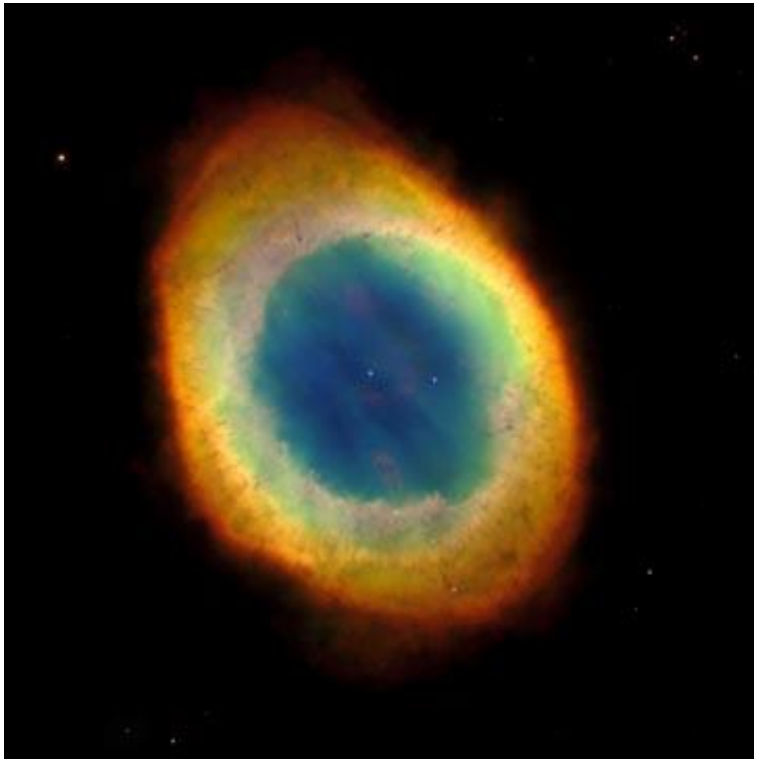
Element abundances and the chemical evolution of the cosmos

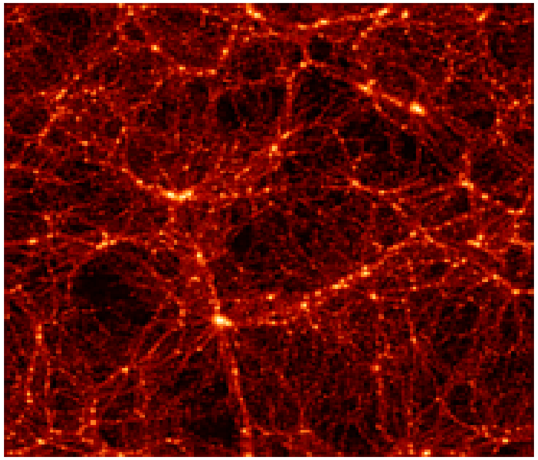
Metals ...

- Metals in Astronomy = everything heavier than helium
- Metals are important coolant agents for the gas, allowing star formation to proceed
- Metals are formed inside stars and then thrown out of them during their evolution and, most importantly, in the final stages of their lifes, either in quiescent events (Planetary Nebula) or SN explosions.
- Metals mix with the stars surroundings and thus polute the interstellar gas out of which new star generations arise = star formation cycle => chemical evolution.



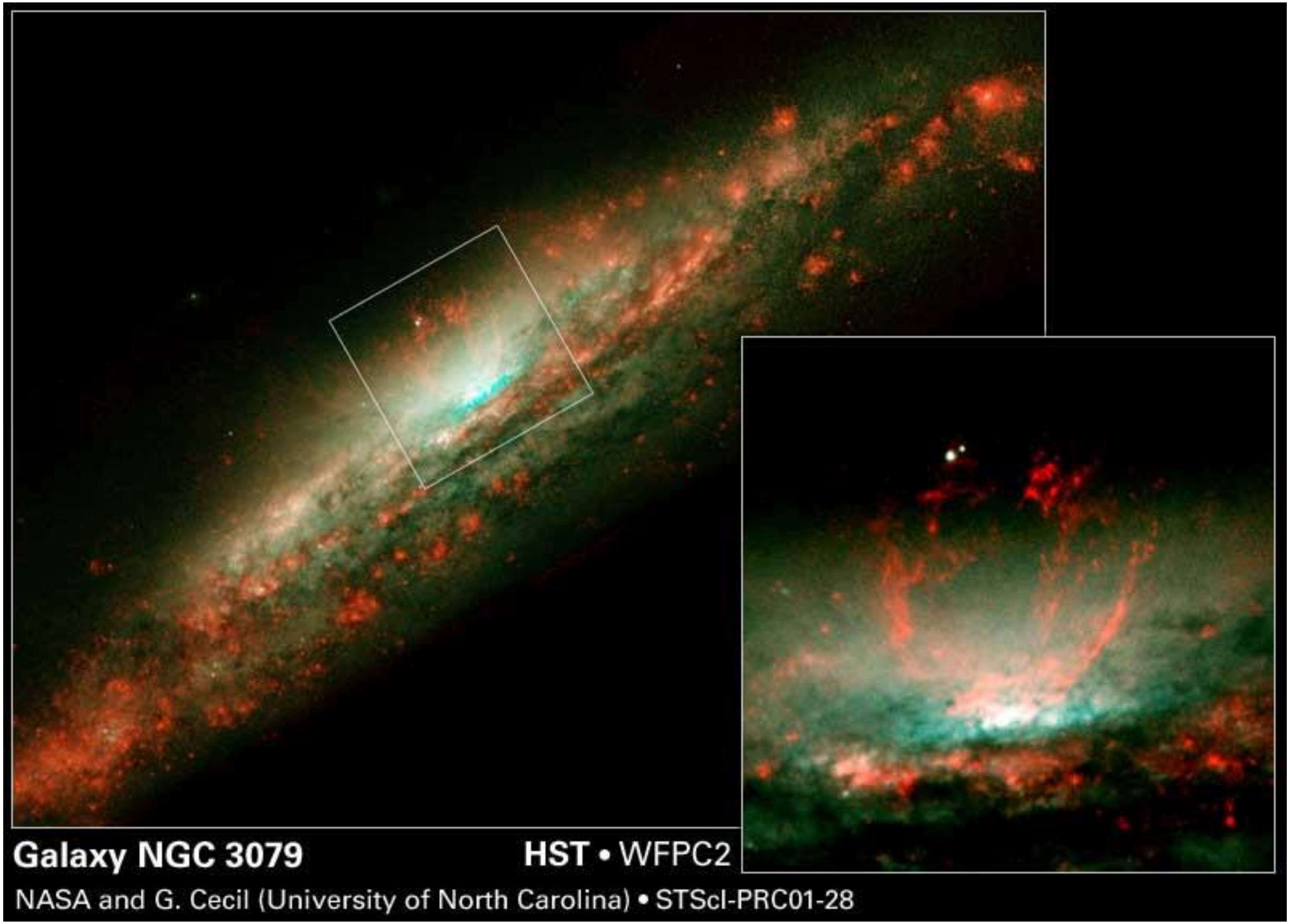
At present, the standard cold dark matter models of cosmic evolution postulates that structure in the Universe grew hierarchally, with small objects forming first and increasingly larger systems forming subsequently by mergers .

The evolution of the mass-metallicity relation in the Universe provides a most important test of present cosmological models.



How far in the Universe (how back in time) metals can be traced will revealed the epoch of the formation of the first stars.

- In current simulations the first galaxies form after the first stars which are responsible for an initial metal enrichment. The gas has to cool down before new stars can be formed. Therefore, chemical enrichment by the first SN is among the most important process in the formation of the first galaxies.
- On the other hand, stars form within galaxies as they get assembled, their massive stars evolve fast (~ 10 Myr) and explode violently as SN. This produces combined gas outflows that deprive galaxies from part of their metals and polute the intergalactic medium.


Galaxy NGC 3079
HST • WFPC2
NASA and G. Cecil (University of North Carolina) • STScI-PRC01-28

The formation and evolution of galaxies at different cosmological epochs are driven mainly by two processes: the star formation history and the metal enrichment. These processes, which are strongly connected in the evolution of individual galaxies, can be altered by the peculiar dynamics of the gas. The rate of star formation can be increased as a consequence of mergers or due to the inflow of gas. Regarding metallicity, it is sensitive to metal losses due to stellar winds, supernovae and active nucleus feedbacks. Therefore, the study of the dominant mechanisms of evolution of galaxies at different redshifts rely on the determination of metallicity and total stellar mass.

Pérez-Montero et al. 2009, for the VIMOS VLT Deep Survey
A&A, 495, 73, 2009

The importance of metals

- Metals play a very important role in star formation and stellar evolution. Amongst other things:
  - they control the cooling of the interstellar gas, thus allowing the formation of stars;
  - they affect the radiation transport, through the opacities involved in the different microscopic processes;
  - they have the most important role in the dust formation;
  - also in the mass loss from stars.

The site of metal formation

- **Metals are formed inside stars →**
  - We expect metal enrichment in the universe to start soon after the formation of the first massive stars.
  - After a very short life, these stars return to the ISM, in explosive events, their newly synthesised chemical elements, heavier than the primordial hydrogen and helium.
  - These ejecta, at some point, will mix with the surrounding gas, help to its cooling and propitiate the appearance of a new generation of stars.

⬇

Cycle of cosmic chemical evolution

The more detailed picture

- Not all the metals are returned to the ISM within the same timescales.
  - O,S, Mg … are synthesised in the nuclei of very massive stars and return to the ISM in only a few million years.
  - C, N … are mainly made by intermediate mass stars whose lifetimes are much longer, of the order of 10^9 years.
  - Fe is produced in close binary systems.
- They do not return to the ISM in the same way.
  - Massive stars → explosive events → core colapse SNe.
  - Intermediate mass stars → envelope ejection → PNe.
  - Close binary systems → Type Ia SN.

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Two ways to exploit this information

- Derive chemical abundances “in situ” → in galaxies at different redshifts.
- Derive chemical abundances at the present epoch (galaxies at redshift zero) + use chemical evolution models to predict their abundances at higher redshifts.

↓

Eventually, both approaches must converge

↓

Then, models can be extrapolated back to even earlier times

↓

Predictions can be made, to be confronted with planned observations

“In situ” abundance determinations

- Increase the spatial resolution of spectroscopic observations using the technique of **IFS** to examine and validate the main assumptions underlying the methodologies at use in the derivation of abundances at intermediate to high redshifts:
  - **that the gas ionisation is due only to young massive stars.**
  - **that the star formation modes have the same properties as the ones observed at the present epoch.**

"In situ" abundance determinations

- make progress in the **determination of precise abundances for star-forming galaxies at intermediate redshifts (up to z=1.5)** making use of different leading-edge instrumentation already at work or foreseen in the near future.
- **design and implement 2D-Chemical Evolution models** for spiral and irregular galaxies with a spatial resolution that can be adjusted to the existing and/or to come 2D abundance distributions and directly confronted with them.
  - Successful models will then be used to predict abundances of galaxies at different epochs that will be compared to the abundances directly obtained thus allowing the further iteration and improvement of models.

The Programme

- Cosmic elemental abundances. Data sources.
  - Stellar abundances.
  - Nebular abundances.
- Primordial nucleosynthesis and abundances of the light elements.
- Outline of stellar structure and evolution.
- Stellar nucleosynthesis and principles of galactic chemical evolution.
- Specific models of galactic chemical evolution and comparison with available data.

- The chemical evolution of external galaxies
- Hints on element abundances at high redshifts and cosmic chemical evolution.

Have fun!!