极大光谱巡天望远镜

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On behalf of

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ASIAA 2023

Taipei, Nov 20 2023

大规模光谱巡天
——天文学前沿的科学需求

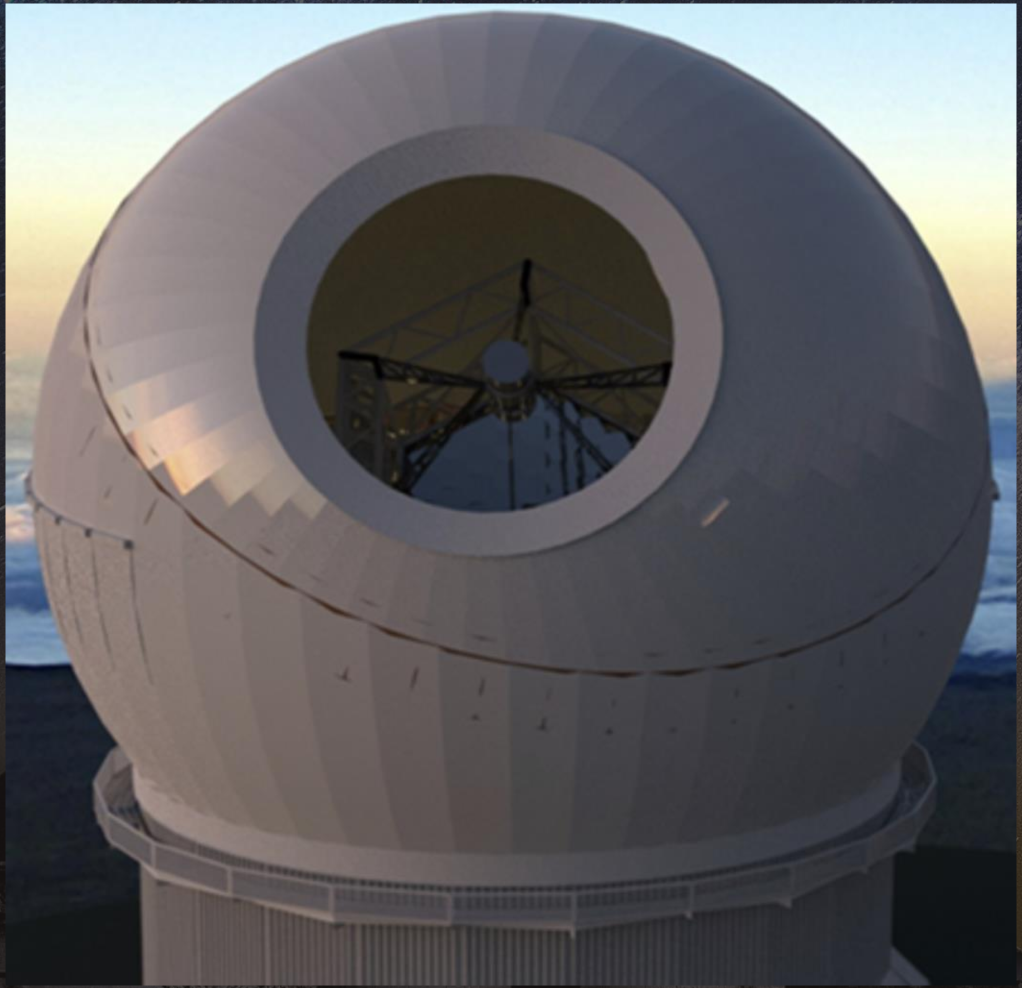
- 天体的光谱包含着丰富的物理信息，通过成像巡天记录了数百亿个天体，但观测光谱只有一万多个。
- 通过大规模光谱巡天，几千条光谱可以同时观测到
- 研制同时具备大口径和大视场的望远镜具有必要性。

新一代10米级光谱巡天

A **general-purpose, wide-field, high multiplex spectroscopic facility**, for a telescope of the 8-10m class. Such a facility will enable a broad range of science investigations and help capitalise on other large investments by providing follow-up capabilities for facilities such as JWST, VRO and Euclid.

www.astronet-eu.org

新一代10米级光谱巡天



THE MAUNAKEA SPECTROSCOPIC EXPLORER

The Maunakea Spectroscopic Explorer is an 11.25m aperture telescope that will lead the world in multi-object spectroscopy, with its unique capability to study up to 4,000 astronomical objects at once.

https://mse.cfht.hawaii.edu/

01 中国光谱巡天望远镜的研制情况

02 棱镜条大气色散改正镜 (S-ADC)

03 极 大 光谱巡天望远镜和coudé系统的光学设计实例

01 中国光谱巡天望远镜的研制情况介绍

世界主要光谱巡天项目

(LAMOST with highest Etendue)

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

Main projects:

SDSS
2dF
LAMOST
DESI
PFS
4MOST
WHT

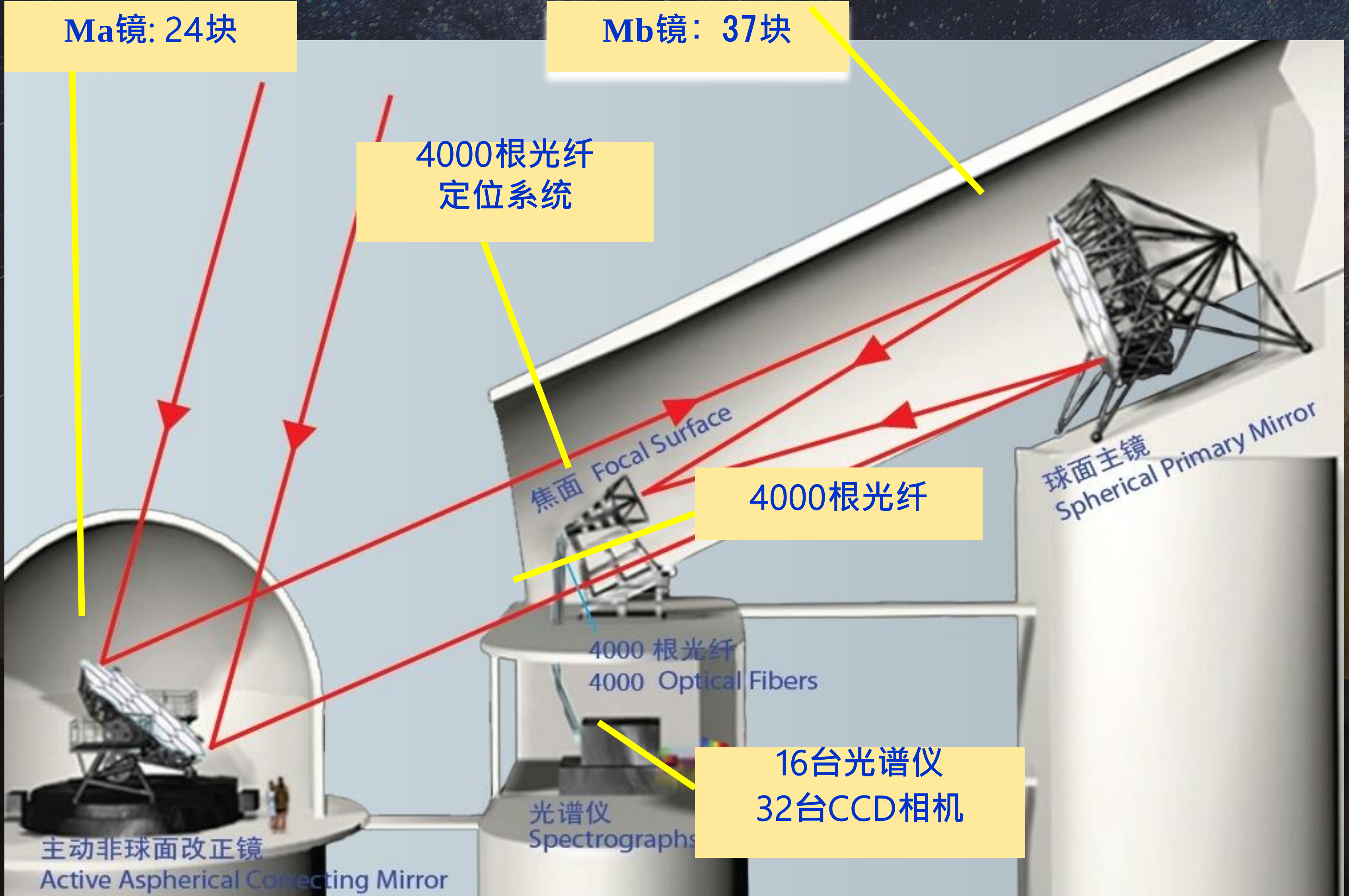
巡天能力
Etendue (AΩ)=
望远镜有效通光面积×观测视场面积

中国光谱巡天技术积累

国家大科学装置 **LAMOST (Guo Shoujing telescope)**

2008 完成
2009 验收
2012 正式巡天

LAMOST- 独特的光学望远镜 - Schmidt 系统的理论拓展

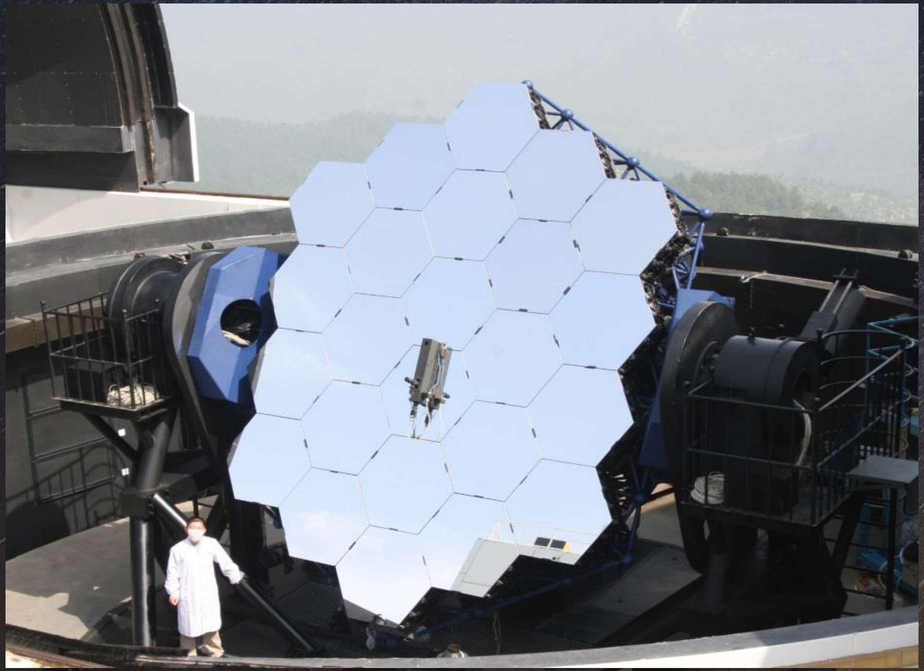


Wang- Su主动反射 Schmidt 系统

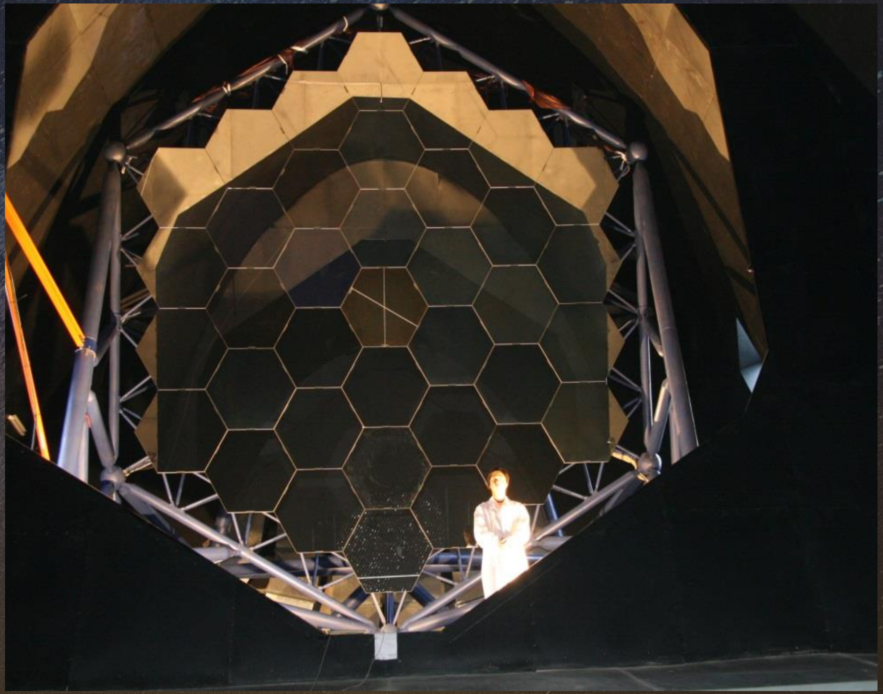
主动变形思想的另一处应用
—FAST

大视场
大口径
最大焦面

拼接变形的主动反射镜-主动光学技术拓展



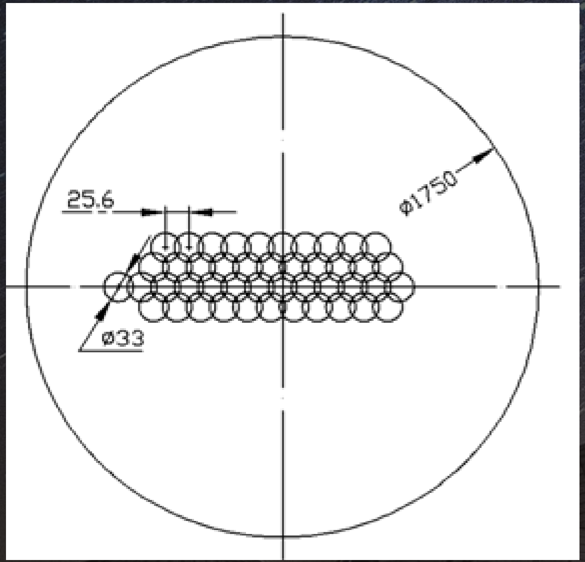
主动反射镜 Ma: 5.72M ×4.4M

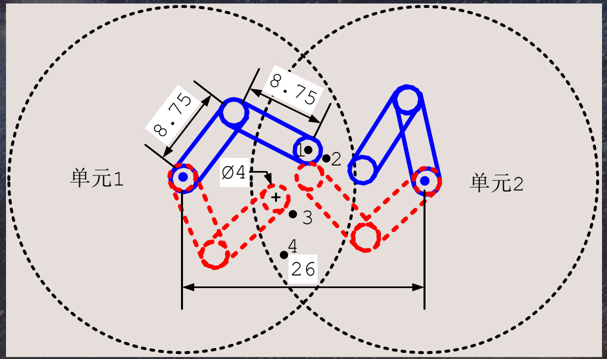


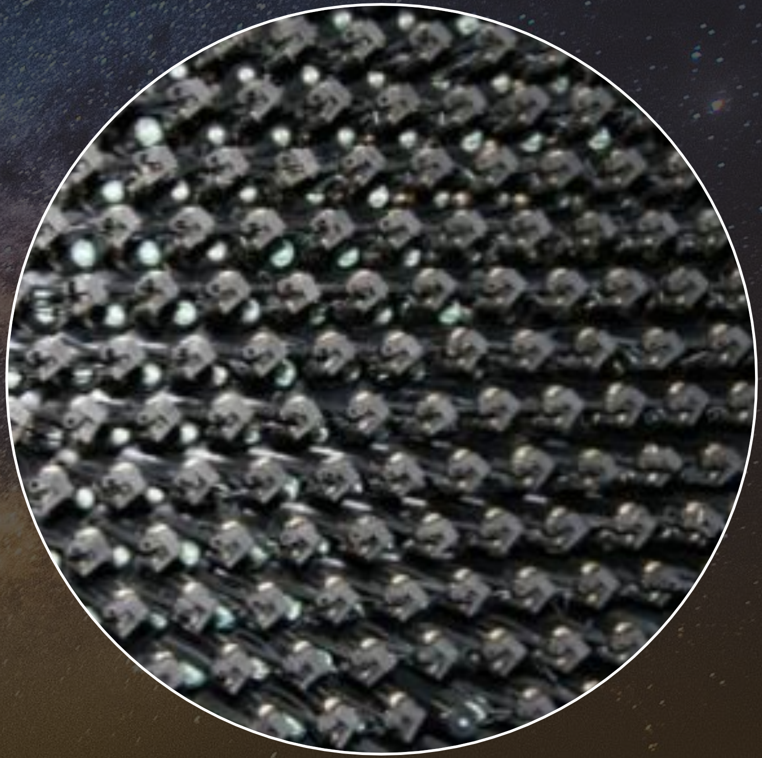
球面镜Mb: 6.67M×6.05M

克服挑战，掌握并拓展了主动光学和望远镜技术

革命性的光纤定位系统——大规模光纤定位实现







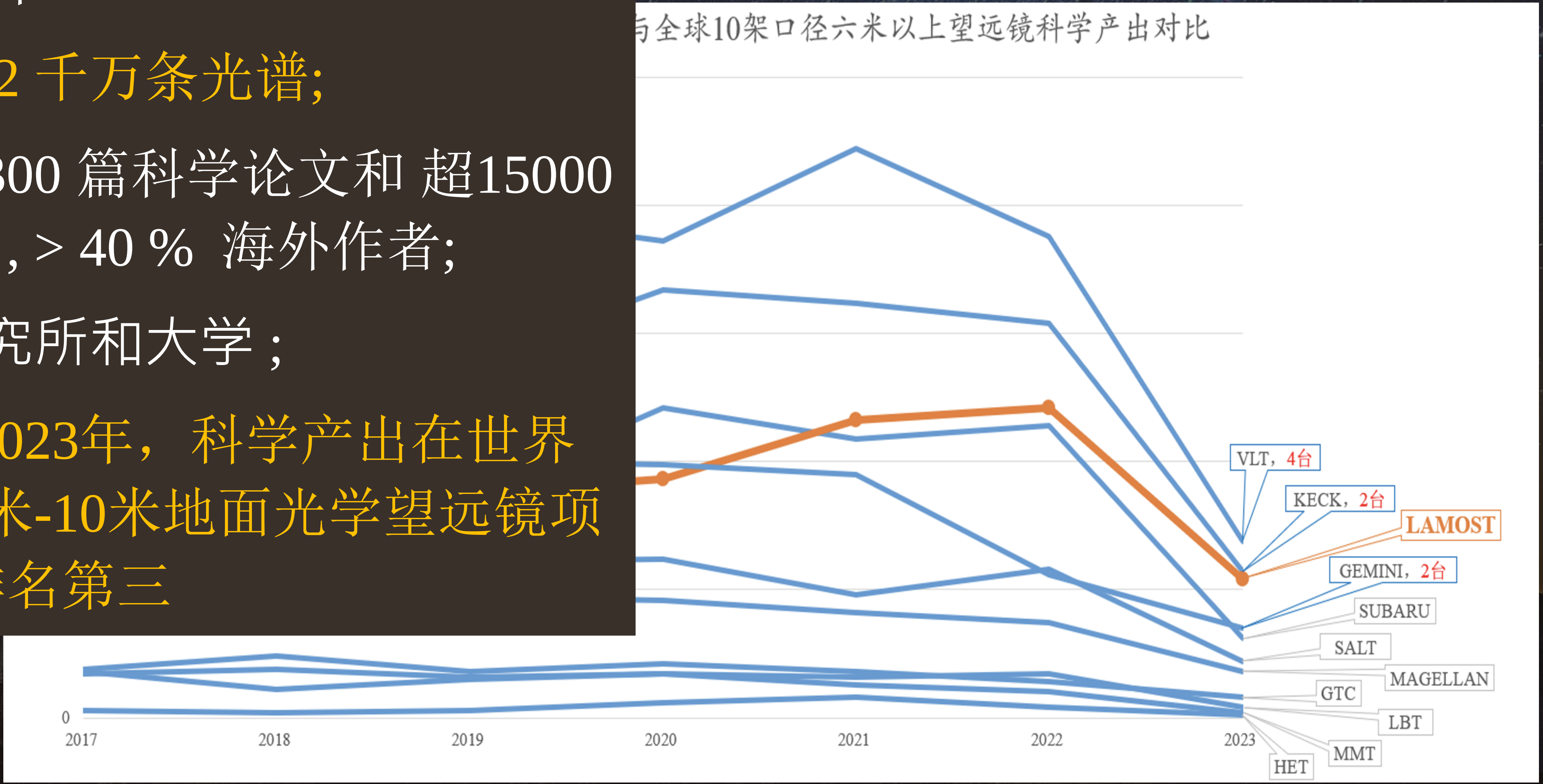
数千根光纤的快速高精度定位技术

在国内外广泛使用

LAMOST科学产出

截至2023年

- ✓ 超过2.2 千万条光谱;
- ✓ 超过1300 篇科学论文和 超15000次引用, > 40 % 海外作者;
- ✓ 190研究所和大学 ;
- ✓ 2017-2023年，科学产出在世界十大6米-10米地面光学望远镜项目中排名第三

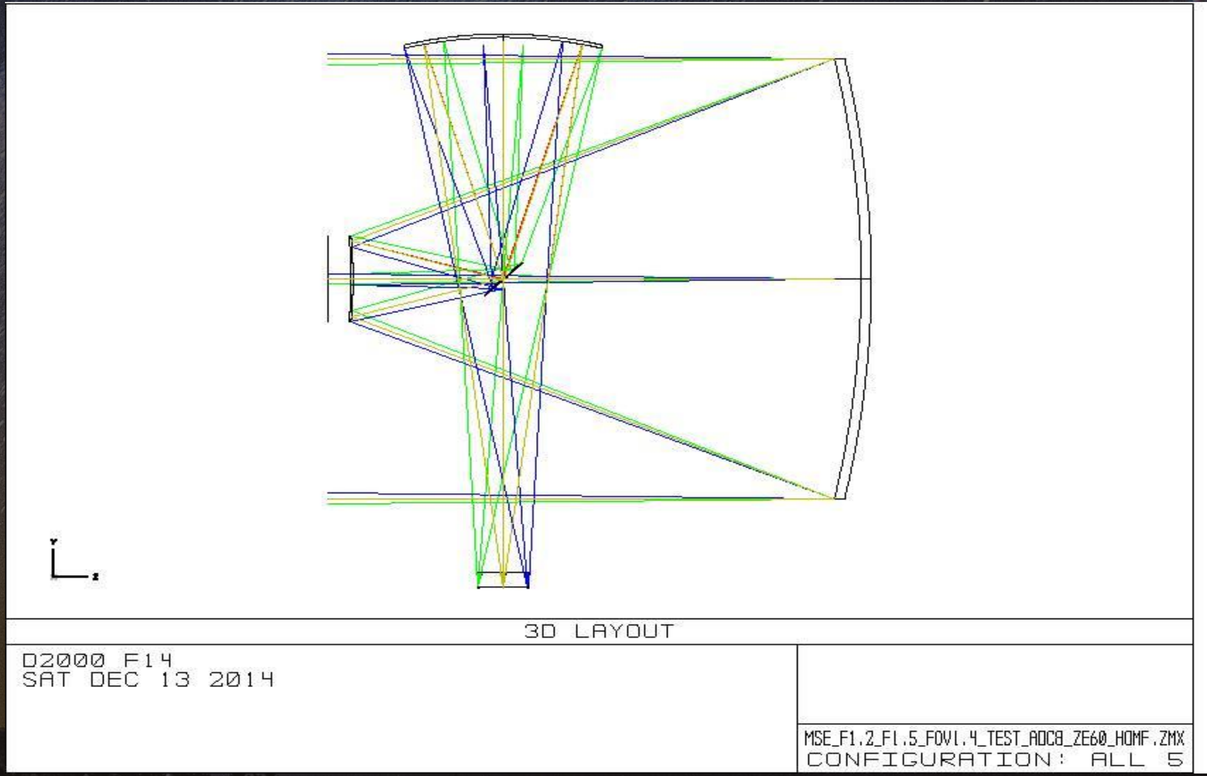


2015年 MSE 光学系统候选之一

2015 Hua Bai et al., 2015

- 2015年设计第一个四镜全反射系统及其相应的S-ADC型大气色散改正镜

（On April 11, 2015 E-mail to Rick Murowinski, the Project manager of MSE. ）

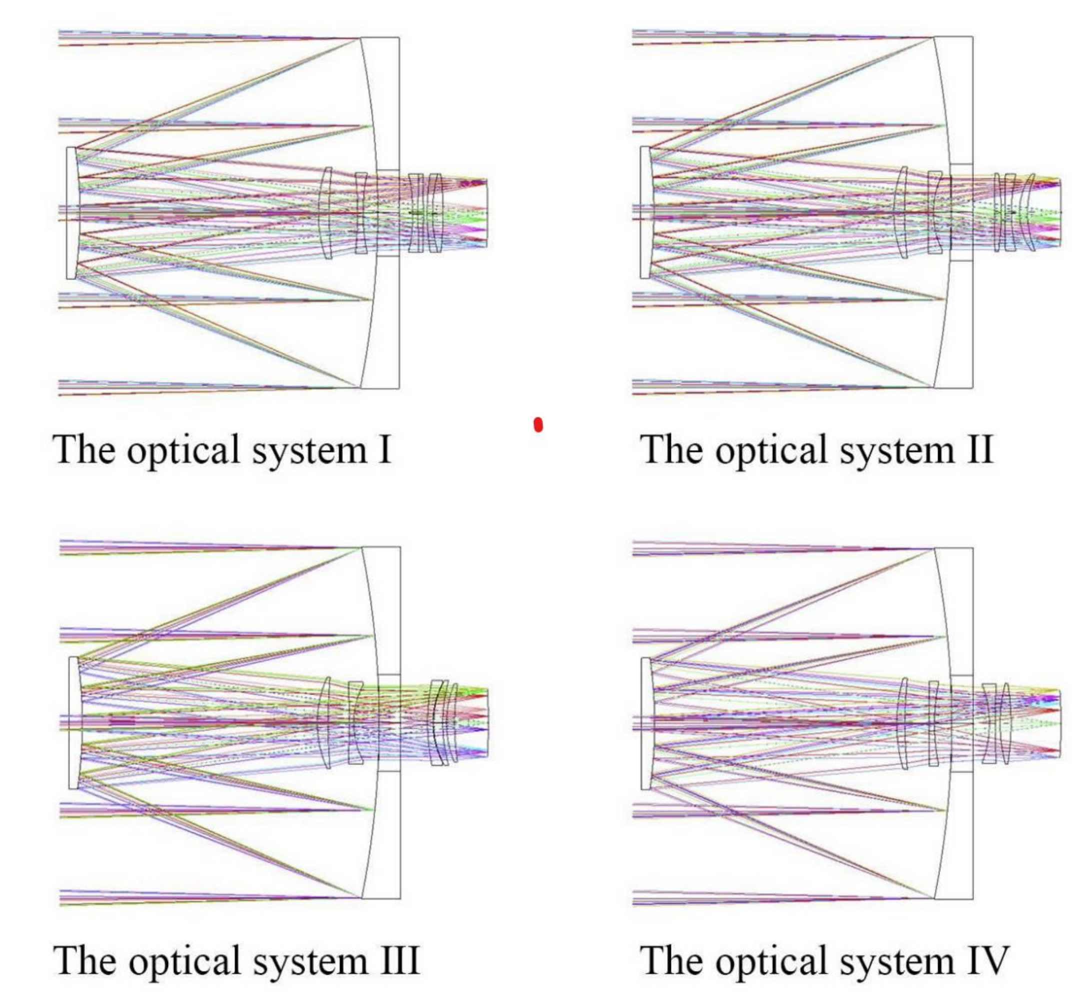


6.5米光谱巡天望远镜

（Bai et al. , RAA, 2021）

2020年，设计了四台带有四种改正器的卡塞格伦望远镜

- ✓ 主镜口径 6.5 m
- ✓ 视场： 3°
- ✓ 观测波长：0.365–1.1μm
- ✓ 最大观测天顶距：60°
- ✓ 焦比：~ 3.7 , 最大改正镜口径 ≤ 1.66 m
- ✓ 改正镜片数：4-5片
- ✓ 成像质量 EE80D≤0.60 arcsec



在光谱望远镜方面的更多工作

- 苏定强提出透棱镜改正镜 lensm (lens-prism) (Su 1986， Su & Liang 1986)该种透棱镜使用于 WHT（Ag´ocs et al. 2010) 和4-MOST (Azais et al. 2016).
- 刘根荣和袁祥岩针对LAMOST提出了几种用于光纤头的小型色散棱镜, (Liu G.& Yuan X., 2005).
- 梁明针对DESI提出单透棱镜ADC，并得到应用 (Doel, Sholl & Liang et al. 2014).
- 梁明为12米LOT望远镜设计了主焦改正器(Su, Liang, Yuan, Bai & Cui 2016).

两种构型的四镜耐焦系统

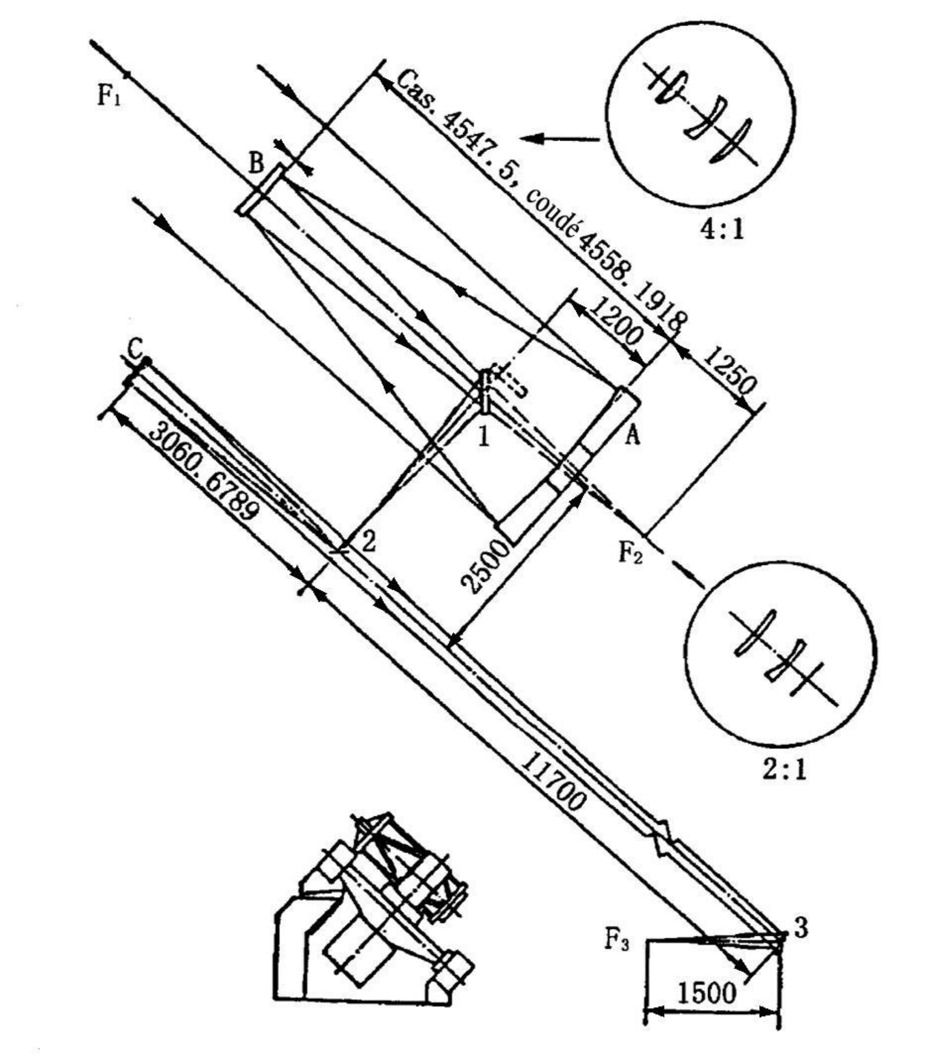
NIAOT concept I
NIAOT concept II

设计思想起源和发展

创新点

- 两个或三个焦点可以共用同一个副镜
- 由于全反射和良好的图像质量，可以用于更宽的波段和更大的视场
- 无论两个非平面镜R-C系统是否预先确定
- 可以使用两个耐式平台，并且更容易切换

SYZ 中继镜创新地用于中国 2.16m 望远镜（1972年）

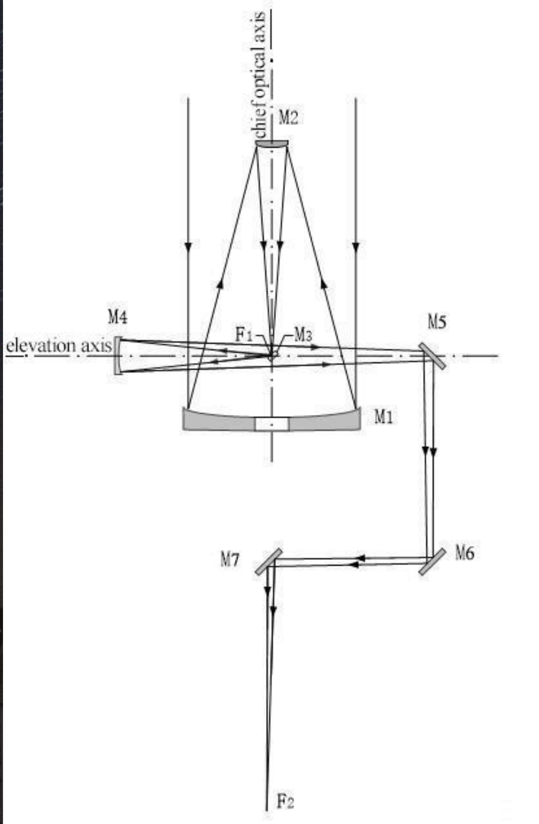


- 1972年7月，苏定强为中国2.16米望远镜设计了中继镜（由A.B.Meinel教授命名为SYZ中继镜）。

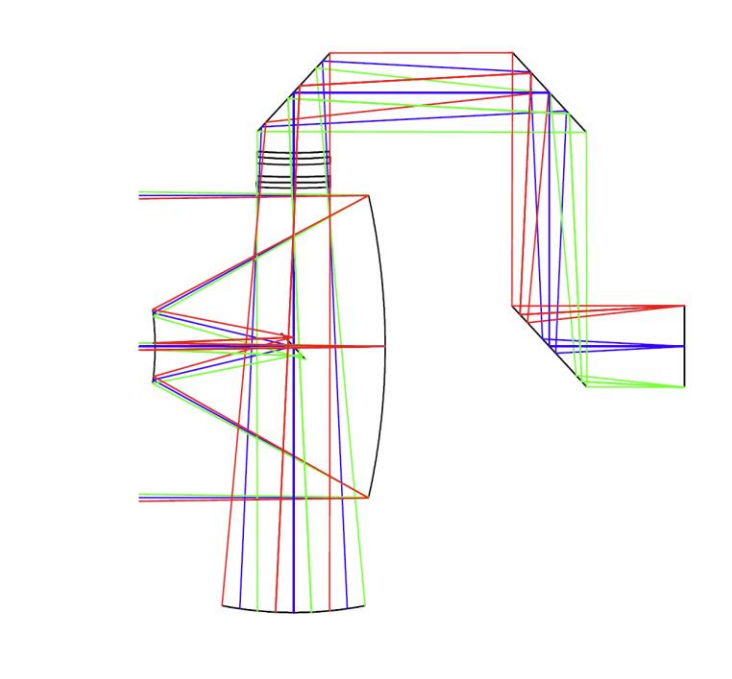
<u>两个优点：</u>

- 卡塞格伦（R-C）和库德系统共用一个副镜，
- 有3个非平面镜，可以获得良好的成像质量

南极昆仑暗宇宙探测望远镜（KDUST）和中国2米空间望远镜的备选光学系统



(Yuan et al. IAU Symposium 288, 2012)
(Su & Cui, RAA, 2014)



The alt-azimuth mounting with a SYZ relay mirror shared secondary mirror two systems or a complete **Coudé system or Nasmyth system**

用于卡塞格伦系统的带有SYZ中继镜的Meinel排布

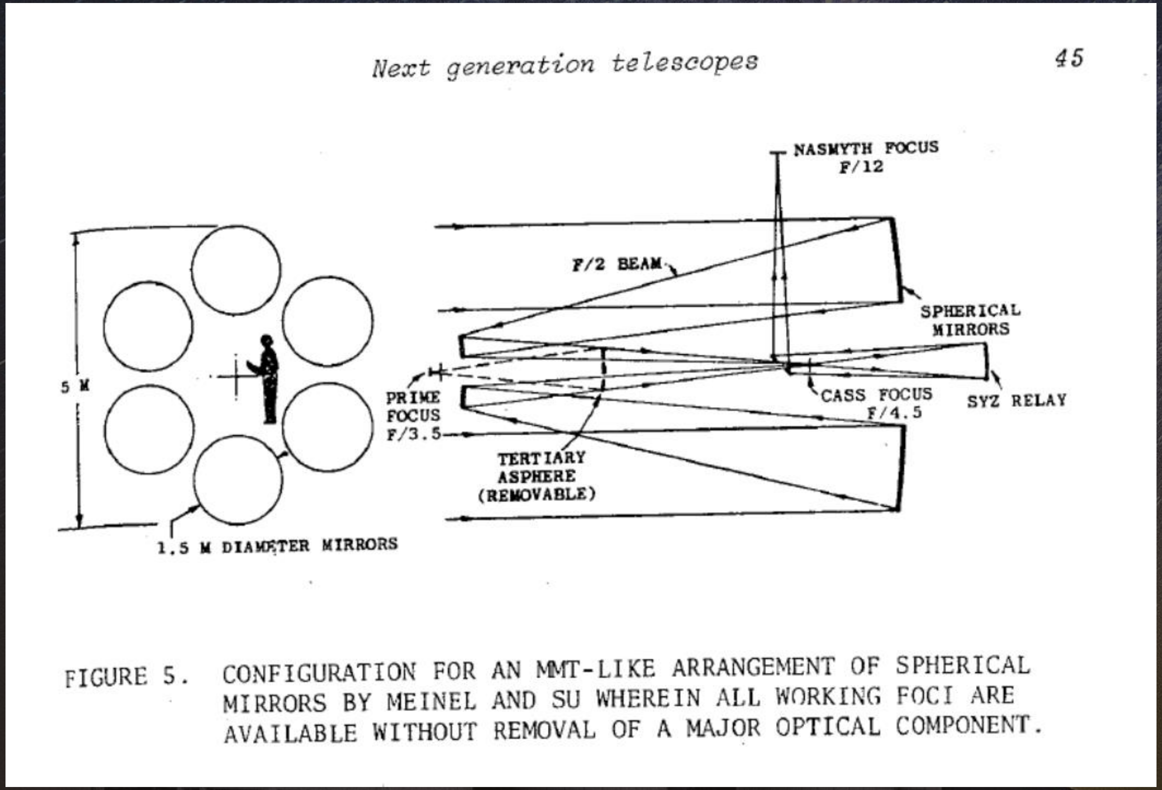

Next generation telescopes 45

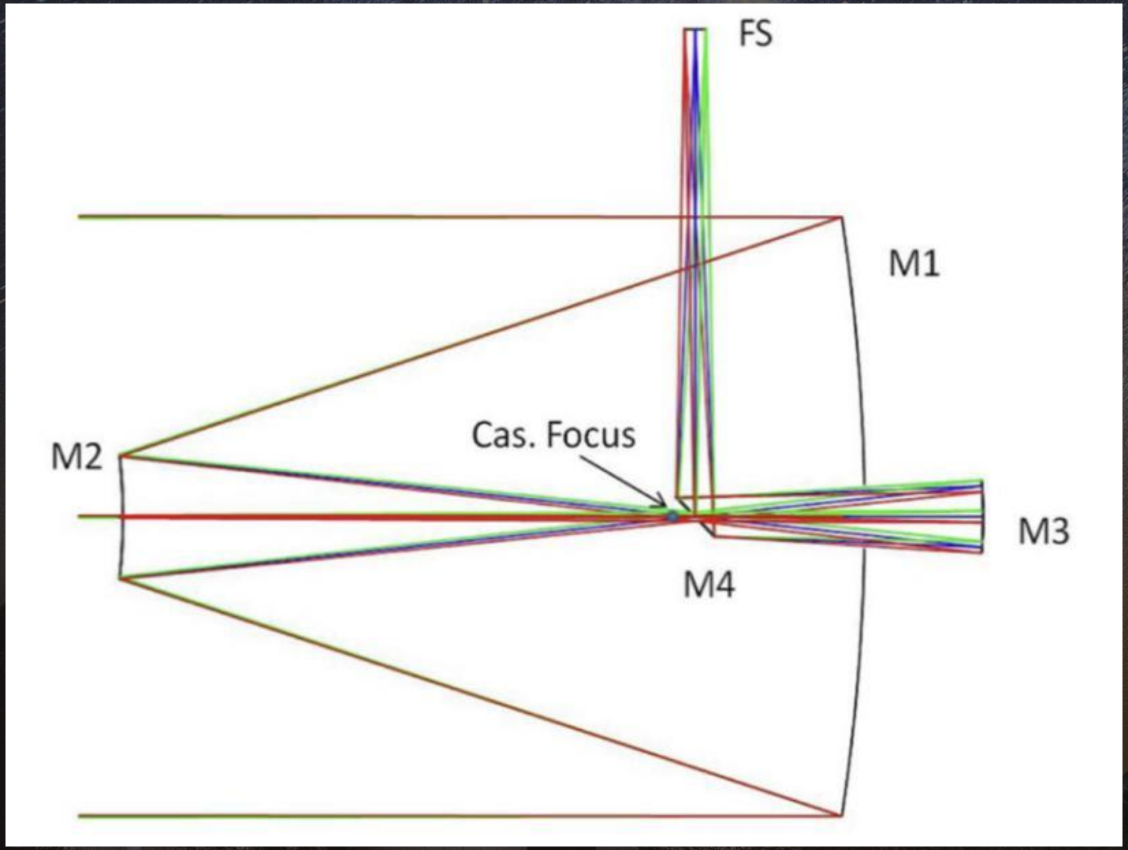
FIGURE 5. CONFIGURATION FOR AN MMT-LIKE ARRANGEMENT OF SPHERICAL MIRRORS BY MEINEL AND SU WHEREIN ALL WORKING FOCI ARE AVAILABLE WITHOUT REMOVAL OF A MAJOR OPTICAL COMPONENT.

- SYZ 中继镜位于主光轴上主镜后方
- 45° 平面镜中孔使得卡塞格伦系统的光从副镜到达SYZ中继镜
- 由45° 平面镜将光束引导到耐氏平台的两侧焦点之

(A.B. Meinel and M.P. Meinel, Fig 5, **Current Trends in Optics, 1981)**

Su-Meinels four-mirror system

中国大光学望远镜 - 12m LOT

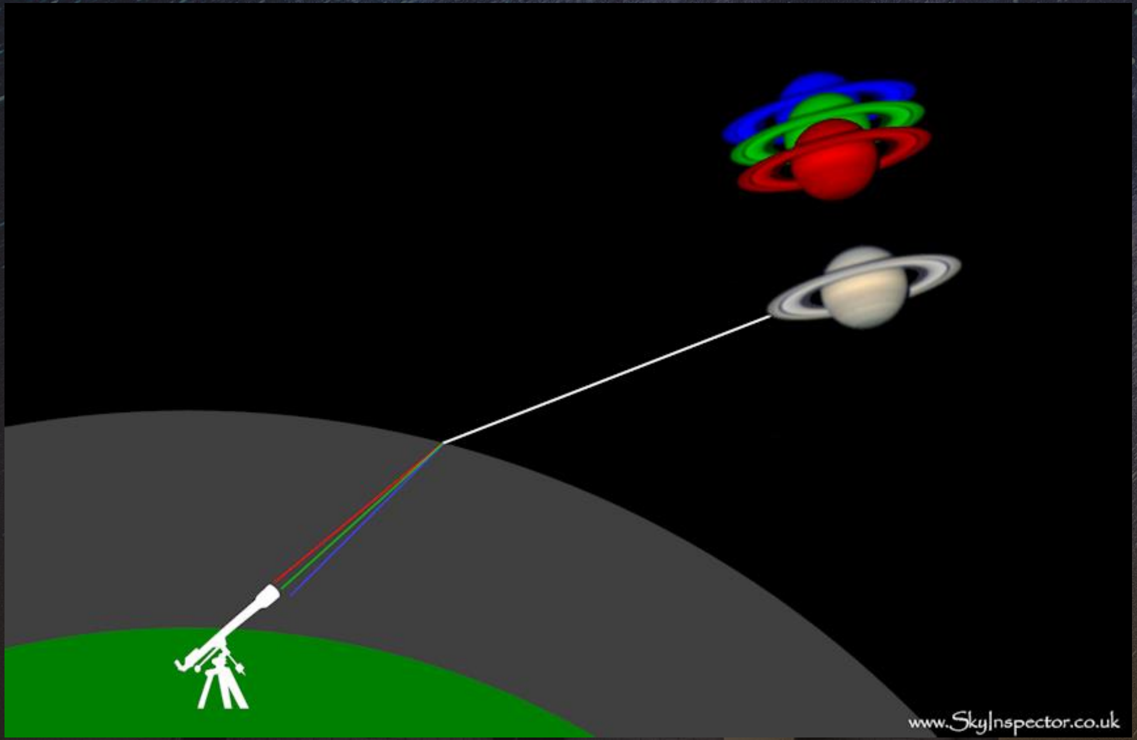


Su et al. , MNRAS, 2016, 2017, Cui et al., SPIE, 2018

The Nasmyth system of 12-m telescope (F/12.8):
M1: primary mirror;
M2: secondary mirror;
M3: SYZ relay mirror;
M4: plane fold mirror.

02

棱镜条大气色散镜 (Strips-ADC)



- 对于地基可见光、近红外和近紫外观测，需要通过大气色散改正器（ADC）对大气色散进行校正
- 大型和超大型望远镜的常规ADC需要大口径高质量光学玻璃透镜，但该种玻璃材料难以获得

基于LAMOST-South望远镜的研究和创新

(Su, Jia, & Liu , MNRAS, 2011)

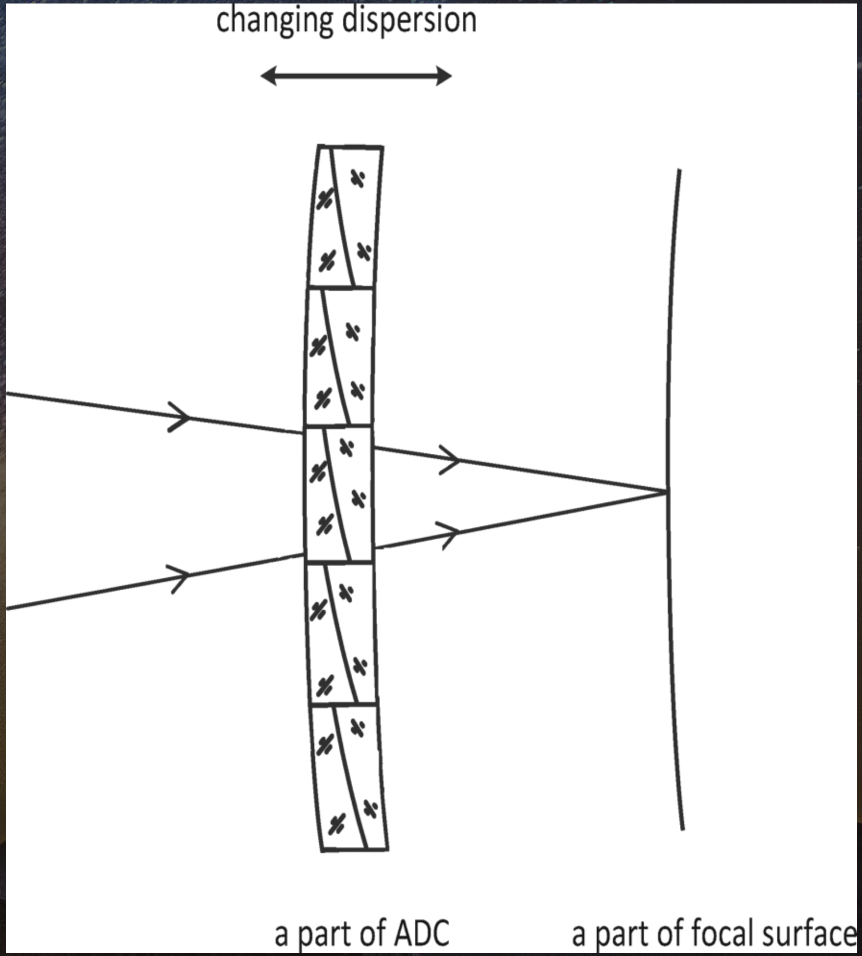
- 2011年，苏定强等人提出了创新的条形大气色散校正器（S-ADC）
- 成像质量优秀
- 解决了大口径ADC透镜材料的尺寸限制
- 这项创新成为超大光谱巡天望远镜的关键组成部分。

S-ADC特征和构成

✓由许多透棱镜组成

✓所有表面均为球面

✓通过沿着光轴移动这样的改正器，可以产生不同的色散，从而补偿不同天顶距离处的大气色散。



S-ADC 优点

- S-ADC引入的像差很小
- 成本低，特别对于极大望远镜具有优势
- 如透棱镜胶合，则只有一个玻璃表面产生鬼像，可以用于极大的光谱巡天望远镜

天顶距： 60°

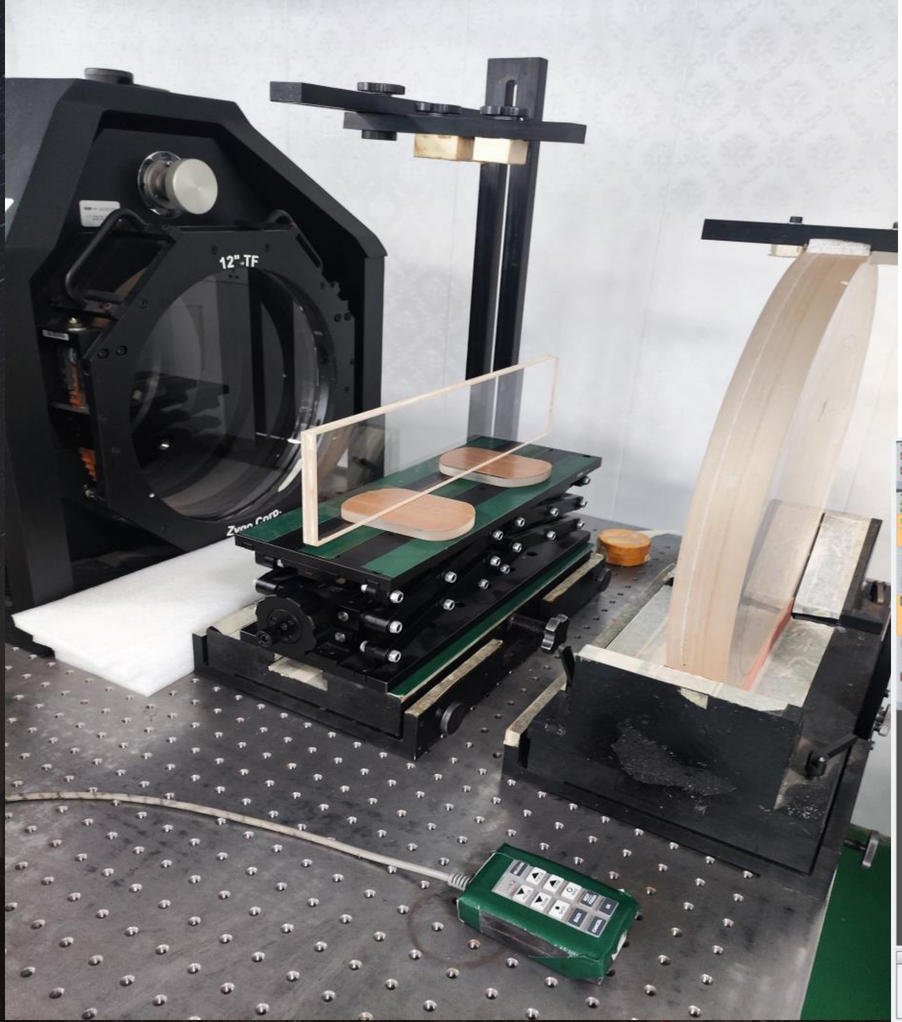
光学波段： 0.36–1.8μm

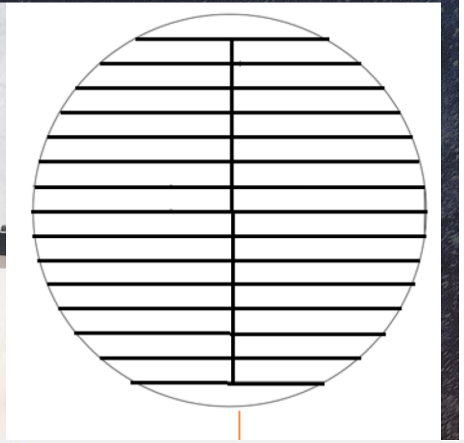
台址高度： 4200 m

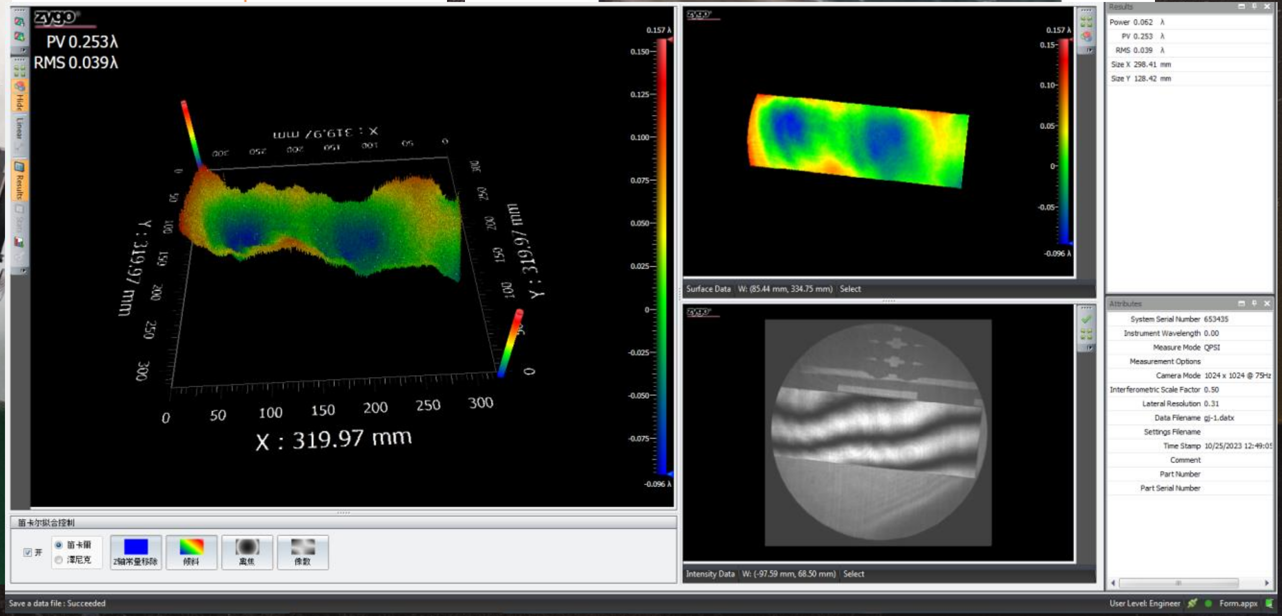
大气色散： 2.8″

大气色散校正后残差： 0.23″

推进中的S-ADC研制


12"-TF



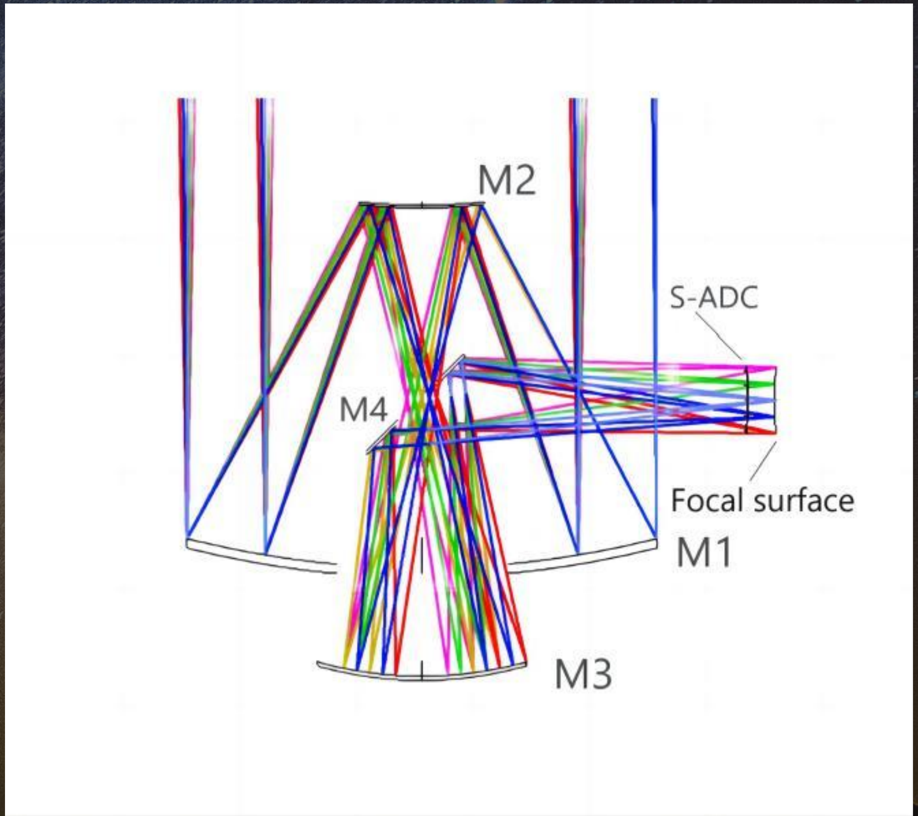

PV 0.253λ
RMS 0.039λ
X : 319.97 mm
Y : 319.97 mm
Save a data file : Succeeded

03

极大光谱巡天望远镜及coudé系统的光学设计实例

NIAOT concept I

- 全反射系统
- SYZ中继镜（M3）和平面镜M4用于对中间卡塞格伦焦点成像，并将光引导到Nasmist焦点
- 出射光瞳刚好位于M4附近。
- 在Nasmist平台的一侧，使用S-ADC，可以进行多目标光纤光谱观测

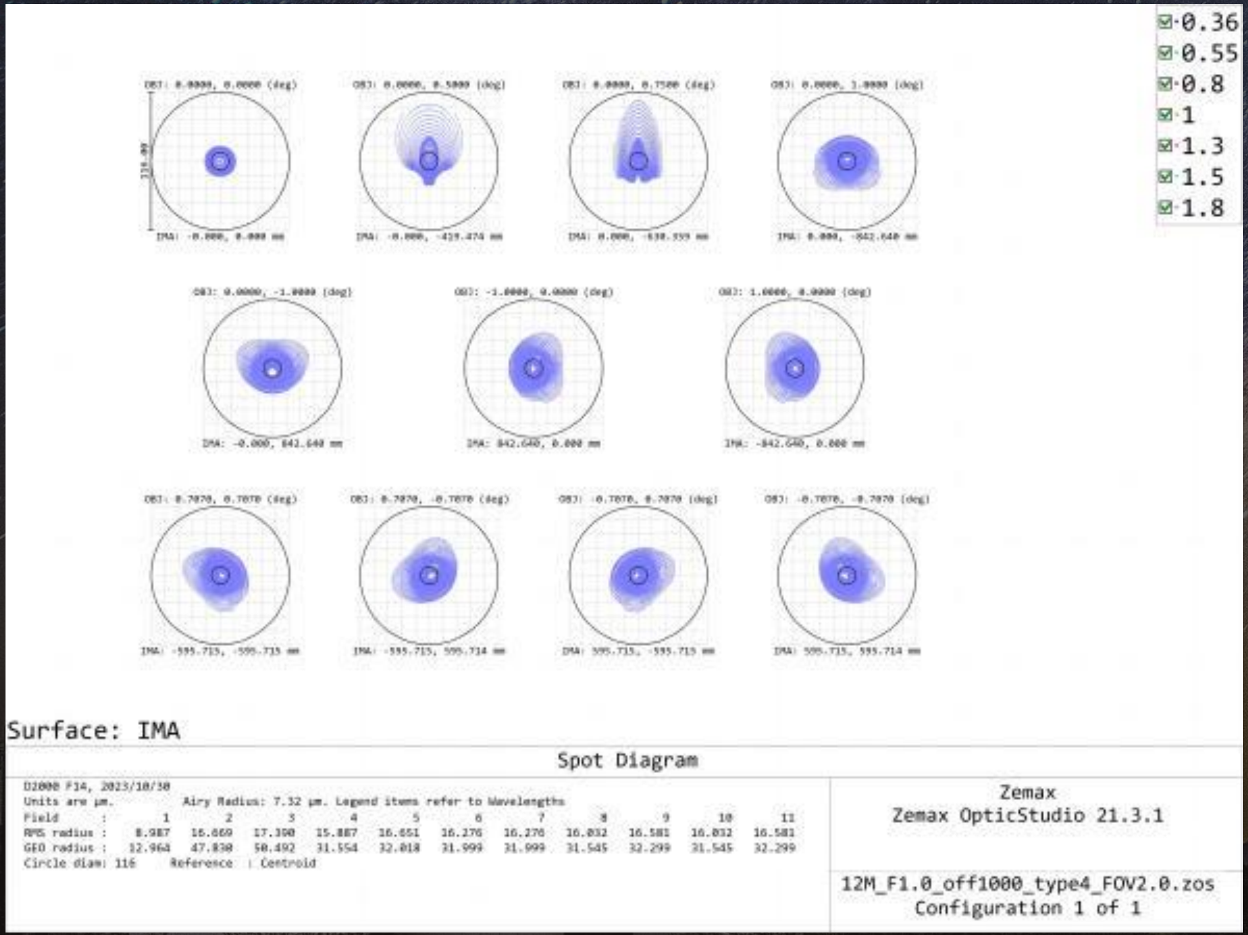


Su-Meinels four-mirror system

主光学参数

- 口径: 12 m (拼接)
- 焦比: F/4.0
- 视场: Φ 2°
- 焦面直径: 1.7m
- 观测波长: 360-1800 nm
- 观测最大天顶距：60°
- 约 20000 根光纤

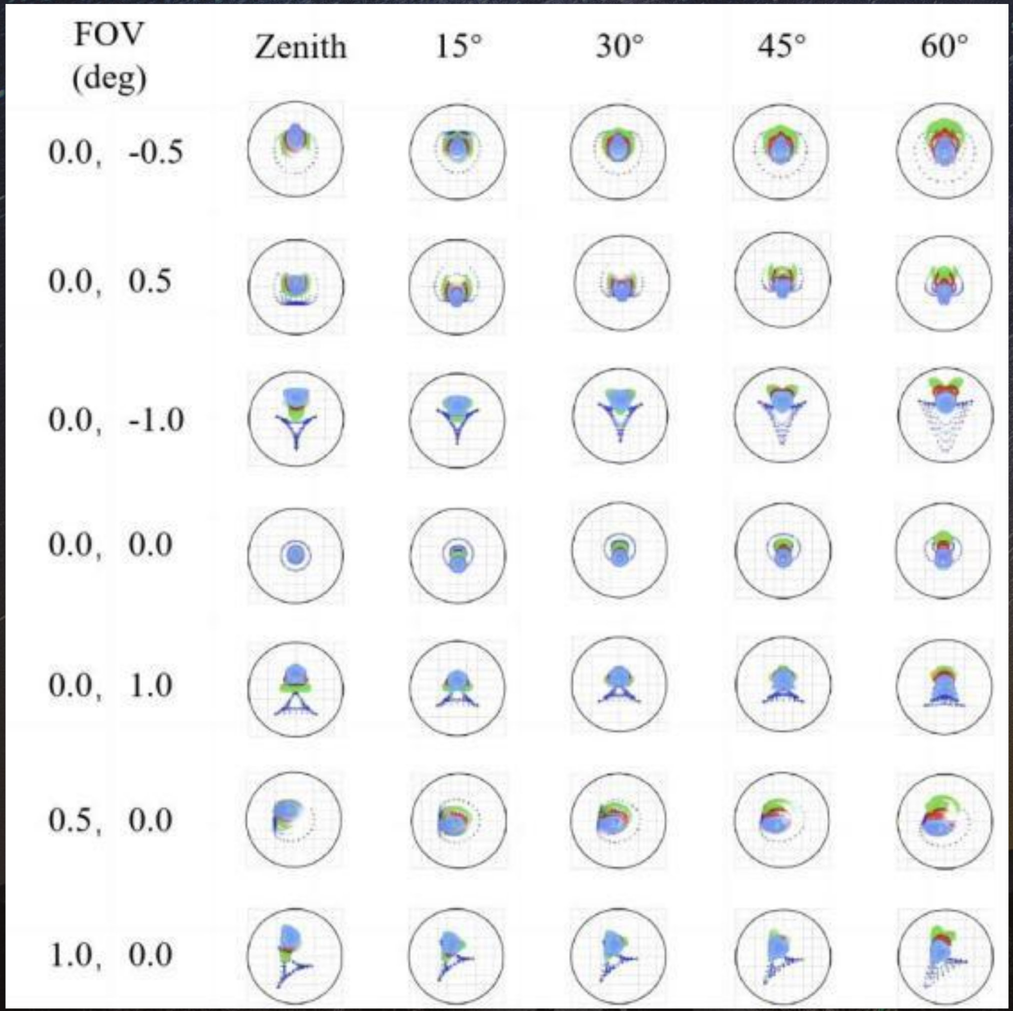
像质



无大气色散的斑点图。圆的直径对应于0.5角秒。

80%能量最大直径（EE80）在0.18角秒

像质



The circle diameters correspond to 1.2 arcsecond.

Zenith Distance	EE80D
0 (without dispersion)	0.18
0(with ADC)	0.33
15	0.26
30	0.27
45	0.32
60	0.39

Coudé system系统设计

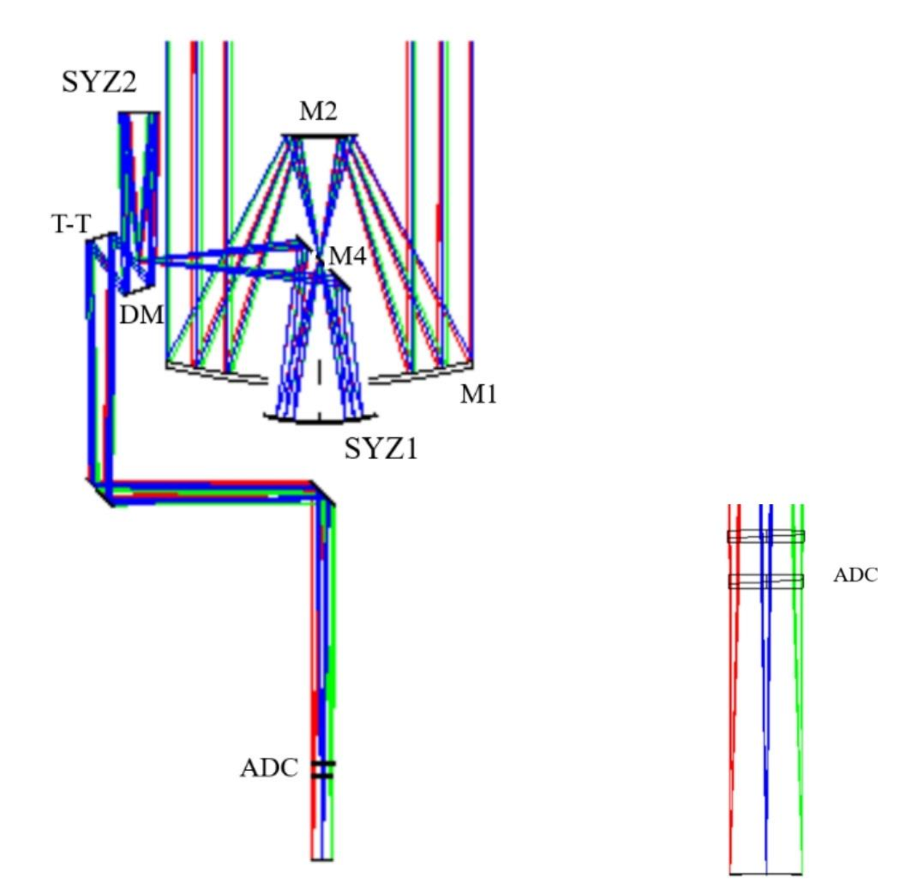
The second SYZ relay mirror images the Nasmyth focus to the coudé focus

- 焦比: F/28.9

  视场: Φ8′

  观测波段:0.36-1.8 μm

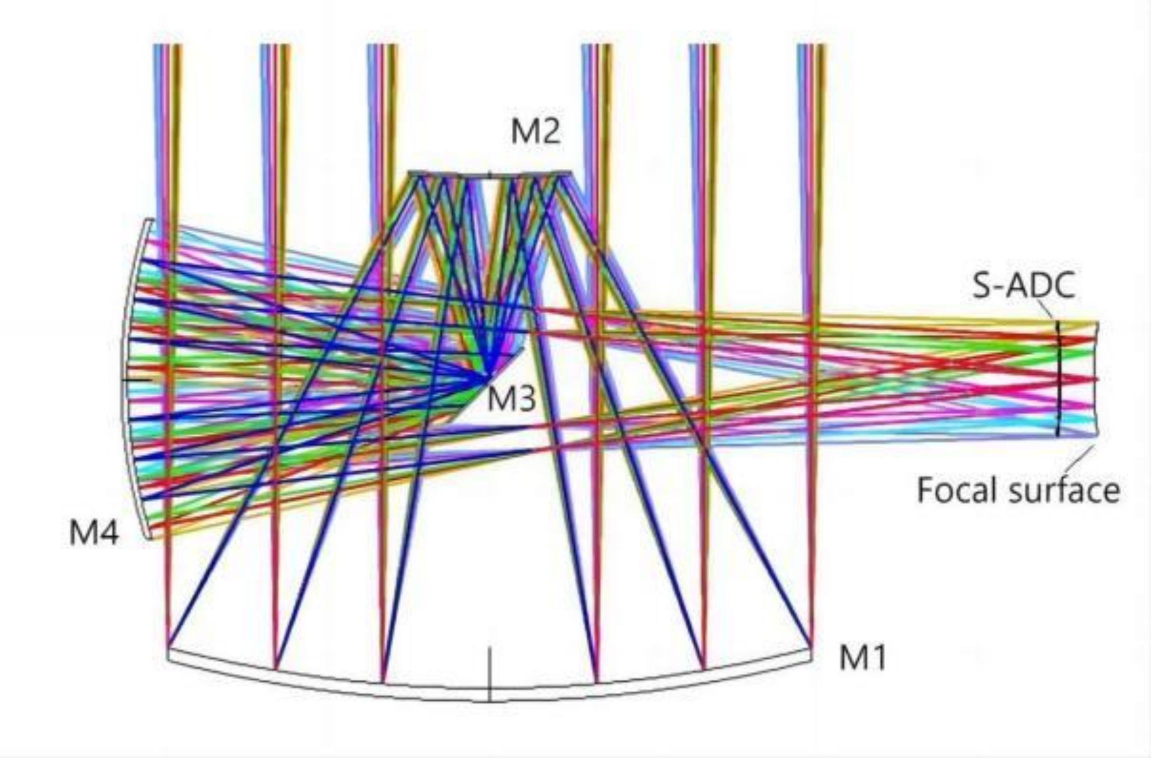
- DM of GLAO 与主镜上方 139 m 以上共轭
- Tip-Tilt mirror was included
- ADC :a pair of counter-rotation lensm



The optical layout of coudé system

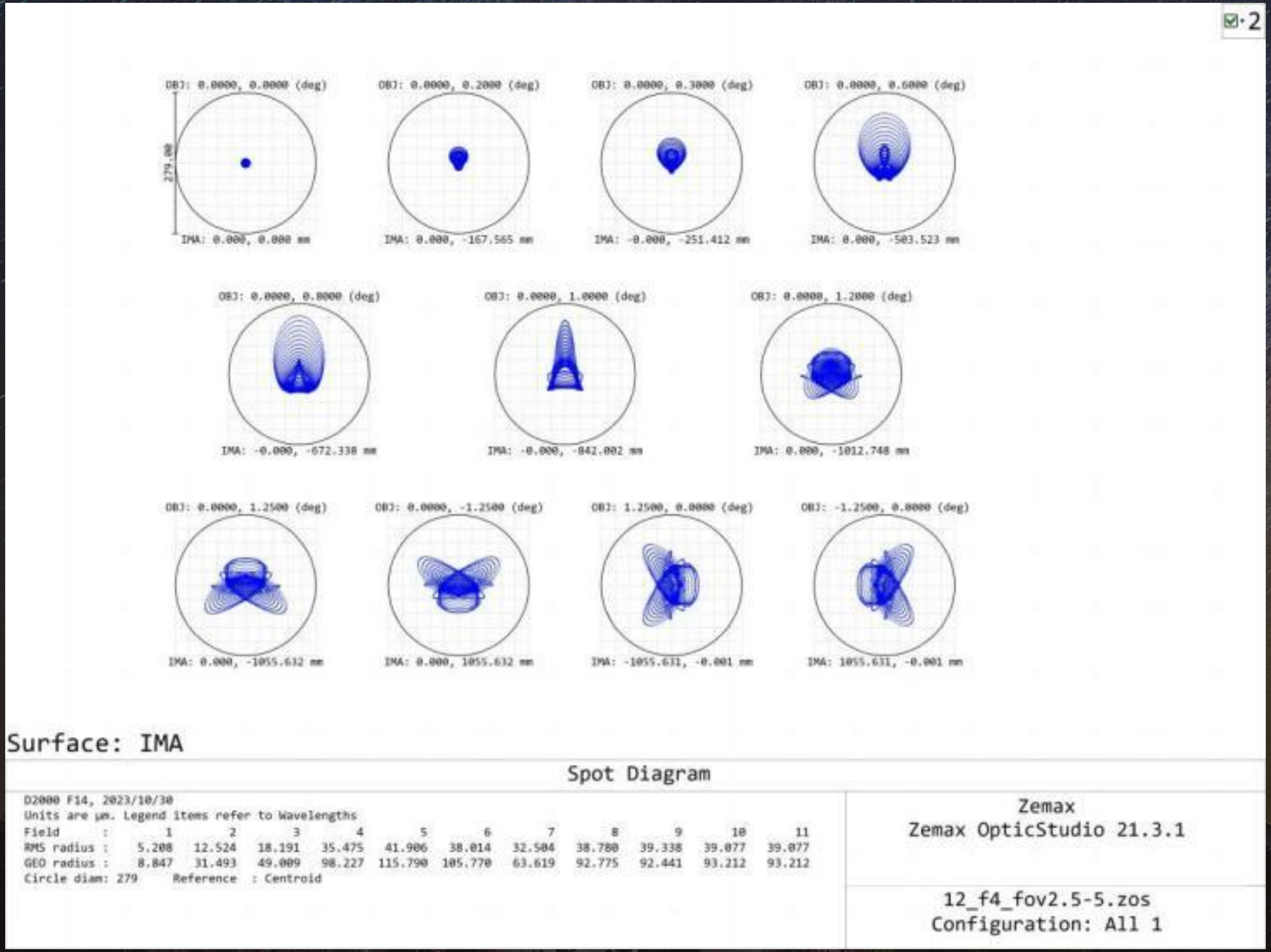
NIAOT concept II

- 口径: 16 m (拼接)
- 焦比: F/4.0
- 视场: Φ2.5°
- 焦距: 64 m
- 最大观测天顶距：60°
- 观测波长: 360-1300 nm
- 约 54000 根光纤



The optical layout of 12m survey telescope

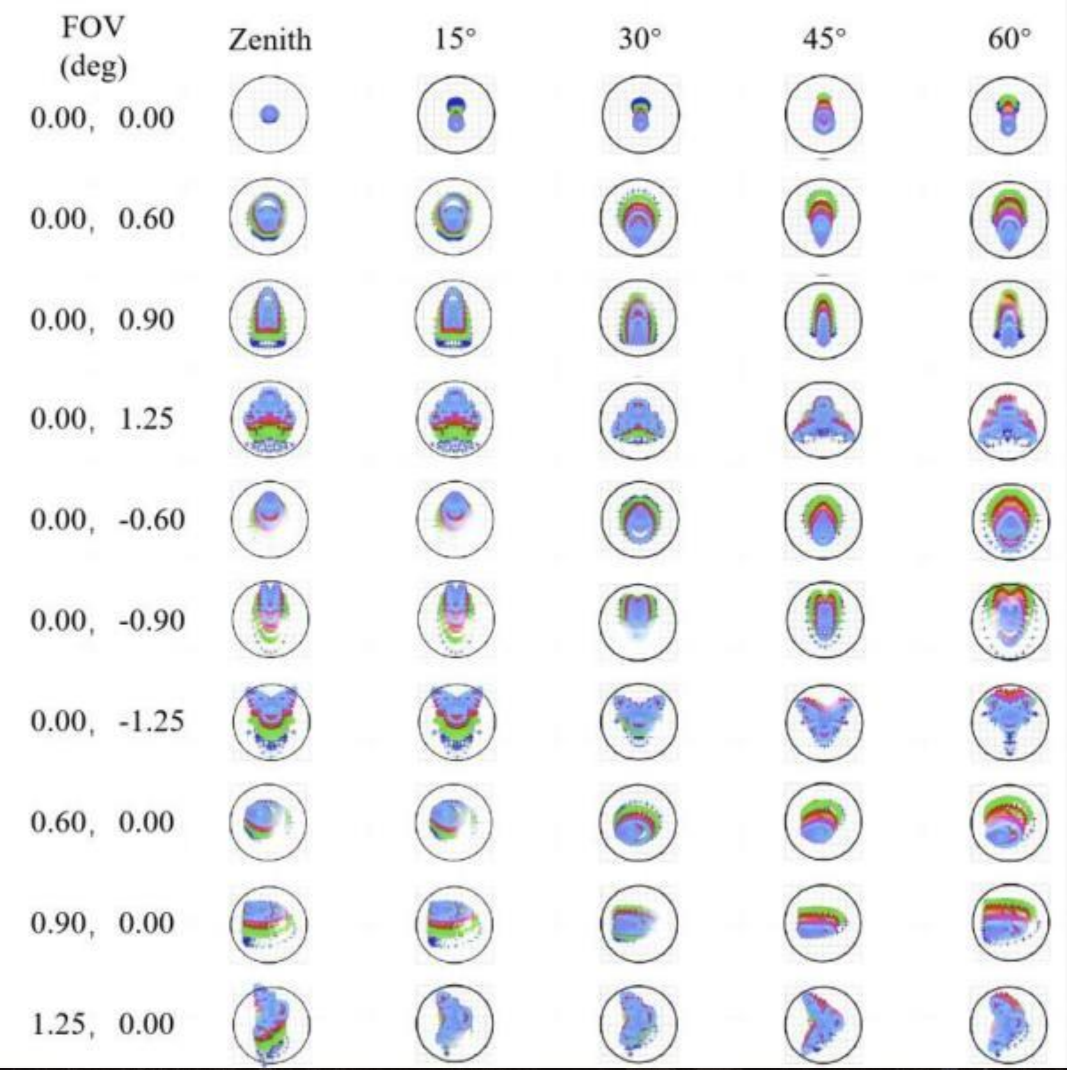
像质



无大气色散的斑点图。圆的直径对应于1.2角秒。

80%能量最大直径（EE80）在0.43角秒

像质



The circle diameters correspond to 1.2 arcsecond.

Zenith Distance	EE80D (arcsec)
0 (without dispersion)	0.43
0(with ADC)	0.65
15	0.48
30	0.50
45	0.52
60	0.62

MSE光学系统方案—Barden（2022）

paper discusses a reduced aperture size with an increased field of view (1.5 degree squared) located at the elevation axis to provide a Nasmyth configuration. We refer to this design as the Quad Mirror or QM design.

2. DESIGN

This design is based upon a 14-meter primary. A version with a 12.5-meter primary is being explored in detail as a viable option for the Maunakea Spectroscopic Explorer (MSE)[10] in which the ADC lens production is more feasible than that presented here. A raytrace schematic of the 14-meter design is shown in Figure 1.

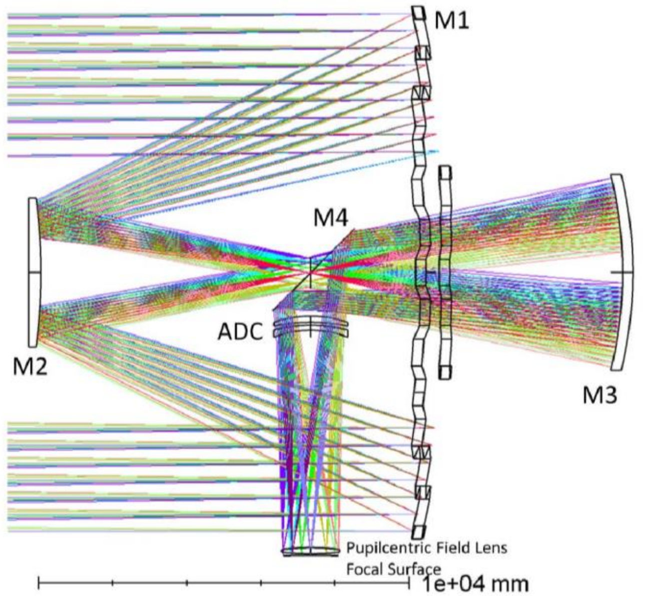


Figure 1. Raytrace schematic of telescope concept showing the four mirrors (M1, M2, M3, and M4), the ADC lenses, and the Pupilcentric Field Lens near the Focal Surface.

The salient features of the 4 mirror, Nasmyth focus are the added versatility of the telescope from the following:

- A Nasmyth focus relaxes gravitational constraints on instruments and allows potential gravitational invariant implementations with an image derotator.

Barden的MSE光学系统方案（2022）

Exploration of a 14-meter, 1.5-degree field of view, quad-mirror anastigmatic telescope concept for wide-field spectroscopy and imaging

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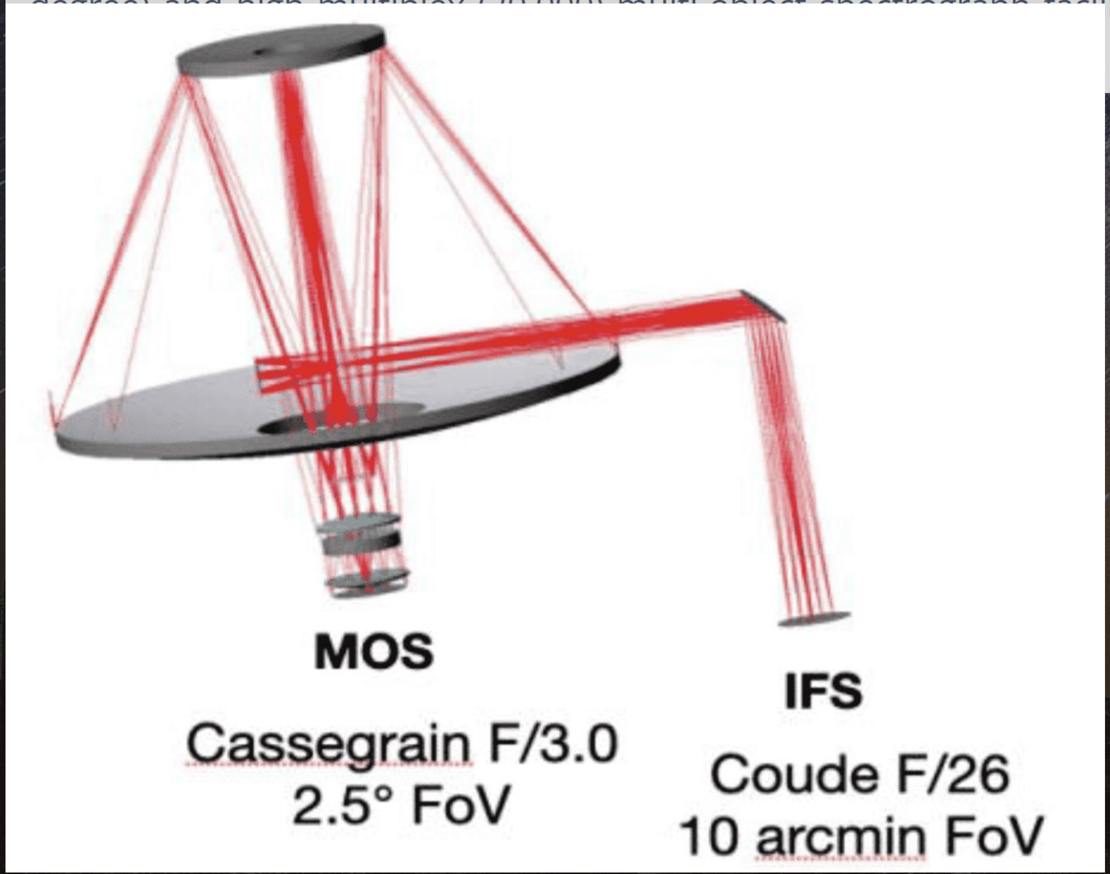
[b]Prime Optics, 17 Crescent Road, Eumundi Q 4562 AUSTRALIA

口径：14米
视场： Φ1.5°
焦点： 耐焦

WST光学系统方案— Pasquini（2016）

WIDE-FIELD SPECTROSCOPIC TELESCOPE

An innovative 10-m class **wide-field spectroscopic telescope (WST)** with simultaneous operation of a large field-of-view (5 sq.
…ity with both medium and high resolution modes (MOS), and a



口径：~10米
视场：Φ2.5°
焦点：卡焦+coude焦点

https://www.wstelescope.com/

比较

Telescope Configs.	DT(m)	Ratio	A (m^2)	FOV (deg)	Ω (deg^2)	DF(m)	SF(m^2)	Etendue1	Etendue2
NIAOT concept I	12	0.80	90.8	2.5°	4.91	2.112	3.50	446	318
NIAOT concept II	16	0.80	161	2.5°	4.91	2.816	6.23	793	1005
ESO concept	11.4	0.86	87.89	2.5°	4.91	1.43	1.61	431	141
Barden (MSE)	14	0.82	127	1.5°	1.77	1.47	1.70	224	216

Etendue1= AΩ ；Etendue2= A×SF

Su-Meinels four mirror optical system + S-ADC

Open a new possibility for Astronomy

Thank you !