B03
Development for high speed CMOS
to probe the nature of dark matter

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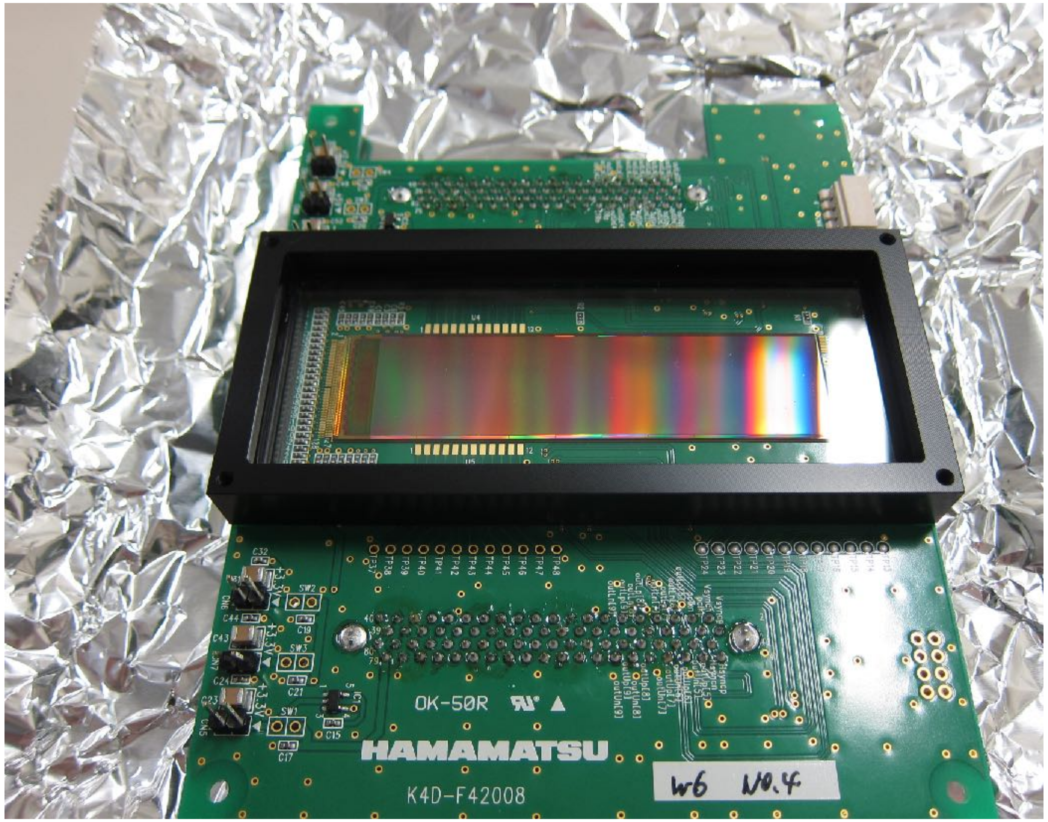
Targets of CMOS observations

- mapping dark matter w/ higher source density weak lensing
  - clusters of galaxies (core, sub-halos, outskirts)
  - dwarf galaxies
- micro-lensing observations w/ high cadence
  - M31
- micro-lensing and transient search at centers of clusters
  - caustic crossings → Oguri's talk
  - gravitationally lensed supernovae

Specifications:

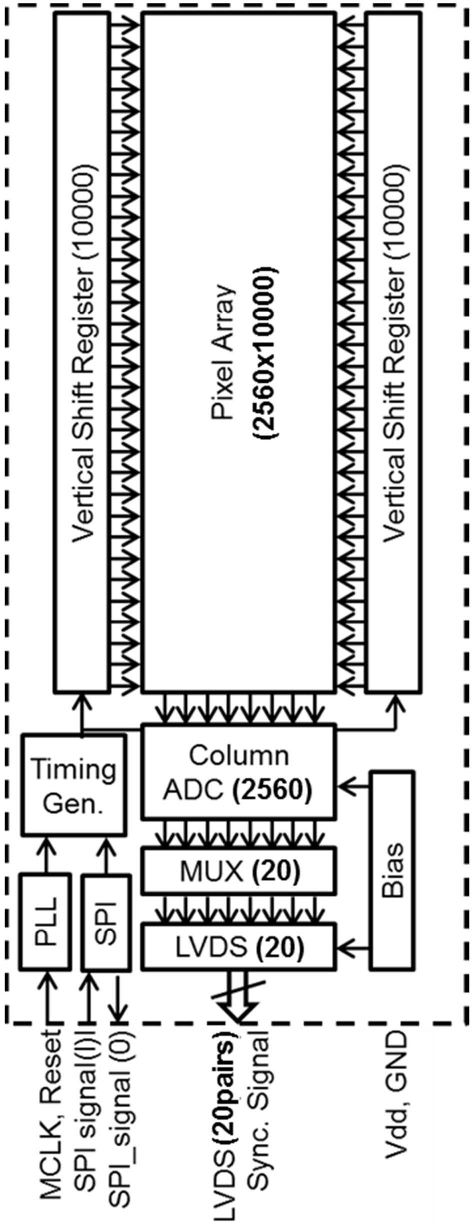
- 2,560 x 10,000 pixels
- 7.5 μm square pixel
- Full well ~ 30,000 e
- R.N. ~ 2 e
- Dark: 90 e/s/pix @ 300 K
- 10 Frame/sec

First prototype front illuminated CMOS



Structure

■ ブロック図



2560 Column ADC
LVDS Digital output from a device

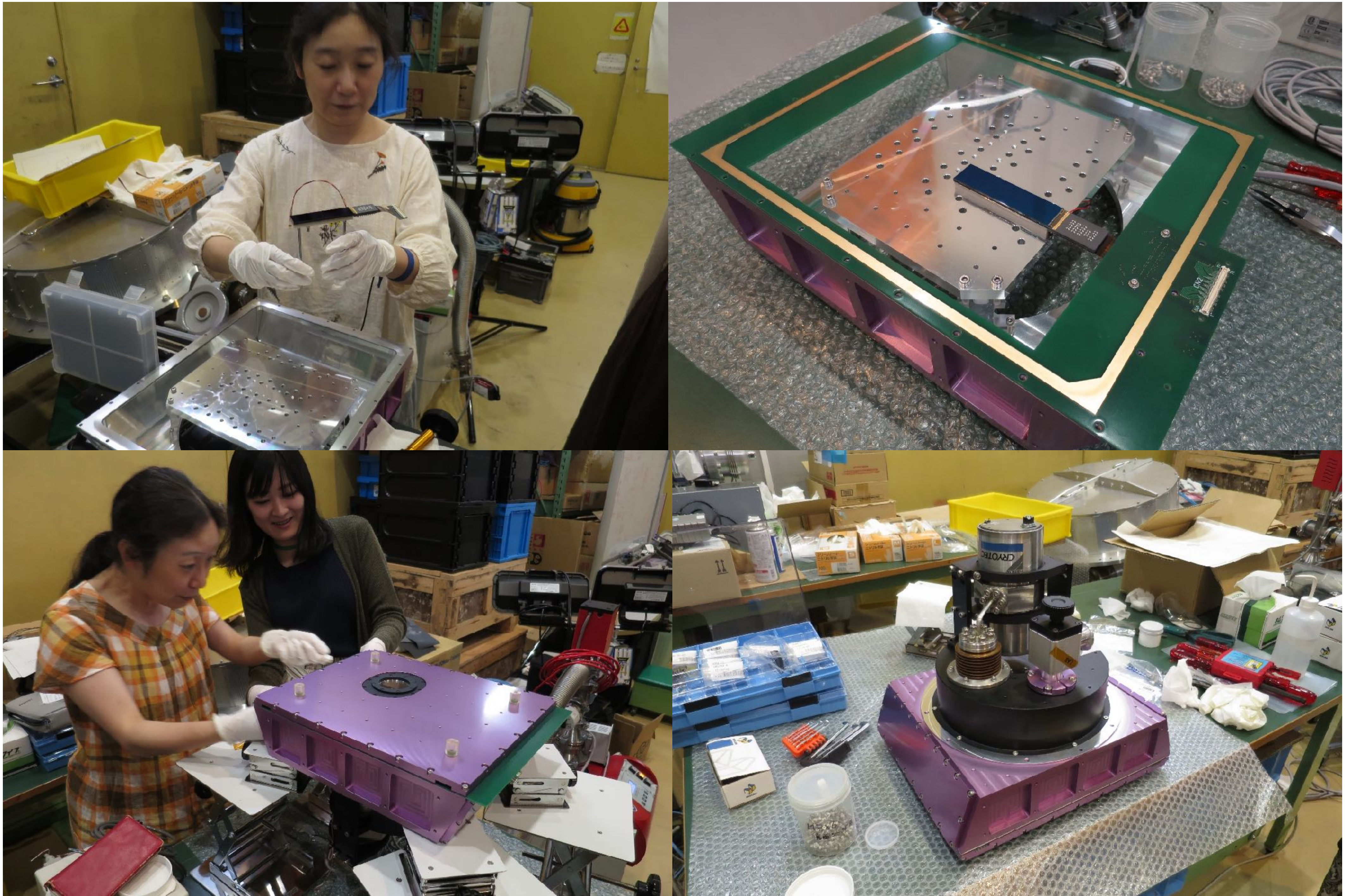
Item	Unit	Back Illuminated	Front Illuminated
Image Size	mm	19.20 x 75.00	
Pixel Size	μm	7.5	
Format	pixel	2560 x 10000	
Fastest Frame Rate	fps	6	10
Quantum Efficiency	%	>= 48 (400 nm) >= 60 (800 nm)	>= 5 (400 nm) >= 11 (800 nm)
Ratio of defect pixels	%	<= 5	
Resolution (*1)	μm	<= 5	<= 5
Dark Current	e / pixel / sec	<= 1000 (Room Temperature)	<= 200 (Room Temperature)
Read Noise (High Gain) (Low Gain)	e rms	<= 5 <= 30	<= 3 <= 25
Full Well (High Gain) (Low Gain)	e	>= 2000 >= 20000	>= 2000 >= 30000
Responsivity (High Gain) (Low Gain)	μV/e	640 40	
ADC Resolution	bit	10 (*2)	

Current status:

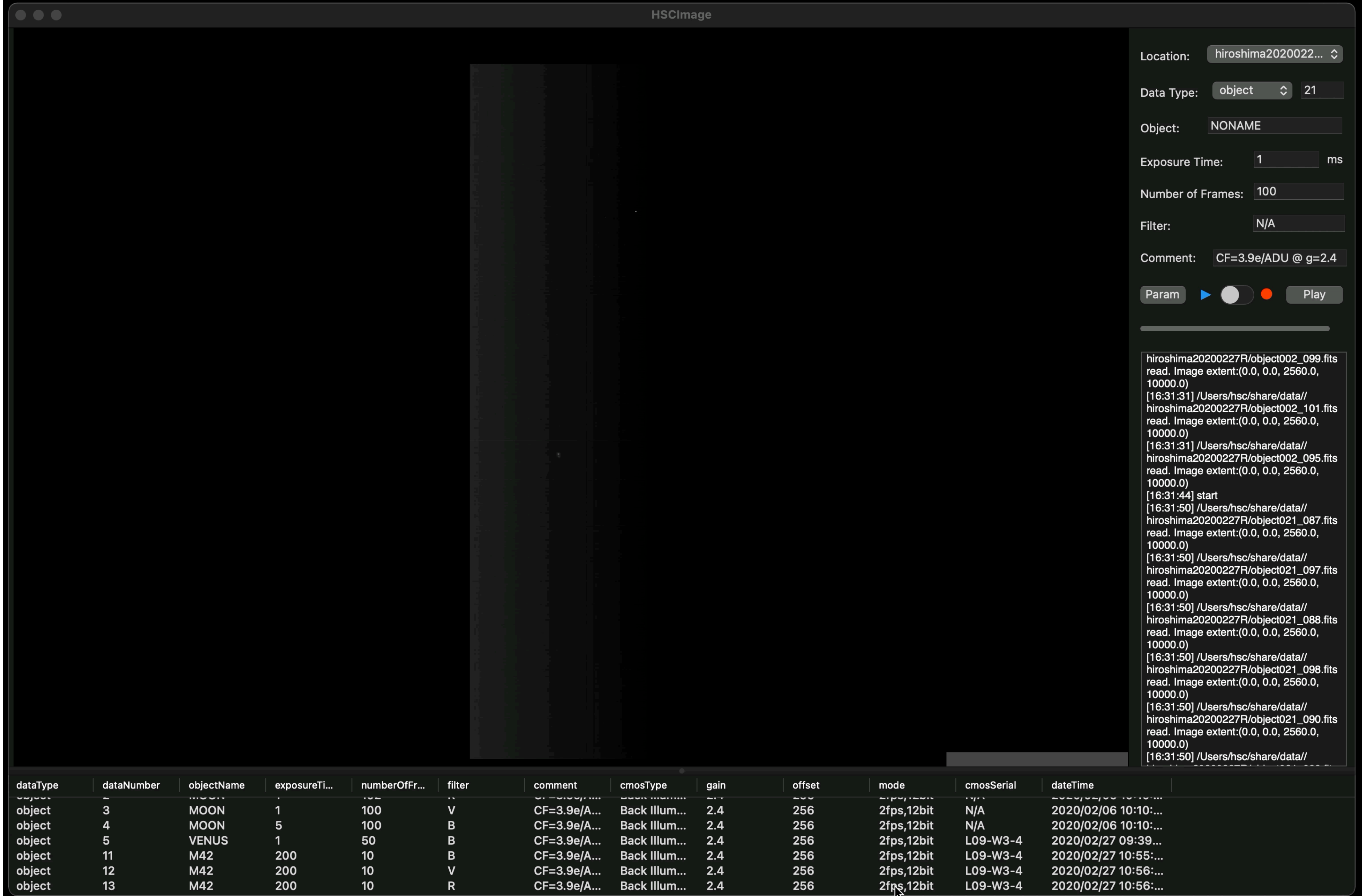
ZDAQ: developed jointly by
JAXA (KIPMU)Takahashi's Lab

Back-illuminated CMOS
delivered in 2019

Assembly of the focal Plane 2019/08



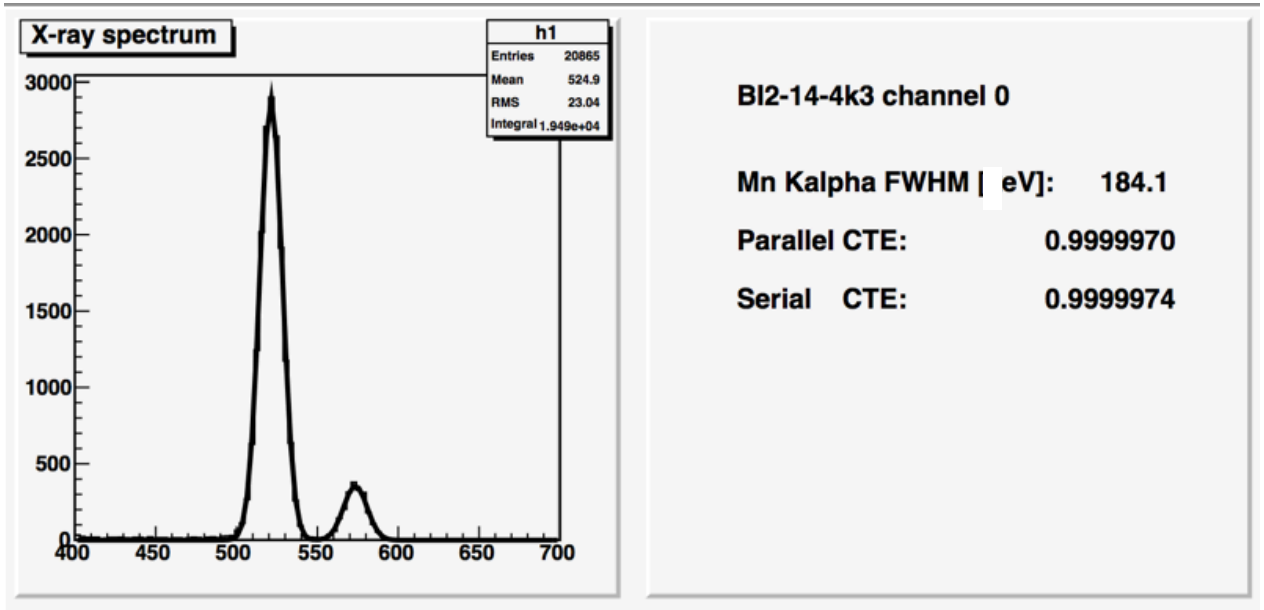

Test Observation at 1.5 m telescope
広島大学 宇宙科学センター
September 2, 2019 @ Hiroshima



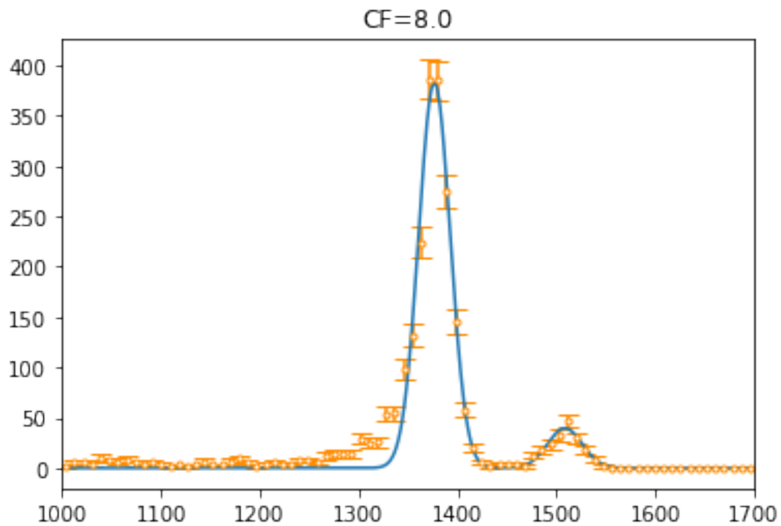
HSCImage
Location: hiroshima2020022...
Data Type: object 21
Object: NONAME
Exposure Time: 1 ms
Number of Frames: 100
Filter: N/A
Comment: CF=3.9e/ADU @ g=2.4
Param
Play
hiroshima20200227R/object002_099.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:31] /Users/hsc/share/data// hiroshima20200227R/object002_101.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:31] /Users/hsc/share/data// hiroshima20200227R/object002_095.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:44] start
[16:31:50] /Users/hsc/share/data// hiroshima20200227R/object021_087.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:50] /Users/hsc/share/data// hiroshima20200227R/object021_097.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:50] /Users/hsc/share/data// hiroshima20200227R/object021_088.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:50] /Users/hsc/share/data// hiroshima20200227R/object021_098.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:50] /Users/hsc/share/data// hiroshima20200227R/object021_090.fits read. Image extent:(0.0, 0.0, 2560.0, 10000.0)
[16:31:50] /Users/hsc/share/data//
dataType dataNumber objectName exposureTi... numberOfFr... filter comment cmosType gain offset mode cmosSerial dateTime
object 3 MOON 1 100 V CF=3.9e/A... Back Illum... 2.4 256 2fps,12bit N/A 2020/02/06 10:10:...
object 4 MOON 5 100 B CF=3.9e/A... Back Illum... 2.4 256 2fps,12bit N/A 2020/02/06 10:10:...
object 5 VENUS 1 50 B CF=3.9e/A... Back Illum... 2.4 256 2fps,12bit L09-W3-4 2020/02/27 09:39...
object 11 M42 200 10 B CF=3.9e/A... Back Illum... 2.4 256 2fps,12bit L09-W3-4 2020/02/27 10:55:...
object 12 M42 200 10 V CF=3.9e/A... Back Illum... 2.4 256 2fps,12bit L09-W3-4 2020/02/27 10:56:...
object 13 M42 200 10 R CF=3.9e/A... Back Illum... 2.4 256 2fps,12bit L09-W3-4 2020/02/27 10:56:...

X-ray test result:

HPK
CCD



HPK
CMOS



Mn Kalpha FWHM: 160 eV

Readout noise: 2.5 e

Demonstration of low noise
and sufficiently low dark current
as designed.

Lucky Imaging and Lucky Fourier:

CMOS Test Camera on Hiroshima 1.5 m telescope

A series data of alpha-Gem was taken.

Number of frames:	1000
Exposure time of each frame:	1 ms

Lucky Imaging (LI) and Lucky Fourier (LF) techniques are applied on the data.

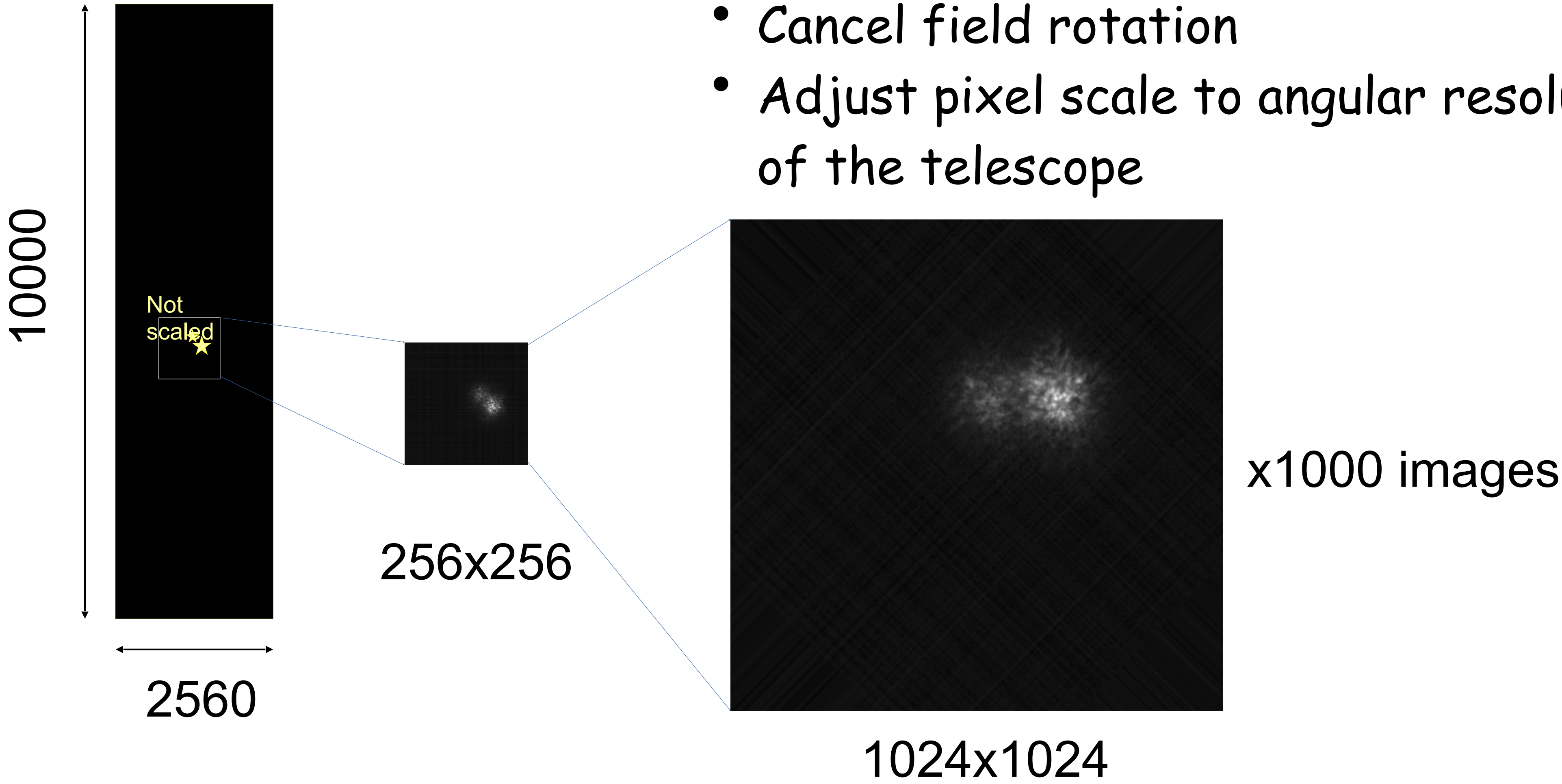
LI:select"good"images from the data set and sum selected images.

LF:same kind of idea of LI, but selection is performed in frequency space.

Reference : High-efficiency lucky imaging C. Mackay MNRAS, 432, 702 (2013)

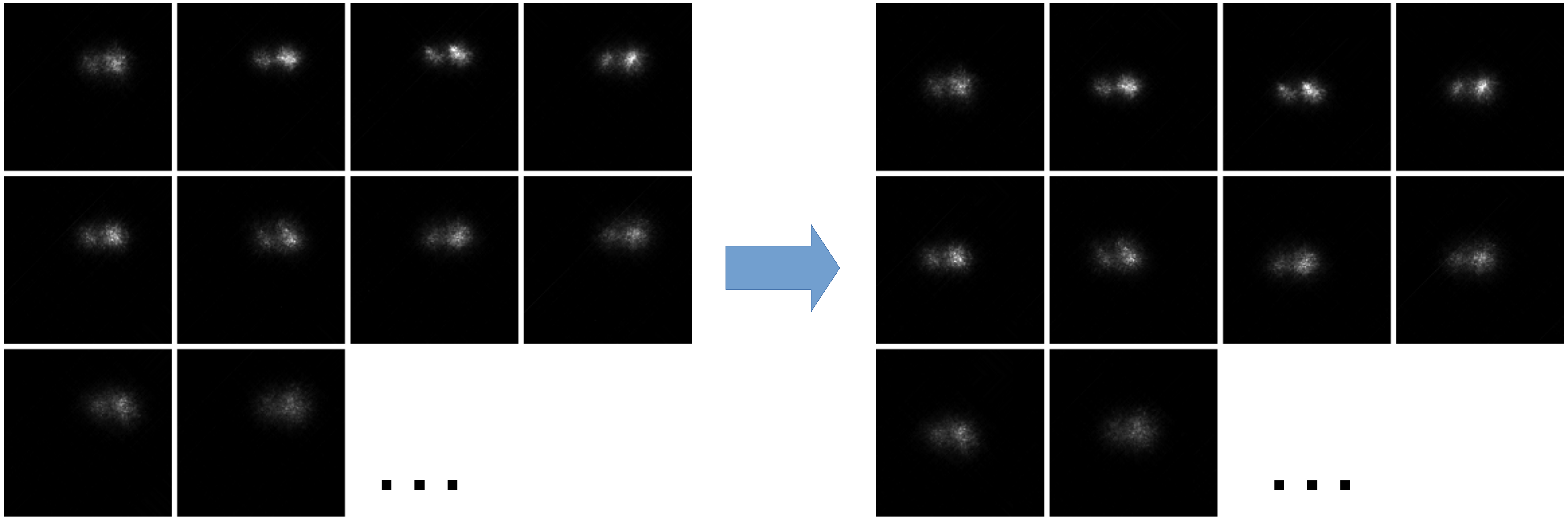
Crop, up-convert, and rotation of images

1. Crop 256x256 area around the stars
2. Up-convert (resample) 4x4 and rotate cropped images
   - Cancel field rotation
   - Adjust pixel scale to angular resolution of the telescope



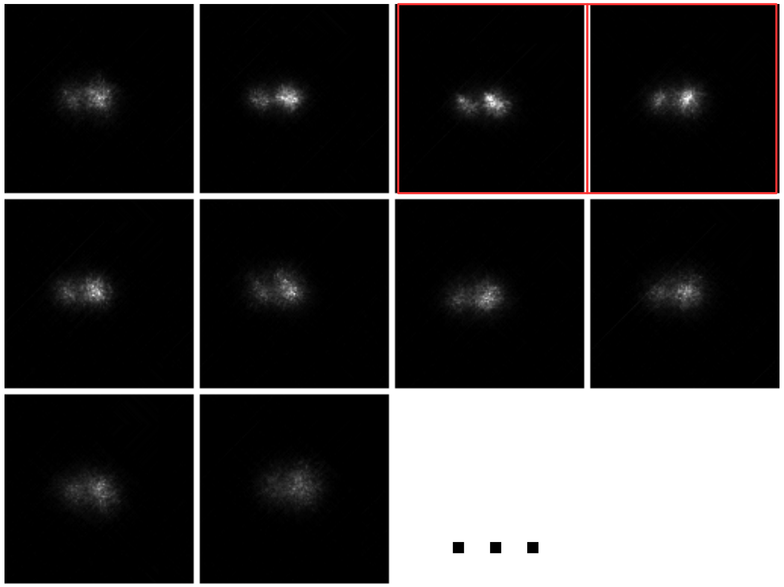
Alignment

Find peak pixel of each image and shift the pixel to the image center

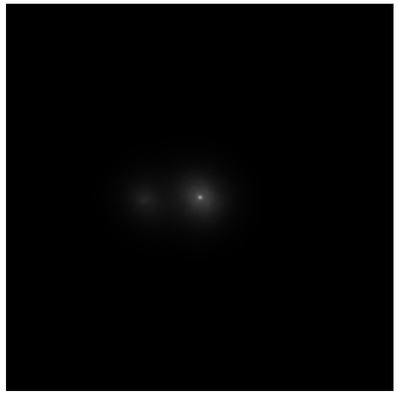


Lucky imaging

Select “good” images from data series and sum up selected images



There are several selection criteria. Now we use images that have “High peak”.(if the intensity of object is constant, higher peak mostly means smaller image size.)



Top 10% selected mean

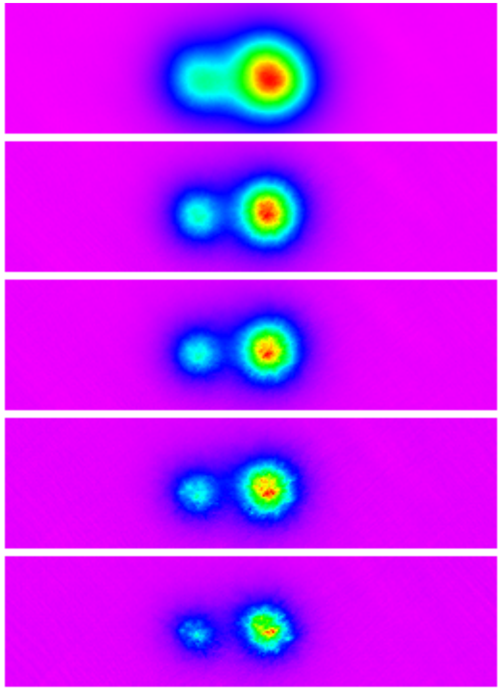
Image improvement

alpha-Gem.: Binary stars with 5 arc sec separation

-Selection options: 1000/1000, 100/1000, 50/1000, 20/1000, 10/1000

- FWHM changes 3.84 ->3.24-> 2.88->2.64-> 2.28 arc-sec

-Improvement confirmed



1000/1000

0100/1000

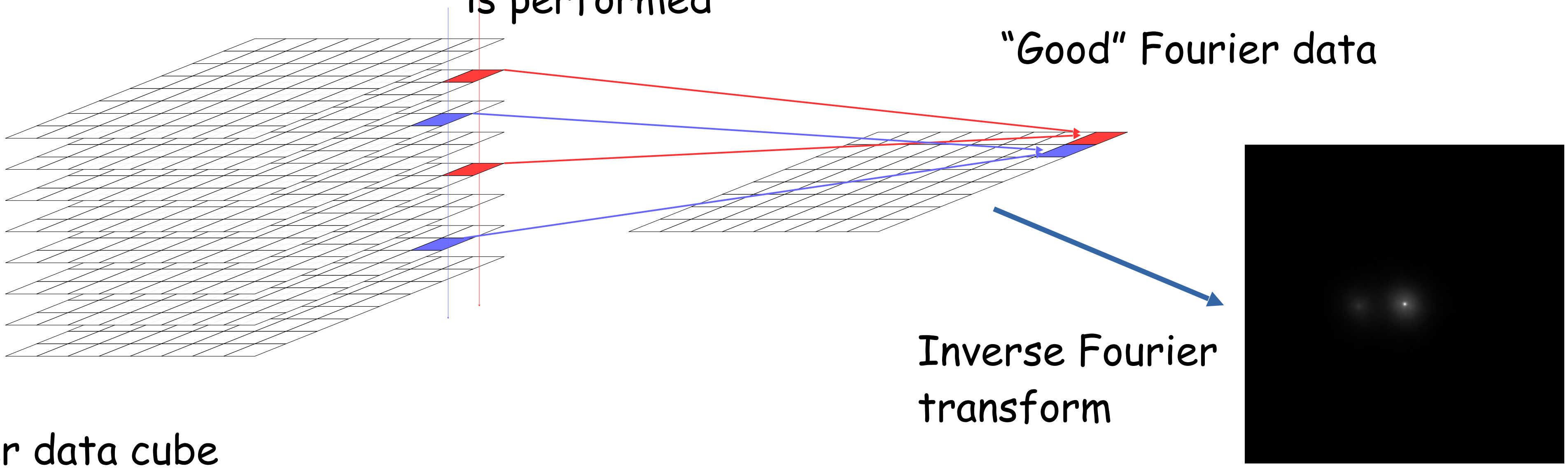
0050/1000

0020/1000

0010/1000

Lucky Fourier

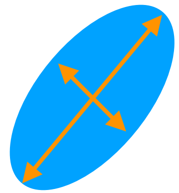
Select "good" data in 2D-Fourier transformed data cube --- top 10% of each spacial frequency are used to reconstruct LF image



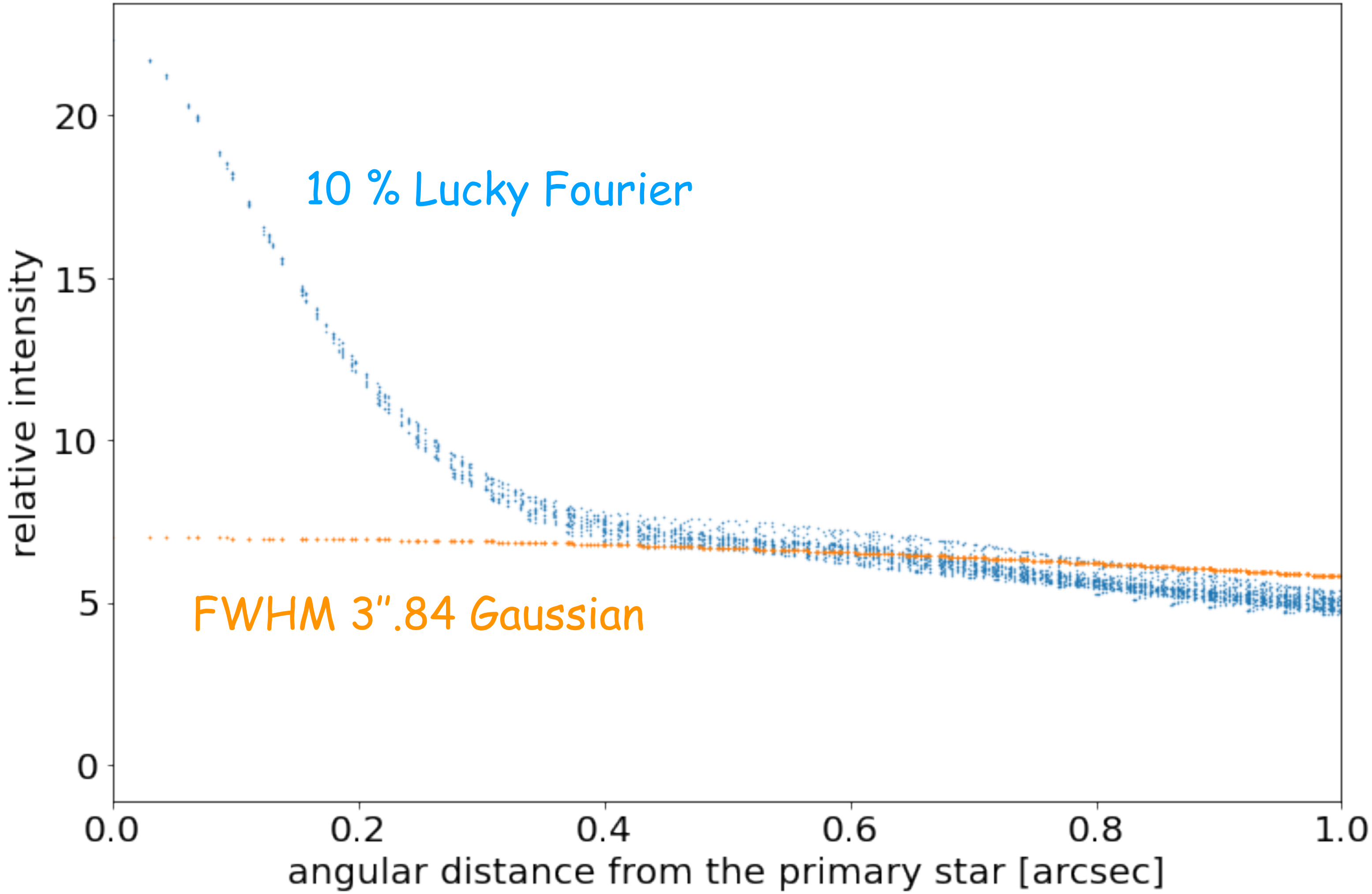
Fourier data cube
(2d Fourier transform of all mages)

Reconstructed image

This method is more effective as anisotropy of PFS is larger.
eg High resolution direction can be incorporated in the Fourier space

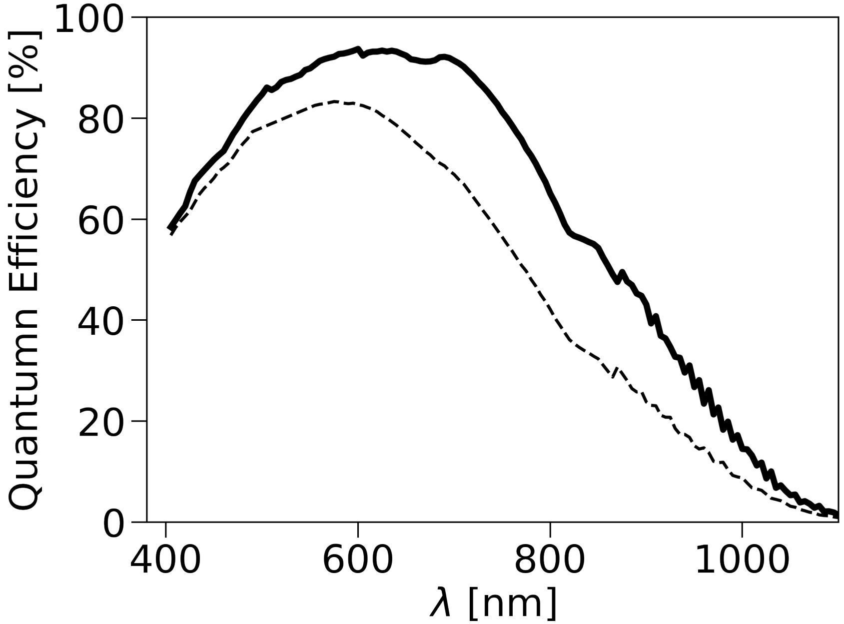


Lucky Fourier: the improvement



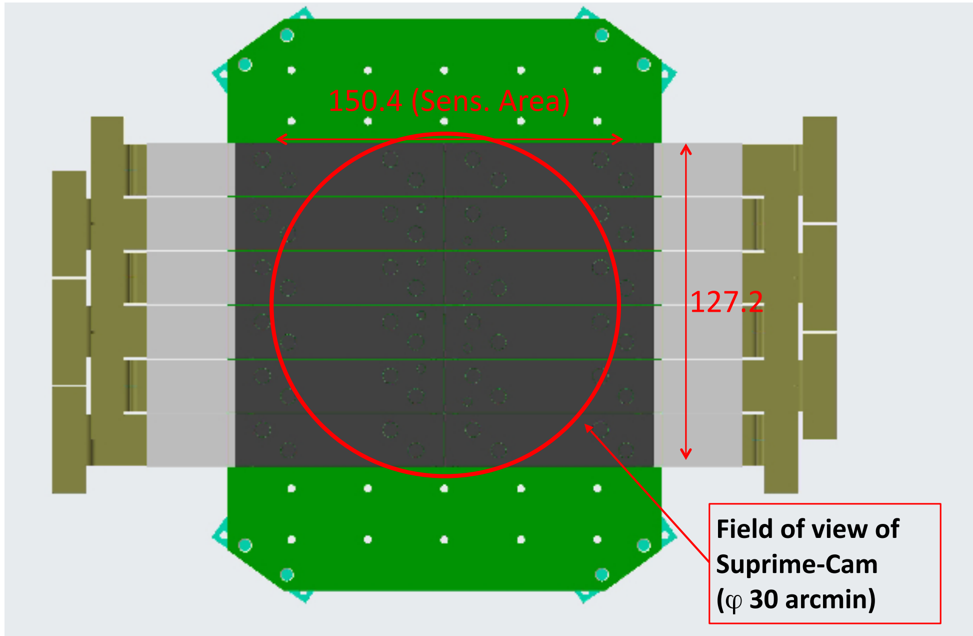
Development plan under this funding phase

Improvement of QE



while maintaining pixel resolution
by adopting high resistivity silicon

Mass production to pave the Subaru Suprime-Cam Focal Plane



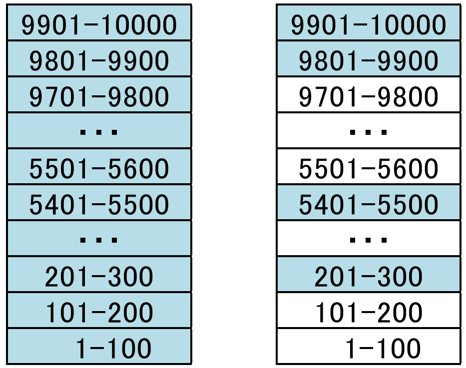
Twelve Devices necessary

New features implemented on our CMOS in FY2021

1. Higher speed (up to 1 k fps) realized by partial readout

100 continuous rows forms a group.
Any group can be selected for readout.

10 fps



250 fps

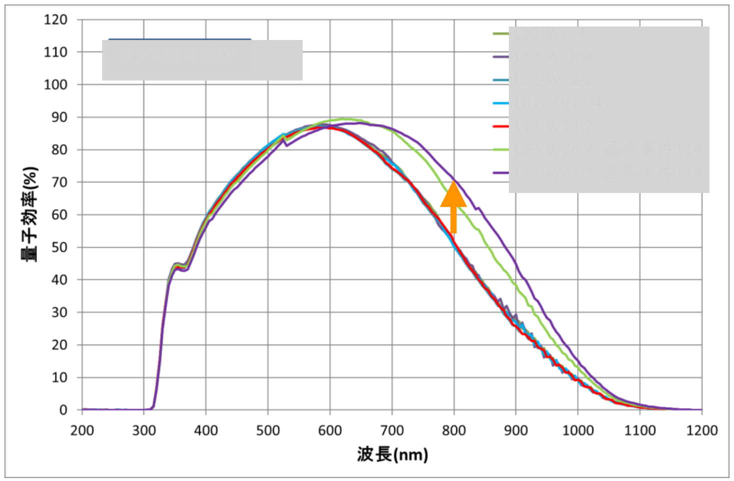
例１：
全行読み出し

例４：
400行読み出し

青セル部分を読み出すイメージで
部分読み出し可能になる予定です

2. Higher resistivity silicon is employed to realize thicker depletion layer

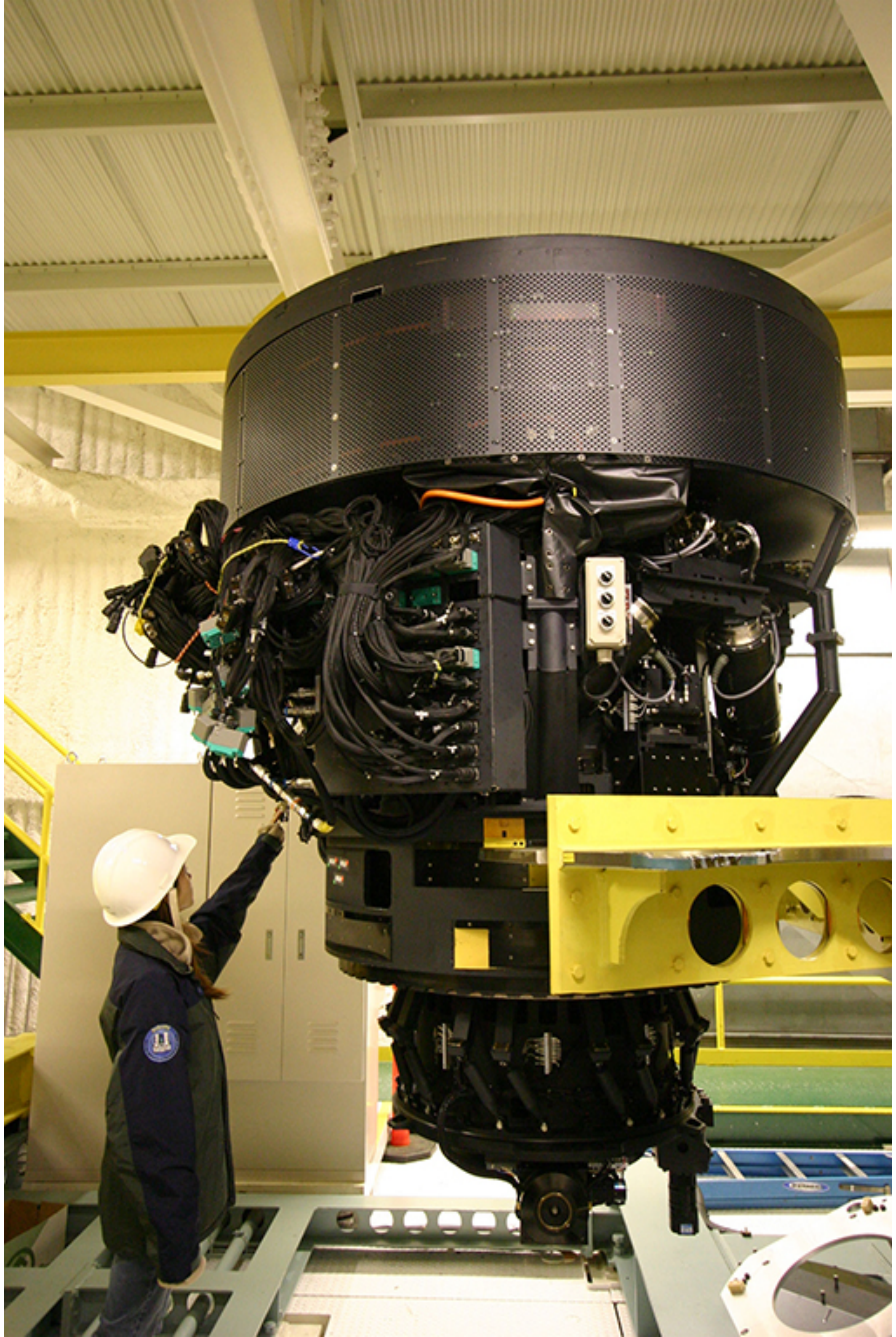
QE improvement 50 -> 70 %
@ 800 nm



Recycling:

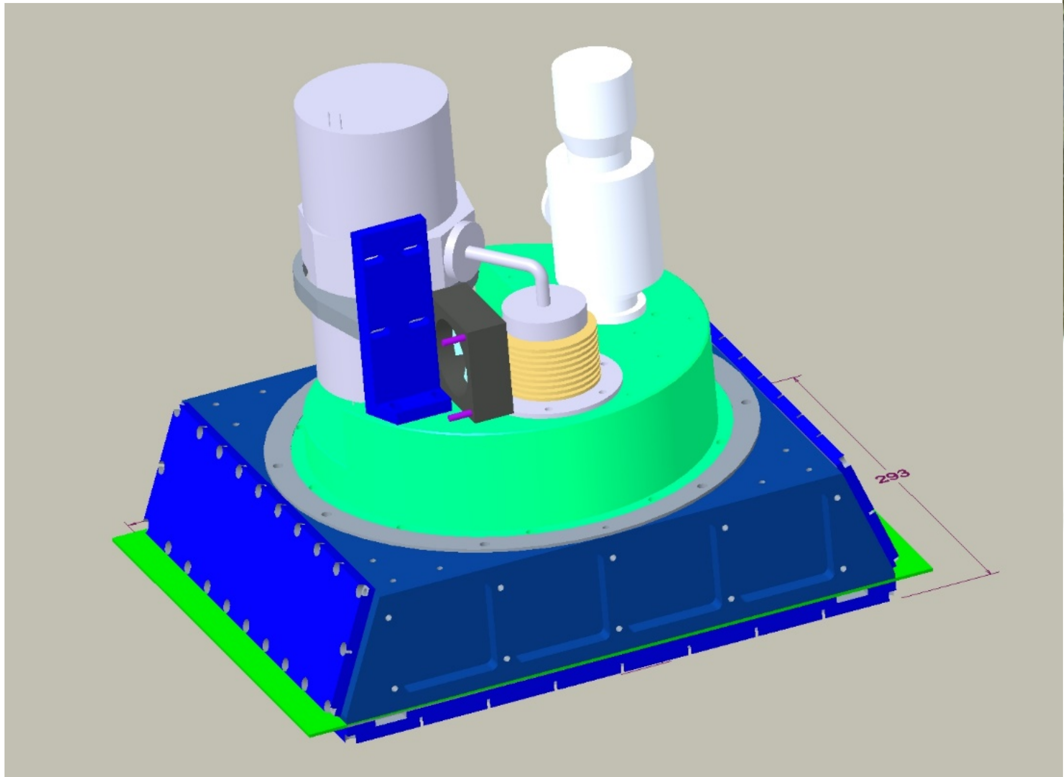
Original Suprime-Cam was retired in 2017. The prime focus bonnette with the wide field corrector (~US$3M) is re-used for this CMOS camera.

8 m aperture
30 arcmin FOV
10 Hz frame rate
will explore unprecedented parameter space as previous Subaru cameras did before.



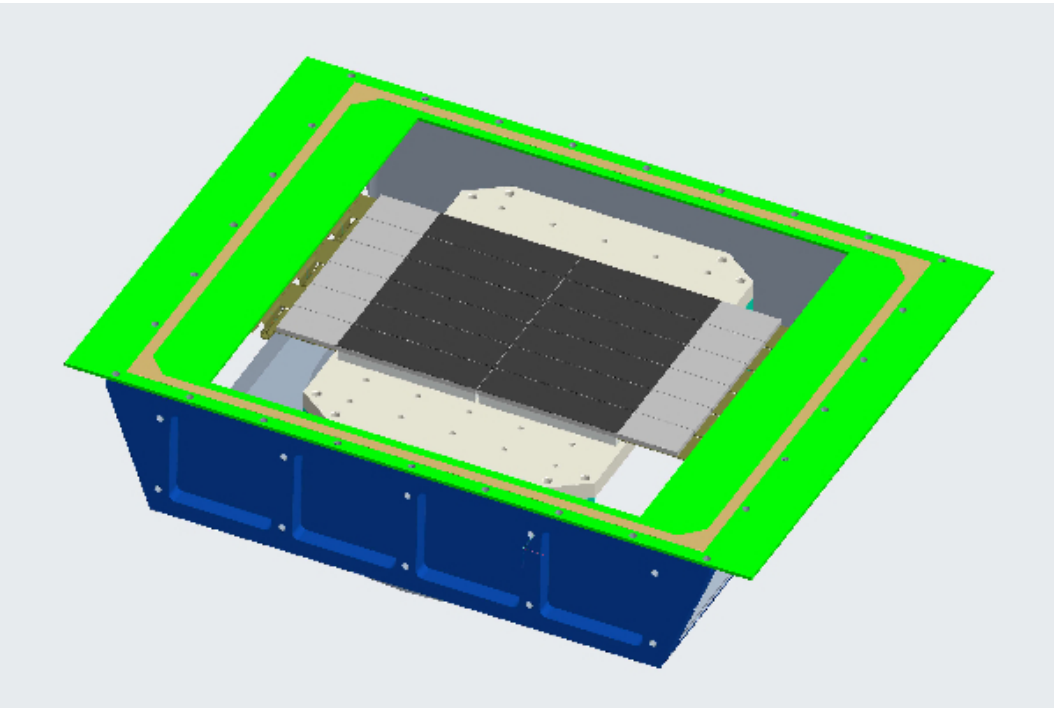
CMOS Camera

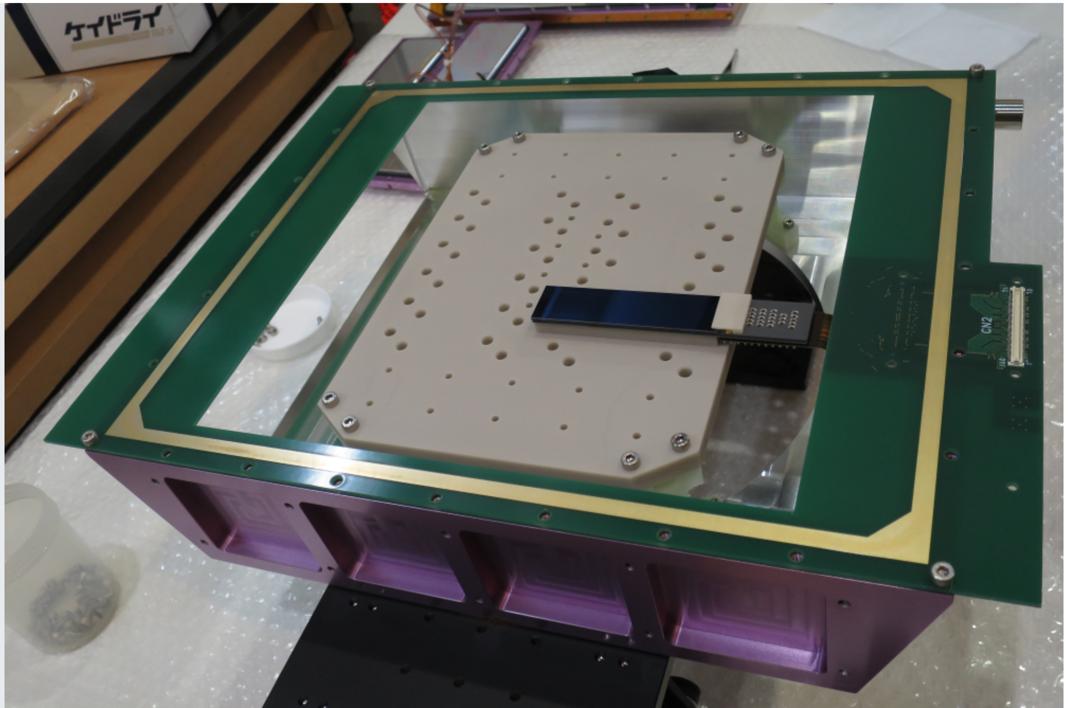
- The mechanical design of CMOS Camera for Subaru Telescope is almost completed.
- Mechanical parts were manufactured. The production model is being assembled.



CMOS Camera

- One CMOS sensor is installed on the cold plate of CMOS Camera and the performance test is being carried out.
- The CMOS Camera will install 12 CMOS sensors to cover the entire FoV of Suprime-Cam (30 arcmin diameter)

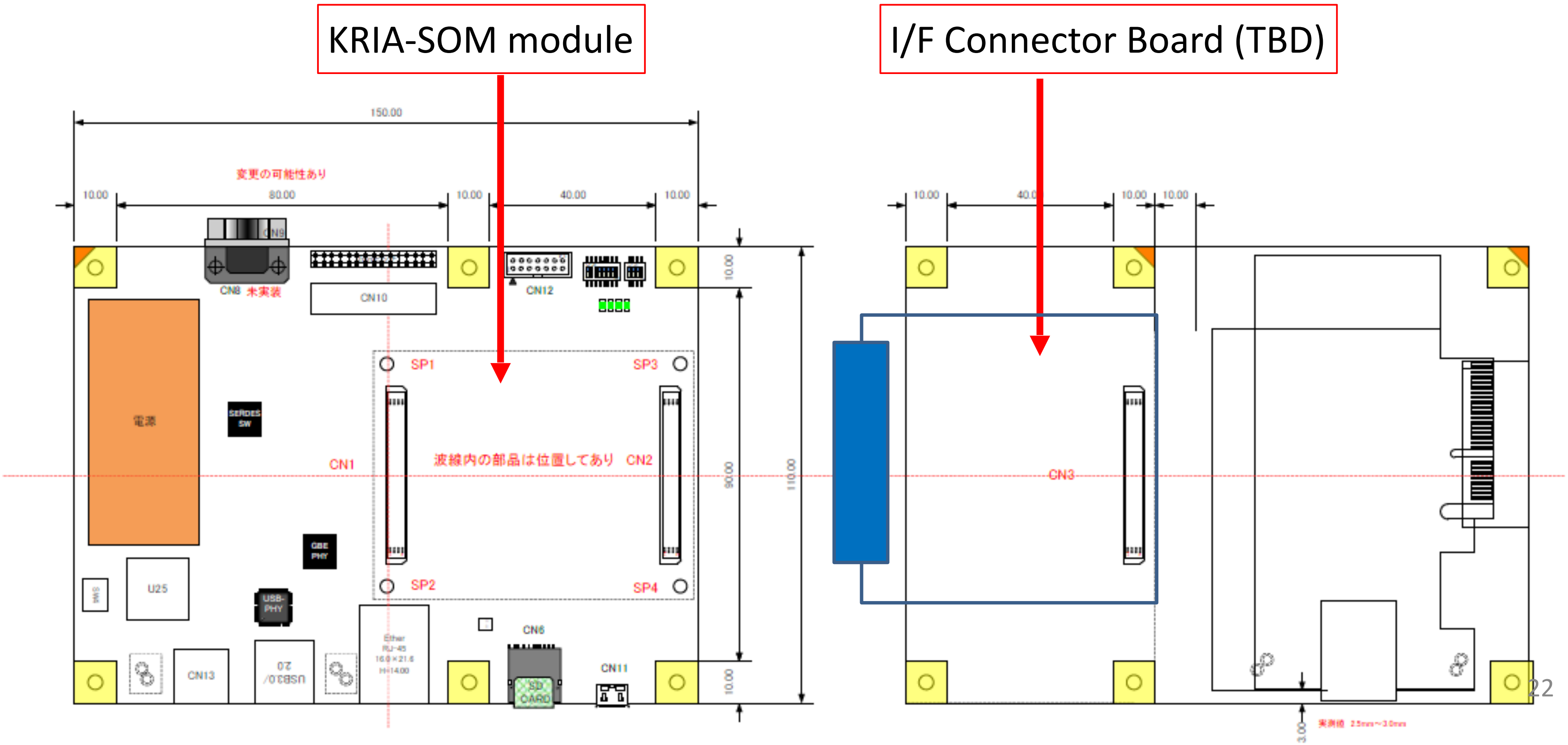




Readout Electronics Design

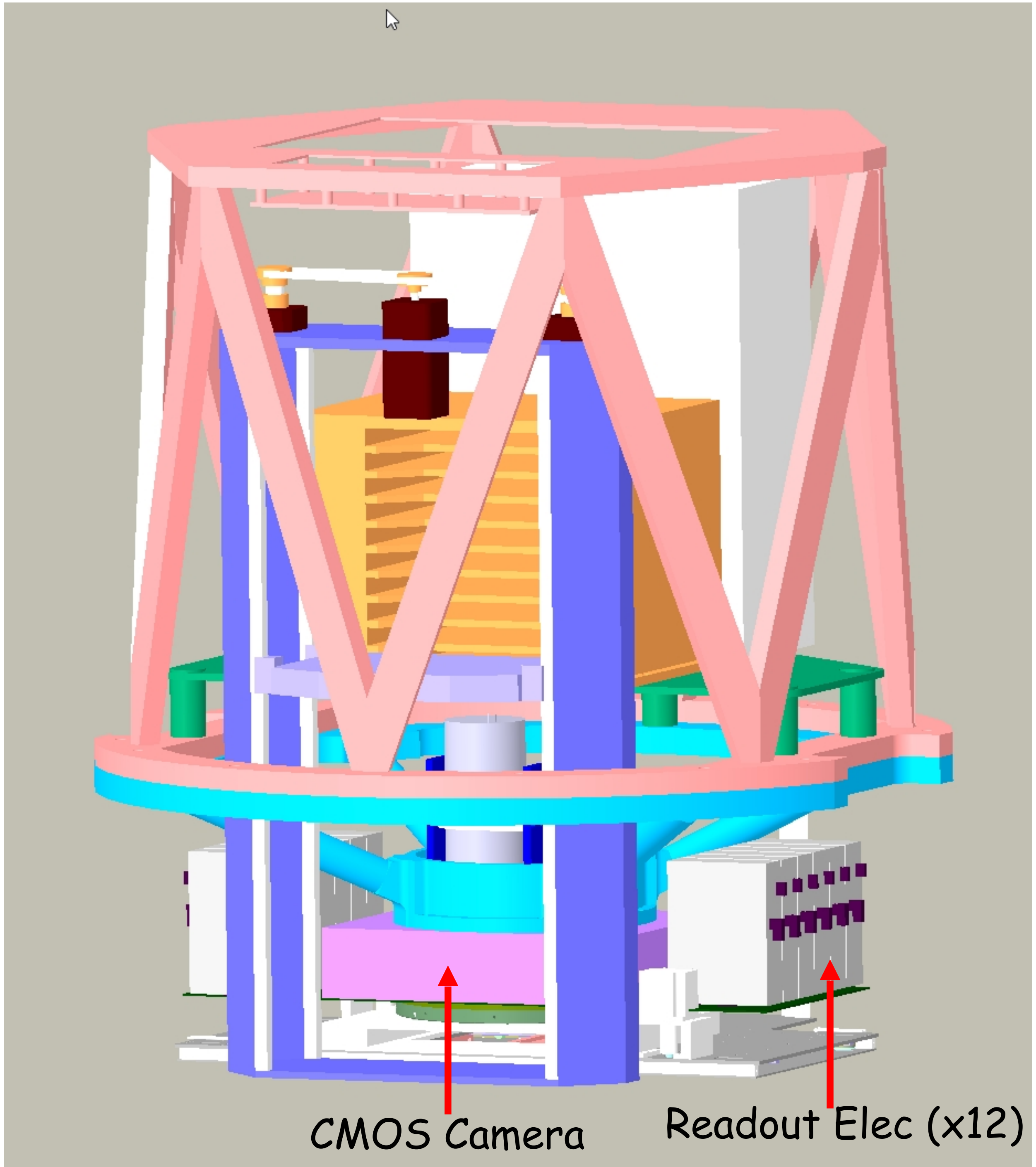
- The implementation of readout electronics, which aims to use at Subaru Telescope, has been discussed with vendor and the design of readout electronics is finalized.
- ZYNQ based IO board drives CMOS and transfers the data via 10GB Ethernet.
- 1 CMOS - 1 DAQ system

KRIA-SOMモジュールの型番は下記2つあります。
民生用：SM-K26-XCL2GC
工業用：SM-K26-XCL2GI



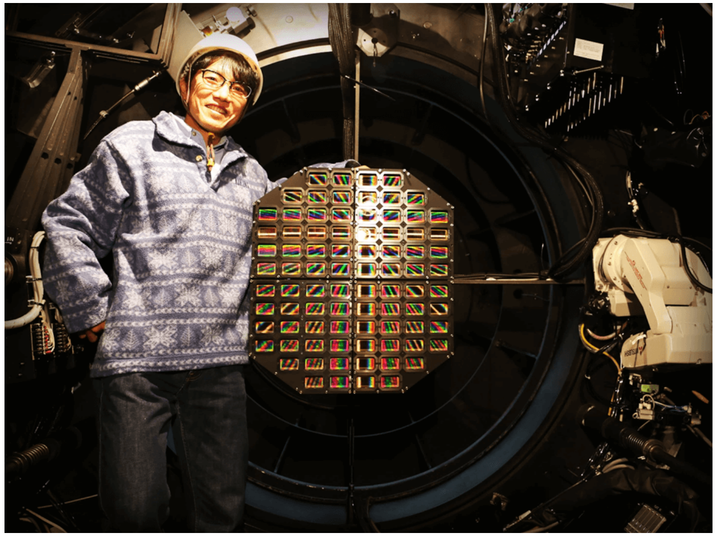
CMOS Camera on Suprime-Cam

- Now, we have a solution to install CMOS camera to Suprime-Cam.
- To Do
  - Design of Vacuum I/F board to handle 12 CMOS sensors
  - Detailed design of entrance window
  - Mechanical design to support readout electronics
  - Implementation of peripheral devices

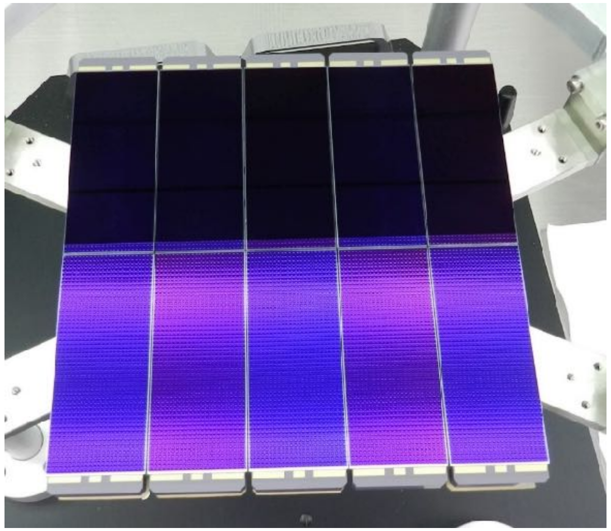


Comparison with other CMOS Cameras

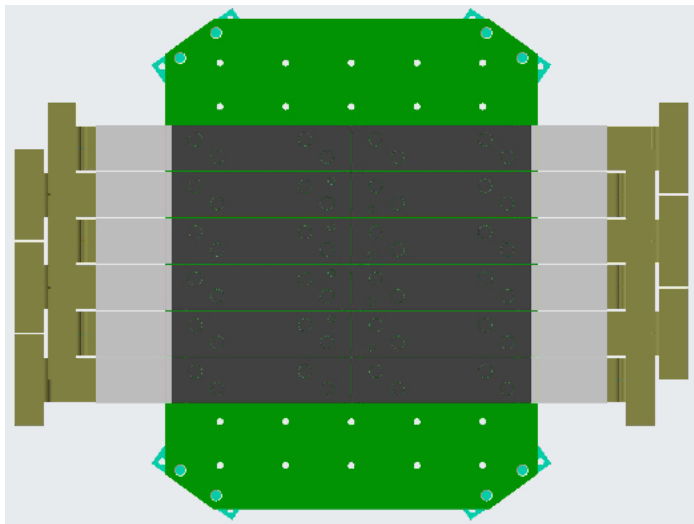
	Tomo-e Gozen	**TAOS II**	**Subaru CMOS**
Tel. Aperture	1.05 m	1.3 m	**8.2 m**
Field of View	20 deg^2	2.3 deg^2	0.25 deg^2
Frame Rate	2 sec^{-1} (20 for part)	20 sec^{-1}	**10 sec^{-1}**
Limiting Mag.	~17 mag	~18 mag	~21 mag
Sensor Format	2000x1128 (19um/pix)	1920x4608 (16um/pix)	2560x10000 (7.5um/pix)
# of Sensors	84	10	12
Vendor	Canon	e2v	Hamamatsu
Site	Kiso	Mexico	**Maunakea**



Tomo-e Gozen



TAOSII Focal Plane



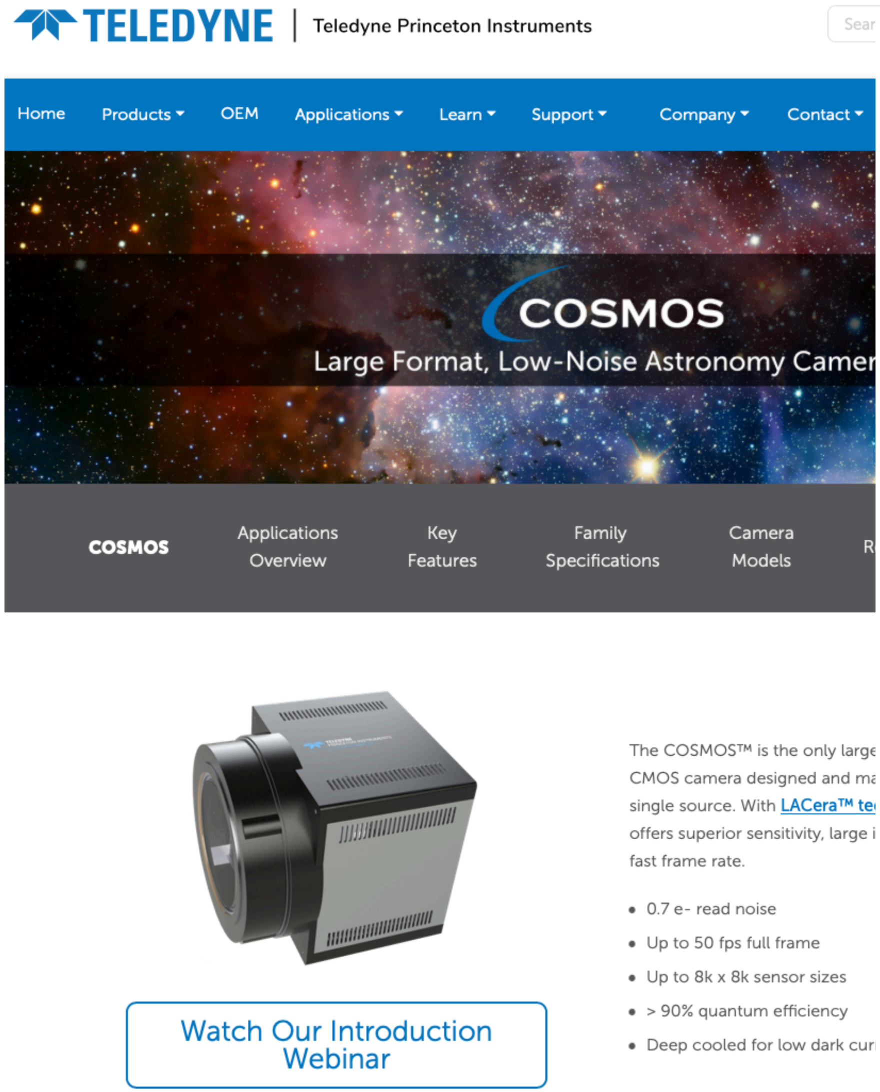
Subaru CMOS Camera

UH 88 inch Telescope ?

- D = 2.2 m F/10 delivers similar plate scale as Subaru Prime focus
  - Wide Field
  - Mana Kea seeing

- Necessity of a field flattener but it can be implemented as the dewar window.
- Other possible telescope: VLT Survey Telescope at Paranal

Rival !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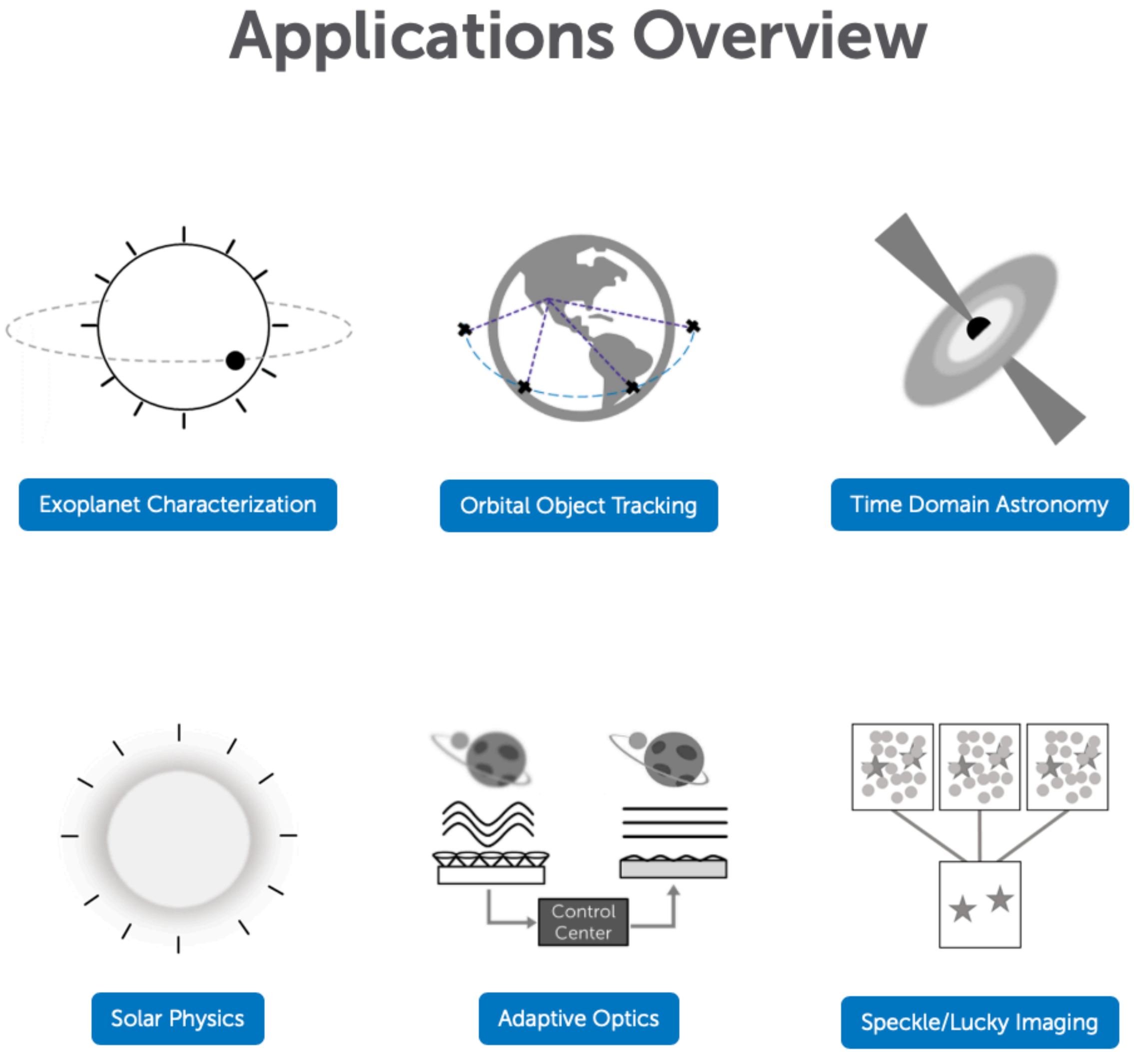
> 90% quantum efficiency
Deep cooled for low dark cur


Applications Overview
Exoplanet Characterization
Orbital Object Tracking
Time Domain Astronomy
Control Center
Solar Physics
Adaptive Optics
Speckle/Lucky Imaging

Thank you very much