The Origin of the Elements

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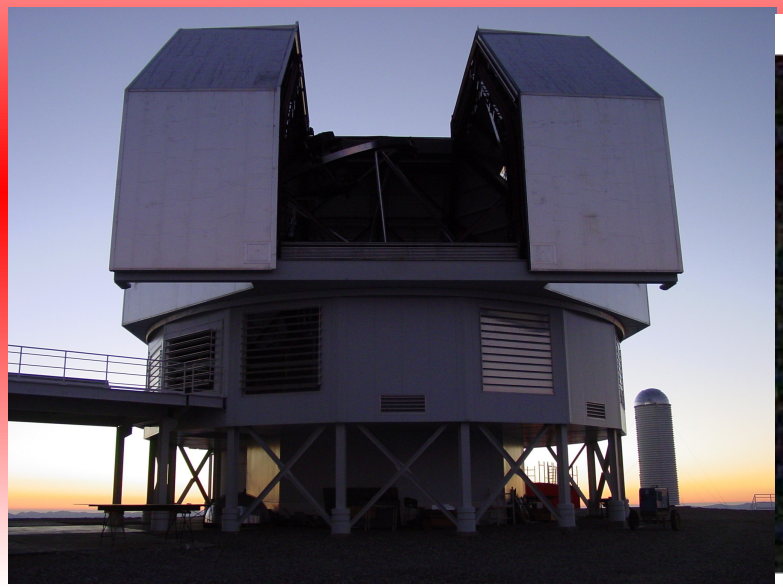
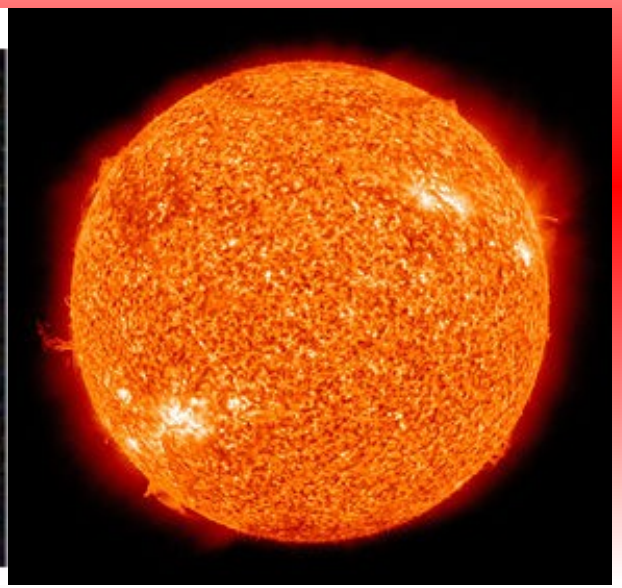
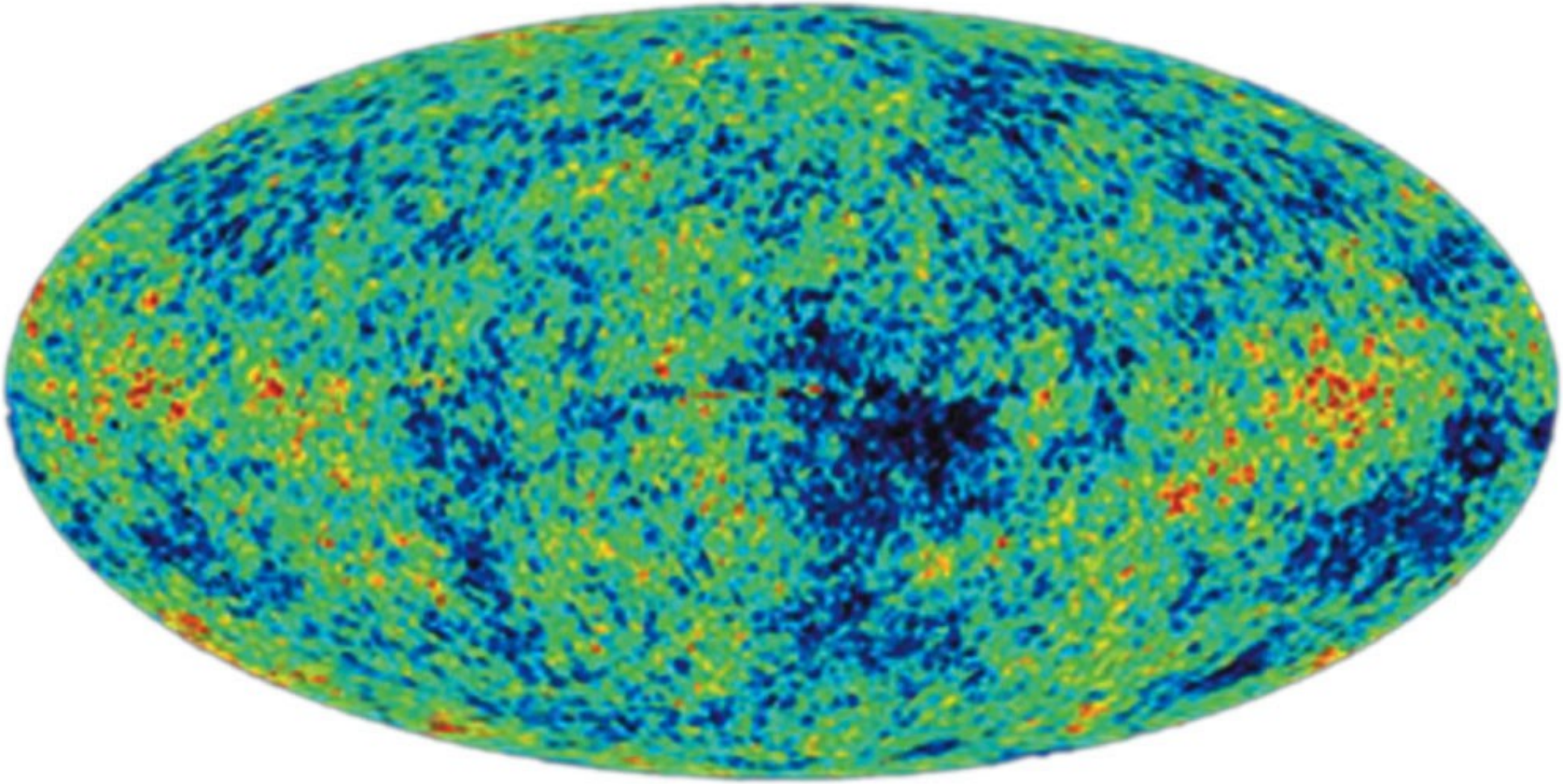
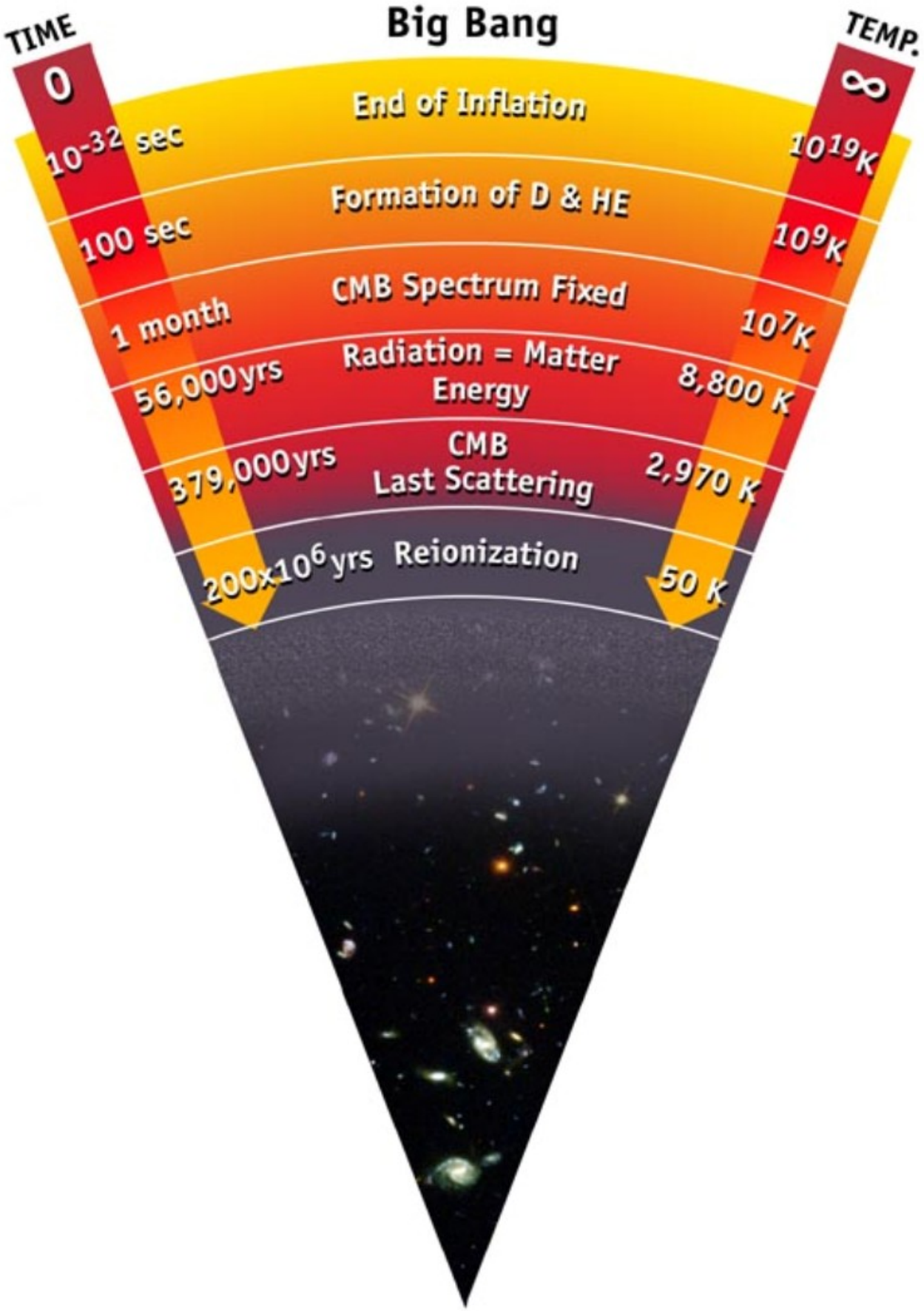




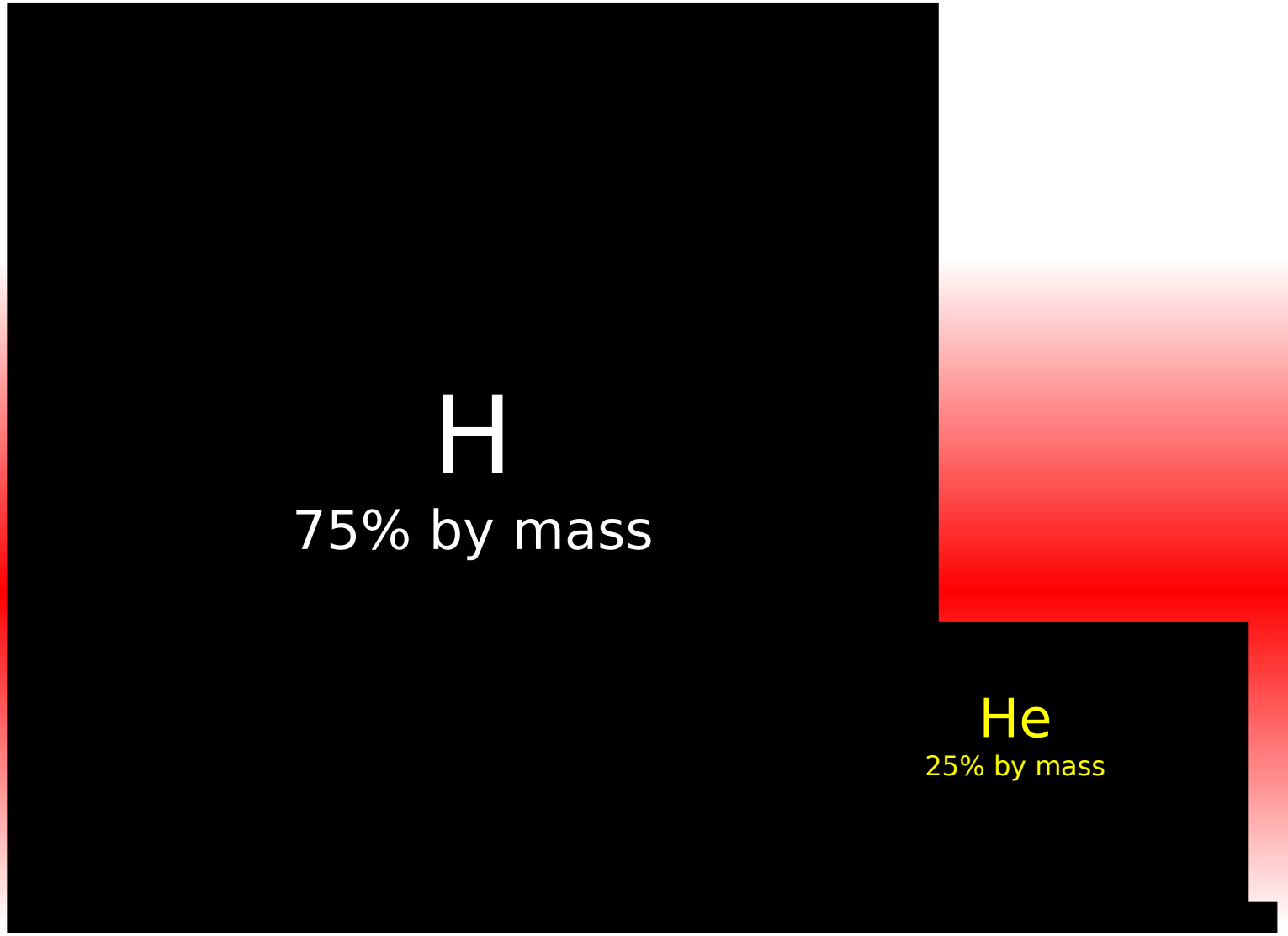
Public Astronomy Lecture Series
The University of Louisville
March 10, 2016



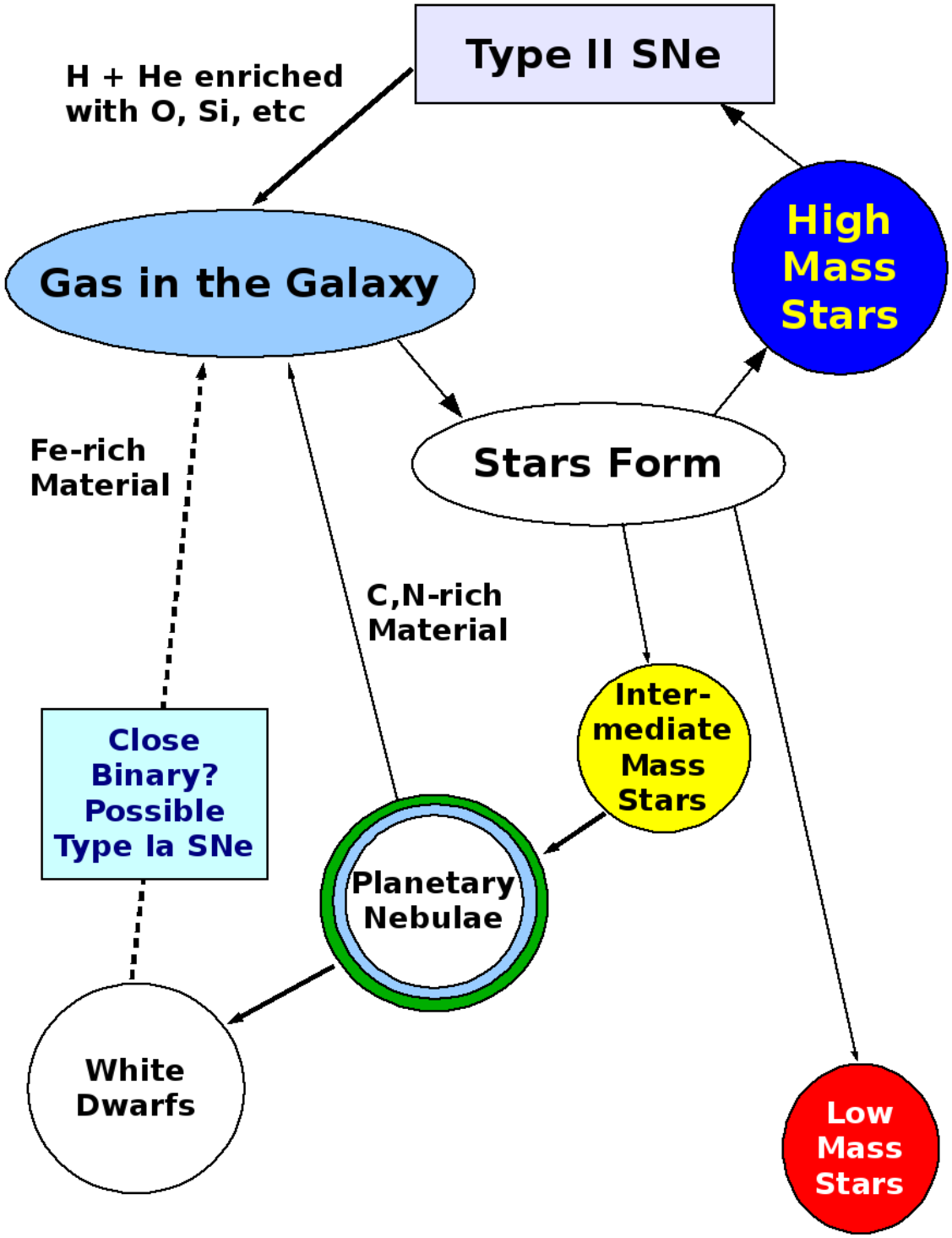
NASA's Wilkinson Microwave Anisotropy Probe (WMAP) Science Team

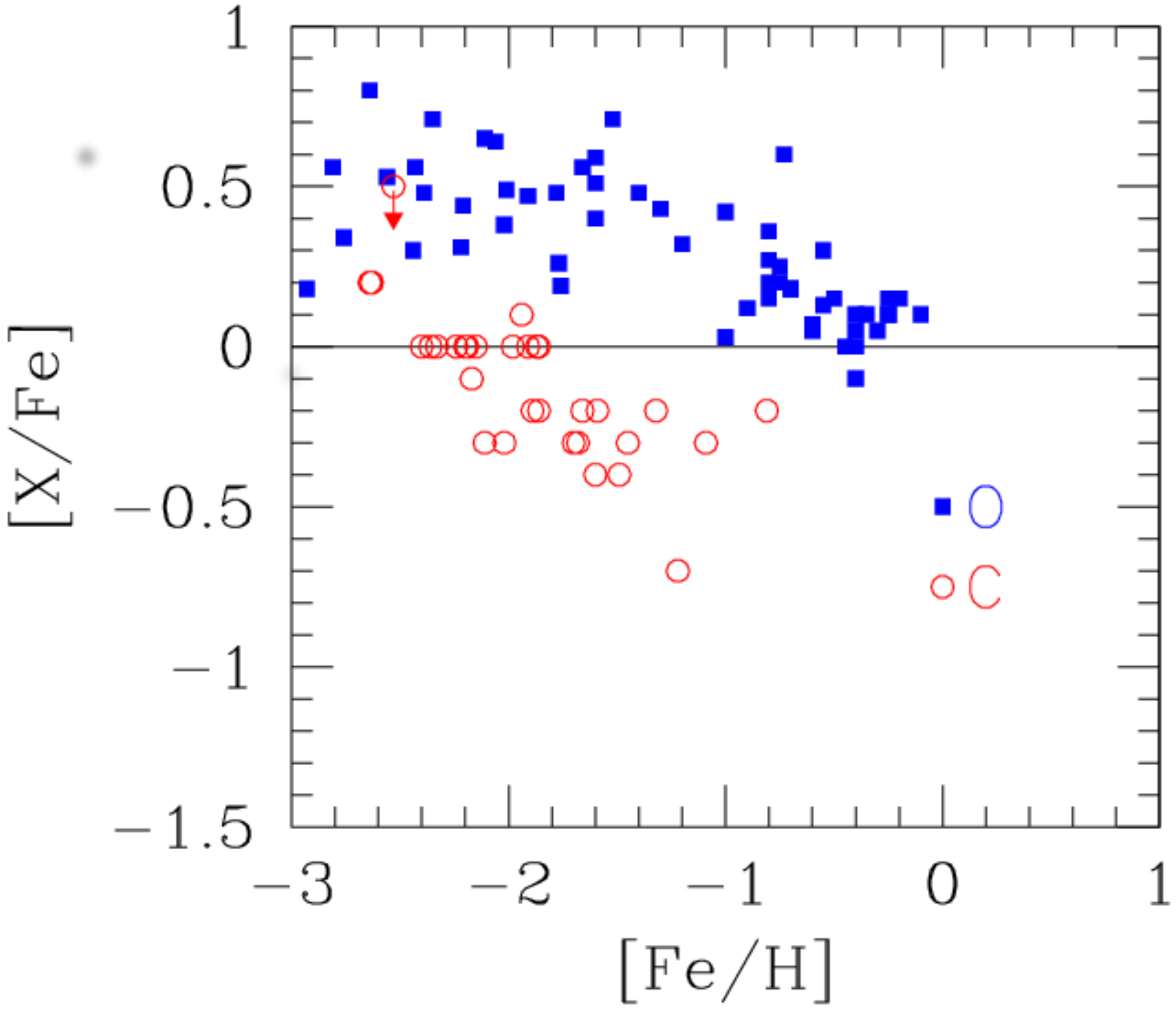


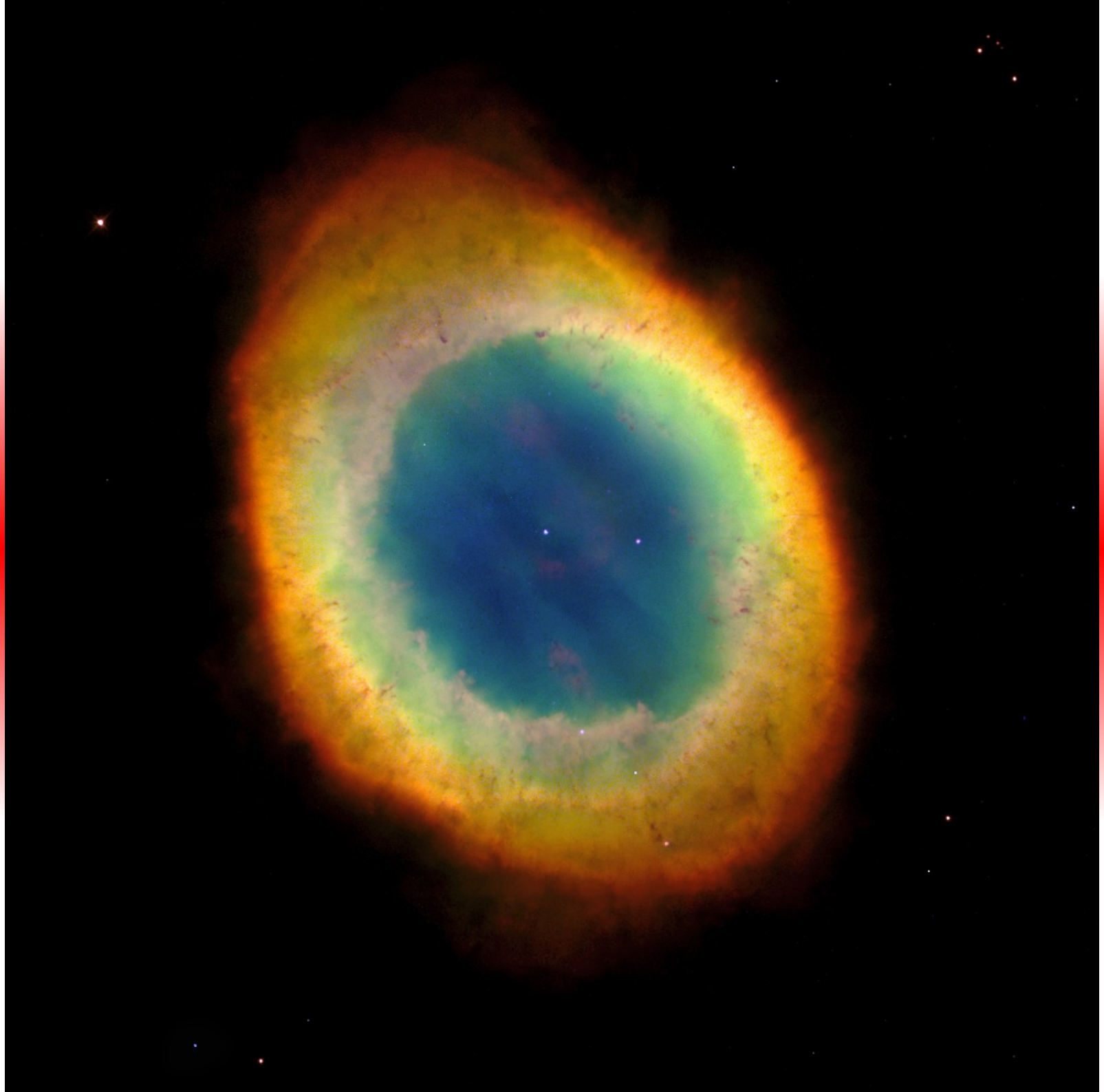
PRESENT
13.7 Billion Years after the Big Bang

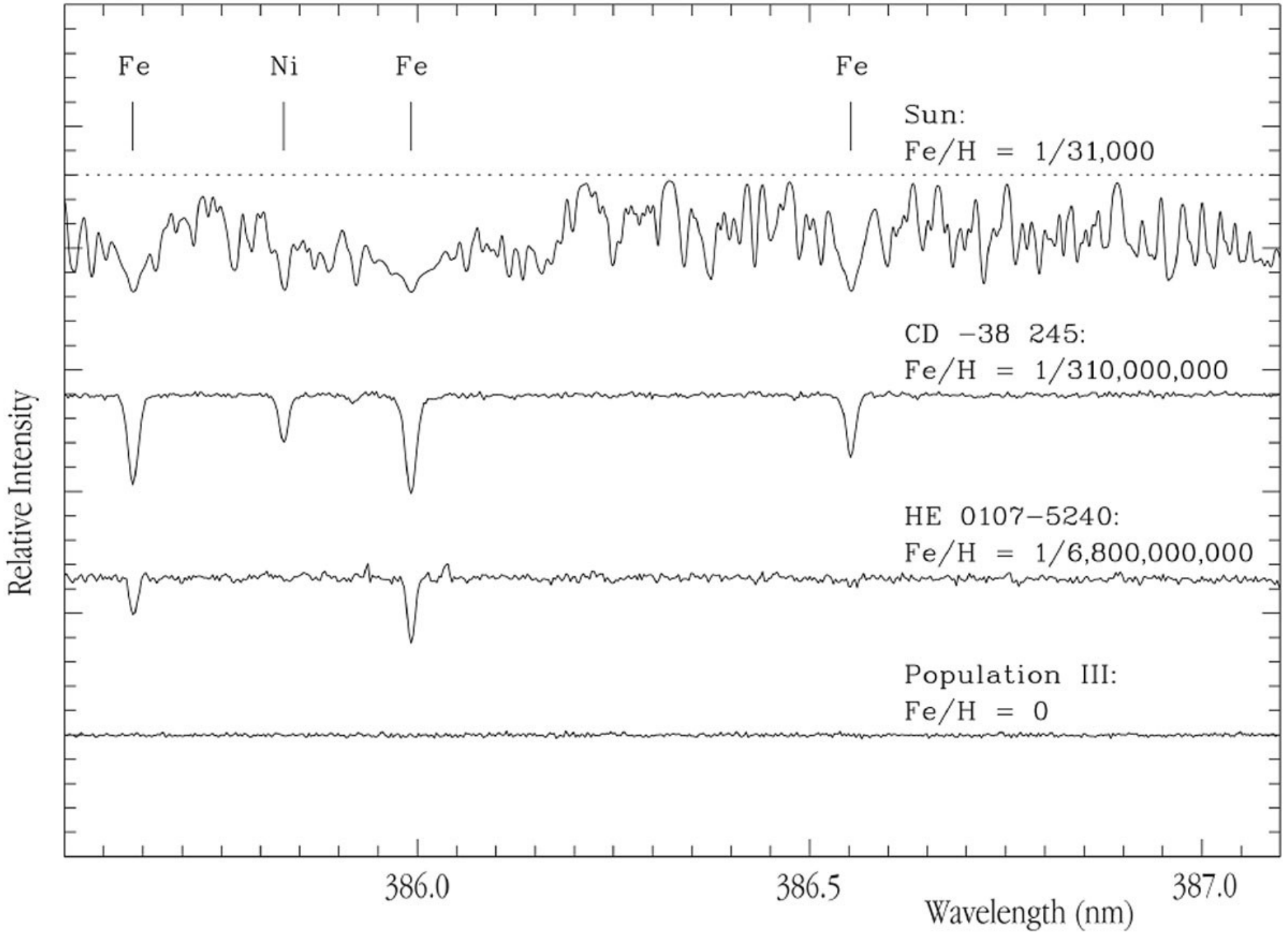


The Big Bang Periodic Table


Type II SNe
H + He enriched
with O, Si, etc
Gas in the Galaxy
High
Mass
Stars
Fe-rich
Material
Stars Form
C,N-rich
Material
Inter-
mediate
Mass
Stars
Close
Binary?
Possible
Type Ia SNe
Planetary
Nebulae
White
Dwarfs
Low
Mass
Stars


1
0.5
0
−0.5
−1
−1.5
[X/Fe]
−3
−2
−1
0
1
[Fe/H]
O
C





Spectra of Stars with Different Metal Content

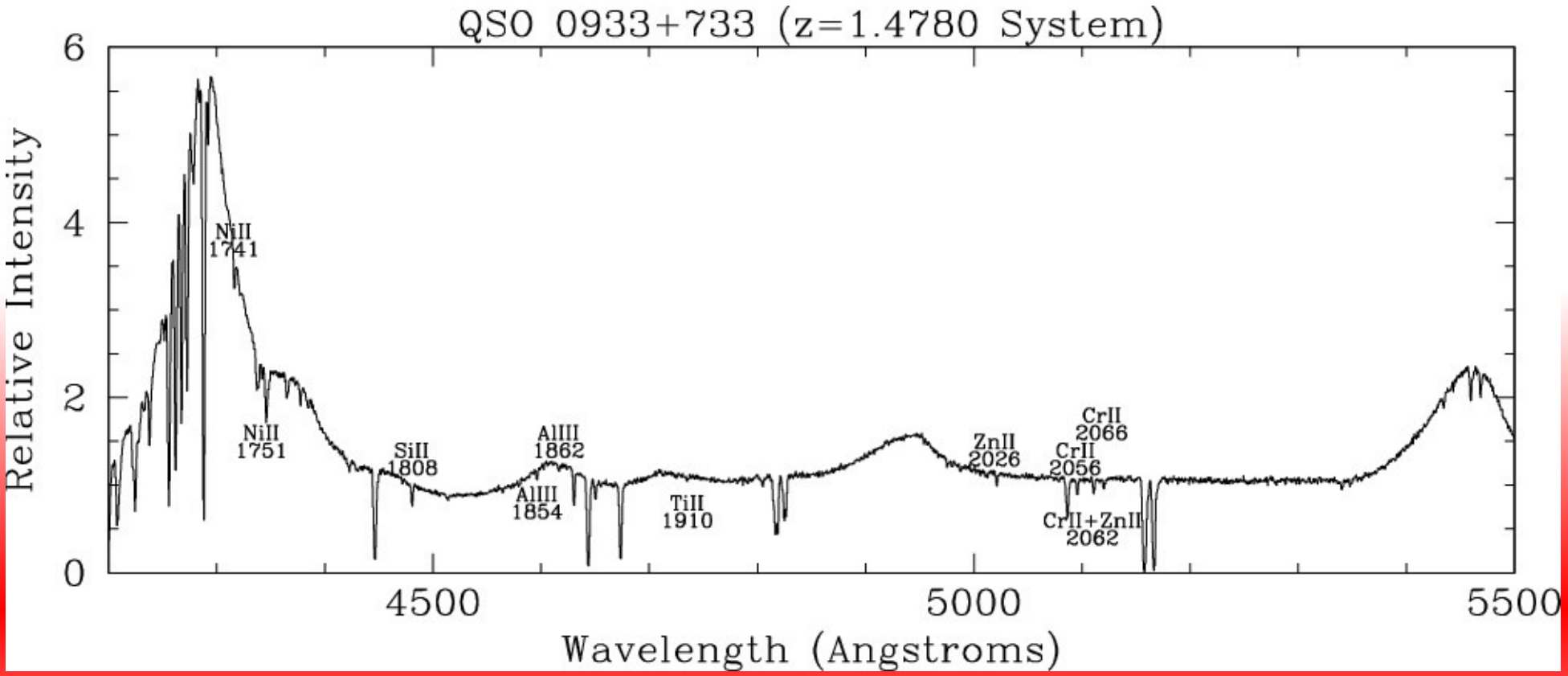
ESO PR Photo 25b/02 (30 October 2002)

How can we study the build up of the elements in the Universe?

1) study the abundances in Galactic stars as a function of age.

2)measure the average star formation history using deep imaging and redshift surveys - then infer the evolution of the elements.

3) directly measure abundances in samples of galaxies at high redshifts.



There is another method to directly measure abundances in galaxies by using the absorption lines which can be seen in the spectra of QSOs due to foreground galaxies.

The technique that my collaborators and I use is to take spectra of quasars (QSOs), the bright point-like emission from gas falling into super-massive black holes in the center of galaxies.

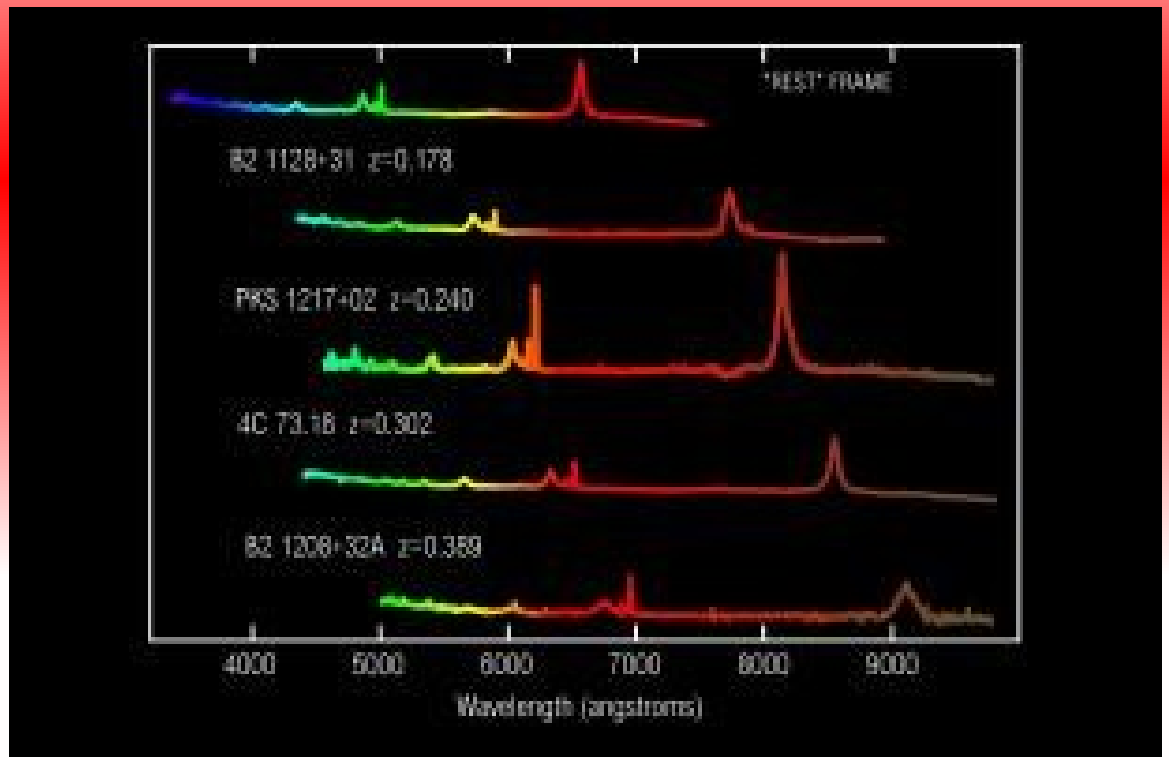
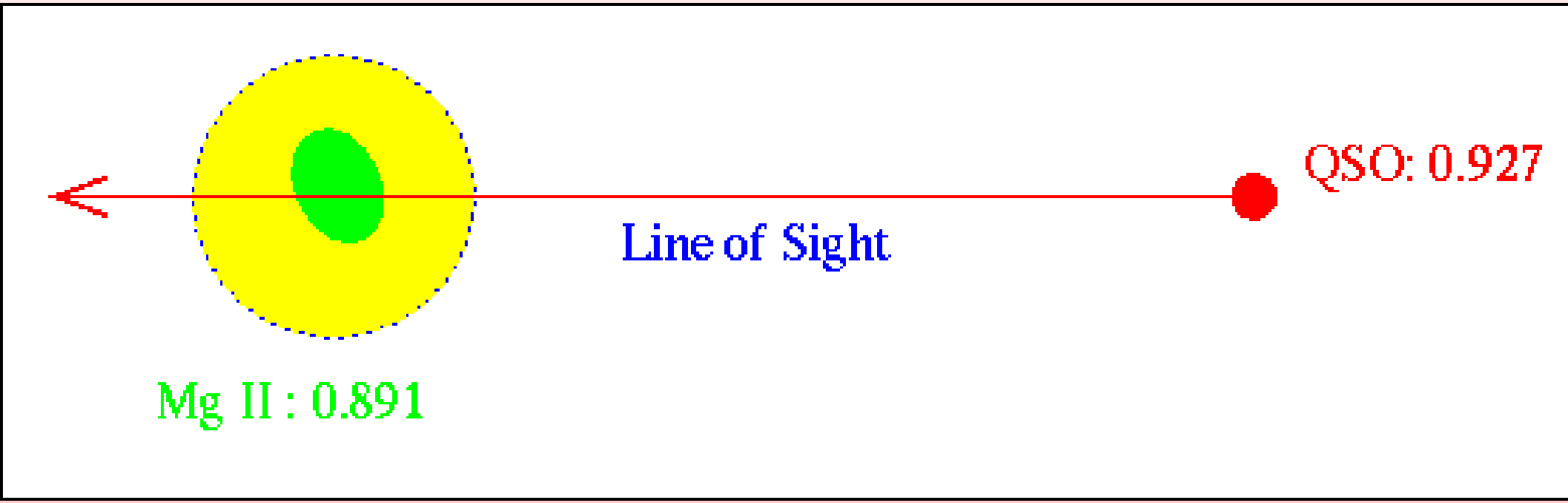


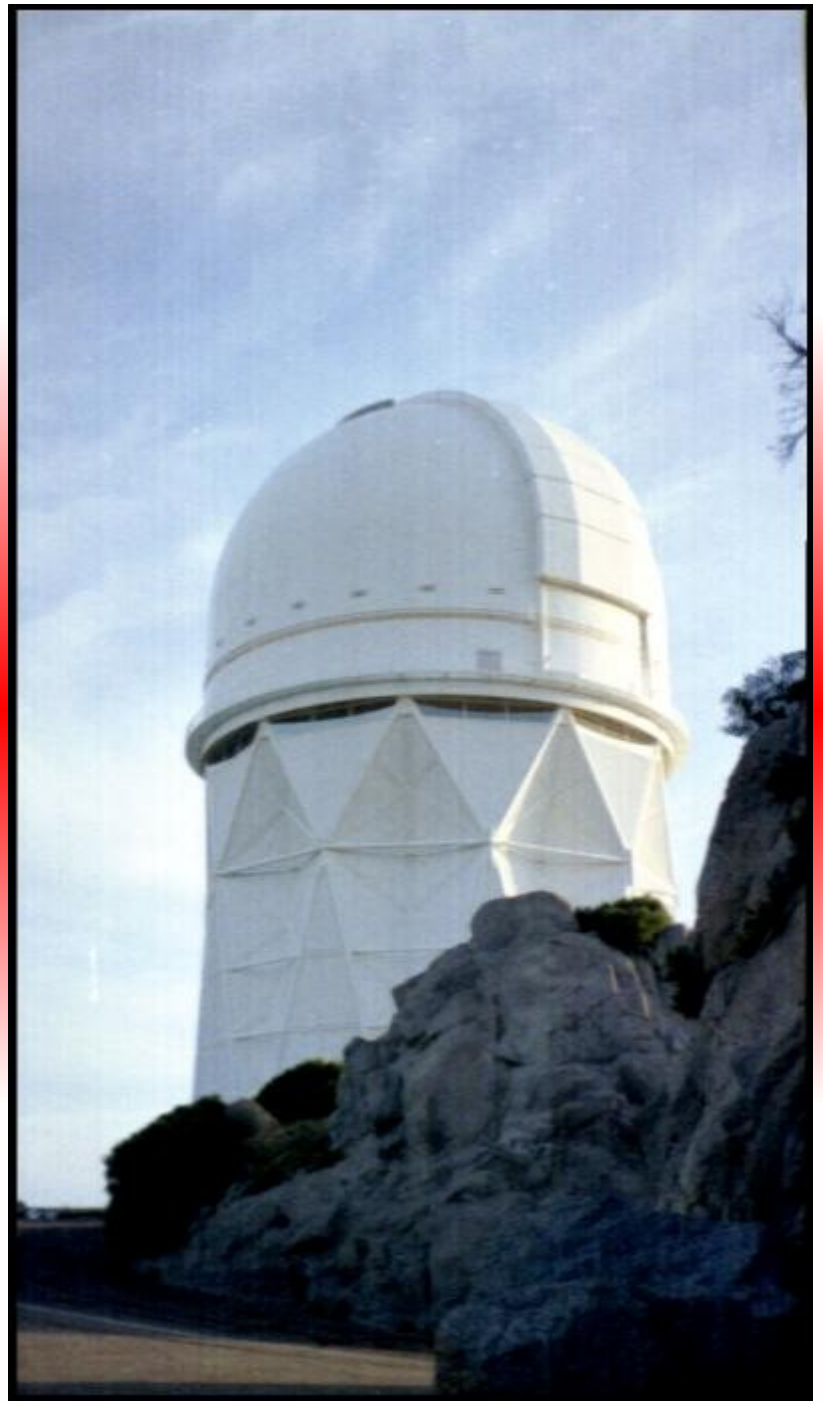
Image courtesy of KPNO (C. Pilachowski, M. Corbin/NOAO/AURA/NSF)



Schematic view of a QSO absorption line system (Chris Churchill, NMSU).

Some Advantages of QSO Absorbers:

1) QSOs are bright point sources.
2) Abundances of many elements can be measured.
3) The galaxies selected are not biased by their luminosities, so galaxies with low amounts of star formation can be probed.



Some Disadvantages of QSO Absorbers:

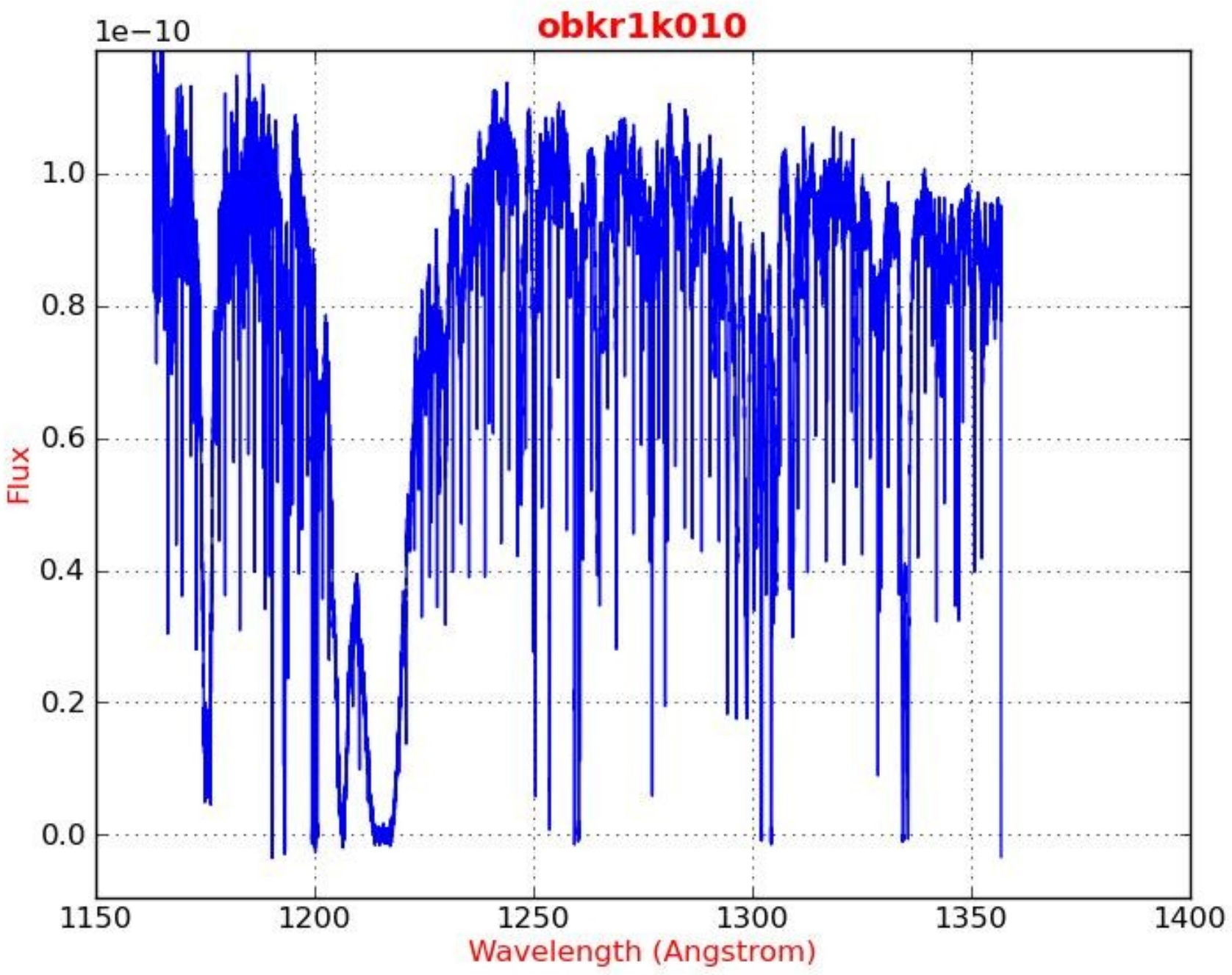
1) Possible obscuration due to foreground dust.
2) The galaxy sample is biased toward objects with large gas contents and/or extents.

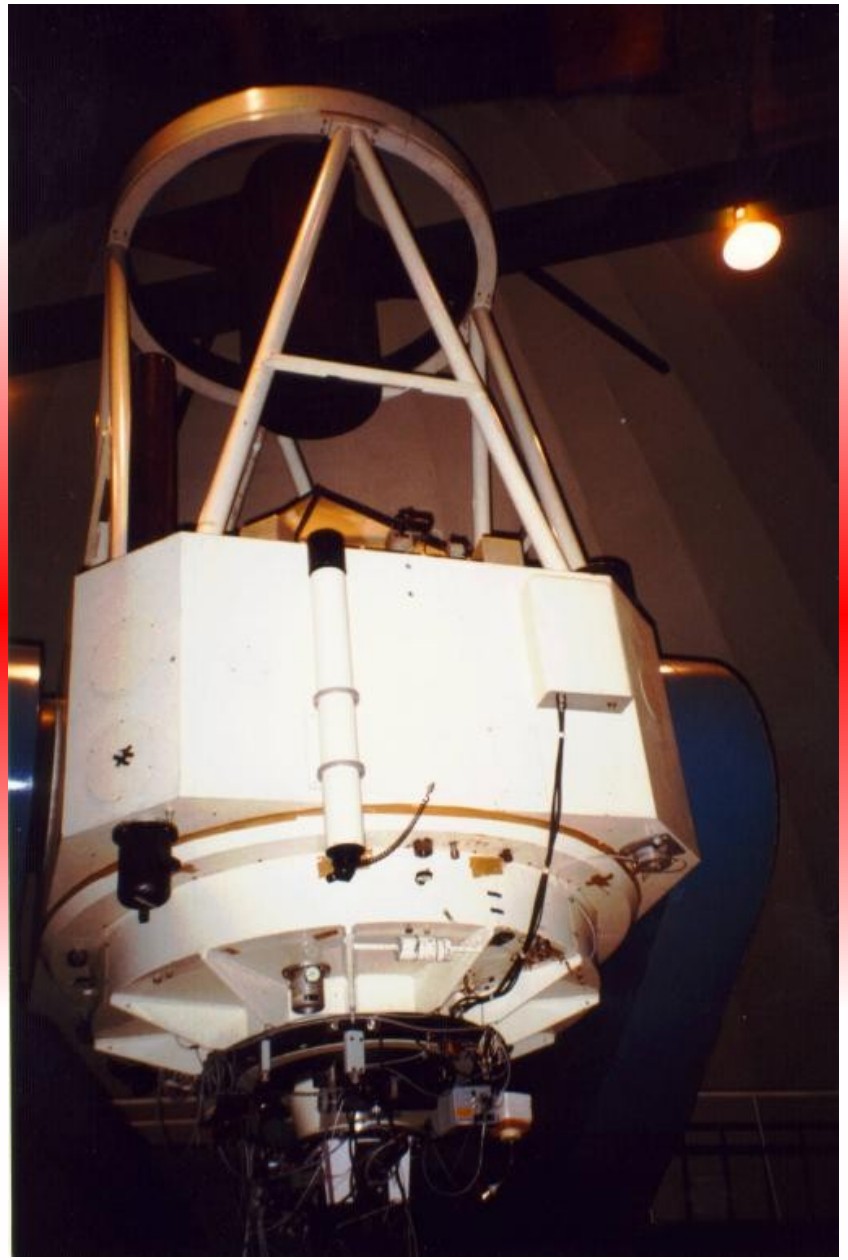
And the Big Disadvantage:

3) Galaxies without gas do not show up in these surveys.

Ultraviolet surveys using satellites such as *HST* of gas in the Milky Way and nearby galaxies provide benchmarks to understand the interstellar abundance patterns and physical condition diagnostics (to determine T, P, ρ) locally for comparison to high redshift galaxies.

Local Benchmarks

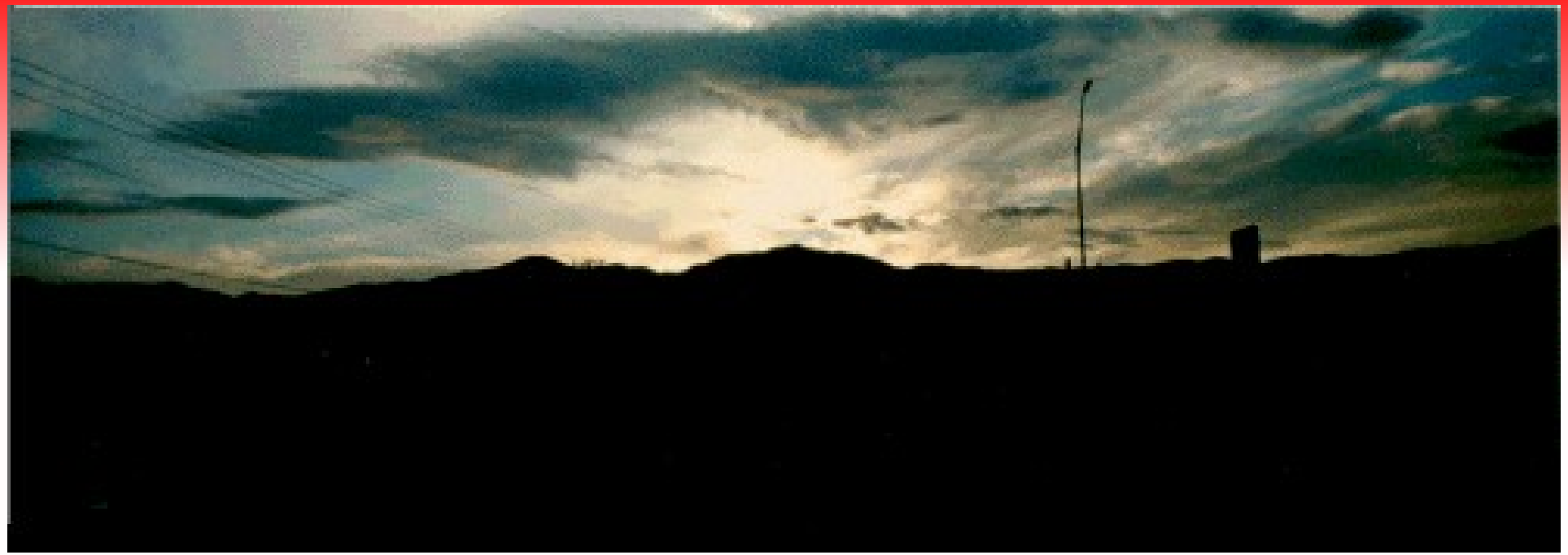


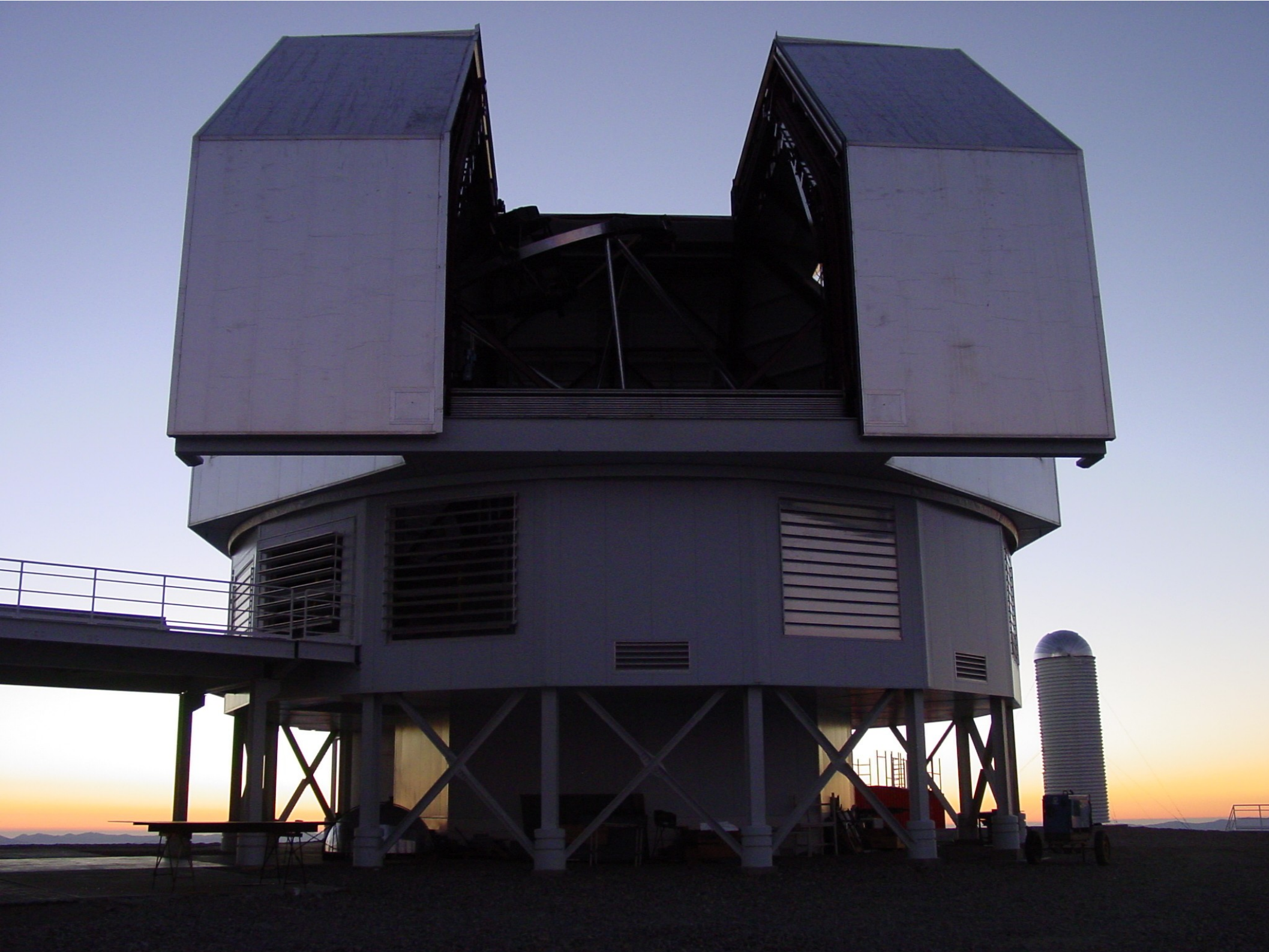


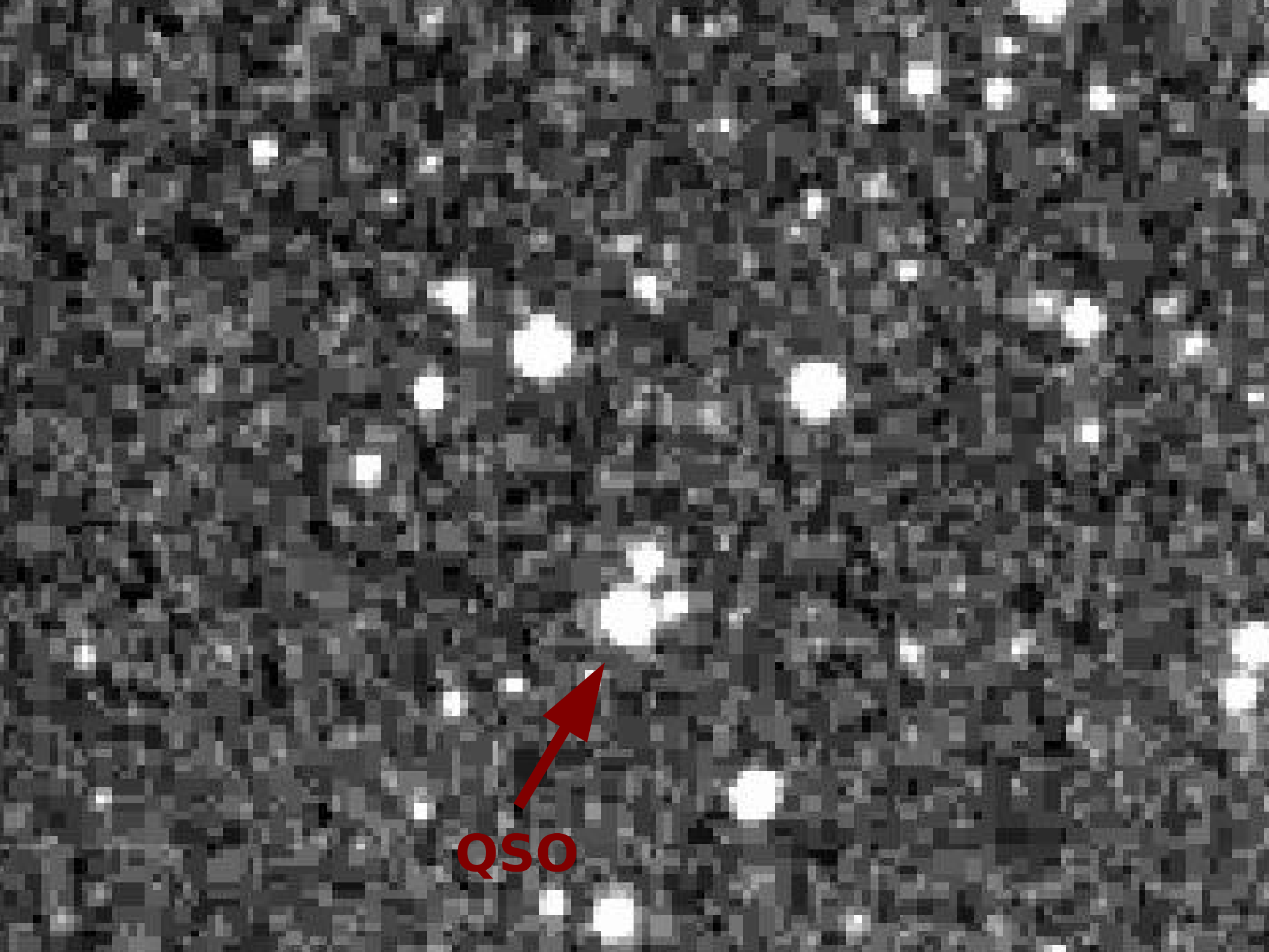
Dust composition can be measured by comparing the abundances of elements not found in dust in the Galaxy and Magellanic Clouds (ex. S and Zn) to elements with the same origin that are found in dust (ex. Si and Fe).

The amount of dust can be inferred from the fraction of Si and Fe which must be in dust.

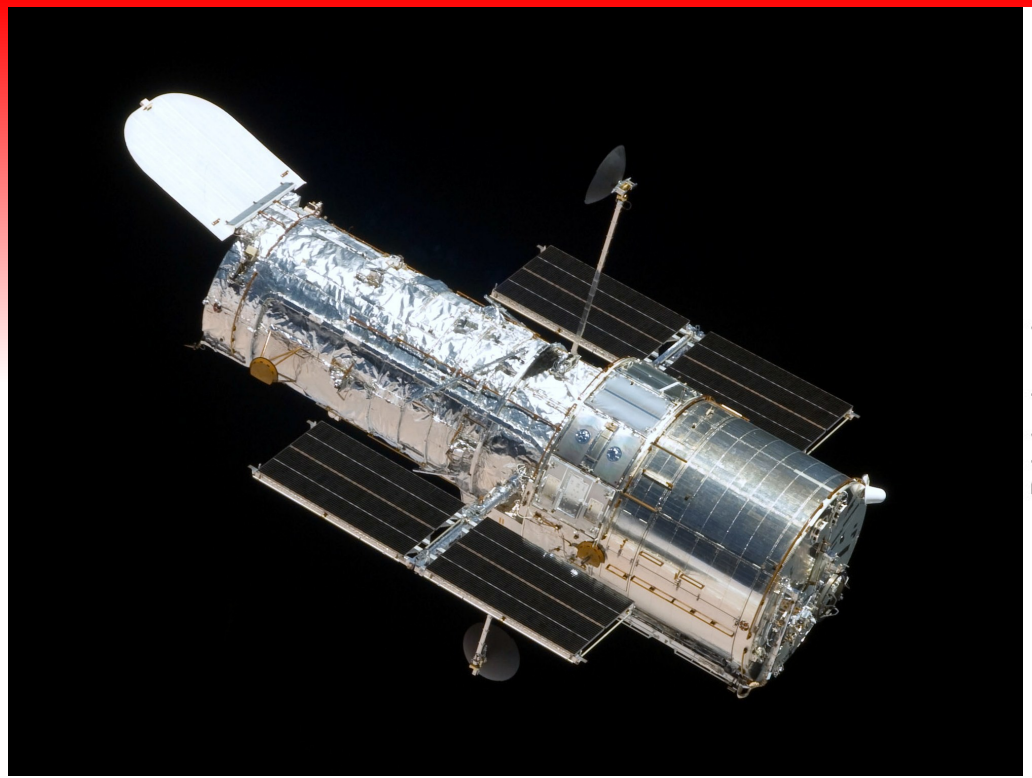
Even for the brightest QSOs, abundance measurements in even a single foreground galaxy can take several hours on the largest telescopes, thus large samples have only recently been measured.

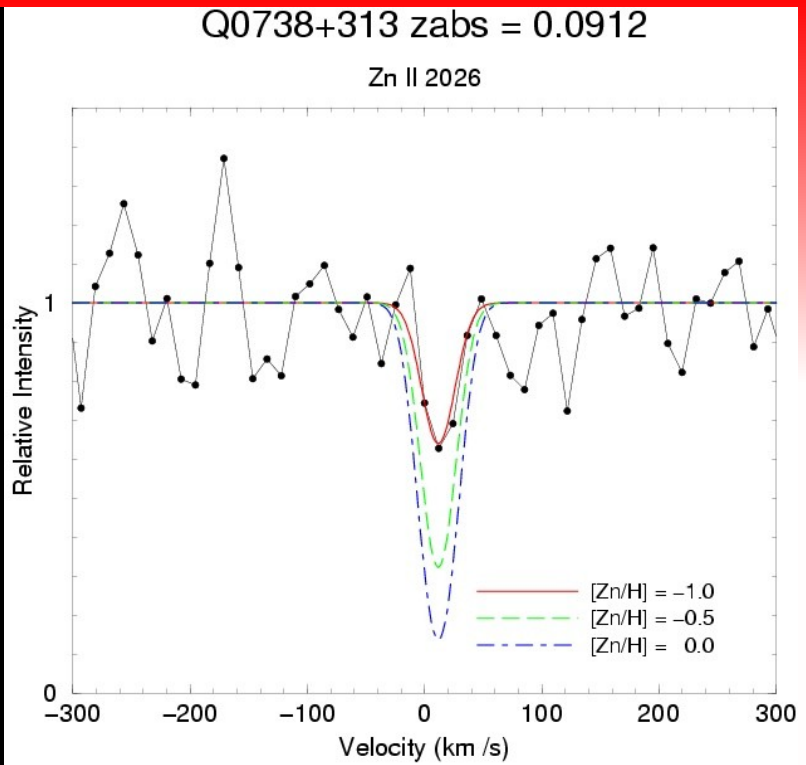





QSO

The lines we wish to study lie in the rest frame ultra-violet portion of the spectrum, so until galaxies are at high enough redshifts these lines do not lie in the optical and thus we must use a space based telescope namely the Hubble Space Telescope.





Sample absorption lines from Magellan/MIKE observations of Q1224+0037.

This galaxy has abundances ~0.025x Solar.

These data took 1.5 hours to obtain.

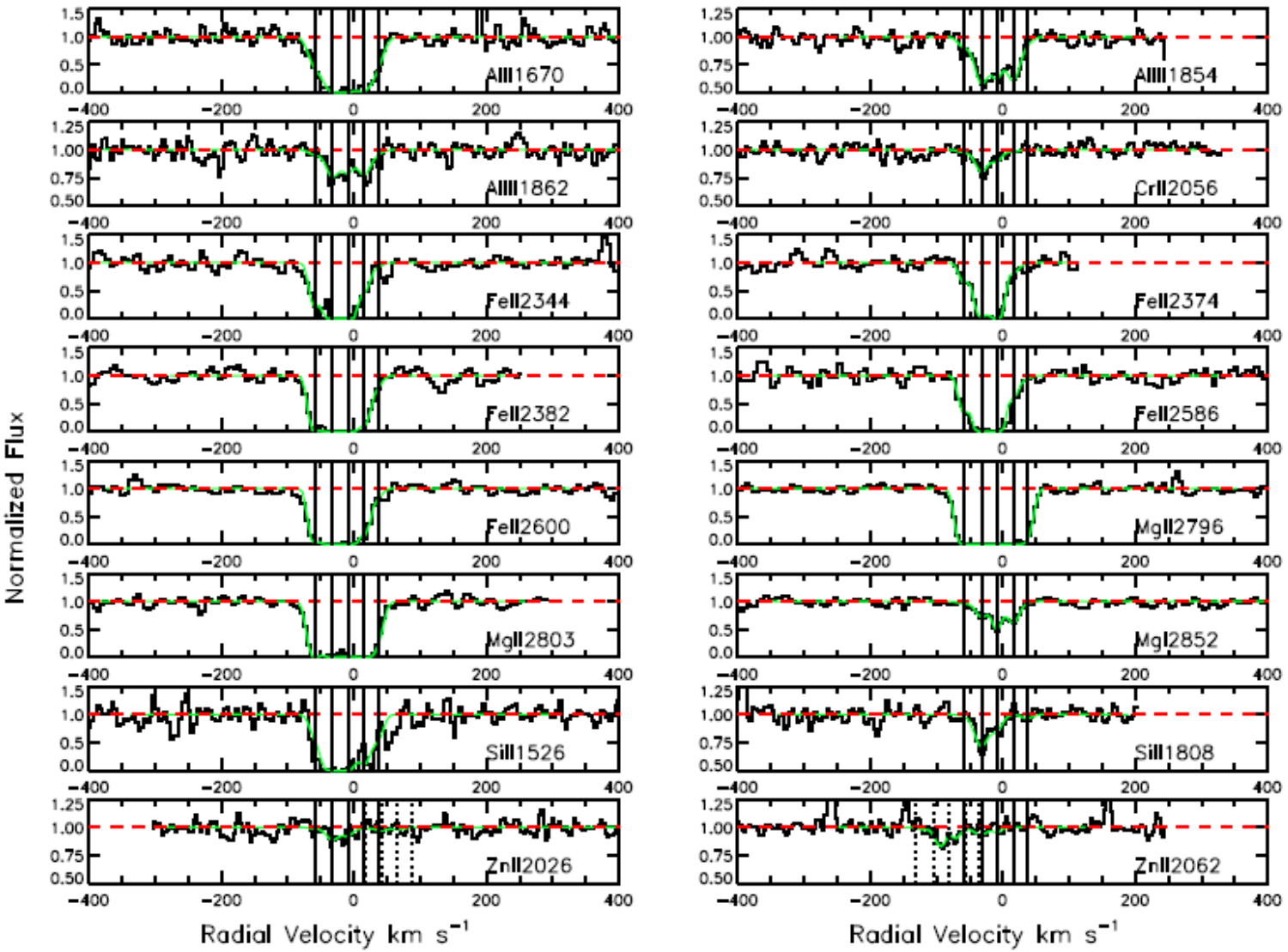
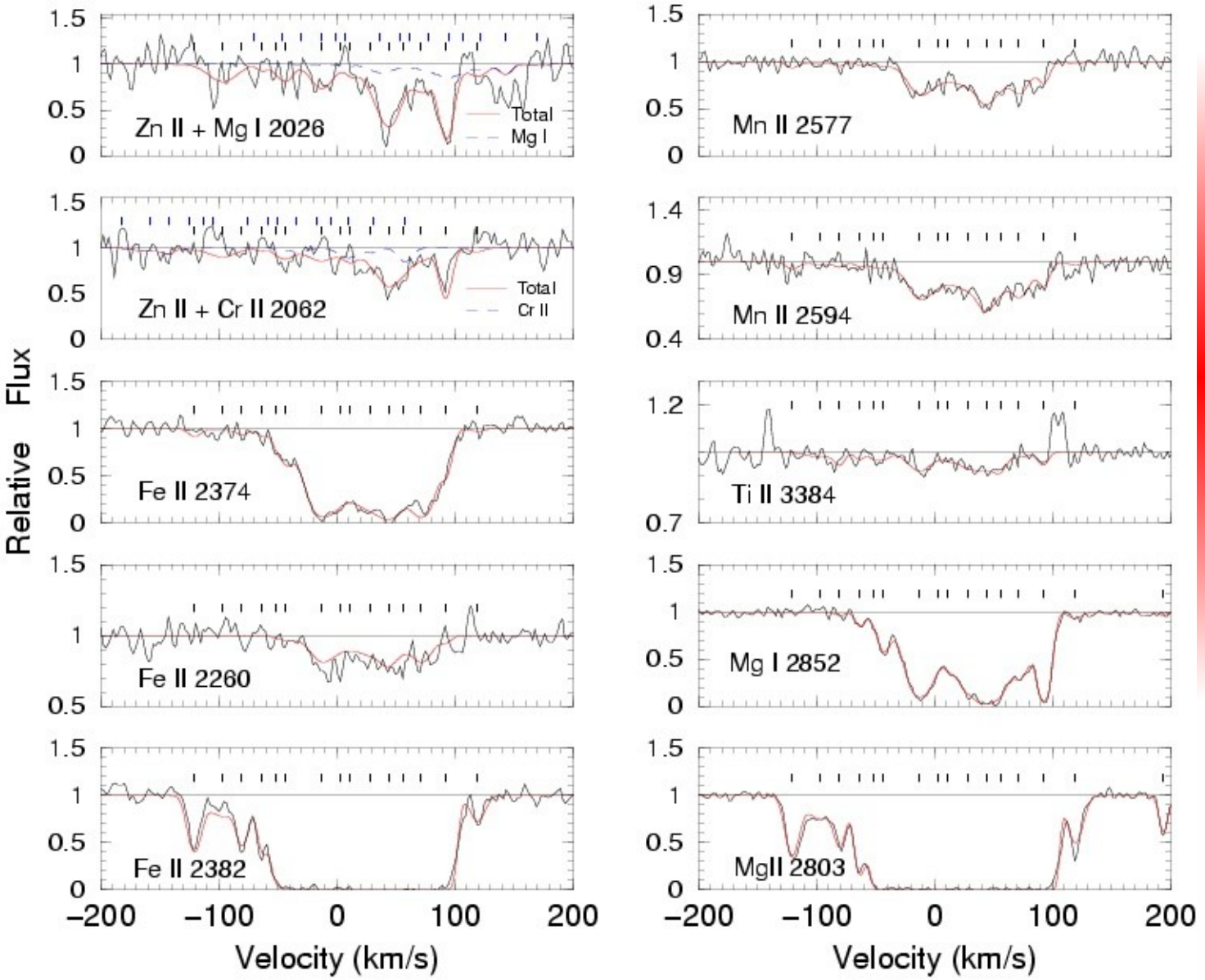


Figure 6. The same as fig.1, but for the z=1.2346 system in the spectrum of Q1224+0037

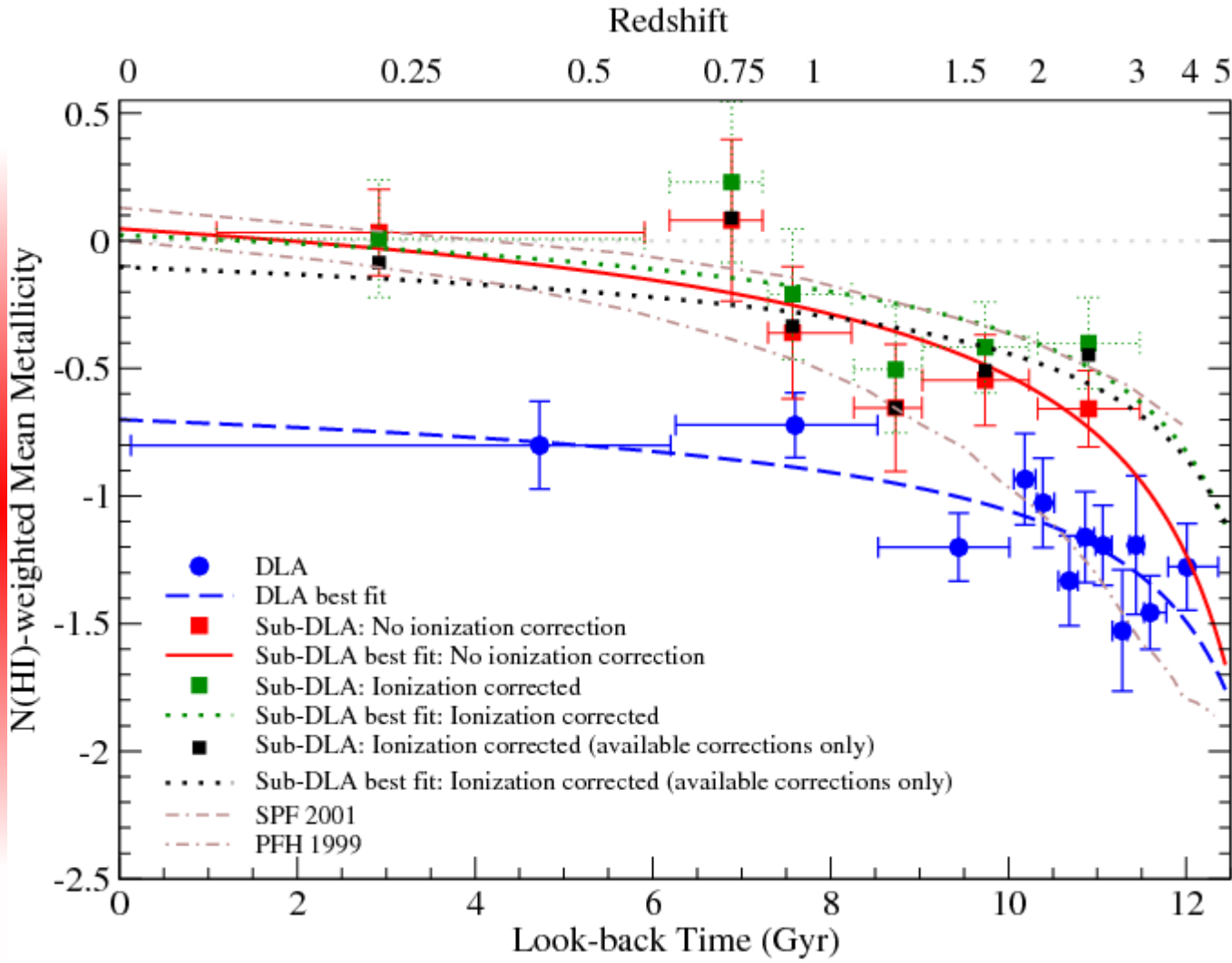
Sample absorption lines from VLT/UVES observations of SDSS J1323-0021.

When observed (March 2005) this was the most metal-rich system known, ~4x Solar.

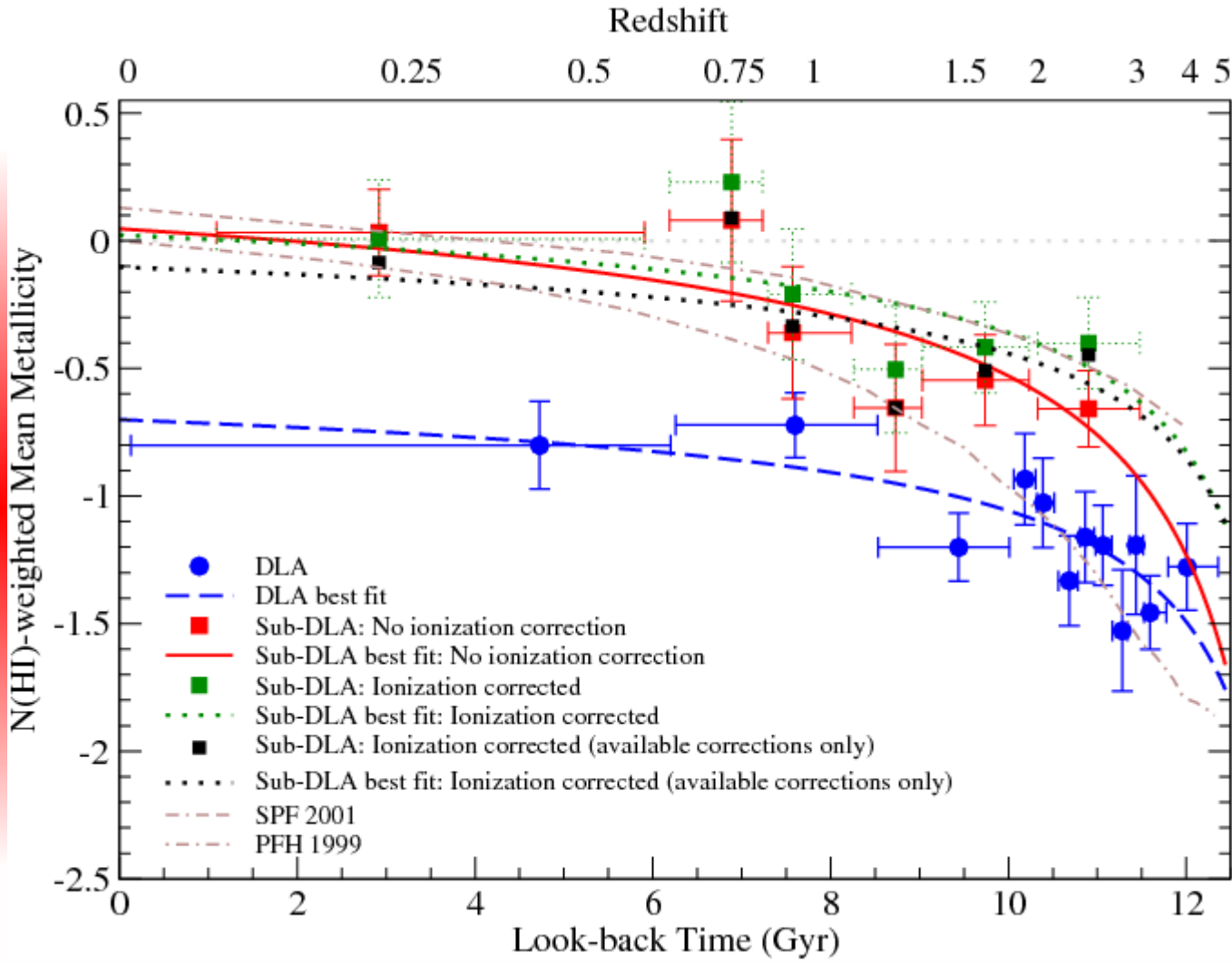
It took 3.2 hours for this one object.

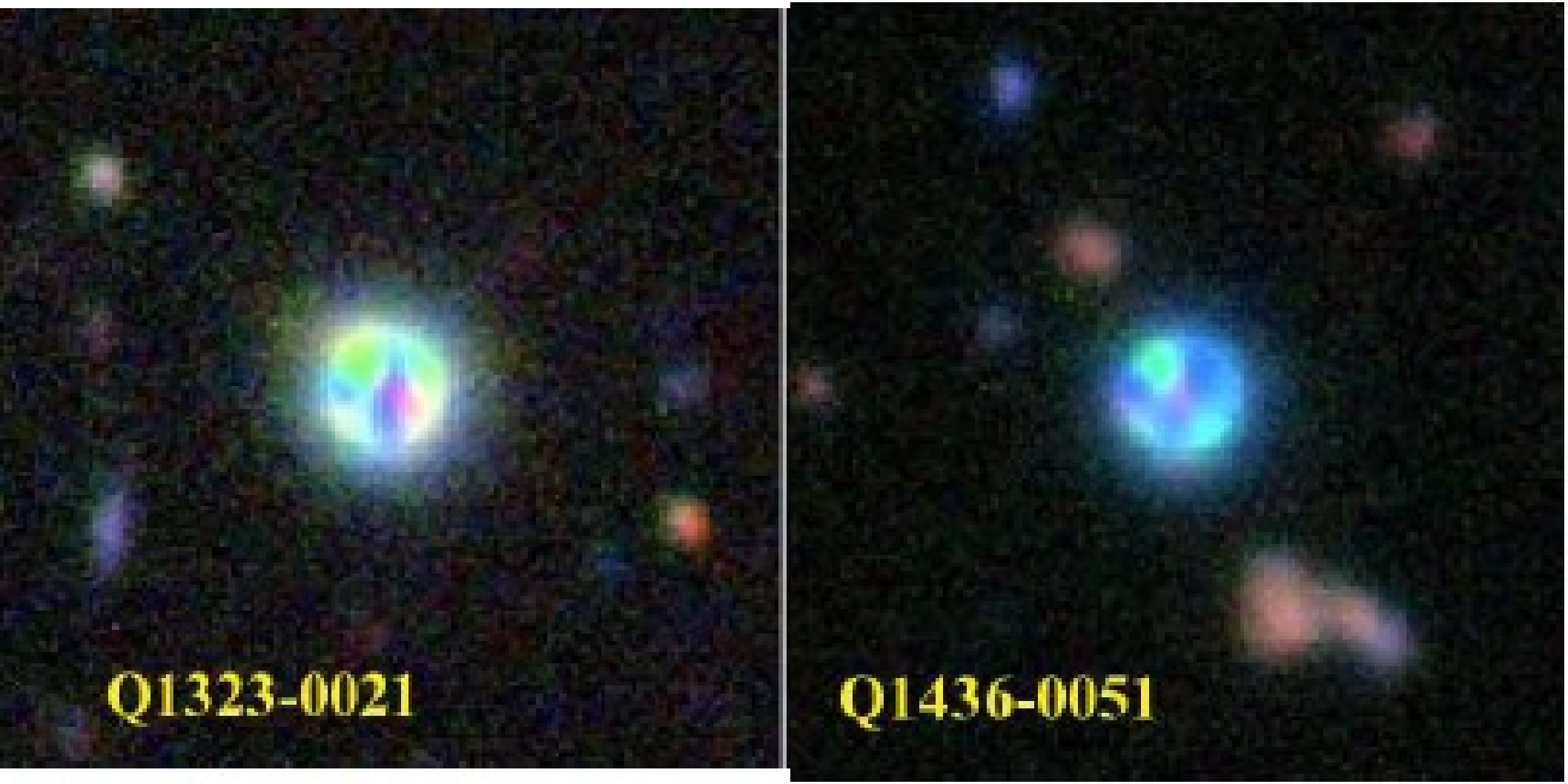


Observations of slightly less gas-rich systems have shown that their abundances are significantly higher than gas rich systems.



Perhaps because they have converted more gas into stars (and thus have had more SNe).




Q1323-0021
Q1436-0051

What does this mean?

We can tie theoretical models of galaxy formation, imaging observations of galaxies and observations of the gas content of galaxies into a coherent picture of how the heavy elements (and then planets and life forms) evolve with time.