测光数据处理

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- 准备知识（不完备）
- 探测器性能标定
- 天测与测光
- 流量定标
- Pipeline in Python: all in all

大规模巡天简史

人眼时代

1609 – 1850s

照相底片时代

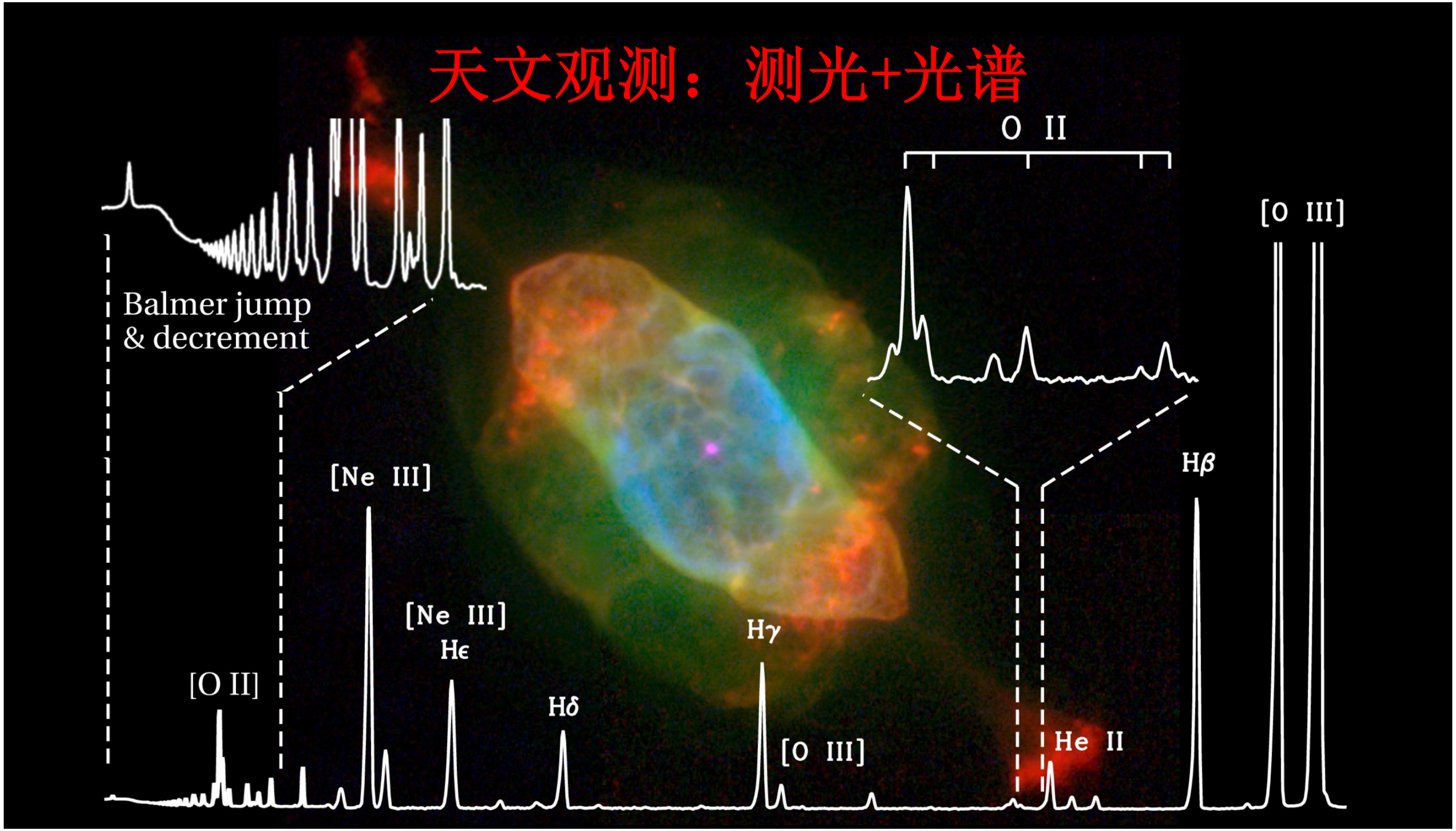
1898 Pleiades negative, drying rack, and darkroom tray

1850s – 1980s

数字化时代

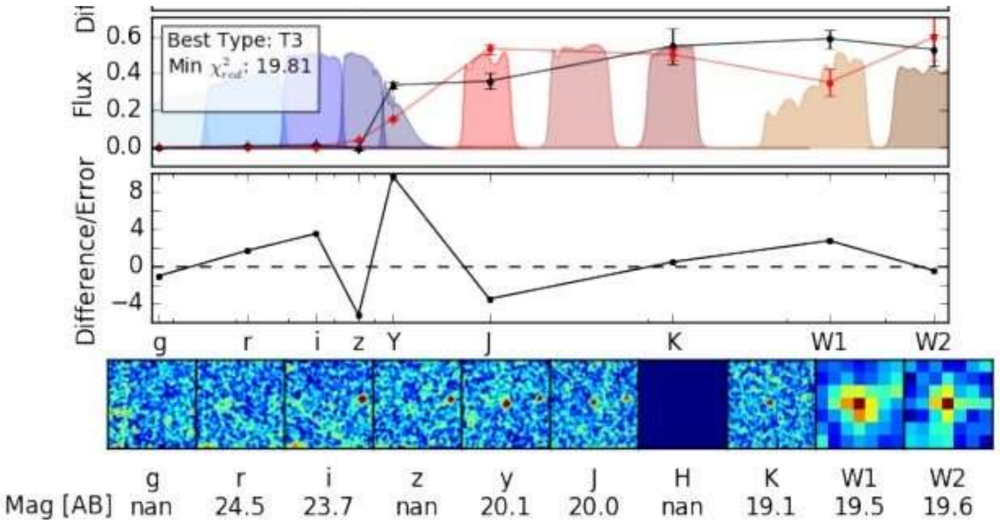
1980s – present

大规模巡天简史



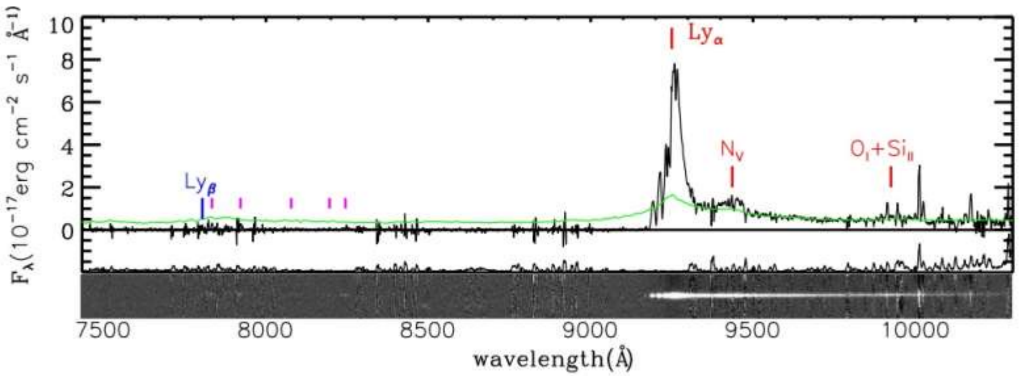
天文观测：测光+光谱
O II
[O III]
Balmer jump
& decrement
[Ne III]
[Ne III]
Hϵ
Hβ
Hγ
Hδ
[O II]
[O III]
He II

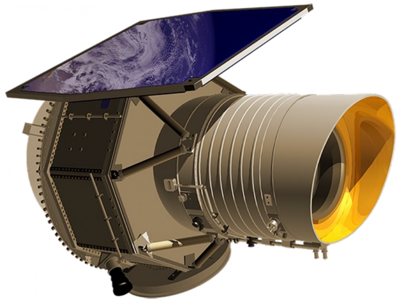
大规模巡天简史



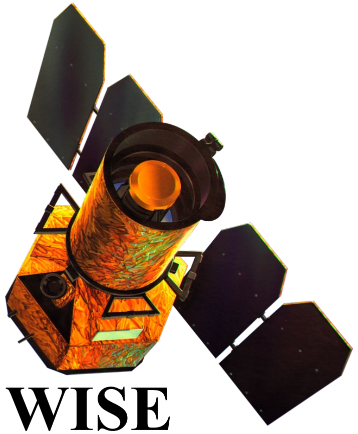
多波段星等

天体红移、化学组成



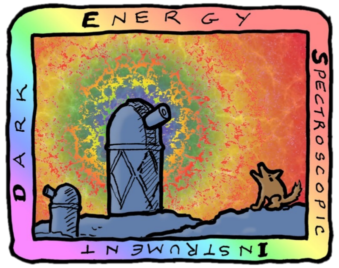


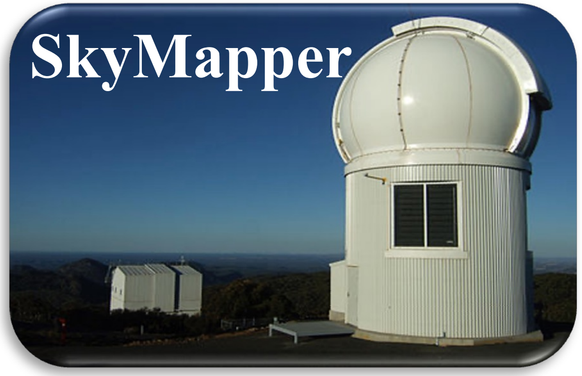
Galex



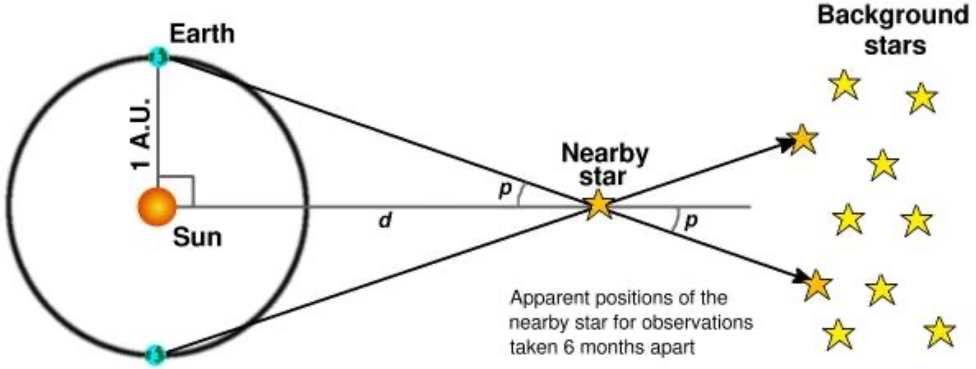
WISE

DESI





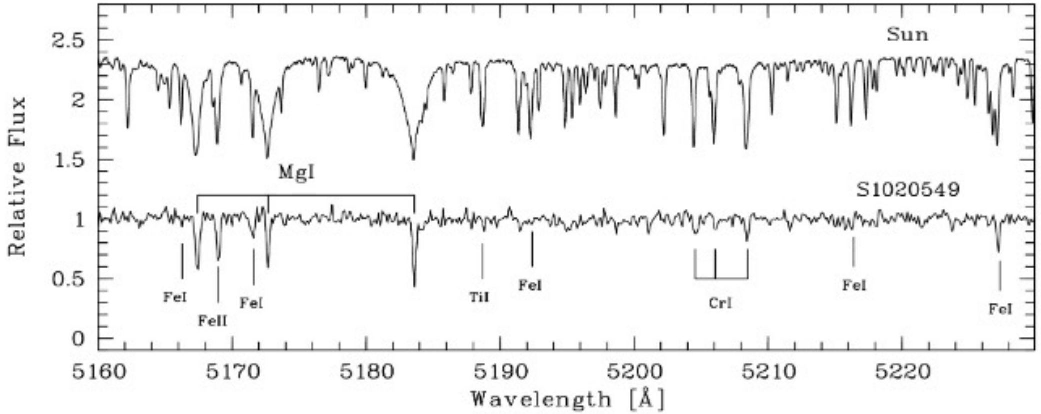
大规模巡天简史



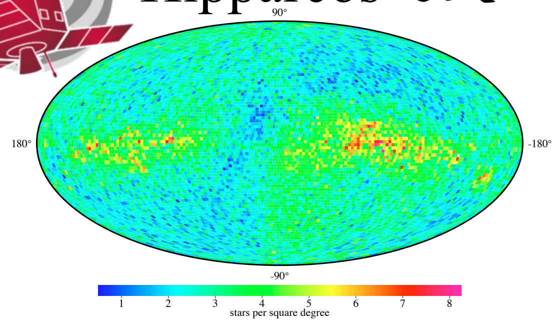
天体位置、自行、视差

天体视向速度、化学组成

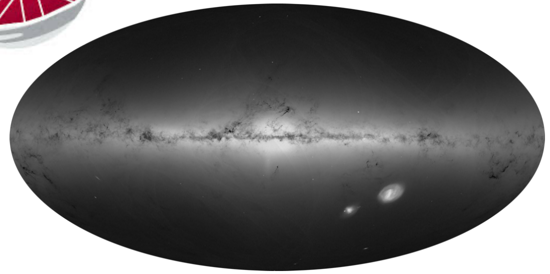
完备相空间信息：**三维位置、三维速度+年龄+*Z***

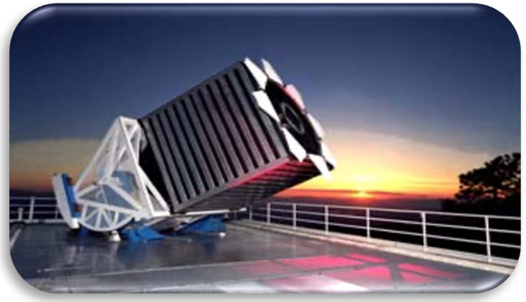


Hipparcos巡天



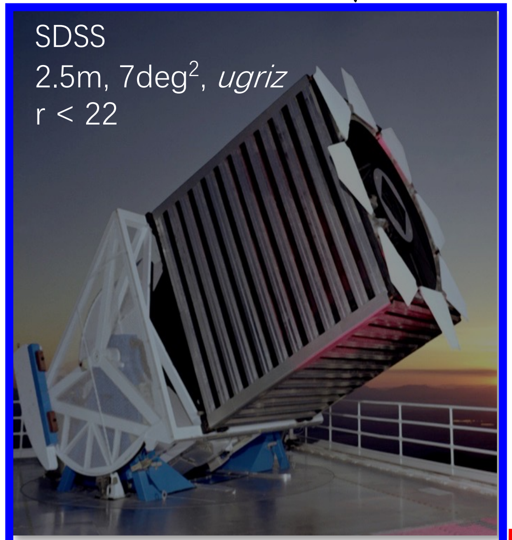
Gaia巡天



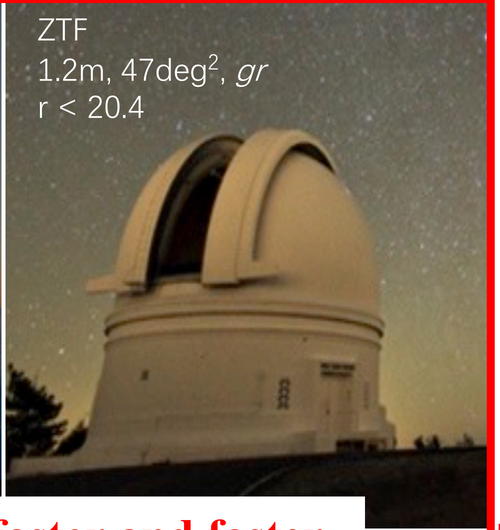


大规模巡天简史

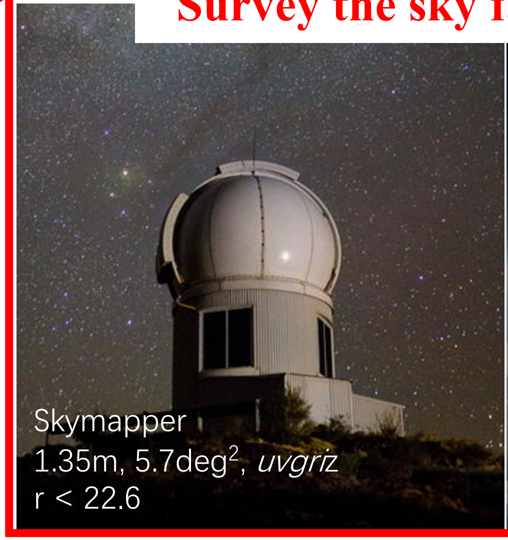
拍照片

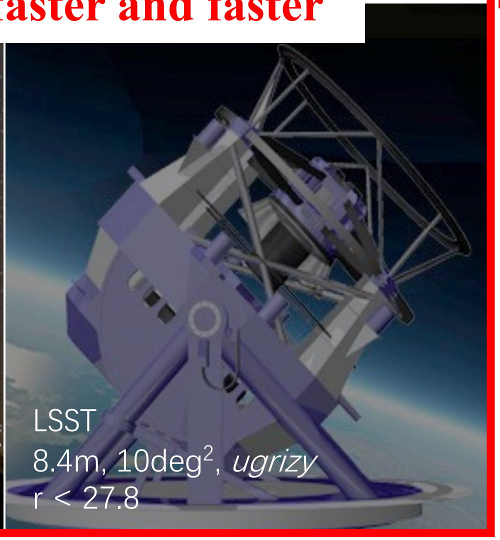


拍动图

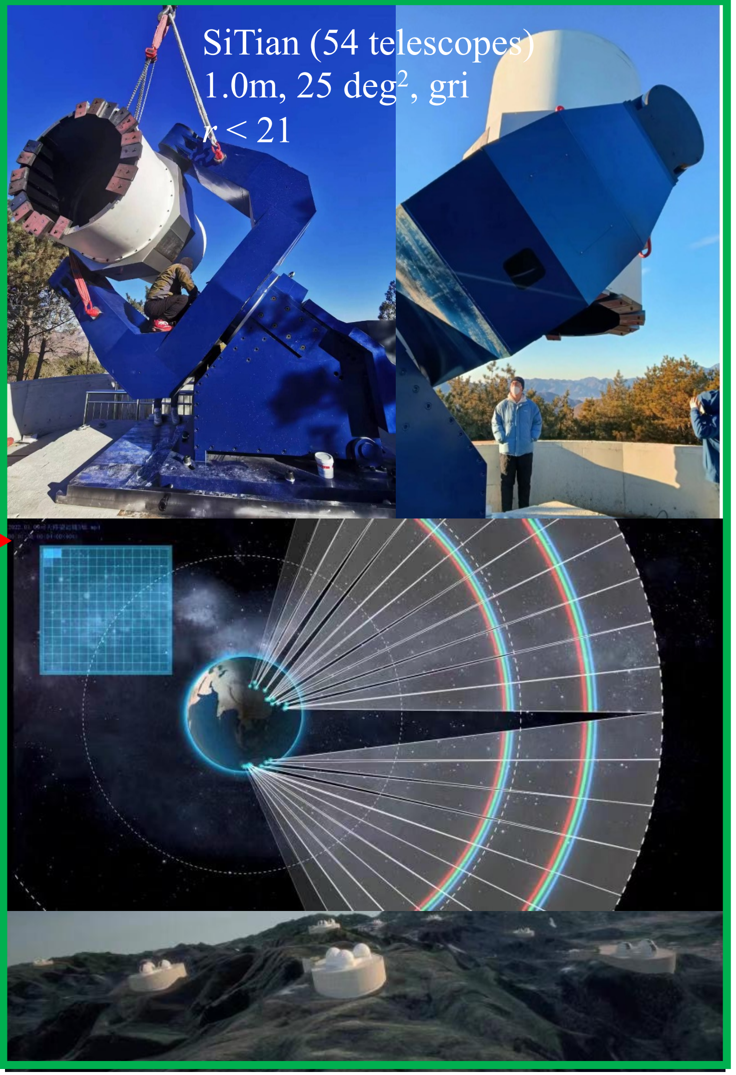


Survey the sky faster and faster





拍电影



大规模巡天简史

自然基金委《天文学十四五及中长期规划》景益鹏+

多信使天文学：使用引力波、中微子、宇宙线等非电磁手段来研究致密天体性质、丈量宇宙时空、追踪剧烈天体物理过程、检验基本物理规律

时域天文学：采用多波段、多时标方式研究动态宇宙，通过重复观测来揭示宇宙中各类天体的变化，发现和探索新天体、揭示未知的新现象、新规律

行星大科学：关乎生命起源的行星大科学，是集系外行星、太阳系行星、天体生物学、天体化学、地质学研究方法于一体的高度交叉学科，旨在探索行星与生命的起源和演化

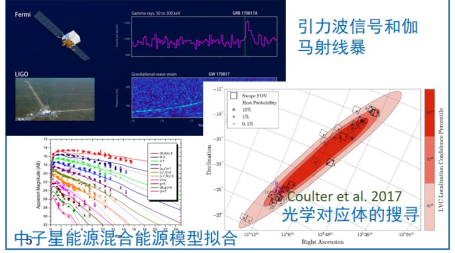
多波段、手段联合观测：不同侧面、不同类型天体更加全面的信息

大天区面积深度巡天：覆盖尽可能多的天体类型和数量

高频率采样、长期持续监测：暂现源和变源的长期/短时标的变化特点

引力波暴电磁对应体：

- 2017年，人类再次从一对中子星的并合事件中，首次实现了引力波和多波段电磁波的联合探测
- 有力推动了短伽马射线暴起源和宇宙中超铁元素（如金、银、铀等）起源等重大科学问题的解决，显示了多信使研究的强大威力



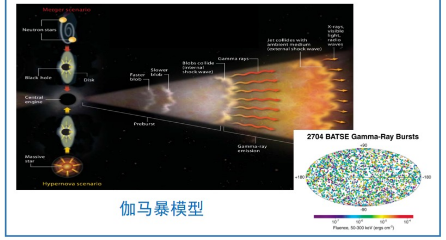
引力波信号和伽马射线暴

光学对应体的搜寻

中子星能源混合能源模型拟合

超新星与伽马射线暴：

- 超新星是大质量恒星在演化末期经历的剧烈爆炸，反映恒星演化最后时刻的空间结构和物理性质
- 伽玛射线暴是宇宙中最为剧烈的恒星尺度爆发现象，是研究早期宇宙的探针，可用于探索第一代/早期恒星、早期金属丰度、宇宙再电离等

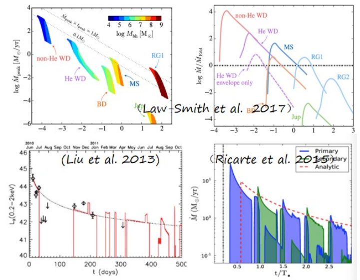


伽马暴模型

＋ ＋ ＋

黑洞潮汐撕裂恒星事件（TDE）

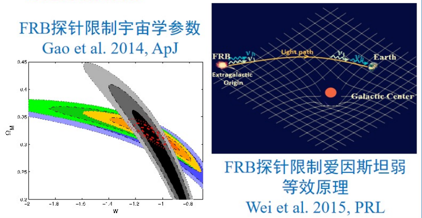
- 发生概率低
- 科学意义显著：理解超大质量黑洞（SMBHs）的起源及其宇宙学成长历史、黑洞吸积物理、引力波多信使观测等



快速射电暴（FRB）

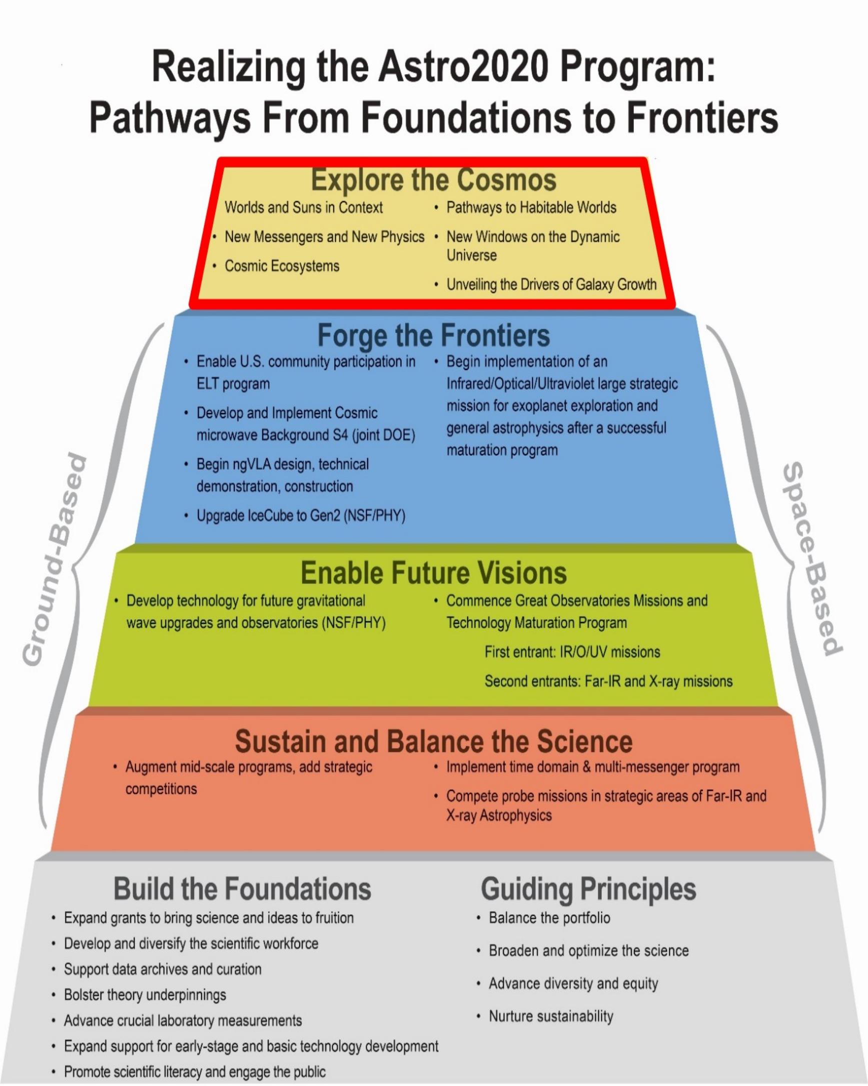
- 一种持续时间仅为数毫秒的爆发性、脉冲式射电辐射天文现象，瞬时辐射流量可达数十央斯基（Jy）
- 全新的天体物理现象，起源未知
- 是从无线电到高能伽马射线，甚至中微子、引力波天文台的探测对象，是从时域天文学到干涉成像多课题的研究目标

FRB探针限制宇宙学参数
Gao et al. 2014, ApJ



FRB探针限制爱因斯坦弱等效原理
Wei et al. 2015, PRL

大规模巡天简史



Priority Area: Pathways to Habitable Worlds

We are on a path to exploring worlds resembling Earth and answering the question: "Are we alone?" The task for the next decades will be finding the easiest of such planets to characterize, and then studying them in detail, searching for signatures of life.

系外行星及宜居性
宿主恒星活动性
系外行星生命信号

Priority Area: New Windows on the Dynamic Universe

The New Windows on the Dynamic Universe priority area involves using light in all its forms, gravitational waves, and neutrinos to study cosmic explosions on all scales and the mergers of compact objects

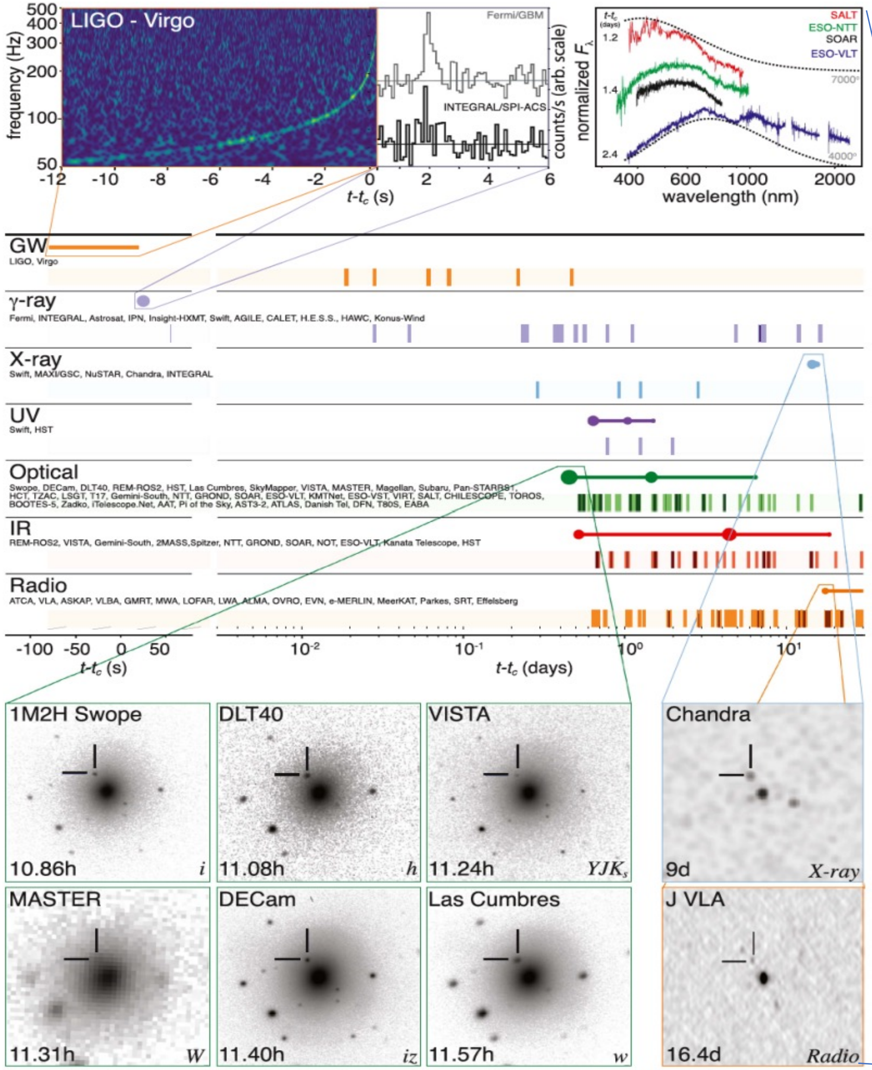
动态宇宙新窗口
多信使多波段
瞬变天体
致密天体

Priority Area: Unveiling the Drivers of Galaxy Growth

The priority area involves unveiling the drivers of galaxy growth, focusing on processes affecting galactic scales

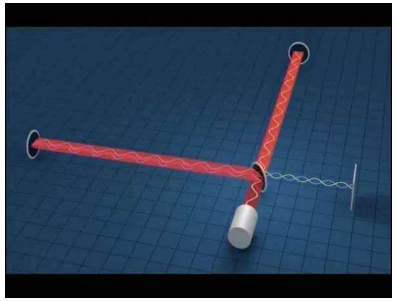
驱动星系生长
黑洞星系共同
演化等

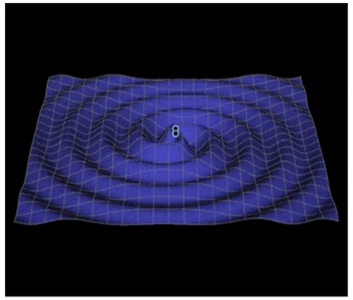
大规模巡天简史

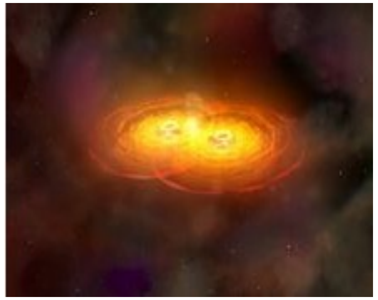


引力波探测获2017年
诺贝尔物理奖

->引力波**天文学**：致密天体并合之电磁对应体







GW170817的电磁对应体观测

❑光学发现：11小时后探测到←1米Swope巡天

❑触发后随光学光谱：1天之后获取

❑探测到后期光变和光谱可以由中子星重元素衰变解释，但反应更关键物理的早期信息被丢失，因此无法区分最核心追求的致密天体模型！

❑问题：需要五个小时内的极早期光变来区分模型！

大规模巡天简史

特点：

天去覆盖：单次曝光>1平方度

数据量：**GB->TB** 每晚

探测器：**CCD/CMOS**

要求：

处理模式：全自动

实效性：数分钟模式（变源瞬变源）/离线模式

精度要求：1-3%/毫星等

大规模巡天简史

Volume： 数据量大

Variety： 种类繁多（图像、时序、不同层级的星表等）

Value： 我们想要的最有价值的信息

Velocity： 时效性（真正的挑战）-- 分钟量级

Veracity： 怎样在大海捞针下捞到针

What happened? What is happening?	What will happen? What will it happen?	What should we do? Why should I do it?

→

我们需要在几十台司天望远镜不停拍摄的同时作上述判断与决定

准备知识

Noises of CCD photometry

$$\frac{S}{N} = \frac{N_*}{\sqrt{N_* + n_{pix}\left(N_{Sky} + N_D + N_{RD}^2\right)}}$$

N_*: the total number of photons collected from the object of interest

n_{pix}: the total number of pixels under the object of interest; for ground based telescope, $n_{pix} = \frac{\pi r^2}{pixel\ size}$ (r given by the typical seeing)

N_{sky}: the total number of photons per pixel from the sky background

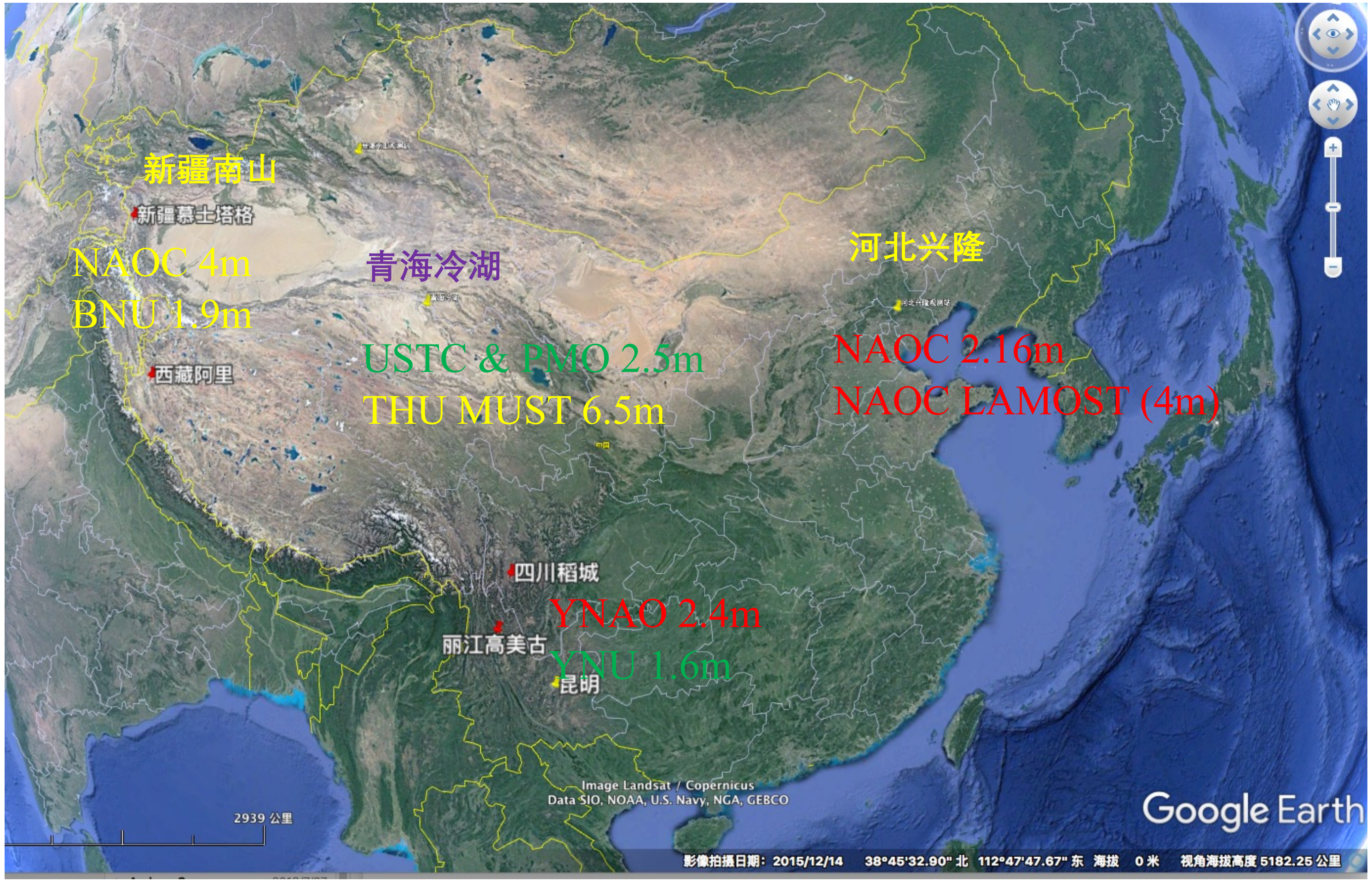
N_D: the total number of dark current electrons per pixel

N_{RD}^2: the total number of electrons per pixel resulting from the read noise

Those noises are determined by the **site station** and **camera properties** and can not be **reduced more** once the station and camera been chosen!

准备知识

一流台址


新疆南山
新疆慕士塔格
NAOC 4m
BNU 1.9m
青海冷湖
USTC & PMO 2.5m
THU MUST 6.5m
西藏阿里
河北兴隆
NAOC 2.16m
NAOC LAMOST (4m)
四川稻城
YNAO 2.4m
丽江高美古
YNU 1.6m
昆明
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
2939 公里
Google Earth
影像拍摄日期：2015/12/14 38°45'32.90" 北 112°47'47.67" 东 海拔 0 米 视角海拔高度 5182.25 公里

准备知识

一流台址

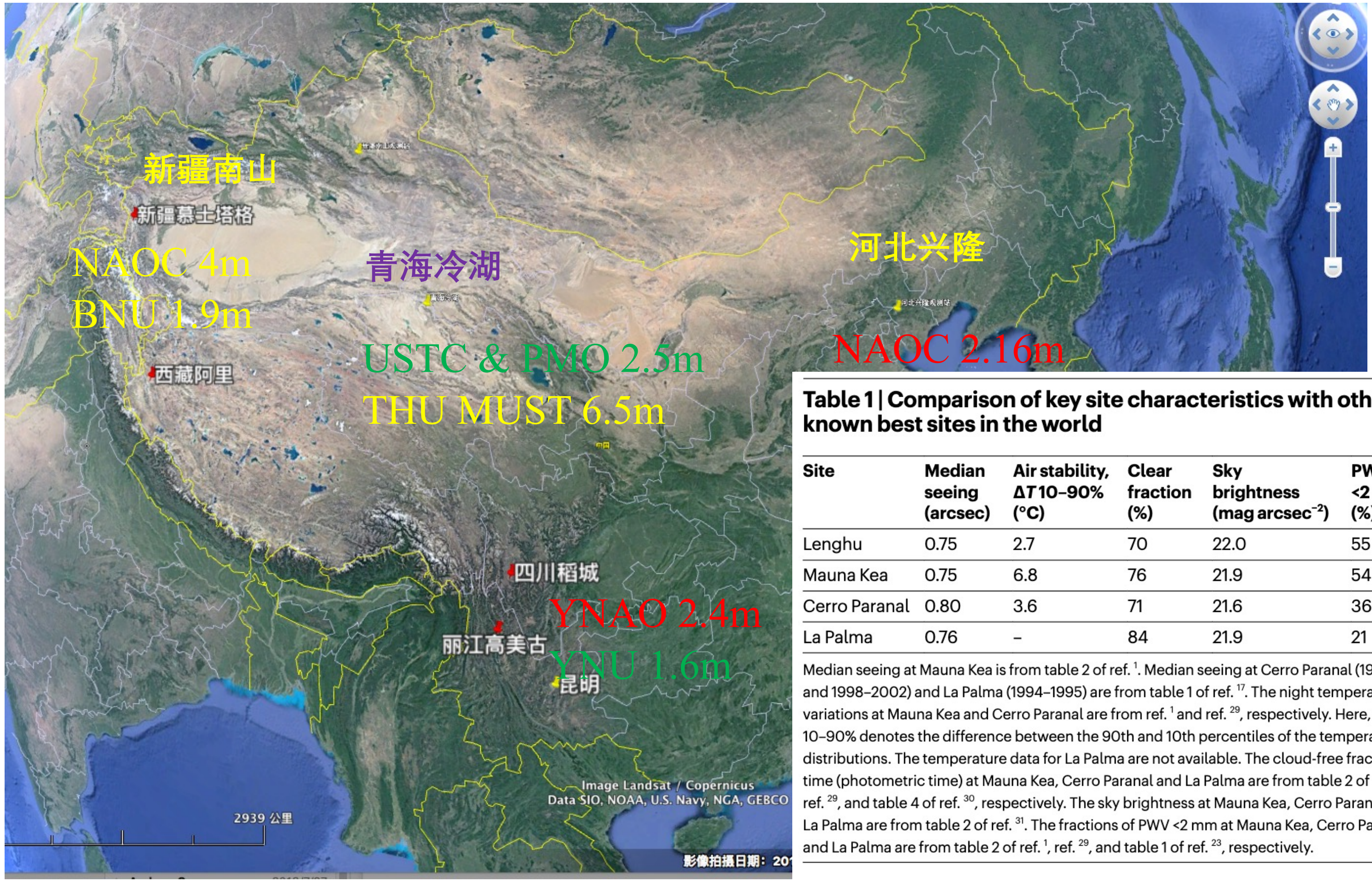
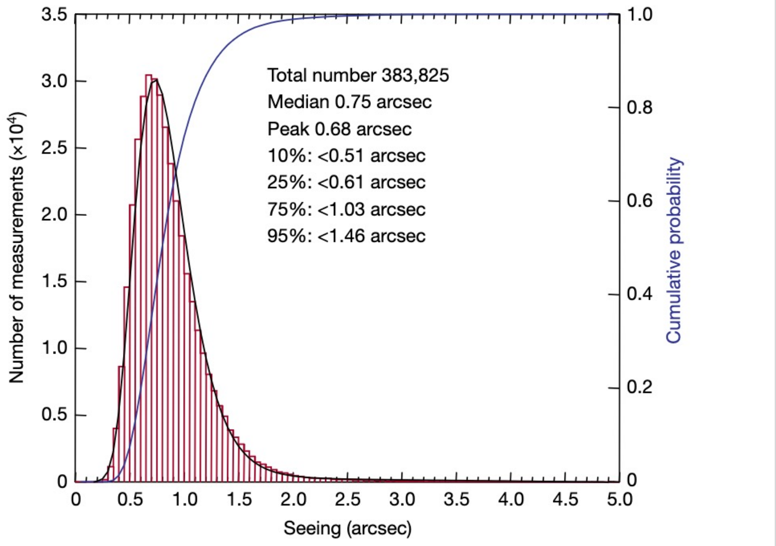


Table 1 | Comparison of key site characteristics with other known best sites in the world

Site	Median seeing (arcsec)	Air stability, ΔT 10–90% (°C)	Clear fraction (%)	Sky brightness (mag arcsec^{-2})	PWV <2 mm (%)
Lenghu	0.75	2.7	70	22.0	55
Mauna Kea	0.75	6.8	76	21.9	54
Cerro Paranal	0.80	3.6	71	21.6	36
La Palma	0.76	–	84	21.9	21

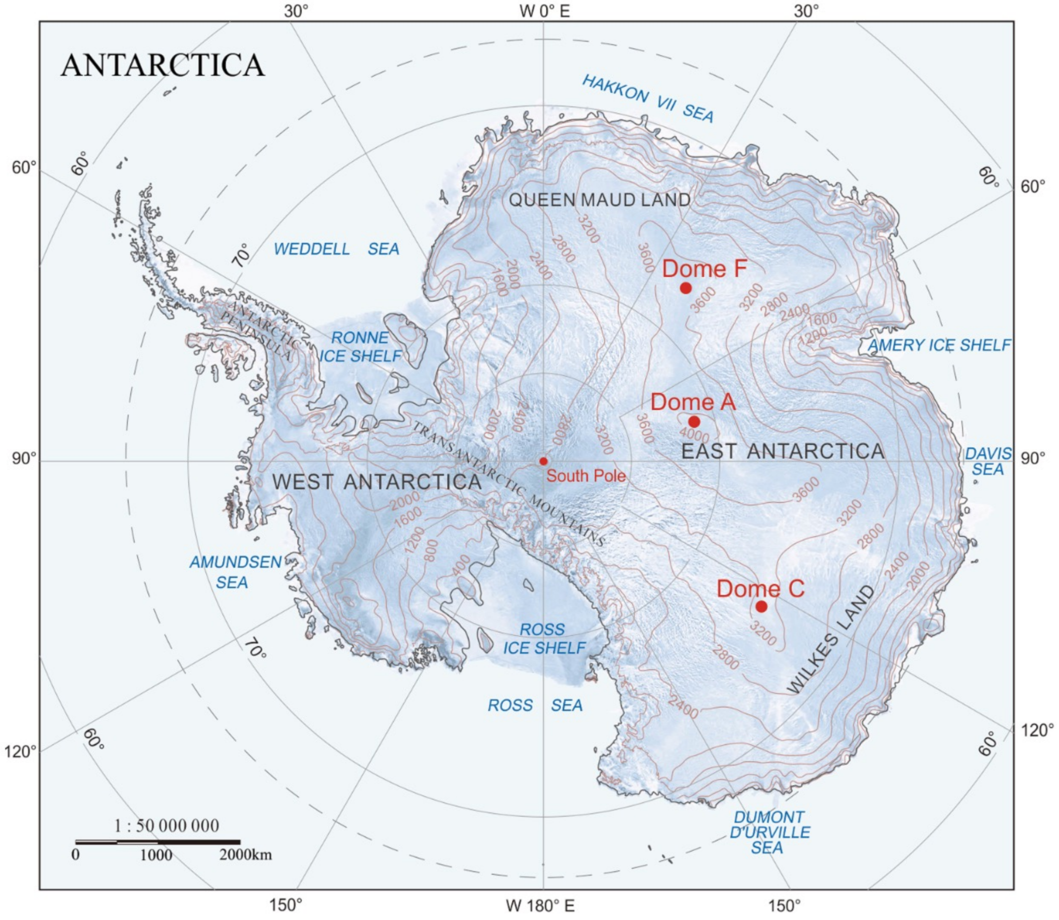
Median seeing at Mauna Kea is from table 2 of ref. [1]. Median seeing at Cerro Paranal (1989–1995 and 1998–2002) and La Palma (1994–1995) are from table 1 of ref. [17]. The night temperature variations at Mauna Kea and Cerro Paranal are from ref. [1] and ref. [29], respectively. Here, ΔT 10–90% denotes the difference between the 90th and 10th percentiles of the temperature distributions. The temperature data for La Palma are not available. The cloud-free fractions of time (photometric time) at Mauna Kea, Cerro Paranal and La Palma are from table 2 of ref. [1], ref. [29], and table 4 of ref. [30], respectively. The sky brightness at Mauna Kea, Cerro Paranal and La Palma are from table 2 of ref. [31]. The fractions of PWV <2 mm at Mauna Kea, Cerro Paranal and La Palma are from table 2 of ref. [1], ref. [29], and table 1 of ref. [23], respectively.

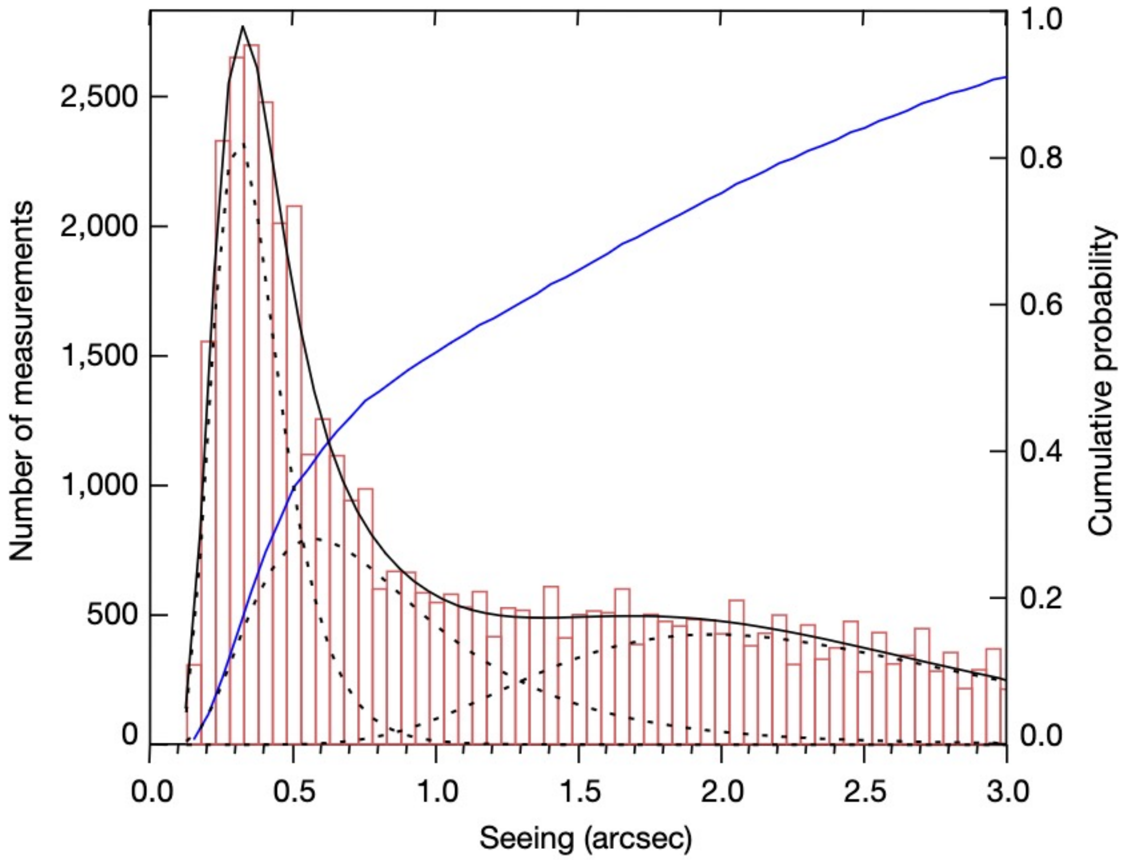


Deng et al. 2021

准备知识

一流台址





Ma et al. 2020

准备知识

https://sites.astro.caltech.edu/~george/ay122/Bessel2005ARAA43p293.pdf

Standard Photometric Systems

Michael S. Bessell
Research School of Astronomy and Astrophysics, The Australian National University, Weston, ACT 2611, Australia; email: bessell@mso.anu.edu.au

TABLE 1 Wavelengths (Å) and widths (Å) of broad-band systems

UBVRI			Washington			SDSS			Hipparcos			WFPC2		
	λeff	Δλ		λeff	Δλ		λeff	Δλ		λeff	Δλ		λeff	Δλ
U	3663	650	C	3982	1070	u'	3596	570	H_P	5170	2300	F336	3448	340
B	4361	890	M	5075	970	g'	4639	1280	B_T	4217	670	F439	4300	720
V	5448	840	T_1	6389	770	r'	6122	1150	V_T	5272	1000	F555	5323	1550
R	6407	1580	T_2	8051	1420	i'	7439	1230				F675	6667	1230
I	7980	1540				z'	8896	1070				F814	7872	1460

准备知识

Homework #1

SUMMARY PERFORMANCE (Typical)

Number of pixels	9216 (H) × 9232 (V)
Pixel size	10 µm square
Image area	92.2 mm × 92.4 mm
Outputs	16
Package size	98.5 × 93.7 mm
Package format	Silicon carbide with two flexi connectors
Focal plane height, above base	20.0 mm
Connectors	Two 51-way micro-D
Flatness	20 µm (peak to valley)
Amplifier sensitivity	7.5 µV/e^-
Read-out noise	4 e^- at 0.5 MHz 2.5 e^- at 50 kHz
Maximum pixel data rate	3 MHz
Charge storage (pixel full well)	90,000 e^-
Dark signal	4 e^-/pixel/hour (at –100 °C)

CCD290-99 Sensor designed by e2v

XingLong Station:

Background: V = 21.0 mag/srcsec^2

Atmospheric extinction: kV = 035 mag/airmass

Telescope efficiency: 40% (assumed)

Aperture: 1m in diameter

Pixel scale: 0.6 arcsec/pixel

Seeing: 1.5 arcsec

	DD silicon Astro Multi-2	Standard silicon Astro Multi-2	Pixel Response Non-Uniformity PRNU (1 σ)
Wavelength (nm)	Minimum QE (%)	Minimum QE (%)	Maximum PRNU (%)
350	30	30	-
400	75	75	3
500	75	75	-
650	80	80	3
900	50	25	5

Limiting magnitude?
(5sigma; @1.2 airmass)
@ 2s
@ 20s
@ 200s
And which one dominates the error?

准备知识

流量标准星

https://www.eso.org/sci/observing/tools/standards/spectra.html

Oke (1990) Spectrophotometric Standards

Oke (AJ, 99, 1621, 1990) has provided absolute spectral energy distributions covering the wavelength range 3200 to 9200Å in AB magnitudes for 25 stars. The measurements were made with the Double Beam Spectrograph of the Hale 5m telescope. The reduced magnitudes are tabulated at 1Å intervals from 3300 to 4700Å and at 2Å intervals from 4700 to 9200Å. Comparison of the fluxes with those determined elsewhere showed that Oke's absolute magnitudes are systematically brighter by 0.04 mag. The magnitudes and fluxes plotted have been corrected for this effect. Colina & Bohlin (AJ, 1931, 1994) tabulate the differences between the original Oke fluxes, in terms of synthesized B and V magnitudes, and Landolt photometry for each star individually.The AB magnitudes were converted to flux (ergs/cm/cm/s/A) using the formula
ABMAG = -2.5 alog10(Fnu) - 48.59
(Hamuy et al., PASP, 104, 533, 1992), where Fnu is in ergs/cm/cm/s/Hz.

Cautionary Note:

These data have larger uncertainties than tabulated in the following spectral regions:

- below 3400Å (atmospheric and instrument transmission);
- 4000–4500Å (CCD flaws);
- 4650–4800Å (overlap between orders, dichroic cut);
- telluric A and B bands (around 7615 and 6875Å respectively);
- above about 8500Å (second-order contamination).

```
No.   Name          alpha (2000) delta     Sp.     V     AB
                                           Type        (5460A)
---------------------------------------------------------------

 1   G158-100      00 33 54.3  -12 07 57   sdG    14.89  14.82
 2   HZ 4          03 55 21.7  +09 47 19   DA4    14.52  14.47
 3   G191B2B       05 05 30.6  +52 49 54   DAO    11.78  11.72
 4   G193-74       07 53 27.4  +52 29 36   DC     15.70  15.58
 5   BD+75d325     08 10 49.3  +74 57 57   O5p     9.54   9.52
```

准备知识

望远镜空间分辨本领：

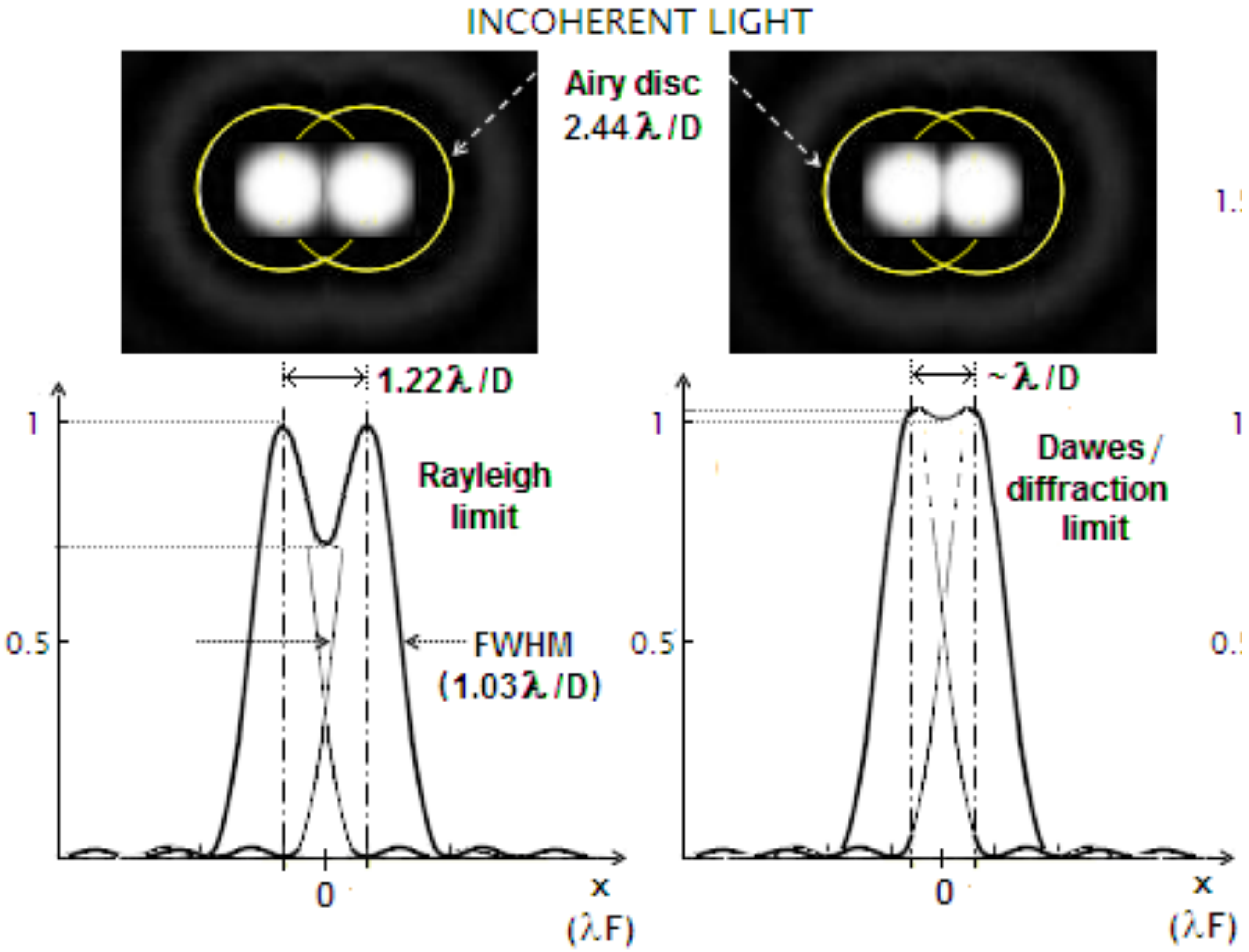
准备知识

望远镜空间分辨本领：

衍射极限

大气湍流

探测器采样
（焦面比例尺）



准备知识

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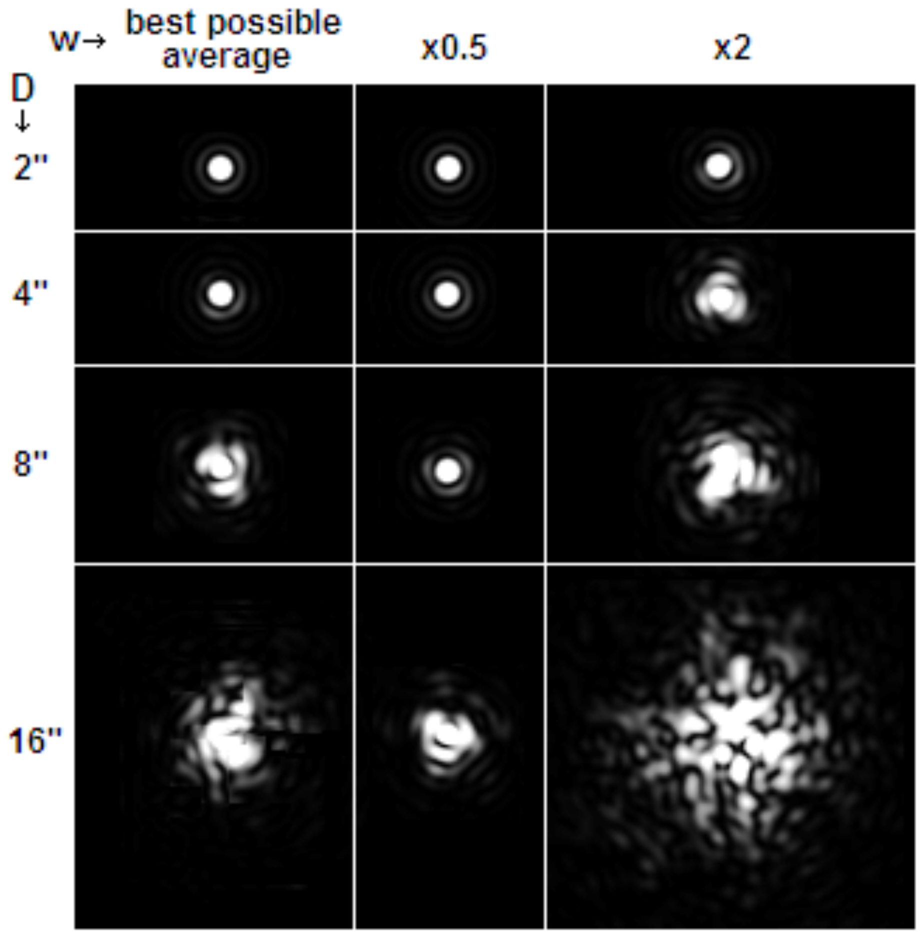


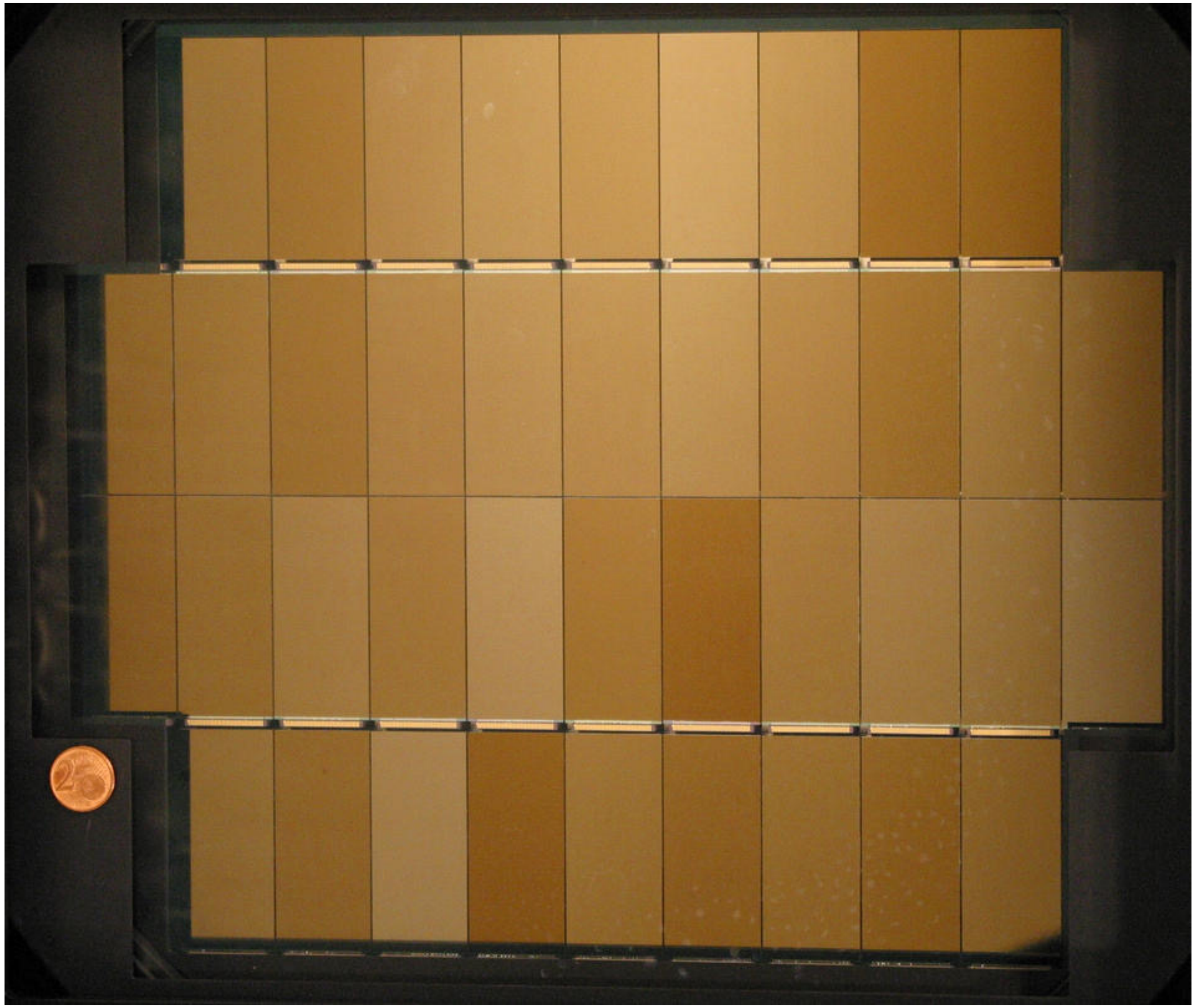
准备知识

望远镜空间分辨本领：

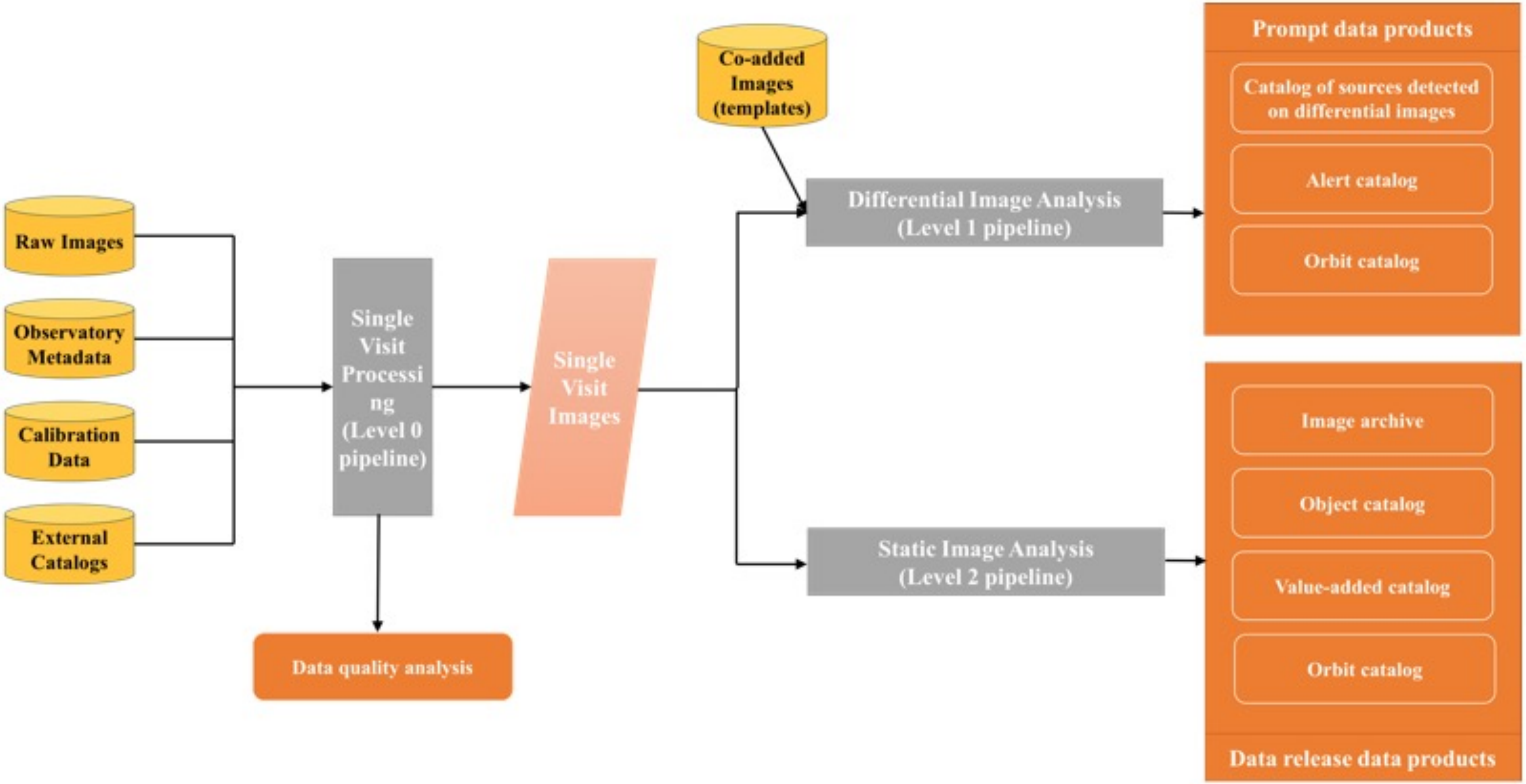
衍射极限

大气湍流

探测器采样
（焦面比例尺）

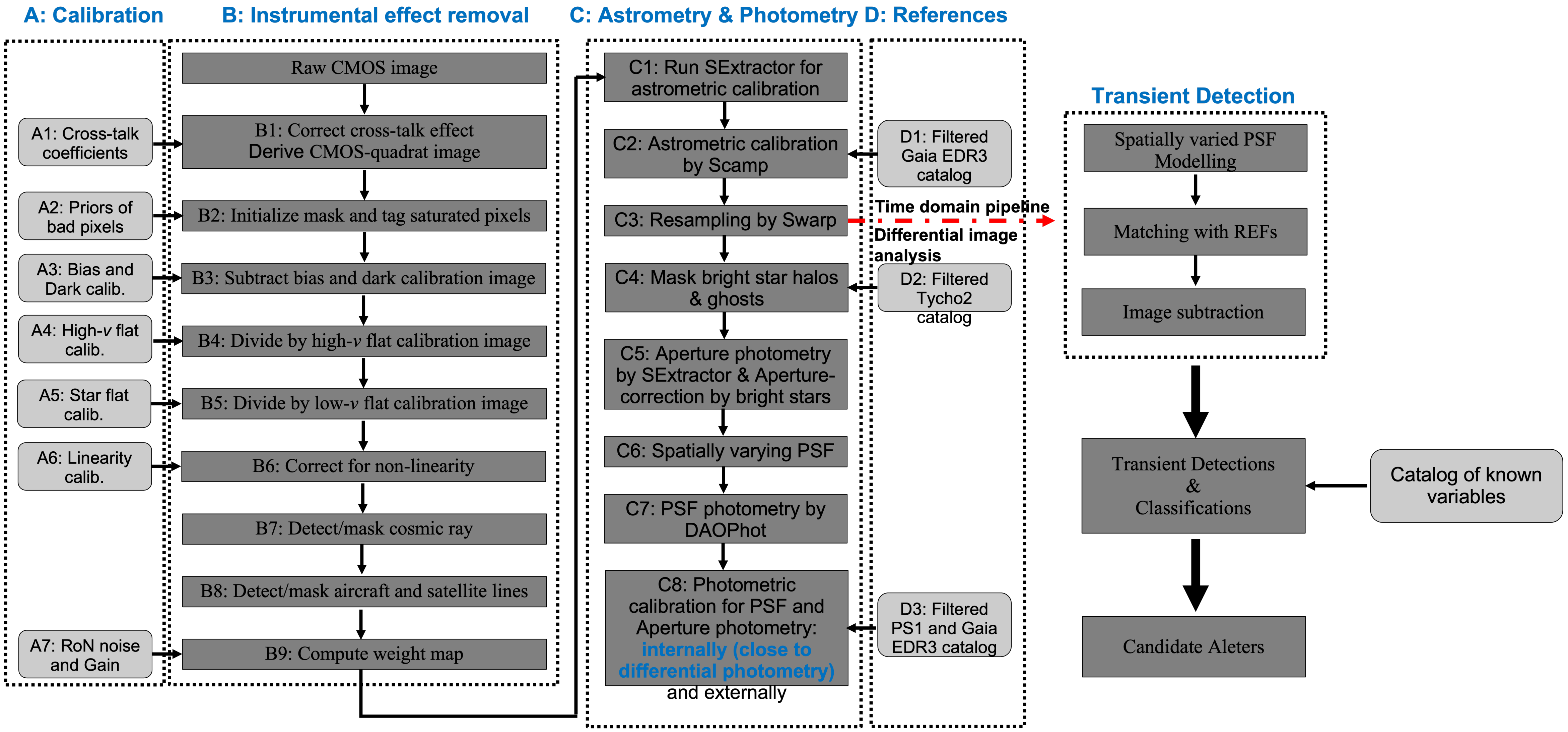


测光数据处理纵览


Raw Images
Observatory Metadata
Calibration Data
External Catalogs
Single Visit Processing (Level 0 pipeline)
Single Visit Images
Data quality analysis
Co-added Images (templates)
Differential Image Analysis (Level 1 pipeline)
Static Image Analysis (Level 2 pipeline)
Prompt data products
Catalog of sources detected on differential images
Alert catalog
Orbit catalog
Image archive
Object catalog
Value-added catalog
Orbit catalog
Data release data products

测光数据处理纵览

SiTian imagE Processesing pipeline (STEP)



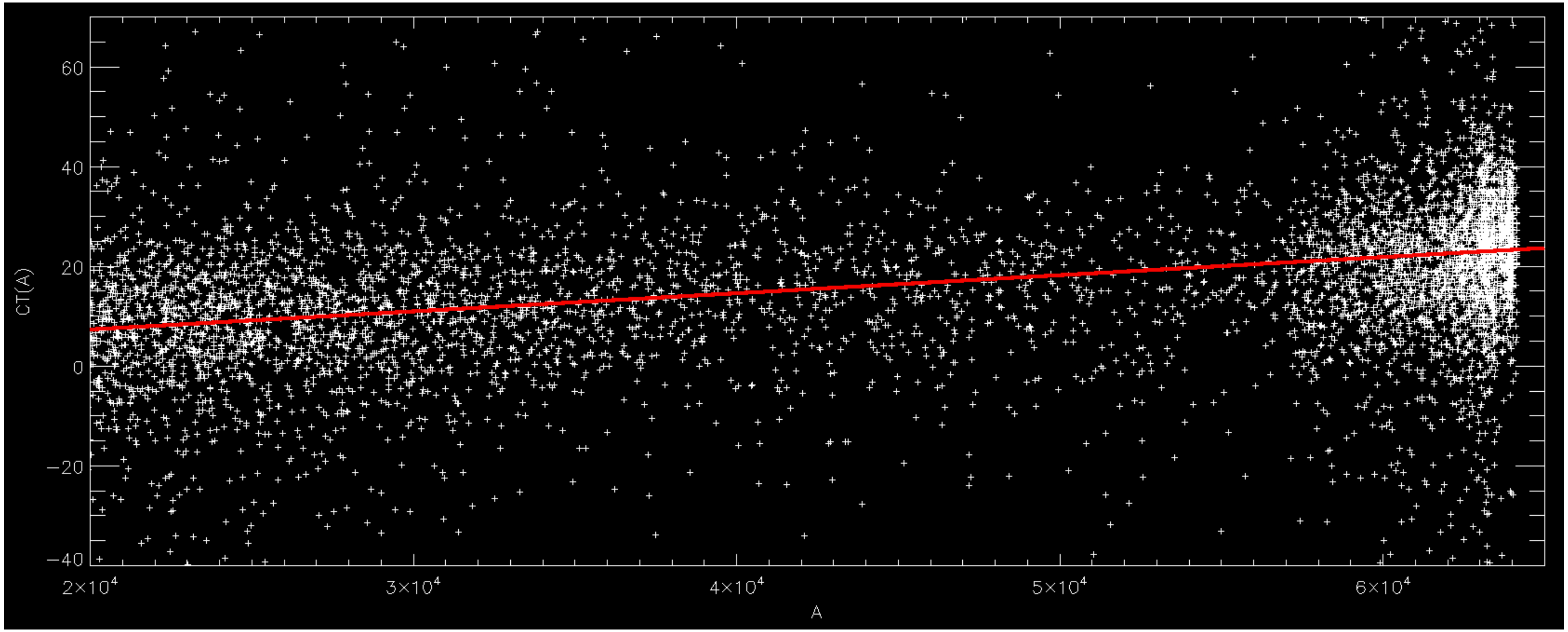
探测器性能标定

CCD Cross-talk:

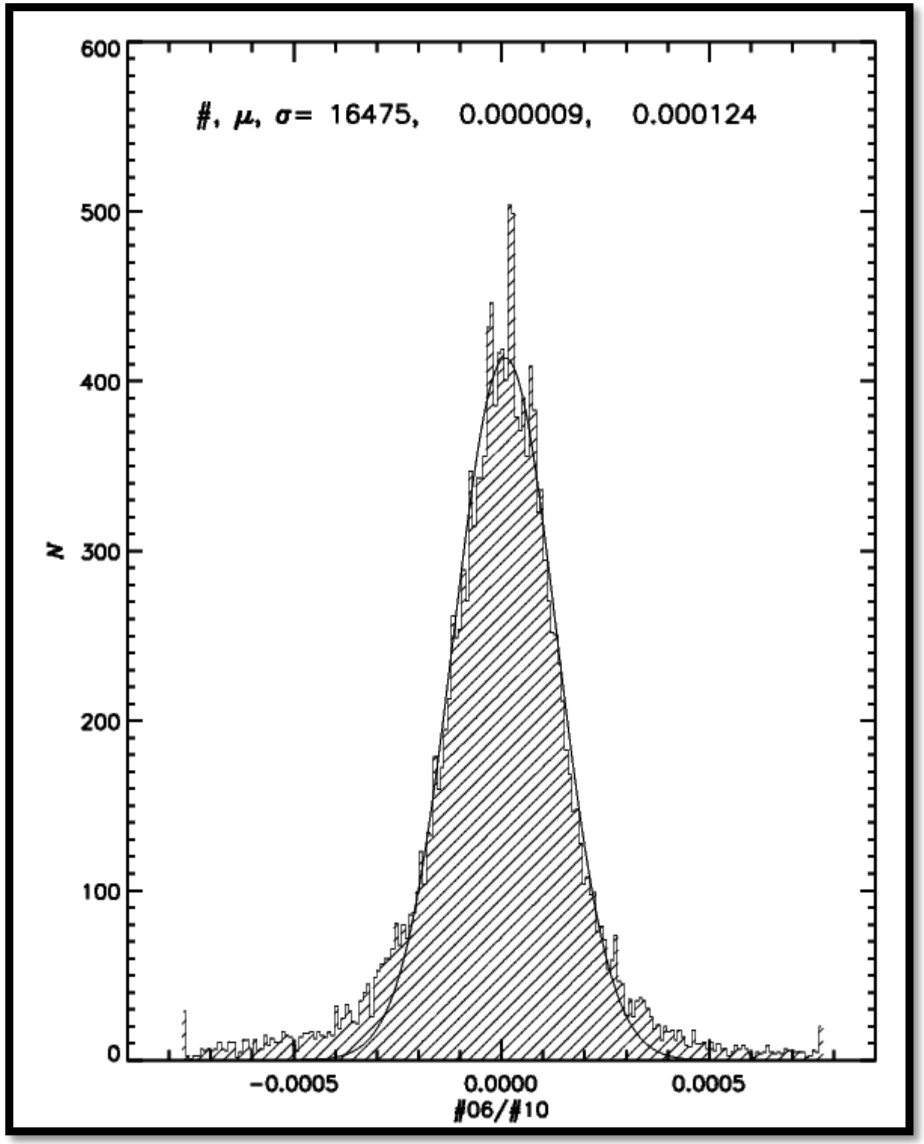
BASS CCD #1 Four amplifiers

Cross-talk effect: typically in the level of 1:1000 to 1:10000.

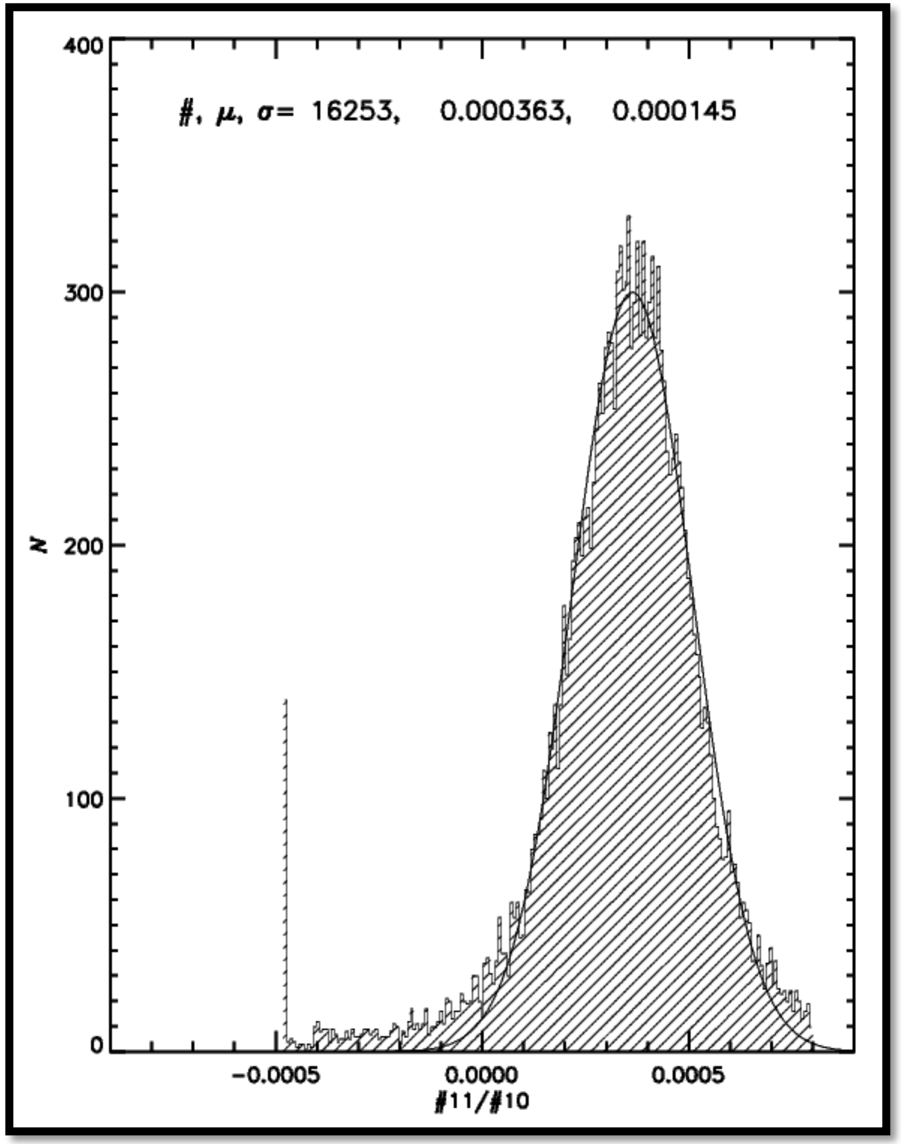
探测器性能标定



探测器性能标定



#, μ, σ= 16475, 0.000009, 0.000124
N
600
500
400
300
200
100
0
−0.0005
0.0000
0.0005
#06/#10



#, μ, σ= 16253, 0.000363, 0.000145
N
400
300
200
100
0
−0.0005
0.0000
0.0005
#11/#10

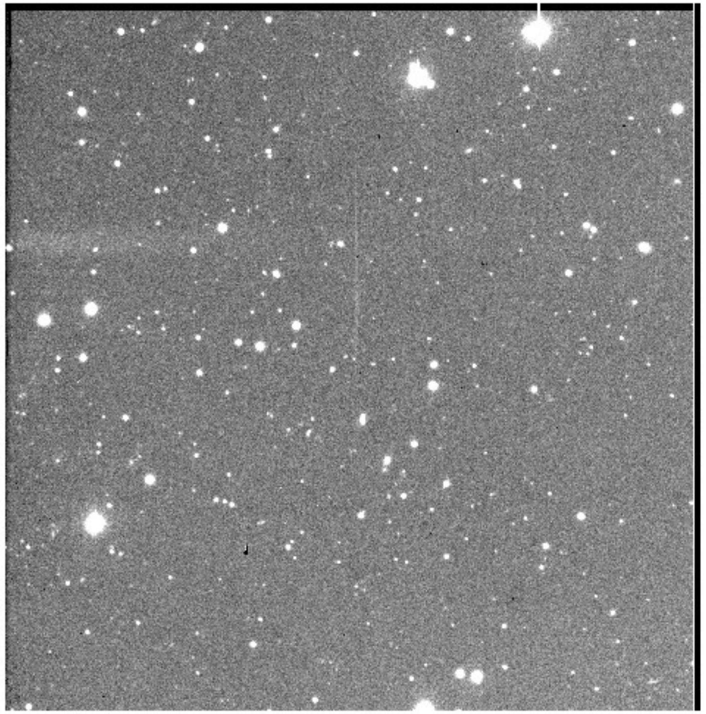
探测器性能标定

HDU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	−23	−33	−30	1	2	2	2	1	−1	1	1	2	2	1	3
2	−17	0	−24	−23	1	1	2	3	1	0	1	1	2	3	3	3
3	−10	−8	0	−11	1	1	2	2	1	0	1	1	2	2	2	4
4	−11	−9	−11	0	2	−4	2	2	1	0	0	1	1	2	2	2
5	3	3	3	3	0	−33	−37	−27	2	−1	2	1	0	0	1	2
6	3	3	4	3	−10	0	−17	−14	3	2	4	3	1	1	1	2
7	3	3	3	3	−11	−14	0	−6	2	1	2	2	1	2	2	2
8	3	3	4	4	−9	−6	−5	0	1	3	4	2	0	1	1	1
9	3	2	3	2	1	1	2	2	0	−16	−23	−19	3	3	2	2
10	2	1	2	1	0	1	1	1	−31	0	−40	−32	2	2	2	2
11	3	2	2	1	0	−1	1	1	−25	−16	0	−17	2	2	1	2
12	3	2	3	2	1	1	2	2	−15	−11	−8	0	−2	1	2	1
13	4	3	4	3	−1	0	1	1	−9	0	1	3	0	−24	−26	−22
14	4	3	4	3	0	1	1	2	−9	1	1	−2	−24	0	−26	−22
15	4	4	5	4	1	1	1	2	−11	0	1	3	−13	−10	0	−5
16	5	5	5	5	−1	1	1	2	−7	−3	−1	0	−15	−14	−12	0

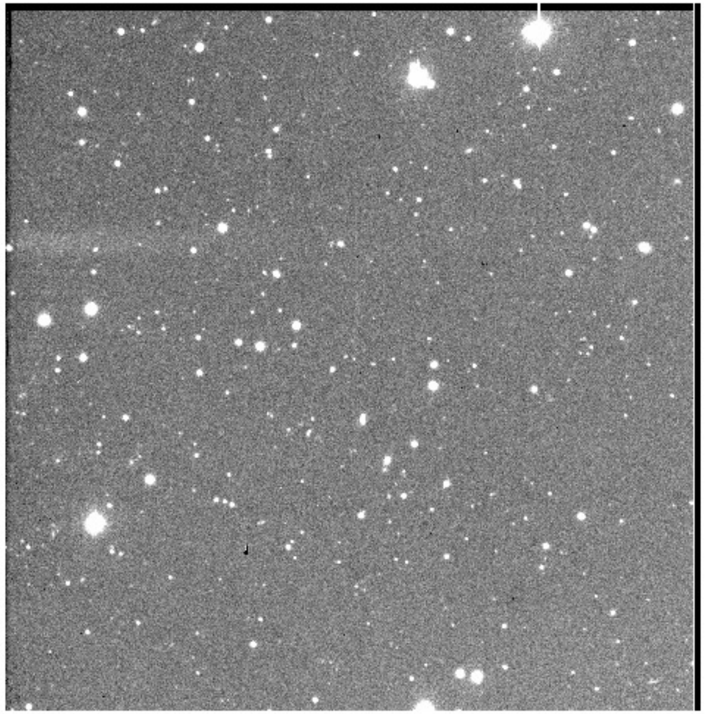
Note. The scale is 10^{-5}.

探测器性能标定

Before



After



探测器性能标定

CCD RoN & Gain:

$$\sigma_{\mathrm{ADU}} = \frac{\mathrm{Readout\ noise}}{\mathrm{Gain}}$$

$$\sigma_{\mathrm{ADU}} = \frac{\sqrt{<\mathrm{F}>\cdot \mathrm{Gain}}}{\mathrm{Gain}}$$

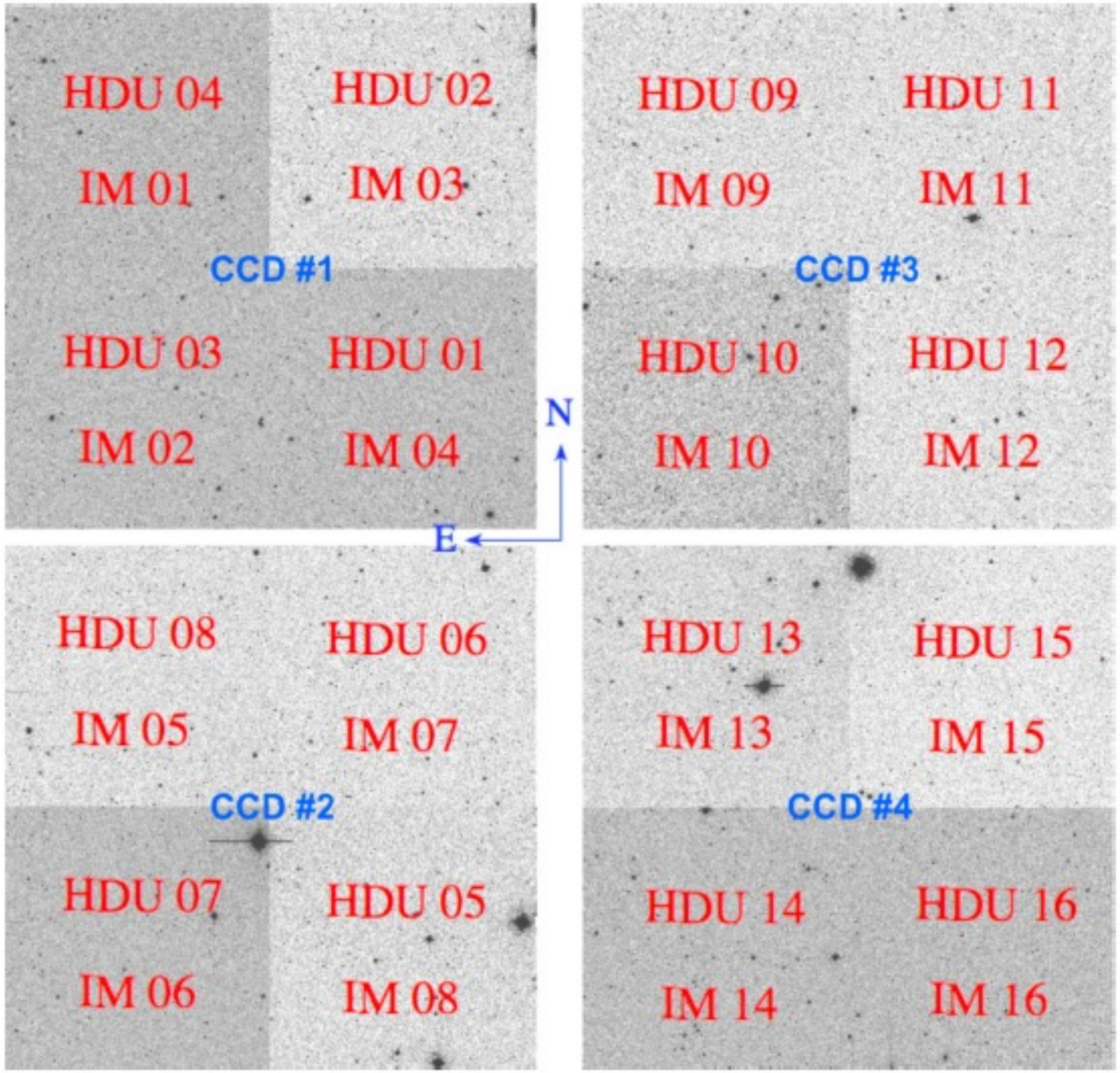
探测器性能标定

CCD RoN & Gain:

$$\mathrm{Gain} = \frac{(<F1>+<F2>)-(<B1>+<B2>)}{\sigma^2_{F1-F2}-\sigma^2_{B1-B2}}$$

$$\text{Readout noise} = \frac{\mathrm{Gain}\cdot\sigma_{B1-B2}}{\sqrt{2}}$$

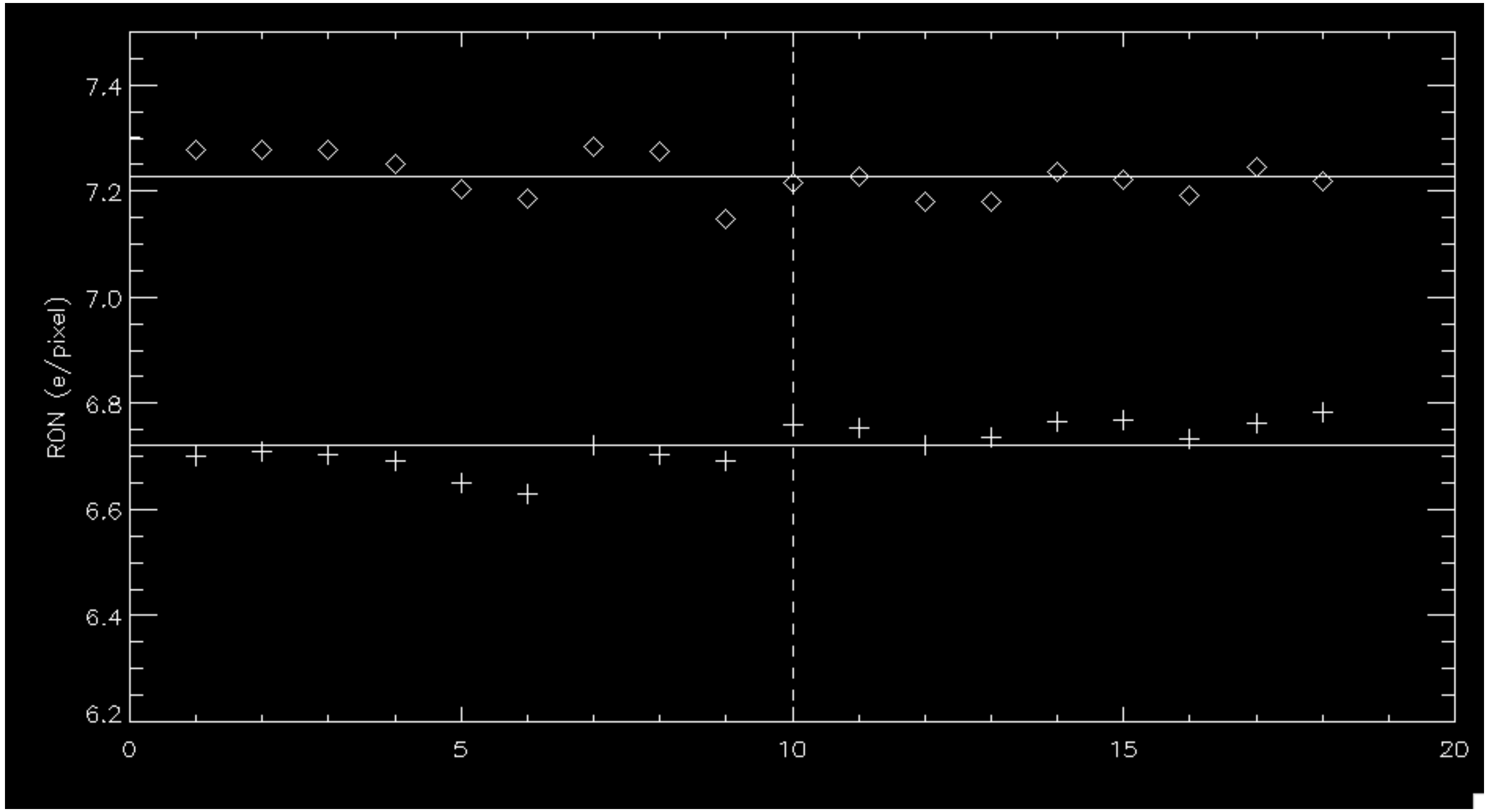
探测器性能标定


HDU 04
IM 01
HDU 02
IM 03
CCD #1
HDU 03
IM 02
HDU 01
IM 04
HDU 09
IM 09
HDU 11
IM 11
CCD #3
HDU 10
IM 10
HDU 12
IM 12
N
E
HDU 08
IM 05
HDU 06
IM 07
CCD #2
HDU 07
IM 06
HDU 05
IM 08
HDU 13
IM 13
HDU 15
IM 15
CCD #4
HDU 14
IM 14
HDU 16
IM 16

探测器性能标定

Readout noise

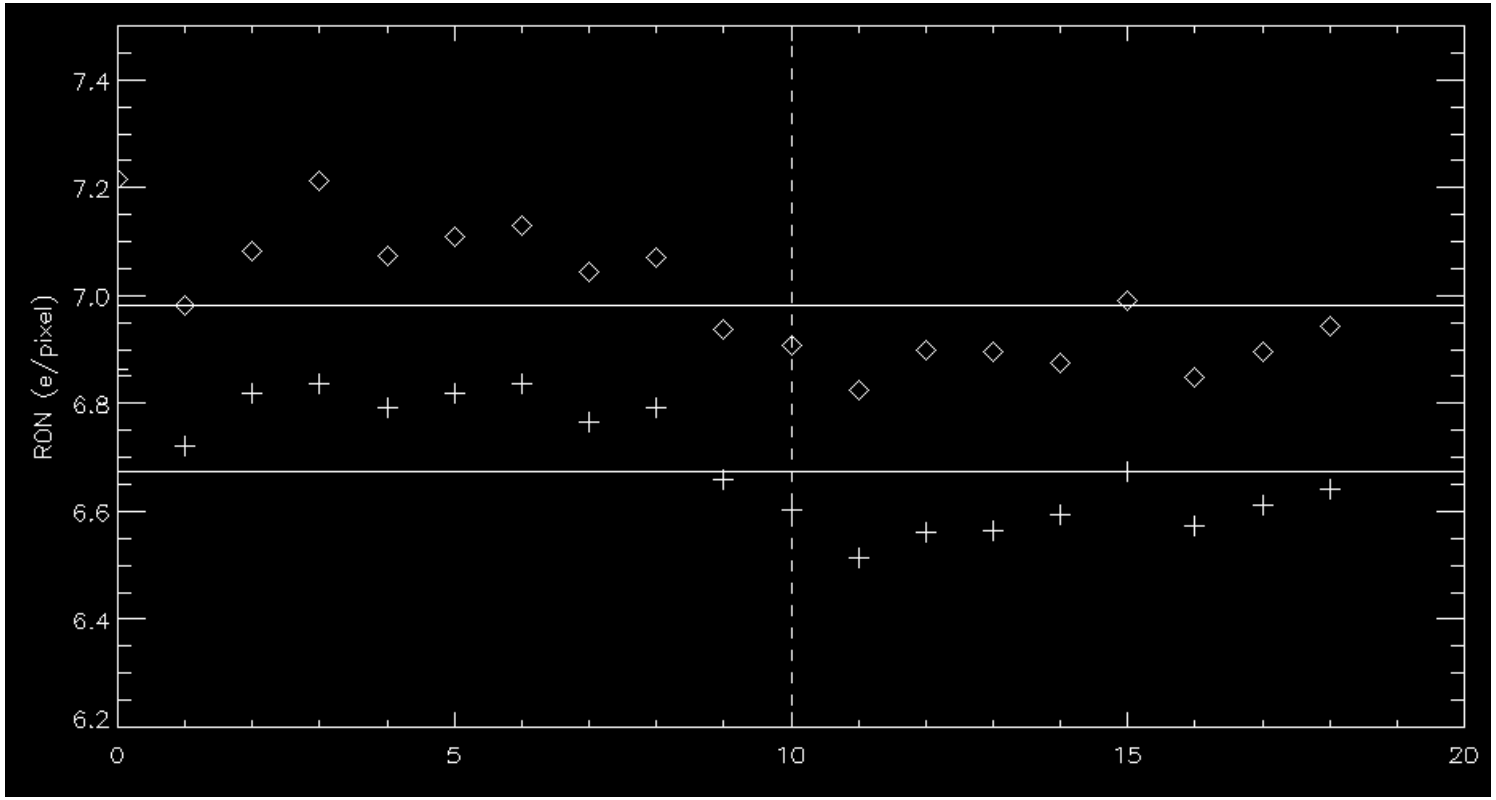
20160207



探测器性能标定

Readout noise

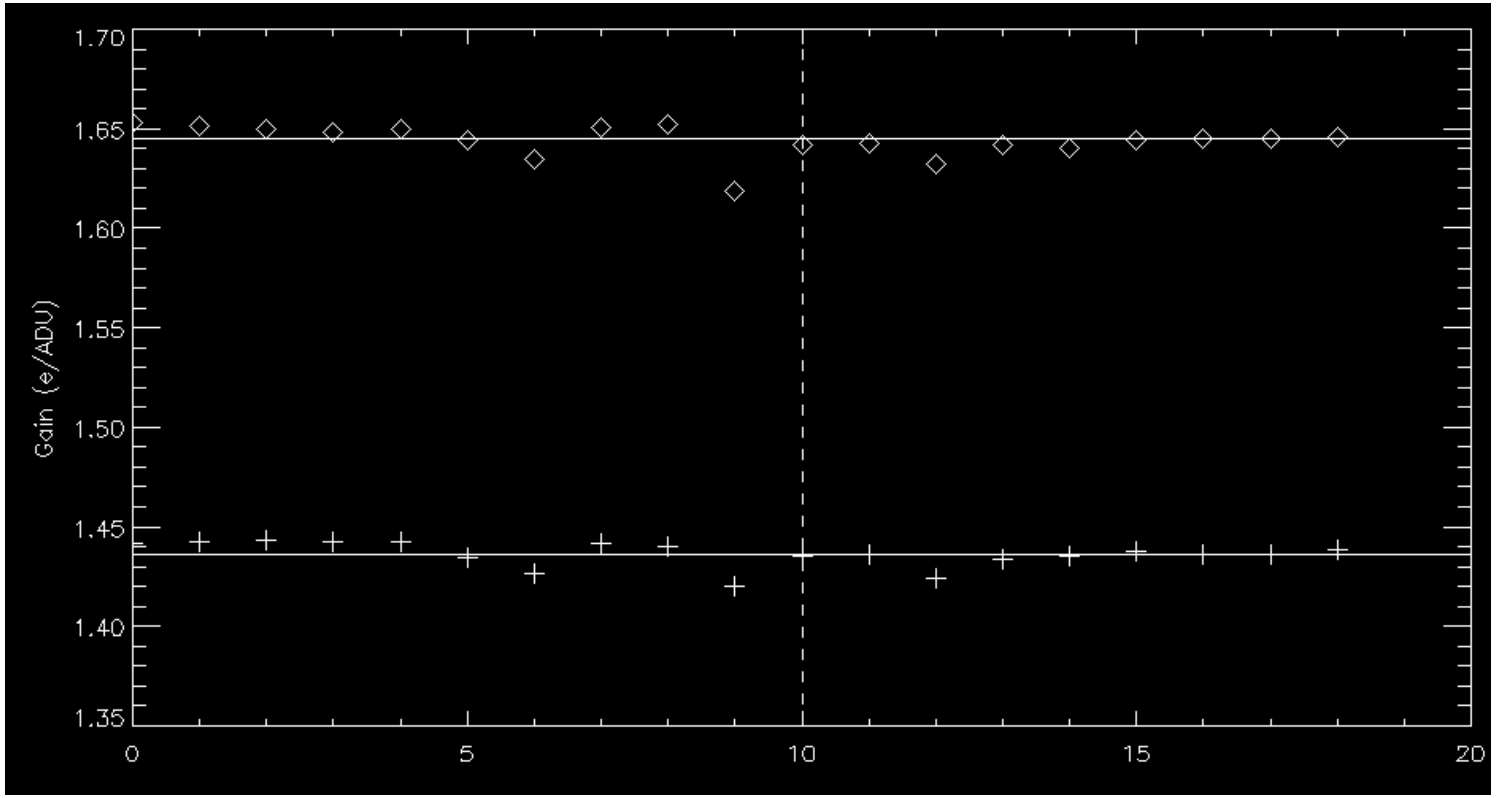
20160204



探测器性能标定

Gain

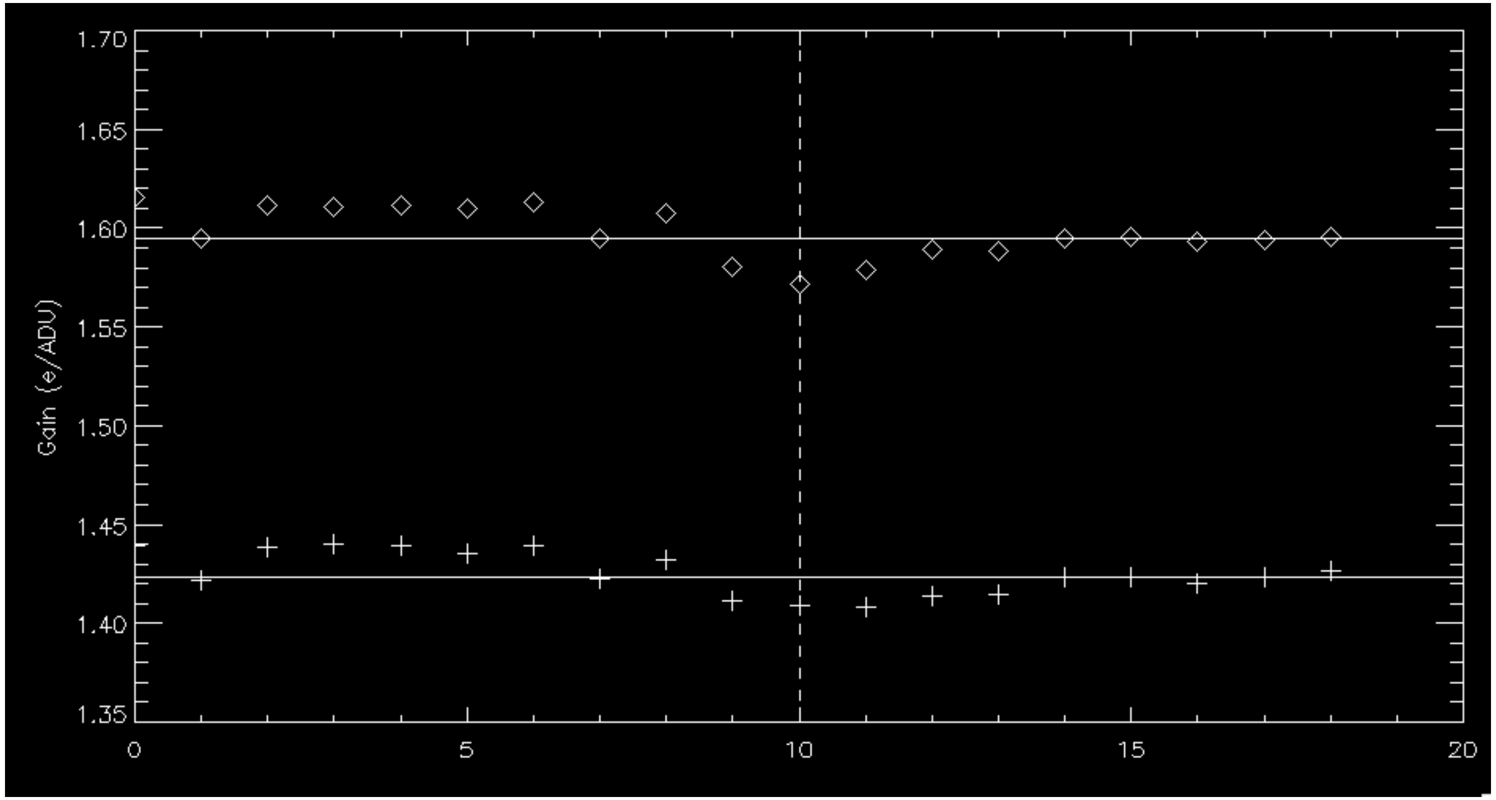
20160207



探测器性能标定

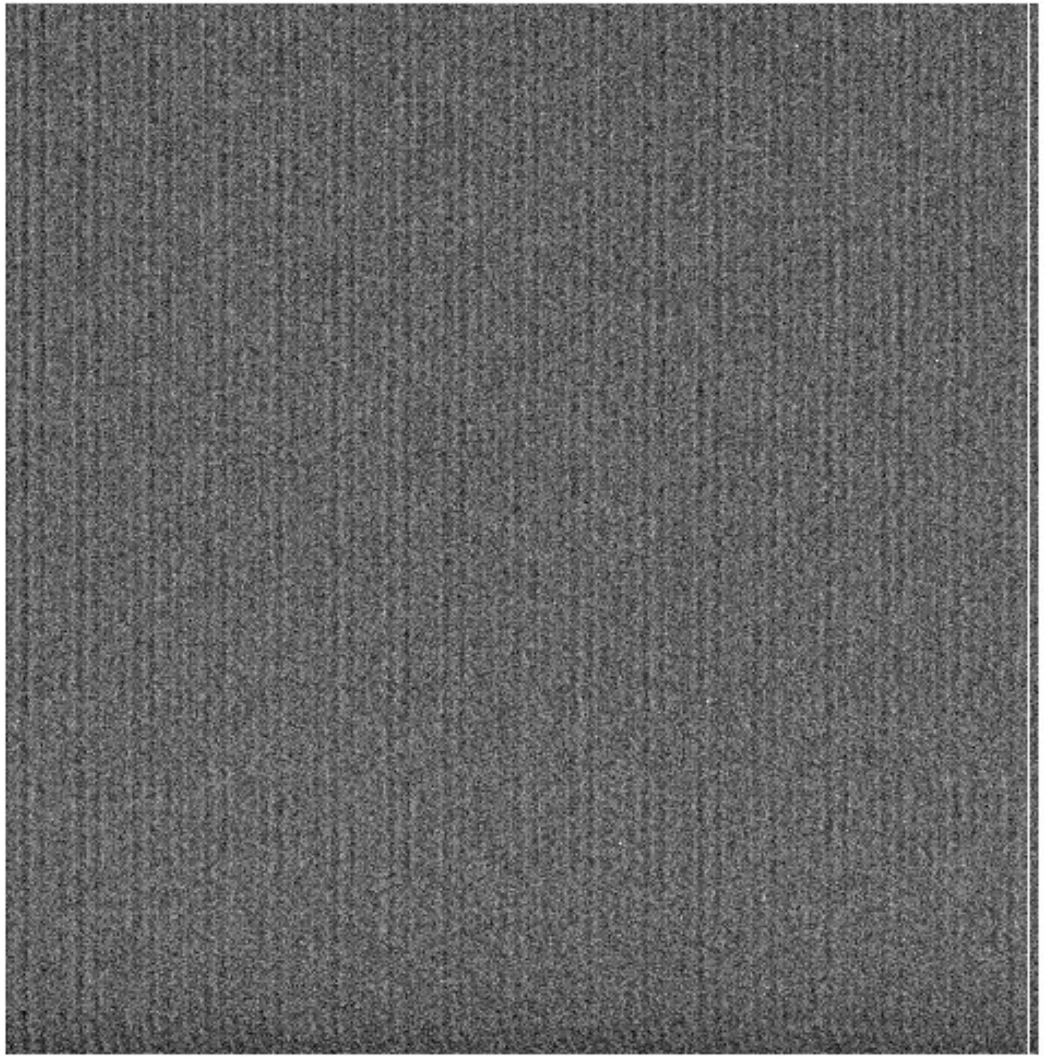
Gain

20160204



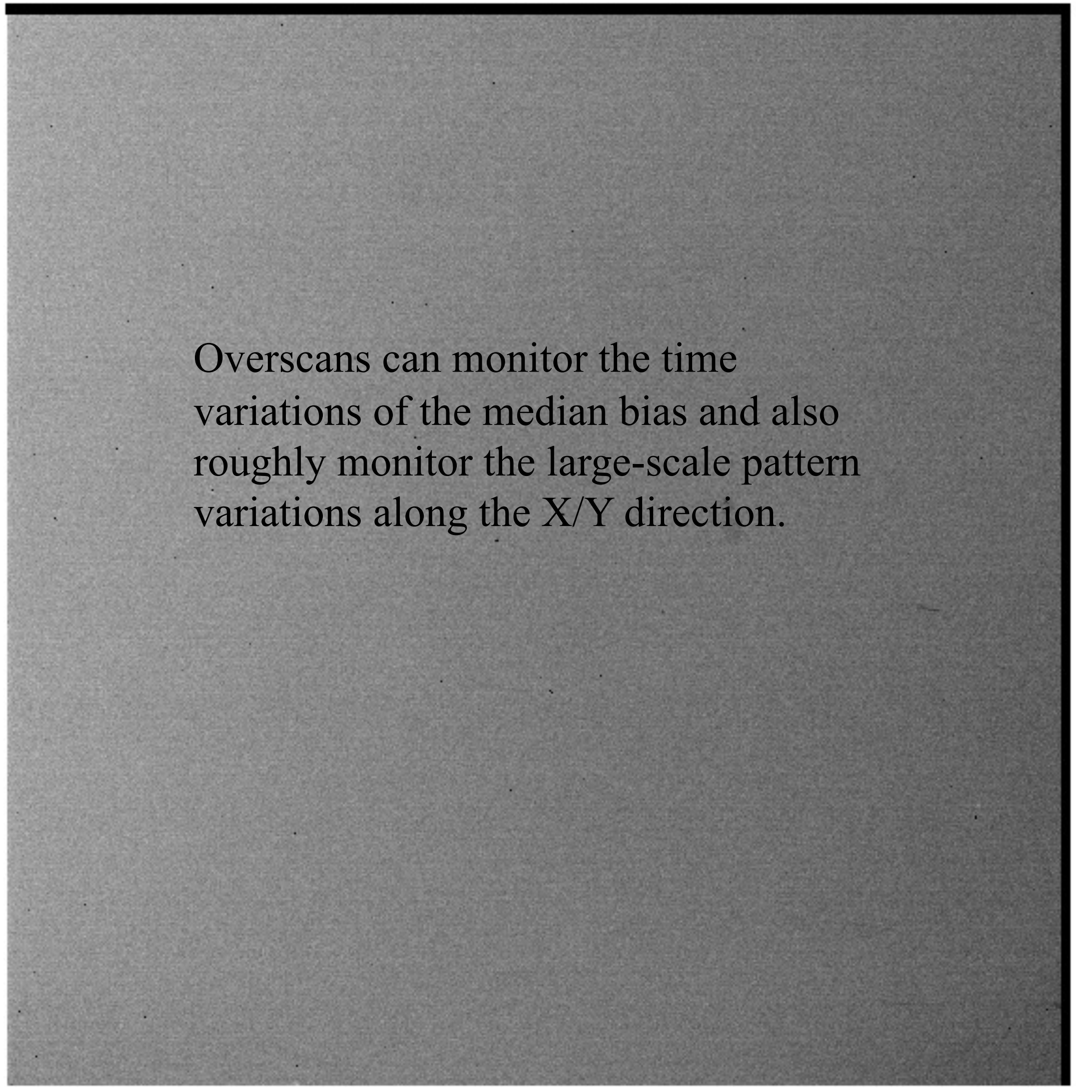
探测器性能标定

Bias (*X*, t)



探测器性能标定

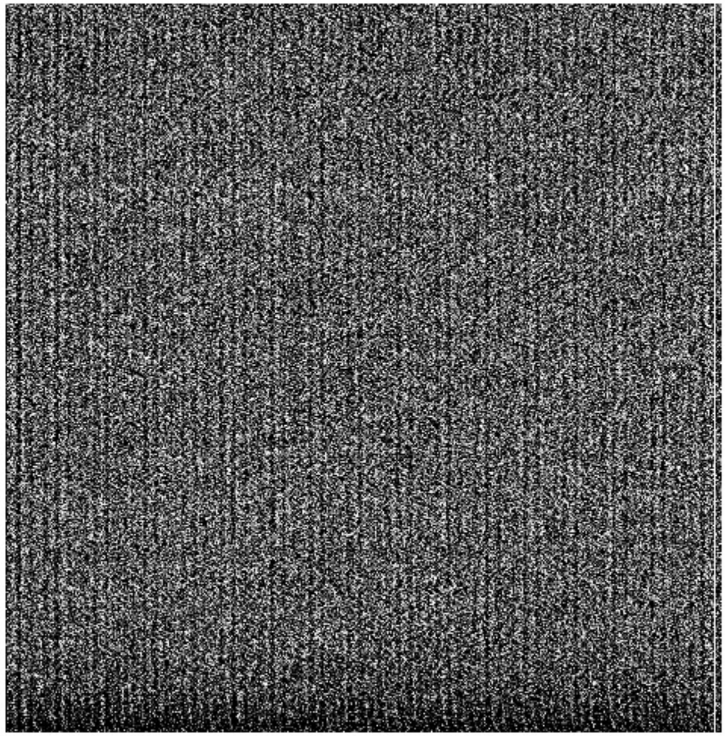
Overscan(s)



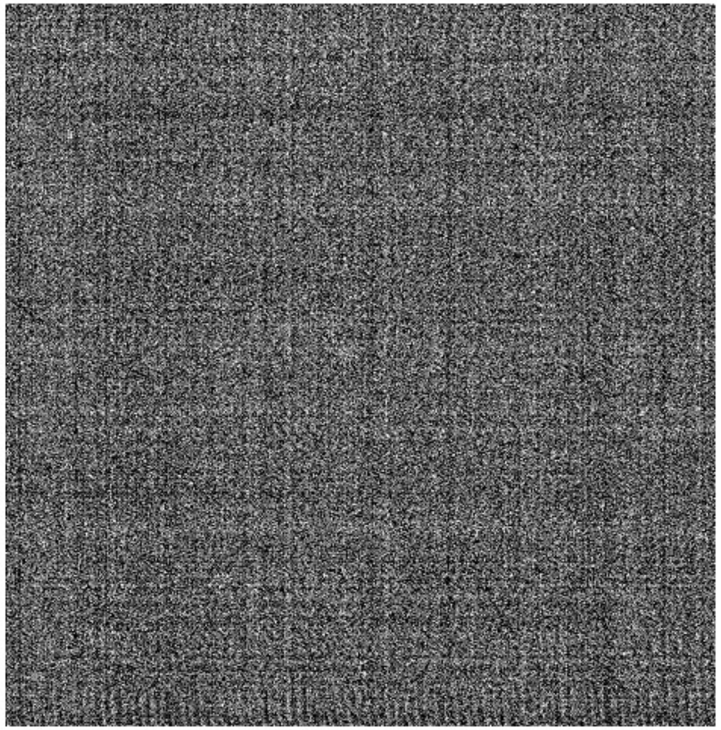
探测器性能标定

Overscan(s)

Bias

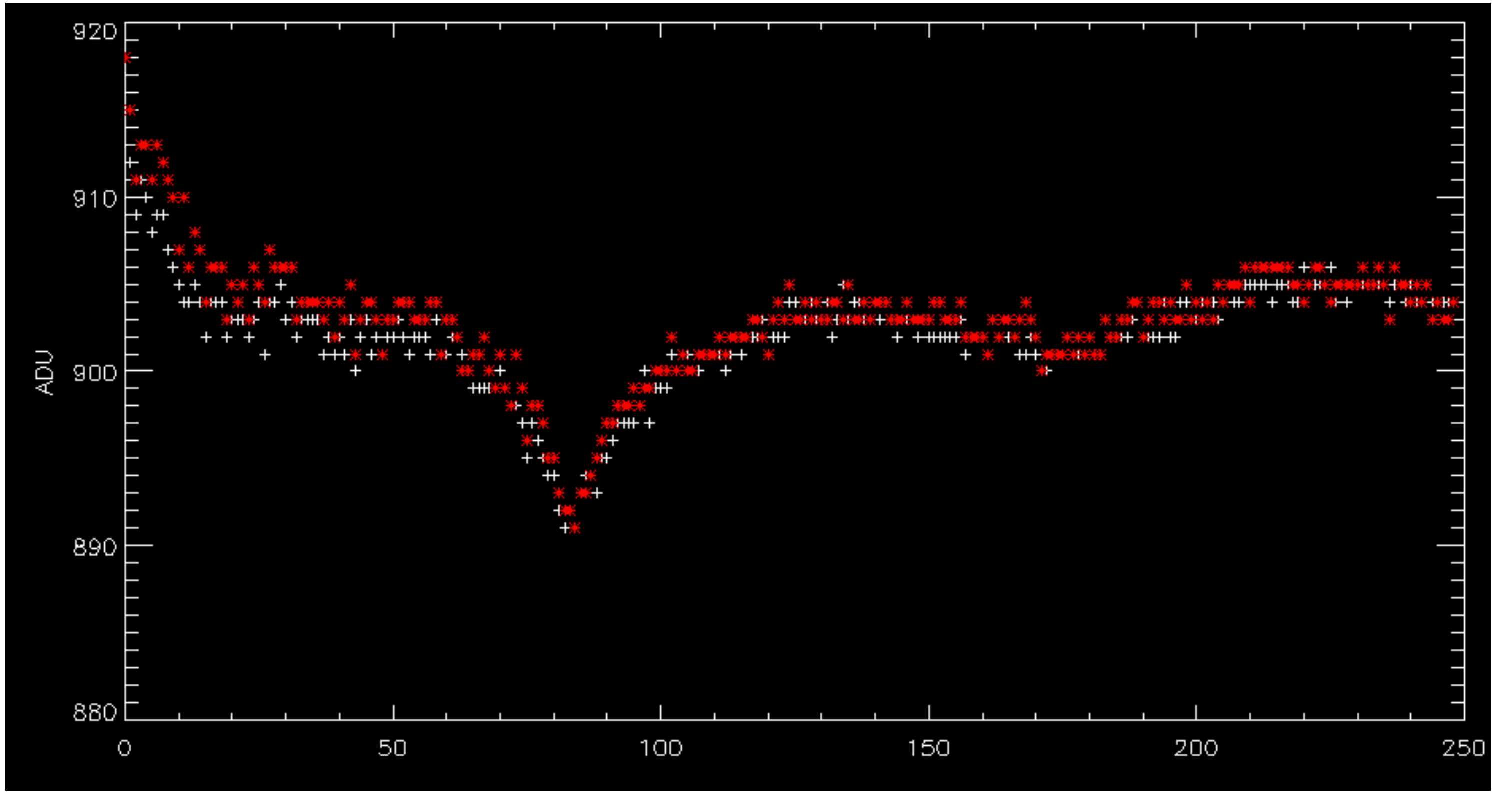


Bias - overscan



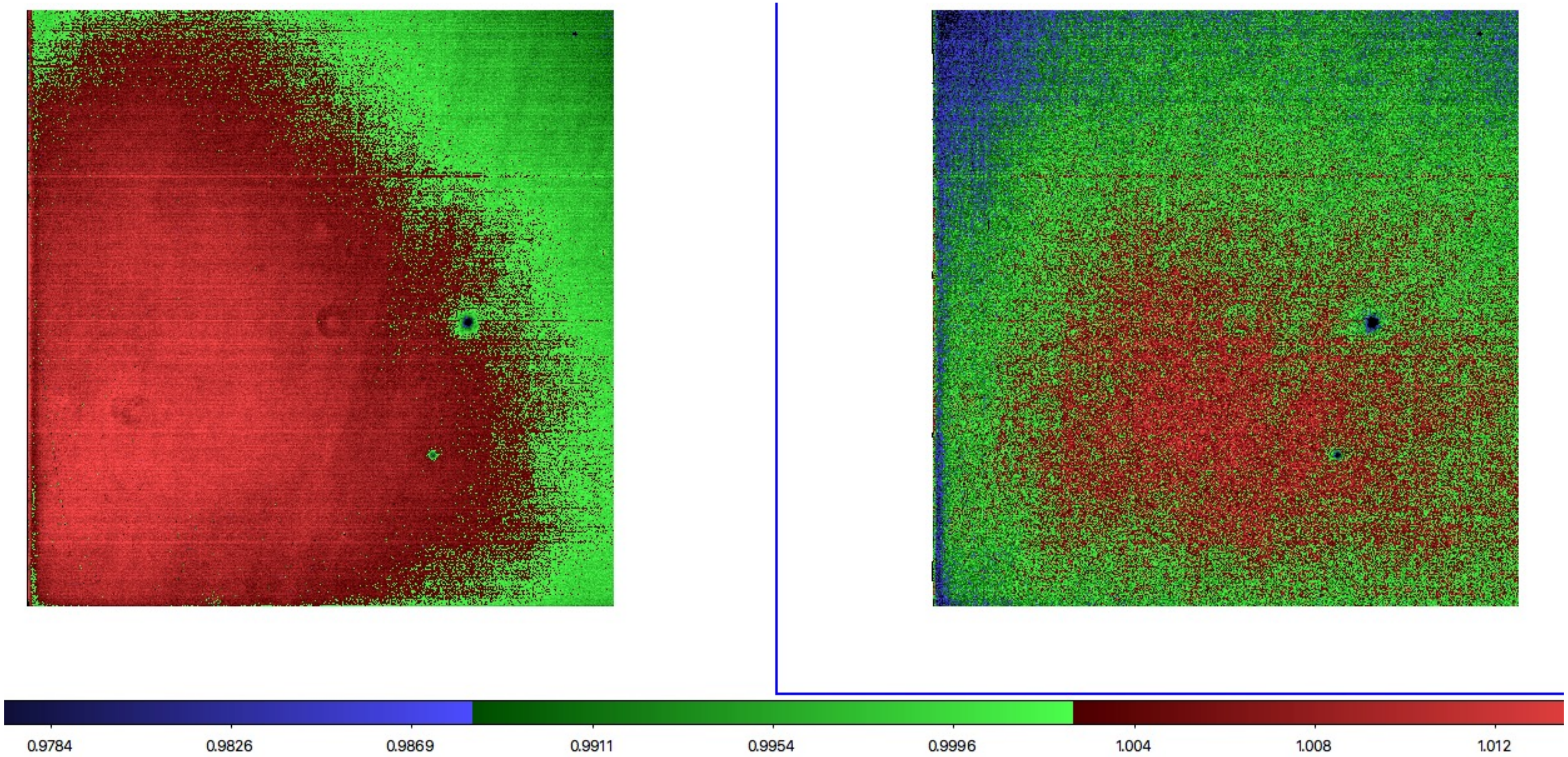
探测器性能标定

Overscan(s)



探测器性能标定

Flat: small (QE) + large (dust, vignetting) spatial variations



Dome flat

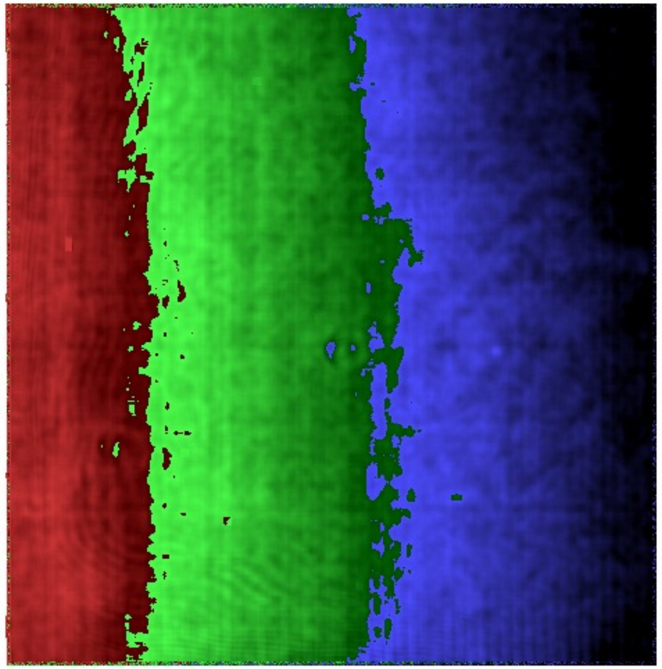
Sky flat

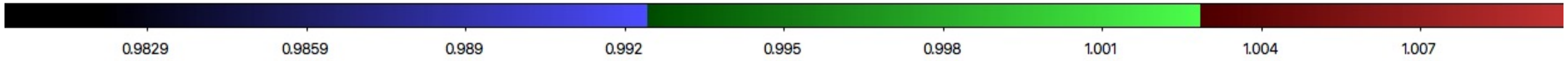
探测器性能标定

Flat: small (QE) + large (dust, vignetting) spatial variations

Dome: S*L*I

Sky: S (low SNR)*L

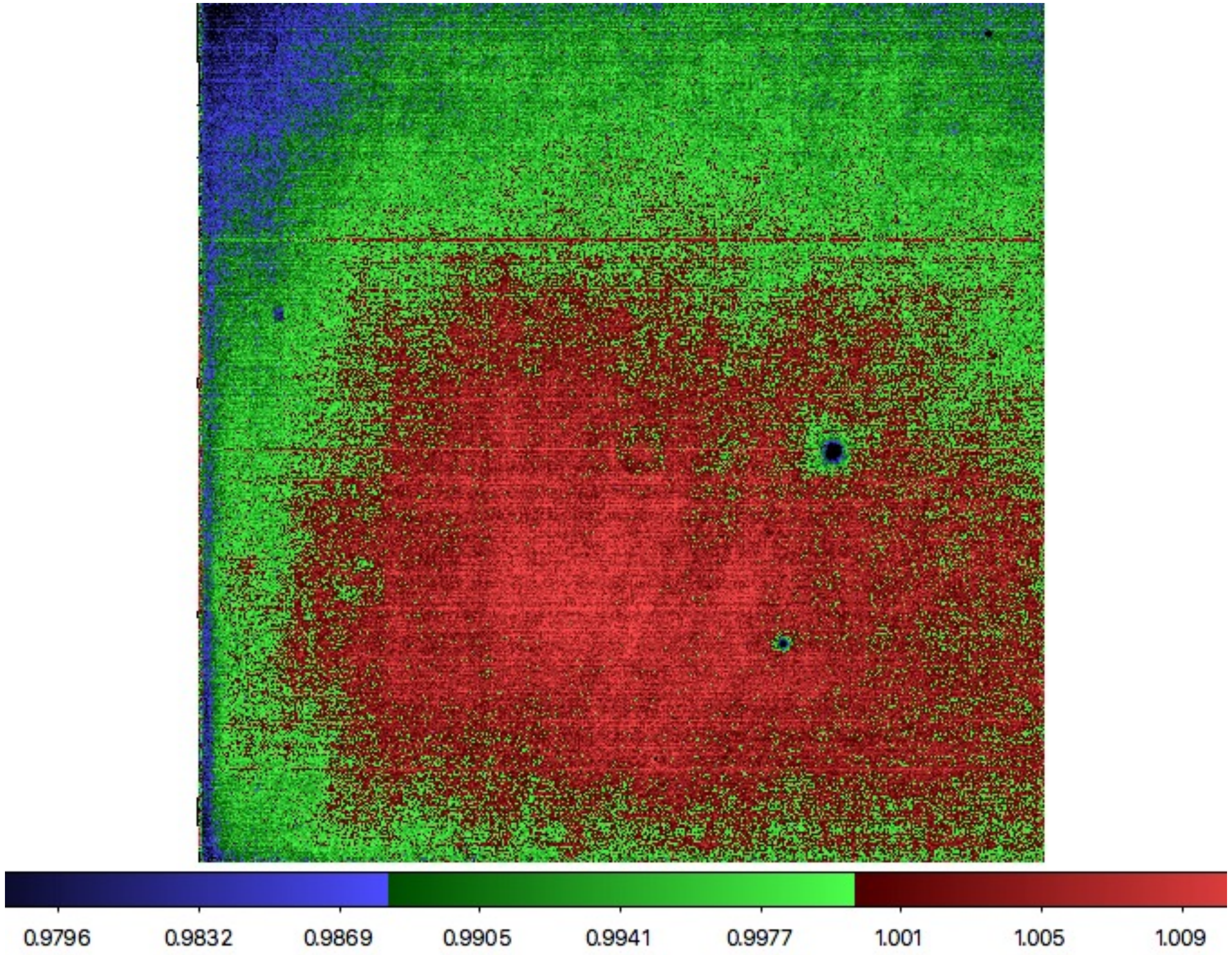




Dome/Sky

探测器性能标定

Flat: small (QE) + large (dust, vignetting) spatial variations



Dome/Smooth(Dome/Sky) Flat

探测器性能标定

Wavelength (& positional)-dependent instrumental response function

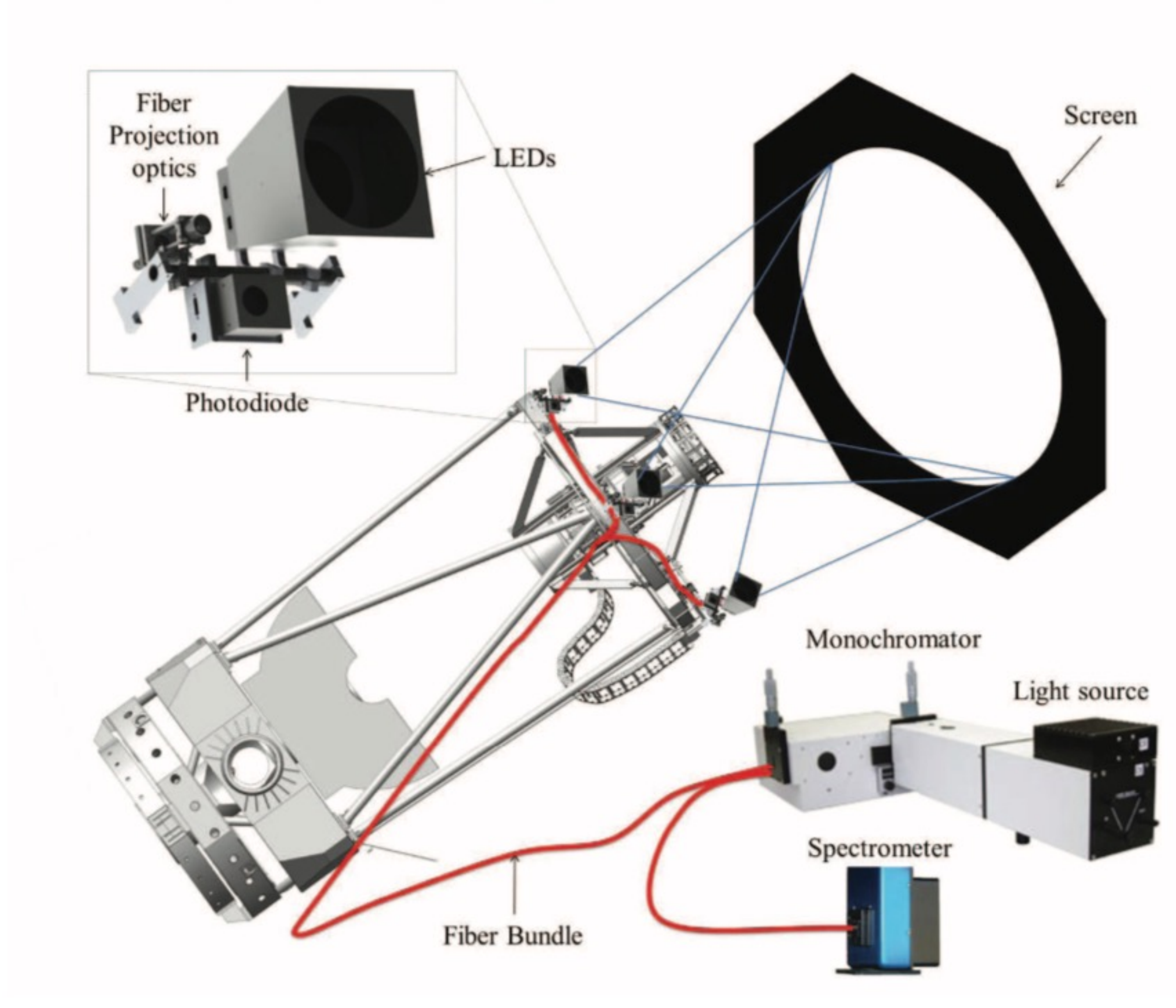
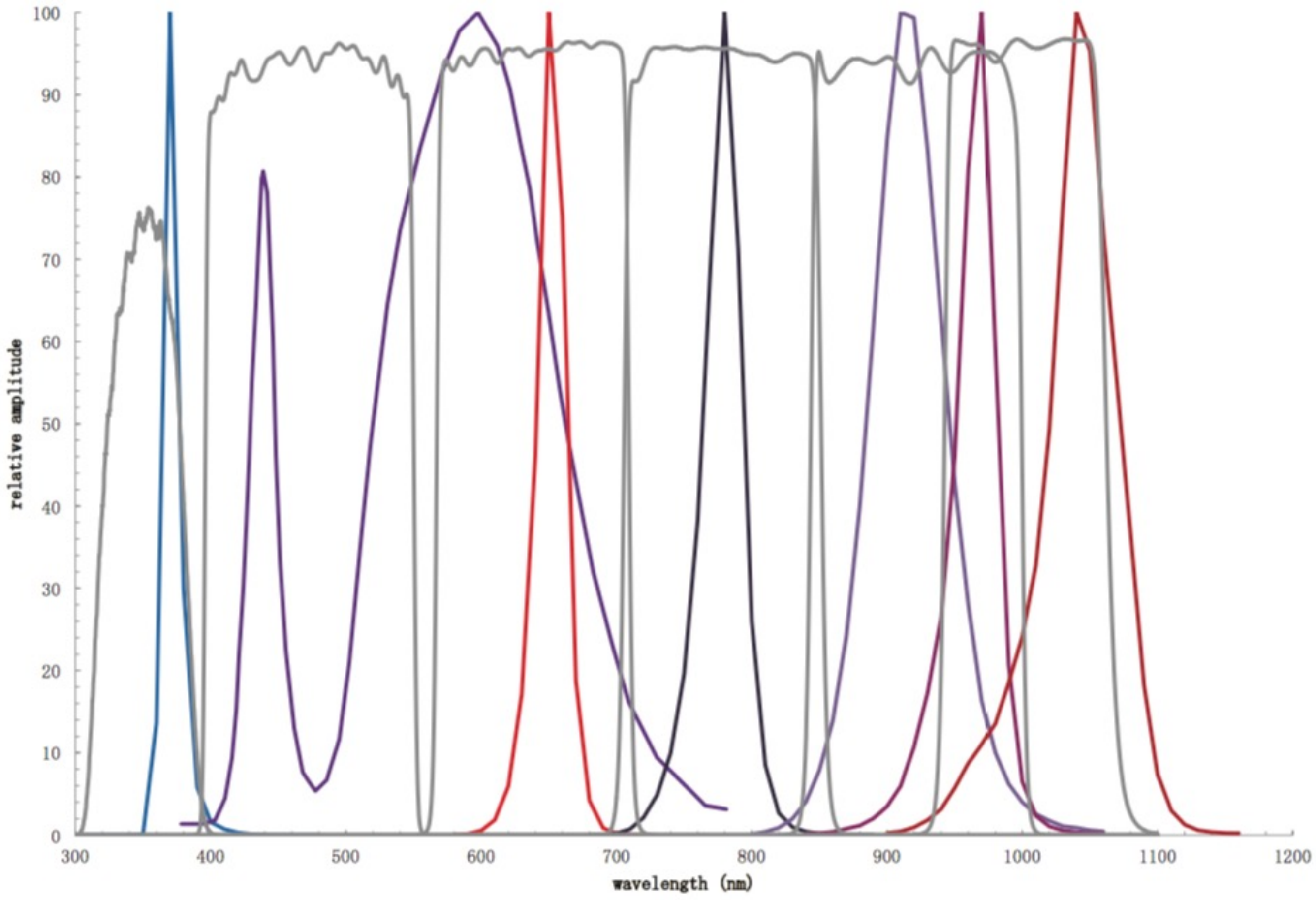


Figure 1. Schematic drawing of the DECal system.

Marshall et al. 2013

探测器性能标定

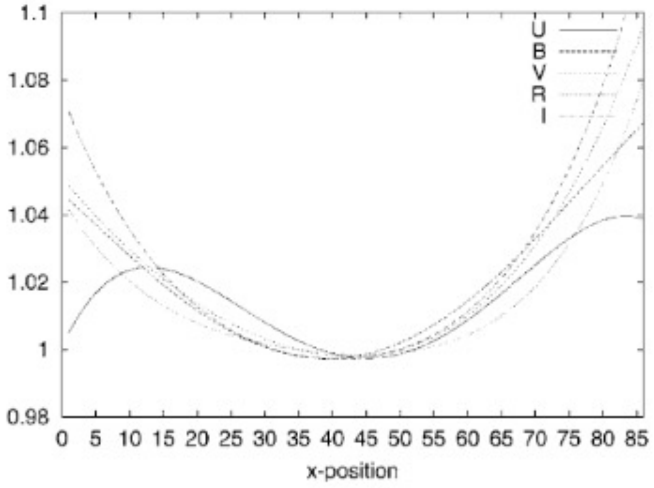
Flat-fielding strategy

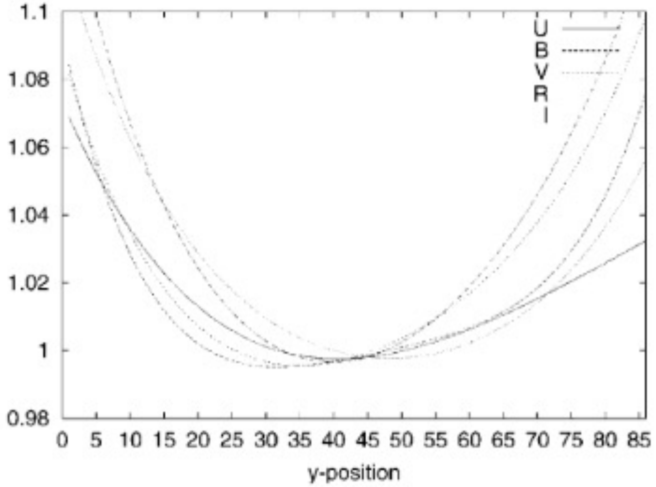


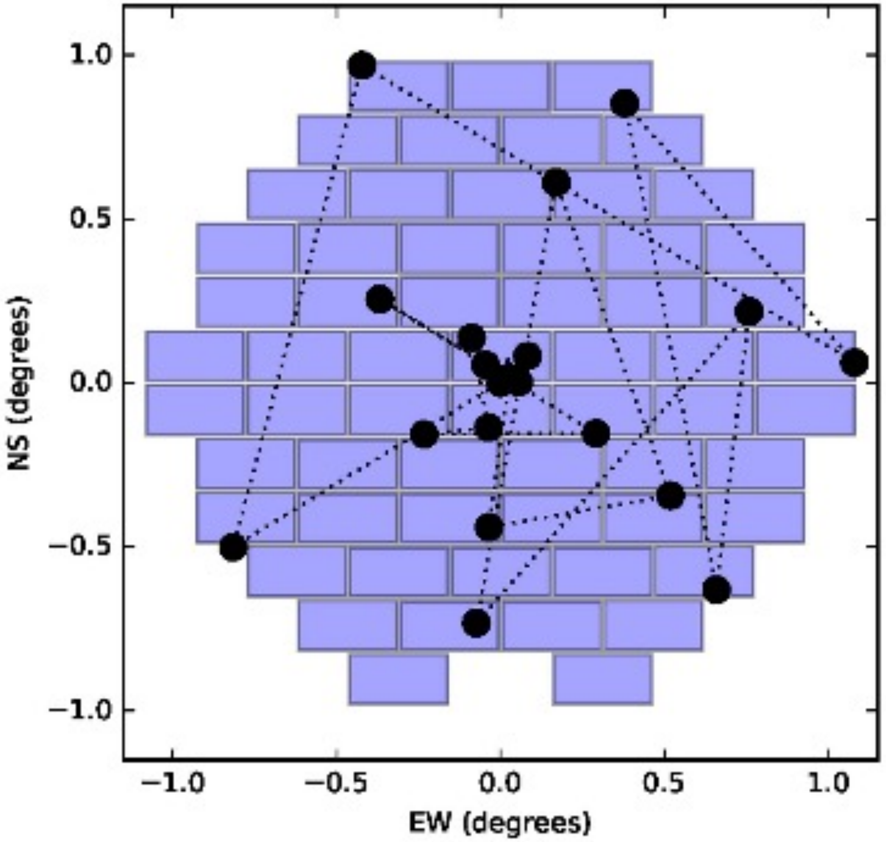
Marshall et al. 2013

探测器性能标定

“Star flats” (Manfroid 1995, 1996)





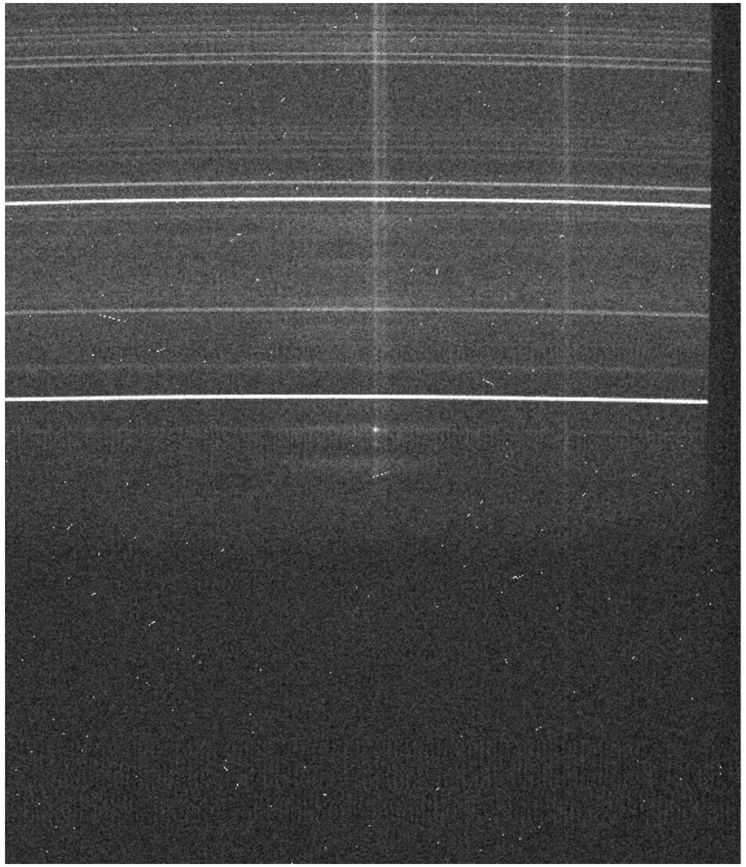


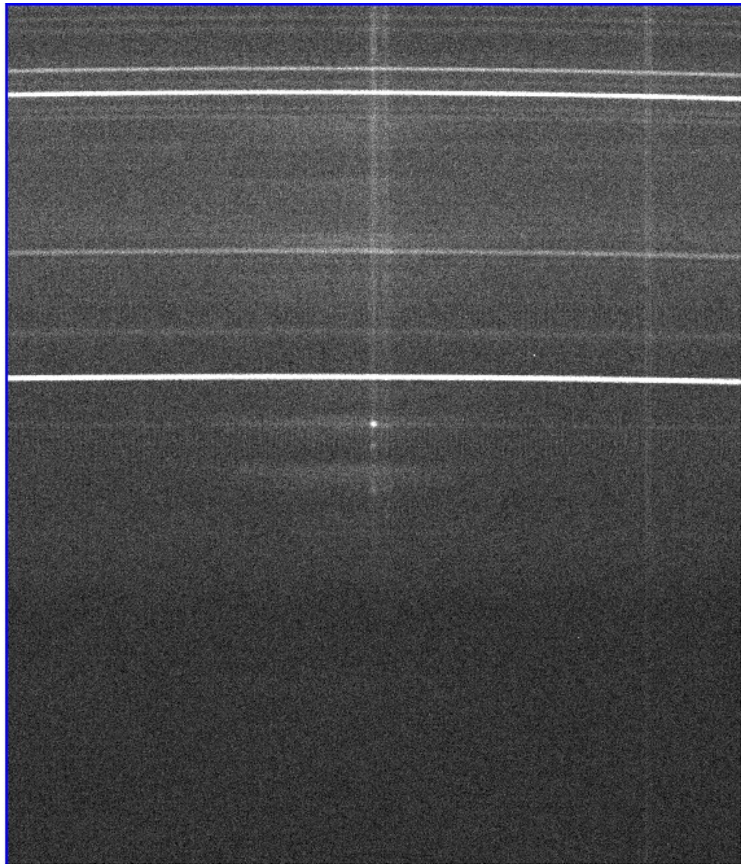
探测器性能标定

Multi-visits (including different bands): comparison or sigma-clipping

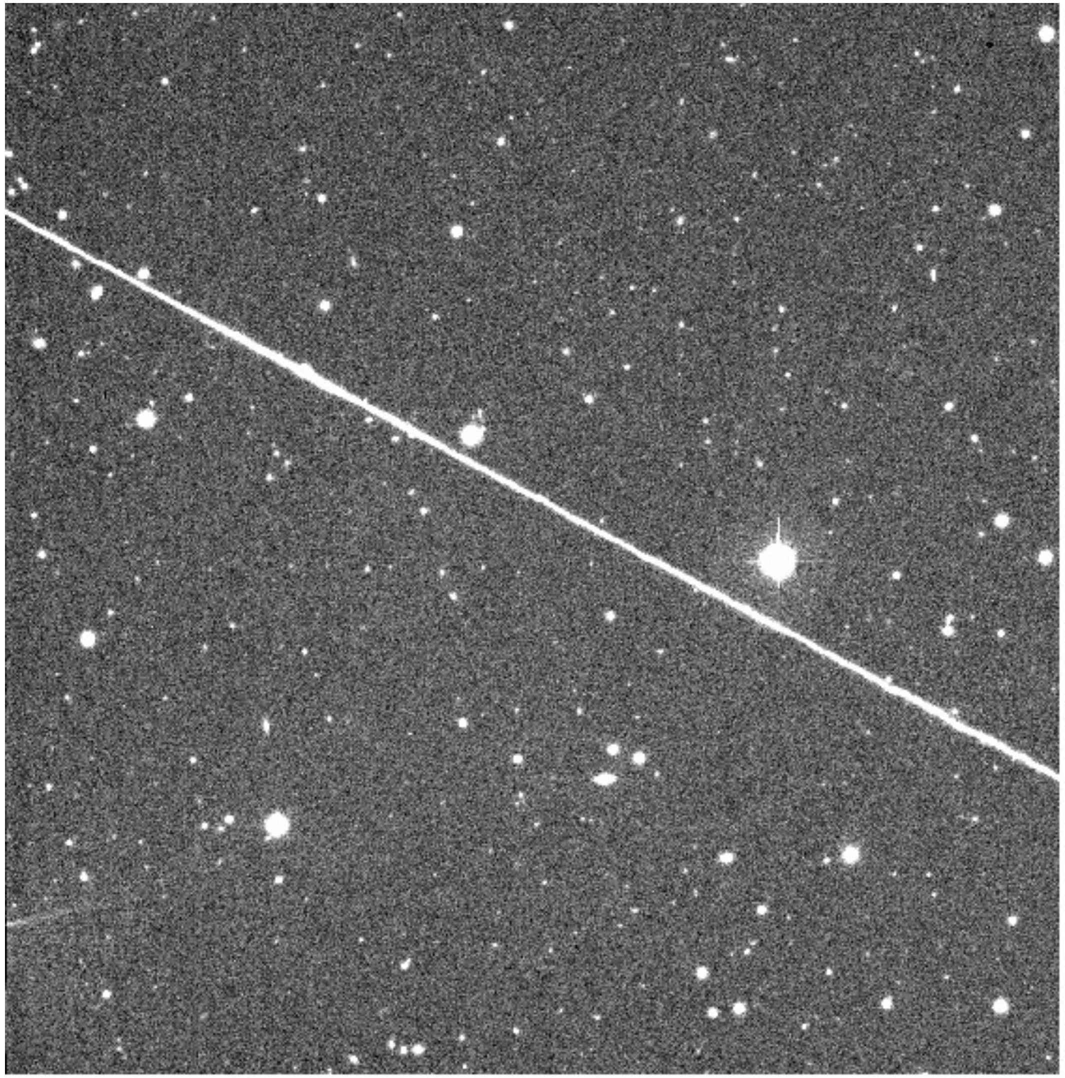
Single visit: median filter (2-3 s/frame)

Cosmic rays





探测器性能标定



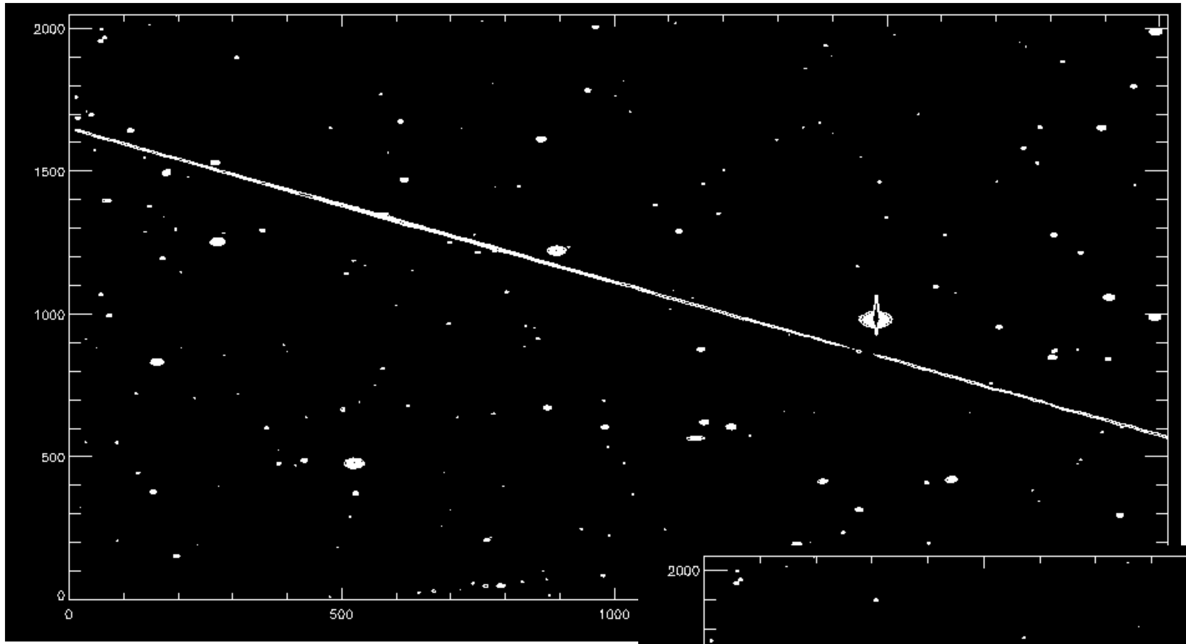
Hough transformation (Hough 1962)

$$y = a \cdot x + b$$

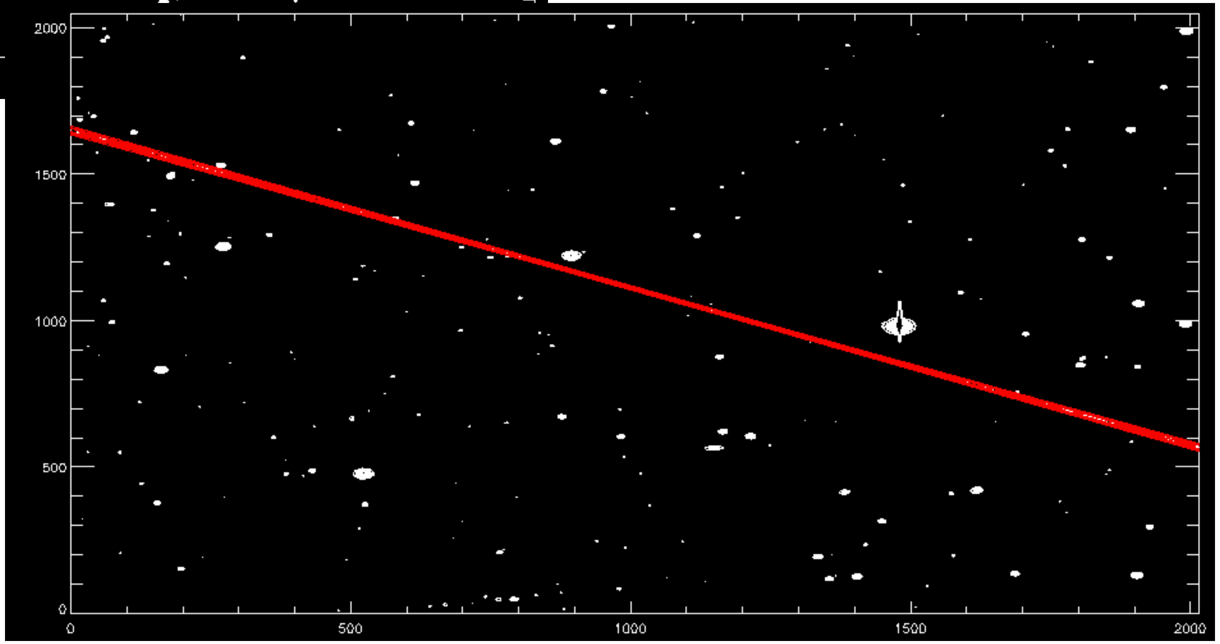
$$r = x \cdot \cos\theta + y \cdot \sin\theta \Leftrightarrow$$
$$y = -\frac{\cos\theta}{\sin\theta} \cdot x + \frac{r}{\sin\theta}$$

Satellite lines

探测器性能标定

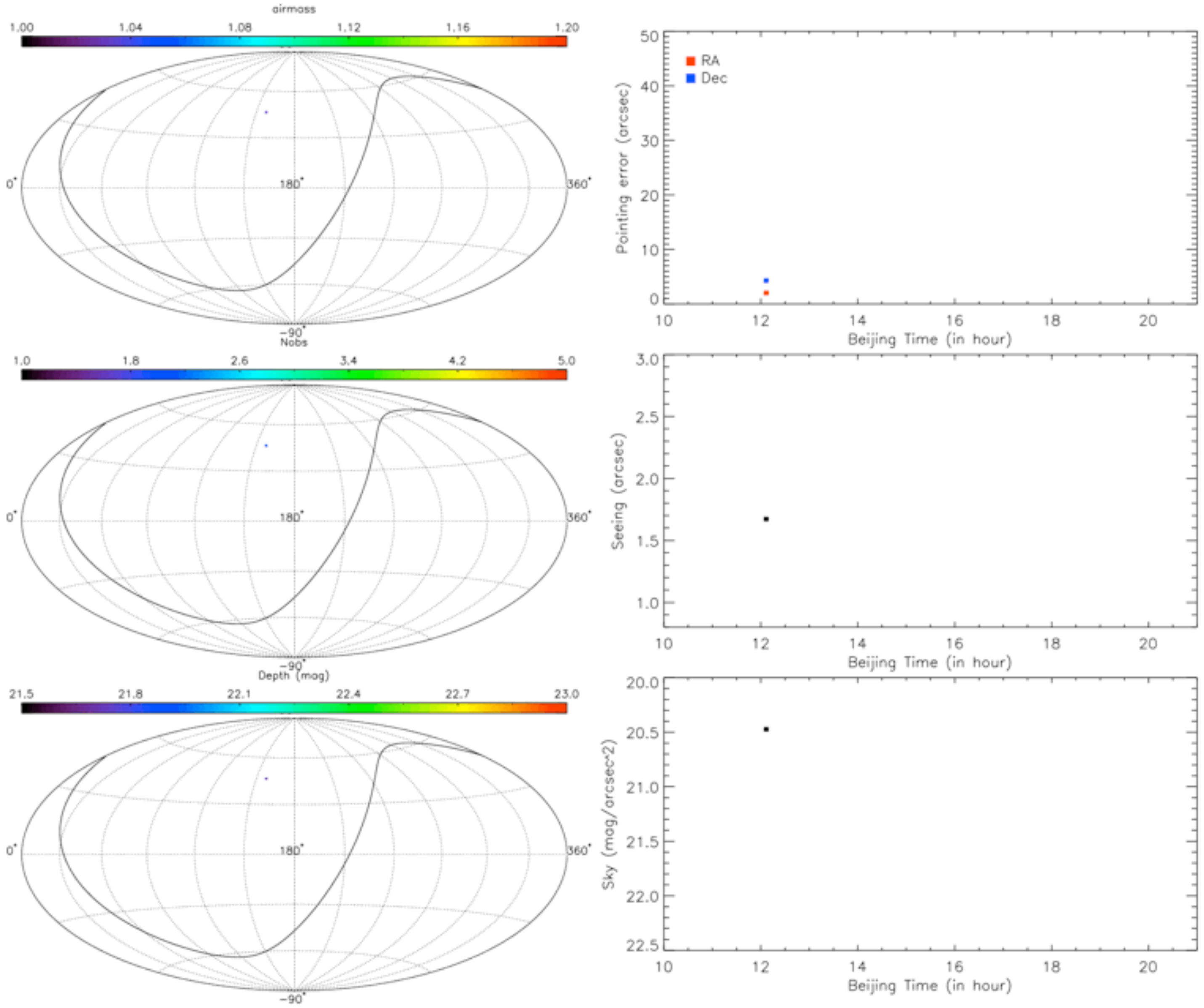


2000
1500
1000
500
0
0
500
1000



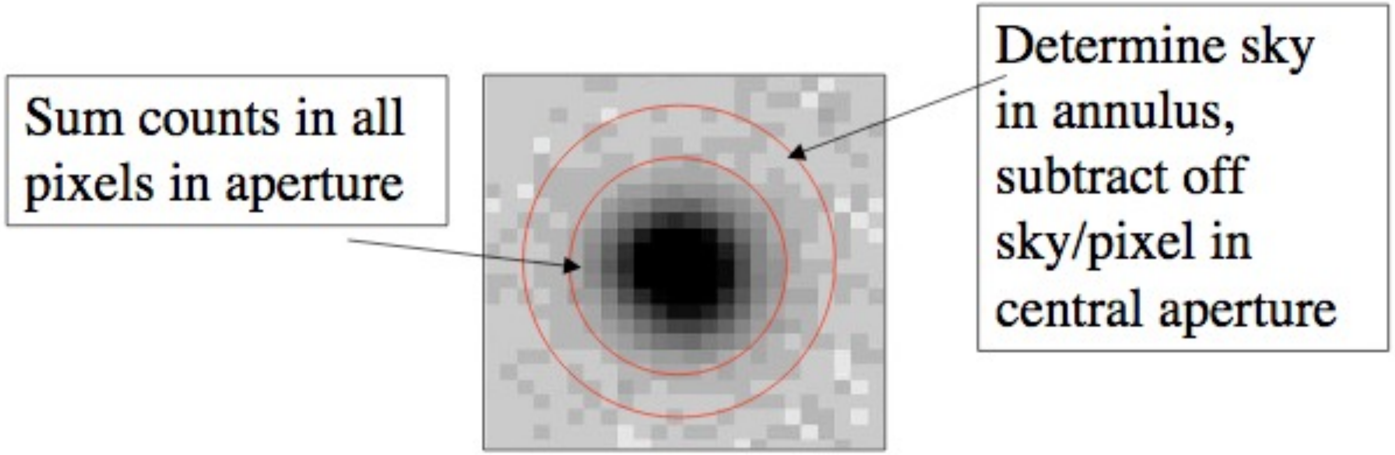
2000
1500
1000
500
0
0
500
1000
1500
2000

天测与测光


airmass
1.00 1.04 1.08 1.12 1.16 1.20
0°
180°
360°
−90°
Nobs
1.0 1.8 2.6 3.4 4.2 5.0
Depth (mag)
21.5 21.8 22.1 22.4 22.7 23.0
RA
Dec
Pointing error (arcsec)
Beijing Time (in hour)
Seeing (arcsec)
Sky (mag/arcsec^2)

天测与测光

Aperture Photometry

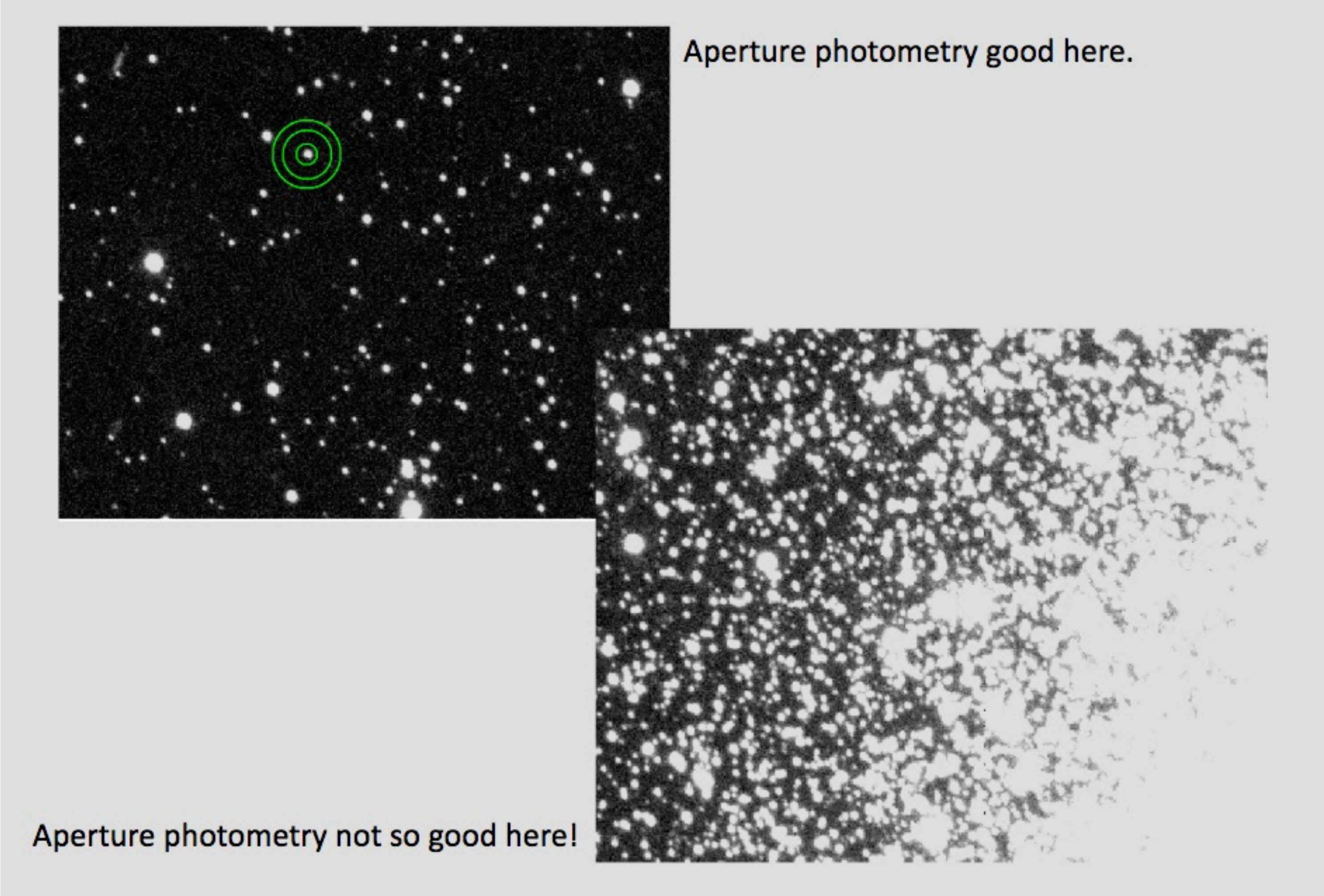


References:

Da Costa, 1992, ASP Conf Ser 23
Stetson, 1987, PASP, 99, 191
Stetson, 1990, PASP, 102, 932

天测与测光

Aperture Photometry



天测与测光

Aperture Photometry

$$I = \sum_{ij} I_{ij} - n_{pix} \times \text{sky/pixel}$$

Total counts in aperture from source

Counts in each pixel in aperture

Number of pixels in aperture

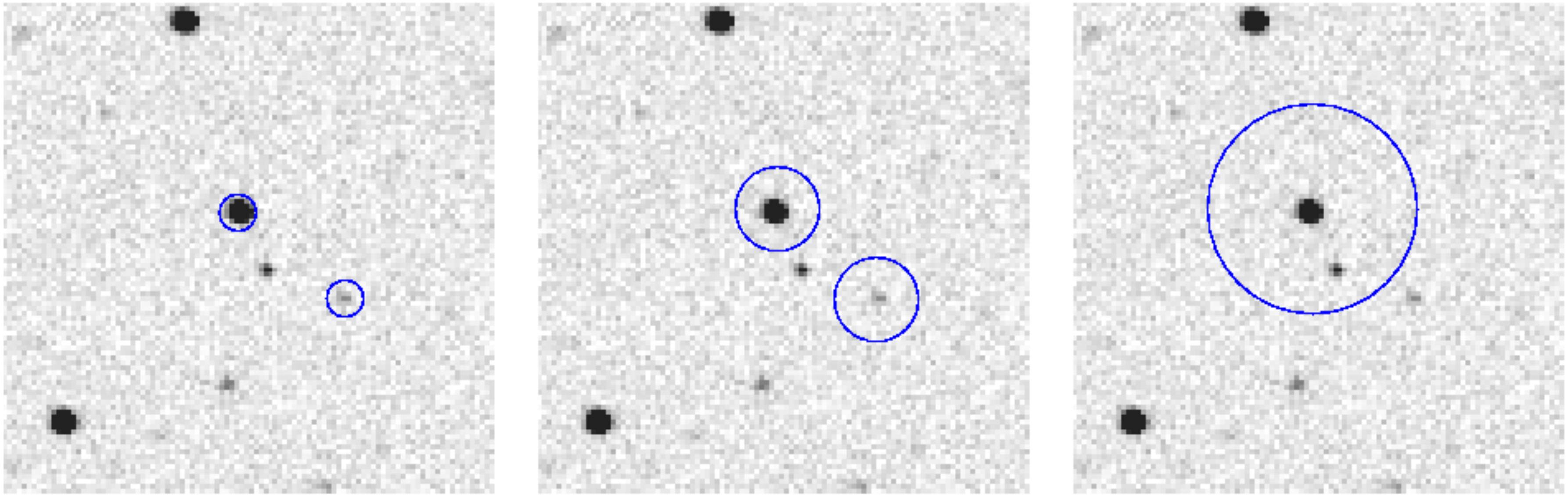
$$m = c_0 - 2.5\log(I)$$

Center
Sky background
Aperture radius

天测与测光

Aperture Photometry

Selecting the right aperture

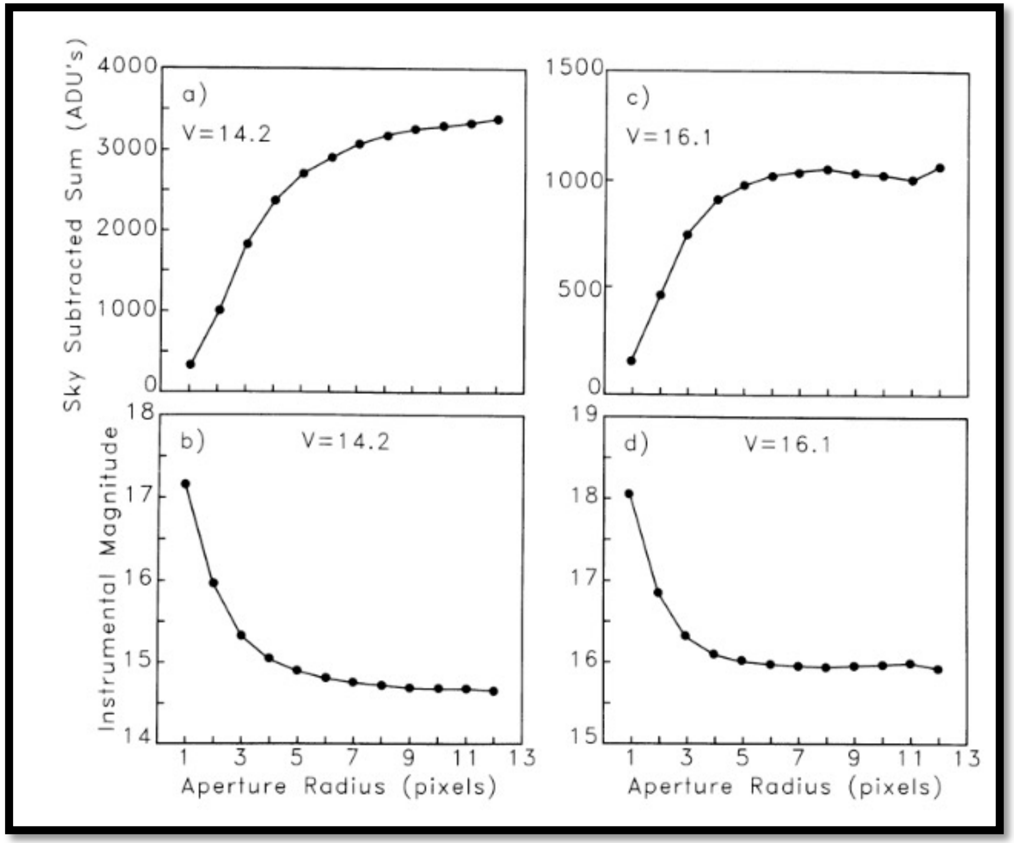


- Too small: not enough to include the whole stellar light
- Too big: too many “noise pixels”

天测与测光

Aperture Photometry

CCD Equation: Signal-to-Noise



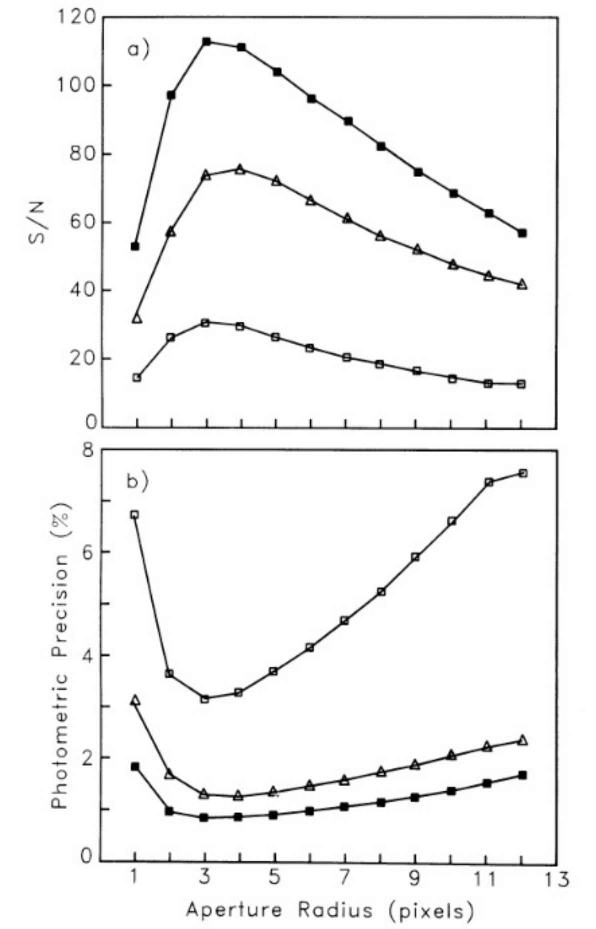


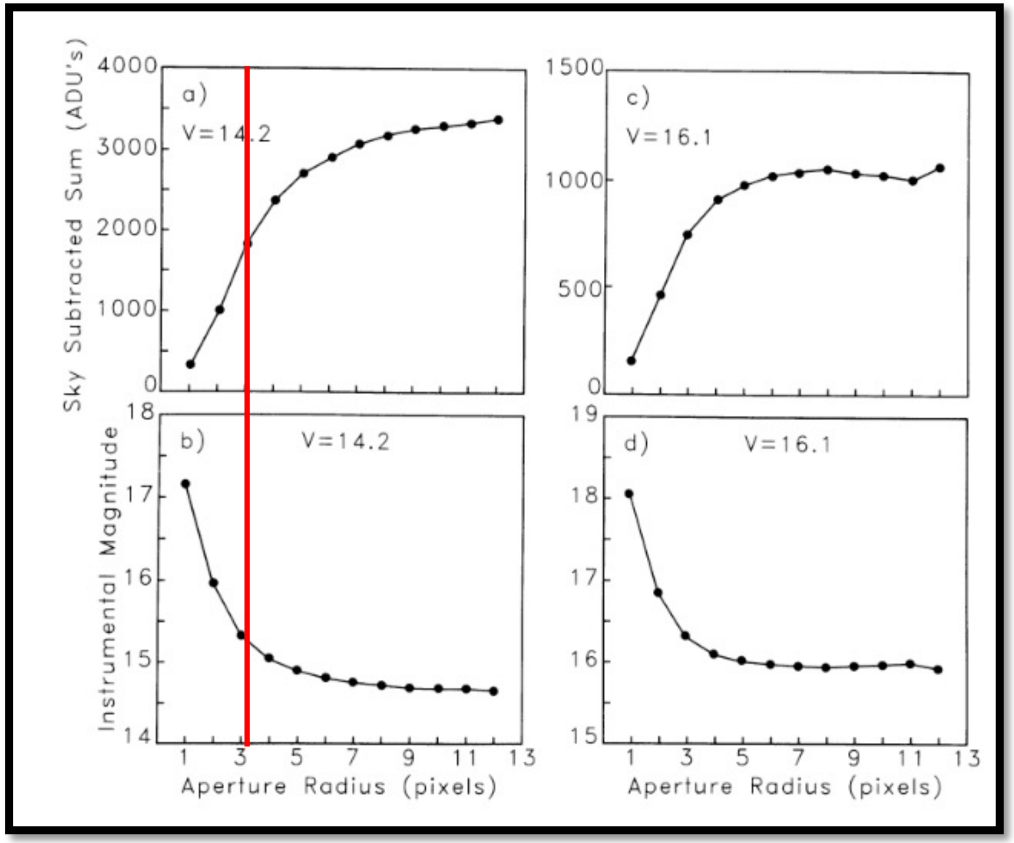
FIG. 6–S/N and photometric precision are plotted as functions of aperture radius for the same three point sources as before. The plots show that for a specific radius, which is fairly small, a point source has a maximum S/N and photometric precision. This maximum is not necessarily at the same radius for different objects. The symbols are ■; V = 14.2, △; V = 14.5, □; V = 16.1. The image scale is the same as in Figure 2.

0.4 arcsec pixel scale
1.2 arcsec FWHM seeing
Howell 1989

天测与测光

Aperture Photometry

CCD Equation: Signal-to-Noise



0.4 arcsec pixel scale
1.2 arcsec FWHM seeing
Howell 1989

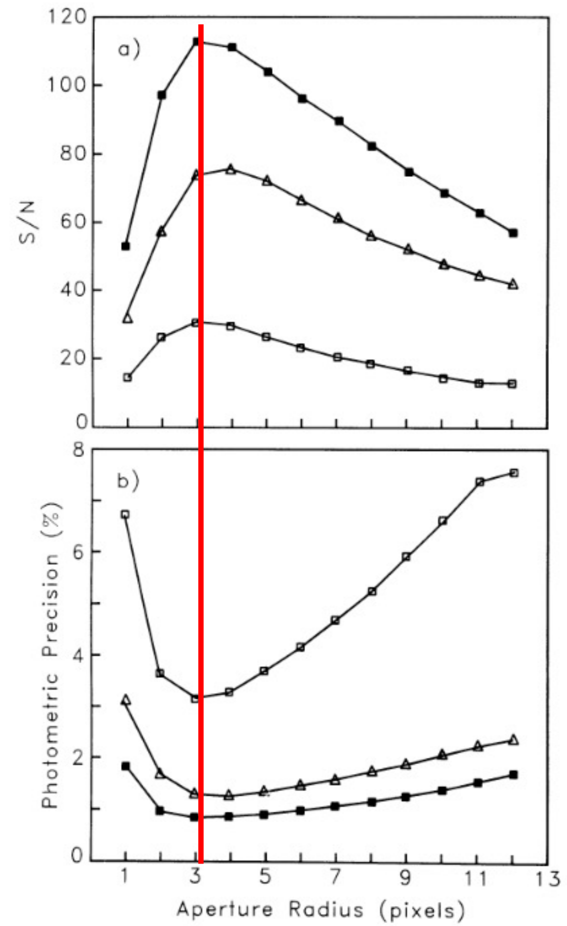
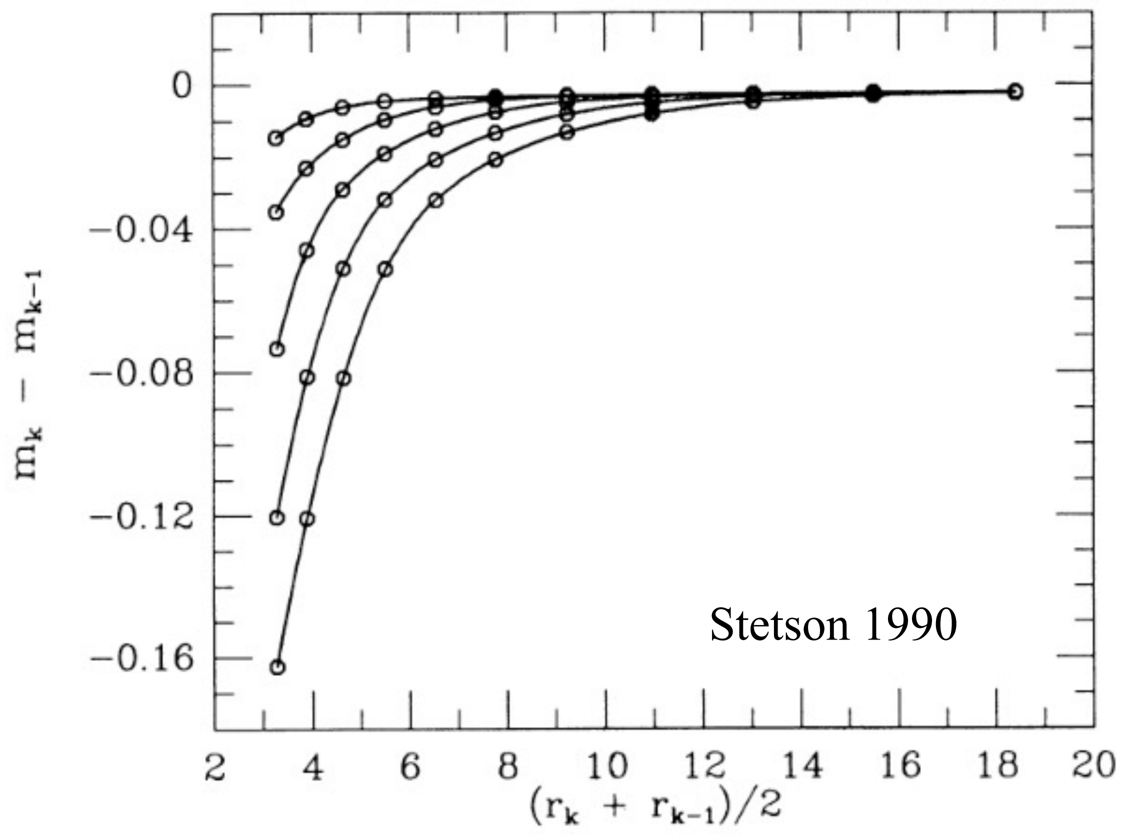


FIG. 6–S/N and photometric precision are plotted as functions of aperture radius for the same three point sources as before. The plots show that for a specific radius, which is fairly small, a point source has a maximum S/N and photometric precision. This maximum is not necessarily at the same radius for different objects. The symbols are ■; $V = 14.2$, △; $V = 14.5$, □; $V = 16.1$. The image scale is the same as in Figure 2.

天测与测光

Aperture Photometry



Aperture correction & growth curves

If stellar PSF Gaussian distribution:

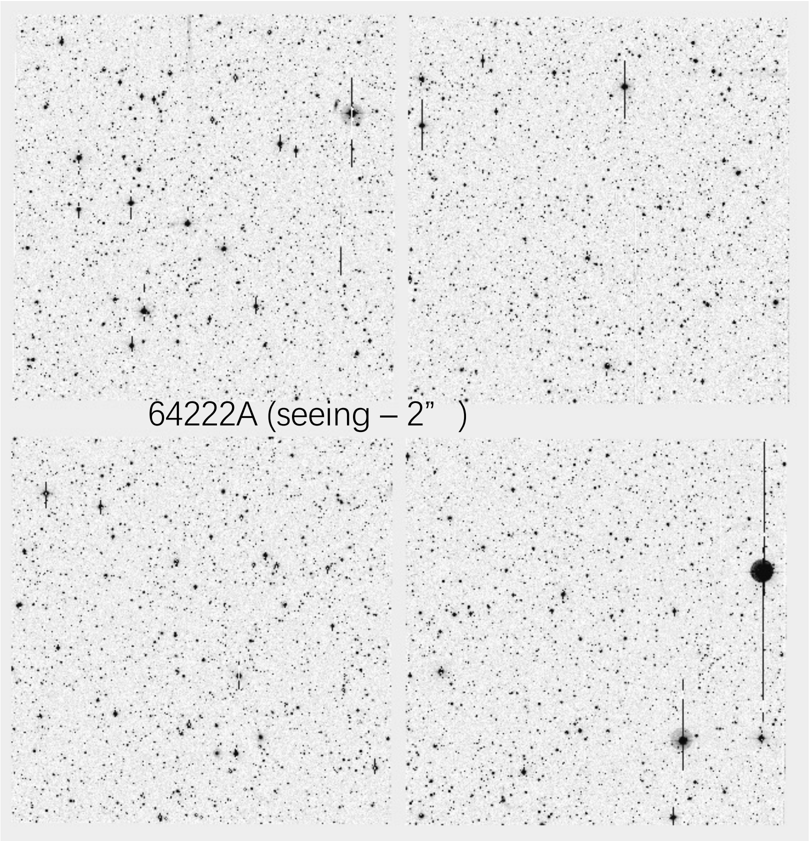
0.85 FWHM = 2 sigma = 95.45%
1.27 FWHM = 3 sigma = 99.73%
1.70 FWHM = 4 sigma = 99.99%
2.12 FWHM = 5 sigma = ~100%

- Select a relative small aperture size (~1.5 FWHM)
- Construct growth curves using isolated and bright stars in the field
- Apply aperture corrections

天测与测光

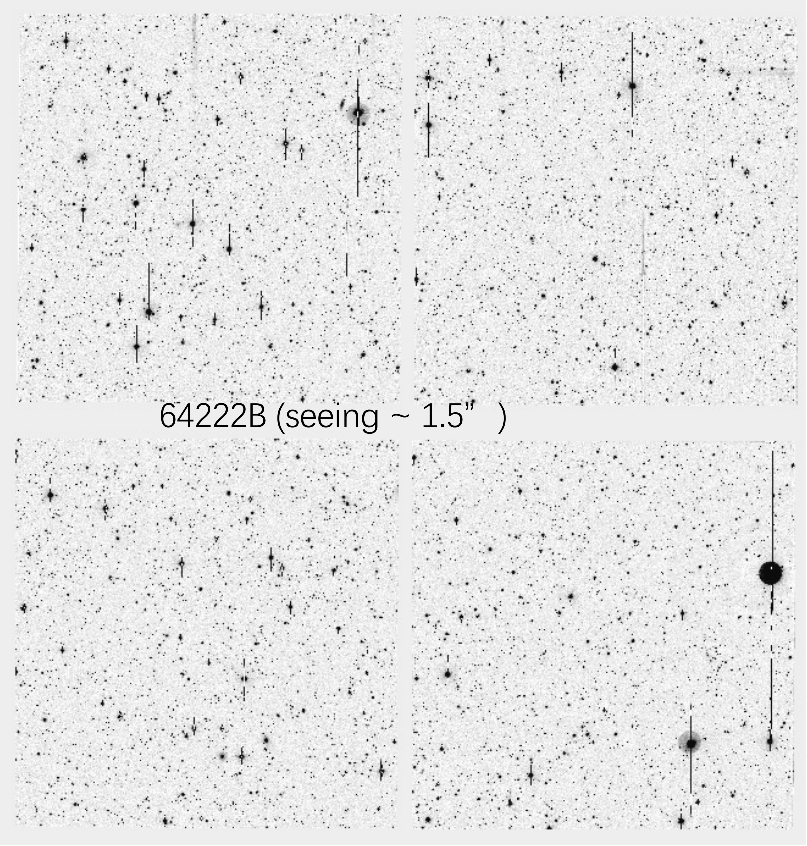
BASS 64222 天区 r波段
RA：06:14:35; Dec：56:15:44
gl: 158.01138; gb: 17.461039

观测时间：20160203 163s 曝光



64222A (seeing – 2”)

观测时间：20160203 212s 曝光

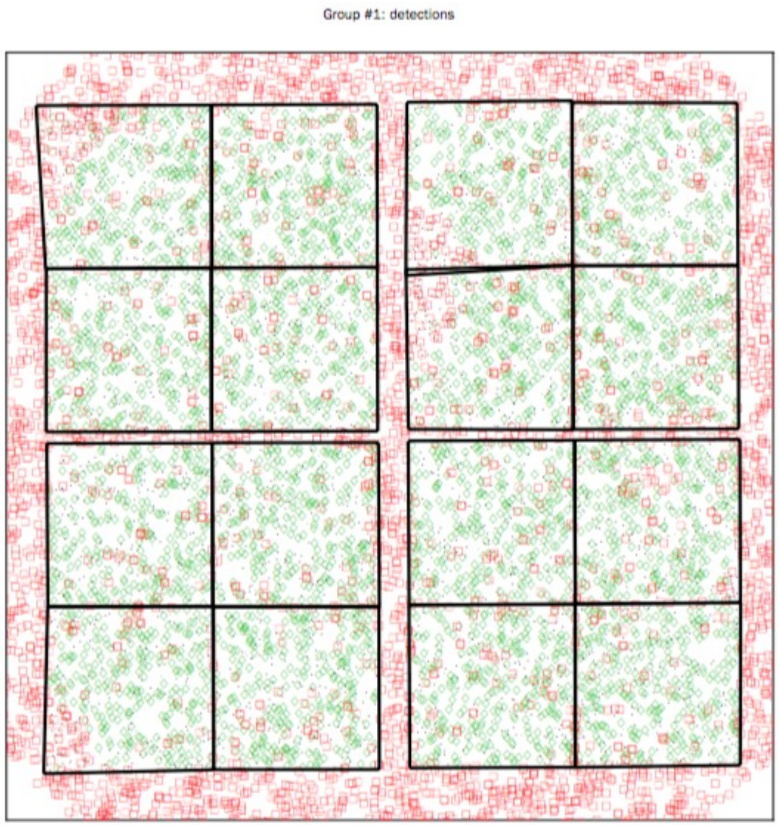


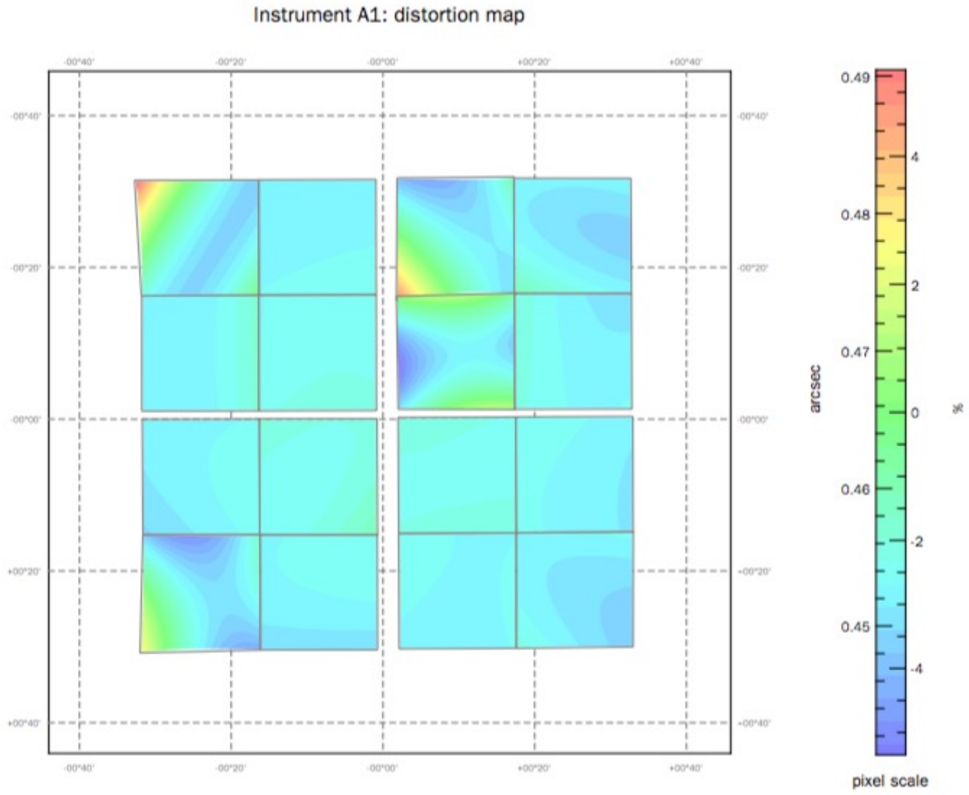
64222B (seeing ~ 1.5”)

天测与测光

64222A
Ref: Gaia EDR3

Scamp



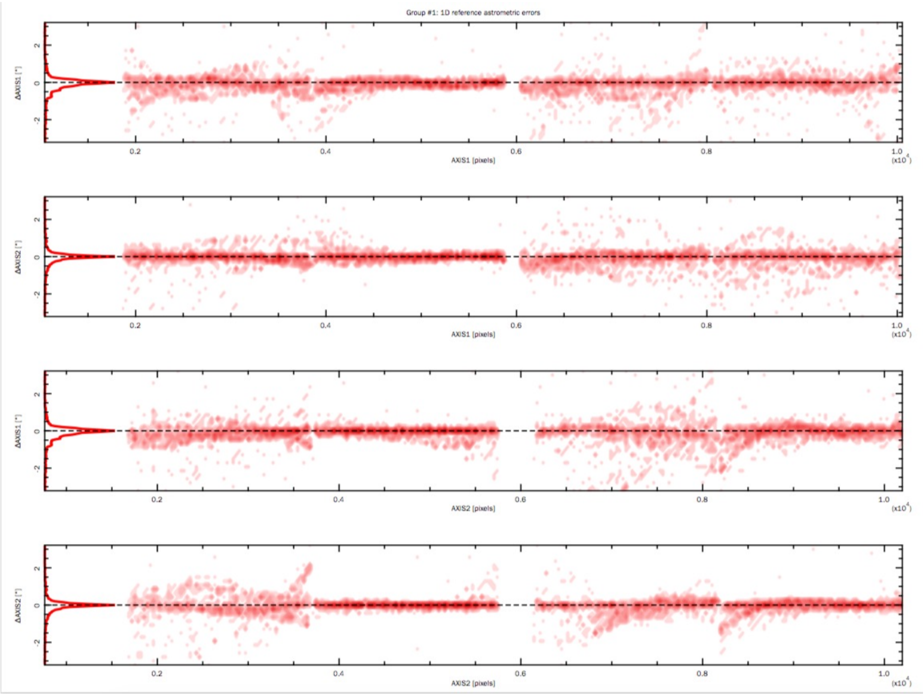


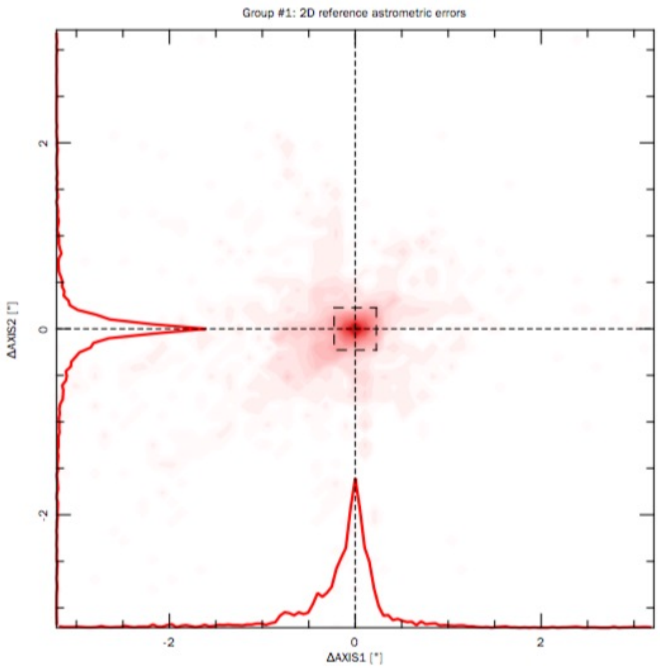
First solution: Run SExtractor of reduced image with initial WCS solution from pointing model from the telescope

天测与测光

64222A
Ref: Gaia EDR3

Scamp



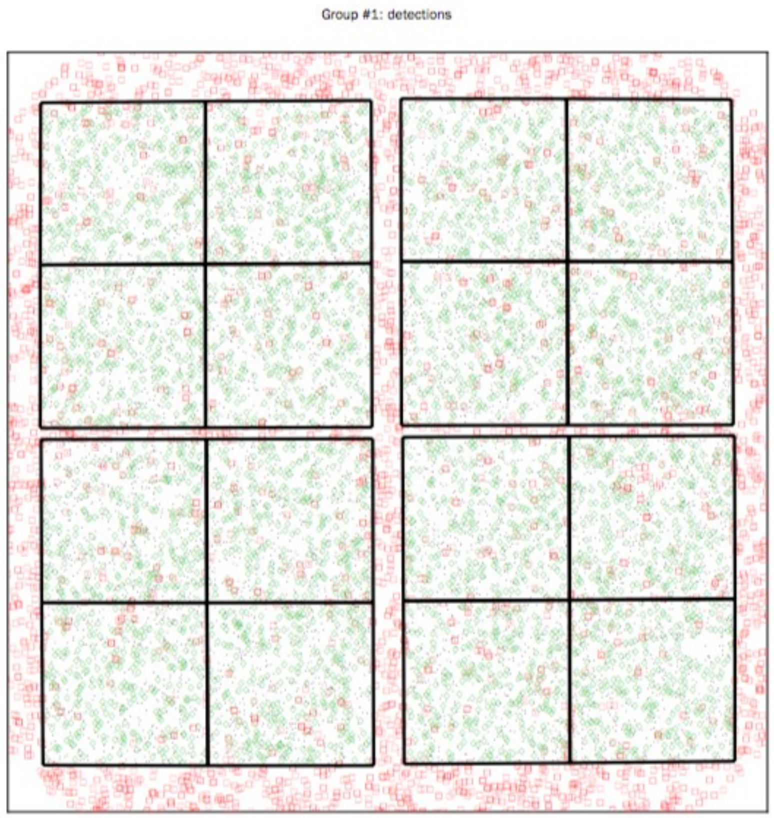


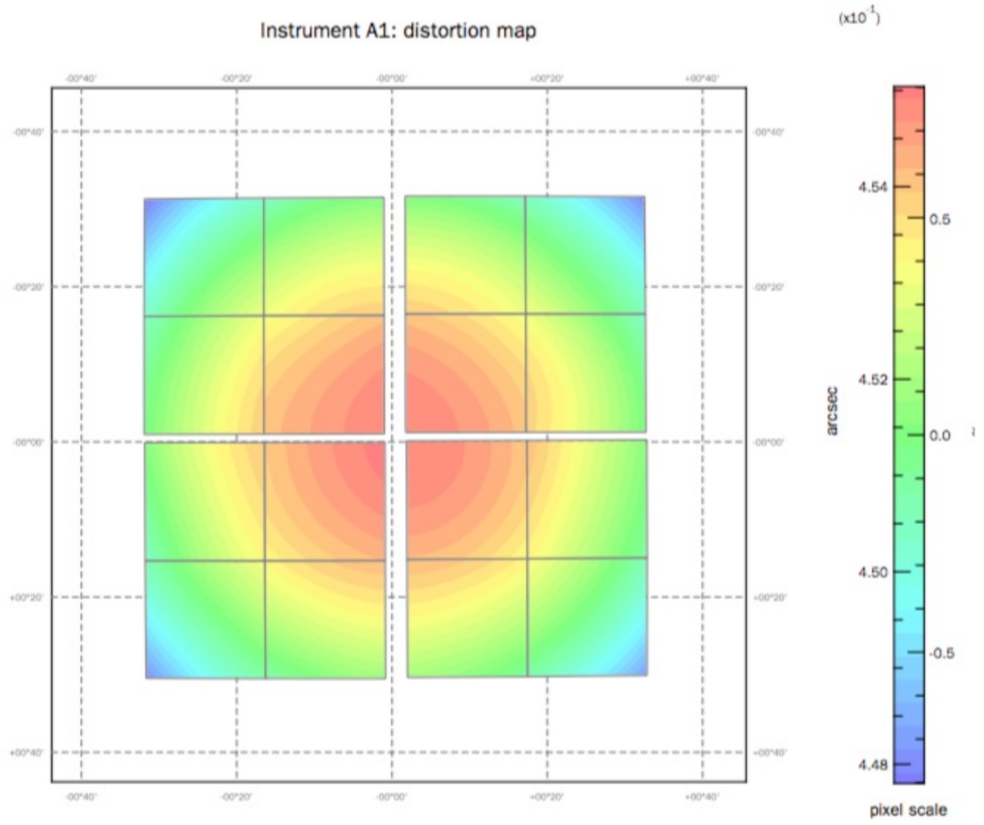
First solution: Run SExtractor of reduced image with initial WCS solution from pointing model from the telescope

天测与测光

64222A
Ref: Gaia EDR3

Scamp

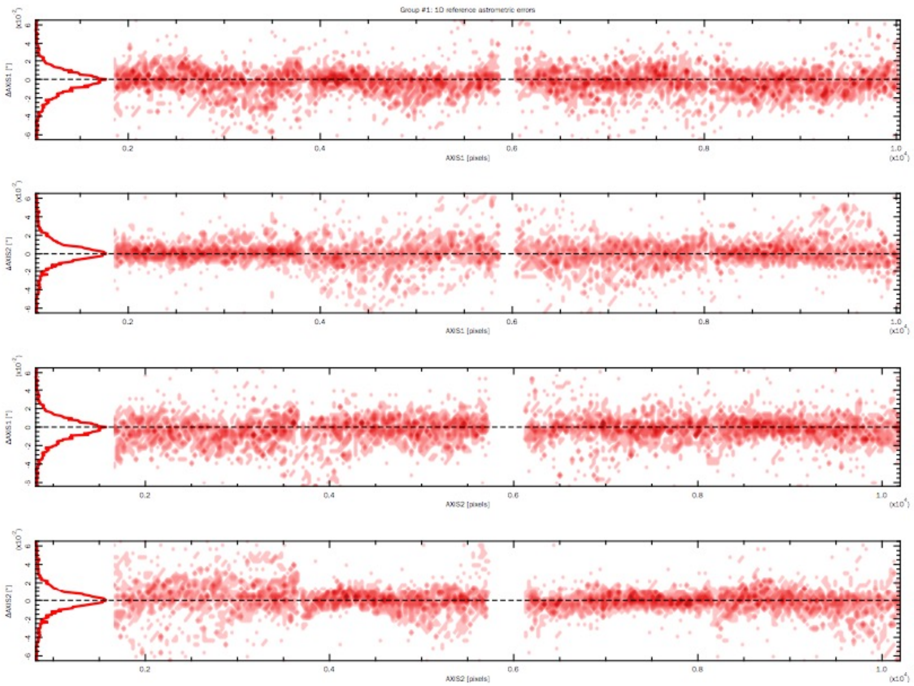


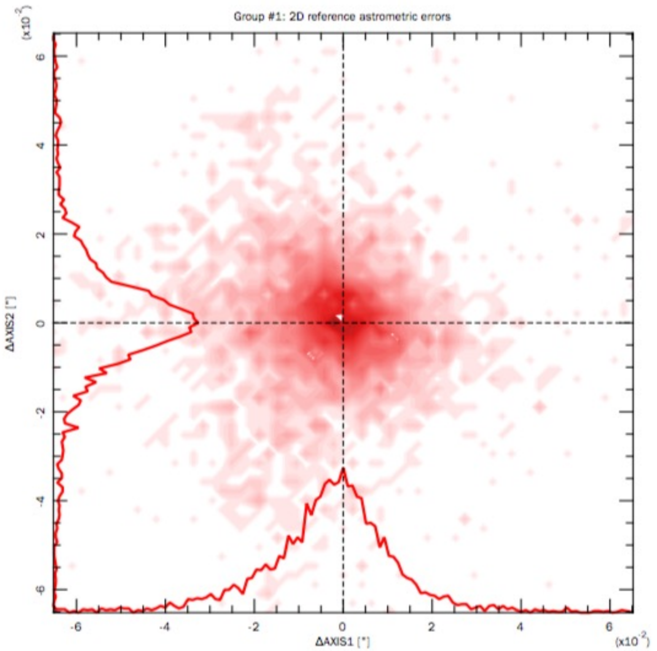


天测与测光

64222A
Ref: Gaia EDR3

Scamp

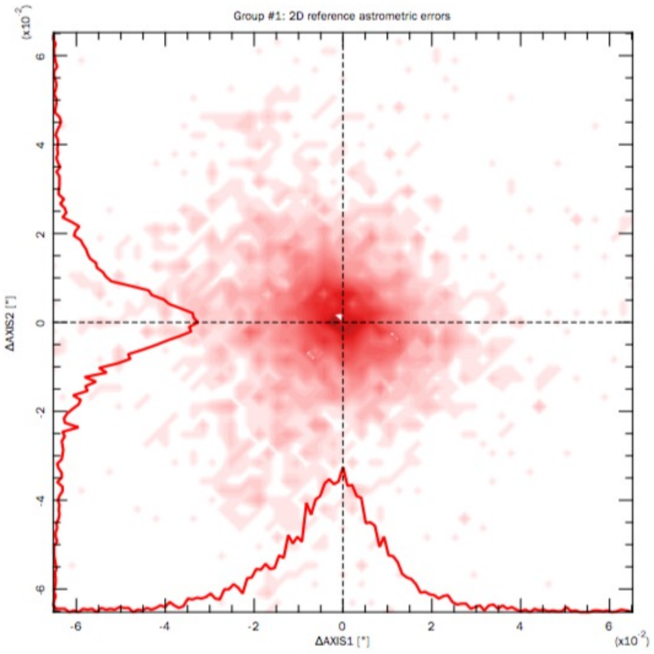




天测与测光

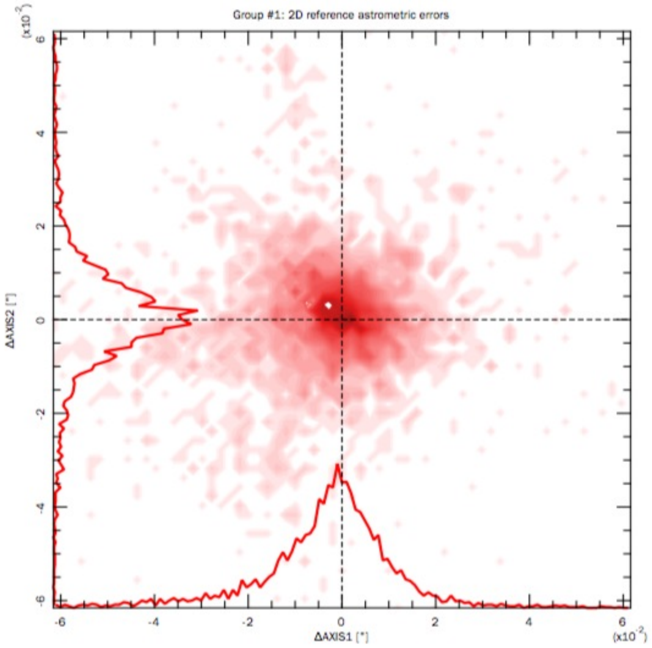
Scamp

64222A



sigma (RA) ~ 22 mas
sigma (Dec) ~ 24 mas

64222B

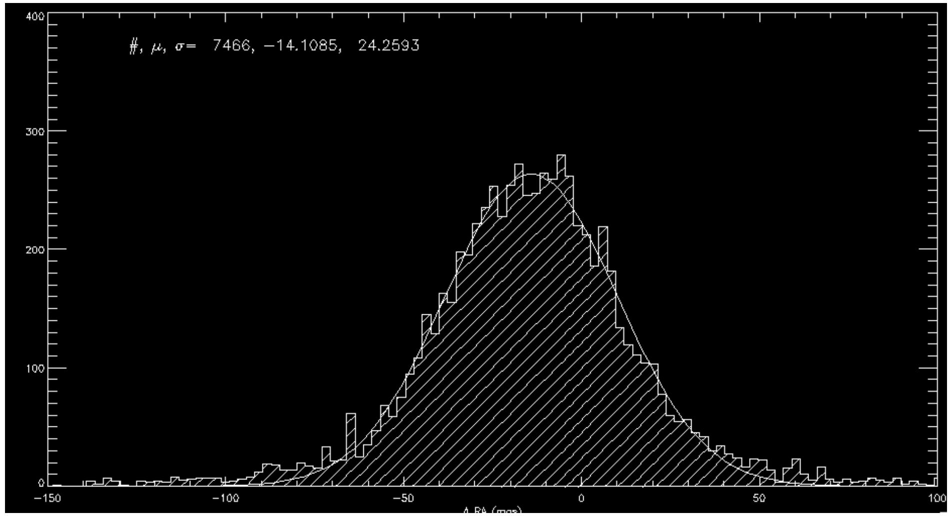


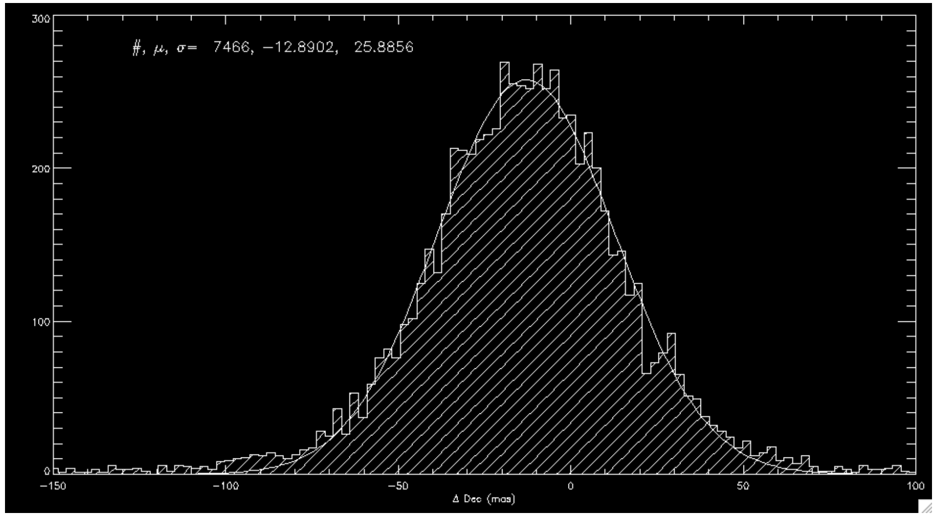
sigma (RA) ~ 20 mas
sigma (Dec) ~ 22 mas

天测与测光

Scamp

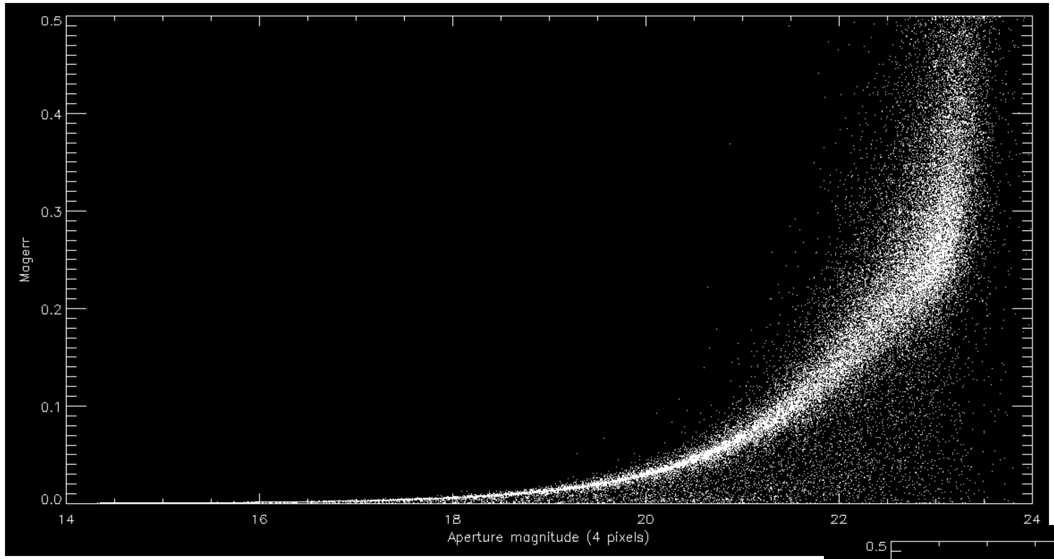
64222 A v.s. B





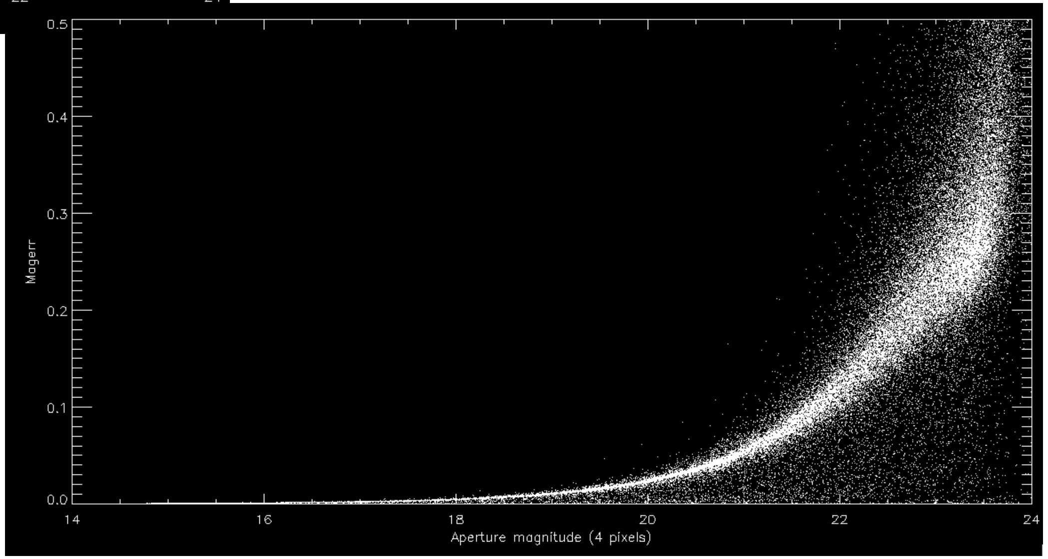
天测与测光

64222 A



Aperture magnitude
(4 pixels)

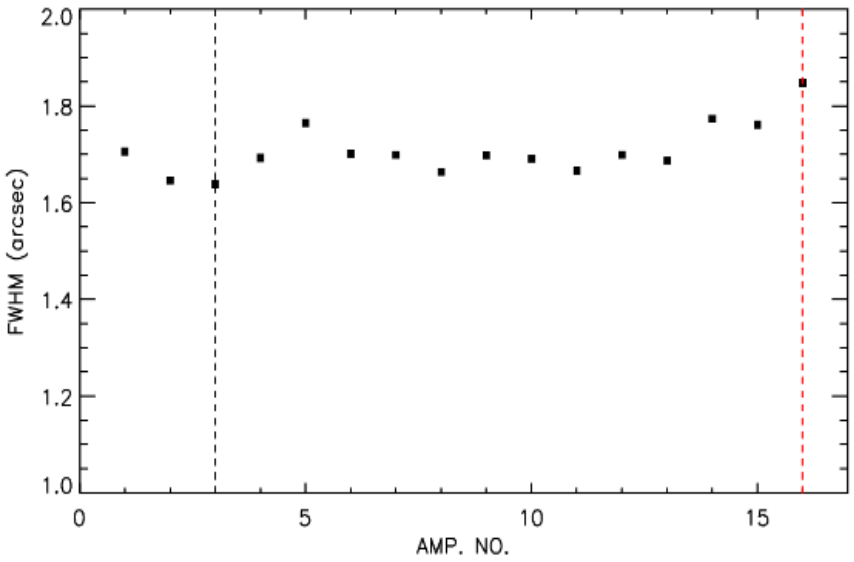
64222 B

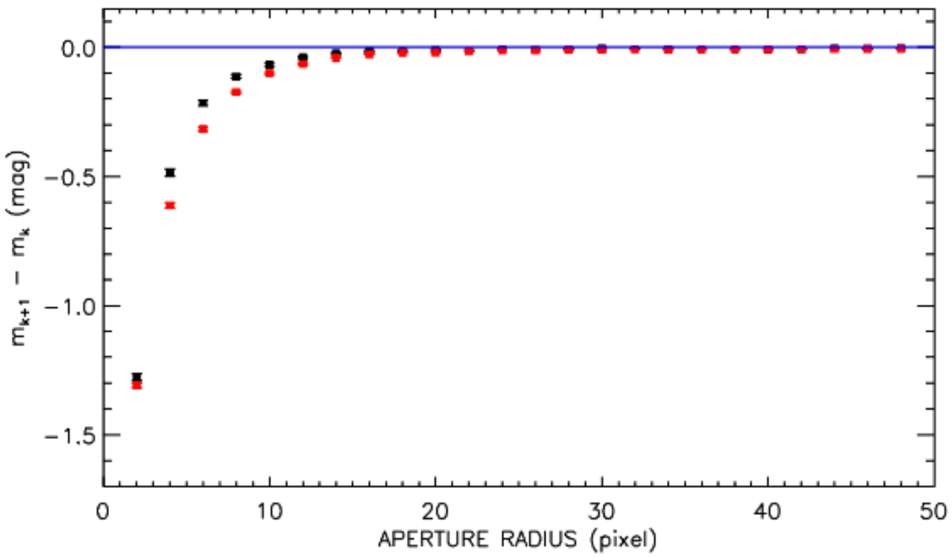


SExtractor + PSFEx

天测与测光

Aperture correction:



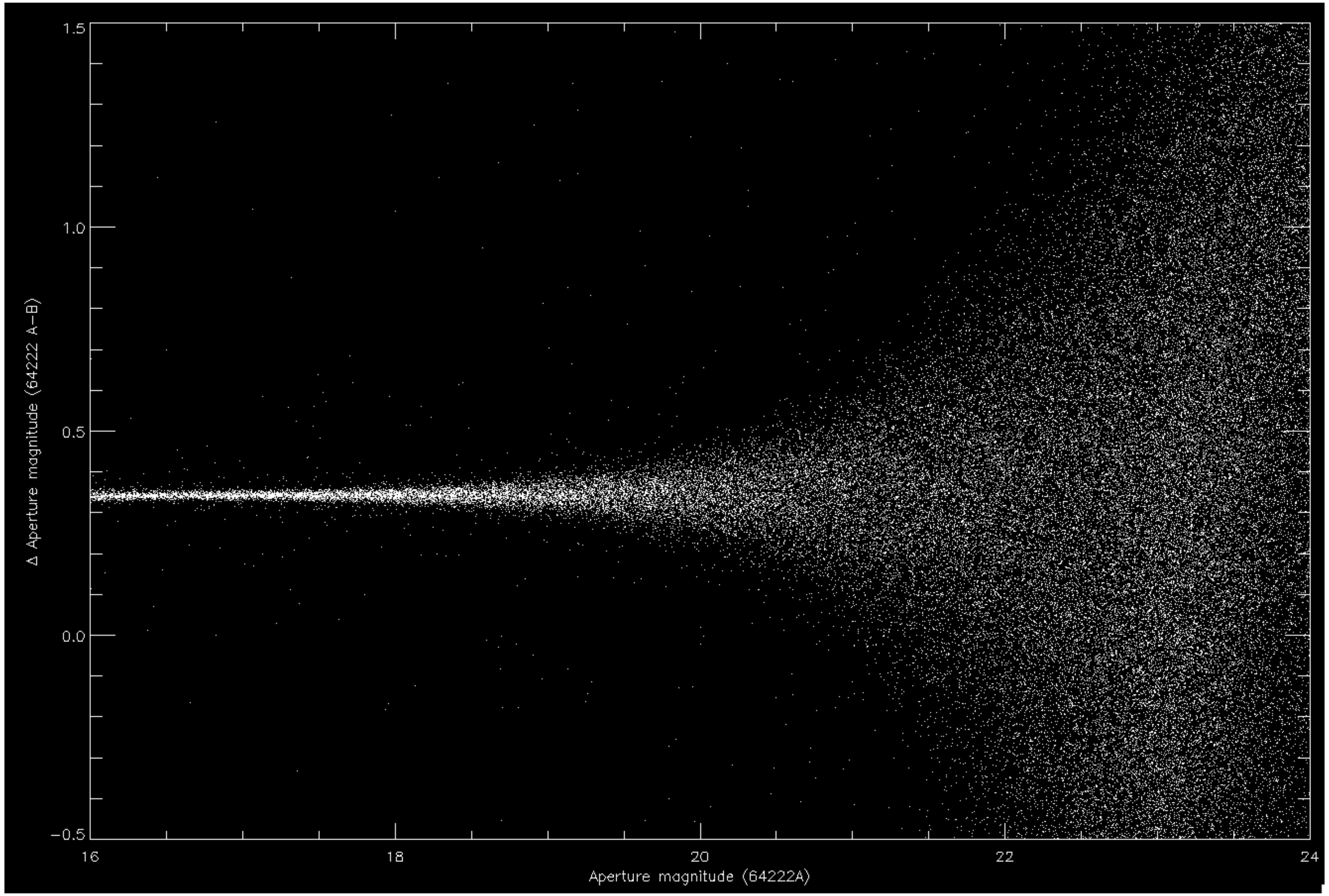


SExtractor + PSFEx

天测与测光

SExtractor + PSFEx

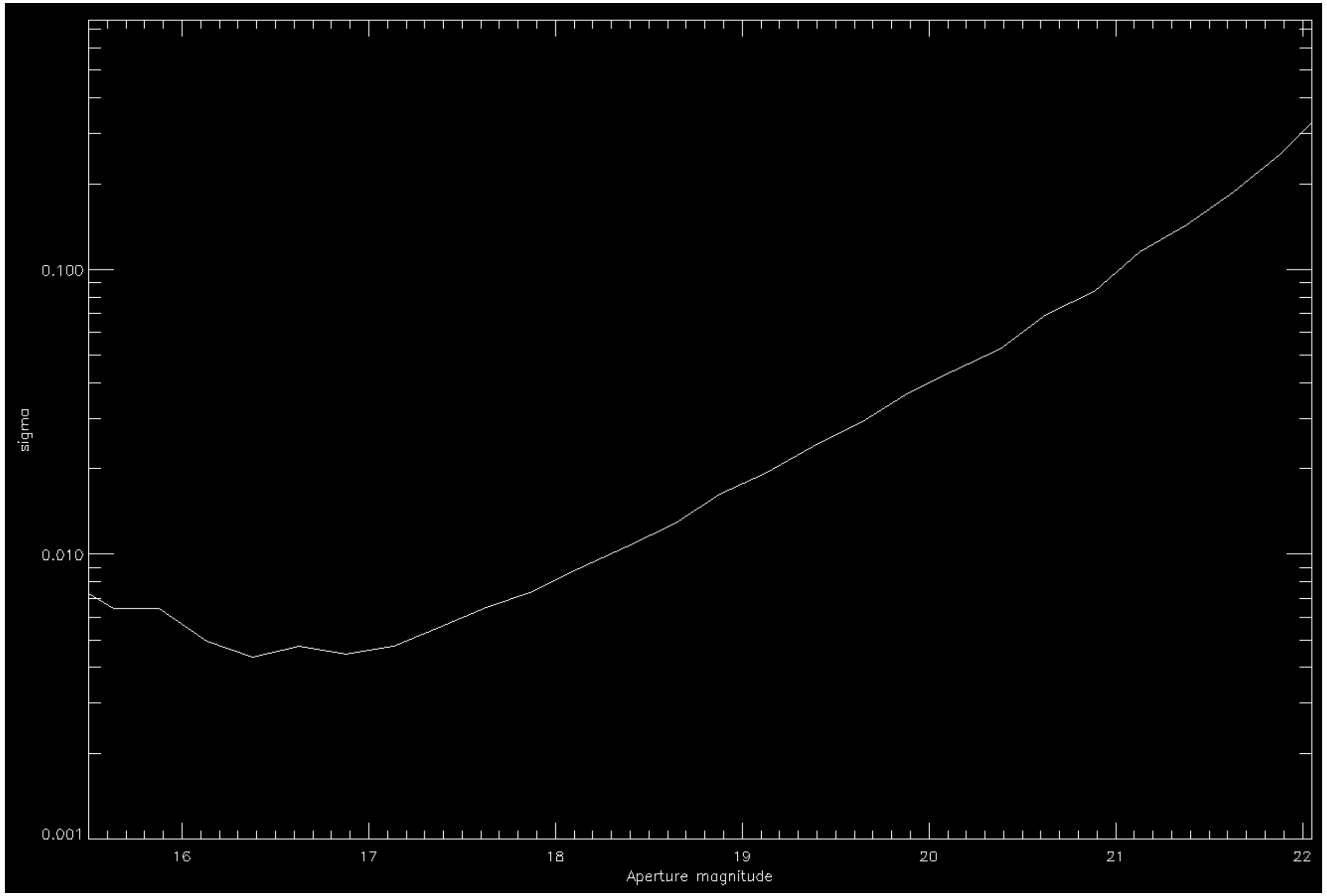
64222 A versus B



天测与测光

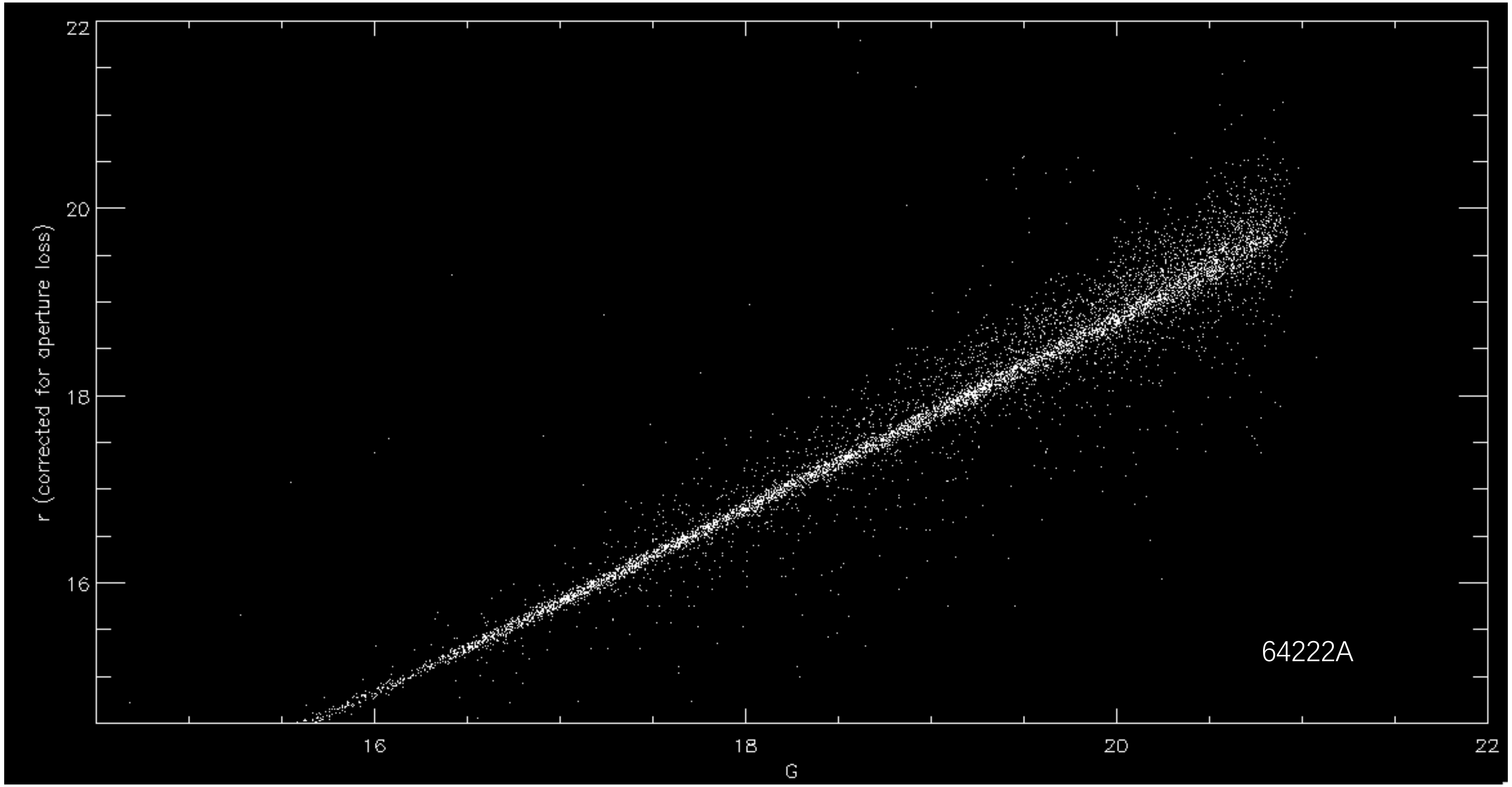
SExtractor + PSFEx

64222 A versus B



天测与测光

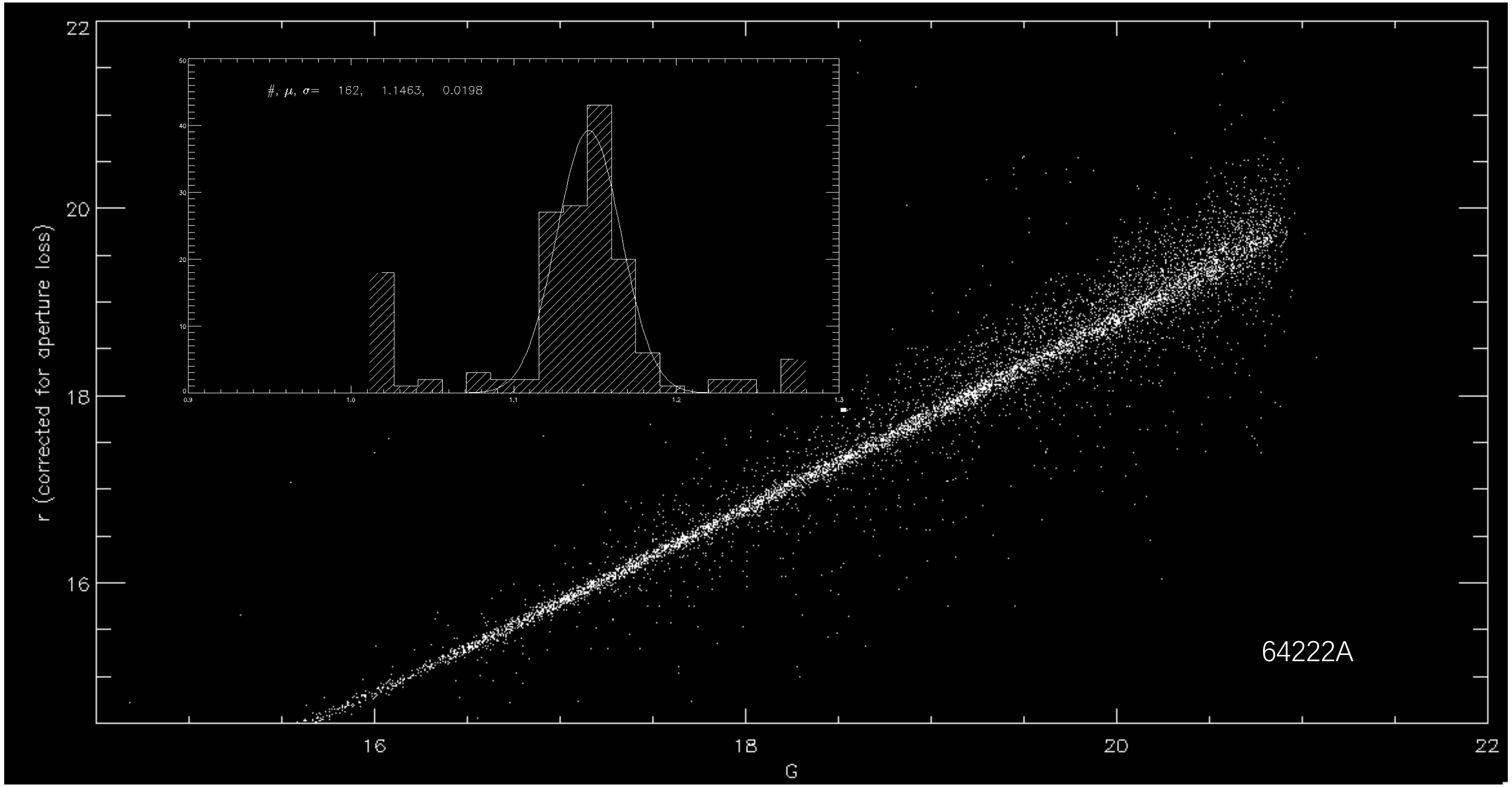
SExtractor + PSFEx



Compared to Gaia G

天测与测光

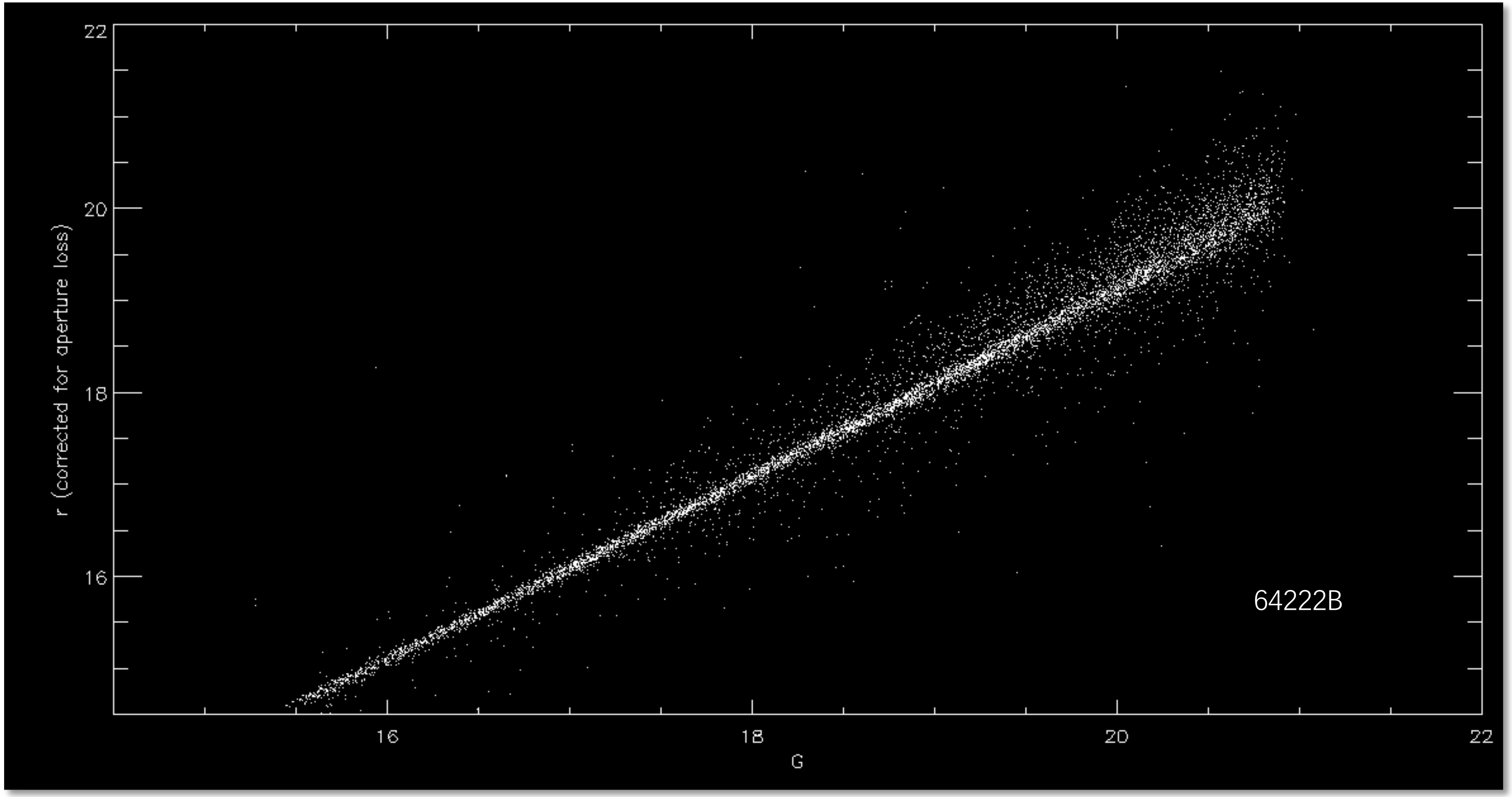
SExtractor + PSFEx



Compared to Gaia G

天测与测光

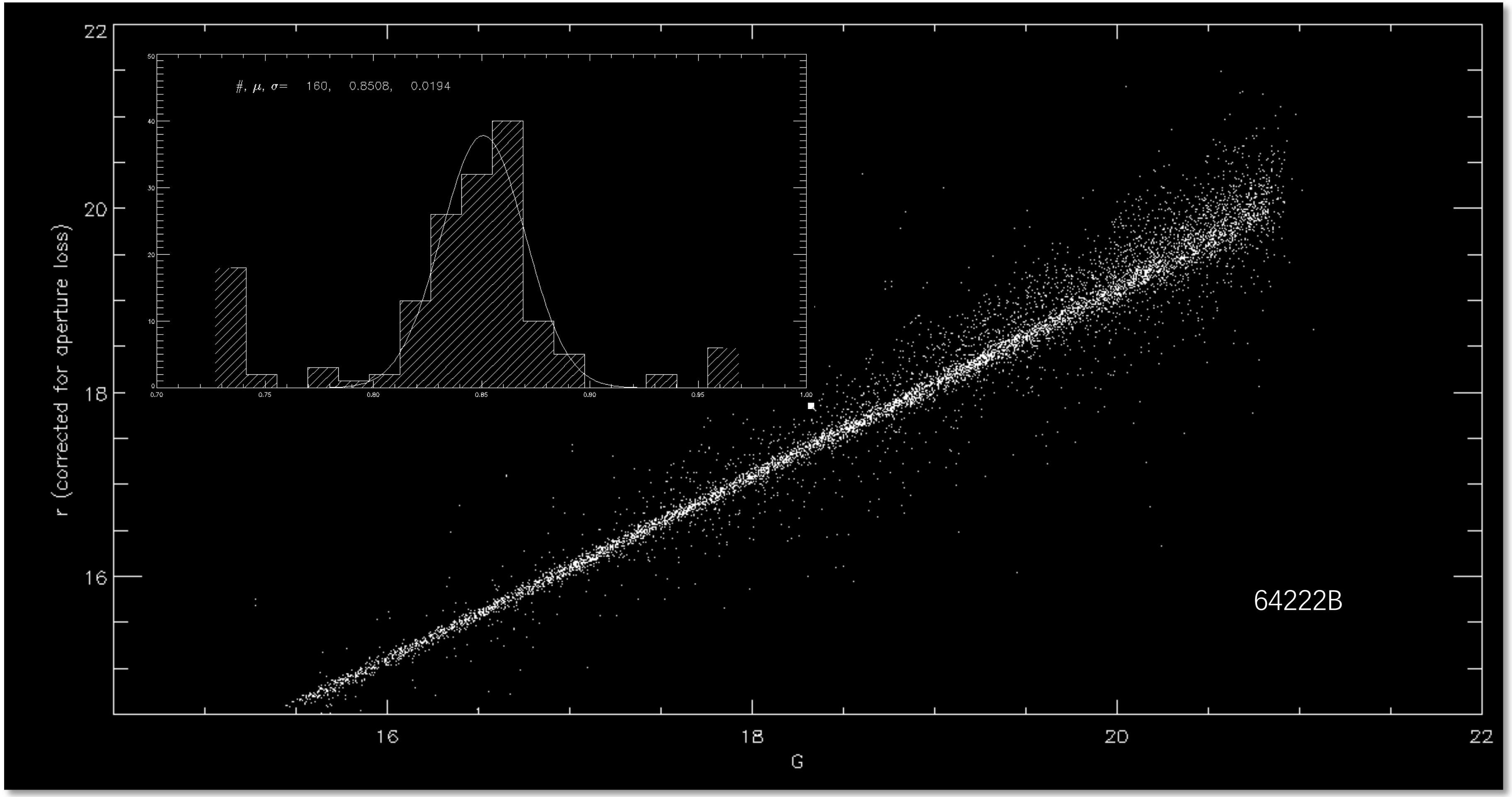
SExtractor + PSFEx



Compared to Gaia G

天测与测光

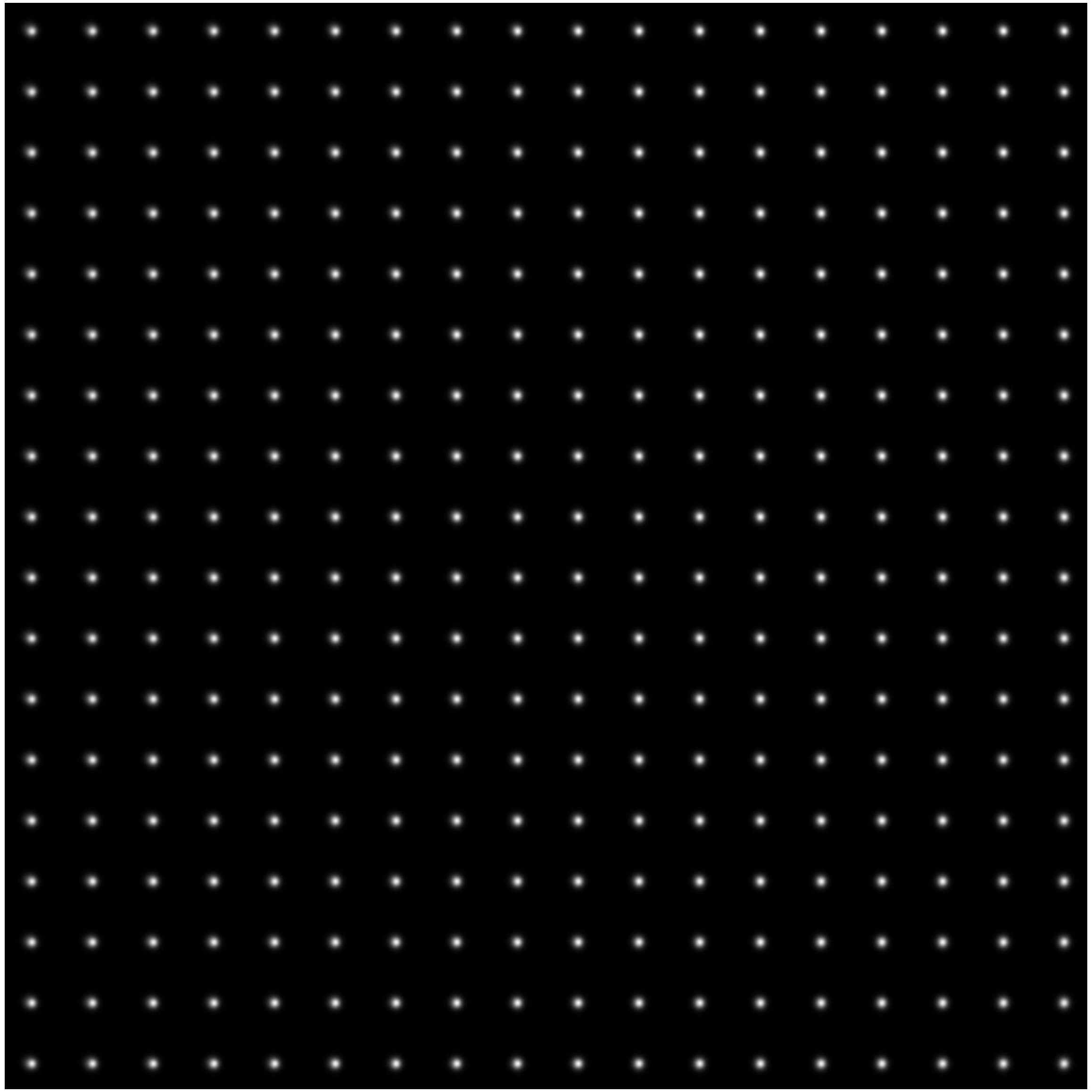
SExtractor + PSFEx



Compared to Gaia G

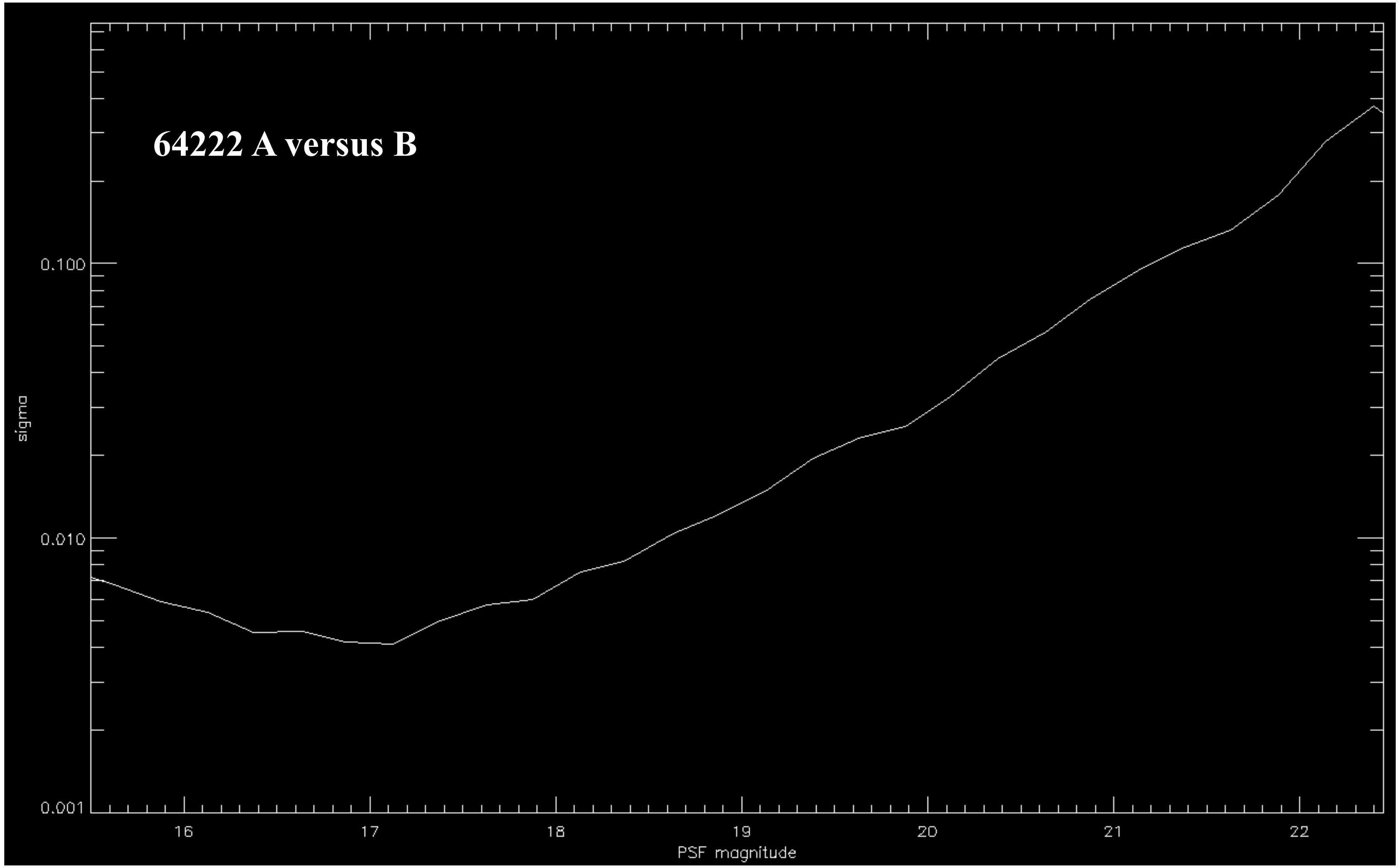
天测与测光

SExtractor + PSFEx



天测与测光

SExtractor + PSFEx



天测与测光

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IDL>
```

流量定标

$$\boldsymbol{f}_{\mathbf{ADU}} = \boldsymbol{\kappa f}$$

f: the flux of an object at earth (above the atmosphere)
f_{ADU}: the detected instrumental flux
κ depends on the exposure time, detector efficiency, filter responses, the telescope optical system, the optical path through the atmosphere, the SED of the objects in question

$$m_{\mathrm{ADU}} = m - 2.5\log_{10}(\kappa)$$

$$-2.5\log_{10}(\kappa) = a(i,j;t) + k(t)x + f(i,j;t) + \ \ldots$$

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The optical response of the telescope and detectors

流量定标

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Atmospheric extinction

流量定标

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f: the flux of an object at earth (above the atmosphere)
f_{ADU}: the detected instrumental flux
κ depends on the exposure time, detector efficiency, filter responses, the telescope optical system, the optical path through the atmosphere, the SED of the objects in question

$$m_{\mathrm{ADU}} = m - 2.5\log_{10}(\kappa)$$

$$-2.5\log_{10}(\kappa) = a(i,j;t) + k(t)x + f(i,j;t) + \ \ldots$$

Detector flat fields

流量定标

Traditional methods: standard stars

Landolt standards (Landolt 1983; 1992): provide magnitudes accurate to < 1% in the *UBVRI* bands for 500 stars in the *V* magnitude range 11.5-16.

Stetson standards (Stetson 2000; 2005): extend Landolt's work to fainter magnitudes and provided the community with ~1-2% accurate magnitudes in the *BVRI* bands for ~15,000 stars in the magnitude range *V* < 20.

Ivezic standards (2007): present 1.01 million nonvariable unresolved objects from the equatorial stripe 82 with <1% accurate magnitudes in ugriz bands in the *V* band magnitude range 14-22.

流量定标

Relative calibrations:

- **Ubercalibration (Ivezic et al. 2007; Padmanabhan et al. 2008)**

- **Stellar locus/color regression (SLR/SCR; High et al. 2009; Yuan et al. 2015)**
  - **Purely based on photometry (High et al. 2009)**
  - **Spectroscopy+photometry (Yuan et al. 2015)**


谢谢！
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