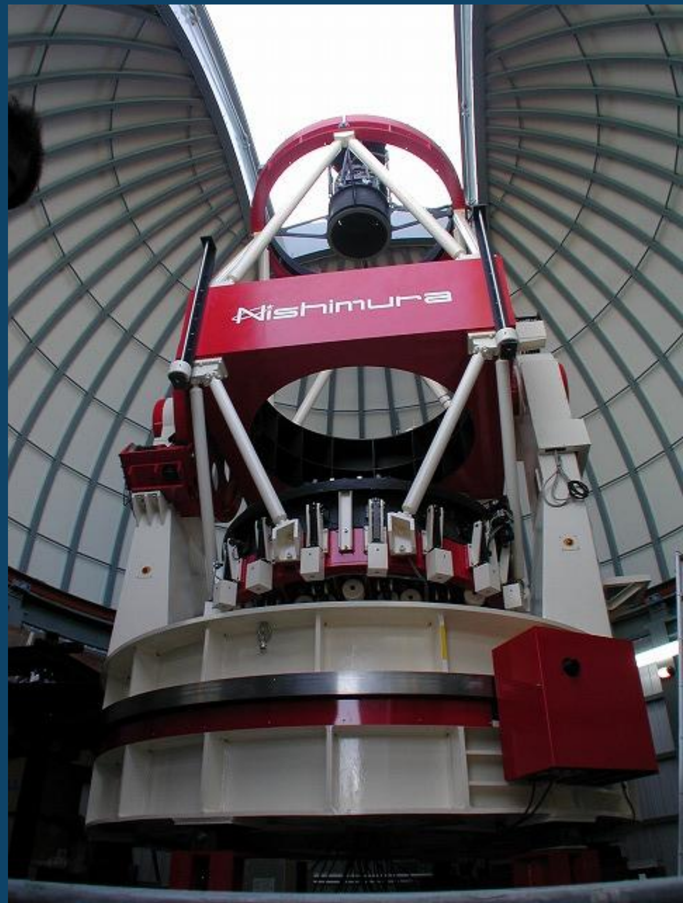
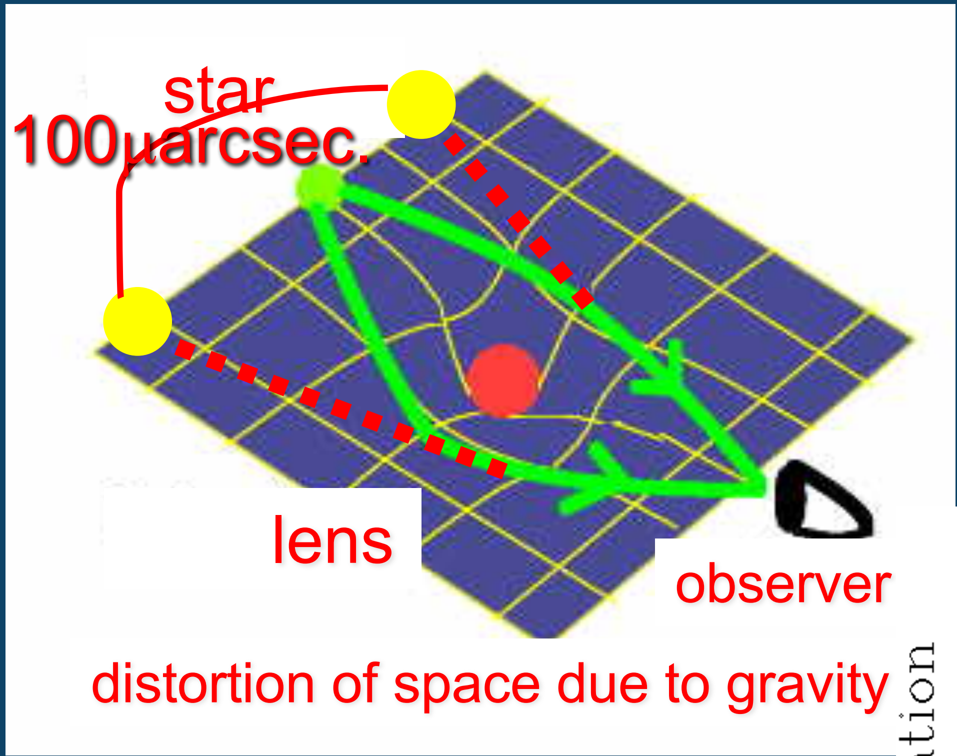
大阪大のMOAの経験と今後への教訓



Takahiro Sumi (Osaka Univ.)

2017/3/28, **Workshop on Studies on variable stars and extinction law in the Milky Way and nearby galaxies** @University of Tokyo

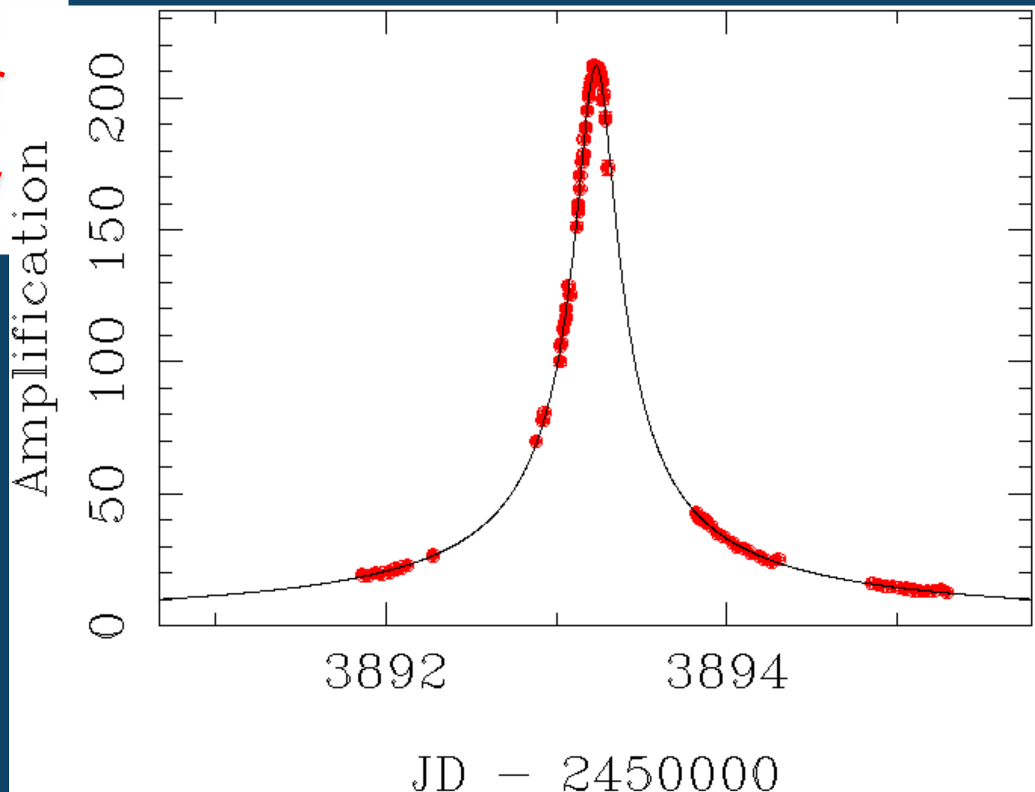
Gravitational Microlensing



✧If a lens is a star, elongation of images is an order of 100μarcsec.

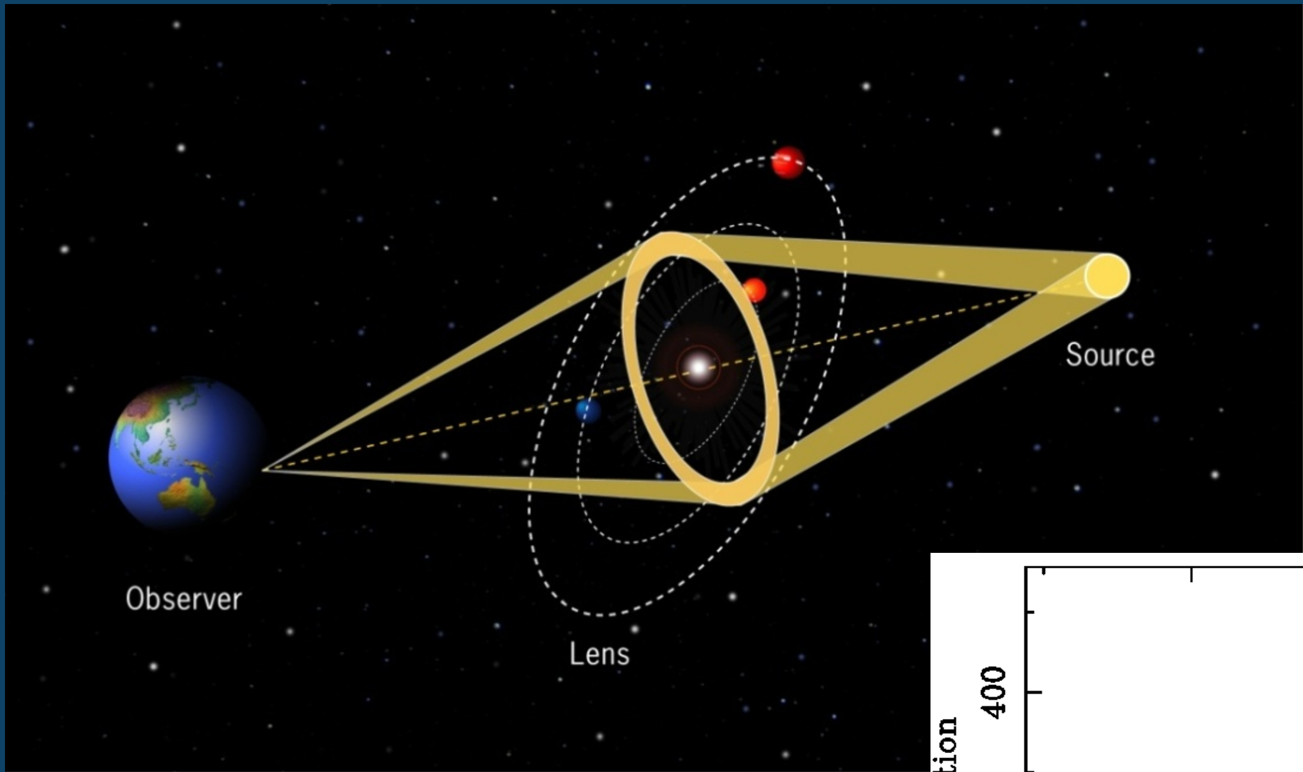
✧Just see a star magnified

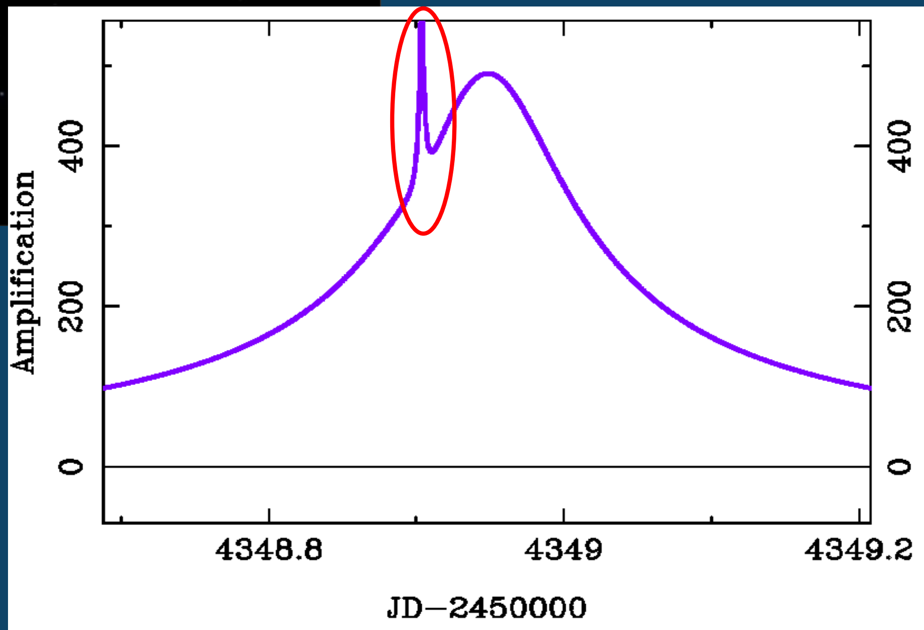
✧Einstein predicted 1936, but concluded impossible to observe. Event rate is 1/1M



- 1986
  Watch Millions stars
  Paczynski

planetary microlensing





Time scale: $t_p \sim M^{1/2} \sim 1\text{day}(M_J)$
$\sim$a few hours (M_E)

Sensitive to Cold planets outside of snowline ($\sim 3a_{snow}$)

MOA (until ~1500)

（NZにいた世界１大きな鳥）

- 体長:　3.5m
- 体重: 250kg
- 飛べない
- 500年前に絶滅
- （マオリ族が食べ尽くした）

MOA (since 1995)

(Microlensing Observation in Astrophysics)

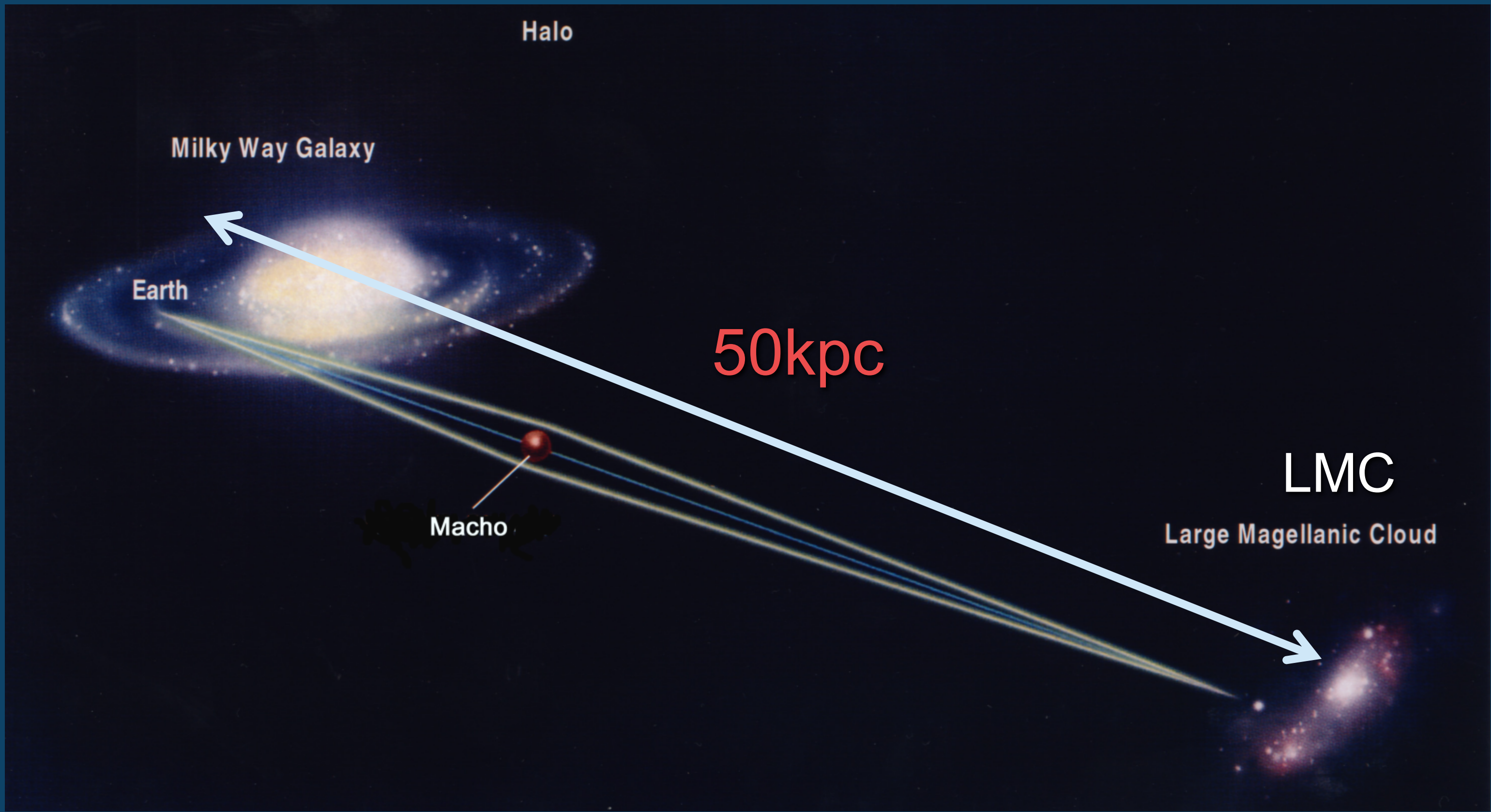
(New Zealand/Mt. John Observatory, Latitude: 44°S, Alt: 1029m)

Seeing ~2arcsec
Clear night: ~50%

なぜ？

Halo Dark Matter & Paczynski's Idea

- 20～40 times more dark matter than visible mass.
- MAssive Compact Halo Objects (MACHOs) ⇔ WINPs
  - MACHO can be observed by Microlensing.（Paczynski 1986)
  - $\tau \sim 10^{-6}$ ➔ then watch 10M stars!.



3 surveys started and found MACHO is not the majority of the galactic DM
But it opened the era of massive time-domain survey.

MOA 0.6m telescope

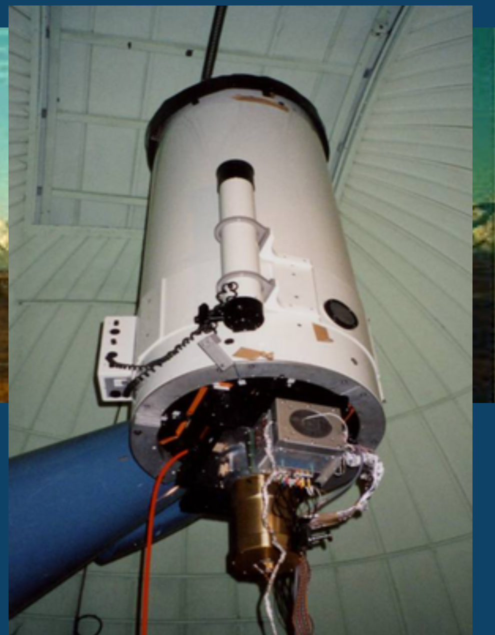
（New Zealand/Mt. John Observatory ）

Mirror : 0.6m

CCD : **4k x 6k** pix.

FOV : 1.3 square deg.

2000–2005 (約6年間)

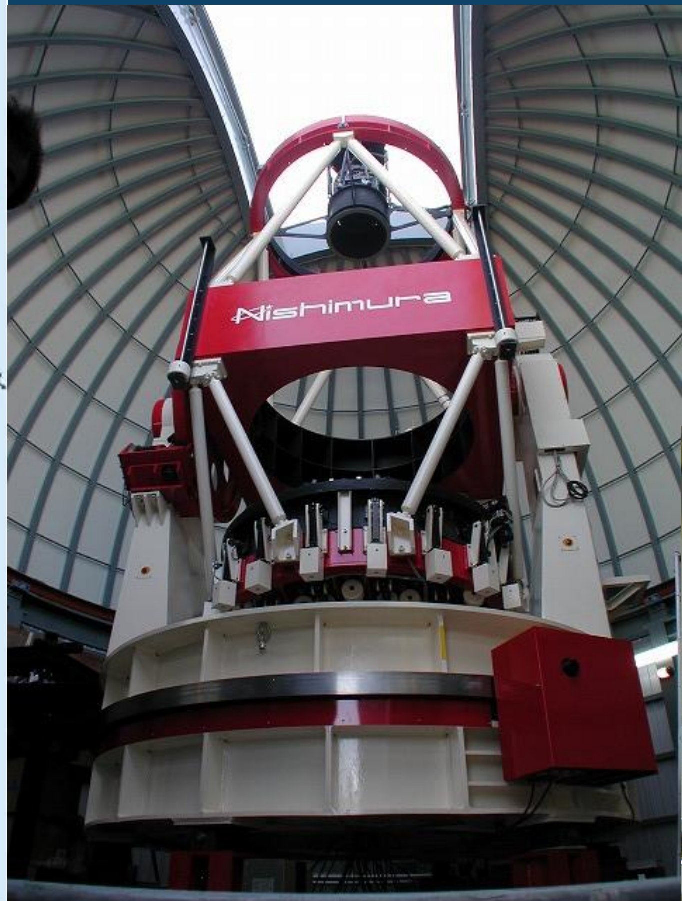


MOA (since 1995)

(Microlensing Observation in Astrophysics)

(New Zealand/Mt. John Observatory, Latitude： 44°S, Alt: 1029m)

2006~

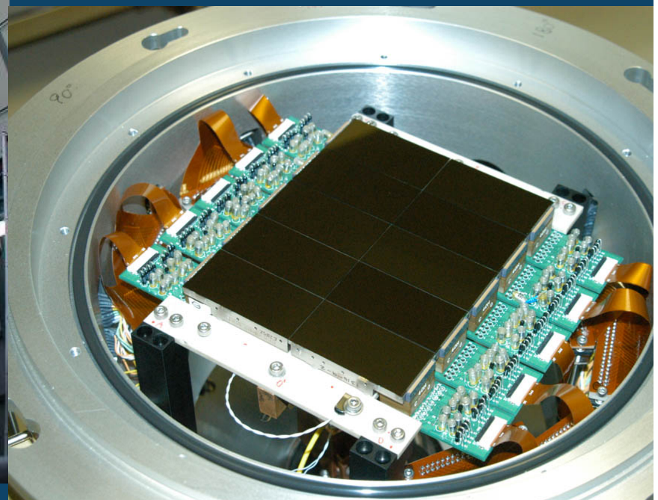


Mirror : 1.8m

CCD : 80M pix.

FOV : 2.2 deg.^{2}

cadence: 15-50 min.



Earth&Sky

小澤さんが立ち上げた星空ツアー会社:

- MOA-II観測室建設
- 現地観測員
- MOA-II見学

Earth & Sky と共に宇宙の不思議を体験してみませんか？頭上に広がる夜空を見上げる「星空ツアー」、テカポの雄大な自然を見下ろせる「アストロカフェ」。私たちは常に宇宙の力、科学を学びそれらを共有しています。カンタベリー大学が管理・運営するマウント ジョン天文台にて星々や私たちの住むこの惑星について楽しみながら知識を高めてみましょう。

- 小澤 英之, Directing Manager

天文台星空ツアー (/index.php/ja/tours)

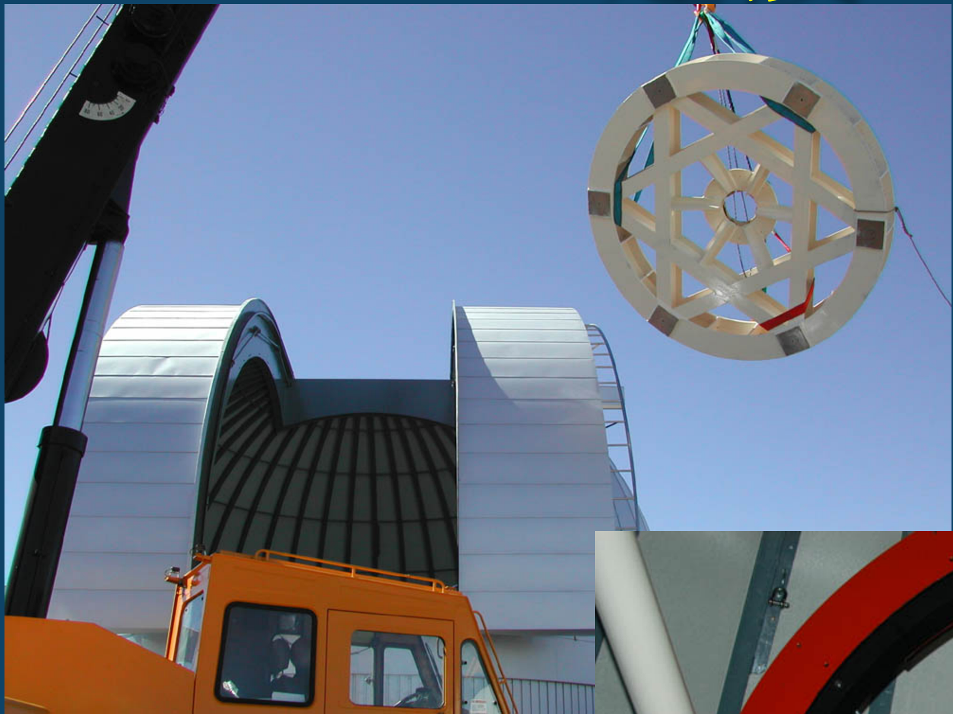
テカポにあるMt.John(マウントジョン)天文台やCowan's(コーワンズ)天文台で南半球ならではの星空をご案内いたします。ツアーの中では望遠鏡を使って天体をご覧いただいたり、また条件が許せばマウントジョンに設置されている、ニュージーランドで一番大きな望遠鏡のある天文台の施設を見学していただけます。

アストロカフェへようこそ (/index.php/ja/astro-cafe)

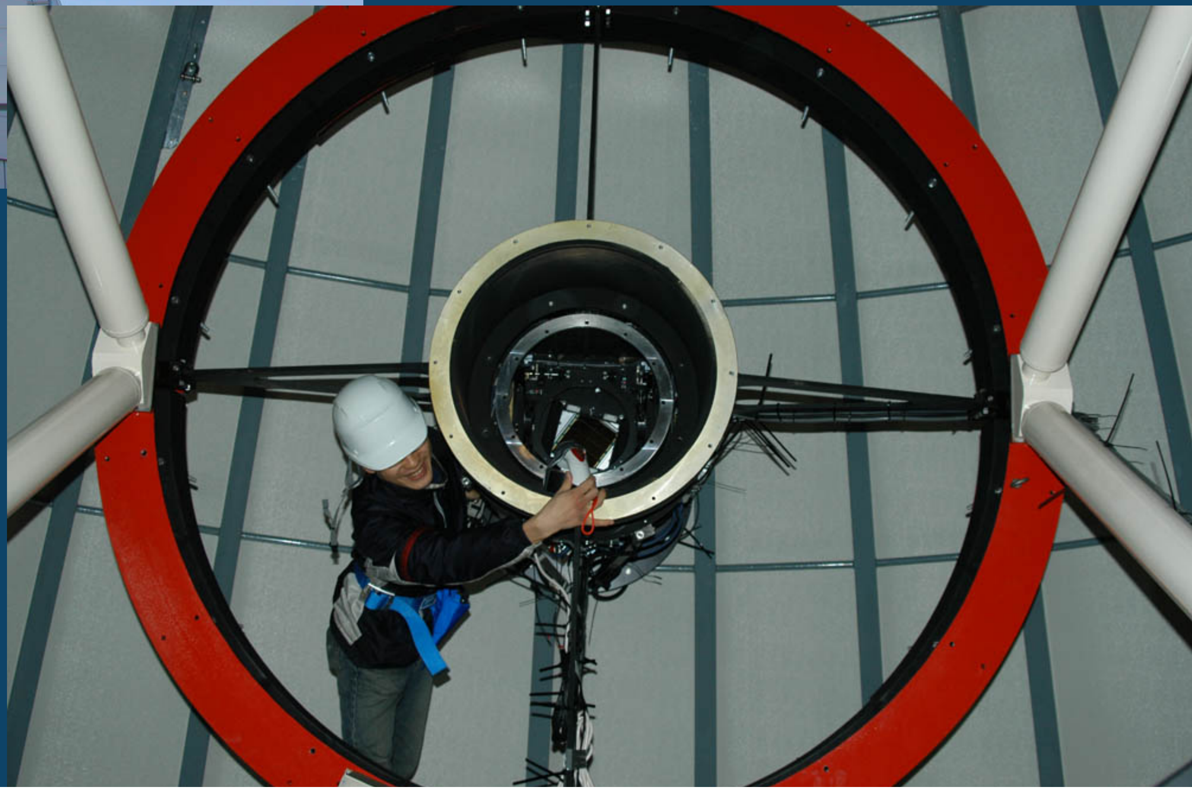
マウントジョンの山頂にある見晴らしの良いカフェ、絶景を見ながら美味しいコーヒーでほっと一息つけるテカポの名所です。 新鮮なテカポの空気と360°広がるパノラマをお楽しみ下さい。

「きっと世界で最も素晴らしい場所にあるカフェかもしれない」 by "Lonely Planet (ガイドブック)"

建設



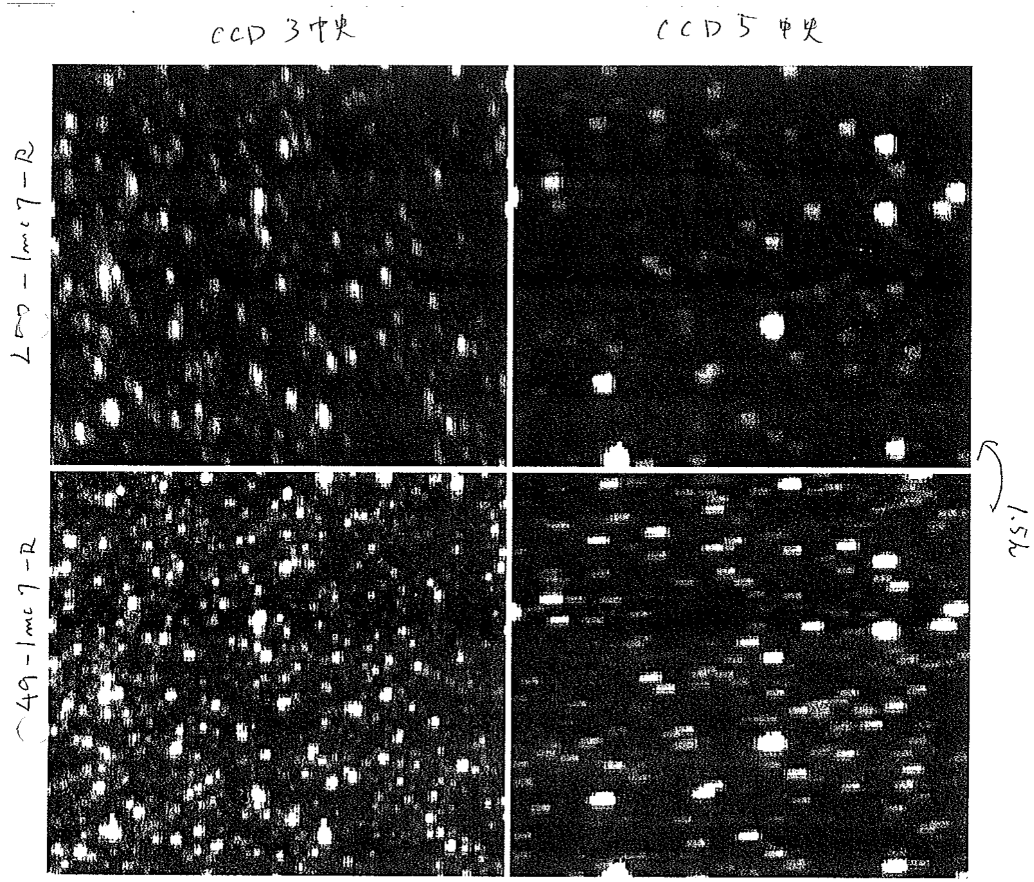
望遠鏡とレンズを
現地で初めて組み立て



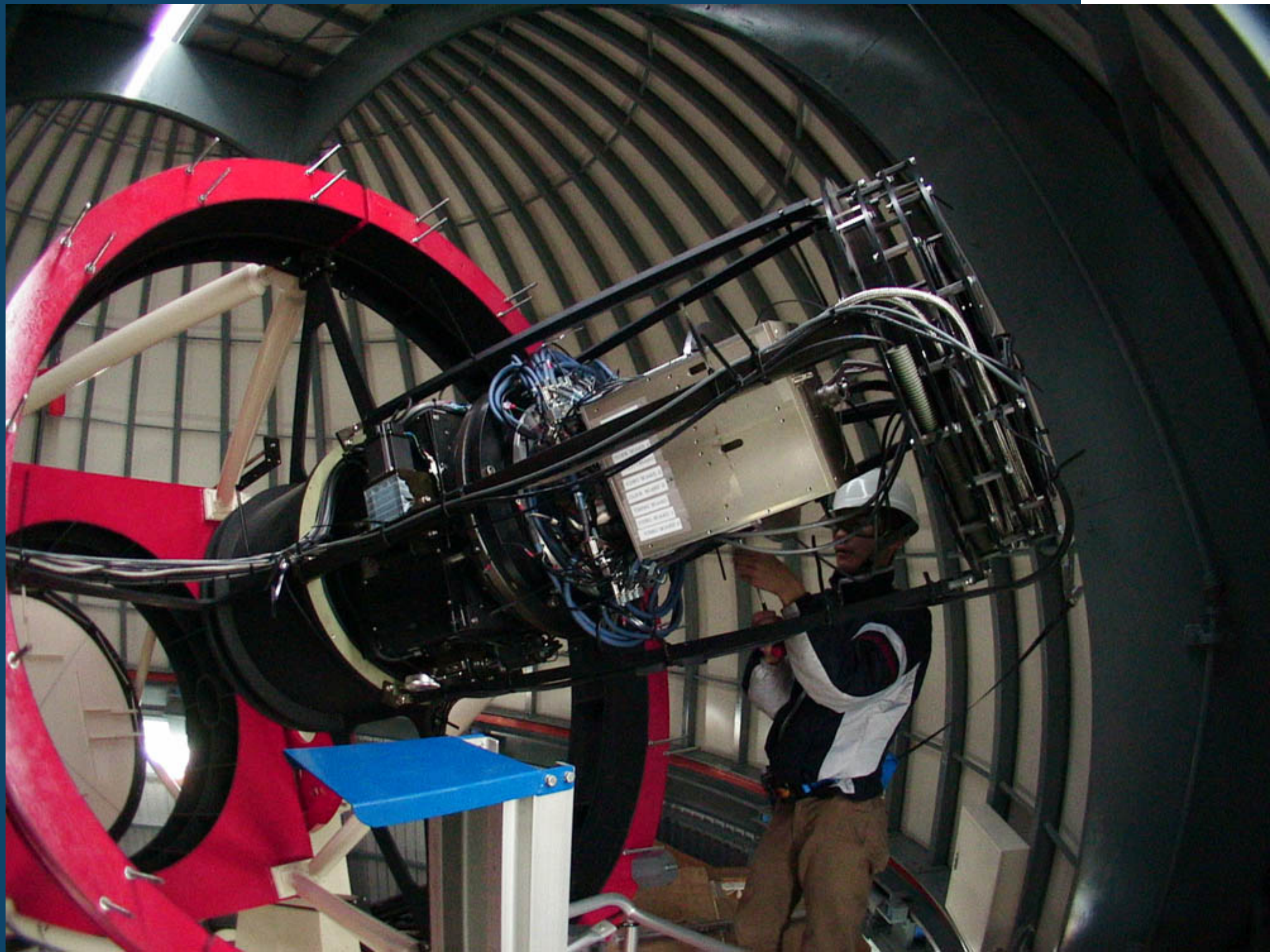
2005年
光学調整難航

カメラーレンズ間に
１cmのギャップ！
NZのPIの友達が発見

Lens3+4とlens1+2のアライメントー＞ハルトマンテストで調整

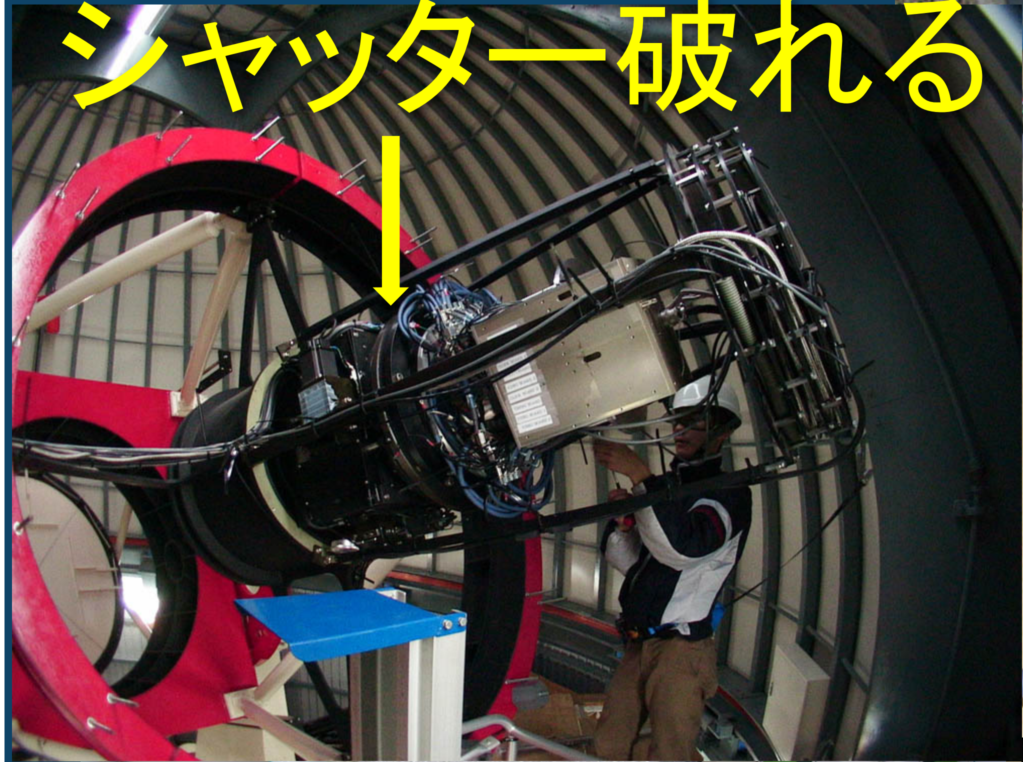


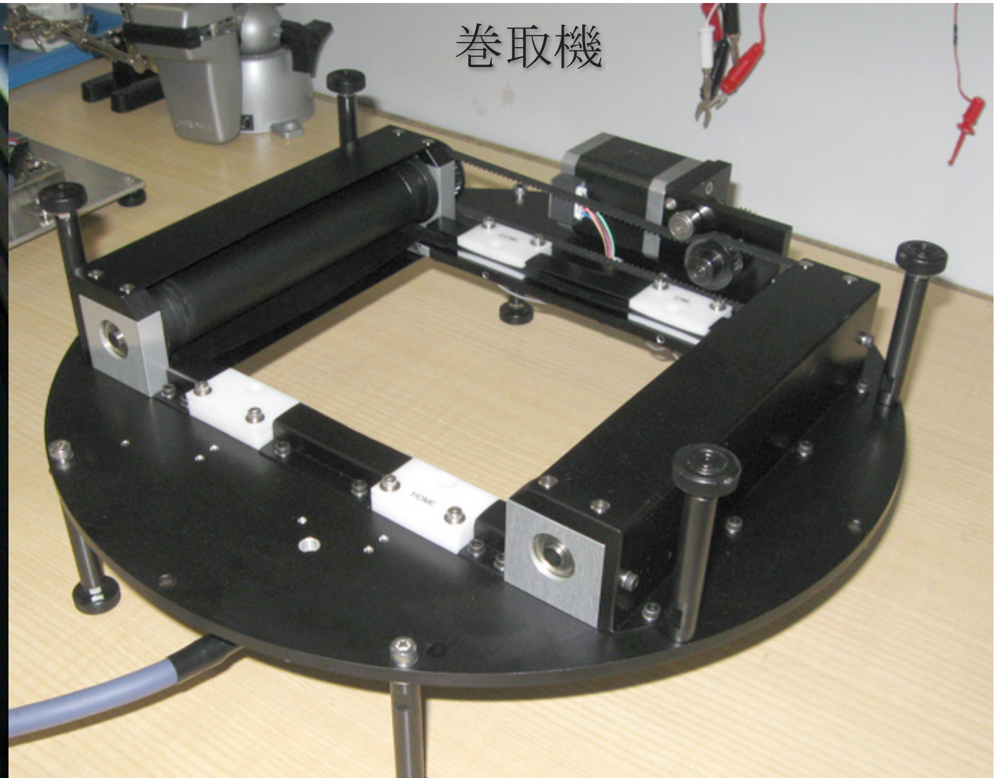
主焦点カメラ

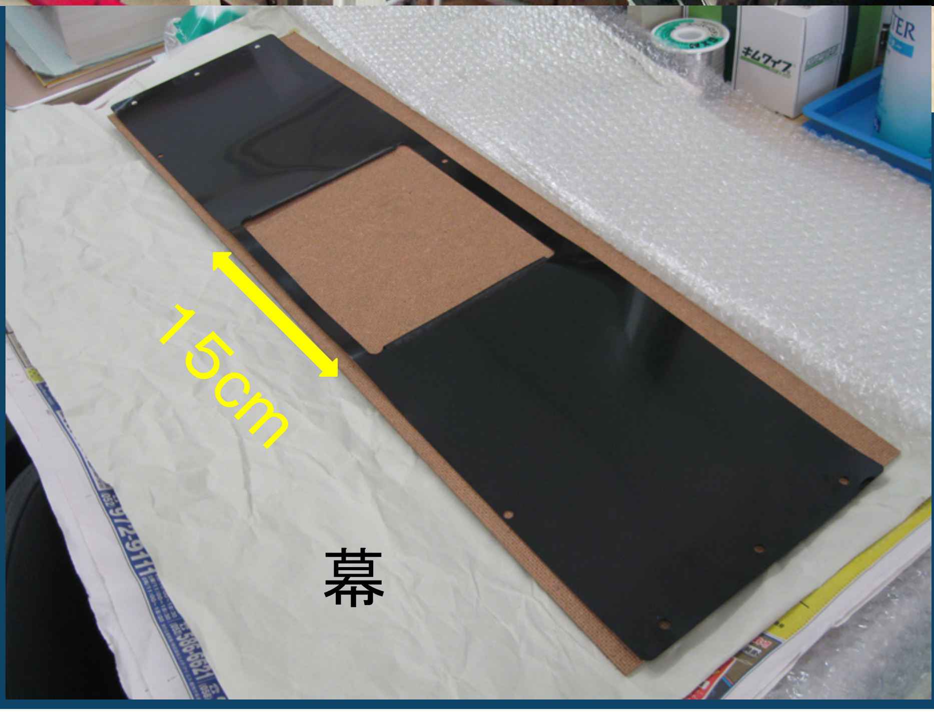


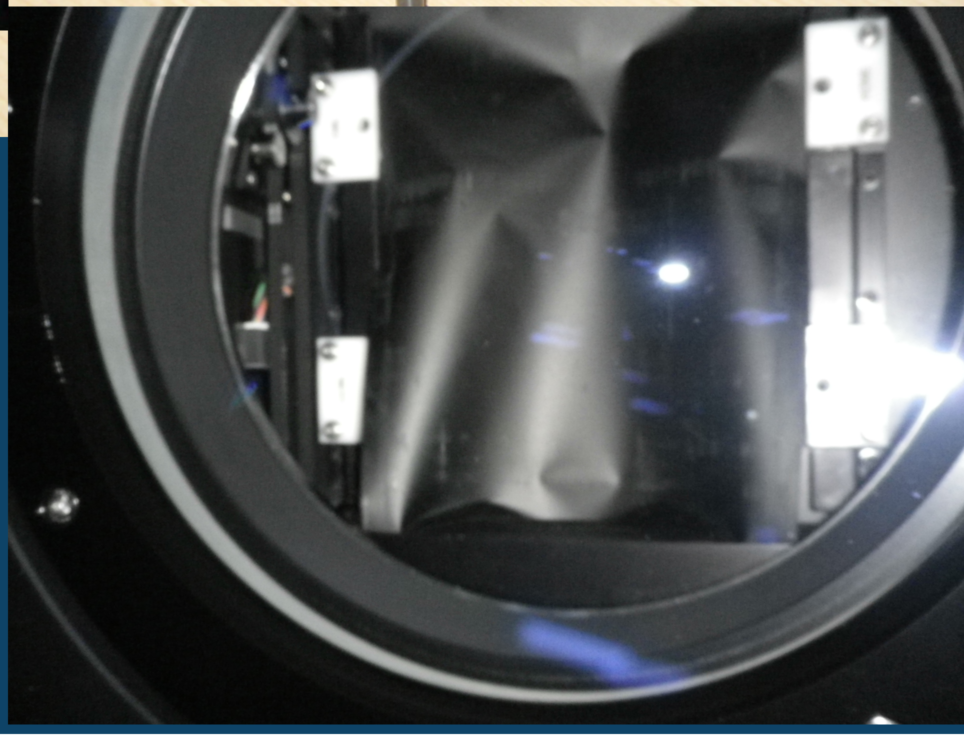
冷えない。60Hz->50Hz　冷凍機をアップグレード

シャッター破れる

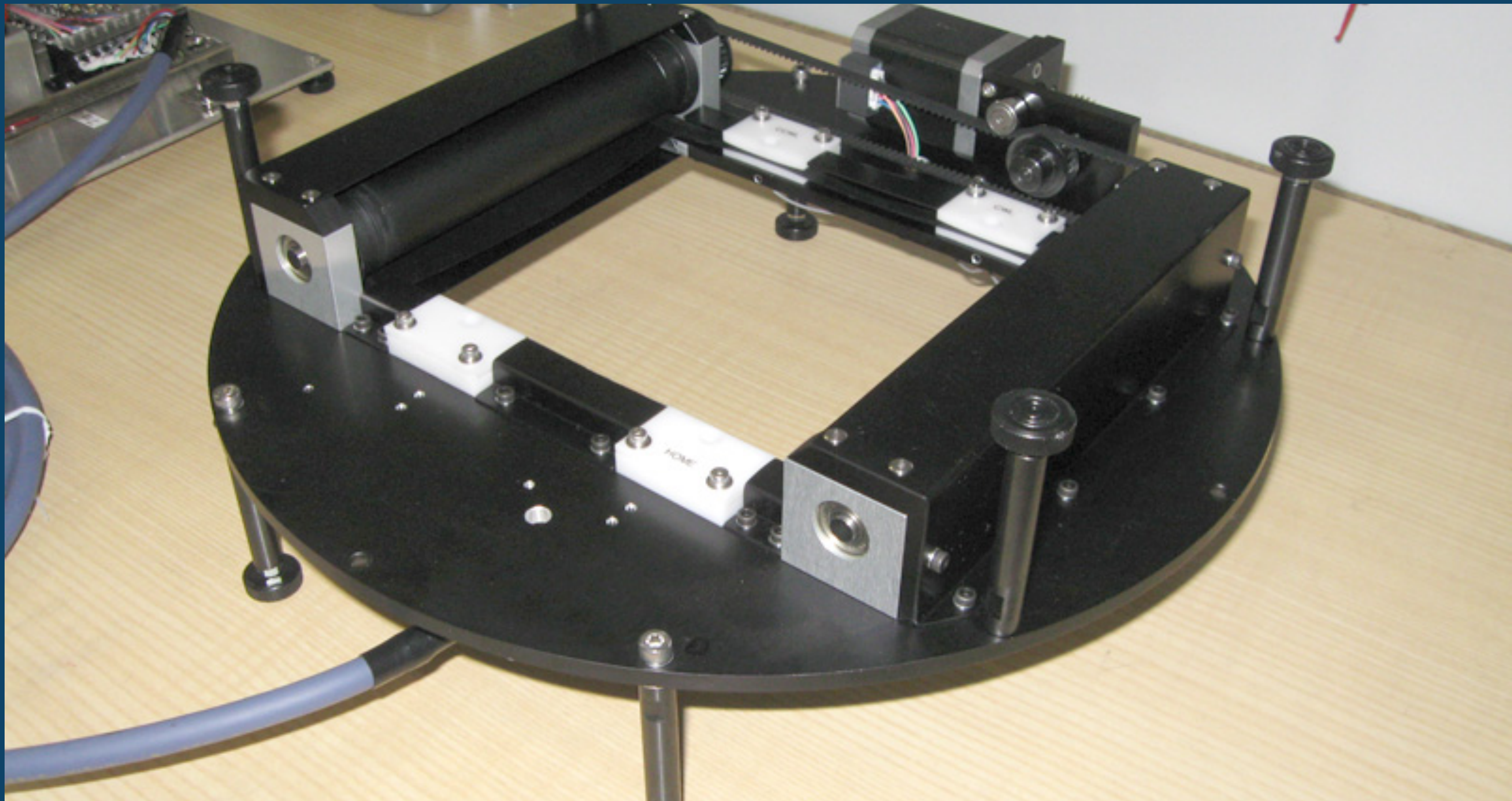




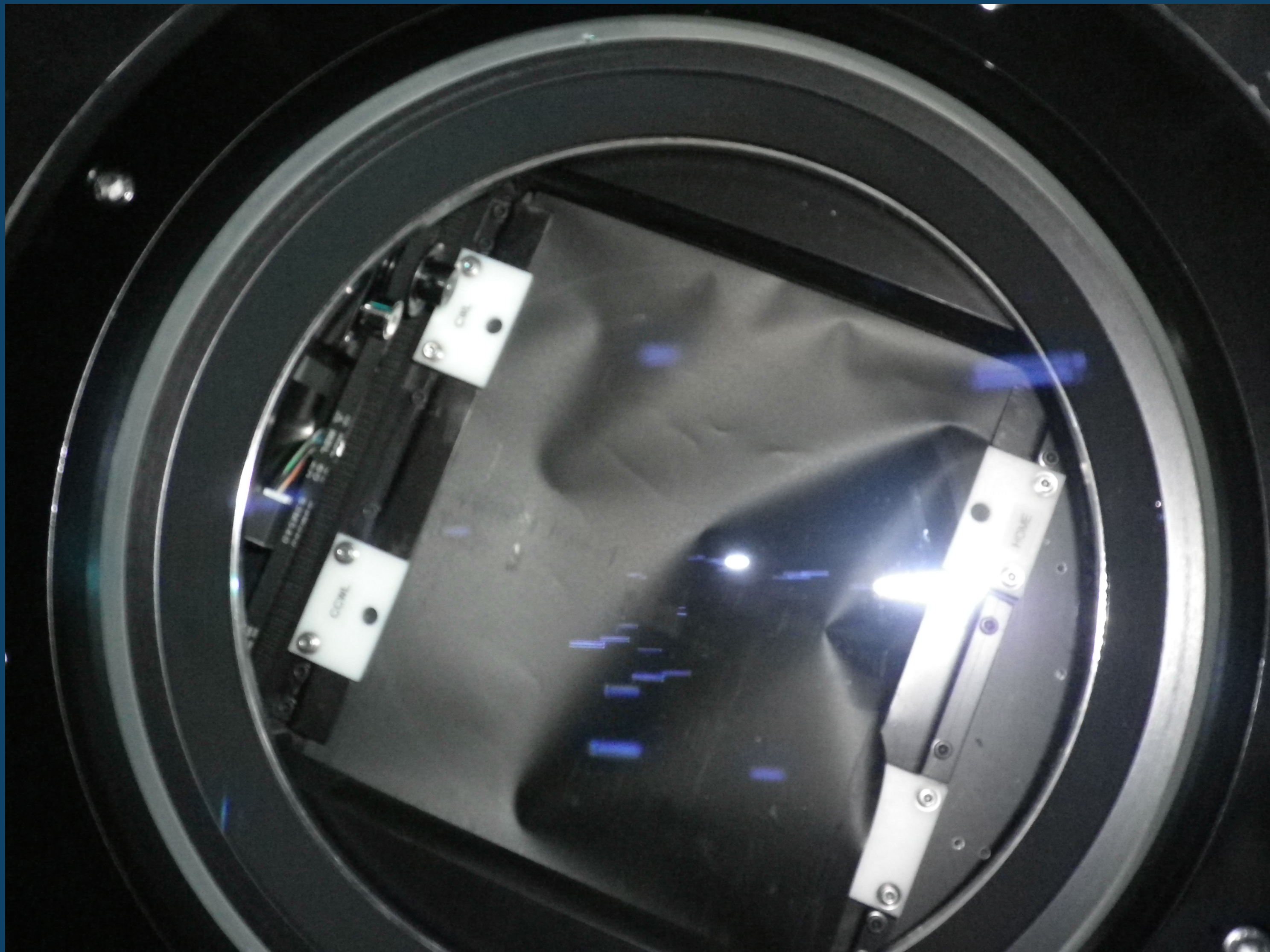




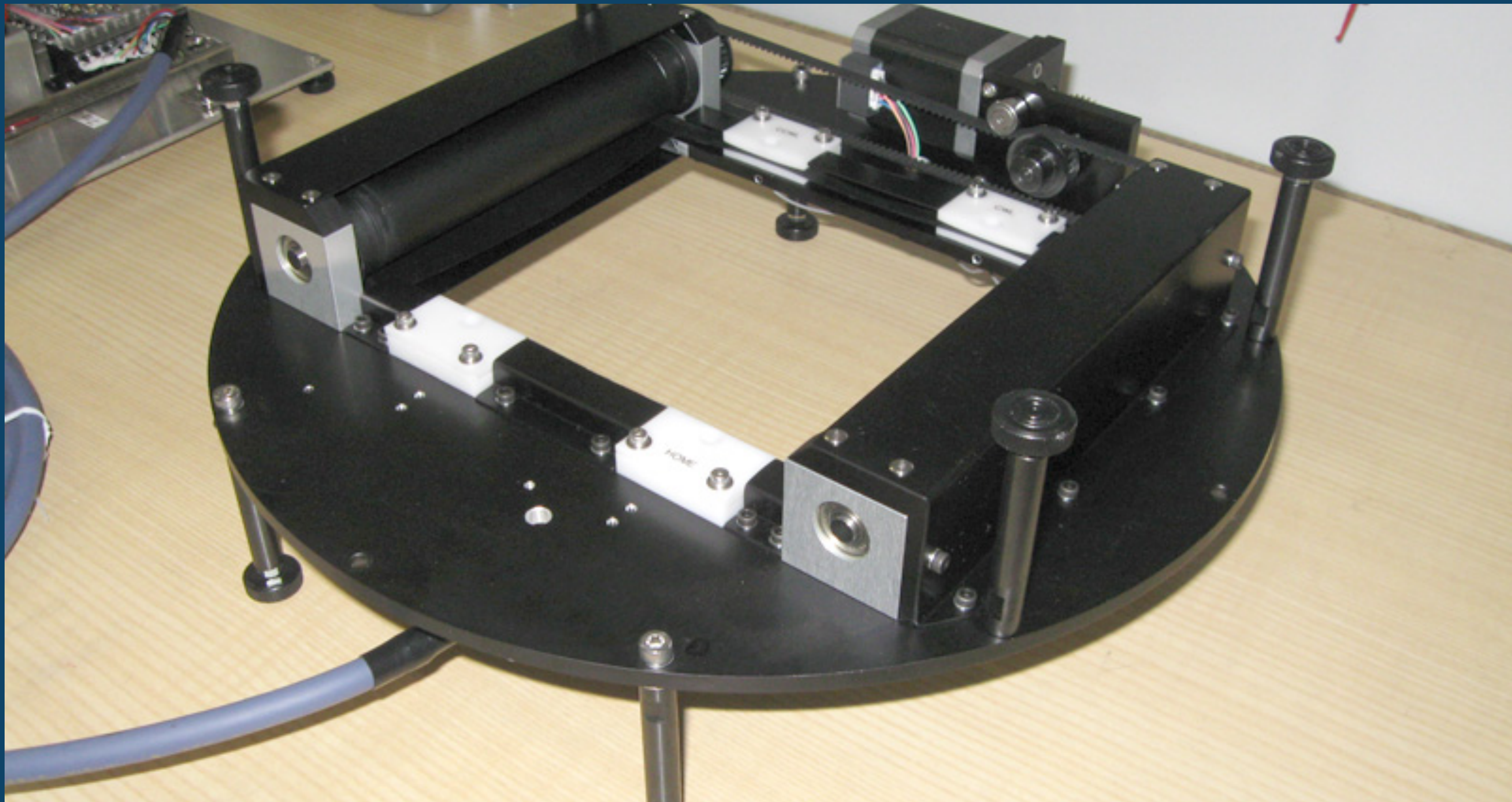
破れないシャッター１号機



破れないシャッター破れる



破れないシャッター２号機



強風

迷光

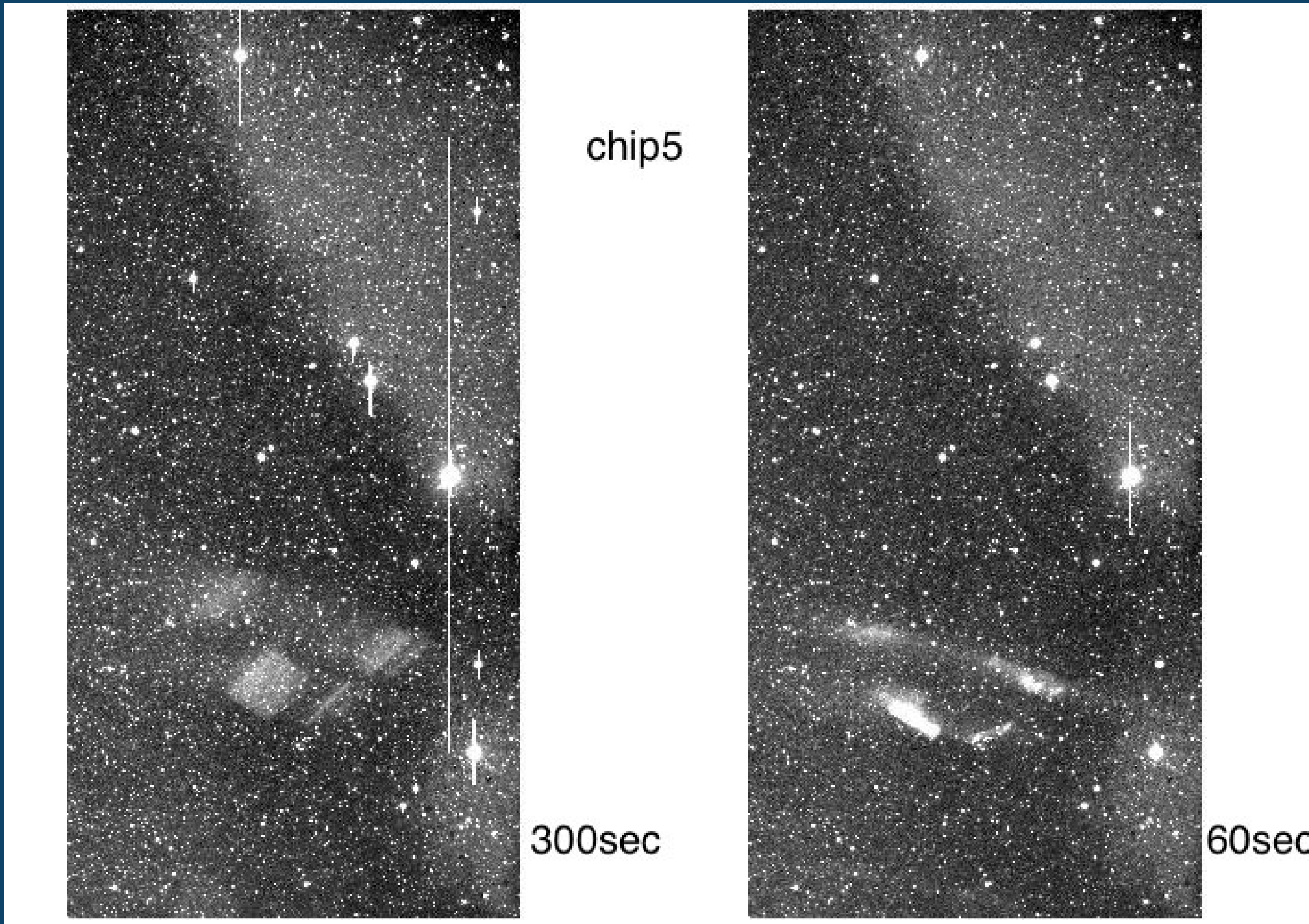
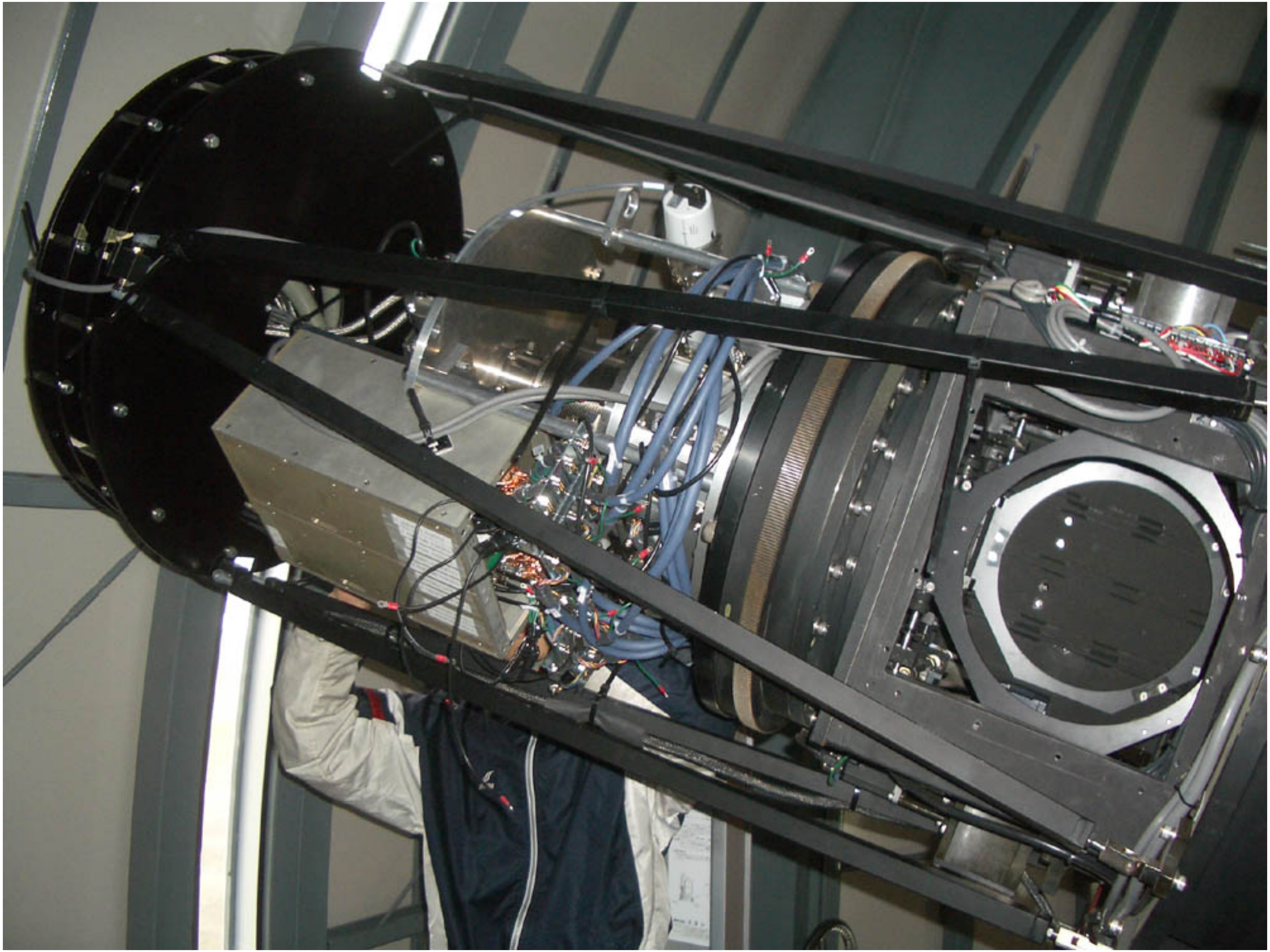
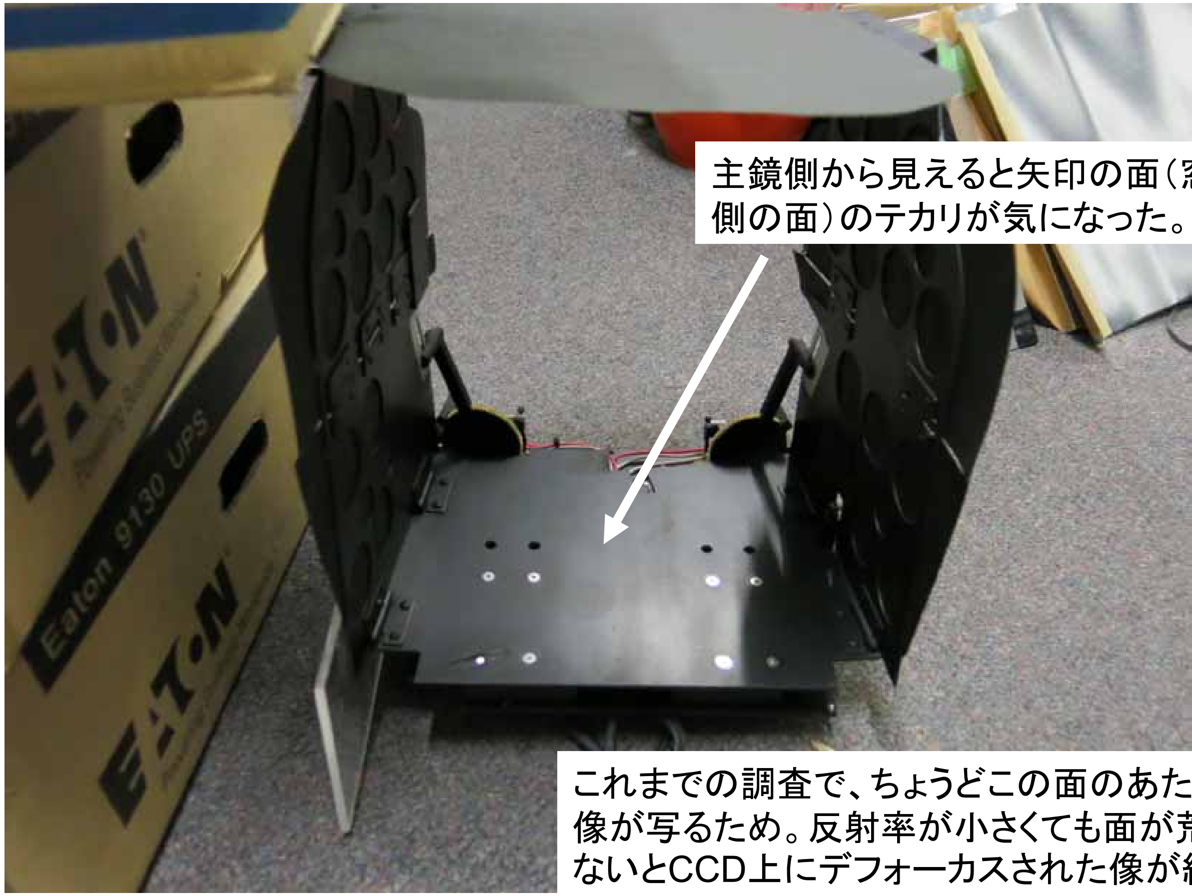


図1



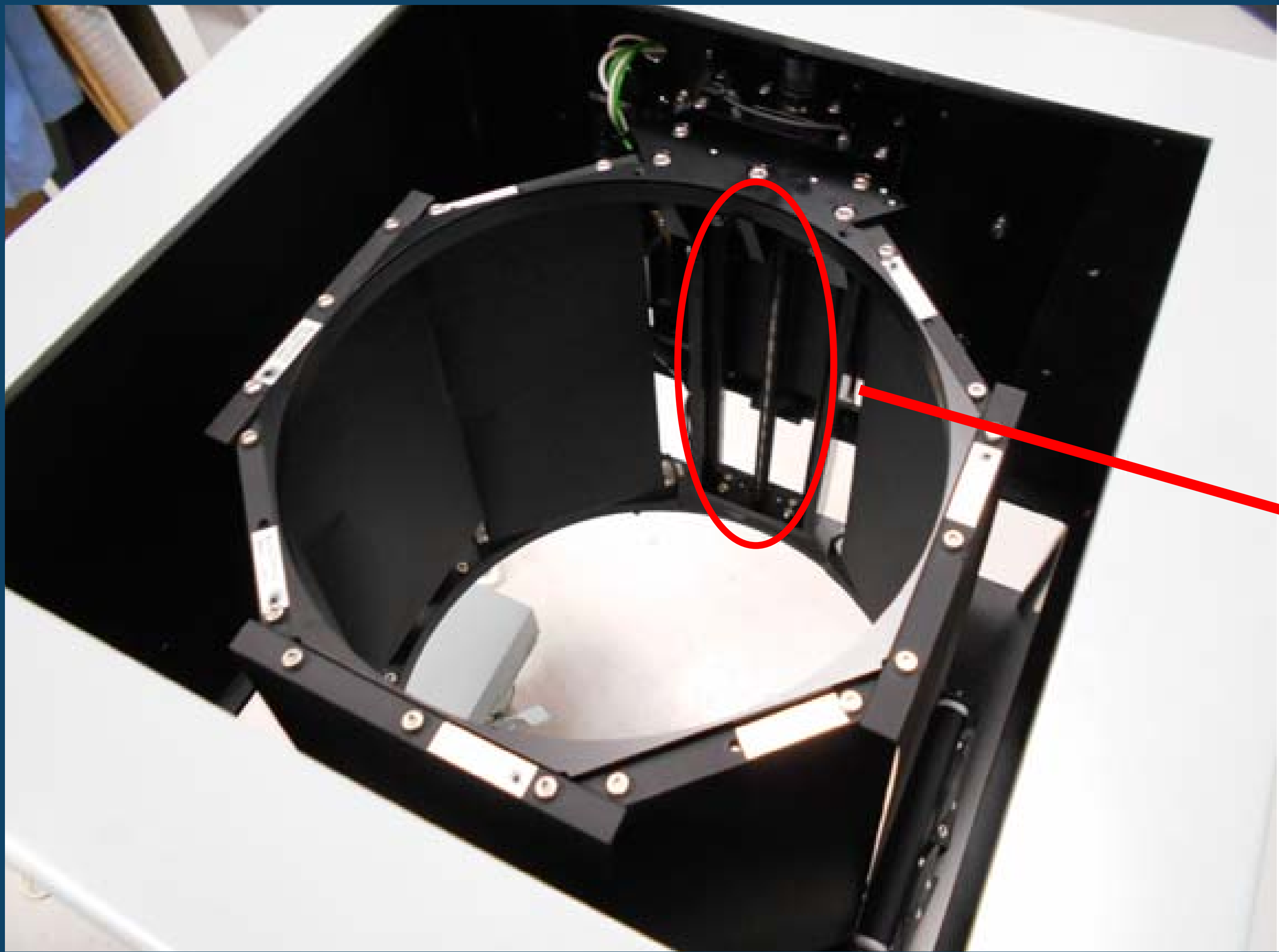
遮光装置1号



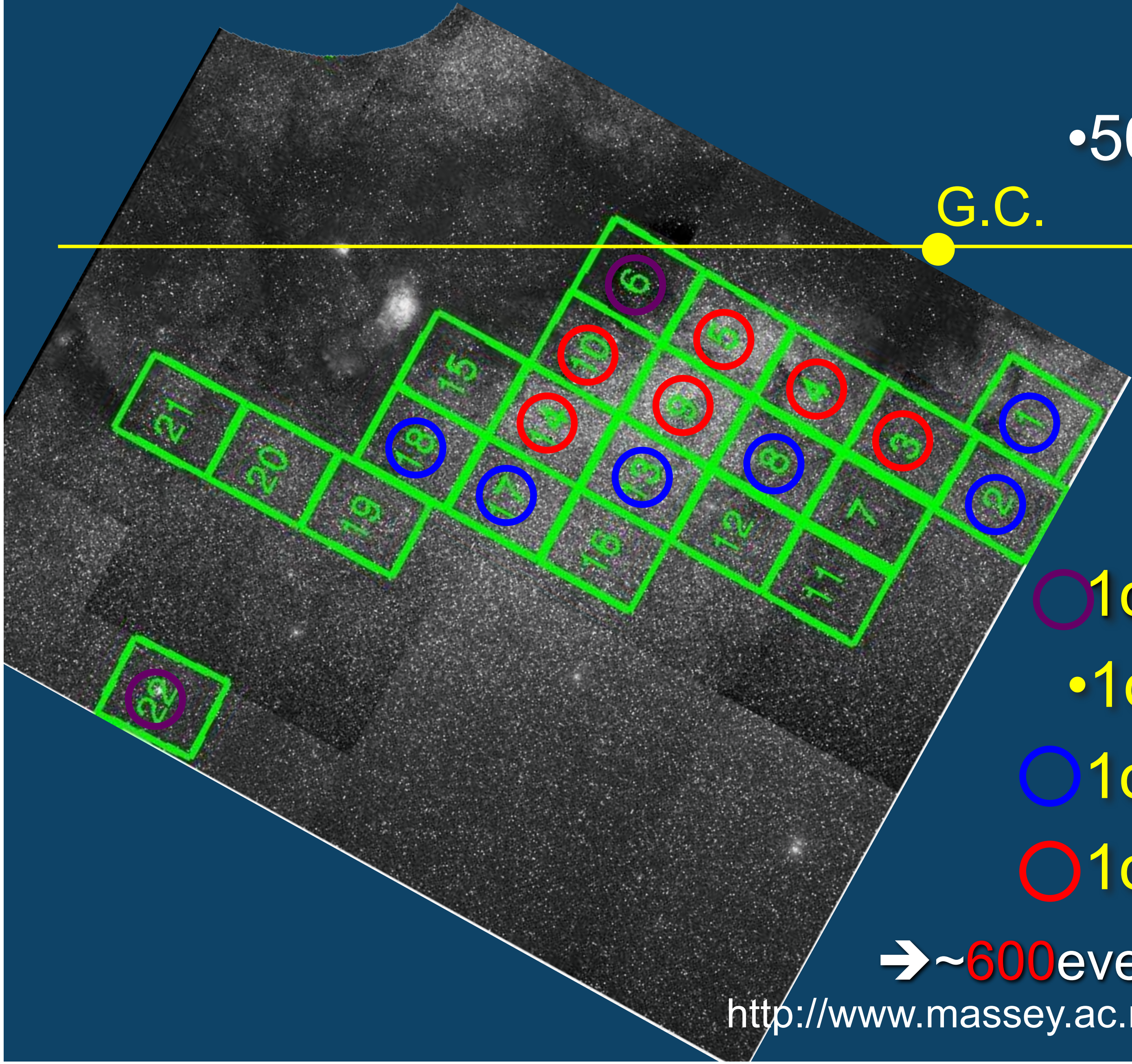
主鏡側から見えると矢印の面（窓側の面）のテカリが気になった。

これまでの調査で、ちょうどこの面のあたりに主鏡像が写るため。反射率が小さくても面が荒れていないとCCD上にデフォーカスされた像が結像してしまう可能性がある。

遮光装置2号



Observation by MOA



- 50 deg.^{2}(20Mstars)

○1obs./night.($>M_{Jup}$)

- 1obs./95min.(M_{jup})

○1obs./47min. (M_{nep})

○1obs./15min. ($M_{\oplus}$)

➔~600events /yr

http://www.massey.ac.nz/~iabond/alert/alert.html

Survey & follow-up to detect exoplanets

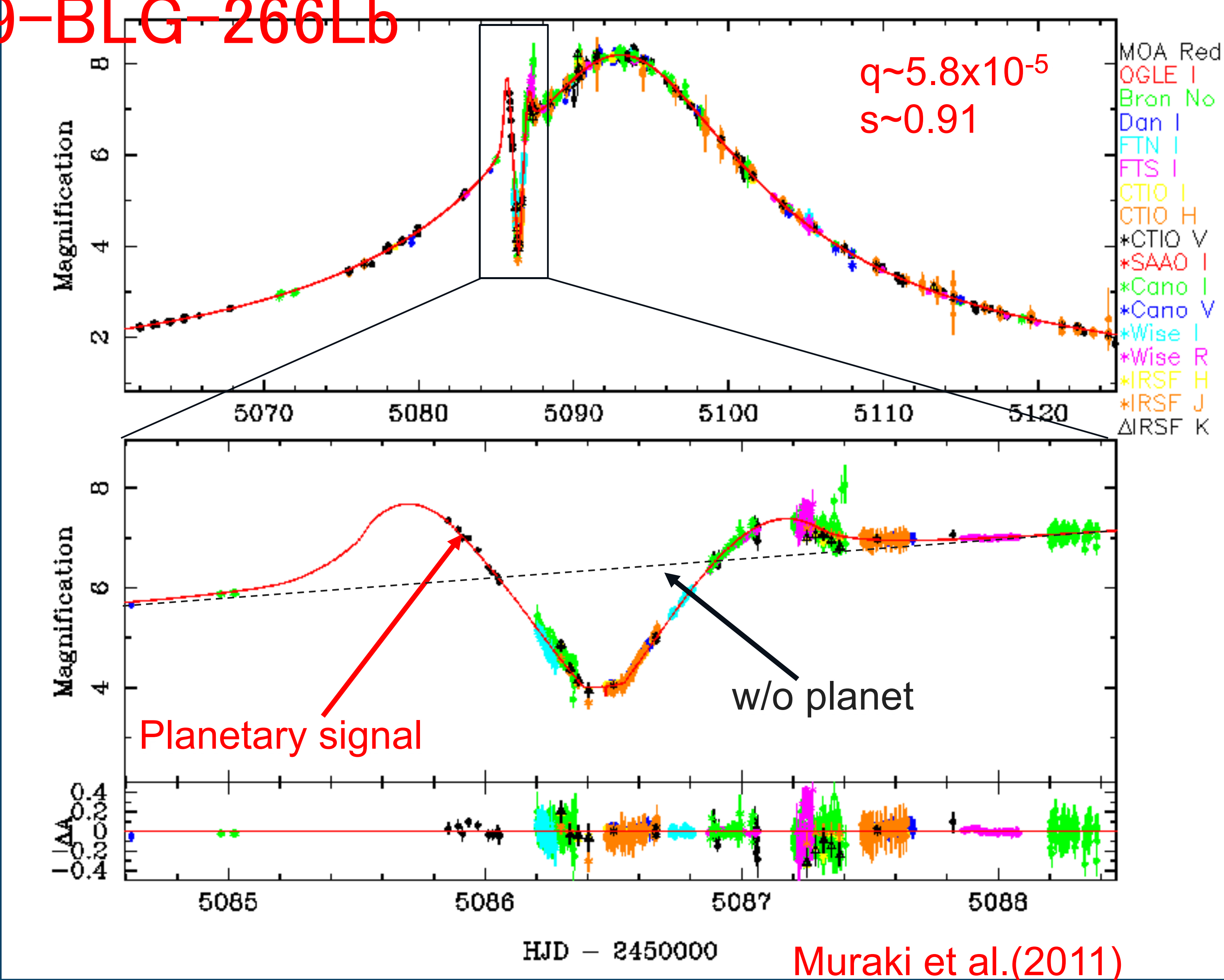
MOA-2009-BLG-266Lb

MOA found planetary deviation in realtime

Followed up by telescopes around the world

データの即時公開:
共同研究:

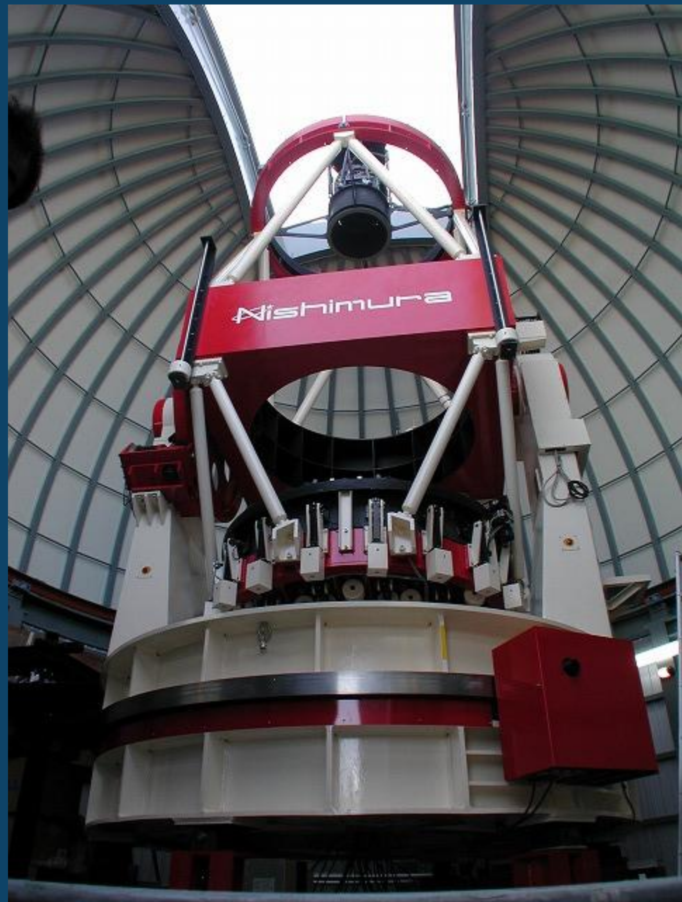
100を超えるオーサー



紛争もあるが。

PRIME (PRime-focus Infrared Microlensing Experiment)

+



Takahiro Sumi (Osaka Univ.)

2017/3/28, **Workshop on Studies on variable stars and extinction law in the Milky Way and nearby galaxies** @University of Tokyo

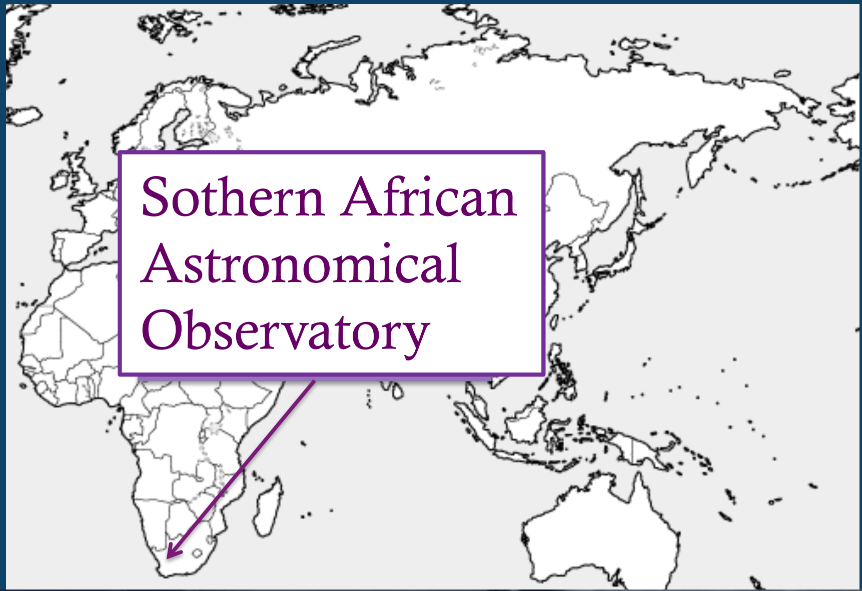
PRIME Wide FOV
1.8m Telescope at SAAO

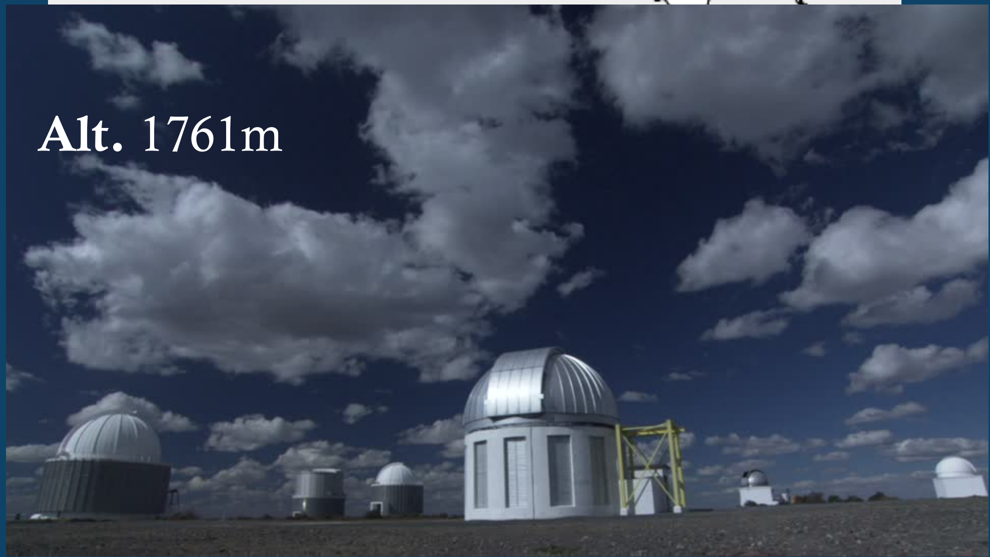
Diameter: 1.8m, (f/2.29)

FOV:1.25° x1.25° =1.56deg^2(0.5”/pix)

(6xfull moon) World Largest FOV

H-band Hi-res spectrograph





PRIME (PRime-focus Infrared Microlensing Experiment)

Objectives:

1. Microlensing Exoplanets (～50%)
   - Study low-mass planets outside of snowline
   - Plant frequency in the Galaxy Center
   - WFIRST microlensing survey field optimization
   - Concurrent observations with WFIRST
   - Characterize H4RG detectors
2. Other sciences （～50%)

PRIME collaboration

- **Osaka Univ.:** T Sumi (PI), H. Shibai, T. Matsuo
- **ABC (Astro-Biology Center):** M. Tamura (U Tokyo)

  →望遠鏡

- **NASA GSFC:** D. Bennett, R. K. Barry , A. Kutyrev,
- **U of Maryland:** Sylvain Veilleux, Drake Deming

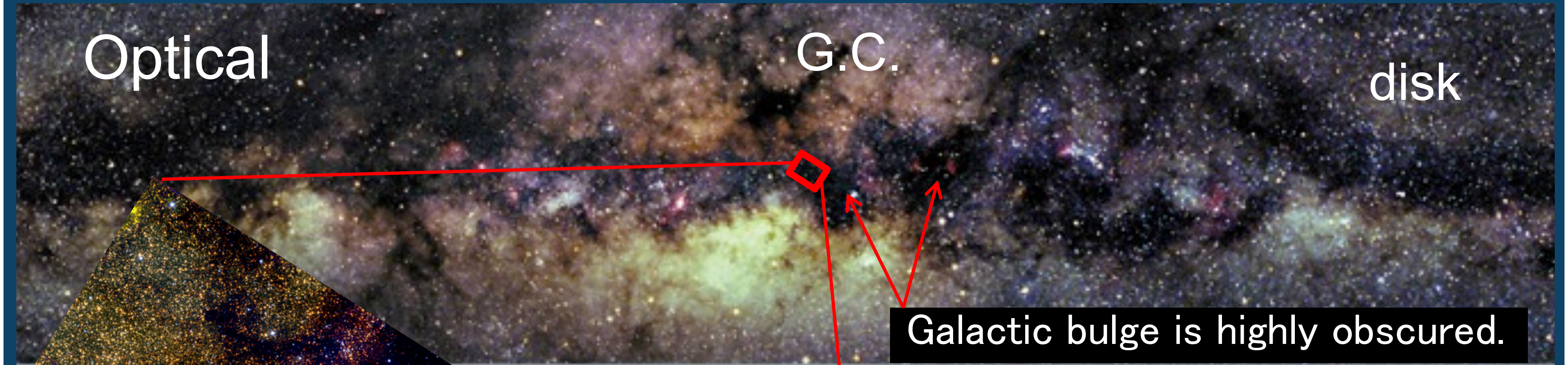
  →カメラ製作

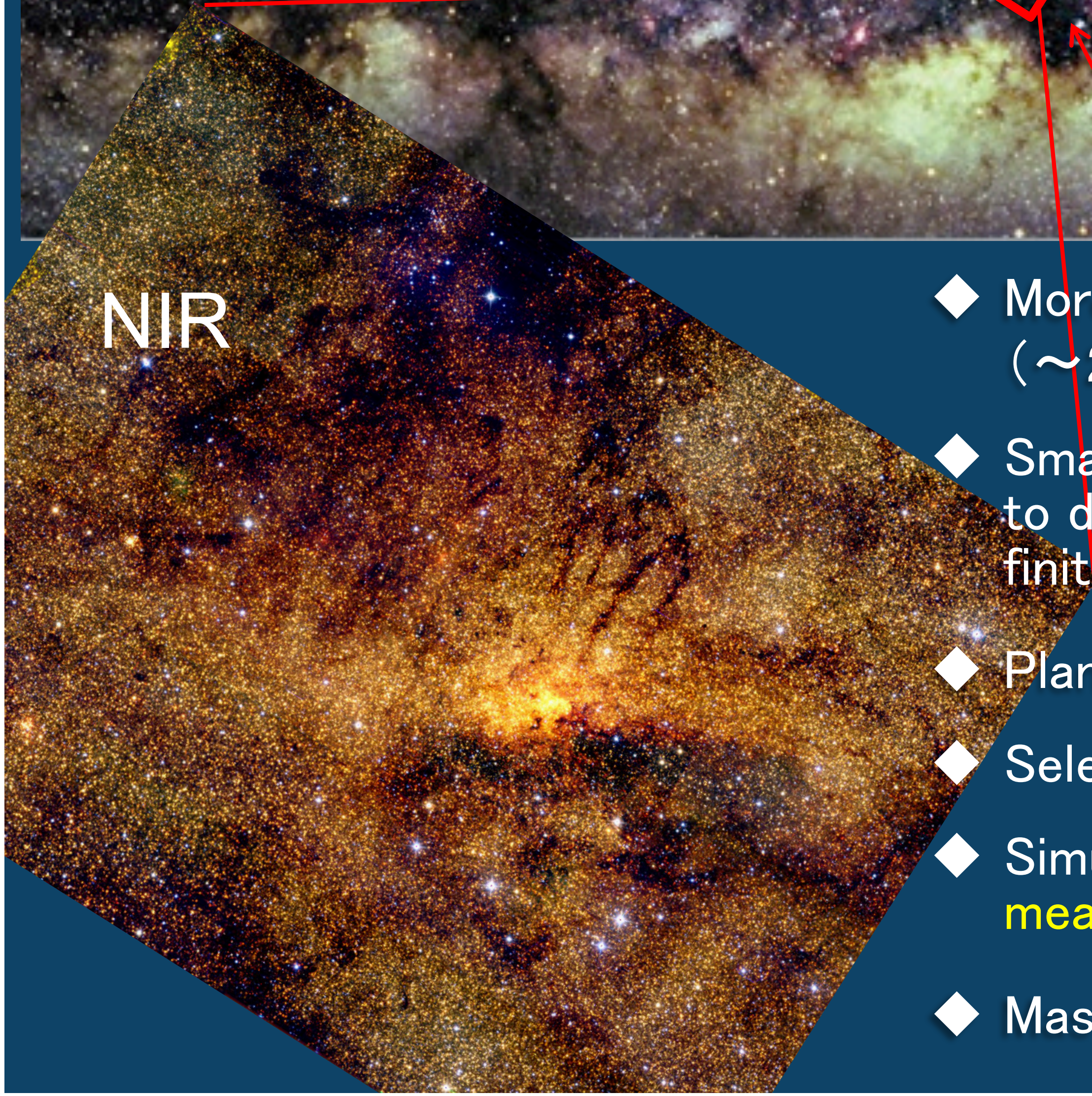
- **SAAO:** Ted Williams (Director)+

  →Dome + building

Bond(Massey U), N. Rattenbury (U Auckland), J-P. Beaulieu (IAP), A. Fukui (NAOJ), T. Nagayama (Kagoshima U), N. Matsunaga, Norio Narita (U Tokyo), Yasushi Muraki, Fumio Abe (Nagoya U), Mikio Kurita (Kyoto U), Joachim Wambsganss, Luigi Mancini (U Heidelberg), Eamonn Kerins (U Manchester), David Charbonneau (Harvard、Mearth PI、TESS CoI)、Cullen Blake (Pennsylvania、TESS CoI)

More events & planets in NIR at G.C.

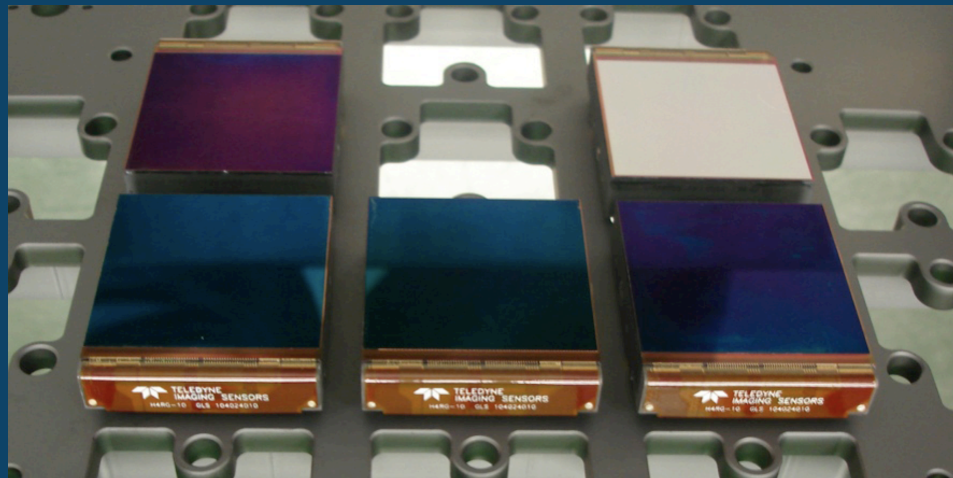




- More stars & more events at GC. (～2400events/yr, ～12planets/yr)
- Smaller radius source (redder) enable us to detect low(Earth)-mass planets. (small finite source effect)
- Planet frequency at GC.
- Select WFIRST fields.
- Simultaneous observation with WFIRST to measure lens mass.
- Mass Function at GC (planet-Black Hole)

The World Widest FOV in NIR with World Largest class NIR camera

Loan Four Teledyne HgCdTe 4kx4k H4RG-10 (10μm pitch) from WFIRST team (NASA)



Four H4RG-10 which WFIRST Team owns. (1 chip is dummy)

Diameter:1.8m, f/2.29,

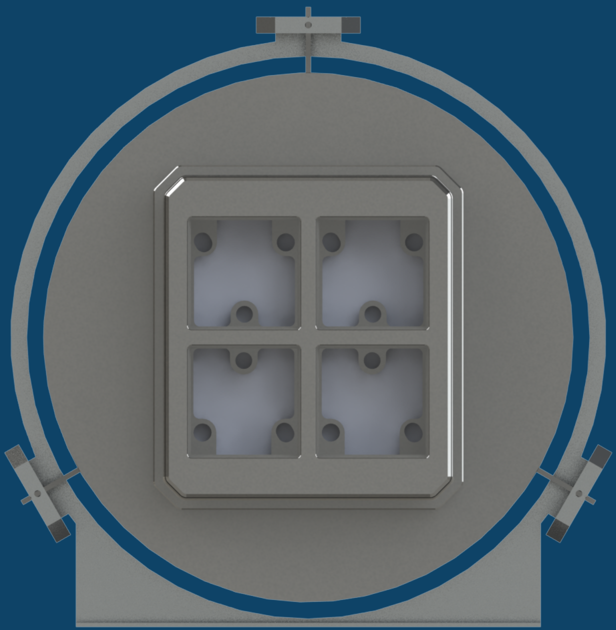
FOV:1.25° x1.125° , 0.5arcsec/pix

Will be Manufactured by NASA @GSFC

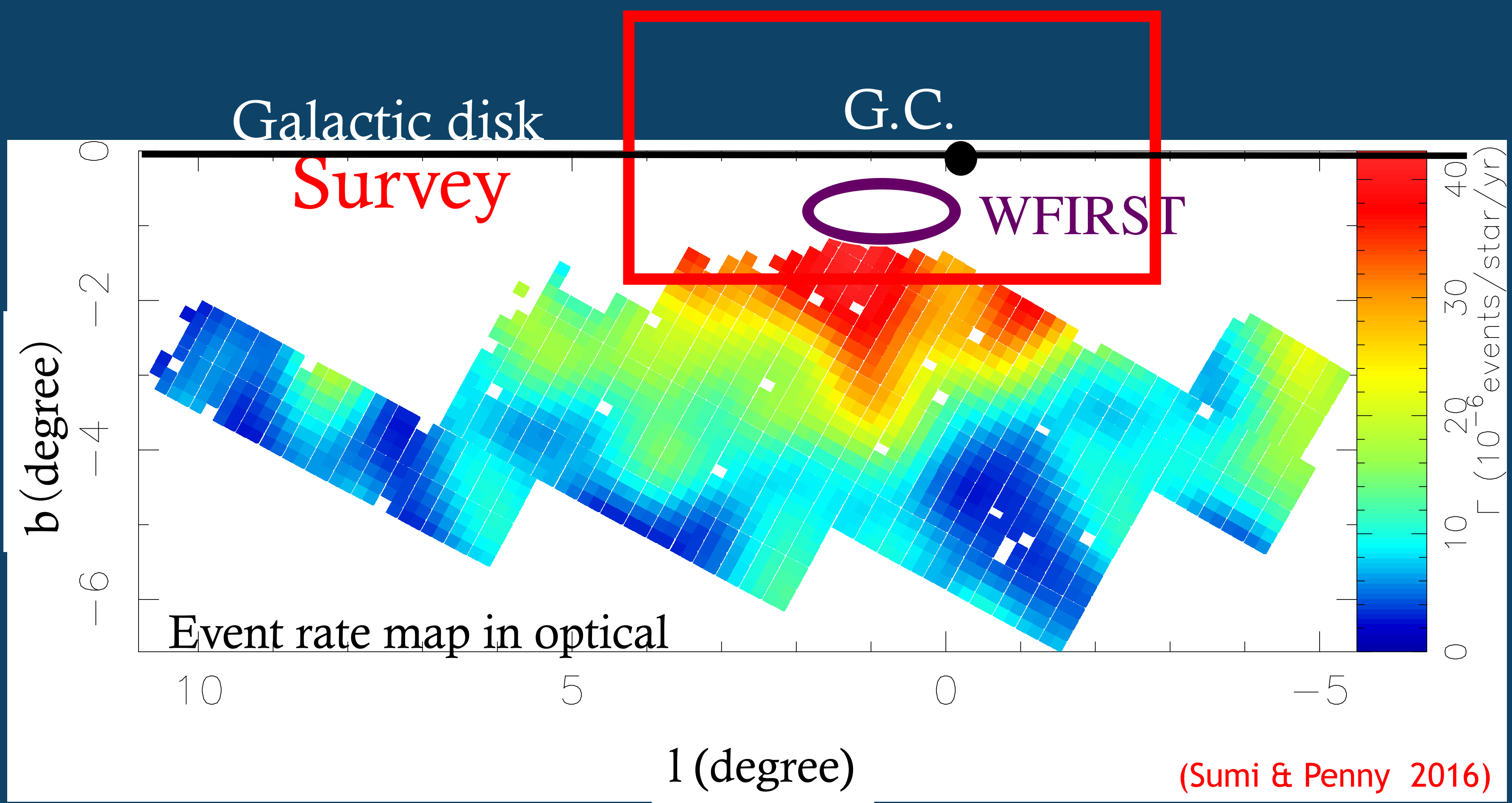
Camera

will be Manufactured by NASA @GSFC

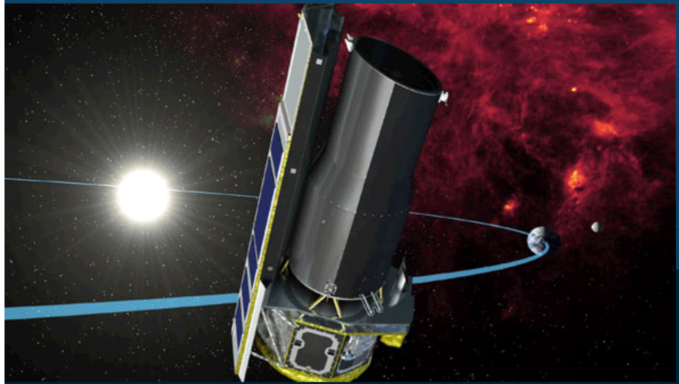
- Operational temperature: 90-100K
- the normal outputs can probably go as high as 500 kHz, but likely something like 300-400 kHz.
- The system reads out the full array in 11 seconds at 100 KHz.
- 16 Read-out ports per chip (64 outputs are available.)
- 16x4chips=64 read out ports.
- I asumme 4seconds for read out w/ 300 kHz.
- Leach controller or Sidecar



Study the galactic structure & Optimize WFIRST microlensing survey fields by mapping the event rate in NIR



Event rate vary by a factor of 2 (peak is at l=1°)

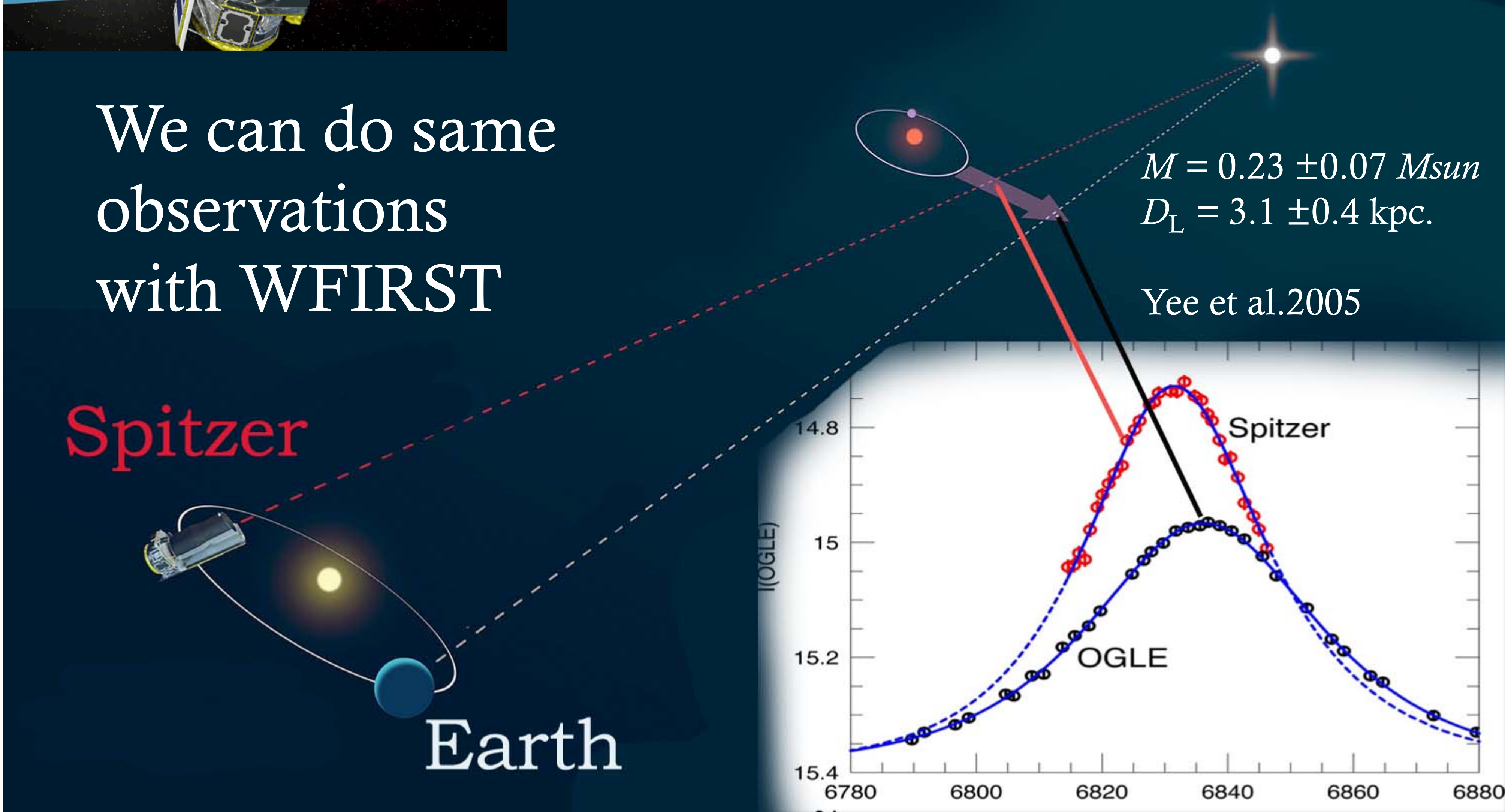


Simultaneous Ground-Space monitoring with Spitzer

We can do same observations with WFIRST

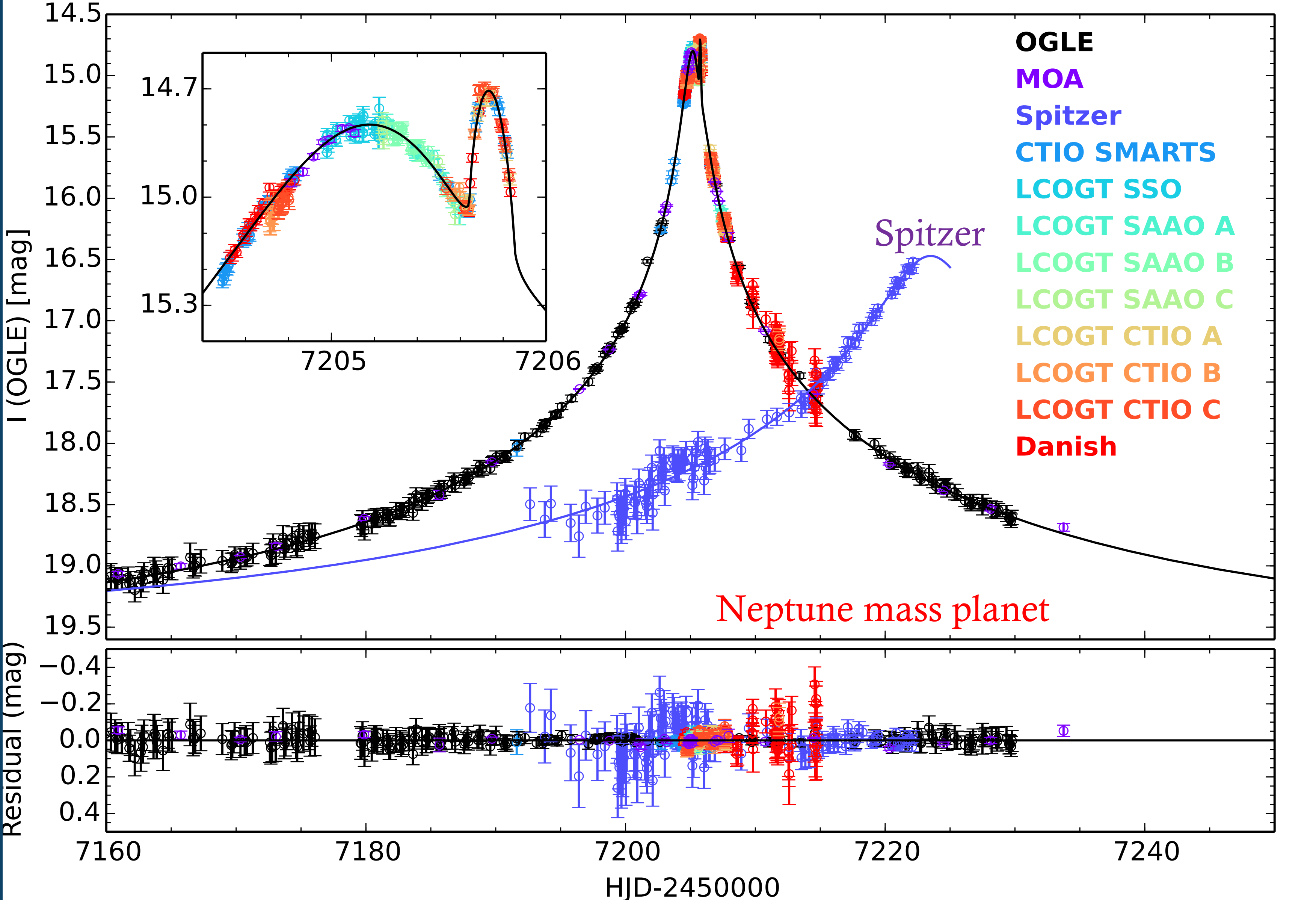
$M = 0.23 \pm 0.07\ Msun$
$D_L = 3.1 \pm 0.4$ kpc.

Yee et al.2005



OGLE-2015-BLG-0966/MOA-2015-BLG-281

(Street et al. 2015)



Off-bulge season sciences

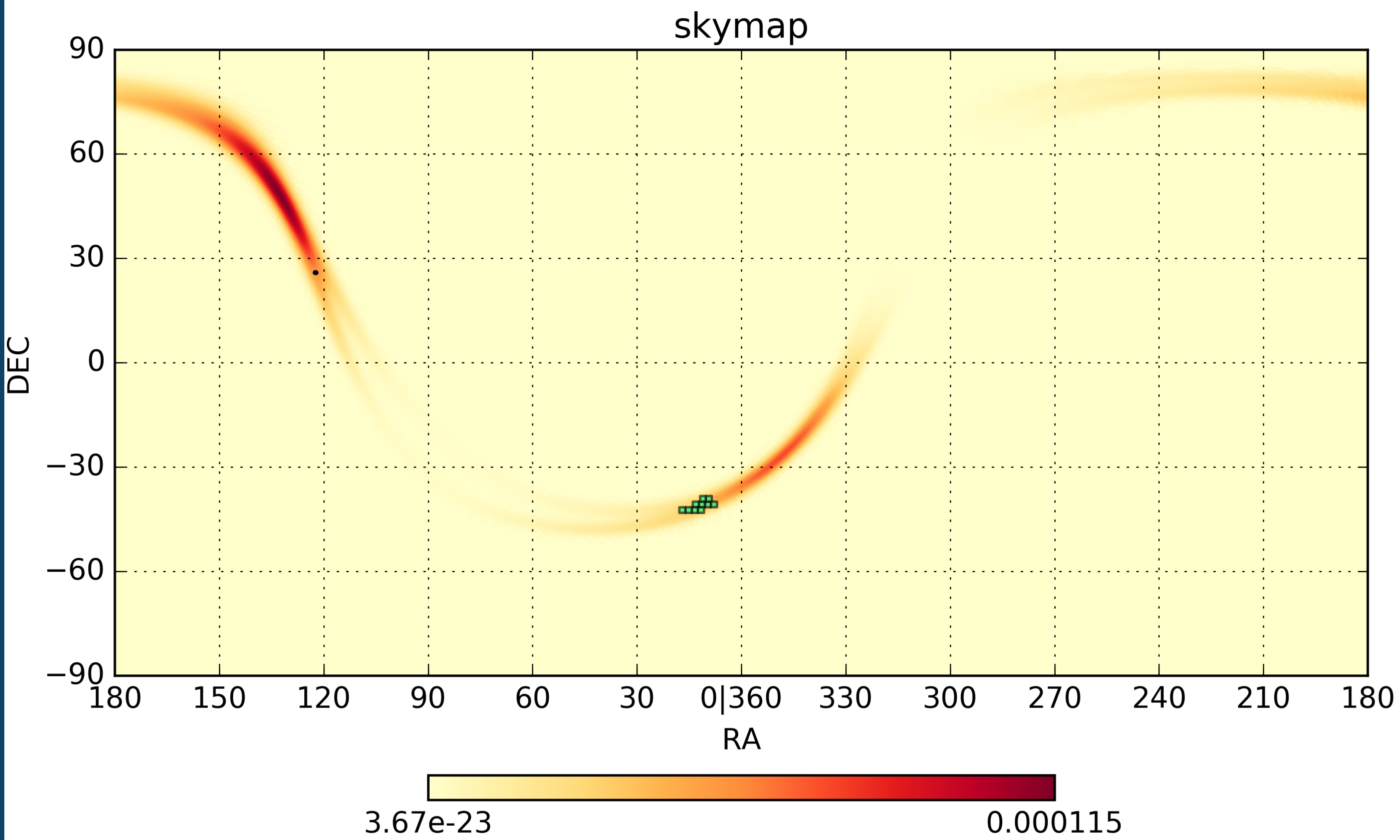
- **Transit search for M-dwarfs:**
  - Search for habitable planets around M-dwarf which is bright in IR
  - Follow-up transit candidates by HAT-South, Mearth projects for select real planets and measure the atmosphere.
  - Systematics due to Sunspot and limb darkening is smaller in IR.
  - Wide FOV enable us to observe many reference stars for high precision photometry.
  - Follow-up TESS candidates. TESS is optical. Need IR for M-dwarfs. Collaborators:

    David Charbonneau（Harvard、Mearth PI、TESS CoI）、
    Cullen Blake (Pennsylvania、TESS CoI)、
    Narita（NAOJ, TESS CoI）、Fukui（Okayama）

- **Search for counterparts of high-z GRB, GW etc. ….**

- **H-band spectrograph: RV for giant planets around M-dwarf.**

Gravitational Wave counter part



Schedule

2016 detail design

2017 manufacture

Agreement of academic exchange with SAAO and University of Maryland

2018 manufacture, construction

2019 install, first light. observation start

～

2023 create event rate map in the bulge

2025 WFIRST launch,

Concurrent observation start

2031 continue to the end of the WFIRST

Summary

中小プロジェクトは、

- 現地コラボレーターが大事
  →維持費が大事 （ベストではないが）

- サイエンスコラボレータが大事
  →データ公開が大事