Cosmology (3)

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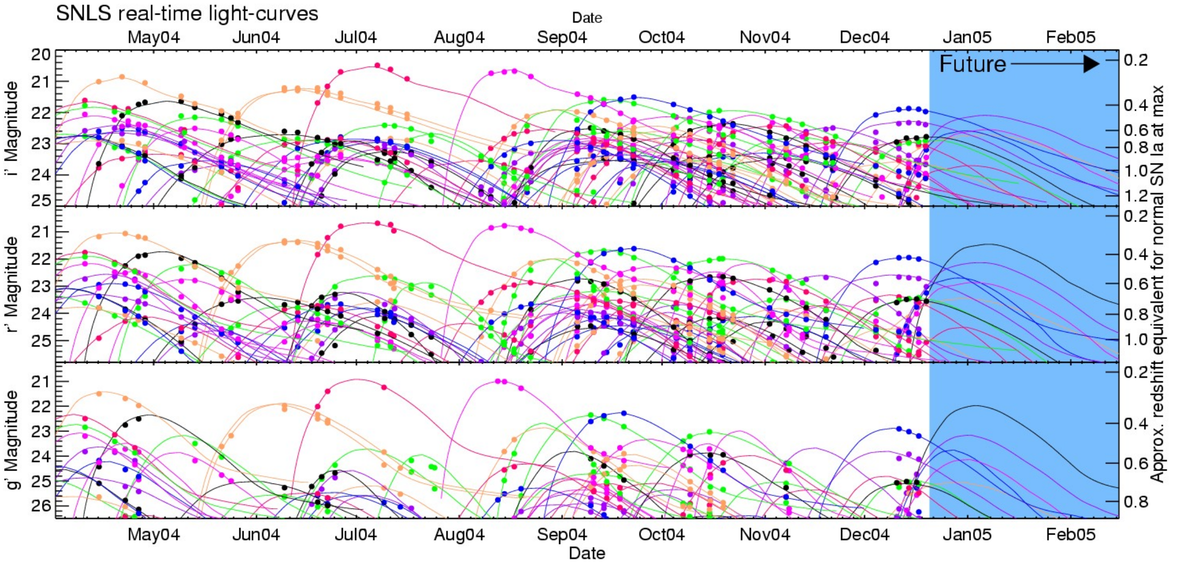
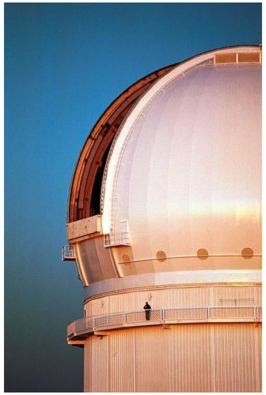
TES School - Bezmiechowa Górna, – July 2023.

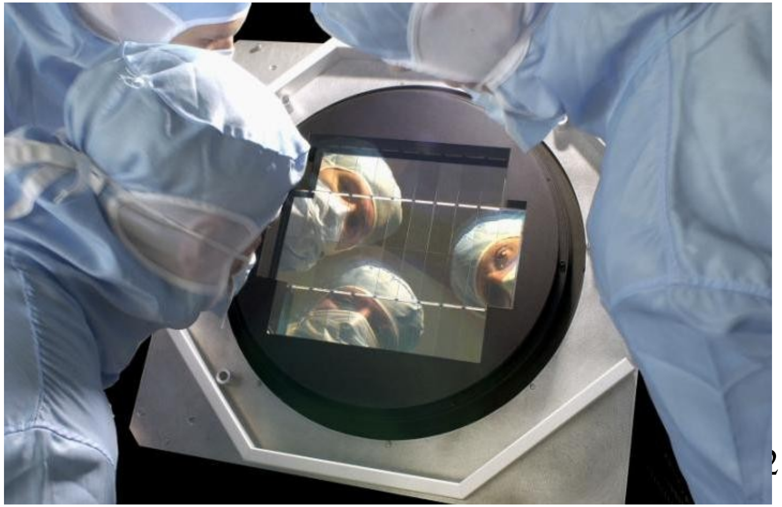


Around 2000, a new instrument

Canada France Hawaii Telescope :
- diameter 3.6m
- Mauna Kea, Hawaii
- 4200 m
- Exceptional image quality

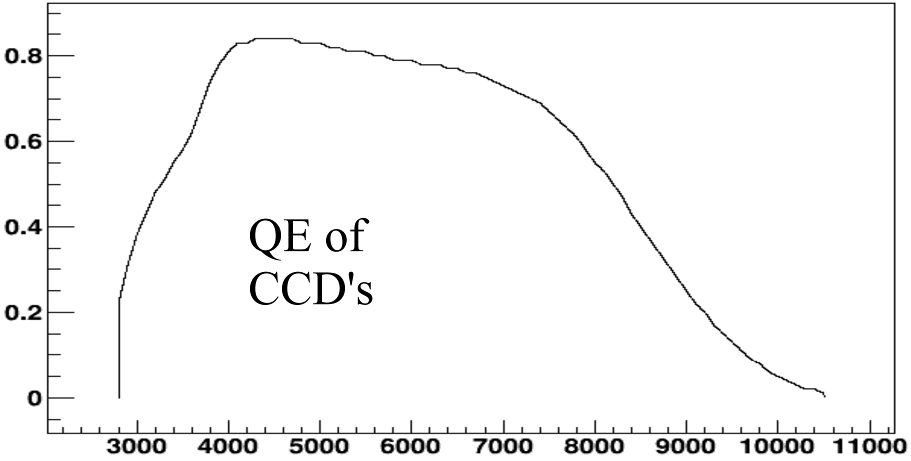


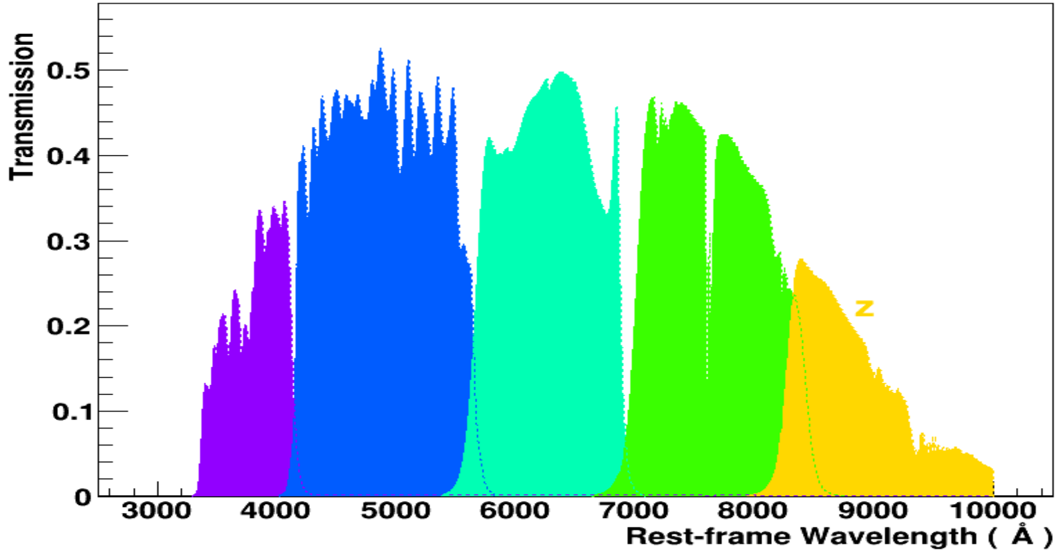
MegaCam:
- 36 2k x 4.5 k CCD's.
- 18 000 x 18 000 pixels
- field of view : 1 deg^2
- first light : end of 2002.
- assembled at CEA.



Instrumental details

The visible spectrum is split into 5 bands. If you want several bands You "just" acquire (successive) images with the corresponding filters in the beam





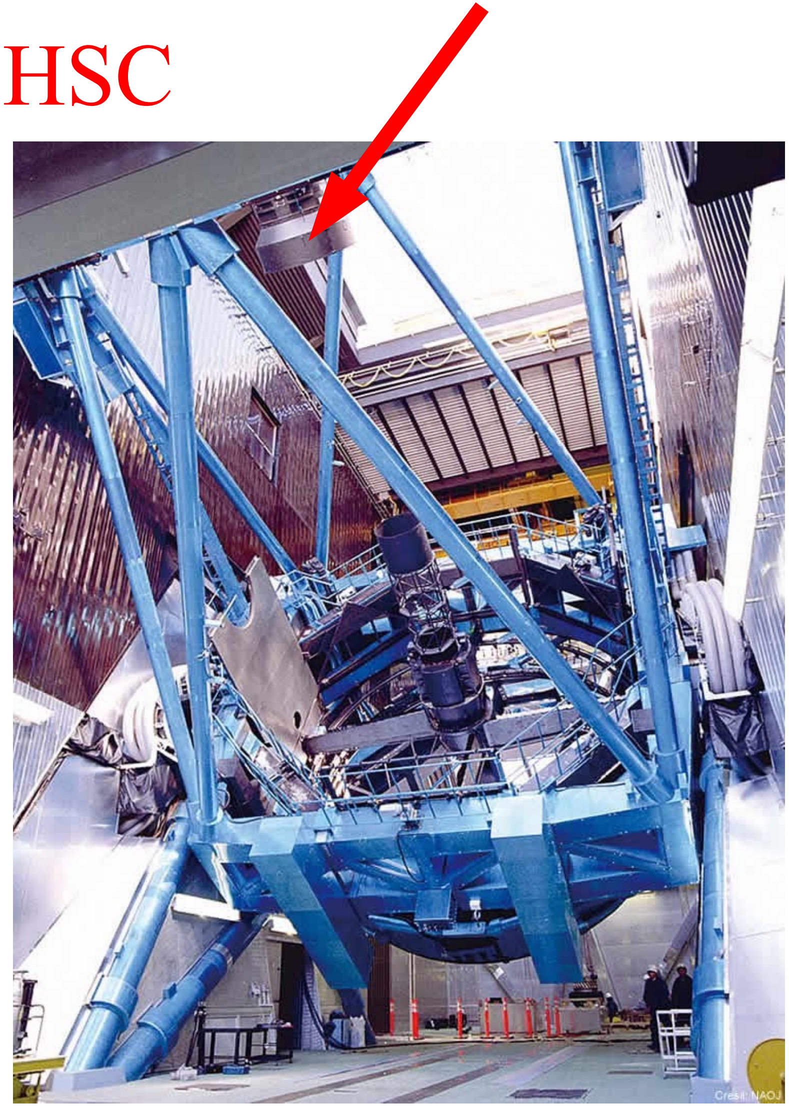
Visible range is split into 5 bands, using filters.
Here are the transmission of the bands, including all optics and atmosphere

Hyper Suprime Cam(era) : HSC

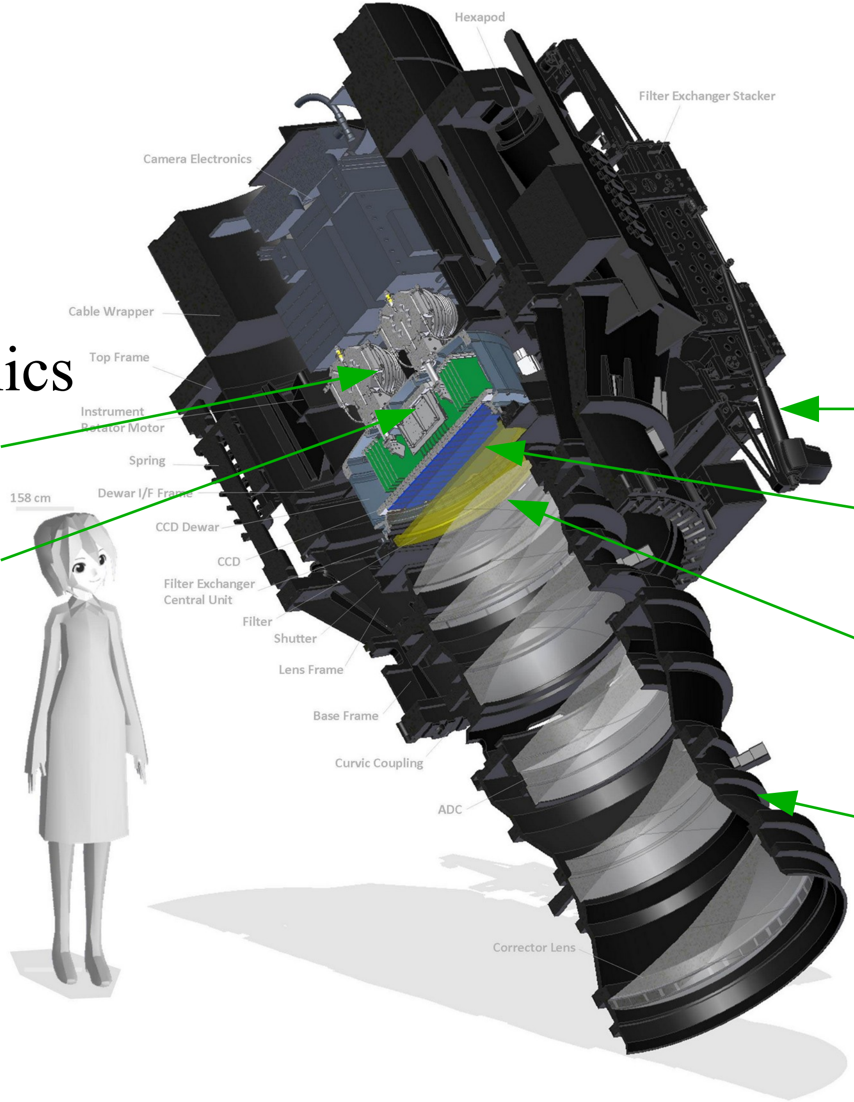
Subaru Telescope
Mauna Kea, mirror:8.2 m

Hyper Suprime Cam(era) : HSC

Subaru Telescope
Mauna Kea, mirror:8.2 m



HSC



Electronics

CCDs

Filter Exchange system

Filter in the beam

Shutter

5-lens image corrector

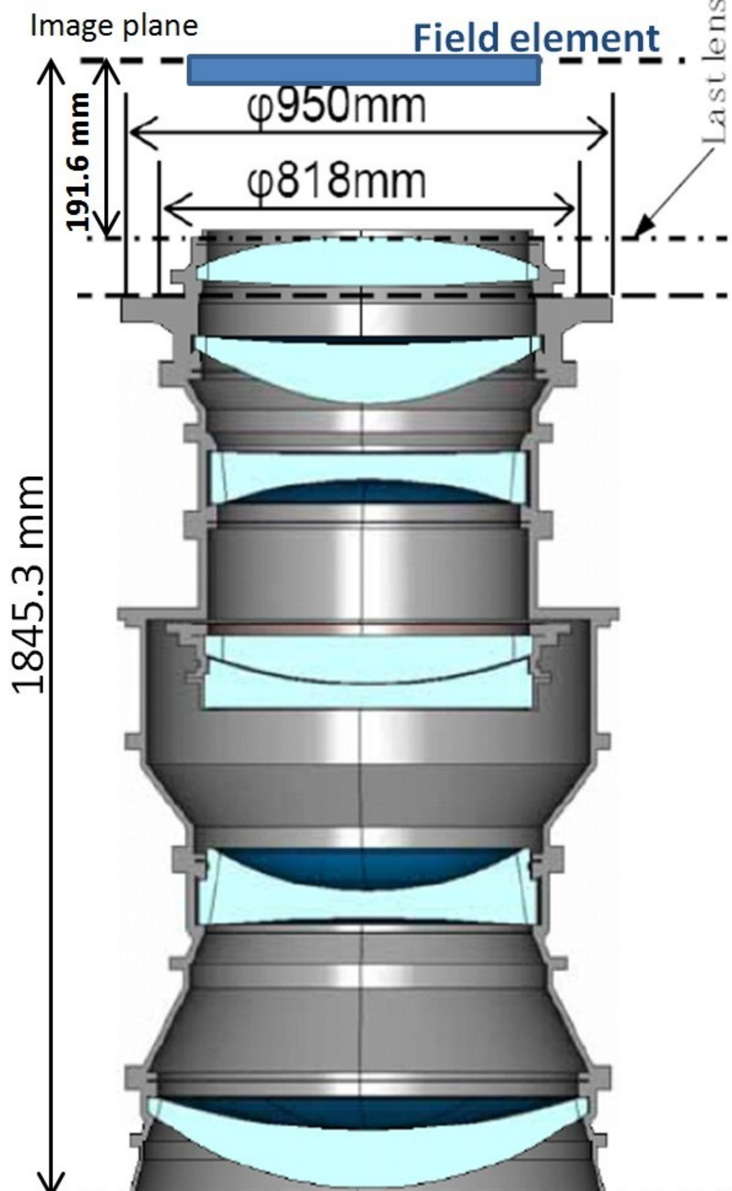
Wide-field corrector

5 groups

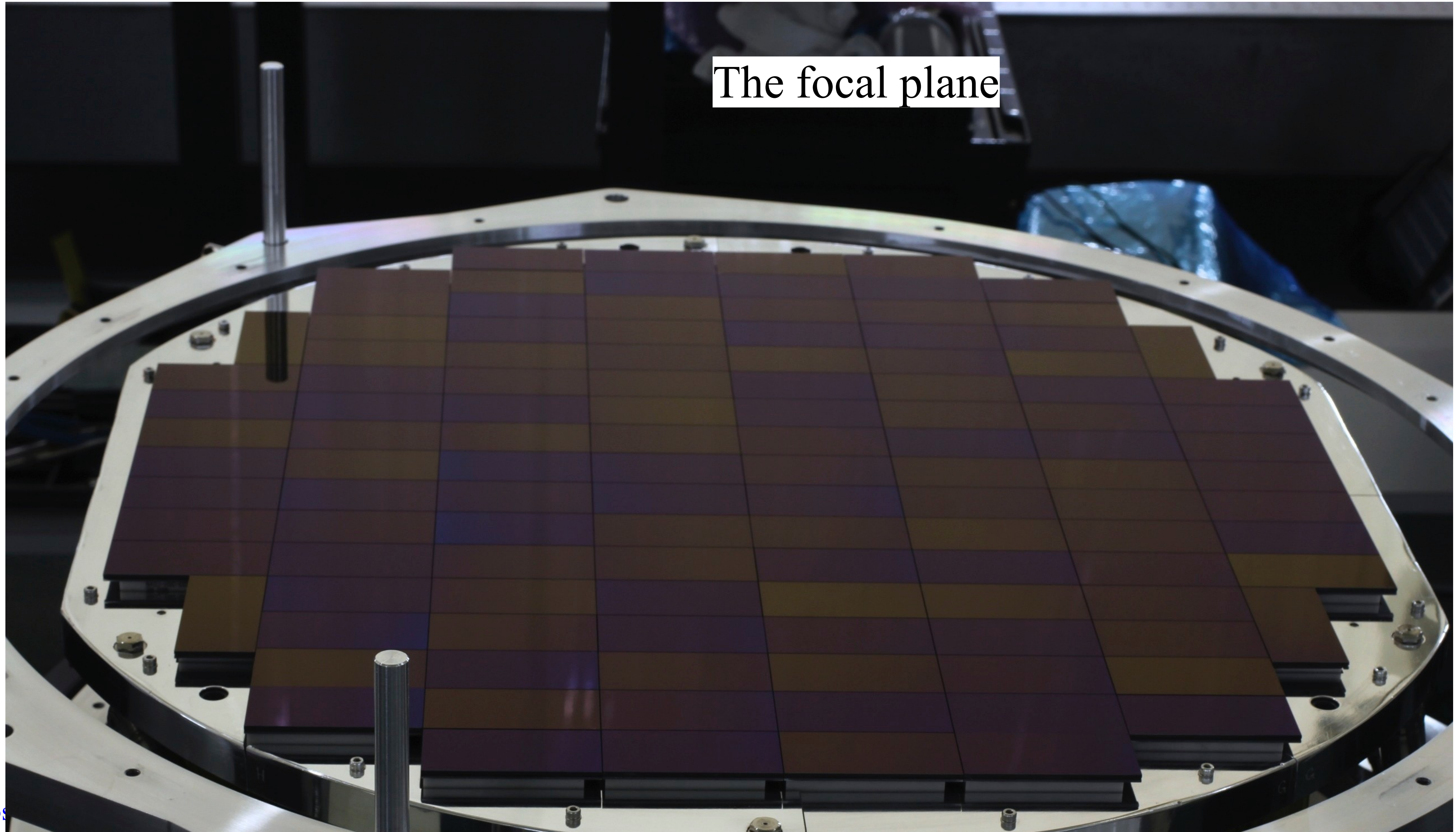
Realized by Canon-inc (!)

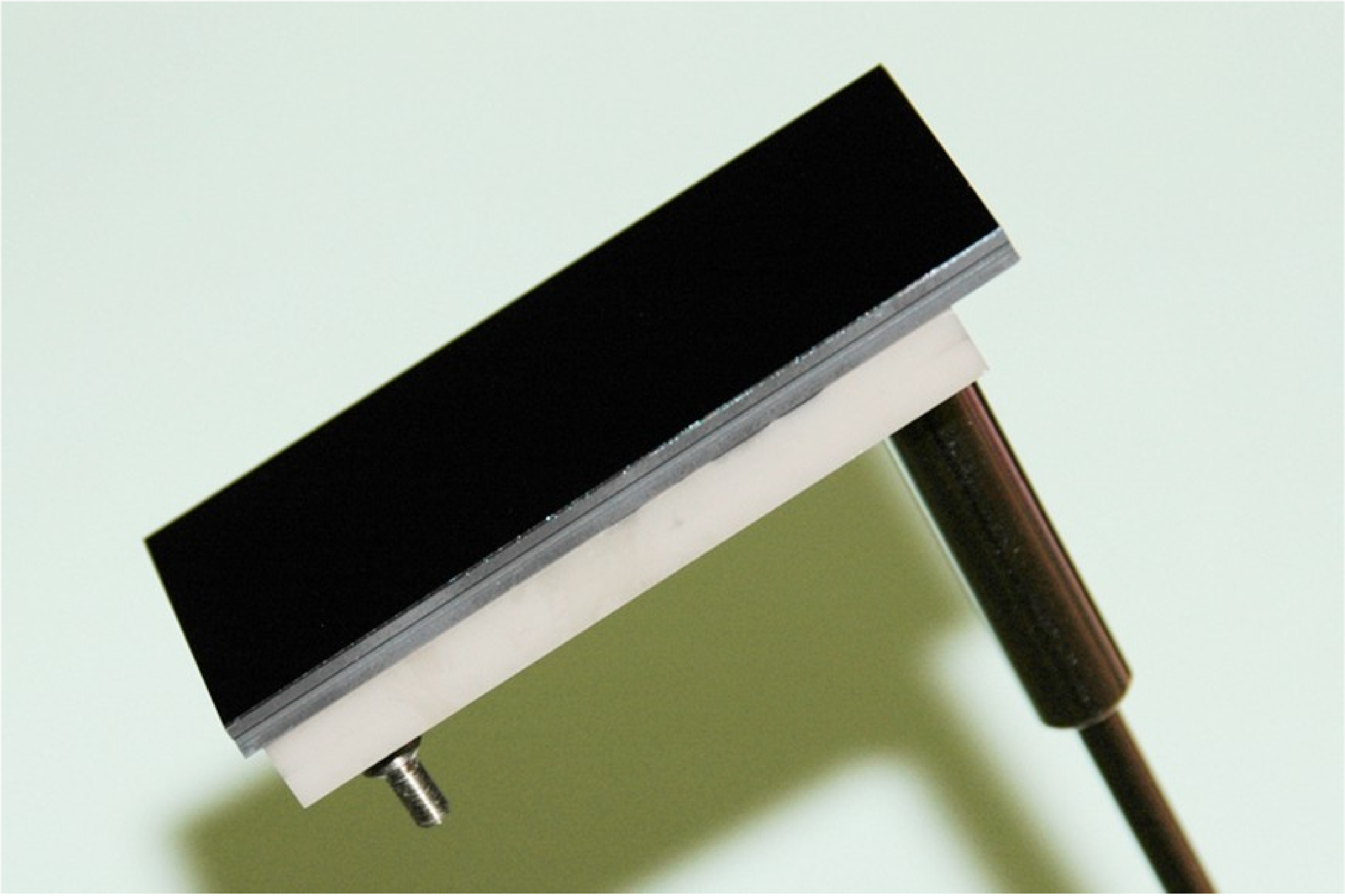
Integrates an atmospheric dispersion corrector

~ 900 kg.



The focal plane

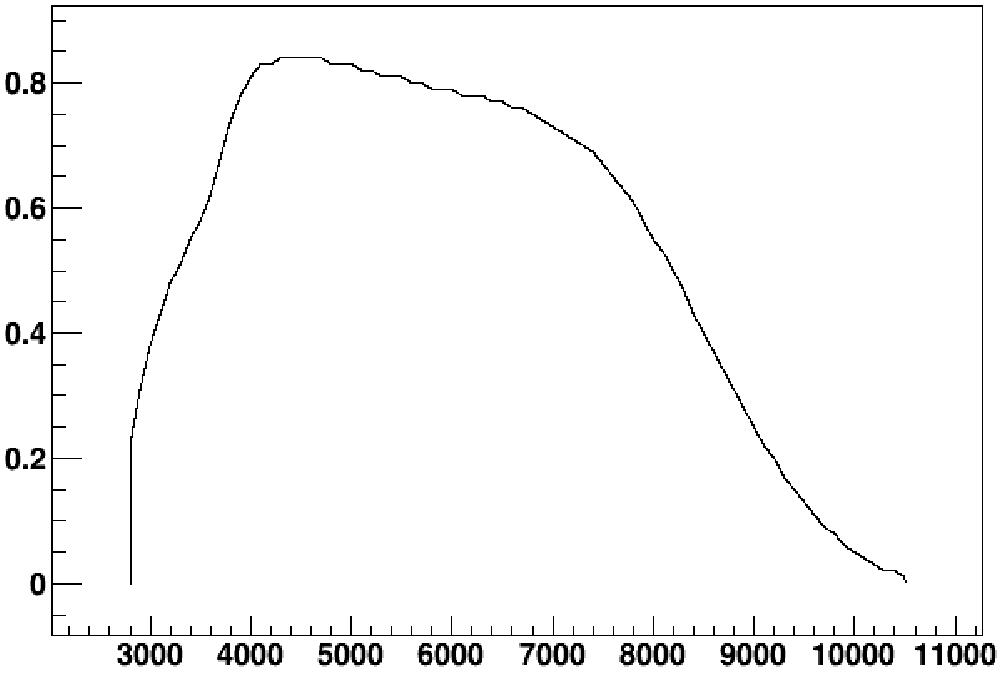




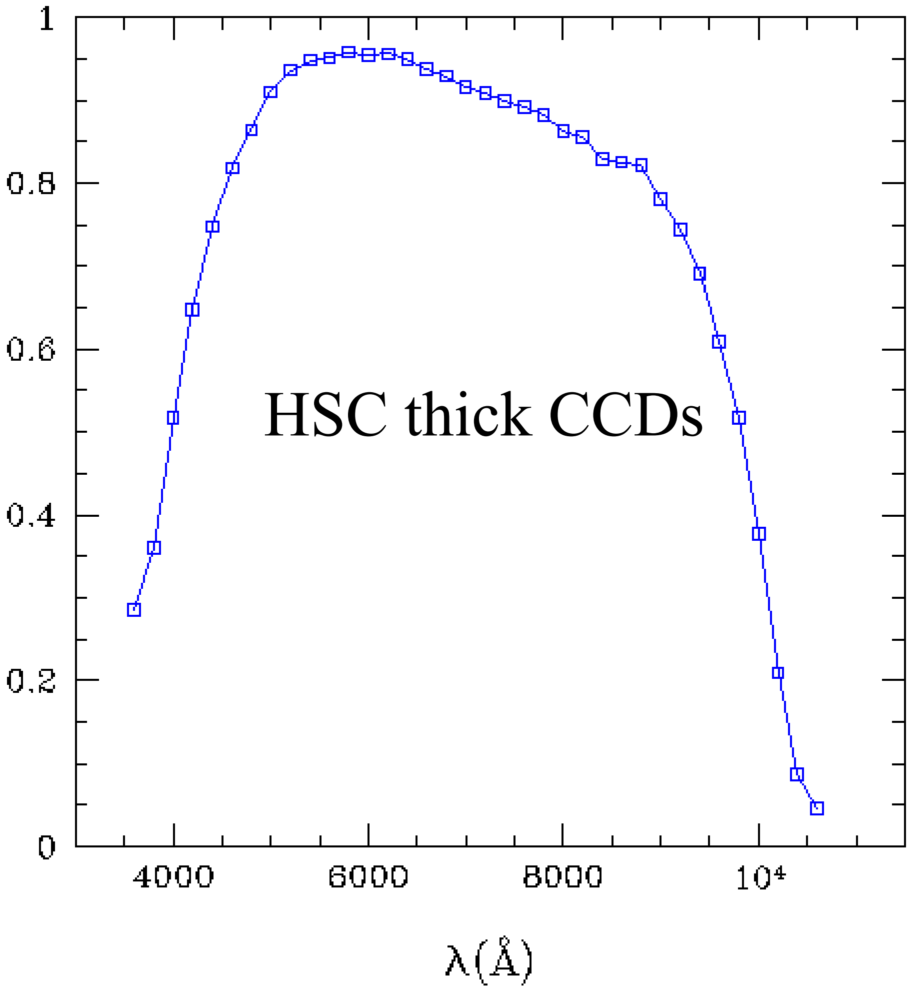
HSC CCDs

Hamamatsu
2k x 4k
15 μm pixels
4 channels (512x4k)
High resistivity
Fully depleted
200 μm thickness
Read out time: ~ 20s

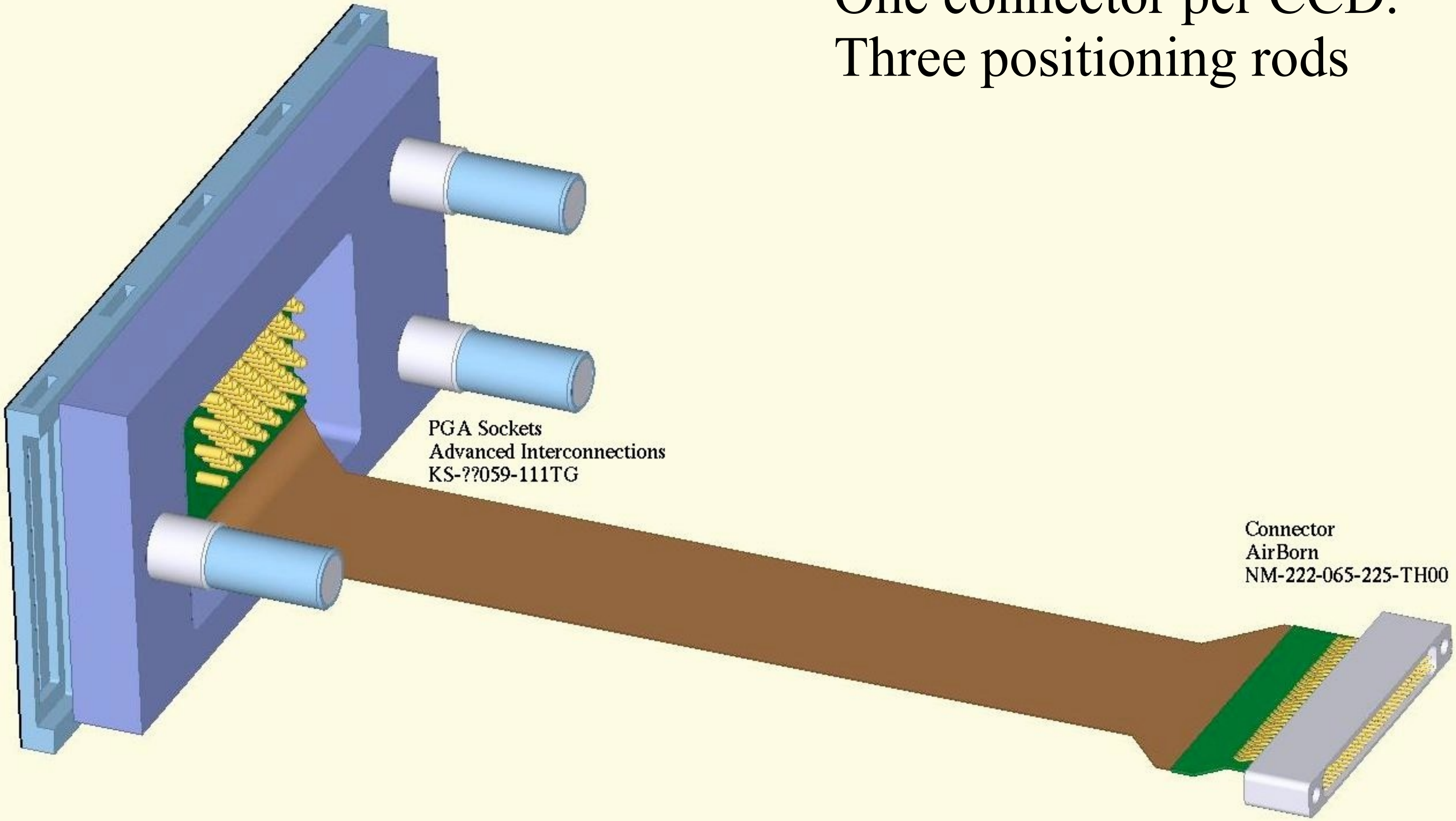
Quantum efficiency



Megacam, thin CCDs

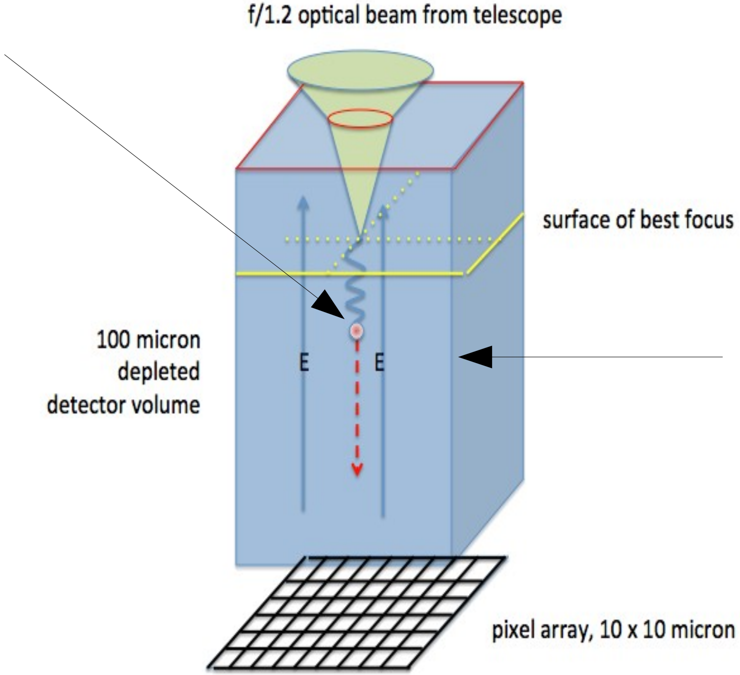


One connector per CCD.
Three positioning rods

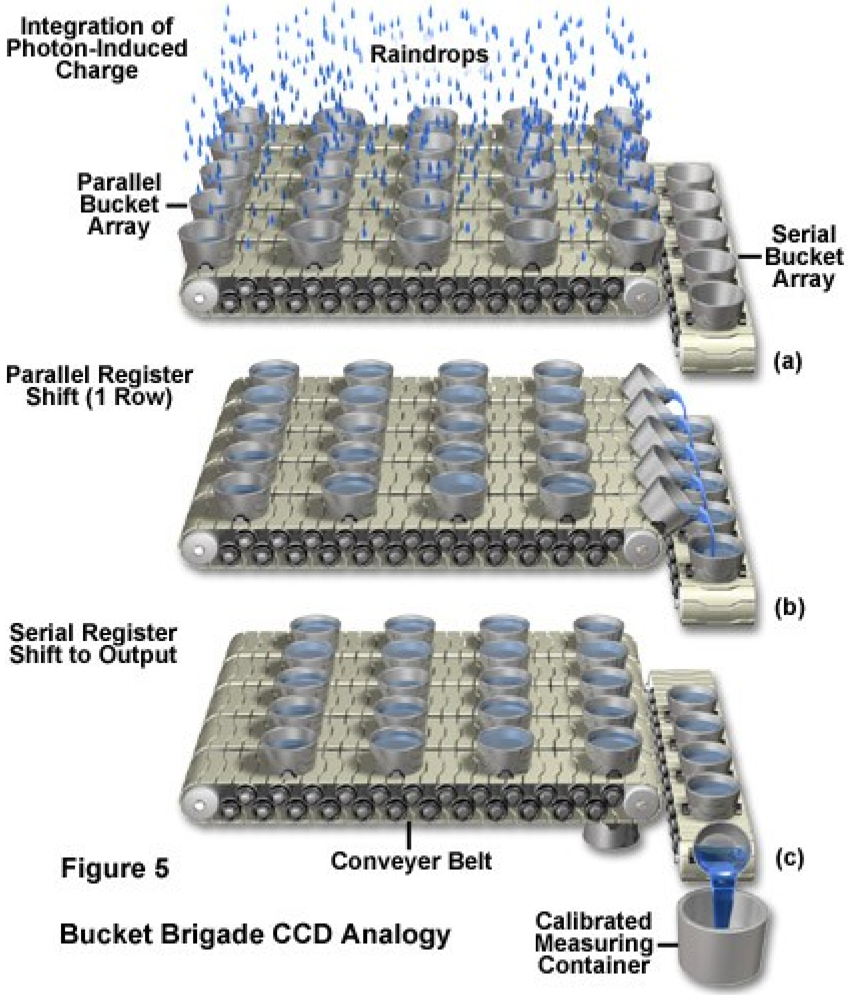


CCD(s)
(Charge-coupled device)

Photoelectric effect



Silicon
Band-gap
= 1.2 eV
~ 1.1 μm



“Serial register”

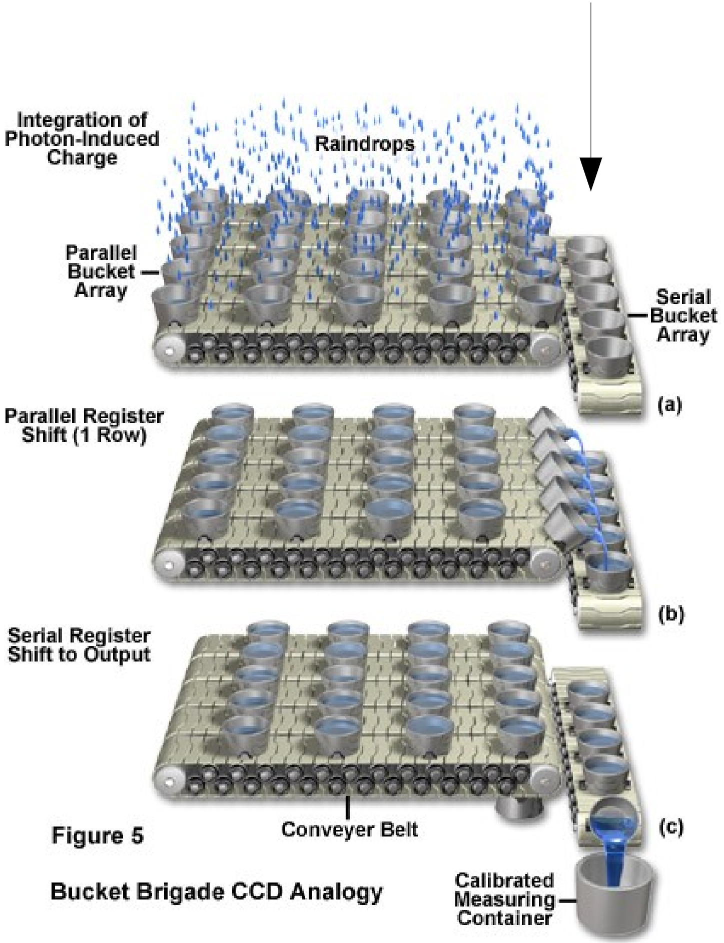


Figure 5

Bucket Brigade CCD Analogy

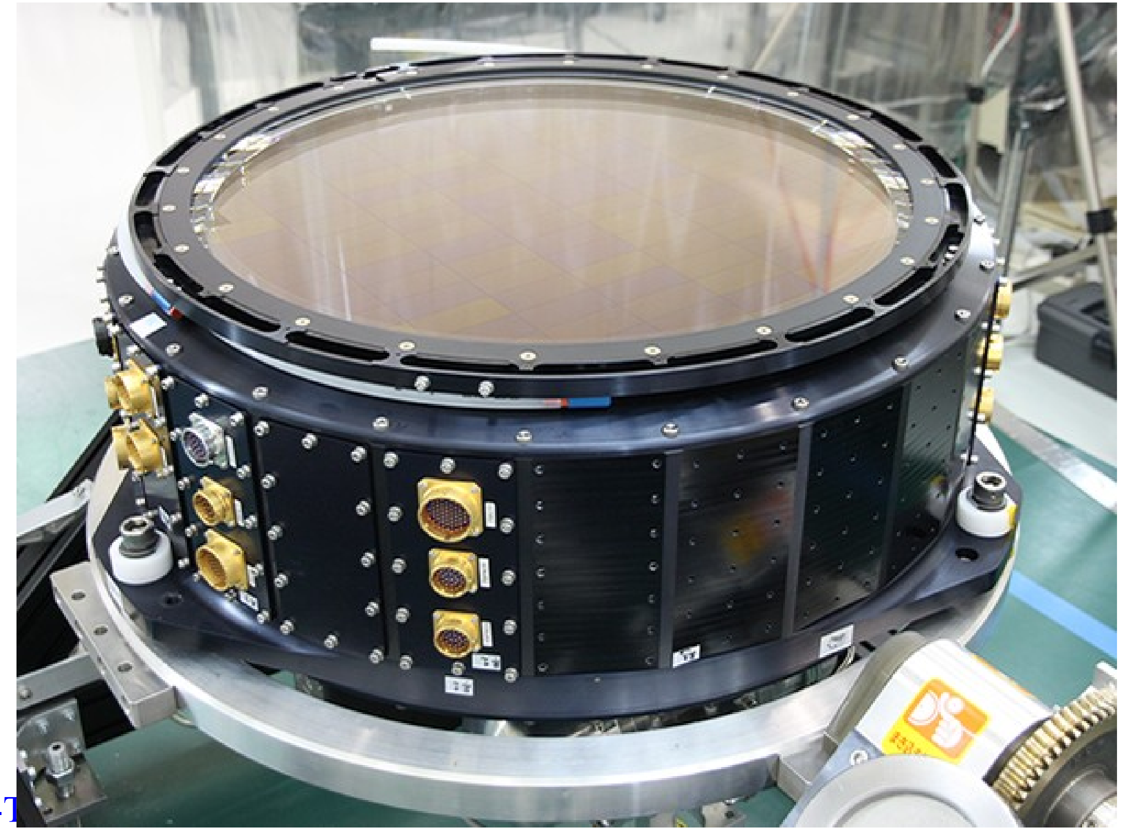
Orders of magnitude :
~10 µs per pixel (for noise)

Several tens of seconds for readout

Why bother with a slow serial scheme ?

Because all charges go through the same electronics!

Refrigeration and vacuum

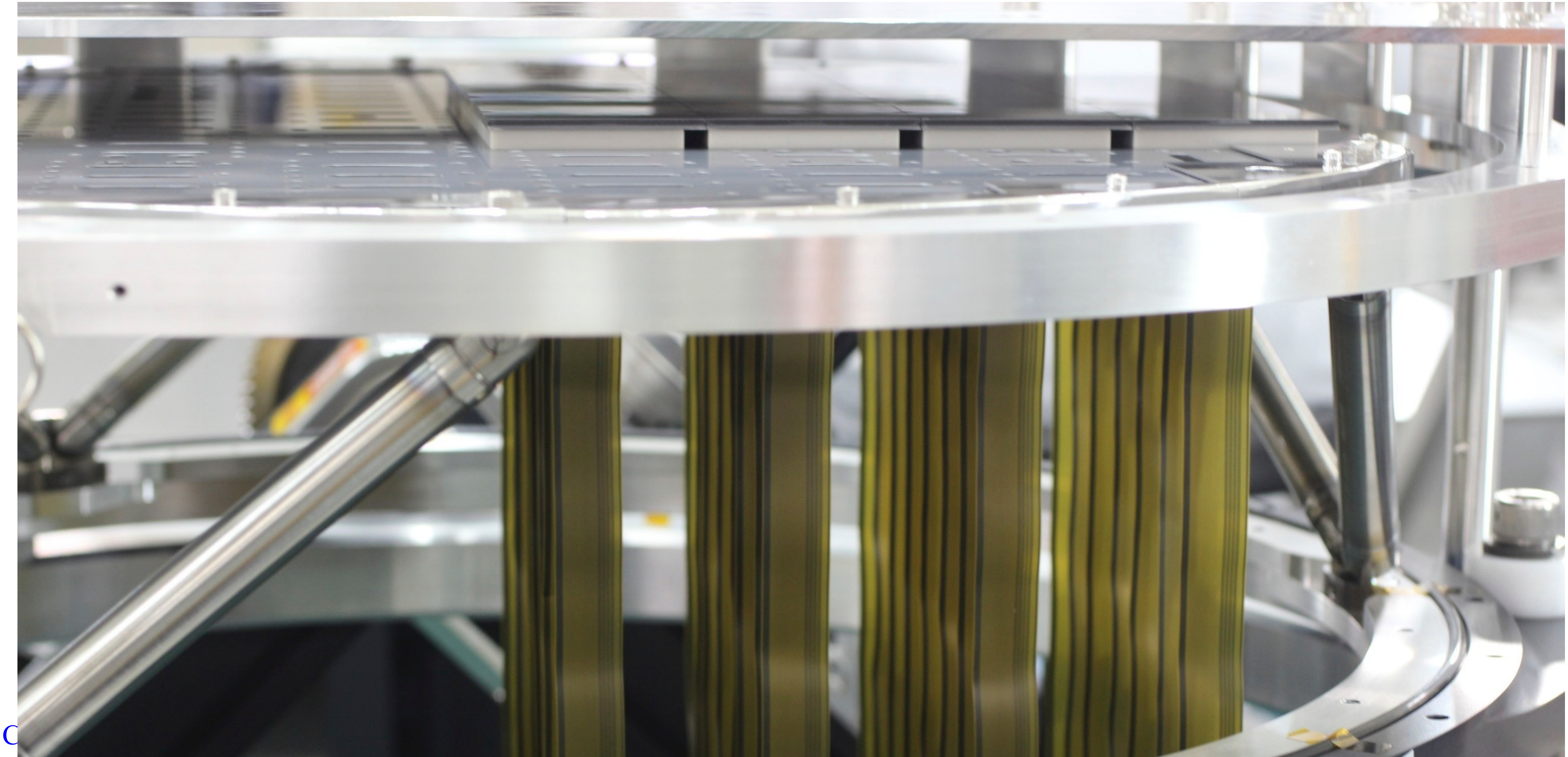


Refrigeration is mandatory
to reduce “dark current”

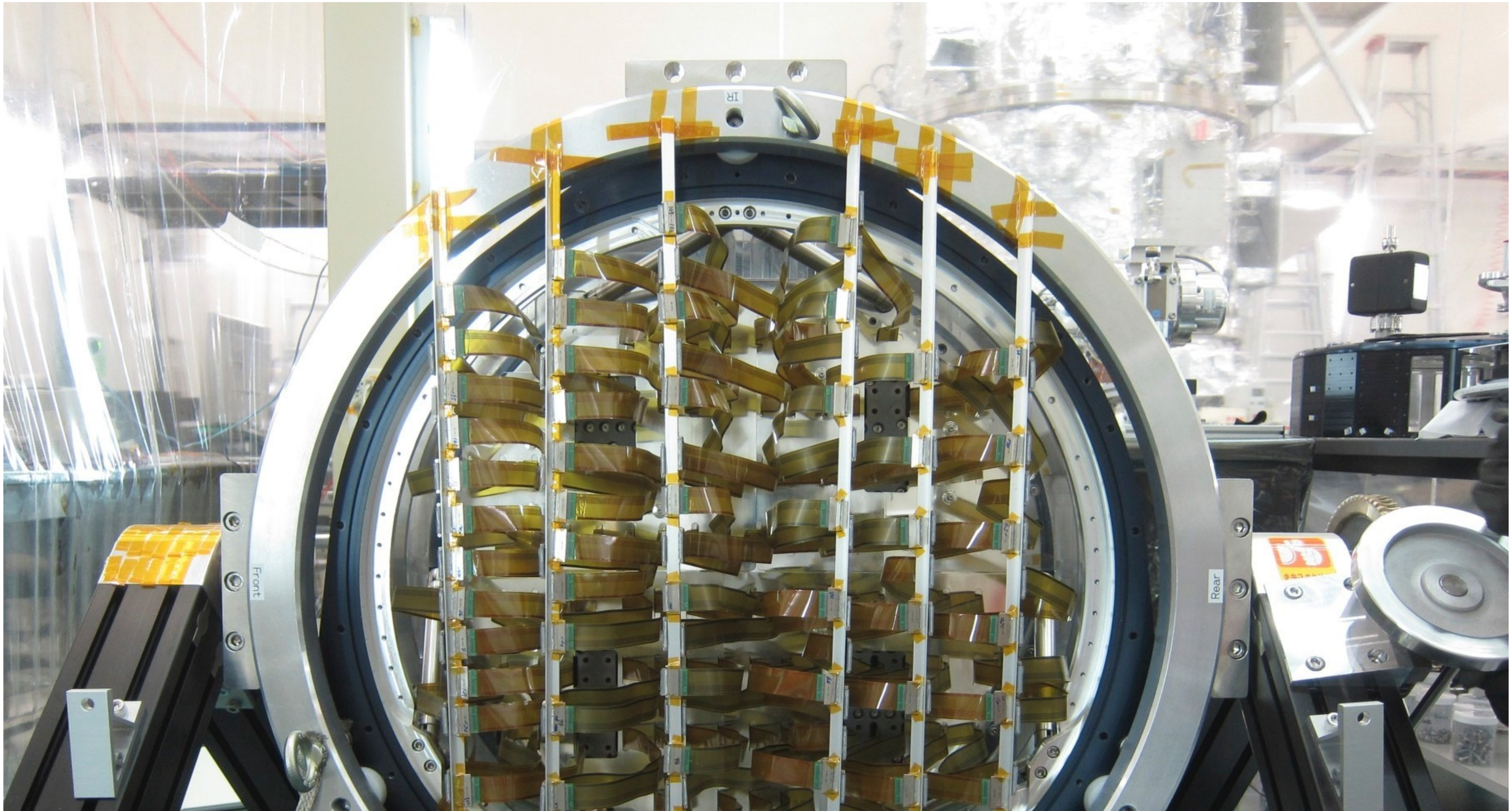
At ~ 170 K, one has to put the sensors in vacuum.
If not ?

Vacuum chamber (« Dewar ») of Hyper-Suprime Cam

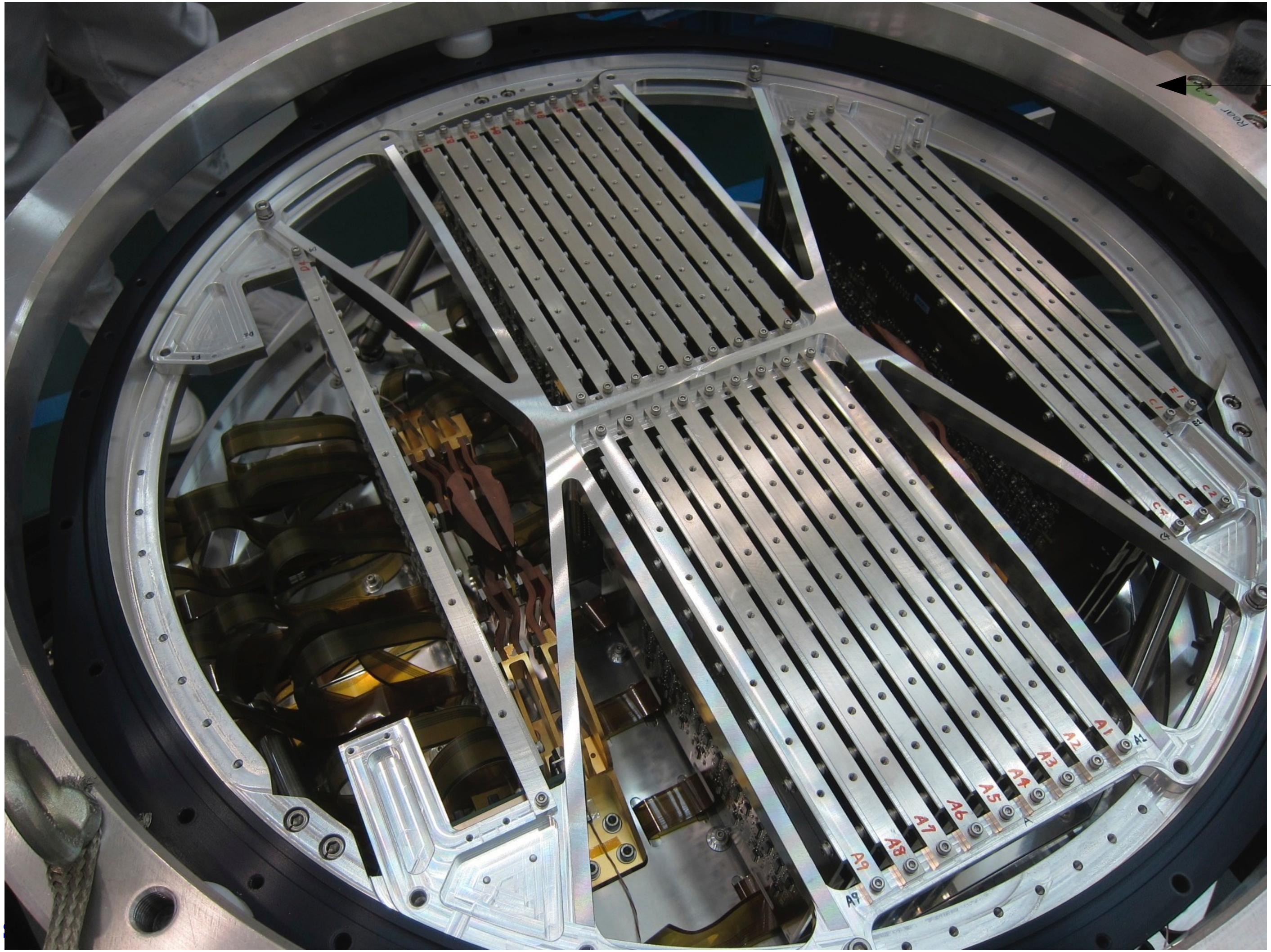
Insertion of CCDs



Back face, CCDs in place

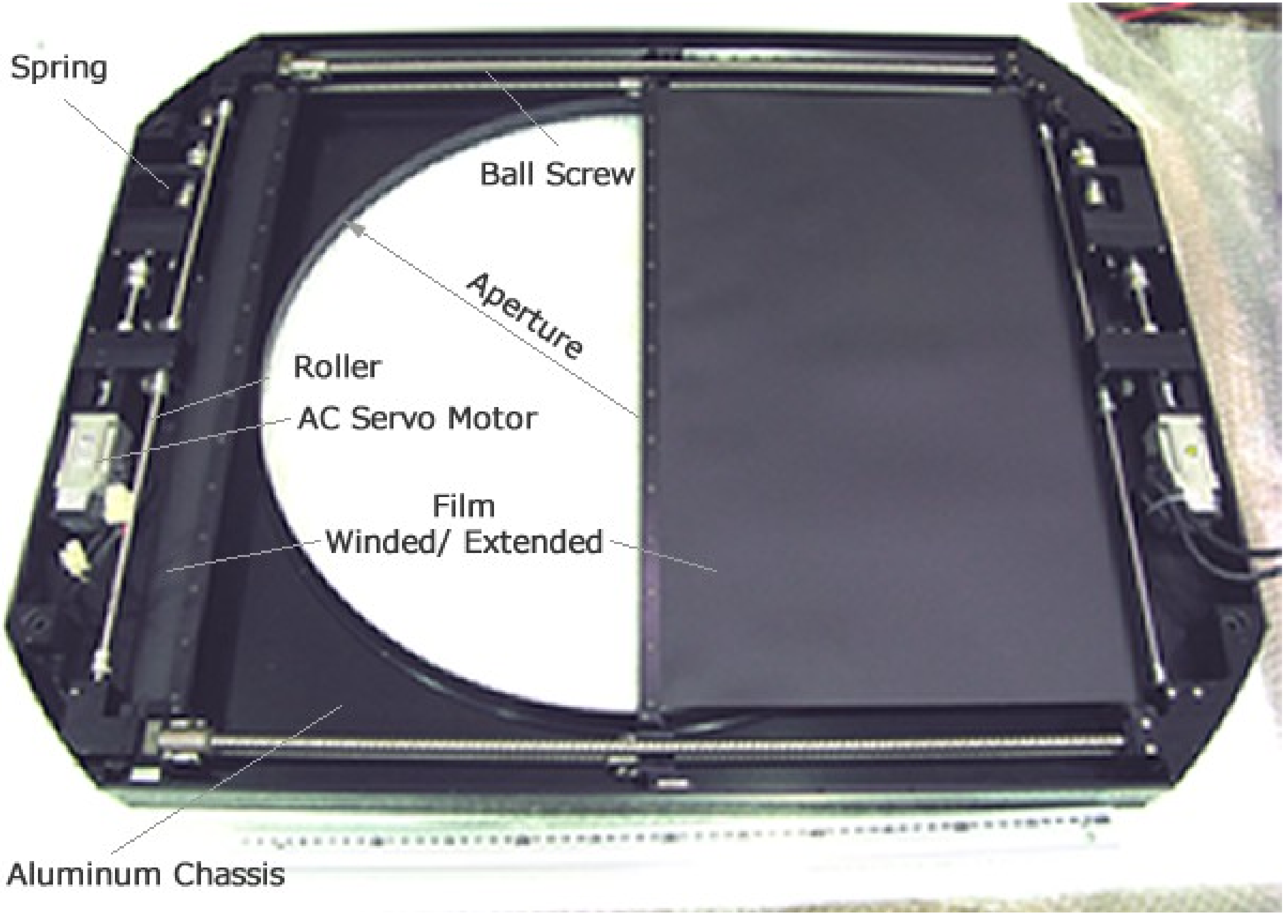


Electronics is connected



Back flenge of the dewar.

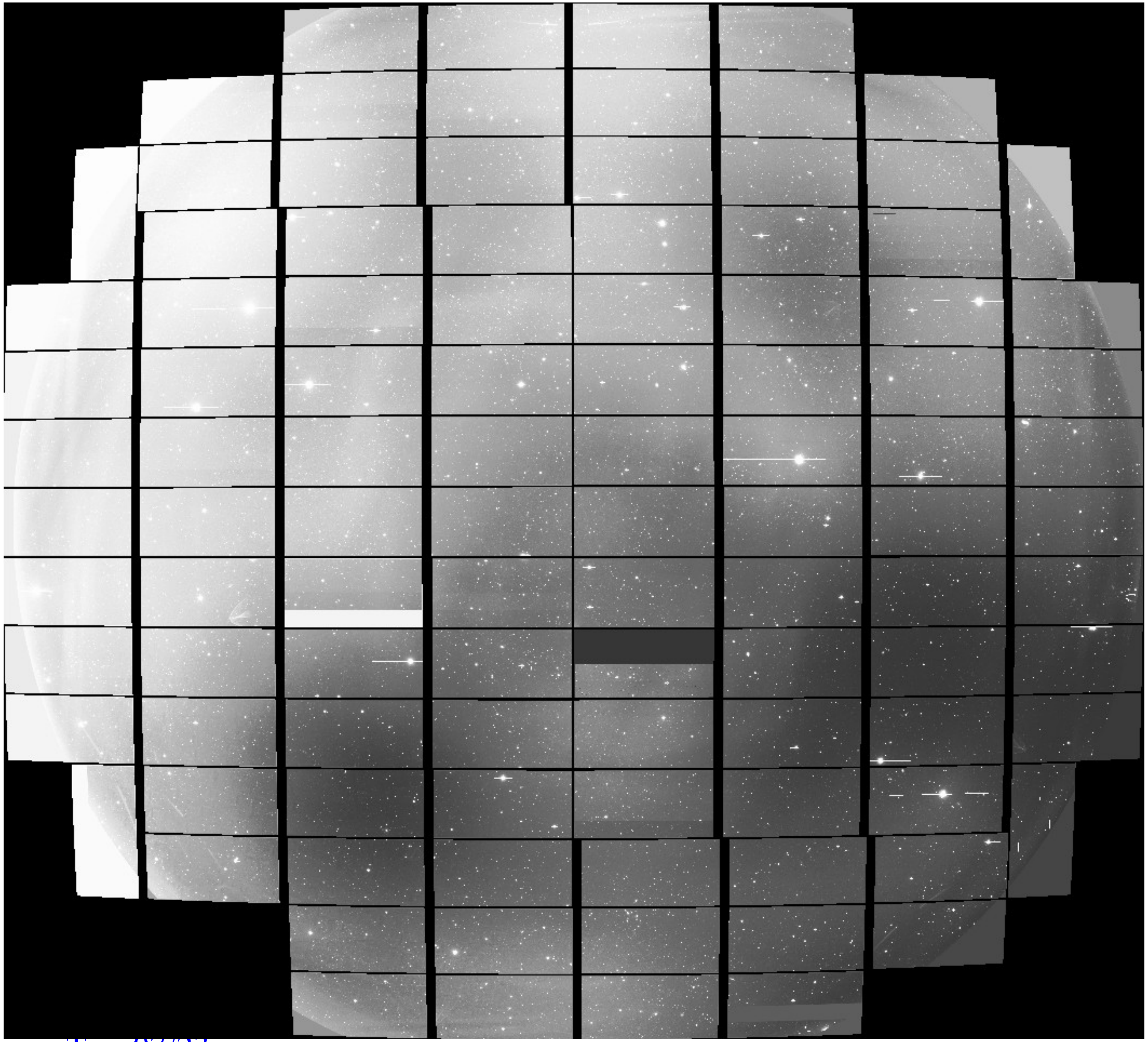
Shutter ("curtain" type)



Why do we need a shutter ?

One observation

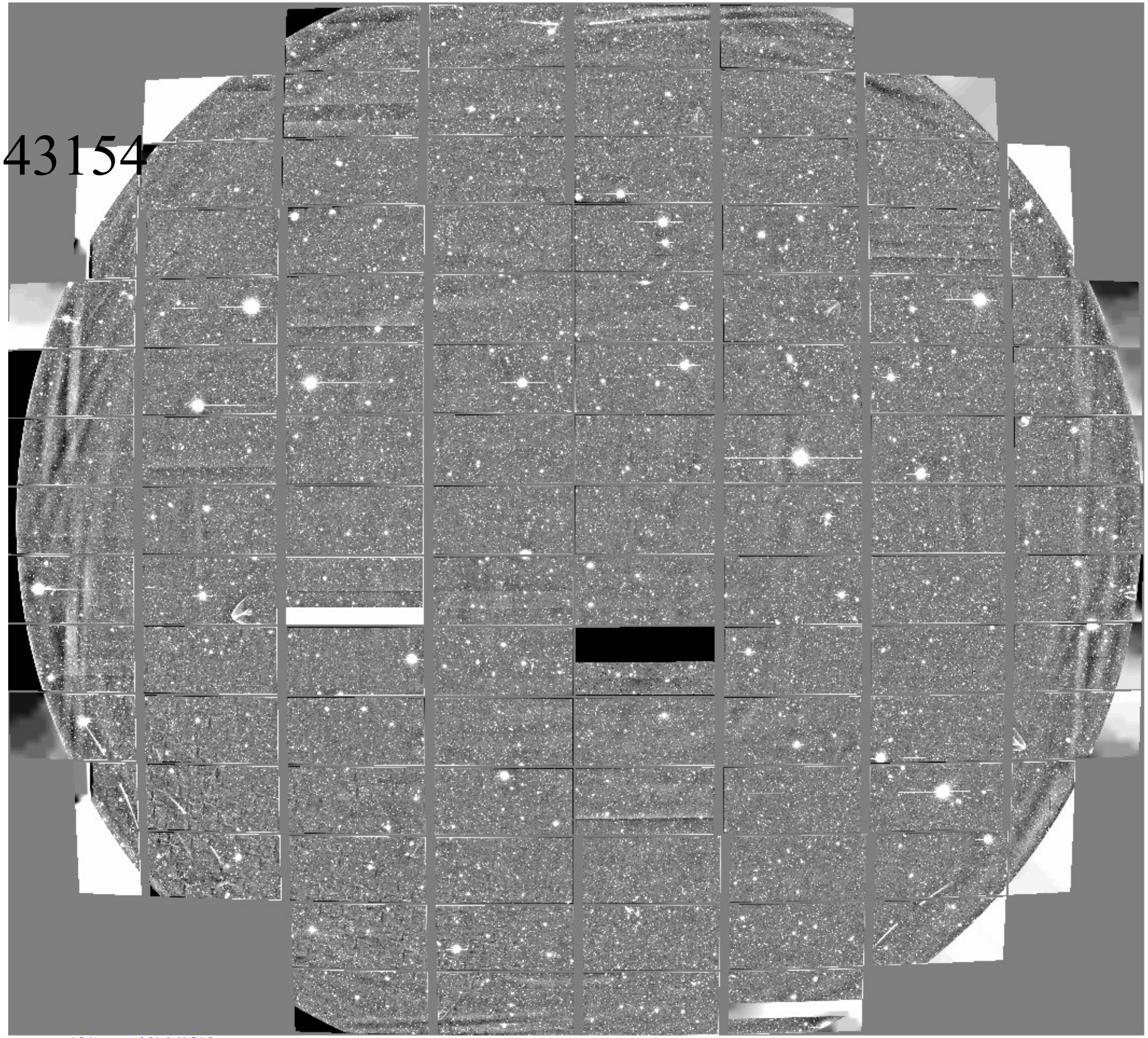
- Point the telescope (!)
- Open the shutter
- Close the shutter after the required integration time (minutes)
- Read out (and move to next field during read out)



We mostly see sky background, which is dominated by (thermal) emission from the atmosphere (exposure time 300 s)

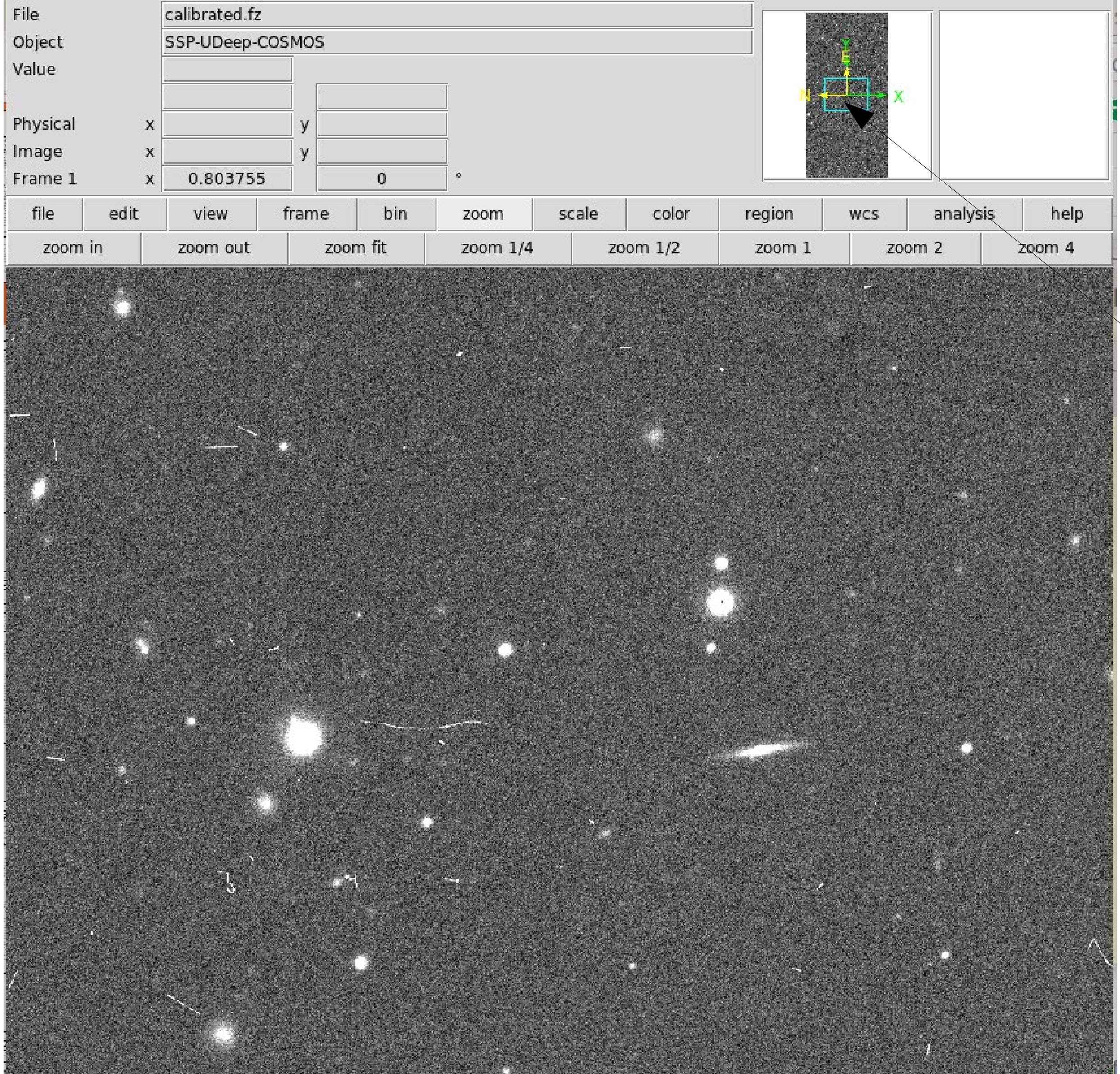
The image is projected on “sky coordinates”, and you can see by eye the large optical distortions

Field diameter : 1.5°
104 science CCDs
~890 Mpixels



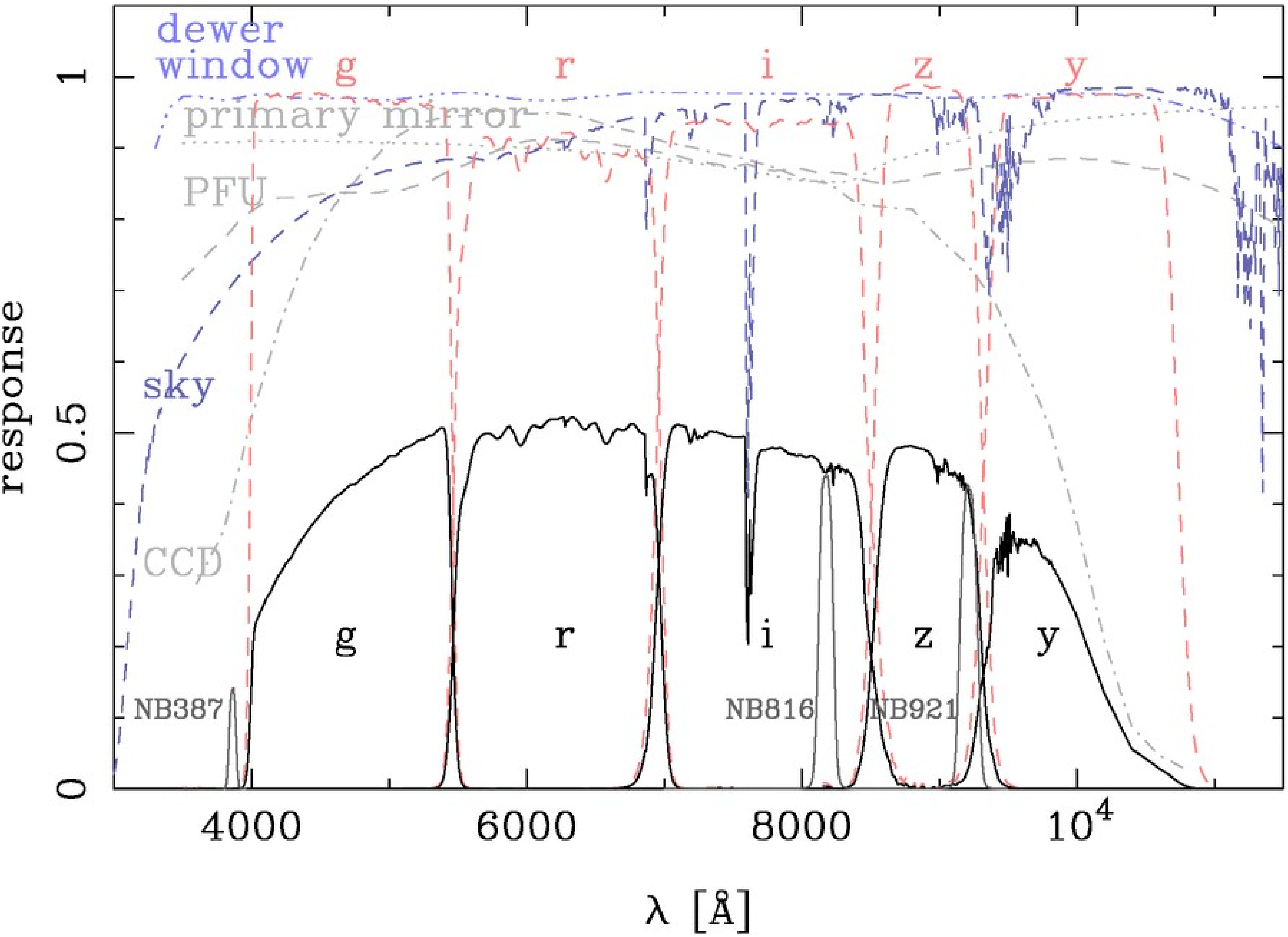
Subtract a smooth background

Left with
- noise
- objects
- artefacts



small part of
a CCD

Extra galactic field



Filter band passes

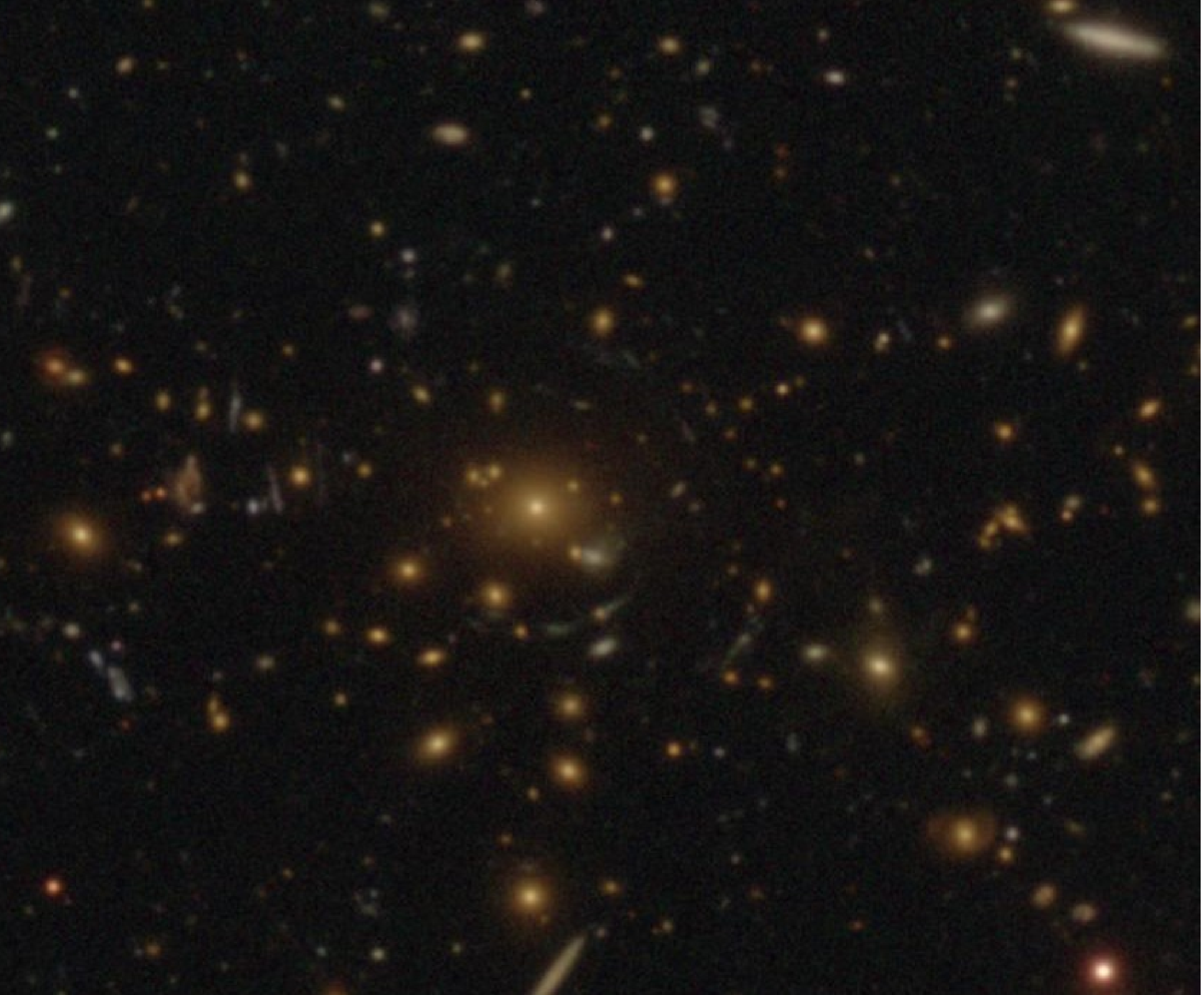


Image from the Archive

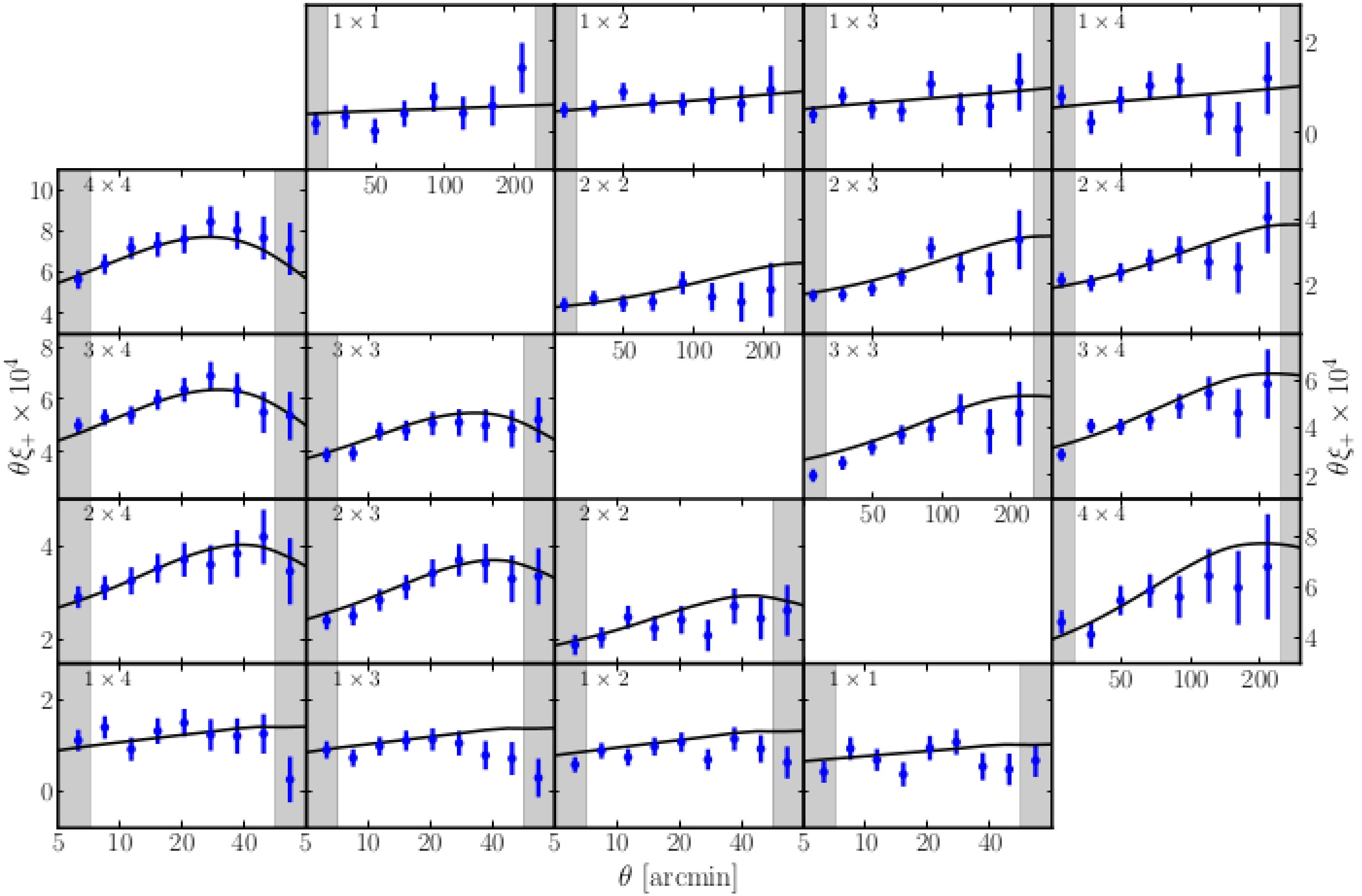
Composite image from g,r,i bands

Galaxy cluster with arcs.

Latest results on weak lensing

Angular correlation functions of galaxy ellipticities (in redshift bins)

With the fit

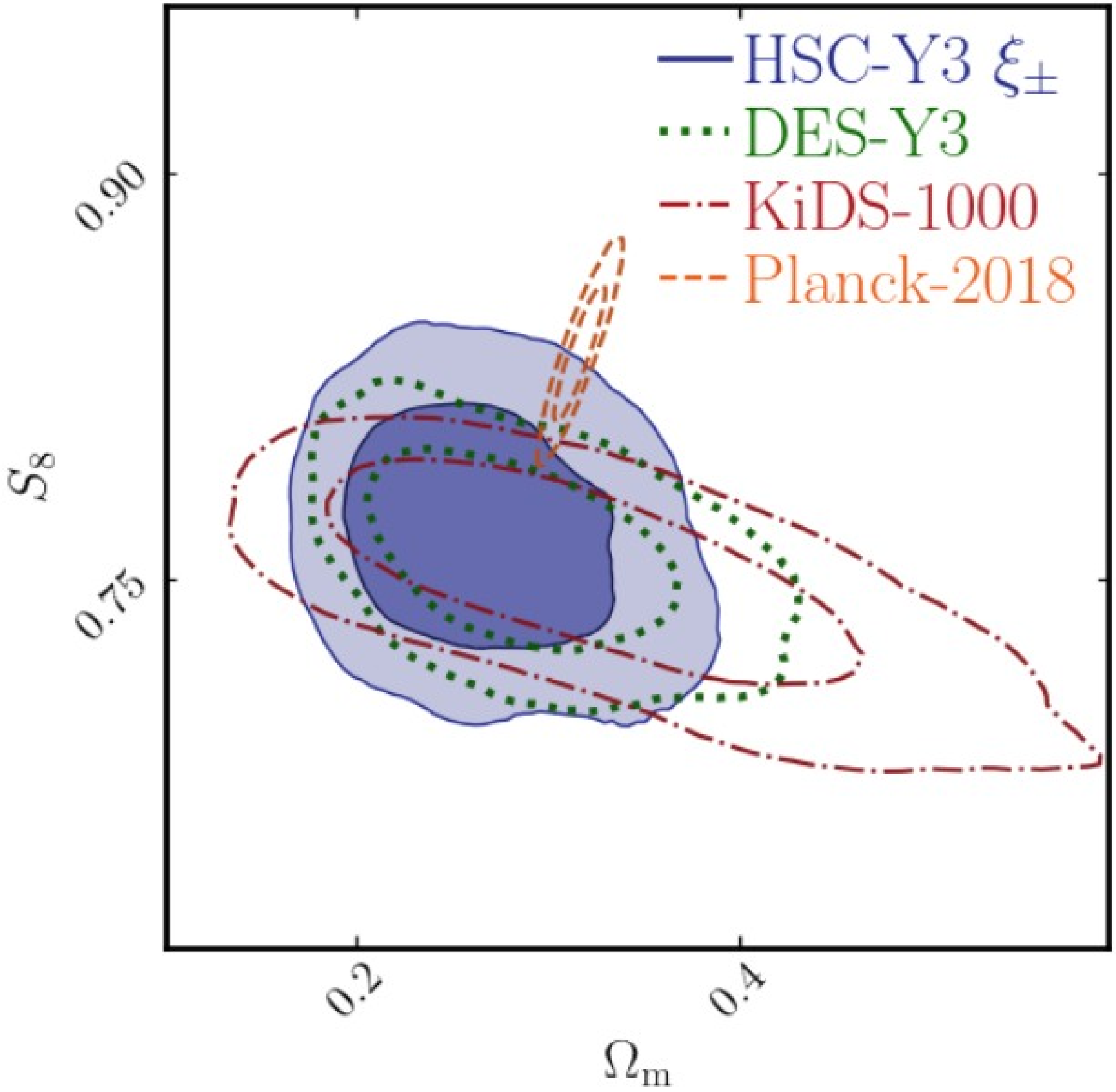


2304.00702

Weak lensing probes
the correlation function
of matter density fluctuations

S_8 is some measure of the
matter density contrasts
today.

Weak lensing analyses
tend to find it smaller
than what we expect from
Planck



Wide field imaging projects

Euclid

- 1.2m telescope in space
- Imaging in the visible for weak lensing, 0.5 deg^2
- Imaging in the NIR for estimating galaxy redshifts
- Spectroscopy in the NIR for BAO.
- First light in a few months, 5-year program

LSST/Rubin

- 6.5m telescope in Chile
- Imaging in the visible for weak lensing, 10 deg^2
- 6 bands for estimating galaxy redshifts
- Deep imaging over the whole southern sky
- First light in ~ 1 year, 10-year program

Dark
Energy
Spectroscopic
Instrument

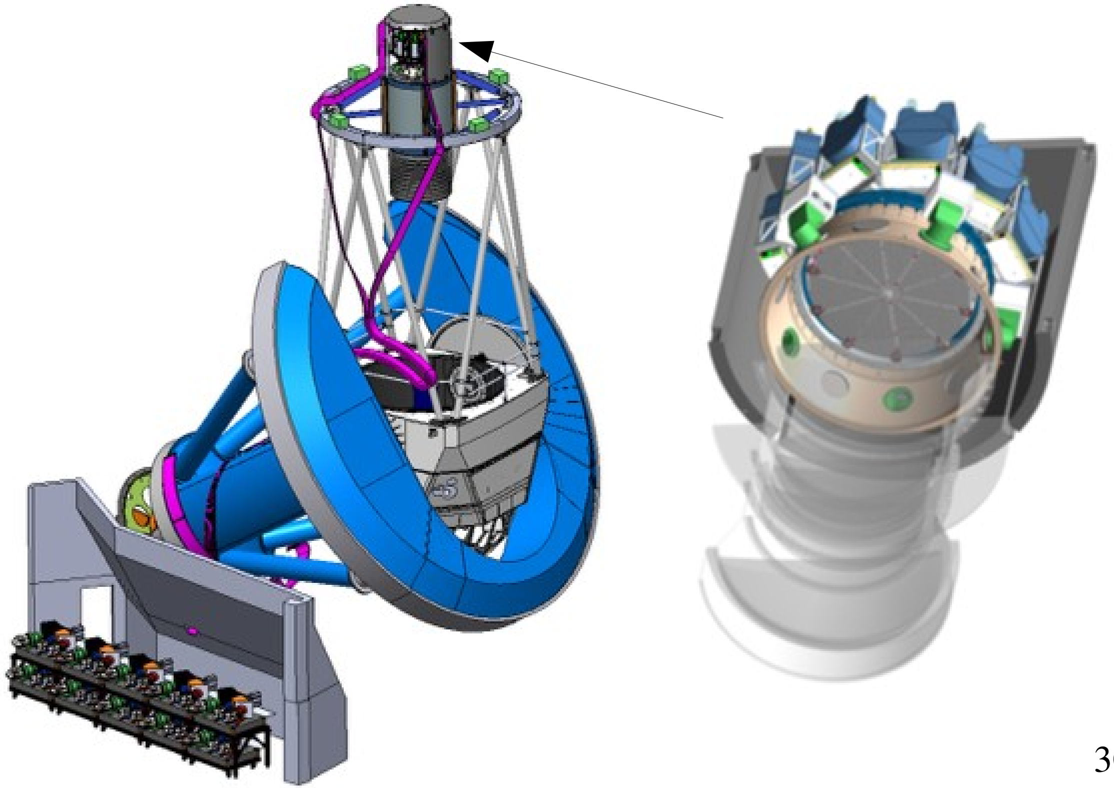
DESI

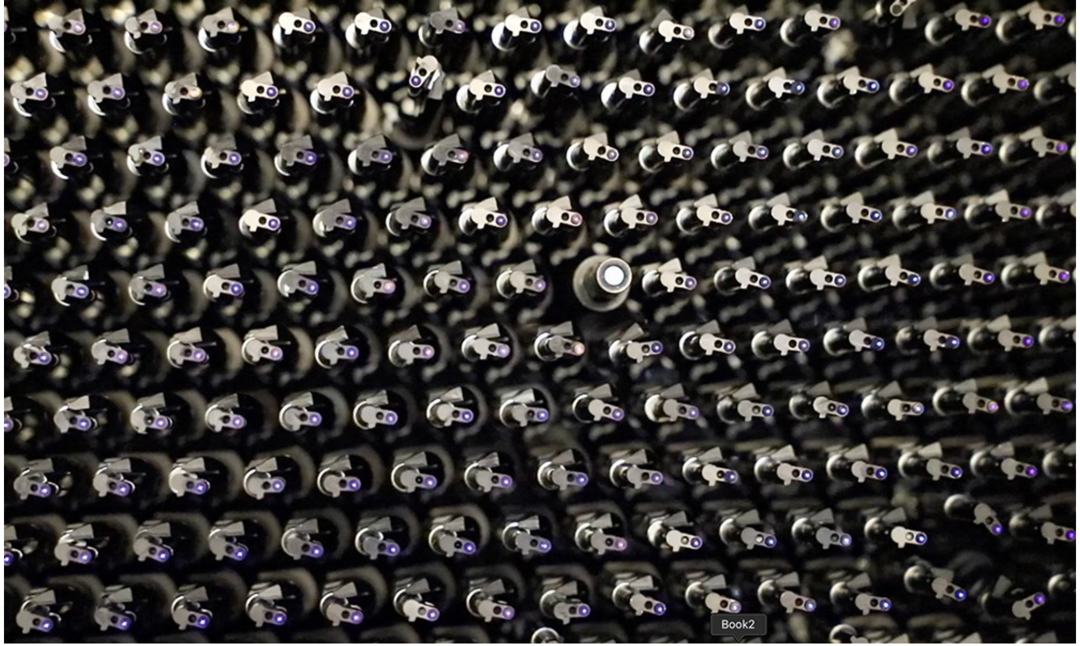
DESI

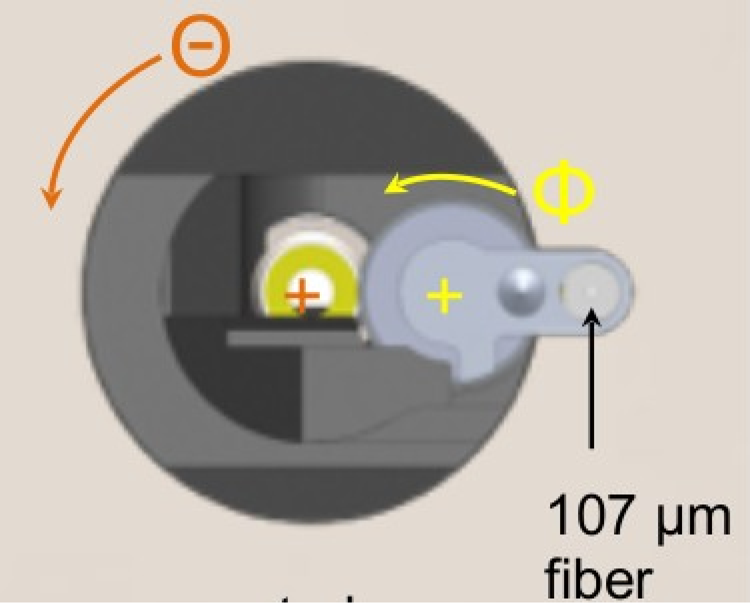
Dark Energy Spectroscopic Instrument

Mounted on the Mayal telescope
(Arizona, USA)
(old 4-m class telescope)

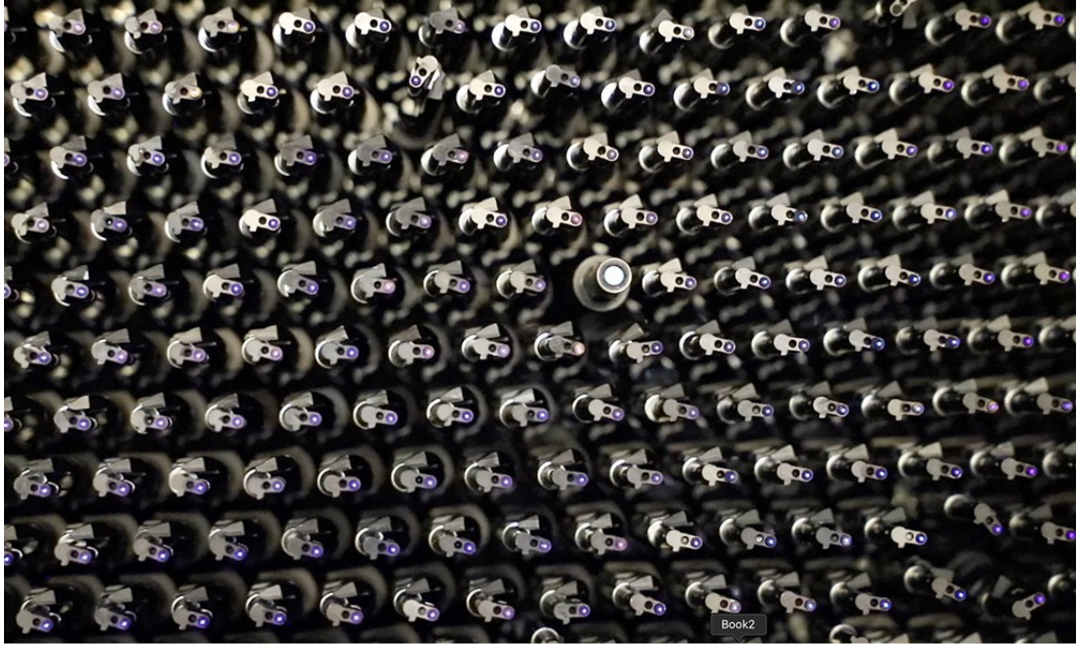
A wide-field massively parallel spectrograph to measure redshifts of millions of galaxies.

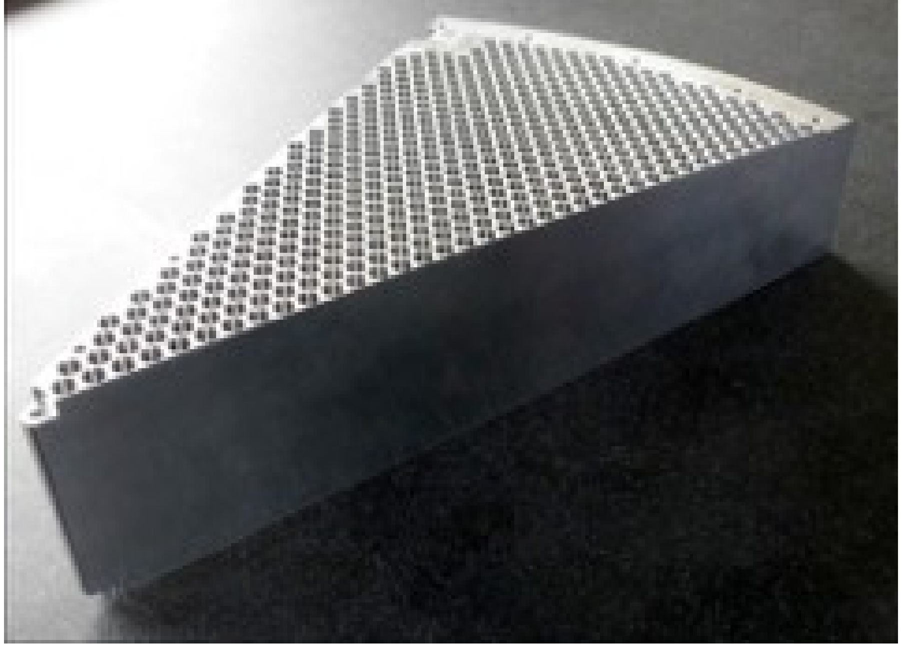






Fiber positioners in the focal plane of the telescope. They position the fibers in front of galaxies that were identified in advance using wide field imaging





Fiber positioners in the focal plane of the telescope. They position the fibers in front of galaxies that were identified in advance using wide field imaging

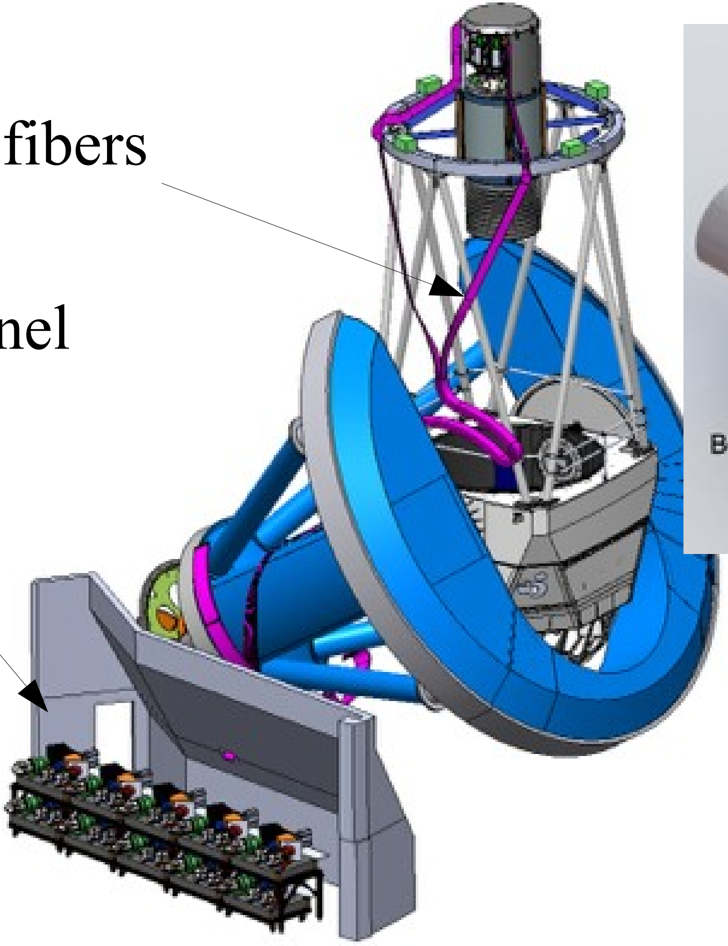
One petal of the focal plane, made of 10 such petals

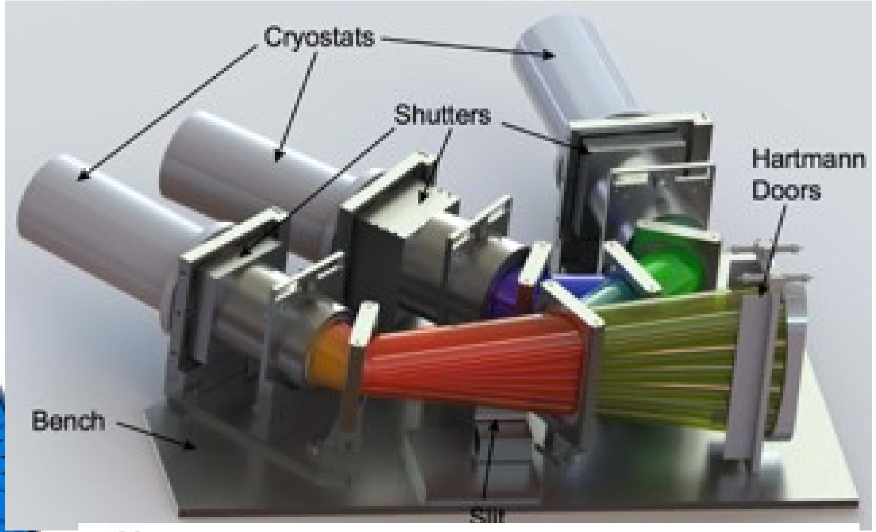
5000 fibers in total

fibers

Ten thermally-controlled 3-channel spectrographs
360-980 nm

30 CCDs
480 Mpixels
in total





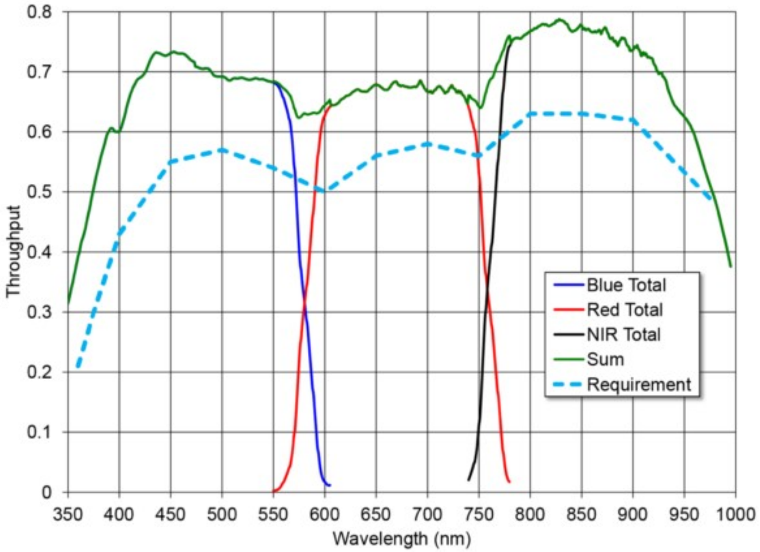
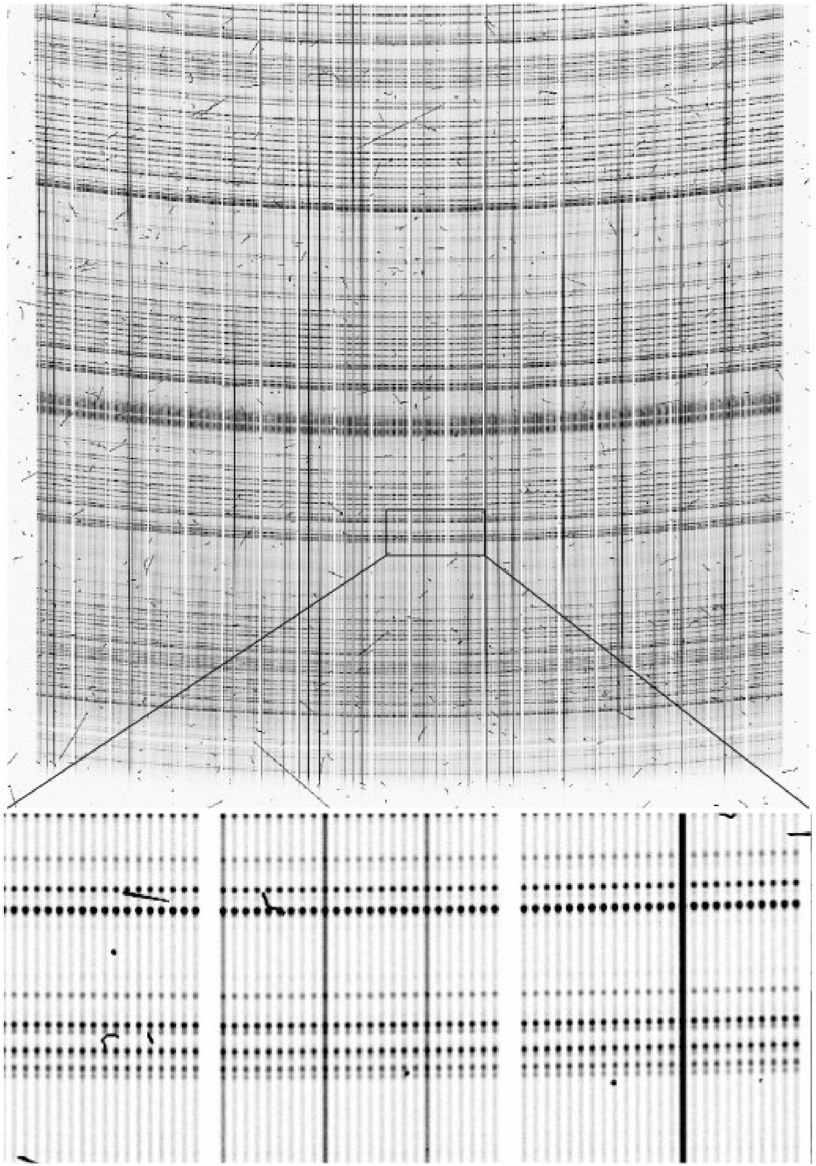
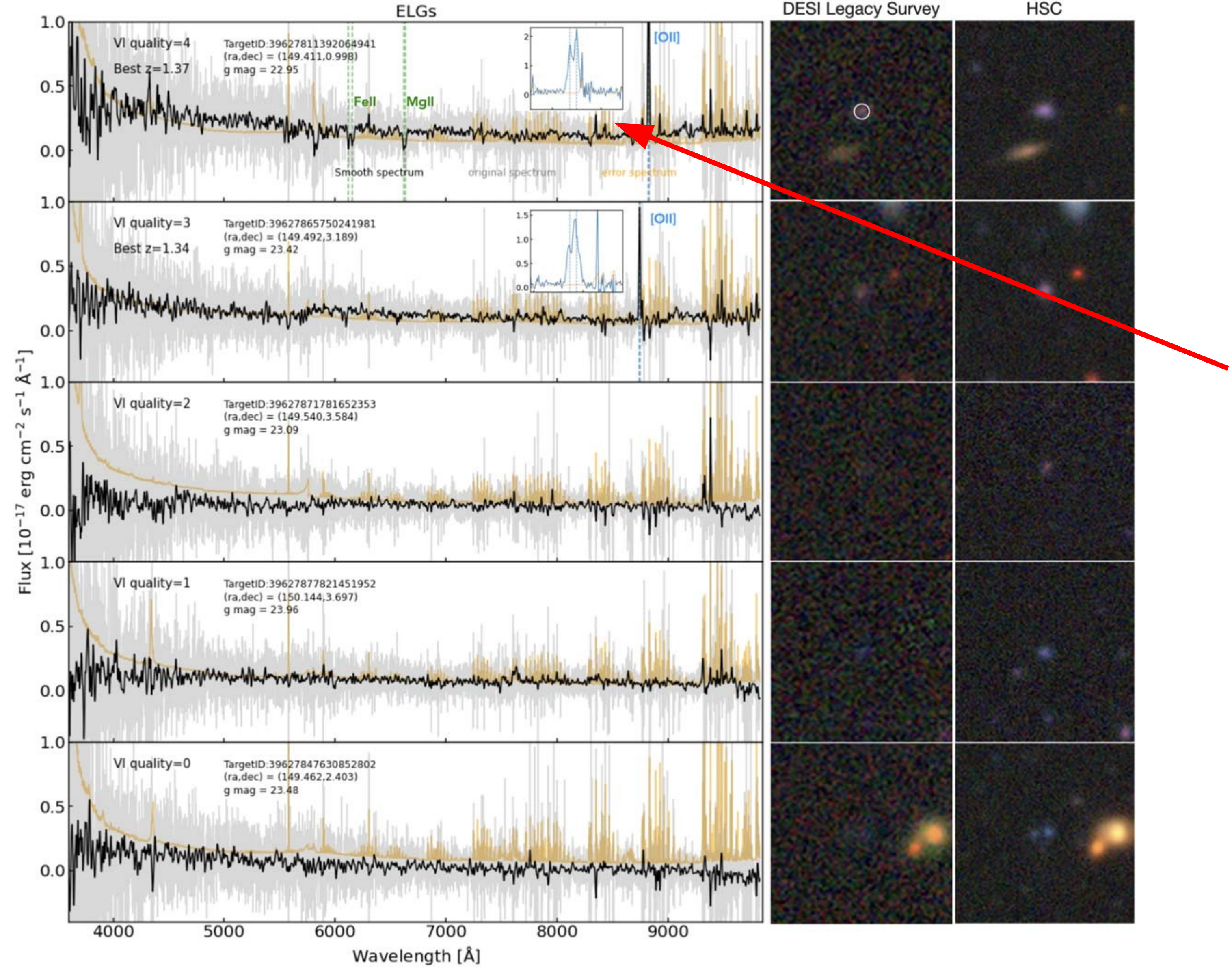


Image from a CCD reading out a spectrograph (750-1100 nm)

One vertical “line” is a spectrum.





Spectra of emission line galaxies, of decreasing quality

Note that the instrument resolves the OII doublet

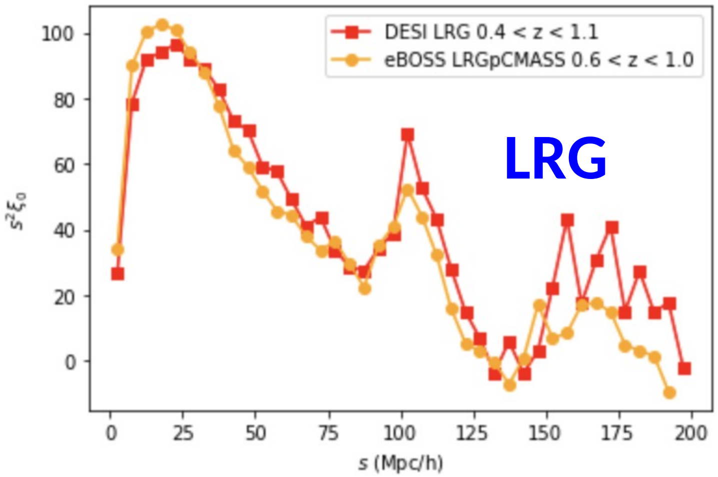
2208.08516

DESI in a nutshell

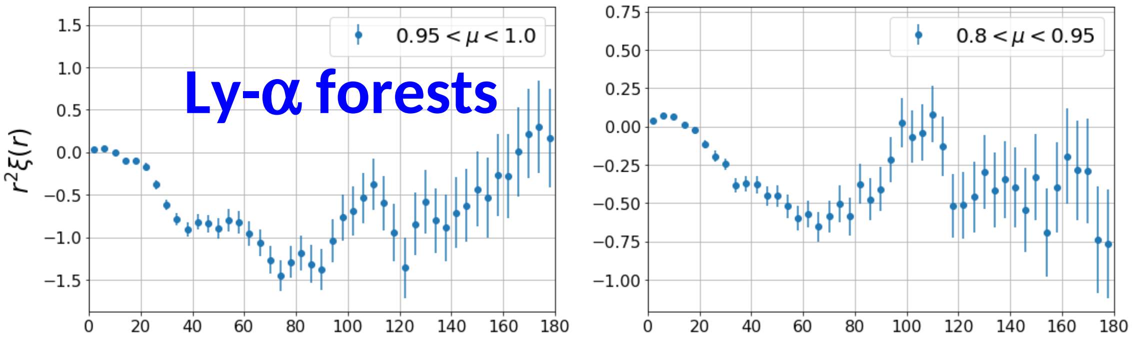
- Aims at measuring BAOs (i.e. measure the expansion history) up to z~3.
- Measurements of the growth rate up to z~1.5
- Aims at ~ 50 million spectra of galaxies (!) in 5 years.
- Field of view of 7 deg^2 and survey of 14 000 deg^2
- First light in 2019, then Covid pause.
- The survey started in May 2021
- The instrument is collecting data faster than anticipated.
- First papers this winter, perhaps with neutrino mass constraints.

BAO peaks in early DESI data

4% of the final statistics



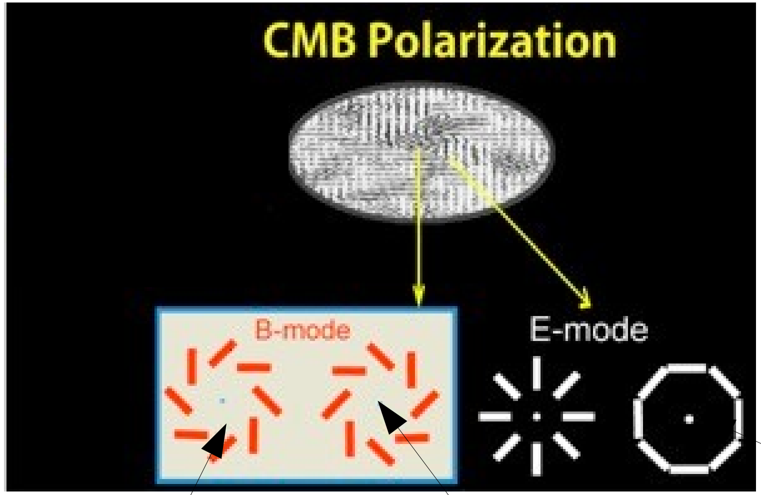
Early DESI (blinded)



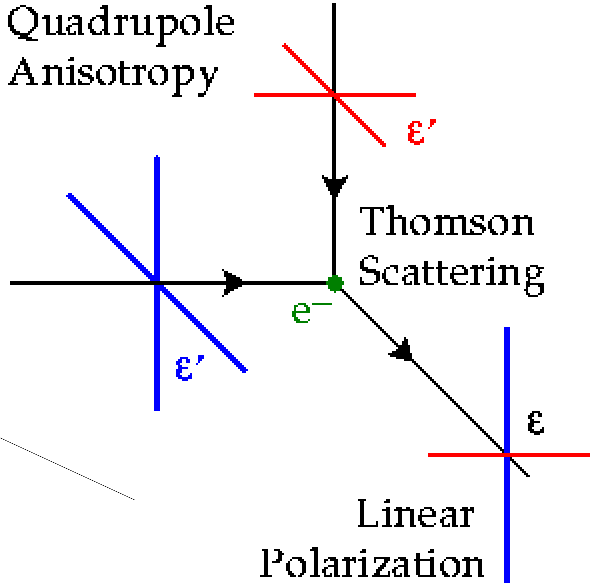
CMB polarisation anisotropies
B modes

CMB polarisation anisotropies

The CMB is slightly polarized, and there is valuable information to be gathered there

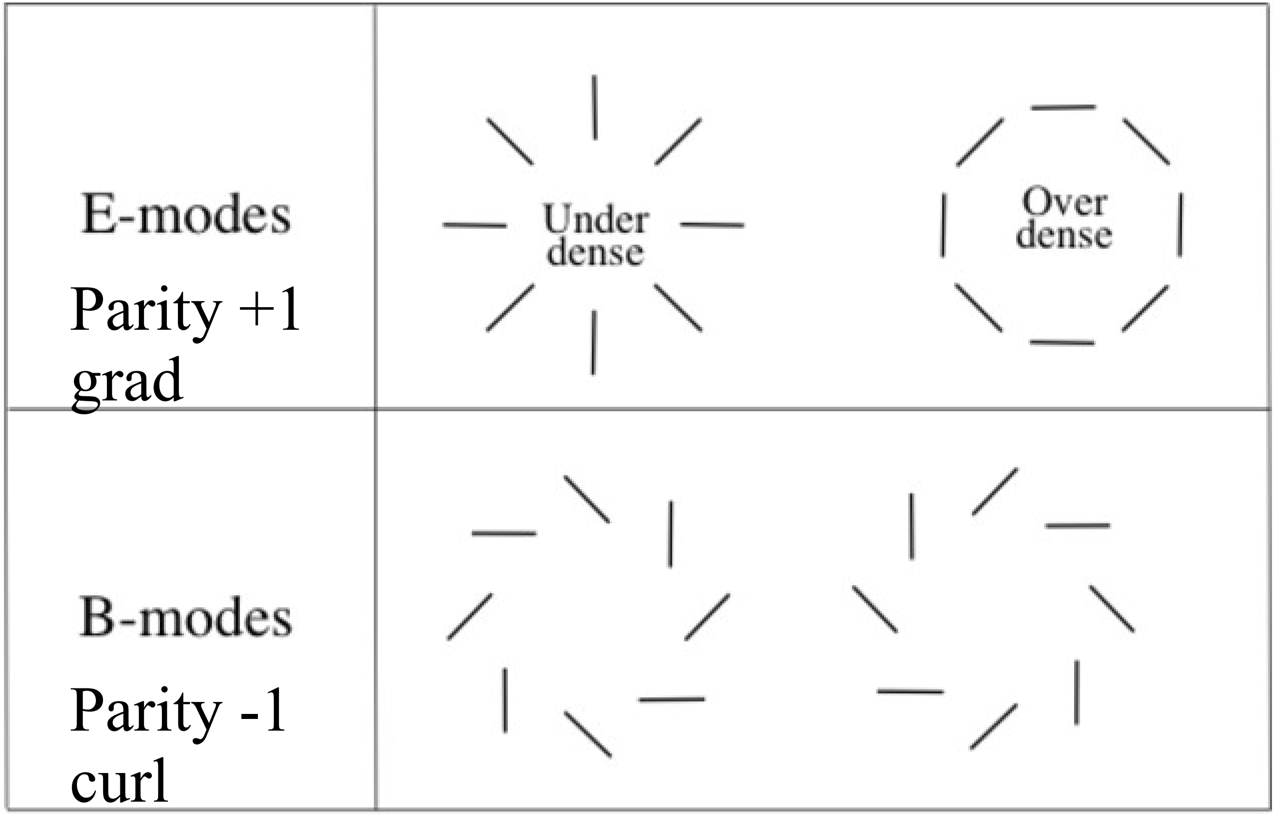


Polarisation at last scattering (at recombination)



Tensor perturbations
From inflation

Lensing by
Large scale
structures

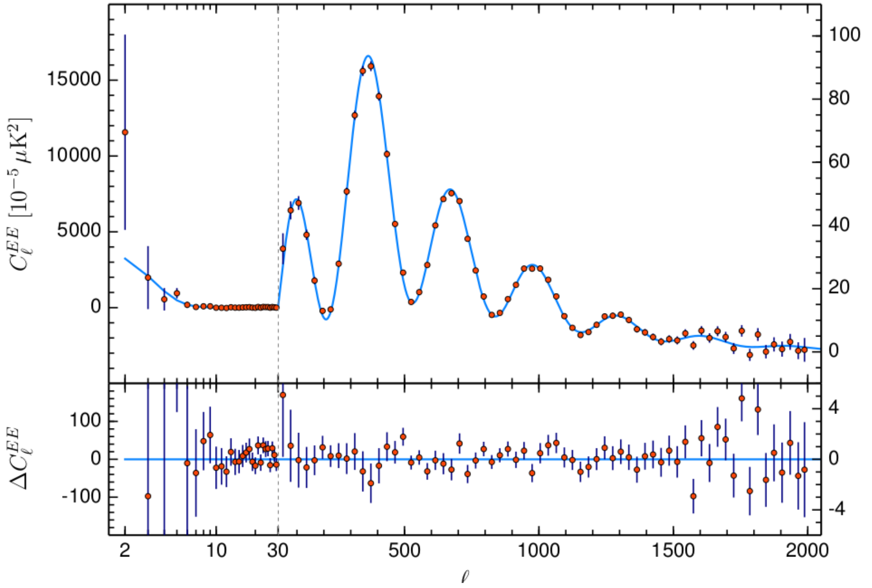


- Convey the same physics as temperature,
- Lift some degeneracies
- A very useful check

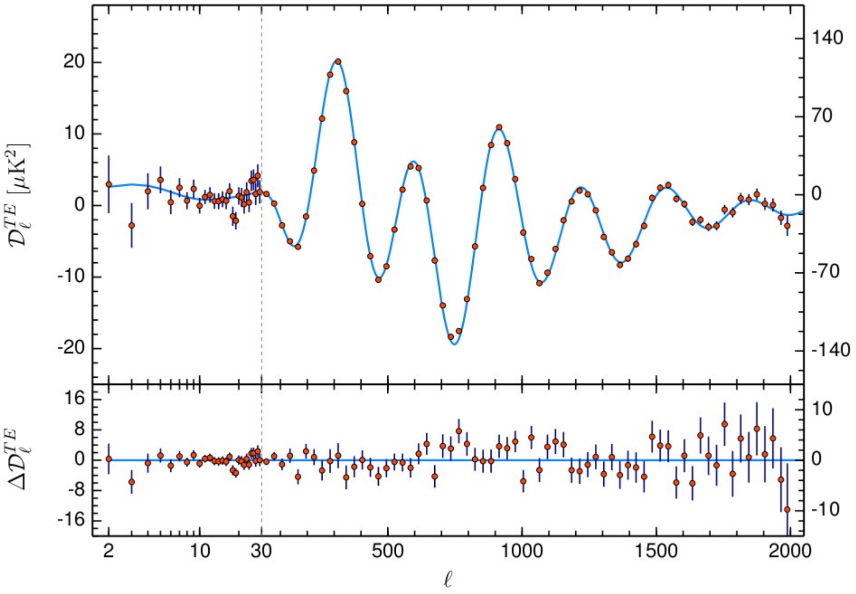
- Generated by other mechanisms
- Track tensor perturbations from inflation
- But the signal level is unknown
- Extremely weak.

1807.06209

Power spectrum of E modes from Planck (EE)

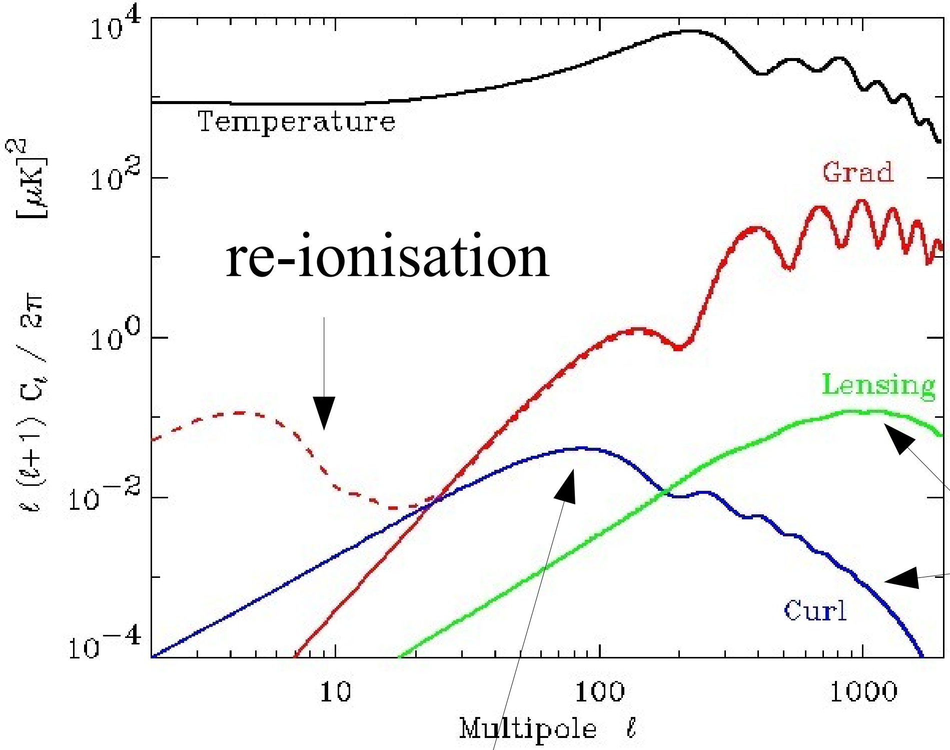


Cross power spectrum Temperature E-mode "TE"



Blue line: best Planck (global) fit: TT, TE & EE

CMB polarisation anisotropies



"E" modes
(positive parity)

"B" modes
(negative parity)

"Lensed E modes"

Primordial B modes from inflation (arbitrary amplitude!)

CMB B modes

- Inflation naturally produces scalar and tensor perturbations, but the ratio depends on the details of the inflation potential
- The only (current) practical path towards securing the inflation theory, and constraining the inflaton potential
- At least 3 orders of magnitude smaller than temperature anisotropies (6 for the power spectra)
- Quantified by r : "tensor to scalar ratio of primordial perturbations". No obvious lower bound
- On top of these "primordial gravitational waves", one has to face a significant contribution from lensing of E modes (peaks around l=1000)

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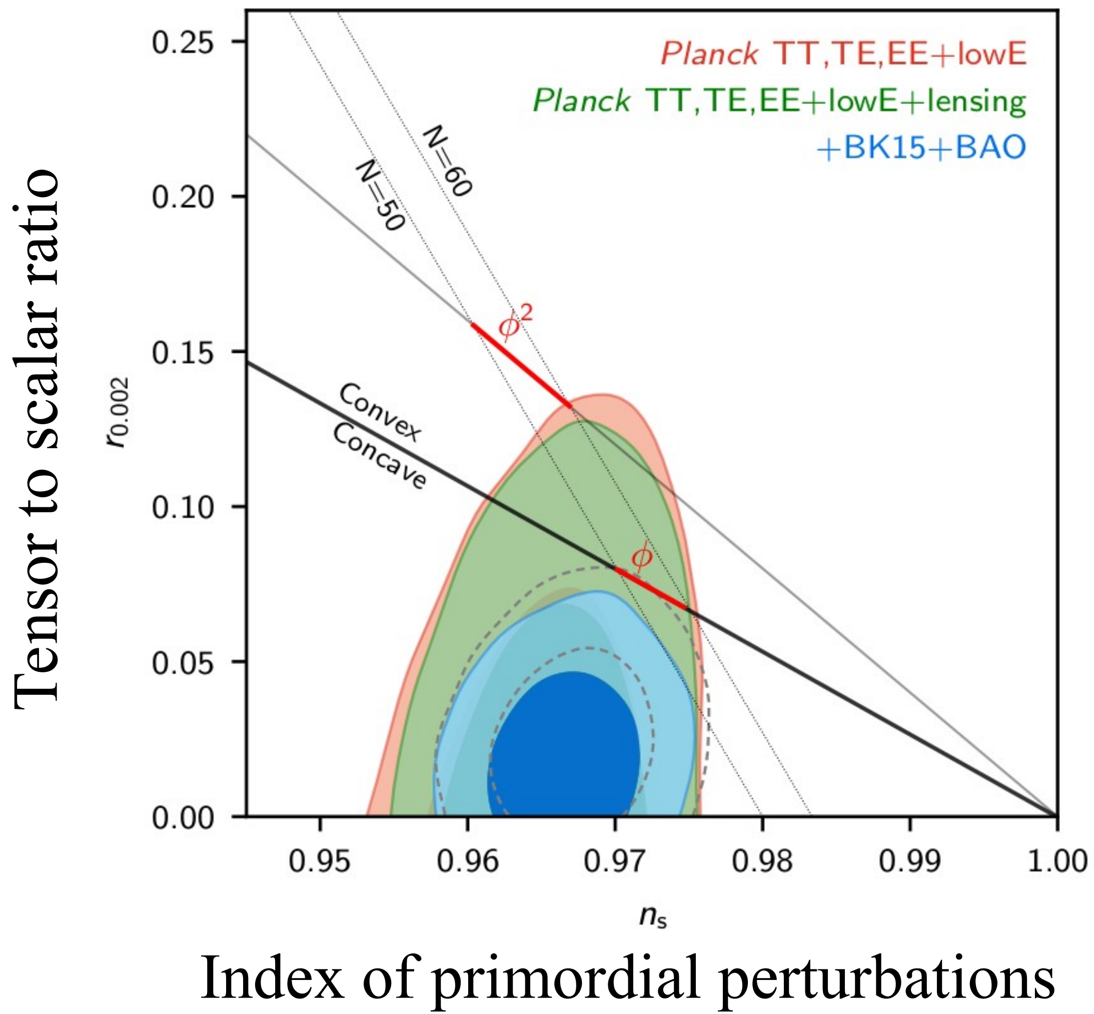


Constraints on inflation parameters

Tensor modes have a small contribution to temperature anisotropies, which is not seen, hence a limit

Instrumental requirements

- Ultimate sensitivity
  - Very large number of detectors (sensor pixels)
- Many observation bands
  - Redder and bluer as compared to the CMB because synchrotron and dust emit polarized radiation
- Need to measure accurately the lensing signal
  - Large telescope to get the small angular scales (diffraction)
- Need extremely accurate calibration of polarisation separation

Ground or space?

- Ultimate sensitivity
  - Very large number of detectors (sensor pixels)
- Many observation bands
  - Redder and bluer as compared to the CMB because synchrotron and dust emit polarized radiation
- Need to measure accurately the lensing signal
  - Large telescope to get the small angular scales (diffraction)
- Need extremely accurate calibration of polarisation separation

Ground or space?

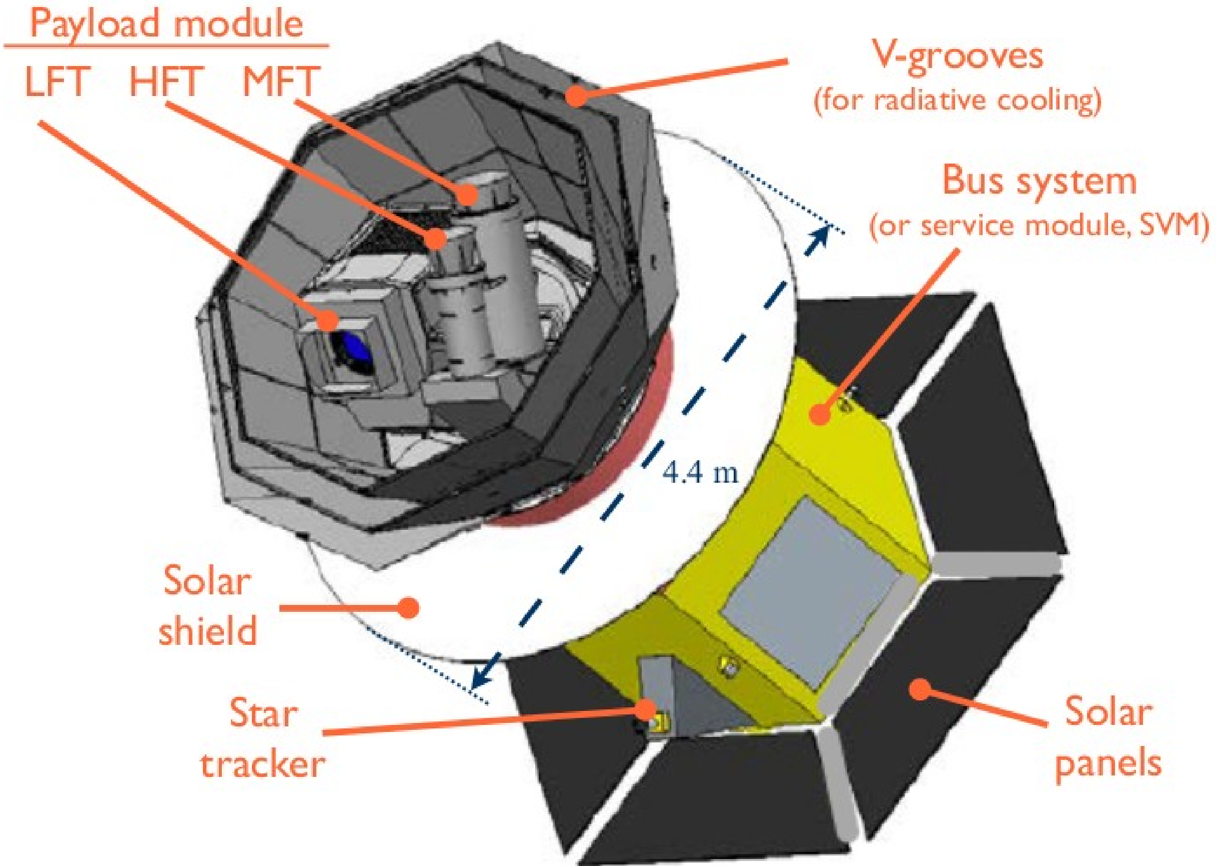
- Ultimate sensitivity
  - Very large number of detectors (sensor pixels) Ground
- Many observation bands Space (atmosphere)
  - Redder and bluer as compared to the CMB because synchrotron and dust emit polarized radiation
- Need to measure accurately the lensing signal Ground
  - Large telescope to get the small angular scales (diffraction)
- Need extremely accurate calibration of polarisation separation ??

Litebird

Spacecraft Overview

- **3 telescopes** are used to provide the **40-402 GHz** frequency coverage
  1. **LFT** (low frequency telescope)
  2. **MFT** (middle frequency telescope)
  3. **HFT** (high frequency telescope)
- Multi-chroic transition-edge sensor (TES) **bolometer arrays** cooled to **100 mK**
- Polarization modulation unit (PMU) in each telescope with **rotating half-wave plate** (HWP), for 1/*f* noise and systematics reduction
- Optics cooled to **5 K**

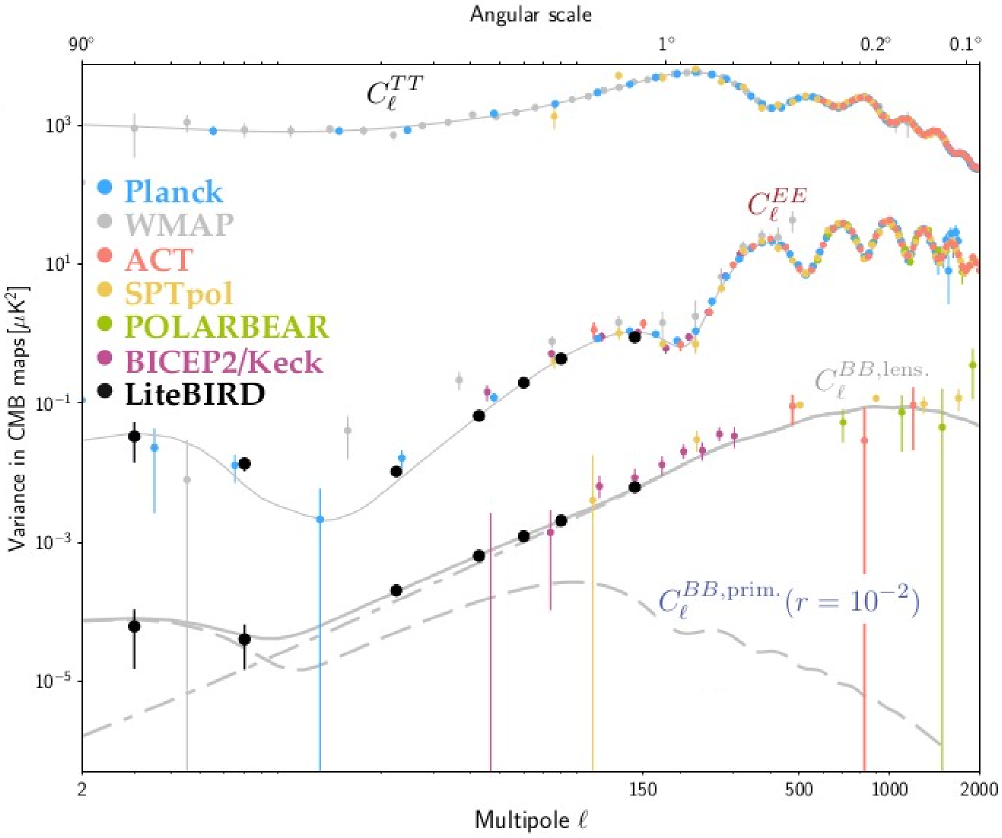
- Mass: 2.6 t
- Power: 3.0 kW
- Data: 17.9 Gb/day



Litebird

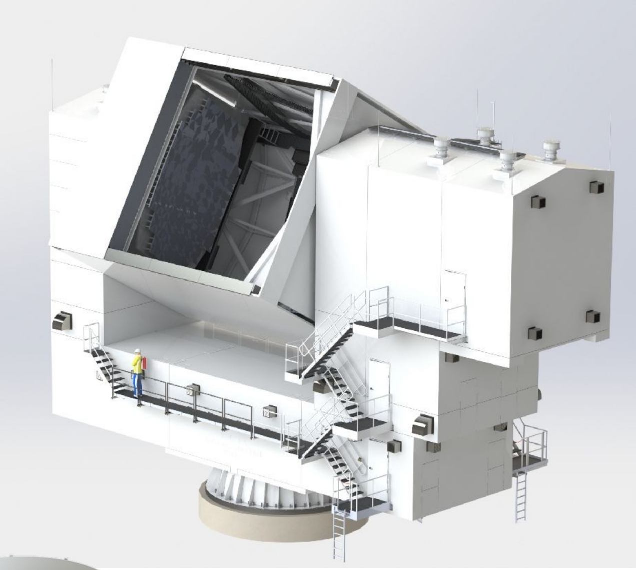
- Japanese space project with hopefully strong contributions from Europe
- 15 spectral bands
- Modest telescope sizes (20,30 and 40 cm)

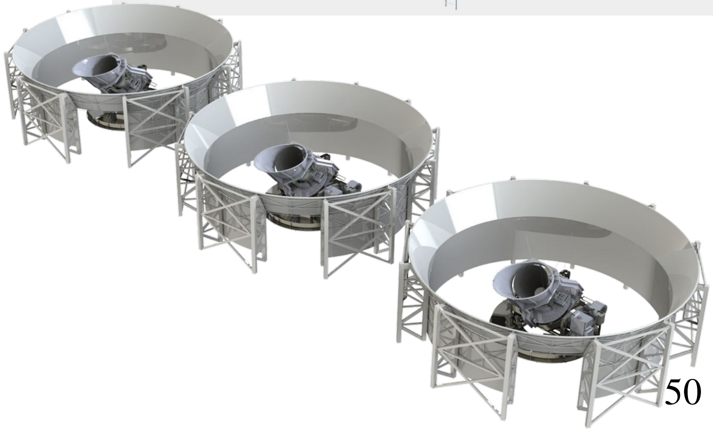
  → no high multipoles
- ~4000 sensors
- Aiming at r<0.001
  - Maybe half of that.
- Current launch date 2029.



Simons observatory

- Ground-based, northern Chile 5200m above sea level.
- One 6-m telescope, three 42cm telescopes.
- All cover 30-280 GHz
- ~ 120 k detectors.
- Expect to start science observations in 2024.



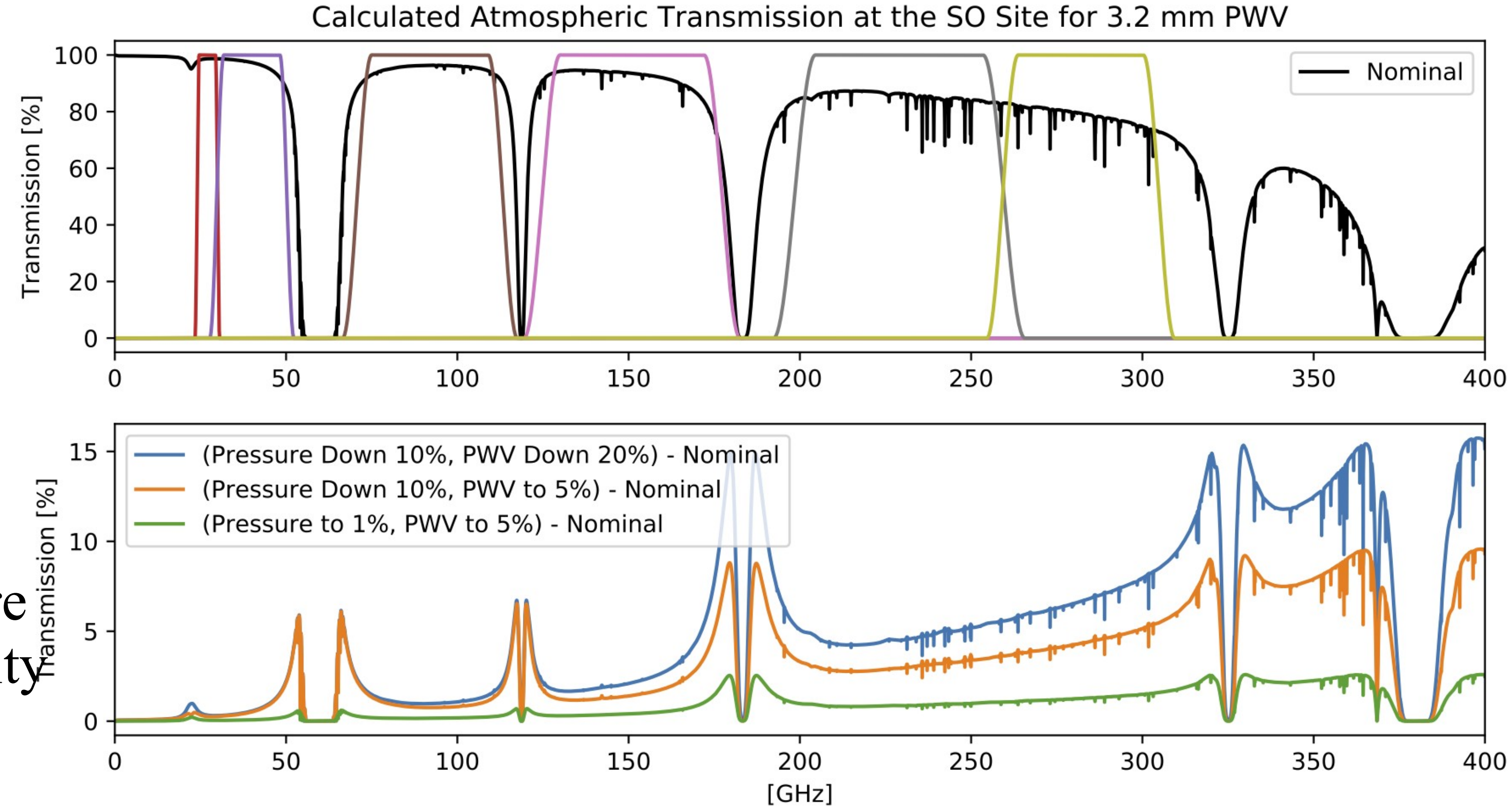


Why choose a desert ?

Maximum acceptable water vapour

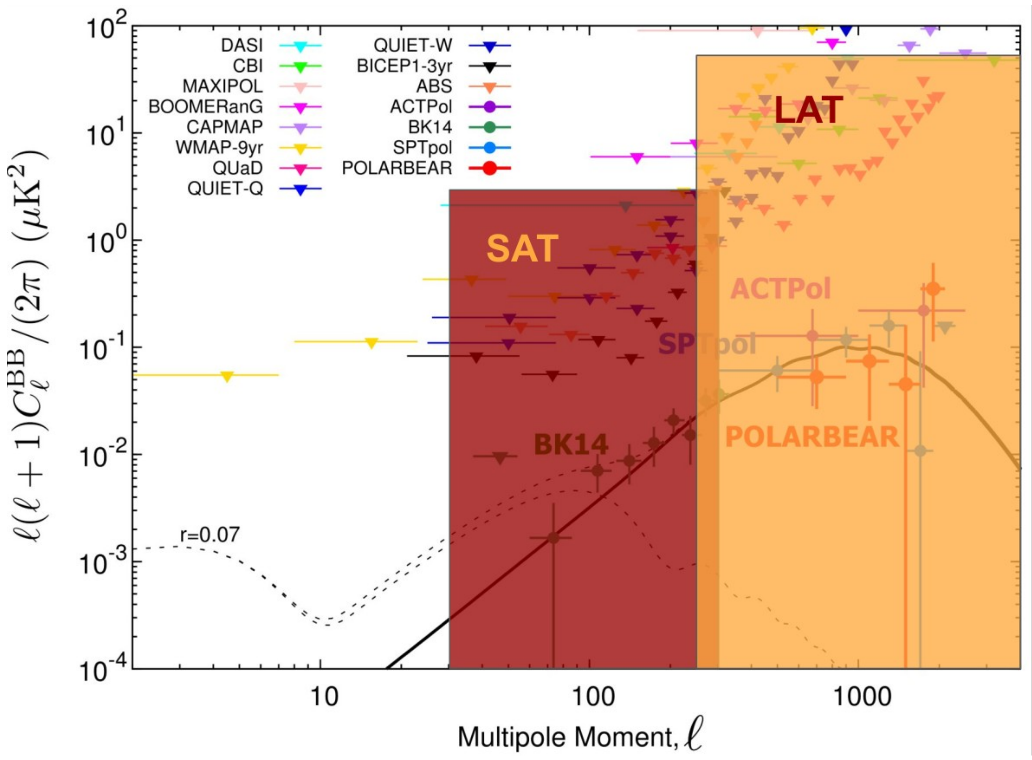
Atmospheric transmission

Variations due to pressure and/or humidity

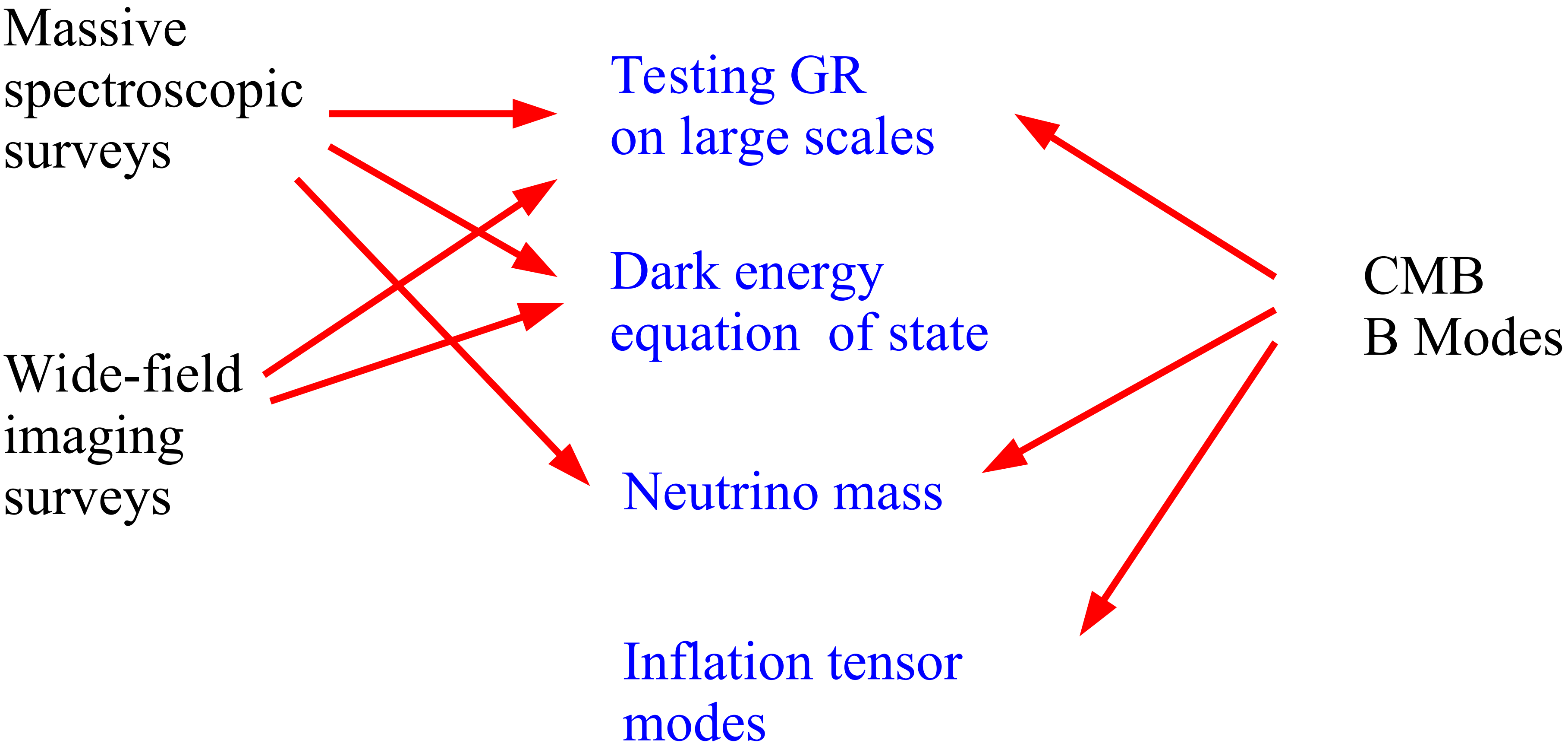


Simons observatory

- Only covers ~5% of the sky
  → missing large scales
- r to 0.002
- Neutrino mass to 0.033 eV
- #neutrinos to 0.07



Summary



Massive spectroscopic surveys
Wide-field imaging surveys
Testing GR on large scales
Dark energy equation of state
Neutrino mass
Inflation tensor modes
CMB B Modes

Summary

Massive
spectroscopic
surveys

DESI (2)
PFS

Wide-field
imaging
surveys

Euclid
LSST/Rubin

Testing GR
on large scales

Dark energy
equation of state

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modes

CMB
B Modes

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Litebird
Simons
CMB S4