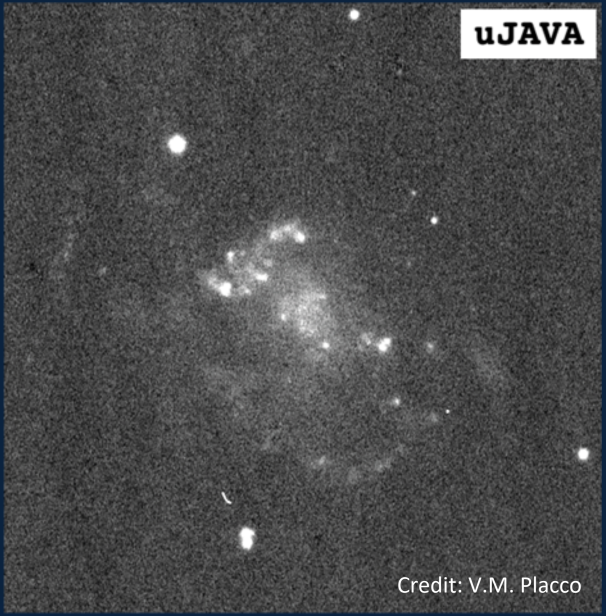
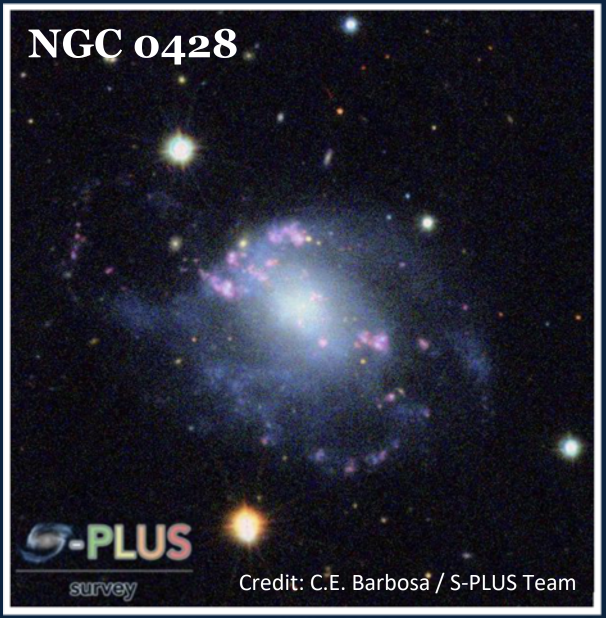
Searching for low-metallicity stars in S-PLUS

Vinicius Placco

June 01st, 2021

From R~30 to R~30,000: Mining narrow-band photometric catalogs in search of low-metallicity stars





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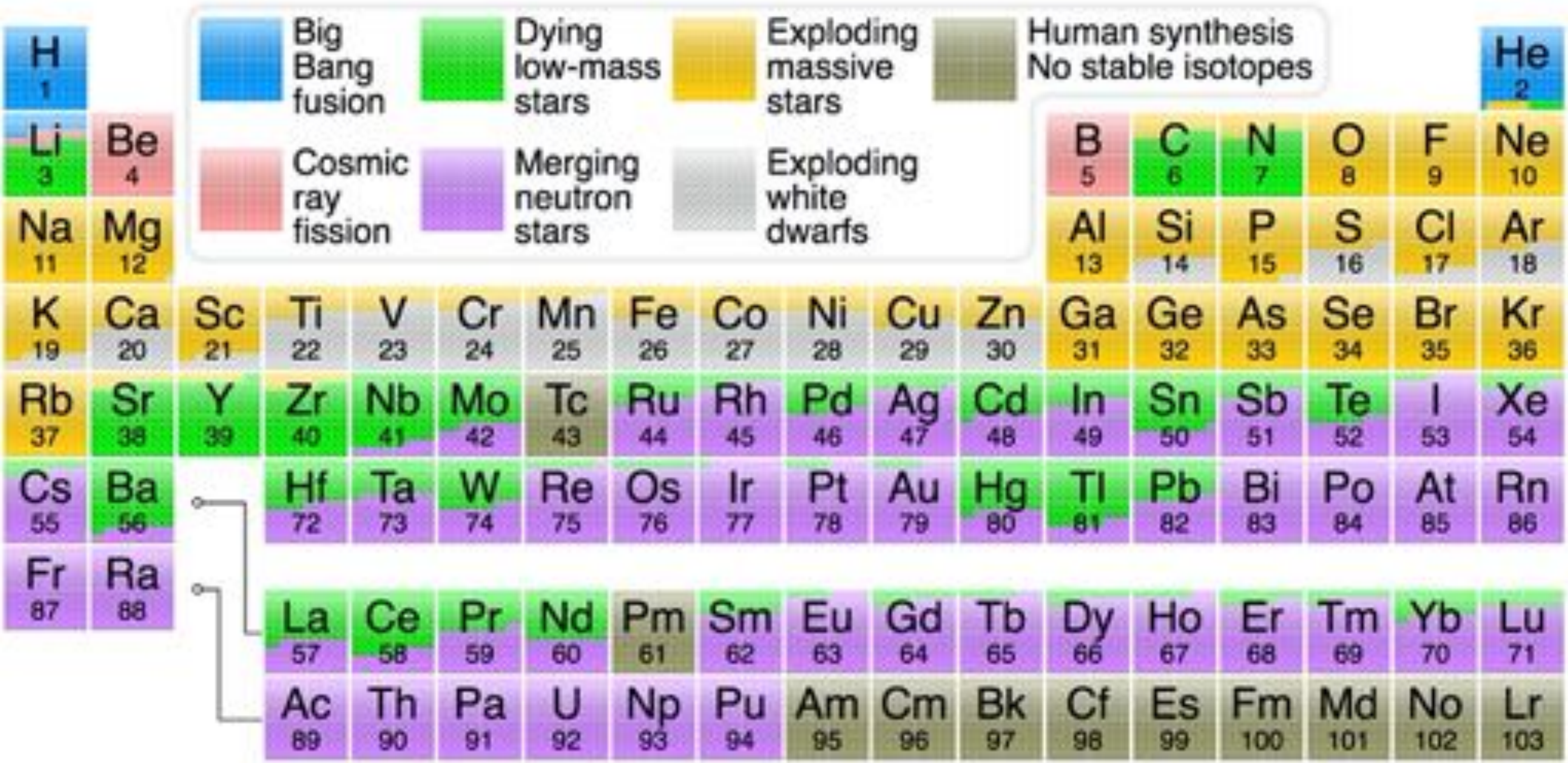
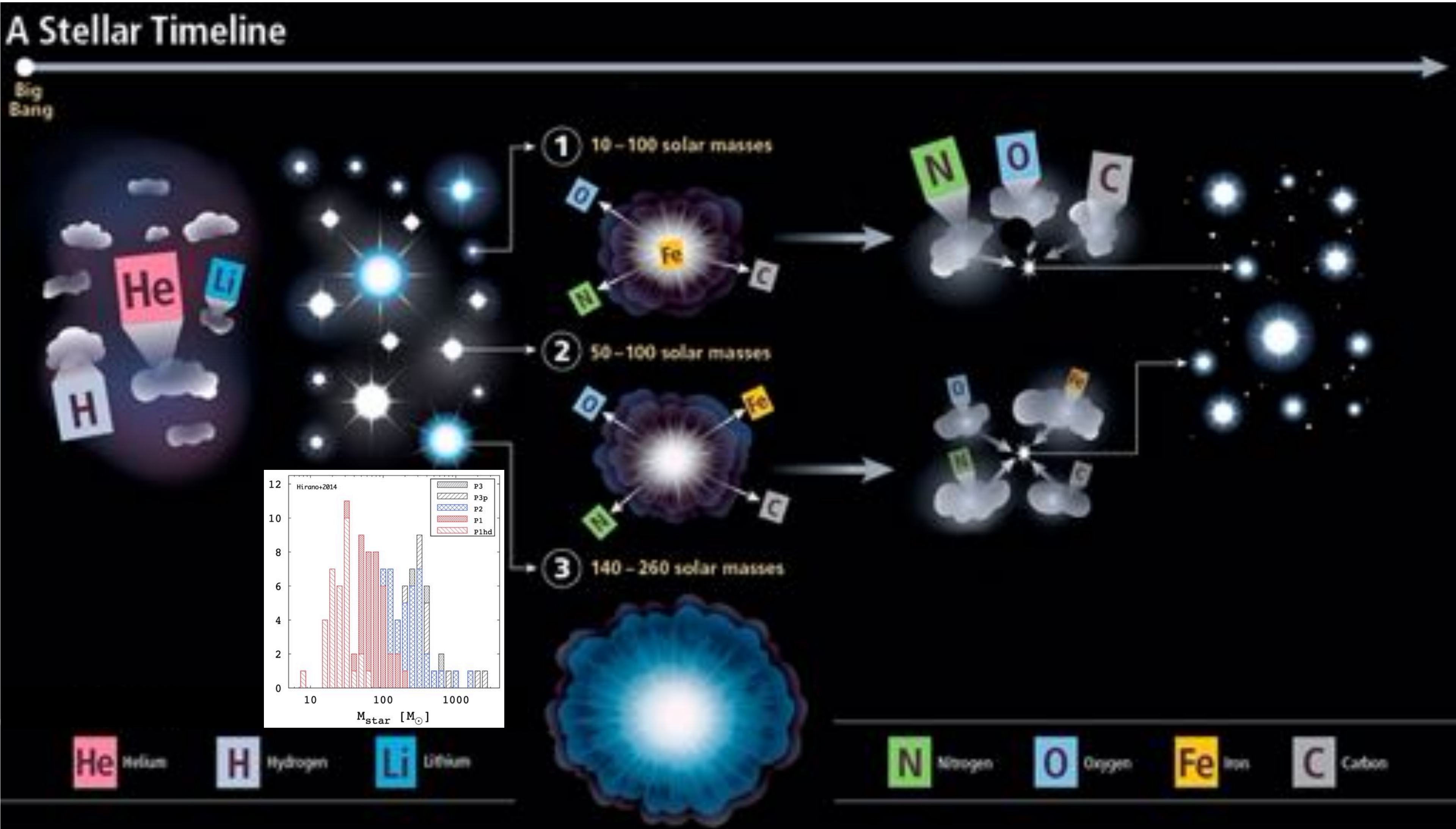
June 01st, 2021

Nucleosynthesis



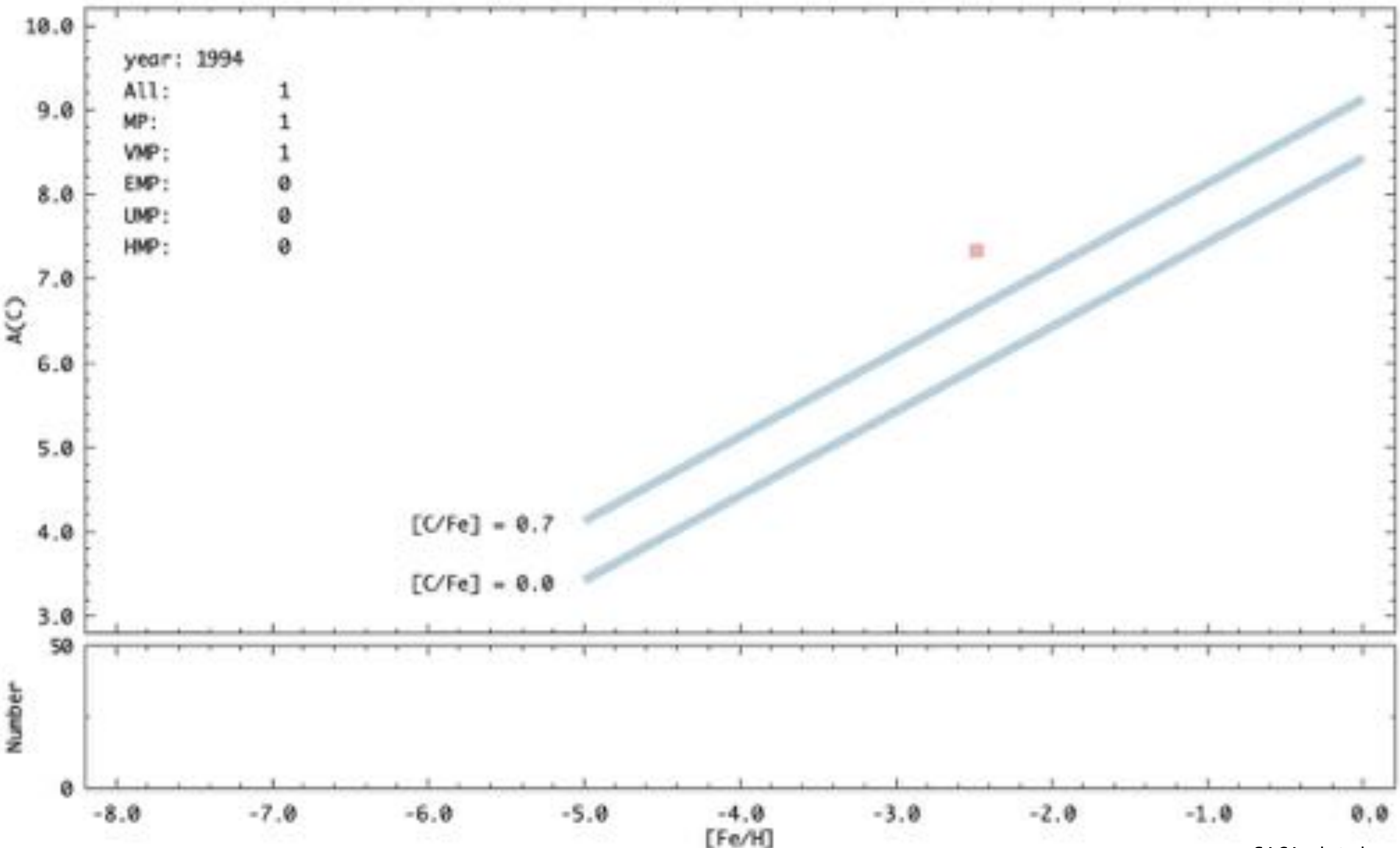
https://upload.wikimedia.org/wikipedia/commons/3/31/Nucleosynthesis_periodic_table.svg

Stellar Archaeology and the First Stars



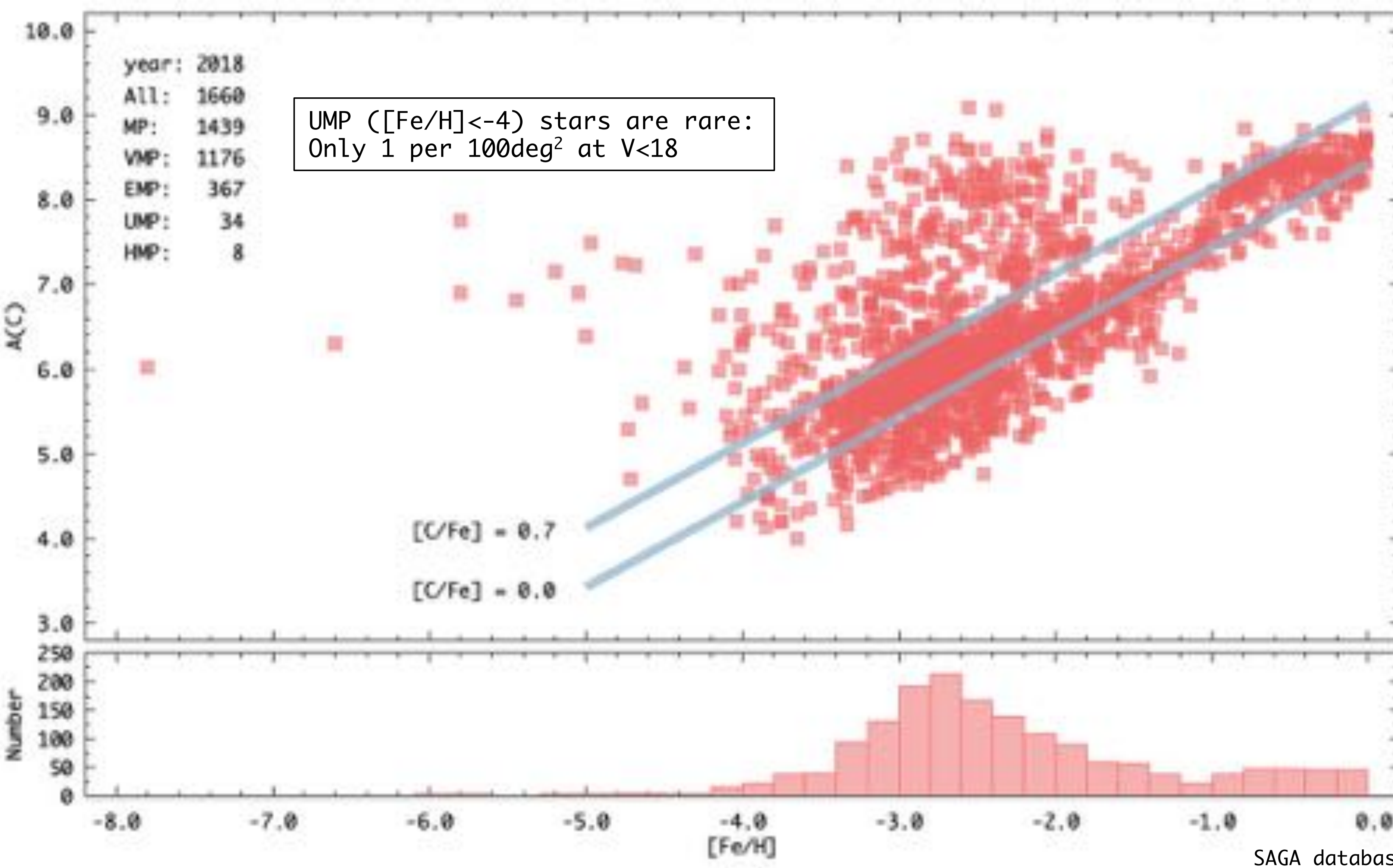
http://discovermagazine.com/~/media/Images/Issues/2015/Dec/stellar_timeline.jpg (edits by Elisa Arizono)

Carbon: empirical evidence



SAGA database

Carbon: empirical evidence



UMP ([Fe/H]<-4) stars are rare:
Only 1 per 100deg^2 at V<18

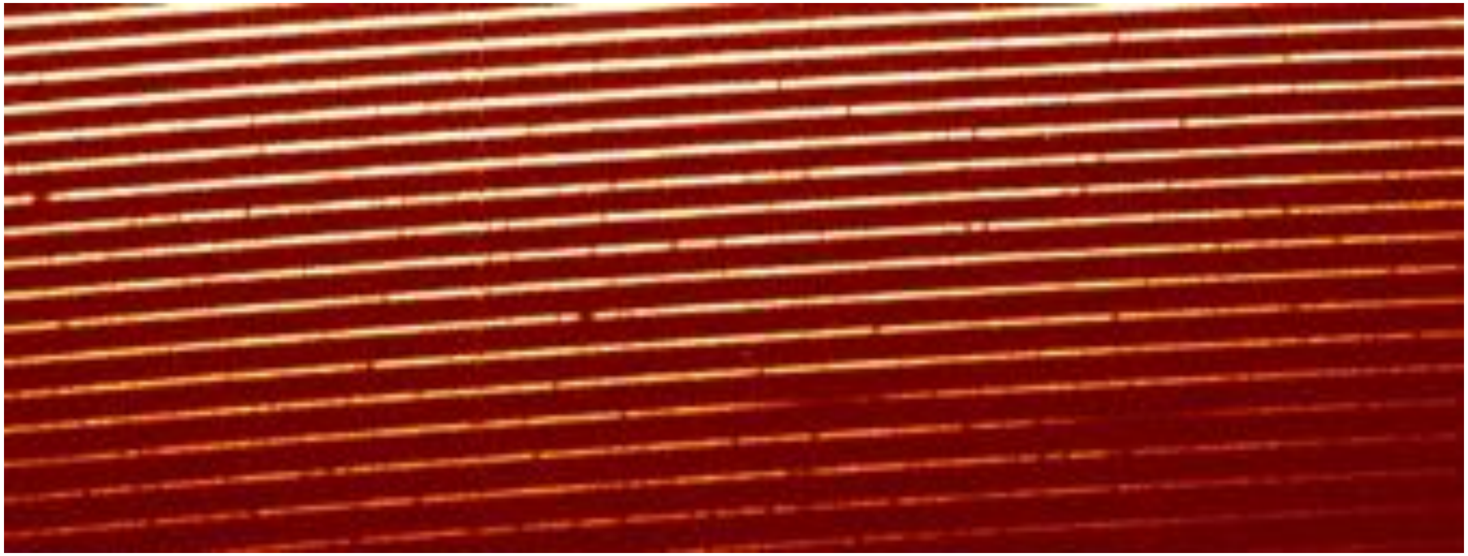
SAGA database

How do we (effectively) choose targets?

Finding low-metallicity stars

Solar type:
[Fe/H] ~ 0.0

Ultra Metal-Poor:
[Fe/H] < -4.0



credit: E. Holmbeck

An image is worth a thousand words

https://space-facts.com/galaxies/andromeda/

The estimated distance of the Andromeda Galaxy from our own was doubled in 1953 when it was discovered that there is another, dimmer type of Cepheid variable star. In the 1990s, measurements of both standard red giants as well as red clump stars from the Hipparcos satellite measurements were used to calibrate the Cepheid distances.[41][42]

Formation and history[edit]

The Andromeda Galaxy was formed roughly 10 billion years ago from the collision and subsequent merger of smaller protogalaxies.[43]

This violent collision formed most of the galaxy's (metal-rich) galactic halo and extended disk. During this epoch, its rate of star formation would have been very high, to the point of becoming a luminous infrared galaxy for roughly 100 million years. Andromeda and the Triangulum Galaxy had a very close passage 2–4 billion years ago. This event produced high rates of star formation across the Andromeda Galaxy's disk—even some globular clusters—and disturbed M33's outer disk.

Over the past 2 billion years, star formation throughout Andromeda's disk is thought to have decreased to the point of near-inactivity. There have been interactions with satellite galaxies like M32, M110, or others that have already been absorbed by Andromeda Galaxy. These interactions have formed structures like Andromeda's Giant Stellar Stream. A galactic merger roughly 100 million years ago is believed to be responsible for a counter-rotating disk of gas found in the center of Andromeda as well as the presence there of a relatively young (100 million yr) stellar population

Distance estimate[edit]

At least four distinct techniques have been used to estimate distances from Earth to the Andromeda Galaxy. In 2003, using the infrared surface brightness fluctuations (I-SBF) and adjusting for the new period-luminosity value and a metallicity correction of −0.2 mag dex^{-1} in (O/H), an estimate of 2.57 ± 0.06 million light-years ($1.625 \times 10^{11} \pm 3.8 \times 10^{9}$ astronomical units) was derived. A 2004 Cepheid variable method estimated the distance to be 2.51 ± 0.13 million light-years (770 ± 40 kpc).[illegible] In 2005, an eclipsing binary star was discovered in the Andromeda Galaxy. The binary[illegible] is two hot blue stars of types O and B. By studying the eclipses of the stars, astronomers were able to measure their sizes. Knowing the sizes and temperatures of the stars, they were able to measure their absolute magnitude. When the visual and absolute magnitudes are known, the distance to the star can be calculated. The stars lie at a distance of $2.52 \times 10^{6} \pm 0.14 \times 10^{6}$ ly ($1.594 \times 10^{11} \pm 8.9 \times 10^{9}$ AU) and the whole Andromeda Galaxy at about 2.5×10^{6} ly (1.6×10^{11} AU).[illegible] This new value is in excellent agreement with the previous, independent Cepheid-based distance value. The TRGB method was also used in 2005 giving a distance of $2.56 \times 10^{6} \pm 0.08 \times 10^{6}$ ly ($1.619 \times 10^{11} \pm 5.1 \times 10^{9}$ AU).[illegible] Averaged together, these distance estimates give a value of $2.54 \times 10^{6} \pm 0.11 \times 10^{6}$ ly ($1.606 \times 10^{11} \pm 7.0 \times 10^{9}$ AU).[illegible] And, from this, the diameter of Andromeda at the widest point is estimated to be 220 ± 3 kly (67,450 ± 920 pc). This is equivalent to an apparent 4.96° angle in the sky.

Mass estimates[edit]

Until 2018, mass estimates for the Andromeda Galaxy's halo (including dark matter) gave a value of approximately $1.5 \times 10^{12} M_{\odot}$,[illegible] compared to $8 \times 10^{11} M_{\odot}$ for the Milky Way. This contradicted earlier measurements that seemed to indicate that the Andromeda Galaxy and Milky Way are almost equal in mass. In 2018, the equality of mass was re-established by radio results as approximately $8 \times 10^{11} M_{\odot}$.[illegible] In 2006, Andromeda Galaxy's spheroid was determined to have a higher stellar density than that of the Milky Way,[illegible] and its galactic stellar disk was estimated at about twice the diameter of that of the Milky Way.[illegible] The total mass of Andromeda Galaxy is estimated to be between $8 \times 10^{11} M_{\odot}$[illegible] and $1.1 \times 10^{12} M_{\odot}$.[illegible] The stellar mass of M31 is 10-15$\times 10^{10} M_{\odot}$, with 30% of that mass in the central bulge, 56% in the disk, and the remaining 14% in the stellar halo.[illegible] The radio results (similar mass to Milky Way galaxy) should be taken as likeliest as of 2018, although clearly this matter is still under active investigation by a number of research groups worldwide.

As of 2019, current calculations based on escape velocity and dynamical mass measurements put the Andromeda Galaxy at $0.8 \times 10^{12} M_{\odot}$,[illegible] which is only half of the Milky Way's newer mass, calculated in 2019 at $1.5 \times 10^{12} M_{\odot}$.[illegible]

In addition to stars, Andromeda Galaxy's interstellar medium contains at least $7.2 \times 10^{9} M_{\odot}$[illegible] in the form of neutral hydrogen, at least $3.4 \times 10^{8} M_{\odot}$ as molecular hydrogen (within its innermost 10 kiloparsecs), and $5.4 \times 10^{7} M_{\odot}$ of dust.[illegible]

Andromeda Galaxy is surrounded by a massive halo of hot gas that is estimated to contain half the mass of the stars in the galaxy. The nearly invisible halo stretches about a million light-years from its host galaxy, halfway to our Milky Way galaxy. Simulations of galaxies indicate the halo formed at the same time as the Andromeda Galaxy. The halo is enriched in elements heavier than hydrogen and helium, formed from supernovae and its properties are those expected for a galaxy that lies in the "green valley" of the Galaxy color–magnitude diagram (see below). Supernovae erupt in Andromeda Galaxy's star-filled disk and eject these heavier elements into space. Over Andromeda Galaxy's lifetime, nearly half of the heavy elements made by its stars have been ejected far beyond the galaxy's 200,000-light-year-diameter stellar disk.[illegible]

Luminosity estimates[edit]

Compared to the Milky Way, the Andromeda Galaxy appears to have predominantly older stars with ages $>7 \times 10^{9}$ years.[illegible][clarification needed] The estimated luminosity of Andromeda Galaxy, $\sim 2.6 \times 10^{10} L_{\odot}$, is about 25% higher than that of our own galaxy.[illegible] However, the galaxy has a high inclination as seen from Earth and its interstellar dust absorbs an unknown amount of light, so it is difficult to estimate its actual brightness and other authors have given other values for the luminosity of the Andromeda Galaxy (some authors even propose it is the second-brightest galaxy within a radius of 10 mega-parsecs of the Milky Way, after the Sombrero Galaxy,[illegible] with an absolute magnitude of around -22.21[illegible] or close[illegible]).

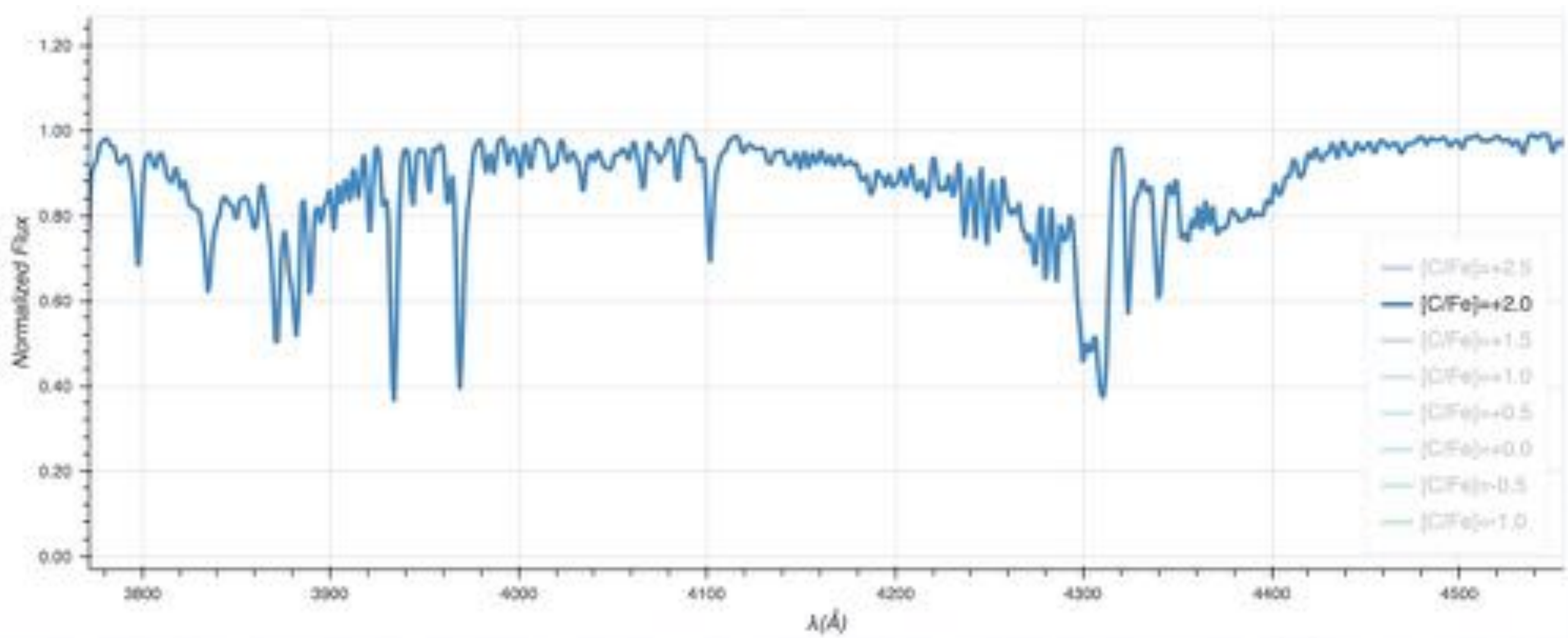
An estimation done with the help of Spitzer Space Telescope published in 2010 suggests an absolute magnitude (in the blue) of −20.89 (that with a color index of +0.63 translates to an absolute visual magnitude of −21.52,[illegible] compared to −20.9 for the Milky Way), and a total luminosity in that wavelength of $3.64 \times 10^{10} L_{\odot}$.[illegible]

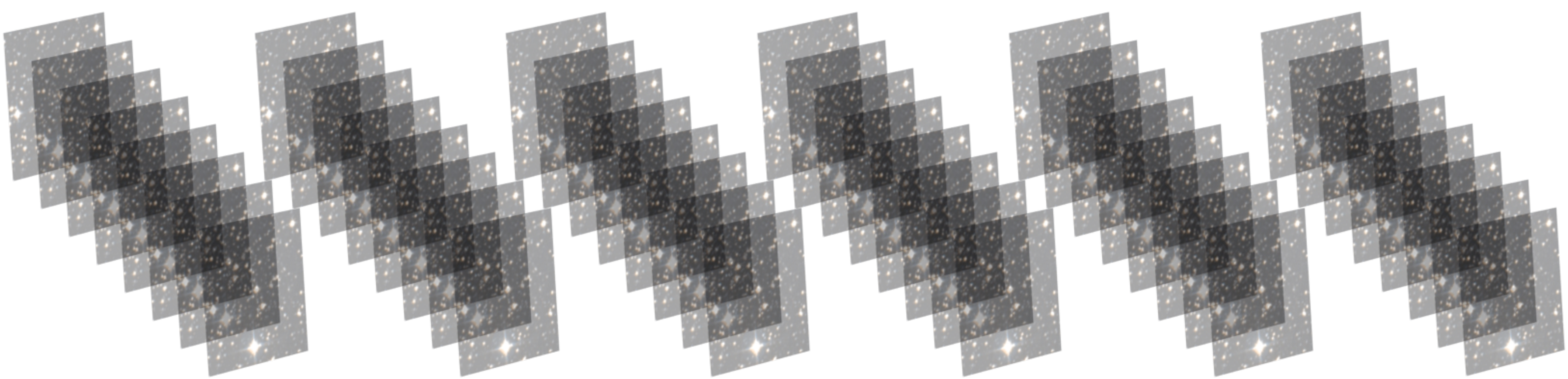
The rate of star formation in the Milky Way is much higher, with Andromeda Galaxy producing only about one solar mass per year compared to 3–5 solar masses for the Milky Way. The rate of novae in the Milky Way is also double that of Andromeda Galaxy.[illegible] This suggests that the latter once experienced a great star formation phase, but is now in a relative state of quiescence, whereas the Milky Way is experiencing more active star formation.[illegible] Should this continue, the luminosity of the Milky Way may eventually overtake that of Andromeda Galaxy.

According to recent studies, the Andromeda Galaxy lies in what in the Galaxy color–magnitude diagram is known as the "green valley," a region populated by galaxies like the Milky Way in transition from the "blue cloud" (galaxies actively forming new stars) to the "red sequence" (galaxies that lack star formation). Star formation activity in green valley galaxies is slowing as they run out of star-forming gas in the interstellar medium. In simulated galaxies with similar properties to Andromeda Galaxy, star formation is expected to extinguish within about five billion years from the now, even accounting for the expected, short-term increase in the rate of star formation due to the collision between Andromeda Galaxy and the Milky Way.[illegible]

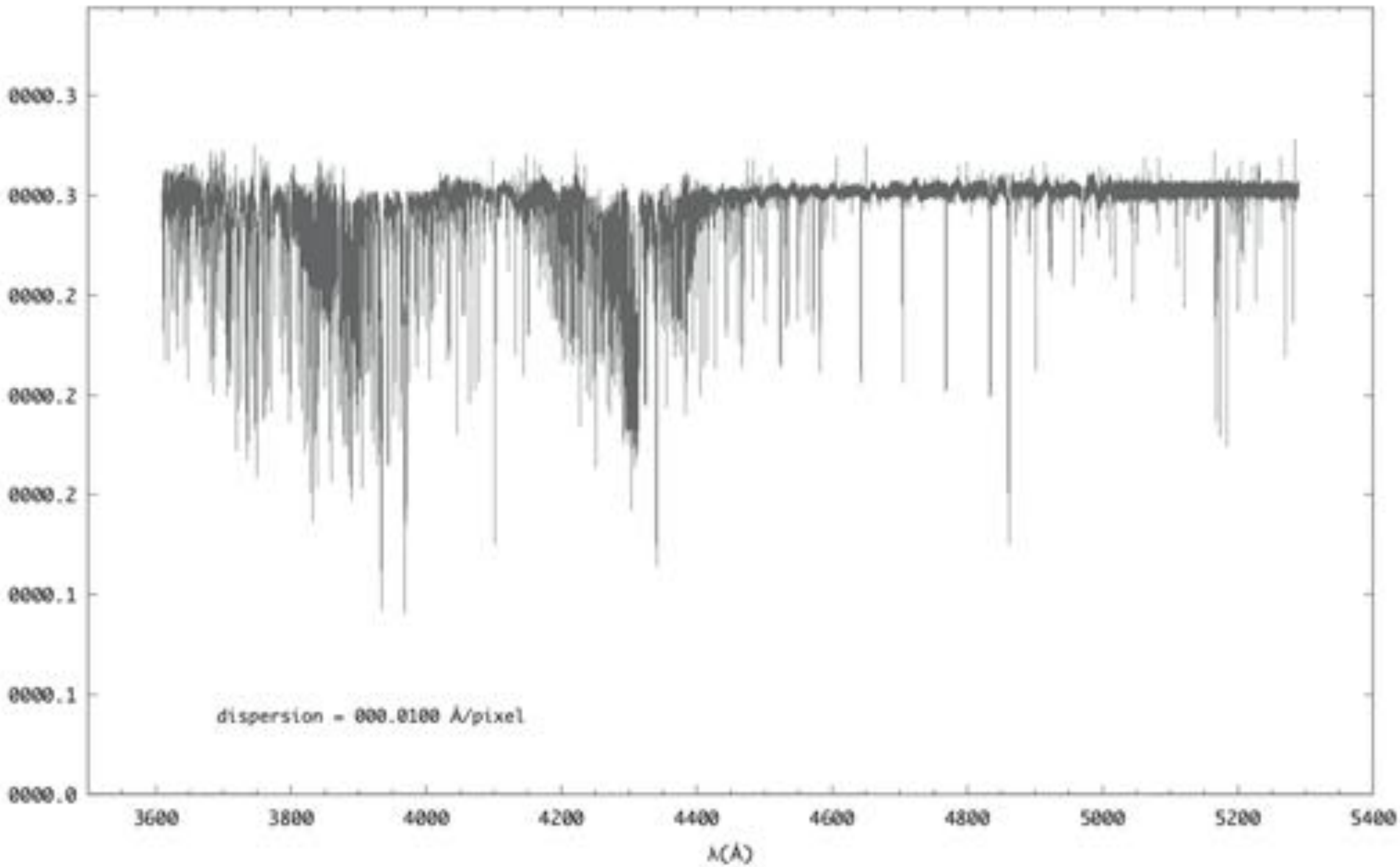
https://en.wikipedia.org/wiki/Andromeda_Galaxy

A spectrum is worth $\underline{n}$ images, where $\underline{n} = \frac{(\lambda_{red} - \lambda_{blue})}{\Delta\lambda}$



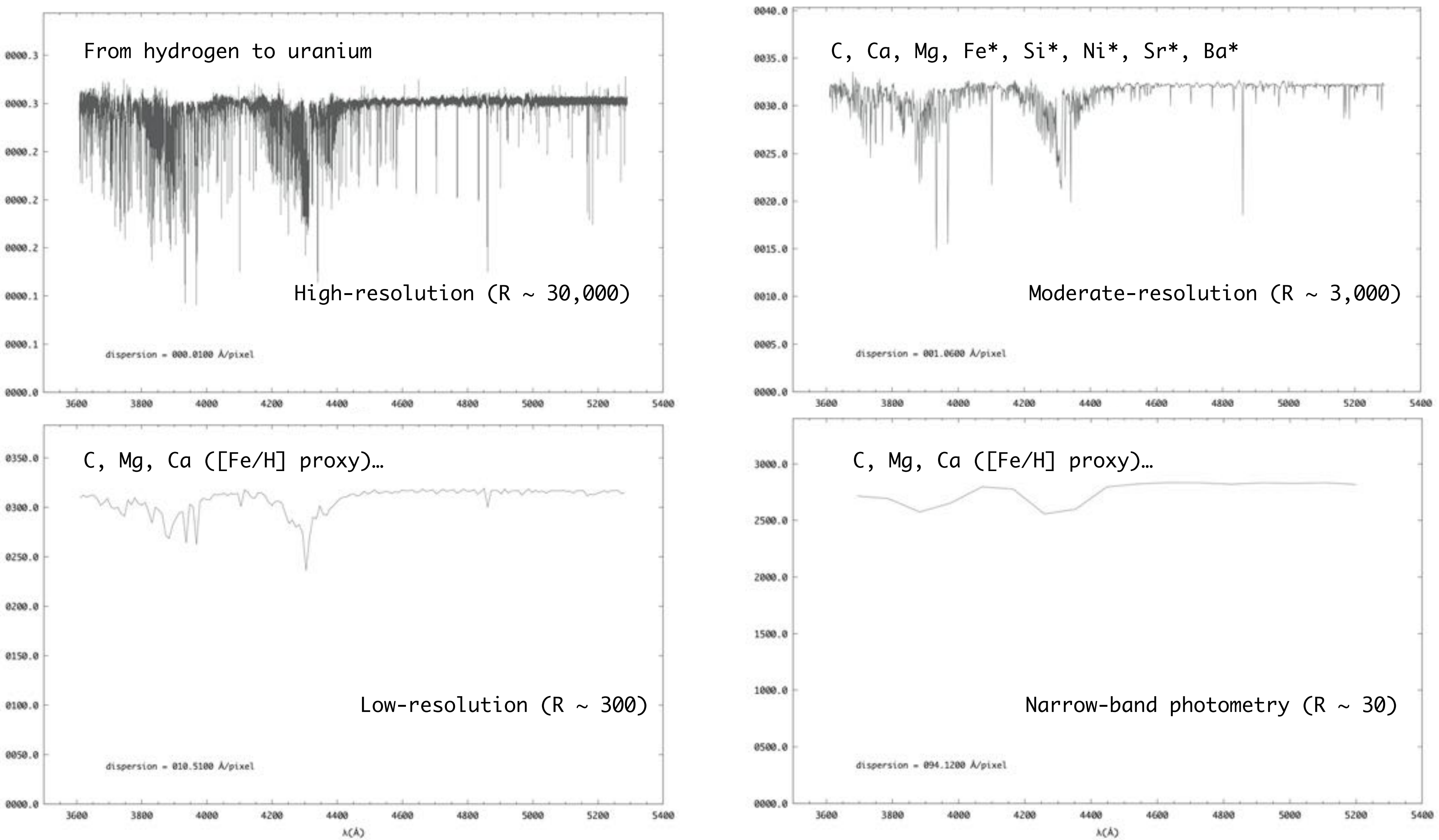


What is the ideal *n*?

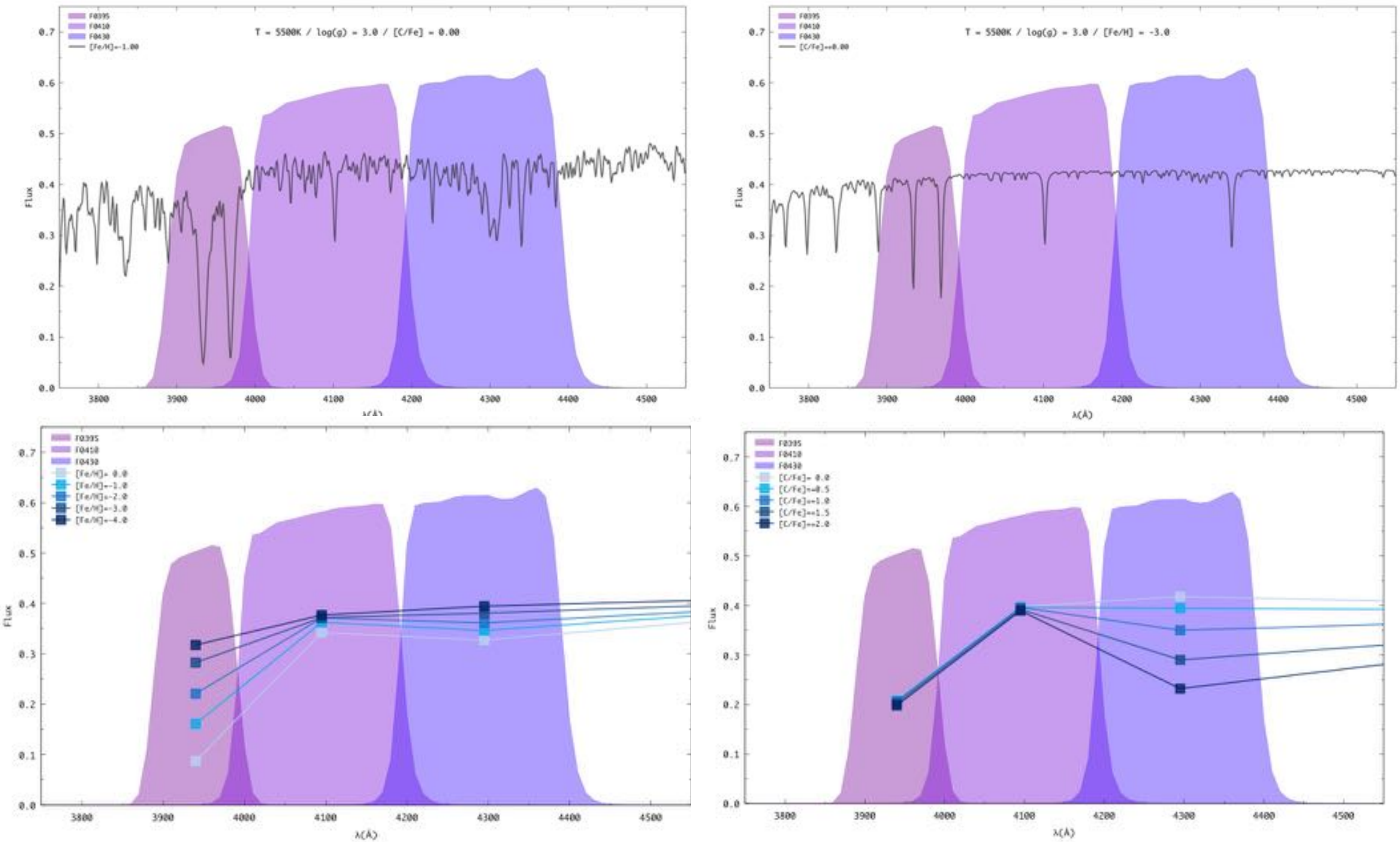


From R~30 to R~30,000

(finding the ideal *n* to determine chemical abundances)

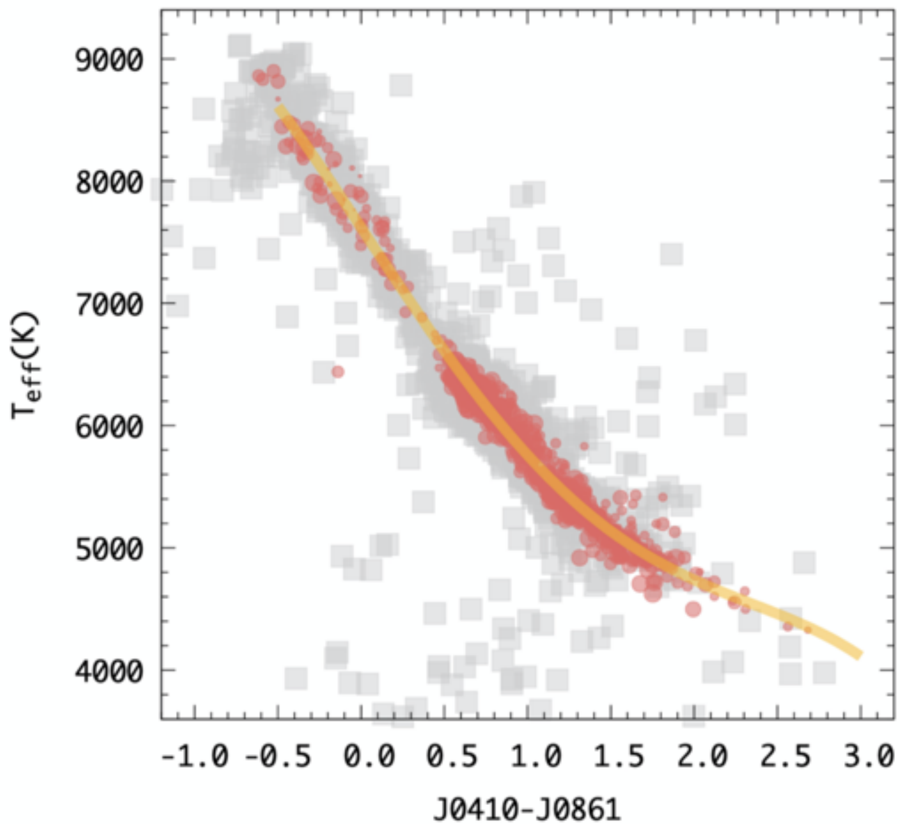


S-PLUS ([Fe/H] and A(C) indicators)

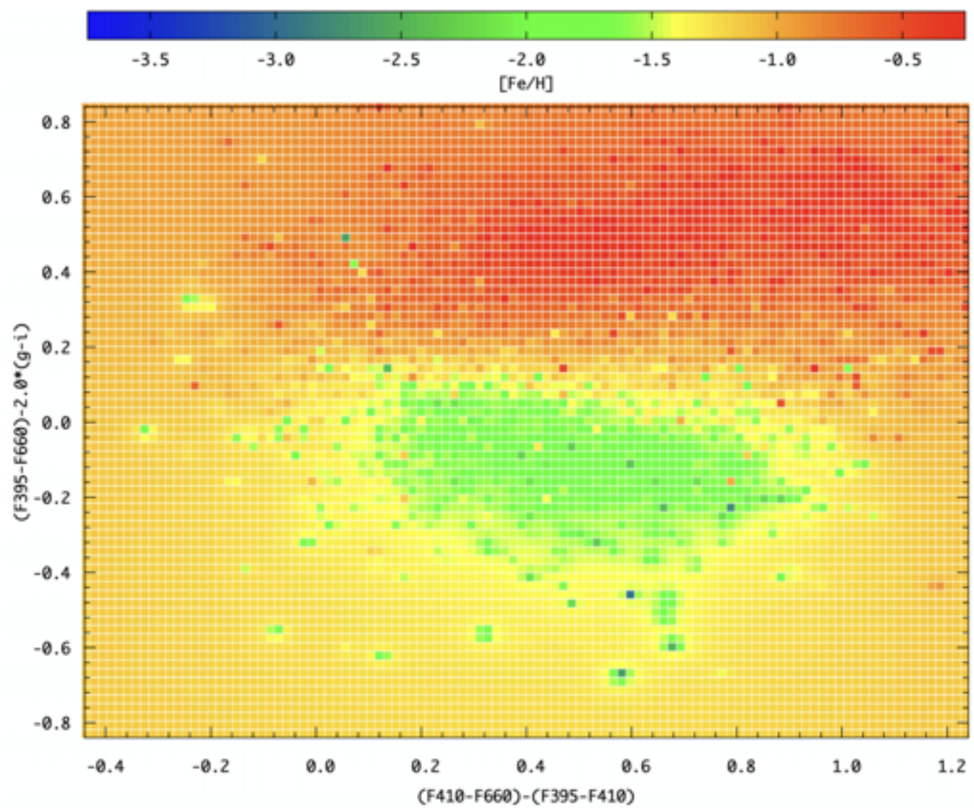


How do stellar parameters affect color?

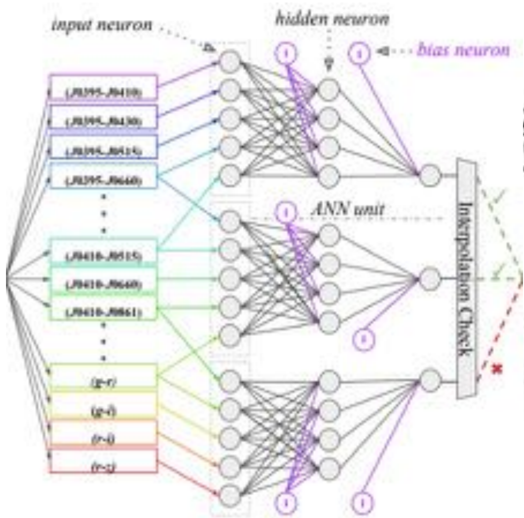
Effective temperature (T_{eff})

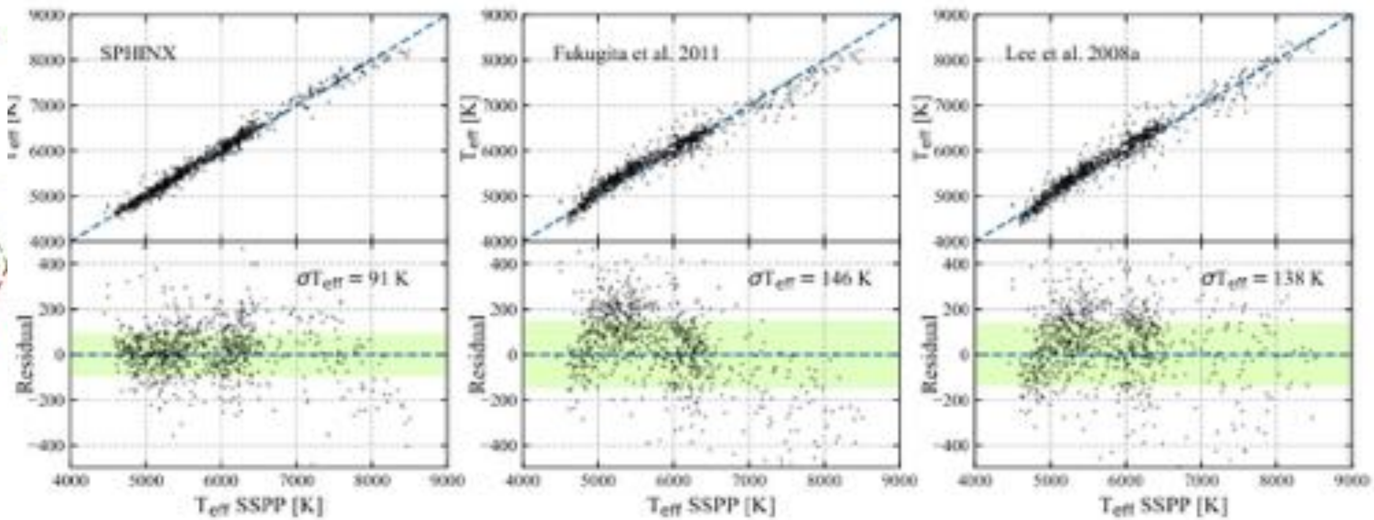


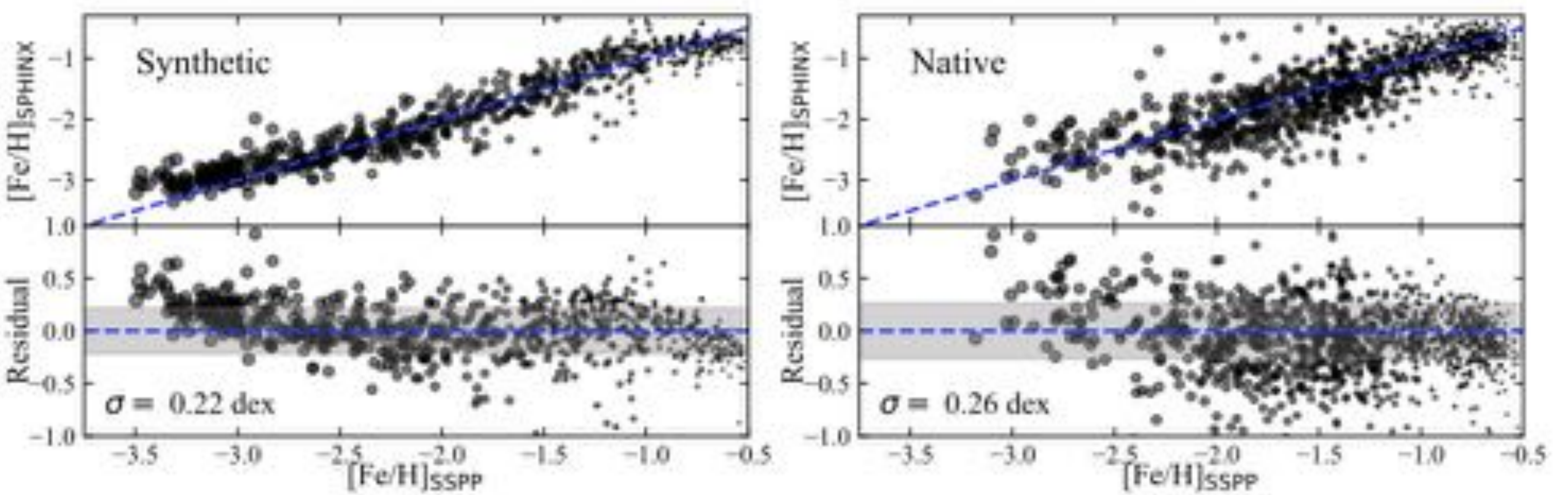
Metallicity [Fe/H]



Artificial Neural Networks – J-PLUS DR1

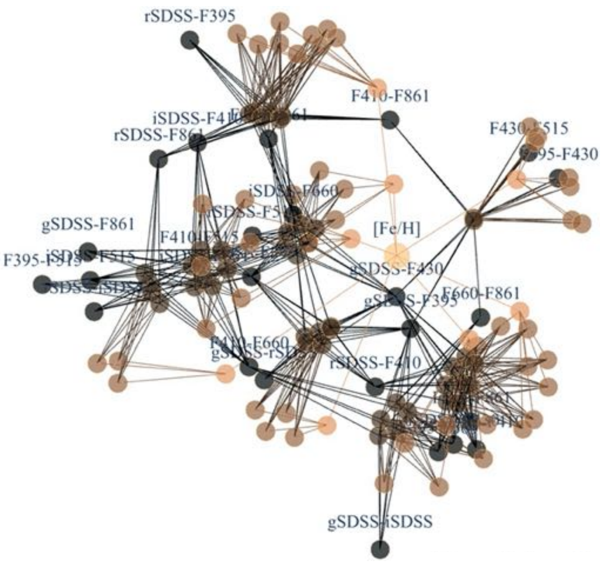


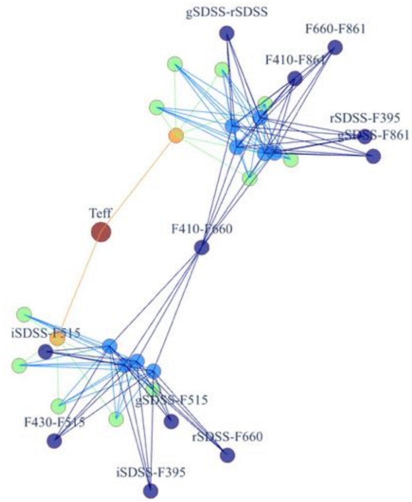


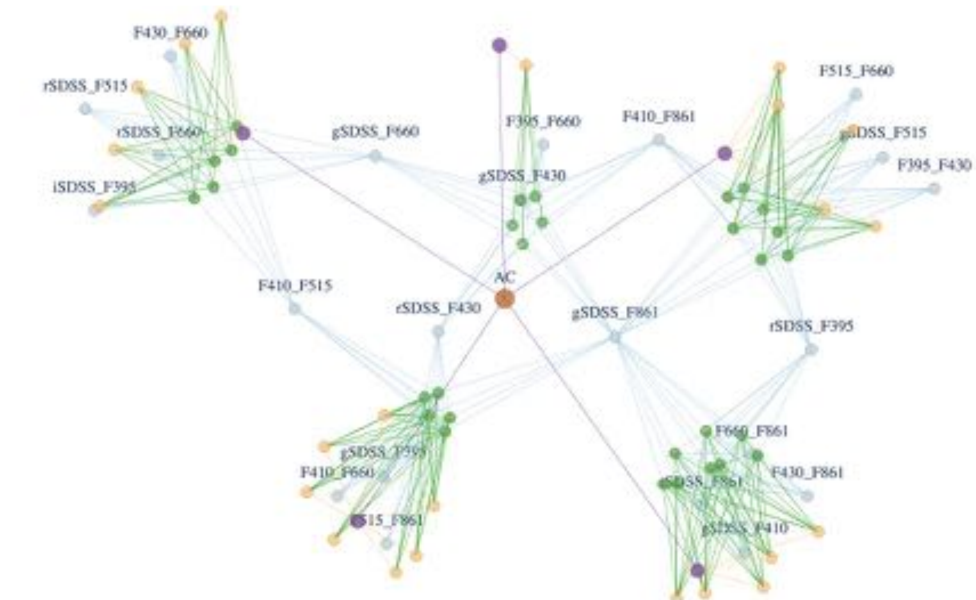


Whitten+2019

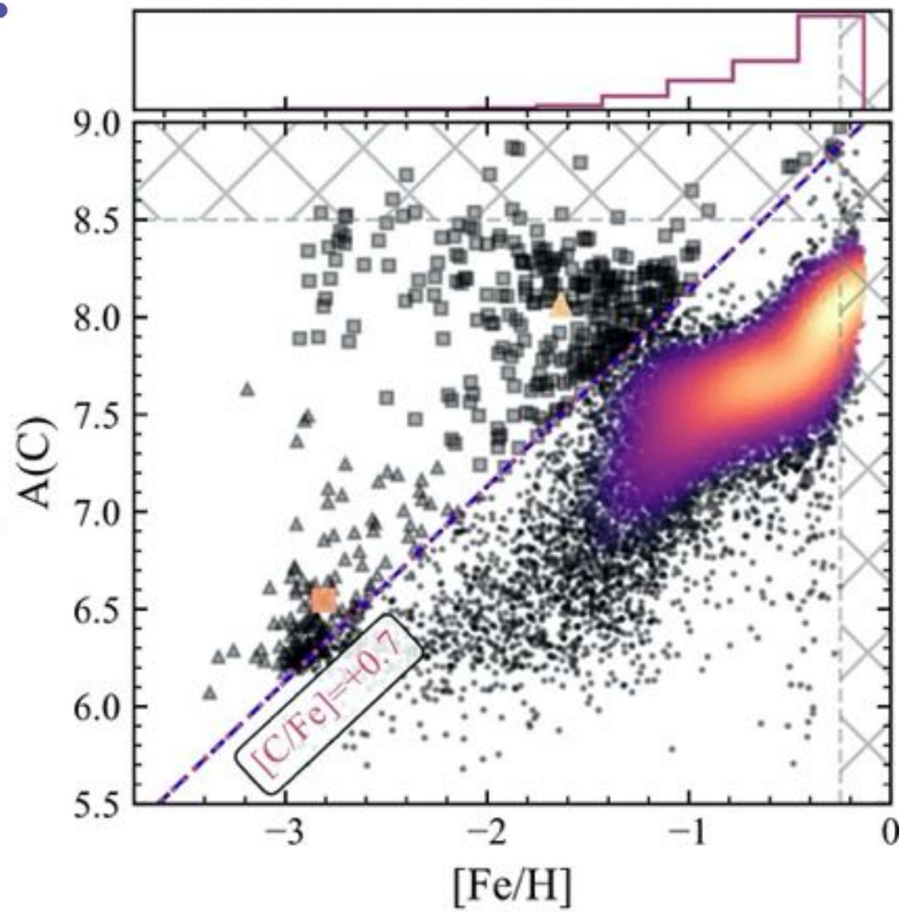
Artificial Neural Networks – S-PLUS Stripe 82







First photometric A (C) vs. [Fe/H] diagram!



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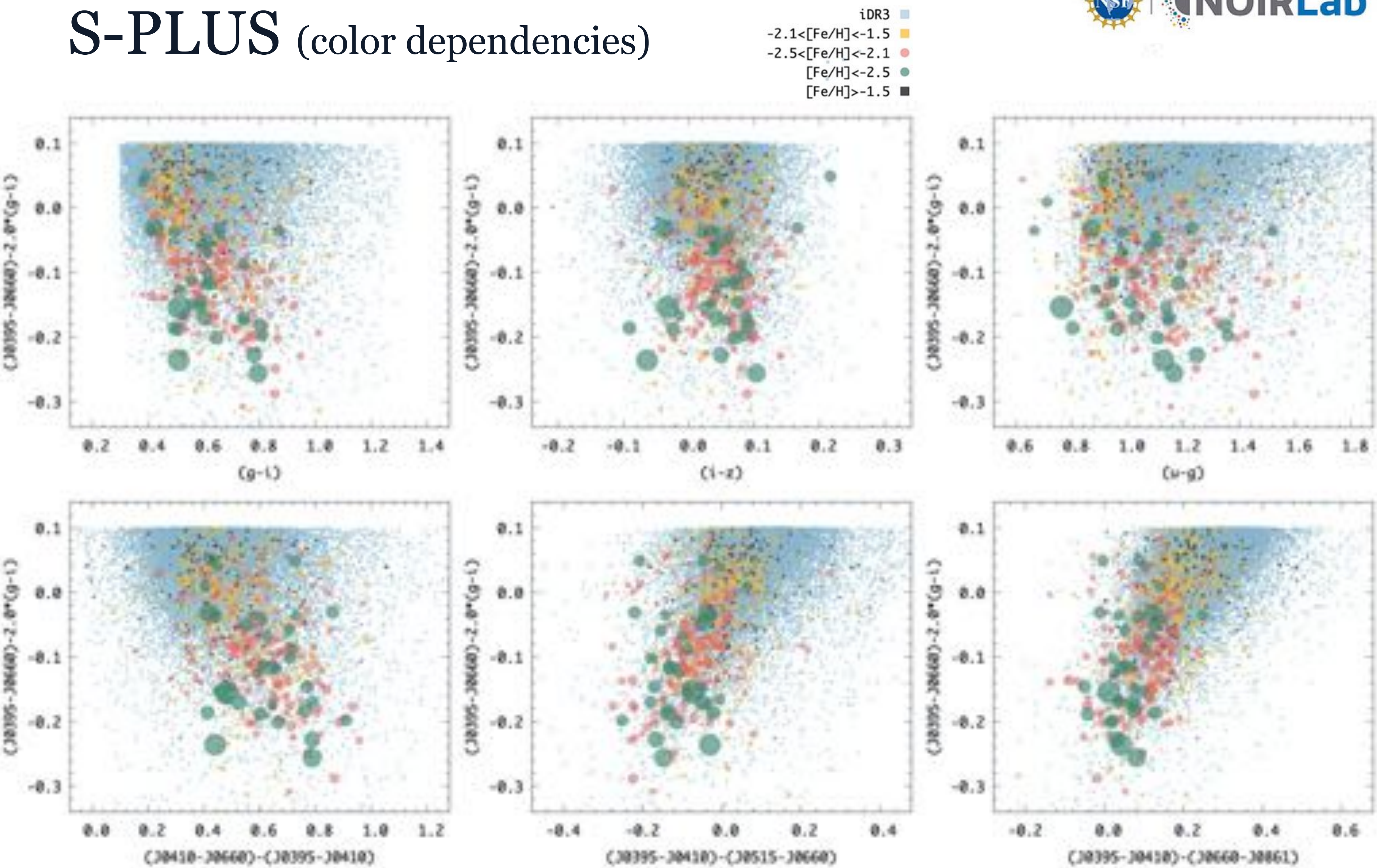
S-PLUS (color dependencies)

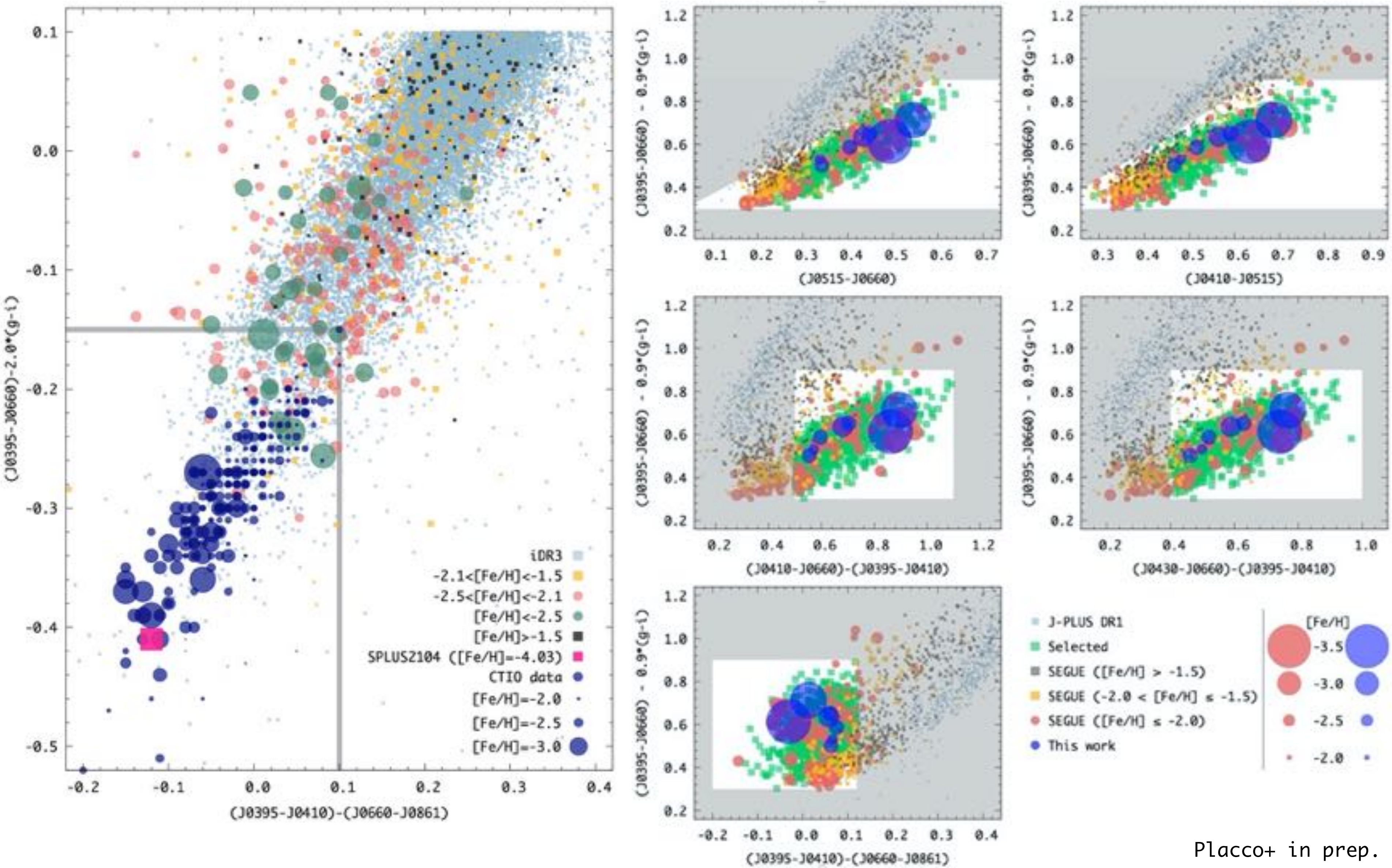


Placco+ in prep.

Spectroscopic follow-up campaign

The power in numbers

S-PLUS colors vs. [Fe/H]



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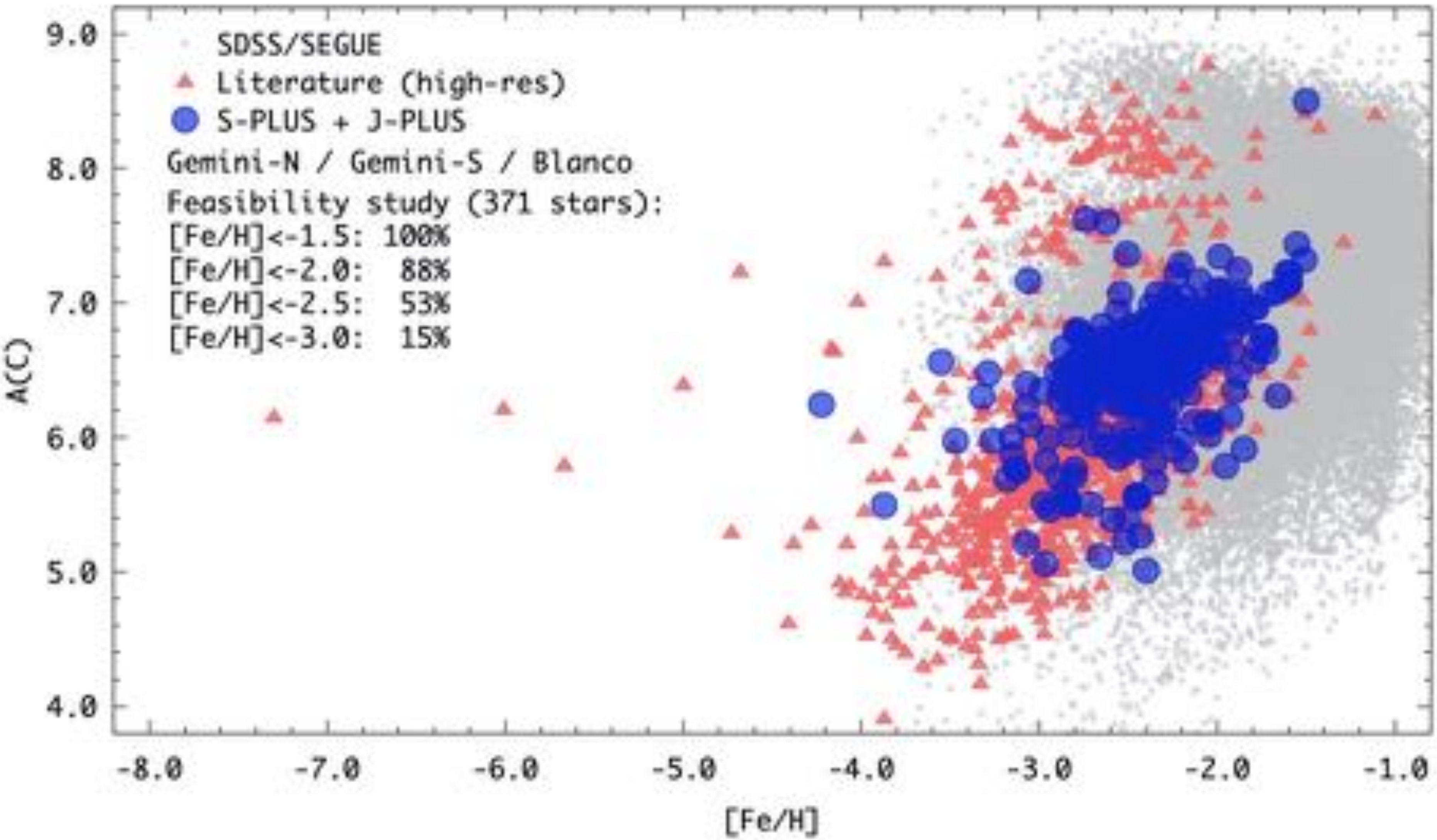
Spectroscopic follow-up campaign



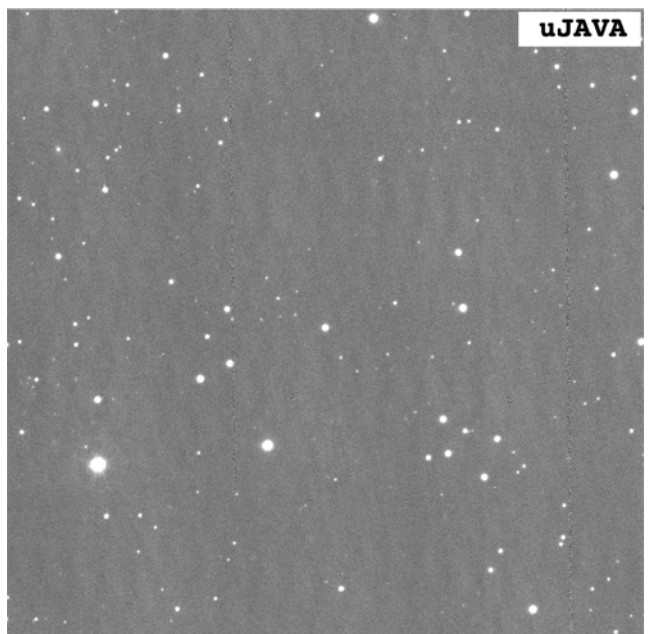
Placco+ in prep.

The Astrophysical Journal Letters, 912:L32 (8pp), 2021 May 10
https://doi.org/10.3847/2041-8213/abf93d

CrossMark

SPLUS J210428.01−004934.2: An Ultra Metal-poor Star Identified from Narrowband Photometry*

Vinicius M. Placco[1], Ian U. Roederer[2,3], Young Sun Lee[4], Felipe Almeida-Fernandes[5], Fábio R. Herpich[5], Hélio D. Perottoni[5], William Schoenell[6], Tiago Ribeiro[7], and Antonio Kanaan[8]
[1] Community Science and Data Center/NSF's NOIRLab, 950 N. Cherry Avenue, Tucson, AZ 85719, USA; vinicius.placco@noirlab.edu
[2] Department of Astronomy, University of Michigan, Ann Arbor, MI 48109, USA
[3] JINA Center for the Evolution of the Elements, USA
[4] Department of Astronomy and Space Science, Chungnam National University, Daejeon 34134, Republic of Korea
[5] Departamento de Astronomia, Instituto de Astronomia, Geofísica e Ciências Atmosféricas da USP, Cidade Universitária, 05508-900, São Paulo, SP, Brazil
[6] GMTO Corporation 465 N. Halstead Street, Suite 250 Pasadena, CA 91107, USA
[7] Rubin Observatory Project Office, 950 N. Cherry Avenue, Tucson, AZ 85719, USA
[8] Departamento de Física, Universidade Federal de Santa Catarina, Florianópolis, SC 88040-900, Brazil
Received 2021 April 7; revised 2021 April 14; accepted 2021 April 15; published 2021 May 12



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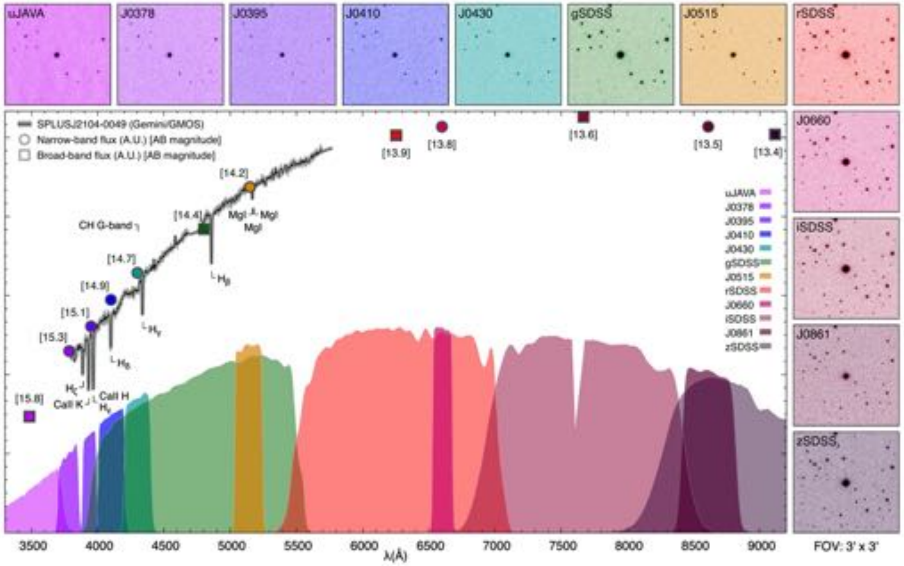
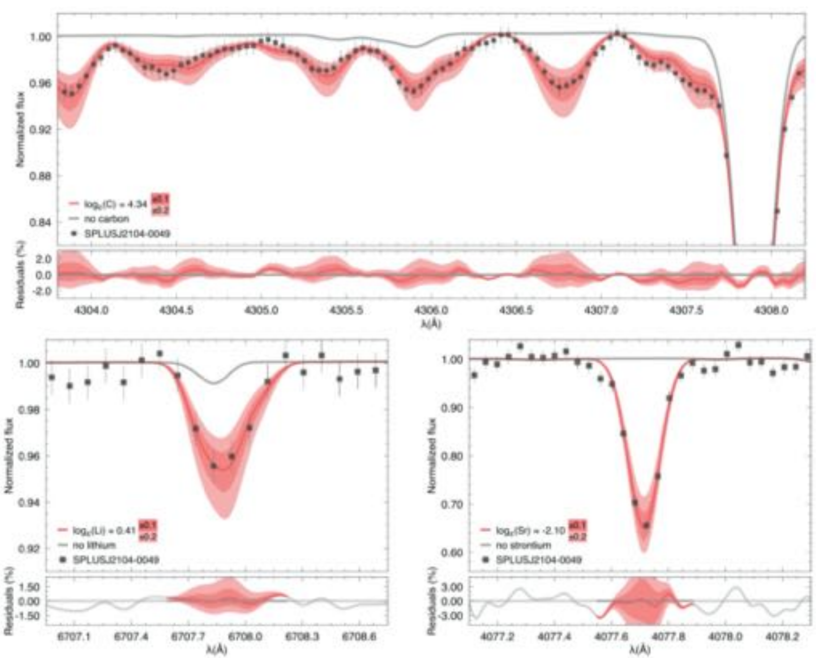
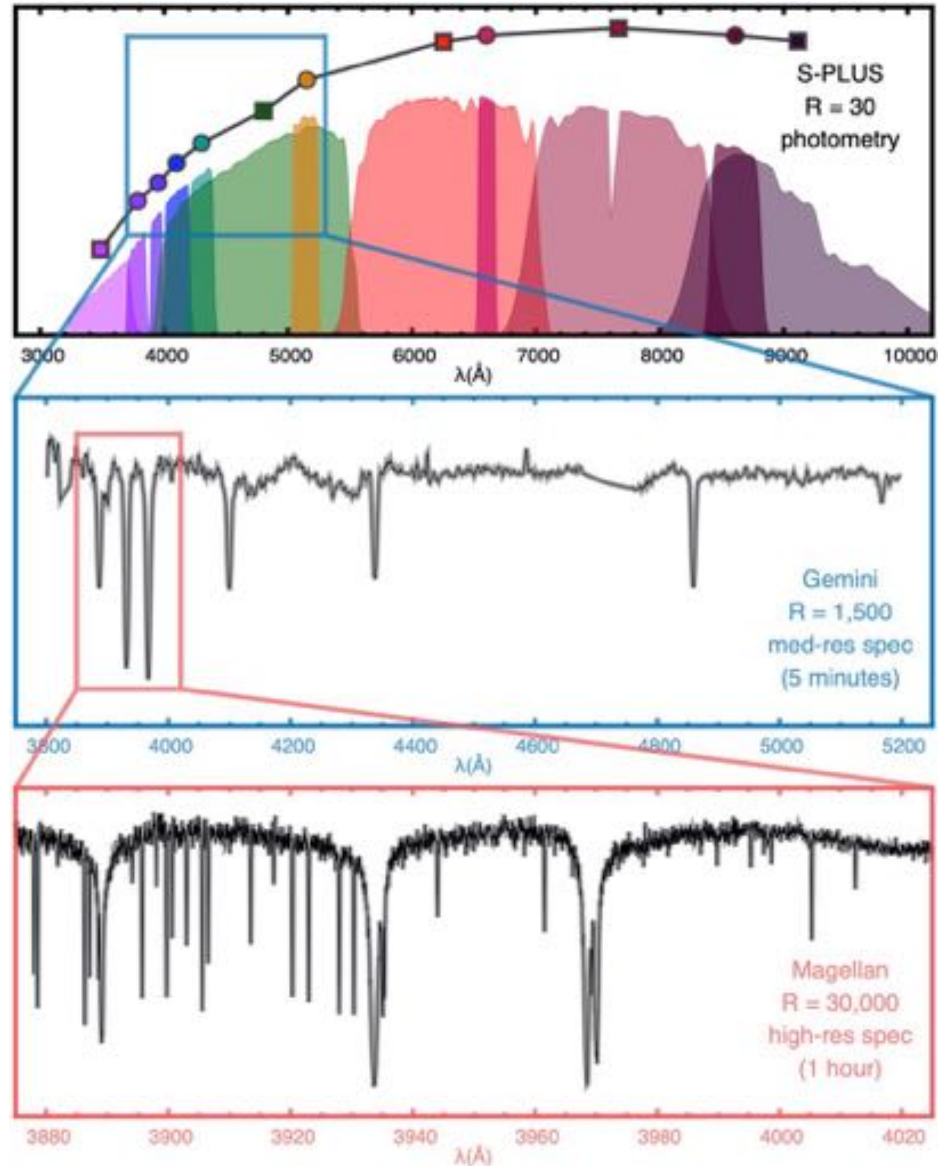
S-PLUS J210428.01-004934.2







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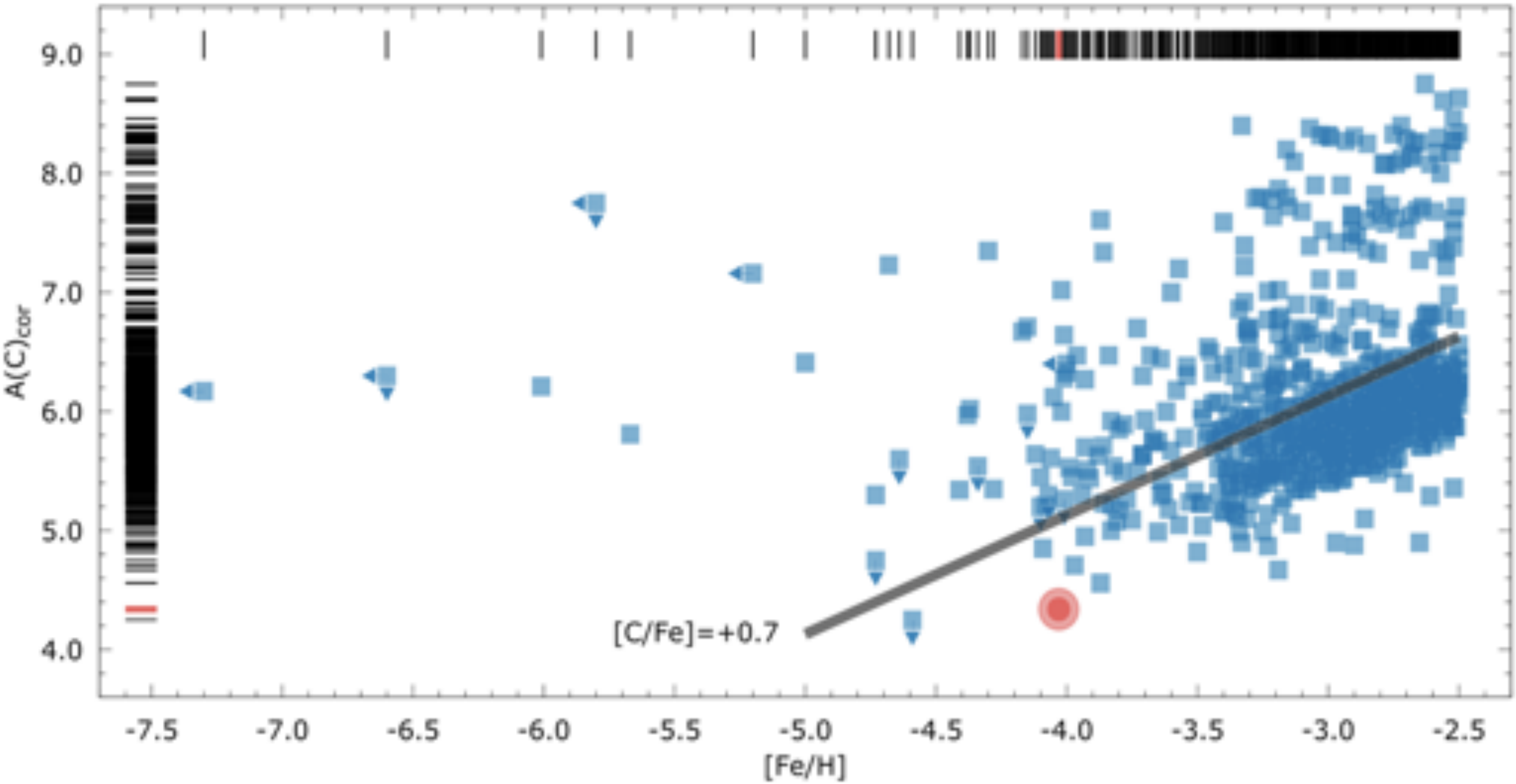
SPLUS J2104-0049 – where is the carbon?



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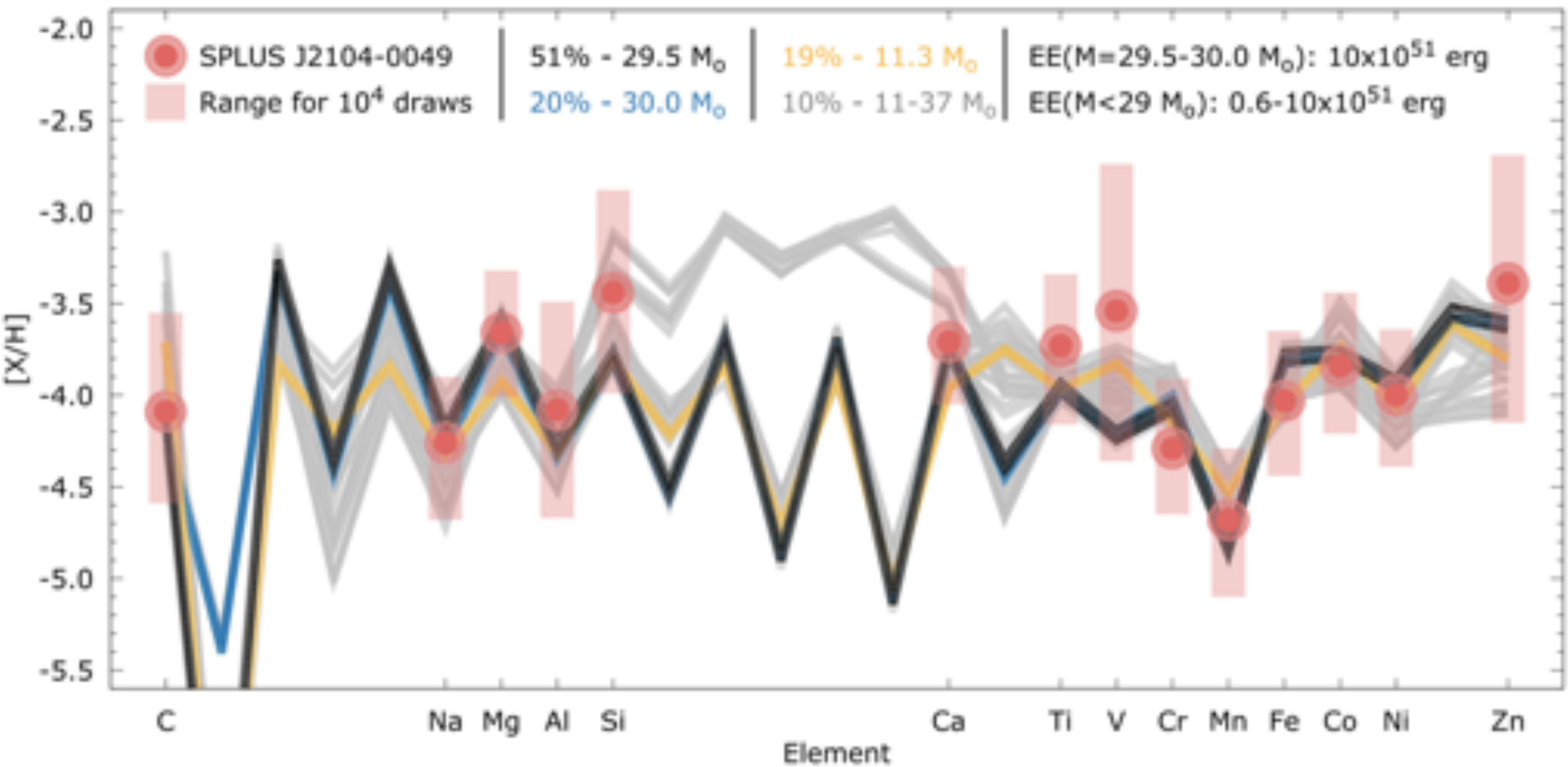
SPLUS J2104-0049 → what type of progenitor?



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Conclusions and next steps

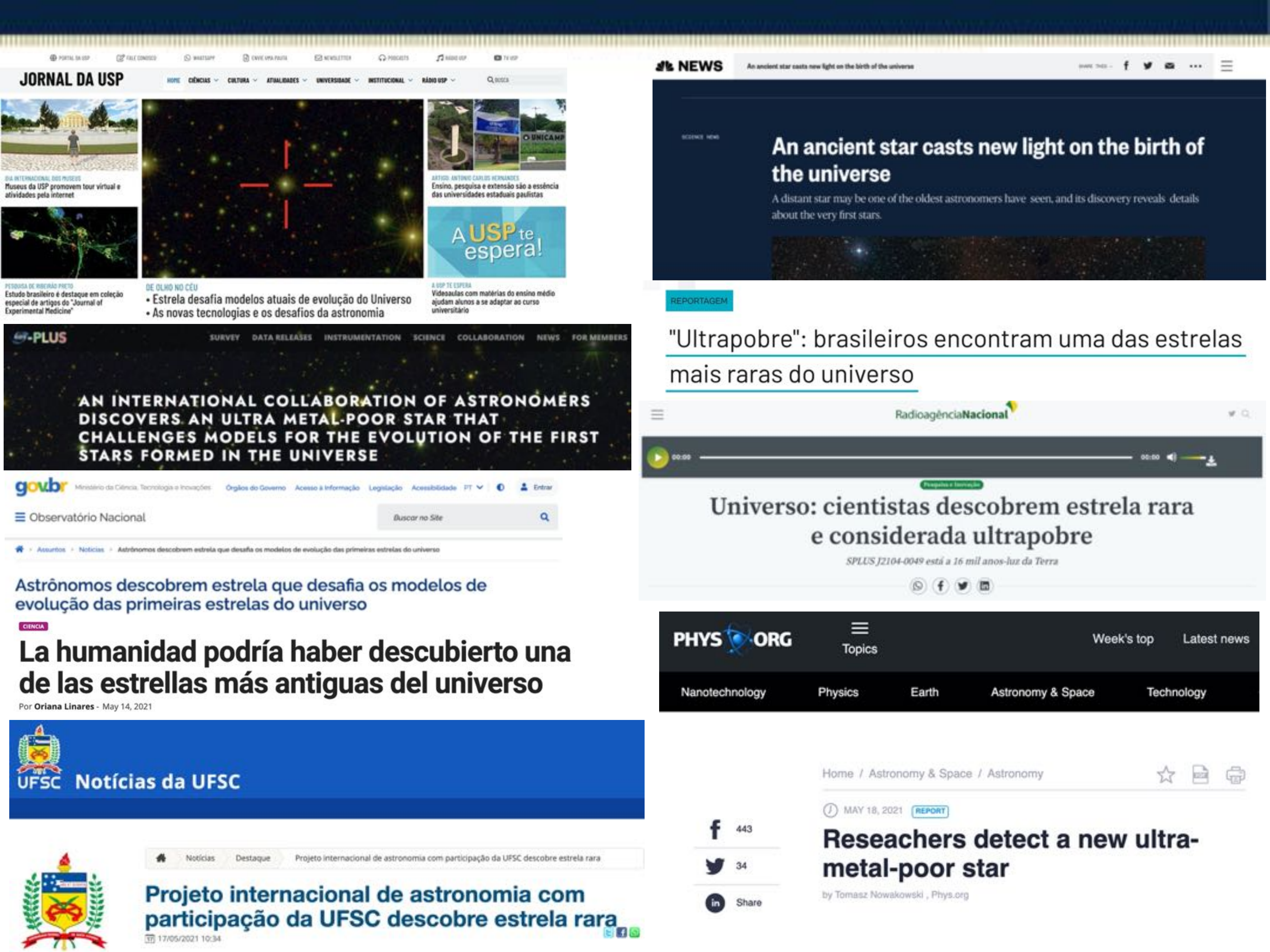
Near-Field Cosmology:
- Provides pieces to our collective “Astro Puzzle”
- Discovery and “incremental science”

Med-res follow-up proof of concept:
- 88% stars with [Fe/H] < -2.0
- 15% stars with [Fe/H] < -3.0

Narrow-band photometry:
- Statistics on metal-poor stars (10^7 stars)
- Conduct detailed chemical studies
- Targeting!!!

Carbon Enhanced Stars:
- Addressing first-star nucleosynthesis
- Constrain the primordial IMF

Chemodynamical studies using GAIA for all of the above!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SURVEY DATA RELEASES INSTRUMENTATION SCIENCE COLLABORATION NEWS FOR MEMBERS
AN INTERNATIONAL COLLABORATION OF ASTRONOMERS DISCOVERS AN ULTRA METAL-POOR STAR THAT CHALLENGES MODELS FOR THE EVOLUTION OF THE FIRST STARS FORMED IN THE UNIVERSE
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Universo: cientistas descobrem estrela rara e considerada ultrapobre
SPLUS J2104-0049 está a 16 mil anos-luz da Terra
gov.br
Observatório Nacional
Astrônomos descobrem estrela que desafia os modelos de evolução das primeiras estrelas do universo
CIENCIA
La humanidad podría haber descubierto una de las estrellas más antiguas del universo
Por Oriana Linares - May 14, 2021
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