united nations educational, scientific and cultural organization

international atomic energy agency

the **abdus salam** international centre for theoretical physics

ICTP 40th Anniversary

H4.SMR/1574-30

"VII School on Non-Accelerator Astroparticle Physics"

26 July - 6 August 2004

Astroparticle Physics in Space

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Astroparticle Physics in Space

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7th School on Non-Accelerator Astroparticle Physics, ICTP Trieste 2004

By the end of the past century the standard model of particle physics has begun to play a prominent role in cosmology.

The idea of the Big Bang has been built on the predicted effect of certain putative particle fields and potentials on the cosmic expansion.

The great improvements in the observational cosmology, and particle physics have left to the 21st Century open questions that require large investments and program plans.

Space is a very hostile environment to men and experiments

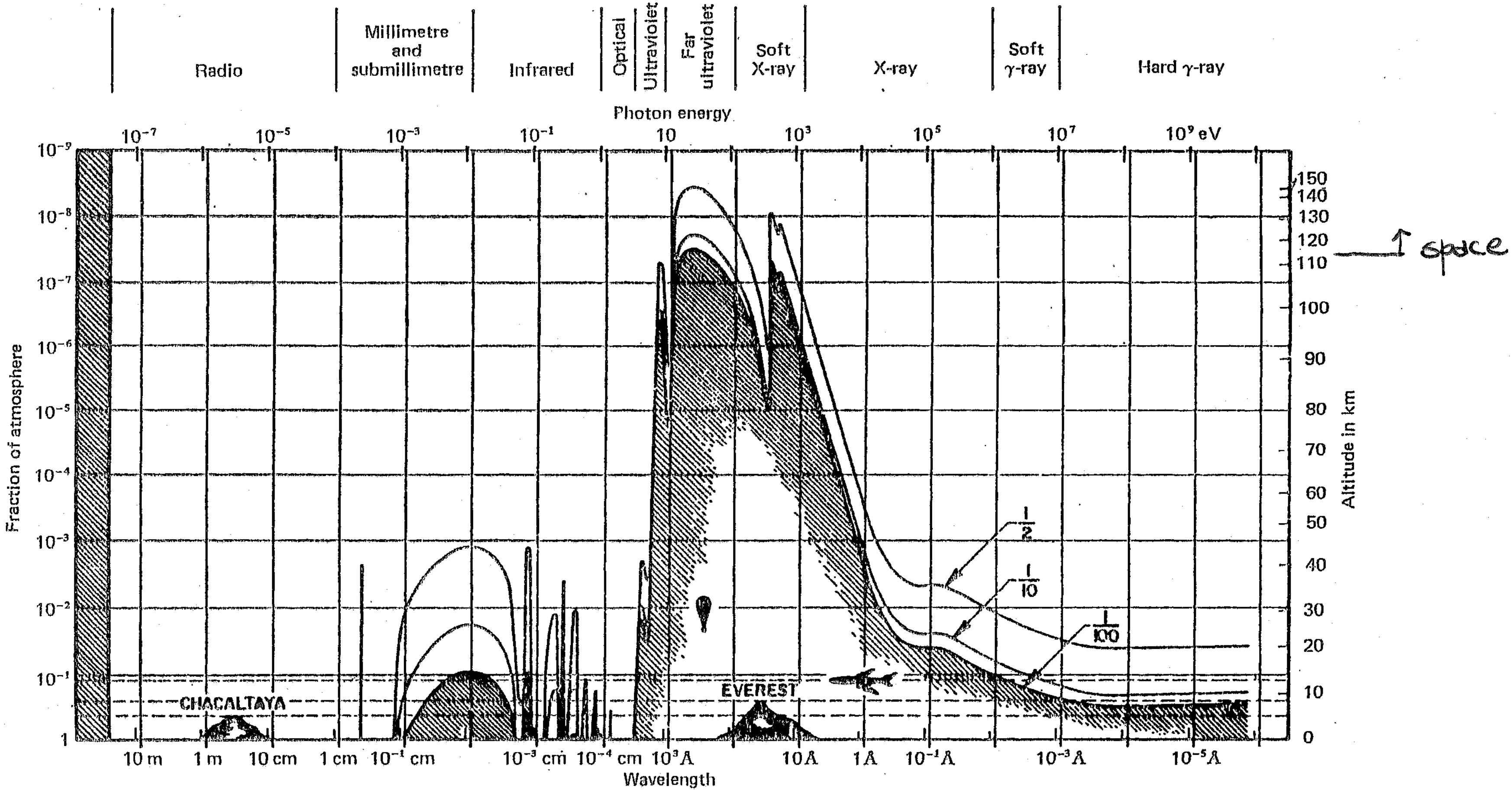
Cons

- the absence of atmosphere
- the low gravity
- the high radiation fields
- low temperature
- energy supply
- manufacturing cost (high redundancy)
- launch/operation cost
  preparation long - tech. old

Pros

- the absence of atmosphere in situ meas.
- the low gravity
- low temperature (noise)
- low backgrounds
- survey the whole sky
- long base (interferometry)
- dedicated instr./mission

Fig. 1.1 Attenuation of electromagnetic radiation in the atmosphere. Solid curves indicate the altitude (and corresponding pressure as a fraction of 1 atmosphere) at which the indicated fractional attenuation occurs for radiation of a given wavelength. Along the top of the diagram are the conventional designations of the different wavebands. (Adapted from Giacconi, Gursky & Van Speybroeck, 1968.)



- <u>Question 1</u>: What is Dark Matter ?
- <u>Question 2</u>: What is the Nature of Dark Energy ?
- <u>Question 3</u>: How did the Universe Begin?
- Question 4: Did Einstein have the last word on Gravity ? LISA Gravity Probe B
- Question 5: What the masses of the Neutrinos and How have they shaped the evolution of the Universe ?
- Question 6: How do cosmic accelerators work and what are they accelerating ? EUSO/OWL
- Question 7: Are protons stable ?
- Question 8: What are the new states of matter at exceedingly high density temperature ? RXTE
- Question 9: Are there additional Space-Time dimensions ?

Question 1: What is Dark Matter ?

Astronomers have shown that the objects in the Universe from galaxies a million time smaller than our to the largest clusters of galaxies are held together by a form of matter that neither emits nor absorbs light and that interacts very weakly with ordinary matter. Its nature is a complete mystery. This matter probably consists of one or more as-yet-undiscovered elementary particles, and aggregations of it produce the gravitational pull leading to the formation of galaxies and large-scale structures in the Universe

These particles may be streaming through our Earth-bound laboratories.

Question 1: What is Dark Matter ?

The fact that the most of the mass in the Universe is non luminous became evident about 65 years ago when F. Zwicky noticed that the speed of galaxies in large clusters is much to great to keep them gravitationally bound together unless they weight over 100 times more than one would estimate on the basis of the number of stars in the cluster.

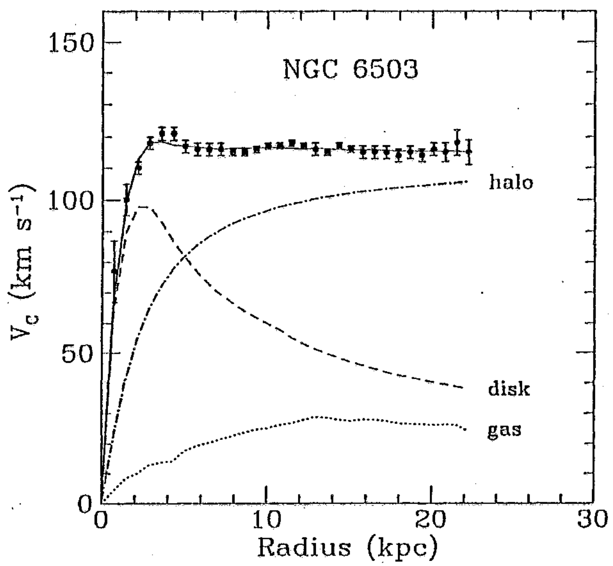
=> $\Omega_m \cong 0.1 - 0.3$ (in units of the critical density)

Also it was known for a long time that if there were matter beyond the luminous we see, the time require for structures we see to form would be very short, thereby requiring fluctuations in the CMBR considerably larger than those observed.

Question 1: What is Dark Matter ?

The most robust observational evidence involves galactic dynamics:

there is not enough luminous matter observed in spiral galaxies to account for their rotation curve => imply the existence of a diffuse halo of dark matter



Begeman et al
MNRAS 249 (91) 523

Question 1: What is Dark Matter ?

However:

Summing the contributions from all galaxies one can infer that dark matter associated with galaxies contributes $\Omega_{halo} \geq 0.1$

$[\Omega_x = \rho_x/\rho_{crit}]$

On the other hand Big-Bang nucleosynthesis suggests a baryon density $\Omega_b \leq 0.1$

$\Rightarrow$ Thus the bulk of the halo must be non-baryonic

CMBR measurements [WMAP, fluctuation spectrum fit] have given independent and precise confirmation

Question 1: What is Dark Matter ?

- Neutrinos of mass $\mathcal{O}$(10eV) could provide the right dark-matter density, but N-body simulations of structure formation in a neutrino-dominated Universe do not succeed in reproducing observations

⇒ favoured candidates Cold Collisionless Dark Matter (CCDM) [particles]

- WIMP such as lightest superpartners in SUSY extension of SM
- Axions

But there are problems, so alternative models

SIDM - Strong self-interacting Dark Matter

WDM - Warm Dark Matter

RDM - Repulsive Dark Matter

FDM - Fuzzy Dark Matter

SADM - Self-Annihilating Dark Matter

DDM -Decaying Dark Matter

MBH - Massive Black Hole

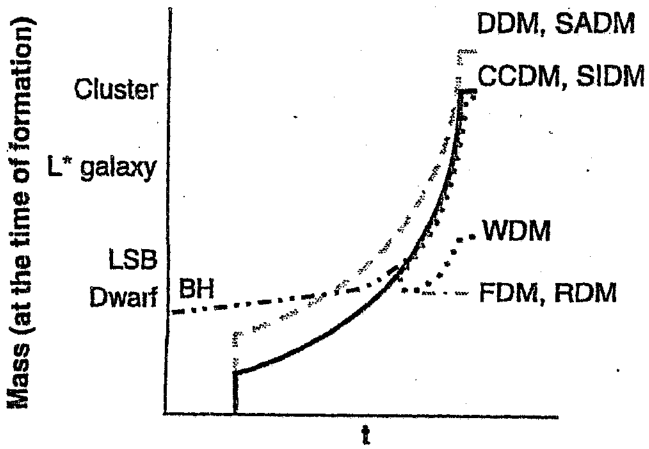


Fig. 2. History of structure formation: the time of formation for objects of a given mass (as measured at formation) for structures with increasing mass [dwarf galaxies, low-surface-brightness (LSB) galaxies, ordinary (L*) galaxies, and galaxy clusters] for different models of dark matter. Structure formation begins shortly after the onset of the matter-dominated epoch (left side).

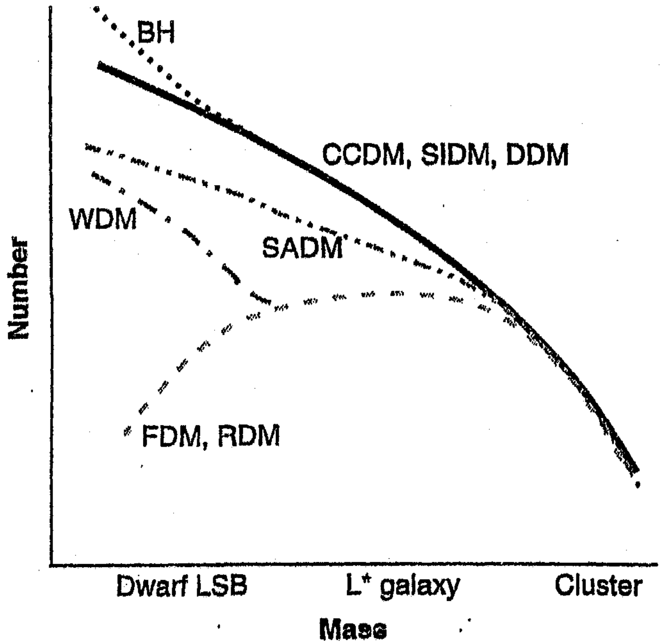


Fig. 3. Demography: how the number of objects of a given type depends on their mass (as observed today) for different dark matter models.

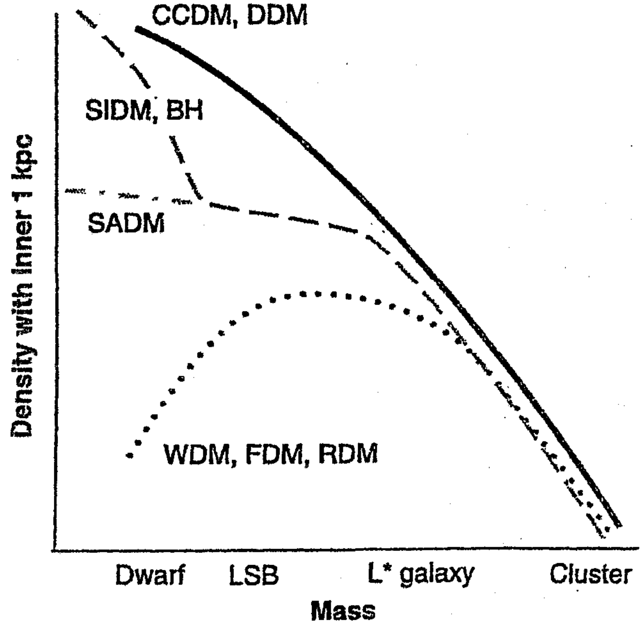


Fig. 4. Internal structure: how the density of the inner 1 kpc depends on the mass of the system for different dark matter models.

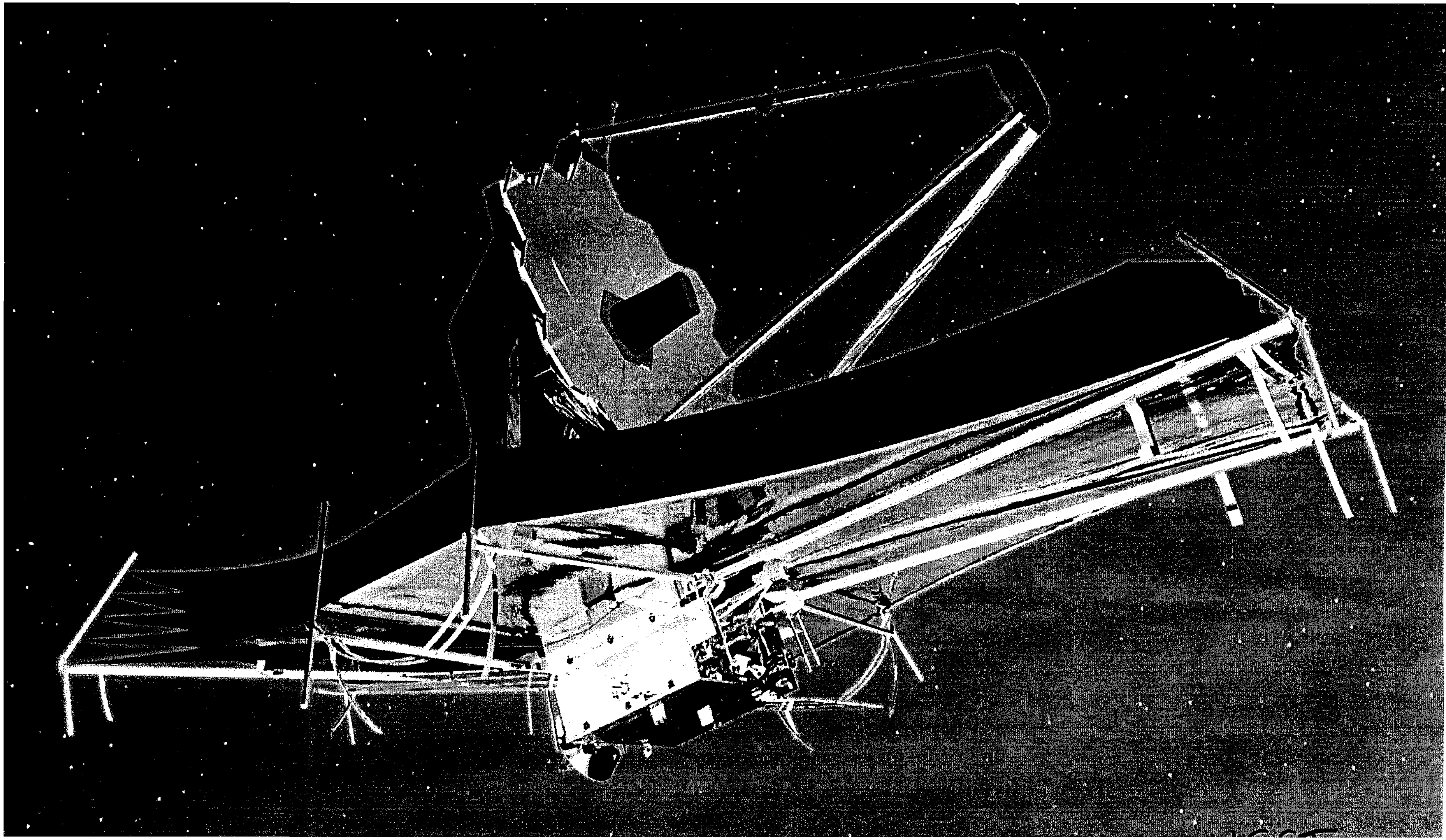
adopted from Ostriker & Steinhardt
Science 300 (03) 1909

Question 1: What is Dark Matter ?

There are 4 different strategies for studying CDM

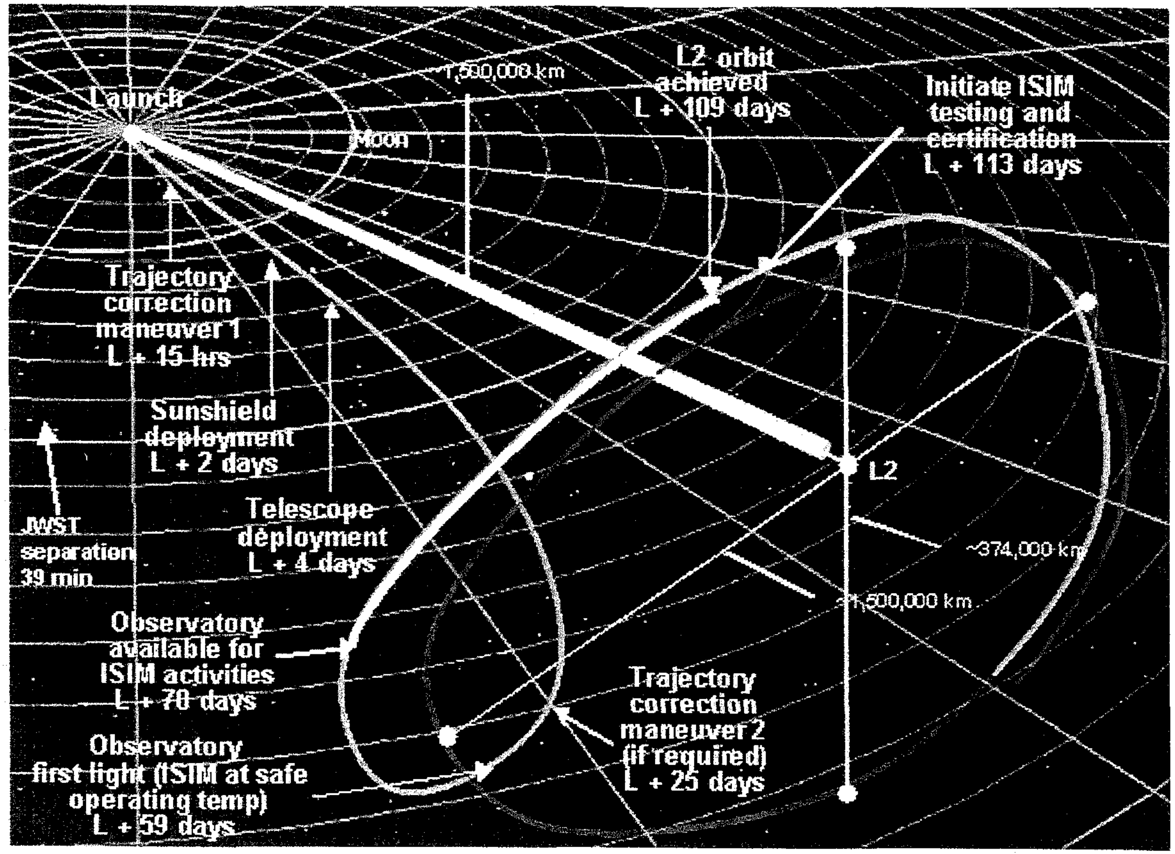
1. Astronomical observations through dynamical studies of the motions of stars, galaxies and X-ray emitting hot gas in clusters of galaxies (e.g. gravitational lensing) ✓ S, G
2. Direct detection of DM particles through highly specialized instruments designed to detect directly the extremely weak signal of rare DM interaction with massive detector ✓ G
3. Gamma rays or neutrino resulting from annihilation of DM particle-antimatter counterpart (e^+ and anti-p) ✓ S, G AMS-PAMELA GLAST
4. Create DM particles by colliding particles of ordinary in HE accelerators ✓ G

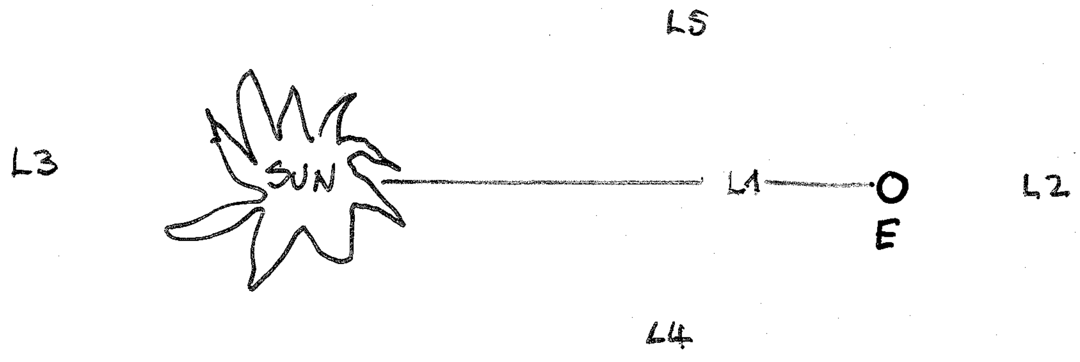
Observe early Universe $10^6 \longrightarrow$ few 10^9 yr



• evolution of galaxies, stars & planets

objects 400 times fainter G based telescopes


Launch
Moon
1,500,000 km
L2 orbit
achieved
L + 109 days
Initiate ISIM
testing and
certification
L + 113 days
Trajectory
correction
maneuver 1
L + 15 hrs
Sunshield
deployment
L + 2 days
JWST
separation
39 min
Telescope
deployment
L + 4 days
L2
~374,000 km
~1,500,000 km
Observatory
available for
ISIM activities
L + 78 days
Observatory
first light (ISIM at safe
operating temp)
L + 59 days
Trajectory
correction
maneuver 2
(if required)
L + 25 days


L5
L3
SUN
L1
L2
E
L4

	Parameter	Requirement	Capability
2010	**Schedule**	Launch readiness: June 2010	Consistent with technology & schedule
	Wavelength	0.6 to >10 μm	0.6 to >30 μm. Reflective gold coatings
400x fainter ground	**Sensitivity**	Targets at the North Ecliptic Pole and with a 100,000 s integration, the minimum sensitivities (see below) shall be met with an SNR of 10. 1.3 nJy at 0.7μm and R = 5 1.6 nJy at 2.0μm and R = 5 160 nJy at 2.0μm and R = 1000 73 nJy at 10μm and R = 3 3,600 nJy at 10μm and R = 1,500 800 nJy at 20μm and R = 3 18,000 nJy at 20μm and R = 1500	SNR margins varying from 20-59%. 29.4 m^2 collecting area with flat-to-flat dimension of 7 m. 0.90 nJy at 0.7μm and R = 5 1.12 nJy at 2 μm and R = 5 93 nJy at 2 μm and R = 1000 50 nJy at 10 μm and R = 3 2,540 nJy at 10 μm and R = 1500 274 nJy at 20μm and R = 3 7,140 nJy at 20 μm and R = 1500
0.15"	**Spatial Resolution & Stability**	Total encircled energy (EE greater than 75% at 0.15 arcsecond radius at a wavelength of 1 μm Strehl ratio at 2 μm greater than or equal to 0.8 Less than 2% RMS variation about the mean over a 24-hour period over FOR	EE of 82% at 1 μm and 150mas radius Strehl ratio of 0.84 at 2 μm. Maximum peak to peak variation less then 0.2% over extended FOR
	Telescope FOV	Spatially Separated FOVs 0.6 – 5 μm ≥ 21 sq arcminutes 1 – 5 μm ≥ 12 sq arcminutes >5 μm, Imaging ≥ 5.2 sq arcminutes >5 μm, Spectroscopy N/A	> 105 square arcminutes FOV. Capability of increasing field stop for a larger FOV; FOV locations and formats to be coordinated with final Science Instrument suppliers
100% sky in 1 yr	**Celestial Sphere Coverage**	Over an interval of one sidereal year, capable of observing anywhere within the celestial sphere, with at least 35% available at any given time 50% of the celestial sphere must have continuous visibility for at least 60 days per year	100% annually 48.9% at any given time 100% of sphere has at least 69 contiguous days visibility 55% for > 196 days
>5y → 10y	**Mission Life**	Lifetime after commissioning 5-year minimum: 10-year goal Consumables sized for 10 years Time from launch to completion of commissioning shall not exceed 6 months	5-year minimum lifetime and no life limited *item except for fuel* 10 years for consumables Commissioning in less than approximately 4 months
L2	**Orbit**	NGST shall orbit about L2 point	Halo orbit about L2
	Overall Observing Efficiency	Goal >70% (science exposure time to total time)	Observatory ~ 77.2% OTE/Spacecraft efficiency ~92%. ISIM allocation: 85%
5400 kg	**Launch & Mass**	5 m fairing, 5400 kg payload mass maximum	509 kg management reserve over and above contingency/margin

Figure 3. Performance of NGST Observatory for Key Driving Requirements

29.4 m^2

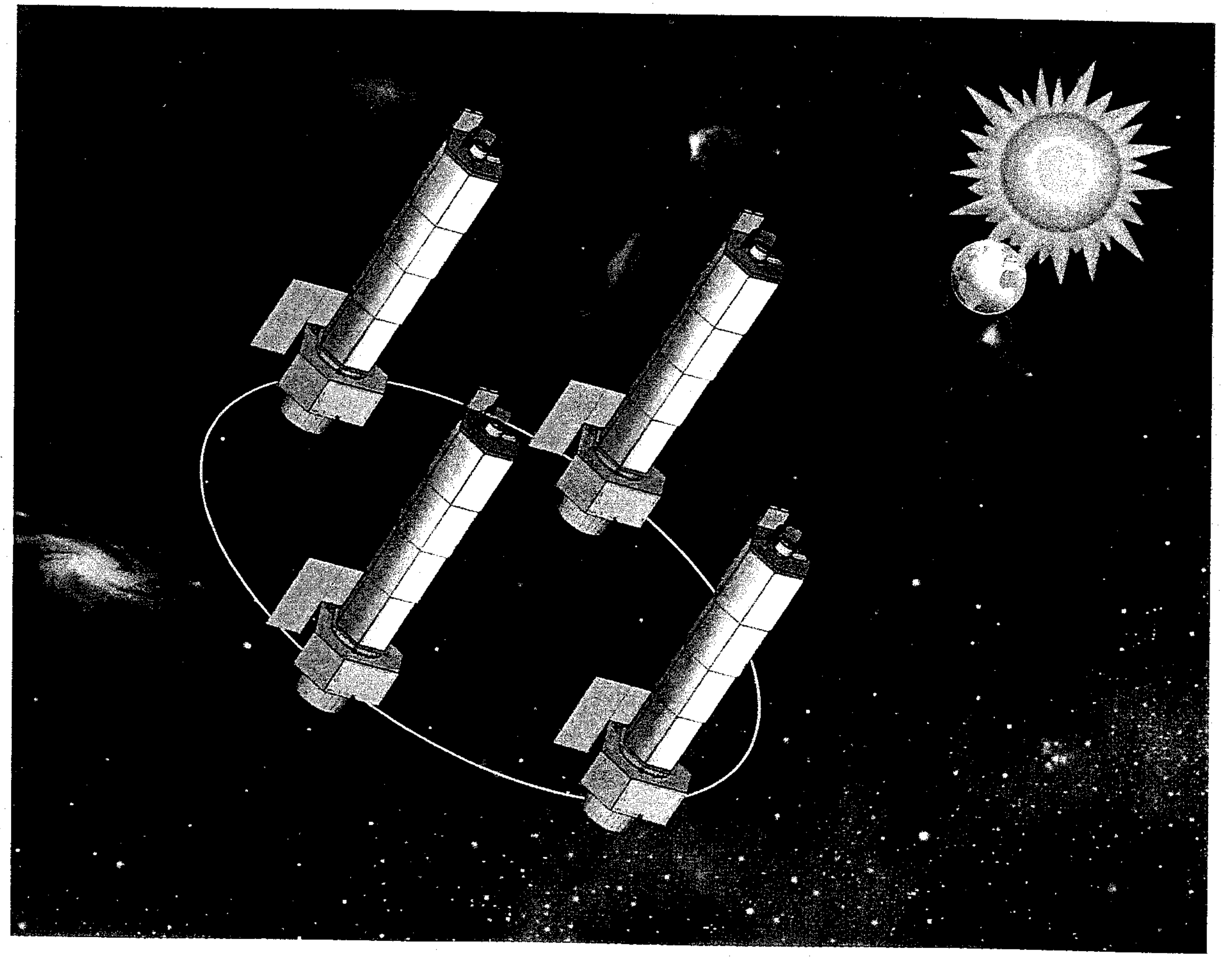
	Feature	Benefit
Optical Telescope Element	• Three mirror anastigmat (TMA) design, f/16.7, 29.4 m^2 collecting area • Fine steering mirror (FSM) to provide line-of-sight (LOS) stabilization 6.6 mas • Four separate deployments • Semi-rigid hexagonal mirror segments and graphite composite backplane structure	• Superior image quality over the ISIM FOV, provides science resolution and sensitivity • Excellent pointing control and stability in conjunction with the spacecraft attitude control • Simple, reliable and robust deployment • Allows ground verification of the OTE, provides stable optical performance over temperature
Primary Mirror	• Primary mirror deploys in two steps (2-chord fold) • 2-chord fold allows for thermal strapping across hinge lines • Composed of 36 semi-rigid hexagonal segments, each with set-and-monitor wavefront control actuators • Baseline mirror segment material is Beryllium	• Highly reliable deployment • Provides radial and azimuthal thermal conductivity for reducing thermal gradients; provides longer mission observation time. • All segments are mechanically identical, achieving efficiencies in manufacturing, assembly and testing • Known material properties with demonstrated optical performance over temperature
Secondary Mirror	• Tripod configuration for support structure • Deployment using a single redundant actuator • Semi-rigid optic with 6 degrees of freedom (DOF) alignment	• Provides rigidity, minimizes obscuration and scattered light into the field of view • Low risk, high margin (torque margin >32 times the friction load) • Permits reliable and accurate telescope alignment
Aft Optics	• Fixed baffle	• Reduces stray light and houses the tertiary mirror and the FSM
ISIM	• Simple 3-point kinematic mount; 9 m^2 of thermal radiators, and 23 m^3 volume. • Large IFOV OTE	• Provides a simple interface for the ISIM to decouple ISIM development from the OTE. • Simultaneous operation of SIs and FGS
Tower	• Integral 1 Hz passive vibration isolators • Thermally isolates the OTE from spacecraft	• Reduces spacecraft dynamic noise in the OTE • Achieves small mirror temperature gradients
Sunshield	• 5 layer "V" groove radiator design reduces solar energy to 23 mwatts • Folded about OTE during launch • Sized (~22 m x 10 m) and shaped to meet or exceed field-of-regard requirements	• Provides a stable thermal environment for passively cooling the OTE and the ISIM • Reliable deployment, protects OTE during launch • Reduces the time and fuel for momentum unloading, Increases operational efficiency
Spacecraft Bus	• Chandra-based attitude control subsystem • Two-axis gimbaled high gain earth-pointing antenna with omnis, X & S band • 232 Gbit solid state recorder • Propellant for >12 years	• Flight-proven low noise dynamic environment that minimizes line-of-sight jitter • Contingency operations and link margin • Store > 2 days of science & engineering data • Extended operation capability

Figure 2. Observatory Key Features and Benefits

CONSTELLATION-X Observatory

factor x100 high resolution X-ray spectroscopy missions

(X-ray astronomy equivalent
- Keck Obs.
- ESO Very Large Telescope)



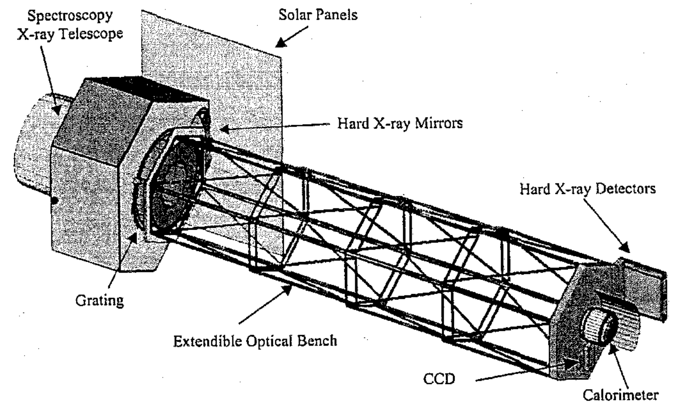


Figure 40. GSFC SAO Design for four-spacecraft constellation. The Extendible Optical Bench (EOB), shown open here to allow a view of the instruments inside, will be enclosed.

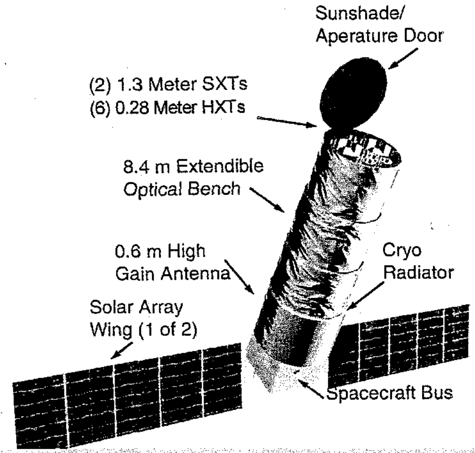


Figure 41. TRW Spacecraft Design.

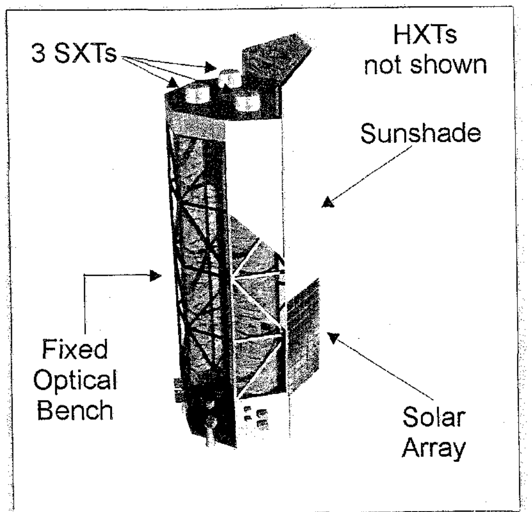
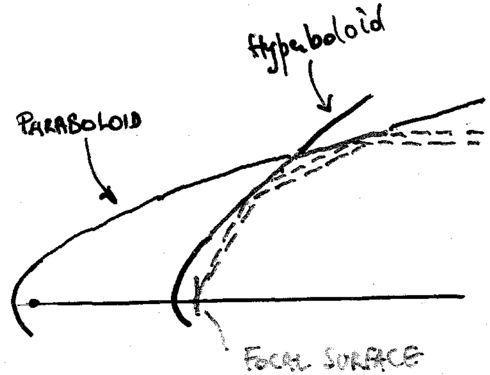


Figure 42. Shown is a version of the Ball design that packages three soft X-ray telescopes into a single spacecraft.

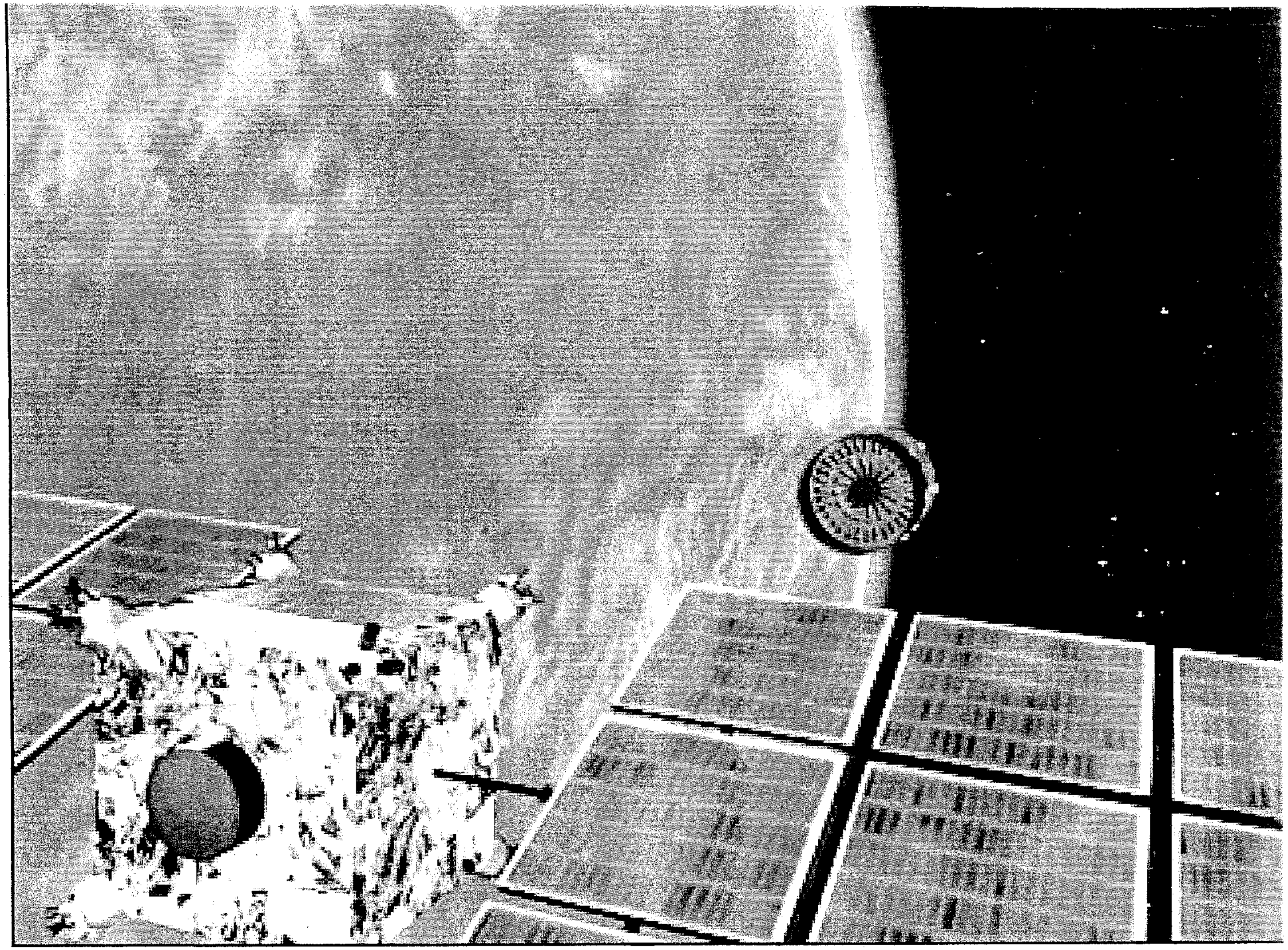


- microcalorimeters 0.3-12 keV
- CCD + gratings < 1 keV
- CdZnTe 10-40 keV

Baseline Mission Cons-X Characteristics

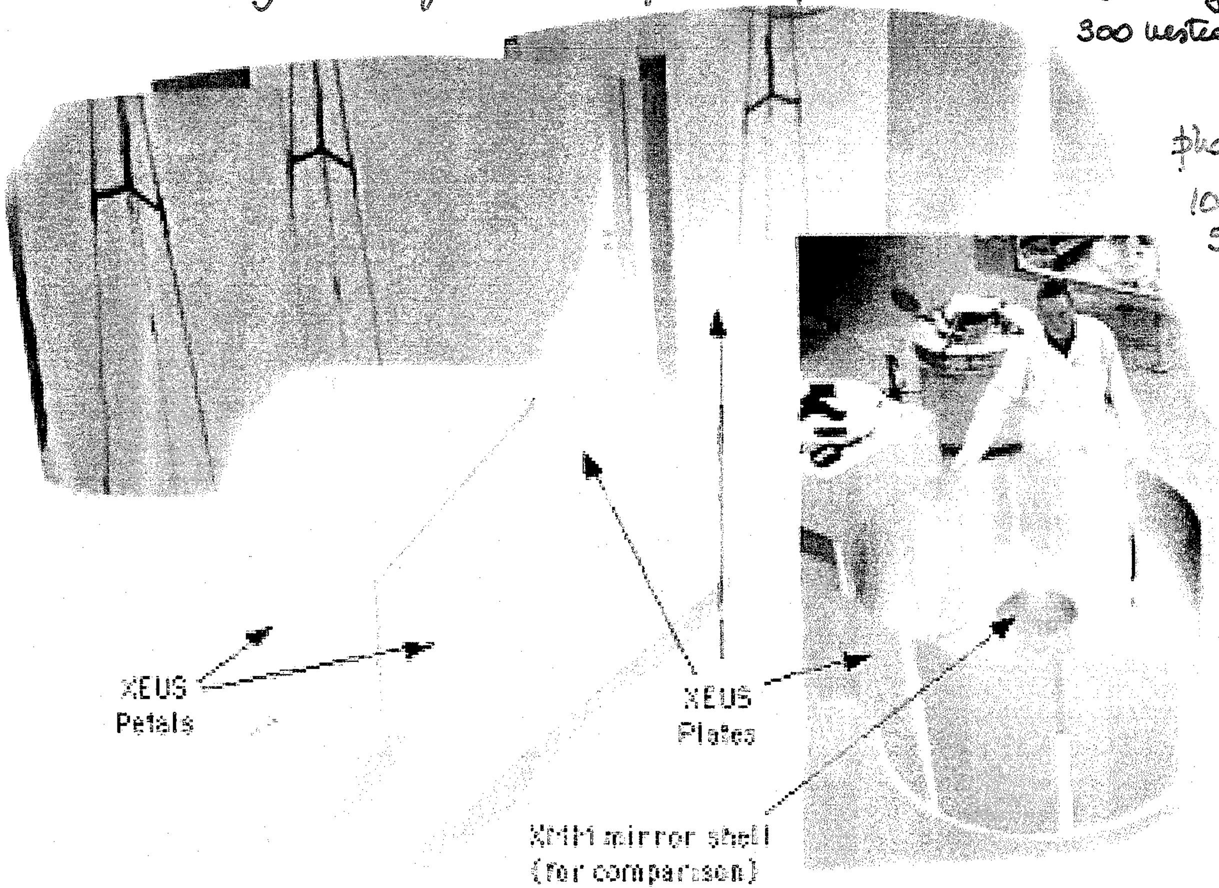
Minimum effective area	$1500 cm^2$ at 1 keV $6000 cm^2$ at 6.4 keV $1500 cm^2$ at 40 keV
Minimum telescope angular resolution	15″ HPD from 0.25 to 10 keV 1′ HPD at about 10 keV
Minimum spectral resolving power $(\Delta E/E)^{-1}$	300 from 0.26 to 6.0 keV 3000 at 6 keV 10 at 40 keV
Maximum source count rate	10^4 counts/s
Band pass	0.25 to 40 keV
Diameter field of view	2.5′ < 10 keV - 8′ < 25 keV
Mission life	3 years minimum/5 years goal

$$F_E \geq \frac{\epsilon (S/N)^2 \Delta E}{A Q W_{min}^2 t}$$



XEUS Xray Evolving Universe Spectroscopy

4.5m wide
1 m long
300 nested mirrors
↓
phase II
10m ⌀
500 mirrors
17 tonnes



Question 2: What is the Nature of Dark Energy ?

- Recent measurements (SNIa, CMBR spectrum, 3-D power spectrum of galaxies) indicate that in our Universe it exist something else besides radiation and matter and it causes the acceleration of the expansion of the Universe.

Few facts about cosmology:

- We know our universe is expanding [Hubble diagram]
- We describe this effect by a *scale factor* a(t)

  [the physical distance is proportional to a(t)]
- The Universe is characterized by its geometry =

  flat [Euclidean], closed, open

Question 2: What is the Nature of Dark Energy

What is needed is a *standard candle*

i.e. a class of objects of known intrinsic brightness

As the light travels through the expanding Universe the relative distances increase and the spectral wavelength λ is redshifted by a factor $z=d\lambda/\lambda$ by which the cosmos has been stretched during the same time interval of the light travel $\Delta t = c\ d_L$

On the other hand $F = L/4\pi d_L$

For any astronomical object one can observe the apparent magnitude m [which is essentially the log (F)] and its redshift. The absolute magnitude of the object is again related to its luminosity in a log fashion

$$m - M = 5 \log (d_L / \text{Mpc}) + 25$$

Question 2: What is the Nature of Dark Energy

If the absolute magnitude of a class of objects can be determined from the study of the light curve then one can obtain the dL of these objects at different redshifts

for example

$d_L = 2/H_0 [(1+z) - (1+z)^{1/2}]$ $\Omega_r=1$ $\Omega_\Lambda=0$

$d_L = z(1+z)/H_0$ $\Omega_r=0$ $\Omega_\Lambda=1$

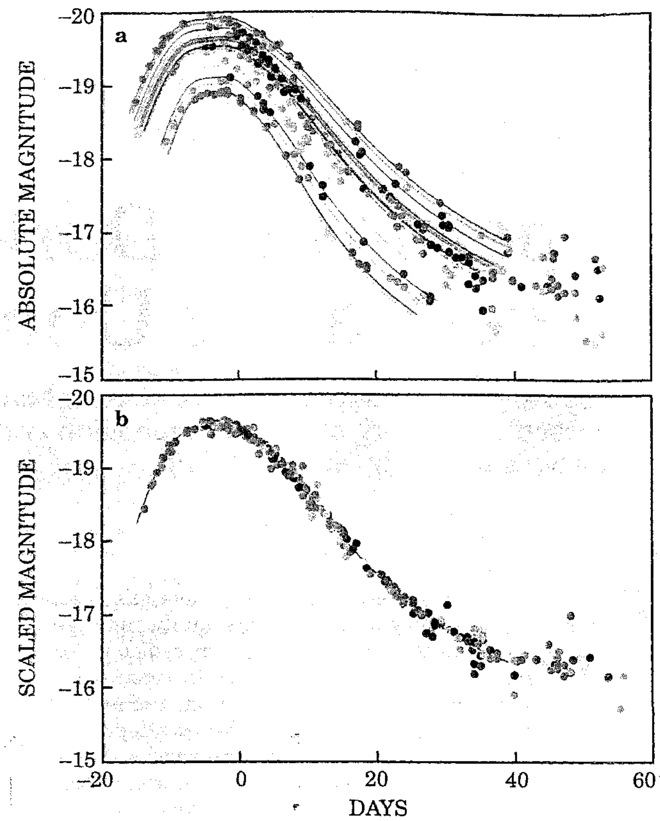
It is clear that at a given z the d_l larger for the cosmological constant model. Hence a given object, located at a certain redshift will appear brighter in the matter dominated model.

These objects are SNIa

Explosive event of a degenerate dwarf star containing CNO

They have hydrogen poor spectra

Figure 1. Light curves of nearby, low-redshift type Ia supernovae measured by Mario Hamuy and coworkers.[7] **(a)** Absolute magnitude, an inverse logarithmic measure of intrinsic brightness, is plotted against time (in the star's rest frame) before and after peak brightness. The great majority (not all of them shown) fall neatly onto the yellow band. The figure emphasizes the relatively rare outliers whose peak brightness or duration differs noticeably from the norm. The nesting of the light curves suggests that one can deduce the intrinsic brightness of an outlier from its time scale. The brightest supernovae wax and wane more slowly than the faintest. **(b)** Simply by stretching the time scales of individual light curves to fit the norm, and then scaling the brightness by an amount determined by the required time stretch, one gets all the type Ia light curves to match.[5,8]



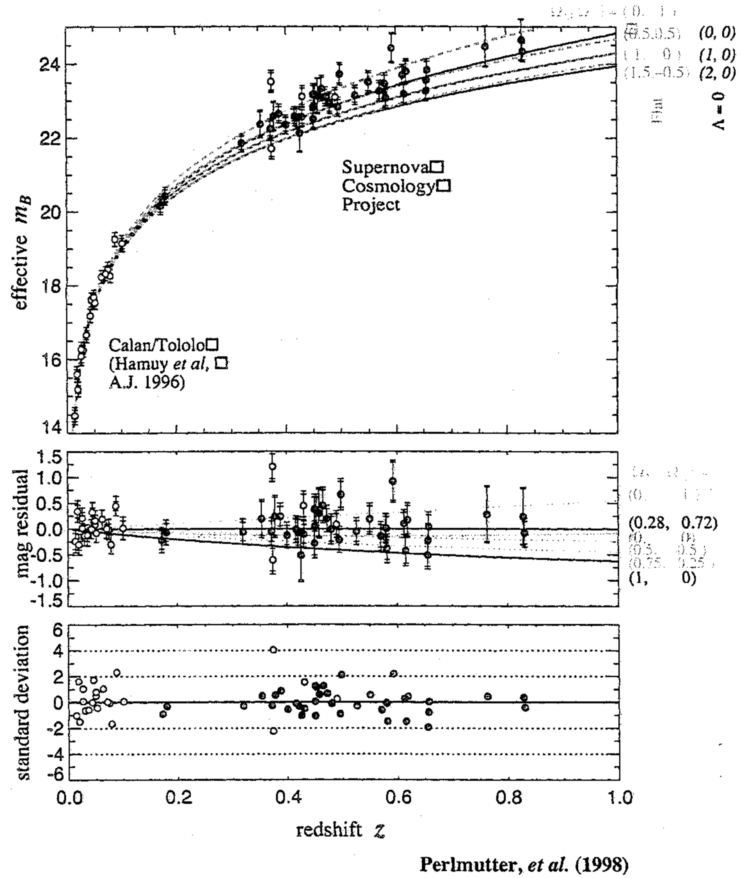
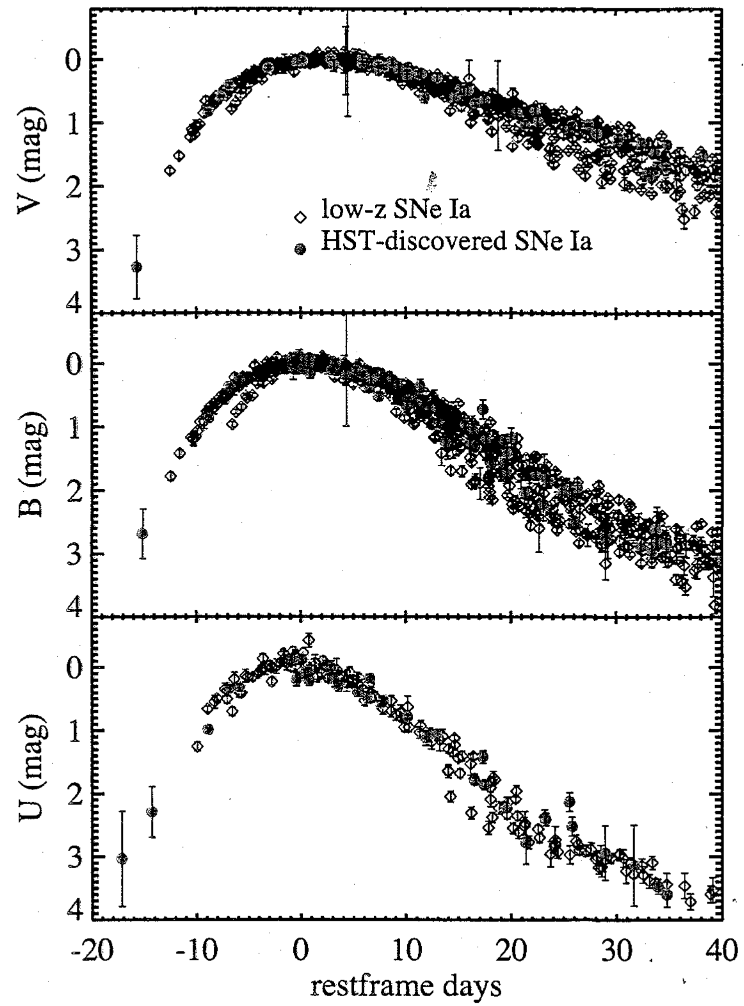
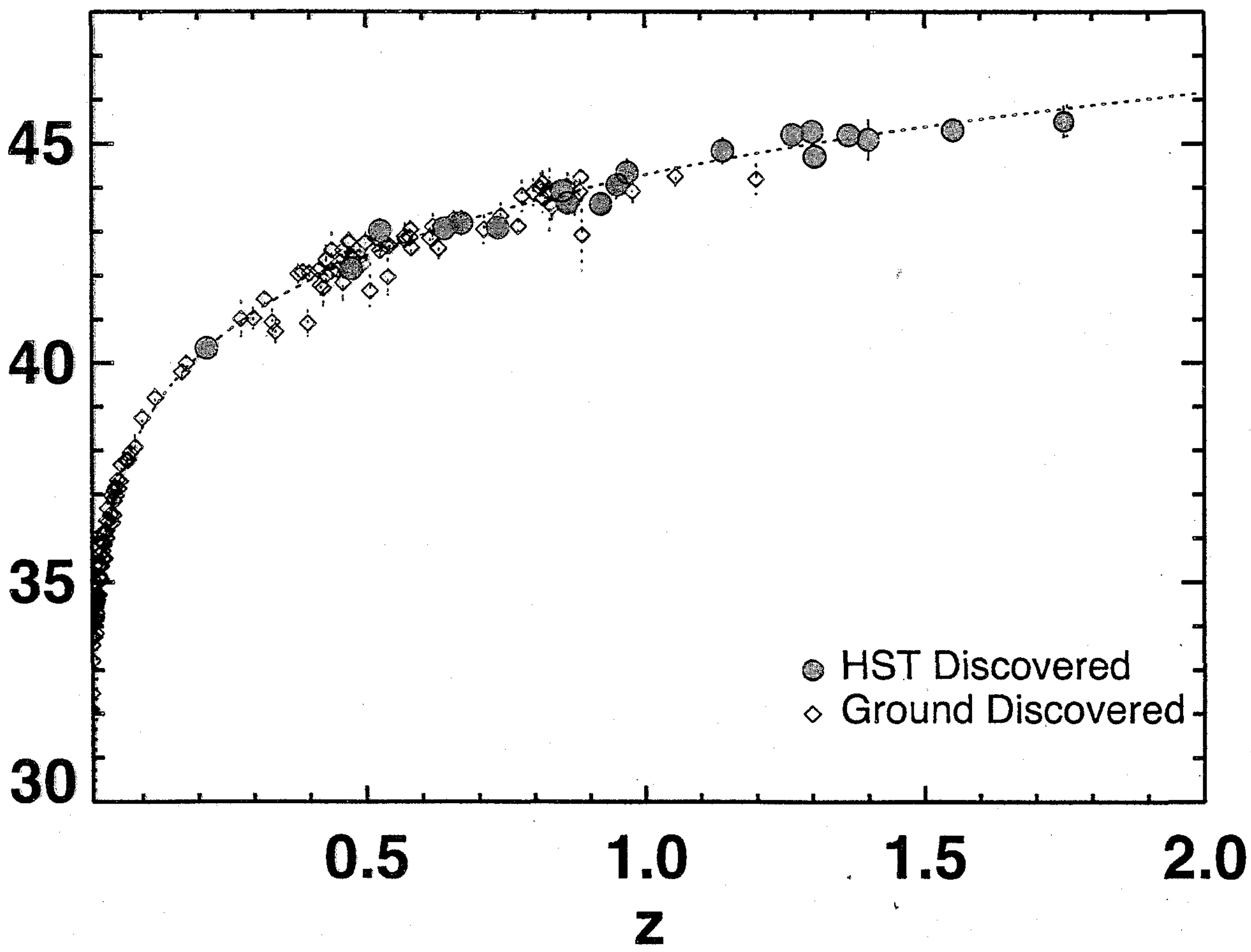


Figure 2. Data from the Supernova Cosmology project [11]. Dimmer objects a higher vertically on the plot. The horizontal axis is redshift. The curves represe: different choices of Ω_M and Ω_Λ. A cosmology with $\Omega_M = 1$ and $\Omega_\Lambda = 0$ is ruled o· to 99% confidence, while a universe with $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$ is a good fit to t] data.

SN Ia Composite Light Curves




45
40
35
30
0.5
1.0
1.5
2.0
z
HST Discovered
Ground Discovered

Question 2: What is the Nature of Dark Energy

Strategic Measurements:

1. DE is diffuse so SNIa 0.5 < z < 1.8 and counts of galaxy clusters, => New class of wide-field telescopes to discover and follow x1000 SNe ✓ S,G

2. CMBR fluctuation spectrum => New class of CMBR anisotropy and polarization observatories ✓ S,G

3. Study of the evolution of galaxy clusters => X-ray surveys at z =2-3, SZ effect and gravitational lensing => new class of optical/IR/X-ray telescope with high spatial/spectral resolution ✓ S,G
   NGST, Cons X etc

The SNAP project is an international collaboration headquartered at the Department of Energy's Lawrence Berkeley National Laboratory in Berkeley, California.

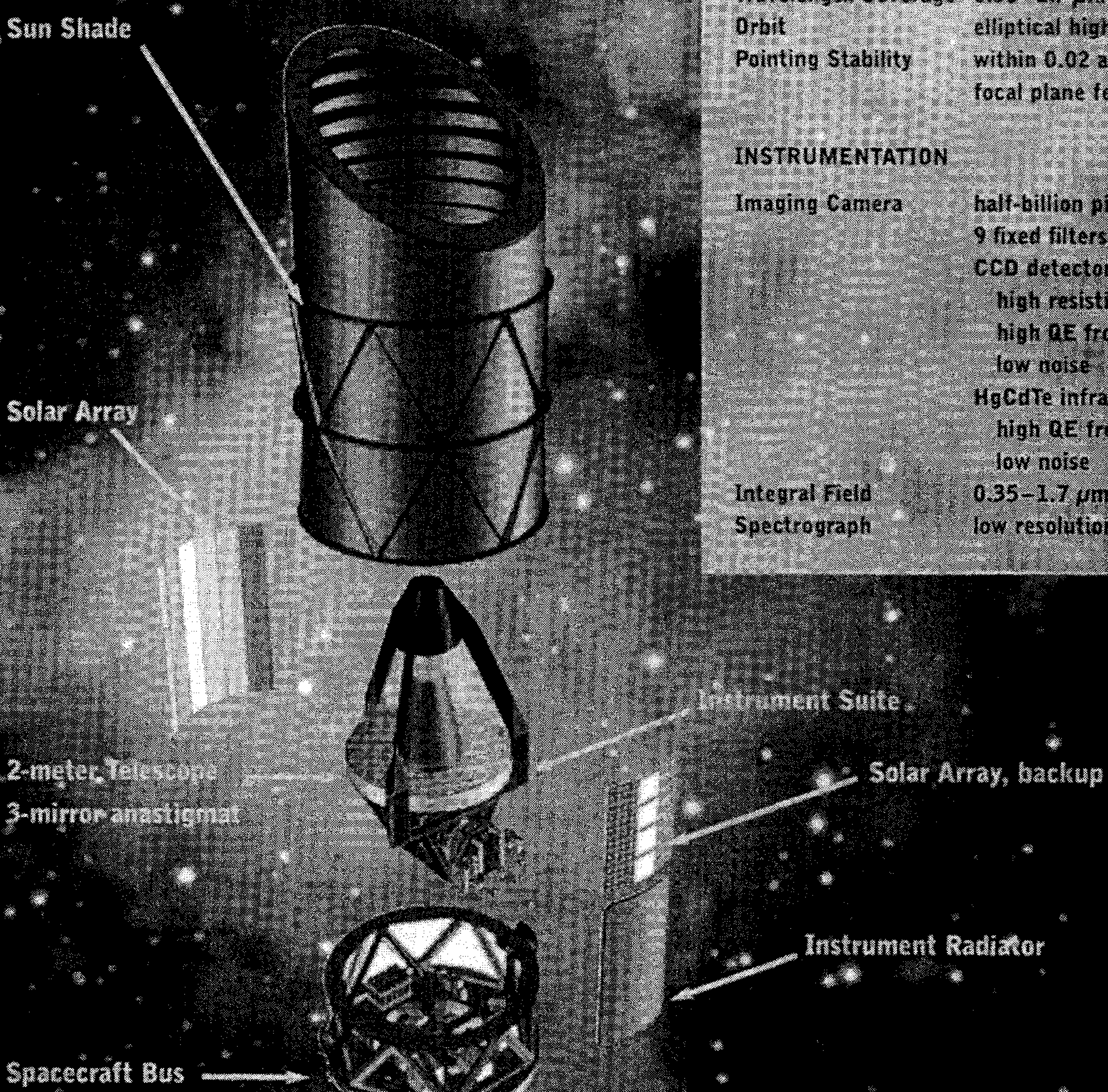
SNAP SUMMARY

Telescope Aperture	2 meter
Optics	diffraction limited, f/10 0.1" pixel scale
Field of View	0.7 sq. degree instrumented equal CCD, NIR coverage
Wavelength Coverage	0.35–1.7 μm
Orbit	elliptical high earth orbit
Pointing Stability	within 0.02 arcsec, focal plane feedback

INSTRUMENTATION

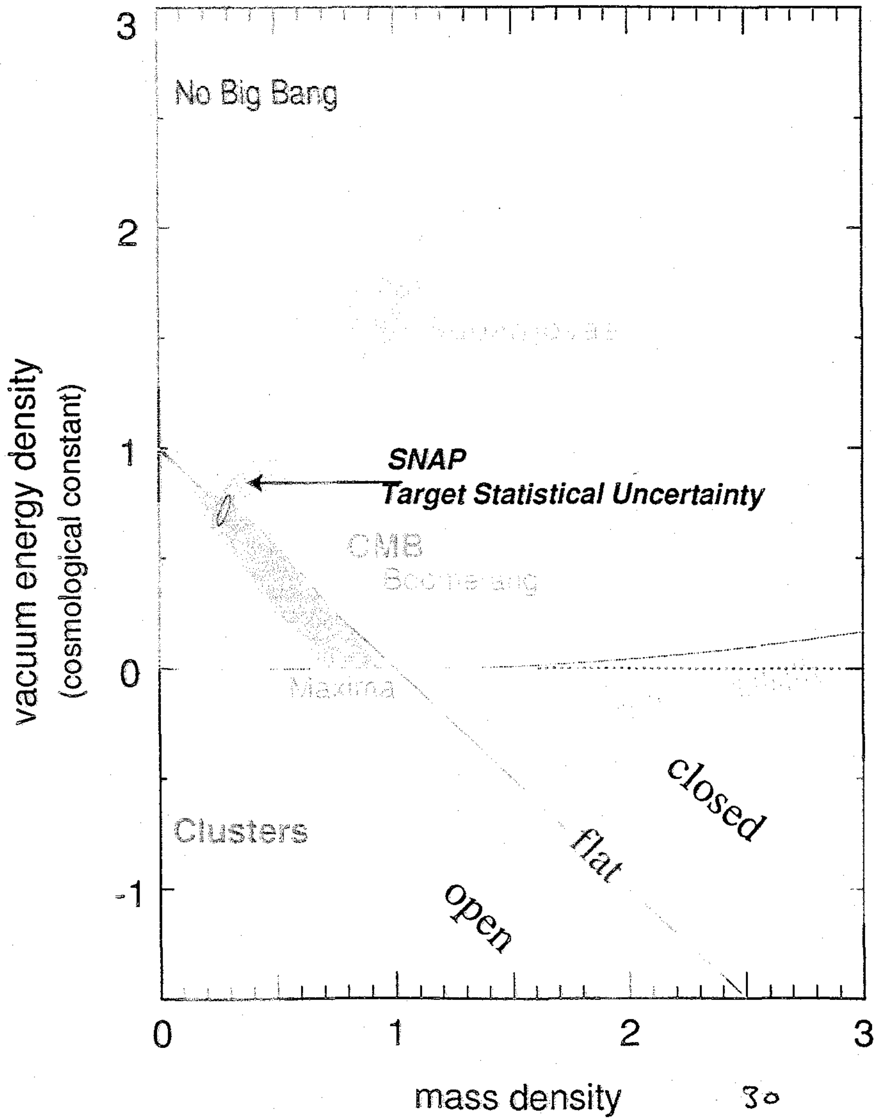
Imaging Camera	half-billion pixel imager 9 fixed filters CCD detectors: high resistivity p-channel high QE from 0.35–1.0 μm low noise HgCdTe infrared devices: high QE from 0.9–1.7 μm low noise
Integral Field Spectrograph	0.35–1.7 μm low resolution R ~100

The SNAP Observatory



http://snap.lbl.gov

background image taken with LBNL CCD, courtesy NOAO



No Big Bang
SNAP
Target Statistical Uncertainty
CMB
Boomerang
Maxima
Clusters
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3

Question 3: How did the Universe Begin?

- One of the large success of cosmology over the past two decades has been the development and initial testing of the inflationary paradigm, which provides an explanation for the large size and uniformity of the Universe as well as the origin of the lumpiness that led to galaxies and clusters of galaxies

Question 3: How did the Universe Begin?

The CMBR ($T=2.728 \pm 0.004$ K) is nearly isotropic on the sky with small fluctuations ~ 10^{-5}

These fluctuations arise from the physics in the early Universe at z ~ 1100:

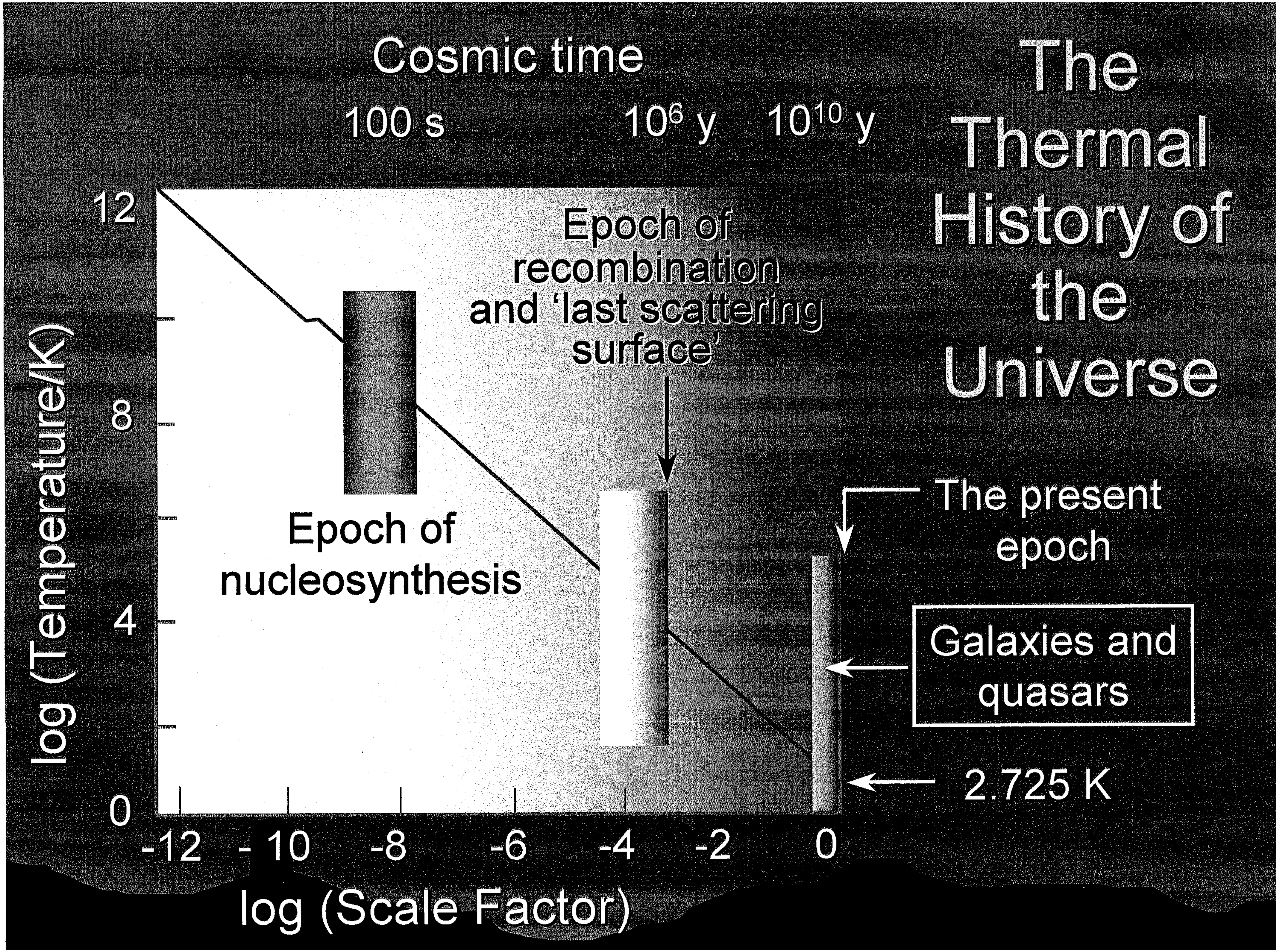
Graviatational redshift

Temperature fluctuations at the last scattering surface

Doppler shift from peculiar velocity a the last scattering surf.

Diffusion dumping through the thickness of the last scattering surface

+ fluctuations and distortions from gravitational and scattering effects at epoch with $z < 3$


The Thermal History of the Universe
Cosmic time
100 s
10^6 y
10^10 y
Epoch of recombination and 'last scattering surface'
Epoch of nucleosynthesis
The present epoch
Galaxies and quasars
2.725 K
log (Temperature/K)
12
8
4
0
-12
- 10
-8
-6
-4
-2
0
log (Scale Factor)

Question 3: How did the Universe Begin?

- The fluctuations are Gaussian (>10°) as expected by inflationary origin

Thus they are fully characterized by their power spectrum

$T(\mathbf{n}) = \sum a_{\ell m}\, a_{\ell m}\, Y_{\ell m}(\mathbf{n})$ $\langle a_{\ell m}\, a_{\ell m} \rangle = \delta_{\ell\ell'}\, \delta_{mm'}\, C_\ell$

$(\Delta T)^2 = \ell\,(\ell+1)\, C_\ell\, /2\pi$ power per log interval in ℓ ($\approx \pi/\theta$)

$\Delta\, C_\ell / C_\ell = (2/\,(2\ell+1)\,/f_{sky})^{1/2}$

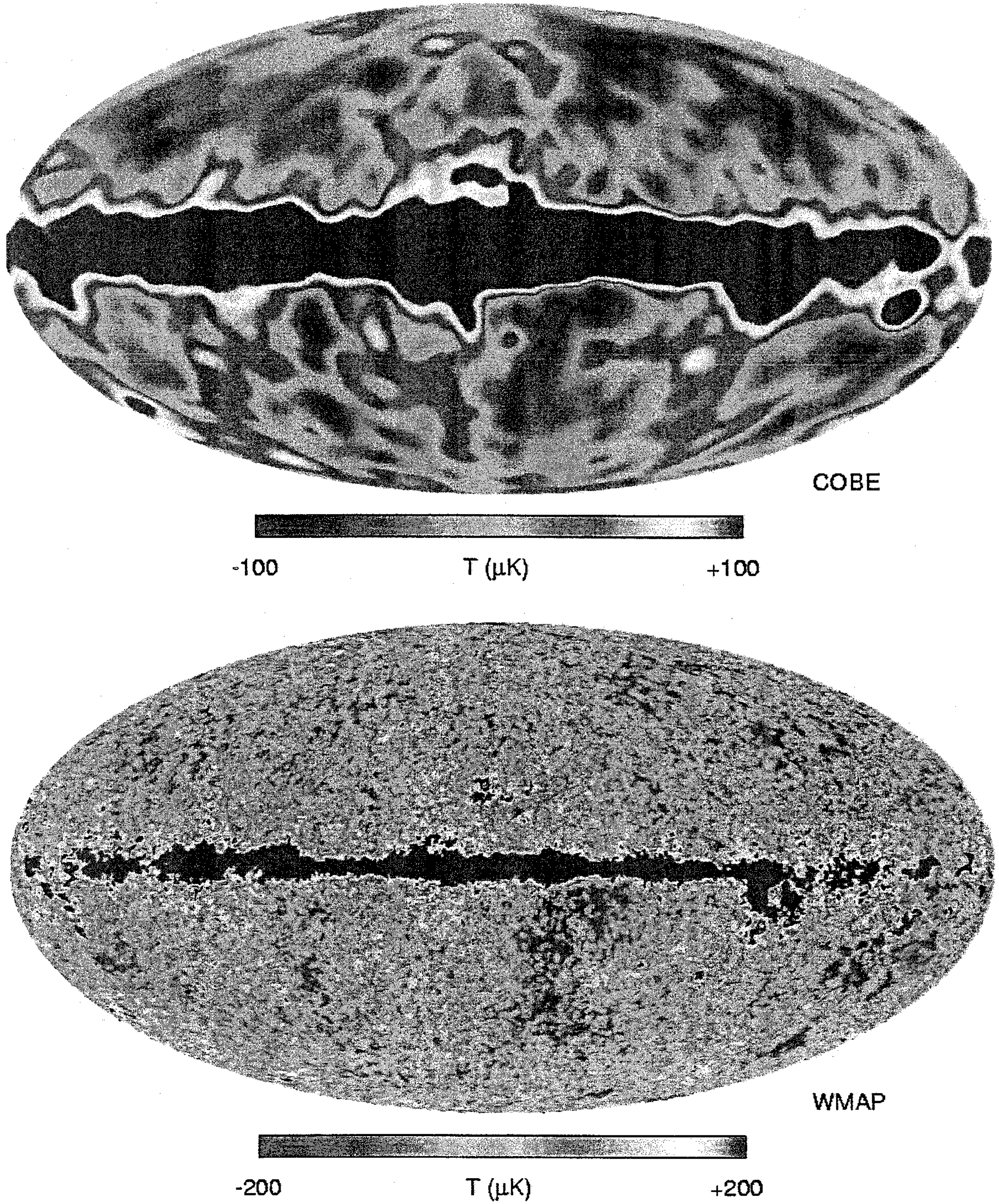


Fig. 7.— A comparison of the *COBE* 90 GHz map (Bennett et al. 1996) with the W-band *WMAP* map. The *WMAP* map has 30 times finer resolution than the *COBE* map.

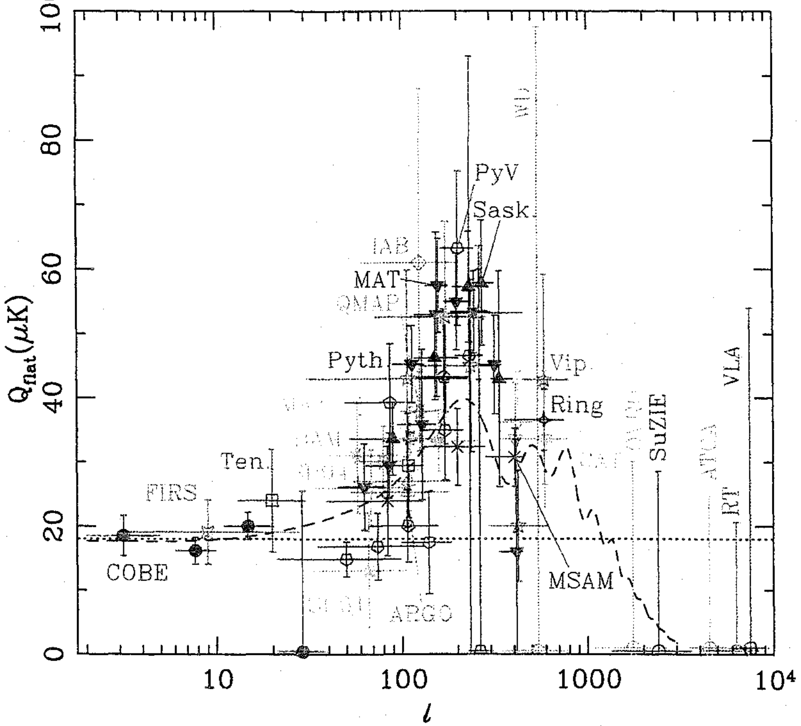


Figure 2. Most of the experiments published to date. See Smoot & Scott (1997) [17] for full references, supplemented with more recent results from: OVRO Ring [25], QMAP [26], MAT TOCO [27], CAT [28], Python V [29] and Viper [30]. The error bars (these are 1□ except for the upper limits which are 95%) have generally been symmetrised for clarity, and calibration uncertainties are included in most cases. The horizontal bars represent the widths of the experimental window functions. The dotted line is the flat power spectrum which best fits the COBE data alone. The dashed curve is the prediction from the vanilla-flavoured standard Cold Dark Matter model.

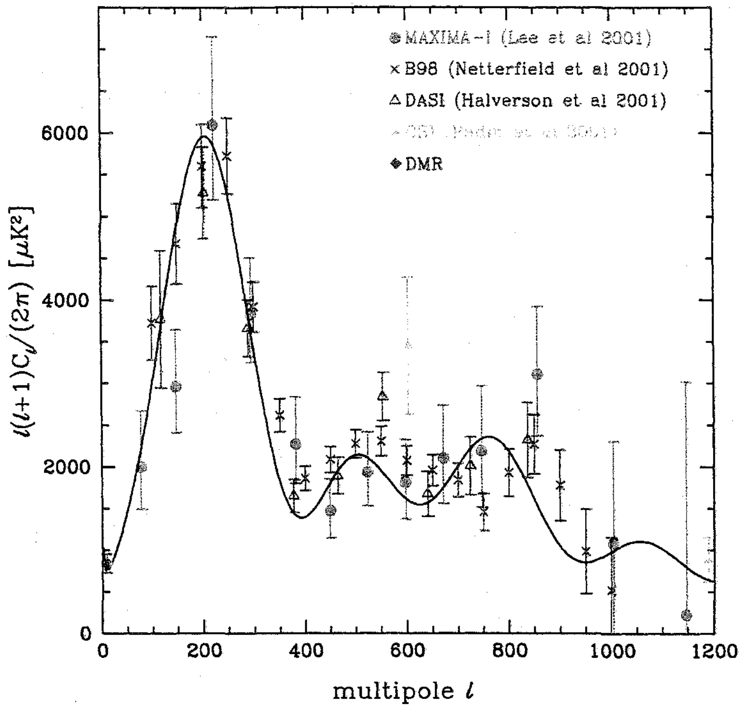


FIG. 3: Recent measurements of the CMB power spectrum, from the experiments as listed and cited in the text. The smooth curve is a model chosen to fit an older subset of the data [12], but remains a good fit to the current data.

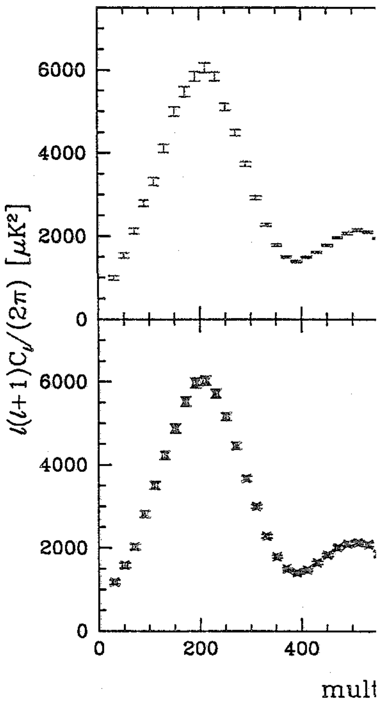


FIG. 5: Projected error bars for the power spectrum from M
with a width $\delta\ell = 20$.

Question 3: How did the Universe Begin?

- The power spectrum contains information about cosmological parameters

$H, \Omega_b, \Omega_{cdm}, \Omega_\Lambda, A_s, n_s, A_t, n_t, \tau$

Existence of the acoustic oscillations of the primordial plasma at the last scattering surface

The amplitude and angular scales of these peaks depend on the entire set of cosmological parameters

Best fit of model to an observed power spectrum

! Problem of Degeneracy

Question 3: How did the Universe Begin?

- Polarization

Quadrupole + Thomson scattering

A linearly polarized radiation coming for a direction **n**, using a base ($\mathbf{e}_1, \mathbf{e}_2$) in the plane perperndicular to **n** is described by a 2x2 tensor whose components are the stokes parameters T, Q, U where Q and U depend on the base ($\mathbf{e}_1, \mathbf{e}_2$) and on the direction on the sky **n**

It is possible to obtain the angular power spectrum

by using spin-weighted harmonics (Zaldarriaga & Seljak, 1997)

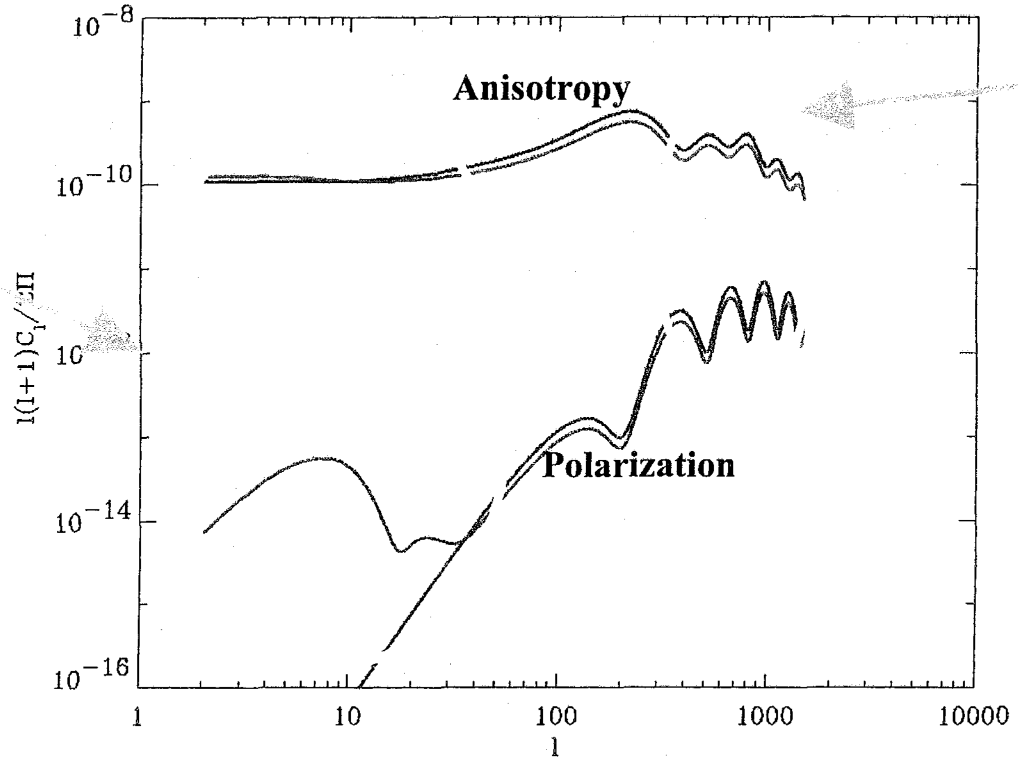
Instead of using Q and U it is more convenient to use *scalar* quantities E and B   NOTE: E, B are non-local

(this decomposition is analogous to the vector field case where divergence-free and curl-free portions are distinguished by the orientation on the velocity vector wrt wavevector , scalar & pseudo-scalar fields)

Why observing CMBP ?

•The polarized component of the CMB provides new information on

•Large angular scales (10°-20°): can disantangle models with different τ better than the anisotropy



•Small angular scales (0.2°-0.4°): can provide confirmation of the inflationary frame. E-mode peaks correspond to anisotropy minima and viceversa.

DASI, WMAP.

Question 3: How did the Universe Begin?

Major Experimental issues

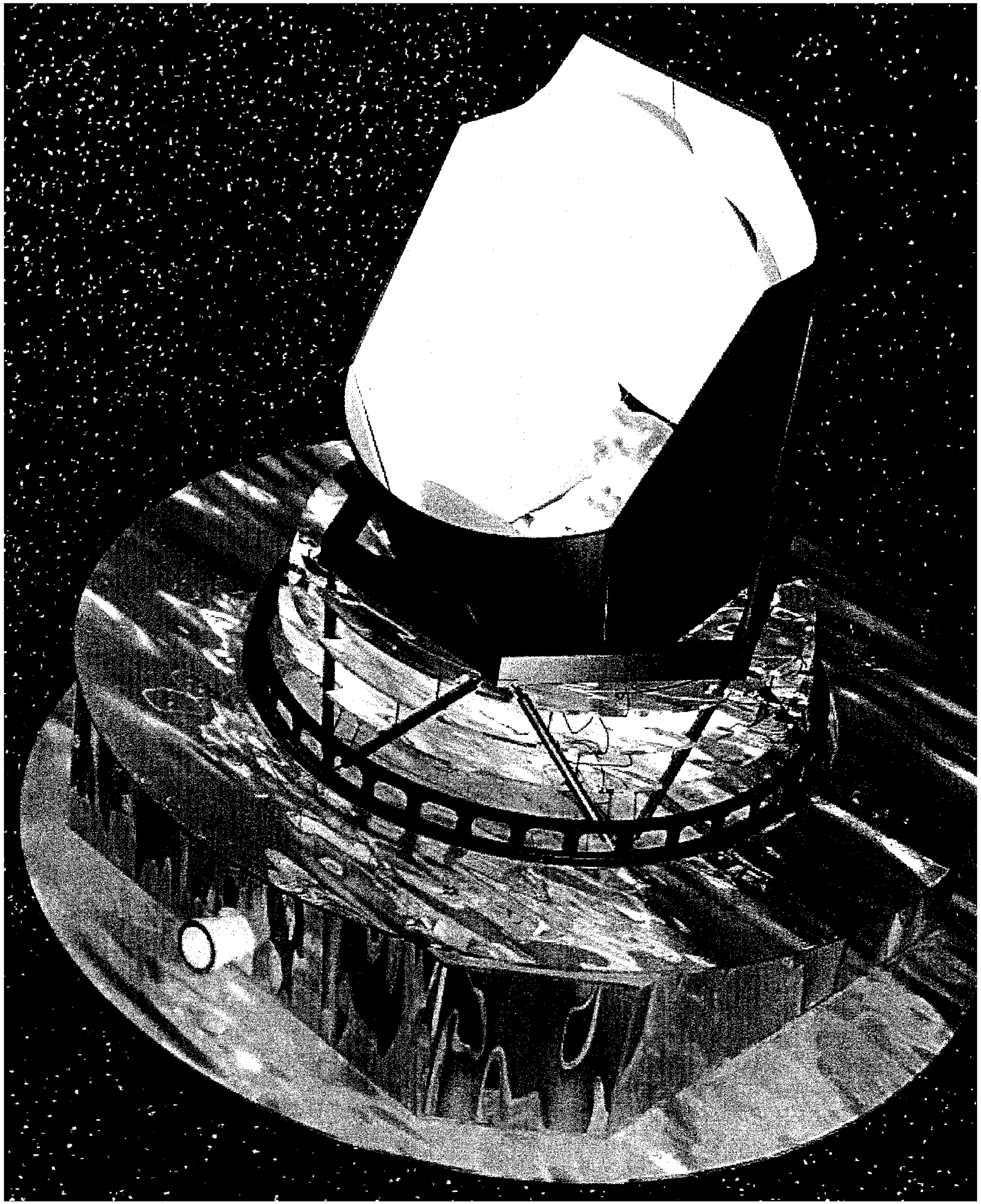
- Sensitivity = several order of magnitude better than CMBR anisotropies but detectors are already photon noise limited => 10000 time more detectors or 10000 times more integration time
- Foregrounds => Multifrequency observations
- Systematic effects (imperfect modelling of the detector) = leakeage of power from E mode to B mode =better detectors

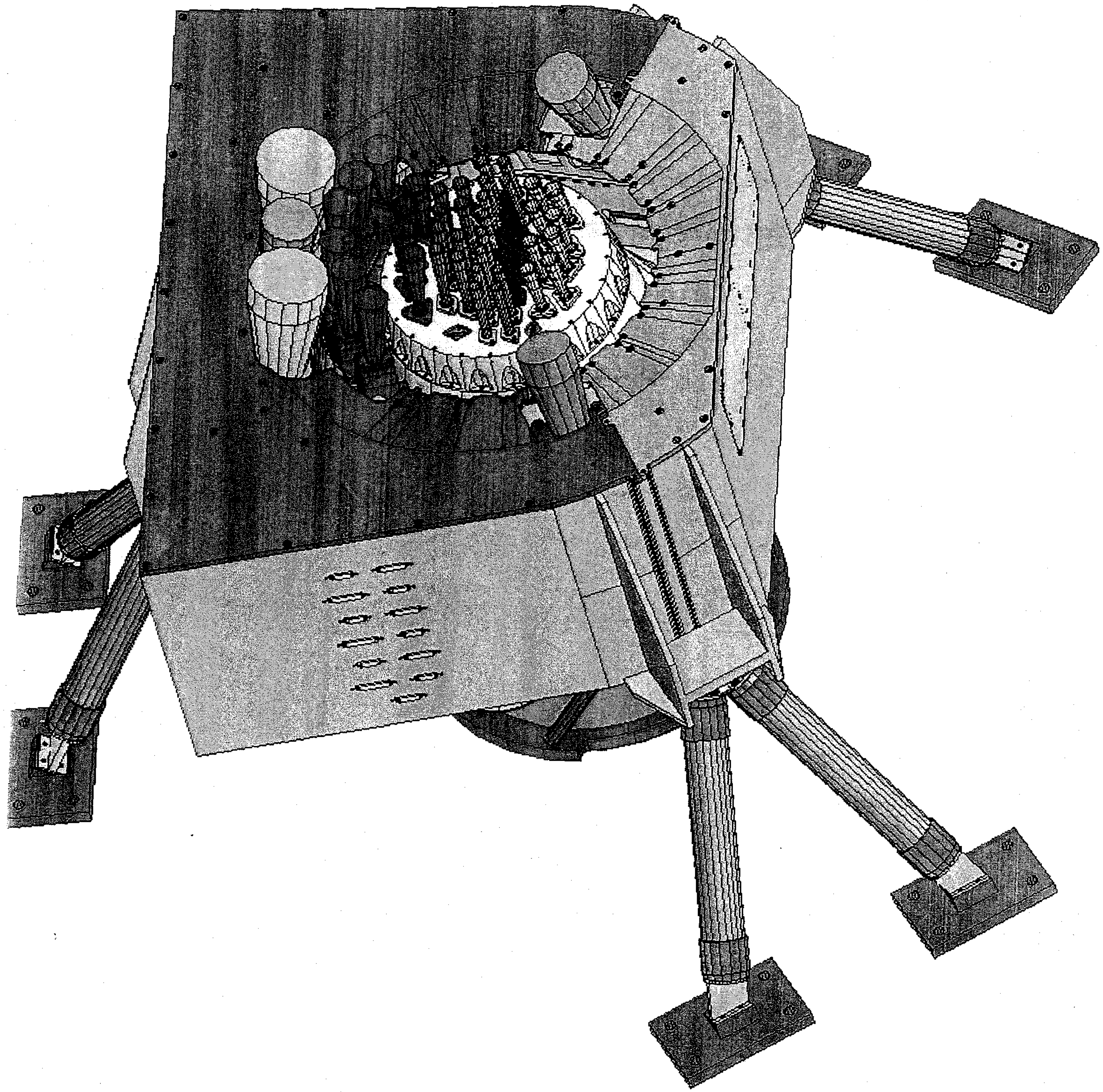
❖ Correlators

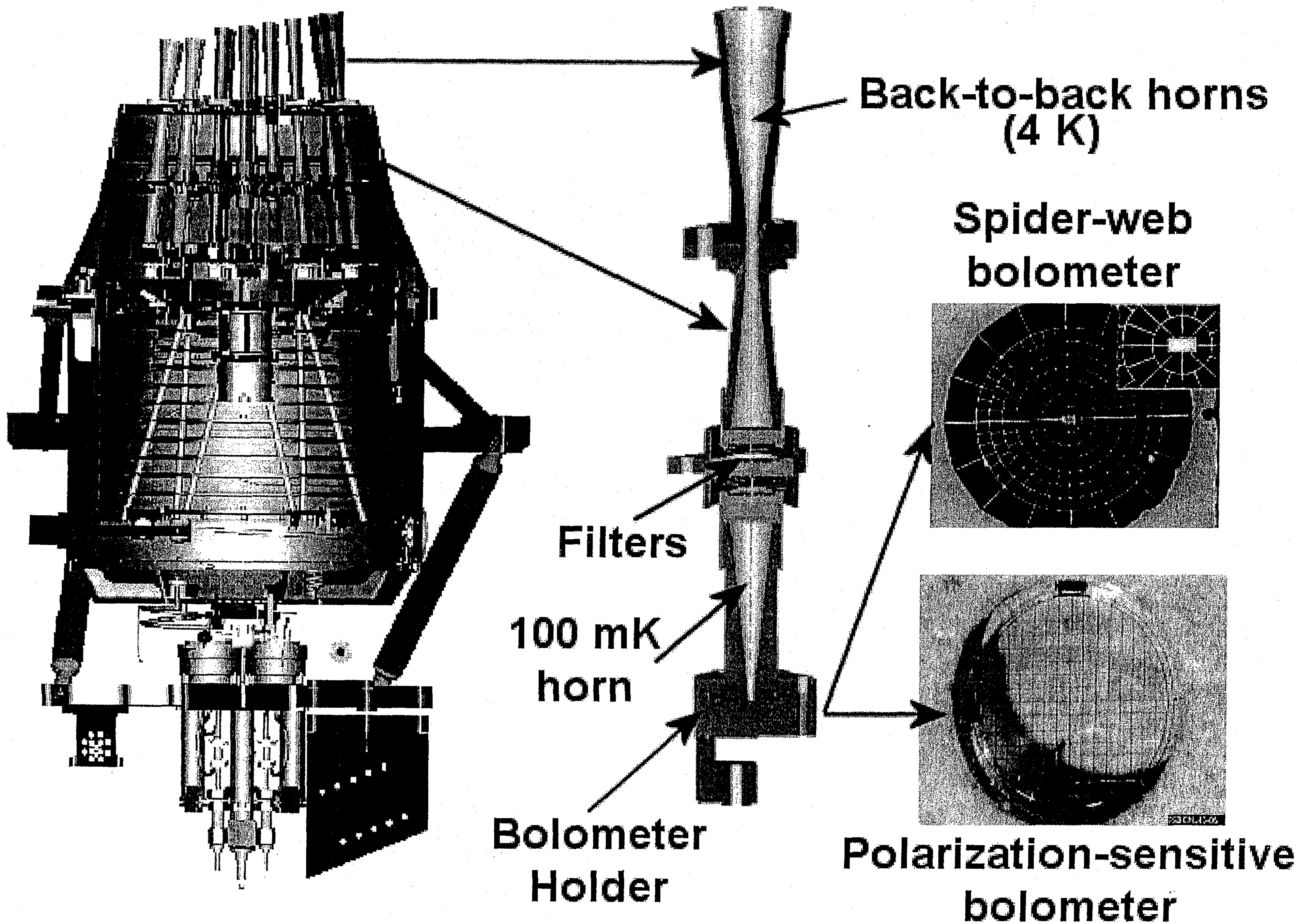
❖ Pol sensitive bolometers

❖ Detectors array = bolometers using superconducting transition edge sensors and SQUID readout

❖ Antenna-coupled bolometers






Back-to-back horns (4 K)
Spider-web bolometer
Filters
100 mK horn
Bolometer Holder
Polarization-sensitive bolometer

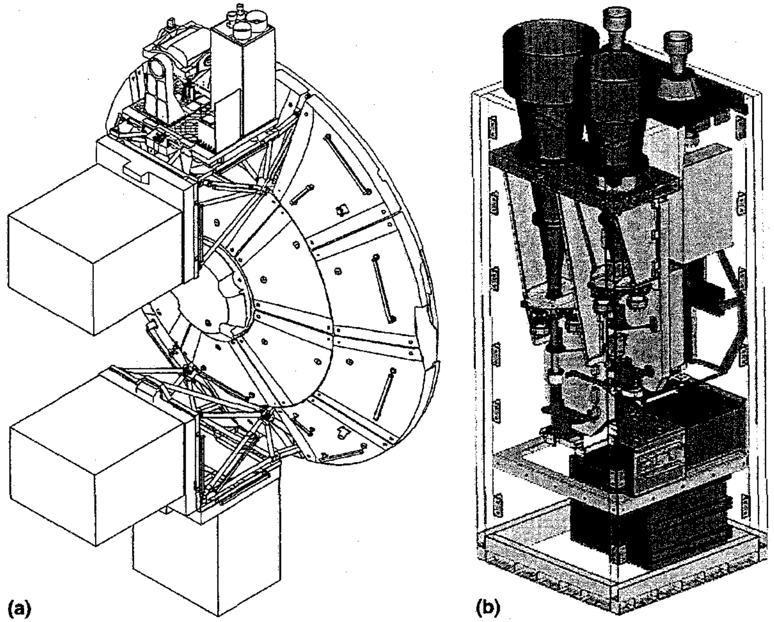


Fig. 7. (a) The SPOrt position on the Columbus External Payload Facility, onboard the ISS (courtesy by Alenia Spazio). (b) Expansion of the SPOrt payload.

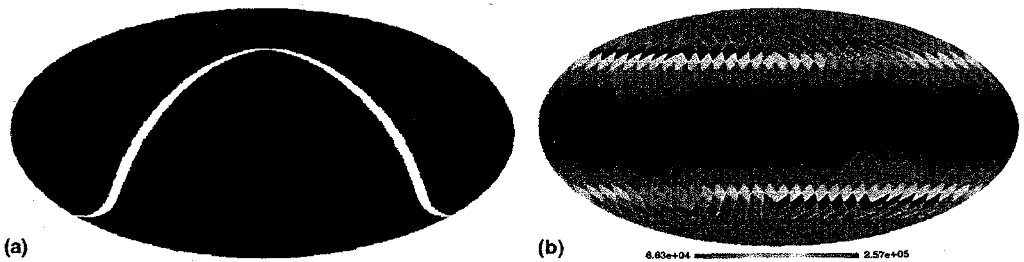


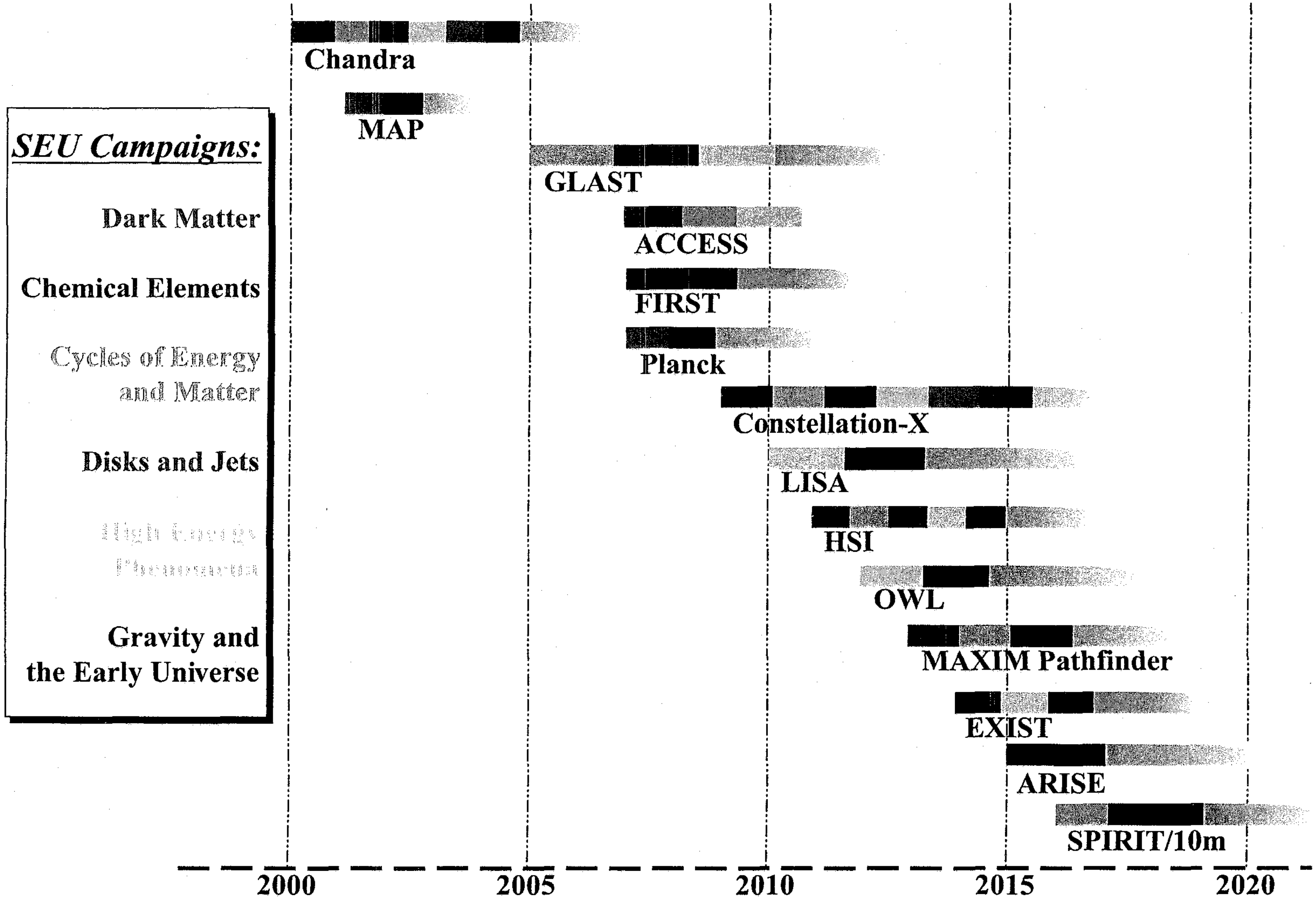
Fig. 8. (a) The sky, in Celestial coordinates, as scanned by SPOrt in few orbits. (b) Pixel observing time (s) for two years of data taking. The pixel size is about 7° (HEALPix parameter *Nside* = 8). (Courtesy by A&A.)

Table 1
SPOrt main features

ν (GHz)	Channels (#)	BW (°)	FWHM	Orbit time (s)	Coverage (%)	N_{pix}	σ_{1s} (mK s$^{1/2}$)	σ_{pix} (μK)
22	1						0.5	1.6
32	1	10%	7	5400	80	660	0.5	1.6
90	2						0.57	1.8

N_{pix} is the number of FWHM pixels covered by SPOrt, σ_{1s} is the instantaneous sensitivity (1 s), and σ_{pix} is the pixel sensitivity for a two-year mission.

Complementary SEU Missions Target the Campaigns with Increasing Technical Sophistication and Scientific Insight



Structure & Evolution Universe 2003-2023

The Journey Through Cosmic Time