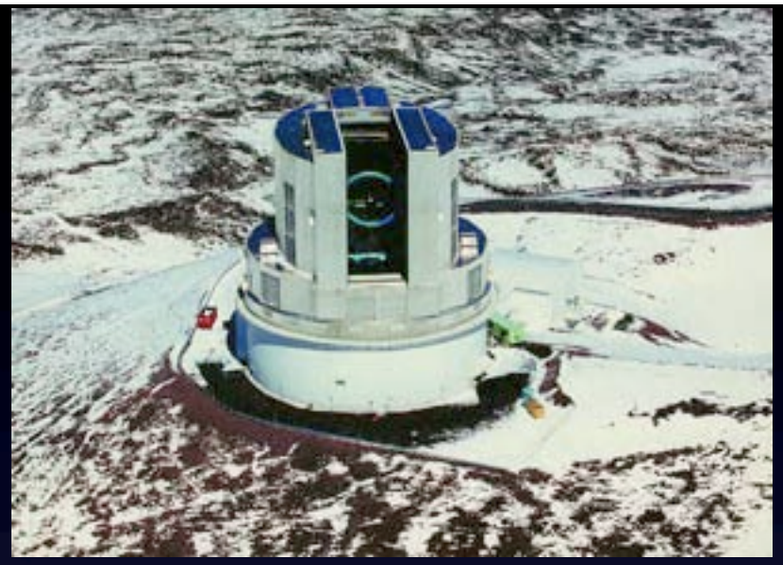
IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO



暗黒エネルギーとすみれ計画

村山斉（IPMU、UC Berkeley）

将来計画タウン・ミーティング@IPMU

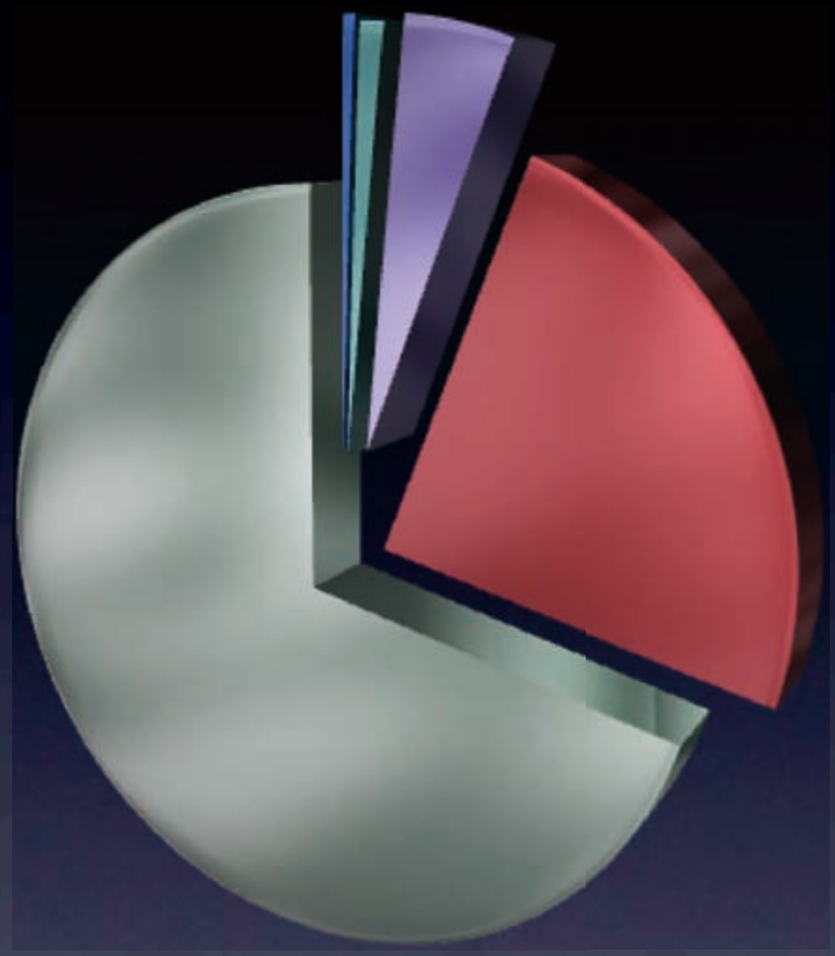
2011年7月29日

BERKELEY CENTER FOR THEORETICAL PHYSICS

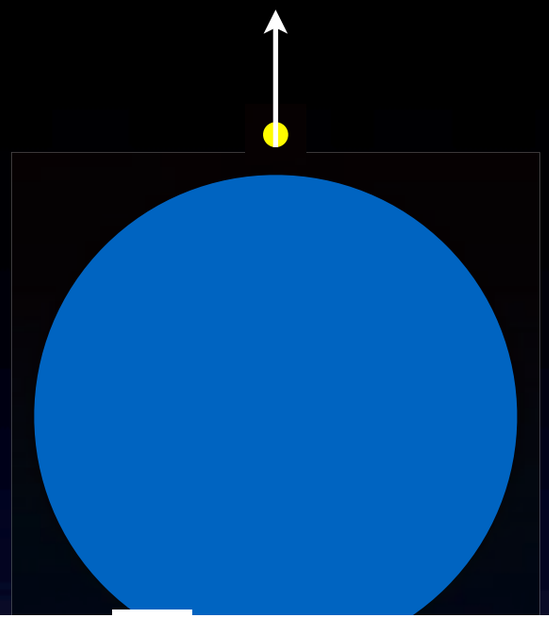
BERKELEY LAB

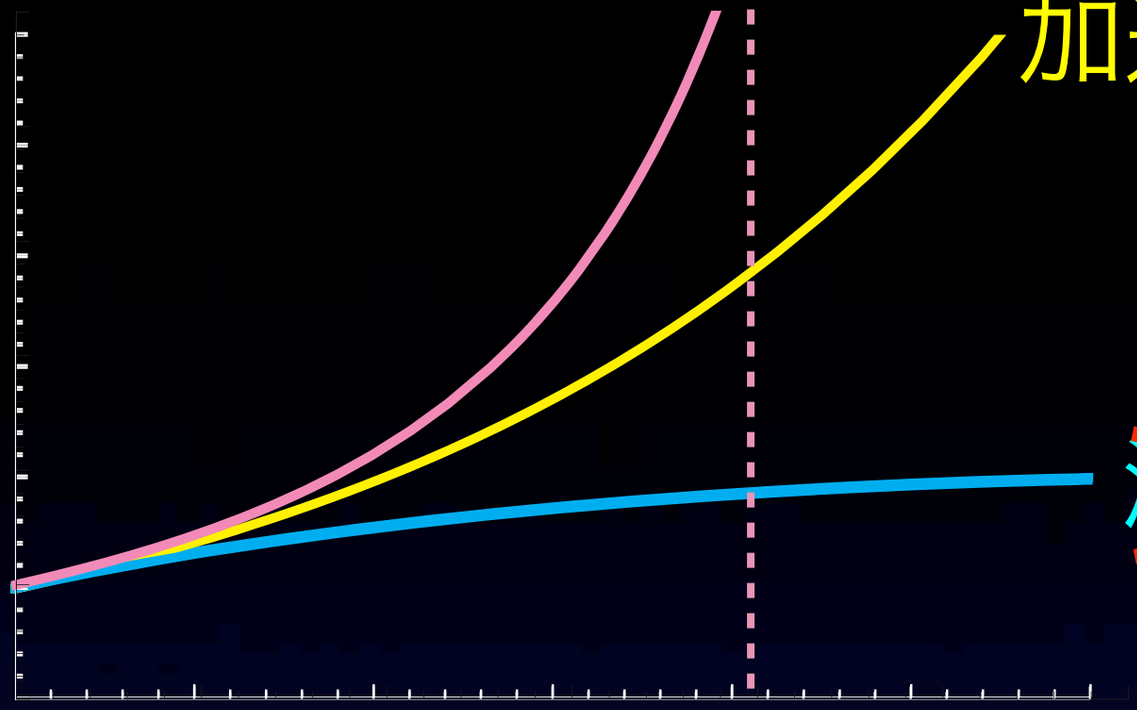
エネルギーの内訳

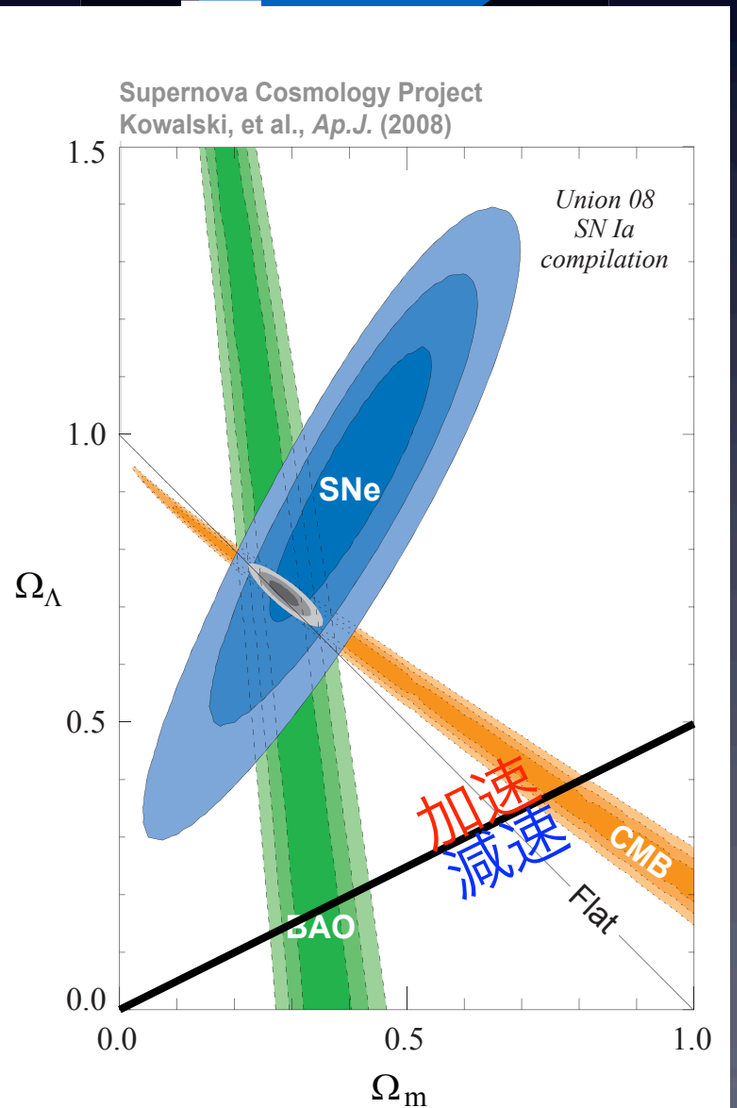
- 星と銀河はたったの ~0.5%
- ニュートリノ ~0.1–1.5%
- 普通の物質（原子）4.5%
- 暗黒物質 22%
- 暗黒エネルギー 74%
- 反物質 0%



宇宙膨張



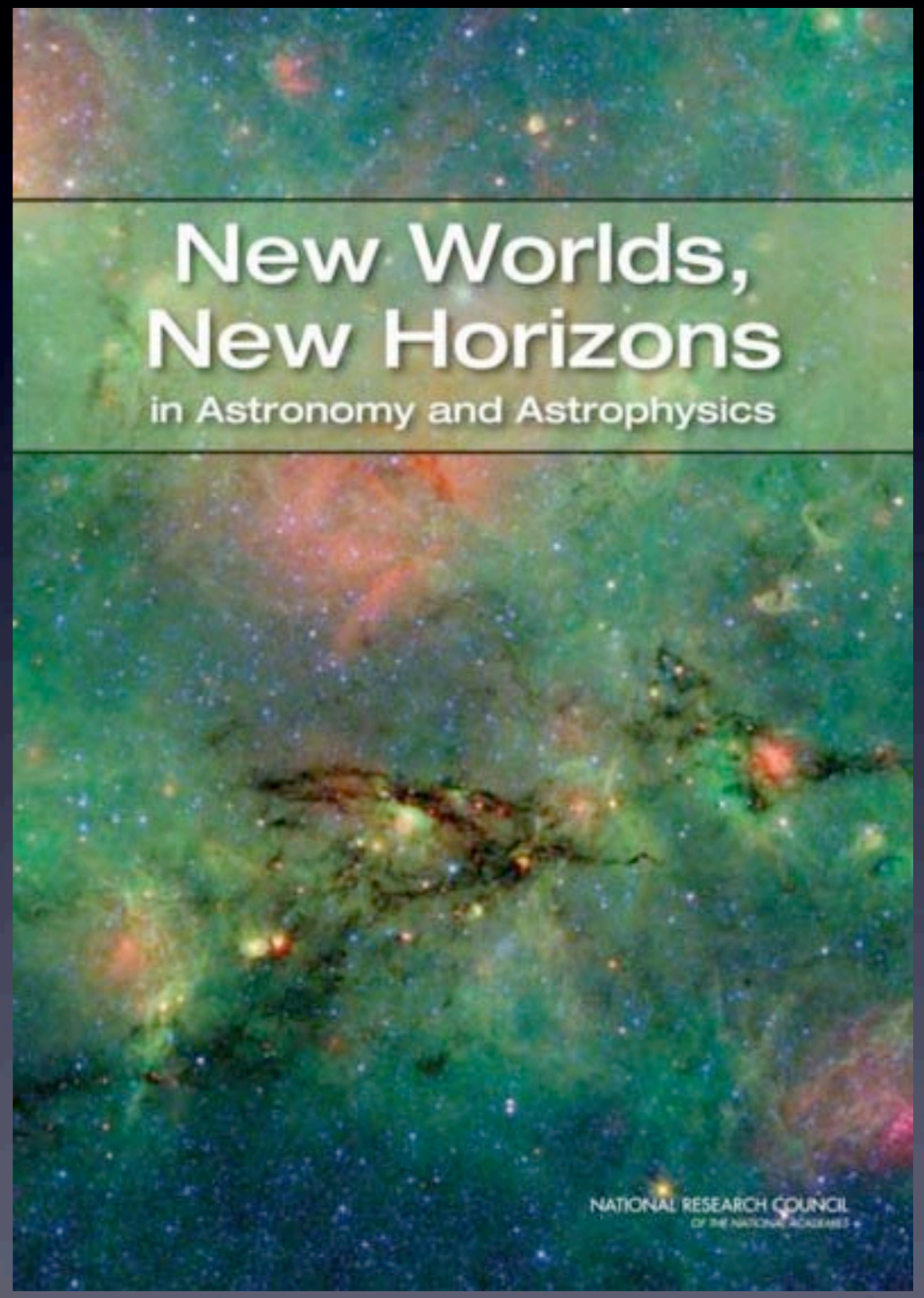




- 宇宙の膨張が最近(約70億年前)加速し始めた
- エネルギーが増えている！
- 無尽蔵のエネルギー源？？暗黒エネルギー
- アインシュタインの間違い？？
- 新しい宇宙像、基本法則
- エネルギーの増え方が速いと、いずれ膨張速度が無限大に ⇒ 宇宙が終わる？？

Astro 2010

- Science Objectives
  - Cosmic Dawn
  - New Worlds
  - Physics of the Universe
    - Dark Energy
    - Dark Matter
    - Inflation
    - Test GR



Large Scale Space Program - Prioritized

1. Wide Field InfraRed Survey Telescope (WFIRST)
   ⇒Dark Energy
2. Explorer Program Augmentation
3. Laser Interferometer Space Antenna (LISA)
4. International X-ray Observatory (IXO)

Roger Blandford ASTRO 2010 roll-out

Large-scale Ground-based Program - Prioritized

1. Large Synoptic Survey Telescope (LSST) ⇒Dark Energy
2. Mid-Scale Innovations Program
3. Giant Segmented Mirror Telescope (GSMT)
4. Atmospheric Cerenkov Telescope Array (ACTA)

Roger Blandford ASTRO 2010 roll-out

Physics of the Universe

- The properties of dark energy would be inferred from the measurement of both its effects on the expansion rate and its effects on the growth of structure (the pattern of galaxies and galaxy clusters in the universe). In doing so it should be possible to measure deviations from a cosmological constant larger than about a percent. Massively multiplexed spectrographs in intermediate-class and large-aperture ground-based telescopes would also play an important role.

すばる (国立天文台)

Cameras & Spectrographs

8-10m classで

すばるだけ

IRCS (AO188)
Infrared imager and spectrograph (λ/Δλ=20,000)

HiCIAO (AO188)
Coronagraphic imager with differential imaging techniques

AO188
188-element curvature sensing adaptive optics system with a laser guide star capability

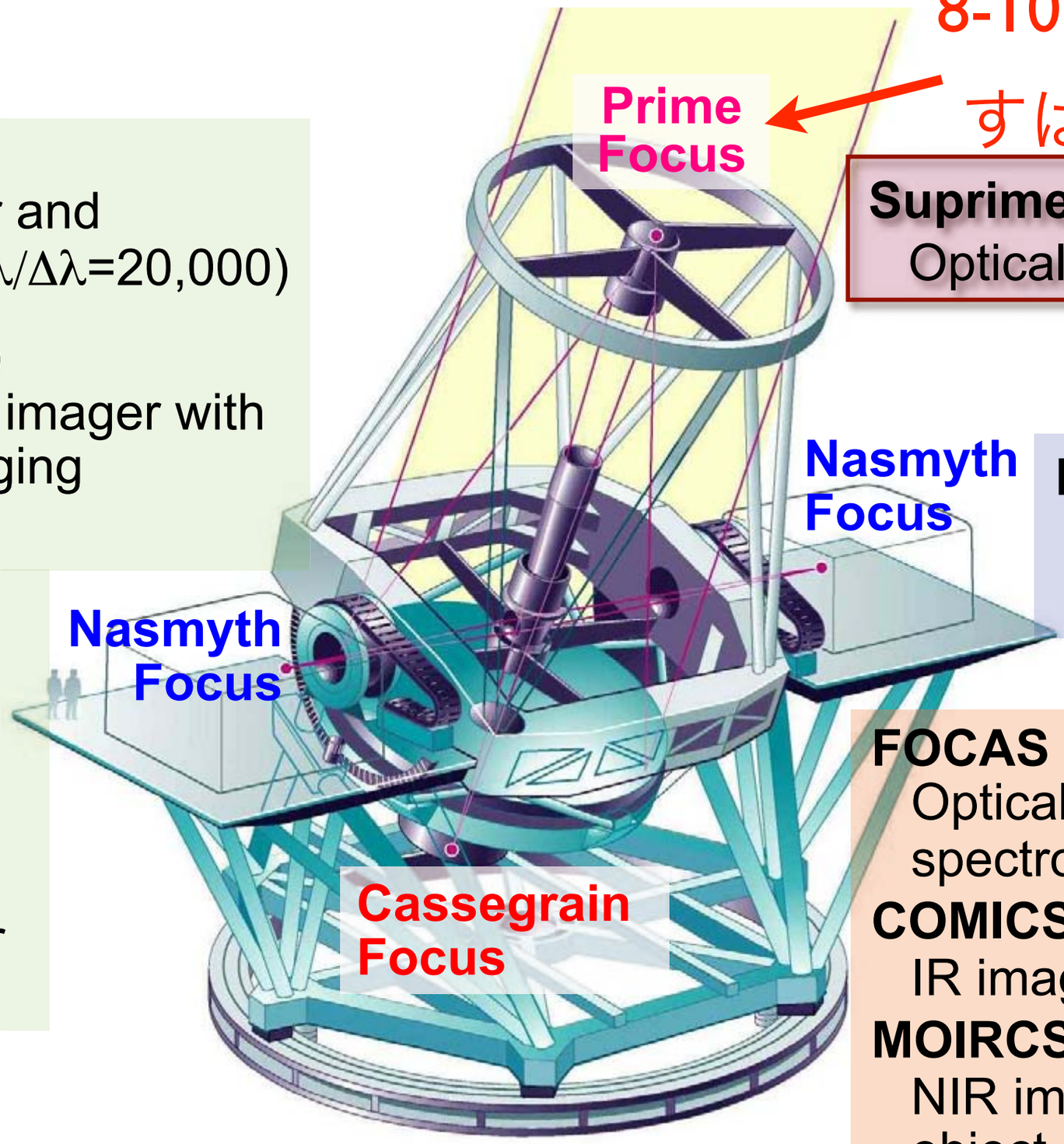


Illustration by Takaetsu Endo, taken from Nikkei Science 1996 □

Suprime-Cam
Optical imager (34′×27′)

HDS
Optical spectrograph (λ/Δλ=100,000)

FOCAS
Optical imager and spectrograph

COMICS
IR imager and spectrograph

MOIRCS
NIR imager (7′×4′) and multi-object (50) spectrograph

~100Mpc(~300M light year)@z~0.5~5deg

Hyper-SC

SC

Other 8m Tels

大規模構造を見るには

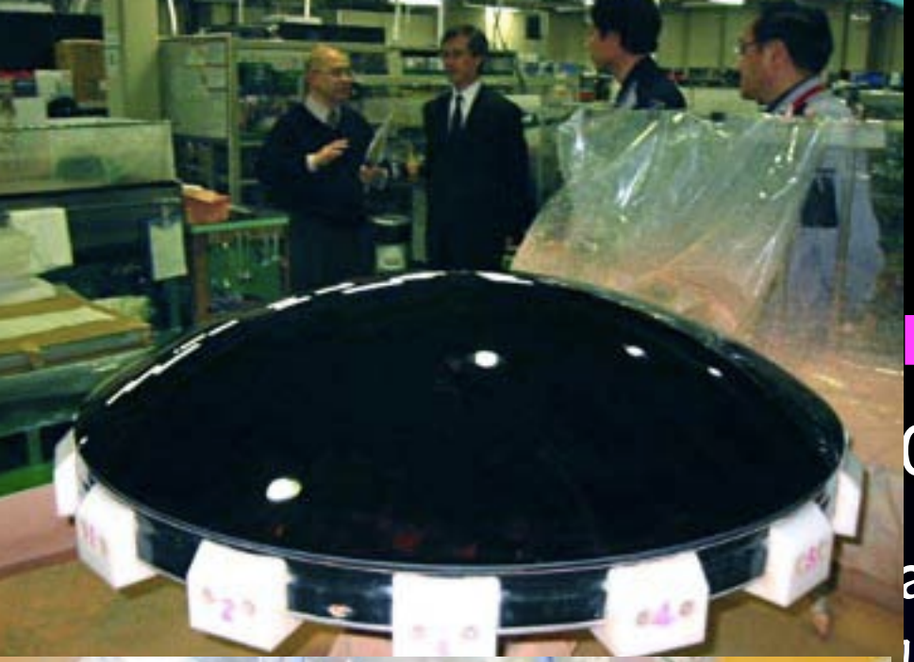
広視野が必要

宇宙の歴史を見るには

深く見られる大口径が必要

宇宙の暗黒面を探るのに

最適な望遠鏡



SuMIRe

rement of Images and Redshifts

0.6”, 広視野1.5°

ak lensing survey

Jメラ

図

oh: バリオン振動

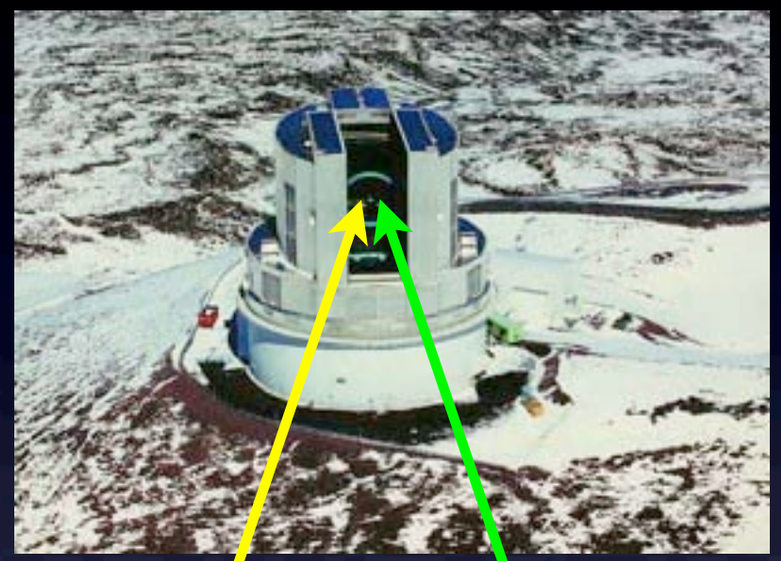
sq. dg.

呆

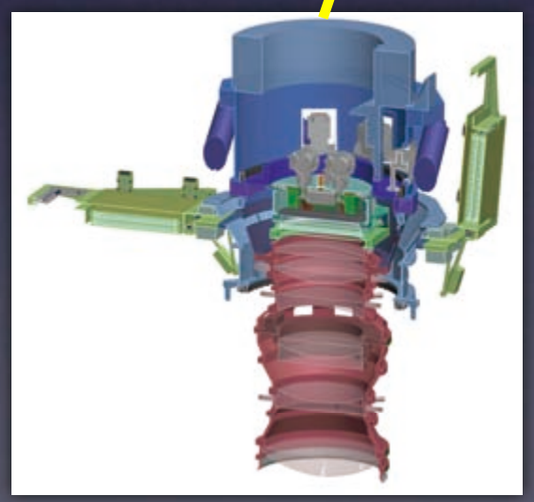
図

ジングと分光

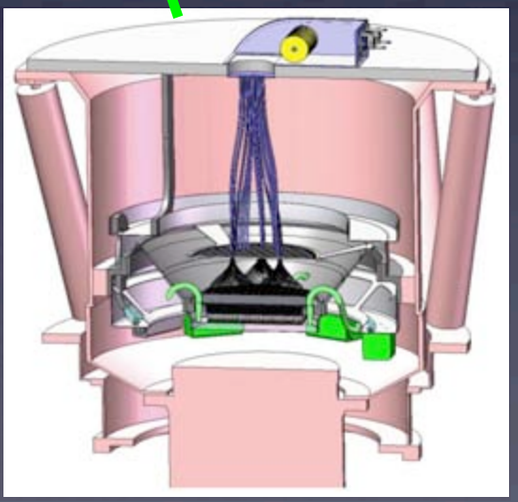
な武器！



すばる



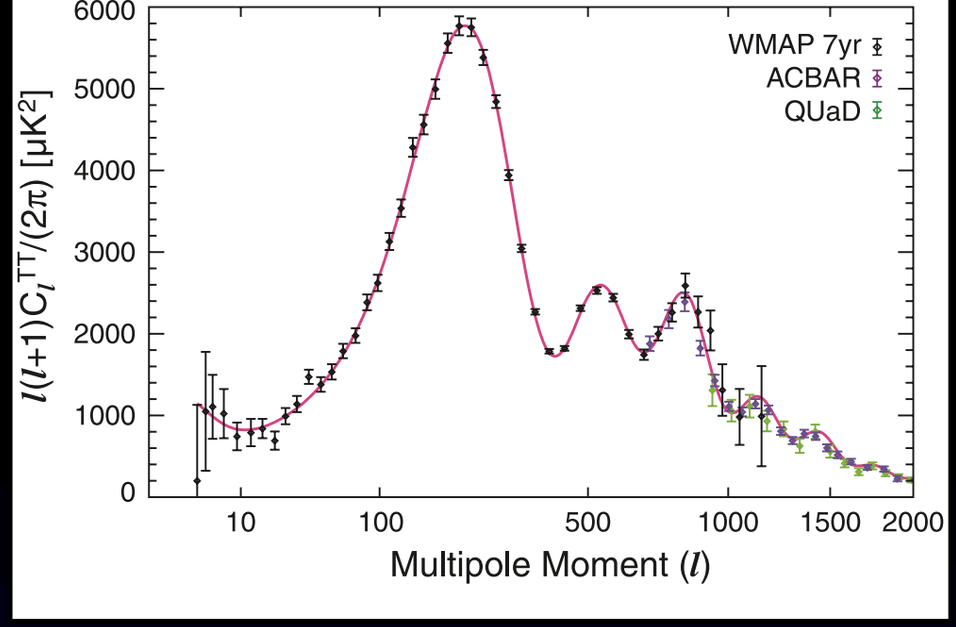
HSC

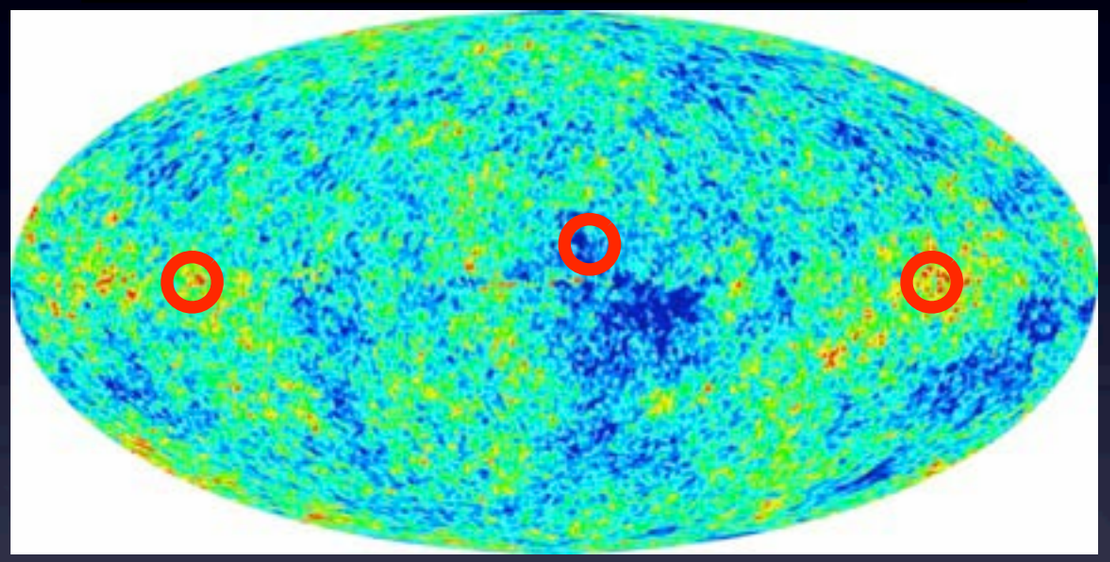


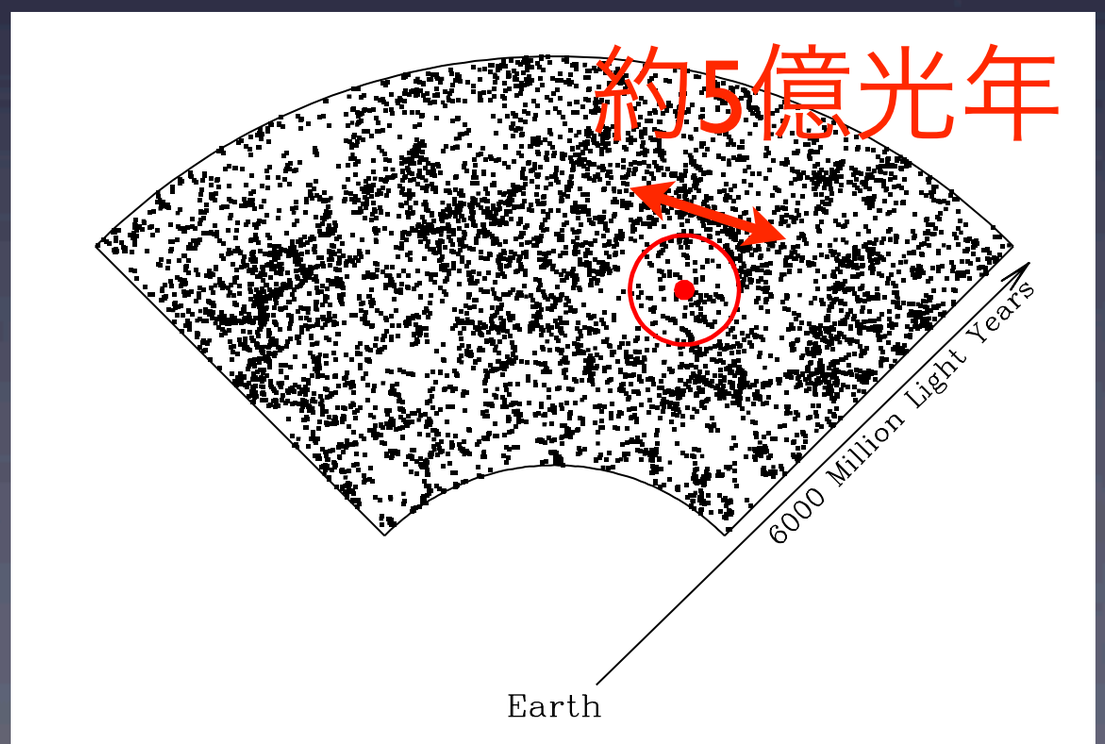
PFS

BAO

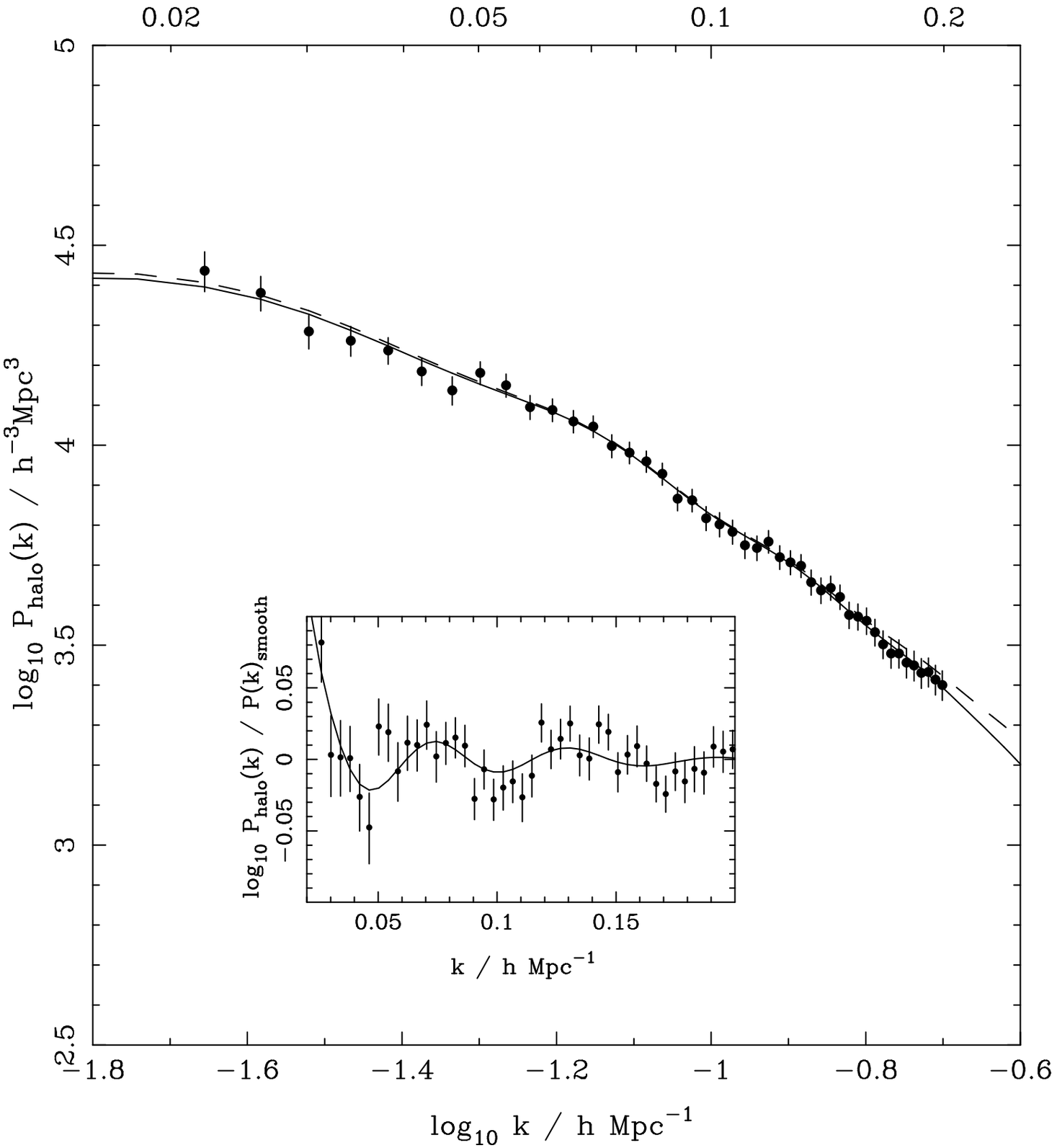
- 銀河の集まり方には特徴的な距離 (148±3 Mpc)
  「バリオン振動」
- 分光器で宇宙膨張の速さ
- 膨張と距離を組合わせると宇宙膨張の歴史が測れる
- 暗黒エネルギーの正体を暴く
- 膨張の将来を予測
- 宇宙に終わりがあるか？

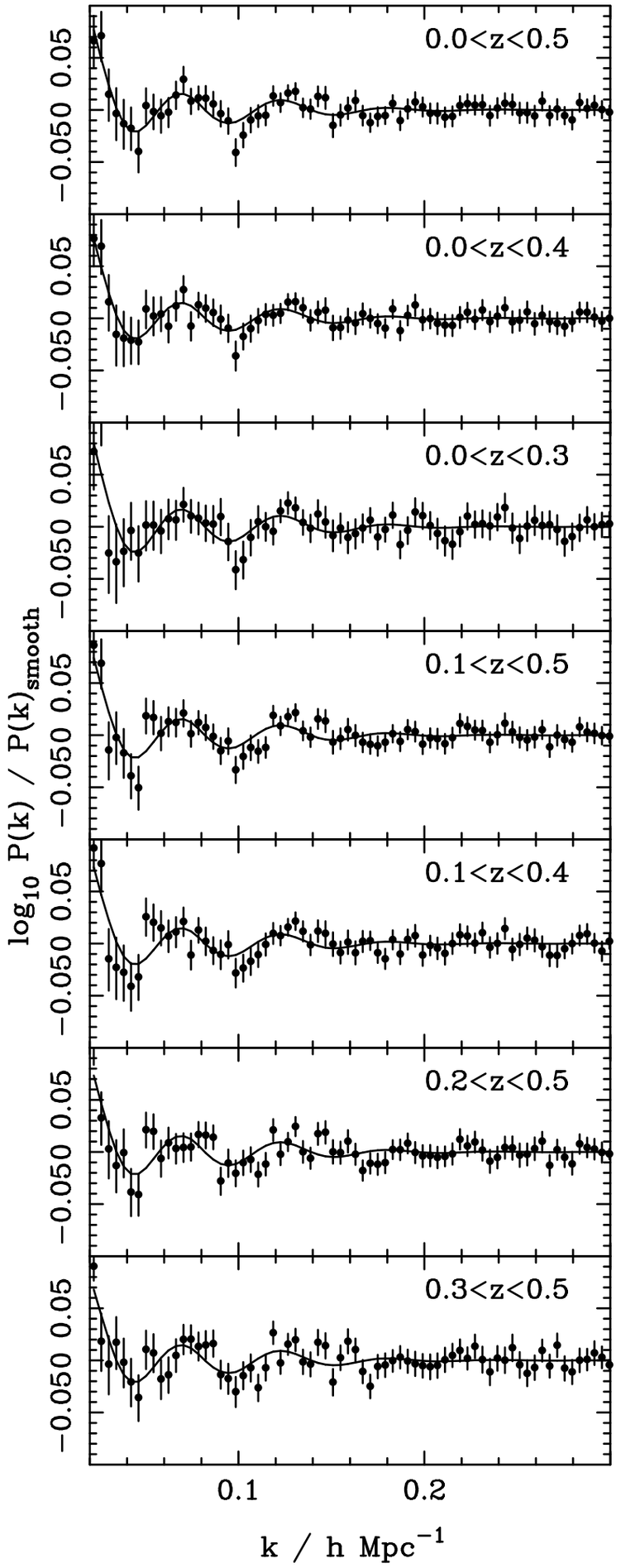


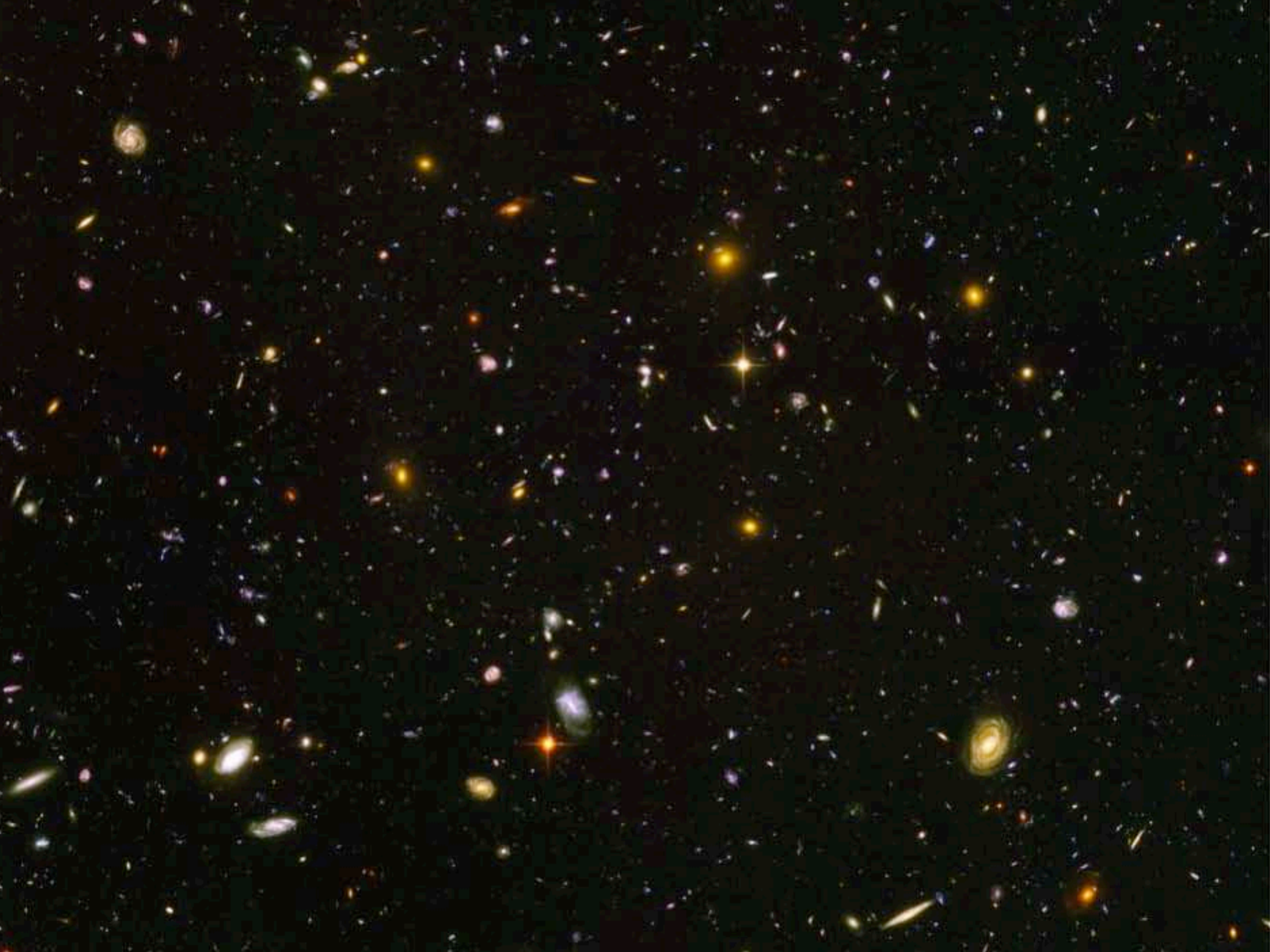




SDSS DR7


0.02
0.05
0.1
0.2
5
4.5
4
3.5
3
2.5
$\log_{10} P_{halo}(k)$ / $h^{-3}Mpc^3$
−1.8
−1.6
−1.4
−1.2
−1
−0.8
−0.6
$\log_{10}$ k / h Mpc^{-1}
$\log_{10} P_{halo}(k) / P(k)_{smooth}$
0.05
0
−0.05
0.05
0.1
0.15
k / h Mpc^{-1}


0.0<z<0.5
0.0<z<0.4
0.0<z<0.3
0.1<z<0.5
0.1<z<0.4
0.2<z<0.5
0.3<z<0.5
$\log_{10} P(k) / P(k)_{smooth}$
−0.050
0.05
0.1
0.2
k / h Mpc^{-1}



遠くの銀河の観測ができるのは今だけ

早く予算を！

SuMIRe

- 自民党政権の景気刺激策
- 30人に2700億円
- 2009/7に提案565件
- SuMIReに95億円提案
- 2009/8 90 件ヒアリングへ
- 査定76位, ぎりぎり通過
- 2009/9 30人に選ばれる
- 総額が1000億円に縮小
- 2010/3/29: 32億交付決定
- 2010/6/1: 2億 「強化」

PFS collaboration

IPMU

BERKELEY CENTER FOR THEORETICAL PHYSICS

Caltech

NASA Jet Propulsion Laboratory California Institute of Technology

NAOJ

ACADEMIA SINICA

PRINCETON UNIVERSITY

THE UNIVERSITY OF CALIFORNIA BERKELEY

IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

ROYAL OBSERVATORY EDINBURGH

John Hopkins?

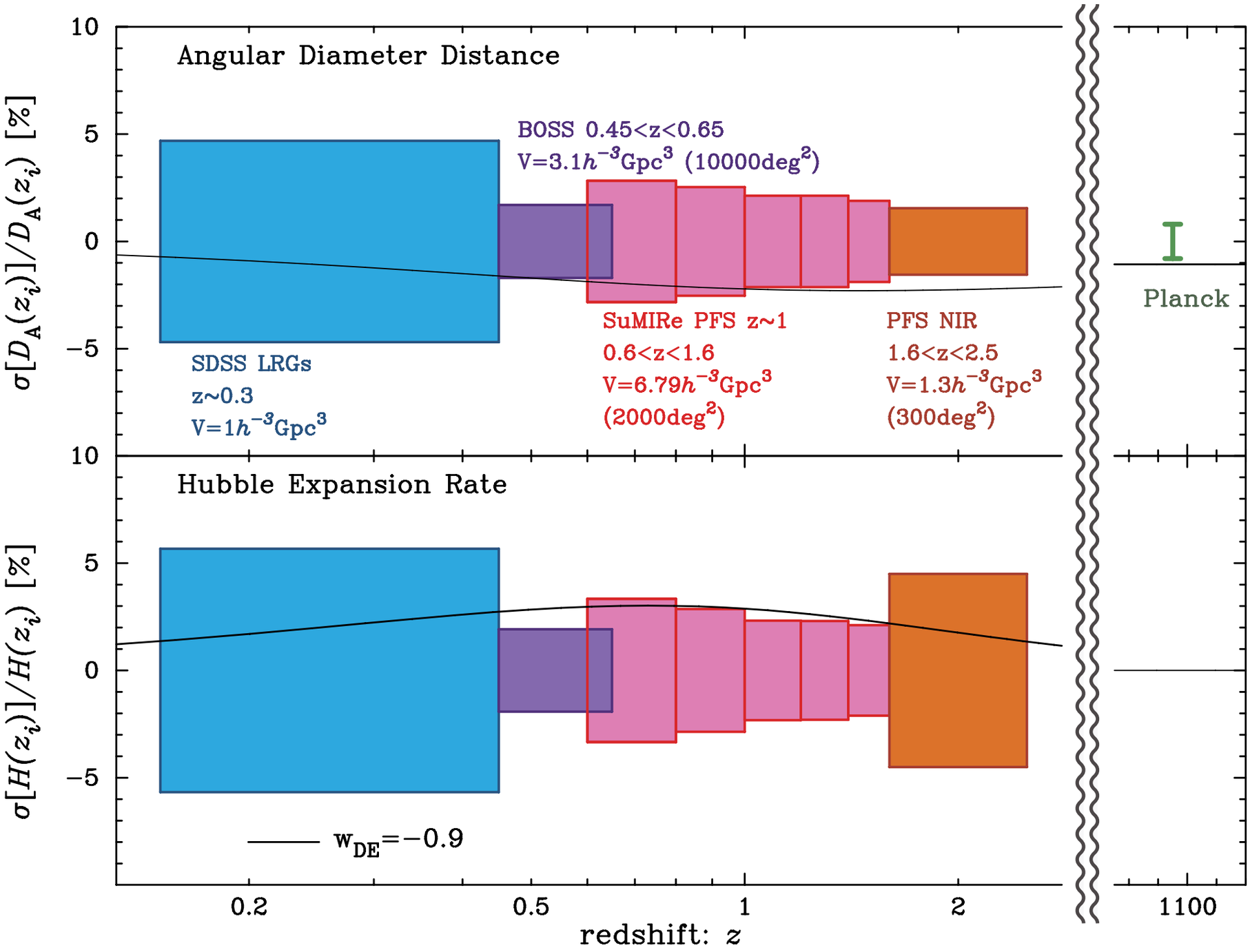


Figure 4.6: Fractional errors in measuring the angular diameter distance and the Hubble expansion rate for each redshift slices for the different BAO surveys, SDSS, BOSS and PFS. For the PFS survey we assumed survey parameters given in Table 4.3. The solid curves in each panel shows the fractional difference of $D_A(z)$ or $H(z)$ when changing the dark energy equation of state w to $w = -0.9$ from $w = -1$ (ΛCDM model).

competitiveness

dark energy figure of merit

400

300

200

100

0

BOSS

DES

HSC WL

PFS BAO

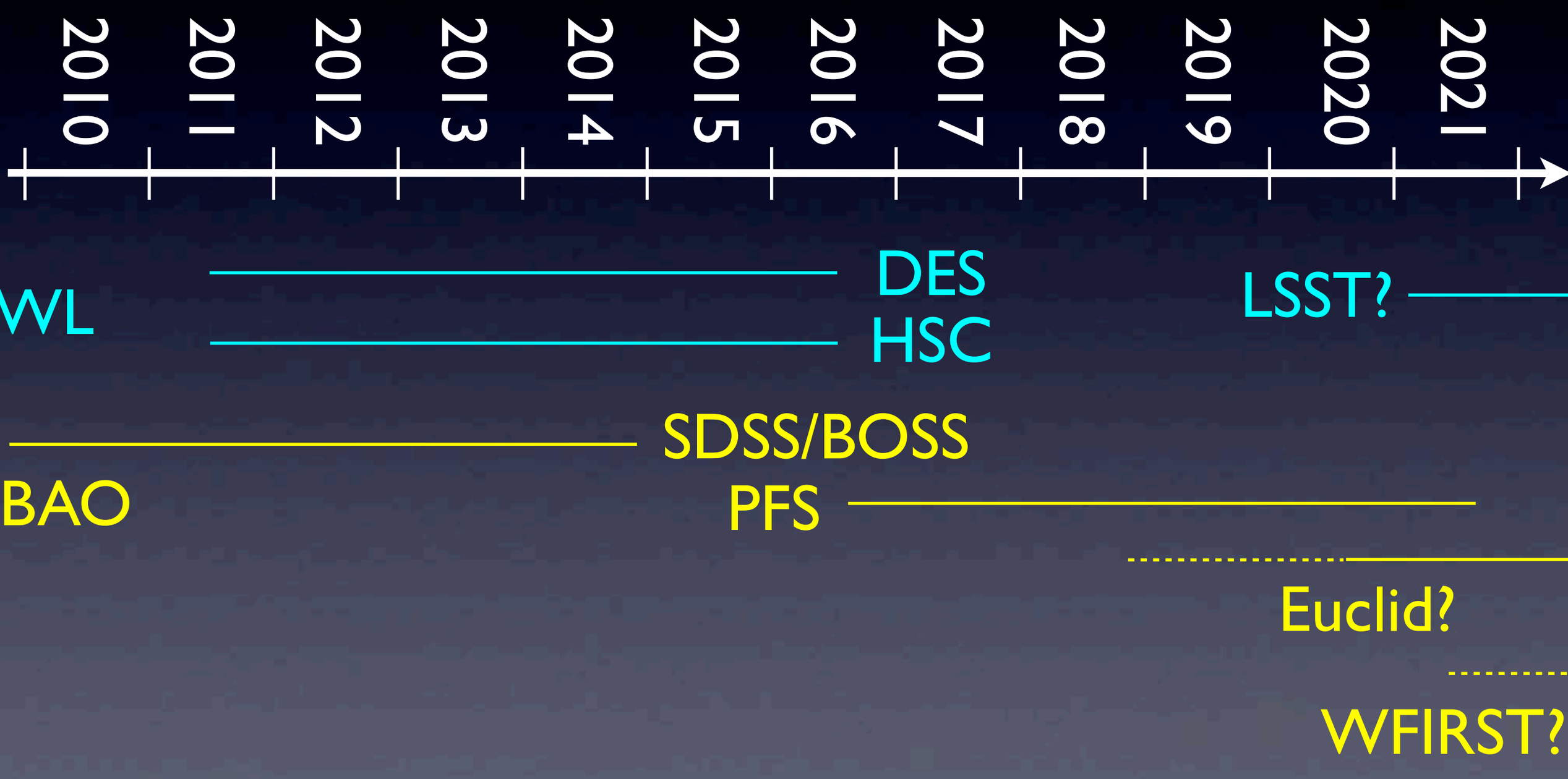
PFS+HSC

better

FoM

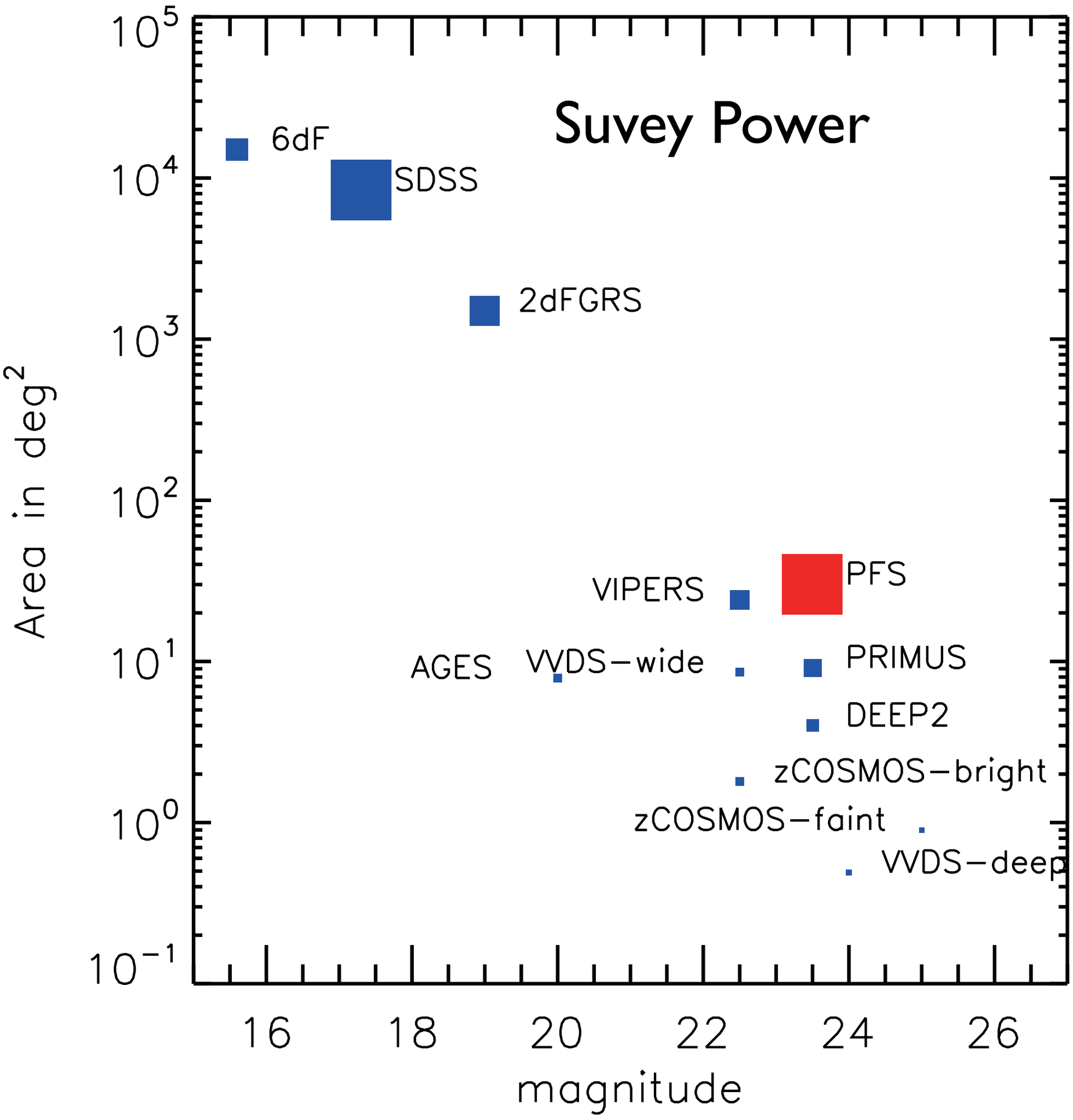
$(\sigma(w_{\rm pivot})\sigma(w_a))^{-1}$

Timeline


2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
WL
DES
HSC
LSST?
BAO
SDSS/BOSS
PFS
Euclid?
WFIRST?

Subaru Users

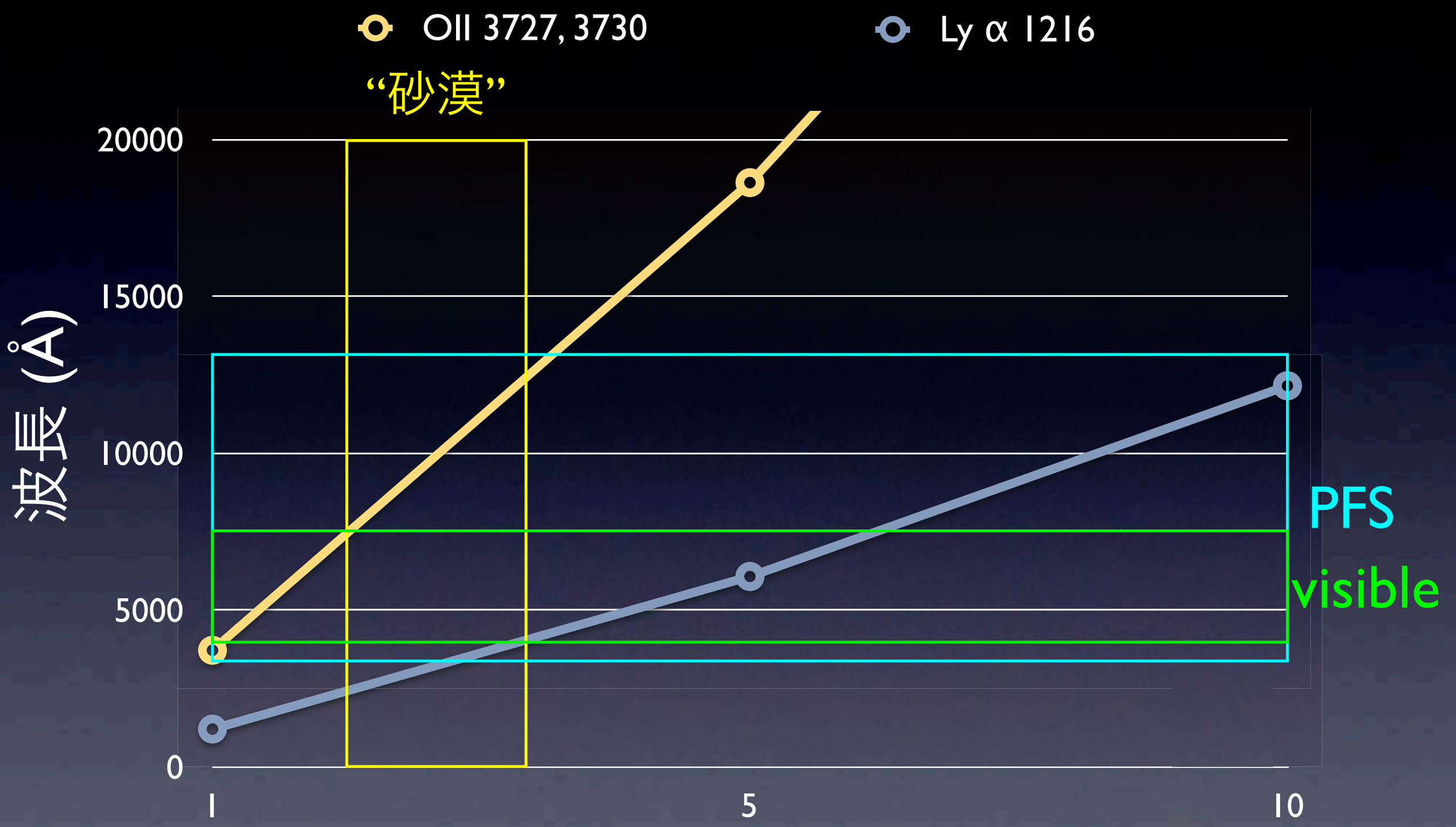
- Subaru is a user facility
- we have to apply for telescope night allocation
- expanded the science scope
  - galaxy evolution
  - galactic archeology
  - added near IR arm to the spectrograph
- other impacts on high-energy physics
  - map out 3D dark matter distribution
  - neutrino mass $\sigma(\Sigma m_\nu)=60$meV
  - test inflation $\sigma(f_{NL})=5$ ($\approx$ Planck)
  - test general relativity @ large distances


Suvey Power
Area in deg^2
magnitude
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
16
18
20
22
24
26
6dF
SDSS
2dFGRS
VIPERS
PFS
AGES
VVDS−wide
PRIMUS
DEEP2
zCOSMOS−bright
zCOSMOS−faint
VVDS−deep

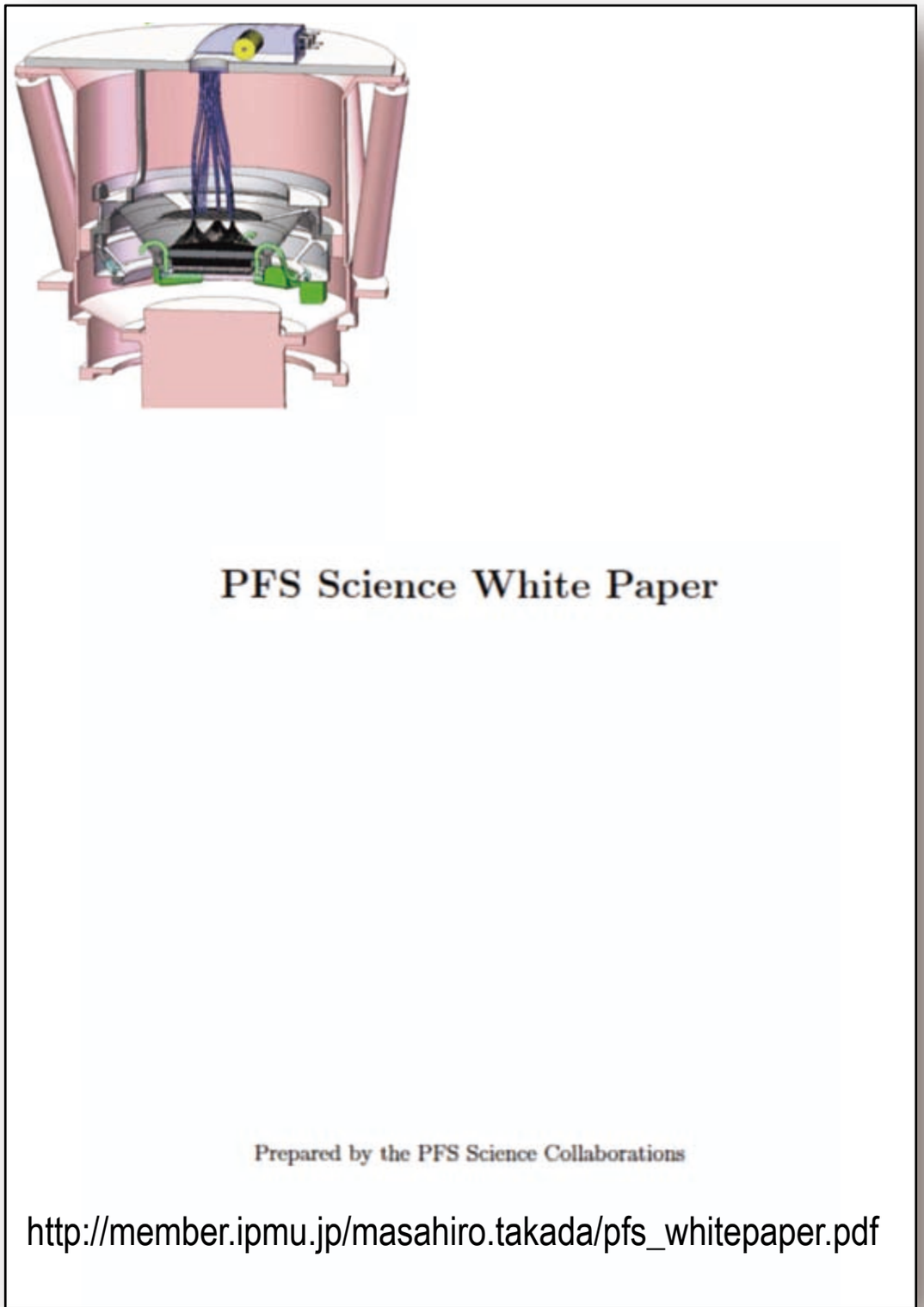
仕様

- BAOに特化したminimum仕様
  - 600-1000nm, R≈3000
  - 一つのアーム、 (4k x 4k)
- 世界最高の銀河サーベイ
  - 380-1300nm, R≈2000-5000
  - 青、赤、近赤の三つのアーム
  - 連続的にz~10までカバー！
- 銀河考古学もかなりできる

ギャップのない銀河サーベイ



PFS: endorsement from the Japanese community



http://member.ipmu.jp/masahiro.takada/pfs_whitepaper.pdf

- *Initiated* by IPMU (not by NAOJ)
- Takada+IPMU have led the feasibility studies since July, 2010
- PFS Science White Paper
  - Cosmology
  - Milky Way
  - Galaxy/QSO astronomy …
- About 70 Japanese astronomers joined
- Realized the unique power of PFS for various science cases
- ***Endorsement from the community*** at Subaru Users' Meeting, in Jan 2011
- NAOJ is now becoming an official partner of PFS project
- Japan, Princeton, Caltech, France, …

National Institutes of Natural Sciences (NINS)
National Astronomical Observatory of Japan
2-21-1 Osawa, Mitaka, Tokyo 181-8588, JAPAN

Jan 26, 2011

Director Hitoshi Murayama
Institute for the Physics and Mathematics of the Universe
The University of Tokyo
5-1-5 Kashiwa-no-Ha, Kashiwa City
Chiba, 277-8583, Japan

Re: Prime Focus Spectrograph (PFS)

Dear Director Murayama,

We, members of Subaru Advisory Committee (SAC) assigned for the Japanese fiscal year of 2010, have continuously had discussion on the Prime Focus Spectrograph (PFS) project. To hear more general comments and opinions on the PFS project from the Japanese community, we had the session intensively discussing the PFS project at the 2010 Subaru Users' meeting held at NAOJ on Jan 19, 2011. In particular, we SAC showed the users the following recommendation on the PFS project (see page 2) in order to stimulate discussion from the users.

There were slightly more than 100 Japanese users attending the PFS session on that day, and the attendees exchanged active, various discussions regarding advantages/disadvantages that PFS can bring for Subaru users.

At the end of the session, after having enough discussion, we had a vote by a show of hands on the proposal "Are you for or against moving ahead on the PFS project as one of the next-generation Subaru instruments?". As a result, the PFS project was endorsed by most of the attendees. Hence we SAC are reporting here that we received endorsement from Subaru users that the PFS project should be further promoted as a next-generation Subaru instrument project.

Sincerely yours,

Jan 26, 2011
Subaru Advisory Committee

National Institutes of Natural Sciences (NINS)
National Astronomical Observatory of Japan
2-21-1 Osawa, Mitaka, Tokyo 181-8588, JAPAN

SAC recommendation on PFS

At the 2010 Subaru Users' Meeting
Jan 19, 2011

Subaru can maintain its position as one of the top telescope facilities in the world by having both a wide-field imager and a wide-field spectrograph.

The PFS instrument concept was initially developed primarily for a BAO survey, but after consideration of the instrument specifications, it was realized that PFS could have much broader scientific impact, in areas such as galactic archaeology and galaxy/AGN evolution.

Thus, with the conditions listed below, SAC recommends further development of the PFS project as a next-generation Subaru instrument.

Collateral Conditions

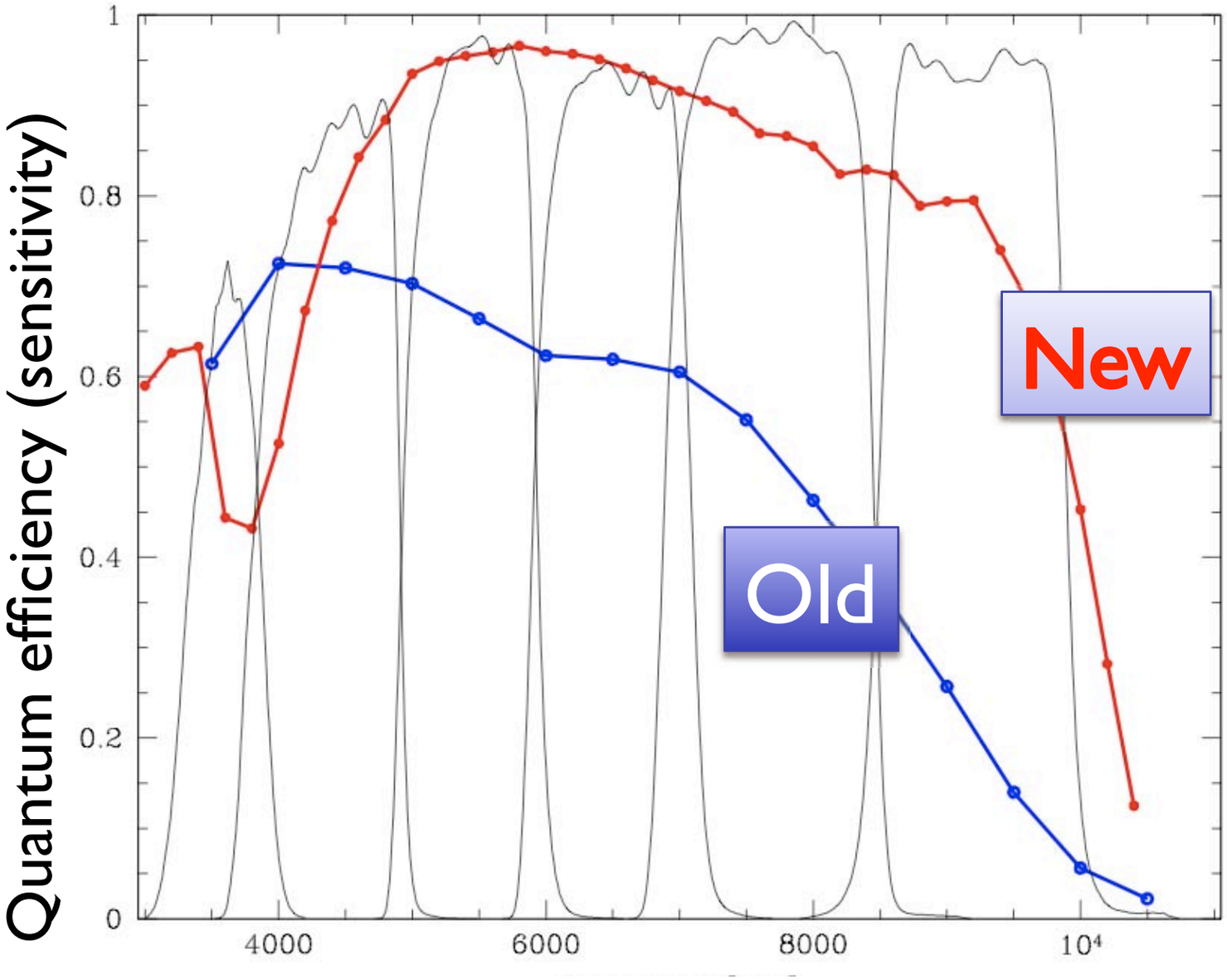
- PFS must satisfy instrument specifications agreed by the Japanese community.
- A firm management structure should be built in Japan to develop PFS, including the assignment of a Japanese project manager.
- SAC representative(s) should participate in important decision-making stages about international collaboration.
- There must be a framework for young Japanese students/researchers to get involved in the PFS instrumentation.

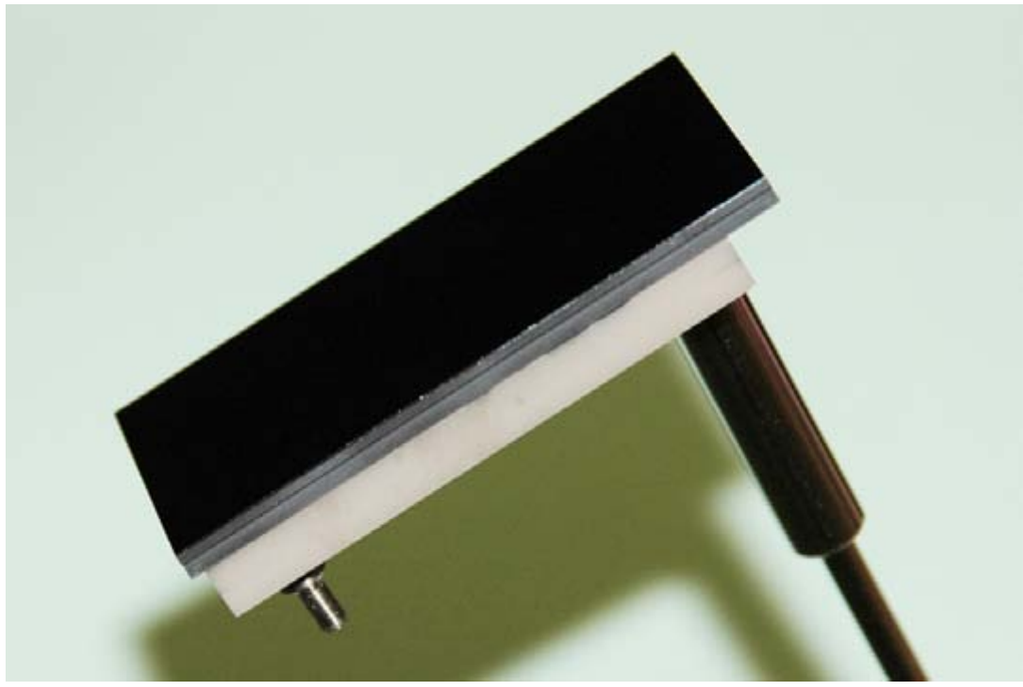
Please note the following premises for further discussion on the PFS project:

- The survey program by the PFS collaboration will be carried out after reviewing processes, under the Subaru Strategic Program framework. The PFS collaboration will include both the Japanese community and international partners.
- PFS will become a Subaru common-use instrument, available to the entire Japanese community, once the instrument is completed.

装置

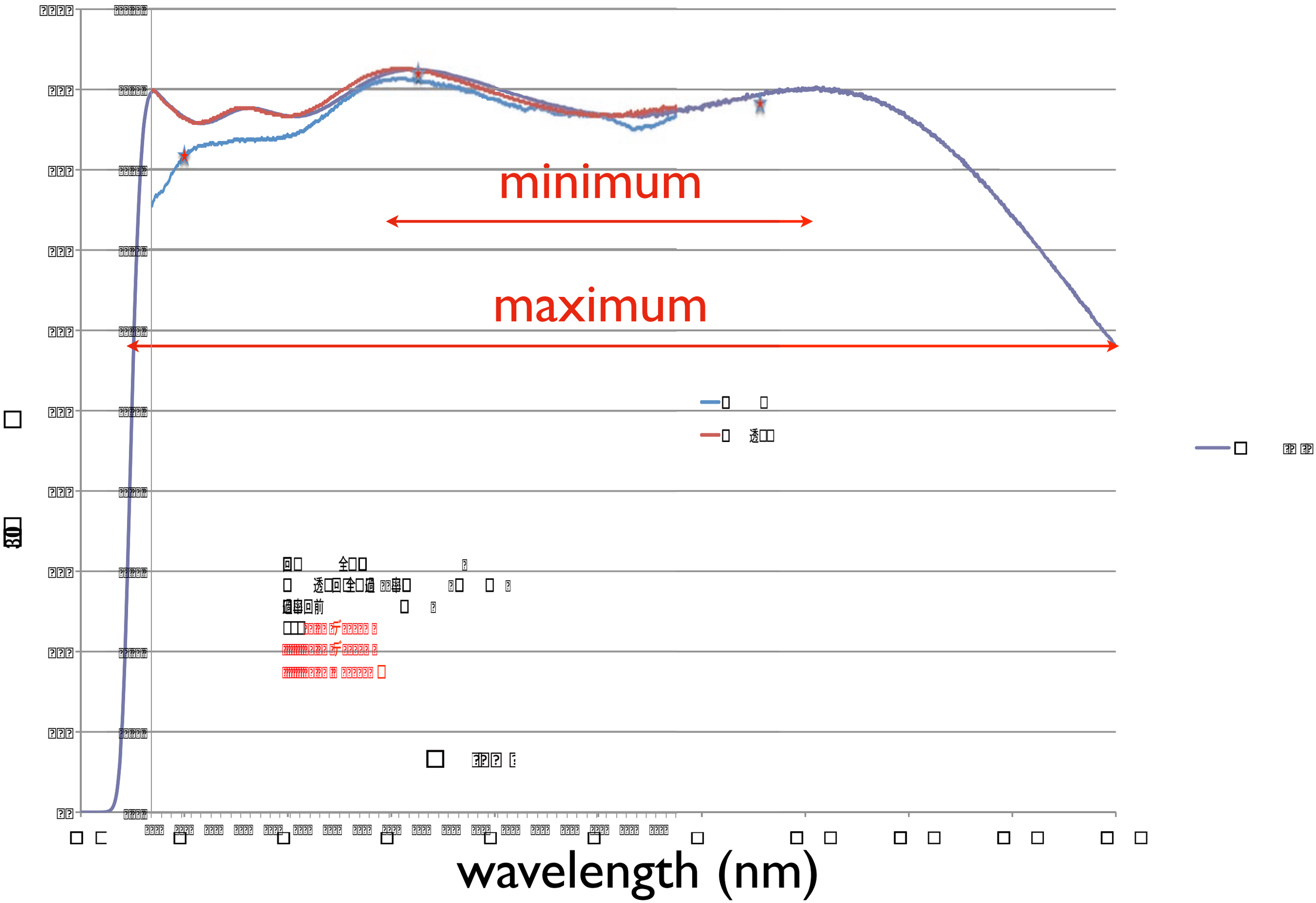
Fully depleted back-illuminated CCD （Red sensitive）
Hamamatsu Photonics





Large format CCD （3cmx6cm）
2048 pixels x 4096 pixels

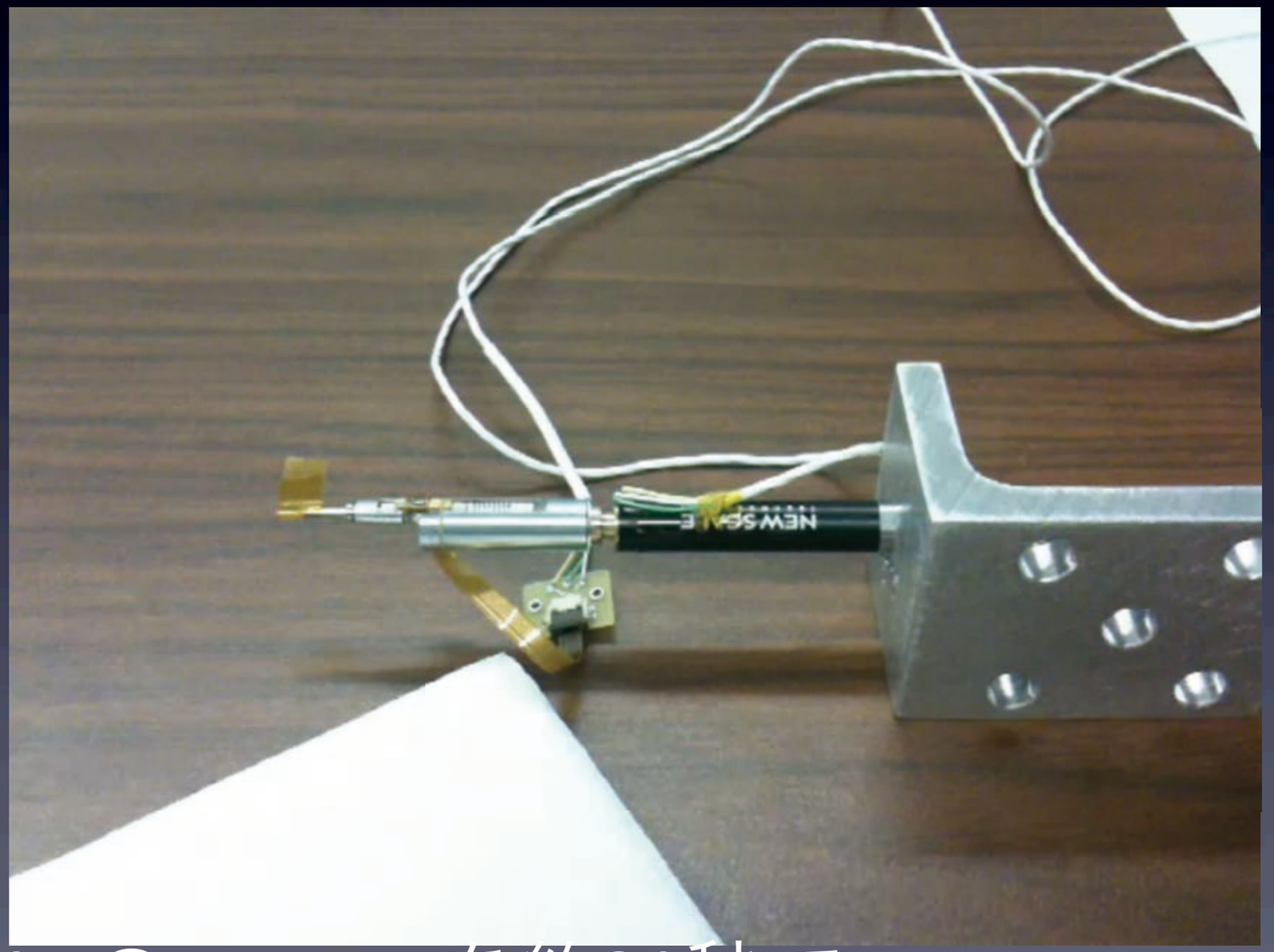
補正レンズシステムの透過率(%)実測値



IPMU

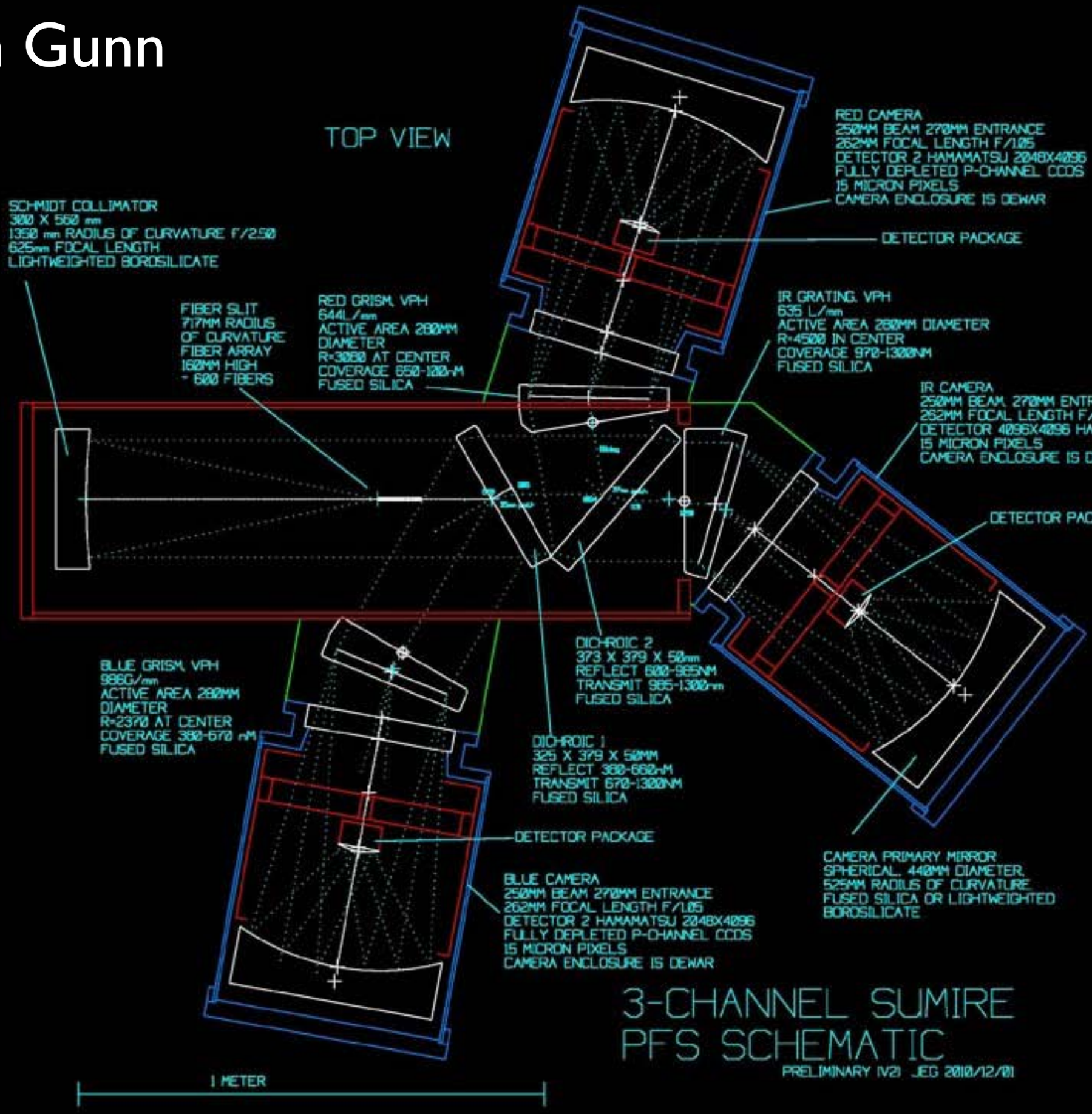
fiber positioner JPL Cobra design

BERKELEY CENTER FOR THEORETICAL PHYSICS

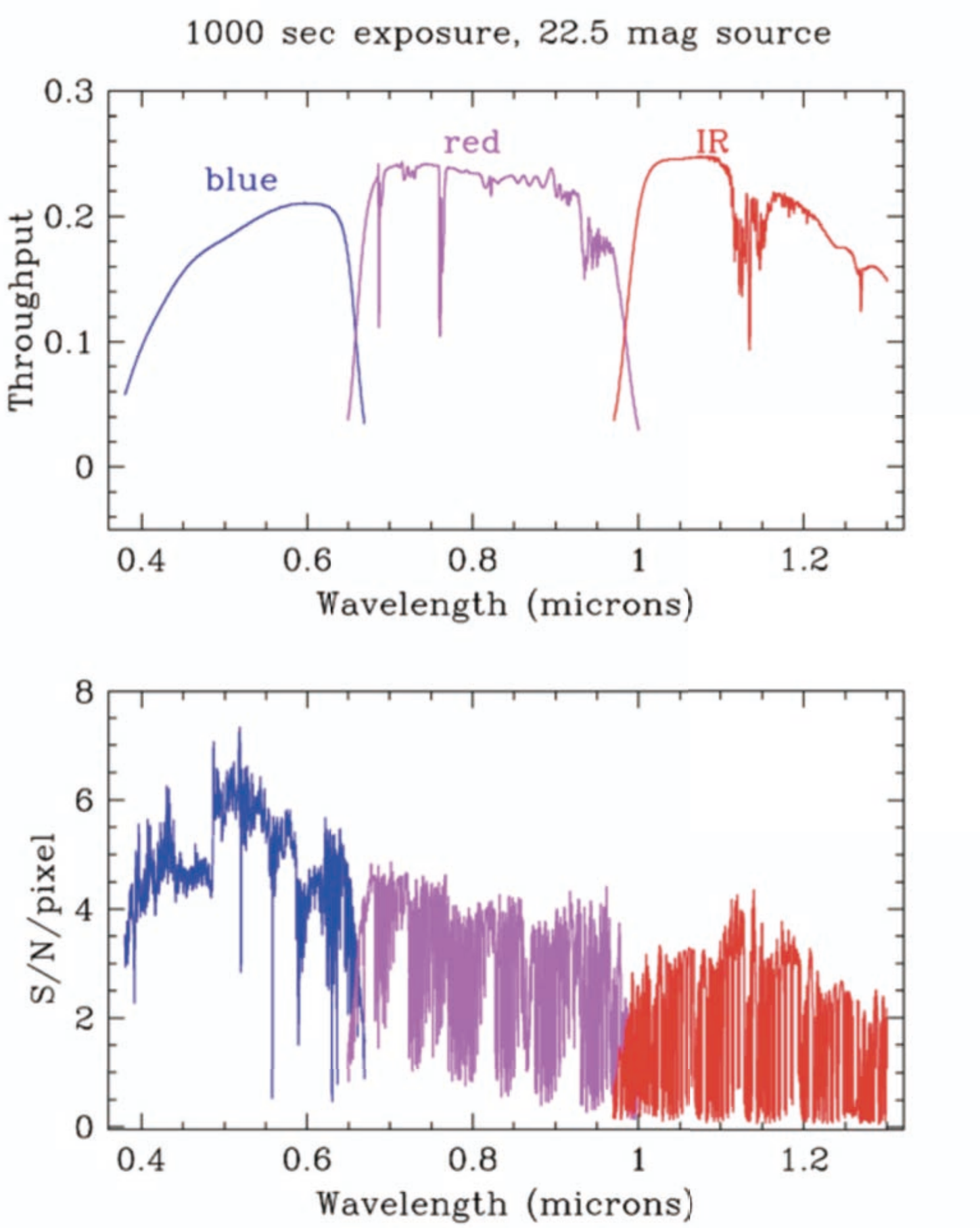


精度~10μのpointingを約30秒で

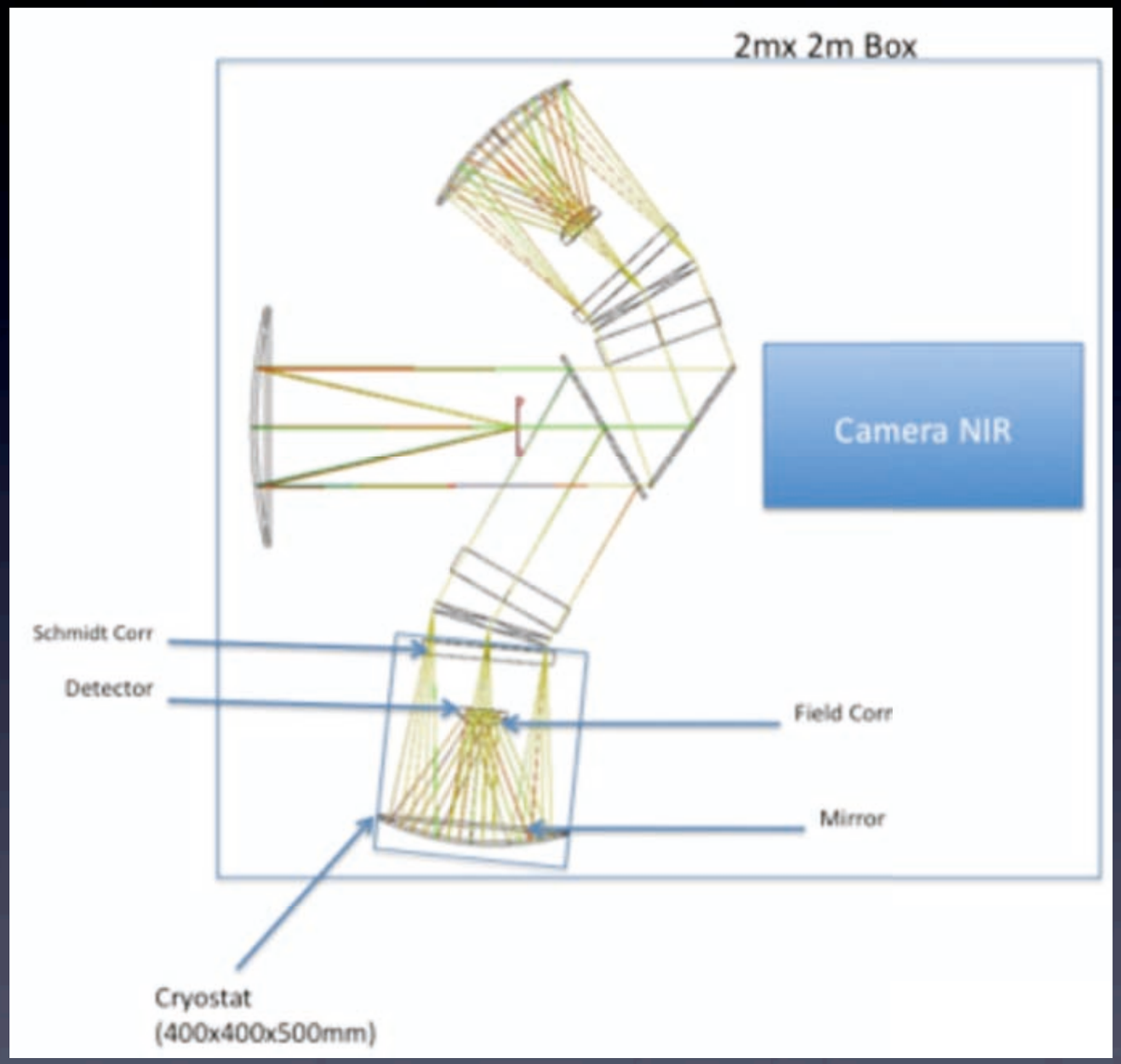
Jim Gunn


TOP VIEW
SCHMIDT COLLIMATOR
300 X 560 mm
1390 mm RADIUS OF CURVATURE f/2.50
625mm FOCAL LENGTH
LIGHTWEIGHTED BOROSILICATE
FIBER SLIT
717MM RADIUS
OF CURVATURE
FIBER ARRAY
160MM HIGH
~ 600 FIBERS
RED GRISM, VPH
644L/mm
ACTIVE AREA 280MM
DIAMETER
R=3080 AT CENTER
COVERAGE 650-120-M
FUSED SILICA
RED CAMERA
250MM BEAM 270MM ENTRANCE
262MM FOCAL LENGTH F/1.05
DETECTOR 2 HAMAMATSU 2048X4096
FULLY DEPLETED P-CHANNEL CCDS
15 MICRON PIXELS
CAMERA ENCLOSURE IS DEWAR
DETECTOR PACKAGE
IR GRATING, VPH
635 L/mm
ACTIVE AREA 280MM DIAMETER
R=4500 IN CENTER
COVERAGE 970-1300NM
FUSED SILICA
IR CAMERA
250MM BEAM 270MM ENTRANCE
262MM FOCAL LENGTH F/1.05
DETECTOR 4096X4096 HAWAII4RG
15 MICRON PIXELS
CAMERA ENCLOSURE IS DEWAR
DETECTOR PACKAGE
DICHROIC 2
373 X 379 X 50mm
REFLECT 600-985NM
TRANSMIT 985-1300nm
FUSED SILICA
BLUE GRISM, VPH
986G/mm
ACTIVE AREA 280MM
DIAMETER
R=2370 AT CENTER
COVERAGE 380-670 nM
FUSED SILICA
DICHROIC 1
325 X 379 X 50MM
REFLECT 380-660nM
TRANSMIT 670-1300NM
FUSED SILICA
DETECTOR PACKAGE
BLUE CAMERA
250MM BEAM 270MM ENTRANCE
262MM FOCAL LENGTH F/1.05
DETECTOR 2 HAMAMATSU 2048X4096
FULLY DEPLETED P-CHANNEL CCDS
15 MICRON PIXELS
CAMERA ENCLOSURE IS DEWAR
CAMERA PRIMARY MIRROR
SPHERICAL, 440MM DIAMETER,
525MM RADIUS OF CURVATURE
FUSED SILICA OR LIGHTWEIGHTED
BOROSILICATE
1 METER
3-CHANNEL SUMIRE
PFS SCHEMATIC
PRELIMINARY (V2) JEG 2010/12/01

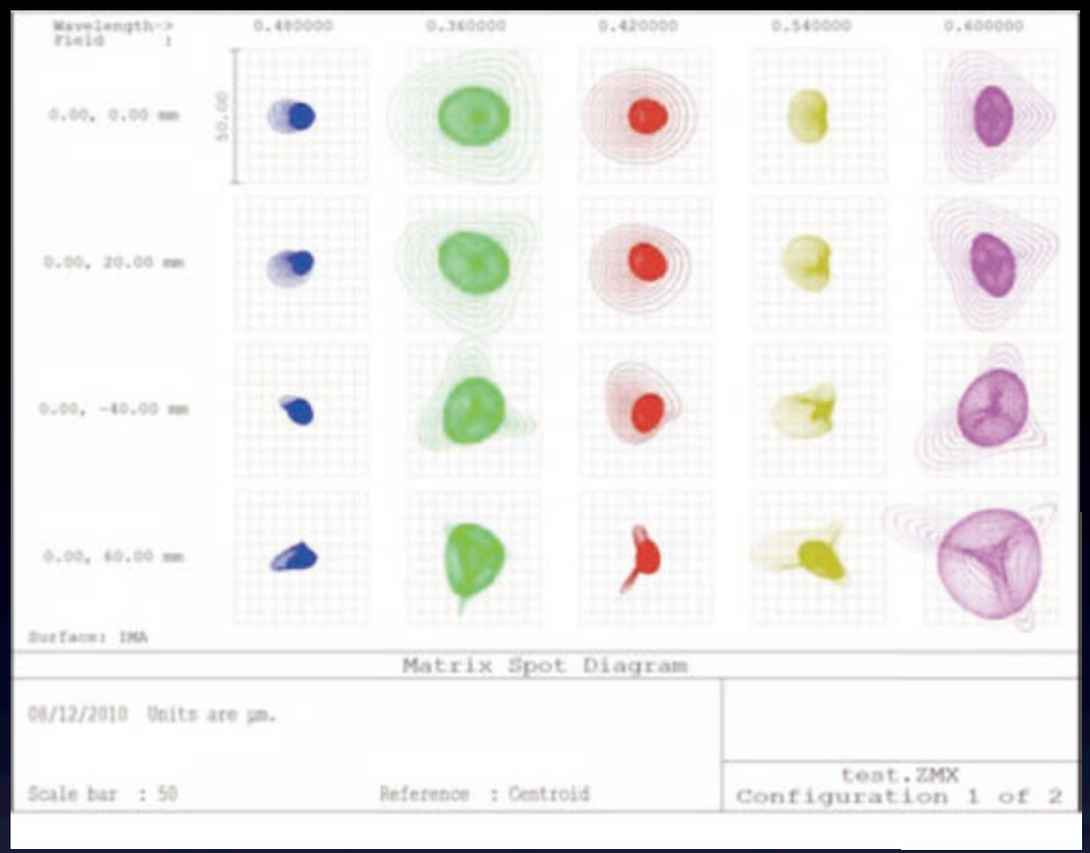
ファイバー分光器としては優秀なthroughput



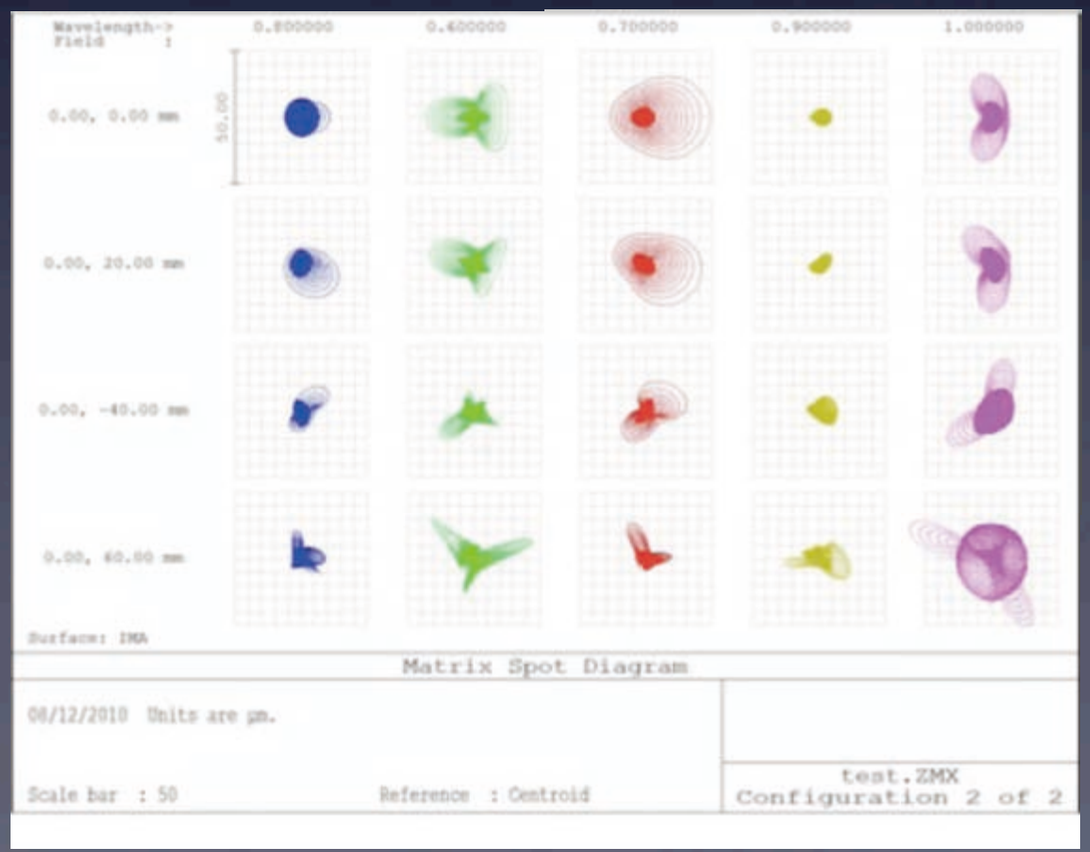
Eric Prieto (Marseille)



blue arm



red arm



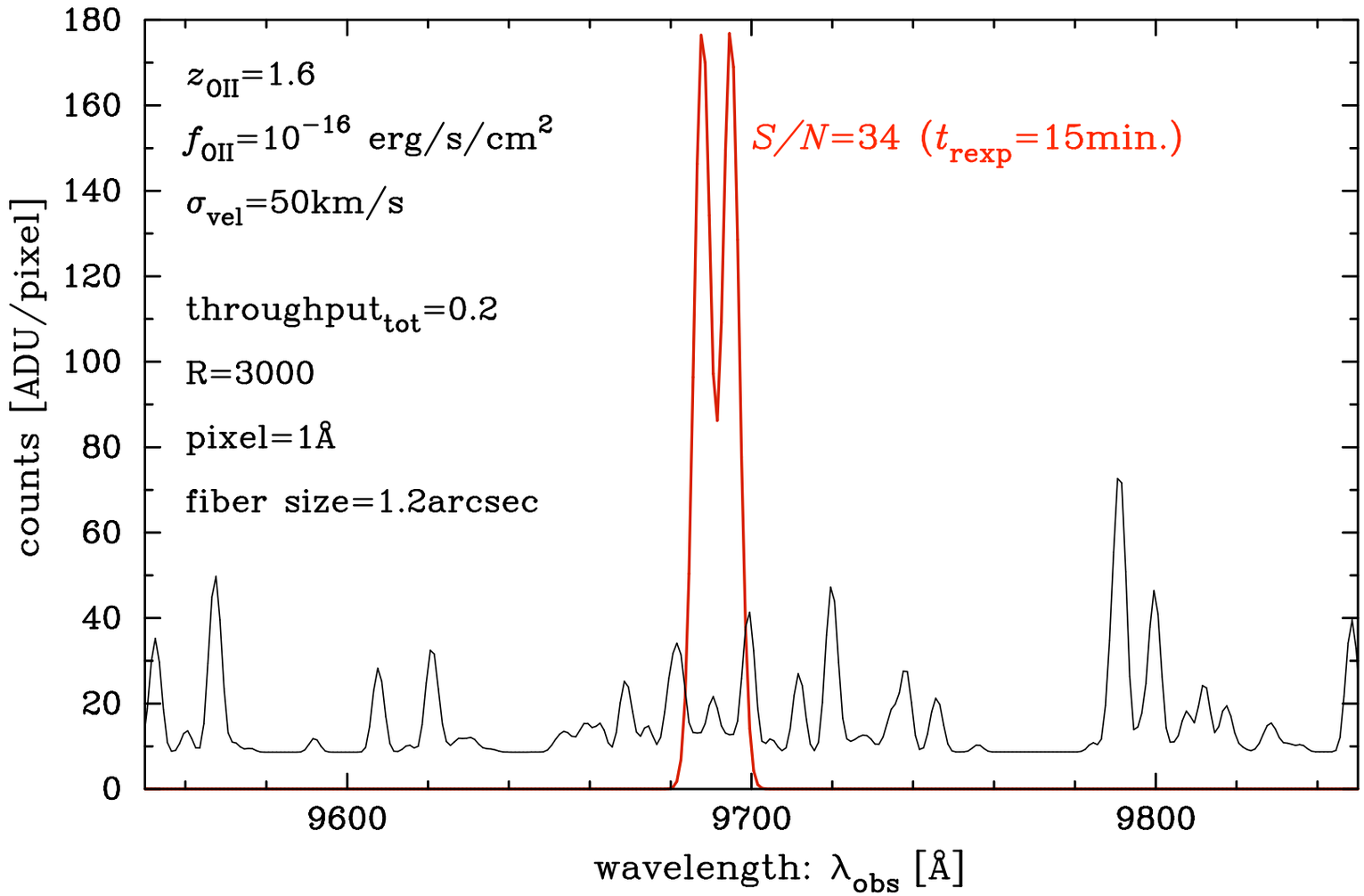
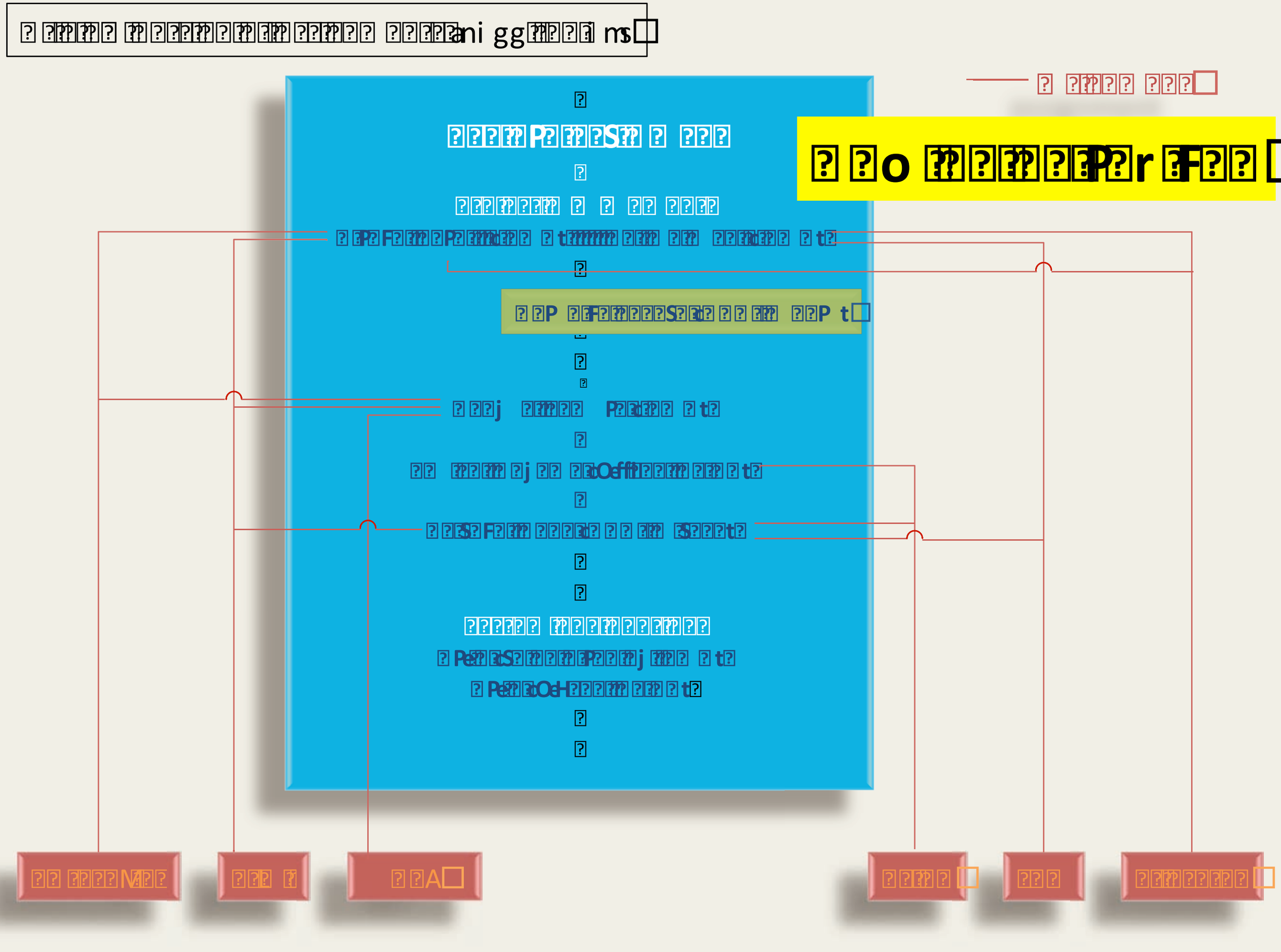


Figure 4.8: A simulated spectrum of [OII] emission line with PFS red arm, assuming 15min exposure, the *observed* line flux, $f_{\rm OII,obs} = 10^{-16}$ erg/s/cm^2, $z_{\rm OII} = 1.6$, and the velocity dispersion $\sigma_{\rm vel} = 50$ km/s. The units in the y-axis is in ADU/pixel, i.e. the expected counts on CCD chips, assuming the PFS specification given in Table 4.7. The black curve shows the expected noise (1σ) assuming the sky spectrum in Figure 4.7 and the Poisson noise. For this OII emission line, the total S/N, integrated over the CCD pixels, is $S/N \simeq 34$.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