大规模时域巡天：机遇与挑战

黄样（中国科学院大学）
huangyang@ucas.ac.cn
2023/07/03

关于信仰

The most incomprehensible thing about the universe is that it is comprehensible.

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Albert Einstein

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细推物理须行乐，何用浮名绊此身。

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杜甫《曲江二首》

大纲

- **测光时域巡天的过去、现在与未来**
- 时域巡天下的新机遇
- 时域巡天的挑战：高精度测光
- 时域巡天的挑战：变源瞬变源快速探测和分类

上课范式

每天：2节理论课+2节实践课

作业：实践课表现

基础知识

望远镜+台址：大口径、多波段、多信使

天体物理：一黑两暗三起源

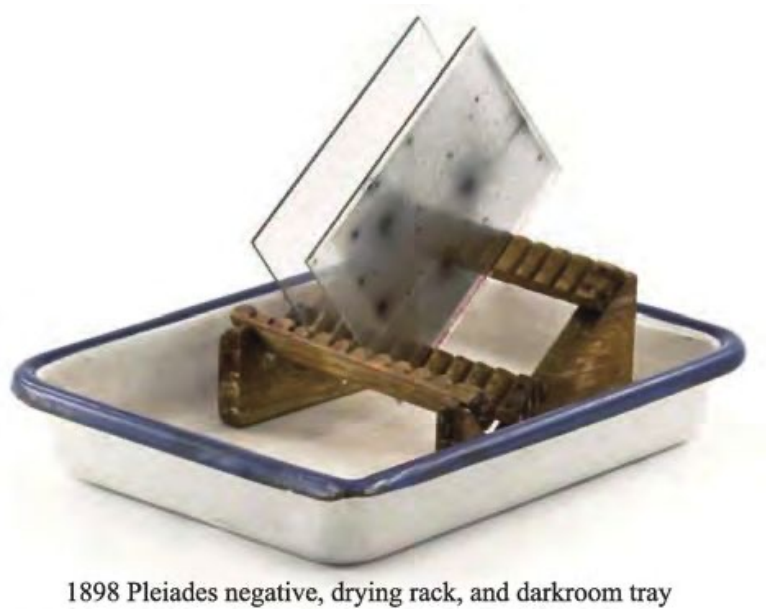
- 黑洞
- 暗物质与暗能量
- 宇宙起源、各尺度天体起源、生命起源

大规模巡天简史

人眼时代

1609 – 1850s

照相底片时代



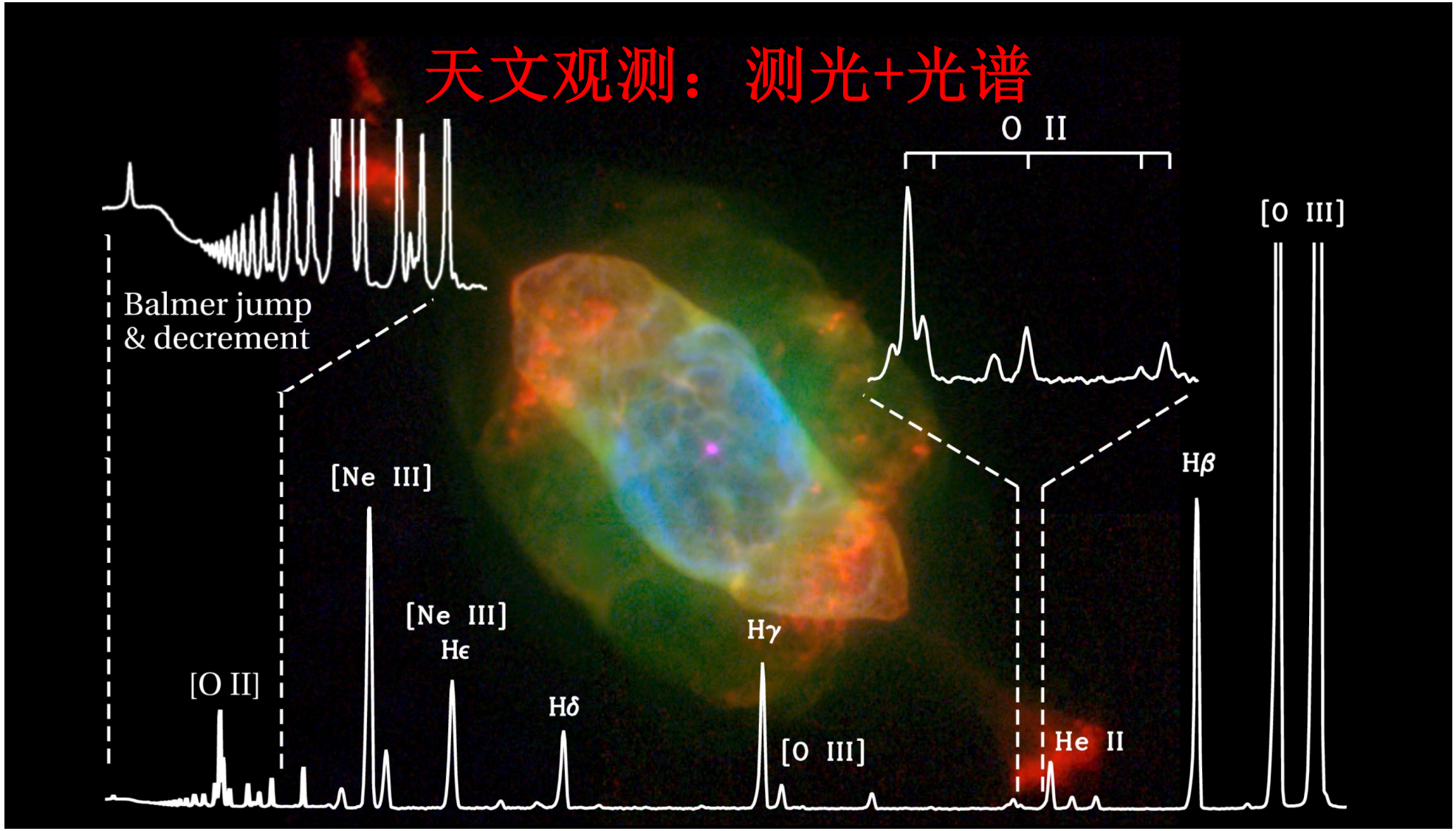
1898 Pleiades negative, drying rack, and darkroom tray

1850s – 1980s

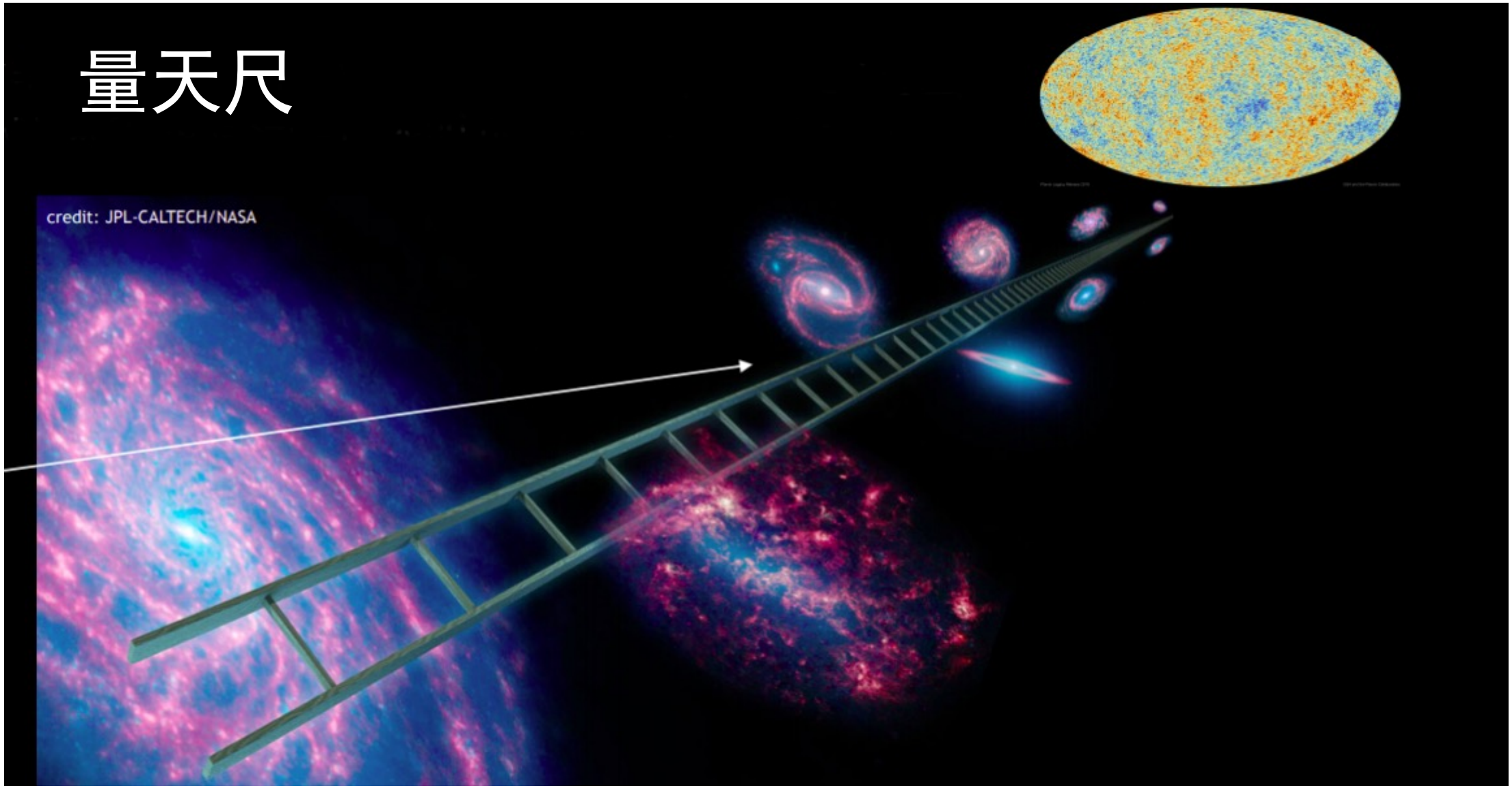
数字化时代

1980s – present

大规模巡天简史


天文观测：测光+光谱
Balmer jump
& decrement
[O II]
[Ne III]
[Ne III]
Hϵ
Hδ
Hγ
[O III]
O II
He II
Hβ
[O III]

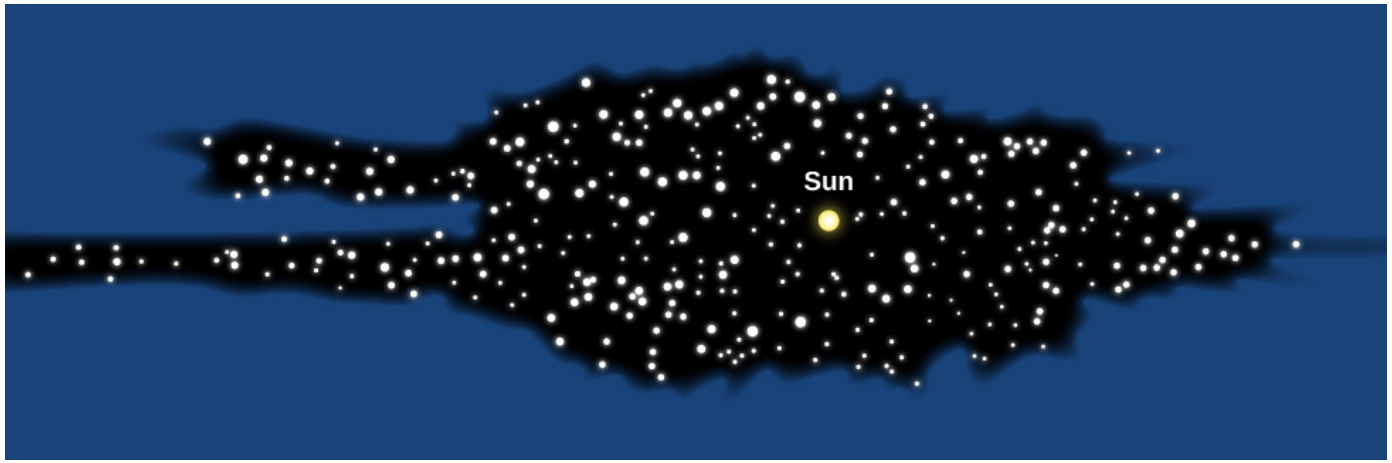
大规模巡天简史



大规模巡天简史

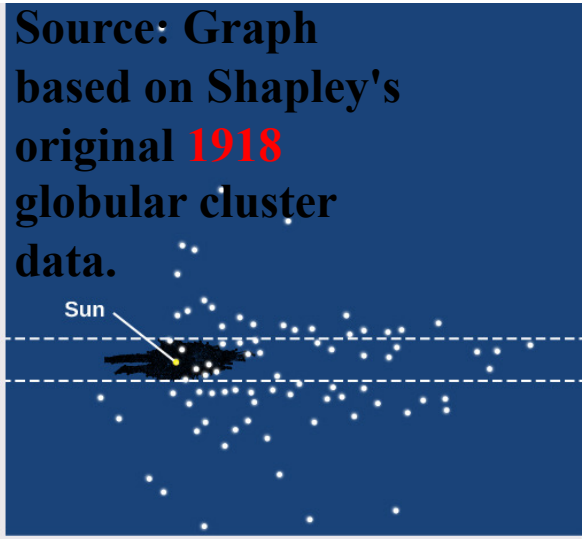
从“宇宙膨胀”到“哈勃常数危机”

序幕：银河系全景图



Source: *On the Construction of the Heavens.* By William Herschel, Esq. F. R. S. Philosophical Transactions of the Royal Society of London, Vol. 75. (1785), pp. 213-266.

(a)



(b)

Source: Graph based on Shapley's original 1918 globular cluster data.

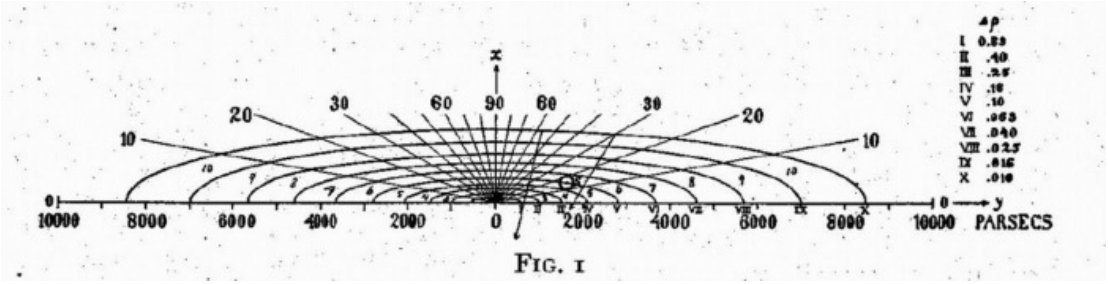


FIG. 1

Source: Kapteyn's Universe from his 1922 publication of his photographic star count survey.

大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”

序幕：勒维特与她的量天尺

HARVARD COLLEGE OBSERVATORY.

CIRCULAR 173.

PERIODS OF 25 VARIABLE STARS IN THE SMALL MAGELLANIC CLOUD.

The following statement regarding the periods of 25 variable stars in the Small Magellanic Cloud has been prepared by Miss Leavitt.

A Catalogue of 1777 variable stars in the two Magellanic Clouds is given in H.A. 60, No. 4. The measurement and discussion of these objects present problems of unusual difficulty, on account of the large area covered by the two regions, the extremely crowded distribution of the stars contained in them, the faintness of the variables, and the shortness of their periods. As many of them never become brighter than the fifteenth magnitude, while very few exceed the thirteenth magnitude at maximum, long exposures are necessary, and the number of available photographs is small. The determination of absolute magnitudes for widely separated sequences of comparison stars of this degree of faintness may not be satisfactorily completed for some time to come. With the adoption of an absolute scale of magnitudes for stars in the North Polar Sequence, however, the way is open for such a determination.

Fifty-nine of the variables in the Small Magellanic Cloud were measured in 1904, using a provisional scale of magnitudes, and the periods of seventeen of them were published in H.A. 60, No. 4, Table VI. They resemble the variables found in globular clusters, diminishing slowly in brightness, remaining near minimum for the greater part of the time, and increasing very rapidly to a brief maximum. Table I gives all the periods which have been determined thus far, 25 in number, arranged in the order of their length. The first five columns contain the Harvard Number, the brightness at maximum and at minimum as read from the light curve, the epoch expressed in days following J.D. 2,410,000, and the length of the period expressed in days. The Harvard Numbers in the first column are placed in Italics, when the period has not been published hitherto. A remarkable relation between the brightness of these variables and the length of their periods will be noticed. In H.A. 60, No. 4, attention was called to the fact that the brighter variables

亨丽爱塔·斯万·勒维特：1868–1921

- 哈佛天文台计算员
- 发现造父变星周光关系

大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”　　**序幕：勒维特与她的量天尺**

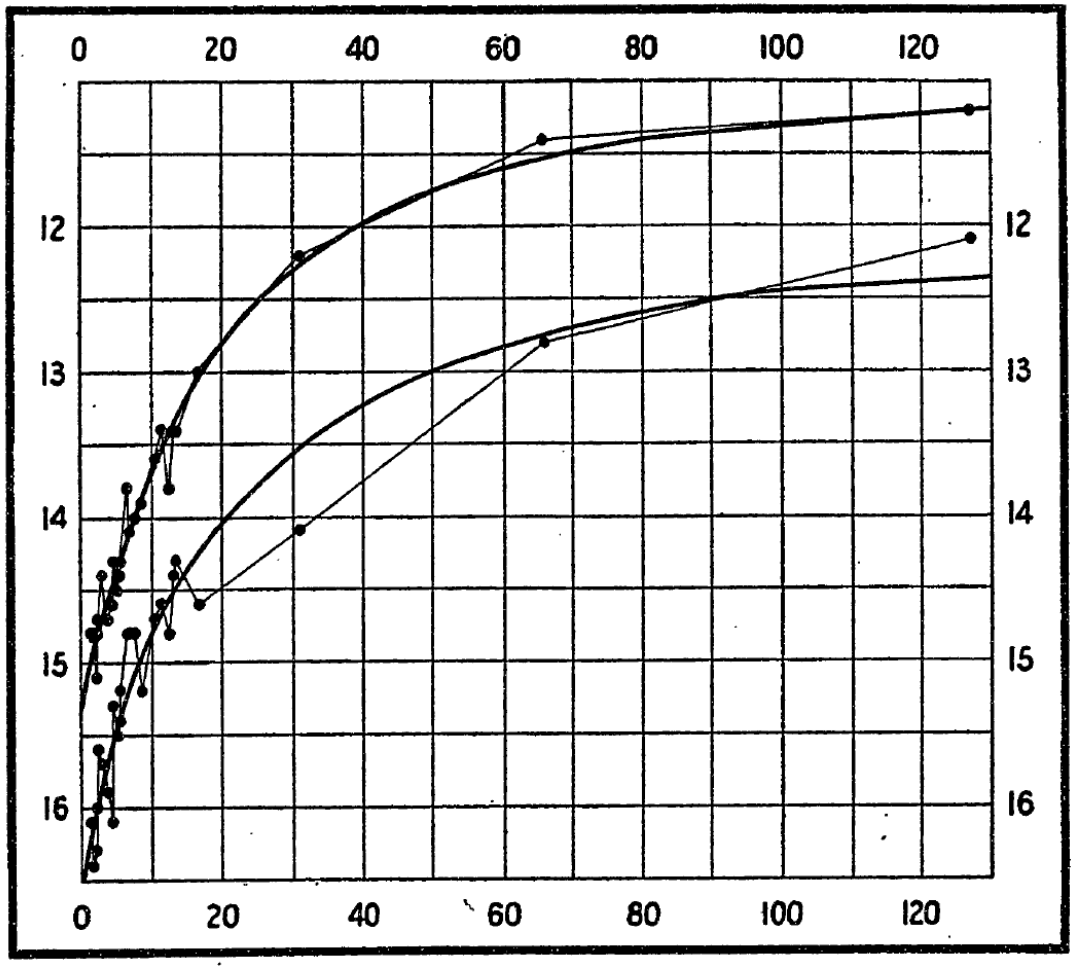


FIG. 1.

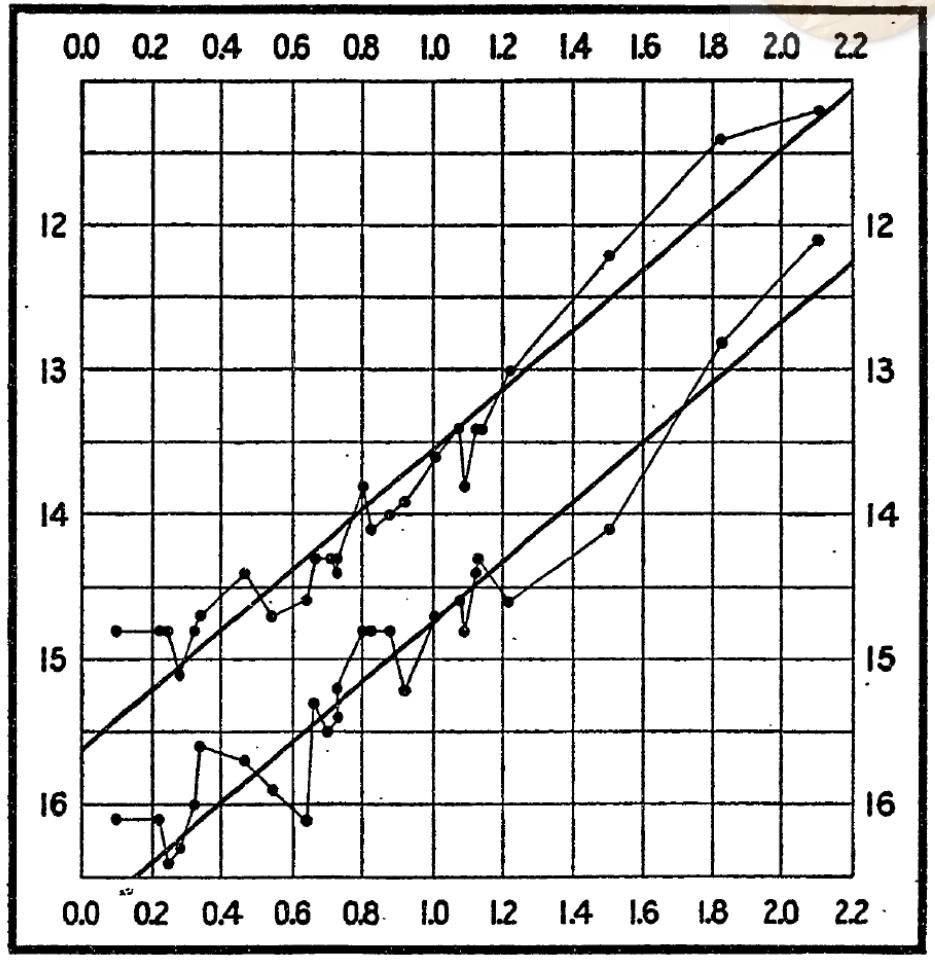


FIG. 2.

大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”

第一章：世纪大辩论

The Shapley - Curtis Debate in 1920

Harlow Shapley

Heber D. Curtis

哈罗·沙普利：1985-1972
（1914年普林斯顿博士毕业；
Willson天文台研究员）

希伯·柯蒂斯：1872-1942
（1902年維吉尼亞大學博士毕业；
利克天文台）

The Scale of the Universe

What the Great Debate was, how it was resolved, and why it was important.
A subjective abstract in three short paragraphs.

Published version of the 'Great Debate.' This is a reprint of the texts of Great Debate published in 1921 in the Bulletin of the National Research Council

The 'Great Debate:' What Really Happened by Michael Hoskin, editor of the Journal for the History of Astronomy. This is a reprint of an article appearin

"The 1920 Shapley-Curtis Discussion: Background, Issues, And Outcome". This excellent review of the historical context, personalities, and scientific is

A long bibliography for the 1920 Great Debate. This collection of over one hundred articles and books was compiled by Robert W. Smith, a historian wo

A short bibliography for the 1920 Great Debate. Five key books and articles about the Great Debate.

A lesson plan for teaching undergraduates about the Great Debate. The lesson plan consists of an outline, a lecture, suggested classroom uses for the plar

A Glossary of terms used in the Great Debate.

https://apod.nasa.gov/diamond_jubilee/debate20.html

MONDAY, APRIL 26

MORNING SESSION

10.30 a. m.—12:30 p. m.

JOHN M. CLARKE: Conservation of natural resources as a proper function of the National Academy. (15 minutes.)
RAYMOND PEARL: On the rate of growth of the population of the United States since 1790 and its mathematical expression (illustrated). (15 minutes.)
FRANZ BOAS: Growth and development as determined by environmental influences. (15 minutes.)
CHARLES B. DAVENPORT: Plural births in man (illustrated). (12 minutes.)
SAMUEL J. MEITZER: The importance of the presence of both sympathetic superior cervical ganglia to the maintenance of life; and their possible relations to respiratory diseases. (15 minutes.)
CHARLES D. WALCOTT: Structure of Marrella and allied Middle Cambrian crustaceans. (15 minutes.)
JAMES R. ANGELL: The National Research Council (illustrated). (20 minutes.)
ROBERT M. YERKES (introduced by E. L. Thorndike): A psychological study of the medical officers in the Army. (15 minutes.)

AFTERNOON SESSION

2.00 p. m.—4.30 p. m.

ROBERT W. WOOD: Spectroscopic phenomena of very long vacuum tubes (illustrated). (25 minutes.)
L. T. E. THOMPSON, C. N. HICKMAN and N. RIFFOLT (introduced by Arthur G. Webster): The measurement of small time intervals and some applications, principally ballistic. (10 minutes.)
ROBERT A. MILLIKAN: The effect of molecular structure upon the reflection of molecules from the surface of liquids and solids (illustrated). (12 minutes.)
ARTHUR G. WEBSTER: The Springfield rifle and the Leduc formulae. (5 minutes.)
ARTHUR G. WEBSTER: Some new methods in internal ballistics of the Springfield rifle. (15 minutes.)
GEORGE E. HALE: The 100-inch Hooker telescope of the Mt. Wilson Observatory (illustrated). (15 minutes.)
A. A. MICHELSON: The vertical interferometer.
Preliminary tests in an attempt to measure the diameter of the stars.
A modification of the Foucault method adapted to long-distance measurement of the velocity of light (illustrated). (30 minutes.)
ARTHUR G. WEBSTER: Preliminary measurements on the pressures in the “Onde de Choc.” (15 minutes.)
ARTHUR G. WEBSTER: On the connection of the specific heats with the equation of state of a gas. (10 minutes).
EDWIN H. HALL: Thermal conductivity of metals. (15 minutes.)

8.15 p. m. WILLIAM ELLERY HALE LECTURES. Discussion: The Scale of the Universe. By Harlow Shapley, Mount Wilson Solar Observatory, and Heber D. Curtis, Lick Observatory. (Illustrated), (open to the public), U. S. National Museum (main auditorium).

9.30 p. m. Conversazione. Galleries, U. S. National Museum.

大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”　　第一章：世纪大辩论

Why the `Great Debate' Was Important

Although the `Great Debate' is important to different people for different reasons, it is a clear example of humanity once again striving to find its place within the cosmic order. In the debate, Shapley and Curtis truly argued over the ``Scale of the Universe,'' as the debate's title suggests. Curtis argued that the Universe is composed of many galaxies like our own, which had been identified by astronomers of his time as ``spiral nebulae''. Shapley argued that these ``spiral nebulae'' were just nearby gas clouds, and that the Universe was composed of only one big Galaxy. In Shapley's model, our Sun was far from the center of this Great Universe/Galaxy. In contrast, Curtis placed our Sun near the center of our relatively small Galaxy. Although the fine points of the debate were more numerous and more complicated, each scientist disagreed with the other on these crucial points.

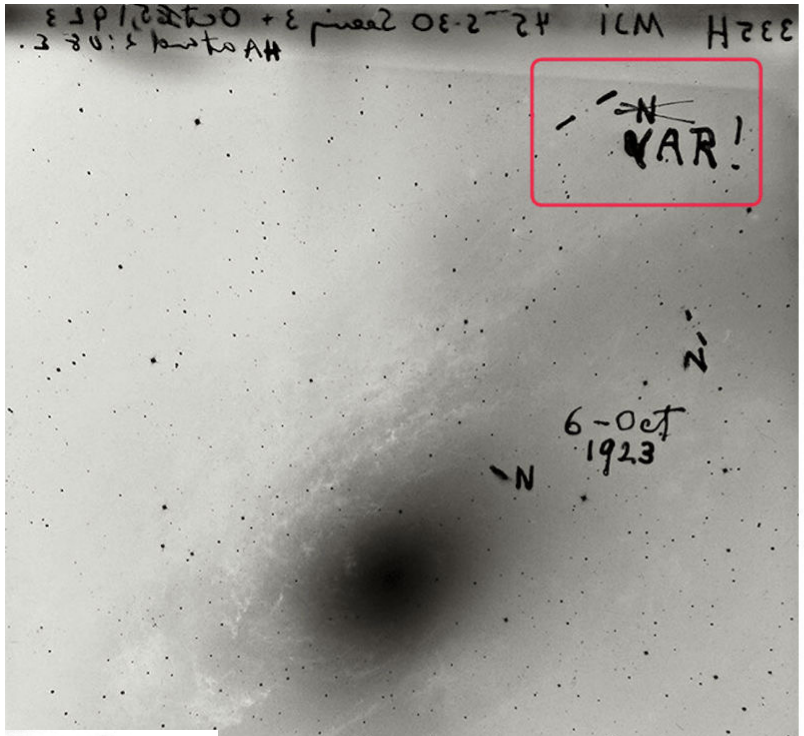
A partial resolution of the debate came in the mid-1920's. Using the 100 inch Hooker Telescope at Mount Wilson, then the largest telescope in the world, astronomer Edwin Hubble identified Cepheid variable stars in the Andromeda Galaxy (M31) . These stars allowed Hubble to show that the distance to M31 was greater than even Shapley's proposed extent of our Milky Way galaxy. Therefore M31 was a galaxy much like our own. In the 1930s, the further discovery of interstellar absorption combined with an increased understanding of the distances and distribution of globular clusters ultimately led to the acceptance that the size of our Milky Way Galaxy had indeed been seriously underestimated and that the Sun was not close to the center. Therefore, Shapley was proved more correct about the size of our Galaxy and the Sun's location in it, but Curtis was proved correct that our Universe was composed of many more galaxies, and that ``spiral nebulae'' were indeed galaxies just like our own.

Another reason the `Great Debate' is important is captured nicely in the book Shu, F., 1982, The Physical Universe, An Introduction to Astronomy, (University Science Books, Mill Valley, California) p. 286: "The Shapley-Curtis debate makes interesting reading even today. It is important, not only as a historical document, but also as a glimpse into the reasoning processes of eminent scientists engaged in a great controversy for which the evidence on both sides is fragmentary and partly faulty. This debate illustrates forcefully how tricky it is to pick one's way through the treacherous ground that characterizes research at the frontiers of science."

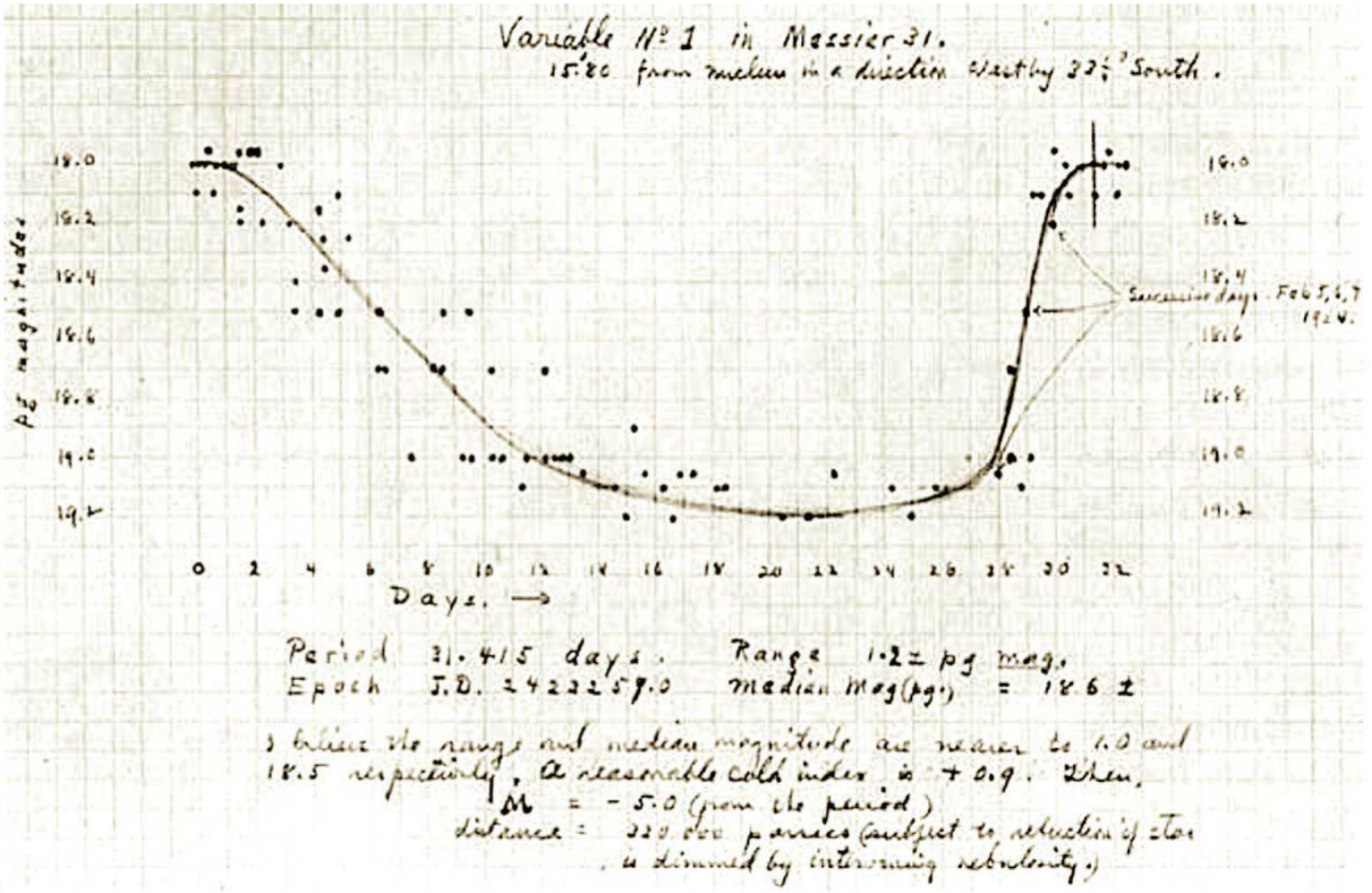
大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”

第二章：哈勃发现宇宙膨胀



哈勃：1889-1953
星系天文学之父
哈勃-勒梅特定律



大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”

第二章：哈勃发现宇宙膨胀

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

Hubble, PNAS, 1929

By Edwin Hubble

Mount Wilson Observatory, Carnegie Institution of Washington

Communicated January 17, 1929

$$V = H_0 D$$

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 upon the zero point of the period-luminosity relation among Cepheids, the other criteria merely check the order of the distances. This method is restricted to the few nebulae which are well resolved by existing instruments. A study of these nebulae, together with those in which any stars at all can be recognized, indicates the probability of an approximately uniform upper limit to the absolute luminosity of stars, in the late-type spirals and irregular nebulae at least, of the order of M (photographic) $= -6.3$.[1] The apparent luminosities of the brightest stars in such nebulae are thus criteria which, although rough and to be applied with caution,

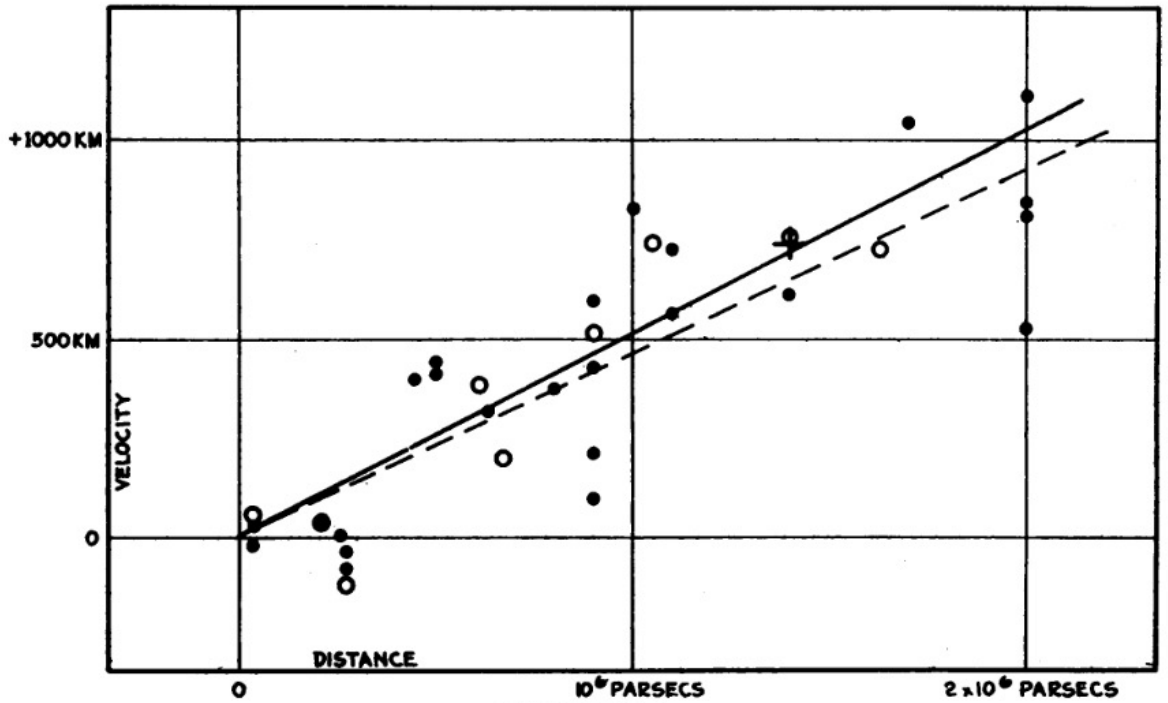
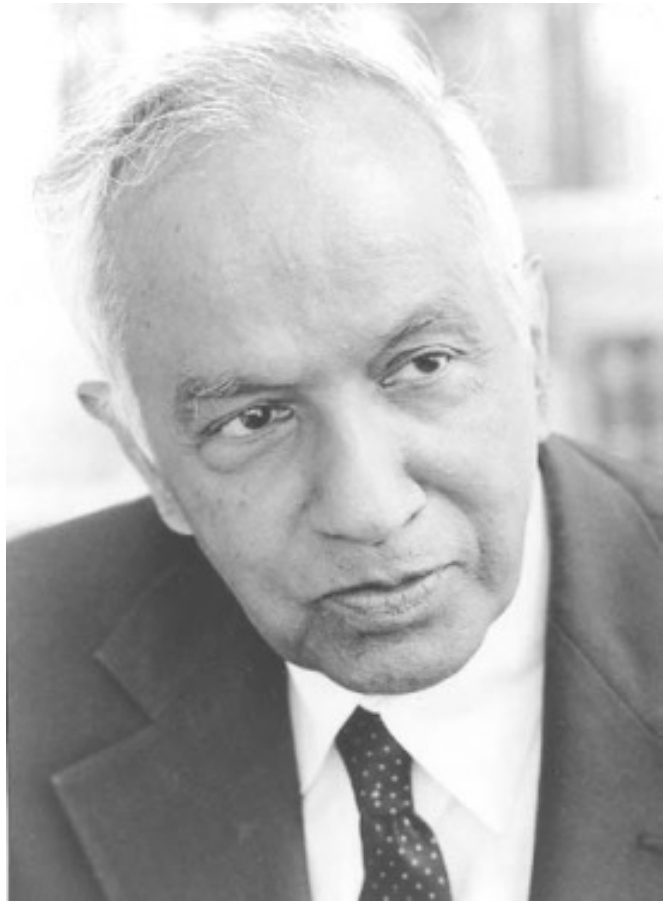


FIGURE 1

大规模巡天简史

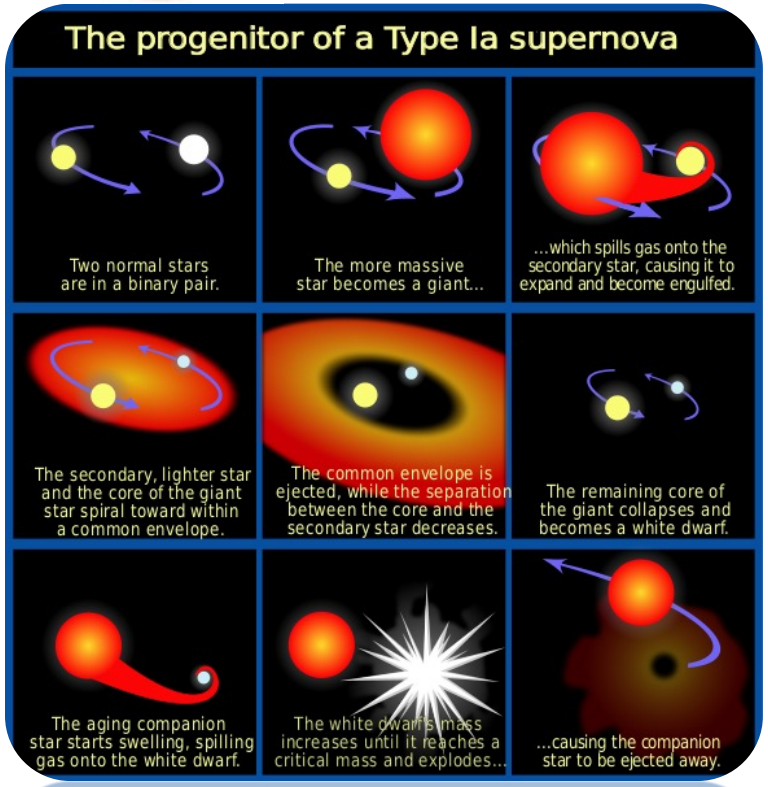
从“宇宙膨胀”到“哈勃常数危机”

第三章：宇宙加速膨胀

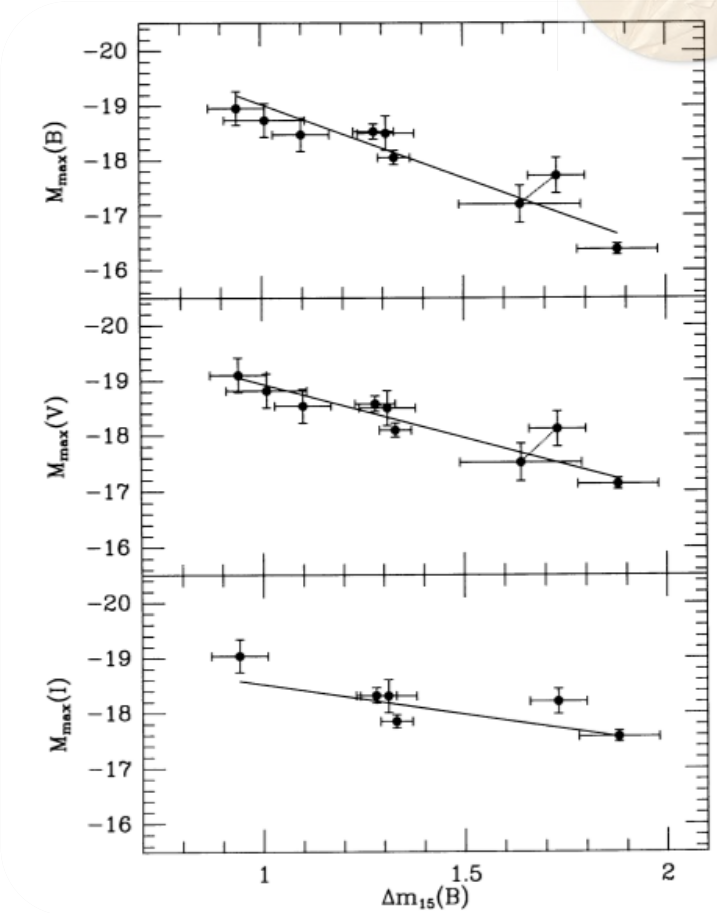


$$M_{\rm limit} = \frac{\omega_3^0\sqrt{3\pi}}{2}\left(\frac{\hbar c}{G}\right)^{3/2}\frac{1}{(\mu_{\rm e}m_{\rm H})^2},$$

1983 Nobel Prize



Phillips 1993



大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”

第三章：宇宙加速膨胀

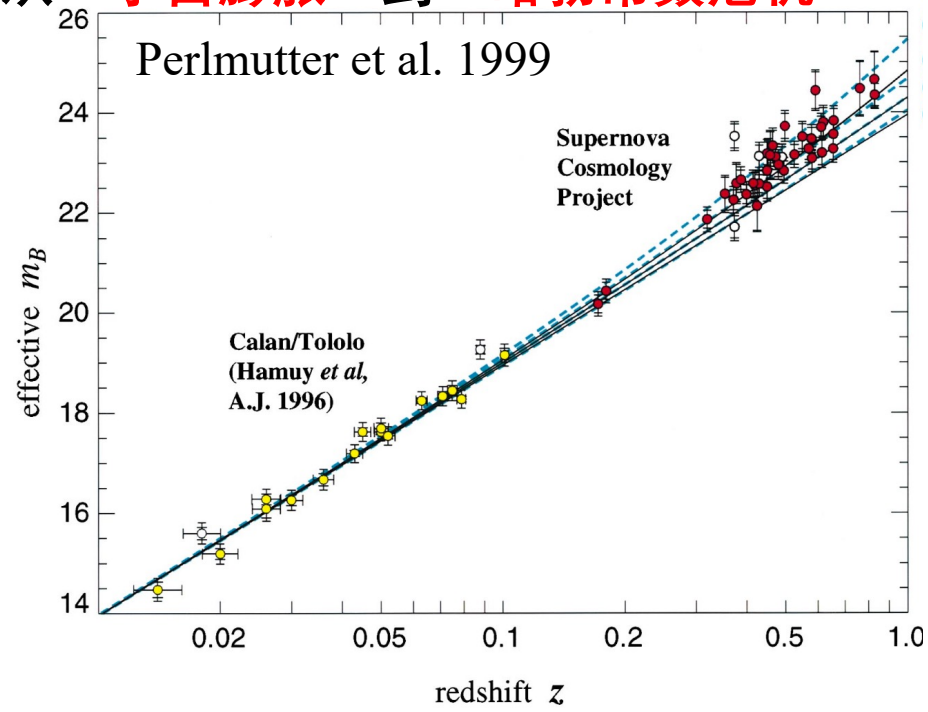
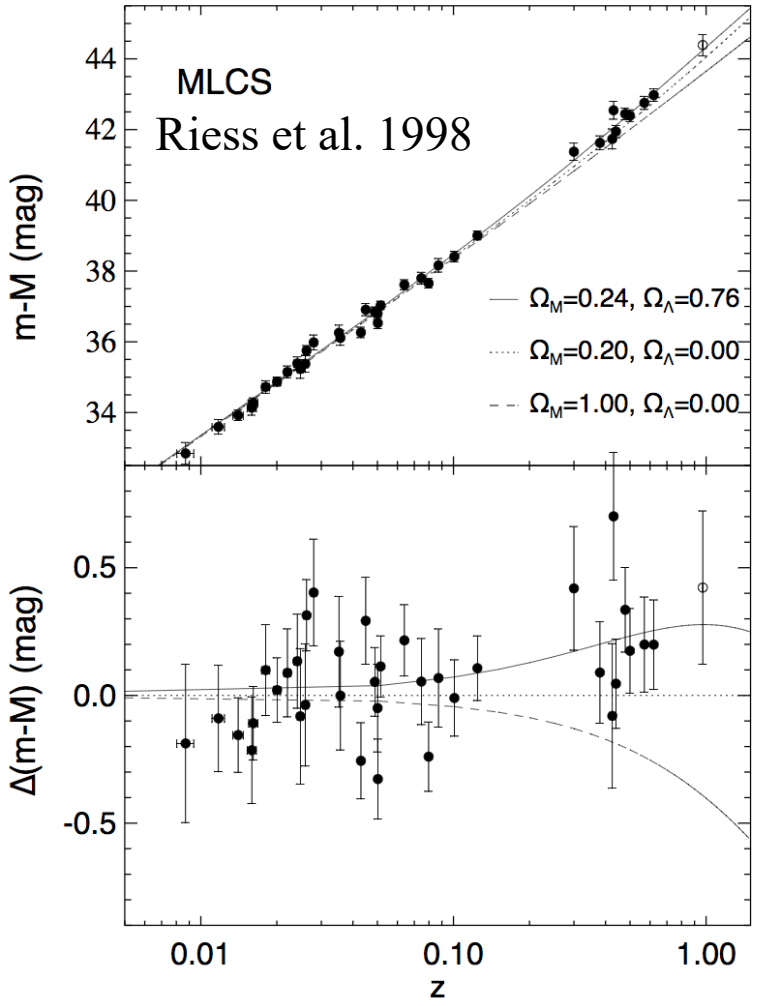


Photo: U. Montan
Saul Perlmutter
Prize share: 1/2

Photo: U. Montan
Brian P. Schmidt
Prize share: 1/4

Photo: U. Montan
Adam G. Riess
Prize share: 1/4

2011 Nobel Prize



大规模巡天简史

从“宇宙膨胀”到“哈勃常数危机”

第四章：再生波澜—哈勃常数危机

Riess et al. 2016, ApJ, 826, 56 (>1700 citations)

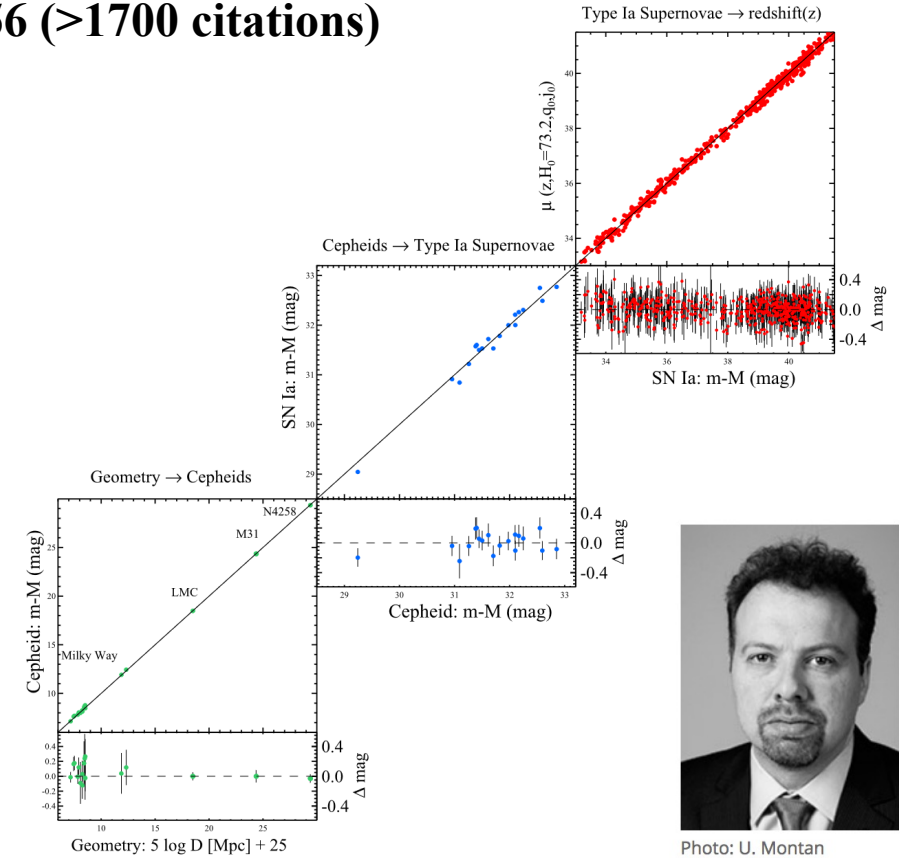


Photo: U. Montan
Adam G. Riess
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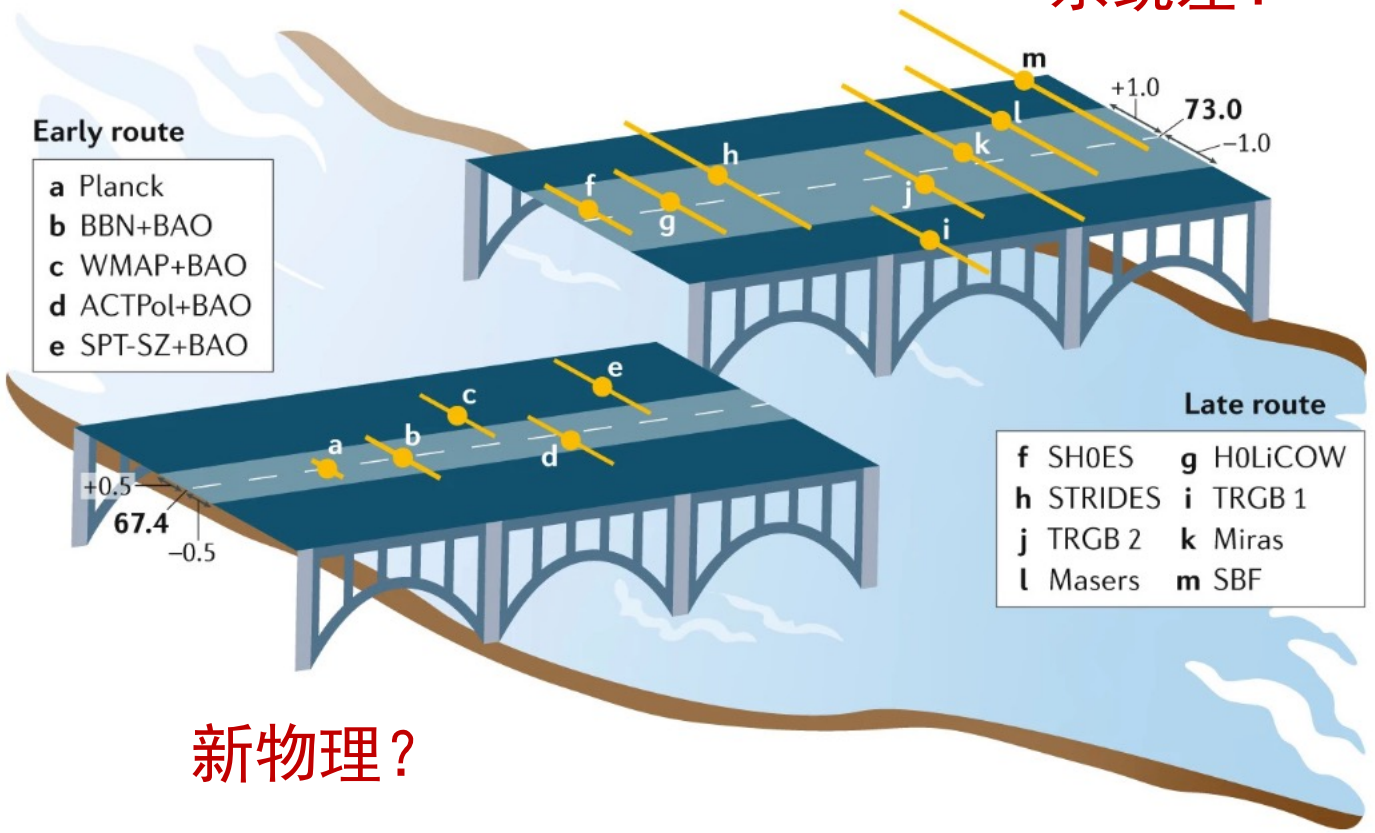
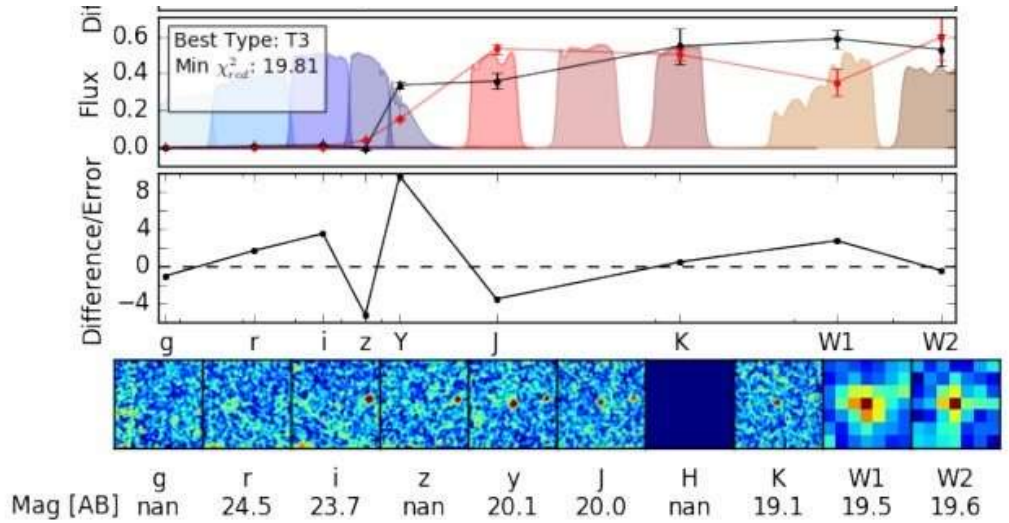
系统差？



新物理？

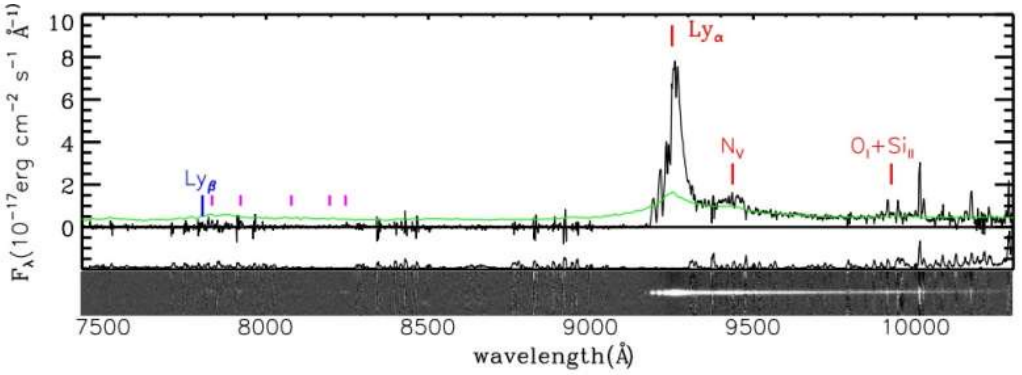
河外天文

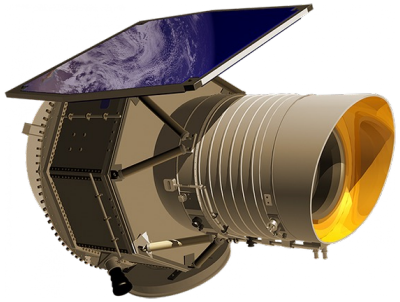
大规模巡天简史



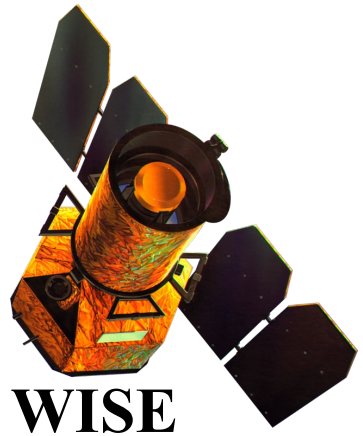
多波段星等

天体红移、化学组成



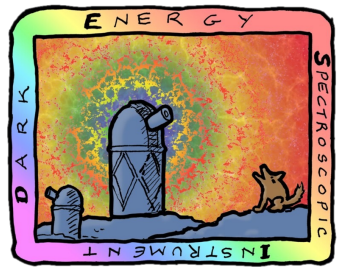


Galex

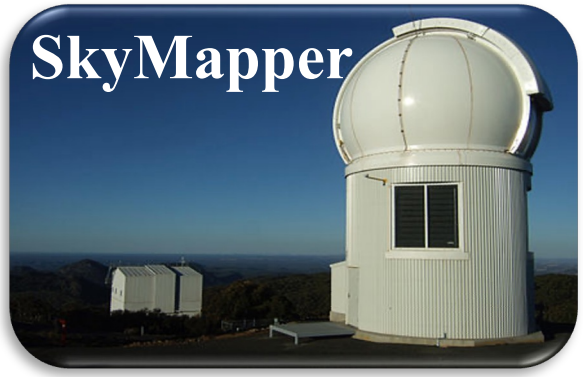


WISE

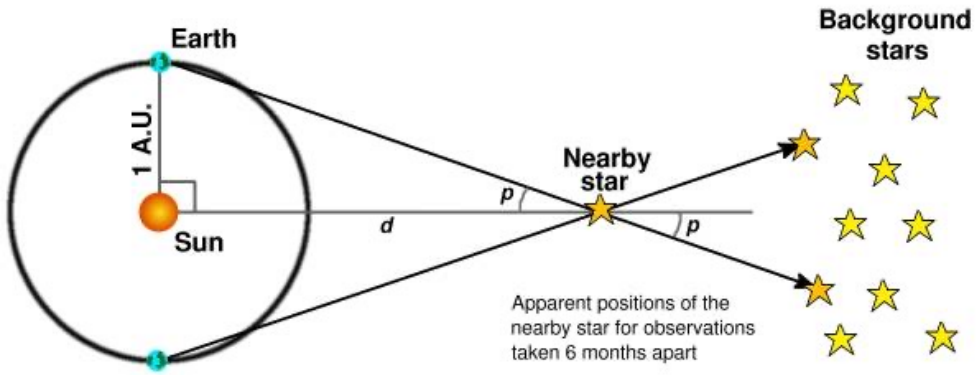
DESI



2MASS



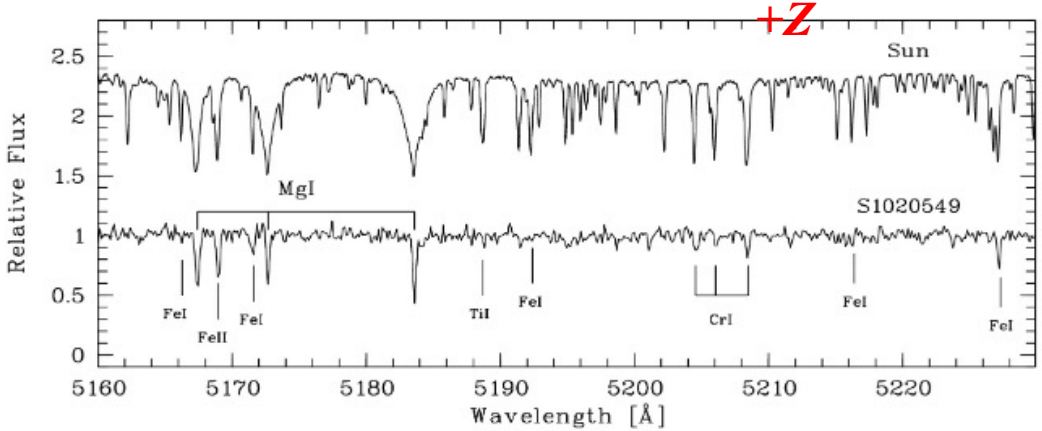
大规模巡天简史

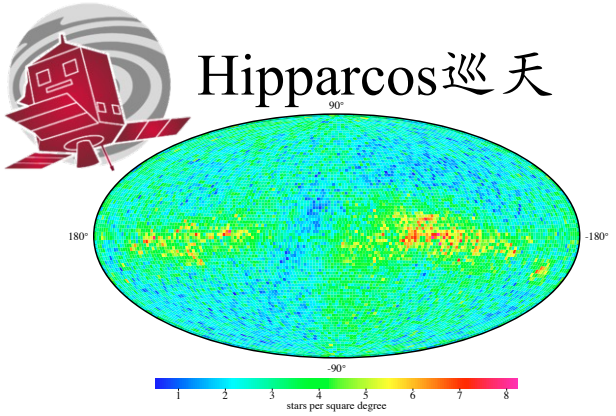


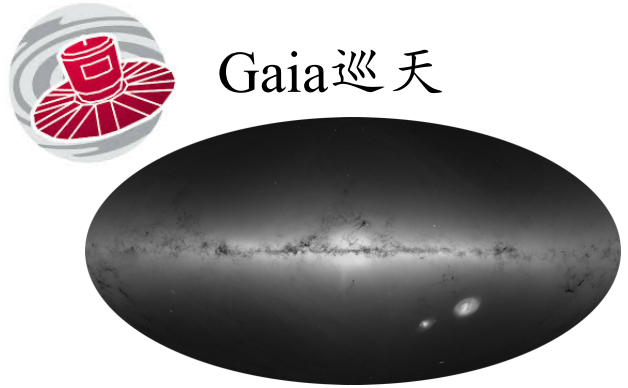
天体位置、自行、视差

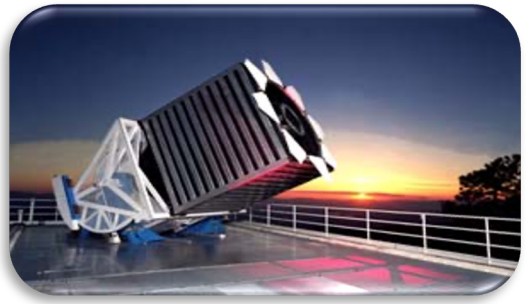
天体视向速度、化学组成

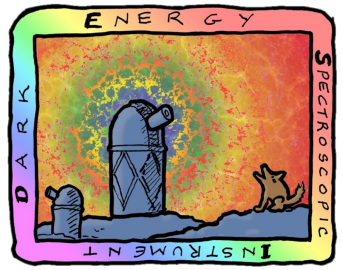
完备相空间信息：**三维位置、三维速度+年龄+Z**



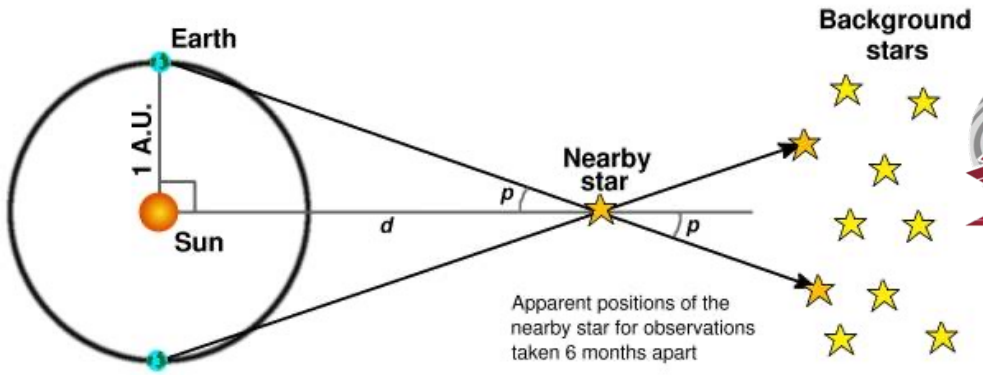








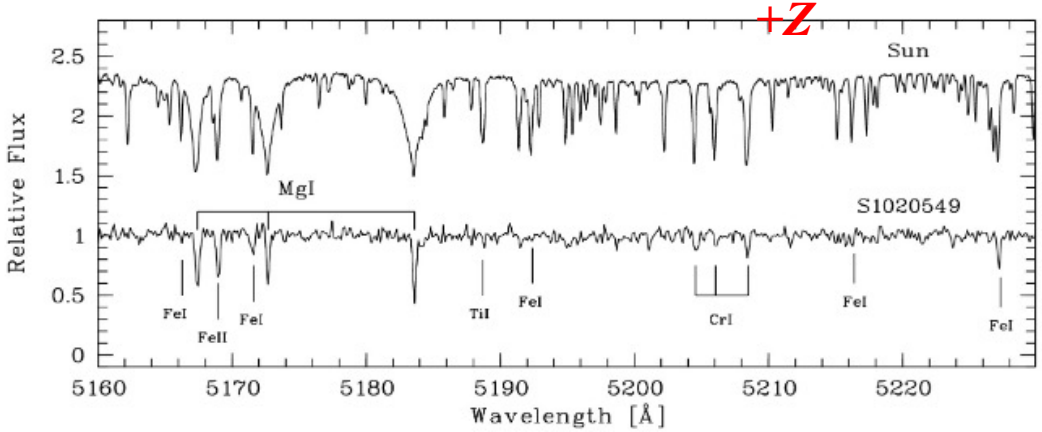
大规模巡天简史

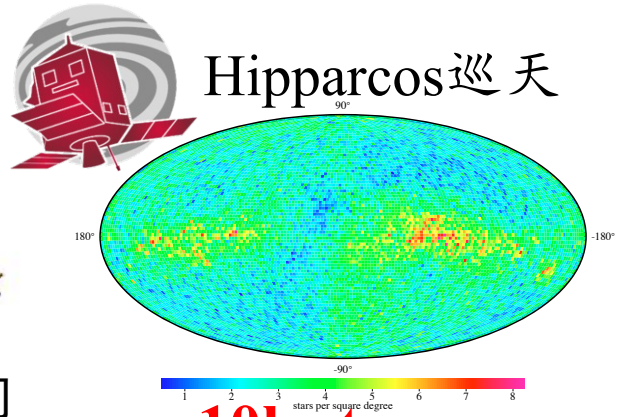


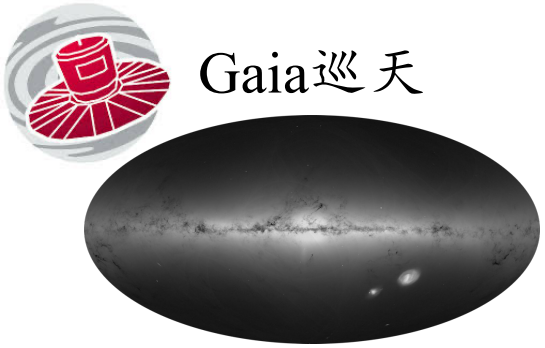
天体位置、自行、视差

天体视向速度、化学组成

完备相空间信息：三维位置、三维速度+年龄+Z





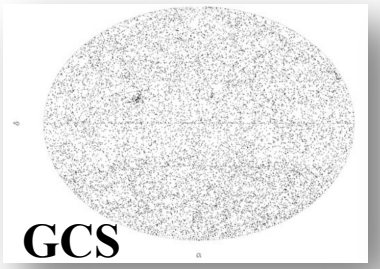


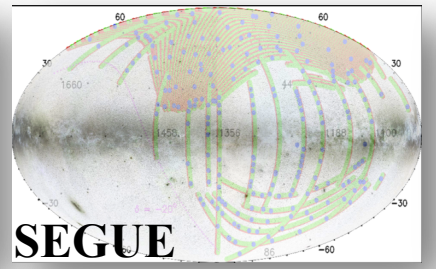
~10k stars

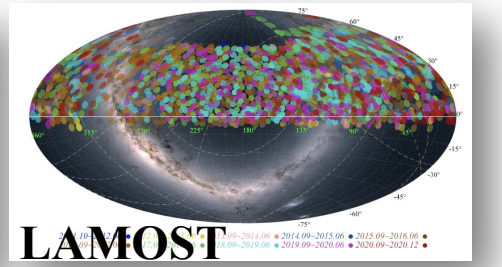
>1B stars

2000年 2010年 2020年

~10k stars ~1M stars ~10M stars





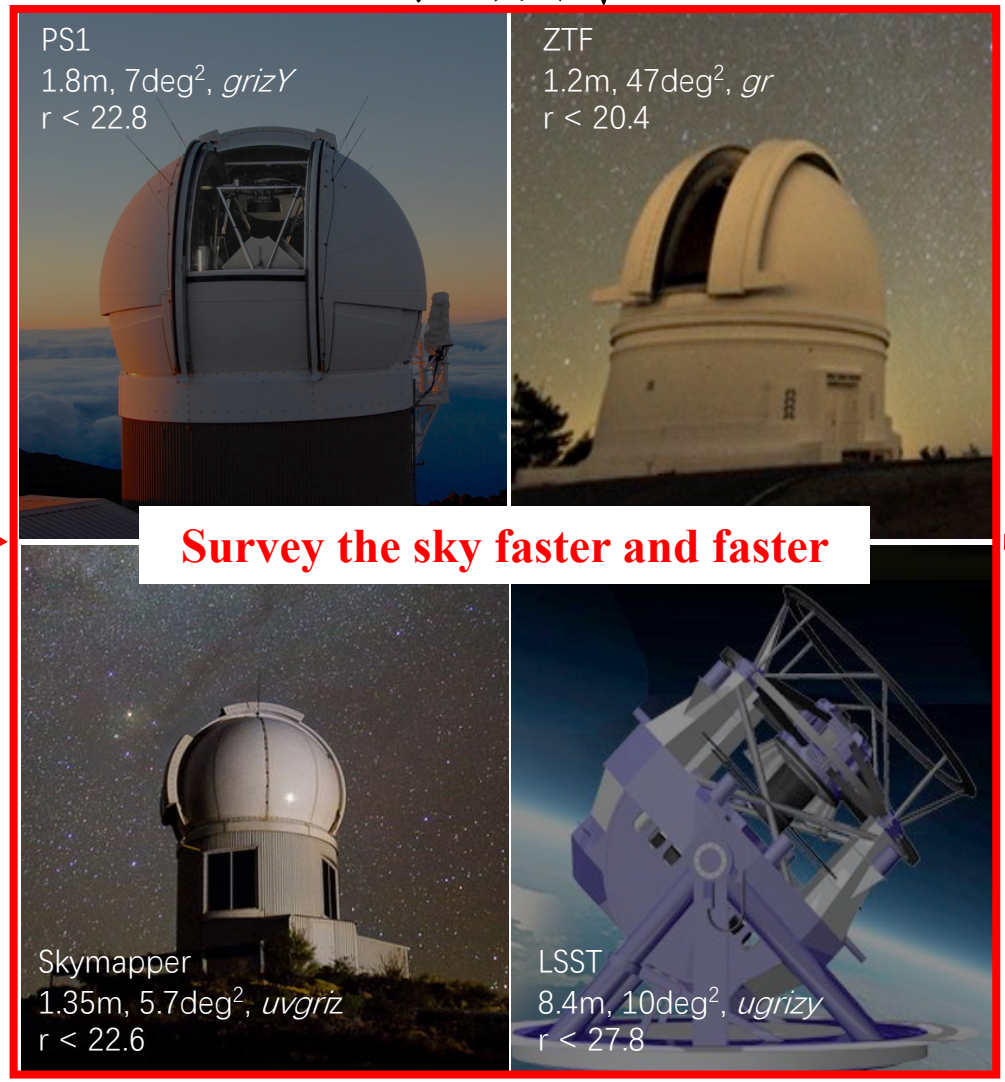


巨大进展：银河系大规模巡天

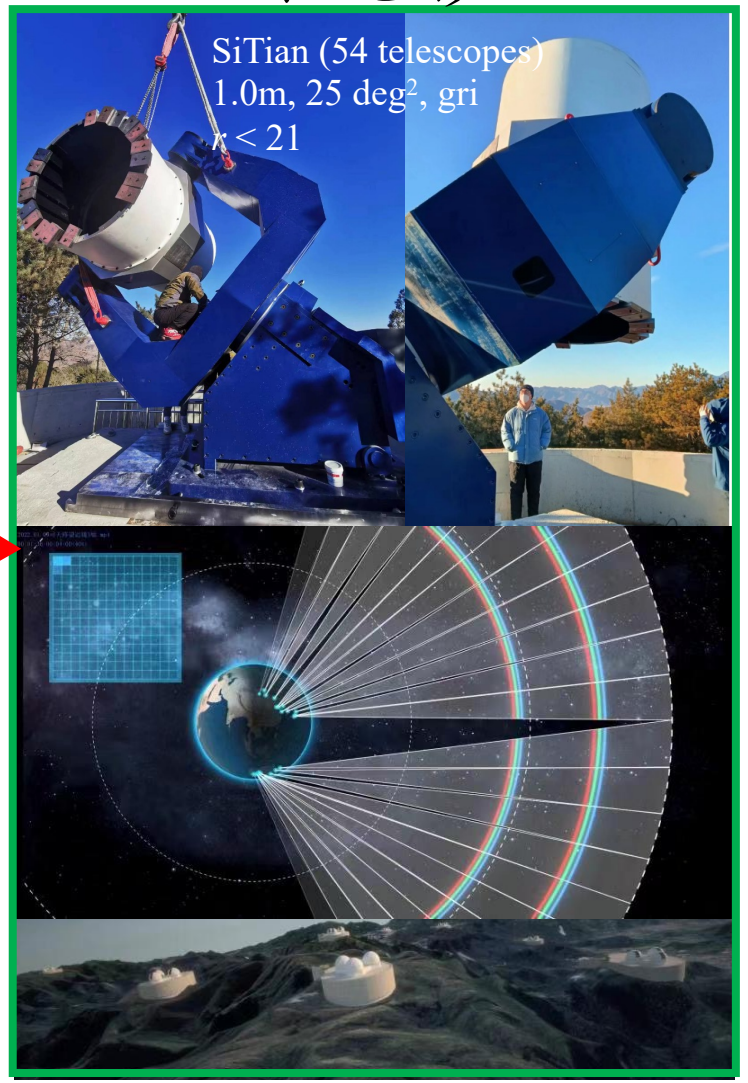
大规模巡天简史

拍照片

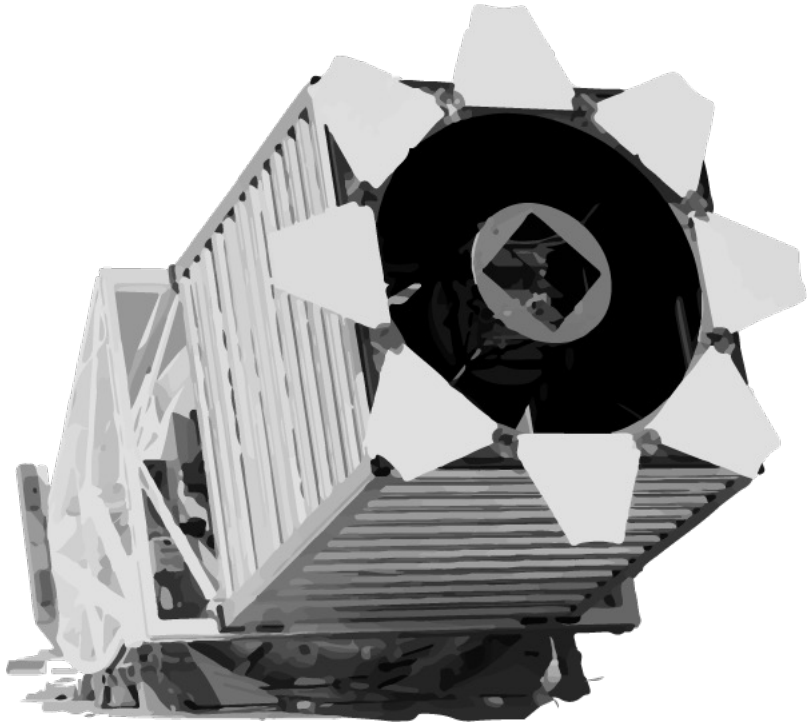
拍动图



拍电影



大规模巡天简史



Sloan Digital Sky Survey – Mapping the universe

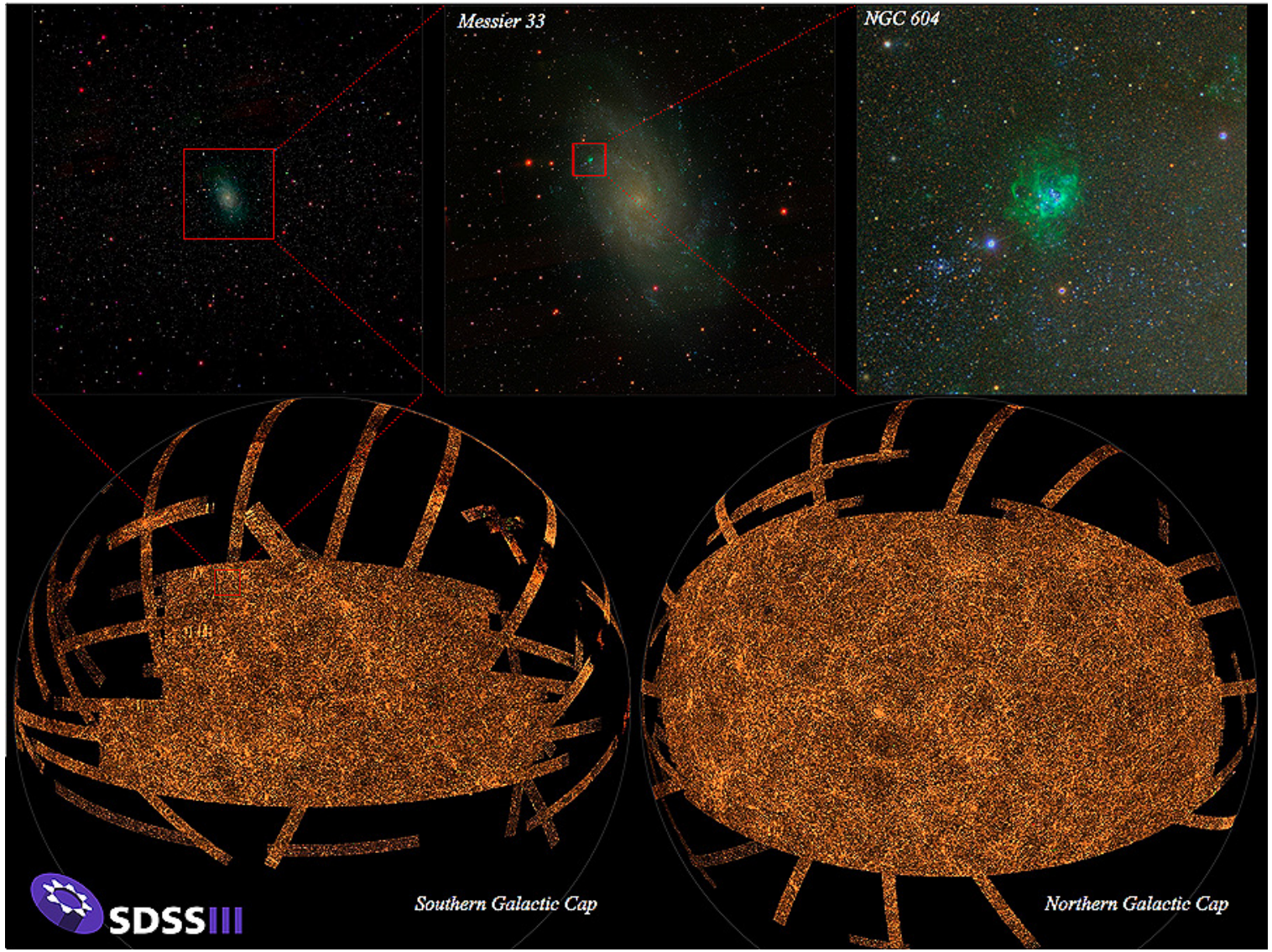
2000—present

Imaging survey (ugriz)

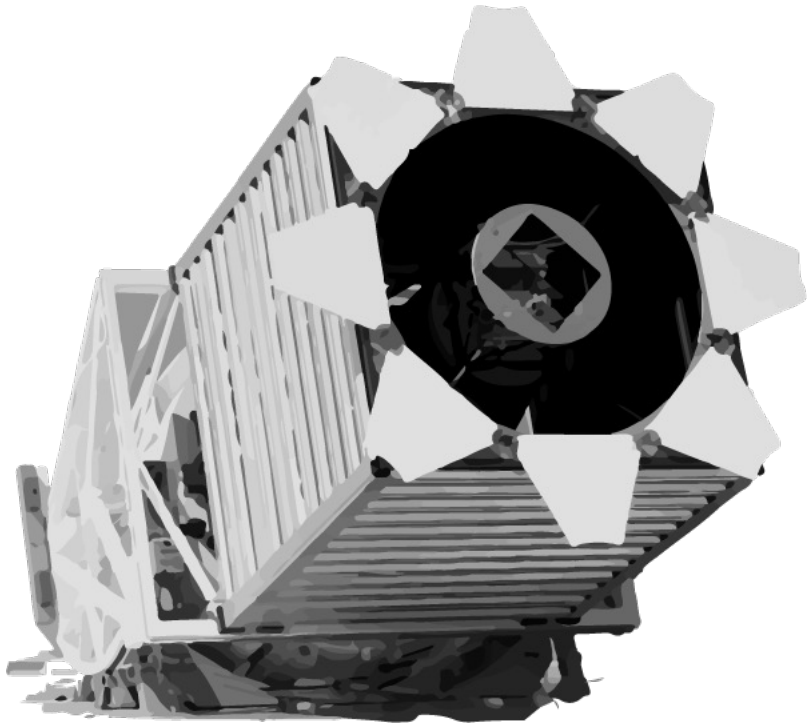
BOSS

SEGUE

APOGEE



大规模巡天简史



Sloan Digital Sky Survey – Mapping the universe

2000—present

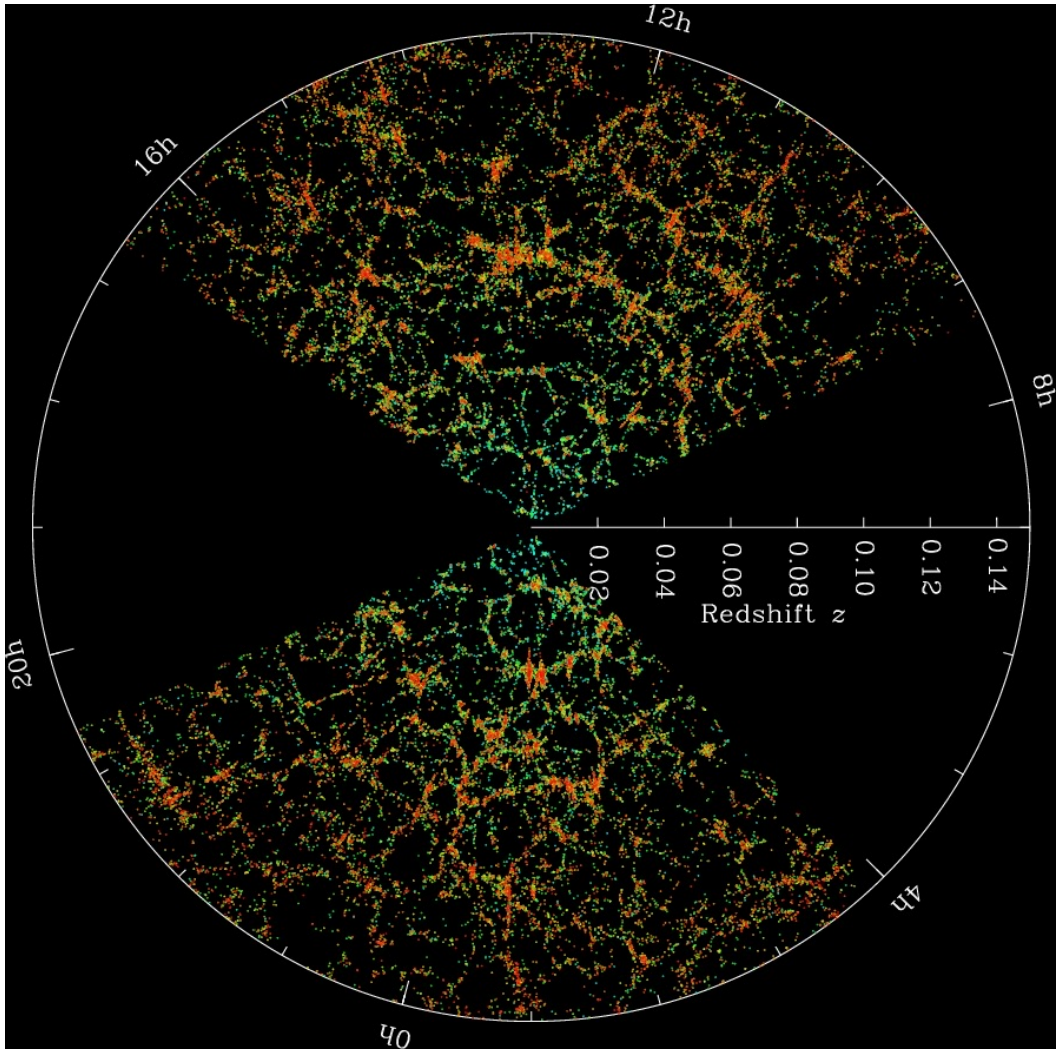
Imaging survey (ugriz)

BOSS

SEGUE

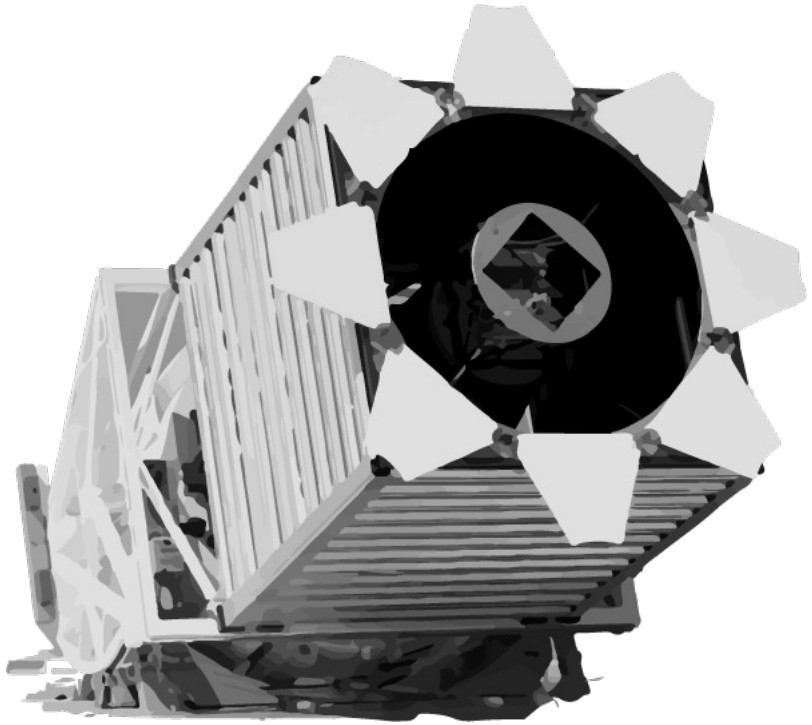
APOGEE

Galaxy map



M. Blanton and the Sloan Digital Sky Survey

大规模巡天简史



Sloan Digital Sky Survey – Mapping the universe

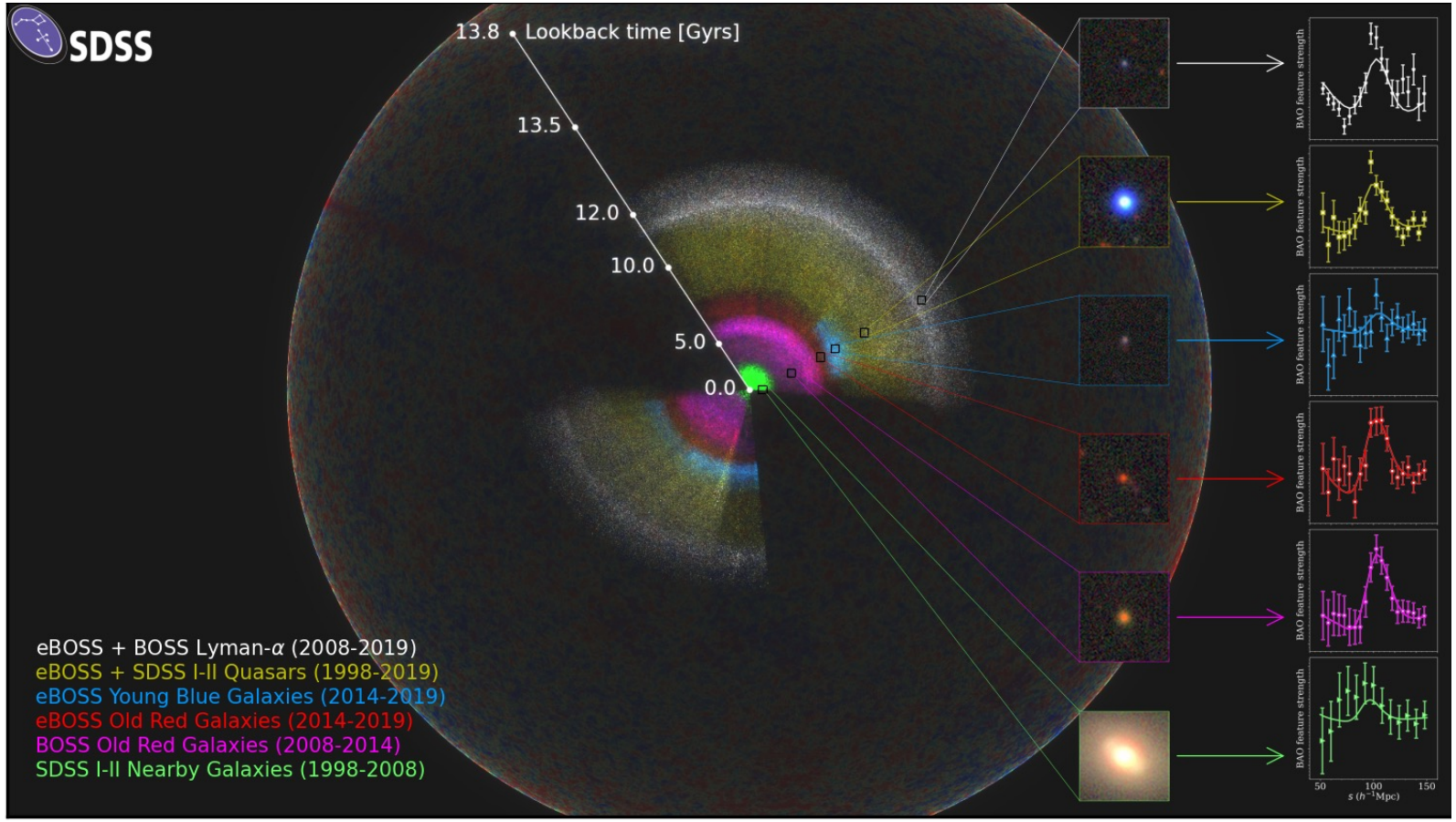
2000—present

Imaging survey (ugriz)

BOSS

SEGUE

APOGEE



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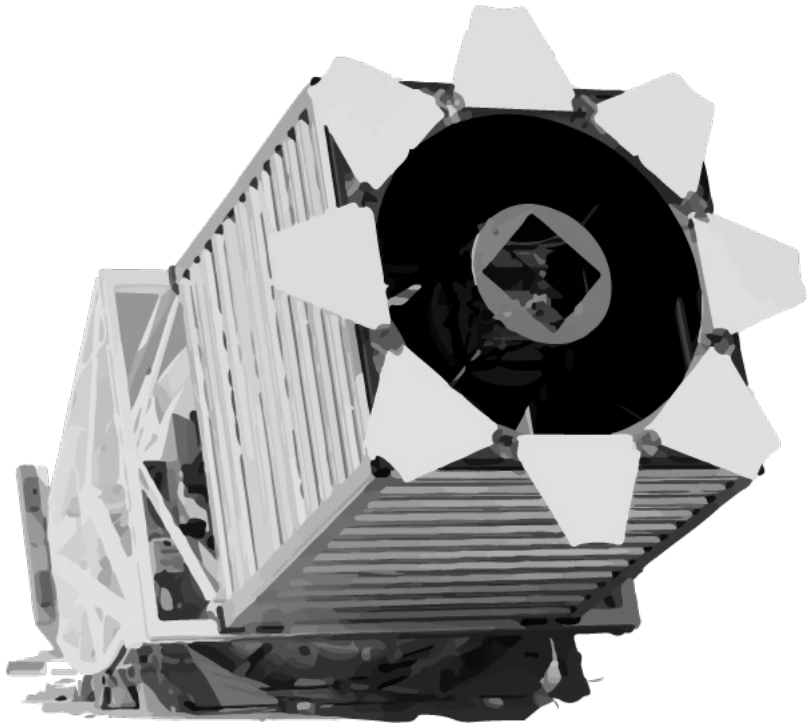


Sloan Digital Sky Survey – Mapping the universe

2000—present

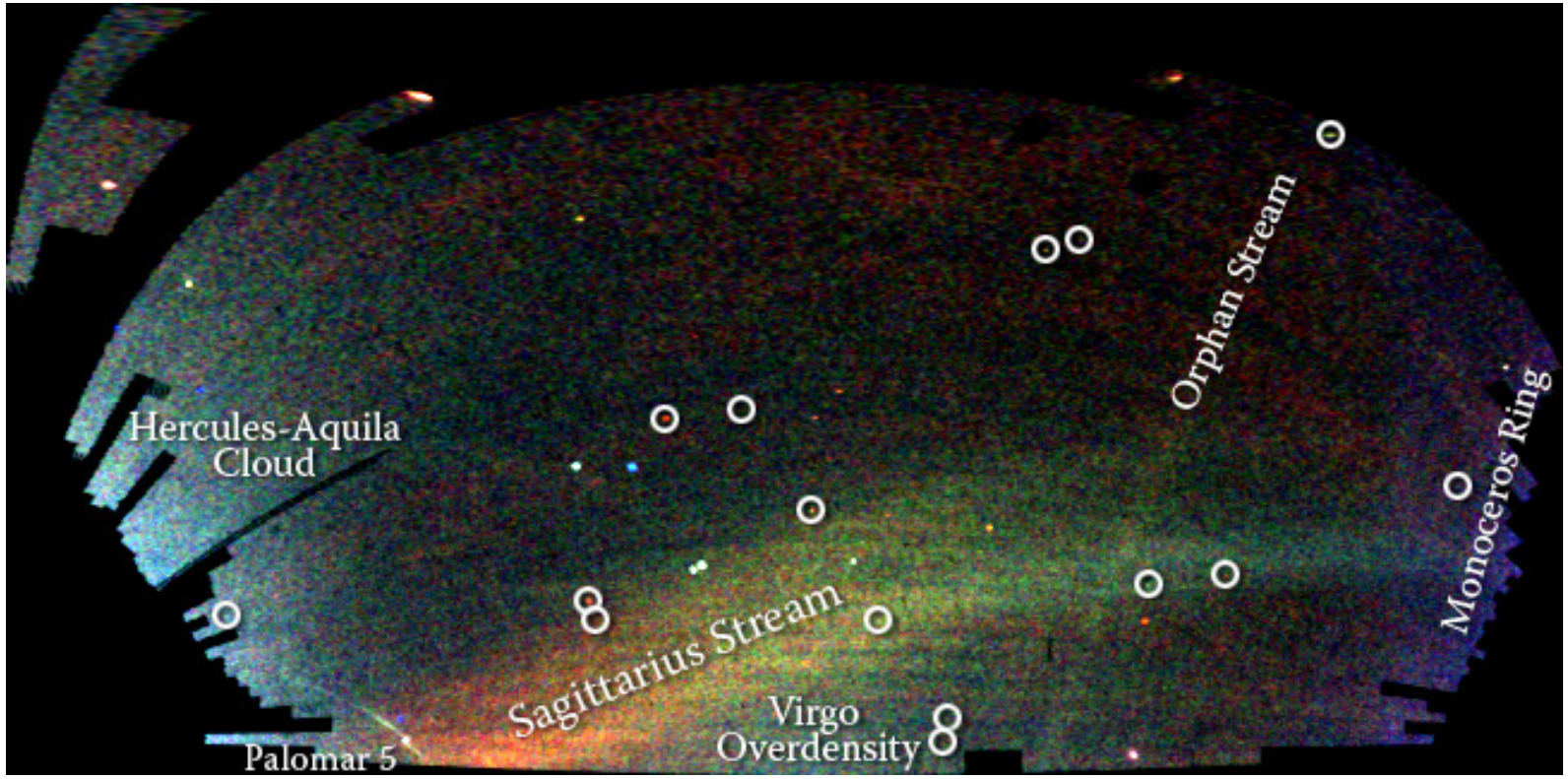
Imaging survey (ugriz)

BOSS

SEGUE

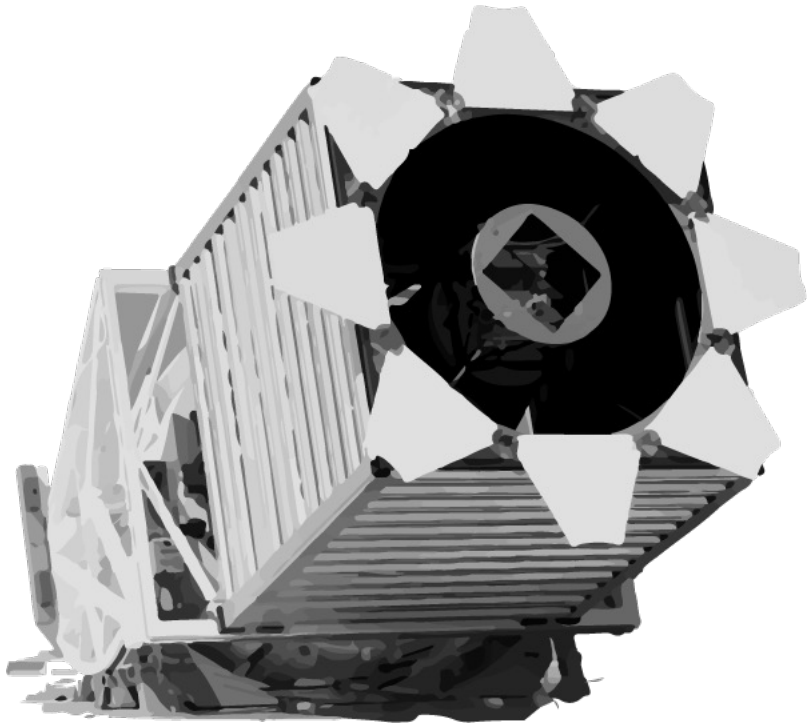
APOGEE

Stellar Streams



V. Belokurov and the Sloan Digital Sky Survey

大规模巡天简史



Sloan Digital Sky Survey – Mapping the universe

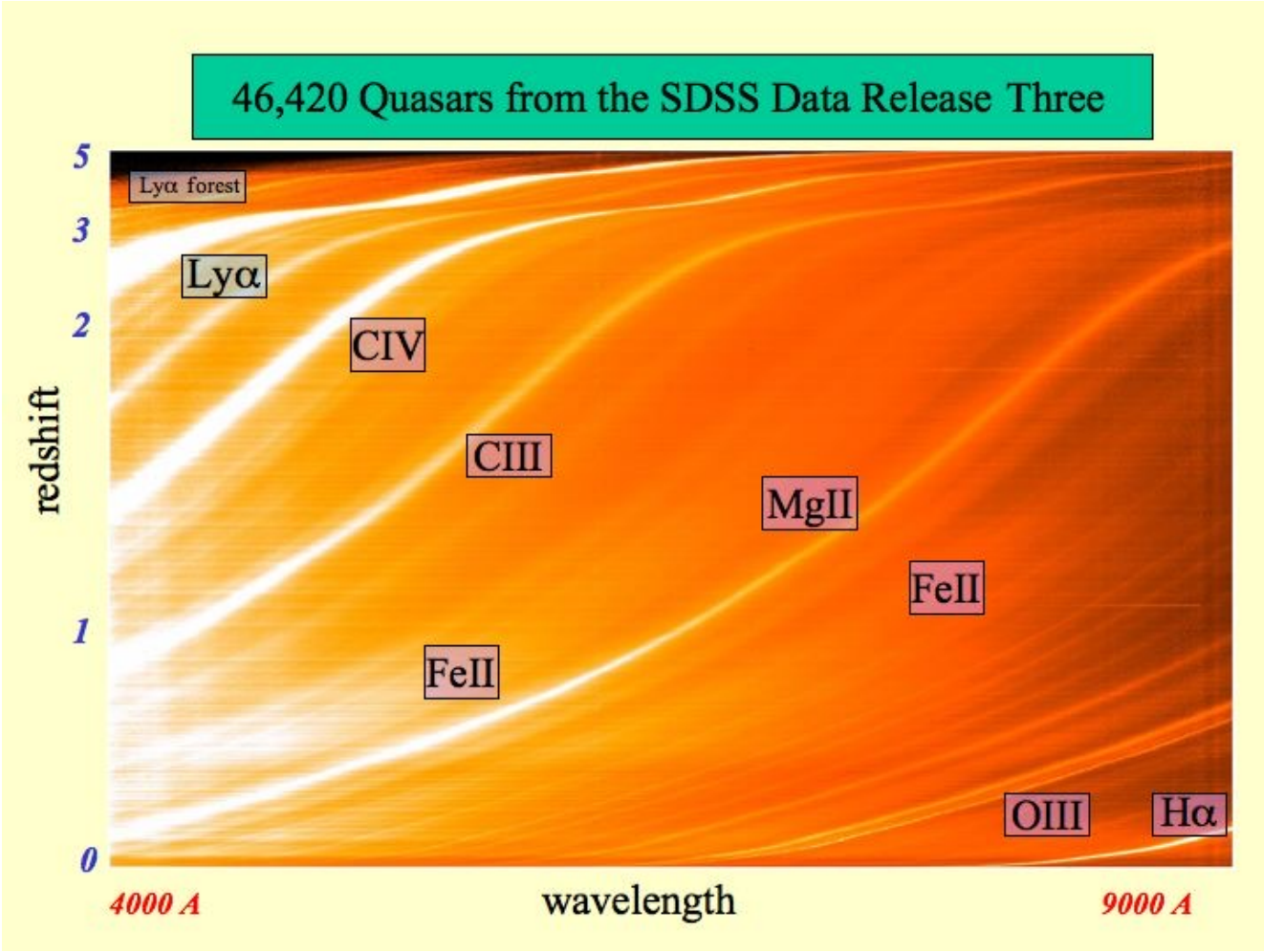
2000—present

Imaging survey (ugriz)

BOSS

SEGUE

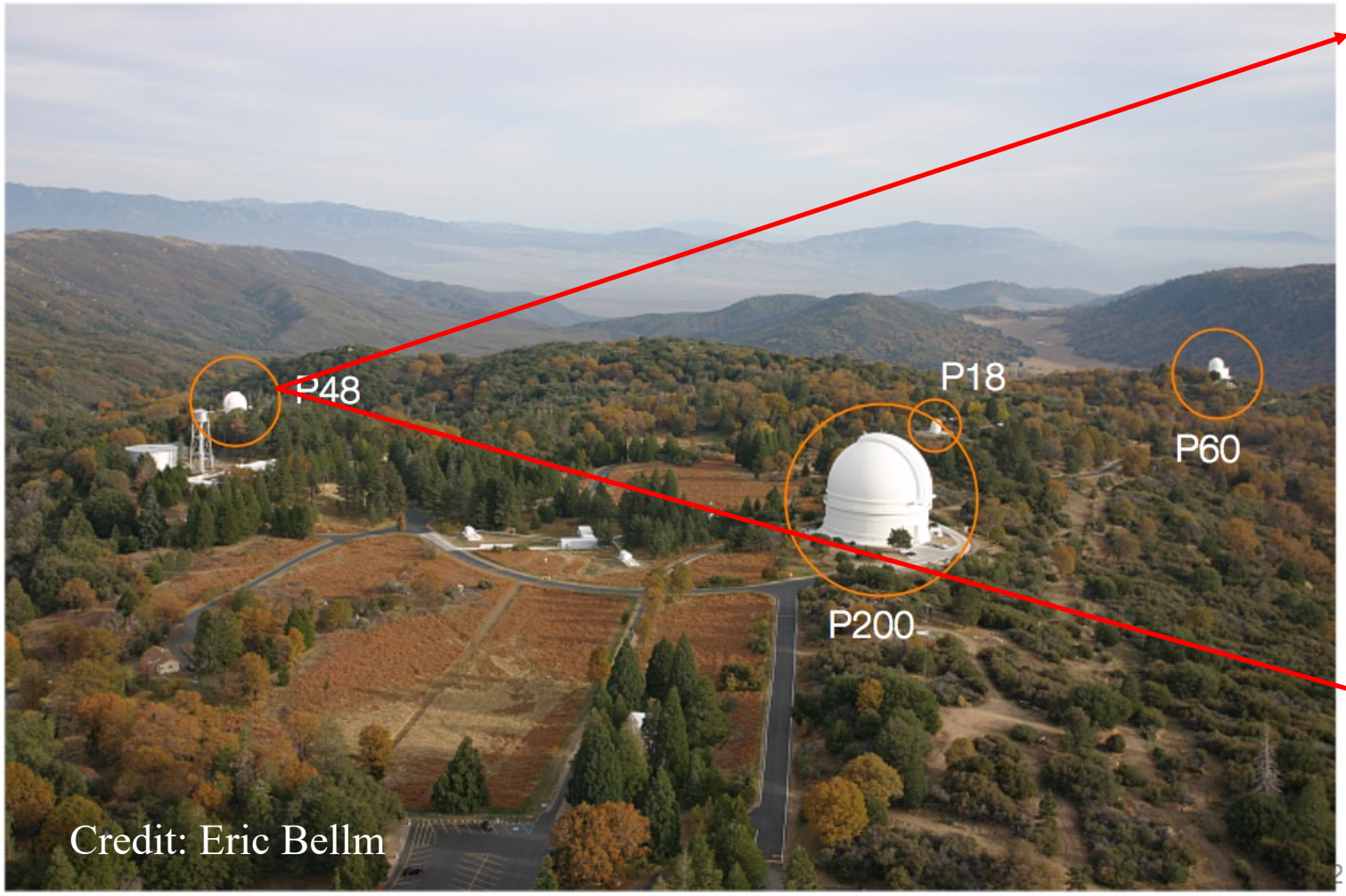
APOGEE



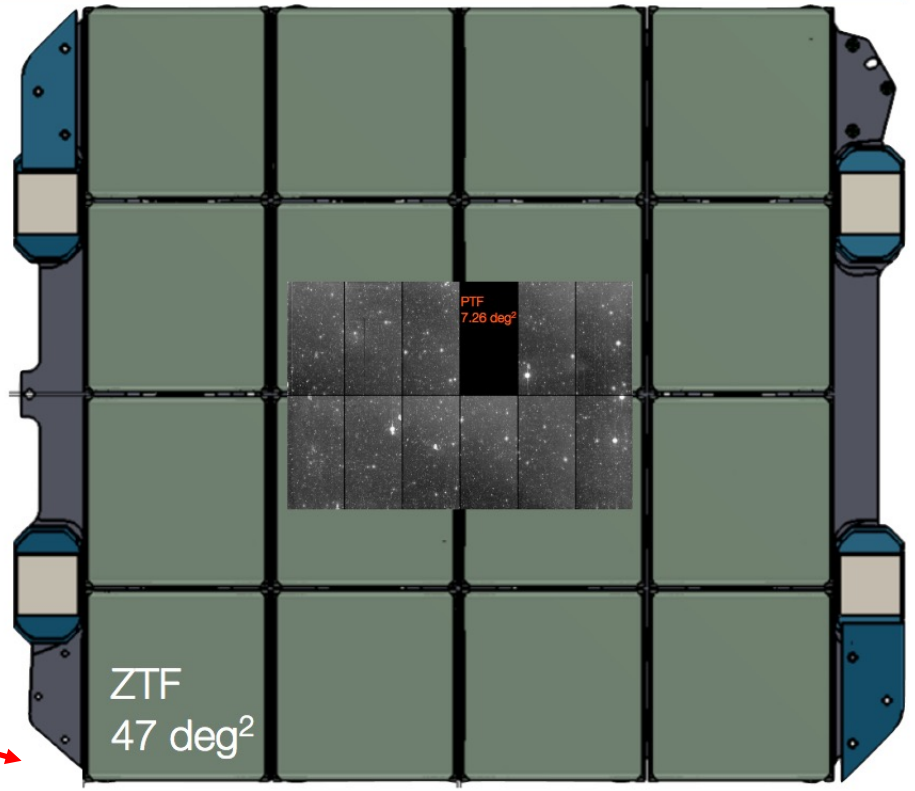
X. Fan and the Sloan Digital Sky Survey

大规模巡天简史

Palomar Observatory uses several telescopes.



new camera will fill the P48 focal plane.



大规模巡天简史

ZTF will survey an order of magnitude faster than PTF.

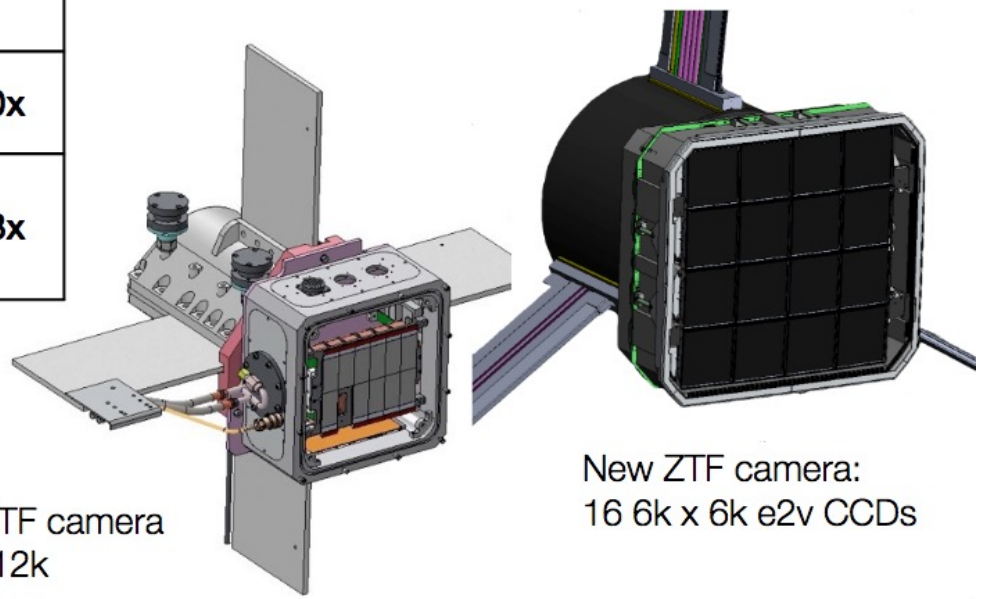
	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Overhead Time	46 sec	<15 sec
Optimal Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**15.0x**
Relative Volumetric Survey Rate	1x	**12.3x**

3750 deg^2/hour

⇒ 3π survey in 8 hours

>250 observations/field/year

for uniform survey



Existing PTF camera
MOSAIC 12k

New ZTF camera:
16 6k x 6k e2v CCDs

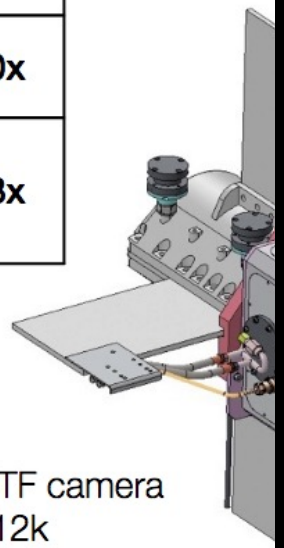
大规模巡天简史

ZTF will survey an order of mag

375(

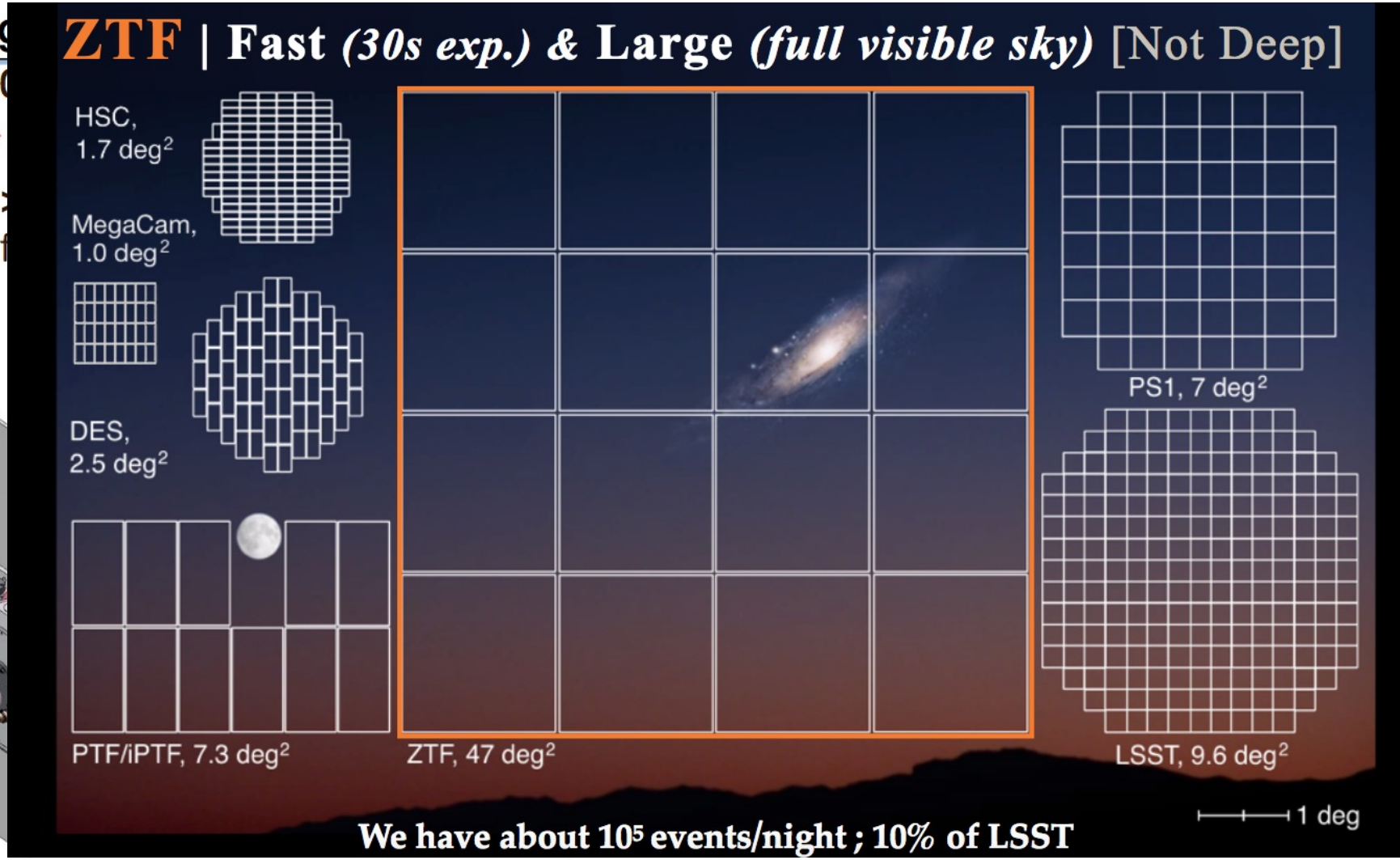
⇒

	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Overhead Time	46 sec	<15 sec
Optimal Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**15.0x**
Relative Volumetric Survey Rate	1x	**12.3x**



Existing PTF camera
MOSAIC 12k

Credit: Eric Bellm



大规模巡天简史

Data Release Guides

DATA RELEASE 17

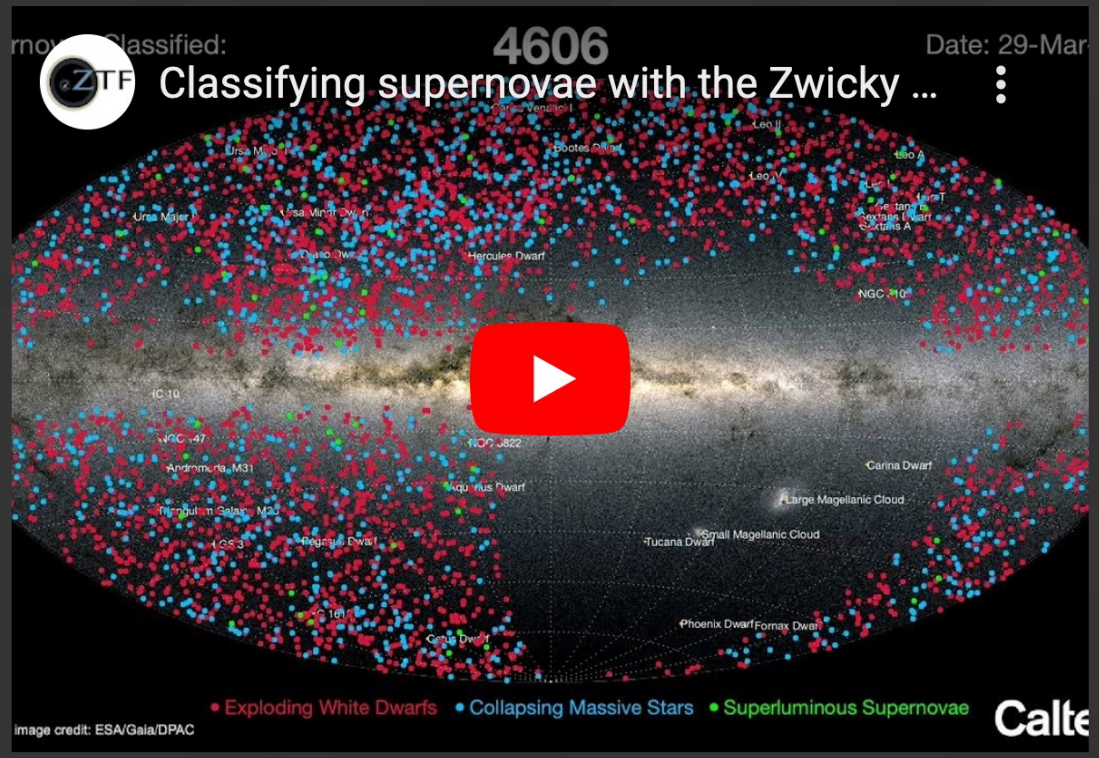
Total observation span: March 2018 - March 2023

This release adds 2 months of observations to the sixteenth data release, up to 9 March 2023 for the public portion of the survey, and private survey time prior to 6 Nov 2021. The products include 48.7 million single-exposure images, 174 thousand co-added images, accompanying source catalog files containing 756 billion source detections extracted from those images, and 4.66 billion light curves constructed from the single-exposure extractions.

Guide | Access

大规模巡天简史

FEATURED VIDEO



DISCOVERED SO FAR...

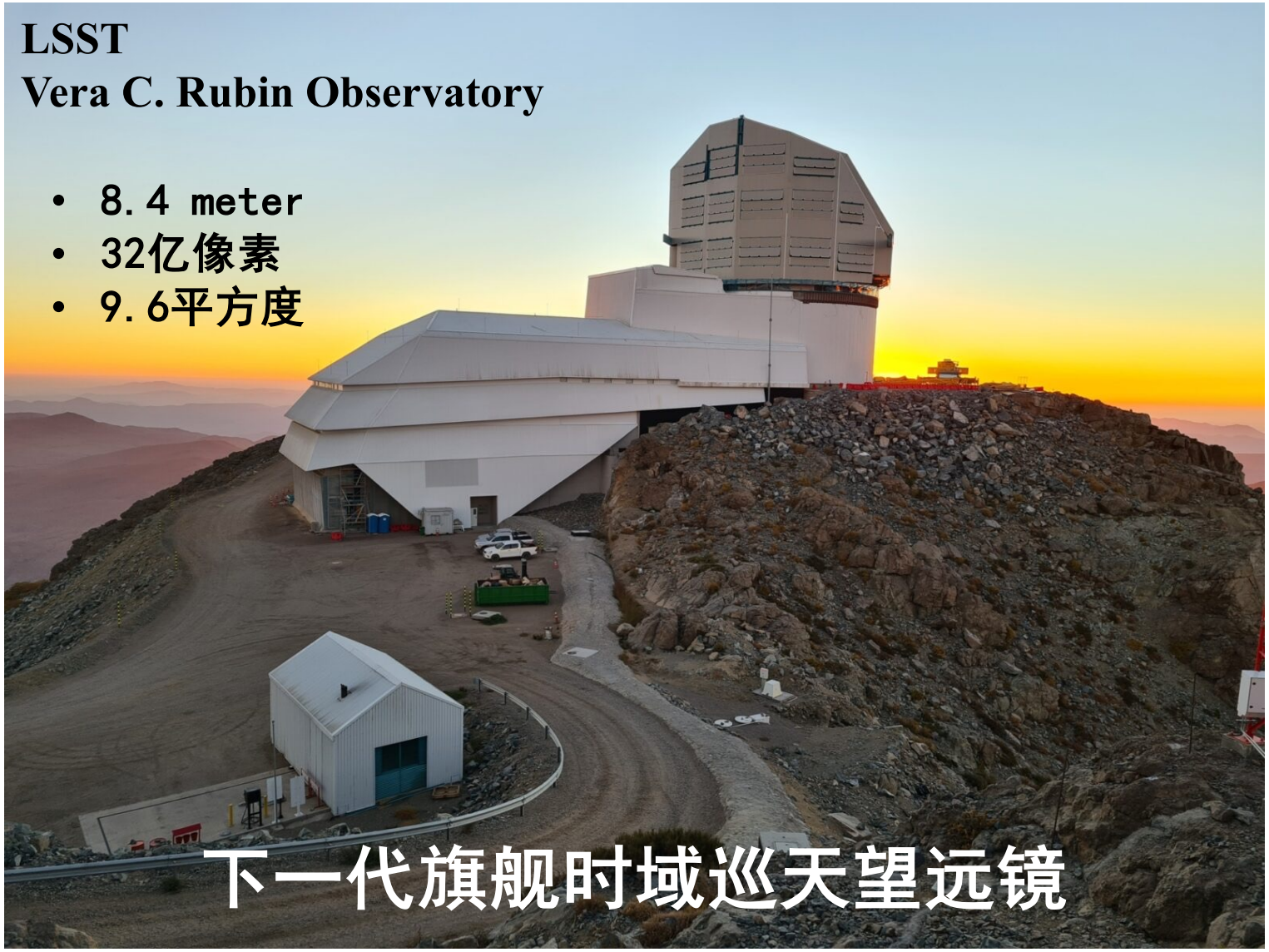
7297
Classified Supernovae

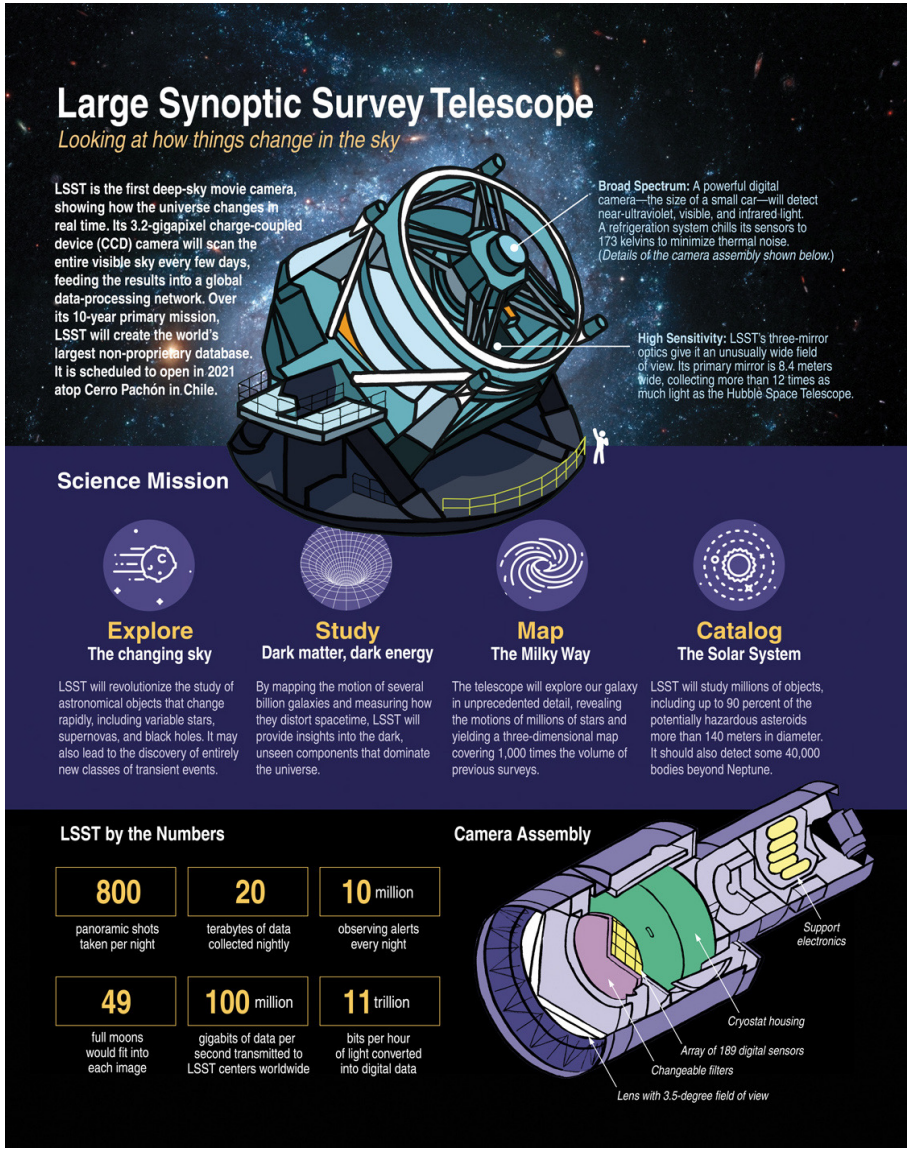
78
Tidal Disruption Events

231
Near Earth Asteroids & Comets

45
Ultra-compact Binaries

大规模巡天简史


LSST
Vera C. Rubin Observatory
• 8.4 meter
• 32亿像素
• 9.6平方度
下一代旗舰时域巡天望远镜


Large Synoptic Survey Telescope
Looking at how things change in the sky
LSST is the first deep-sky movie camera, showing how the universe changes in real time. Its 3.2-gigapixel charge-coupled device (CCD) camera will scan the entire visible sky every few days, feeding the results into a global data-processing network. Over its 10-year primary mission, LSST will create the world's largest non-proprietary database. It is scheduled to open in 2021 atop Cerro Pachón in Chile.
Broad Spectrum: A powerful digital camera—the size of a small car—will detect near-ultraviolet, visible, and infrared light. A refrigeration system chills its sensors to 173 kelvins to minimize thermal noise. (Details of the camera assembly shown below.)
High Sensitivity: LSST's three-mirror optics give it an unusually wide field of view. Its primary mirror is 8.4 meters wide, collecting more than 12 times as much light as the Hubble Space Telescope.
Science Mission
Explore
The changing sky
LSST will revolutionize the study of astronomical objects that change rapidly, including variable stars, supernovas, and black holes. It may also lead to the discovery of entirely new classes of transient events.
Study
Dark matter, dark energy
By mapping the motion of several billion galaxies and measuring how they distort spacetime, LSST will provide insights into the dark, unseen components that dominate the universe.
Map
The Milky Way
The telescope will explore our galaxy in unprecedented detail, revealing the motions of millions of stars and yielding a three-dimensional map covering 1,000 times the volume of previous surveys.
Catalog
The Solar System
LSST will study millions of objects, including up to 90 percent of the potentially hazardous asteroids more than 140 meters in diameter. It should also detect some 40,000 bodies beyond Neptune.
LSST by the Numbers
800
panoramic shots taken per night
20
terabytes of data collected nightly
10 million
observing alerts every night
49
full moons would fit into each image
100 million
gigabits of data per second transmitted to LSST centers worldwide
11 trillion
bits per hour of light converted into digital data
Camera Assembly
Support electronics
Cryostat housing
Array of 189 digital sensors
Changeable filters
Lens with 3.5-degree field of view

实践一：

（一）：用档案数据刻画银河系的尺寸（含太阳的位置）以及大小麦和M31的距离

（二）：用档案数据重新测定造父变星周光关系和Phillips关系

（三）：用档案数据测定哈勃常数

（四）：用档案数据测定宇宙是否加速膨胀


谢谢！
LAMOST与银河 ©Jin Ma 2012
2012.08.22 Nikon D90 + 10-24mm, F3.5, 14x30s, ISO2500
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