底片数字化的报告

中国科学上海天文台

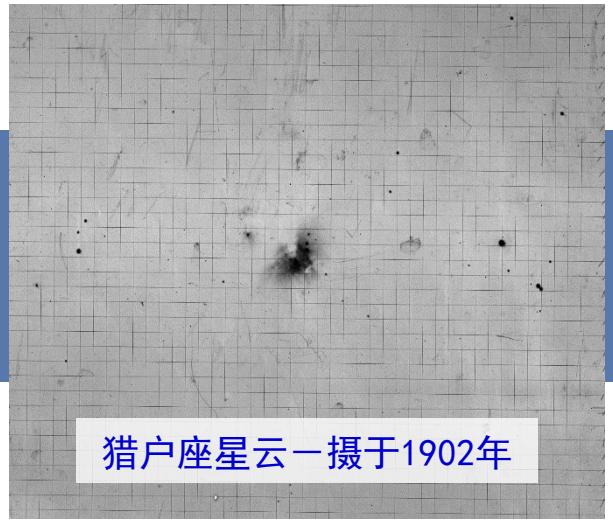
底片数字化项目组

报告人：杨美婷

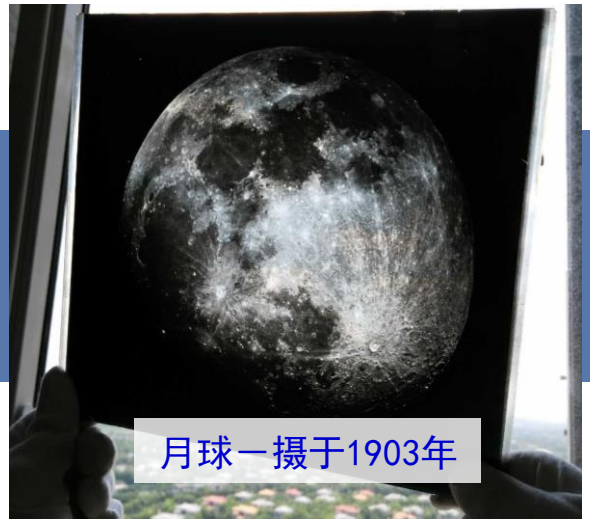
一、底片数字化工作的意义

天文底片与数字化

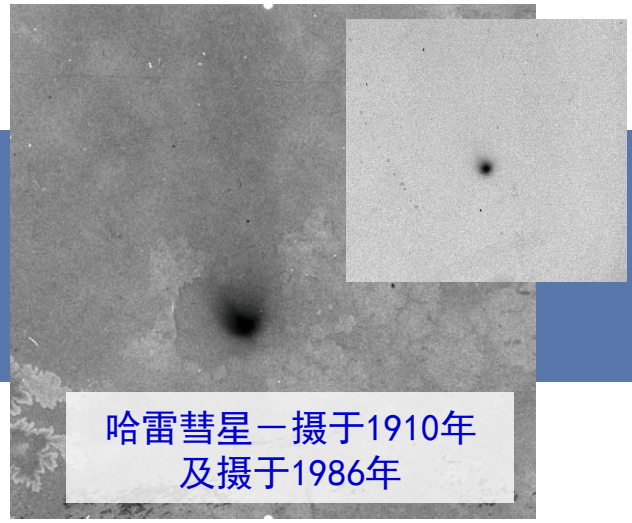
- 19世纪40年代，天文学家利用照相底片记录了150多年的天体活动。所有天体都处于不断运动和变化中，这些底片是当时天区不可再现的唯一观测记录，在科学上是无价的，是当代天文学研究的重要基础数据来源之一。
- 20世纪初，佘山天文台第一任台长蔡尚志（法国耶稣会天文学家）等人用佘山天文台40cm望远镜拍摄的天文影像，是国内最早的一批天文照相底片。



猎户座星云－摄于1902年



月球－摄于1903年



哈雷彗星－摄于1910年
及摄于1986年

天文底片与数字化

由于底片表面为溴化银药膜，受保存条件的限制，随着时间推移，底片质量逐渐退化。

只有扫描变成数字化资料后，才能有效保护底片信息，更充分地用于科学研究。

发霉、脱膜的天文底片示例

国际科学组织的呼吁

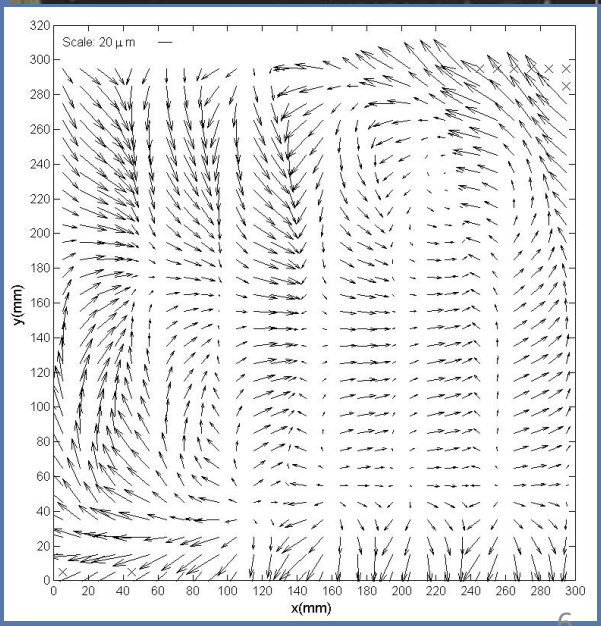
- 国际上总共现存约**300多万**张天文底片，大部分底片尚未被数字化，它们携带的海量信息未被充分解读。
  - 2000年，IAU成立“天文底片保存与数字化”工作组。
  - 2010年，天文底片数据被国际科学联合会列为濒危科技数据资源。
  - 2018年，IAU再次通过决议，呼吁全世界天文同行共同努力、加强国际合作，加快各国开展天文底片数字化。
- **对天文底片的数字化保存与研究是当前各国天文机构的共性紧迫需求。**

底片数字化的历史和现状

- 上世纪八、九十年代，各国天文工作者利用测微密度计（PDS）扫描底片，但PDS扫描一张底片需20小时左右，因此底片数字化工作受技术及设备限制而中断。
- 本世纪国际上不少天文台采用高端商用扫描仪开展底片数字化，但商用扫描仪位置误差大（～几十微米），不能满足高精度测量要求。

Epson平板扫描仪的扫描位置误差：～22 um

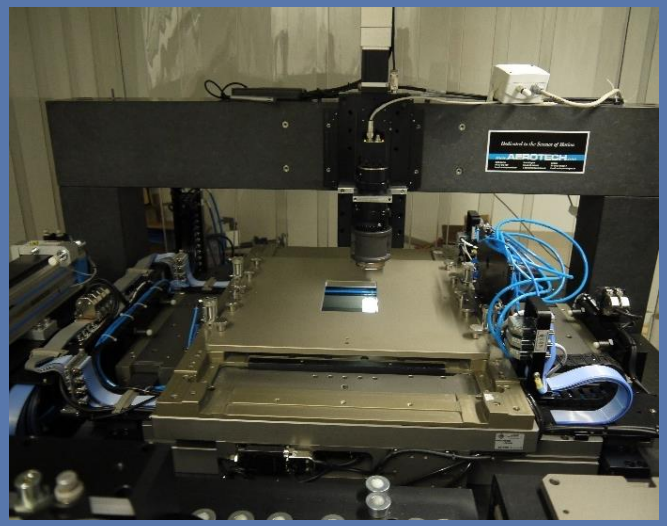
PDS显微密度计



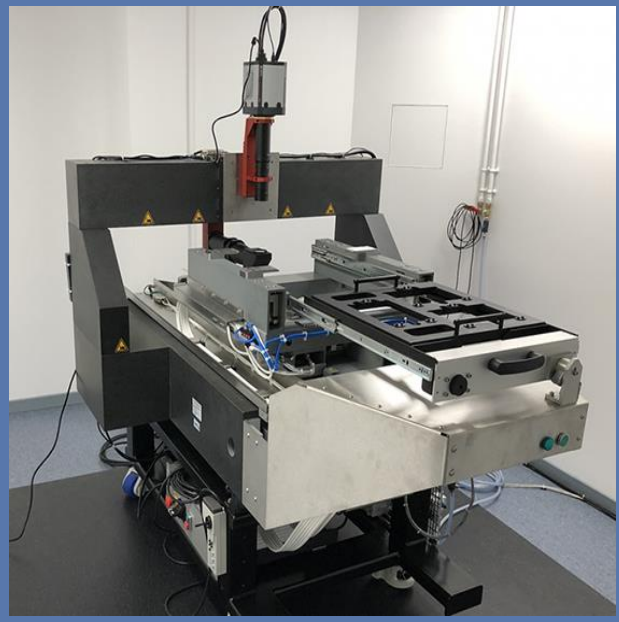
底片数字化的历史和现状

- 当今国际上有条件开展高精度数字化的机构仅有美国哈佛大学天文台、比利时皇家天文台、上海天文台以及法国巴黎天文台等。

哈佛大学天文台扫描仪



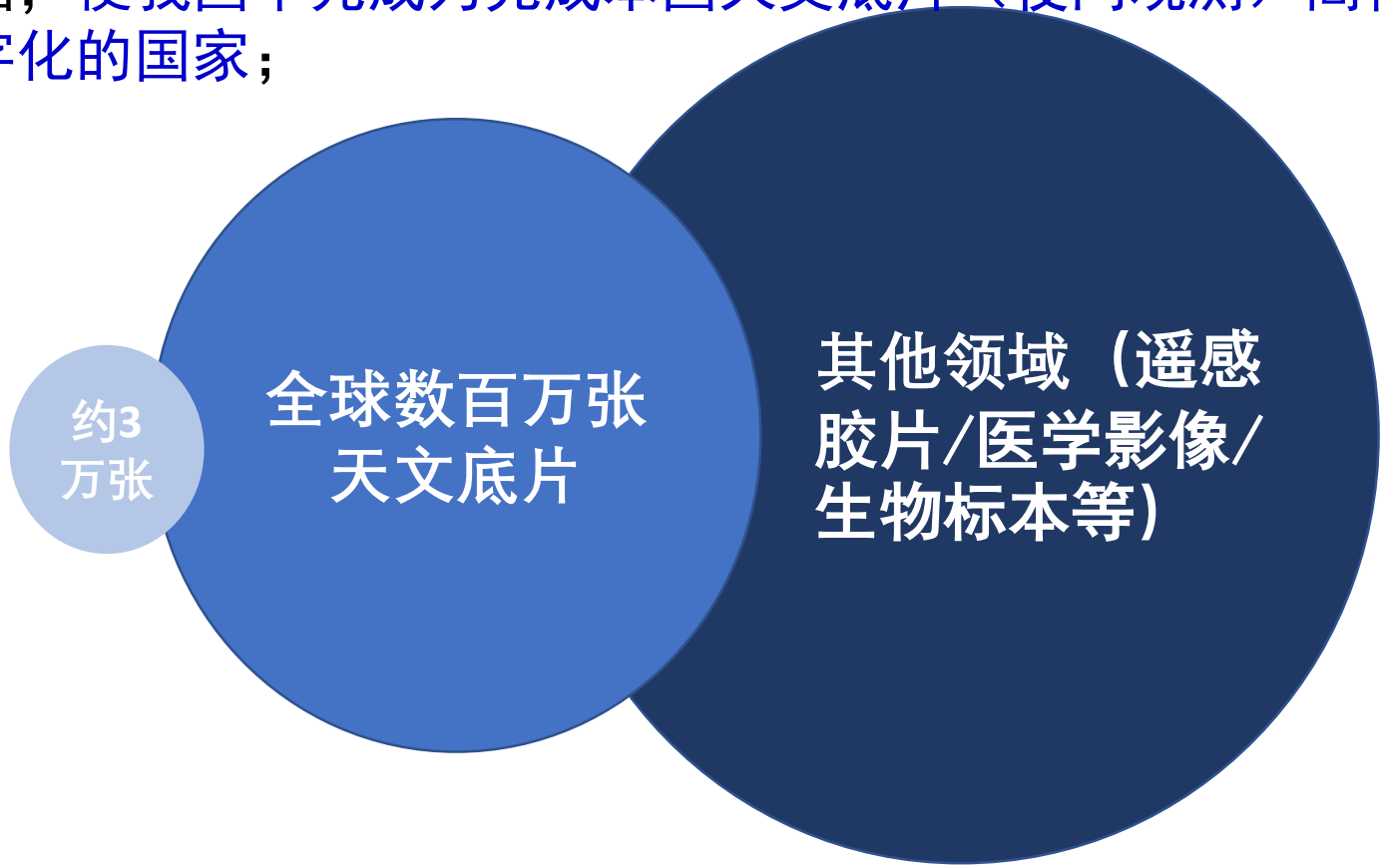
比利时皇家天文台扫描仪



巴黎天文台扫描仪

天文底片数字化的研究

- 2009年开始底片数字化研究，2012年至2017年，在科技部科技基础性专项重点项目的支持下，上海天文台利用中日合作研发的第一代高精度底片扫描仪完成国内天文底片（～3万张）的扫描，使我国率先成为完成本国天文底片（夜间观测）高精度数字化的国家；

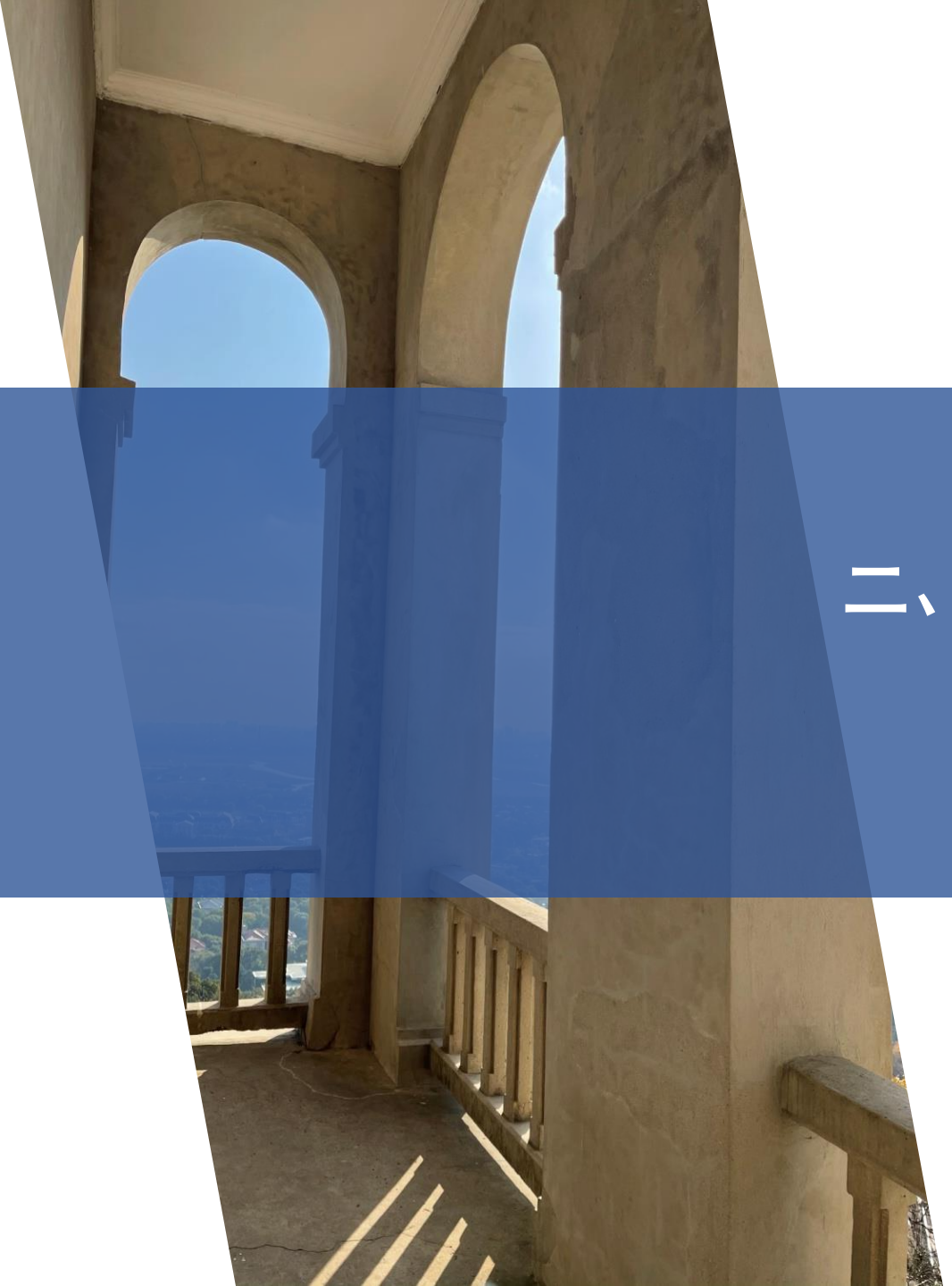


天文底片数字化的研究

- 2018年，我们团队负责人审时度势，充分利用已研发的世界一流底片扫描仪，在国家“一带一路”框架下，响应国际组织的呼吁，汲取一带一路沿线各国的天文底片数据及延伸资源，为国际天文学遗产保护和时域天文学研究做出中国贡献。

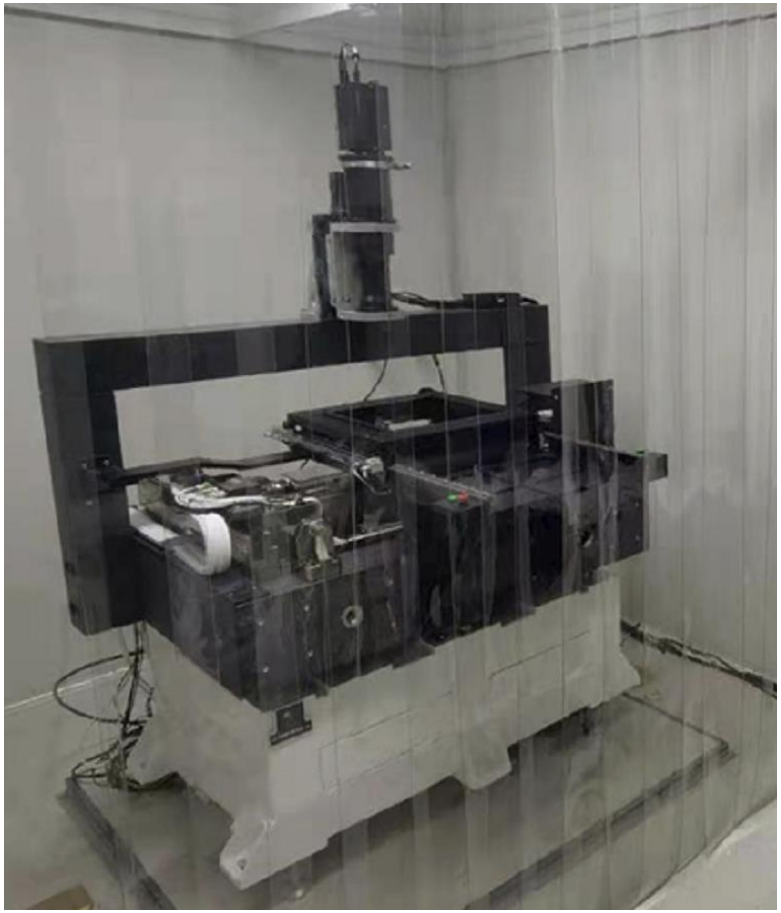
底片数字化实验室的十五年发展规划

- **第一阶段（2019-2021年）**：在上海市科委重大项目支持下，筹备建设“上海底片数字化实验室”：自主研发成功两台高精度底片扫描仪，开展了国际天文底片的高精度扫描工作；
- **第二阶段（2022-2024年）**：在上海市科委重大项目持续支持下，进一步开展高精度底片扫描仪二期研发工作，继续研发两台新的速度更快、适用范围更广的高精度底片扫描仪，争创上海市重点实验室，建立底片数字化跨域技术转移中心。同时正在申请中国科学院国际大科学计划，期望使我国在天文底片数字化领域成为国际主导力量。
- **第三阶段（2025-2034年）**：建成国际底片数字化数据库，产出高水平时域天文学研究成果，解决国内其他领域的高精度底片数字化需求。

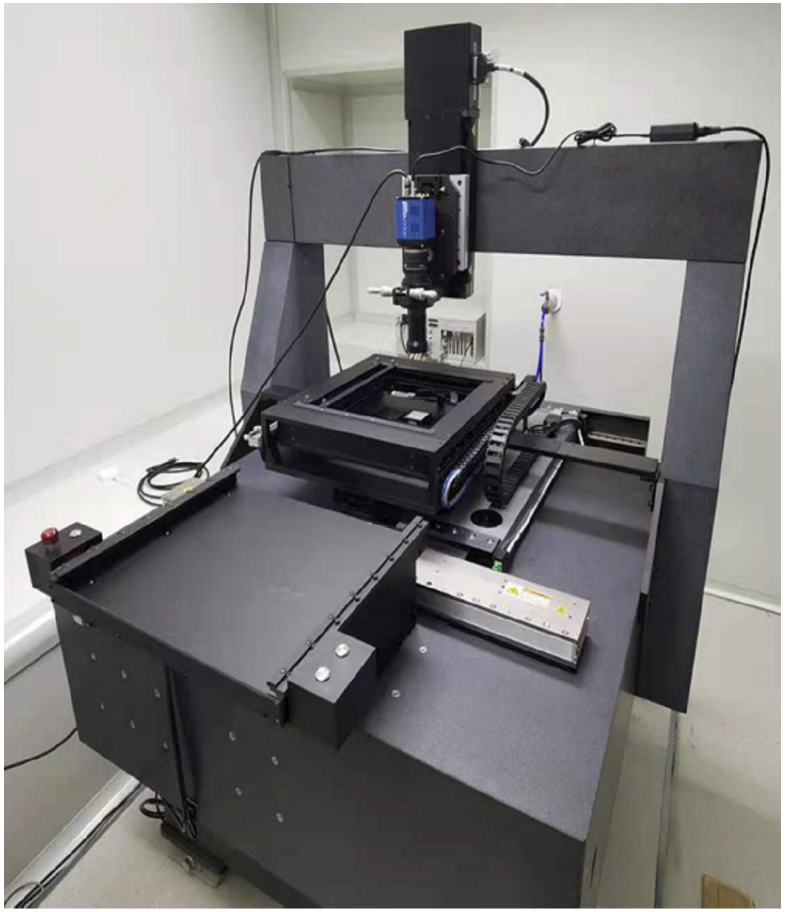


二、高精度底片扫描仪的自主研发

设备研发—第二代高精度底片扫描仪



2020年9月，自主研发完成第二代高精度黑白透射式底片扫描仪



2021年6月，自主研发完成第二代高精度彩色/反射多功能扫描仪

设备研发—第二代高精度底片扫描仪

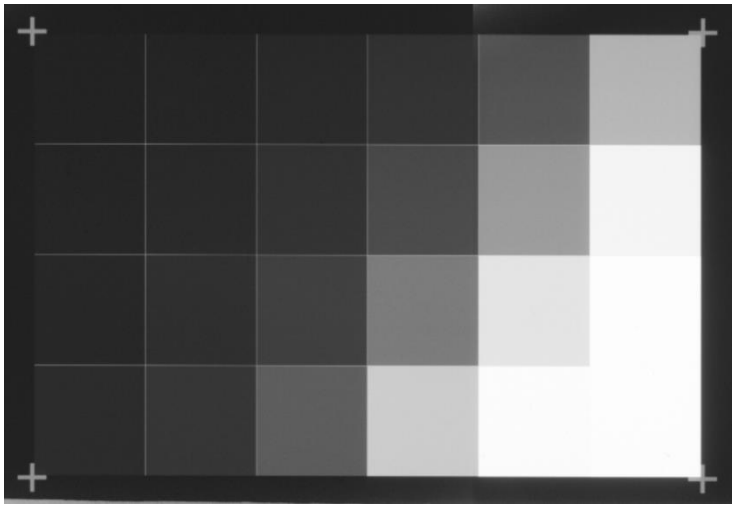
序号	内容	第一代扫描仪 实测结果	第二代扫描仪 实测结果
1	研制方式	中日合作	自主研发
2	扫描模式	线扫描	面扫描
3	导轨	机械式	气浮式
3	光学分辨率	2540 DPI	2309 DPI
4	光度重复精度	0.02mag	0.005mag
5	动态范围	3.0 OD	3.9 OD
6	位置精度	＜1μm	0.3μm
7	最大扫描范围	300×300 mm	350×350 mm
8	扫描耗时	10 minutes	＜2 minutes
9	图像格式	16 位fits图像	16 位fits图像

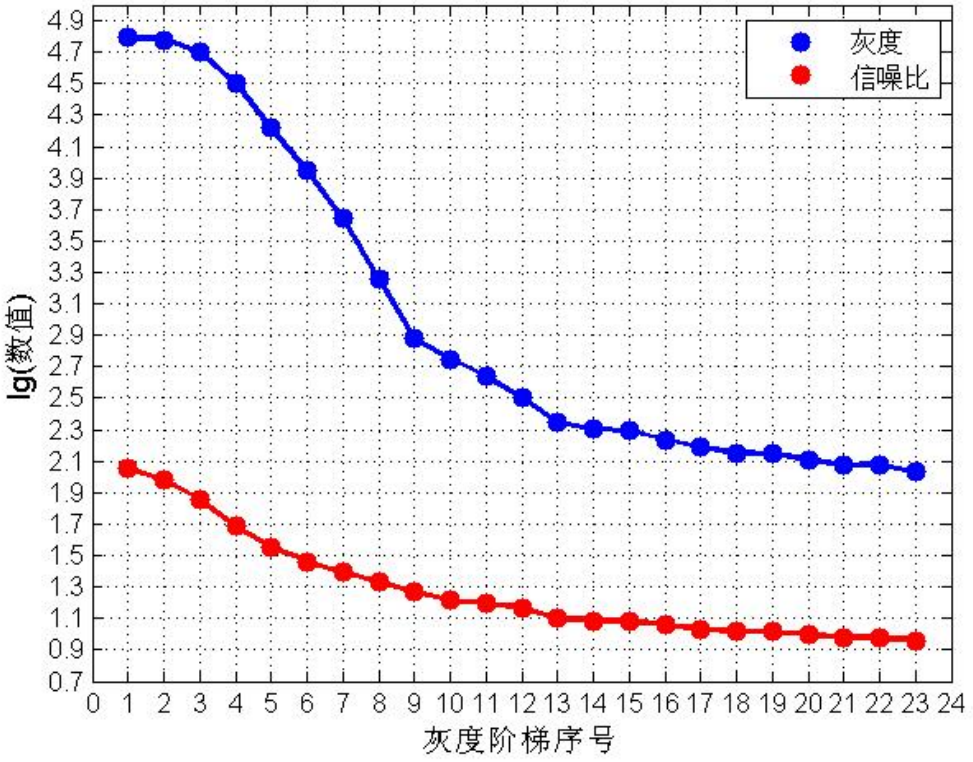
设备研制—第二代高精度底片扫描仪

扫描仪基本性能：

- 扫描动态范围
- 扫描重复性（位置和星象强度）
- 扫描耗时
- 扫描图像保存形式

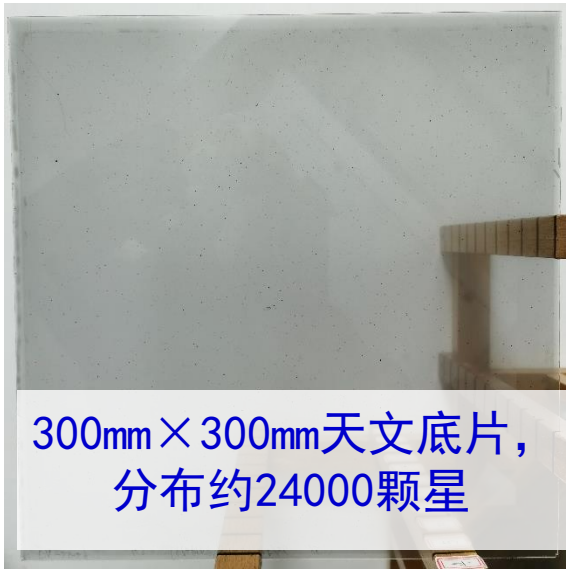
• 设备基本性能——动态范围

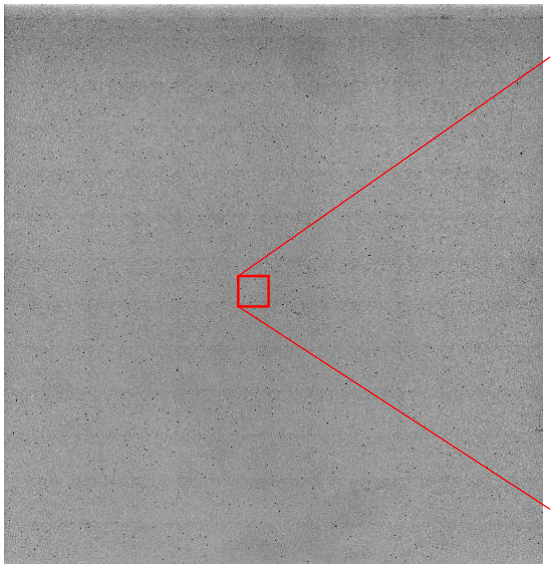


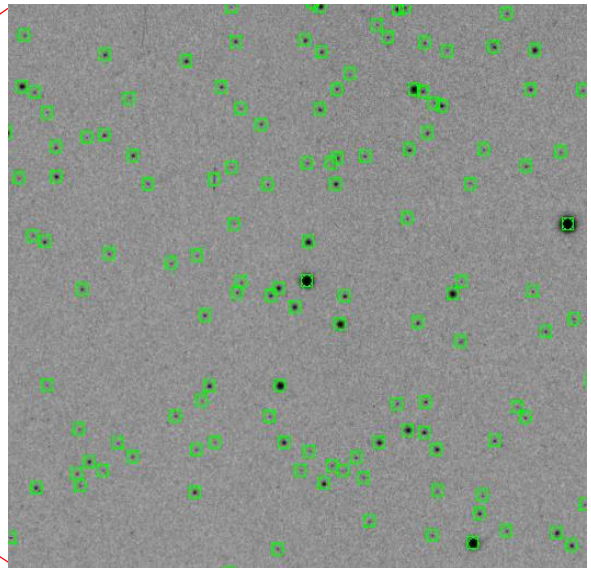


利用灰度阶梯尺，测试扫描动态范围：＞3.9 OD。

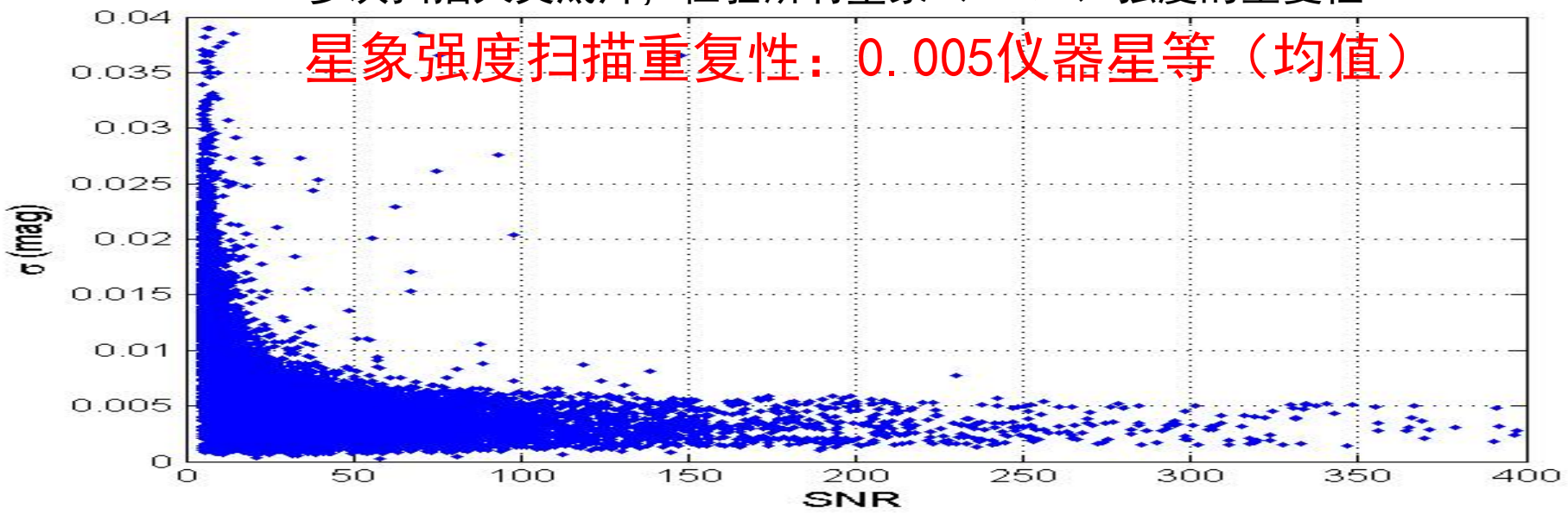
• 设备基本性能——星象强度扫描重复性



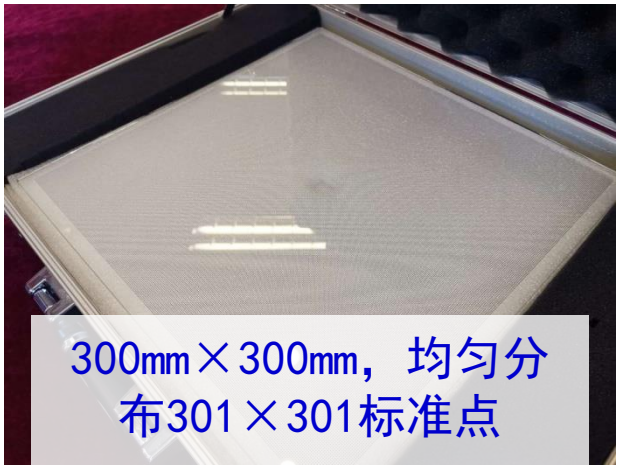


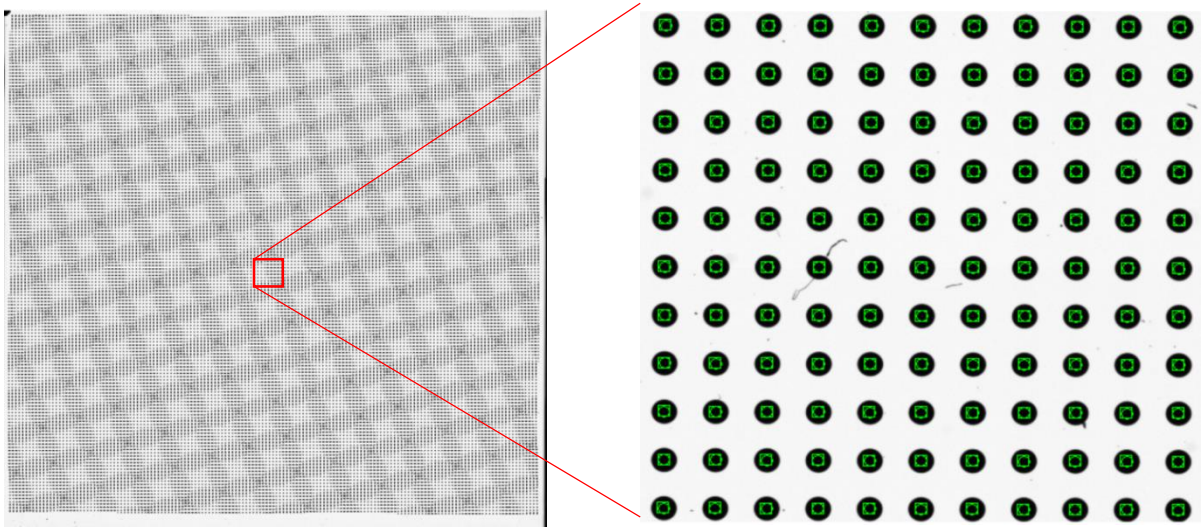


多次扫描天文底片，检验所有星象（SNR>5）强度的重复性

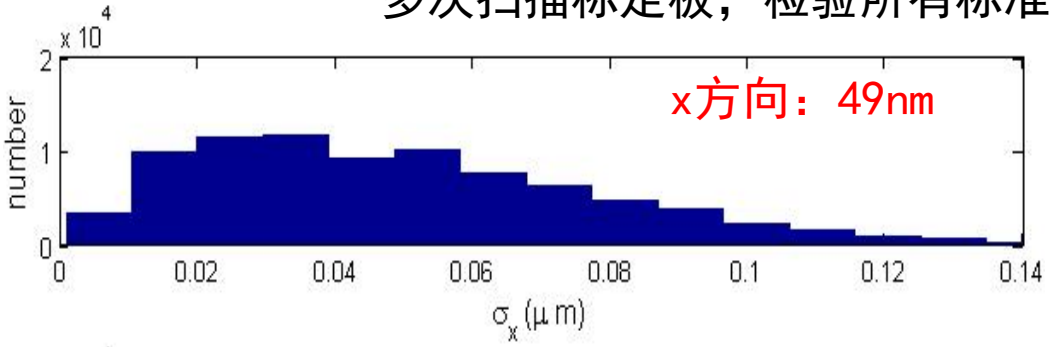


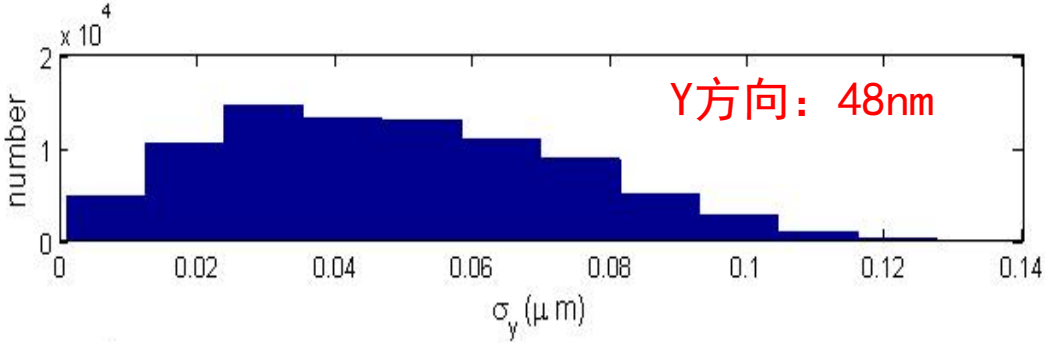
• 设备基本性能——位置扫描重复性





多次扫描标定板，检验所有标准点的重复性





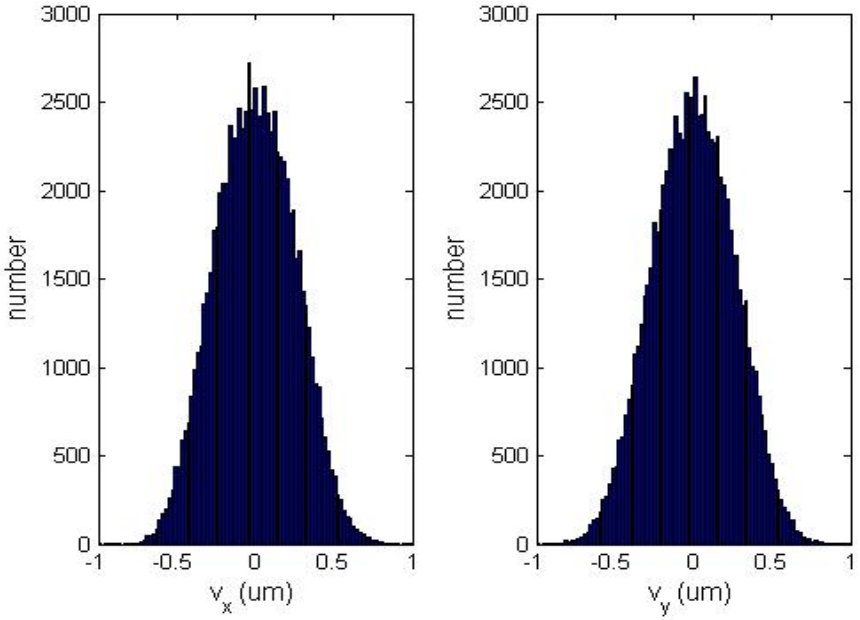
位置重复性～50nm

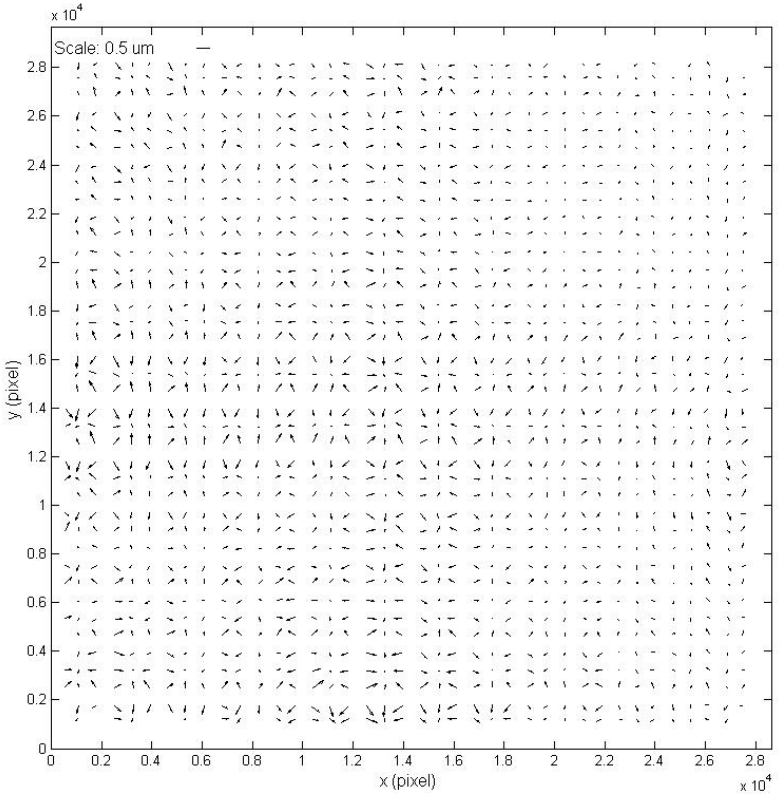
• 系统差修正

- 检测各类系统差，采取相应的补偿措施进行消除：
  - A. 镜头的指向偏差
  - B. 镜头的光学畸变
  - C. 成像比例尺检测
  - D. 相机与平台运动方向的非正交性
  - E. 拼接误差

- 系统差修正

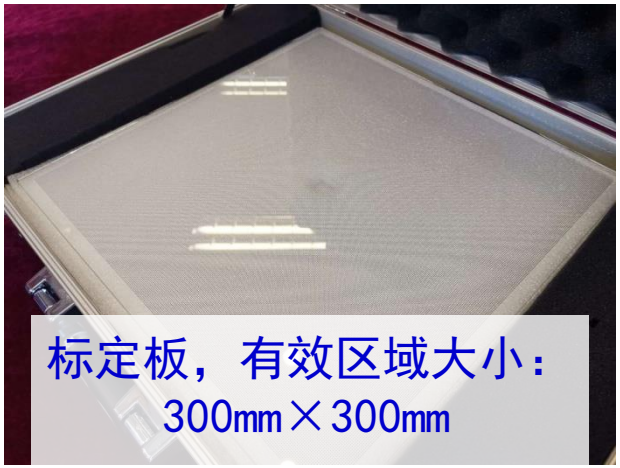
系统差修正后，扫描位置精度优于0.3um

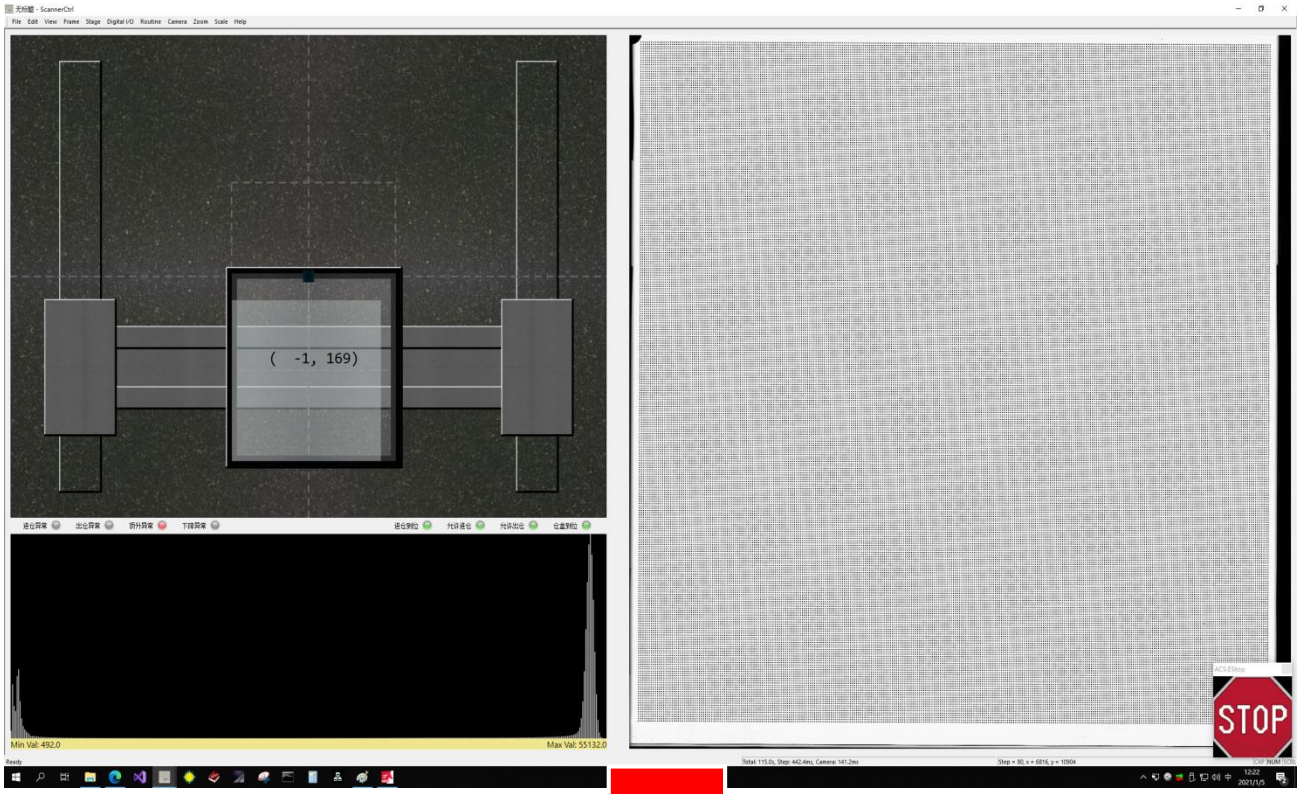


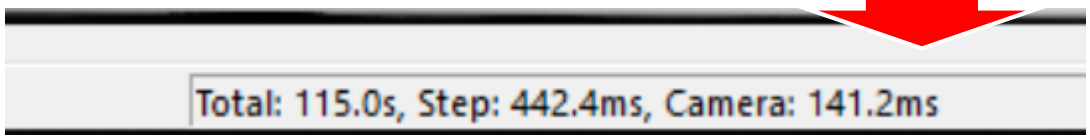


• 基本性能参数——扫描耗时

- 扫描方式：面扫描；
- 单块面扫描的大小：22mm×22mm（取决于sCMOS和镜头放大率）；
- 对于300mm×300mm区域，总计需扫描14×14块，进行拼接，完成全覆盖。

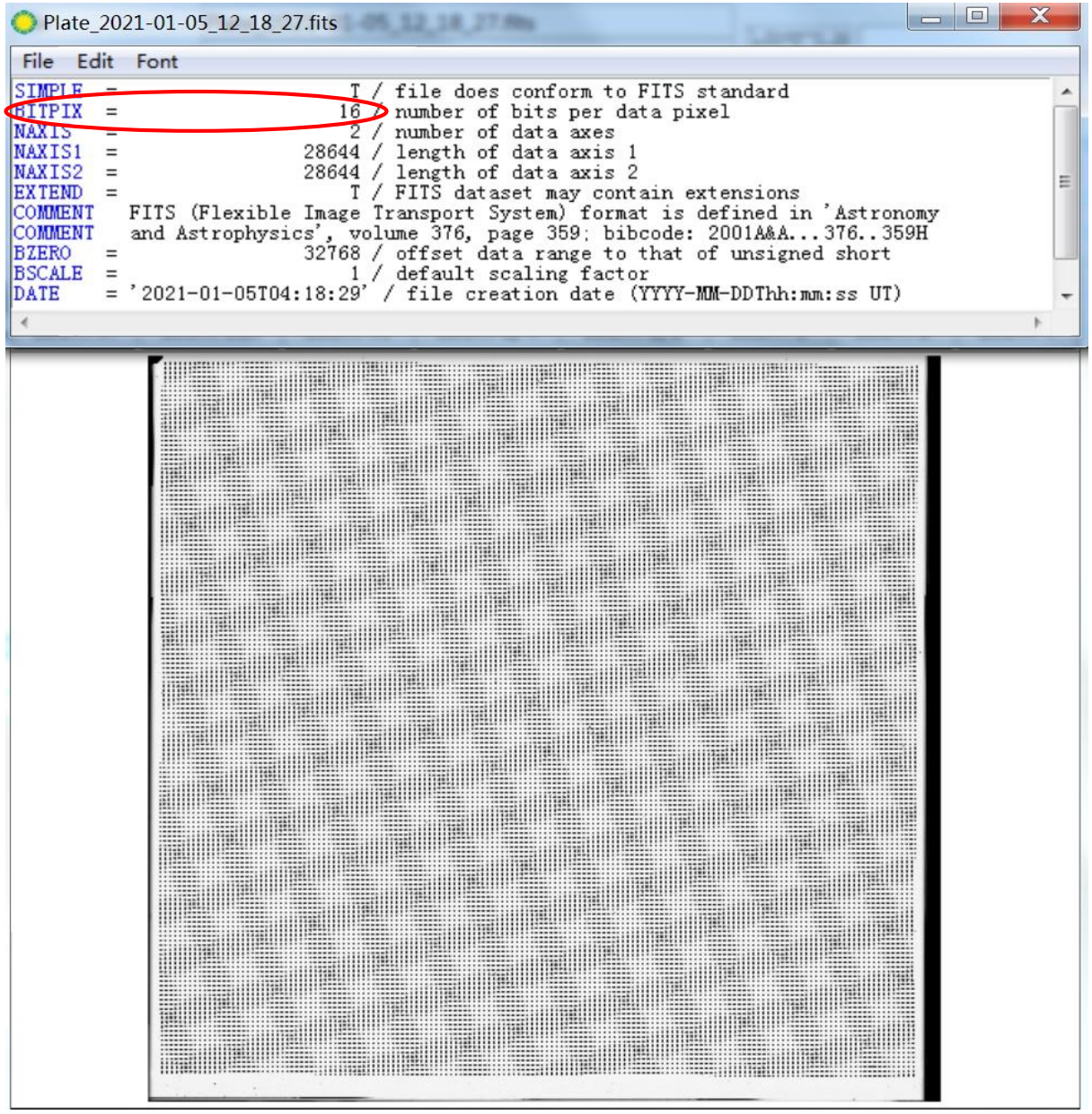






实现300mm×300mm区域的完整扫描，耗时115秒，优于设计指标5分钟。

• 设备基本性能——扫描图像保存形式



对于300mm×300mm的标定板：

- ✓ 图像大小：28644×28644 pixel；
- ✓ 每个像素灰度值用16-bit（2-Byte）保存，整幅图像占1.5GB磁盘空间。

扫描图像保存为16位fits格式

天文底片图像处理

底片处理主要分为三类：

- 单次曝光底片
- 多次曝光底片
- 复杂底片

天文底片图像处理

- **单次曝光底片的计算流程**

（1）使用SExtractor进行目标提取，得到目标信息

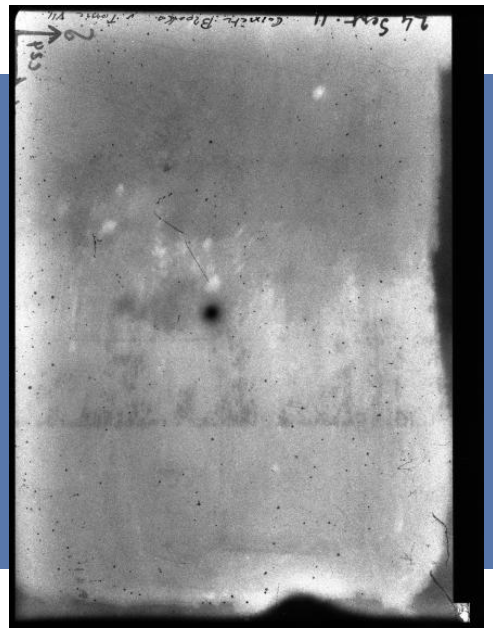
（2）使用Astrometry.net进行星象的初匹配，得到初匹配结果

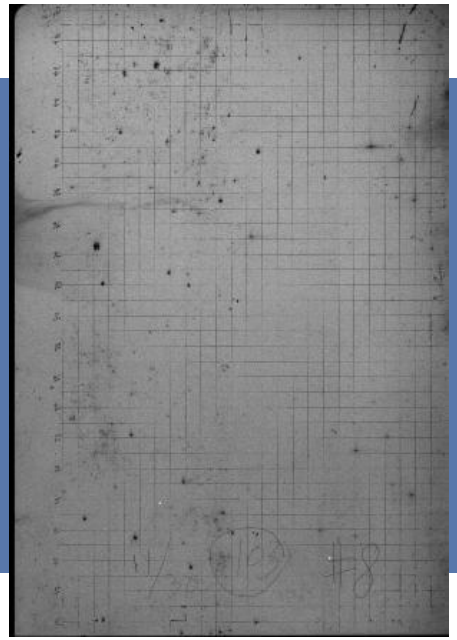
（3）利用上步的初匹配结果结合Gaia DR2星表，进行二次匹配，得到底片参数模型、最终星表以及新的WCS。

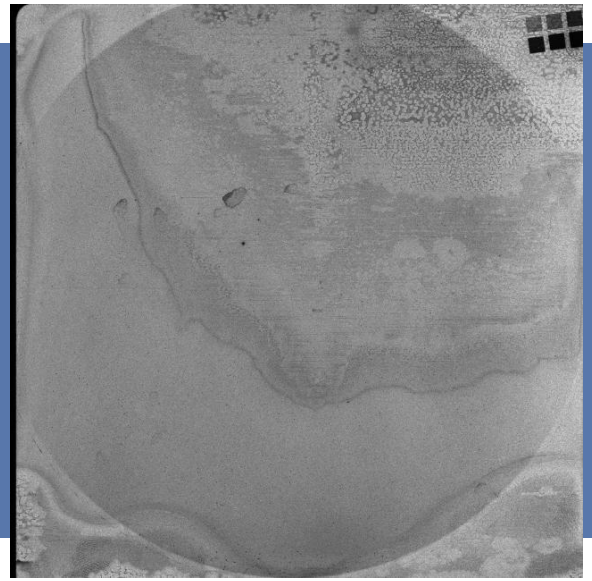
天文底片图像处理

- 存在的难点

  有些底片上的杂点较多，影响了星象匹配工作。这里需要在星象匹配前进行杂点的剔除，提高星象目标在提取到的目标中的比例，来提升匹配成功率。





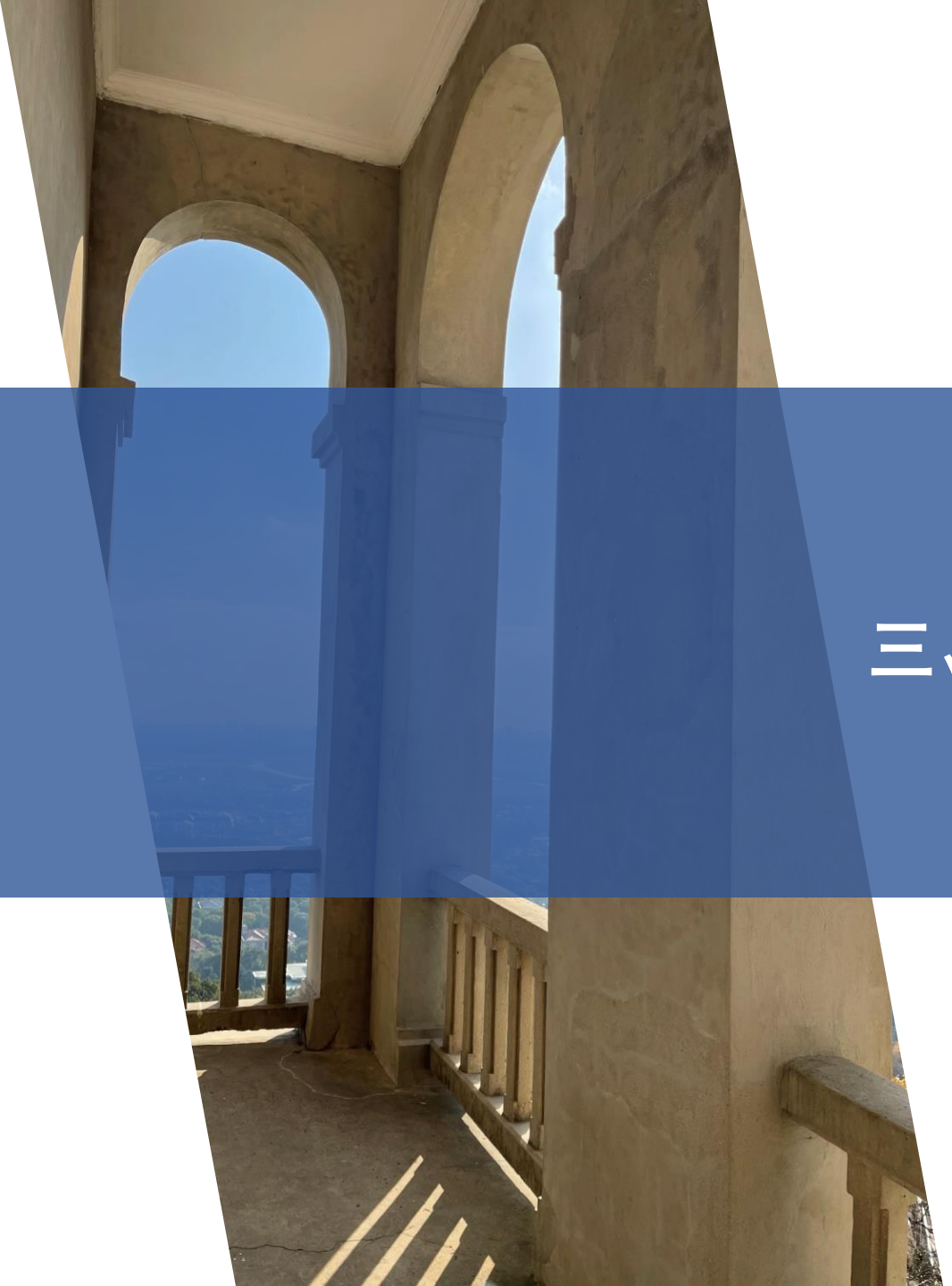


天文底片图像处理

- **两个解决方法：**

（1）通过分析已经成功处理的底片上的星象和杂点，设置某些特征的**阈值筛选目标**，提升匹配成功率，但效果有限，并且不同望远镜的阈值均不同，需要单独设置，不具有通用性。

（2）先后与上海理工大学李菲菲团队、太原理工大学贾鹏团队合作，通过**深度学习的方法**，对提取到的目标中的杂点进行剔除。



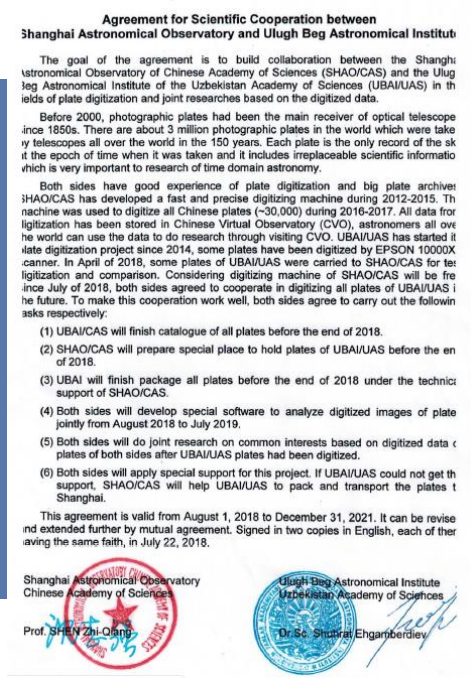
三、底片数字化的拓展

国际天文底片数字化

2019年上海天文台分别与意大利都灵天文台、乌兹别克斯坦兀鲁伯天文研究所签署合作备忘录。

2020年，通过中科院国际合作局，联合乌兹别克斯坦兀鲁伯天文研究所获批“国家重点研发计划－政府间国际合作重点专项” 。

2021年11月，两国底片均先后运抵底片数字化实验室并完成数字化工作。



Agreement for Scientific Cooperation between
Shanghai Astronomical Observatory and Ulugh Beg Astronomical Institut

The goal of the agreement is to build collaboration between the Shangh
Astronomical Observatory of Chinese Academy of Sciences (SHAO/CAS) and the Ulug
Beg Astronomical Institute of the Uzbekistan Academy of Sciences (UBAI/UAS) in th
fields of plate digitization and joint researches based on the digitized data.

Before 2000, photographic plates had been the main receiver of optical telescope
since 1850s. There are about 3 million photographic plates in the world which were take
by telescopes all over the world in the 150 years. Each plate is the only record of the sk
at the epoch of time when it was taken and it includes irreplaceable scientific informatio
which is very important to research of time domain astronomy.

Both sides have good experience of plate digitization and big plate archive
SHAO/CAS has developed a fast and precise digitizing machine during 2012-2015. Th
machine was used to digitize all Chinese plates (~30,000) during 2016-2017. All data fro
digitization has been stored in Chinese Virtual Observatory (CVO), astronomers all ove
the world can use the data to do research through visiting CVO. UBAI/UAS has started it
plate digitization project since 2014, some plates have been digitized by EPSON 10000X
scanner. In April of 2018, some plates of UBAI/UAS were carried to SHAO/CAS for te
digitization and comparison. Considering digitizing machine of SHAO/CAS will be fre
since July of 2018, both sides agreed to cooperate in digitizing all plates of UBAI/UAS i
the future. To make this cooperation work well, both sides agree to carry out the followin
tasks respectively:

(1) UBAI/CAS will finish catalogue of all plates before the end of 2018.

(2) SHAO/CAS will prepare special place to hold plates of UBAI/UAS before the en
of 2018.

(3) UBAI will finish package all plates before the end of 2018 under the technic
support of SHAO/CAS.

(4) Both sides will develop special software to analyze digitized images of plate
jointly from August 2018 to July 2019.

(5) Both sides will do joint research on common interests based on digitized data
plates of both sides after UBAI/UAS plates had been digitized.

(6) Both sides will apply special support for this project. If UBAI/UAS could not get th
support, SHAO/CAS will help UBAI/UAS to pack and transport the plates
Shanghai.

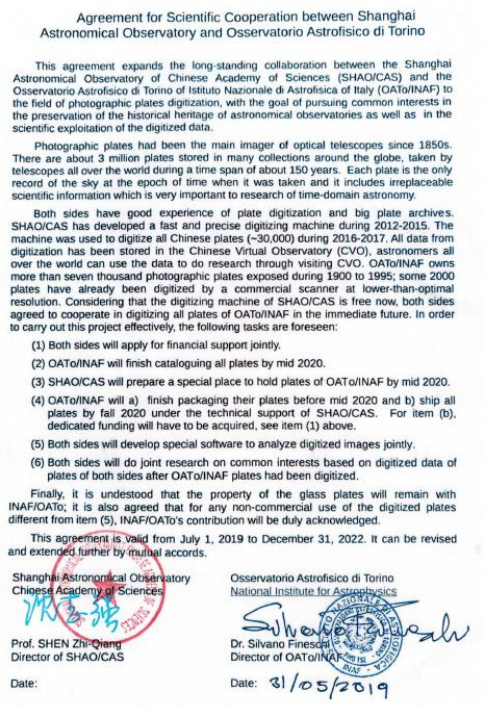
This agreement is valid from August 1, 2018 to December 31, 2021. It can be revise
and extended further by mutual agreement. Signed in two copies in English, each of ther
having the same faith, in July 22, 2018.

Shanghai Astronomical Observatory
Chinese Academy of Sciences

Prof. SHEN Zhi-Qiang

Ulugh Beg Astronomical Institute
Uzbekistan Academy of Sciences

Dr. Sc. Shuhrat Ehgamberdiev



Agreement for Scientific Cooperation between Shanghai
Astronomical Observatory and Osservatorio Astrofisico di Torino

This agreement expands the long-standing collaboration between the Shanghai Astronomical Observatory of Chinese Academy of Sciences (SHAO/CAS) and the Osservatorio Astrofisico di Torino of Istituto Nazionale di Astrofisica of Italy (OATo/INAF) to the field of photographic plates digitization, with the goal of pursuing common interests in the preservation of the historical heritage of astronomical observatories as well as in the scientific exploitation of the digitized data.

Photographic plates had been the main imager of optical telescopes since 1850s. There are about 3 million plates stored in many collections around the globe, taken by telescopes all over the world during a time span of about 150 years. Each plate is the only record of the sky at the epoch of time when it was taken and it includes irreplaceable scientific information which is very important to research of time-domain astronomy.

Both sides have good experience of plate digitization and big plate archives. SHAO/CAS has developed a fast and precise digitizing machine during 2012-2015. The machine was used to digitize all Chinese plates (~30,000) during 2016-2017. All data from digitization has been stored in the Chinese Virtual Observatory (CVO), astronomers all over the world can use the data to do research through visiting CVO. OATo/INAF owns more than seven thousand photographic plates exposed during 1900 to 1995; some 2000 plates have already been digitized by a commercial scanner at lower-than-optimal resolution. Considering that the digitizing machine of SHAO/CAS is free now, both sides agreed to cooperate in digitizing all plates of OATo/INAF in the immediate future. In order to carry out this project effectively, the following tasks are foreseen:

(1) Both sides will apply for financial support jointly.

(2) OATo/INAF will finish cataloguing all plates by mid 2020.

(3) SHAO/CAS will prepare a special place to hold plates of OATo/INAF by mid 2020.

(4) OATo/INAF will a) finish packaging their plates before mid 2020 and b) ship all plates by fall 2020 under the technical support of SHAO/CAS. For item (b), dedicated funding will have to be acquired, see item (1) above.

(5) Both sides will develop special software to analyze digitized images jointly.

(6) Both sides will do joint research on common interests based on digitized data of plates of both sides after OATo/INAF plates had been digitized.

Finally, it is undestood that the property of the glass plates will remain with INAF/OATo; it is also agreed that for any non-commercial use of the digitized plates different from item (5), INAF/OATo's contribution will be duly acknowledged.

This agreement is valid from July 1, 2019 to December 31, 2022. It can be revised and extended further by mutual accords.

Shanghai Astronomical Observatory
Chinese Academy of Sciences

Prof. SHEN Zhi-Qiang
Director of SHAO/CAS

Date:

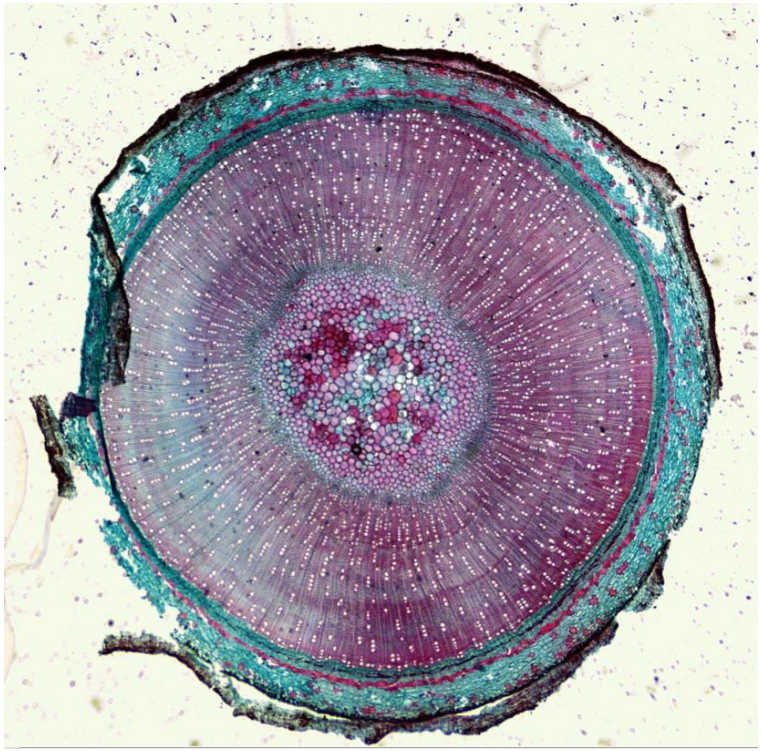
Osservatorio Astrofisico di Torino
National Institute for Astrophysics

Dr. Silvano Fineschi
Director of OATo/INAF

Date: 31/05/2019

国内底片数字化的技术转移

2021年6月，受上海自然博物馆委托，扫描显微镜标本玻片和动植物彩色胶片，为其数字化博物馆提供基础数据。



古生物玻片扫描样本

植物胶卷扫描样本

四、底片数字化的成果评估

底片数字化成果评估

- ✓在中科院“十三五”时期院属“一三五”规划任务书验收中评为优秀代表性科技成果；
- ✓“国际天文数字底片研究计划”列入《上海市建设具有全球影响力的科技创新中心“十四五”规划》。

上海市建设具有全球影响力的科技创新中心“十四五”规划

发布日期：2021-09-29

加快建设具有全球影响力的科技创新中心，是以习近平同志为核心的党中央赋予上海的重大任务和战略使命，是上海加快推动经济社会高质量发展、提升城市能级和核心竞争力的关键驱动力，是我国建设世界科技强国的重要支撑。根据《上海市推进科技创新中心建设条例》《中共上海市委、上海市人民政府关于加快建设具有全球影响力的科技创新中心的意见》《上海市国民经济和社会发展第十四个五年规划和二〇三五年远景目标纲要》，为进一步加快推进上海向具有全球影响力的科技创新中心进军，制定本规划。

3、大科学计划和大科学工程

加快推进上海在国际上参与和发起大科学计划和大科学工程，打造创新开放合作平台，提升战略前沿领域国际影响力。重点方向：（1）牵头发起“全脑介观神经联接图谱”大科学计划，加快筹备国际人类表型组等新一批大科学计划，加快推进平方公里阵列射电望远镜（SKA）等大科学工程，继续支持参与国际大洋发现计划（IODP）、国际天文数字底片研究计划。（2）实施国际科技合作伙伴项目，培育和提升有条件的科研单位参与或发起大科学计划和大科学工程的能力。


所级公共技术服务中心
天体物理实验、仿真及大数据
应用服务部
天文底片数字化平台

谢谢

中国科学院上海天文台
底片数字化项目组
联系人:杨美婷
ymt@shao.ac.cn