



**Big Bang: astrophysical fantasy
or
fantastic fact?**

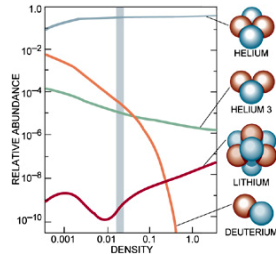
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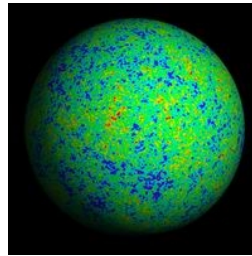
The evolution of the Cosmos



Big Bang



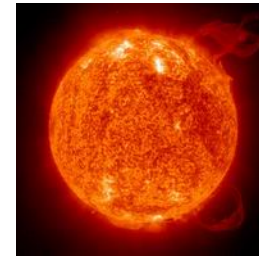
Big-Bang
nucleosynthesis



microwave
background



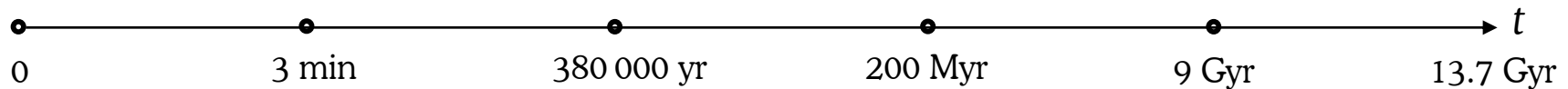
formation of
galaxies



formation of
the Sun



astronomers
on Earth



Using a variety of techniques, we can,
in principle, study *all* phases of cosmic
evolution

The pillars of the Big-Bang theory

1. The expansion of the Universe

Distant objects are receding following a simple $v = H_0 d$ law with $H_0 \approx 70 \text{ km/s/Mpc}$

2. The Cosmic Microwave Background (CMB)

The afterglow of the Big Bang emitted when the Universe became transparent to photons (380 000 yr after the Big Bang)

3. Big-Bang Nucleosynthesis (D, He, Li)

The observed abundances of light elements in the oldest objects can be explained by fusion reactions shortly after the Big Bang

4. Component ages

All objects we can date accurately indicate a finite period of structure formation

Accumulating evidence...

- **Hubble expansion**
(1920s, Hubble's original value ≈ 500 km/s/Mpc)
- **cosmic 3K microwave background**
(predicted in the 1940s,
serendipitous discovery 1965,
detailed study since the late 1980s)
- **Big-Bang Nucleosynthesis**
(theory developed in the 1940s)
- **He/Li/D in old objects**
(observations since the 1970s)

DAGENS NYHETER.

Nätupplagan måndag 21 augusti 2006

Nyheter Ekonomi Debatt Ledare Sport Kultur På stan Mer ur DN Mat & D

Hemsidan Sverige Stockholm Politik/EU Världen Val 2006 Vetens



Foto: European Southern Observatory

Rymdmysterium löst i Uppsala

Ett hål i Big Bang-teorin har täppts till. En kombination av

Följ F

Christe
astrona
rymdfär

Annons:

Special

DN ger
bakgru
läsarfrå
kröniko
vetensk
Bojs. D
kunska

Trans

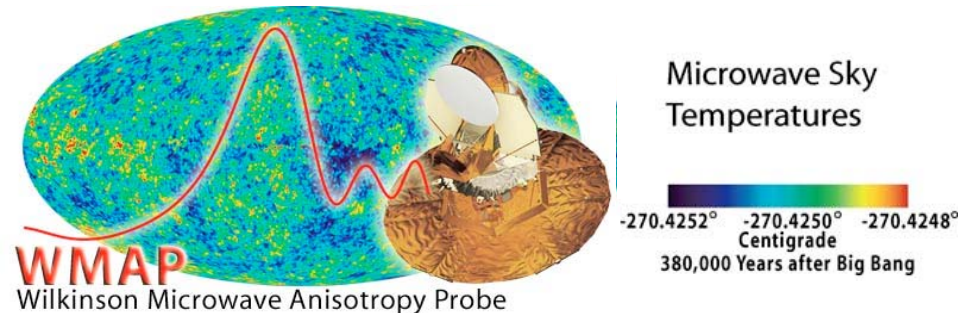
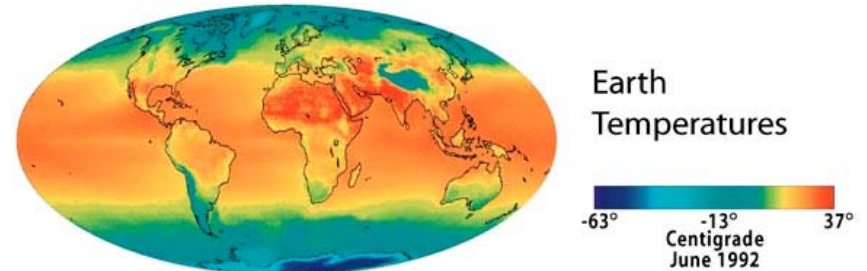
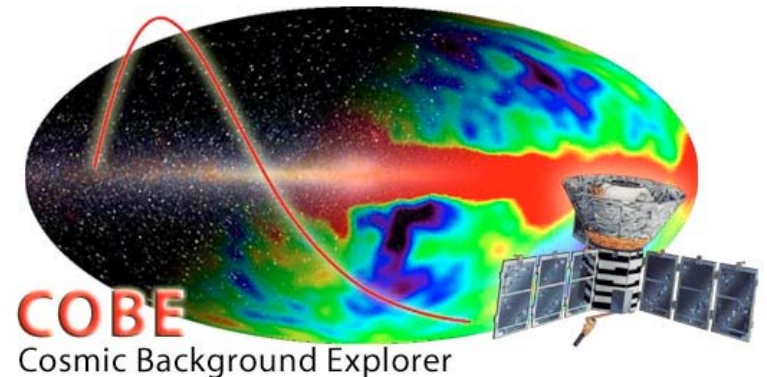
Små gu
kex son

The cosmic 3K background radiation

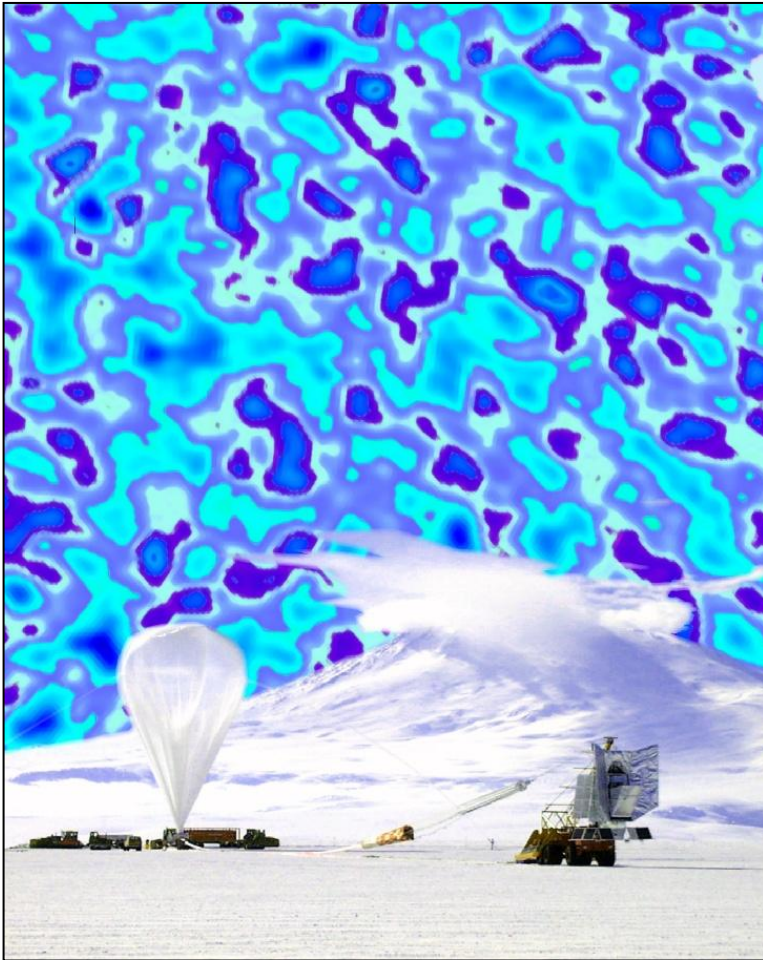
380 000 yr after the Big Bang: the Universe has expanded and cooled sufficiently for electrons to bind to nuclei (*recombination*).

For photons, the universe turns transparent, the *state of the cosmos is preserved* in the photon distribution to the present day.

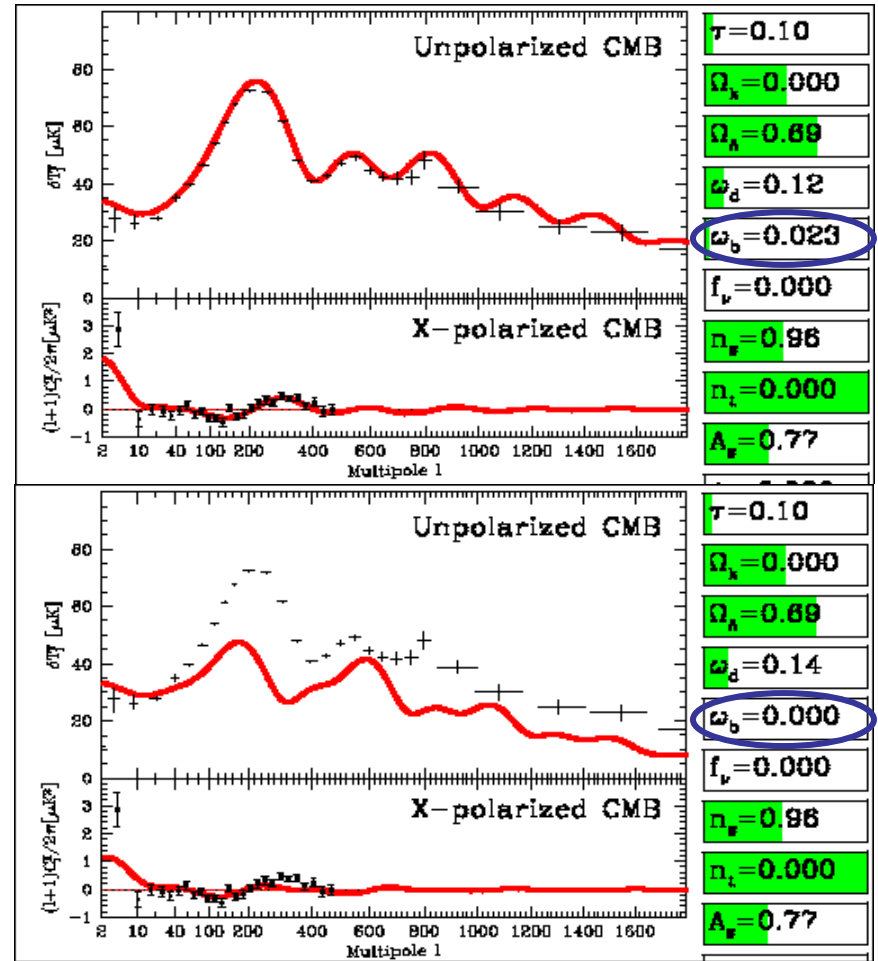
The microwave background resembles a near-perfect blackbody of 2.7 K temperature. *Temperature fluctuations* (= fluctuations in density at the time of photon emission) are in the $100 \mu\text{K}$ range (Nobel price 2006).



BOOMERanG and WMAP



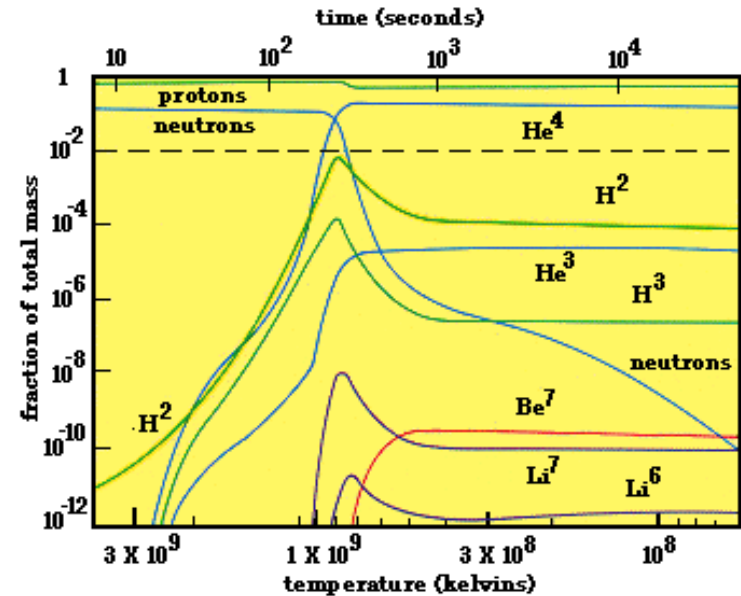
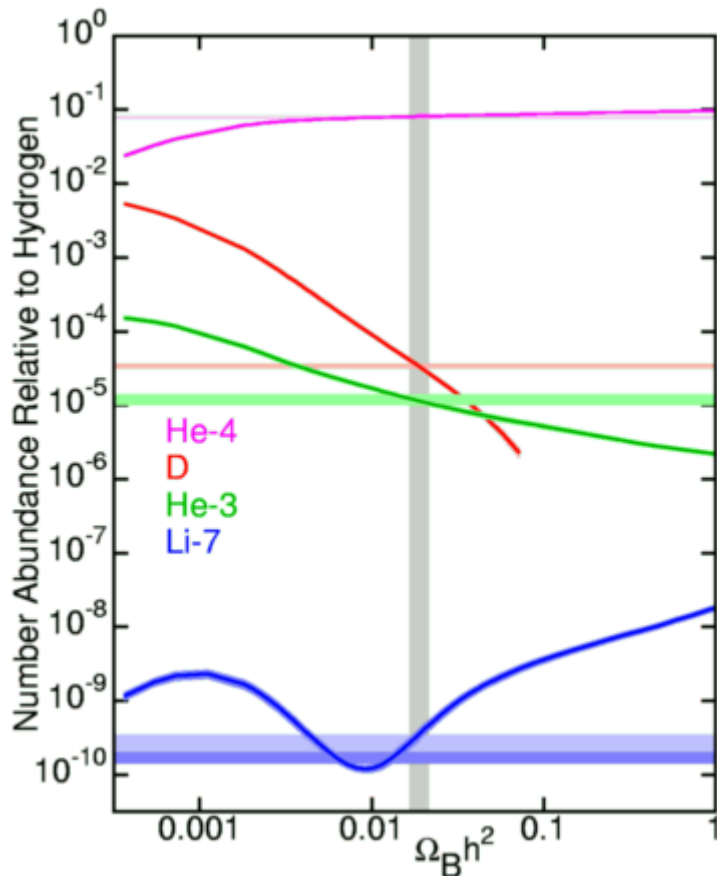
www.lbl.gov



<http://space.mit.edu/home/tegmark/index.html>
(CMB movies)

Big-Bang Nucleosynthesis

Three minutes after the Big Bang, the universe has the right temperature ($\approx 10^9$ K) to act as a fusion reactor.



The expansion continues and the neutrons decay, thus quenching the fusion after a few minutes. According to computation, highly accurate abundance ratios of hydrogen, helium, and lithium are predicted as a function of the matter density Ω_B .

Early results

since the 1970s: helium in different cosmic sources

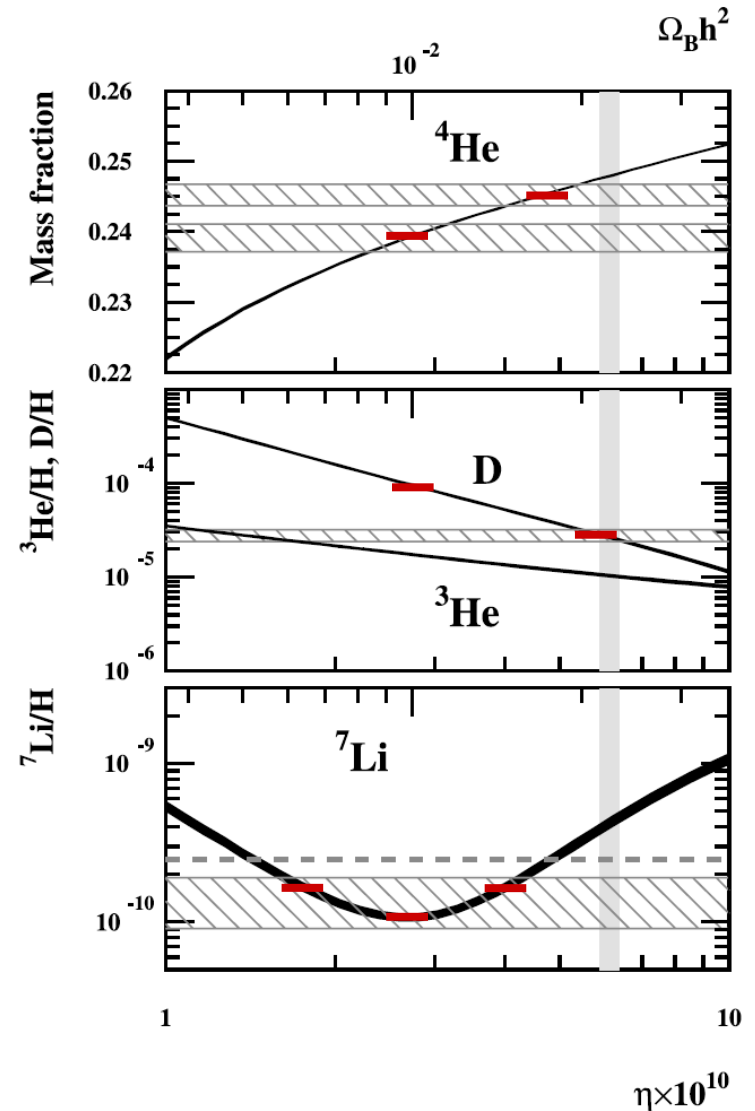
1980s:

lithium in old stars

1990s:

deuterium in the spectra of high-redshift quasars

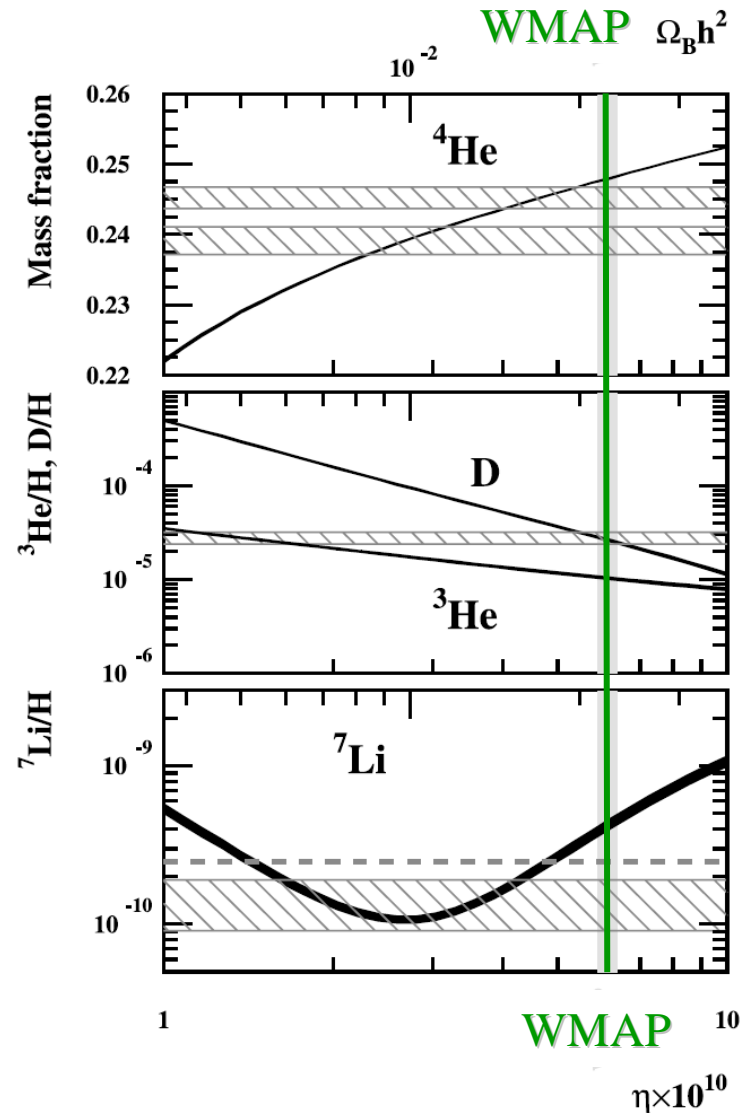
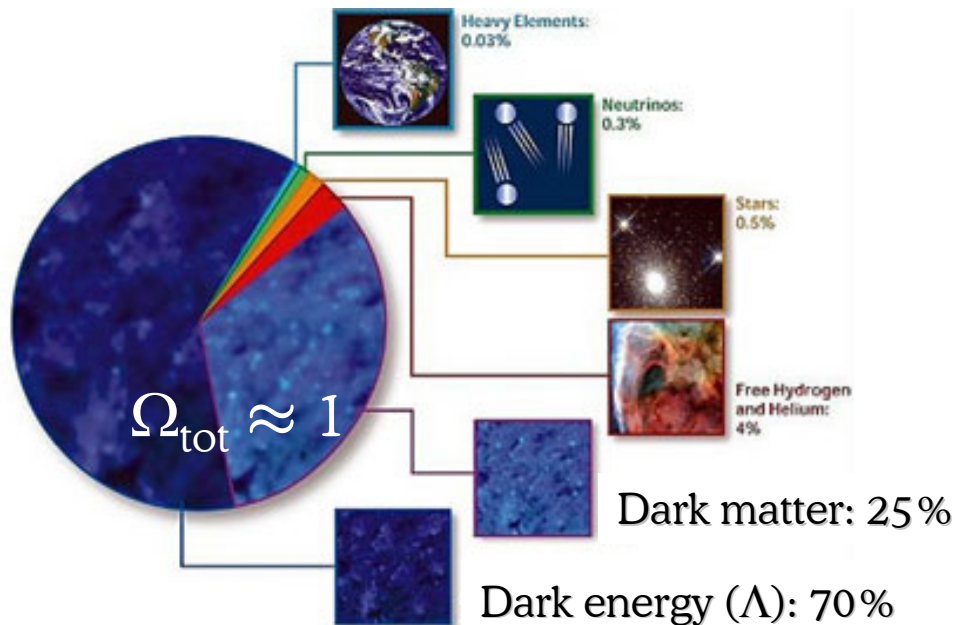
Ω_B is predicted to be 1-2% of the critical matter density required to close the universe.



The post-WMAP picture

WMAP: $\Omega_B / \Omega_c = (4 \pm 0.2) \%$

- somewhat more helium than measured,
- somewhat less deuterium, surprisingly large scatter,
- markedly more lithium than measured.



Where half of the cosmic lithium went...

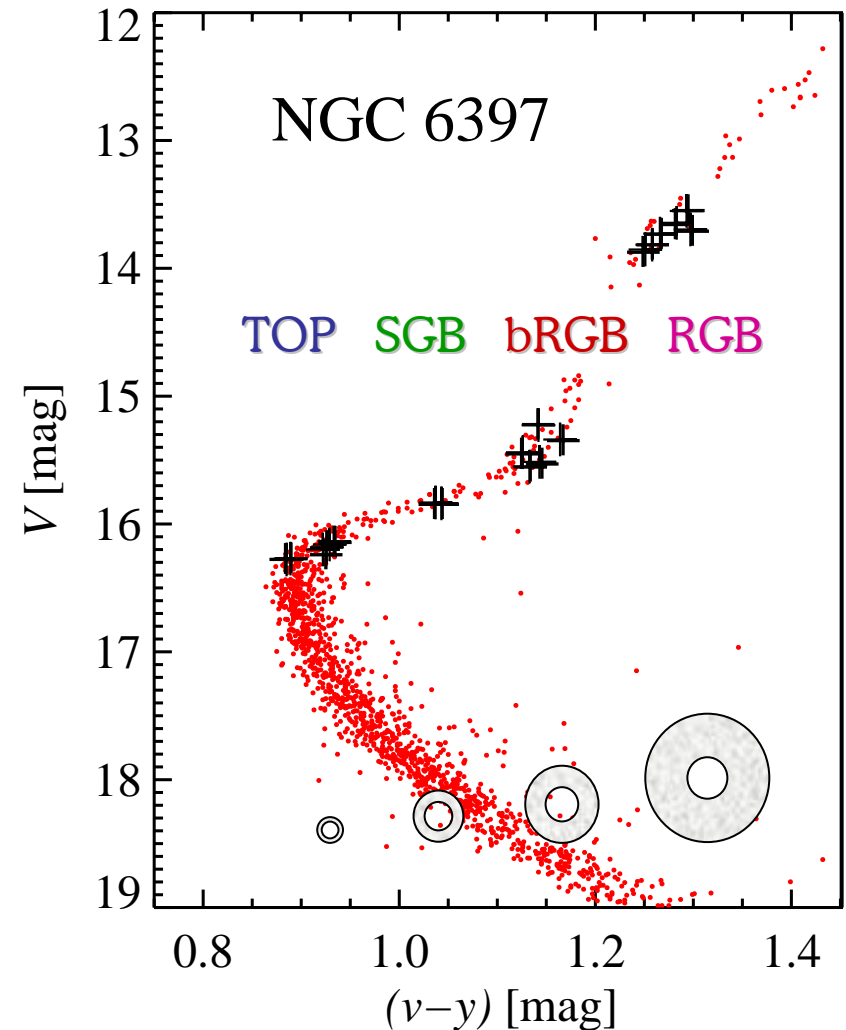
Diffusive processes inside stars can lead to surface depletions of heavy elements. This expectation is testable using globular cluster stars.

Observations with VLT UT2/
FLAMES+UVES

5 TOP-, 2 SGB-, 5 bRGB- und
6 RGB stars. Exposure times up
to 20 hours!

Techniques:

high-resolution spectroscopy,
quantitative spectral analysis &
stellar photometry



NGC 6397



ESO's *Very Large Telescope*

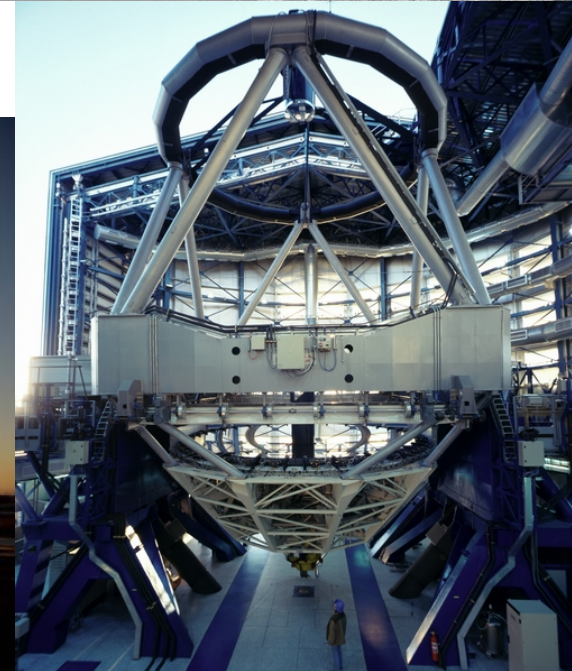


The Very Large Telescope

4 telescopes with primary mirrors of 8.2 m diameter.
In use since 1999.

This project: 3 nights at
Unit Telescope 2

This corresponds to a
European investment of
 $\geq 1\,000\,000$ SEK.



Big Bang: a self-contained theory?

Big Bang is a vastly successful theory. However, since the late 1990s it has led us to realize that **we practically know nothing about 95% of the universe's content.**

The need for **dark matter** may be **reminiscent of the ether** discussion in the latter half of the 19th century. However, no other theory (e.g. of *MOND*-type) has been able to explain a variety of observables equally well.

Indications for dark-matter candidates may come from the *Large Hadron Collider* soon.

Dark energy is even more enigmatic. It will likely take decades to unravel its nature.

optical / X-ray / DM



Ante omnia saecula?

We refer to the **Big Bang** as the moment in time when a mathematical **singularity** (infinitely dense, infinitely hot) arises in calculating backwards in time.

In principle, nothing requires the universe to ever be in or pass through this **unphysical state**.

Prior to the creation of the present space-time, the universe could have been in a seed state for an unspecified amount of *time*.

We calculate the age of the universe from the moment the expansion started. The best estimate currently comes from the microwave background and indicates $t_0 = 13.7 \pm 0.2 \text{ Gyr}$.

