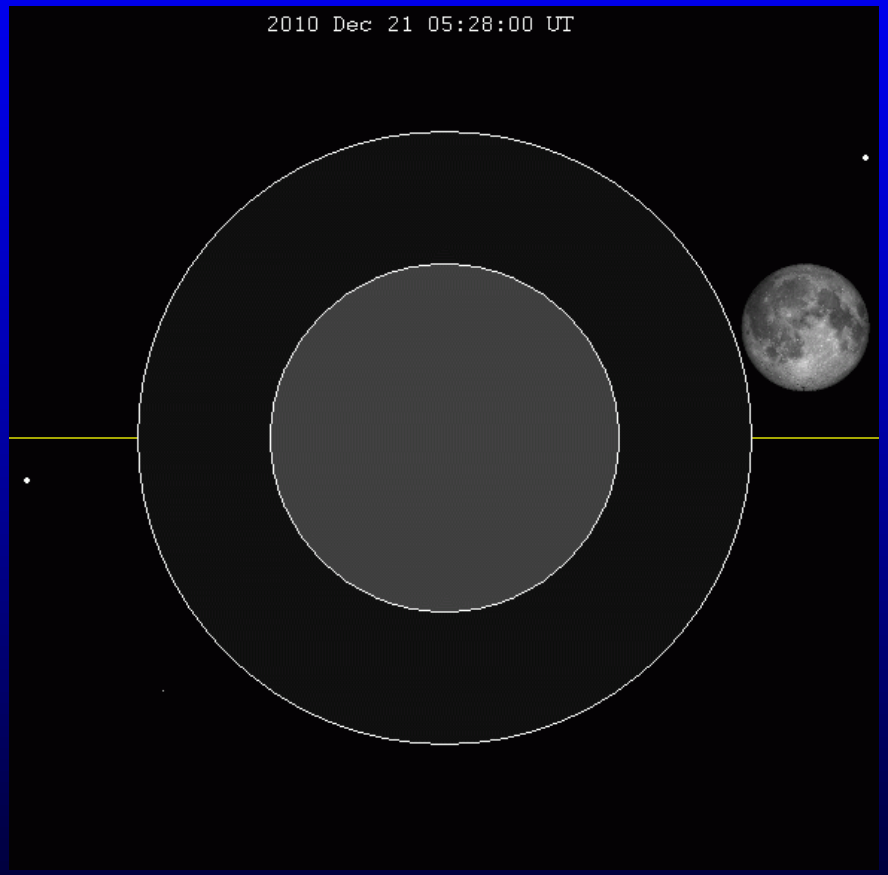
GRESHAM COLLEGE

Mysteries of the Universe

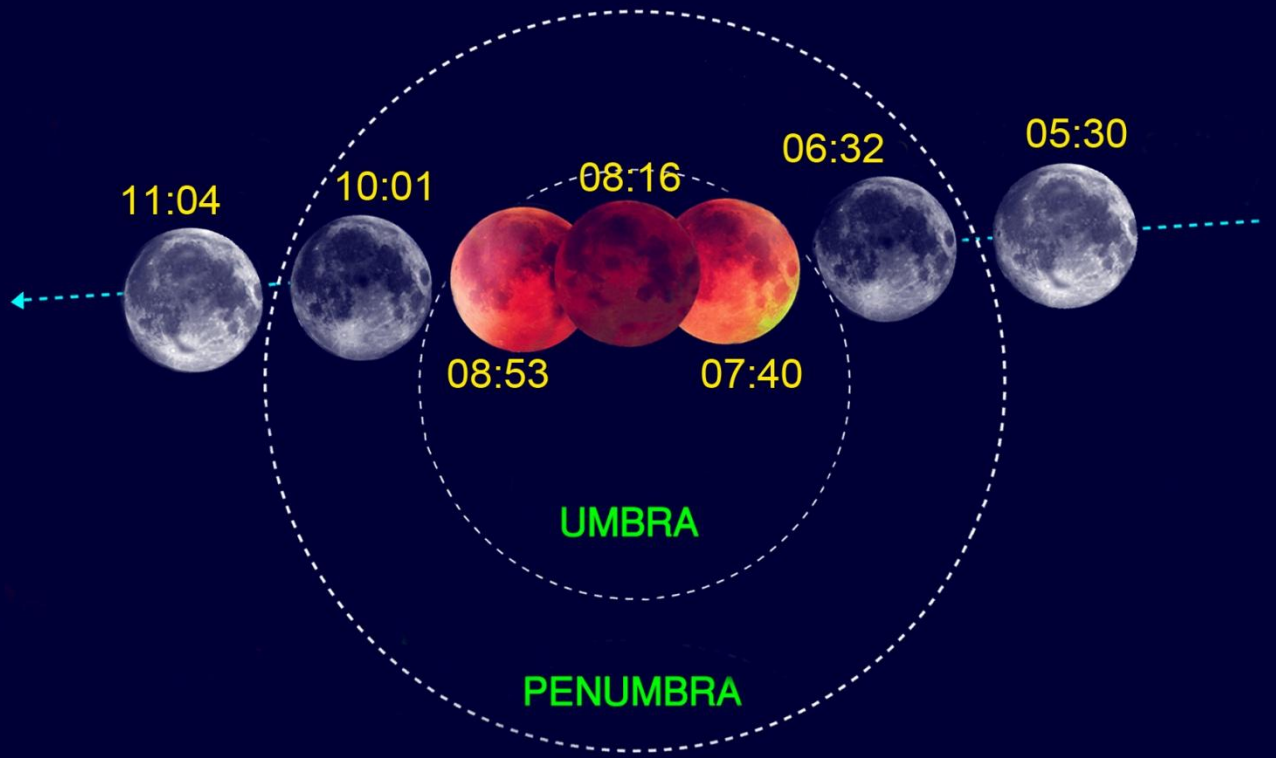
Ian Morison

Gresham Professor of Astronomy

Lunar Eclipse 21st December



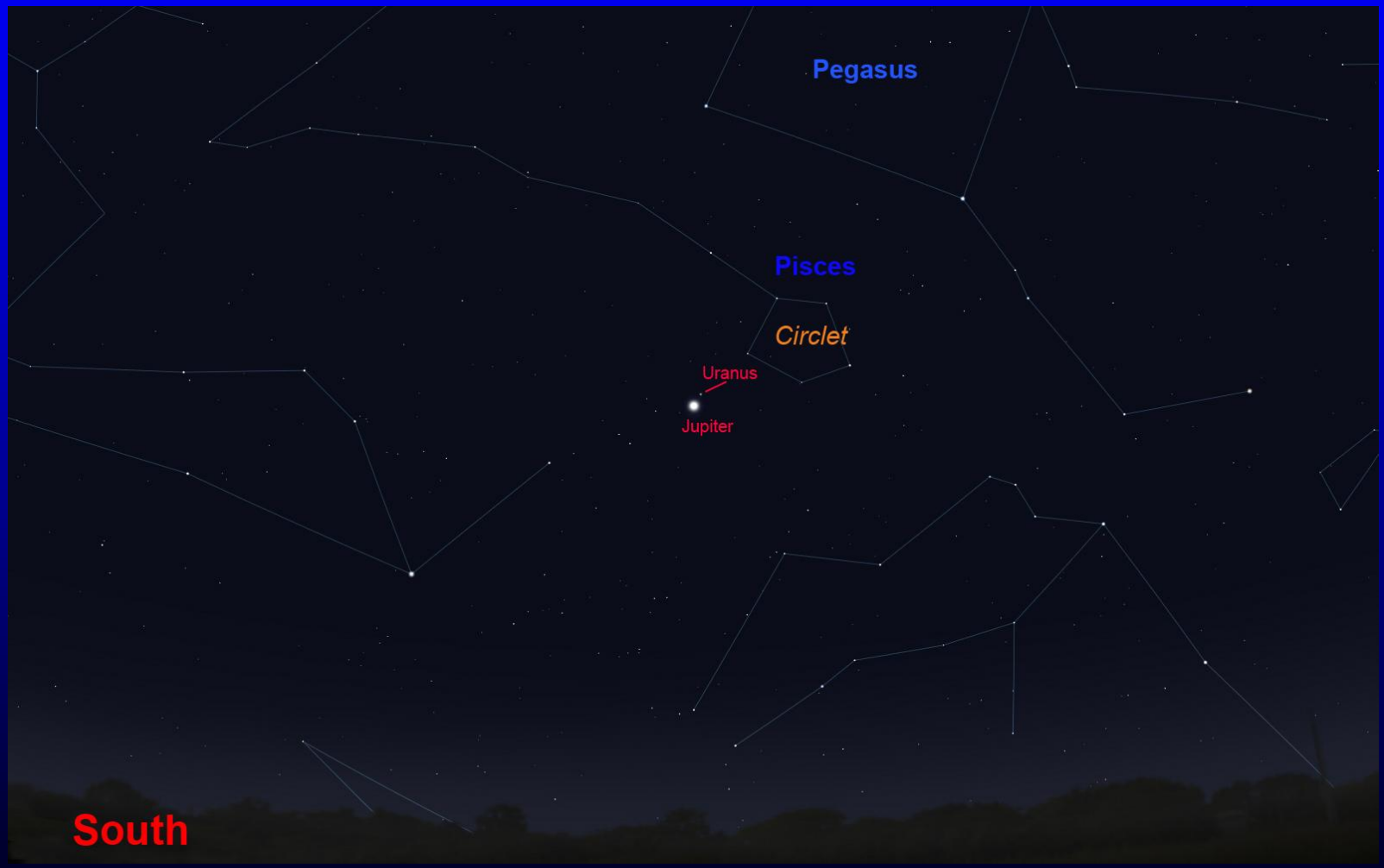
Total Eclipse of the Moon Dec 21st 2010



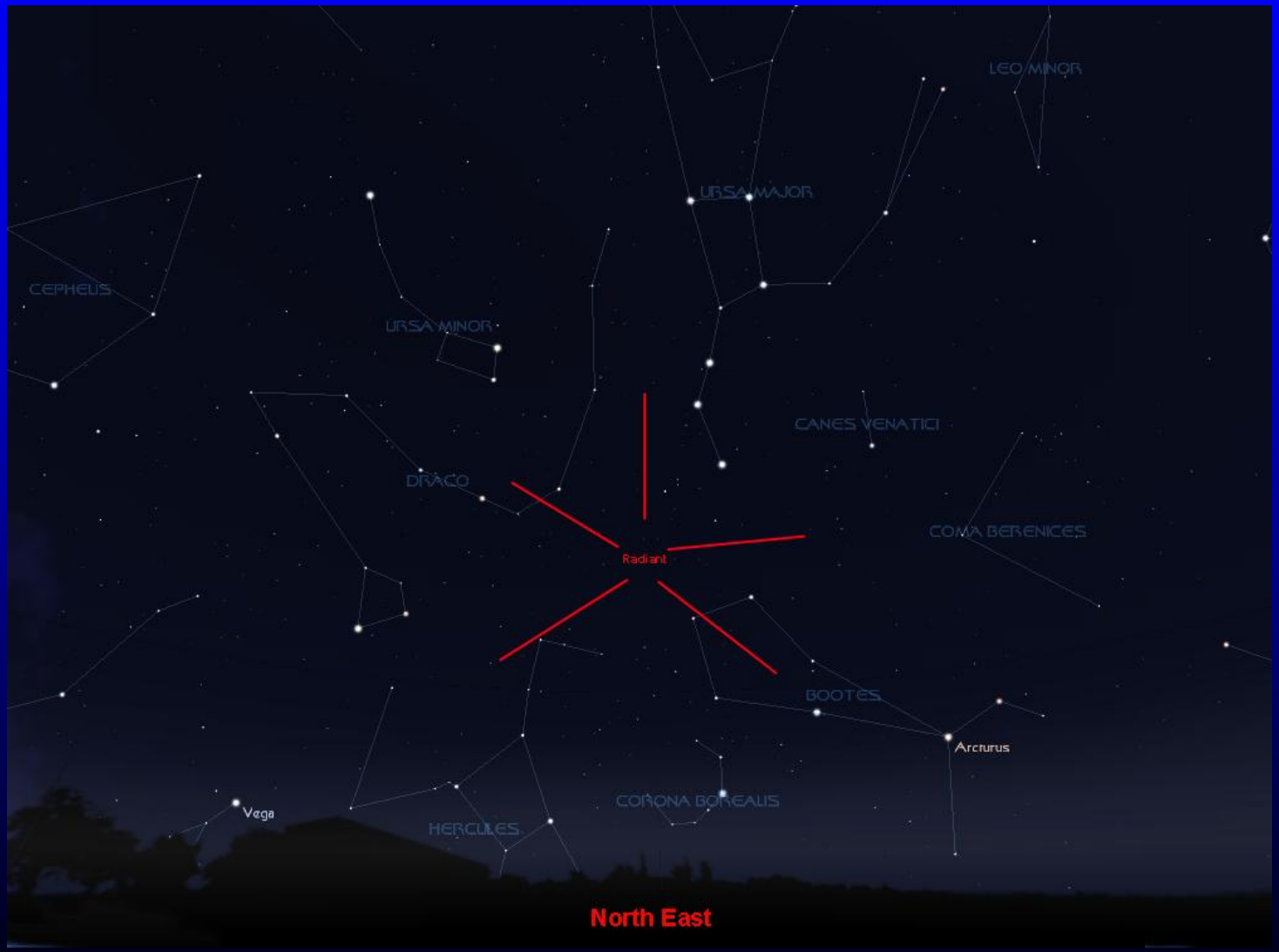
Ian Morison
Jodrell Bank Observatory,
University of Manchester


Randy Brewer
October 27, 2004

Spot Uranus 1st - 3rd January



Jan 4th: The Quadrantids



Tycho's Mural Quadrant

Just Google “Nightsky”

GRESHAM COLLEGE

Mysteries of the Universe

Ian Morison

Gresham Professor of Astronomy

There is a, now famous, quotation from the American Secretary of Defence, Donald Rumsfeld, in which he says (put in a slightly clearer way):

- **There are known "knowns." These are things we know that we know.**

- **There are also unknown unknowns. These are things we do not know we don't know.”**

- European Extremely Large Telescope:

“On top of this astronomers are also planning for the unexpected — new and unforeseeable questions that will surely arise from the new discoveries made with the E-ELT.”

SKA-The Exploration of the Unknown

- The history of science tells us that many of the greatest discoveries happen unexpectedly and reveal objects which are completely different from those which had been envisaged during the planning phase of a new-generation telescope.

- The unique sensitivity of the SKA will certainly reveal new classes of cosmic objects which are totally beyond our present imagination. We are looking forward to such surprises.

- **But there are also known unknowns - that is to say there are things that we now know we don't know.**

For astronomers, these are some of the Mysteries of the Universe

Matter – Mass, Antimatter and Dark Matter.

What is Dark Energy?

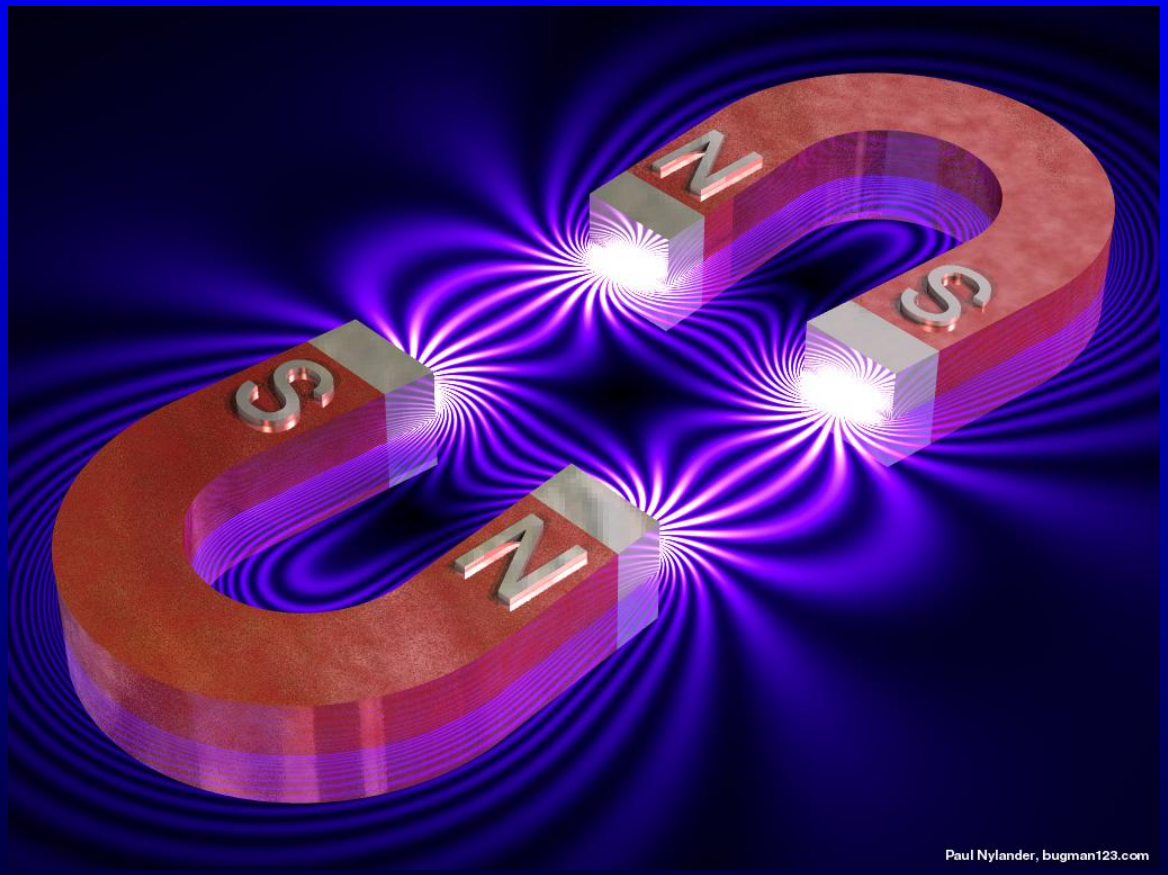
The Dark Ages of the Universe.

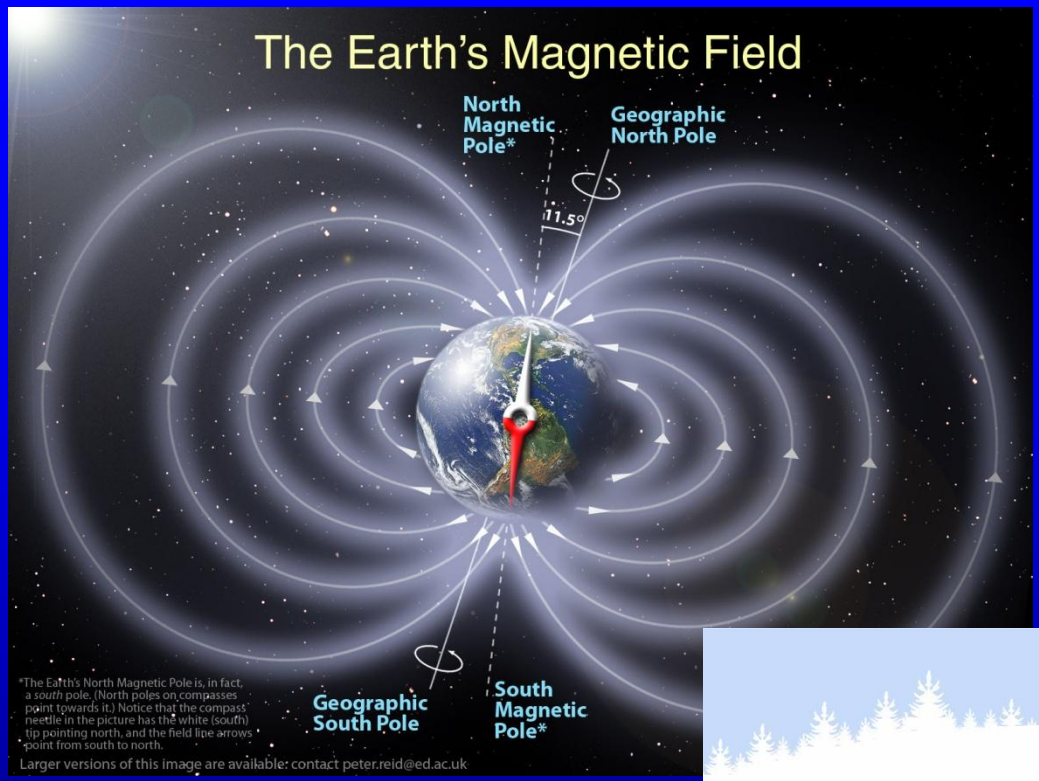
How did the first stars and galaxies form?

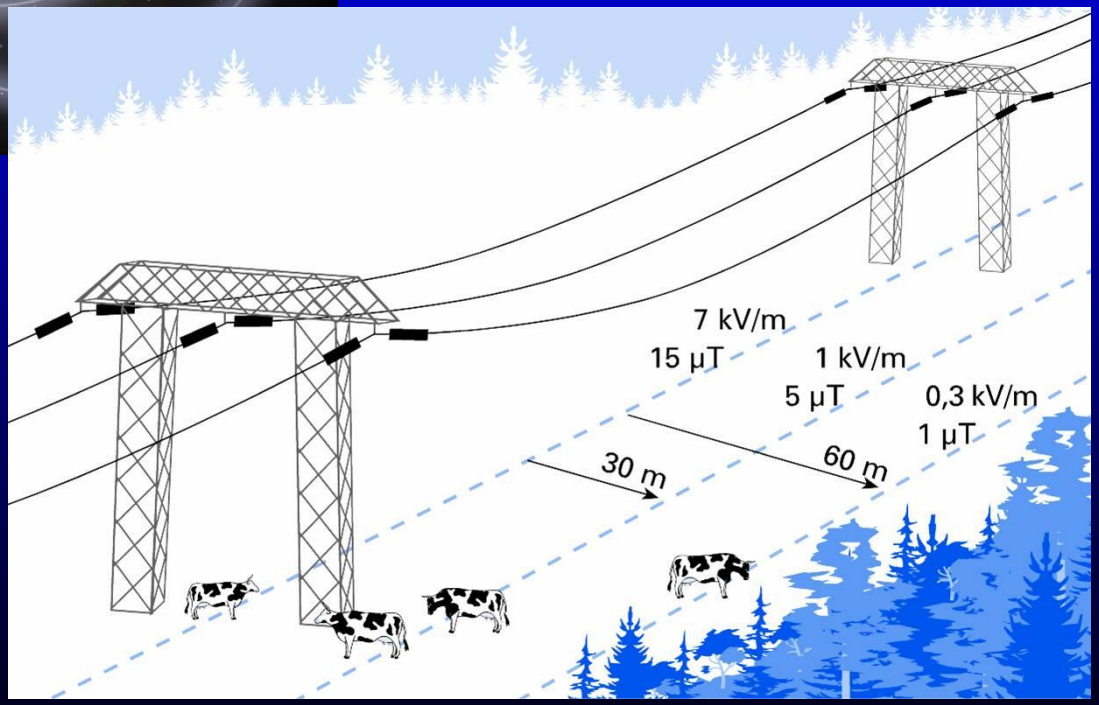
Is there other life in the Universe?

What gives Matter Mass?

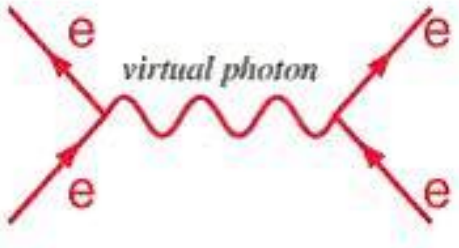
Fields




The Earth's Magnetic Field
North Magnetic Pole*
Geographic North Pole
11.5°
Geographic South Pole
South Magnetic Pole*
*The Earth's North Magnetic Pole is, in fact, a south pole. (North poles on compasses point towards it.) Notice that the compass needle in the picture has the white (south) tip pointing north, and the field line arrows point from south to north.
Larger versions of this image are available: contact peter.reid@ed.ac.uk


7 kV/m
15 µT
1 kV/m
5 µT
0,3 kV/m
1 µT
30 m
60 m

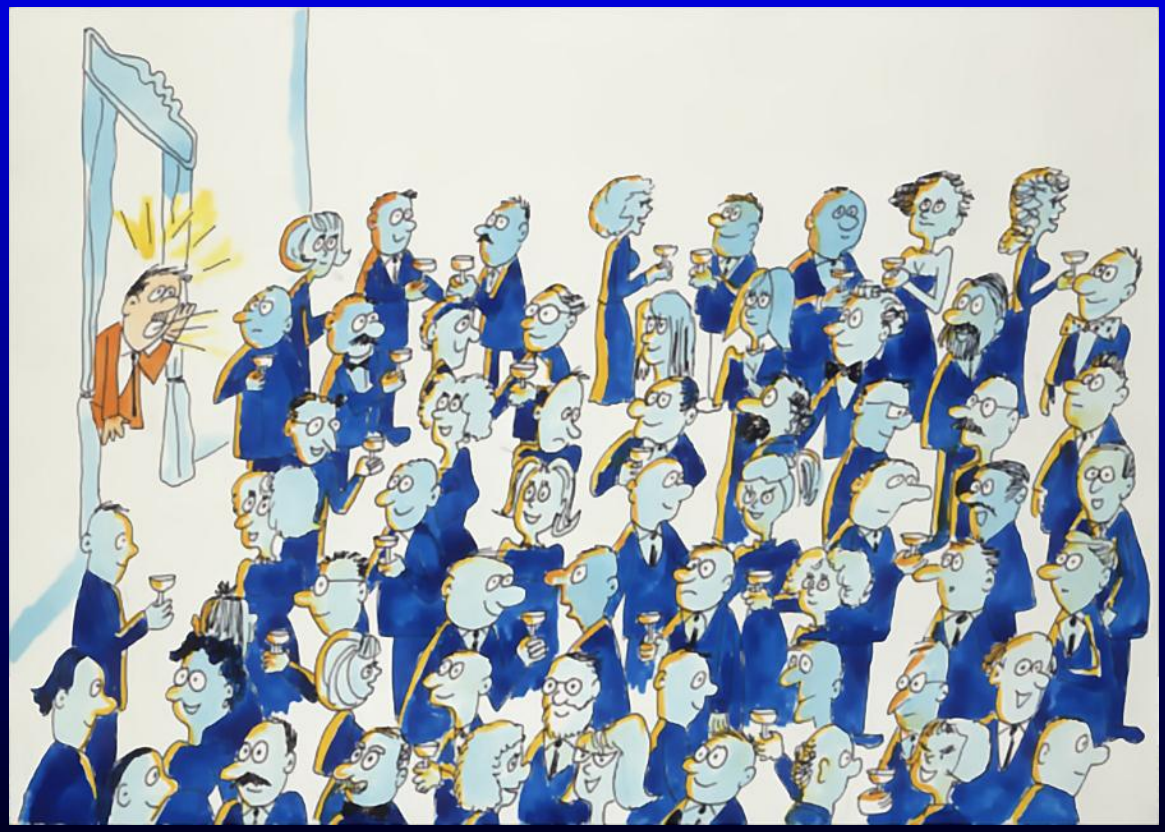
- The forces that we observe due to fields are the result of the exchange of virtual particles.
- In the case of electric and magnetic fields these are **Virtual Photons**



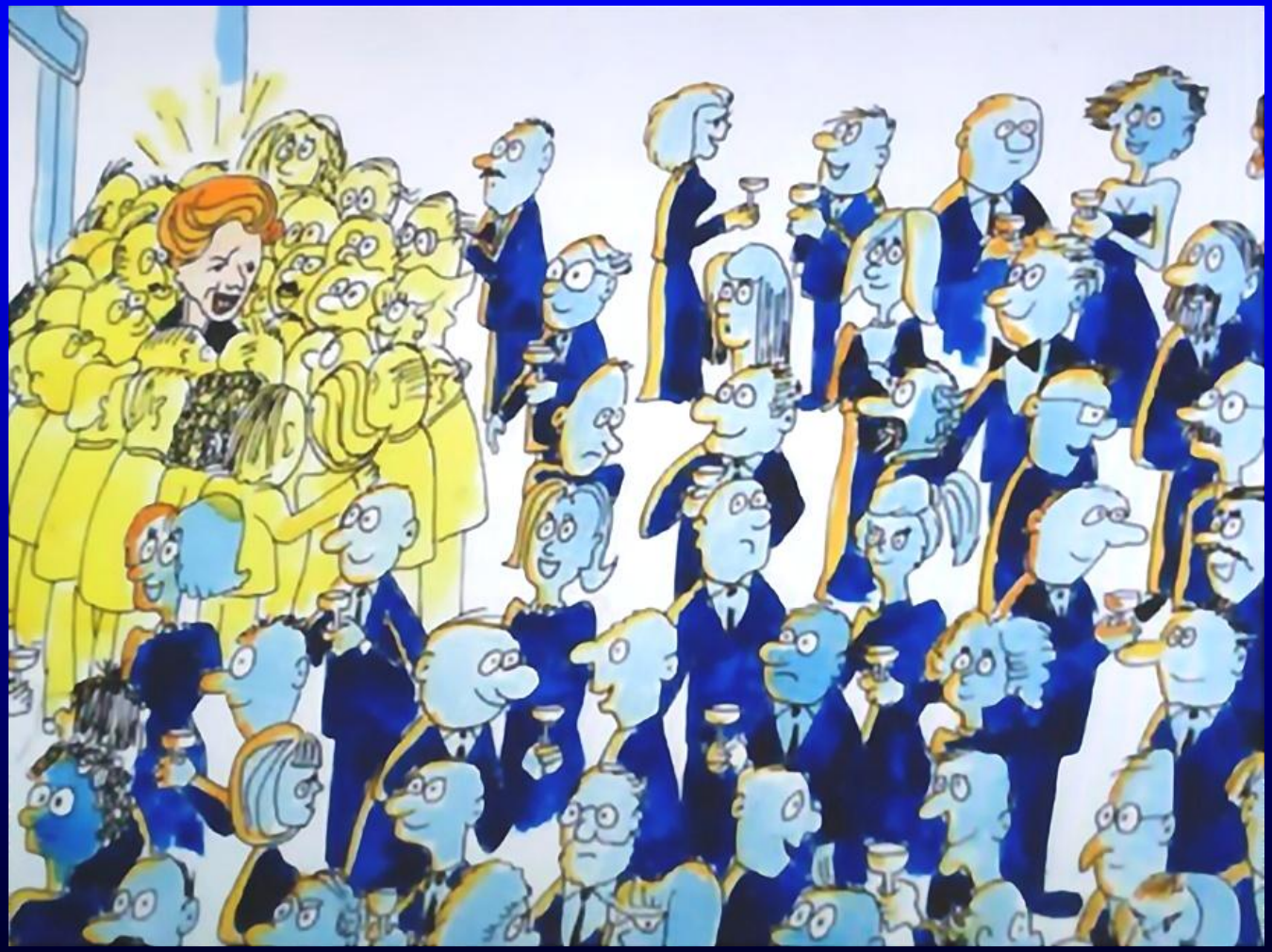
Feynman diagram for the electromagnetic force between two charges.

The Higgs Field

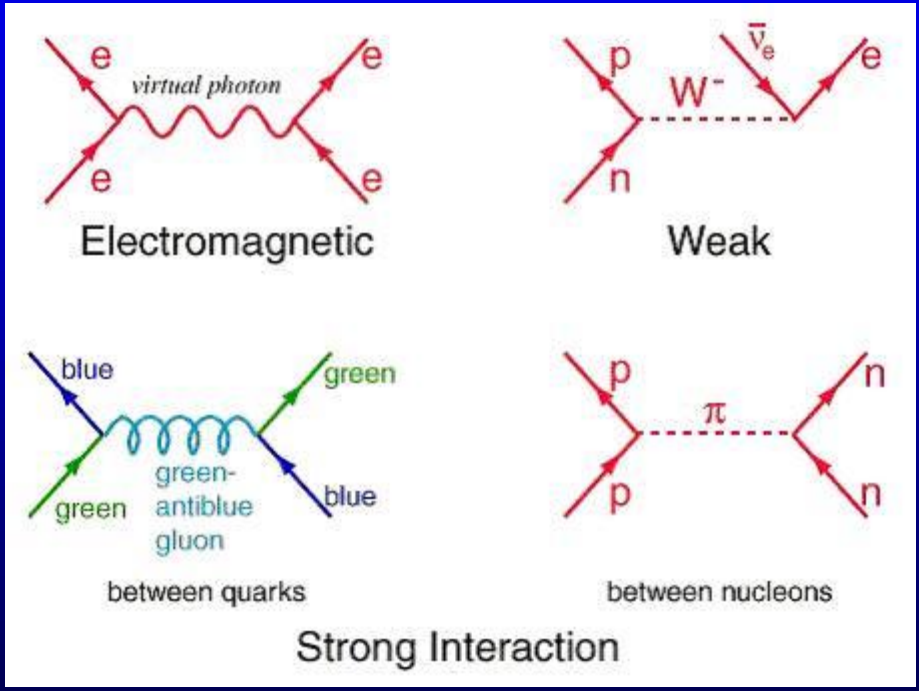
- This is what it is believed to give matter mass.



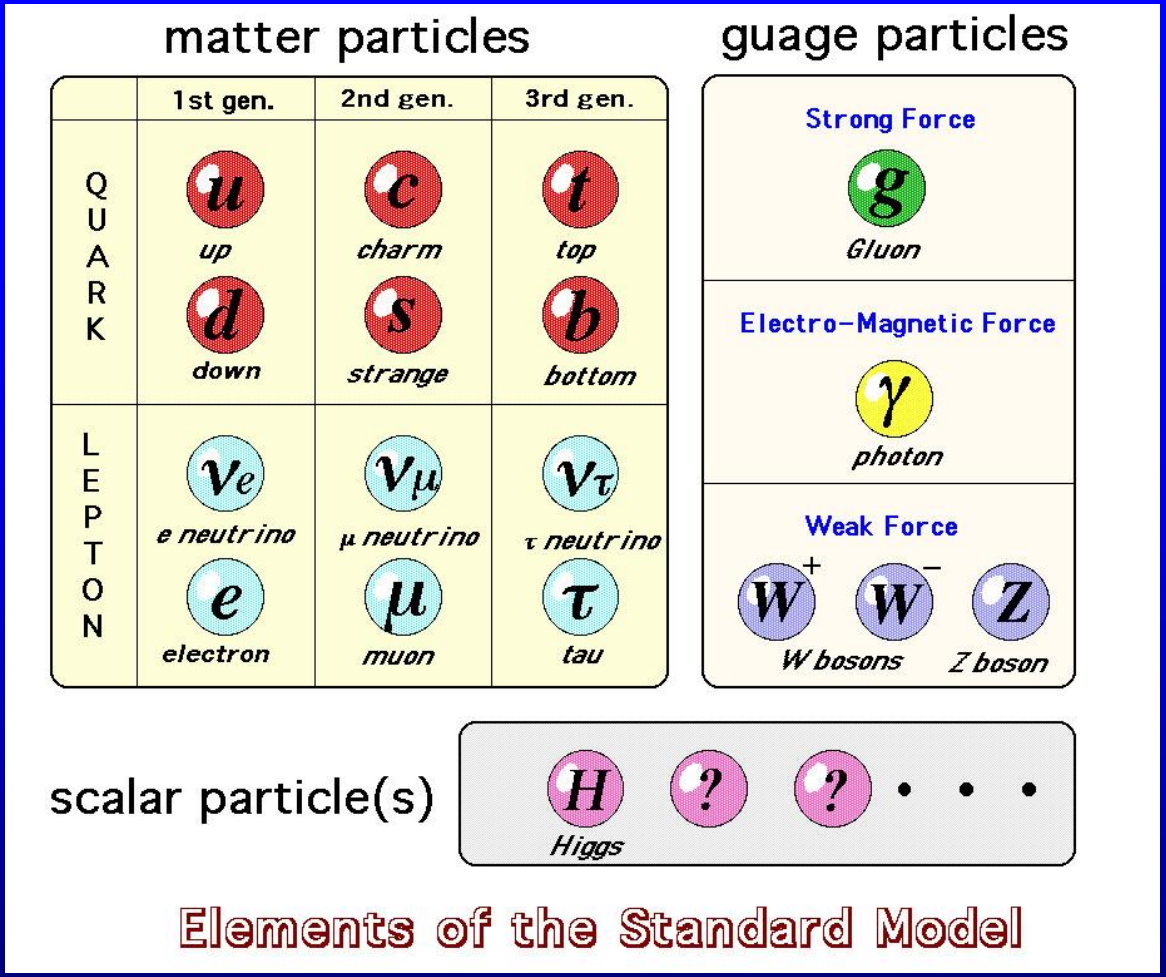
A Massive Particle!



All fields have a virtual exchange particle



Standard Model



- The particle that is related to the Higgs Field is called the Higgs Boson.

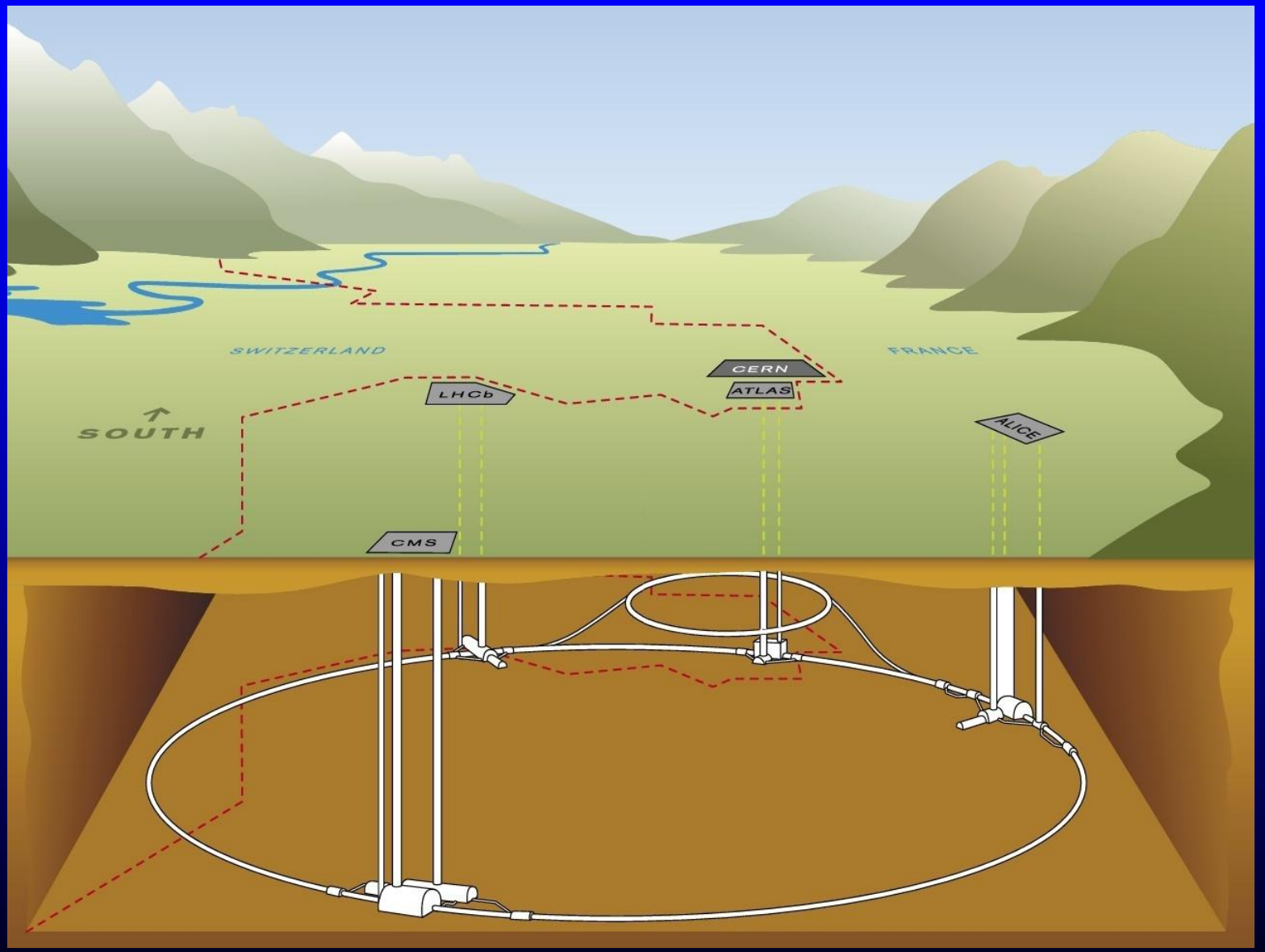
How to make a Higgs Boson

- If during its brief existence, a virtual particle can be given sufficient energy it can become a real particle and hence detected.

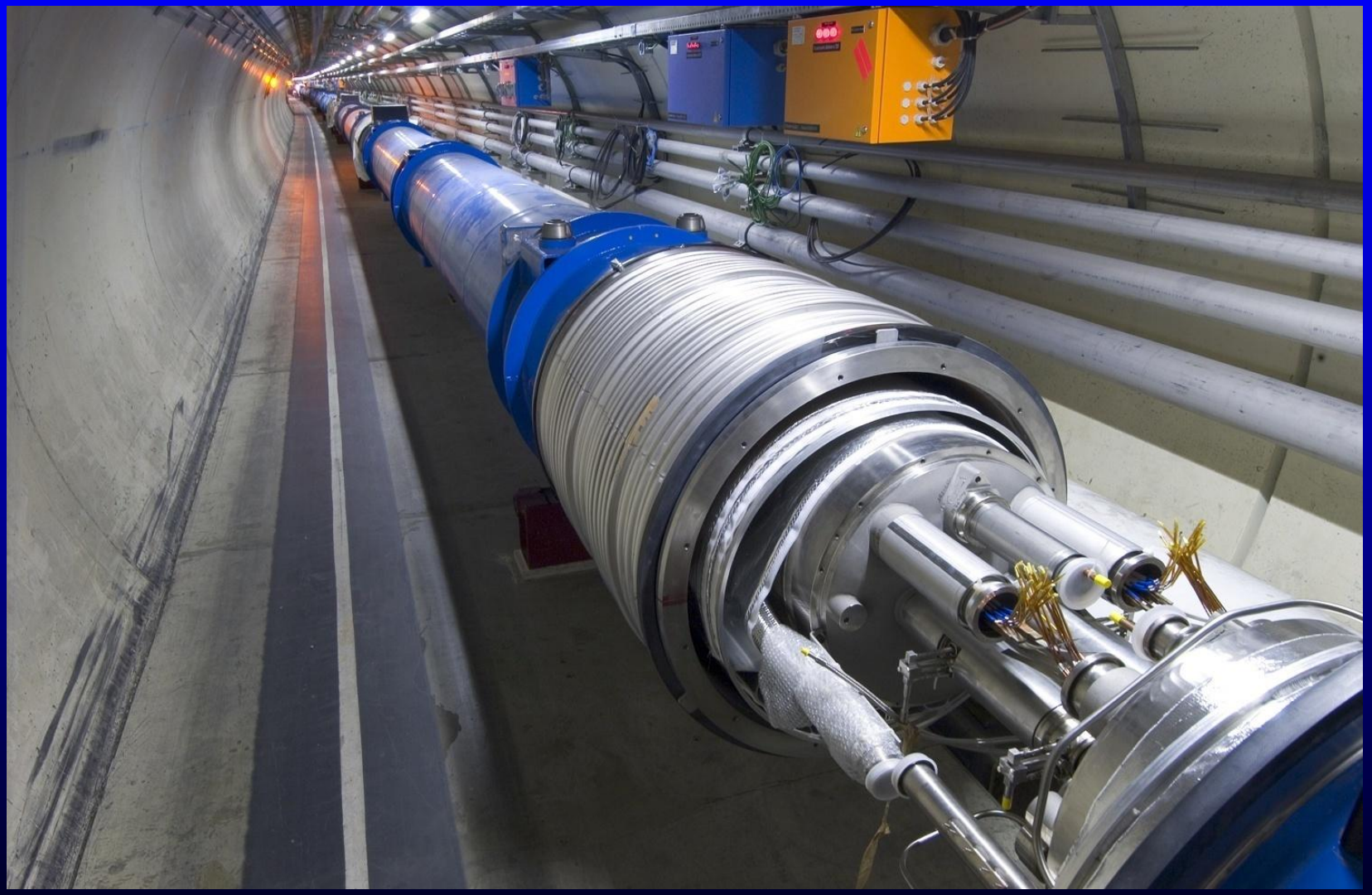
- A Higgs Boson will decay into other particles which can be detected and hence prove that it had existed.

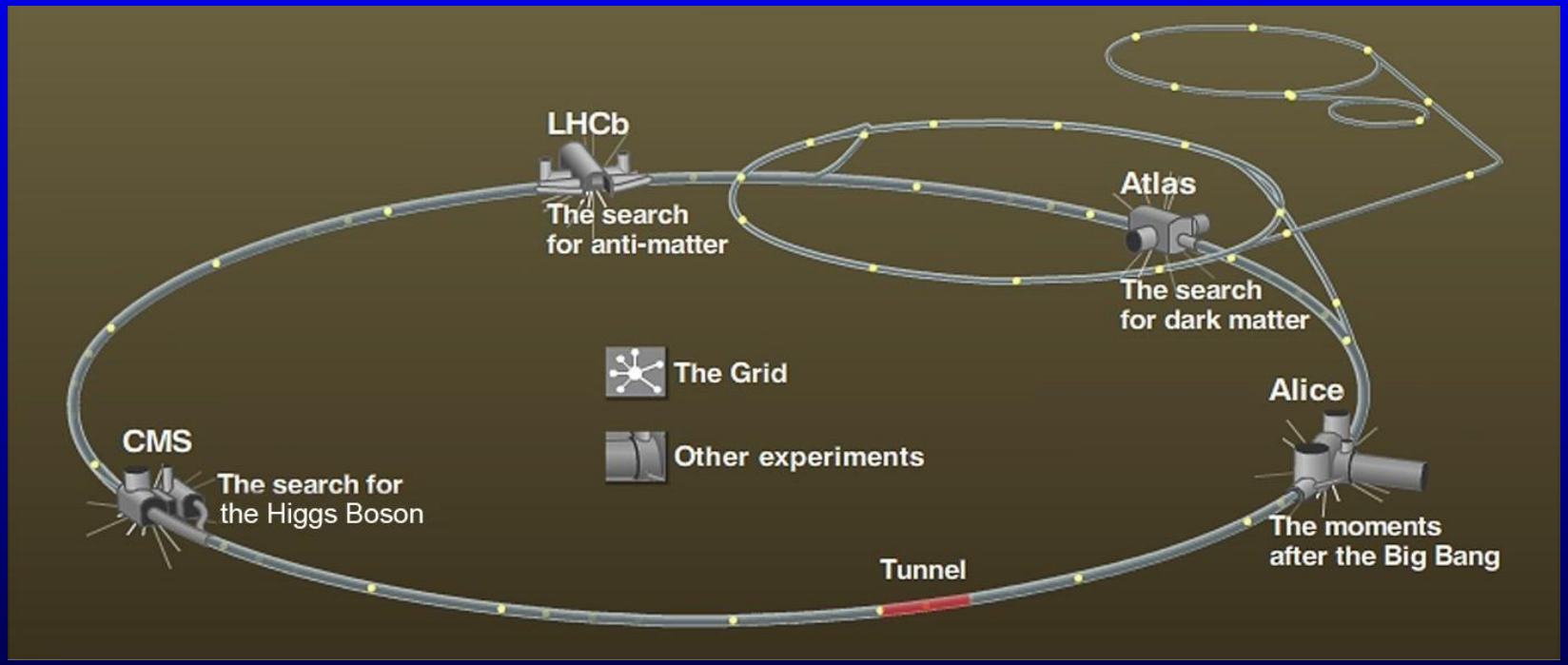
The Large Hadron Collider

CERN - Europe's Accelerator located below the Franco-Swiss boarder

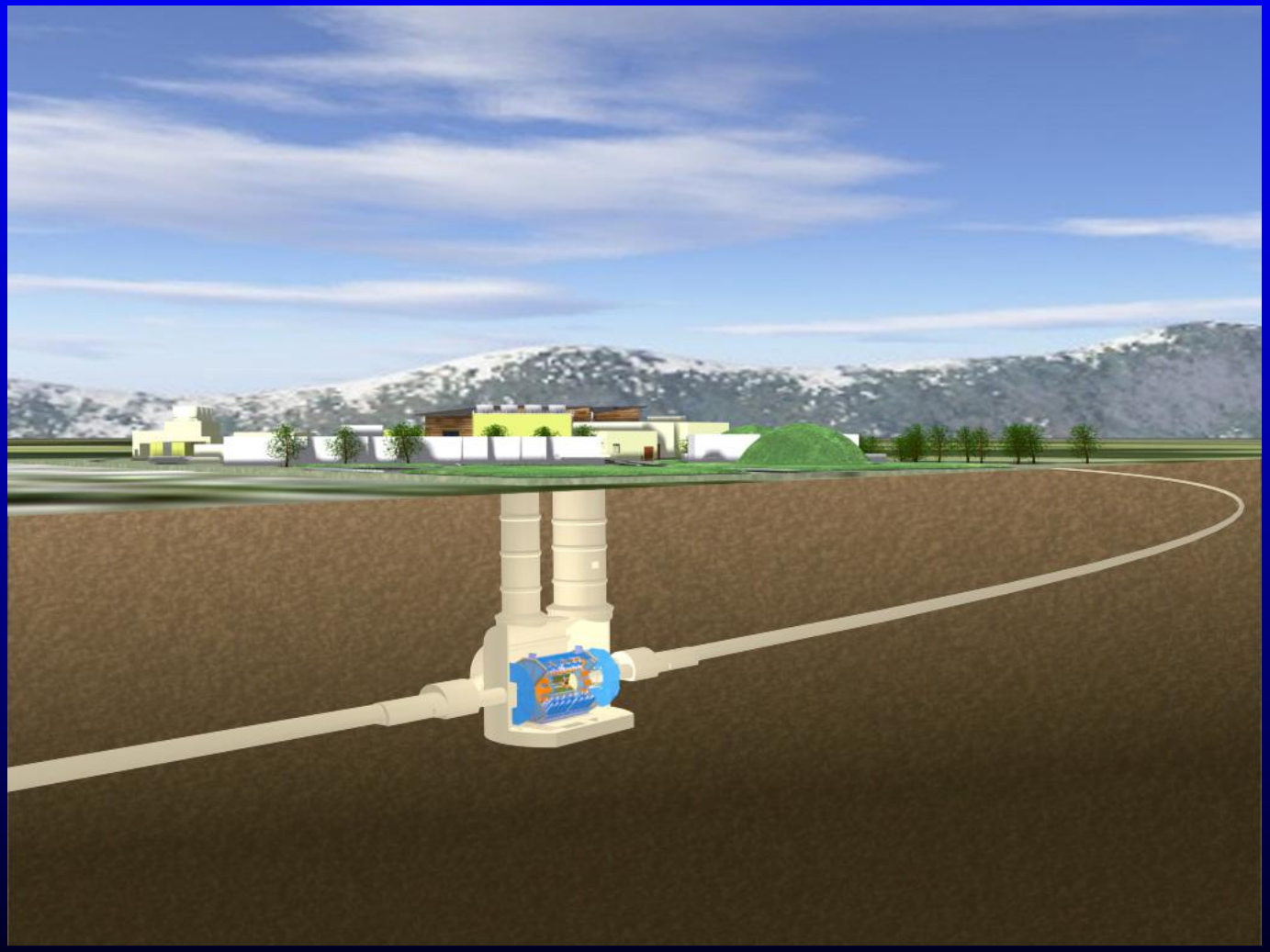

SWITZERLAND
FRANCE
CERN
ATLAS
LHCb
ALICE
CMS
SOUTH

27 km circumference tunnel

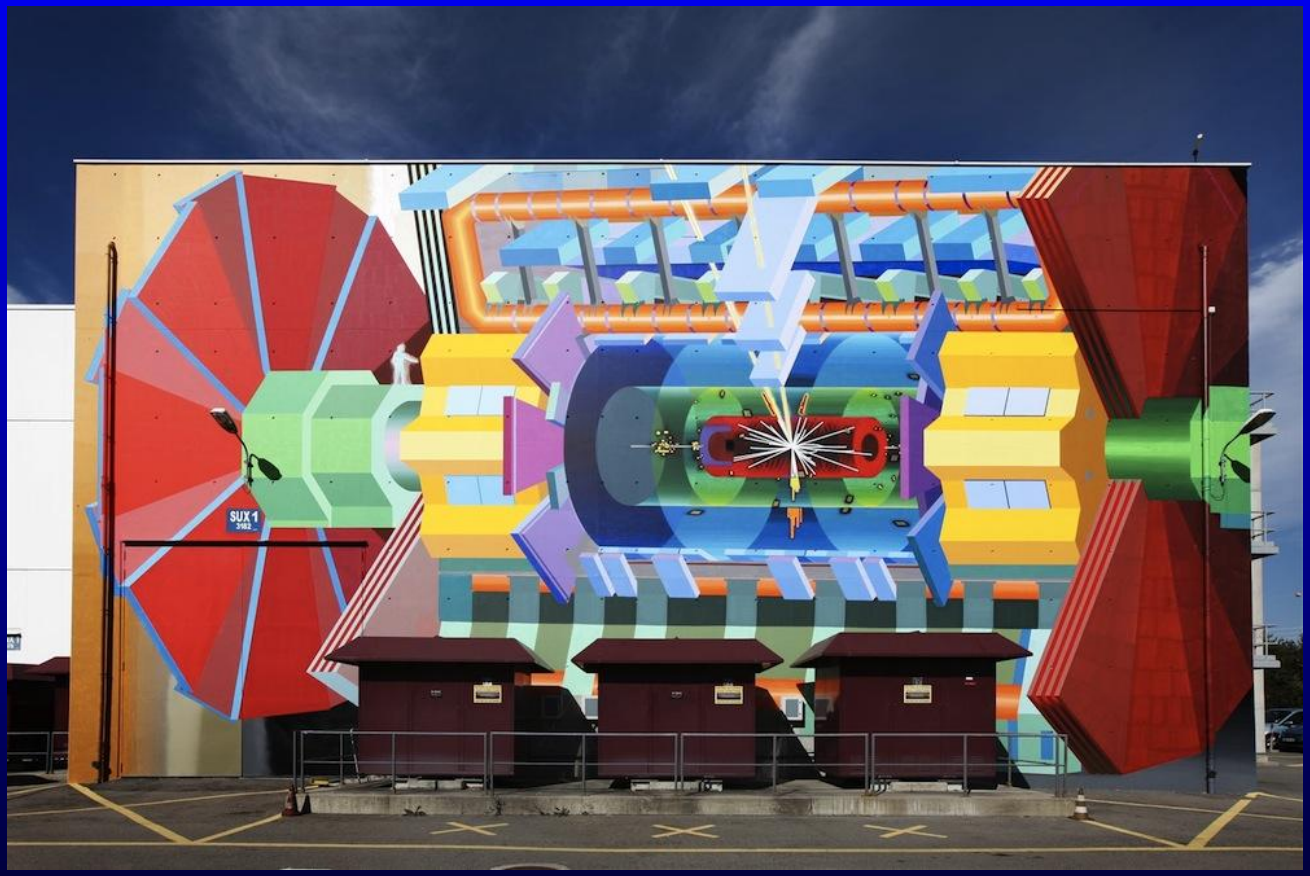


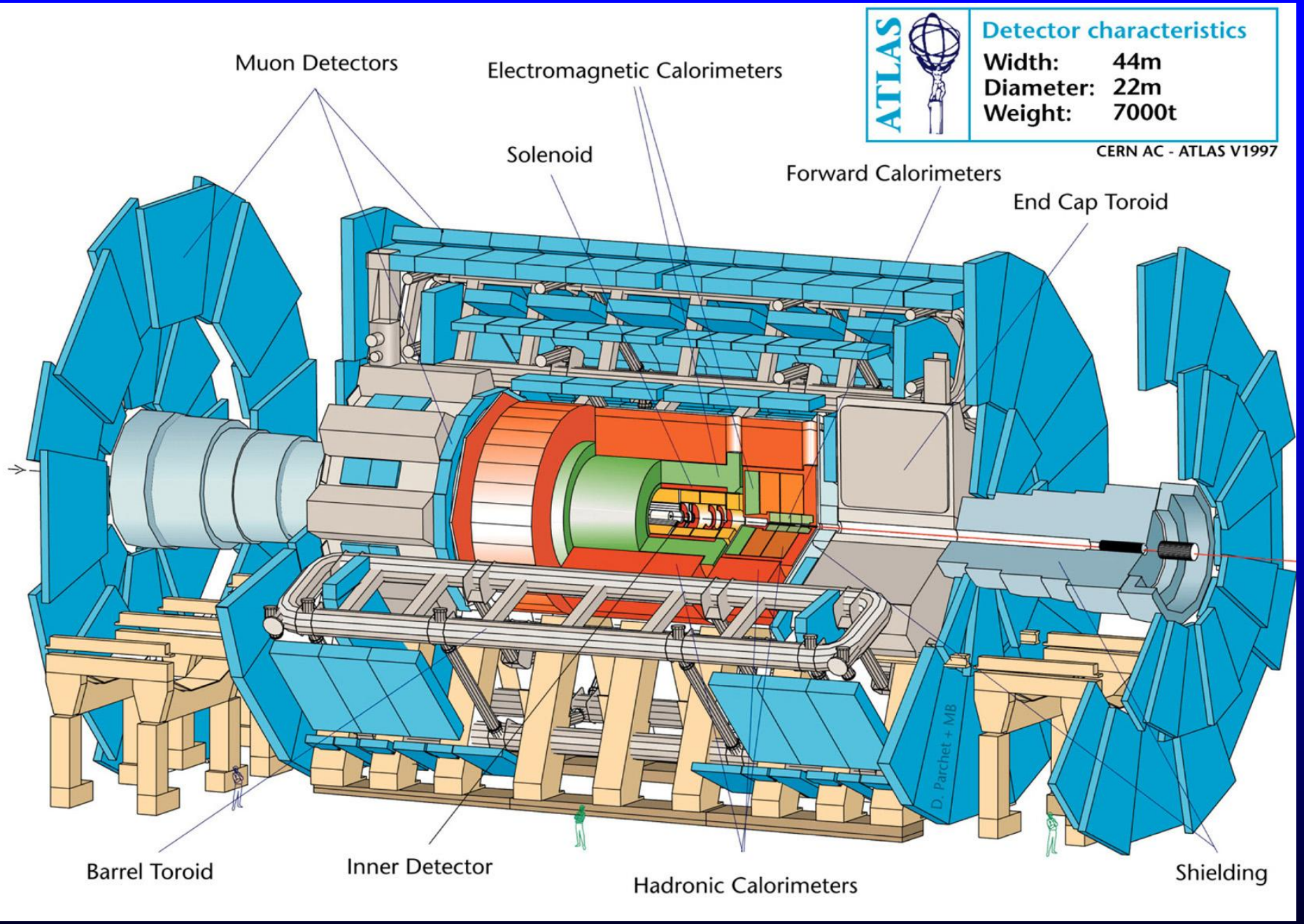

LHCb
The search
for anti-matter
Atlas
The search
for dark matter
The Grid
Other experiments
CMS
The search for
the Higgs Boson
Alice
The moments
after the Big Bang
Tunnel

ATLAS

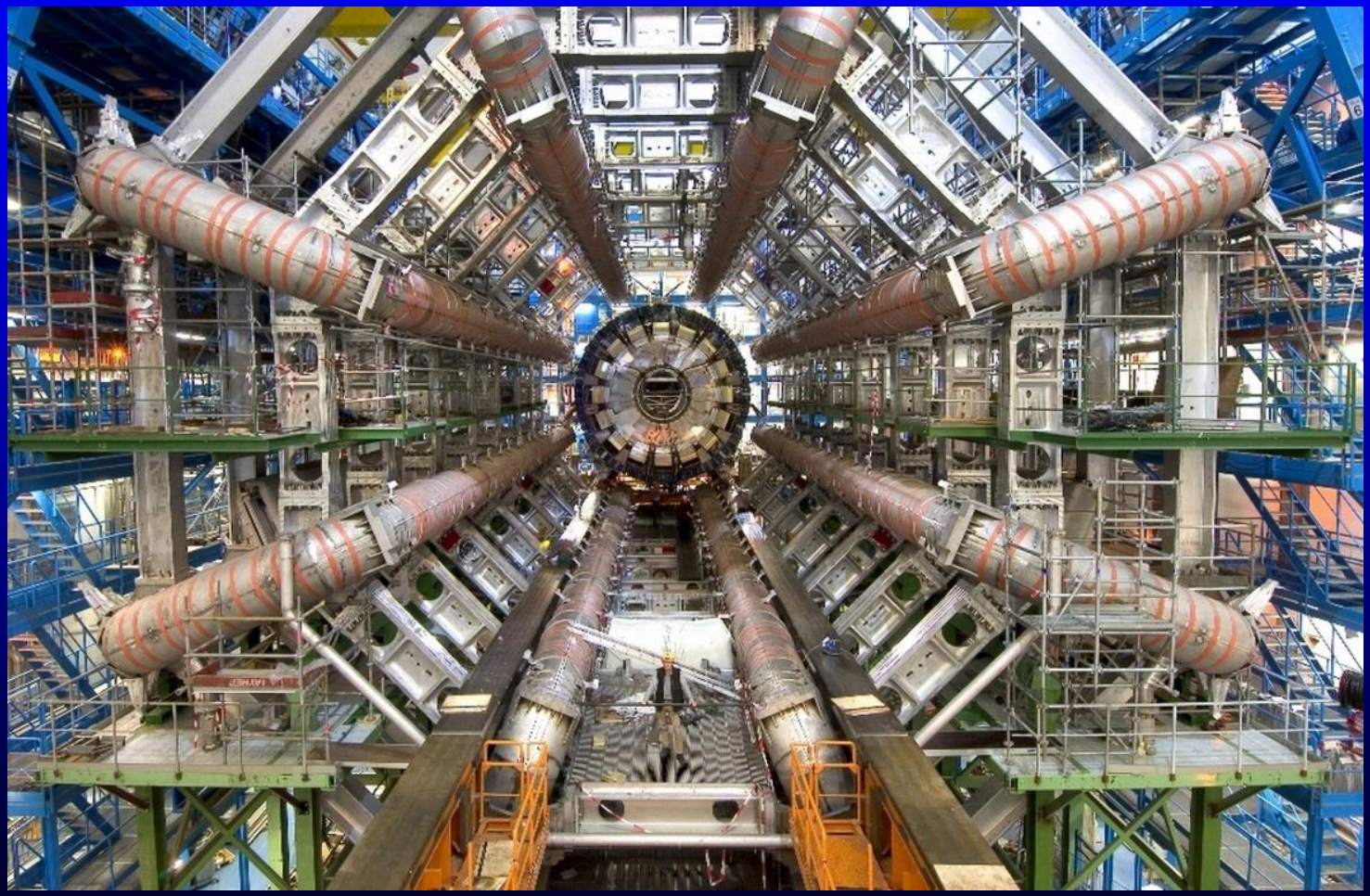


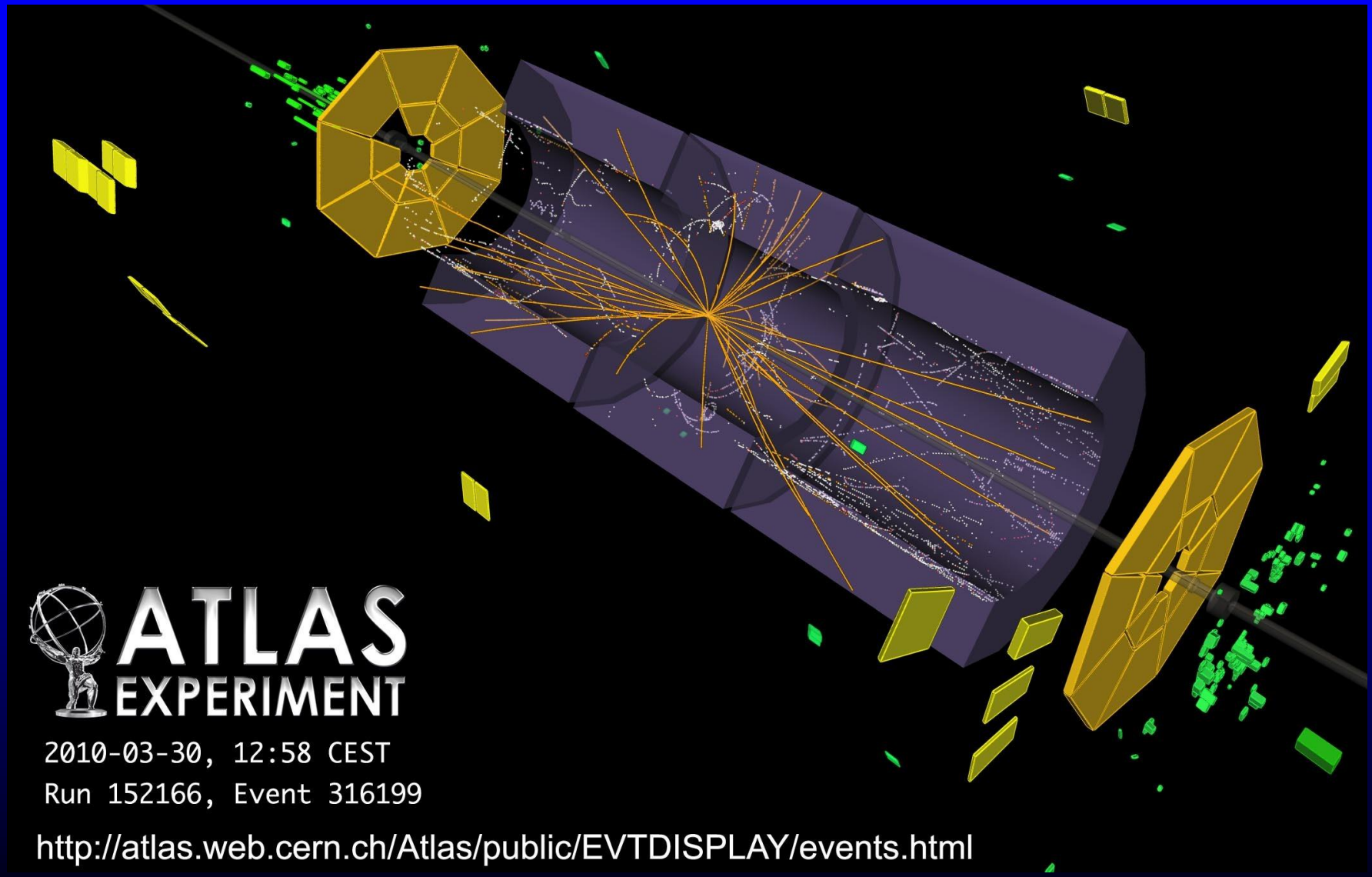
An ATLAS Mural




ATLAS
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding
D. Parchet + MB

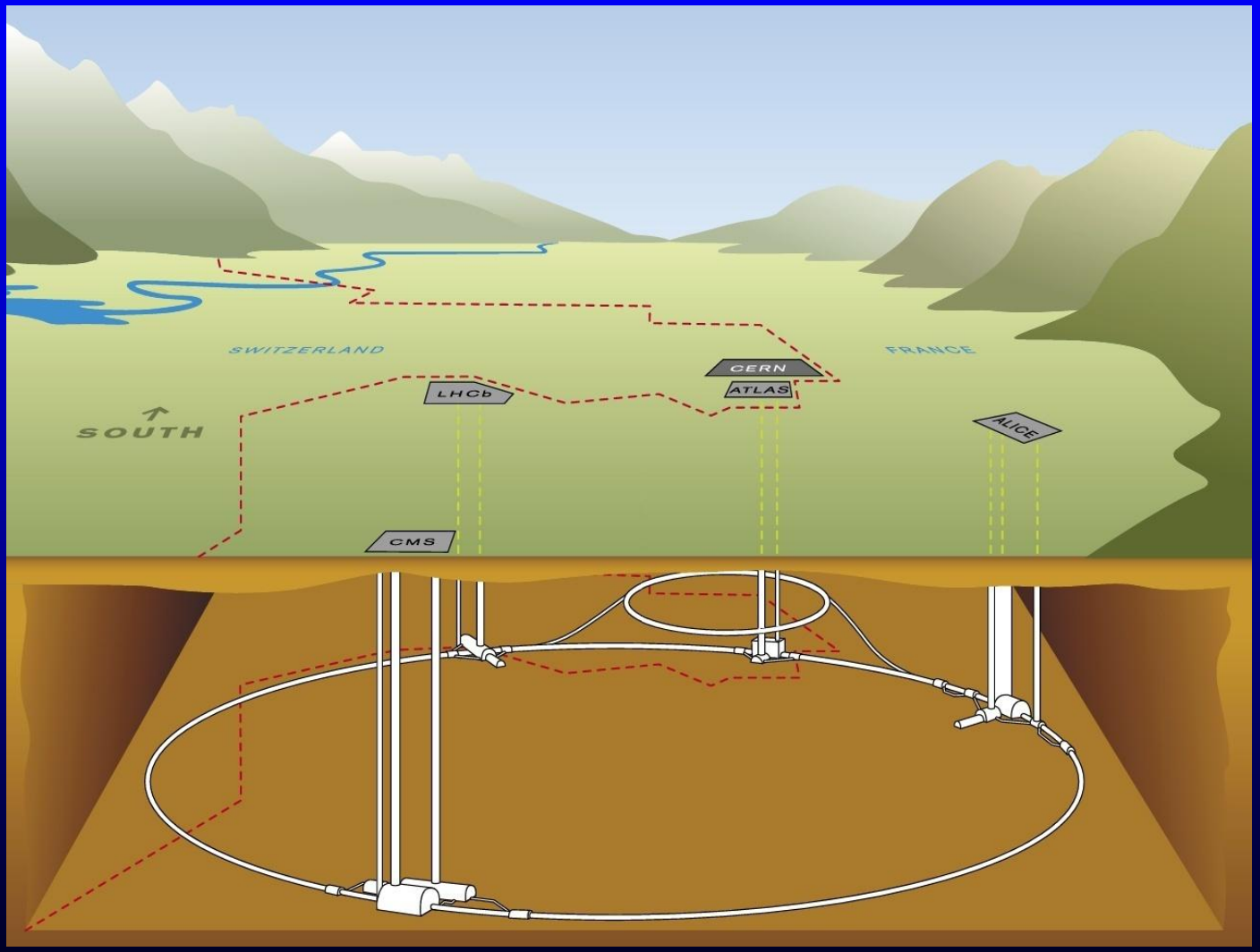
Looking into ATLAS

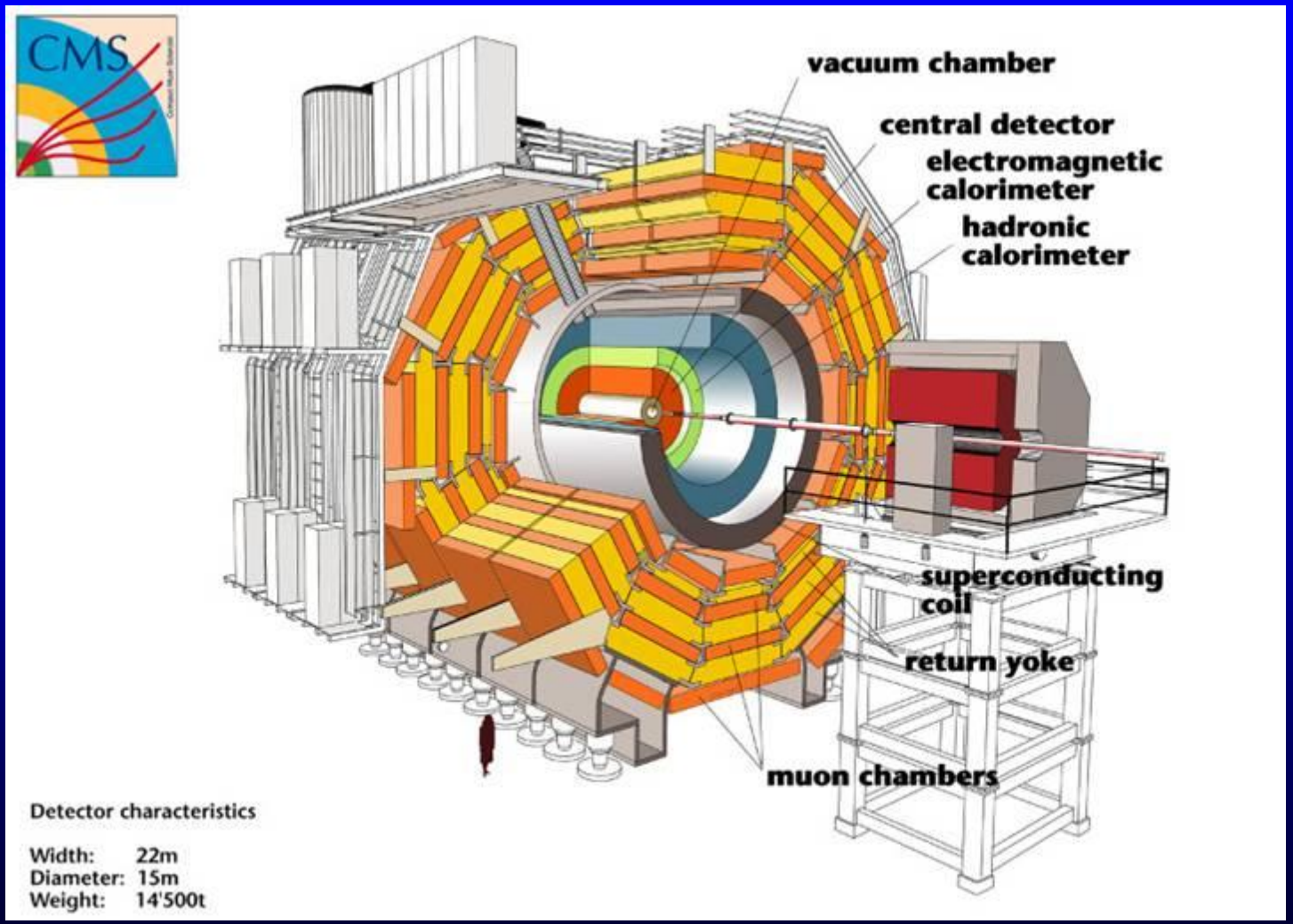


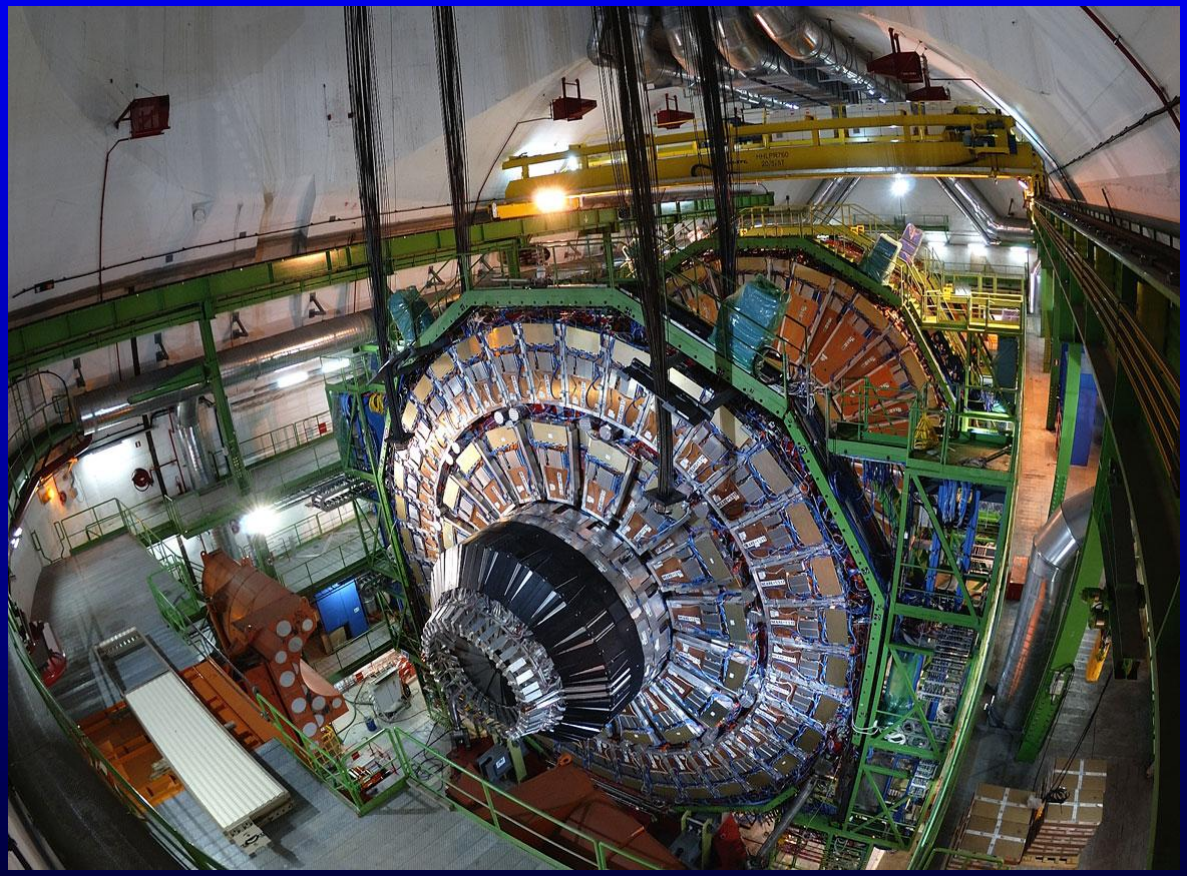

ATLAS
EXPERIMENT
2010-03-30, 12:58 CEST
Run 152166, Event 316199
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

CMS Detector

Compact Muon Solanoid


SWITZERLAND
FRANCE
CERN
ATLAS
LHCb
ALICE
CMS
SOUTH


CMS
vacuum chamber
central detector
electromagnetic calorimeter
hadronic calorimeter
superconducting coil
return yoke
muon chambers
Detector characteristics
Width: 22m
Diameter: 15m
Weight: 14'500t



Simulated Higgs Boson Event

Don’t hold your breath!

- The LHC will probably need to run at full power for a couple of years to get an unambiguous detection.
- In March 2010 the LHC began to run at 3.5 TeV – so impact energy is 7 TeV.
- Following a winter break at the end of 2010, it will run at this energy until the end of 2011.

- The LHC will then shut down for 1 year to allow for upgrade work.

- Experiments at the full power of 14 TeV will begin in 2013.

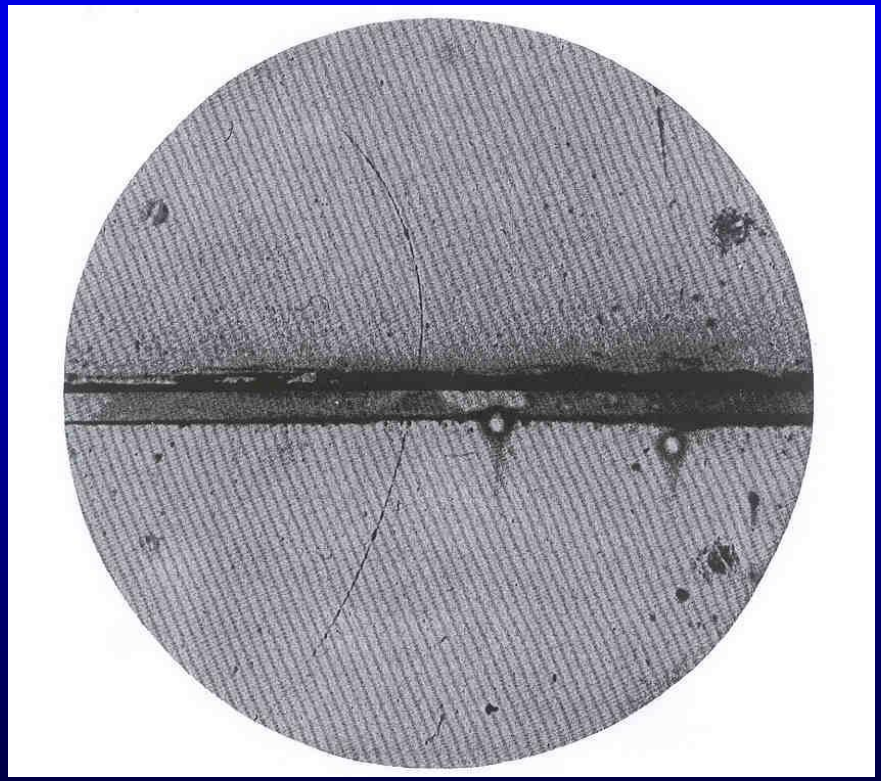
Why do we live in an Matter Universe?

Anti-Matter

- In 1928 Paul Dirac realised that his theory of the electron allowed for the existence of an anti-electron (called the Positron) that had positive, rather than negative charge.

Discovery of the Positron

- In 1932, Carl Anderson found the track of a positron in a Wilson Cloud Chamber.



- Today anti-matter is primarily created by cosmic rays, but may also be made in particle accelerators.
- Scientists at CERN have made around 38 atoms of anti-hydrogen (anti proton plus positron) and trapped them for ~ 6 seconds.

We can now study anti-matter!

Anti-matter production

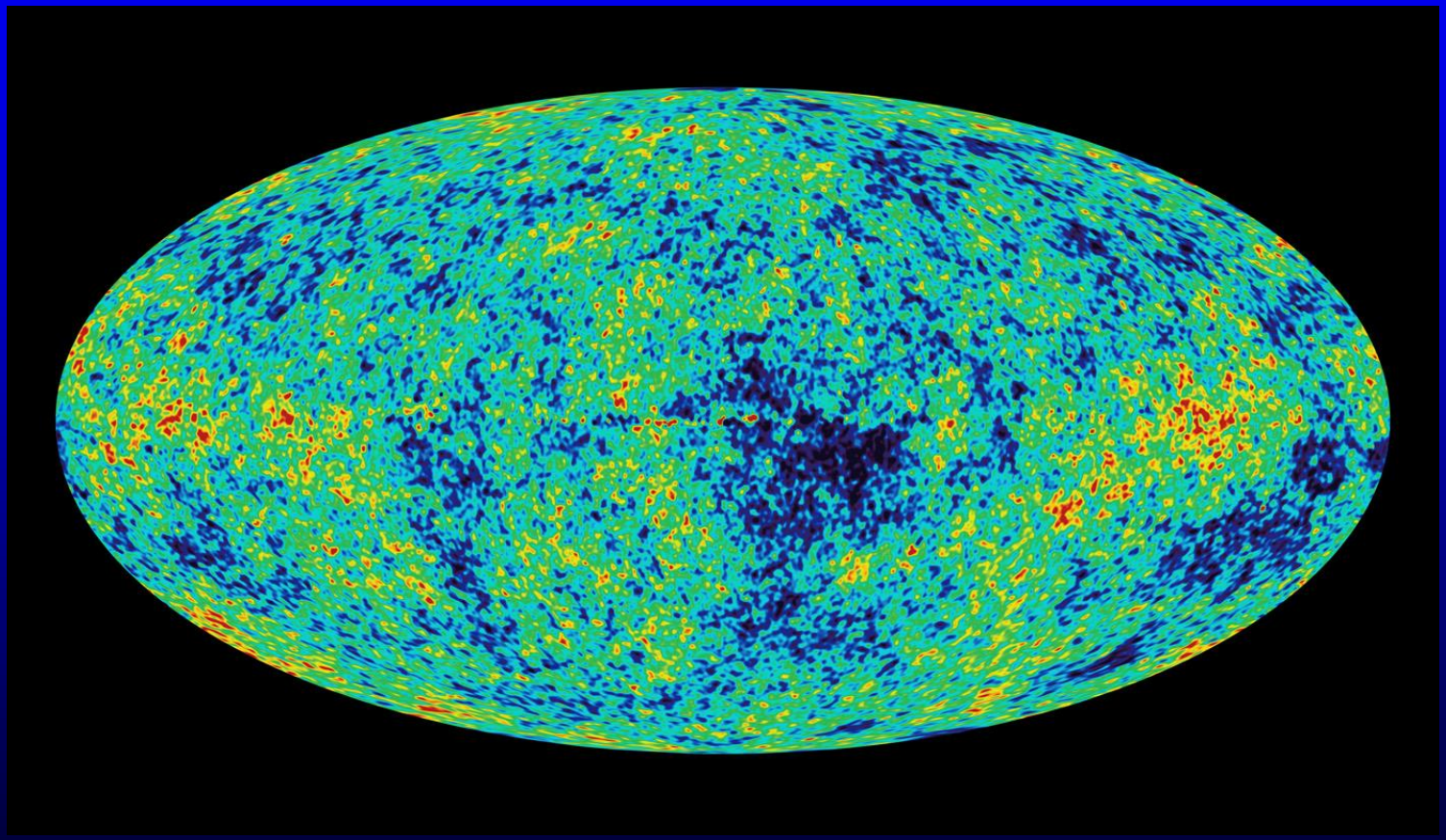
Quick Time Movie

The Big Bang

- We believe that, initially, almost equal amounts of matter and anti-matter were created. But there was a very small excess of matter - ~1 part per billion!

- All anti-matter particles annihilated with an equivalent number of matter particles giving rise to the Cosmic Microwave Background.

The Cosmic Microwave Background

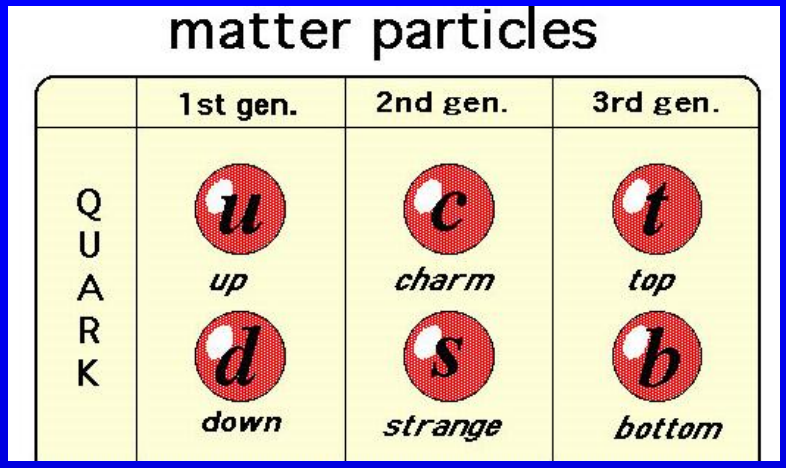


C-P Violation

- So far physicists have not been able to identify the cause of this apparent “asymmetry”.

- In 1967 the Russian physicist Andrei Sakharov proposed several possible mechanisms including “charge-parity” violation which is an effect that affects how particles decay.

The Beauty Quark



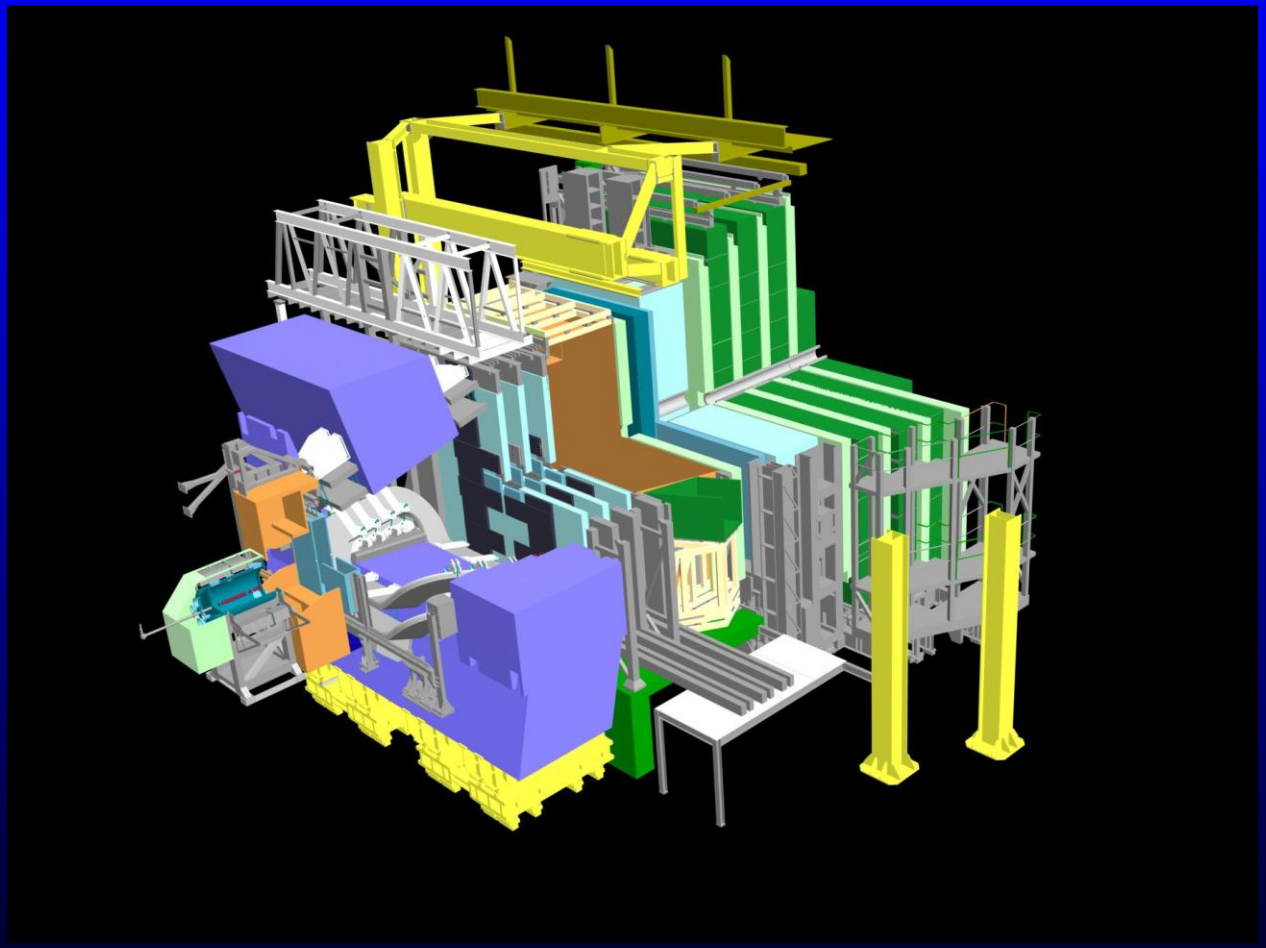
- Also known as the Bottom Quark.

- The beauty quark, is a third-generation quark with a charge of −1⁄3 e.

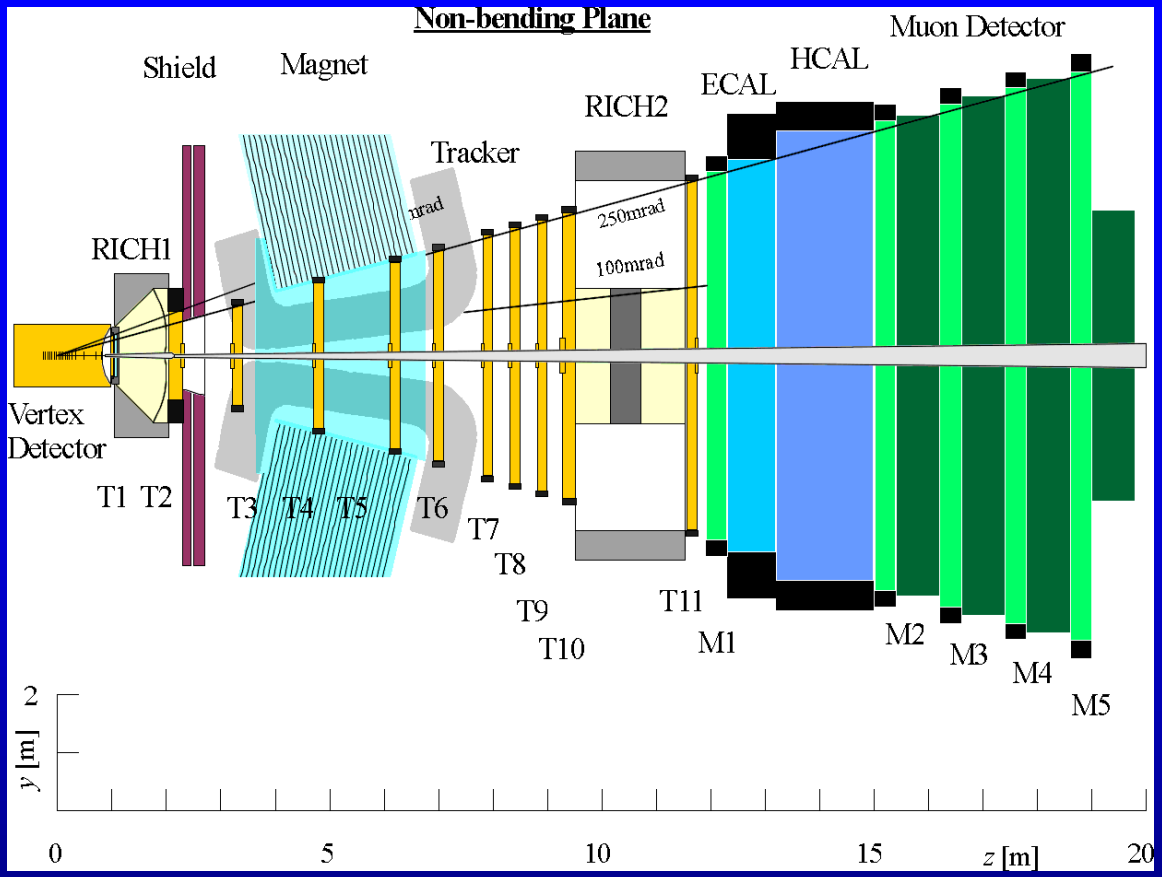
  It has a mass a little more than four times the mass of a proton.

LHCb – **the Large Hadron Collider Beauty** experiment

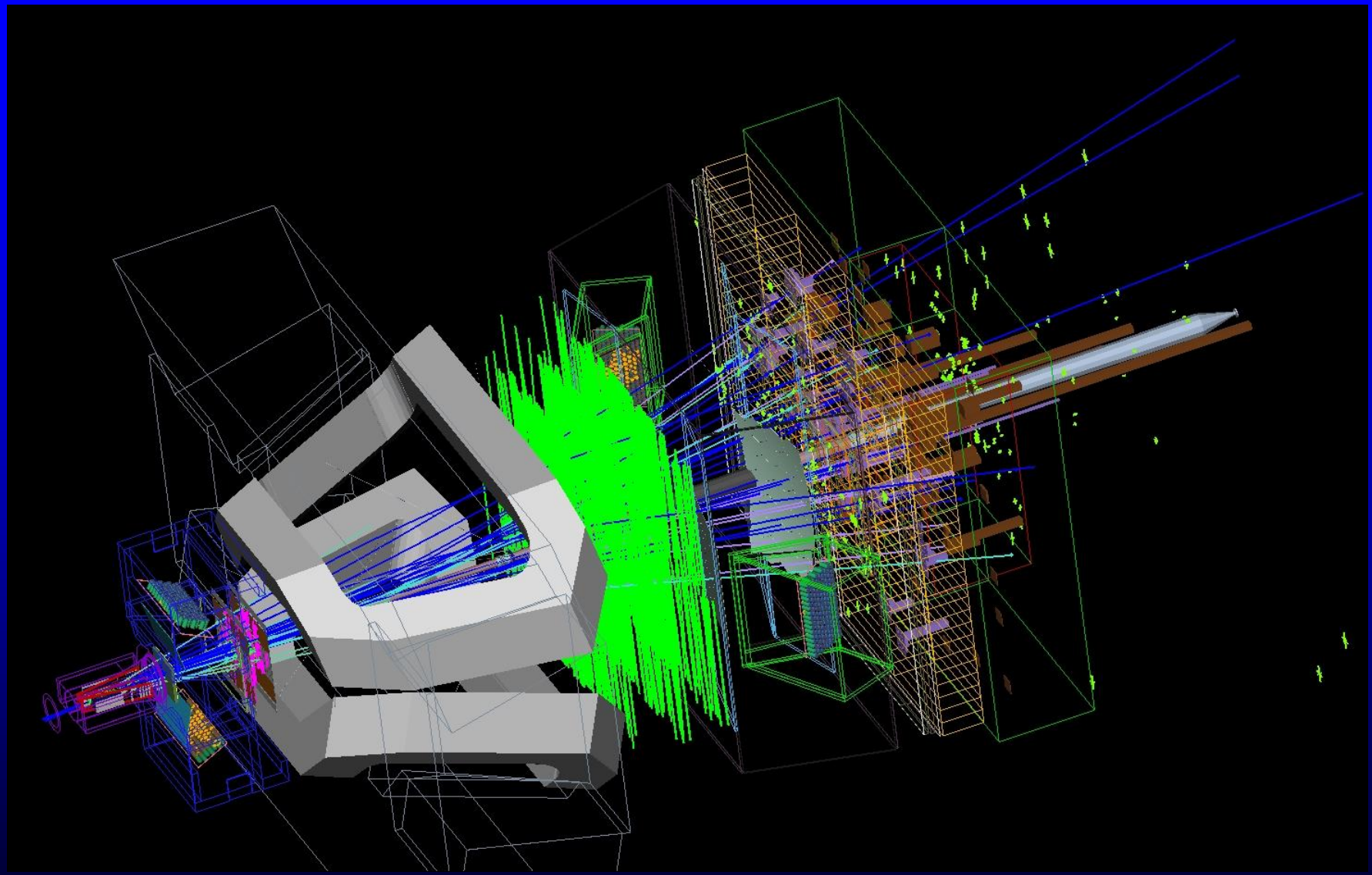
To explore how matter triumphed over anti-matter



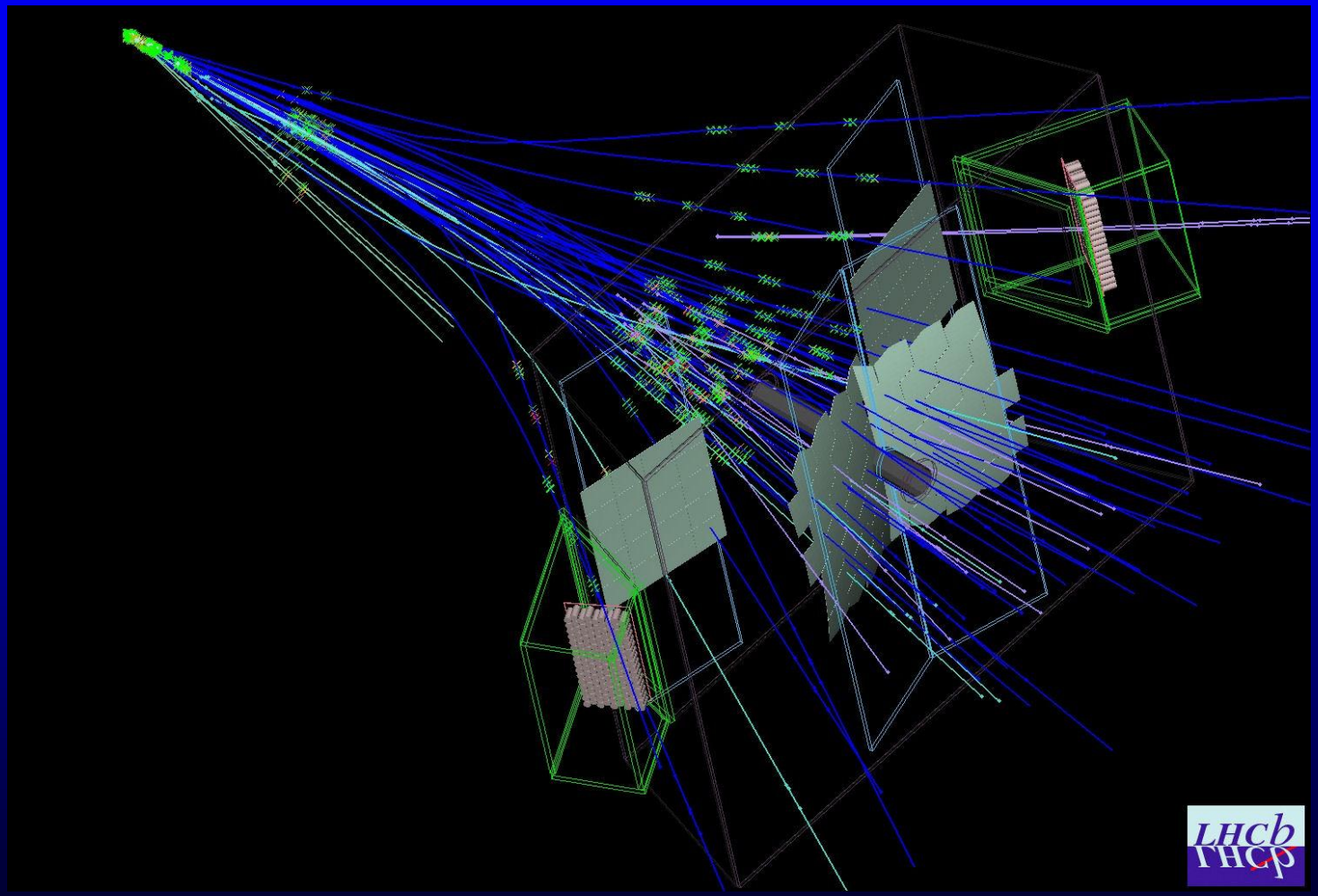
LHCb

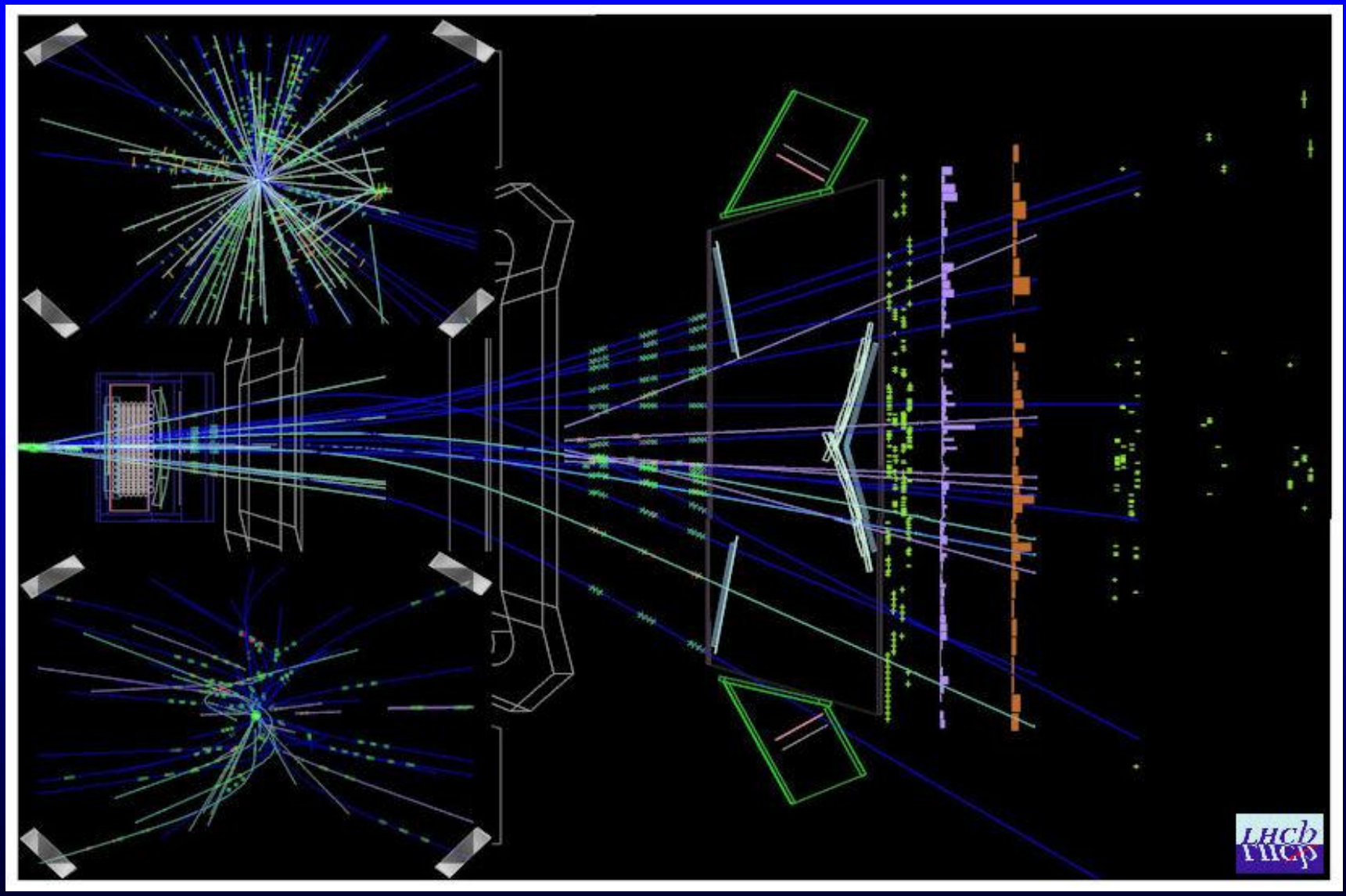


- LHCb is a specialized experiment, aimed at measuring the parameters of CP violation in the interactions of b-hadrons (heavy particles containing a beauty quark).

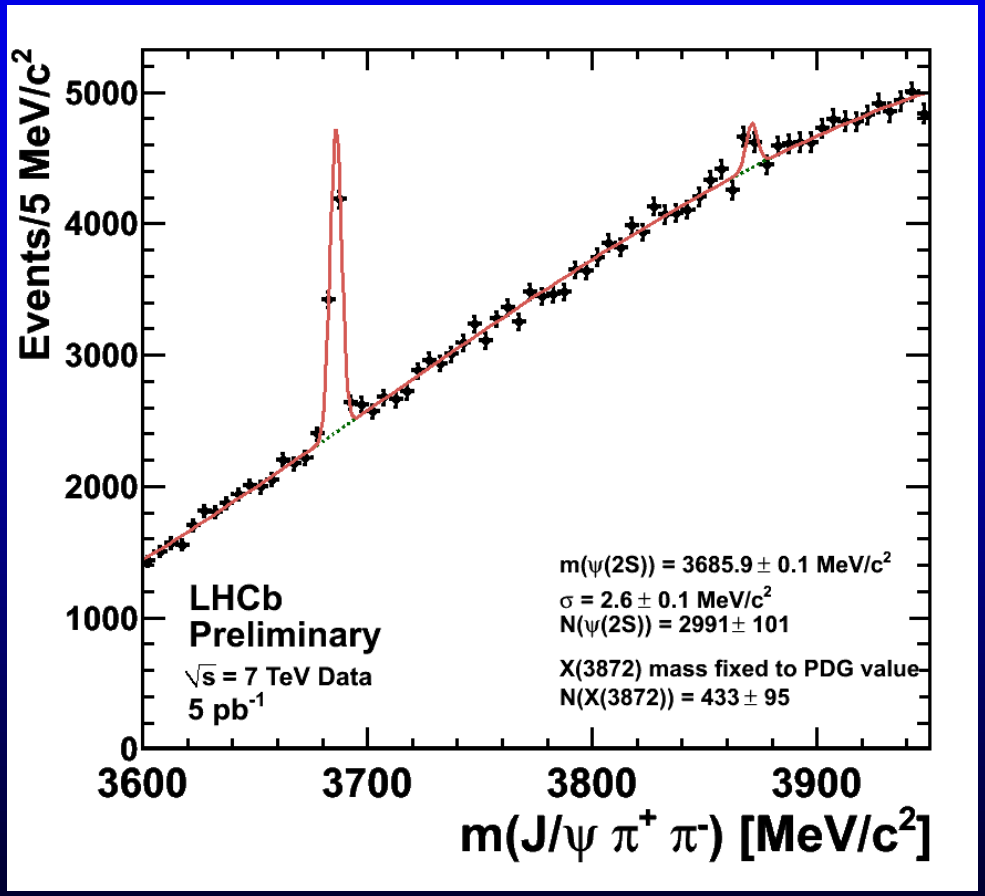


One of the first interactions




LHCb

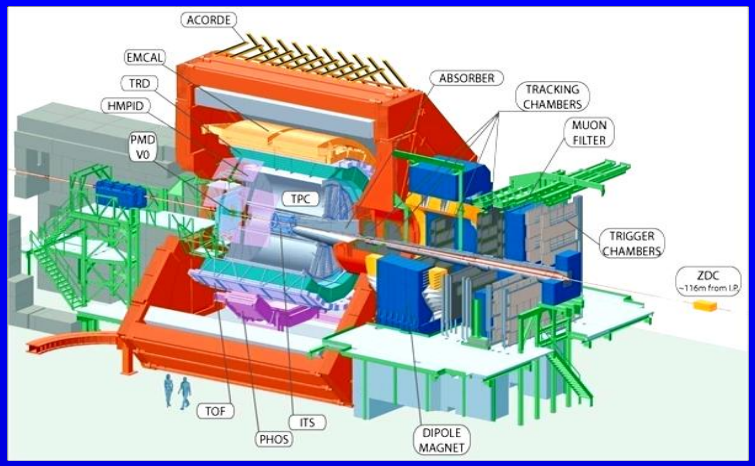
An new unexpected Particle: a Tetraquark?



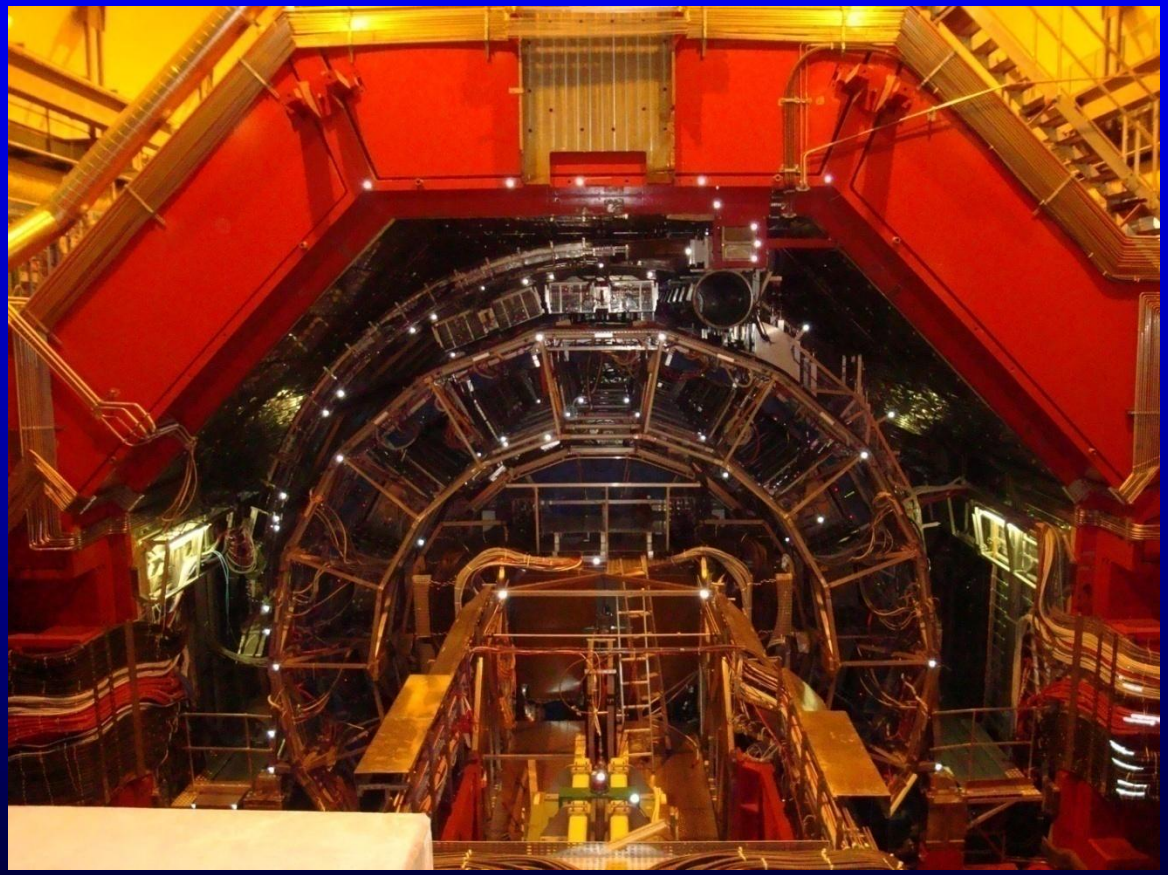
ALICE

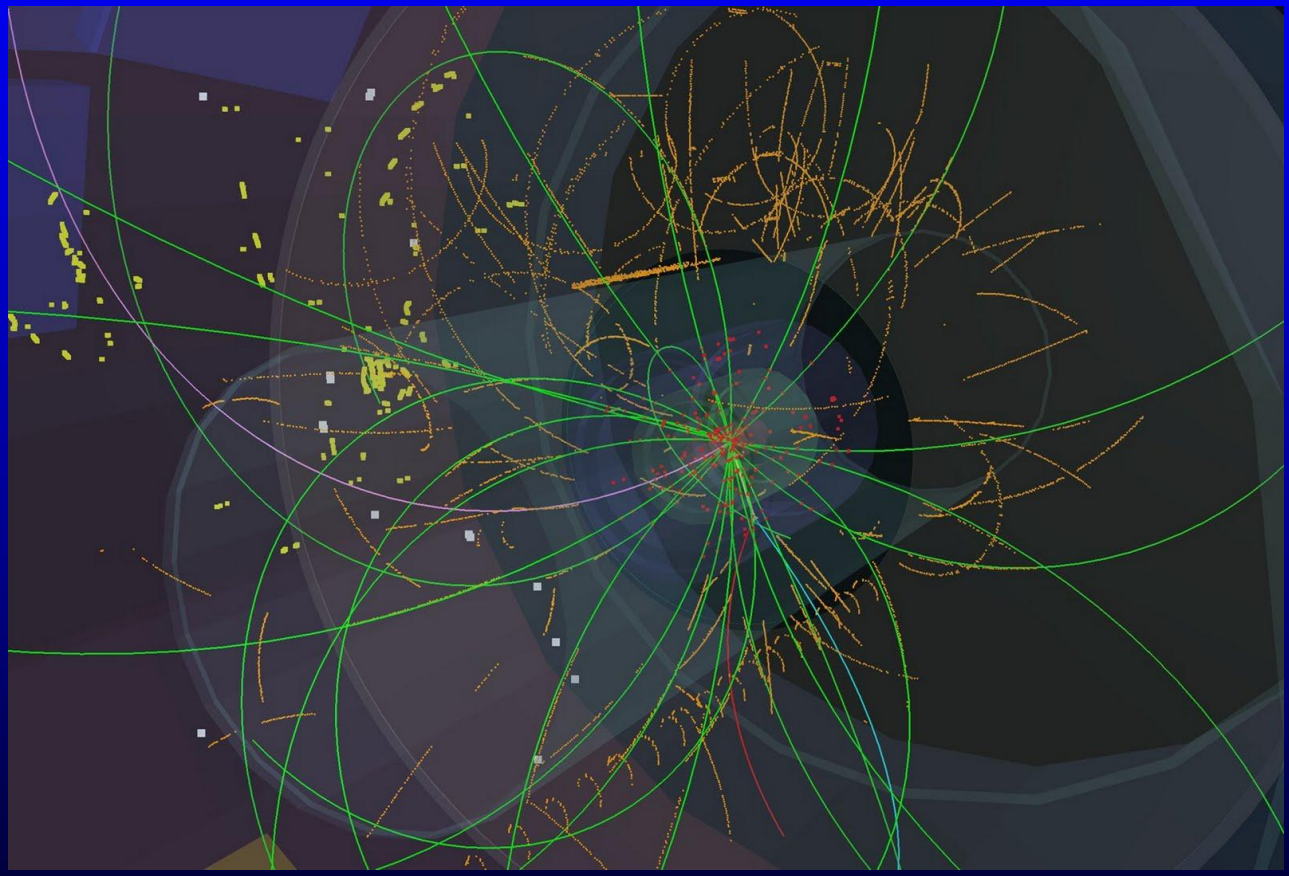
Creating the conditions one billionth of a second after the Big Bang

ALICE

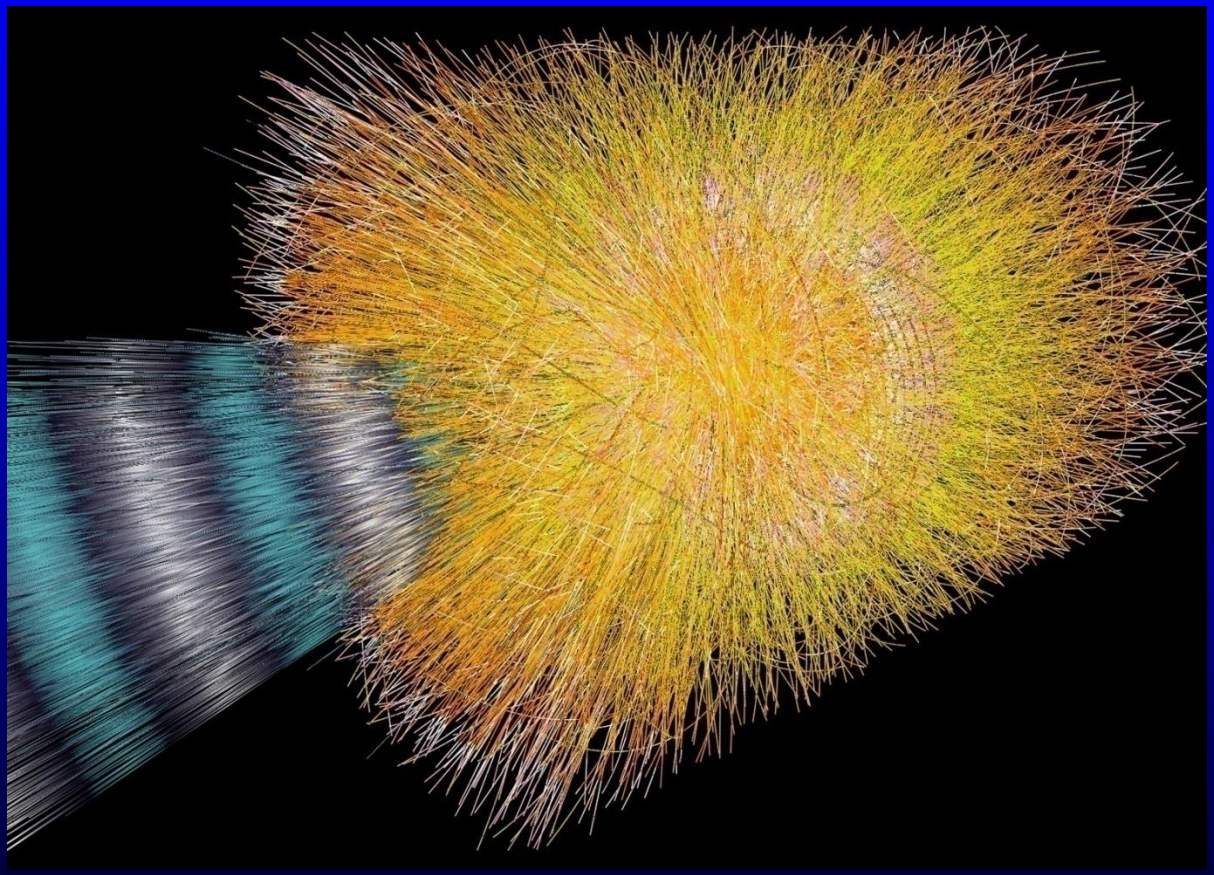


- Since November 2010, Alice has been impacting beams of lead nuclei (208 times the mass of a proton).
- They have just announced that they have managed to create a quark-gluon soup - like the primordial “soup” that existed around a billionth of a second after the Big Bang.

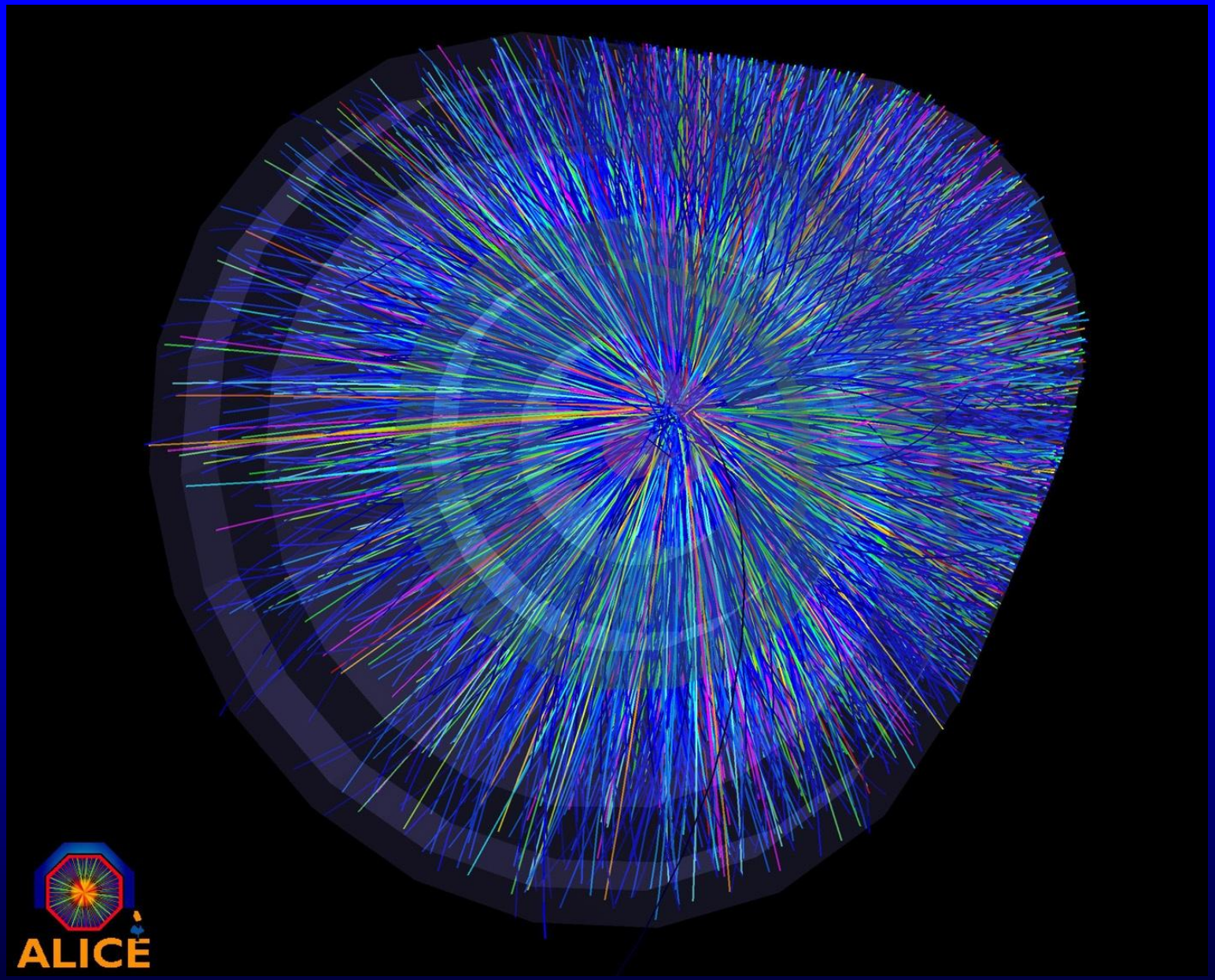


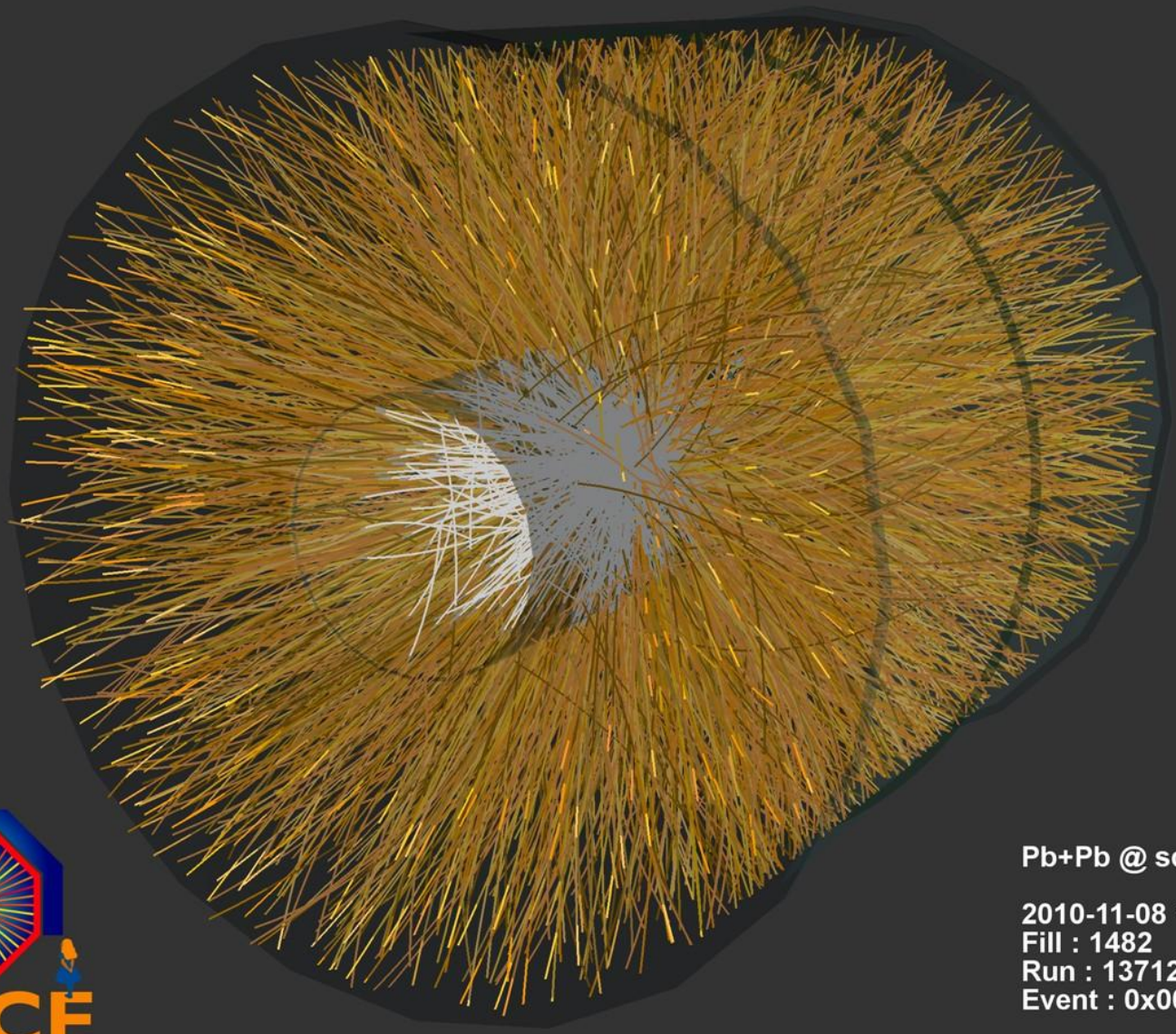


Simulated Collision



First Real Data



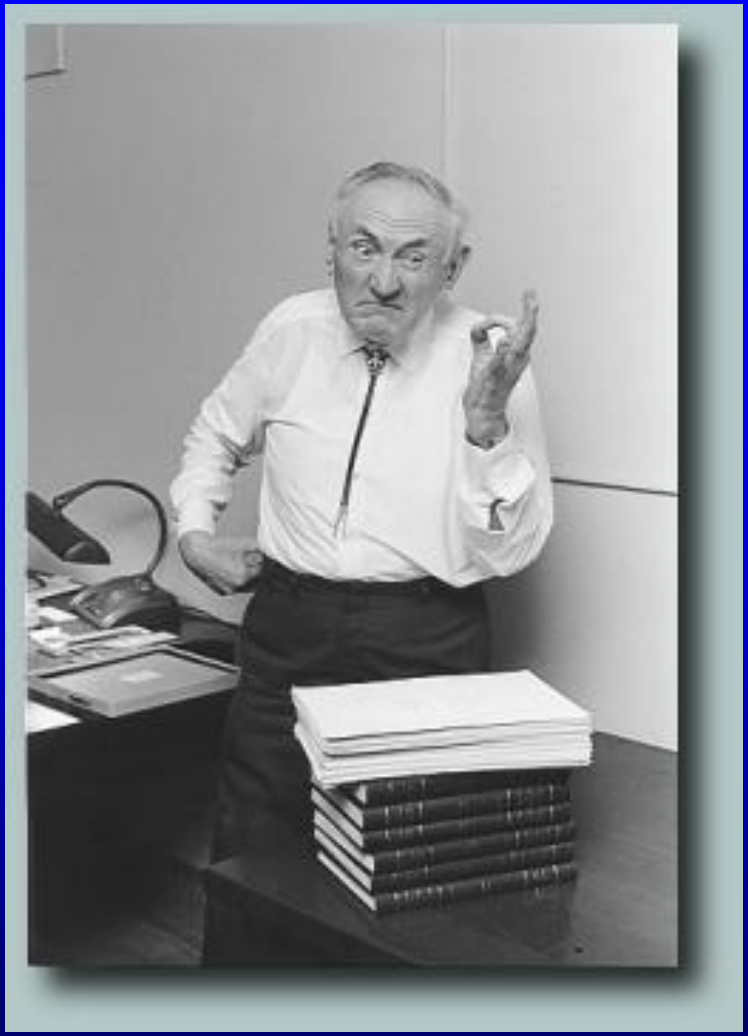


ALICE

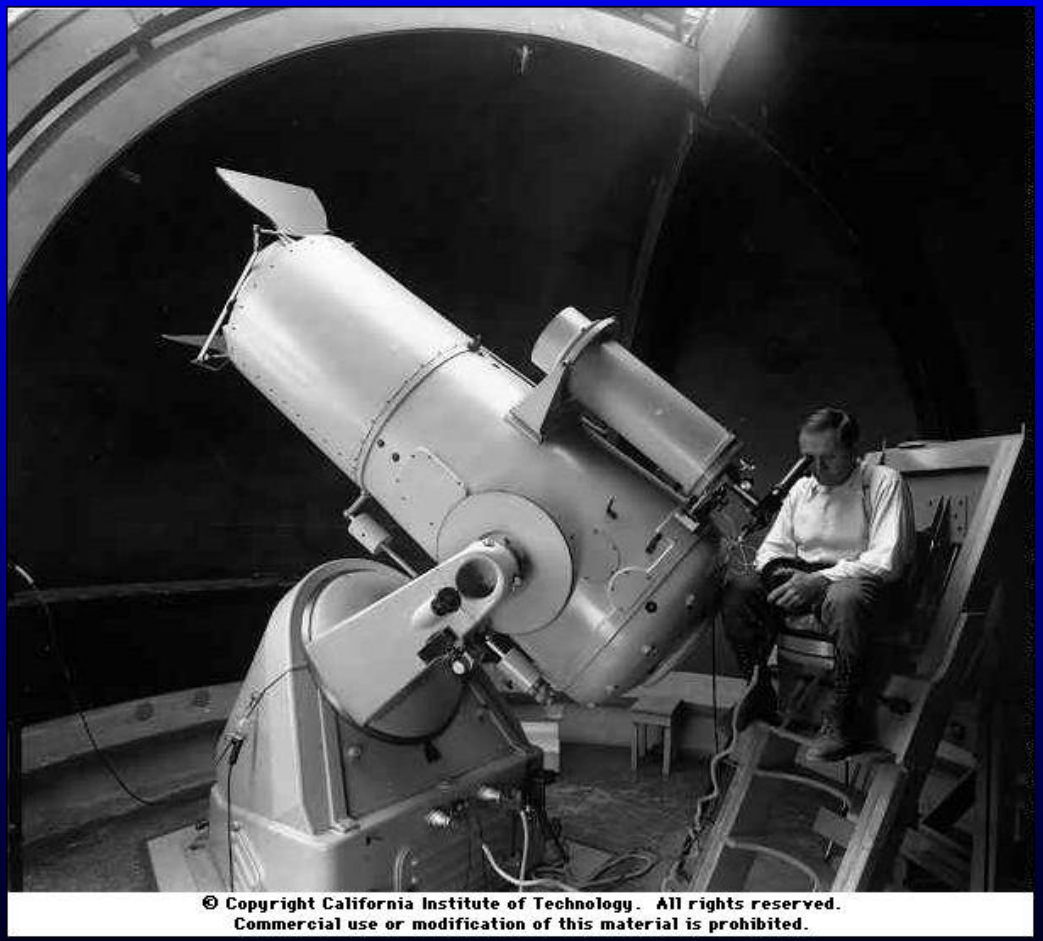
Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

What is Dark Matter?



Fritz Zwicky



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The Coma Cluster
A Massive, Local
Cluster of Galaxies

Vera Rubin

Detecting Dark Matter Particles

- A theory called “supersymmetry” predicts possible dark matter candidates such as the **neutralino** which is the lowest mass neutral supersymmetric particle.

- It is possible that the LHC using the **ATLAS** and **CMS** detectors may be able to create dark matter particles such as the neutralino or “neuclearites” which are combinations of up, down and strange quarks.

Studying Dark Matter by Gravitational Lensing

1) Strong lensing

When a foreground galaxy is in-line with a distant galaxy or quasar


November 1972: 966 MHz Survey

The Double Quasar

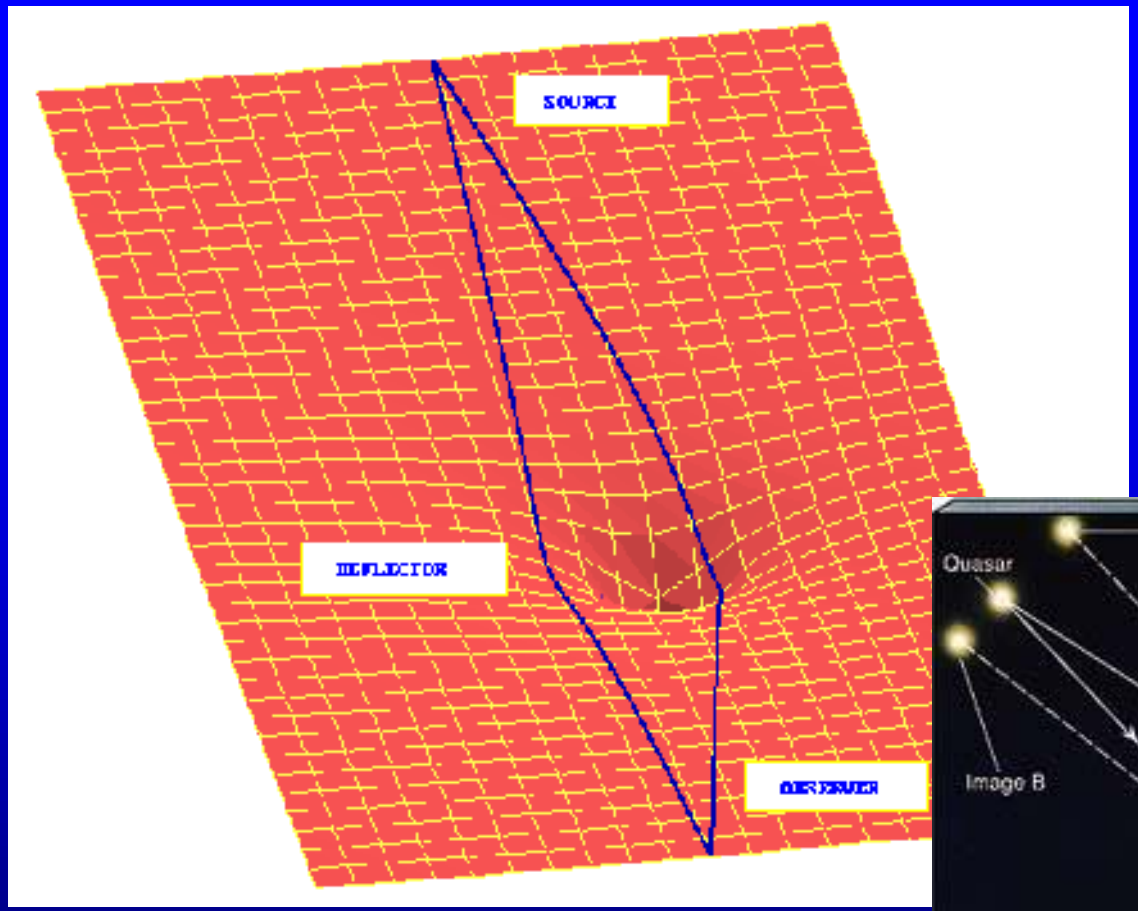
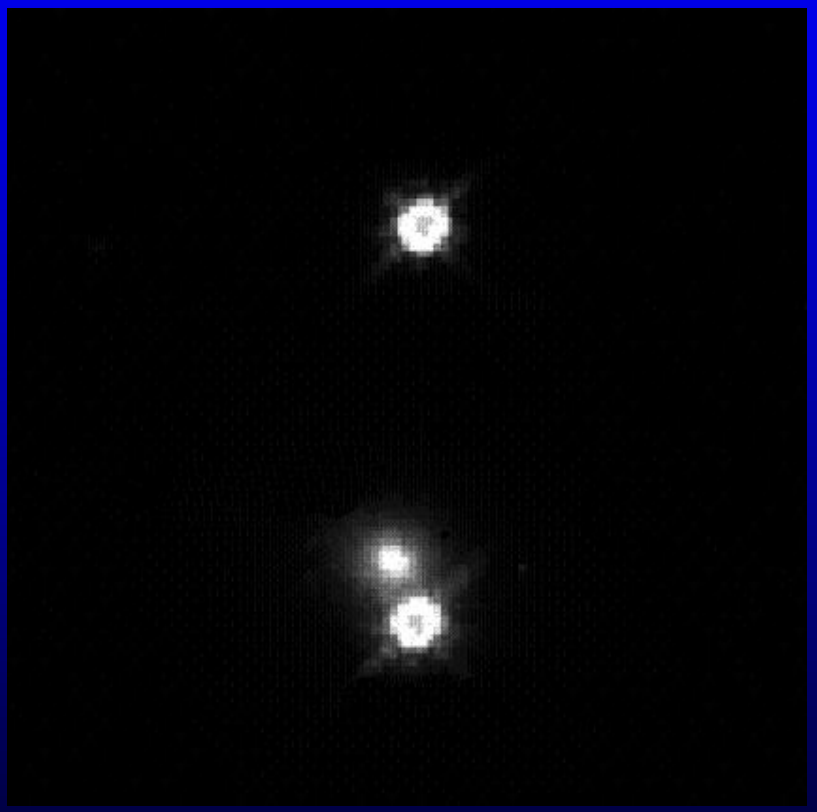

SOURCE
REFLECTOR
OBSERVER


Image A
Quasar
Image B
Lensing galaxy
Observer on earth

“Two” Quasars and a Galaxy

Quasar 0957+561 mirage www.astr.ua.edu



e-MERLIN

Jodrell Bank

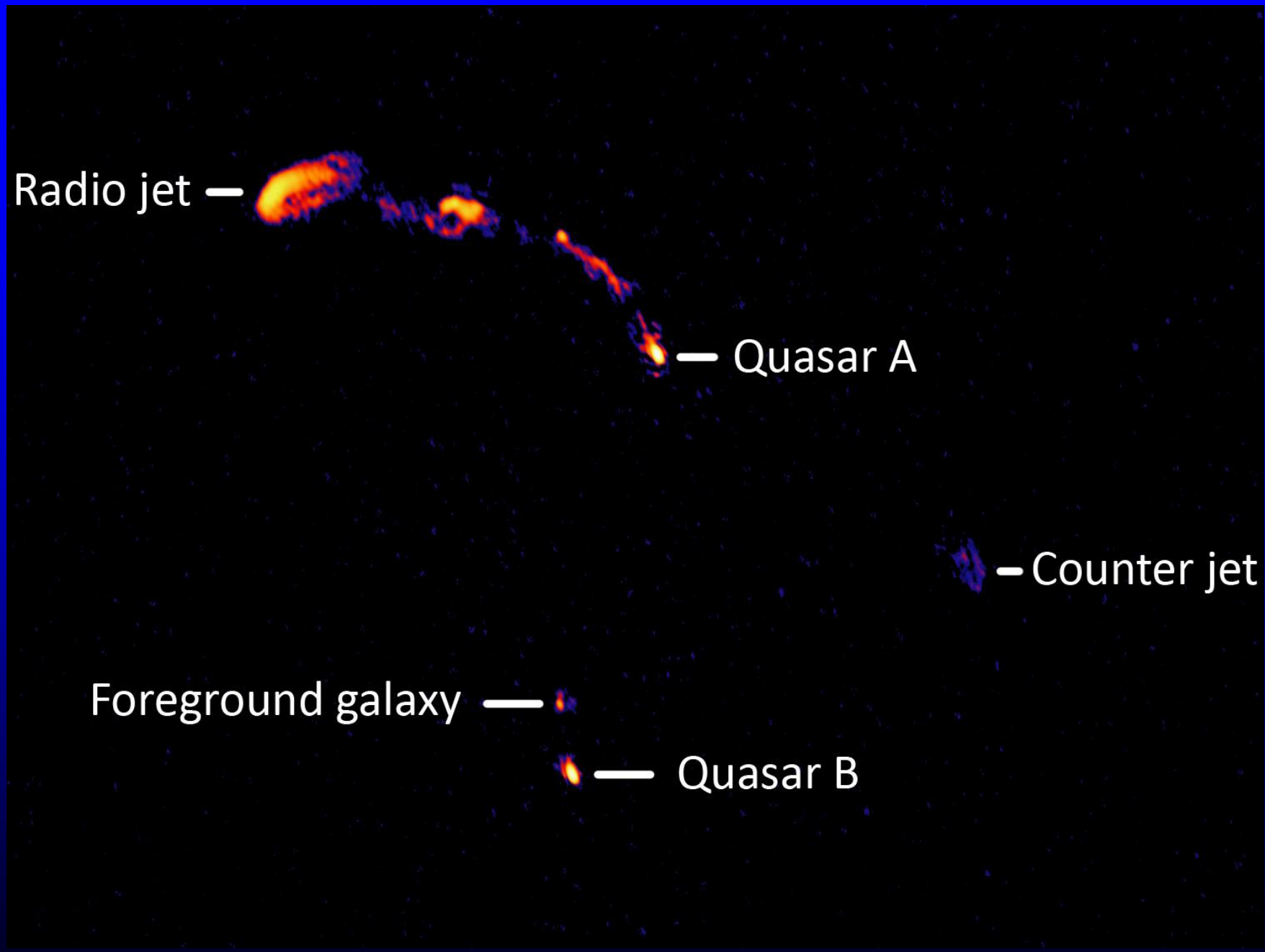
Tabley

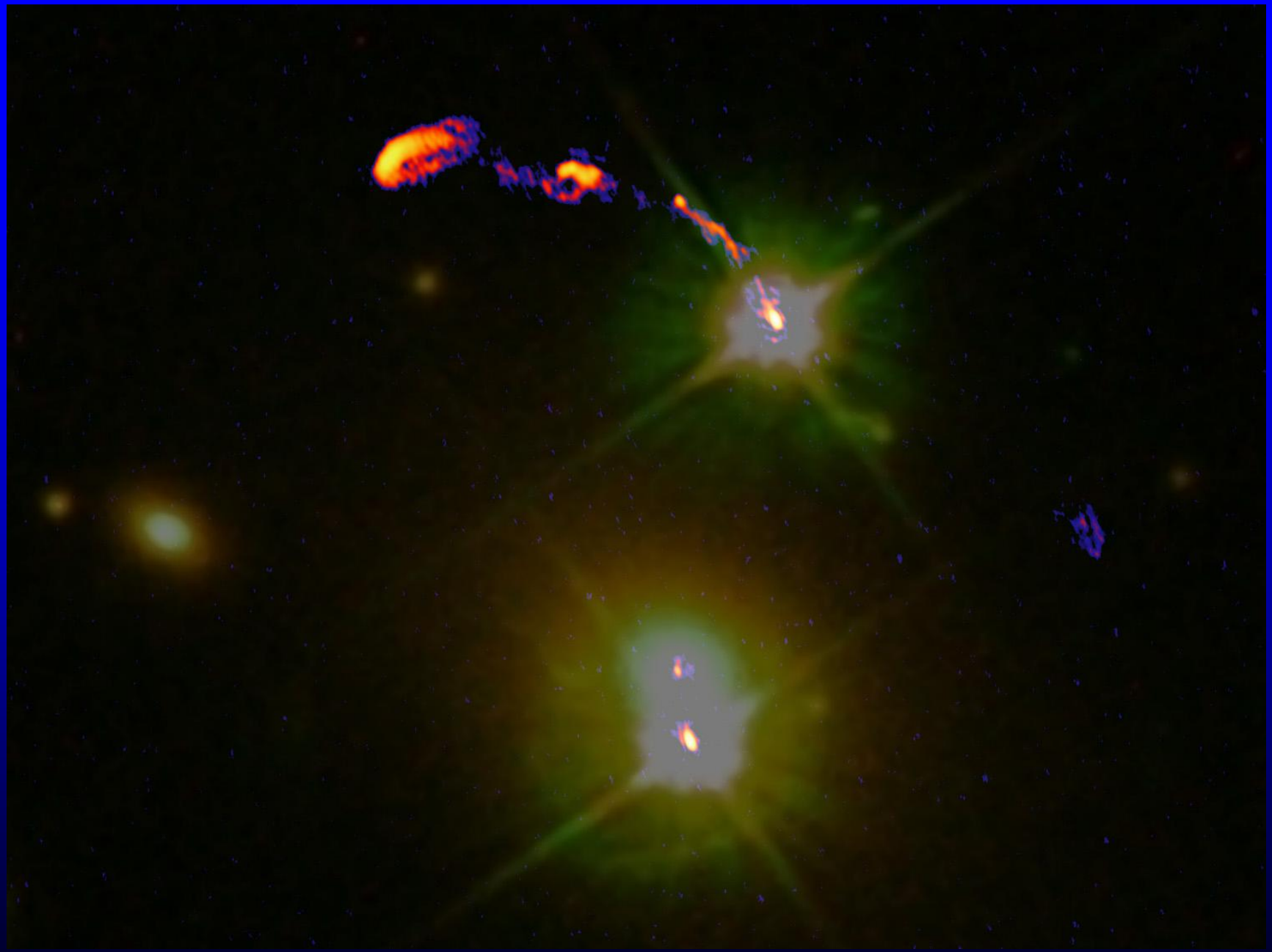
Knockin

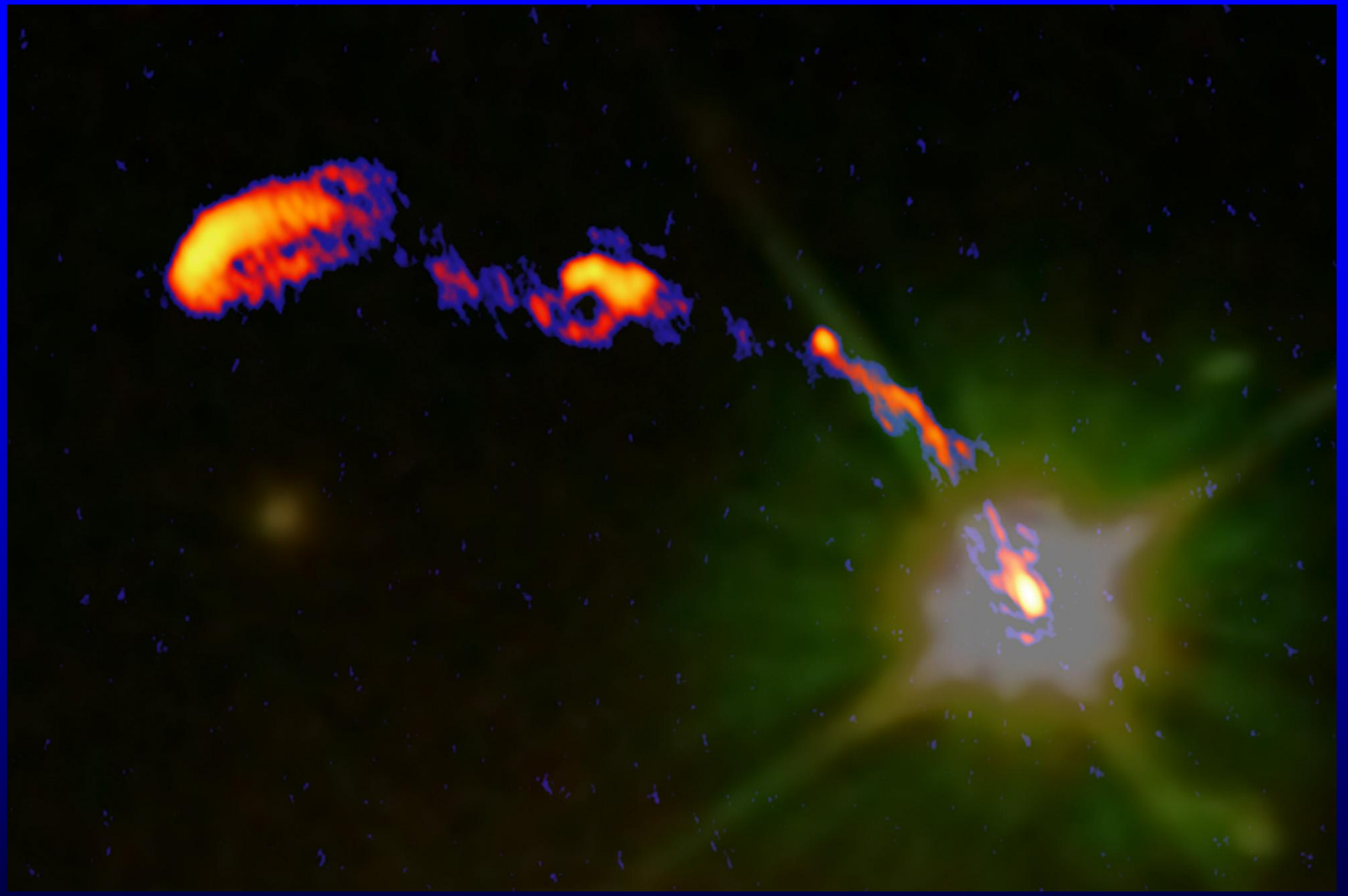
Cambridge

Darnhall

Defford

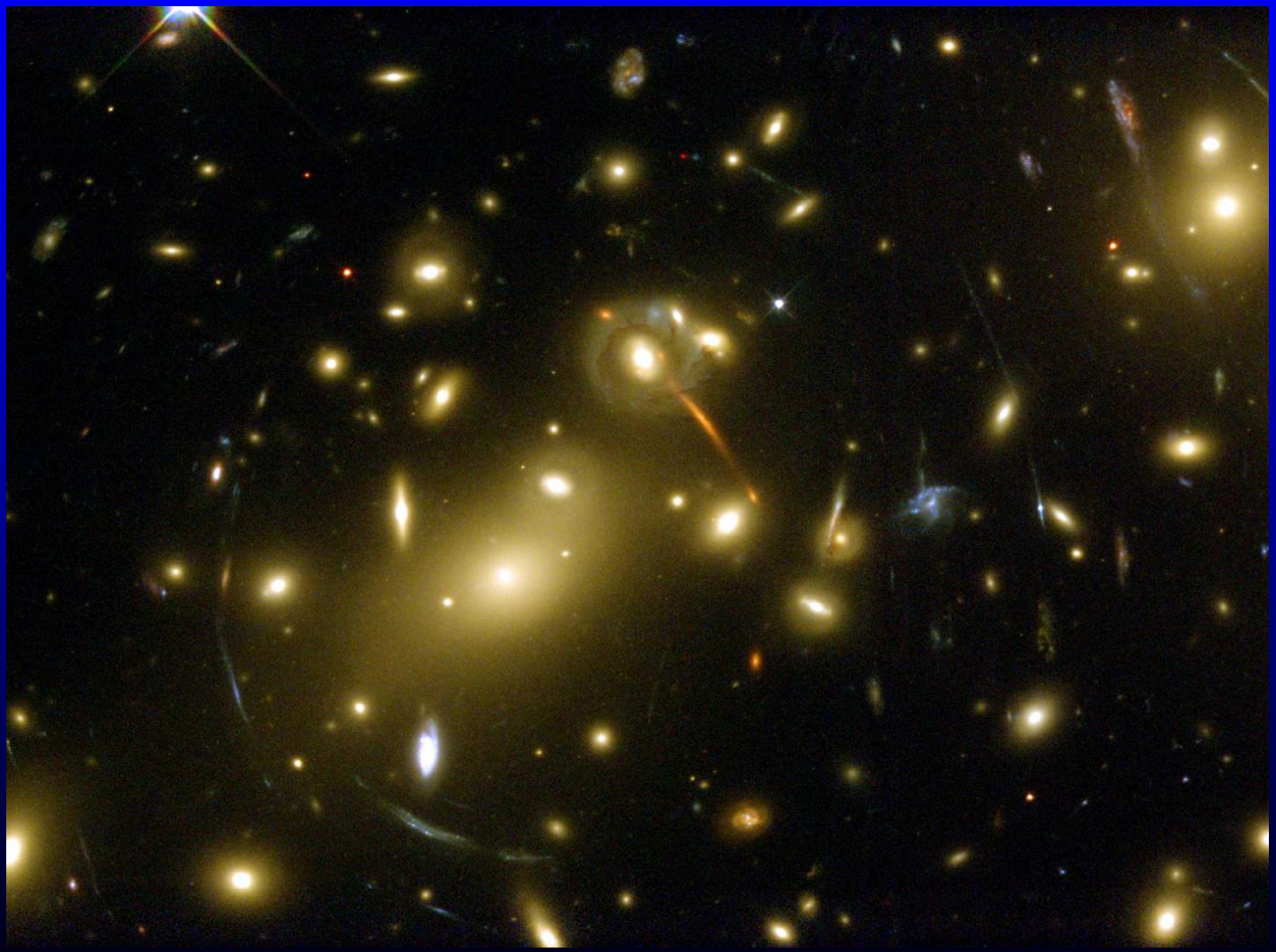

Radio jet
Quasar A
Counter jet
Foreground galaxy
Quasar B

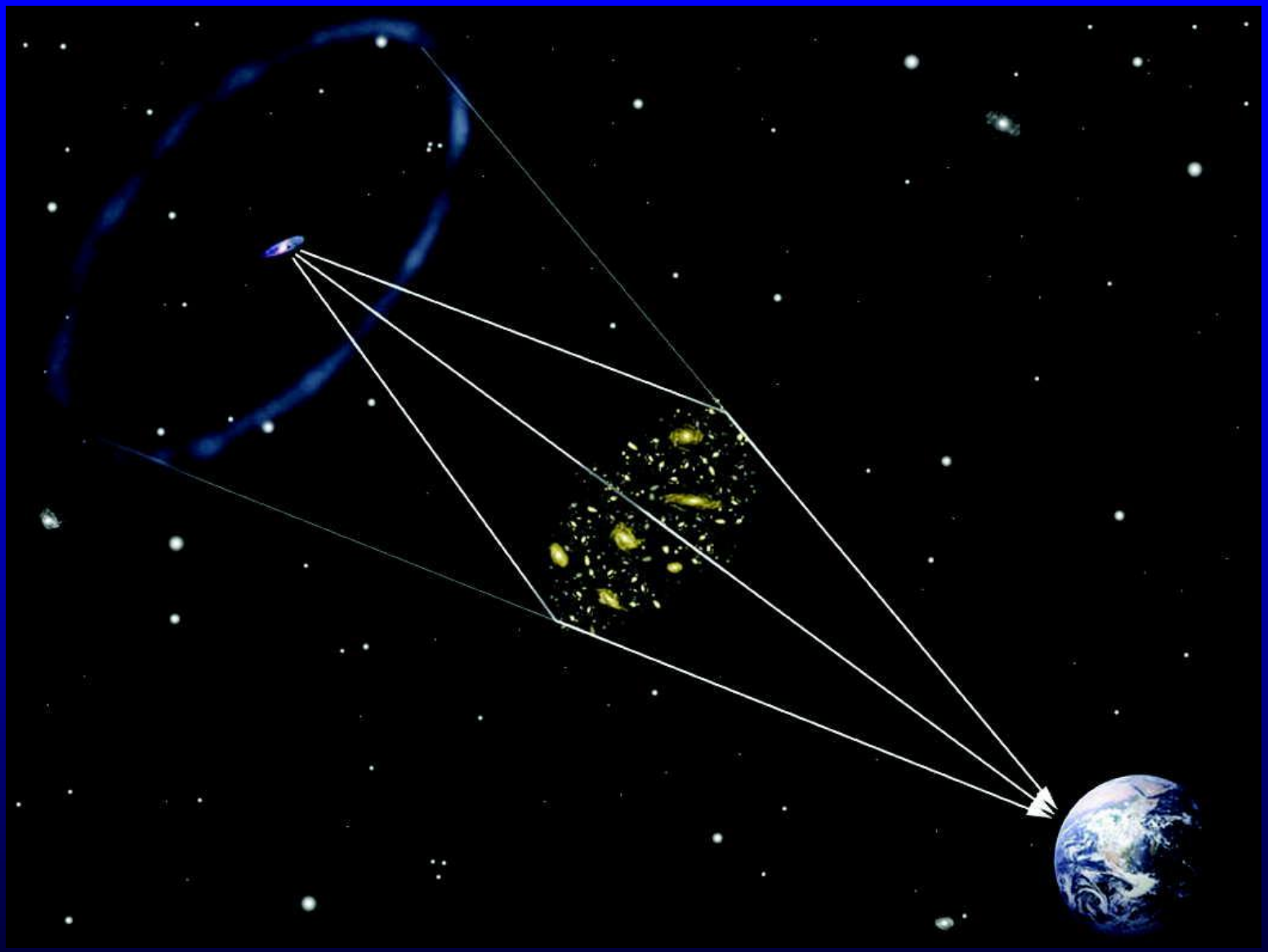




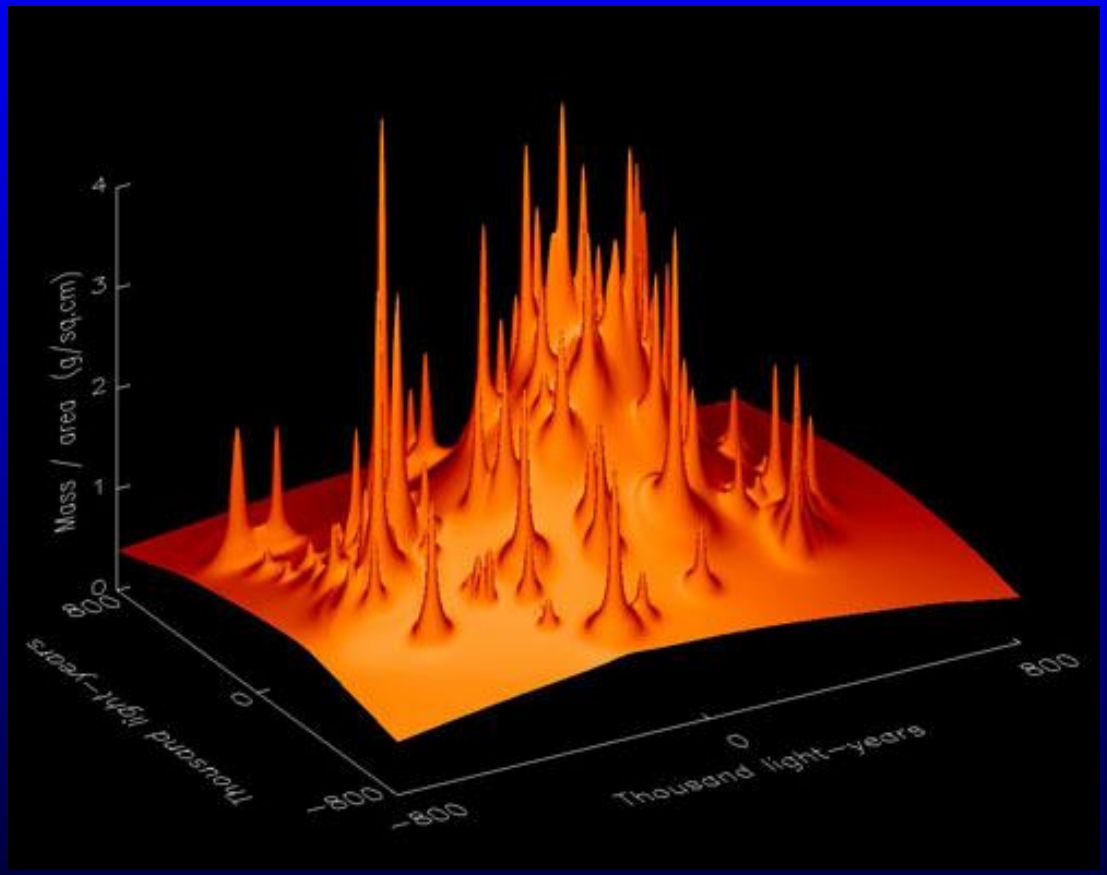
Weak Gravitational Lensing

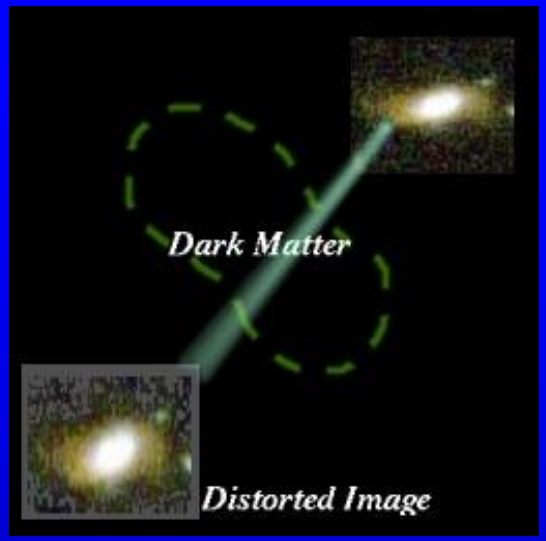
Abell Cluster 2218

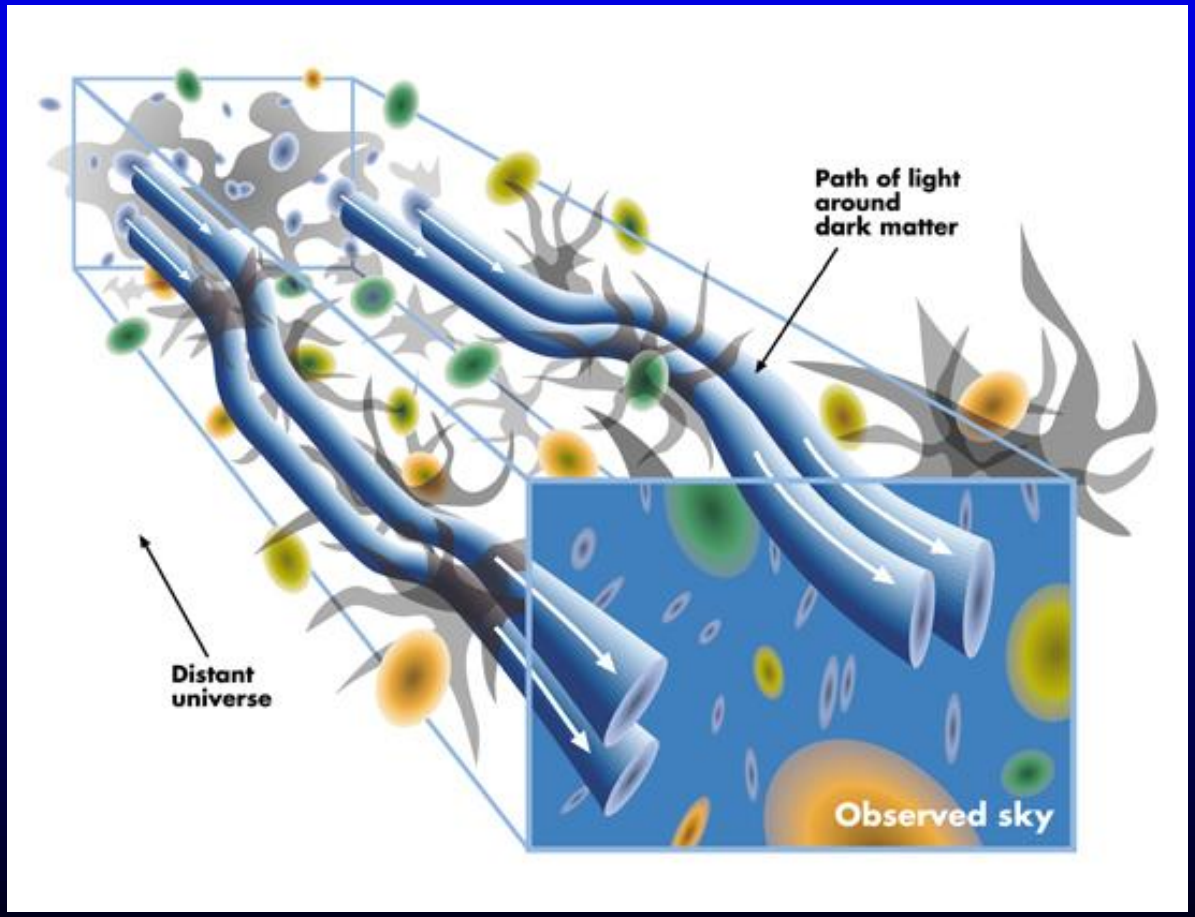


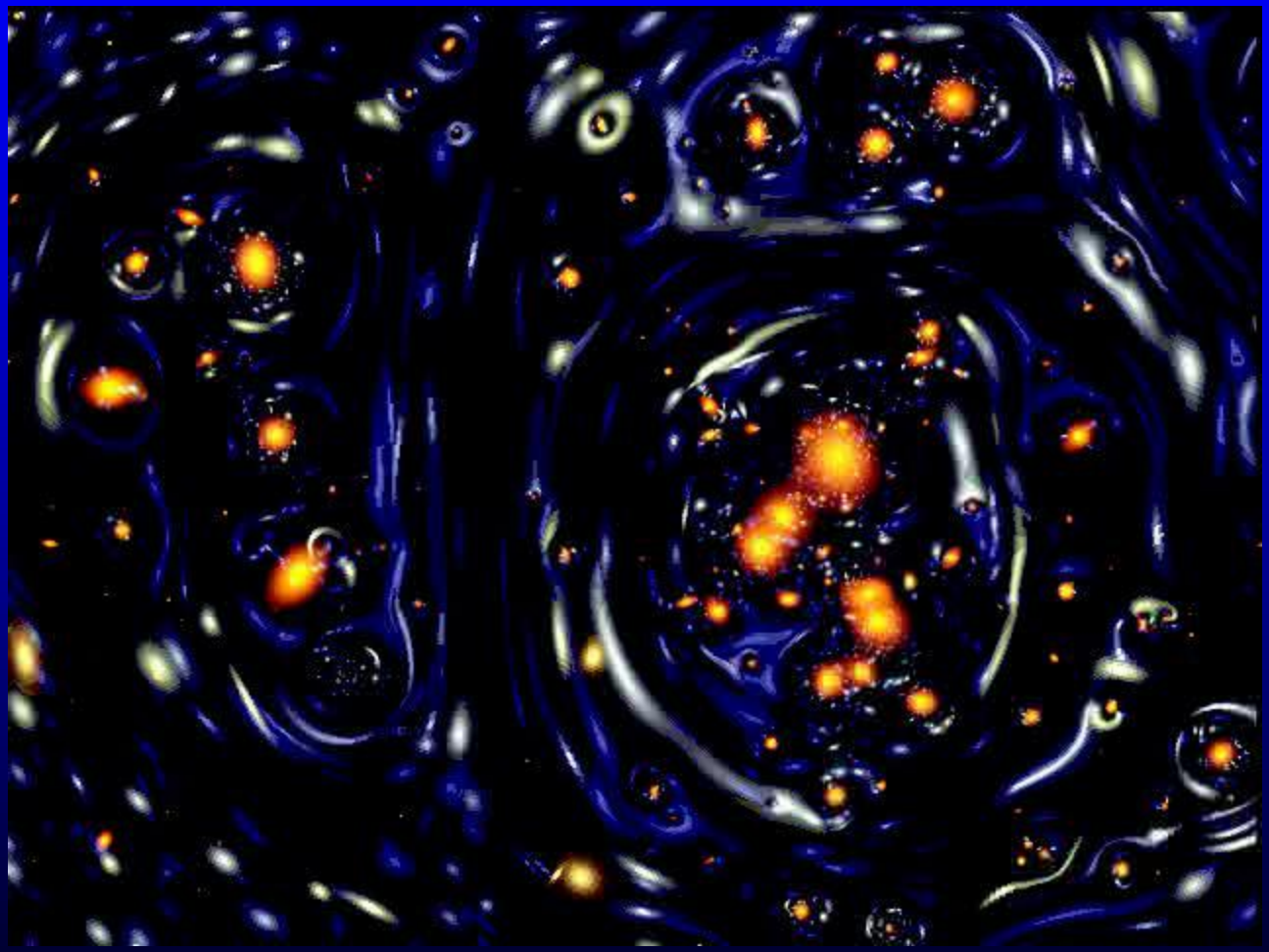


Dark Matter Distribution



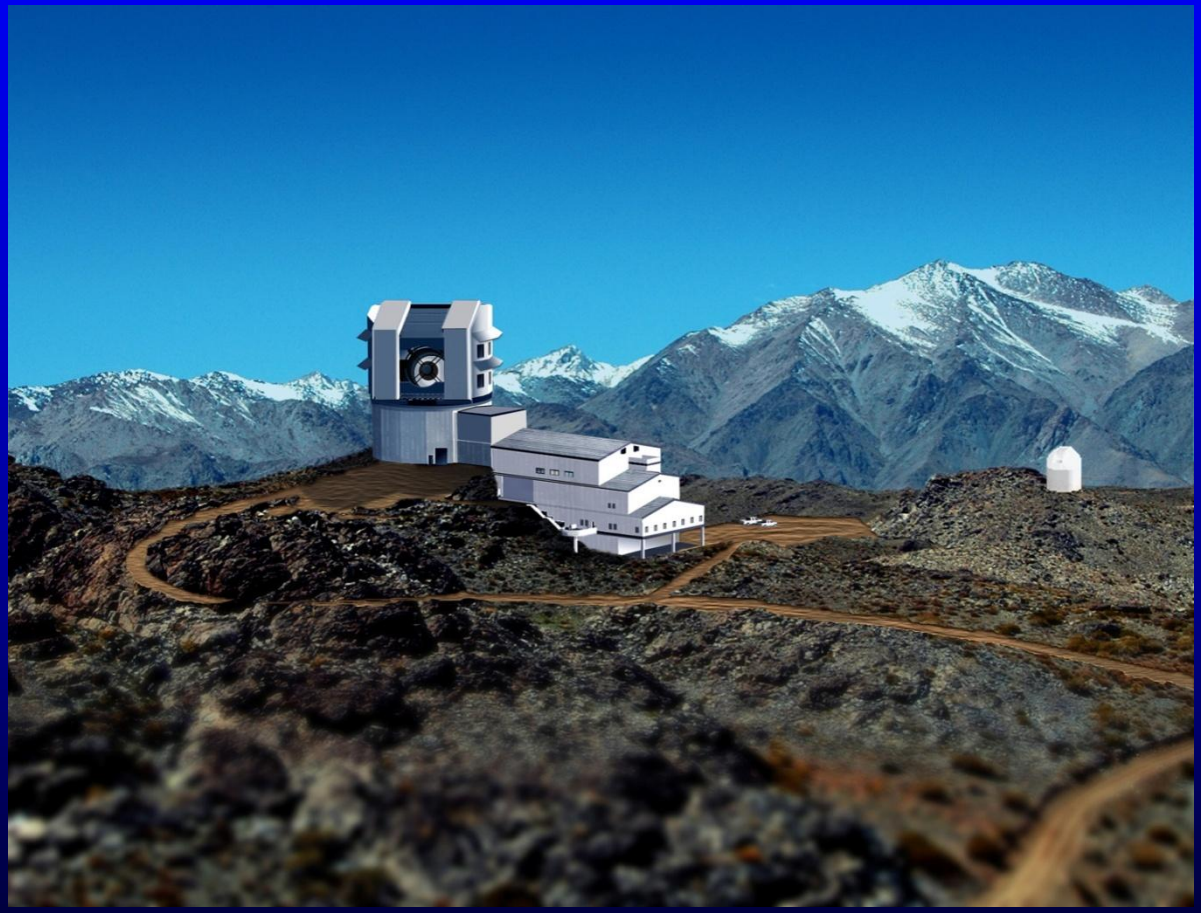

Dark Matter
Distorted Image


Path of light
around
dark matter
Distant
universe
Observed sky

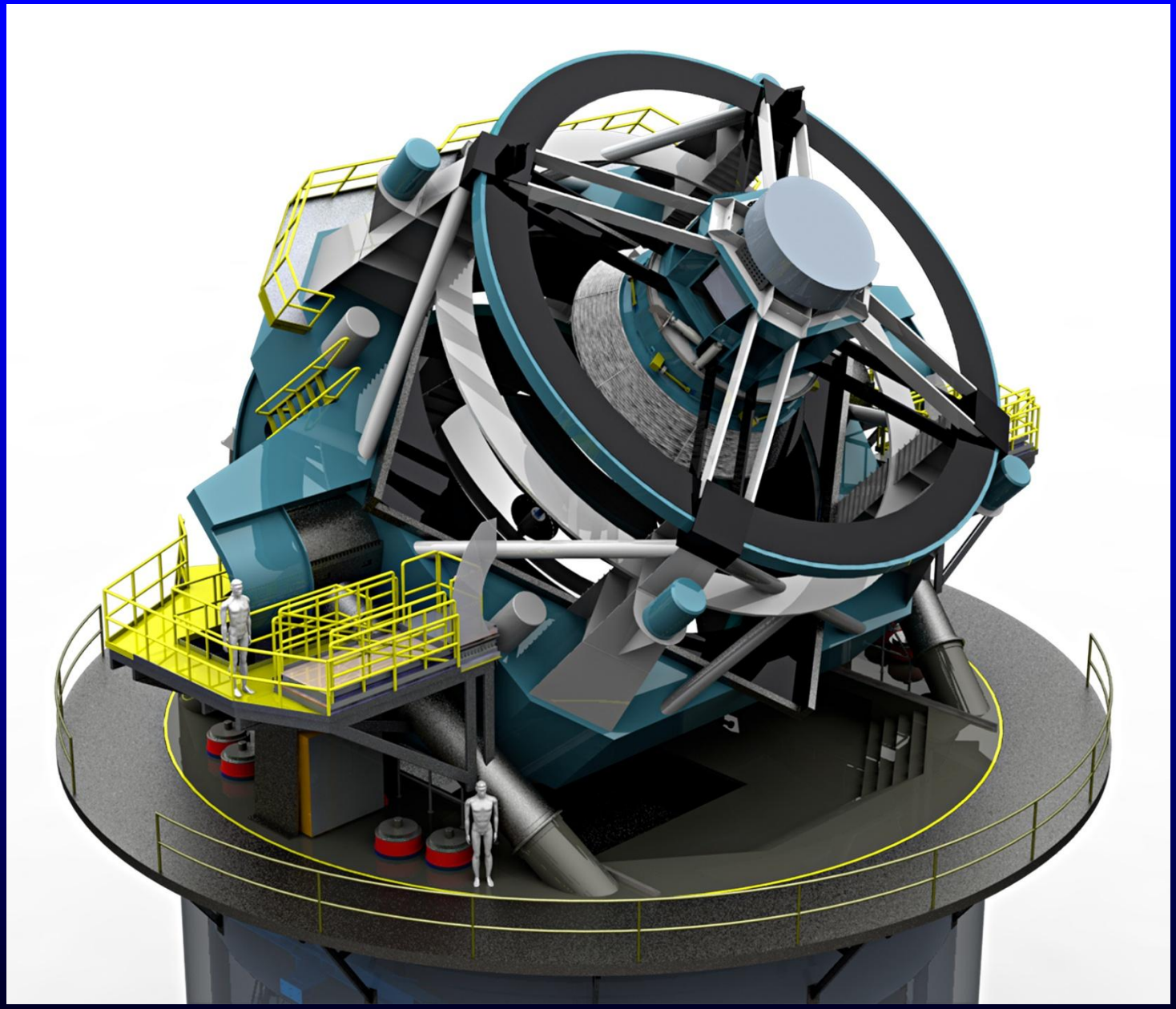


Looking back 6 billion years

Large Synoptic Survey Telescope

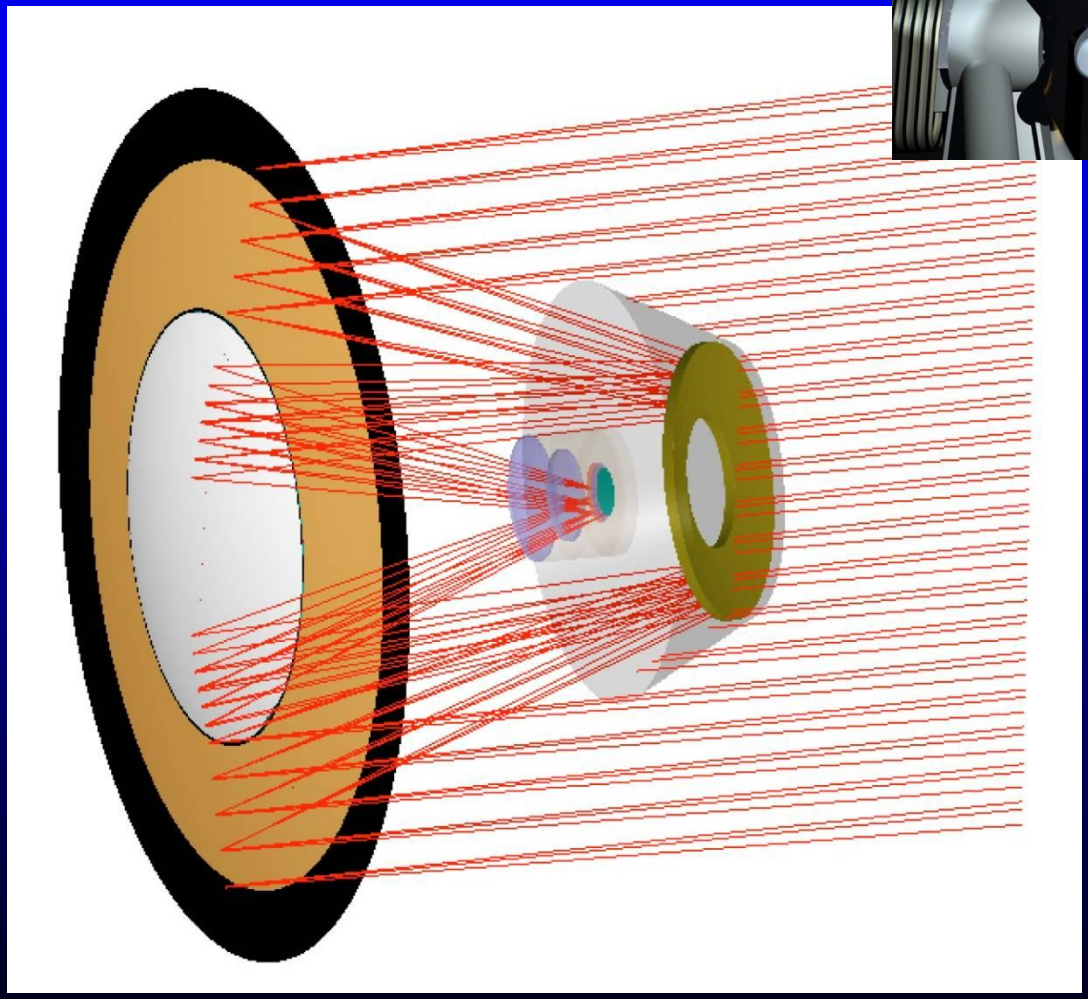



Cerro Pachón – Future site of the LSST
LSST Rendering on El Peñón
SOAR
Gemini
Cerro Pachón ridge – view from northwest

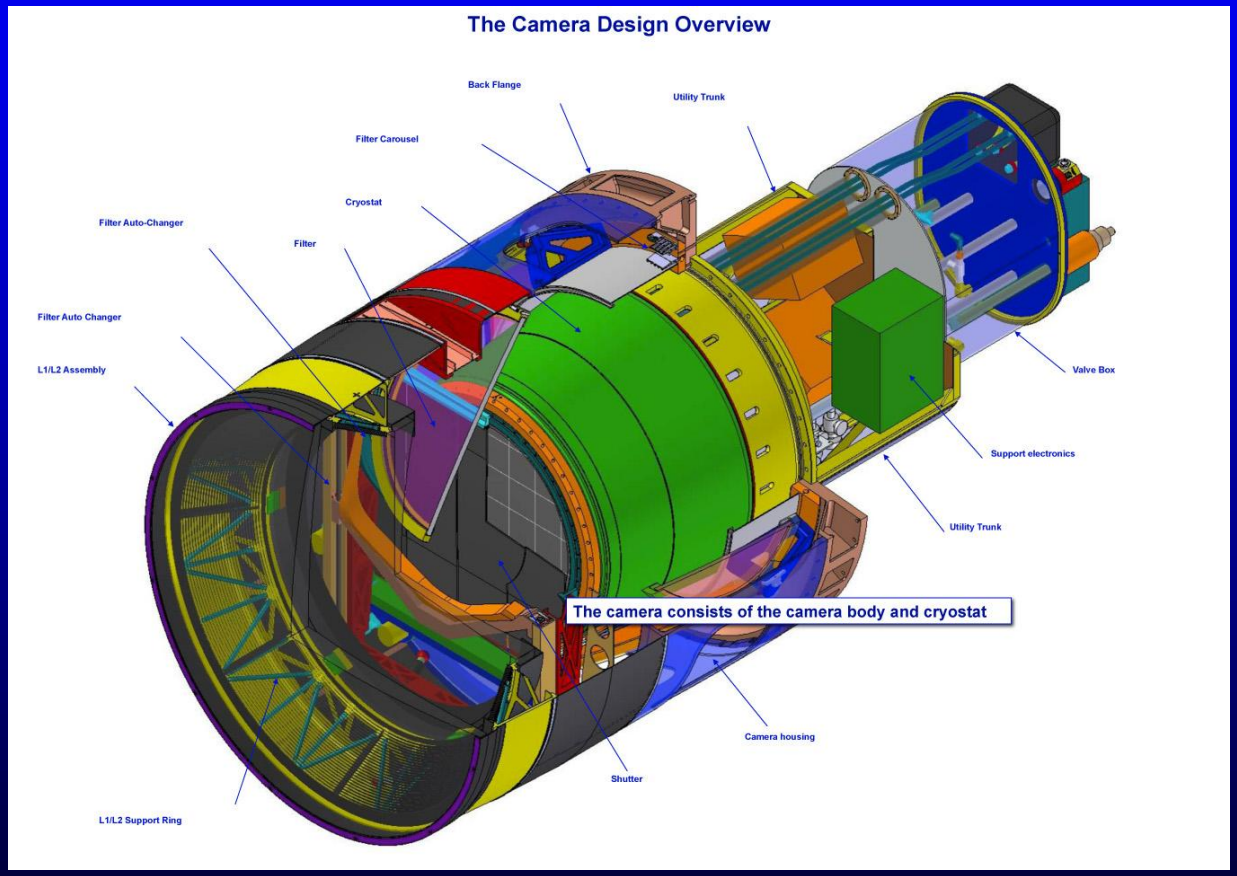


Complex Mirror-Lens Optics

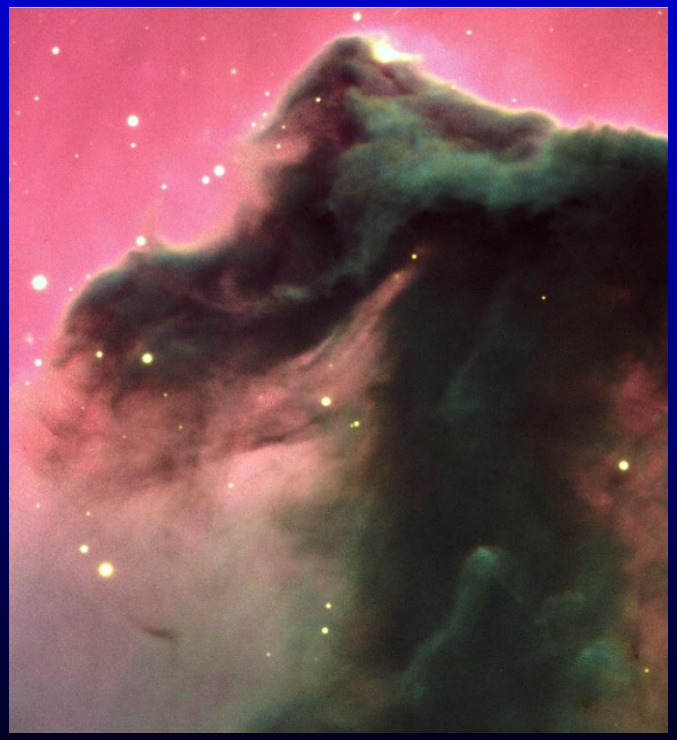
3 Mirrors and 3 lenses



3.2 Gigapixel CCD Array!



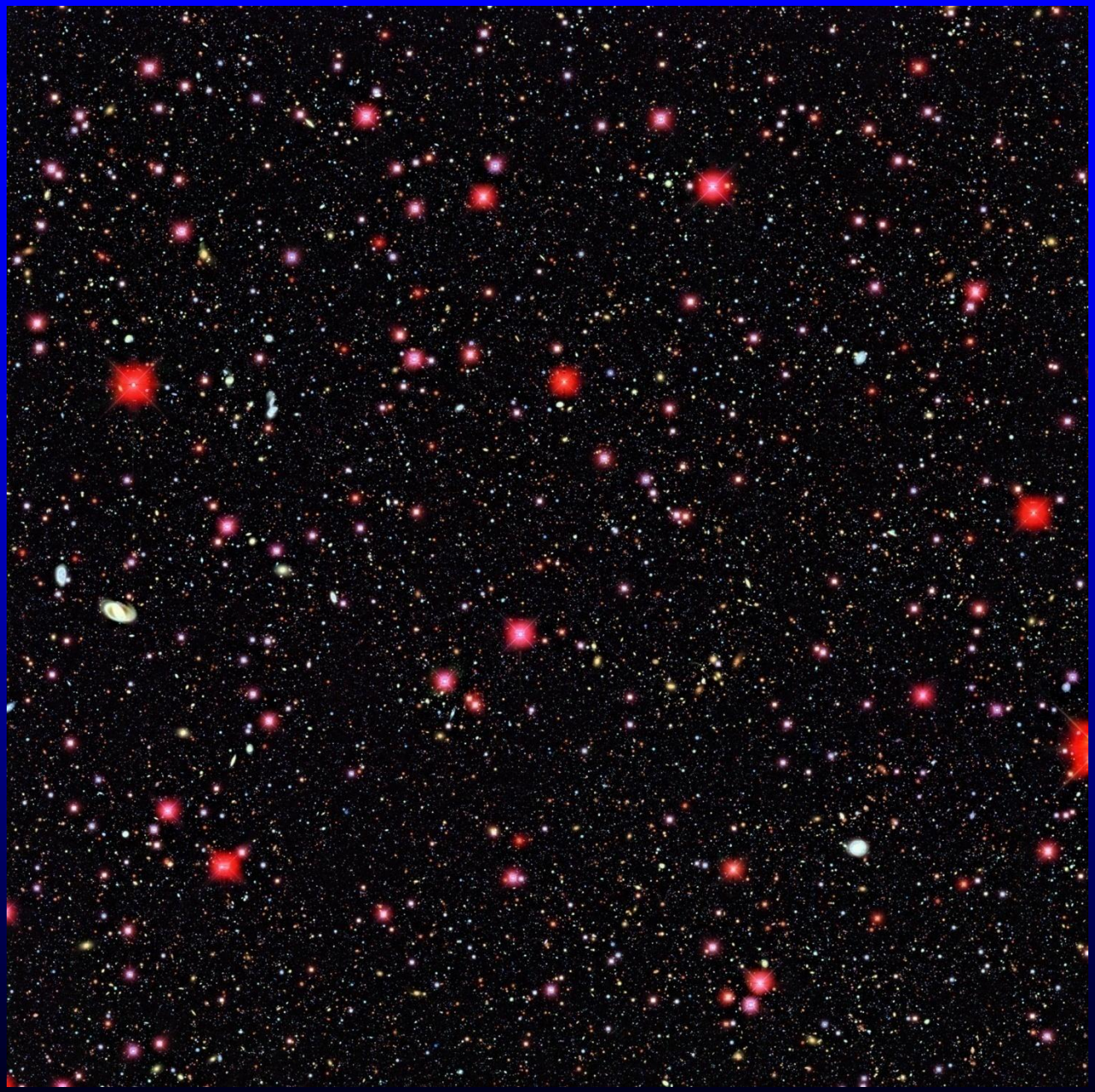
Horsehead Nebula



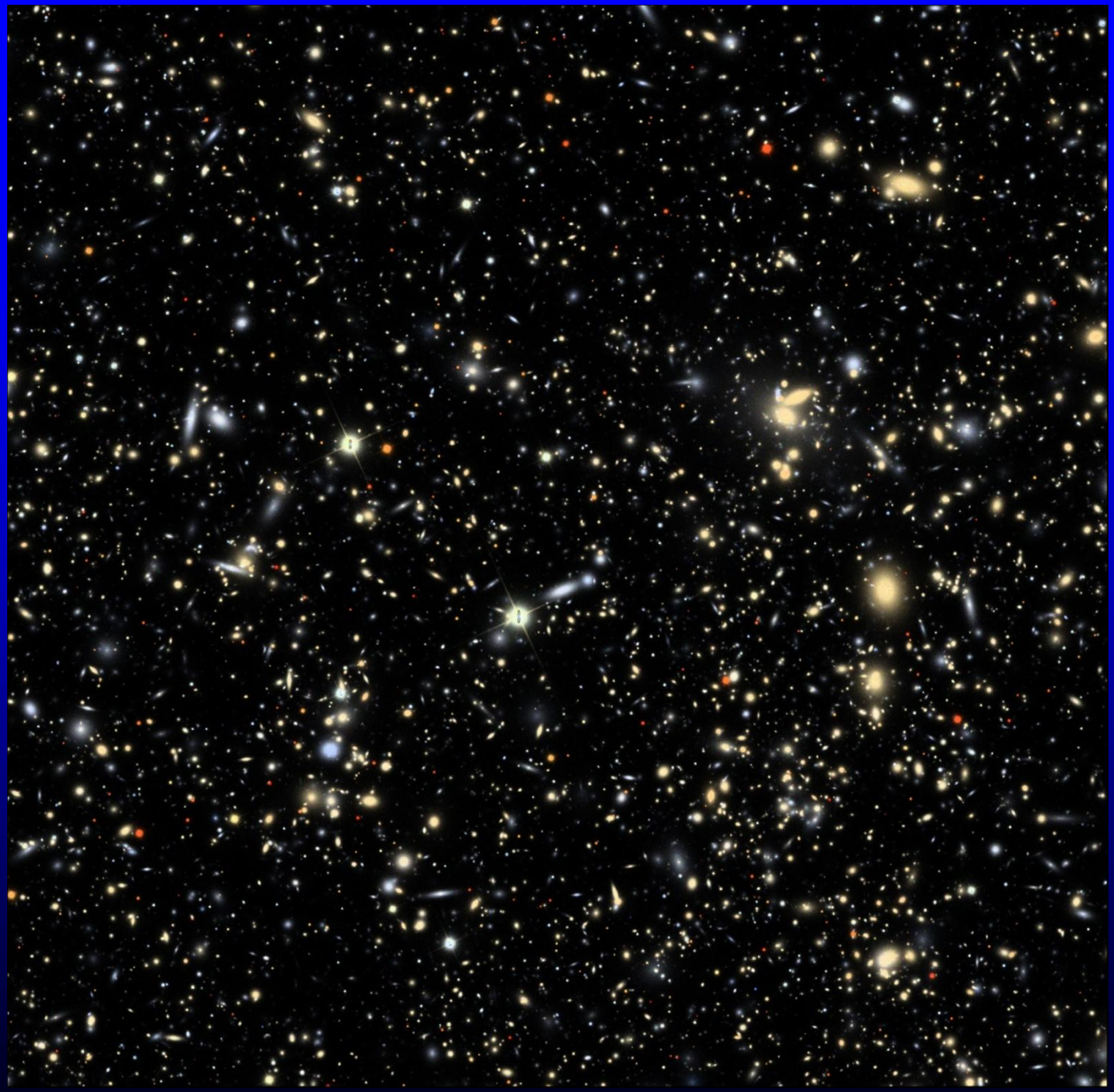
Deep Lens Survey

1 Moon's diameter

LSST will go deeper still



Simulated Sky View



- The LSST camera is expected to take over 200,000 pictures per year - each of 15 seconds and taken every 20 seconds!

- It is expected to come into operation by the end of the decade.

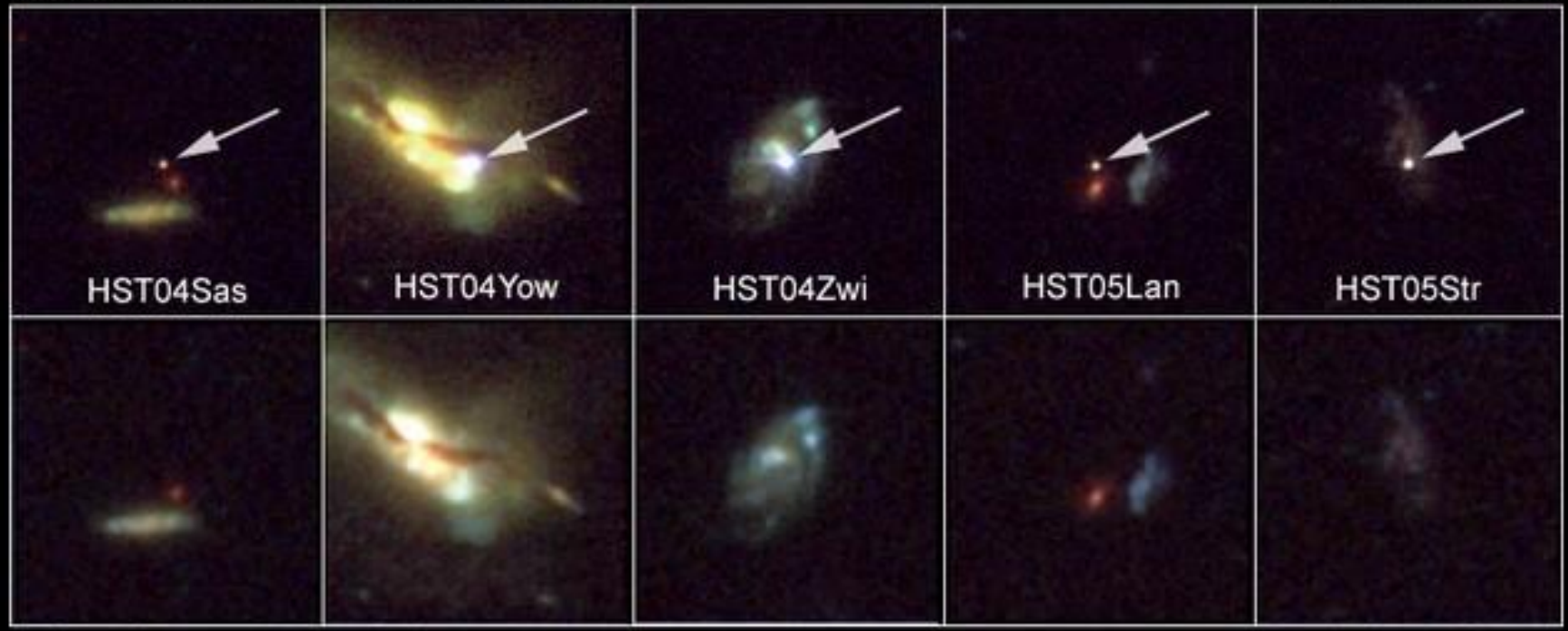
What is Dark Energy?

Distant galaxies are fainter and further away than would be the case in the standard “Big Bang” models.

A supernova in M51

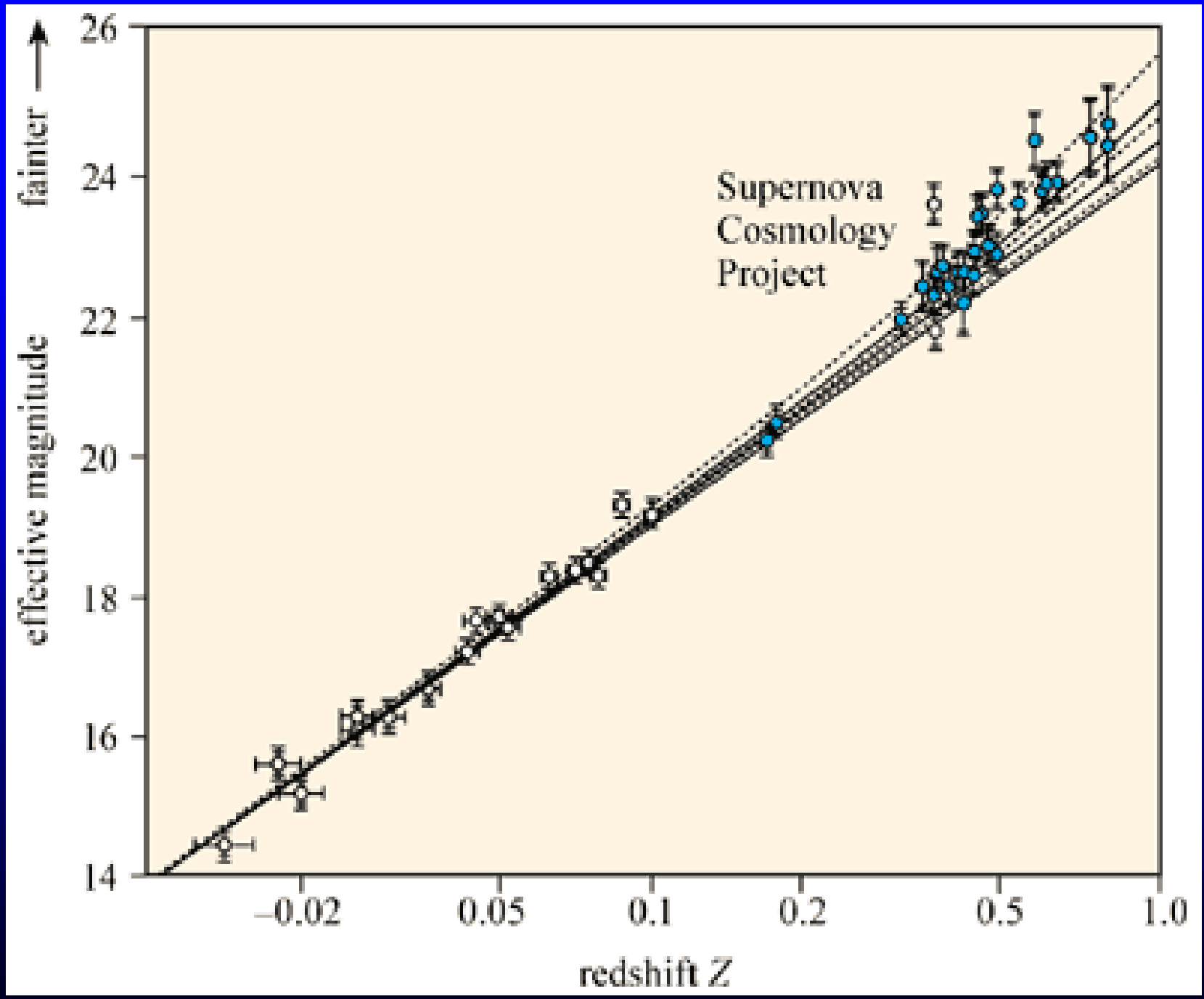
Host Galaxies of Distant Supernovae

HST ▪ ACS/WFC

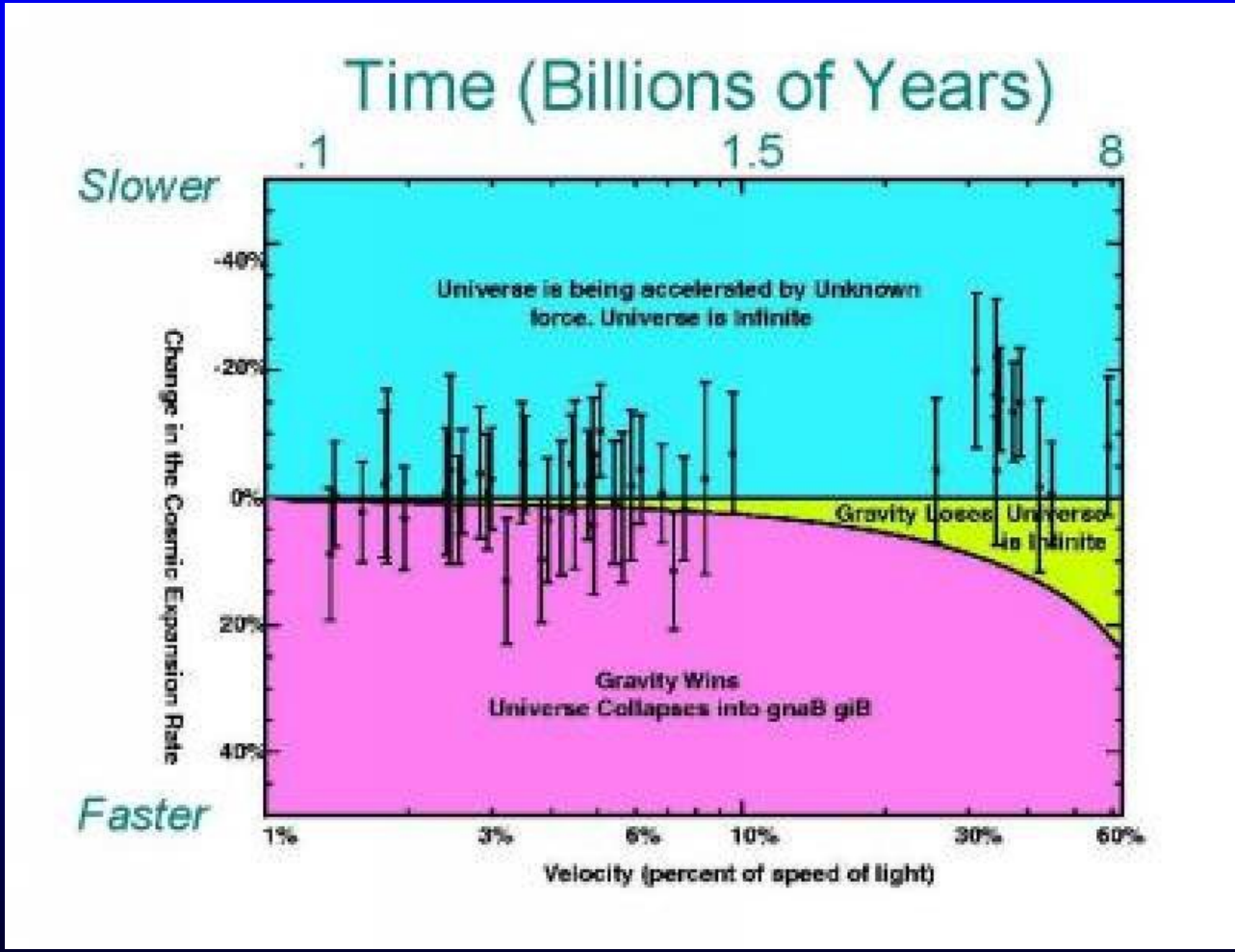


NASA, ESA, and A. Riess (STScI)

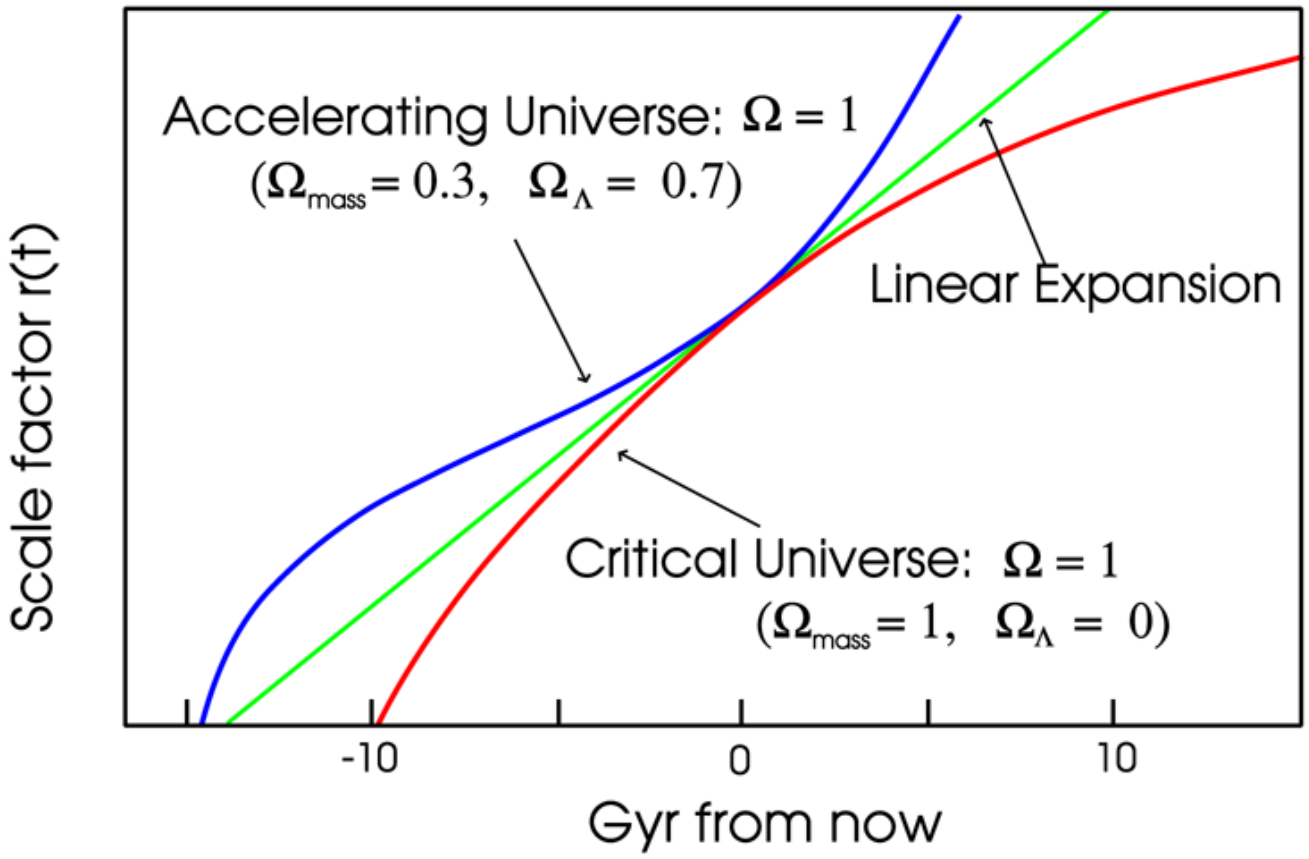
STScI-PRC06-52

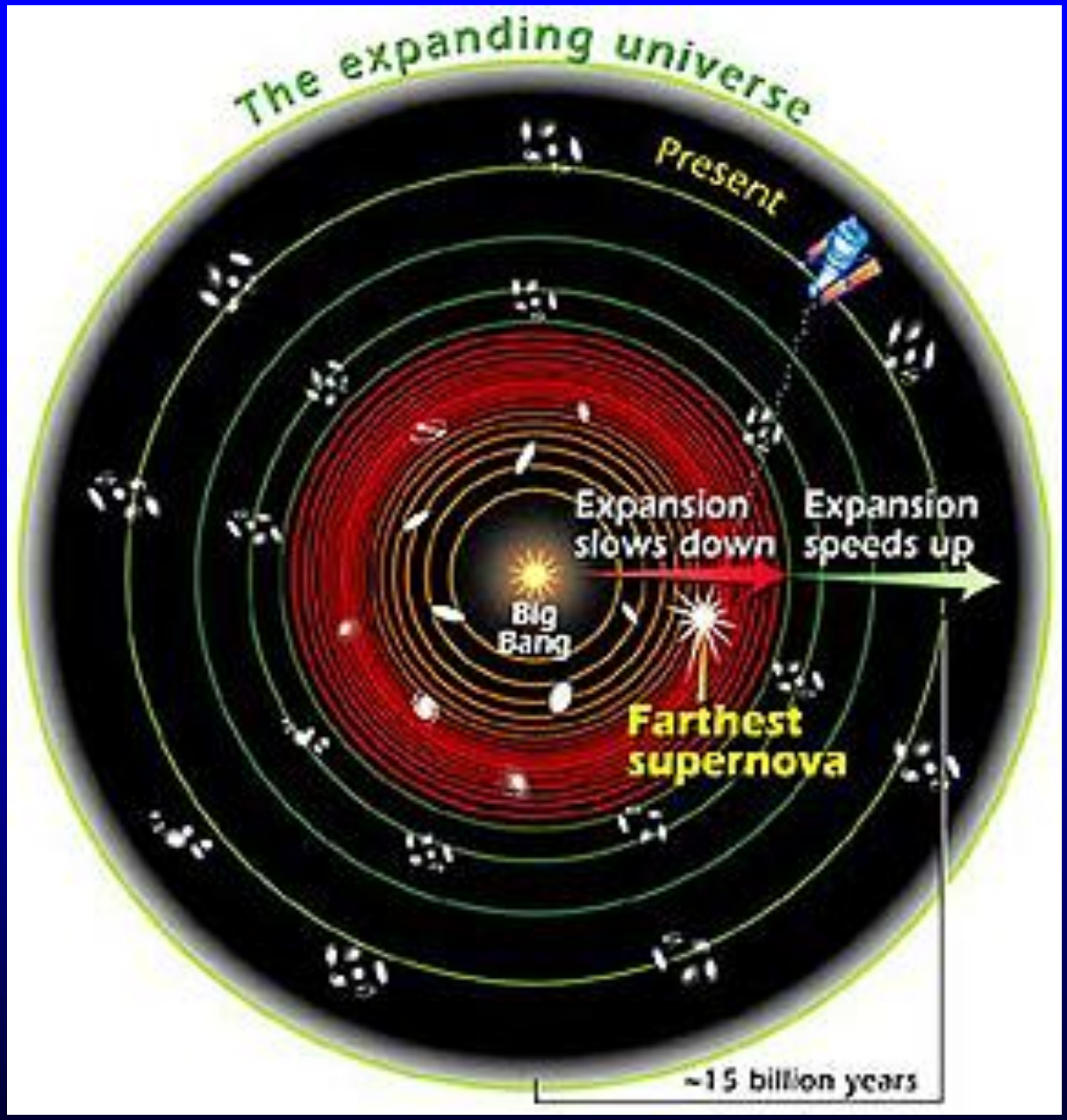

Supernova
Cosmology
Project
effective magnitude
fainter
26
24
22
20
18
16
14
–0.02
0.05
0.1
0.2
0.5
1.0
redshift Z

Not was expected!

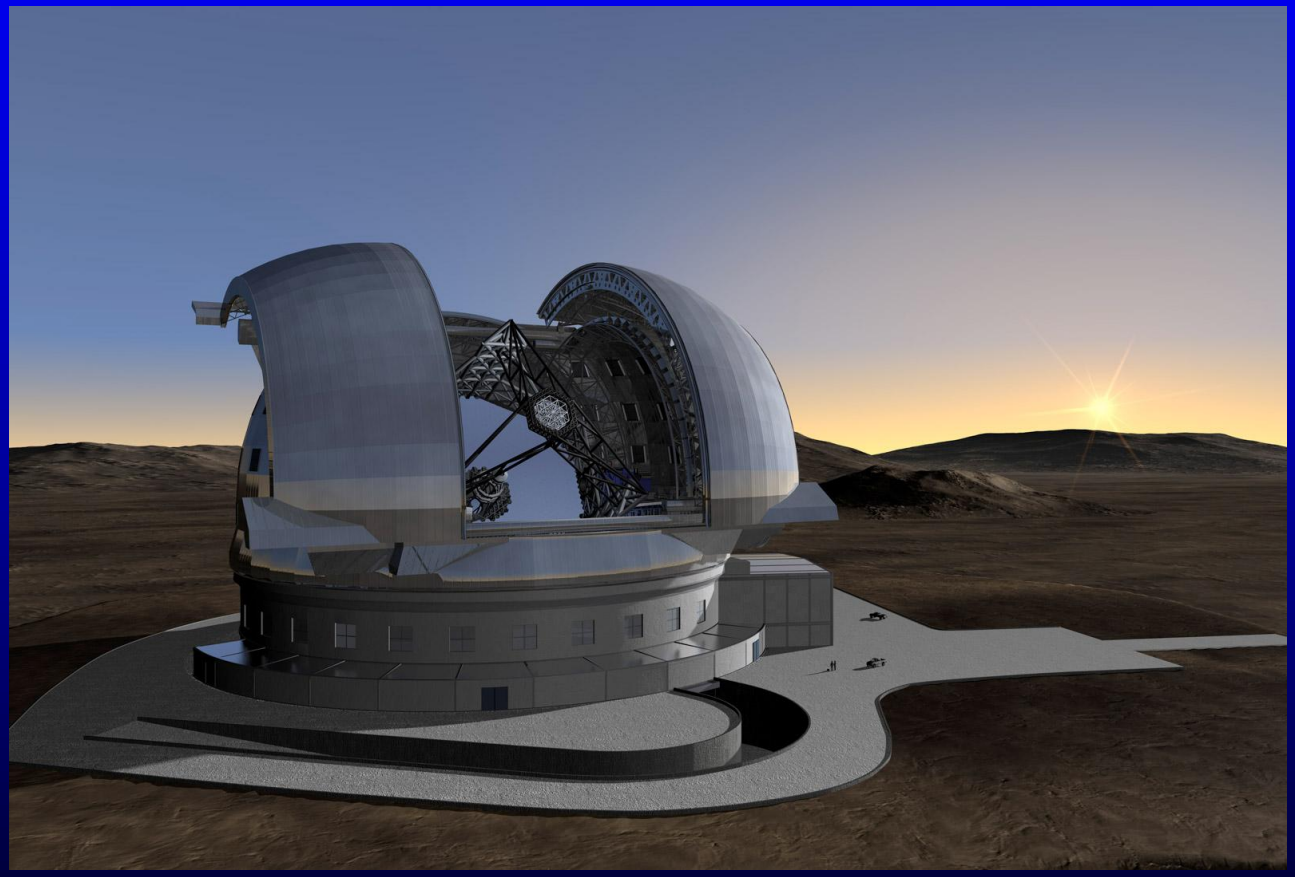


The size of the Universe over time.



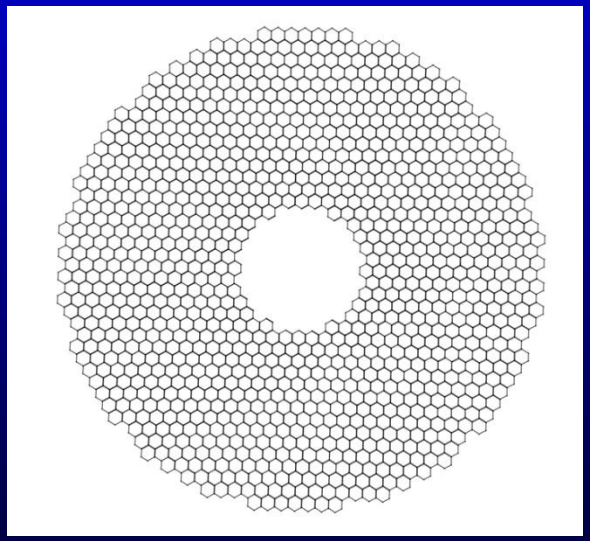

The expanding universe
Present
Expansion slows down
Expansion speeds up
Big Bang
Farthest supernova
~15 billion years

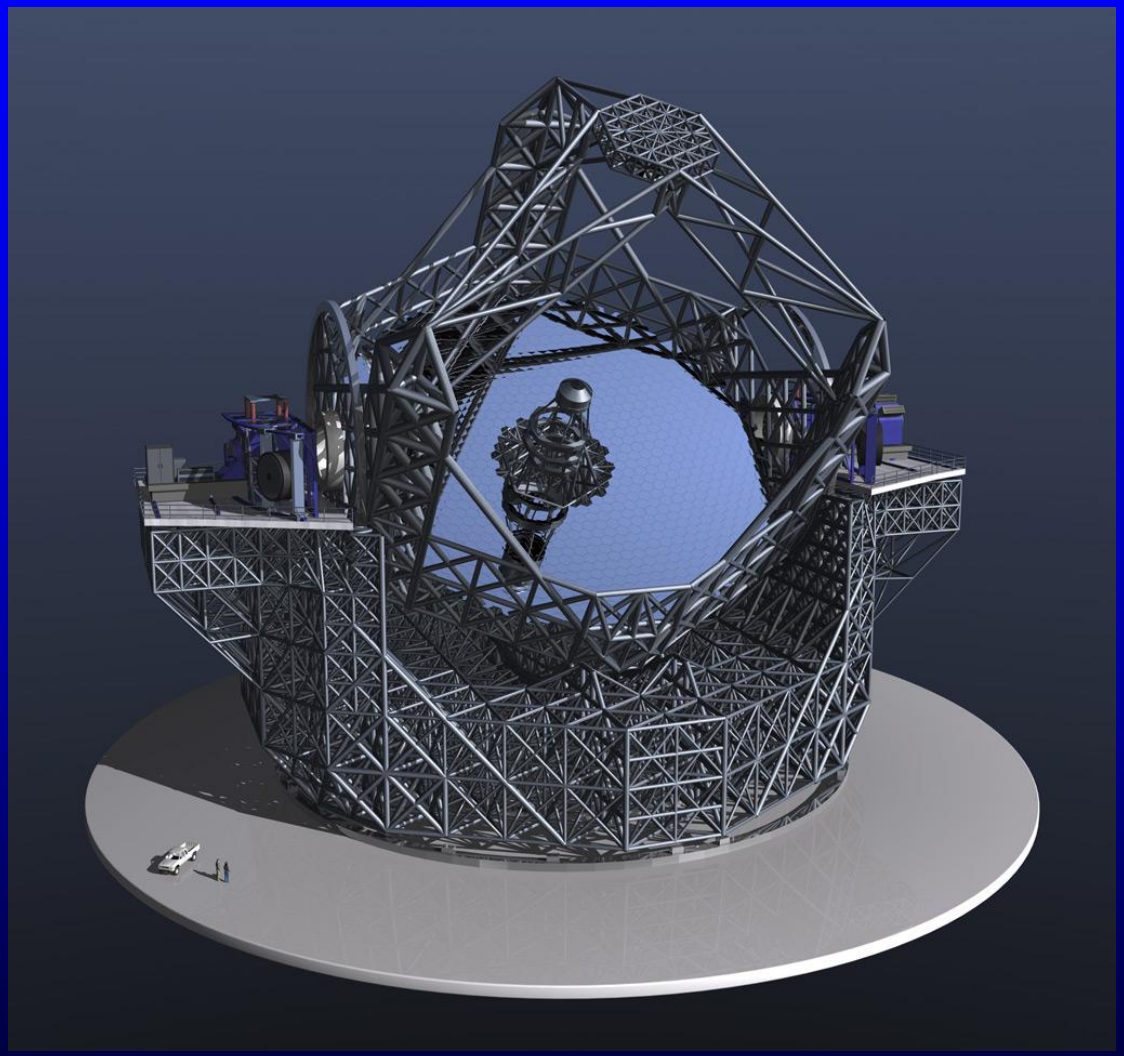
European Extremely Large Telescope



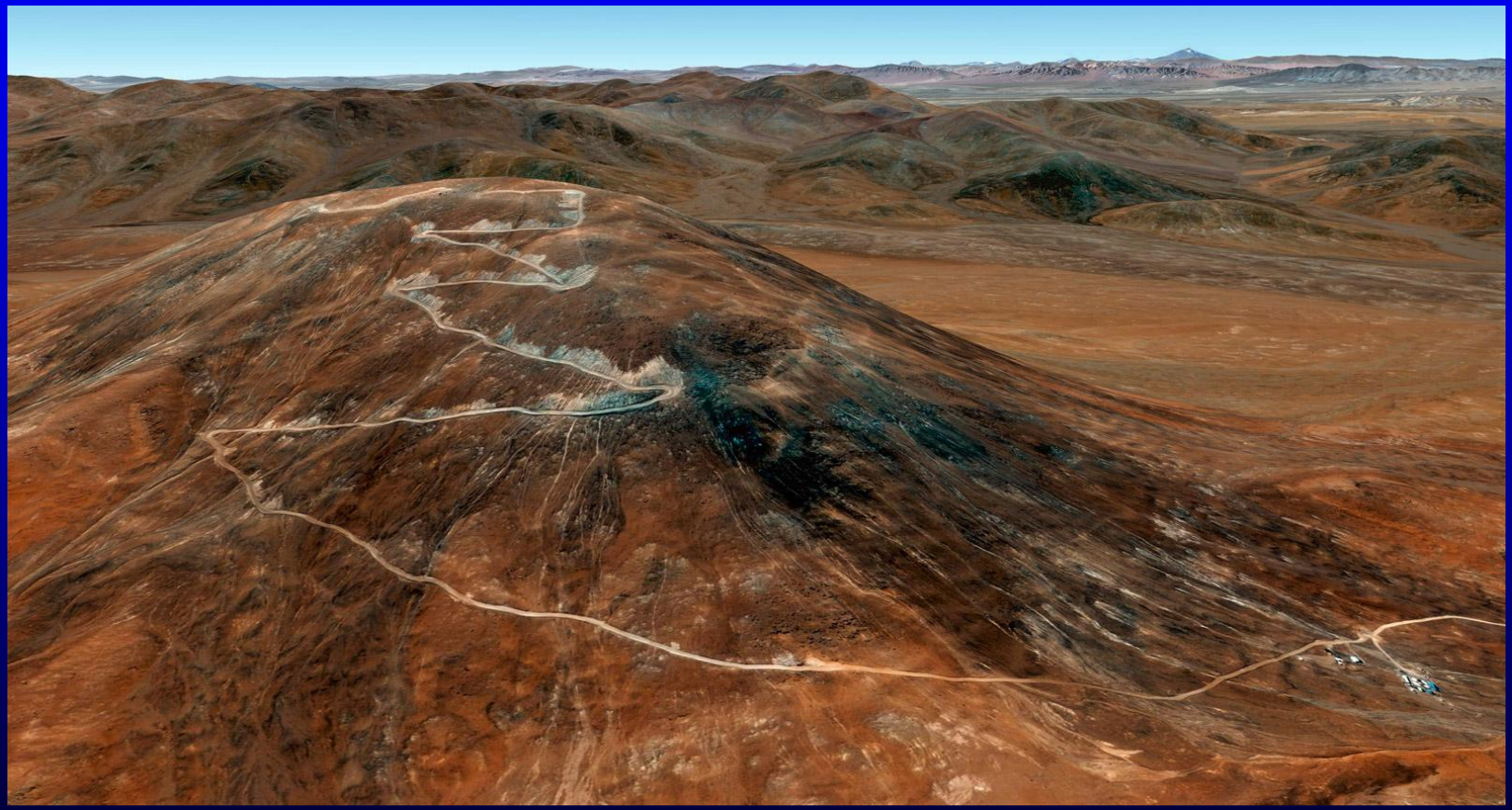
42m Primary Mirror

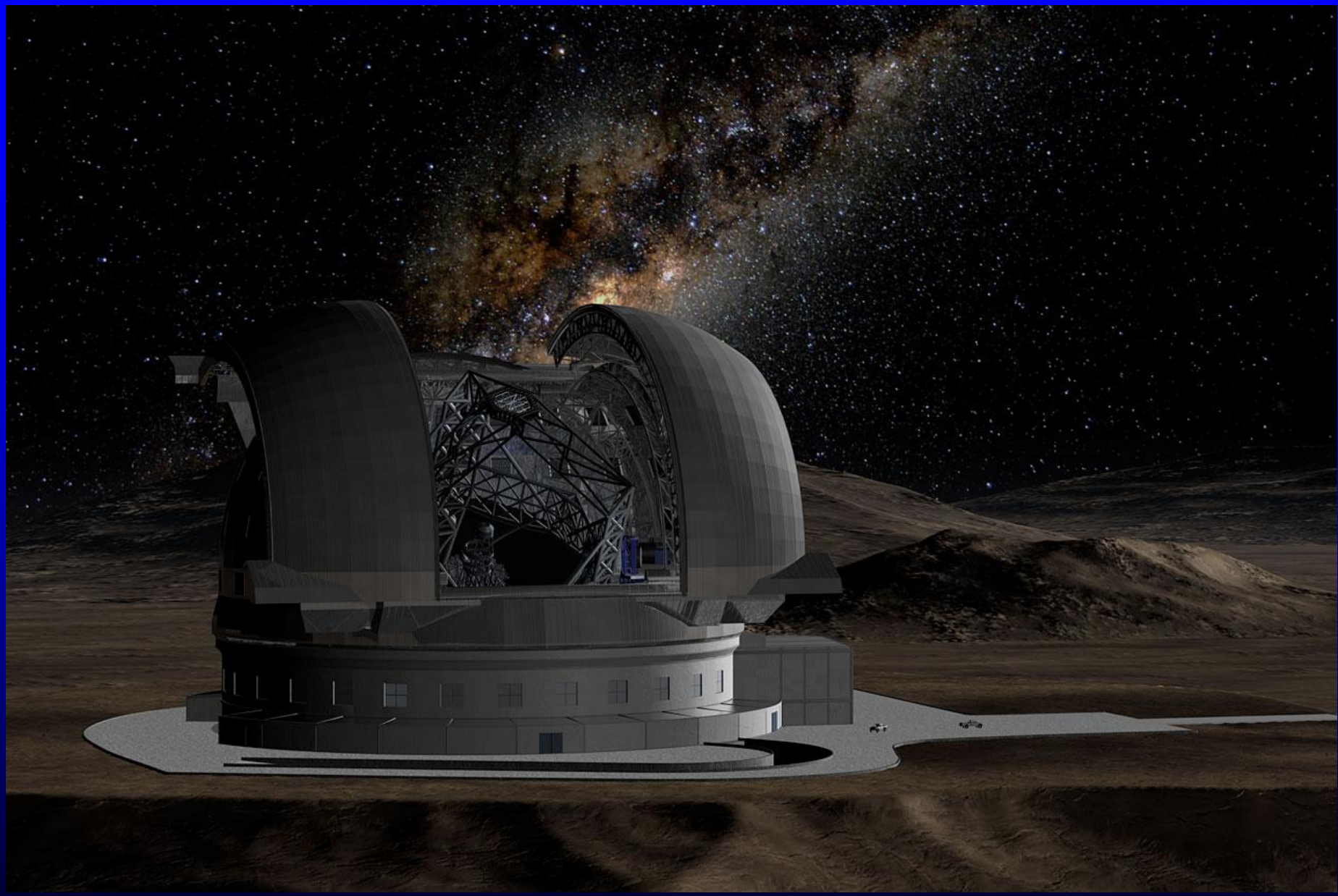
~1000 1.4m hexagonal segments





Cerro Armazones, Chile





- The E-ELT will gather 15 times more light than any telescope in use today and will provide images that are 15 times sharper that the Hubble Space telescope!

- It will be able to detect many Type 1a Supernovae and directly determine the evolution of the expansion rate.

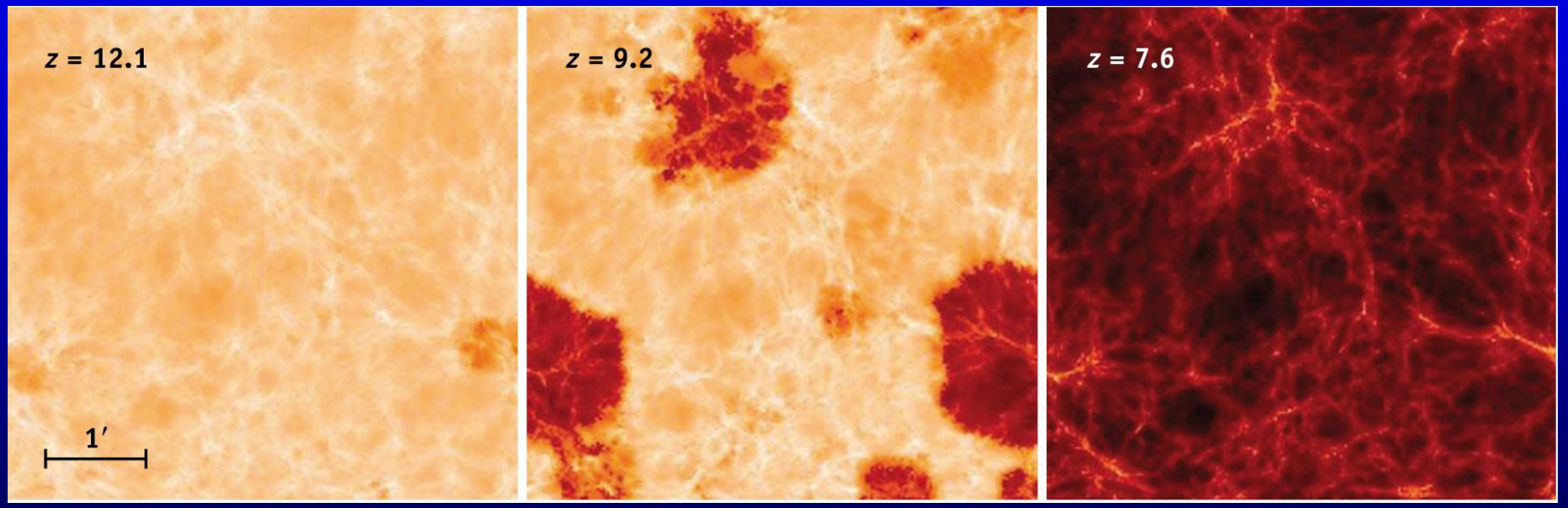
- The E-ELT will also search for possible variations over time of some of the fundamental constants such as the fine-structure constant and the proton to electron mass ratio.
- If found, Physics will need to change!

- Final go-ahead for the E-ELT is expected in 2011 and it is hoped that the telescope will be operational by the end of the decade.

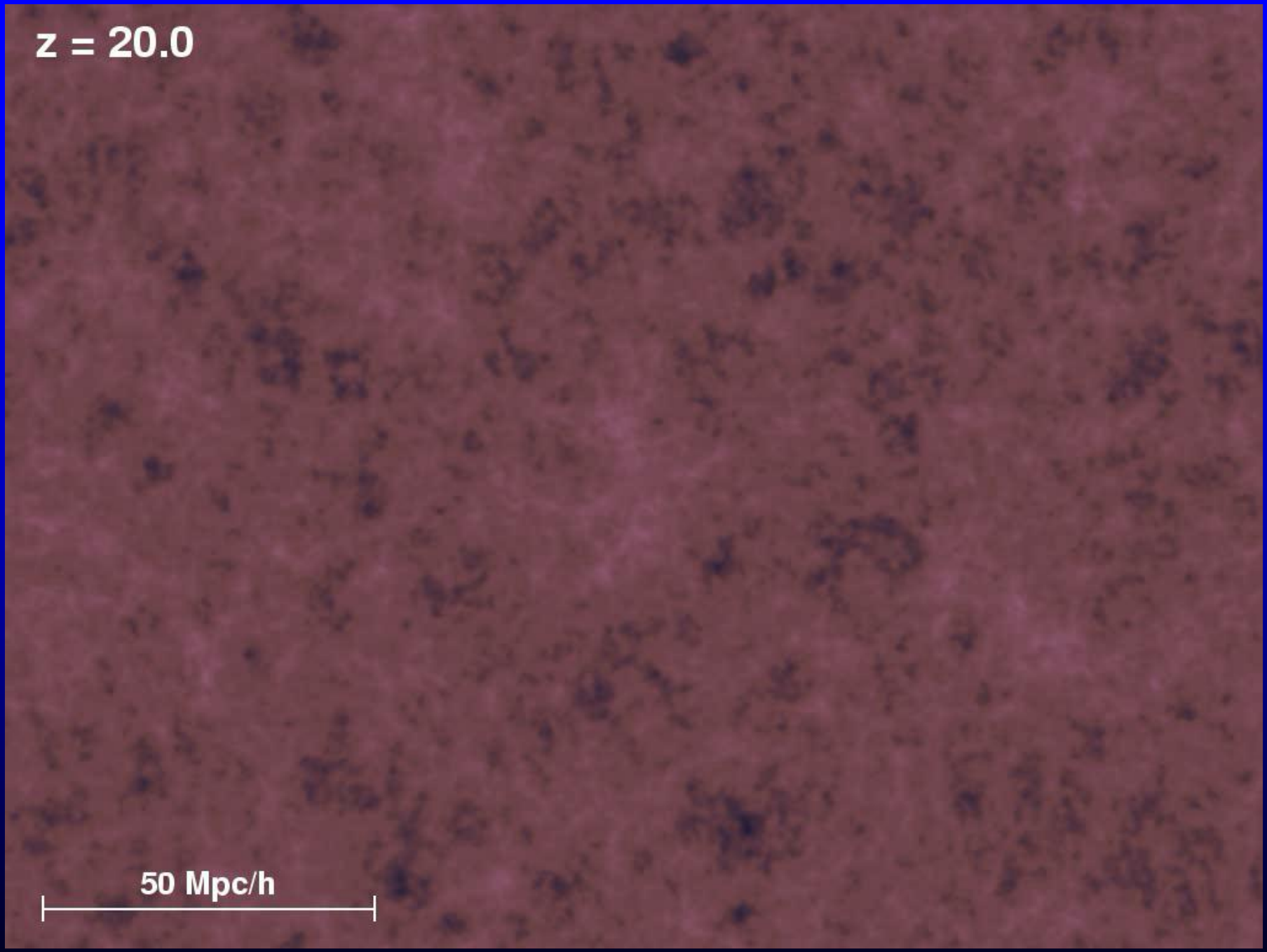
The Cosmological Dark Ages

How did hydrogen and helium come together to form the first stars and galaxies?

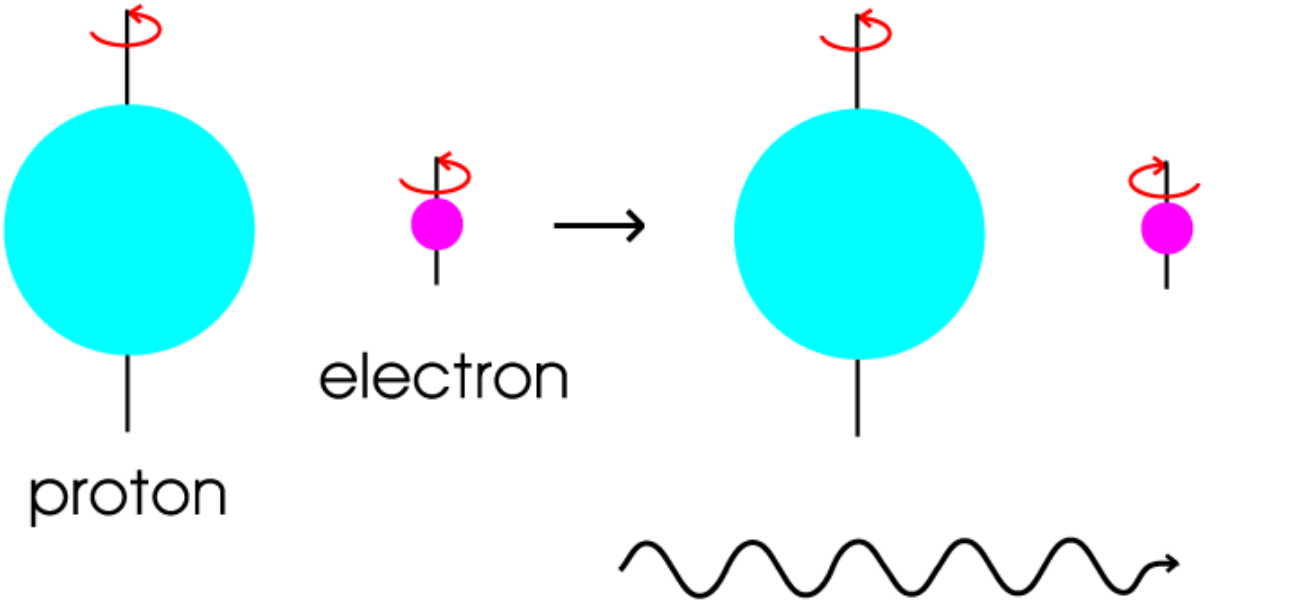
Clumping of Hydrogen and Helium



Dark Age Simulation

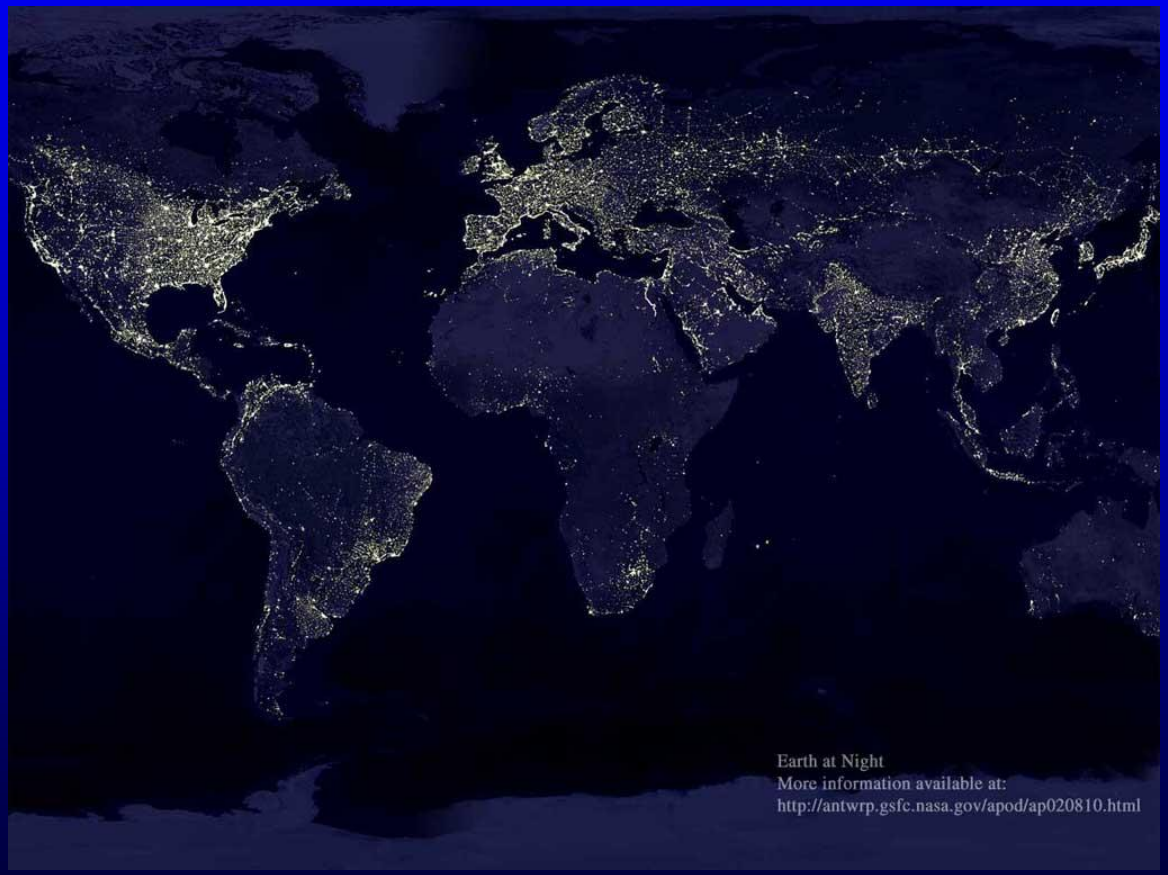

z = 20.0
50 Mpc/h

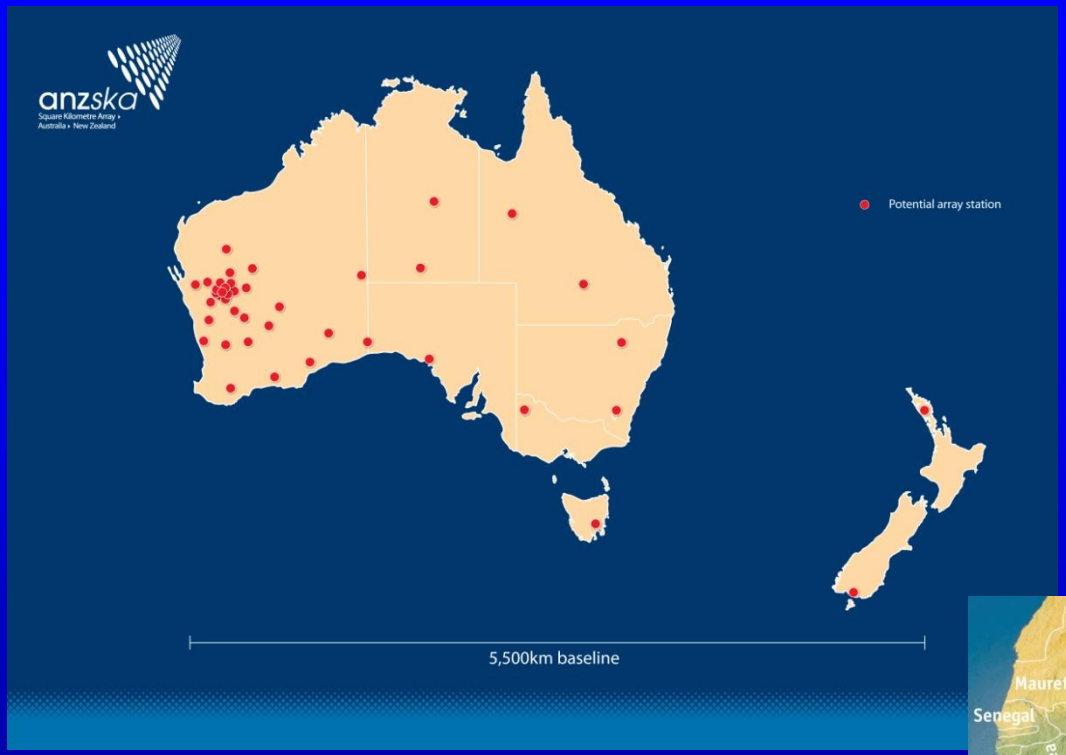
21cm Hydrogen Line



The Square Kilometre Array

Where should it be located?

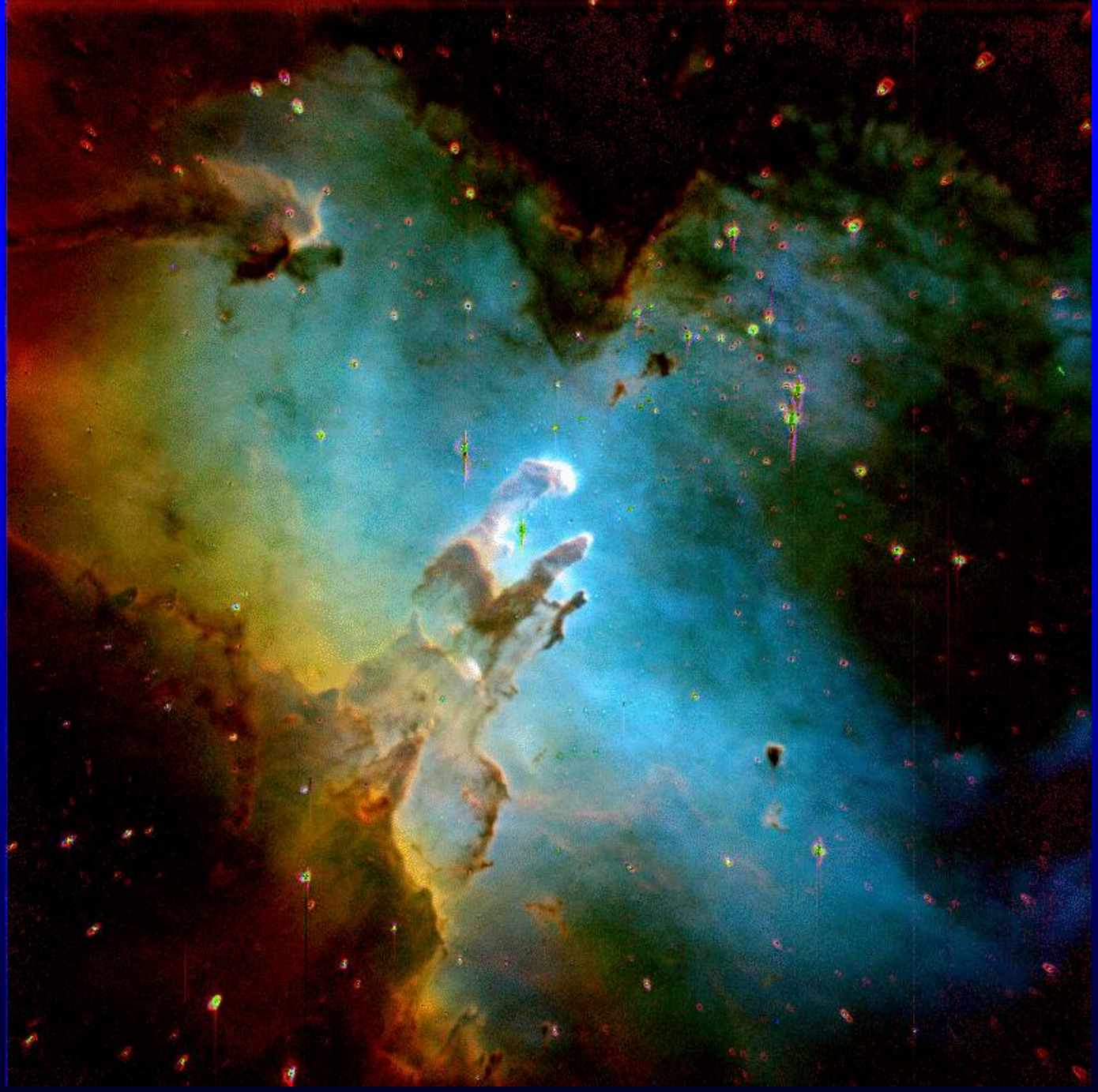


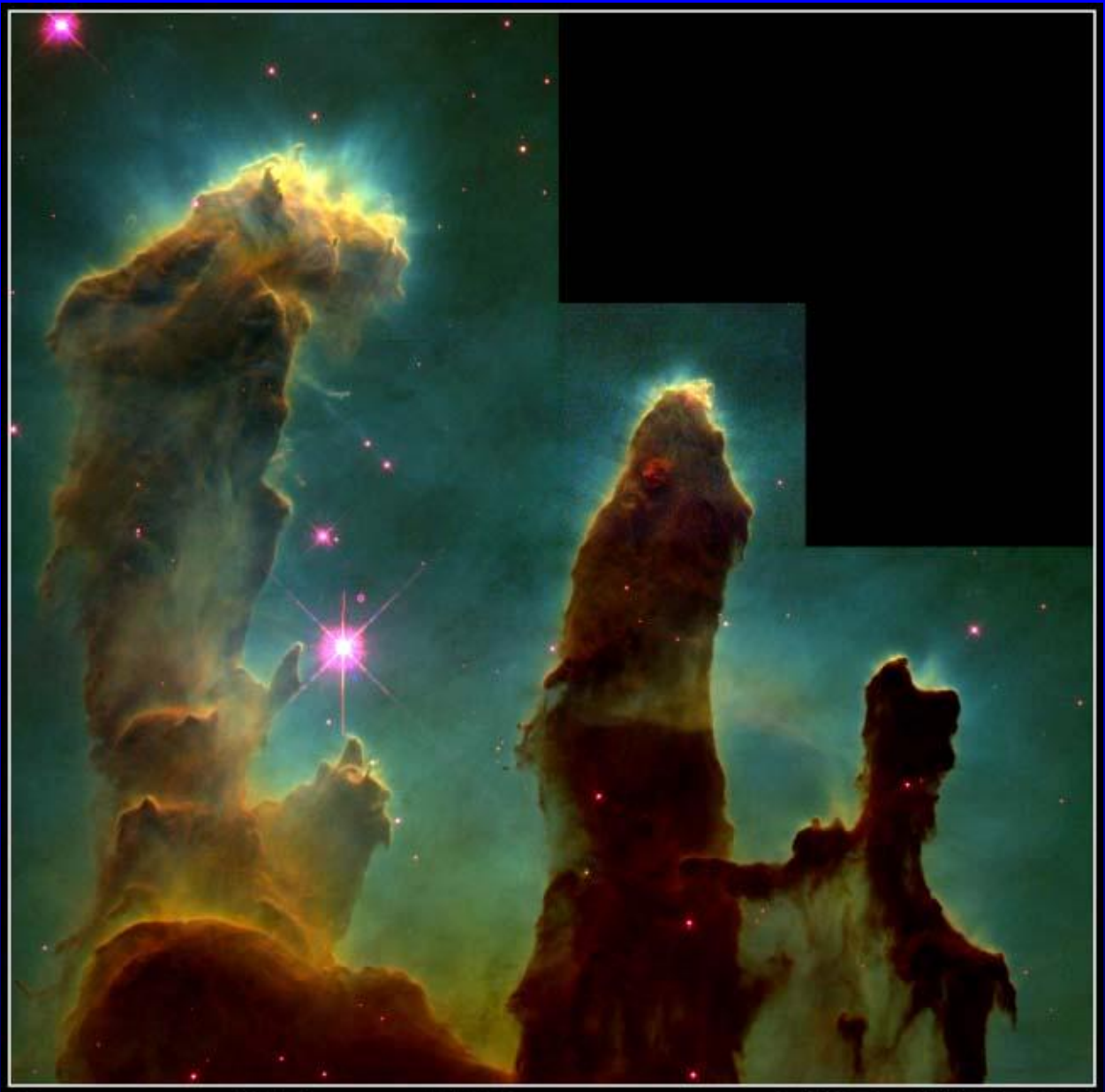


Australia or South Africa

How do stars form?

Visible and Infrared Images

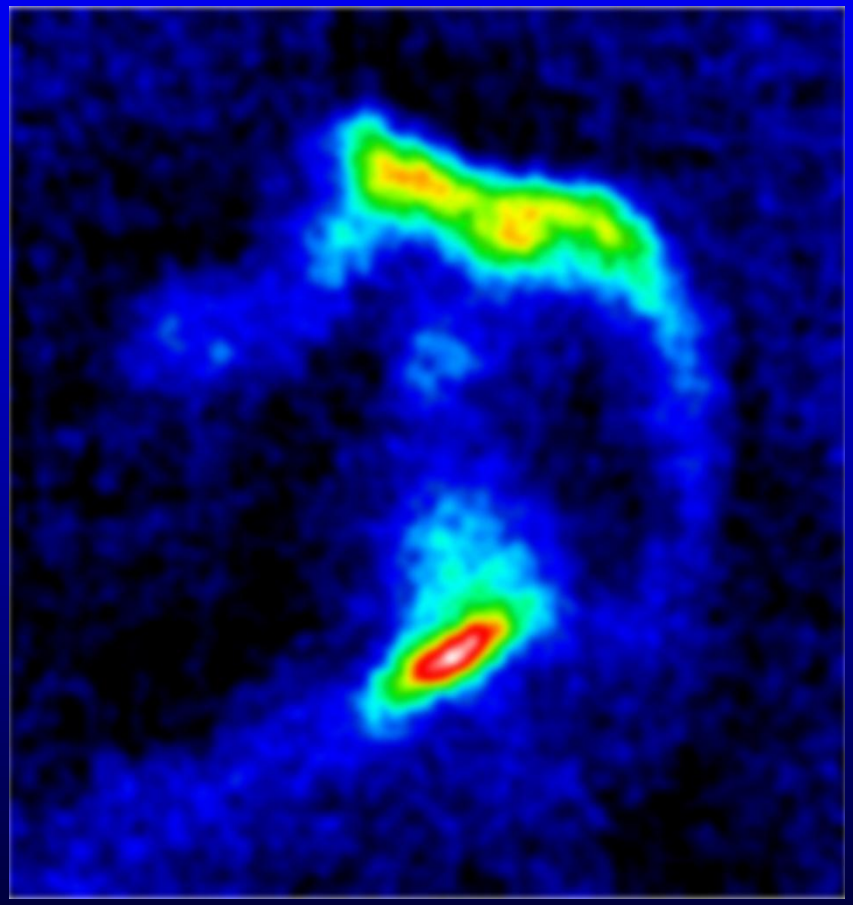




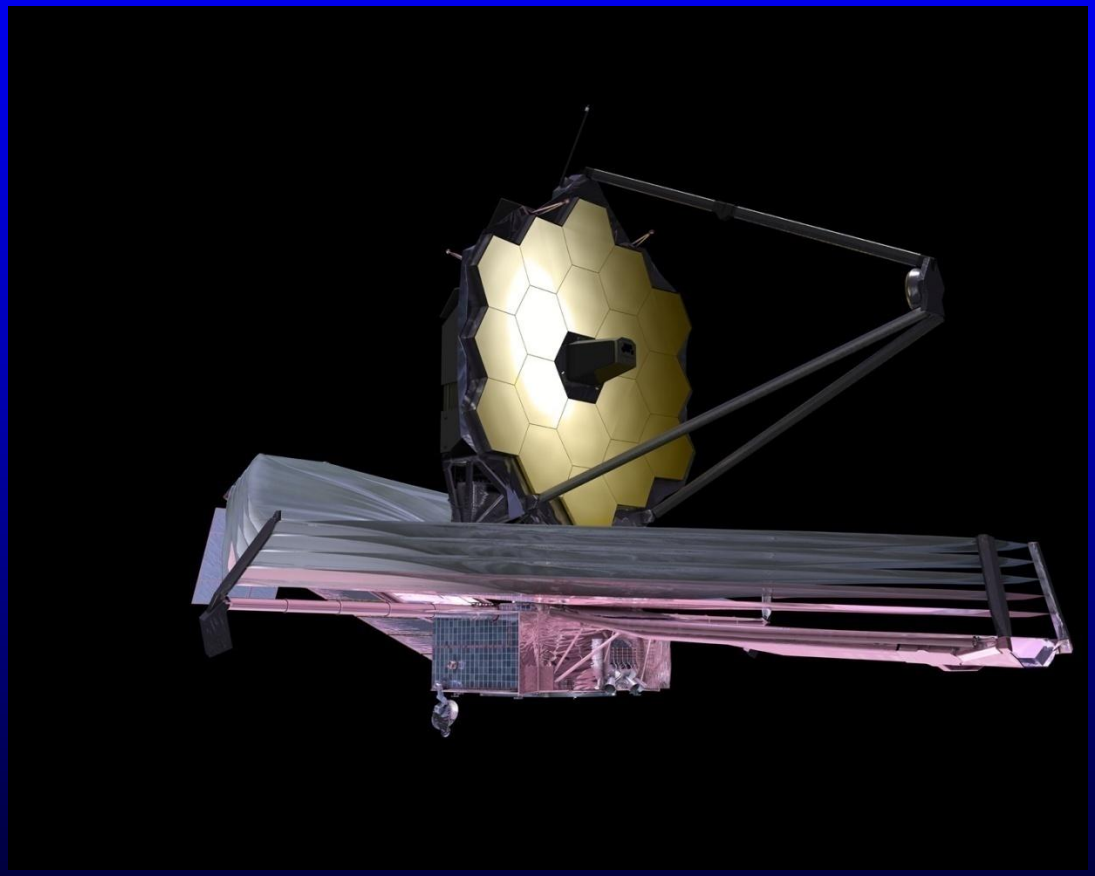
Gaseous Pillars · M16 HST · WFPC2

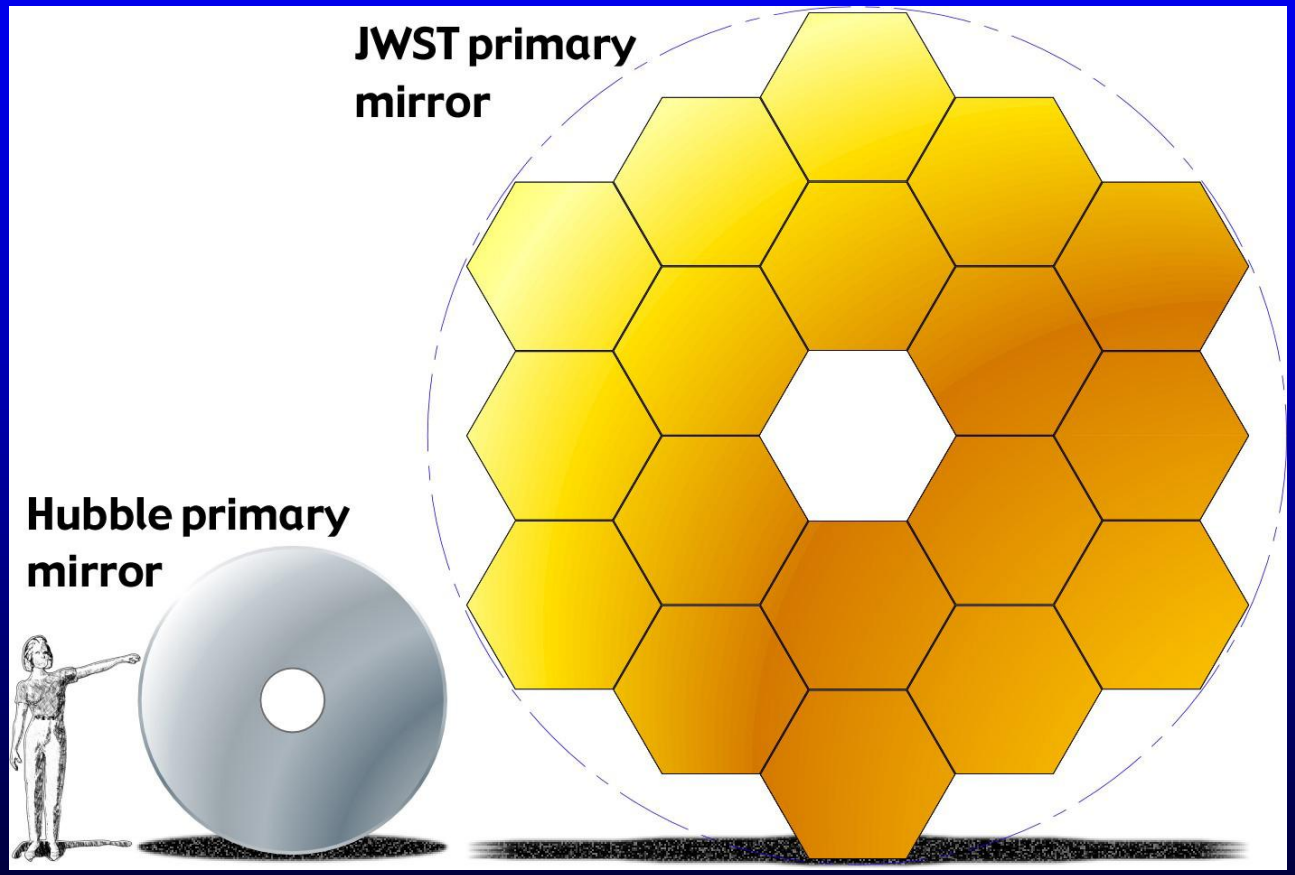
PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

A star being born!



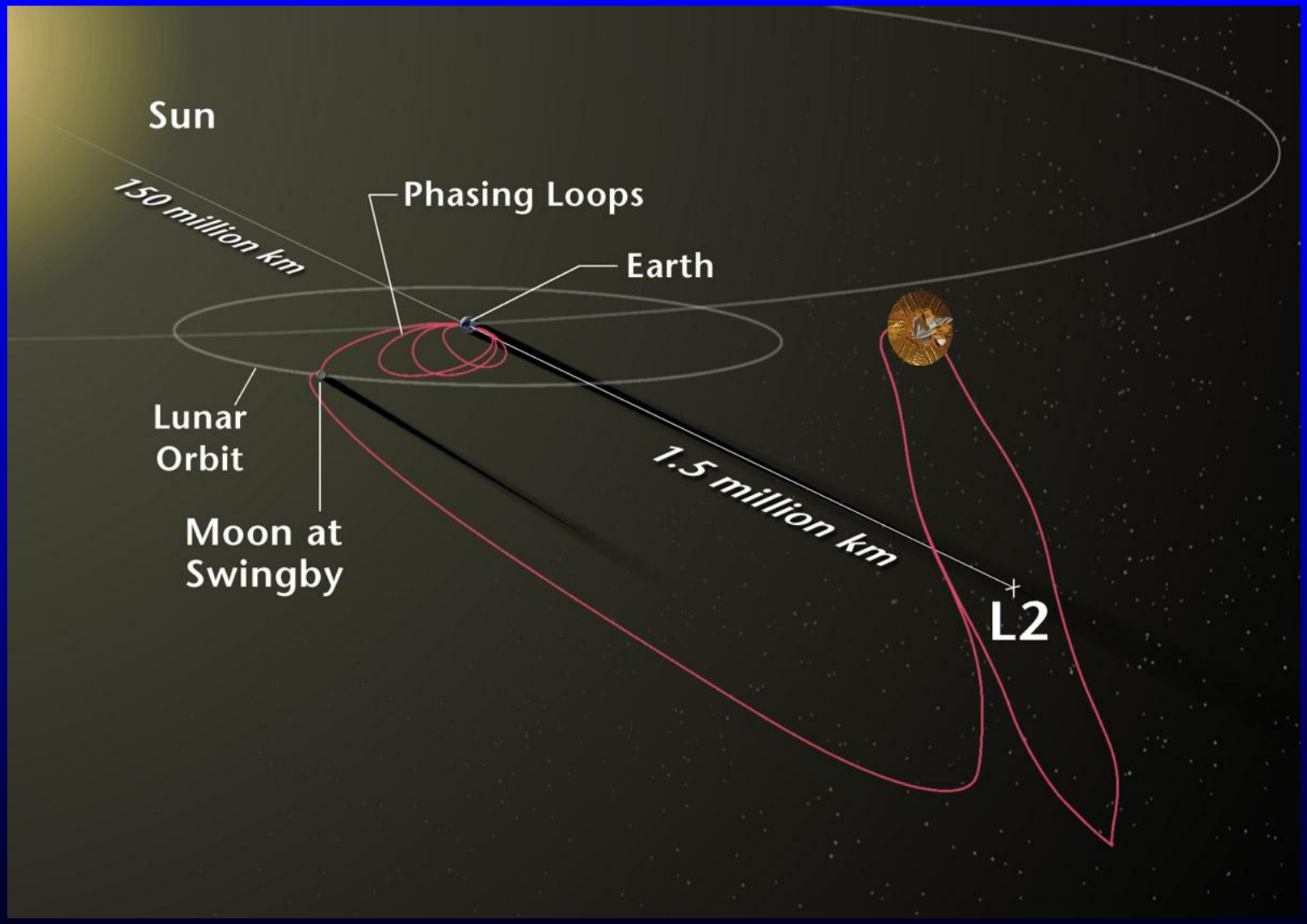
James Webb Space Telescope



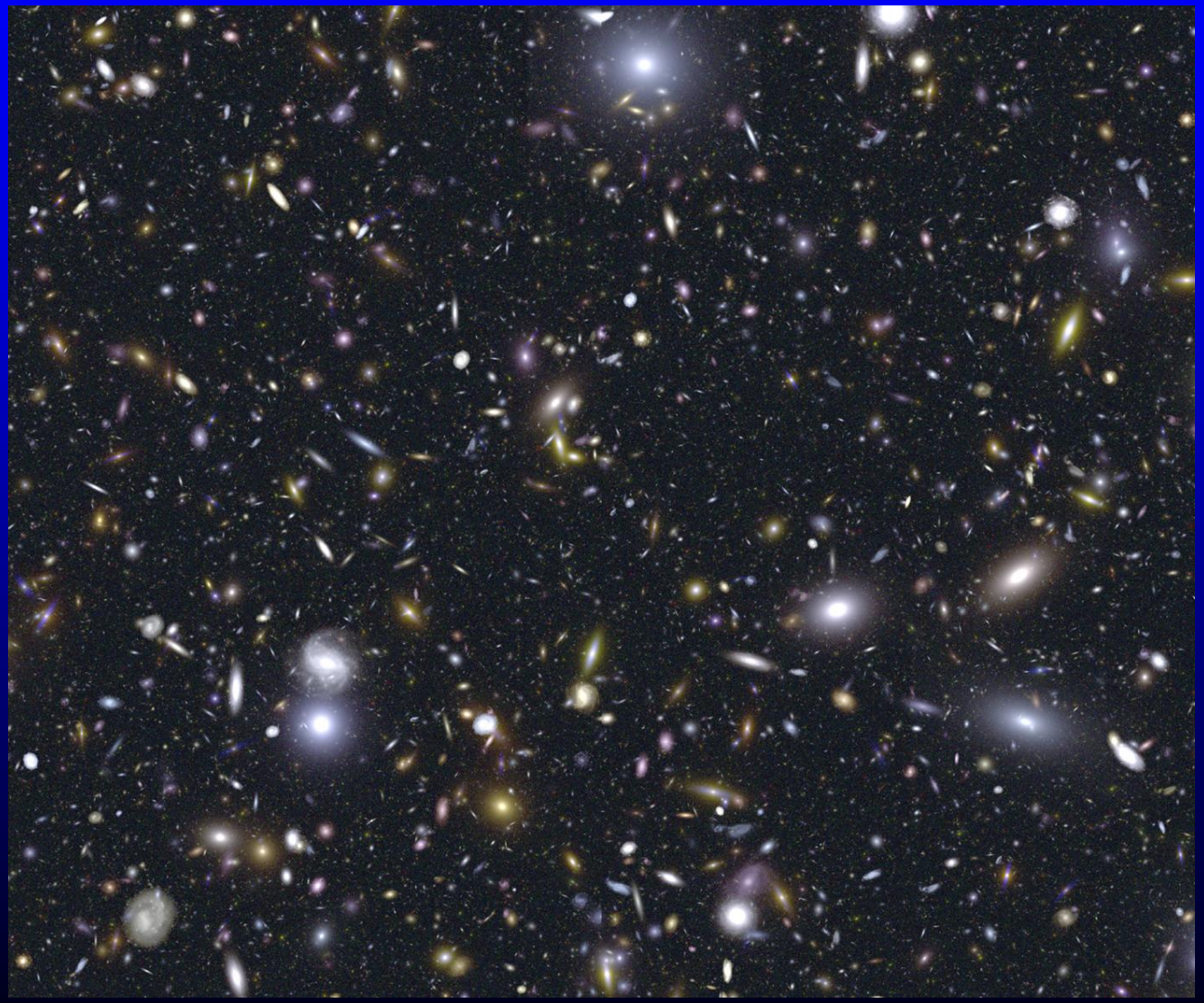

JWST primary mirror
Hubble primary mirror

5 mirrors undergoing cryogenic testing

The Second Lagrangian point



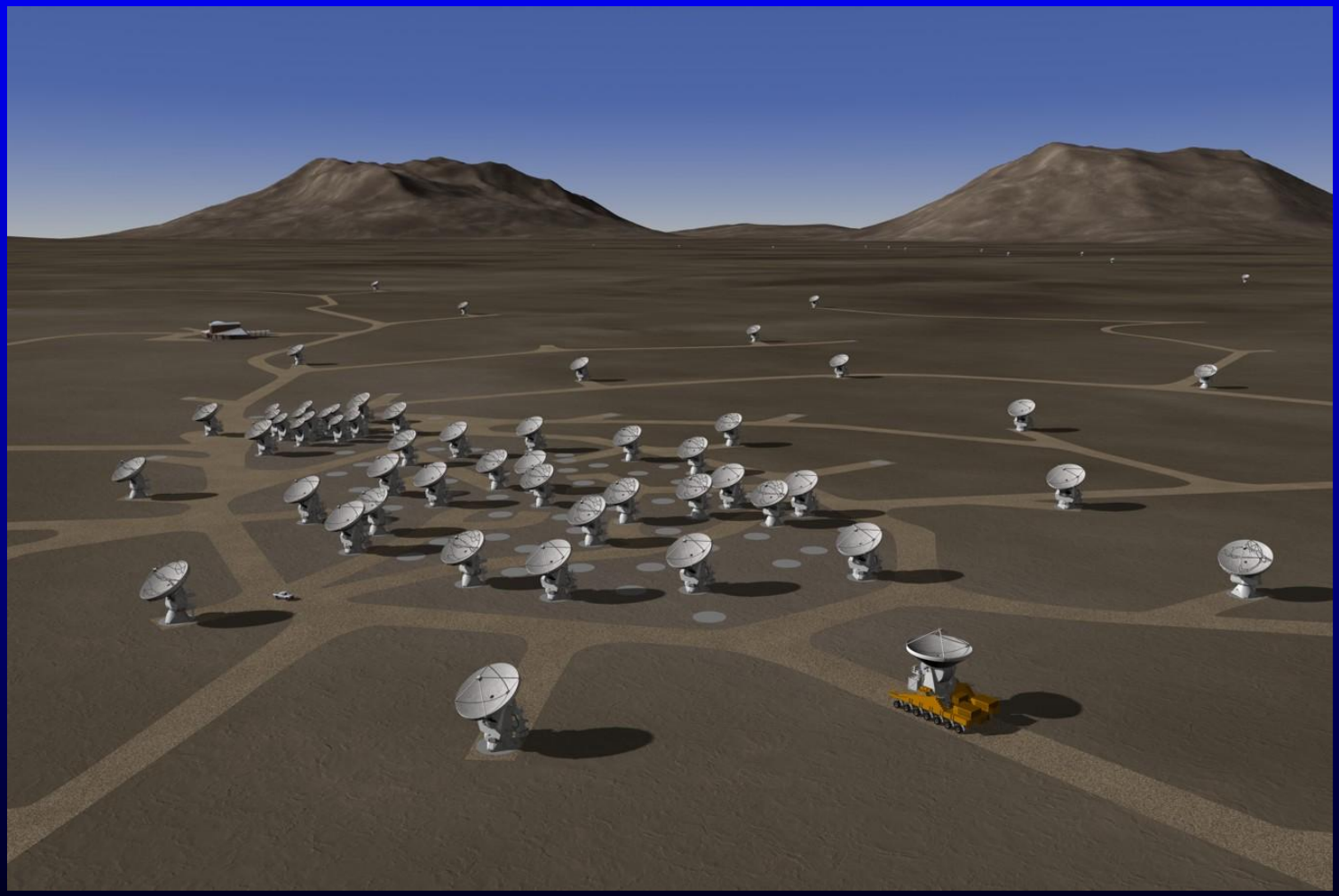
A view of the early Universe



- By studying some of the earliest galaxies and comparing them to today's galaxies we hope to be able to understand their growth and evolution.

- It should help us to understand how the heavier elements were built up as stars evolved and died.

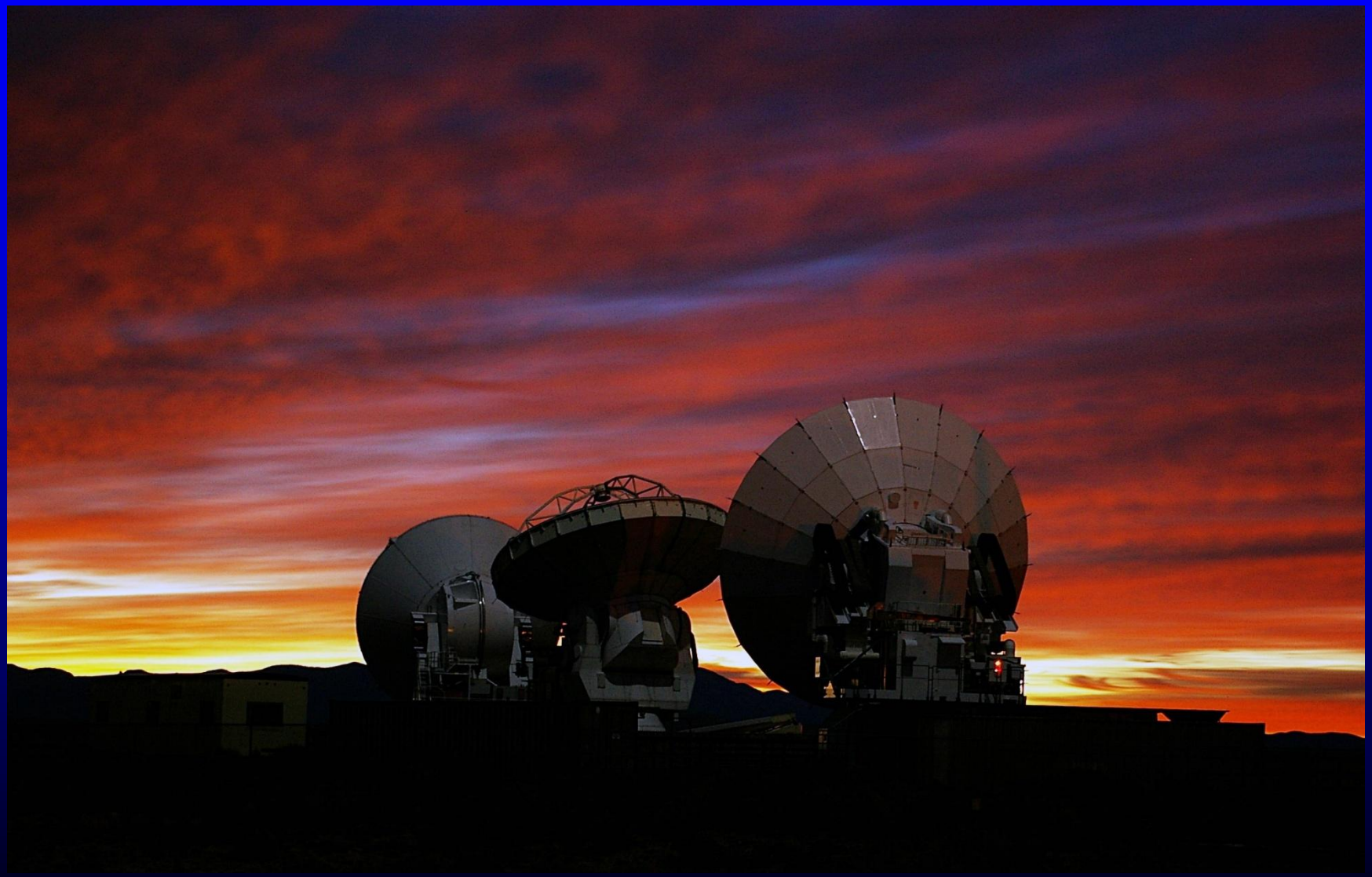
Atacama Large Millimetre Array



At a height of 5000m

50, 12m Diameter Antennas

ALMA test facility



Oct 2010: Eight Antennas

- ALMA will provide unprecedented sensitivity and resolution in the millimetre and sub-millimetre bands of the electromagnetic spectrum.

- ALMA is expected to provide insight on star birth during the early universe and detailed imaging of local star and planet formation.

- ALMA will begin scientific observations in the second half of 2011 and is scheduled to be fully operational by the end of 2012.

- At a cost of around 1 Billion Pounds, ALMA is the largest and most expensive ground-based astronomical project currently under construction.

ALMA time lapse movie

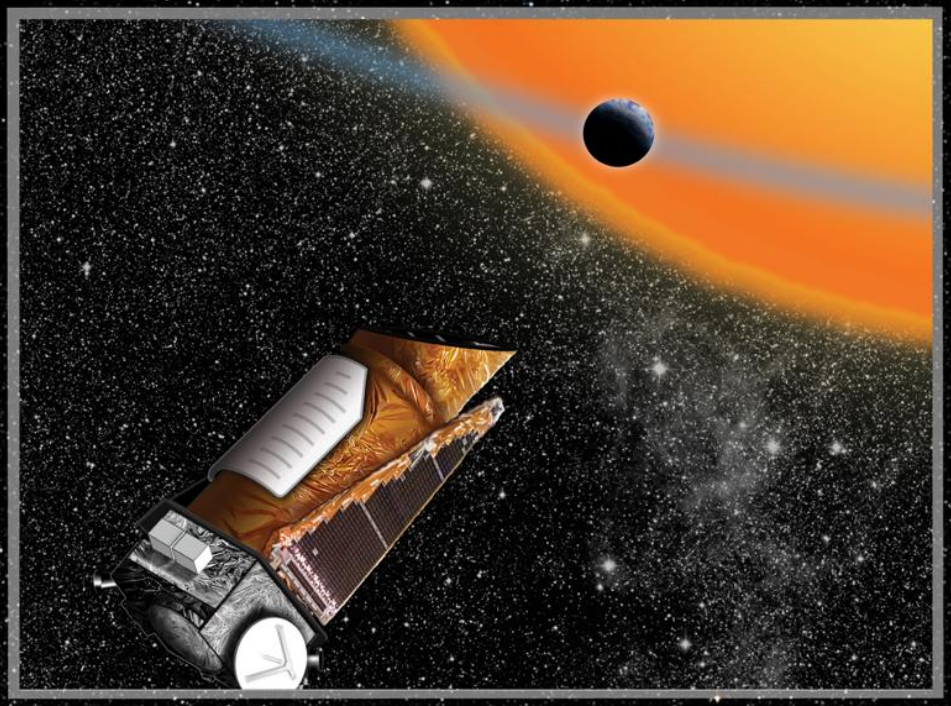
Is there other life in the Universe?

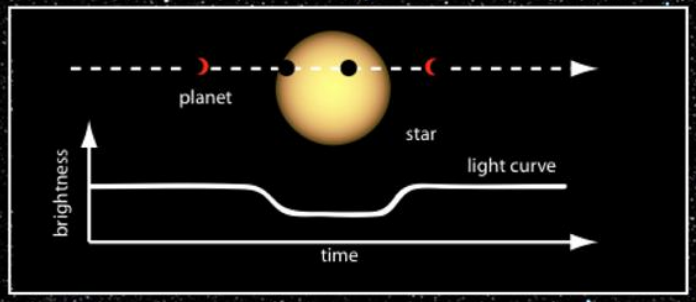
A Holy Grail of Astronomy:

the discovery of an Earth sized planet in its star's habitable zone.

Kepler Mission

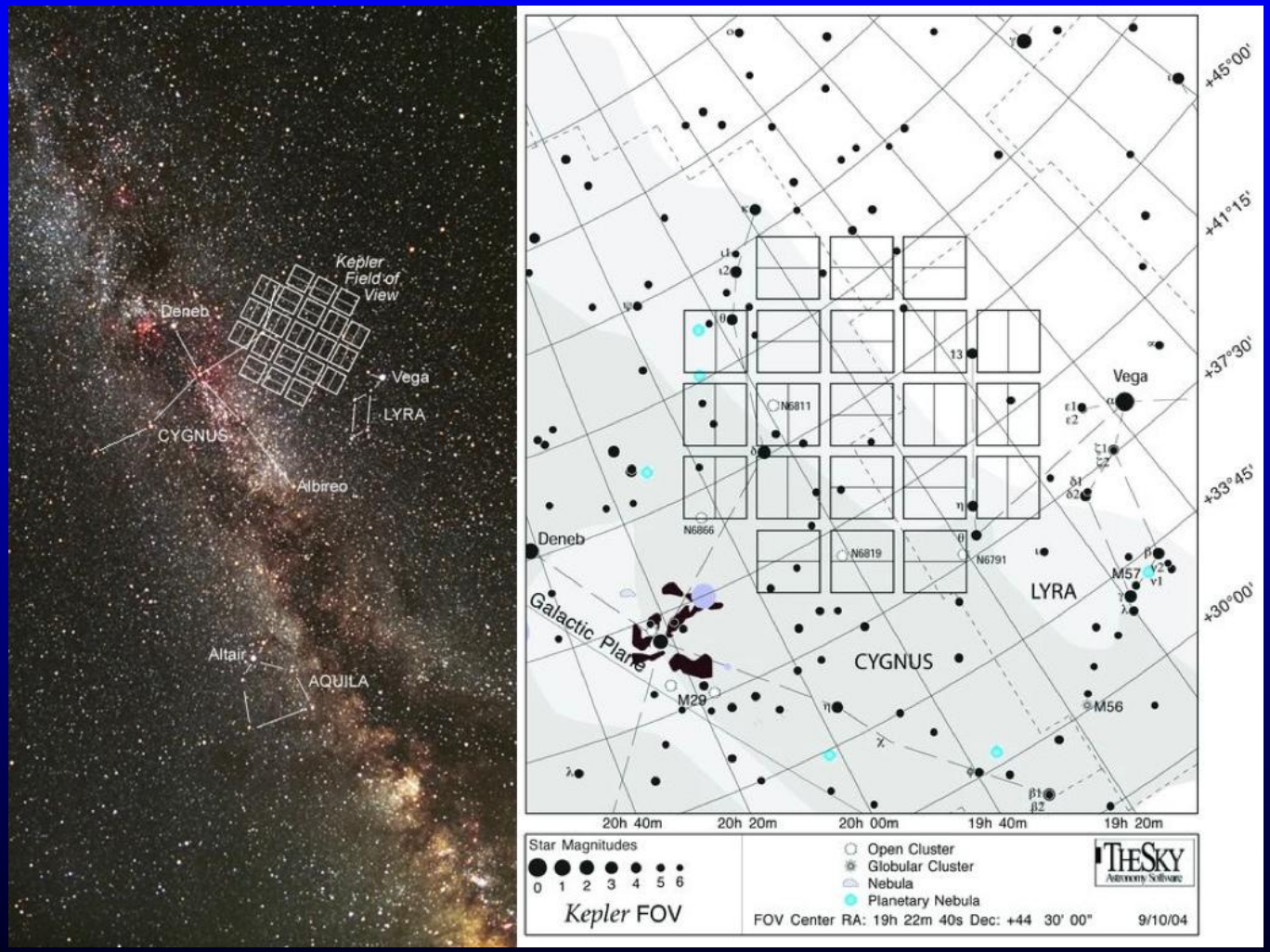
The determination of the frequency of Earth-size & larger planets in and near the habitable zone of solar-like stars

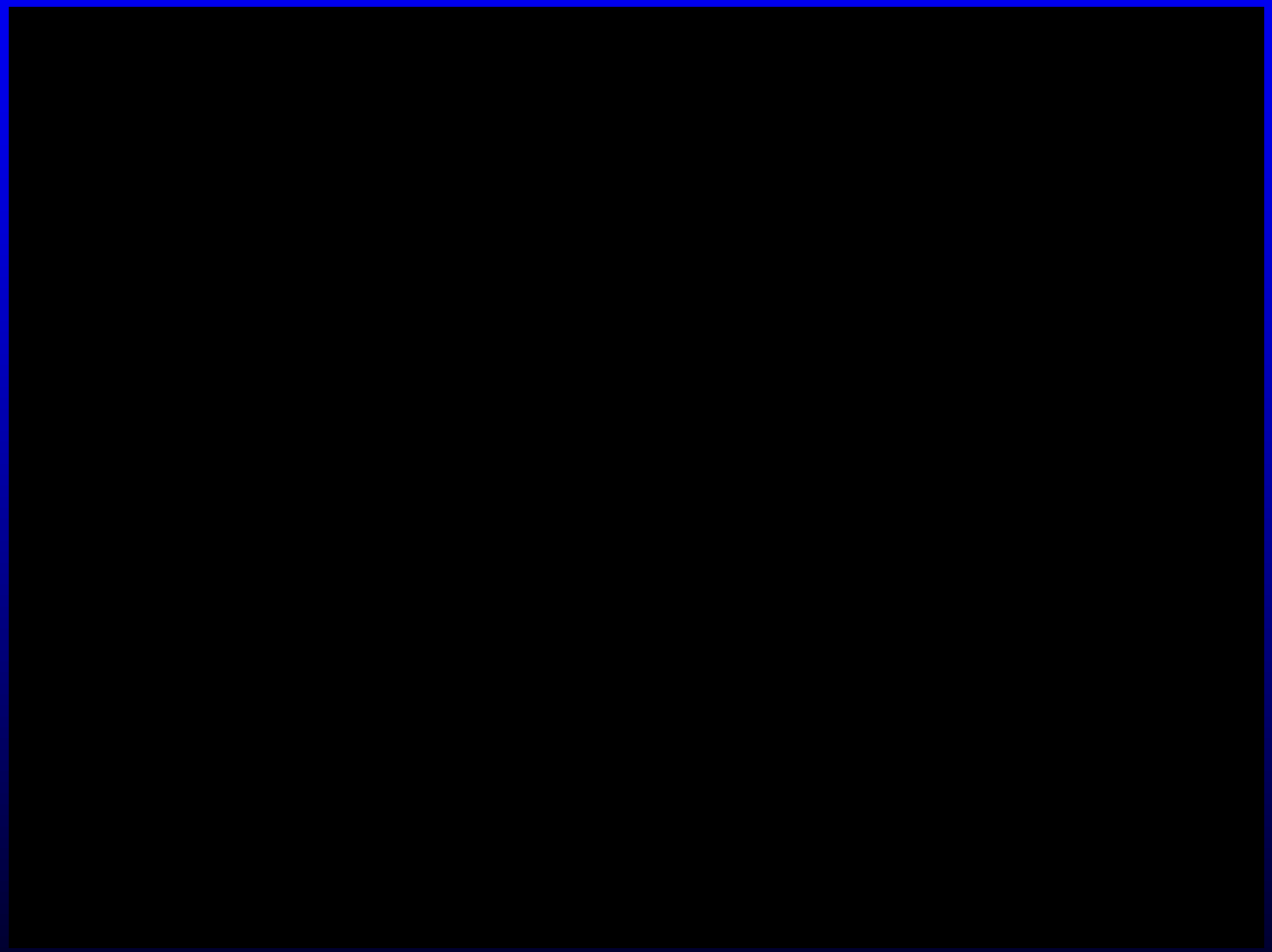




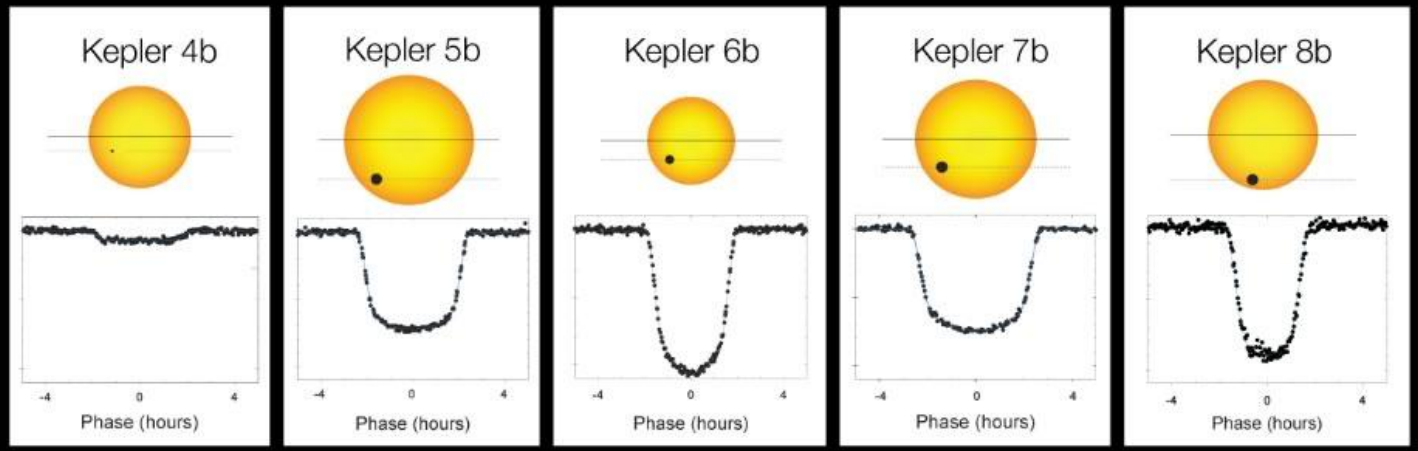

RSC

Observing >140,000 stars every 30 minutes

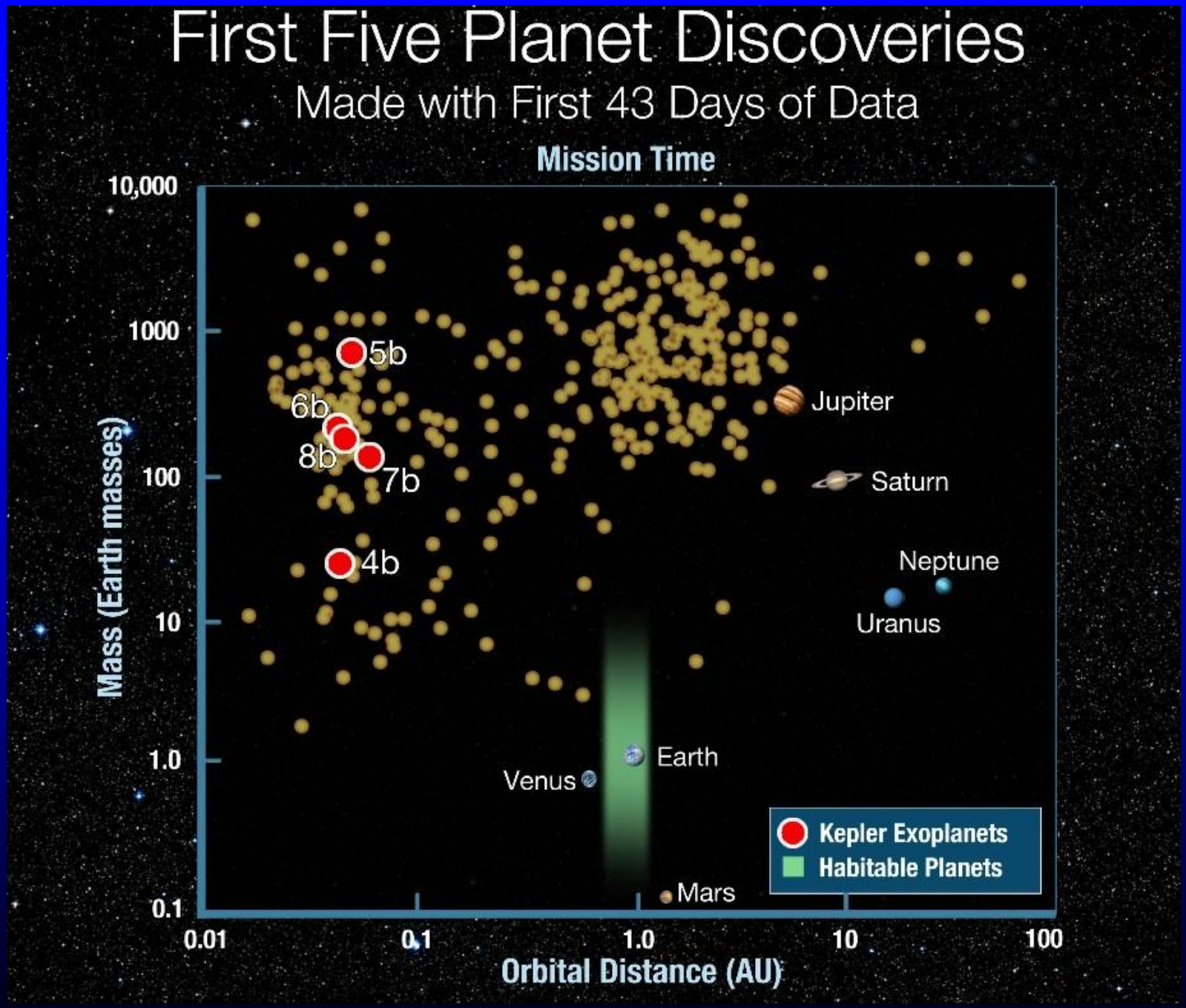




Transit Light Curves

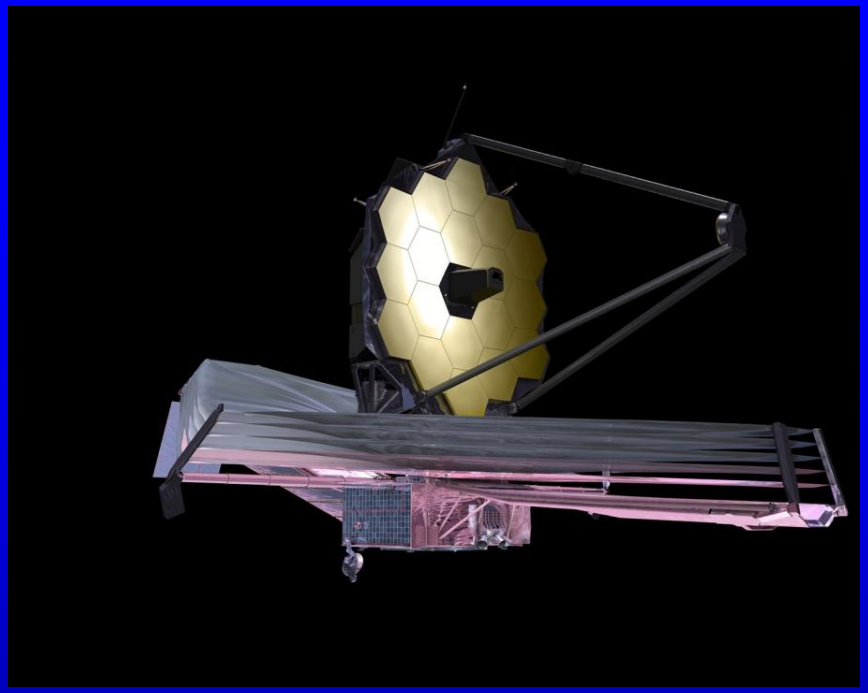


Orbital Period (days)	3.2 days	3.5 days	3.2 days	4.9 days	3.5 days

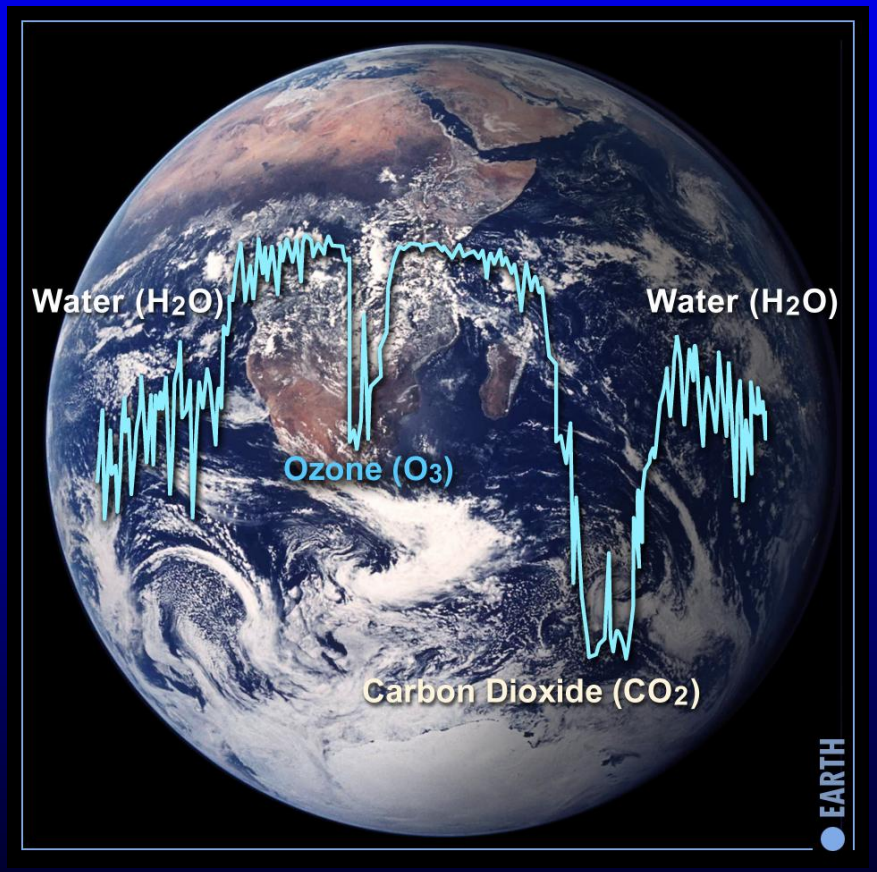

First Five Planet Discoveries
Made with First 43 Days of Data
Mission Time
10,000
1000
100
10
1.0
0.1
Mass (Earth masses)
5b
6b
8b
7b
4b
Jupiter
Saturn
Neptune
Uranus
Earth
Venus
Mars
Kepler Exoplanets
Habitable Planets
0.01
0.1
1.0
10
100
Orbital Distance (AU)

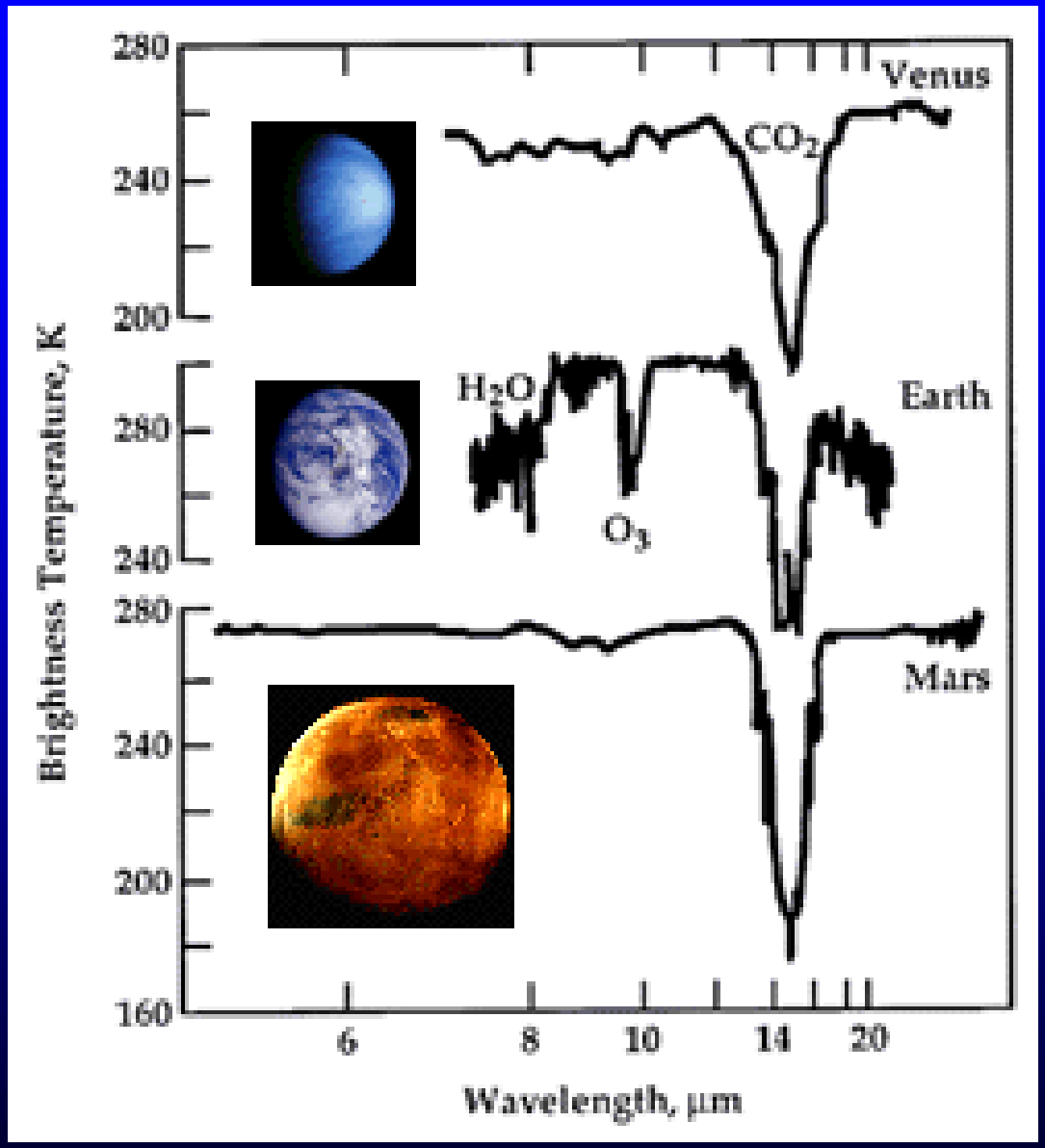
- To date, Kepler has discovered ~700 planetary candidates.

- So far, eight of these have been confirmed.

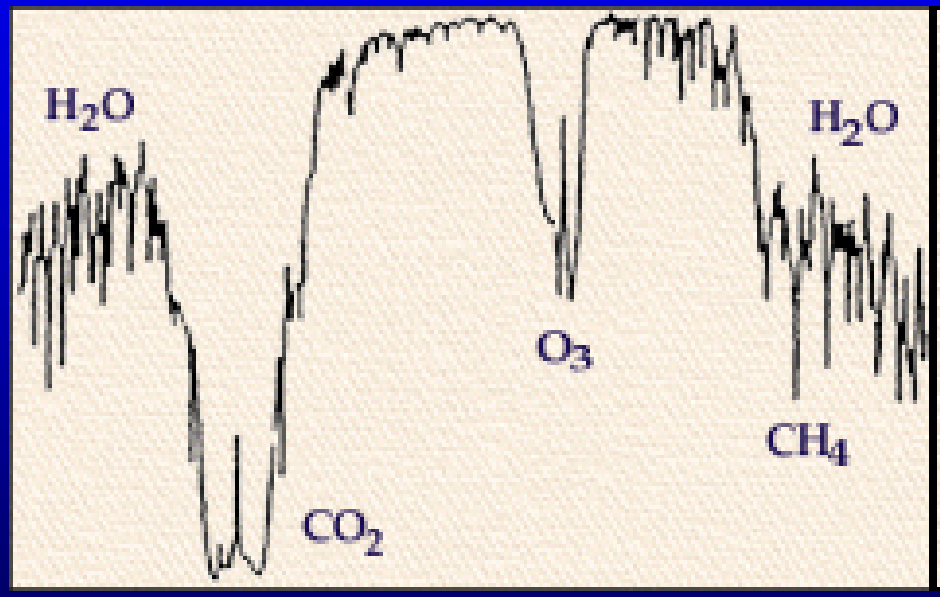


Study the Infra-Red Spectrum of a planet's atmosphere




Venus
CO_2
Earth
H_2O
O_3
Mars
Brightness Temperature, K
280
240
200
280
240
280
240
200
160
6
8
10
14
20
Wavelength, μm

What does it tell us?



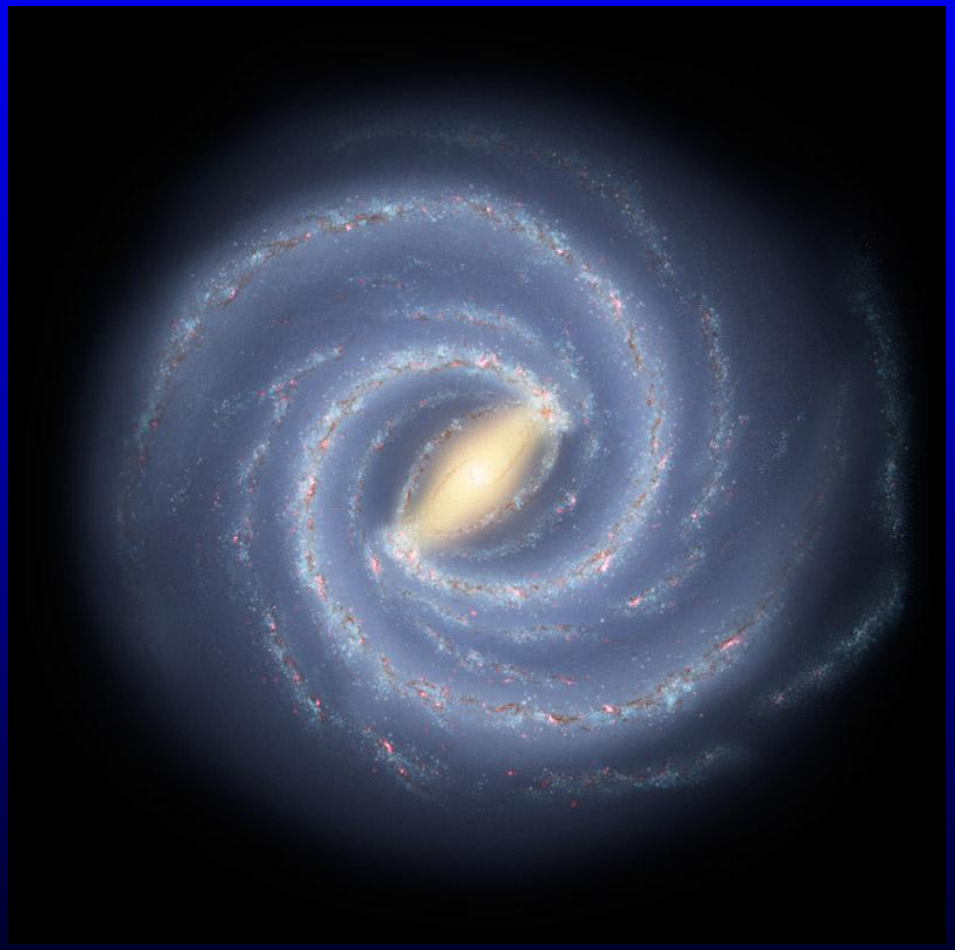
Spectrum - some signs of life:

- The spectral shape shows the temperature of the planet and it is right for water to be liquid
- The strong carbon dioxide band shows we have a planet with an atmosphere
- The ozone band shows plentiful oxygen, probably produced by life
- The spectral features of water show abundant water, indicating a planet with an ocean

Listening out for ET

Project Phoenix has been the most sensitive search so far – but has only looked out to 200 light years!

The SKA could detect a beamed signal from across the galaxy



SKA over-flight