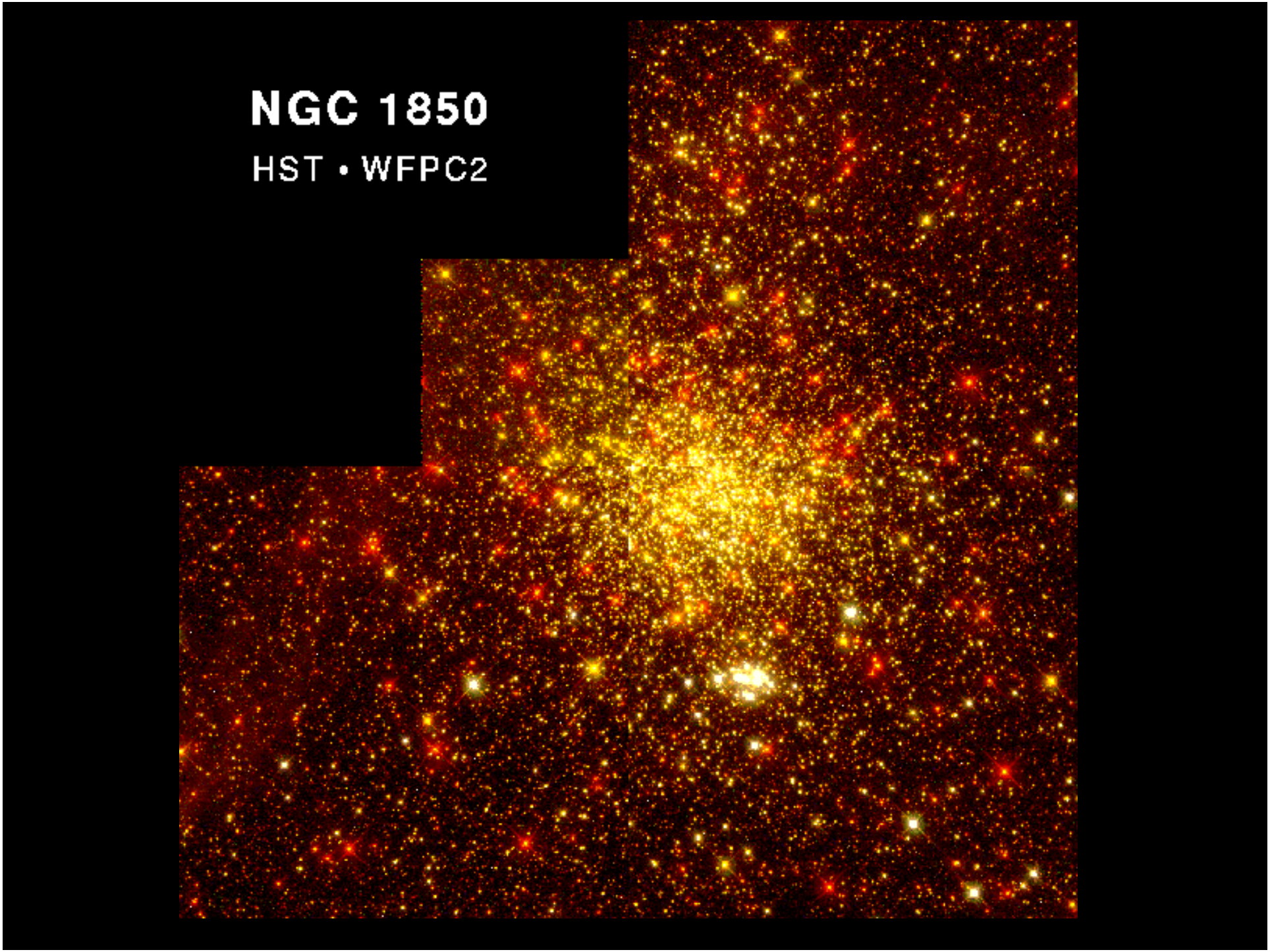
UNIVERSAL QUESTIONS: Where did we come from and are we alone?"

George Ellis

- *How did we come to be here?*
- *Are there other beings similar to us?*
- *How similar might they be?*

1: The Universe

- The universe is of vast scale
- It is expanding
- It started off in a Hot Big Bang
- Structures such as galaxy clusters formed by gravitational attraction
- Stars and planets formed in this environment


NGC 1850
HST • WFPC2

The Milky Way

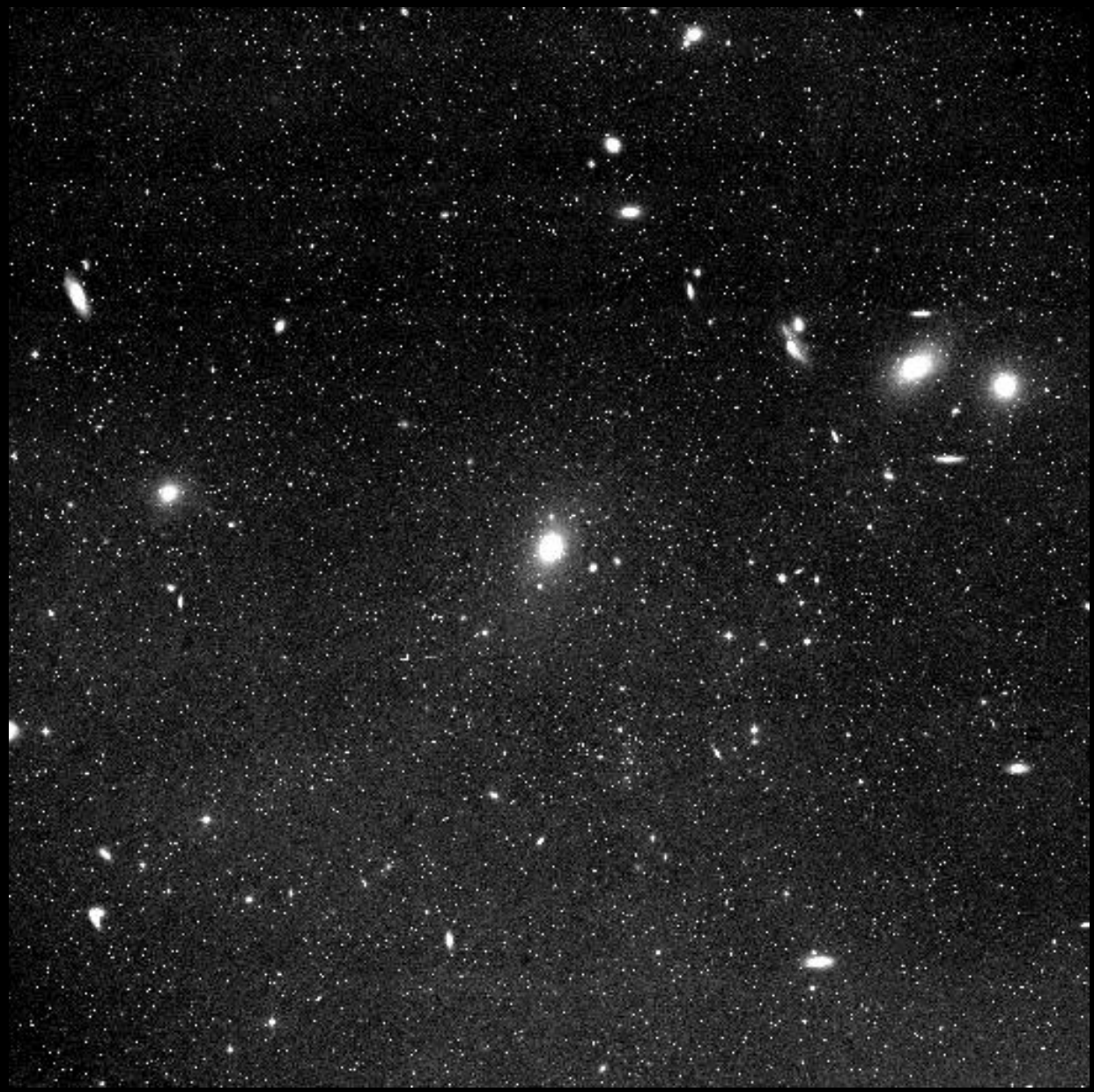
Circinus Galaxy **Hubble Space Telescope** • WFPC2

NASA and A. Wilson (University of Maryland) • STScI-PRC00-37

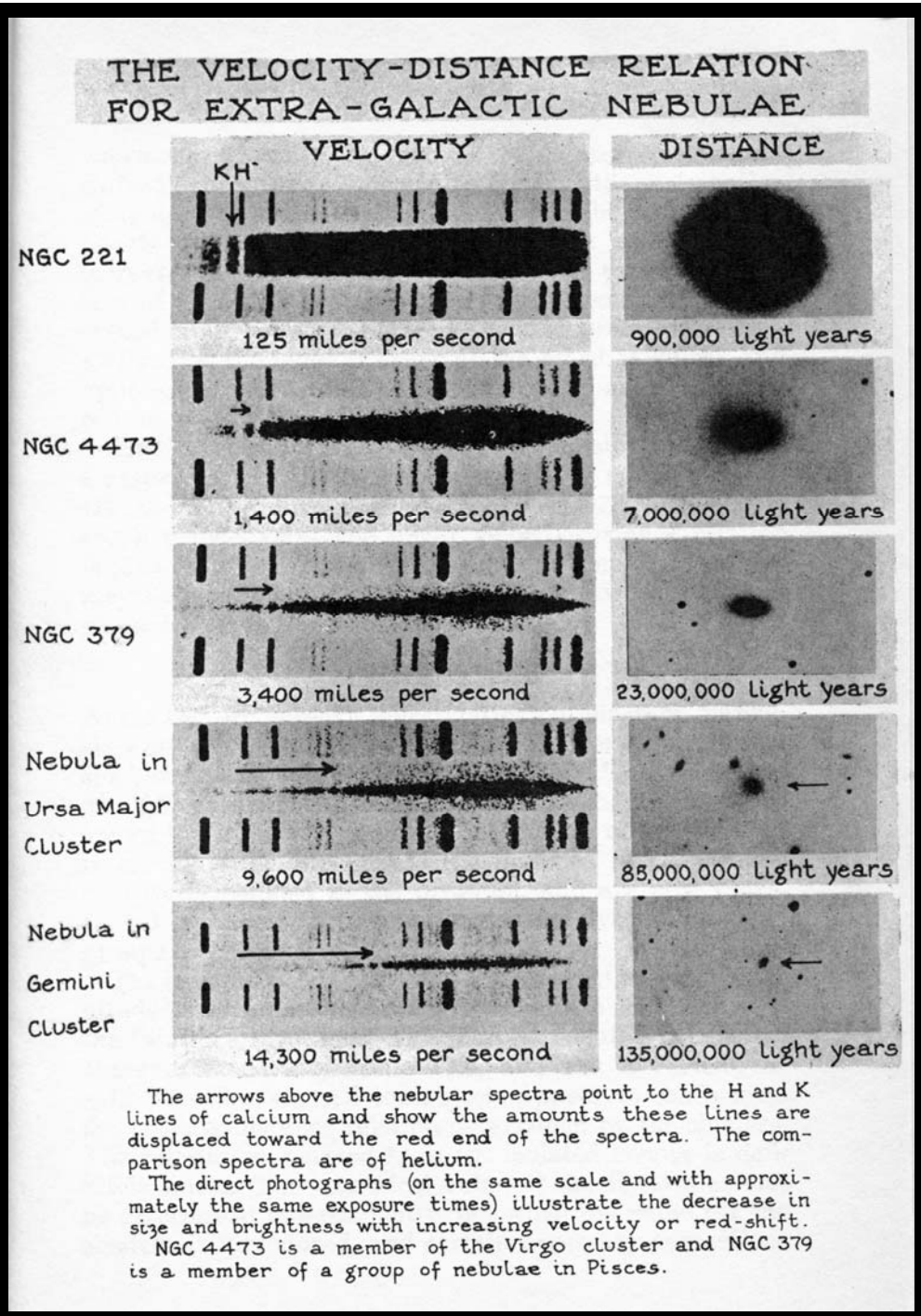
M87 © Anglo-Australian Observatory
Photo by David Malin

Coma cluster

Virgo cluster



Edwin Hubble, 1929



Hubble's data

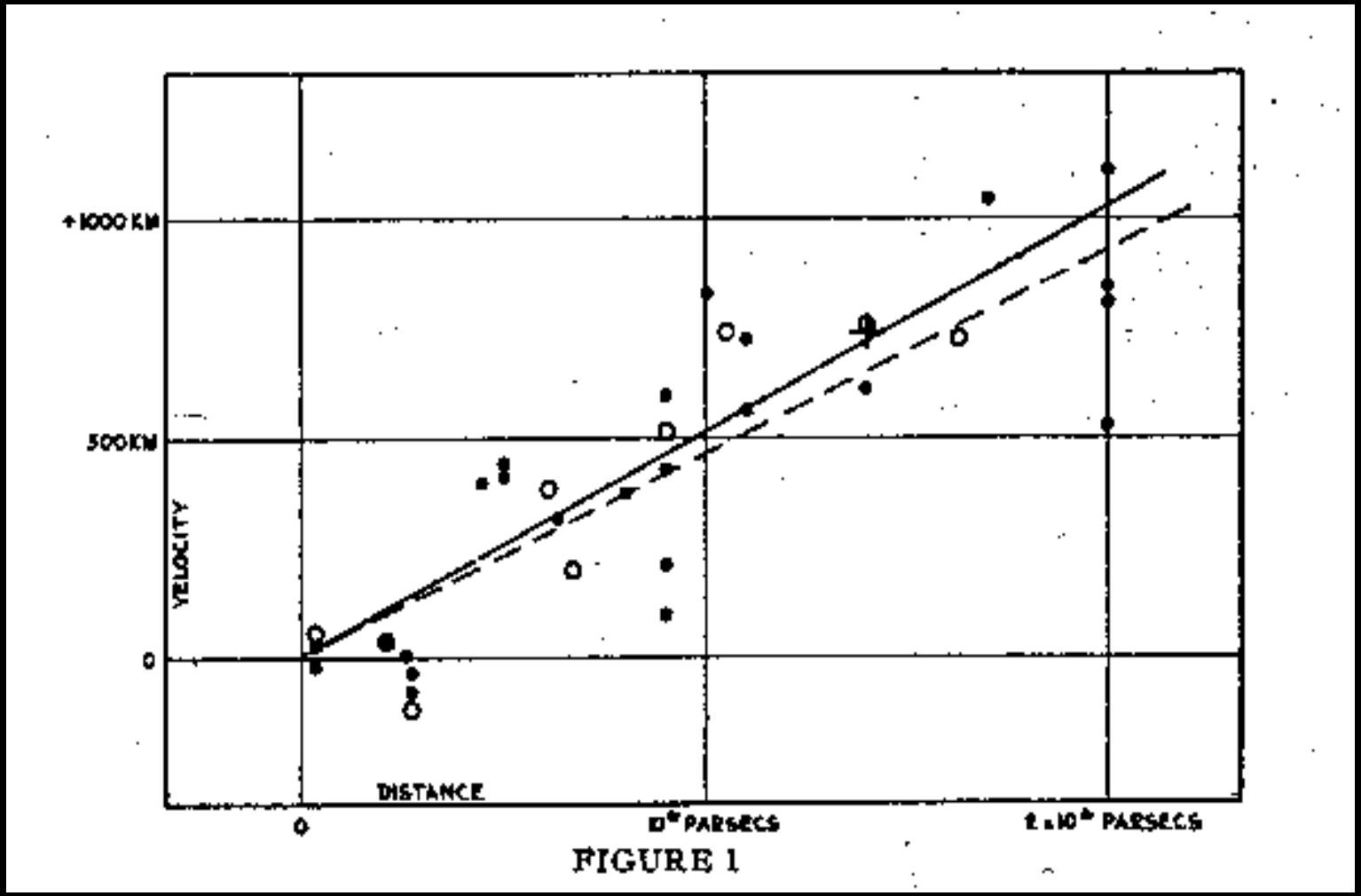
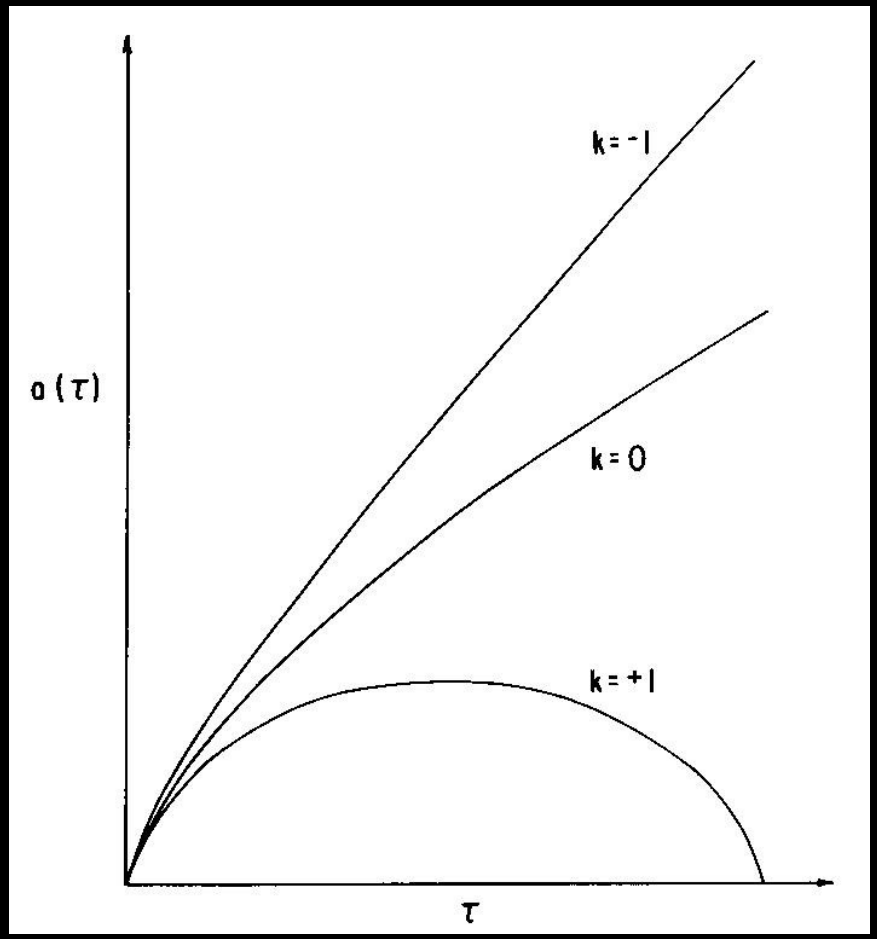


FIGURE 1

Velocity is proportional to distance

Size of universe vs time



If $\Lambda = 0$ the critical density $\Omega_0 = 1$ separates the ever-expanding from recollapsing. [More complex when Λ is non-zero].

Observational relations

- *galaxy number counts*: (n,m)
- *galaxy magnitude – redshift relation*: (m,z)

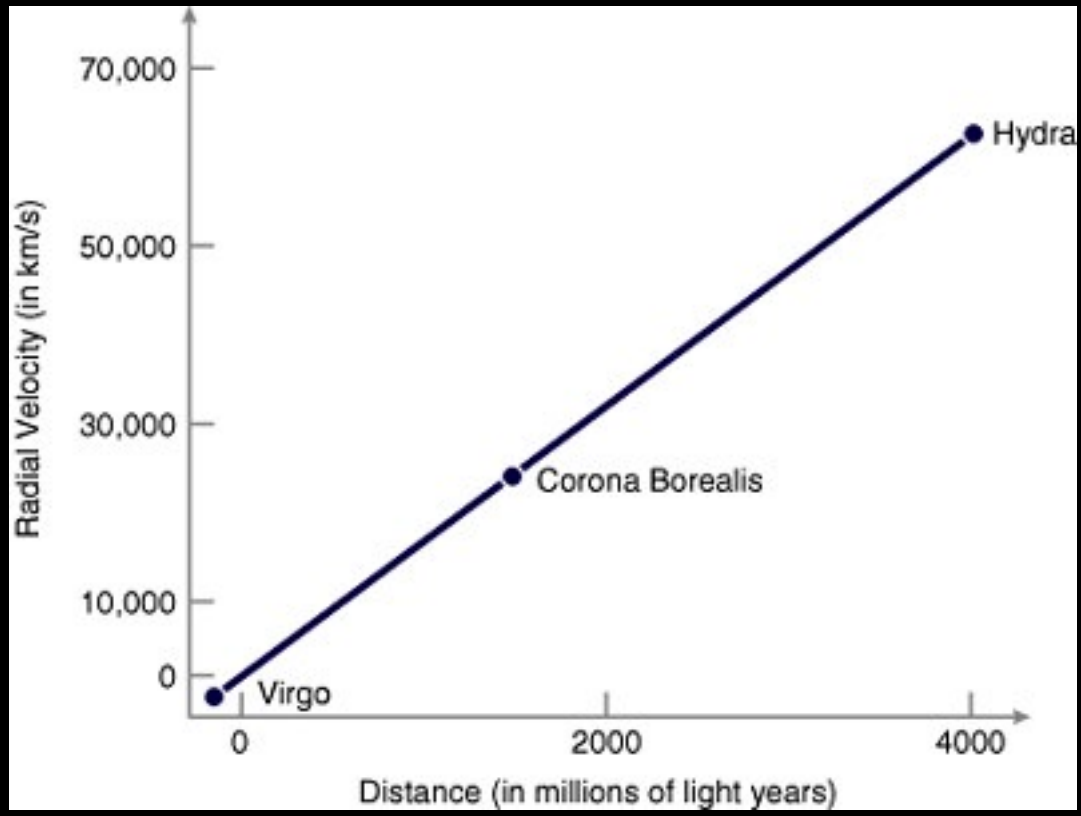
  applied to ‘standard candles’
- Major observational programmes

BUT: No good standard candles

- *Source evolution*
- *Source statistics/ variation*

  prevented determining deceleration parameter

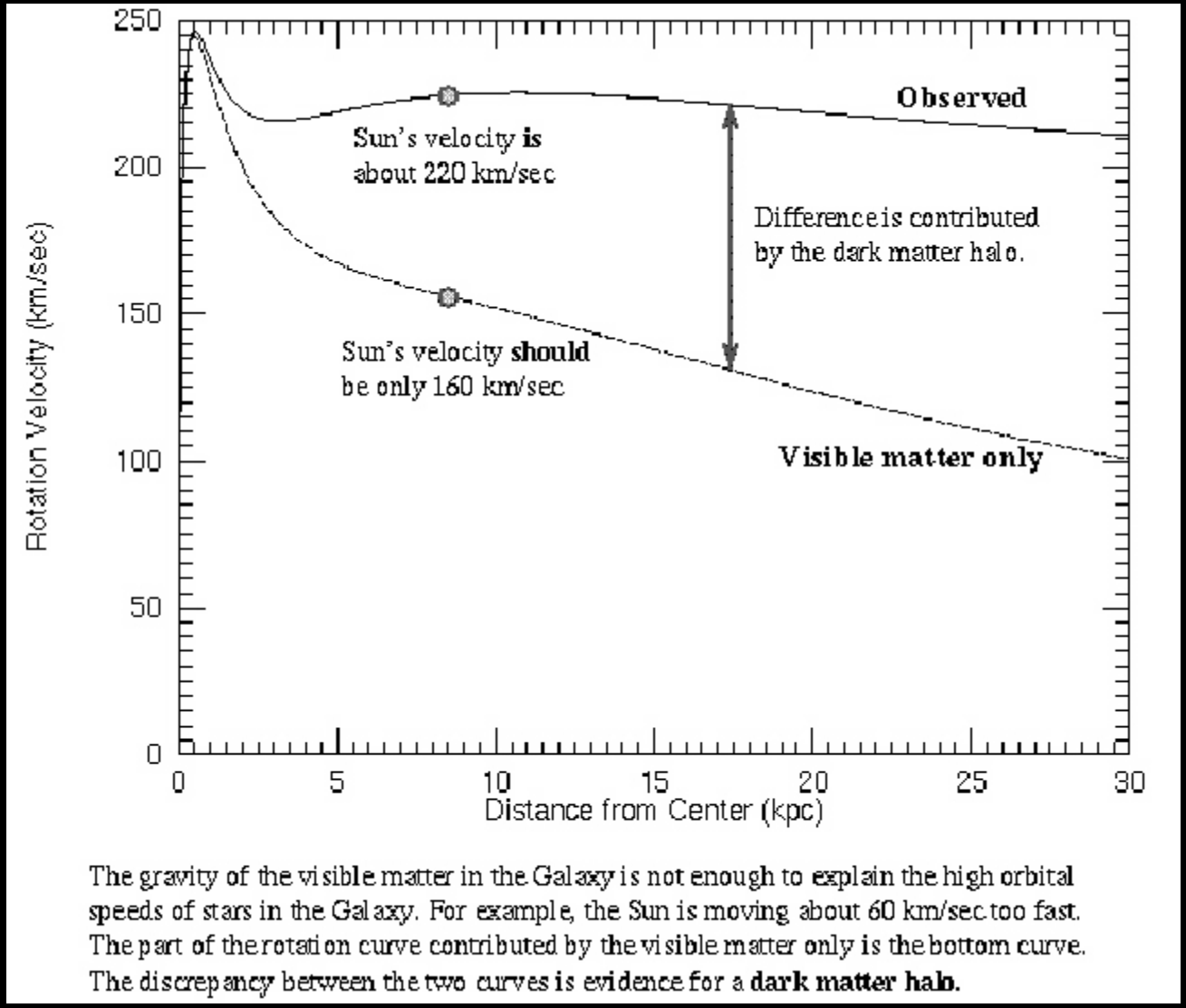
Velocity-distance relation



Key Discovery

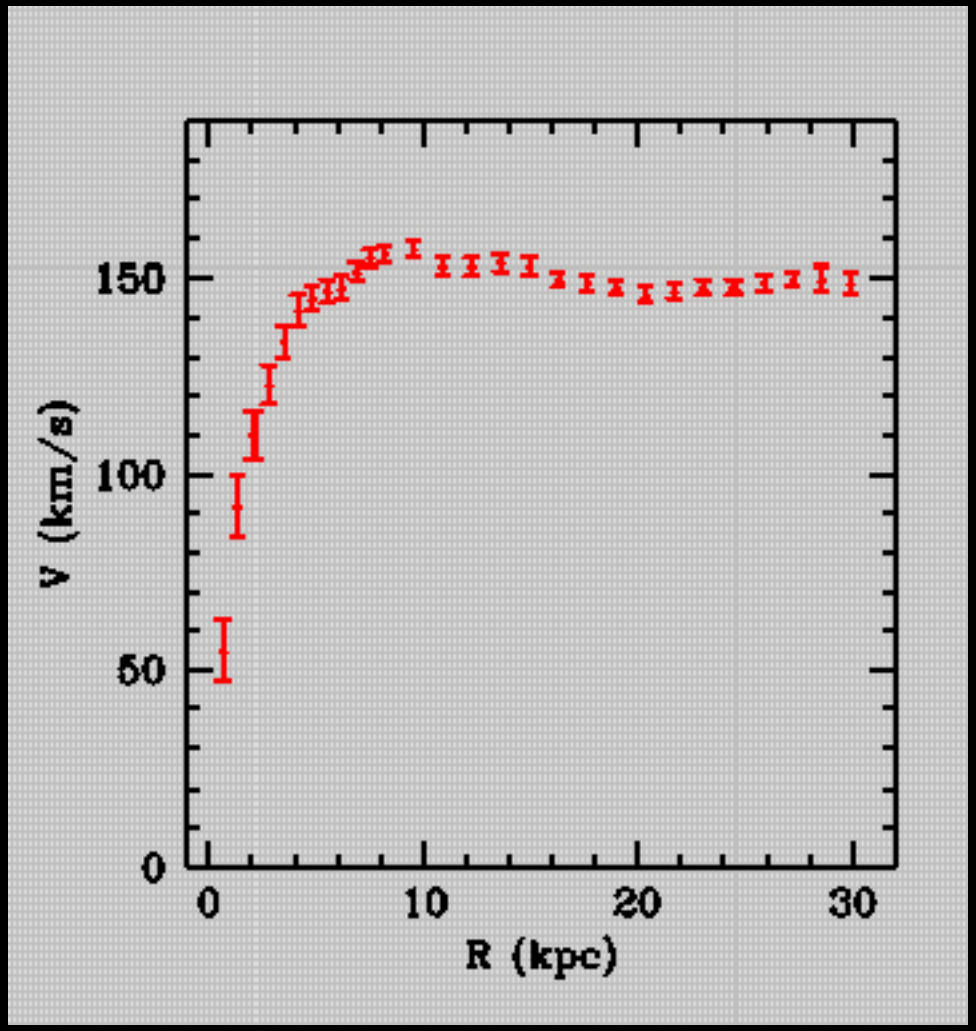
- Rotation curves of galaxies and motions of galaxies in clusters indicate *presence of dark matter*
- Unseen – does not radiate – but felt through its gravitational field
- Density of dark matter varies with scale; cosmologically contributes about $\Omega_0 \sim 0.3$

Our own galaxy

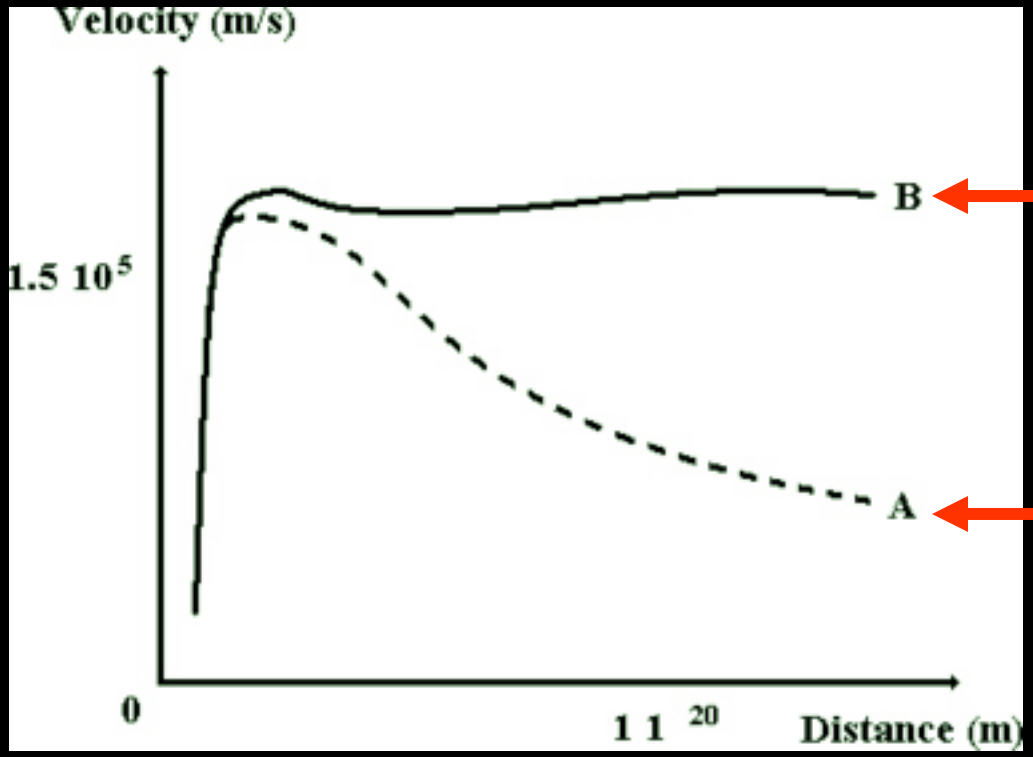


The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two curves is evidence for a **dark matter halo.**

Other galaxies



Dark matter is required …



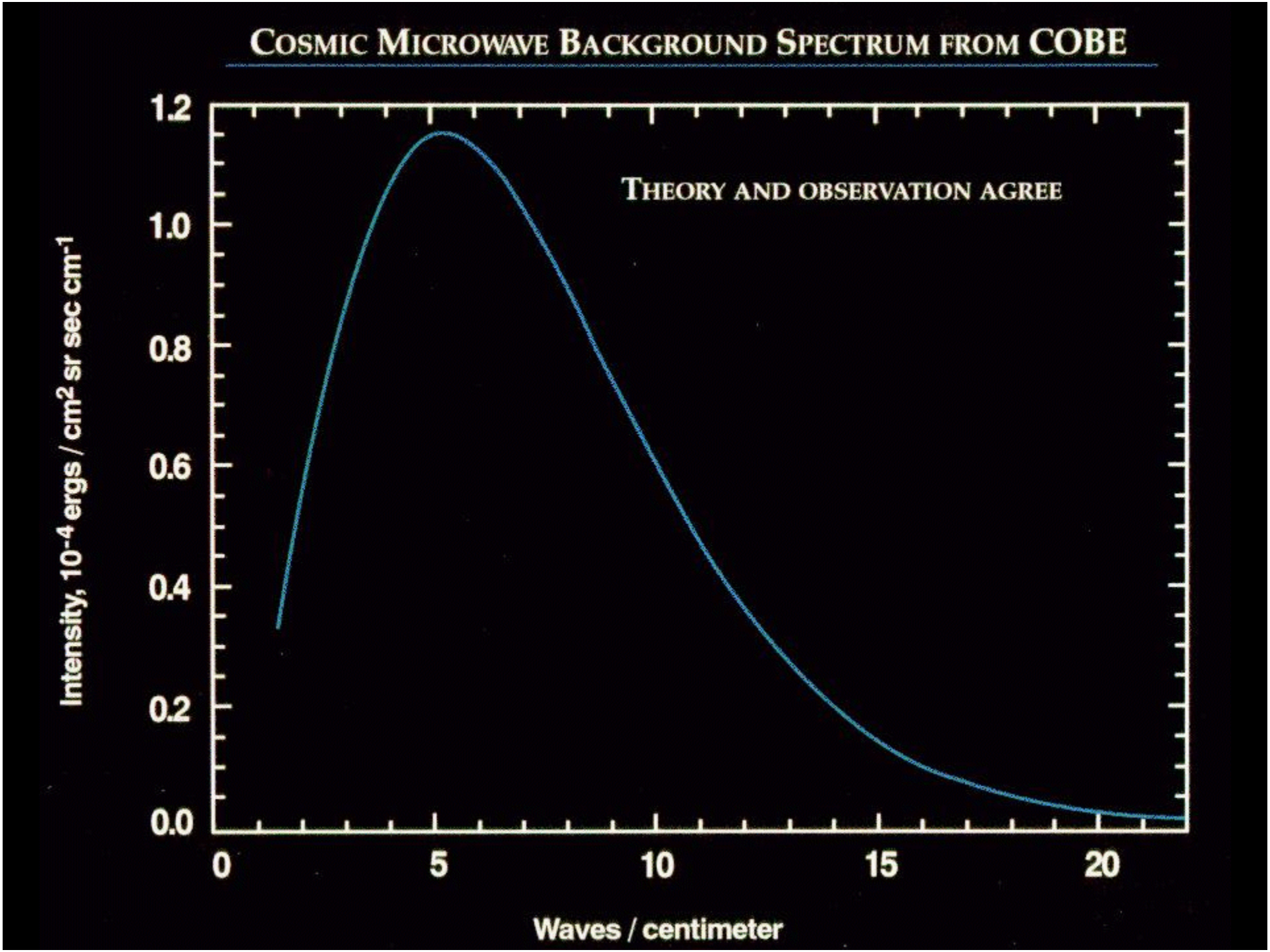
Hot Big Bang

- Follow universe back in time: heats up; hence, ***Hot Big Bang (HBB)*** era in early universe

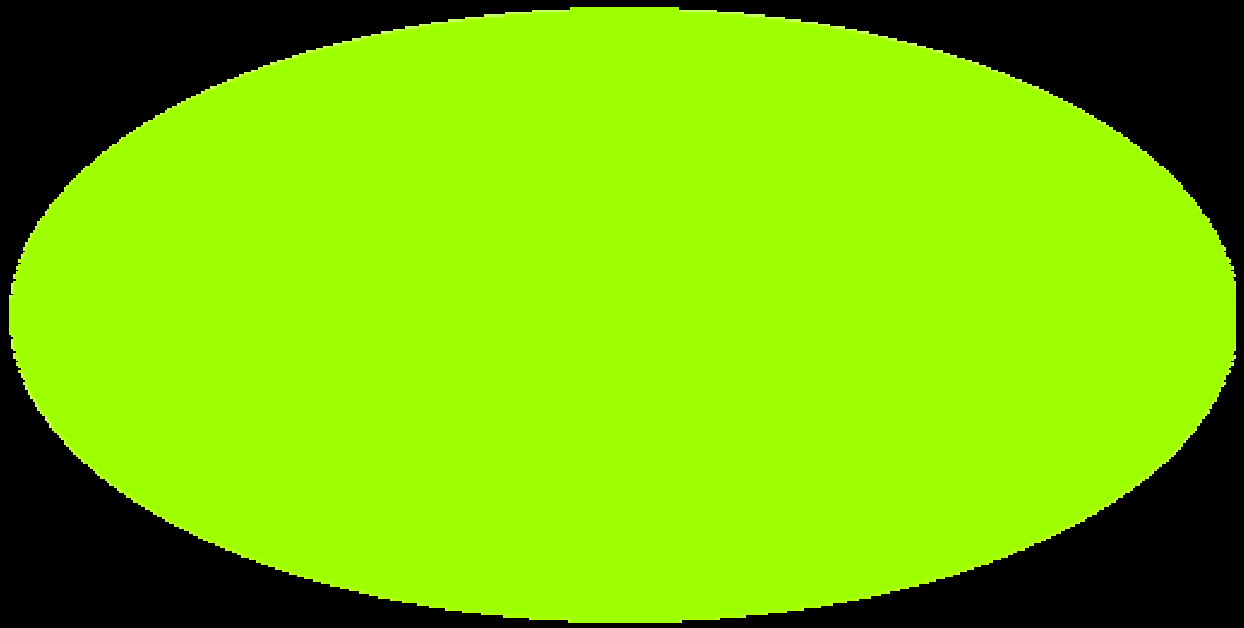
- Equilibrium occurs between matter and radiation, hence ***Cosmic Blackbody Radiation*** (CBR) left over as a remnant of the HBB era; observationally discovered in 1965 at a temperature of 2.75K

- Vindicates application of standard physics to the early Universe

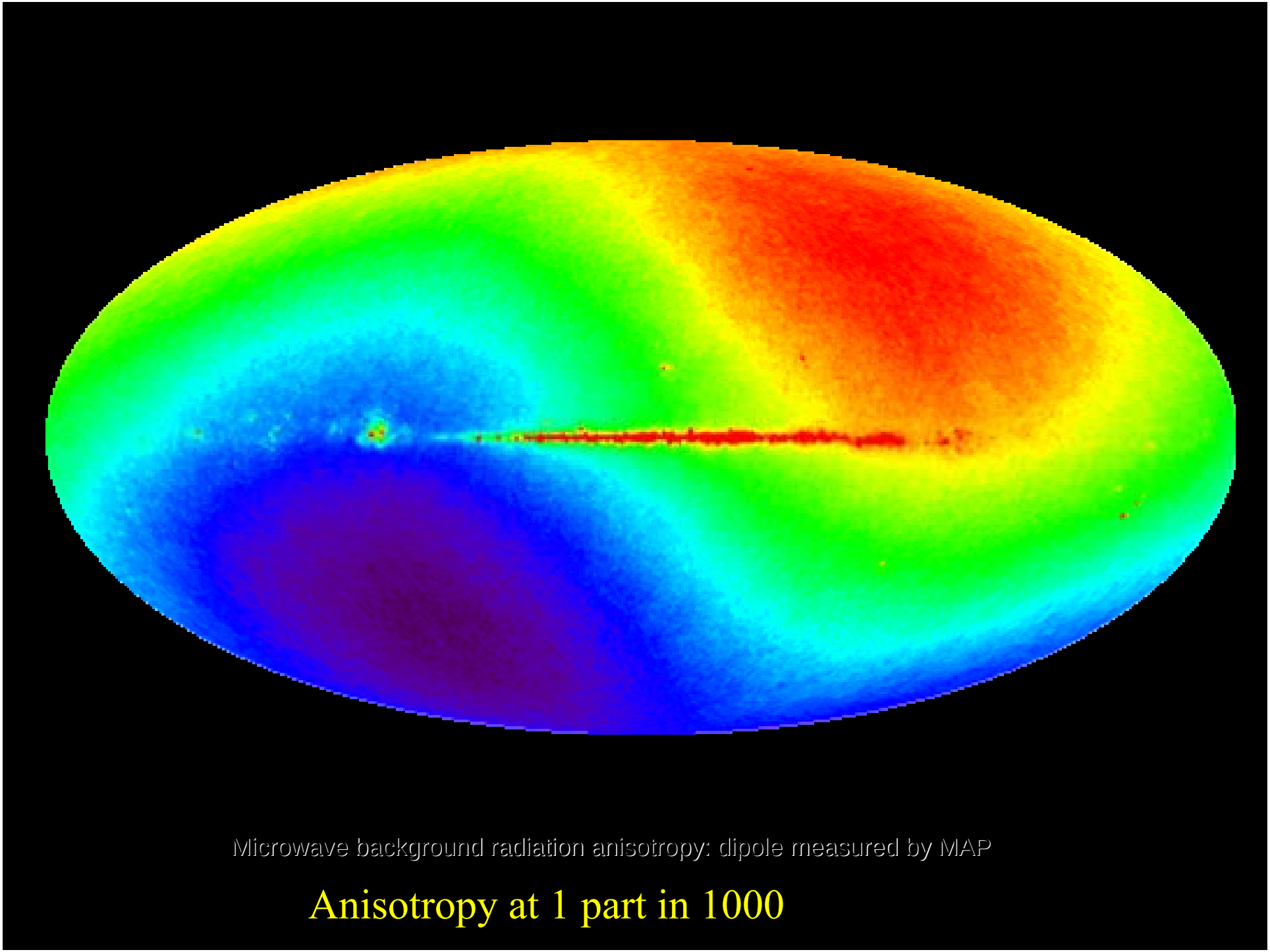
- CBR reaches us from *surface of last scattering at a temperature* of 4000K [a redshift of 1100]


COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE
THEORY AND OBSERVATION AGREE
Intensity, 10-4 ergs / cm2 sr sec cm-1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Waves / centimeter

CBR isotropy 1

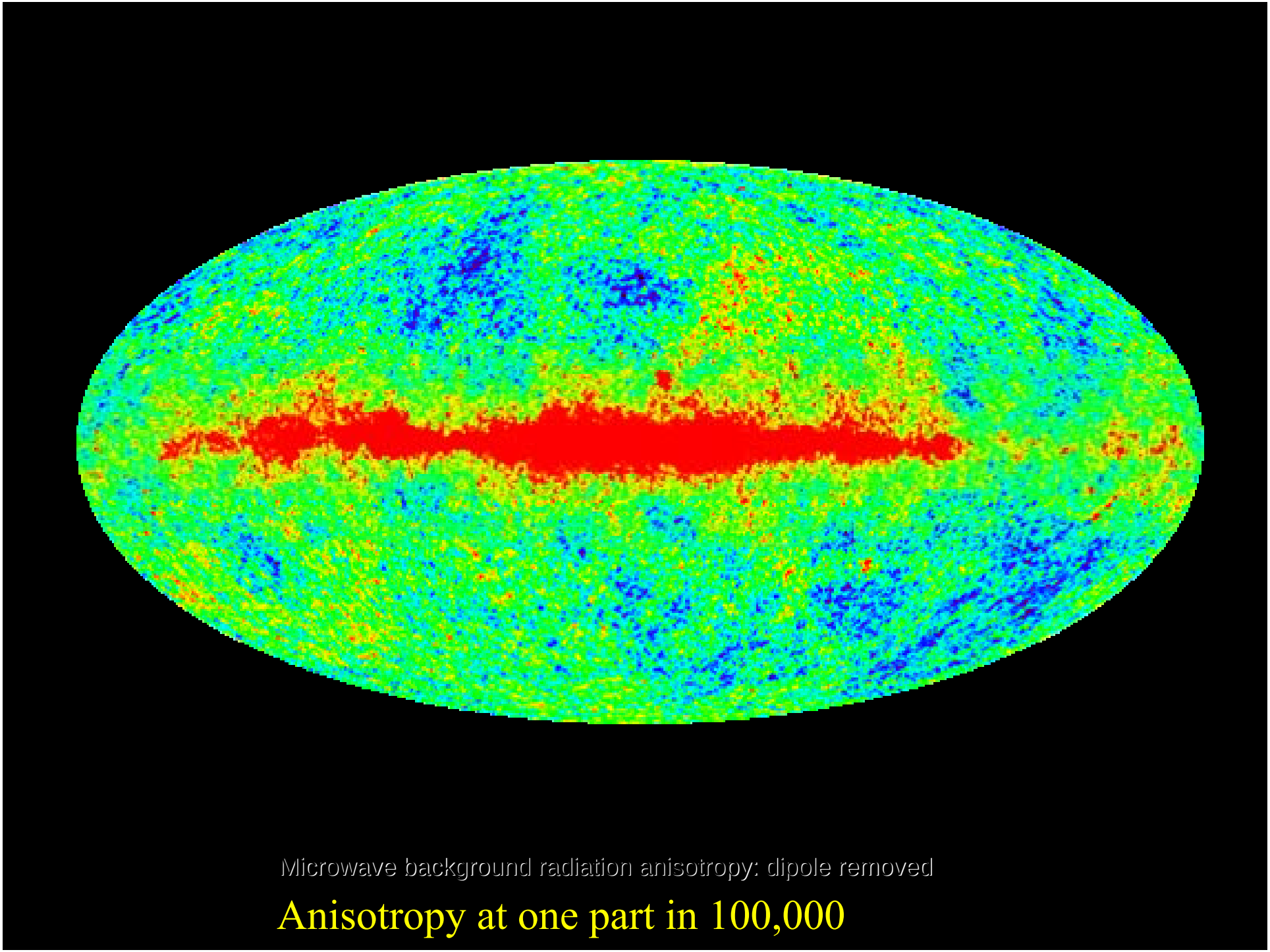


Isotropic at 1 part in 100



Microwave background radiation anisotropy: dipole measured by MAP

Anisotropy at 1 part in 1000

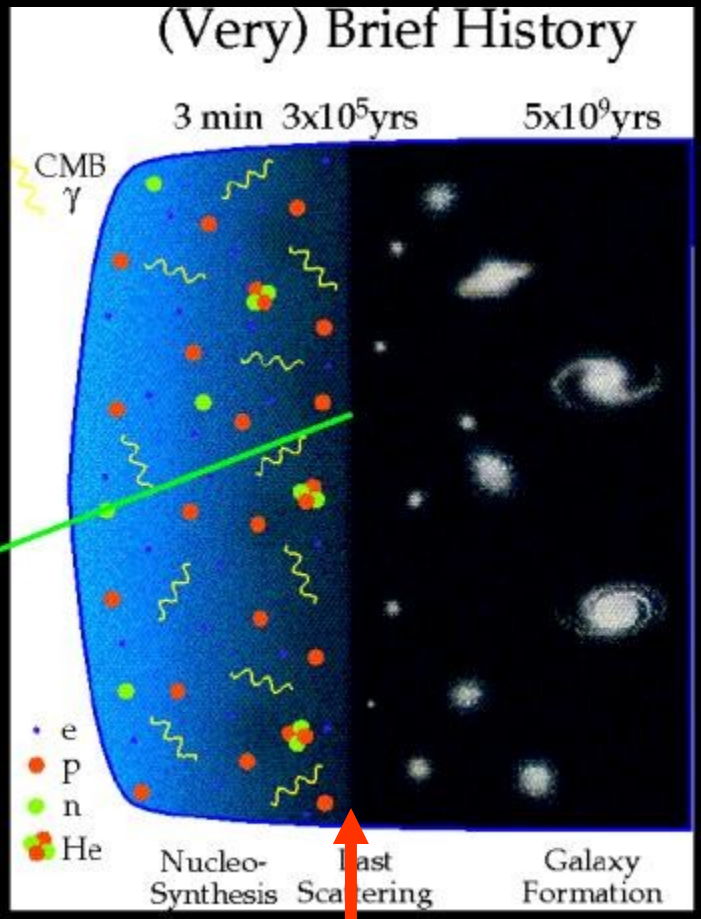


Microwave background radiation anisotropy: dipole removed

Anisotropy at one part in 100,000

This radiation is due to the CMB photons that are now arriving from the "last scattering surface", red shifted by a factor of 1000 or so.

About 1% of the "snow" on a tv is due to CMB photons.



opaque | transparent

Last scattering surface

Origin of the elements

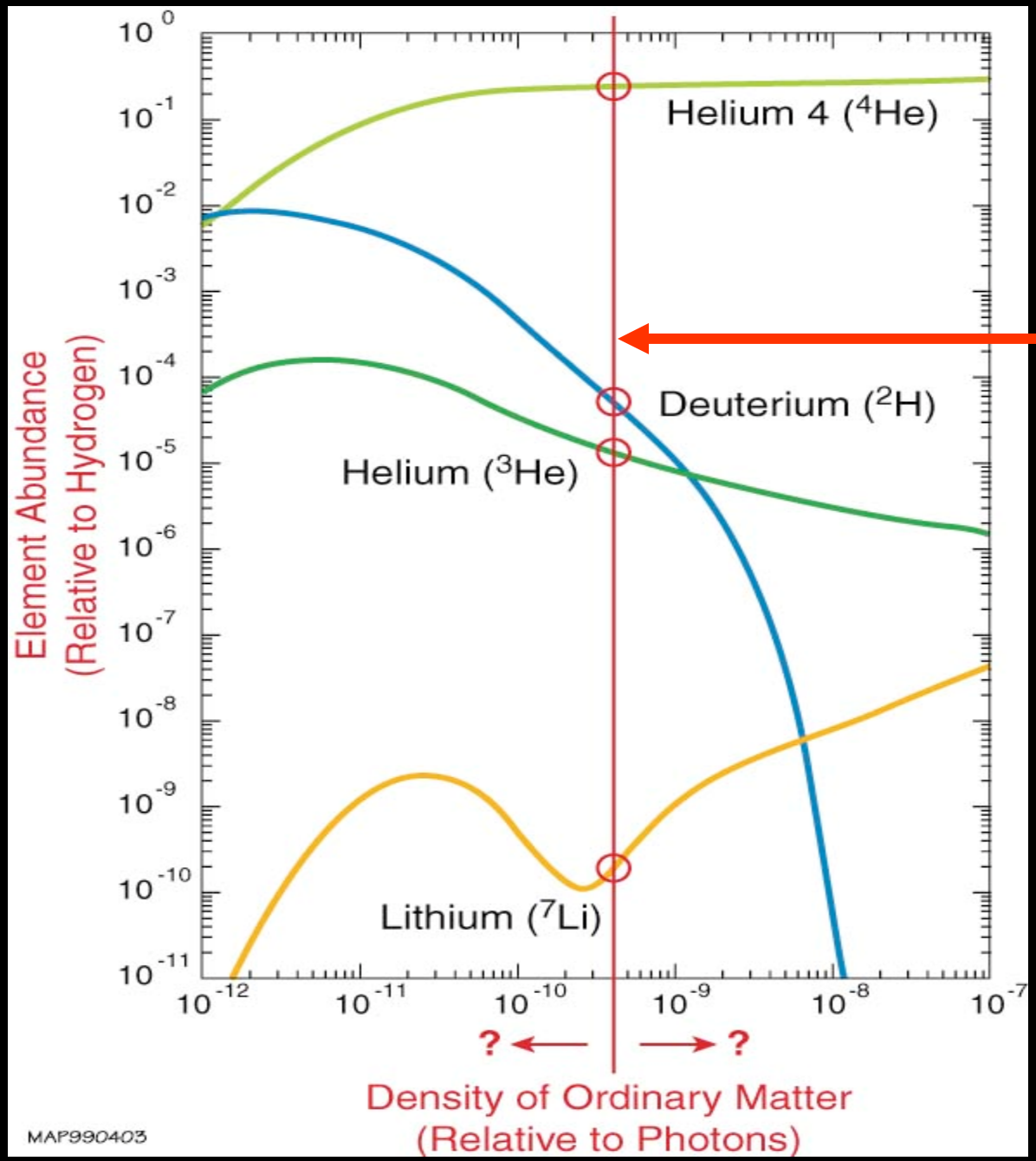
- nuclear physics processes during the HBB era

- The unbounded temperature in this era implies *matter-radiation equilibrium*:

Previous state is then irrelevant

- an epoch of *nucleosynthesis* when the light elements form in the early Universe at a temperature of about 10^9K [neutrons and protons combine to form nuclei]

- heavy elements form much later in stars



All four observations agree

Relation to observations

- nucleosynthesis *theory and element abundance observations agree* provided the baryon density in the early Universe is low: $\Omega_{b0} \sim 0.01$

- together with the density estimates from astrophysical cosmology $\Omega_0 \sim 0.3$, provides evidence for *much more non-baryonic dark matter than baryonic matter* in the Universe

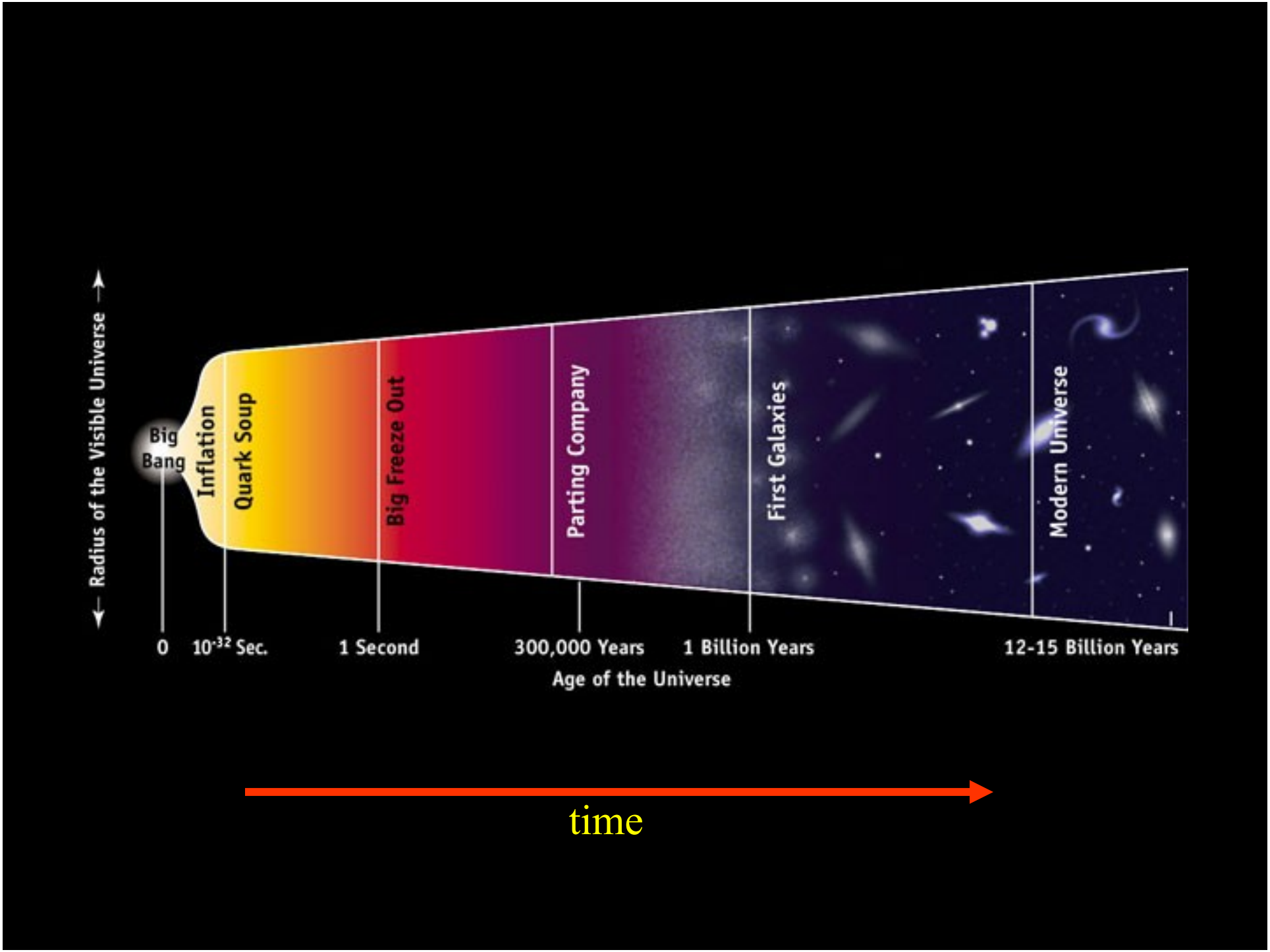
- requires there be *no more than three neutrino species*, a conclusion confirmed later by experiments at CERN

Particle cosmology and inflation

- In the very early Universe particle physics plays a major role.

- Because quantum field theory allows a violation of the standard energy condition $\rho+3p>0$, at very early times there can be a *period of accelerated expansion* driven by scalar fields

- '***inflation'*** with expansion accelerating rapidly takes place through many e-foldings before a subsequent HBB era begins (when the inflationary field has decayed to ordinary matter and radiation).


← Radius of the Visible Universe →
Big Bang
Inflation
Quark Soup
Big Freeze Out
Parting Company
First Galaxies
Modern Universe
0
10-32 Sec.
1 Second
300,000 Years
1 Billion Years
12-15 Billion Years
Age of the Universe
time

Quantum cosmology

- Before the inflationary era, some kind of quantum gravity effects will dominate the dynamics of the Universe and provide the initial conditions for inflation

Attempts to describe this quantum cosmology era include:

- the *wave function of the Universe*, either through the Wheeler-DeWitt equation or path integral methods
- *'pre-big bang'* theory based on string dualities
- *brane cosmology* : our Universe lives on a 4-dimensional 'brane' imbedded in a 5-dimensional spacetime
- the *ekpyrotic universe* where two such branes collide

Quantum cosmology

- In all cases the problem is making a solid link to observational tests, because the proposed particle interactions and/or extension of classical gravitational theory is not directly testable

- however, these theories are indirectly testable via their effects on the inflationary perturbation spectrum, and so on structure formation

- there is no fully formulated theory of quantum gravity

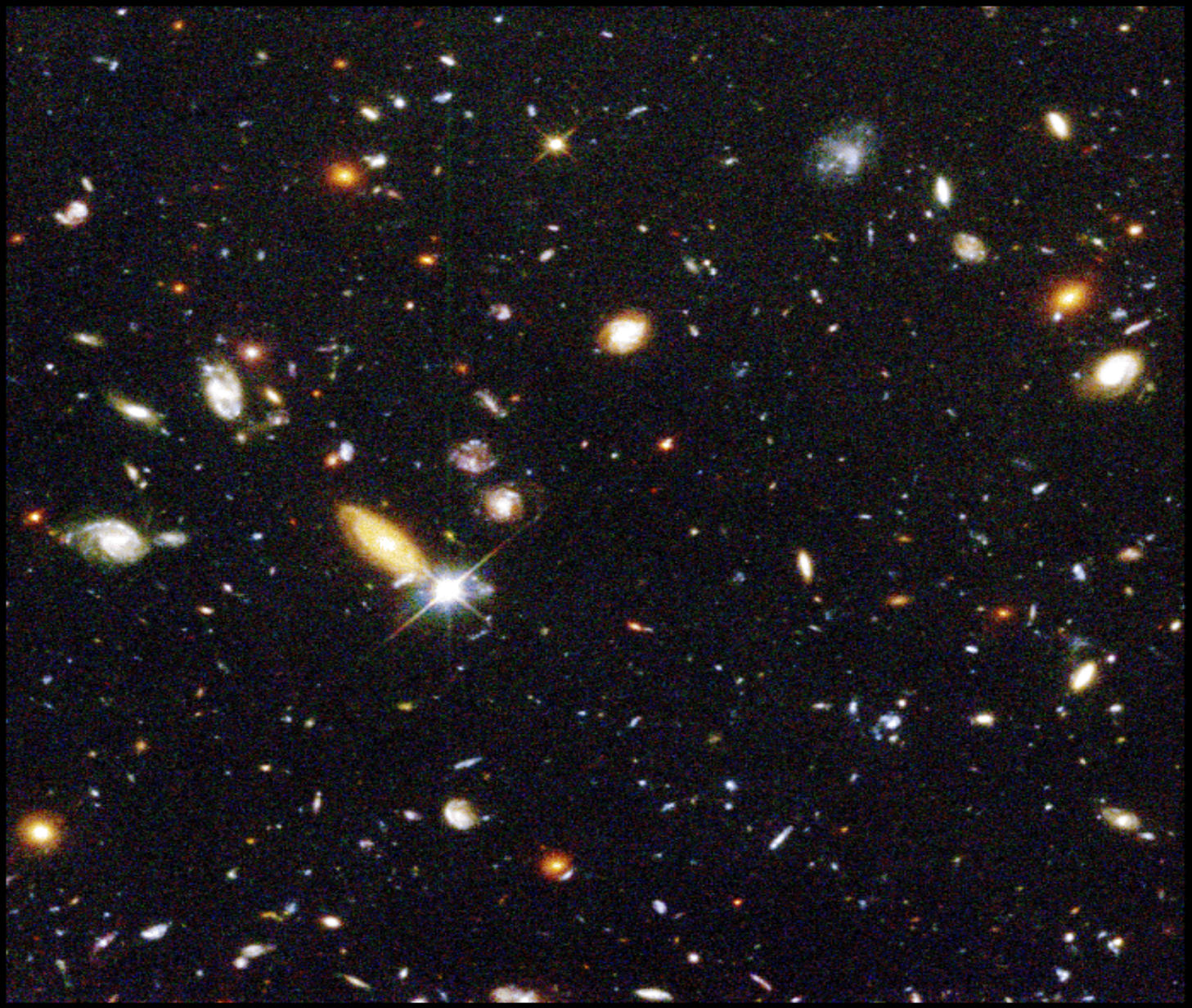
- *In the end we do not know if there was a start to the universe or not*

Observational transformation

Since the 1960's, observational cosmology has gone through a major transformation: discovery of quasi-stellar objects, X-ray sources, gravitational lenses, and so on. This has been made possible by a revolution in observational technology

- new telescopes, both ground-based (e.g. Keck) and borne aloft in balloons and satellites (e.g. IRAS, the Hubble Space Telescope)
- operating at all wavelengths from radio to γ-ray
- with features such as multiple-mirrors and adaptive optics

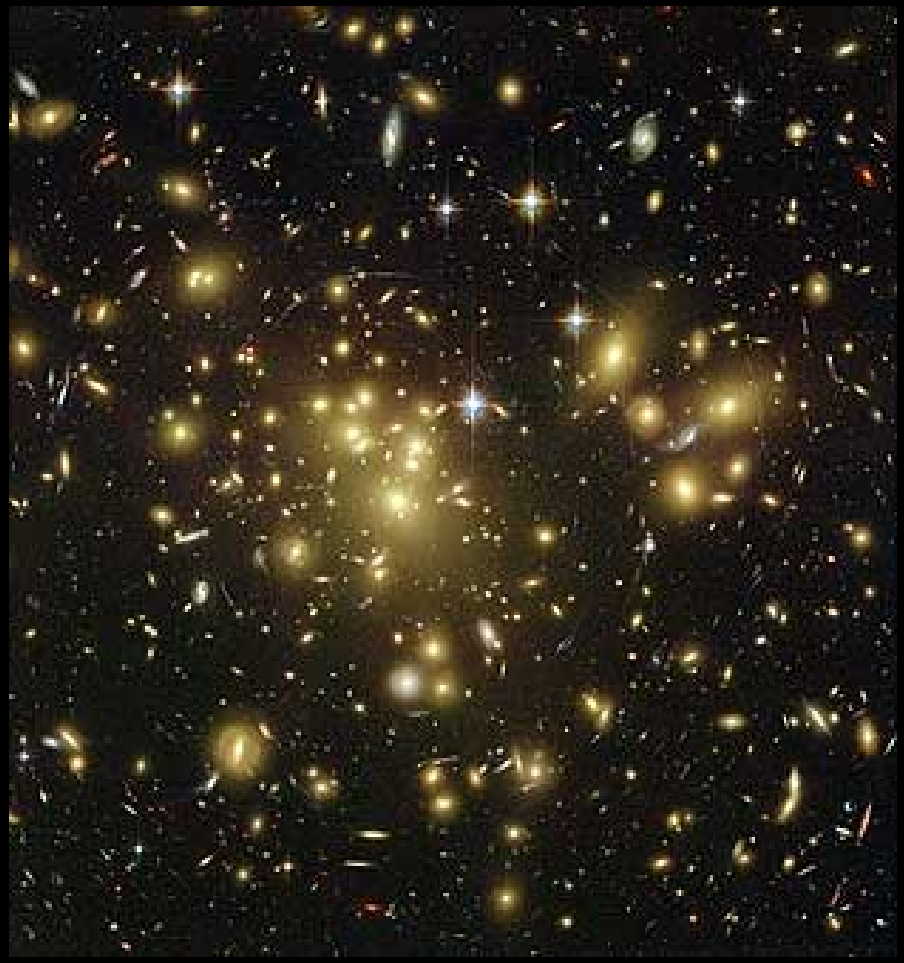
- improved detectors have allowed much deeper observations and number counts than before e.g. CCD's.

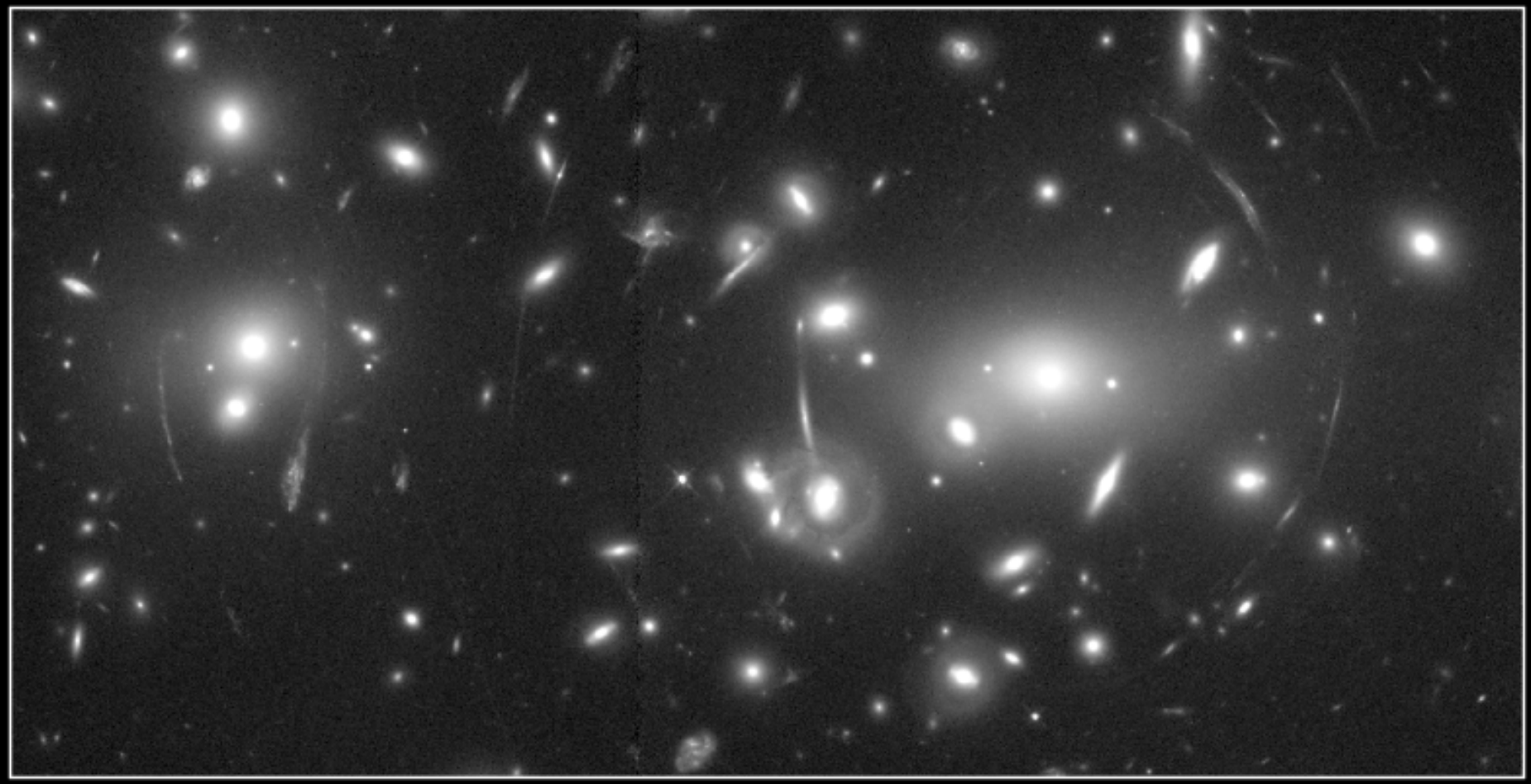


Hubble Deep Field HST • WFPC2

PRC96-01a · ST ScI OPO · January 15, 1996 · R. Williams (ST ScI), NASA

Gravitational lensing





Gravitational Lens in Abell 2218

HST • WFPC2

PF95-14 · ST ScI OPO · April 5, 1995 · W. Couch (UNSW), NASA

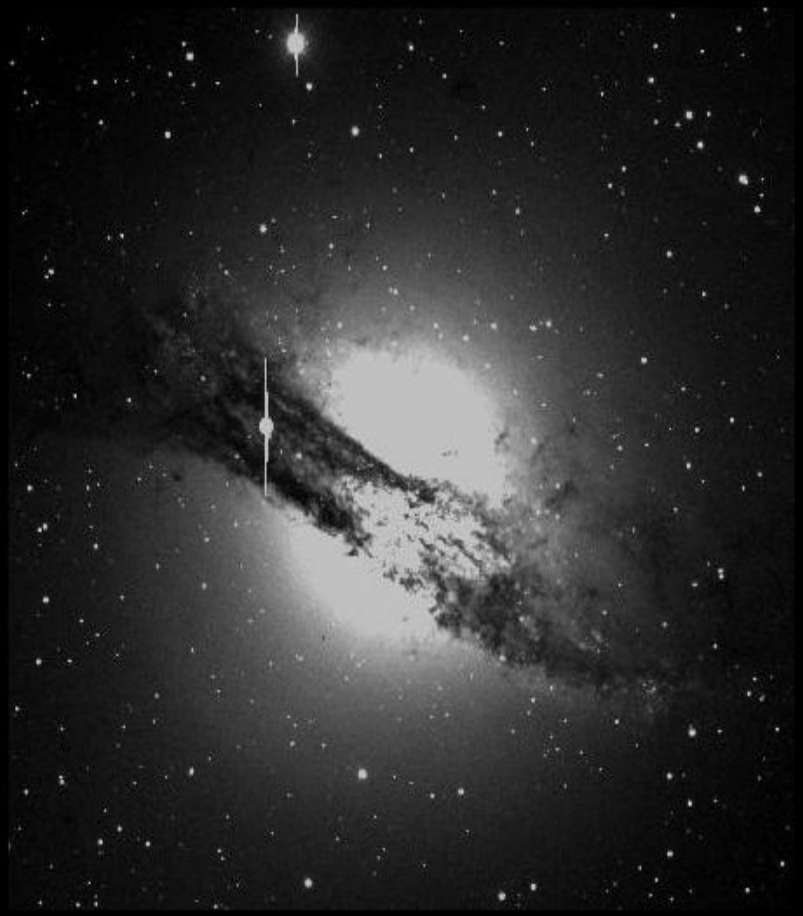
First key set of observations:

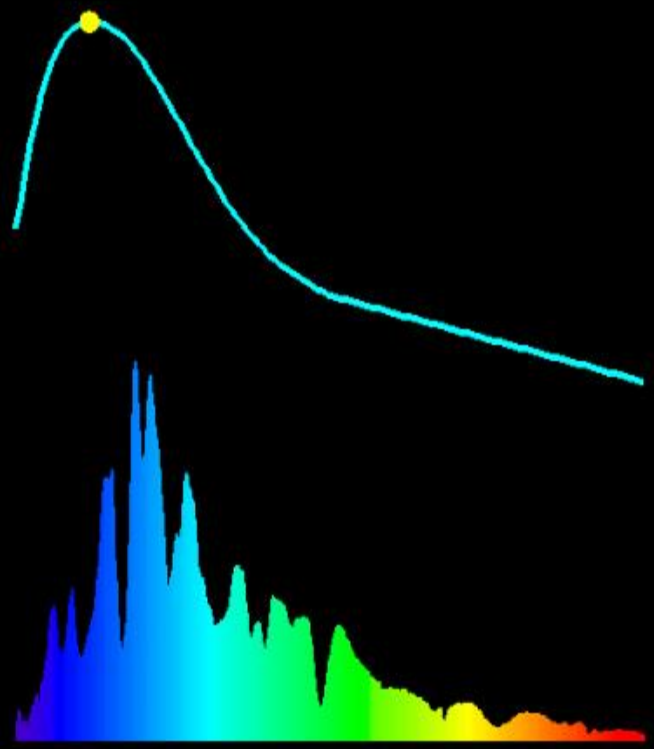
Study of decay of supernovae in distant galaxies provides a usable standard candle (because the maximum brightness is correlated to its decay rate)

- with their redshifts, gives the first reliable detection of the deceleration parameter q_0 showing the universe is *presently accelerating*

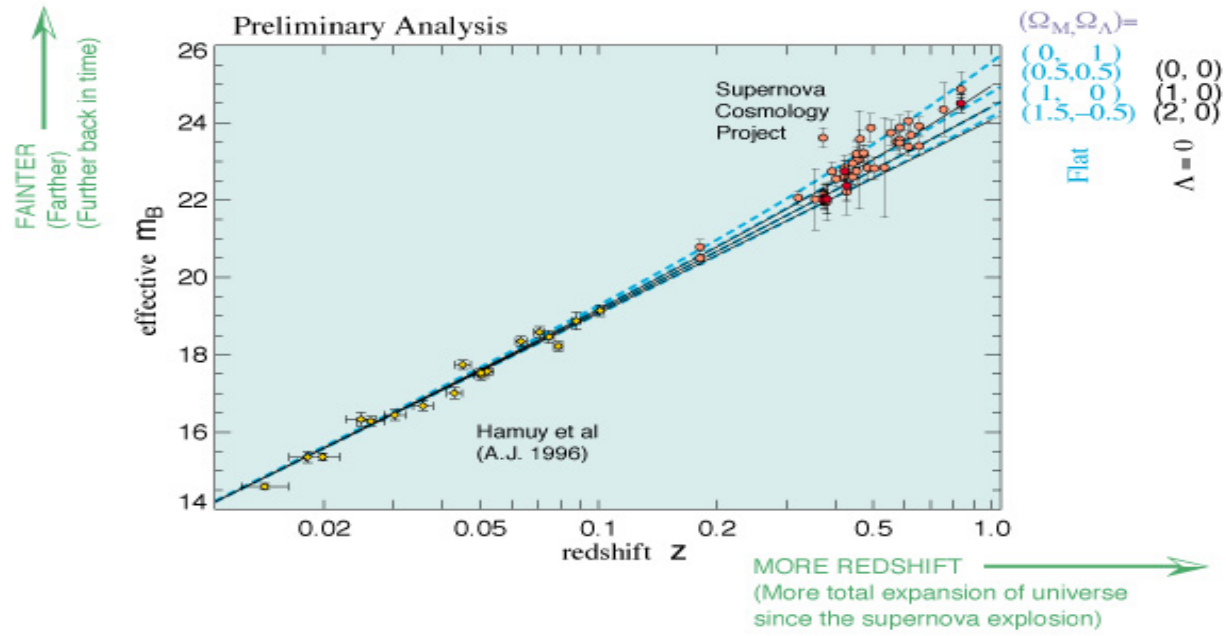
- consequently there is presently an effective positive cosmological constant with $\Omega_\Lambda \sim 0.7$

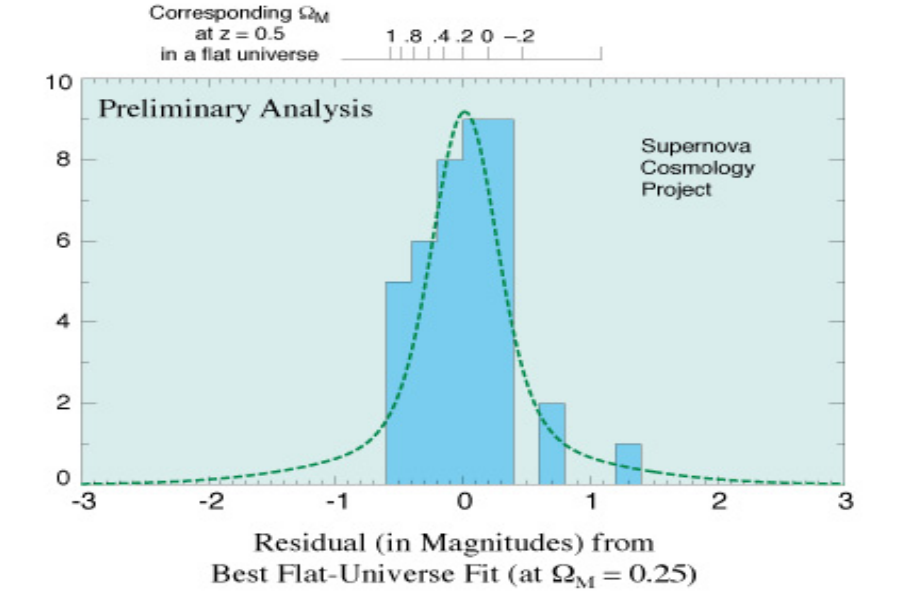
- 'dark energy' or 'quintessence'





Hubble Plots

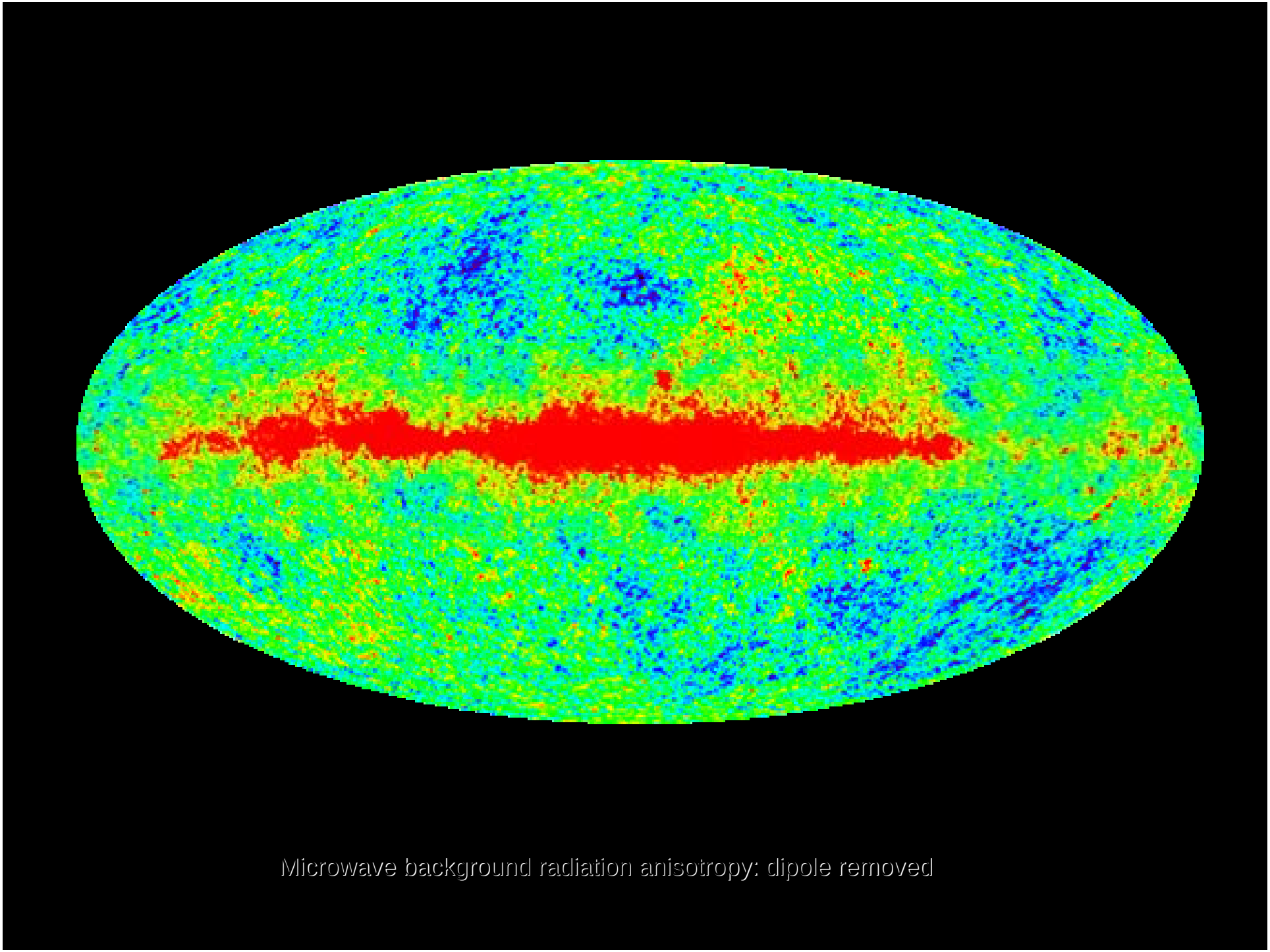




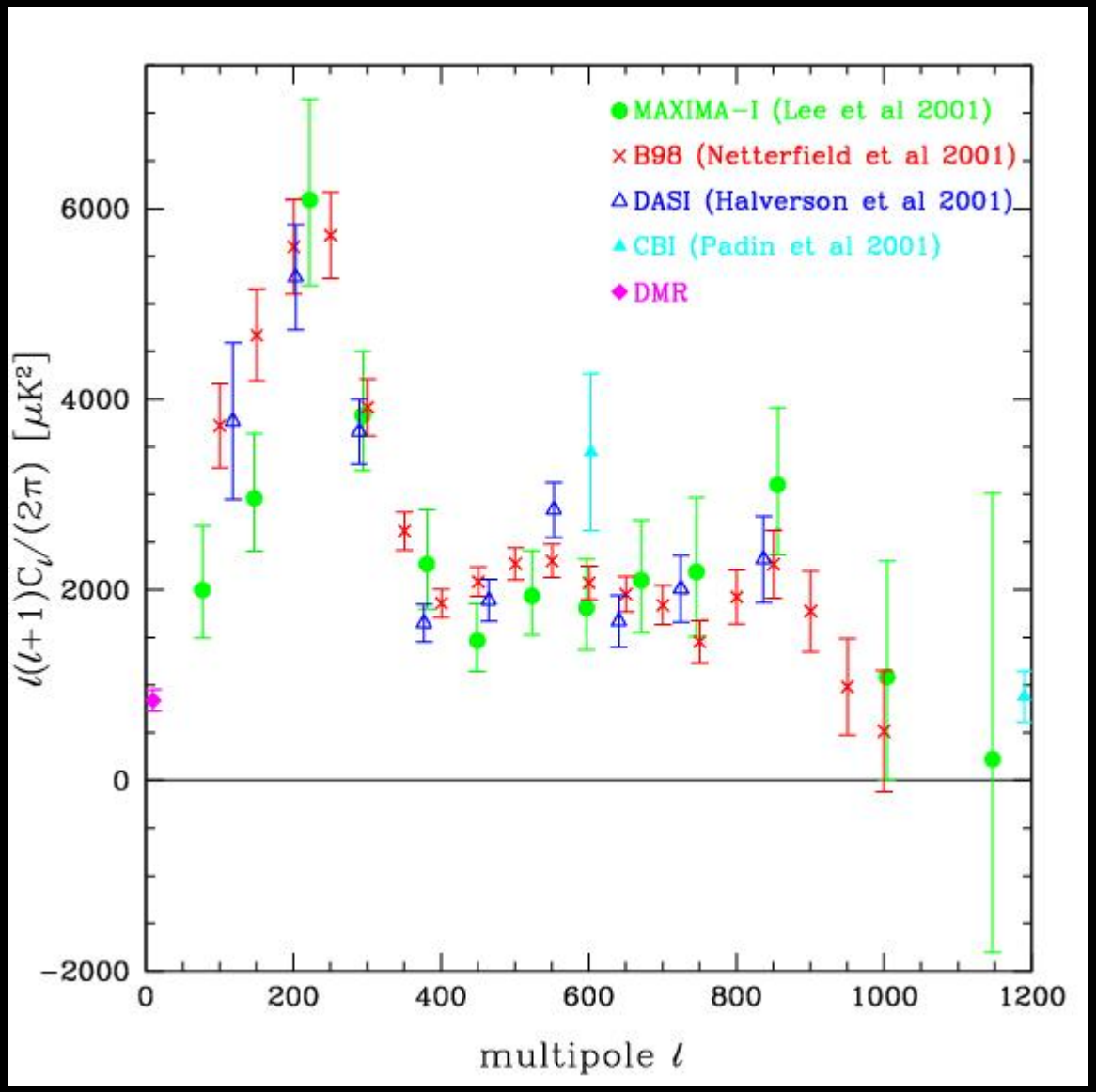
Second key set of observations:

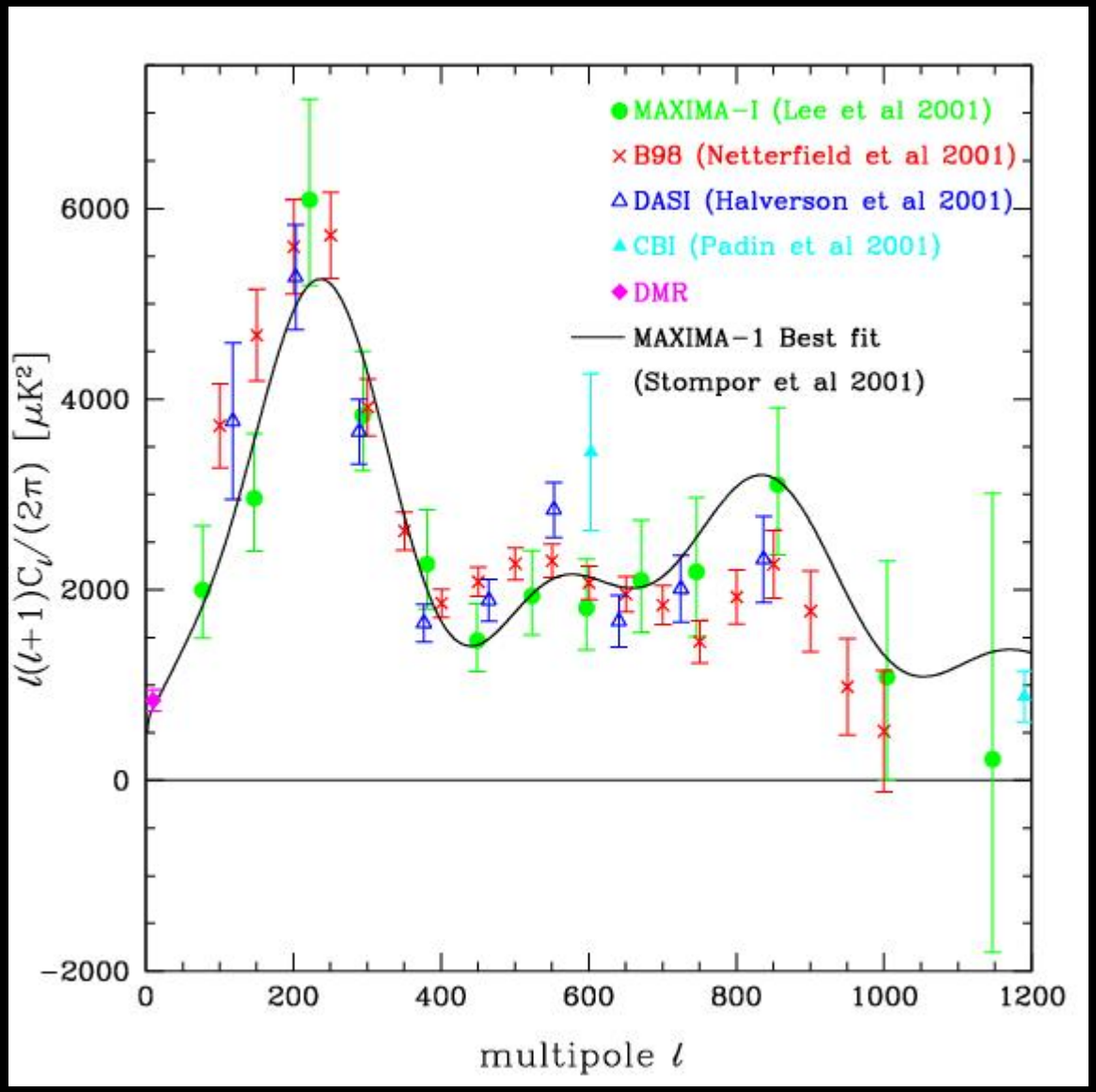
Measurements of the spectrum and anisotropy of the CBR by the COBE satellite and Boomerang and Maxima balloons

- extraordinarily accurate *Black Body spectrum*
- reliable detection of
  - *the quadrupole anisotropy*
  - *angular power spectrum peaks*
  - *predicted polarisation*

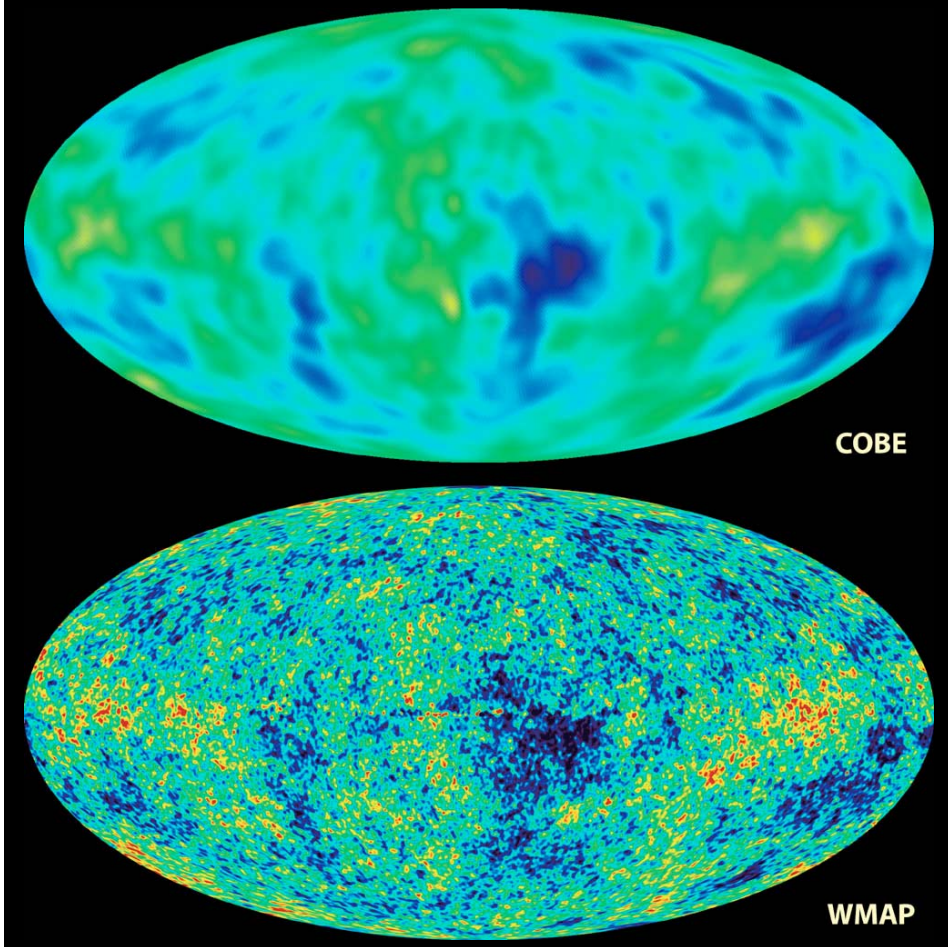


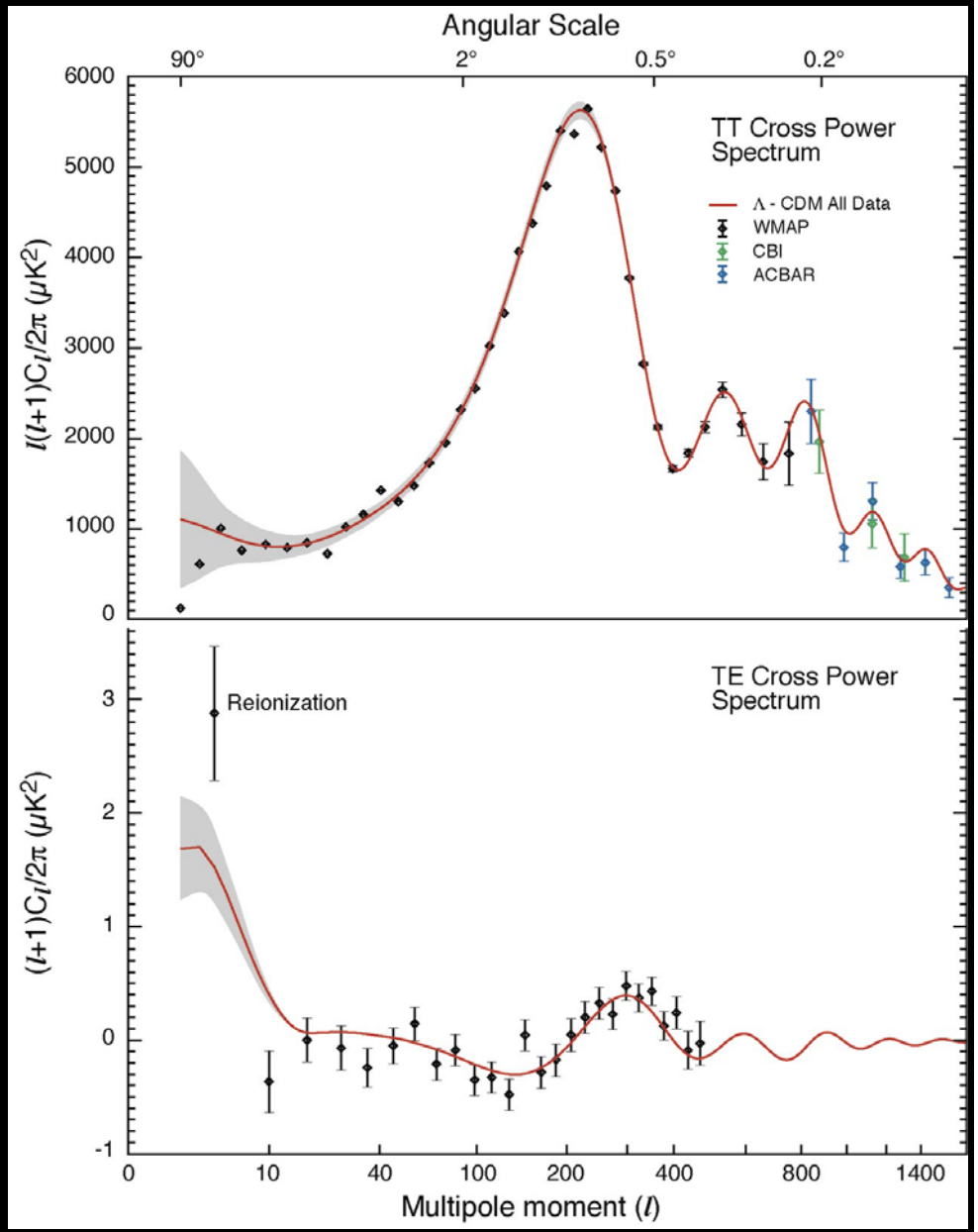
Microwave background radiation anisotropy: dipole removed


MAXIMA-I (Lee et al 2001)
B98 (Netterfield et al 2001)
DASI (Halverson et al 2001)
CBI (Padin et al 2001)
DMR
$\ell(\ell+1)C_\ell/(2\pi)$ [μK^2]
multipole ℓ
6000
4000
2000
0
−2000
0
200
400
600
800
1000
1200


MAXIMA−I (Lee et al 2001)
B98 (Netterfield et al 2001)
DASI (Halverson et al 2001)
CBI (Padin et al 2001)
DMR
MAXIMA−1 Best fit
(Stompor et al 2001)
$\ell(\ell+1)C_\ell/(2\pi)$ $[\mu K^2]$
multipole ℓ
6000
4000
2000
0
−2000
0
200
400
600
800
1000
1200

WMAP main results





low-redshift galaxy surveys : 2dFGRS
Agrees with CBR results

- collaboration of 30 astronomers split between Australia and the UK

- survey is now complete and has measured redshifts for 220000 galaxies in the local Universe (b-band selection)

http://www.mso.anu.edu.au/2dFGRS/

Hence, concordance model:

- Expanding Friedmann-Lemaitre model

- Evolves from hot big bang era when nucleosynthesis took place, preceded by inflation

- The Universe has nearly flat space sections, as expected on the basis of inflationary theory

$$\Omega_0 = \Omega_{m0} + \Omega_\Lambda$$
$$\sim 0.3 + 0.7 \sim 1.0$$

- Both dark matter and dark energy at late times

$H_0 \sim 66 \pm 10$ km/sec/Mpc, $t_0 \sim 1.4 \pm 0.2 \times 10^{10}$ years

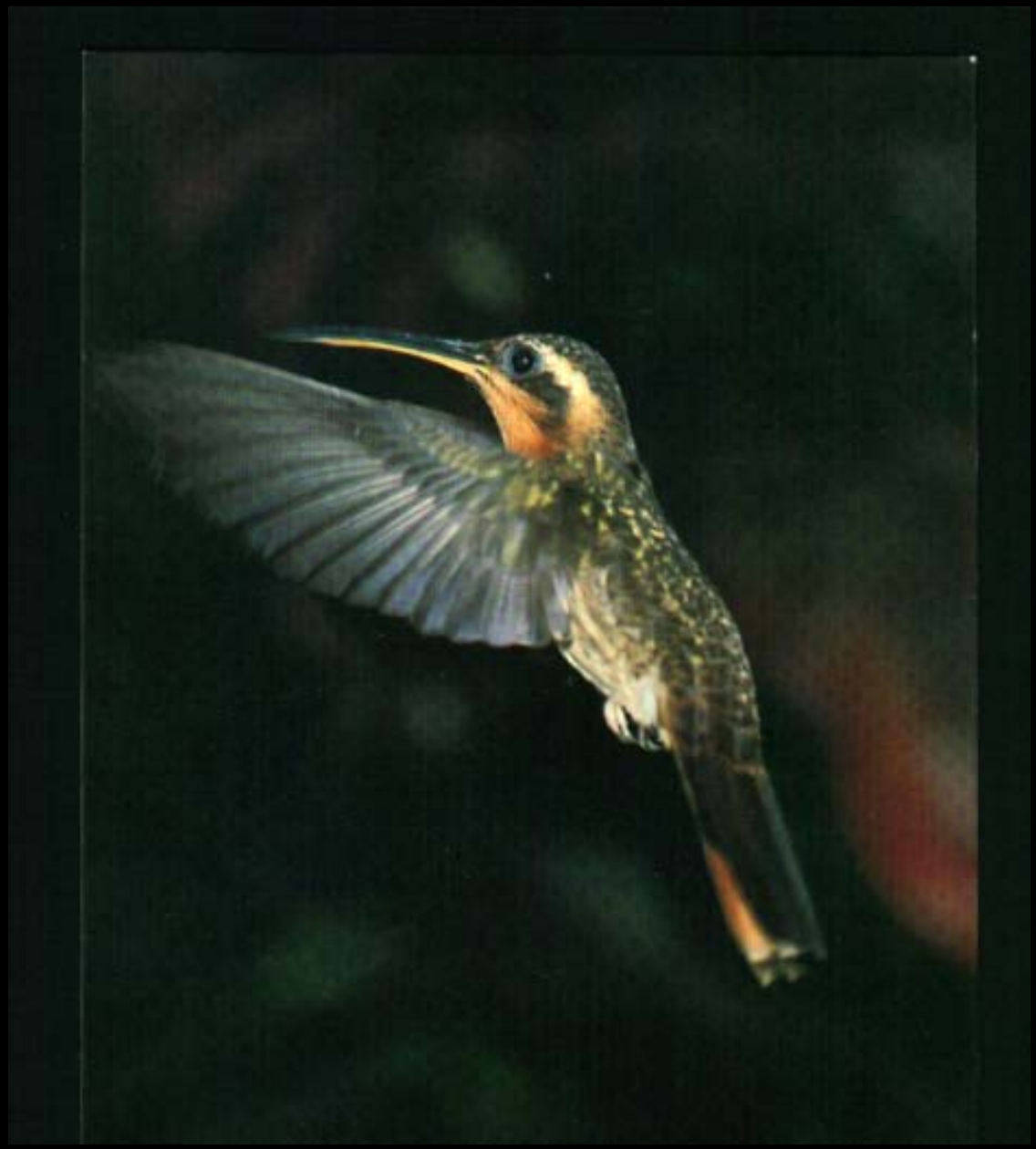
Context for humanity

Life occurs in this context:

The laws of physics plus boundary conditions for the universe allow life to exist

First life by accident then continual improvement by Darwinian processes – continual accretion of biological information and creation of higher order structures: emergence of complexity

Eventual emergence of mind and consciousness then language society and social constructions



The universe and our existence

Our existence and nature is allowed by the initial data but not uniquely implied by it

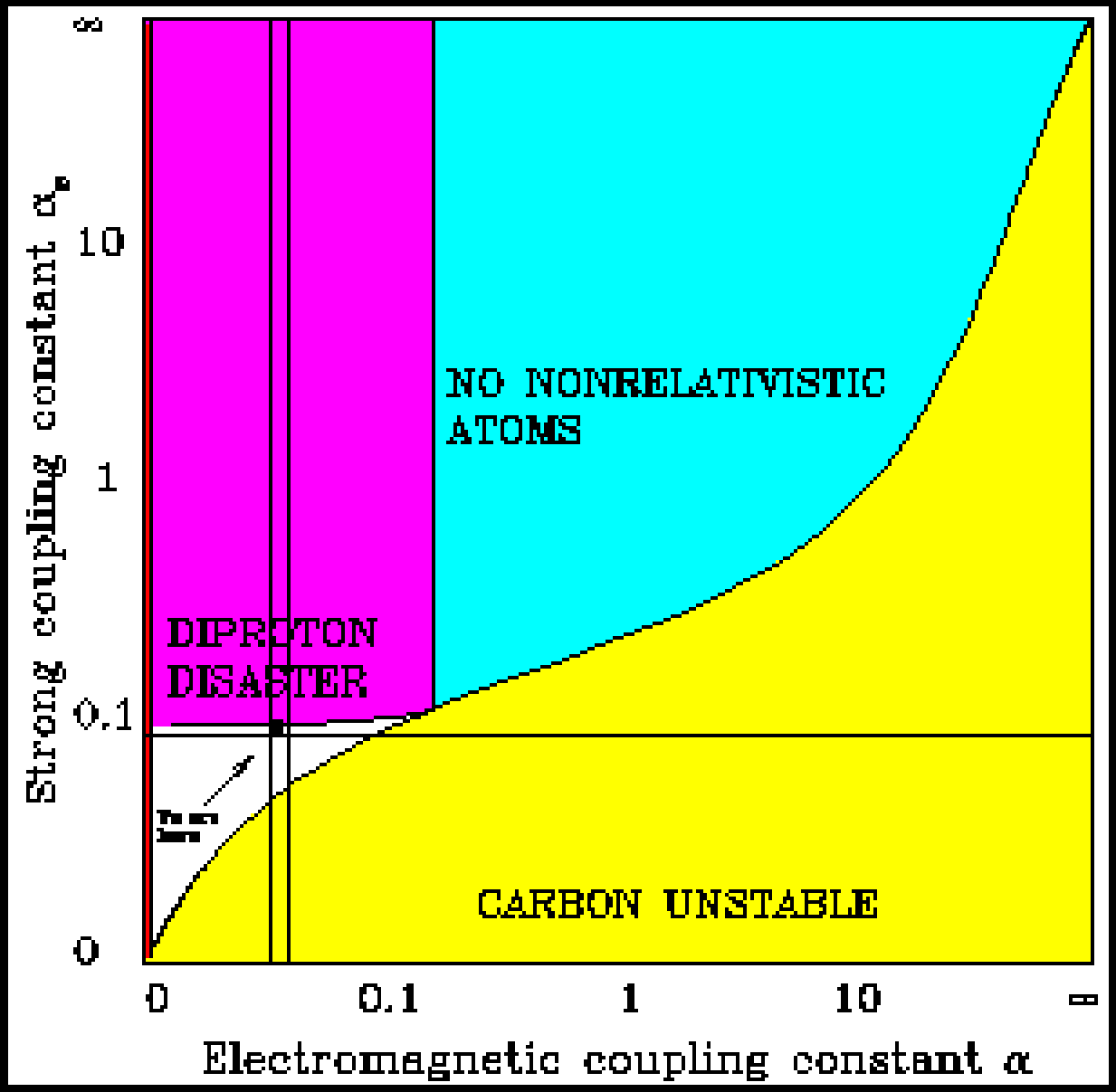
Higher levels of structure and order come into being with their own autonomous causal powers

Physics allows this but does not uniquely imply it

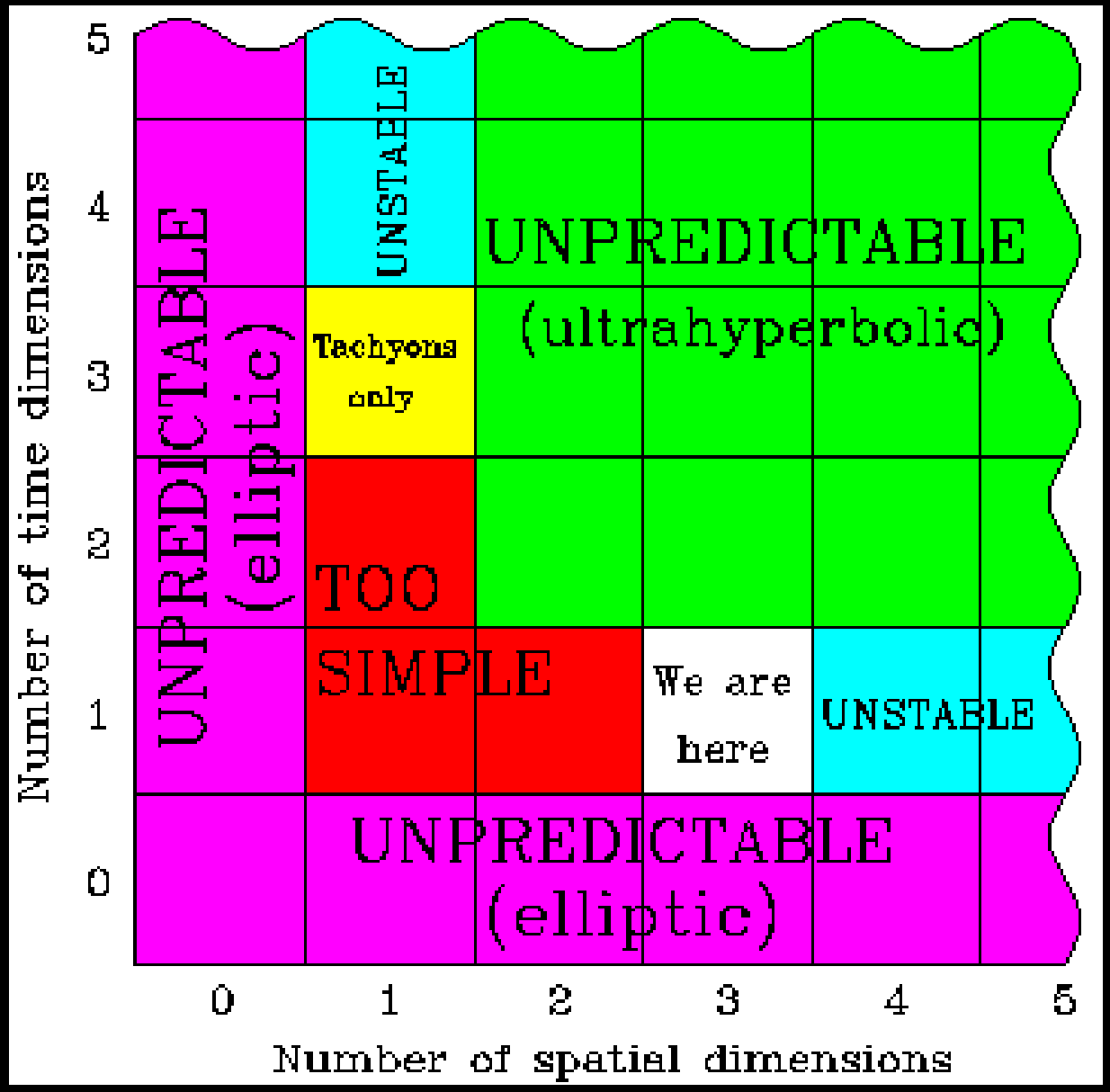
The conditions for the existence of life

Significant alteration of either physical laws or boundary conditions at the beginning of the universe would prevent the existence of intelligent life as we know it in the universe.

If physical laws were altered by a remarkably little amount, no evolutionary process at all of living beings would be possible; so these laws appear fine-tuned to allow the existence of life.



Limits on physics allowing complex structures [Max Tegmark]



Only special dimensions allow complex systems [M Tegmark]

Fine tuning: *Just Six Numbers* [Martin Rees]

- *1. N = electrical force/gravitational force =10^{36}*
- *2. E = strength of nuclear binding = 0.007*
- *3. Ω = normalized amount of matter in universe = 0.3*
- *4. Λ= normalised cosmological constant = 0.7*
- *5. Q = inhomogeneous seeds for cosmic structures = 1/100,000*
- *6. D = number of spatial dimensions = 3*

Emergence and the Laws of Nature

- Laws of nature underlie this
- Permit but do not completely causally control what happens

- Hence are of *fine-tuned nature*
- How they do it is not fully clear – what fine-tunings at the lower levels are needed for the entire higher level hierarchy to exist

Fundamental physics

- *What feature of physics is the key to existence of truly complex structures?*

-What for example allows modular separation of sub-nuclear, nuclear, atomic, and molecular properties from each other in such a way as to allow the development and functioning of DNA, RNA, proteins, and living cells?

- Whatever it is, this must claim to be the `truly fundamental' feature of physics

- *what physics underlies supramolecular chemistry?*

- it is the foundation of the complexity we see

The Hierarchy of Structure:

Psychology/ Behaviour

Botany/zoology/physiology

Cell biology

Biochemistry

Chemistry

Physics

Particle physics

Separation of structural levels, independence of levels

Fundamental physics

Is the key:

- the general nature of *quantum theory* (e.g. superposition, entanglement, decoherence) and its classical limit?

- the specific nature of *quantum field theory* and *quantum statistics* [Yes: stability of matter] and/or Yang-Mills *gauge theory* ?

- the specific *potentials* and *interactions* of the standard particle physics model and its associated *symmetry groups* ?
- *basic particle properties* (existence of three families of quarks, leptons, and neutrinos, for example)?
- *basic properties of forces* (effective existence of four fundamental forces; their unification properties)?

Fundamental physics

Is the key:

- the specific *masses* and *force strengths* involved?
- the value of *specific constants* such as the fine structure constant?

Or is it

- *The combination of all of these?*

[Craig Hogan: *out of the twenty parameters of the standard model, complexity depends on just five of its parameters.* *Rev.Mod.Phys.* **72** (2000) 1149-1161]

- But then why do they work together so cunningly?
- they are the foundation of human life and of the brain

Ensembles/Multiverses

Why does the Universe have the peculiar properties that allow intelligent life to exist? (the anthropic issue)

It is claimed by some that this is because of the physical existence of ensembles of universes, or 'multiverses'.

This is being increasingly defended, because it is the only purely scientific approach to solving the puzzles raised by the anthropic issue: if enough variety of properties occur then somewhere conditions will be right

For example, this argument has been used to explain the value of the cosmological constant *[Weinberg]*

Probability and ensembles

This potentially brings cosmology within the realm of statistical analysis, giving a basis for probability

This provides the only scientific basis for attempts to use the anthropic principle to determine the values of parameters such as the cosmological constant, for which we otherwise have no plausible explanation:

BUT it is completely unverifiable –
metaphysics rather than physics

- It denies the uniqueness of the universe

Philosophical issues

Relation of observations to theory:

Because of the existence on the one hand of visual and causal horizons and on the other of the physics horizon, there are many limits on what can be observationally proven in cosmology

Which has priority in one's cosmological theory: physical explanation or observation and testability? Depending on one's attitude leads to different priorities.

For example, in the chaotic inflation proposal, theory takes precedence over geometrical and physical testability.

Also a major tension between theory and testability arises as regards the issue of the multiverses

Existence of other life

Are we alone?

•Given these laws and existence of planets, life is almost inevitable

• Almost certainly we are not alone: there are many others out there

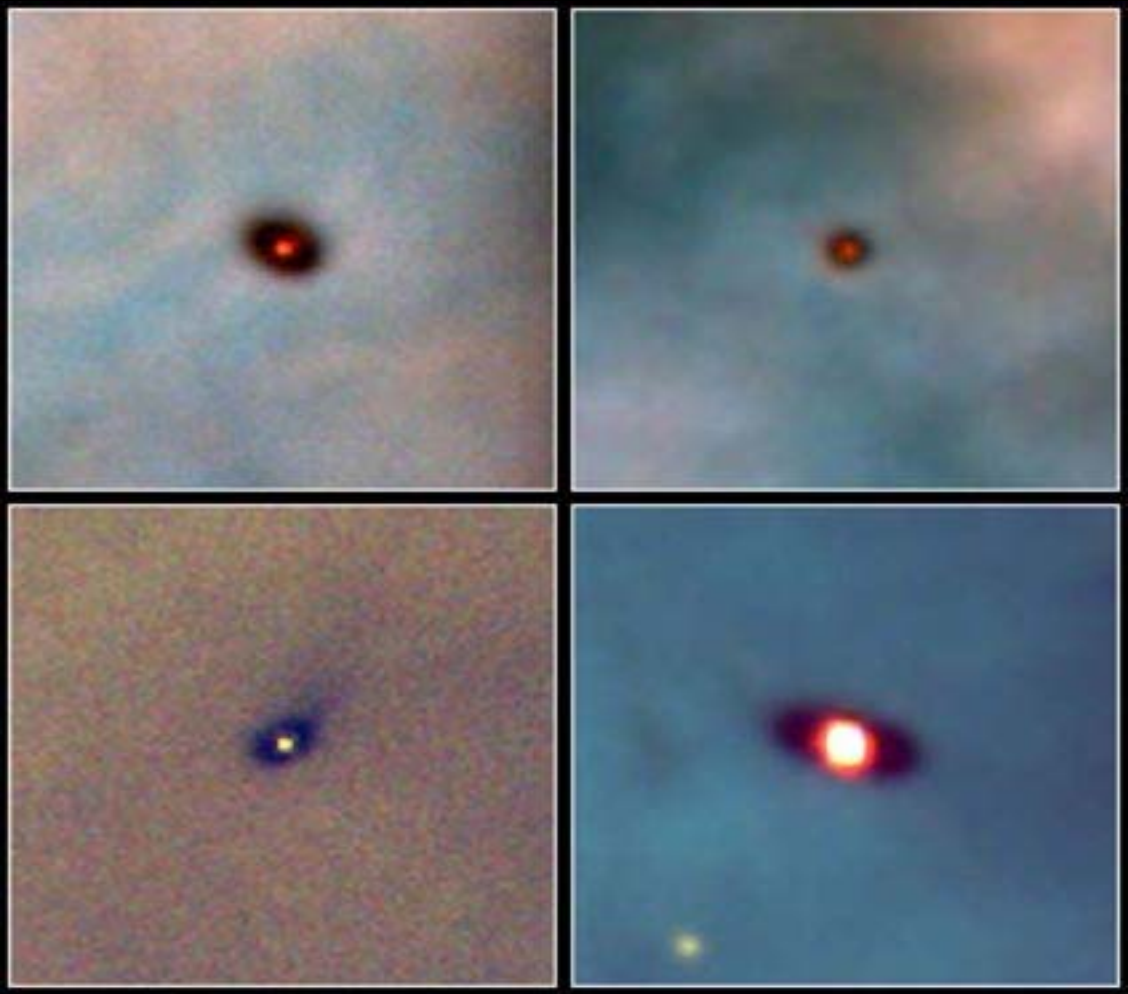
• But they may not be in communicable distance

• If they are there how like us will they be? Will we still be alone even if they exist?

Existence of other planets

Planetary proto disk

Existence of other planets



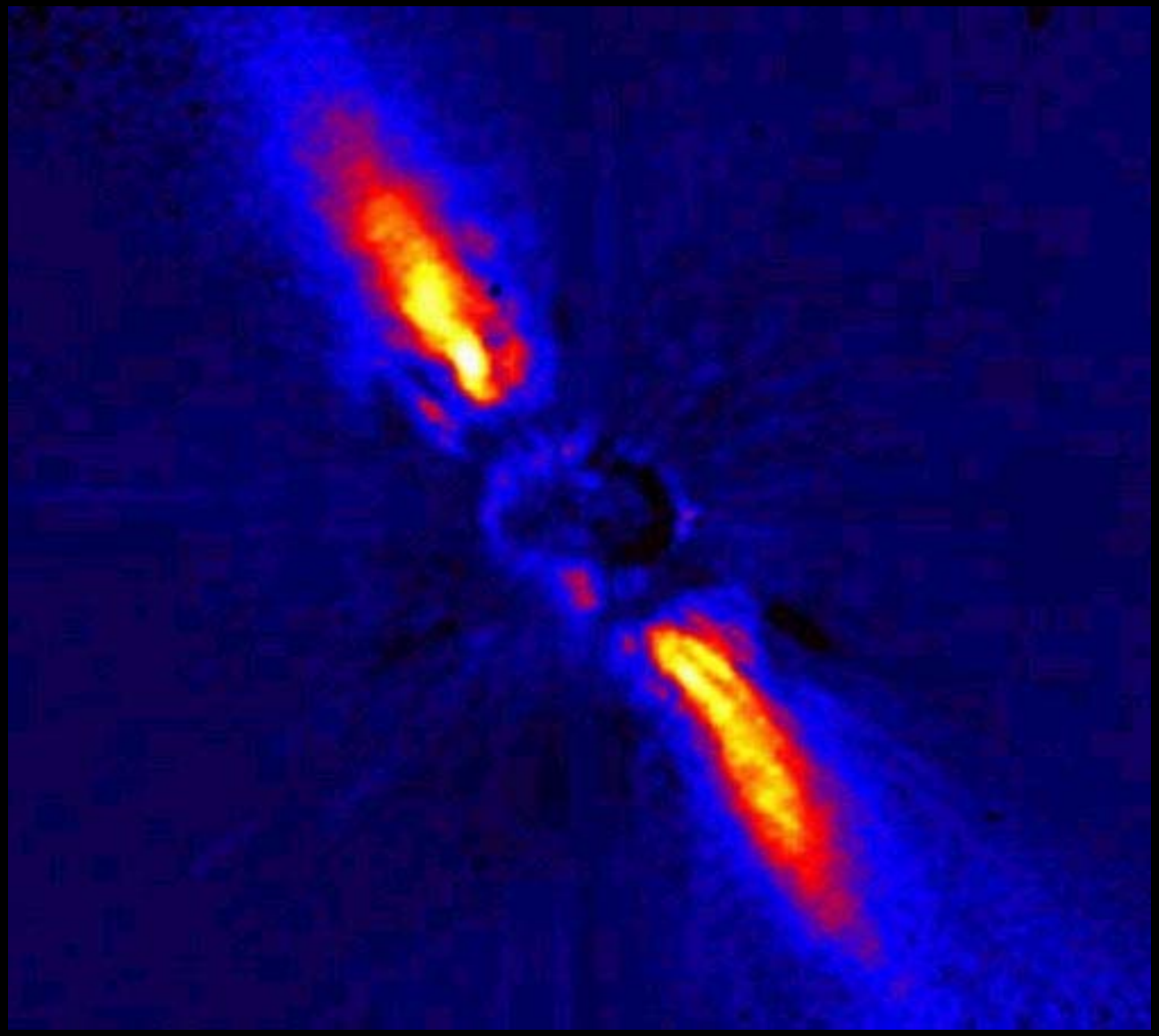
Protoplanetary Disks
Orion Nebula

HST · WFPC2

PRC95-45b · ST ScI OPO · November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

Existence of other planets

β pictoris



Existence of other life

Are we alone?

•Given these laws and existence of planets, life is almost inevitable

• Almost certainly we are not alone: there are many others out there

• But they may not be in communicable distance

• If they are there how like us will they be? Will we still be alone even if they exist?

Nature of life

- ***Convergence of biochemistry and of mechanics of life***

- Only a restricted number of ways to solve the problems of life which has universal necessities

- Simon Conway Morris, *Life's Solution: Inevitable Humans in a Lonely Universe*
- S Vogel: *Cats' Paws and Catapults: Mechanical Worlds of Nature and People*

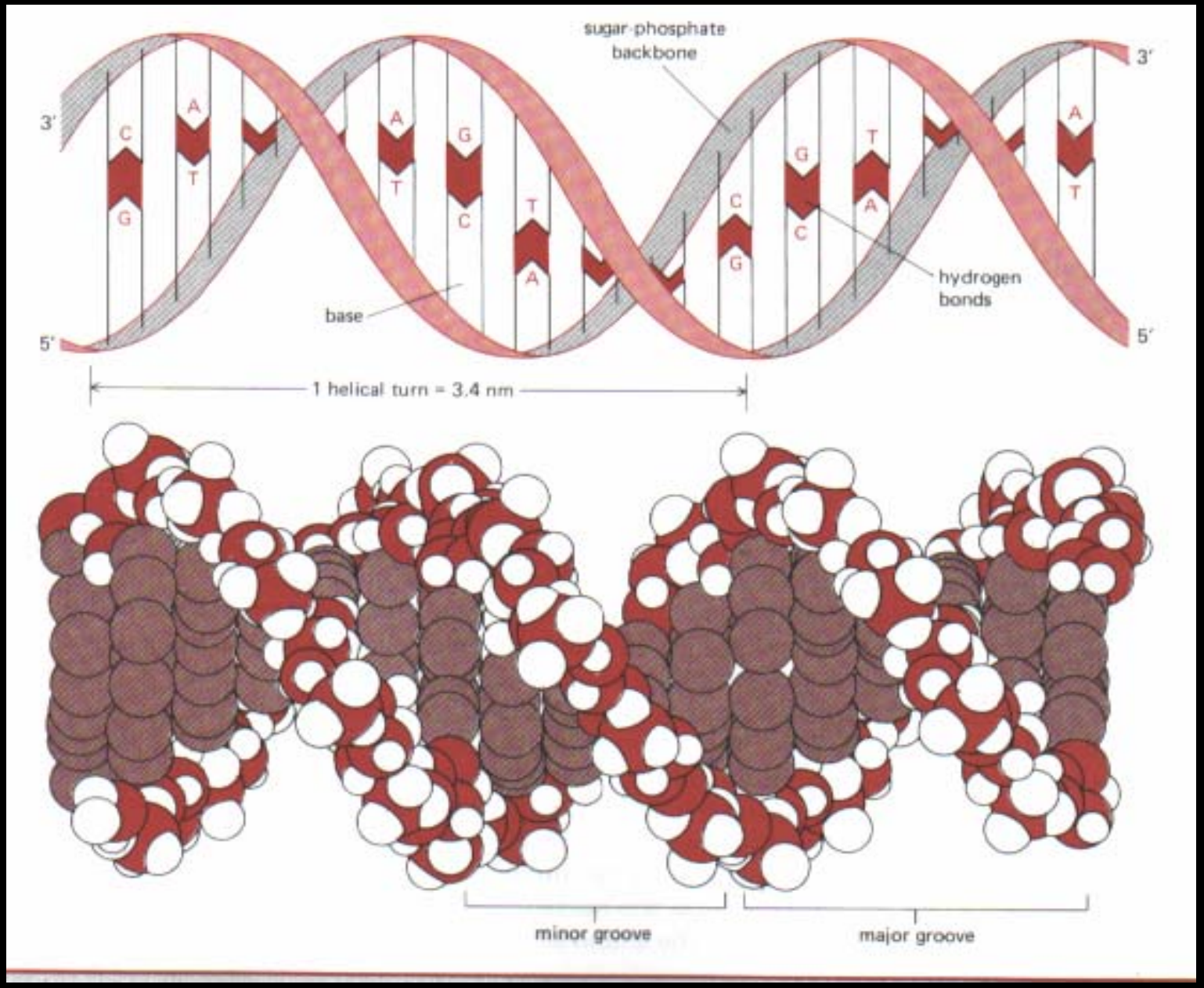
- ***almost certainly Carbon-based, RNA, DNA***

- senses: eyes ears smell, brain
- limbs, food ingestion, waste disposal

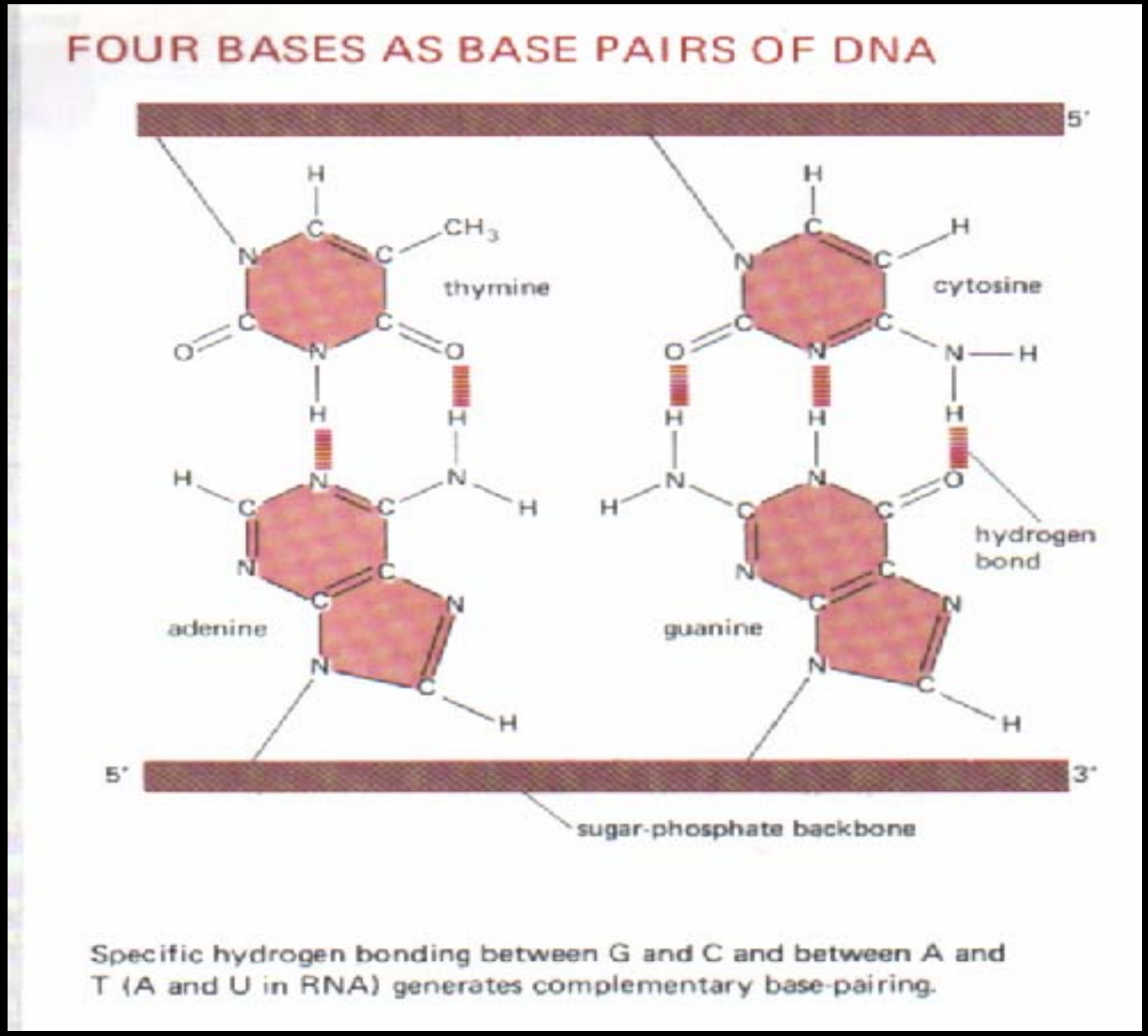
Hierarchical structure of life

- **The biosphere** - Global resource cycles
- **Biomes** - Energy and material interchange
- **Ecosystems** - Species interdependence
- **Animal populations** - Competition and the food chain
- **Individual organisms** - Physiological functioning
- **Limbs, physiological systems** - Organism homeostasis
- **Tissues** - Growth, maintenance, repair
- **Cells** - Growth, specialisation, death
- **Organelles** - Cell homeostasis
- **Macro Molecules** - Folding, recognition, binding
- **Building Block Molecules** - Combine to form polymers
- **Chemical elements** - Chemical binding

- probably duplicated



The DNA double helix with complementary base pairs

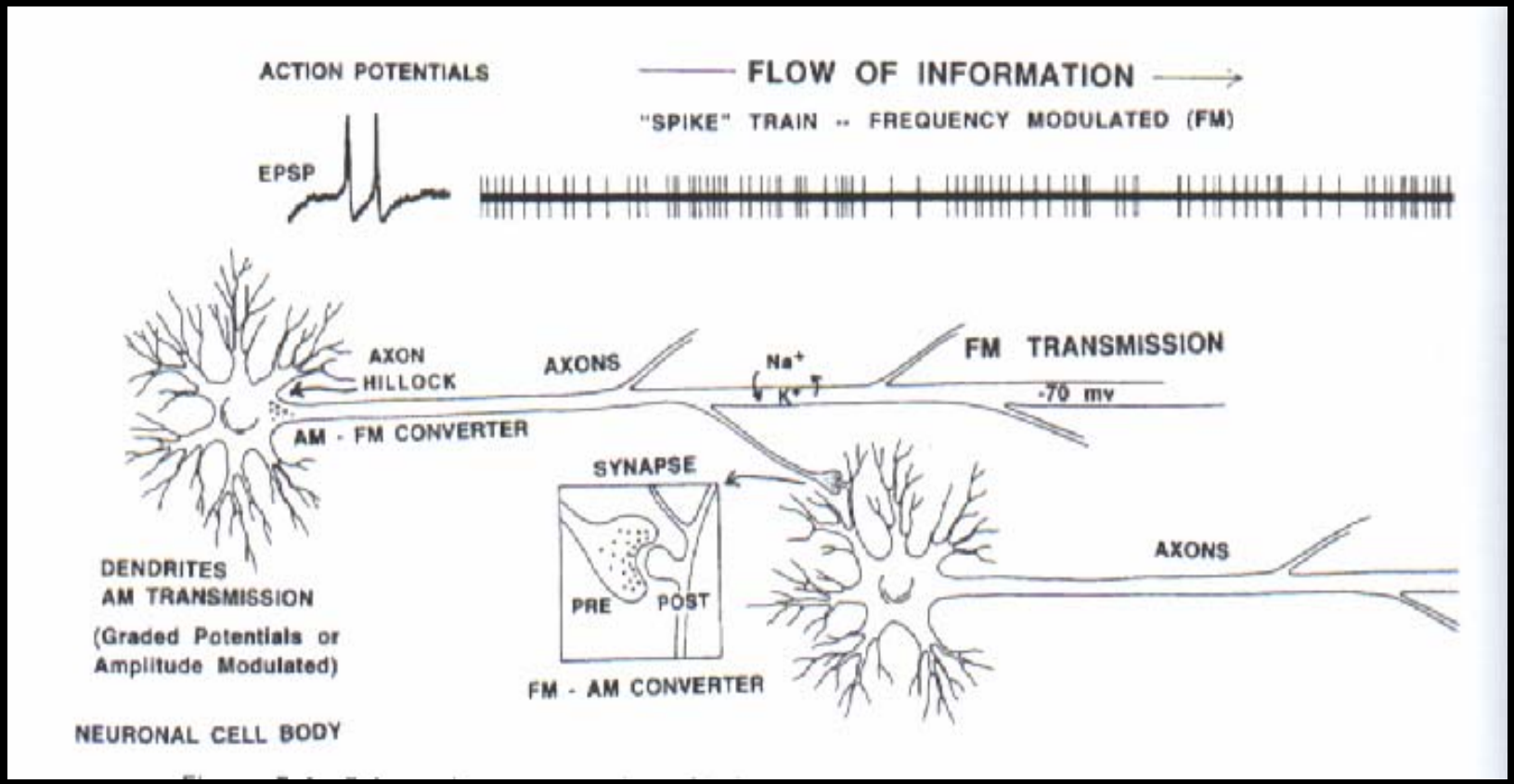


Complementarity of base pairs: maybe duplicated

1st position (5′ end)	2nd position U	2nd position C	2nd position A	2nd position G	3rd position (3′ end)
U	Phe	Ser	Tyr	Cys	U
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	STOP	STOP	A
	Leu	Ser	STOP	Trp	G
C	Leu	Pro	His	Arg	U
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A
	Val	Ala	Glu	Gly	G

Figure 3–15 The genetic code. Sets of three nucleotides (codons) in an mRNA molecule are translated into amino acids in the course of protein synthesis according to the rules shown. For example, the codons GUG and GAG are translated into valine and glutamic acid, respectively. Note that those codons with U or C as the second nucleotide tend to specify the more hydrophobic amino acids (compare with Panel 2–5, pp. 54–55).

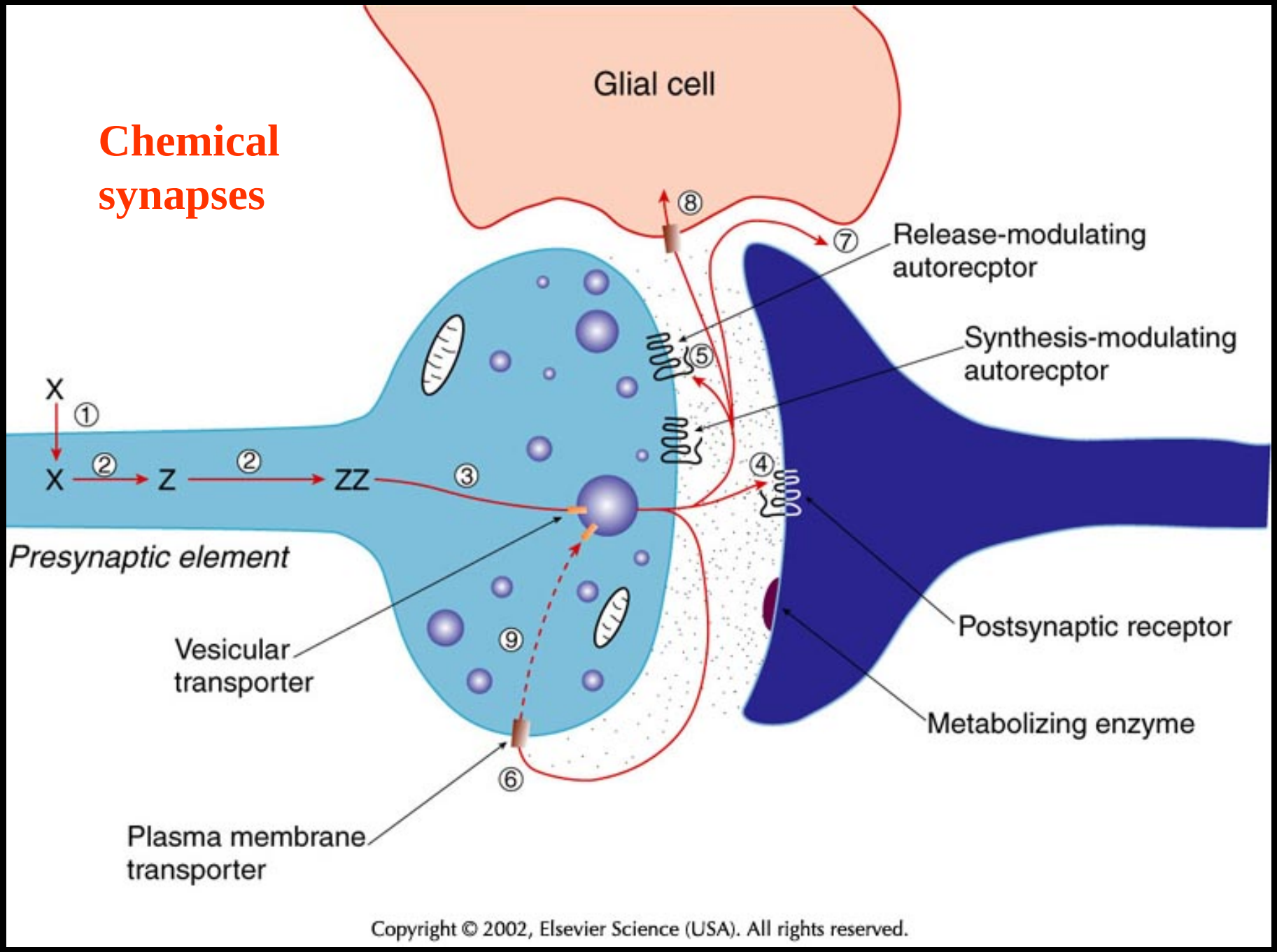
The genetic code: triplets of bases code for amino acids that form proteins: ***not necessarily unique***



Information flows: dendrites to nucleus to axon to synapse

- Somewhat ideosyncratic?

Chemical synapses



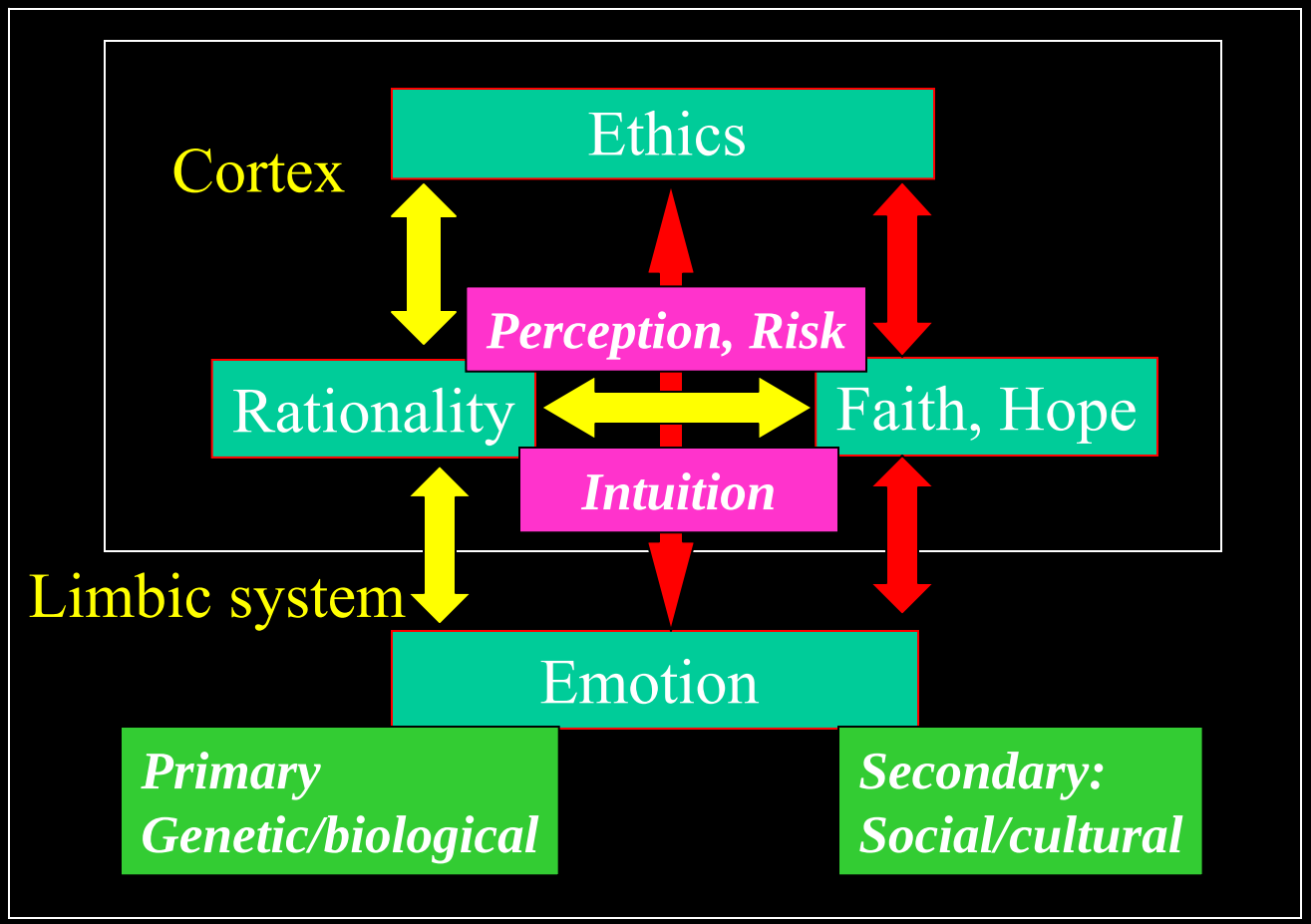
"Are we alone ?"

- Convergence also of way brain works – to meet universal necessities

- "Are we alone" – will we find them companionable beings or total aliens??

- Psychological universals: may well find them similar in psychological makeup as well

- The processes here are probably universal



Each of Rationality, Emotions, Ethics, Faith and Hope are influenced by each of the other, with reason being the key player trying to bring the others into harmony. The instinctive brain underlies this as does intuition [not depicted].

Conditions for life

• It is the overall set of laws and initial conditions that make our own existence possible.

• ***There is a considerable degree of fine-tuning of initial conditions and laws that underlies this existence.***

• The ultimate reason this is so is a metaphysical issue that is undecidable through any scientific experimentation.

• *Science need not undermine our sense of wonder and awe as regards the remarkable feature of our joint and individual existence.*

1: Initial data and our existence

The initial data for the observed universe is on the last scattering surface

Key issue: to what degree does it determine the nature and behaviour of what we see around us?

For instance: does that data determine what I am saying and what you are thinking at this moment?

No: that does not make sense: meaning cannot be directly implied by random initial data

Autonomously effective mind has to come into being as an emergent phenomenon