大天区面积多目标光纤光谱天文望远镜

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope

LAMOST

大天区面积多目标光纤光谱天文望远镜是一架我国科学家自主创新设计和研制的反射施密特望远镜，反射施密特改正镜为5.72米X4.40米，主镜为6.67米X6.05米。应用主动光学技术控制反射施密特改正镜，使它成为大口径兼大视场光学望远镜的世界之最。由于它的大口径，在曝光1.5小时内可以观测到20.5等的暗弱天体； 由于它在相应于5度视场的焦面上放置了4000根光纤，连接到16台光谱仪上，可以同时获得4000个天体的光谱，成为世界上光谱获取率最高的望远镜。

在技术上，LAMOST在其反射施密特改正镜上同时采用了薄镜面主动光学和拼接镜面主动光学技术，以其新颖的构思和巧妙的设计实现了在世界上光学望远镜大视场同时兼备大口径的突破。并行可控式光纤定位技术解决了同时精确定位4000个观测目标的难题，也是一项国际领先的技术创新。

LAMOST工程分为8个子系统：光学、主动光学和镜面支撑、机架和跟踪装置、望远镜控制、焦面仪器、圆顶、观测控制和数据处理、输入星表和巡天战略。

该望远镜座落在国家天文台兴隆观测站，作为国家设备向天文界开放。随着项目建设在二十一世纪初的完成，它将使我国天文学在大规模光学光谱观测中、在大视场天文学研究上，居于国际领先的地位。

LAMOST望远镜主要性能

MAIN CHARACTERISTICS OF LAMOST

主镜口径 Aperture of primary mirror	6.67m x 6.05m
反射改正镜口径 Aperture of reflecting corrector	5.72m x 4.40m
等效通光口径 Effective aperture in diameter	ϕ3.6m-4.9m
视场角直径 Field of view	ϕ5°
焦面线直径 Focal plane	ϕ1.75m
焦距 Focal length	20m
光纤数 Number of fibers	4000
光谱覆盖范围 Spectral ranges	370～900nm
光谱分辨率 Spectral resolution	1～0.25nm
观测天区 Sky coverage	Declination -10°to+90°

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is an innovative reflecting Schmidt telescope with its active reflecting corrector of 5.72m x 4.40m and primary mirror of 6.67m x 6.05m. The overall concept and key technical innovations make it a unique astronomical instrument in combining a large aperture with a wide field of view. The available large focal plane accommodates up to 4000 fibers, by which the collected light of distant and faint celestial objects down to 20.5 magnitude is fed into the spectrographs, promising a very high spectrum acquiring rate of several ten-thousands of spectra per night.

LAMOST adopts the active optics technique both for thin mirror and segmented mirror on the Schmidt corrector M_A, as well as the parallel controllable fiber positioning system. With these new concepts and design, it is expected to be a unique astronomical instrument in combining a large clear aperture and wide field of view.

LAMOST consists of eight subsystems, optics, active optics and mirror supporting, mounting and tracking, telescope control, focal plane instruments, telescope enclosure, observatory control and data processing, and input catalogue and survey strategy.

LAMOST is located at the Xinglong Station of National Astronomical Observatories, Chinese Academy of Sciences, as a national facility open to the whole astronomical community. It will bring Chinese astronomy into the 21st century with a leading role in wide field spectroscopy and in the fields of large scale and large sample astronomy and astrophysics.

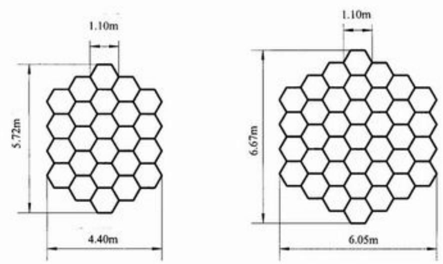
覺宇宙之無窮
識盈虛之有數

王綬琯 二〇〇七年

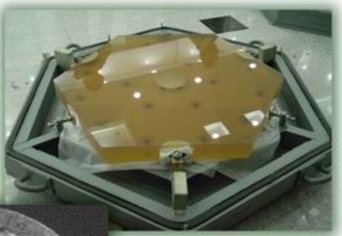
光学系统
Optical System

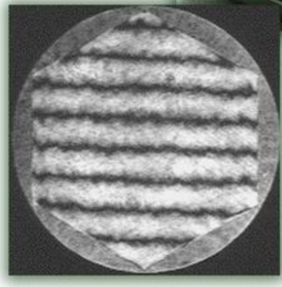
- LAMOST是一架中星仪式反射施密特望远镜。其主镜口径6.67米 x 6.05米、反射施密特改正镜口径5.72米 x 4.40米、等效通光口径3.6米 -- 4.9米（与天区和跟踪位置有关）、5°视场和20米焦距。望远镜光轴与地平呈25°角，南高北低，以适应台址纬度，扩大观测天区。观测天区范围覆盖赤纬从-10°到+90°。位于北端的反射改正镜M_A和位于南端的球面主镜M_B都是拼接镜面，分别由24块和37块子镜拼接而成。

- LAMOST is a quasi-meridian reflecting Schmidt telescope. The size of spherical primer mirror M_B is 6.67m x 6.05m, reflecting Schmidt corrector M_A is 5.72m x 4.40m, and the effective aperture in diameter is 3.6m -- 4.9m (depending on the different observing sky area and the tracking position). The field of view is 5° and the focal length is 20m. Its optical axis is tilted down by an angle of 25° to the horizon from south to north for the sky coverage. The declination of observable sky area ranges from -10° to +90°. Its corrector M_A at the northern end and primary mirror M_B at the southern end are segmented mirrors with 24 and 37 sub-mirrors respectively.

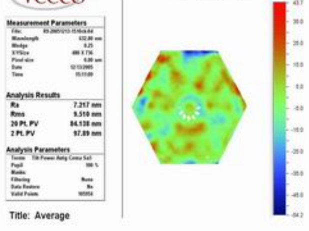


反射施密特改正镜M_A（左）和球面主镜M_B（右）
Left: The reflecting Schmidt corrector M_A,
Right: The spherical primary mirror M_B





M_B 子镜及干涉条纹图
The M_B sub-mirrors and its interferometer pattern



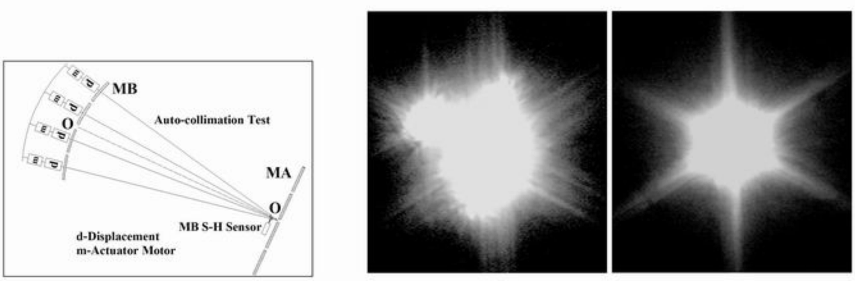
M_A子镜（薄镜面）及表面误差等高图
The M_A thin sub-mirrors and its surface contour map

主动光学系统

Active Optical System

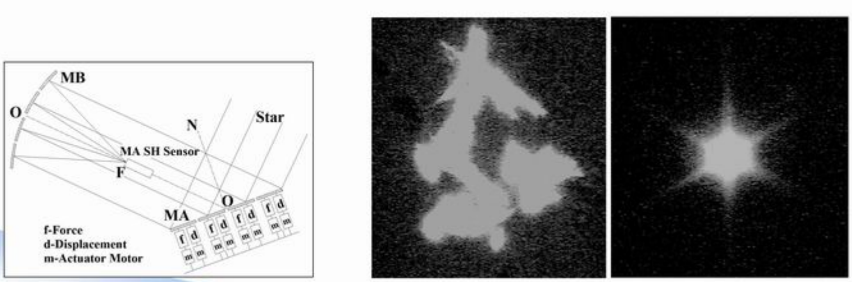
- LAMOST创新地发明了中星仪式主动反射施密特光学系统，用主动光学技术实时得到一个在观测过程中用传统方法不能得到的变化非球面面形的施密特改正镜M_A。为了降低造价，它的反射施密特改正镜M_A和球面主镜M_B均采用了分别用24块和37块六角形子镜拼接的镜面。它的主动光学系统不仅能够实时校正光学系统的球差，同时还能校正镜面支撑结构的重力变形、热变形、加工和安装误差。主动光学技术是LAMOST项目最有挑战性和最核心的关键技术。其创新和技术难点是：1）在M_A镜面上同时应用薄变形镜面和拼接镜面的主动光学技术；2）在一个光学系统中同时应用两块大口径拼接镜面；3）非圆形可变形子镜；4）在形状变化的入瞳上进行波前检测。

- LAMOST is an active meridian reflecting Schmidt Telescope. With the active optics, a variable aspherical surface on Schmidt plate could be obtained in real time during the observation, which could not be realized by the conventional way. For reducing the cost, both Schmidt plate M_A and Primary mirror M_B are segmented with 24 and 37 hexagonal sub-mirrors respectively. This active optics can correct not only the spherical aberration of M_B, but also the gravitational and thermal deflection of the structure, the manufacturing and alignment errors. The active optics is the most challenge and key part in LAMOST. Its innovations and challenges are: (1) Both thin deformable and segmented active optics are applied on one mirror (M_A); (2) Two segmented mirrors in one optical system; (3) Non-round deformable mirror; (4) Wave front sensing on a shape variable pupil.



M_B主动光学原理图和主动光学校正前后的星像

M_B active optics principle and the images before and after correction by active optics



M_A主动光学原理图和主动光学校正前后的星像

M_A active optics principle and images before and after correction by active optics

镜面支撑与结构

Mirror Supports and Structures

- LAMOST的反射施密特改正镜M_A和球面主镜M_B均采用空间桁架作为镜面主体支撑结构。在半球形的支撑桁架上，每块M_A子镜又有一套二级支撑机构。M_A子镜有37个主动力促动器和定位点支撑并联接于下一级的3个主动位移促动器调节机构之上，从而可同时实现薄镜面和拼镜面主动光学技术。每块M_B子镜则采用了whiffle-tree机构支撑，并直接通过主动位移促动器调节机构联接于主体桁架之上。

- Both the reflecting Schmidt plate, M_A, and the primary mirror, M_B, employ spatial truss type structure to construct their gross mirror cells. Attached on the top of the hemisphere-shaped truss, each sub-mirror of M_A uses a two-stage supporting mechanism. As the upper stage, the M_A sub-mirror is supported by 37 active force actuators and defining points, which are connected to 3 lower active displacement actuators on the stage, thus, the M_A is able to fulfill deformable mirror active optics and segmented mirror active optics simultaneously. While on the gross mirror cell of M_B, every sub-mirror uses a whiffle-tree which is further connected on the rear active displacement actuators to serve segmented mirror active optics

M_A支撑桁架
Gross mirror cell of M_A during installation

M_A子镜及其支撑系统
M_A Sub-mirror and its support system

M_B桁架吊装
Gross mirror cell of M_B during installation

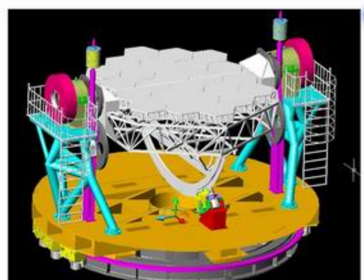
M_B子镜在安装中
The installation of M_B sub-mirror

机架和跟踪系统
Mounting and Tracking System

- LAMOST是一架中星仪式的望远镜，由于它的球面主镜M_B是固定的，对天体的指向跟踪运动完全由反射施密特改正镜M_A 担任。M_A 采用地平式机架，其指向和跟踪由方位和高度两个方向旋转实现。观测主要在子午面附近进行。整个跟踪运动过程较缓慢且运动速度变化较少。采用静压轴承，使用摩擦驱动，并用带状码盘测角。相应地焦面也要旋转，需有像场旋转补偿机构。另外还有调焦机构和焦面板的倾斜机构等。

- LAMOST is a meridian telescope with a fixed spherical mirror M_B, an alt-azimuth mounting reflecting Schmidt corrector M_A and a focal plane. The celestial objects are pointed and tracked by the movements of M_A. Observations are made mainly around the meridian. The required tracking speed is slow and its acceleration is small, without any blind spot. Hydrostatic bearing is adopted, direct friction drive is used for azimuth and altitude drive, and tape encoder is for precisely positioning. Focal plane rotates during tracking, so a de-rotating mechanism to compensate the field rotation is used. A focusing unit is also equipped.

焦面机架
Mounting and tracking mechanism of the focal plate



M_A和其地平式跟踪机架
M_A and its altitude and azimuth mounting and tracking system

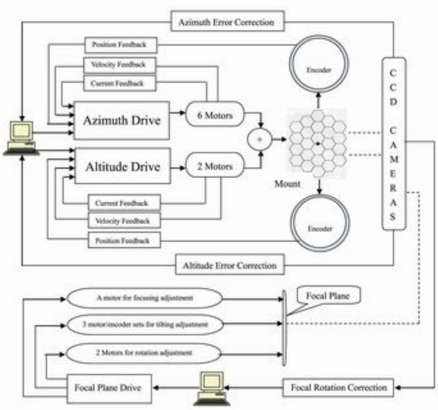
在车间装配中的M_A机架和跟踪装置
Mounting and tracking mechanism of M_A in workshop

望远镜控制系统

Telescope Control System

- 望远镜控制系统具有当代国际上大型天文望远镜控制系统的一系列特点：实时、可靠、网络化、多层次、分布式和易于扩展。主要由如下三个子系统组成：（1）指向跟踪控制子系统，包括M_A的高度和方位驱动、焦面板的像场旋转以及依据导星进行校正等；（2）薄镜面主动光学控制和拼镜面主动光学控制子系统，以控制数以千计的力促动器和位移促动器；（3）实时环境监测和故障诊断子系统，包括圆顶控制、观测室温度监控、风屏通风窗控制、雨露监控、安警和远程监控等。

- The telescope control system has the system features as real time, reliability, networking based, multilayer, distributed and expansibility just like other modern large astronomical telescopes in the world. The control system mainly consists of 3 subsystems: (1) The tracking system to operate the M_A alt-azimuth mount, the rotation of field of view on the focal plane as well as the guiding correction with the guiding star system. (2) The system of thin mirror active optics correction and segmented mirror co-focusing correction to drive approximate 1000 force actuators and displacement actuators in total. (3) The system of real time environmental monitor and control and fault-diagnosis including the dome control, temperature monitor and control in the enclosure, the wind screens and the ventilation windows control, the rain and dew monitor and control，the alarming facilities, the remote monitor and control, etc.



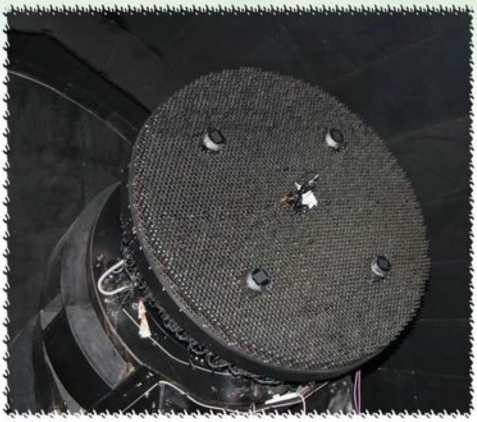
机架驱动和焦面控制伺服示意图
Schematic of mount drive and focal plane servo

主动光学控制系统
Control system of the active optics

焦面仪器
Focal Plane Instrument

- 通过望远镜收集来自天体的微弱辐射并成像在焦面上，焦面上的光纤将天体的光分别传输到光谱仪的狭缝上，通过光谱仪分光后由CCD探测器接收，同时获得大量天体的光谱。焦面仪器是LAMOST直接获取天体光谱信息的部分，包括：4000个光纤定位装置、4000根光纤、16台光谱仪和32台探测器等主要部分。

- The lights of celestial objects are collected by LAMOST and formed image of the observed sky on the focal plane. The light of individual objects is fed into the front ends of optical fibers accurately positioned on the focal plane, and then transferred into spectrographs fixed in the room underneath, to be dispersed into spectra and recorded on the CCD detectors, respectively and simultaneously.



焦面板及4000个光纤定位单元
The focal plane with 4000 fiber positioning units

双回转运动示意图
The movement of double rotation

光纤定位单元
Fiber positioning units

光纤定位装置
Fiber Positioning System

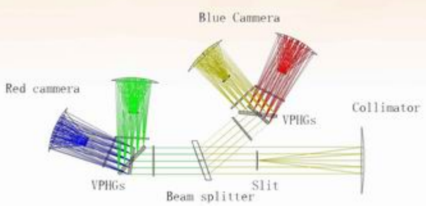
LAMOST采用并行可控的光纤定位技术，可在数分钟的时间里将光纤按星表位置精确定位，并提供光纤位置的微调。4000个光纤定位单元在焦面上以25.6毫米等距离排列，每个单元驱动光纤在直径33毫米的范围内工作。光纤定位单元采用双回转运动形式，由两只步进电机驱动，最大定位误差40微米。这是LAMOST首先提出的方法。

By using the parallel controllable fiber positioning technique, LAMOST makes reconfiguration of fibers accurately according to the positions of objects in minutes and fine adjusting the fibers. 4000 fiber positioning units are accommodated on the focal plane with a 25.6mm distance between each others. Each unit drives a fiber moving in a circle of 33mm in diameter. The unit is driven by two step motors in double rotation movement. The positioning error is 40 micron maximum. It is an innovation by LAMOST.

低分辨率多目标光纤光谱仪
The Low Resolution Spectrographs

- LAMOST拥有16台低分辨率多目标光纤光谱仪，每台光谱仪可安插250根光纤，光纤芯径为3.3″(320μm)。低分辨率模式下蓝区通道工作波段370nm-590nm，红区通道工作波段570nm-900nm，光谱分辨率本领为1000-2000，光学系统效率好于30%。每台光谱仪还可以增加中分辨率光栅，使光谱分辨率本领达到5000-10000。

- There are 16 low resolution spectrographs (LRS) on the LAMOST. Each spectrograph accommodates 250 fibres of 320 micron in diameter (corresponding 3.3 arcsec). The blue channel is optimized for 370nm-590nm, and the red channel for 570nm-900nm. The spectral resolution power is 1000-2000. The throughput of the spectrograph is better than 30%. The resolution can be reached R=5000-10000 by turning to medium resolution gratings.



低分辨率光谱仪的光学系统
Optical system of the low resolution spectrograph

低分辨率光谱仪
The low resolution spectrograph

CCD相机
CCD Camera

LAMOST的16台光谱仪共配有32台低噪声的天文CCD相机，每台光谱仪各配红、蓝两台CCD相机。CCD幅面是4096x4136像素，分为红敏CCD和蓝敏CCD两种。它们具有很低的噪声特性，在200Kpix/s的快速读出速度下读出整幅图像只需40秒时间，读出噪声低于4个电子。

LAMOST has 32 CCD cameras. CCD chip is scientific CCD sensor with 4096 by 4136 active pixels. There is a red band CCD camera and a blue band CCD camera for each spectrograph. They can read out image with a very low readout noise by two output channels for each chip. With a speed of 200Kpix/s, CCD cameras can read out a full image in 40 seconds, while the read-out noise is less than 4 electrons.

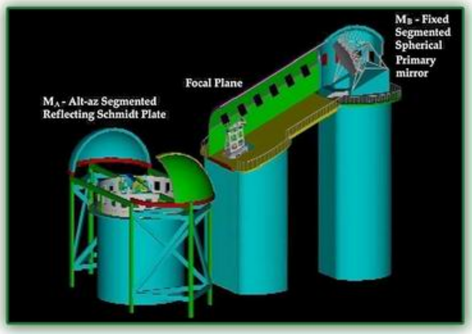
CCD芯片和相机
CCD chip and camera

圆顶温度、视宁度及风载的控制

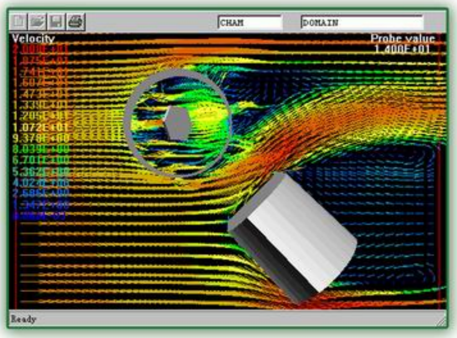
Enclosure Temperature, Seeing and Wind Load Control

- LAMOST望远镜的光路有60米长，比世界上大多数望远镜的光路都长，反射施密特改正镜MA观测时必须完全开放，因此必须解决圆顶中的温度、光路视宁度和M_A风载的控制问题。LAMOST采取特别的制冷通风装置，加上温度传感器的监测，可以较好地解决温度一致性和视宁度的问题。利用固定风屏和6块可分别升降的活动风屏相结合能够显著地降低主动反射施密特改正镜M_A在观测中的风载问题。

- The optical path of LAMOST is about 60 meters, much longer than those of most large telescopes in the world, which causes serious dome seeing problems and distortions in telescope structure. Also, during observation, the reflecting Schmidt plate M_A is in open air, which causes the heavy wind load on such a very thin and highly accurate mirror. To resolve these problems, the enclosure is designed with some ventilation and refrigerates controlling the temperature gradient and improving the seeing. A fixed wind screen and 6 active wind screens can be protected M_A from the heavy wind load on the M_A mirror surface during the observation .



通风、制冷系统及活动风屏
Ventilation and refrigeration systems and the moving wind screens



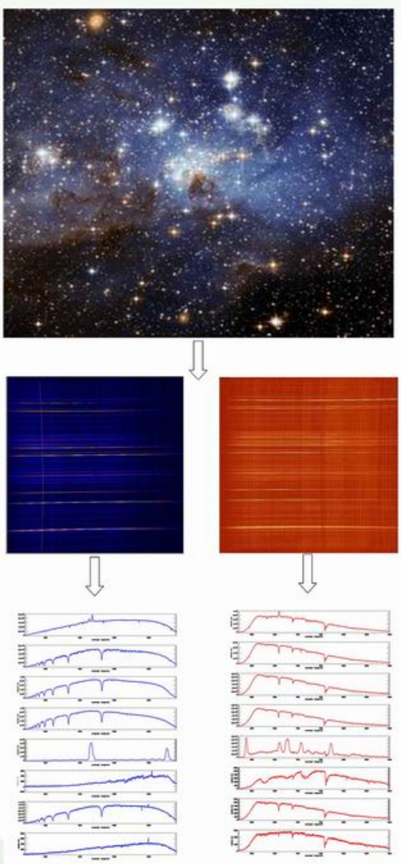
数值模拟和风洞试验优化风屏设计
Numerical simulation and wind tunnel test for the wind screen

观测控制和数据处理系统

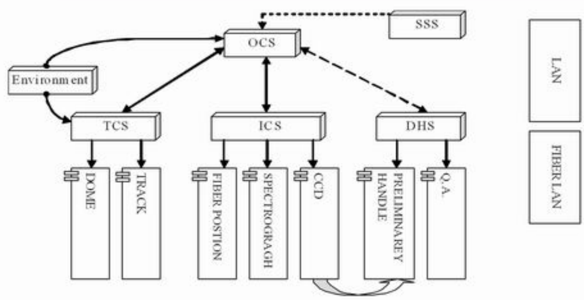
Observatory Control System and Data Processing System

- LAMOST每夜将观测上万个天体的光谱，数据量达到数京字节；而整个的计划是观测上千万条光谱。为最有效地获得观测数据和取得最大的科学成果，LAMOST拥有一套完整的自动化观测、数据处理和存储的软件系统，其中主要包括巡天战略系统(SSS)、观测控制系统(OCS)、数据处理、分析和存储系统(DPS)。

- LAMOST will obtain up to ten-thousands of spectra per night and the data volume will be several gigabytes. It is planed to acquire ten-millions of spectra as a whole. In order to obtain the data high efficiently and gain more scientific results, LAMOST has an automatic software system for its observation and data processing. For this purpose, a set of software system for observation, process and storage, has been developed including Survey Strategy System (SSS), Observation Control System (OCS) and Data Processing System (DPS).



自动观测控制系统
Automated observatory control system



自动数据处理和分析软件
Automated Data Reduction and Analysis

自动数据处理和分析软件包括2维处理和1维处理两大部分。原始的CCD光谱图像输入2维处理程序后抽出1维光谱，并定标和修正。1维处理程序对已经定标的光谱进行分析，得到有用的天体物理信息。

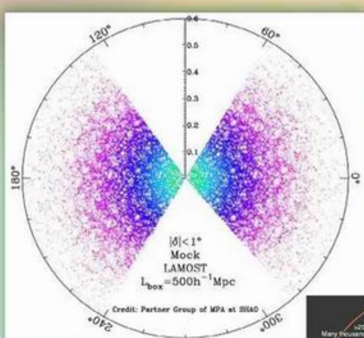
Automated reduction and analysis software includes 2-dimension (2D) pipeline and 1-dimension (1D) pipeline. The CCD spectral images are fed to 2D reduction pipeline to extract 1D spectra and then for calibration. 1D pipeline measures the calibrated spectra and analyzes them to obtain useful astrophysical information.

LAMOST的科学目标
Scientific Goals of LAMOST

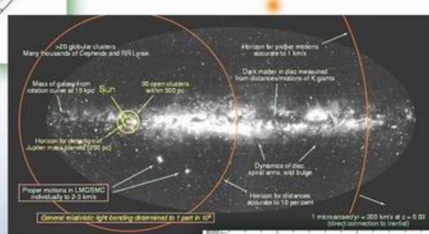
高效率地获取大样本天体光谱

三大核心课题：
* 河外光谱巡天— 宇宙大尺度结构等
* 恒星光谱巡天— 银河系结构等
* 天体多波段交叉证认

Key programs：
* Extra-galactic spectroscopic survey — Large scale structure of the universe
* Stellar spectroscopic survey — Structure of the Galaxy
* Cross identification of multi-waveband surveys

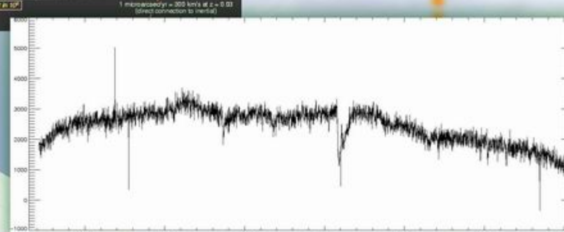


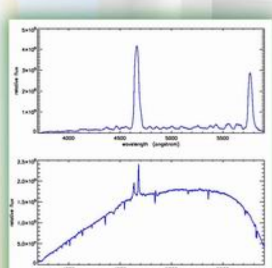
宇宙大尺度结构
Large scale structure of the Universe

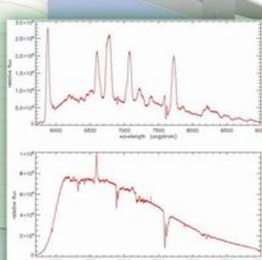


银河系结构
Structure of the Galaxy

LAMOST小系统获得的第一条恒星光谱
The first stellar spectrum obtained by "Small LAMOST"







LAMSOT观测到的特殊恒星光谱（左为蓝端光谱、右为红端光谱，未定标）
Spectra of peculiar stars observed by LAMOST （left is blue band, right is red band； un-calibrated ）

LAMOST大事记

1993年4月　以王绶琯、苏定强为首的研究集体提出LAMOST项目，建议作为中国天文重大观测设备

1994年12月-1995年6月　经过中国天文学会、中科院数理学部、中国科学院、国家科委、国家计委先后组织的多次各级评议和评审，LAMOST项目一直位居前列

1996年7月　国家科技领导小组决策启动国家重大科学工程计划，LAMOST列入首批启动项目

1996年10月　中国科学院成立国家重大科学工程“大天区面积多目标光纤光谱天文望远镜”项目工程指挥部，项目科学技术委员会，项目管理委员会

1997年4月　国家计委批复《LAMOST项目建议书》

1997年8月　国家计委批复《LAMOST项目可行性研究报告》

1999年6月　中国科学院受国家计委委托批复《LAMOST项目初步设计与概算》

2001年8月　国家计委批准LAMOST项目开工报告，项目正式进入施工阶段

2004年6月　在国家天文台兴隆观测站举行“LAMOST观测楼奠基典礼”，项目主体望远镜观测楼开始建造

2005年6月　中国科学院组织国际著名专家对LAMOST项目进行了中期评估

2005年9月　LAMOST项目首件大型设备(8米机架底座)在兴隆观测站成功吊装，开始了项目主体设备安装

2007年6月　LAMOST完成3米口径的镜面、250根光纤的定位系统、一台光谱仪及其CCD相机（被称为“小系统”）以及完整的望远镜地平式机架、焦面机架、跟踪和控制系统的装调，达到望远镜设计的光学指标，并获得天体光谱

2008年8月　望远镜全部硬件(24块M_A子镜、37块M_B子镜、4000个光纤定位单元、4000根光纤、16台光谱仪、32台CCD相机)安装到位

2008年10月　LAMOST项目落成典礼

LAMOST发起人-王绶琯和苏定强院士
LAMOST proponents - Academicians Wang Shouguan and Su Dingqiang

LAMOST观测楼奠基
The ground-breaking ceremony

LAMOST项目中期评估
The interim review and assessment

首批大部件在南京启运剪彩
Ceremony of the fist large parts shipment in Nanjing

LAMOST项目望远镜开始安装
The installation of the first large parts

LAMOST Events

Apr. 1993 A group headed by Academicians Wang Shouguan and Su Dingqiang proposed LAMOST as the major astronomical facility in China

Dec. 1994 -Jun 1996 - LAMOST project ranked as one of the top priority after a series of review organized by Chinese Astronomical Society and Division of Mathematics and Physics of Chinese Academy of Sciences, Chinese Academy of Sciences and the related government agencies

Jul. 1996 The government authority determined to launch the national major science projects, with LAMOST project as one of the first startup projects

Oct. 1996 The Academy formed the Project Managements, Project Science and technology Committee and the Board of the LAMOST Project

Apr. 1997 LAMOST project Proposal was reviewed and officially approved

Aug. 1997 LAMOST project Feasibility Study was reviewed and approved

Jun. 1999 LAMOST project Preliminary Design was reviewed and approved

Aug. 2001 LAMOST project Detailed Design was reviewed and approved. The project entered in its construction phase

Jun. 2004 The ground-breaking ceremony of LAMOST was held in Xinglong Station, National Astronomical Observatories (NAOC), Chinese Academy of Sciences

Jun. 2005 An international experts committee organized by the Academy for interim review and assessment of LAMOST project

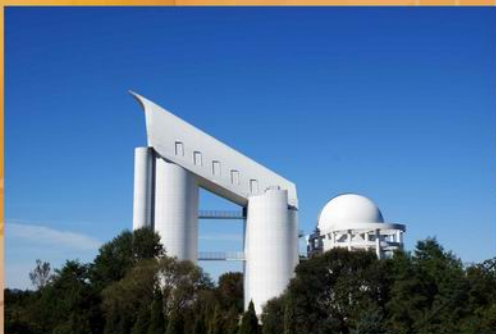
Sept. 2005 The 8m mounting base, which is the first large parts of LAMOST, was successfully installed in Xinglong Station， marking the start of overall equipment installation stage

Jun. 2007 The mirrors with 3 meter equivalent aperture, 250 fiber positioning units, 1 spectrograph and 2 CCD cameras（so-called “Small LAMOST”）, as well as the entire mounting, tracking and control systems were completed. optical quality had met the specification and stellar spectra were obtained

Aug. 2008 The installation and assembly of all telescope systems was completed

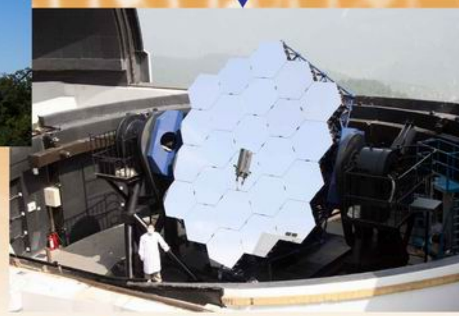
Oct. 2008 LAMOST inauguration ceremony was held in Xinglong Station, NAOC

LAMOST全部安装完成
Installation Completed

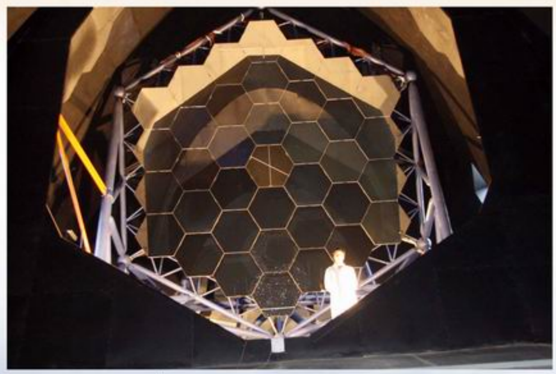


LAMOST观测楼
The enclosure of LAMOST

反射施密特改正镜M_A
The reflecting Schmidt corrector M_A



焦面板和光纤定位单元
The focal planeand fiber positioning units



球面主镜M_B
The primary mirror M_B

低分辨率光谱仪（16台）和CCD相机（32台）
16 low resolution spectrographs and 32 CCD cameras

光纤定位单元

国际合作与交流
International Cooperation & Exchange

Prof. A. Meinel from U.S.A. in China

Prof. C. Fehrenbach from France in NIAOT

The review committee visit LAMOST in Nanjing

LAMOST delegation in Europe

Participating the International Conference on Telescope & Instru

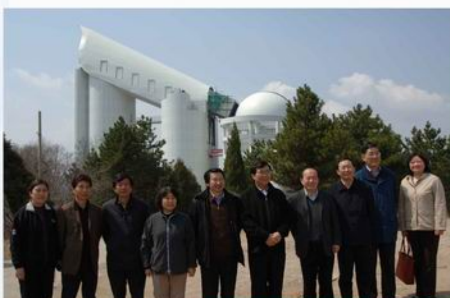
MB acceptance test in LZOS, Russion

LAMOST delegation in SDSS, Apache Point

领导视察
Leaders Inspection

中国科学院路甬祥院长视察LAMOST
Lu Yongxiang, President of CAS, inspected LAMOST

中国科学院路甬祥院长和李志刚秘书长在天光所检查项目进展
President Lu Yongxiang and Secretary-general Li Zhigang, CAS, inspected progress of LAMOST in NIAOT



中国科学院常务副院长白春礼检查工作
Bai Chunli, Vice president of CAS, inspected LAMOST

白春礼副院长在天光所视察M_A镜的磨制
Vice president Bai Chunli inspected the M_A mirror polishing in NIAOT

国家发展与改革委员会张晓强副主任（左），国家科技部马颂德副部长（右）参观LAMOST 展台
Zhang Xiaoqiang, Vice director of National Development and Reform Commission (left), and Ma Songde, Vice minister of the Ministry of Science and Technology (right) inspected LAMOST exhibition stand

LAMOST设计者和建设者
The Designers and Constructors of LAMOST

LAMOST建议人
LAMOST proponents