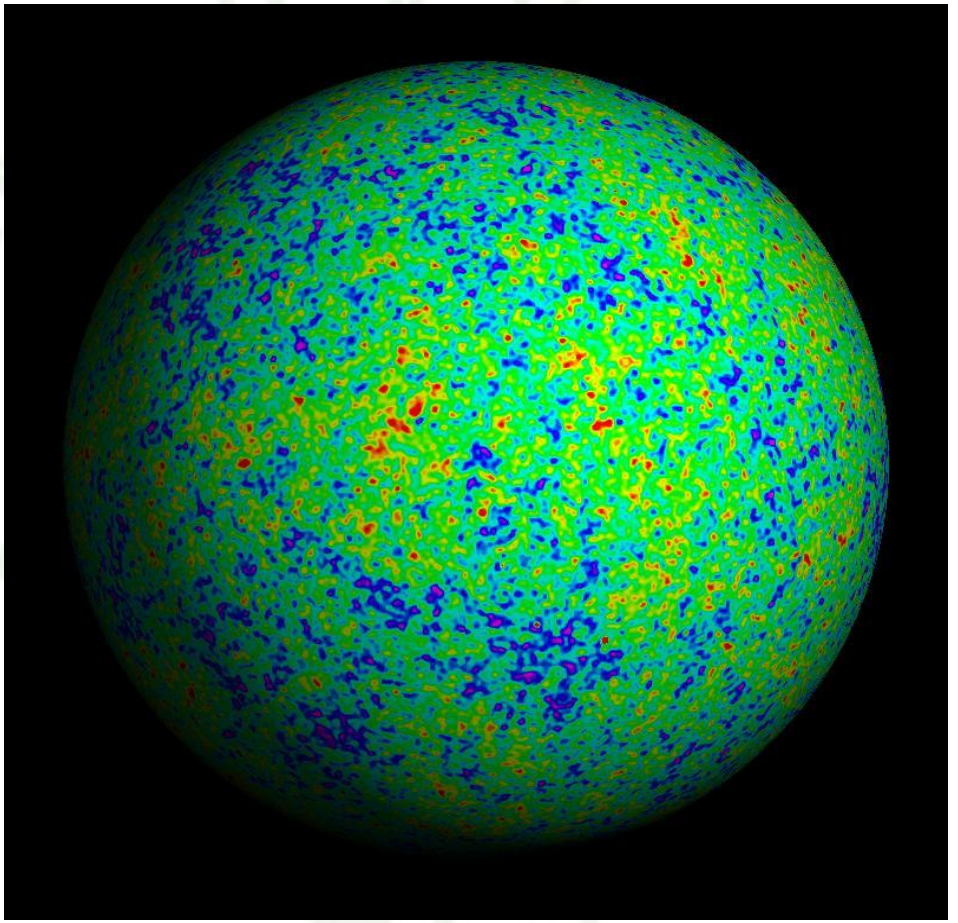
HOVO cursus Kosmologie

Voorjaar 2011



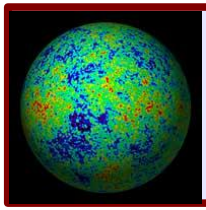
prof.dr. Paul Groot
dr. Gijs Nelemans

Afdeling Sterrenkunde,
Radboud Universiteit Nijmegen

HOVO cursus Kosmologie

Overzicht van de cursus:

• 17/1	Groot	Historische inleiding + afstandsladder
• *24/1*	*Nelemans*	*Observationele kosmologie, CMB*
• 31/1	Nelemans	Friedmann vgl., Nucleosynthese
• 7/2	Nelemans	Donkere materie en Structuurvorming
• 14/2	Nelemans	Supernovae, donkere energie
• 21/2	Groot	Weak lensing, EUCLID, toekomst



De wet van Hubble

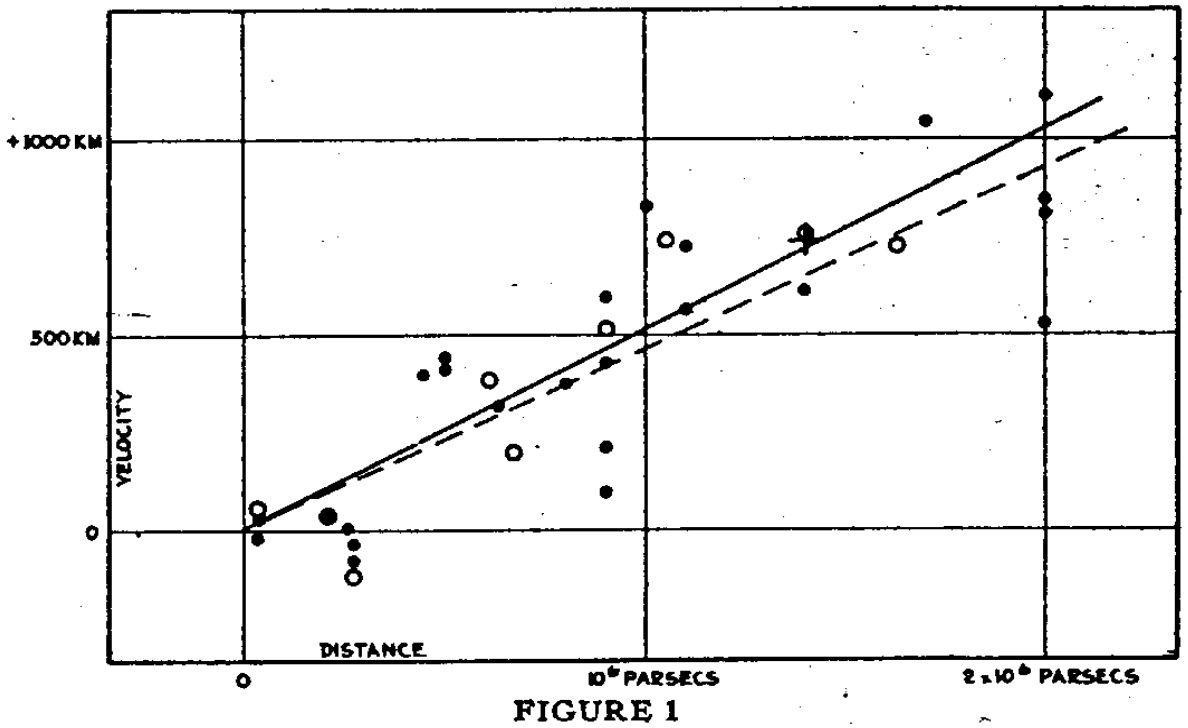
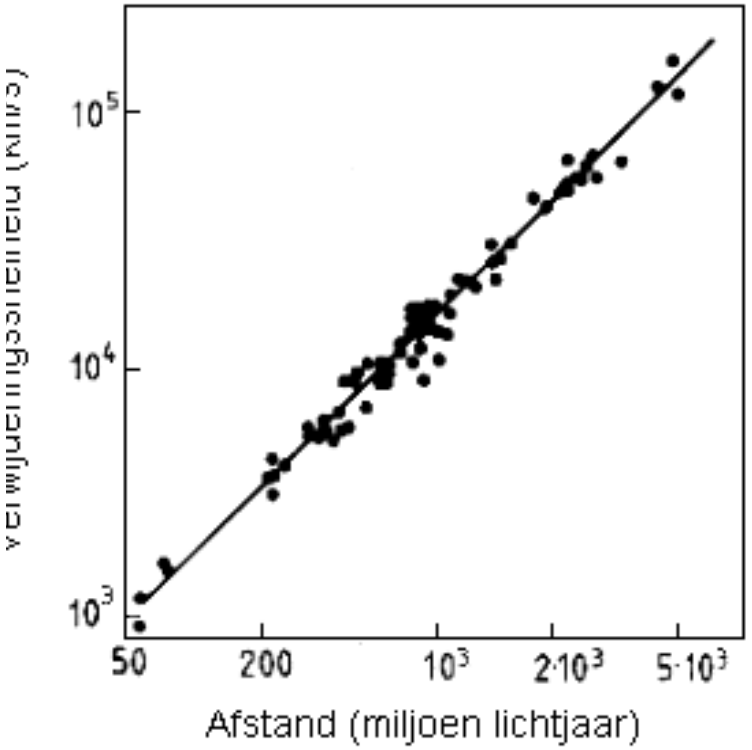
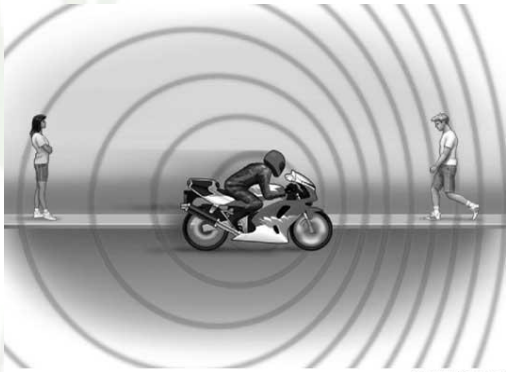


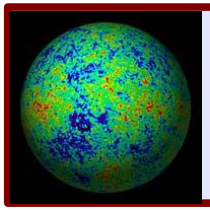
FIGURE 1



De wet van Hubble $v = H_0 d$

Doppler effect: $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$





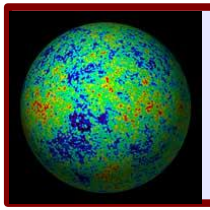
Het expanderende Heelal

Conclusie: Het Heelal expandeert!

Consequenties:

- Afstanden worden groter!
- Vroeger was de schaal kleiner!
- Het heelal koelt af!
- Vroeger was het kleiner!

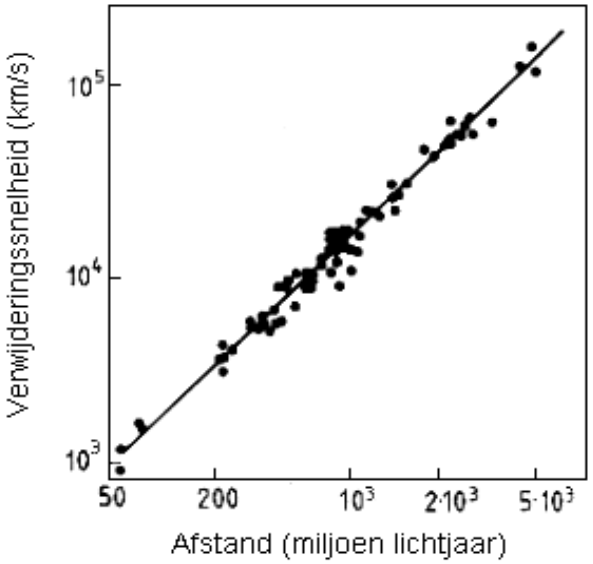
Het heelal is begonnen in een hete Oerknal!

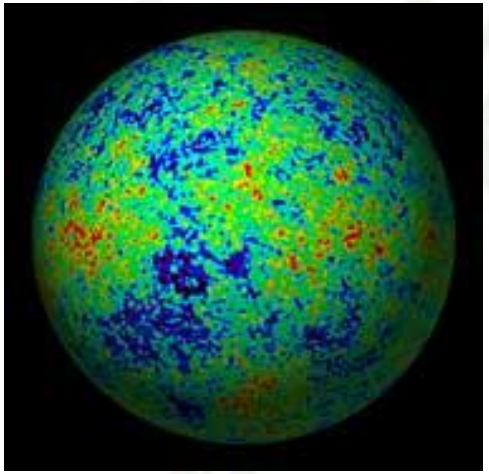


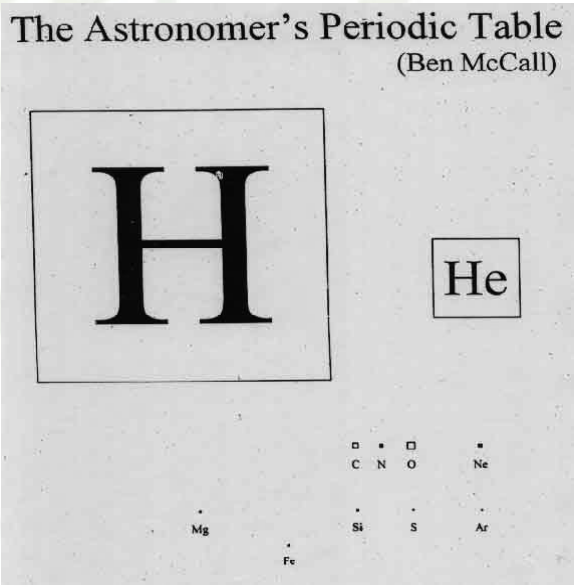
De hete Oerknal

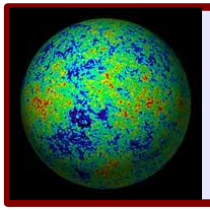
Hete Oerknal model spectaculair bevestigd:

- De expansie van Hubble
- De microgolfachtergrond straling
- Nucleosynthese van de elementen



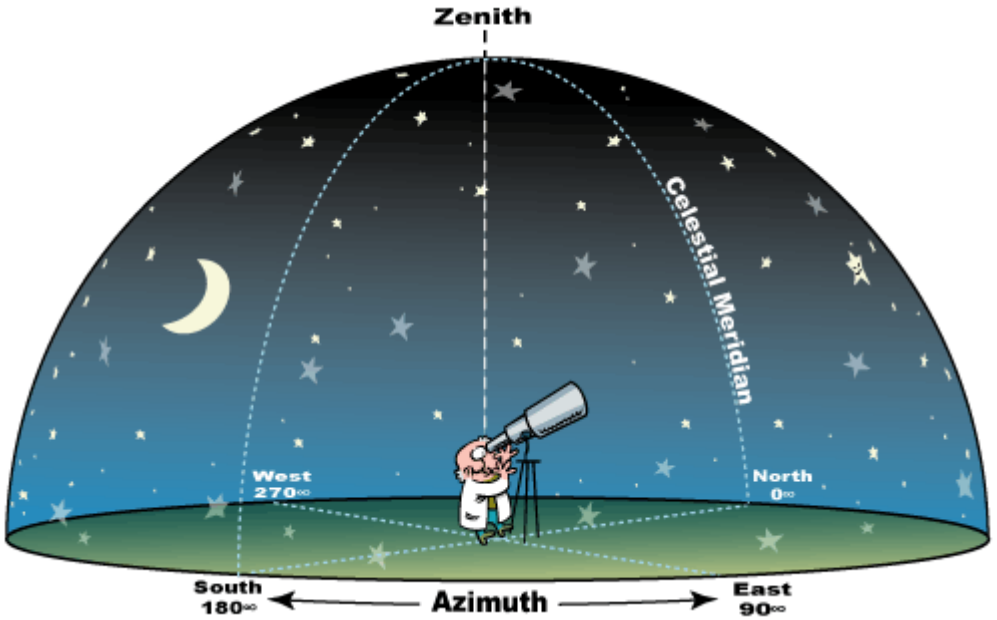


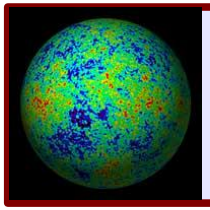




De Afstandsladder

Kosmologie hangt helemaal samen met afstanden meten in het Heelal





De Afstandsladder

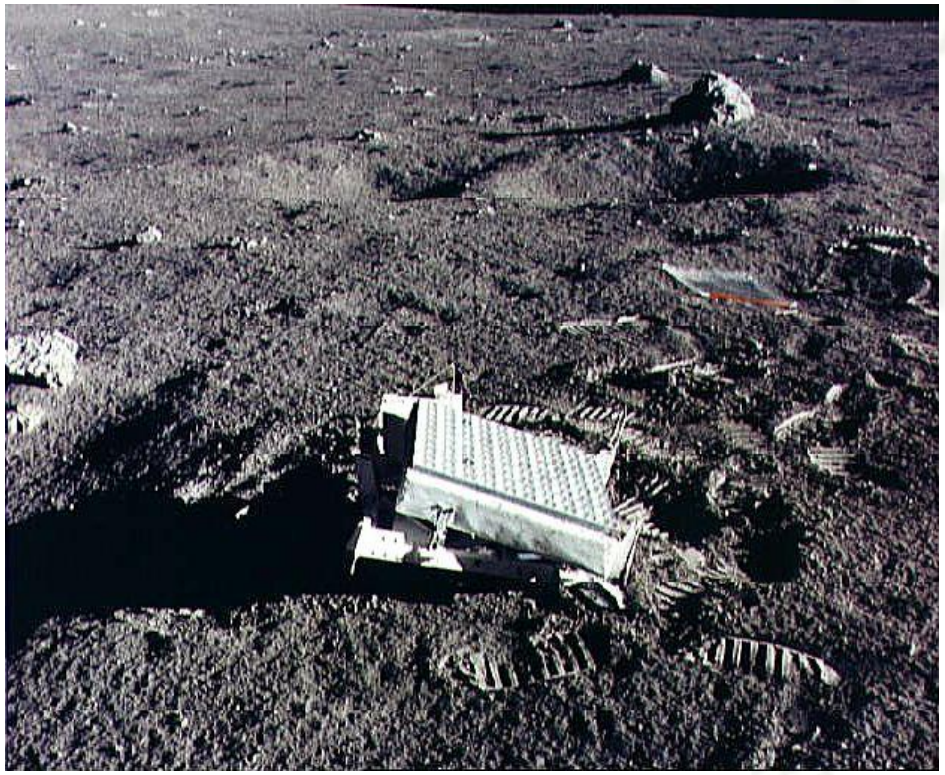
Aaneenschakeling van methodes:

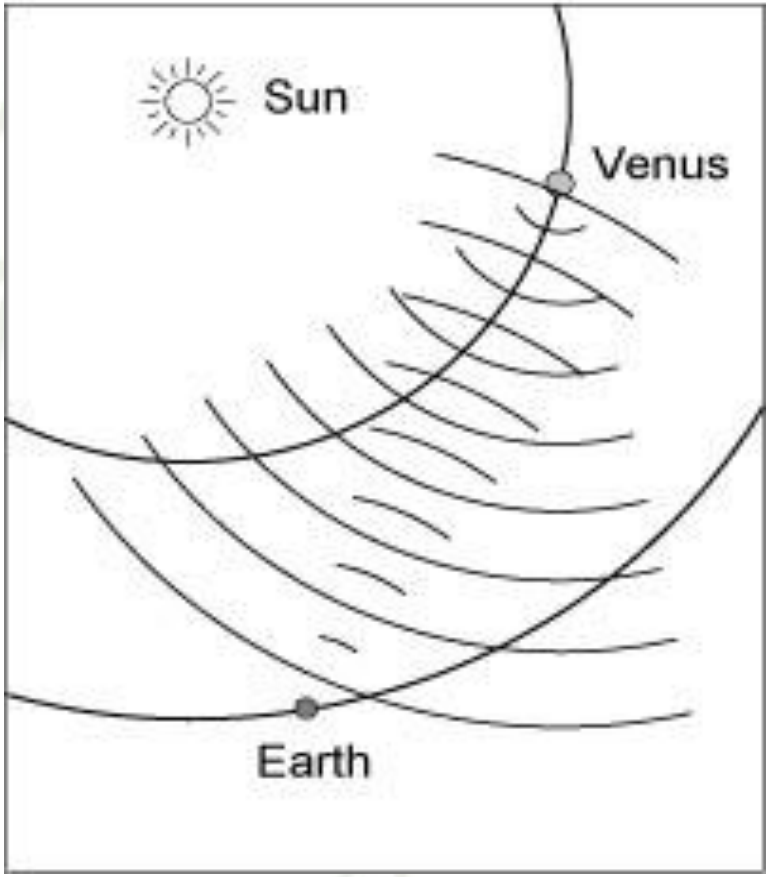
- Radar ranging
- Parallax
- Variabele sterren (RR Lyrae & Cepheiden)
- Maser afstanden
- Supernovae
- Tully-Fisher & Fundamental Plane
- Hubble expansie

Radar/Laser Ranging

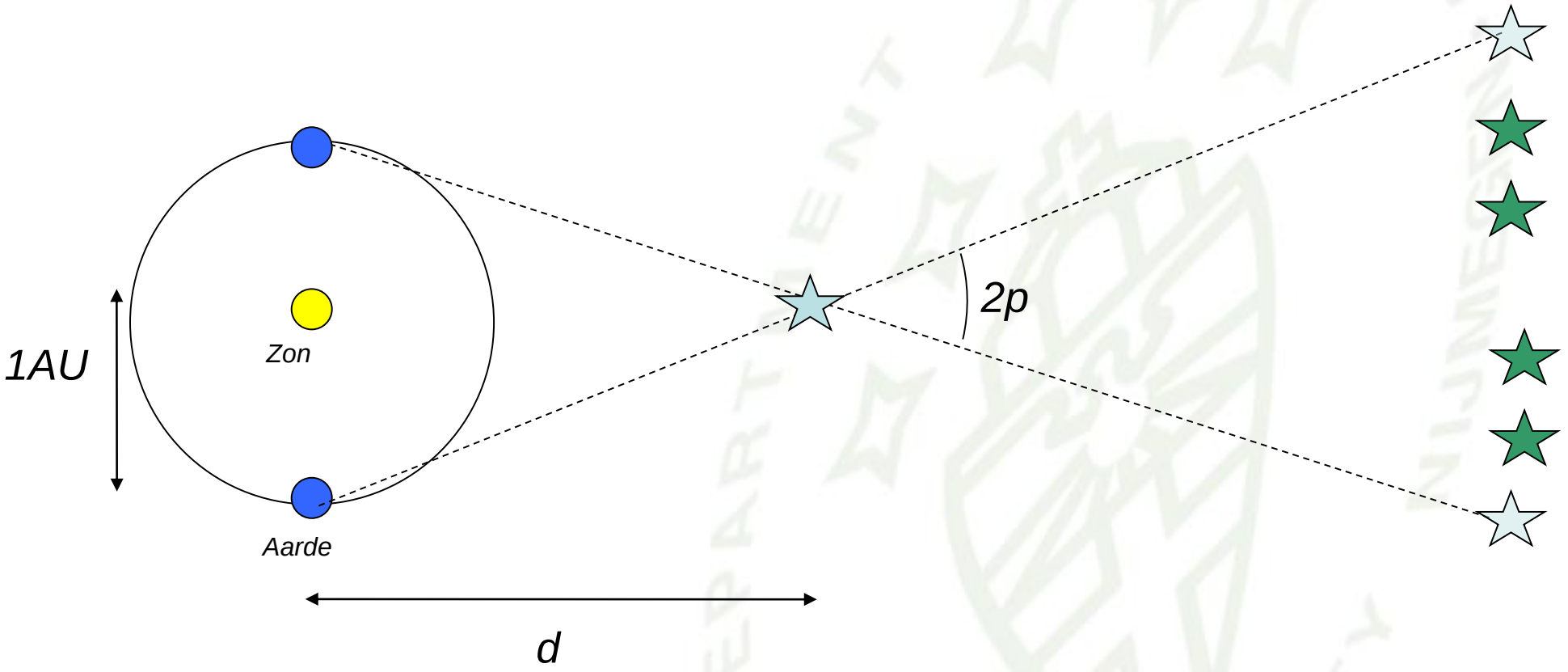
Uitgangspunt: ***lichtsnelheid is constant***

Bereik: Zonnestelsel



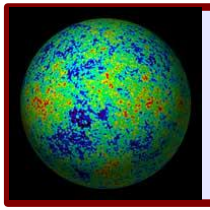


De parallax meting

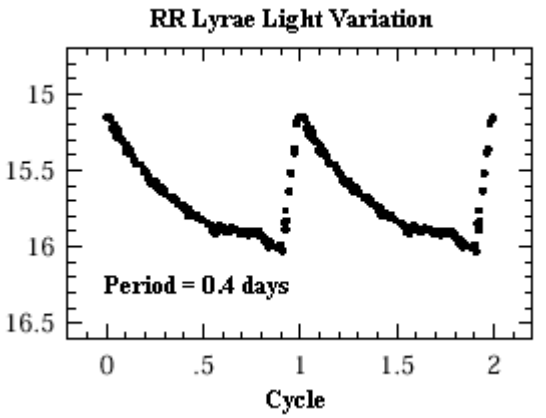


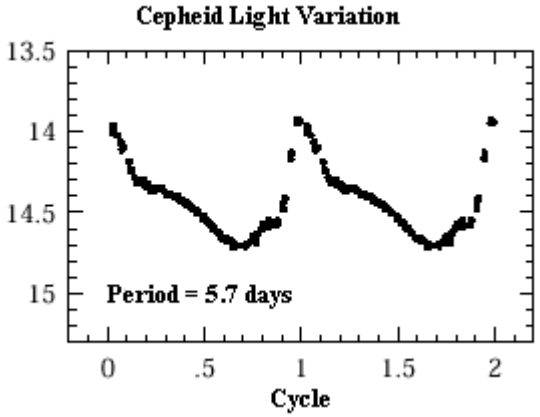
De afstand van de ster: $\tan p = d / 1\ AU \approx p$

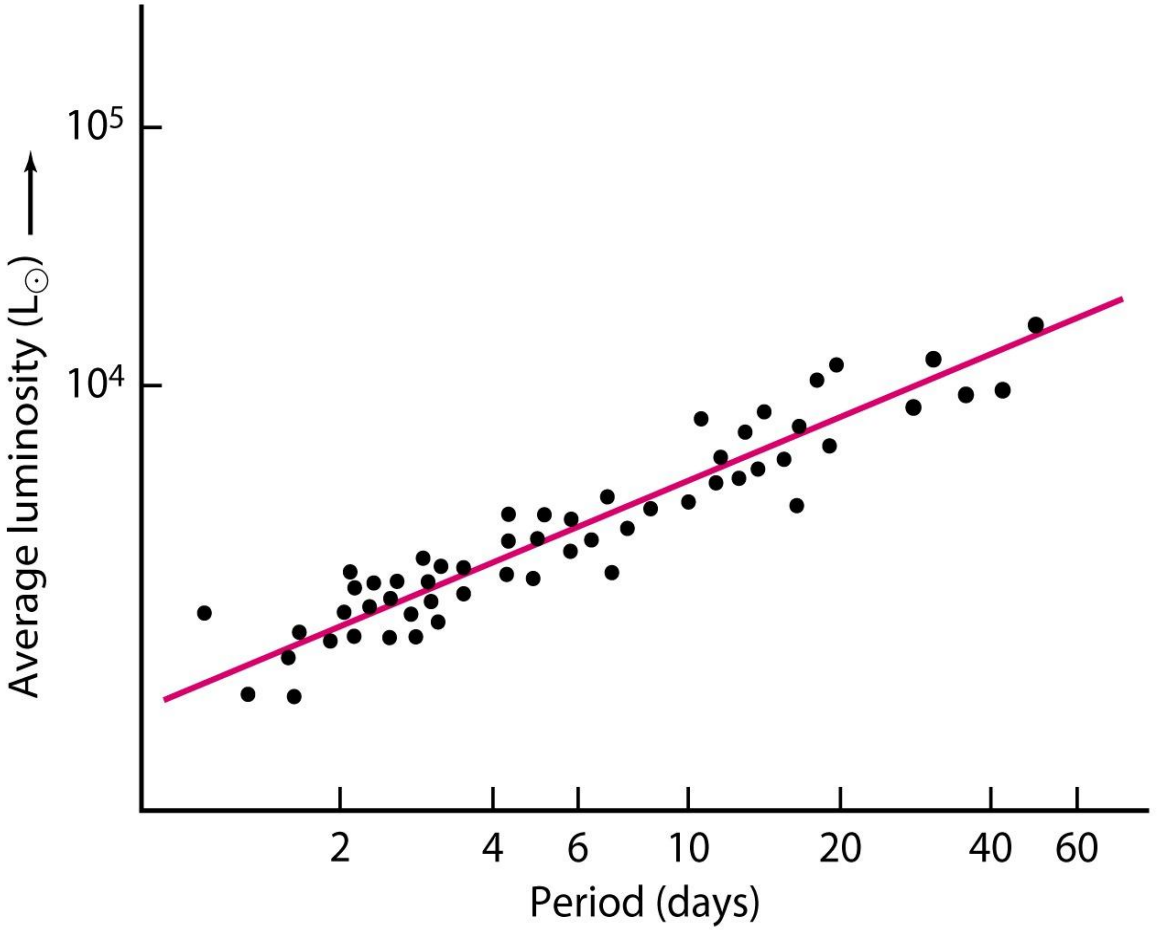
Dit is de definitie van de afstandsmaat 'parsec' : een ster staat op 1 parsec afstand als hij een parallax vertoont van 1 boogseconde.

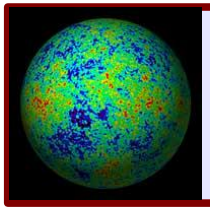


Variabele Sterren

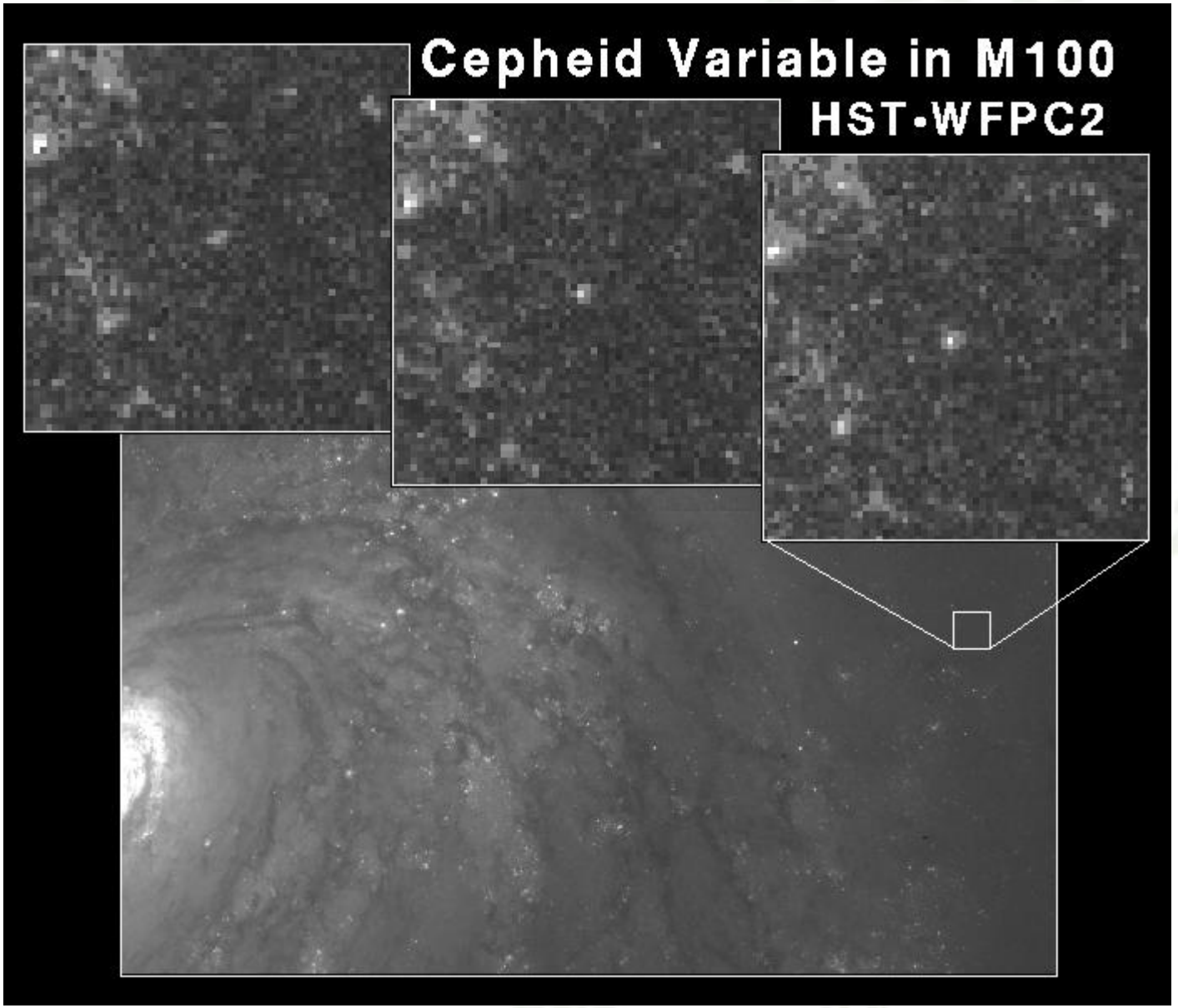


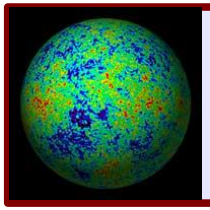






Variabele Sterren



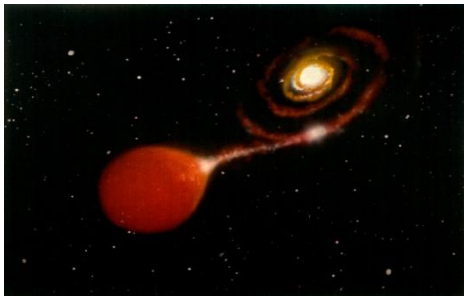


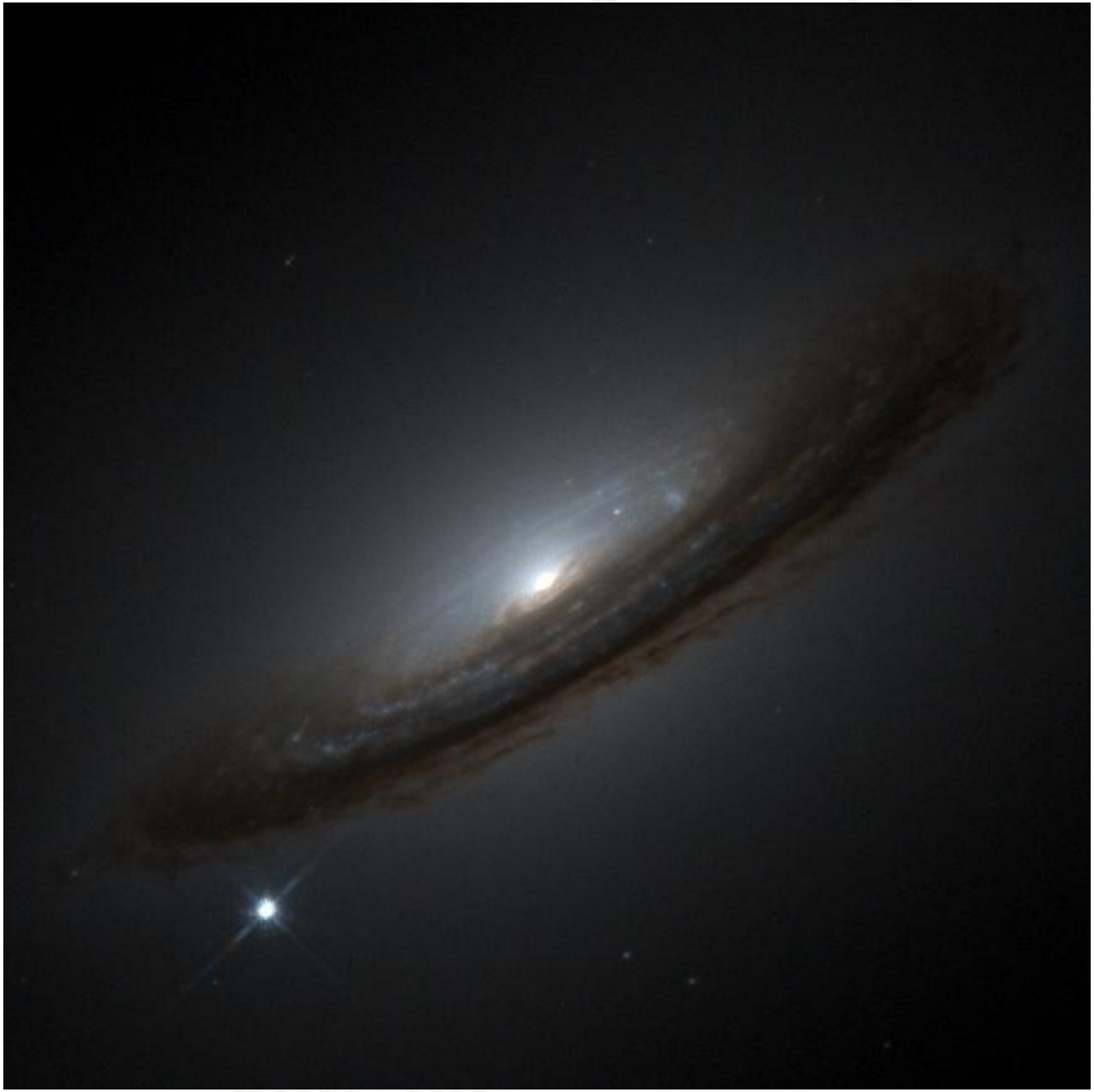
Supernovae Type Ia

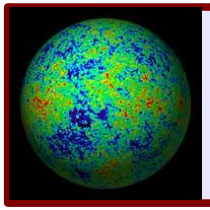
Ontbranding van koolstof in witte dwerg onder gedegenereerde omstandigheden

Relatie tussen helderheidsverloop en helderheid!

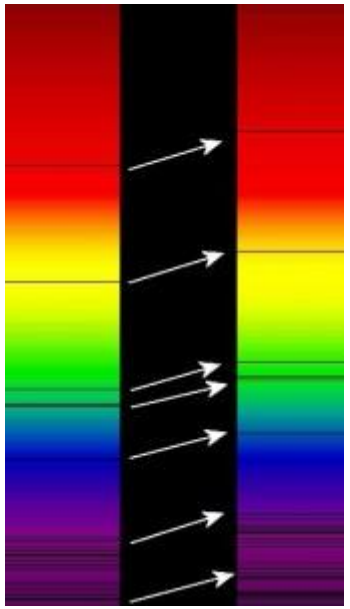
→ afstand

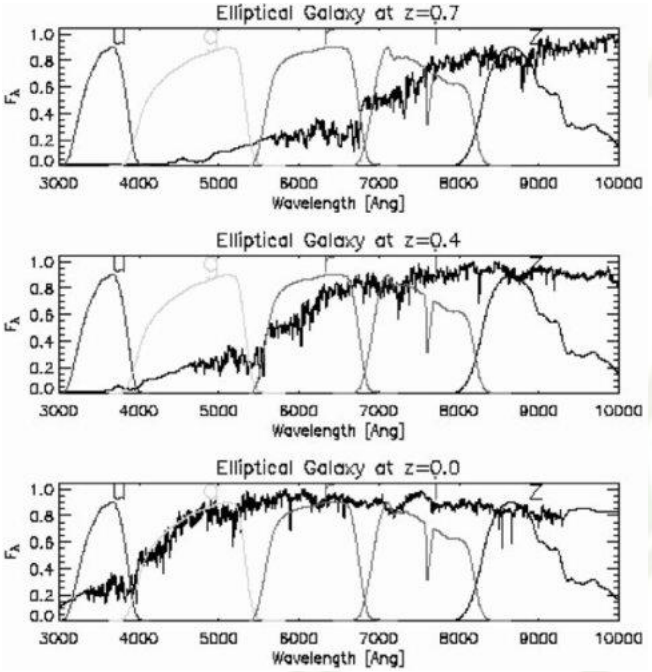






Wet van Hubble



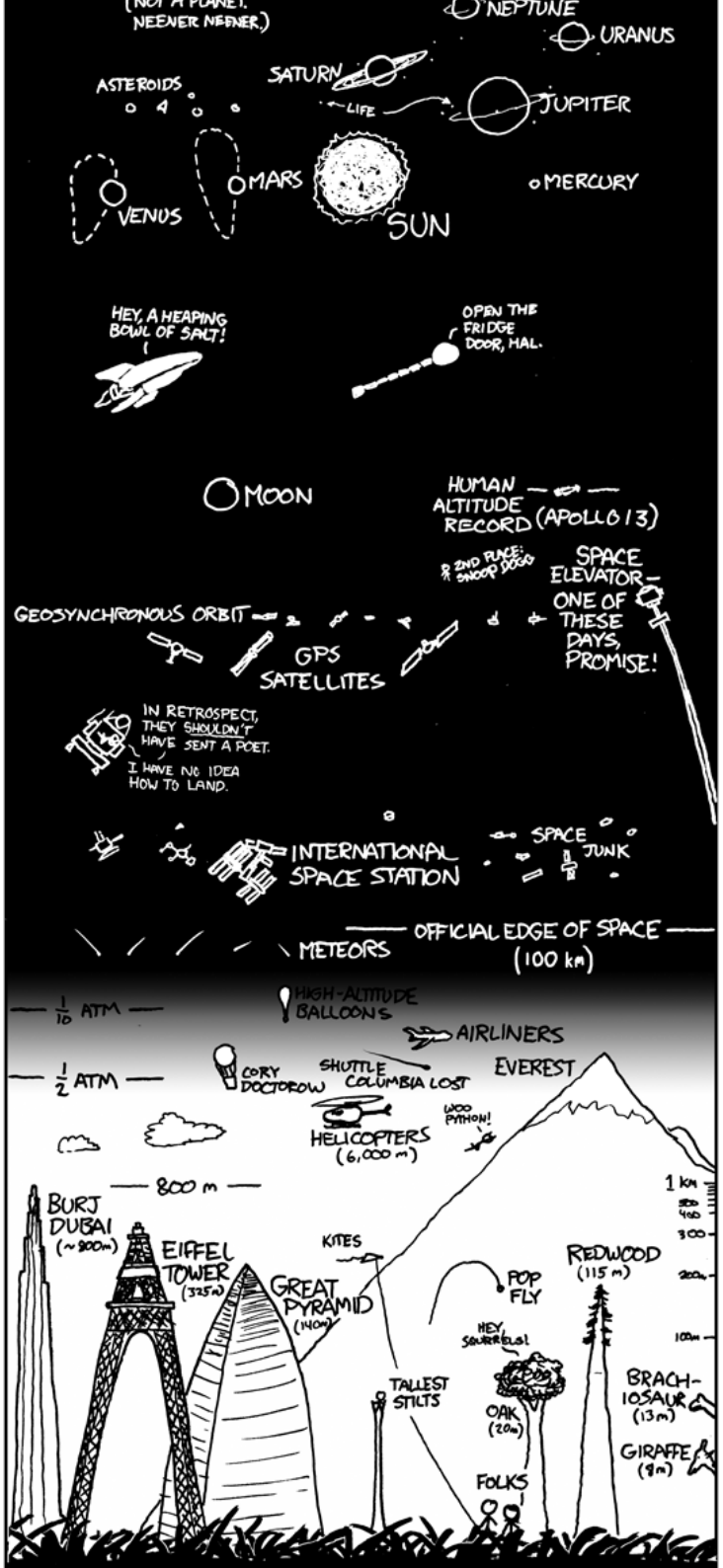


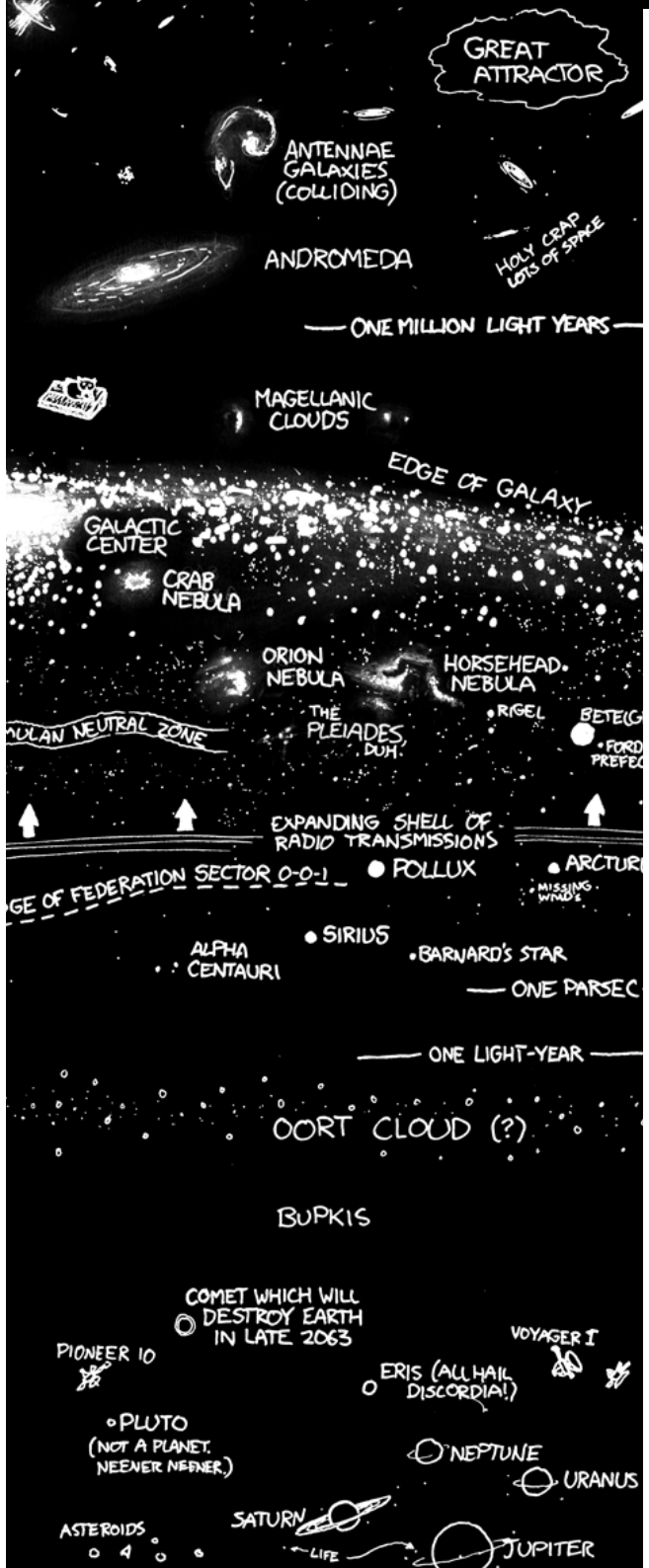
$$z = 1 + \frac{\Delta\lambda}{\lambda_0} = \frac{\lambda - \lambda_0}{\lambda_0}$$

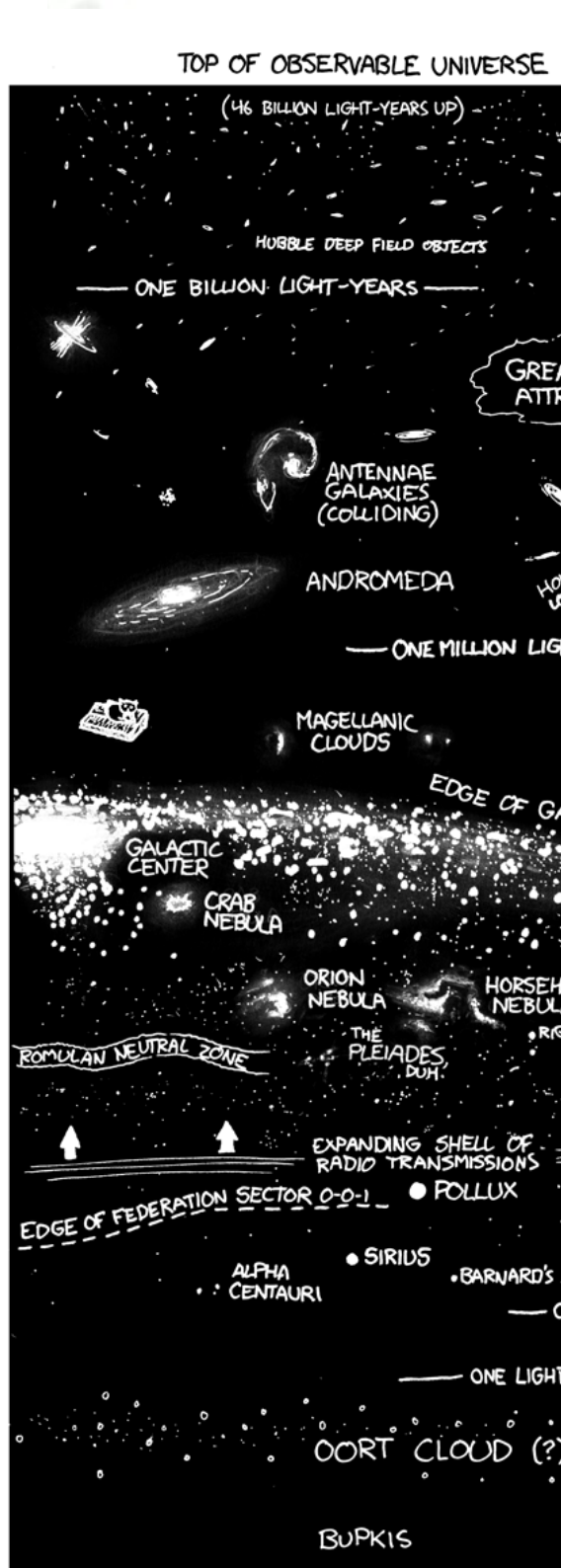
Roodverschuiving

z+1 = 'terug-kijktijd' = $a(t)/a(t_0)$

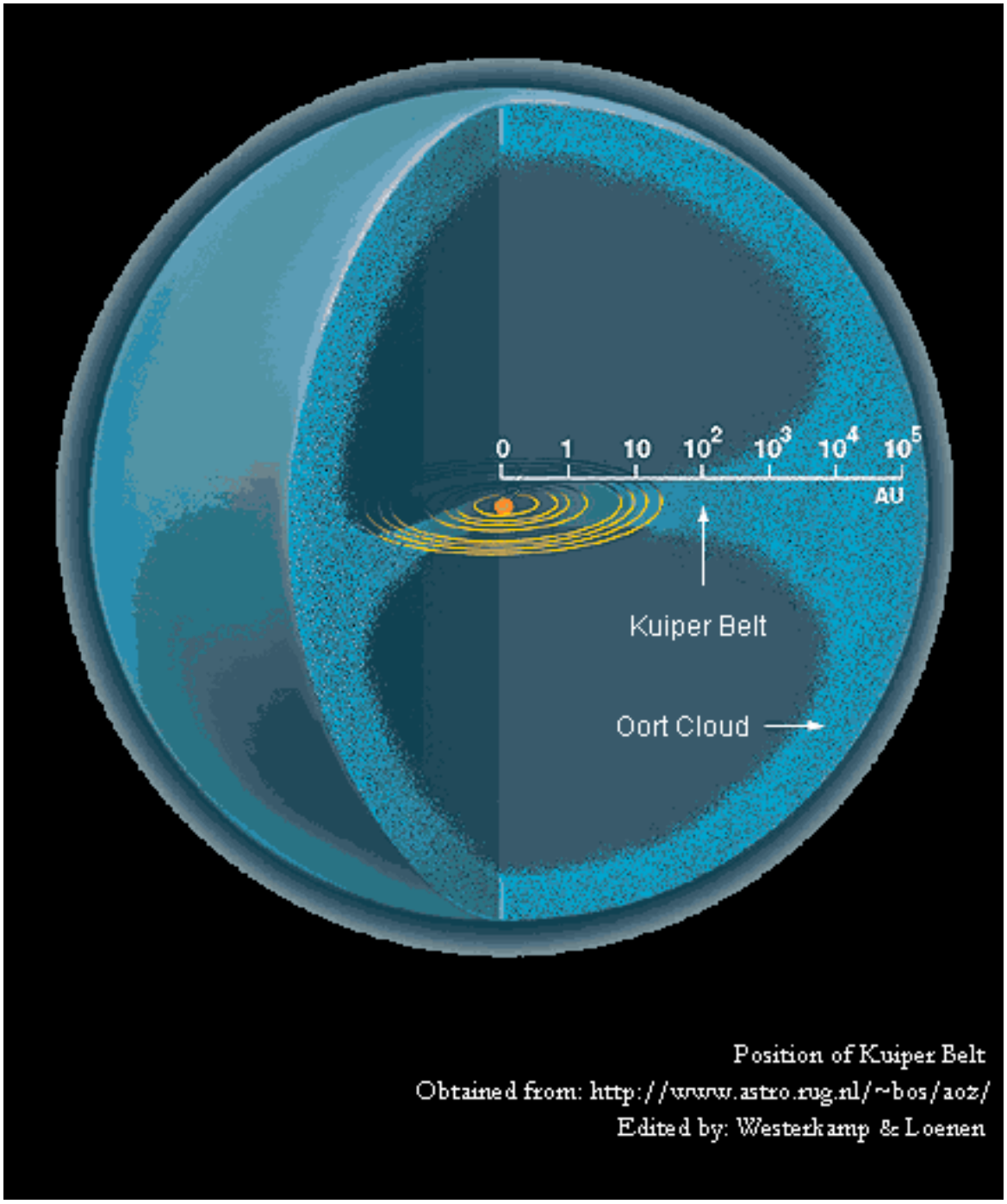
Fractionele grootte van het Heelal, i.e. op *z* = *5*: grootte heelal 1/6 van nu, etc.


(NOT A PLANET. NEENER NEENER.)
NEPTUNE
URANUS
ASTEROIDS
SATURN
LIFE
JUPITER
MARS
MERCURY
VENUS
SUN
HEY, A HEAPING BOWL OF SALT!
OPEN THE FRIDGE DOOR, HAL.
MOON
HUMAN ALTITUDE RECORD (APOLLO 13)
2ND PLACE: SNOOP DOGG
SPACE ELEVATOR— ONE OF THESE DAYS, PROMISE!
GEOSYNCHRONOUS ORBIT
GPS SATELLITES
IN RETROSPECT, THEY SHOULDN'T HAVE SENT A POET.
I HAVE NO IDEA HOW TO LAND.
INTERNATIONAL SPACE STATION
SPACE JUNK
OFFICIAL EDGE OF SPACE (100 km)
METEORS
1/10 ATM
HIGH-ALTITUDE BALLOONS
AIRLINERS
1/2 ATM
CORY DOCTOROW
SHUTTLE COLUMBIA LOST
EVEREST
HELICOPTERS (6,000 m)
WOO PYTHON!
800 m
1 km
BURJ DUBAI (~800m)
EIFFEL TOWER (325m)
KITES
GREAT PYRAMID (140m)
POP FLY
REDWOOD (115 m)
HEY, SQUIRREL!
TALLEST STILTS
OAK (20m)
BRACHIOSAUR (13m)
GIRAFFE (9m)
FOLKS

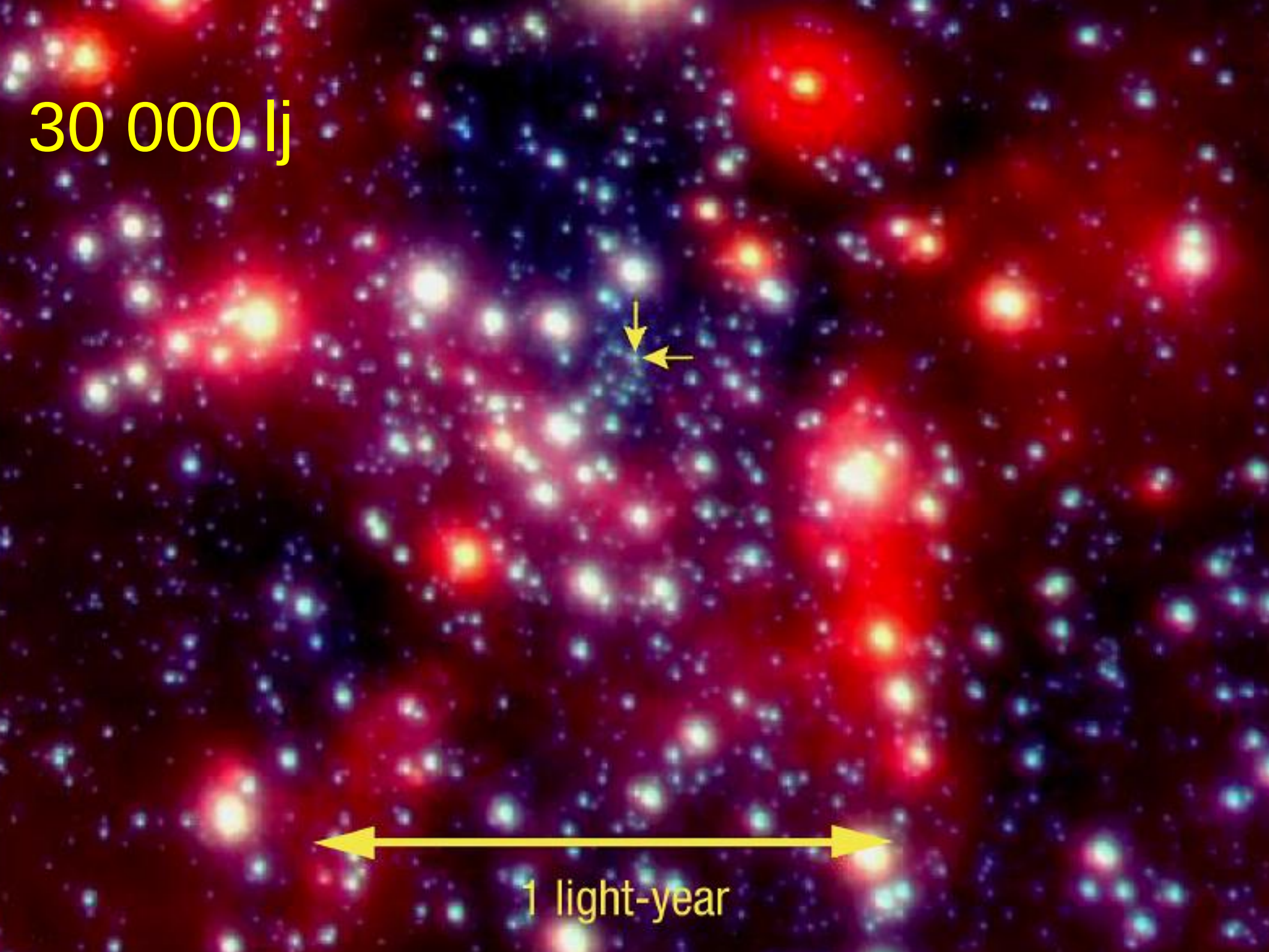

GREAT ATTRACTOR
ANTENNAE GALAXIES (COLLIDING)
ANDROMEDA
HOLY CRAP LOTS OF SPACE
ONE MILLION LIGHT YEARS
MAGELLANIC CLOUDS
EDGE OF GALAXY
GALACTIC CENTER
CRAB NEBULA
ORION NEBULA
HORSEHEAD NEBULA
RIGEL
THE PLEIADES, DUH.
ROMULAN NEUTRAL ZONE
EXPANDING SHELL OF RADIO TRANSMISSIONS
POLLUX
EDGE OF FEDERATION SECTOR 0-0-1
SIRIUS
ALPHA CENTAURI
BARNARD'S STAR
ONE PARSEC
ONE LIGHT-YEAR
OORT CLOUD (?)
BUPKIS
COMET WHICH WILL DESTROY EARTH IN LATE 2063
PIONEER 10
VOYAGER I
ERIS (ALL HAIL DISCORDIA!)
PLUTO (NOT A PLANET. NEENER NEENER.)
NEPTUNE
URANUS
ASTEROIDS
SATURN
LIFE
JUPITER

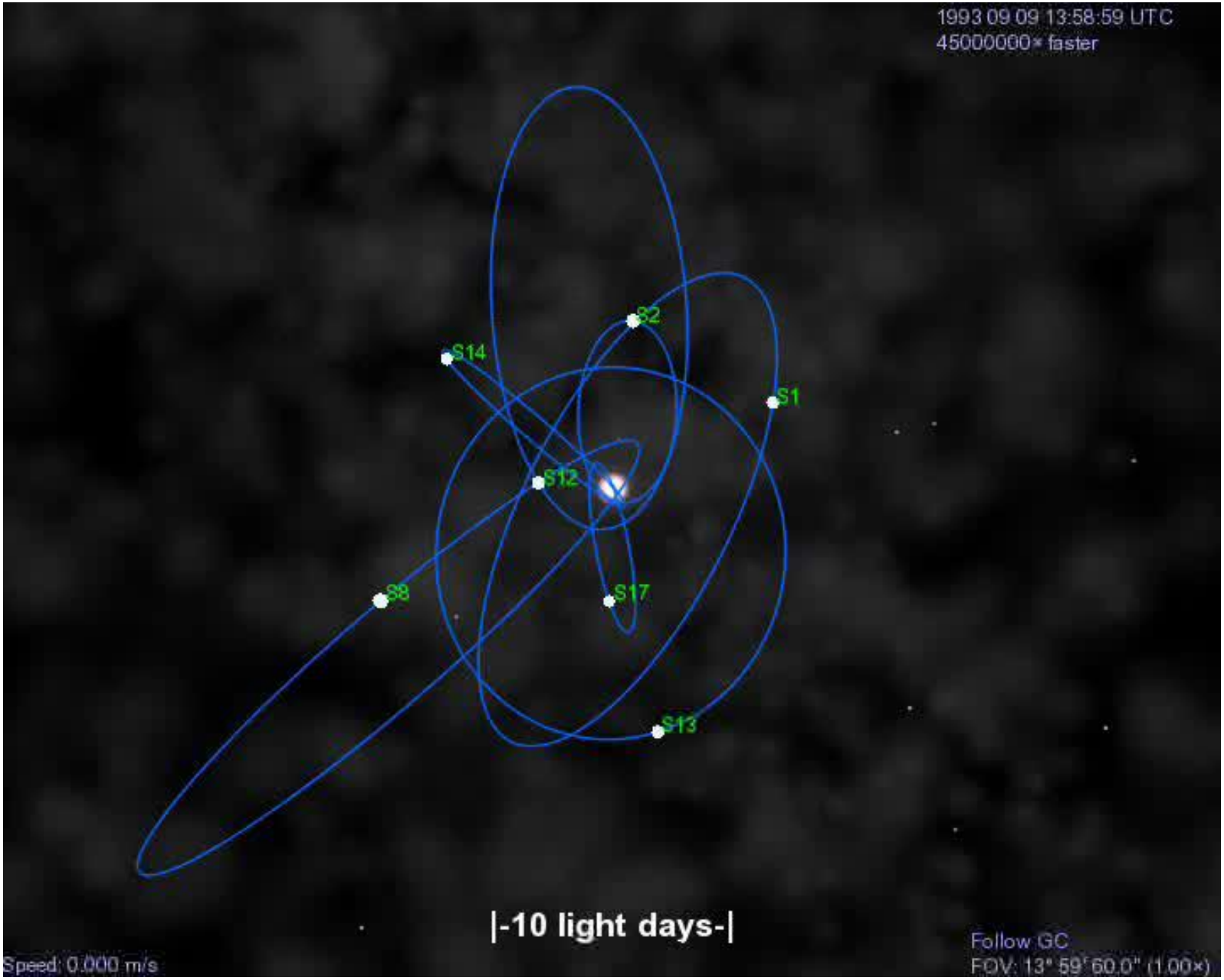

TOP OF OBSERVABLE UNIVERSE
(46 BILLION LIGHT-YEARS UP)
HUBBLE DEEP FIELD OBJECTS
ONE BILLION LIGHT-YEARS
ANTENNAE GALAXIES (COLLIDING)
ANDROMEDA
ONE MILLION LIG
MAGELLANIC CLOUDS
GALACTIC CENTER
CRAB NEBULA
ORION NEBULA
THE PLEIADES, DUH.
ROMULAN NEUTRAL ZONE
EXPANDING SHELL OF RADIO TRANSMISSIONS
POLLUX
EDGE OF FEDERATION SECTOR 0-0-1
SIRIUS
ALPHA CENTAURI
OORT CLOUD (?)
BUPKIS

1 lj

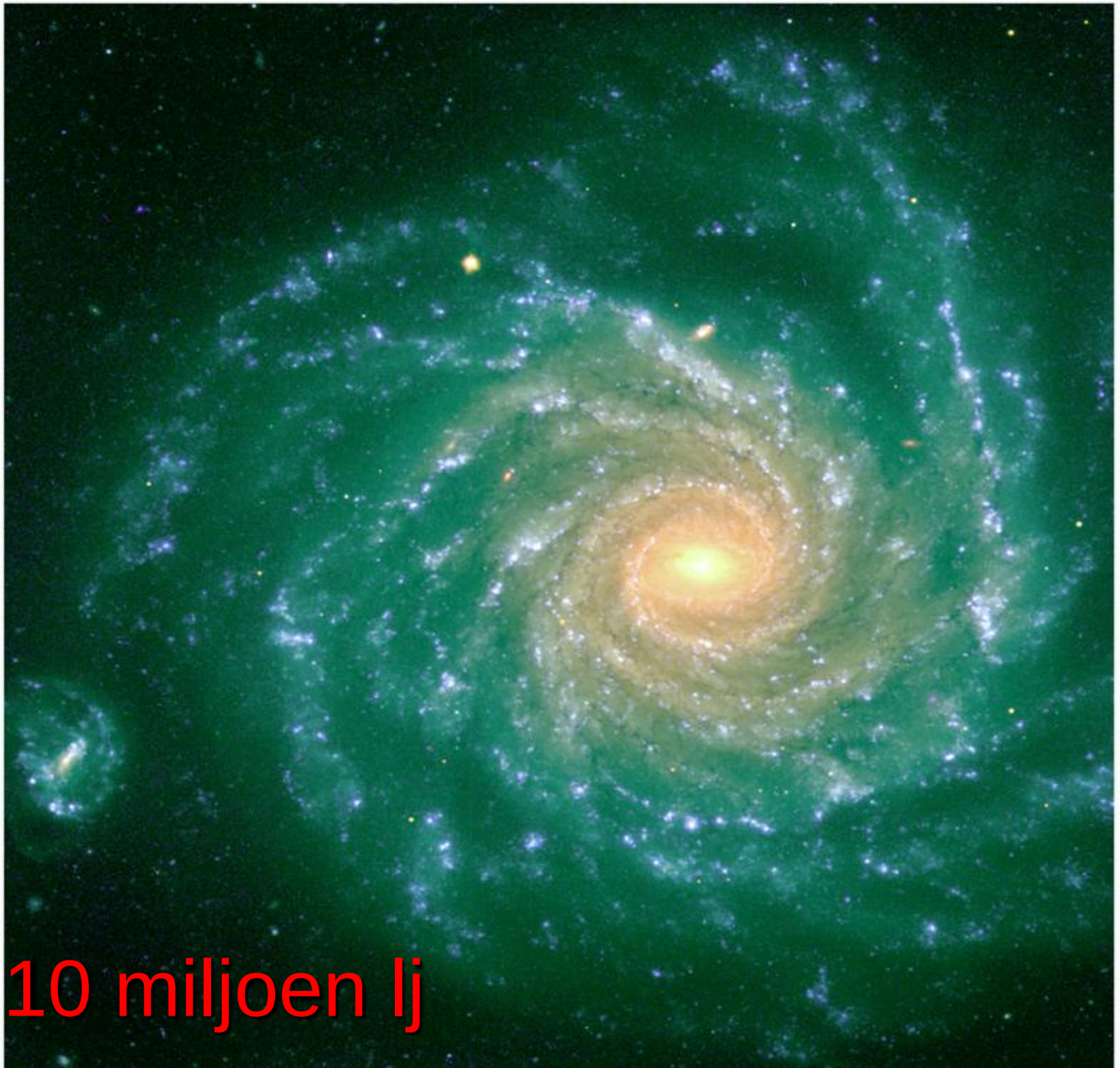

0
1
10
10^2
10^3
10^4
10^5
AU
Kuiper Belt
Oort Cloud
Position of Kuiper Belt
Obtained from: http://www.astro.rug.nl/~bos/aoz/
Edited by: Westerkamp & Loenen

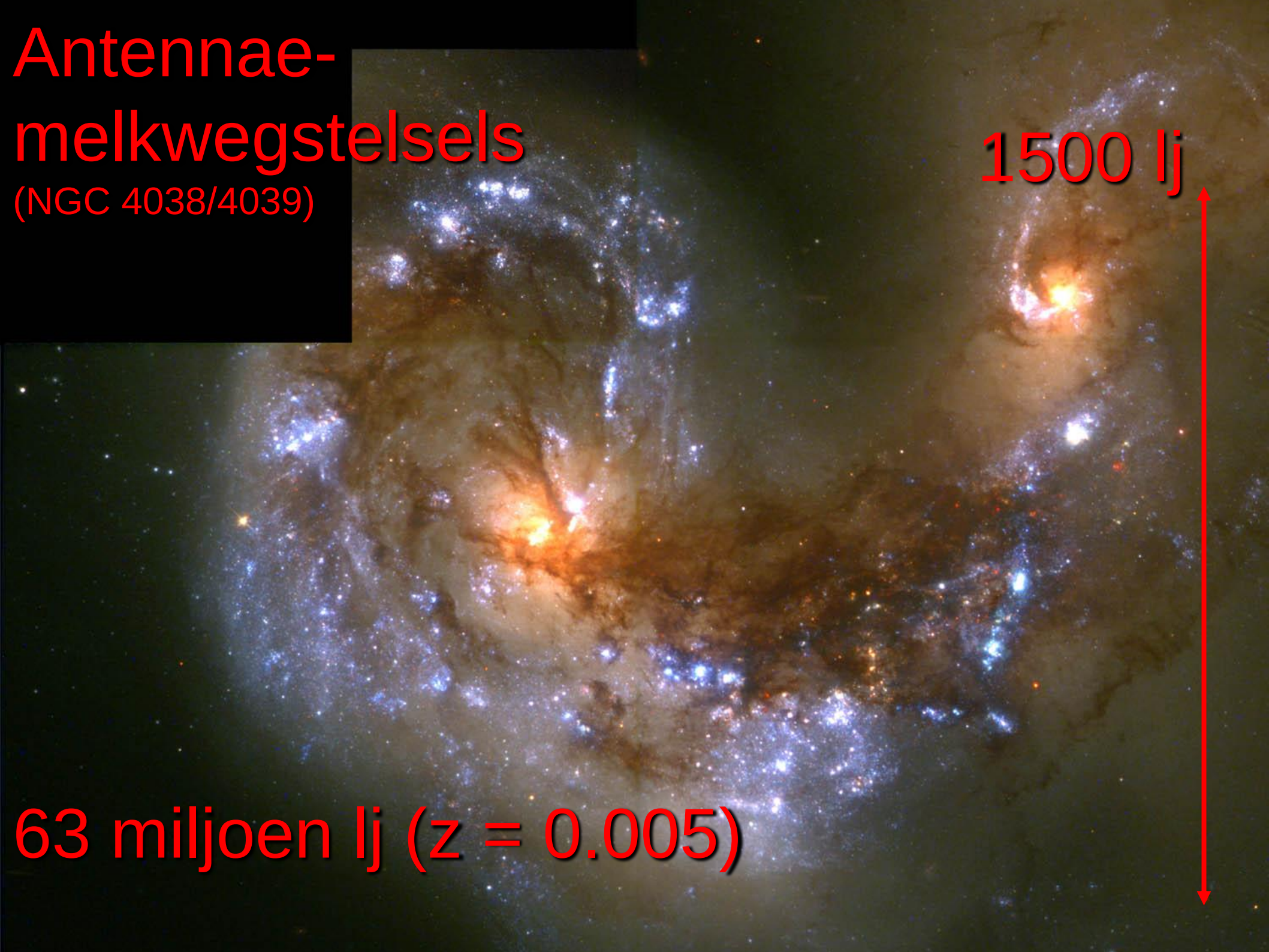

100 lj

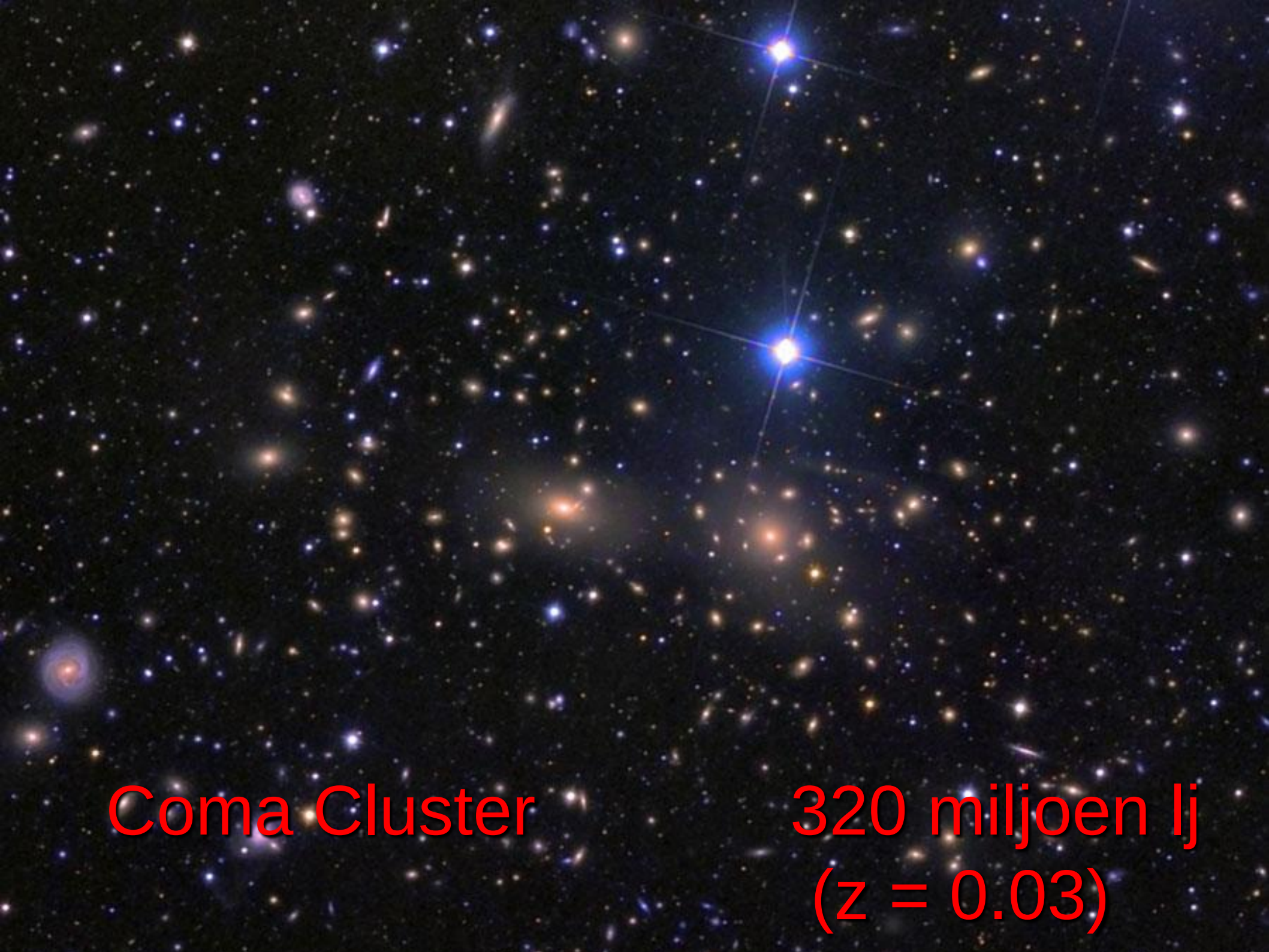

30 000 lj
1 light-year


1993 09 09 13:58:59 UTC
45000000× faster
S2
S14
S1
S12
S8
S17
S13
|-10 light days-|
Speed: 0.000 m/s
Follow GC
FOV: 13' 59' 60.0" (1.00×)

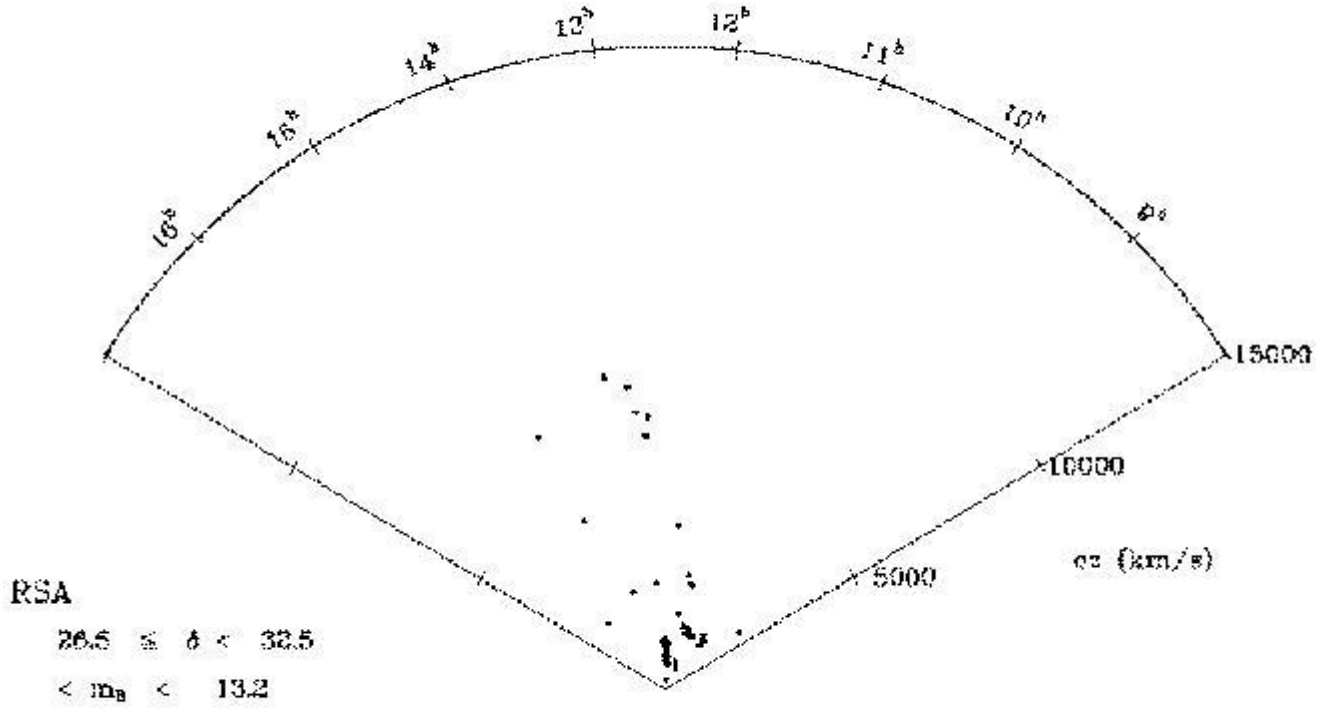
Andromeda, ruim 2 miljoen lj

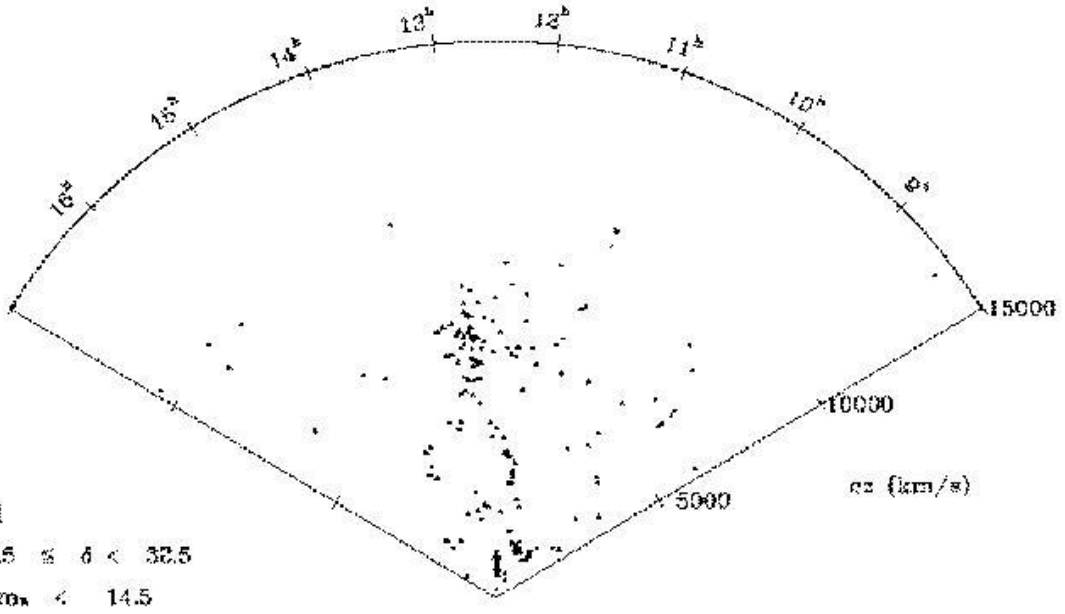

10 miljoen lj


Antennae-
melkwegstelsels
(NGC 4038/4039)
1500 lj
63 miljoen lj (z = 0.005)


Coma Cluster
320 miljoen lj
(z = 0.03)

Jaren ’70: surveys

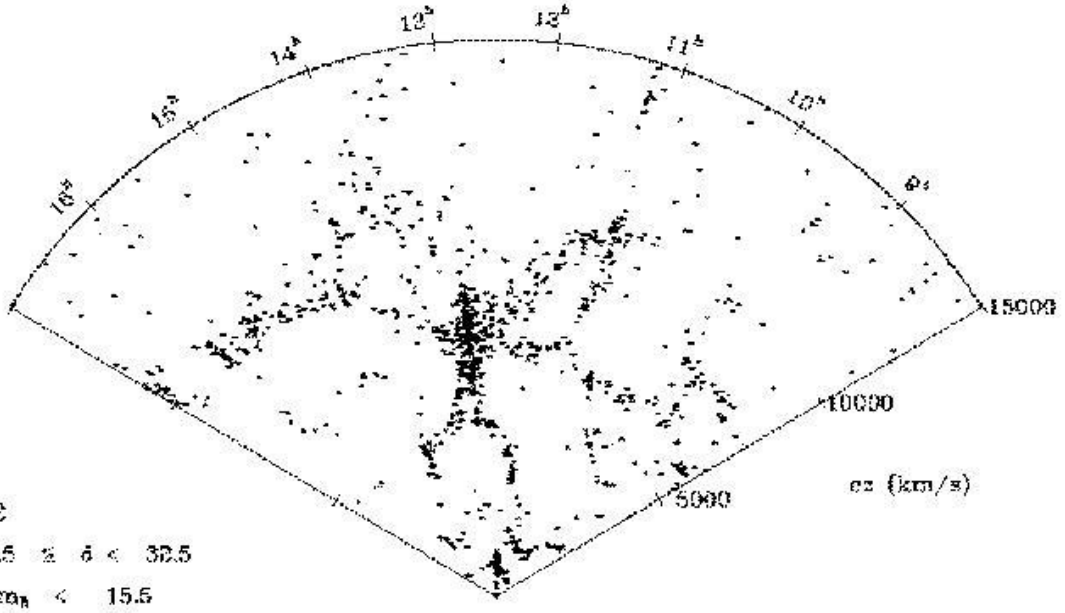




CIA 1

26.5 ≤ δ < 32.5

< m_R < 14.5

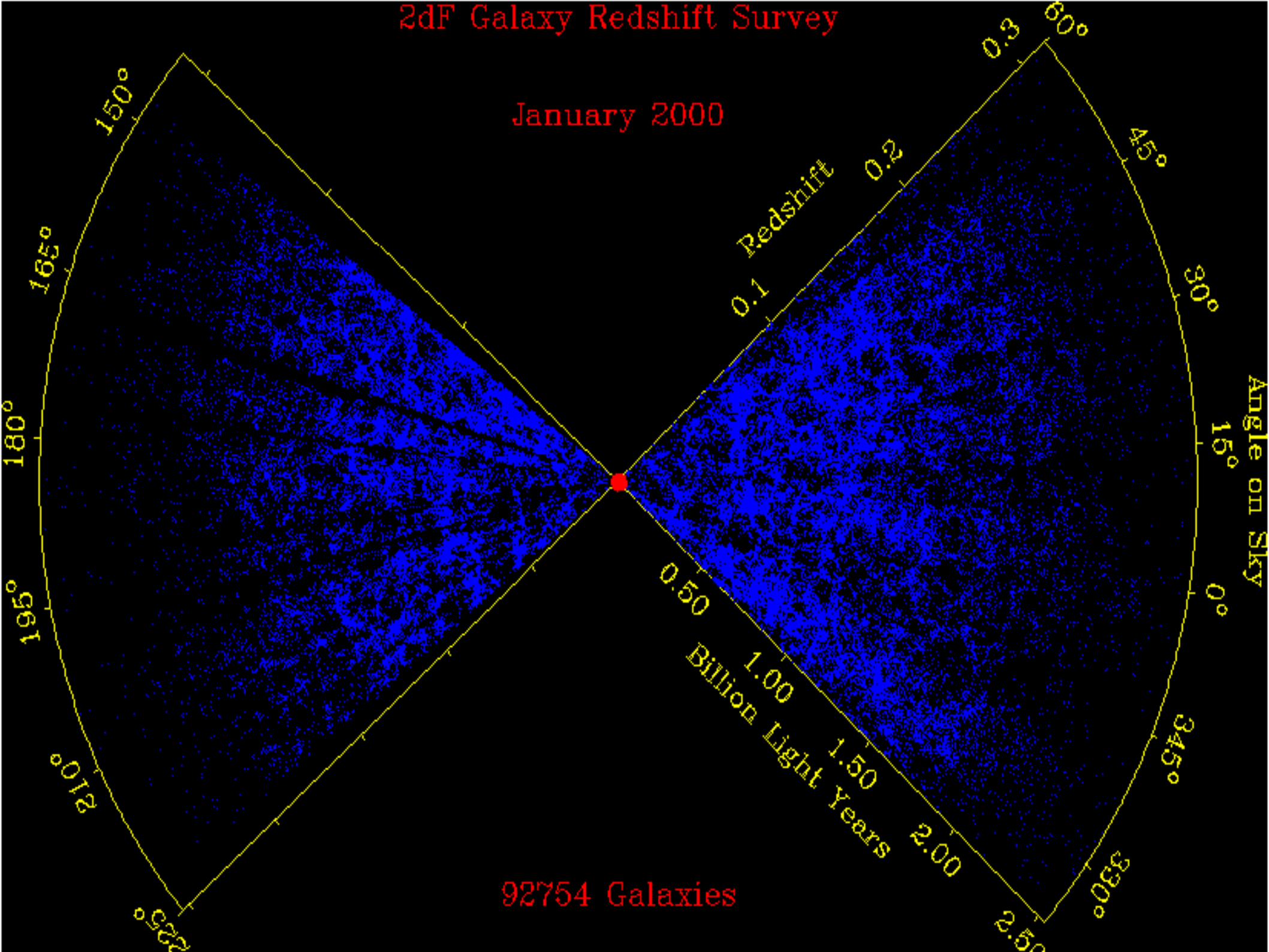


CIA 2

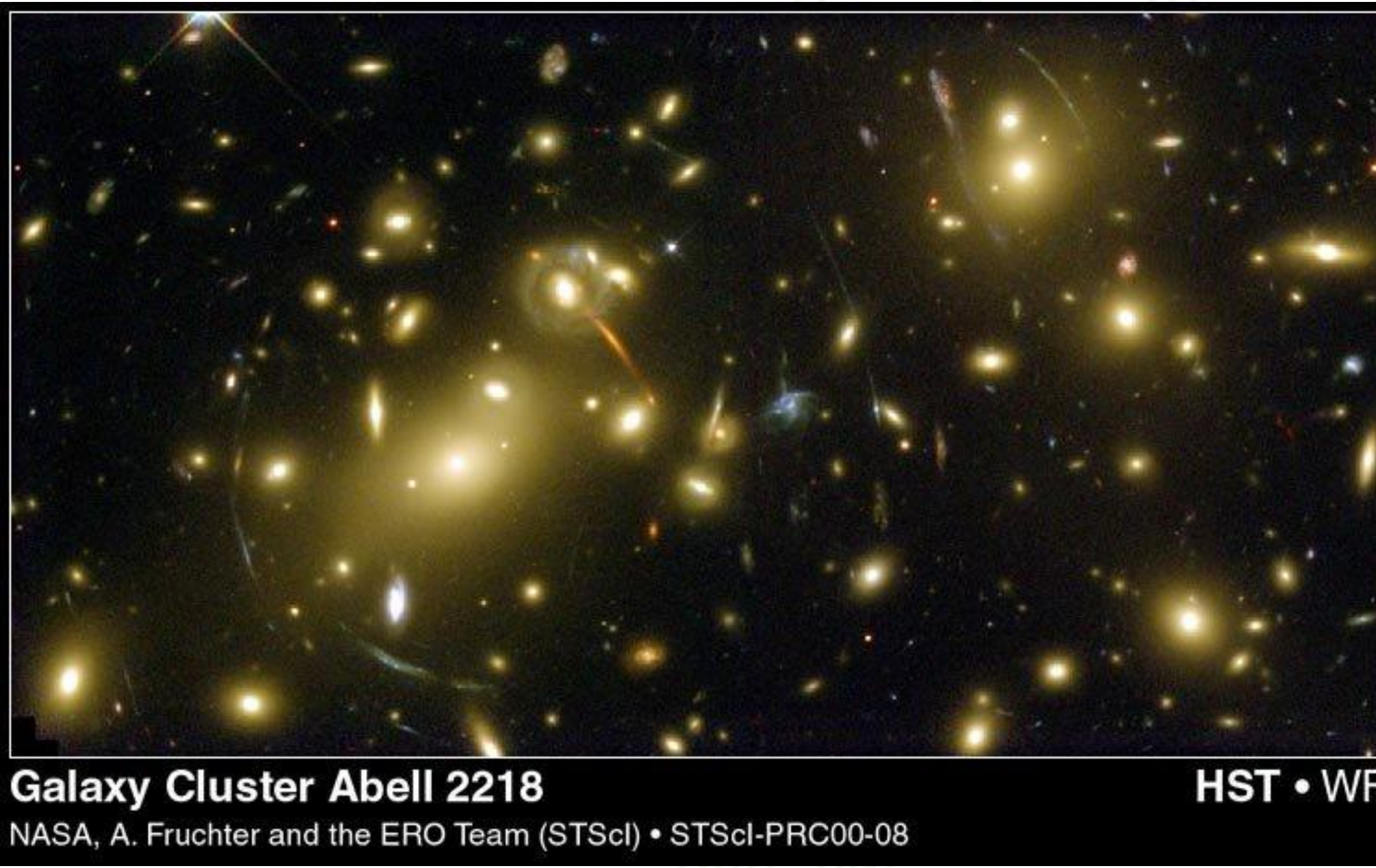
26.5 ≤ δ < 32.5

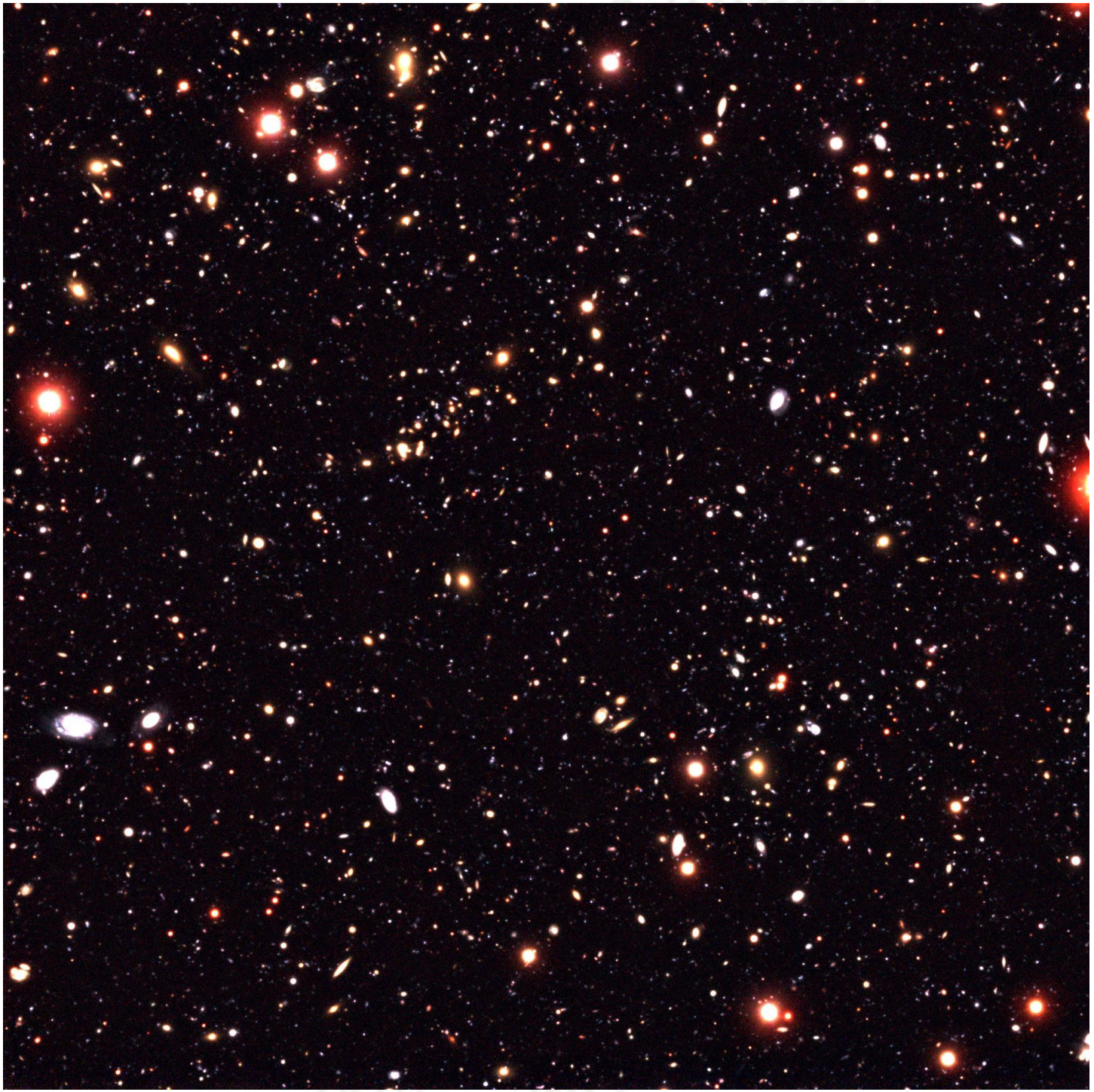
< m_R < 15.5

Schuimachtige structuur!


2dF Galaxy Redshift Survey
January 2000
92754 Galaxies
Redshift
0.1
0.2
0.3
0.50
1.00
1.50
2.00
Billion Light Years
Angle on Sky
0°
15°
30°
45°
60°
150°
165°
180°
195°
210°
330°
345°

Z = 0.17


Galaxy Cluster Abell 2218
HST • WF
NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

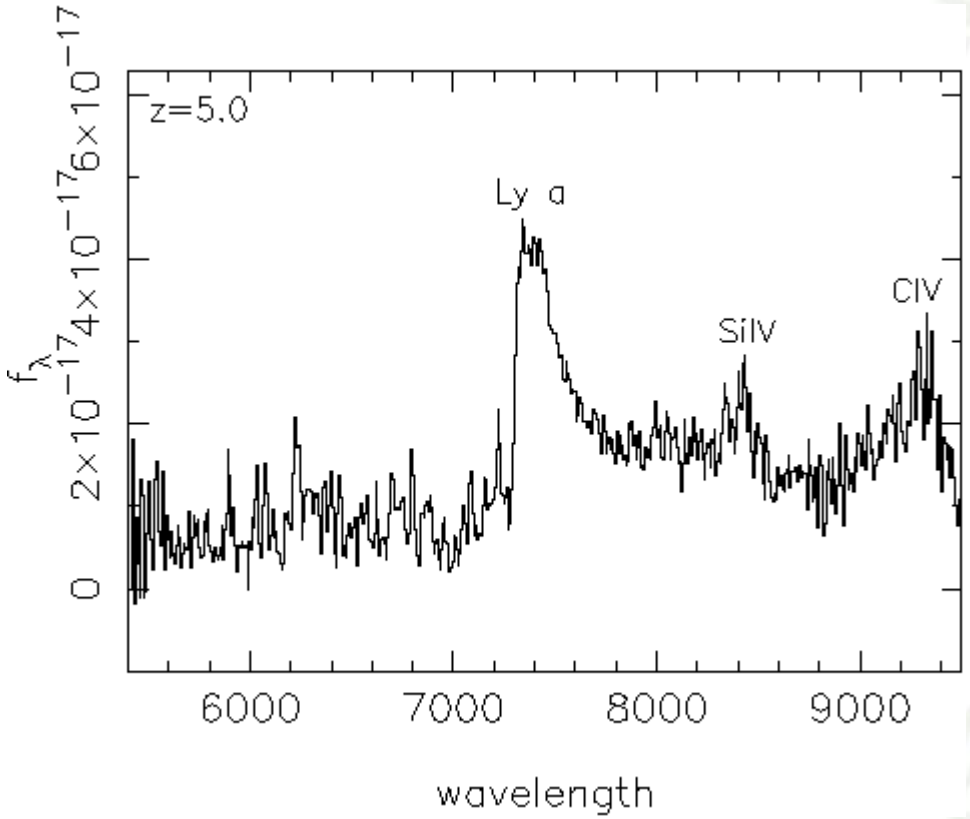


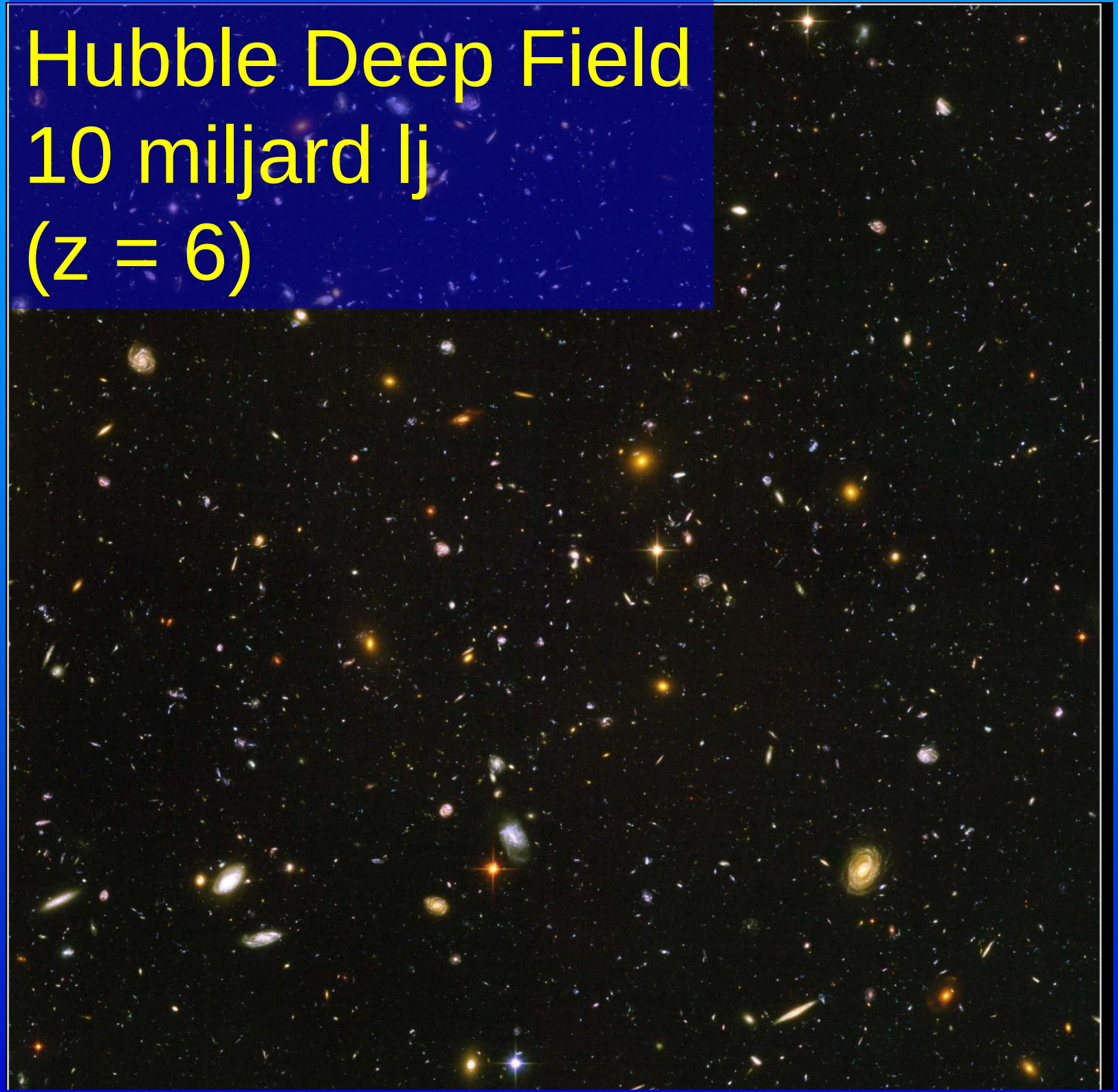
z = 0.7

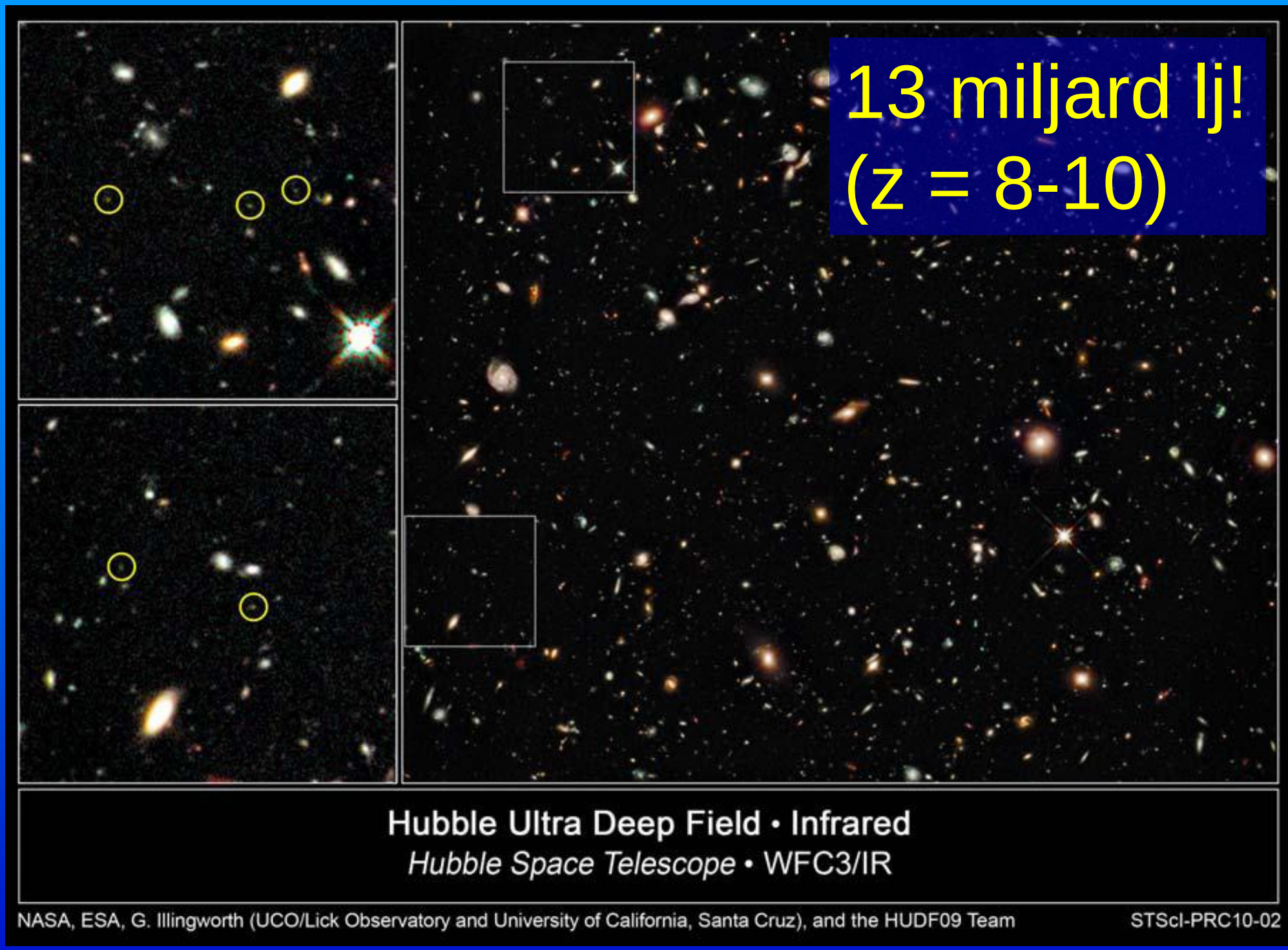
Sloan Digital Sky Survey

z = 4.75 Quasar

z = 5.0 Quasar

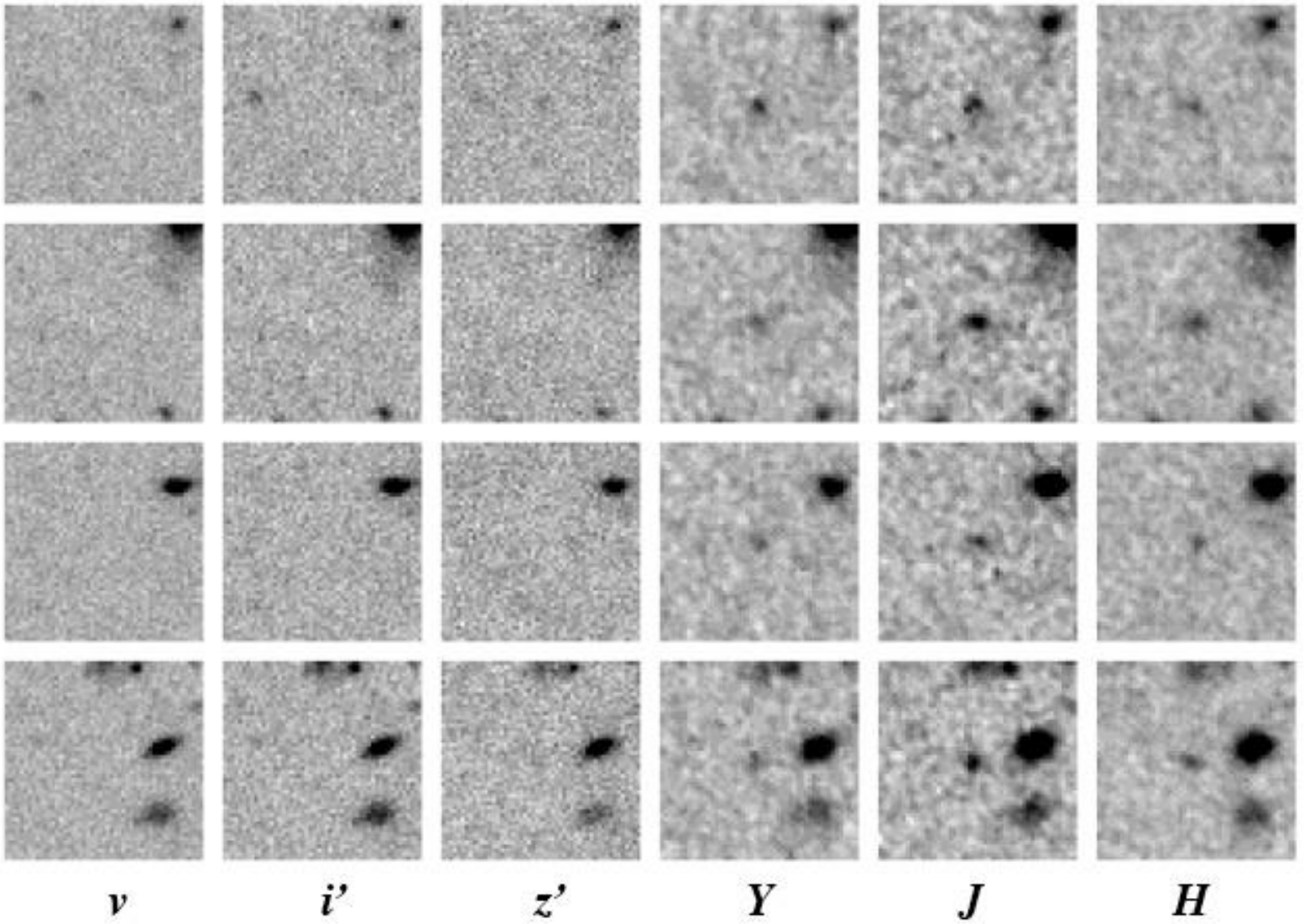


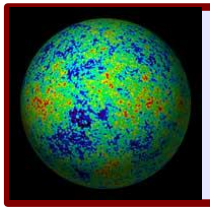

Hubble Deep Field
10 miljard lj
(z = 6)


13 miljard lj!
(z = 8-10)
Hubble Ultra Deep Field • Infrared
Hubble Space Telescope • WFC3/IR
NASA, ESA, G. Illingworth (UCO/Lick Observatory and University of California, Santa Cruz), and the HUDF09 Team
STScI-PRC10-02


19
20
21
22
23
24
25
26
Brightness [mag AB]

J drop outs





Hoe ver kunnen we terug?

- Terug in tijd: heelal steeds heter

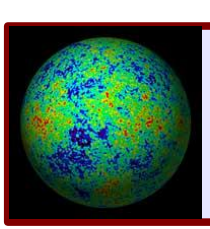
- Gamow, Alpher (1948)
  - Mogelijke verklaring elementen He etc. (temperatuur voor H fusie ~10^9 K) → volgende week

  - Bij temperatuur ~10 000 K → waterstof ioniseert ($p + e^-$)
  - Daarvoor: straling “gevangen” door verstrooiing met electronen
  - Daarna: straling beweegt vrij door Heelal
  - Door uitzetting Heelal worden fotonen “langer”. Temperatuur daalt, nu T ~ 5K

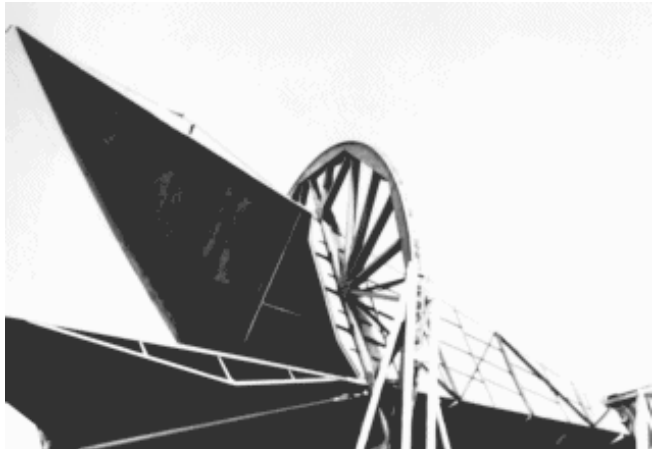
- Nog zichtbaar?
  - Jaren 60: Dicke, Peebles (Princeton) gaan op zoek

Gamow

Alpher



1964 Penzias & Wilson



high pressure, such as the zero-mass scalar, capable of speeding the universe through the period of helium formation. To have a closed space, an energy density of 2×10^{-29} gm/cm^3 is needed. Without a zero-mass scalar, or some other "hard" interaction, the energy could not be in the form of ordinary matter and may be presumed to be gravitational radiation (Wheeler 1958).

One other possibility for closing the universe, with matter providing the energy content of the universe, is the assumption that the universe contains a net electron-type neutrino abundance (in excess of antineutrinos) greatly larger than the nucleon abundance. In this case, if the neutrino abundance were so great that these neutrinos are degenerate, the degeneracy would have forced a negligible equilibrium neutron abundance in the early, highly contracted universe, thus removing the possibility of nuclear reactions leading to helium formation. However, the required ratio of lepton to baryon number must be $> 10^9$.

We deeply appreciate the helpfulness of Drs. Penzias and Wilson of the Bell Telephone Laboratories, Crawford Hill, Holmdel, New Jersey, in discussing with us the result of their measurements and in showing us their receiving system. We are also grateful for several helpful suggestions of Professor J. A. Wheeler.

R. H. Dicke

A MEASUREMENT OF EXCESS ANTENNA TEMPERATURE AT 4080 Mc/s

Measurements of the effective zenith noise temperature of the 20-foot horn-reflector antenna (Crawford, Hogg, and Hunt 1961) at the Crawford Hill Laboratory, Holmdel, New Jersey, at 4080 Mc/s have yielded a value about 3.5° K higher than expected. This excess temperature is, within the limits of our observations, isotropic, unpolarized, and

——— 1964, in *Relativity, Groups and Topology*, ed C. DeWitt and B. DeWitt (New York: Gordon & Breach).
Zel'dovich, Ya. B. 1962, *Soviet Phys.—J.E.T.P.*, **14**, 1143.

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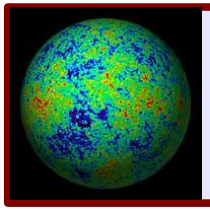
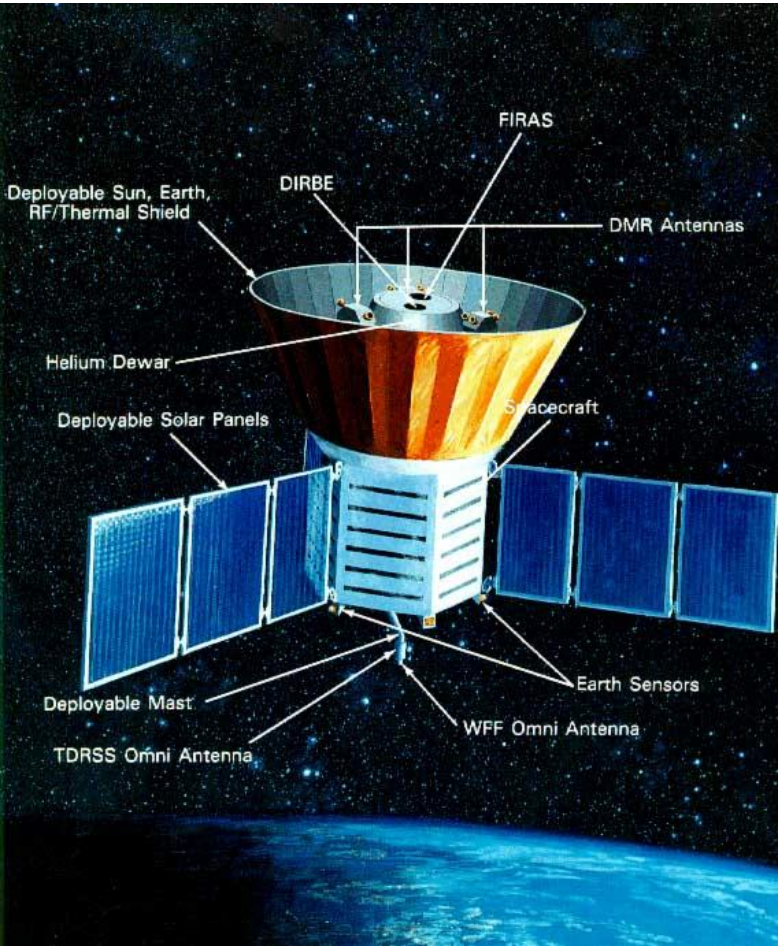
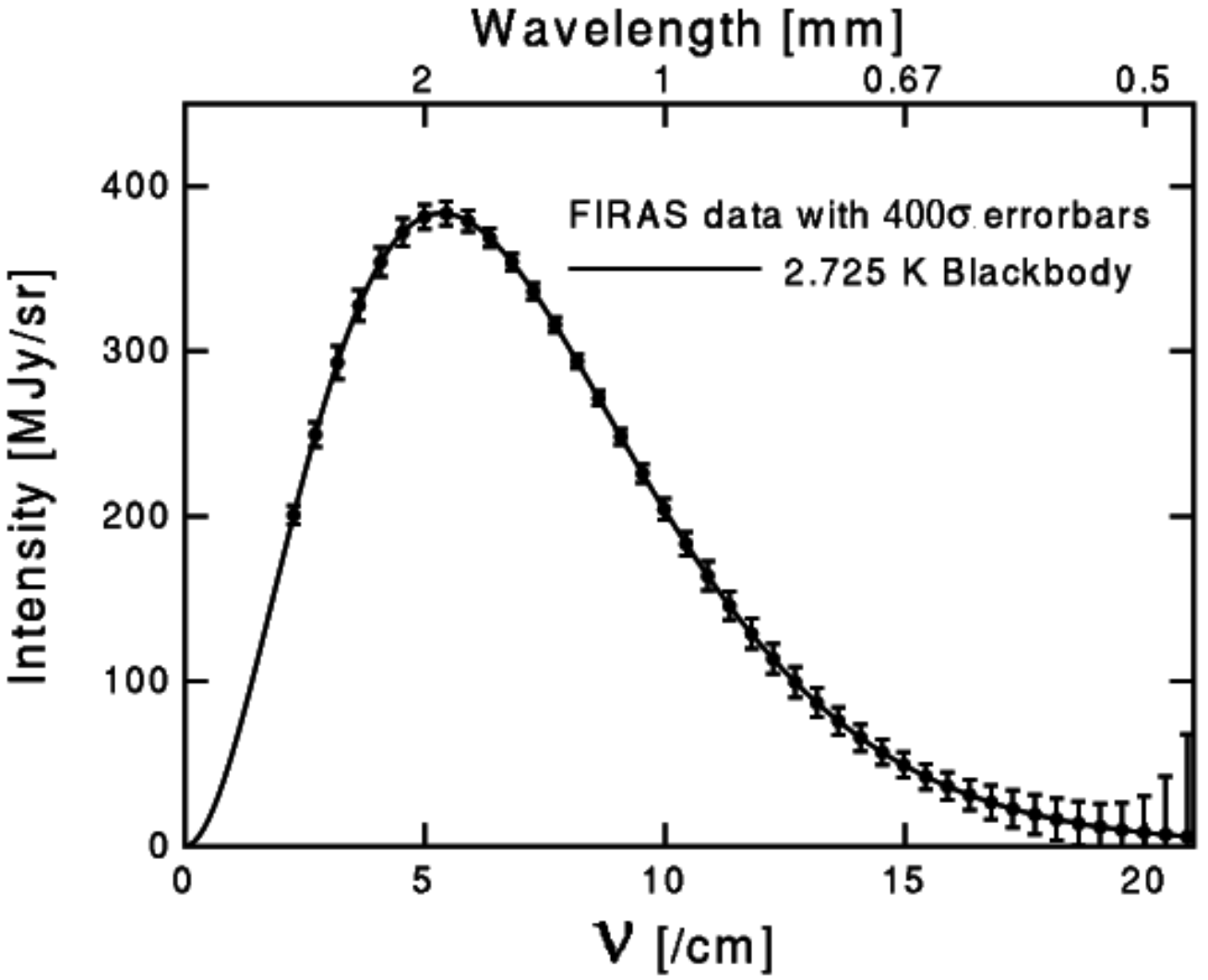
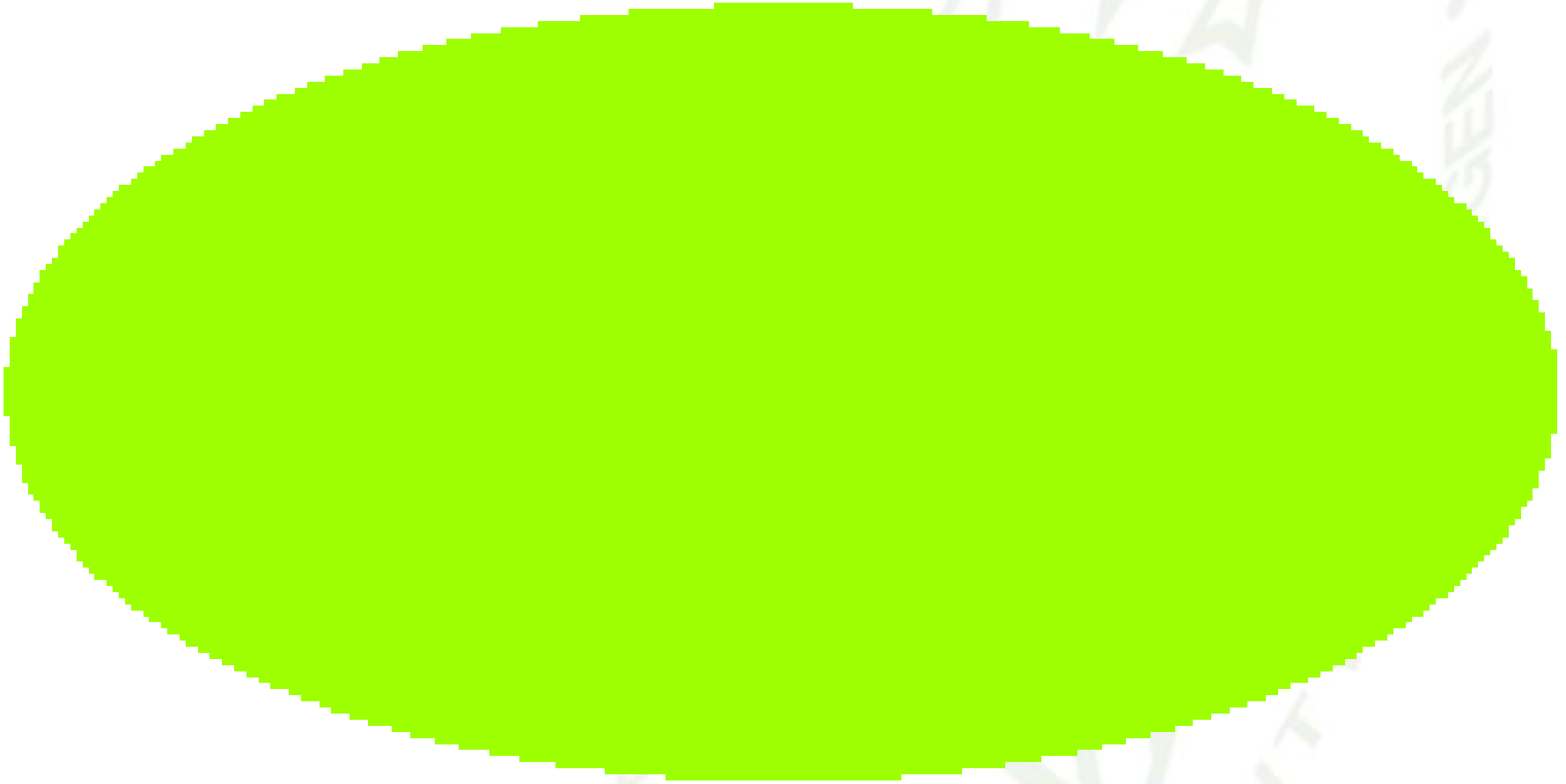


Jaren ’90: COBE



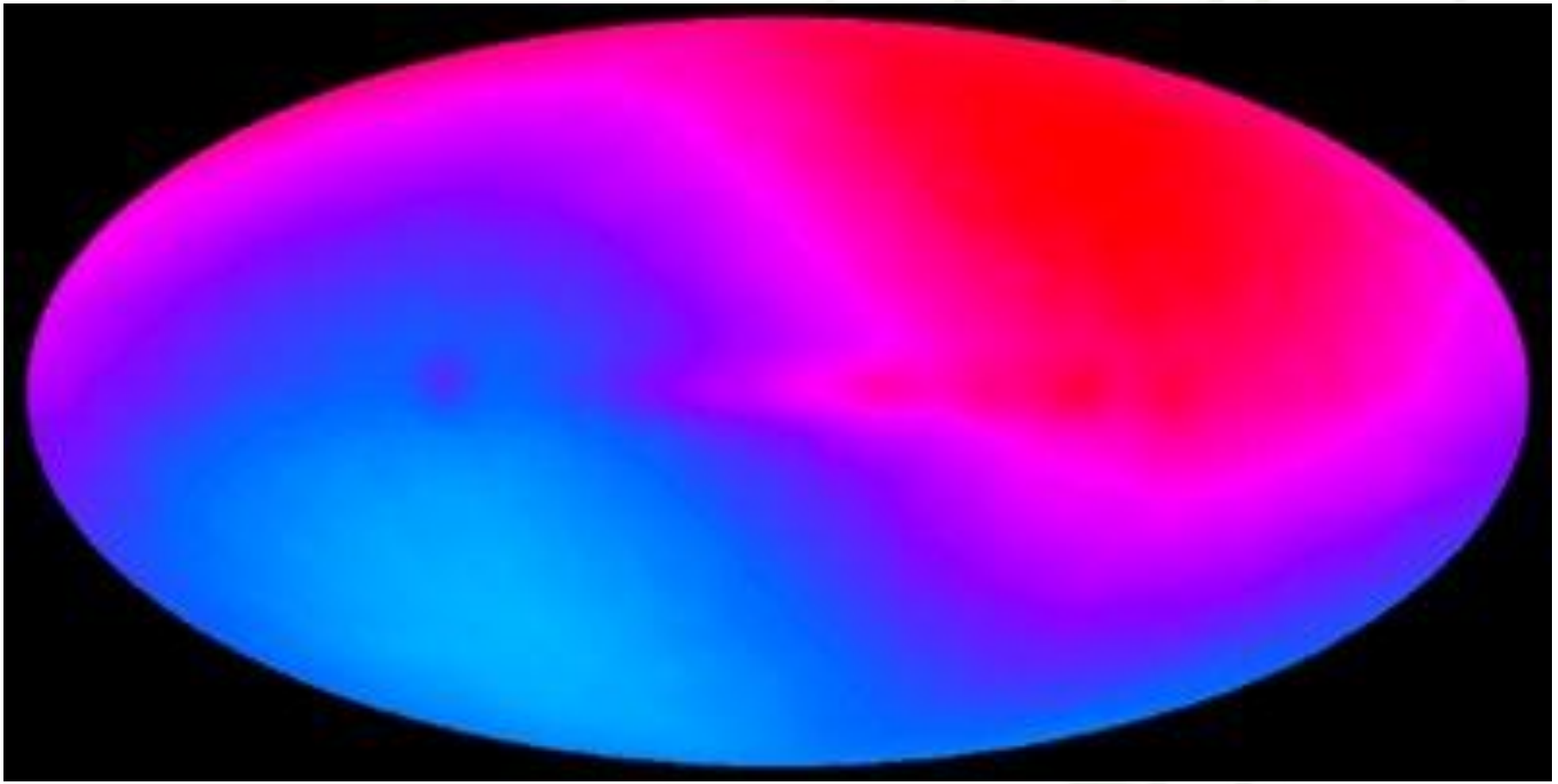


Anisotropie in CMB



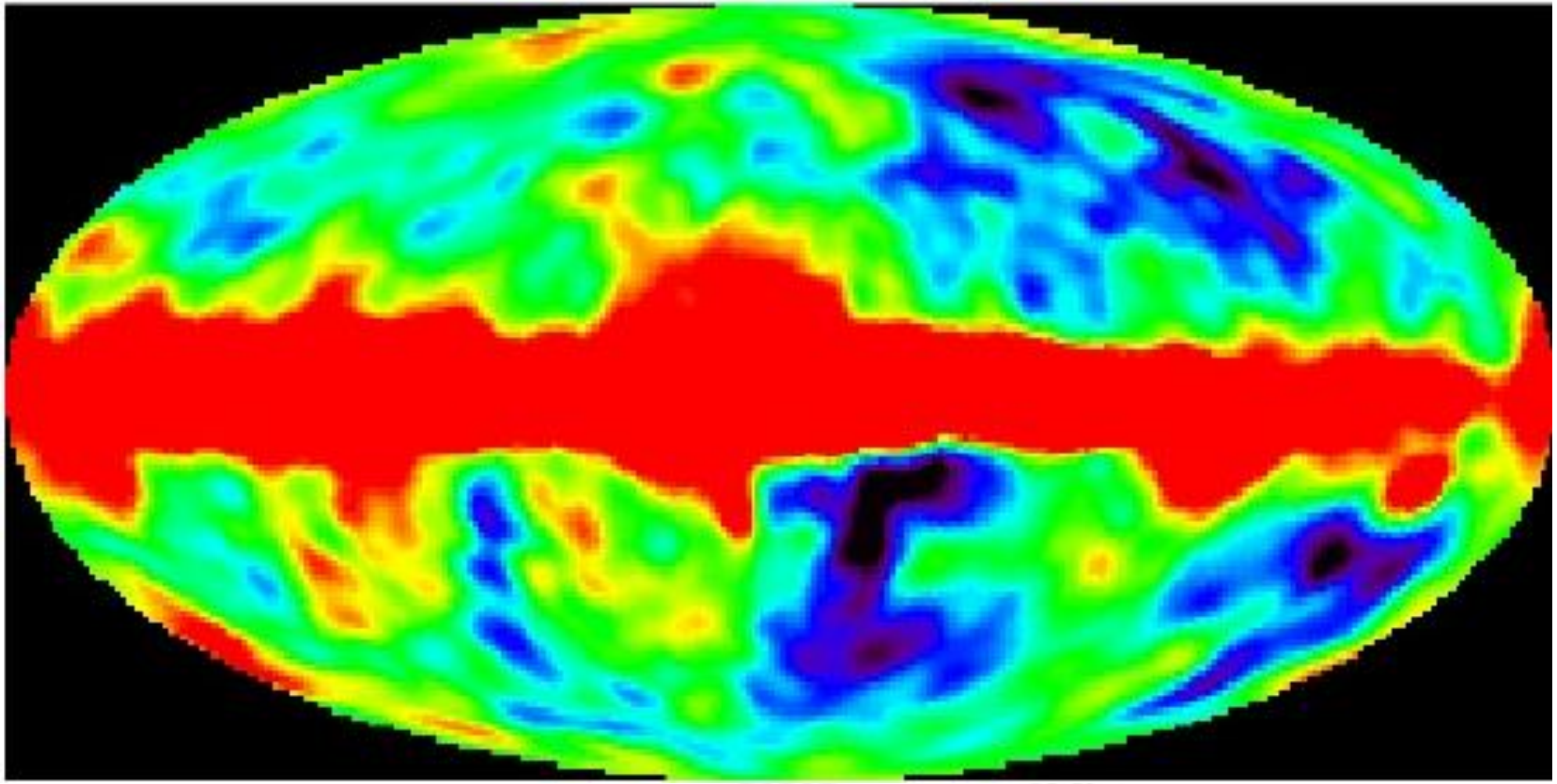
Temperatuur van de CMB (Cosmic Microwave Background**) aan de hemel in kleurcode: 0 K is blauw en 4 K is rood (COBE). Het melkwegvlak loopt horizontaal en het centrum van de figuur is in de richting van het centrum van ons Melkwegstelsel.**

Dipoolanisotropie: $\Delta T = \pm 0{,}00335$ K



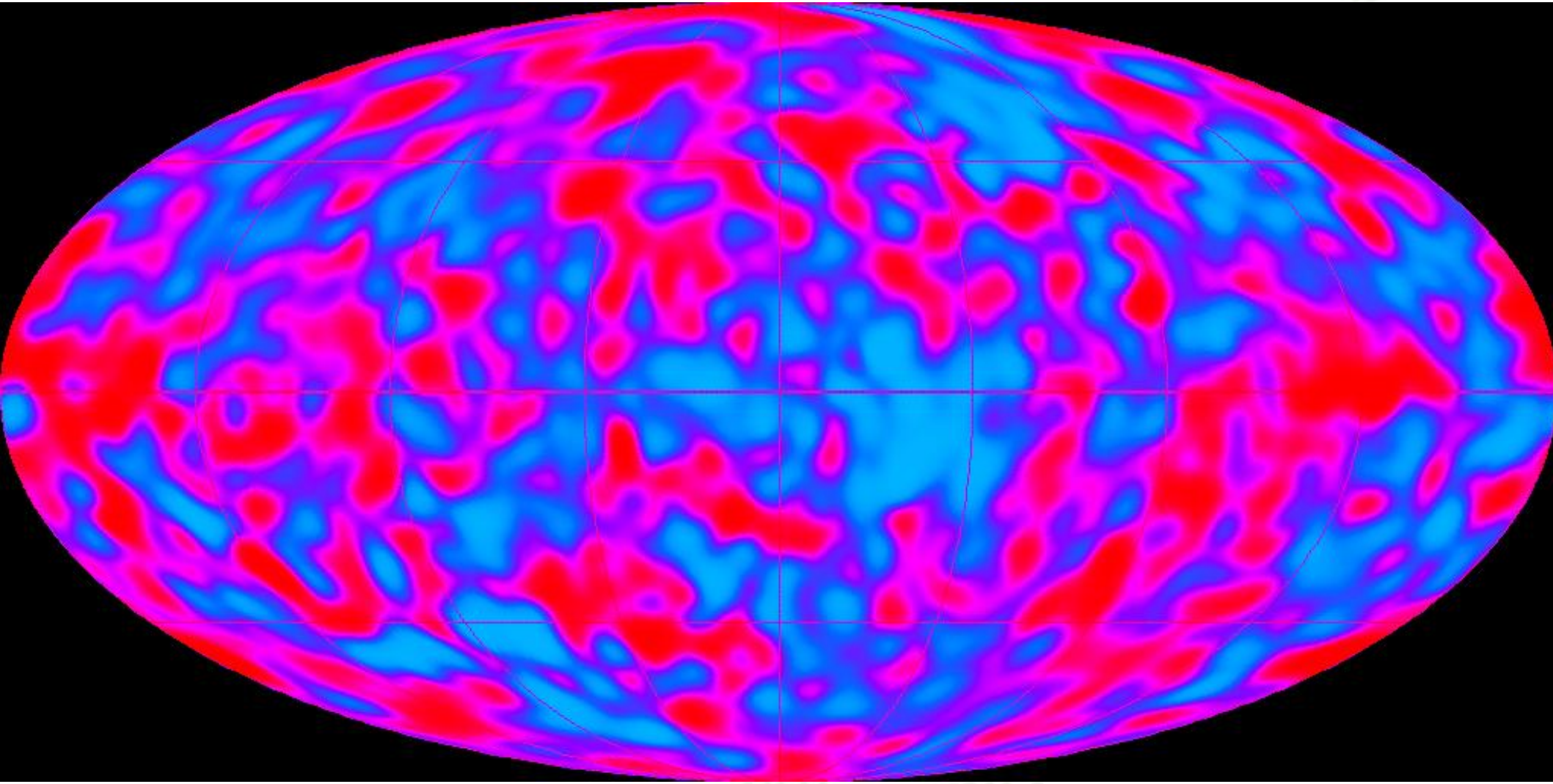
Fluctuaties in de CMB-temperatuur aan de hemel op een schaal tussen 2,724 K (blauw) en 2.732 K (rood) met COBE.

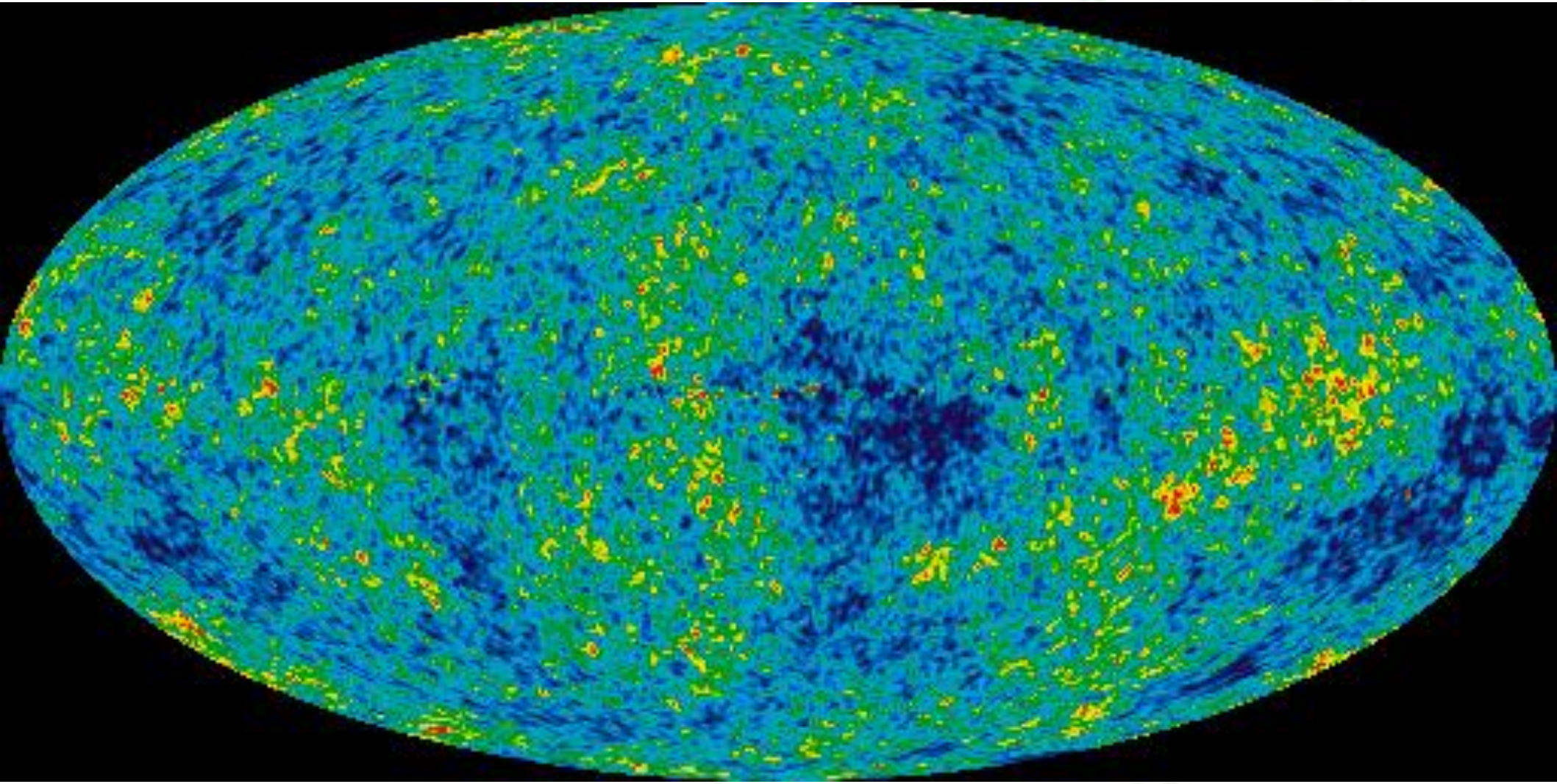
Temperatuurfluctuaties na aftrekken van de dipoolcomponent:
van blauw naar rood $\Delta T = 0{,}000018$ K



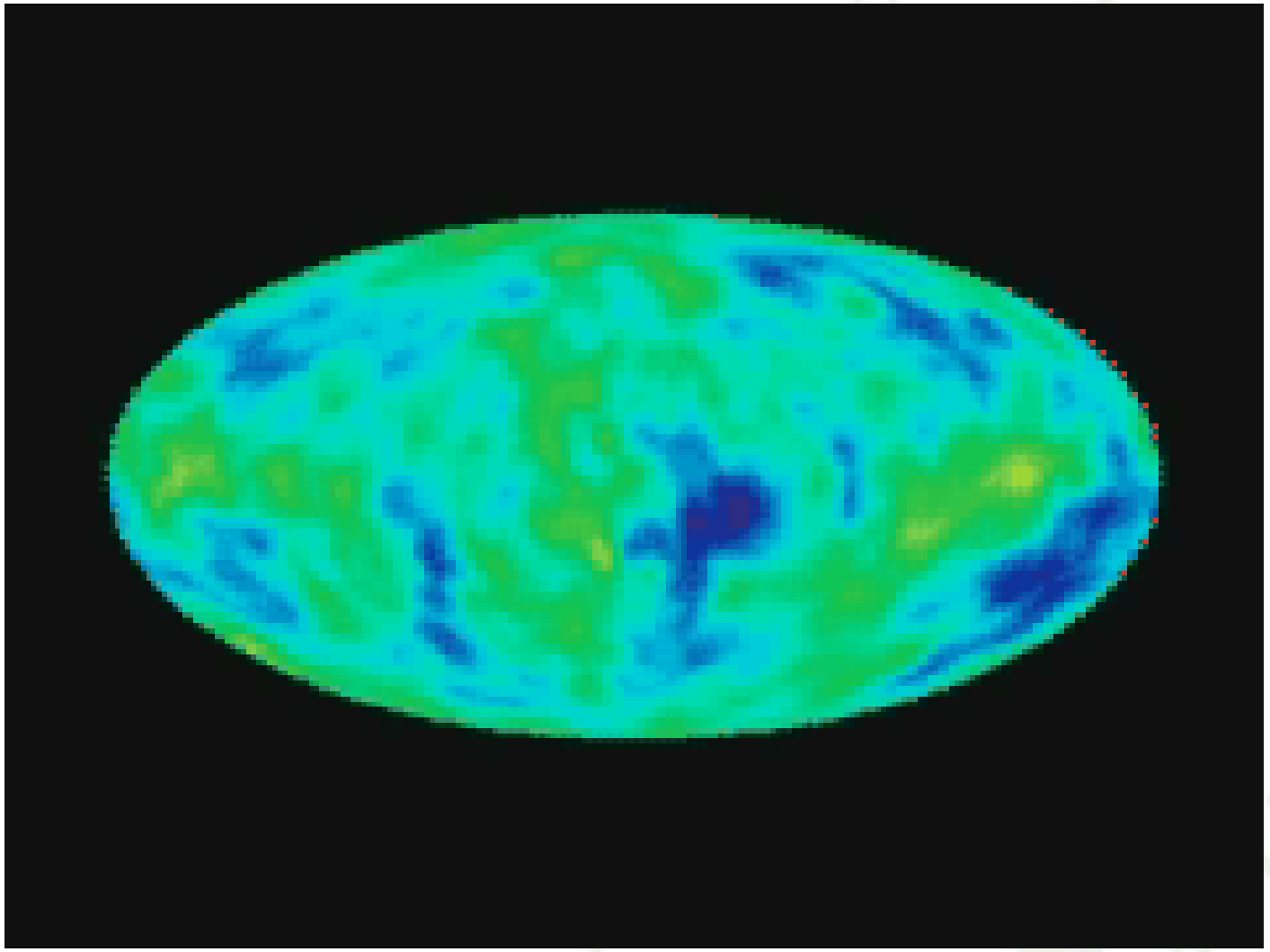
Fluctuaties in achtergrondstraling!

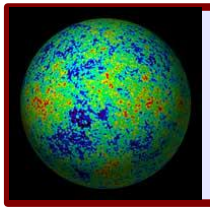
Na aftrek van dipoolcomponent en galactische straling van stof (termisch), heet gas (vrij-vrij),





WMAP

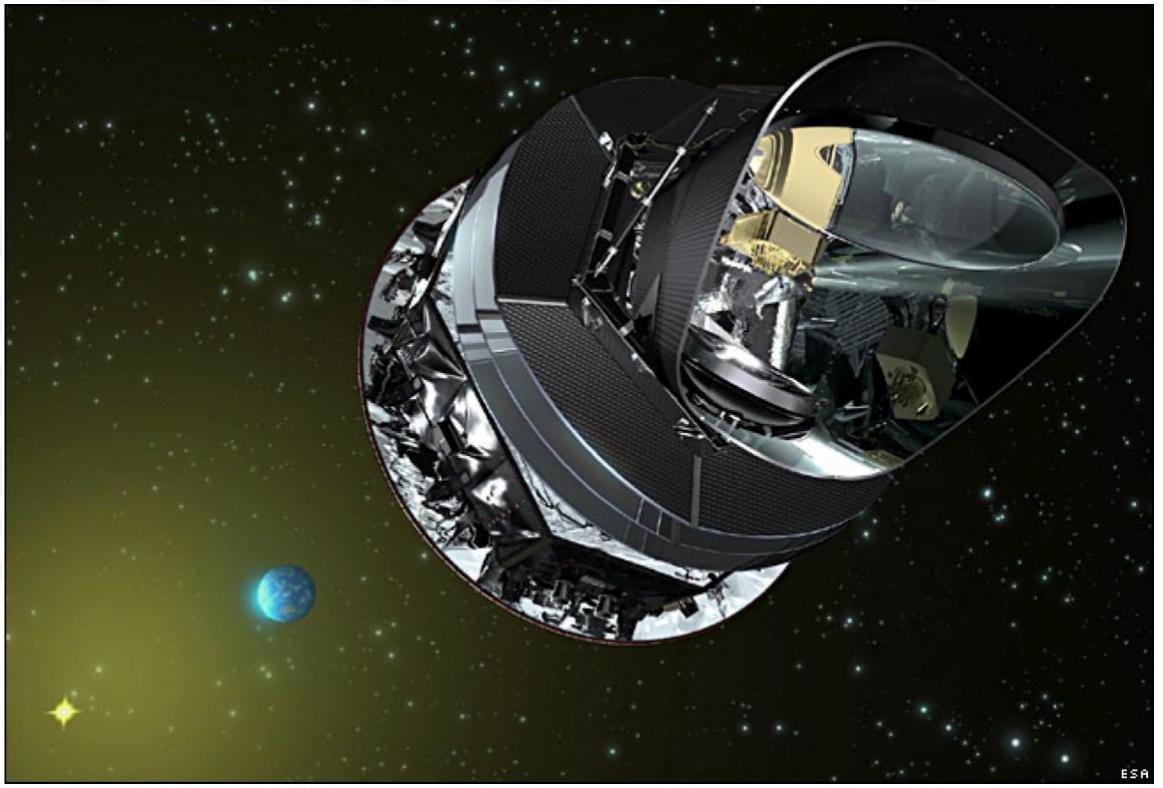




Planck

- Nieuwe ESA satelliet
- Gelanceerd in 2009 (samen met Herschel)

•Gaat nog gedetailleerdere kaart van de achtergrondstraling maken



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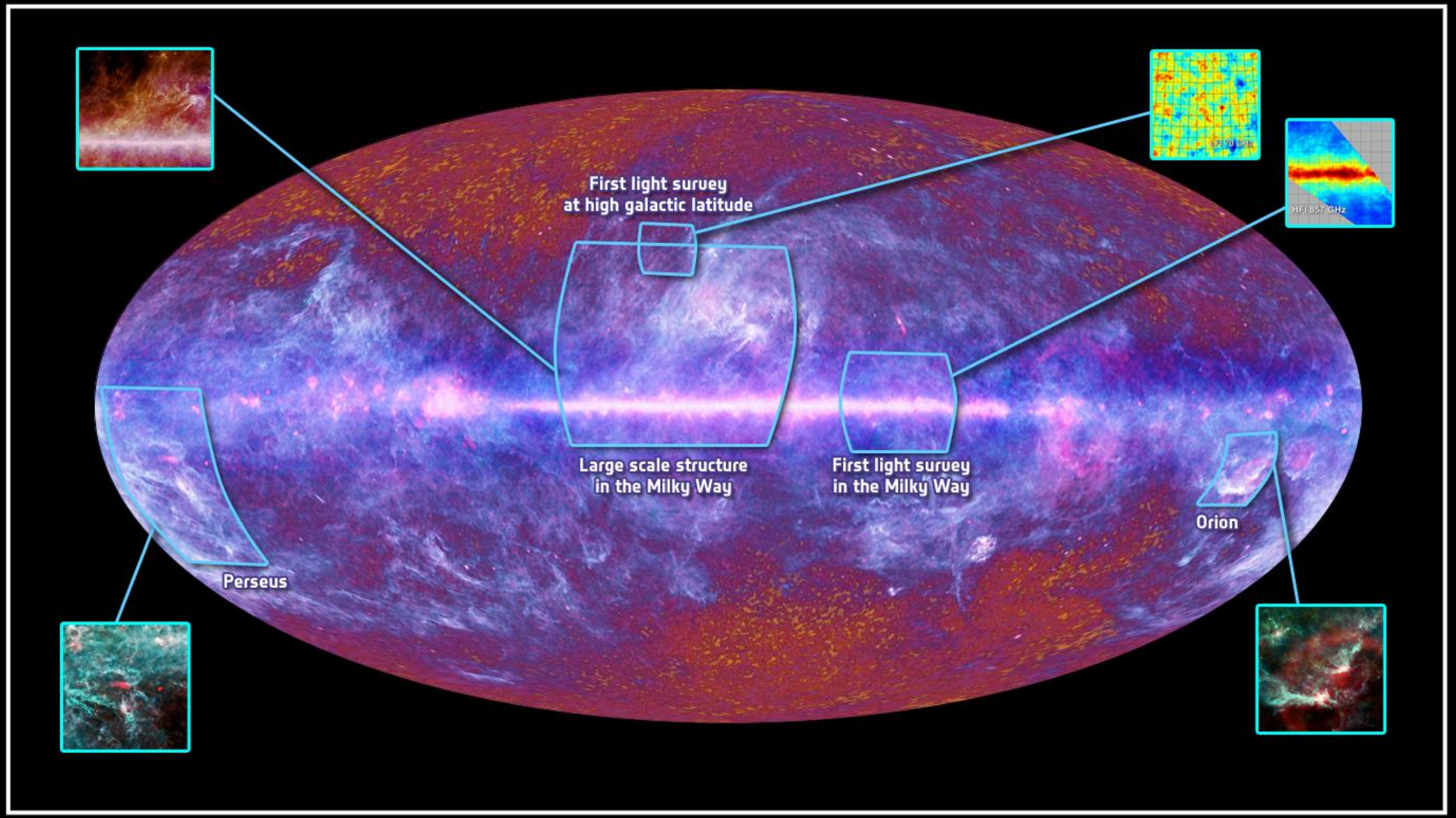
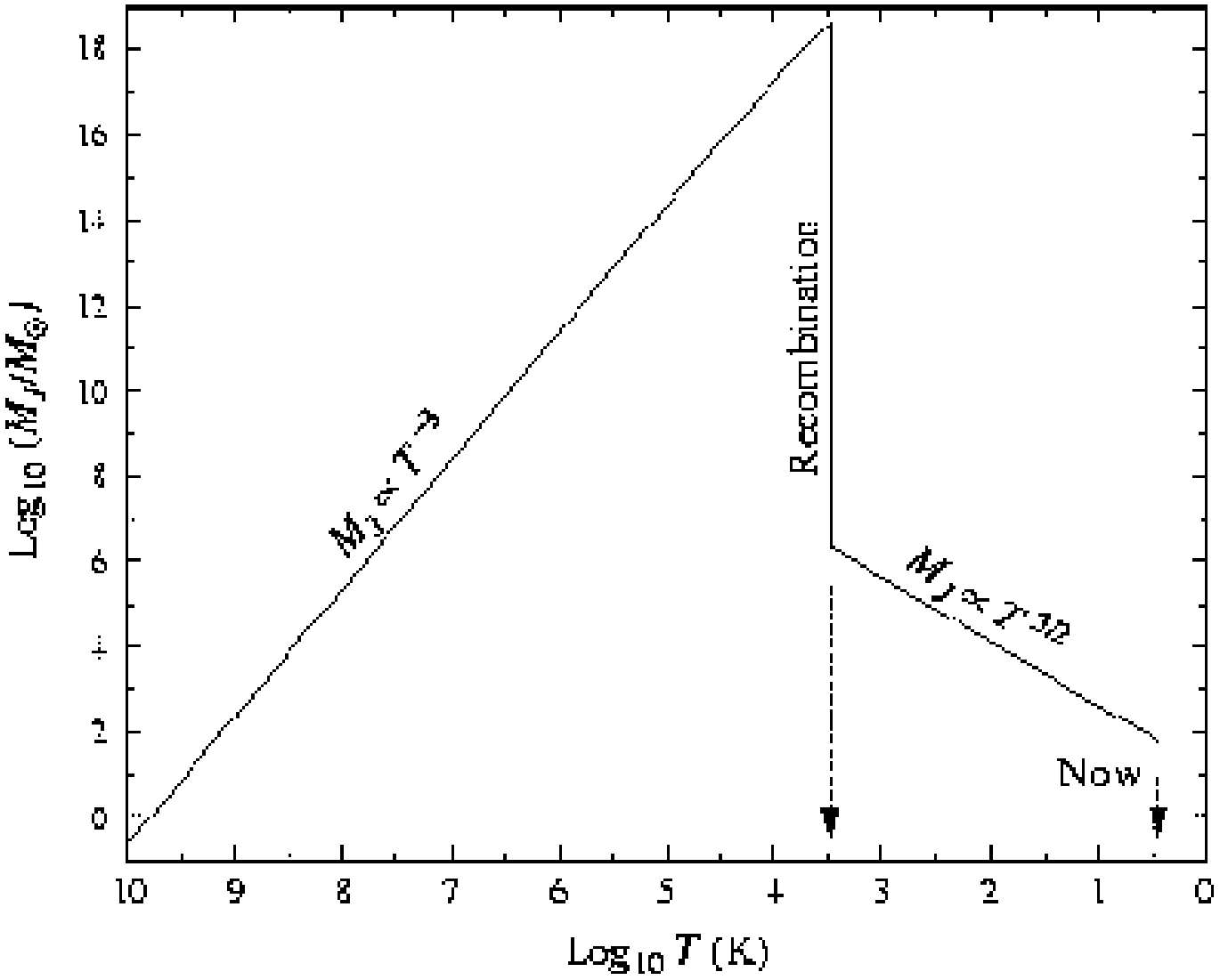


The Planck one-year all-sky survey

esa

Jeansmassa

Een gaswolk kan zich slechts samentrekken als zijn interne gasdrukkracht klein genoeg is ten opzichte van de zwaartekracht:



WMAP

structuurvorming uit fluctuaties

Ook: meting uitdijing!

(laatste college)