Hyper Suprime-Cam

Subaru's next generation wide field Camera

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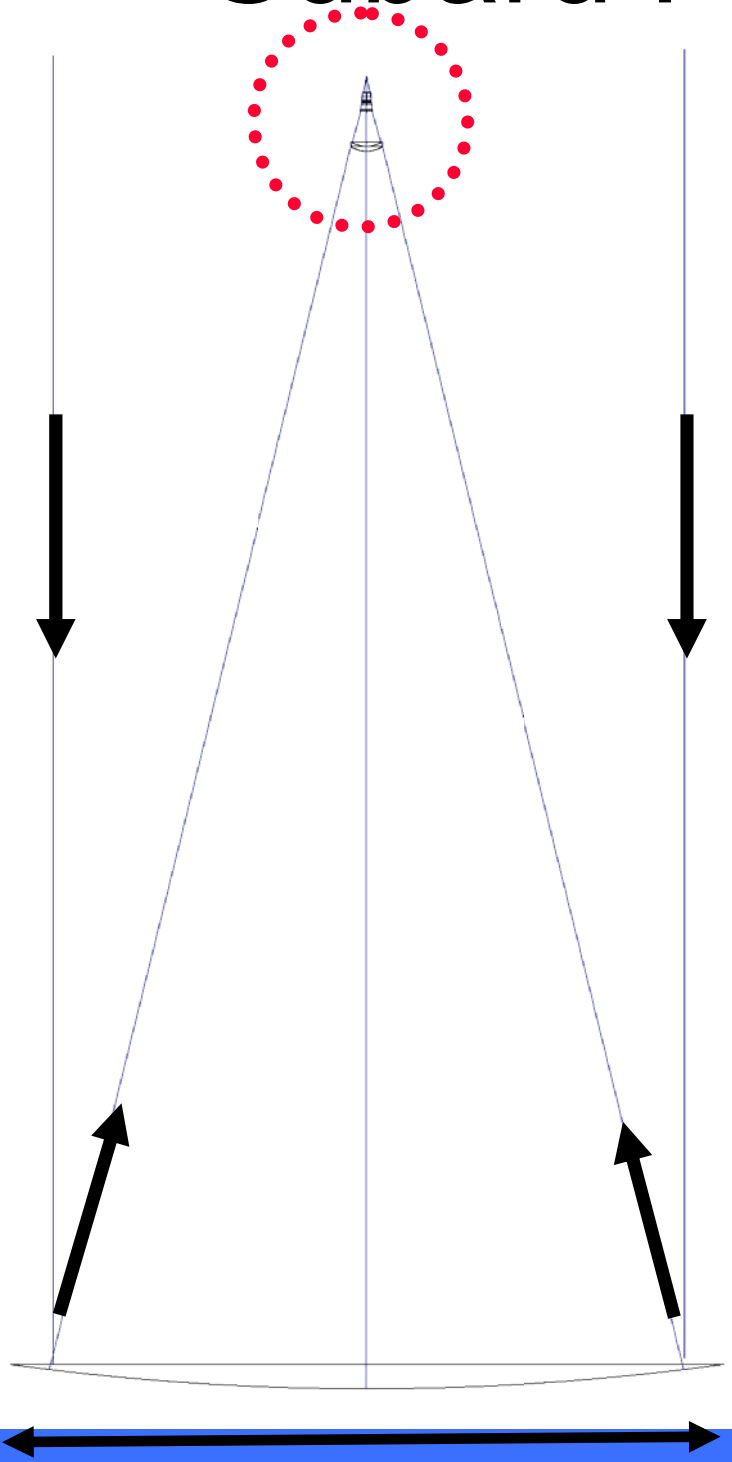
HSC Collaboration

National Astronomical Observatory of Japan
University of Tokyo (J)
KEK (J)
ASIAA (Taiwan)
Princeton University (US)

Mitsubishi Electric
Canon
Hamamatsu Photonics

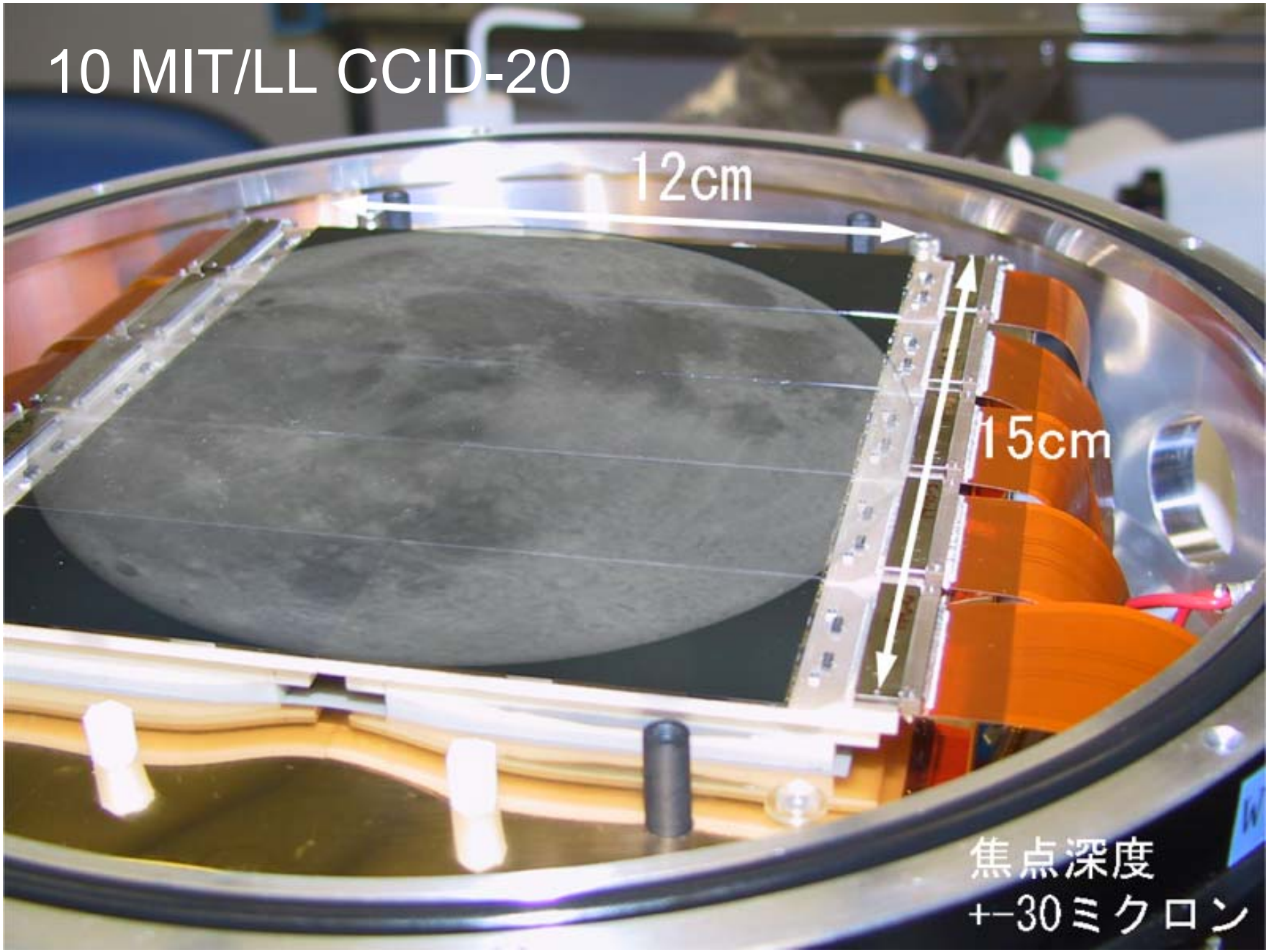
Subaru Prime Focus



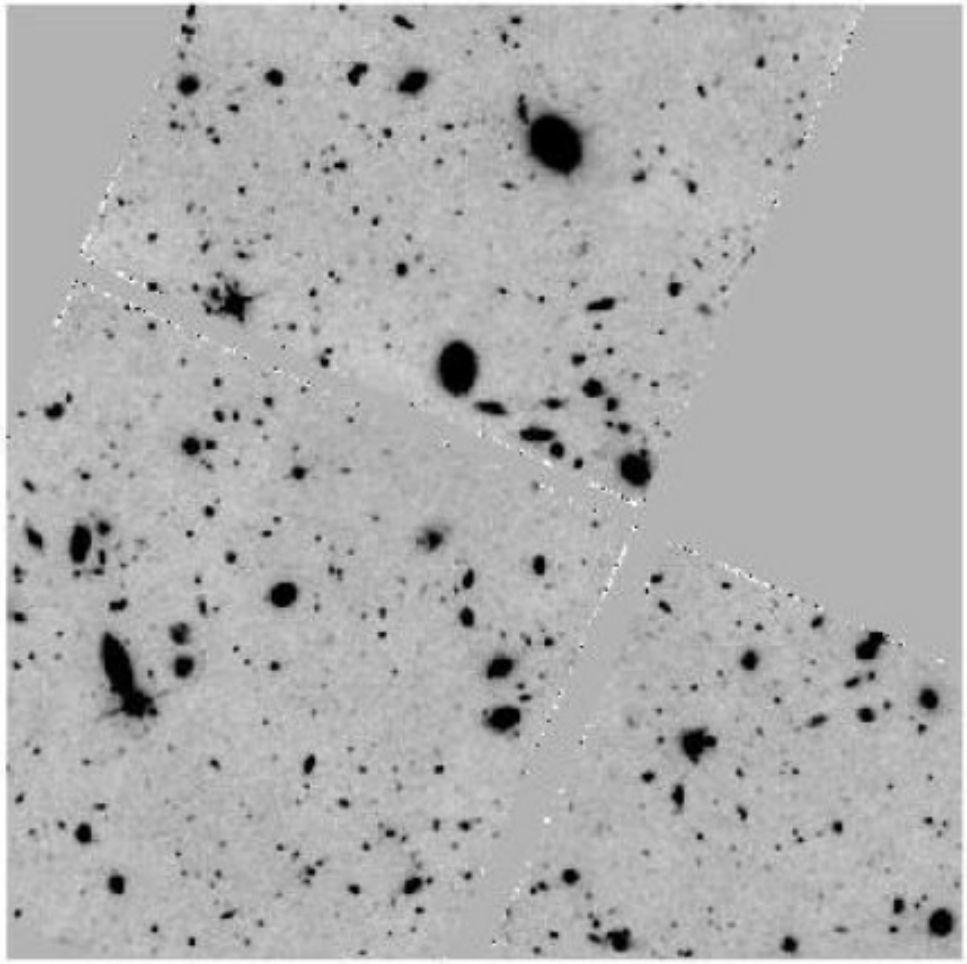
Wide field corrector
developed by Canon

F/2.0
f = 16400 mm
FOV 30 arcmin

Suprime-Cam

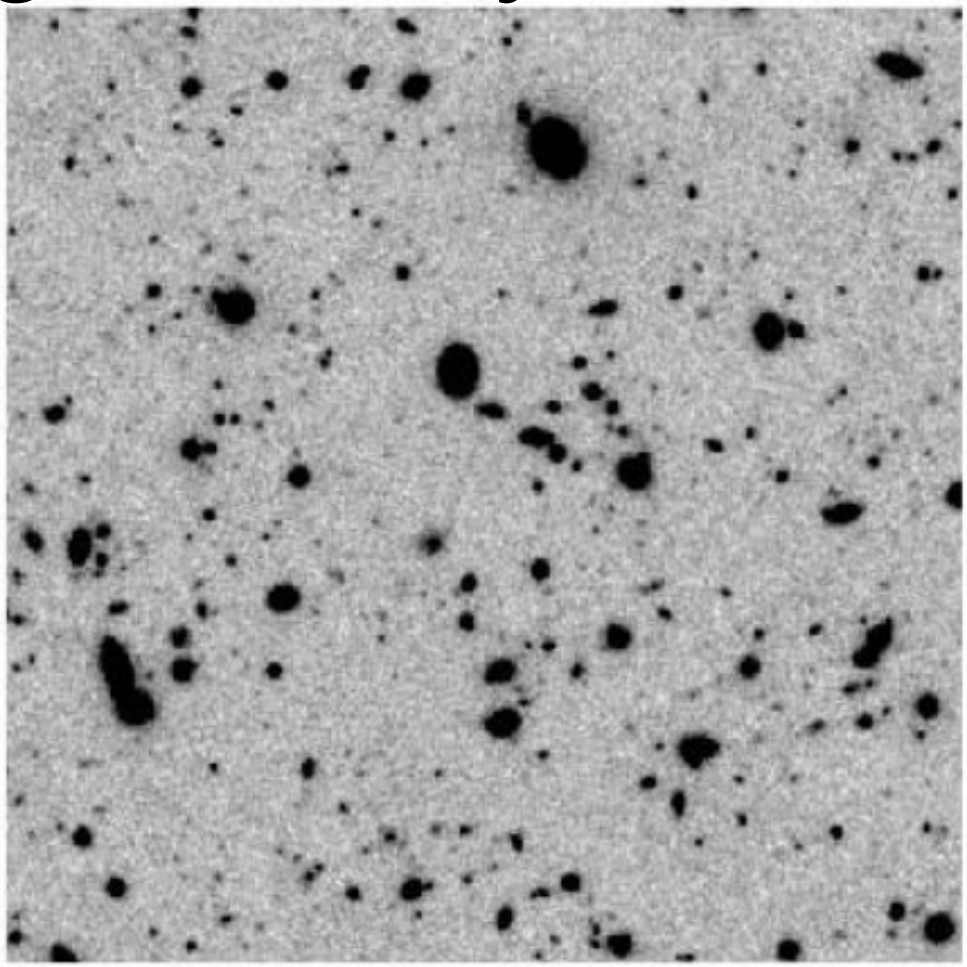


Good Image Quality



HST 'wide-I' continuum

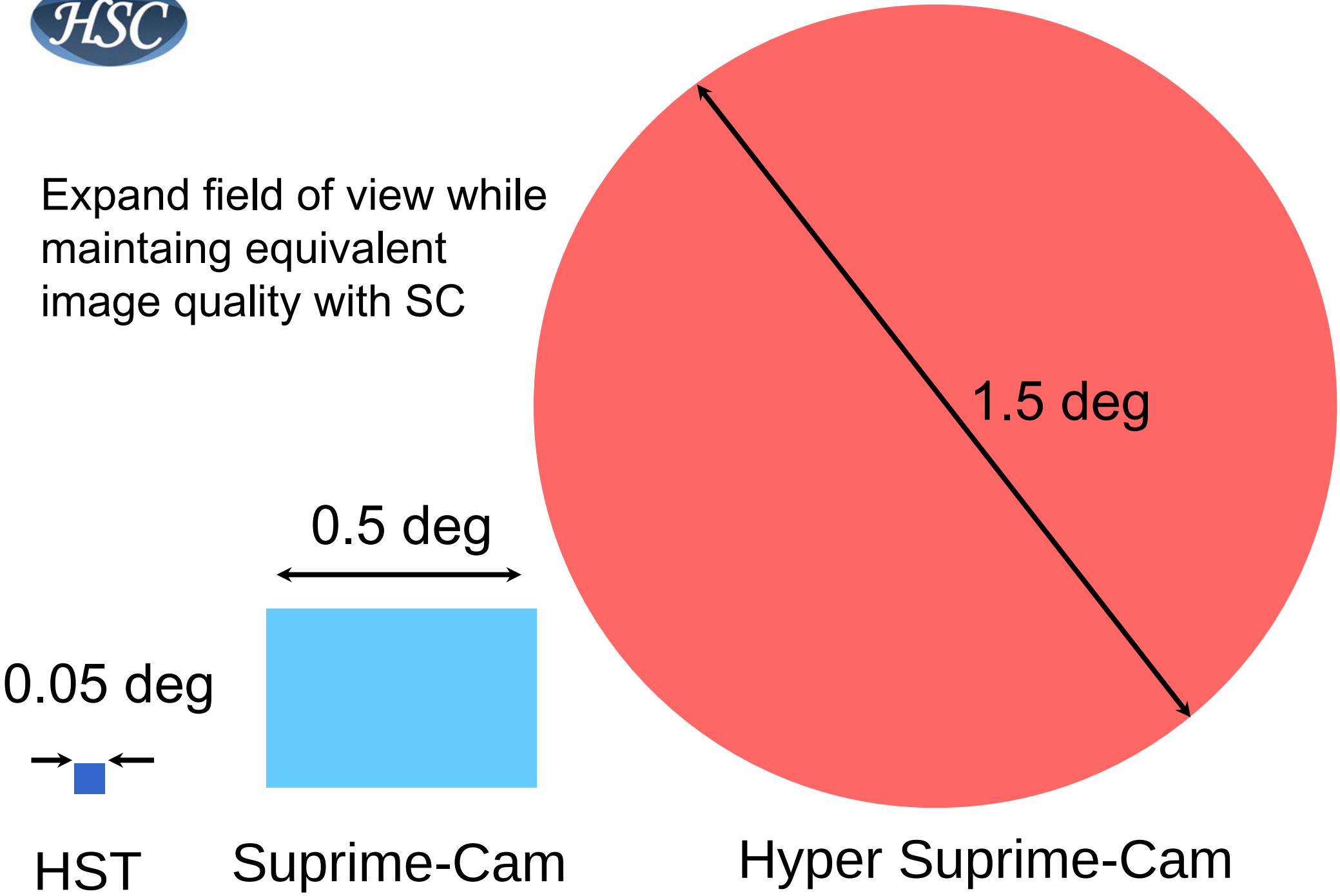
HST WFPC2
(All FOV)



NB816 narrowband

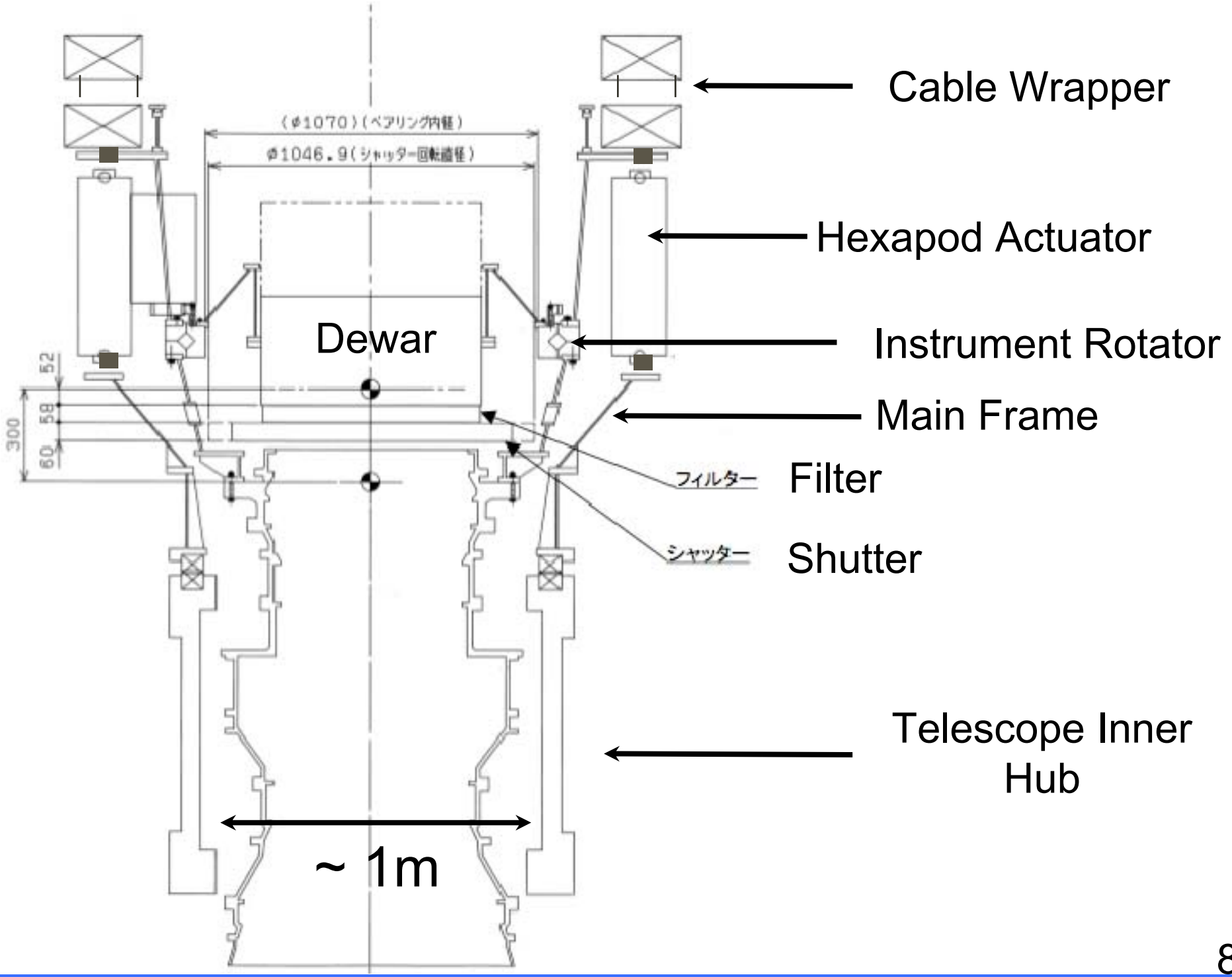
Suprime-Cam
(FOV/100)

Expand field of view while maintaing equivalent image quality with SC



Hyper Suprime-Cam Overview

- FOV: 1.5 deg in diameter
- Image quality equivalent with SC in r, i, z, Y band
  - Instrumental PSF < 0.4 arcsec FWHM
  - Crucial for weak lensing survey
- Even Higher QE in red


Cable Wrapper
Hexapod Actuator
Dewar
Instrument Rotator
Main Frame
フィルター
Filter
シャッター
Shutter
Telescope Inner Hub
~ 1m

HSC Components

PFU Mechanics

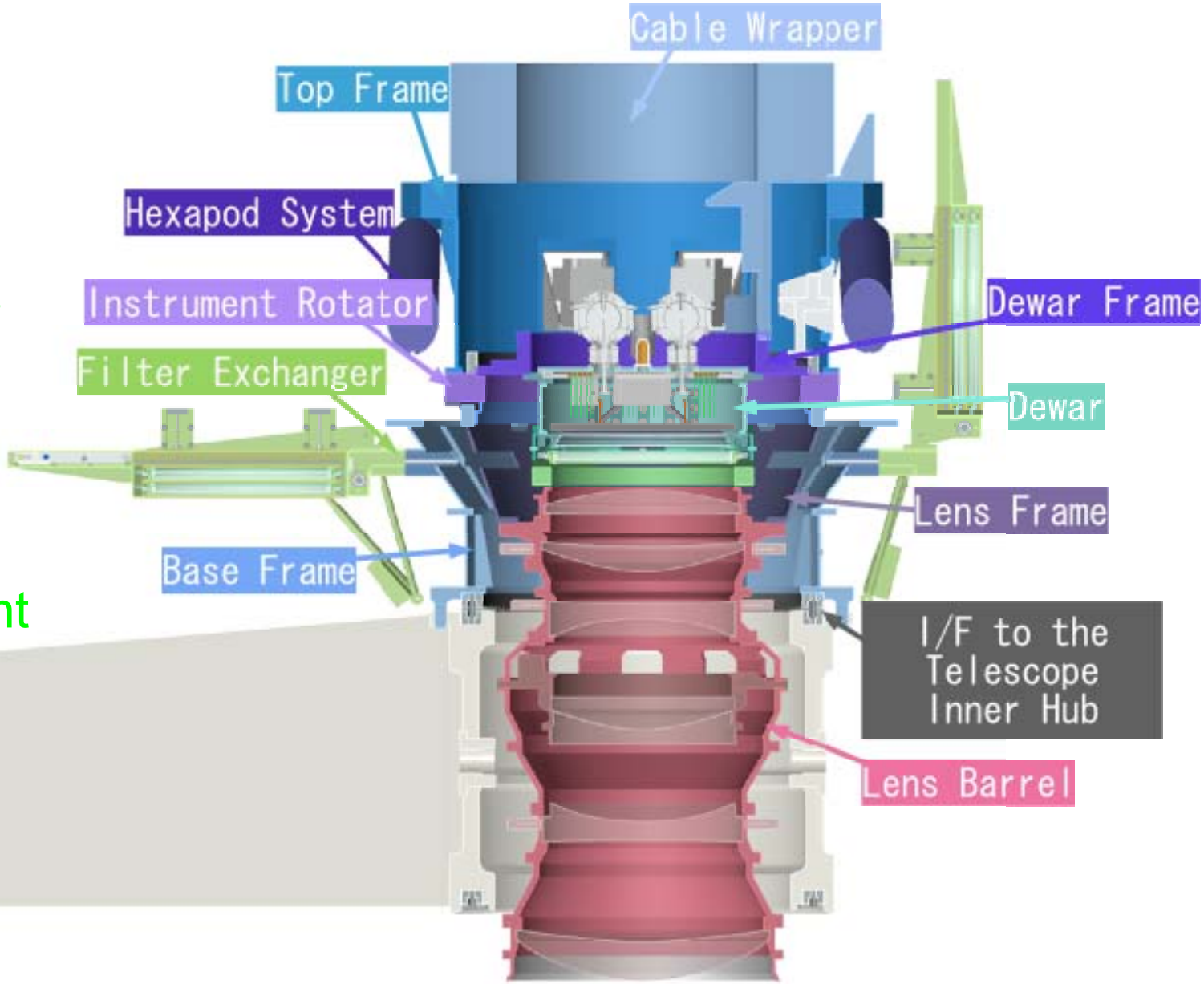
WFC

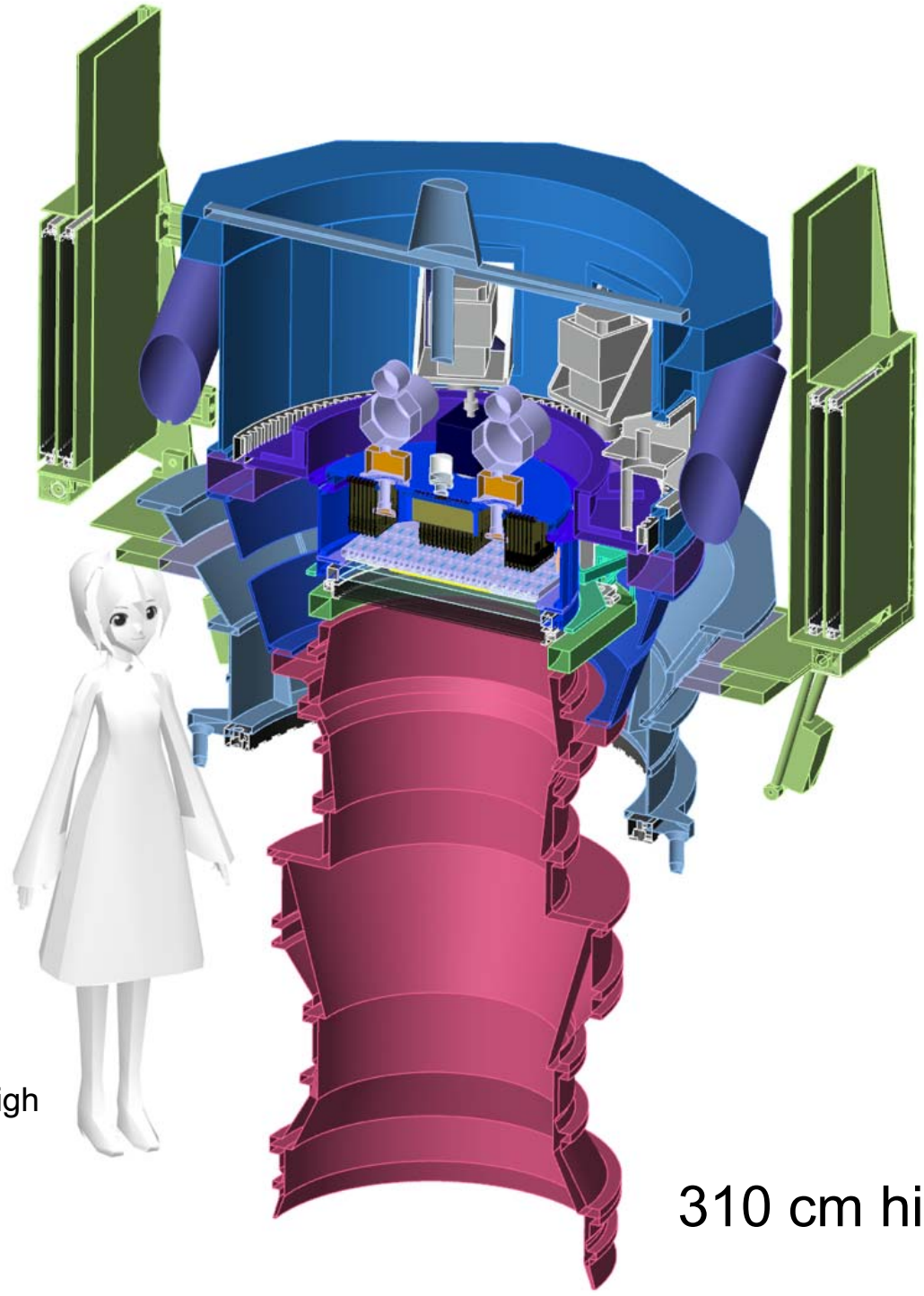
HSC Mechanics

Sensor

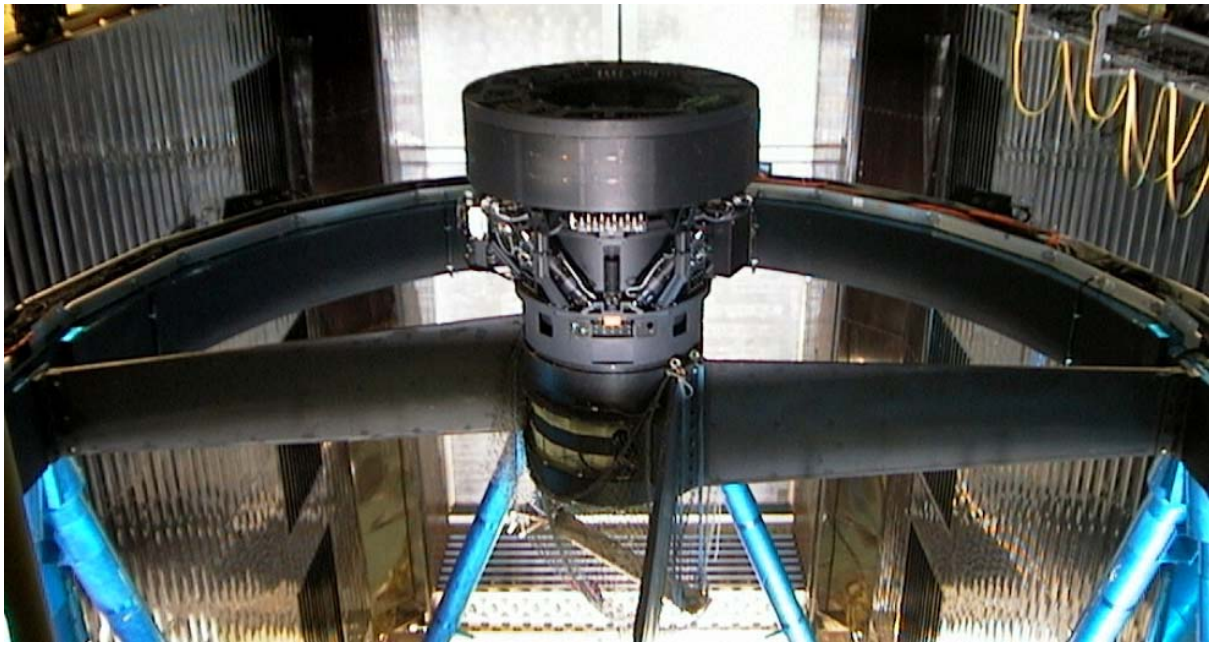
Filter

Data Management

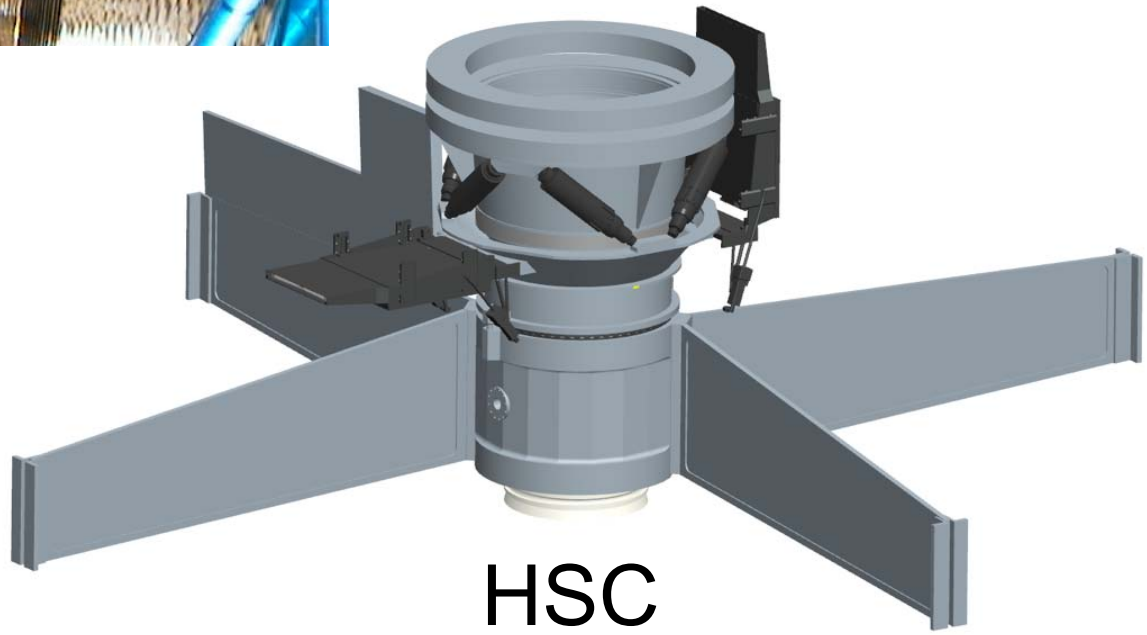



158 cm high
310 cm high

Suprime-Cam and HSC



SC



HSC

SC is already very large.

HSC Components

Wide Field Corrector (WFC)
Sensor
Filter

Attitude Control Mechanism
Telescope Interface
Dewar
Shutter
Filter Changer

Wide Field Corrector

WFC Specifications

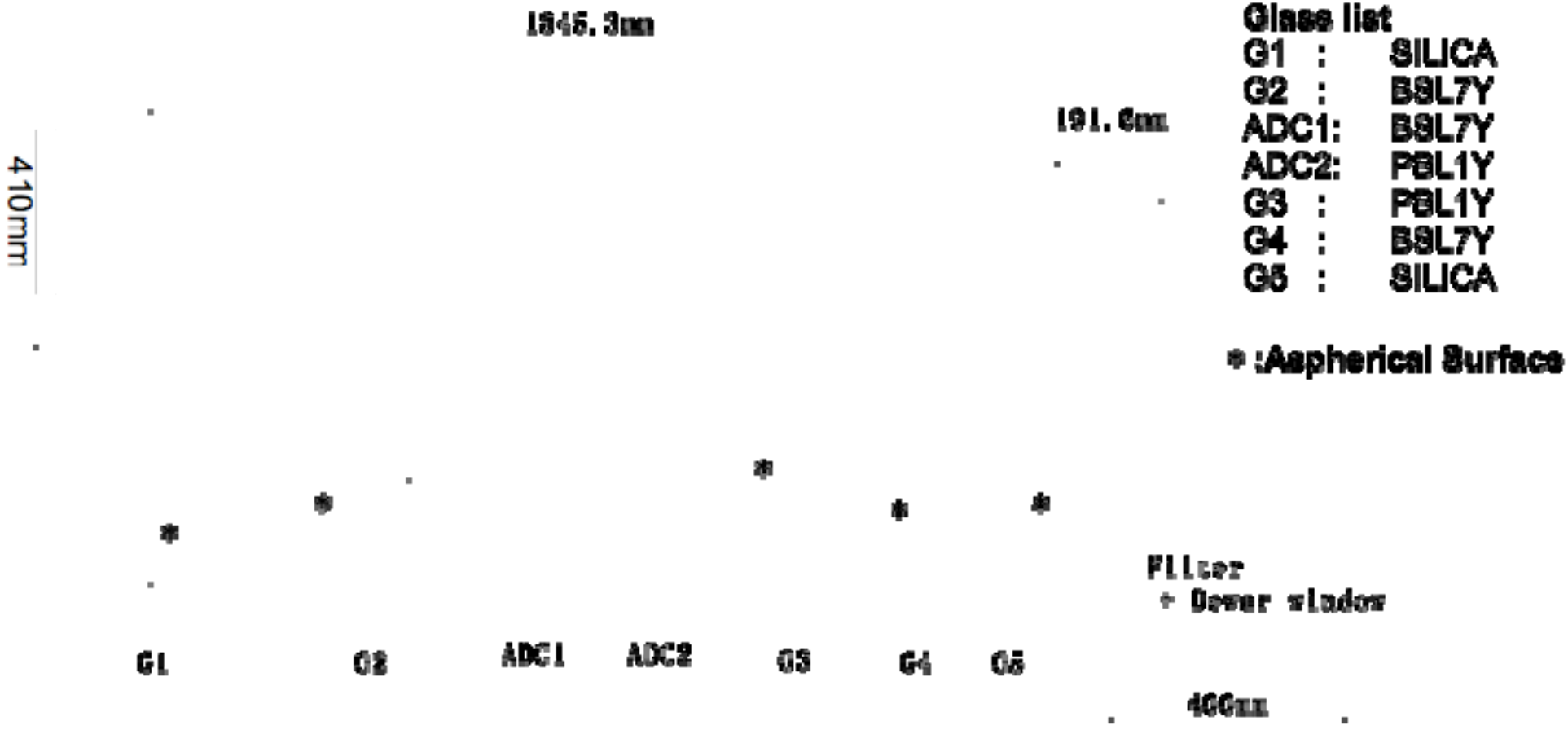
80% Encircled Energy Diameter(D80")	
g filter	< 0.5" (420,470,530nm)
r filter	< 0.3" (570,620,670nm)
i filter	< 0.3" (710,760,820nm)
z filter	< 0.3" (870,910,960nm)
y filter	< 0.4" (970,1020,1070nm)

Nominal designed performance < 0.2" (r,i,z filter),
< 0.25"(g,y filter)
Manufacturing and fabrication errors < 0.22" (r,i,z filter)

$$\mathrm{sqrt}\{(\text{Nominal error})^2 + (\text{MF error})^2\} = 0.3"$$

Wide Field Corrector

Details of Design



General Optical Datas

focal length	18320mm
image scale	0.0888[mm/arcsec]
image size(1.5deg	Φ495mm

designed by Canon

Wide Field Corrector

Availability of the glass

- **Fused silica:**

Φmax ≧ 820mm, homogeneity ≦ 5ppm (for G1 ≦ 3ppm)

Available from Shin-etsu Quartz or Corning

- **BSL7Y:**

Φmax ≧ 630mm, homogeneity ≦ 5ppm

Available from Ohara or Schott

- **PBL1Y:**

Φmax ≧ 610mm, homogeneity ≦ 5ppm

Available from Ohara or Schott

PBL6Y, PBM8Y, PBM18Y, PBL25Y, PBL26Y also

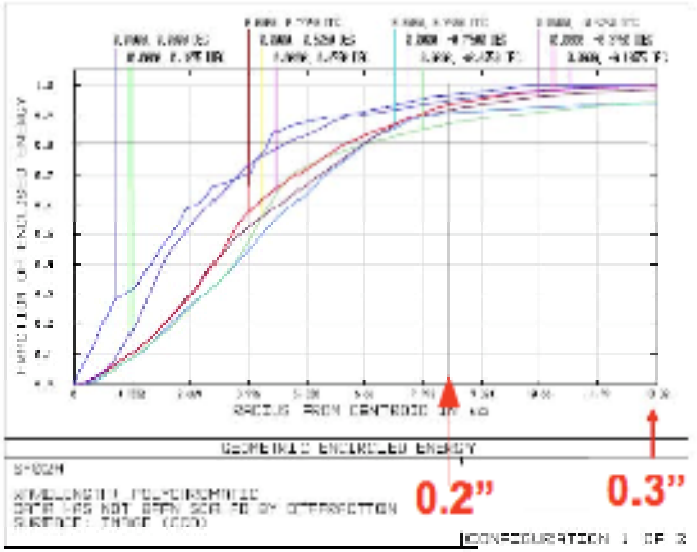
can be ~ 600 mm (t50)

Required common qualities

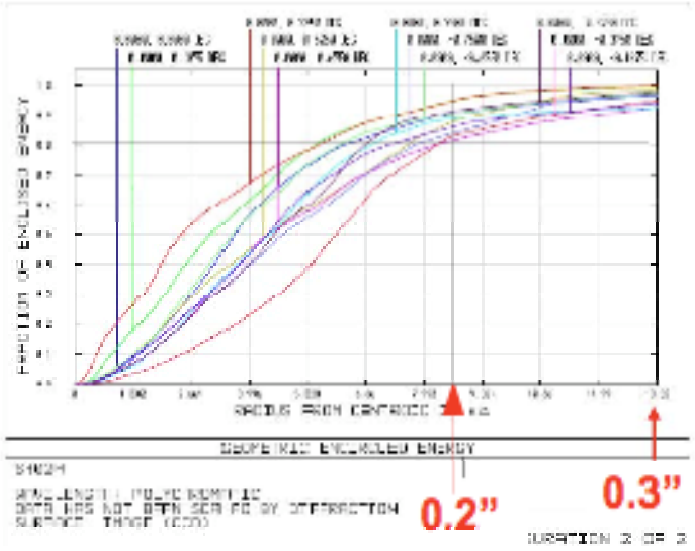
striae	no visible striae
birefringence	≦ 5 nm/cm
bubble,inclusion	the total cross section of bubbles(mm^2/100ml) ≦ 0.1 ~ 0.25
refractive index	±0.00050
Abbe number	±0.5%

WFC Designed Performance

EL–90°



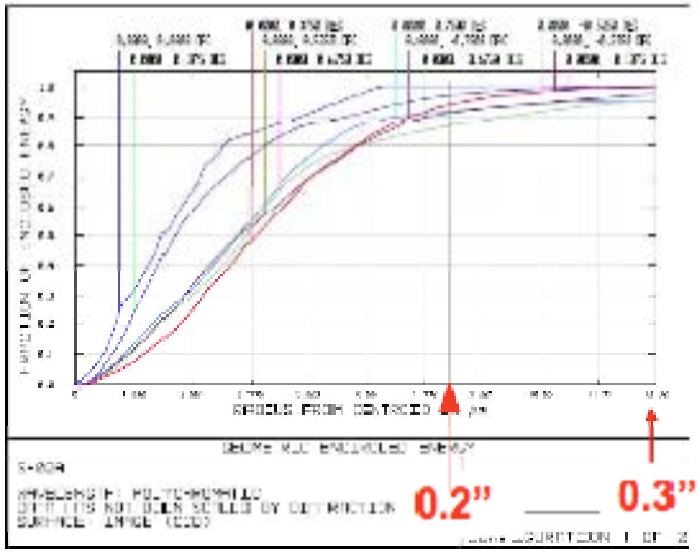
EL–30°



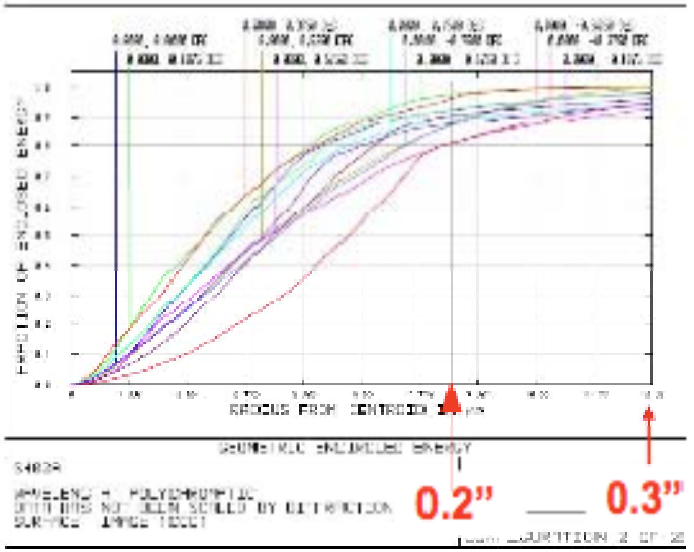
r-filter

i-filter

EL–90°



EL–30°



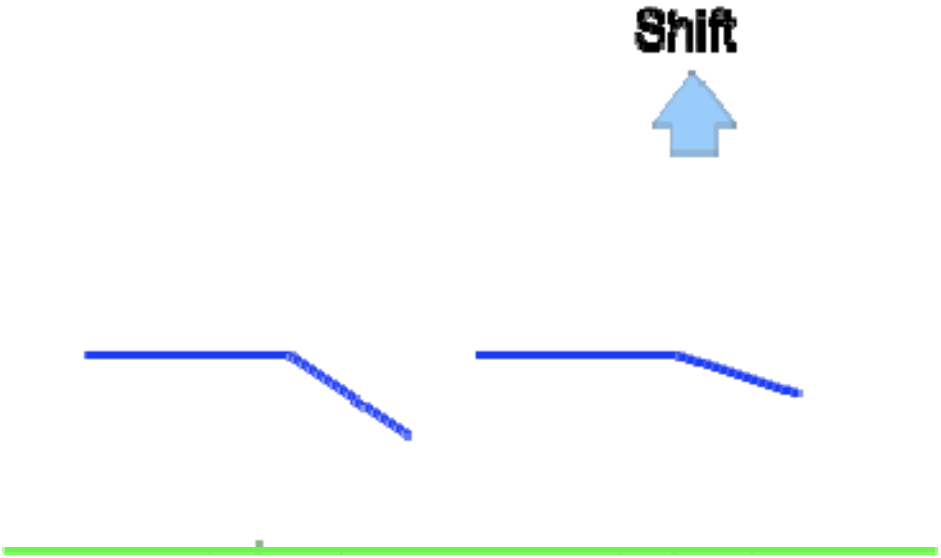
WFC Designed Performance

		Suprime-Cam	HSC
field of view		0.5deg	1.5deg
transmission		400nm > 65% *1	400nm > 80.9% *2
		648.1nm > 90% *1	800nm > 89.0% *2
		950nm > 67% *1	1050nm > 81.5% *2
Performance(D80") EL=90°	g	0.18	0.18
	r	0.09	0.15
	i	0.11	0.15
	z	0.15	0.15
	y	0.17	0.20
Performance (D80") EL=30°	g	0.21	0.20
	r	0.13	0.19
	i	0.13	0.19
	z	0.18	0.19
	y	0.19	0.22
focus length		18000mm	18320mm
ADC		lateral shift type ADC	lateral shift type ADC
Vignetting		Non	max 25.6%
Image curvature		Non(Plane image)	Non(Plane image)
Distortion		+0.9%	+3.19%
lens weight		~57kg	428kg
Ghost(illuminance ratio)		< 1.1E-07	< 5.4E-08 *3

0''.1 in FWHM

*1)measured value *2)designed value *3)not include the ghost between filter surfaces.

ADC



Lateral shift type ADC was invented by the late Dr.Takeshi (the designer of the Suprime-Cam WFC)

- consists of two glasses
- BSL7Y + PBL1Y
  (not cemented)

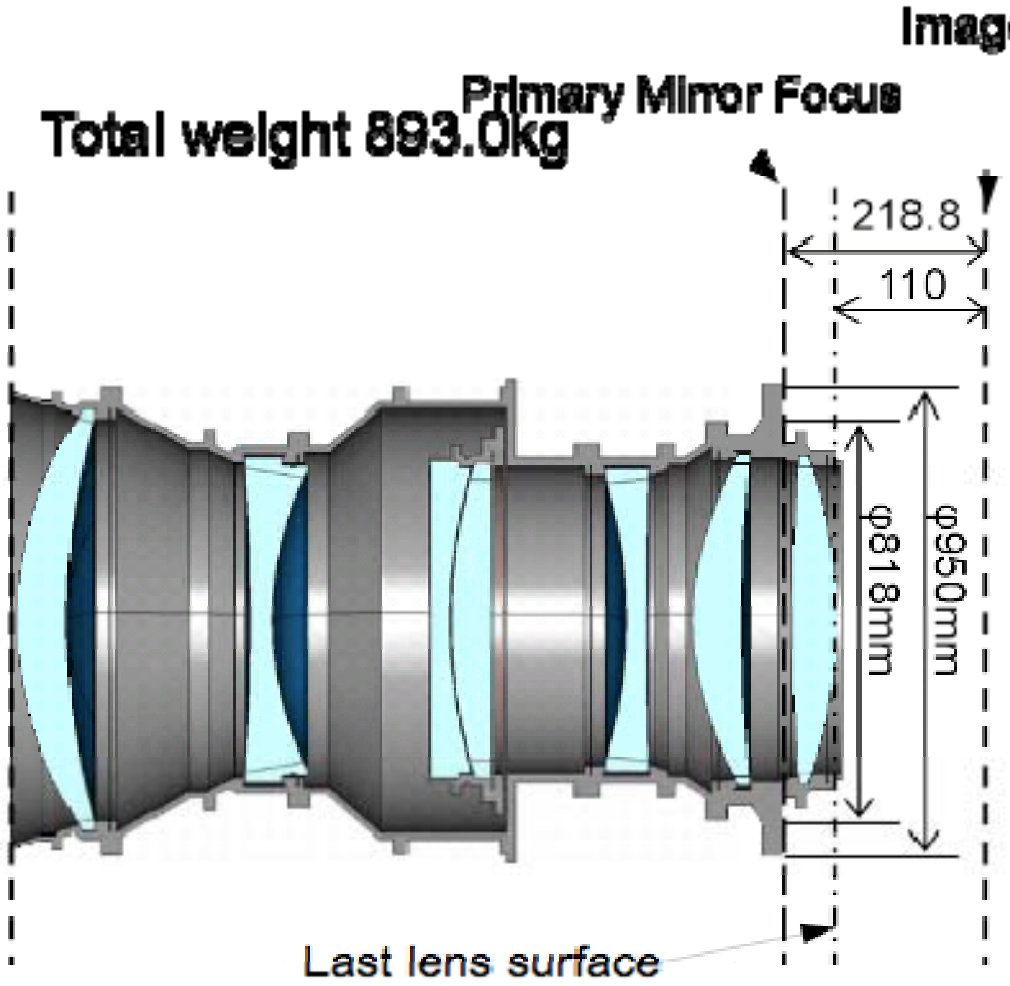
Merits

- use only two lenses
  (prism ADC uses four glasses)
- works as an achromatic doublet

This ADC is the best because of the tight weight constraint.

Lens Barrel

Pile of Lens Ring Frames



Each Lens Element is retained by each lens frame.

The lens frames are stacked and formed the lens barrel assembly.

Lens Frame Material
CORDIERITE

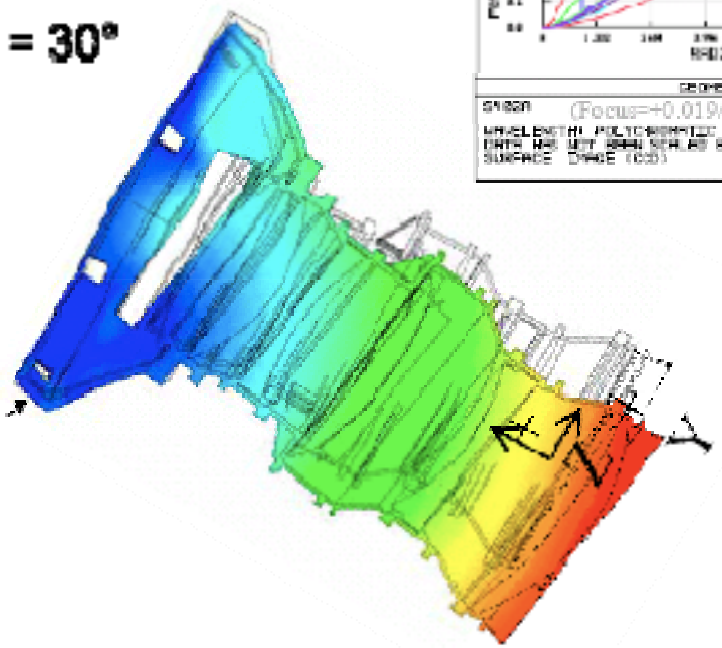
Feature

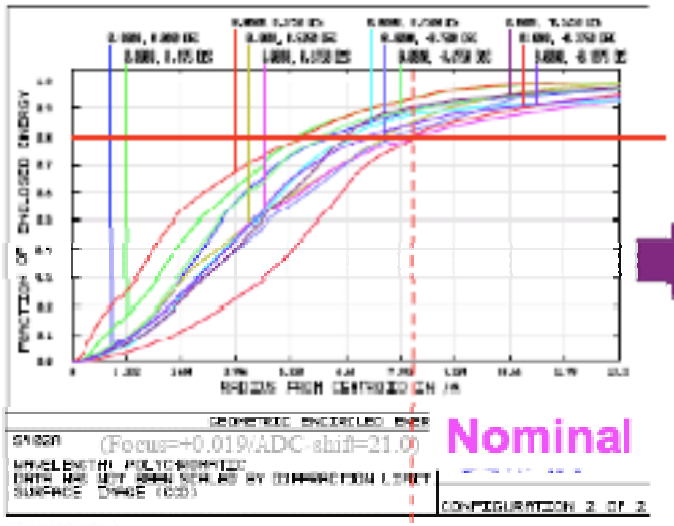
- Low CTE (< |0.1| ppm)
- High Young's modulus (~ 140 Gpa)
- mass density ~ 2.7 kg/m^3

Flexure of lens Barrel

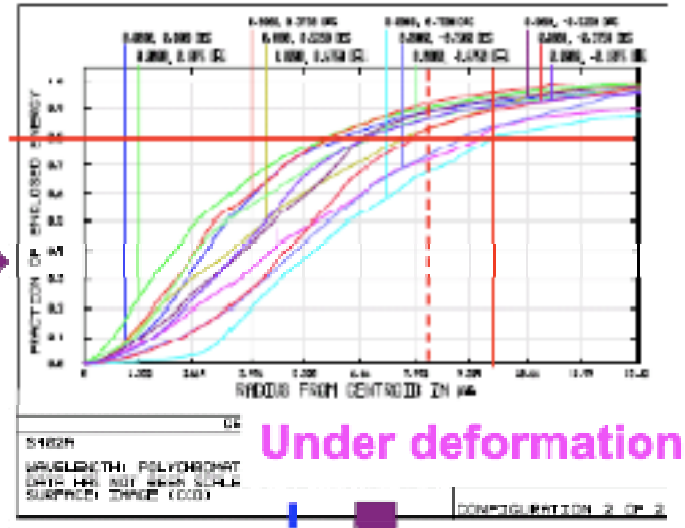
Deformation under the barrel own weight(EL=30° r-filter)

EL = 30°

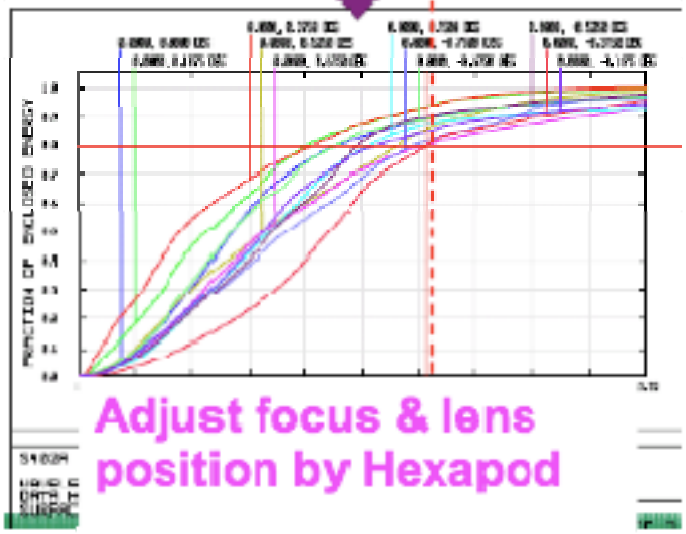




Nominal



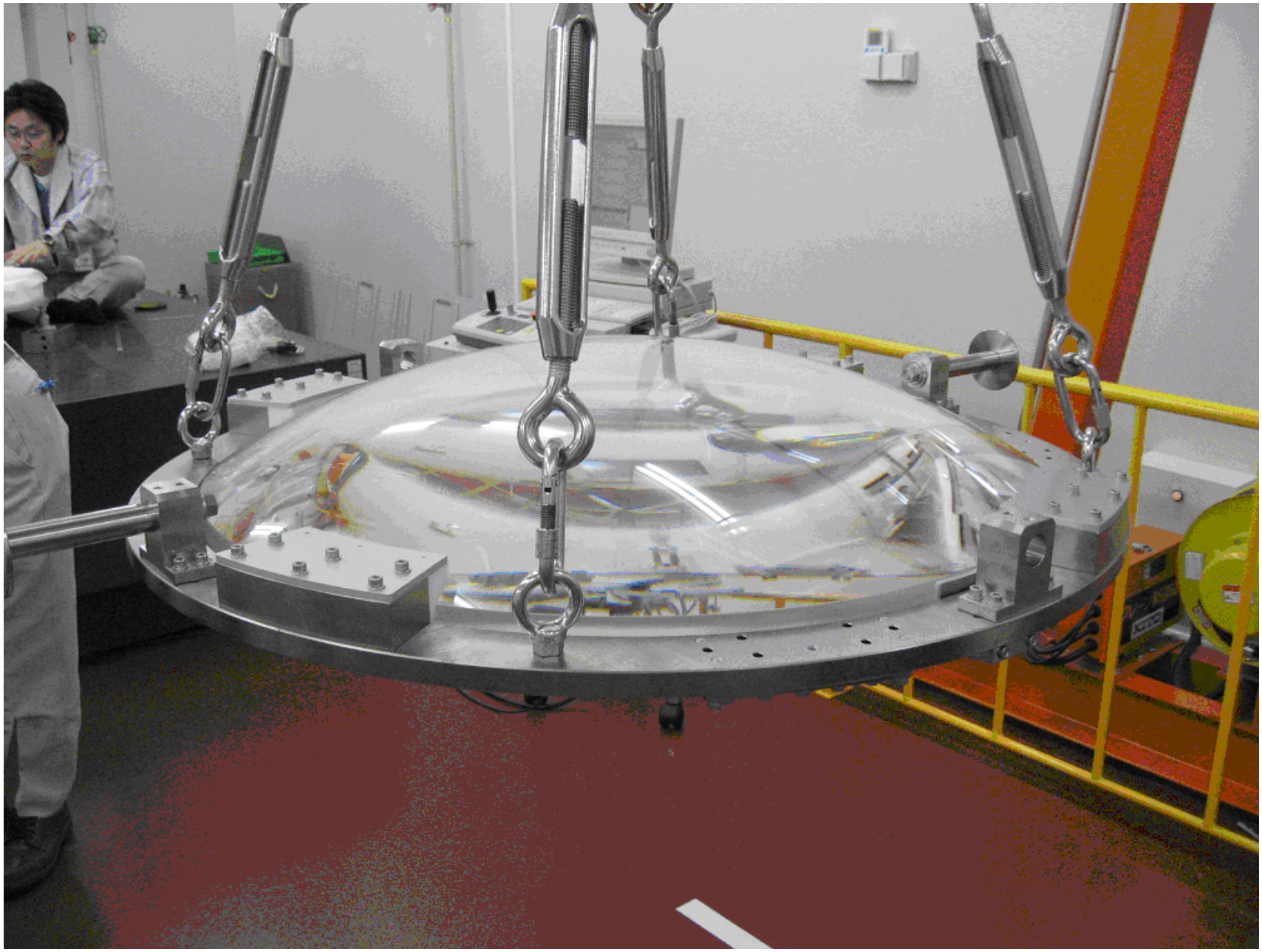
Under deformation



Adjust focus & lens position by Hexapod

Lens Barrel Flexure makes D80 worse but not so serious

Fabrication underway



Sensor

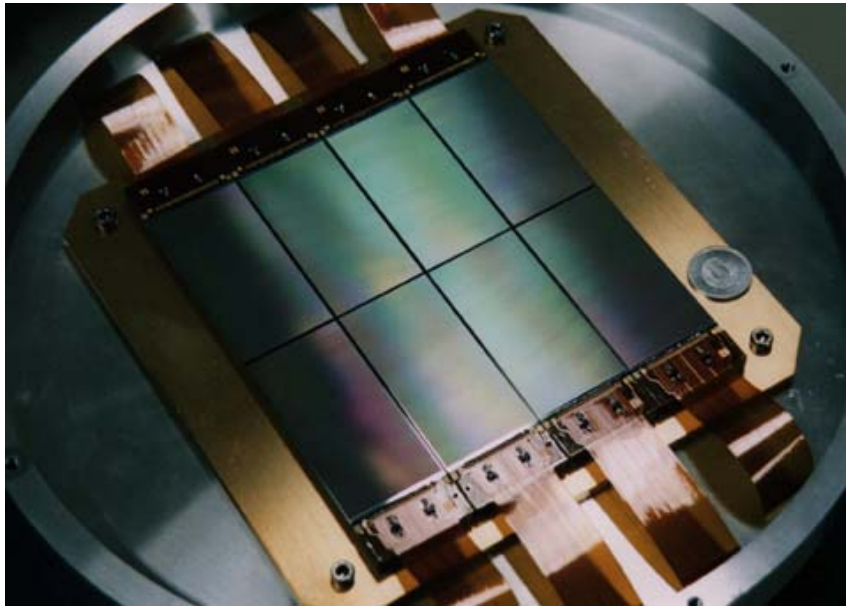
CCD Requirements

Items		Requirement (-100°C)
Packaging	Format (pixel size)	2048×4096 (15 μm□)
	Pixel to Package edge	< 0.5 mm
	(Serial register side)	< 5.0 mm
	Global height variation	< 25 μm Peak-to-Valley
QE	400 nm	> 45 %
	550 nm	> 85 %
	650 nm	> 90 %
	770 nm	> 85 %
	920 nm	> 80 %
	1000 nm	> 40 %
CTE (per pix)	Parallel direction	> 0.999995 (1600 e)
	Serial direction	> 0.999995 (1600 e)
Dark Current		< a few e/hour/pix
Charge diffusion		σ < 7.5 μm (400 < λ< 1050 nm)
Full well	1 % depature	> 150,000 e
Amp. Responsivity		> 4 μV/e
Readout noise	150 kHz readout	< 5 e

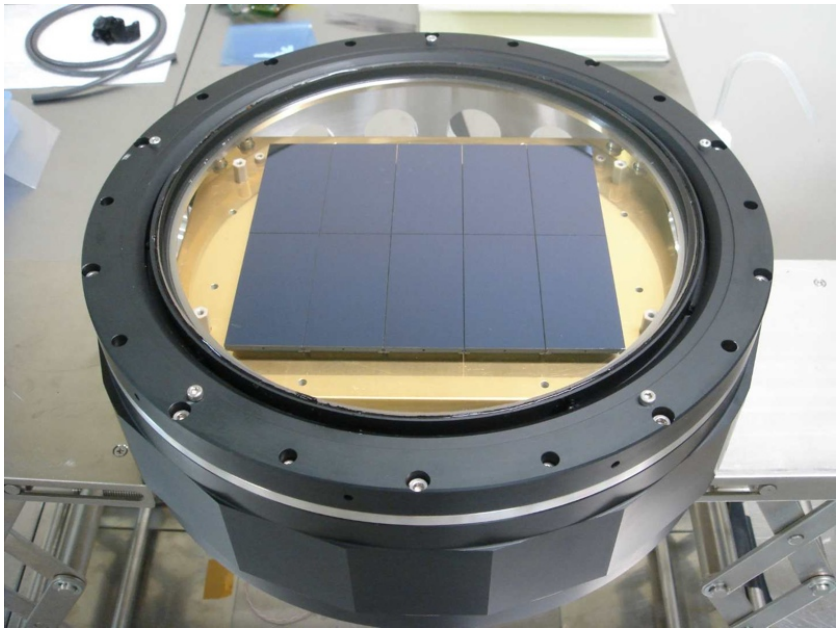
CCD needs to be thick enough to achieve high QE in red

NAOJ-Hamamatsu Collaboration

1994 - 1996 Back Illuminated small CCD
1996 - 1998 2k4k Front illuminated CCD
1999 - 2008 BI 2k4k Fully Depleted CCD

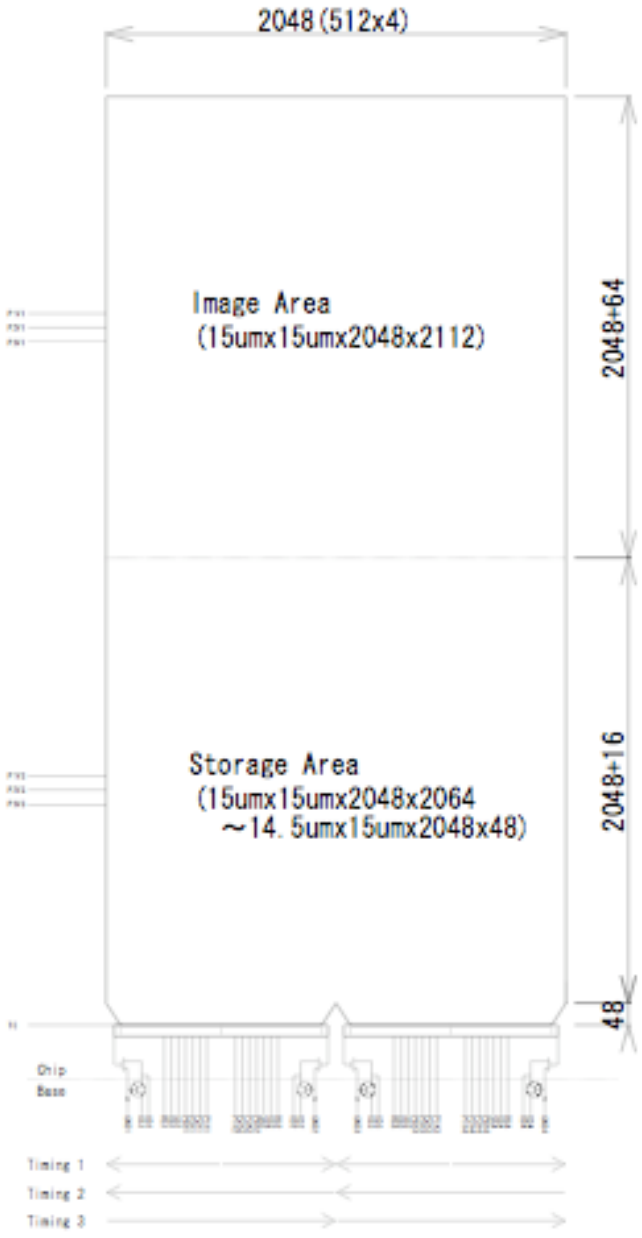


1998

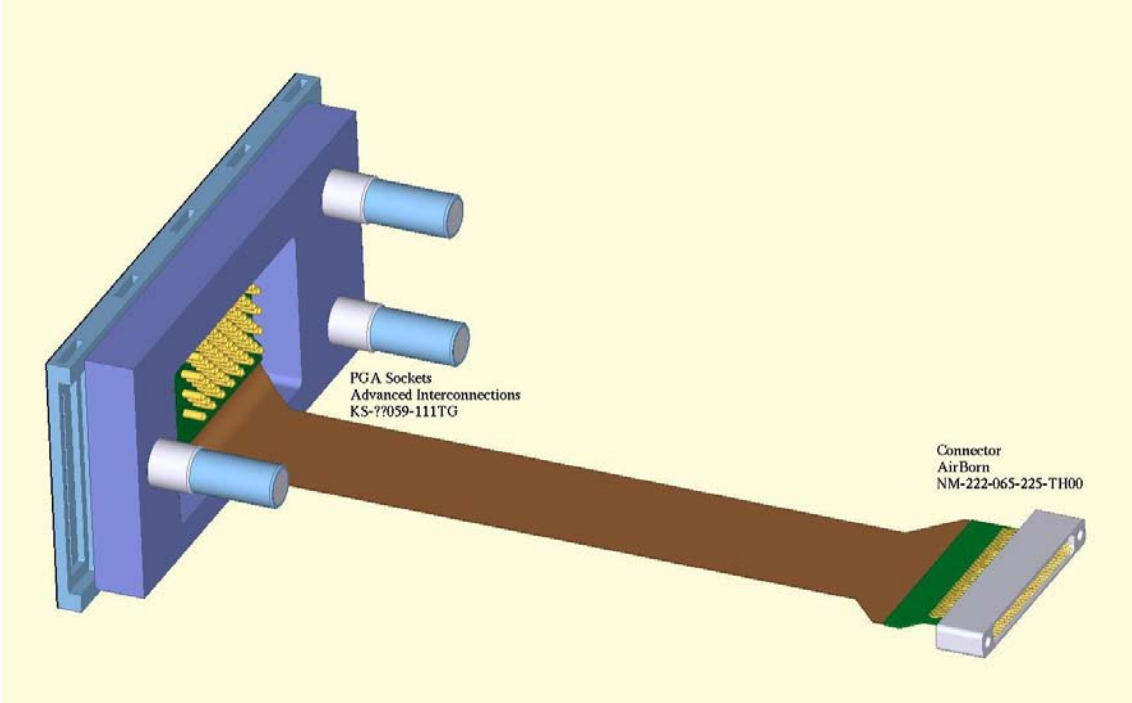


2008

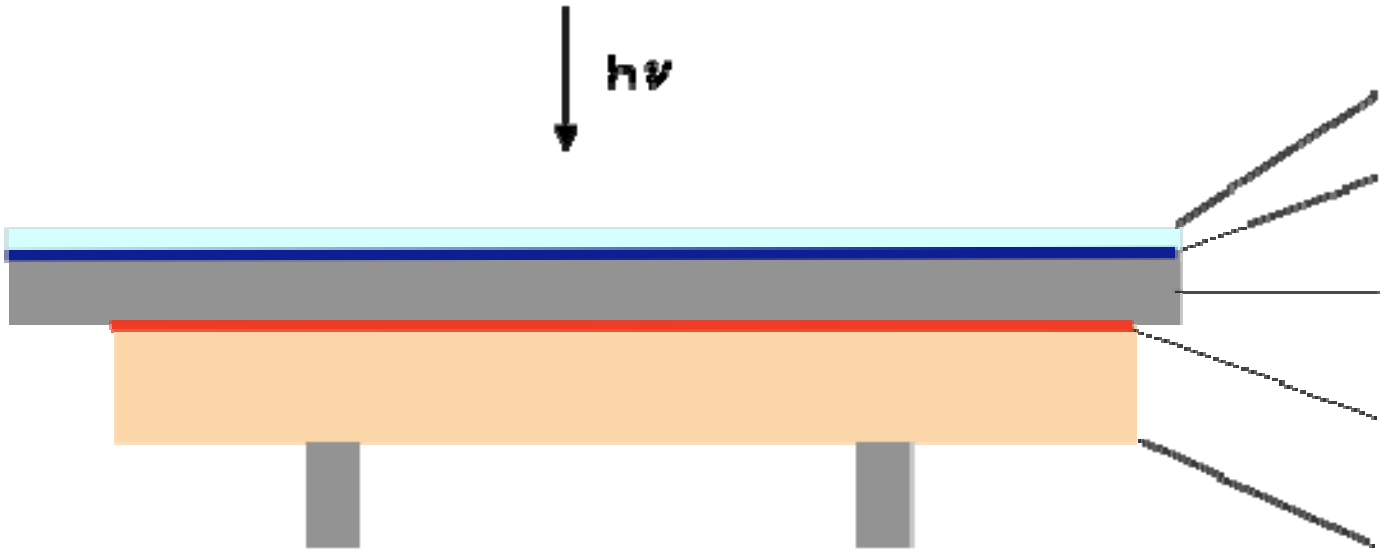
HPK Fully Depleted CCD



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



Package Structure



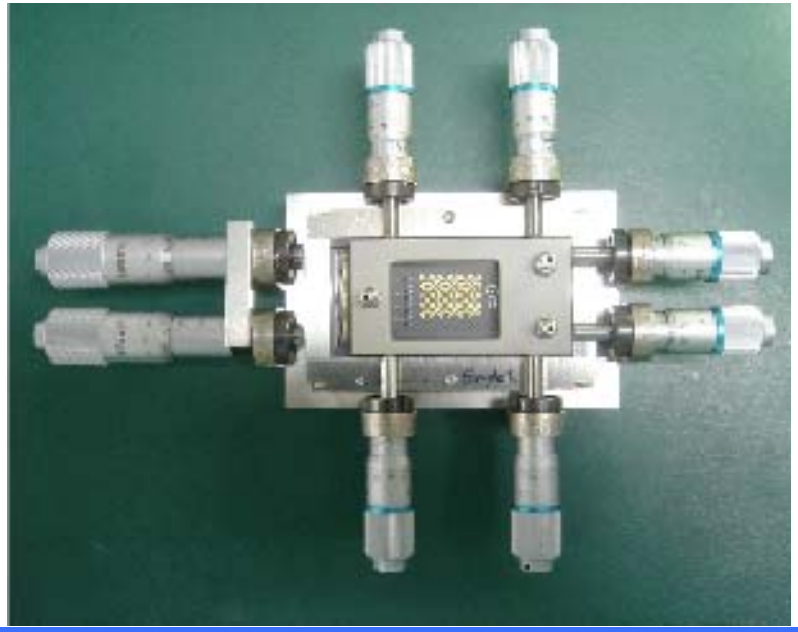
CCD chip

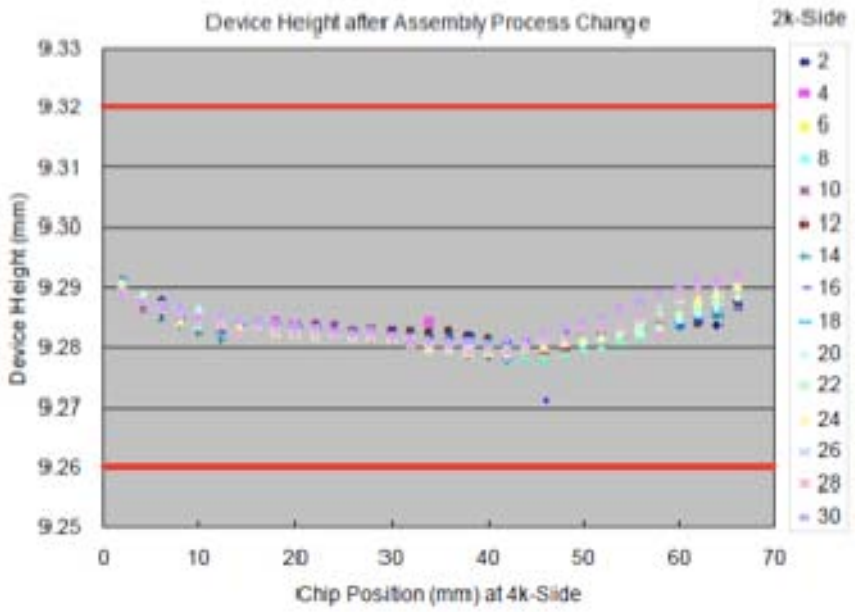
Low viscosity epoxy

CCD base

Printed epoxy resin adhesive

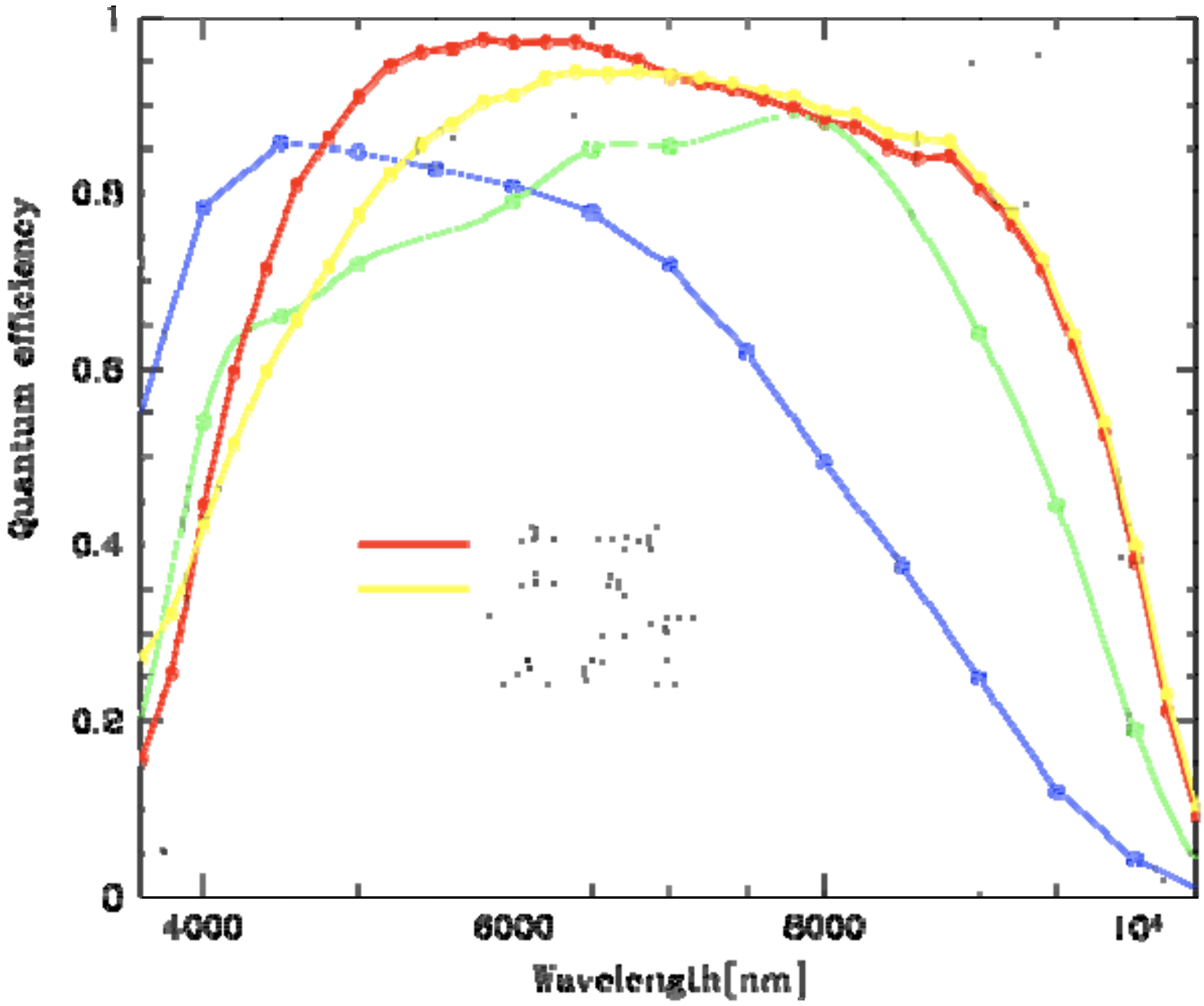
Pin base





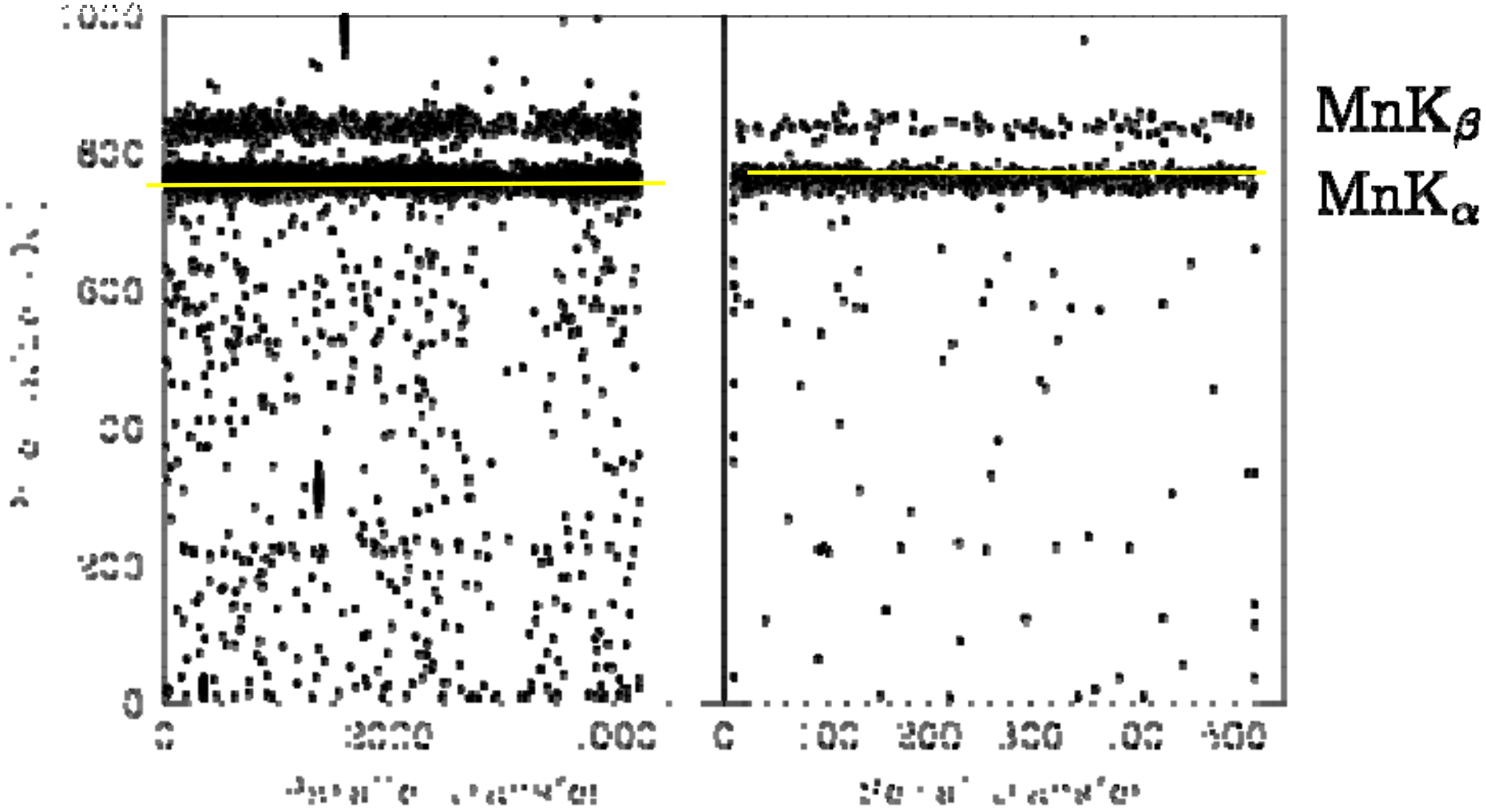
10um flatness achieved

Quantum Efficiency



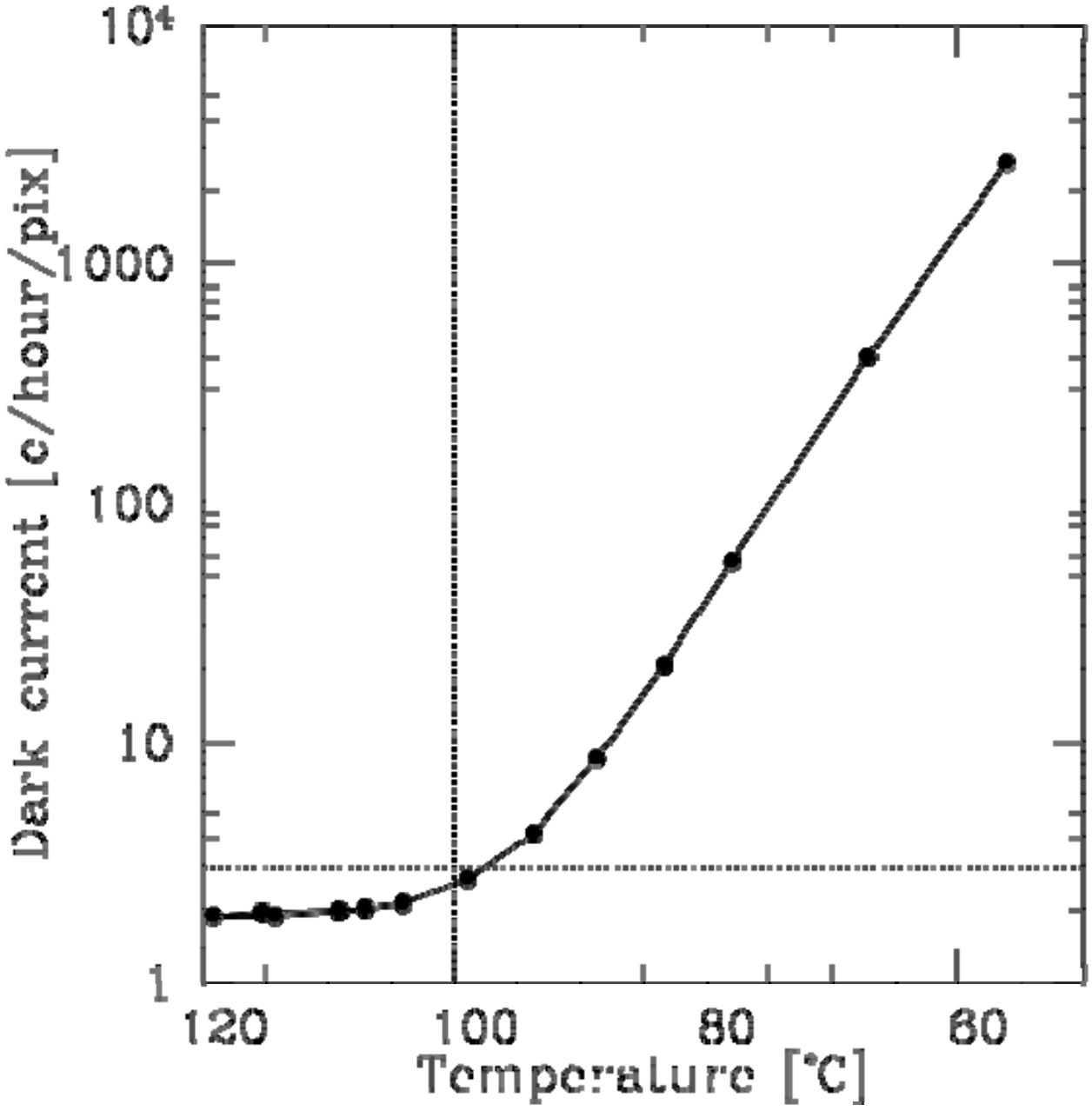
Charge Transfer Efficiency

X-ray test

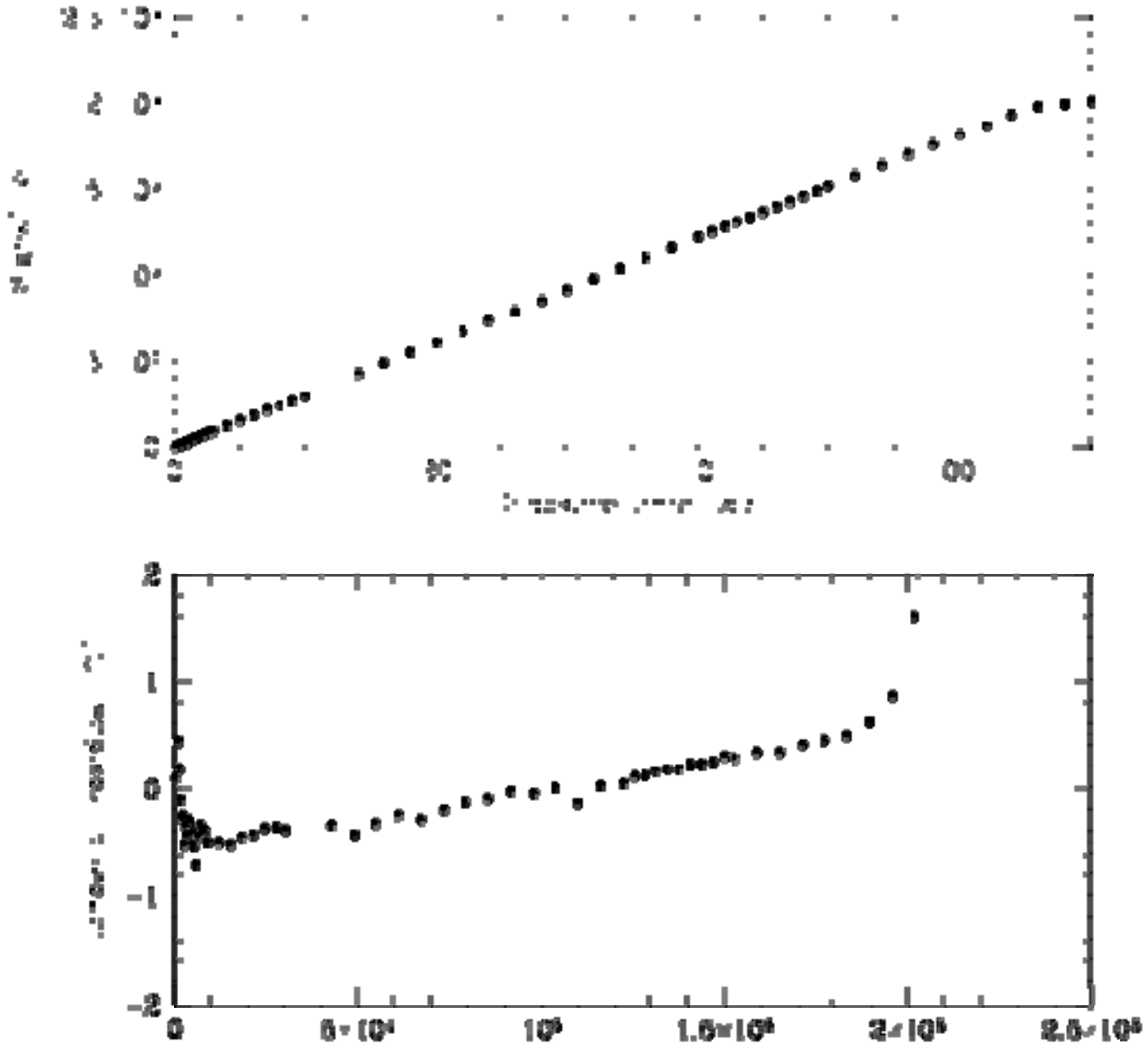


No slope indicates good CTE (>0.999995)

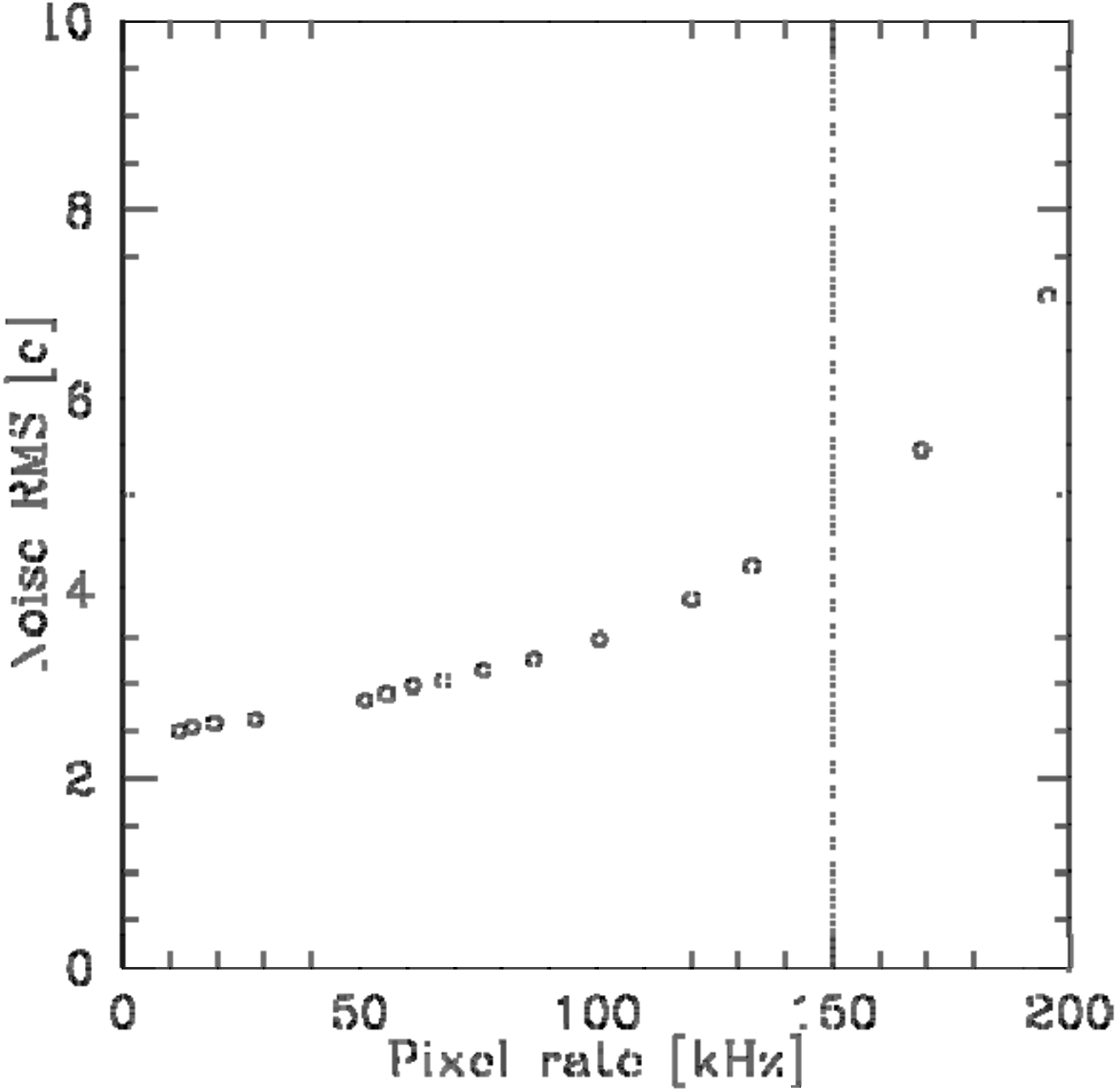
Dark Current



Full well



Read noise



4.5 e rms
(150 kHz)
MFront2

Charge Diffusion

Expected Charge diffusion: $\sigma_D = 7\mu\mathrm{m},\ \mathrm{t} = 200\ \mu\mathrm{m}$

Suprime-Cam

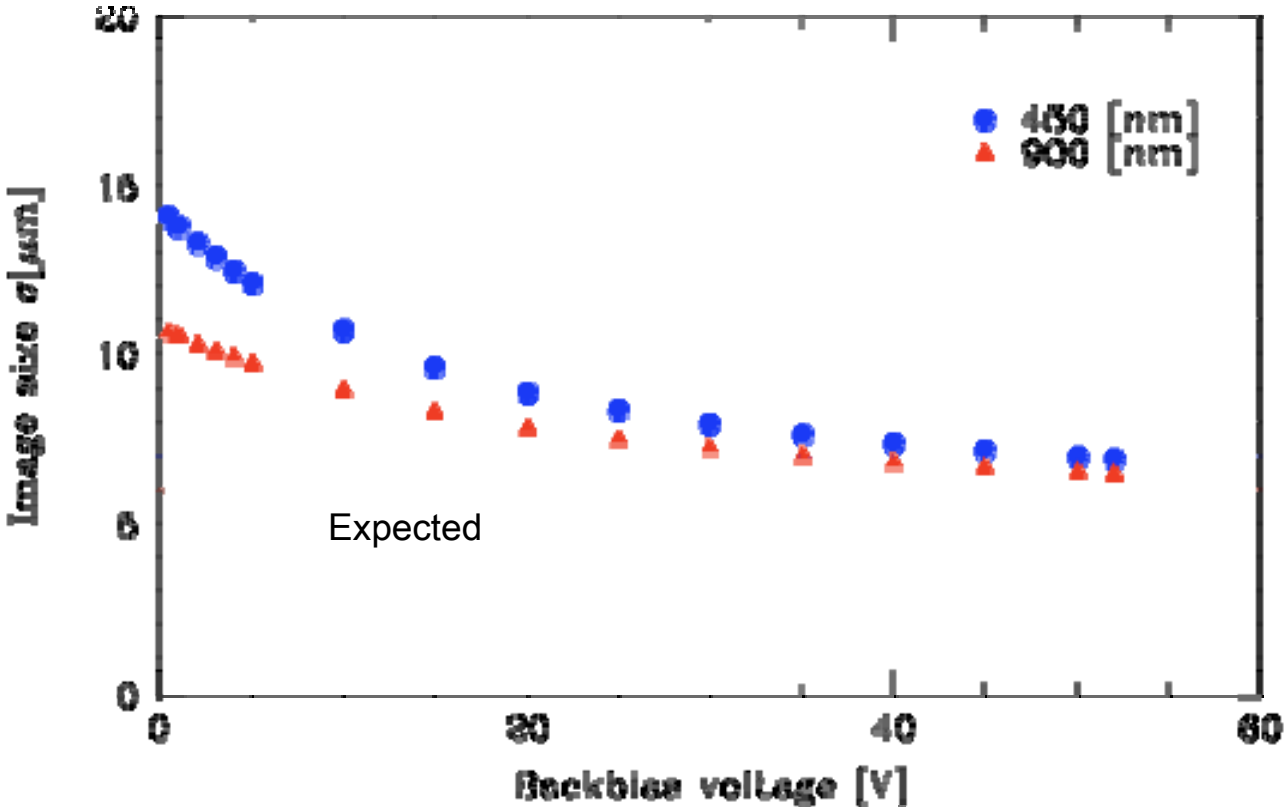
λ [nm]	focus pos. [μm]	σ [μm]	FWHM ["]
700	5.6	6.9	0.21
800	19.2	6.6	0.20
900	43.8	5.8	0.18
1000	84.7	4.5	0.14

lambda of 700 nm results can be adopted for shorter lambda

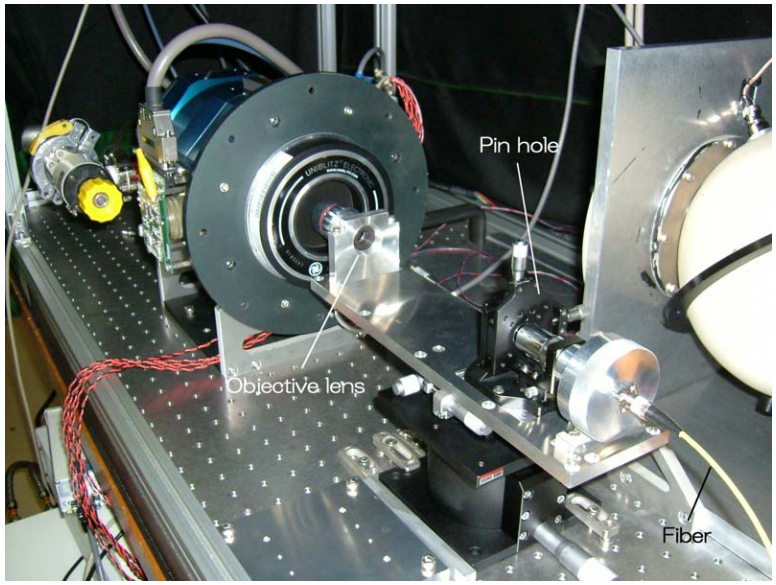
Sufficiently small charge spread

(HSC pixel scale is 15 % smaller)

Measurement



Measurement setup

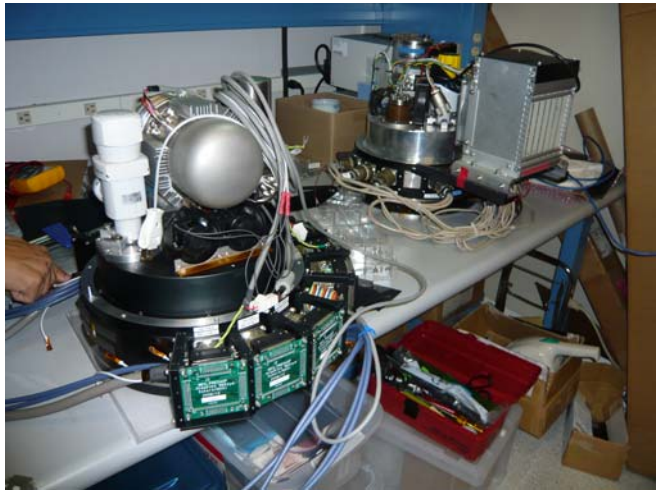


10 micron pin hole is projected with X 1/10 (NA ~ 0.25) optics

Measurement is consistent with expected value.

Mounted on Subaru

Replacement of MIT/LL CCID-20
July, 2008



Mounted on Subaru

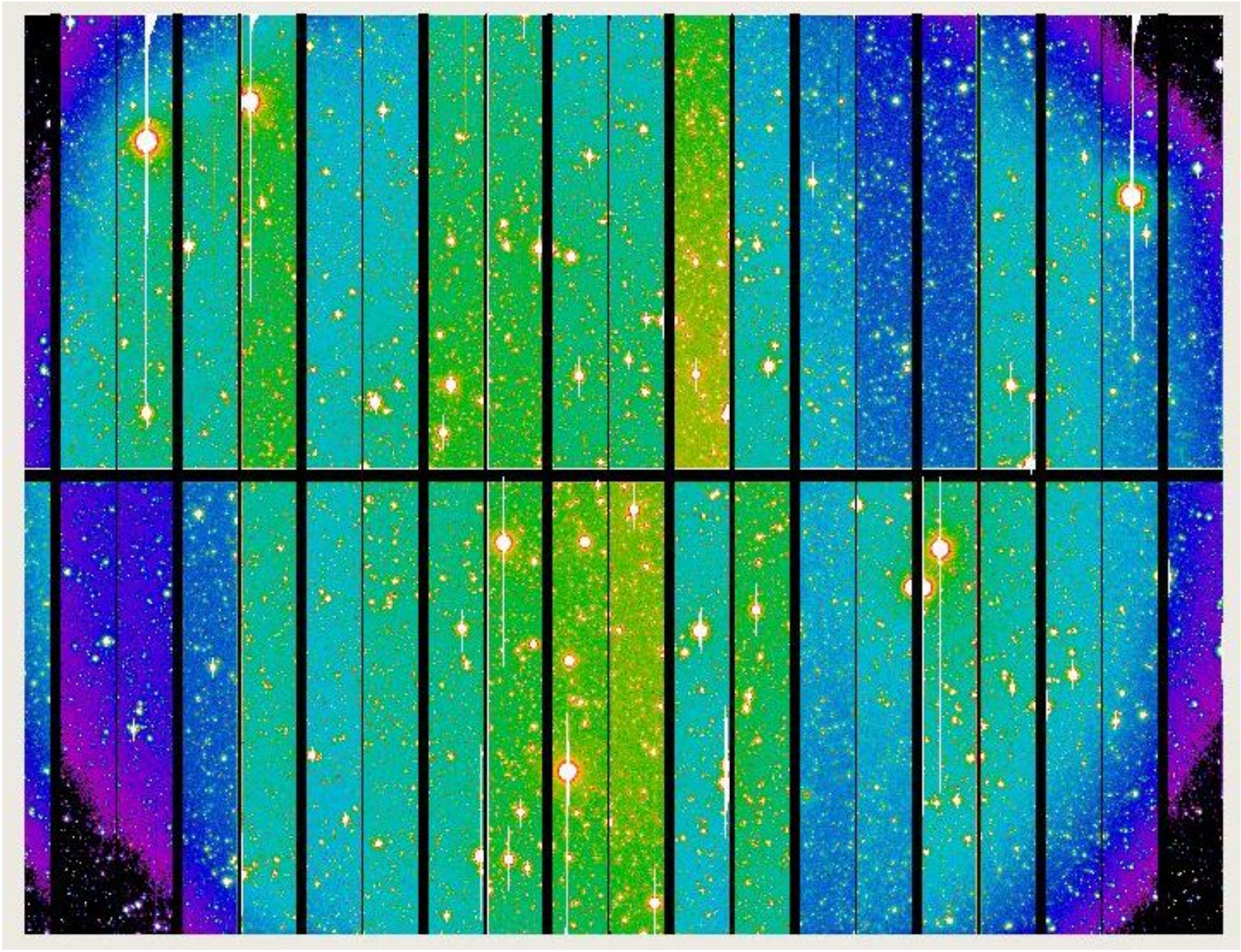
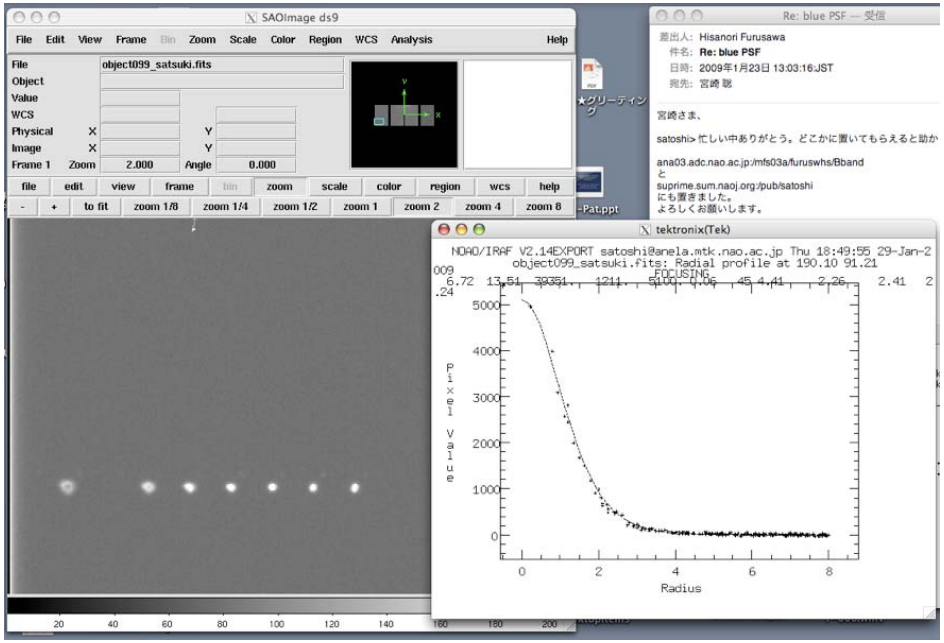
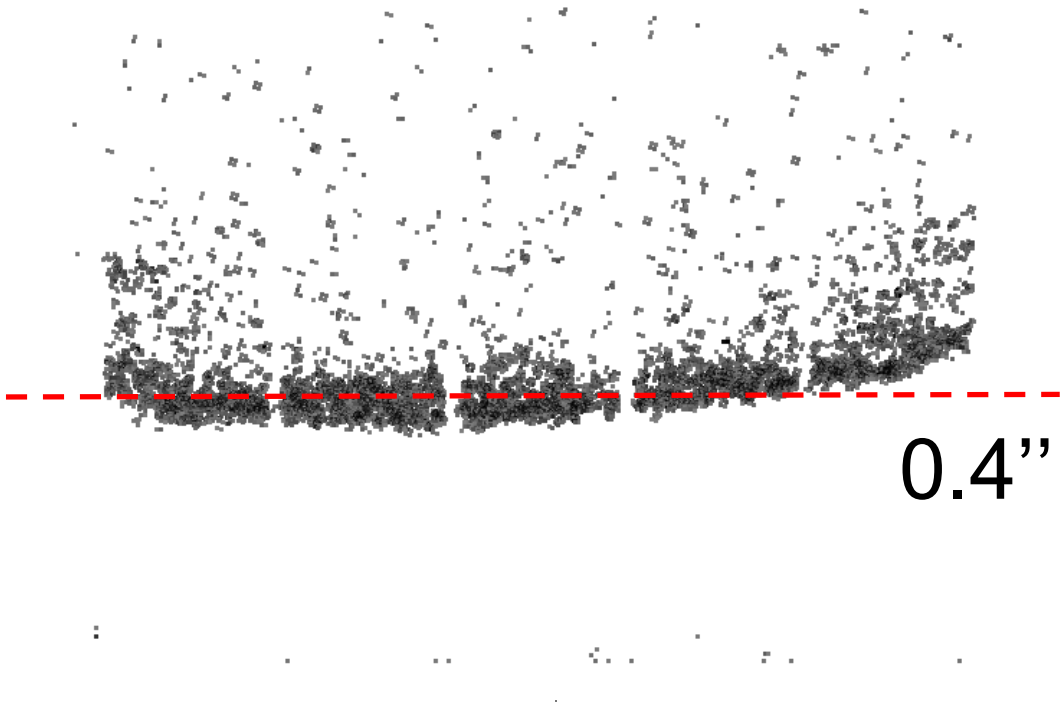


Image size at Subaru

B band

z’ band





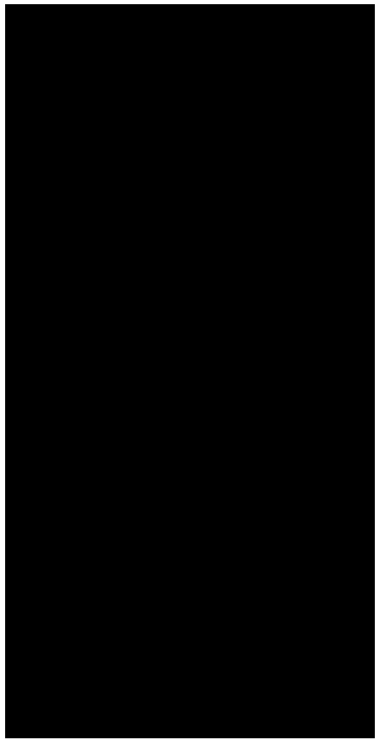
0.48” FWHM

0.38” FWHM

Cosmetic defects

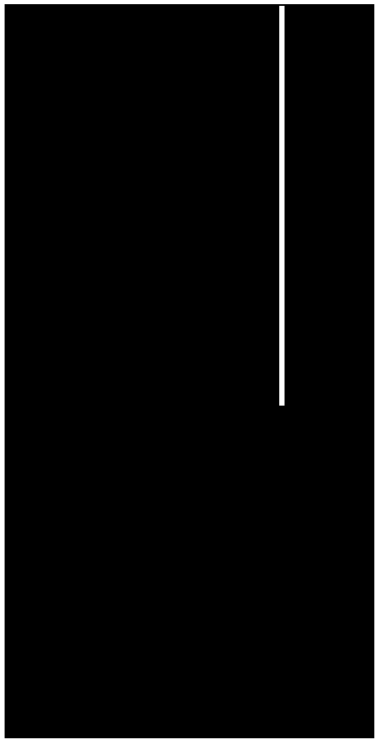
New Suprime-Cam case (10 CCDs):

No defect



3 CCD

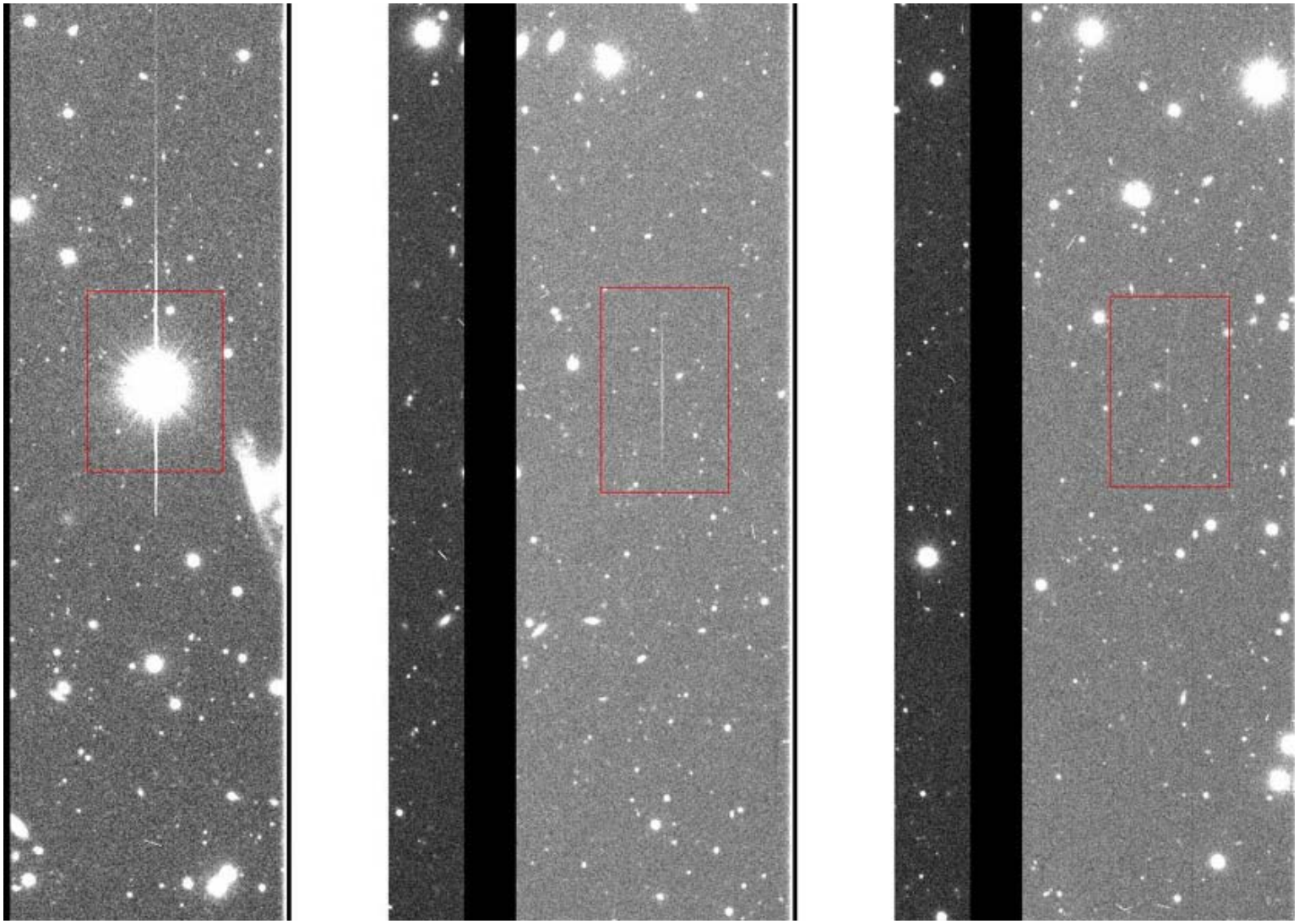
One block of bright columns



Block width:
6 CCD: 2 column
1 CCD: 5 column

7 CCD

Residual Images



Delayed charge emission from the surface traps

Pinning clock sequence between exposures fixes this entirely.

CCD Performance

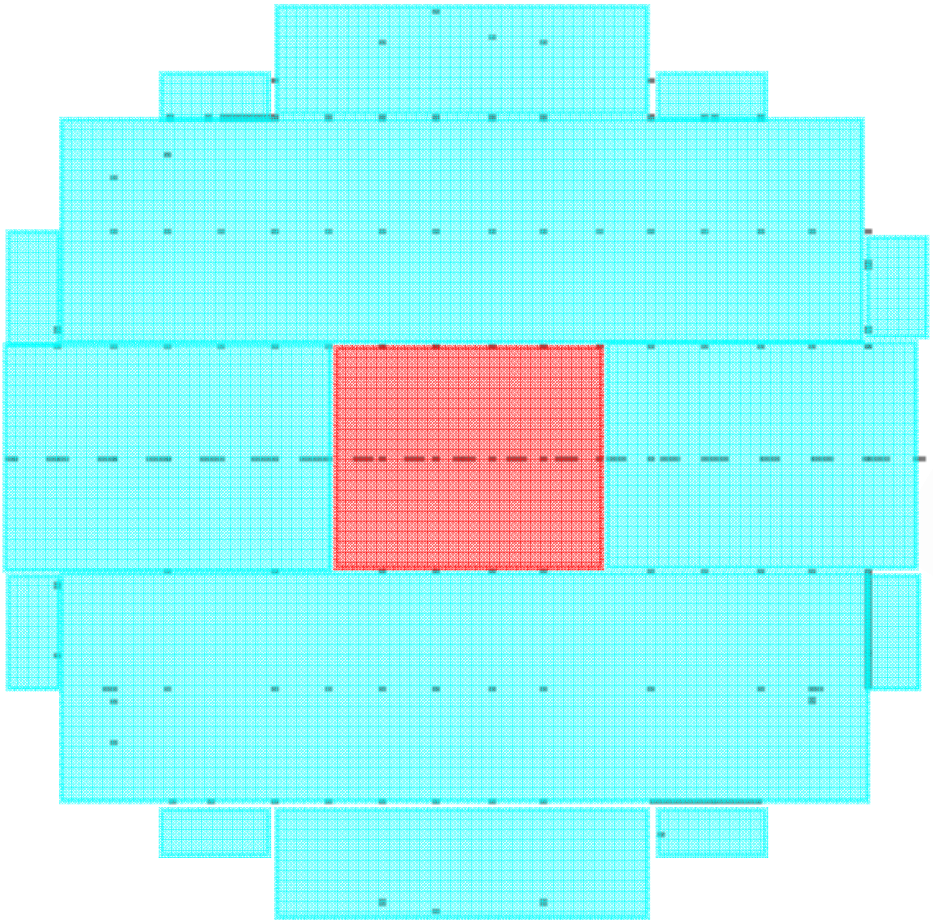
Items		Requirement (-100°C)	Measured
Packaging	Format (pixel size)	2048×4096 (15 μm□)	-
	Pixel to Package edge	< 0.5 mm	0.410±0.025
	(Serial register side)	< 5.0 mm	4.975±0.025
	Global height variation	< 25 μm Peak-to-Valley	
QE	400 nm	> 45	42
	560 nm	> 86	87
	650 nm	> 90	94
	770 nm	> 85	91
	920 nm	> 80	78
	1000 nm	> 40	40
CTE (per pix)	Parallel direction	> 0.999995 (1600 e)	0.999990
	Serial direction	> 0.999995 (1600 e)	0.999998
Dark Current		< a few e/hour/pix	1.4
Charge diffusion		σ_0 < 7.5 μm (400 < λ < 1050 nm)	7.5
Full well	1 % departure	> 150,000 e	180,000
Amp. Responsivity		> 4 μV/e	4.5
Readout noise	150 kHz readout	< 5 e	4.5

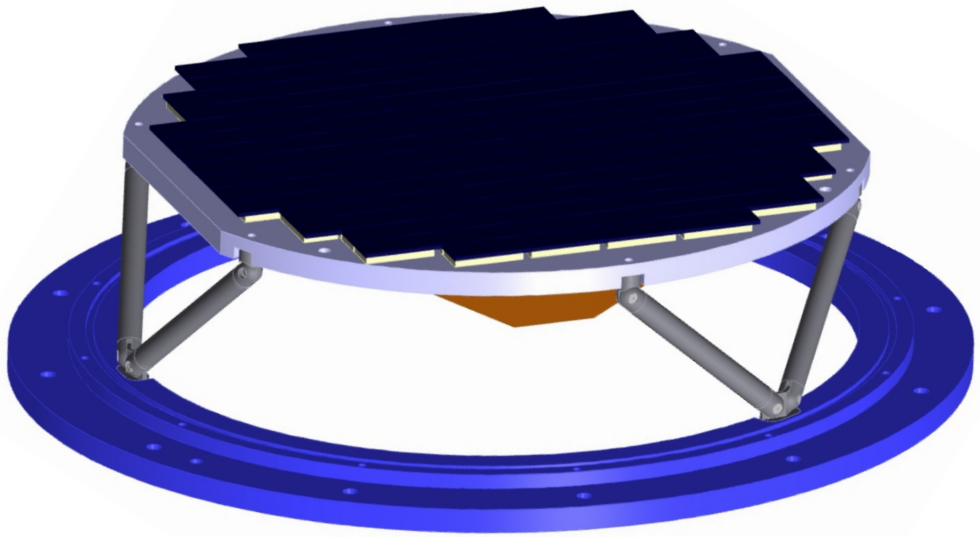
Hamamatsu FDCCD

- Installation on Subaru FOCAS multi object spectrograph underway
- Now Commercially Available
- Gemini GMOS North and South placed an order.

Next Japanese X-ray satellite decided to employ Hamamatsu's FDCCD

HSC Focal Plane





112 + 4 Guides

Filter

Filter Specification

	Suprime-Cam
Substrate	BK7
Diameter	205x170mm
Clear aperture(CA)	192x158mm
Thickness	20mm
Thickness error	< 0.2mm
Parallelism	< 1 arcmin
Sub aperture(SA)	30mm
Wavefront error in SA	N/A
Peak transmission	> 95%
Out of band leak	< 0.1%
Cut-off wavelength error	0.6%-1.0%
Uniformity(wavelength)	0.4%
Uniformity(transmission)	1%
Ripple of transmission	5%

Suprime-Cam's spec

Filter Configuration

- “Combination of color glass and interference film” used be traditional.
- No large color glass is available
- Pure Interference filter is the only option for D > 50 cm

Two ways of coating

- Vacuum evaporation
- Advantage
  - Good uniformity
  - Large surface
- Disadvantage
  - Porous film
  - Low durability
  - less number of layer can be accumulated

Three substrate required

- Sputter deposition
- Advantage
  - Dense film
  - Good durability
  - more number of layers can be accum.
- Disadvantage
  - Difficulty to realize uniformity over large area

One substrate is enough

Prototypes

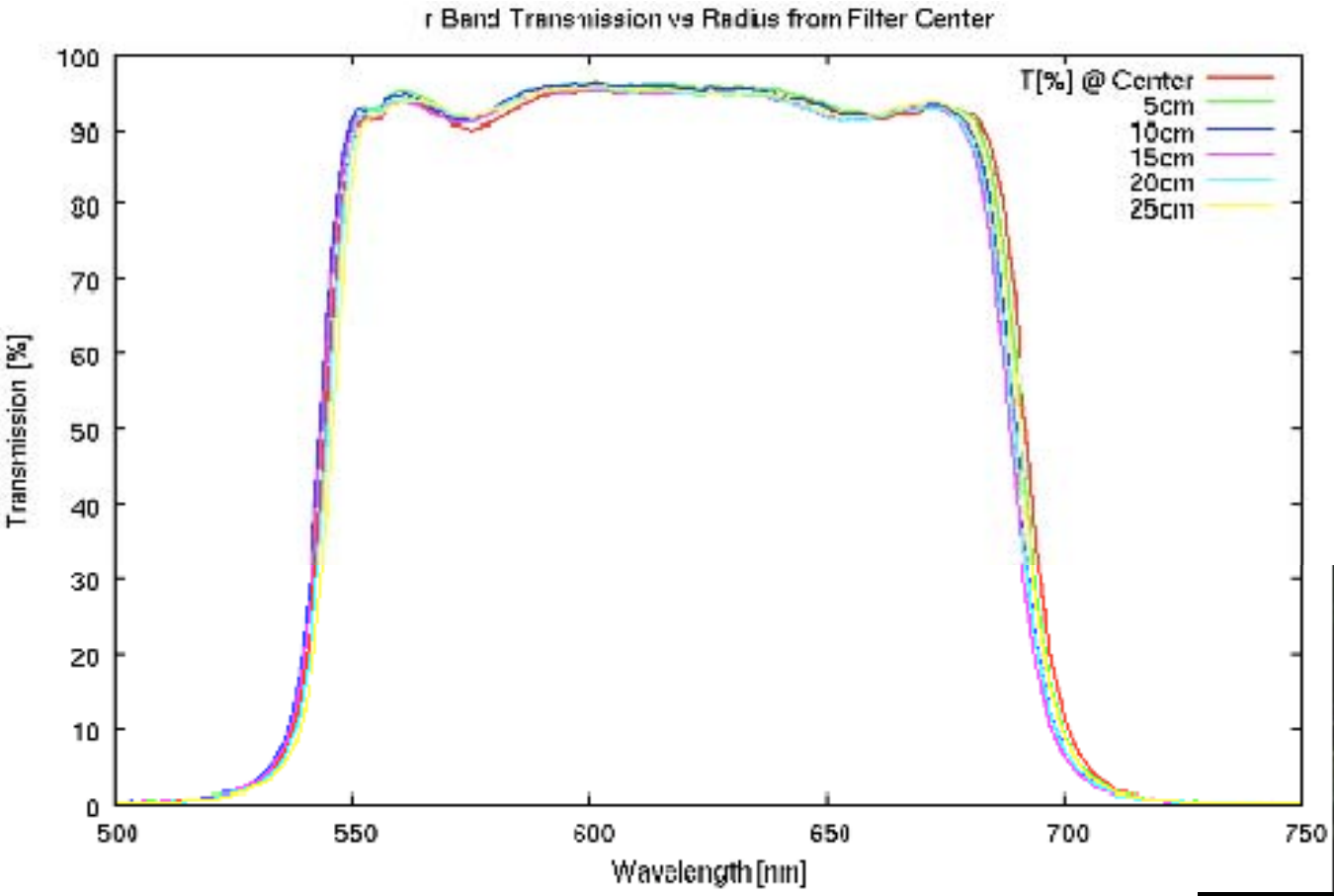
- Broad band filter
  - Vacuum evaporation
  - r' band
    - 550-695nm
  - No out-of-band blocking layer

- Narrow band filter
  - Sputter deposition
  - λc= 600nm
    - Band width = 8nm
  - No out-of-band blocking layer

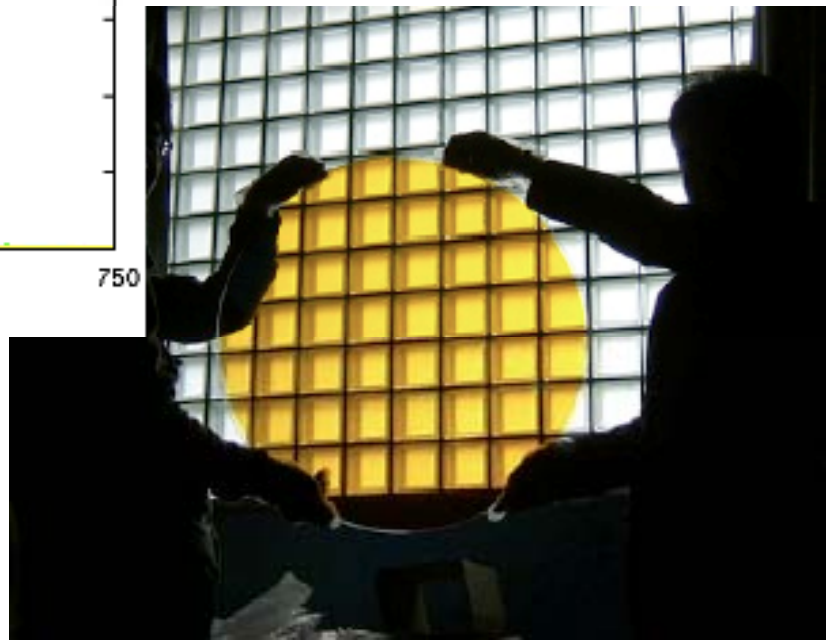
Optics Coating Japan Inc.

Barr Associates

Broad band prototype



D = 60cm



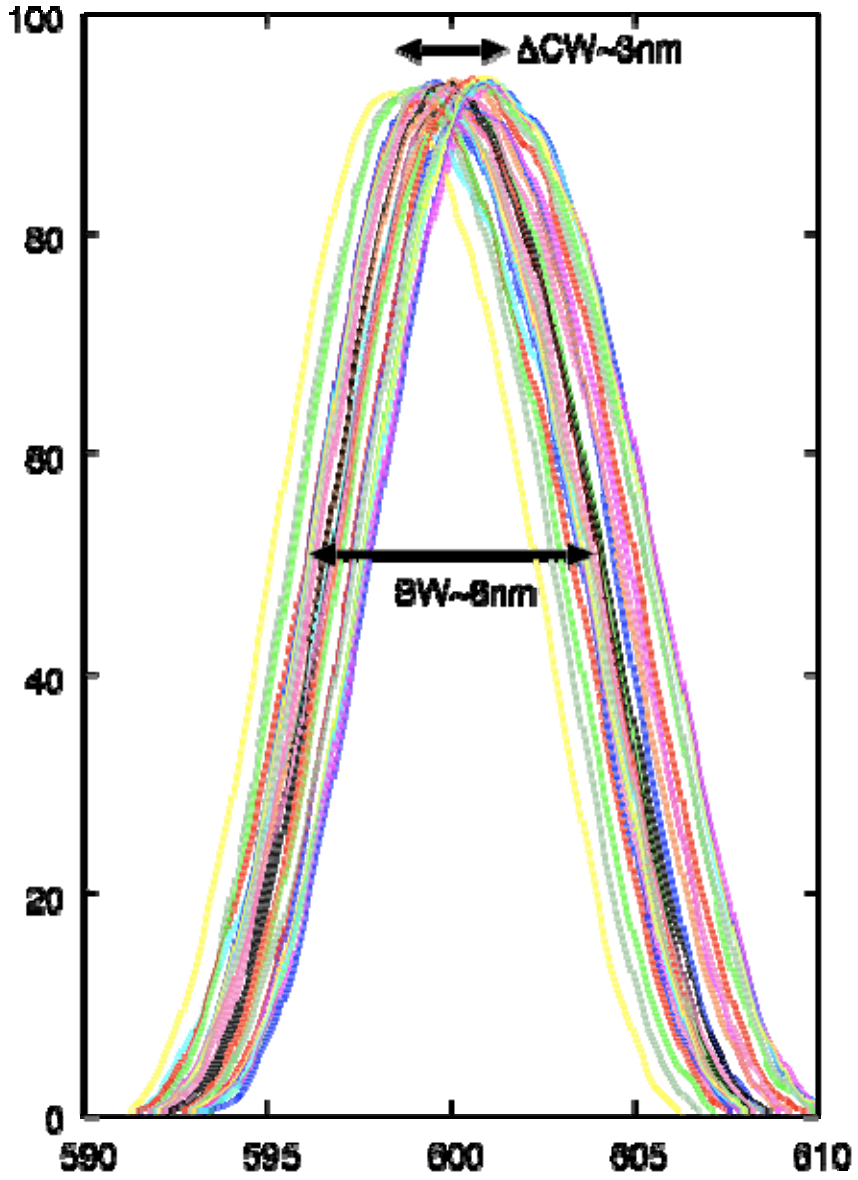
Uniformity
cut off 3 nm
Trans. 2-3 %

Broadband prototype

	Results	Suprime-Cam(BB)
Substrate	N/A	BK7
Diameter	600mm	205x170mm
Clear aperture(CA)	580mm	192x158mm
Thickness	10mm	15mm(w/o frame)
Thickness error	N/A	< 0.2mm
Parallelism	N/A	< 1 arcmin
Sub aperture(SA)	N/A	30mm
Wavefront error in SA	N/A	N/A
Peak transmission	94%	> 95%
Out of band leak	0.4%, 0.2%	< 0.1%
Cut-off wavelength	546nm, 692nm	g, r, i, z(example)
Cut-off wavelength error	0.9%, 0.4%	0.6% to 1.0%
Uniformity(wavelength)	0.5%	0.4%
Uniformity(transmission)	1%	1%
Ripple of transmission	2%	5%

All the performance satisfied Suprime-Cam specification except “out of band leak”

Transmission Measurement



mostly radial variation

Narrowband prototype

	Results	Suprime-Cam(NB)
Substrate	N/A	
Diameter	600mm	205x170mm
Clear aperture(CA)	580mm	192x168mm
Thickness	15mm	15mm(w/o frame)
Thickness error	N/A	< 0.2mm
Parallelism	N/A	< 1 aromin
Sub aperture(SA)	N/A	30mm
Wavefront error in SA	N/A	N/A
Peak transmission	90%	84%
Out of band leak	N/A	
Central wavelength(CW)	600nm	816nm(example)
CW error(r<200mm)	1.7nm	3nm
CW error(r<250mm)	3nm	
Band-pass width(BW)	8nm	10nm
BW error(r<200mm)	0.6nm	0.3nm
BW error(r<250mm)	0.8nm	

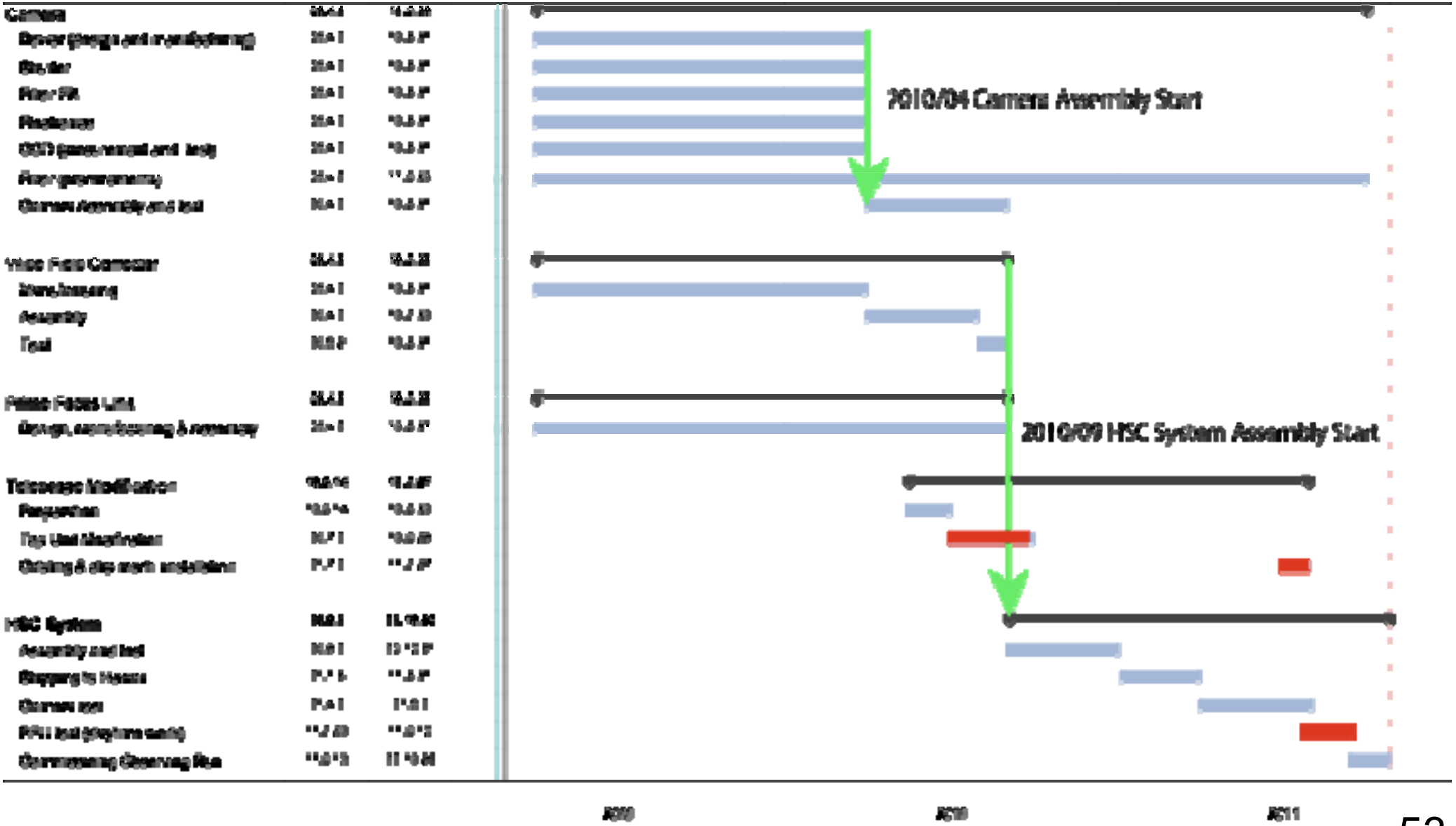
Only band pass error do not meet the spec.

Direction of HSC Filter development

- Barr's result is much better than originally expected.
- Sputtering deposition seems the most favorable option.
- Development of Sputtering chamber is underway at Asahi Spectra

Barr and/or Asahi would be the likely option for us

HSC Schedule



Summary

- HSC is being built. (Upgrade of 10 years old Suprime-Cam)
  - featuring superb inst. image quality < 0’’.4
  - the fastest survey speed ever
- Most of the technical risks have been reduced through prototyping.
- HSC will see the first light in late 2011.

We are happy to share technical information