Spectroscopic survey of LAMOST

Yongheng Zhao
(National Astronomical Observatories of China)

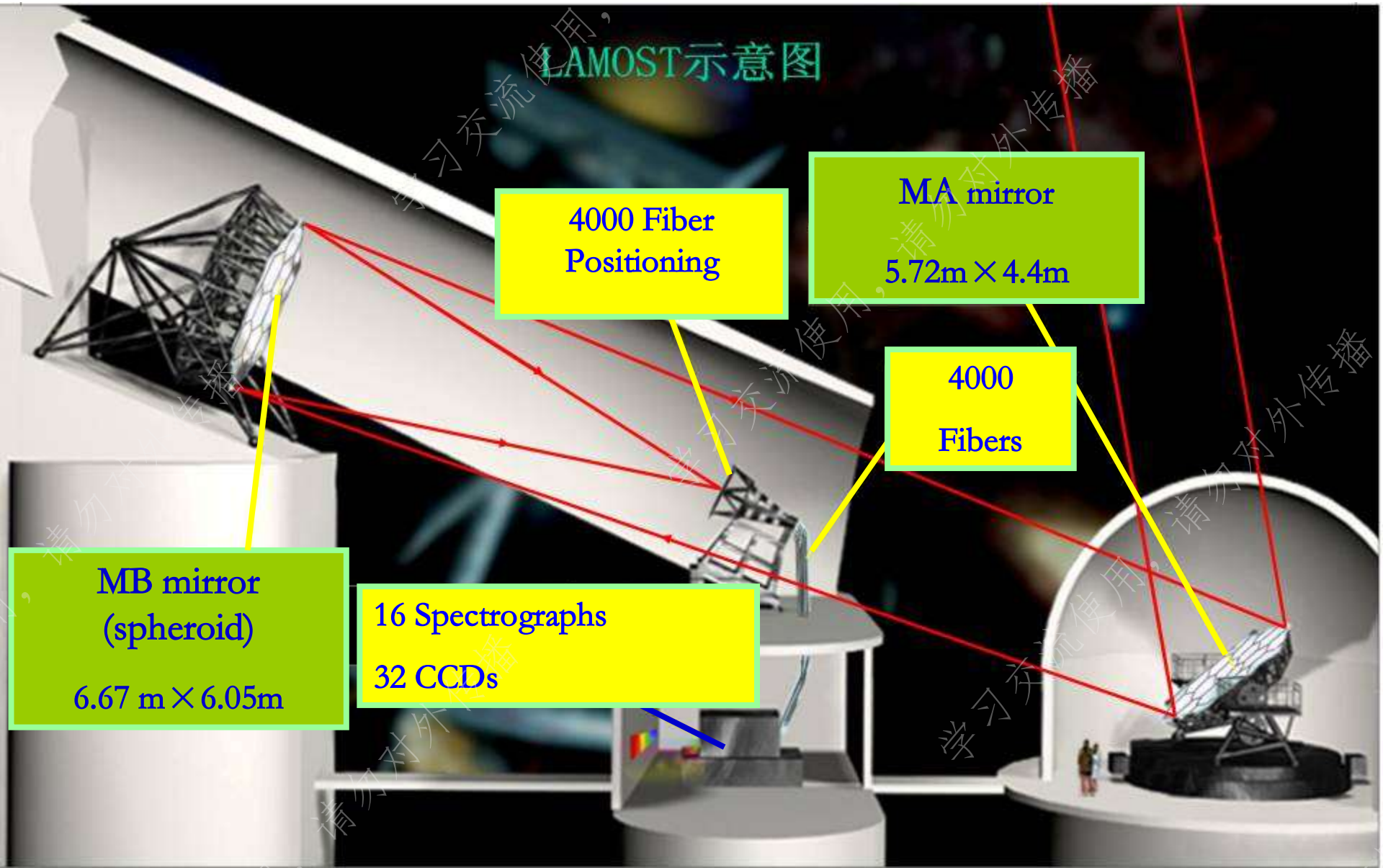
On behalf of the LAMOST operation team

Outline

- **LAMOST**
- **Spectroscopic Survey of LAMOST**
- **LAMOST Sciences**

LAMOST – A unique survey telescope

Structure of LAMOST



Innovations in LAMOST

a active reflecting Schmidt telescope

the Wang-Su type telescope which could get the largest aperture for wide field of view

large field of view (5 deg) +large aperture (4m)

achieved by new type of active optics — thin deformable segmented mirrors active optics

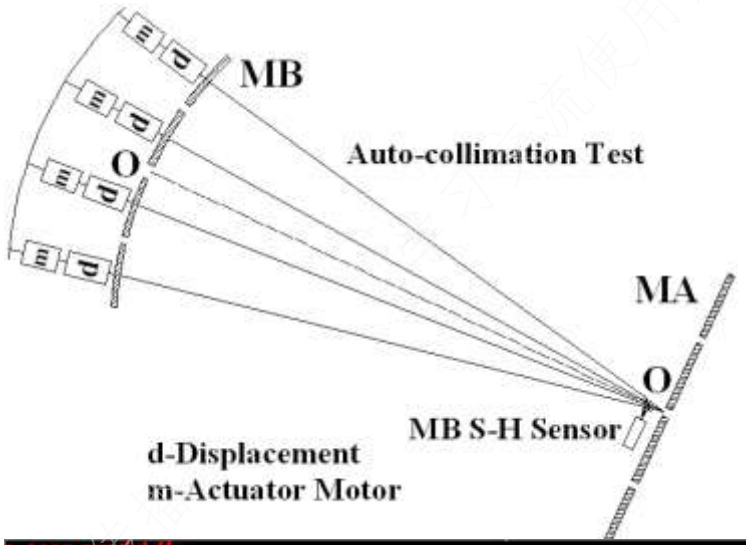
4000 optical fibers on focal surface

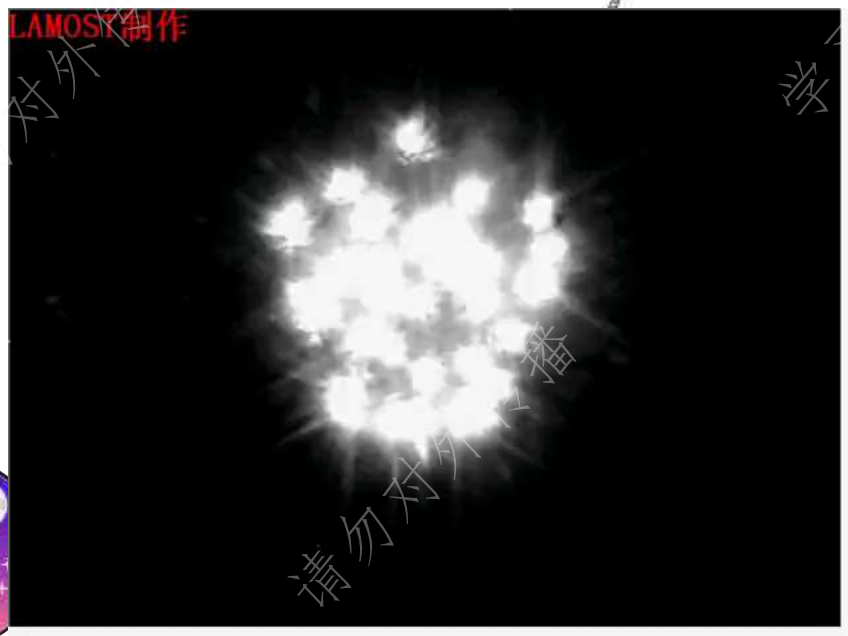
Parallel controllable fiber positioning opened the way to take thousands optical fibers observing in short time

MB: 37 sub-mirrors (6.67m x 6.05m)

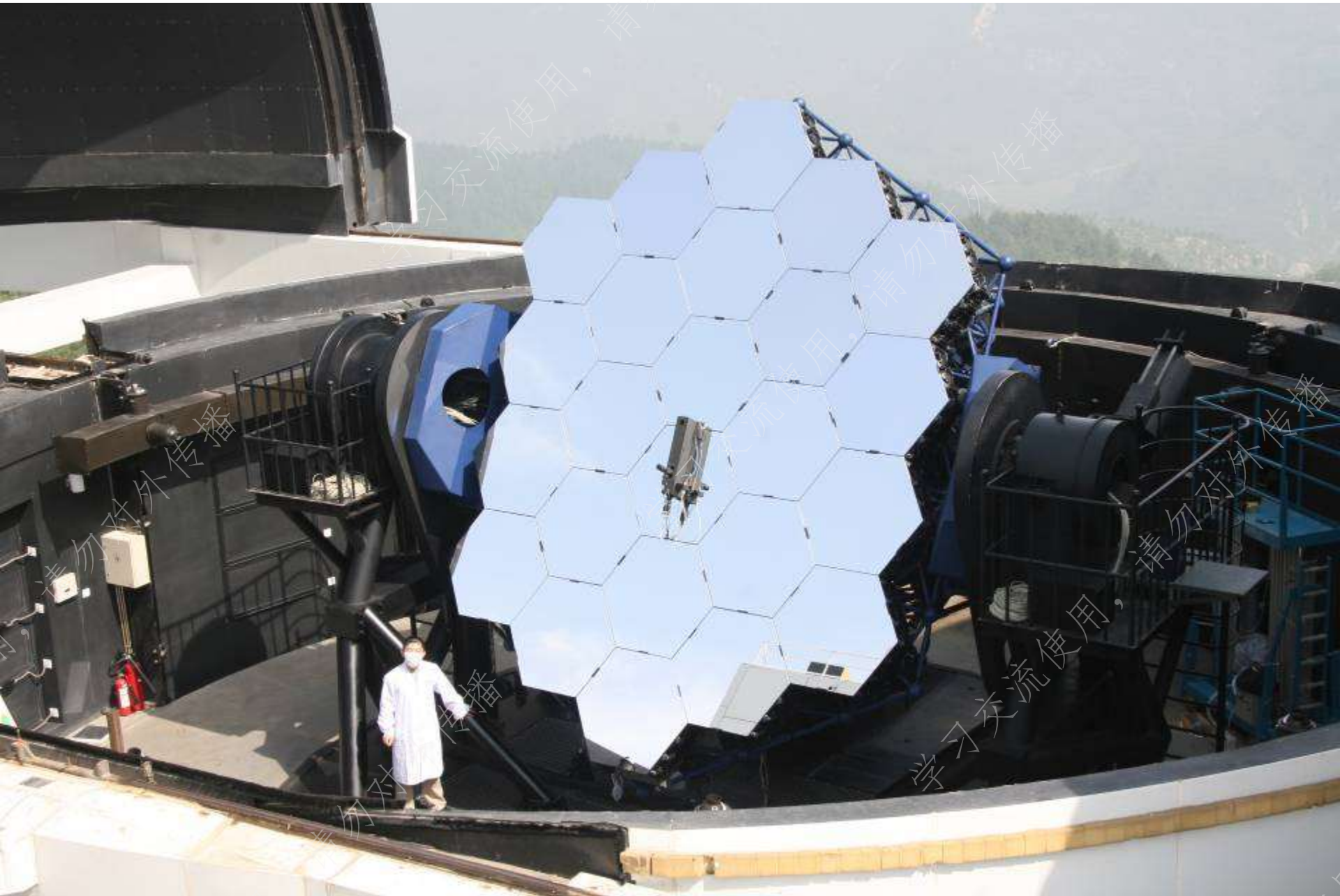
- **Active optics for segmented**

37 MB sub-mirrors

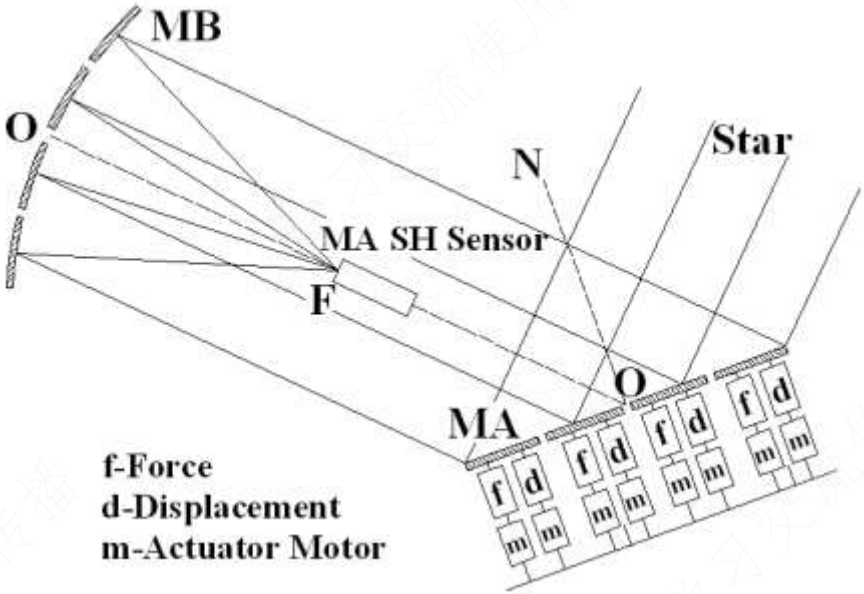


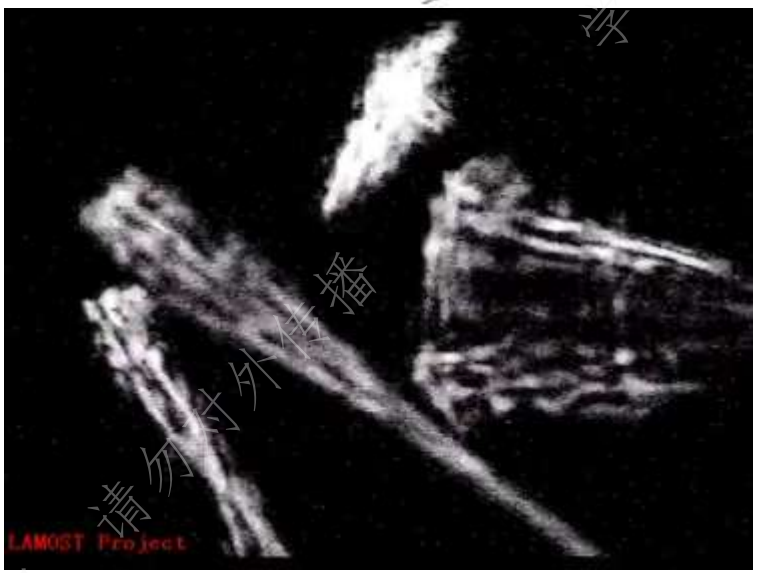


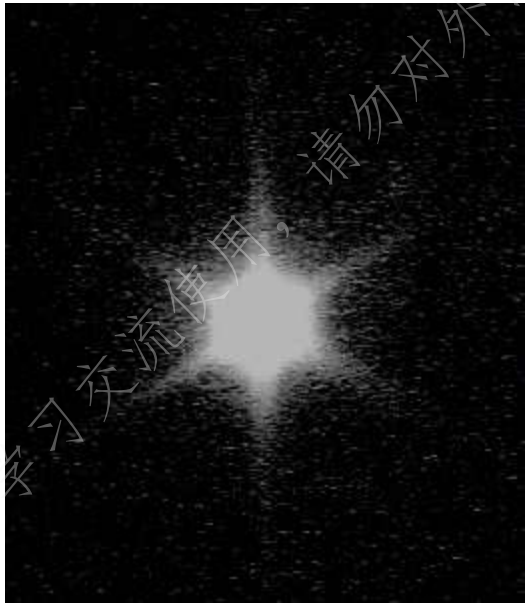
MA: 24 sub-mirrors (5.72m x 4.4m)



Active reflecting Schmidt optical system
Ma (24 sub-mirrors) + Mb (37 sub-mirrors)



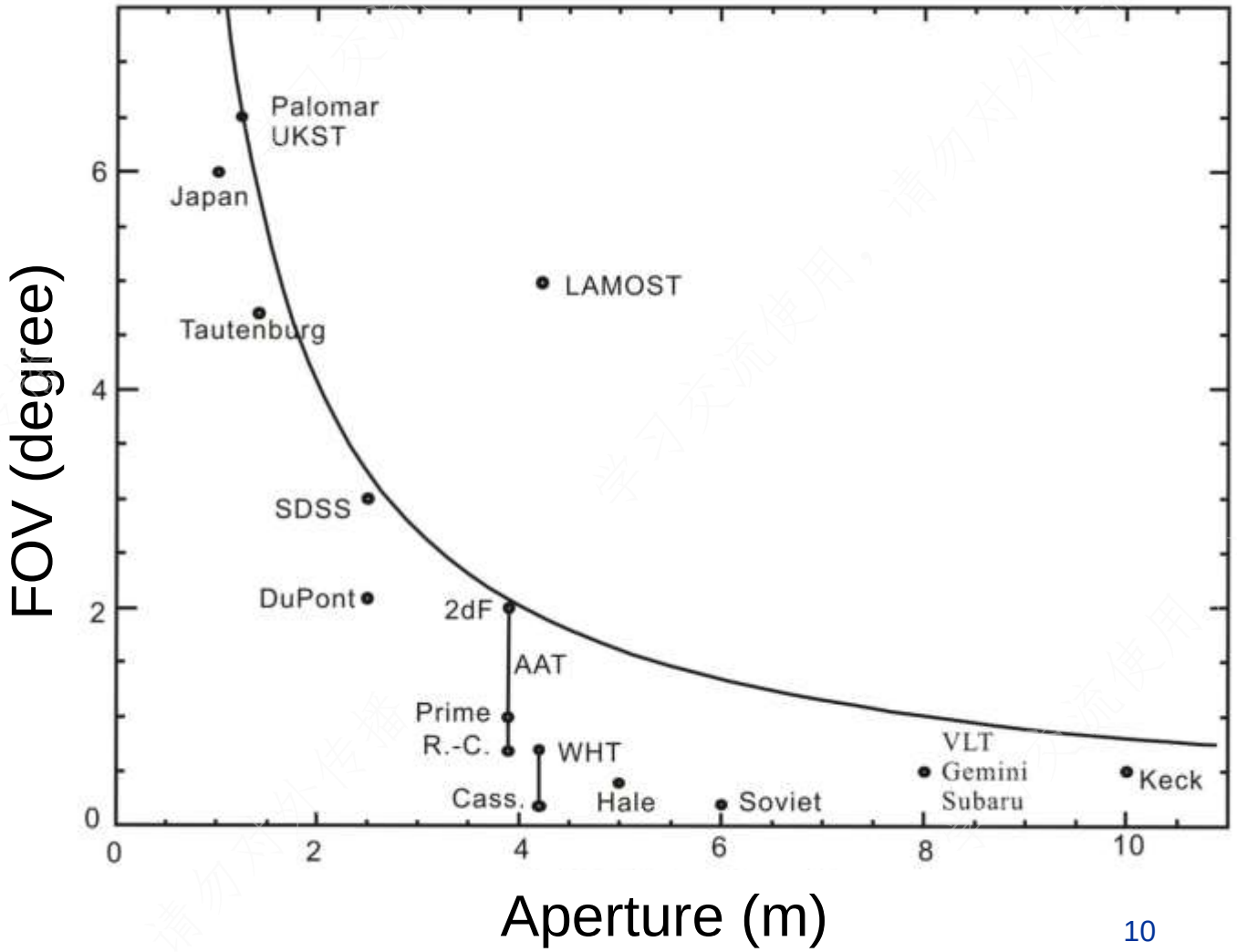




Aperture – field of view

(prof. Wilstrop in Cambridge University)

《Astronomical Optics and Elasticity Theory》，2009，p. 41



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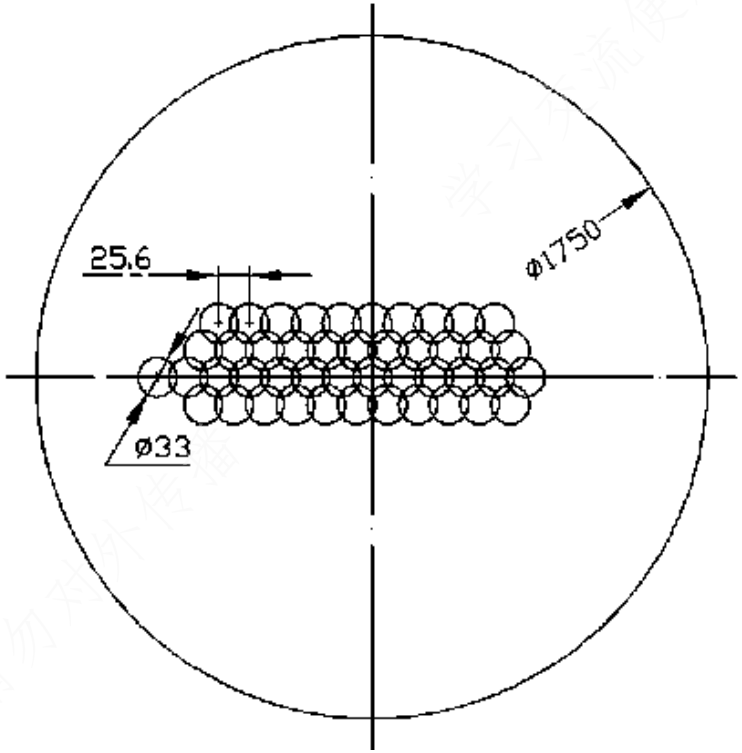
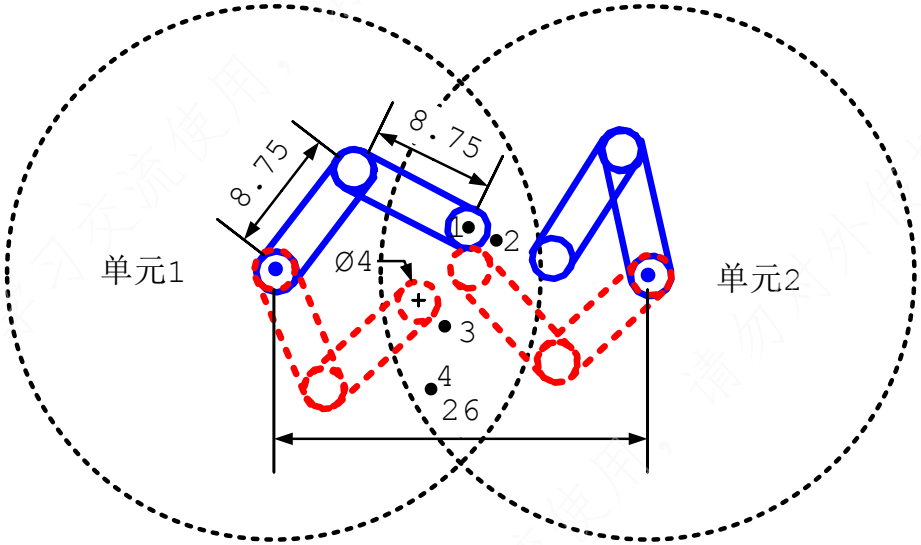
New technique:
Parallel controllable fiber positioning

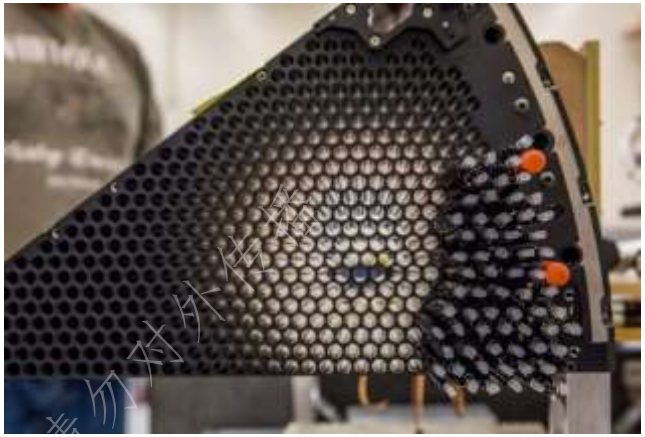




4000 fiber positioning units

并行可控式光纤定位单元

New spectroscopical survey projects



DESI (USA)

Figure 3.10-1. Positioner Bench Populated with One Module and a Single Positioner

SUBARU / PFS (Japan)

SDSS-Ⅴ (USA)

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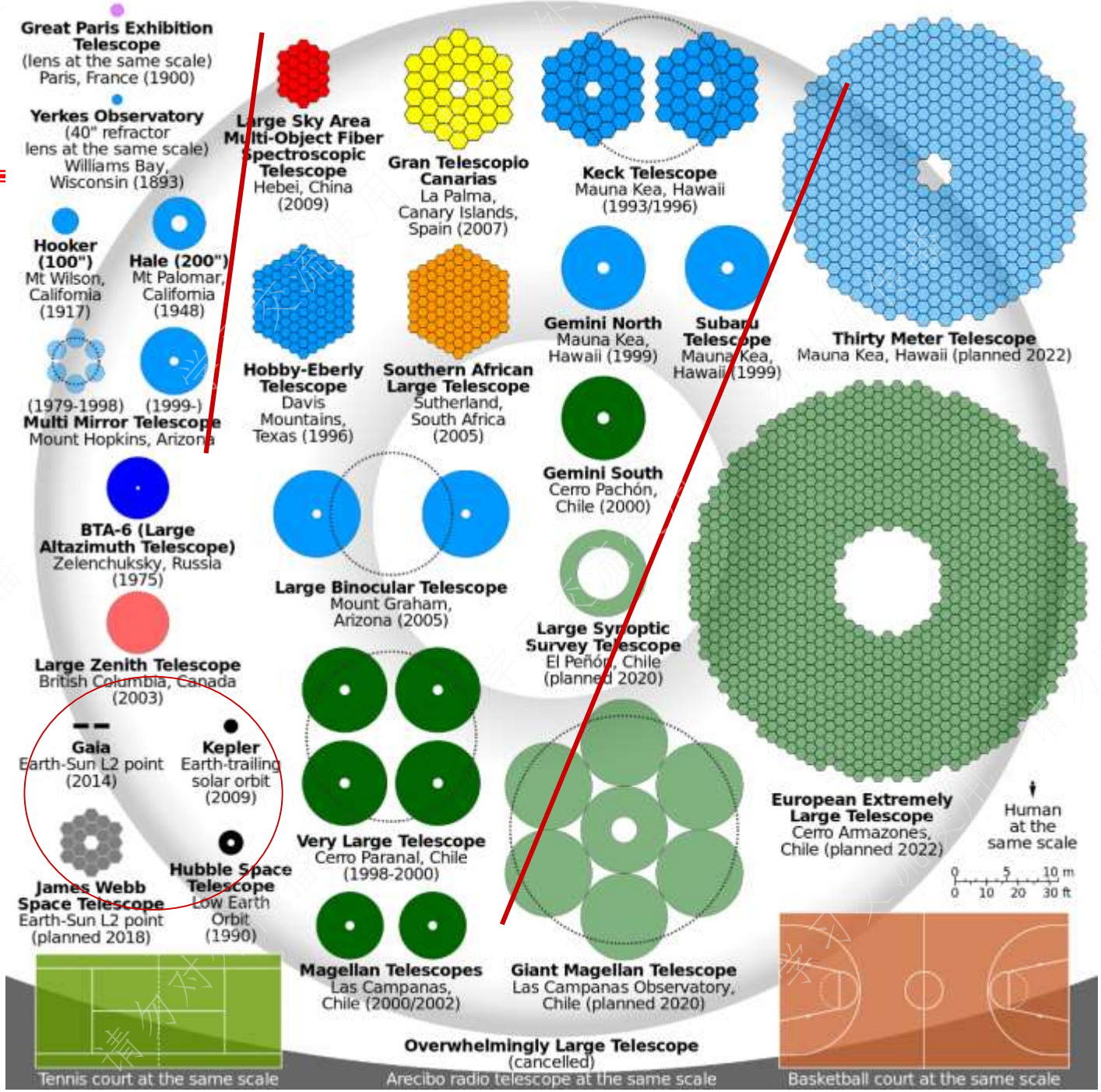
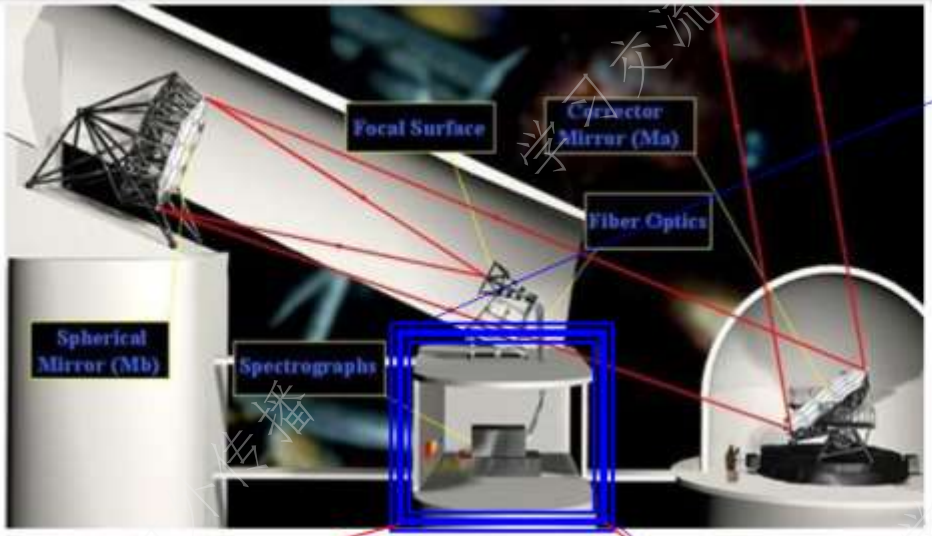

Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor
lens at the same scale)
Williams Bay,
Wisconsin (1893)
Hooker (100")
Mt Wilson,
California
(1917)
Hale (200")
Mt Palomar,
California
(1948)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia
(1975)
Large Zenith Telescope
British Columbia, Canada
(2003)
Gaia
Earth-Sun L2 point
(2014)
Kepler
Earth-trailing
solar orbit
(2009)
James Webb Space Telescope
Earth-Sun L2 point
(planned 2018)
Hubble Space Telescope
Low Earth
Orbit
(1990)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China
(2009)
Gran Telescopio Canarias
La Palma,
Canary Islands,
Spain (2007)
Keck Telescope
Mauna Kea, Hawaii
(1993/1996)
Hobby-Eberly Telescope
Davis
Mountains,
Texas (1996)
Southern African Large Telescope
Sutherland,
South Africa
(2005)
Gemini North
Mauna Kea,
Hawaii (1999)
Subaru Telescope
Mauna Kea,
Hawaii (1999)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
Gemini South
Cerro Pachón,
Chile (2000)
Large Binocular Telescope
Mount Graham,
Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile
(planned 2020)
Very Large Telescope
Cerro Paranal, Chile
(1998-2000)
Magellan Telescopes
Las Campanas,
Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory,
Chile (planned 2020)
European Extremely Large Telescope
Cerro Armazones,
Chile (planned 2022)
Human at the same scale
0 5 10 m
0 10 20 30 ft
Overwhelmingly Large Telescope
(cancelled)
Arecibo radio telescope at the same scale
Tennis court at the same scale
Basketball court at the same scale

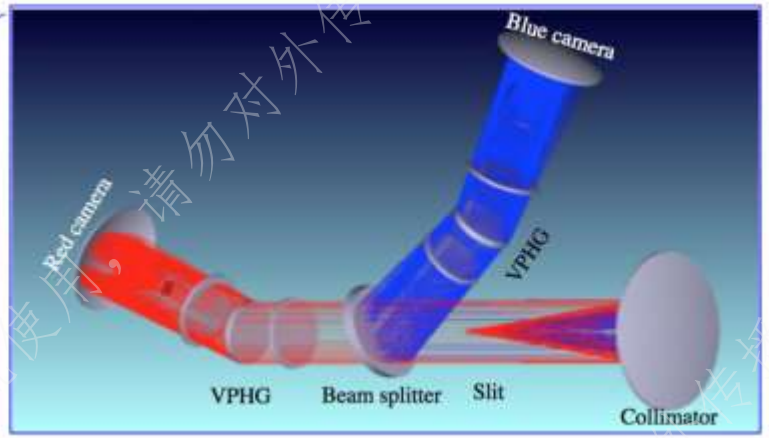
Spectroscopic Survey of LAMOST

		low resolution mode	medium resolution mode
Sep. 2011 – Jun. 2012	1 year	pilot survey	
Sep. 2012 – Jun. 2017	5 years	**1st regular survey**	
Sep. 2017 – Jun. 2018	1 year	continue	test survey
Sep. 2018 – Jun. 2023	5 years	**2nd regular survey**	**2nd regular survey**

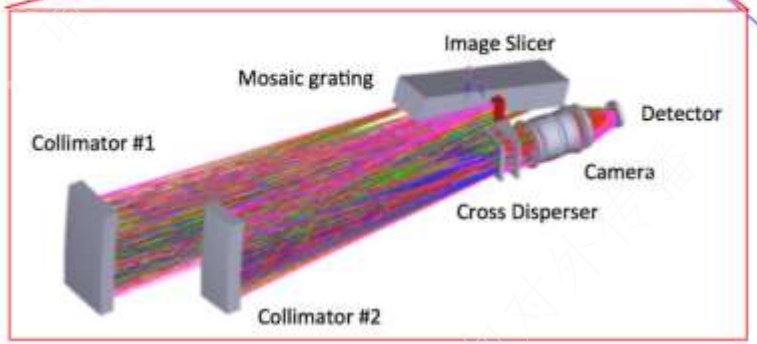
- **Scientific goals:**
  - **Structure & evolution of the Milky Way**
  - **Stellar astrophysics**
  - **Quasars & galaxies**

low & medium resolution modes

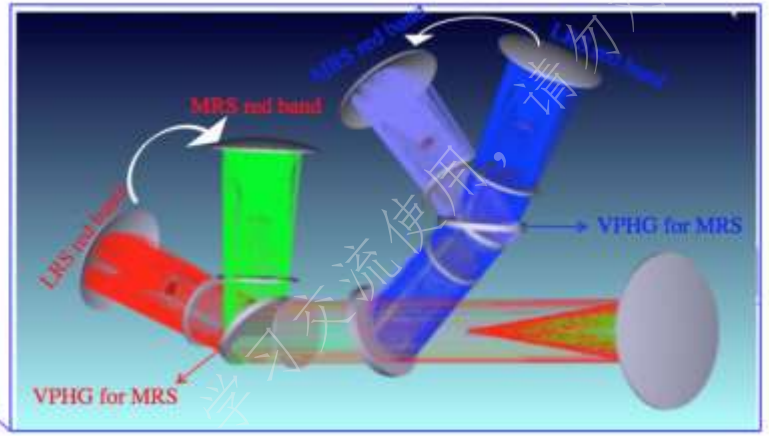




16 spectrographs in low-resolution mode



1 spectrographs in high-resolution mode



16 spectrographs in medium-resolution mode

Medium-resolution survey (MRS)

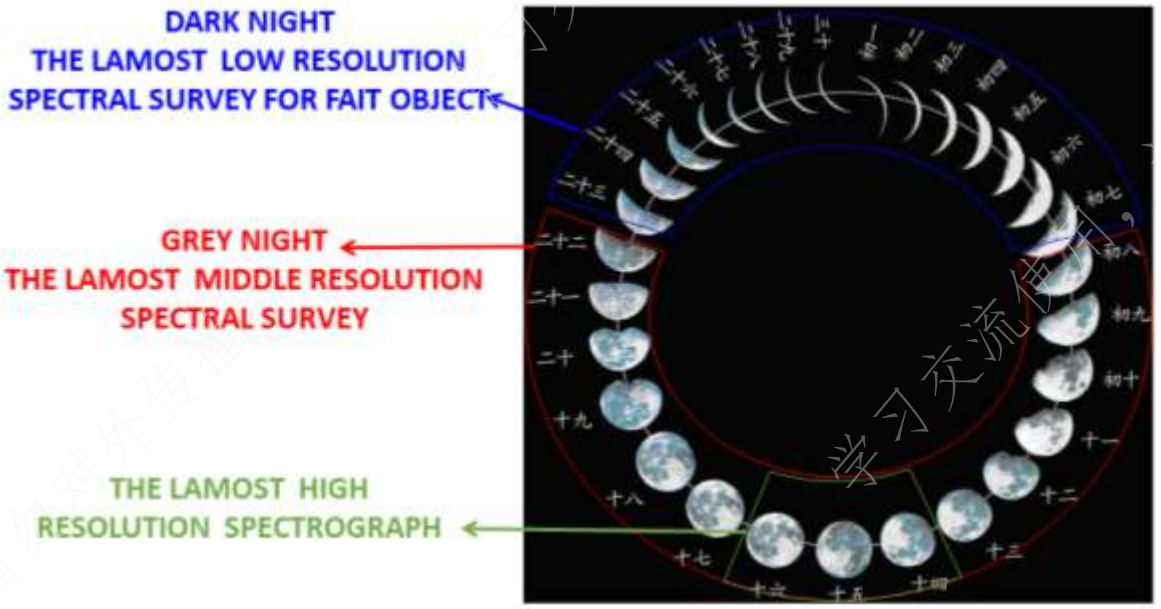
- **Accuracy： Vr < 1km/s**
- **~ 20 elements abundances**
  - **Li, C, Na, Mg, Si, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Y, Sm, Nd and Ba etc.**
- **4000 fibers**
- **g<15 Mag.**
- **R ~ 7500**

	R～1800	R～7500
Vr	⩽ 5km/s	⩽1km/s
T_{eff}	200k	100k
Log g	0.2dex	0.1 dex
[Fe/H]	0.2dex	0.1 dex
[α/Fe]	0.2dex	0.1 dex

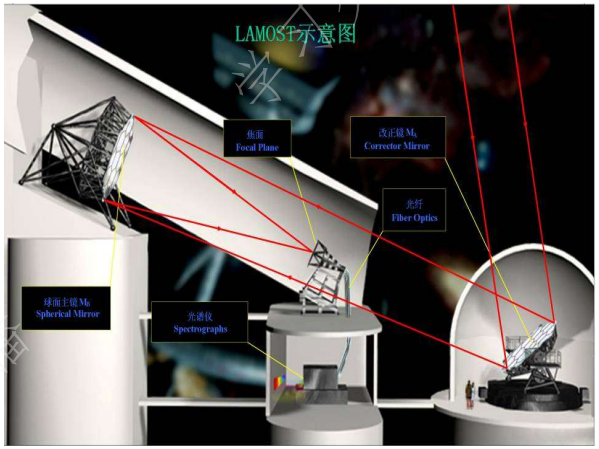
The 2nd regular survey of LAMOST

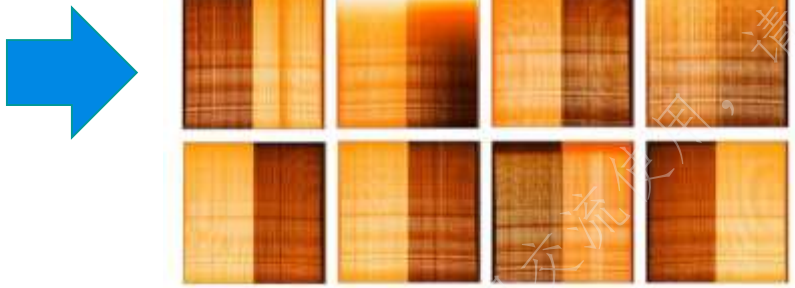
2018.9 - 2023.6:

- survey in low-resolution (dark nights)
- survey in median-resolution (bright nights)
- observations in high-resolution (full moon nights)

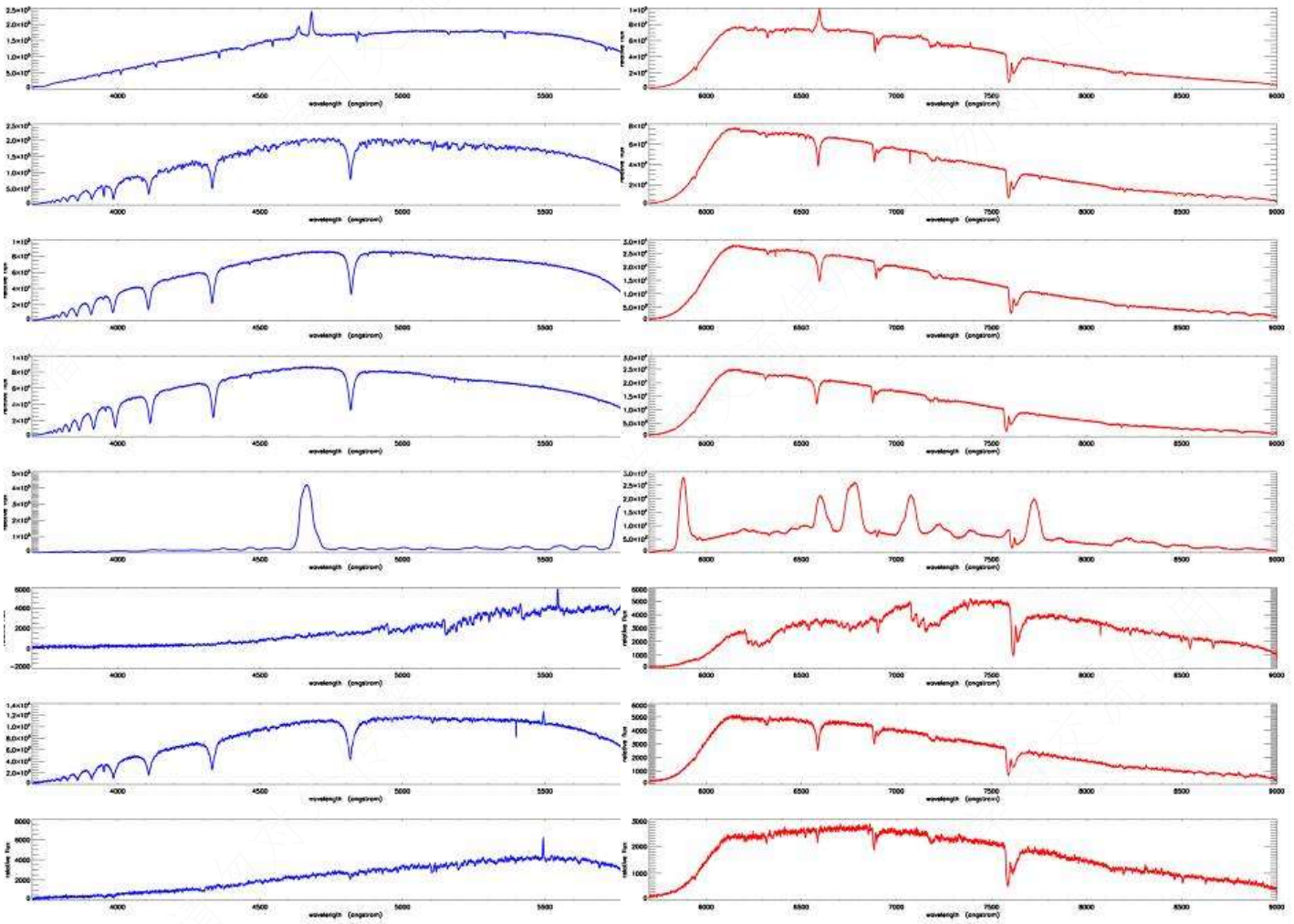


Raw data by LAMOST

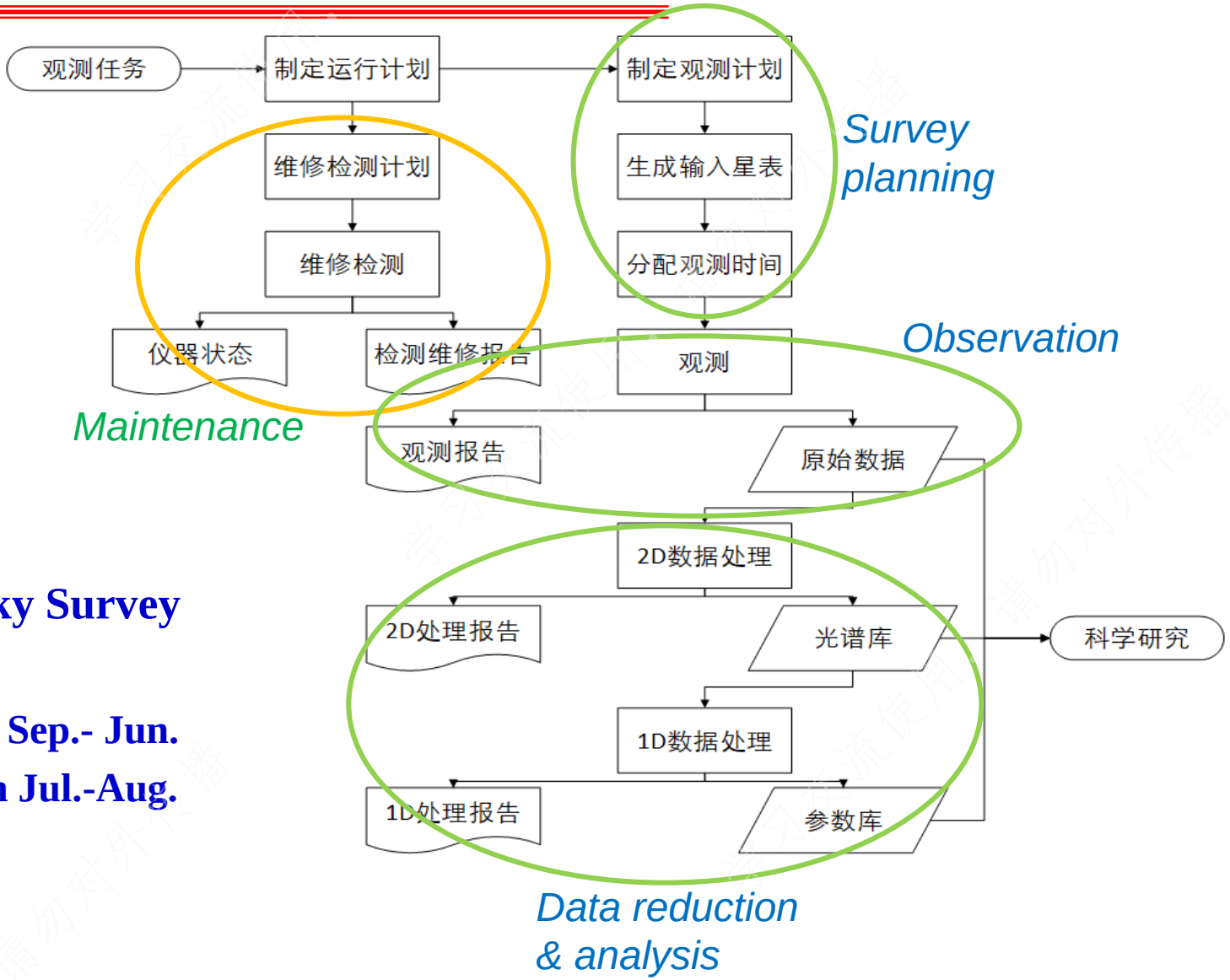




Data reduction



Operation of LAMOST



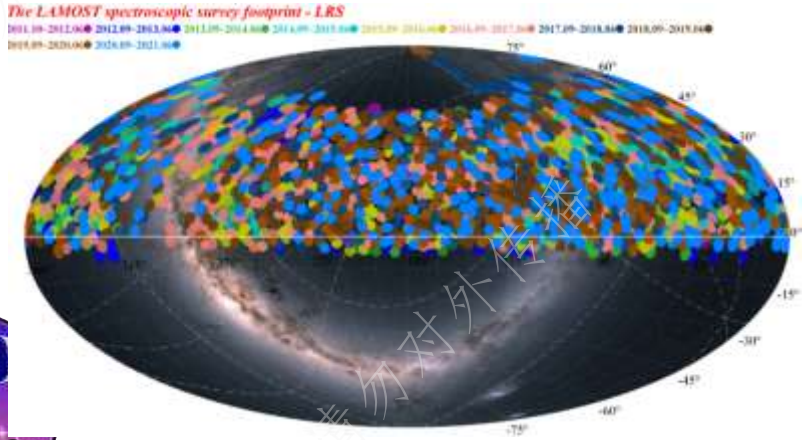
Observation of Sky Survey

- **Observation in Sep.- Jun.**
- **Maintenance in Jul.-Aug.**

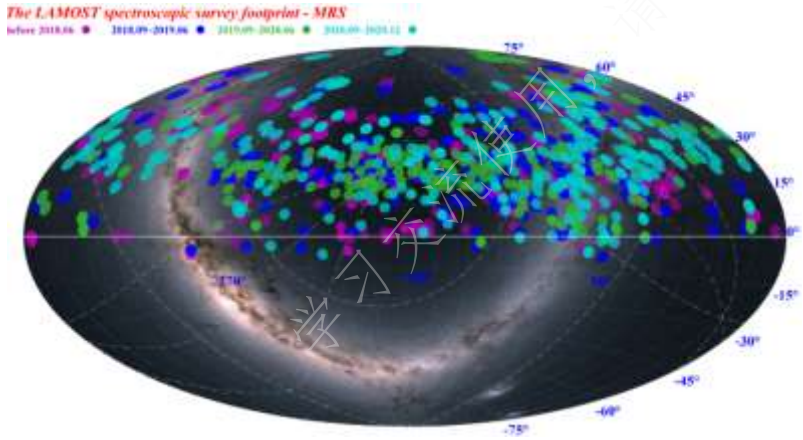
~ 20,000,000 spectra by LAMOST

- **DR9 dataset (Mar. 2022)**
  - **Observed: Sep. 2011 – Jun. 2021**

	Low-resolution data	Medium-resolution non time-domain data	Medium-resolution time-domain data	Total
Total spectra	1226252	1841959	6384475	**19452686**
Spectra (S/N>10)	10109779	1194264	3662548	14966591
Star parameter	7060436	906003	771211	8737650



Low resolution obs. of LAMOST DR9



Midium resolution obs. of LAMOST DR9

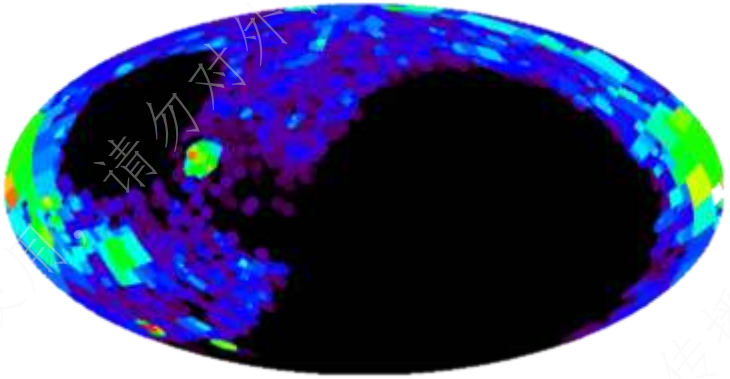
Data release of LAMOST

- **Data police:**
  - **Released to Chinese astronomers and international parteners**
  - **Released to Public after 18 months**

Dataset	Spectra with S/N>10	Stellar parameters	Data release to domestic / public
Pilot survey （PDR）	0.55 M	0.36 M	2012.08 / 2012.08
Pilot + 1 year Normal survey: (DR1)	1.74 M	1.06 M	2013.09 / 2015.03
Pilot + 2 year Normal survey: (DR2)	3.27 M	2.20 M	2014.12 / 2016.07
Pilot + 3 year Normal survey: (DR3)	4.66 M	3.17 M	2015.12 / 2017.07
Pilot + 4 year Normal survey: (DR4)	6.21 M	4.20 M	2016.12 / 2018.07
Pilot + 5 year Normal survey: (DR5)	7.77 M	5.34 M	2017.12 / 2019.07
Pilot + 6 year Normal survey: (DR6)	9.37 M	6.36 M	2019.03 / 2020.10
Pilot + 7 year Normal survey: (DR7)	14.48 M	7.00 M	2020.03 / 2021.10
Pilot + 8 year Normal survey: (DR8)	17.23 M	7.75 M	2021.03 / *2022.10*
Pilot + 9 year Normal survey: (DR9)	**19.45 M**	**8.73 M**	2022.03 / *2023.10*

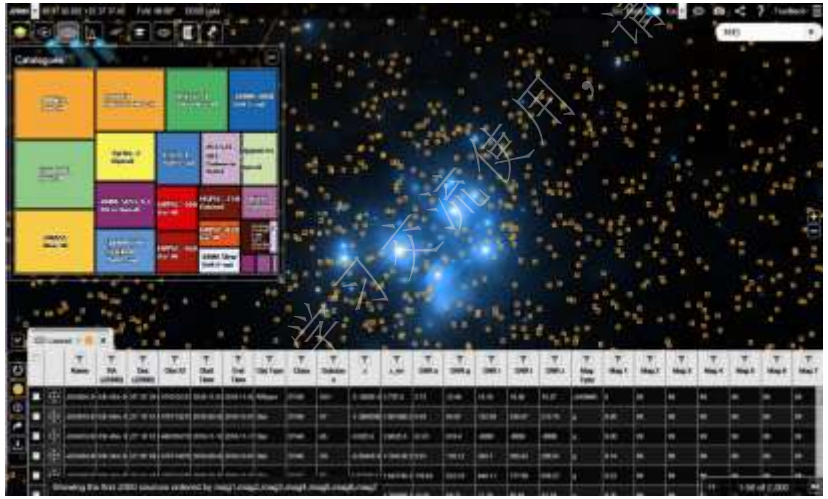
Collaborations with CDS & ESA

- **LAMOST datasets collected by ViziR/CDS from 2016**



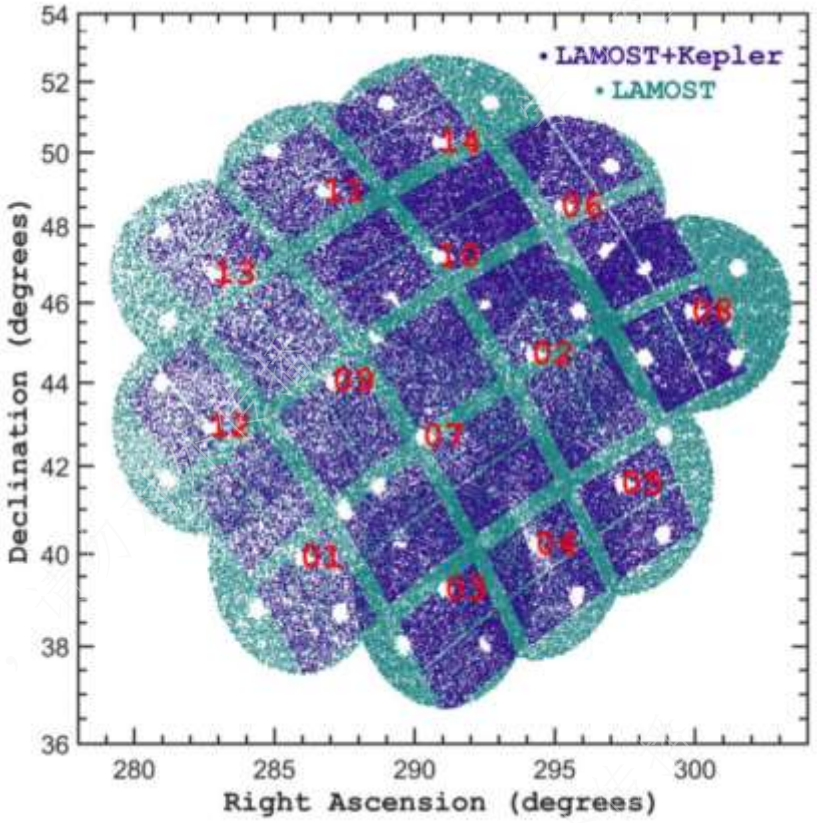
LAMOST DR5 in VizieR

- **Fusion with ESASky astronomical data system**



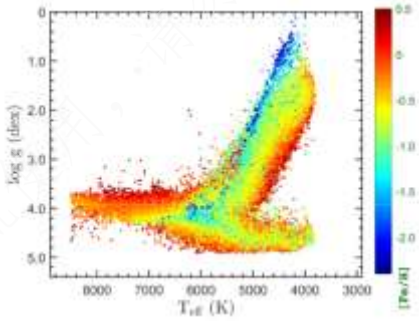
Collaboration with Kepler project

LAMOST-Kepler project (2012-2017, 2018…)



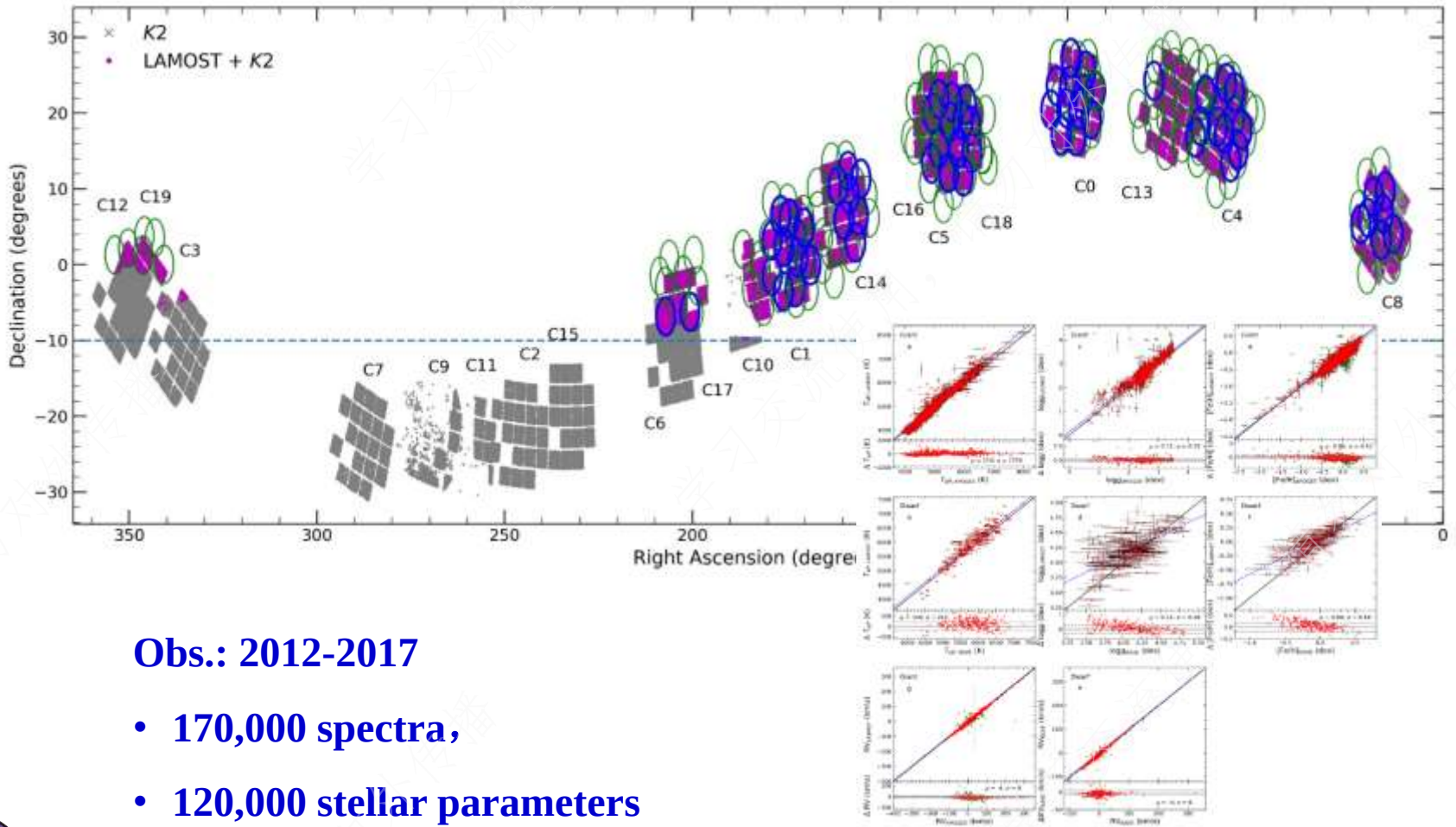
Year	#Fields	#Plates	#Spectra
2012	3	7	17,659
2013	6	14	39,309
2014	7	14	38,516
2015	11	32	97,247
2017	6	16	35,139
2018	1	2	4892
total	*33*	*83*	*238,386*

- **~39% of *Kepler* stars observed**



De Cat & Fu et al. 2015, *ApJS*, 220, 19
Zong, Fu & De Cat et al. 2018, *ApJS*, 238, 30
Fu, De Cat & Zong, 2020, *RAA*, 20, 167

LAMOST-K2 project

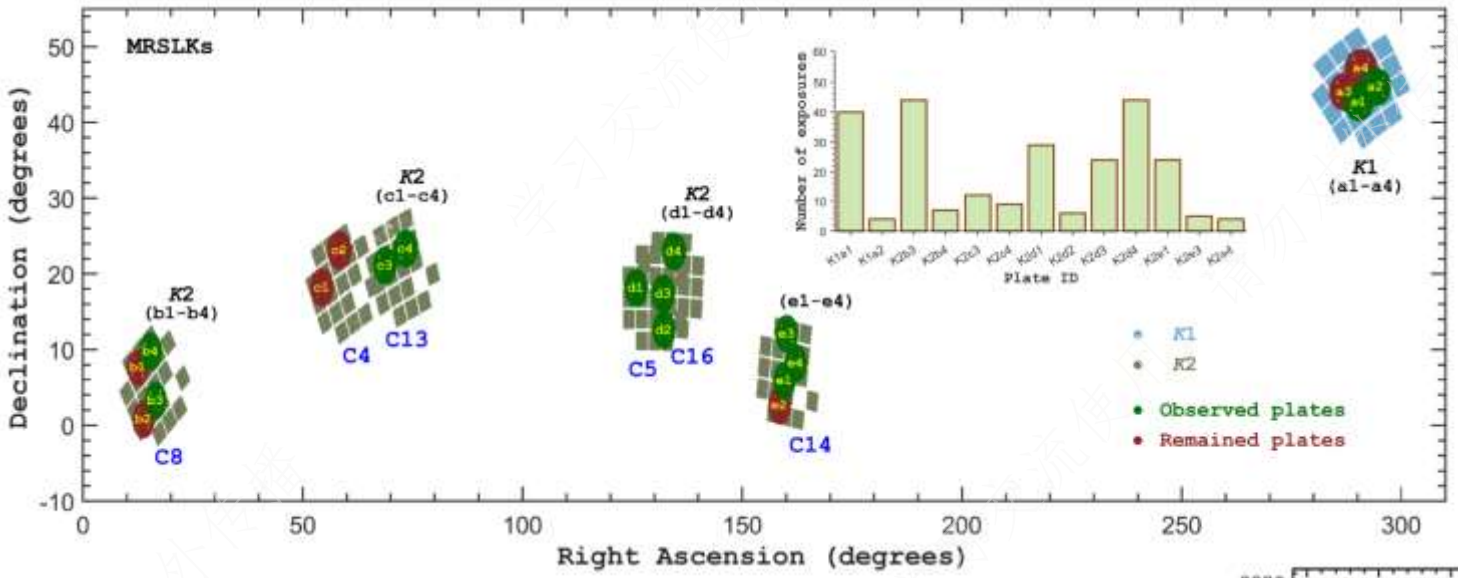


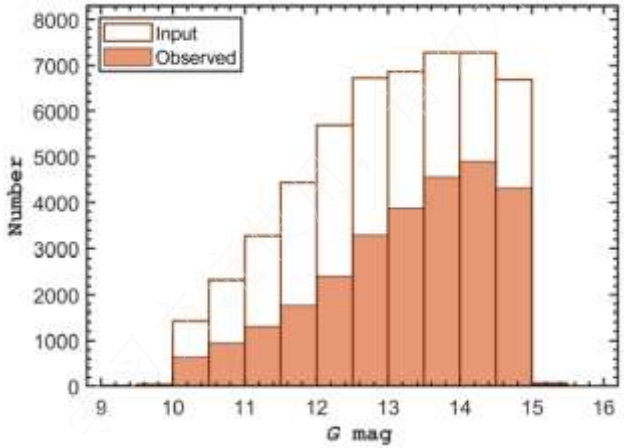
Obs.: 2012-2017

- **170,000 spectra，**
- **120,000 stellar parameters**
- **K2 objects: 86,000 (~20%)**

Wang, Fu & Zong et al. 2020, *ApJS*, 251, 27

Medium resolution survey for LAMOST-KEPLER/K2

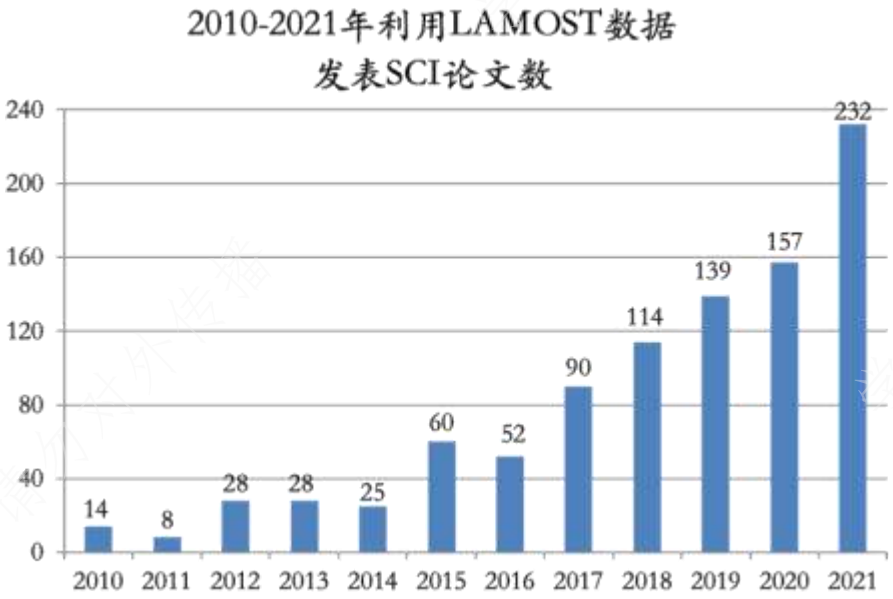




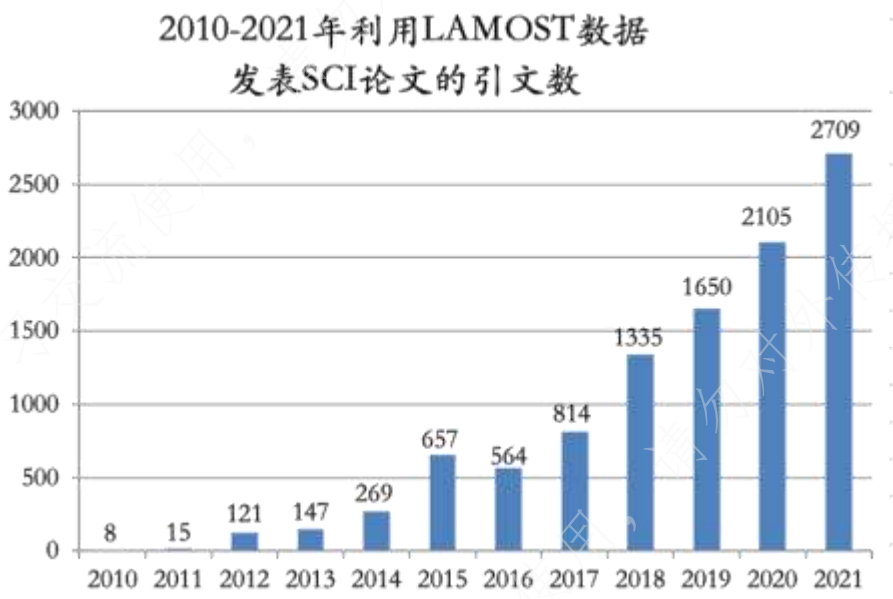
- 20 plates in Kepler & K2 regions
- 50,000 stars
- 60 obs. for each plate

Publications by used of LAMOST data

No. of papers: 947



No. of citations: 10,394



No. of papers by foreign astronomers

	2017	2018	2019	2020	2021
No. of SCI by foreign astronomers	35	37	50	60	**112**
No. of SCI by Chinese astronomers	55	77	89	97	120
Ratio	38.9%	32.5%	36.0%	39.3%	**48.3%**

Abundances in the Milky Way across Five Nucleosynthetic Channels from 4 Million LAMOST Stars

Show affiliations

Wheeler, Adam; Ness, Melissa; Buder, Sven; Bland-Hawthorn, Joss; De Silva, Gayandhi; Hayden, Michael; Kos, Janez; Lewis, Geraint F.; Martell, Sarah; Sharma, Sanjib; Simpson, Jeffrey D.; Zucker, D. B.; Zwitter, Tomaž

美国哥伦比亚大学和澳大利亚悉尼大学研究团队

Large stellar surveys are revealing the chemodynamical structure of the Galaxy across a vast spatial extent. However, the many millions of low-resolution spectra observed to date are yet to be fully exploited. We employ The Cannon, a data-driven approach for estimating chemical abundances, to obtain detailed abundances from low-resolution (R = 1800) LAMOST spectra, using the GALAH survey as our reference. We deliver five (for dwarfs) or six (for giants) estimated abundances representing five different nucleosynthetic channels, for 3.9 million stars, to a precision of 0.05-0.23 dex. Using wide binary pairs, we demonstrate that our abundance estimates provide chemical discriminating power beyond metallicity alone. We show the coverage of our catalog with radial, azimuthal and dynamical abundance maps and examine the neutron capture abundances across the disk and halo, which indicate different origins for the in situ and accreted halo populations. LAMOST has near-complete Gaia coverage and provides an unprecedented perspective on chemistry across the Milky Way.

LAMOST基本覆盖Gaia天区，对银河系化学性质的研究提供了前所未有的视角

Publication: The Astrophysical Journal, Volume 898, Issue 1, id.58

Pub Date: July 2020

DOI: 10.3847/1538-4357/ab9a46

(Wheeler et al. 2020, ApJ, 898)

Article

A stellar stream remnant of a globular cluster below the metallicity floor

https://doi.org/10.1038/s41586-021-04162-2
Received: 14 June 2021
Accepted: 19 October 2021
Published online: 5 January 2022
Check for updates

Nicolas F. Martin[1,2], Kim A. Venn[3], David S. Aguado[4,5,6], Else Starkenburg[7], Jonay I. González Hernández[5,6], Rodrigo A. Ibata[1], Piercarlo Bonifacio[8], Elisabetta Caffau[8], Federico Sestito[3], Anke Arentsen[1], Carlos Allende Prieto[5,6], Raymond G. Carlberg[10], Sébastien Fabbro[3,11], Morgan Fouesneau[7], Vanessa Hill[12], Pascale Jablonka[9,13], Georges Kordopatis[12], Carmela Lardo[14], Khyati Malhan[15], Lyudmila I. Mashonkina[16], Alan W. McConnachie[11], Julio F. Navarro[3], Rubén Sánchez-Janssen[17], Guillaume F. Thomas[5,6], Zhen Yuan[1] & Alessio Mucciarelli[14,18]

Stellar ejecta gradually enrich the gas out of which subsequent stars form, making the least chemically enriched stellar systems direct fossils of structures formed in the early Universe[1]. Although a few hundred stars with metal content below 1,000th of the solar iron content are known in the Galaxy[2–4], none of them inhabit globular clusters, some of the oldest known stellar structures. These show metal content of at least approximately 0.2% of the solar metallicity ([Fe/H] ≥ −2.7). This metallicity floor appears universal[5,6], and it has been proposed that protogalaxies that merged into the galaxies we observe today were simply not massive enough to form clusters that survived to the present day[7]. Here we report observations of a stellar stream, C-19, whose metallicity is less than 0.05% of the solar metallicity ([Fe/H] = −3.38 ± 0.06 (statistical) ± 0.20 (systematic)). The low metallicity dispersion and the chemical abundance
stream is the tidal remnant of the most metal-poor g
and is significantly below the purported metallicity
metallicities than observed today existed in the pas
Milky Way halo.

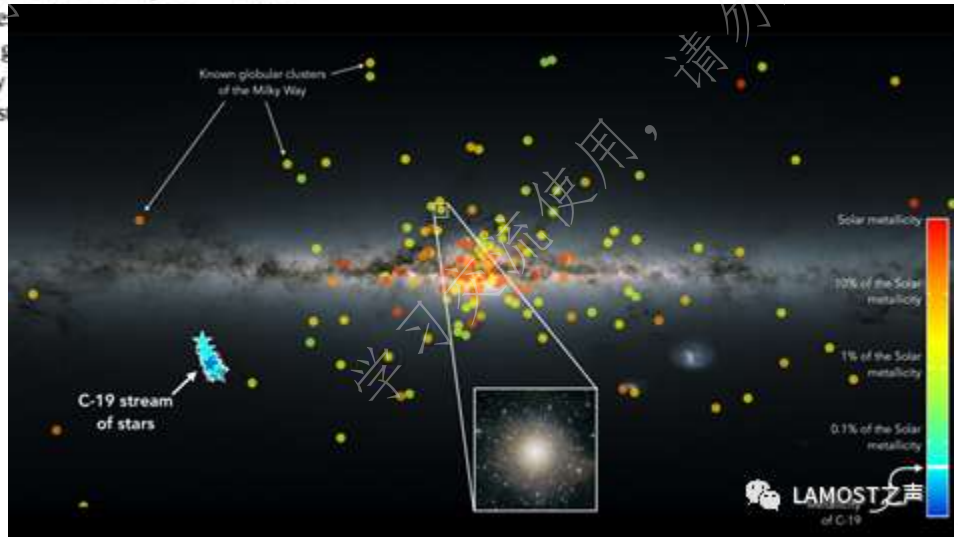
Research group from France, Canada, Italy, China et al.

Z. Yuan: LAMOST fellow

C-19: stellar stream

LAMOST: 1 star

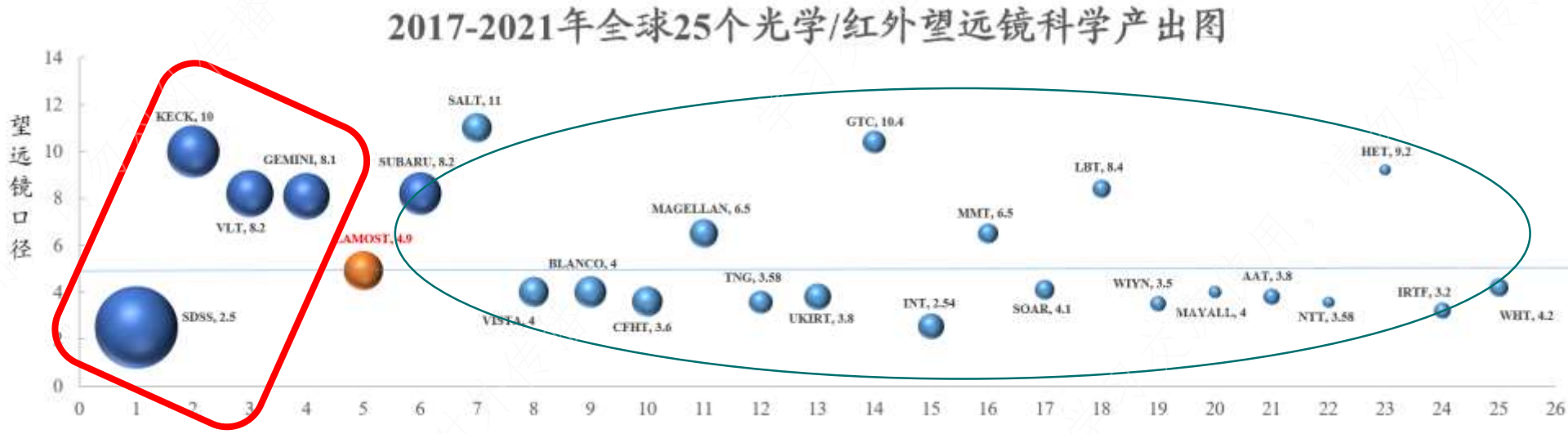
Gemini N: 3 stars
GTC: 6 stars



Publications by optical telescopes

Jan. 2017 – Dec. 2021

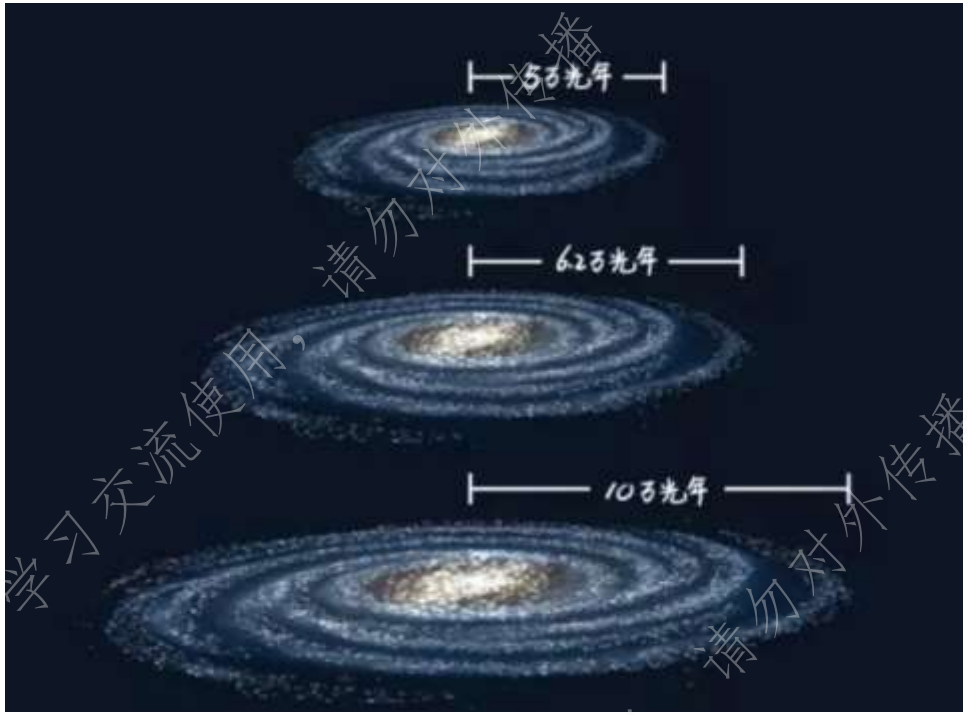
LAMOST is the 5th with the 25 O/IR telescopes in the world



LAMOST sciences

Structure of the galactic disk: radius

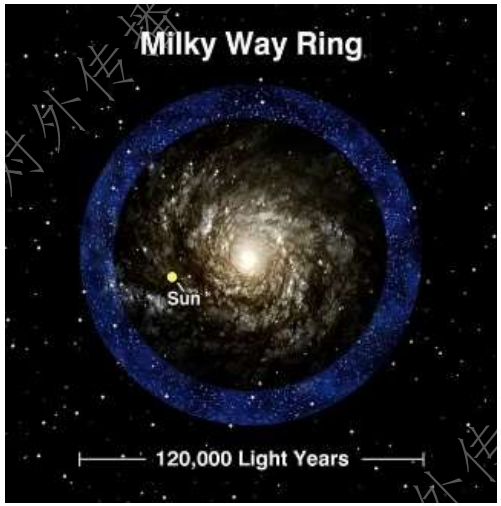
- In textbook
  50,000 light years
- 2017:
  Liu et al. RAA
  62,000 light years
- 2018:
  Lopez-Corredoira et al. AA
  100,000 light years
- 2021:
  Li et al. ApJ
  97,800 light years

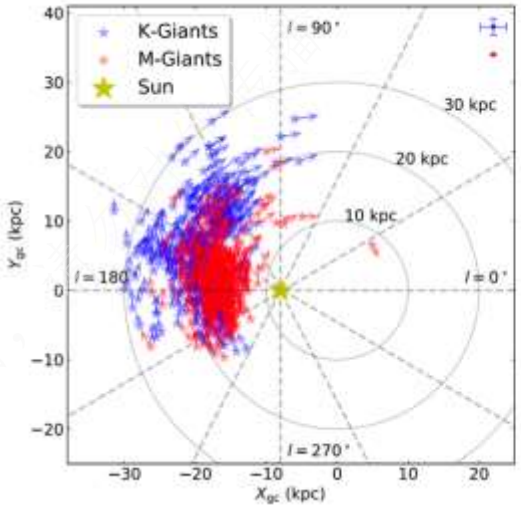


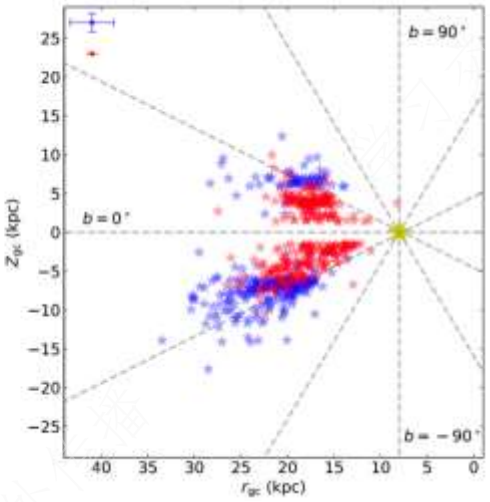
银盘半径大小变化示意图

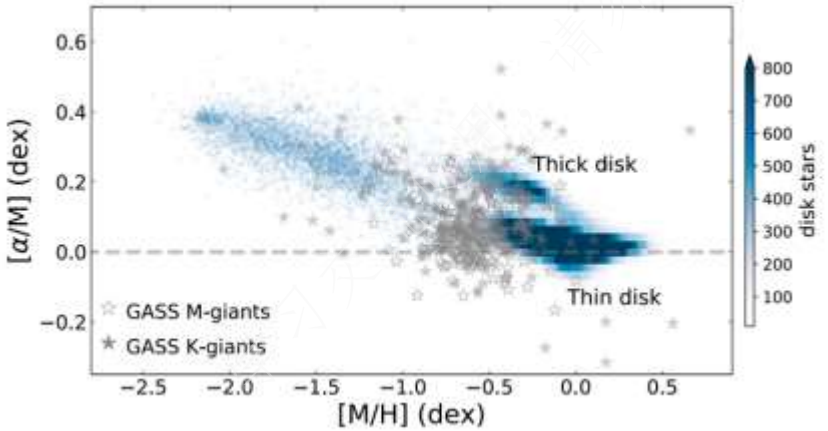
Monoceros ring

- **Origin from disk**
- **Extended to 30 kpc**



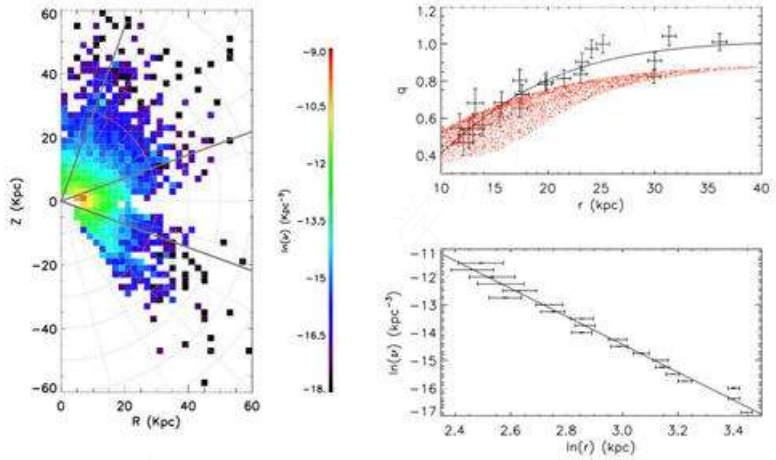


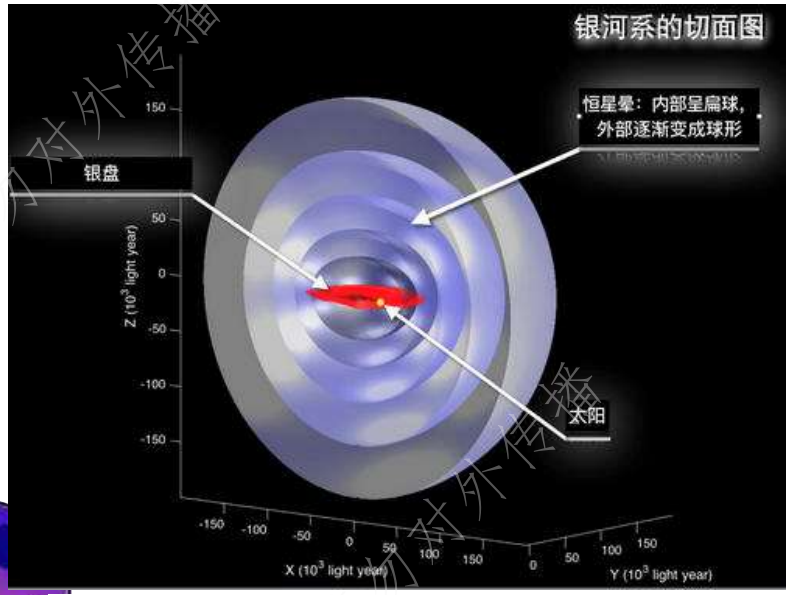


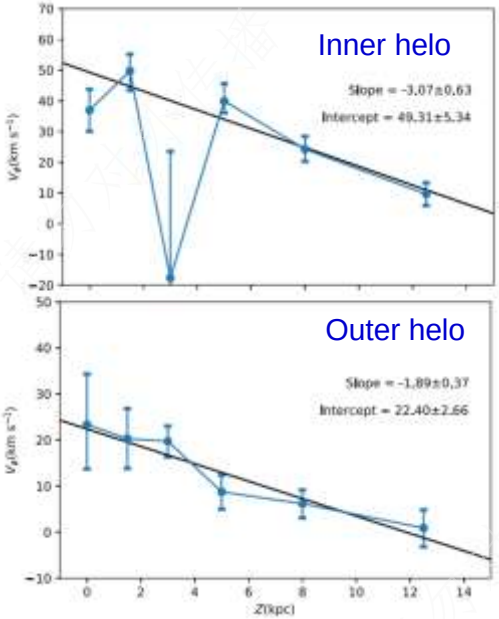


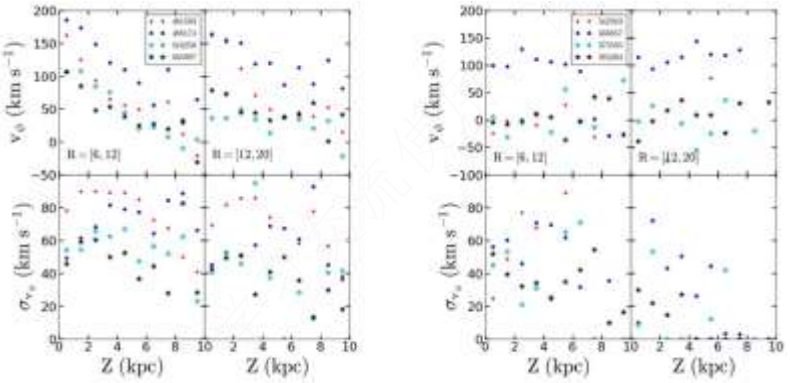
Li, Xue+ ApJ, 2021

Structure of the halo









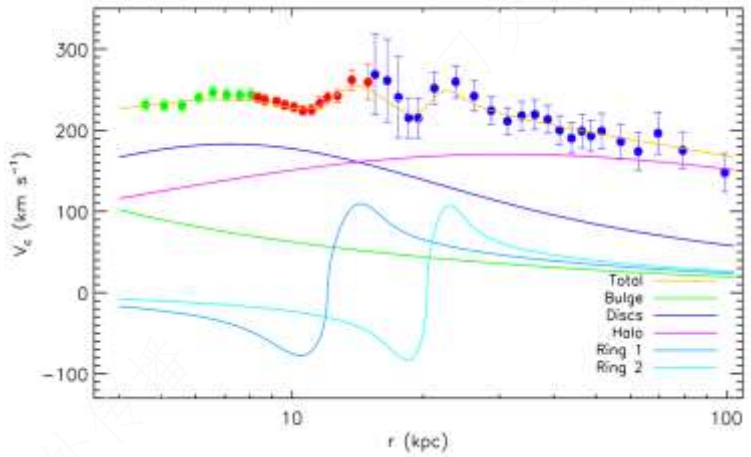
Xu et al. 2018, MNRAS, 473, 1244

Tian+2020 ApJ

Total Mass of the Milky Way

$M_{Vir} = 0.90\ (+0.07, -0.08) \times 10^{12}\ M_{\odot}$

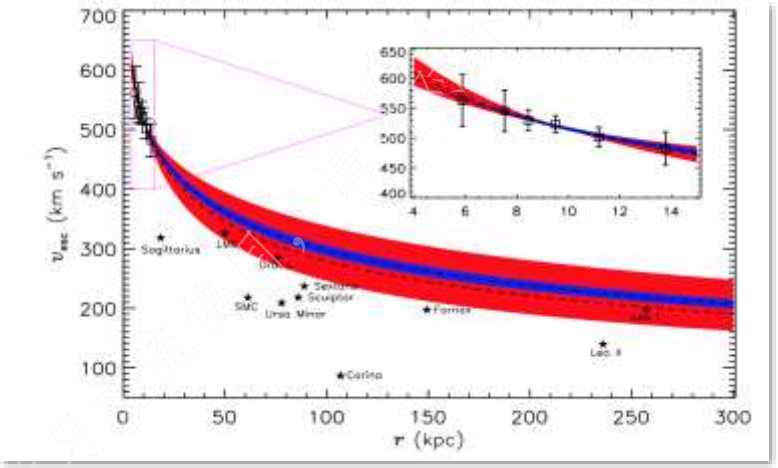
$\varrho_{DM} = 0.32\ (+0.02, -0.02)\ GeV\ cm^{-3}$



Huang et al. 2016

$M_{vir} = (0.91 \pm 0.05) \times 10^{12}\ M_{\odot}$

$v_{esc}\ (R_0) = 529 \pm 29$ km/s



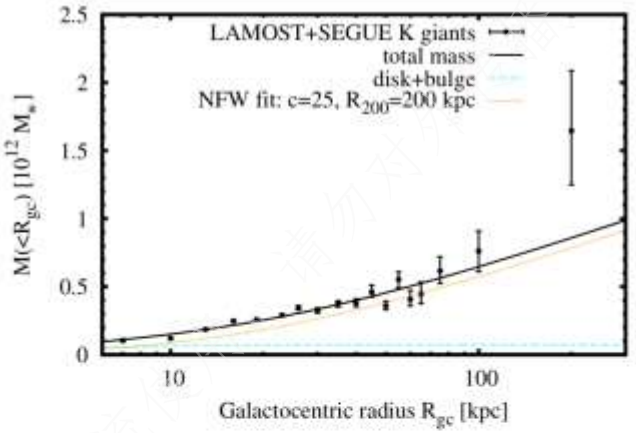
Huang et al. submitted

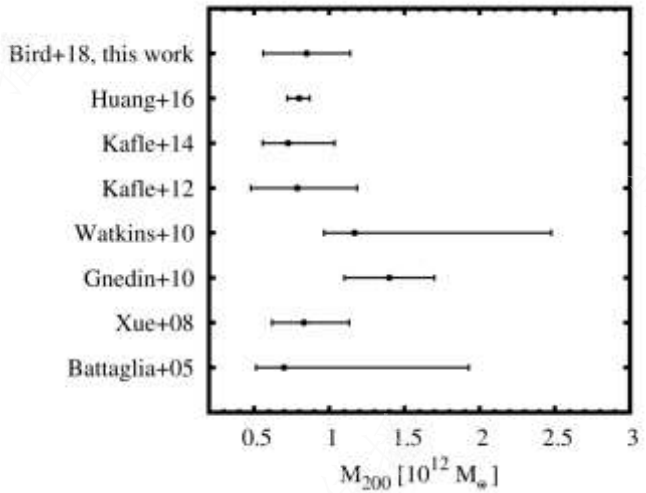
- Hitherto the most accurate Galactic rotation curve extending to 100 kpc based on 12000 selected from LSS-GAC DR2 and 4000 selected from APOGEE low Galactic latitude (|b| < 3o) primary red clump stars, and 6000 halo K giants selected from SDSS

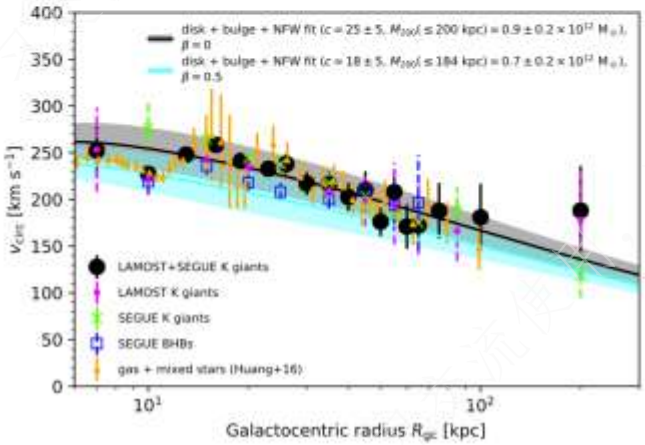
- Measurements of the Galactic escape velocities at Galactocentric radii between 5 and 14 are presented based on a sample of 527 high velocity halo stars (|vr| > 300 km/s, [Fe/H] < -1) selected from the LAMOST Galactic spectroscopic surveys

Star counts:

M_{200}=0.85±0.05 10^{12} Msun







Bird, Xue, Liu et al. 2018a

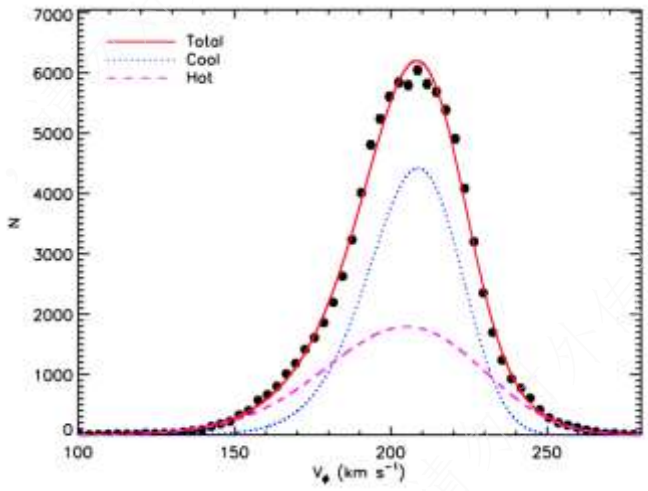
The Local Standard of Rest

Table 1. Measurements of the LSR in the literatures and from the current work.

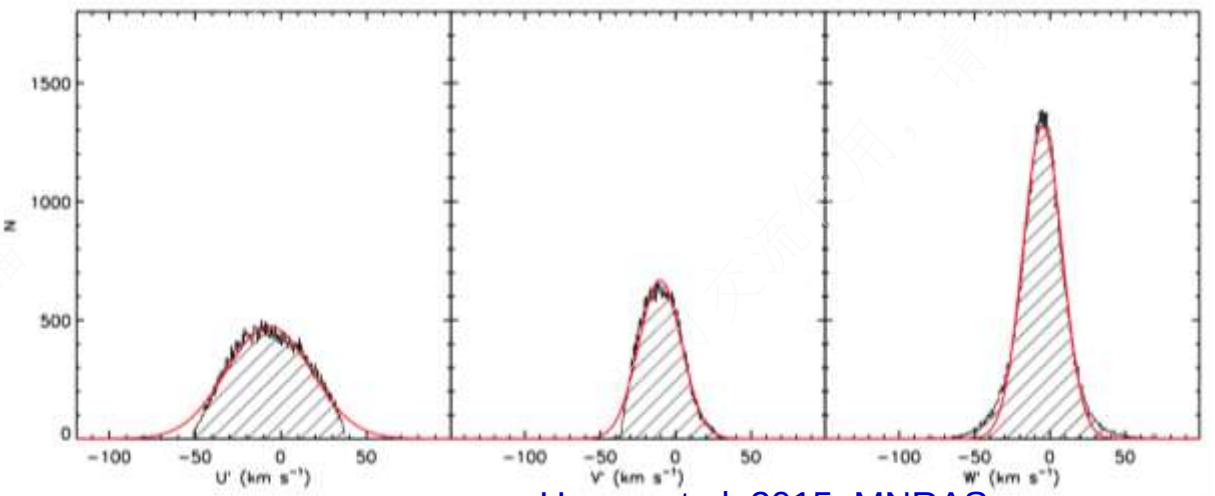
Source	Data	$U_\odot$ (km s^{-1})	$V_\odot$ (km s^{-1})	$W_\odot$ (km s^{-1})
This study (2014)	LSS-GAC DR1	7.01 ± 0.20	10.13 ± 0.12	4.95 ± 0.09
Bobylev & Bajkova (2014)	Young objects	6.00 ± 0.50	10.60 ± 0.80	6.50 ± 0.30
Coşkunoğlu et al. (2011)	RAVE DR3	8.50 ± 0.29	13.38 ± 0.43	6.49 ± 0.26
Bobylev & Bajkova (2010)	Masers	5.50 ± 2.2	11.00 ± 1.70	8.50 ± 1.20
Breddels et al. (2010)	RAVE DR2	12.00 ± 0.60	20.40 ± 0.50	7.80 ± 0.30
Schönrich et al. (2010)	*Hipparcos*	$11.10^{+0.69}_{-0.75}$	$12.24^{+0.47}_{-0.47}$	$7.25^{+0.37}_{-0.36}$
Reid et al. (2009)	Masers	9.0	20	10
Francis & Anderson (2009)	*Hipparcos*	7.50 ± 1.00	13.50 ± 0.30	6.80 ± 0.10
Bobylev & Bajkova (2007)	F & G dwarfs	8.70 ± 0.50	6.20 ± 2.22	7.20 ± 0.80
Piskunov et al. (2006)	Open clusters	9.44 ± 1.14	11.90 ± 0.72	7.20 ± 0.42
Mignard (2000)	K0-K5	9.88	14.19	7.76
Dehnen & Binney (1998)	*Hipparcos*	10.00 ± 0.36	5.25 ± 0.62	7.17 ± 0.38
Binney et al. (1997)	Stars near South Celestial Pole	11.00 ± 0.60	5.30 ± 1.70	7.00 ± 0.60
Mihalas & Binney (1981)	Galactic Astronomy (2nd Ed.)	9.00	12.00	7.0
Homann (1886)	Solar neighbourhood stars	17.40 ± 11.2	16.90 ± 10.90	3.60 ± 2.30

- Based on 94,332 thin disk FGK dwarfs within 600 pc of the Sun.
  $(U_\odot, V_\odot, W_\odot)$ =
  $(7.01 \pm 0.20, \mathbf{10.13 \pm 0.12}, 4.95 \pm 0.09)$ km/s
- V is 2 times of one in "Galactic Dynamics" (Dehnen & Binney 1998)

Method I: VDF



Method II: CTDS

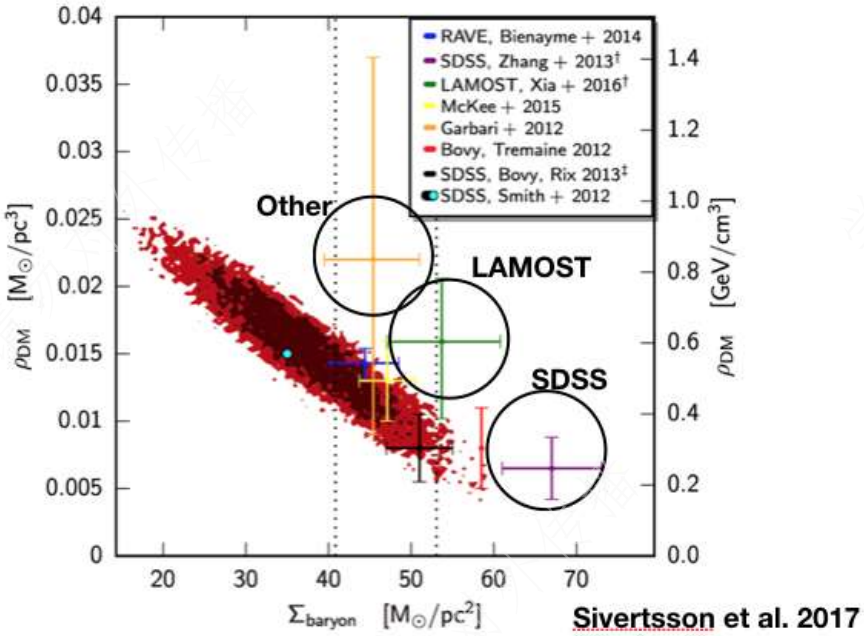


Huang et al. 2015, MNRAS

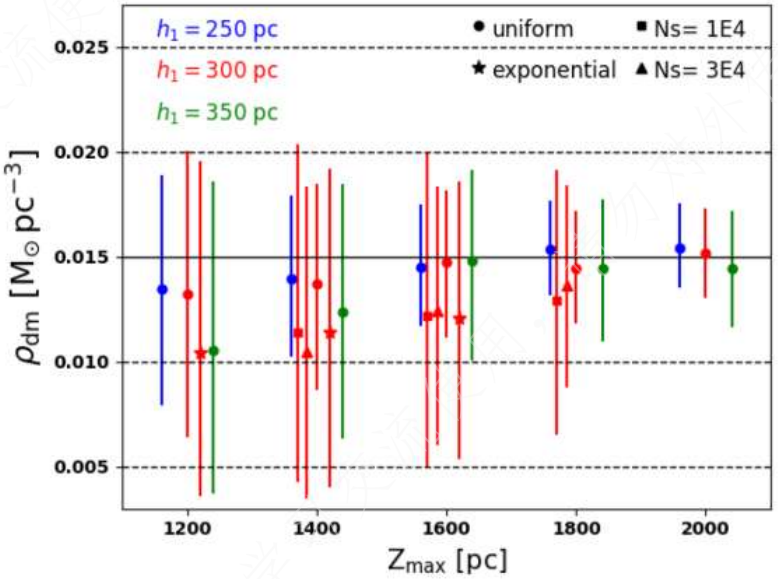
Dark matter mass density in the solar neighborhood

- **With LAMOST data and a simple analytical Kz force model depending on less assumptions**
- **the volume density of the dark matter around us is $0.018 \pm 0.005 M_{\odot} pc^{-3}$**

We apply the vertical Jeans equation to the kinematics of Milky Way stars in the solar neighbourhood to measure the local dark matter density. More than 90 000 G- and K-type dwarf stars are selected from the cross-matched sample of LAMOST (Large Sky Area Multi-Object Fibre Spectroscopic Telescope) fifth data release and *Gaia* second data release for our analyses. The mass models applied consist of a single exponential stellar disc, a razor thin gas disc, and a constant dark matter density. We first consider the simplified vertical Jeans equation that ignores the tilt term and assumes a flat rotation curve. Under a Gaussian prior on the total stellar surface density, the local dark matter density inferred from Markov chain Monte Carlo simulations is $0.0133^{+0.0024}_{-0.0022}$ $M_{\odot}$ pc^{-3}. The local dark matter densities for subsamples in an azimuthal angle range of $-10^{\circ} < \phi < 5^{\circ}$ are consistent within their 1σ errors. However, the



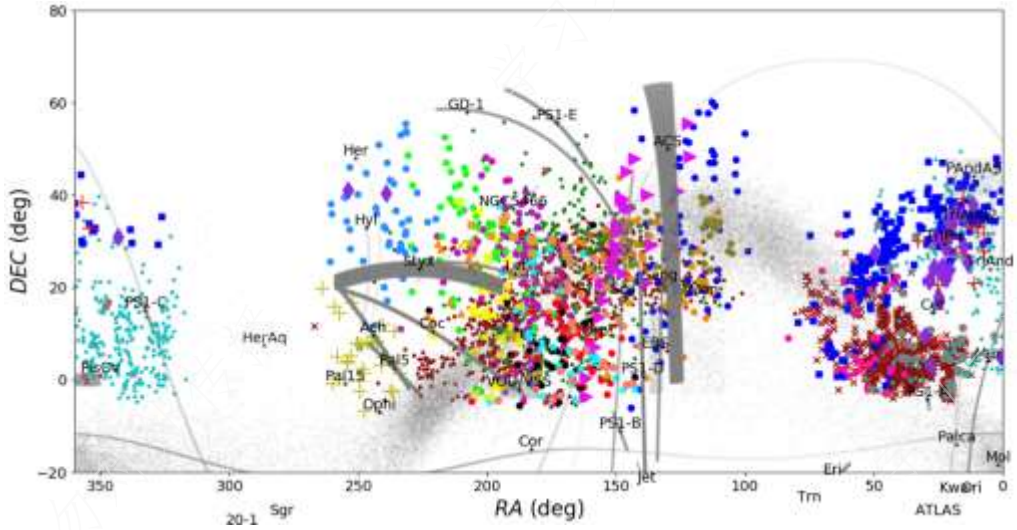
Xia, Liu, et al., MNRAS,2016

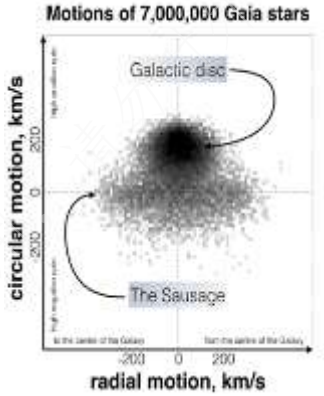


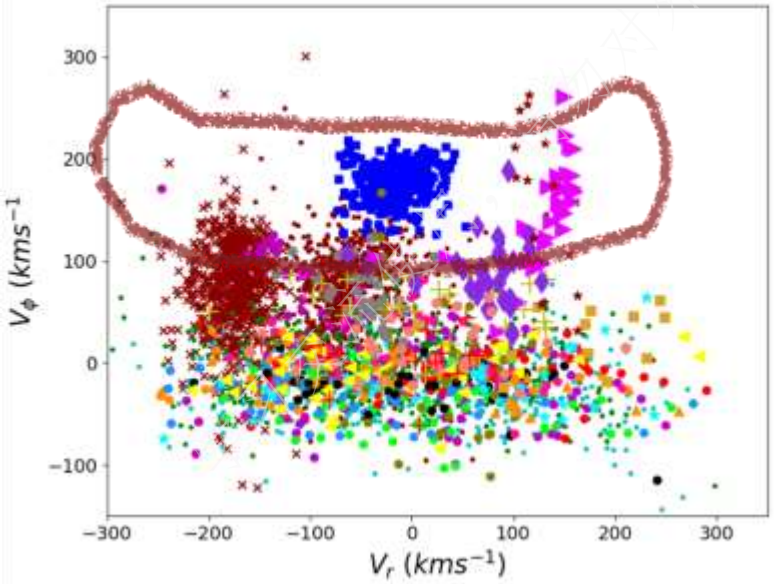
Guo, Liu, et al., MNRAS,2020

Steller stream in the halo

LAMOST K giants







- Monoceros Ring
- Sagittarius streams
- Orphan stream
- Cetus stream
- Gaia-Sausage

Yang, Xue et al. ApJ, 2019a

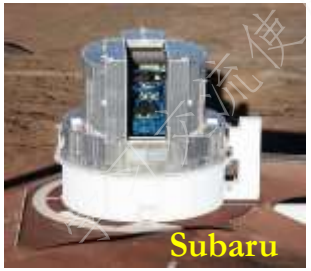
Steller stream in the halo

- 33000 M giants in DR4
- 3d space orbit of the Sgr stream
- The far side in 130 kpc from the Sun

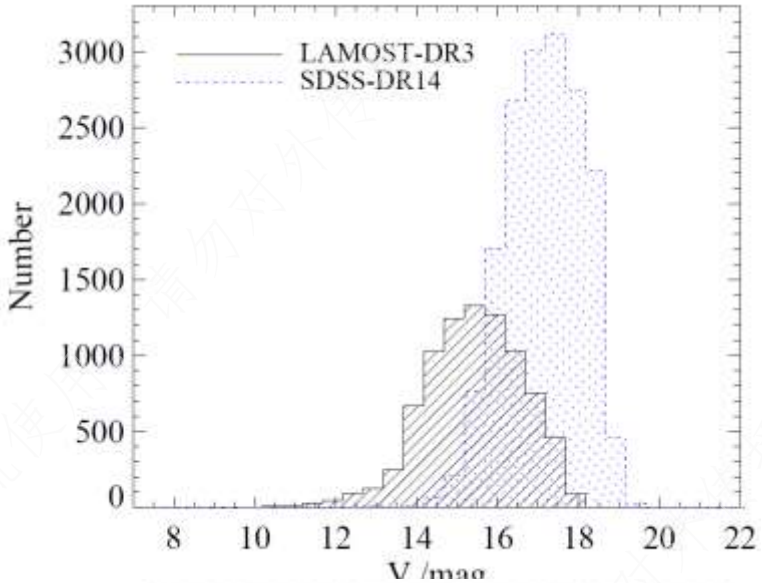
Li et al. 2019, ApJ, 874, 138

42

Metal-poor stars

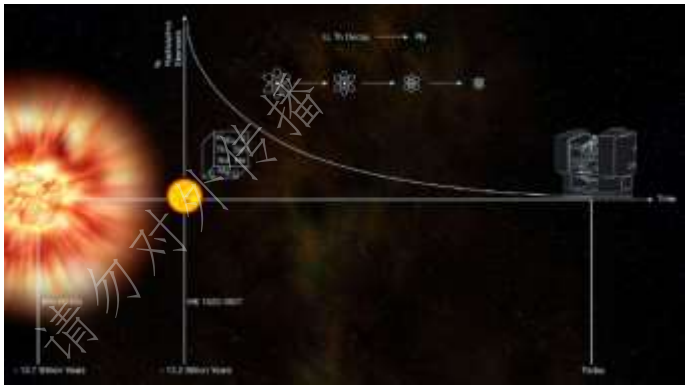


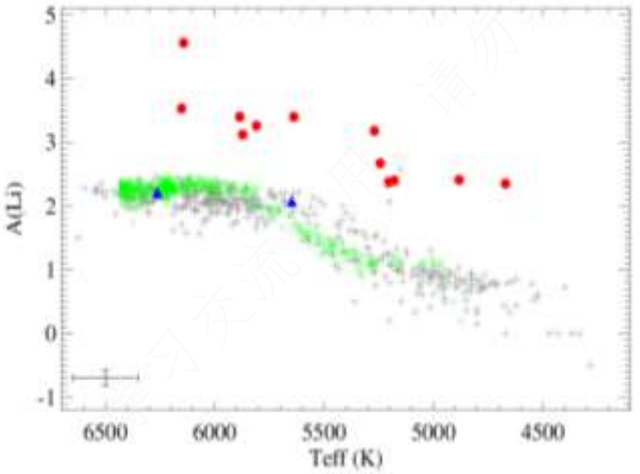
- **100,000 candidates of bright metal-poor stars**
- **90% to search [Fe/H]<-2**



- **"Millstone" sample:**

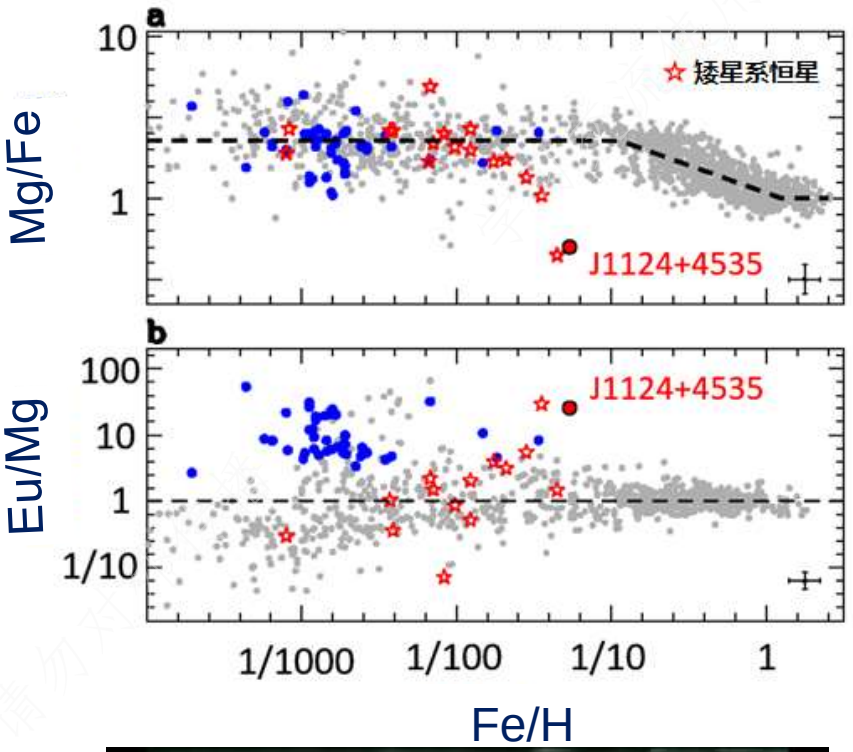
400 high resolution spectra

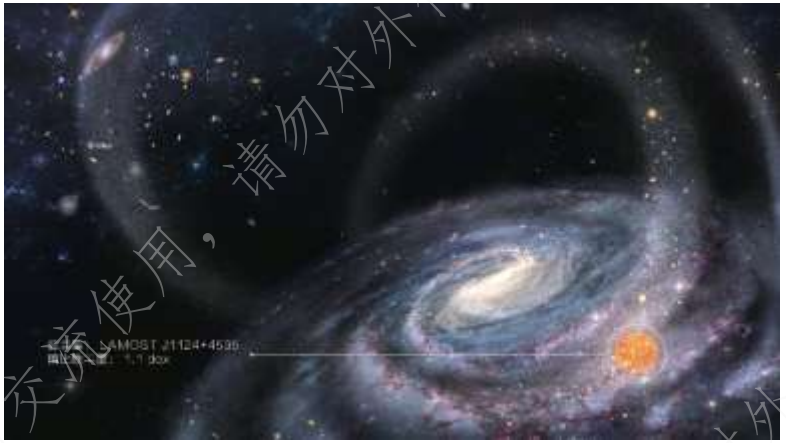


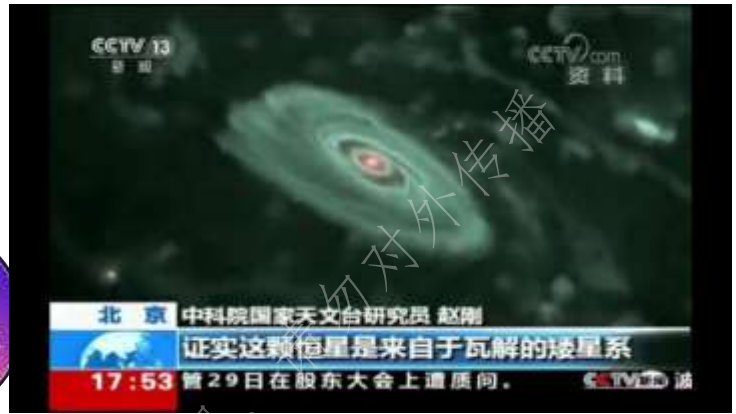


Li et al. 2020, ApJ

Evidence for the accretion origin of a holo star



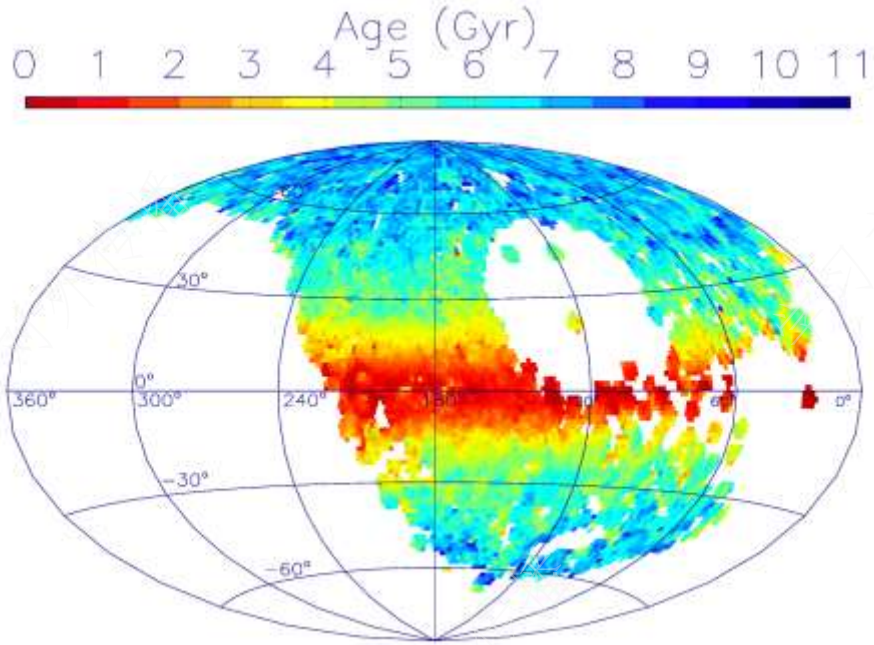


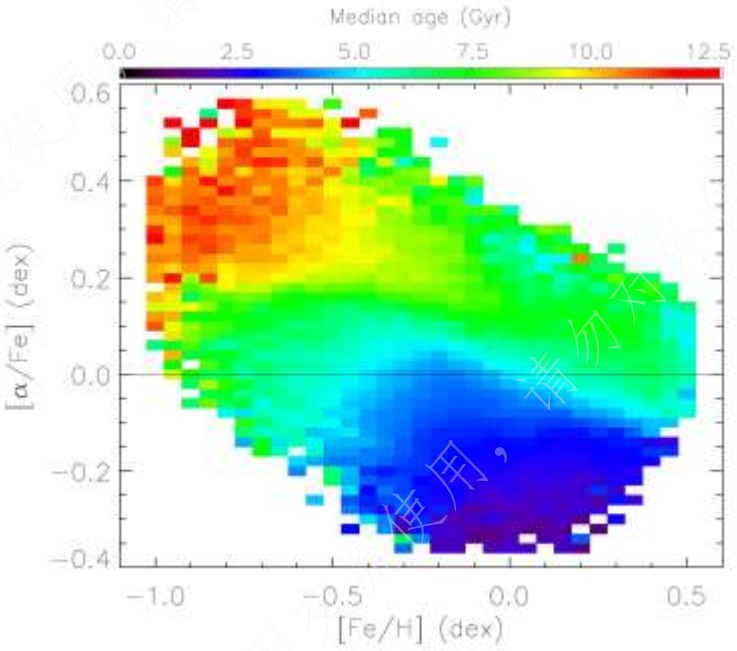


Xing et al. 2019, Nature Astronmy, 3, 631

Ages of 1,000,000 stars

- **Turn-off stars: 1 M** **(Xiang et al. 2015, 2017)**
- **RC stars: 0.2 M**
- **Red giants : 0.64 M**





Reviewer's Comments: This is a solid body of work that makes a significant contribution to the field, and which is especially valuable as a benchmark for Galactic evolution modeling.

Article

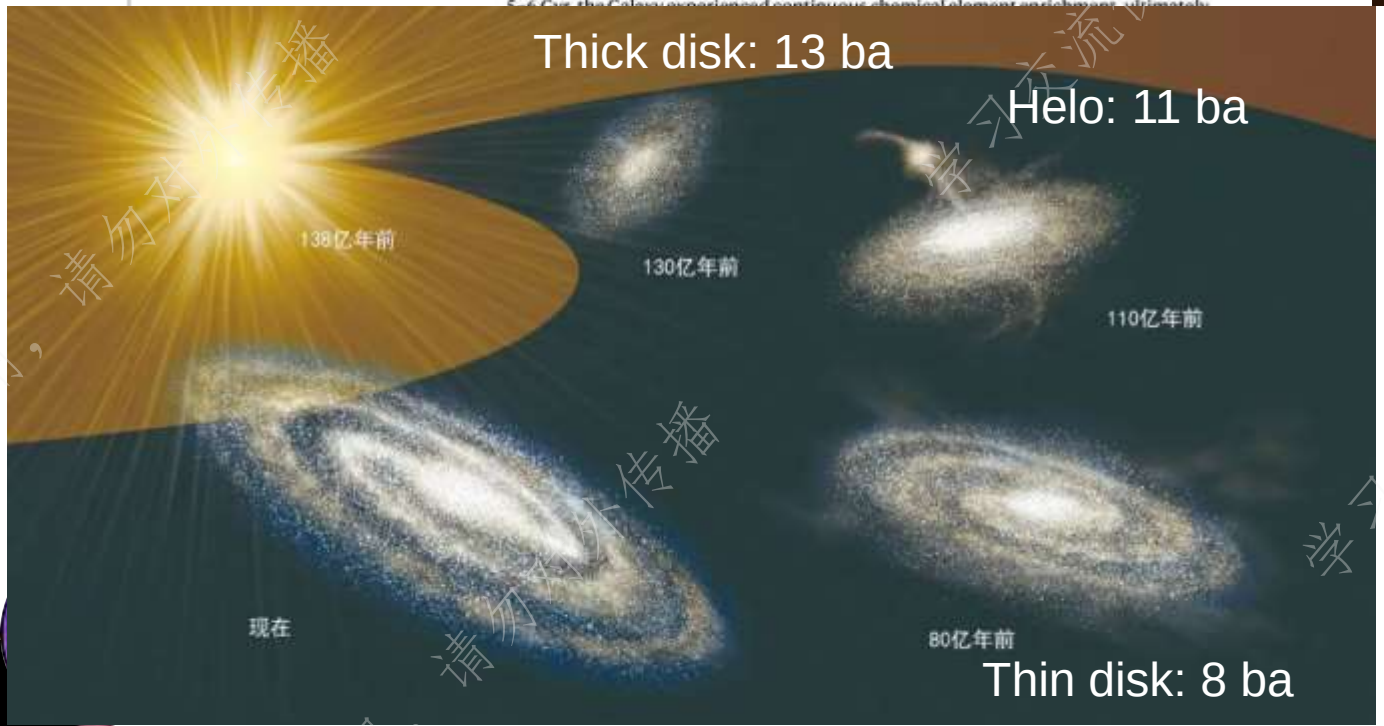
A time-resolved picture of our Milky Way's early formation history

https://doi.org/10.1038/s41586-022-04496-5
Received: 1 November 2021
Accepted: 1 February 2022
Published online: 23 March 2022
Open access
Check for updates

Maosheng Xiang[1✉] & Hans-Walter Rix[2✉]

M. Xiang: LAMOST fellow

The formation of our Milky Way can be split up qualitatively into different phases that resulted in its structurally different stellar populations: the halo and the disk components[1–3]. Revealing a quantitative overall picture of our Galaxy's assembly requires a large sample of stars with very precise ages. Here we report an analysis of such a sample using subgiant stars. We find that the stellar age–metallicity distribution $p(\tau, [Fe/H])$ splits into two almost disjoint parts, separated at age $\tau \simeq 8$ Gyr. The younger part reflects a late phase of dynamically quiescent Galactic disk formation with manifest evidence for stellar radial orbit migration[4–6]; the other part reflects the earlier phase, when the stellar halo[7] and the old α-process-enhanced (thick) disk[8,9] formed. Our results indicate that the formation of the Galaxy's old (thick) disk started approximately 13 Gyr ago, only 0.8 Gyr after the Big Bang, and 2 Gyr earlier than the final assembly of the inner Galactic halo. Most of these stars formed around 11 Gyr ago, when the Gaia-Sausage-Enceladus satellite merged with our Galaxy[10,11]. Over the next

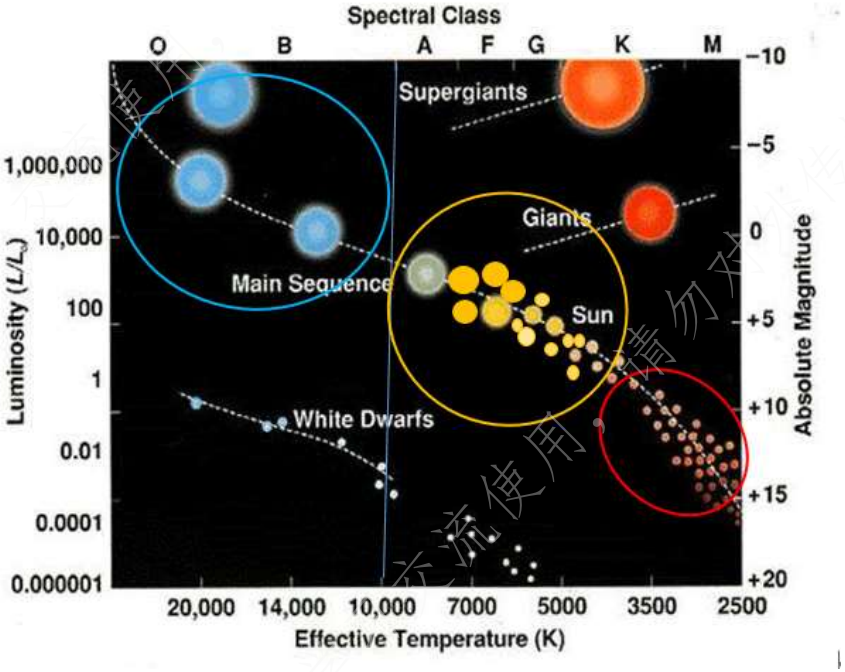


- **LAMOST DR7**
- **Gaia eDR3**

- **250,000 sub-giants**
- **age < 7%**

The largest OB catalog

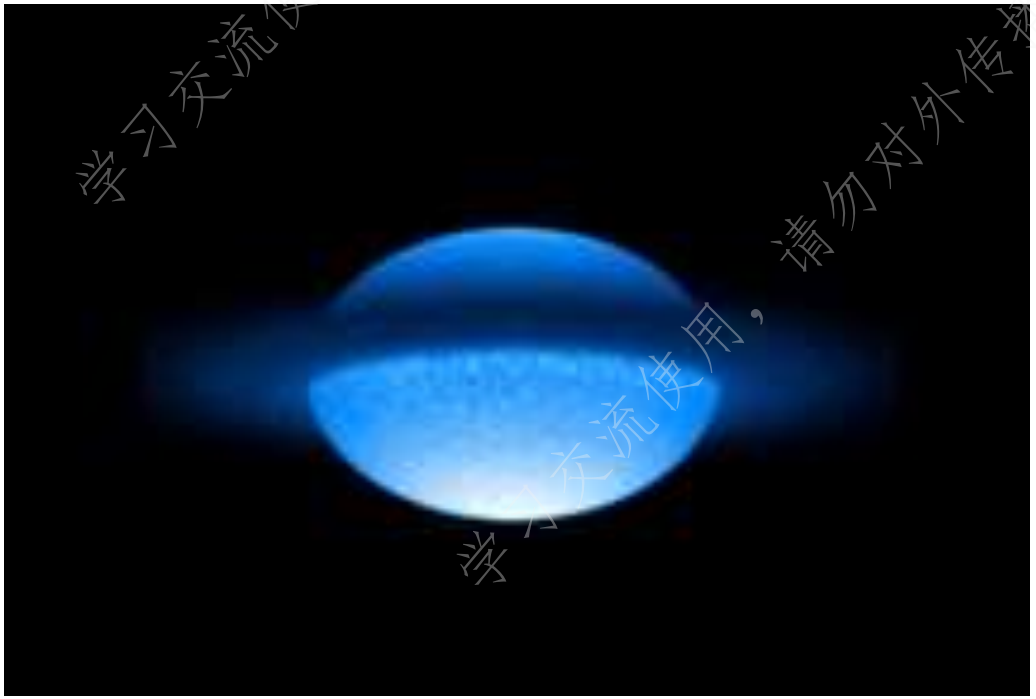
- OB stars: high tepereture, high mass, short life, rare
- 16032 OB stars discoveried by LAMOST
- The fundamental data for young stars in the out disk of the Galaxy



Liu et al. 2019, ApJS, 241, 32

New Oe stars

- **Oe star: very few**
  - **high speed rotation**
  - **with disk**
- **6 Oe stars discovered by LAMOST, 13 Oe stars in total before**
- **To understand the origin of the Oe stars**



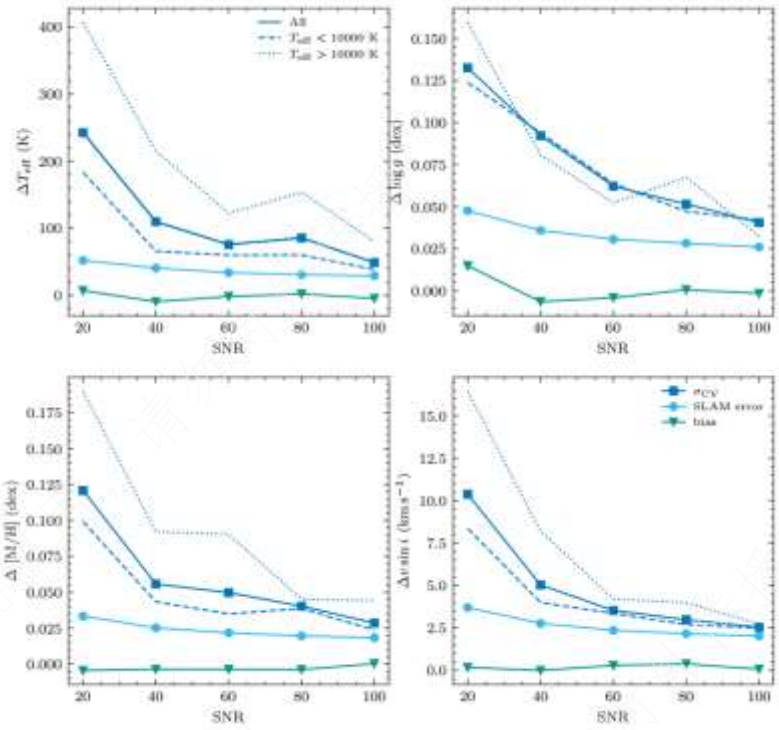
Li et al. 2018, ApJ, 863, 70

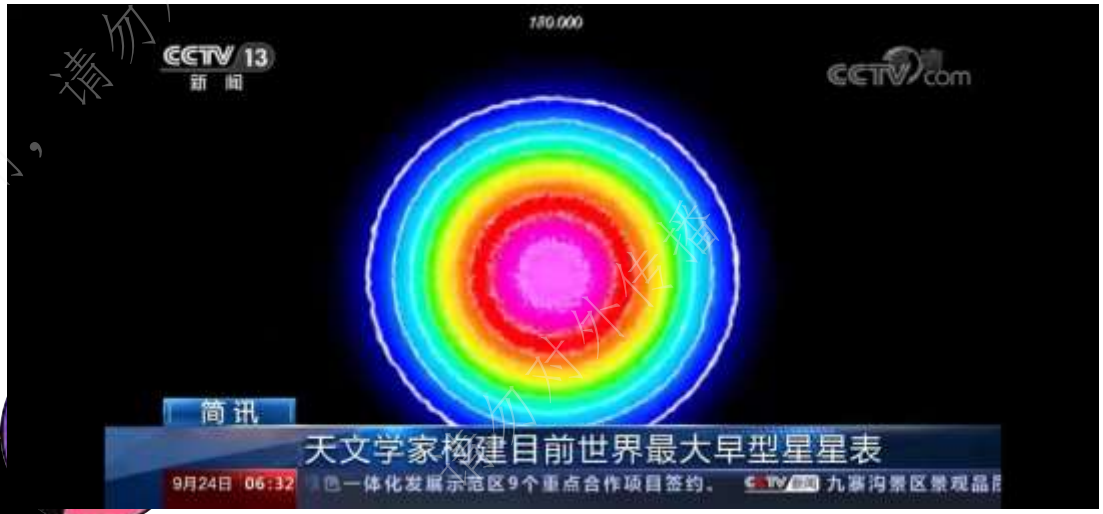
Early-type stars

- **40,034 early-type stars**

with vsini,Teff, log g, [M/H]

Medium resolution obserced by LAMOST

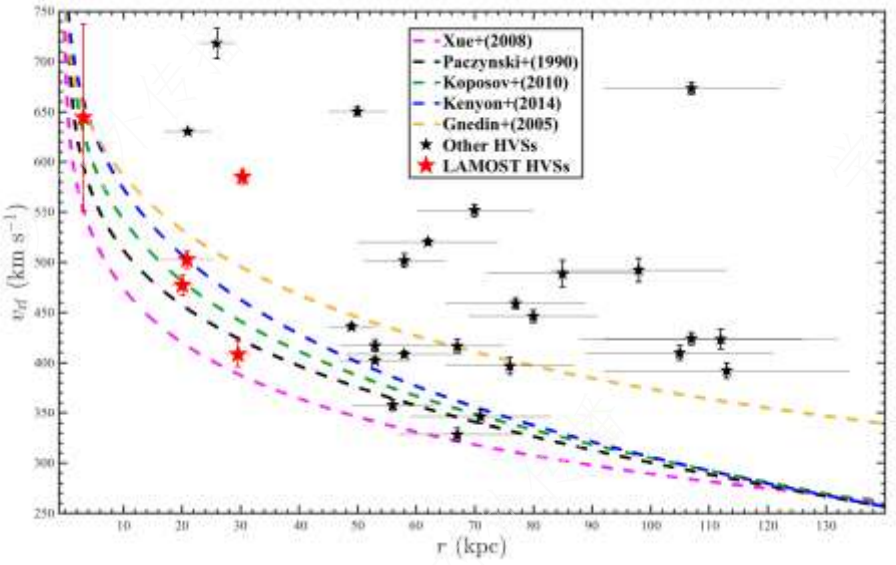




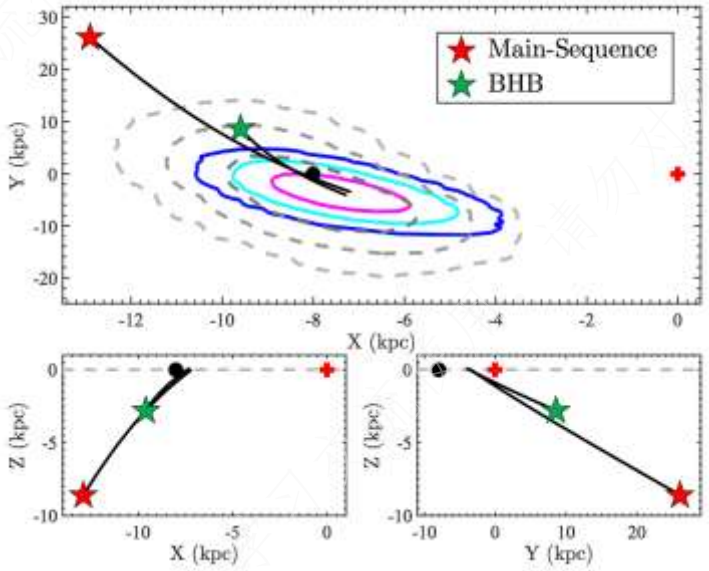
Sun et al. 2021 ApJS

Hyper-velocity stars: 4 from LAMOST

- Letter of prof. Brown: “an exciting pair of hypervelocity star discoveries”
- Websites: Universe Today, Phys.org, AAS Nova



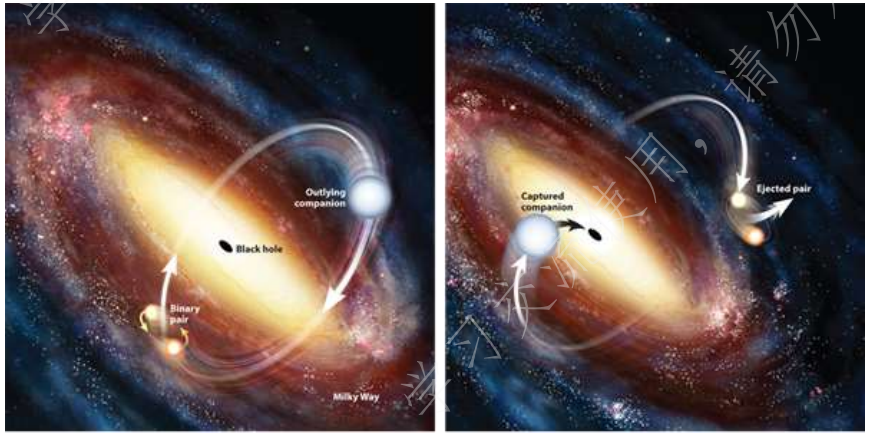
Huang et al. 2017



Li et al. 2018

High-velocity stars

- 591 high-velocity stars (2x before)
- 42 candidates of hyper-velocity stars (2x before)



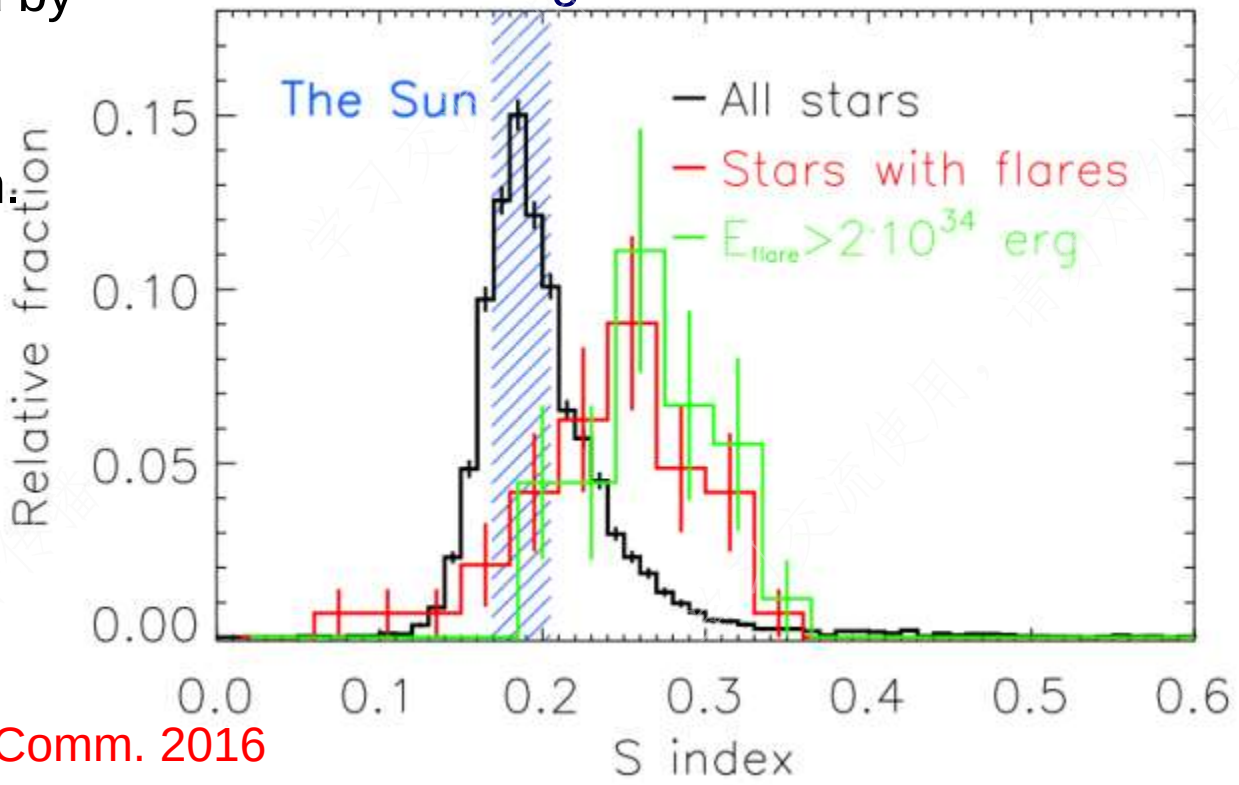
Li et al. 2020, ApJS

Superflare stars characterised by enhanced magnetic activity

- 5648 solar-like stars
- 48 superflare stars.

Superflare stars are generally characterised by larger chromospheric emissions than other stars, including the Sun.

1-6 orders higher than solar flares



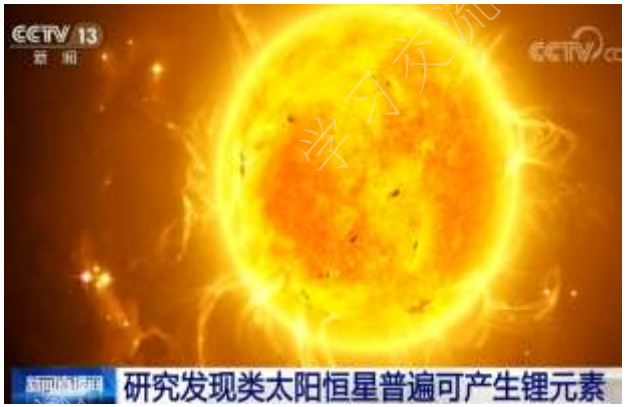
Karoff et al. Nature Comm. 2016

Highest Li abundance in the Li-rich giants

Highest Li abundance in the Li-rich giants

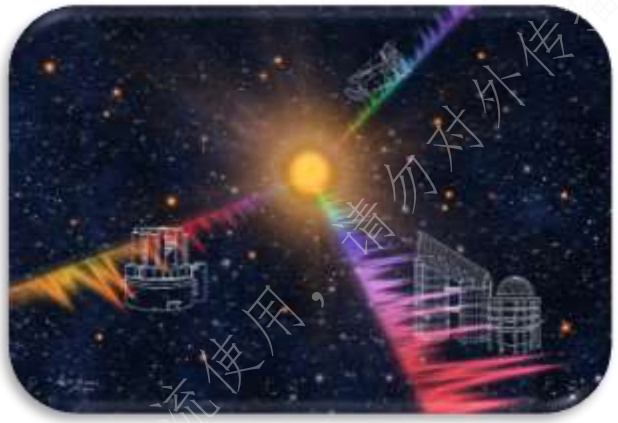
Yan et al. 2018, Nature Astronmy

Li produced by solar-like stars



Kumar et al. 2020, Nature Astronmy

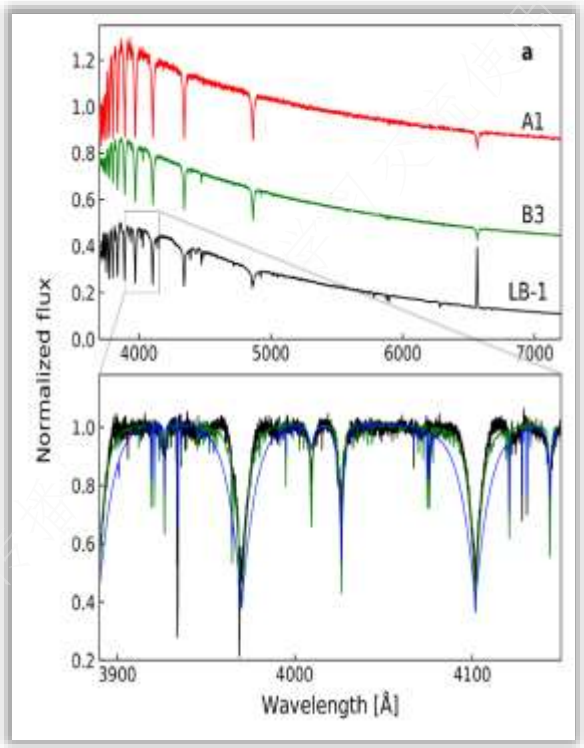
Li-rich in red clump stars, not in red giants

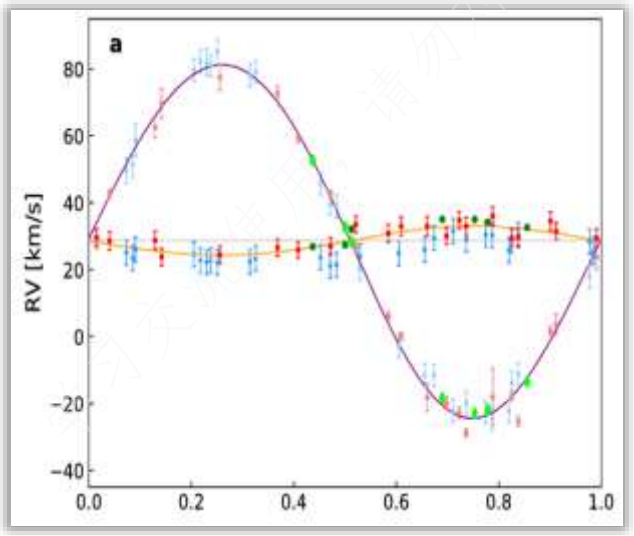


Yan et al. 2021, Nature Astronmy

Discovery of stellar-mass black hole

- **70 $M_\odot$ black hole**
- **New method to discover black holes**



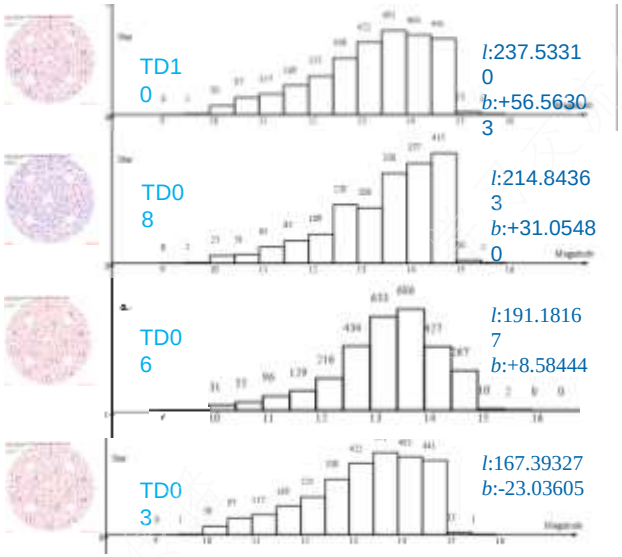


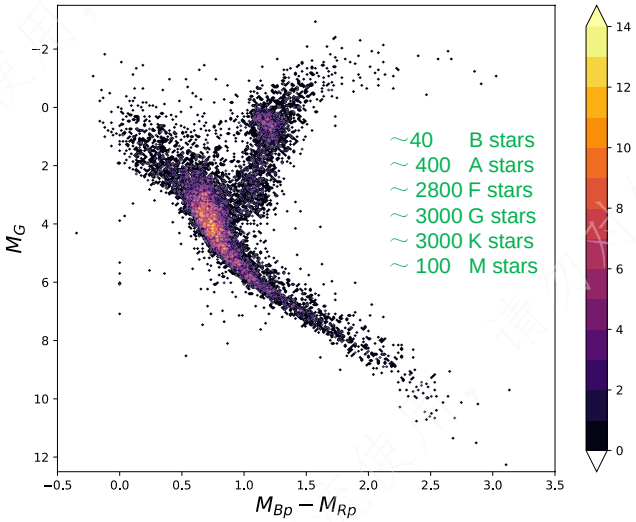
Liu et al. 2019, Nature

“Black-hole hunter”

黑洞猎手计划

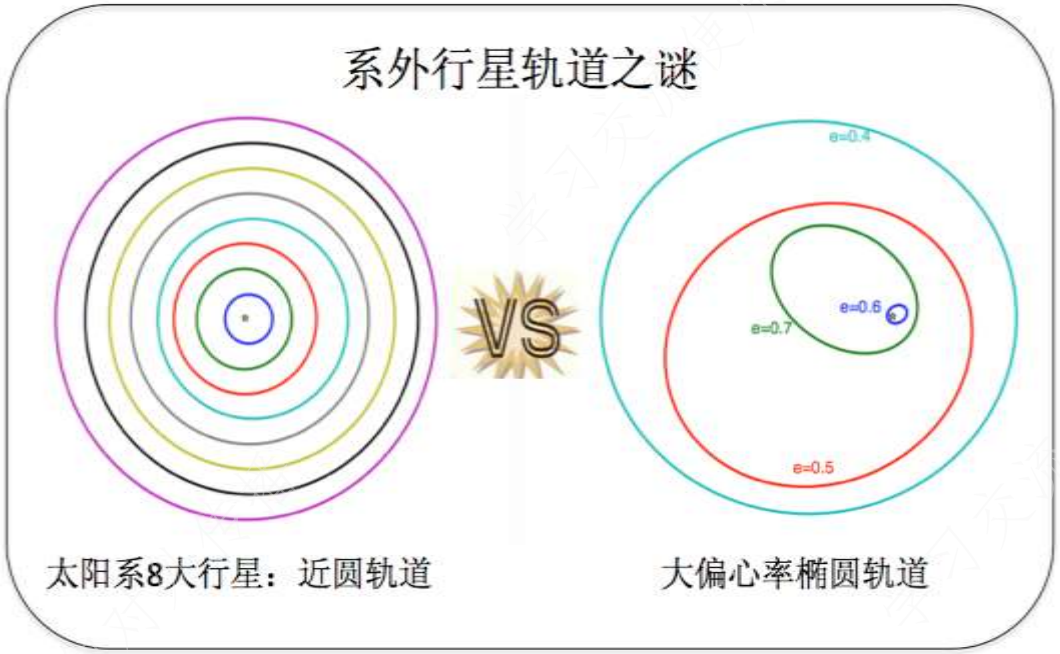
Four plates of LAMOST



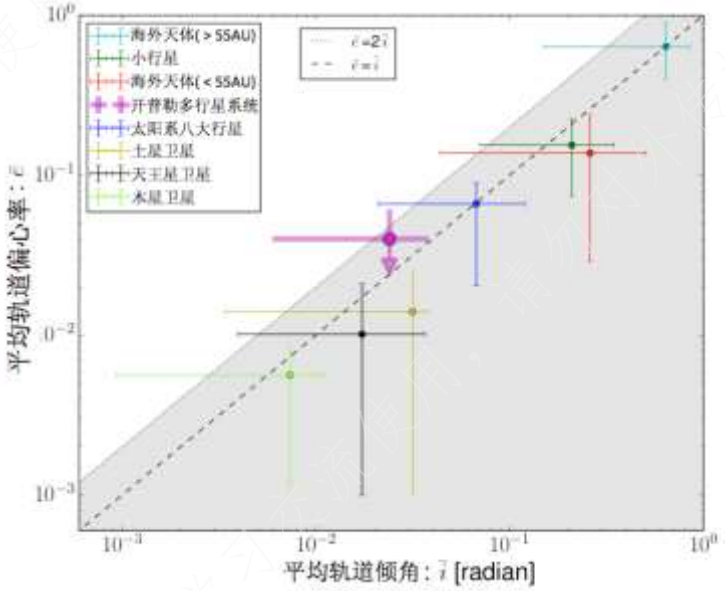


Wang et al. 2020b

Puzzle of Exoplanet Orbits



The eccentricity distributions for a large (698) and homogeneous Kepler planet sample with transit duration statistics.



The prevalence of circular orbits and the common relation may imply that the solar system as well as its formation is not so atypical in the Galaxy after all.

Xie, et al. 2016, PNAS

New type of exoplanets: Hoptunes

Proceedings of the National Academy of Sciences of the United States of America www.pnas.org

From the Cover

January 9, 2018 | vol. 115 | no. 2

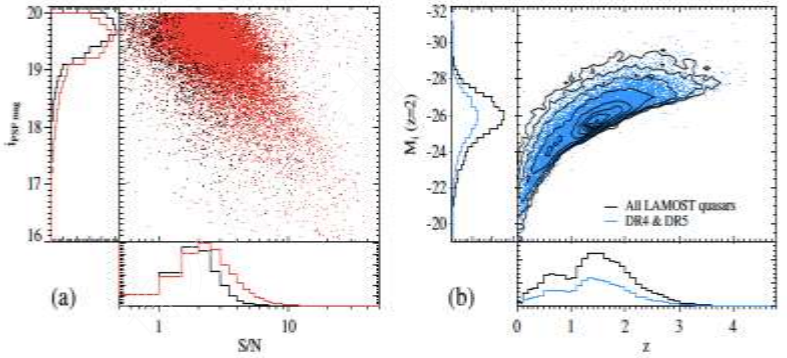
266 **LAMOST telescope reveals that Neptunian cousins of hot Jupiters are mostly single offspring of stars that are rich in heavy elements**

Subo Dong, Ji-Wei Xie, Ji-Lin Zhou, Zheng Zheng, and Ali Luo

Dong & Xie et al., 2018, PNAS,115, 266–271

LAMOST Quasar Survey

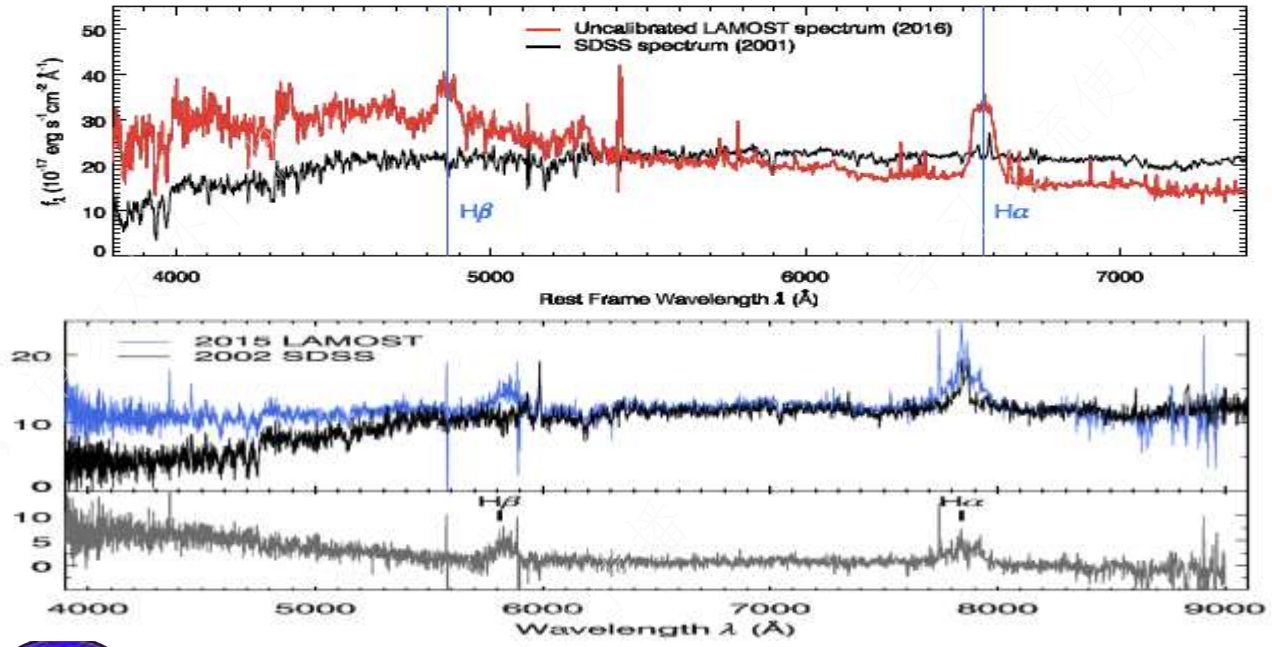
- **Identified 56000 quasars**
  - **28000 independently discovered**
  - **22500 new discovered**



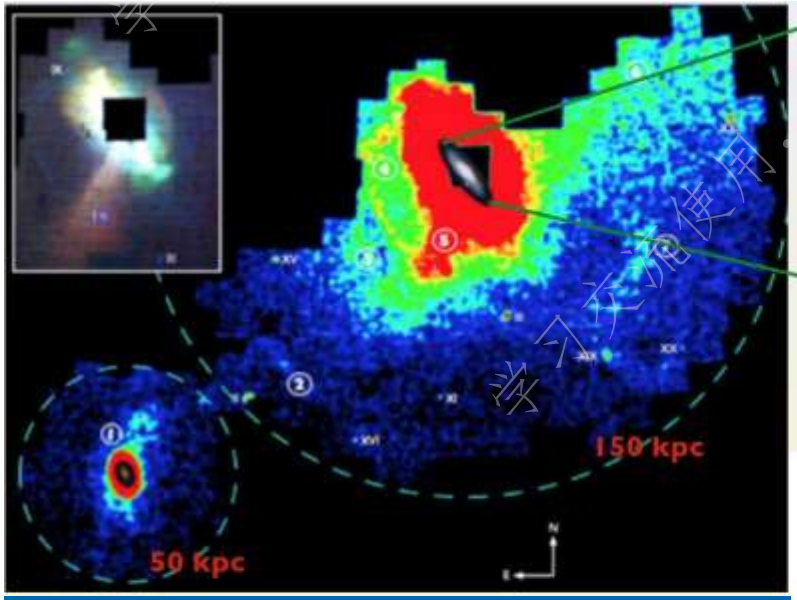
  - **DR1: Ai, Wu, Yang, et al., 2016, AJ, 151, 24**
    - 3921 quasars identified, 1180 new
  - **DR2/DR3: Dong, Wu, Ai, et al., 2018, AJ, 155, 189**
    - 19935 identified, 12126 independent, 8100 new
  - **DR4/DR5: Yao, Wu, Ai, et al., 2019, ApJS, 240, 6**
    - 19246 identified, 11446 independent, 8149 new
  - **DR6-DR8: Jin, Wu, Fu, et al., 2021, to be submitted**
    - 12761 identified, 7071 independent, 5380 new

- **LAMOST quasar survey has become one of the top 3 quasar surveys, after SDSS & 2dF.**

- **21 “face-change” QSOs**



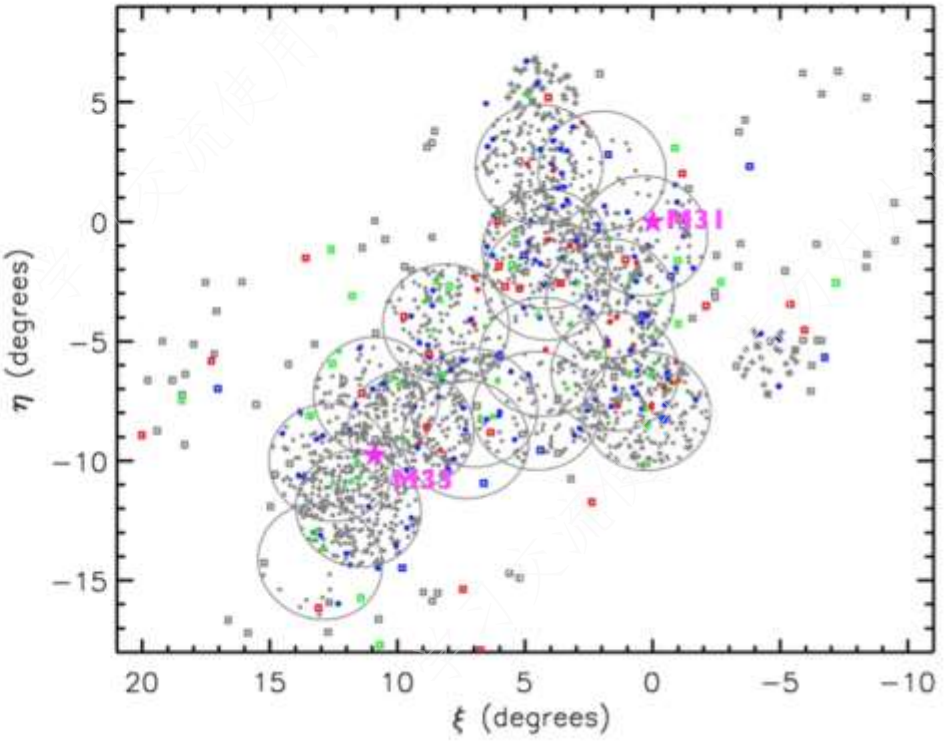
Yang et al. 2018



1, M33 structure;
2, 125-kpc stream (stream A);
3, stream C; 4, eastern arc (stream D);
5, giant stellar stream;
6, northwest minor-axis stream;
7, southwest cloud
(McConnachie et al. 2009)

Background QSOs in the vicinity fields of M31/M33

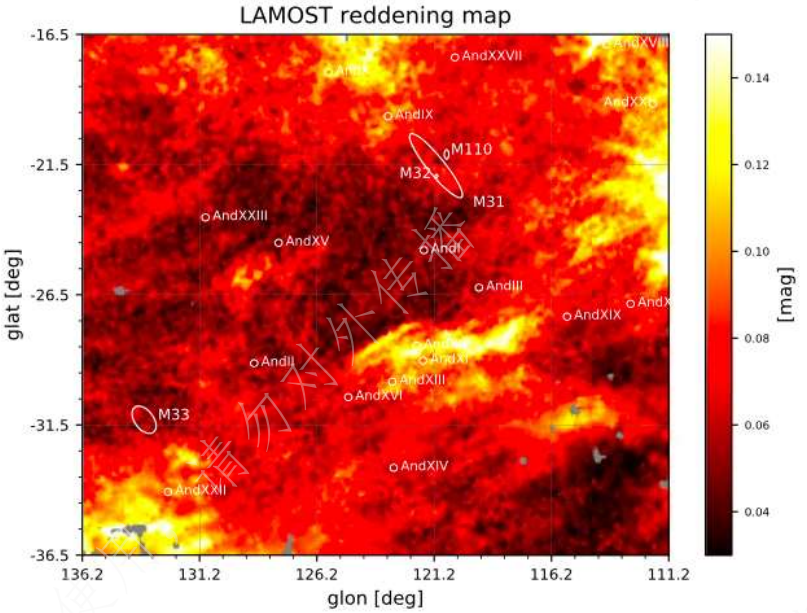
~4000 QSOs
~100 PNs



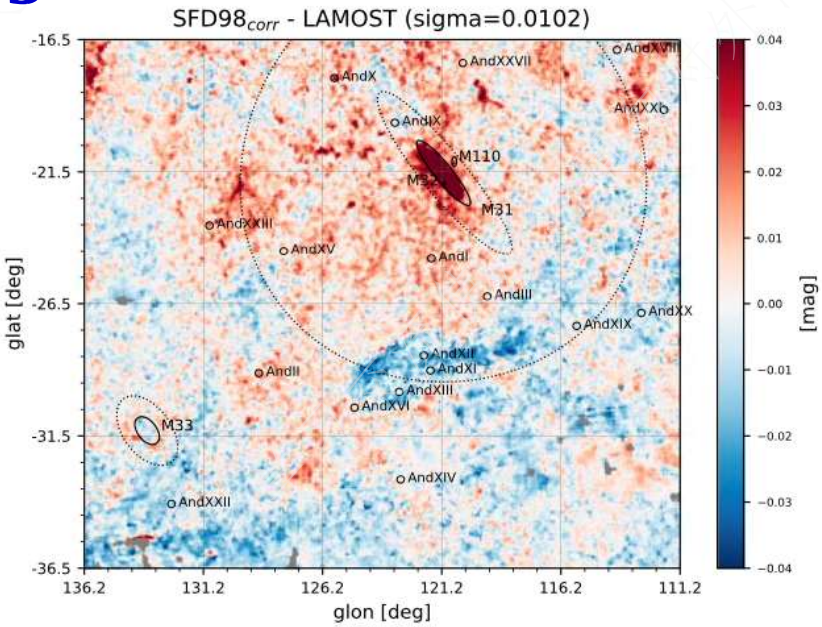
Huo et al., 2010, 2013, 2015

Dust around M31

- LAMOST + Gaia
- 190,000 stars
- Reddening Map of MW



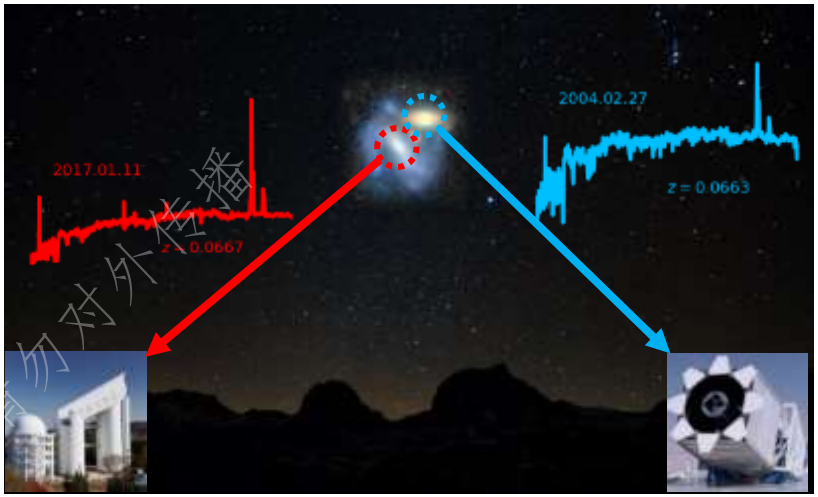
- Dust distribution of M31/M33



Zhang+2020 ApJL

Pair of galaxies

- **LAMOST + SDSS**



Mass function of pairs

Interaction of galaxies: 150 kpc

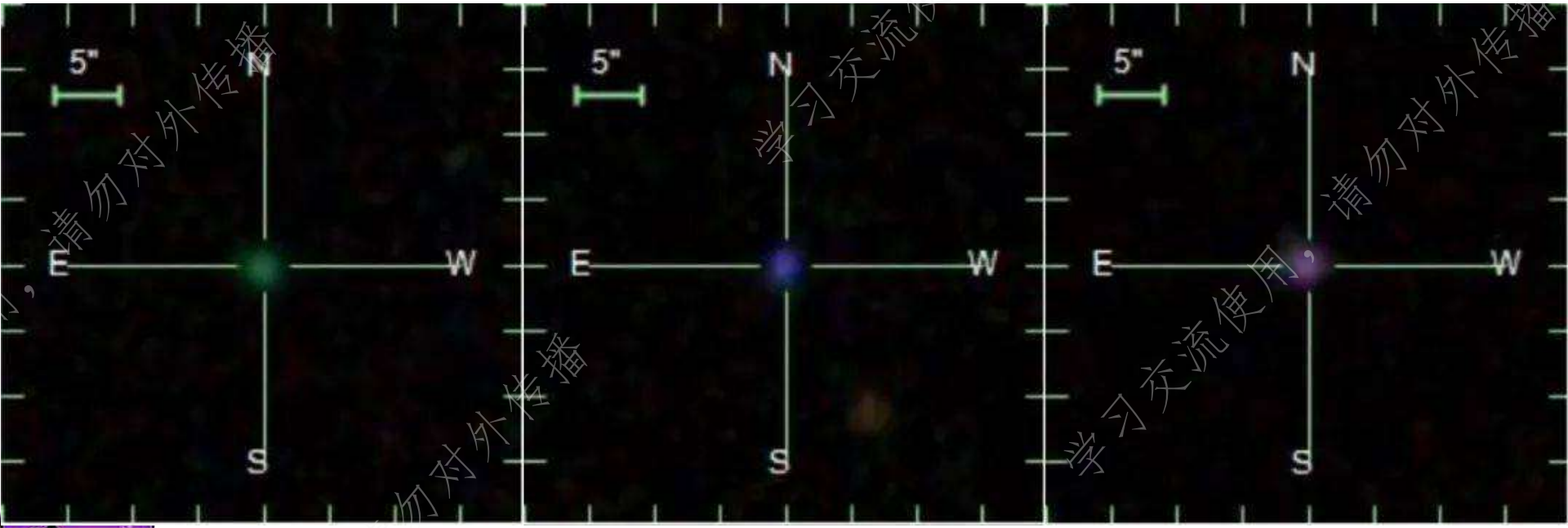
Feng et al. 2019, ApJ

Compact galaxies:

“extragalctic fruit & vegetable garden”

1417 new discovery (before 800)

- **739 green pea**
- **270 blueberry**
- **388 purple grape**



Liu, Luo et al., 2022, ApJ, 927, 57

Review

Overview of the LAMOST survey in the first decade

Hongliang Yan,[1,2] Haining Li,[1] Song Wang,[1] Weikai Zong,[3] Haibo Yuan,[3] Maosheng Xiang,[4] Yang Huang,[5] Jiwei Xie,[6,7] Subo Dong,[8] Hailong Yuan,[1] Shaolan Bi,[3] Yaoquan Chu,[9] Xiangqun Cui,[10,11] Licai Deng,[1] Jianning Fu,[3] Zhanwen Han,[12] Jinliang Hou,[2,13] Guoping Li,[10,11] Chao Liu,[2,14] Jifeng Liu,[1,2,15] Xiaowei Liu,[5] Ali Luo,[1,2] Jianrong Shi,[1,2] Xuebing Wu,[8,16] Haotong Zhang,[1] Gang Zhao,[1,2] and Yongheng Zhao[1,2,*]

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www.the-innovation.org

GRAPHICAL ABSTRACT

PUBLIC SUMMARY

- LAMOST is an innovative telescope designed with both a large-aperture and a wide-FOV for astronomical spectroscopic survey
- LAMOST observed over 10 million objects in our Galaxy, and constructed the largest spectroscopic dataset
- LAMOST data changed the astrophysical viewpoint in the fields including stars, the Milky Way, exoplanets, and black holes

https://arxiv.org/abs/2203.14300

LAMOST亮点科研成果

- **富锂巨星系列成果**

发现锂丰度最高的巨星
Yan et al. 2018, Nature Astronmy

类太阳恒星可以产生锂
Kumar et al. 2020, Nature Astronmy

富锂巨星真身探秘
Yan et al. 2021, Nature Astronomy

- **银河系结构研究**

发现宇宙中金属含量最低的球状星团遗迹
Nicolas et al. 2022, Nature

揭示银河系早期形成和演化历史
Xiang et al. 2022, Nature

- **黑洞**

发现最大质量恒星级黑洞
Liu et al. 2019, Nature

预期成果

Capability of LAMOST: AΩ =247

Existing and planned multi-object spectroscopic projects

Table 1: Existing and planned multi-object spectroscopic capabilities, with defining characteristics. These include wavelength range, field of view, etendue, the number of simultaneous spectra per field, the spectral resolution, the fraction of time the capability is in use, the image quality, and the discovery efficiency (defined in the text)

Telescope/Instrument	D_{M1} (m)	Status	Available	λ (μm)	Ω (deg^2)	$A\Omega$ (m^2 deg^2)	N_{mos}	$\mathcal{R}$	f	IQ	$\log \eta$
Ground-Based											
AAT/AAOmega	3.9	Existing	1996	0.37–1.00	3.14	37.5	392	1000–17000	0.5	1.5	3.5
SDSS	2.5	Existing	2000	0.38–0.92	1.54	7.6	640	1800	1.0	1.4	3.6
Keck/DEIMOS	10.0	Existing	2002	0.41–1.10	0.023	1.8	150	2500–5500	0.4	0.7	2.1
VLT/VIMOS	8.2	Existing	2002	0.37–1.00	0.062	3.3	600	180–2500	0.2	0.8	2.9
VLT/FLAMES	8.2	Existing	2003	0.37–0.95	0.136	7.2	8–130	5600–25000	0.2	0.8	1.3–2.6
MMT/Hectospec	6.5	Existing	2004	0.36–0.92	0.79	26.1	240–300	1000-40000	0.2	1.0	2.6–2.7
WIYN/Hydra	3.5	Existing	2005	0.37–1.00	0.79	7.5	90	800–40000	0.2	0.8	2.4
Magellan/IMACS	6.5	Existing	2008	0.36–1.00	0.16	5.3	400	1100–16000	0.2	0.6	3.3
SDSS/APOGEE	2.5	Existing	2011	1.51–1.70	1.54	7.6	300	27000–31000	0.5	1.4	2.8
Subaru/FMOS	8.2	Existing	2012	0.8–1.8	0.20	10.4	400	600-2200	0.2	0.7	3.3
LAMOST†	4.0	Existing	2012	0.37-0.90	19.6	247	4000	1000–10000	1.0	3.0	5.1
AAT/HERMES	3.9	Existing	2013	4 windows	3.14	37.5	392	28000	0.5	1.5	3.6
Subaru/PFS	8.2	Planned	2017	0.38–1.30	1.1	70	2400	1900-4500	0.3	0.7	5.0
WHT/WEAVE	4.2	Planned	2018	0.37–1.00	3.14	41	~1000	5000–20000	0.7	0.8	4.8
Mayall/DESI	4.0	Planned	2018	0.36–1.05	7.1	89	5000	3000–4800	0.5	1.5	5.1
VLT/MOONS	8.2	Planned	2018	0.8–1.8	0.14	7.3	1000	4000-20000	0.3	0.8	3.3
VLT/4MOST	4.1	Planned	2019	4 windows	3.0	40	1500	3000-20000	1.0	0.8	5.1
MSE	10.0	Planned	2021	0.37–1.30	1.5	118	3200	2000	1.0	0.7	6.0
				0.37–1.00			3200,800	6500,20000	1.0	0.7	5.4
Space-Based											
Gaia	2×(1.4×0.5)	Existing	2014	0.85–0.87	all sky survey (V < 17)			11500			
Euclid	1.2	Planned	2020	1.10–2.00	0.55	0.62		250			
WFIRST	1.5	Planned	2025:	1.10–2.00	0.5	0.89		75–320			

† – *Also known as the Guo Shou Jing Telescope (GSJT).*

A. McConnachie, R.Murowinski, D. Salmon, D.Simons, P.Côté c，2014，SPIE

LAMOST II project

Site: Xinglong ➔ Lenghu

- Mirrors: MA24 MB37
- Fibers: 4,000 ➔ 12,000
- Limit mag.: 17.8m ➔ 19.3m
- Spectra： 10 M ➔ 100 M