Observational cosmology

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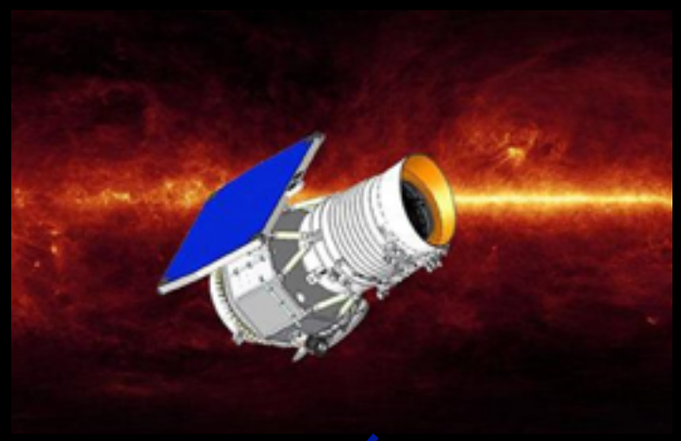
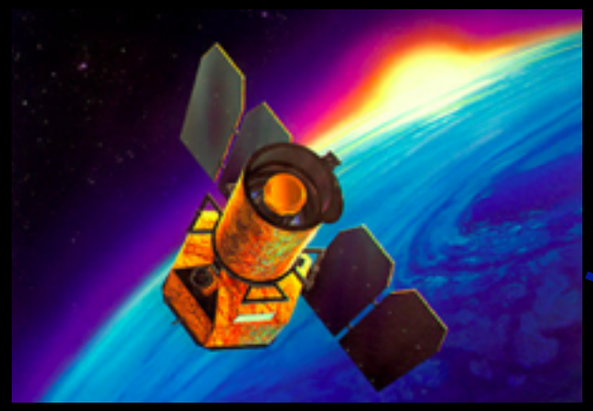
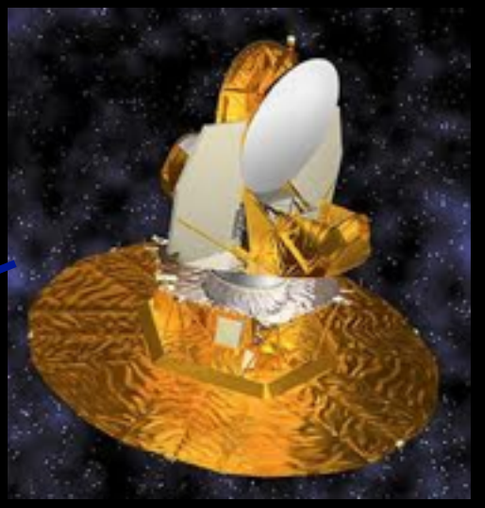
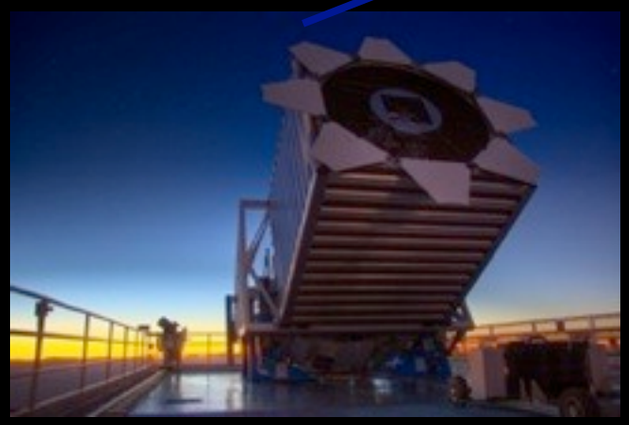
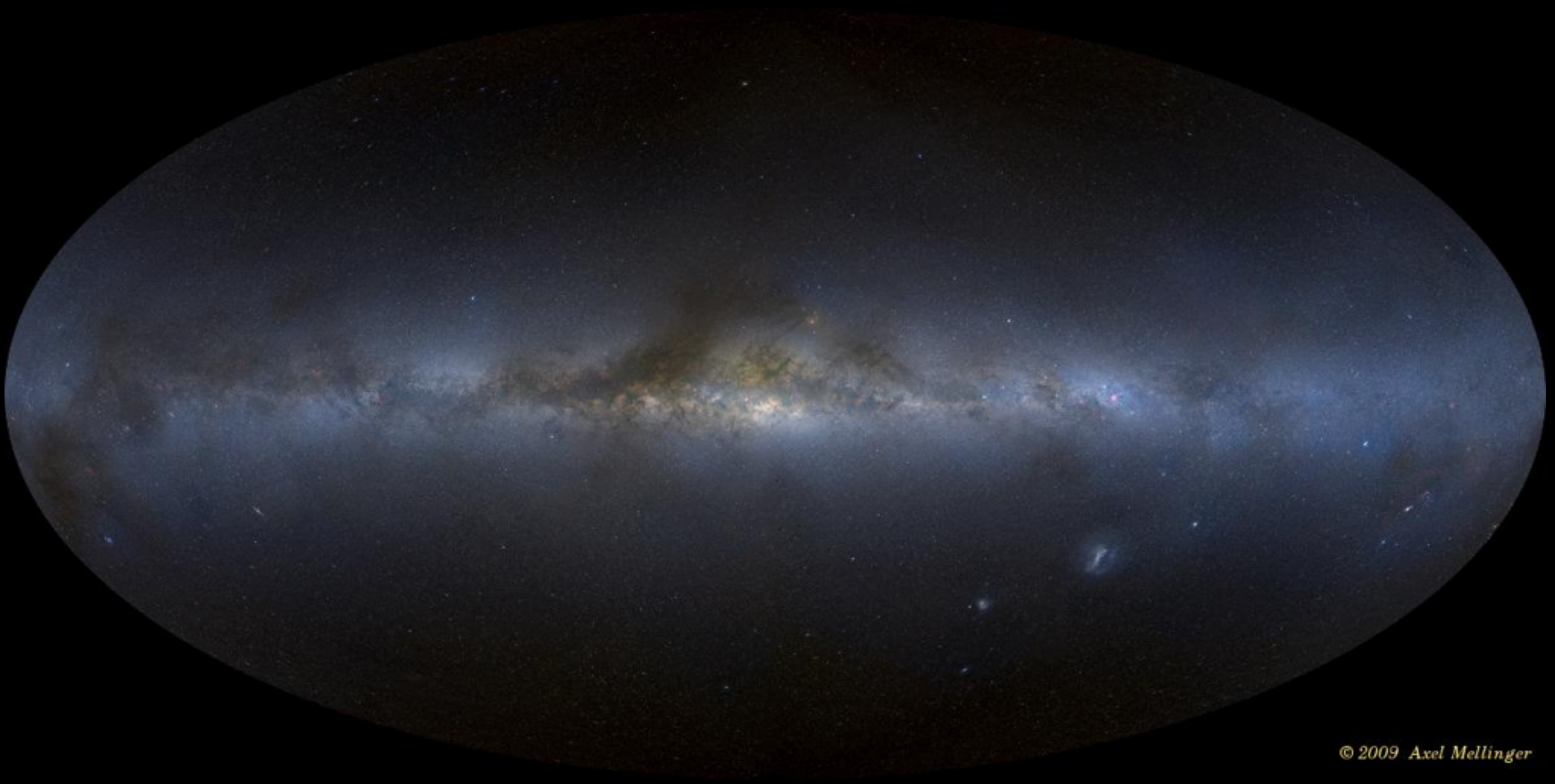


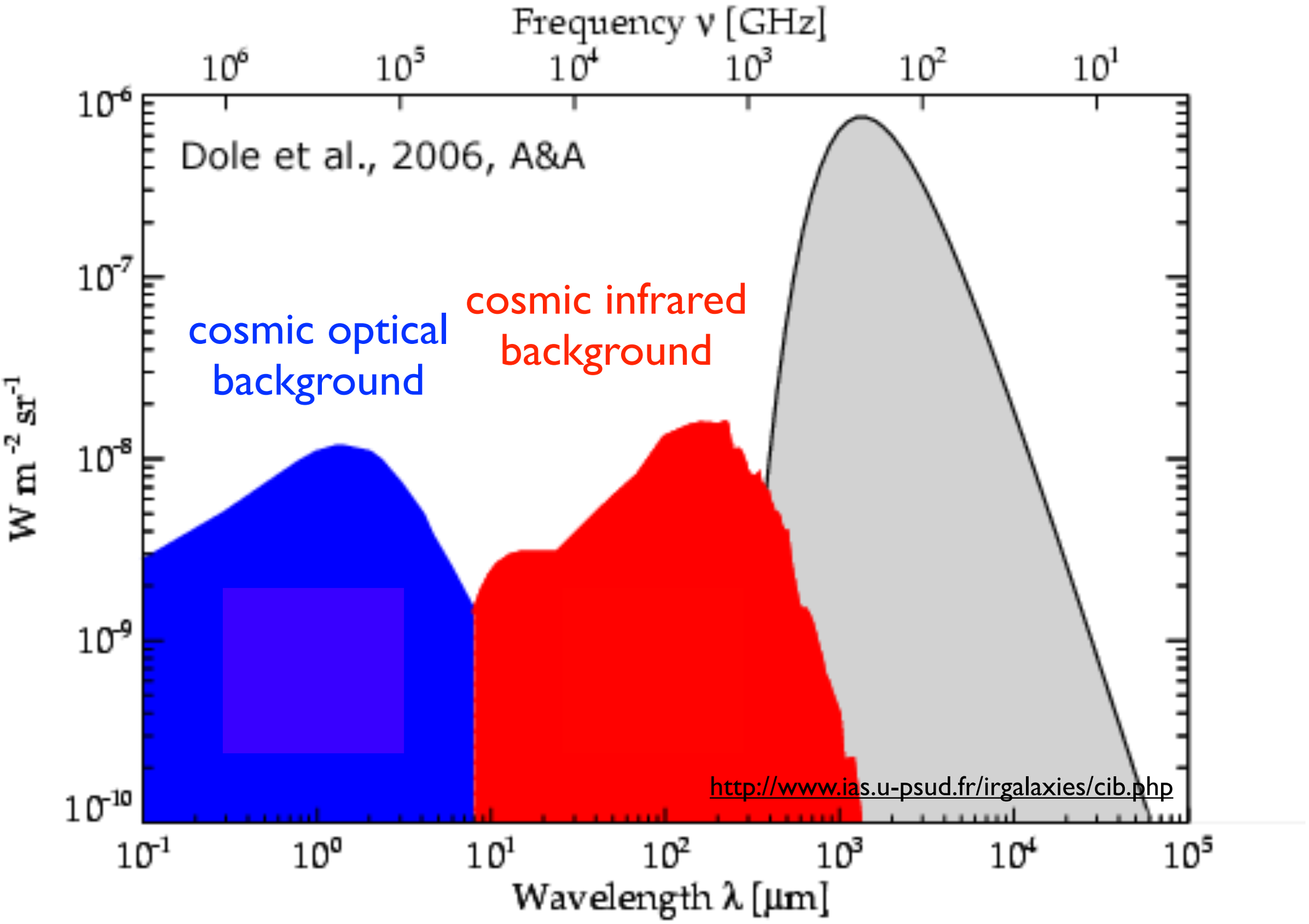


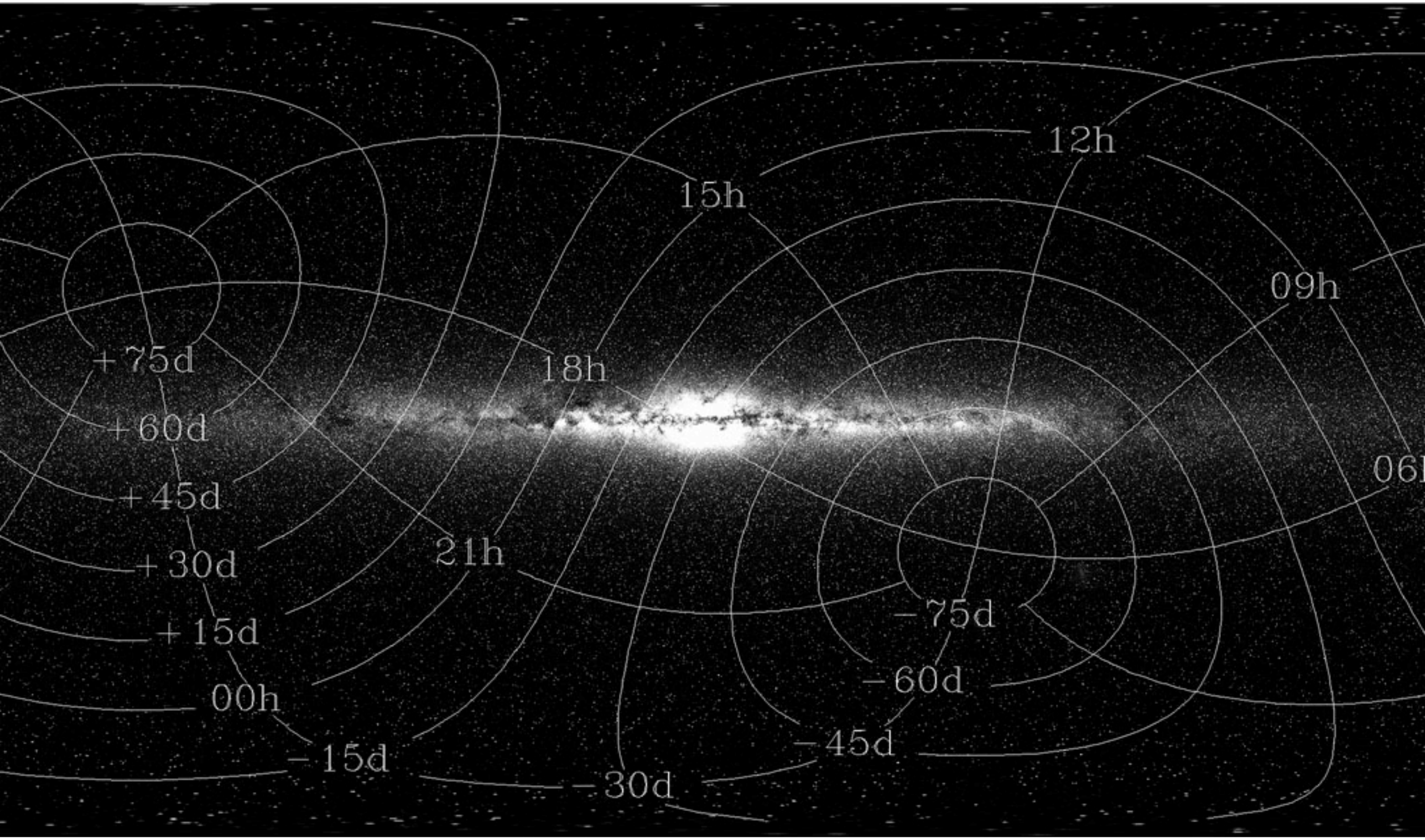


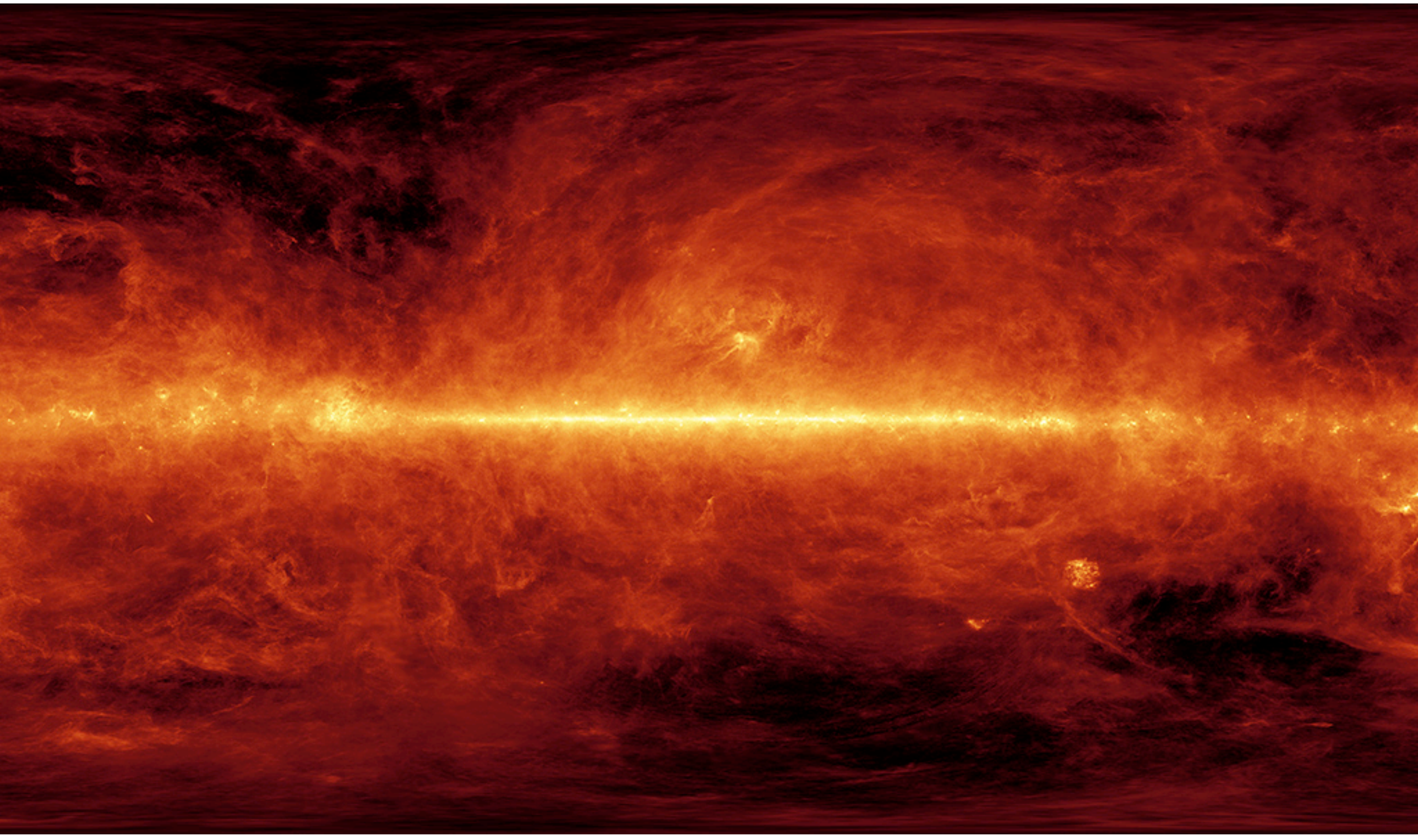



© 2009 Axel Mellinger

The spectrum of the sky

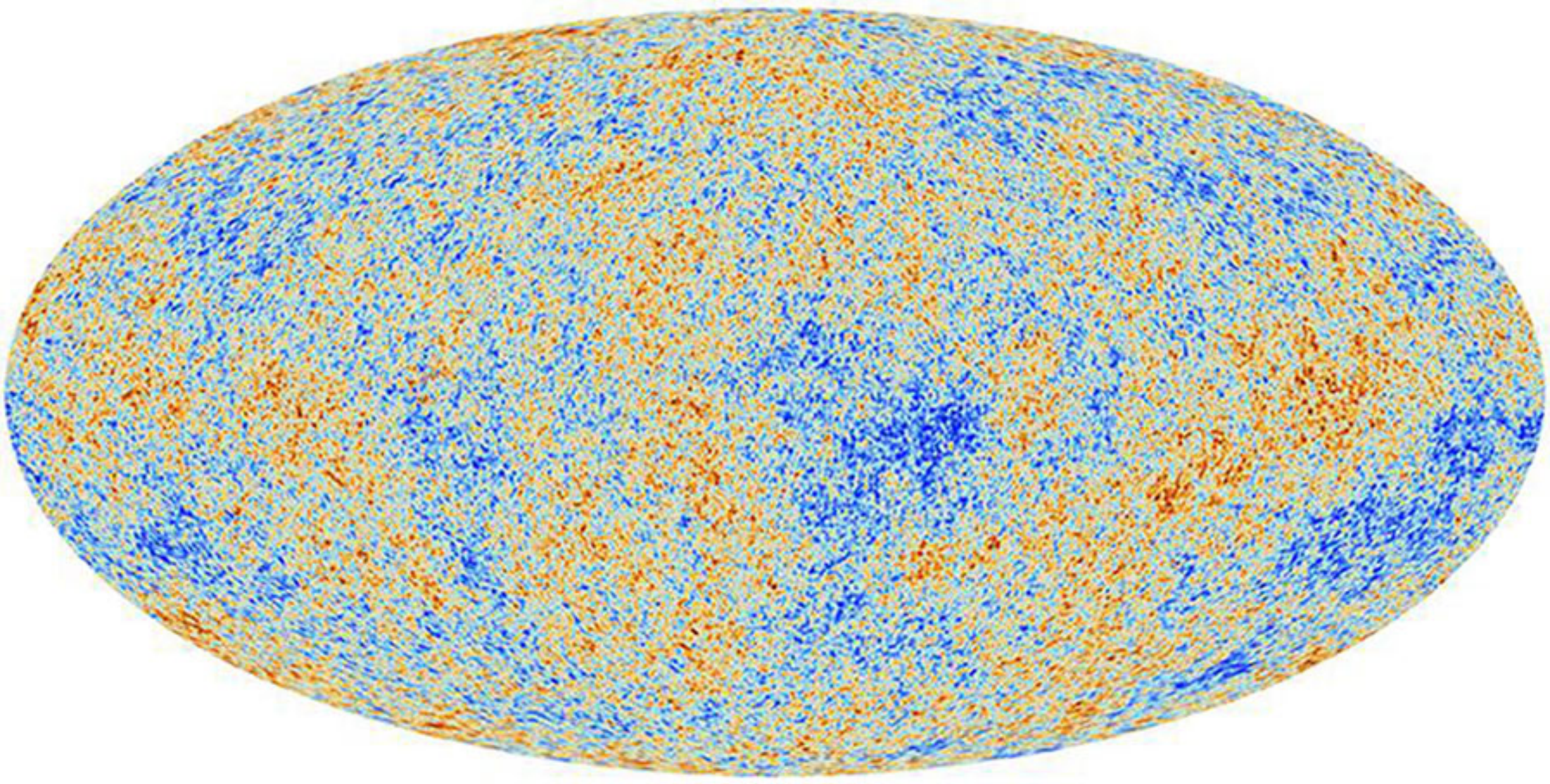



12h
15h
09h
+75d
18h
+60d
06h
+45d
21h
+30d
−75d
+15d
−60d
00h
−45d
−15d
−30d



IRAS/COBE Galactic Dust

100 micron map



Some basics

The resolution of an image-forming device is given by the Rayleigh criterion (invented by Lord Rayleigh (1842-1919)):

$$\delta\theta \simeq 1.22\,\frac{\lambda}{D}$$

The sensitivity of an image-forming device is proportional to its collecting area:

$$\text{collecting area} \propto D^2$$

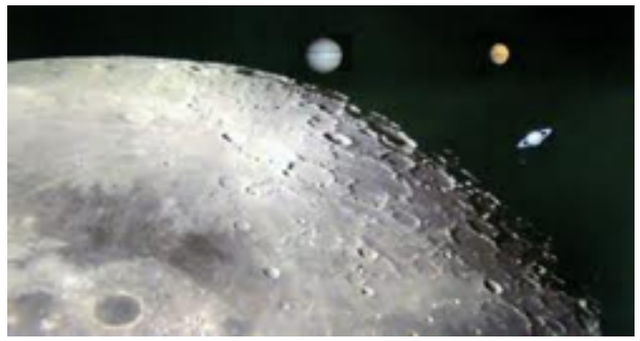
Angular scales

http://operavision.org/2008/08/02/the-man-on-the-moon/

Angular scales

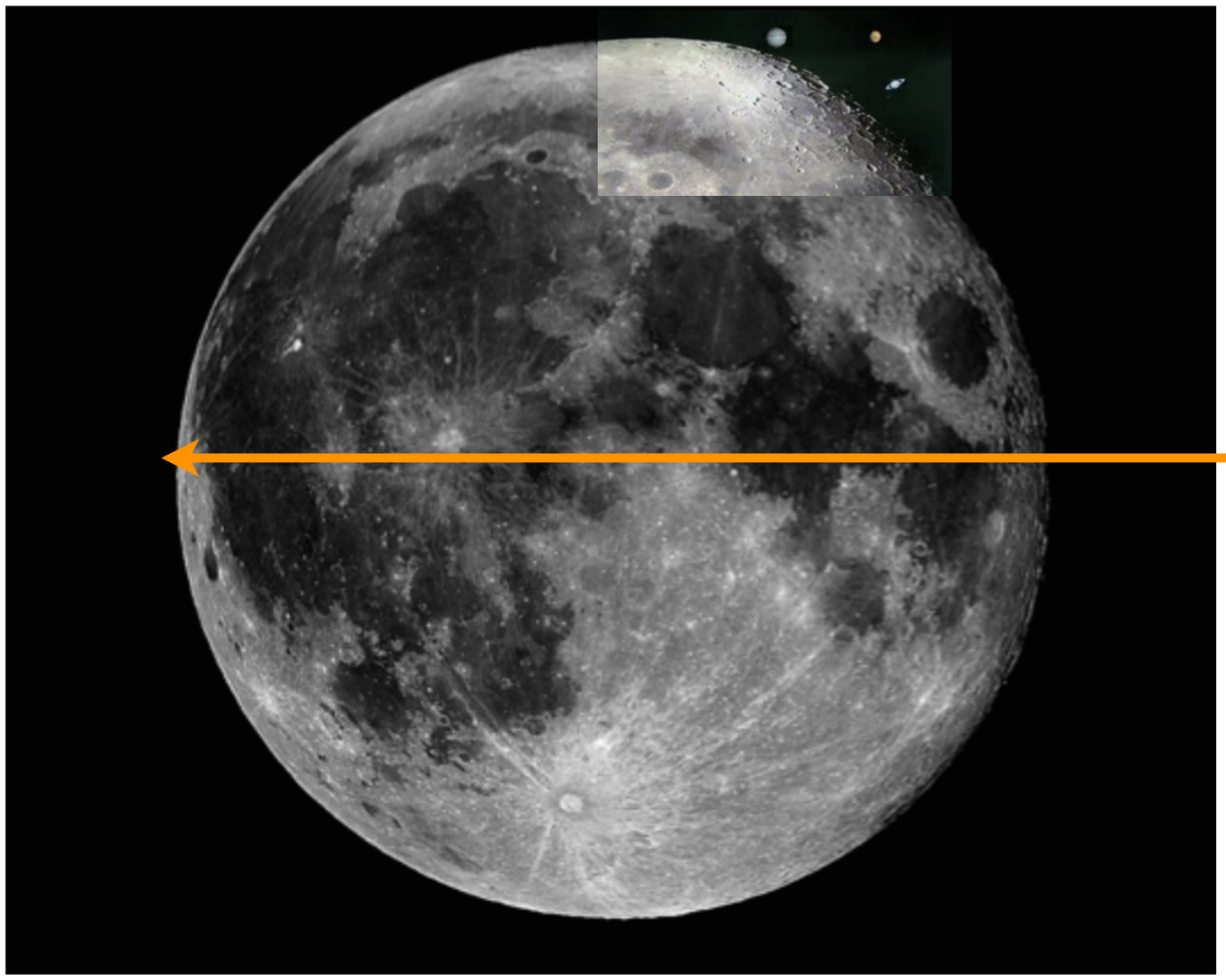
a human hair held ten metres away

1 arcsec



1 arcmin

The eye resolution



1 degree

The resolving power of a pupil is:
(Rayleigh criterion)

$$\Delta\theta = 1.22\frac{\lambda}{D}$$

The human eye

diameter: a few mm

Rayleigh limit: ~30”

actual resolution: 1-2’
(cones need to be separated by unexcited cones)

exposure time: 1/50 s

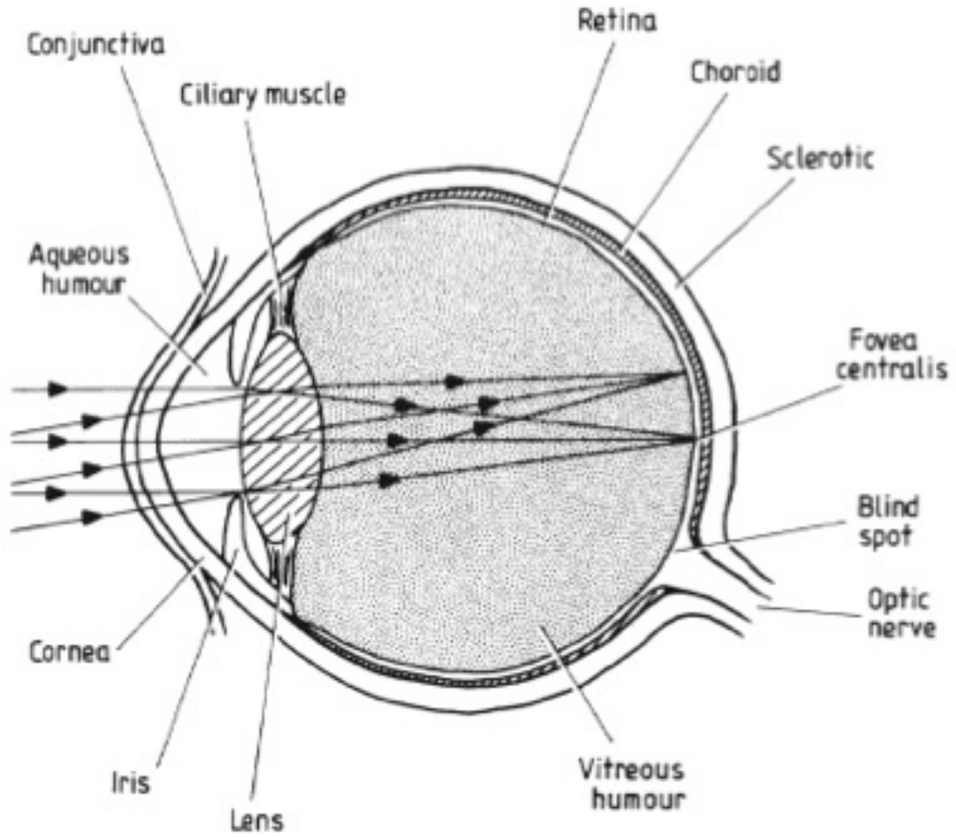


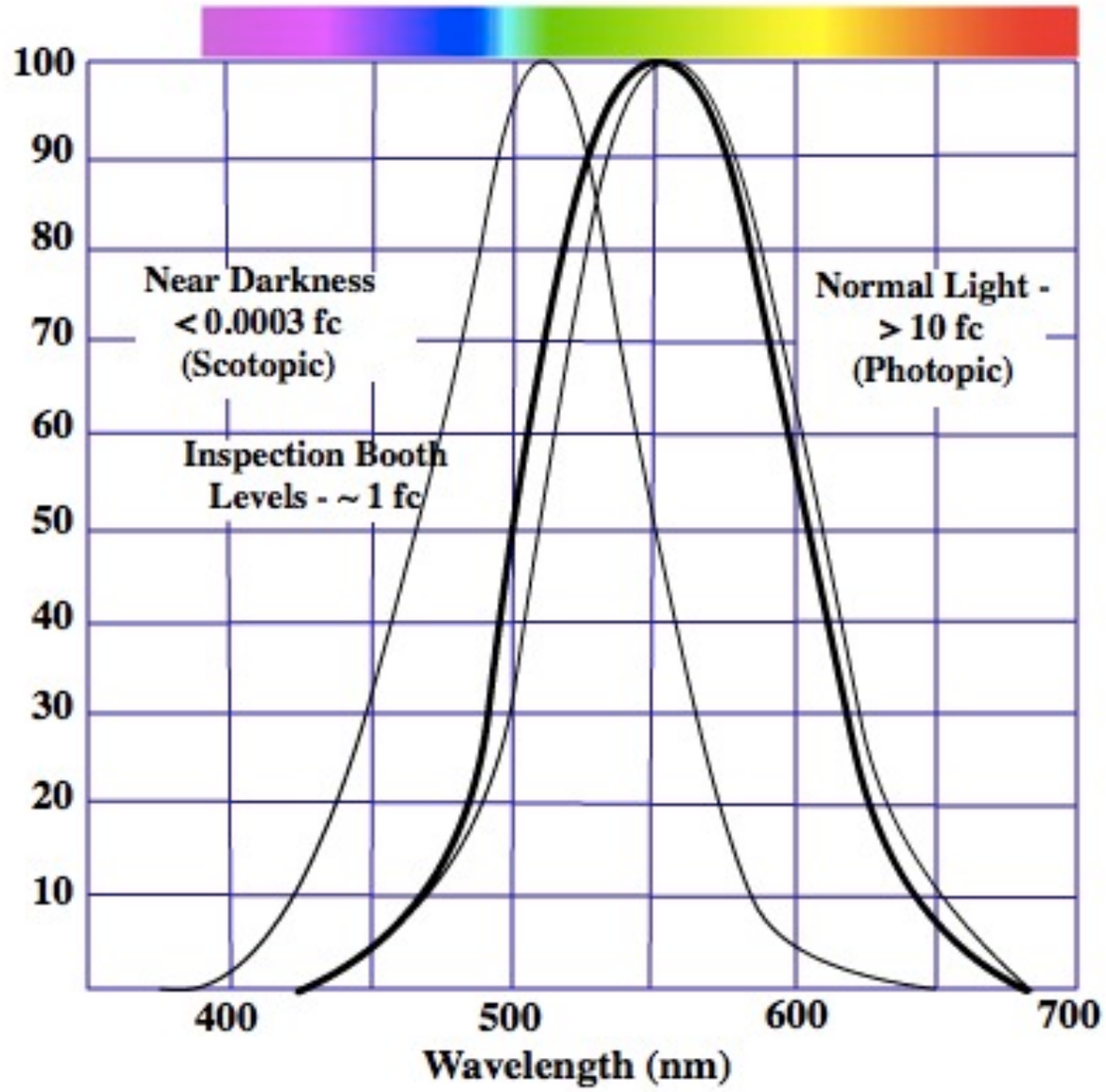
Figure 1.1.1. Optical paths in a horizontal cross-section of the eye.

The human eye

lambda_min ~ 0.4 micron
lambda_max ~ 0.7 micron

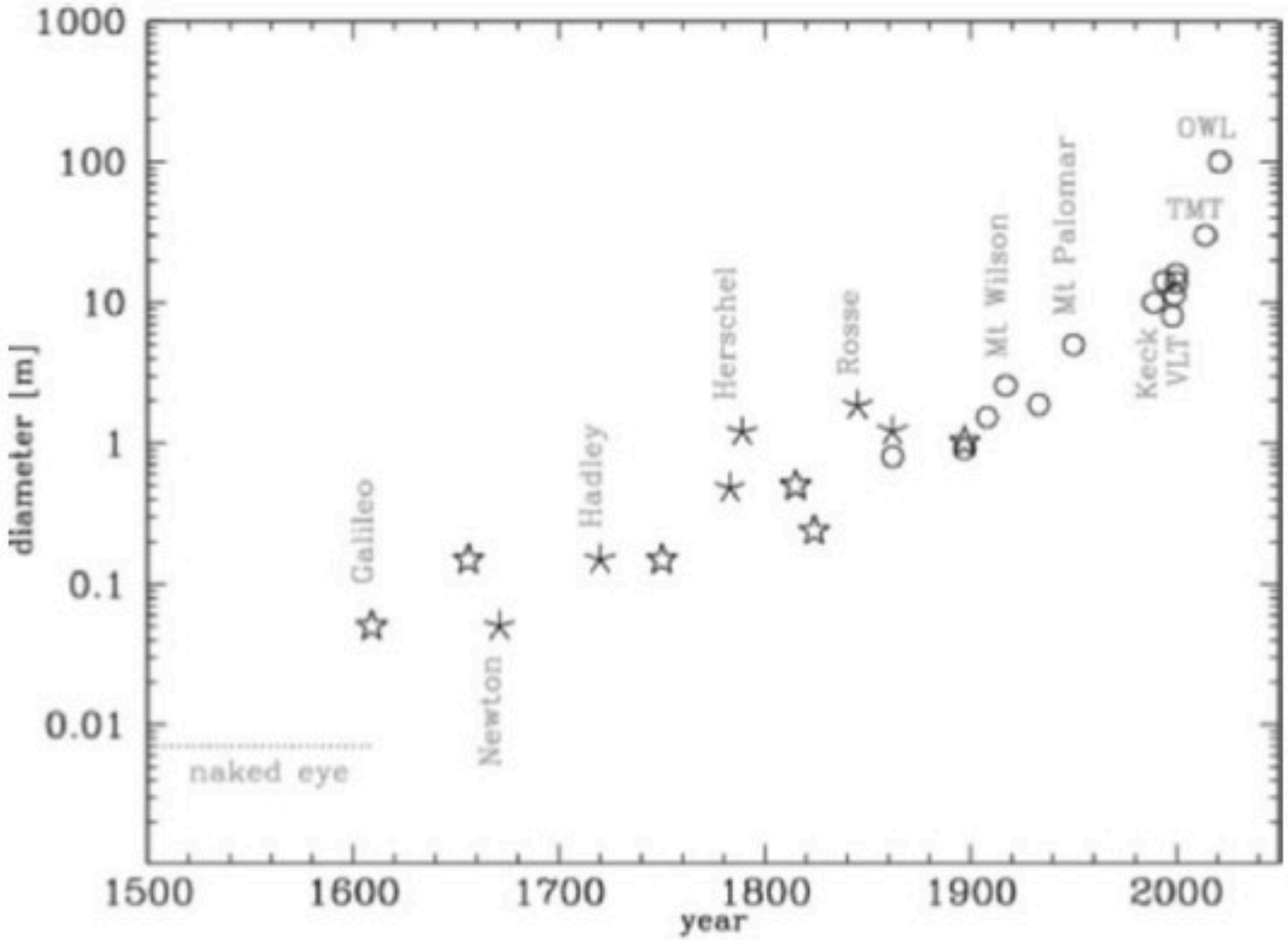
resolution elements:
- 6e6 cones (bright vision)
- 1e8 rods (faint)

dynamical range: 1e9-10

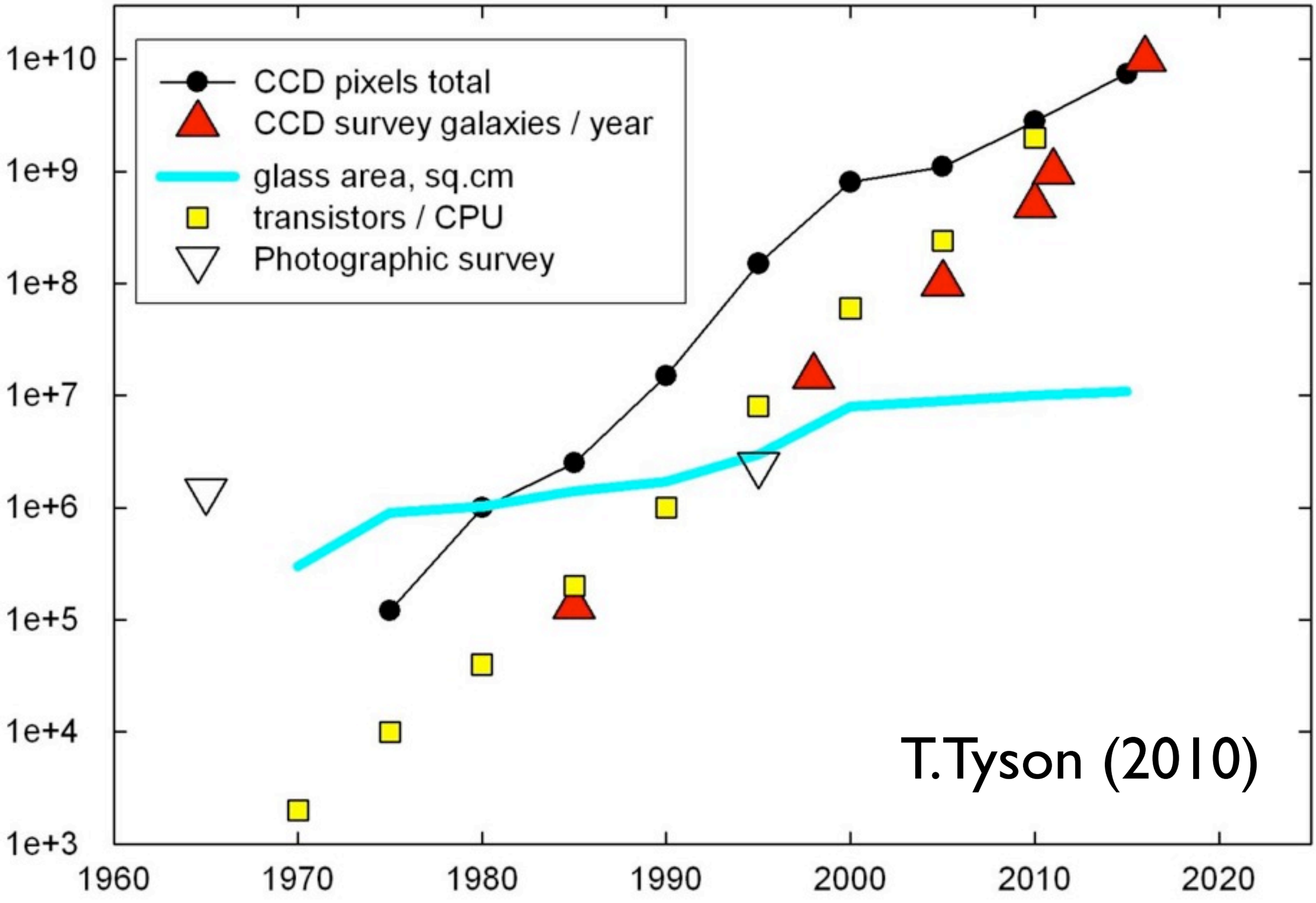


Questions:
- What is the stimulation threshold (in terms of number of photons for the eye?)
- What is the wavelength of a standard remote control?

A brief history of the telescope

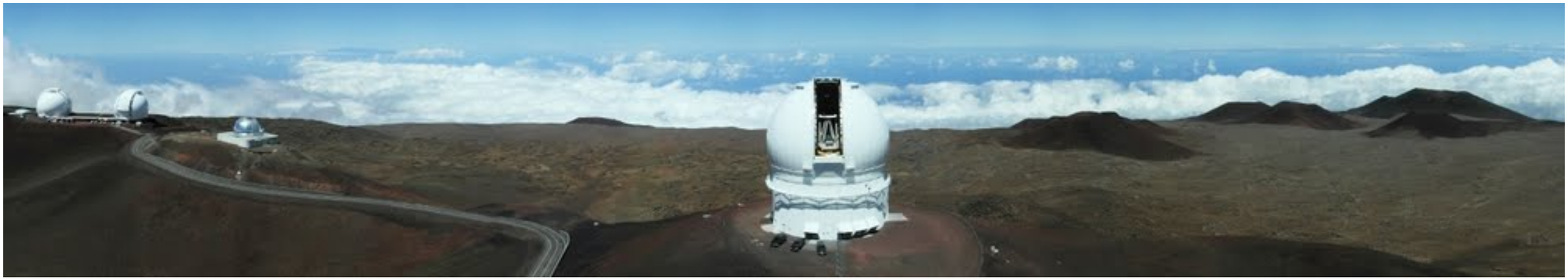


What has been the main driver of ground-based astronomy in the past 20 years?



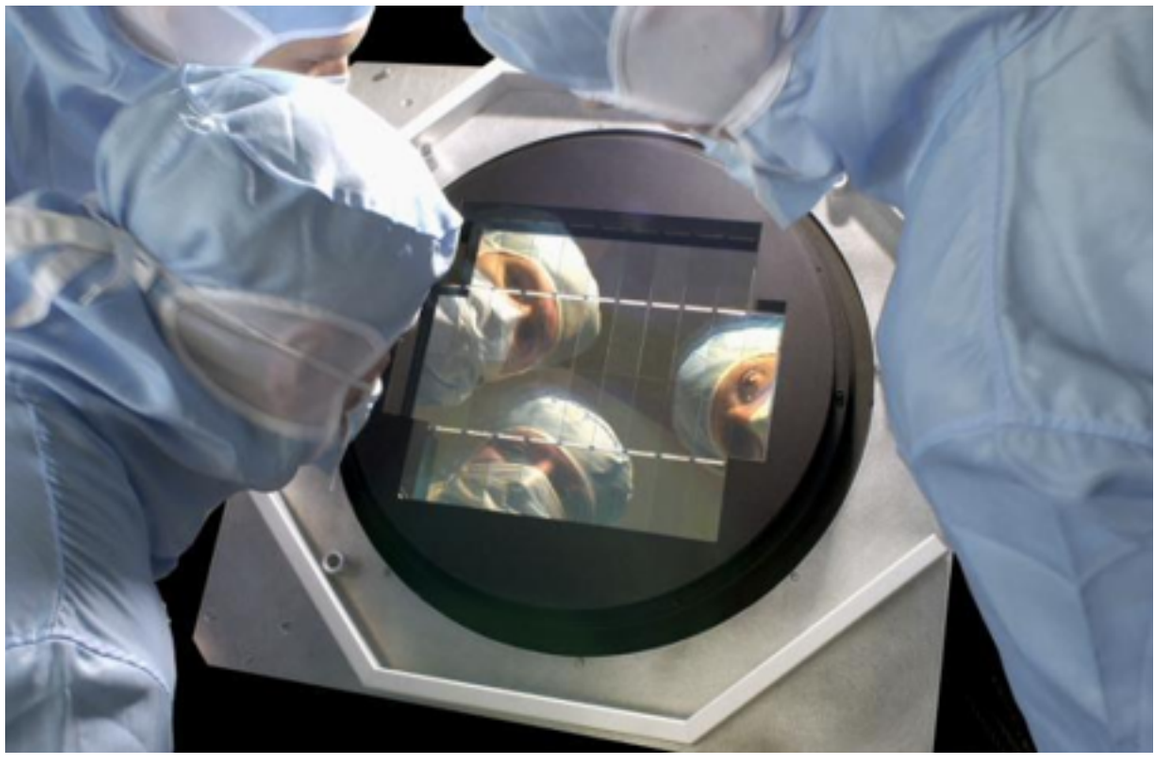
- Scientific data doubles every year

An example: the CFH Telescope



The Canadian-France-Hawaii telescope:
- operational since 1979 (>30 years old)
- mirror: D=3.6 m

Still (one of) the most competing telescope for weak lensing studies



Many fundamental problems in astronomy can be addressed with a common (usually large) dataset. Astronomy is more and more based on large surveys.

In the context of surveys, the figure of merit of a telescope is given by the étendue: $E = A \times \Omega$

= (telescope area) x (opening angle)

5th INPE ADVANCED COURSE

An Overview of Cosmology in the Era of Large Telescopes: Theory, Observations and Simulations.

September 16 - 20, 2013

In Honor of Prof. José Antônio de Freitas Pacheco

detectors

surveys

Invited Lecturers

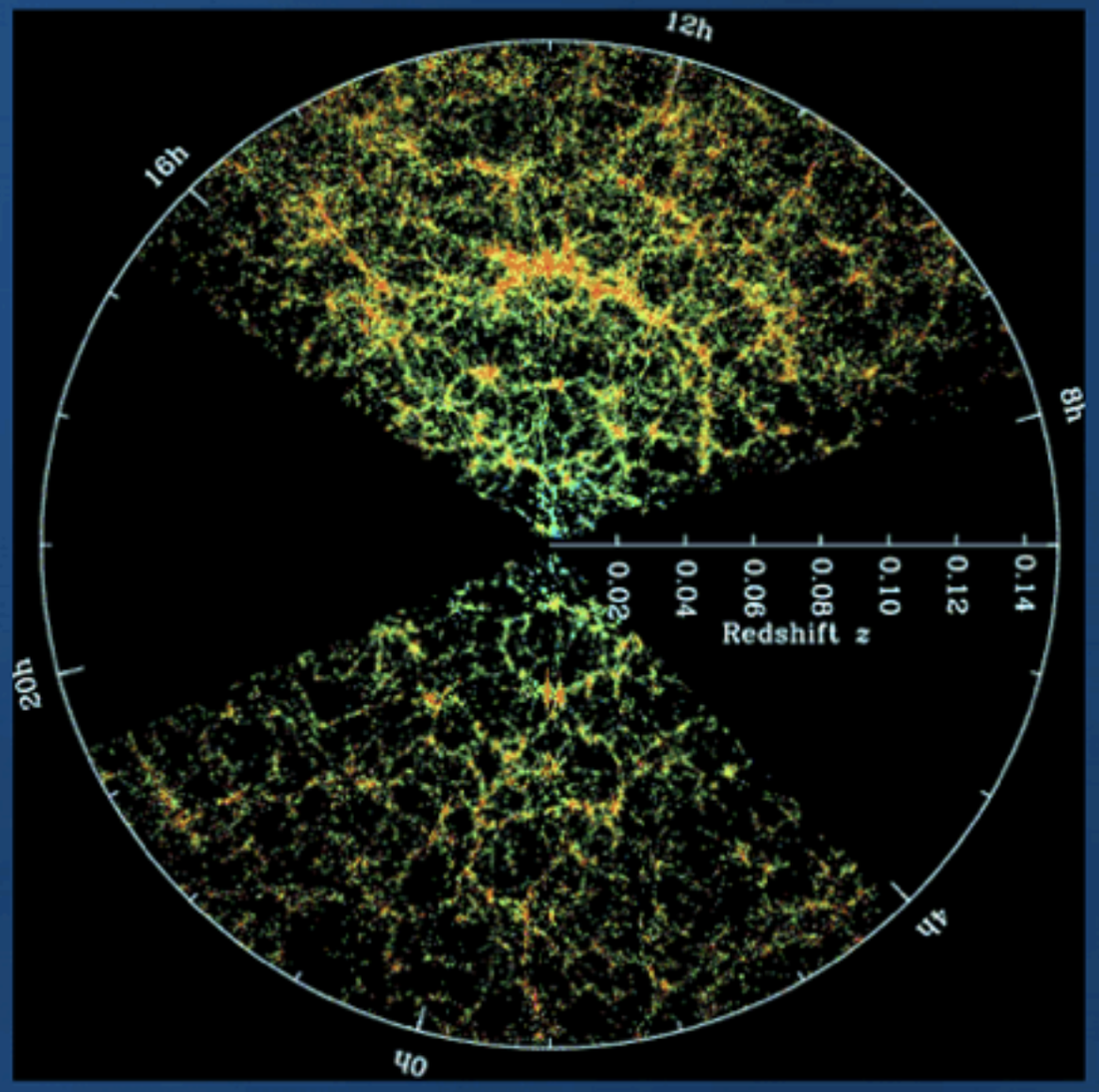
Dr Brice Menard (John Hopkins Univ., USA)
Large Scale Structure of the Universe - Large Surveys

Dr Graça Rocha (Caltech/JPL, USA)
CMB/Planck

Dr John Leslie (Univ. of Guelph, Canada)
The Mystery of Existence: Why is there anything at all?

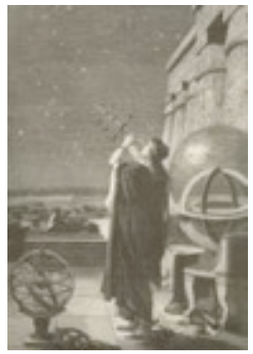
Dr Krzysztof M. Gorski (JPL/Caltech, and Warsaw University Observatory, USA & Poland)
Flattening the Sphere: HEALPix – Concept and Applications to Effective Handling and Analysis of Full Sky Data Sets

Dr Neal Katz (Univ. of Massachussets, USA)
Cosmological Simulations



Science is Changing

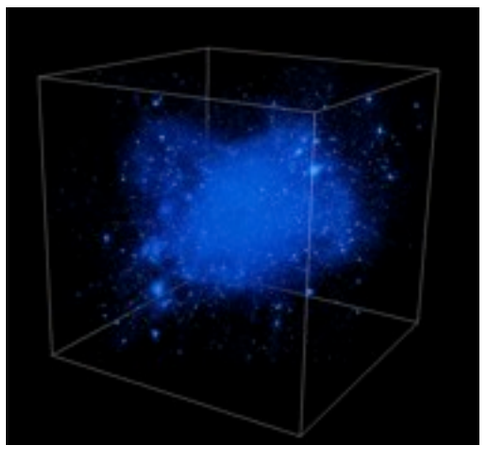
THOUSAND YEARS AGO
science was empirical
describing natural phenomena



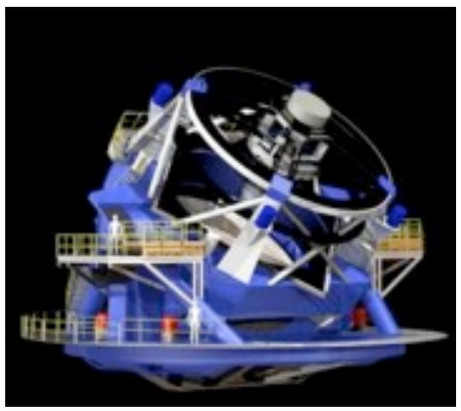
LAST FEW HUNDRED YEARS
theoretical branch using models, generalizations

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{4\pi G\rho}{3} - \mathrm{K}\frac{c^2}{a^2}$$

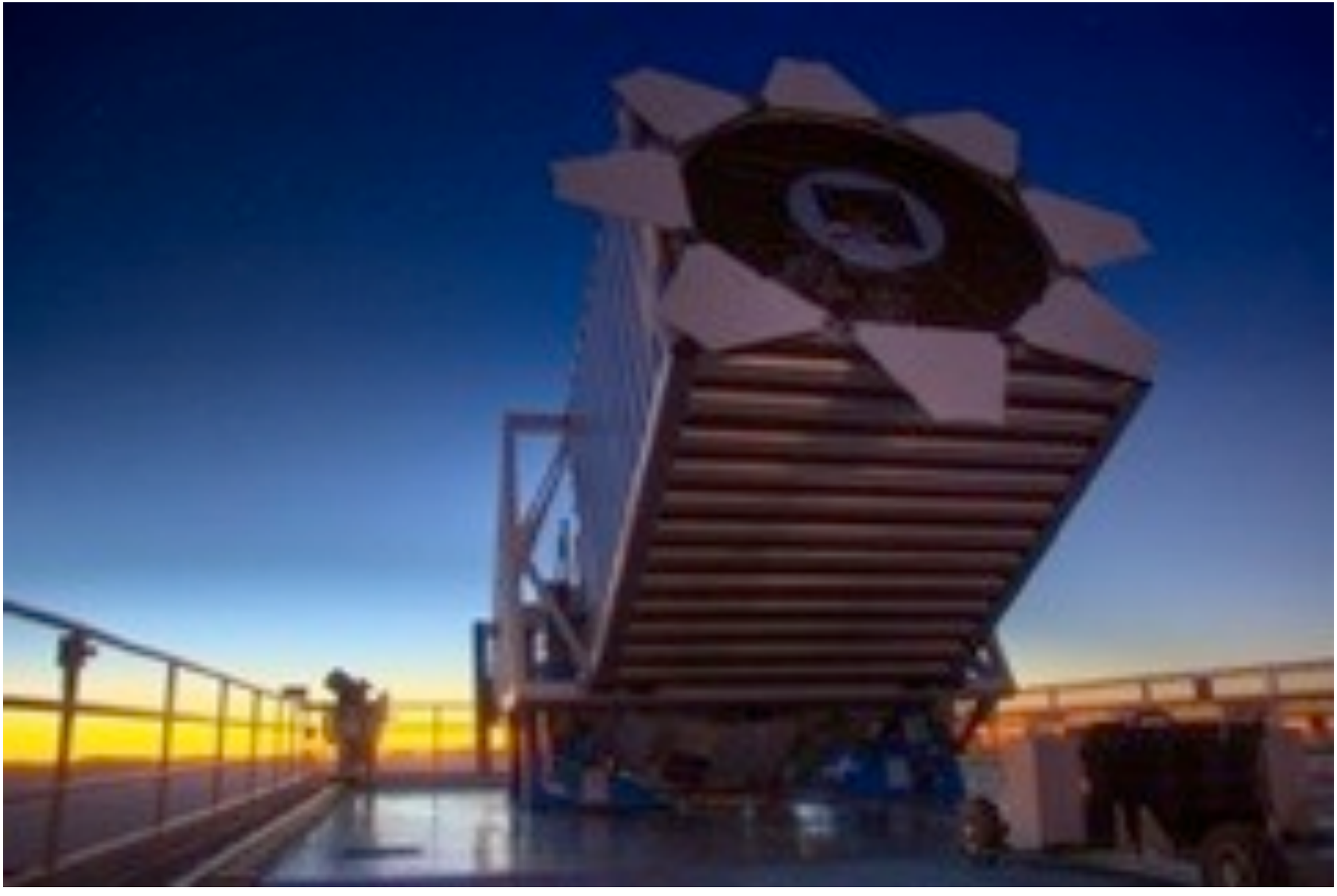
LAST FEW DECADES
a computational branch simulating complex phenomena



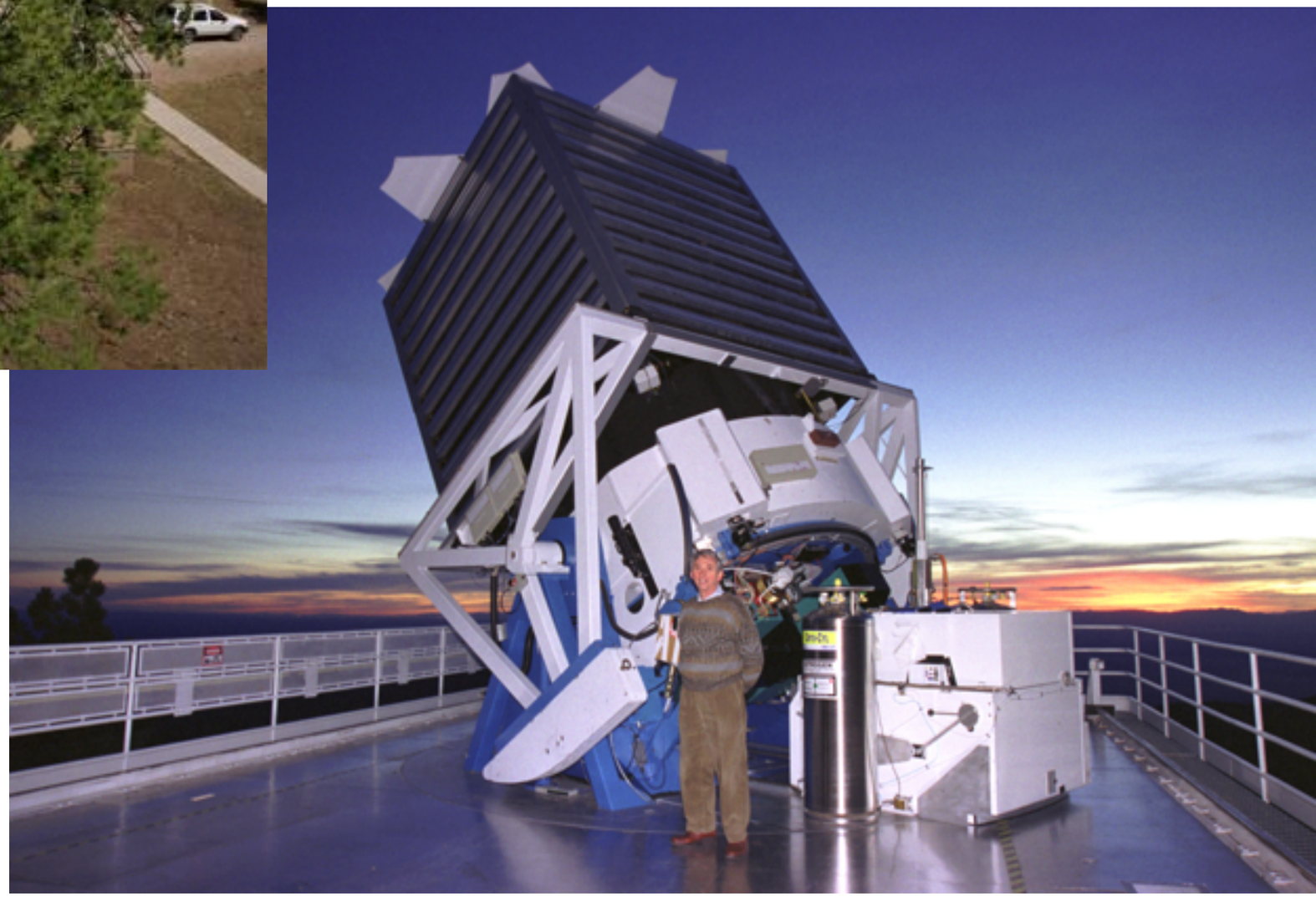
TODAY
data intensive science, synthesizing theory, experiment and computation with statistics
►new way of thinking required!



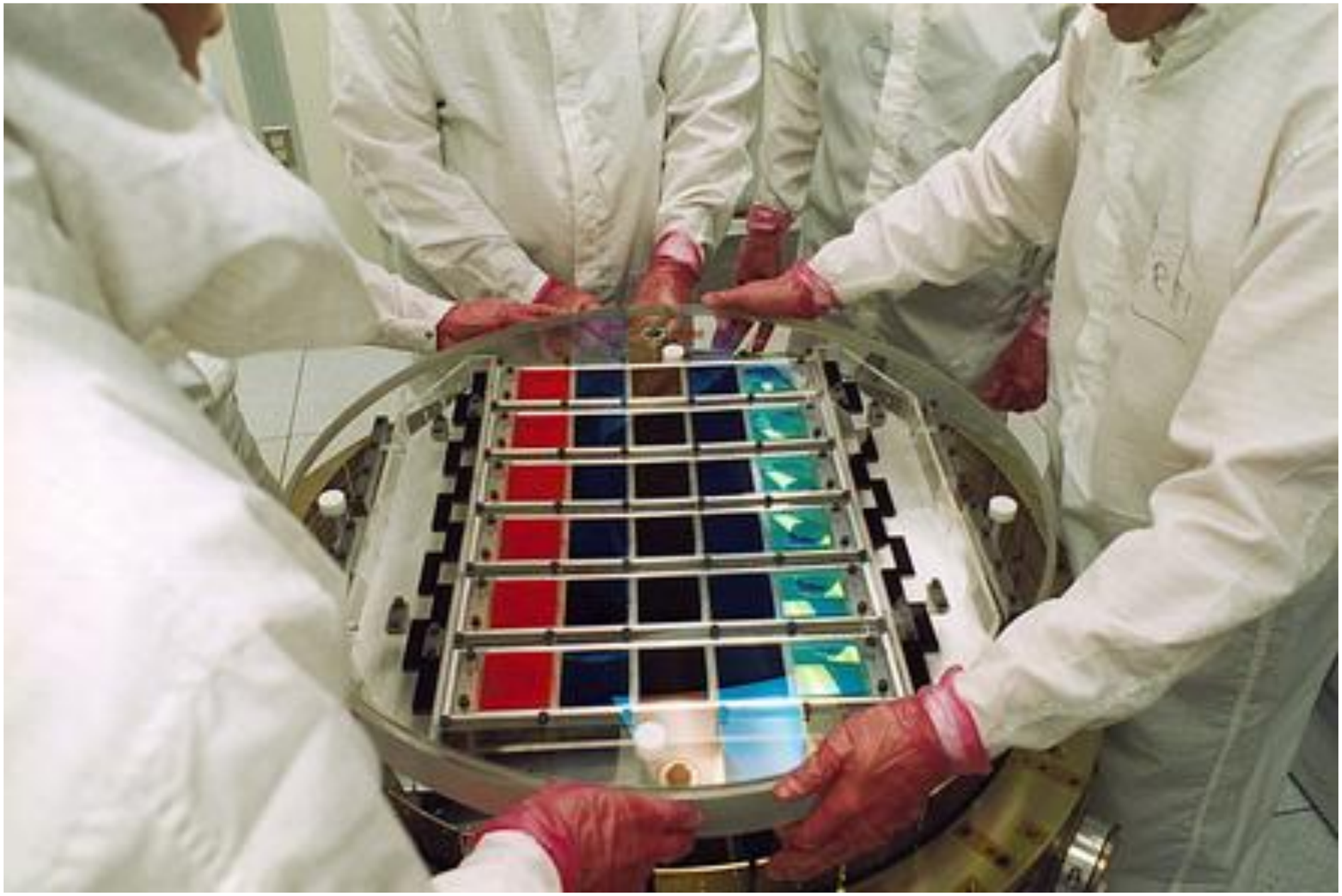
The Sloan Digital Sky Survey



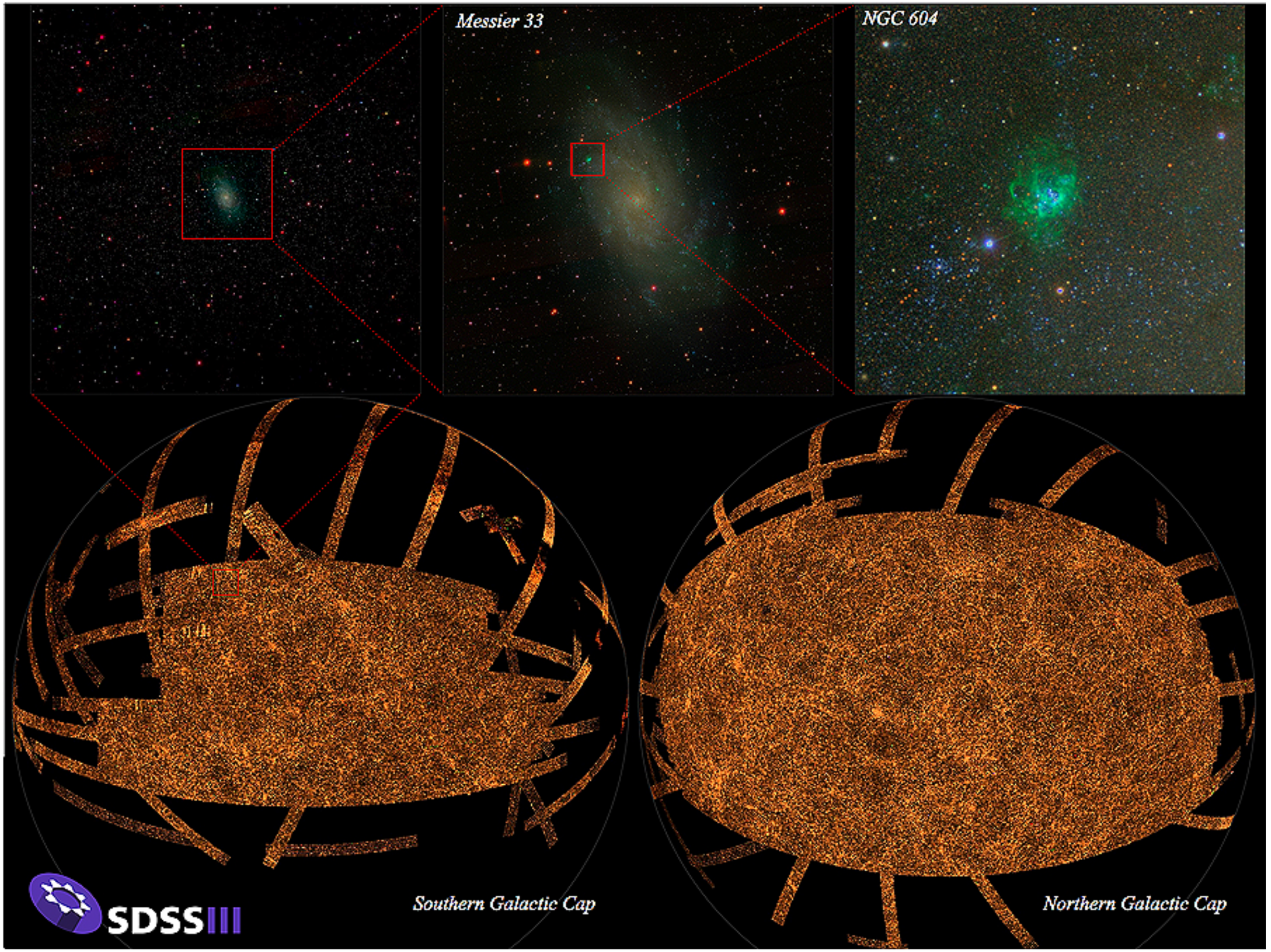
The Sloan Digital Sky Survey (SDSS)

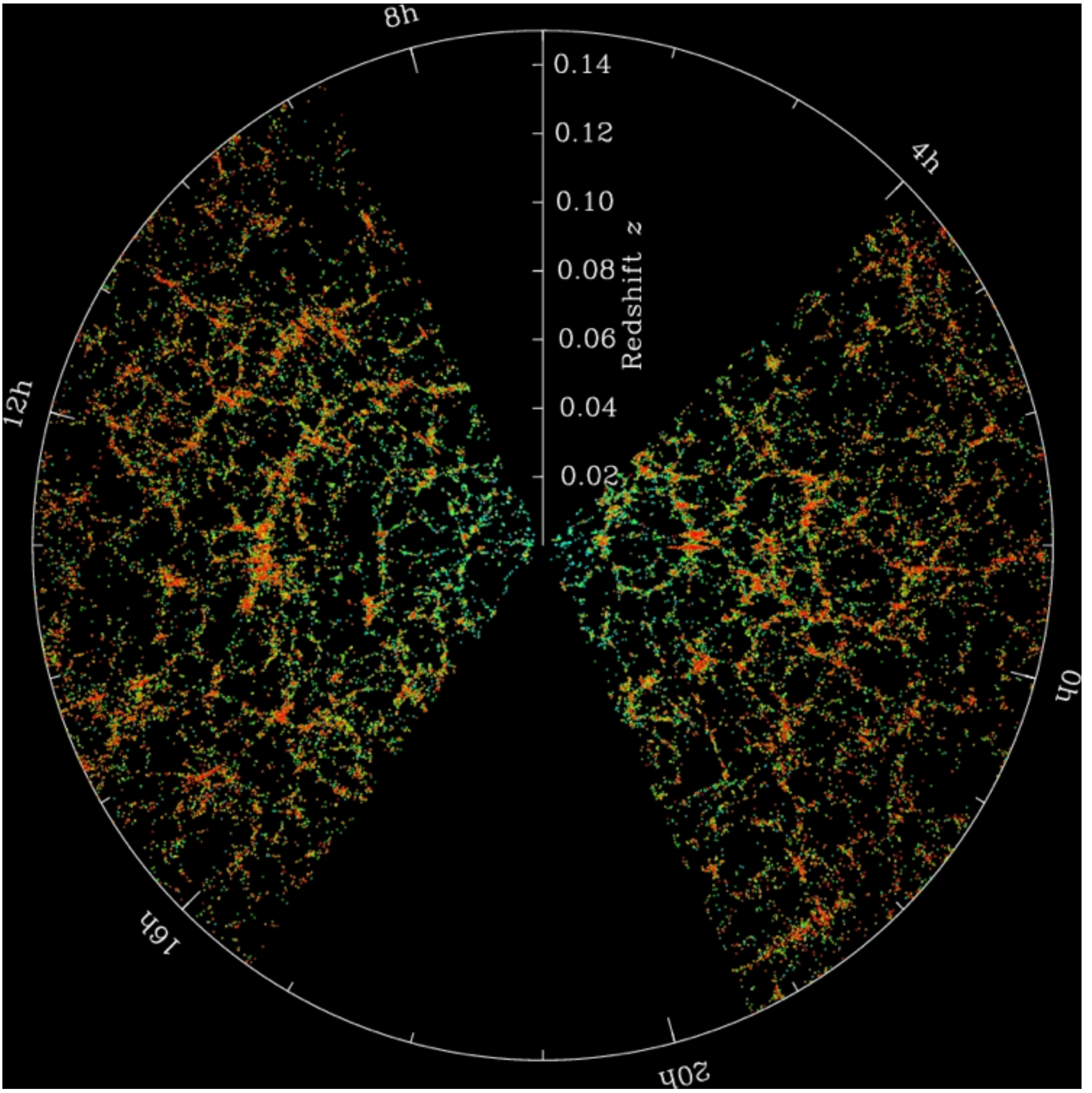


The SDSS camera



Drift scan


Messier 33
NGC 604
Southern Galactic Cap
Northern Galactic Cap
SDSS III


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

The impact of sky surveys

Astronomy

Sloan Digital Sky Survey tops astronomy citation list

NASA's Sloan Digital Sky Survey (SDSS) is the most significant astronomical facility, according to an analysis of the 200 most cited papers in astronomy published in 2006. The survey, carried out by Juan Madrid from McMaster University in Canada and Duccio Macchetto from the Space Telescope Science Institute in Baltimore, puts NASA's Swift satellite in second place, with the Hubble Space Telescope in third (arXiv:0901.4552).

Madrid and Macchetto carried out their analysis by looking at the top 200 papers using NASA's Astrophysics Data System (ADS), which charts how many times each paper has been cited by other research papers. If a paper contains data taken only from one observatory or satellite, then that facility is awarded all the citations given to that article. However, if a paper is judged to contain data from different facilities – say half from SDSS and half from Swift – then both facilities are given 50% of the citations that paper received.

The researchers then totted up all the citations and produced a top 10 ranking (see table). Way out in front with 1892 citations is the SDSS, which has been running since 2000 and uses the 2.5 m telescope at Apache Point in New Mexico to obtain images of more than a quarter of the sky. NASA's Swift satellite, which studies gamma-ray bursts, is second with 1523 citations, while the Hubble Space Telescope (1078 citations) is third.

Although the 200 most cited papers make up only 0.2% of the references indexed by the ADS for papers published in 2006, those 200 papers account for 9.5% of the citations. Madrid and Macchetto also ignored theory papers on the basis that they do not directly use any telescope data. A similar study of papers published in 2004 also puts SDSS top with 1843 citations. This time, though, the European Southern Observatory, which has telescopes in Chile, comes second with 1365 citations and the Hubble Space Telescope takes third spot with 1124 citations.

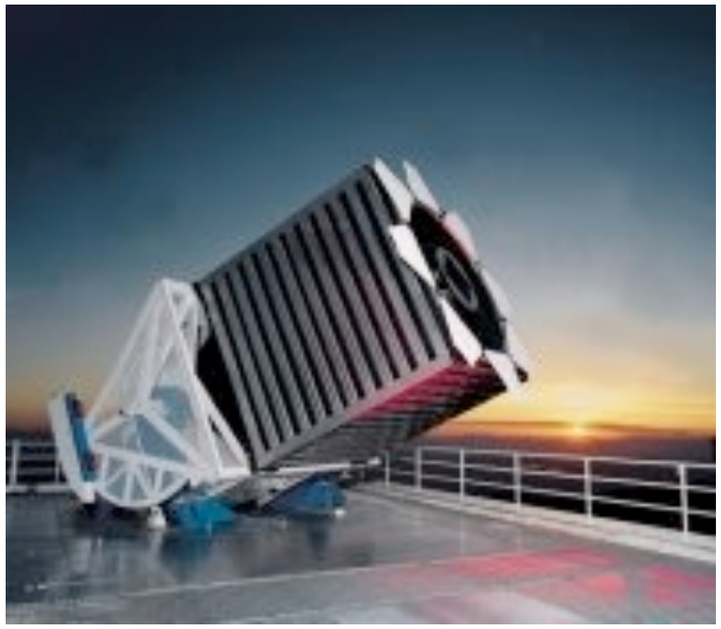
Michael Banks

Top 10 telescopes

Rank	Telescope	Citations	Ranking in 2004
1	Sloan Digital Sky Survey	1892	1
2	Swift	1523	N/A
3	Hubble Space Telescope	1078	3
4	European Southern Observatory	813	2
5	Keck	572	5
6	Canada–France–Hawaii Telescope	521	N/A
7	Spitzer	469	N/A
8	Chandra	381	7
9	Boomerang	376	N/A
10	High Energy Stereoscopic System	297	N/A

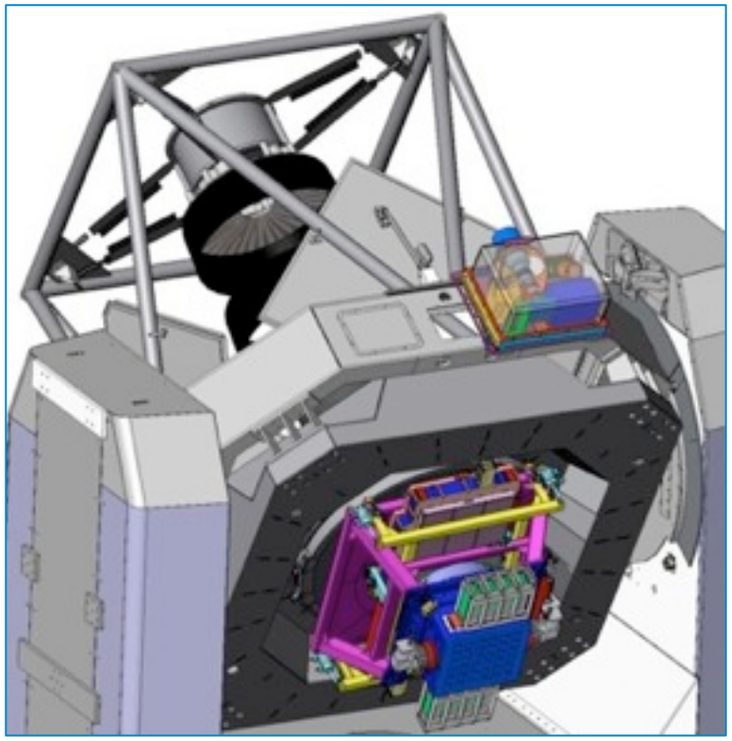
The SDSS has changed the way we do astronomy

SDSS
2.4m 0.12Gpixel



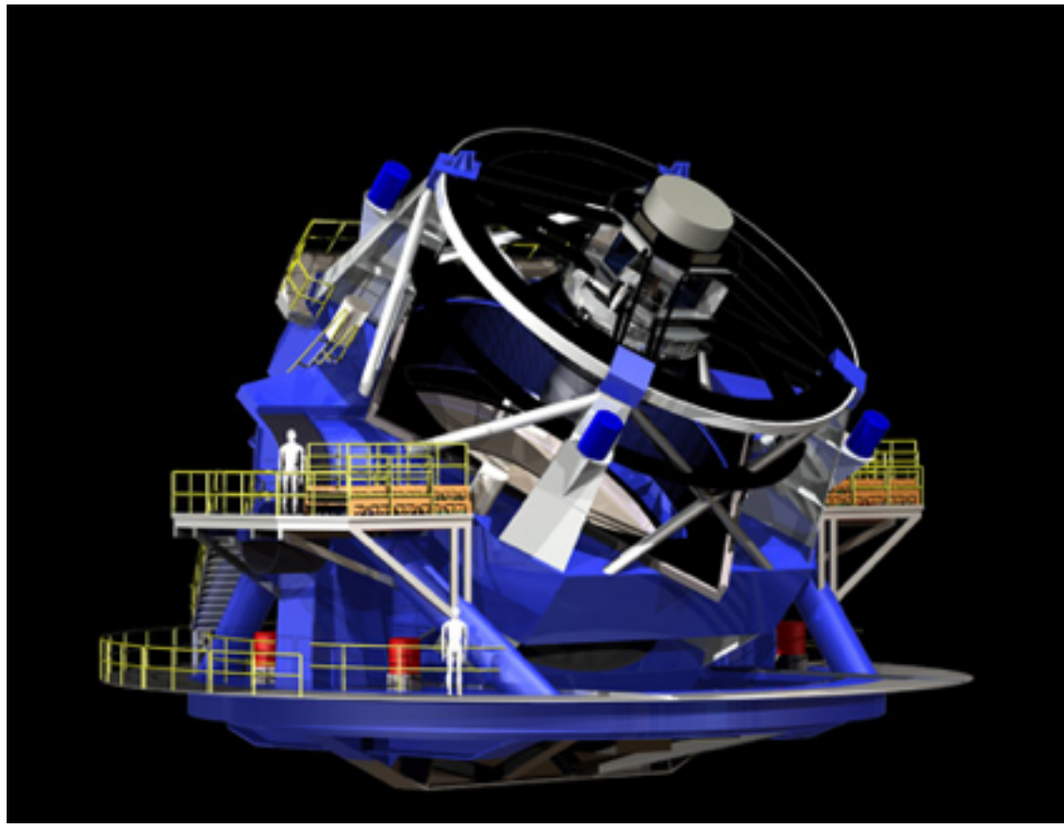
2000-2014+
operating

PanSTARRS
1.8m 1.4Gpixel



2010+
operating

LSST
8.4m 3.2Gpixel



2018+
in construction

15 terabytes
over 10 years

→

30 terabytes
per night

(world's largest digital cameras)

SUMMARY

Astrophysics is mostly driven by observations and observational astronomy is mostly driven by advances in (detector) technology.

Aperture size is no longer driving optical astronomy.

The avalanche of data keeps changing the way we think of data analysis.