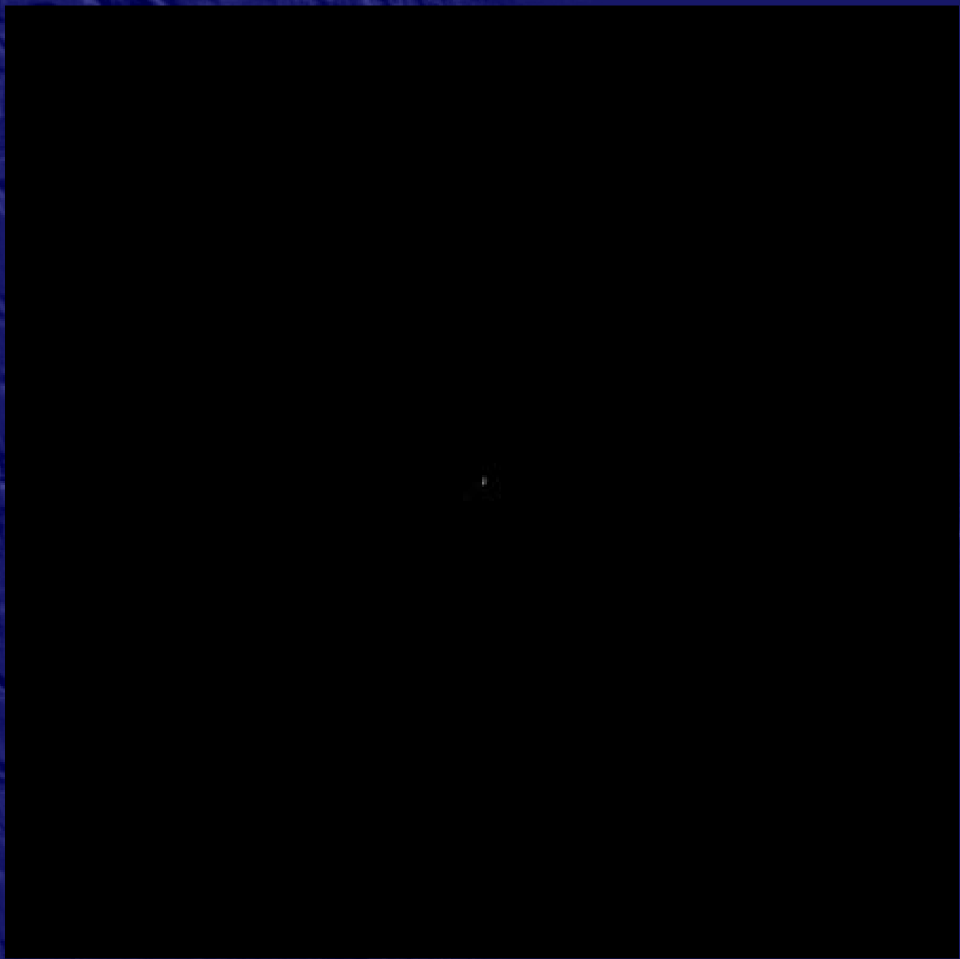
Astroparticle Physics

1. High Energy Particles from the Cosmos
2. The new Astronomy
3. **The Cosmic Microwave Background Radiation**
4. Search for Dark Matter (DM)

CMBR and the history of the universe

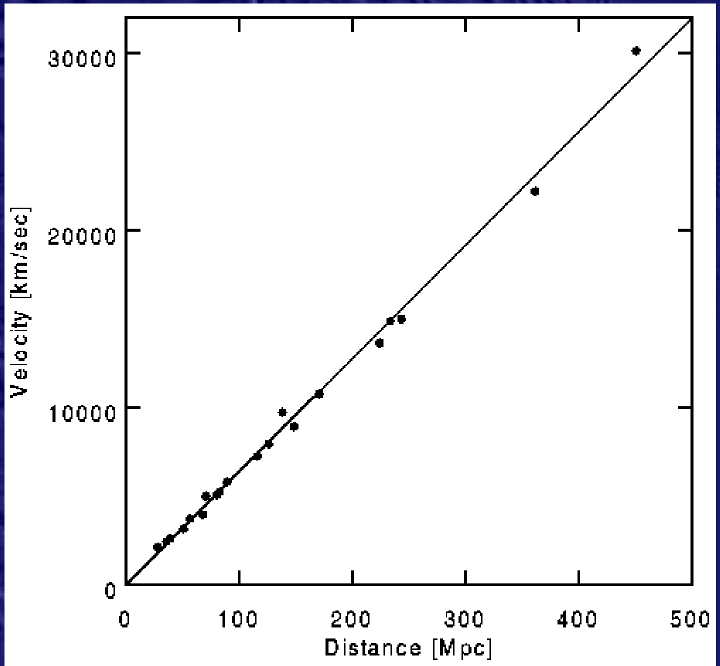


Short History of Cosmological Ideas:
http://www.physics.fsu.edu/courses/spring99/ast1002h/cosmology/cosmol.htm

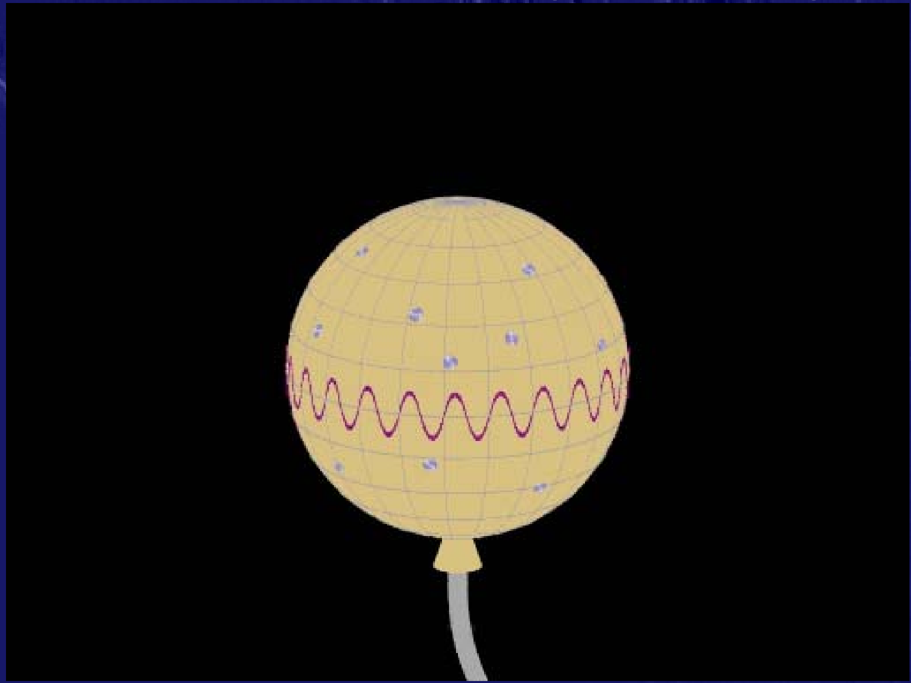
Expansion of the Universe

The universe expands and thus "cools" down

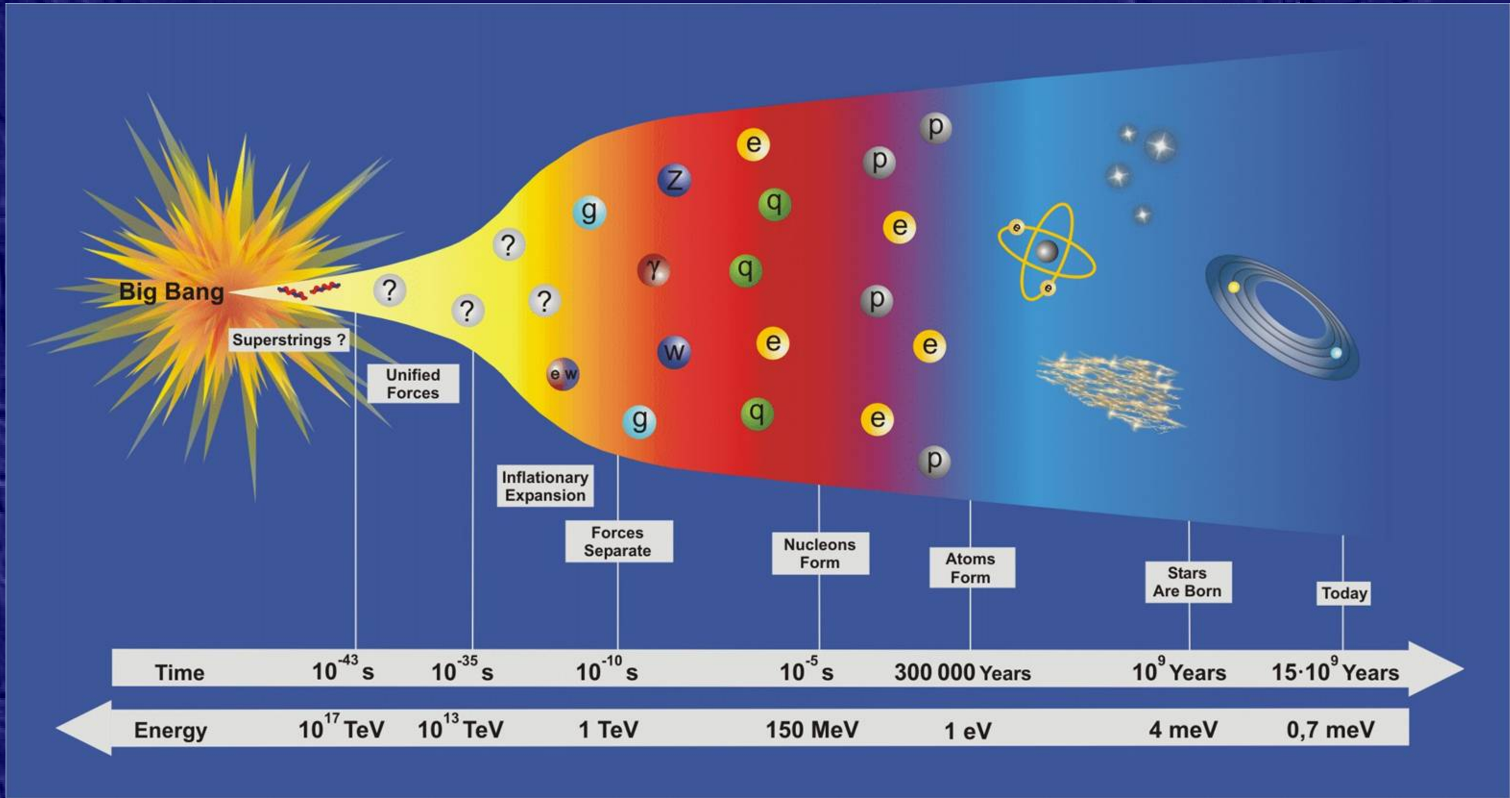
Hubble 1928: the universe expands!



Photons are shifted to larger wavelengths



Introduction to the CMBR (1)



Do we understand the cosmos?

What teaches the cosmos on HEP?

Analyze the oldest radiation!

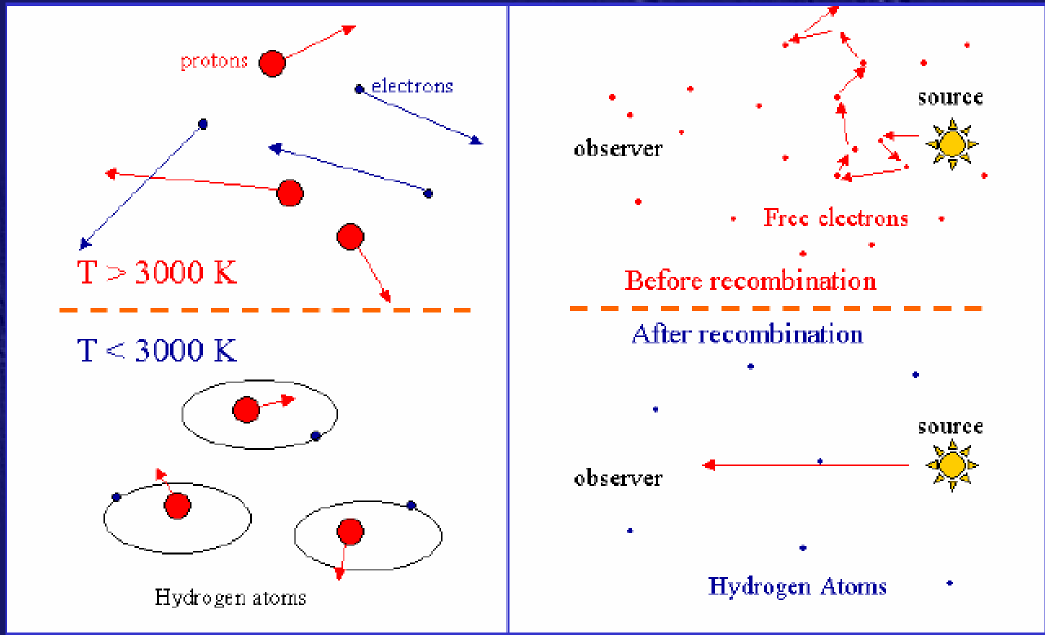
Wayne Hu:
http://background.uchicago.edu/~whu/

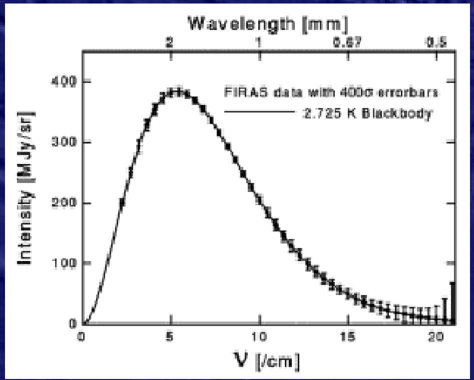
Max Tegmark:
http://www.hep.upenn.edu/~max

Introduction to the CMBR (2)

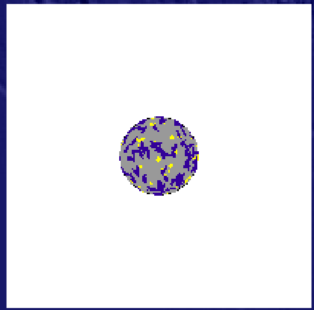
380.000 years after Big Bang (at z=1089) the universe becomes transparent.

The first unscattered photons are now observed as a black body radiation with T= (2.725 ± 0.001) K





The spectral shape is (nearly) unaffected by the later development of the cosmos.



The Physicist's Interest in the CMBR

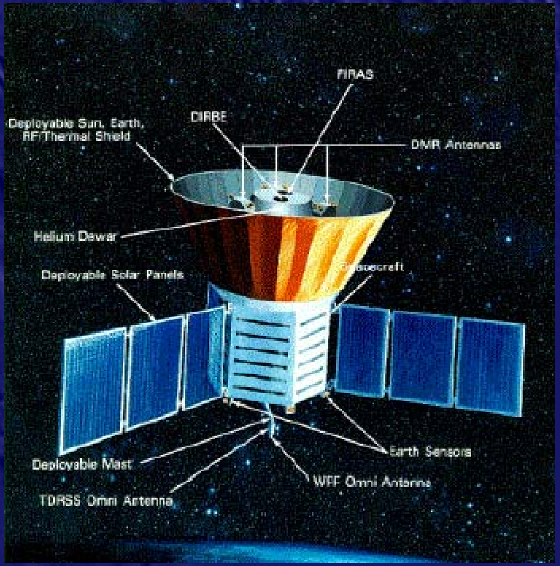
- THE most convincing proof of the Big Bang theory (predicted by Gamov 17 years before discovery)

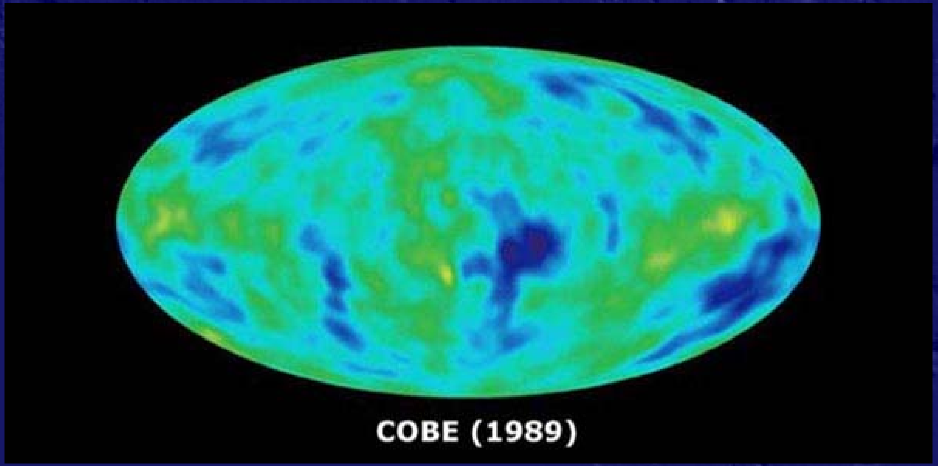
Penzias und Wilson

✓

The Physicist's Interest in the CMBR

- THE most convincing proof of the Big Bang theory (predicted by Gamov 17 years before discovery)
- A CMBR sky map should show tiny temperature fluctuations (level 10^{-5})





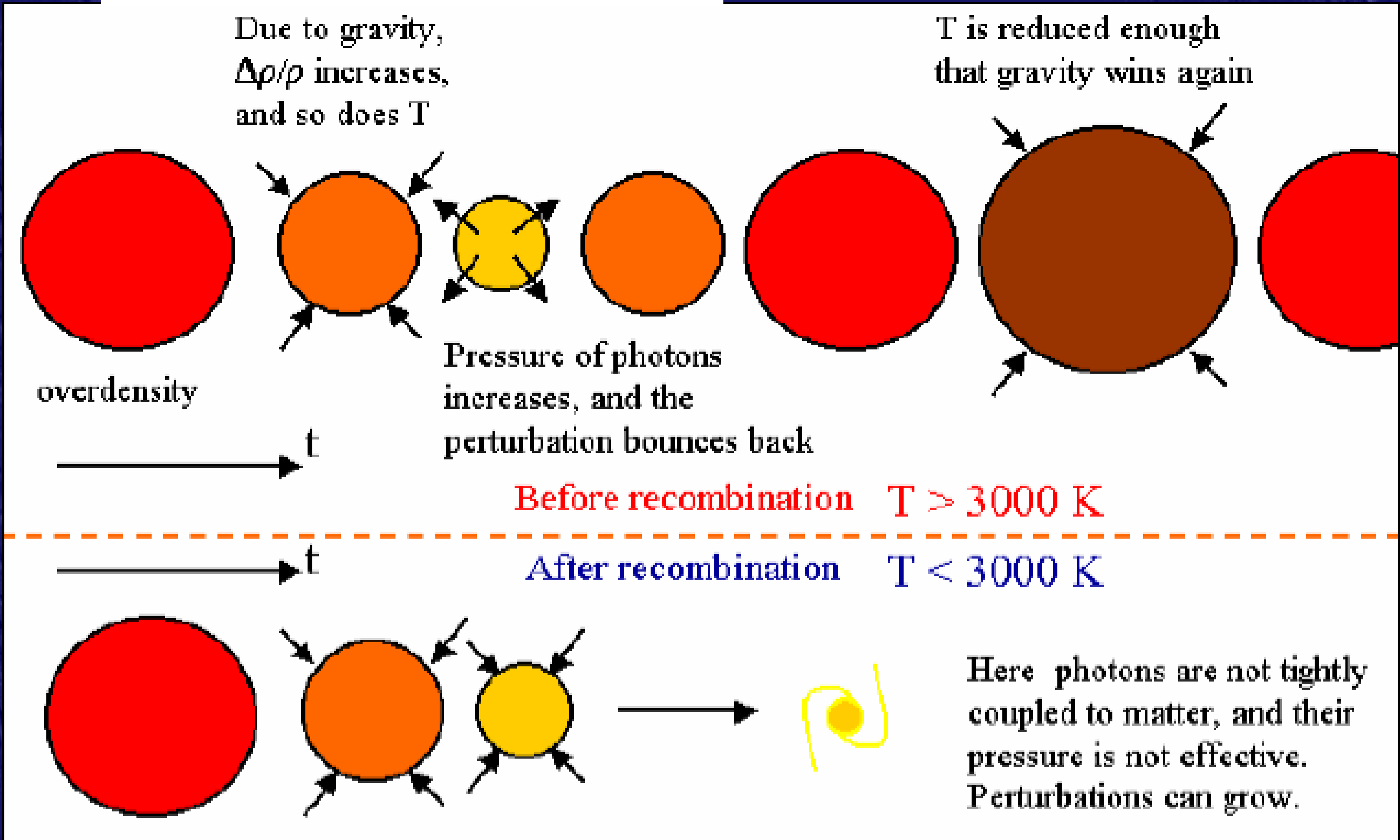
The Physicist's Interest in the CMBR

- THE most convincing proof of the Big Bang theory (predicted by Gamov 17 years before discovery)
- A CMBR sky map should show tiny temperature fluctuations (level 10^{-5})
  – Quantum fluctuationss of the very early universe enlarged by inflation
  – Seeds of structures in the universe (amplified by gravitation after recombination)

The CMBR provides experimental access to the early and probably very early universe and hence
indirect information on extremely high energy physics.

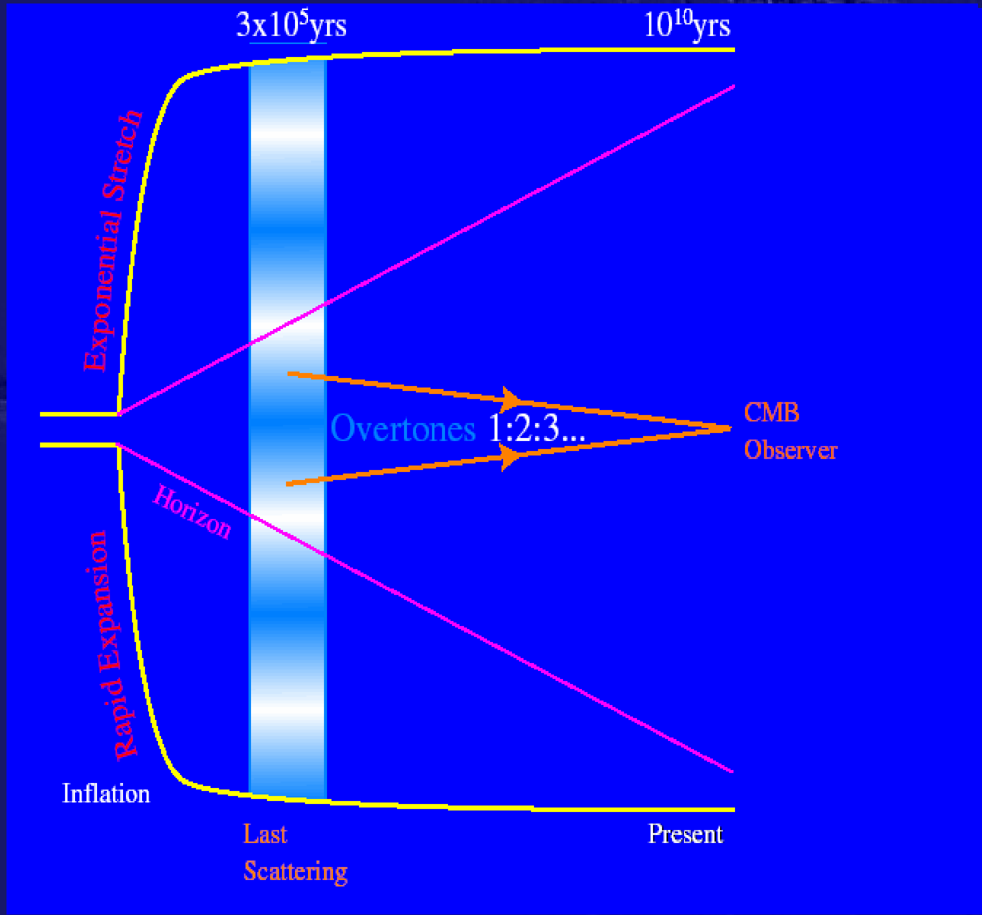
Fluctuations in the CMBR

seeds: quantum fluctuations (?)

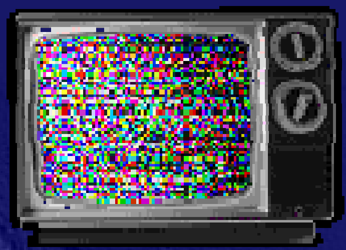


Acoustic Oscillations in the early Universe

Measure small angle temperature anisotropies
(interacting plasma, "within horizon")
over large parts of the sky
(non interacting regions, "beyond horizon")



Everyone's CMBR detector

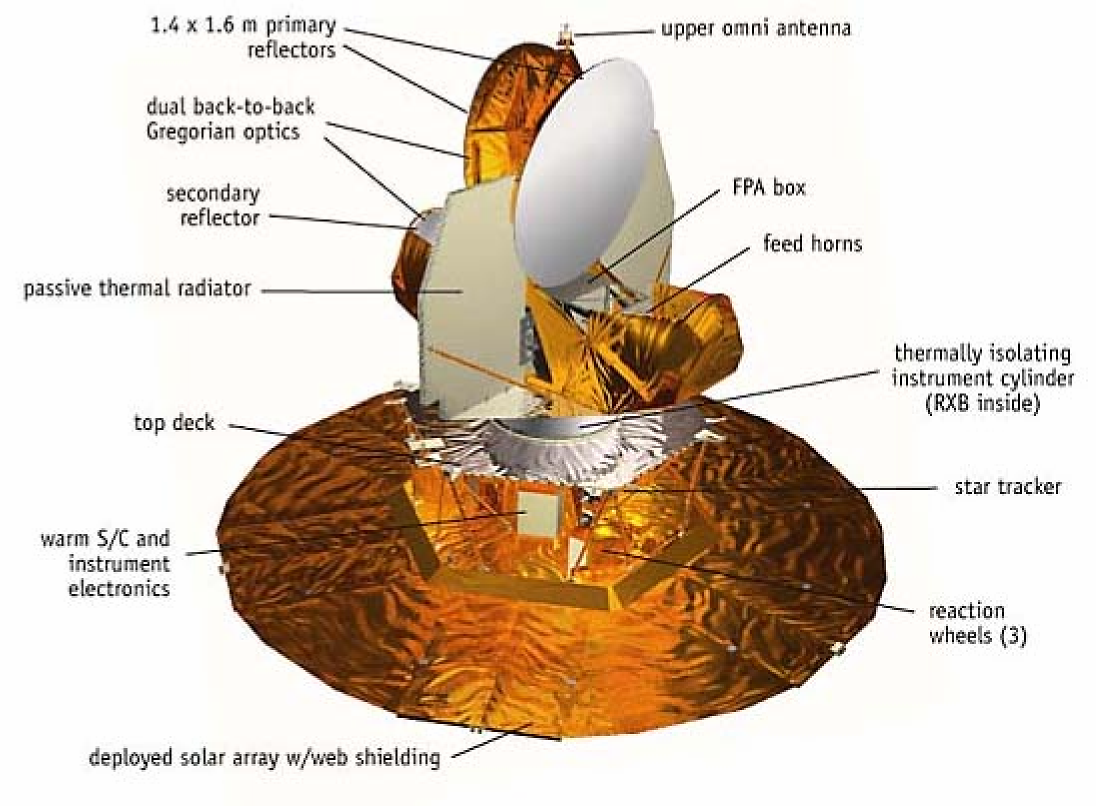


About 1% of the TV noise originates from the CMBR

A more sophisticated CMBR detector

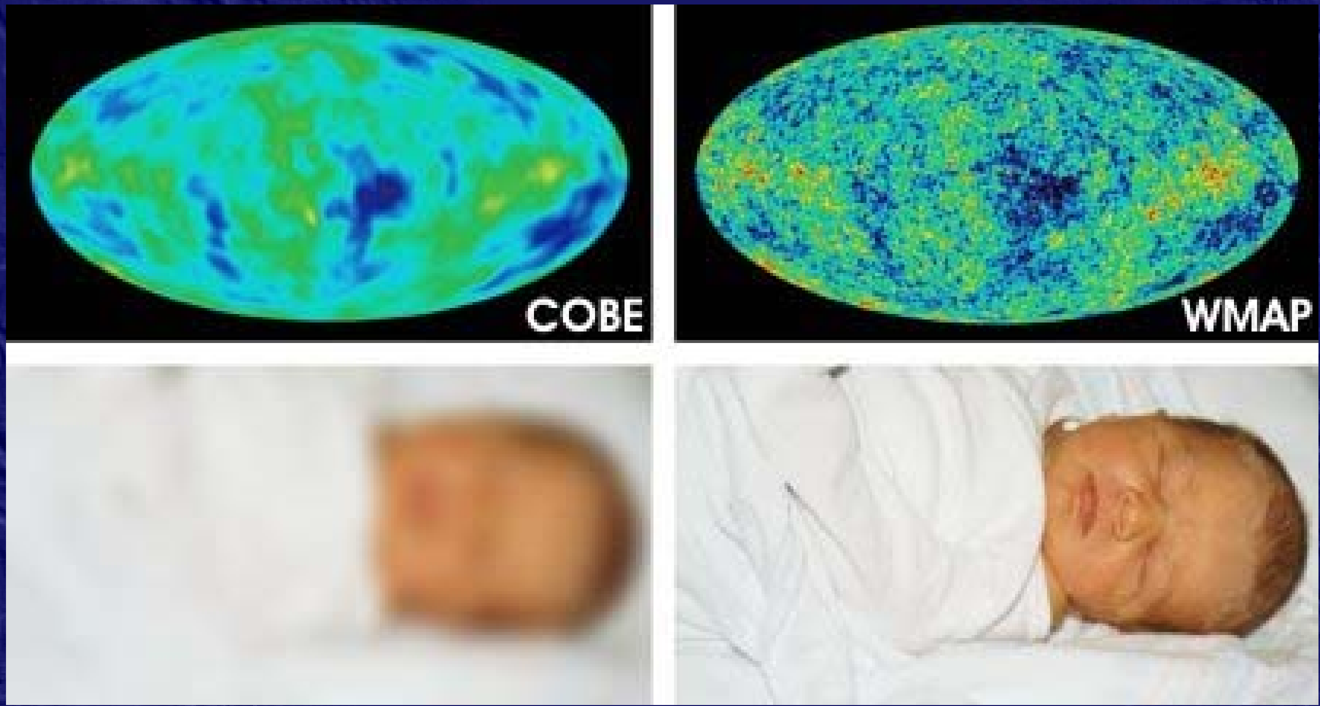
Wilkinson Microwave Anisotropy Probe (WMAP)

Launched 2001, June 30



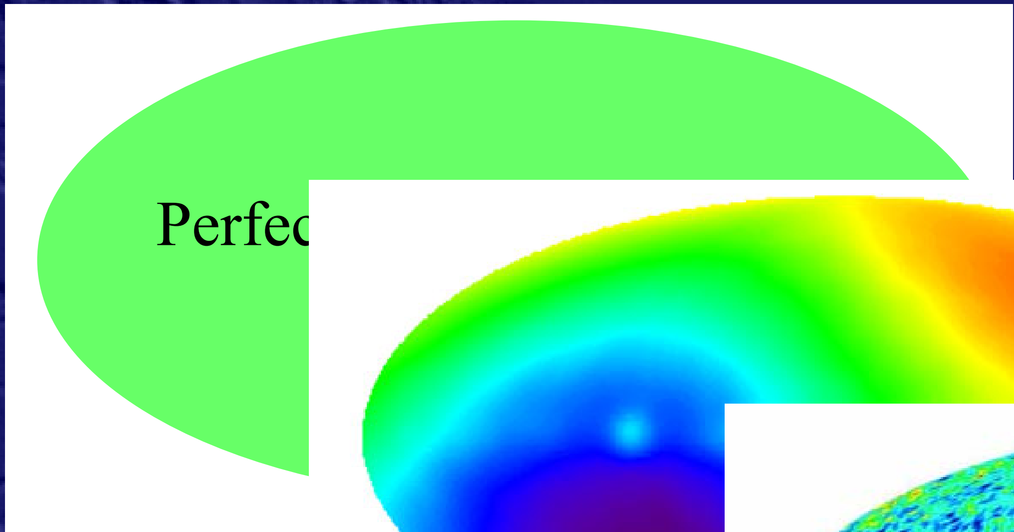
From COBE to WMAP

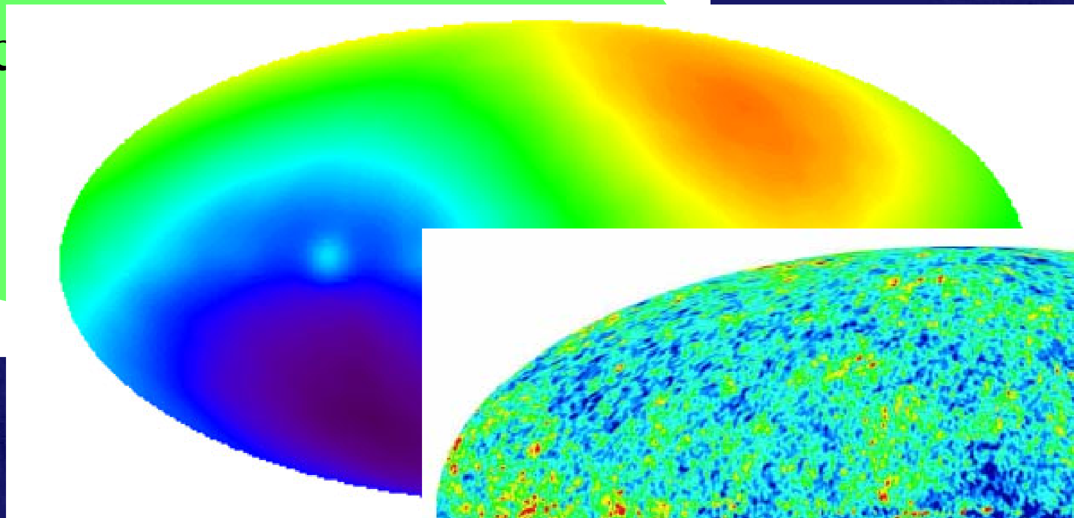
2001 launch of the *Wilkinson Microwave Anisotropy Probe*



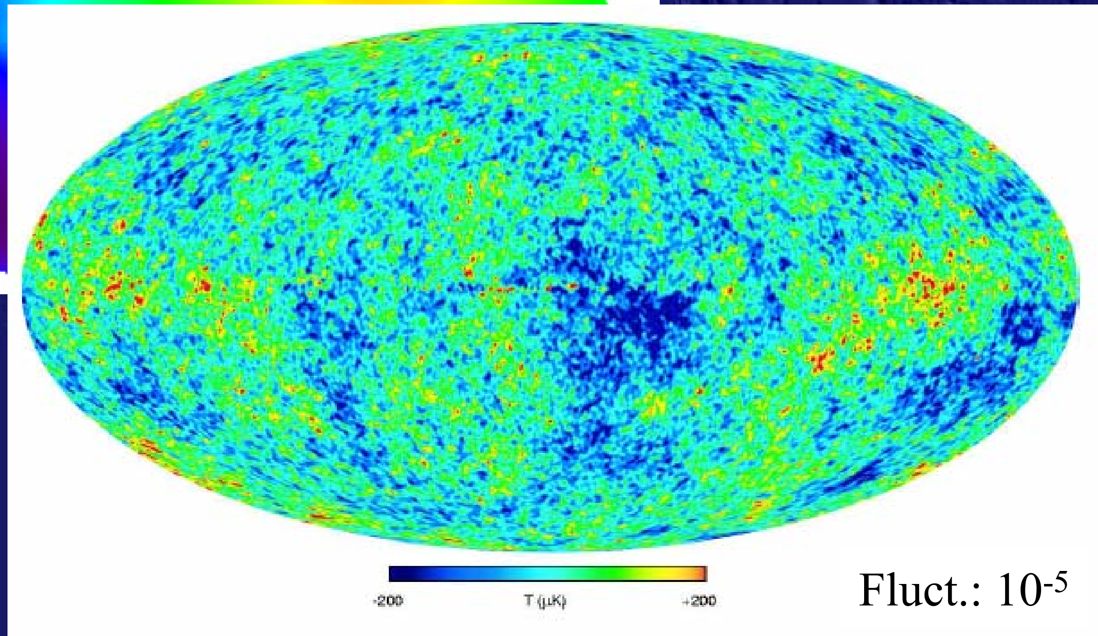
Angular resolution of WMAP up to 0.2° (COBE 7°), experimental information on higher order temperature fluctuations

The CMBR Skymap





Fluctuations: 10^{-3}
Dipole radiation
(v = 600 km/s)

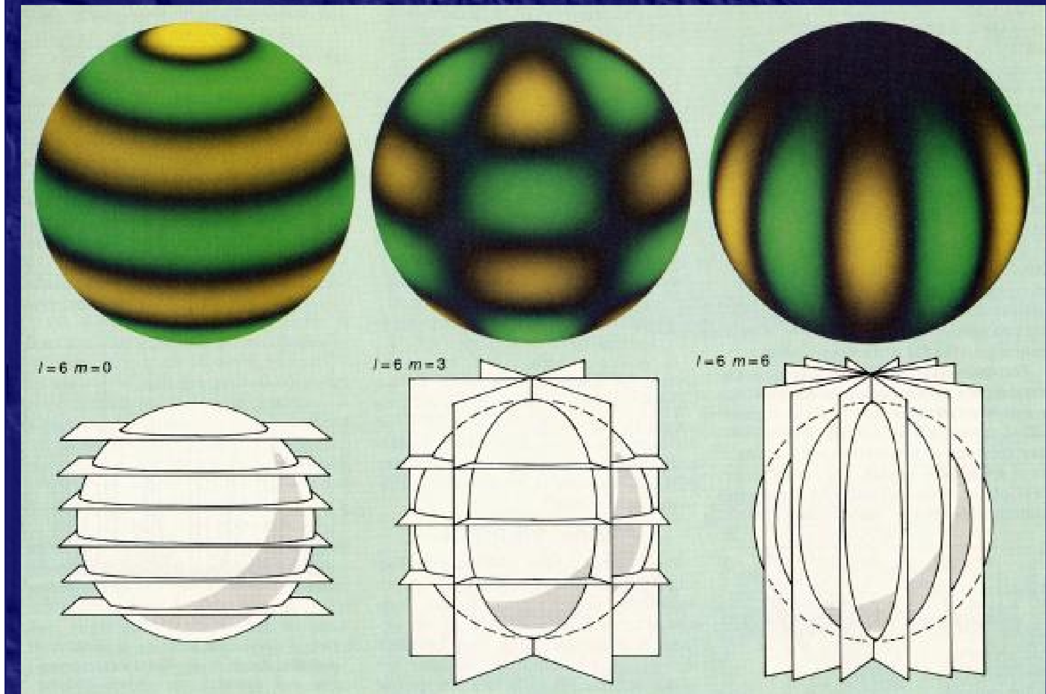


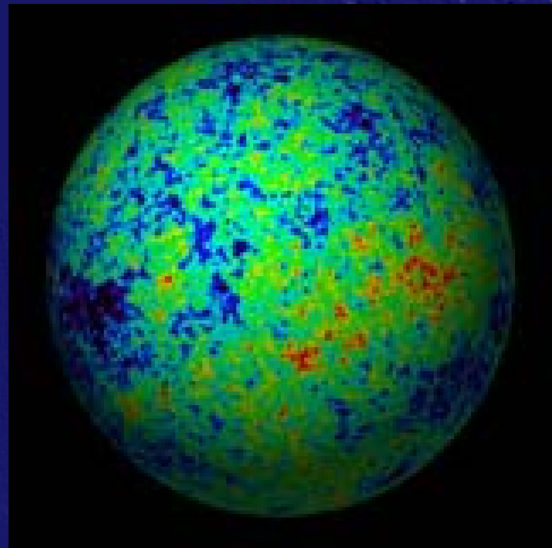
Scale:
-200 to +200 μK

Analysis of WMAP Data

Multipole expansion of the temperature fluctuations in spherical harmonics:

$\delta T(\varphi,\theta) = \Sigma_{l,m} \cdot a_{l,m} \cdot Y^{l}_{m}(\varphi,\theta)$



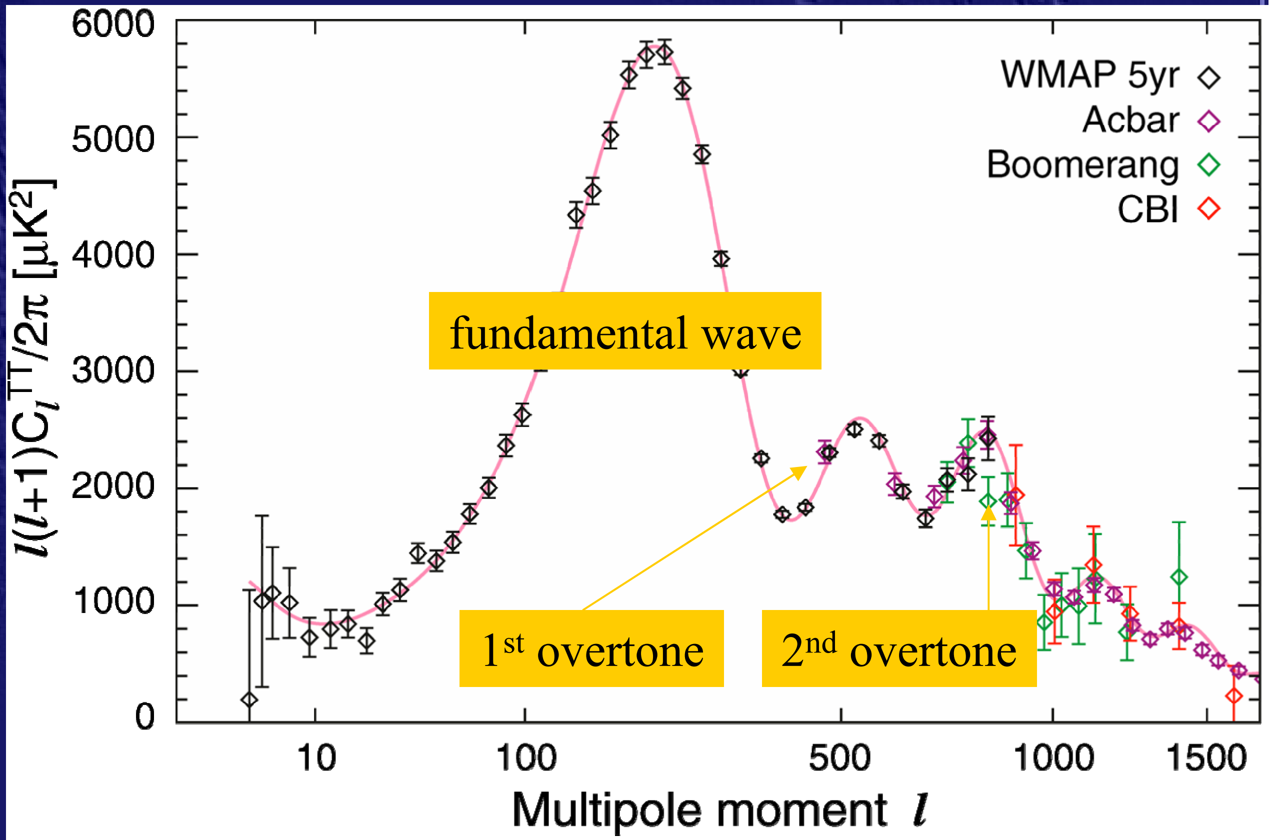


Analysis of WMAP Data

Multipole expansion of the temperature fluctuations:

$\delta T(\varphi,\theta) = \Sigma_{l,m} \cdot a_{l,m} \cdot Y^l_m(\varphi,\theta)$

Plot $c_l = \Sigma_m |a_{l,m}|$



WMAP 5-year Paper Figures, Nolta et al.

Main Goals of CMBR Analyses

- Age of the universe
- Ω : total energy density ⇔ geometry
- Ω_b : baryons
- Ω_ν : dark matter (non baryonic, "hot")
- Ω_{dm}: dark matter (non baryonic, "cold")
- Ω_Λ : cosmological constant ("dark energy")

New form of matter! Supersymmetry?

New (scalar) field?

- Spectrum and origin of temperature fluctuations
- Time of first starlight
- On a way to a "standard model of cosmology"?

Geometry of the Universe (1)

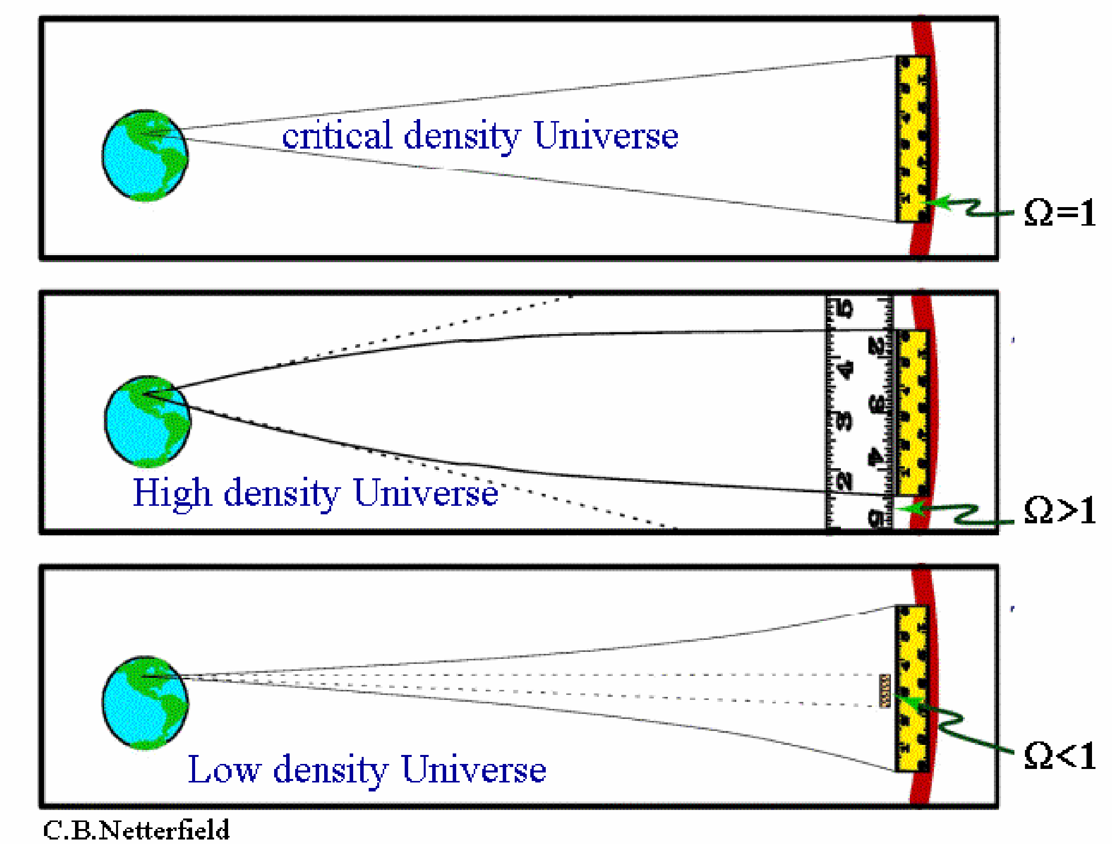
- Calculate absolute size of the fundamental wave of the temperature perturbations in the CMBR:
  absolute size ≈ acoustic horizon
  ≈ f(sound velocity, recombination time, general relat.)
  ≈ 149 Mpc

  Standard ruler independent of geometry of the universe!

- Measure apparent angular size of fluctuations

- Calculate geometry from apparent and absolute size

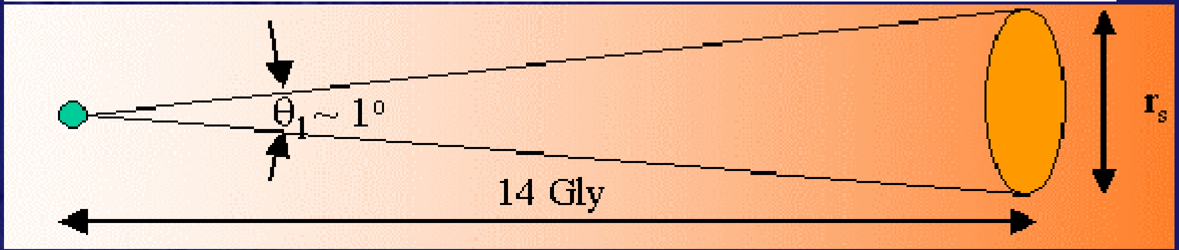
Geometry of the Universe (2)



$\Omega = \Omega_c$: flat universe

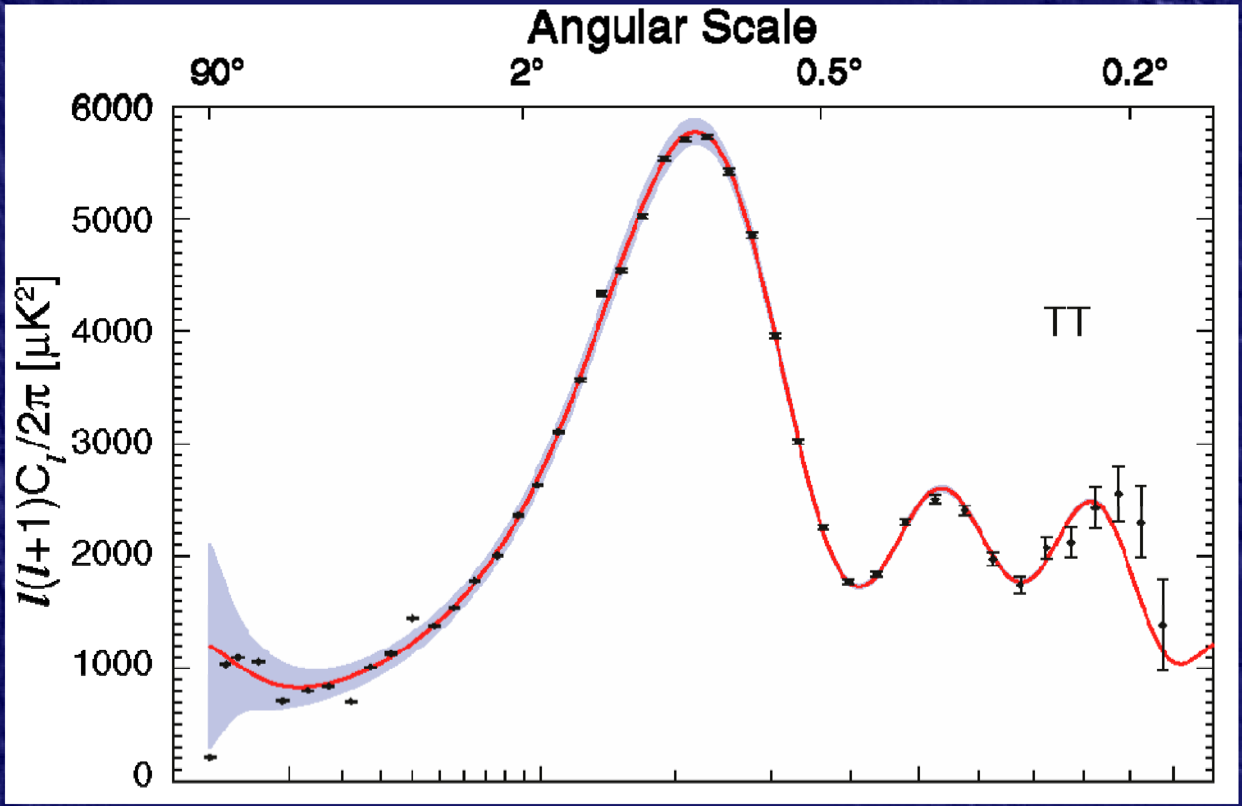
$\Omega > \Omega_c$: closed universe

$\Omega < \Omega_c$: open universe



$\Theta_1 = 0.81° \cdot (\Omega/\Omega_c)^{½}$

Geometry of the Universe (3)



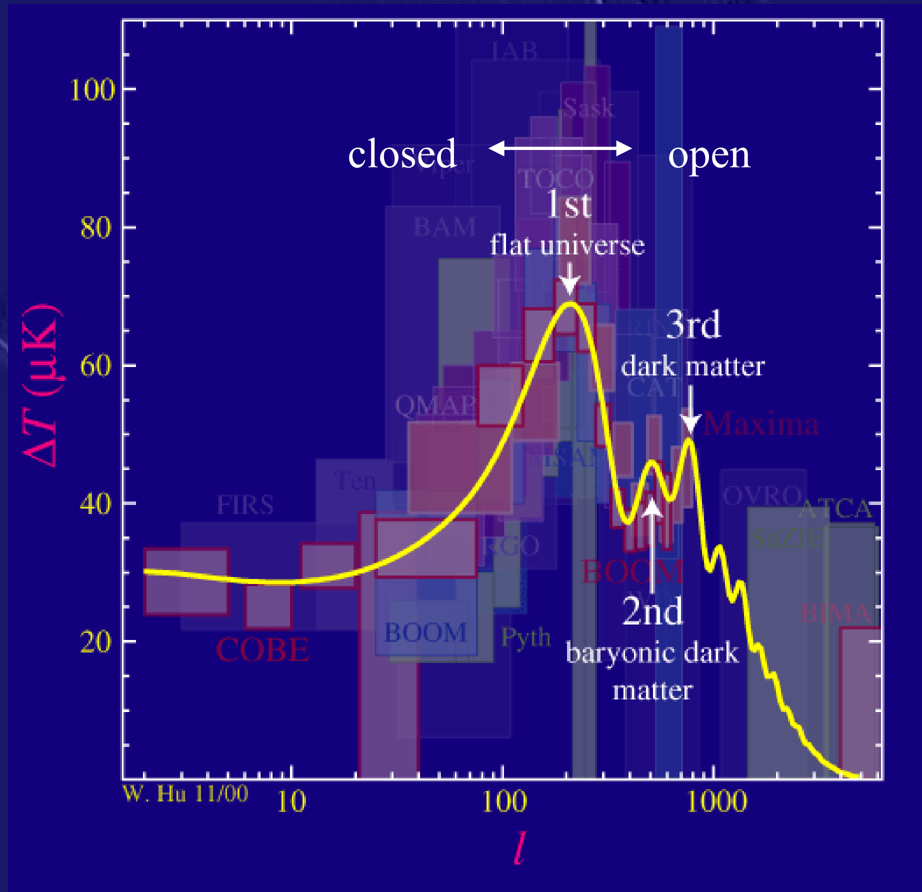
The universe is flat!

Geometry from Multipole Analysis

Geometry and hence total energy density given by position of the first peak:

$$\Omega = \Omega_c \cdot (1.01 \pm 0.1)$$

The universe is flat!

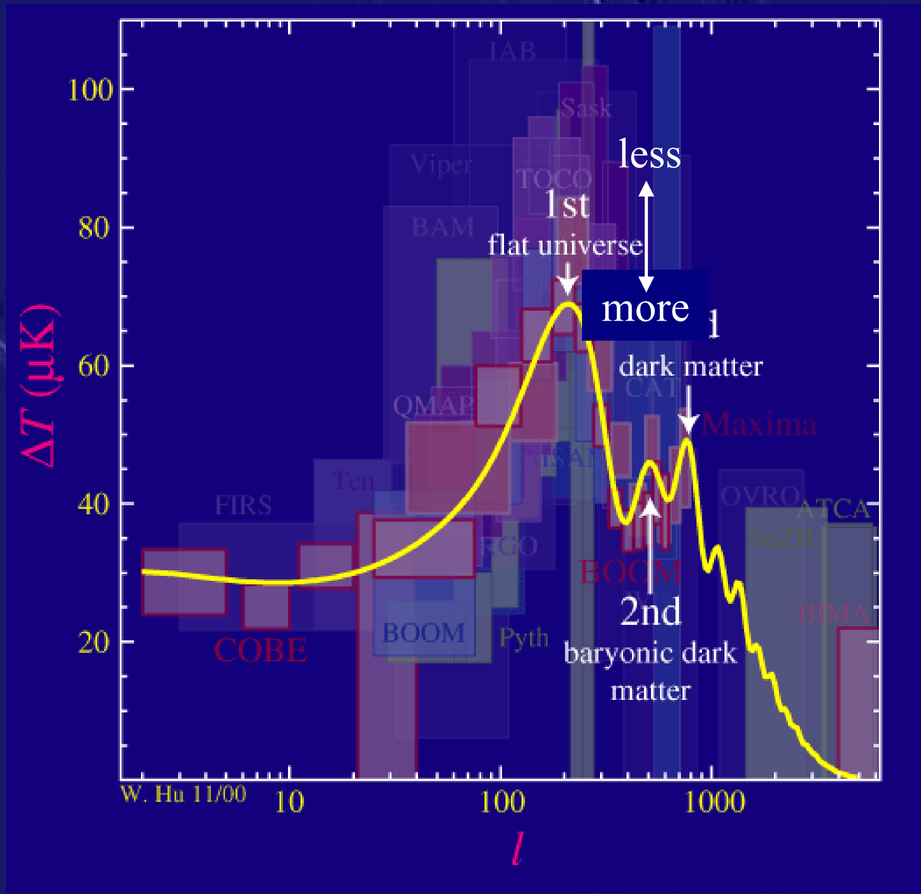


Total baryonic Matter from Multipole Analysis

Baryonic matter: matter (nuclei, electrons) coupling to photons

Acoustic wave (1st overtone) and gravitation fight each other at recombination time

$\Omega_b = \Omega_c \cdot (0.044 \pm 0.003)$

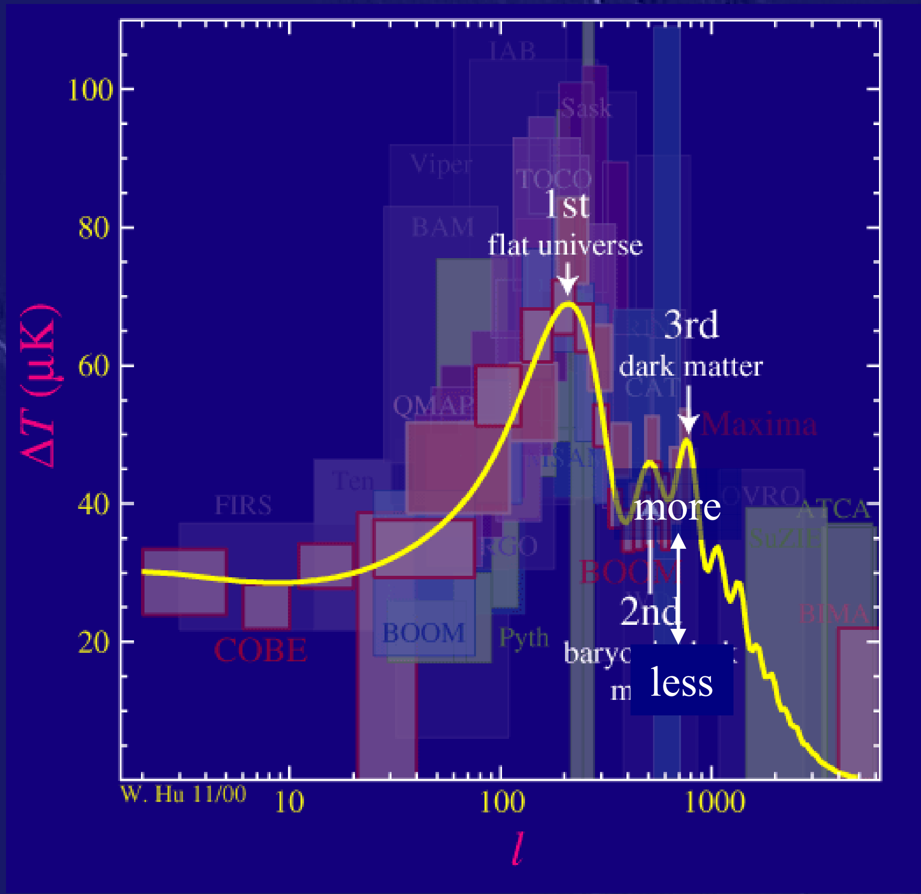


Dark Matter from Multipole Analysis

Dark matter: matter not coupling to photons (i.e. weakly interacting particles)

Only matter not interacting with photons maintains the gravitational potential for higher order modes.

$\Omega_{matter} = \Omega_c \cdot (0.23 \pm 0.03)$



Main Results of CMBR Analysis

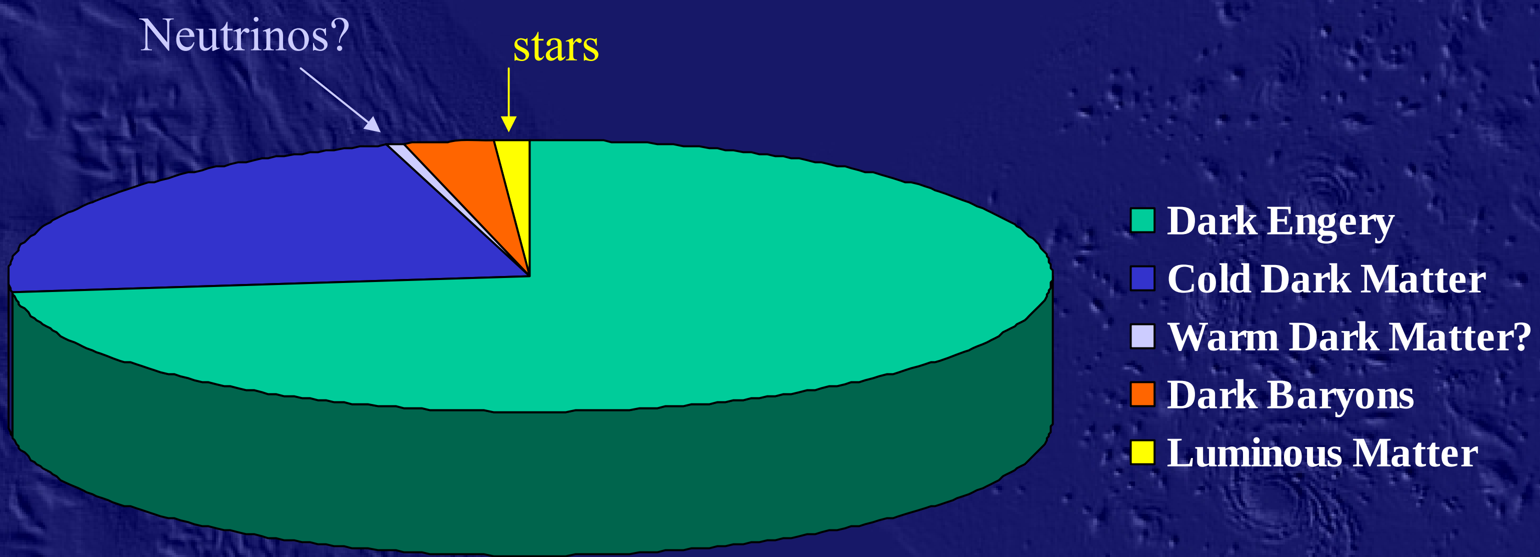
http://lambda.gsfc.nasa.gov/

- Geometry of the Universe: flat
- Age of the Universe: 13.69 ± 0.13 Gyr
- Hubble Constant: 72 ± 3 km s^{-1} Mpc^{-1}
- Fluctuations compatible with inflation

- Ω_b (baryons): 0.044 ± 0.003
- Ω_c (dark matter): 0.214 ± 0.027
- Ω_Λ (dark energy): 0.742 ± 0.030
- Early star light (reionisation): $\Omega_\nu \ll \Omega_{dm}$

In very good agreement to all other data (supernova search with HST, galaxy counting, Big Bang Nucleon-synthesis, ...)

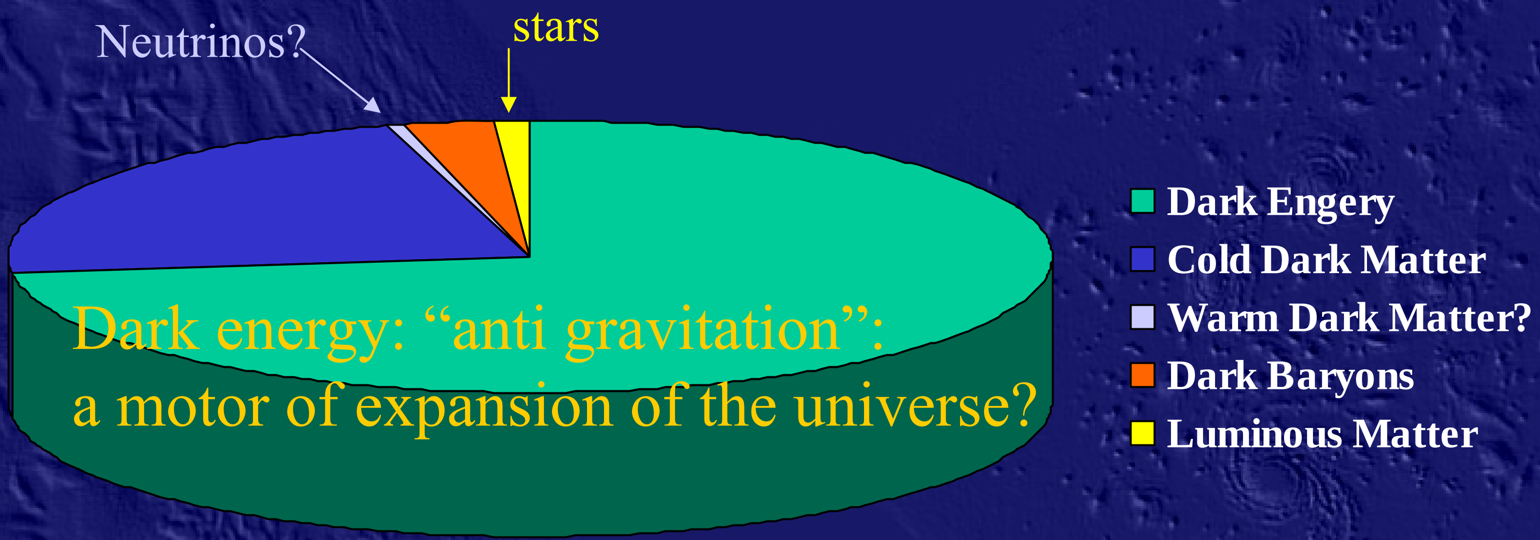
CMBR: Mass – Energy Budget of the Universe



- 96% of the mass-energy budget are of unknown constituents
- 80% of the mass are made of unknown particles

There is (much) more physics than in the HEP standard model!

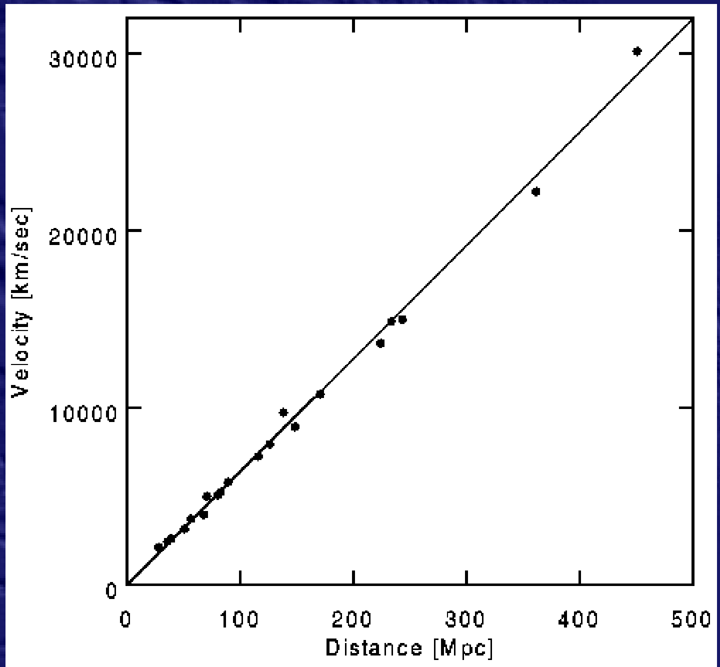
A new ingredient: dark energy



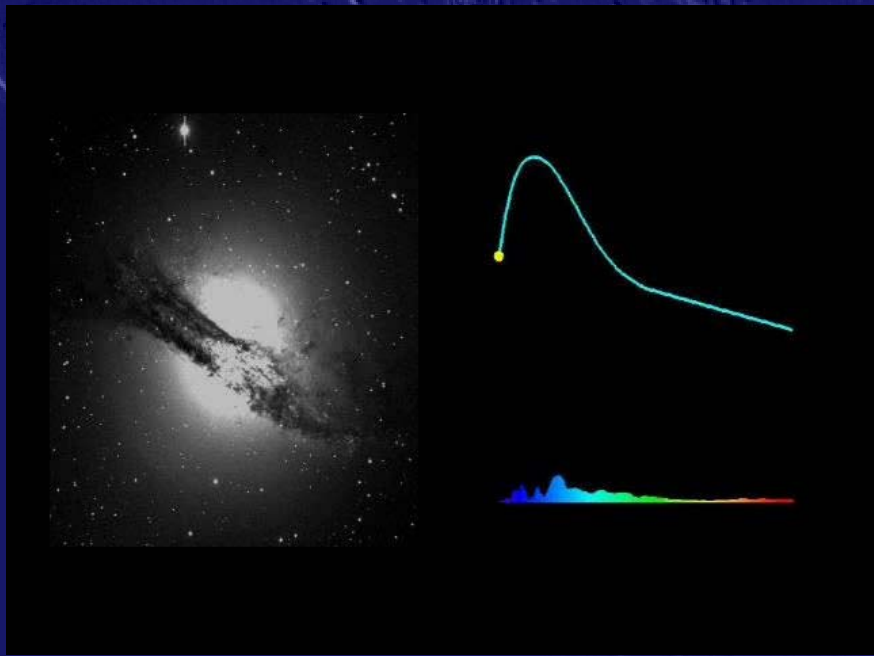
Dark energy: “anti gravitation”:
a motor of expansion of the universe?

Expansion of the Universe

Hubble: the universe expands!



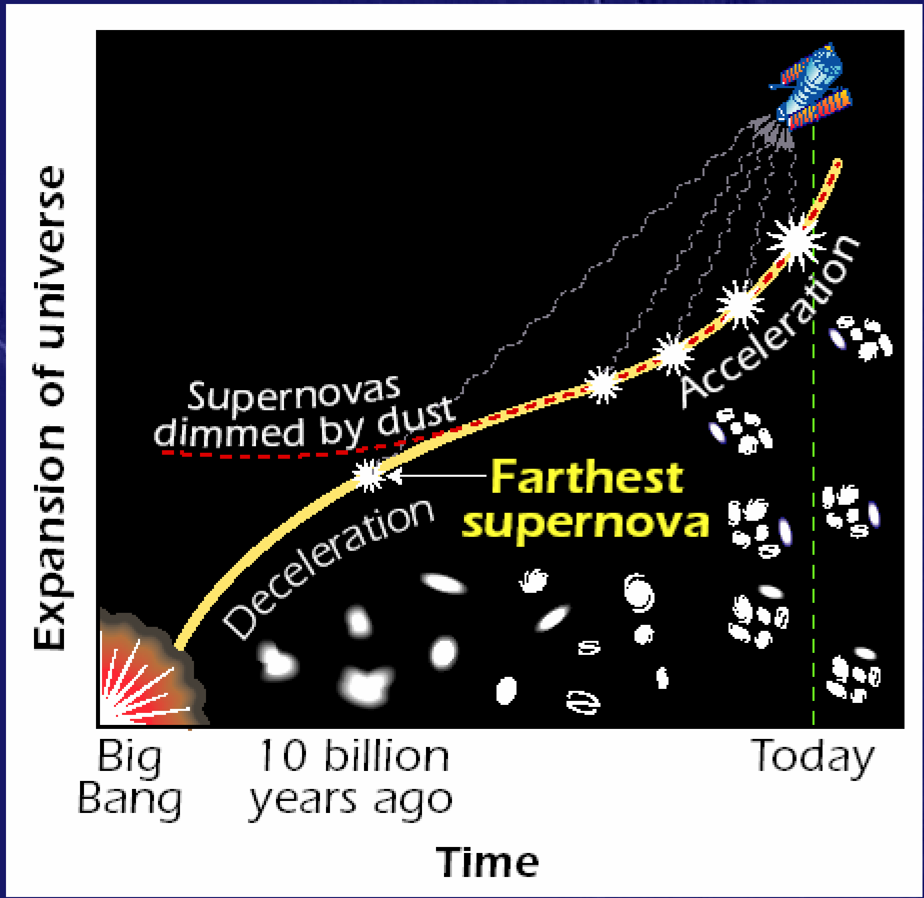
Hubble Space Telescope: expand "Hubble plot" to larger distances by observing supernova explosions



Expansion of the Universe: Dark Energy:

Measurements of Supernovae Ia by the Hubble Space Telescope:

- The dark energy has a repulsive force ("anti-gravitation")
- The universe expands currently with increasing speed!



Cosmology from CMBR and other data

Summary:

- On the way to an experimental "precision" cosmology?
  - Surprising agreement of many different data
- Many open questions to particle physics:
  - Where are the dark baryons?
  - What is Dark Matter?
  - What is Dark Energy? Why is it not exactly zero?
  - Why is the universe exactly flat ("fine tuning problem")?
  - Why is the amount of energy and matter nearly the same?
  - ....

Or do we have too many strange hypotheses
(i.e. inflation, accelerated expansion, “multiverses”)?
Do we need a new physics revolution?

Hitchhiker's Guide to the Galaxy

There is a theory which states that if ever anybody discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable.

There is another theory which states that this has already happened.

Douglas Adams

English humorist & science fiction novelist (1952 – 2001)

Most challenging: Dark Energy

10 years after discovery no significant progress in understanding (in spite of numerous theoretical ideas)

- Vacuum energy:
  theoretical predictions from Standard Model ≈10^{120} too large,
  with supersymmetry expectation exactly zero!
- Fifth force? New scalar field (like needed for inflation).
  ☞ new particles with mass <≈ $(\rho\, h^3/c^3)^{1/4}$ = 0.001 eV
- Is gravitation to be modified for very large distances or very weak fields ?
- Are basic assumptions wrong?

Basic Assumptions in Cosmology

Copernican principle: The Universe in our neighborhood is not special.

- Homogeneity (similarity in all regions of space)
- Isotropy (similarity in all directions).

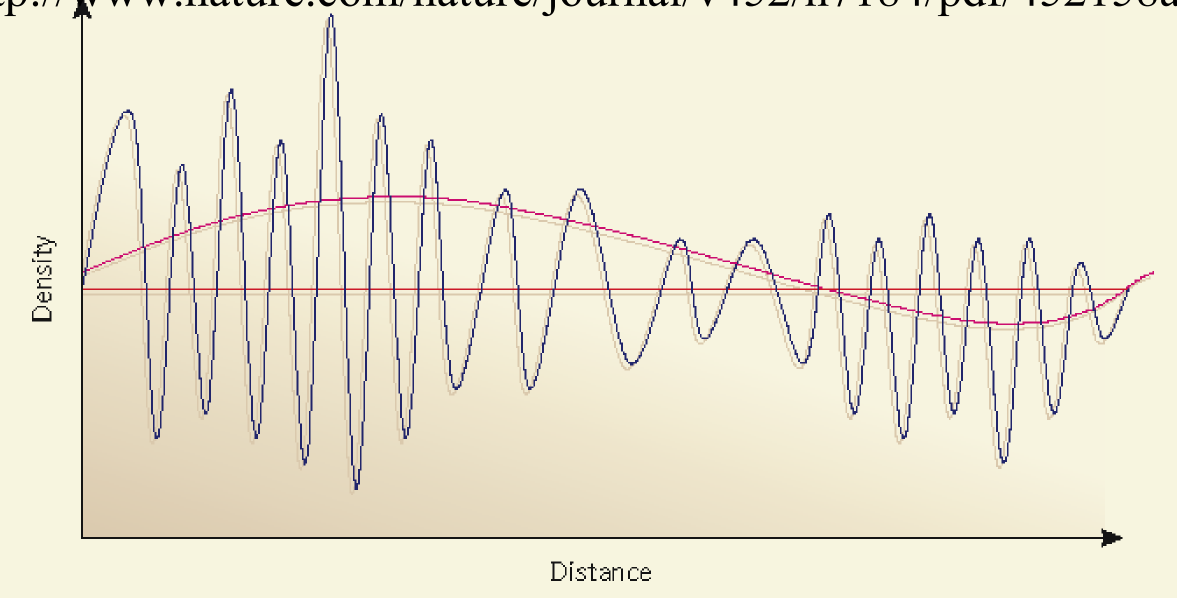
This principle is
- compatible with observations (if you accept "Dark Energy"!),
- but fundamentally untested!

Basic Assumptions in Cosmology

Example:

Which is the relevant scale for homogeneity of the Universe?

http://www.nature.com/nature/journal/v452/n7184/pdf/452158a.pdf



- Does one has to take into account in-homogeneities when calculating cosmological parameters?

A Way out?

- A primordial epoch of inflation generated cosmological perturbations of wavelengths much larger than the Hubble radius.
- The perturbations evolve coherently with time and influence the time evolution of the local expansion.

1. We observe only a small part of the universe which accidentally expands.
2. Dark energy does not exist.
3. The universe is composed of baryonic and dark matter.

Experimental test: luminosity-distance–redshift correlation.

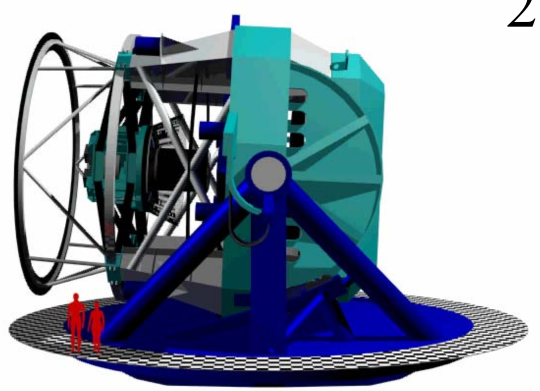
see e.g. E.W. Kolb et al., hep-th/0503117

Future Data

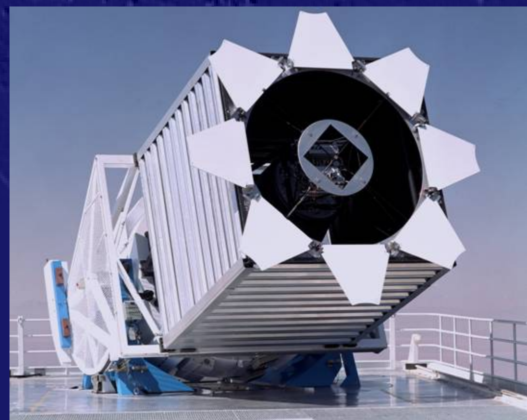
Planck (launch 2009) with higher spatial resolution, much improved polarization measurements.

Large Synoptic Survey Telescope (LSST)

2015?



SDSS-II
(up to 2008)



CMBR: topics for discussion

- Which observations / experiments in addition to CMBR analyses might help to understand the very early cosmos?
- In which way might other research fields profit from detailed cosmology studies?
- What do you expect for the future of the universe?

Astroparticle Physics

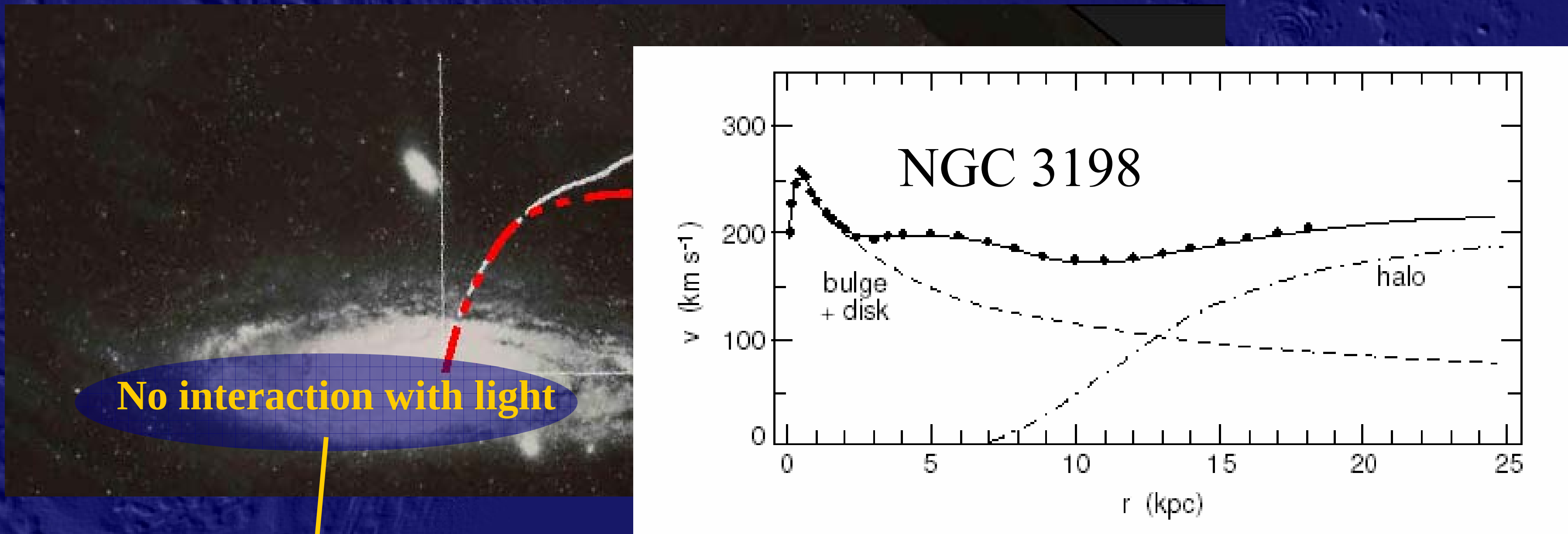
1. High Energy Particles from the Cosmos
2. The new Astronomy
3. The Cosmic Microwave Background Radiation
4. **Search for Dark Matter (DM)**

Observational Evidence for DM (1)

(besides analysis of the CMBR)

Dark Matter and experiments:
http://cdms.berkeley.edu/experiment.html

Rotation of galactic disks:



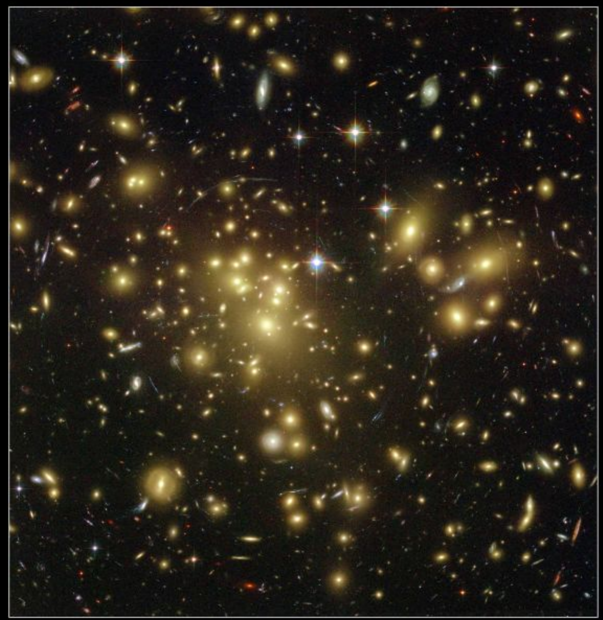
Dark Matter $\approx$ 10 · Luminous Matter

Observational Evidence for DM (2)

Motions of galaxies in clusters:

Clusters do not diffuse in spite of high speed of galaxies.

(Dark component first proposed 1933 by F. Zwicky after analysis of the Coma cluster)


Galaxy Cluster Abell 1689
Hubble Space Telescope • Advanced Camera for Surveys

NASA, N. Benitez (JHU), T. Broadhurst (The Hebrew University), H. Ford (JHU), M. Clampin (STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA
STScI-PRC03-01a

Dark Matter $\approx$ 30 · Luminous Matter

Observational Evidence for DM (3)

Hot gas in galaxy clusters:

Hot gas (measured by X-ray emission due to e^--bremsstrahlung) contains too much kinectic energy to be bound by luminous matter in the cluster.

Mass (hot gas) ≈
5 · Luminous Matter

Dark Matter ≈ 30 · Luminous Matter

How to find Dark Matter in the Universe?

Search for Dark Matter via gravitational effects:

- bound systems (galaxies, clusters of galaxies, hot gas)

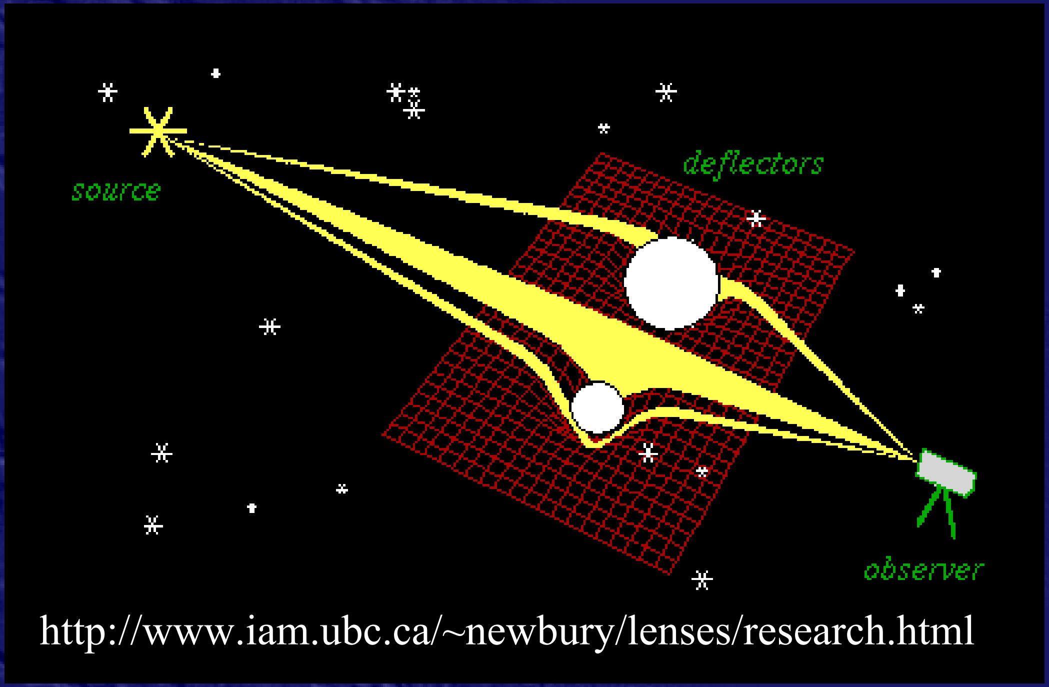
- distortion of images due to gravitational force on light

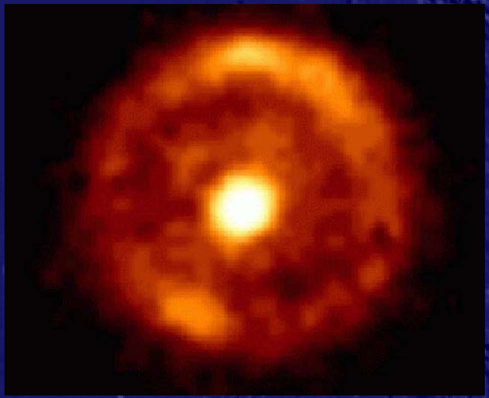
  "gravitational lensing"

Gravitation distorts images

http://astronomyonline.org/Cosmology/GravitationalLensing.asp

Gravitation distorts images

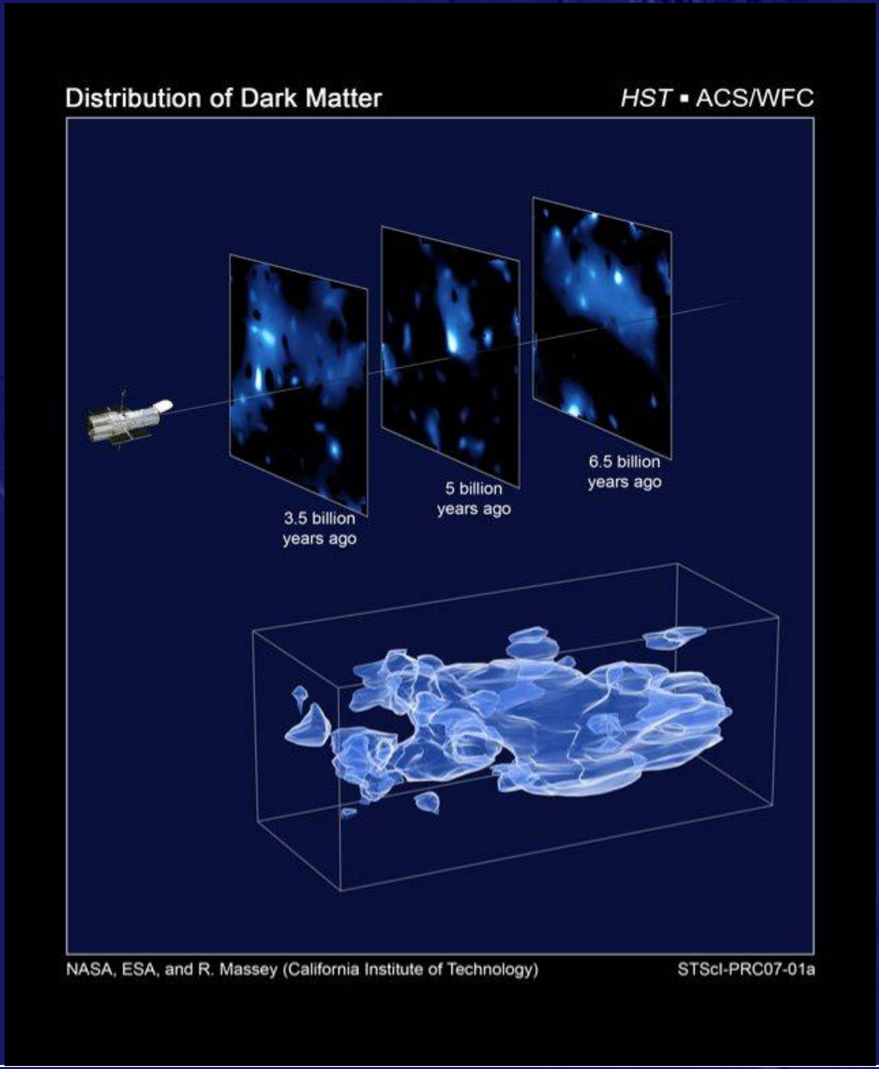




Gravitational lensing:

Derive mass of "lens" from properties of image .

Observational Evidence for DM (4)

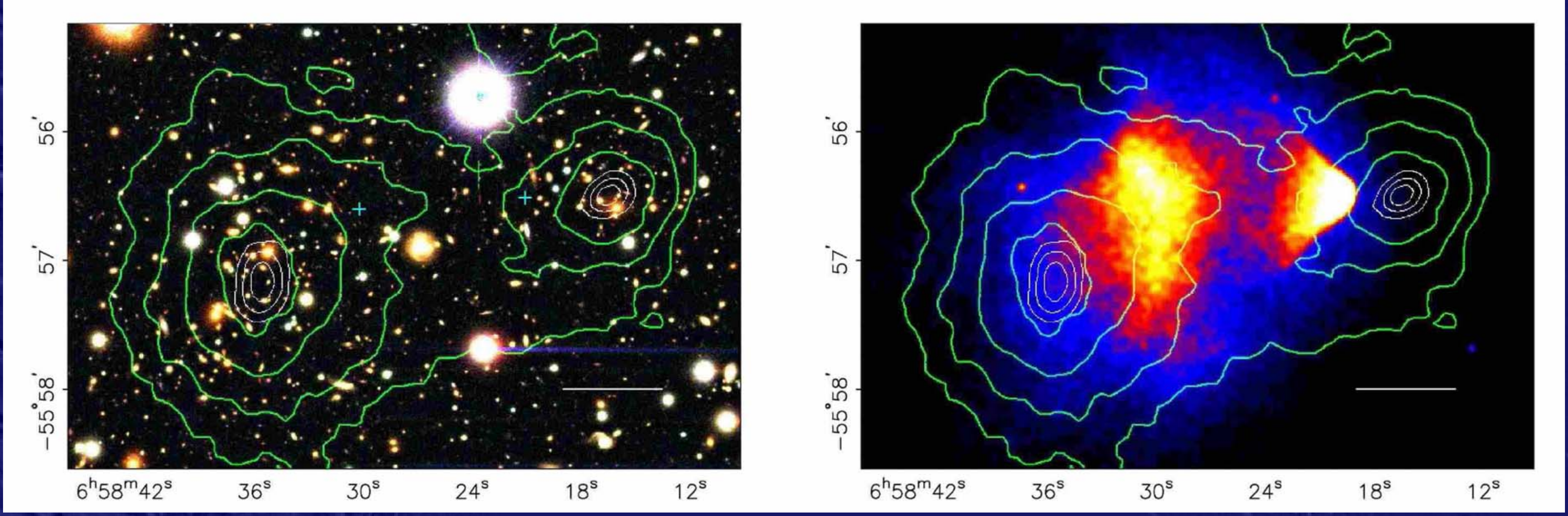


Dark Matter $\approx$ 30 $\cdot$ Luminous Matter

The Smoking Gun Observation

Bullet cluster 1E 0657-56: merging of two galaxy clusters

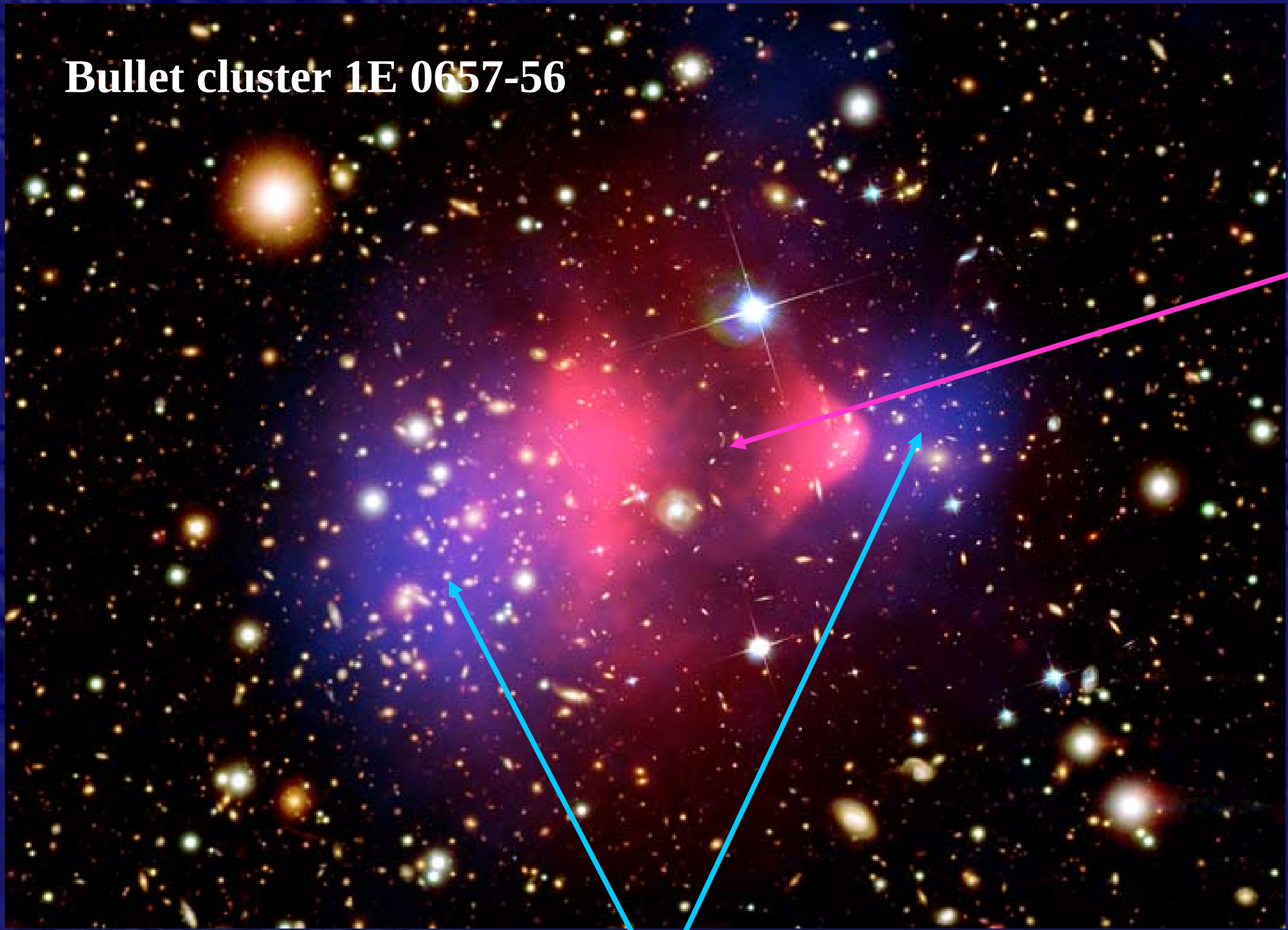
(Clowe et al., astro-ph/0608407v1)



Contours from gravitational lensing

hot gas from X-rays

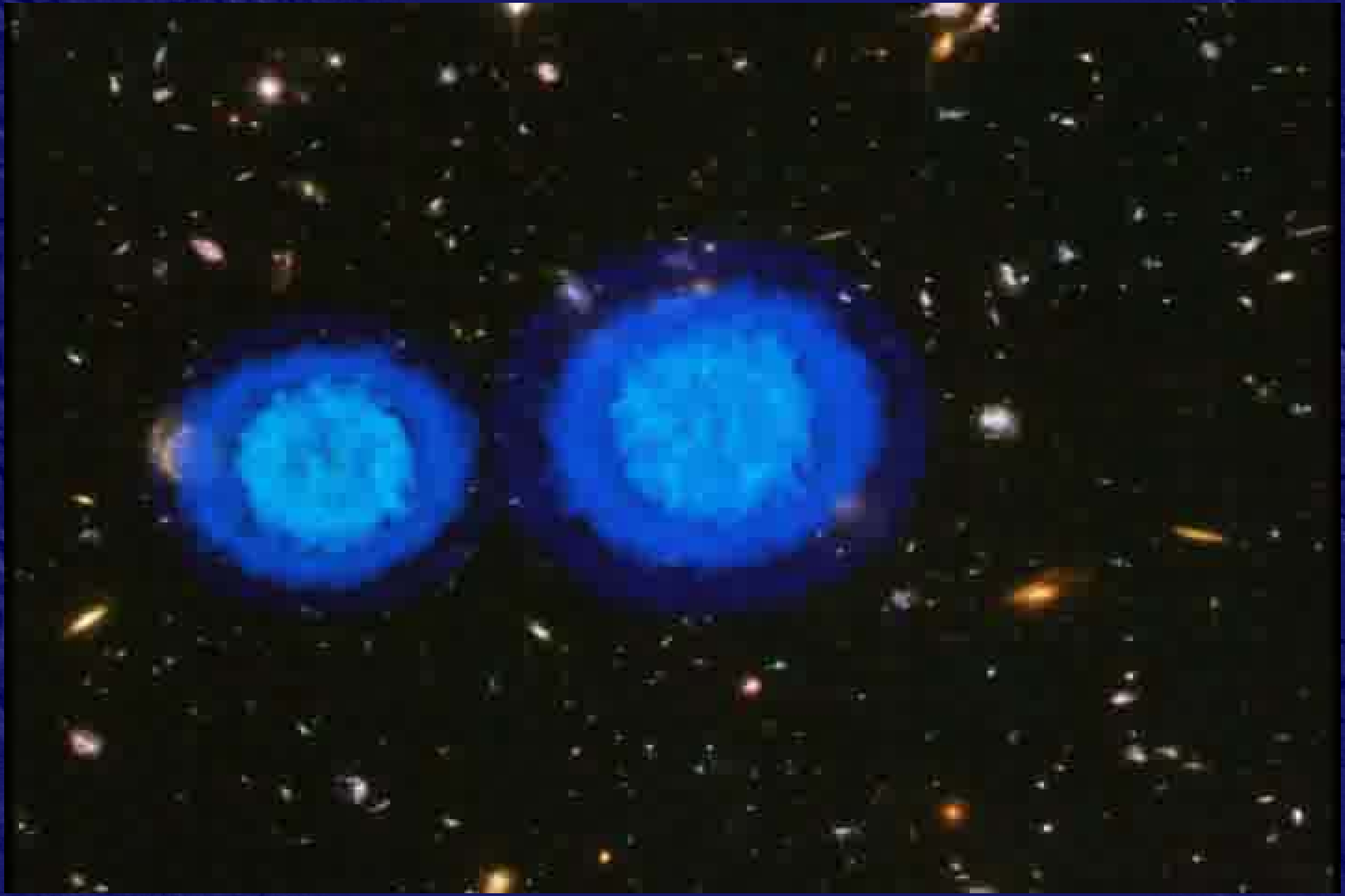
The Smoking Gun Observation



hot gas (X-ray)

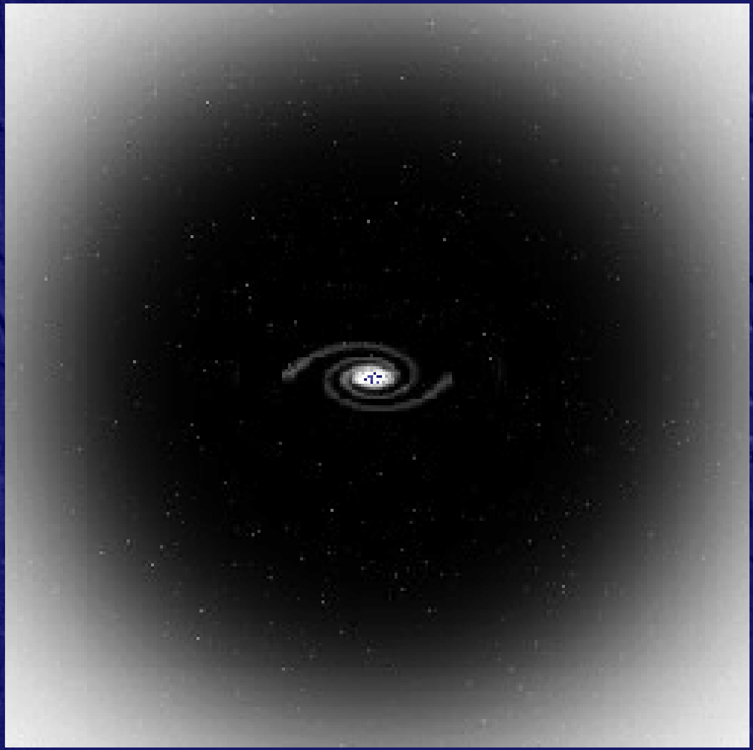
from gravitational lensing

The Smoking Gun Observation



http://chandra.harvard.edu/photo/2006/1e0657/animations.html#1e0657_zoom

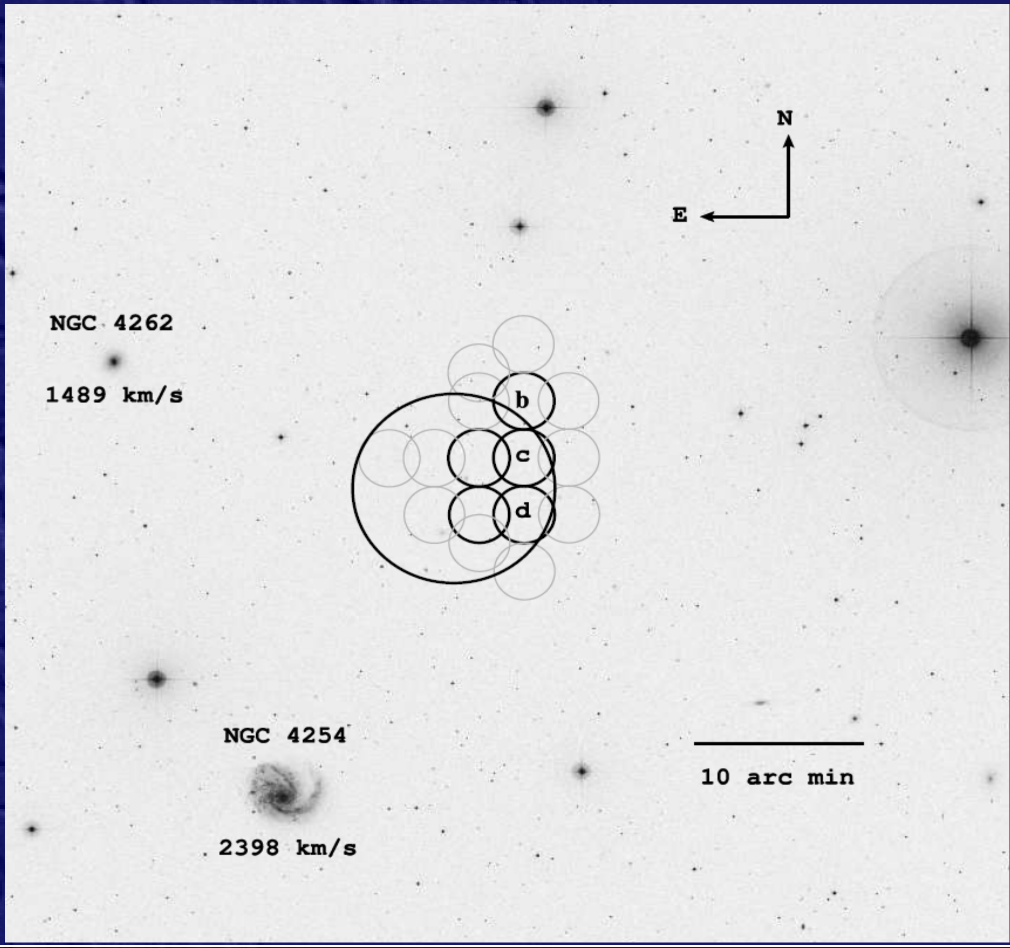
Model: galaxies “swim“ within a halo of dark matter



Are there also galaxies purely made of dark matter?

What is happening with NGC 4254?

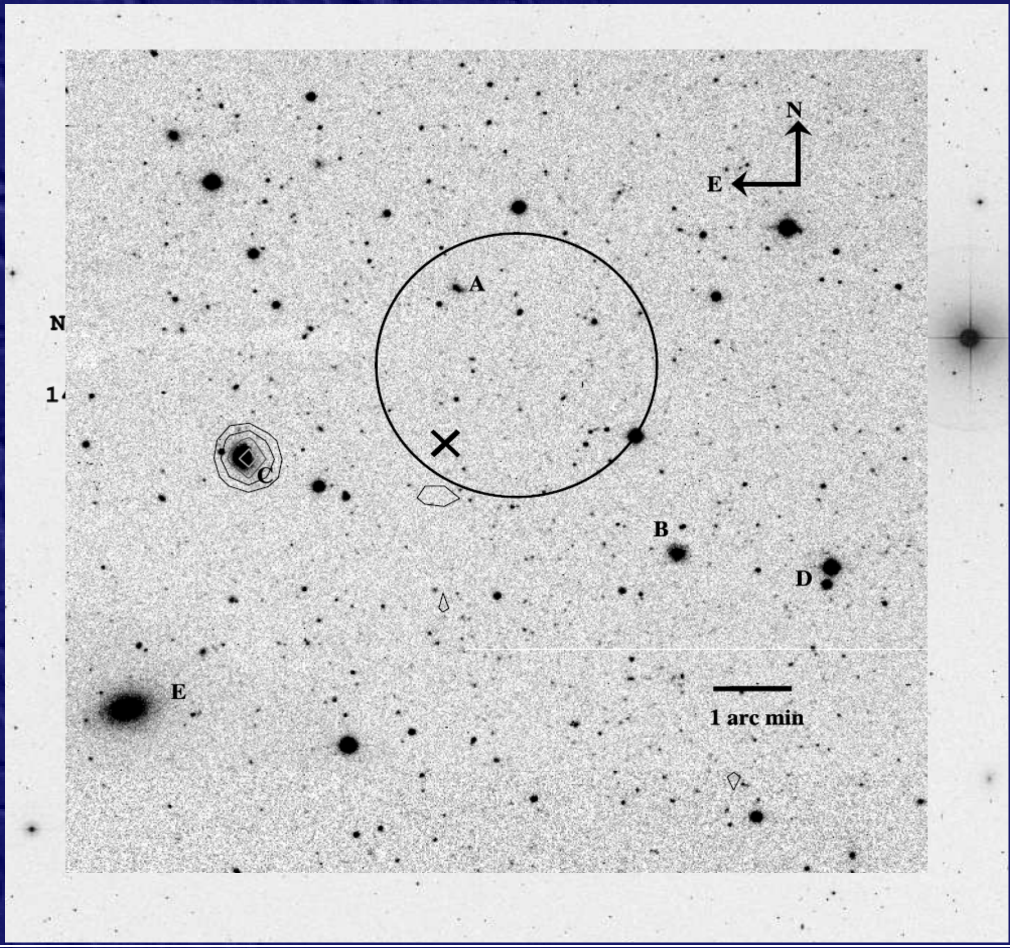
something is pulling one spiral arm of NGC 4254 apart



Observation:
weak radio emission (H gas) out of an empty area!

What is happening with NGC 4254?

something is pulling one spiral arm of NGC 4254 apart



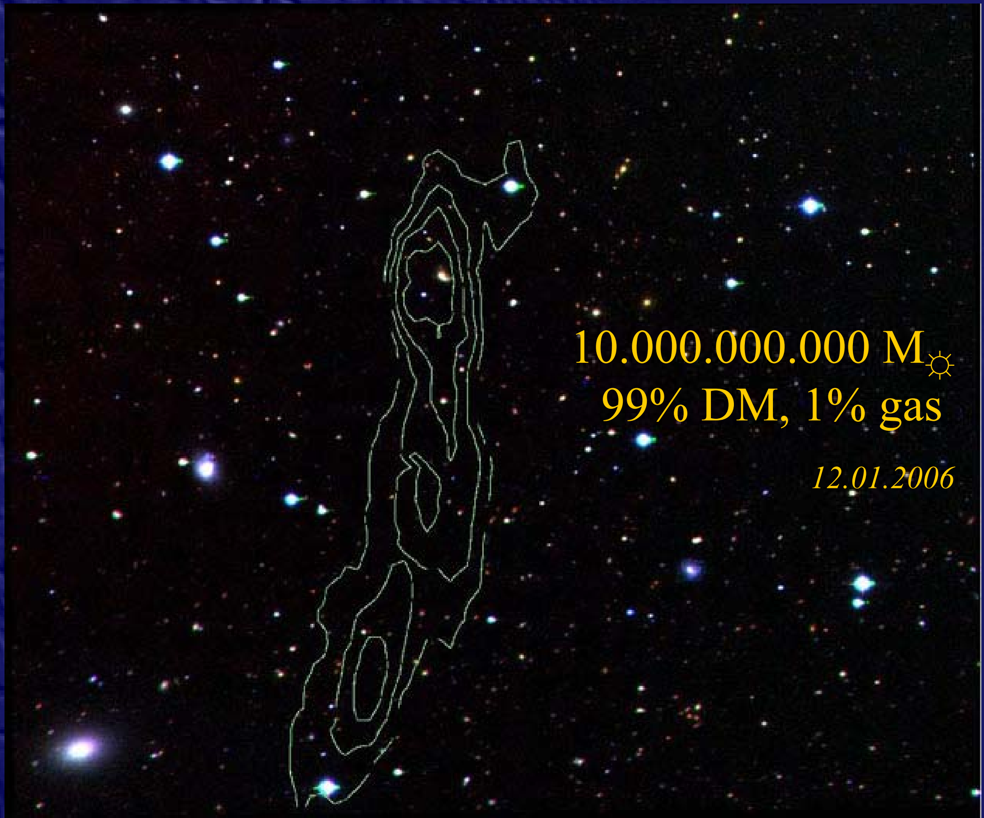
Observation:

weak radio emission (H gas) out of an empty area!

no stars visible!

The first "dark galaxy"!

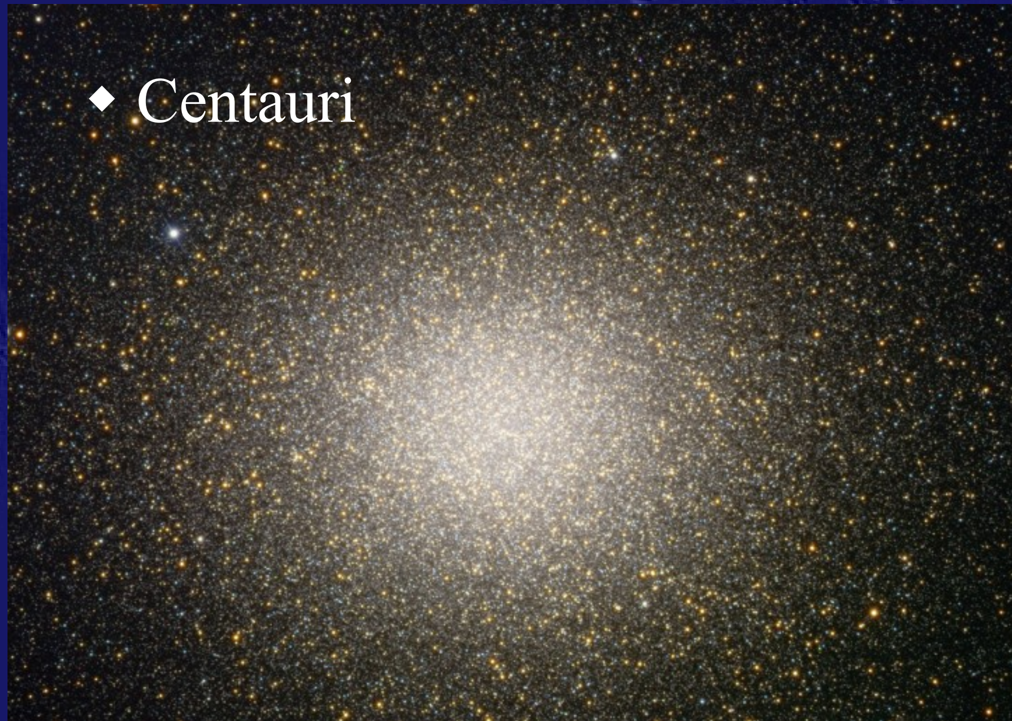
Observation



Expectation

However …

… do we really understand gravity in the weak acceleration regime?



Globular clusters should not contain Dark Matter:
Analysis of velocity of stars probes gravity!

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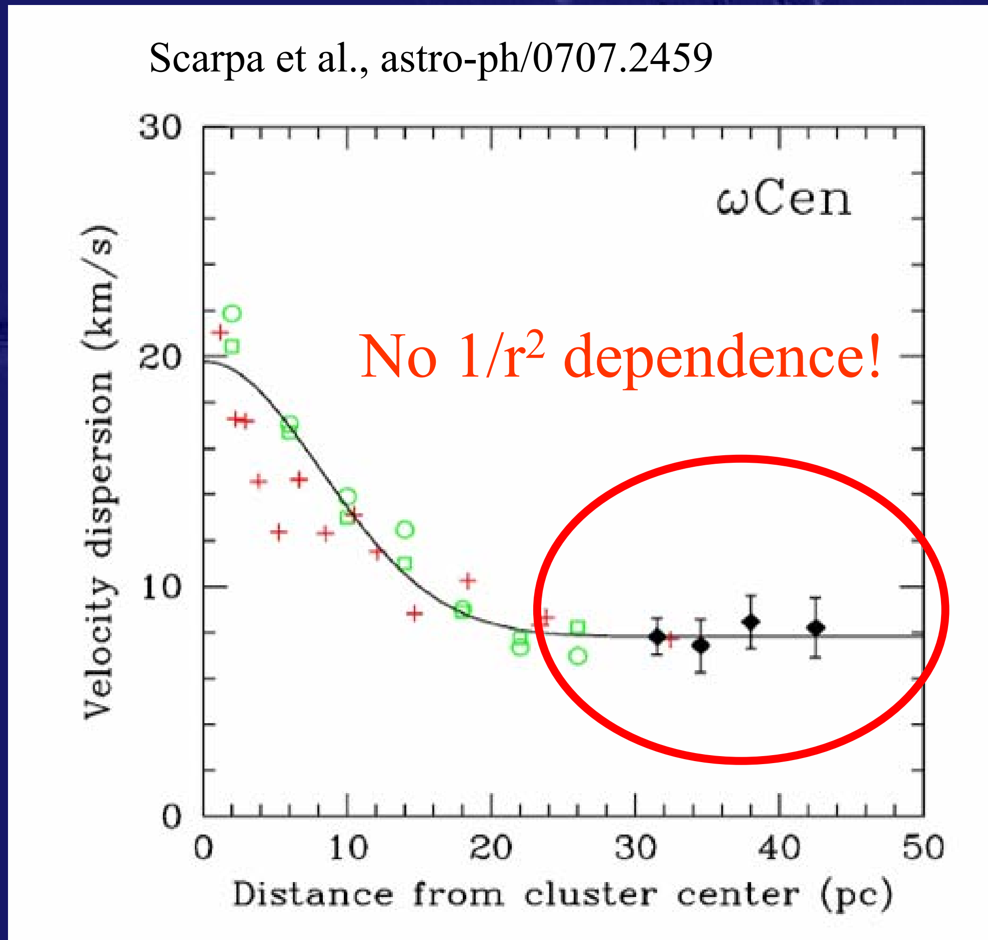

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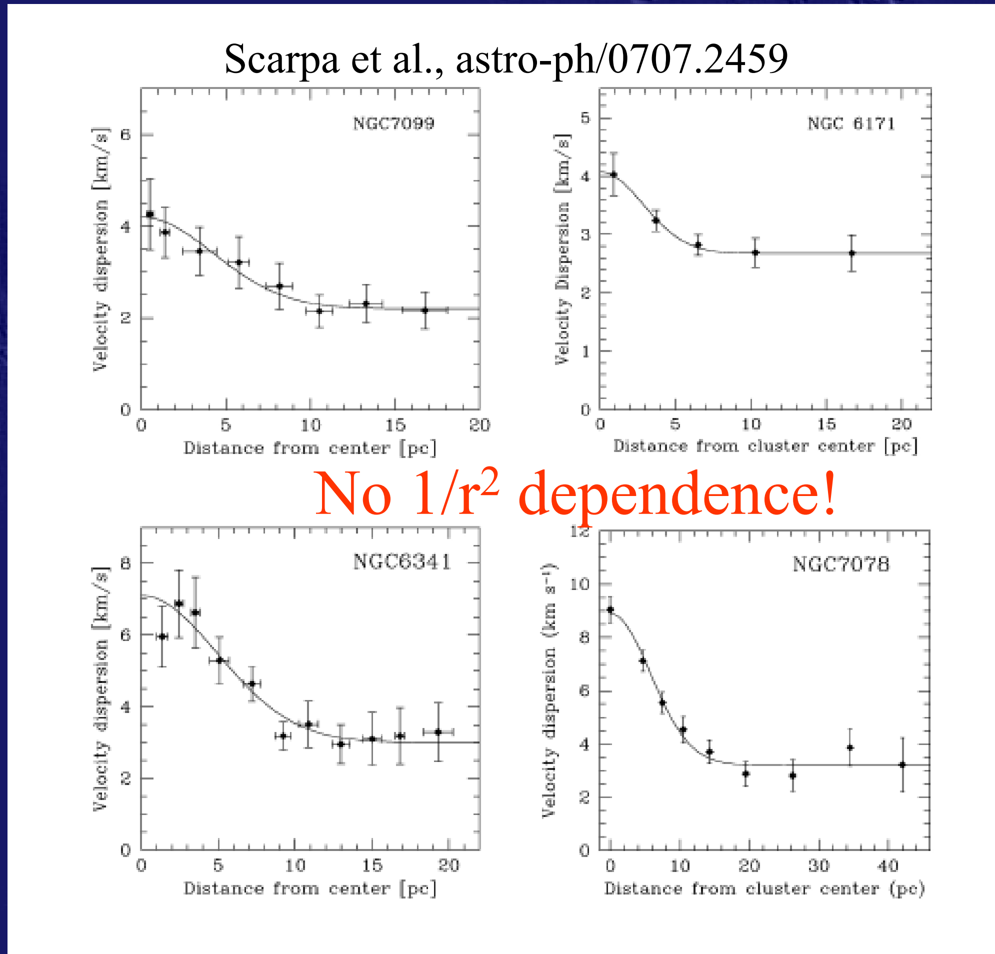

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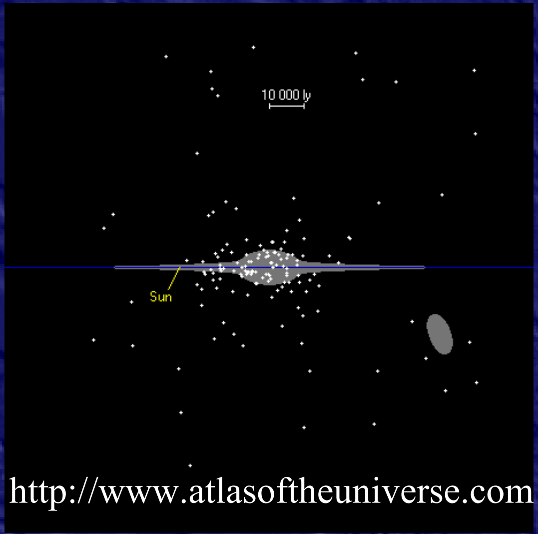

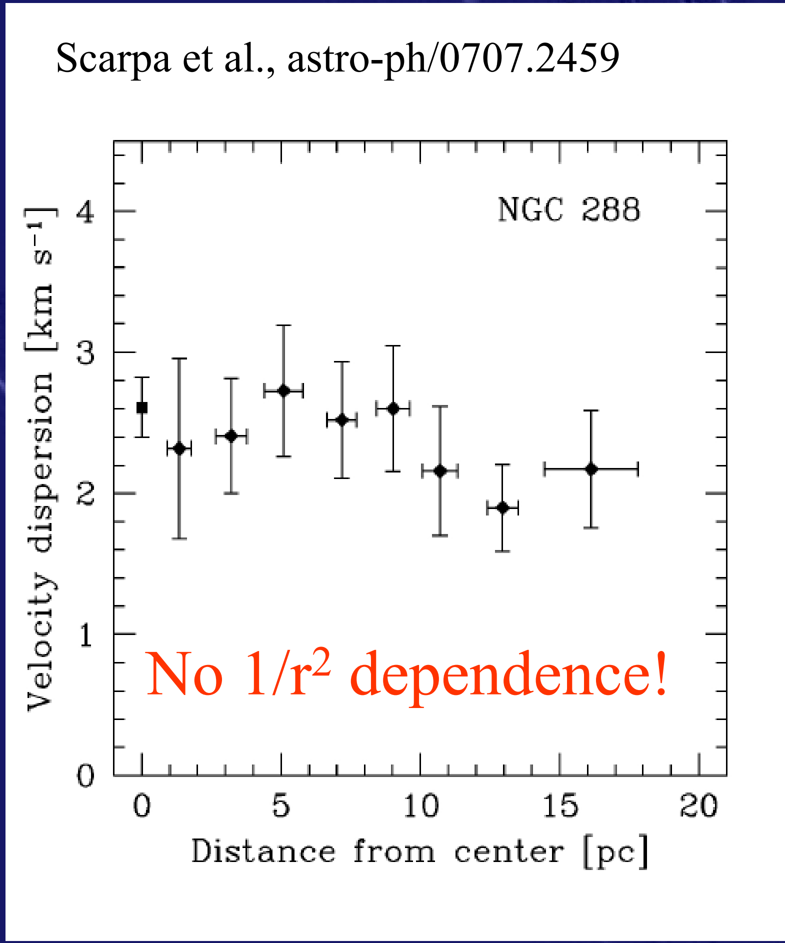

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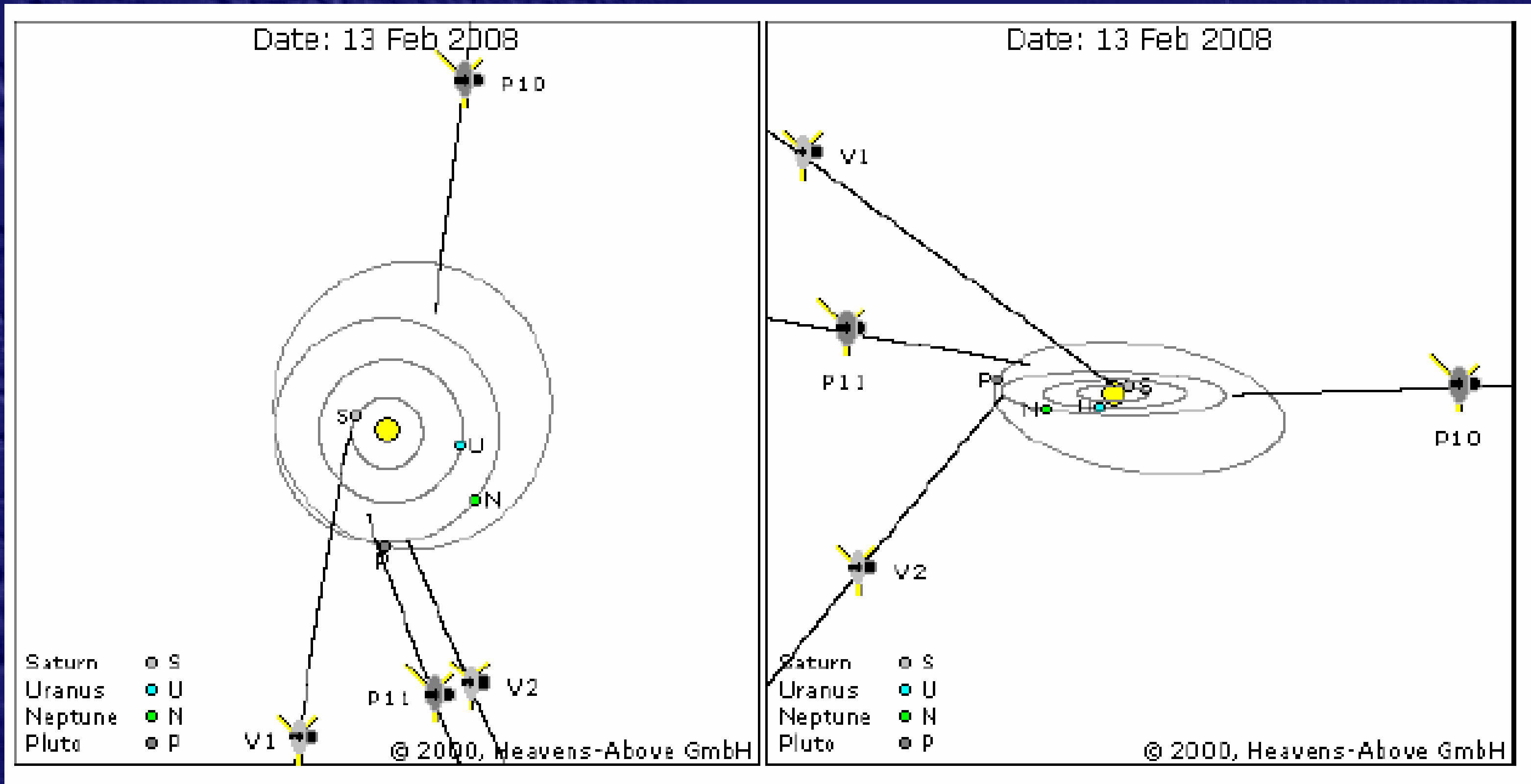
"Pioneer anomaly" http://arxiv.org/ftp/arxiv/papers/0807/0807.1088.pdf



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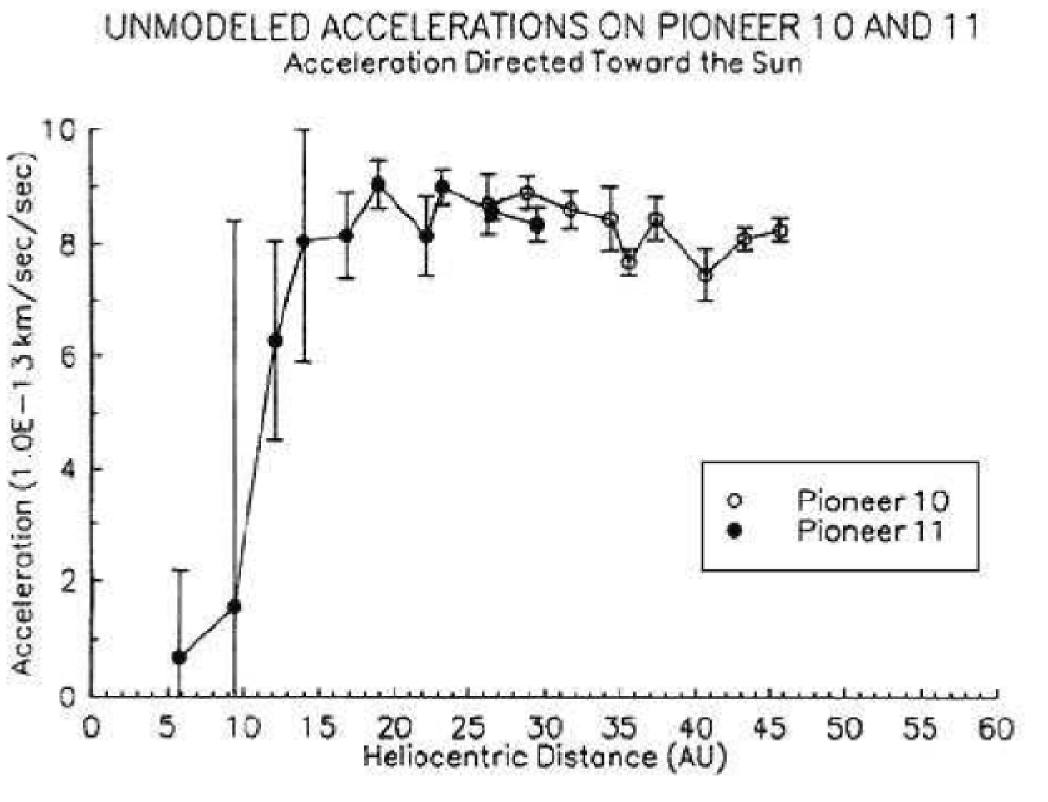


However …

… do we really understand gravity in the weak acceleration regime?

Un-modeled acceleration:

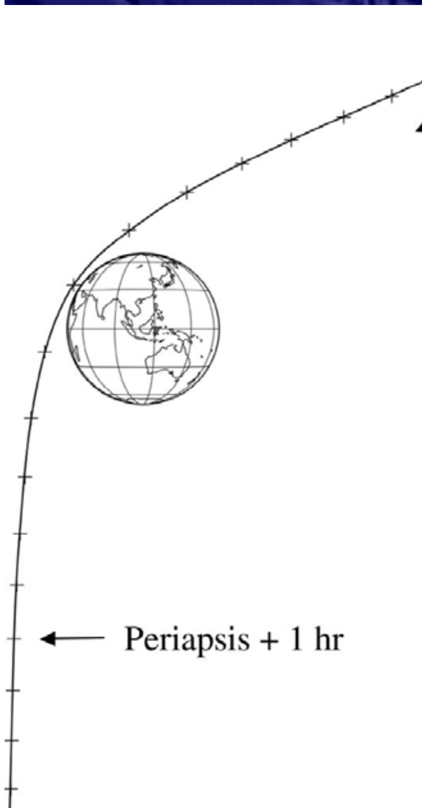
- Velocities in globular clusters:
  $\approx 2 \cdot 10^{-10}$ m/s^2
- Pioneer anomaly:
  $\approx 8 \cdot 10^{-10}$ m/s^2
- Rotation of galaxies:
  $\approx 10^{-10}$ m/s^2

(gravitational pull of a human in 7 m distance)

However …

… do we really understand gravity in the weak acceleration regime?

"Swing-by anomaly" J.D. Anderson et al., PRL 100, 091102 (2008)

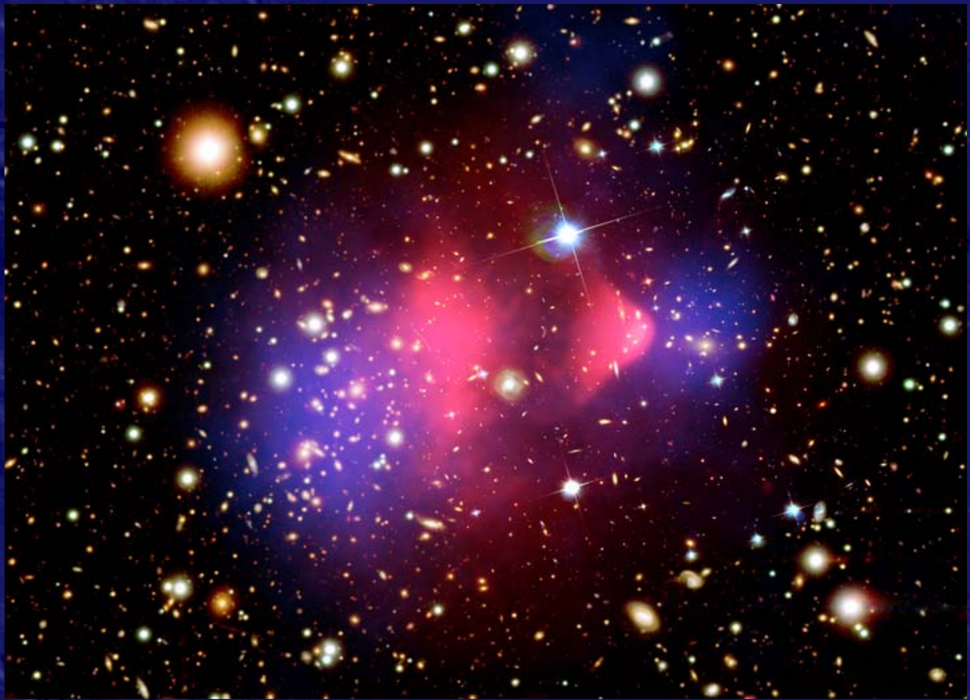


velocity differences of few mm/s not understood!

Parameter	GLL-I	GLL-II	NEAR	Cassini	Rosetta	M'GER
Date	12/8/90	12/8/92	1/23/98	8/18/99	3/4/05	8/2/05
H (km)	960	303	539	1175	1956	2347
ϕ (deg)	25.2	−33.8	33.0	−23.5	20.20	46.95
λ (deg)	296.5	354.4	47.2	231.4	246.8	107.5
V_f (km/s)	13.740	14.080	12.739	19.026	10.517	10.389
V_∞ (km/s)	8.949	8.877	6.851	16.010	3.863	4.056
DA (deg)	47.7	51.1	66.9	19.7	99.3	94.7
I (deg)	142.9	138.7	108.0	25.4	144.9	133.1
α_i (deg)	266.76	219.35	261.17	334.31	346.12	292.61
δ_i (deg)	−12.52	−34.26	−20.76	−12.92	−2.81	31.44
α_o (deg)	219.97	174.35	183.49	352.54	246.51	227.17
δ_o (deg)	−34.15	−4.87	−71.96	−4.99	−34.29	−31.92
M_{SC} (kg)	2497	2497	730	4612	2895	1086
ΔV_∞ (mm/s)	3.92	−4.6	13.46	−2	1.80	0.02
σ_{V_∞} (mm/s)	0.3	1.0	0.01	1	0.03	0.01
Equation (1) (mm/s)	4.12	−4.67	13.28	−1.07	2.07	0.06

However …

Looking into details:



new interaction between Dark Matter particles and/or modified gravity necessary to understand the bullet cluster?

http://arxiv.org/PS_cache/astro-ph/pdf/0701/0701848v2.pdf

However ...

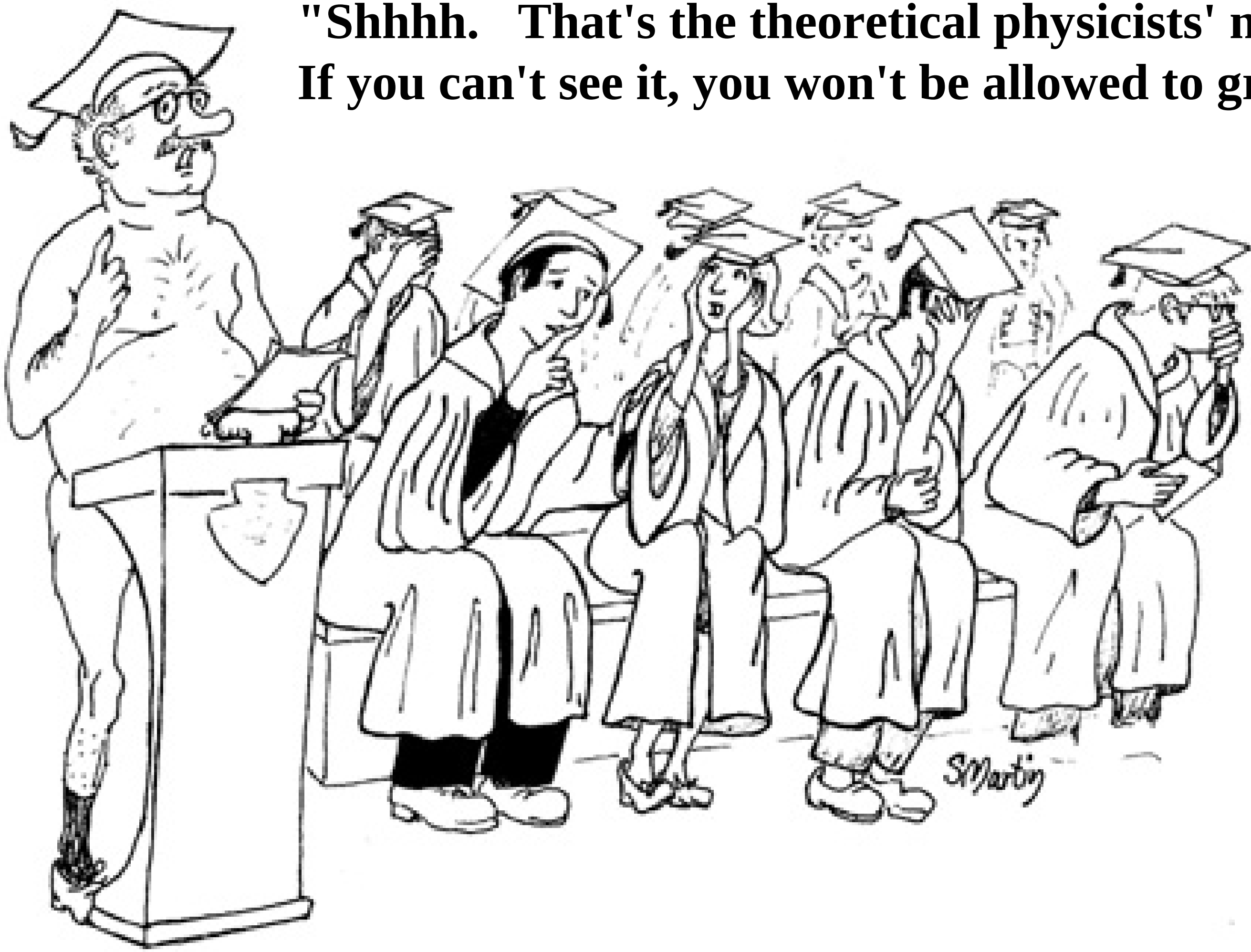
Looking into details:

???

new interactions between Dark Matter particles and/or modified gravity necessary to understand the bullet cluster?

http://arxiv.org/PS_cache/astro-ph/pdf/0701/0701848v2.pdf

For the time being …
… let's stick to the general accepted paradigm.

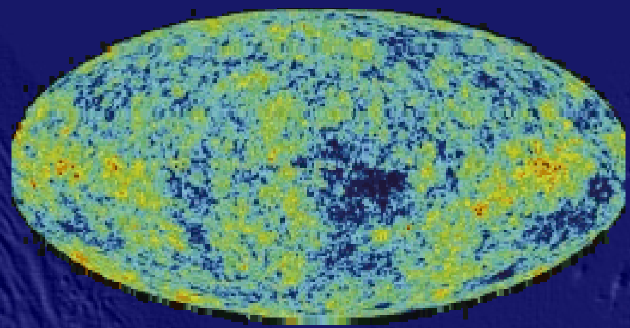


"Shhhh. That's the theoretical physicists' new particle uniform. If you can't see it, you won't be allowed to graduate."

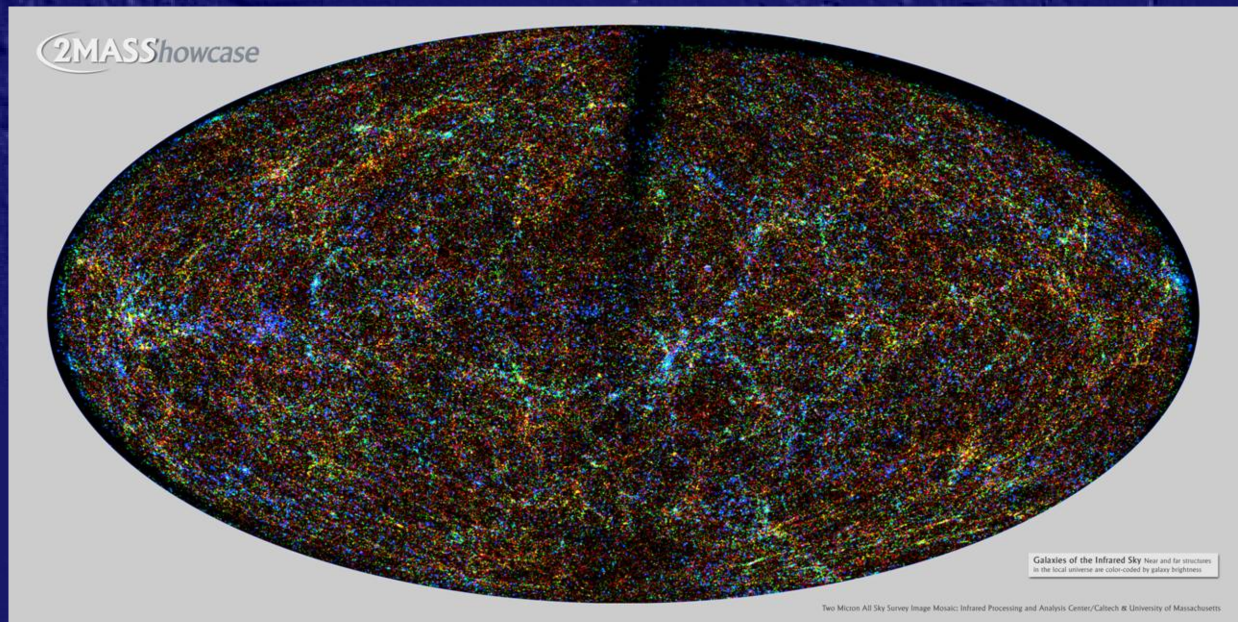
http://www.softcom.net/users/greebo/laugh.htm

Further Evidences for Dark Matter

- CMBR analyses



- Structure formation in the universe
  ➢ non relativistic "cold" dark matter!



Properties of the Dark Matter

- Dark Matter $\approx$ 30 · luminous matter (stars)
  - Dark baryons (p, n) $\approx$ 5 · luminous matter
    (indirect observations (gas), big bang nucleosynthesis, CMBR)
  - Unknown "dark" particles $\approx$ 6 · baryonic matter
    - Only gravitational (and weak) interaction
    - Should be non-relativistic ("cold")

The prime DM Candidates

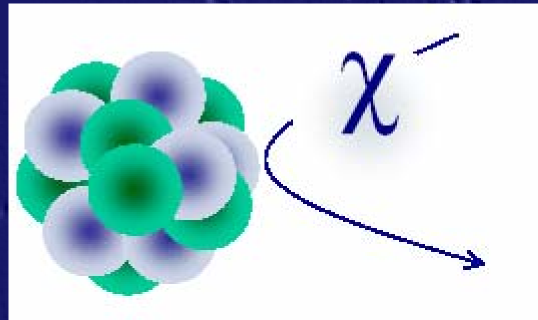
1. Weakly Interacting Massive Particles: WIMPs
   Most promising candidate: lightest supersymmetric particle (neutralino, a linear combination of photino, zino and higgsinos, to be found at LHC?),
   very heavy (around 10^{11}eV).

2. Axion or Axion Like Particles: ALPs
   Invented to explain CP conservation in QCD ("why is the electric dipole moment of the neutron zero or extremely small?").
   Non-thermal production in the early universe,
   very light (around 10^{-4}eV).

Direct Detection of WIMPs

Basic Idea:

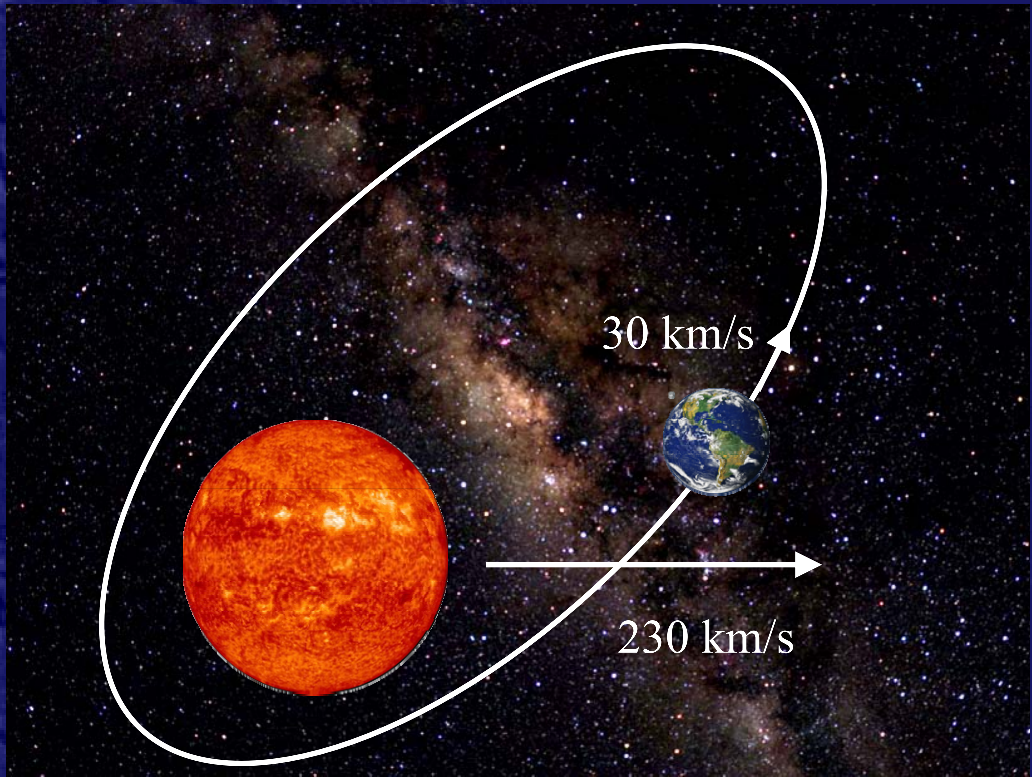
- elastic scattering of WIMPS on nuclei
- Measure nuclear recoils



Experimental challenge:

- WIMPS mass: 45 GeV to TeV (≈ mass of nuclei)
- Relative speed (earth - WIMP in galactic halo): 250 km/s
  ↳ kinetic energy ≈ keV
- Very low cross sections: $\sigma_\chi < 10^{-40}$ cm$^2 = 10^{-4}$ pb $\approx 10^{-14}\, \sigma_{pp}$
- Local density ≈ 0.3 GeV / cm^3
  ↳ Event rate < 0.1 / day / kg (10^{-6} Hz / kg)

The "smoking Gun" of WIMP Detection



Speed relative to WIMP halo:
(230 ± 15) km/s

(10^4 to 10^6 WIMPs/cm^2/s)

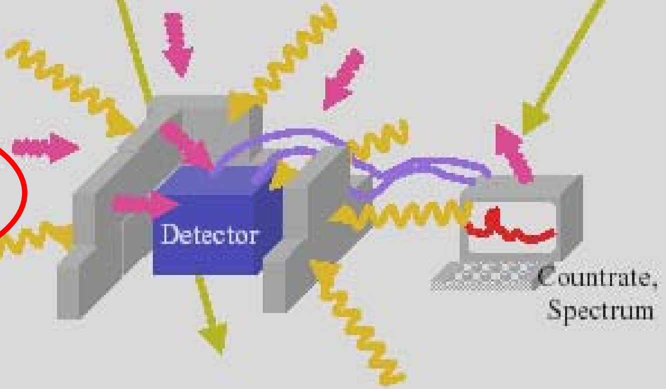
Due to varying speed of earth relative to galactic halo:
7% annual modulation of WIMP detection rate

Basic Detector Considerations

Cosmic Rays

- Radioactivity from the surrounding: 1 Hz/kg
- Muons from cosmic rays: 0.01 Hz/kg

⇘ Shield and / or identify radioactivity induced events
Shield cosmic rays ⇨ underground laboratory (1.5 km rock)

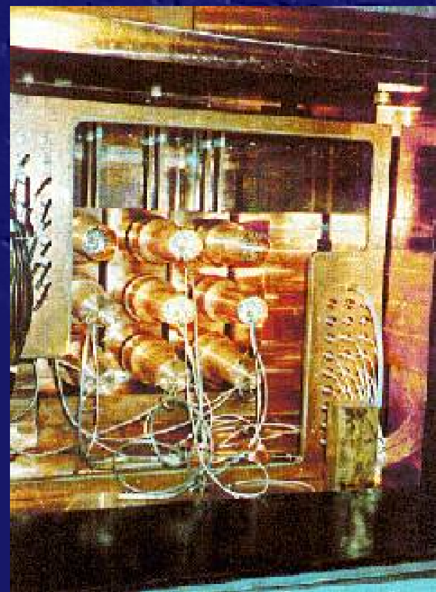


Expected Rate:
10^{-6} Hz / kg

DAMA/LIBRA: a "classical" Experiment

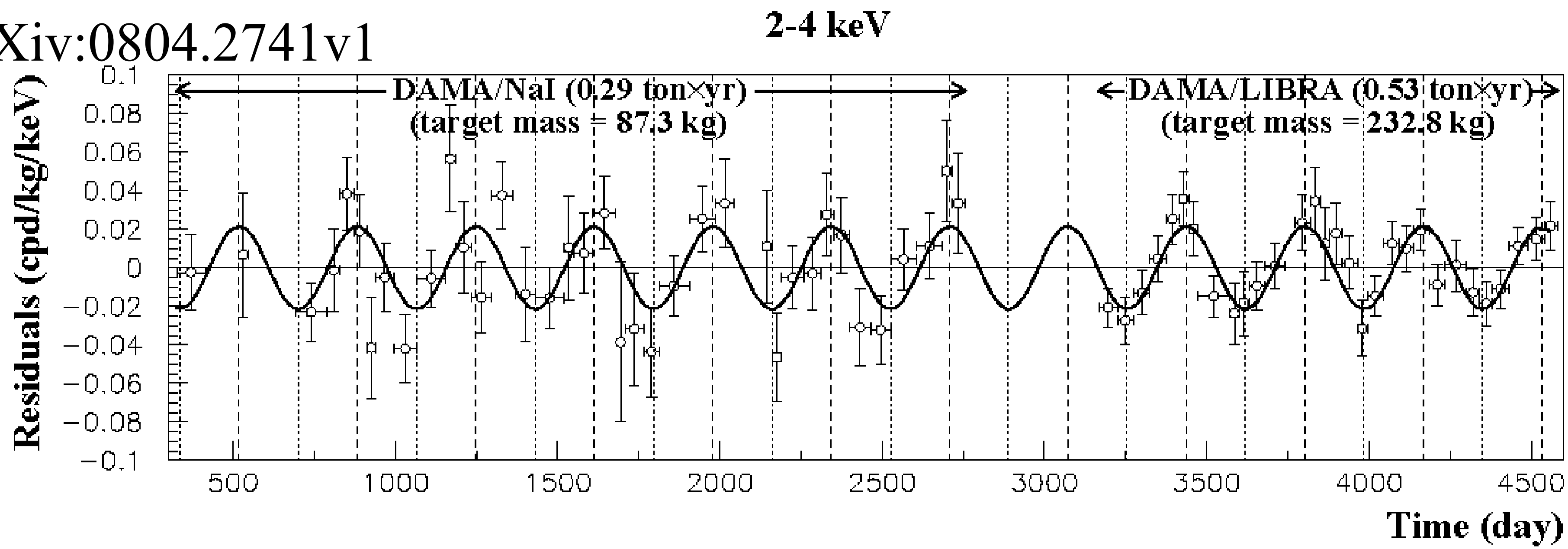
Detection of scintillating light from recoiled nuclei

- Large mass (240 kg NaI(Tl) detectors), careful shielding of radioactivity and cosmic muons
- No event-by-event background / signal identification



DAMA/LIBRA: Evidence for WIMPs?

arXiv:0804.2741v1

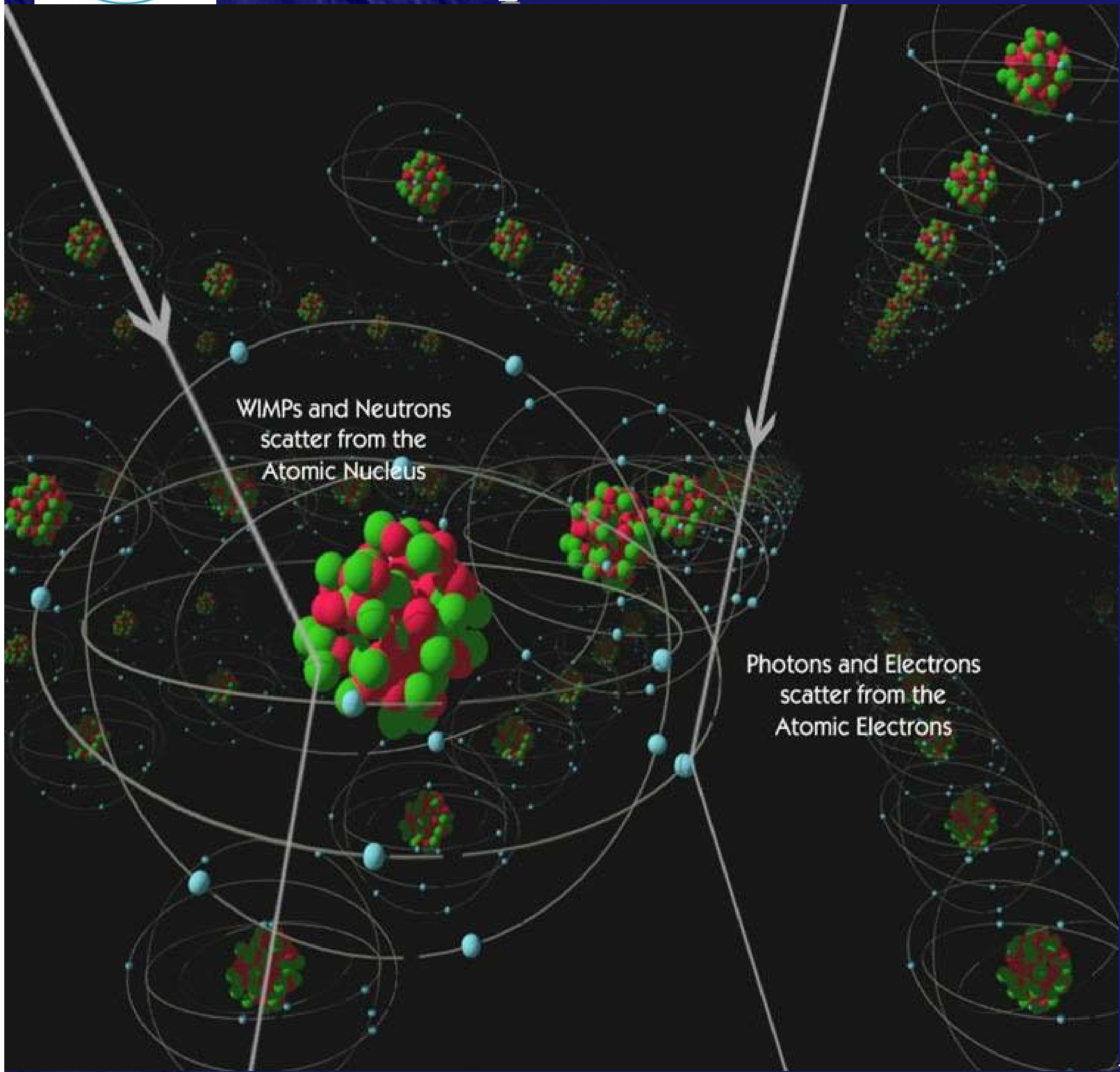


Annual modulation!

Results (model dependent): $M_\chi \approx$ 15-100 GeV, $\sigma_\chi \approx 10^{-5}$ pb

Compatible with results of other experiments?

New Experiments with Background Rejection



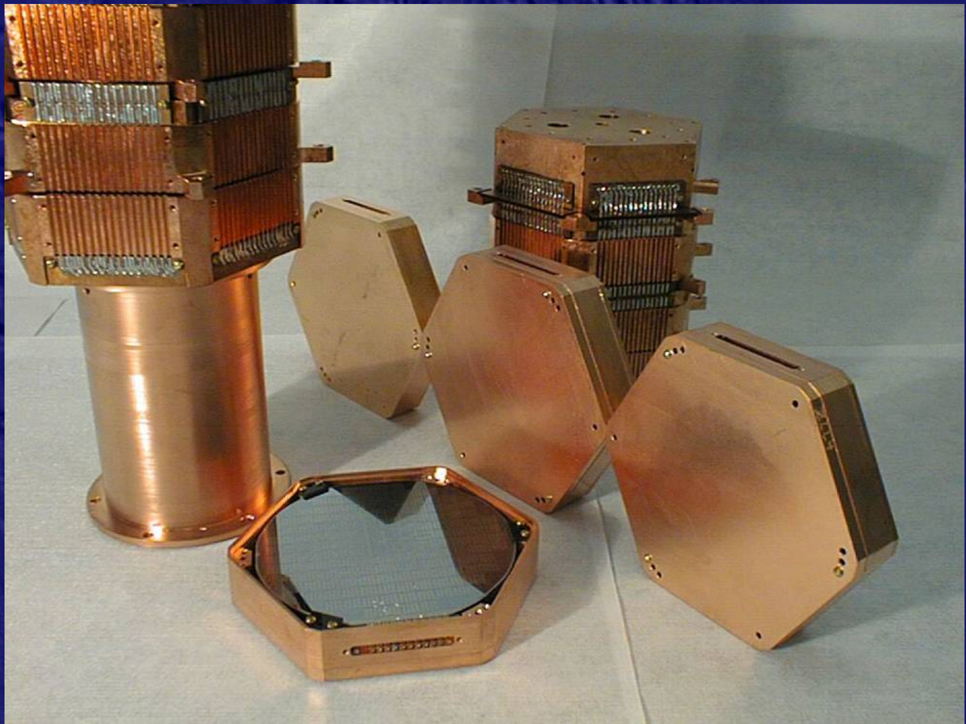
If ionisation could be measured (charge, scintillating light):

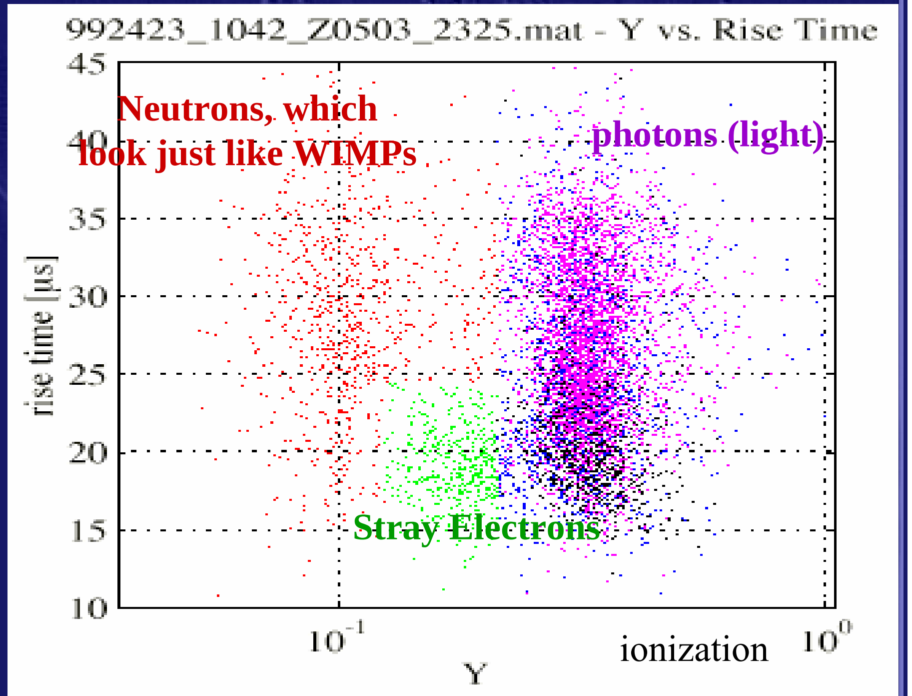
Distinguish em. radiation and nuclear recoils by the ratio E(phonon)/E(ion.)

Example: the CDMS Experiment

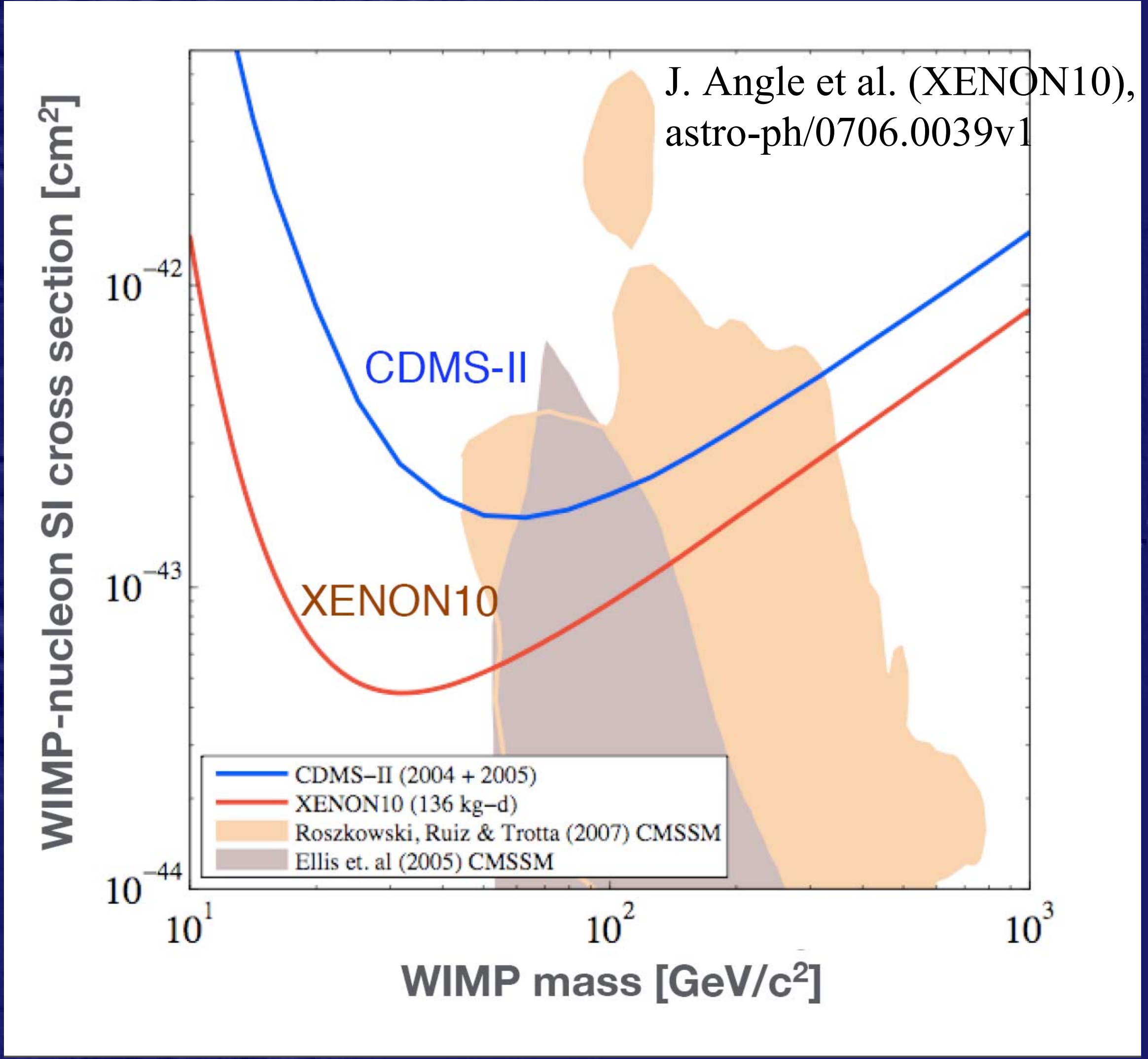
Cryogenic Dark Matter Search in the Soudan underground facilty

Simultaneous measurements of phonons and ionization in silicon and germanium crystals at 0.02 K Crystal mass 0.1 and 0.25 kg.





Summary: Direct WIMP Detection



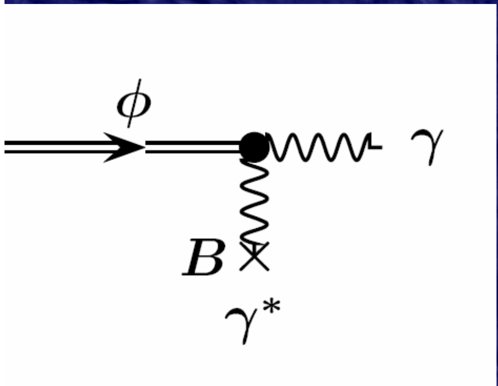
- Evidence from DAMA incompatible with other experimental results
- Has DAMA seen an "ALP" and not a "WIMP"?
- Much progress expected by upgrades of experiments in the next years

Outside the mainstream

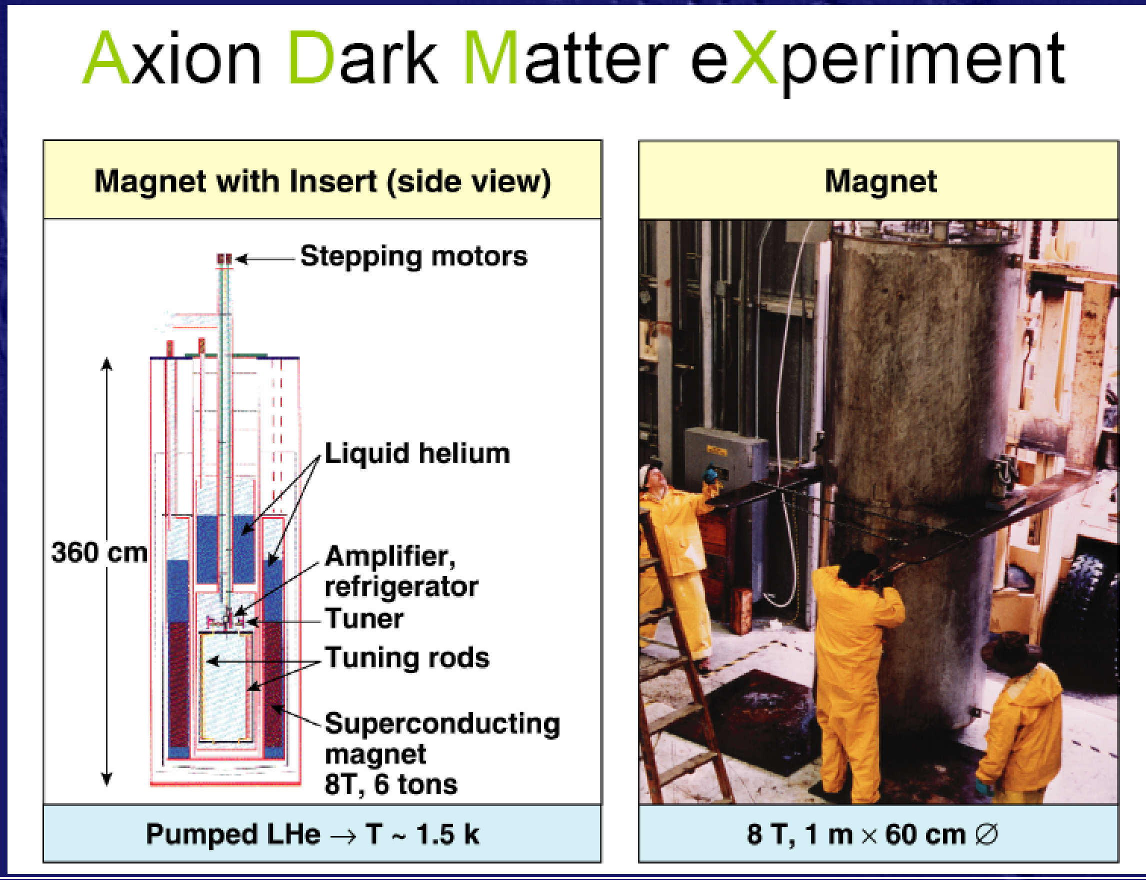
- Axions or axion-like particles could constitute very light but cold dark matter
(originating from phase transition, not from freeze out).
- New particles as predicted by string-theory may be also very light (sub-eV):
WISPs (weakly interacting sub-eV particles)
- Dark Energy could be related to WISPs:
WISPs could be scalar or pseudoscalar and hence provide indirect information on the scalar field related to DE.
- (non) Absorption of cosmic teV photons could be related to these new particles.
- …


WIMPs @ LHC ILC
meV scale
neutrinos, Dark Energy

Looking for Axion Dark Matter



Axions (ALPs) convert to photons via coupling to a magnetic field.

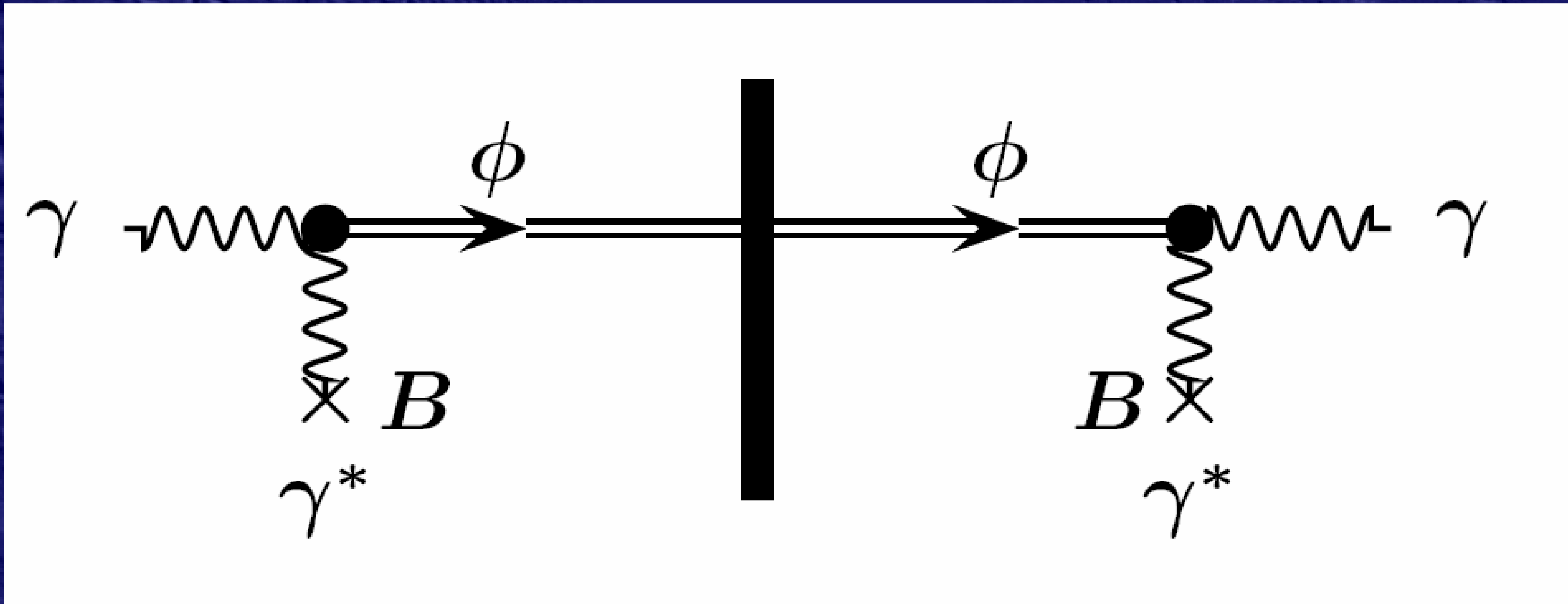


Look for resonant signal in a microwave cavity when tuning frequency.

No signal found yet!

Axion-Like Particle Search @ DESY

The ALPS Project



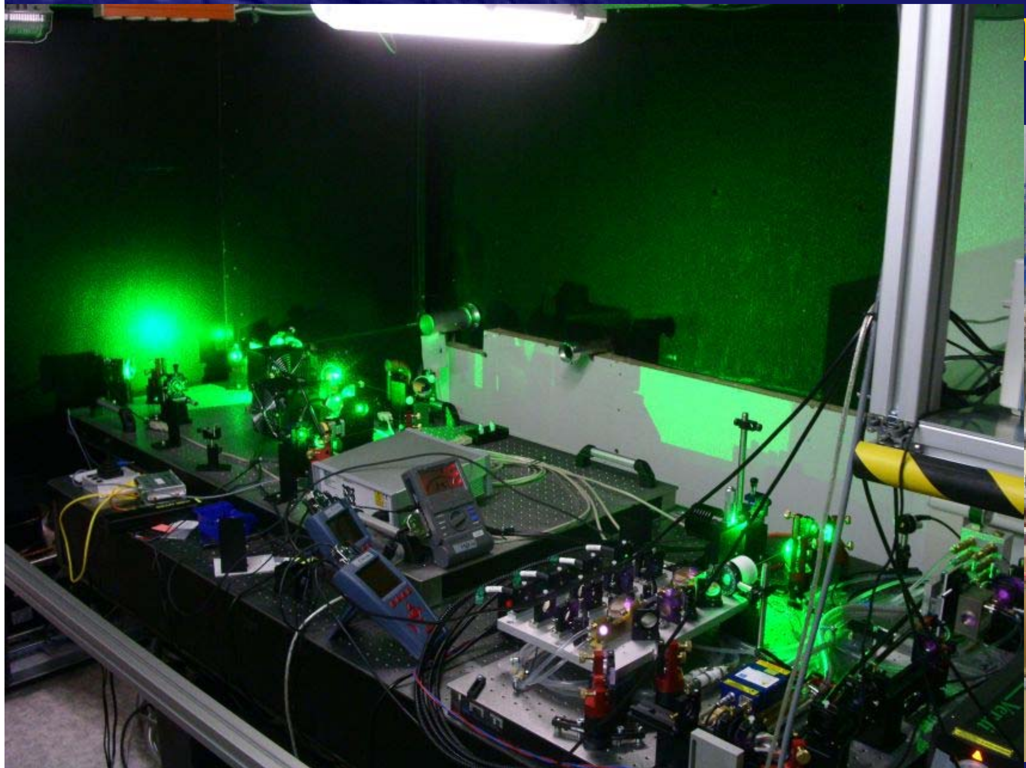
A light-shining-through-a-wall experiment

Axion-Like Particle Search @ DESY

The ALPS Project

A light-shining-through-a-wall experiment

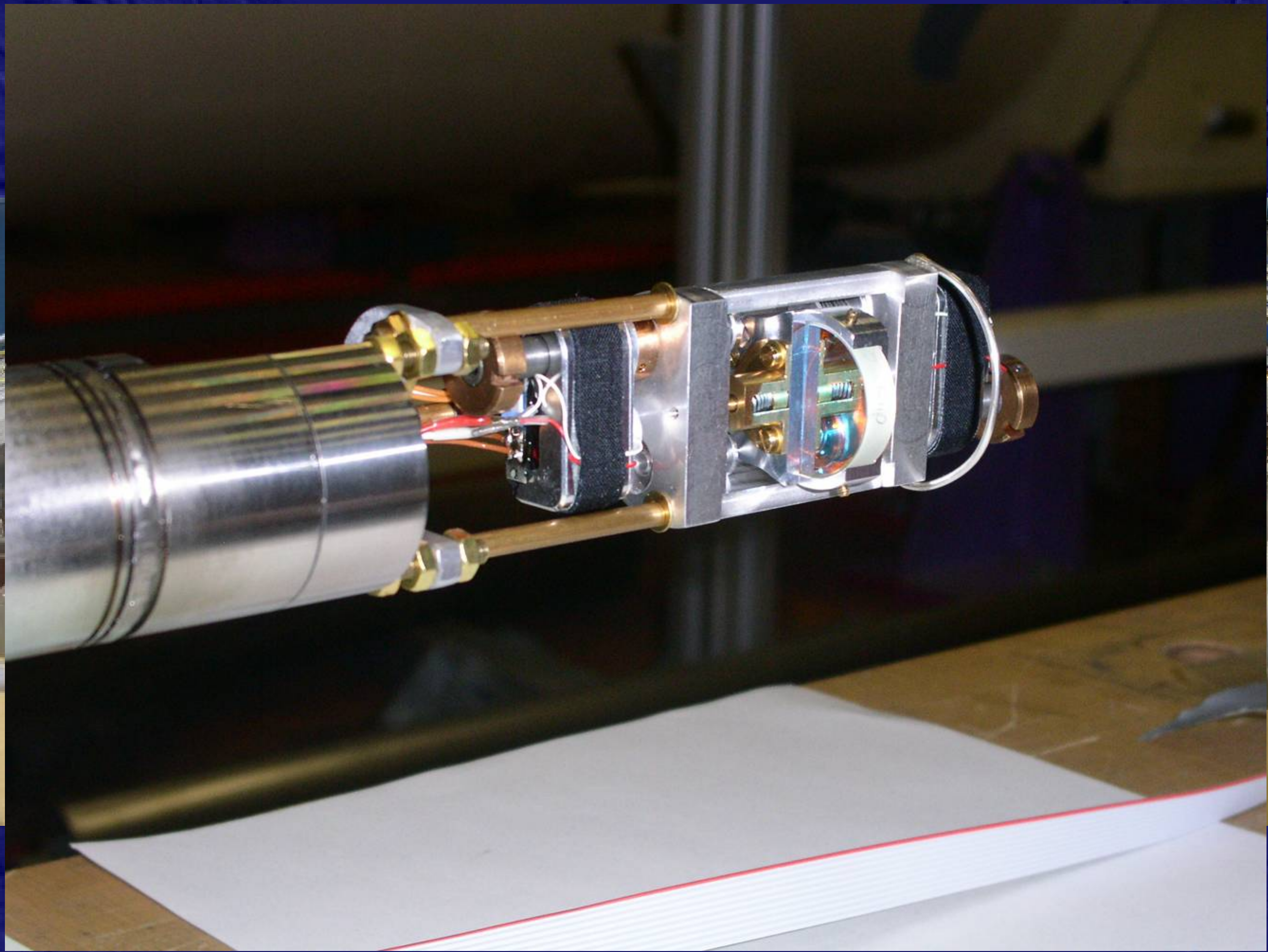
Axion-Like Particle Search @ DESY



Project

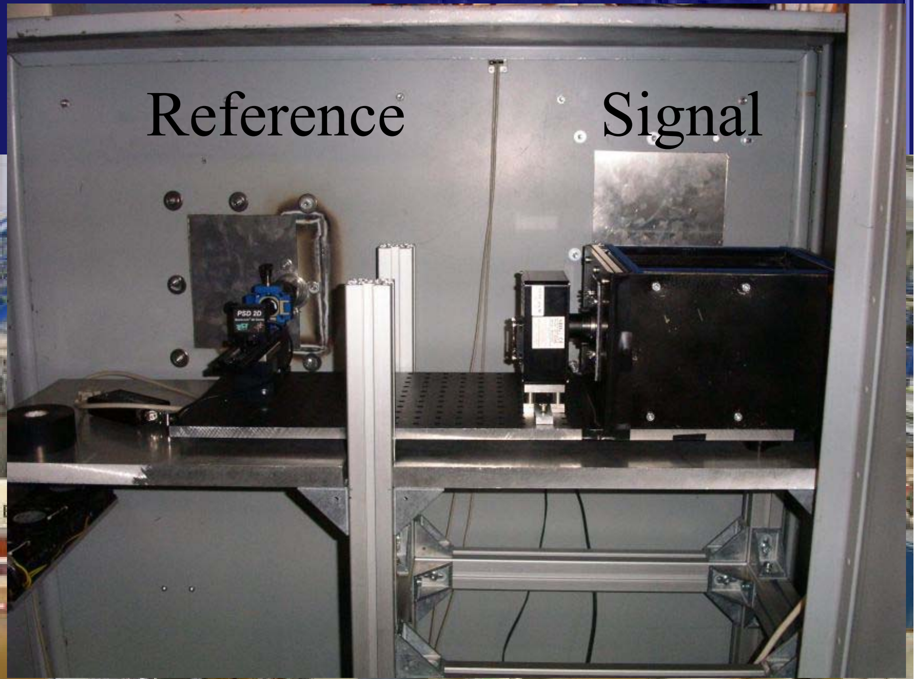
A light-shining-through-a-wall experiment

The ALPS Project


The ALPS Project

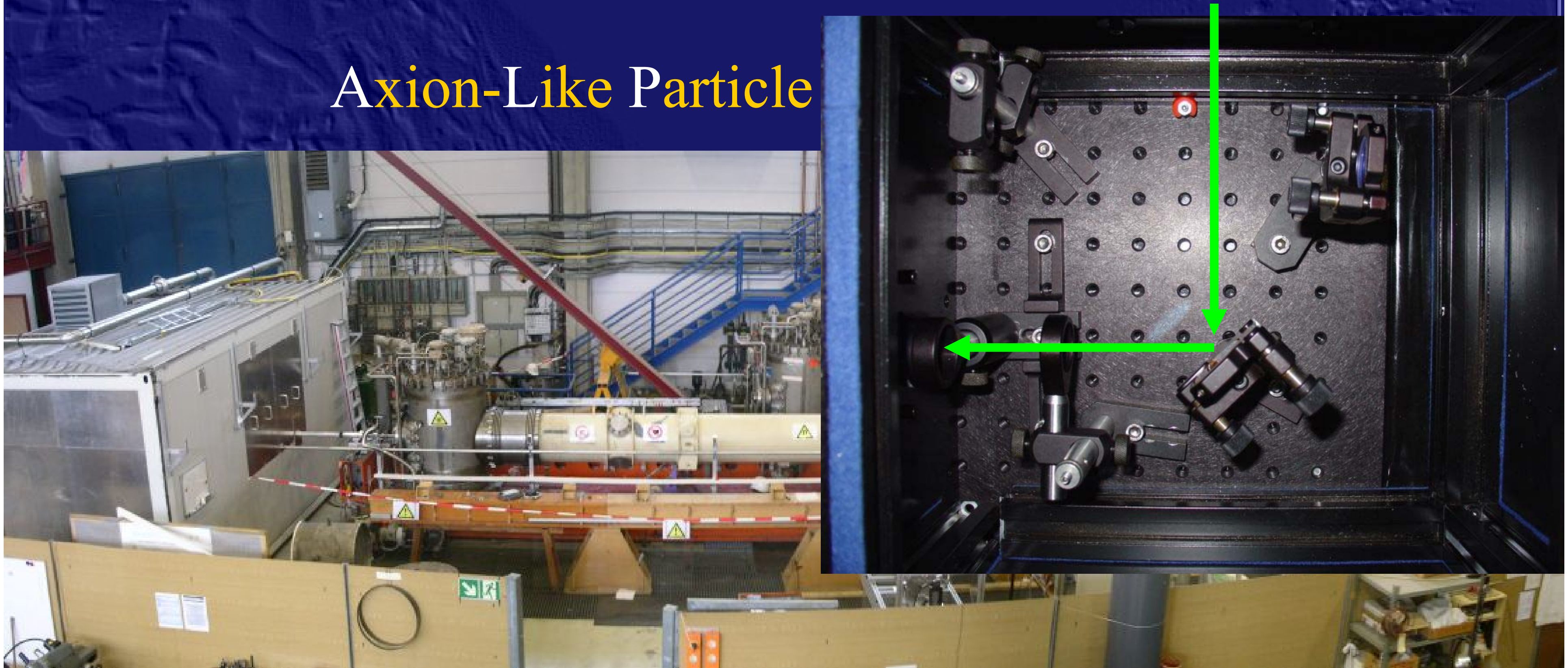
Axion-Like Particle



A light-shining-through-a-wall experiment

The ALPS Project

Axion-Like Particle



A light-shining-through-a-wall experiment

The ALPS Project

Axion-Like Particle Sea

A light-shining-through-a-wall experiment

The ALPS Project

Searching for potentially revolutionary physics in a small collaboration

DESY, Hamburger Sternwarte, Laser Zentrum Hannover and Max-Planck-Institute for Gravitational Physics (AEI)

with few people.

http://alps.desy.de

http://axion-wimp.desy.de

Dark matter: topics for discussion

- Why should dark matter be "cold"?
- Could neutrinos or black holes be the dark matter?
- Which other candidates exist for dark matter?
- Does dark matter exist at all? How to identify its constituents?
- Is there any connection between "dark matter" and "dark energy"?
- Why don't we feel the influence of dark matter on earth? Why does it not affect the flight path of satellites?
- Could a "dark world" with "dark" intelligent beings made of dark matter be possible?

Many open Questions

- Is there Dark Matter?
  What are the constituents of Dark Matter?
- Do we understand gravity?
- What is Dark Energy?
- Where are the sources of Cosmic Rays?
- What happens in AGNs?
- Will there be more sources in the neutrino sky?

And even more

- What are the masses of neutrinos?
- How do they oscillate?
- Do the constants of nature vary with time?
  Controversial results for α_{em} obtained by observation of very distant quasars and galaxies.
- What does the CMBR teach on the Grand Unification?

Applications

news feature

Pyramid power

Archaeologists have failed to learn the secrets of Mexico's largest ancient monument. Particle physicists might save the day, says Michael Hopkin.

It's not the kind of place you'd expect to find a particle-physics laboratory. The ancient Pyramid of the Sun at Teotihuacán is an hour's drive from Mexico City at the end of a bumpy jeep track. But deep inside this massive monument a state-of-the-art particle detector is being assembled, and my companions, both physicists, have brought me here to see how it's getting on.

The project is the brainchild of researchers from the National Autonomous University of Mexico (UNAM) in Mexico City, who hope to succeed where traditional archaeology has failed. Instead of taking up pickaxes and shovels to get at the pyramid's secrets, they will use their machine to detect the cosmic rays that continually pass through this mass of stone and dirt. With patience, the researchers believe, the rays will generate a picture of what is inside the monolith.

"The mass of the pyramid is so huge that we need twenty-first-century technology to study it," concedes UNAM archaeologist Linda Manzanilla, who is collaborating with the physicists.

The Pyramid of the Sun is believed to be the third largest pyramid in the world, with a base that is roughly 200 metres on each side. Built some 2,000 years ago, it formed the centrepiece of a bustling city for five centuries until Teotihuacán was abandoned. When archaeologists first dug into it in 1922, they hoped to find the bones of Teotihuacán's rulers. But unlike the neighbouring Pyramid of the Moon, which contains numerous stone chambers, the Sun pyramid is filled with earth and volcanic debris. Further digging seemed likely only to damage the structure.

Going underground

The physicists didn't need to dig. A cramped tunnel just below ground level that leads to several chambers at the heart of the pyramid was discovered in 1971. Although it provided scant clues for archaeologists as to what lies above, it made a perfect, if humid, spot for a particle detector.

As tourists admire the views from the top of the pyramid some 65 metres above us, we don hard hats and open a rusting metal door at the base of the great structure. My guides, UNAM particle physicists Arturo Menchaca and Ernesto Belmont, lead me down an iron staircase beyond the door to the tunnel opening. After several minutes of walking stooped through the stifling humidity of the tunnel we come to the metal shed that the researchers have set up to house their instrument.

Menchaca's team has been working on the detector for more than a year. Once this is ready, the group will begin looking for muons, charged particles that rain down on Earth at a rate of about 12,000 per square metre every minute. Muons penetrate most things, including rocks, earth and people, but the denser the medium, the less likely they are to get through. This means that a pyramid that contains burial chambers or other cavities will absorb fewer muons than one without.

The detector itself is a metre-square sandwich of several layers, each strung with tiny tungsten wires like a miniature piano. The wires, each thinner than a human hair, sit in an electric field. A muon passing through the detector charges the gas inside it, and the wires pick up the tiny current. With different layers strung in different directions, the researchers can build up a picture of the muon's direction, and hence the position of any rooms in the pyramid above.

The set-up should spot any cavity larger than about 80 centimetres across, Menchaca says, gesturing at the hundreds of thousands of tonnes of rock and earth above our heads.

M. HOPKIN

M. HOPKIN

Catching rays: Arturo Menchaca (right) and Ernesto Belmont hope their muon detector will let them see inside the Pyramid of the Sun (above).

But he warns that even if something that looks like a room is spotted, it could simply be the result of subsidence over the centuries, rather than architectural design. "Everyone's expecting Tutankhamun," he says, "but we may find something that means nothing."

Subterranean blues

Doing science down here creates unusual problems. The researchers had to install their own power supply and encase it in a metal pipe to protect it from thieves. Once the detector is running, they will have to ventilate the chamber and tunnel before entering to avoid suffocating on the mix of carbon dioxide and noble gases used in the instrument.

No one should expect results any time soon. The researchers are testing parts of the detector in the lab and installing them underground piece by piece, a process they hope to complete within the next two months. They will then collect data for at least a year before releasing it to archaeologists. Should any of the tiny wires break, as has been known to happen, everything gets set back a week.

Perhaps there's no rush. As we emerge blinking into the sunshine to the curious stares of camera-clutching sightseers, the baking sun reminds me that it's better not to hurry in this climate. "This problem has been waiting 2,000 years," Menchaca says. "Nothing's going to happen if we're delayed another month." ■

Michael Hopkin is a reporter for news@nature.com.

nature Vol 447 | 24 May 2007

RESEARCH HIGHLIGHTS

Cosmic rays peek inside

Nucl. Instrum. Methods Phys. Res. A **575**, 489–497 (2007)

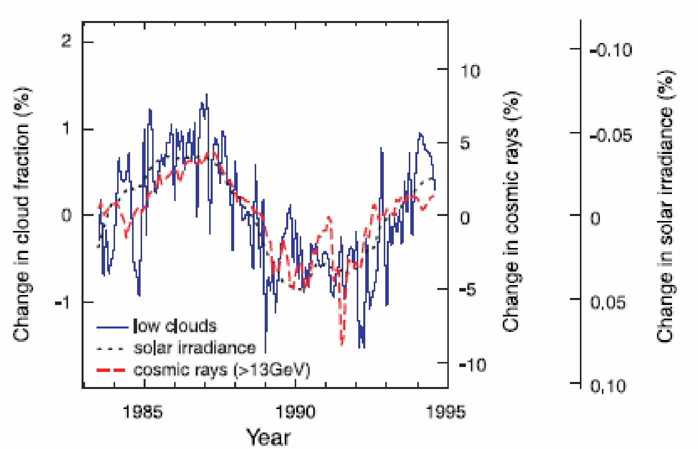
Researchers in Japan have taken advantage of cosmic rays to image the inside of an active volcano. This approach has previously been used to search for chambers inside pyramids.

Hiroyuki Tanaka of the University of Tokyo and his colleagues placed an instrument that detects particles known as muons on the side of Mount Asama (pictured). Muons are sent off in all directions when cosmic rays hit Earth's atmosphere.

Some muons reach the detector having passed through the rocks of the volcano. By calculating the number of muons absorbed en route, the researchers determined the density of the volcano's innards. With more devices and real-time readings, the method may help in predicting eruptions.

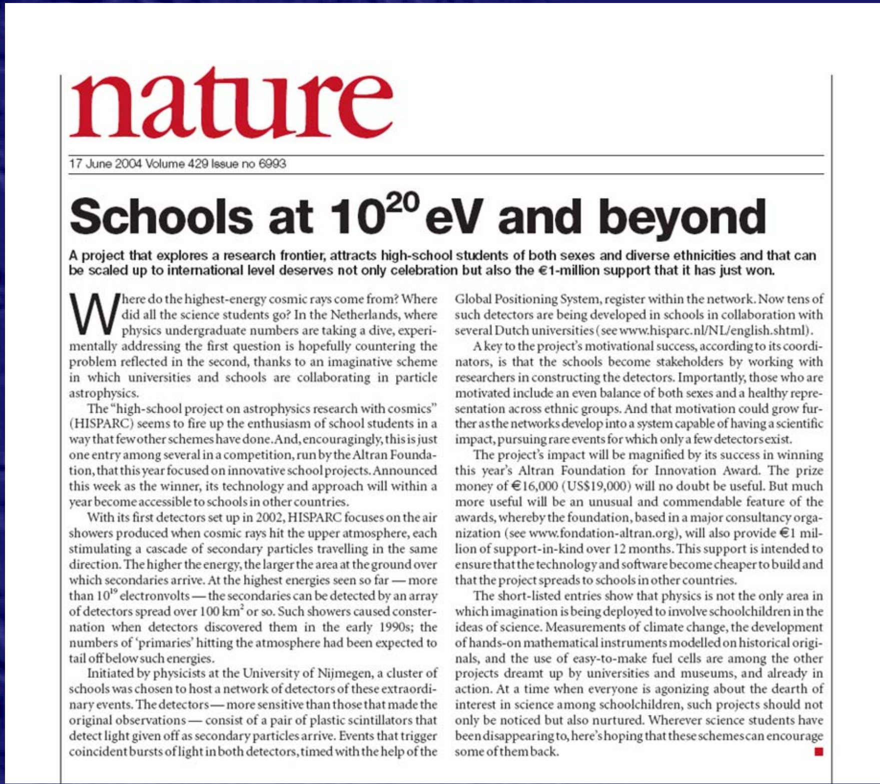
KYODO NEWS/AP

Climate and Cosmic Rays



Svensmark, Friis-Christensen (1997)

Outreach



nature

17 June 2004 Volume 429 Issue no 6993

Schools at 10^{20} eV and beyond

A project that explores a research frontier, attracts high-school students of both sexes and diverse ethnicities and that can be scaled up to international level deserves not only celebration but also the €1-million support that it has just won.

Where do the highest-energy cosmic rays come from? Where did all the science students go? In the Netherlands, where physics undergraduate numbers are taking a dive, experimentally addressing the first question is hopefully countering the problem reflected in the second, thanks to an imaginative scheme in which universities and schools are collaborating in particle astrophysics.

The "high-school project on astrophysics research with cosmics" (HISPARC) seems to fire up the enthusiasm of school students in a way that few other schemes have done. And, encouragingly, this is just one entry among several in a competition, run by the Altran Foundation, that this year focused on innovative school projects. Announced this week as the winner, its technology and approach will within a year become accessible to schools in other countries.

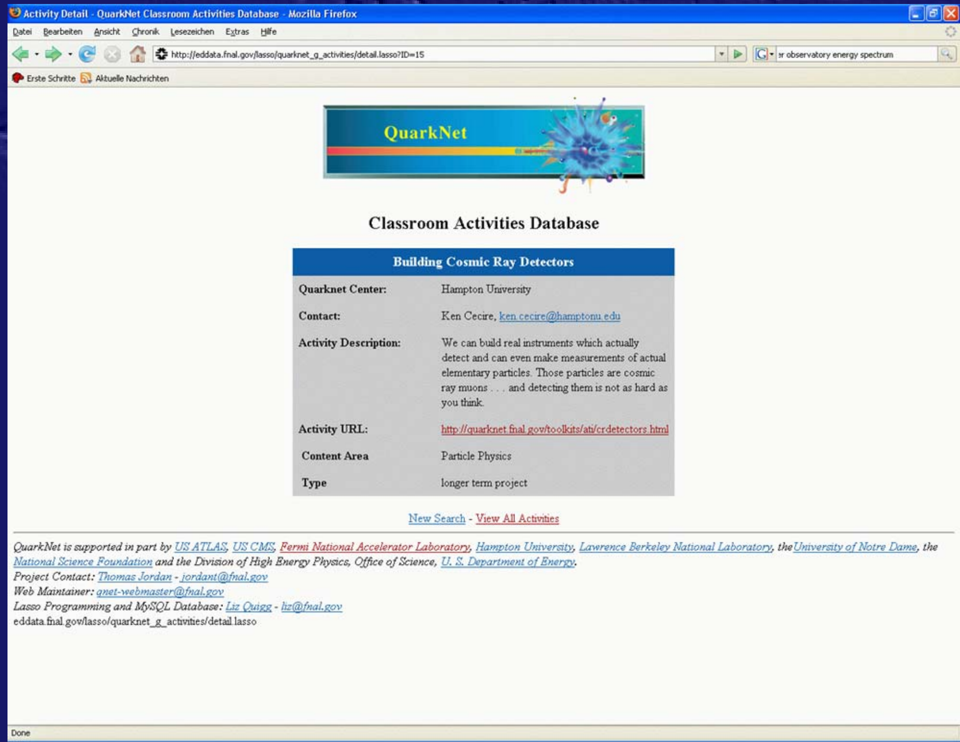
With its first detectors set up in 2002, HISPARC focuses on the air showers produced when cosmic rays hit the upper atmosphere, each stimulating a cascade of secondary particles travelling in the same direction. The higher the energy, the larger the area at the ground over which secondaries arrive. At the highest energies seen so far — more than 10^{19} electronvolts — the secondaries can be detected by an array of detectors spread over 100 km^2 or so. Such showers caused consternation when detectors discovered them in the early 1990s; the numbers of 'primaries' hitting the atmosphere had been expected to tail off below such energies.

Initiated by physicists at the University of Nijmegen, a cluster of schools was chosen to host a network of detectors of these extraordinary events. The detectors — more sensitive than those that made the original observations — consist of a pair of plastic scintillators that detect light given off as secondary particles arrive. Events that trigger coincident bursts of light in both detectors, timed with the help of the Global Positioning System, register within the network. Now tens of such detectors are being developed in schools in collaboration with several Dutch universities (see www.hisparc.nl/NL/english.shtml).

A key to the project's motivational success, according to its coordinators, is that the schools become stakeholders by working with researchers in constructing the detectors. Importantly, those who are motivated include an even balance of both sexes and a healthy representation across ethnic groups. And that motivation could grow further as the networks develop into a system capable of having a scientific impact, pursuing rare events for which only a few detectors exist.

The project's impact will be magnified by its success in winning this year's Altran Foundation for Innovation Award. The prize money of €16,000 (US$19,000) will no doubt be useful. But much more useful will be an unusual and commendable feature of the awards, whereby the foundation, based in a major consultancy organization (see www.fondation-altran.org), will also provide €1 million of support-in-kind over 12 months. This support is intended to ensure that the technology and software become cheaper to build and that the project spreads to schools in other countries.

The short-listed entries show that physics is not the only area in which imagination is being deployed to involve schoolchildren in the ideas of science. Measurements of climate change, the development of hands-on mathematical instruments modelled on historical originals, and the use of easy-to-make fuel cells are among the other projects dreamt up by universities and museums, and already in action. At a time when everyone is agonizing about the dearth of interest in science among schoolchildren, such projects should not only be noticed but also nurtured. Wherever science students have been disappearing to, here's hoping that these schemes can encourage some of them back. ■



The scientific Prospects

All (nearly) questions may be answered by the next generation of experiments within the next decade:

- CMBR: Planck mission
- Dark Matter: XENON, CRESST, CDMS, ...
- Cosmic Rays: AUGER
- TeV astronomy: HESS, MAGIC, VERITAS, CTA, ...
- Neutrino astronomy: ICECUBE, KM3NET, …
- Searches for new physics at sub-eV scales
- …

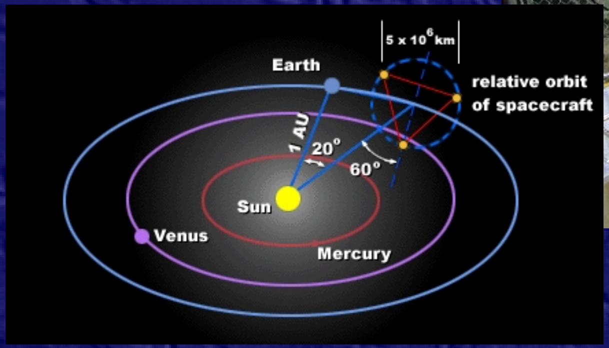
complemented by new particle physics and astronomy projects (LHC, SNAP, James Webb Space Telescope, …)

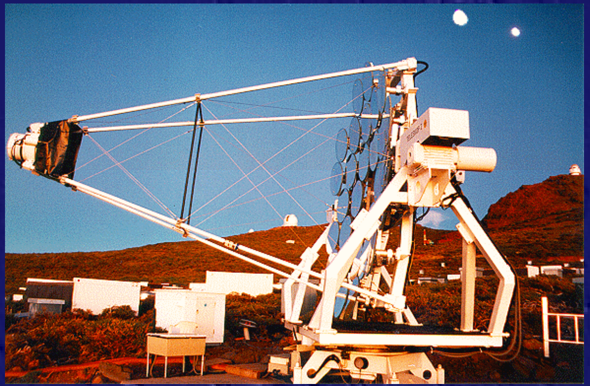
and most likely many unforeseen phenomena will be discovered!

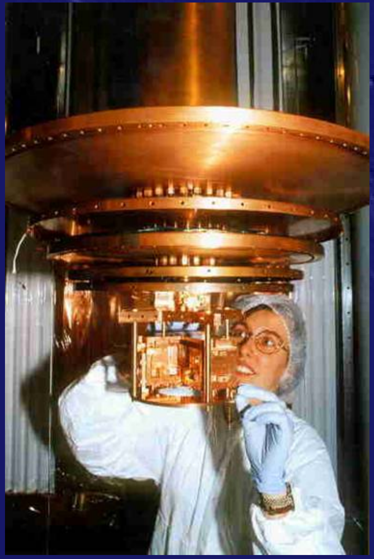

COSMOLOGY MARCHES ON
Where the hell did it all come from?
Where the hell did it all come from?

Astroparticle Physics

Multifaceted ...







Astroparticle Physics

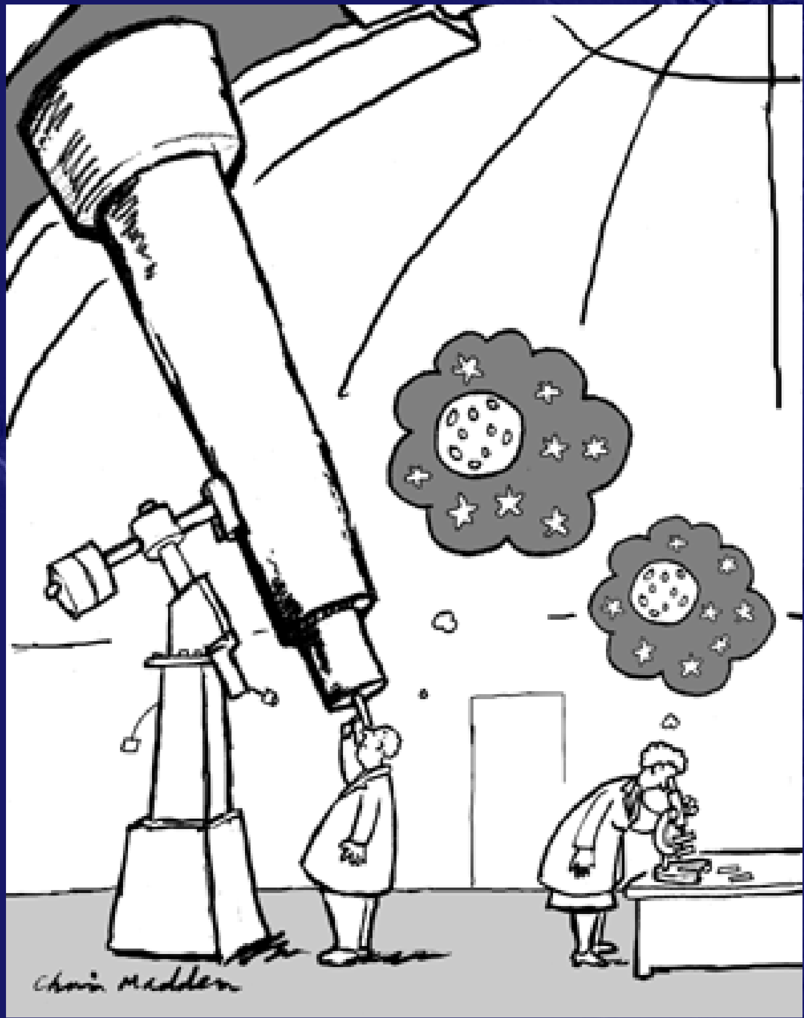
... and thrilling!

Fire and ice at the HEGRA experiment on the Canary island La Palma

Astroparticle Physics

Most fascinating (to me):

If research on smallest and largest scales complement each other in the way most evident in astroparticle physics we can be confident to catch a glimpse of reality!



Astro and Particles

Particle physics detectors

⇓

Cherenkov Telescopes

⇓

TeV Astronomy with AGNs

⇓

Hints for new elementary particles, quantum gravity?

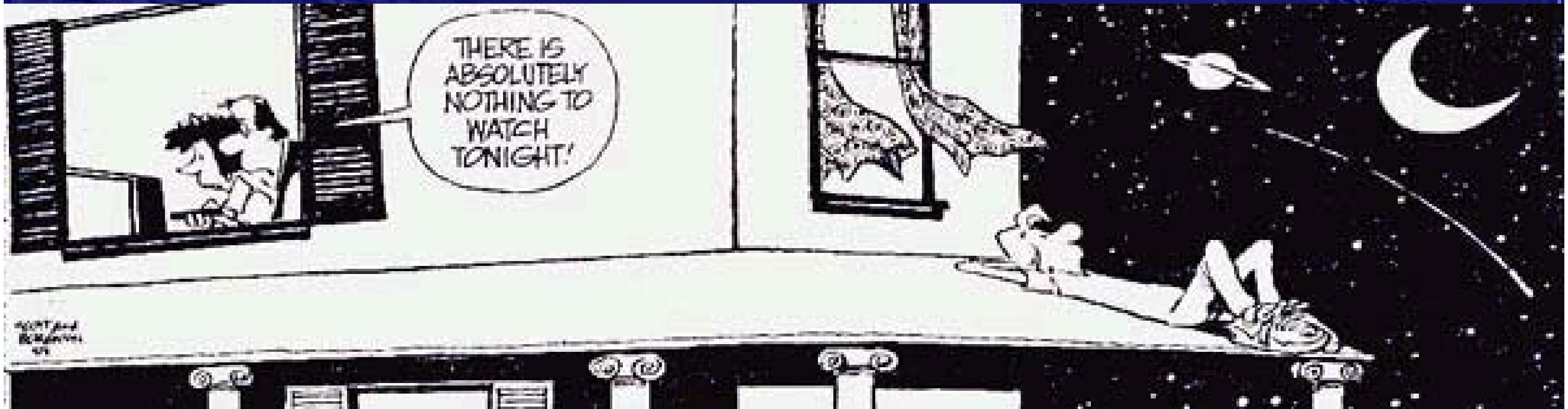
Some results seem to be confusing or weird (Dark Matter, Dark Energy)

⇓

really basic questions are being addressed

⇓

hope to understand fundamentals!



Enjoy it!

Suggestions for further reading

- “Astrophysics” (M. S. Longair),
  Cambridge 1992
- “Cosmic Rays and Particle Physics” (T. K. Gaisser),
  Cambridge 1999
- “Very High Energy Cosmic Gamma Radiation (F. Aharonian),
  World Scientific 2004
- “Astroparticle Physics (Claus Grupen),
  Springer 2005