B03

Probing the nature of dark matter by wide field and high angular resolution astronomical imaging observations

広視野かつ高分解能天体イメージングによるダークマター探索

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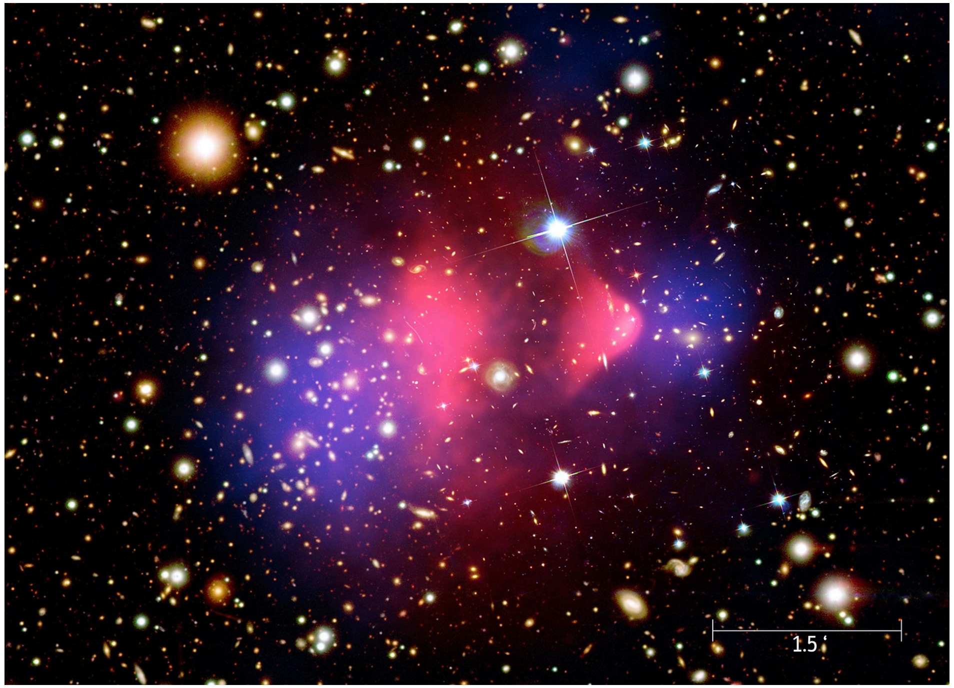
Oguri（U-Tokyo/KIPMU）

Dark matter from Astronomical Observations

Dean Rowe

Kinematics of galaxies in clusters
(Zwicky 1937)

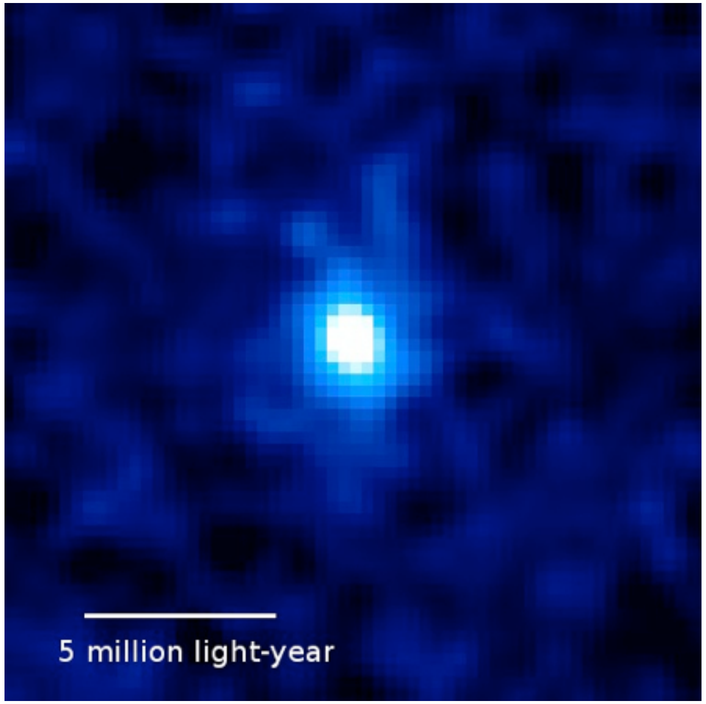


NASA/CXC/M. Weiss

Gravitational lensing
(Clowe et al 2006)

- proof of existence
- constraints on its nature (cold, small cross section)

Testing Dark Matter: Cluster Shapes



Oguri et al. (2012)

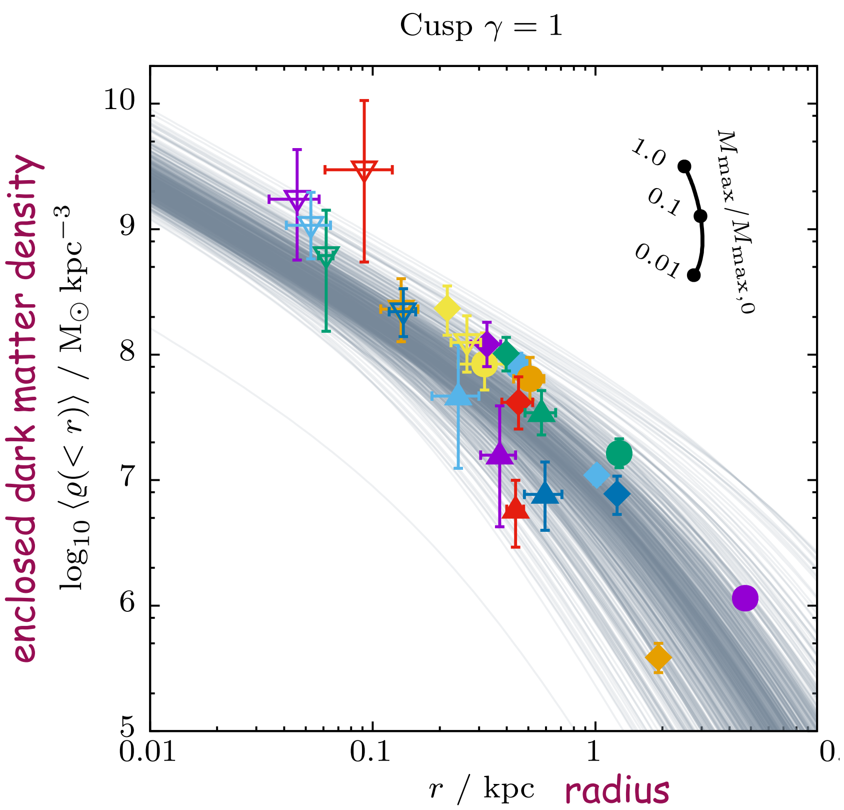
- Subaru gravitational lensing analysis reveals highly elongated (not spherical) dark matter distribution

  (Oguri et al. 2010, 2012, Umetsu et al. 2018, ..)

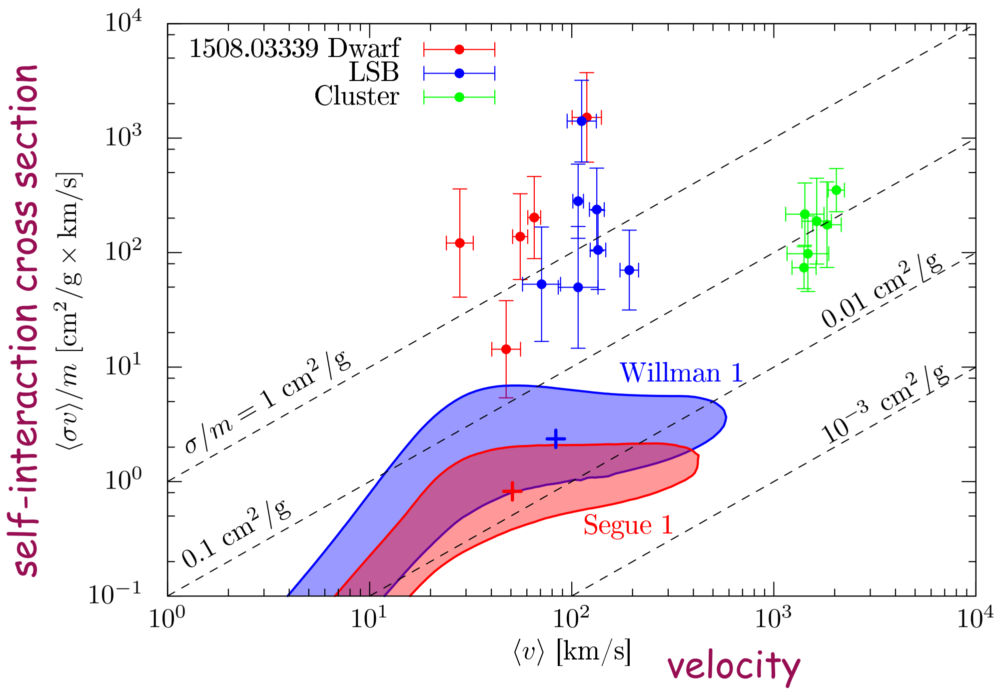
mostly cold and collisionless at cluster scale

- more information can be extracted by substructures, edge of cluster (splashback radius), etc.
  → need higher-resolution lensing observations

Testing Dark Matter: dwarf galaxies



Errani et al. (2018)



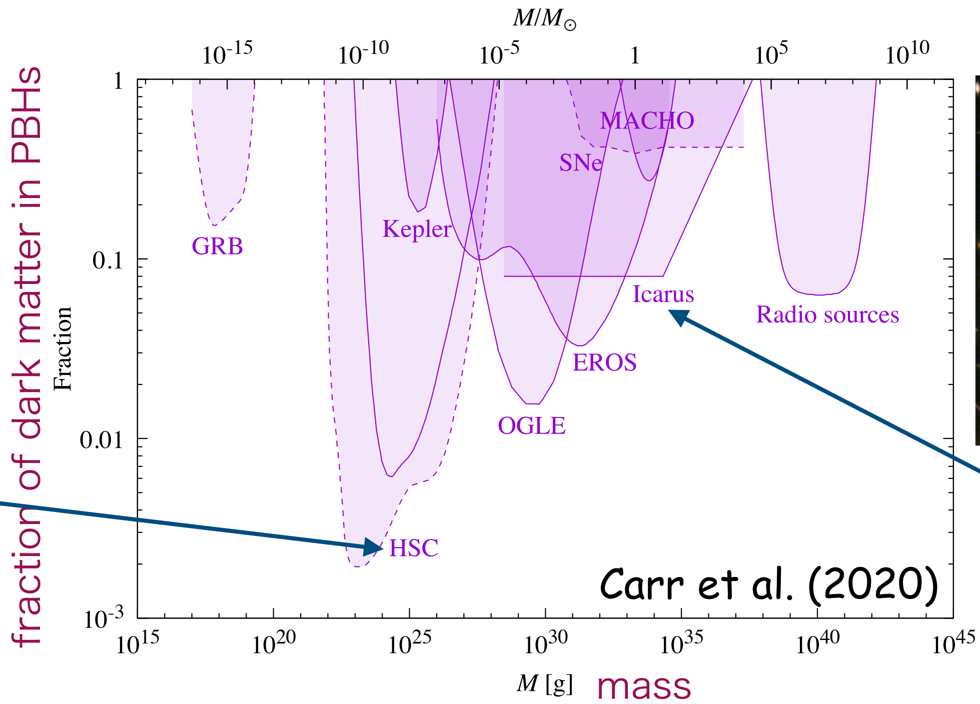
Hayashi et al. (2021)

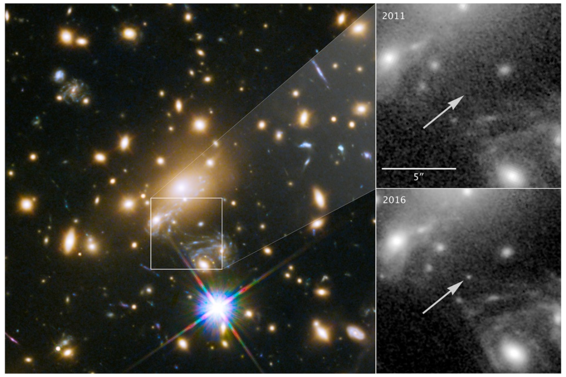
- current kinematics measurements suggest cuspy profiles consistent with cold and collisionless dark matter
  → improve constraints by kinematics+lensing?

Testing Dark Matter: Primodial Black Hole (PBH)

Microlensing is useful for constraining PBHs

M31 microlensing
(Niikura et al. 2019)

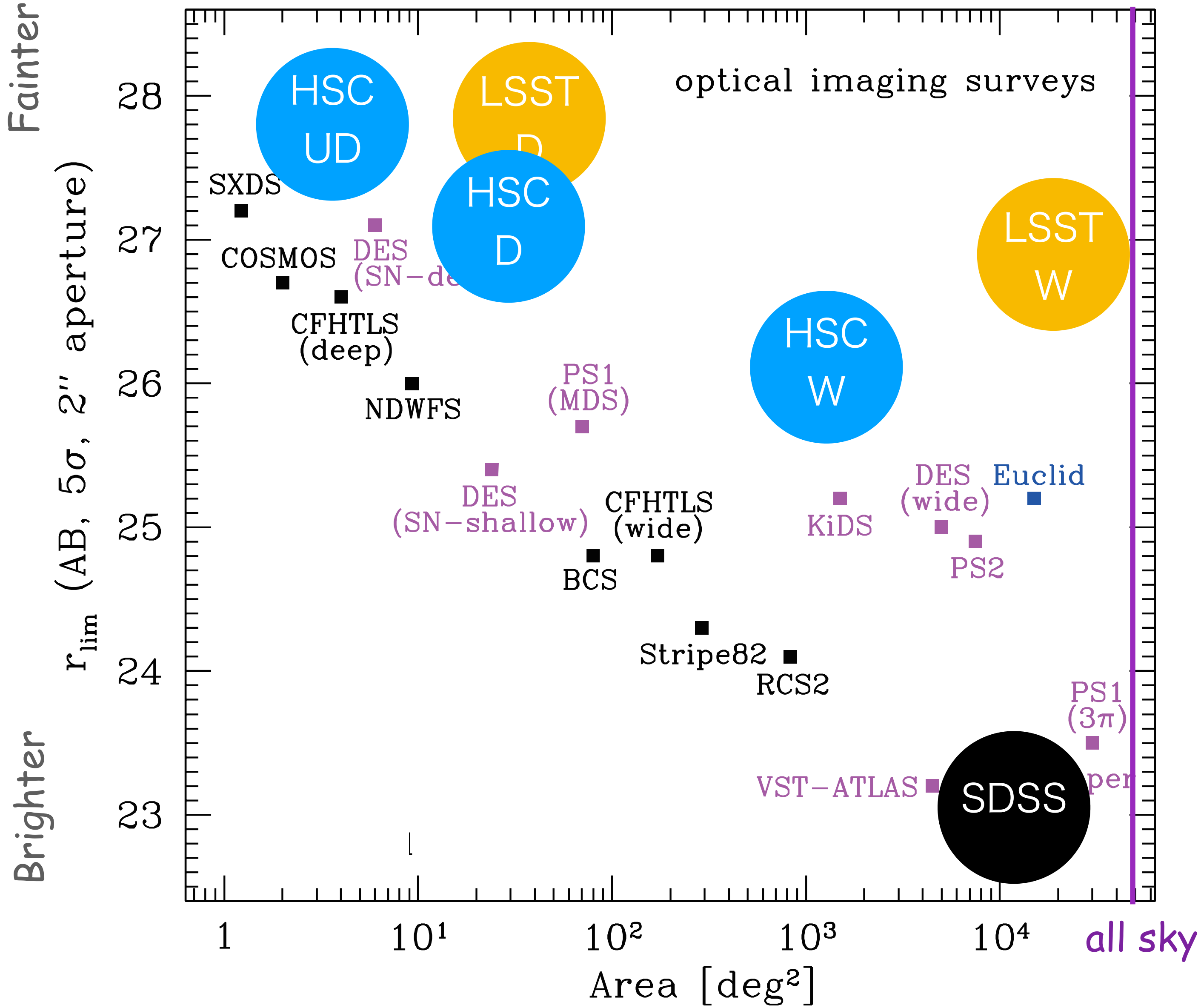




caustic crossing
(Oguri et al. 2018)

much of parameter space is still unconstrained

Modern Astronomical Imaging Surveys (optical)



Future: 2023-2030's
LSST Survey
20,000 sq. degs r ~ 27

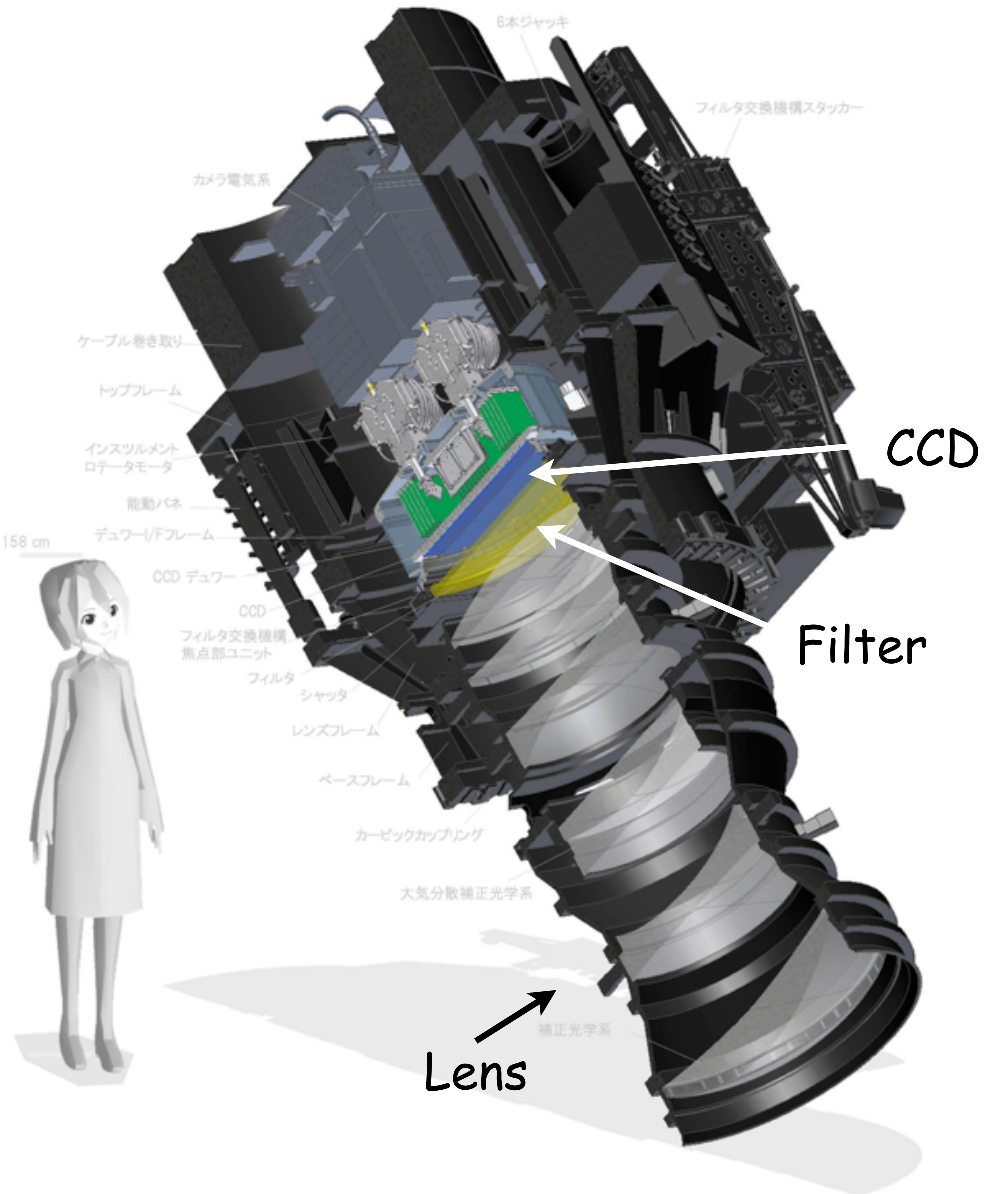
Current: 2014-2022
HSC Survey
1,200 sq. degs r ~ 26

Past: 2000's
Sloan Digital Suvey
10,000 sq. degs r ~ 23

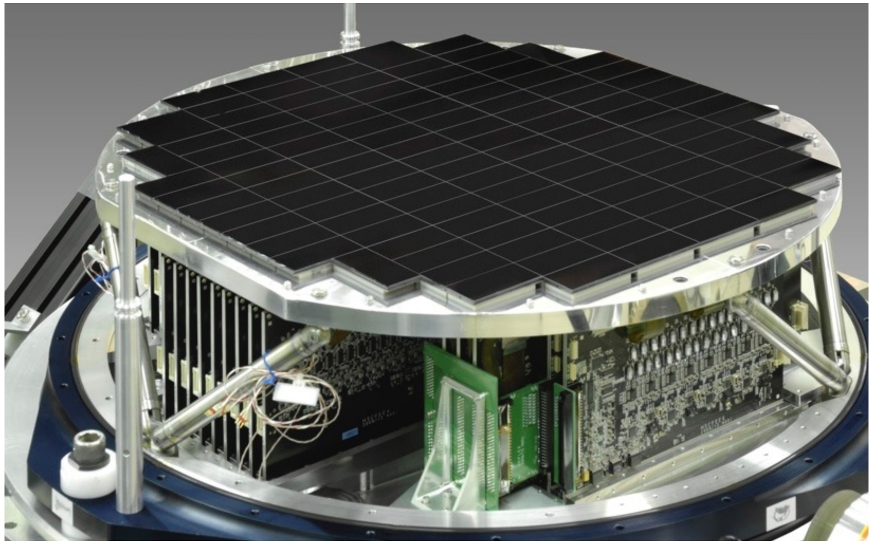
Future in parallel: Near Infrared Surveys from Space — Euclid, WFIRST

Hyper Suprime-Cam

~ 3 m tall ~ 3 tons



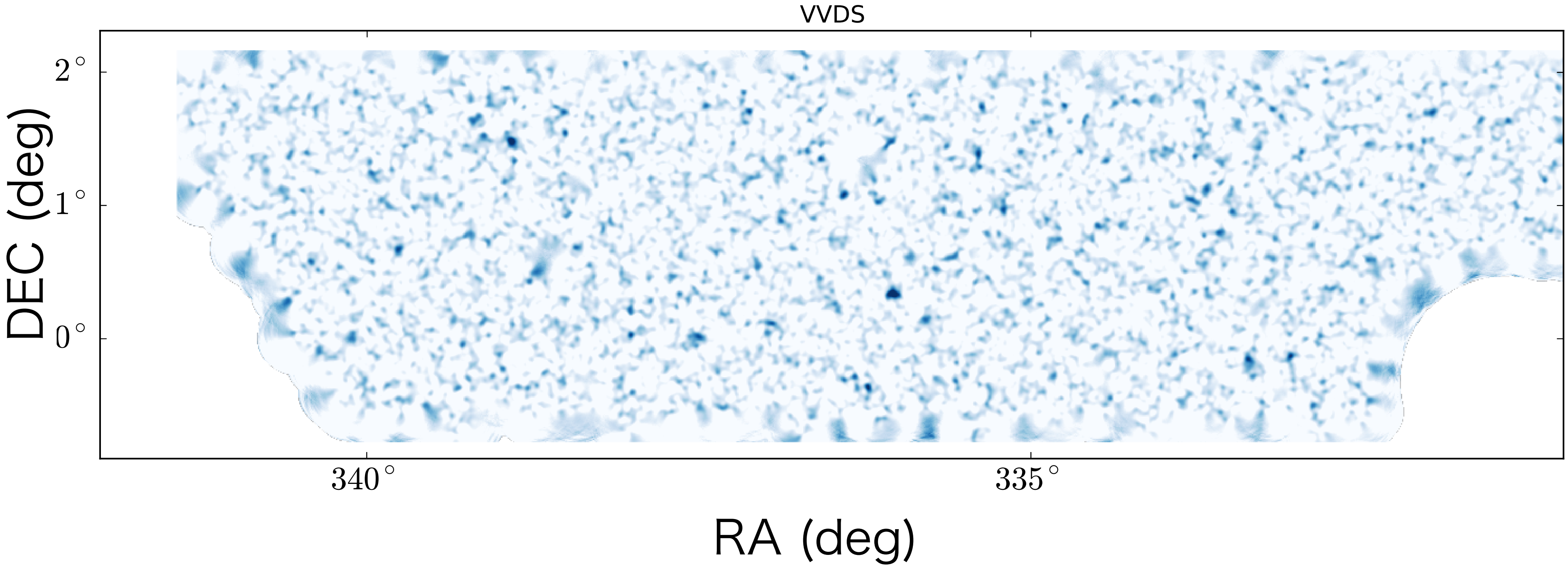
nearly GB pixel



116 200 μm thick
fully depleted CCDs
built by Hamamatsu

Wide Area Dark Matter Map

30 sq. deg (out of planned 1200 sq. deg)



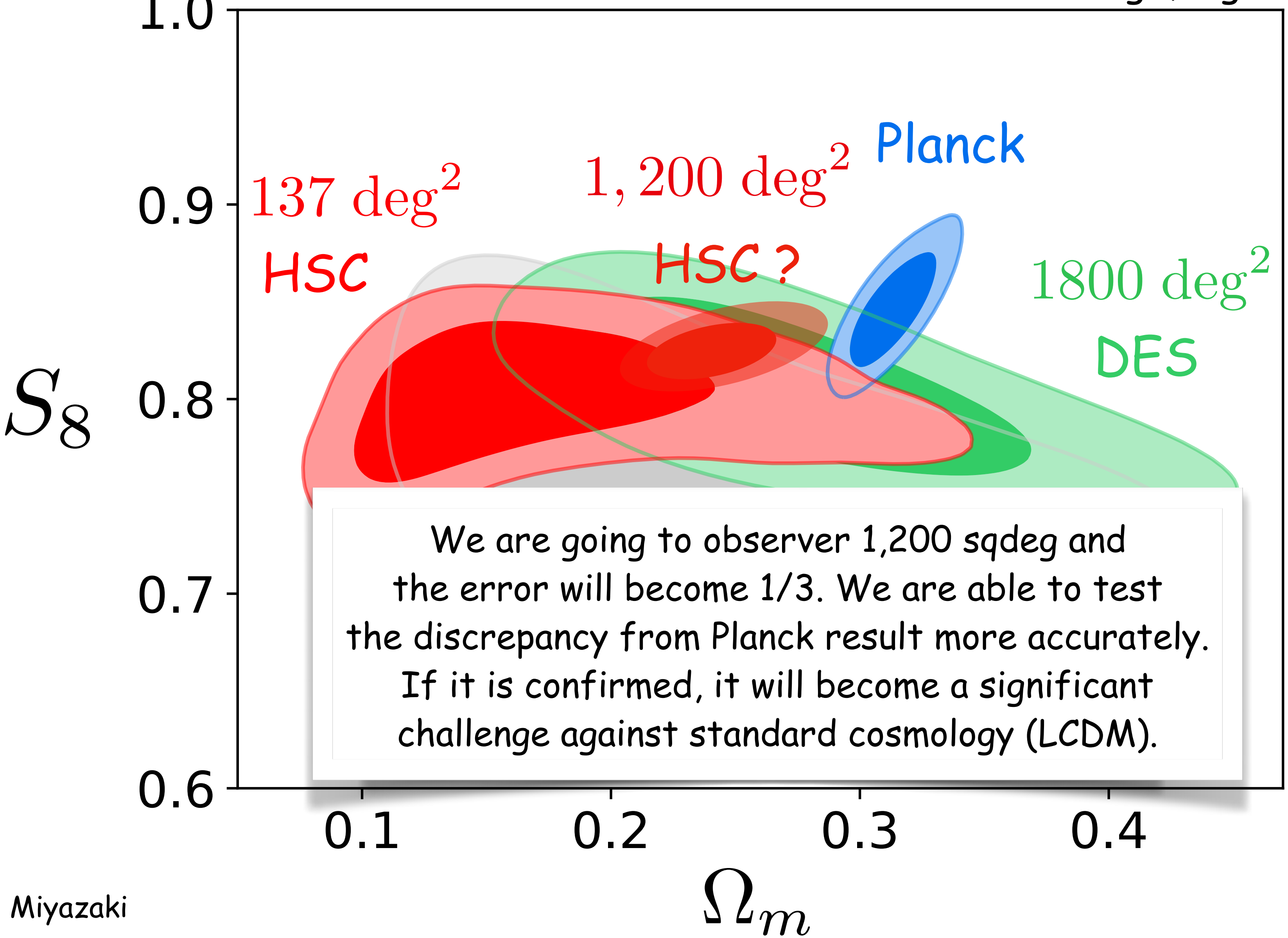
Miyazaki, Oguri, et al. (2018)

Latest Cosmology Result

Cosmic Shear Tomography to constrain Ω_m S_8

Hikage, Oguri et al. 2019

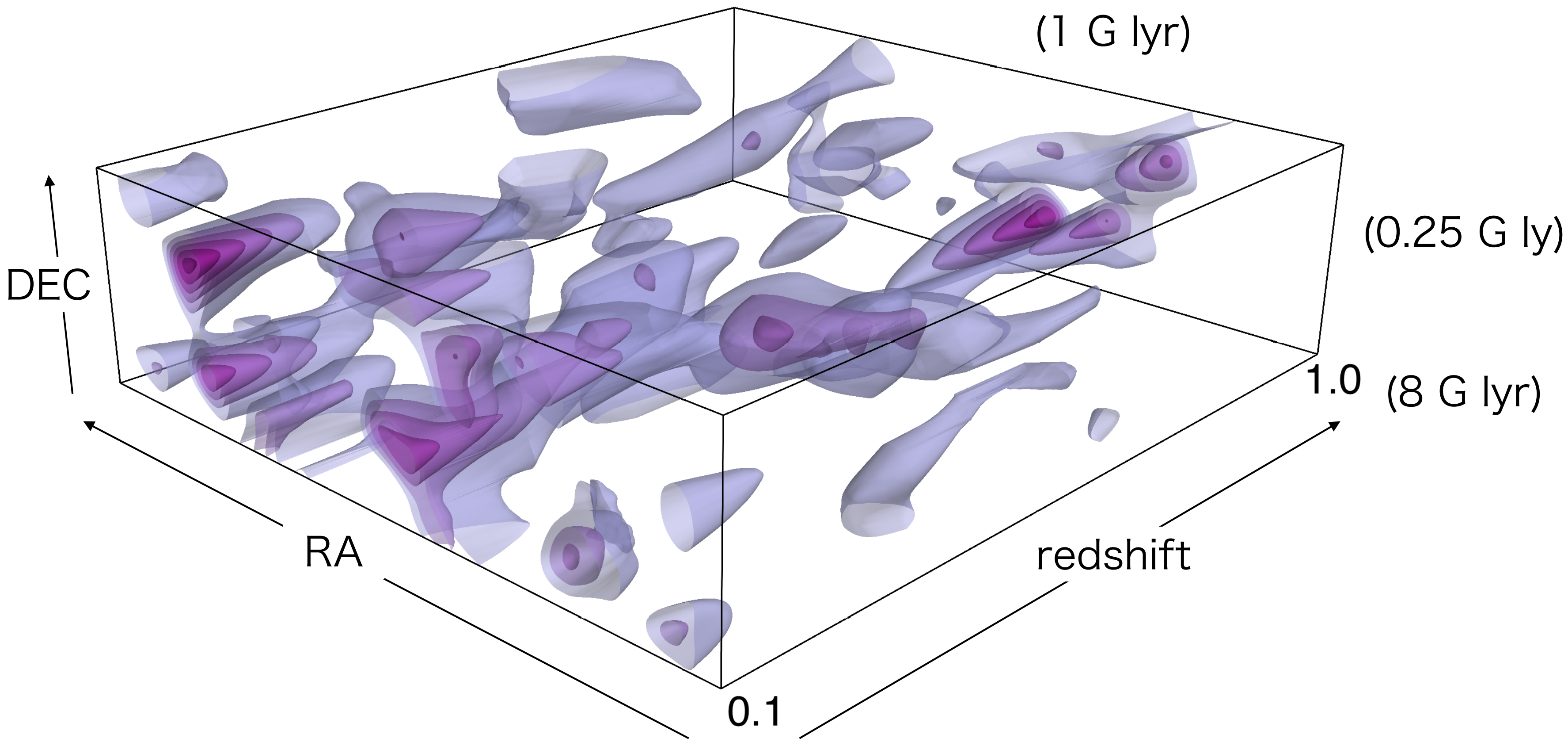
PASJ Excellent Paper Award 2020



We are going to observer 1,200 sqdeg and the error will become 1/3. We are able to test the discrepancy from Planck result more accurately. If it is confirmed, it will become a significant challenge against standard cosmology (LCDM).

Wide Area Dark Matter Map (3D)

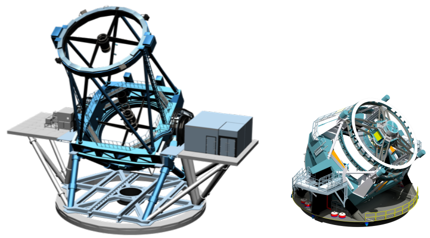
Growth of the structure clearly visible for the first time.
Only Subaru/HSC can draw this map for now.



Oguri, Miyazaki et al. (2018)

But these tell almost nothing about the nature of dark matter
Even higher angular resolution map is necessary.

Beyond Hyper Suprime-Cam



- More powerful rivals showing up: LSST, Euclid, and WFIRST

- CCD read out time (30 sec) makes the short time exposure observation quite inefficient

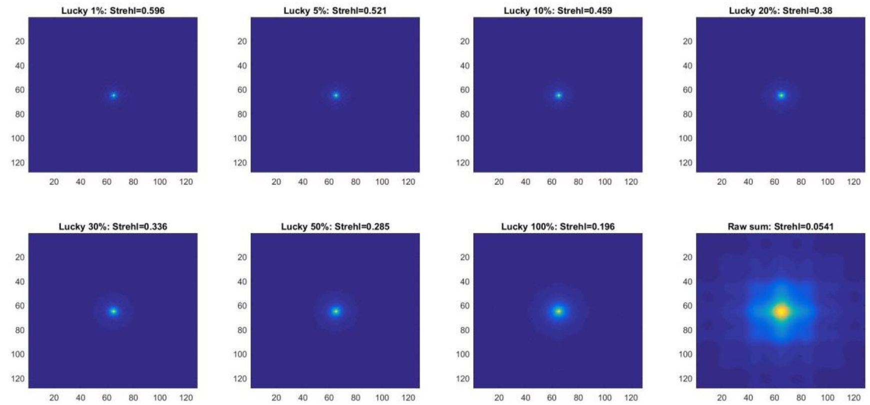
	HSC	LSST
Survey Period	6 yr	10 yr
Nights	300	~3000
Rel. Inst. Survey Speed	1	3.4
Rel. Yearly progress	1	20 !!!

$$3.4 \times \frac{3000}{10} / \frac{300}{6}$$

Introduction of high speed CMOS might be one way to go where we might be able to explore unprecedented parameter space

Thus, we resumed a collaboration with Hamamatsu to build fast readout CMOS sensor.

Beyond Hyper Suprime-Cam



Mackey et al. (2018)

High Speed CMOS enables:

- Lucky Imaging
  - Image quality of ground base telescope is limited by the atmospheric disturbance
  - Selecting "luckily" less disturbed images from a series of short time exposures makes sharper imaging possible
  - Angular resolution of mass map improves as N_g increases (0".7->0".5 doubles N_g)
- Micro-lensing observation in more crowded field
  - Exploring new parameter space

We resumed a collaboration with Hamamatsu to build fast readout CMOS sensor armed with the former "新学術領域研究" of Murayama-san's PI.

Observing Plans

Revival of the retired Suprime-Cam with the new detectors

- High cadence observation of PBH

- Blind optical pulsar surveys in globular clusters

Lucky imaging on D = 2 ~ 3 m telescopes

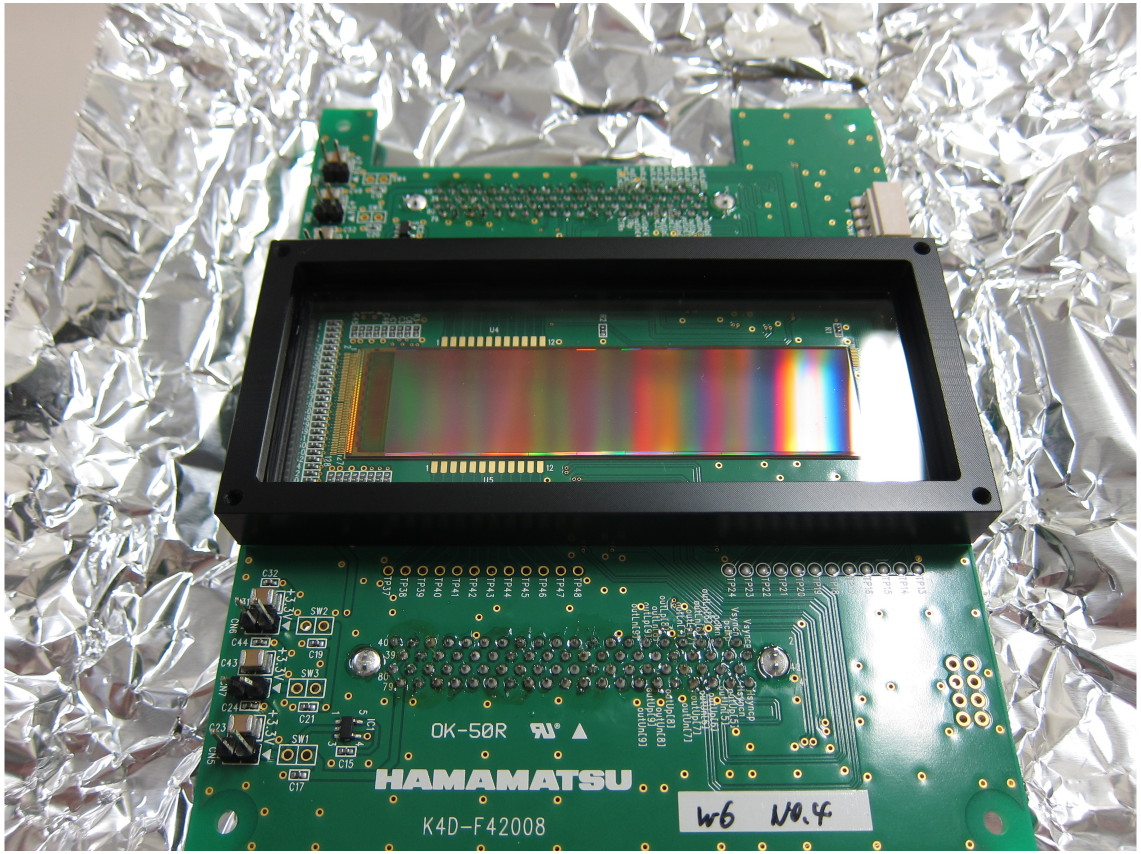
Shift-and-Add on 0.5 m SuperBIT balloon telescope

- Massive cluster (z ~ 0.5) center and outer skirts

- Caustic crossing observations

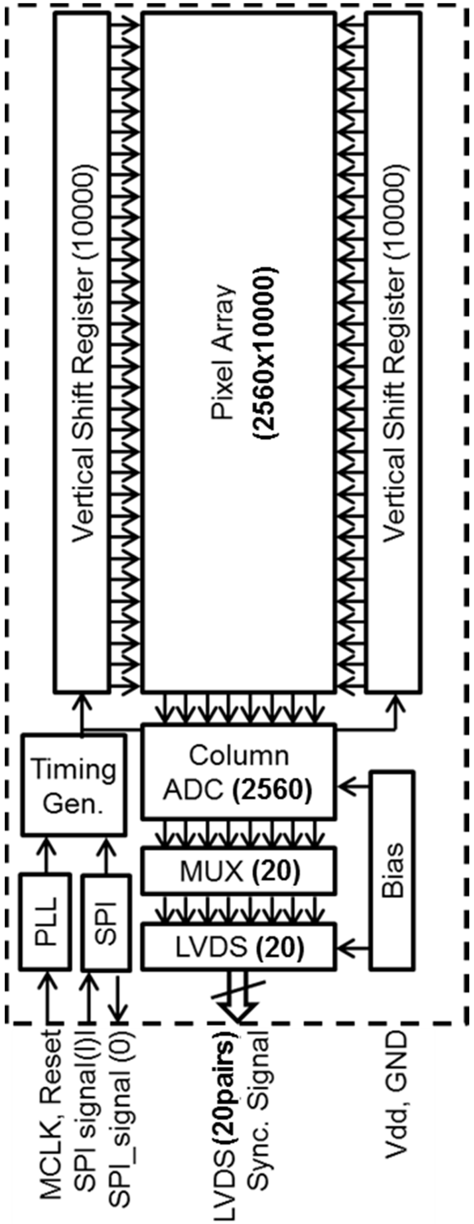
Prototyping since 2017

- Design goals
  - 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



Structure

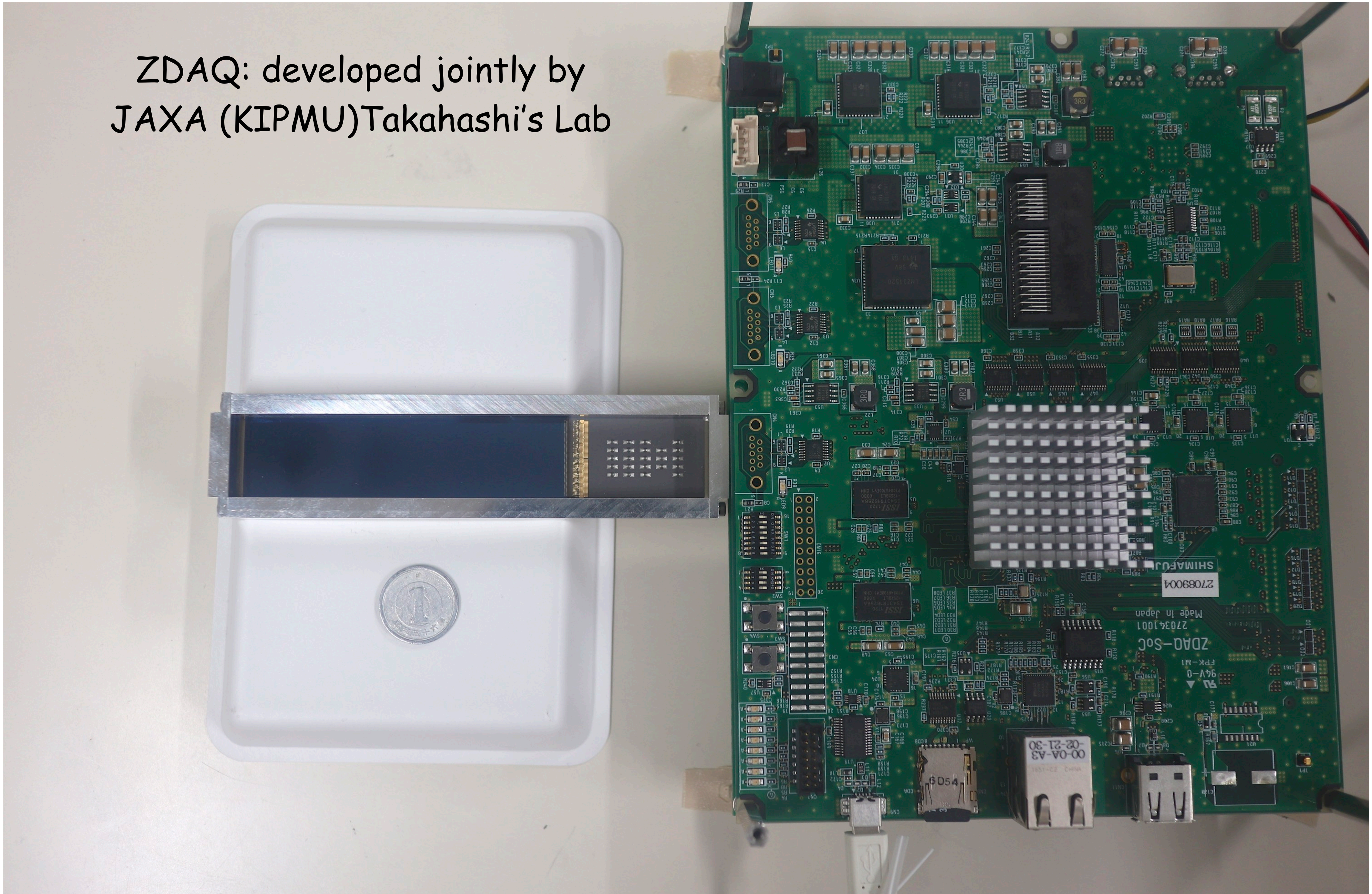
■ ブロック図



2560 Column ADC
Digital output from a device

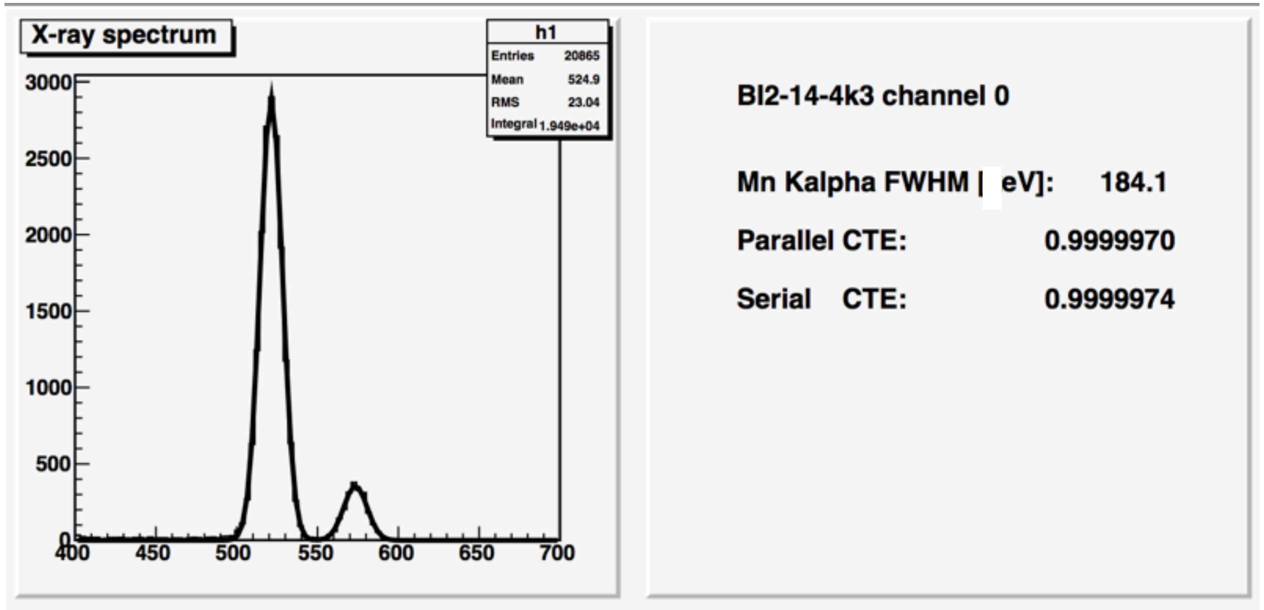
Item	Unit	Back Illuminated	Front Illuminated
Image Size	mm	19.20 x 75.00	
Pixel Size	µm	7.5	
Format	pixel	2560 x 10000	
Fastest Frame Rate	fps	6	10
Quantum Efficiency	%	>= 48 (400 nm) >= 60 (800 nm)	>= 5 (400 nm) >= 11 (800 nm)
Ratio of defect pixels	%	<= 5	
Resolution (*1)	µm	<= 5	<= 5
Dark Current	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)	

Data Acquisition Board

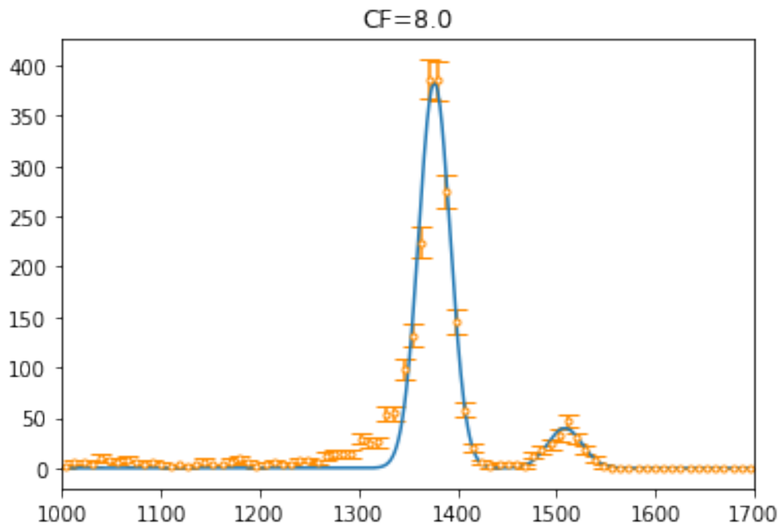


X-ray test result

HPK
CCD



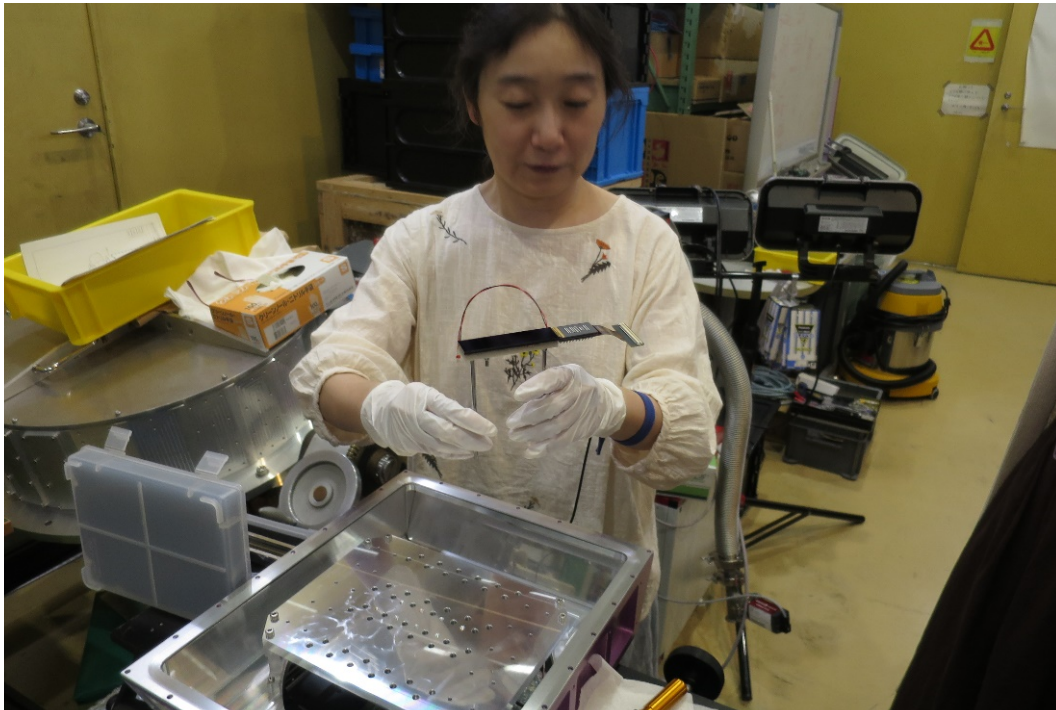
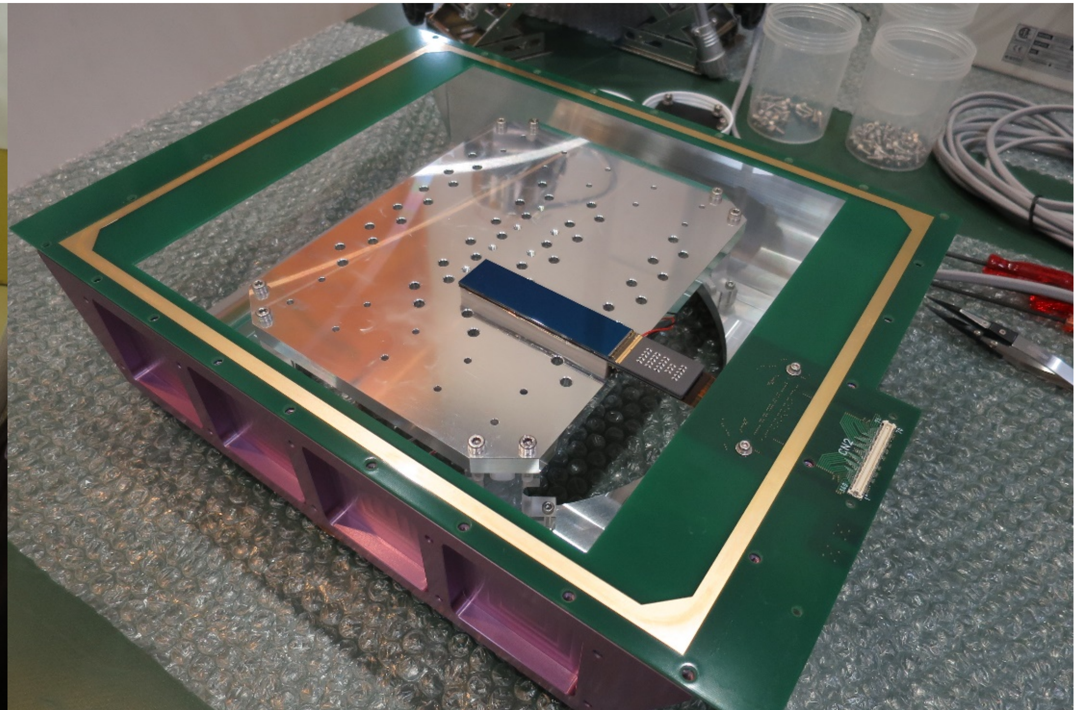
HPK
CMOS

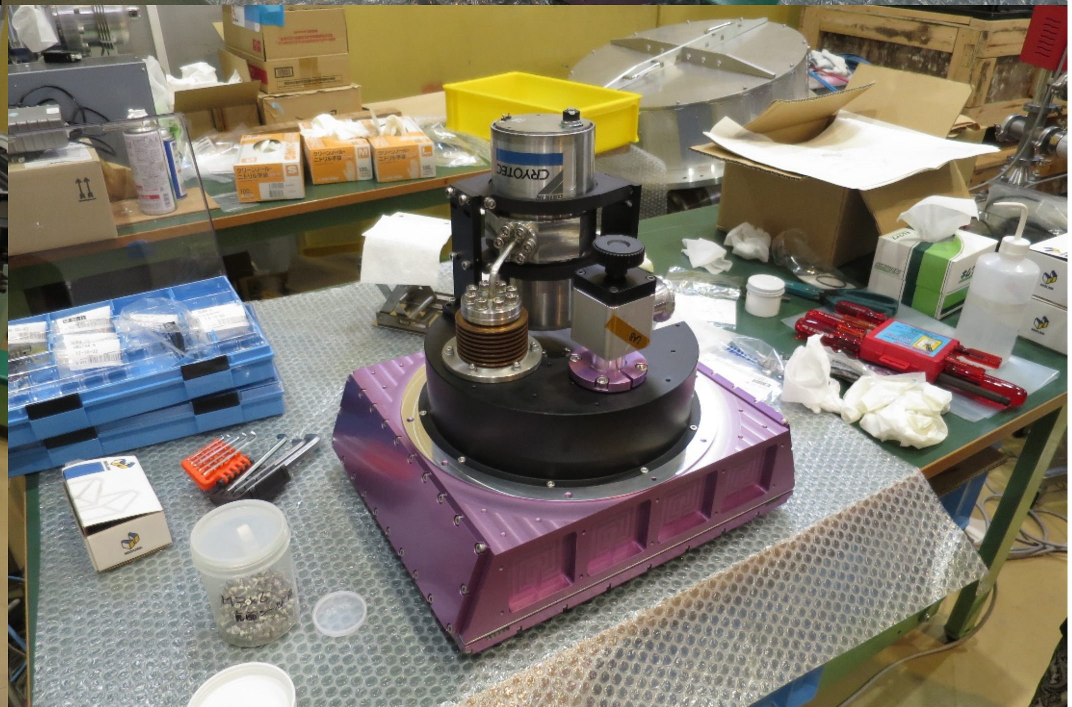


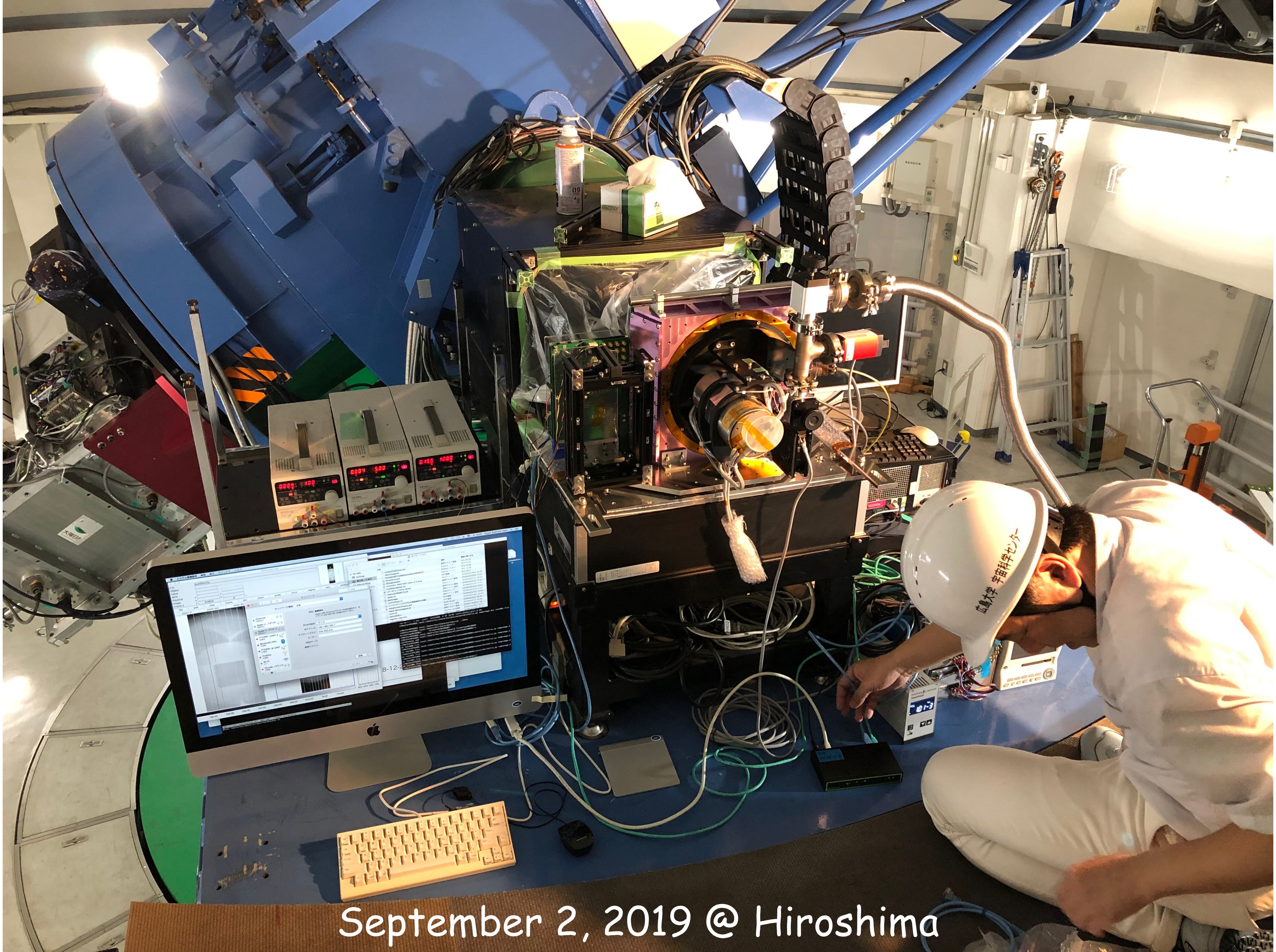
Mn Kalpha FWHM: 160 eV

Readout noise: 2.5 e

Assembly of the focal Plane 2019/08





September 2, 2019 @ Hiroshima

Lucky Imaging Trial

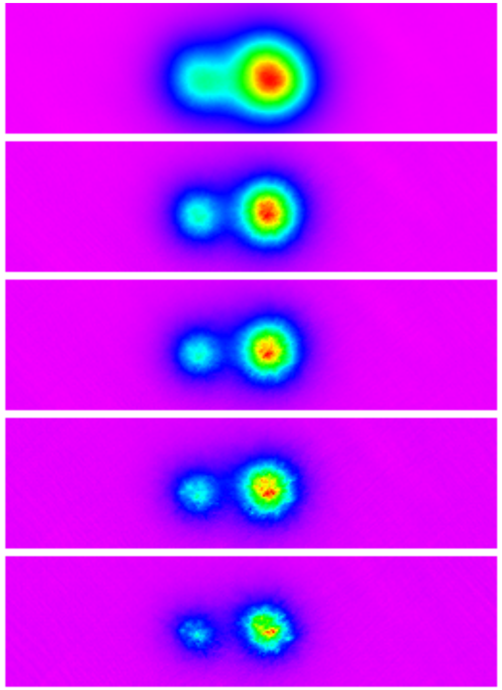
alpha-Gem.: Binary stars with 5 arc sec separation

- R-band、1 ms、1000 exposures

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

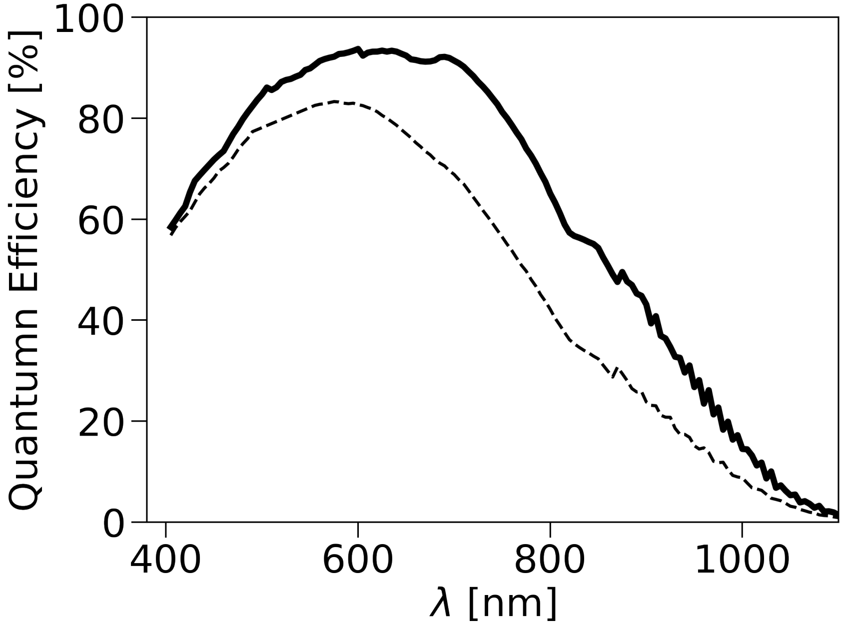
- FWHM changes 3.84 ->3.24-> 2.88->2.64-> 2.28 arc-sec

-Improvement confirmed



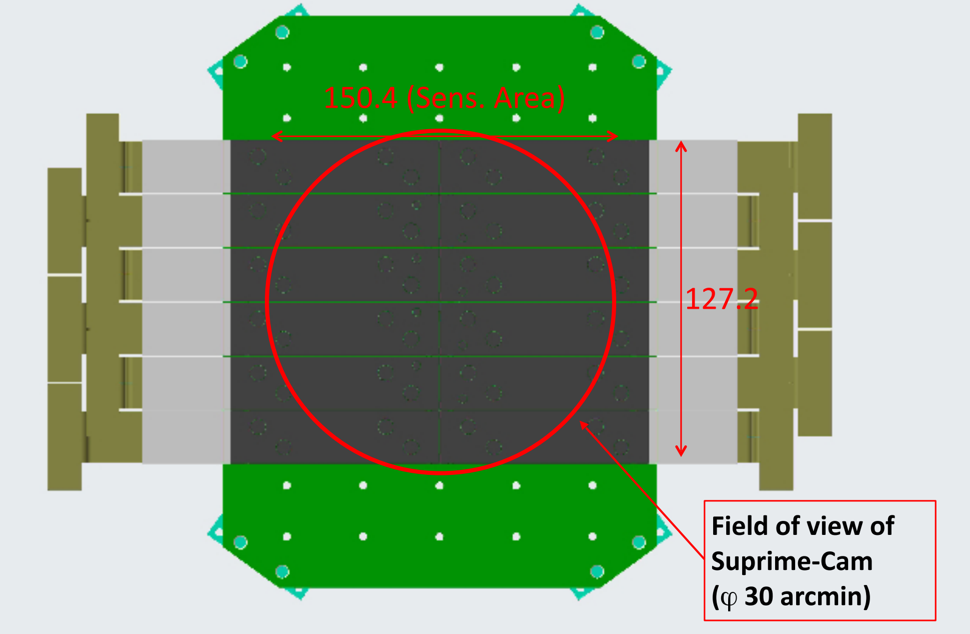
Development plan under this funding phase

Improvement of QE



while maintaining pixel resolution
by adopting high resistivity silicon

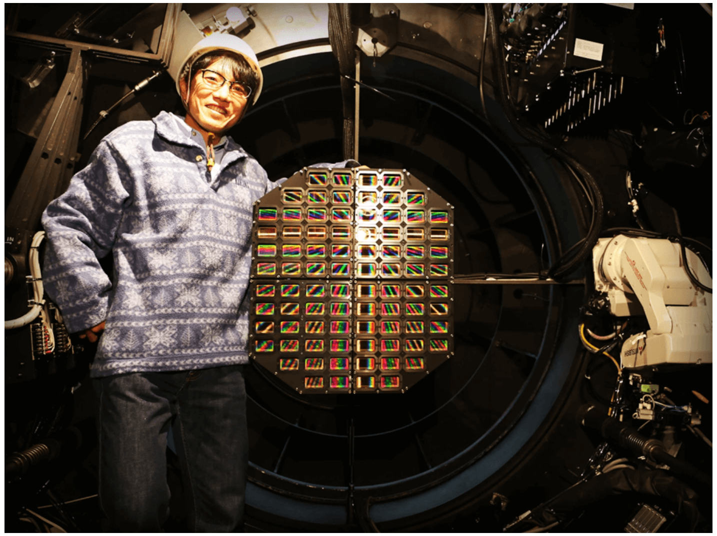
Mass (!?) production to pave the Subaru Suprime-Cam Focal Plane



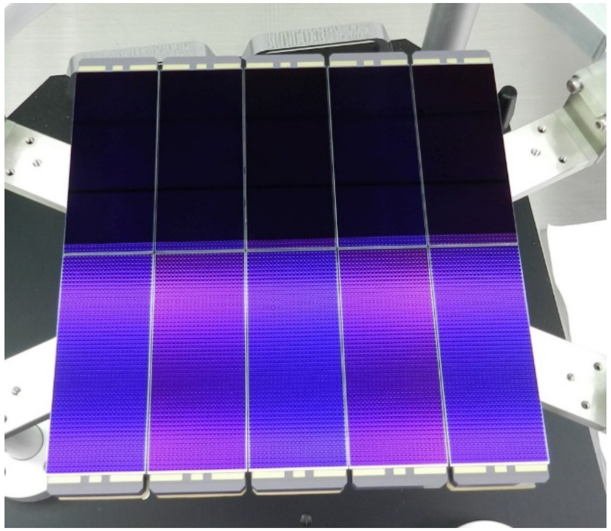
Twelve Devices necessary

Comparison with other CMOS Cameras

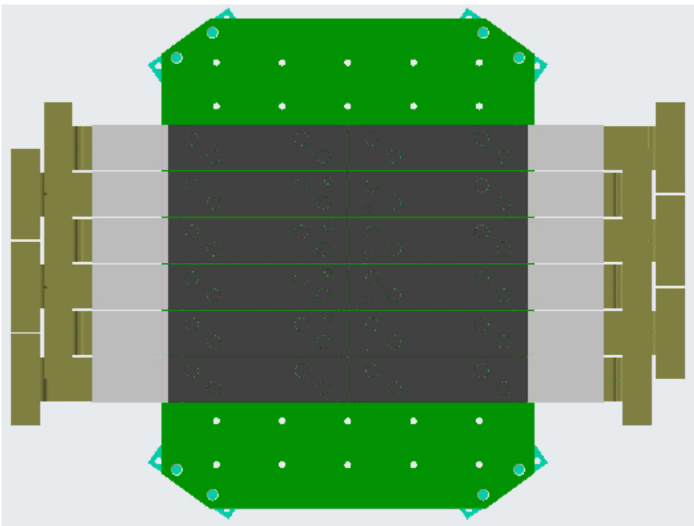
	Tomo-e Gozen	TAOS II	Subaru CMOS
Tel. Aperture	1.05 m	1.3 m	**8.2 m**
Field of View	20 deg^2	2.3 deg^2	0.25 deg^2
Frame Rate	2 sec^{-1} (20 for part)	20 sec^{-1}	**10 sec^{-1}**
Limiting Mag.	~17 mag	~18 mag	~21 mag
Sensor Format	2000x1128 (19um/pix)	1920x4608 (16um/pix)	2560x10000 (7.5um/pix)
# of Sensors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



Tomo-e Gozen



TAOSII Focal Plane



Subaru CMOS Camera

Challenges

- Data Acquisition System

- Post Processing Data Analysis System

50 MByte x 10 Hz x 12 = 6 GByte/sec

Summary

- Please contact us if you are interested in the project.
  - New ideas for observations wanted
  - New ideas to handle massive dataset wanted
  - We encourage you to apply for the “公募研究” to promote the collaboration.