Subaru Wide Field Survey to Probe Dark Matter Distribution and Nature of Dark Energy

Satoshi Miyazaki

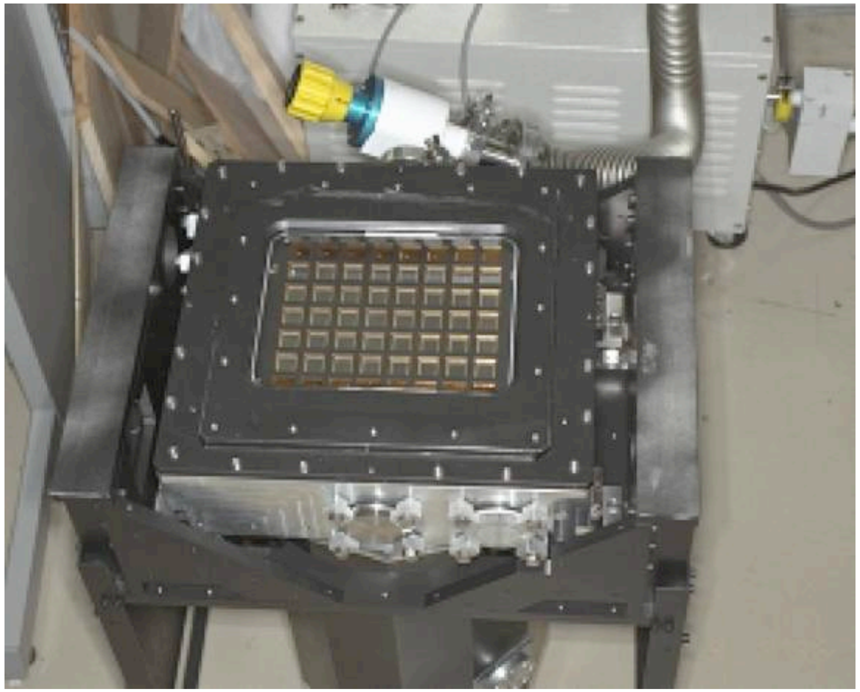
National Astronomical Observatory of Japan

COSMO CosPA 2010

Talk Outline

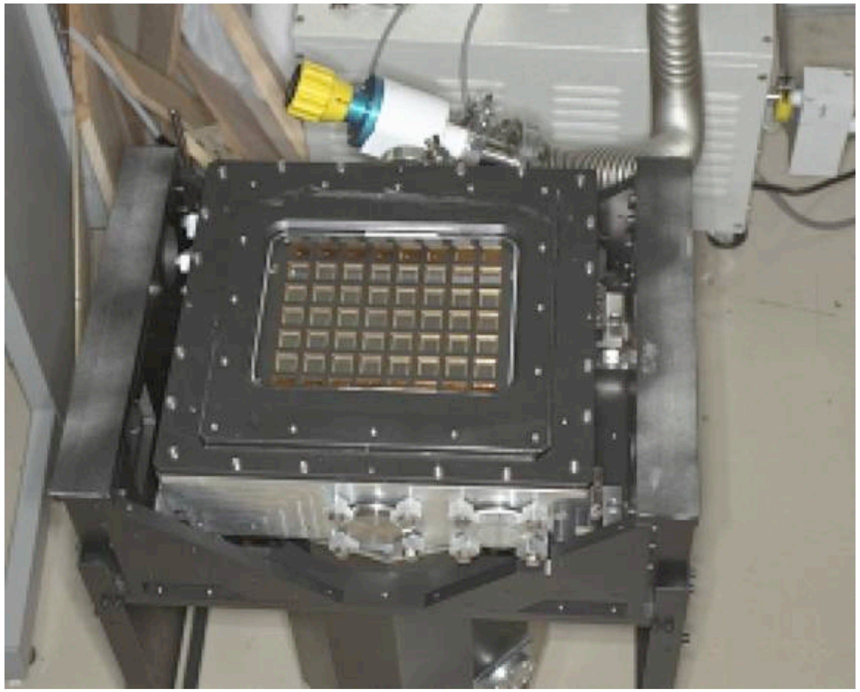
1. Subaru Telescope and Suprime-Cam
2. Weak Lensing Survey
3. Building Hyper Suprime-Cam
4. HSC Survey Plan

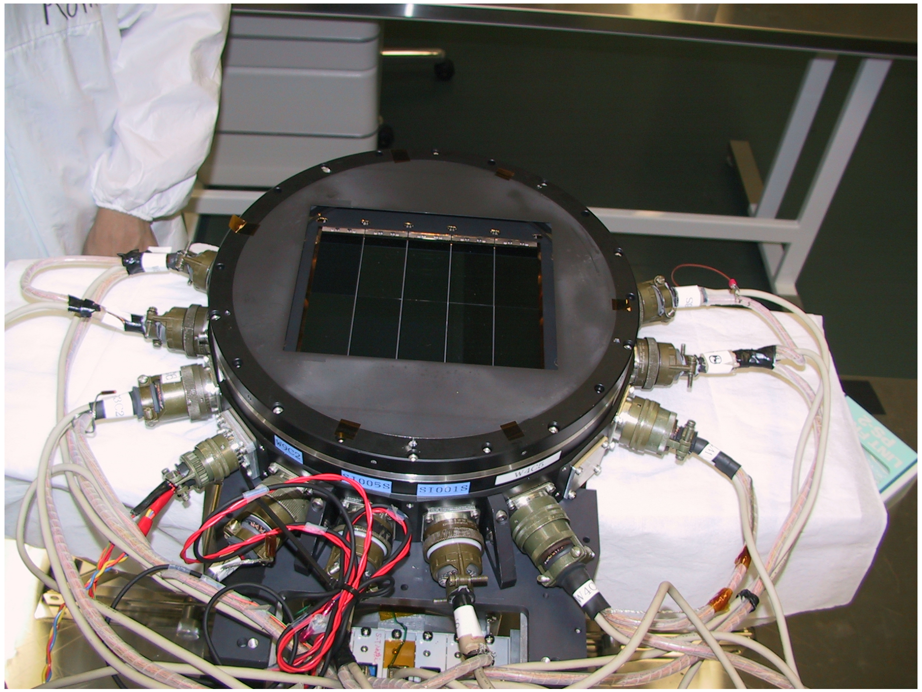
Mosaic Camera History



NAOJ-UT Mosaic for Kiso Schmidt
Sekiguchi et al. 1992
8 x 8 (1 cm^2 CCD)
CCD:TI TC215
World largest forcal plane in 1992

Mosaic Camera History





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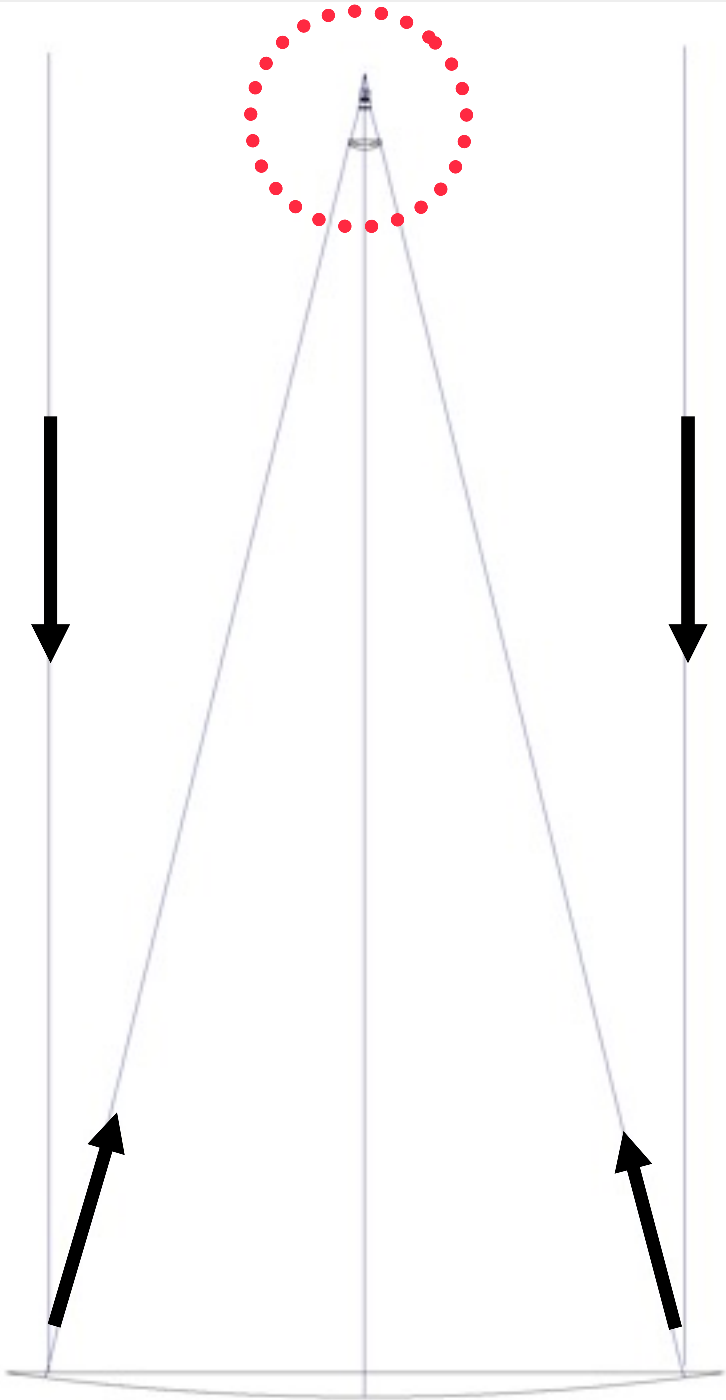
Suprime-Cam
Miyazaki et al. 2002
5 x 2 x (3cm 6cm CCD)
MIT/LL CCID20
World fastest discovery speed 2002

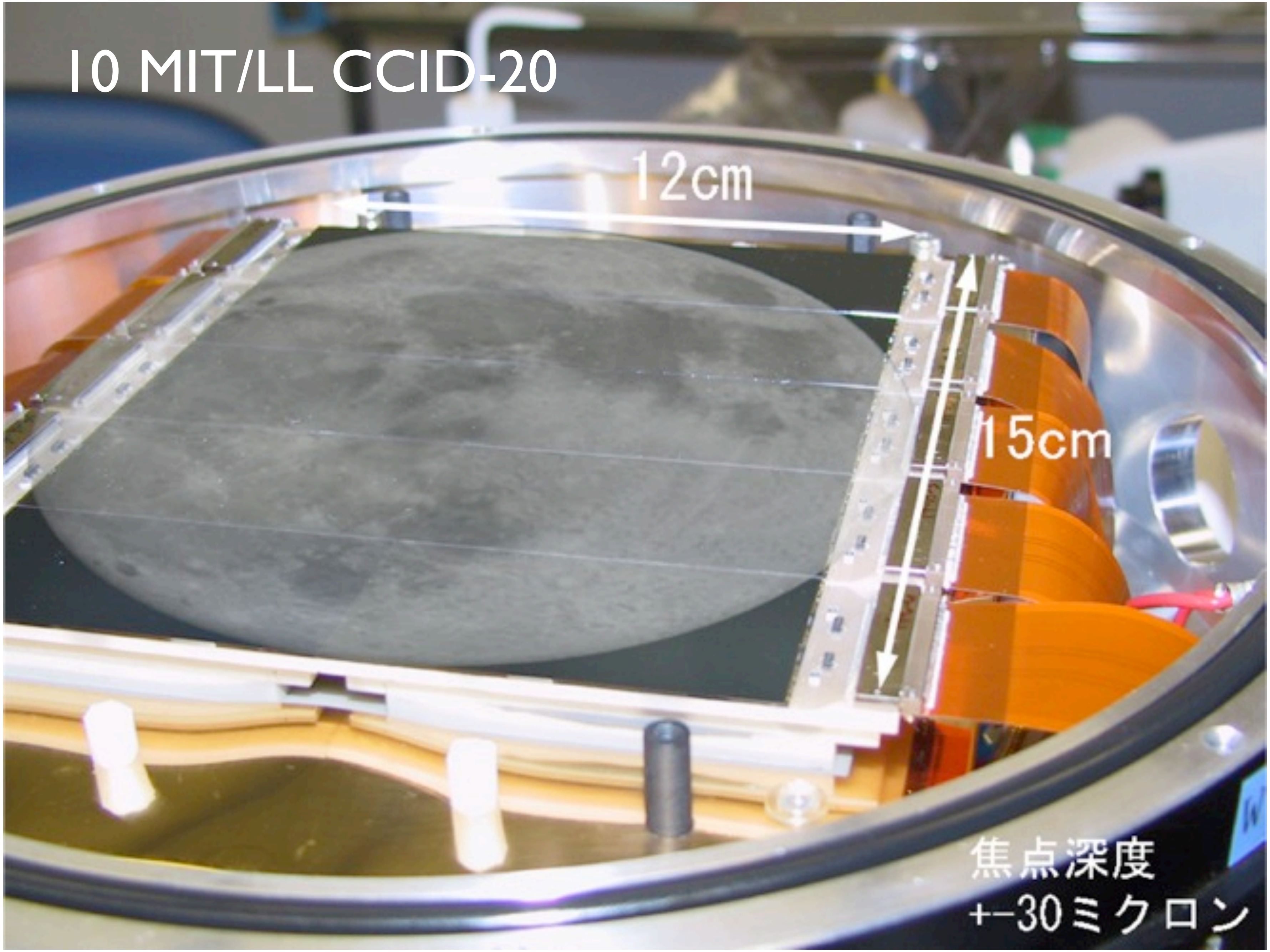
Subaru Prime Focus



F/2.0
f = 16400 mm
Field of View 30 arcmin

M1 **8.2 m**

Suprime-Cam



Strength of Suprime-Cam

Wide Field Corrector

Canon

Prime Focus Unit

MITSUBISHI

Opt-mechanics were built by experienced Japanese firms

Strength of Suprime-Cam

Wide Field Corrector

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Prime Focus Unit

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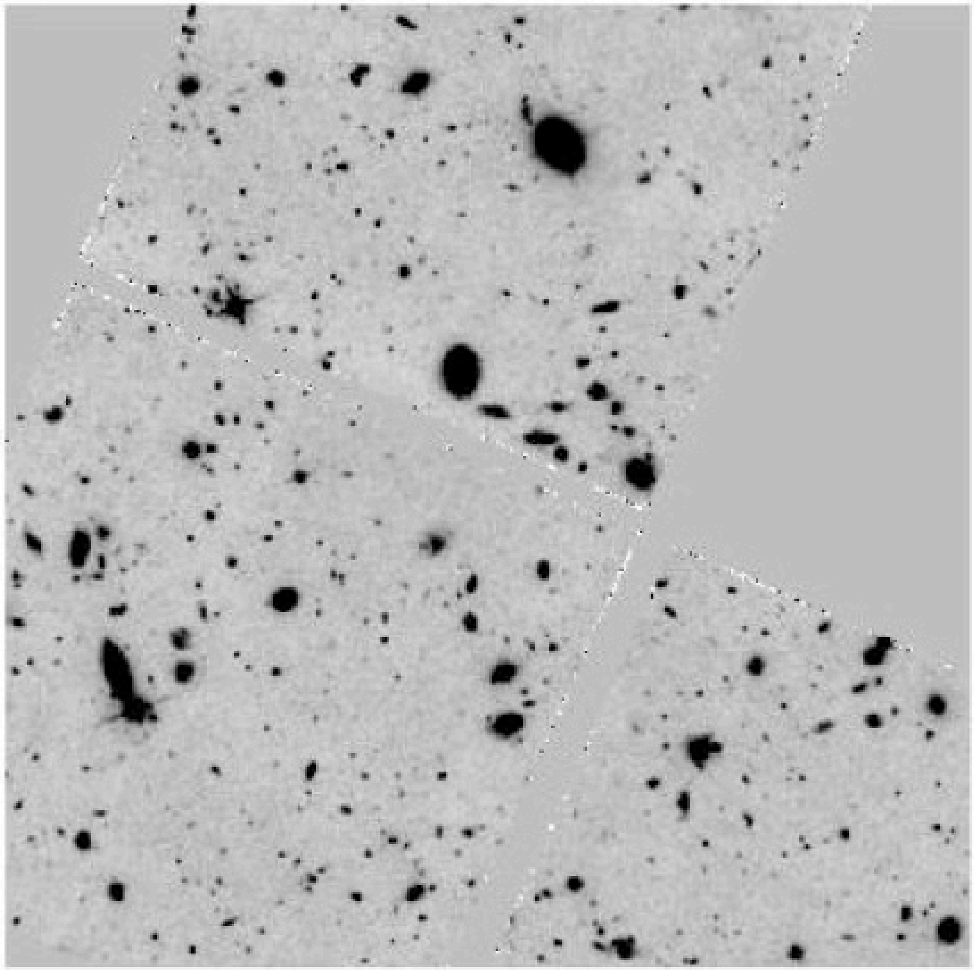
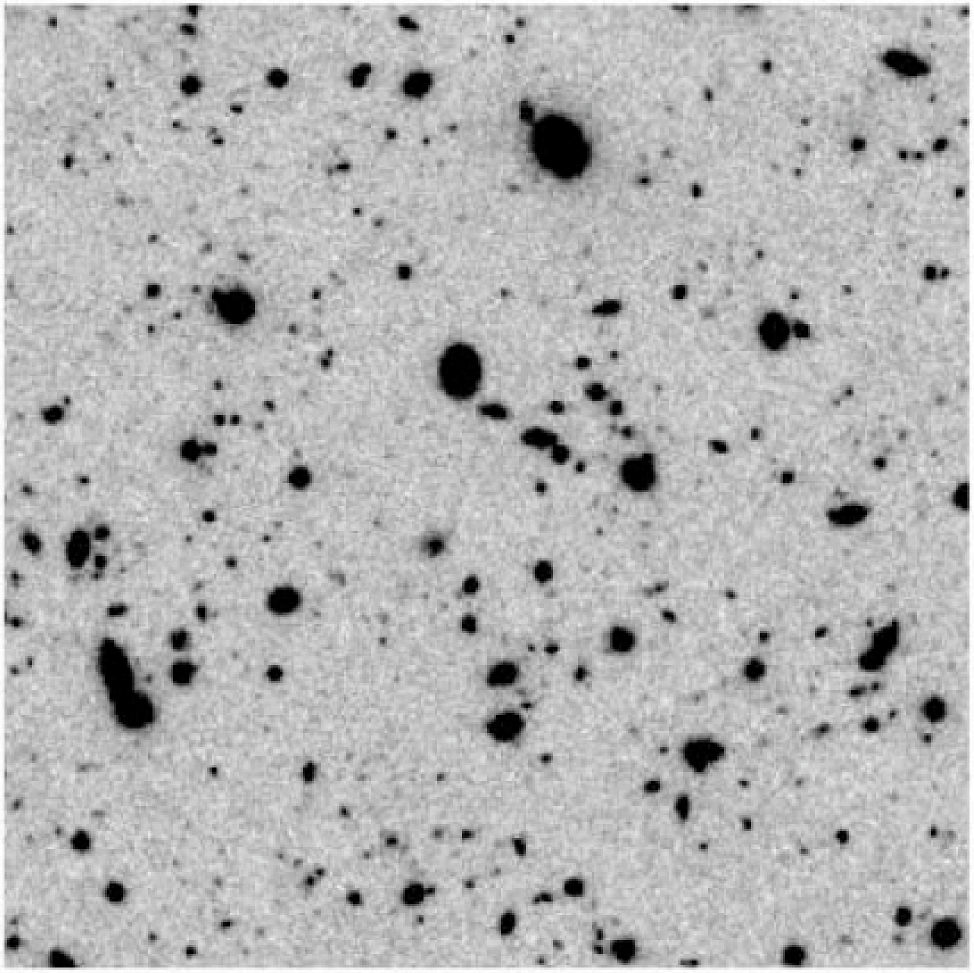
Opt-mechanics were built by experienced Japanese firms	→	Superb Image Quality

Good Image Quality



HST 'wide-I' continuum

HST WFPC2
(All FOV)



NB816 narrowband

Suprime-Cam
(FOV/100)

Suprime-Cam Strength

1. Large Aperture Telescope
2. Wide Field of View
3. Superb image quality

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Optimized for Weak Lensing Survey (unintentionally)

Wide Survey and DE

1. Obtain Wide Field Imaging Data

Wide Survey and DE

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↓

2. Measurement of DM Clustering Evolution

Cosmic Shear

Cluster of Galaxies count

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3. Measurement of Cosmic Expansion History H(z)

Wide Survey and DE

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3. Measurement of Cosmic Expansion History H(z)

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4. Measurement of DE (time variation)

Wide Survey and DE

1. Obtain Wide Field Imaging Data

↓

Weak Lensing Technique

2. Measurement of DM Clustering Evolution

Cosmic Shear

Cluster of Galaxies count

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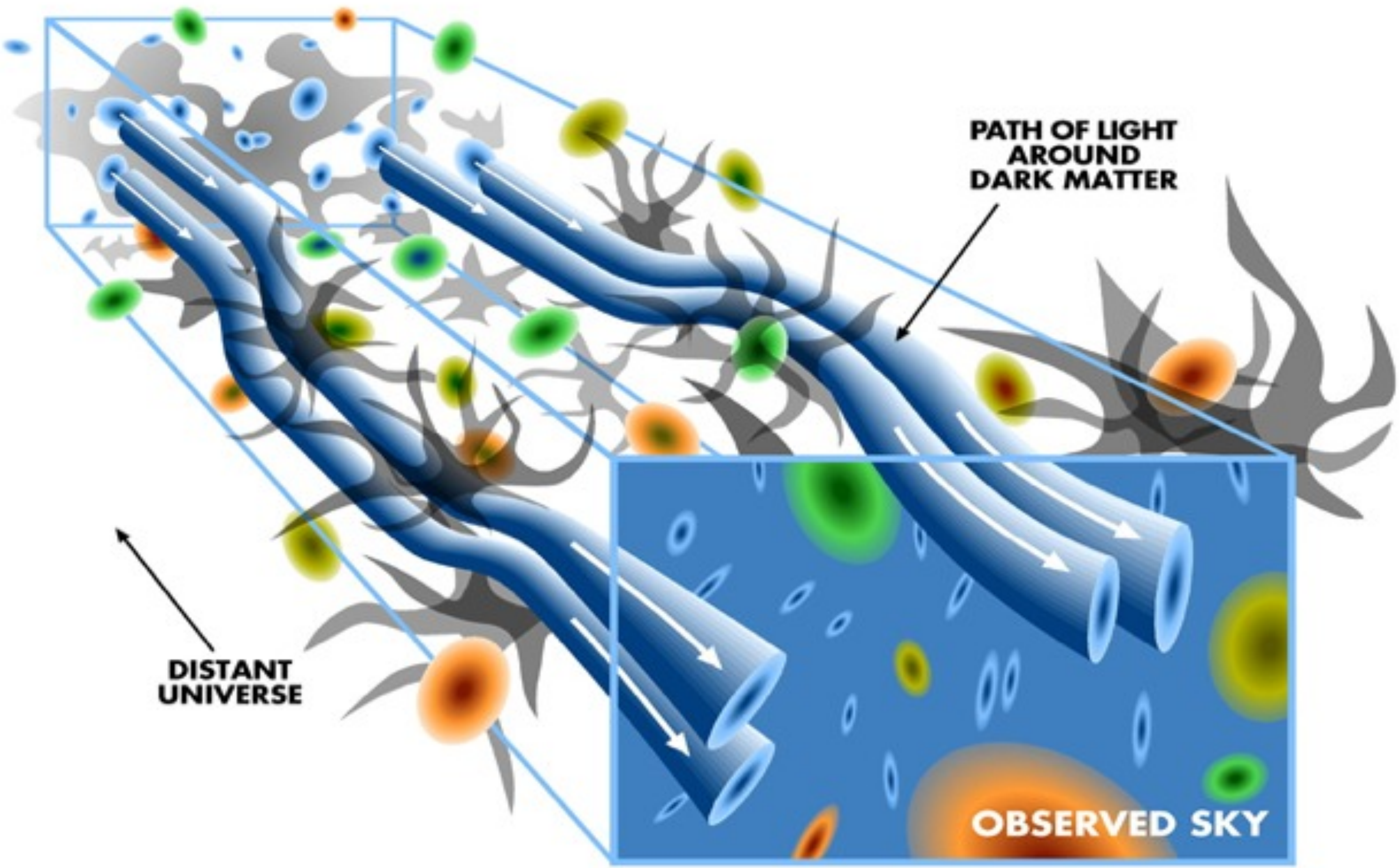
3. Measurement of Cosmic Expansion History H(z)

↓

4. Measurement of DE (time variation)

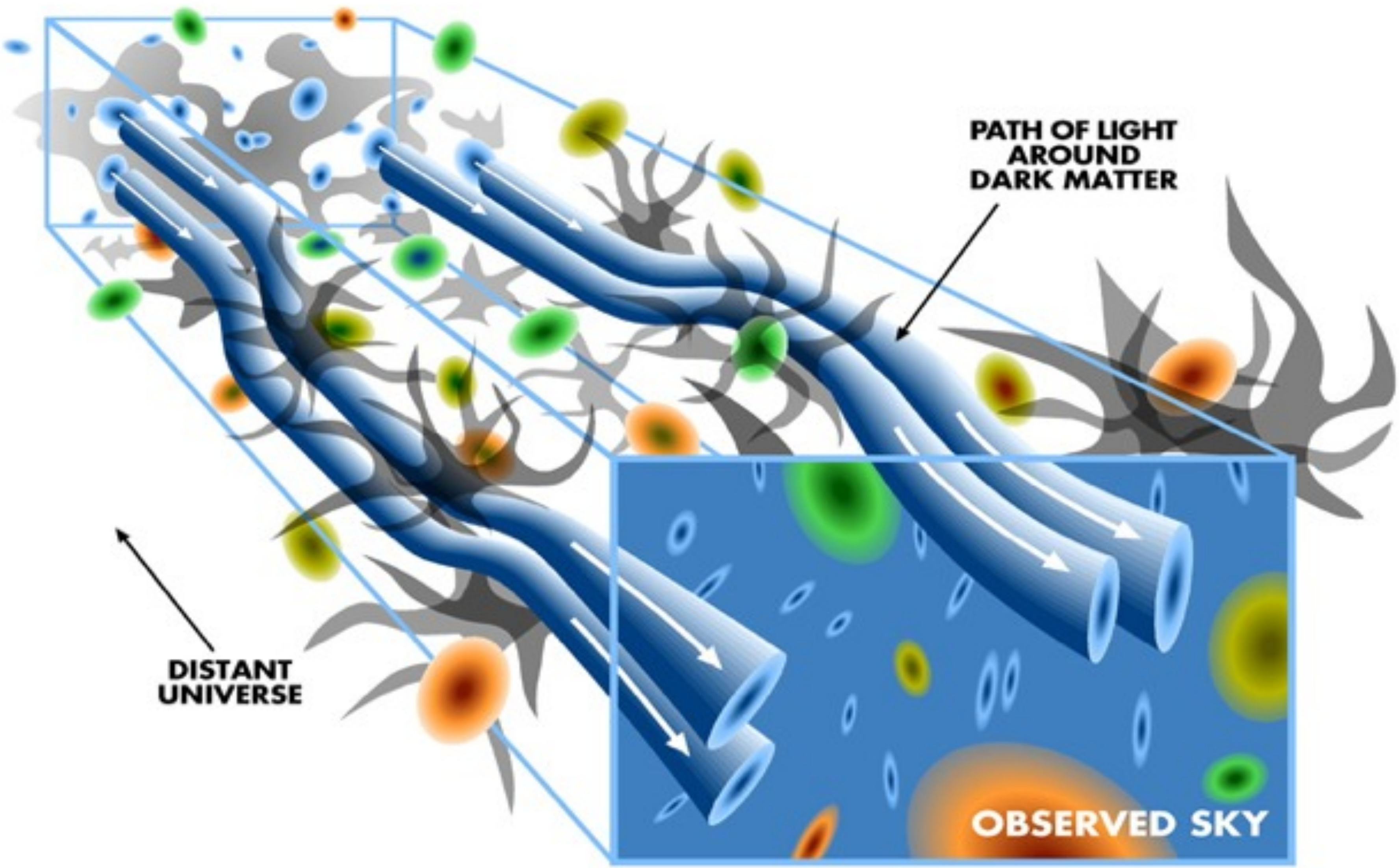
Cosmic Shear



Cosmic Shear: Weak Lensing by Large Scale Structure

HSC

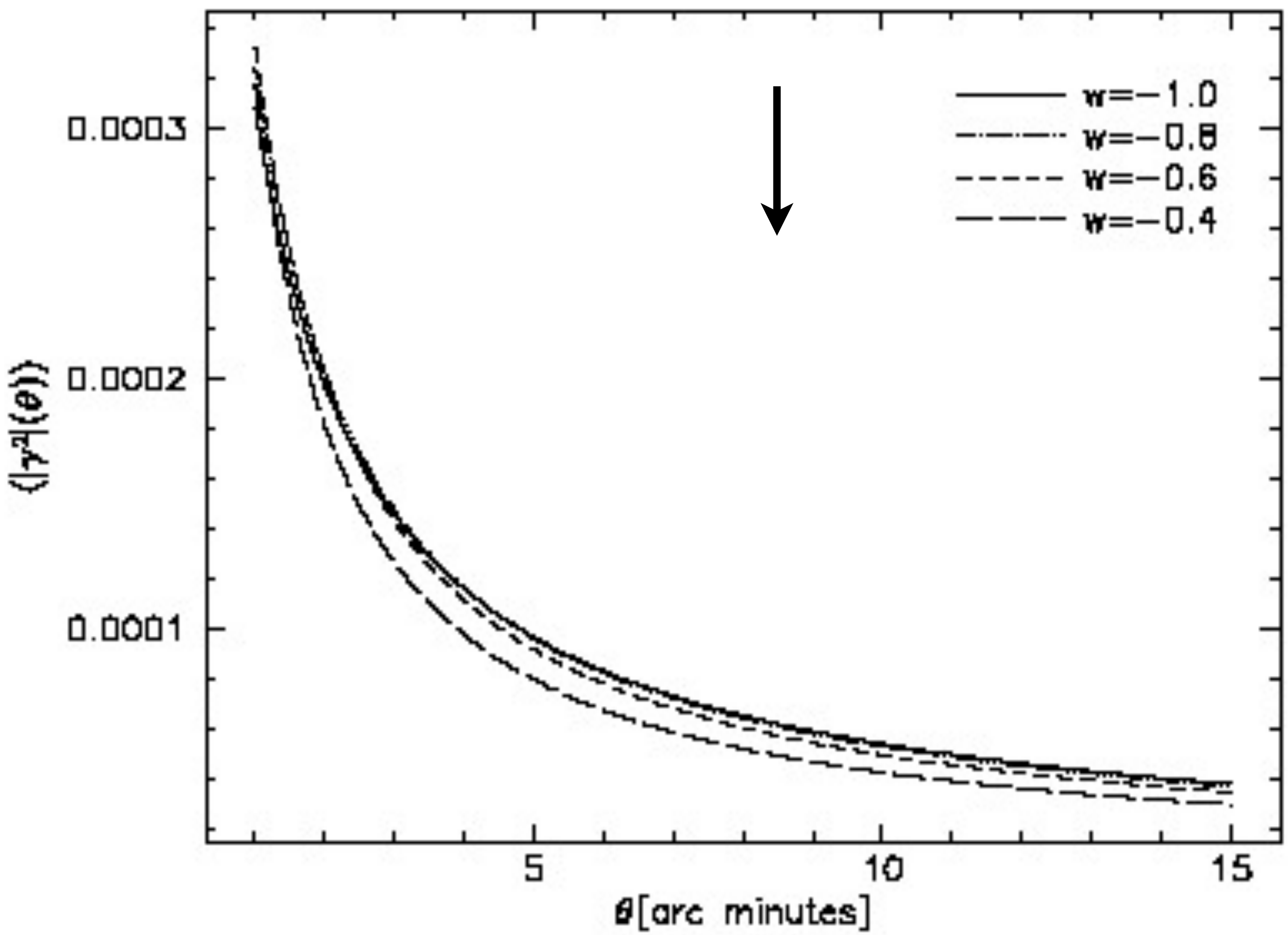
Cosmic Shear



Cosmic Shear: Shape correlation of neighboring galaxy pairs

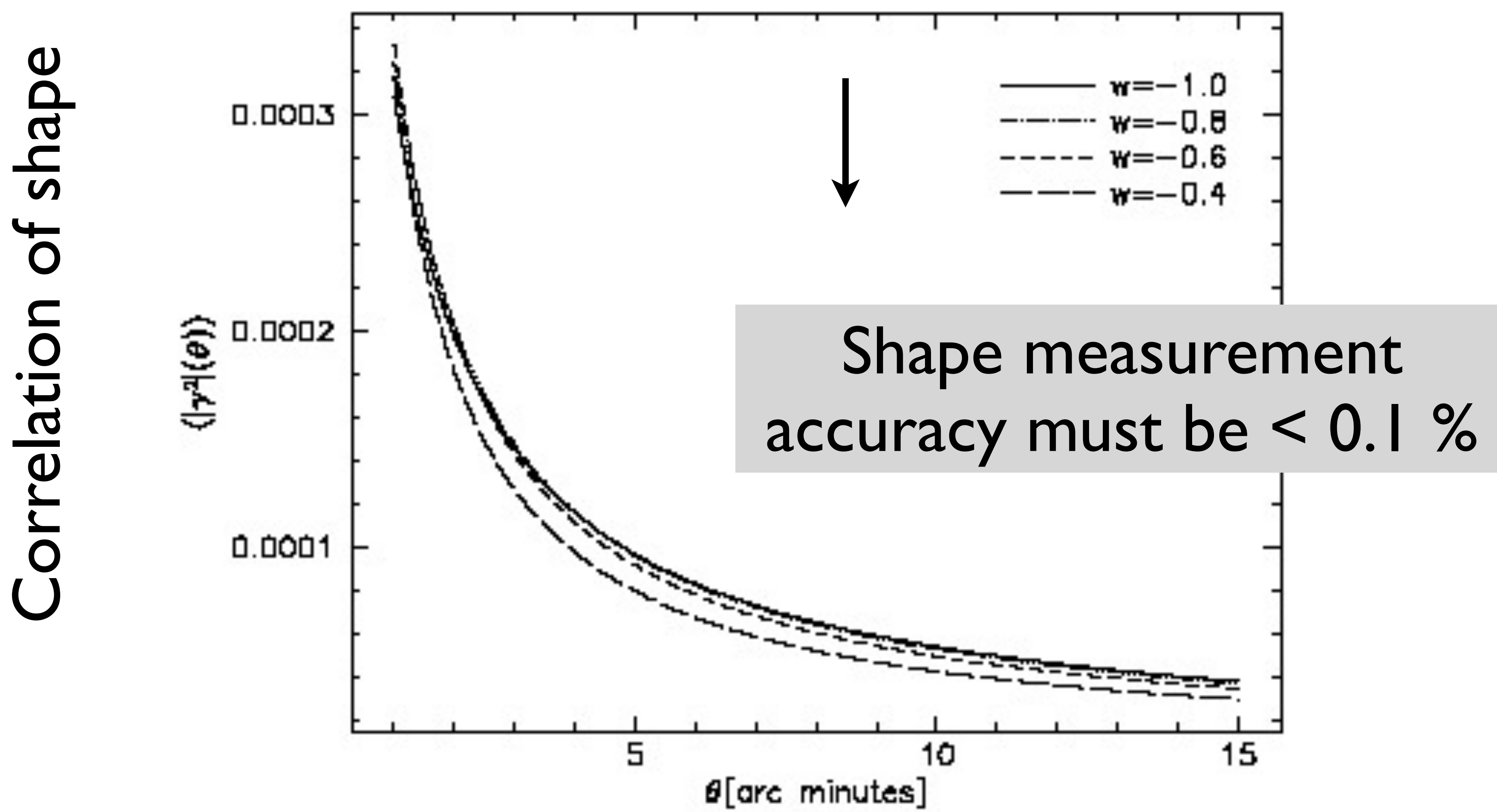
Cosmic Shear Obs. & DE

Correlation of shape



correlation weak → DM clustering weak
→ cosmic acceleration fast → w large

Cosmic Shear Obs. & DE



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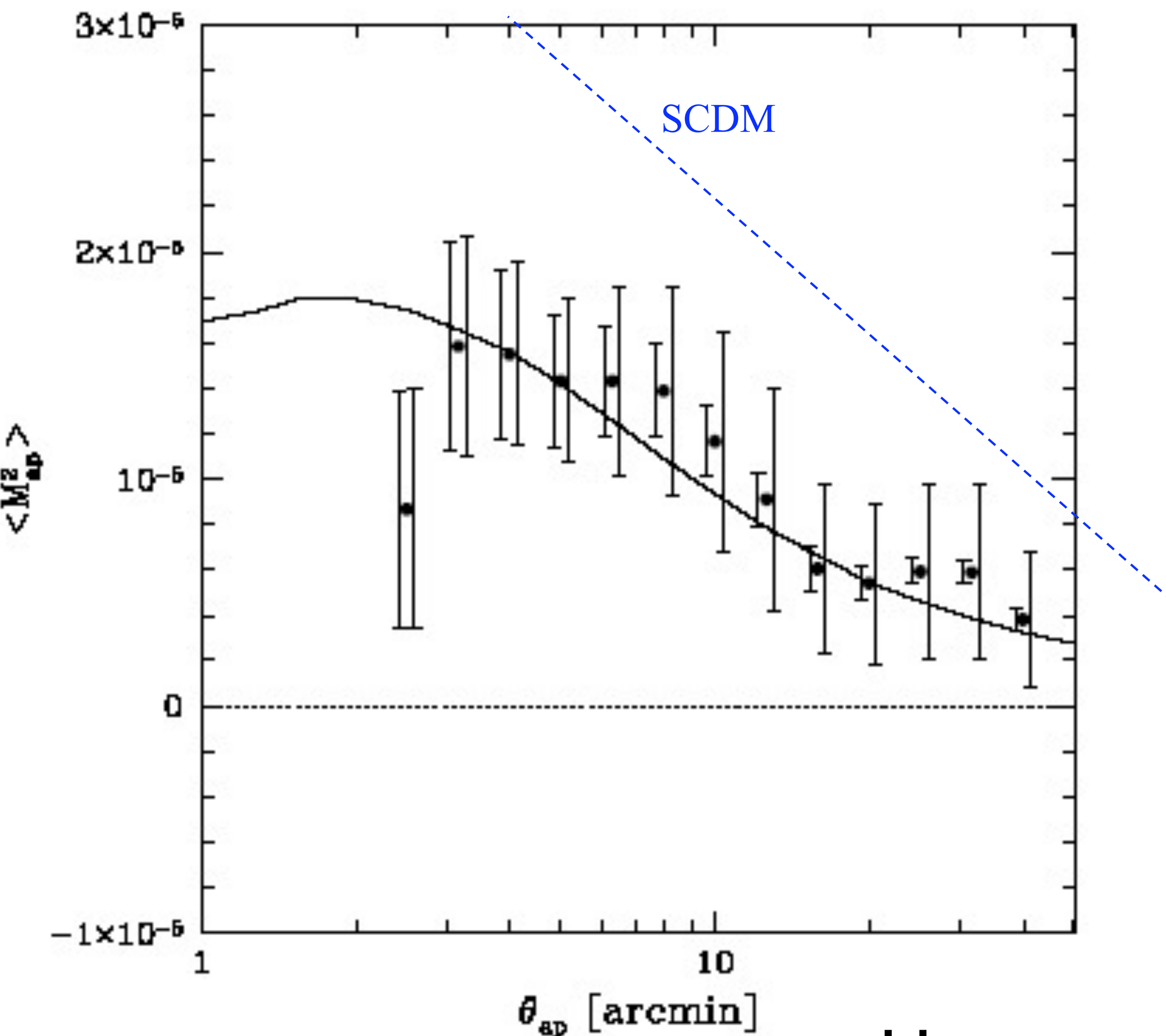
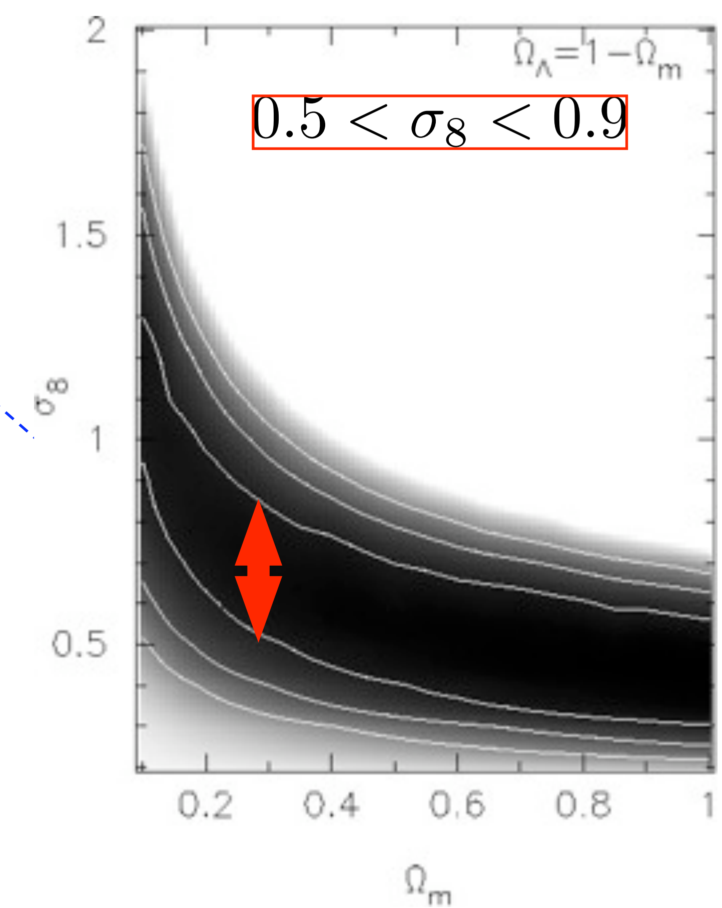
Cosmic Shear on 2 sqdeg



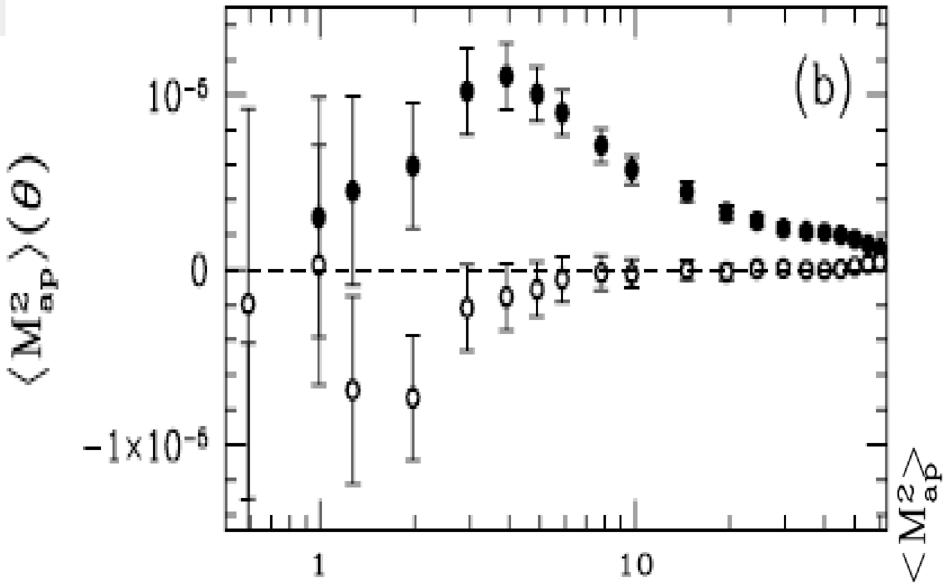


Hamana et al. 2003

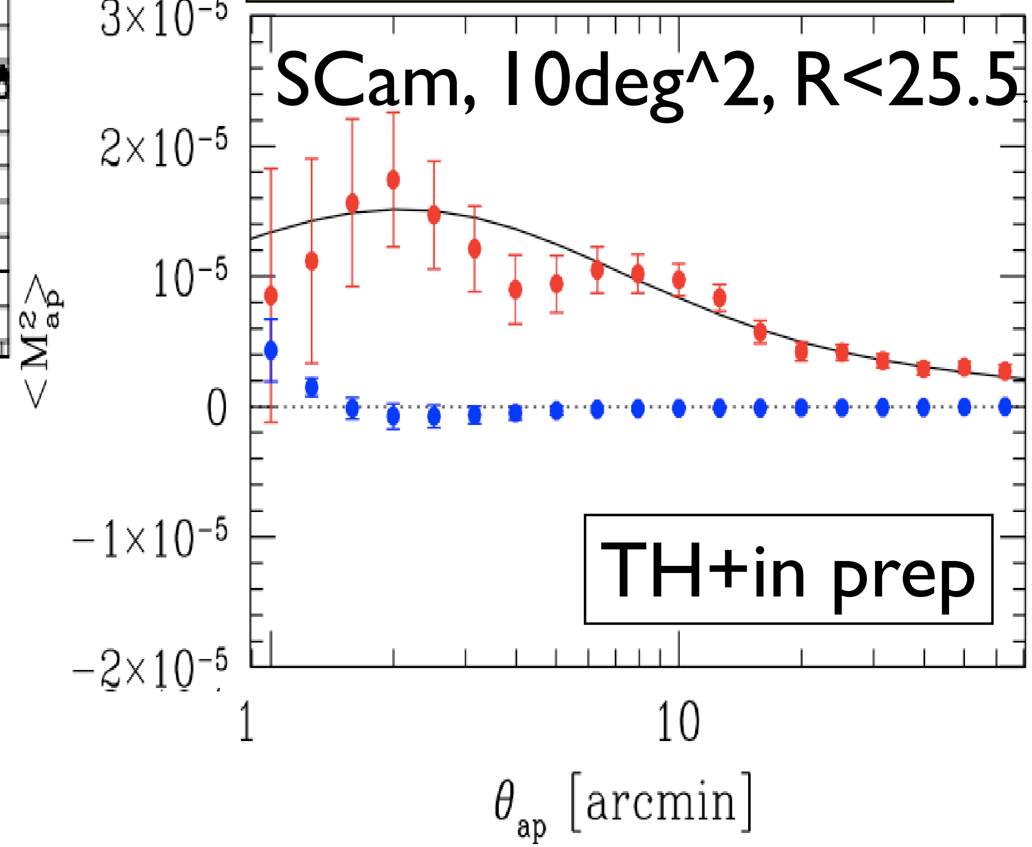
Measurements of WL PS

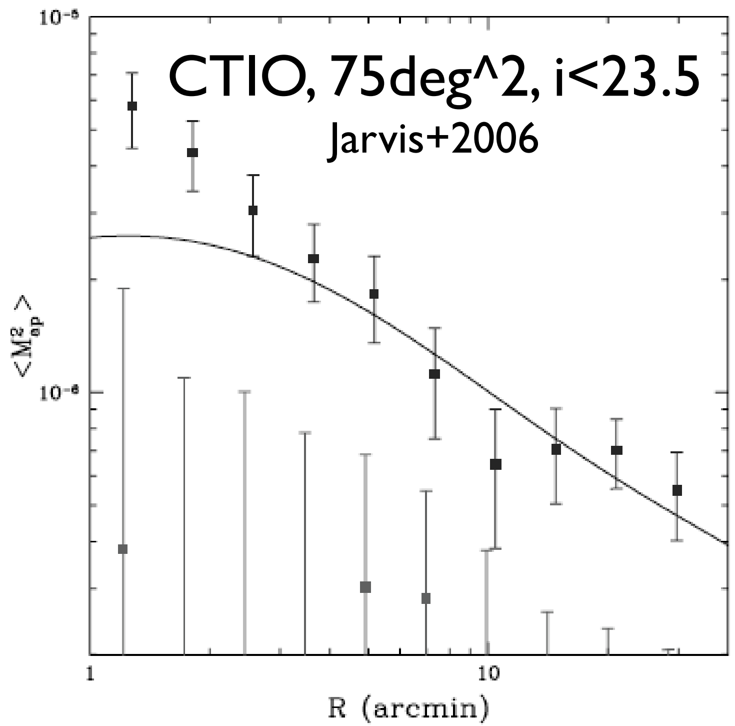
CFHTLS-wide, 22deg^2, i<24.5

Hoekstra+2006



WL-PS measurement is now very feasible





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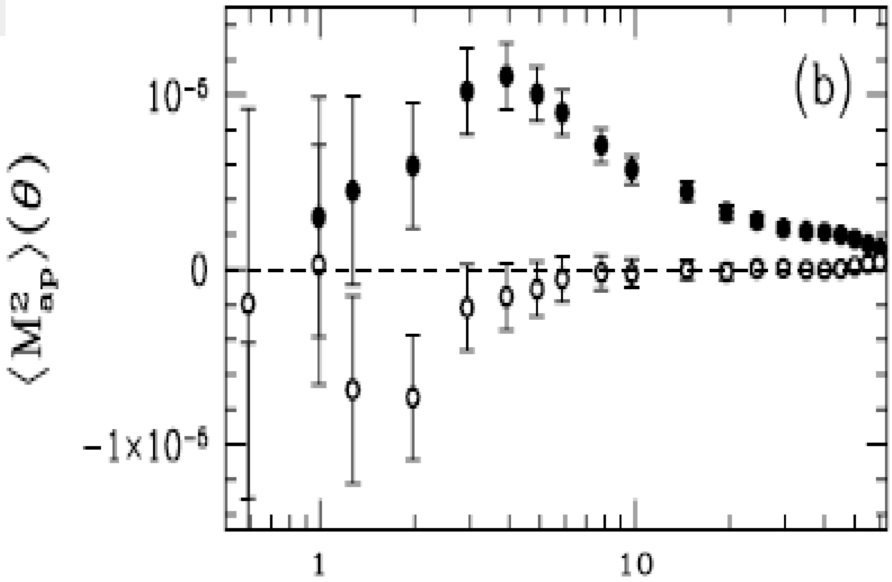

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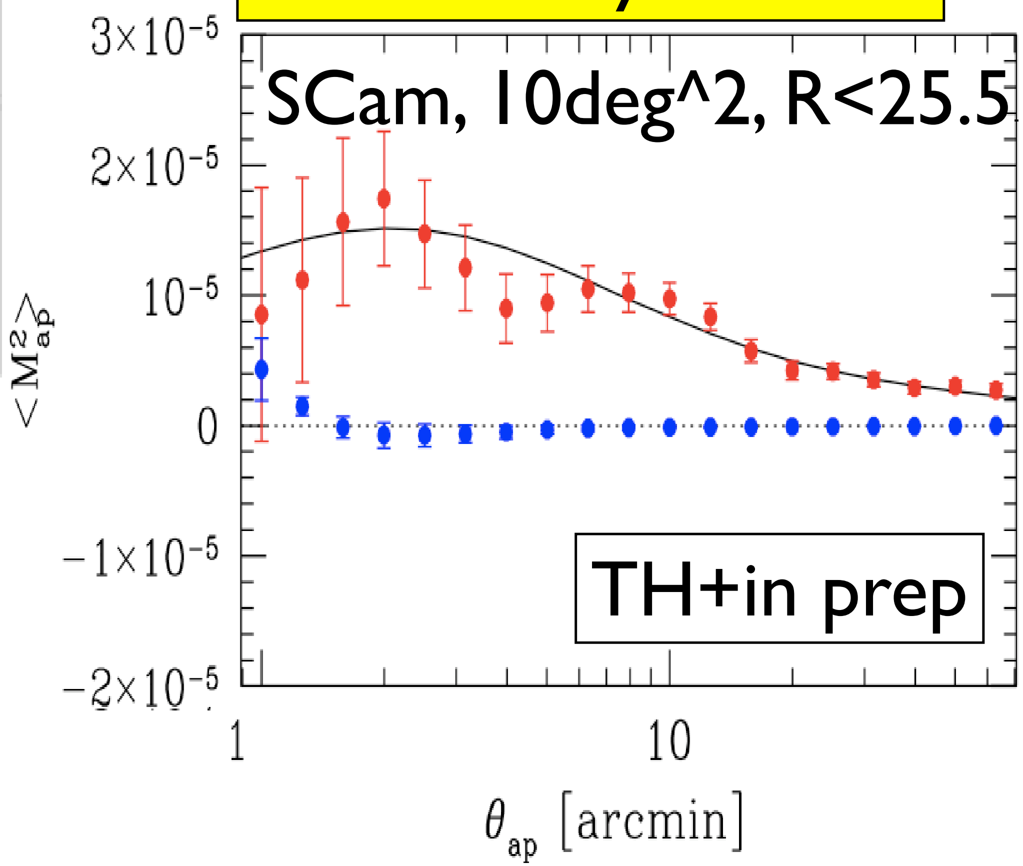
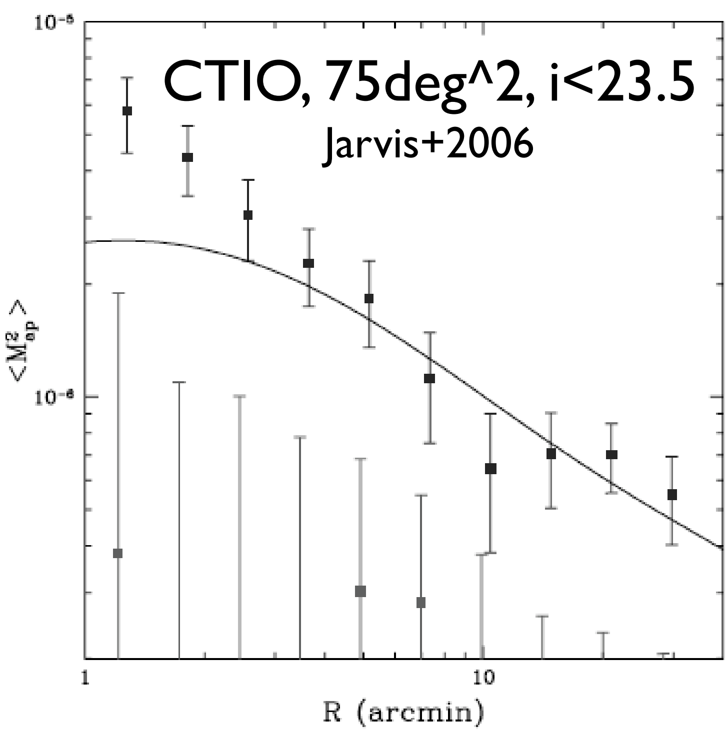


CTIO, 75deg^2, i<23.5

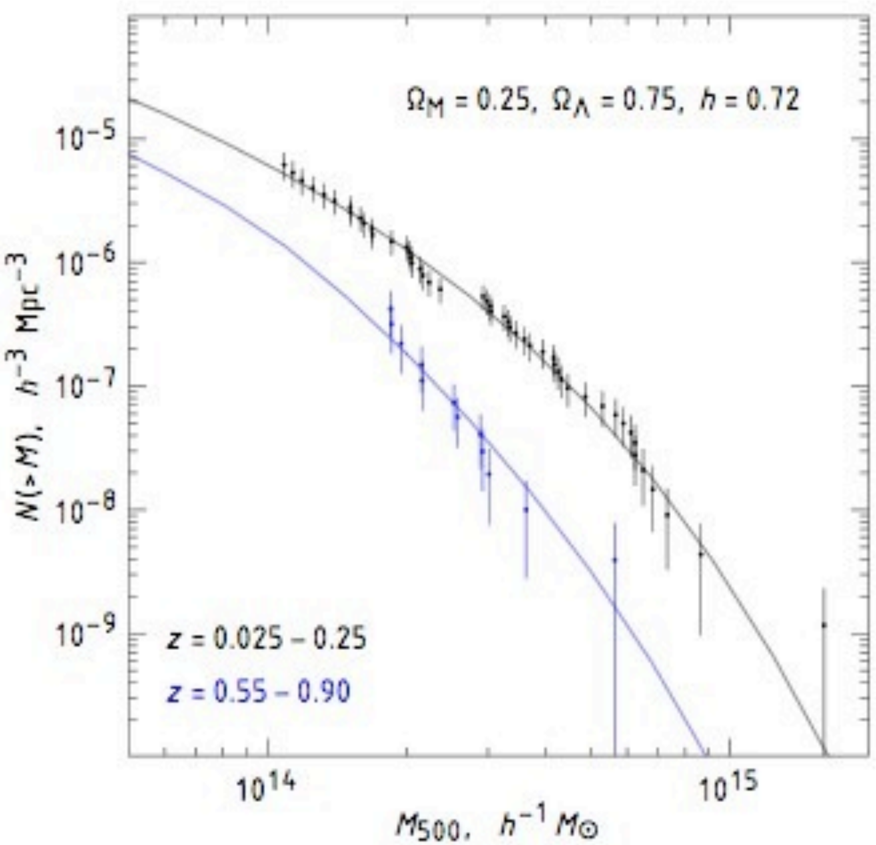
Jarvis+2006

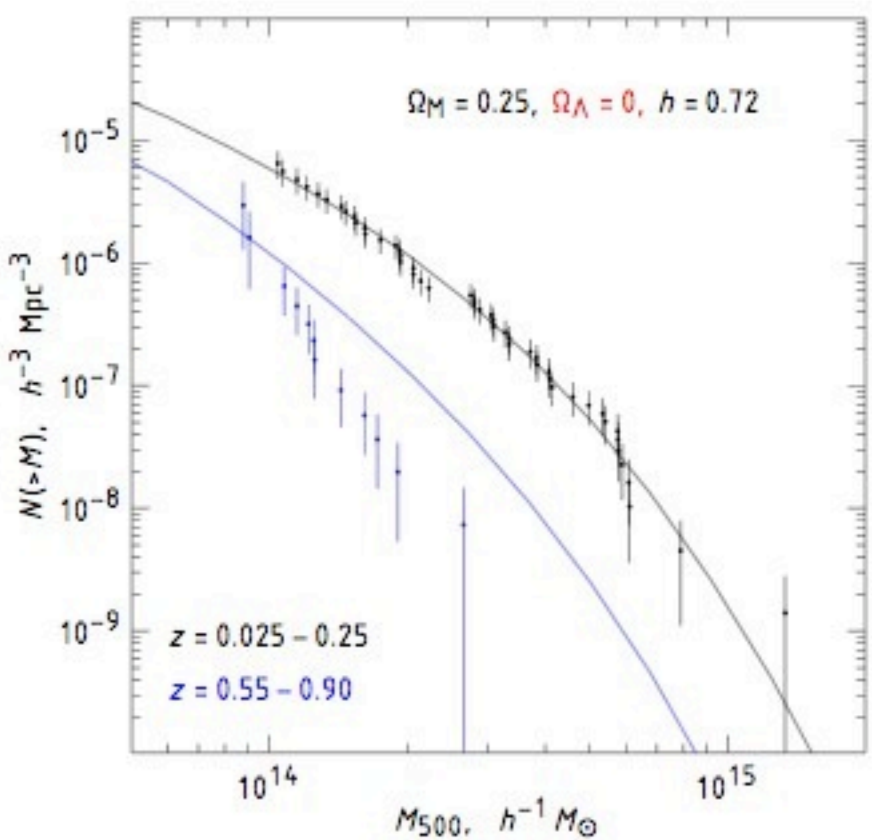


Wider Field Data necessary to argue DE

Cluster Count

Vikhlinin et al. 2008





Fewer Clusters of galaxies

↓

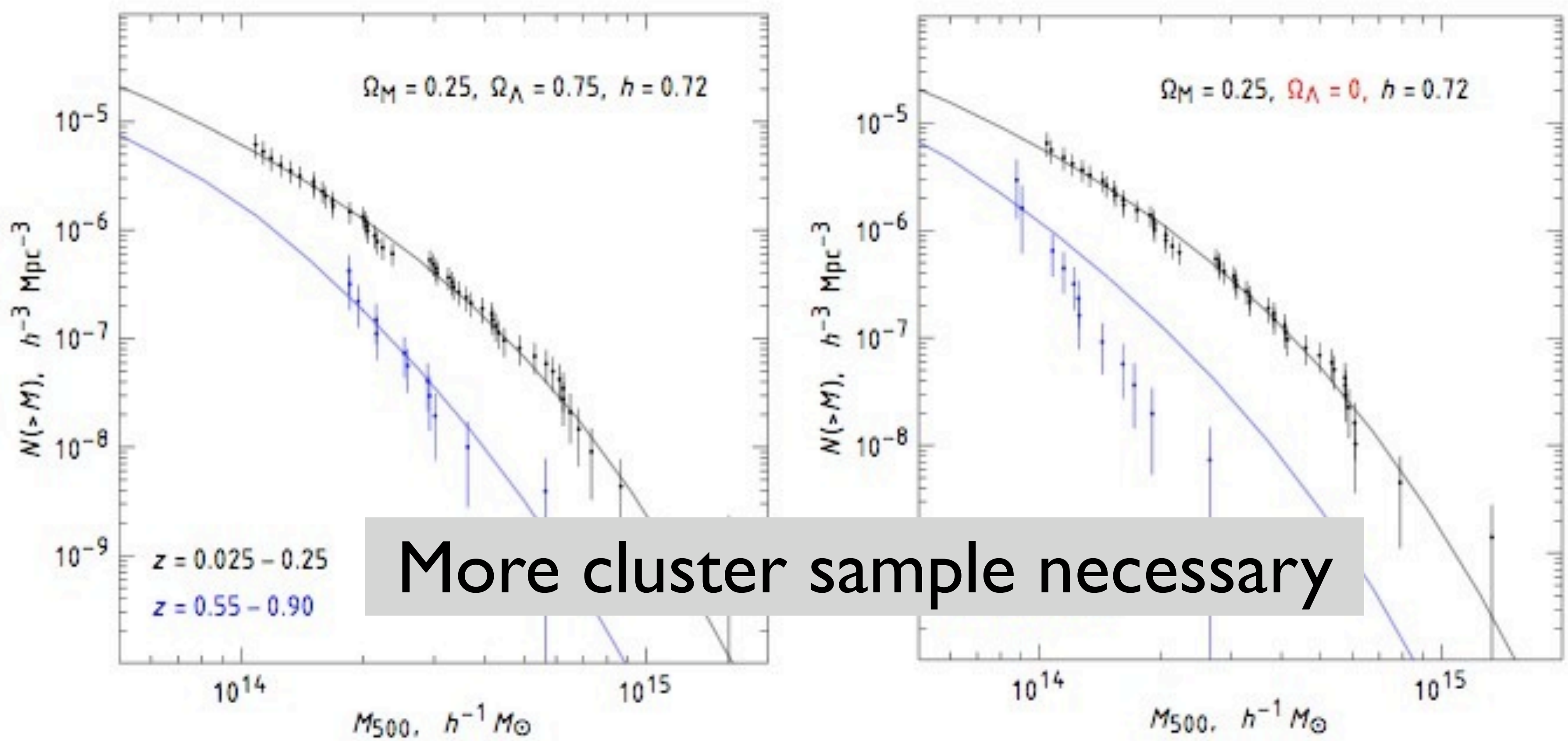
Smaller DM clustering・smaller volume

↓

Faster cosmic acceleration→larger w

Cluster Count

Vikhlinin et al. 2008



More cluster sample necessary

Fewer Clusters of galaxies

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Smaller DM clustering・smaller volume

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Weak Lensing Cluster Search

- Standard search: baryon tracer (optical, X-ray)
- Weak Lensing directly probes dark matter concentration

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Number Count of Clusters

$$N_i = \Delta\Omega\Delta z \frac{d^2V}{dz d\Omega}(z_i) \int_{M_{min}(z_i)}^{\infty} \frac{dn(M, z_i)}{dM} dM$$

Obs. Theory

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Obs.

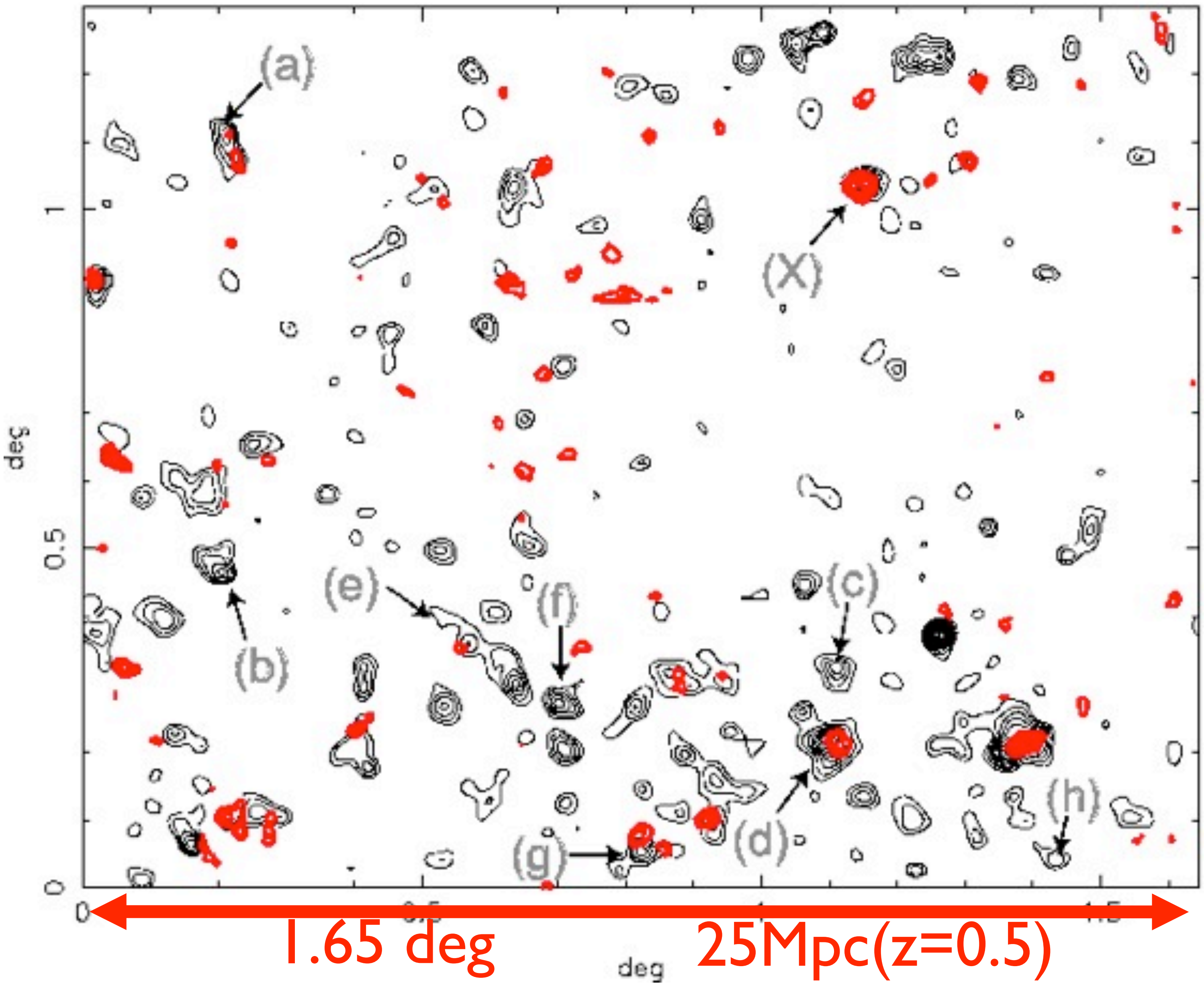
Theory

WL sampling is natural and efficient.

Pilot WL Cluster Survey

- Use Kappa S/N map to select cluster candidate
- Spectroscopic follow-up by multi object spectrographs (FOCAS)
  - to identify superposition of small systems
- ~ 20 square degree: 100 clusters candidates

Suprime-Cam GTO 2 deg2 weak lensing survey



Red

Mass map

(S/N > 3)

~10

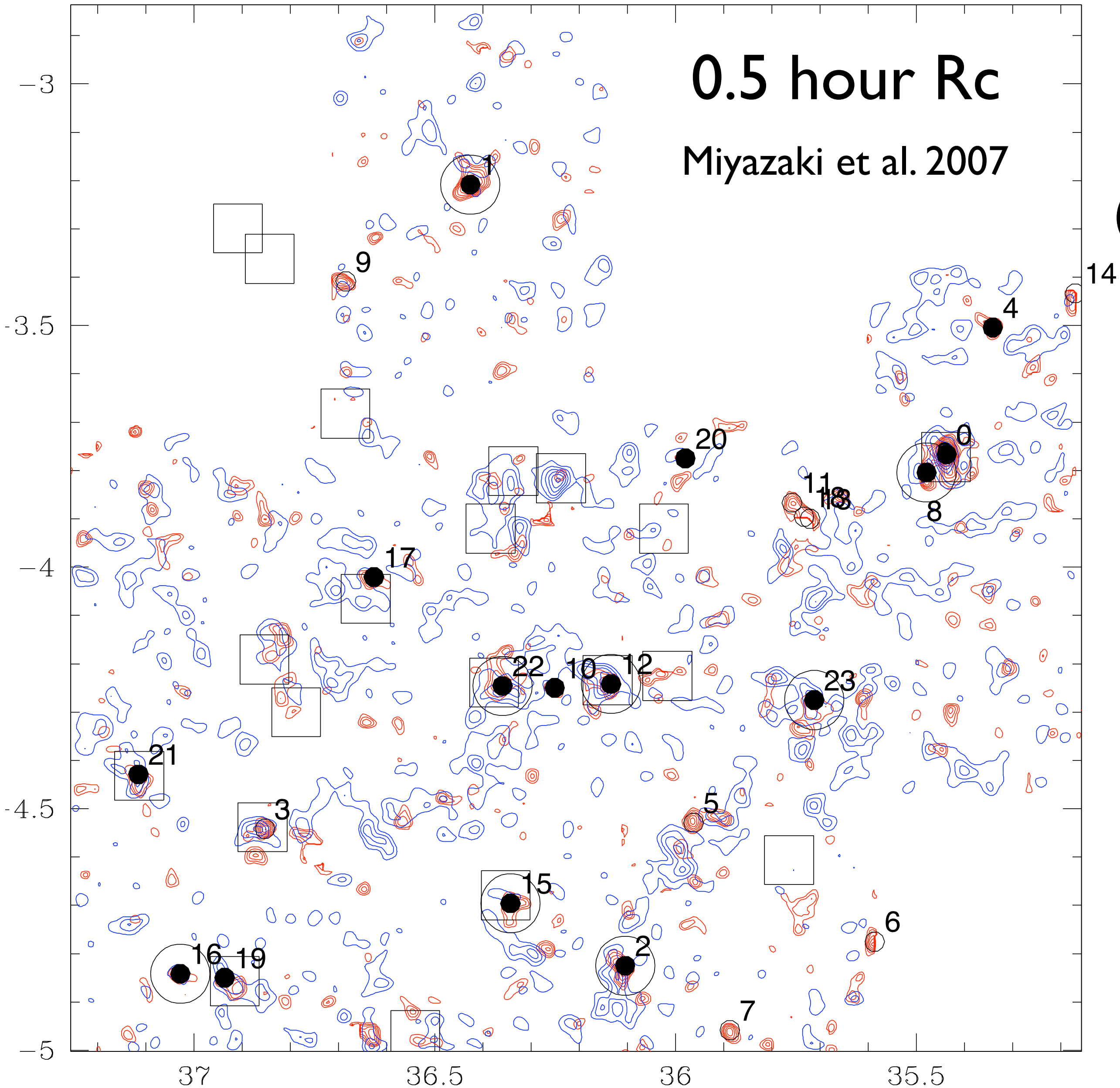
14Msolar Halo

Black

Light map

Miyazaki et al. 2002 ApJ Lett 580 L97

Cluster Identification



n: peaks in SN map

● secure halos (15)

○ This work follow-up

□ X-ray clusters

XMM-LSS 10 ks

red: kappa S/N
blue: galaxy density

Blind Cluster Survey

Field	n	ID	RA	DEC	κS/N	κ	N_g[a]	FOCAS[b]	Known[c]	NEDG[d]	Note
XMM-Wide	00	SL J0221.7-0345	35.44	-3.77	8.15	0.156	72	-	0.43	-	XLSSC 006
	01	SL J0225.7-0312	36.43	-3.21	5.72	0.108	41	0.14	-	-	LRIS z = 0.14
	02	SL J0224.4-0449	36.10	-4.82	5.06	0.074	40	0.49	-	-	
	04	-	35.34	-3.50	4.91	0.082	21	-	-	-	
	08	SL J0222.3-0446	35.48	-3.80	4.33	0.081	29	-	-	-	LRIS z = 0.41
	10	-	36.25	-4.25	4.20	0.062	23	-	-	-	
	12	SL J0224.5-0414	36.13	-4.24	4.06	0.057	70	0.26	-	-	LRIS z = 0.26
	15	SL J0225.3-0441	36.34	-4.70	3.94	0.091	34	0.26	-	-	
	16	SL J0228.1-0450	37.03	-4.84	3.94	0.072	31	0.29	-	-	
	17	SL J0226.5-0401	36.63	-4.02	3.90	0.079	37	-	0.34	-	XLSSC 014
	19	SL J0227.7-0450	36.94	-4.85	3.81	0.064	43	-	0.29	-	Pierre et al. (2006
	20	-	35.98	-3.77	3.81	0.048	20	-	-	-	
	21	SL J0228.4-0425	37.12	-4.43	3.80	0.055	49	-	0.43	-	XLSSC 012
	22	SL J0225.4-0414	36.36	-4.25	3.72	0.073	43	0.14	-	-	
	23	SL J0222.8-0416	35.71	-4.27	3.69	0.049	52	0.43,0.19,0.23	-	-	

Miyazaki et al. 2007

12/15 (= 80 %) is identified as clusters (S/N > 3.7)

(3 unidentified halos have not yet been observed spectroscopically.)

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Miyazaki et al. 2007

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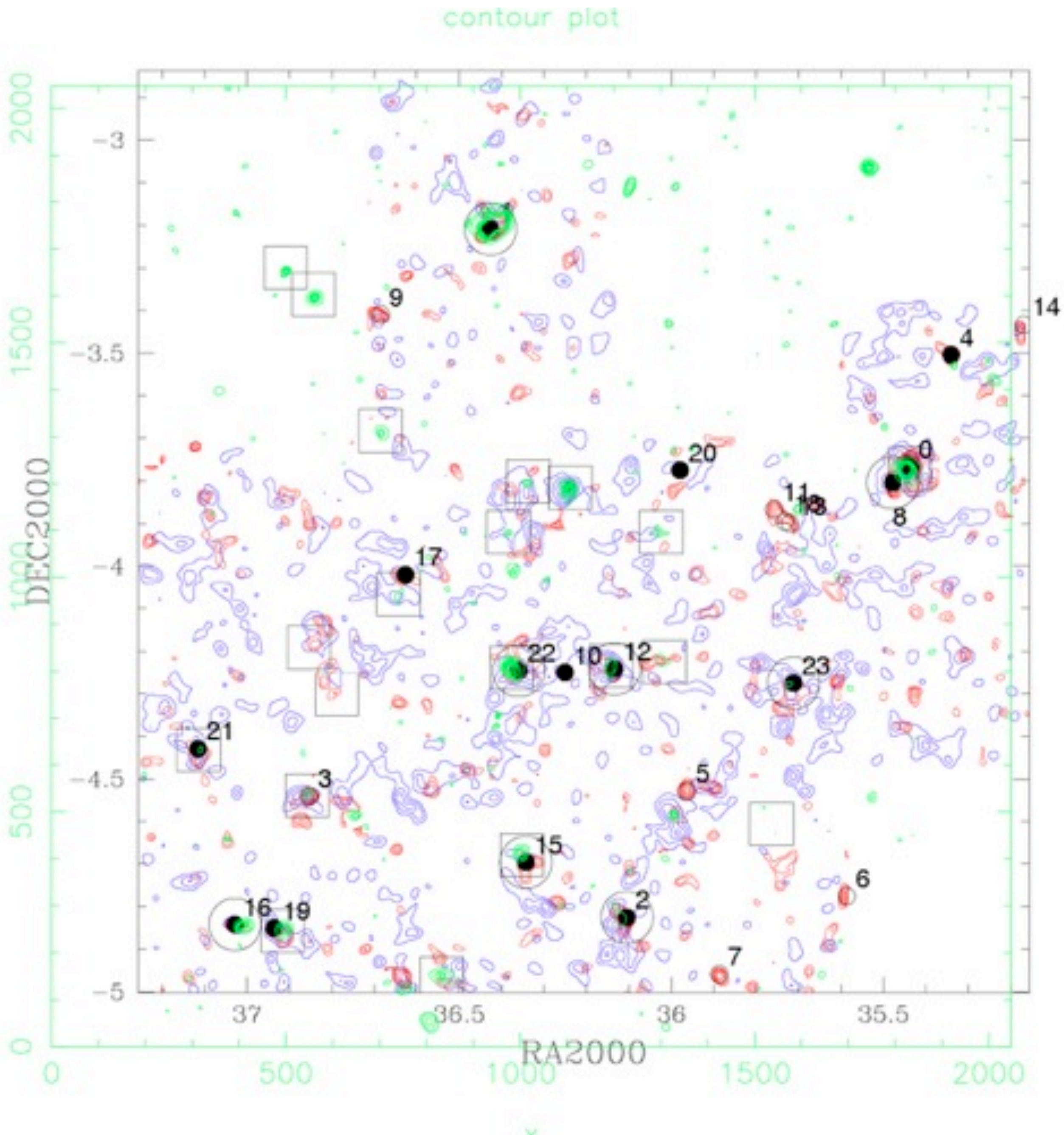
WL Cluster survey is feasible

(3 unidentified halos have not yet been observed spectroscopically.)

WL vs X-ray

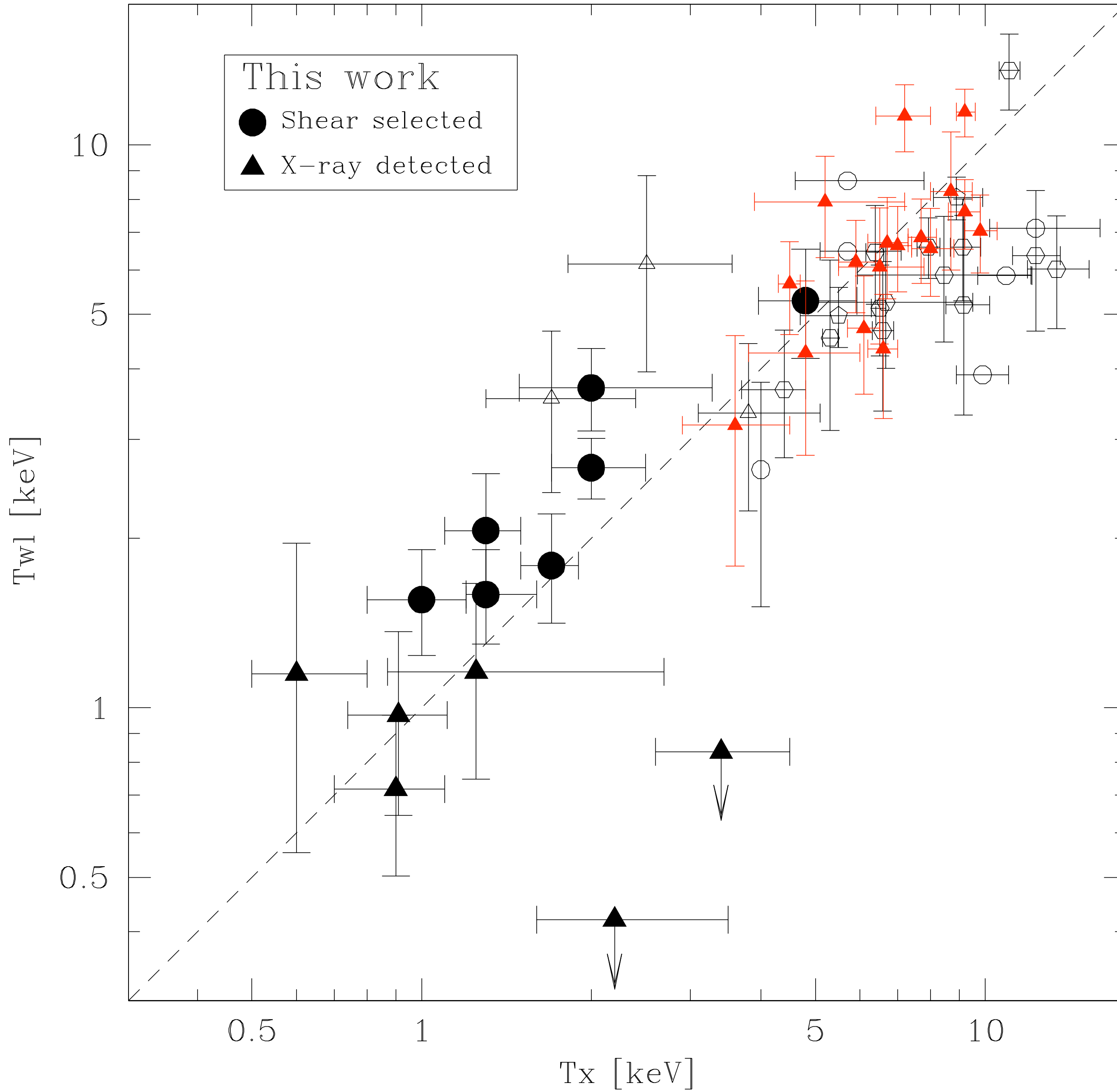


Relatively Deep X-ray Survey (10 ks) is necessary to obtain Tx (mass proxy)

Weak Lensing at large aperture telescope requires moderate exposure time (0.5 hr)

WL offers more economical way to collect samples

SIS fit to derive Twl



Miyazaki et al. in prep.

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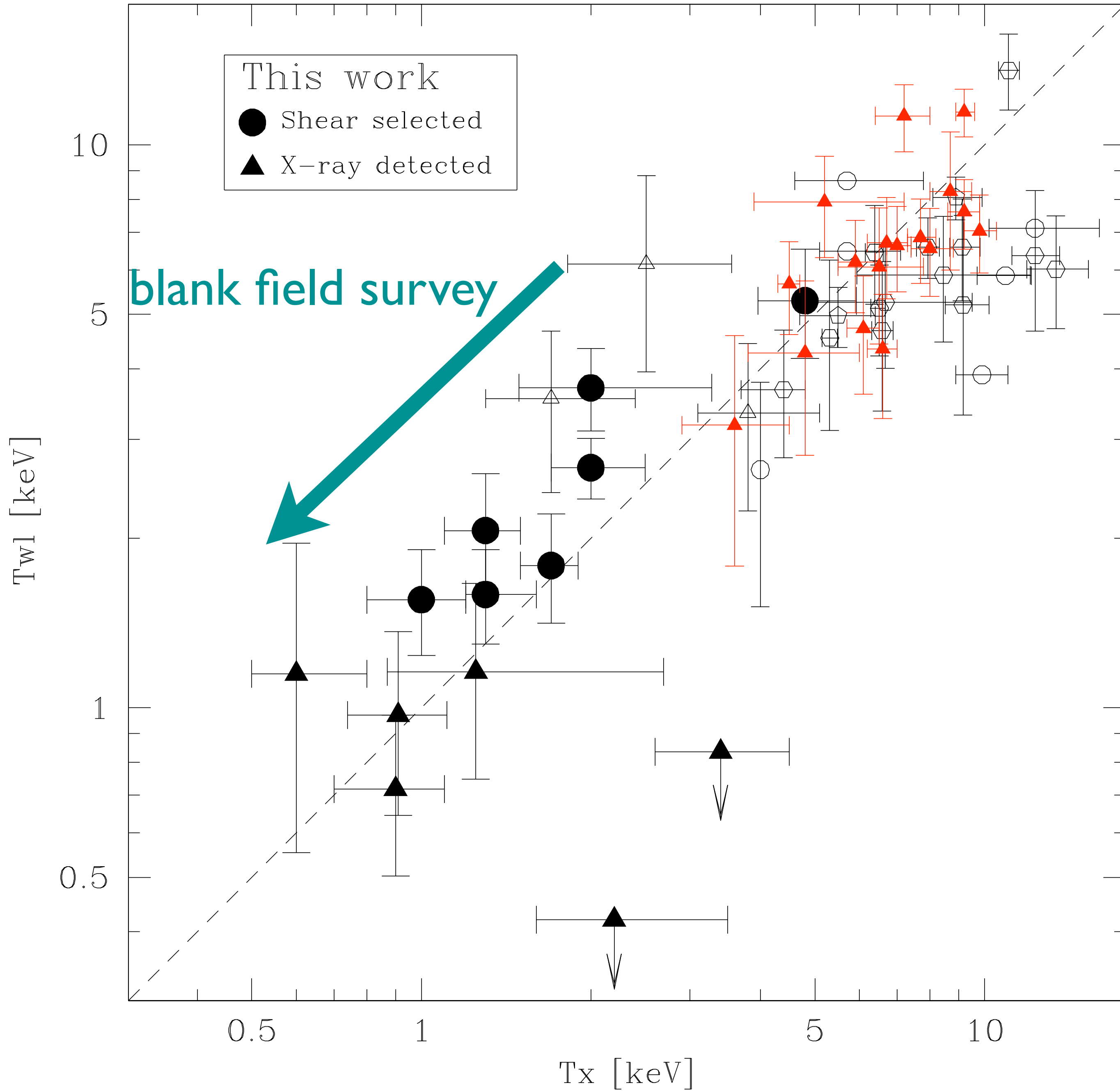

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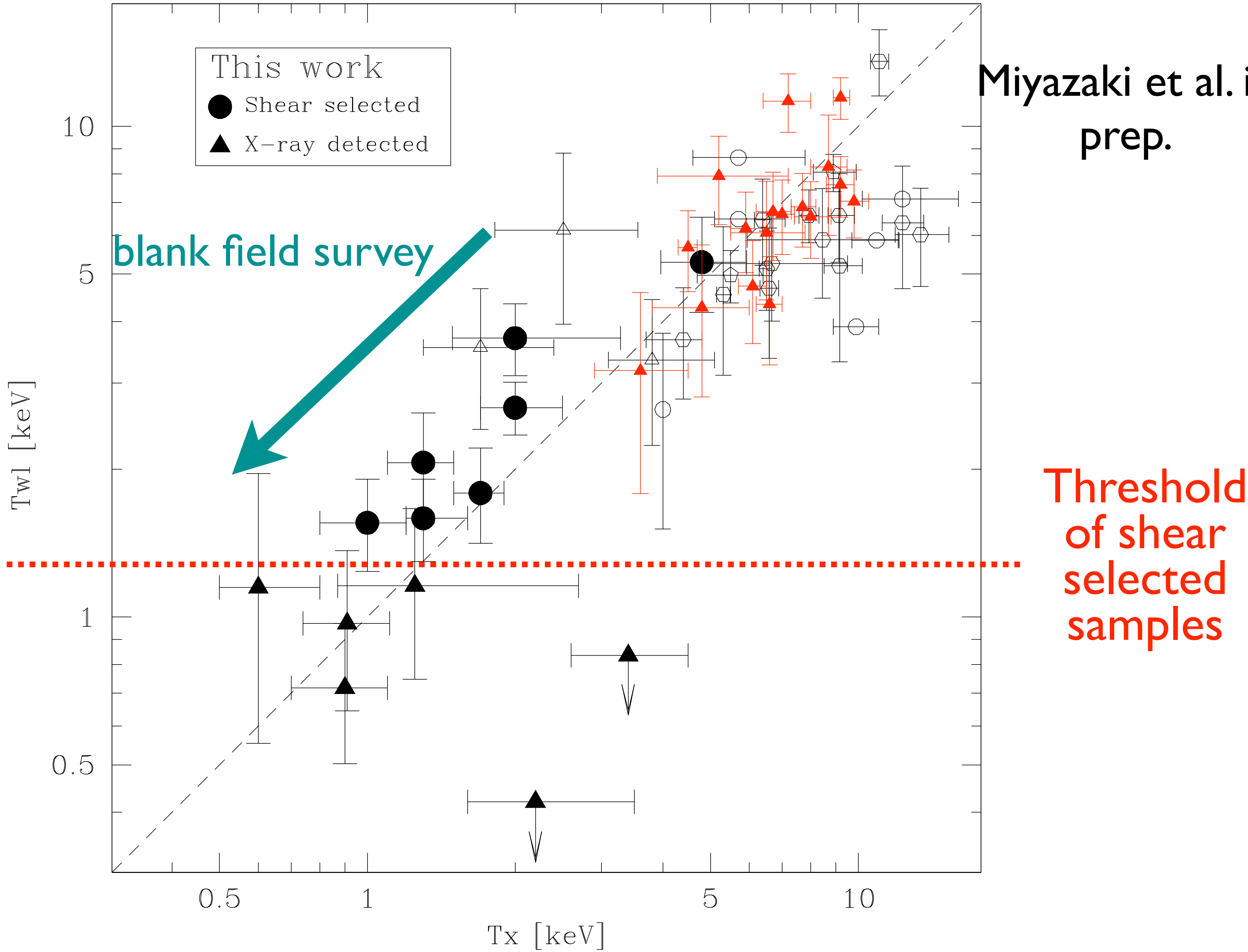

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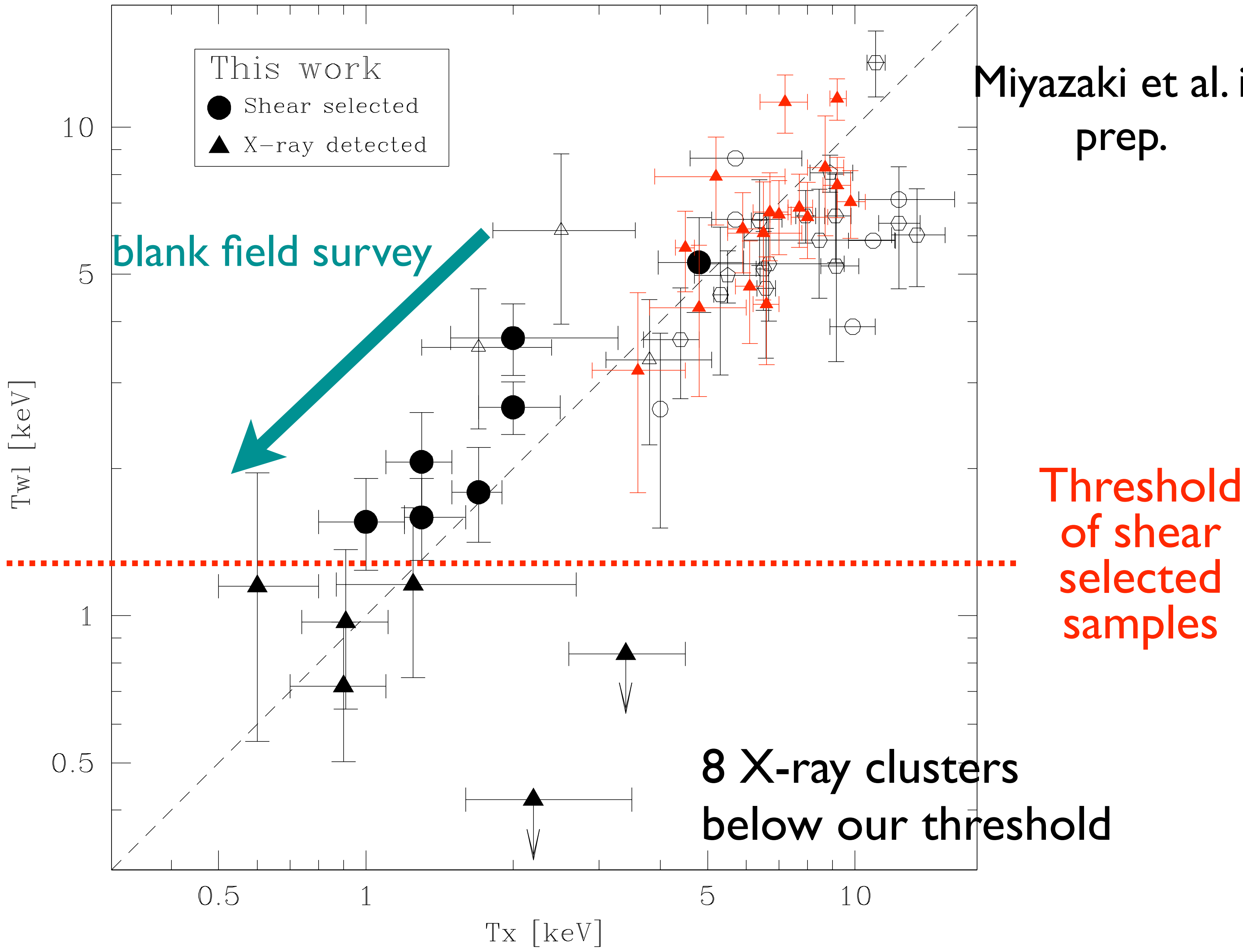

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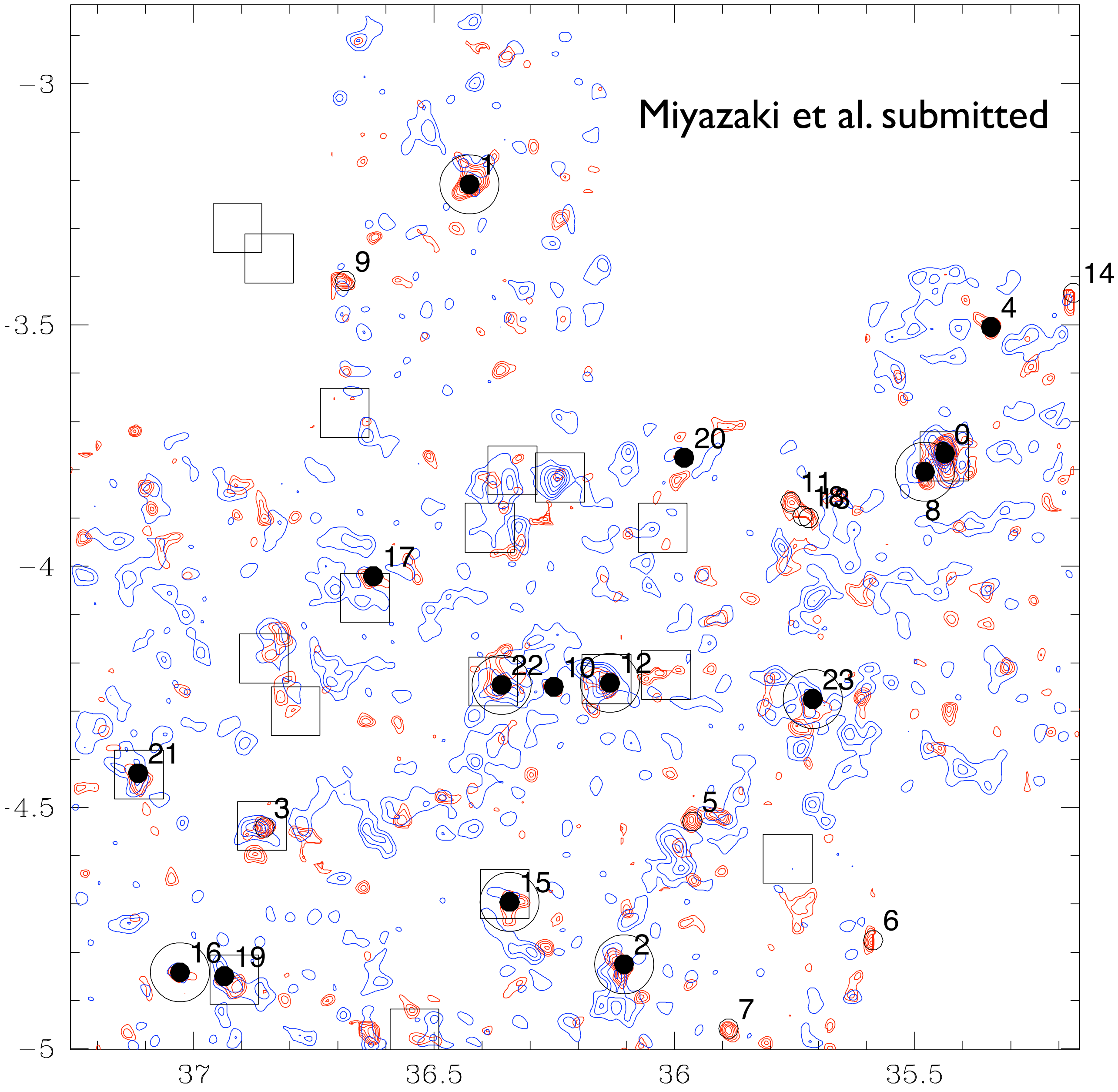
Comparison at CFHLS D1



Rc: 0.5 hour (x 13p)

30-40 gals/arcmin2

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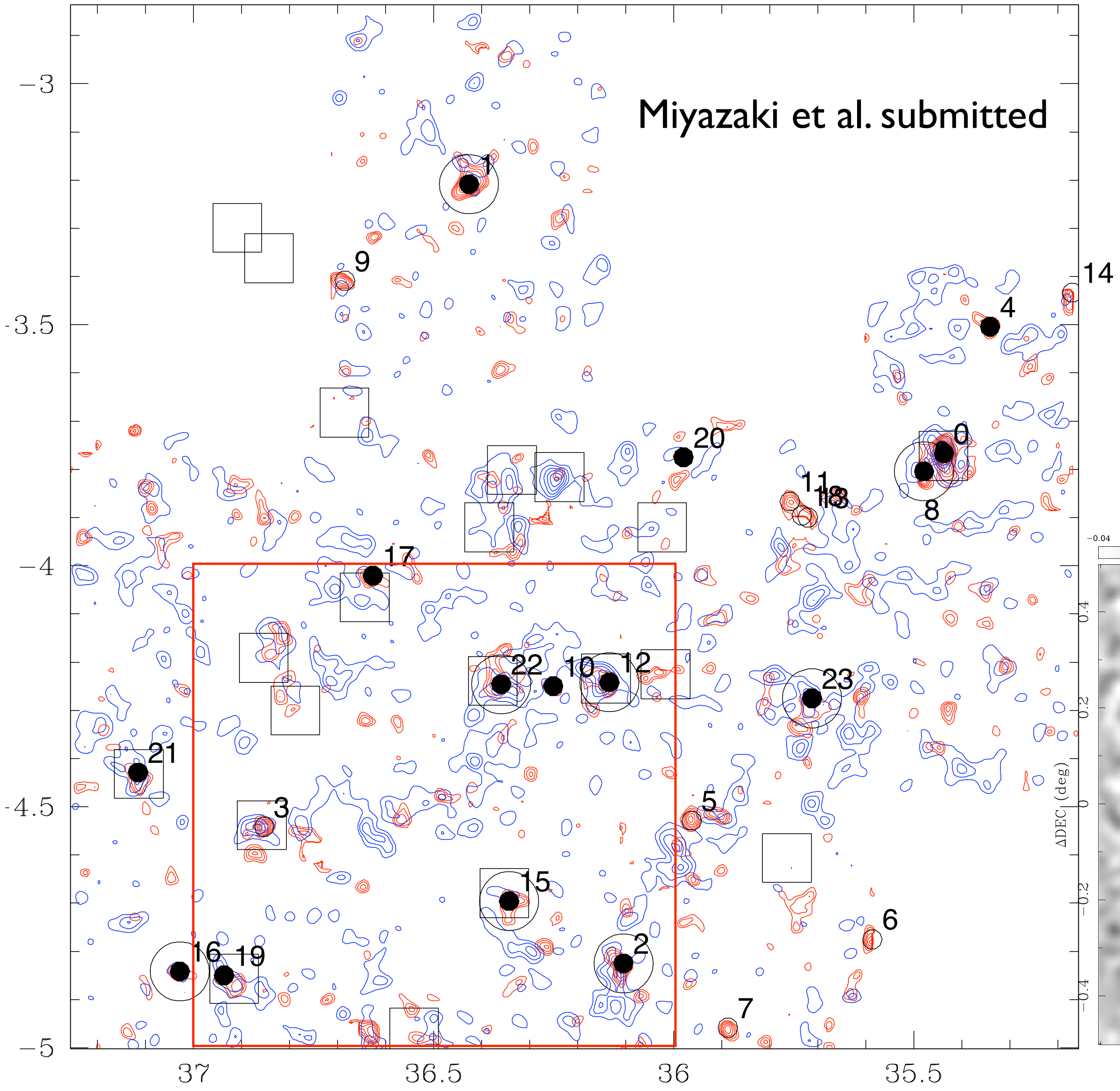
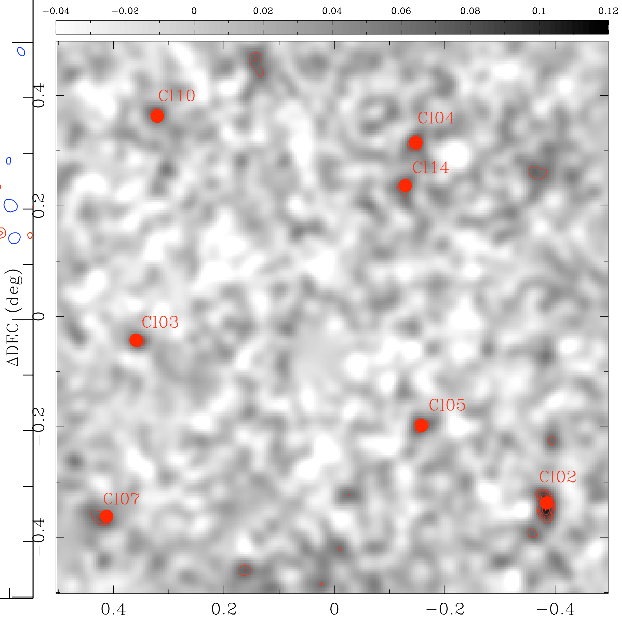


Rc: 0.5 hour (x 13p)

30-40 gals/arcmin2

tens of hours i'

T00003 DR



Gavazzi & Soucail (2007)

LSST Science Book

Version 2.0

November 2009

14.3.7 Shear-selected Clusters

The mass maps lead naturally to the idea of searching for clusters with weak lensing. Weak lensing has traditionally been used to provide mass measurements of already known clusters, but fields of view are now large enough(2–$20\ \mathrm{deg}^2$) to allow blind surveys for mass overdensities (Wittman et al. 2006; Dietrich et al. 2007; Gavazzi & Soucail 2007; Miyazaki et al. 2007; Massey et al. 2007b). Based on these surveys, a conservative estimate is that LSST will reveal two shear-selected clusters deg^{-2} with good signal-to-noise ratio, or 40,000 over the full survey area. Results to date suggest that many of these will not be strong X-ray sources, and many strong X-ray sources will not be selected by shear. This is an exciting opportunity to select a large sample of clusters based on mass only, rather than emitted light, but this field is currently in its infancy. Understanding selection effects is critical for using cluster counts as a cosmological tool (see Figure 12.22 and § 13.6) because mass, not light, clustering is the predictable quantity in cosmological models; simulations of structure formation in these models (§ 15.5) will be necessary to interpret the data. Shear selection provides a unique view of these selection effects, and LSST will greatly expand this view.

Prepared by the LSST Science Collaborations,
with contributions from the LSST Project.

Suprime-Cam and WL

We have demonstrated that Subaru/Suprime-Cam is powerful facility to carry out weak lensing survey that can probe dark matter clustering.

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More data is necessary to argue the nature of Dark Energy

Upgrade of Suprime-Cam

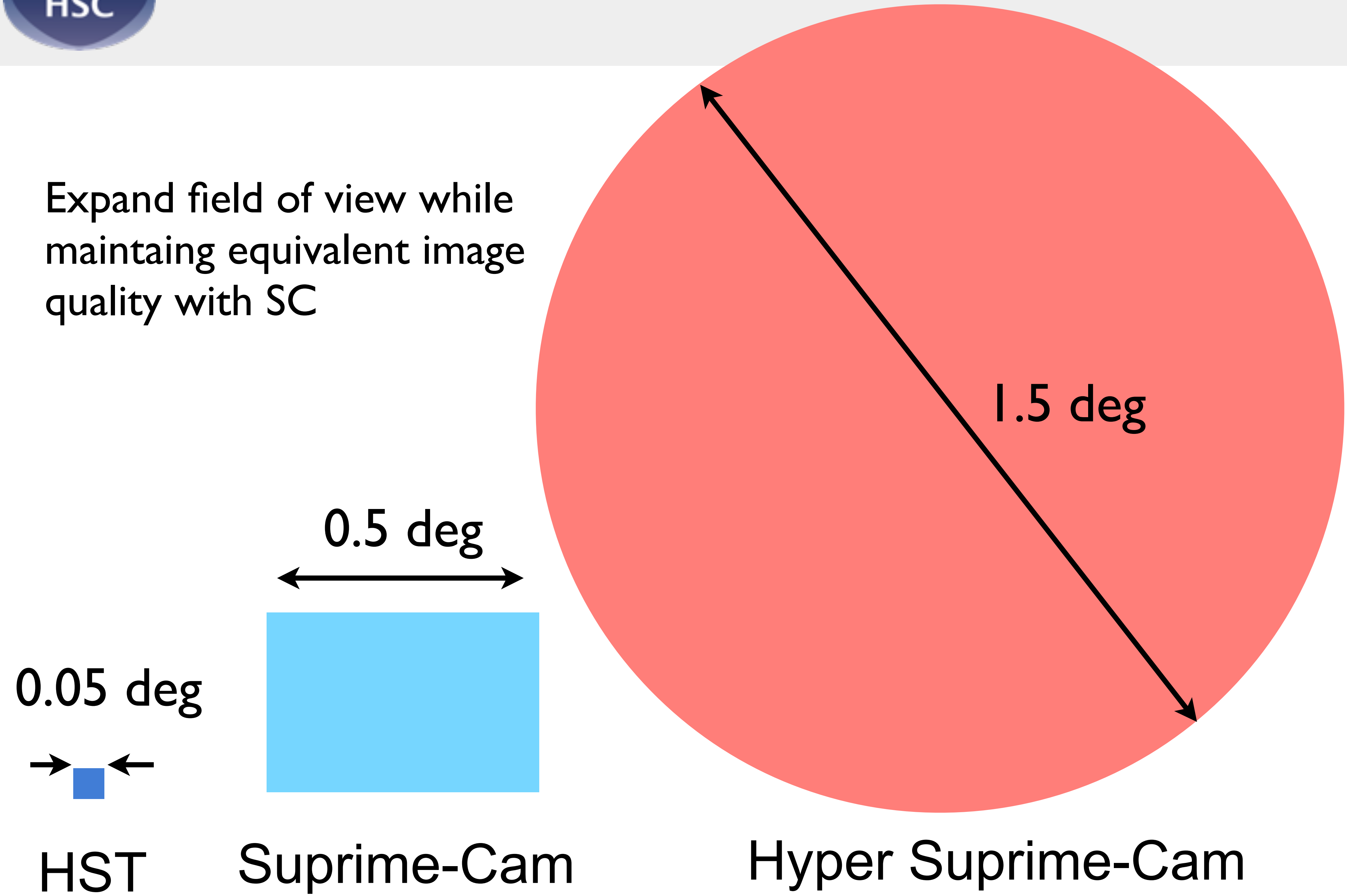
Suprime-Cam Strength and Upgrade

1. Large Aperture	
2. Wide Field of View	Wider
3. Superb image quality	Keep it
4. High QE in red	Higher

Wider Field of View

Hyper Suprime-Cam

Expand field of view while maintaing equivalent image quality with SC



HSC Collaboration

National Astronomical Observatory of Japan

University of Tokyo (J)

KEK (J)

ASIAA (Taiwan)

Princeton University (US)

Mitsubishi Electric
Canon
Hamamatsu Photonics

Industrial Partners

- Larger Focal Plane　1.5 deg diameter
  - More CCDs
  - Large Filters
- New Wide Field Corrector
- New Prime Focus Unit
  - Optics alignment system
  - mechanical interface to the telescope

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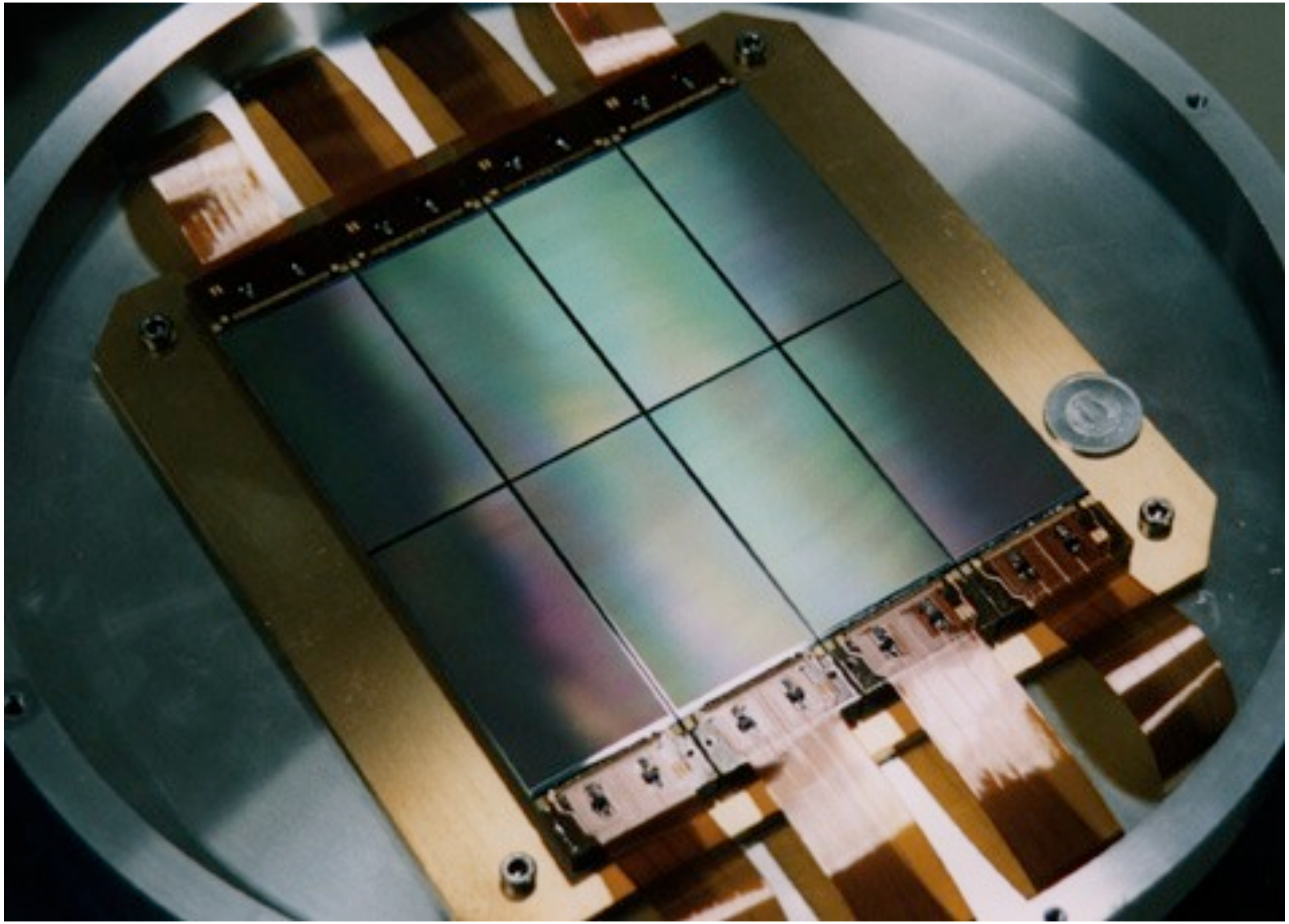
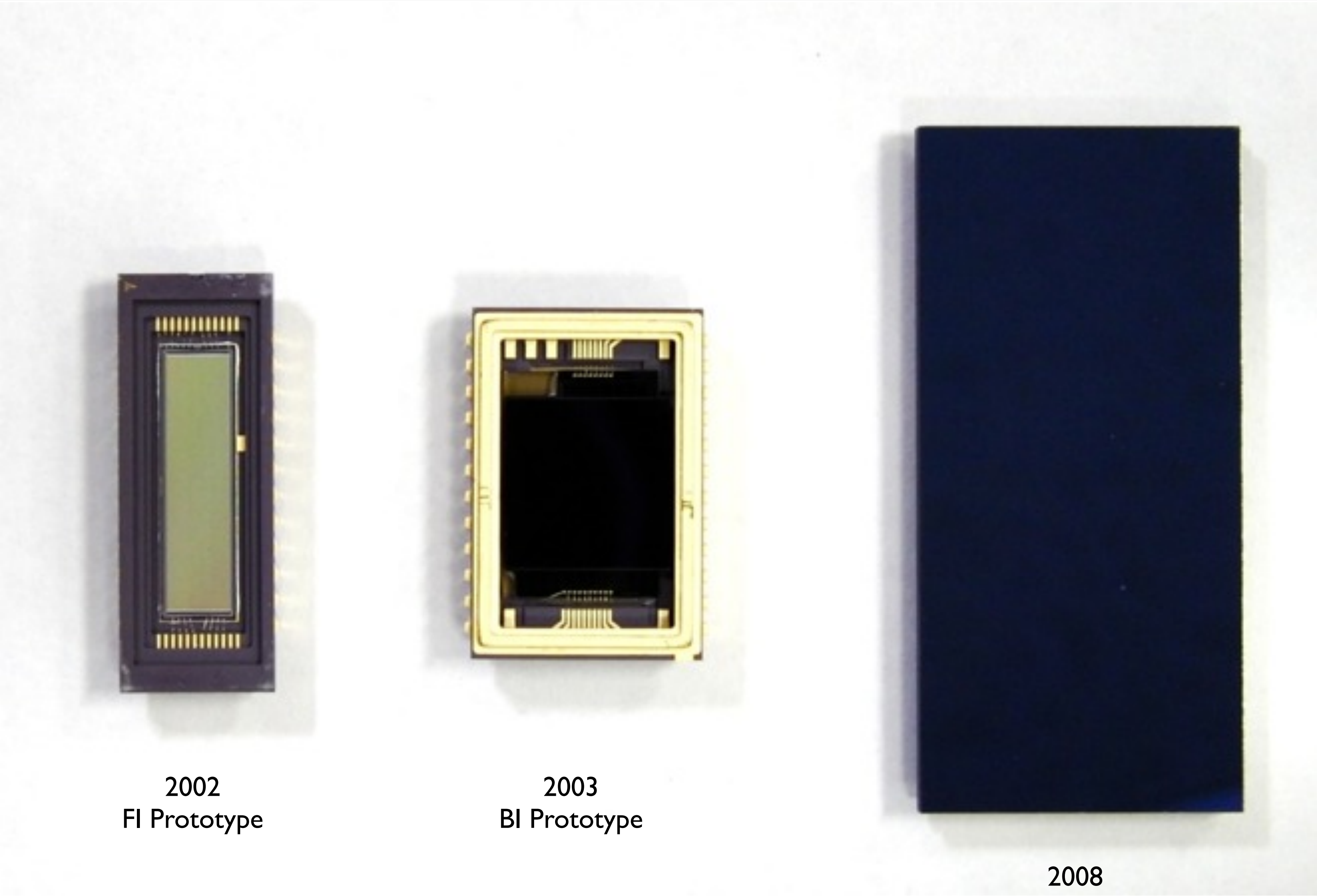
Detector

NAOJ-Hamamatsu Collaboration



1998 n-ch Front Illminated CCD

p-ch Development History

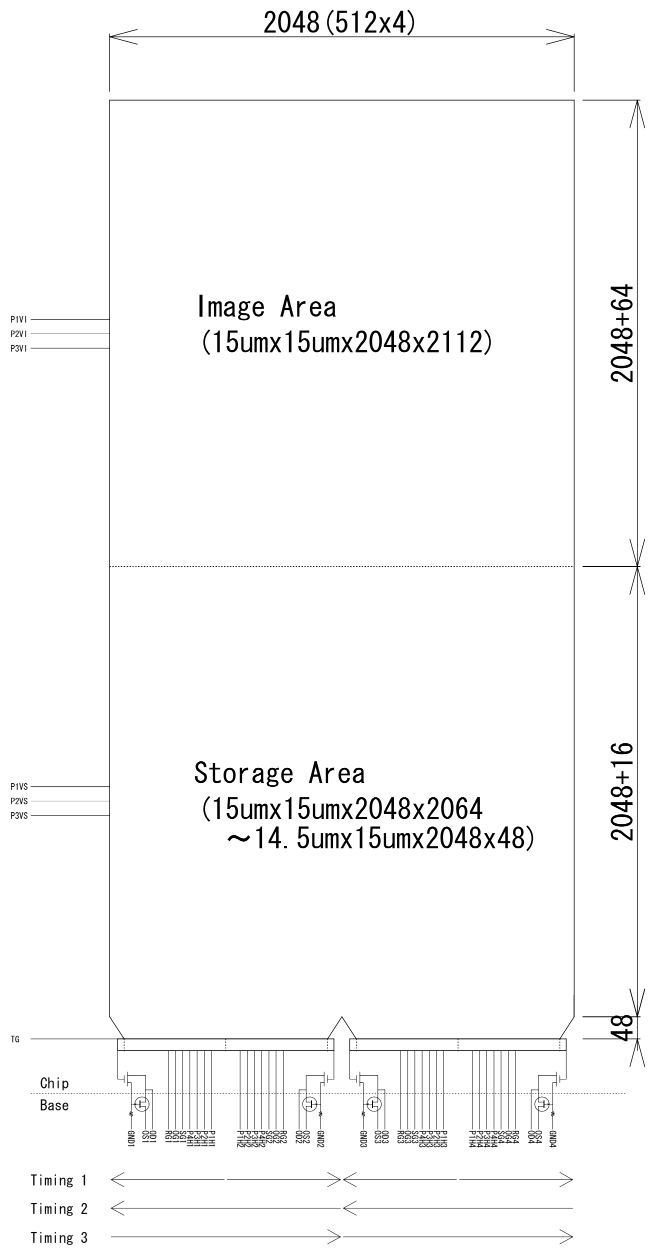


2002
FI Prototype

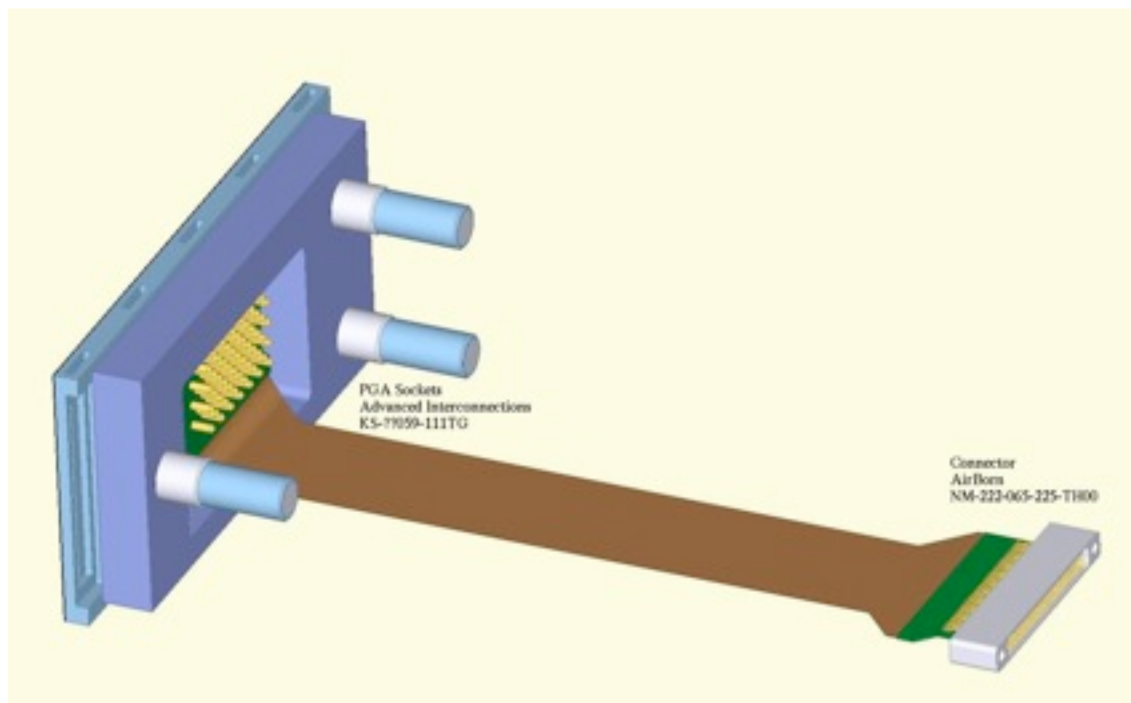
2003
BI Prototype

2008
2k4k BI

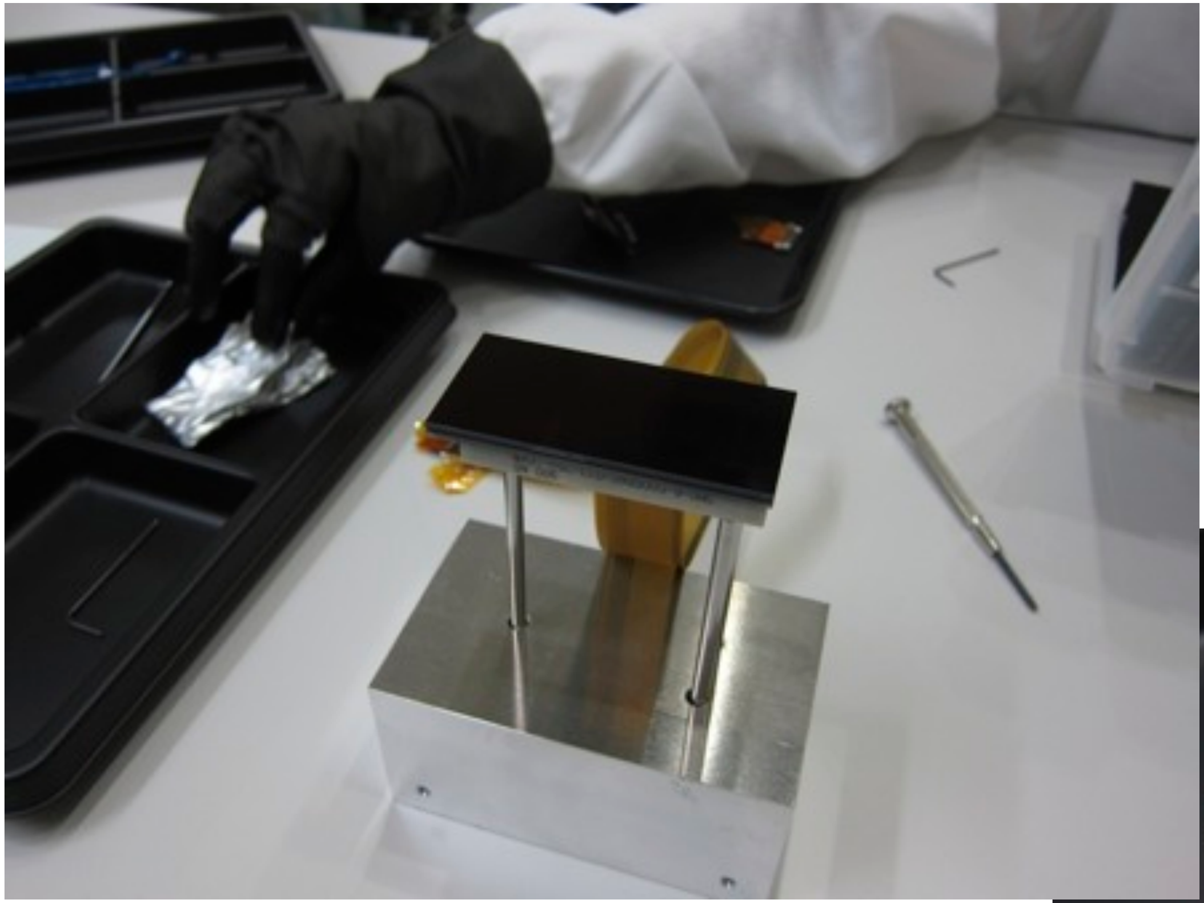
HPK p-ch CCD

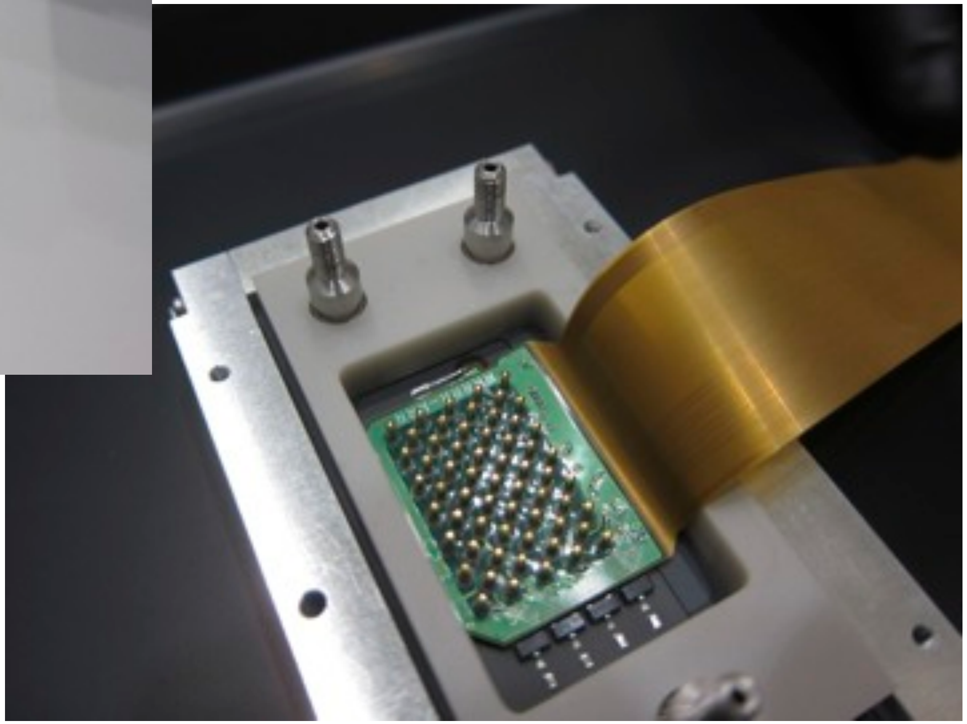


CCD Structure	Full Frame Transfer
Si Thickness	200 μm (Can be 100 $\sim$ 300 μm)
Vertical clock phase	3 phases
Horizontal clock phase	2 phases or 4 phases
Output Amprilfiers	4 one stage MOSFET on chip and one J-FET on the package
Package Material	Aluminum Nitride

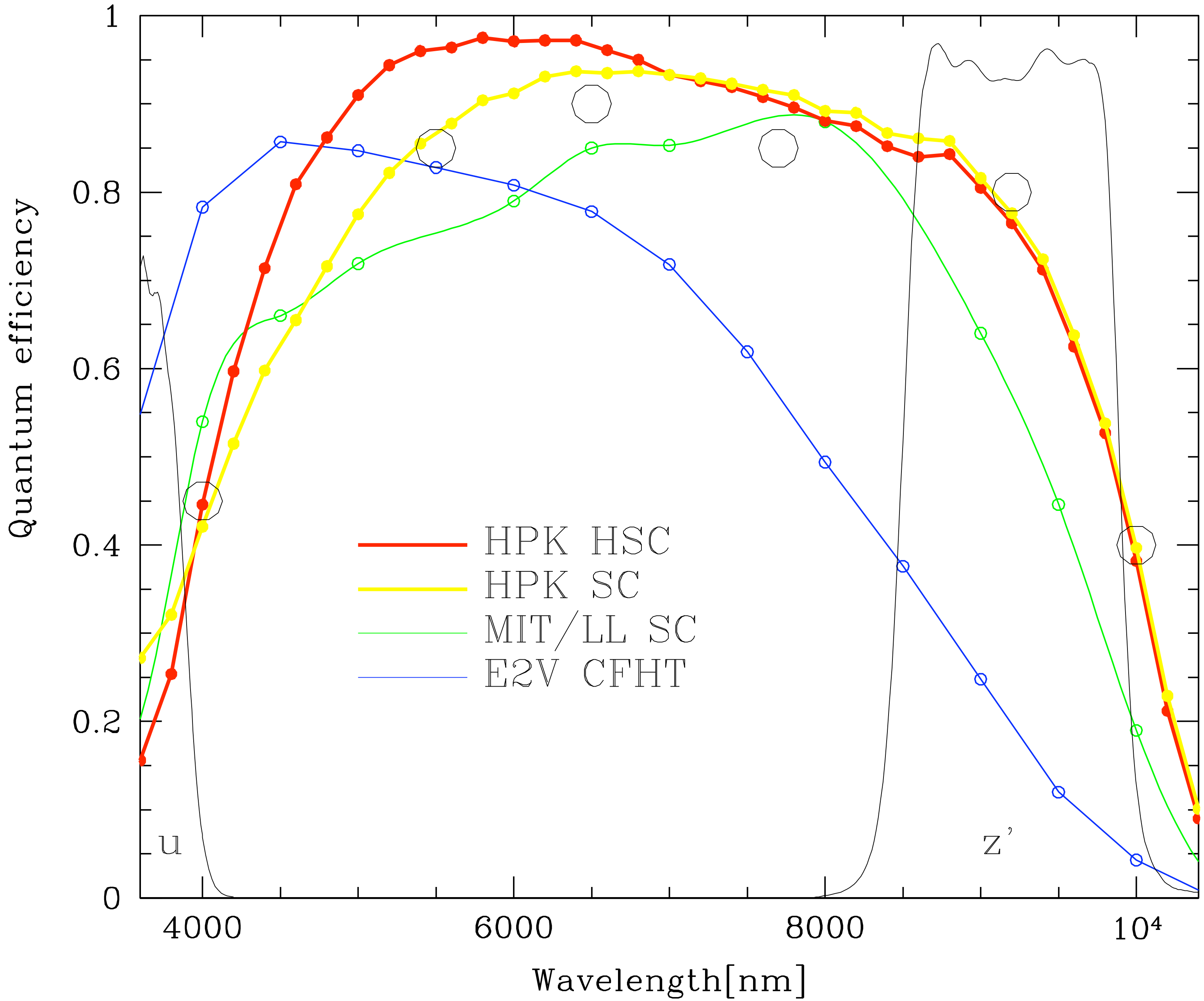


HPK pch CCD



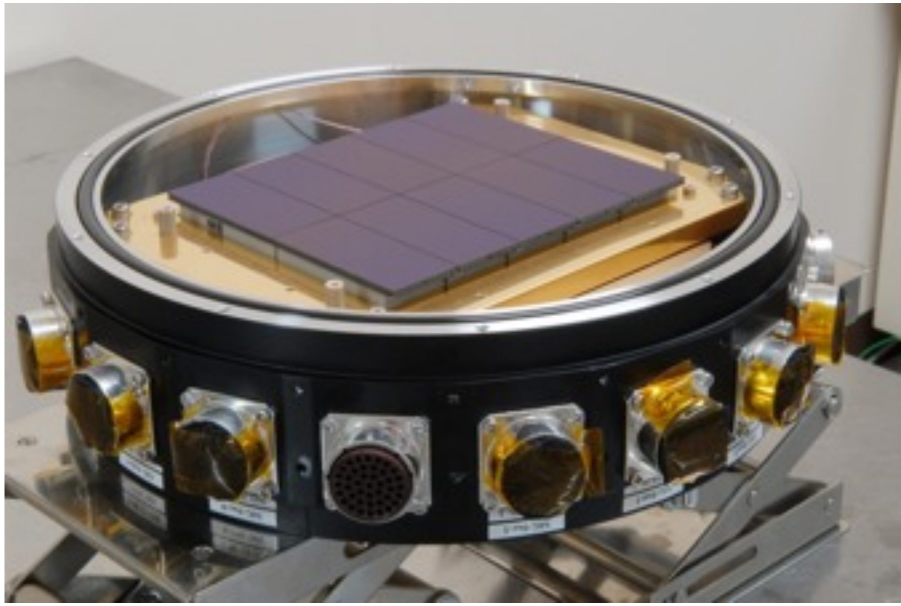


Quantum Efficiency

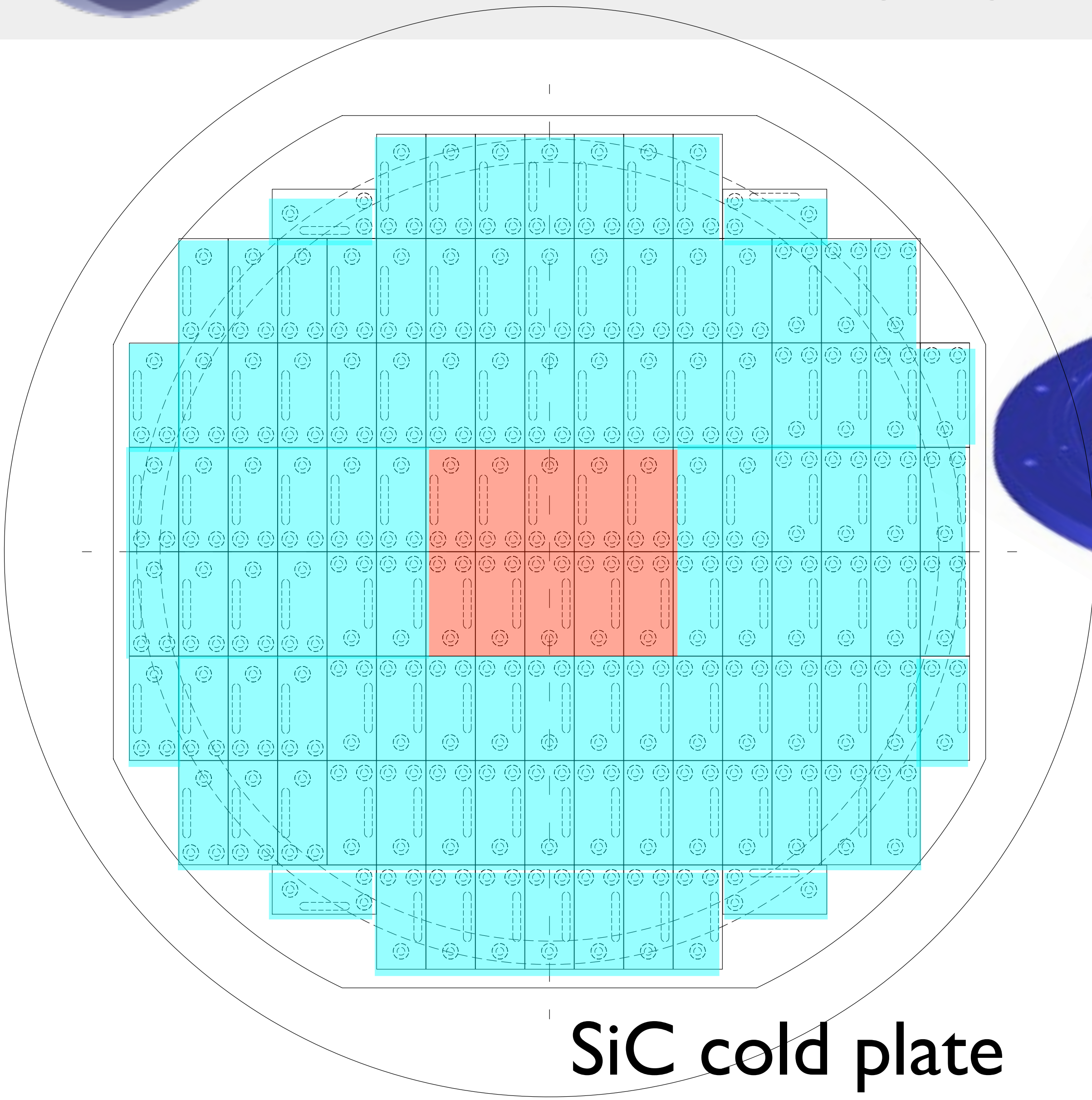


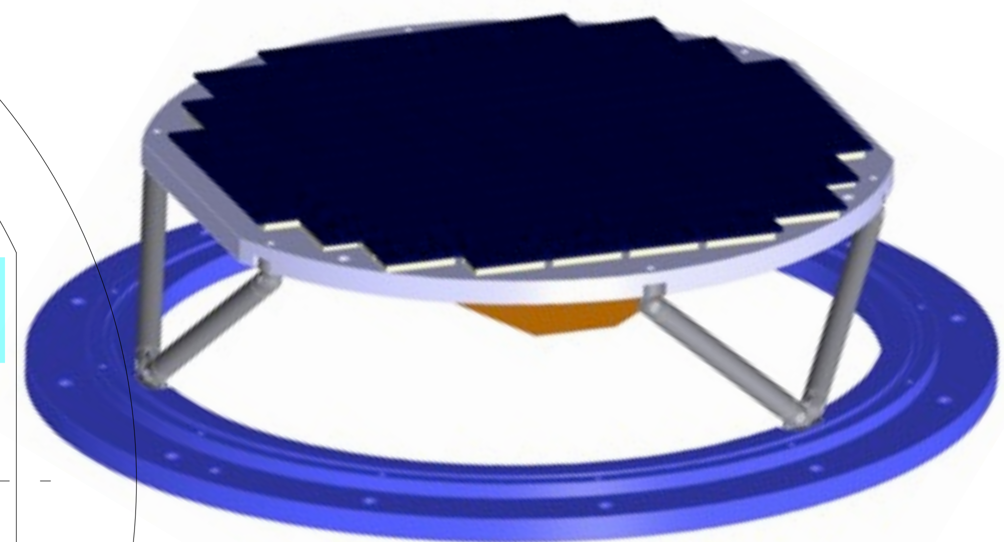
Mounted on Subaru

Replacement of MIT/LL CCID-20
July, 2008

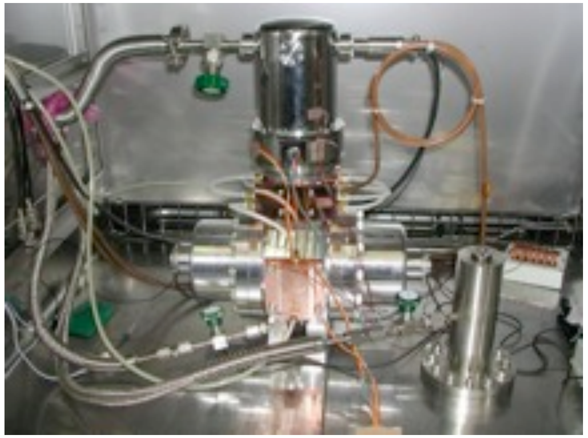



HSC Focal Plane



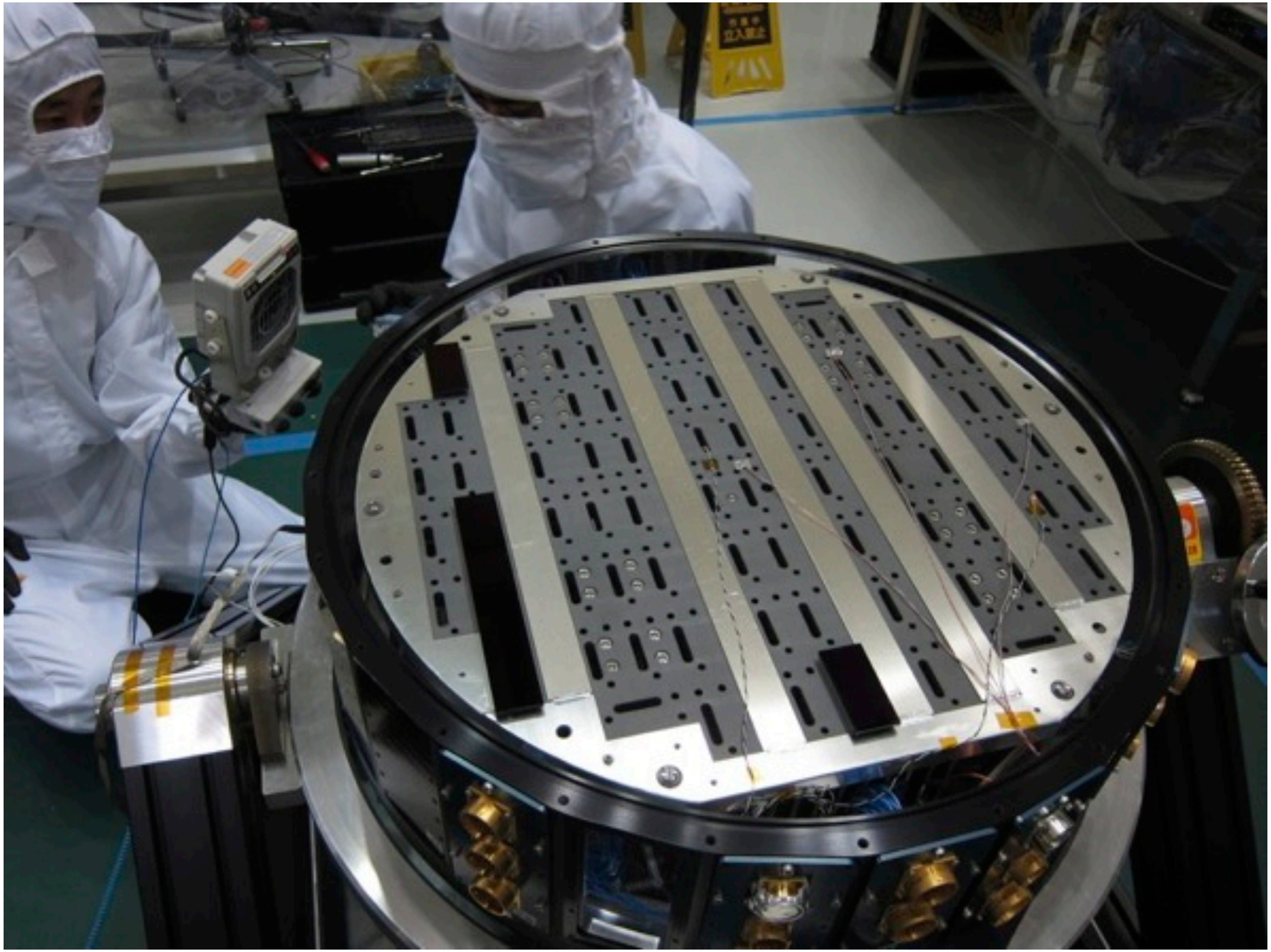


104 Science
4 Guides
8 Focus check



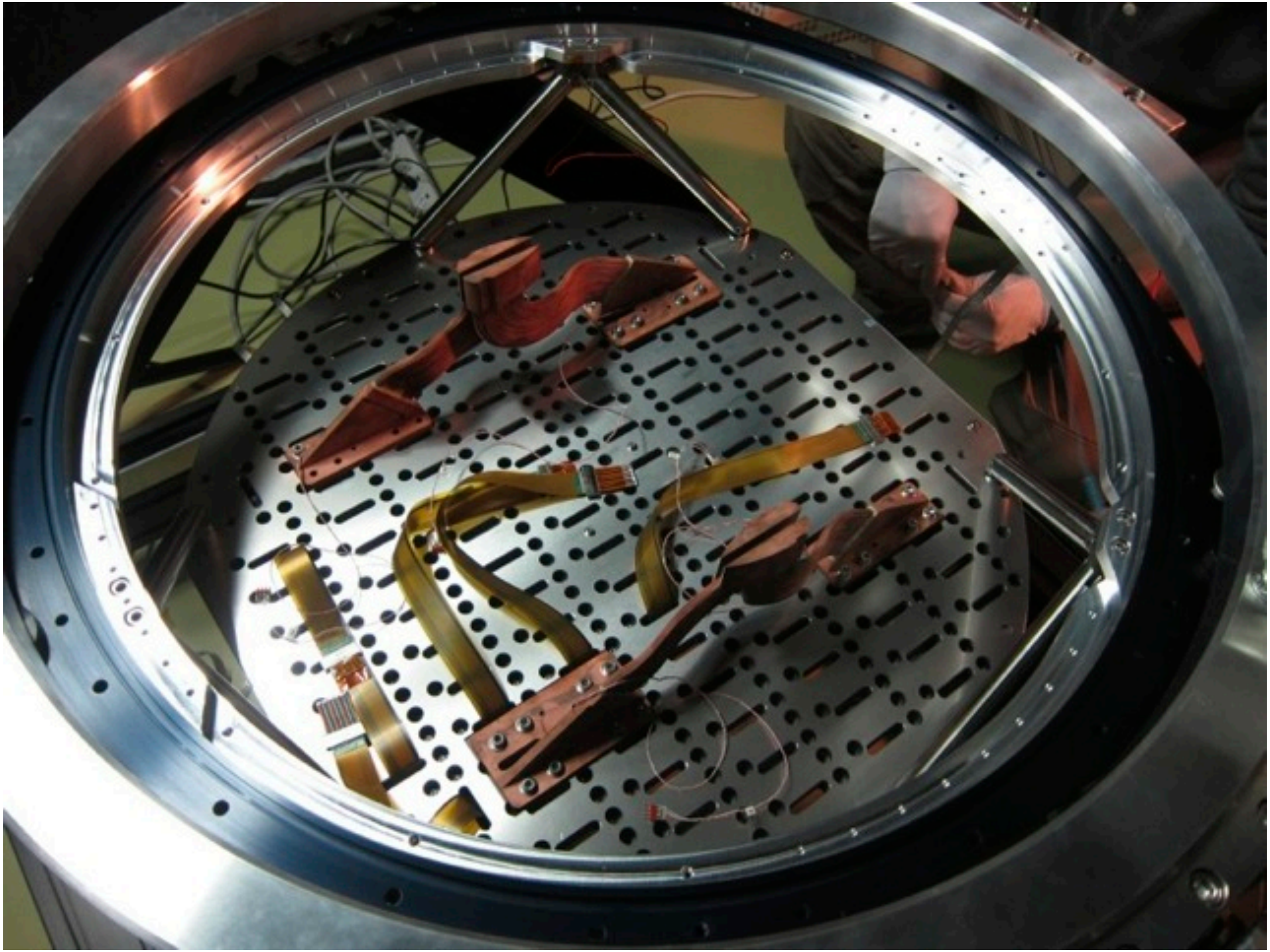
SiC cold plate
Cooled by two pulse tube coolers
45 W@-100 C each

HSC Focal Plane

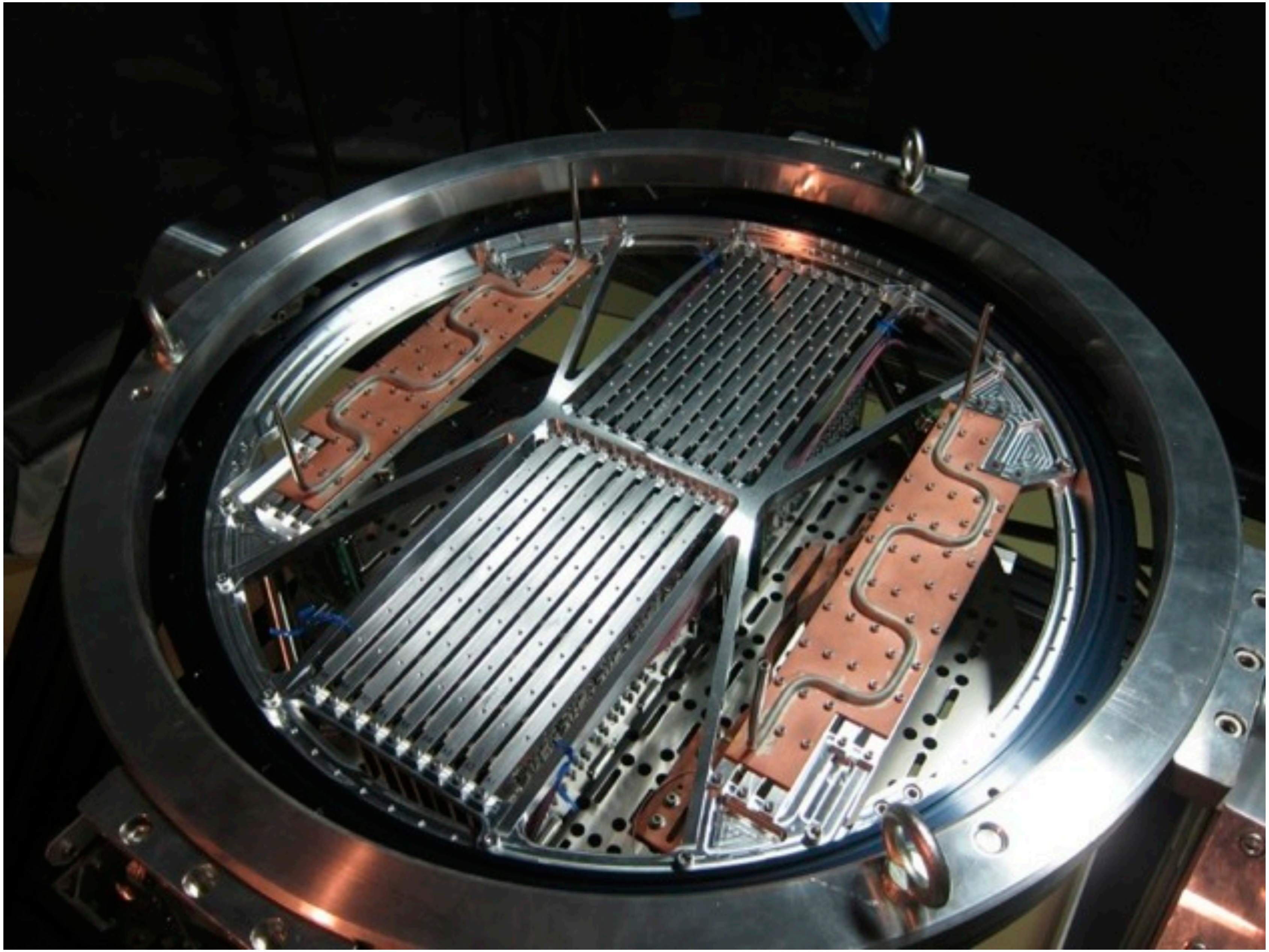


five installed and being tested

HSC Focal Plane



Electronics Assembly

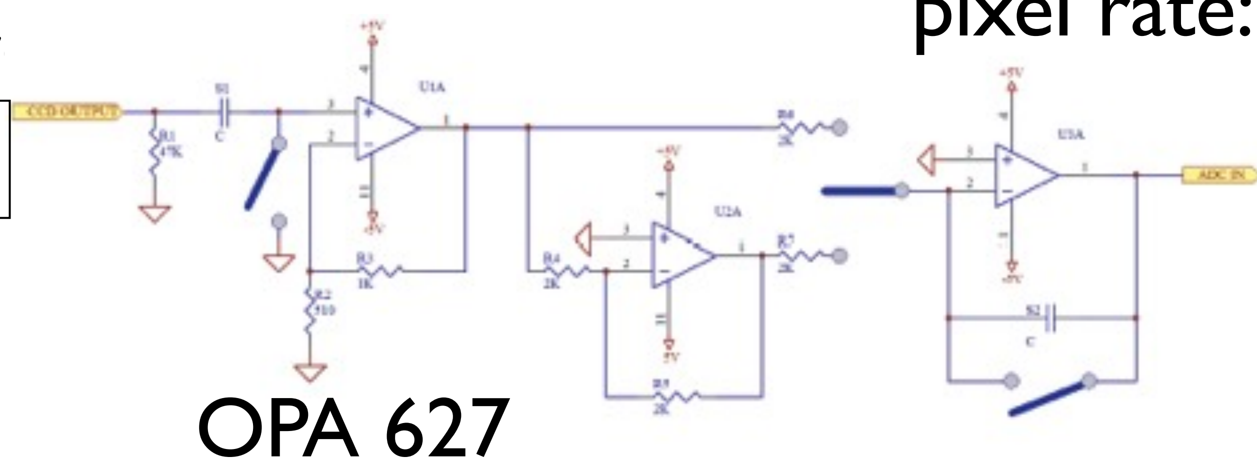


FEE: Signal processing circuit

- Double-slope type CDS circuit based on SDSS photometric camera
- 3 op-amps signal processor to achieve low power consumption
  - Pre-amp
  - Inverting amp
  - Integration amp
- AC coupling with DC level restoration
- Low power and fast op-amps with quick overload recovery (No need of clamp diode)
- 0.05% linearity error over the full signal range
- -150ppm/

pixel rate: 250 kpix/s

CCD



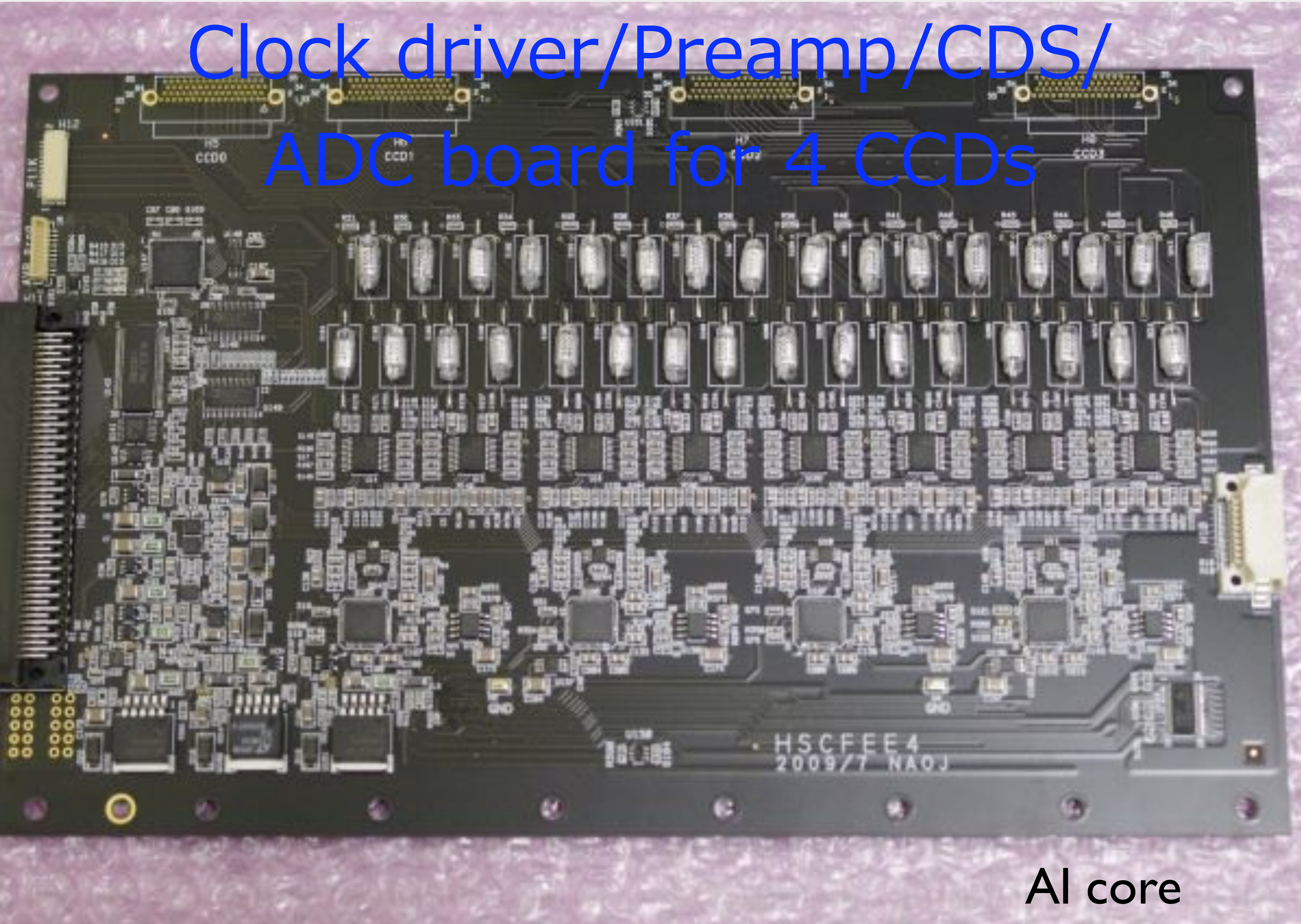
ADC

OPA 627

AD7686

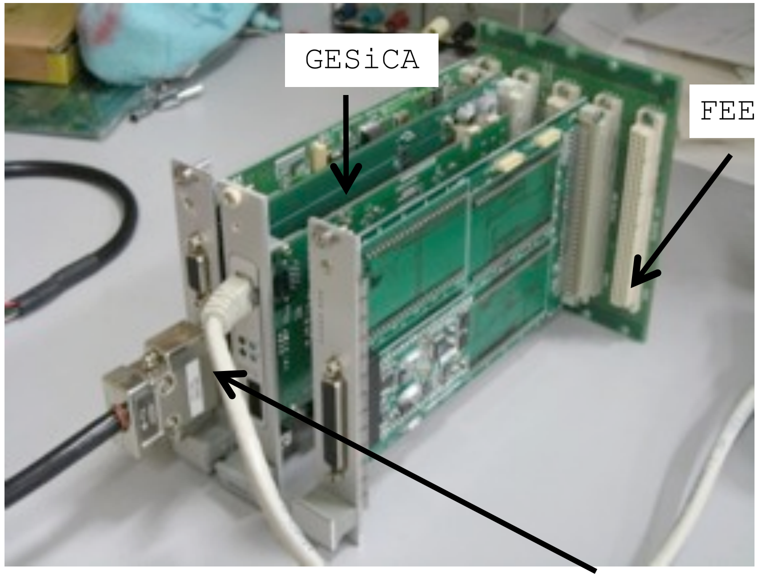
Figure 1.4: Pre-amplifire and CDS circuit

Clock driver/Preamp/CDS/ADC board for 4 CCDs



AI core

Back End Electronics

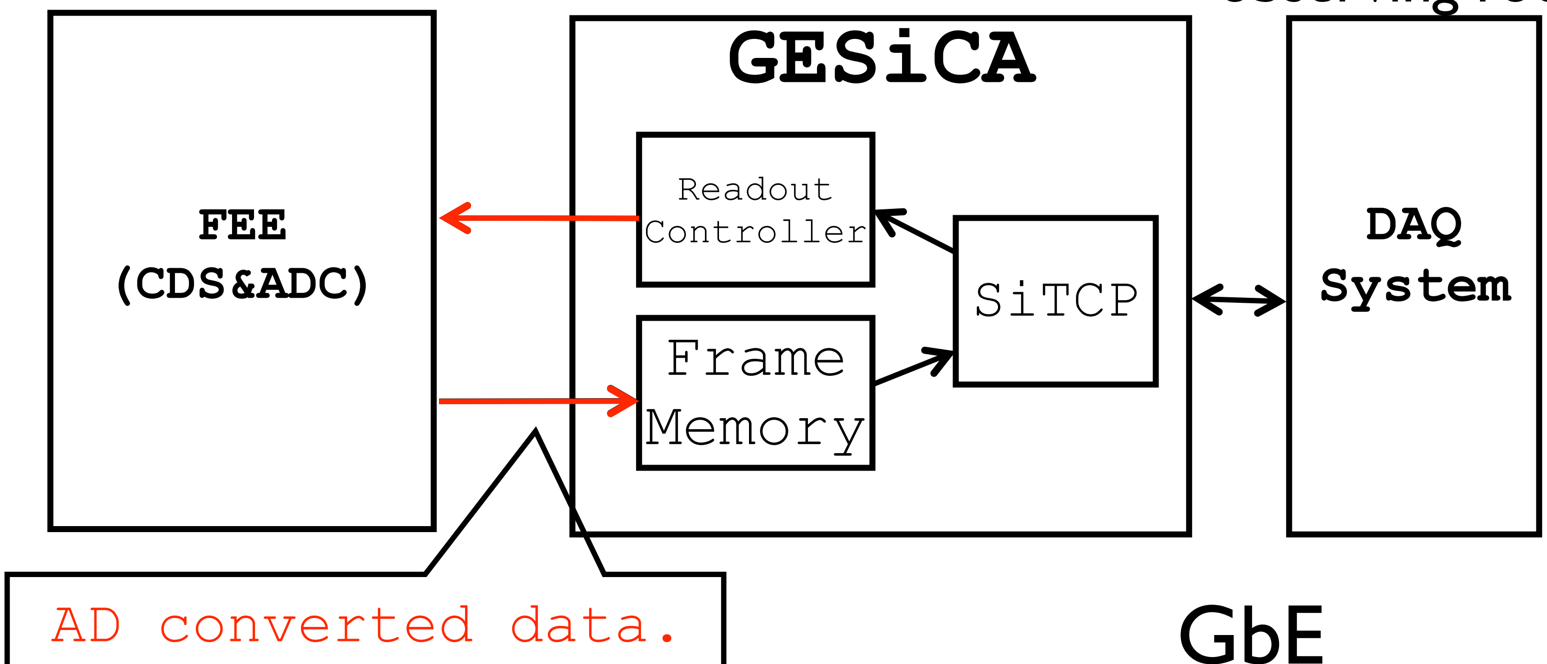


Ethernet Connection to the DAQ System

Designed by U-tokyo and KEK
(Uchida et al. 2008 SPIE)

Custom ASICs

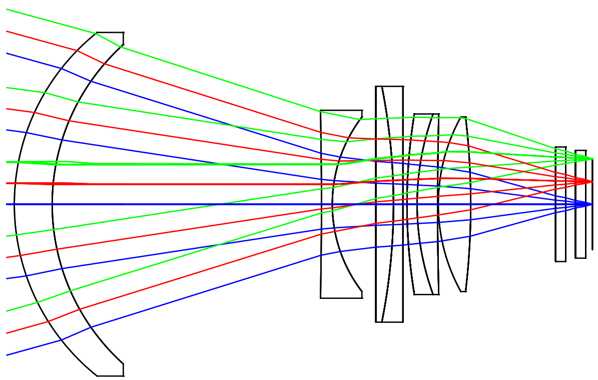
Linux box at observing room



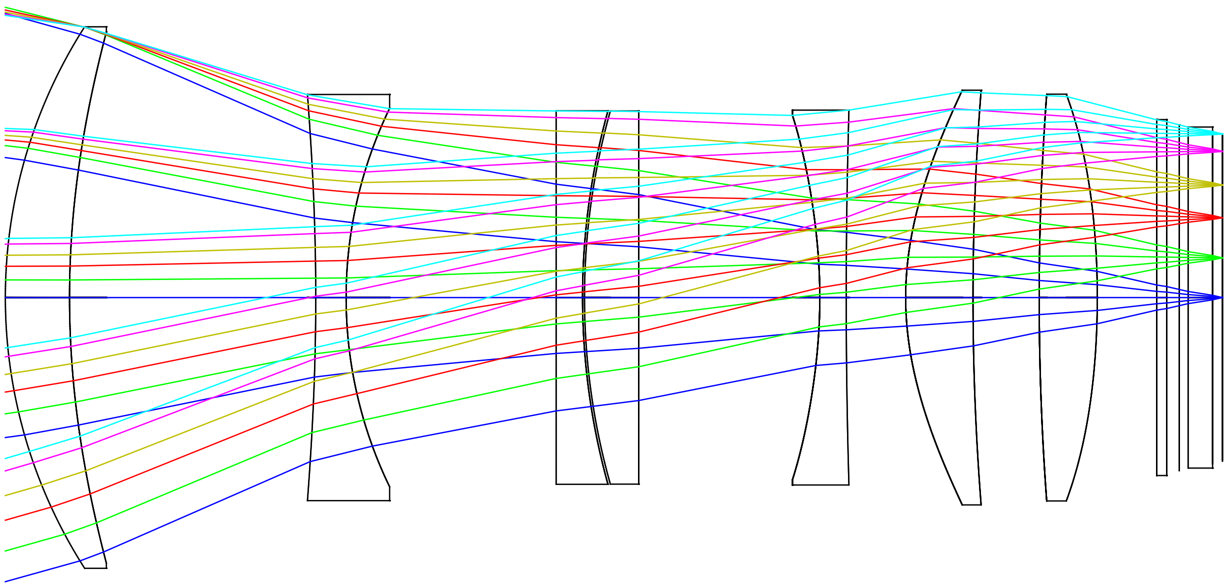
GbE

Wider Field Corrector

Wide Field Corrector



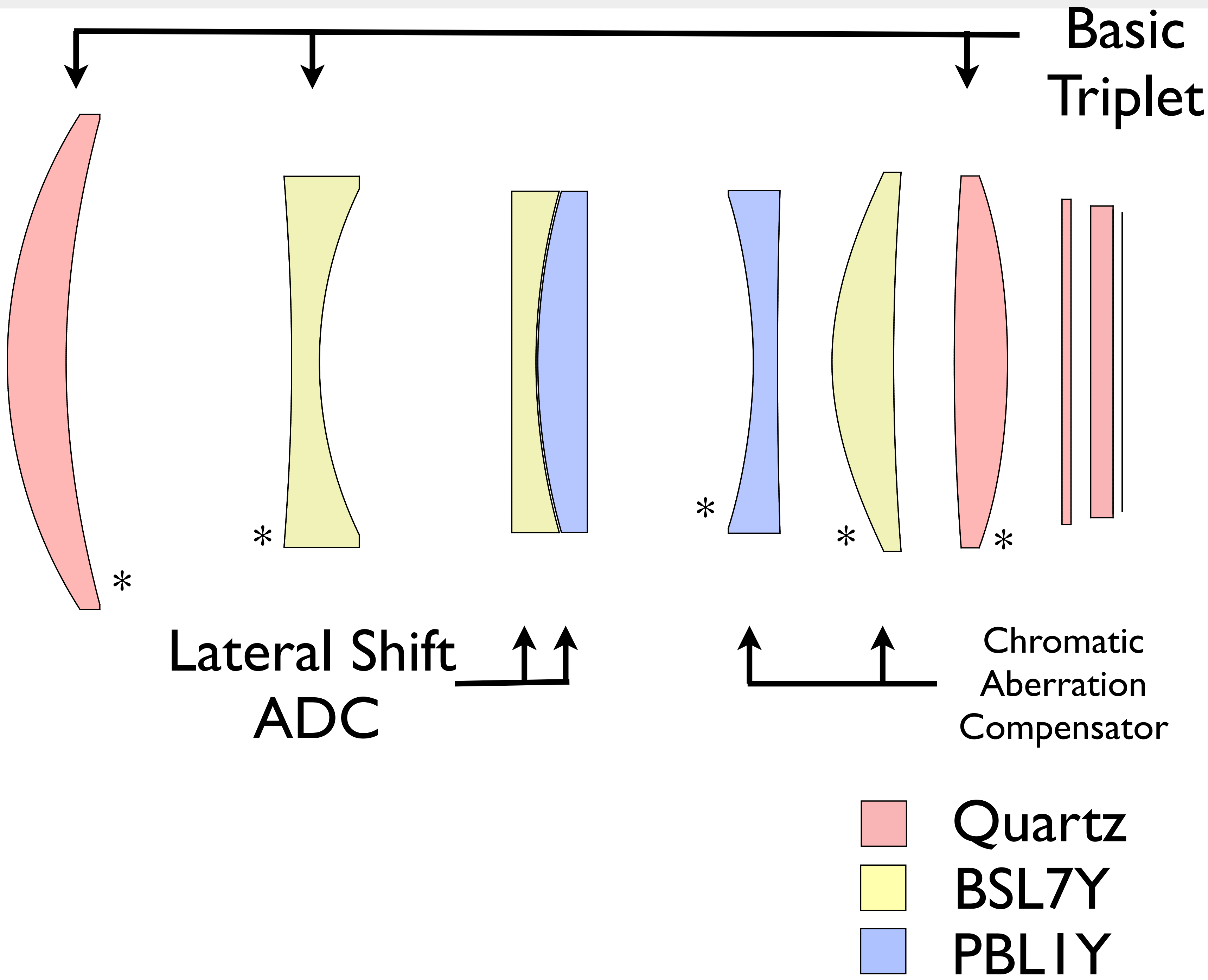
Current



New

G1 Diameter 820 mm

New Wide Field Corrector



WFC Design Performance

	0	0.125	0.25	0.5	0.75	[deg]
g	1.0	2.7	3.6			
(0.49)	5.8	5.5	6.3	9.2	5.2	
r	1.9	3.0	4.2			
(0.63)	1.3	1.5	3.4	4.0	4.5	
i	3.1	3.8	5.7			
(0.77)	2.8	3.8	5.1	5.3	4.4	
z	3.8	4.3	6.7			
(0.90)	2.8	4.1	5.0	6.3	4.6	

RMS spot radius (micron)

upper:SC, lower:HSC

WFC Design Performance

	0	0.125	0.25	0.5	0.75	[deg]
g	1.0	2.7	3.6			
(0.49)	5.8	5.5	6.3	9.2	5.2	
r	1.9	3.0	4.2			
(0.63)	1.3	1.5	3.4	4.0	4.5	
i	3.1	3.8	5.7			
(0.77)	2.8	3.8	5.1	5.3	4.4	
z	3.8	4.3	6.7			
(0.90)	2.8	4.1	5.0	6.3	4.6	

0''.12 (FWHM)

RMS spot radius (micron)

upper:SC, lower:HSC

WFC Design Performance

	0	0.125	0.25	0.5	0.75	[deg]
g	1.0	2.7	3.6			
(0.49)	5.8	5.5	6.3	9.2	5.2	
r	1.9	3.0	4.2			
(0.63)	1.3	1.5	3.4	4.0	4.5	
i	3.1	3.8	5.7			
(0.77)	2.8	3.8	5.1	5.3	4.4	
z	3.8	4.3	6.7			
(0.90)	2.8	4.1	5.0	6.3	4.6	

0''.12 (FWHM)

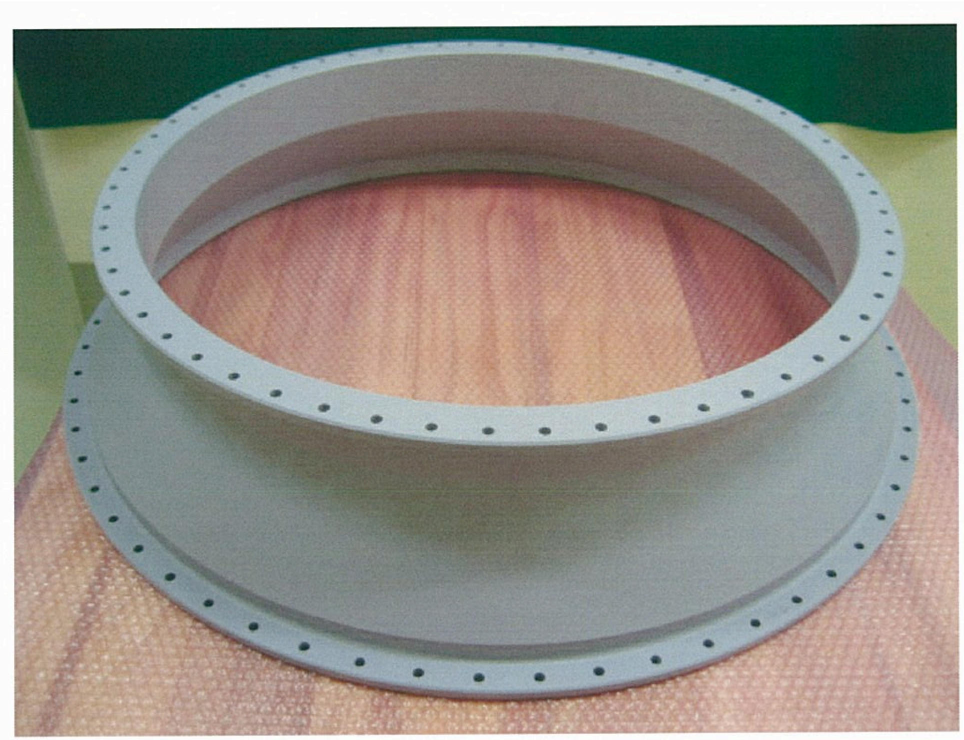
RMS spot radius (micron)

upper:SC, lower:HSC

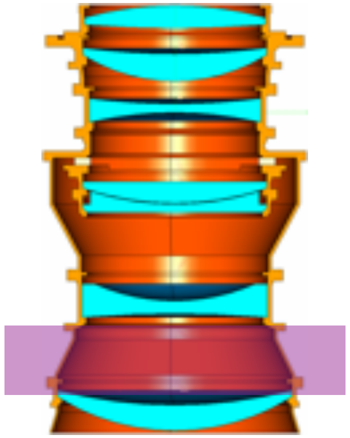
0''.2 (FWHM) is allocated including manufacturing error

Lens Barrel from Kyocera

Sintered



Machined



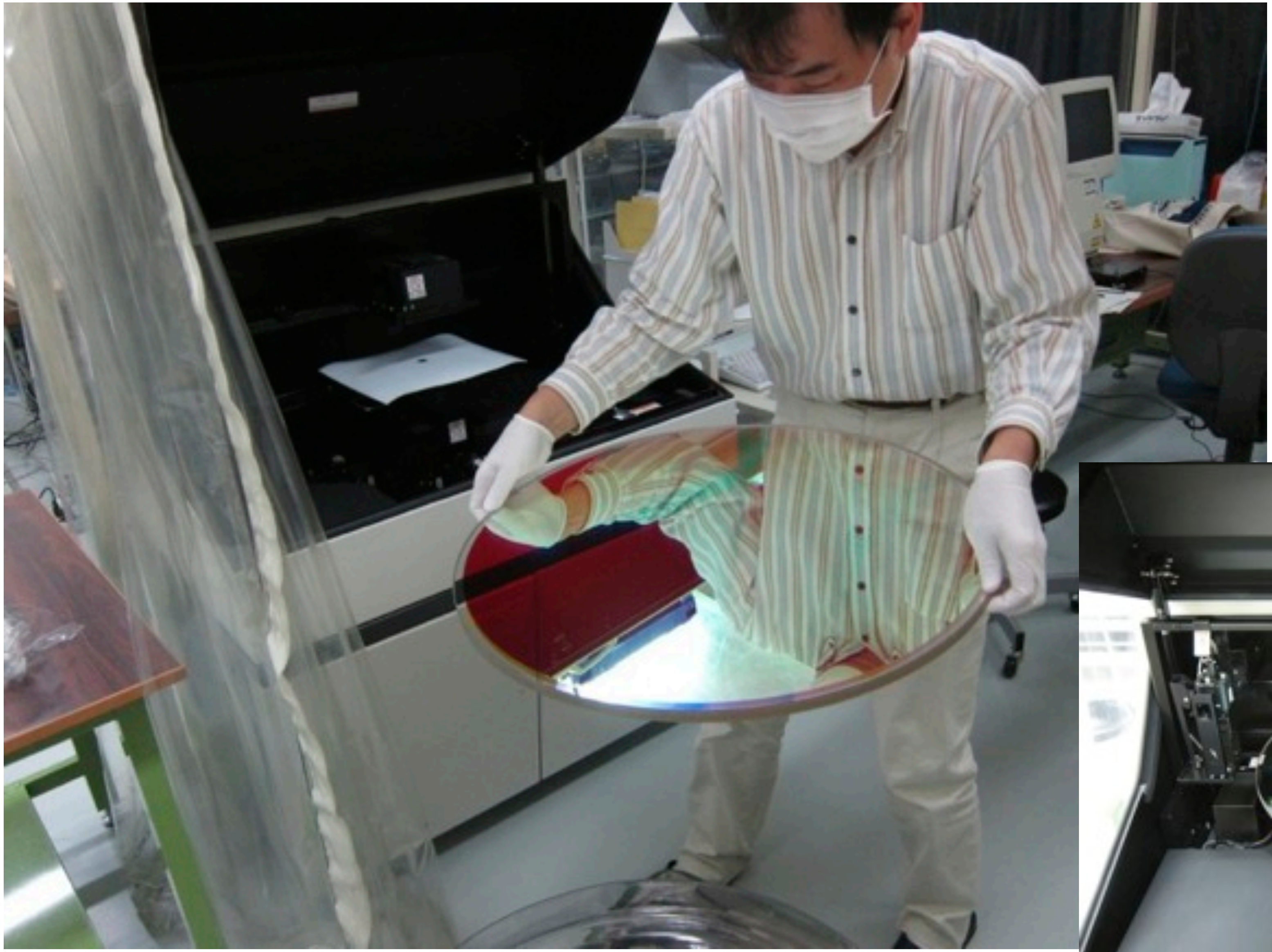
New WFC G1

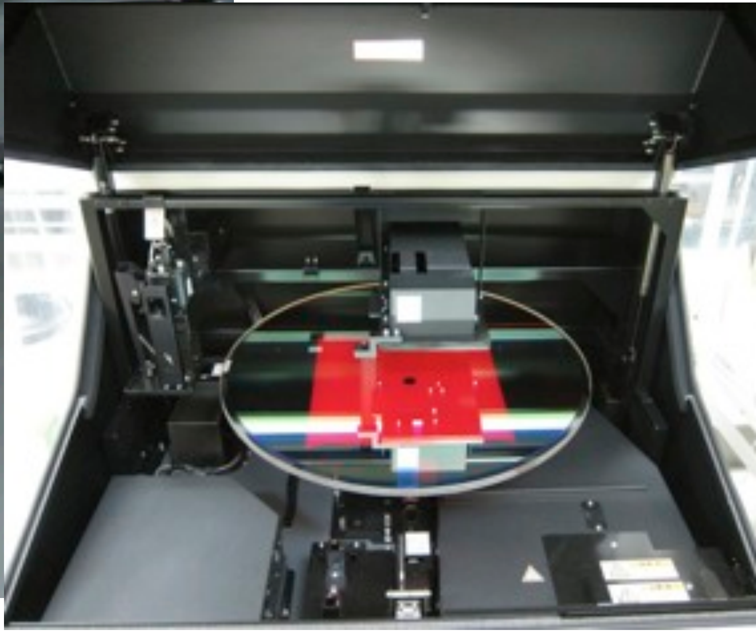
New WFC

New WFC

Mechanical Mockup used for fit check at the telescope

Filter





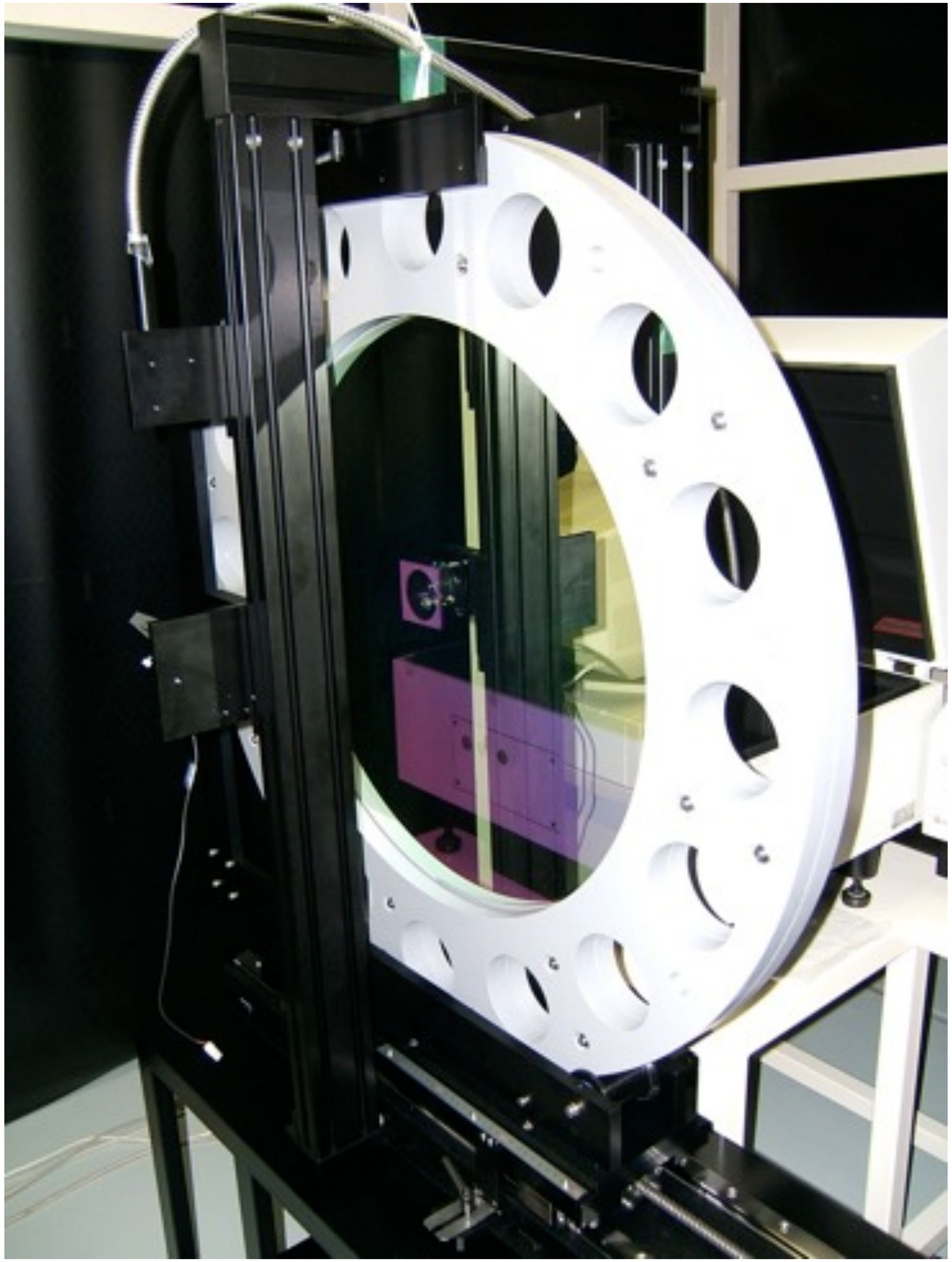
i'- filter : Barr

Filter

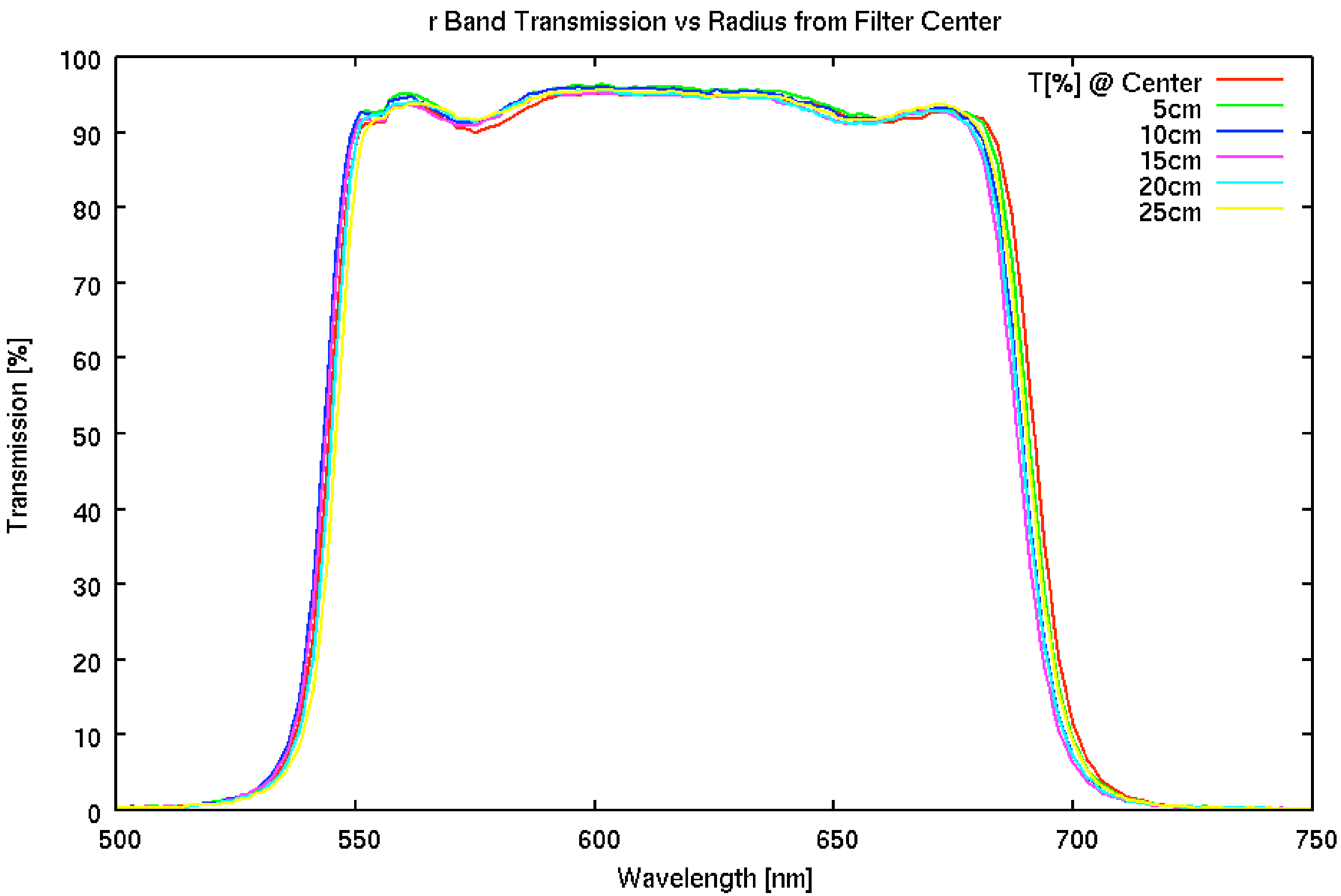
Prototyping

- Optics coating Japan
- Asahi Spectra
- Barr

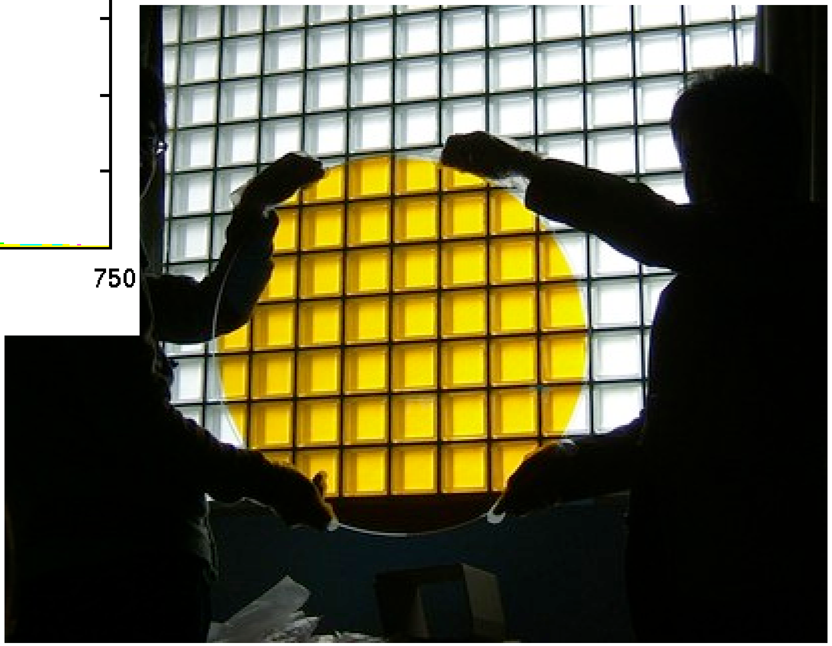
They all look promising.



Broad band prototype



D = 60cm



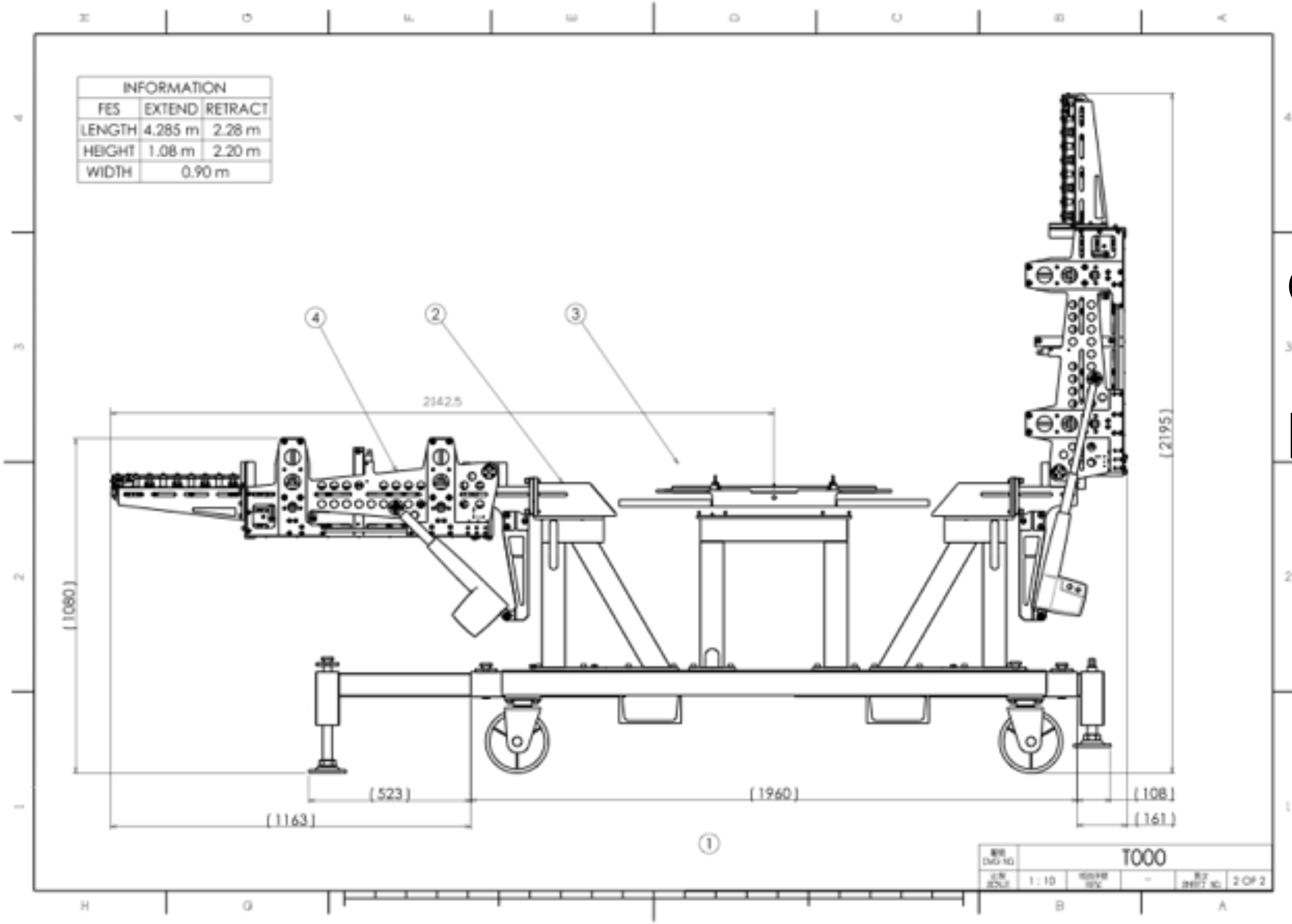
Uniformity
cut off 3 nm
Trans. 2-3 %

r' & i' filter already procured

HSC

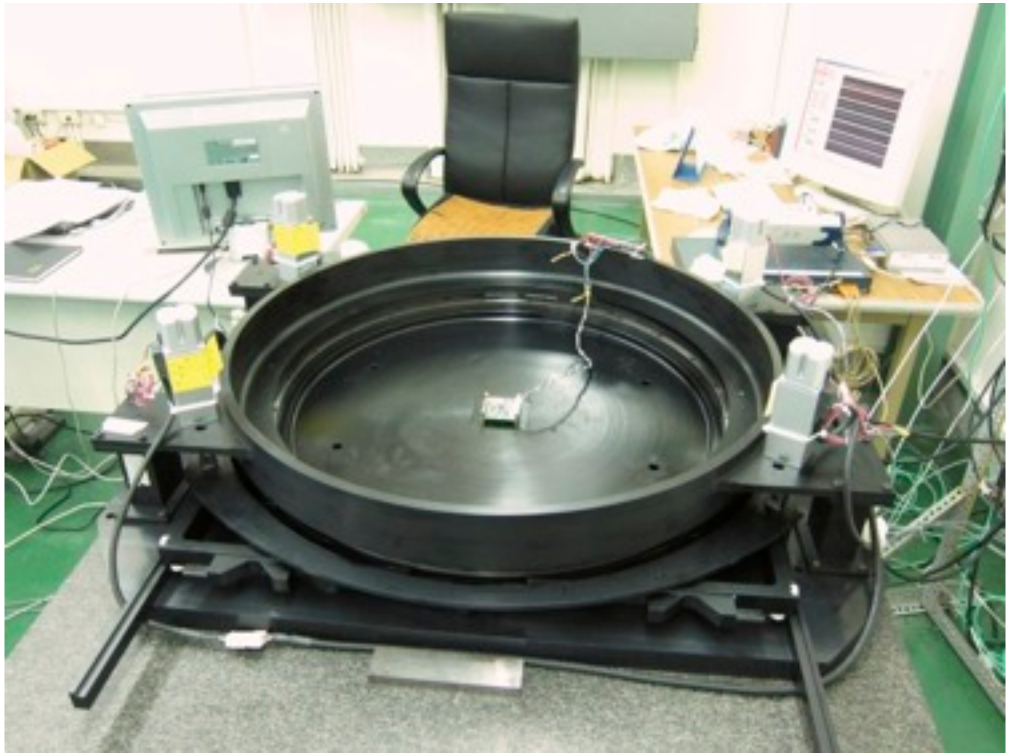
Filter Exchanger

6 filters



Concept:
NAOJ
Builder
ASIAA

Filter Exchanger



Central Unit

Stacker

Carrier

Shutter 600 mm phi

HSC Assembly

PFU Mechanics

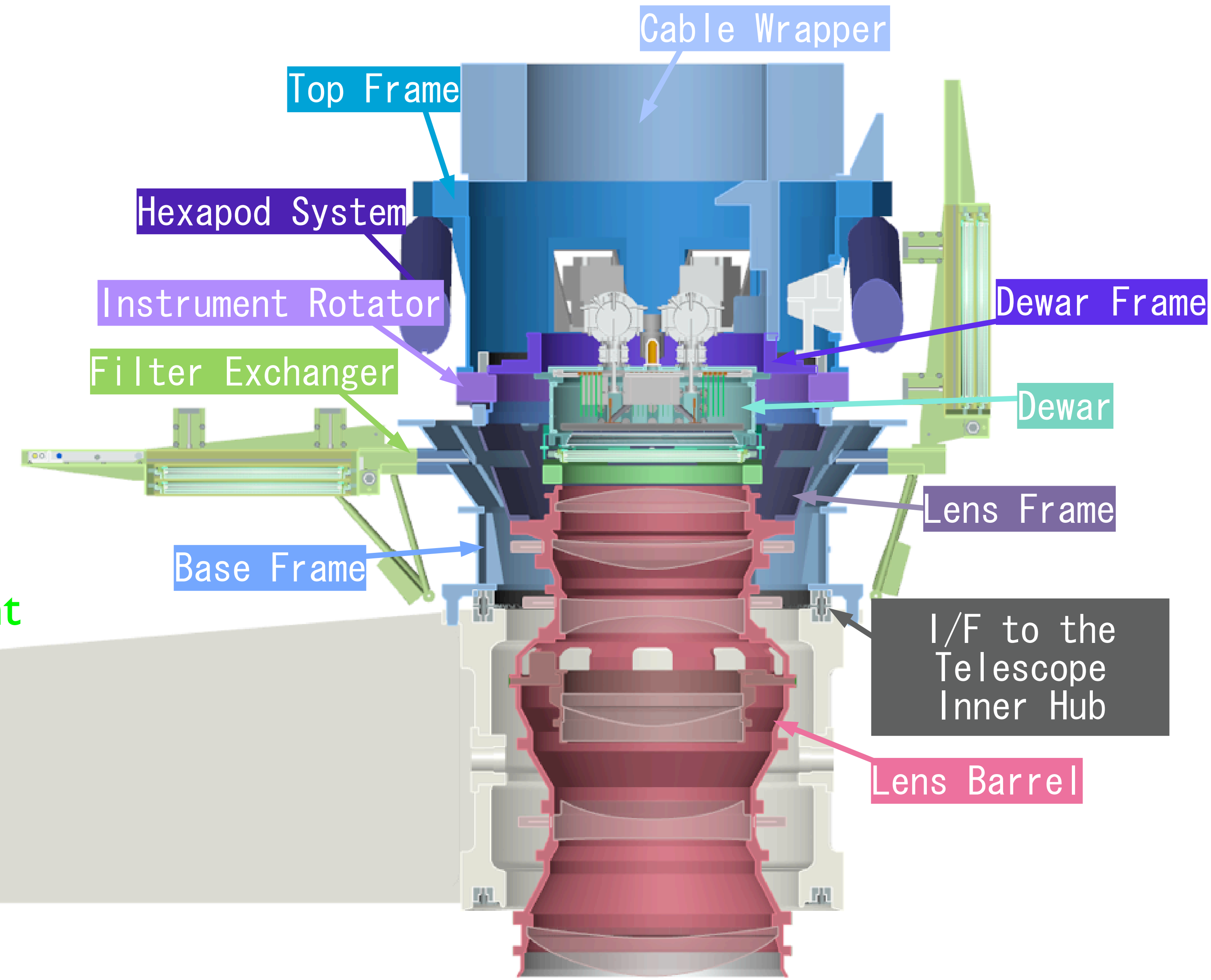
WFC

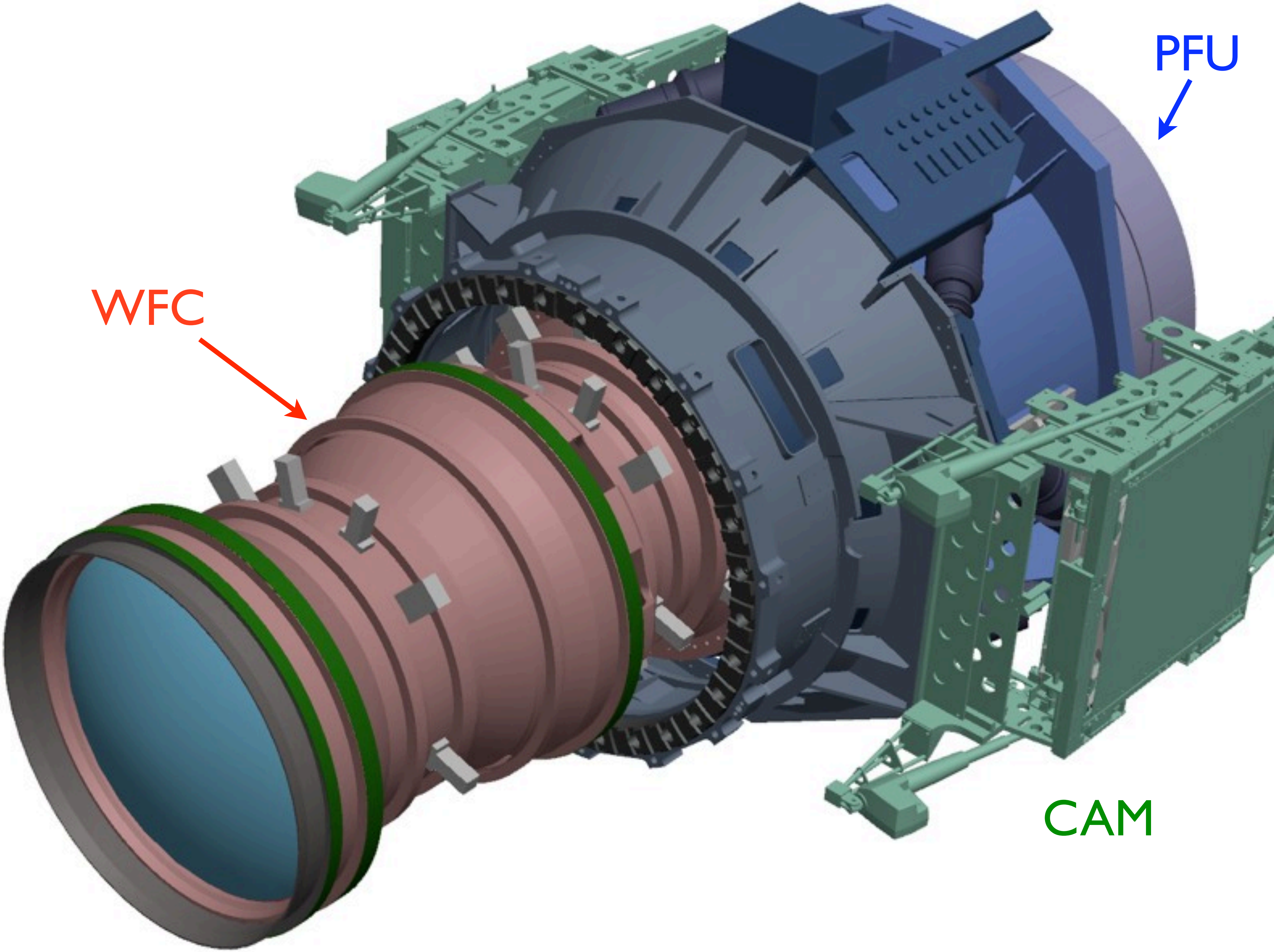
HSC Mechanics

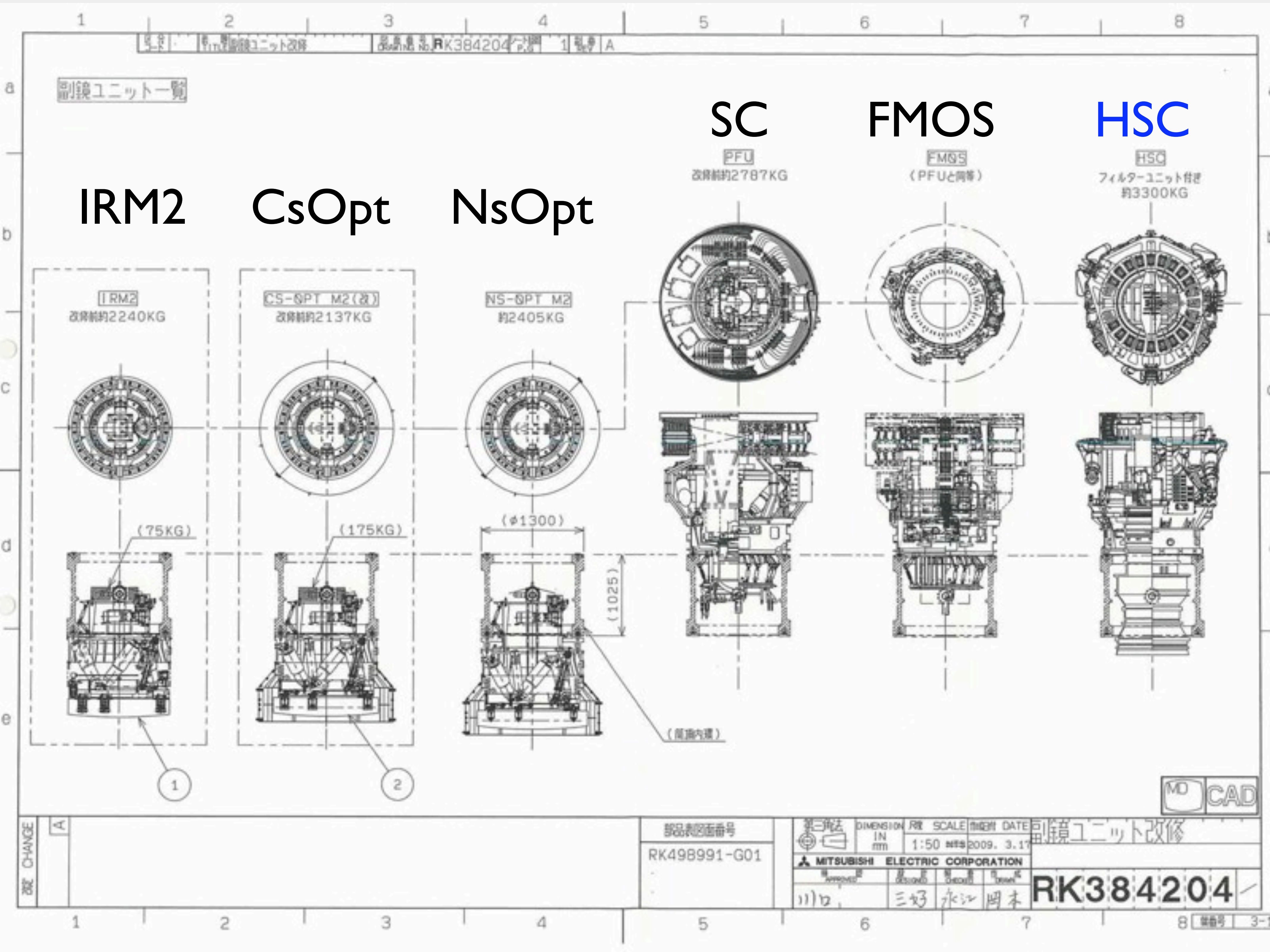
Sensor

Filter

Data Management




PFU
WFC
CAM


副鏡ユニット一覧
IRM2
CsOpt
NsOpt
SC
FMOS
HSC
PFU
改修前約2787KG
FMOS
(PFUと同等)
HSC
フィルターユニット付き
約3300KG
IRM2
改修前約2240KG
CS-OPT M2(改)
改修前約2137KG
NS-OPT M2
約2405KG
(75KG)
(175KG)
(φ1300)
(1025)
1
2
RK498991-G01
1:50
2009. 3.17
MITSUBISHI ELECTRIC CORPORATION
副鏡ユニット改修
RK384204
CAD

Schedule

2010/12	New PFU + Camera fitting Test
2011/01	Filter Exchanger Env. Test
2011/02	CCD Final Installation
2011/03	New PFU -WFC fitting Test
2011/04	Shipping to Hawaii
2011/9	Engineering F.L.

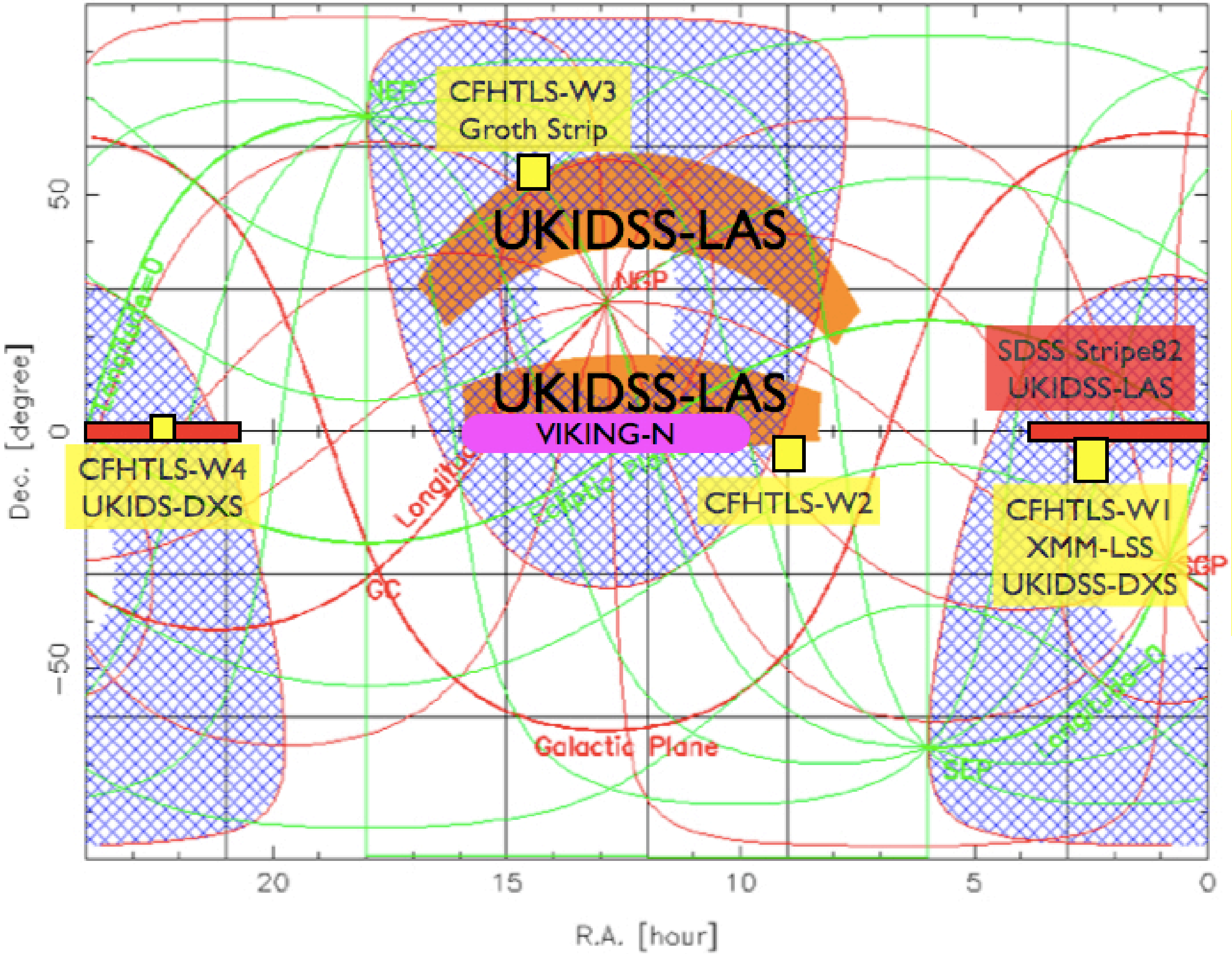
Draft Survey Plan (wide)

1500 square degree

filter	g	r	i	z	Y
T [min]	15	20	30	20	25
mag	26.5	26.4	26.2	24.9	23.7
DES	25.6	25.1	25.2	24.4	22.3

5 sigma Point source 0.8 arcsec Seeing

Candidates of survey fields

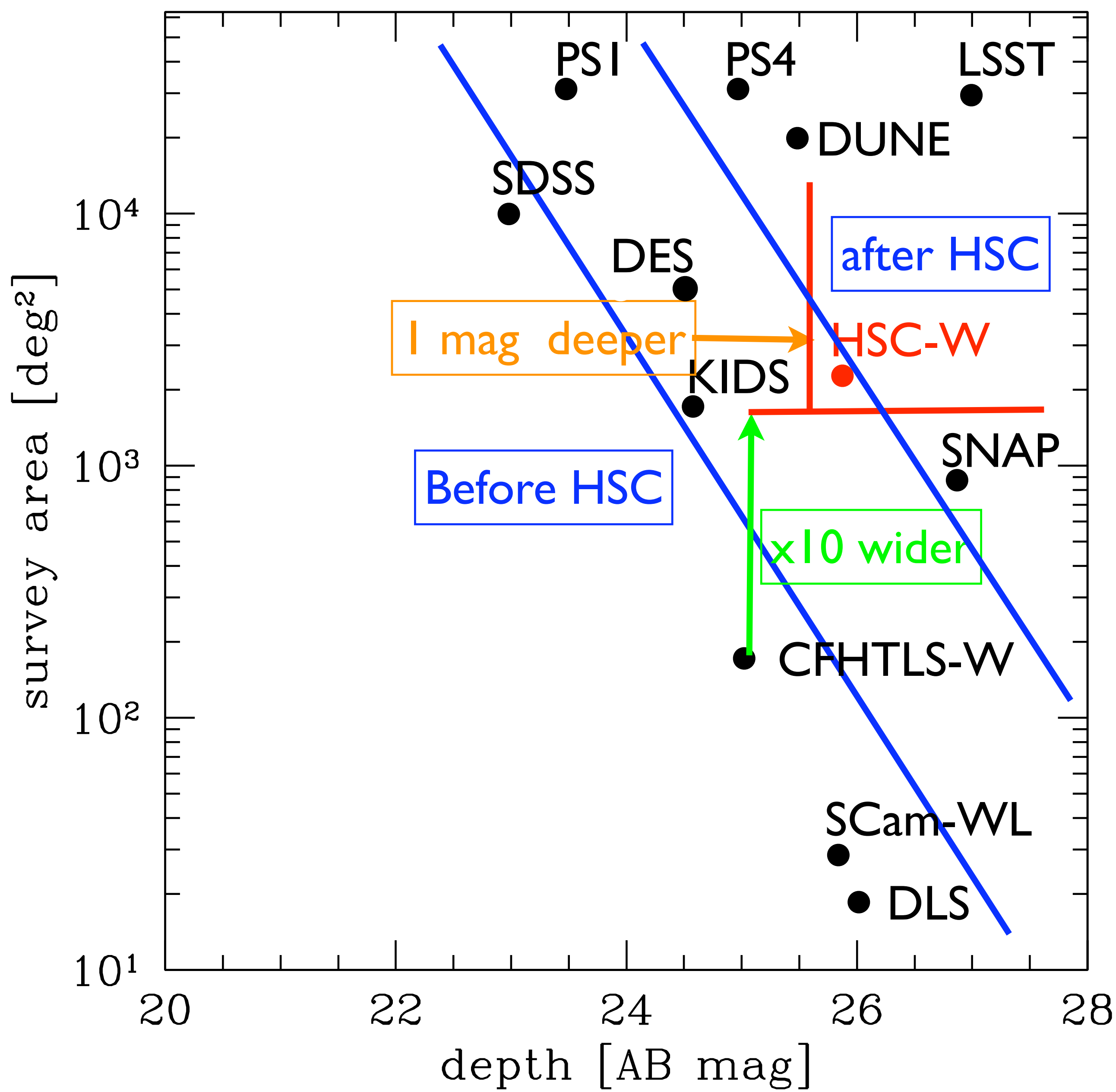


Selection criteria:

- Availability of NIR/U data (for accurate photo-z)
- Xray/SZE survey (Cluster study)

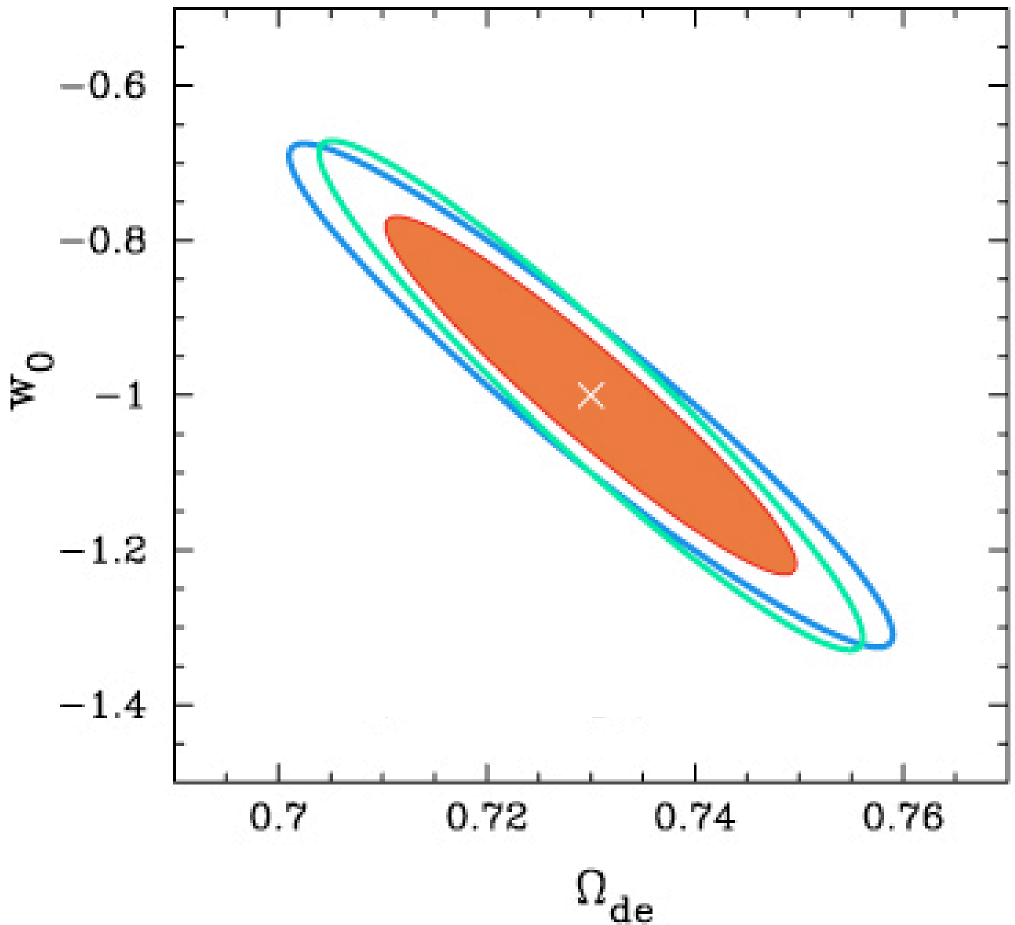
Name	R.A.	Dec.	area [deg^2]	Note
wide1	20h40m – 3h55m	-1.25 – 1.25	270	SDSS Stripe-82/UKIDSS-LAS
wide2	10h – 16h	−5 – 3	780	VIKING/KIDS/UKIDSS-LAS
wide3	∼8h – ∼ 17h	20 – 50	900	UKIDSS-LAS
wide4	2h18m	−7	50	XMM-LSS/CFHTLS-w1/UKIDSS-DXS

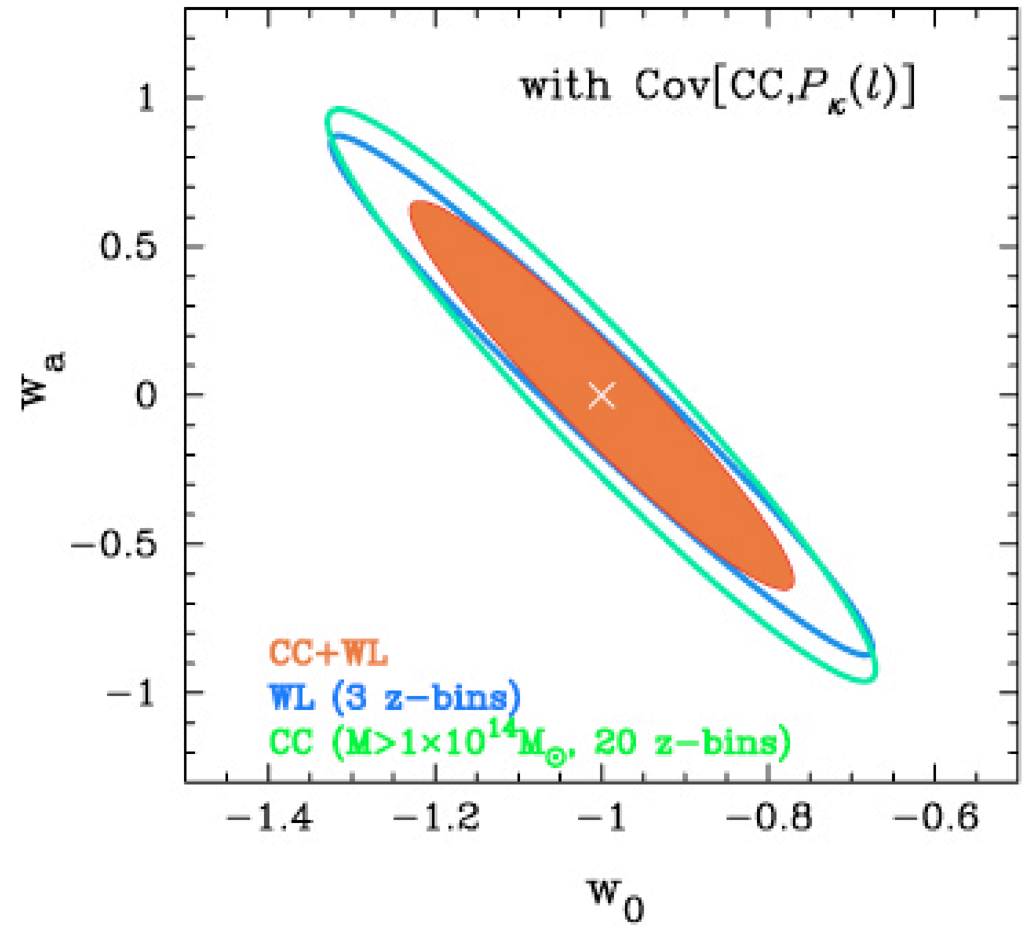
Comparison



PS1
PS4
LSST
DUNE
SDSS
DES
after HSC
1 mag deeper
HSC-W
KIDS
SNAP
Before HSC
x10 wider
CFHTLS-W
SCam-WL
DLS
10^4
10^3
10^2
10^1
survey area [deg^2]
20
22
24
26
28
depth [AB mag]

DE Constraint

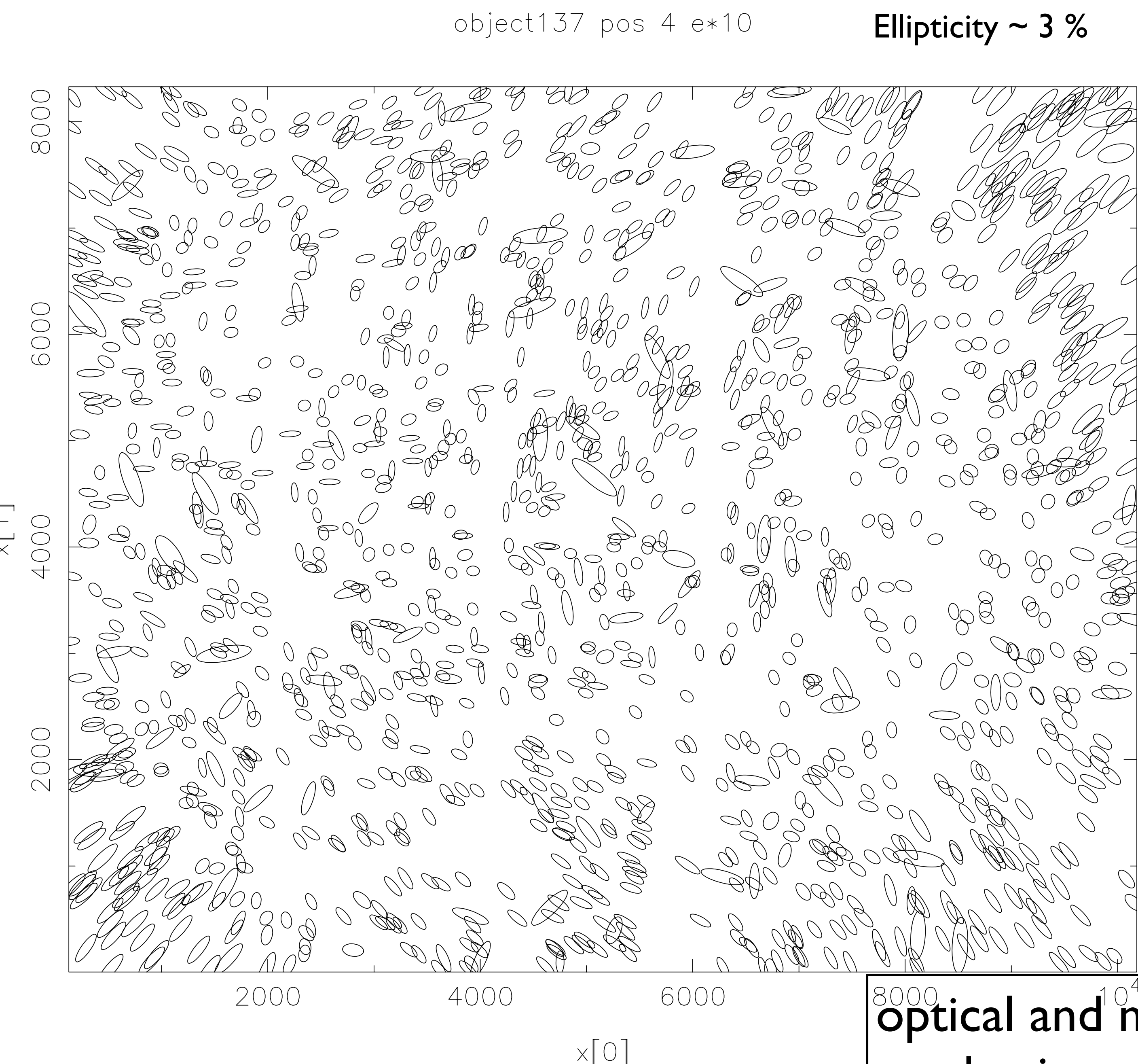




$$\delta w_0 \sim 5\% \ \ (w_a = 0)$$

Stage III

Actual Data [PSF map]



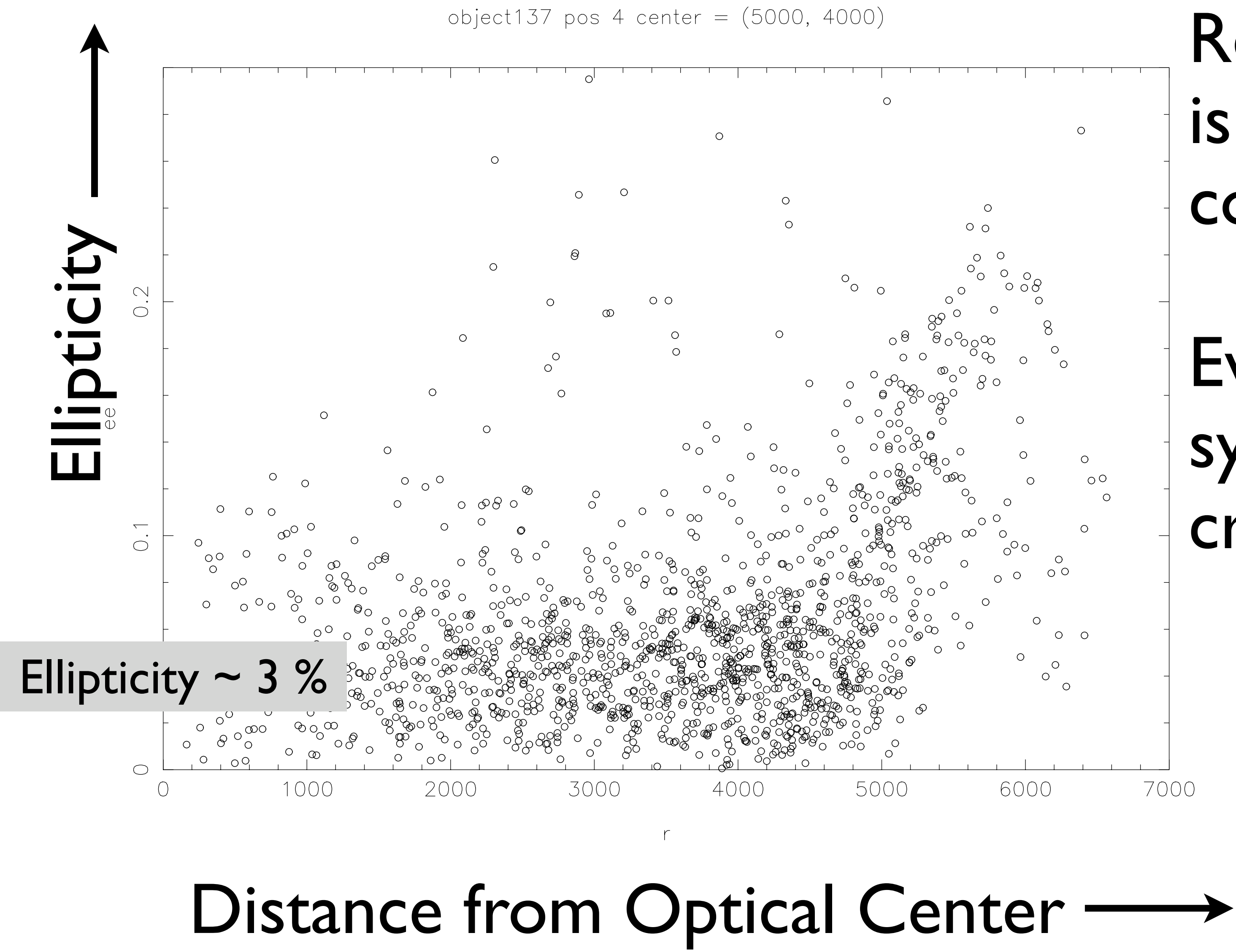
PSF Modeling using stars

Galaxy shape collection based on the model

Extensive understanding of the instruments necessary to make model

optical and mechanical mis-alignment, mechanics motion error

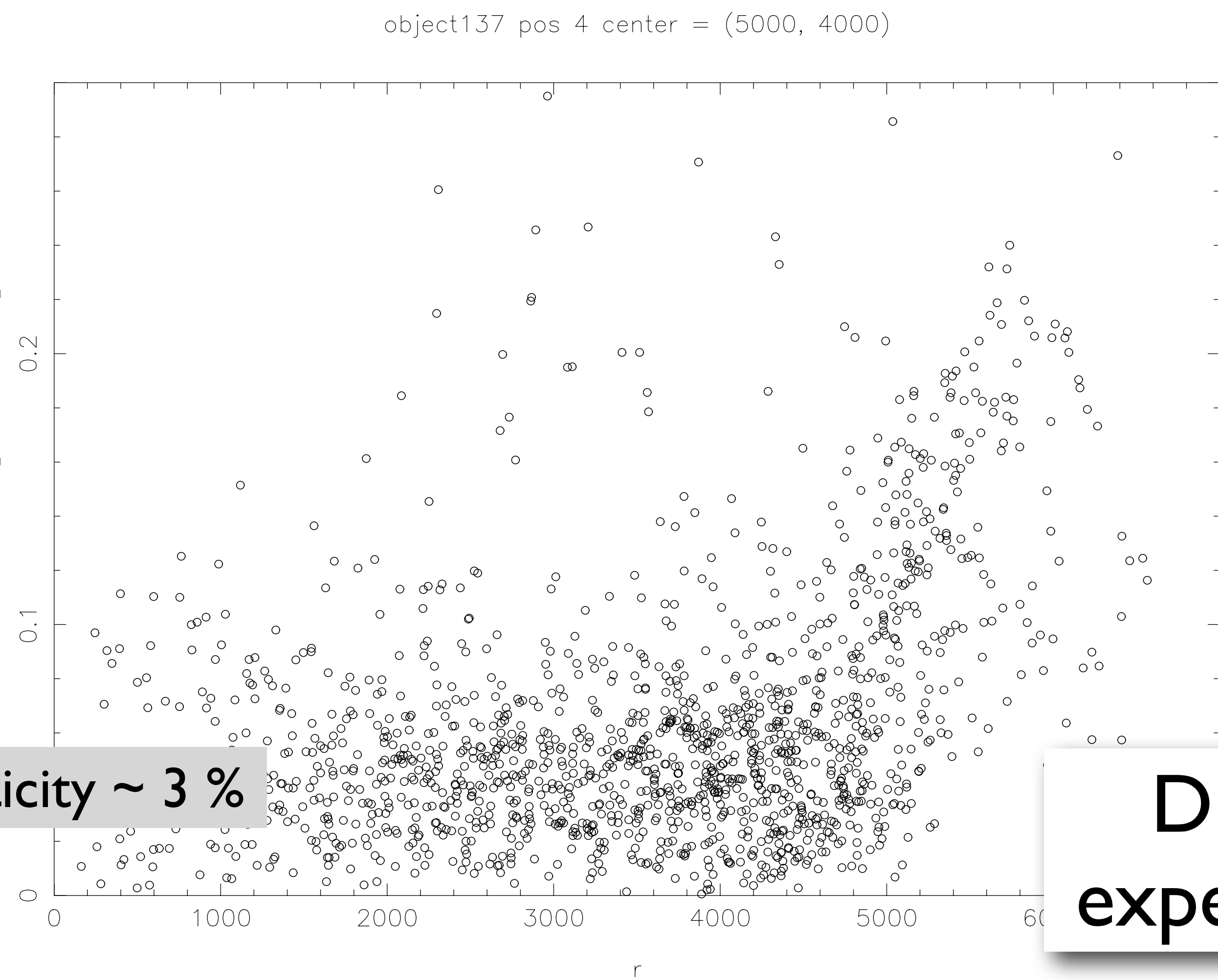
Observed ellipticity of stars



Required accuracy is smaller than the correction

Evaluation of the systematic error is crucial.

Observed ellipticity of stars



Ellipticity

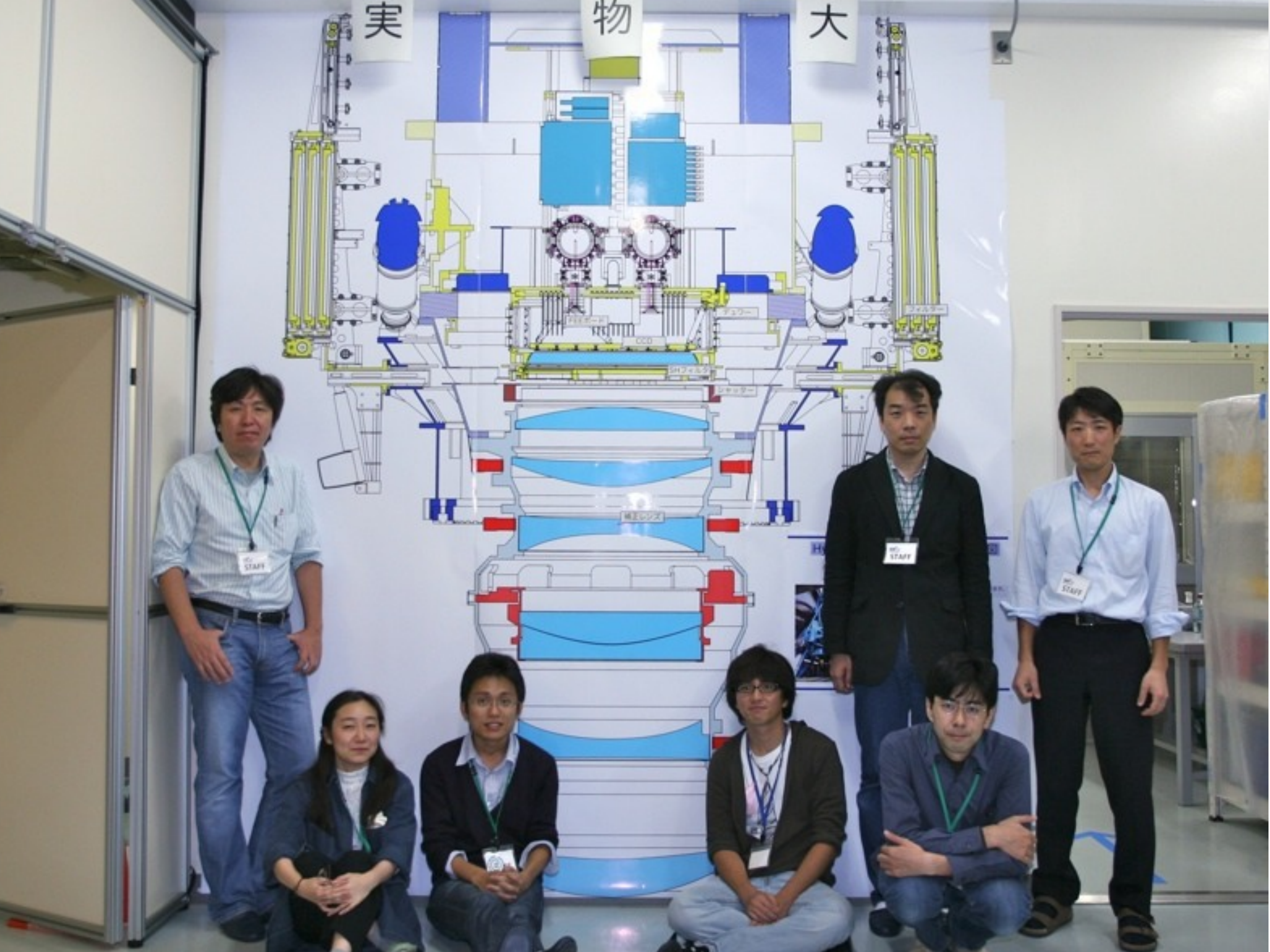
Ellipticity ~ 3 %

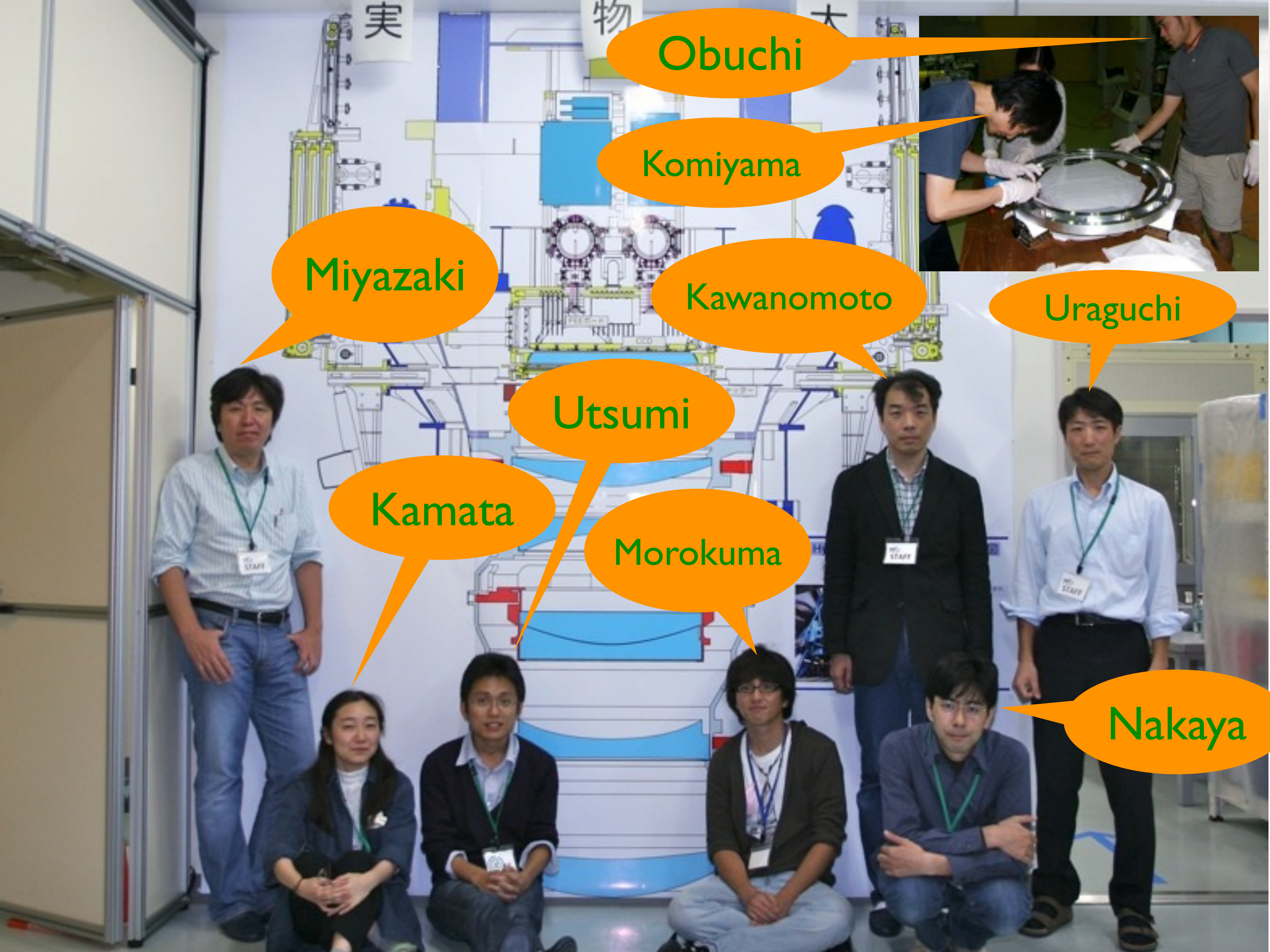
Distance from Optical Center

Required accuracy is smaller than the correction

Evaluation of the systematic error is crucial.

DE measurement is experimentalist's work !


実
物
大
CCD
シャッター
STAFF


Obuchi
Komiyama
Miyazaki
Kawanomoto
Uraguchi
Utsumi
Kamata
Morokuma
Nakaya

Summary

Hyper Suprime-Cam is being built at NAOJ and will see the first light in fall 2011.

Large survey (1500 sqdeg) is planned to carry out 2012 - 2017.

Stage III dark energy constraint is expected and a lot of unexpected is also expected.

LSST- Science

- Efficient, deep optical survey telescope
- Will transform observation of the variable universe and address broad questions:
  - Dark energy using gravitational lensing and supernovae
  - Dark matter
  - Near-Earth, Kuiper-belt objects
  - Solar neighborhood
  - Transient phenomena
    - Gamma-ray bursts, Variable stars, Supernovae…
- Publicly accessible archive – >100 Pbyte

2010/07/02 at La Jolla near San Diego

Thank you