Current Status of PS1 Sky Survey and Lulin 2-m Telescope

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CPS Seminar at Kobe Univ.

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Outline

- Pan-STARRS
- 2-m Telescope
- 4-Color Simultaneous Imager
  - Science
  - Design
  - Current Status

Visible 4-color simultaneous imager

is the 1st generation instrument

for 2-m telescope.

Why do we need 2-m telescope?

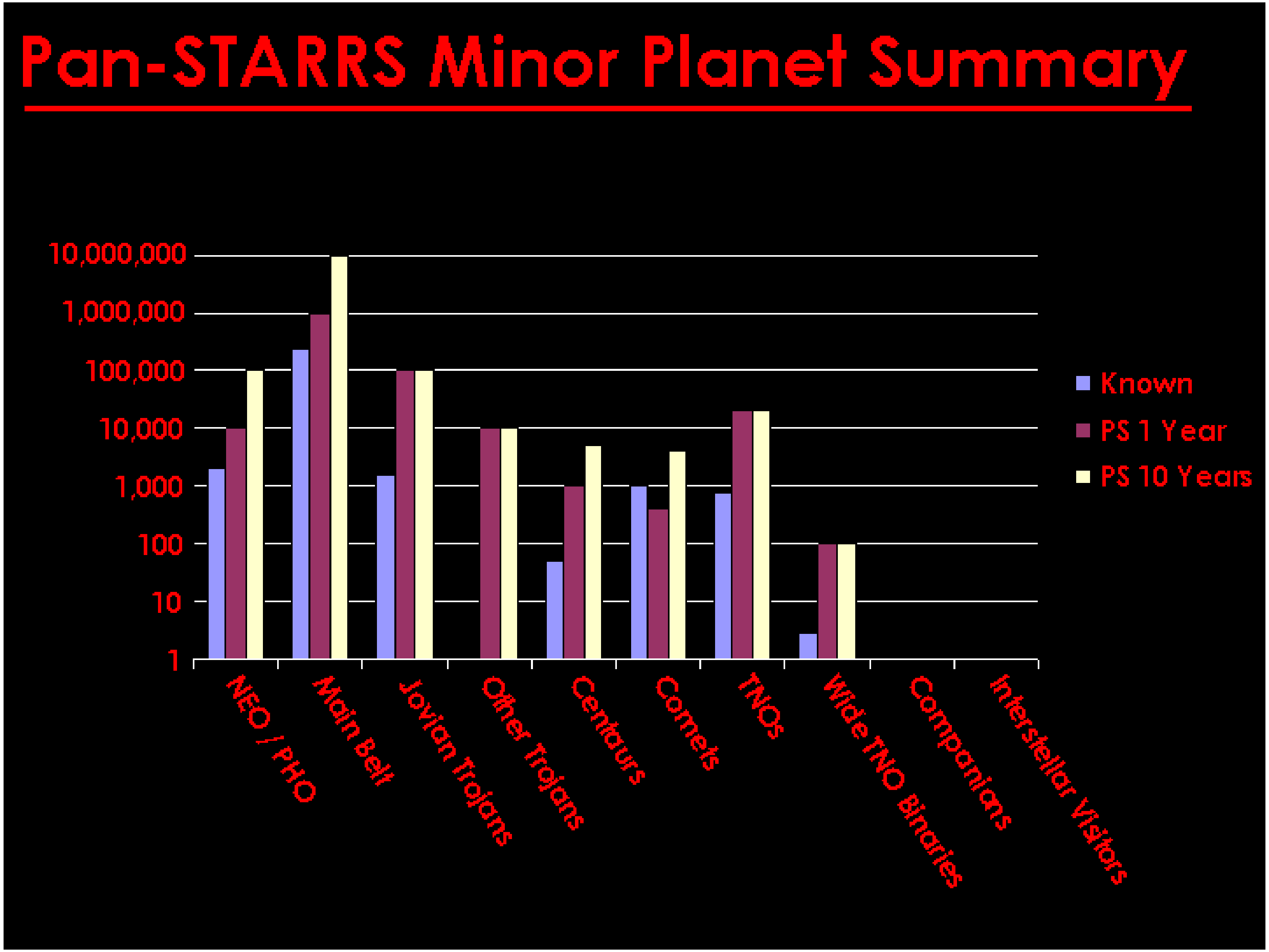
Pan-STARRS

Pan-STARRS

Pan-STARRS

- Panoramic Survey Telescope And Rapid Response System
- cyclical sky survey
- four 1.8-m telescopes (F/4)
- 1.4G pix camera (FOV: 7 deg^2)
- 0.3 arcsec per pixel
- 6,000 deg^2 per night
- detector: orthogonal transfer CCDs (on-chip guiding)
- limiting mag. = 24 mag (5σ)
- PS1 at Haleakala, PS4 at Mauna Kea

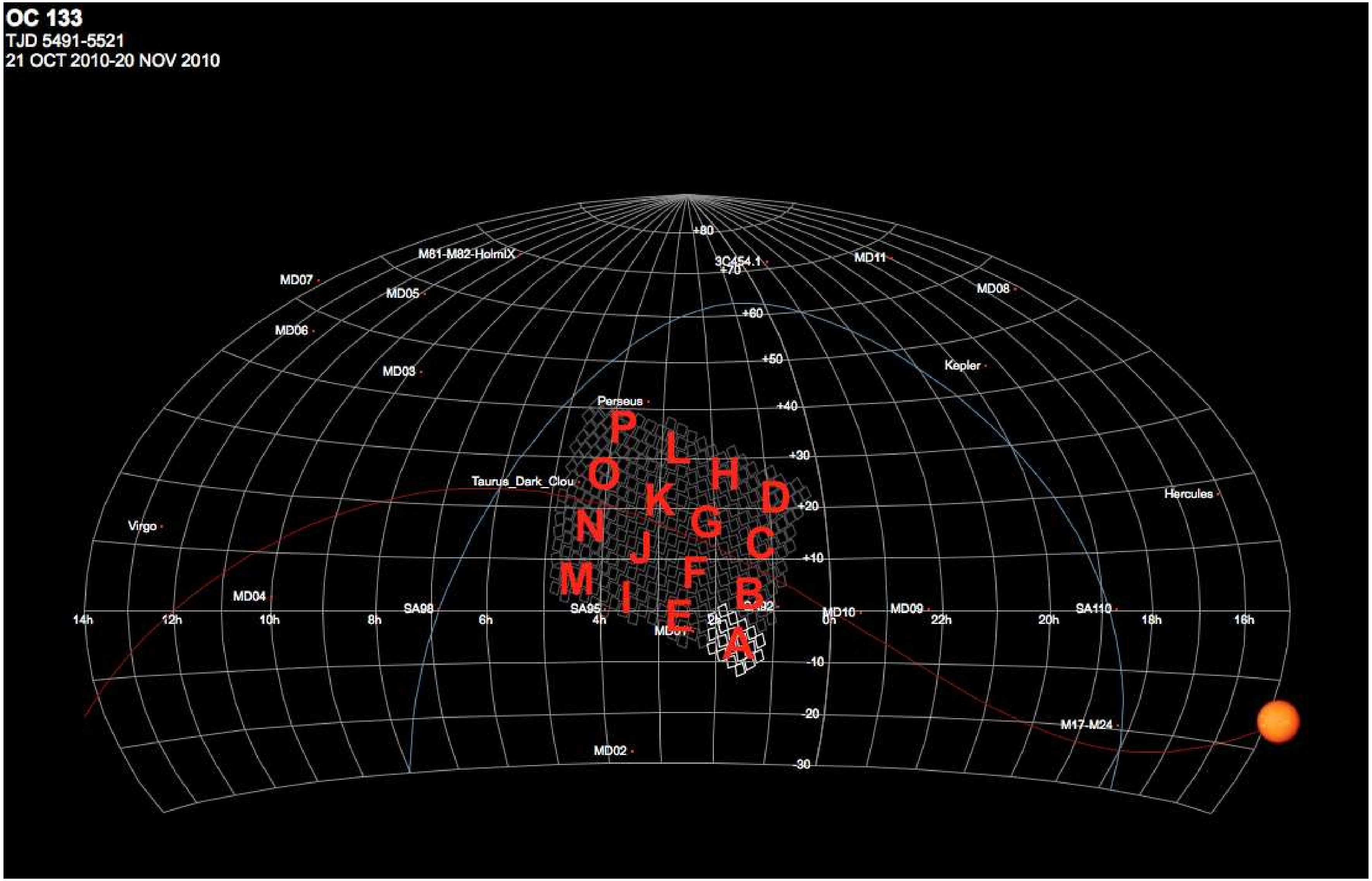
Pan-STARRS Minor Planet Summary



Current Status of PS1 Sky Survey

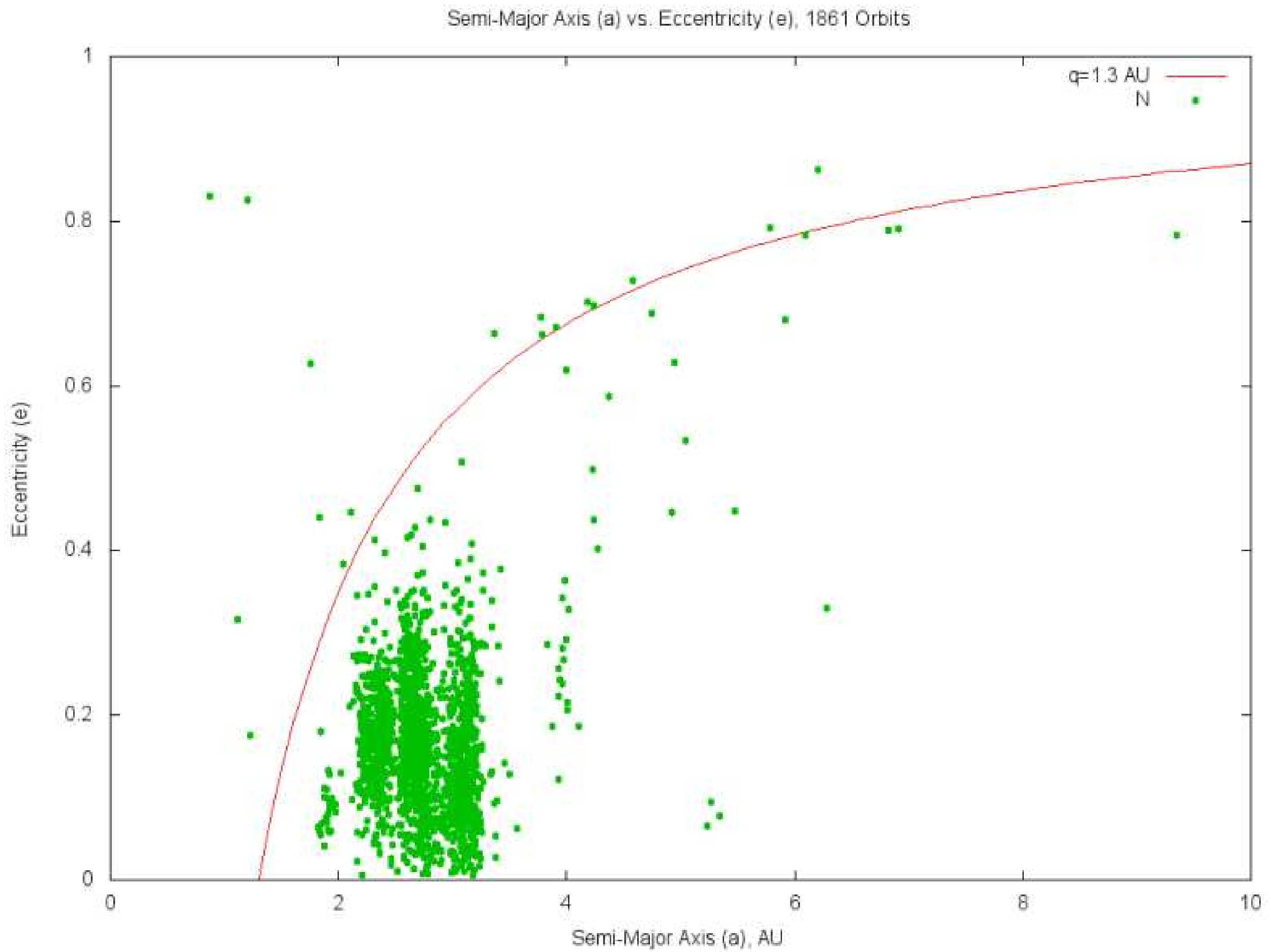
- PS1 Sky Survey officially started in May 2010.
  - 2.5 yr operation (with possible 0.5 yr extension of the mission)
- Discoveries of a comet, TNOs, and NEOs
  - comet P/2010 T2 (PANSTARRS) (IAUC 9173)
  - 3 TNOs
  - PHO: 2010 ST3

Opposition Sweet Spot Survey



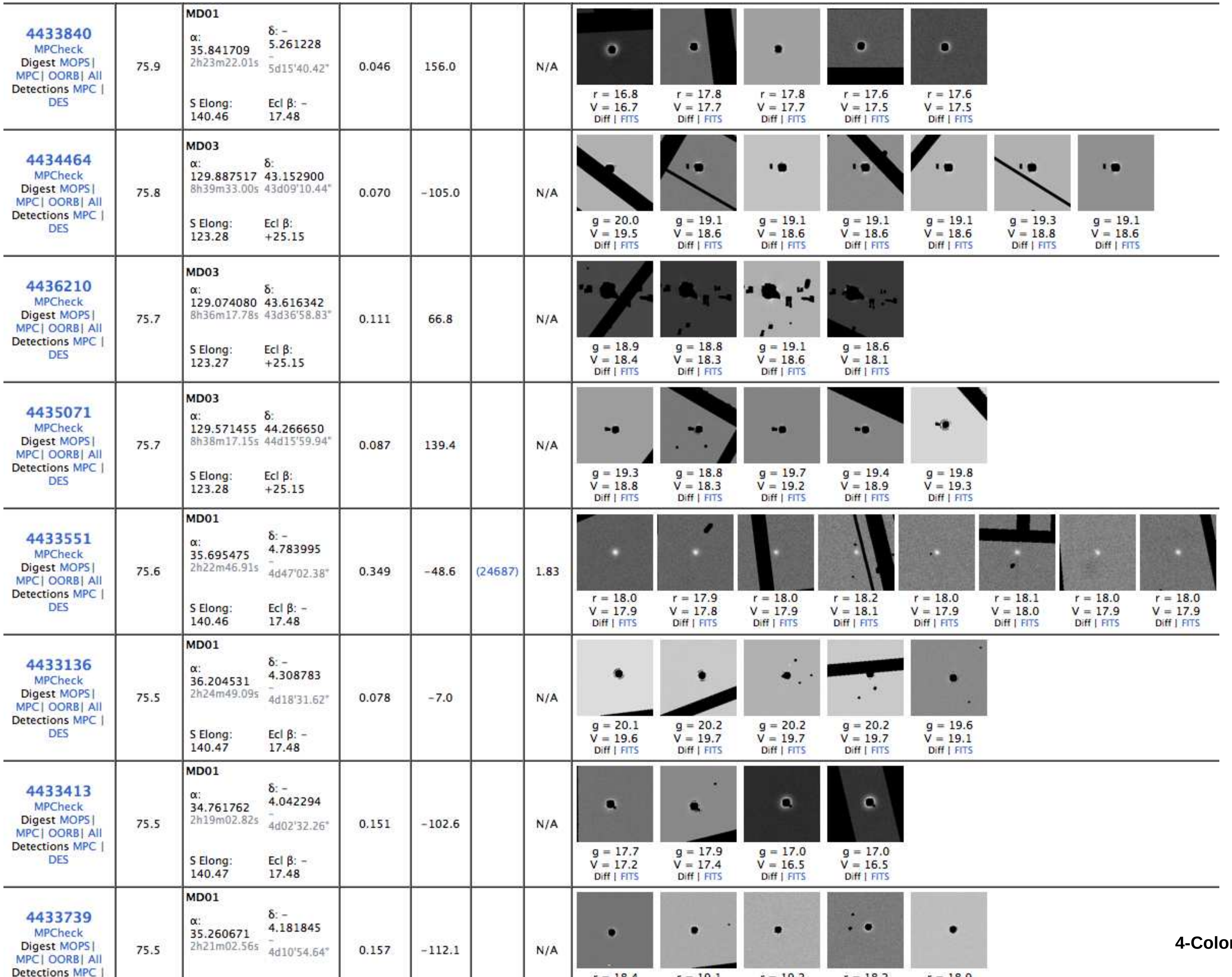
OC (Observing Cycle) 133 (Oct-Nov 2010)

MOPS Derived Objects



03/Nov/2010

NEO Discoveries



4433840 MPCheck Digest MOPS | MPC| OORB| All Detections MPC | DES	75.9	MD01 α: 35.841709 2h23m22.01s δ: -5.261228 -5d15'40.42" S Elong: 140.46 Ecl β: -17.48	0.046	156.0		N/A	r = 16.8 V = 16.7 Diff | FITS; r = 17.8 V = 17.7 Diff | FITS; r = 17.8 V = 17.7 Diff | FITS; r = 17.6 V = 17.5 Diff | FITS; r = 17.6 V = 17.5 Diff | FITS
4434464 MPCheck Digest MOPS | MPC| OORB| All Detections MPC | DES	75.8	MD03 α: 129.887517 8h39m33.00s δ: 43.152900 43d09'10.44" S Elong: 123.28 Ecl β: +25.15	0.070	-105.0		N/A	g = 20.0 V = 19.5 Diff | FITS; g = 19.1 V = 18.6 Diff | FITS; g = 19.1 V = 18.6 Diff | FITS; g = 19.1 V = 18.6 Diff | FITS; g = 19.1 V = 18.6 Diff | FITS; g = 19.3 V = 18.8 Diff | FITS; g = 19.1 V = 18.6 Diff | FITS
4436210 MPCheck Digest MOPS | MPC| OORB| All Detections MPC | DES	75.7	MD03 α: 129.074080 8h36m17.78s δ: 43.616342 43d36'58.83" S Elong: 123.27 Ecl β: +25.15	0.111	66.8		N/A	g = 18.9 V = 18.4 Diff | FITS; g = 18.8 V = 18.3 Diff | FITS; g = 19.1 V = 18.6 Diff | FITS; g = 18.6 V = 18.1 Diff | FITS
4435071 MPCheck Digest MOPS | MPC| OORB| All Detections MPC | DES	75.7	MD03 α: 129.571455 8h38m17.15s δ: 44.266650 44d15'59.94" S Elong: 123.28 Ecl β: +25.15	0.087	139.4		N/A	g = 19.3 V = 18.8 Diff | FITS; g = 18.8 V = 18.3 Diff | FITS; g = 19.7 V = 19.2 Diff | FITS; g = 19.4 V = 18.9 Diff | FITS; g = 19.8 V = 19.3 Diff | FITS
4433551 MPCheck Digest MOPS | MPC| OORB| All Detections MPC | DES	75.6	MD01 α: 35.695475 2h22m46.91s δ: -4.783995 -4d47'02.38" S Elong: 140.46 Ecl β: -17.48	0.349	-48.6	(24687)	1.83	r = 18.0 V = 17.9 Diff | FITS; r = 17.9 V = 17.8 Diff | FITS; r = 18.0 V = 17.9 Diff | FITS; r = 18.2 V = 18.1 Diff | FITS; r = 18.0 V = 17.9 Diff | FITS; r = 18.1 V = 18.0 Diff | FITS; r = 18.0 V = 17.9 Diff | FITS; r = 18.0 V = 17.9 Diff | FITS
4433136 MPCheck Digest MOPS | MPC| OORB| All Detections MPC | DES	75.5	MD01 α: 36.204531 2h24m49.09s δ: -4.308783 -4d18'31.62" S Elong: 140.47 Ecl β: -17.48	0.078	-7.0		N/A	g = 20.1 V = 19.6 Diff | FITS; g = 20.2 V = 19.7 Diff | FITS; g = 20.2 V = 19.7 Diff | FITS; g = 20.2 V = 19.7 Diff | FITS; g = 19.6 V = 19.1 Diff | FITS
4433413 MPCheck Digest MOPS | MPC| OORB| All Detections MPC | DES	75.5	MD01 α: 34.761762 2h19m02.82s δ: -4.042294 -4d02'32.26" S Elong: 140.47 Ecl β: -17.48	0.151	-102.6		N/A	g = 17.7 V = 17.2 Diff | FITS; g = 17.9 V = 17.4 Diff | FITS; g = 17.0 V = 16.5 Diff | FITS; g = 17.0 V = 16.5 Diff | FITS
4433739 MPCheck Digest MOPS | MPC| OORB| All Detections MPC |	75.5	MD01 α: 35.260671 2h21m02.56s δ: -4.181845 -4d10'54.64"	0.157	-112.1		N/A	r = 18.4; r = 19.1; r = 19.2; r = 18.2; r = 18.9

How to search young families?

- Comparison of orbital elements of two objects
  - semimajor axis
  - eccentricity
  - inclination
  - longitude of ascending node
  - argument of perihelion
- Amount of calculations is the order of O(N^2).
- We need a smart way...
  - KD-tree
  - machine learning, heuristic approach
  - GPGPU
- a collaboration with a group at Computer Science Department.

How to search young families?

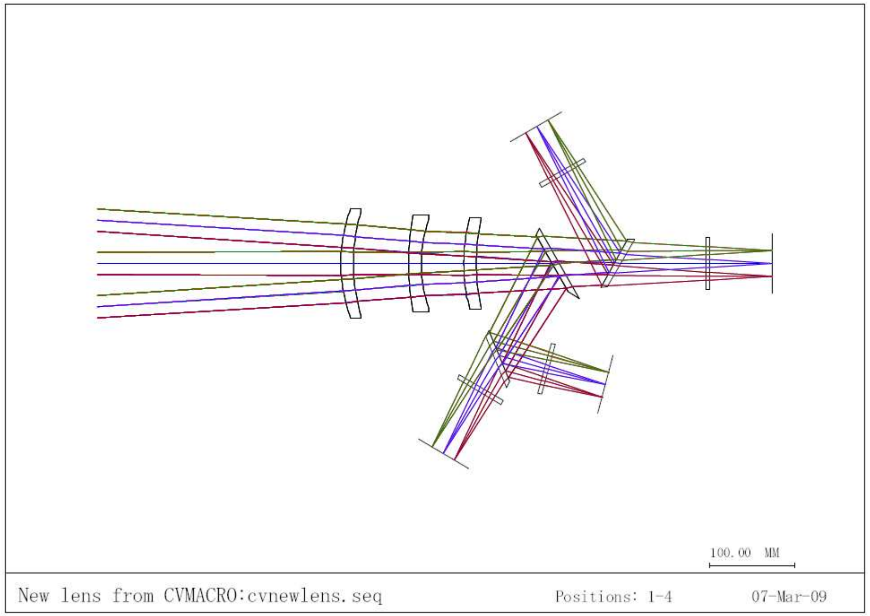
- Kinoshita's test program using OpenMP
  - written in C with OpenMP
  - a single computer with 2 quad-core CPUs
  - a few hours to complete the calculation ($>$ 0.5M objects)
- A code by NCU Computer Science group
  - written in C using MPI
- We have actually found some pairs which are not in any publication.
  - Some astrometric observations done in Nov/2010.
  - Color measurements using a new 2K $\times$ 4K are planned in Jan/2011.

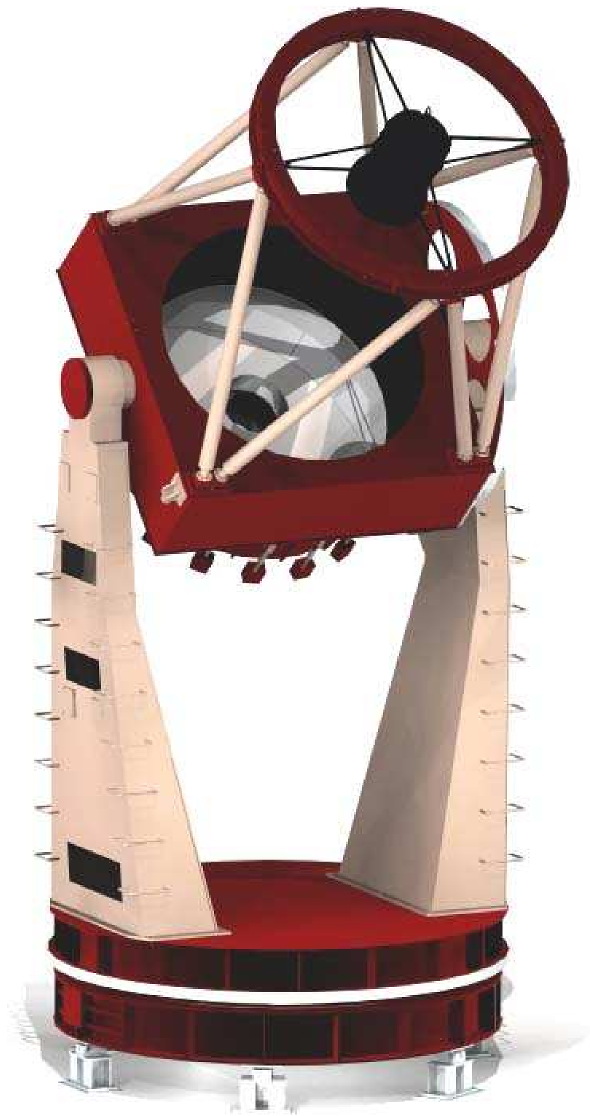
Search for small ΔV objects

- Search for small ΔV objects for space missions
  - Hayabusa 2, Marco Polo
- Solar system sweet spot survey
  - western sky in the evening
  - eastern sky in the morning
- a, e, $i \rightarrow \Delta V$
- Having more mission candidates as back-up targets is extremely useful.
- List of small ΔV object from Pan-STARRS database.
- Coordinated observations by Taiwan-Japan collaboration.

Lulin 2-m Telescope and 4-Color Imager

- New discoveries by PS1 sky surveys
- Quick follow-up observations by 2-m telescope





Our 2-m Telescope in March 2010

in Kyoto, Japan, 08/Mar/2010

Why visible 4-color simultaneous imager?

Multi-color photometry

- PS1 3π survey
  - powerful cyclical wide-field survey in g'r'i'z'y
  - different passband data acquired on different night
  - color measurements of a single object may not be reliable enough...
    - asteroid rotation $\rightarrow$ change in cross-section
    - transient objects have variability for their nature.
- 2-m telescope as a color measurement machine!
  - discovery of an asteroid with peculiar orbit.
  - color information gives us a rough idea what it is.
    - primitive carbonanscious asteroid?
    - differentiated igneous asteroid?
  - if we have a small set of data, it'll be easier to apply for more observing time.

Why simultaneous imaging?

- Difficulty for color measurements at Lulin
  - Site characteristics
    - The sky at Lulin is variable.
    - Limited number of photometric night.
  - Nature of our targets
    - transient objects
    - moving objects
- Problem for conventional method
  - The sky and/or target changes during the filter exchange.

One possible solution

- Use of 2 or more telescope at the same time
- A conversation with my former advisor Olivier Hainaut at Paranal in 2001
  - “Here, we do not change filters, but we change telescopes.”
  - We were using FORS1 on VLT UT1 and FORS2 on VLT UT2.
- Problem: expensive!

Our solution

- Dichroic beam splitting and simultaneous imaging by multiple cameras
  - 3 dichroic mirrors
  - 4 bandpass filters
  - 4 CCD imagers
- Advantages of simlutaneous imaging
  - Higher observing efficiency
  - Relatively poor condition nights can also be used.
    - assuming that thin cloud has neutral transmittance
  - Easier calibration

Advantages of Simultaneous Imaging

- Required total time for conventional method

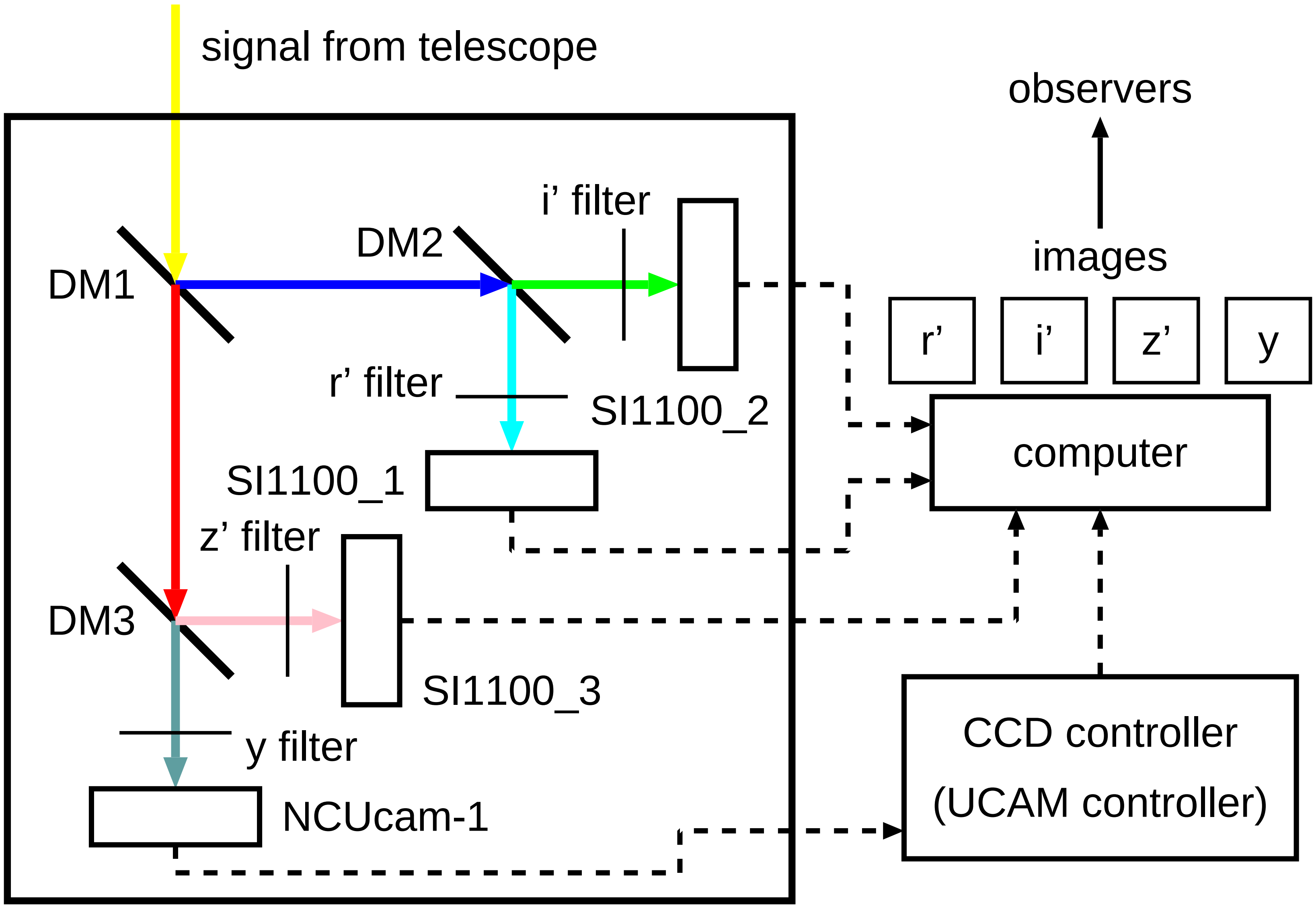
$$T_c = (t_{exp} + t_{ro}) \times N_{band}$$

- Required total time for simultaneous imager

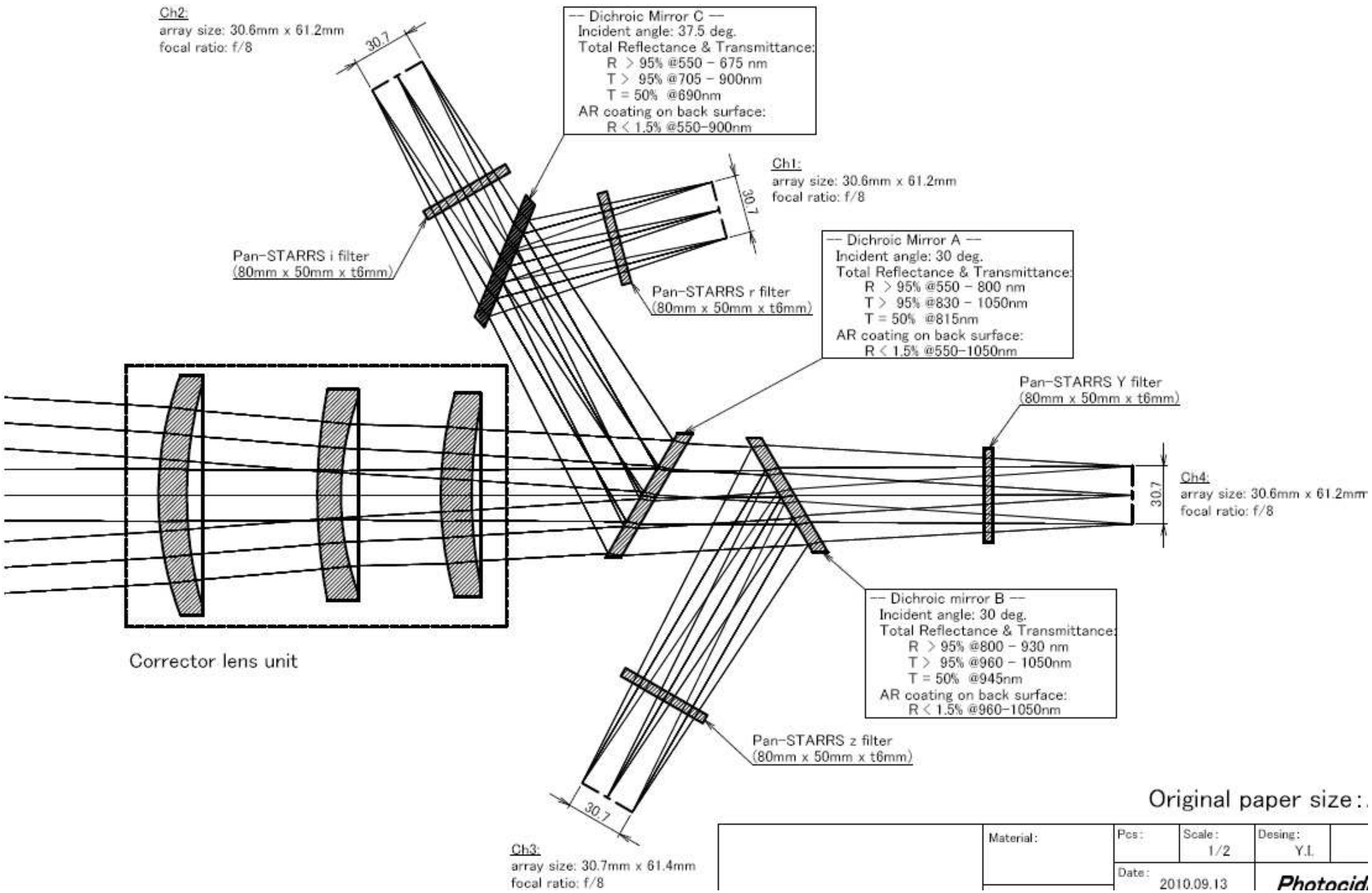
$$T_s = \frac{t_{exp}}{E_{throughput}} + t_{ro}$$

- Assuming $t_{exp} = 60$ sec, $t_{ro} = 8$ sec, $N_{band} = 4$, and $E_{throughput} = 0.8$
- Observing efficiency improves by a factor of $\sim$ 3.3.

Conceptual Design of the Instrument

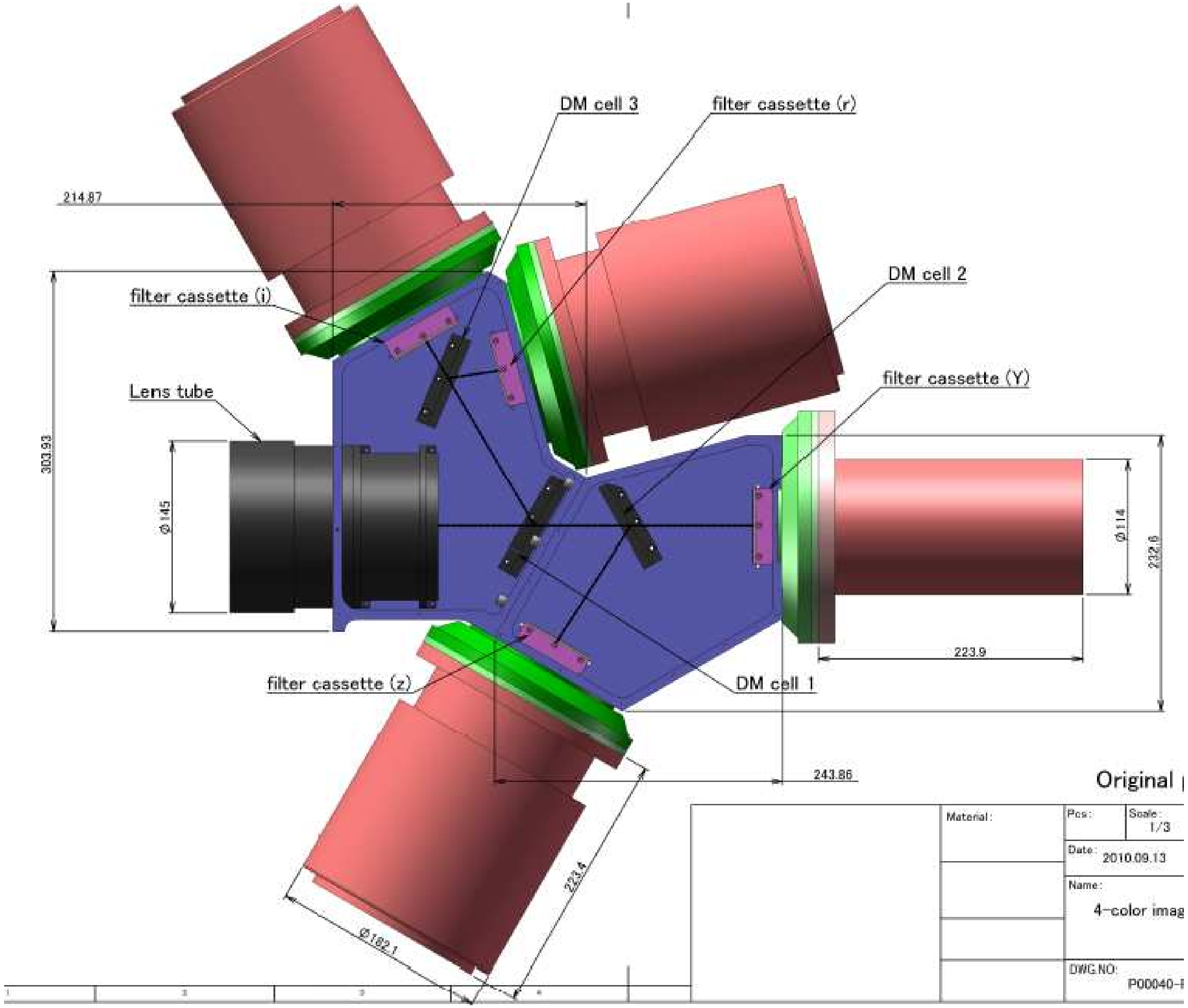


Optical Design of the Instrument



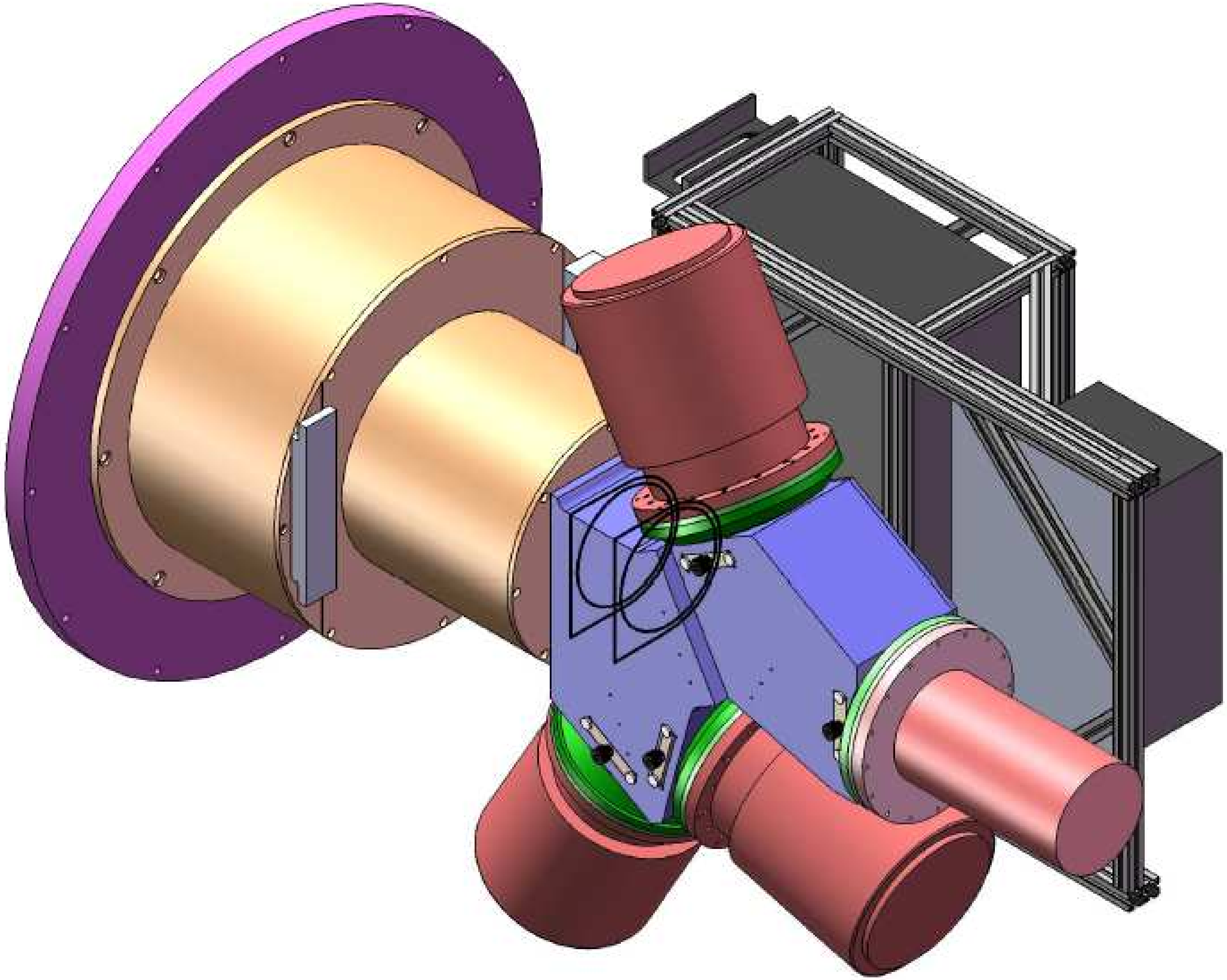
designed by Photocoding

Design of the Instrument



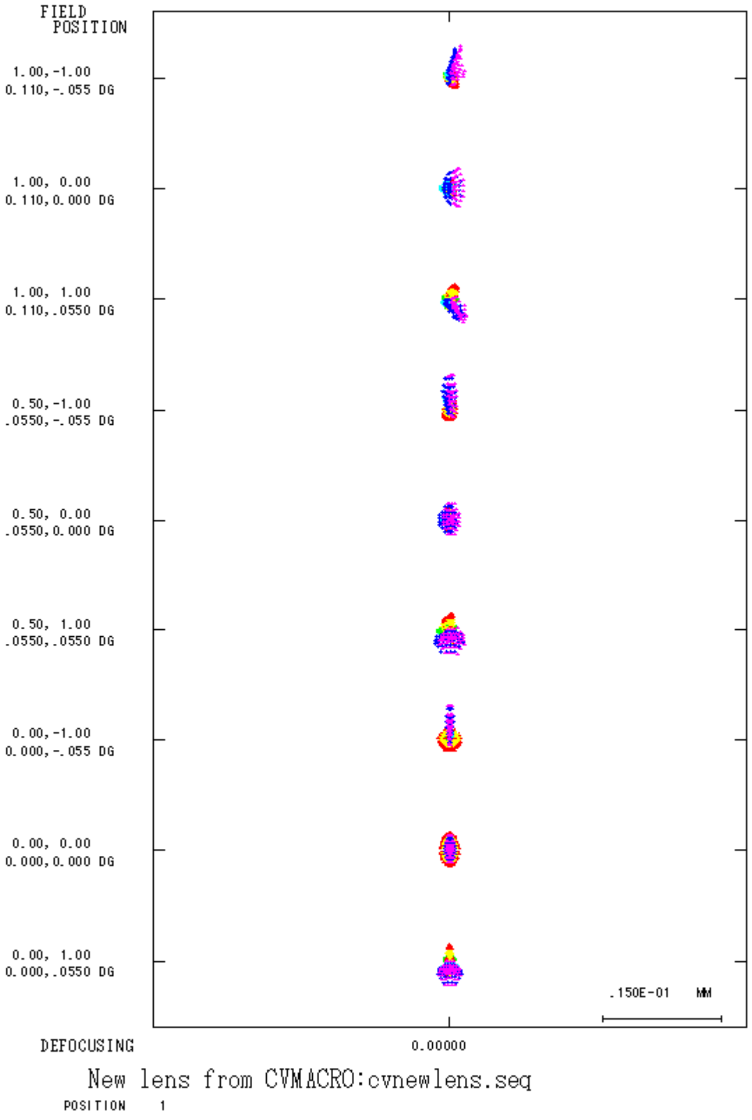
designed by Photocoding

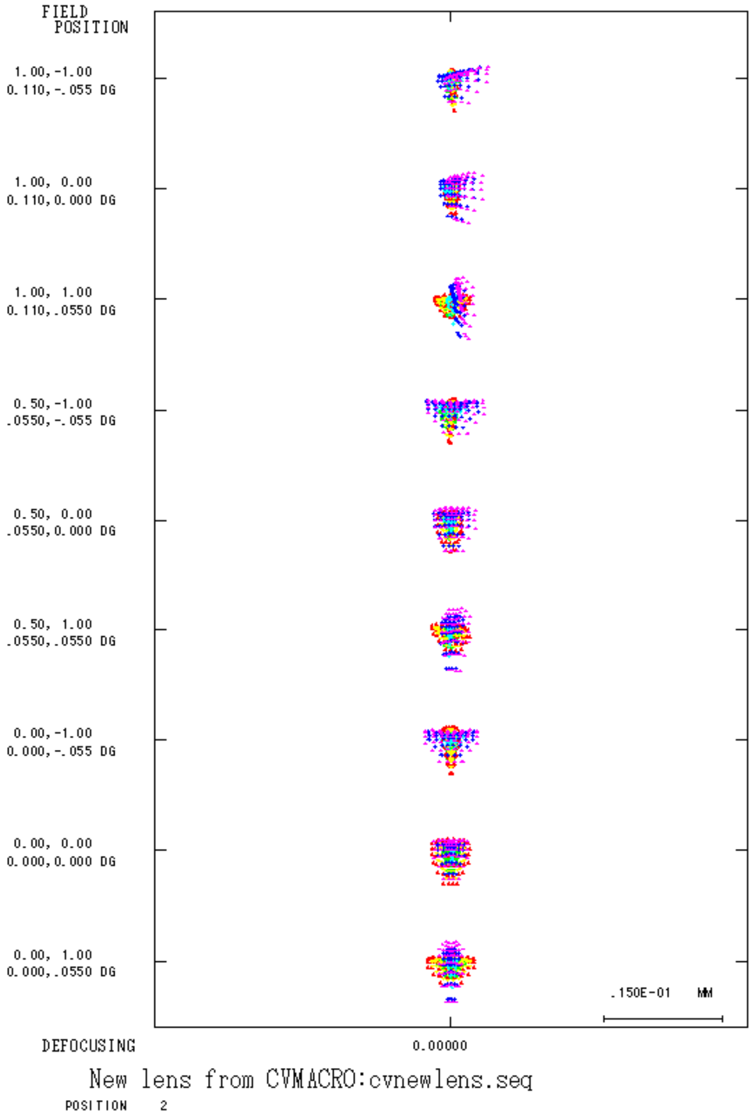
Design of the Instrument



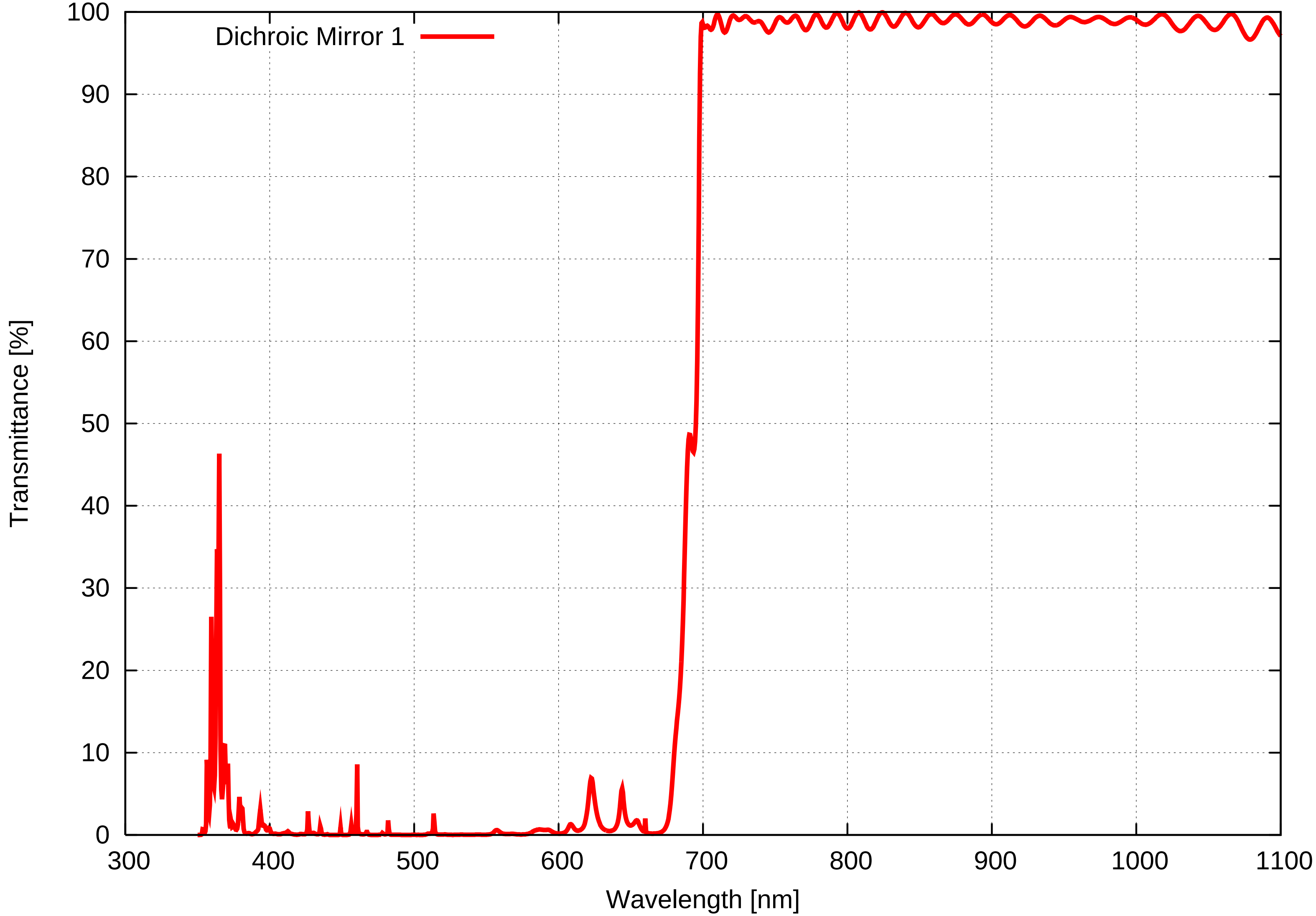
designed by Photocoding

Spot Diagrams

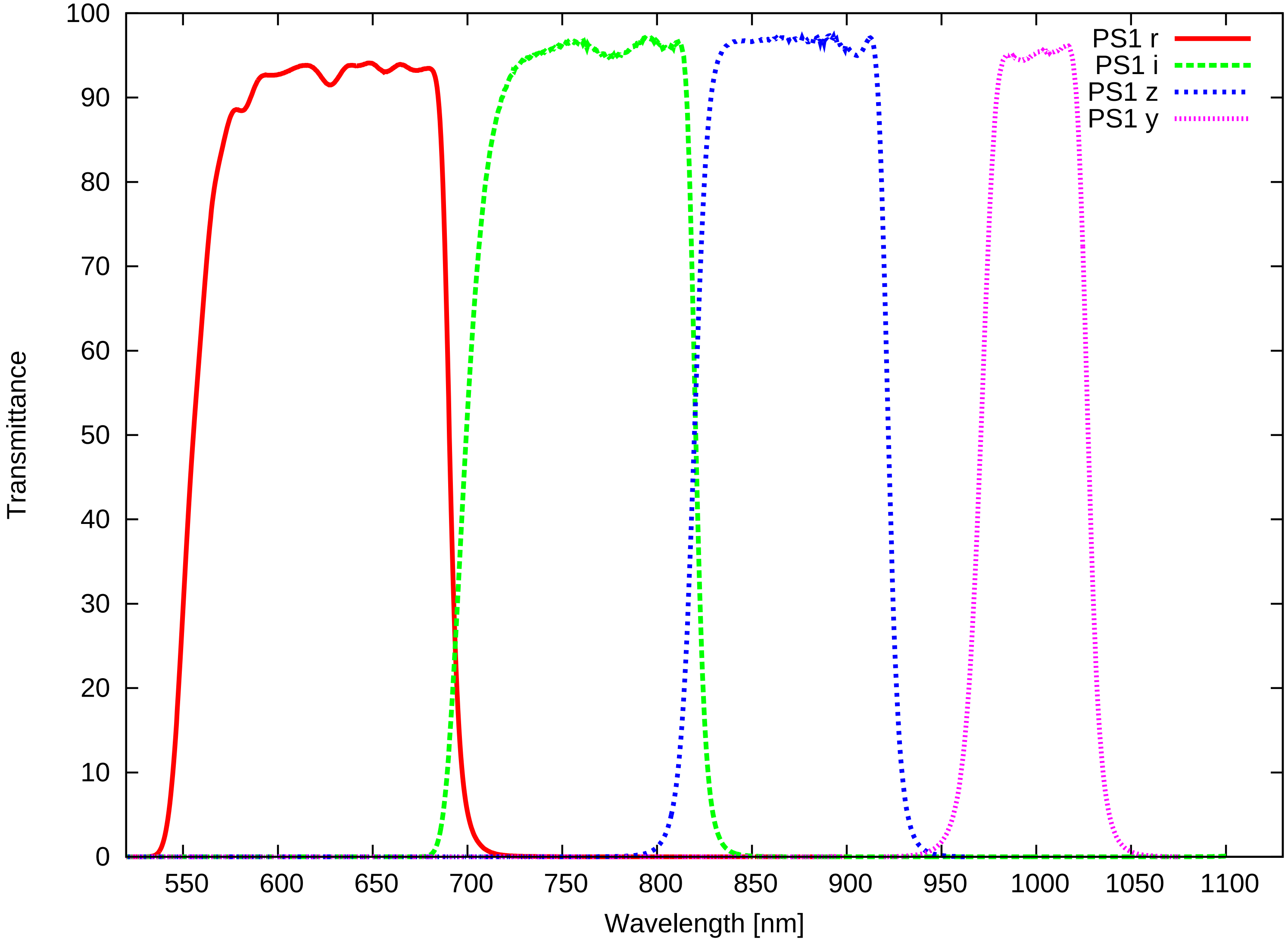




Dichroic Mirrors



Filters Design (PS1 compatible)



(Asahi Spectra)

Two Important Aspects for Development

- quick delivery of the instrument for early science
  - on-time delivery $\rightarrow$ early scientific outputs right after the telescope installation
  - important for future funding requests
- in-house development to accumulate experiences
  - improving the ability
  - more possibility in the future
    - instrument with unique features $\rightarrow$ unique scientific outputs
    - preparation for larger projects in the future

Our Strategy for the Development

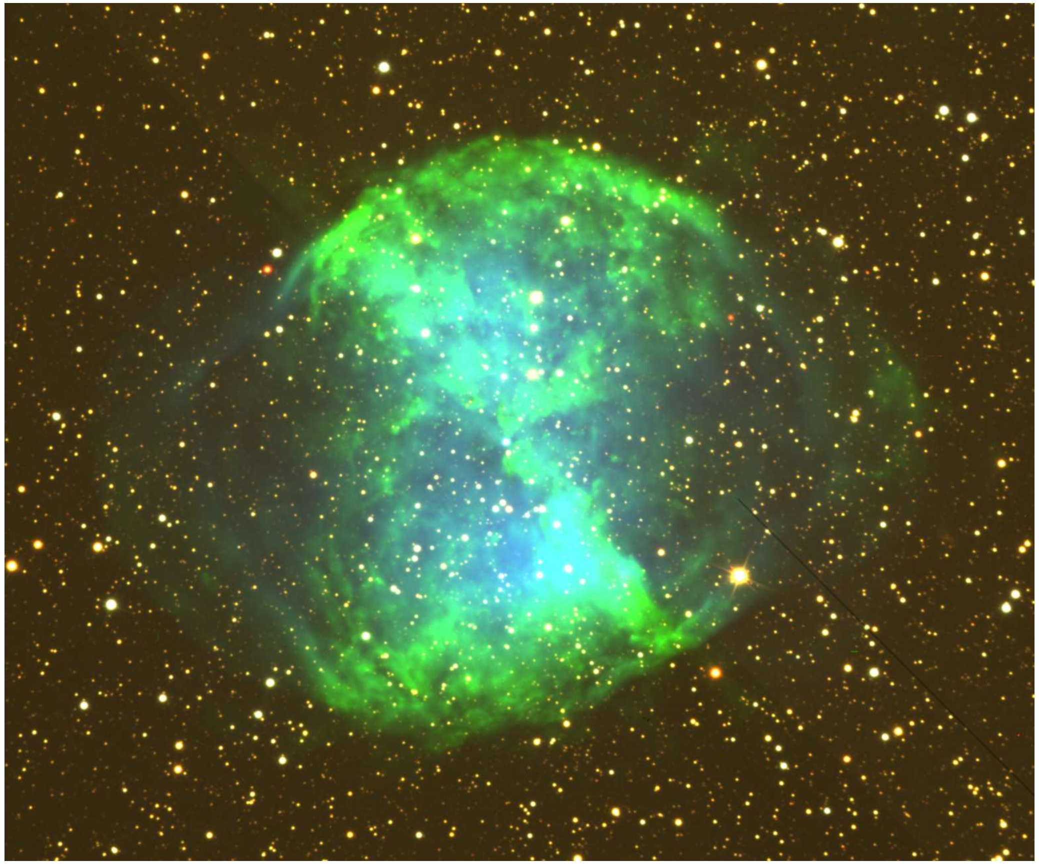
- balance between quick delivery and in-house development
- 3 CCD cameras for r', i', and z'-bands
  - purchase of commercially available products
  - good enough specifications for scientific observations
  - use of deep depletion CCDs of E2V
- 1 more CCD camera for y-band
  - in-house development
  - use of fully depleted CCD of Hamamatsu Photonics

3 Cameras for r', i', and z'-band

- E2V 44-82-1-D23 CCD chips
  - 4K $\times$ 2K, 15 μm pixel
  - deep depletion CCD (thickness $\sim$ 40 μm)
  - 16-bit digitization
- -100 deg C operation temperature
- readout speed: 100, 400, and 800 MHz
- Quantum efficiency:
  - $>$ 20% at $\lambda = 350$ nm
  - $>$ 35% at $\lambda = 400$ nm
  - $>$ 65% at $\lambda = 500$ nm
  - $>$ 80% at $\lambda = 650$ nm
  - $>$ 45% at $\lambda = 900$ nm

First-Light Image of SI1100

M27 (Dumbbell Nebula)



Lulin 1-m Telescope + SI1100 series camera
20/Jul/2010, g' (10 min), r' (10 min), i' (10 min)

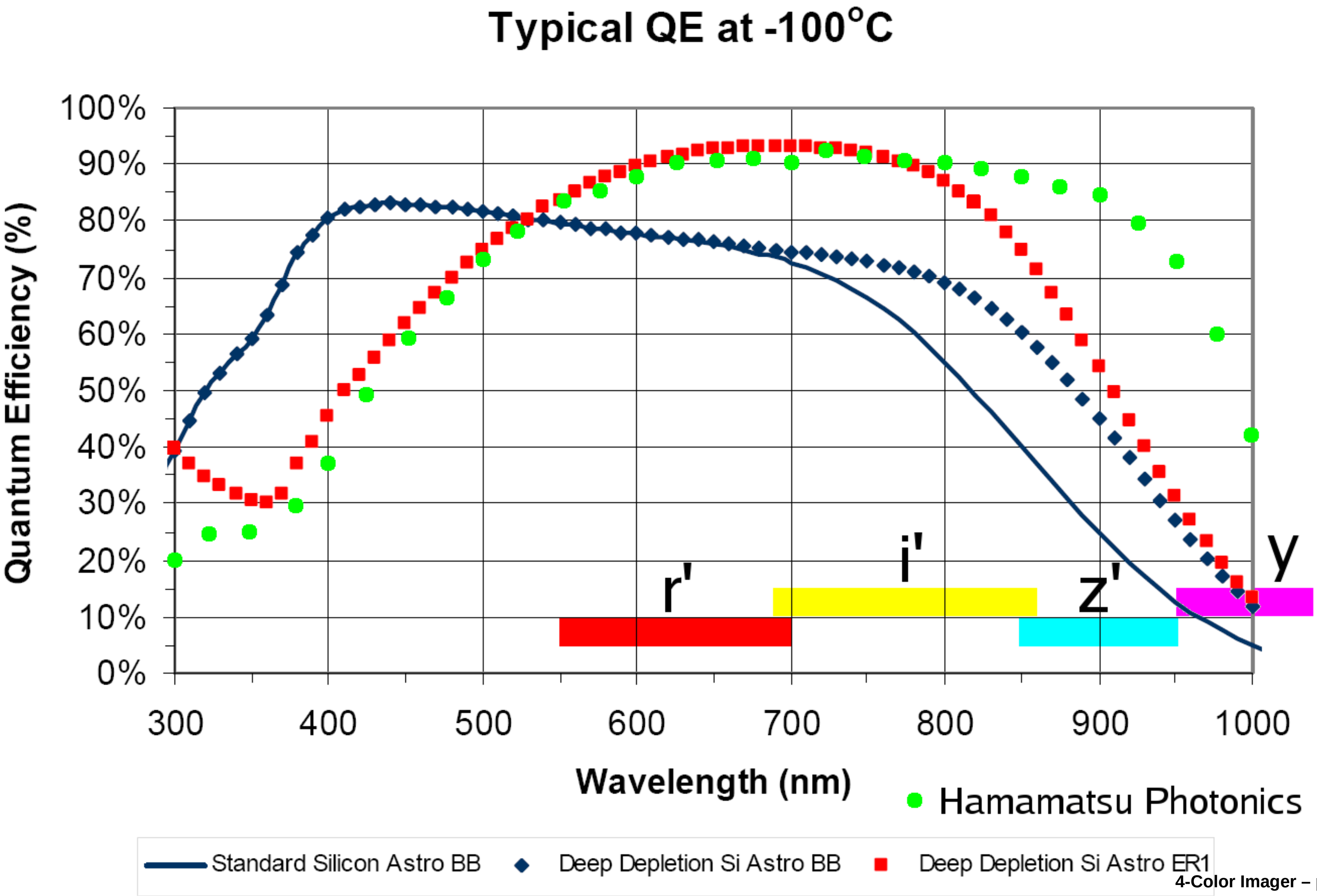
Detectors for NCUcam-1

- Sensitivity at $\lambda \sim 1$ μm is important!
  - mineral features of asteroids
  - brown dwarfs
  - photometric redshift
- Use of fully depleted CCDs
  - thickness of depletion layer $\sim$ 100-300 μm
  - cf. thickness of thinned back-illuminated CCDs $\sim$ 10-20 μm
  - advantages
    - significant improvement of longer wavelength sensitivity
    - negligible fringe pattern
    - lower cost

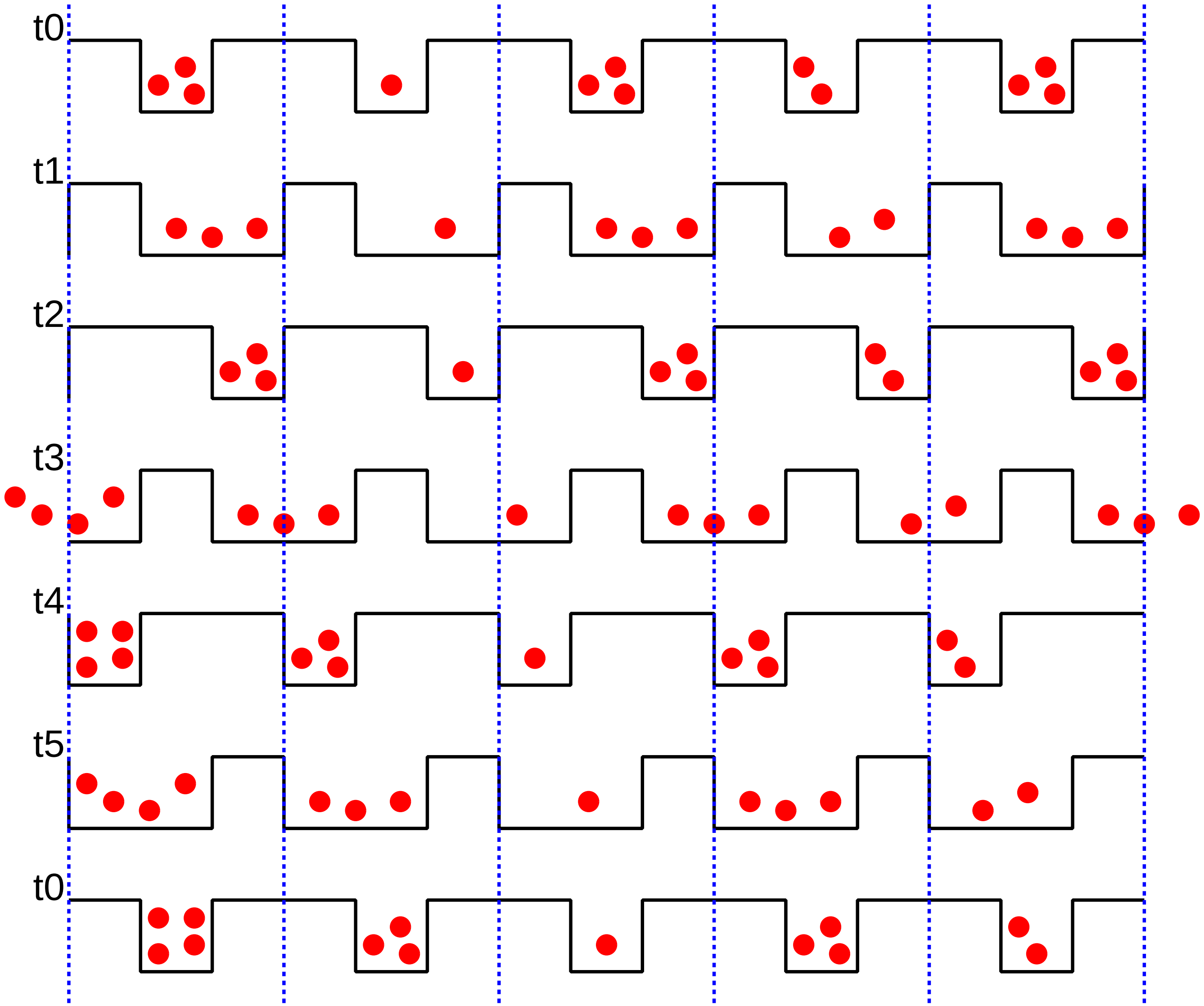
Fully Depleted CCDs

- Development at LBNL
  - 2K $\times$ 4K chips
  - test observations at KPNO
- Development by NAOJ + Hamamatsu Photonics
  - 2k $\times$ 4K chips
- Commercialization by E2V
  - to be available soon (?)

Fully Depleted CCDs: QE



Detector readout: Charge transfer

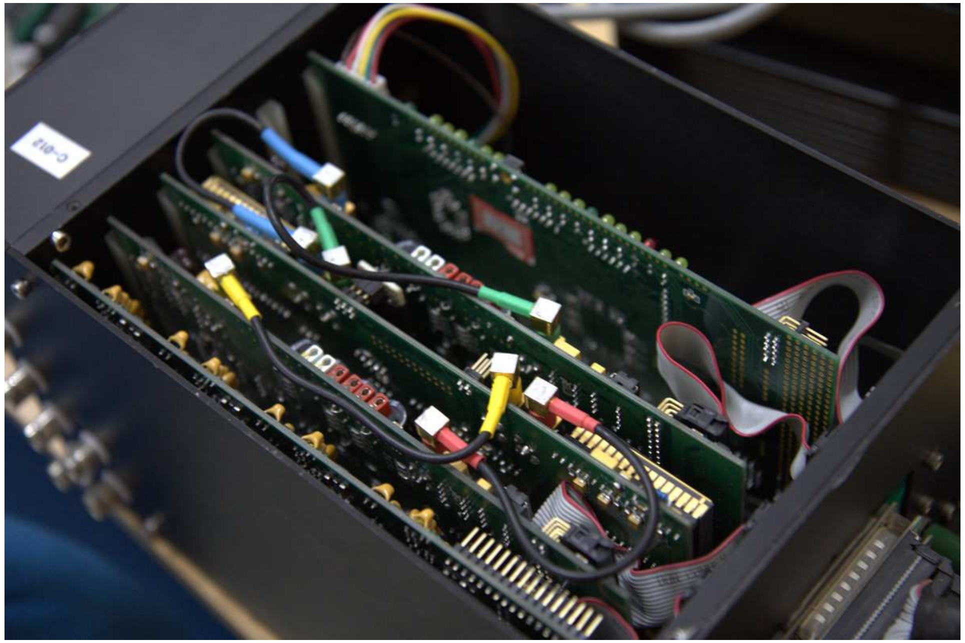


Readout Electronics

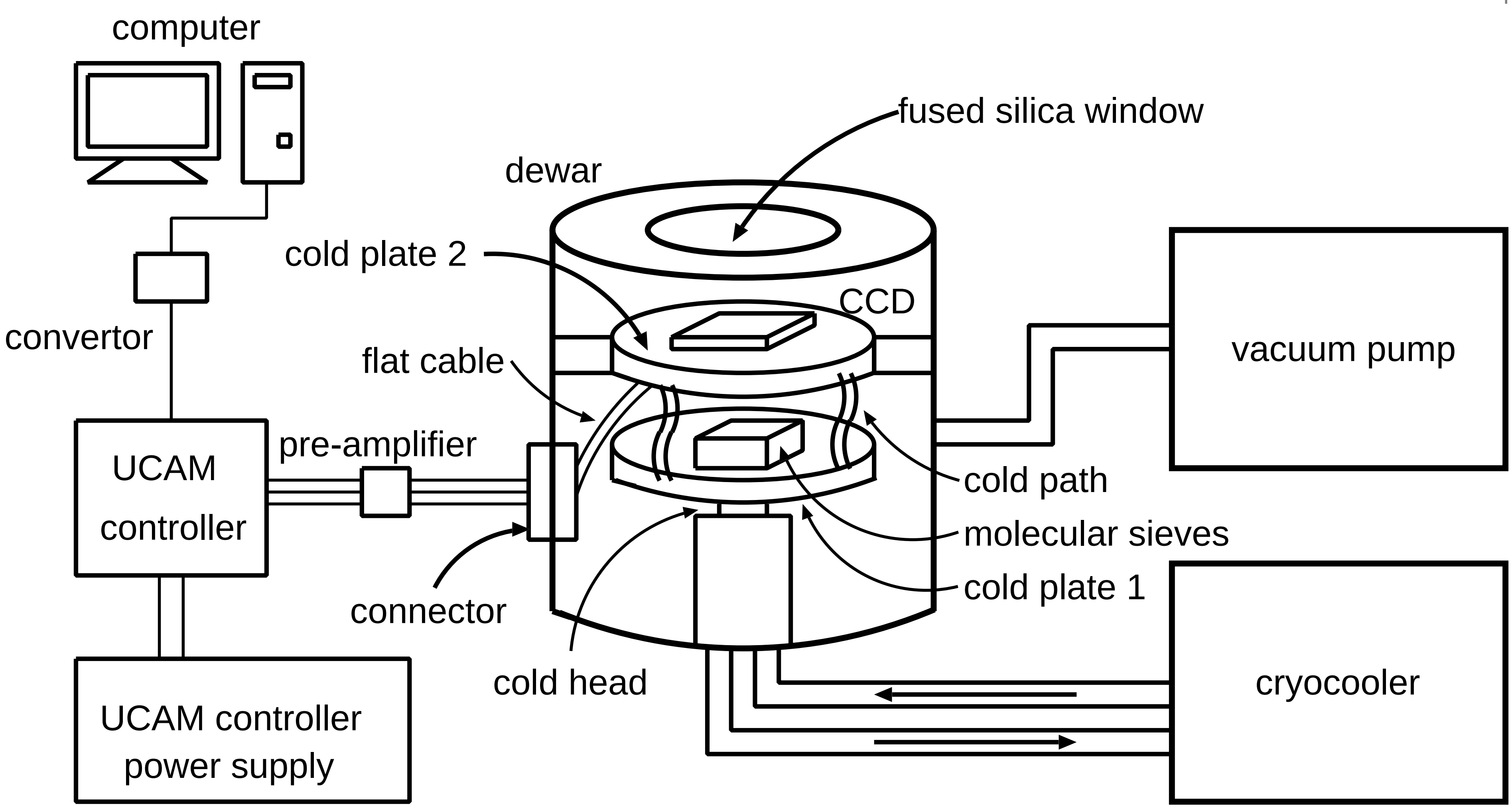
- NAOJ Messia5 + M-Front2
  - We turned down to have a collaboration with NAOJ...
- Development of original readout electronics
  - with Univ. of Tokyo
- Leach Controller
  - collaboration with Univ. of Nagoya
- Lick Observatory / AET
  - UCAM controller

Lick/AET UCAM Controller

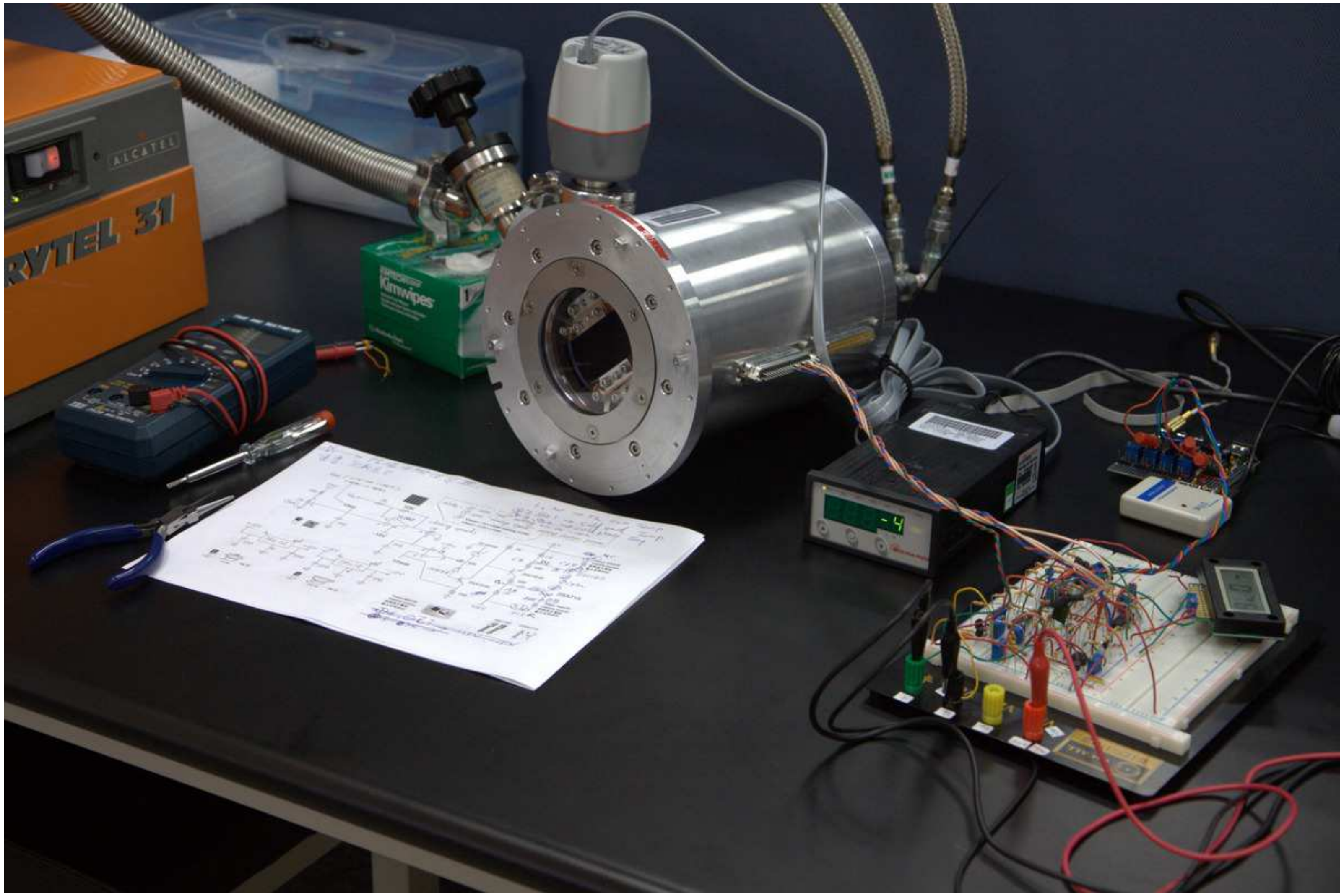
- timing board, clock board, DSP board, video board
- flexible configurations
- low noise
- support from Beijing



Schematic Diagram of NCUcam-1

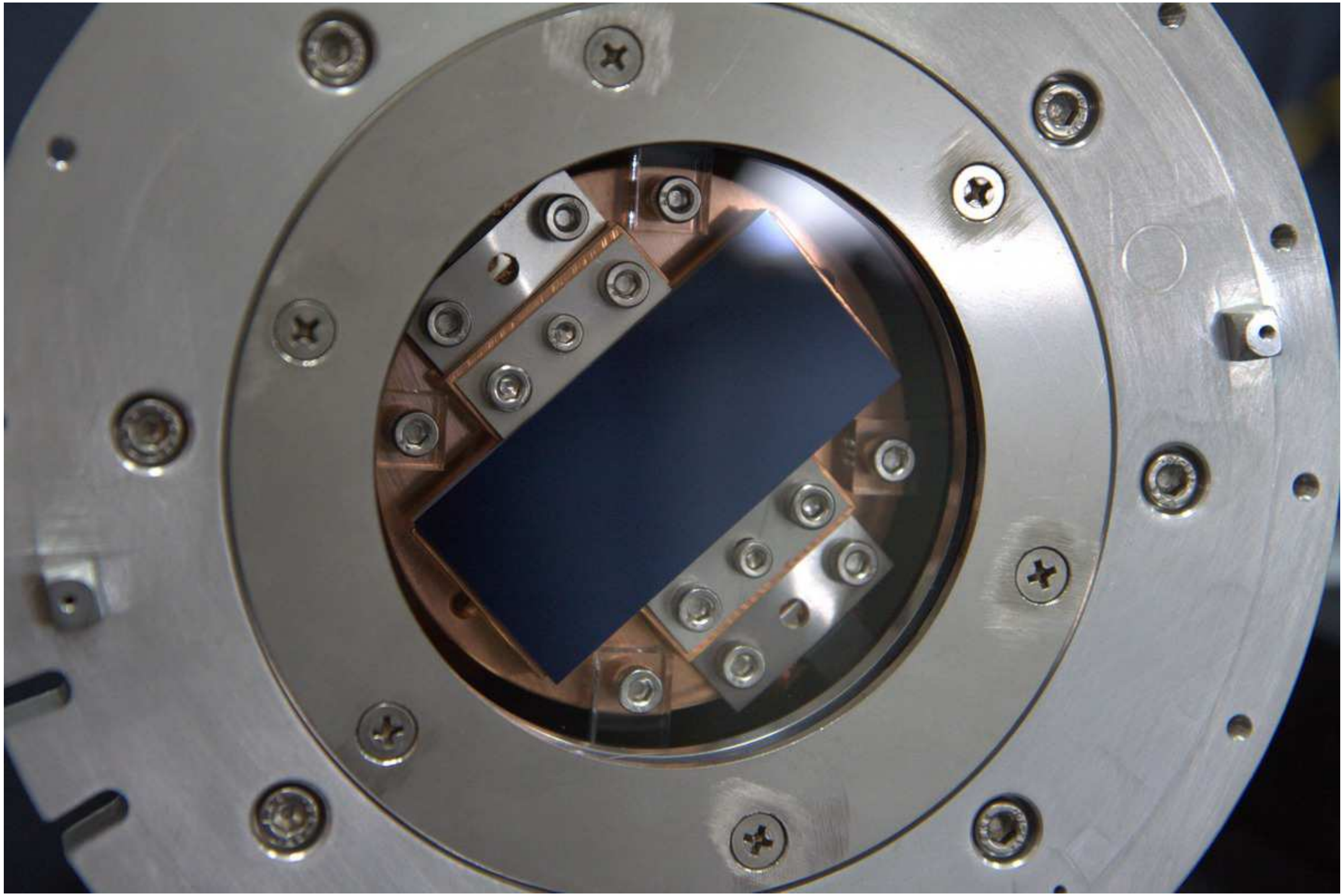


NCUcam-1



Nov/2010

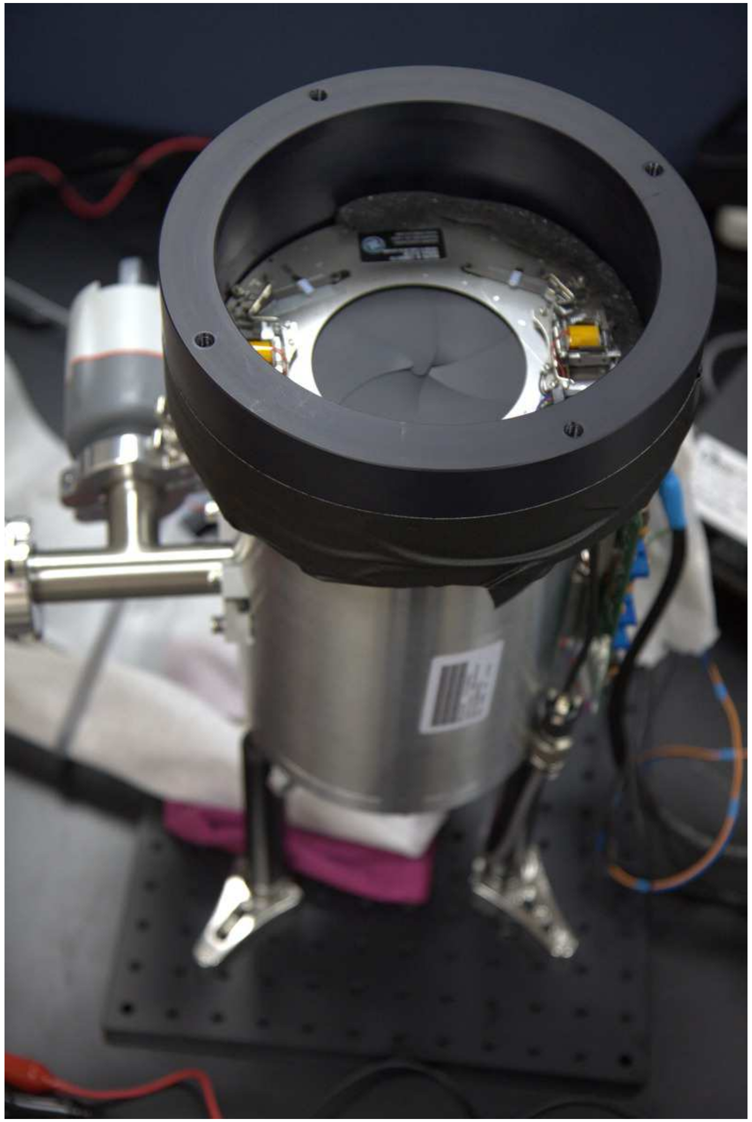
NCUcam-1



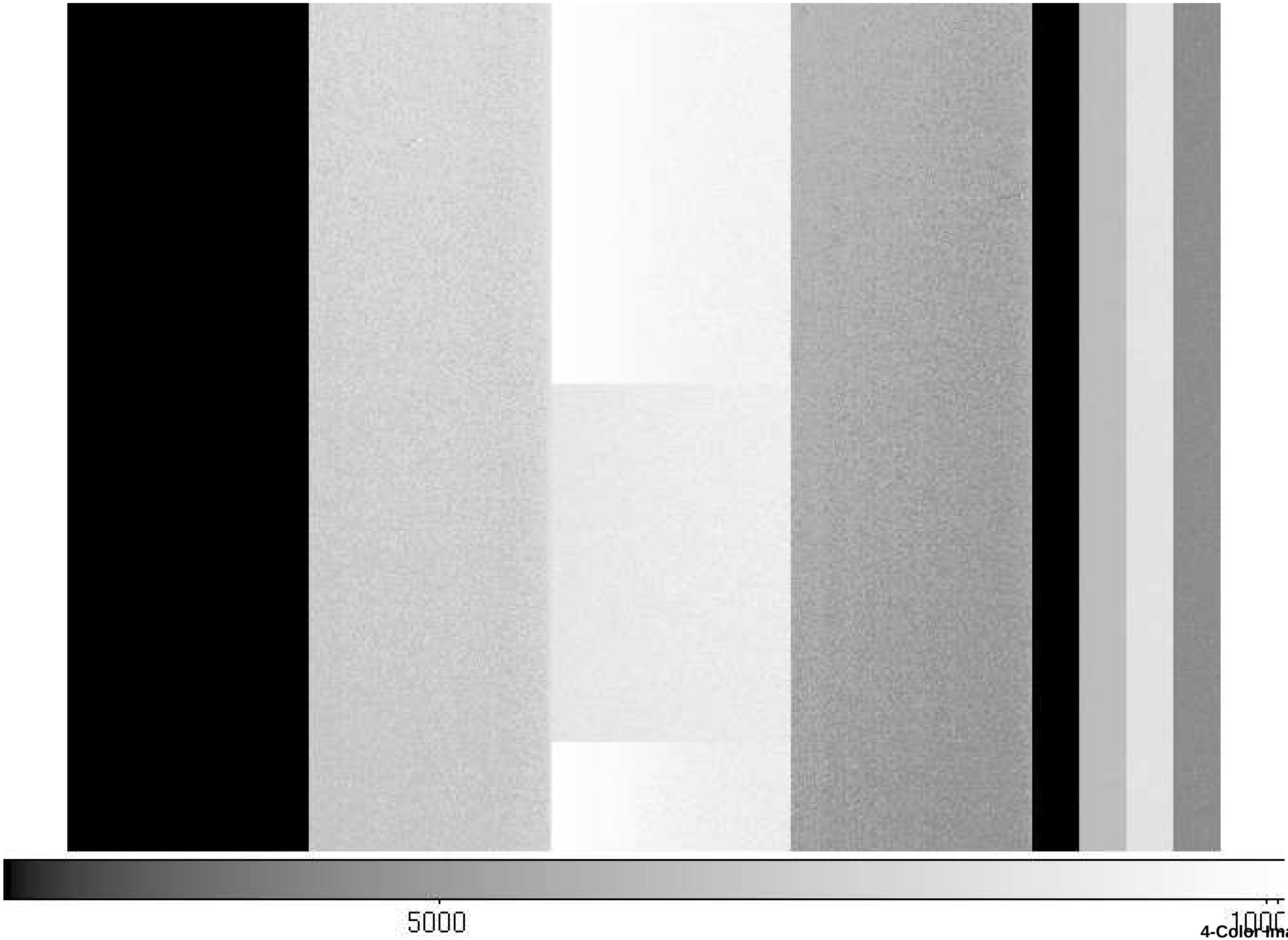
Nov/2010

NCUcam-1

- NCUcam-1
  - Hamamatsu fully depleted CCD (science grade chip)
  - Lick / AET UCAM CCD controller
  - cryocooler: Polycold PT-30
  - vacuum pump: turbo pump
  - dewar, temperature sensor, temperature control system developed at NCU



Lab. First-Light of NCUcam-1



Readout Noise of NCUcam-1

- Readout noise $\sim$ 5 electrons
  - cooling temperature: -100 deg C
  - sampling speed: 125 kHz
  - Good enough for us.

Current Status

- SI1100 series cameras: 3 cameras ready
  - characterization being done (Chen et al., Huang et al.)
- NCUcam-1: OK, waiting for the delivery of our chip (Mar/2011) (Wu et al.)
  - test observation using 1-m tel. in May-Jul/2011
- Filters: to be delivered in Feb/2011
- Optics: to be delivered in Apr/2011
- Control software: being developed (Shen et al.)
- Integration: Jun/2011
- Test observation in autumn 2011 (?)

Summary

- Lab. space is now ready, and lots of work is being done there.
- First-light of SI1100 cameras were achieved with 1-m tel.
- We have successfully drived Hamamatsu chip in the lab.
  - Laboratory first-light of NCUcam-1
- First-light of NCUcam-1 with 1-m tel. is planned in spring 2011.
- Integration of the whole instrument in summer 2011.