Galaxisfelmérések: az Univerzum térképei

Bevezetés a csillagászatba 4.

Miről lesz szó?

- Hubble vagy nem Hubble?
- Galaxisok, galaxishalmazok és az Univerzum szerkezete
- A műszerfejlődés útjai
- Galaxisfelmérések

Two Nebulae with Unparalleled Velocities.—Recent observations here with the nebular spectrograph have shown that the nebulæ N. G. C. 584 and N. G. C. 936, both evidently of the spiral family, possess much the highest velocities yet observed for any objects.

A plate exposed to N. G. C. 584, (R.A. = $1^h\,27^m.3$. Dec. = —7° 16′), on the useful parts of the clear nights from December 31 to January 14, total exposure about 28 hours, gave a serviceable, although somewhat weak, spectrogram. The spectrum, approximately of the solar type, shows its lines enormously displaced toward the longer wave lengths, corresponding to the exceptional velocity of 1800 kilometers per second. The motion is away from the Sun.

Nebula N. G. C. 936, (R.A. = $2^h\,23^m$., Dec. = —1° 33′), was recently photographed for its spectrum with an exposure of about 34 hours. The resulting spectrogram, having a spectrum similar to that of the sun, exhibits also a very large displacement of the nebular lines. The provisional result from the plate is that the nebula is receding from the Sun with a velocity of fully 1300 kilometers per second.

Brief descriptions of these objects by Mr. Lampland from his direct photographs of them made with the 40-inch reflector are as follows:

> "The nebula N.G.C. 584 is of the type having a brilliant nucleus, and apparently with but little detail in the surrounding nebulous matter. In our photograph not much of the fainter outlying nebulosity is shown. Elongation is apparently in P. A. about 60°. The nucleus is catalogued in the Bonn Durchmusterung as star —7°.248, magnitude 9.7.
>
> The photograph of the nebula N.G.C. 936 shows it to be an interesting object. The most conspicuous structure is the rather large and brilliant nucleus with extensions on diametrically opposite sides, resembling somewhat the view of the ball of Saturn and the ansæ of the rings when the rings are presented at less than half their maximum opening. This brilliant part of the image is placed centrally in an oval-shaped disk of nebulosity rather faint and showing but little structure. The bright Saturn-like part is approximately 85″ in length in P. A. 80°. The elliptic disk of faint nebulosity has dimensions about $2'.5 \times 3'.5$ with the longer axis in P. A. about 160°. In photographs of short exposure the nucleus is small and rather well defined.
>
> Both of these nebulae should doubtless be classed with the spirals."

Lowell Observatory Observation Circular. V. M. SLIPHER.
Flagstaff, Arizona, January 17, 1921.

two kinds of star-aggregations is quite different. Moreover, the cluster-variables, like RR Lyræ, found isolated in the sky are evenly distributed over all galactic latitudes in spite of their faintness (generally between 9^m and 11^m). It is, therefore, probable that these variables are absolutely faint stars. This view is strengthened by the considerable proper-motion of RR Lyræ—viz., 0″·25 yearly.

I am, Gentlemen,
Yours faithfully,
EJNAR HERTZSPRUNG.

Groningen, 1917, June 7.

Radial Velocity Observations of Spiral Nebulæ.

GENTLEMEN,—

In the *Observatory*, No. 511, p. 131, Mr. Reynolds has a letter which I fear might lead the reader to suppose that little confidence should be placed in the velocity-observations of spiral nebulæ such as I initiated in 1912 and have had in progress since at the Lowell Observatory, and I beg space for a few remarks upon this work.

It is indeed true—as Mr. Reynolds points out—that the extreme faintness of the spectra of the spiral nebulæ makes very long exposures necessary, and this seriously retards the securing of plates for their spectrographic investigation. Because these spectra are continuous, their linear dispersion must be made small in order to keep the exposure-times within practicable limits. The scale of the instrument I have used is somewhat greater than that of the Mt. Wilson one referred to.

My observations of the spiral nebulæ are carried out with the same precautions as are star-velocity observations, which includes test-observations of objects whose velocities are known. The method of exposing the comparison-spectrum I employ is very different from the faulty one Mr. Reynolds mentions—namely,

in my observations a number of brief exposures to the spark are distributed throughout the long nebular exposure in order that the comparison-lines may be subjected, as far as possible, to the same influences as are the nebular lines.

In consequence of the extraordinary velocities of the spiral nebulæ, these can, in spite of the small scale of their spectra, be observed with sufficient accuracy to give trustworthy results. I have observed about thirty of these nebulæ, and find their average velocity to be about 570 km. per second. For the stars, the average velocity is about 20 km., and two observers with different instrumental means and a single plate each of an average star will sometimes differ by 20 per cent. of the quantity measured. Nebular observations may then be of equal accuracy and still differ by upwards of 100 km. While the linear scale of the Lowell nebular spectrograph is only one-fifteenth the scale of a powerful 3- or 4-prism star-spectrograph, it, on the other hand, is observing a velocity twenty-five times as great as that which the star-spectrograph is required to measure. Thus, so far as scale of the spectra is concerned, the nebular spectrograph, in consequence of the great nebular velocities, is at no disadvantage as compared with the stellar instrument. And I cannot agree to Mr. Reynolds's statement that "we are bound to recognize that the results cannot carry the same weight as those obtained on the brighter stars." One finds less discouragement in the inaccuracy of the results than in the great difficulties met in

A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By Edwin Hubble

Mount Wilson Observatory, Carnegie Institution of Washington

Communicated January 17, 1929

Determinations of the motion of the sun with respect to the extra-galactic nebulae have involved a K term of several hundred kilometers which appears to be variable. Explanations of this paradox have been sought in a correlation between apparent radial velocities and distances, but so far the results have not been convincing. The present paper is a re-examination of the question, based on only those nebular distances which are believed to be fairly reliable.

Distances of extra-galactic nebulae depend ultimately upon the application of absolute-luminosity criteria to involved stars whose types can be recognized. These include, among others, Cepheid variables, novae, and blue stars involved in emission nebulosity. Numerical values depend

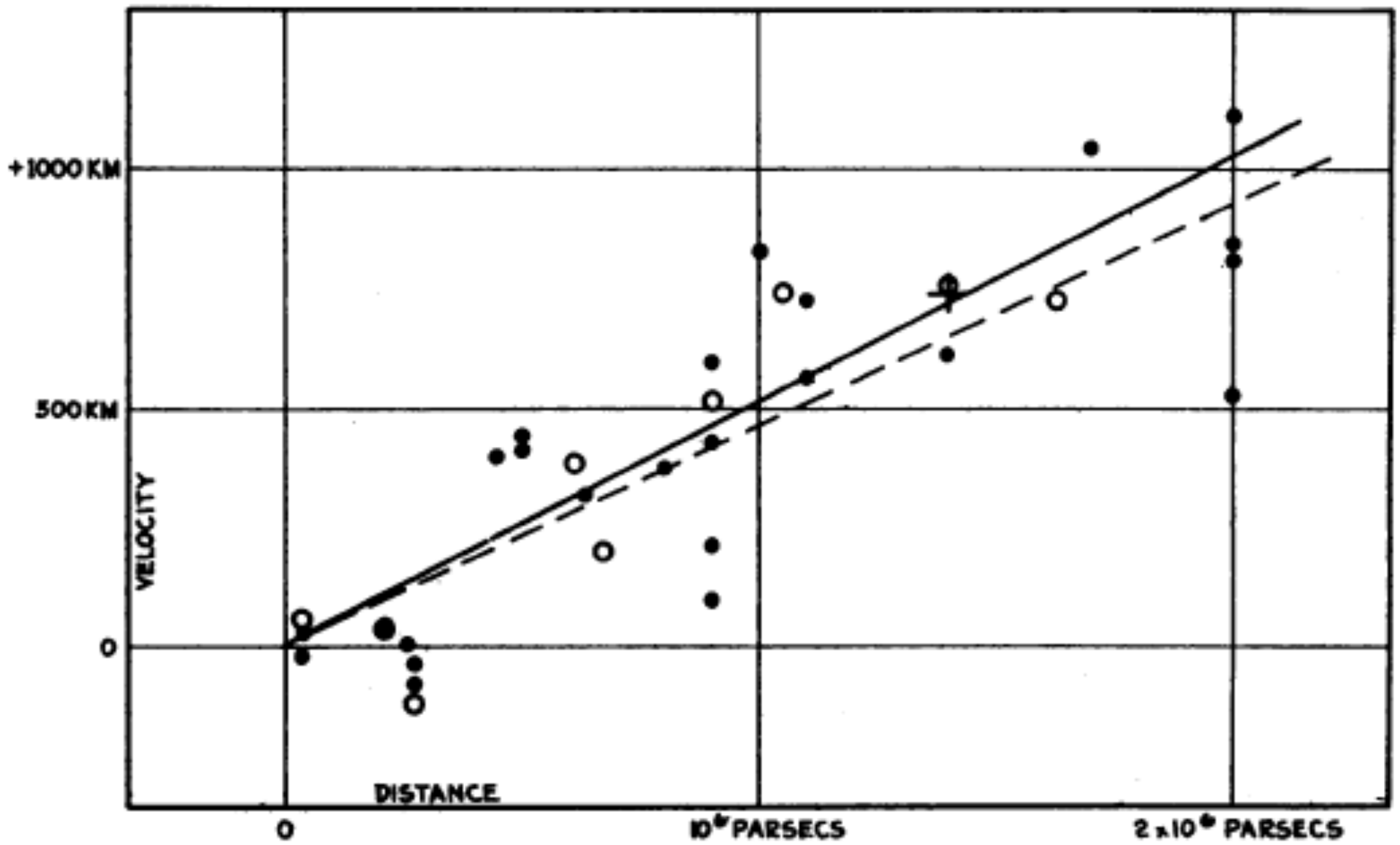
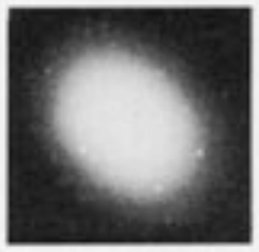
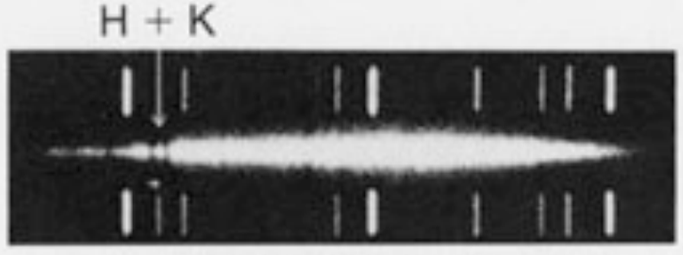
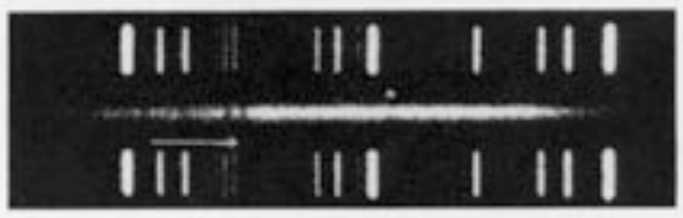
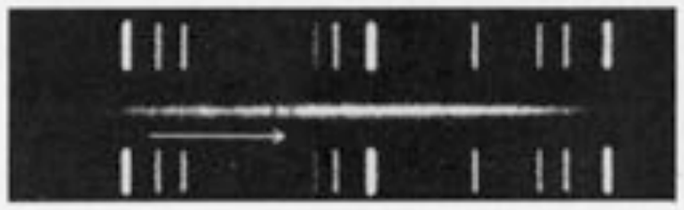
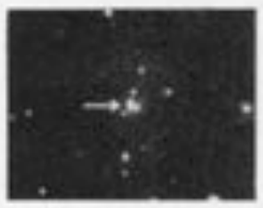
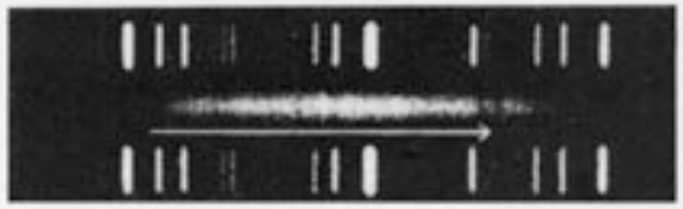
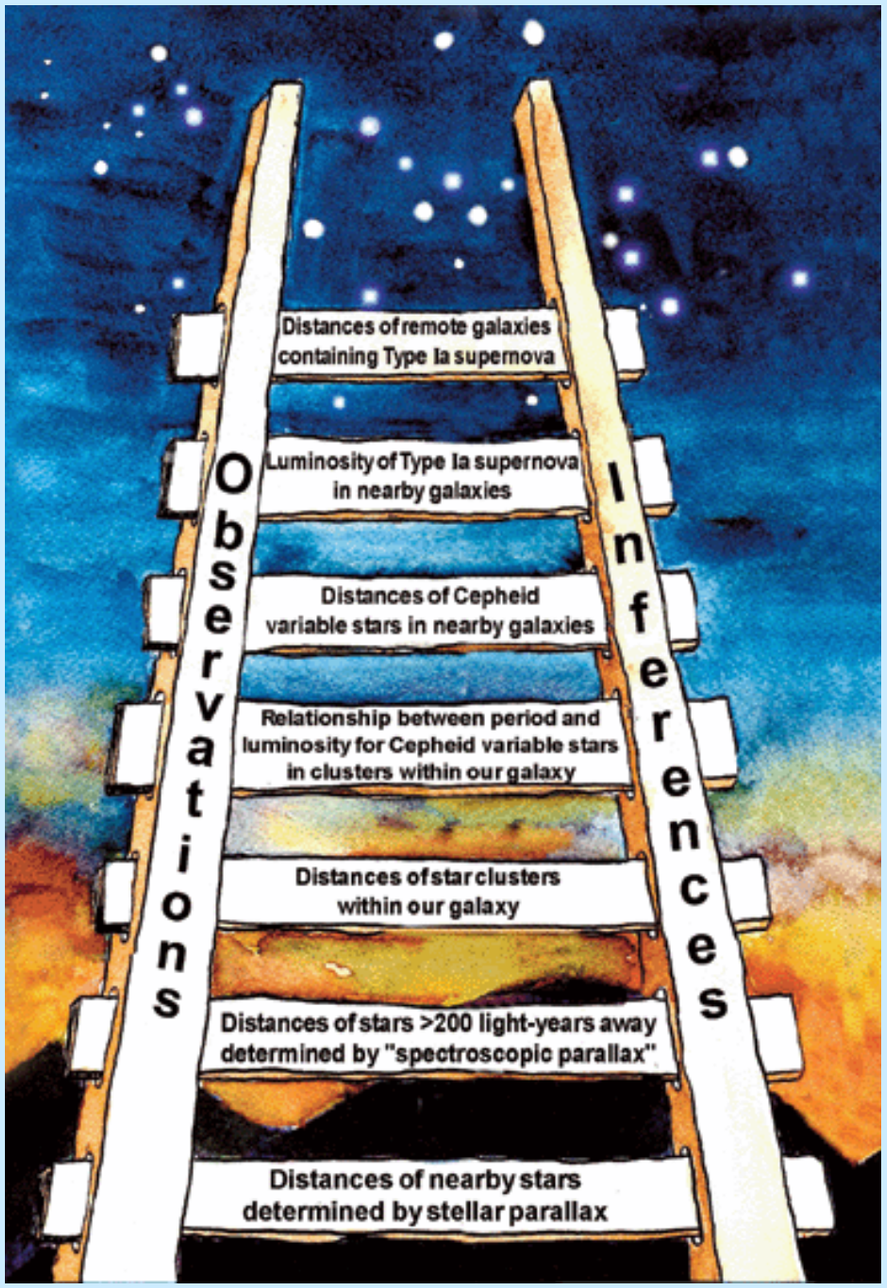


FIGURE 1

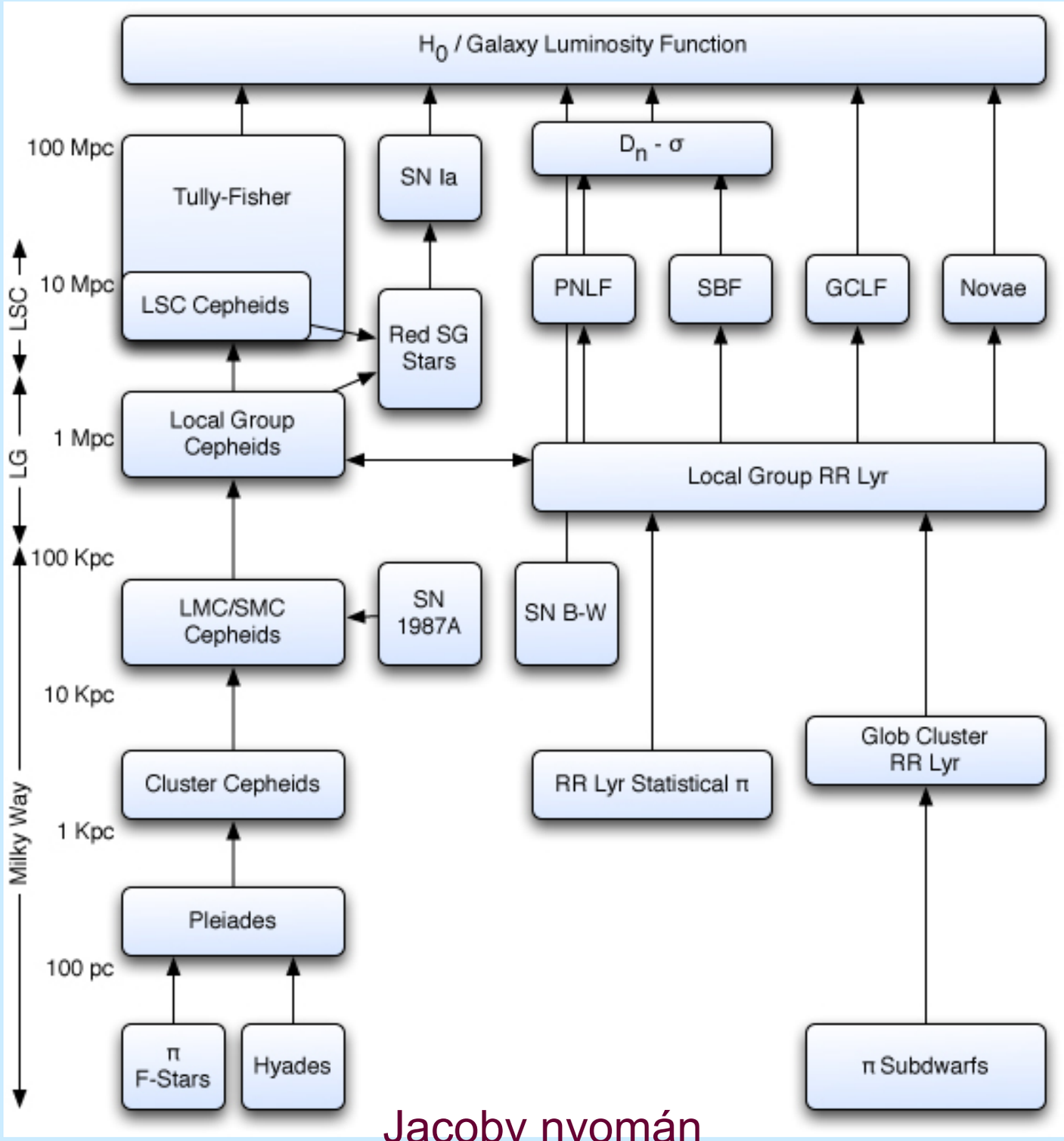
Velocity-Distance Relation among Extra-Galactic Nebulae.

Cluster nebula in	Distance in light-years	Redshifts
 Virgo	78,000,000	 1,200 km s^{-1}
 Ursa Major	1,000,000,000	 15,000 km s^{-1}
 Corona Borealis	1,400,000,000	 22,000 km s^{-1}
 Bootes	2,500,000,000	 39,000 km s^{-1}
 Hydra	3,960,000,000	 61,000 km s^{-1}

A kozmikus távolságlétra

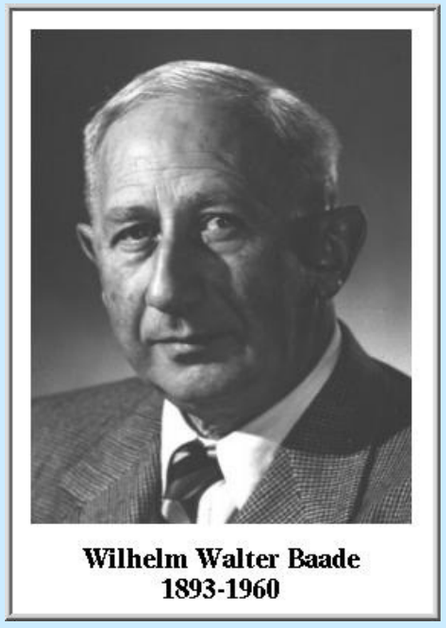


Murphy nyomán

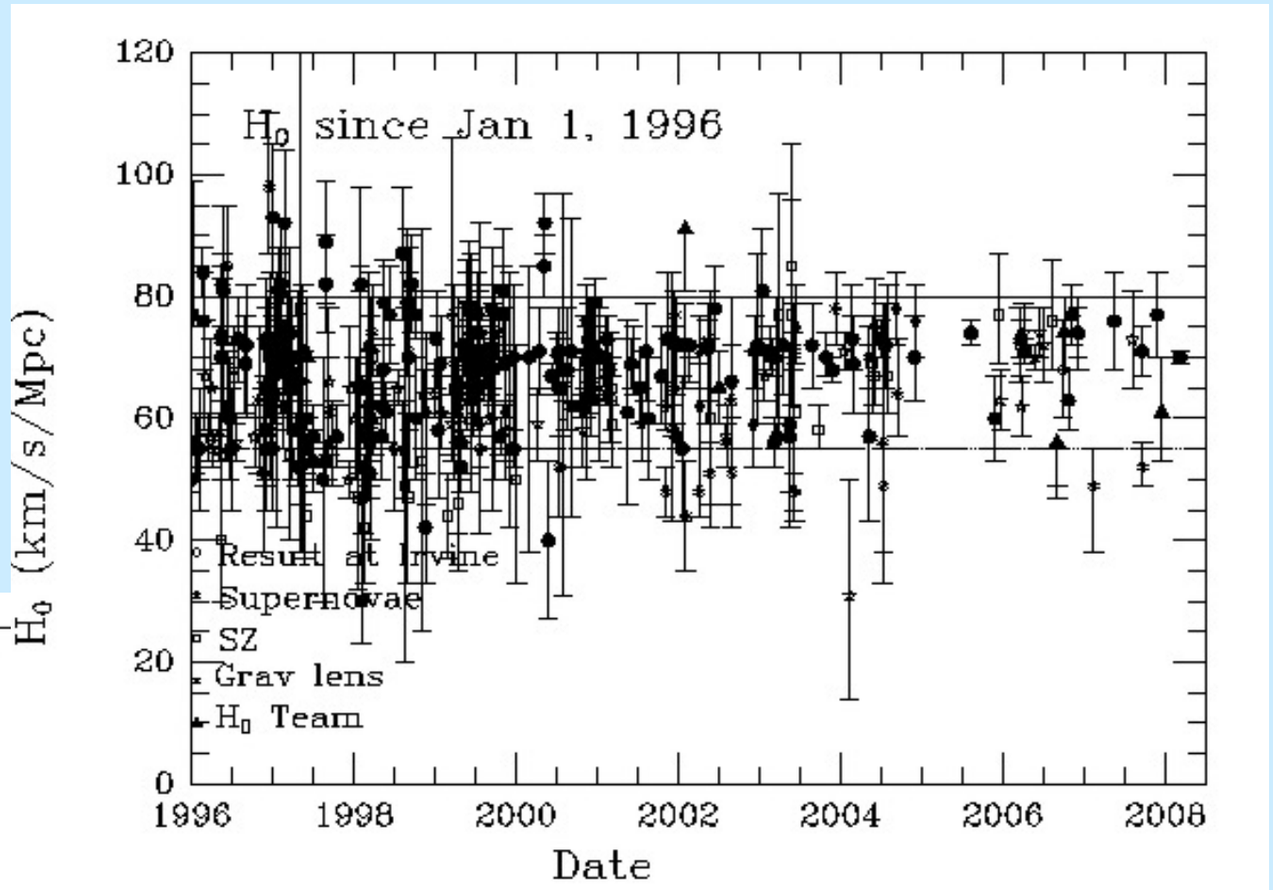


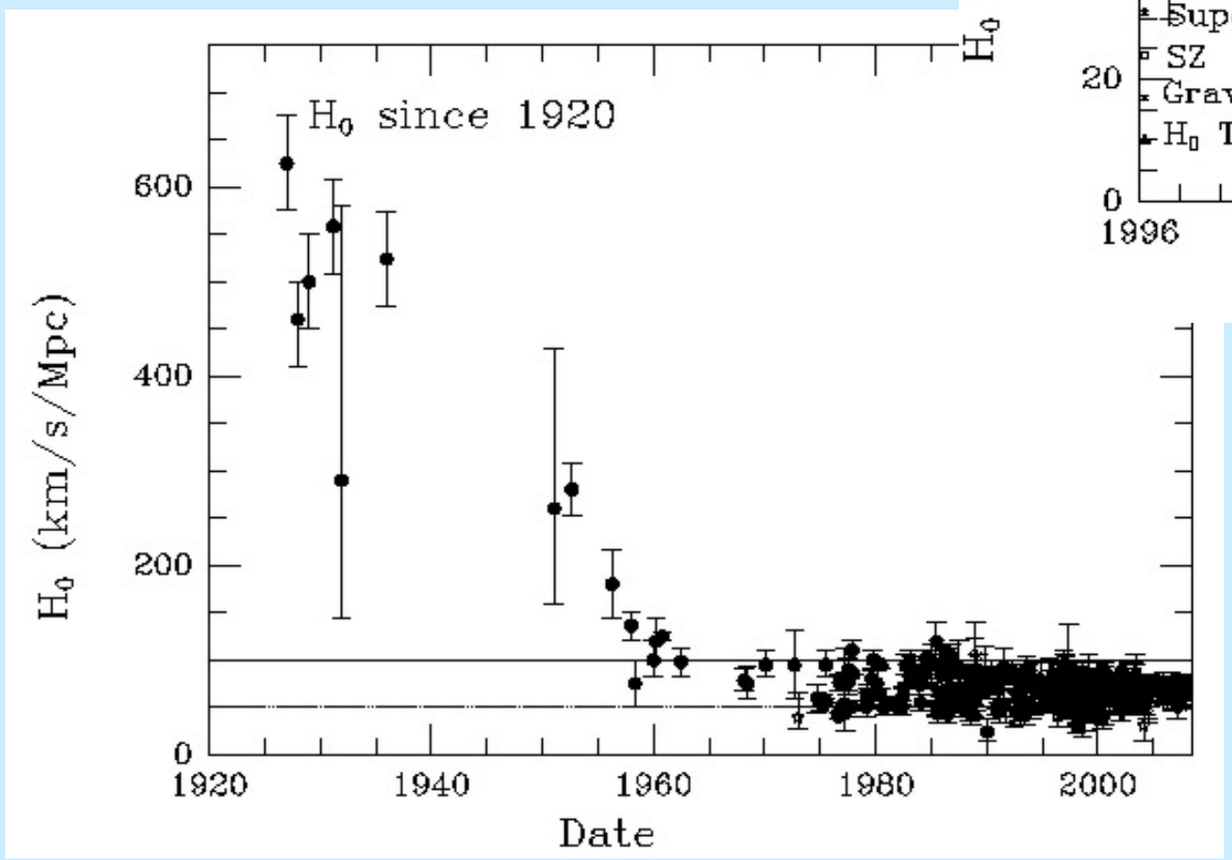
Jacoby nyomán

(Edwin) Hubble-tól a Hubble-ig (HST)



Wilhelm Walter Baade
1893-1960





Huchra nyomán

A Hubble-űrtávcső kulcsprogramja a Hubble-állandó meghatározására

Az 1990-es indítást követő 3 kulcsprogram egyike:

- 25 Mpc-nál közelebbi 17 galaxisban cefeidák felfedezése
- A galaxisok távolságának meghatározása
- 5 másodlagos távolságindikátor kalibrálása a cefeidák *P–L* összefüggése alapján (Tully–Fisher-reláció, az ellipszoidális galaxisok „alapsíkja” [Faber –Jackson-reláció], a galaxis felületi fényességének fluktuációja, SNIa, SNII)
- A H_0 Hubble-állandó meghatározása legalább 10% pontosan
- A *P–L* reláció univerzalitásának vizsgálata (pl. függés a fémtartalomtól)

A végeredmény:

$H_0 = 72 \pm 3 \pm 7$ km/s/Mpc

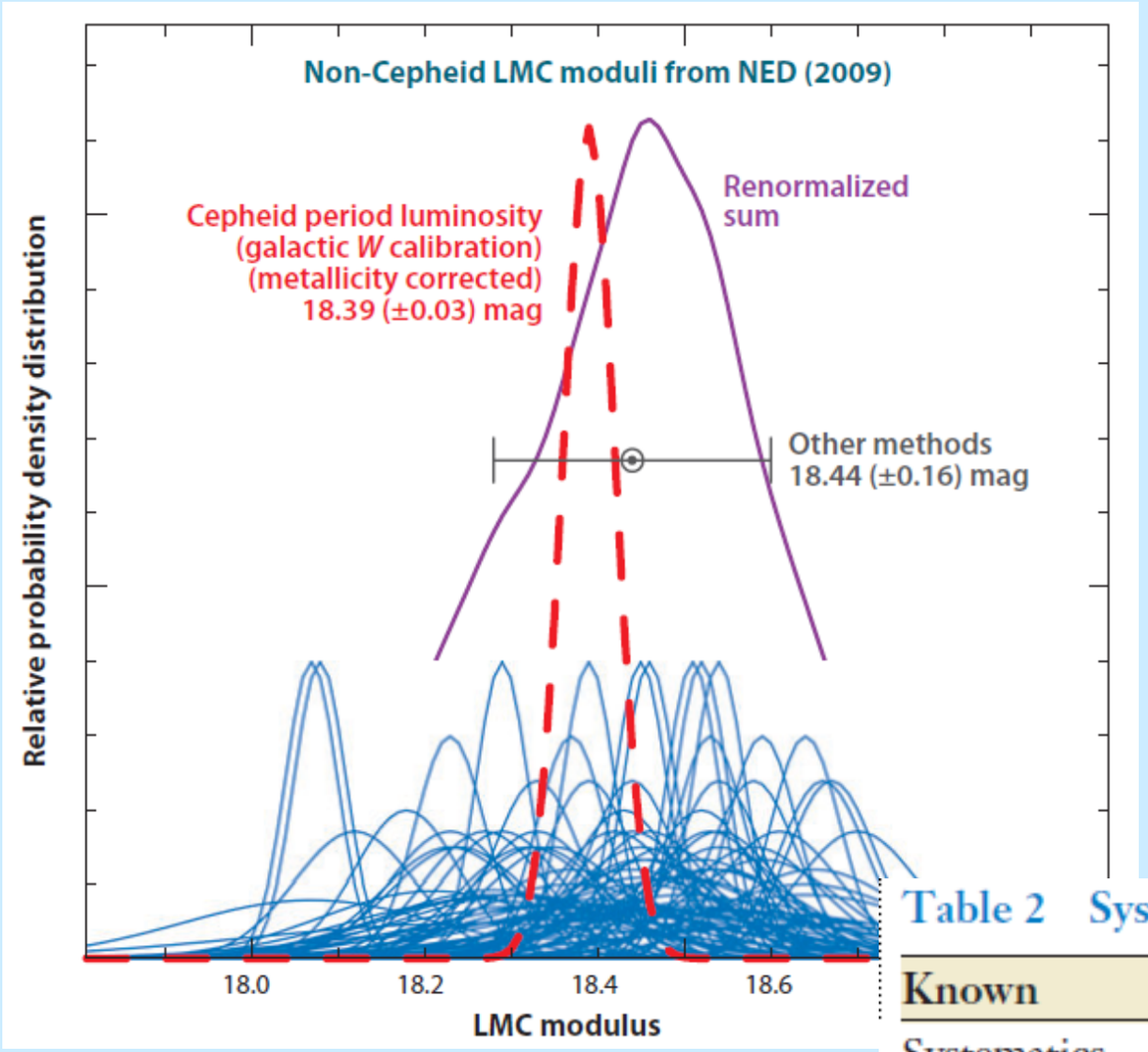
random sziszt.

hiba

Table 1: Chronology of finding the first Cepheids in various host galaxies

Year	Galaxy
1784	Milky Way
1904	Small Magellanic Cloud, Large Magellanic Cloud
1925	NGC 6822, M31, M33
1950	Sculptor (the first anomalous Cepheid)
1967	Ursa Minor
1968	NGC 2403 (first Cepheids beyond the Local Group), Leo II
1971	IC 1613
1976	Draco
1978	Leo I
1982	Sextans A
1984	M81, NGC 300
1985	Fornax, Sextans B, WLM
1986	M101 (first Cepheids revealed by CCD-photometry), Carina
1988	NGC 247, NGC 3109, NGC 7793
1990	NGC 147, NGC 185, DDO 216
1992	NGC 205, IC 4182
1994	NGC 4571 (first Cepheids in Virgo Cluster), NGC 5253, DDO 69
1995	M96, NGC 2366, DDO 155, Sagittarius, Sextans
1996	M100, NGC 925, NGC 4496A, NGC 4536, NGC 4639, IC 10
1997	M95, NGC 3621
1998	NGC 2090, NGC 2541, NGC 4414, NGC 7331, DDO 50, DDO 187
1999	M66, M91, M106, NGC 1326A, NGC 1365, NGC 3198, NGC 3319, NGC 4535, NGC 4603, NGC 4725
2000	NGC 1425
2001	NGC 2841, NGC 3982, NGC 4527
2002	IC 342, And III, And VI
2003	M83, NGC 1637
2004	NGC 4395, And II, Phoenix
2005	NGC 55, NGC 3370
2006	NGC 5128
2007	I Zw 18
2008	CVn I
2009	NGC 1309, NGC 3021, Cetus, Tucana
2011	NGC 4038, NGC 5584
2015	NGC 1313

A cefeidák így is jobban teljesítenek

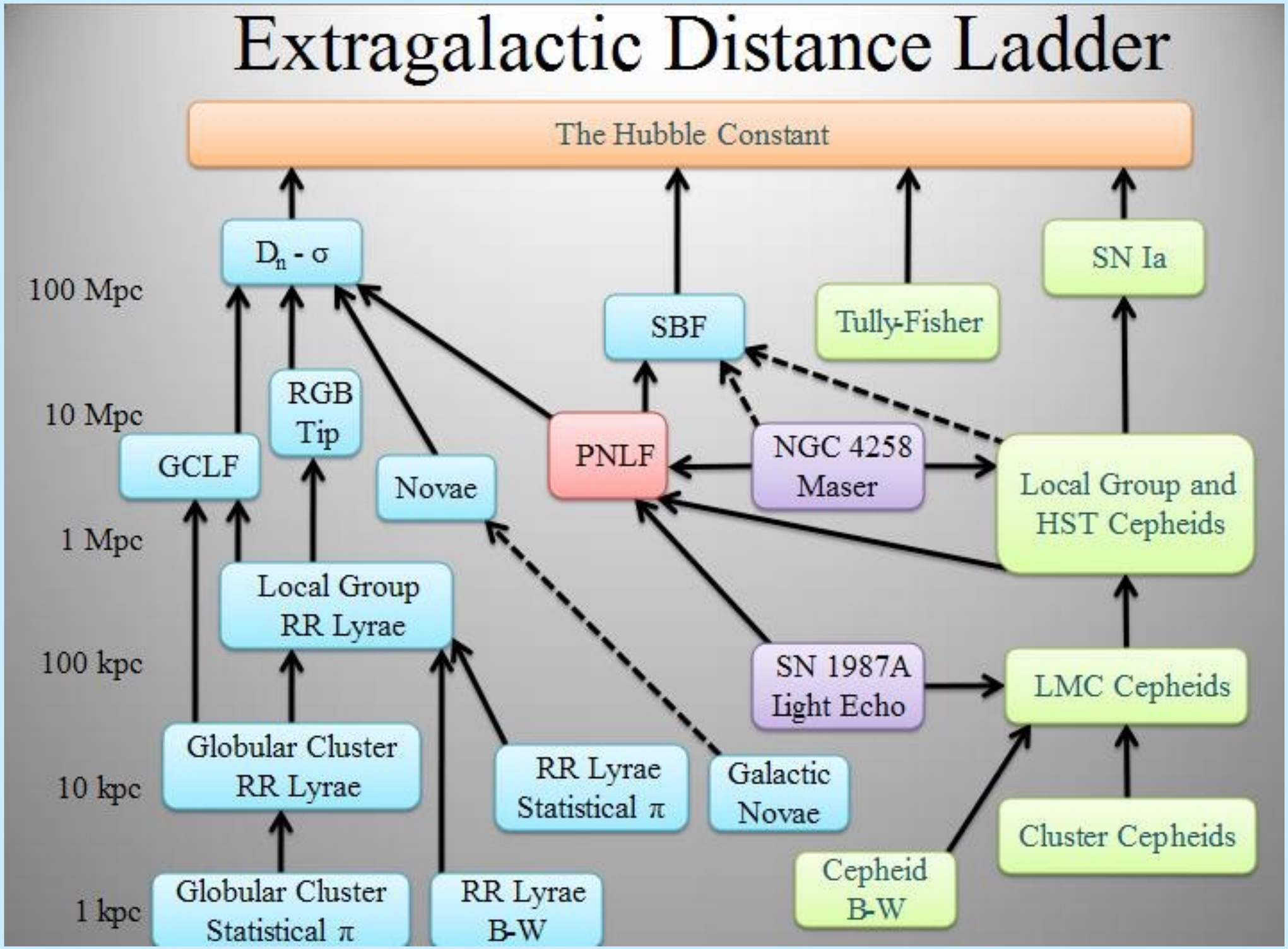


Freedman és Madore
2010-es áttekintő
ARA&A-cikkéből

Table 2 Systematics error budget on H_0: past, present, and future

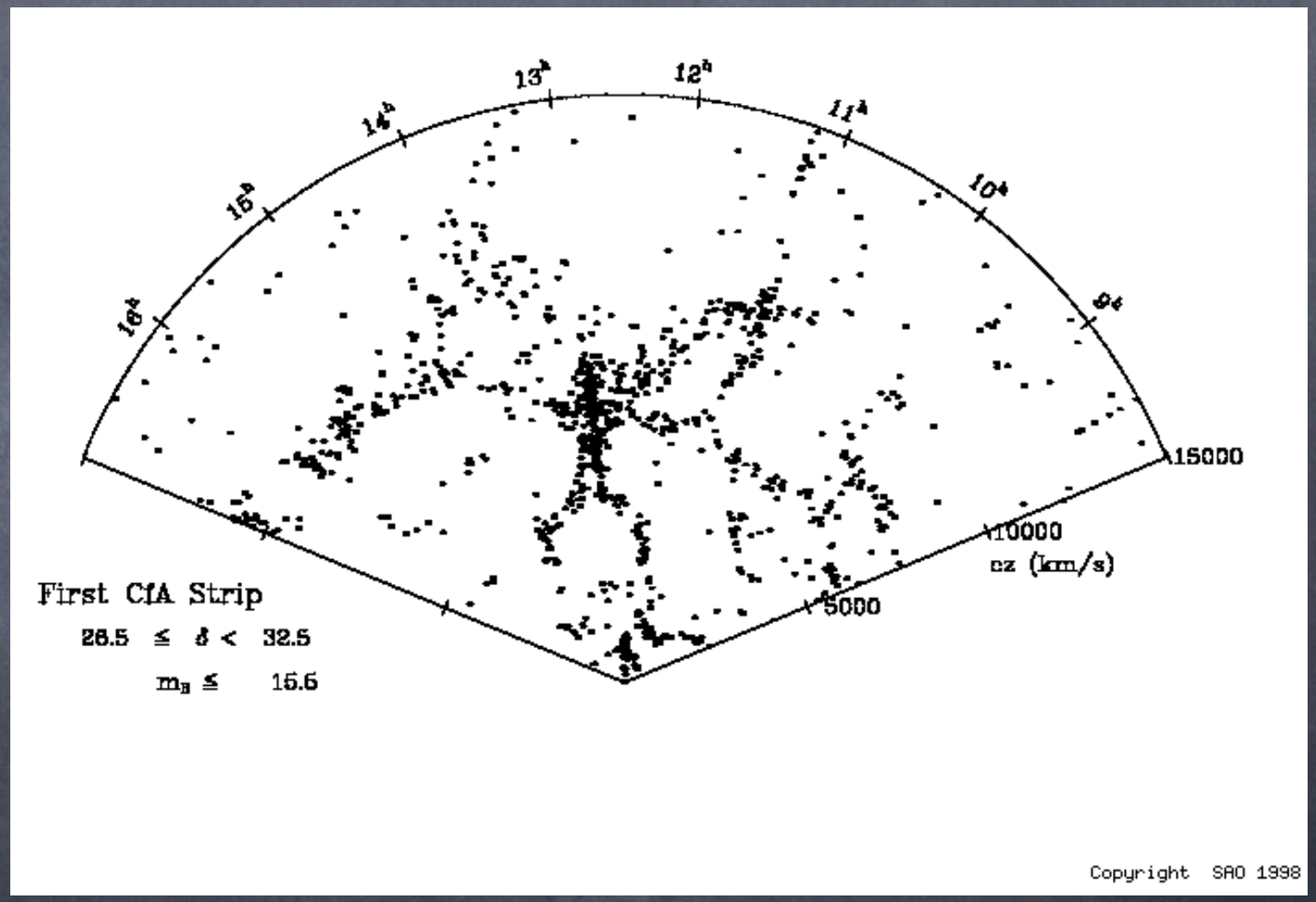
Known	Key Project	Revisions	Anticipated
Systematics	(2001)	(2007/2009)	*Spitzer*/JWST
(1) Cepheid Zero Point	±0.12 mag	±0.06 mag	±0.03 mag
(2) Metallicity	± 0.10 mag	±0.05 mag	±0.02 mag
(3) Reddening	±0.05 mag	±0.03 mag	±0.01 mag
(4) Transformations	±0.05 mag	±0.03 mag	±0.02 mag
Final Uncertainty	±0.20 mag	±0.09 mag	±0.04 mag
Percentage Error on H_0	±10%	±5%	±2%

Egyéb távolságmeghatározási módszerek



Hogyan lehet tesztelni a bonyolult szimulációkat?

- Fel kell térképezni a látható anyag eloszlását
- Kozmológiai távolságokon a galaxisok jelentik a nyomjelző tesztrészecskéket
- Probléma: RENGETEG galaxis
- Távolságok: vöröseltolódás-mérésből

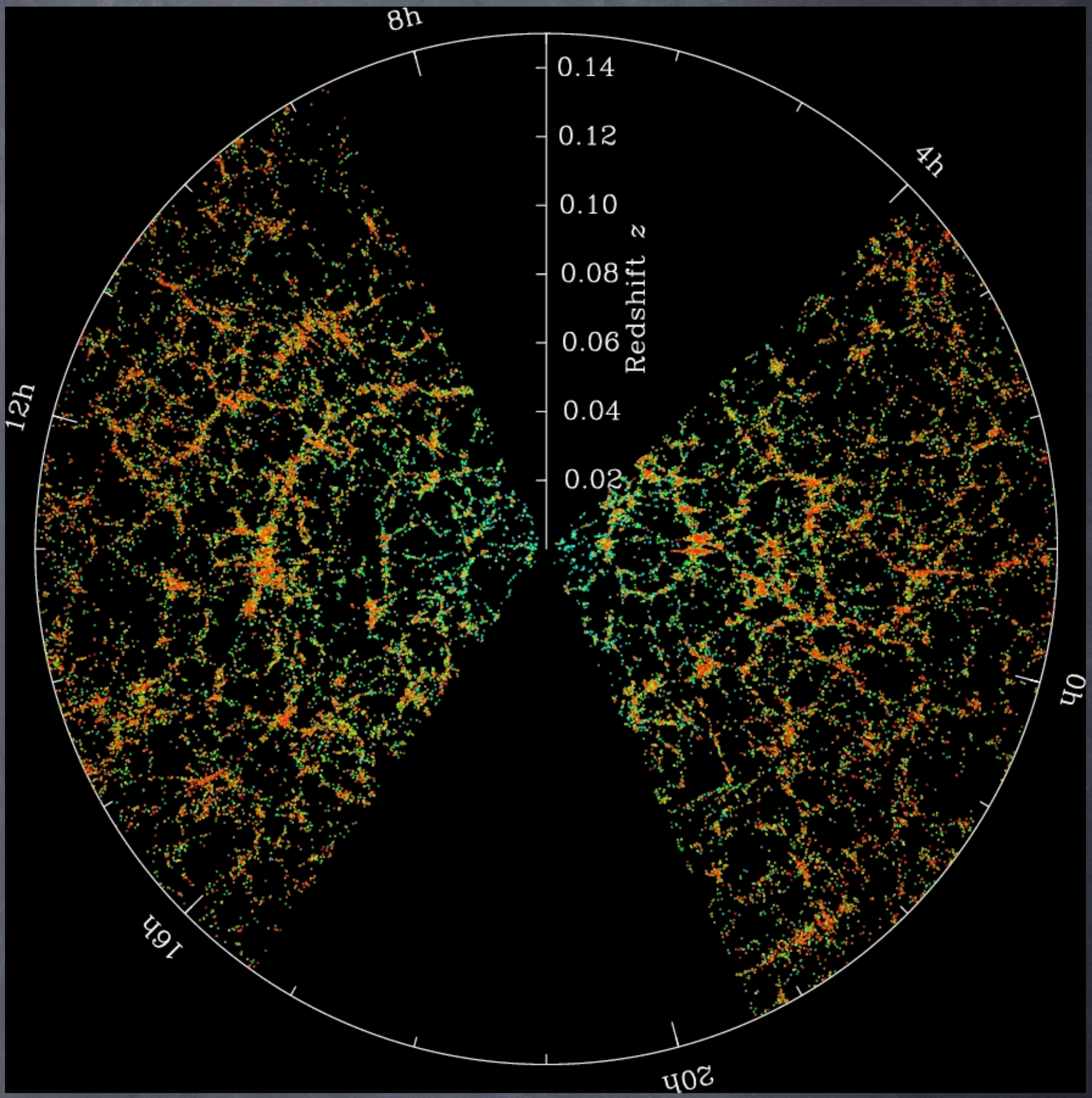


Jelentősebb (spektroszkópiai) galaxisfelmérések az elmúlt 30 évben

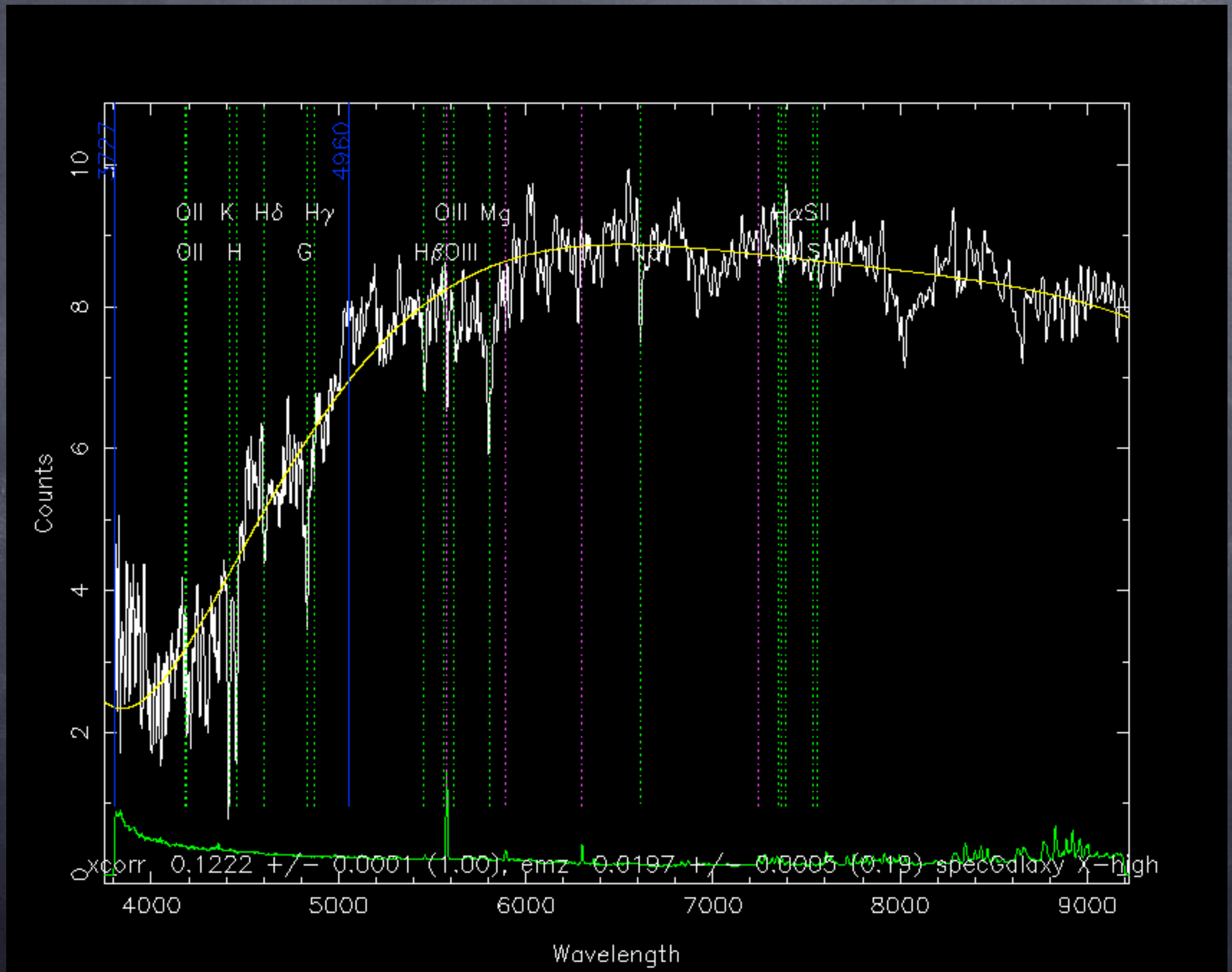
- CfA és CfA2 felmérés (Huchra, Geller, et al.). Több periódus 1977 és 1995 között, 18 ezer galaxis
- DEEP2 survey, 38 ezer galaxis (2003)
- SDSS, több felmérés, >700 ezer galaxis, spektrumok és színek (2,5m SDSS teleszkóp)
- 2dF GRS, 220 ezer galaxis, egyedi spektrumok alapján (AAT)
- 6dF, 125 ezer galaxis (UK Schmidt)
- WiggleZ, 250 ezer galaxis (AAT)
- GAMA, 126 ezer galaxis (AAT)

Sloan Digital Sky Survey

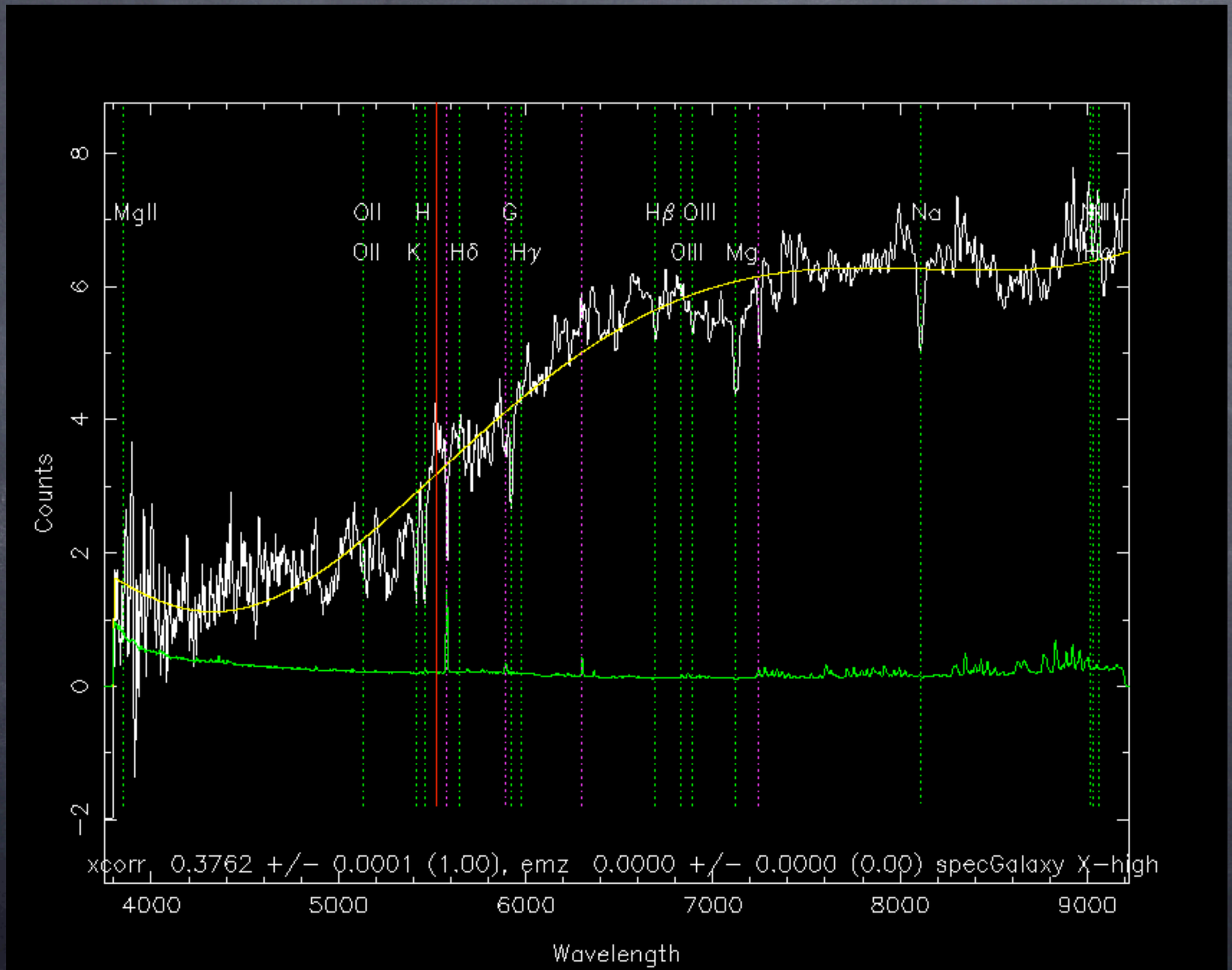
- Új-Mexikó, 2,5m-es teleszkóp Apache Pointban
- Öt színben képalkotás több mint 100 millió égitestről
- Kb. 700 ezer spektrum galaxisokról, kvazárokról és csillagokról
- Fontos magyar részvevők (Szalay Sándor, Csabai István és tanítványaik)


8h
4h
0h
20h
16h
12h
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Redshift z

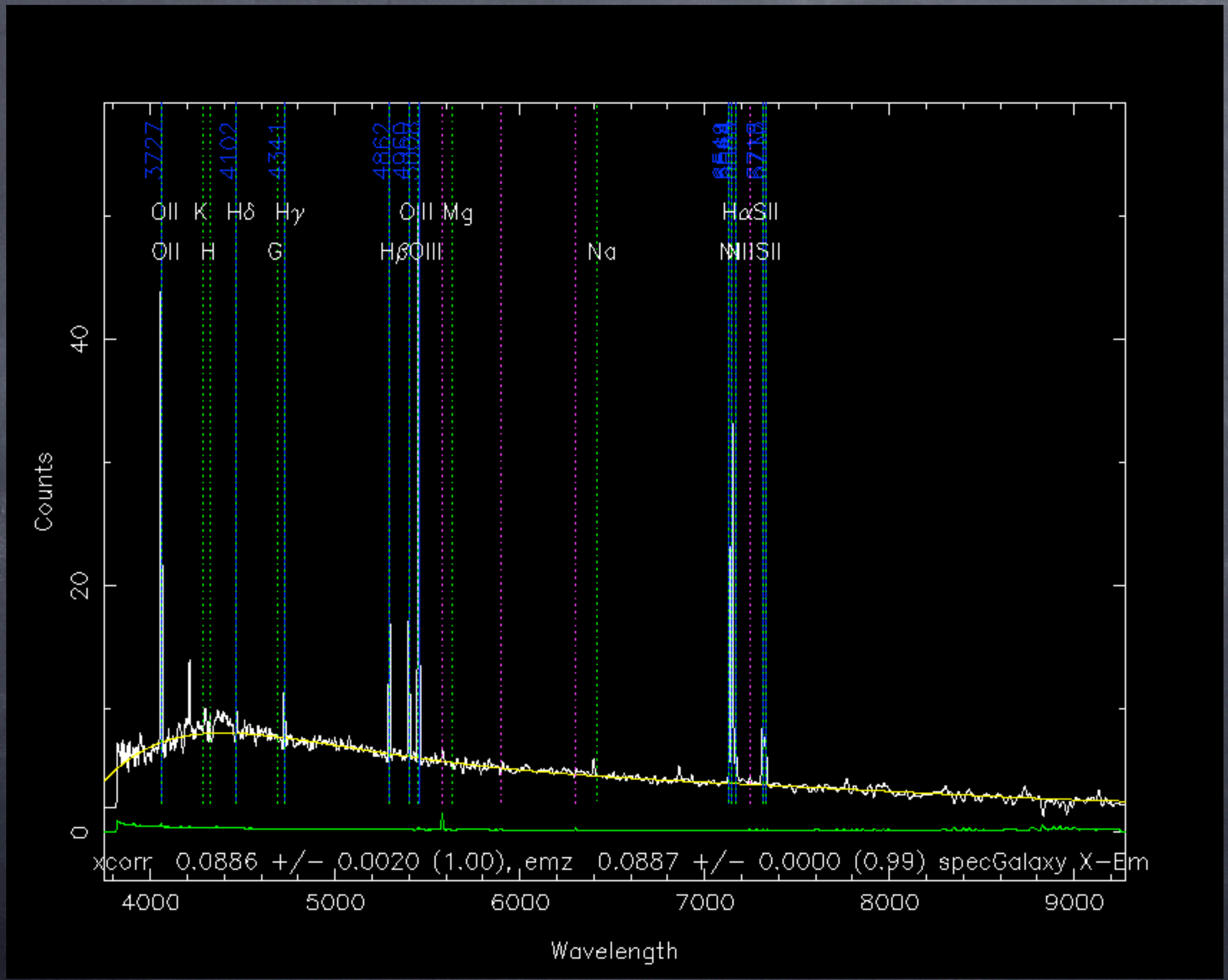
Tipikus galaxis



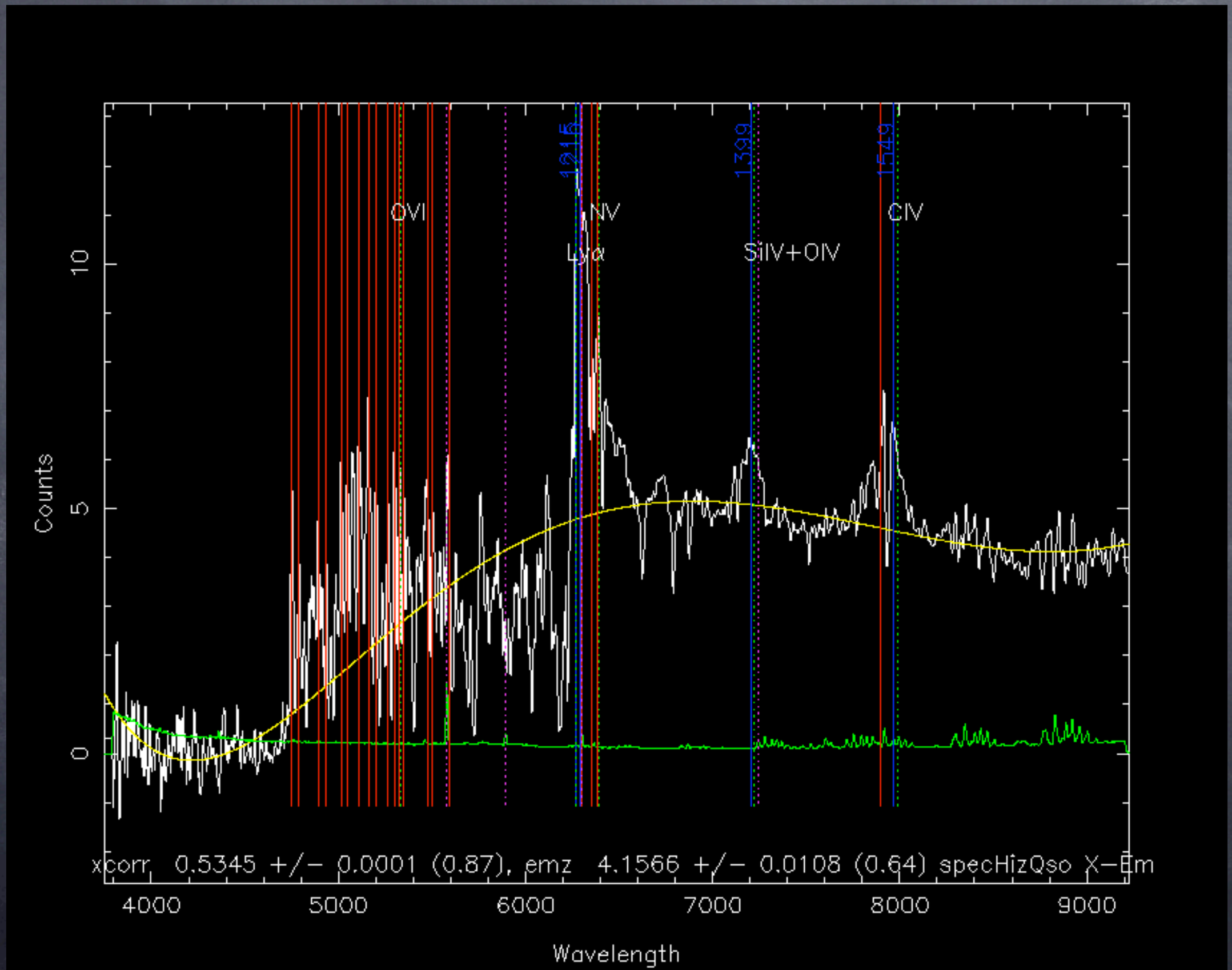
Fényes vörös galaxis



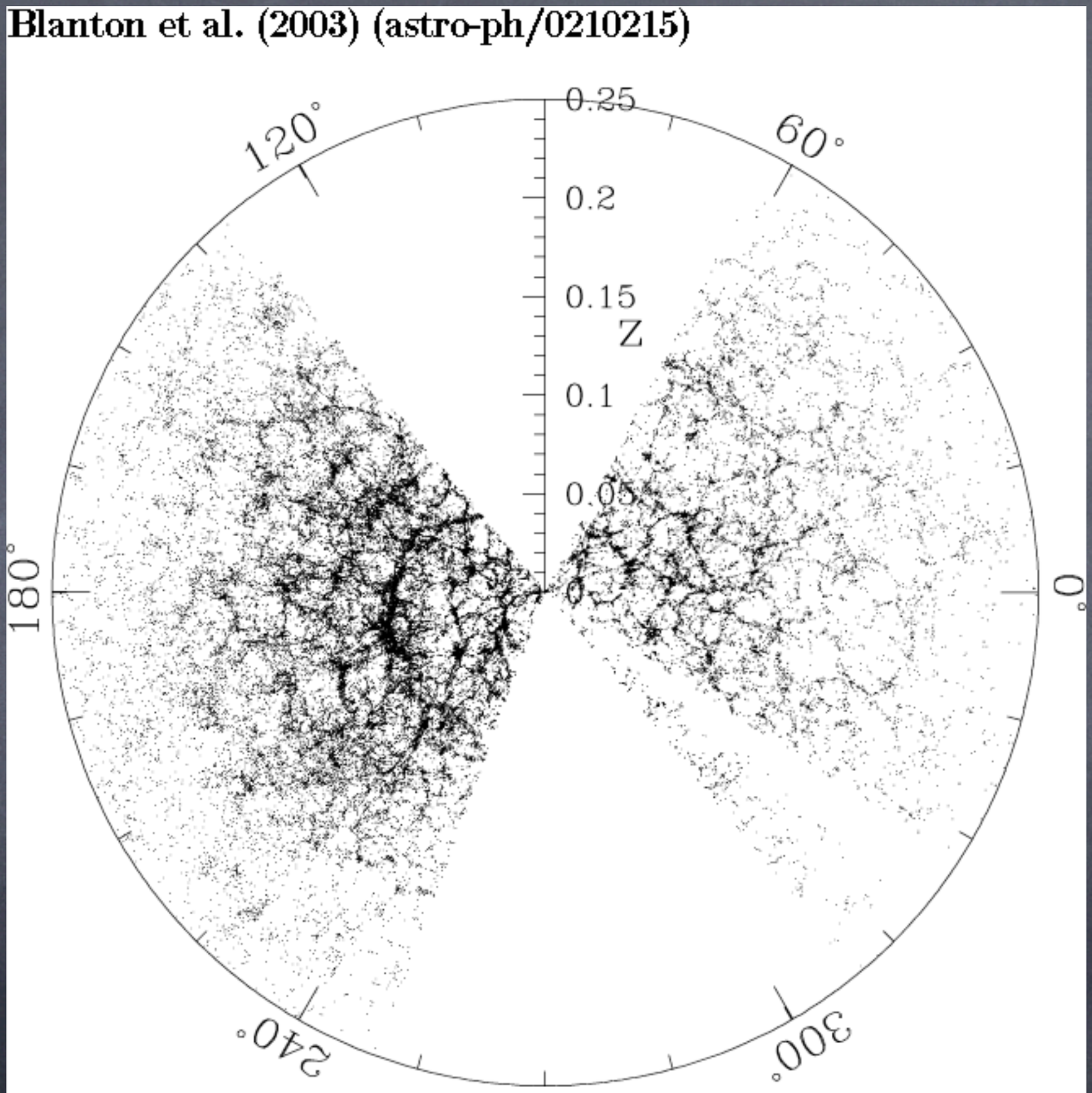
Emissziós vonalas galaxis



Nagy vöröseltolódású kvazár (z=4,16)



Blanton et al. (2003) (astro-ph/0210215)

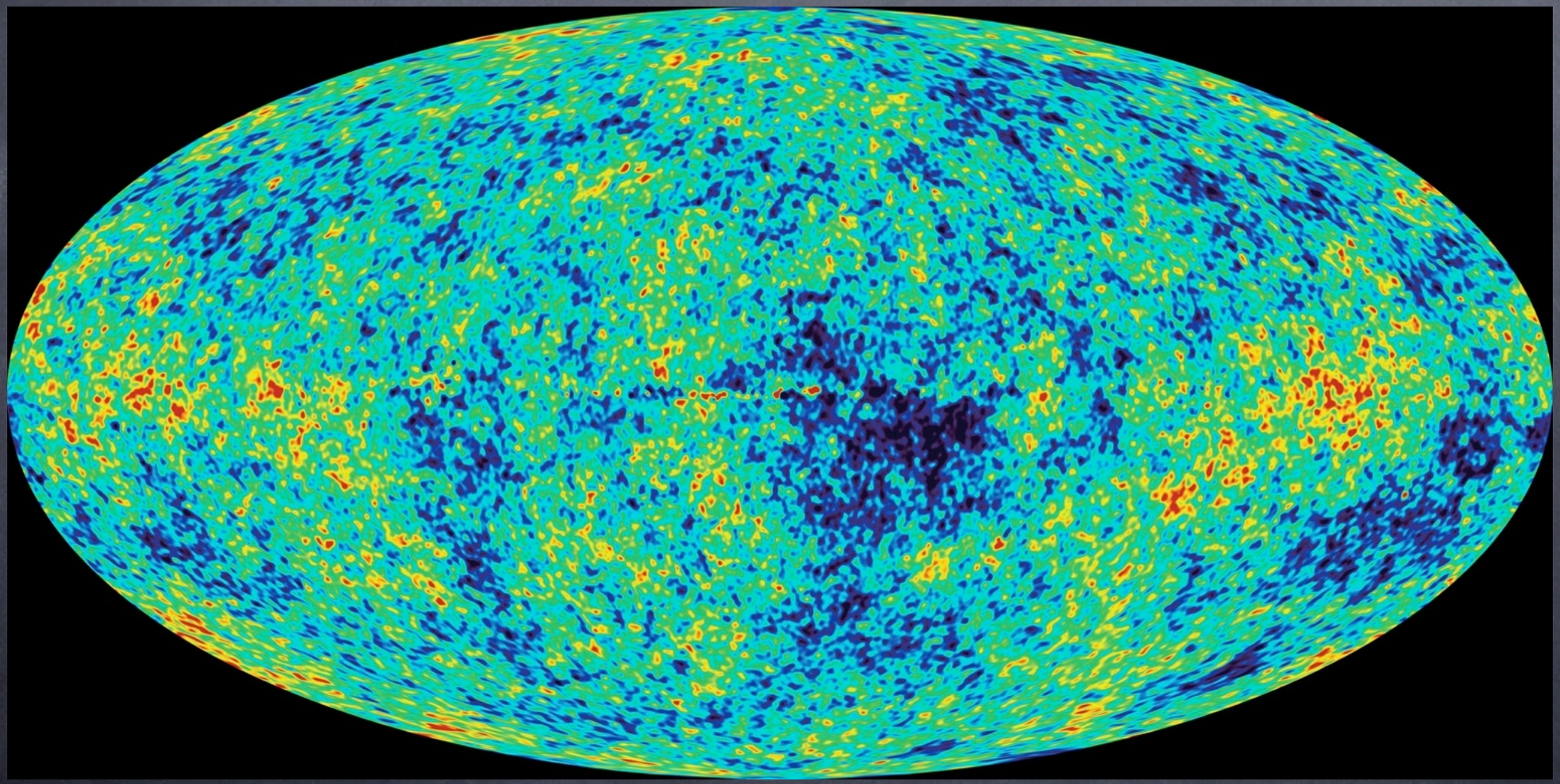


Large−Scale Structure sample10

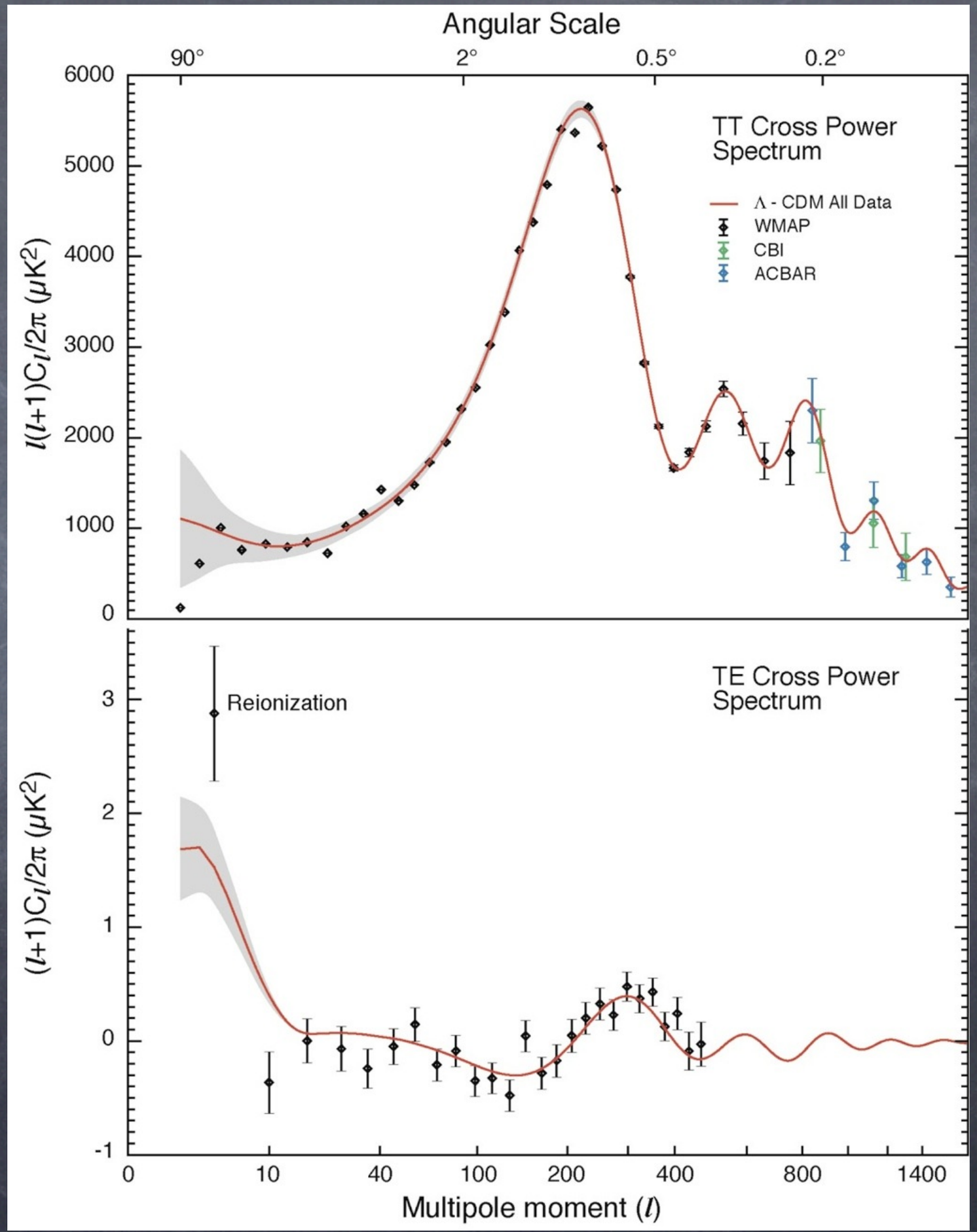
Kulcskérdések

- Miről árulkodnak a térbeli csomósodások?
- Hogyan kell figyelembe venni a kiválasztási effektusokat?
- Ezek miként módosítják az eloszlások értelmezését?
- Hogyan függ a galaxisok eloszlása a kozmológiai paraméterektől?

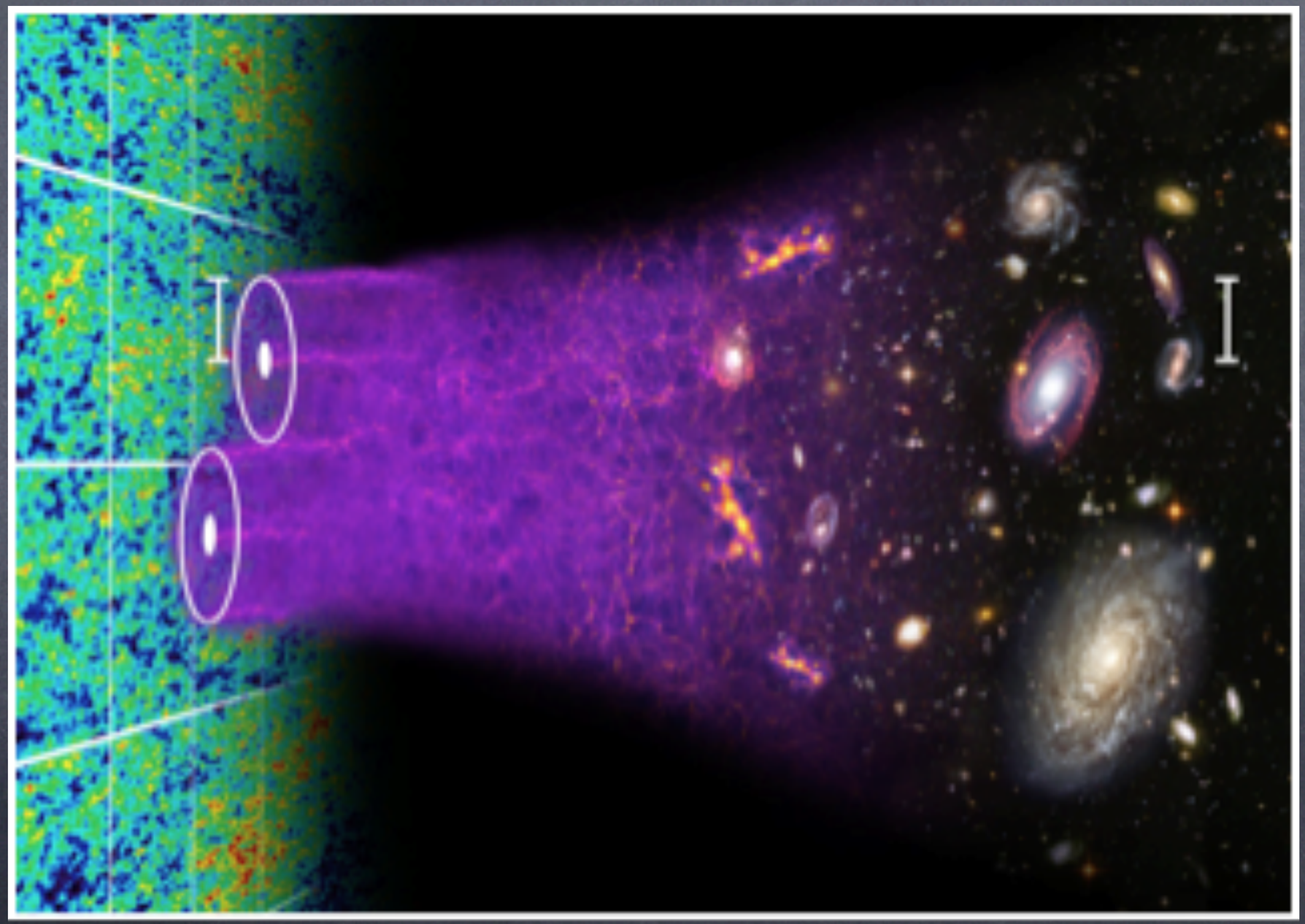
A WMAP térképe a mikrohullámú háttérsugárzásról: csomósodás irány szerint

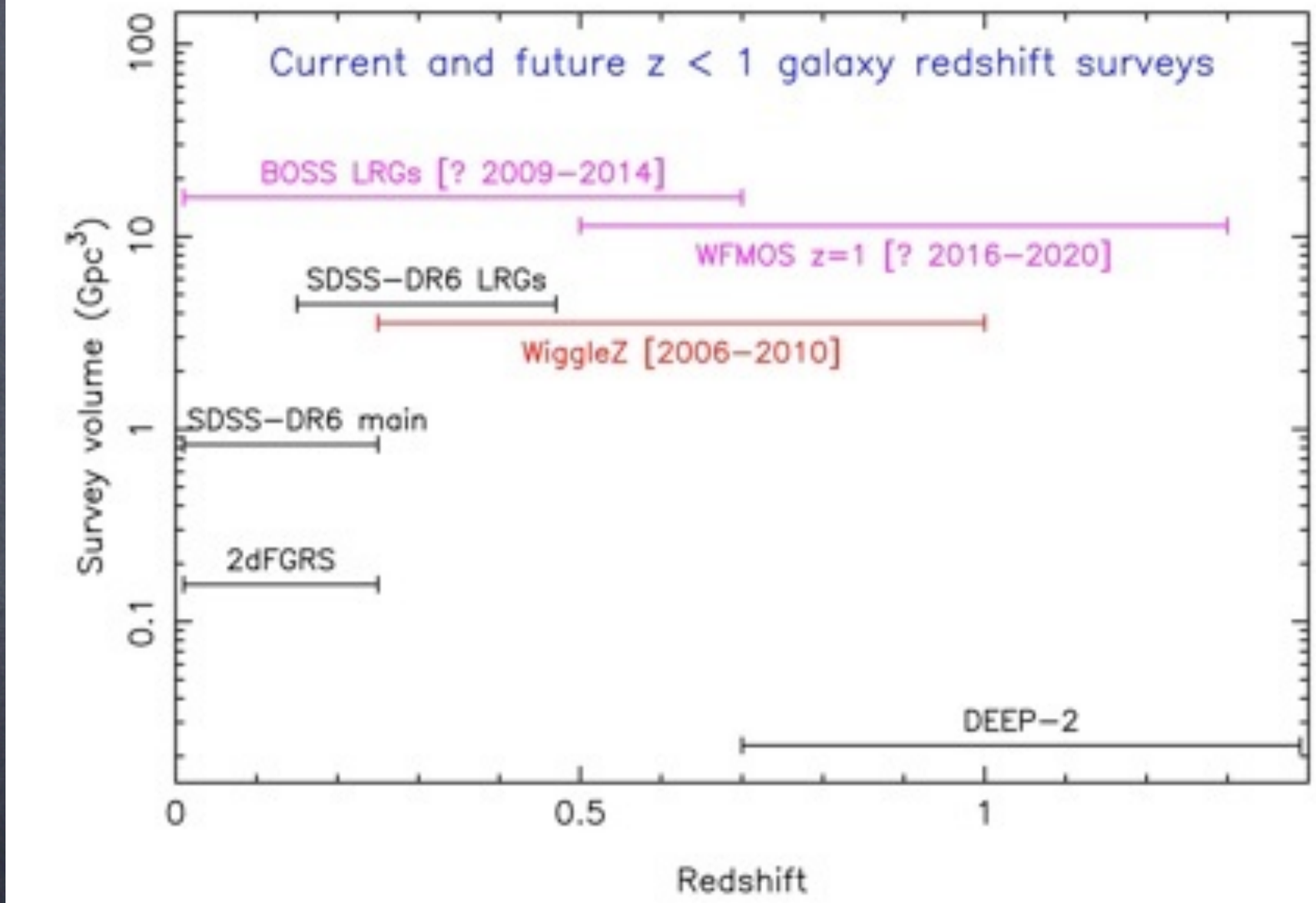


A WMAP szögspektruma

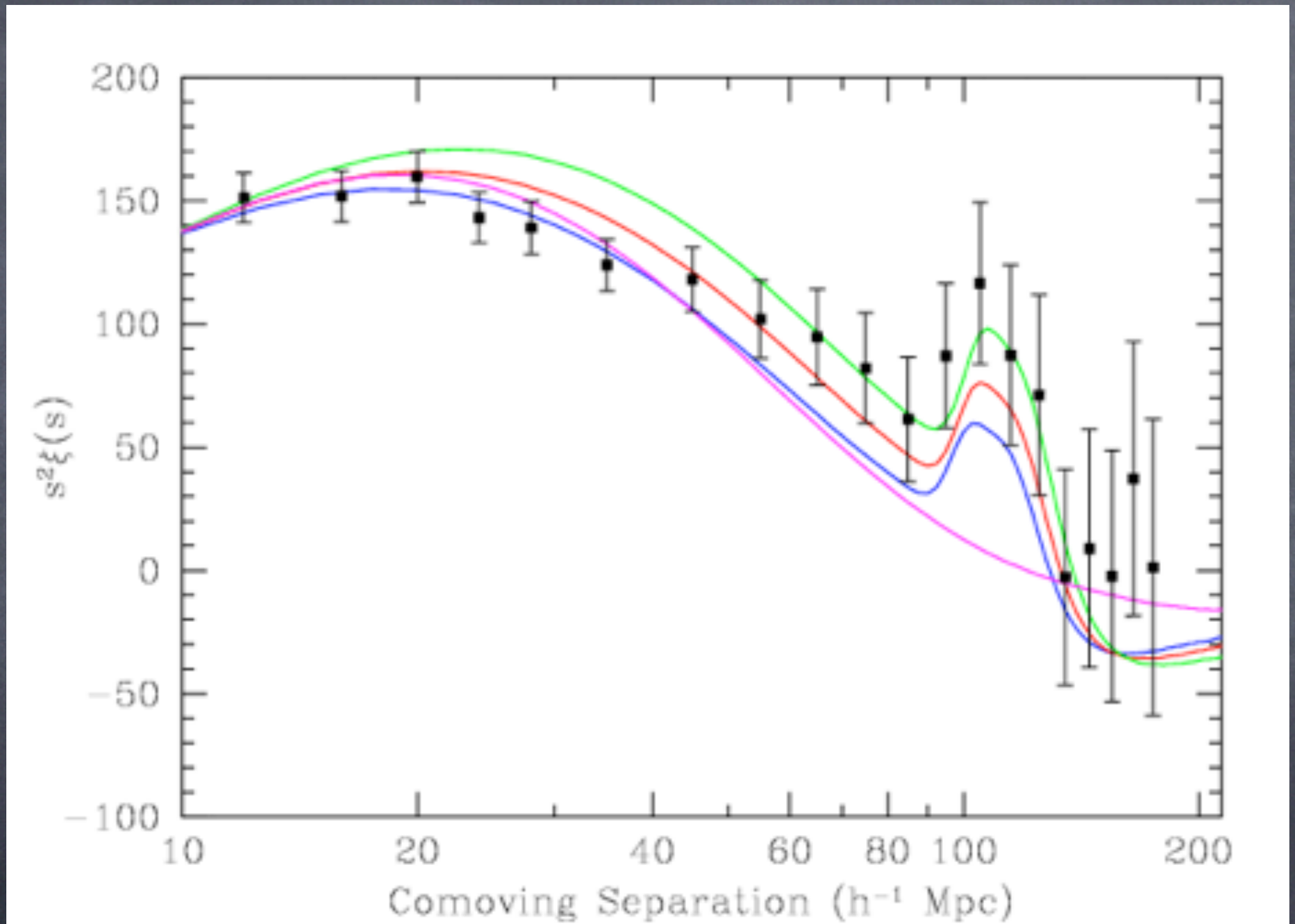


BAO: barionikus akusztikus oszcillációk




Current and future z < 1 galaxy redshift surveys
BOSS LRGs [? 2009–2014]
WFMOS z=1 [? 2016–2020]
SDSS–DR6 LRGs
WiggleZ [2006–2010]
SDSS–DR6 main
2dFGRS
DEEP–2
Survey volume (Gpc^3)
100
10
1
0.1
0
0.5
1
Redshift

SDSS LRG csomósodási skála



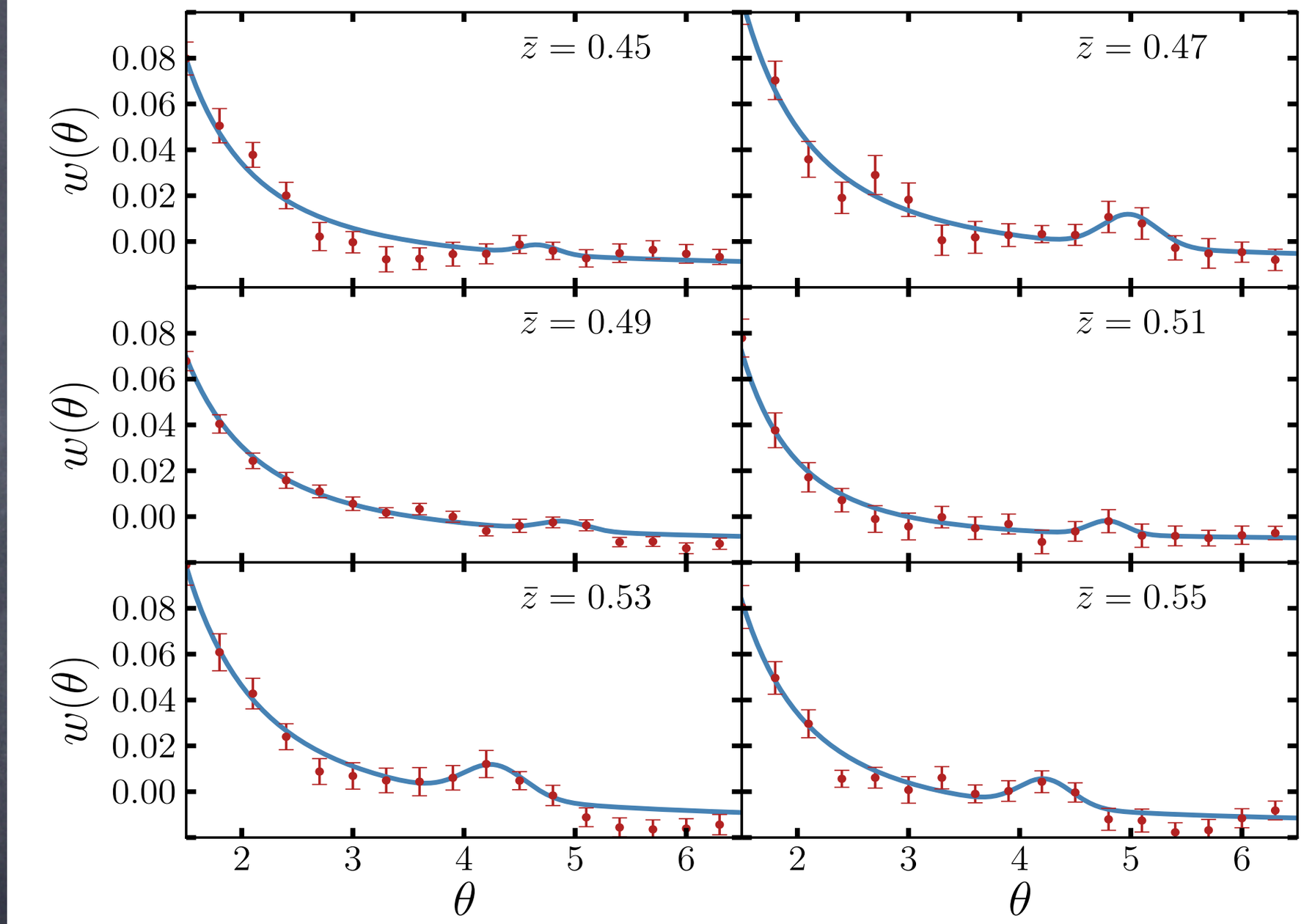
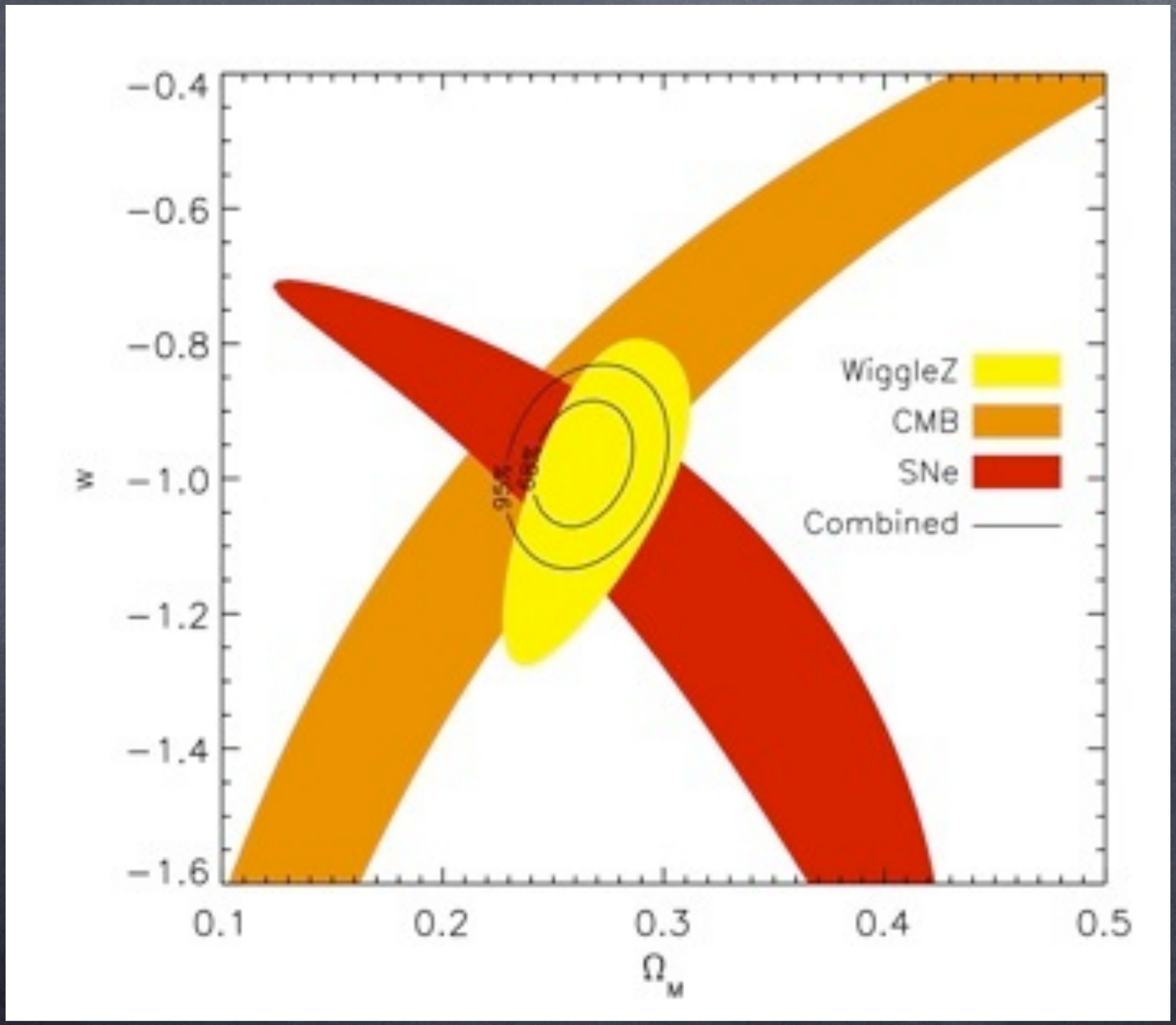


FIG. 3: The 2PACF for six bin redshift intervals using the DR10-SDSS data (bullets) and Eq. 7 (continuous line). The amplitude of the BAO bump corresponds to C, the BAO location and the width are related to θ_{FIT} and σ, respectively. In these plots we used $N_b = 40$.

Carvalho et al. (2016)

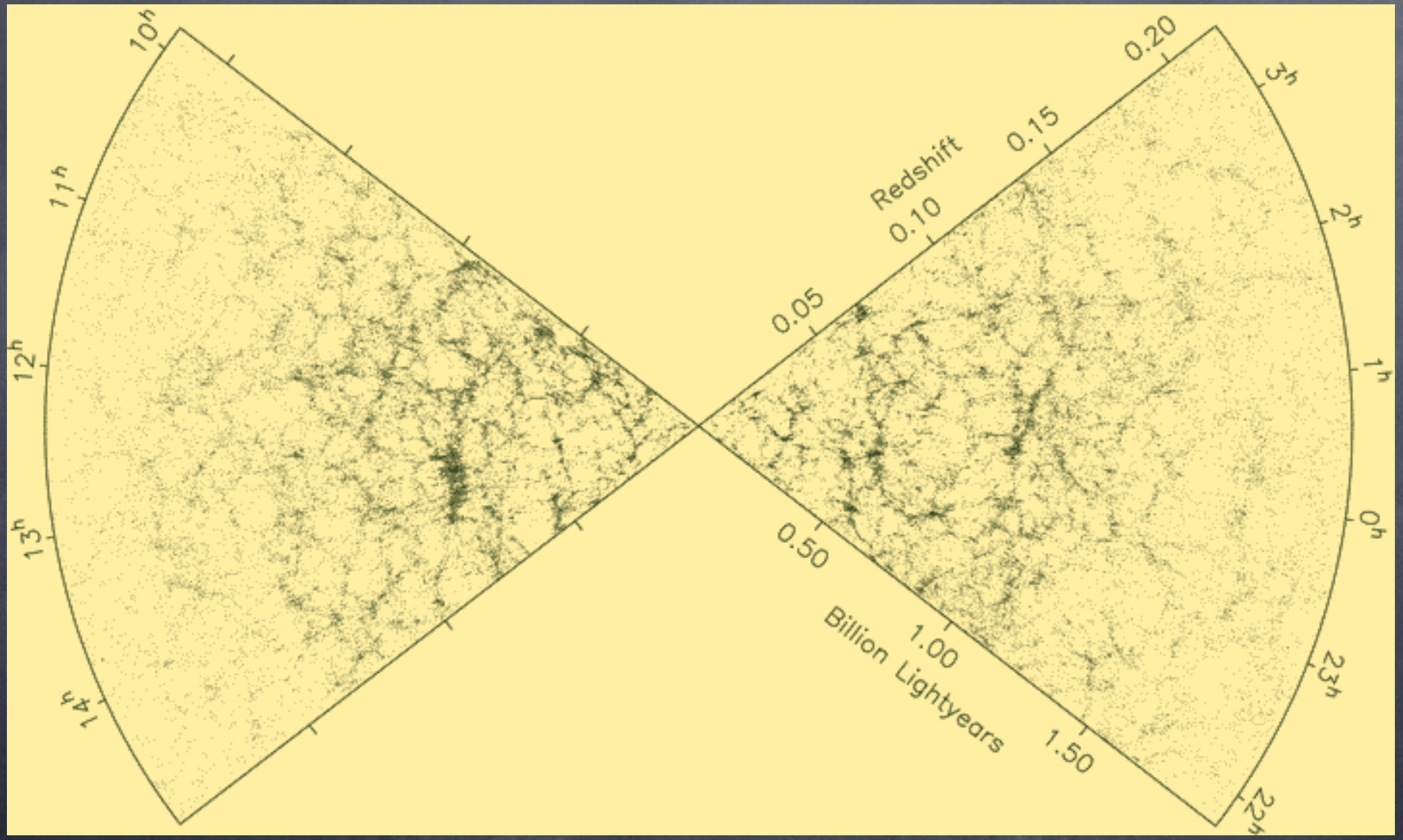
Kozmológiai paraméterek független pontosítása



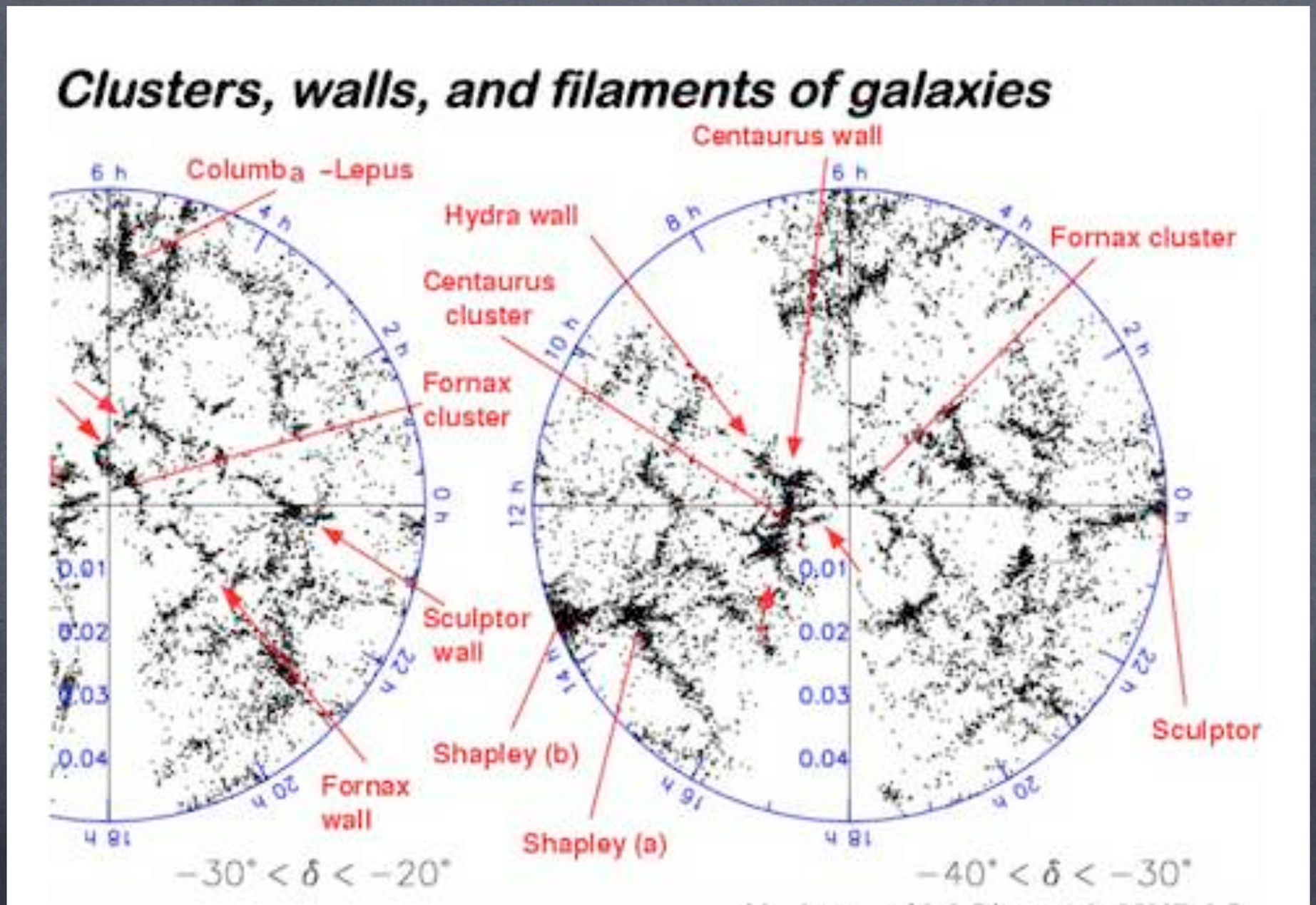
Ausztrália: vöröseltolódás-nagyhatalom

- 2dF Galaxy Redshift Survey
- 6dF Galaxy Survey
- WiggleZ
- Galaxy and Mass Assembly (GAMA)
- Mindegyik: multiobjektum-spektroszkópia
- Műszerek: 1,2 m-es UK Schmidt, 3,9m-es AAT

2dF GRS (2003)


10h
11h
12h
13h
14h
Redshift
0.05
0.10
0.15
0.20
0.50
1.00
1.50
Billion Lightyears
3h
2h
1h
0h
23h
22h

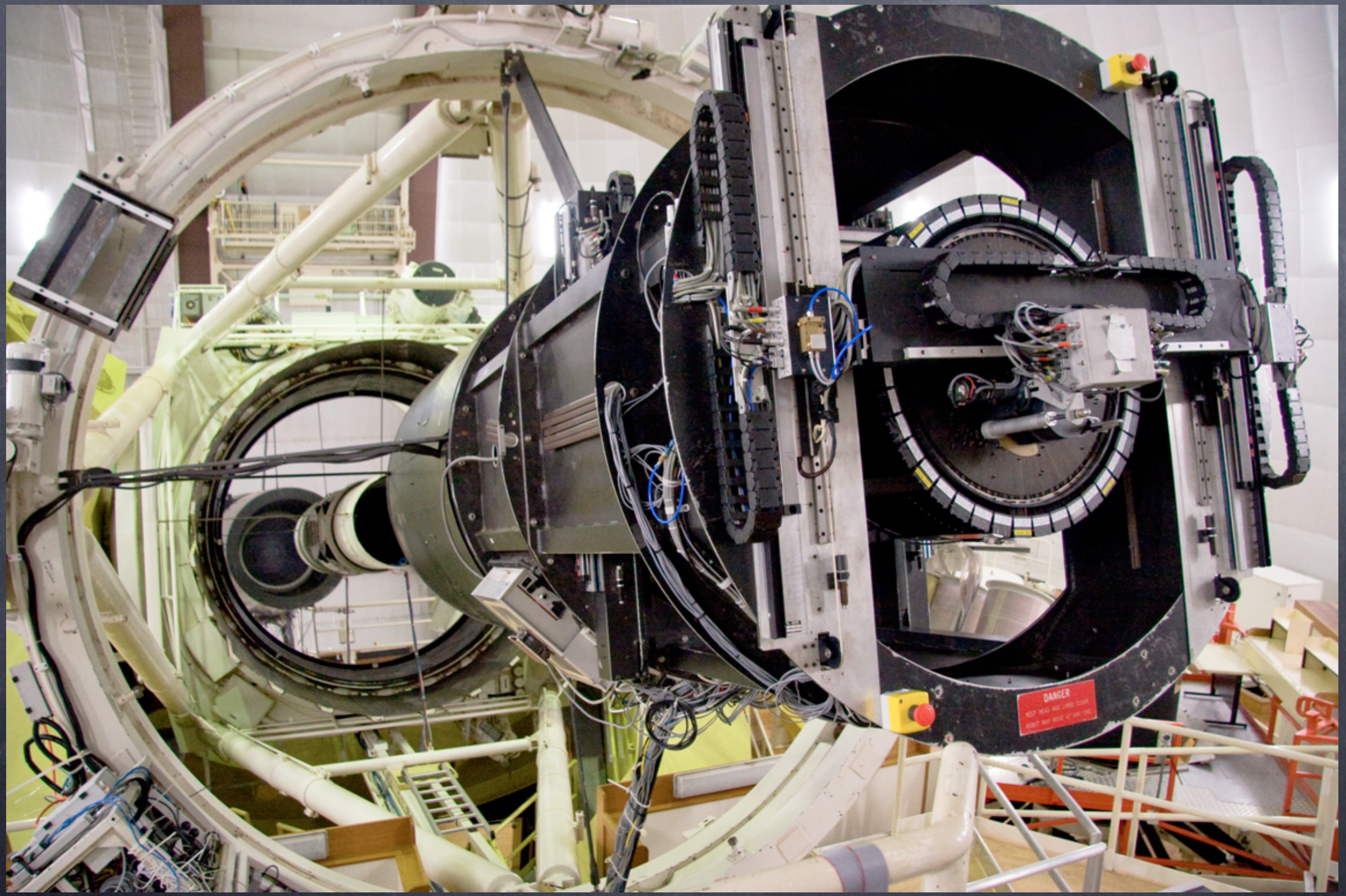
6dF Galaxy Survey

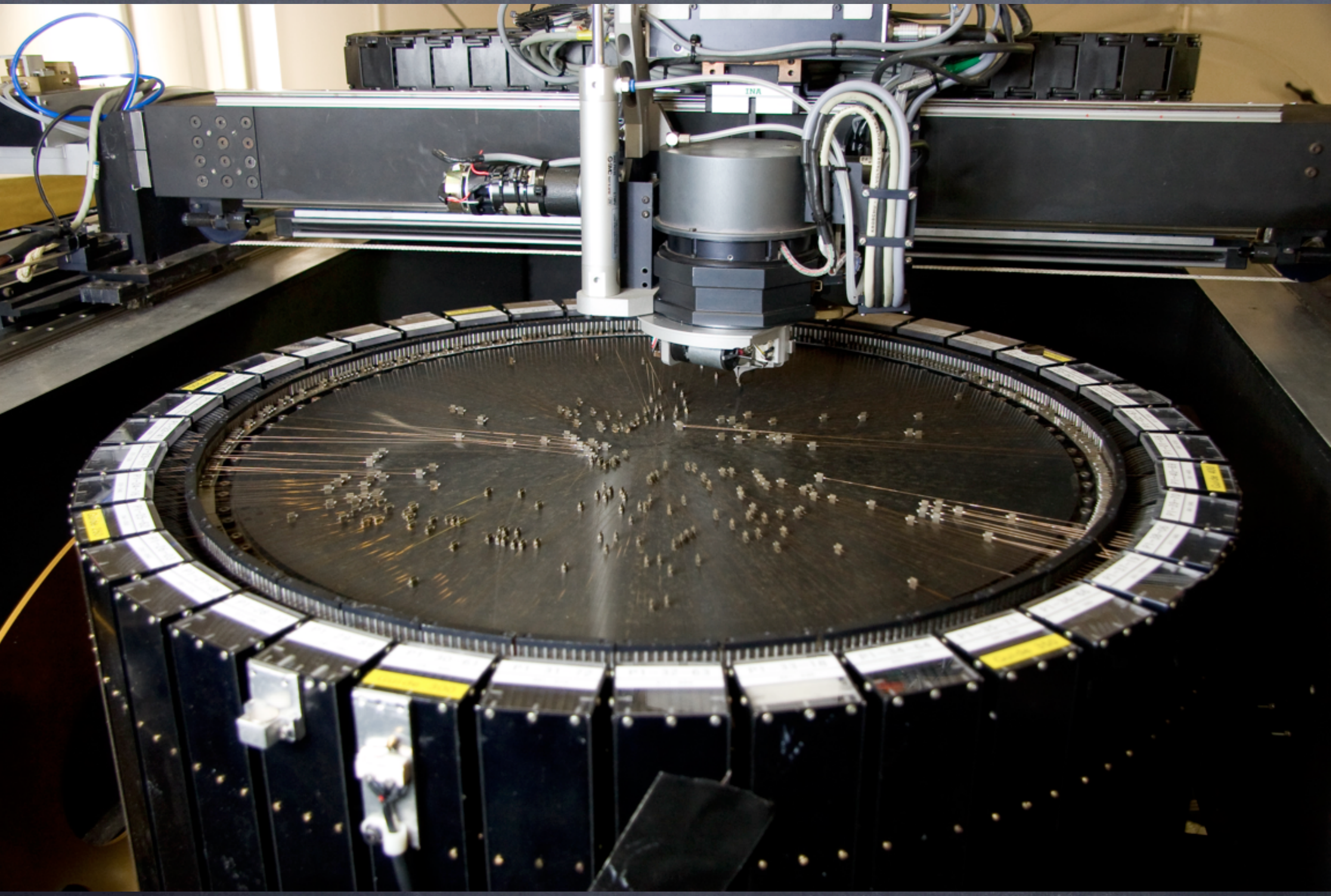


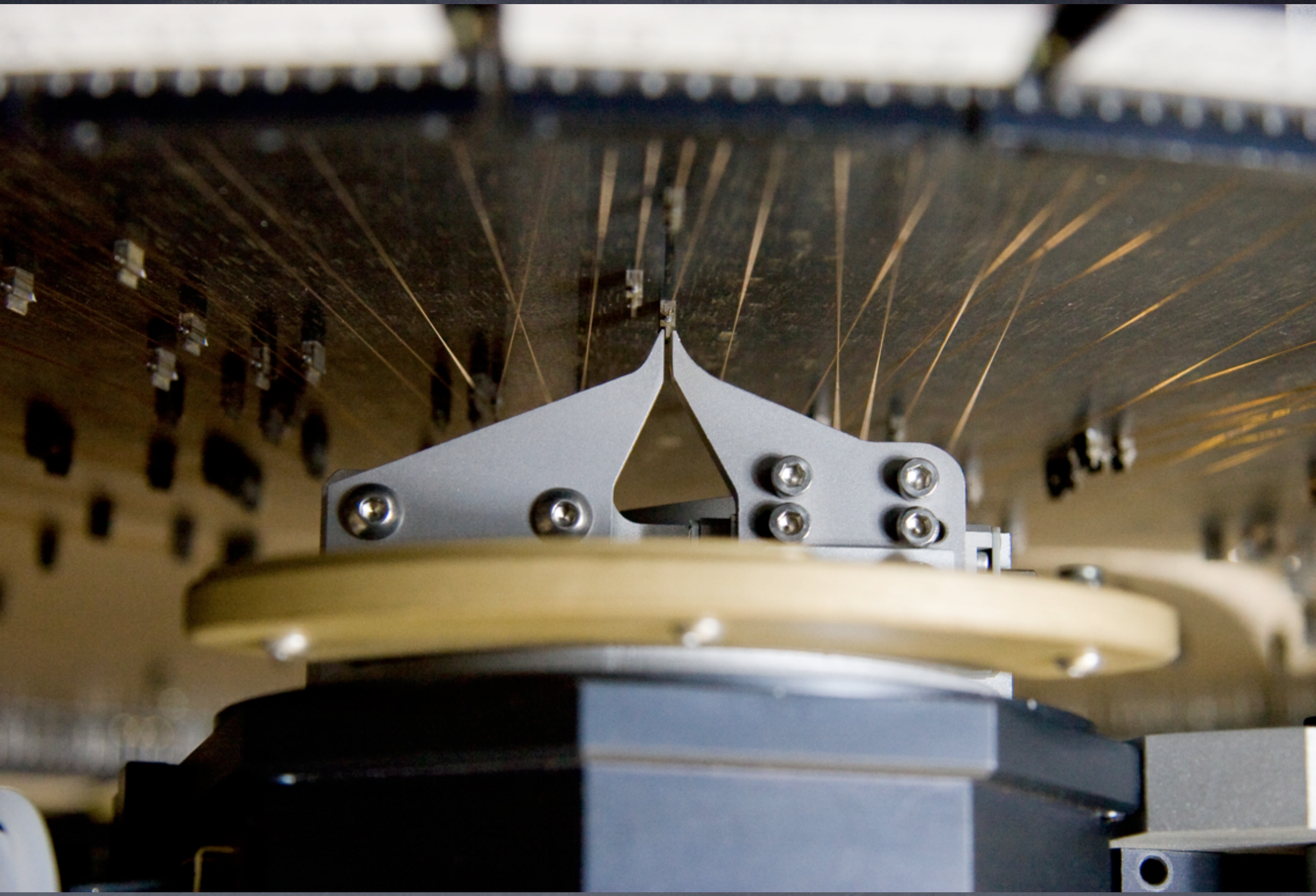
UK Schmidt telescope and 6dF robotic positioner

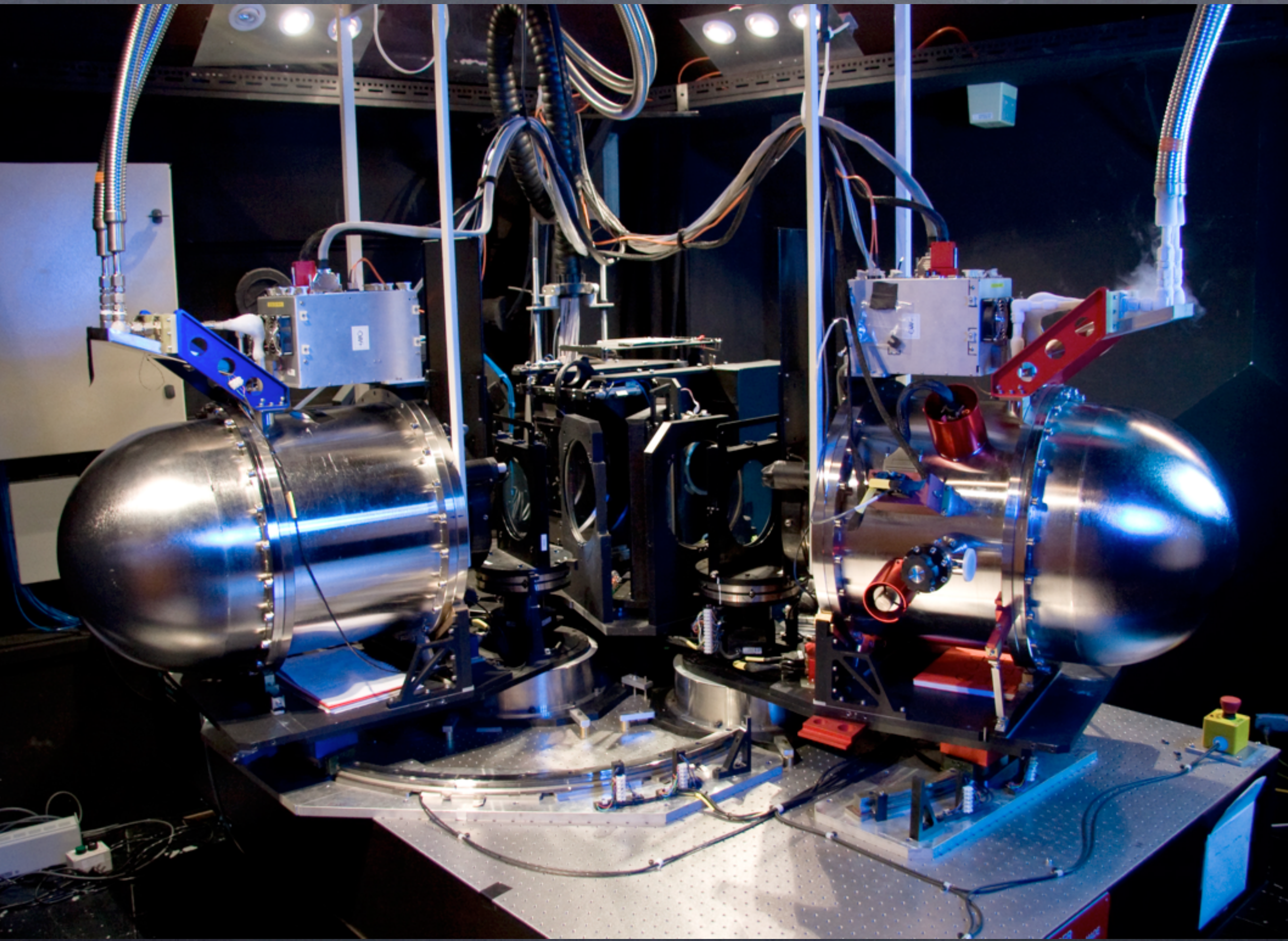
Upper Image:
Anglo-Australian Obervatory

Lower Image:
L. Campbell


DANGER


INA

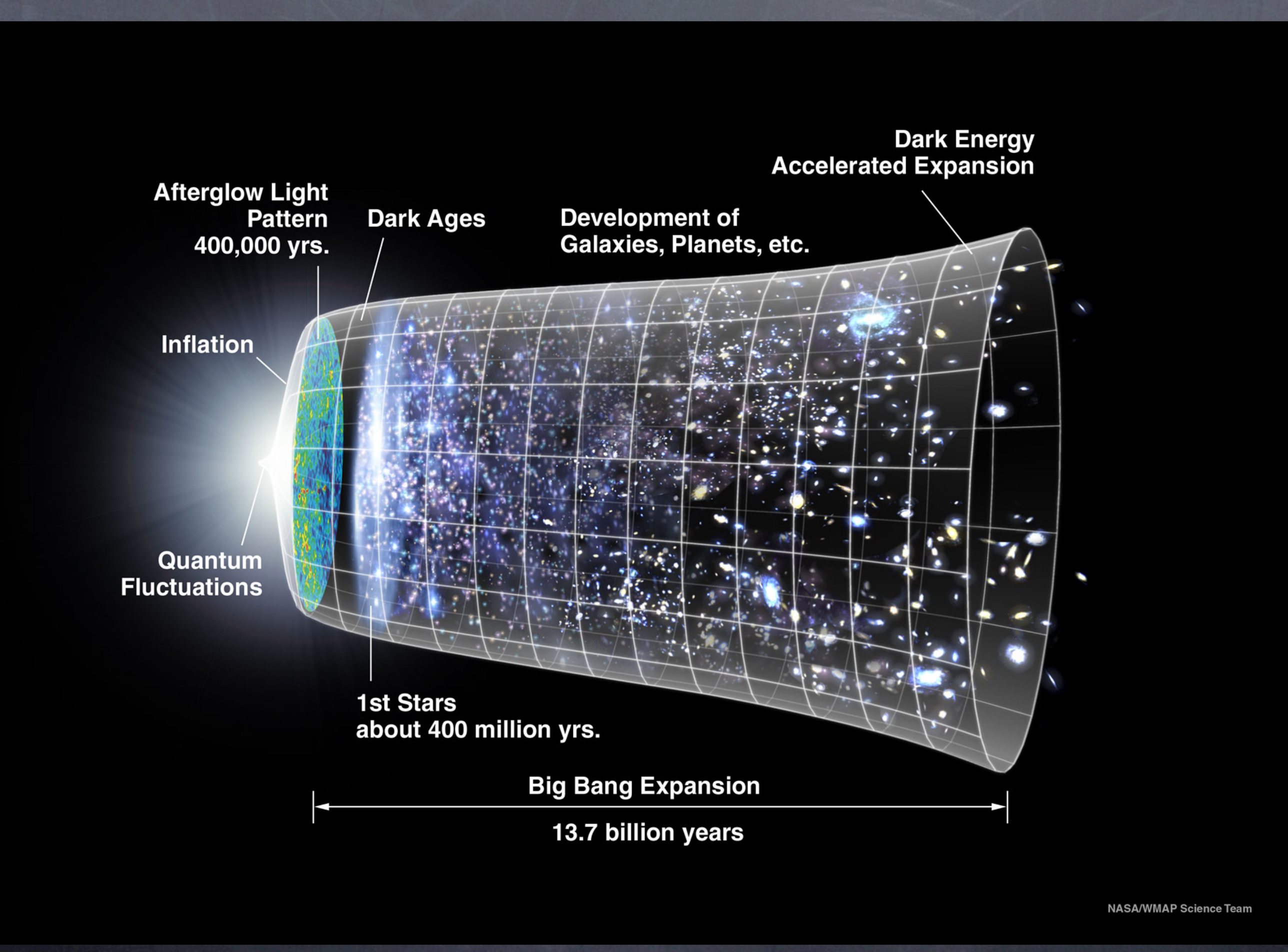


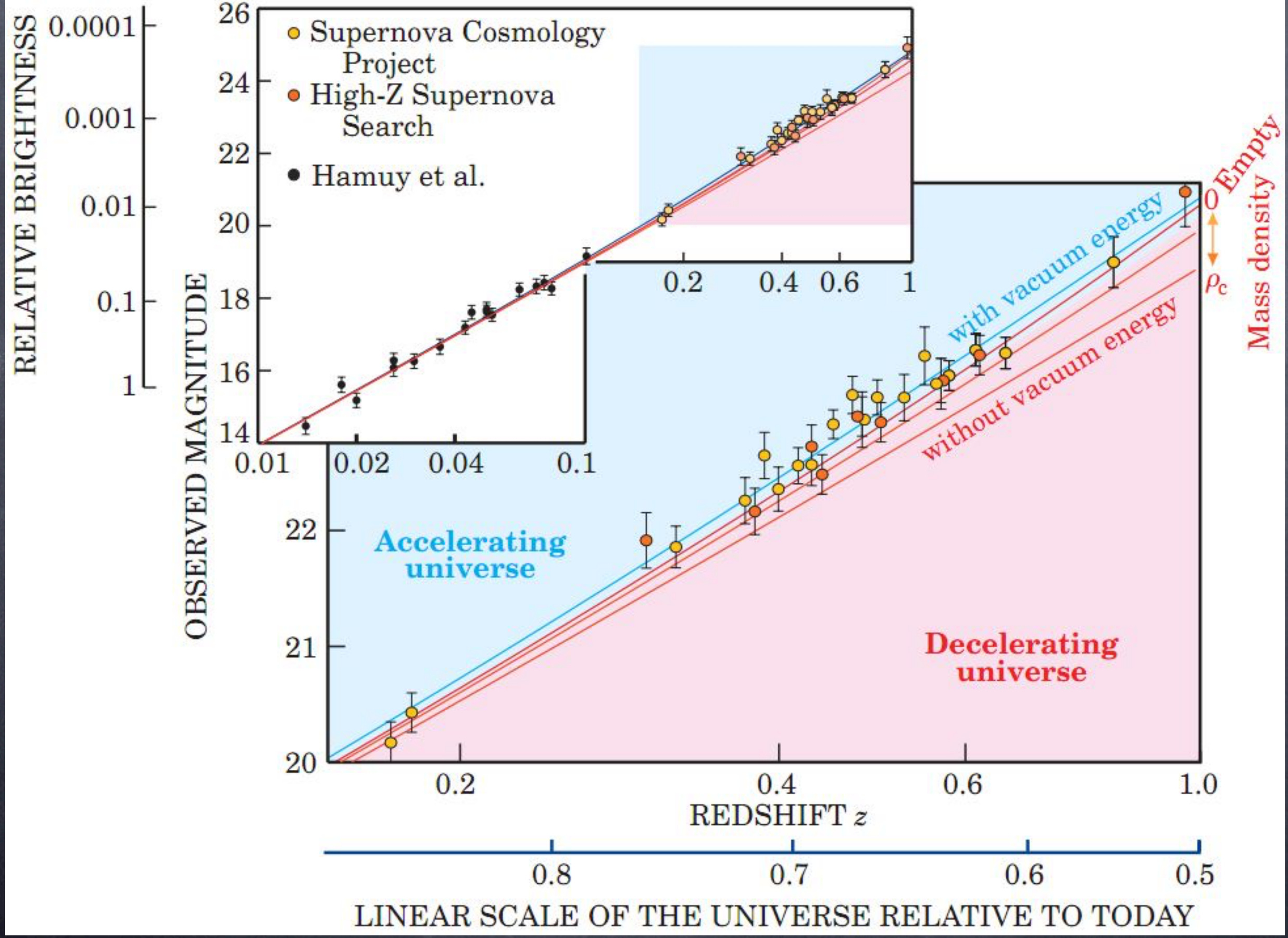


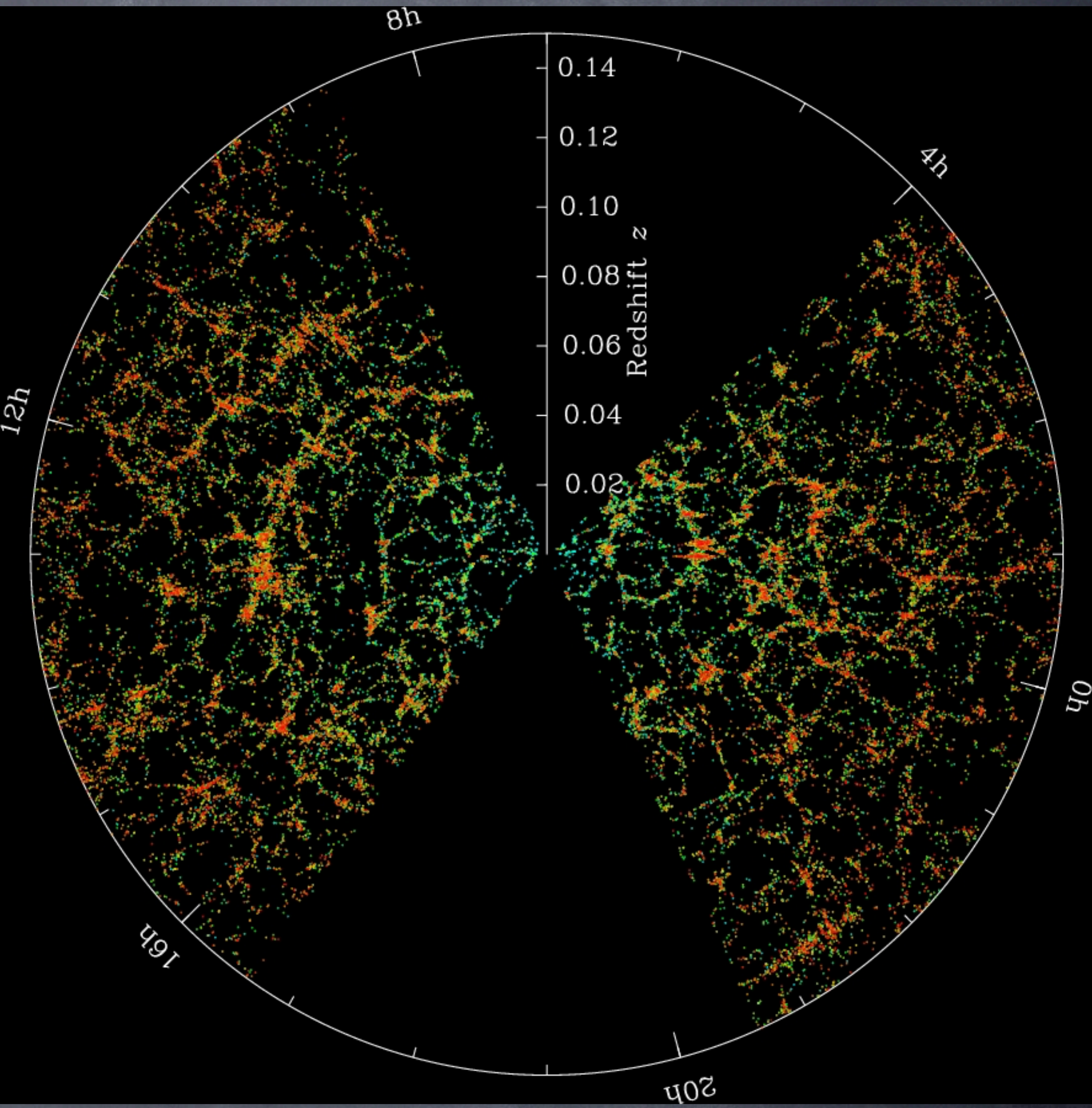
A jelen

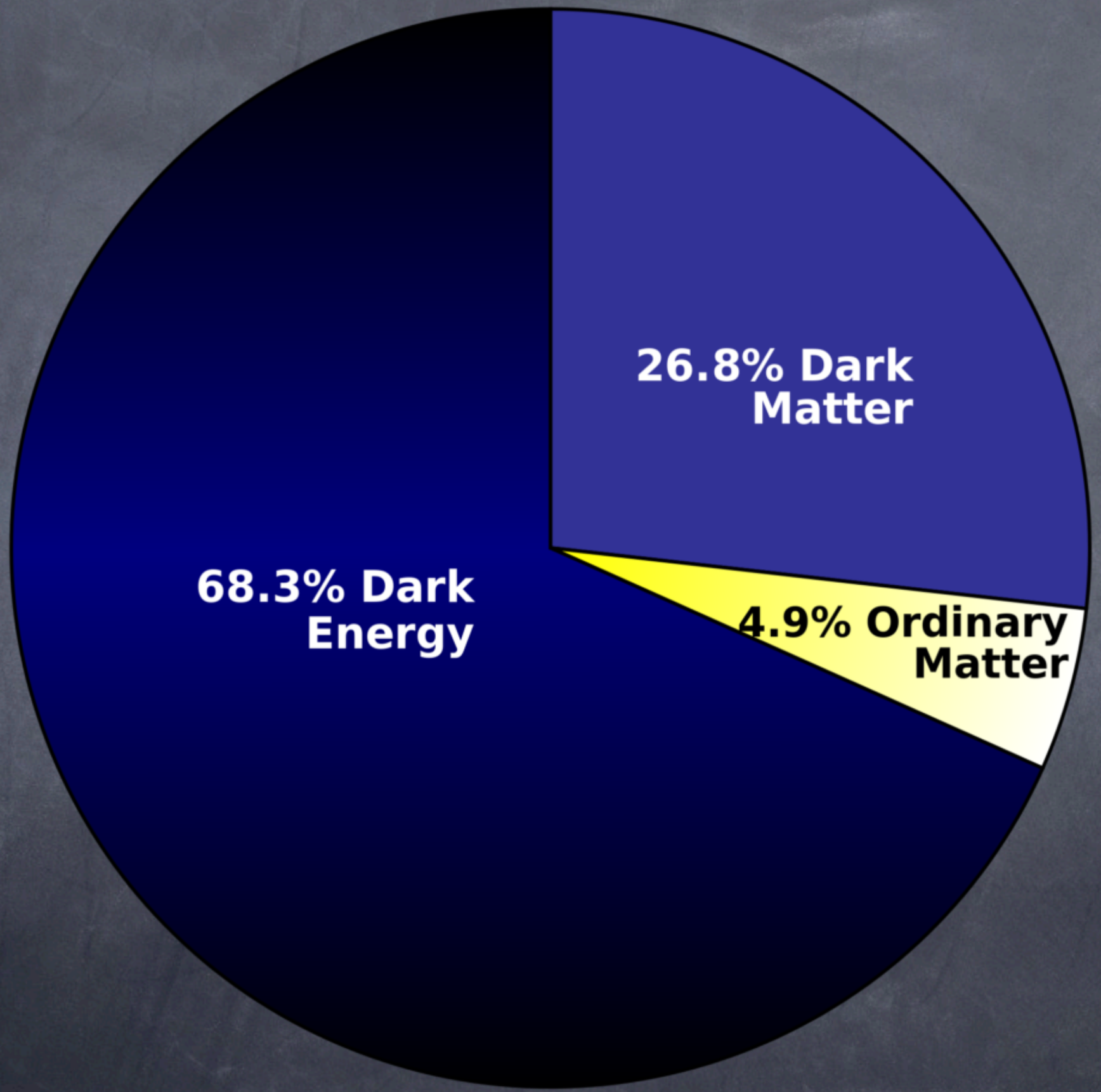
- Dark Energy Survey (DES) felmérés
- Hobby-Eberly Dark Energy Experiment (HETDEX) felmérés


THE DARK ENERGY SURVEY
ESPAÑOL
ENGLISH
THE DES PROJECT
NEWS AND RESULTS
DATA ACCESS
MULTIMEDIA
EDUCATION
CONTACT US
SEARCH HERE
DES
Exploring 14 billion years of cosmic history

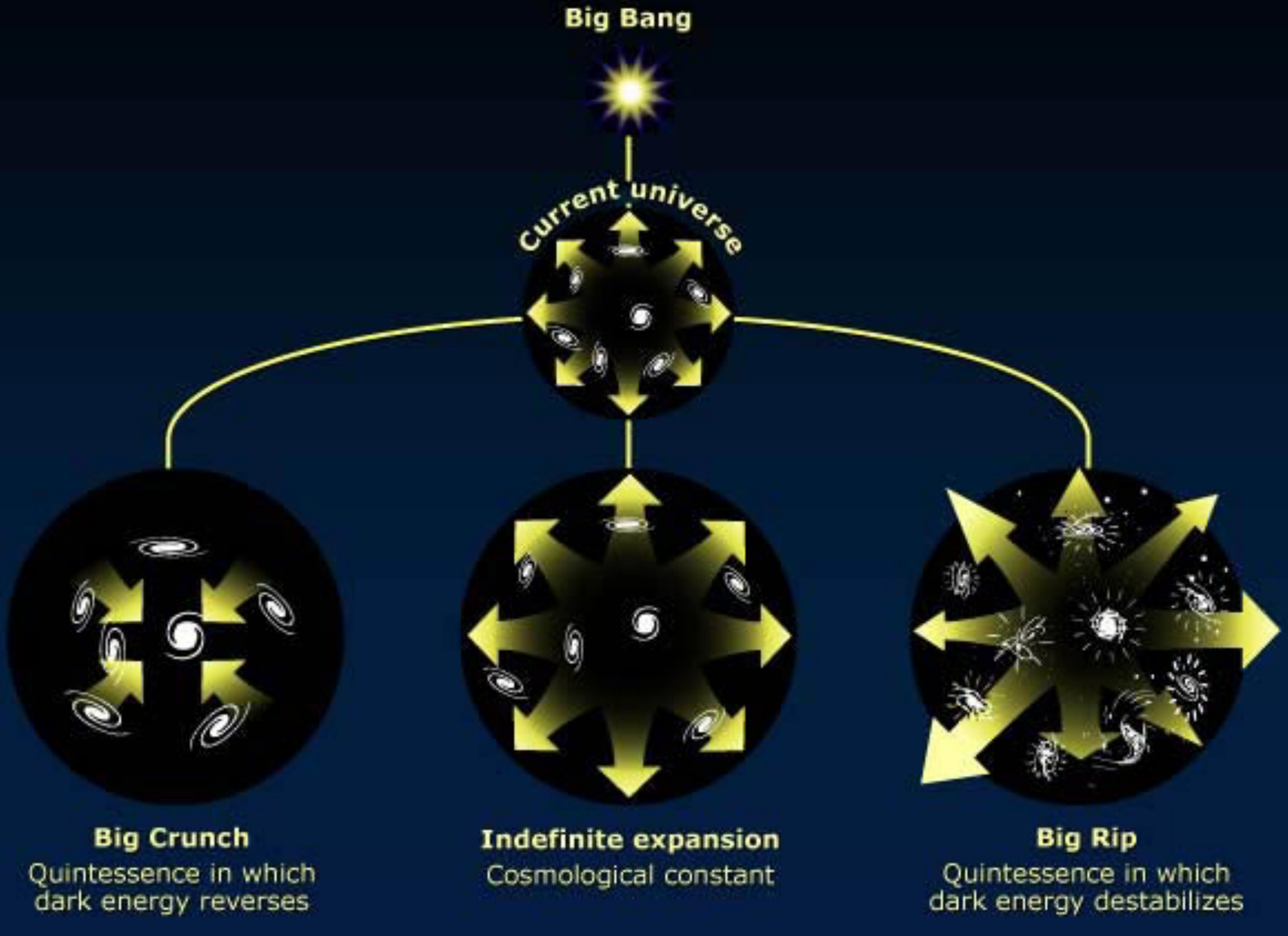

Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
NASA/WMAP Science Team

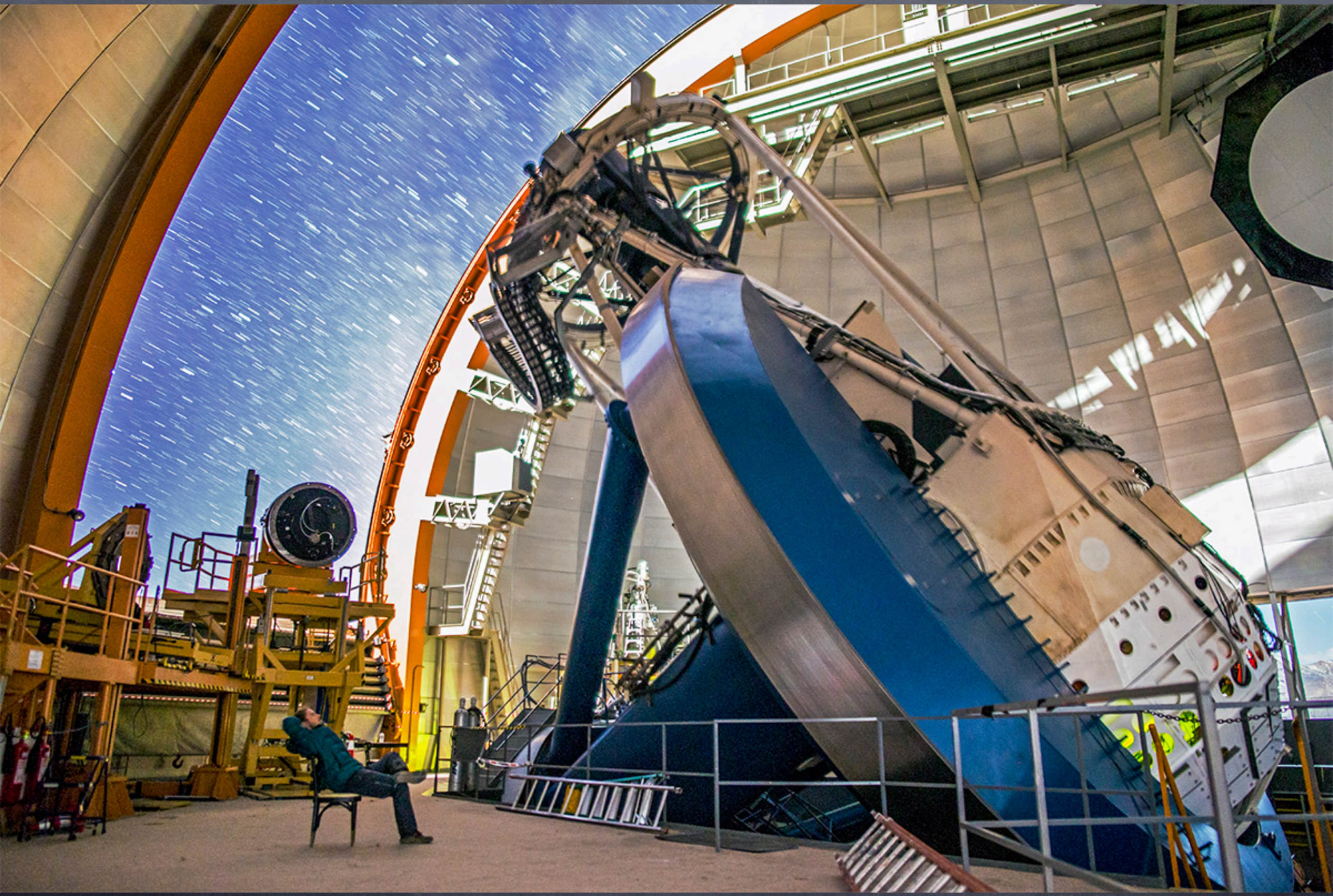

RELATIVE BRIGHTNESS
0.0001
0.001
0.01
0.1
1
OBSERVED MAGNITUDE
26
24
22
20
18
16
14
Supernova Cosmology Project
High-Z Supernova Search
Hamuy et al.
0.01
0.02
0.04
0.1
0.2
0.4
0.6
1
with vacuum energy
without vacuum energy
Accelerating universe
Decelerating universe
0 Empty
ρ_c
Mass density
22
21
20
0.2
0.4
0.6
1.0
REDSHIFT z
0.8
0.7
0.6
0.5
LINEAR SCALE OF THE UNIVERSE RELATIVE TO TODAY

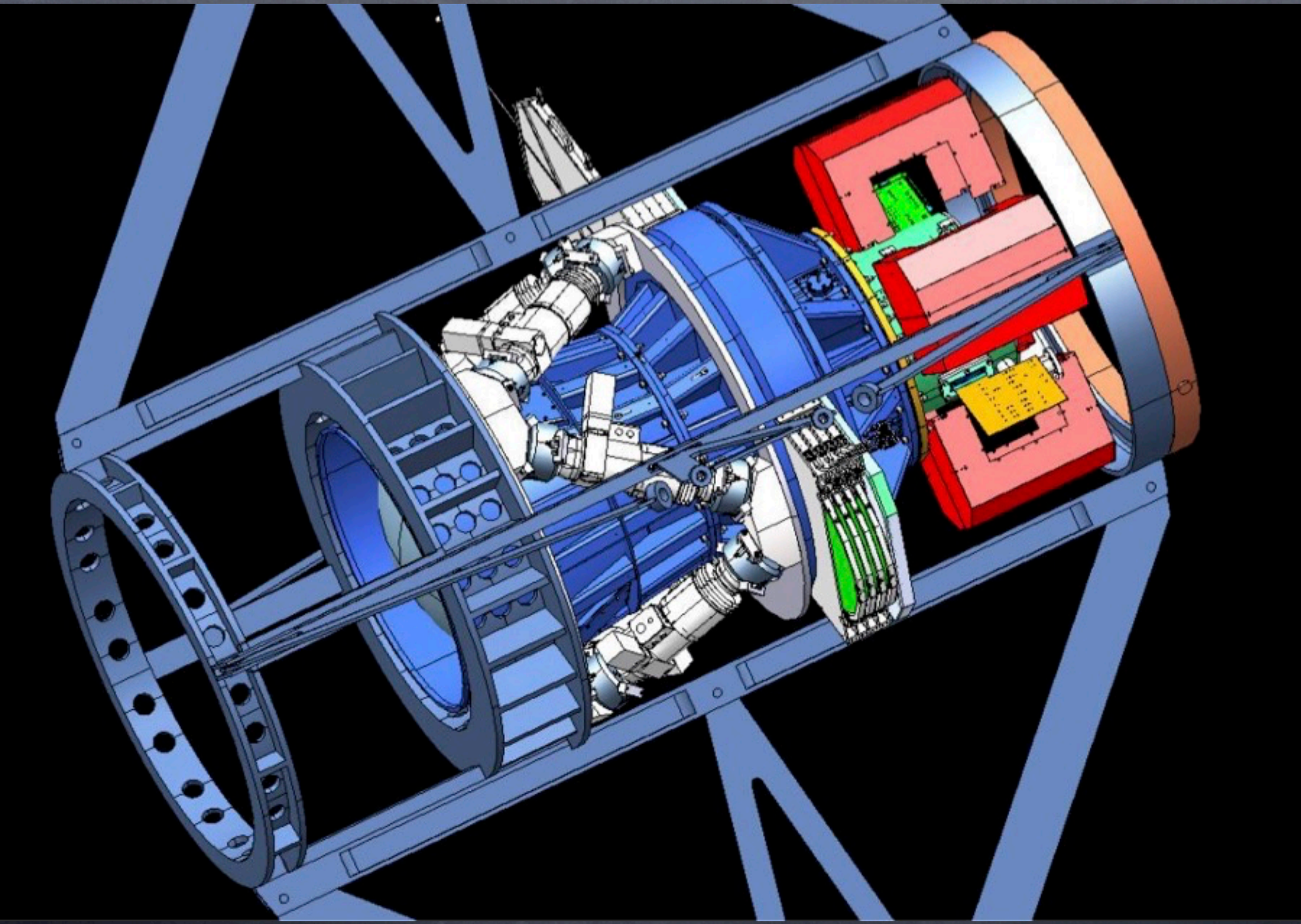

8h
4h
0h
20h
16h
12h
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Redshift z

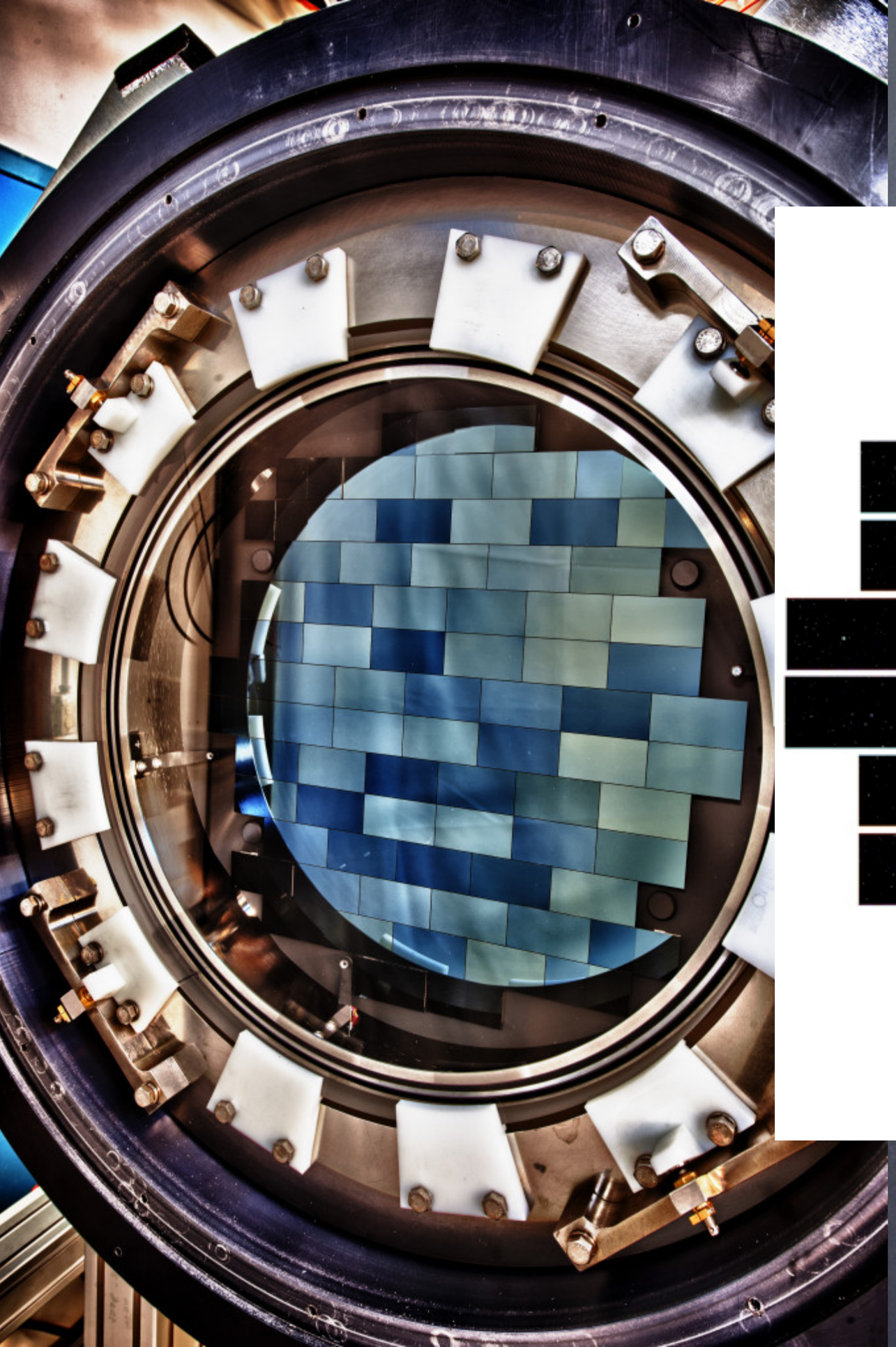

26.8% Dark Matter
4.9% Ordinary Matter
68.3% Dark Energy

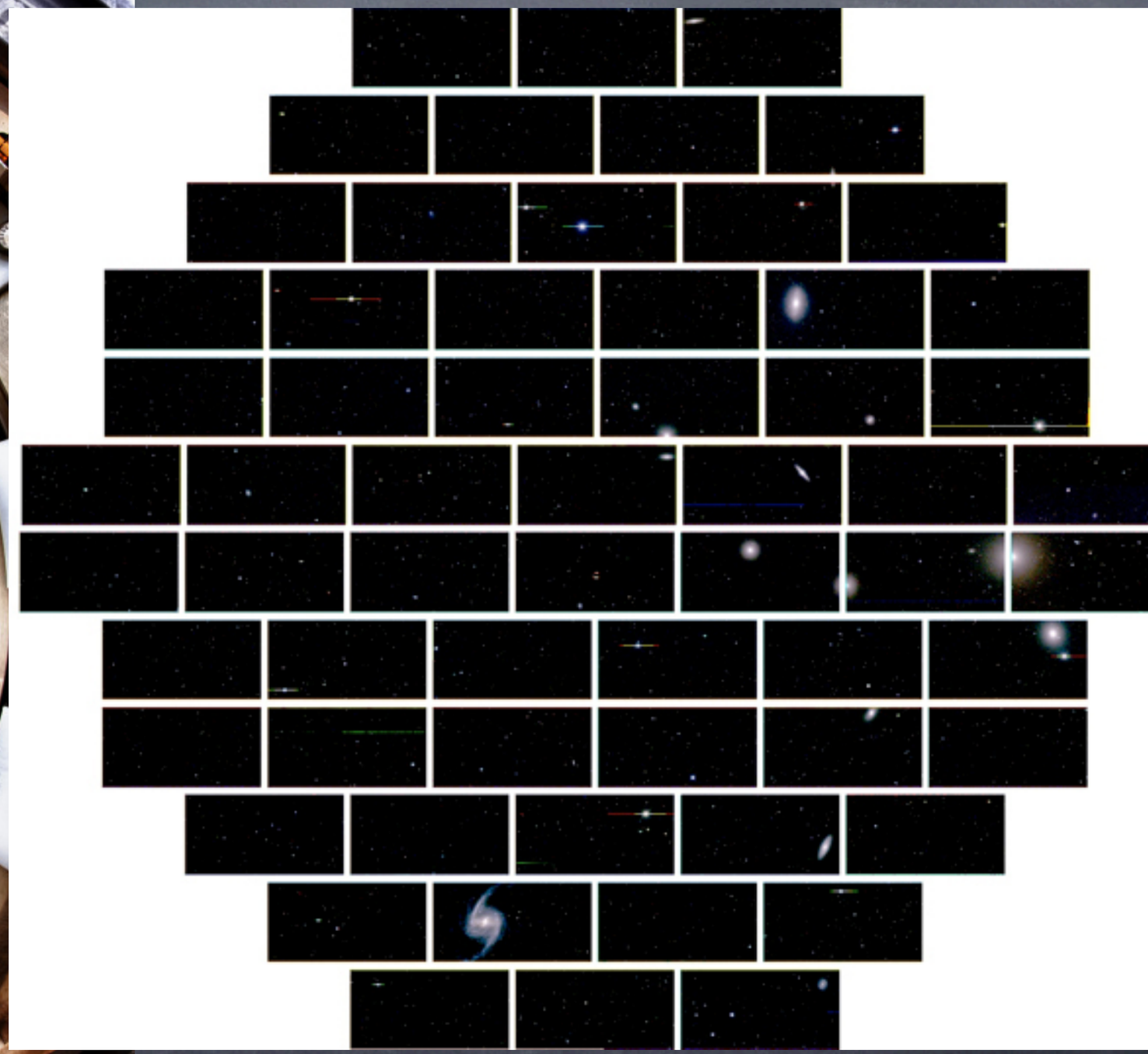
Future fates of the dark-energy universe

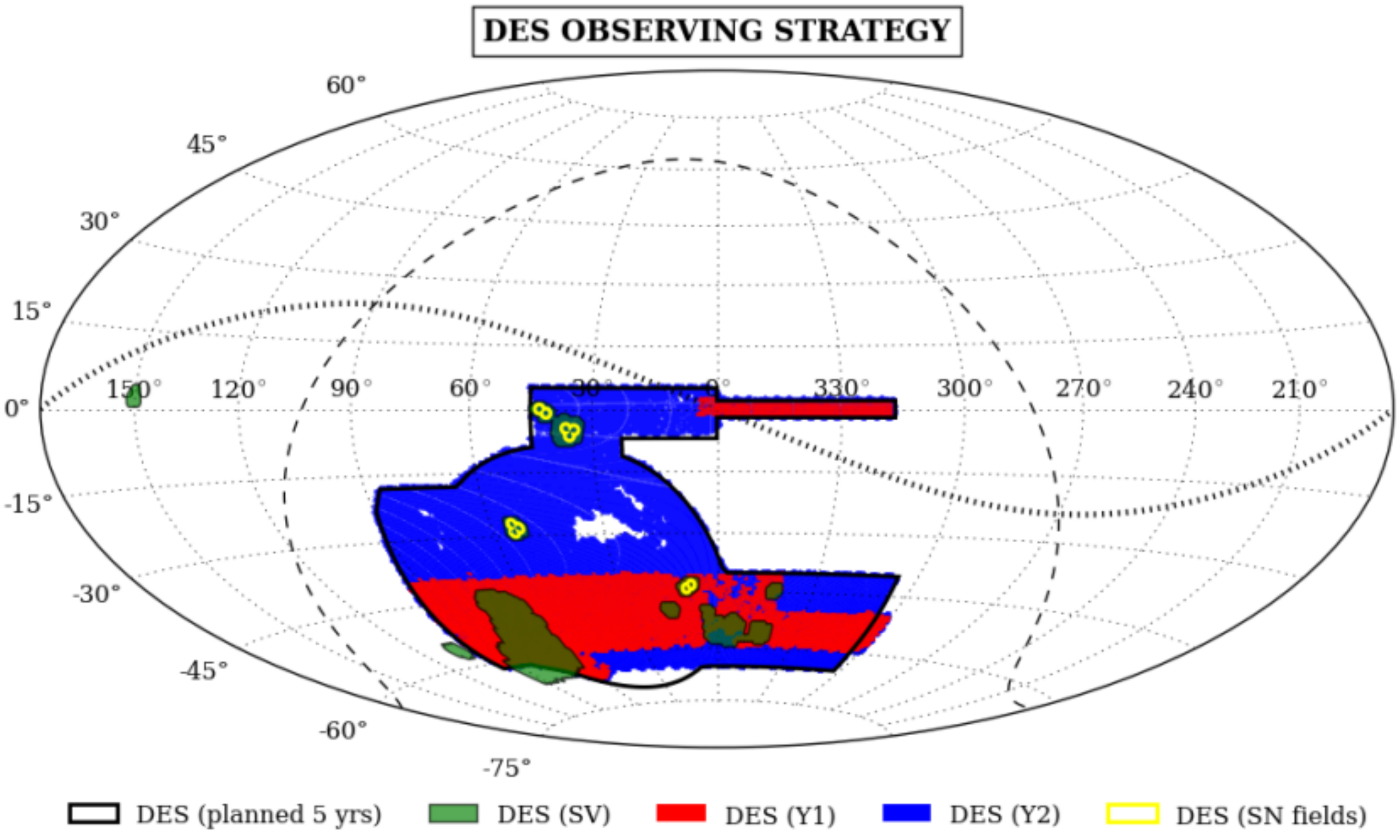




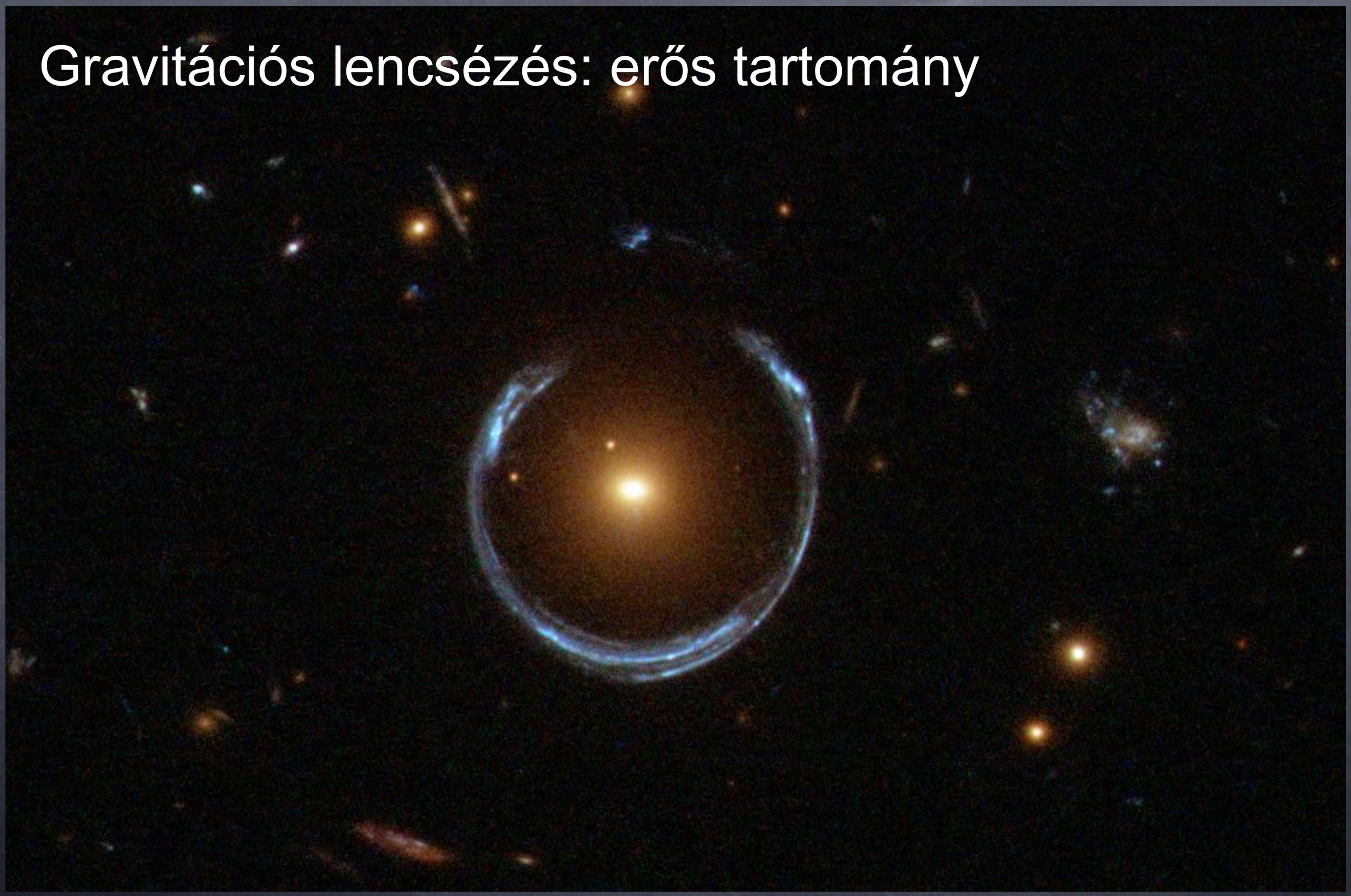




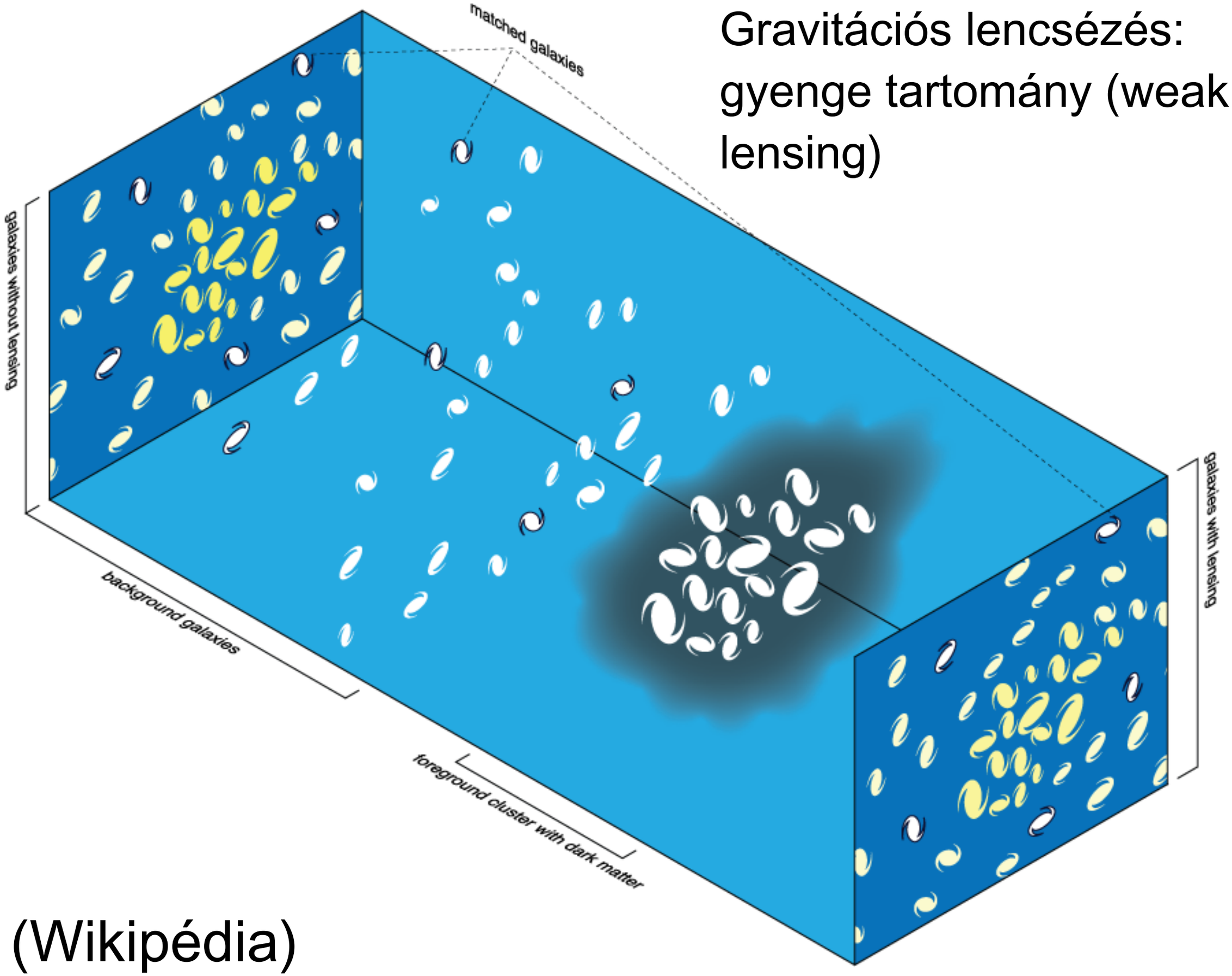



DES OBSERVING STRATEGY
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
150°
120°
90°
60°
30°
0°
330°
300°
270°
240°
210°
DES (planned 5 yrs)
DES (SV)
DES (Y1)
DES (Y2)
DES (SN fields)

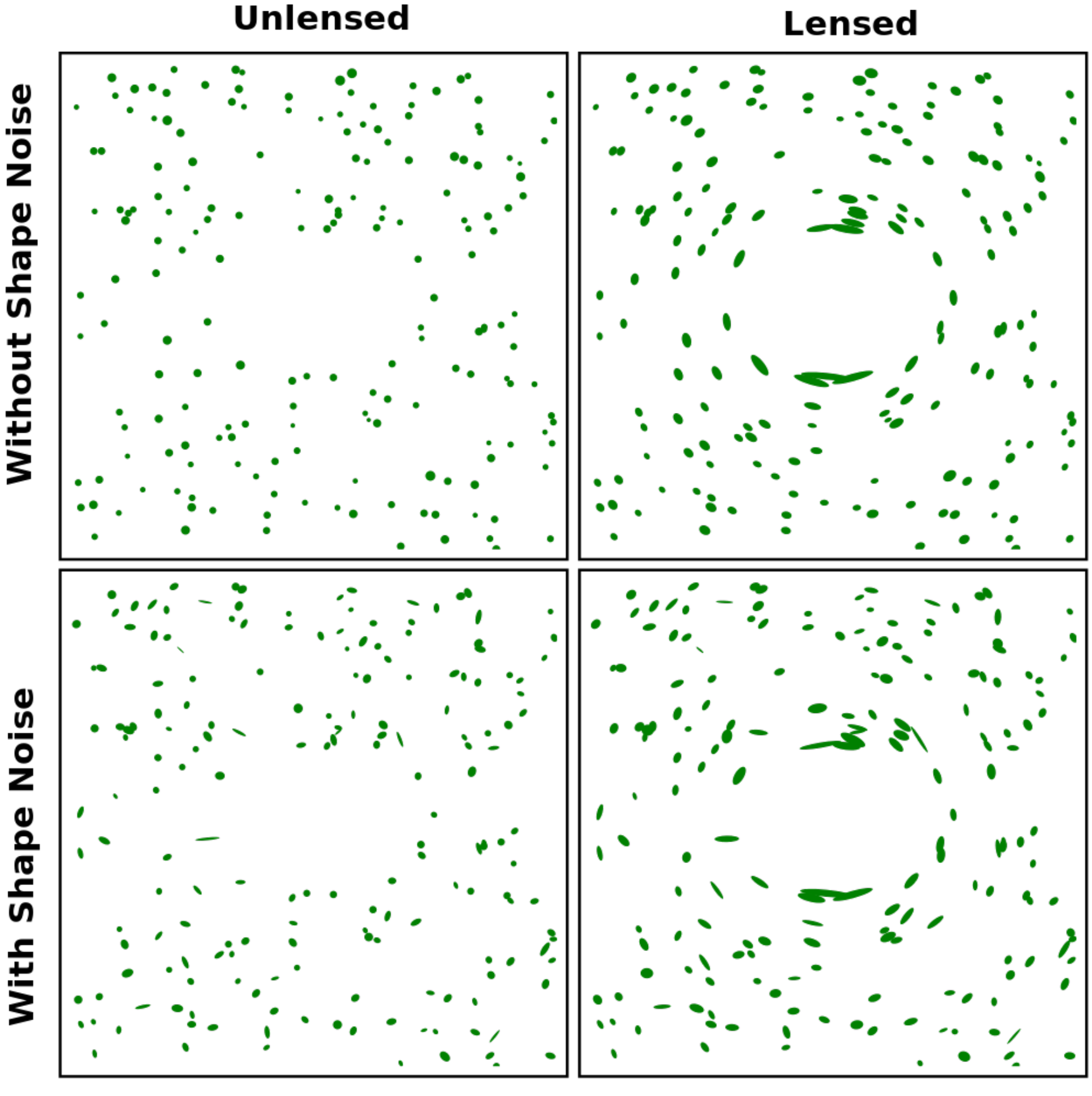
Gravitációs lencsézés: erős tartomány



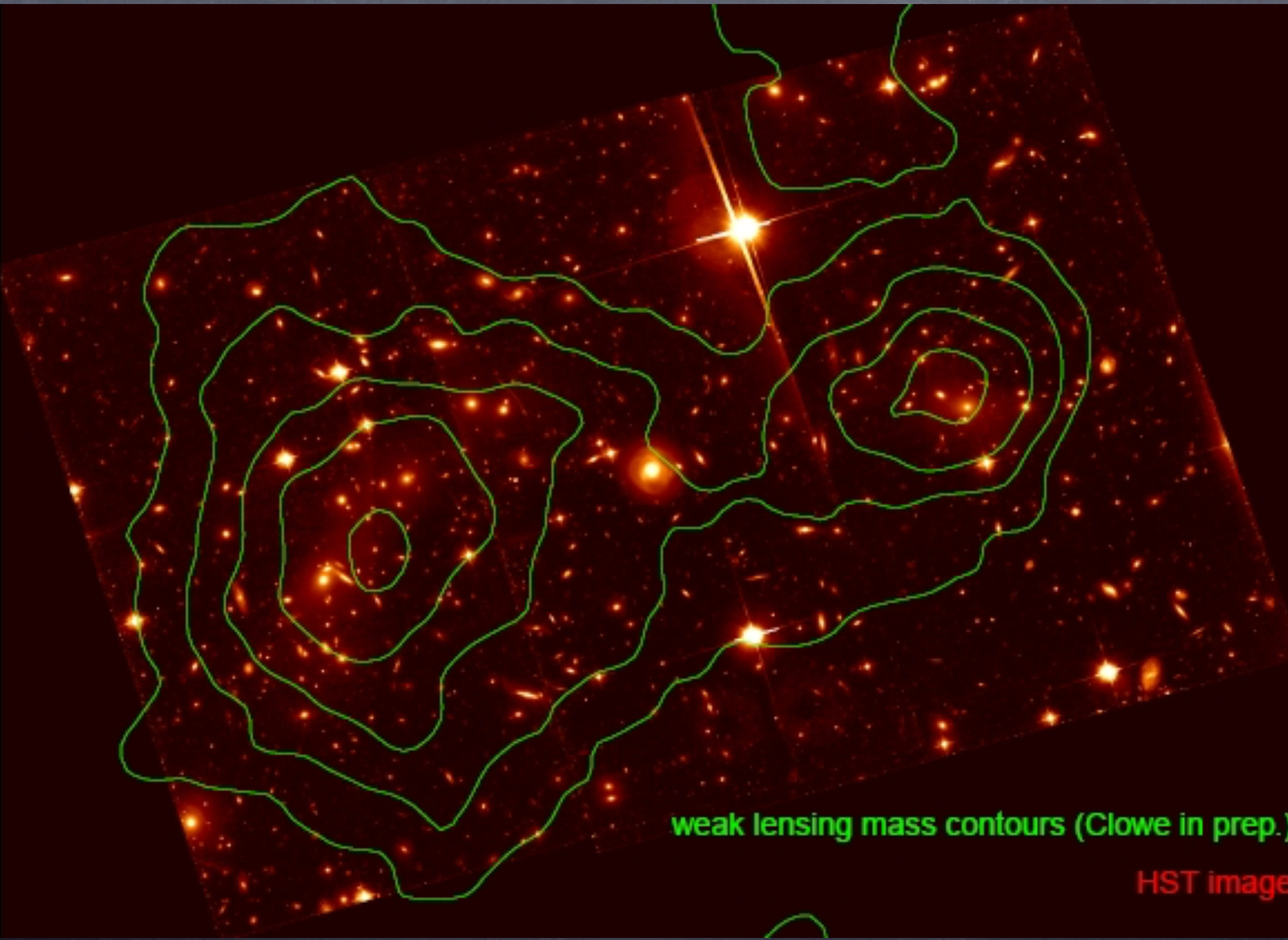
Gravitációs lencsézés: gyenge tartomány (weak lensing)



(Wikipédia)



(Wikipédia)


weak lensing mass contours (Clowe in prep.)
HST image

HETDEX

Hobby-Eberly Telescope Dark Energy Experiment

Illuminating the Darkness

News & Updates

10 April 2017
Upgraded Telescope Ready to 'Unlock the Mysteries of the Universe'

5 November 2015
Upgraded Hobby-Eberly Telescope Sees First Light

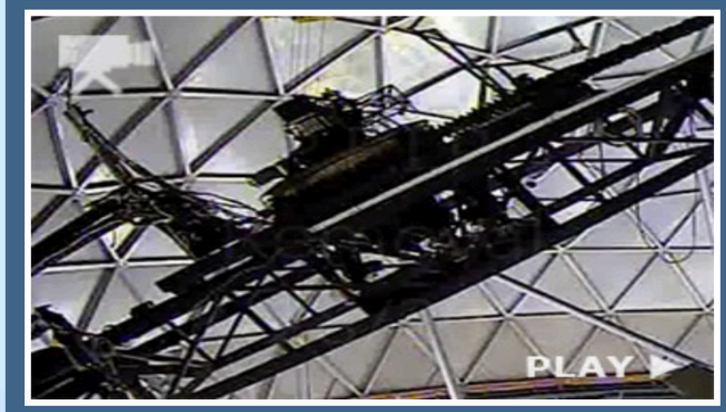
28 June 2015
Sophisticated set of mirrors will sharpen, widen HET's view of the sky

31 March 2015
Engineers install, test cryogenic system

17 March 2014
Tracking HET's Progress

"Dark energy is not only terribly important for astronomy, it's the central problem for physics. It's been the bone in our throat for a long

Video



H.E.T. PFIP Removal - Play video

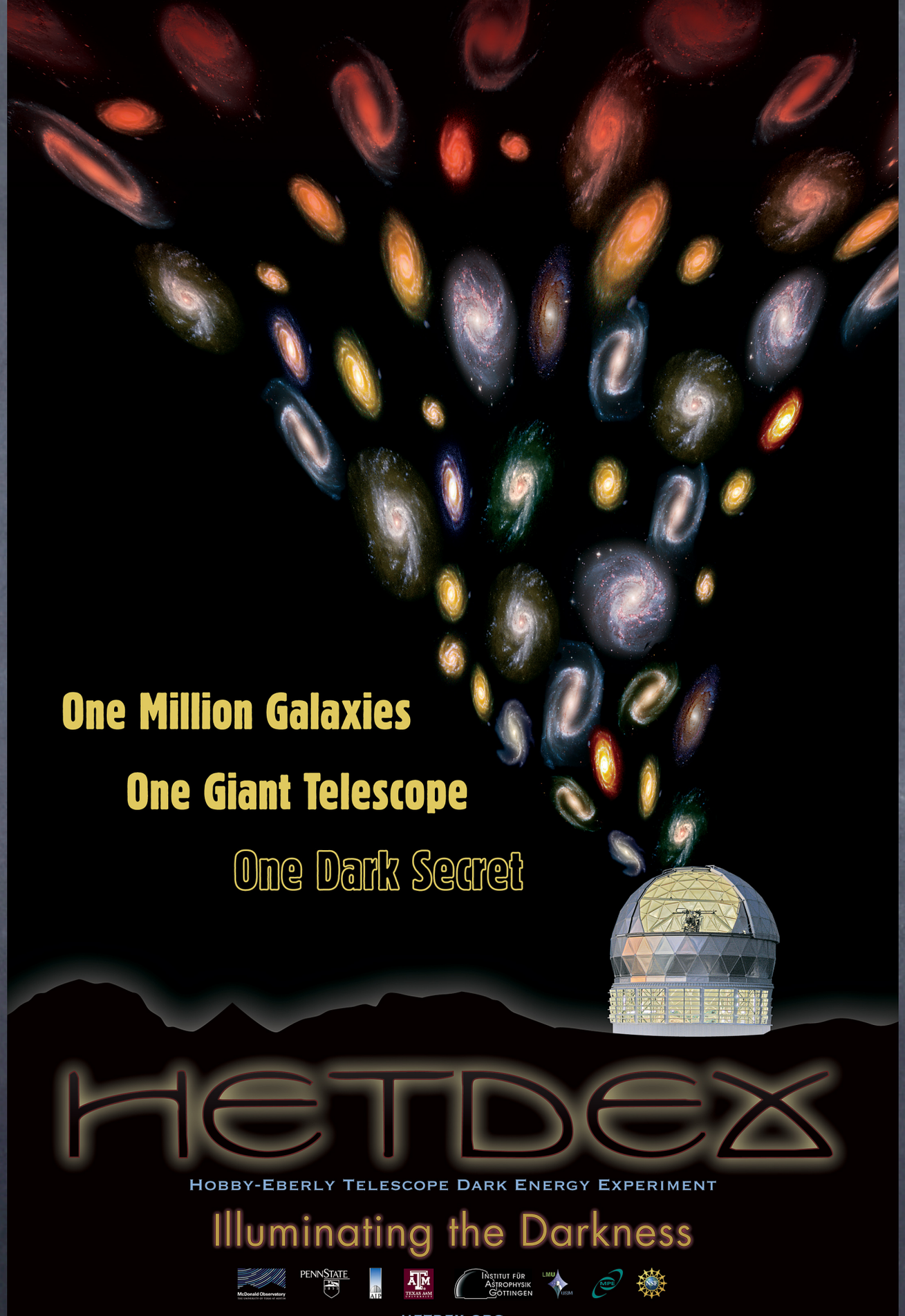
Glossary

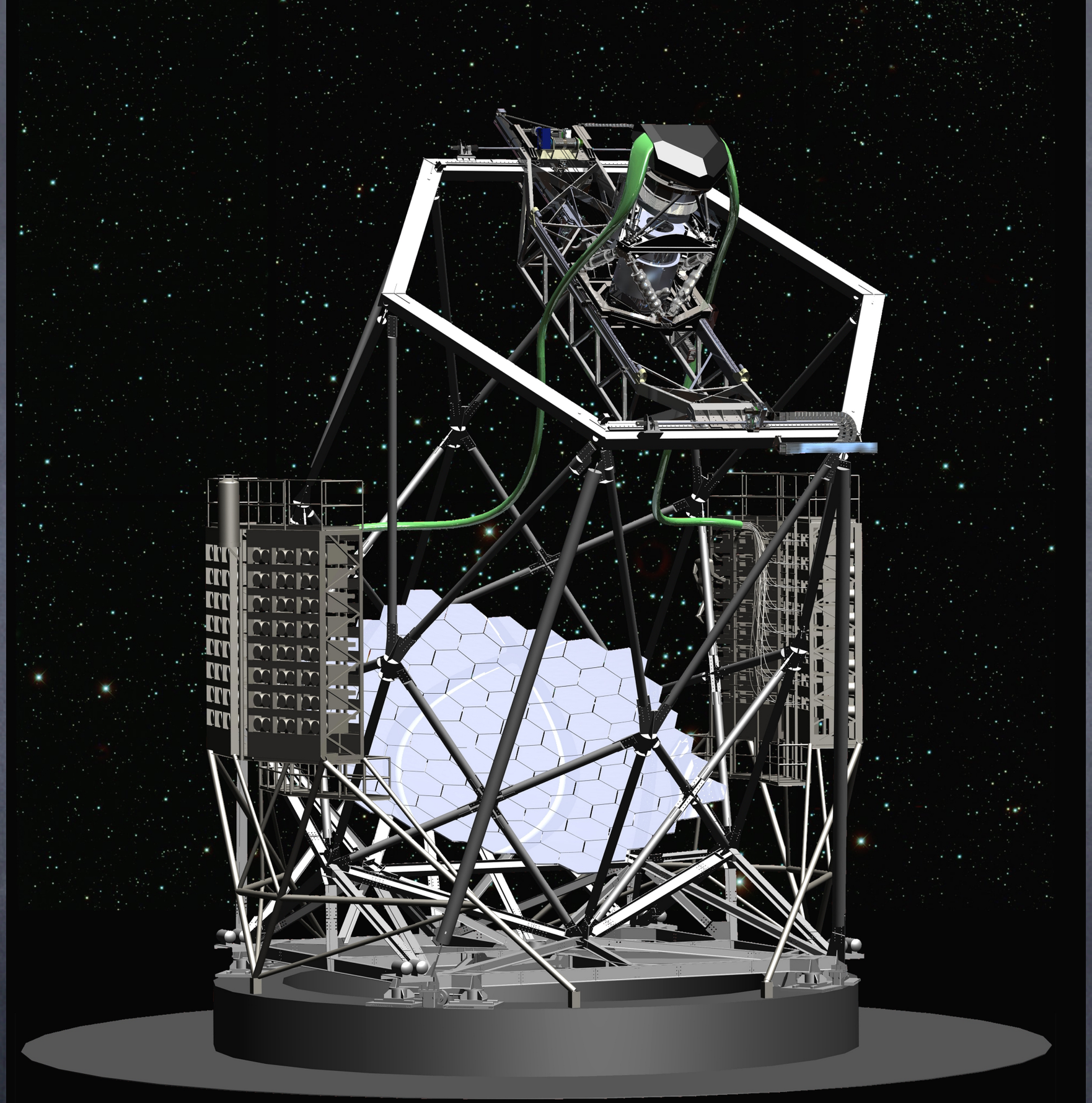
Gravity
One of the four fundamental forces in the universe, it is a property of matter that "warps" the space around it, causing an attraction

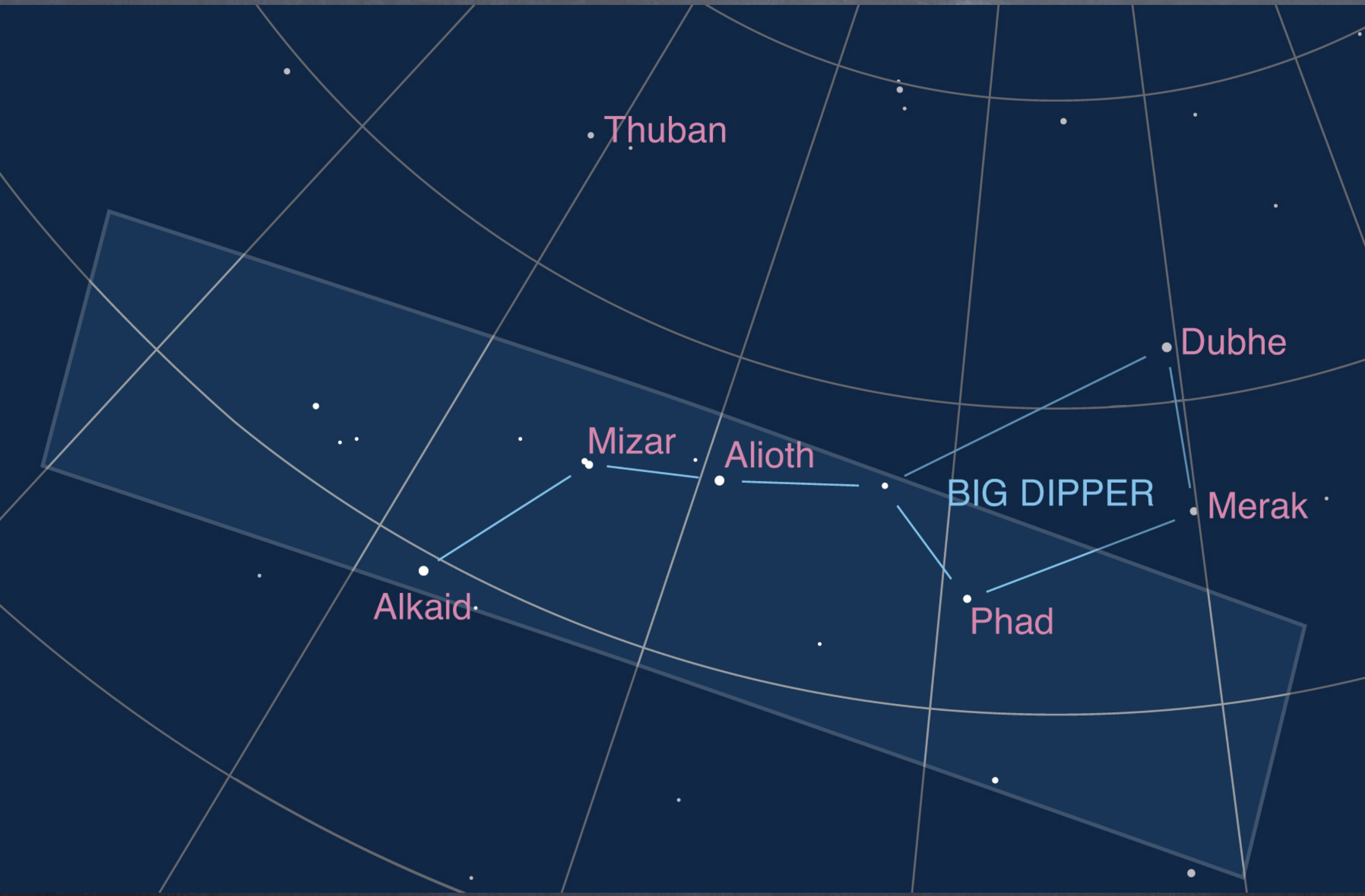
Media Gallery

Gary Hill & Phillip MacQueen with VIRUS-P

Find more images, video, and podcasts in


One Million Galaxies
One Giant Telescope
One Dark Secret
HETDEX
Hobby-Eberly Telescope Dark Energy Experiment
Illuminating the Darkness
McDonald Observatory
PennState
Institut für Astrophysik Göttingen
LMU
MPE
NSF
HETDEX.ORG




Thuban
Dubhe
Mizar
Alioth
BIG DIPPER
Merak
Alkaid
Phad

SCALING UP

30 arcminutes

22 arcminutes

4 arcminutes

A jövő

- Futó és újabb nagy felmérések
- Spektroszkópiai mellett fotometriai vöröseltolódással (kisebb pontosságú, de sokkal nagyobb mintákra válik lehetségessé)
- A kozmológia a spekulációk vad tudománya helyett valódi empirikus diszciplínává válik