百年银河系研究

黄样

中国科学院大学

2026/08/14@雁栖湖

The Milky Way

ASTROPHYSICS

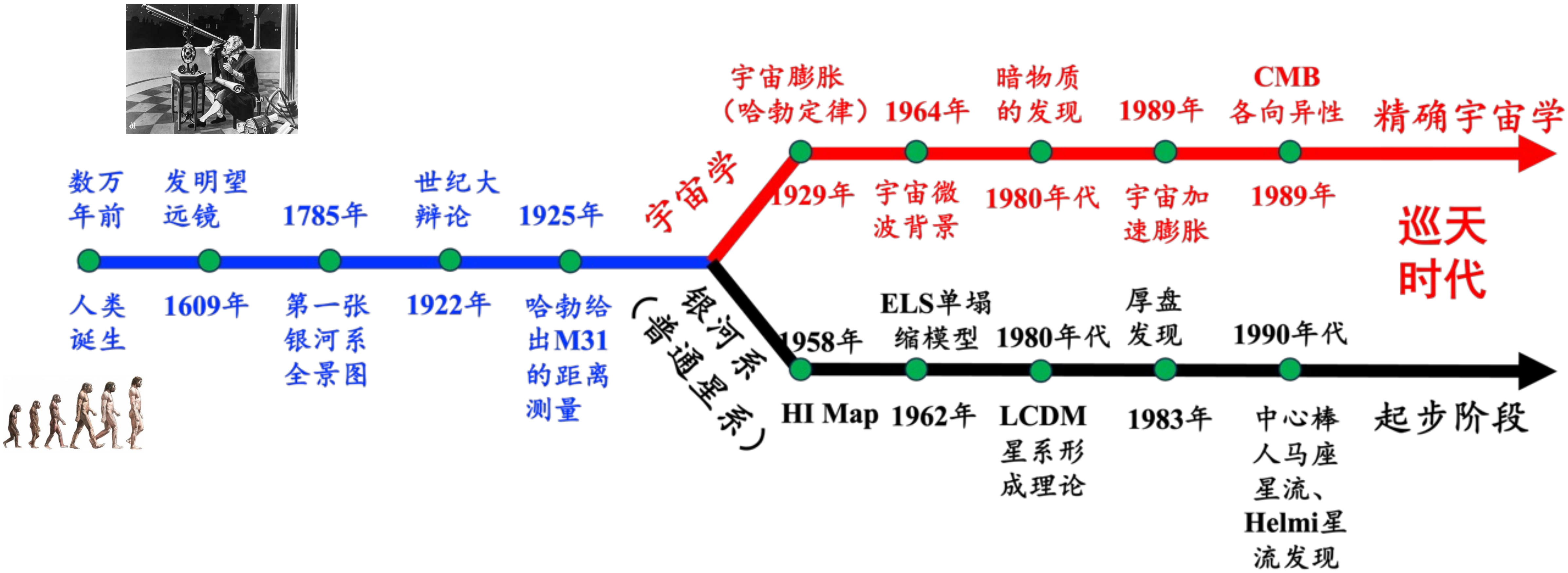
A history of violence: How mergers are rewriting the Milky Way's past

Vasily Belokurov, University of Cambridge, UK
Amina Helmi, University of Groningen, The Netherlands
Rodrigo Ibata, CNRS and University of Strasbourg, France

THE KAVLI PRIZE 2026

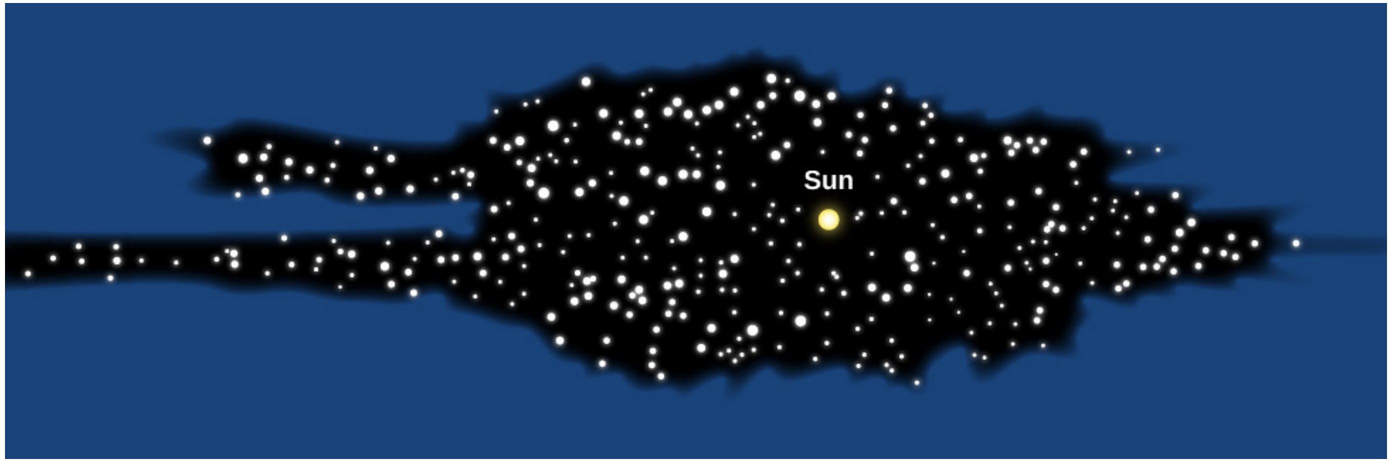
Vasily Belokurov, Amina Helmi and Rodrigo Ibata

银河系研究发展史


数万年前
人类诞生
发明望远镜
1609年
1785年
第一张银河系全景图
世纪大辩论
1922年
1925年
哈勃给出M31的距离测量
宇宙学
银河系（普通星系）
宇宙膨胀（哈勃定律）
1929年
1964年
宇宙微波背景
暗物质的发现
1980年代
1989年
宇宙加速膨胀
CMB各向异性
1989年
精确宇宙学
巡天时代
1958年
HI Map
ELS单塌缩模型
1962年
1980年代
LCDM星系形成理论
厚盘发现
1983年
1990年代
中心棒人马座星流、Helmi星流发现
起步阶段

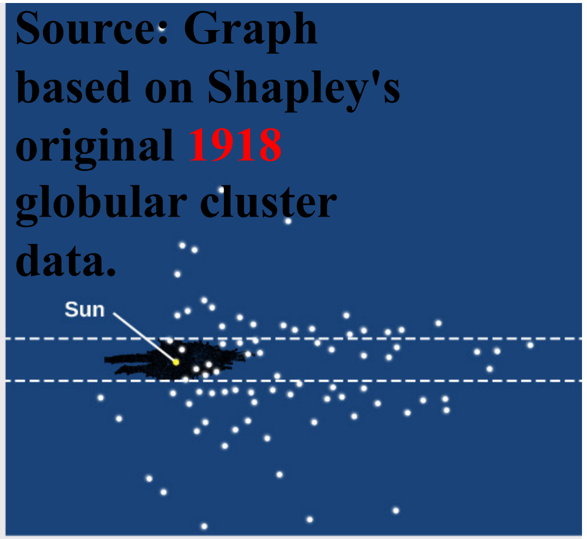
“中兴时代”

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)



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

(b)

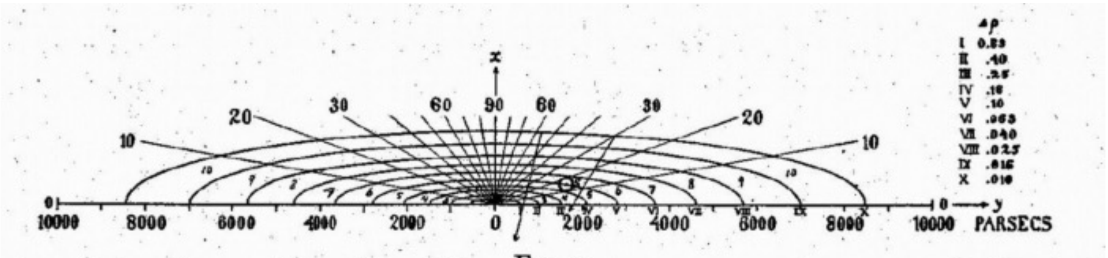


FIG. 1

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

“中兴时代”

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

“中兴时代”

勒维特与她的量天尺

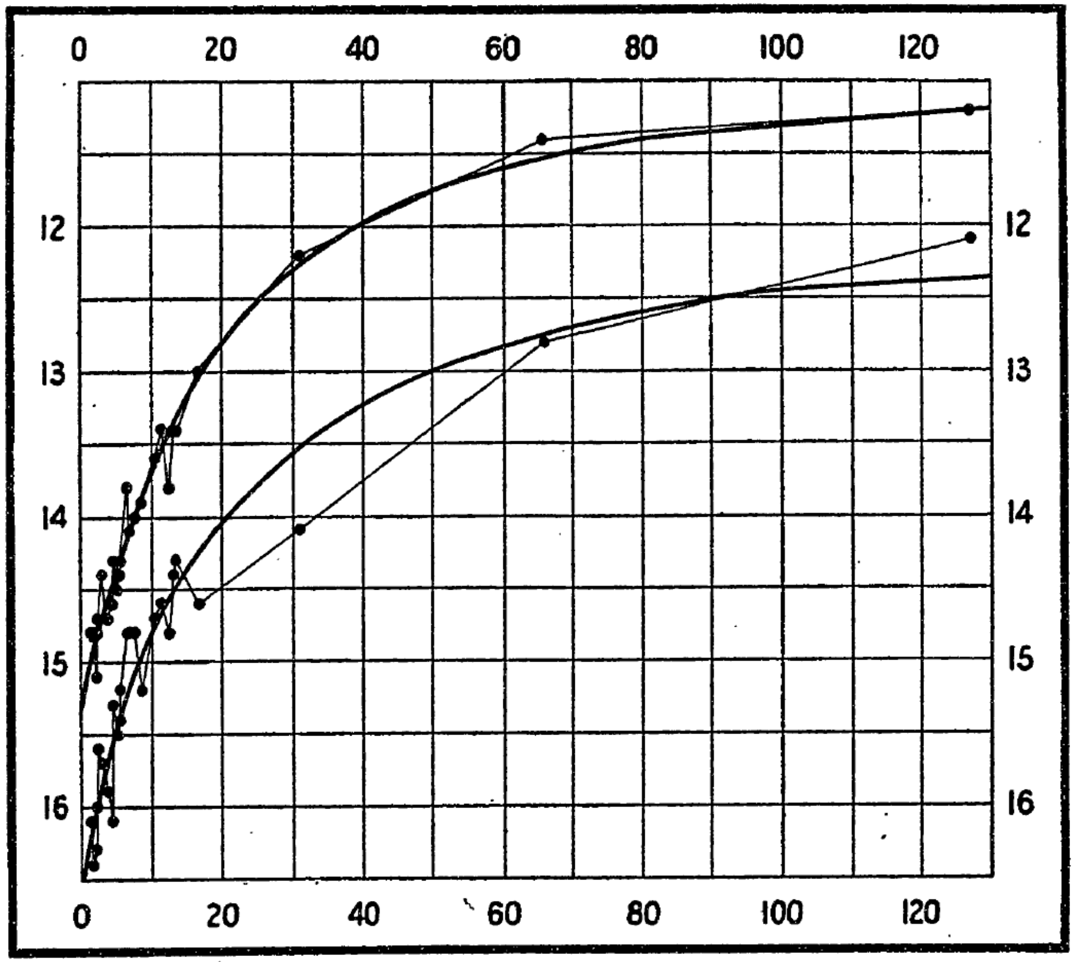


FIG. 1.

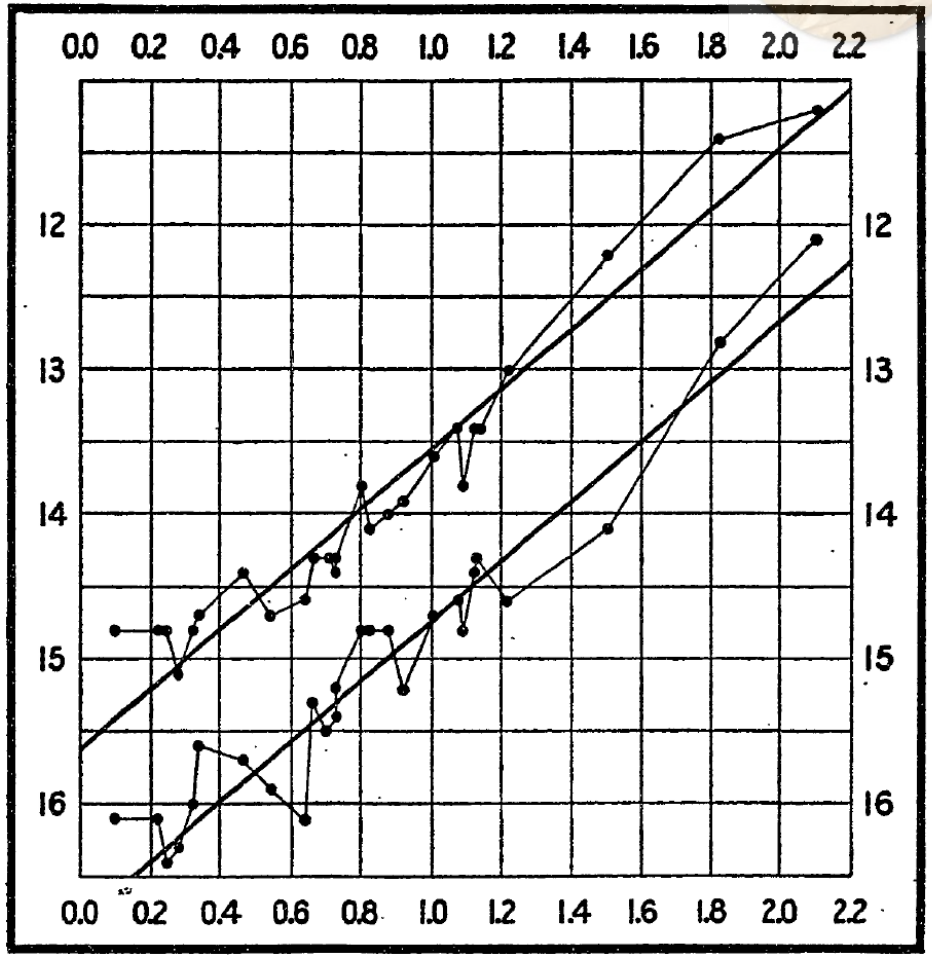
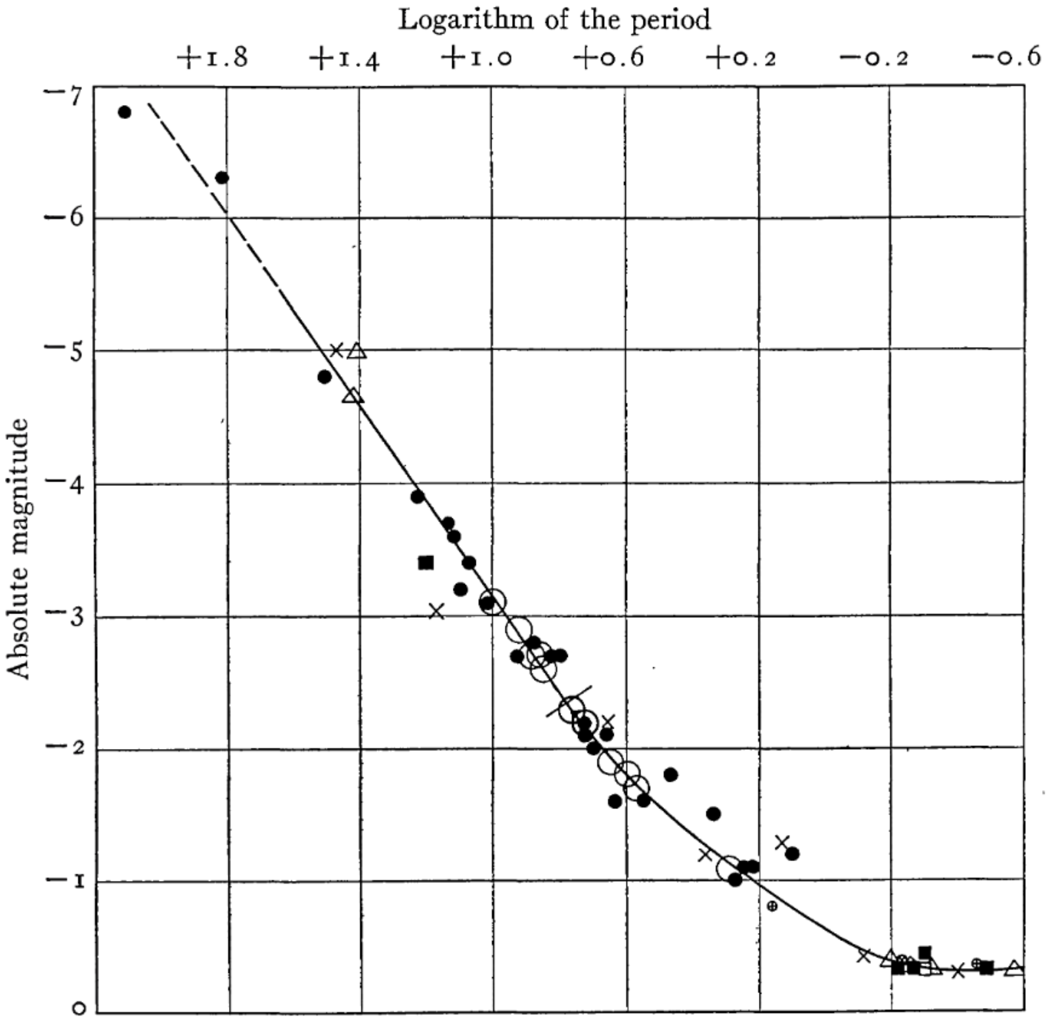


FIG. 2.

“中兴时代”



沙普利的绝对定标

“中兴时代”

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 l

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. MELTZER: 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.

“中兴时代”

世纪大辩论

Why the `Great Debate' Was Important

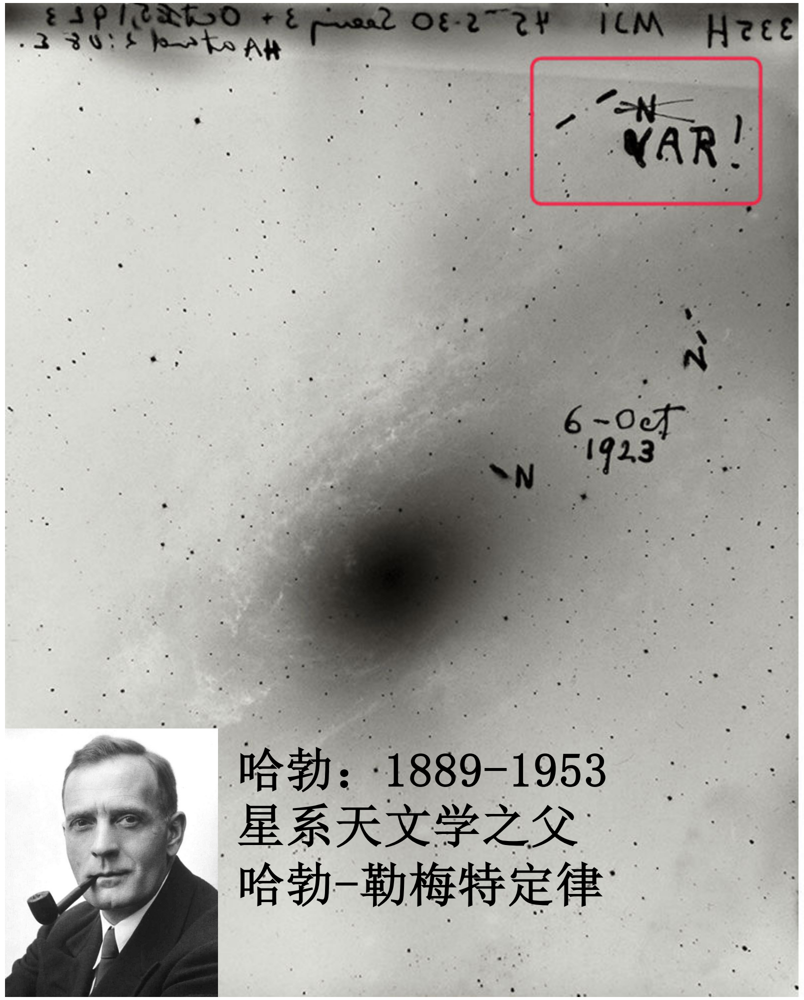
Although the `Great Debate' is important to different people for different reasons, it is a clear example of humanity once again striving to find its place within the cosmic order. In the debate, Shapley and Curtis truly argued over the ``Scale of the Universe," as the debate's title suggests. Curtis 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.

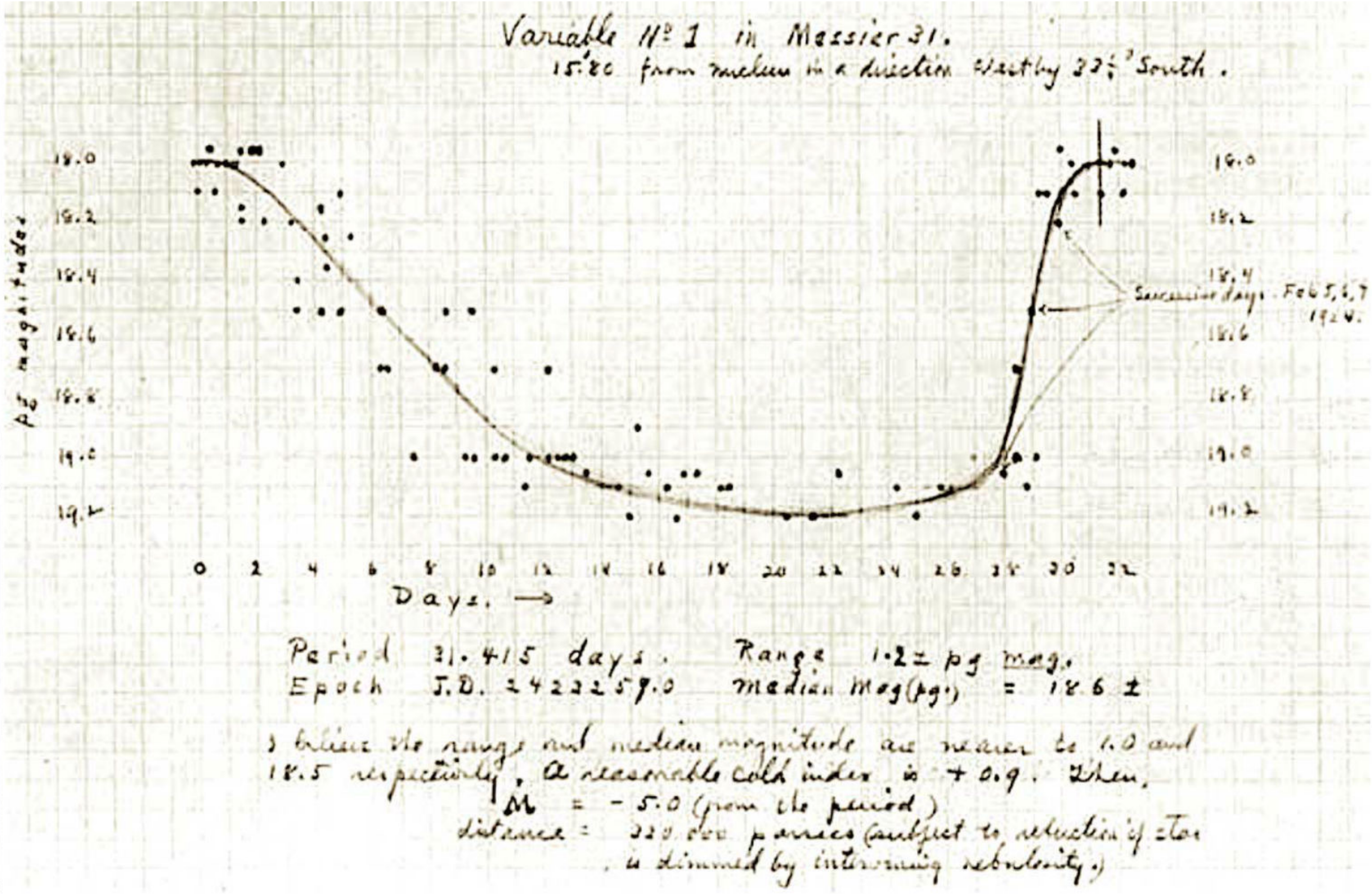
Another reason the `Great Debate' is important is captured nicely in the book Shu, F., 1982, The Physical Universe, An Introduction to Astronomy, (University Science Books, Mill Valley, California) p. 286: "The Shapley-Curtis debate makes interesting reading even today. It is important, not only as a 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."

“中兴时代”

哈勃测量M31距离



哈勃：1889-1953
星系天文学之父
哈勃-勒梅特定律



“中兴时代”

哈勃测量M31距离

A SPIRAL NEBULA AS A STELLAR SYSTEM, MESSIER 31[1]

By EDWIN HUBBLE

ABSTRACT

Material.—The present discussion of M 31 is *based on the study of about 350 photographs* taken with the 60- and 100-inch reflectors, distributed over an interval of about eighteen years. Two-thirds of the total number were obtained by the writer during the five years 1923–1928. Since the image of the nebula is much larger than the usable fields of the telescopes, *attention was concentrated on four regions centered* on (1) the nucleus, (2) 23′ north following, (3) 17′ south, (4) 48′ south preceding the nucleus. The combined *area*, with allowance for overlapping, *represents about 40 per cent of the entire nebula.*

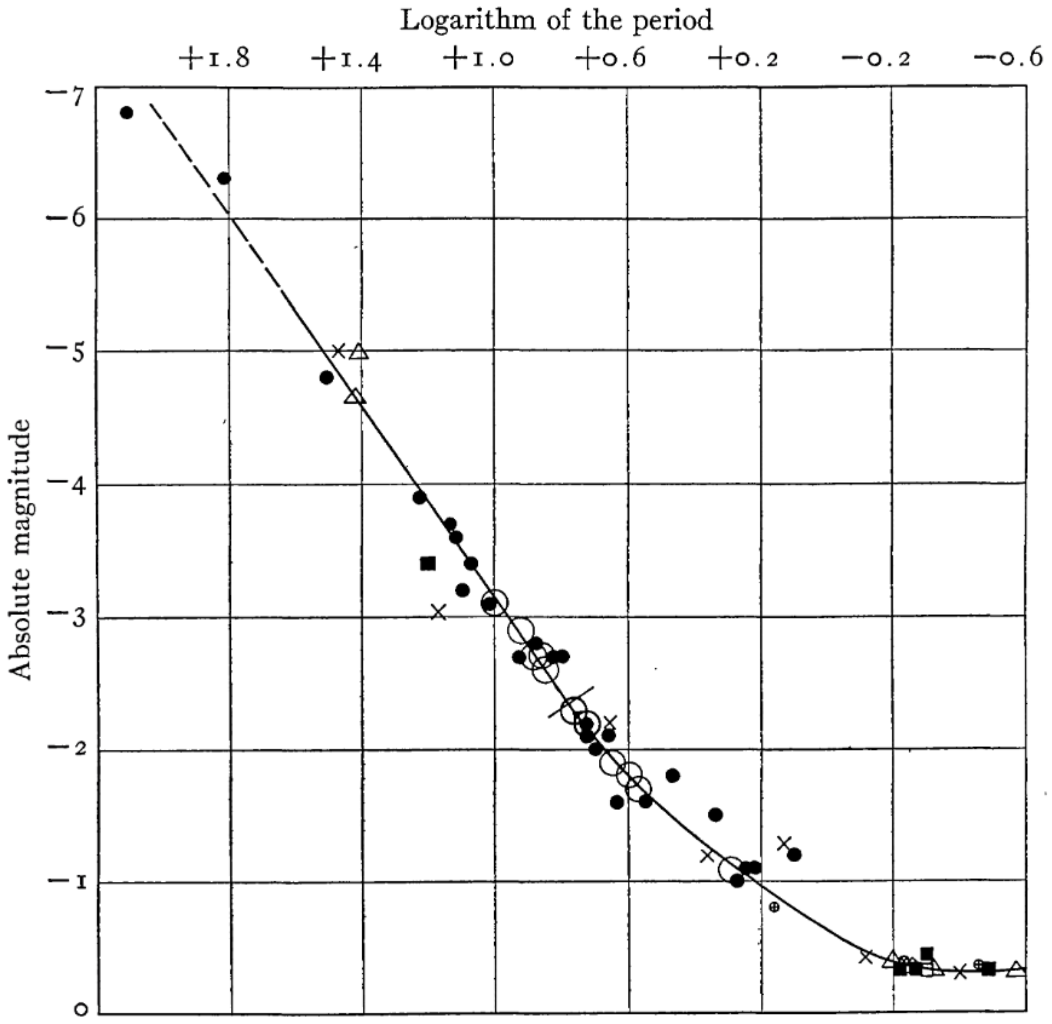
Resolution.—The *outer regions* of the spiral arms are *partially resolved into swarms of faint stars*, while the *nuclear* region *shows no* indications of *resolution under any conditions* with the 100-inch reflector. Intermediate regions show isolated patches where resolution is pronounced or suggested.

Variables.—*Fifty variables* have been found, nearly all in the outer regions where resolution is pronounced. The *survey* is believed to be *fairly exhaustive in the four selected regions down to 19.0 photographic magnitude.*

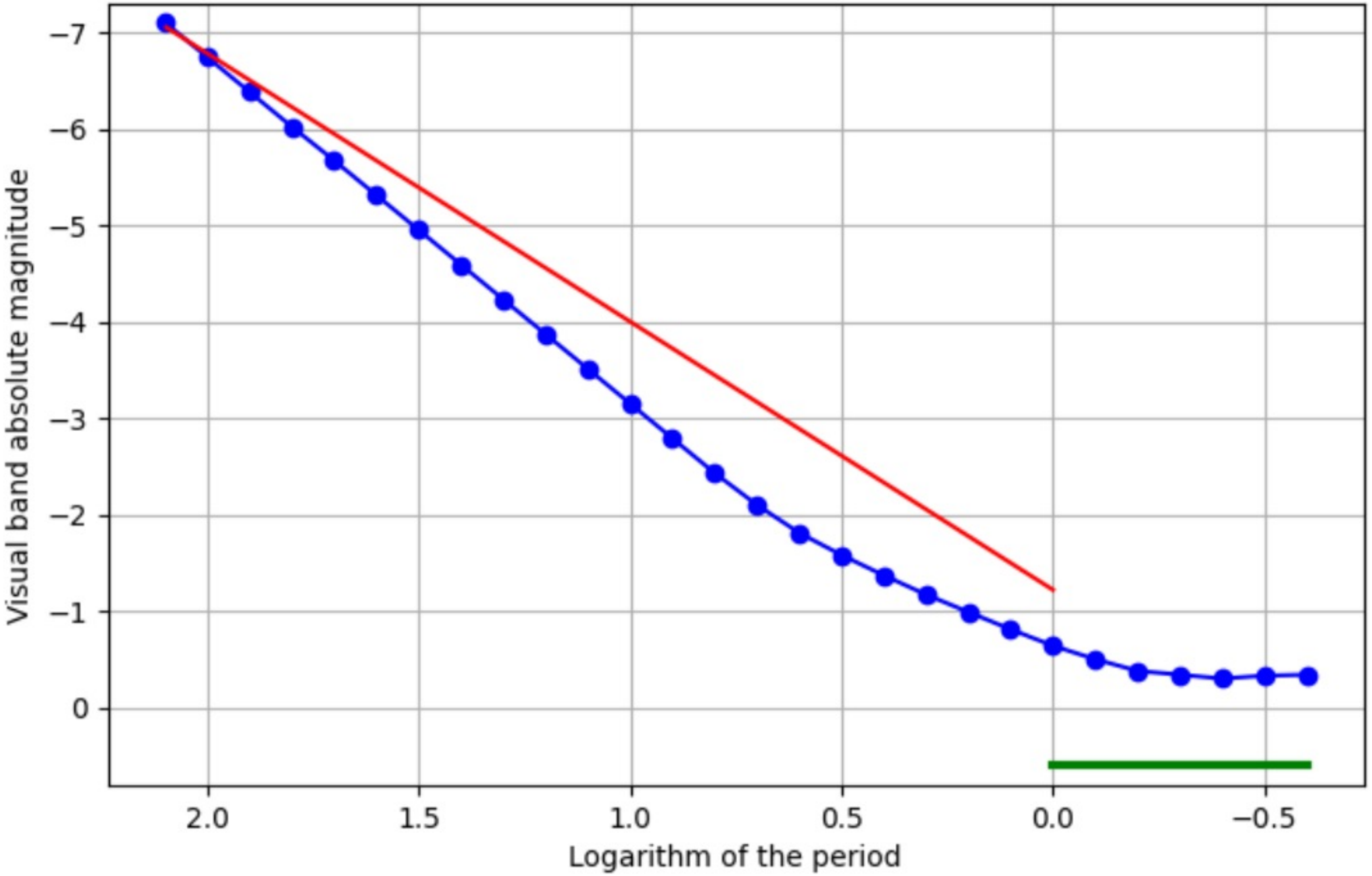
Cepheids.—*Forty* of the *variables* are *known to be Cepheids* with periods from *48 days to 10 days* and *maxima from 18.1 to 19.3 photographic magnitude;* one exceptional star varies from 17.9 to 19.2 in a period of 175 days. The *period-luminosity relation is conspicuous*, and the slope is *approximately that* found among *Cepheids in other extra-galactic systems.*

Distance of M 31 derived from Cepheid criteria.—Comparisons of period-luminosity diagrams indicate that M 31 is about 0.1 mag. or 5 per cent more distant than M 33, and about 8.5 times more distant than the Small Magellanic Cloud. Using Shapley’s value for the Cloud, we find the *distance of M 31* to be *275,000 parsecs.*

“中兴时代”



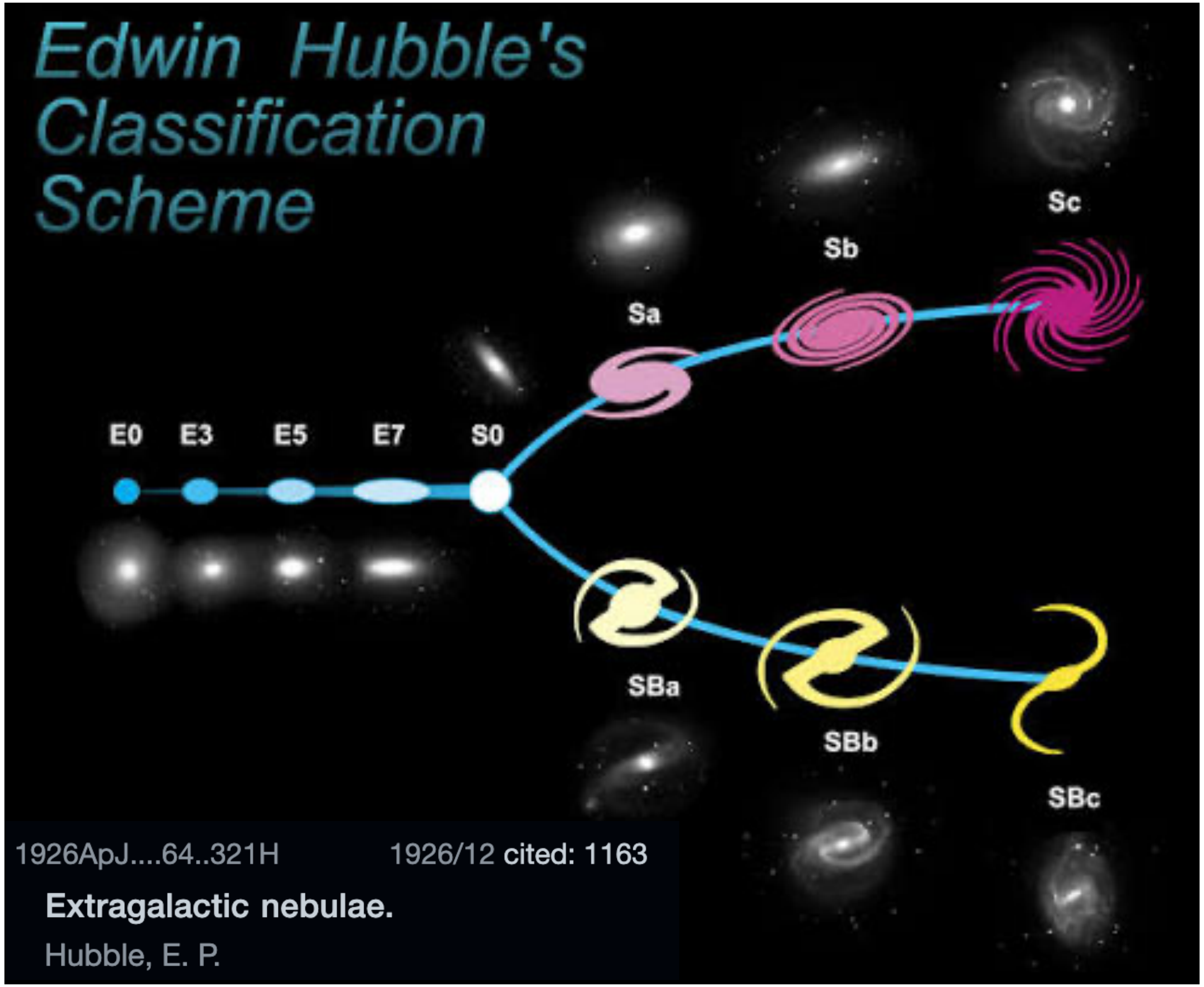
Logarithm of the period
+1.8
+1.4
+1.0
+0.6
+0.2
−0.2
−0.6
Absolute magnitude
−7
−6
−5
−4
−3
−2
−1
0



Visual band absolute magnitude
−7
−6
−5
−4
−3
−2
−1
0
2.0
1.5
1.0
0.5
0.0
−0.5
Logarithm of the period

“滑落后的复兴”

哈勃分类


Edwin Hubble's Classification Scheme
E0
E3
E5
E7
S0
Sa
Sb
Sc
SBa
SBb
SBc
1926ApJ....64..321H
1926/12 cited: 1163
Extragalactic nebulae.
Hubble, E. P.

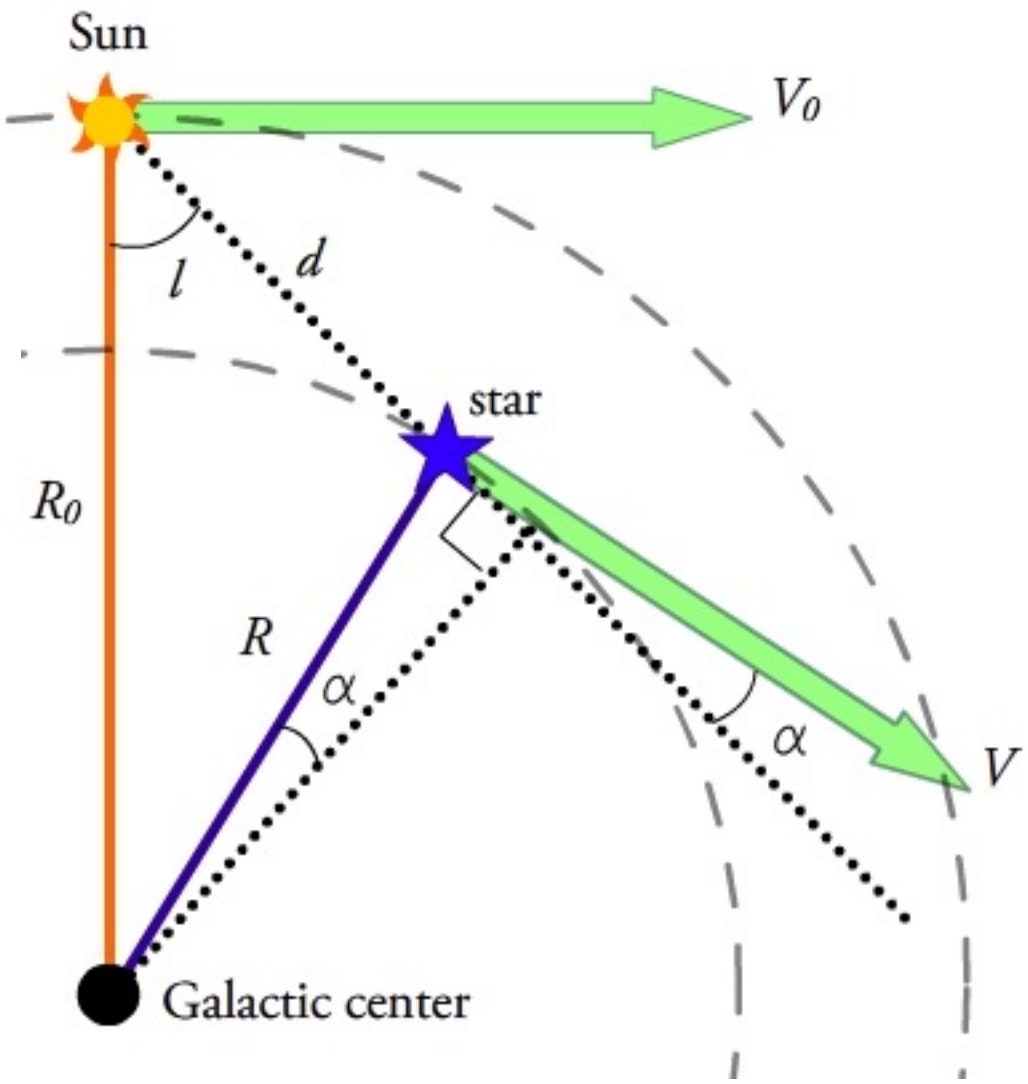
“滑落后的复兴”

旋转与否？

$$V_{\text{obs, r}} = Ad\sin(2l)$$
$$V_{\text{obs, t}} = Ad\cos(2l) + Bd$$

$$A = -\frac{1}{2}R_0\left.\frac{d\Omega}{dr}\right|_{R_0}$$

$$B = -\frac{1}{2}R_0\left.\frac{d\Omega}{dr}\right|_{R_0} - \Omega$$



“滑落后的复兴”

旋转与否？

BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS.

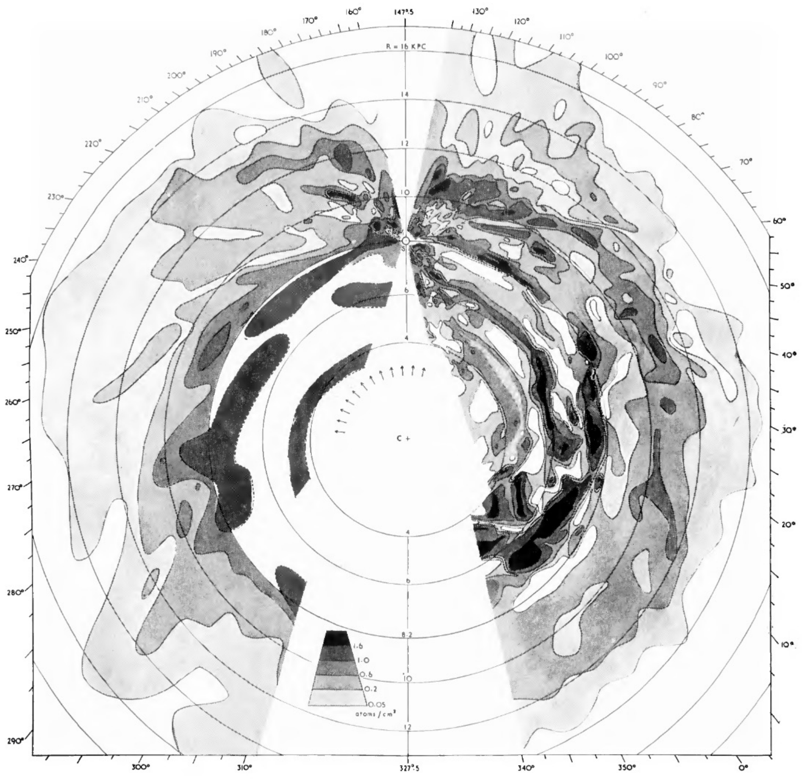
1927 April 14 Volume III. No. 120.

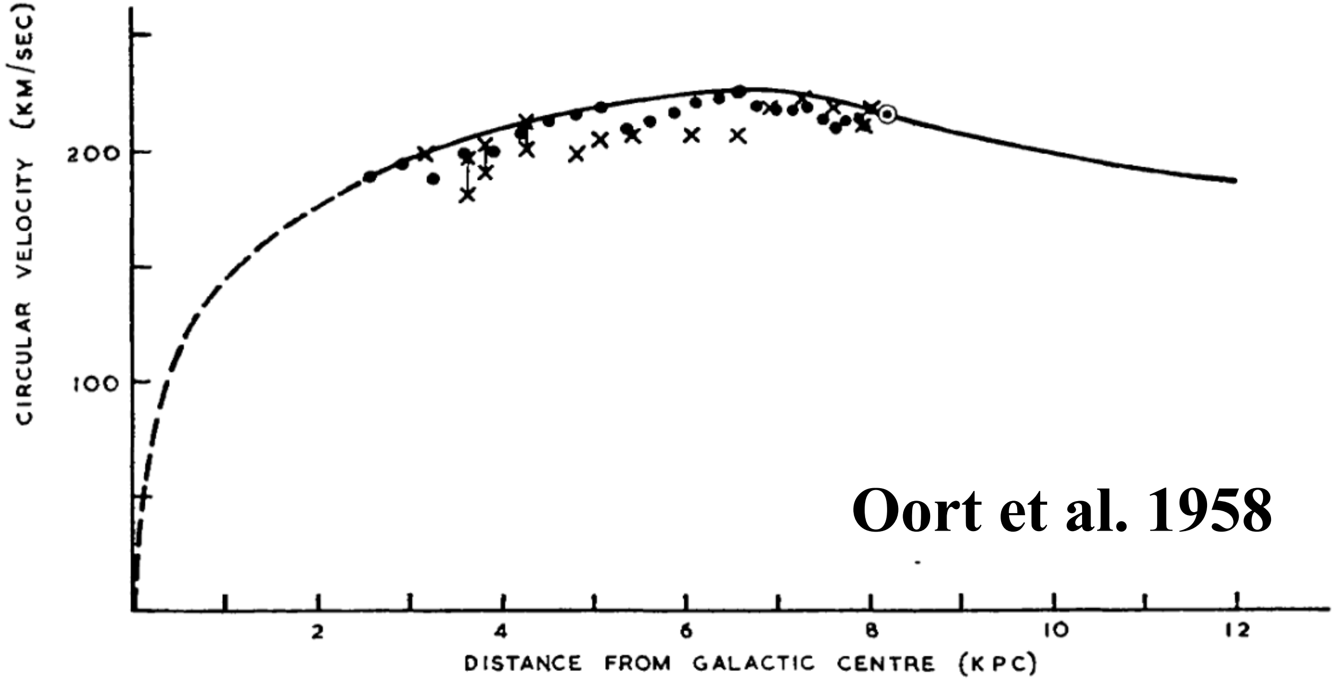
COMMUNICATION FROM THE OBSERVATORY AT LEIDEN.

Observational evidence confirming Lindblad's hypothesis of a rotation of the galactic system, by *J. H. Oort.*

“滑落后的复兴”

旋转与否？





Oort et al. 1958

“滑落后的复兴”

旋臂几条

“滑落后的复兴”

旋臂几条

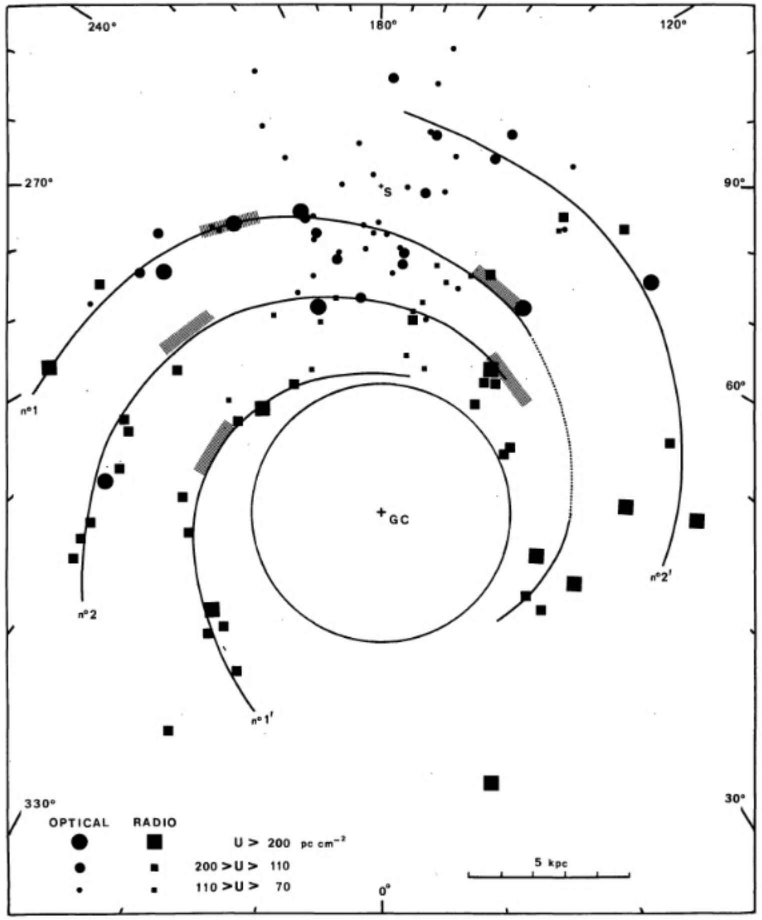
NGC2775 (52%)

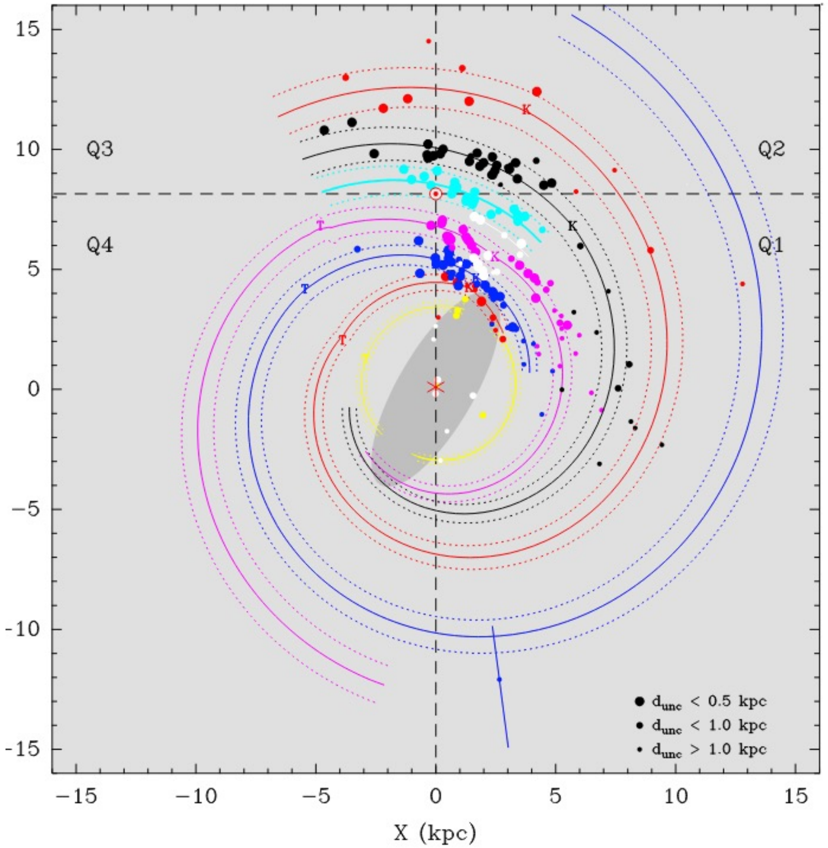
NGC3184 (32%)

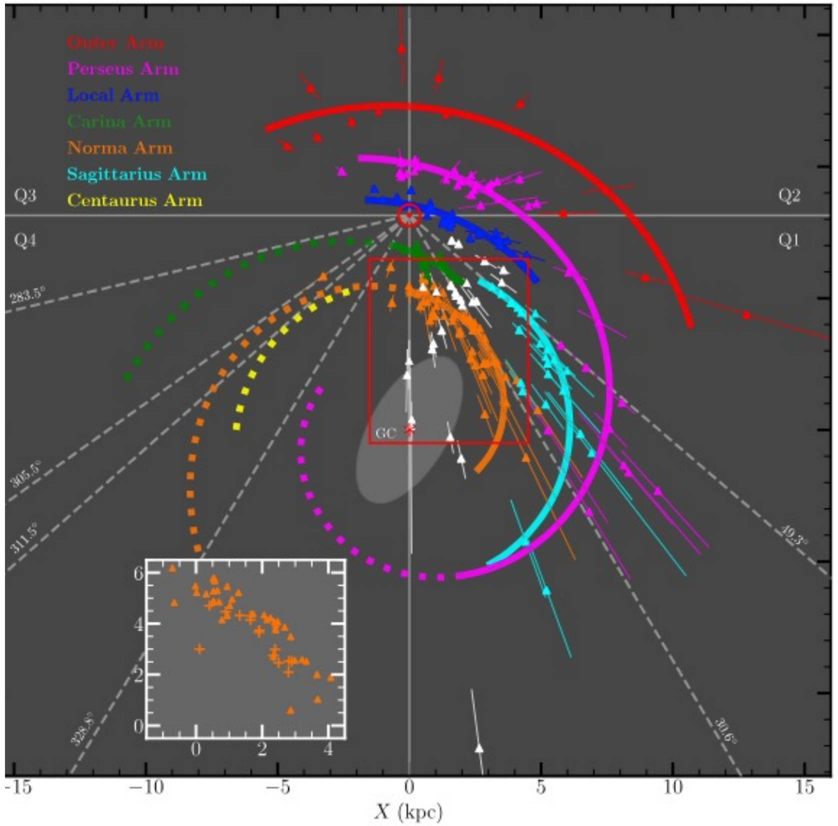
NGC1300 (18%)

“滑落后的复兴”

旋臂几条

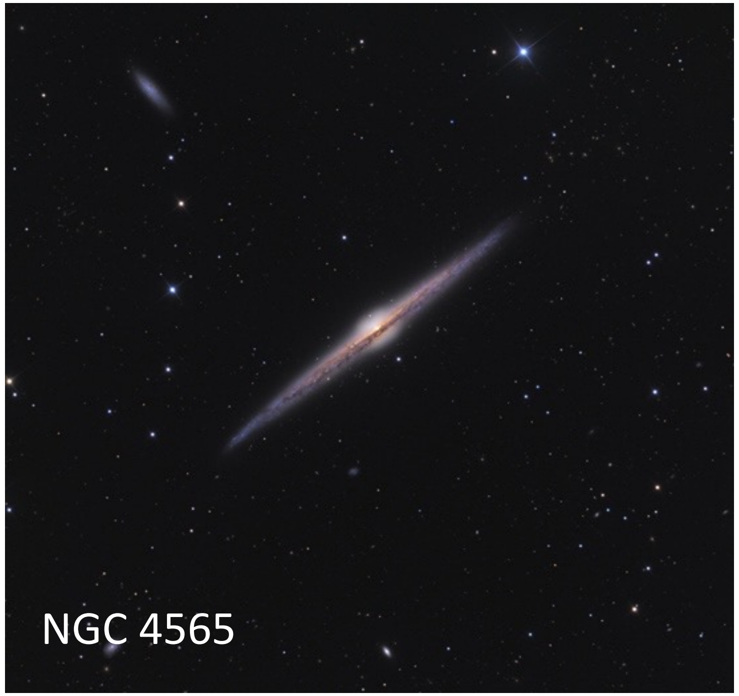

240°
180°
120°
270°
90°
60°
30°
330°
0°
GC
n°1
n°2
n°2′
n°1′
OPTICAL
RADIO
U > 200 pc cm⁻²
200 > U > 110
110 > U > 70
5 kpc

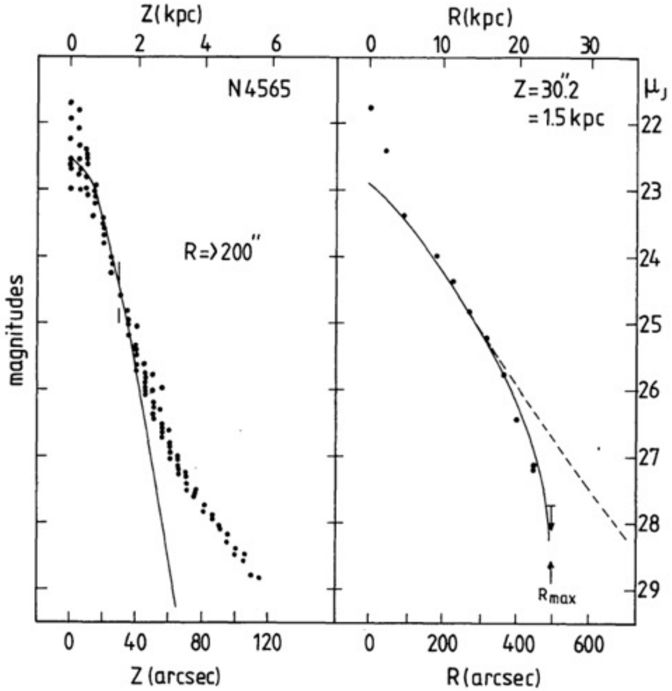

Q3
Q2
Q4
Q1
X (kpc)
d_unc < 0.5 kpc
d_unc < 1.0 kpc
d_unc > 1.0 kpc

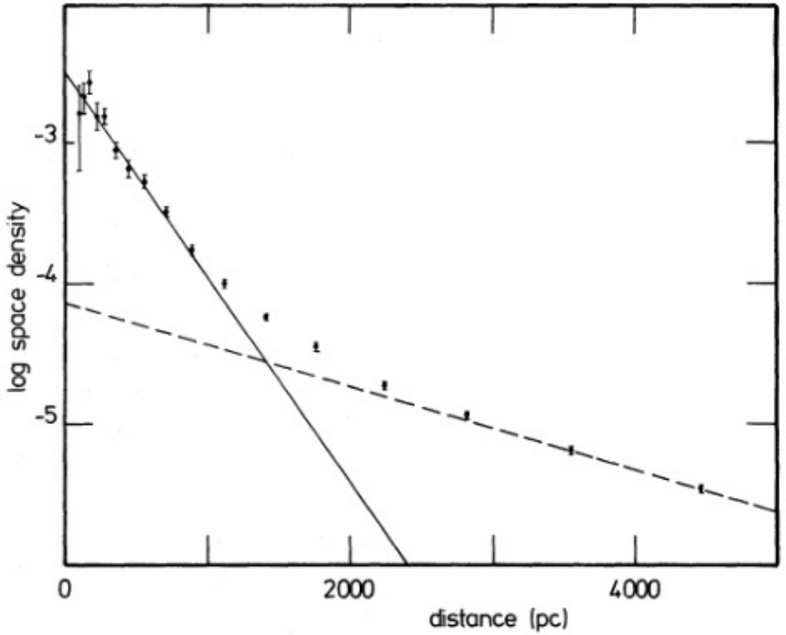

Outer Arm
Perseus Arm
Local Arm
Carina Arm
Norma Arm
Sagittarius Arm
Centaurus Arm
Q3
Q2
Q4
Q1
GC
X (kpc)

“滑落后的复兴”

银盘的薄与厚

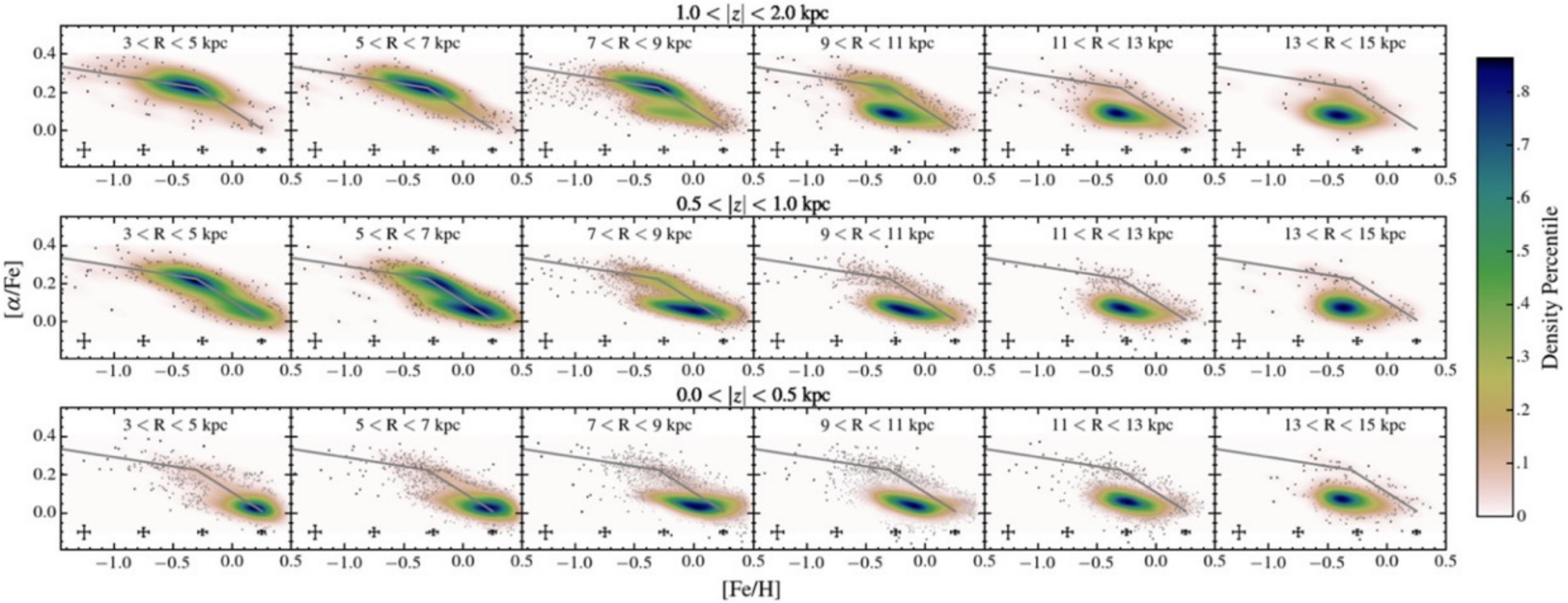






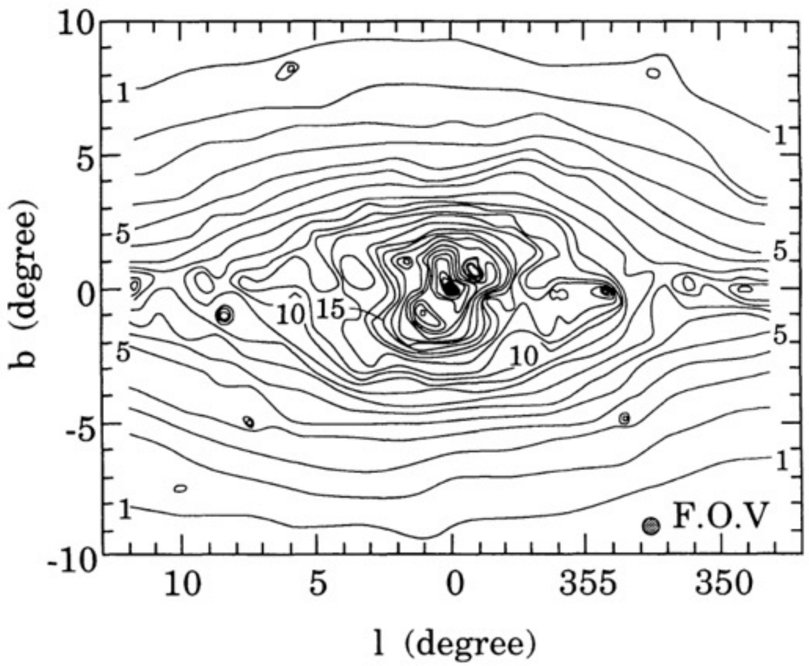
“滑落后的复兴”

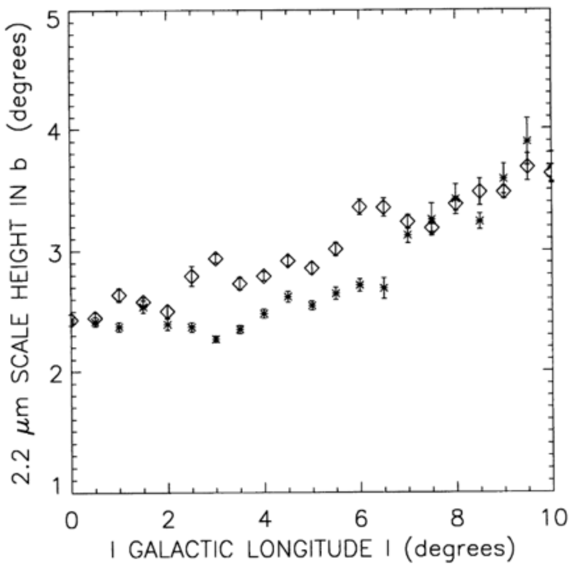
银盘的薄与厚

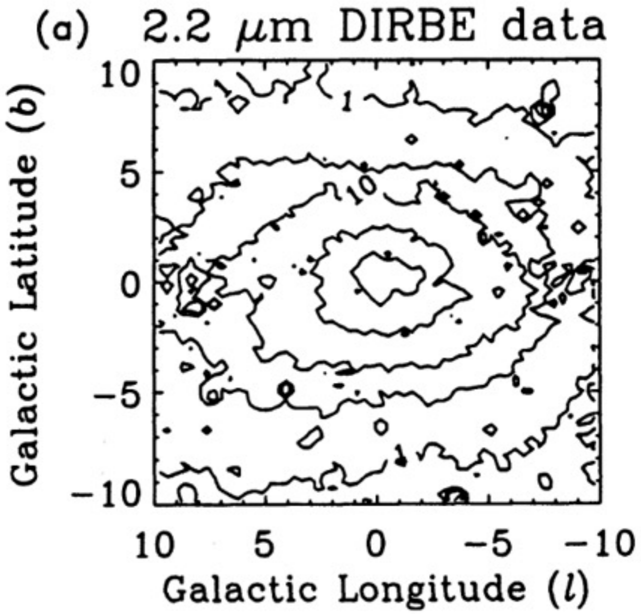


“滑落后的复兴”

真假核球？

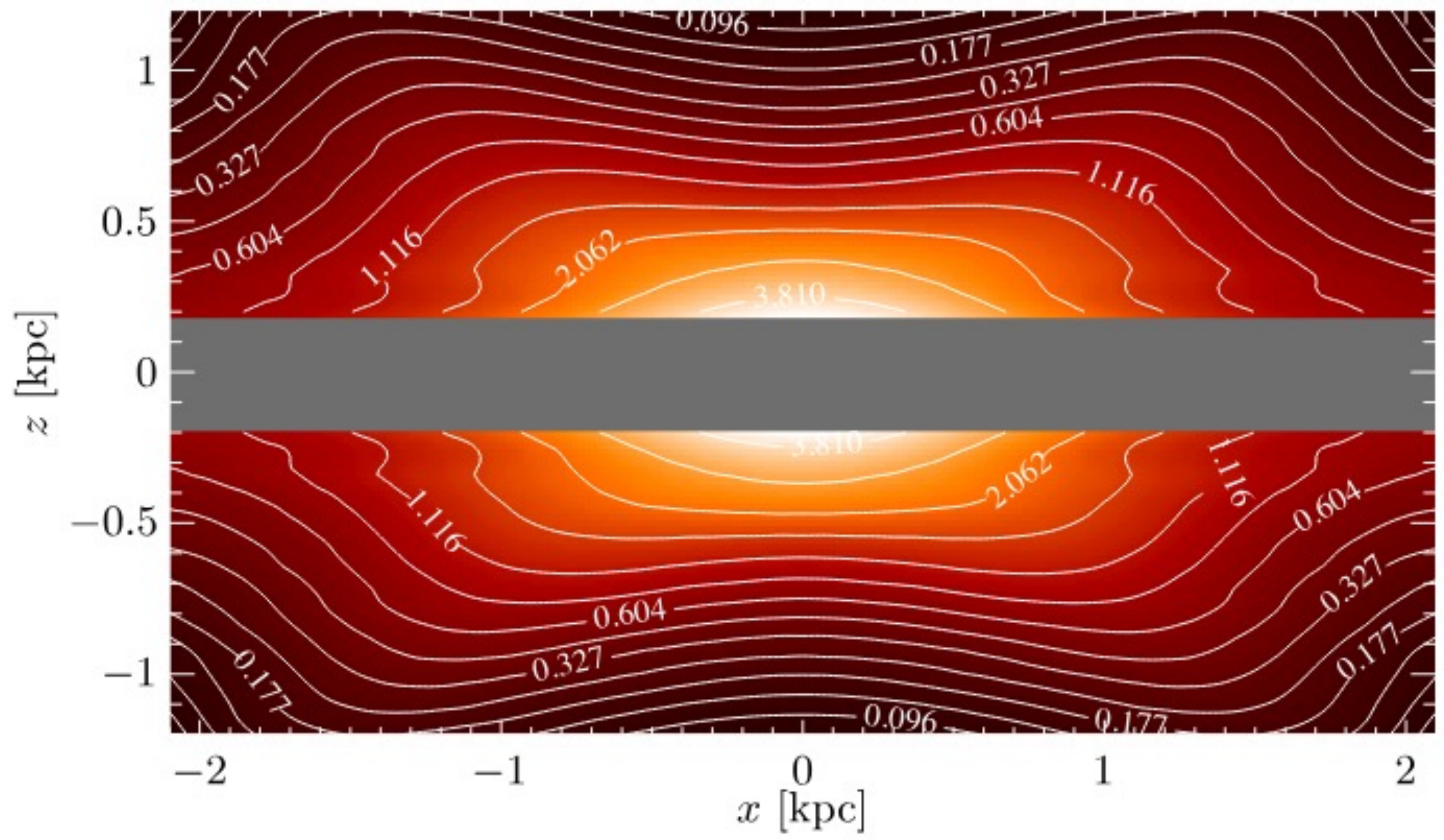

b (degree)
l (degree)
F.O.V


2.2 μm SCALE HEIGHT IN b (degrees)
l GALACTIC LONGITUDE l (degrees)


(a) 2.2 μm DIRBE data
Galactic Latitude (b)
Galactic Longitude (l)

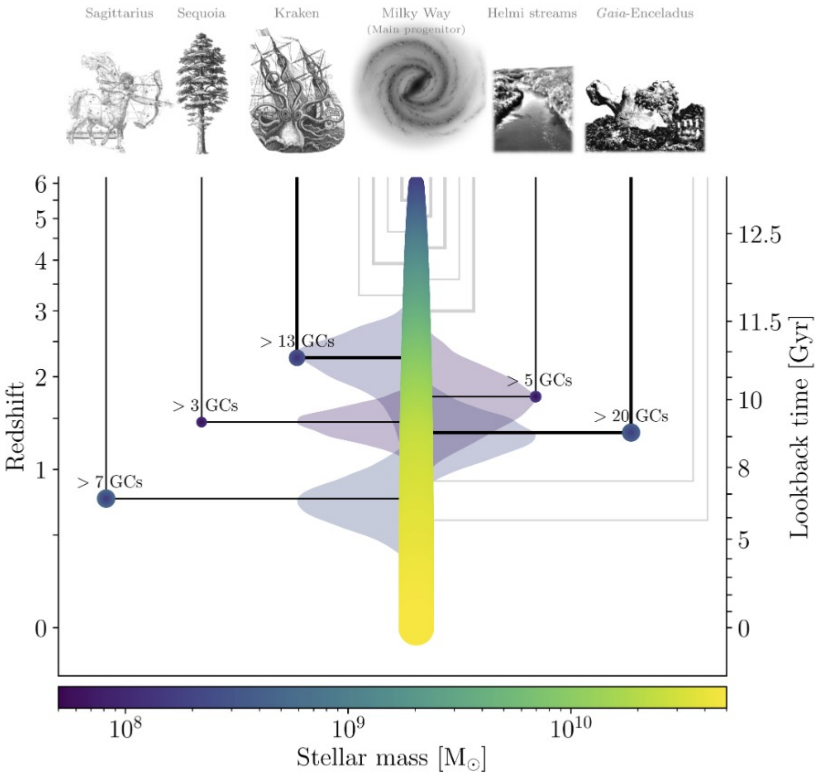
“滑落后的复兴”

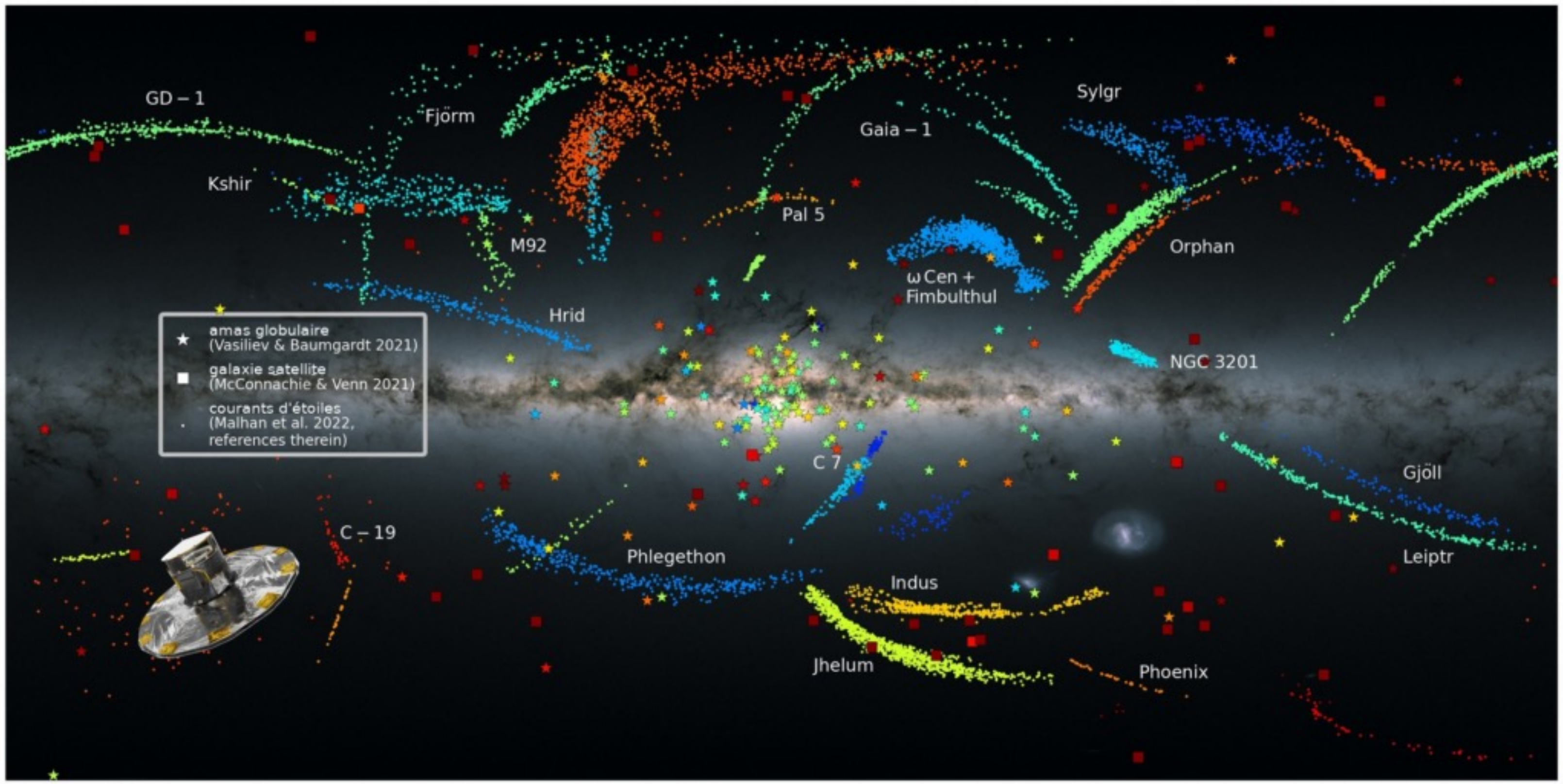
真假核球？



“滑落后的复兴”

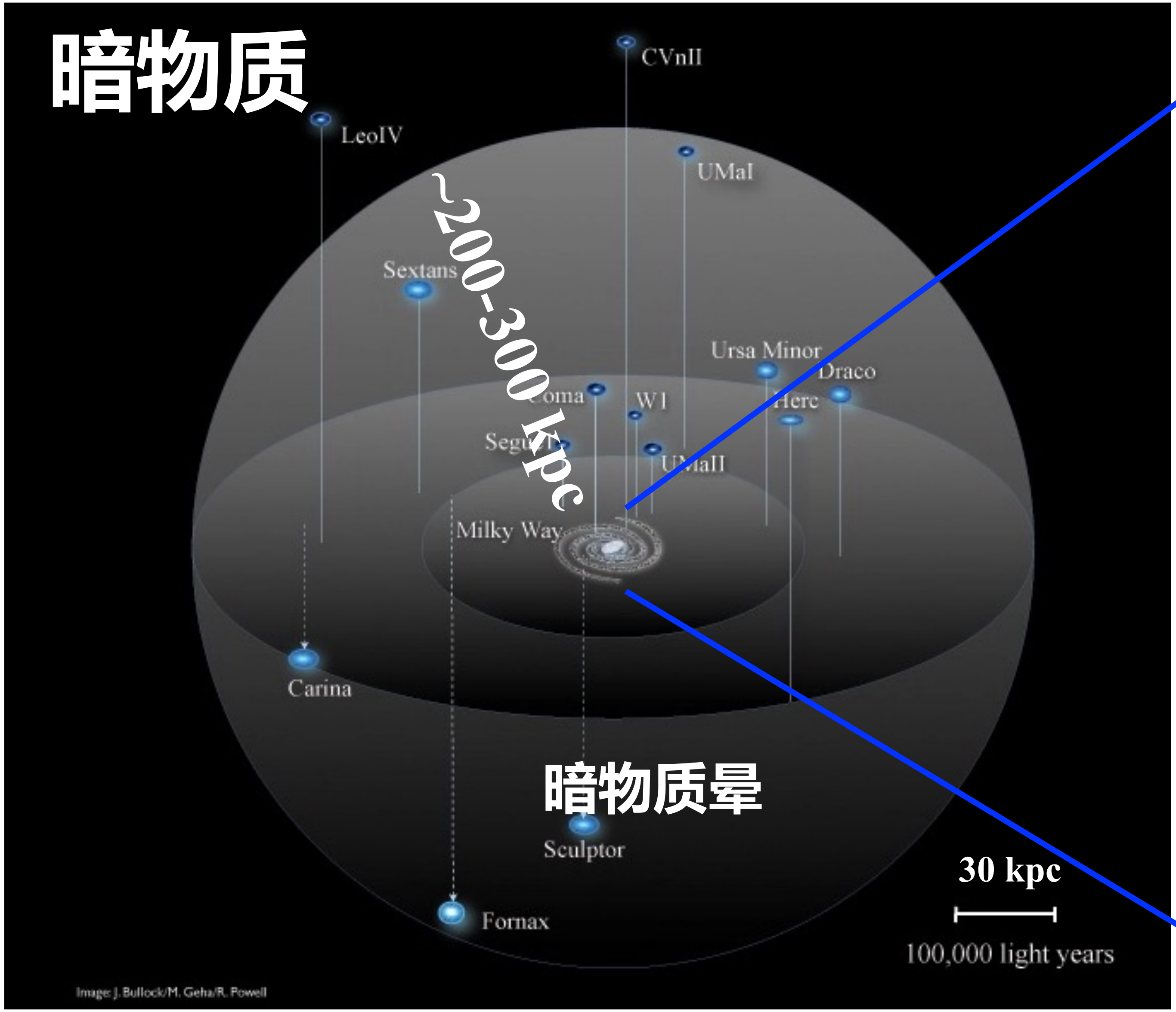
银晕



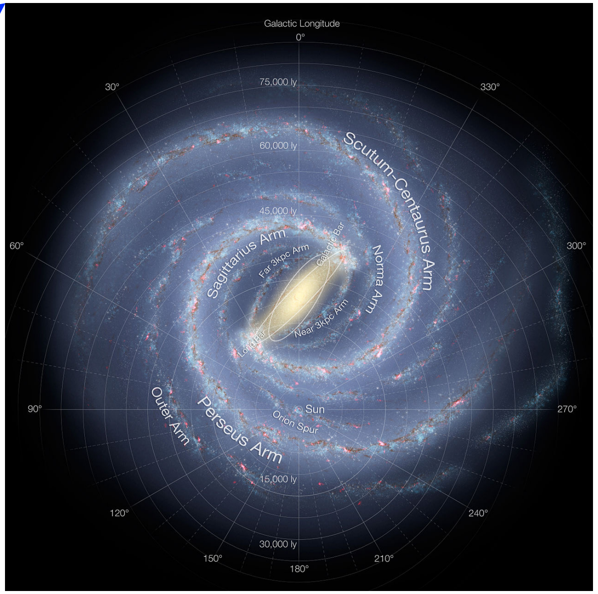


Diederik Kruijssen et al. 2020

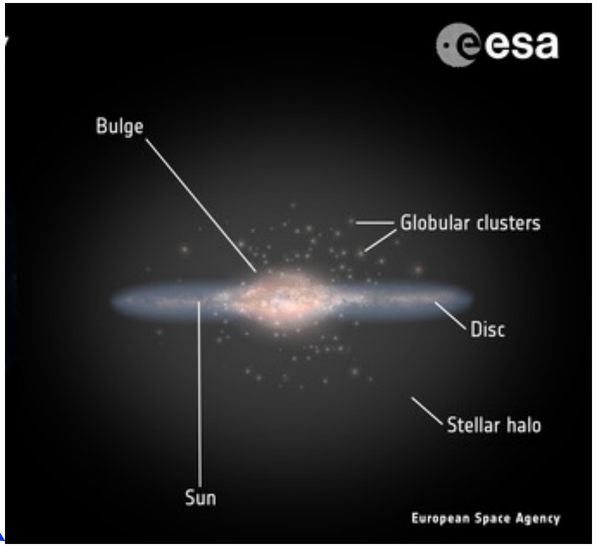
“滑落后的复兴”



暗物质
CVnII
LeoIV
UMaI
~200-300 kpc
Sextans
Ursa Minor
Draco
Coma
W1
Herc
Segue
UMaII
Milky Way
Carina
暗物质晕
Sculptor
Fornax
30 kpc
100,000 light years
Image: J. Bullock/M. Geha/R. Powell

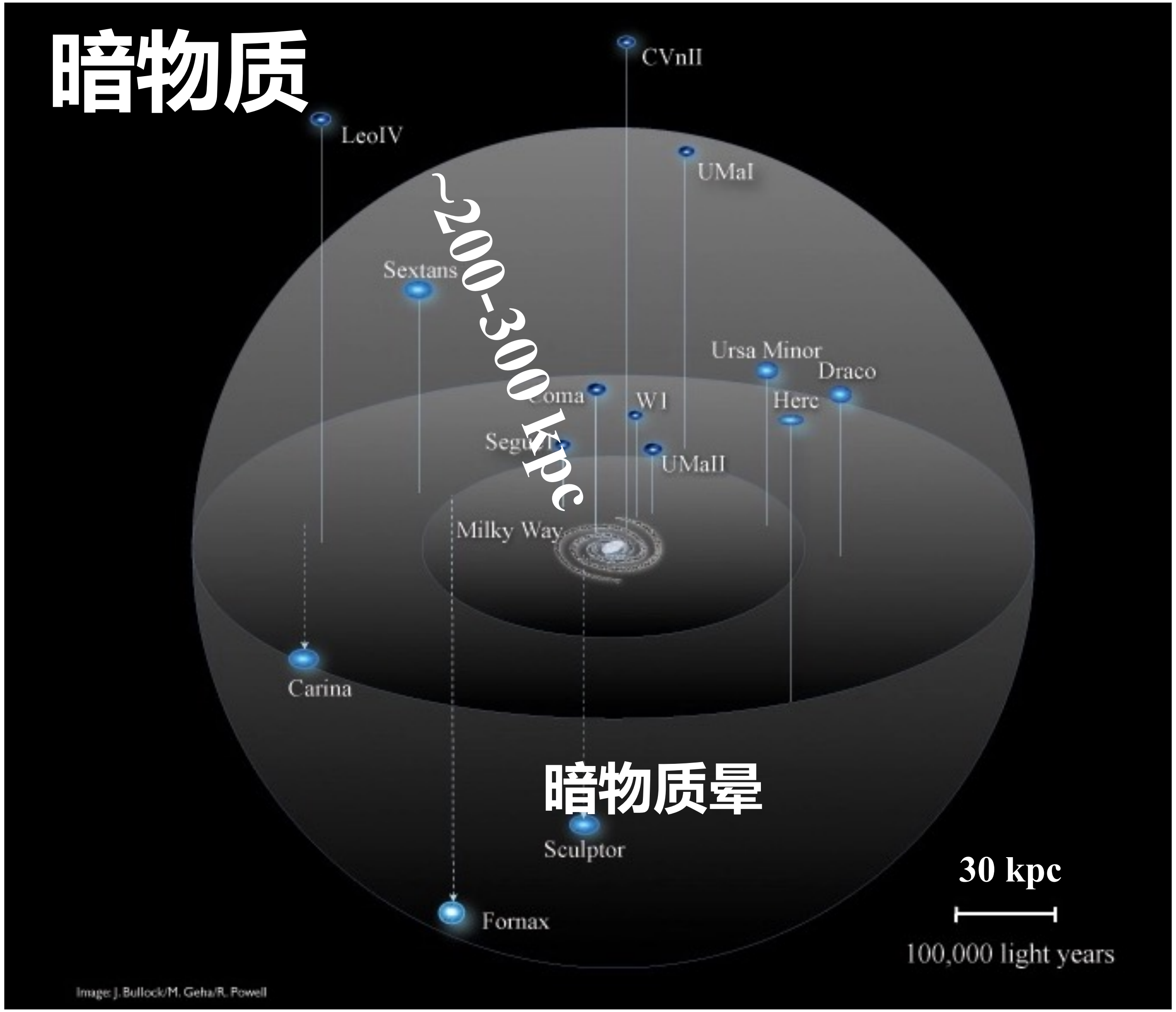


Galactic Longitude
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Sun
Orion Spur



esa
Bulge
Globular clusters
Disc
Stellar halo
Sun
European Space Agency

“滑落后的复兴”



Q1：暗物质晕质量有多少？ （银河系多重）

Q2：太阳周围有多少暗物质？ （暗物质探测）

Q3：暗物质晕是什么形状？

Q4：暗物质粒子属性是啥？

“滑落后的复兴”

银河系主要成分	尺寸	质量	化学性质	运动学性质	年龄
核球	核球主体位于中心约 2 kpc；箱状/花生结构半长约 2 kpc；长棒半长约 5 kpc；垂向厚度约 0.5–1 kpc。	约(1-2)×10^{10}M$_\odot$	金属丰度分布很宽，约[Fe/H]~−1.5 至 +0.5；总体[α/Fe]偏贫，更接近盘；贫金属星通常拥有更富[α/Fe]，可能混有早期厚盘、原位晕及少量经典核球成分。	明显的**圆柱旋转**；主要由棒轨道族支撑。金属丰度偏富的恒星更强烈地参与棒和 X 形结构；贫金属星速度弥散更大、动力学更热。	绝大多数恒星较老，通常>8–10 Gyr；存在少量中年轻金属丰星。中心核星盘区域还存在更年轻恒星。
银盘	恒星盘径向标长约 2.0–3.0 kpc；薄盘标高约 0.20–0.30 kpc；厚盘约 0.8–1.0 kpc。主要恒星盘延伸至约 15–20 kpc，外盘存在翘曲和边缘增厚。	恒星盘约 (3–5) × 10^{10} M$_\odot$；若包括冷气体和尘埃，盘内重子质量约可达(4-6)× 10^{10} M$_\odot$。	薄盘：总体较富金属、低α，具有负径向金属丰度梯度；[Fe/H] 可从约−0.7 延伸到超太阳。厚盘：通常较贫金属且富α，典型 [Fe/H]~−1.0 至−0.3。	以旋转支撑为主，太阳附近圆周速度约 230 km/s。薄盘动力学冷、近圆轨道占主导；厚盘速度弥散大，平均转动比薄盘慢约数十 km/s。	薄盘：约 0–10 Gyr，今天仍在形成恒星；厚盘：大多约 8–12 Gyr。
恒星晕	通常用扁率和幂律密度轮廓；典型密度断裂半径约 20–30 kpc；可追踪至 100 kpc 以上。内晕明显压扁，典型轴比 c/a~0.5–0.8，外晕趋于更圆。	约 10^9 $M_\odot$，只占银河系总恒星质量约 1%–2%，但在空间上非常延展。	总体贫金属，典型 [Fe/H] ~ −1.5，分布很宽；多数老年星富α，但不同并合遗迹具有不同的化学序列。外晕通常比内晕更贫金属。	主要由随机运动和速度弥散支撑；内晕受 GSE 遗迹主导的部分具有很强的径向轨道各向异性；同时包含恒星流、壳层和相空间团块，远非平衡光滑系统。	绝大多数很老，通常>10 Gyr；主体在约 8–12 Gyr 以前形成或被吸积。
暗物质晕	常用维里半径 R_{200}约 180–230 kpc。形状可能轻度扁平或三轴。	对应银河系总维里质量约 10^{12} $M_\odot$。	--	--	--

“终极问题”

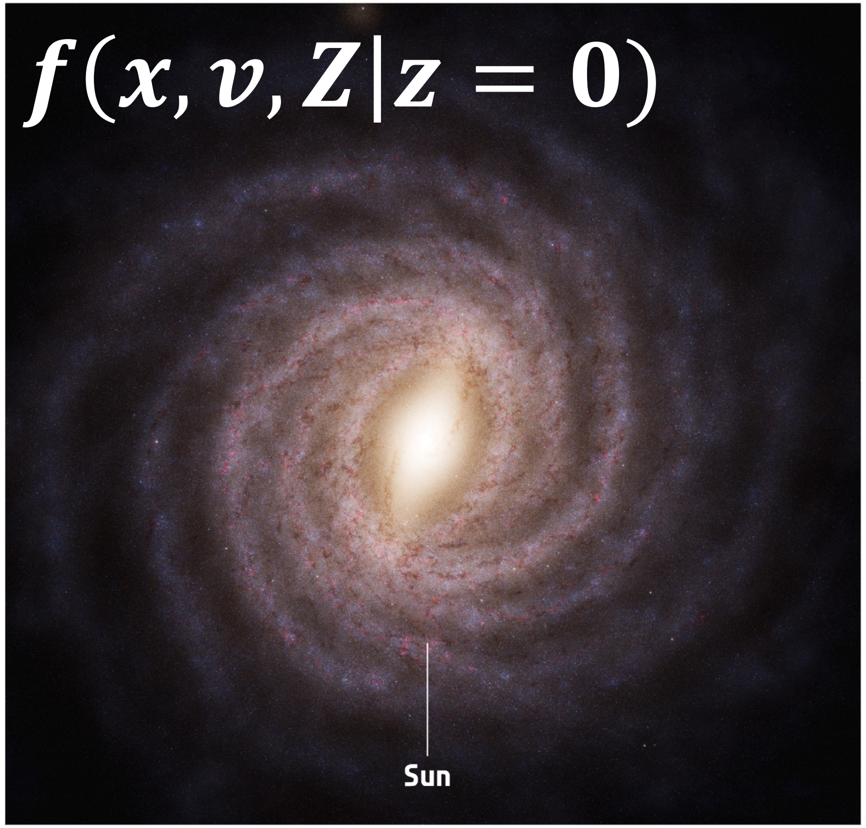
- 银河系最初是怎样诞生的?
- 银河系是如何组装起来的?
- 银盘是如何形成的?
- 银河系中心是怎样形成的?
- 银河系如何获得和循环物质?
- 暗物质究竟是什么?
- 银河系究竟普通还是特殊?

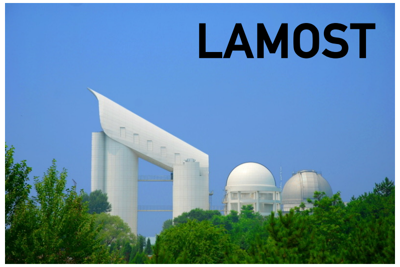
“终极问题”

Present-day MW

“终极问题”

Present-day MW



Gaia + 

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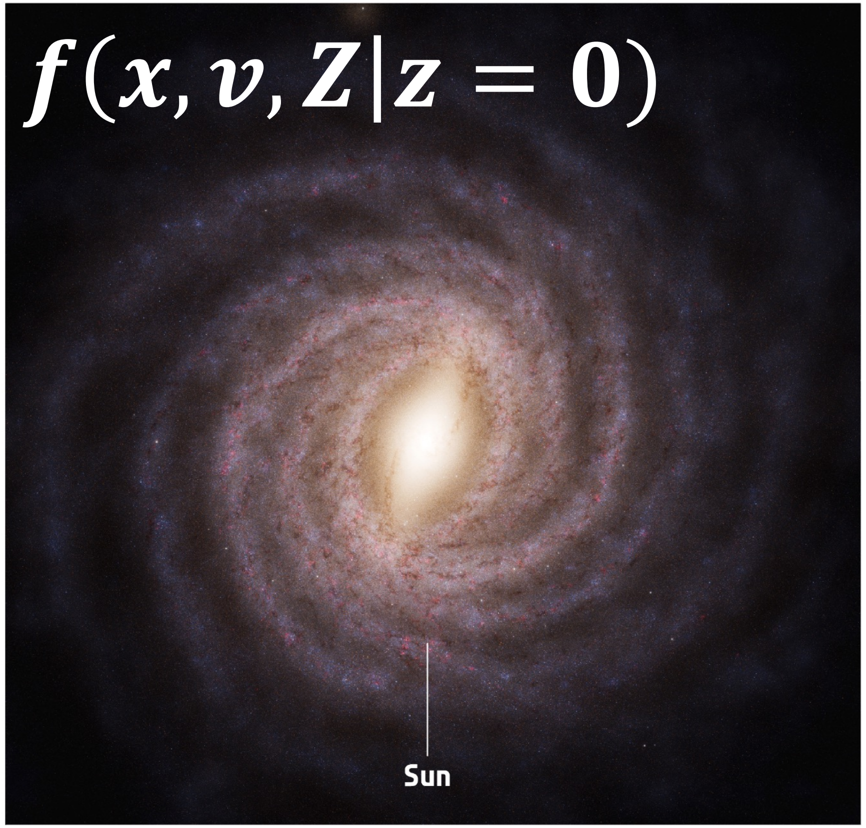
"终极问题"

Proto-type MW

?

$$f^{-1}\,(x, v, Z|t)$$

Present-day MW



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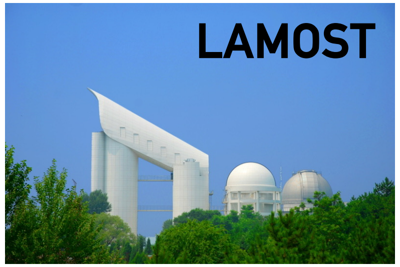

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“终极问题”

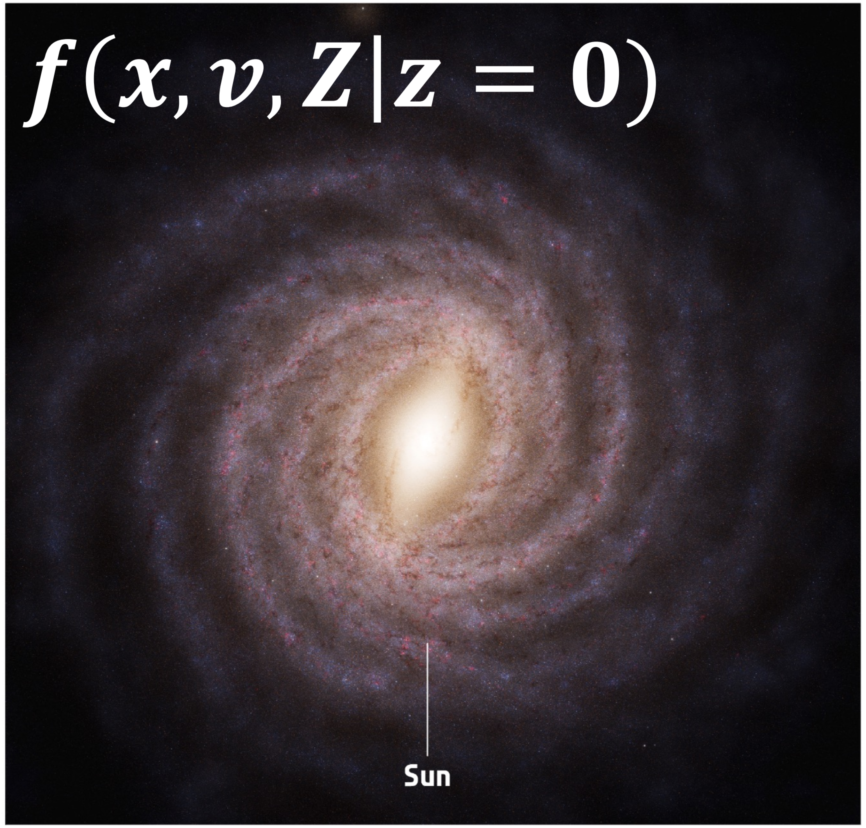
Structural Decomposition

Proto-type MW

?

$$f^{-1}\,(x, v, Z|t)$$

Present-day MW



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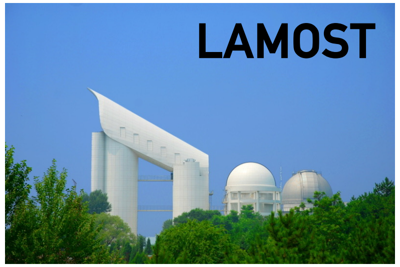

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“终极问题”

Proto-type MW

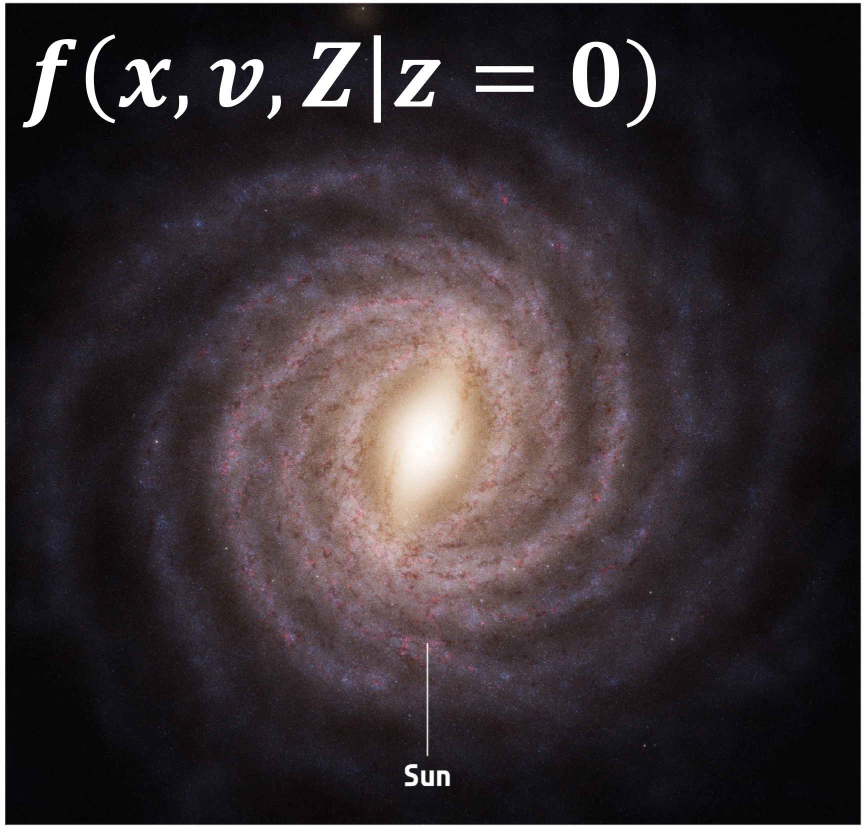
Structural Decomposition

Dynamical Tagging

?

$$f^{-1}\,(x, v, Z|t)$$

Present-day MW



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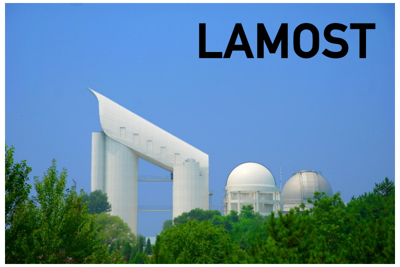

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“终极问题”

Proto-type MW

Structural Decomposition

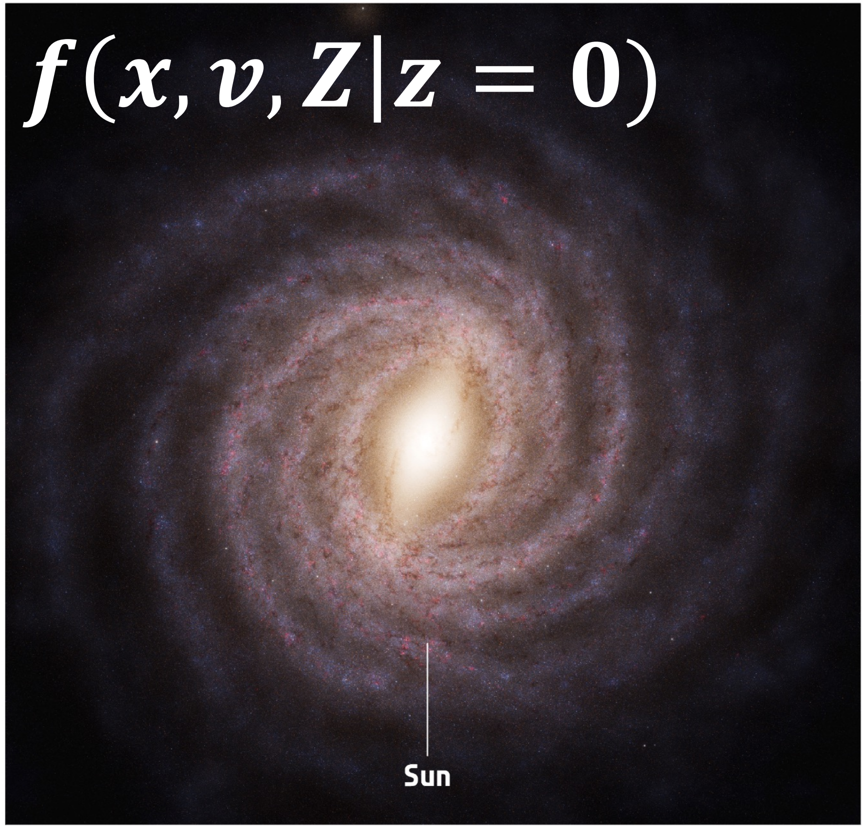
Dynamical Tagging

Chemical Tagging

$$f^{-1}\left(x, v, Z \mid t\right)$$

?

Present-day MW



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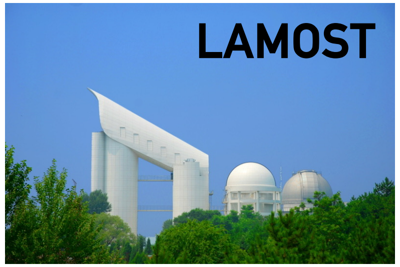


+ …

“终极问题”

Proto-type MW

Structural Decomposition

Dynamical Tagging

Chemical Tagging

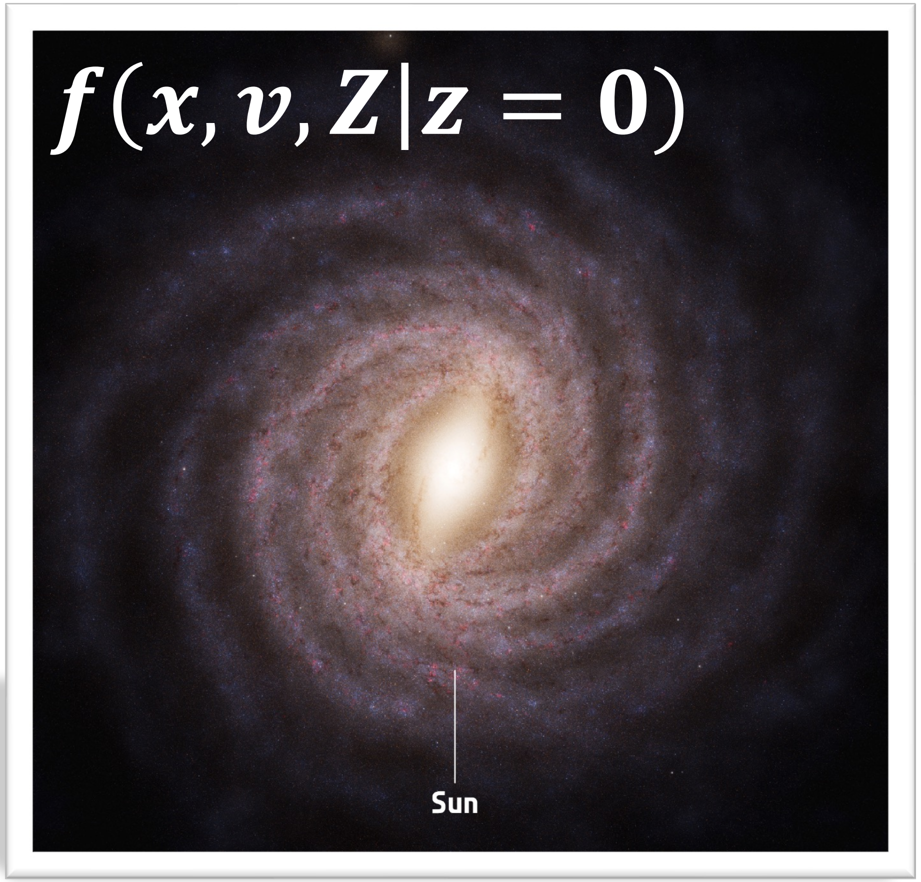
$$f^{-1}\,(x, v, Z|t)$$

?

$$f(x, v, Z|t)$$

Numerical/Semi-analytical Simulations

Present-day MW



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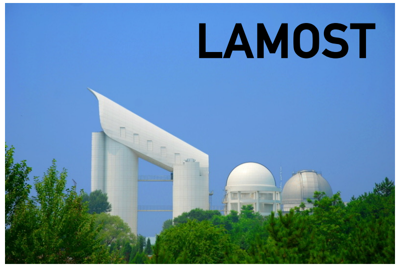


+ …

Proto-type MW

?

Structural Decomposition

Dynamical Tagging

Chemical Tagging

$$f^{-1}(x, v, Z|t)$$

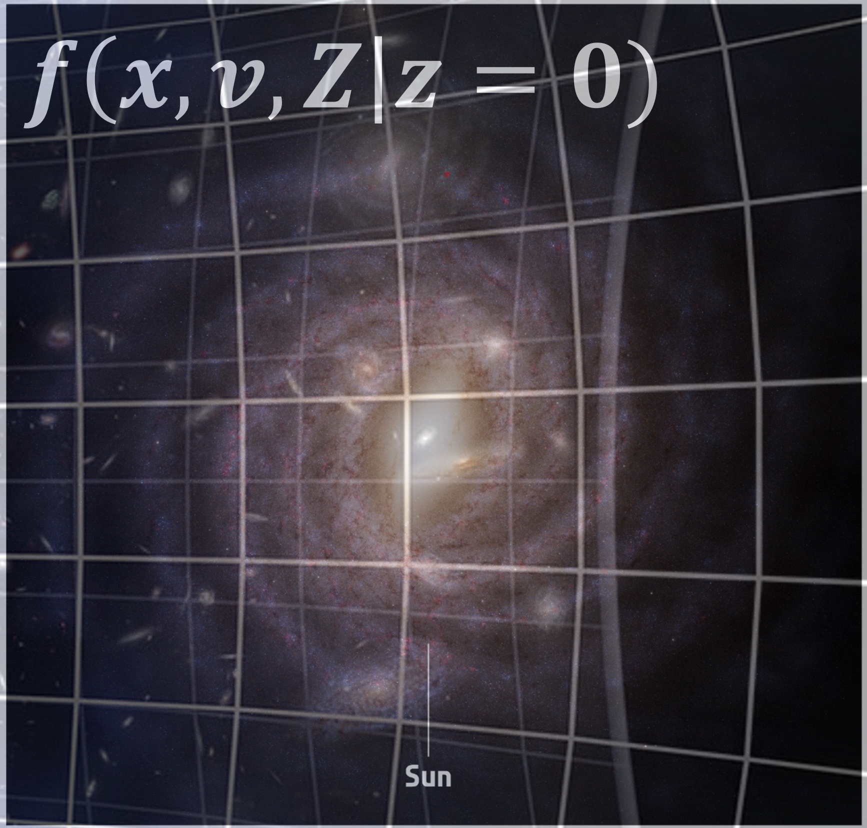
This Talk

$$f(x, v, Z|t)$$

Numerical/Semi-analytical Simulations

Present-day MW

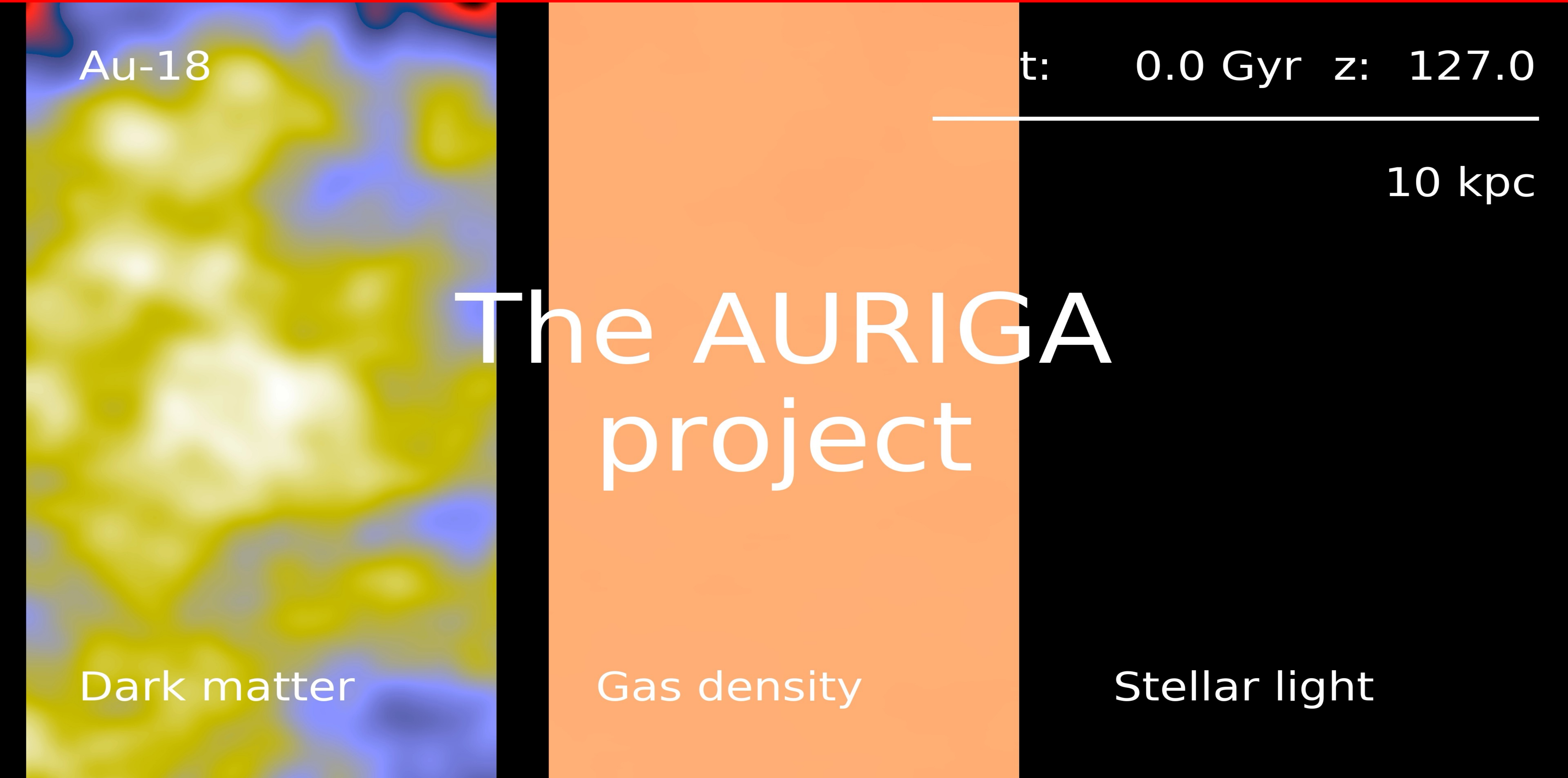
$$f(x, v, Z|z=0)$$



Gaia + LAMOST + …

理解和检验标准宇宙学模型至关重要！

骨架 血液 肌体


Au-18
t: 0.0 Gyr z: 127.0
10 kpc
The AURIGA project
Dark matter
Gas density
Stellar light