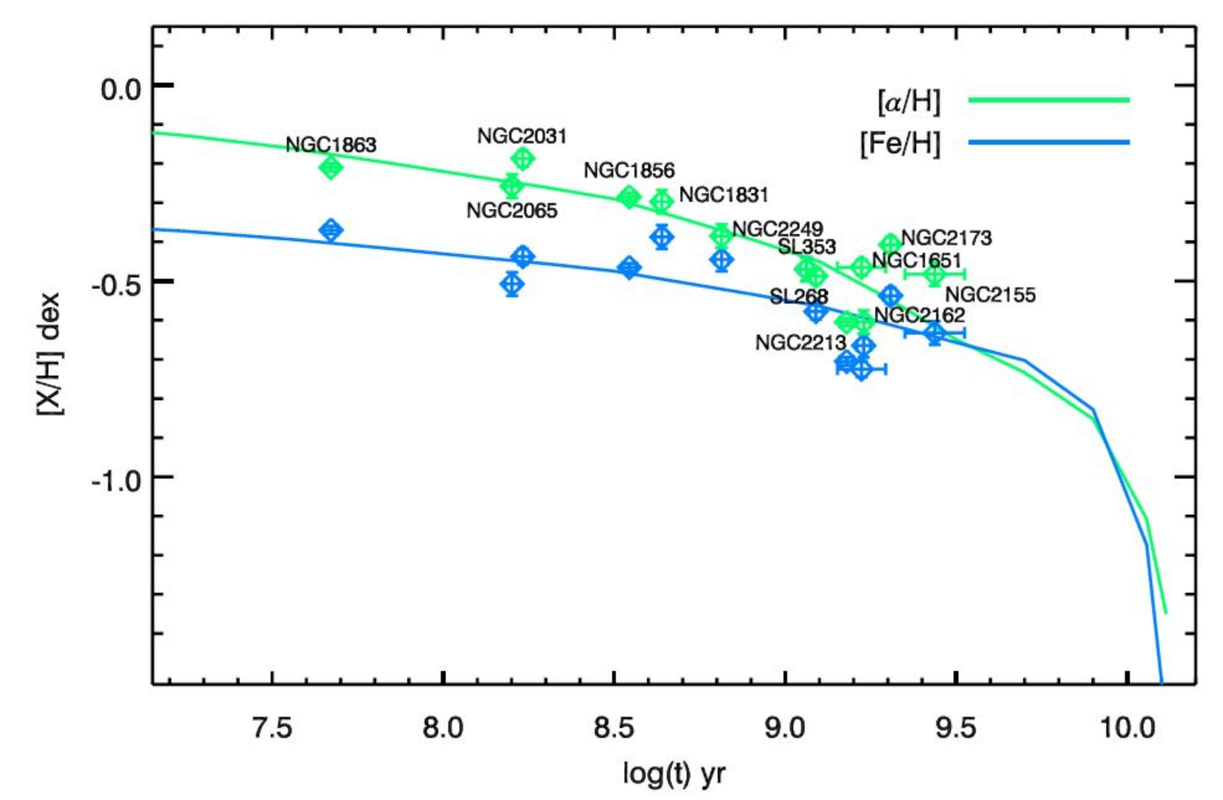
Comparison of the age–metallicity diagram from this study to the predictions of the IRA chemical evolution model



Chilingarian & Asa'd (2018)

α- enhanced ISM

The chemical enrichment with α- elements (O, Ne, Mg, Si, S, Ar, Ca, and Ti) is not at the same time as Fe-peak elements (Sc, V, Cr, Mn,Fe, Co and Ni)



Chilingarian & Asa'd (2018)

Conclusion based on the initial sample:

- We showed the first evidence that we can use integrated spectra to trace the star formation history (SFH) and chemical enrichment history (CEH) of the host galaxy.
- This is significant because our approach can be used to study CEH of distant galaxies at the level of details that are currently available only in a handful of nearby galaxies.

On the precision of full-spectrum fitting technique

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **00**, 1 (2020) doi:10.1093/mnras/staa2515
Advance Access publication 2020 September 2

On the precision of full-spectrum fitting of simple stellar populations – I. Well-sampled populations

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Accepted 2020 July 30. Received 2020 July 22; in original form 2020 May 15

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **501,** 440–466 (2021) doi:10.1093/mnras/staa3617
Advance Access publication 2020 December 3

On the precision of full-spectrum fitting of simple stellar populations – II. The dependence on star cluster mass in the wavelength range 0.3–5.0 μm

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Accepted 2020 November 2. Received 2020 October 6; in original form 2020 August 6

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **00,** 1 (2021) doi:10.1093/mnras/stab969
Advance Access publication 2021 April 30

On the precision of full-spectrum fitting of stellar populations – III. Identifying age spreads

Randa Asa'd,[1,2]★ Paul Goudfrooij,[2] A. M. As'ad,[3] H. G. El-Mir,[4] L. Begum,[4] A. Aljasmi[4] and O. Almatroushi[4]
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Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **512,** 2014–2024 (2022) https://doi.org/10.1093/mnras/stac566
Advance Access publication 2022 March 7

On the precision of full-spectrum fitting of simple stellar populations – IV. A systematic comparison with results from colour–magnitude diagrams

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Accepted 2022 February 23. Received 2022 February 23; in original form 2021 November 24

One Step Further: Detailed Abundances

The Astrophysical Journal, 929:174 (10pp), 2022 April 20
https://doi.org/10.3847/1538-4357/ac5f3e

Detailed Chemical Abundances of Star Clusters in the Large Magellanic Cloud

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Received 2021 November 15; revised 2022 March 14; accepted 2022 March 14; published 2022 April 27

Table 1
Our Results

	NGC 1831	NGC 1856	[SL63]268
RV (km s^{-1})	290 ± 7	279 ± 4	278 ± 4
σ_{sm} (km s^{-1})	23.9	26.9	24.6
[Z]	-0.418 ± 0.07	-0.574 ± 0.06	-0.51 ± 0.04
[Fe/H]	-0.375 ± 0.12	-0.455 ± 0.11	-0.506 ± 0.1
[Ca/Fe]	0.814 ± 0.41	0.375 ± 0.2	-0.277 ± 0.39
[Na/Fe]	0.023 ± 0.77	0.093 ± 0.38	0.357 ± 0.08
[Mg/Fe]	0.082 ± 0.16	-0.074 ± 0.13	0.07 ± 0.11
[Ti/Fe]	0.547 ± 0.42	0.262 ± 0.2	0.233 ± 0.19
[Cr/Fe]	0.002 ± 0.5	0.132 ± 0.16	0.111 ± 0.0
[Mn/Fe]	0.323 ± 0.38	-0.263 ± 0.32	-0.199 ± 0.21
[Ni/Fe]	0.318 ± 0.5	-0.194 ± 0.08	-0.224 ± 0.41

Asa'd et al. (2022)

Interesting Results.. MSP?

MSP phenomenon: star-to-star variations in the inferred abundances of light elements. It was only confirmed for star clusters older than about 2 Gyrs.

Our results from NGC 1831 and NGC 1856 show a possible depletion in the [Mg/Fe] abundance compared with [Ca/Fe] and [Ti/Fe].

We also observe slightly enhanced [Na/Fe] ratios in cluster [SL63]268 when compared with the abundances of the field stars. This trend can be an indication of intracluster Na variations.

More analysis is needed for this sample of LMC clusters to accurately investigate the MSP phenomenon.

Summary

- The chemical composition of a galaxy is enriched with time.
- Star clusters allow us to study the chemical history of galaxies.
- Because of the large distance and the dust, clusters near the Galactic center can only be identified by the presence of very bright red supergiants.
- For far away galaxies we need to rely on integrated light.
- Both theoretical models and observations are needed to be able to understand the chemical composition and history of galaxies.

Questions?