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

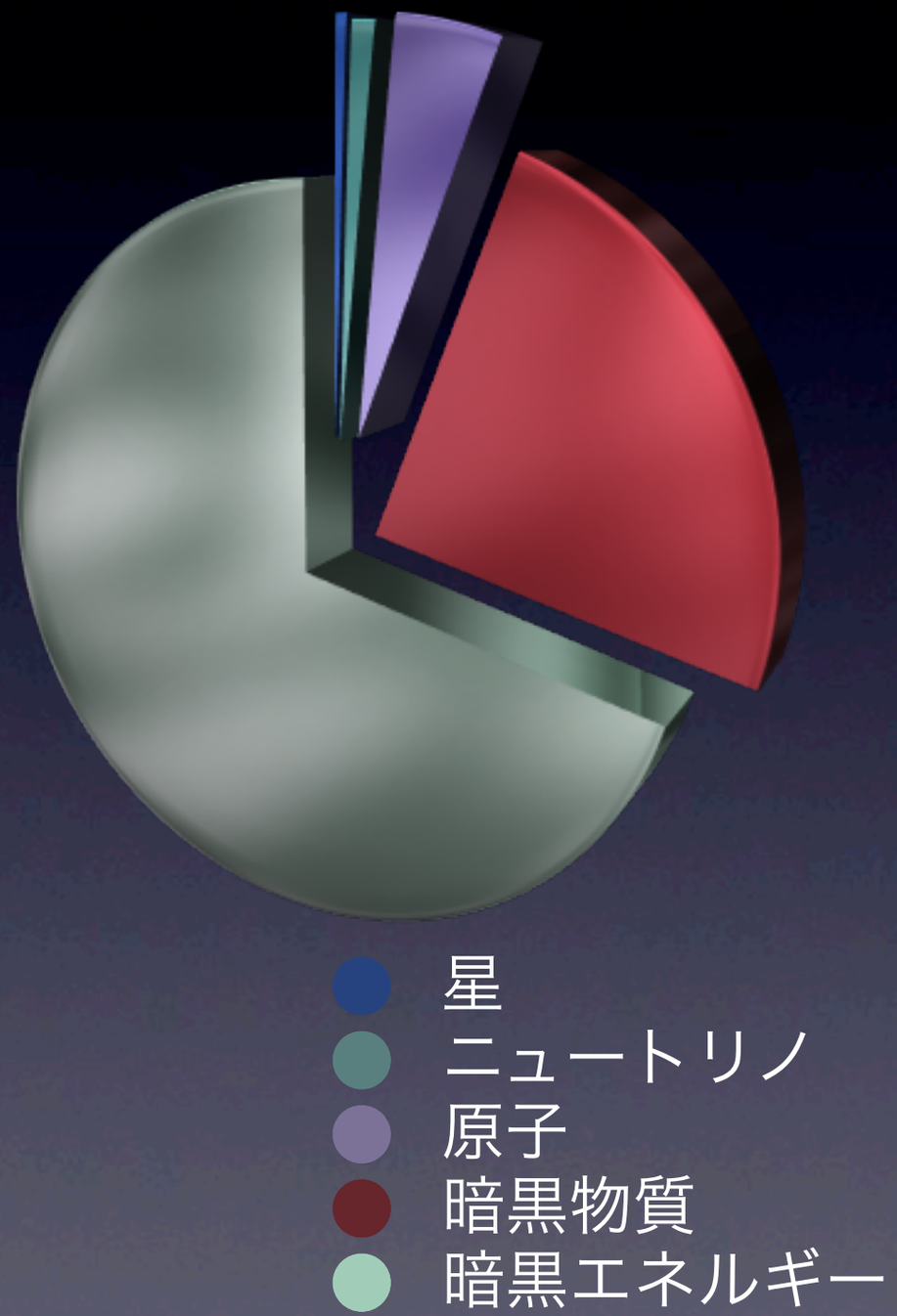
2011年7月29日

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%



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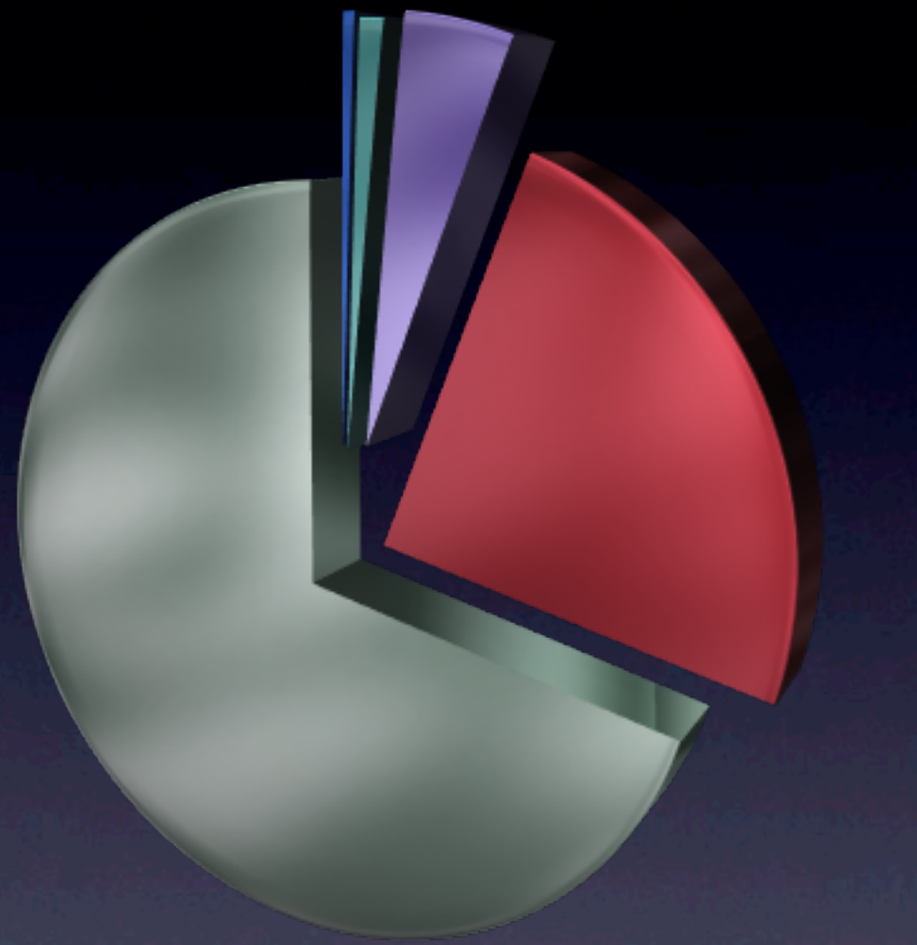
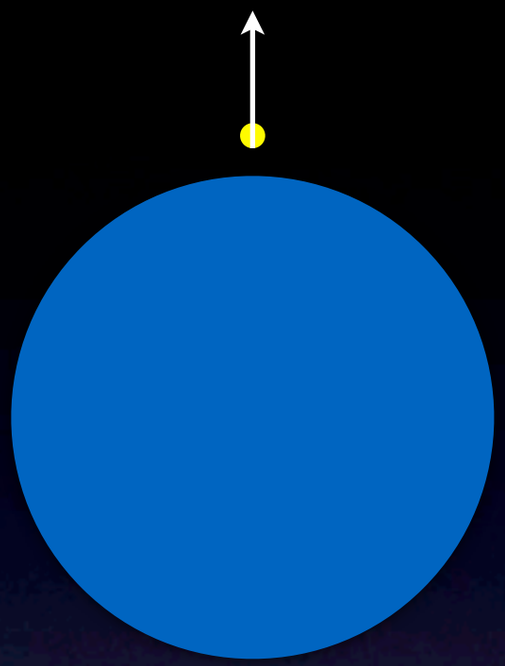
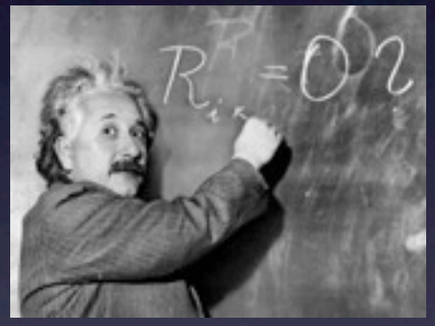


宇宙膨張





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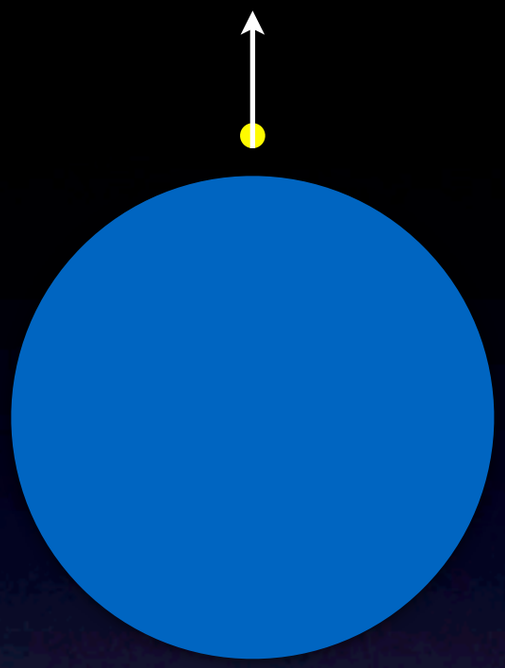

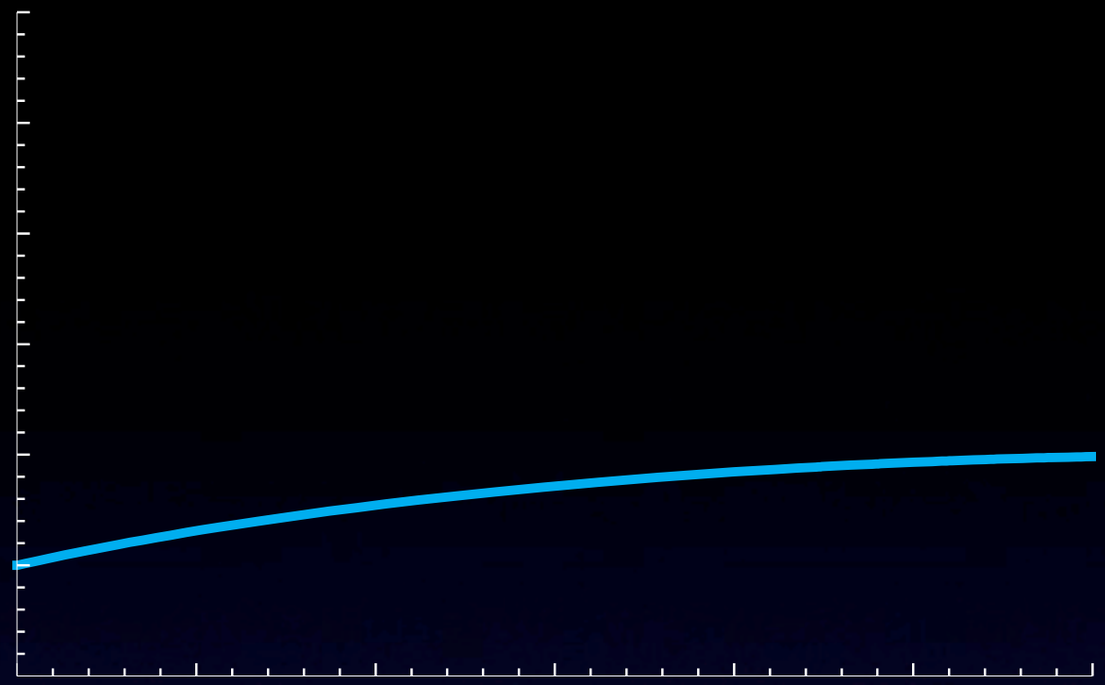

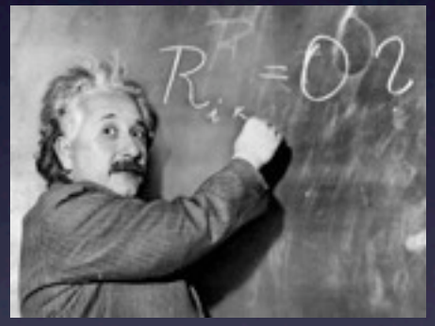

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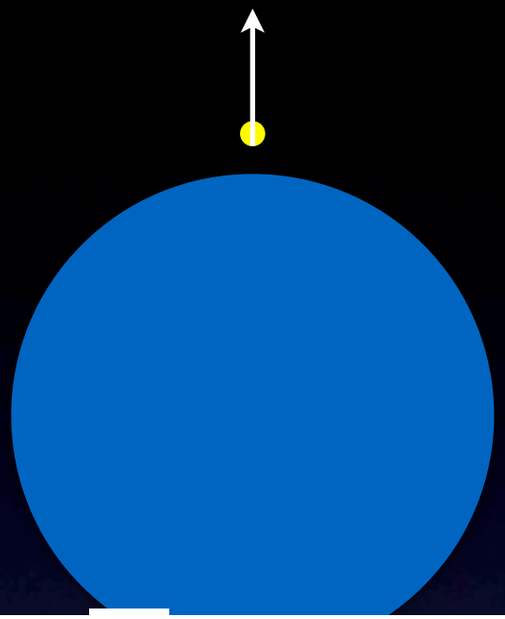
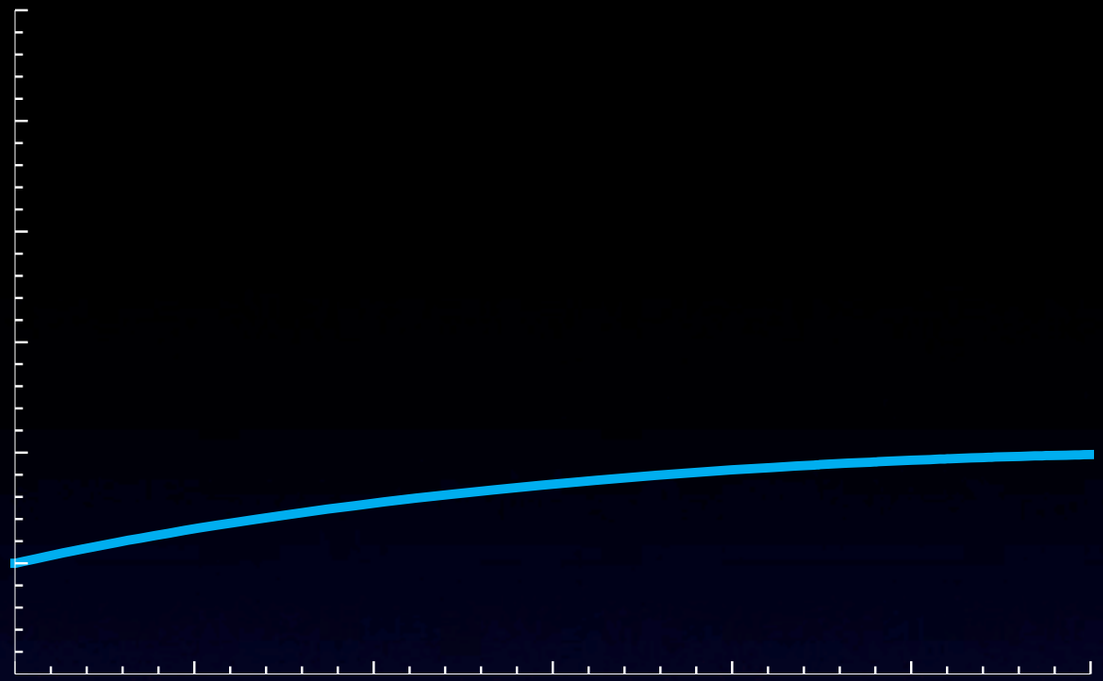
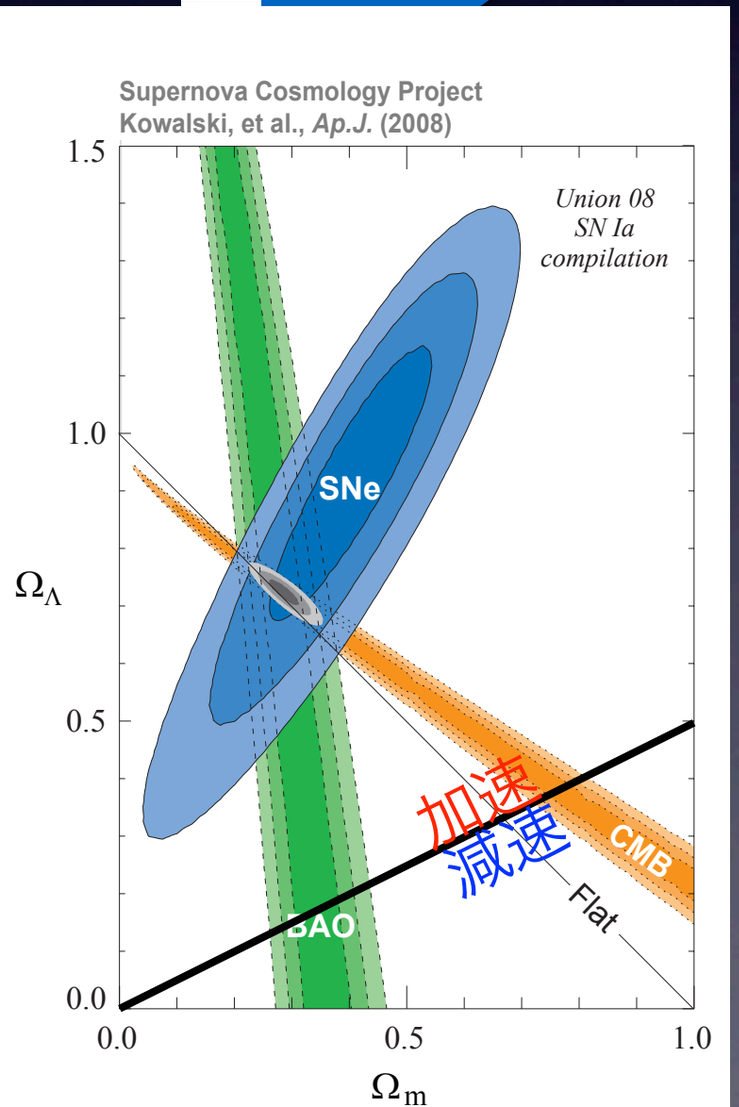




減速するはず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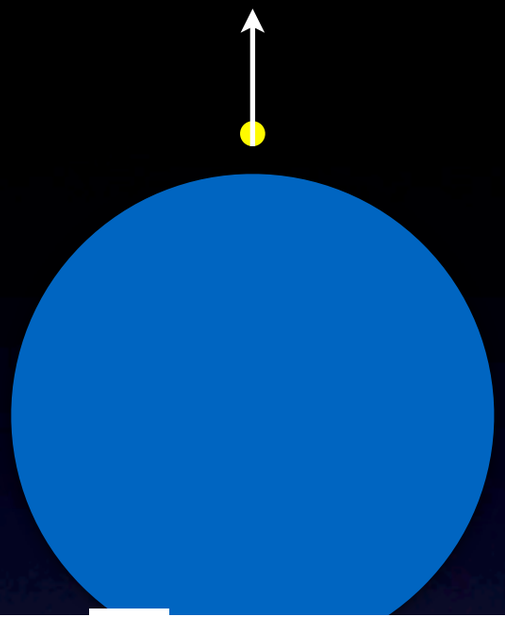

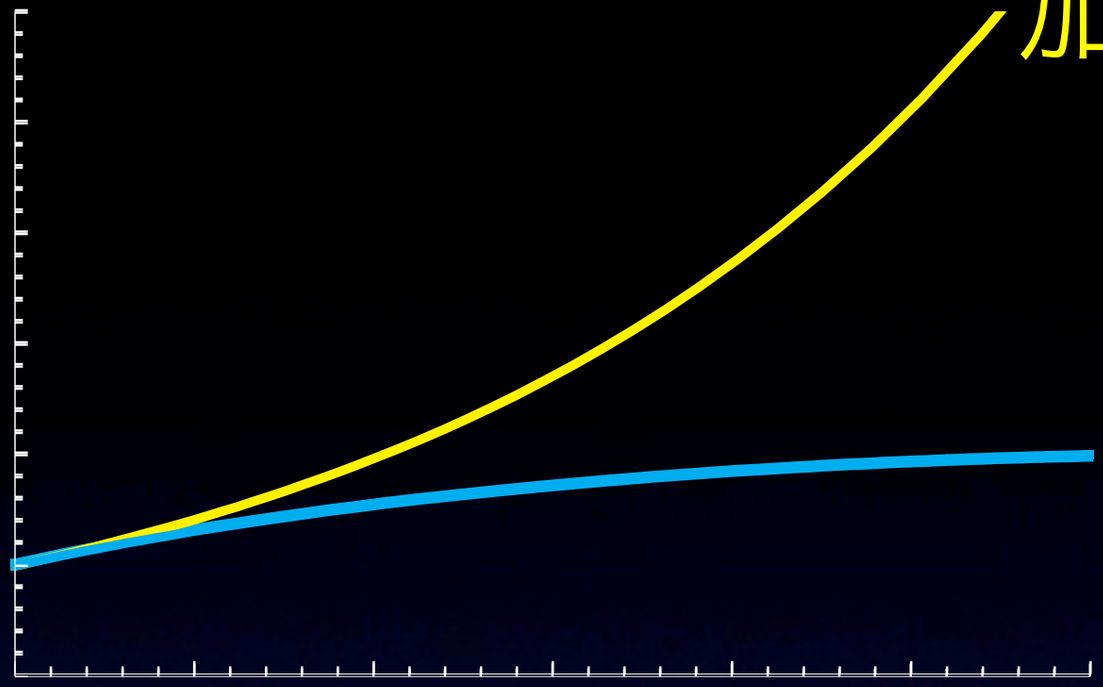
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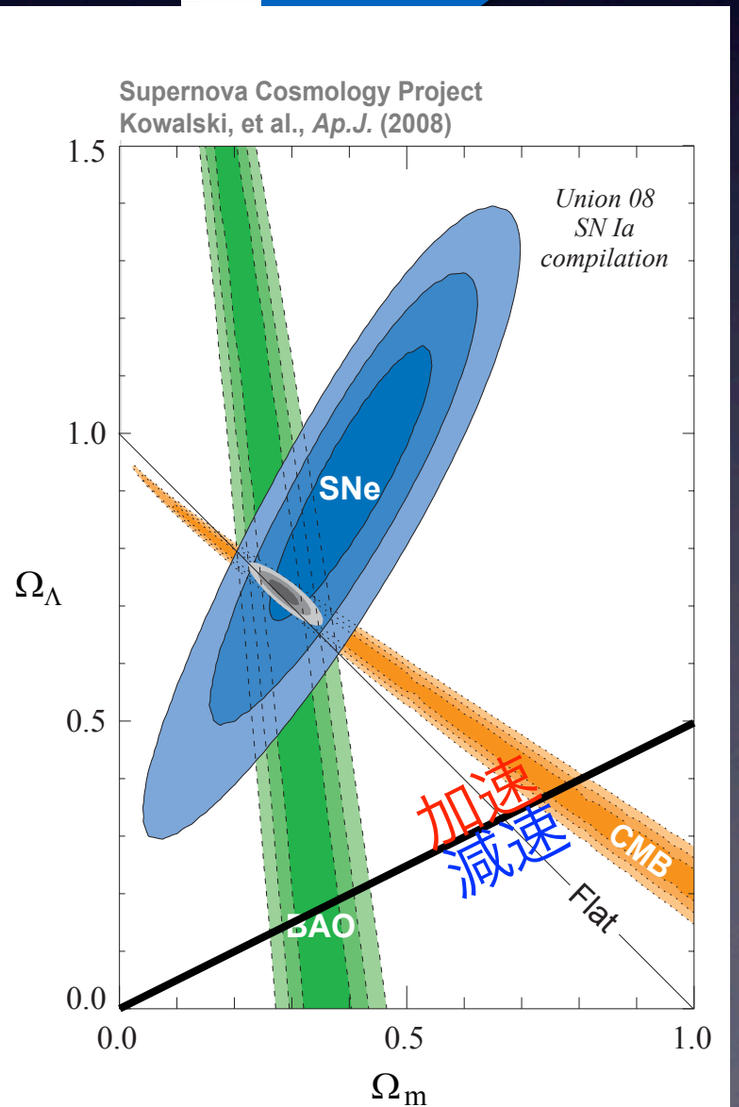
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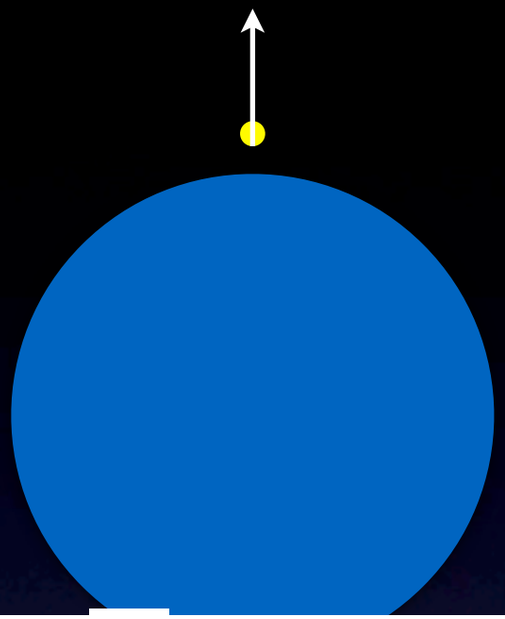

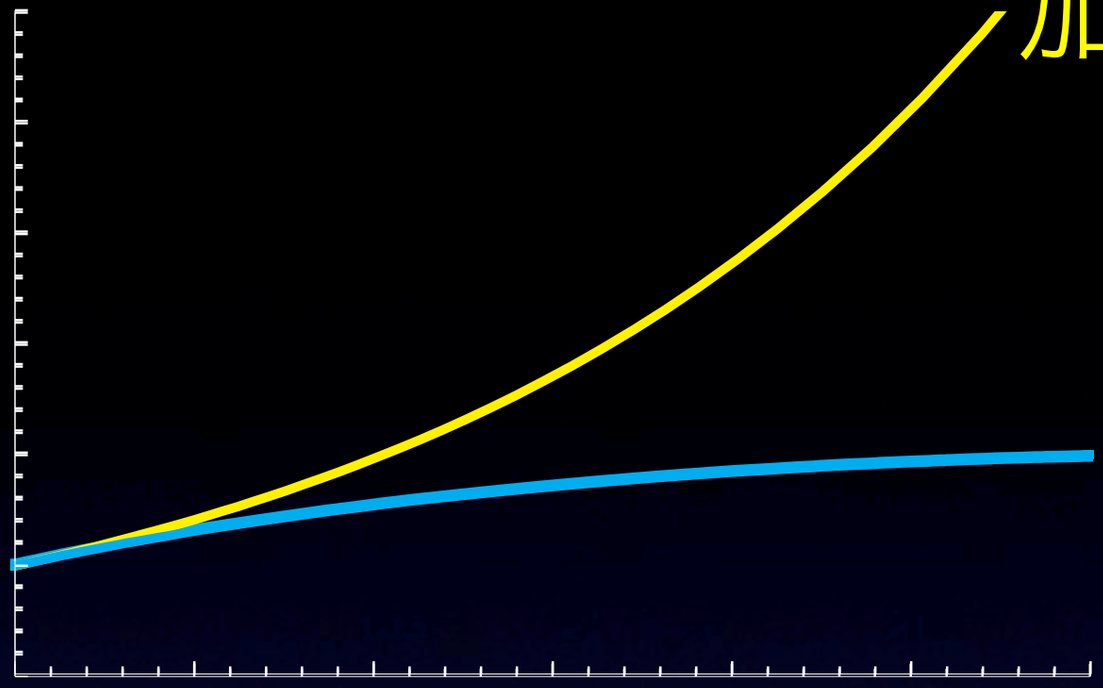

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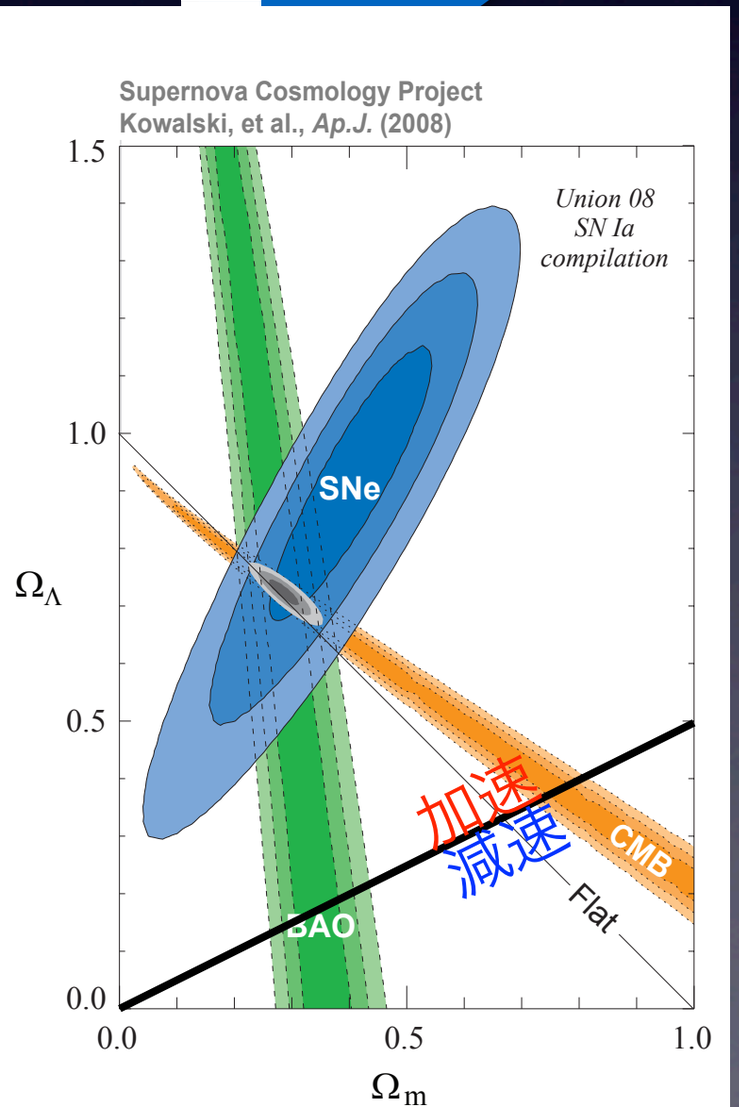

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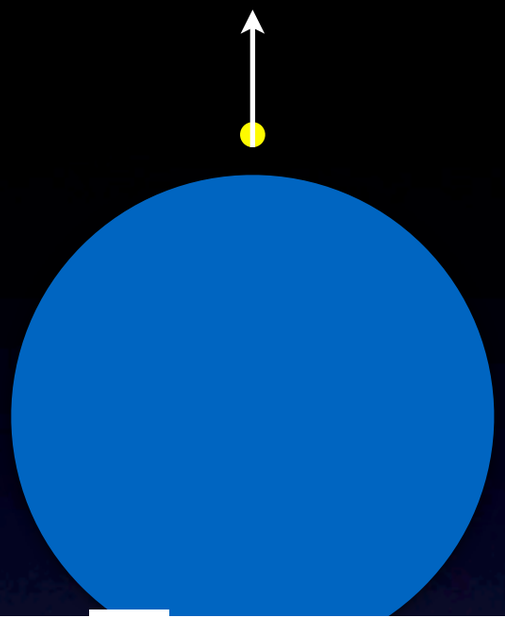

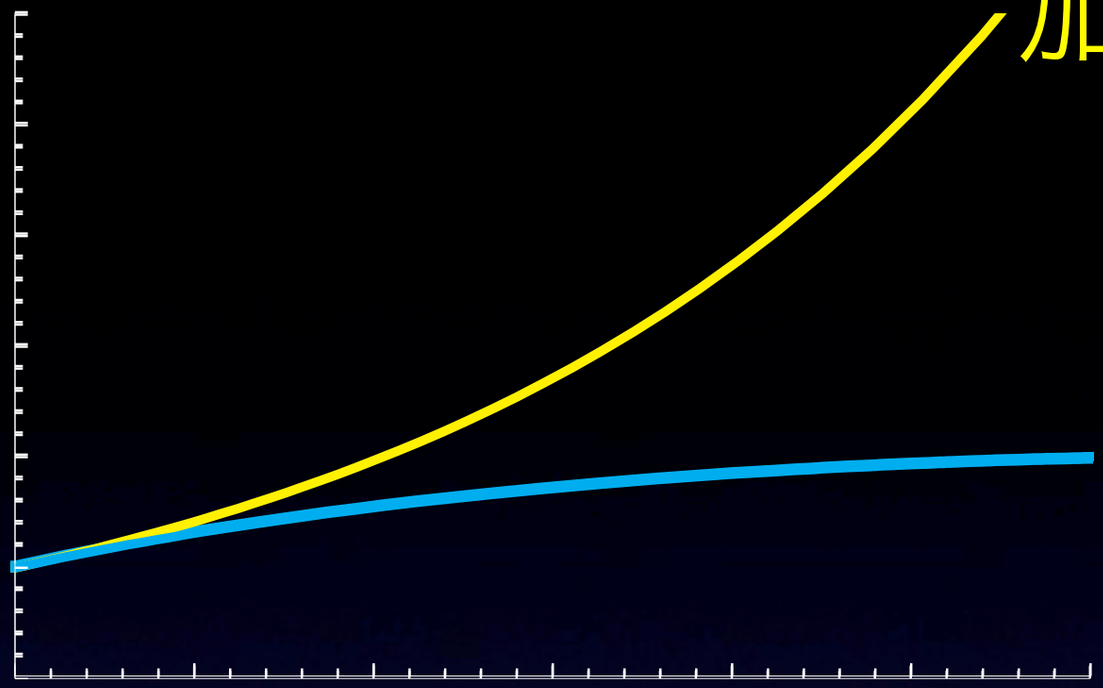

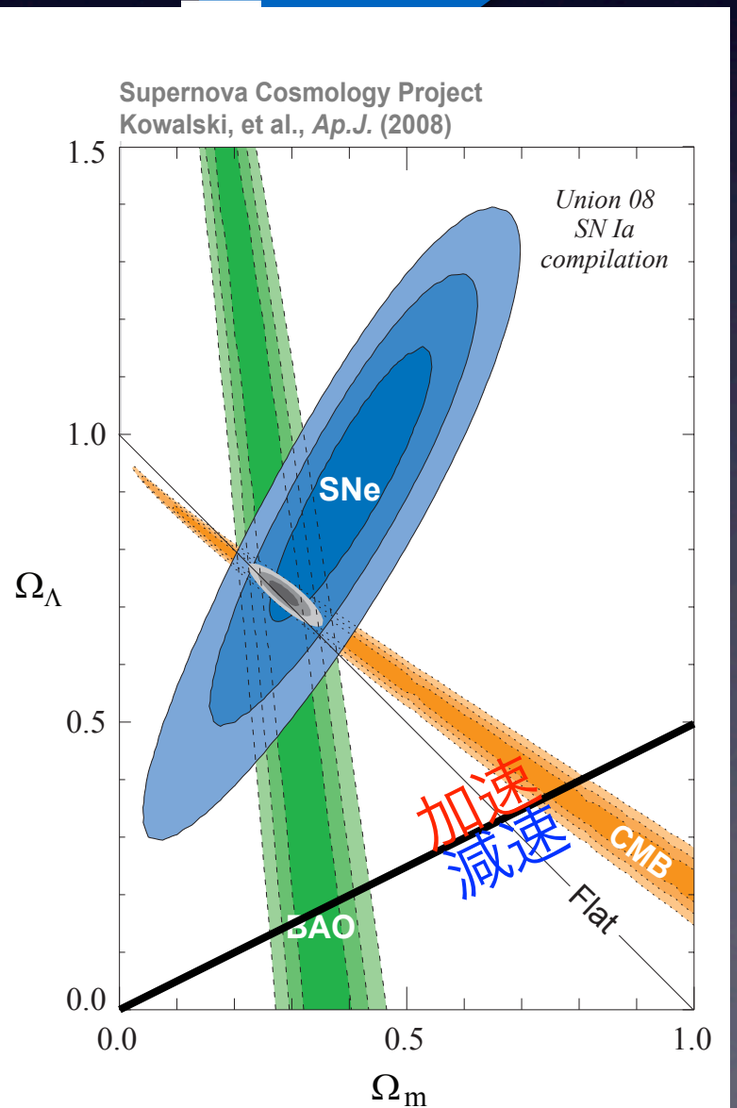

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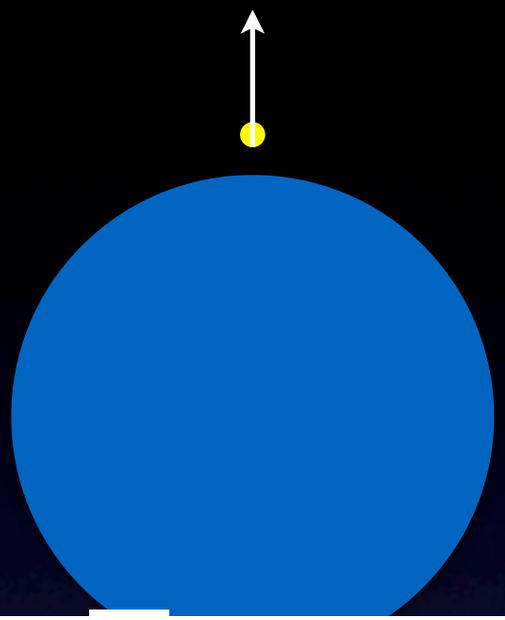

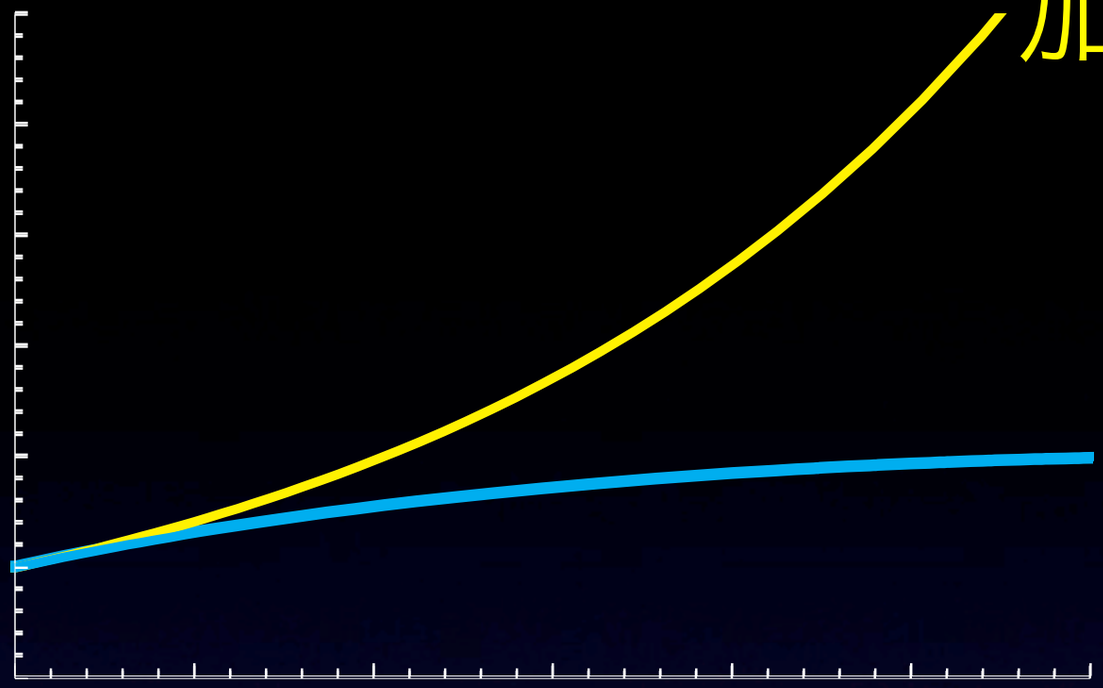

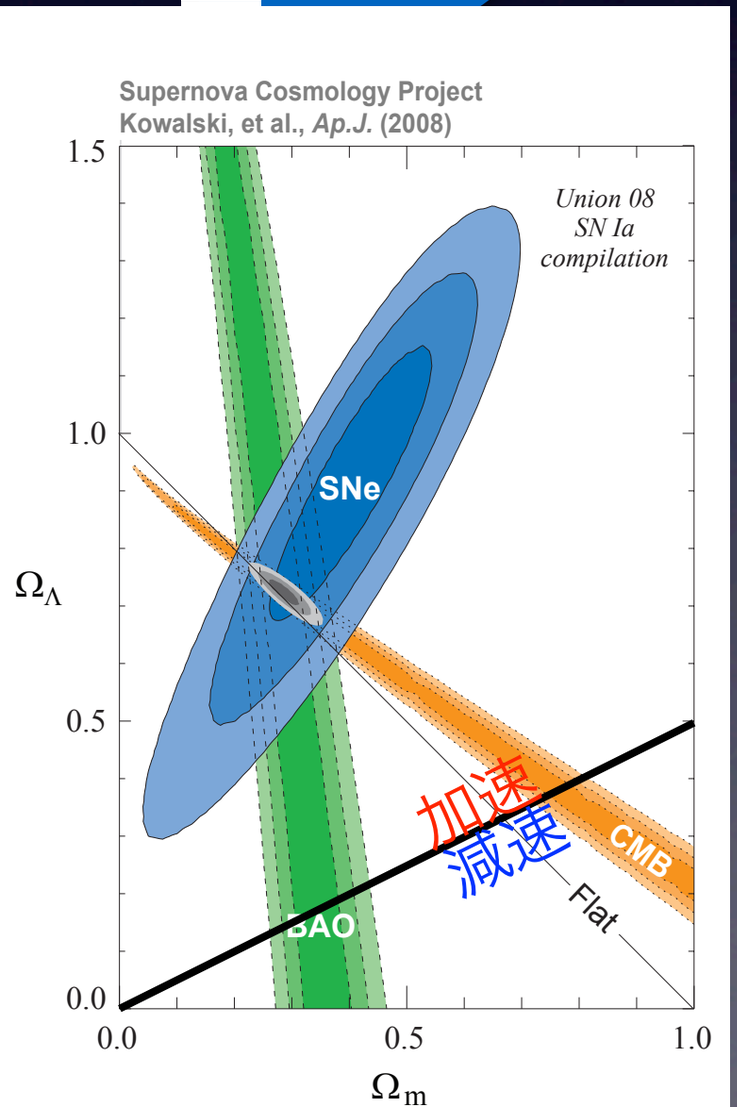

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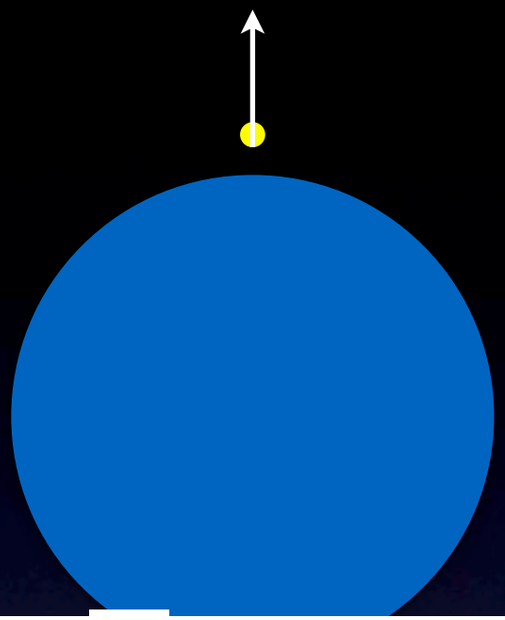

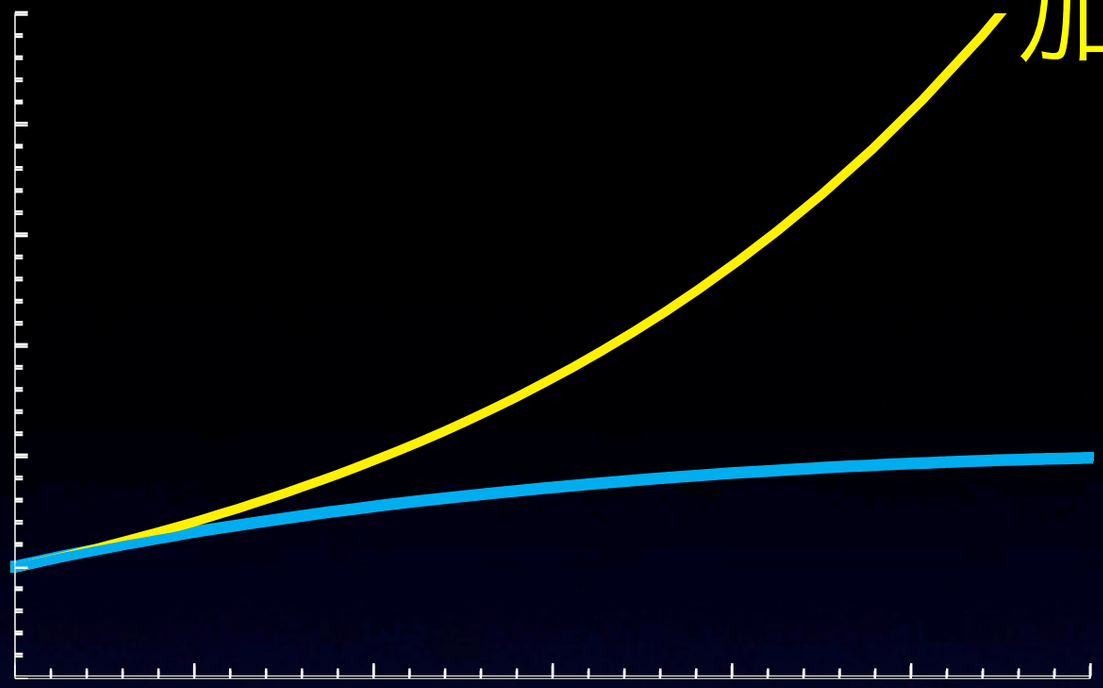

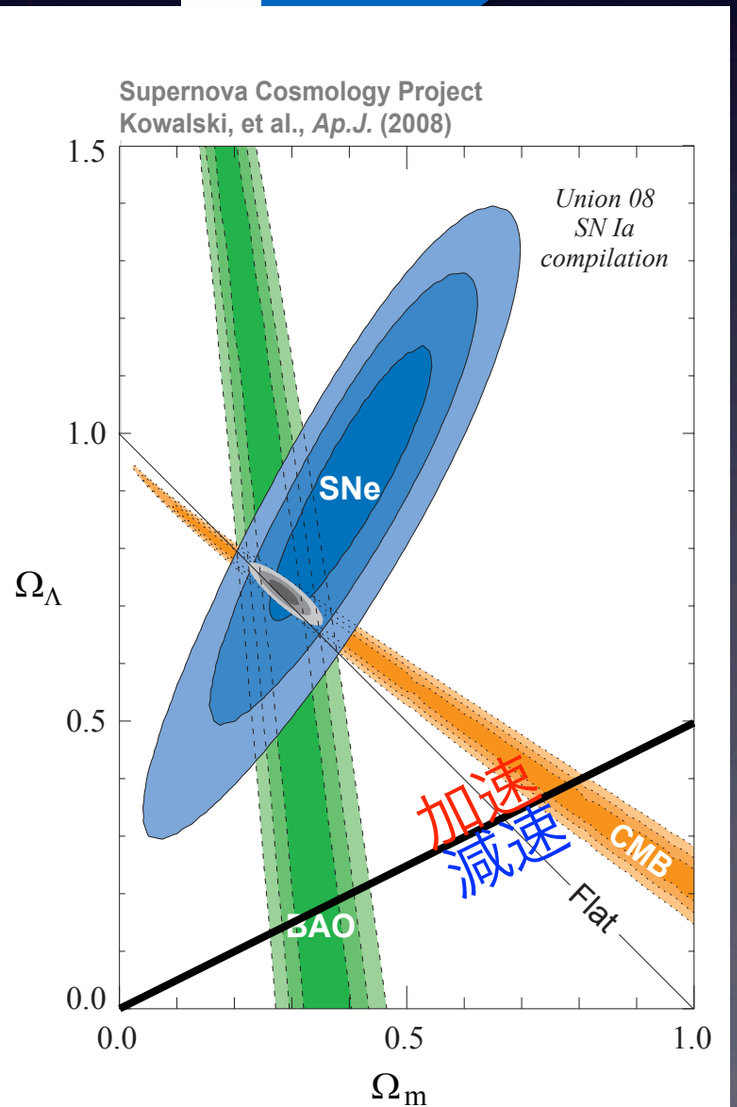

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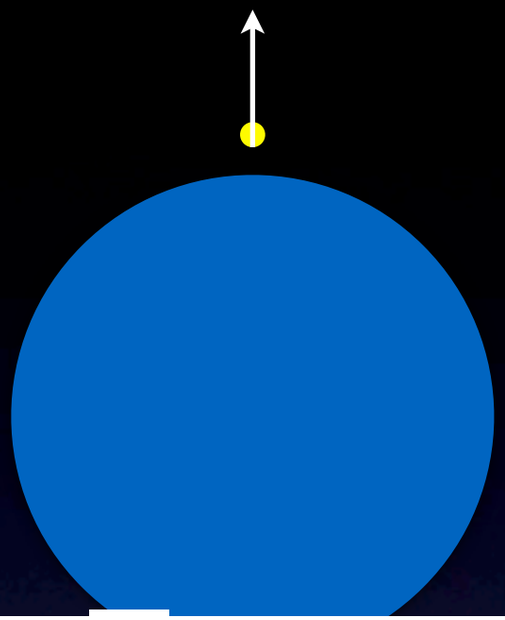

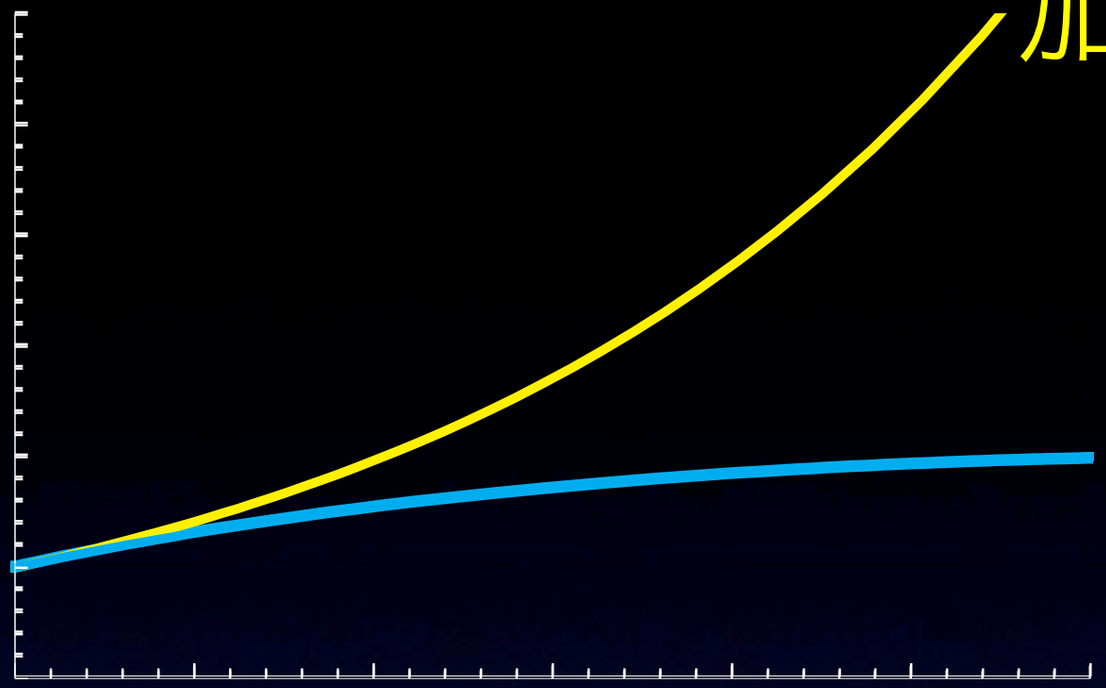

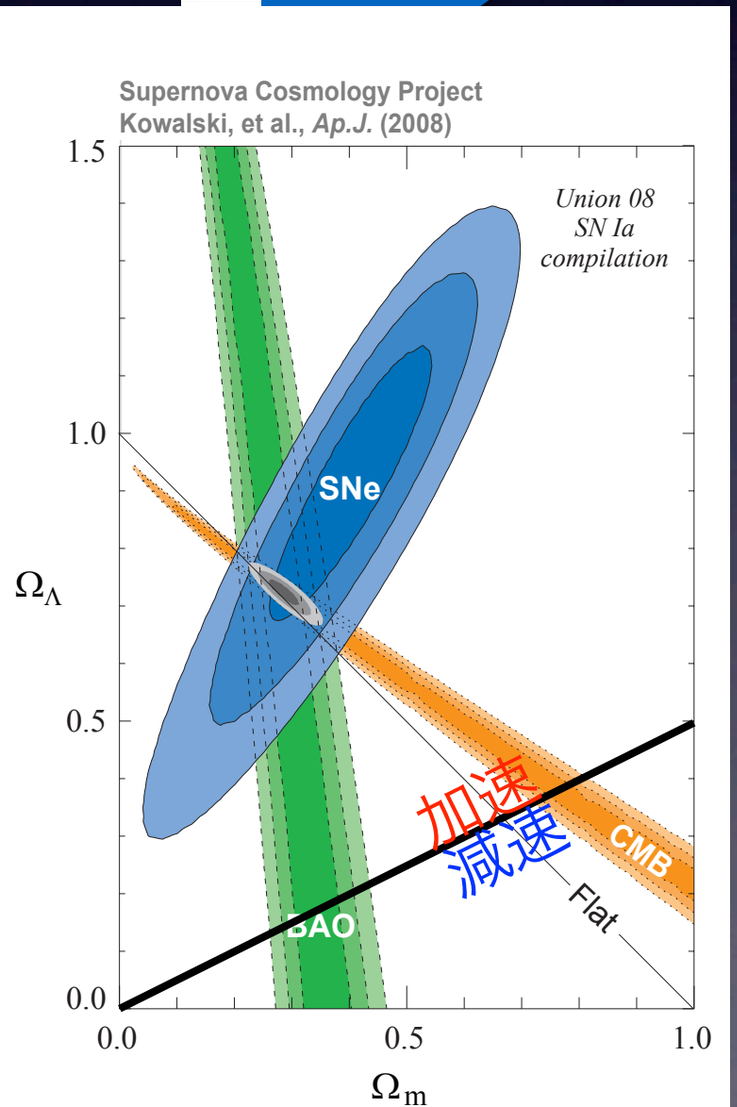

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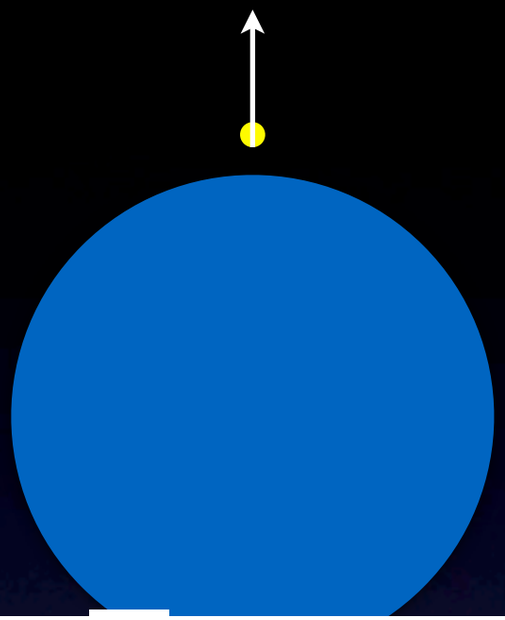

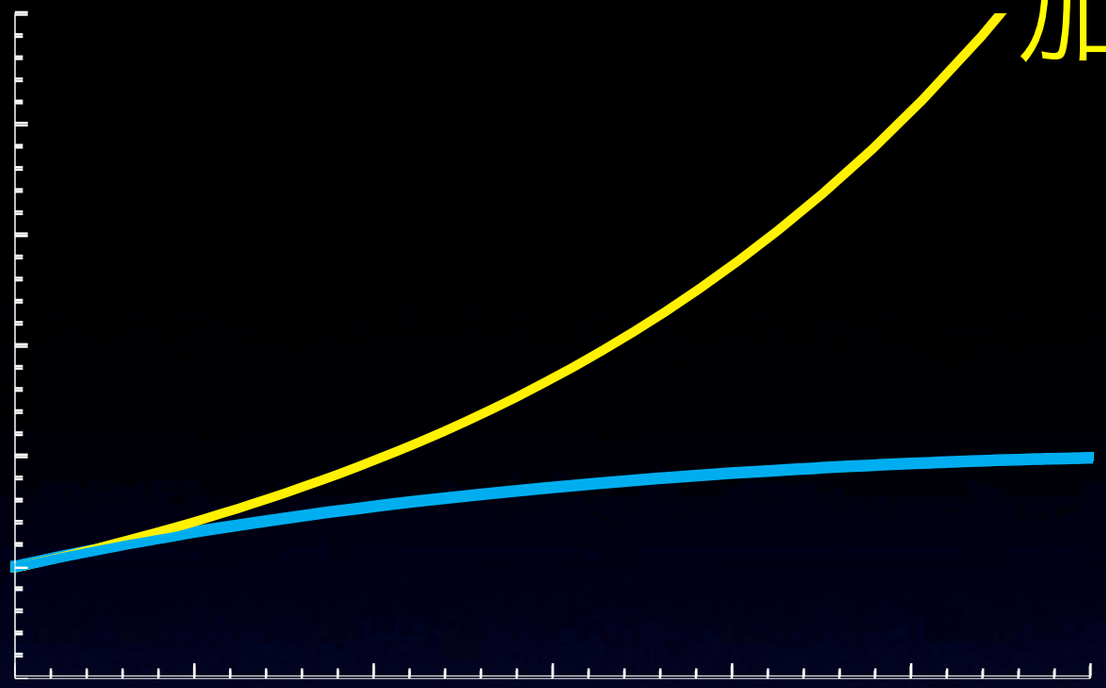

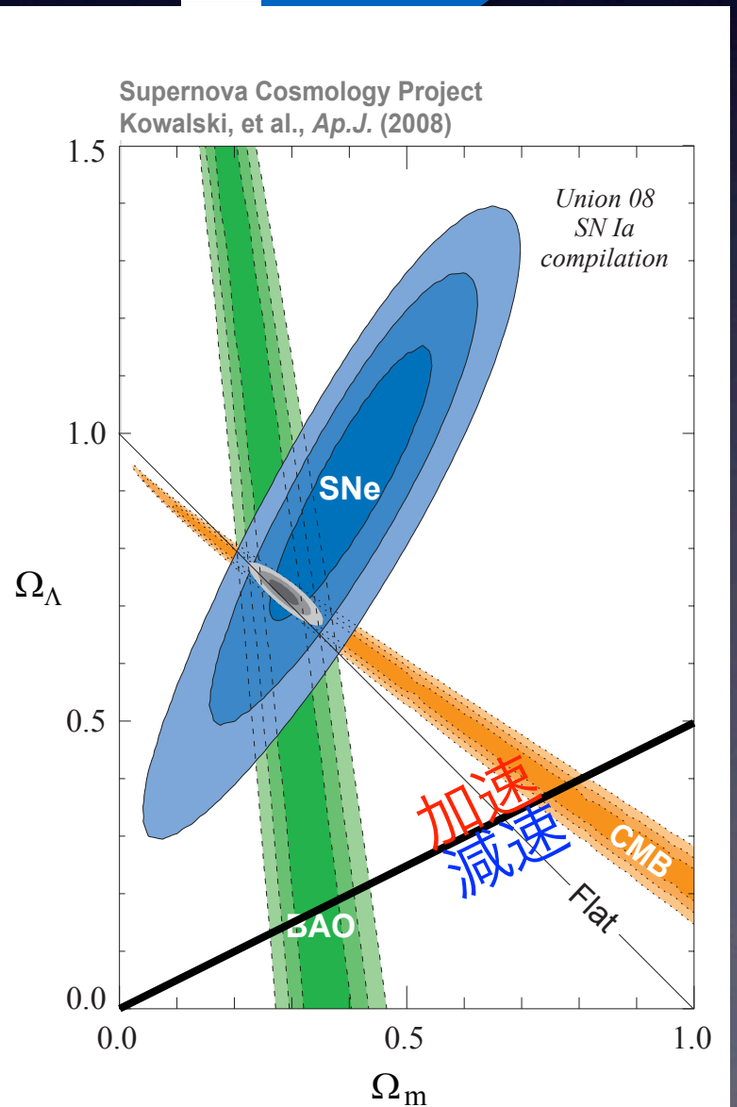

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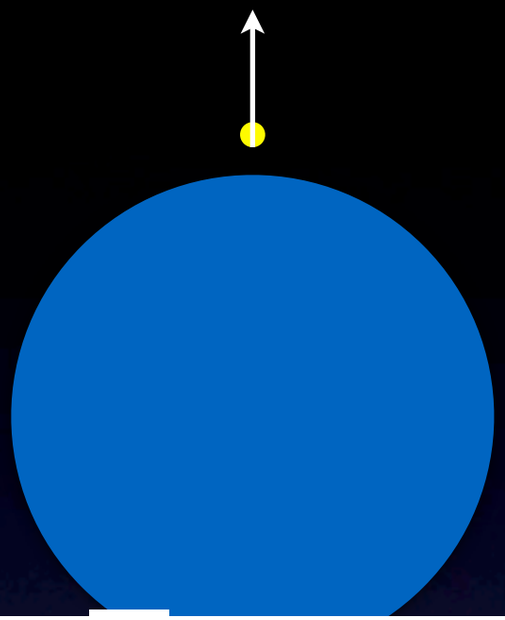

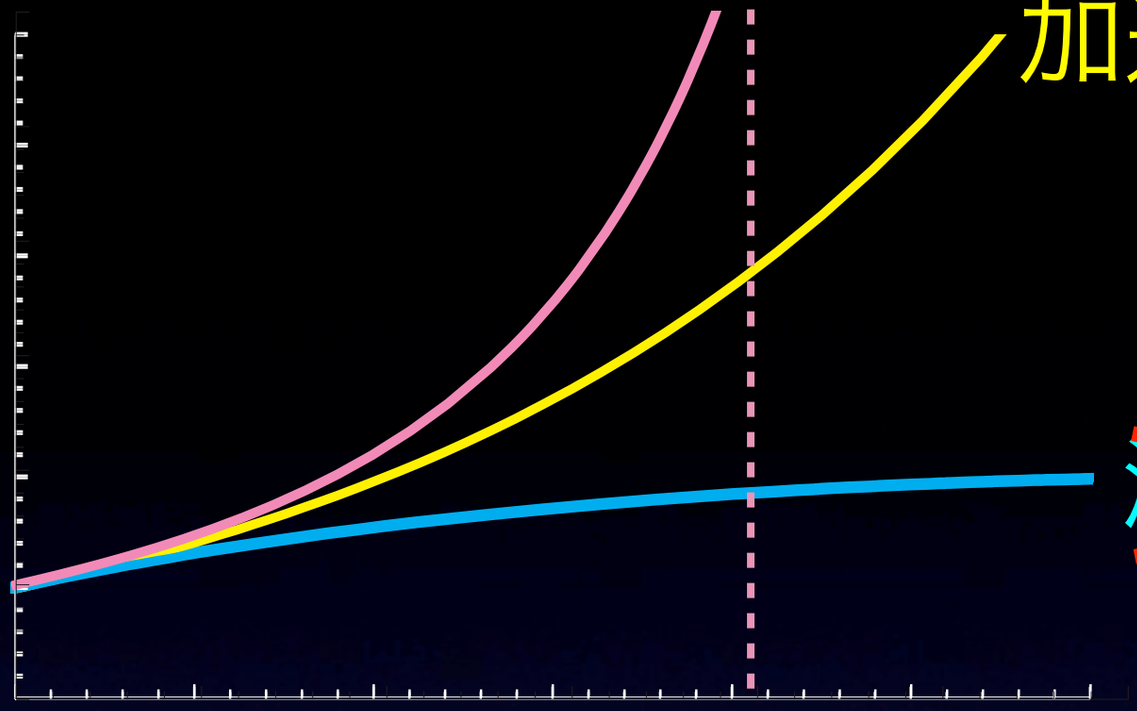

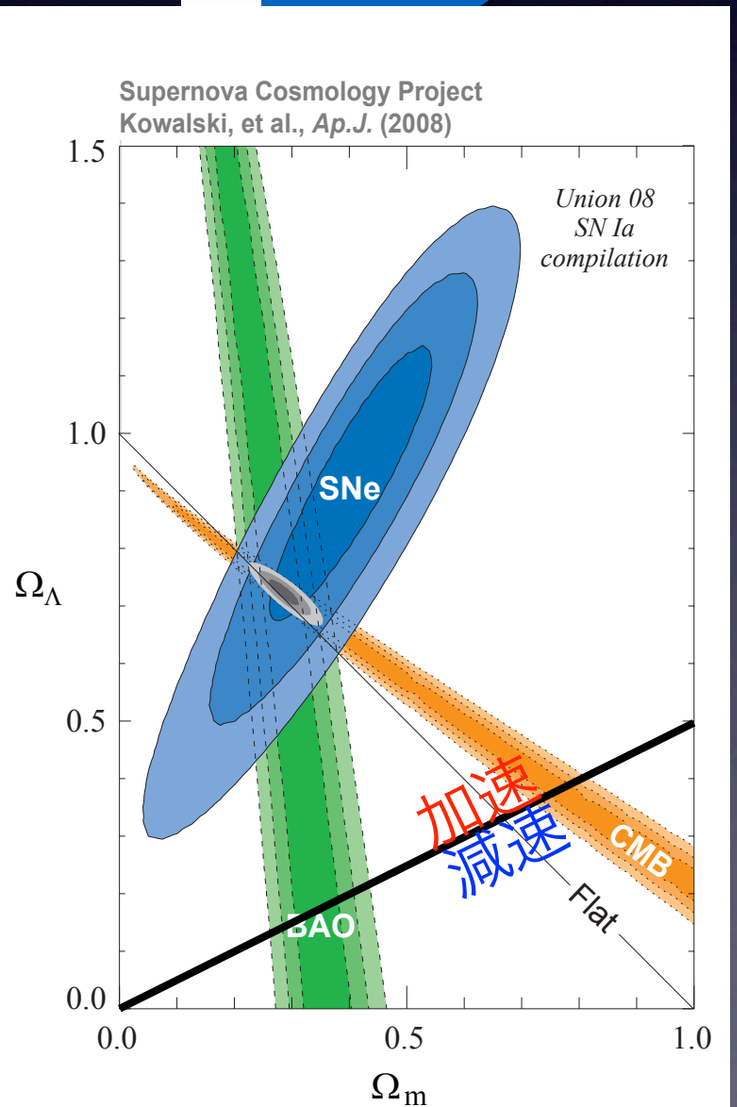

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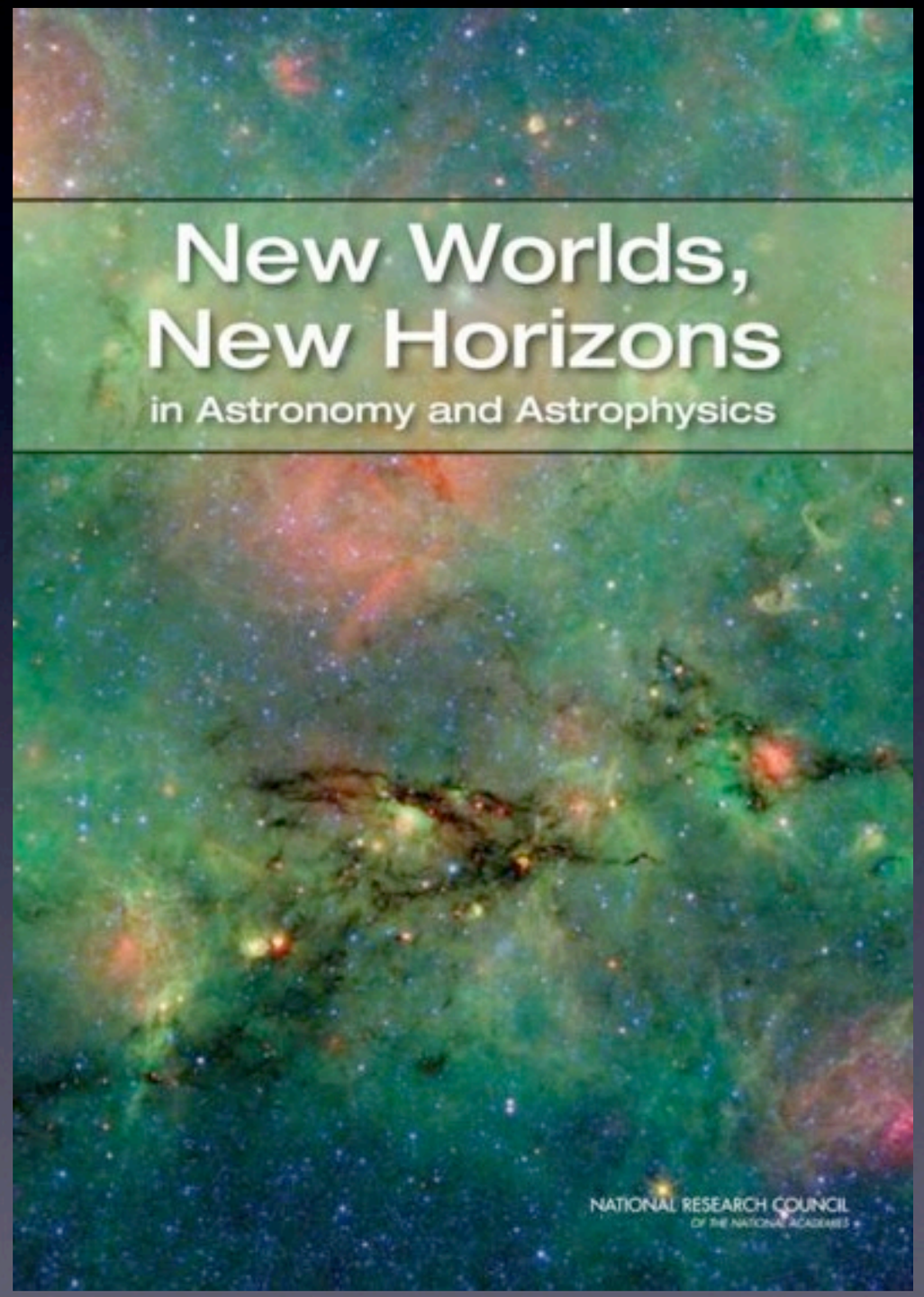
Astro 2010

- 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)

2. Explorer Program Augmentation

3. Laser Interferometer Space Antenna (LISA)

4. International X-ray Observatory (IXO)

Roger Blandford ASTRO 2010 roll-out

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Roger Blandford ASTRO 2010 roll-out

Large-scale Ground-based Program - Prioritized

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

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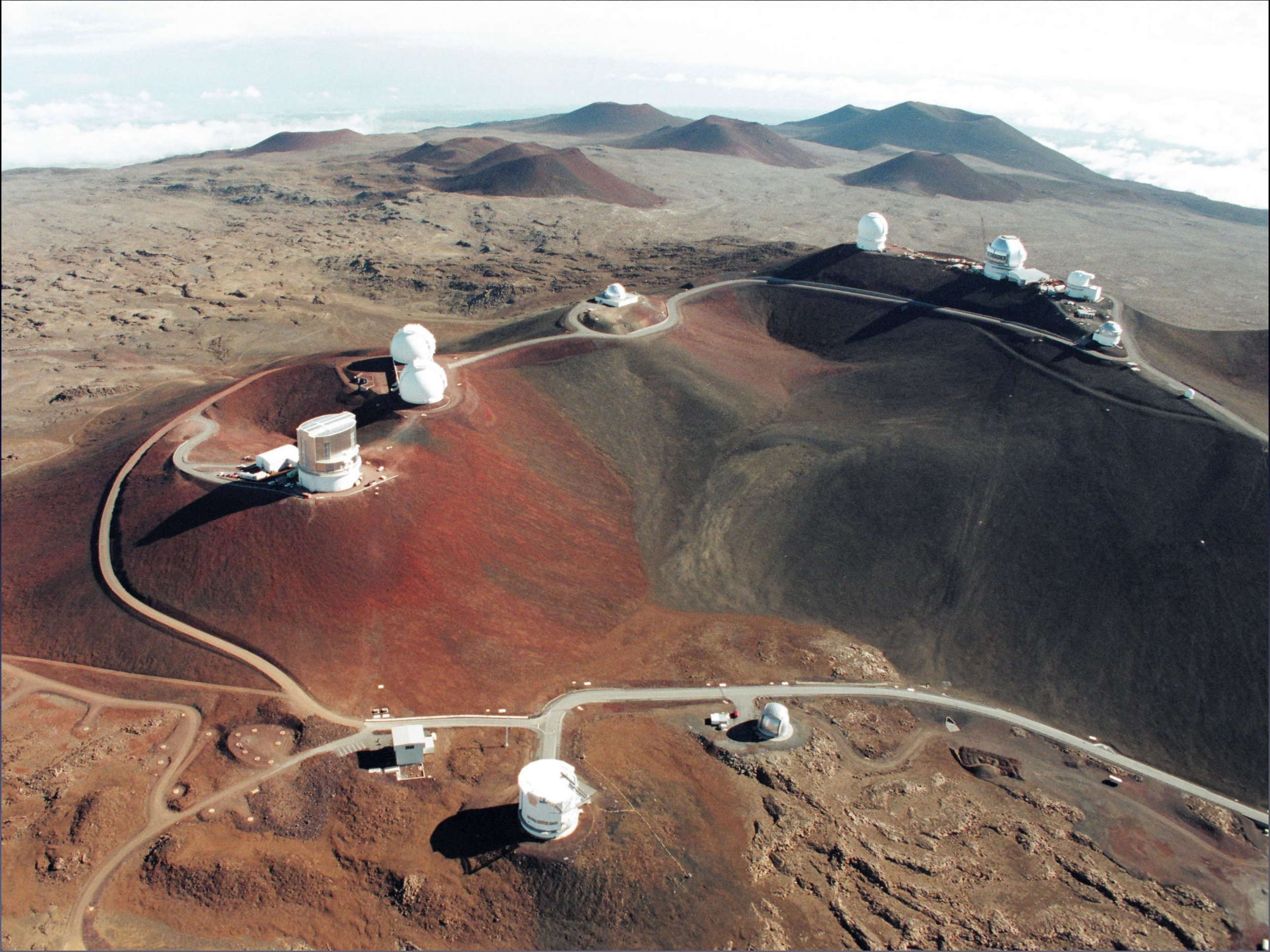
Roger Blandford ASTRO 2010 roll-out

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

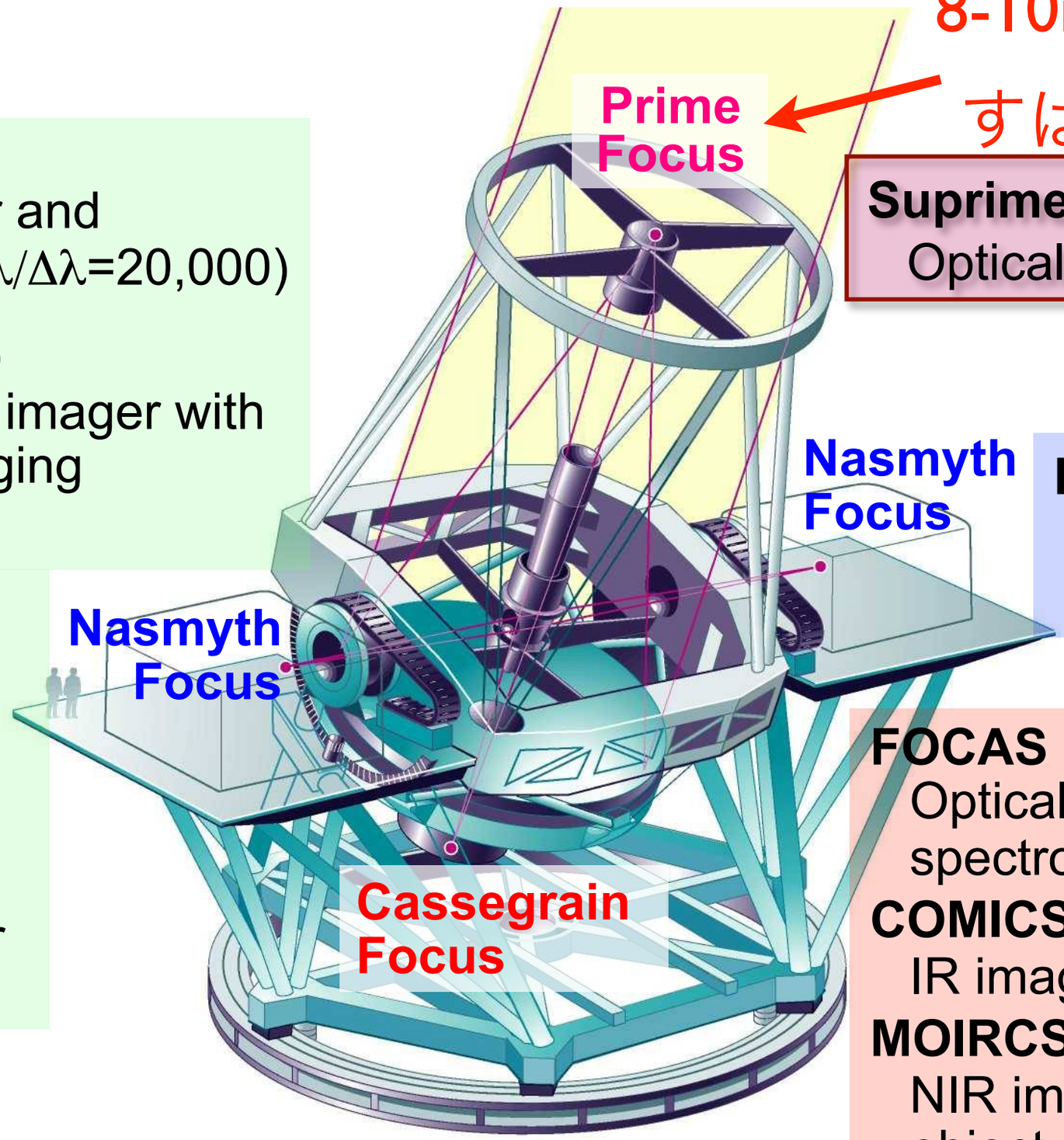


Illustration by Takaetsu Endo, taken from Nikkei Science 1996

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

Subaru Measurement of Images and Redshifts

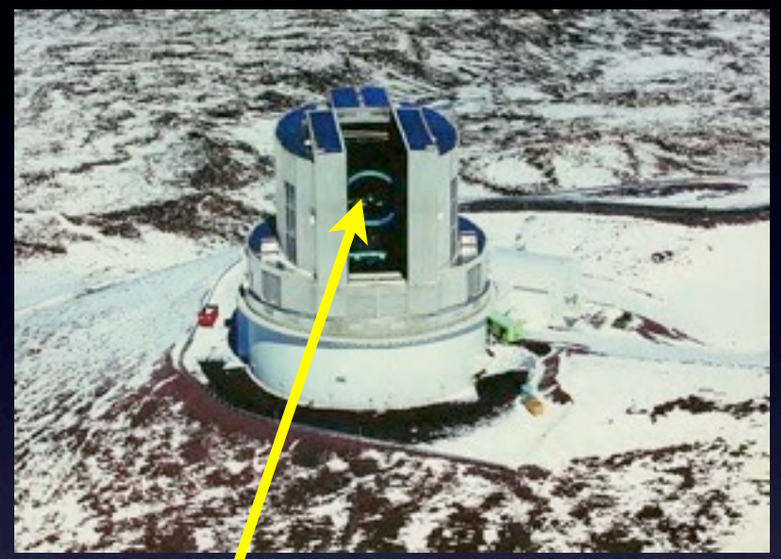
- 8.2 m, excellent seeing 0.6”, 広視野1.5°

すばる

SuMIRe

Subaru Measurement of Images and Redshifts

- 8.2 m, excellent seeing 0.6”, 広視野1.5°
- HyperSuprimeCam: weak lensing survey
  - 0.9 B pixels, 3 ton カメラ
  - 何10億もの銀河
  - ~40億円, ほぼ確保
  - 暗黒物質２次元地図



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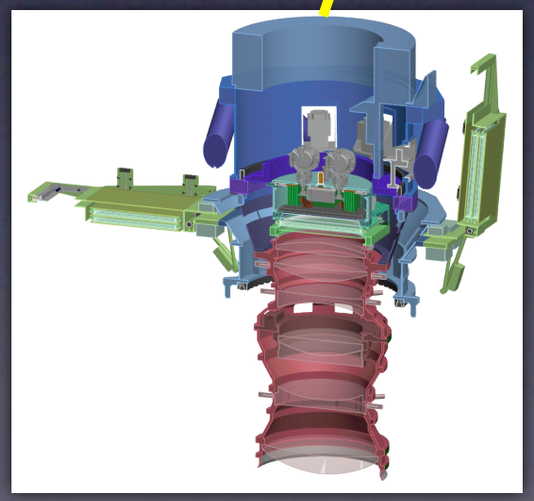

HSC

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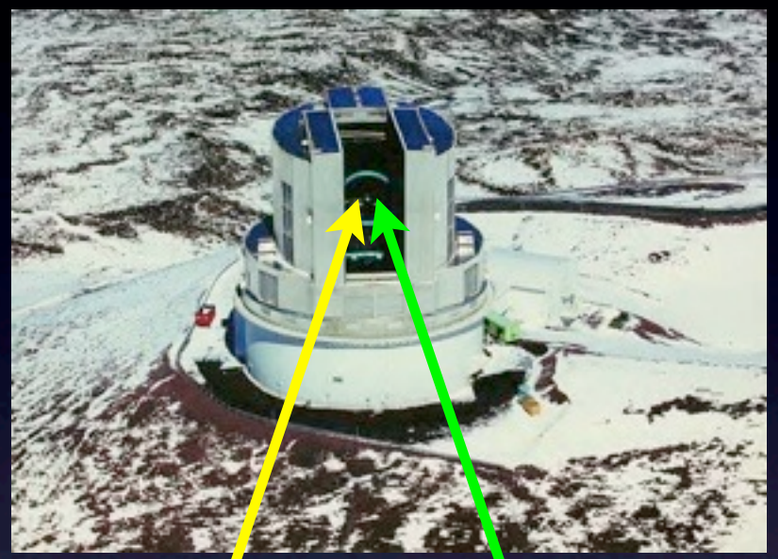
  - 暗黒物質２次元地図
- PrimeFocusSpectrograph: バリオン振動
  - 2400 fibers, ~2000 sq. dg.
  - >1M redshifts
  - ~50億円, ~40億確保
  - 暗黒物質３次元地図



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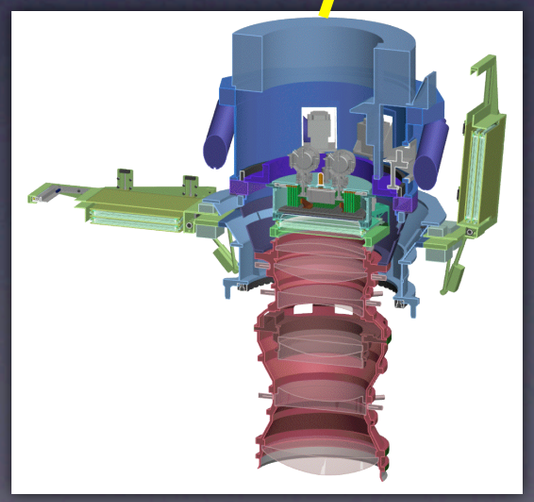
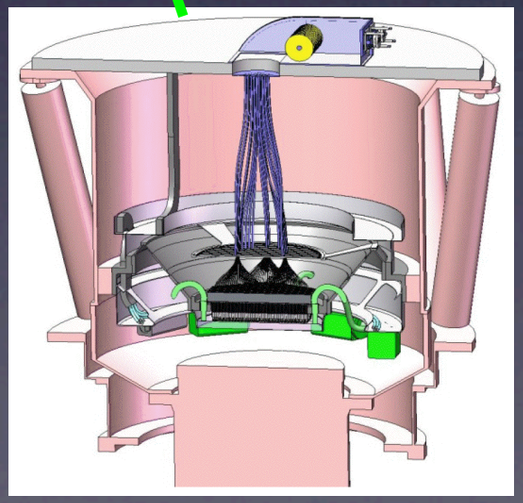


HSC



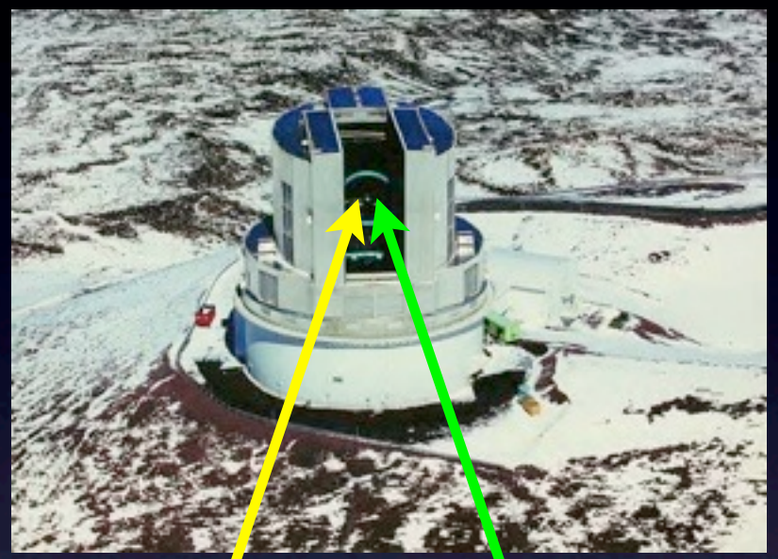
PFS

SuMIRe

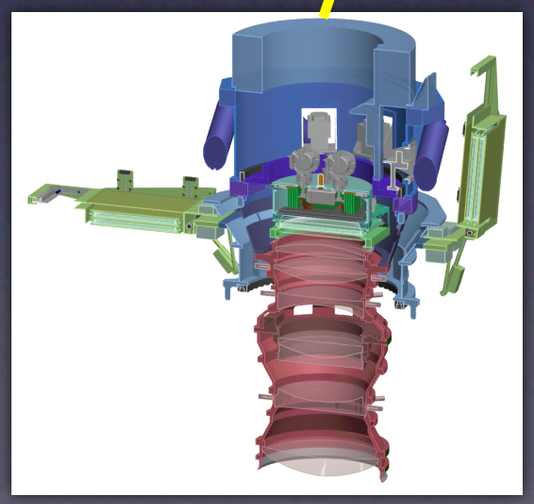
Subaru Measurement of Images and Redshifts

- 8.2 m, excellent seeing 0.6”, 広視野1.5°
- HyperSuprimeCam: weak lensing survey
  - 0.9 B pixels, 3 ton カメラ
  - 何10億もの銀河
  - ~40億円, ほぼ確保
  - 暗黒物質２次元地図
- PrimeFocusSpectrograph: バリオン振動
  - 2400 fibers, ~2000 sq. dg.
  - >1M redshifts
  - ~50億円, ~40億確保
  - 暗黒物質３次元地図
- 同じ望遠鏡でイメージングと分光

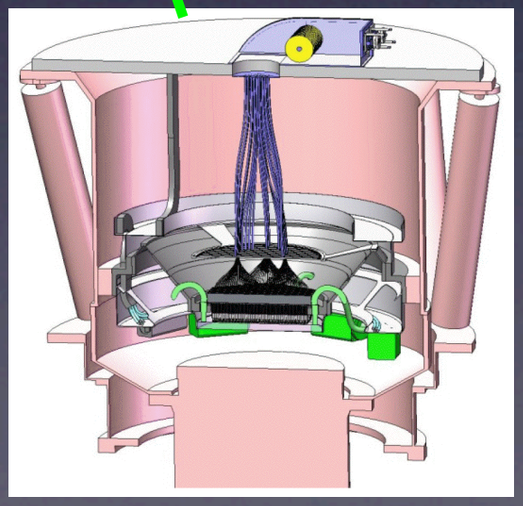
  SDSSを8.2mで：強力な武器！



すばる



HSC



PFS

SuMIRe

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- ak lensing survey
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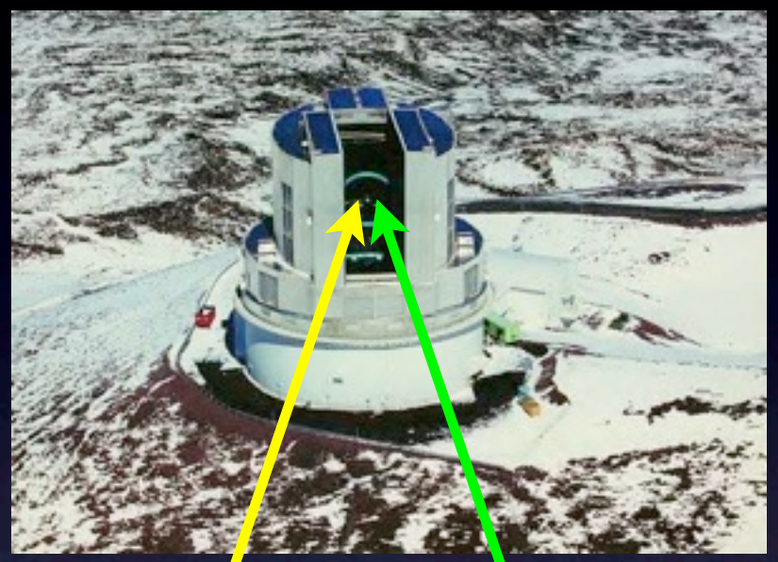

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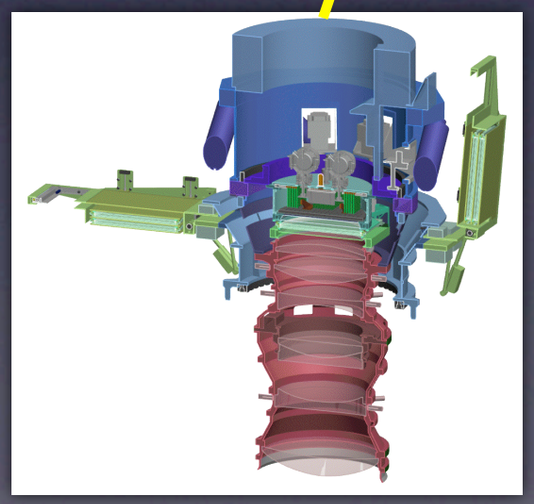

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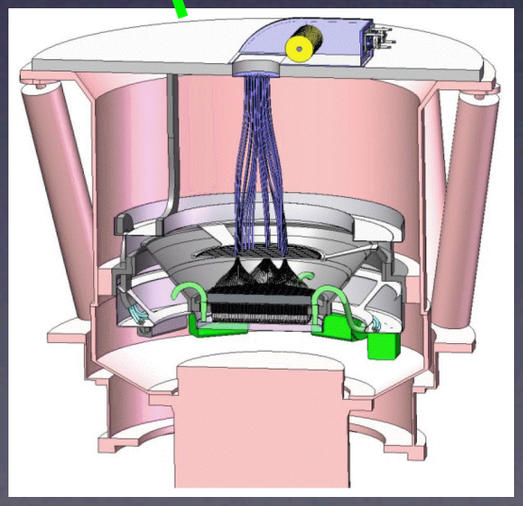
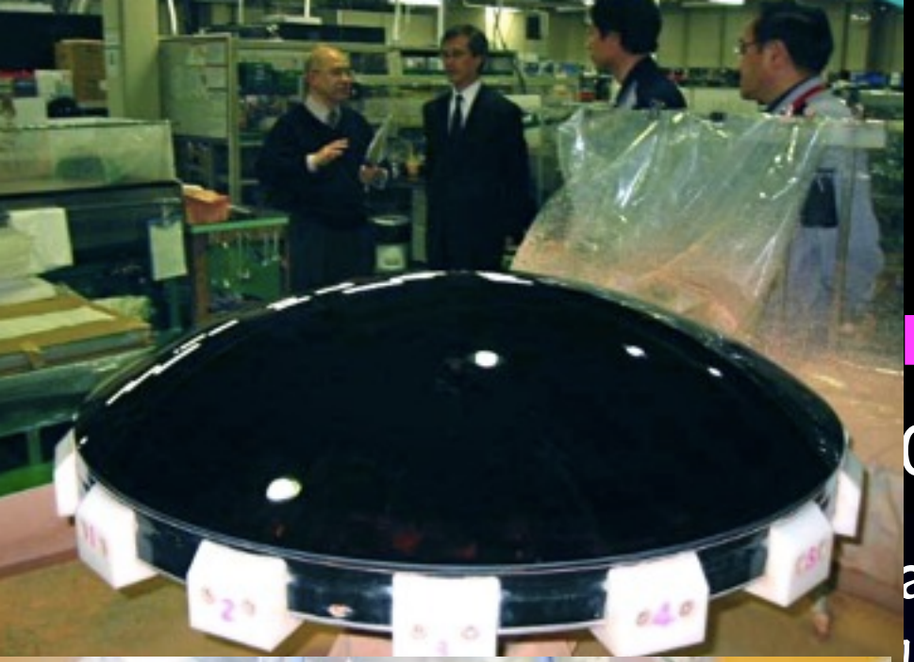


PFS



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

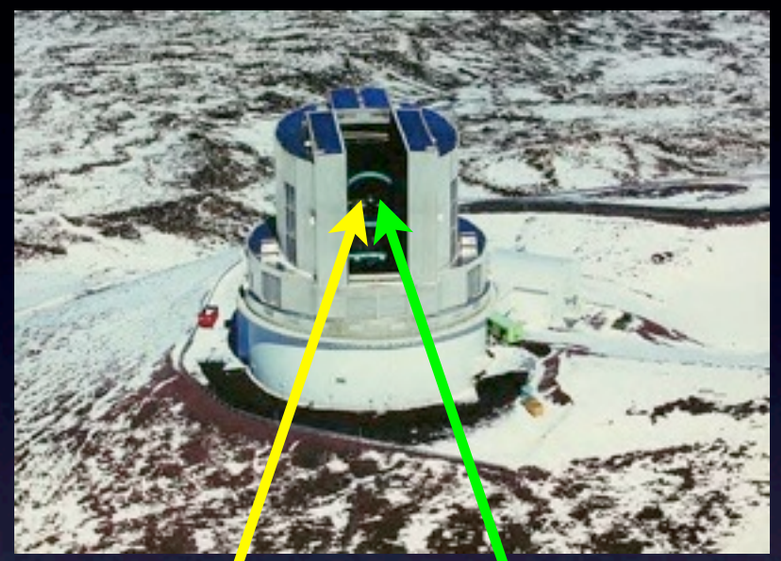
sq. dg.

呆

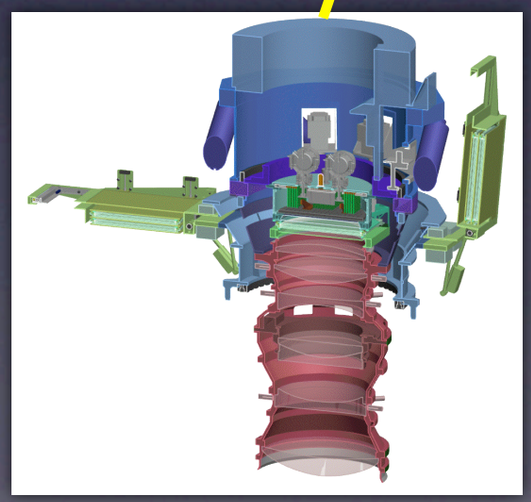
図

ジングと分光

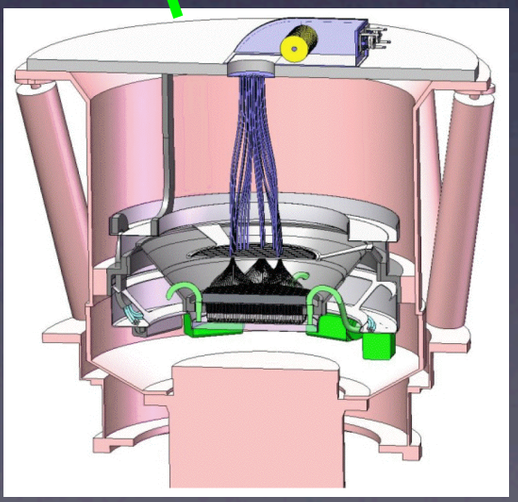
な武器！



すばる

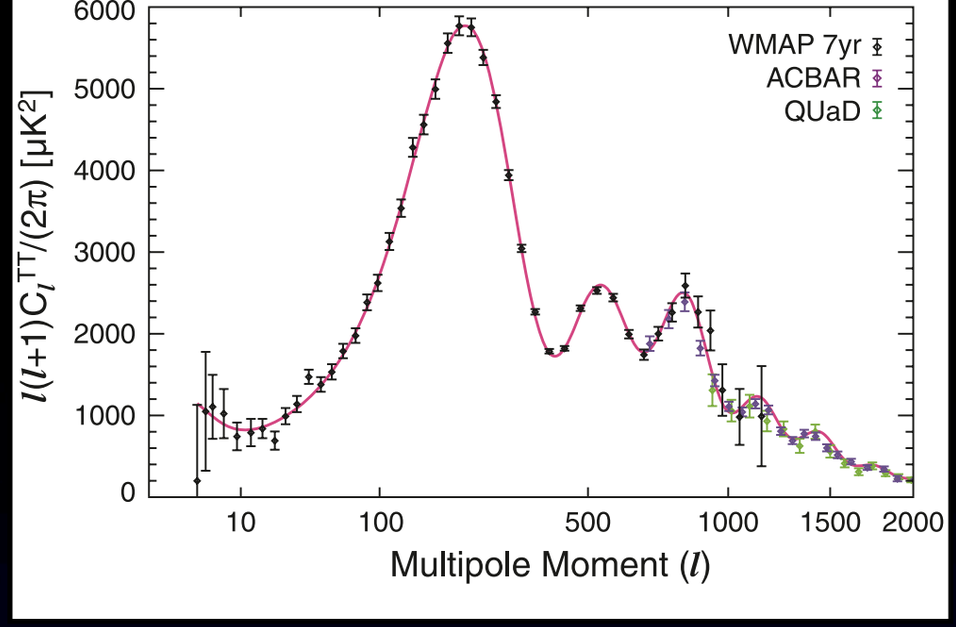


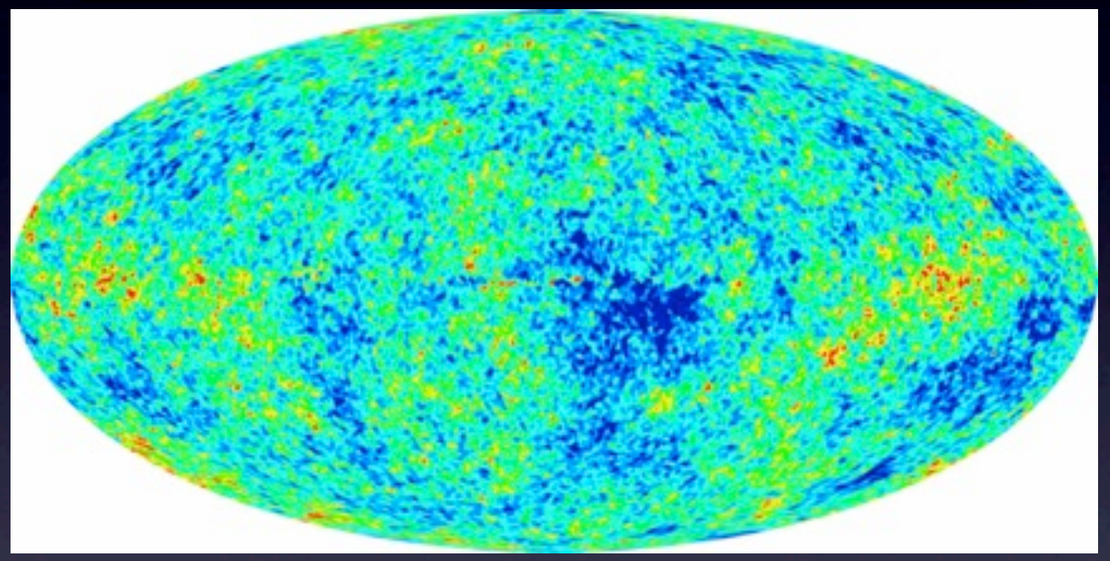
HSC



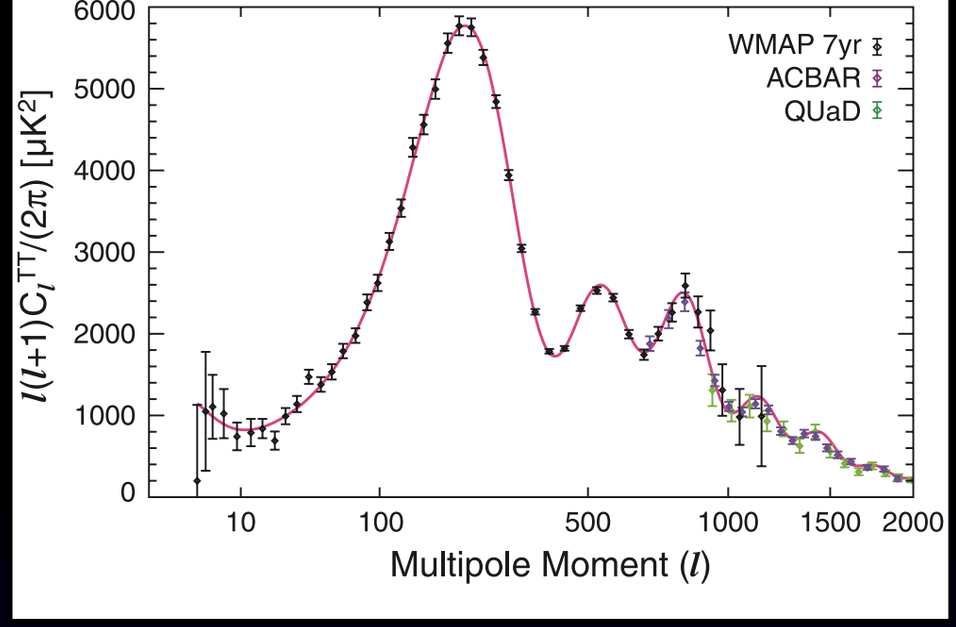
PFS

BAO


WMAP 7yr
ACBAR
QUaD
$l(l+1)C_l^{TT}/(2\pi)$ [μK²]
6000
5000
4000
3000
2000
1000
0
10
100
500
1000
1500
2000
Multipole Moment (l)



BAO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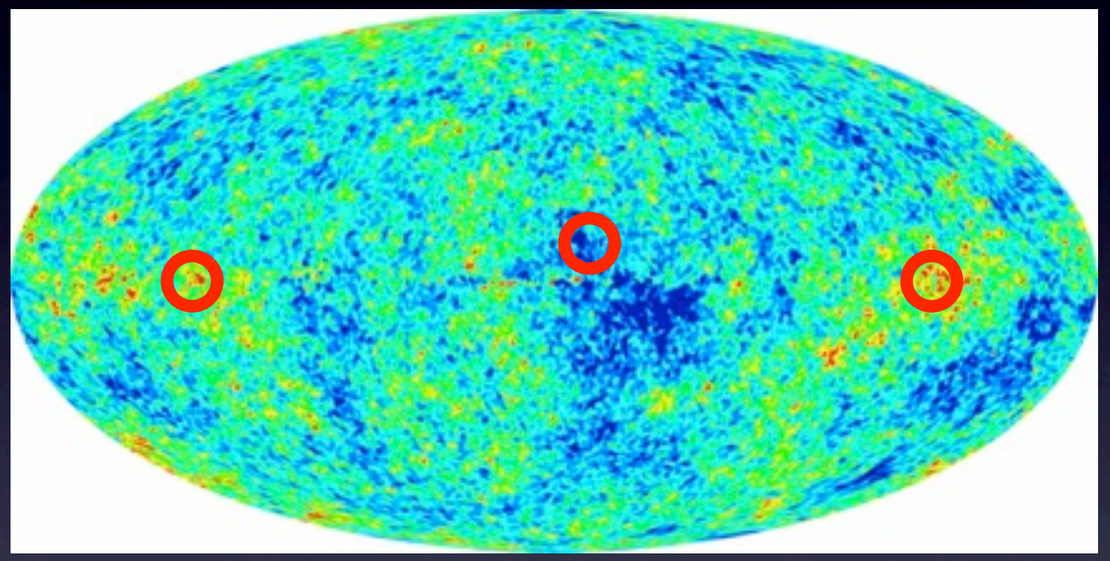
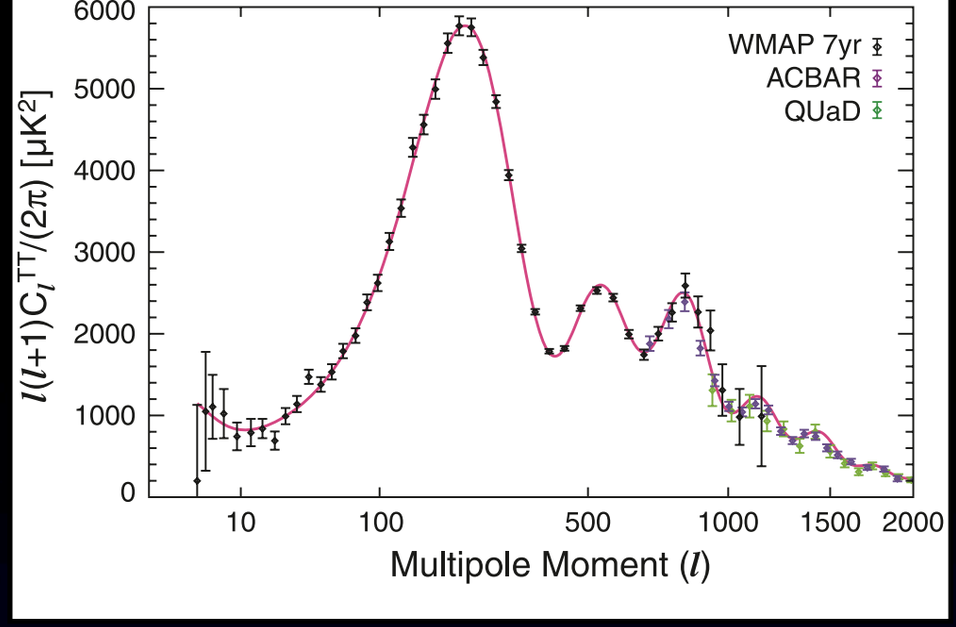


BAO


WMAP 7yr
ACBAR
QUaD
$l(l+1)C_l^{TT}/(2\pi)$ [μK²]
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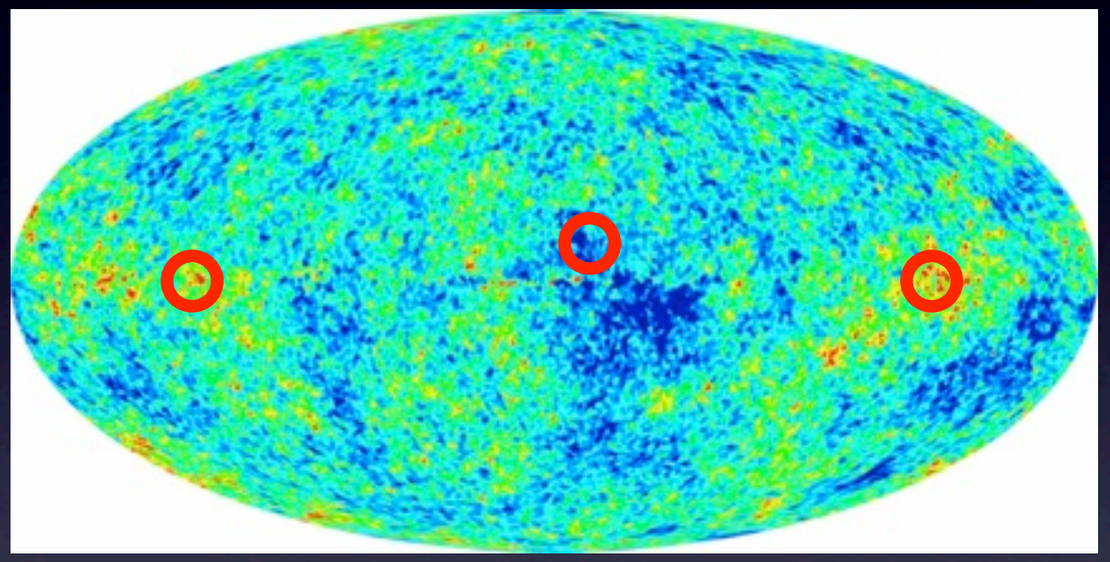
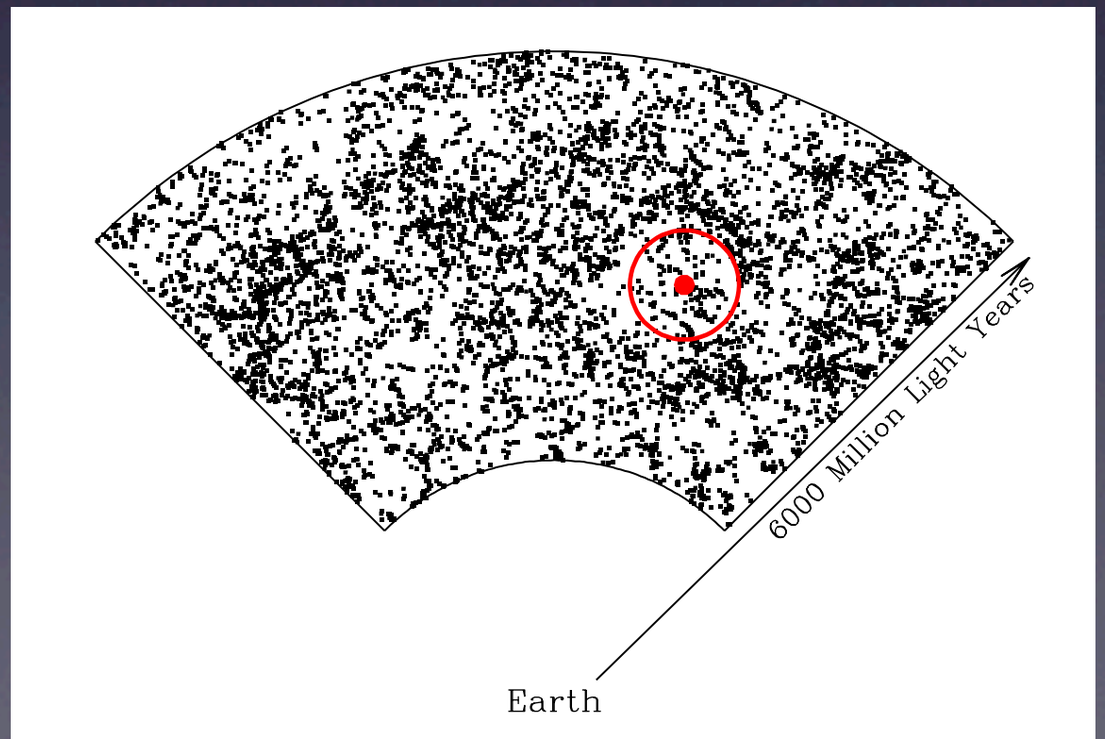
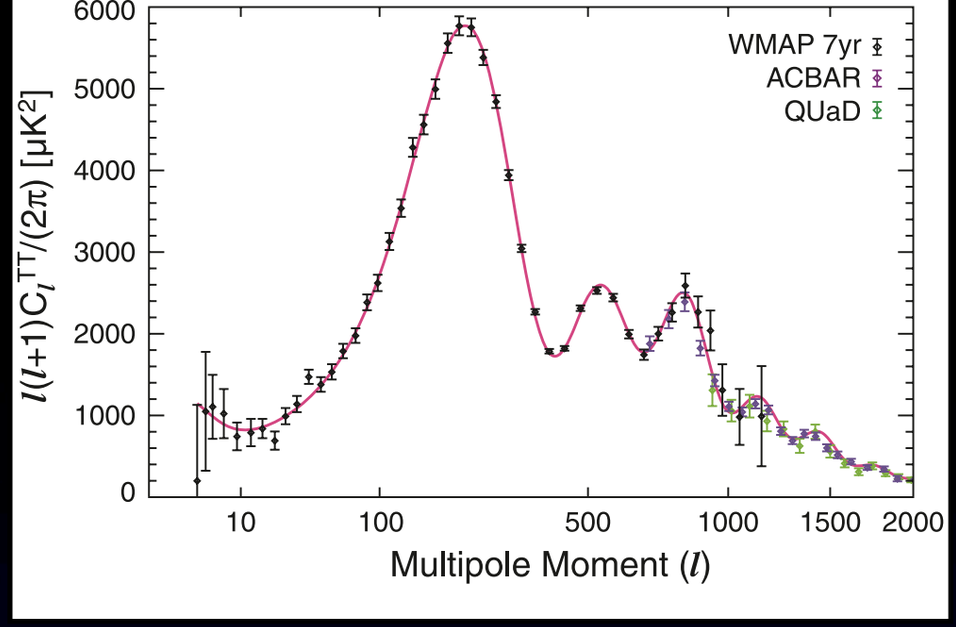
Multipole Moment (l)




6000 Million Light Years
Earth

BAO


WMAP 7yr
ACBAR
QUaD
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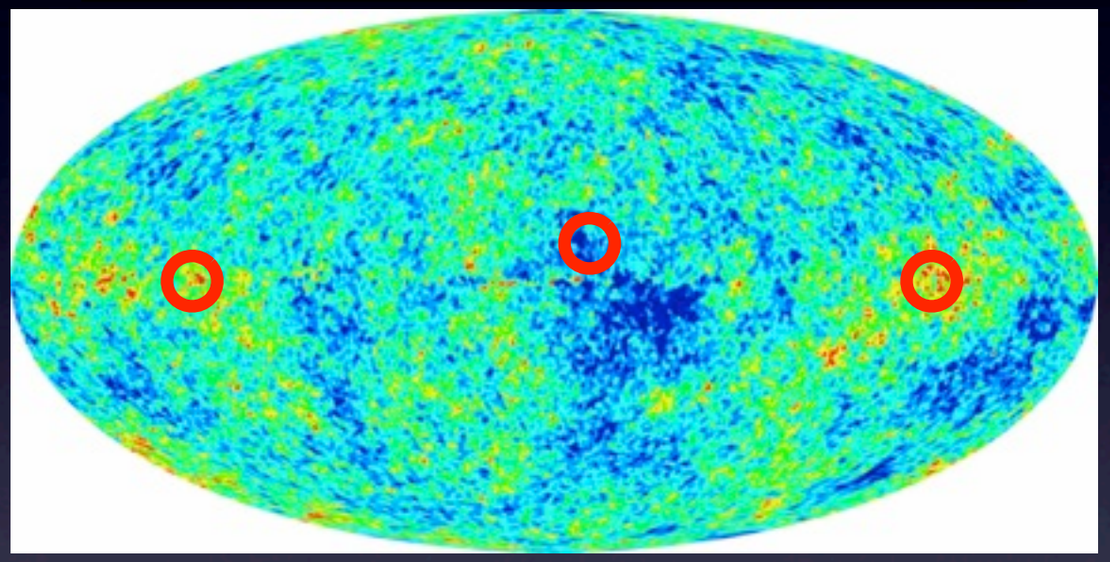
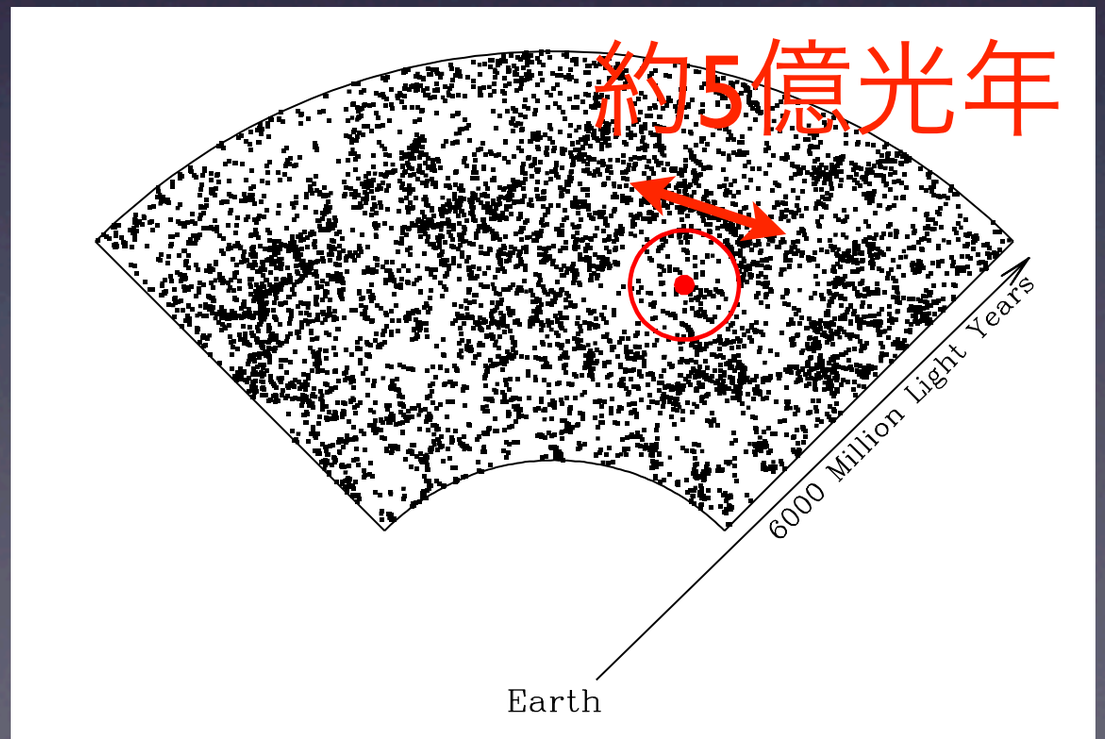
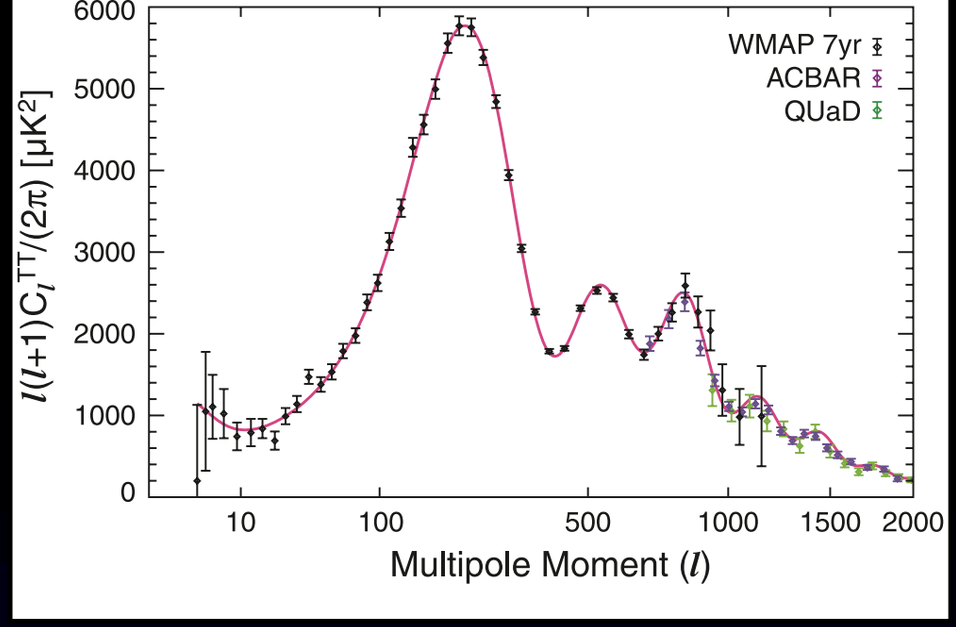
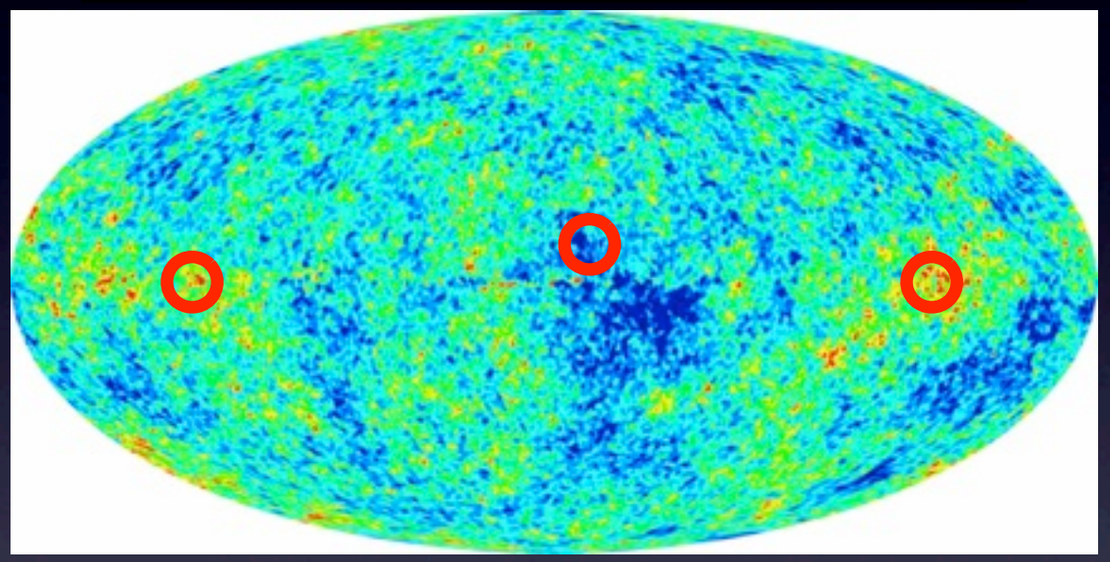


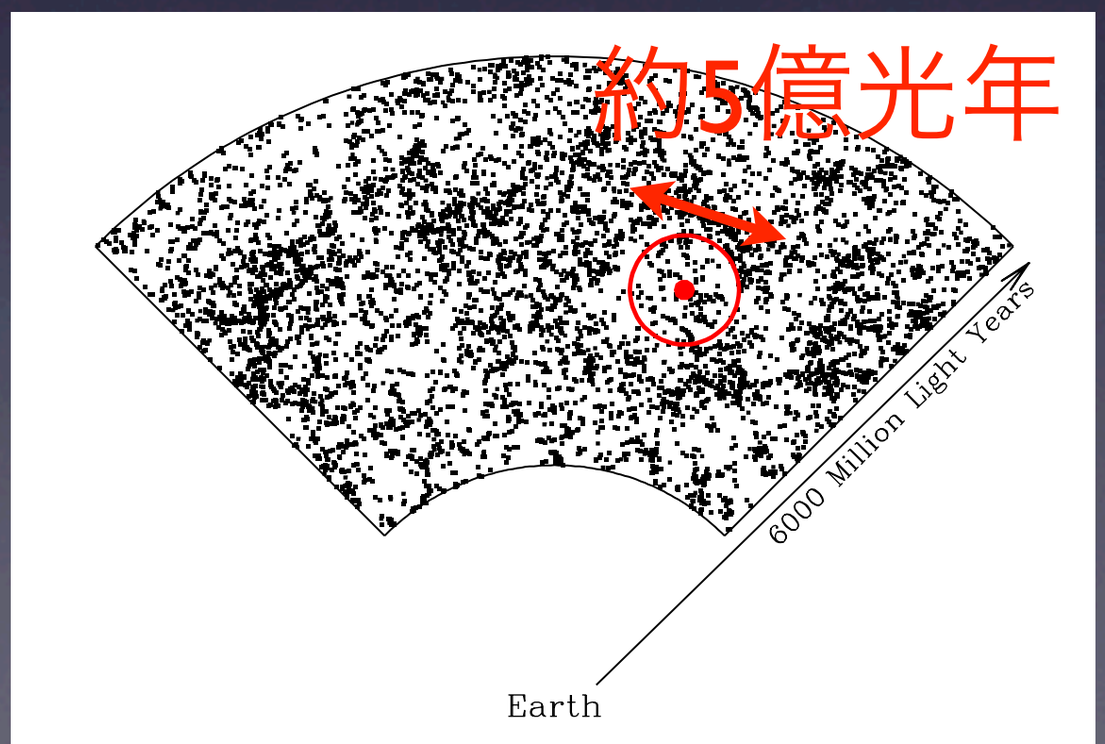

約5億光年
6000 Million Light Years
Earth

BAO

- 銀河の集まり方には特徴的な距離 (148±3 Mpc)

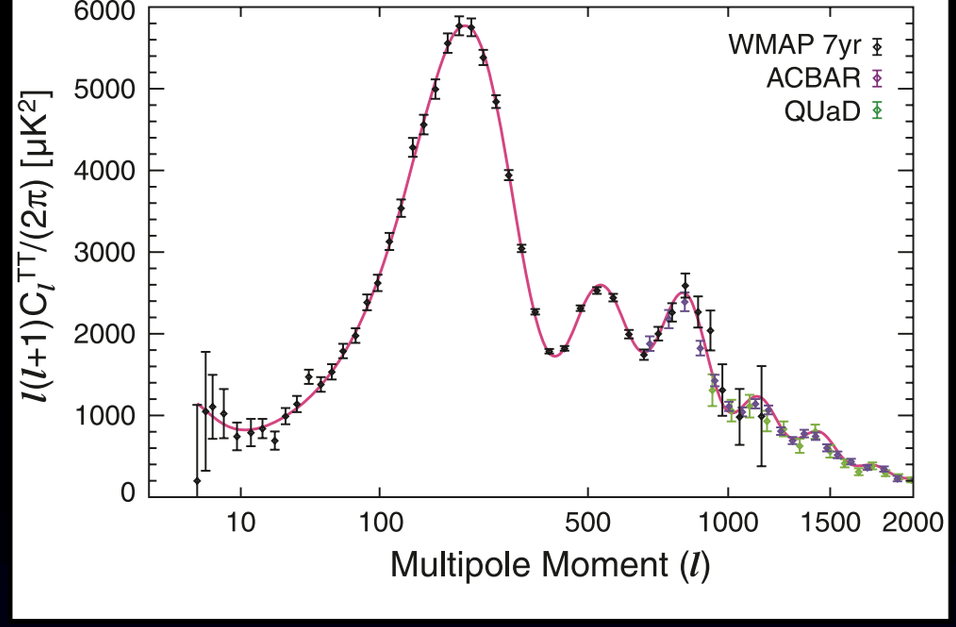


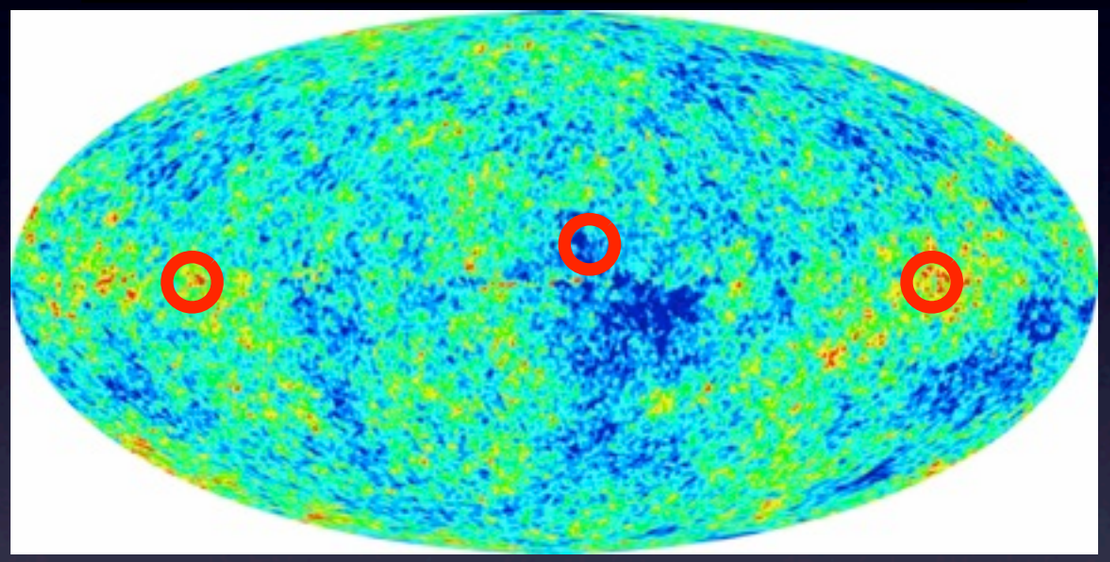


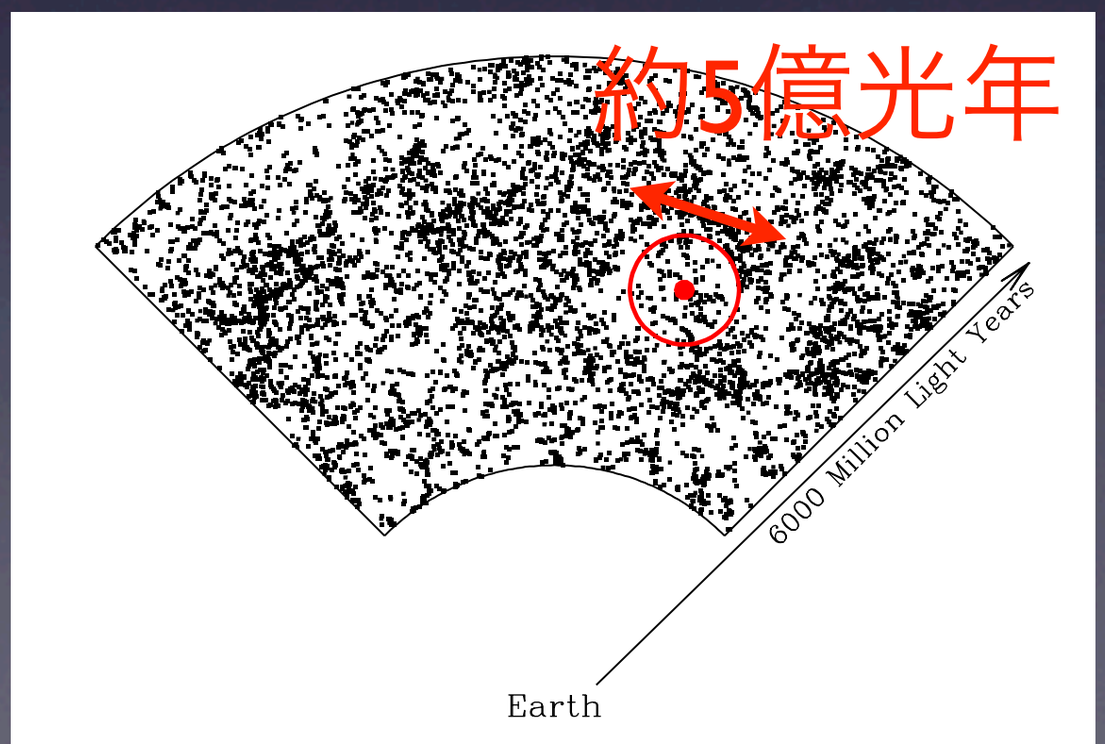


BAO

- 銀河の集まり方には特徴的な距離 (148±3 Mpc)
  「バリオン振動」







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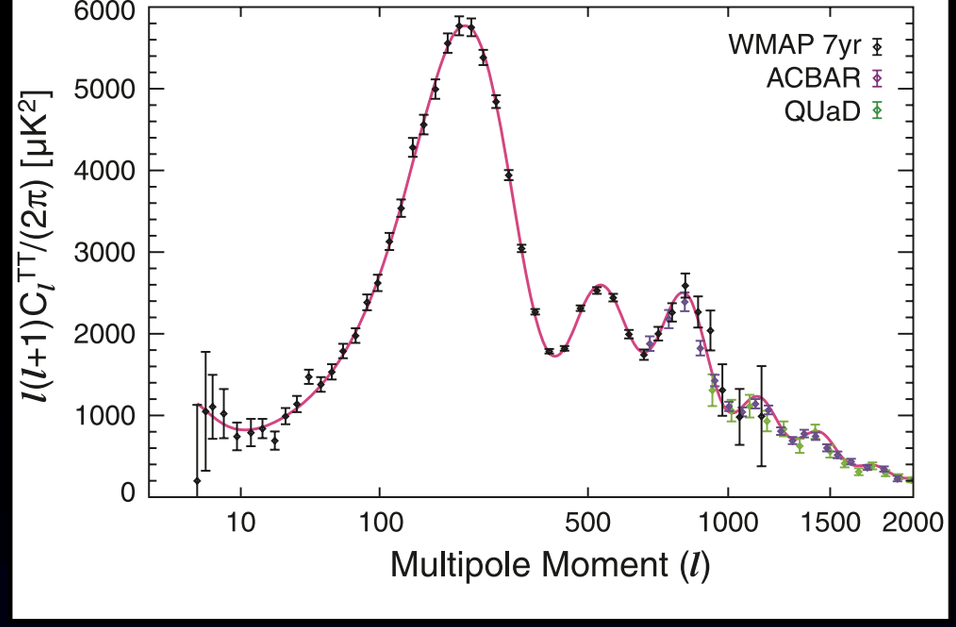

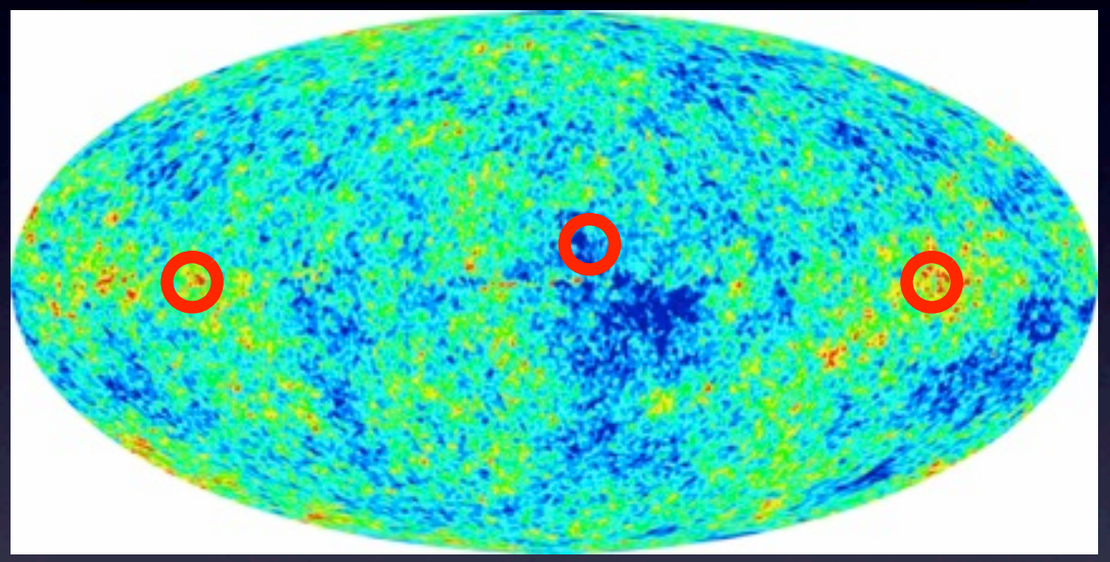

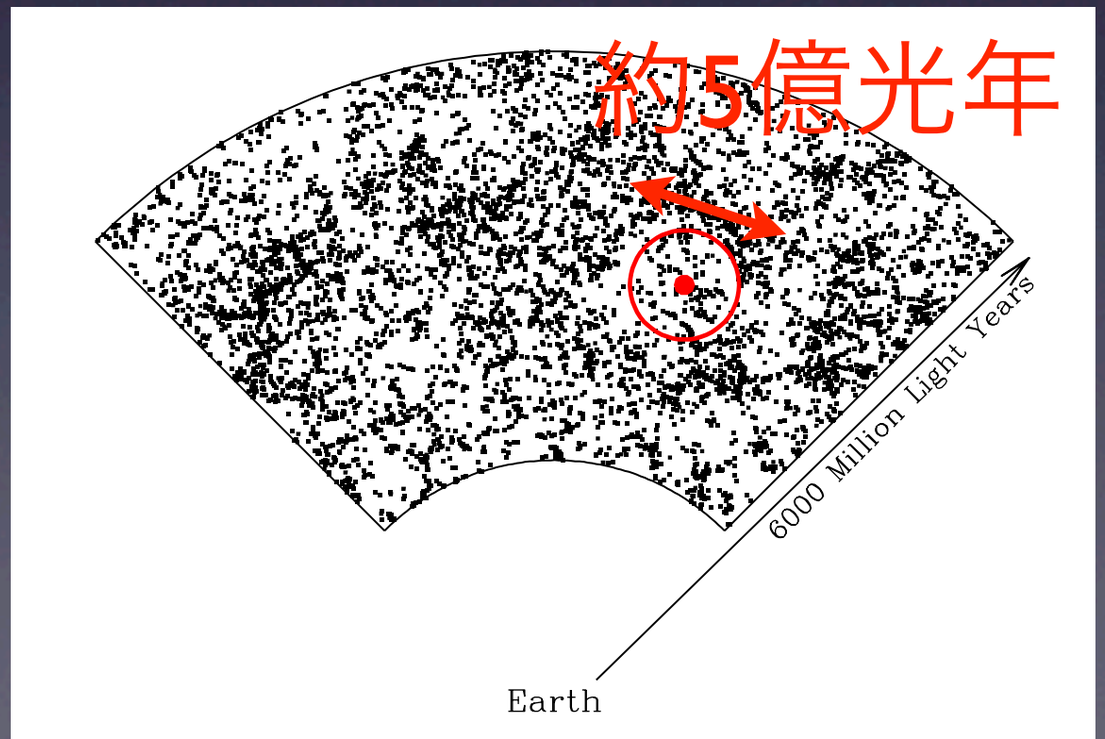

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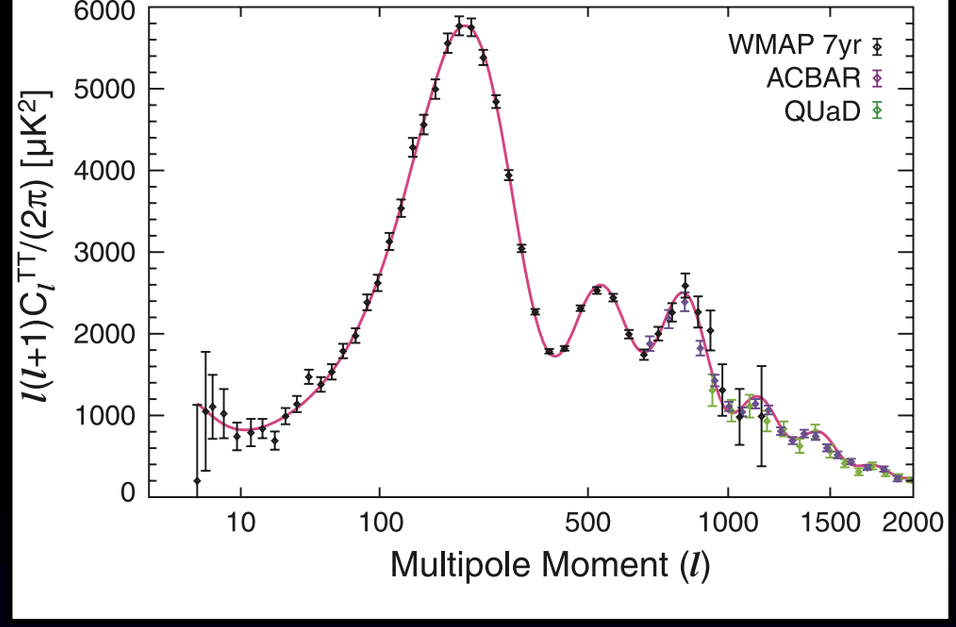
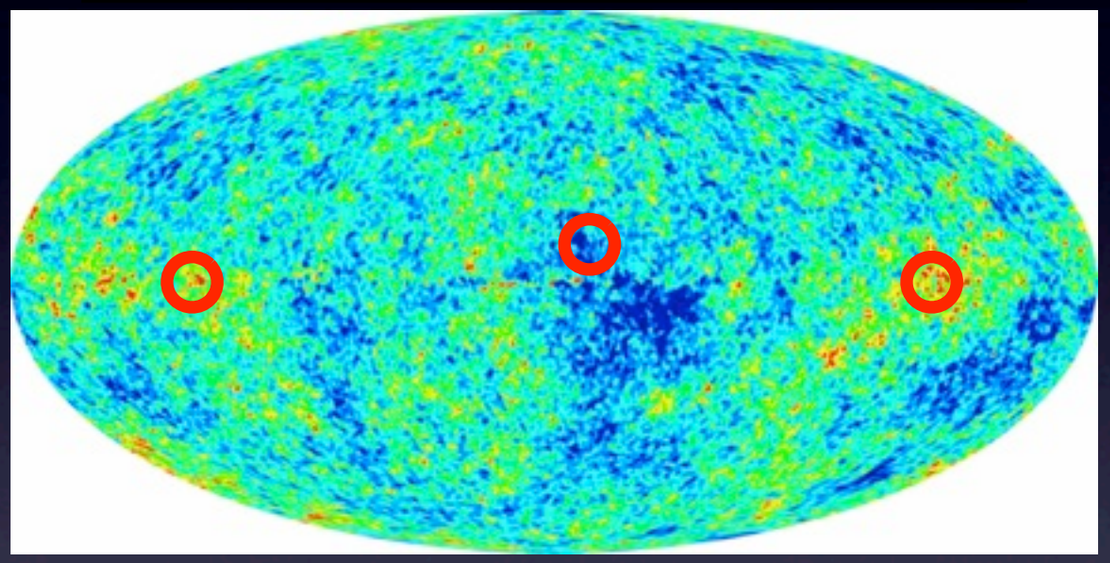
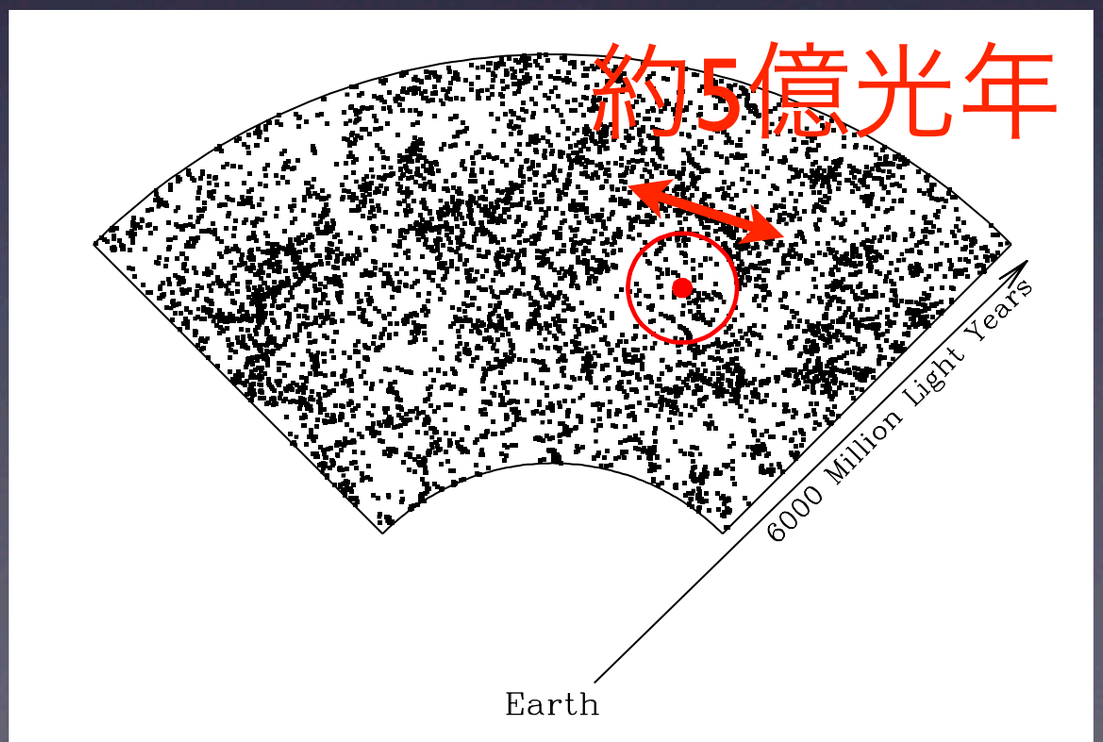
- 膨張と距離を組合わせると宇宙膨張の歴史が測れる







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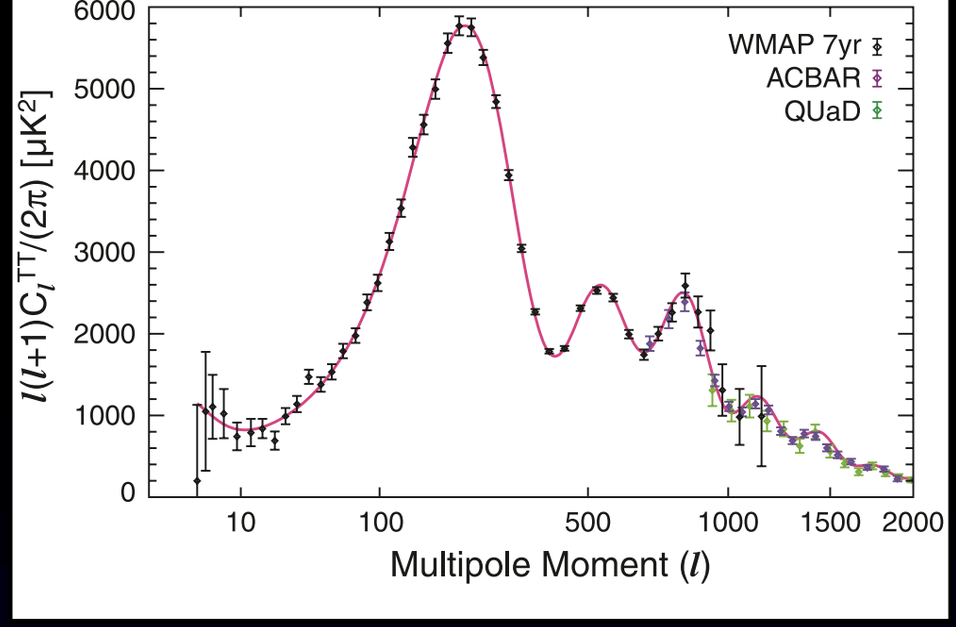

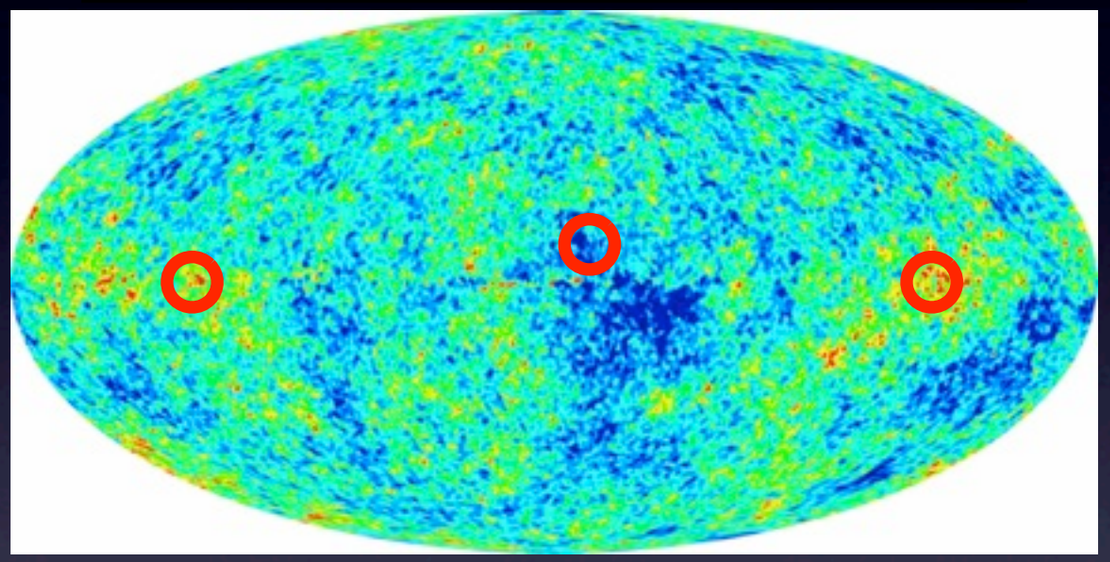

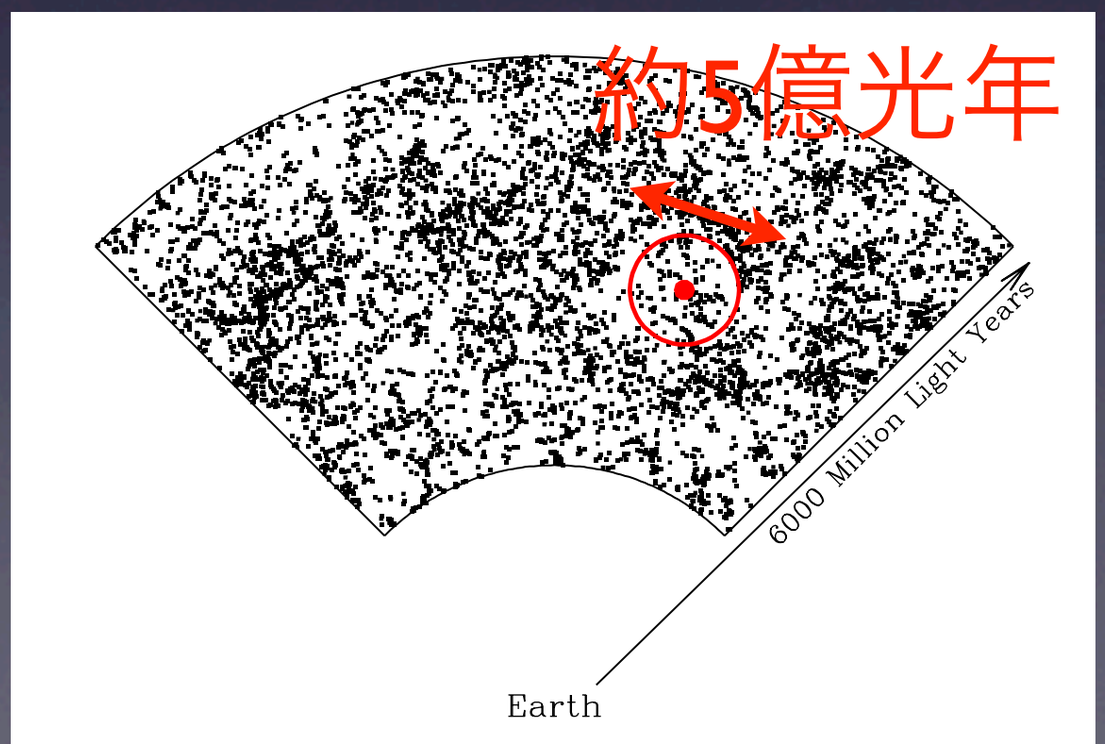

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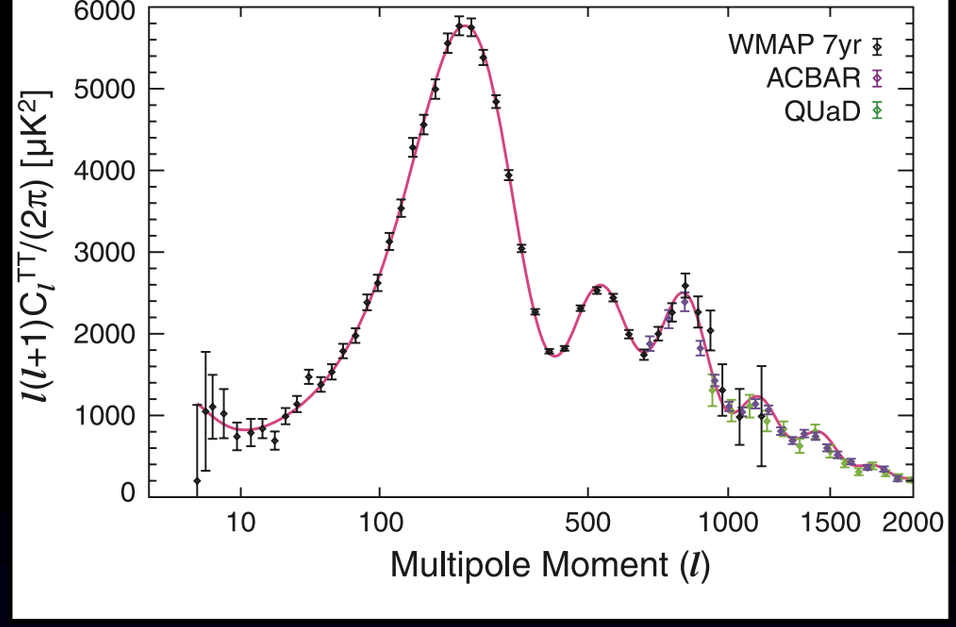
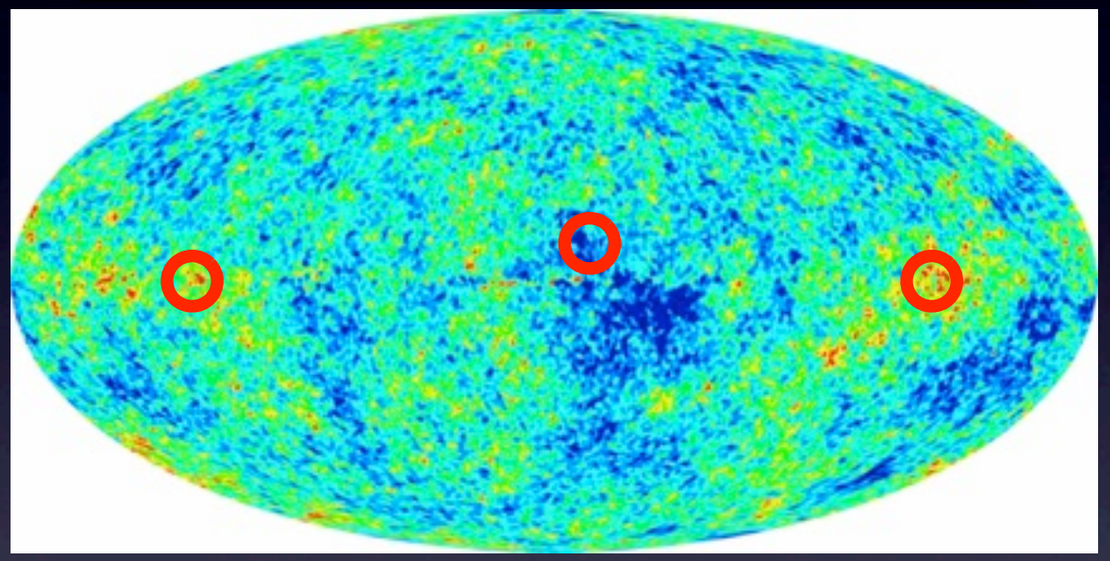
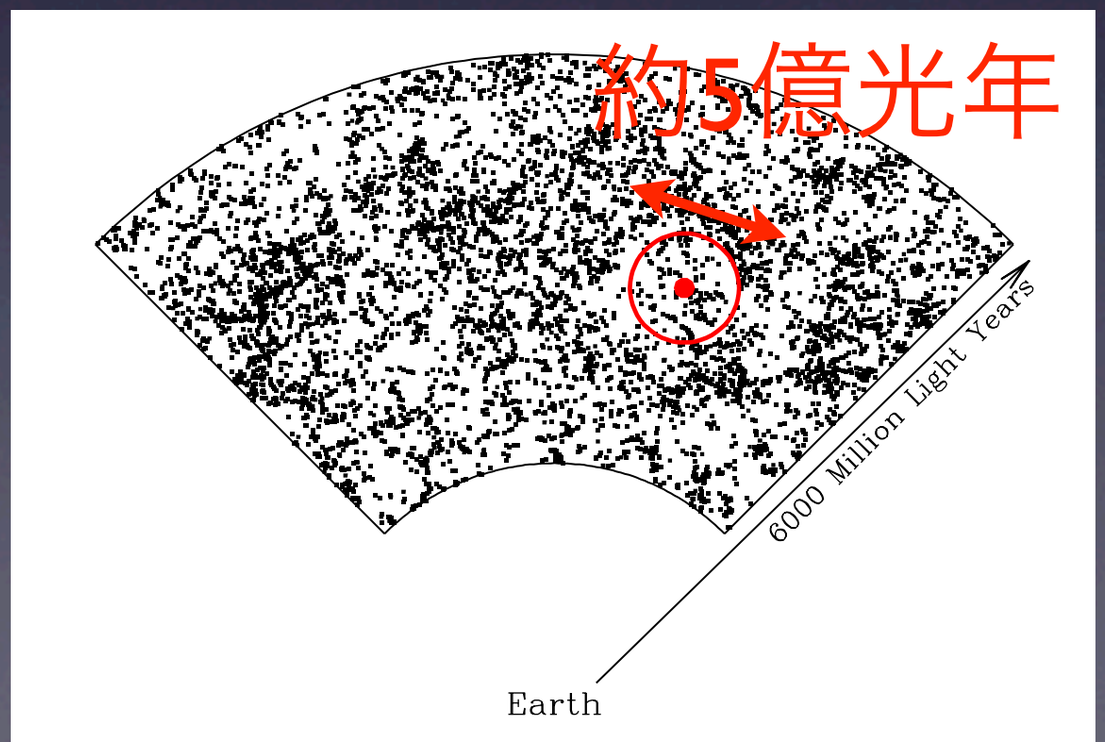
- 膨張の将来を予測







BAO

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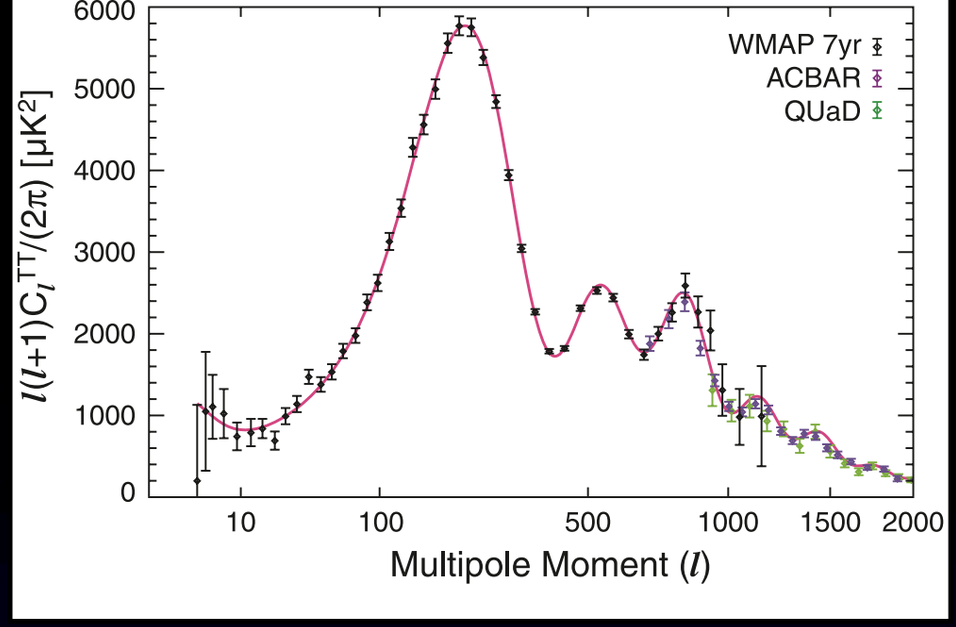
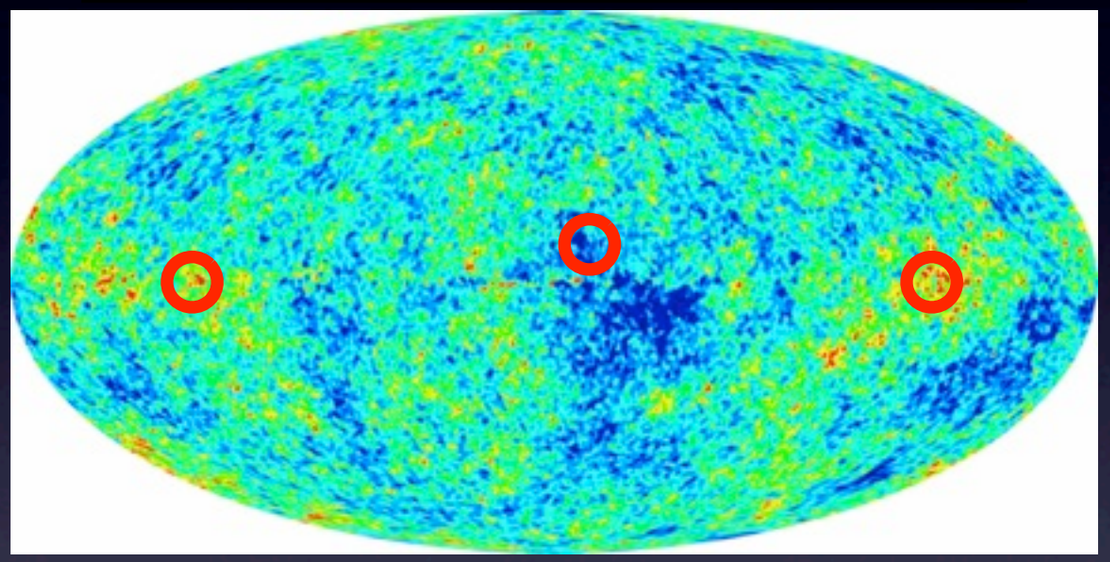
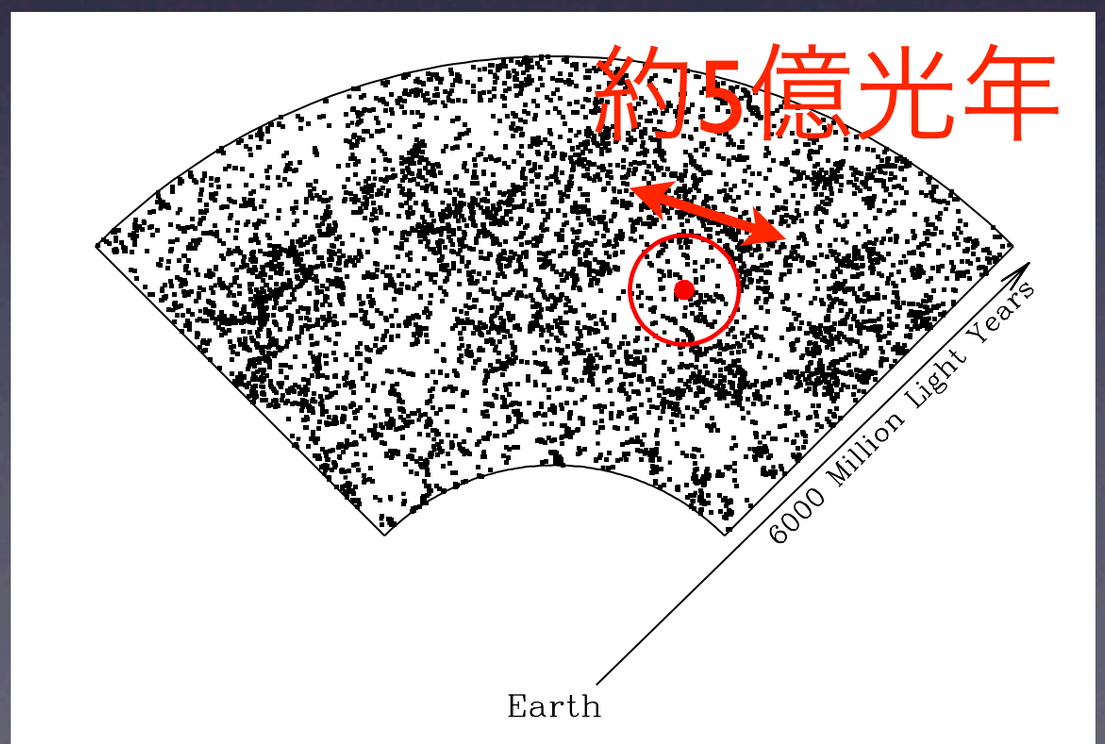
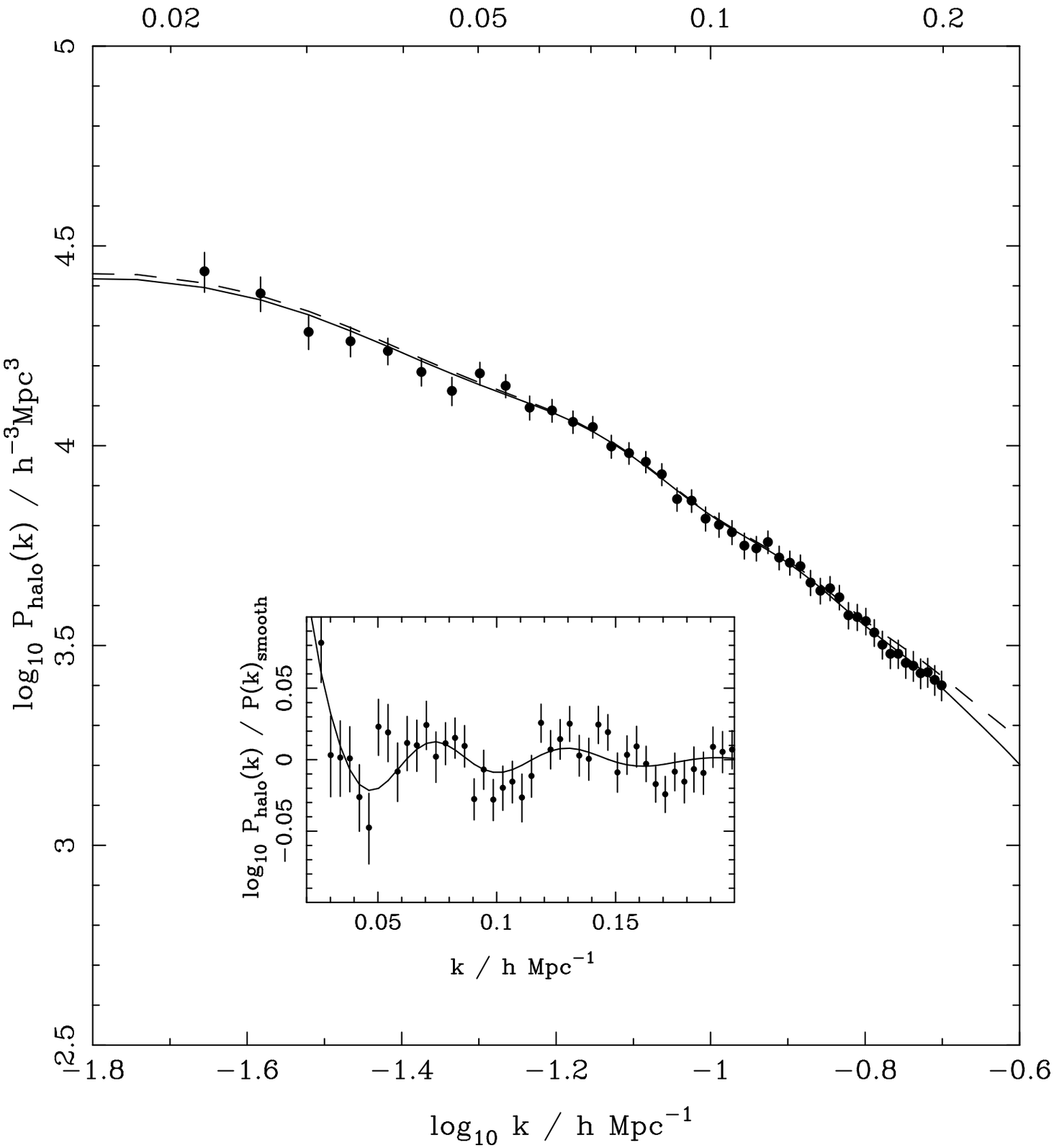
- 膨張と距離を組合わせると宇宙膨張の歴史が測れる
- 暗黒エネルギーの正体を暴く
- 膨張の将来を予測
- 宇宙に終わりがあるか？



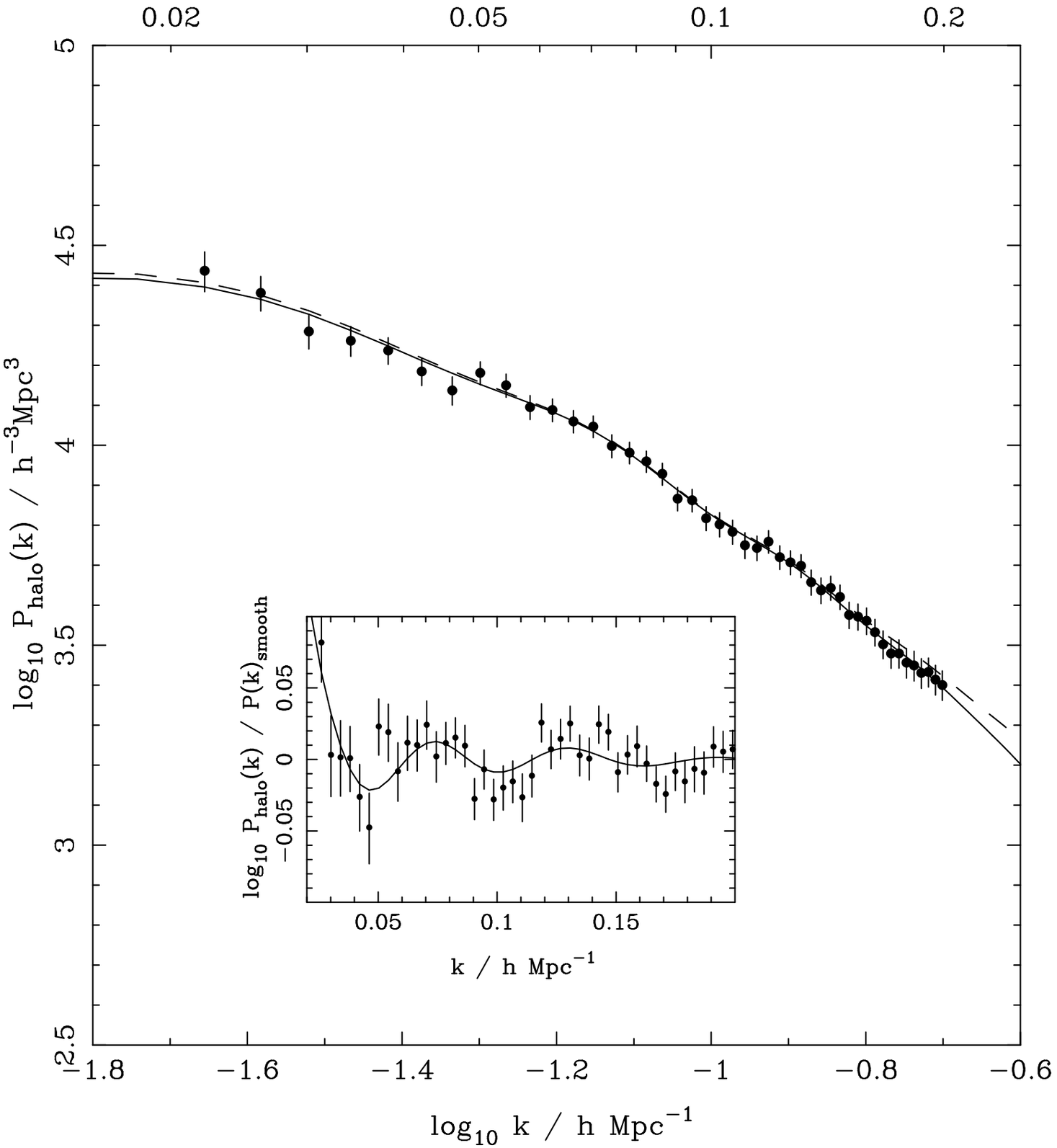


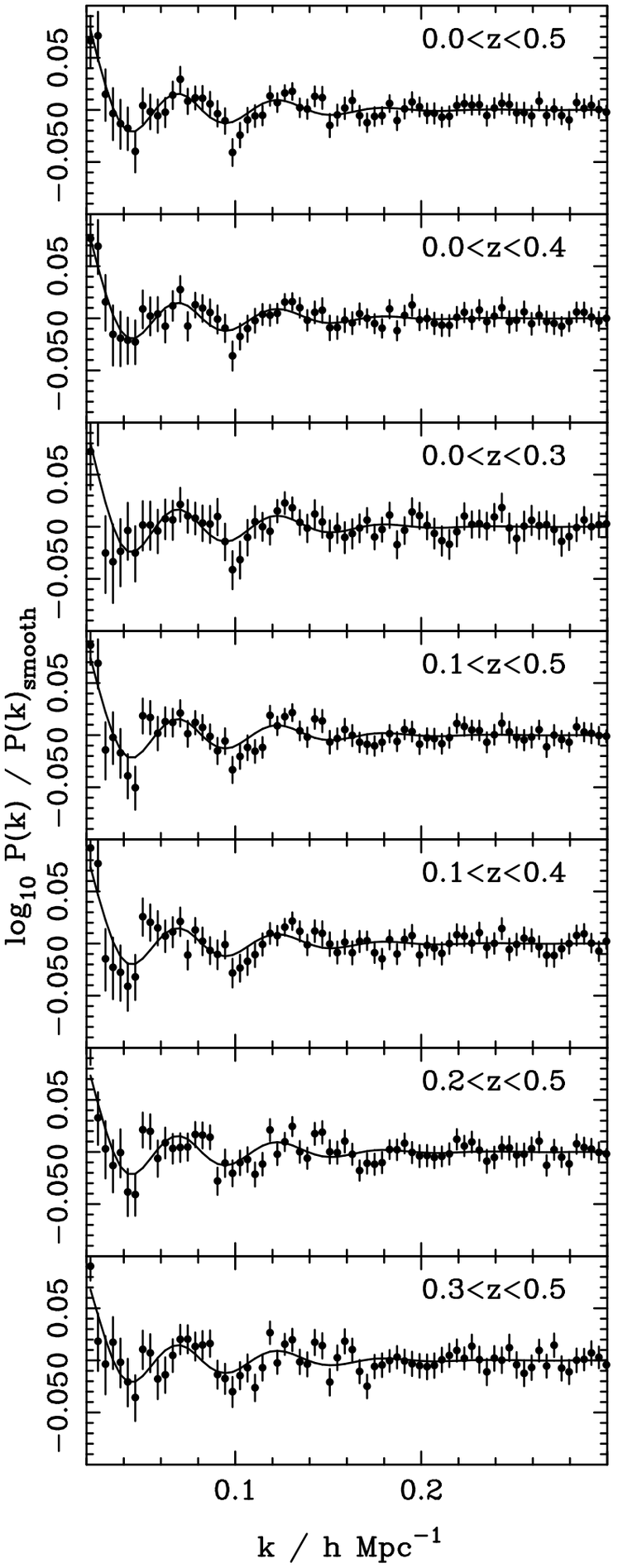


SDSS DR7


0.02
0.05
0.1
0.2
5
4.5
4
3.5
3
2.5
−1.8
−1.6
−1.4
−1.2
−1
−0.8
−0.6
log10 Phalo(k) / h−3Mpc3
log10 k / h Mpc−1
log10 Phalo(k) / P(k)smooth
0.05
0
−0.05
0.05
0.1
0.15
k / h Mpc−1

SDSS DR7


0.02
0.05
0.1
0.2
5
4.5
4
3.5
3
2.5
−1.8
−1.6
−1.4
−1.2
−1
−0.8
−0.6
log10 Phalo(k) / h−3Mpc3
log10 k / h Mpc−1
log10 Phalo(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
log10 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

SuMIRe

- 自民党政権の景気刺激策
- 30人に2700億円

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

- 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

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

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

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- 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

SuMIRe

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- 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

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SuMIRe

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- 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

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

国立天文台 NAOJ

中央研究院 ACADEMIA SINICA 1928

PRINCETON UNIVERSITY

THE UNIVERSITY OF CALIFORNIA BERKELEY 1868

IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

OBSERVATÓRIO DE SÃO PAULO

LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

ROYAL OBSERVATORY EDINBURGH

PFS collaboration

John Hopkins?

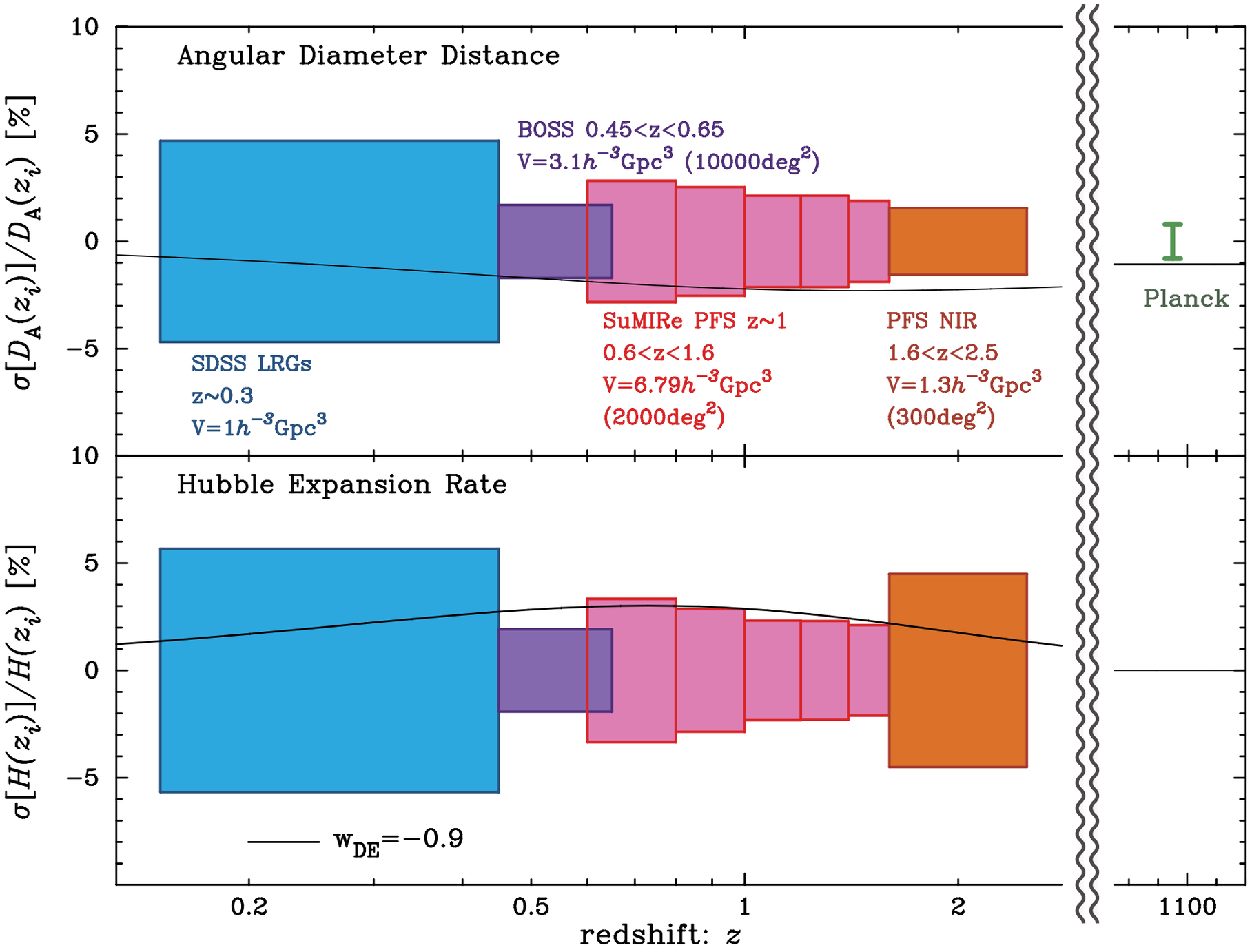

Figure 4.6: Fractional errors in measuring the angular diameter distance and the Hubble expansion rate for each redshift slices for the different BAO surveys, SDSS, BOSS and PFS. For the PFS survey we assumed survey parameters given in Table 4.3. The solid curves in each panel shows the fractional difference 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

better

FoM

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

BOSS

DES

HSC WL

PFS BAO

PFS+HSC

competitiveness

dark energy figure of merit

400

300

200

100

0

better

FoM

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

BOSS

DES

HSC WL

PFS BAO

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BOSS

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HSC WL

PFS BAO

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0

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BOSS

DES

HSC WL

PFS BAO

PFS+HSC

competitiveness

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400

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100

0

better

FoM

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

BOSS

DES

HSC WL

PFS BAO

PFS+HSC

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

2021
2020
2019
2018
2017
2016
2015
2014
2013
2012
2011
2010

WL

BAO

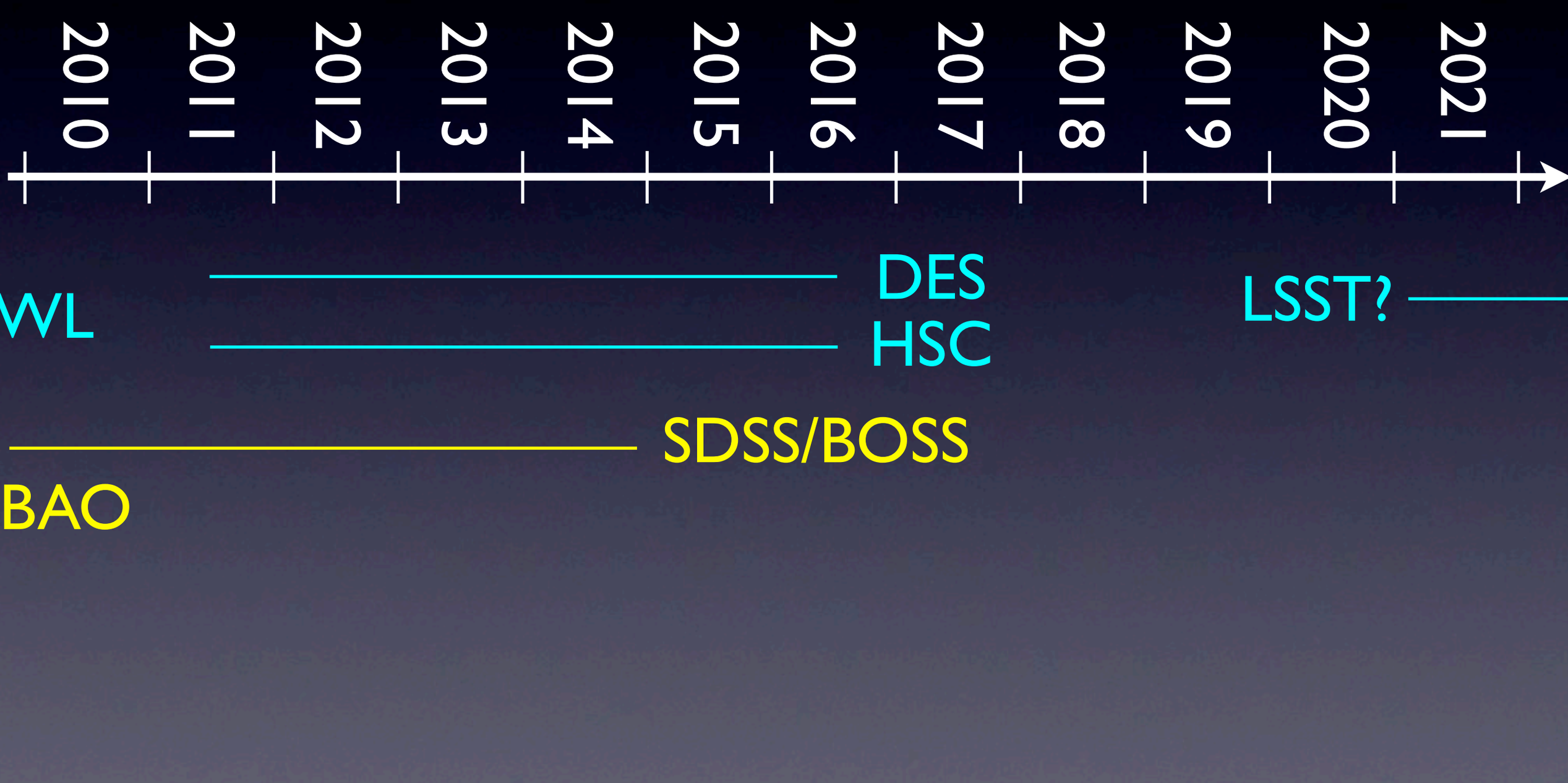
Timeline


2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
WL
DES
HSC
BAO

Timeline


2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
WL
DES
HSC
LSST?
BAO

Timeline


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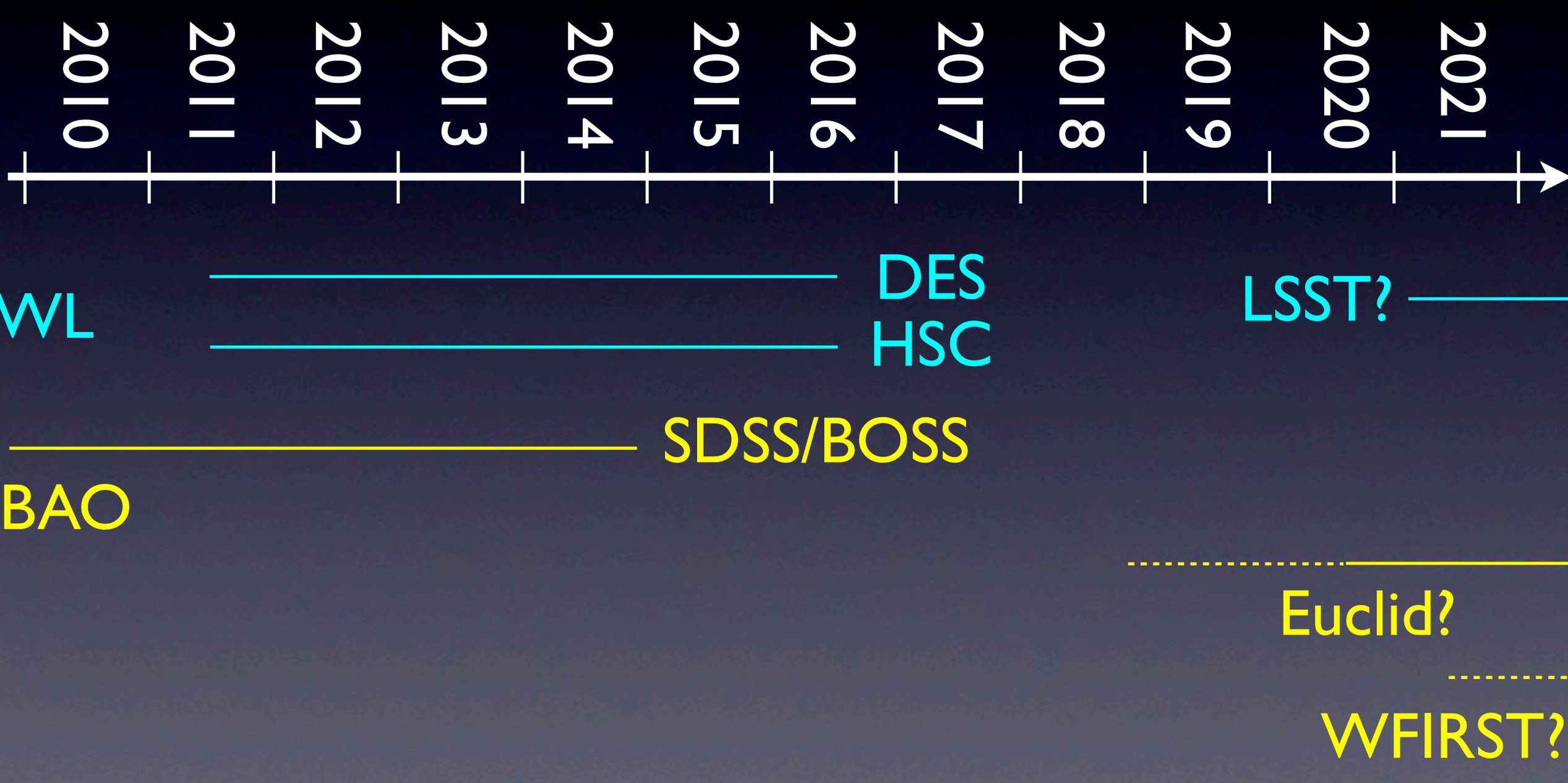
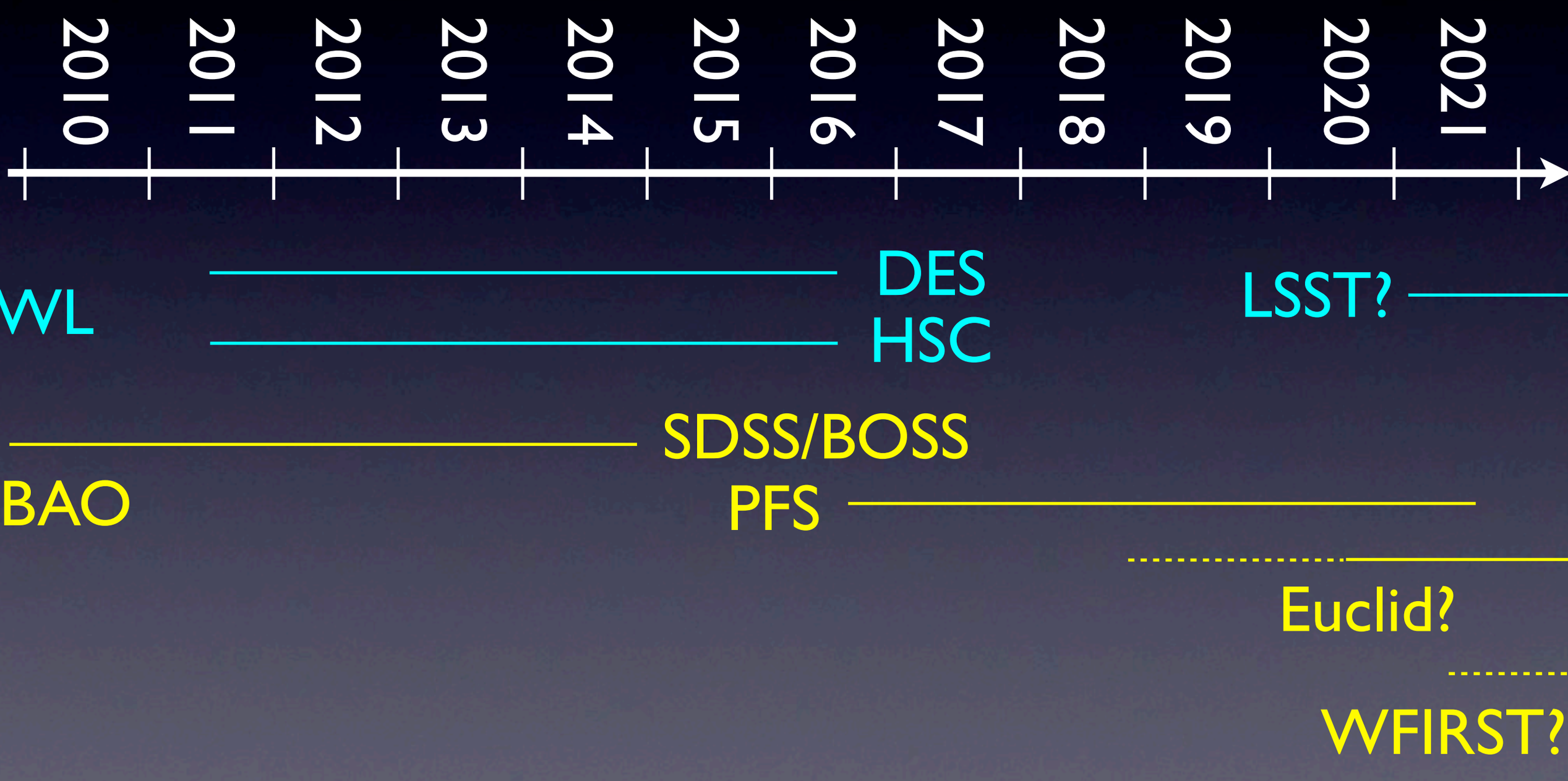
2018
2019
2020
2021
WL
DES
HSC
LSST?
SDSS/BOSS
BAO

Timeline

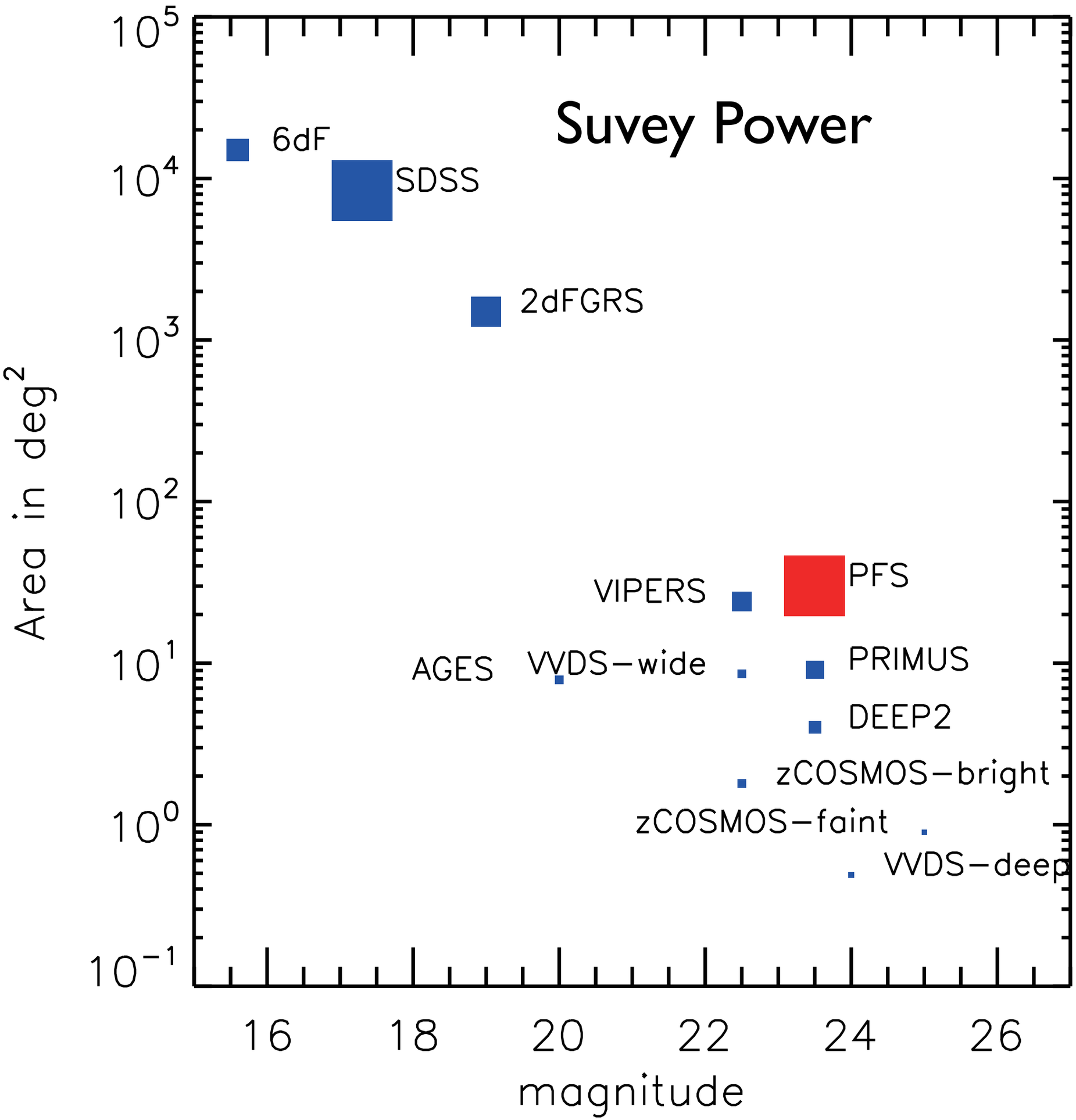

2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
WL
DES
HSC
LSST?
SDSS/BOSS
BAO
Euclid?
WFIRST?

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

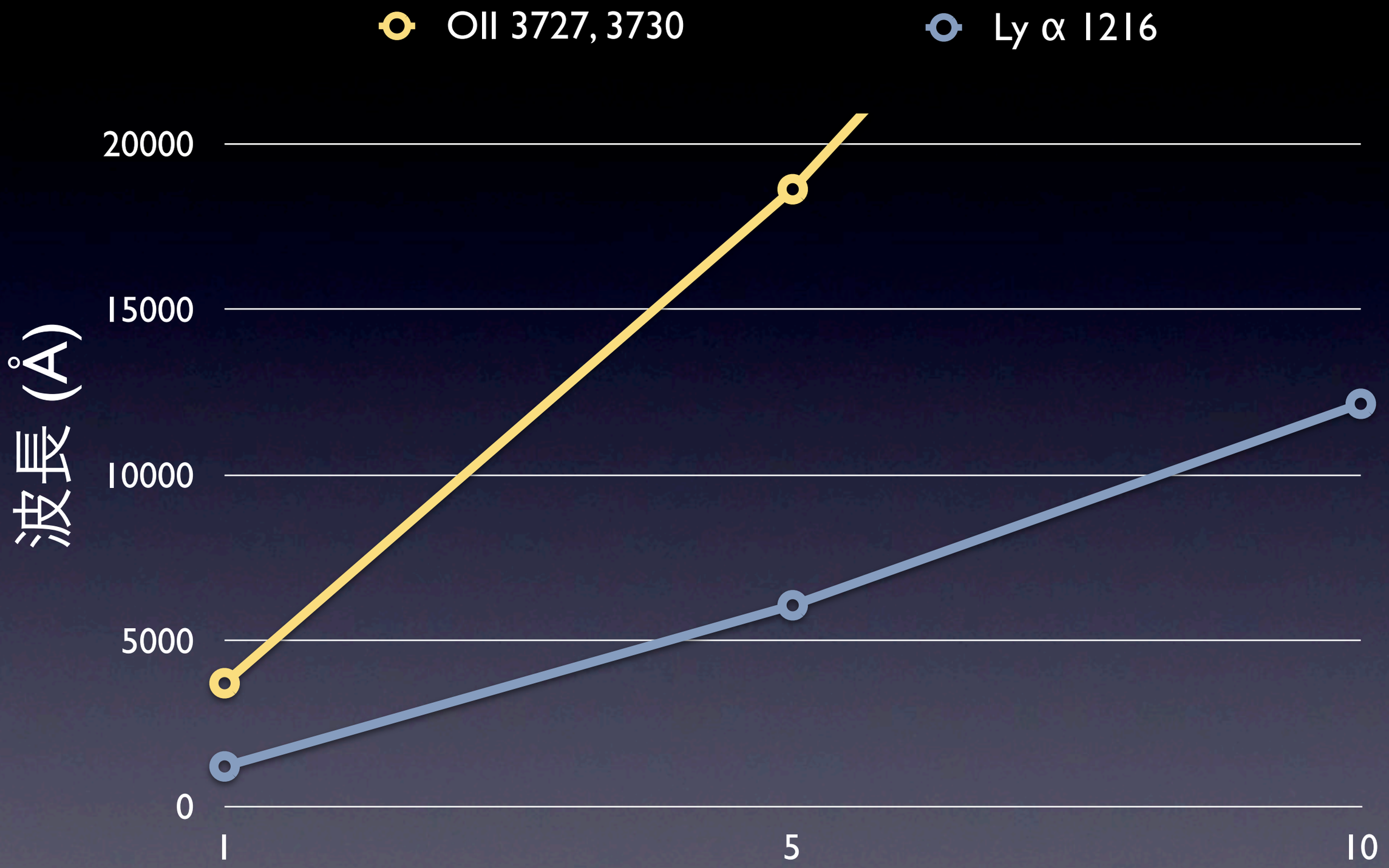
- Subaru is a user facility
- we have to apply for telescope night allocation
- expanded the science scope
  - galaxy evolution
  - galactic archeology
  - added near IR arm to the spectrograph
- other impacts on high-energy physics
  - map out 3D dark matter distribution
  - neutrino mass $\sigma(\Sigma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


Suvey Power
6dF
SDSS
2dFGRS
VIPERS
PFS
AGES
VVDS−wide
PRIMUS
DEEP2
zCOSMOS−bright
zCOSMOS−faint
VVDS−deep
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

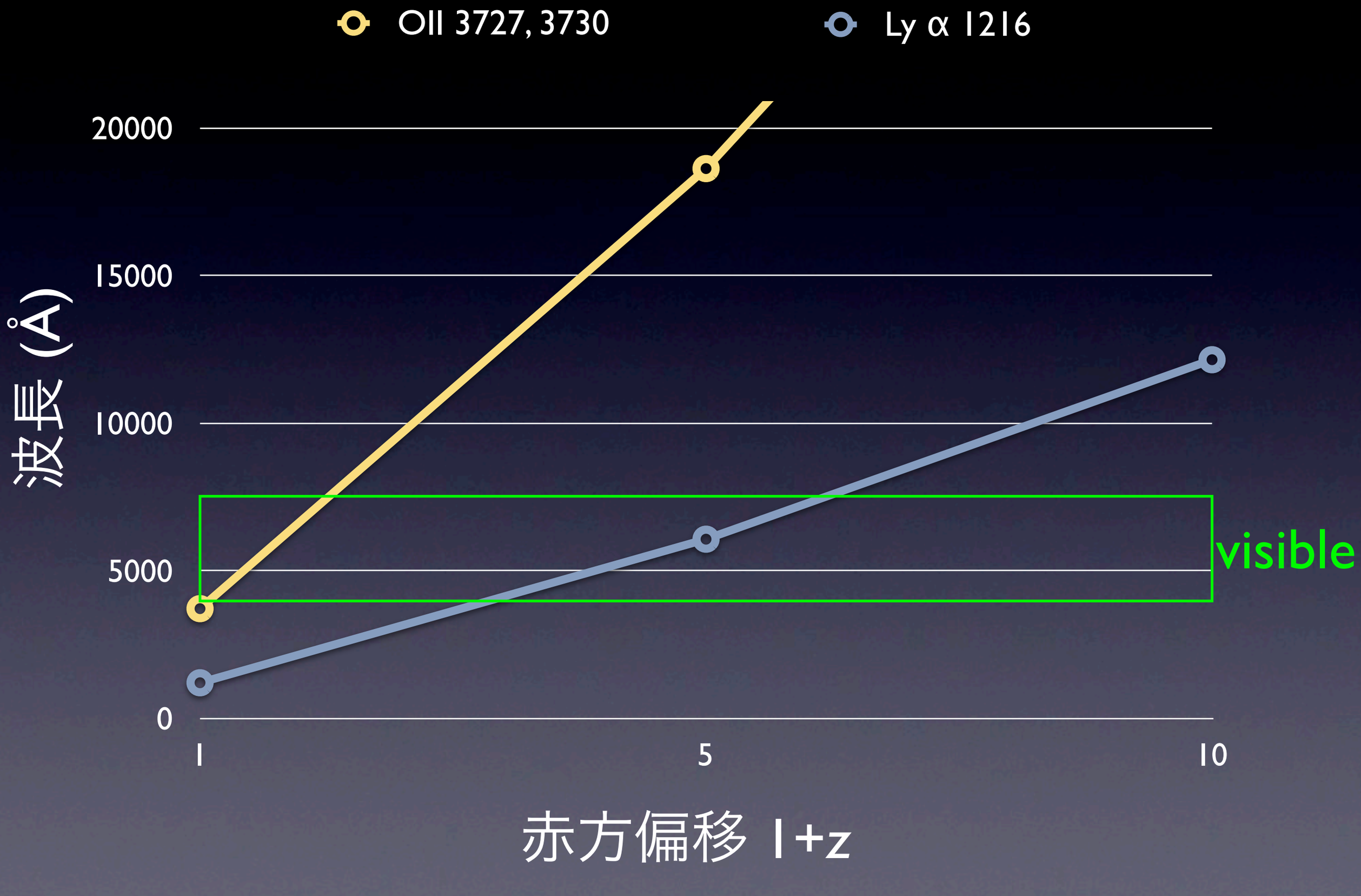
仕様

- 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

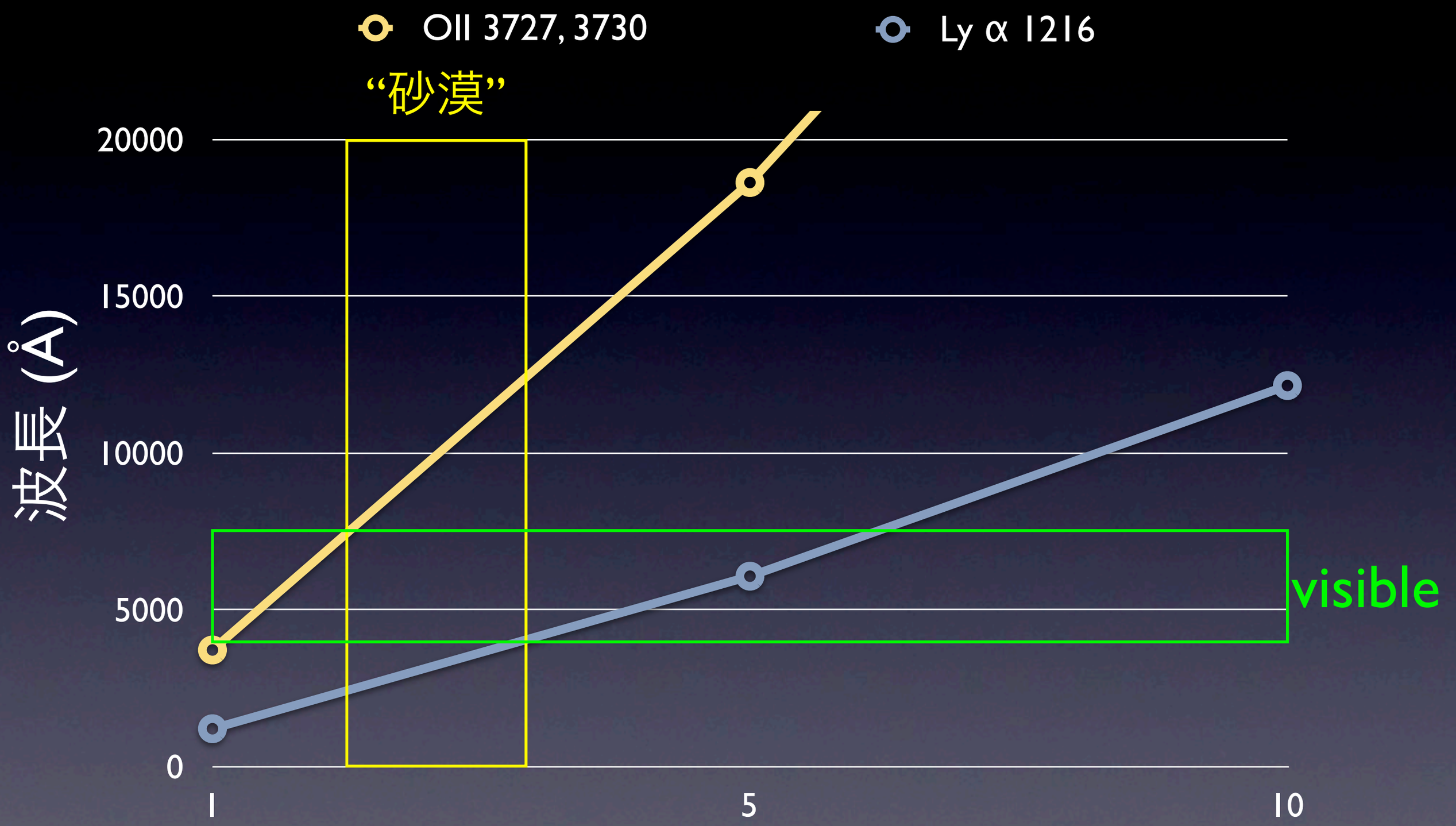
ギャップのない銀河サーベイ



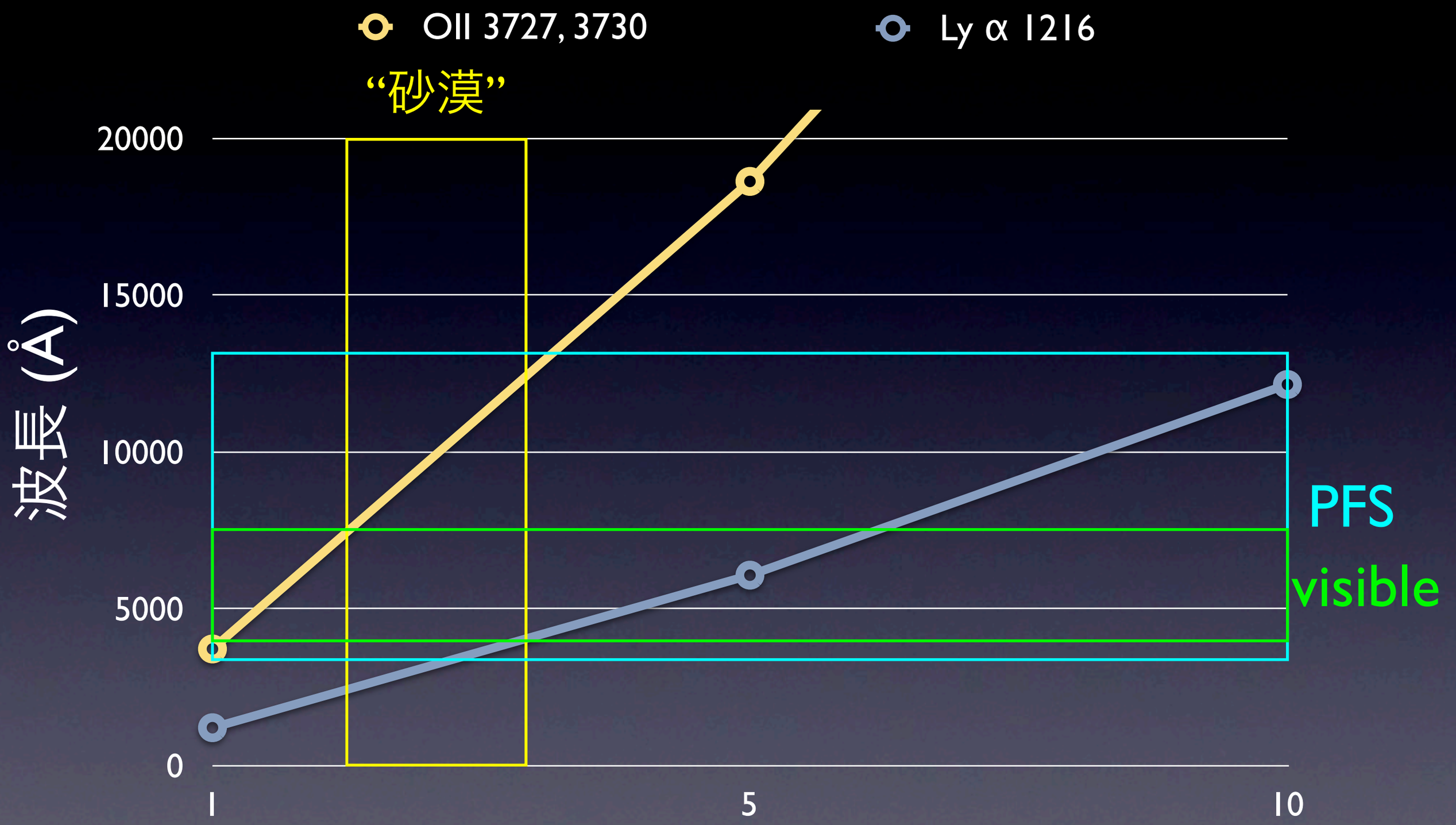
ギャップのない銀河サーベイ



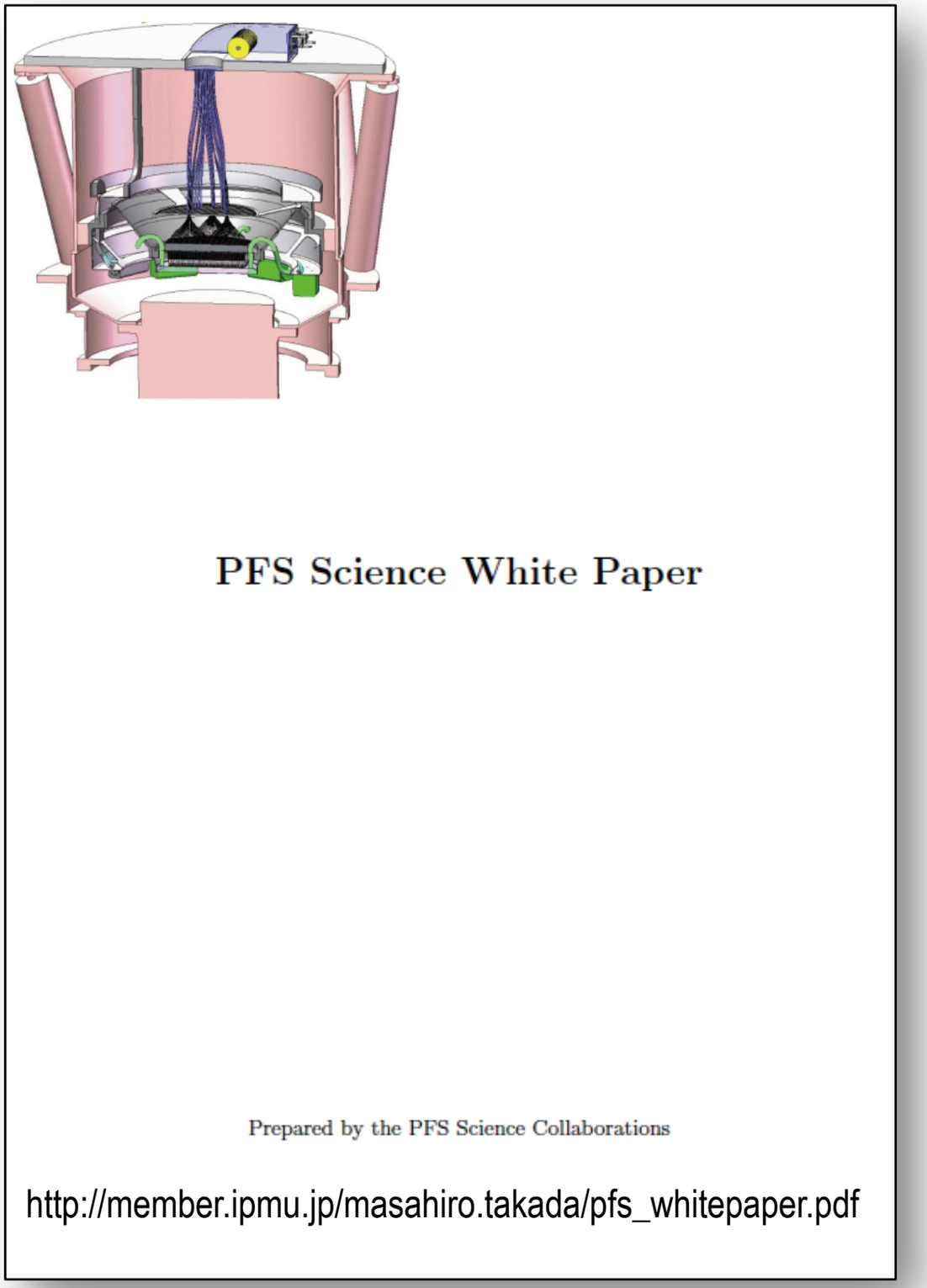
ギャップのない銀河サーベイ



ギャップのない銀河サーベイ



PFS: endorsement from the Japanese community



- *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

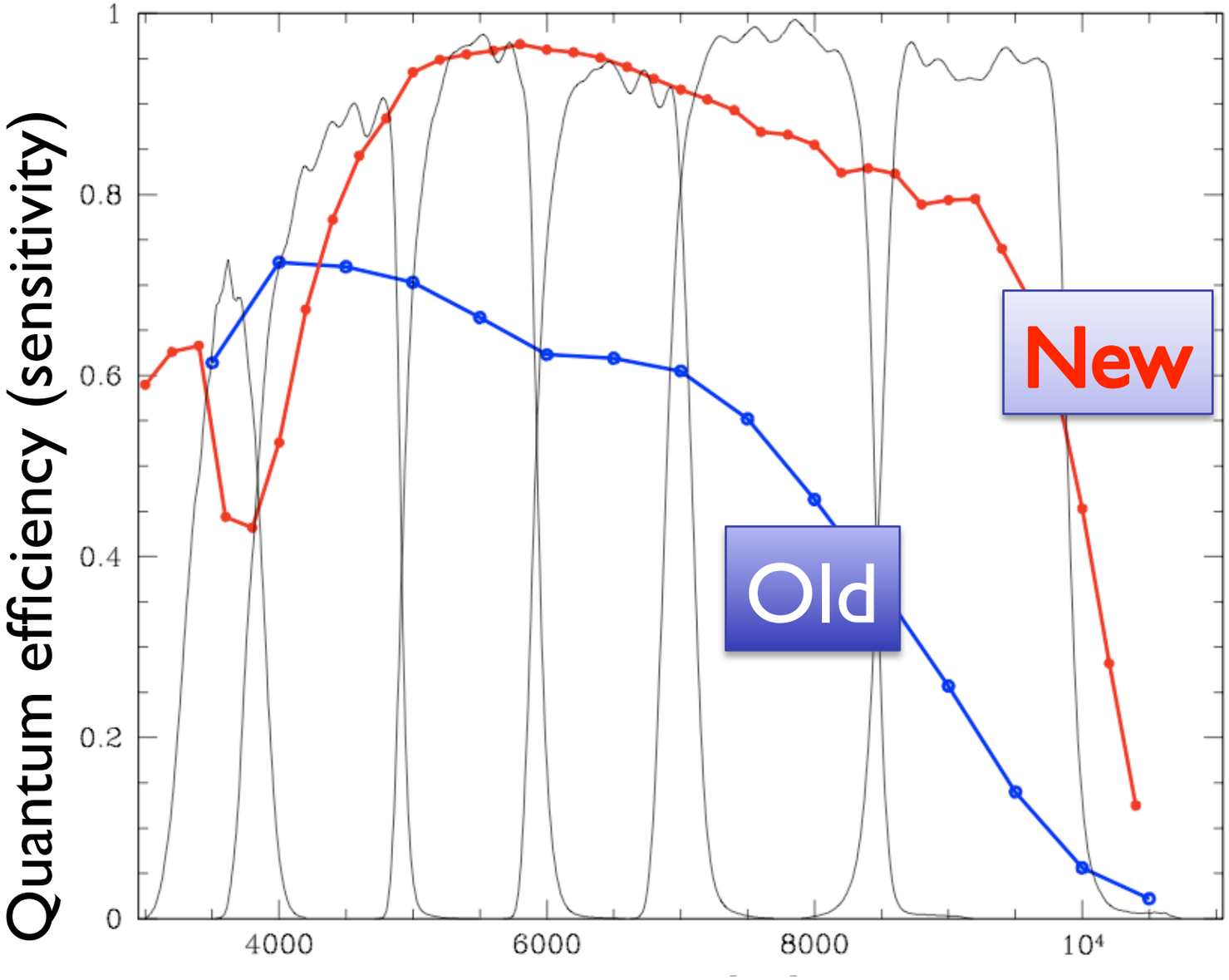
- PFS must satisfy instrument specifications agreed by the Japanese community.
- A firm management structure should be built in Japan to develop PFS, including the assignment of a Japanese project manager.
- SAC representative(s) should participate in important decision-making stages about international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

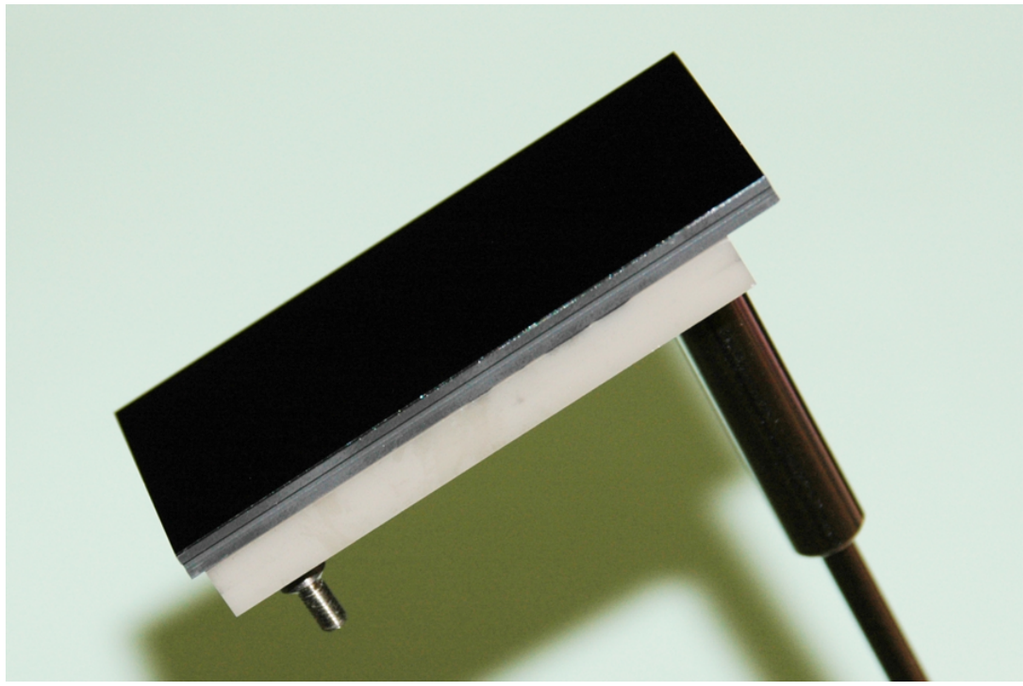
Please note the following premises for further discussion on the PFS project:

- 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.

特異装置

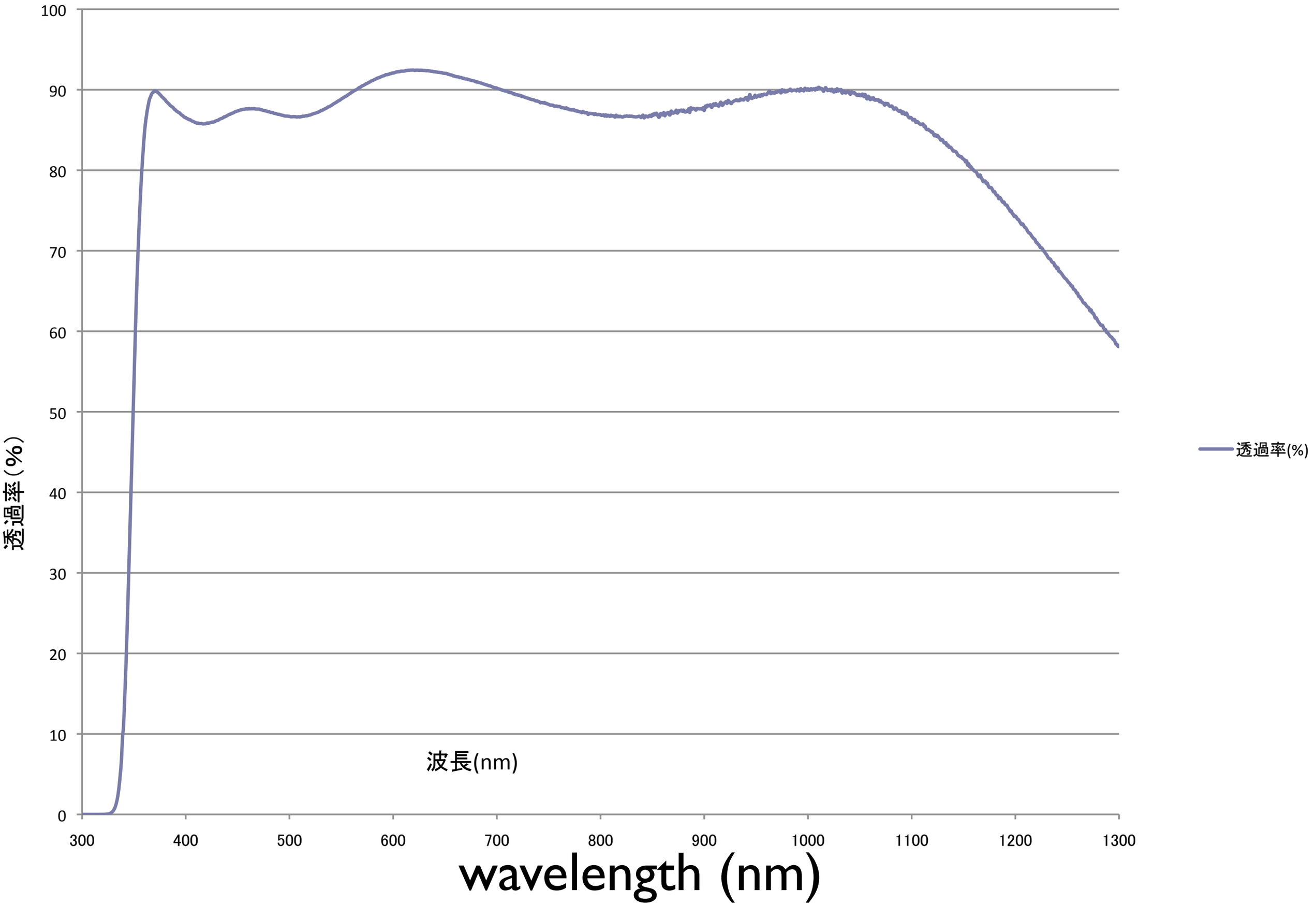
Fully depleted back-illuminated CCD （Red sensitive）
Hamamatsu Photonics



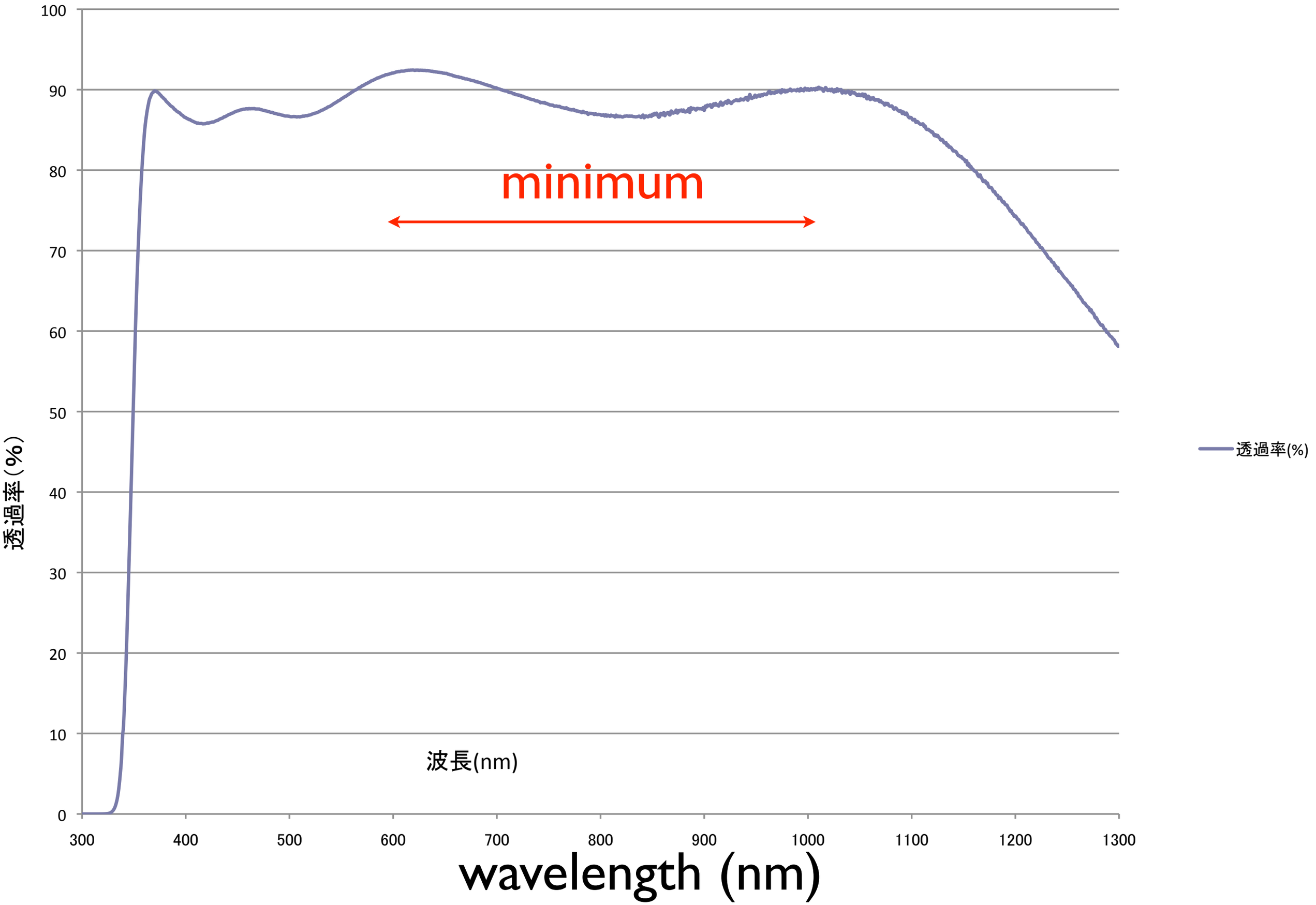


Large format CCD （3cmx6cm）
2048 pixels x 4096 pixels

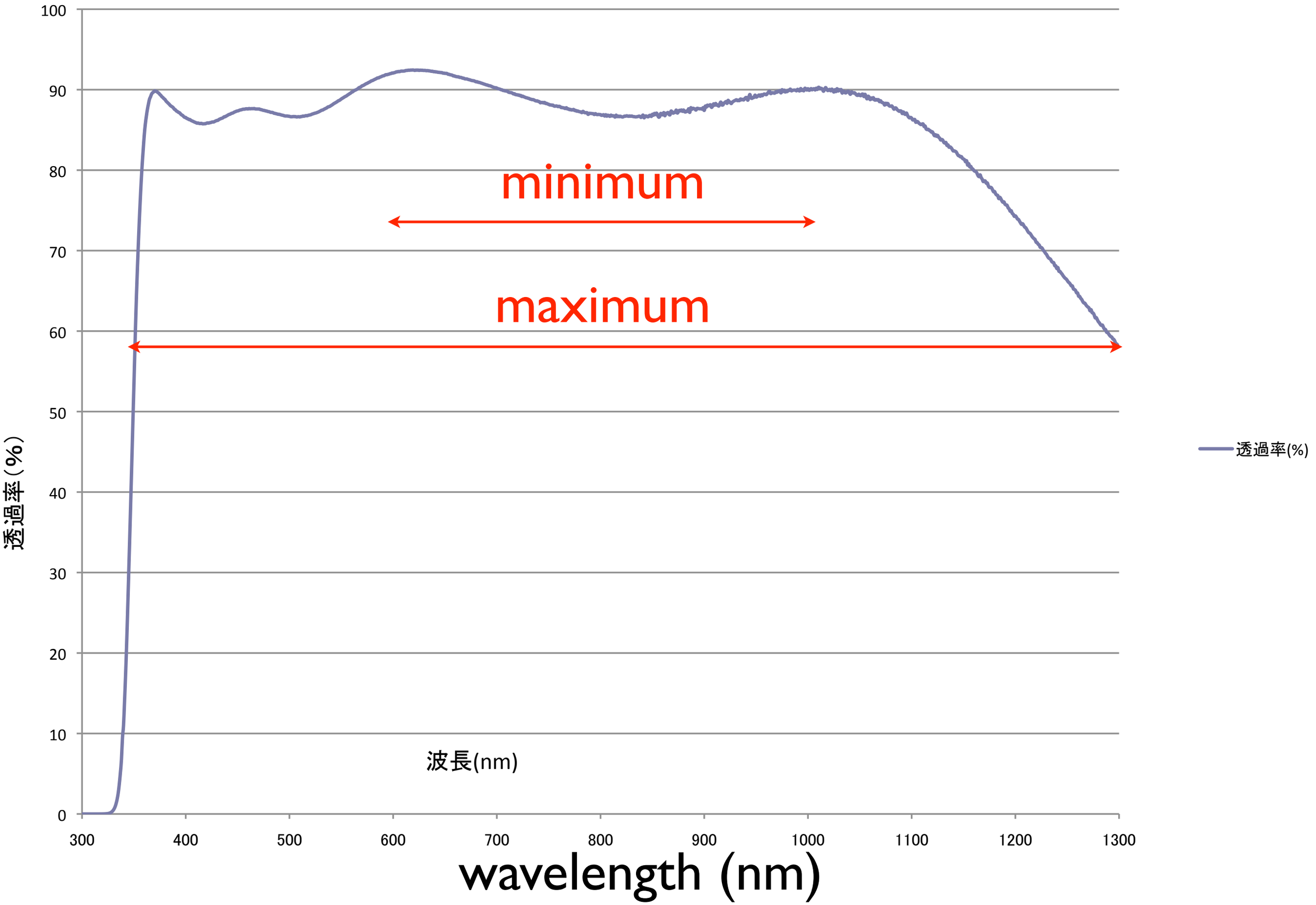
補正レンズシステムの透過率(%)計算値



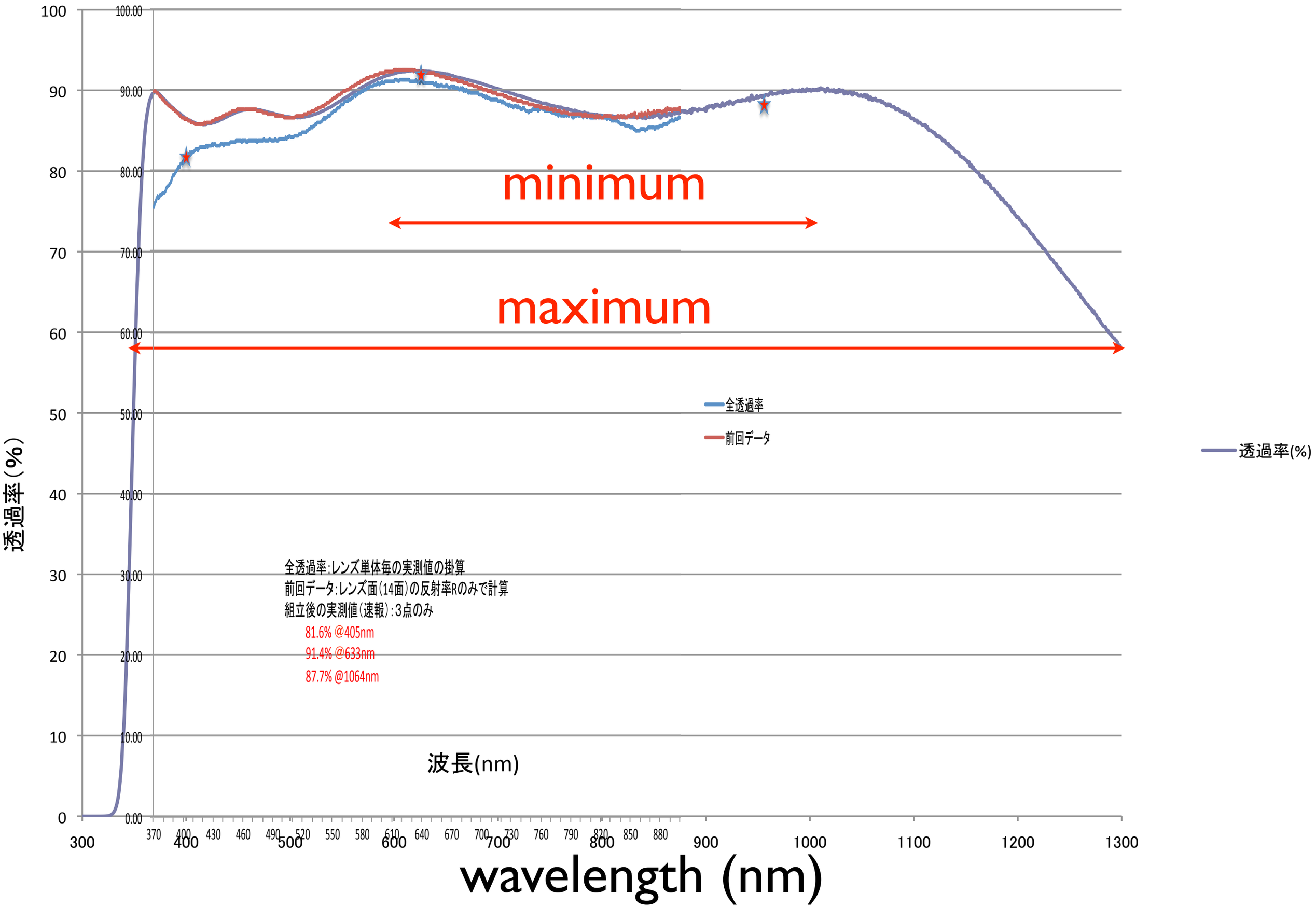
補正レンズシステムの透過率(%)計算値



補正レンズシステムの透過率(%)計算値



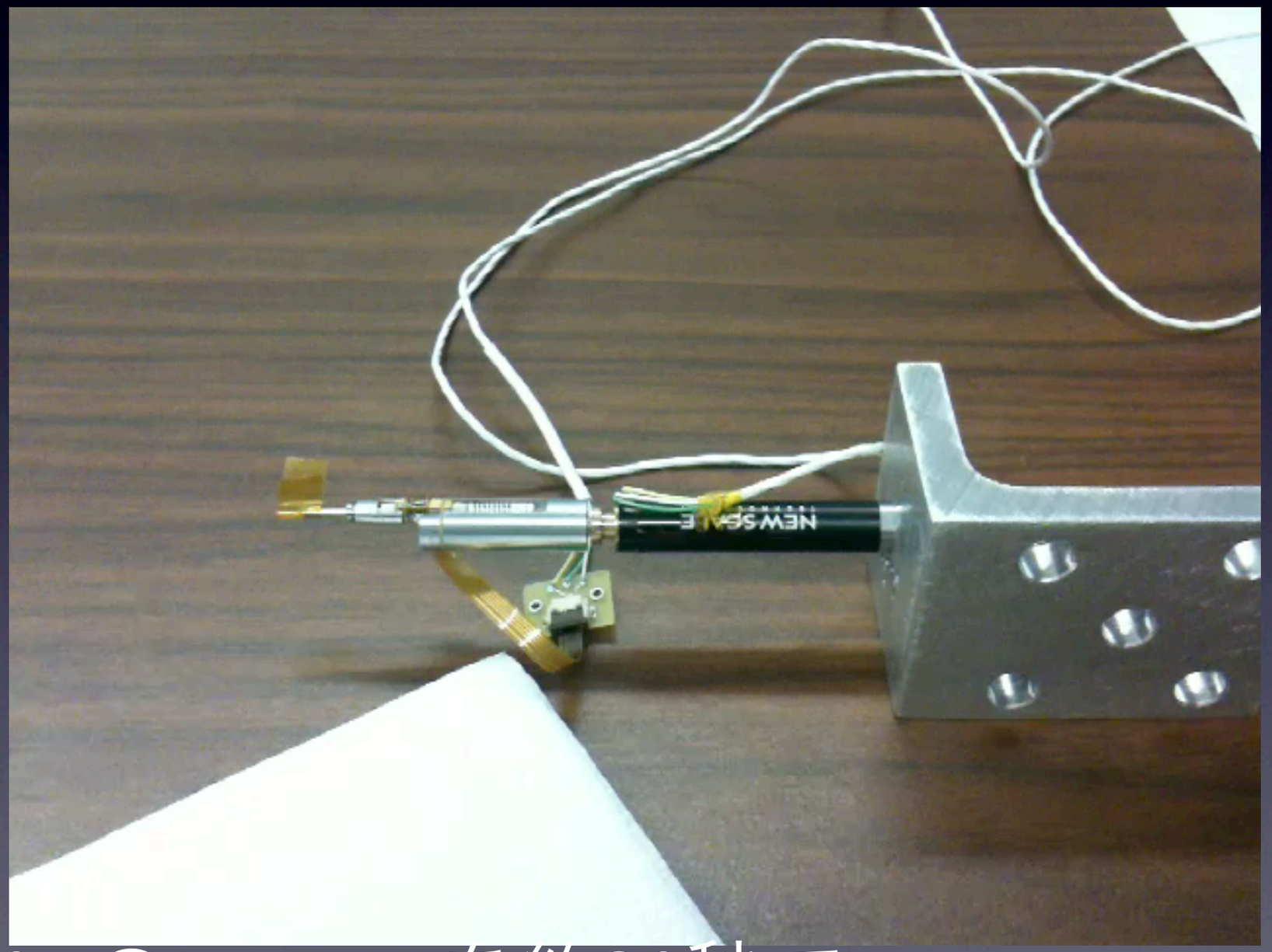
補正レンズシステムの透過率(%)実測値



IPMU

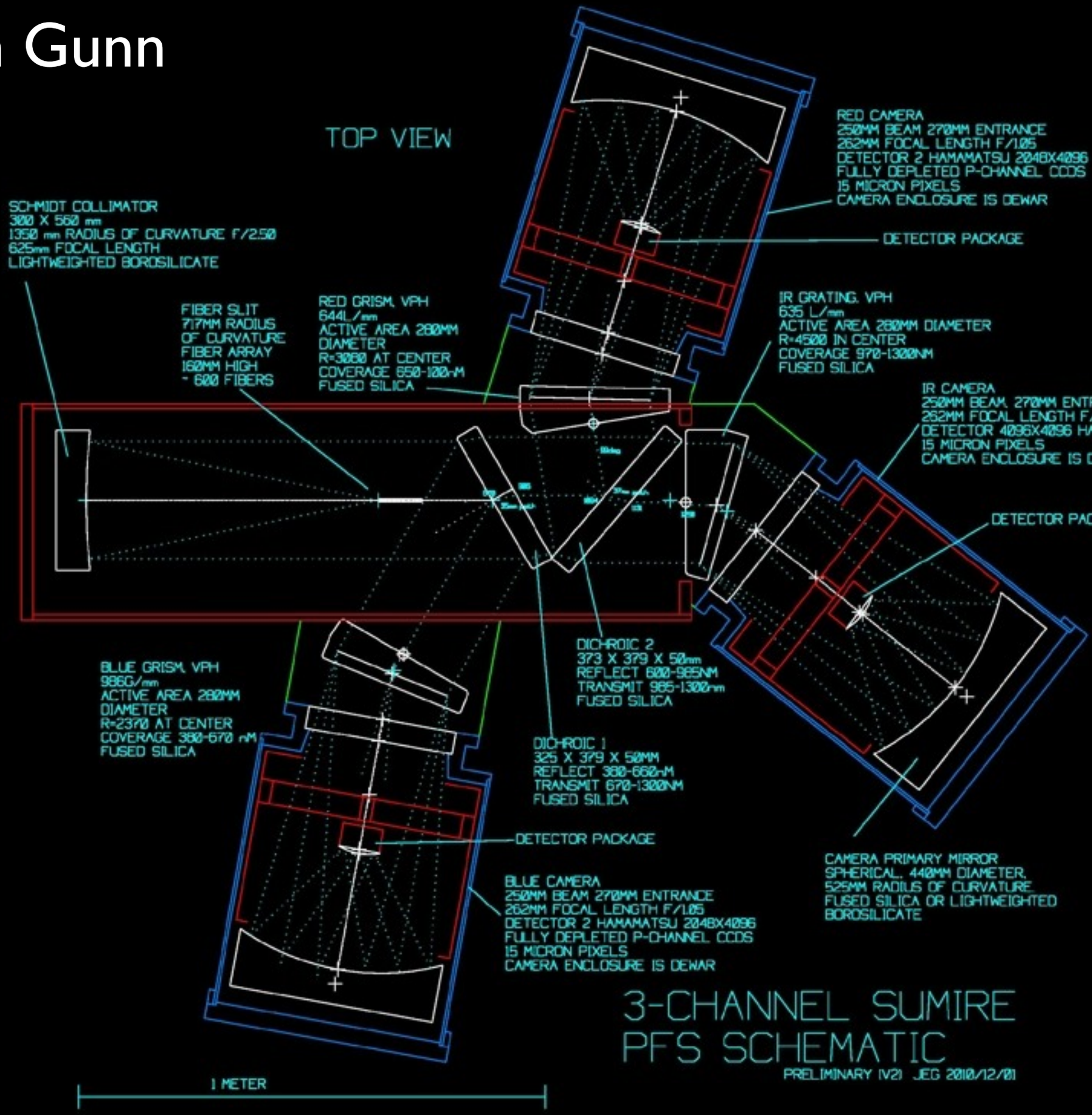
fiber positioner JPL Cobra design

BERKELEY CENTER FOR THEORETICAL PHYSICS

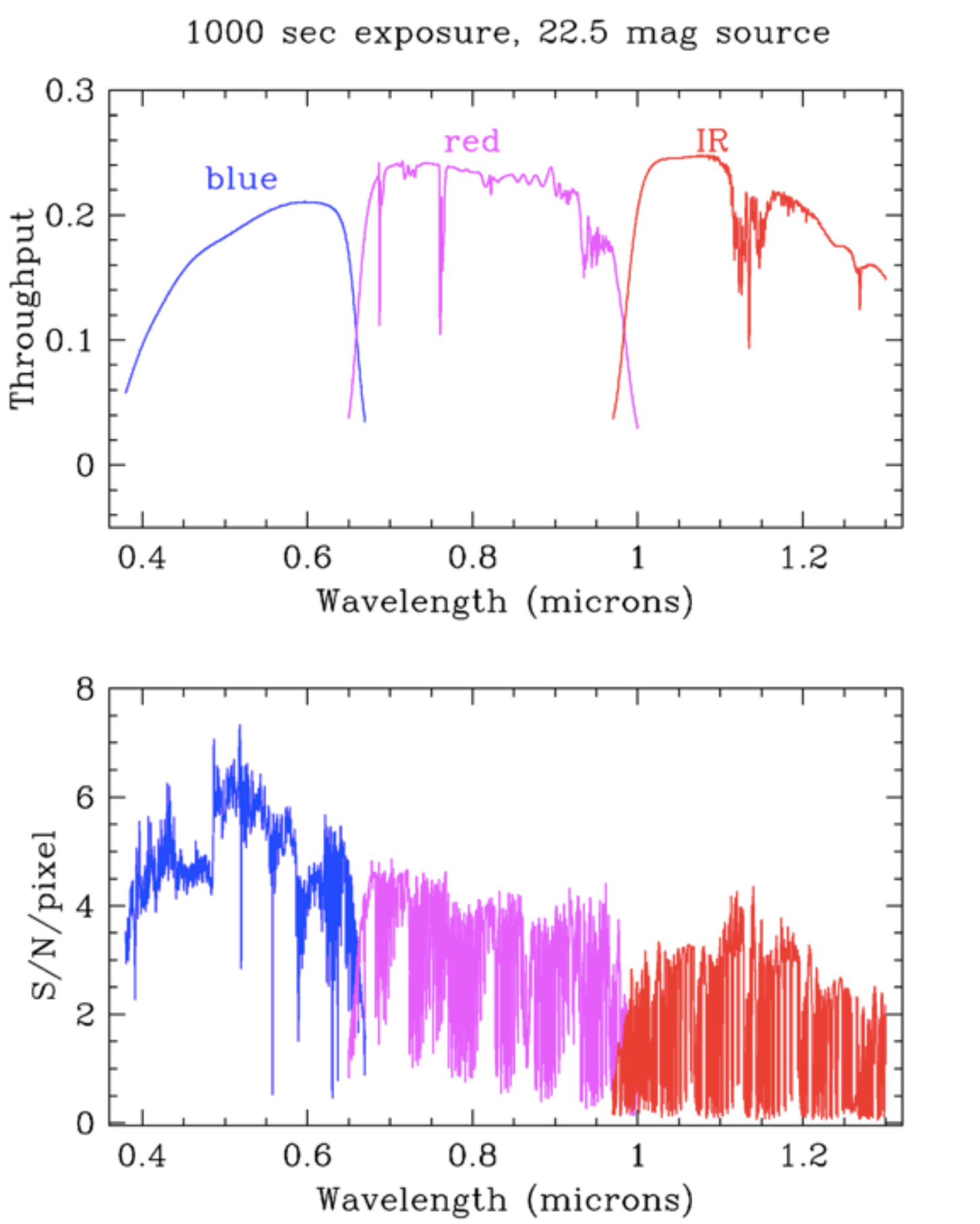


精度~10μのpointingを約30秒で

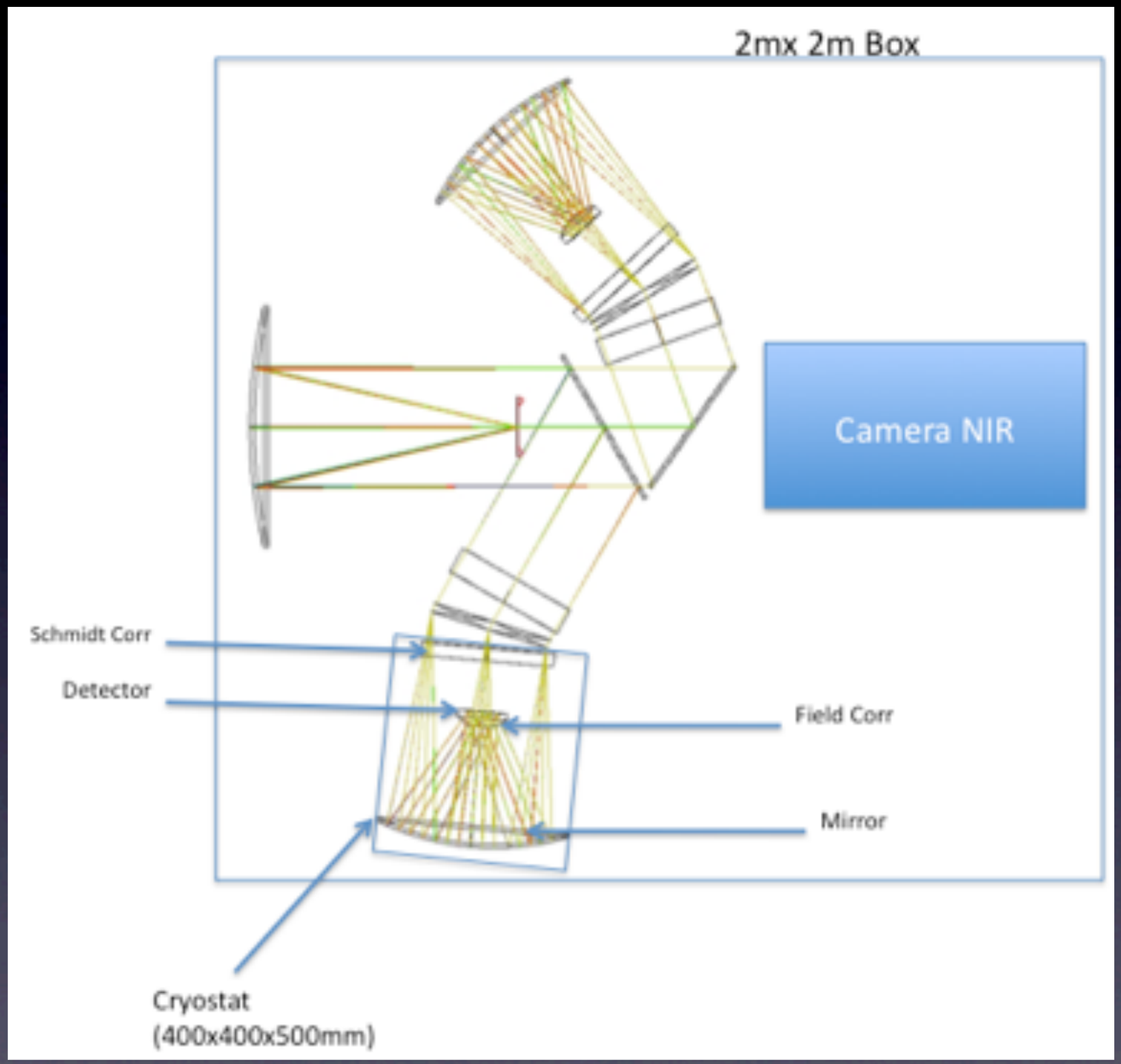
Jim Gunn


TOP VIEW
SCHMIDT COLLIMATOR
300 X 560 mm
1350 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=3060 AT CENTER
COVERAGE 650-100-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
3-CHANNEL SUMIRE
PFS SCHEMATIC
PRELIMINARY (V2) JEG 2010/12/01
1 METER

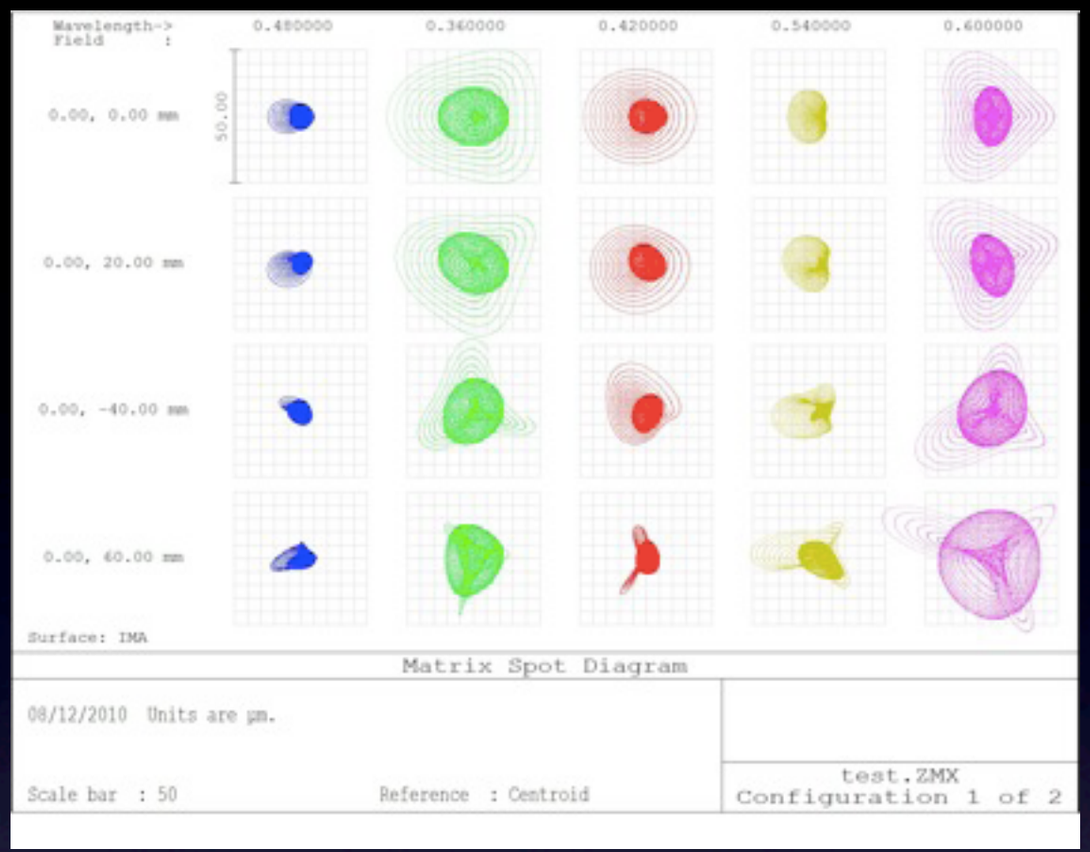
ファイバー分光器としては優秀なthroughput



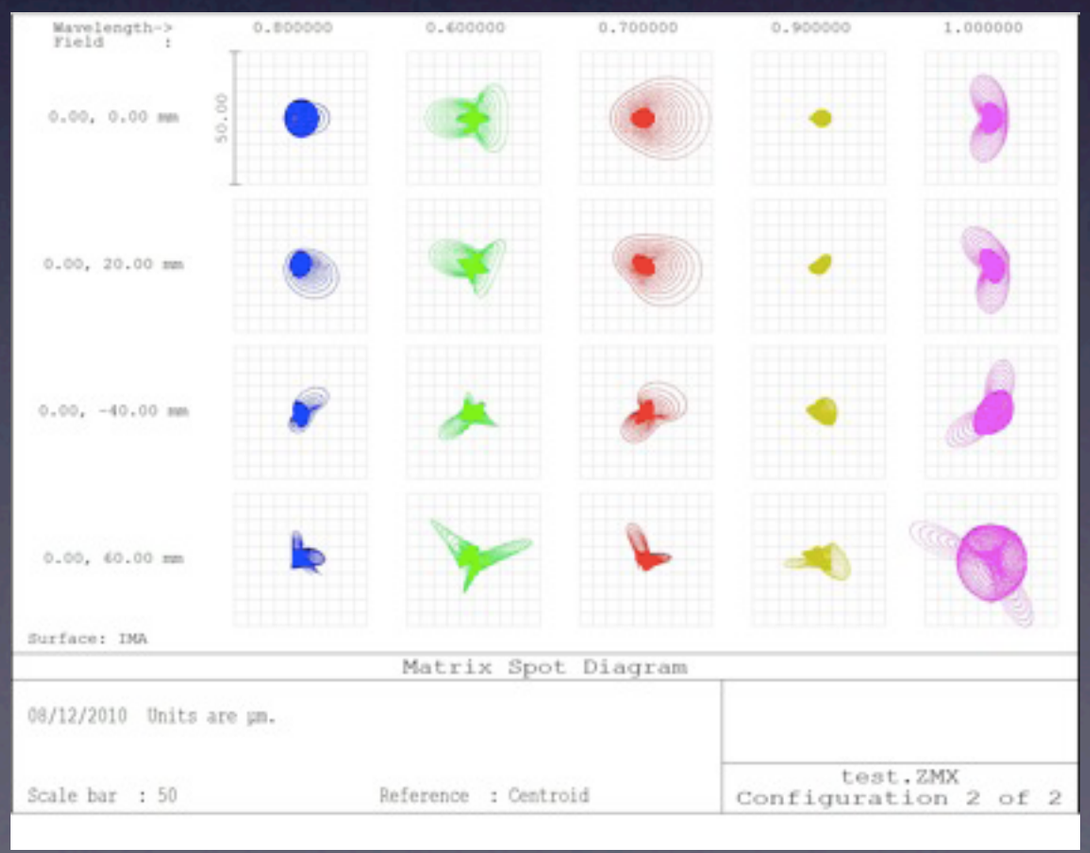
Eric Prieto (Marseille)



blue arm



red arm



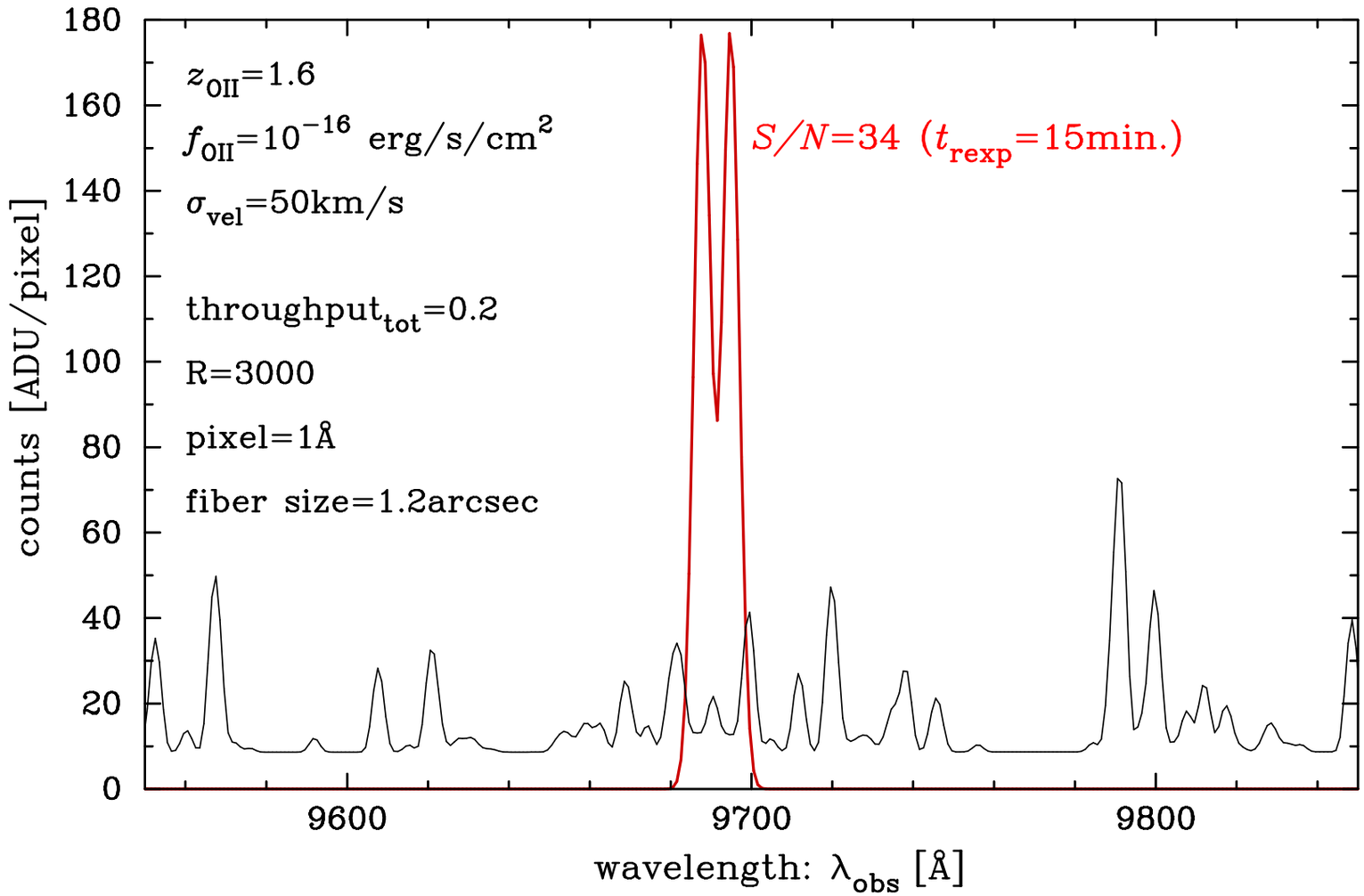


Figure 4.8: A simulated spectrum of [OII] emission line with PFS red arm, assuming 15min exposure, the *observed* line flux, $f_{\rm OII,obs} = 10^{-16}$ erg/s/cm^2, $z_{\rm OII} = 1.6$, and the velocity dispersion $\sigma_{\rm vel} = 50$ km/s. The units in the y-axis is in ADU/pixel, i.e. the expected 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 $S/N \simeq 34$.

Original Version of Assignments [2011 Jun 03]

assignment

Now being revised

PFS Project Office

Project Management

Hiroshi Karoji (IPMU)

Hajime Sugai (IPMU)

Naruhisa Takato (NAOJ Subaru)

Naoyuki Tamura (IPMU)

Youichi Ohyama (0.3FTE ASIAA)

Akitoshi Ueda (NAOJ Mitaka)

System Engineering

Dr. X (to be hired by IPMU)

Dr. Y (0.7FTE ASIAA)

Caltech/JPL

Brazil

UK?

ASIAA

LAM

Princeton

一緒にやりませんか？