天体計測学特論 I
Observational Astronomy I

Lecture 07:
Designing systems
for imaging observations

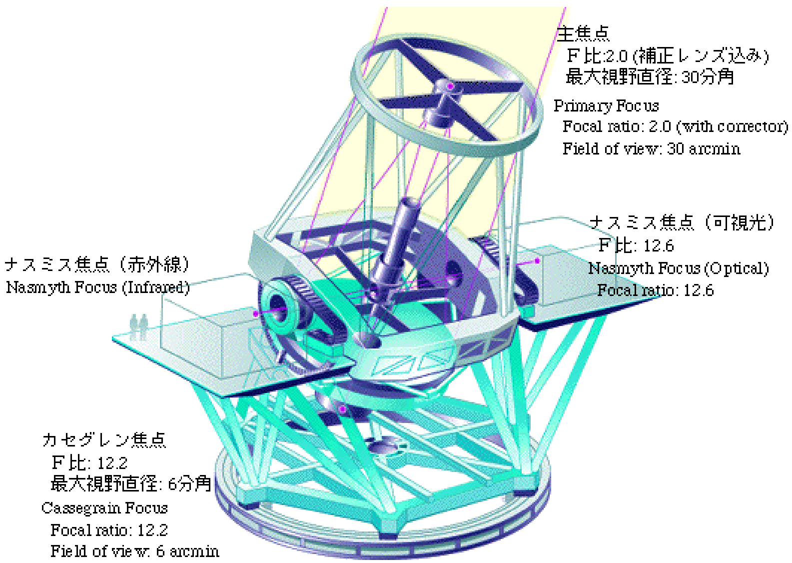
Resolution and sampling

- Resolution
  - Diffraction-limited : $1.22 \lambda / D$

  - Seeing-limited : $1.22 \lambda / r0$
    - r0 : Fried parameter
    - r0 @ 500nm ~ 0.2m @ Maunakea
    - r0 @ 500nm ~ 0.05m @ Sendai
    - $r0 \propto \lambda$^6/5

- Sampling (mm/arcsec)
  - f_eff x tan(1”)

Imaging observation with Subaru



遠藤孝悦・画　日経サイエンス1996年2月号より
Illustration by Takaetsu Endo, taken from Nikkei Science 1996

- Prime focus (F/2.0)
  - (Suprime-Cam), Hyper SC

    f~16m

    77 μm / "
- Cassegrain focus (F/12.2)
  - MOIRCS

    f~ 97.6m

    473 μm / "
- Nasmyth focus (F/12.6)
  - IRCS

    f~ 100.8m

    489 μm / "
- In IRCS imaging mode

  f_eff ~ 268m, F_eff ~ 34

  1300 μm / "

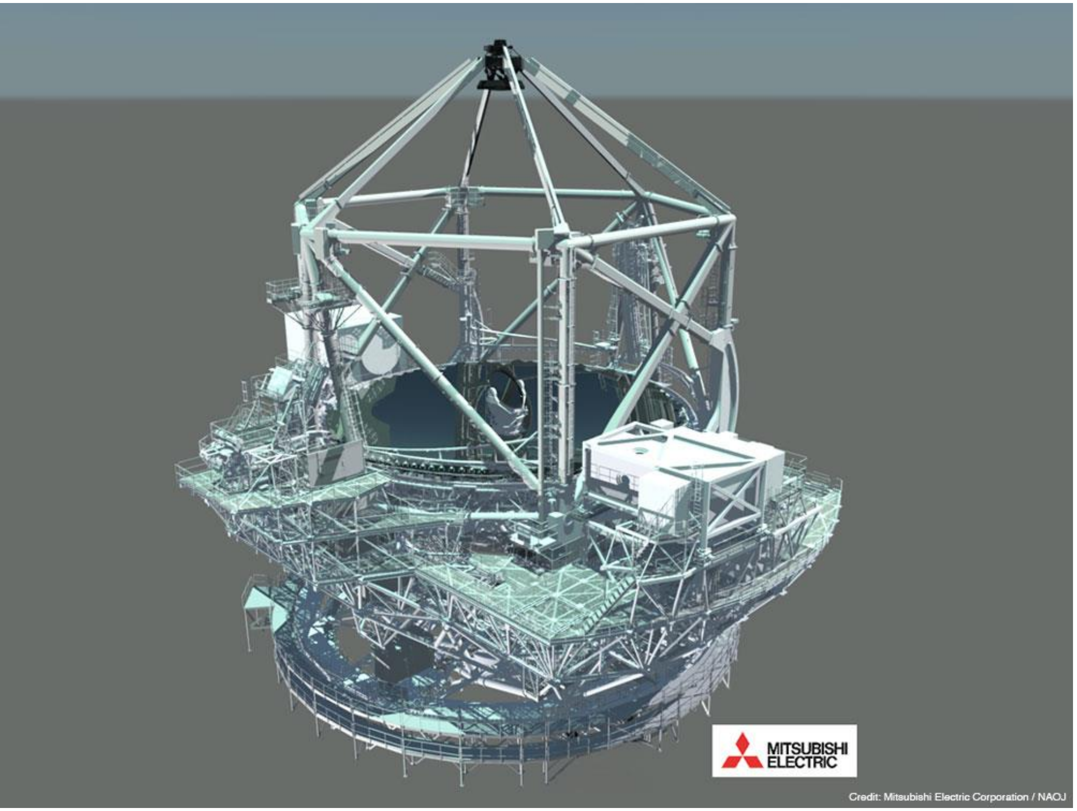
Detector pixel size

- Full-depletion CCD in Hyper Suprime Cam : 15 μm
- Science CMOS (sCMOS) sensor : 6.5 μm
- InSb IR array in IRCS : 27 μm
- HgCdTe HAWAII-2RG array in MOIRCS : 18 μm

- If you put FD-CCD directory on the prime-focus : 0.19”/pix
  - With one 2K x 4K CCD you can cover 6.3’ x 12.6’ FoV.
  - Good for survey instruments.
  - Mosaic CCD wide field visible imager, etc.

- If you put sCMOS camera directory on Ns focus : 0.013”/pix
  - With one 2K x 4K detector, you cover 26” x 52” FoV.
  - Good for high-spatial resolution instruments.
  - AO-supported IR imager, etc.

With TMT ?



- Nasmyth focus (F/15)
  - f~ 450m
  - 2183 μm / “
  - 1309 mm / 10 arcmin
- IRIS imager (Feff/25.8)
  - f_eff ~ 774m
  - 3755 μm / “
  - 4 masec / 15um pixel

Signal and noise

- Photons follow Poisson statistics

- Signal-to-noise ratio, we assume object is observed with Npixels :

$$SN = \frac{n_{\text{object}}\tau A t \eta}{\sqrt{(n_{\text{object}}\tau + n_{\text{sky}})At\eta + (n_{\text{background}} + n_{\text{dark}})t + N_{\text{pixel}}\text{RON}^2}}$$

- A : aperture area
- t : integration time
- η : efficiency of the system (through put, filter transmission, quantum efficiency)
- τ : atmospheric transmission
- nobject: number of photons per sec coming to the unit area of the earth
- nsky : number of photons per sec detected by the unit area of the aperture
- nbackground : number of instrumental background photons per sec per Npixels
- ndark : see detector lecture slides. Per Npixels
- Npixel : number of pixels for the signal calculation
- RON : read-out noise, see lecture 5 and 6 slides.

Signal and noise

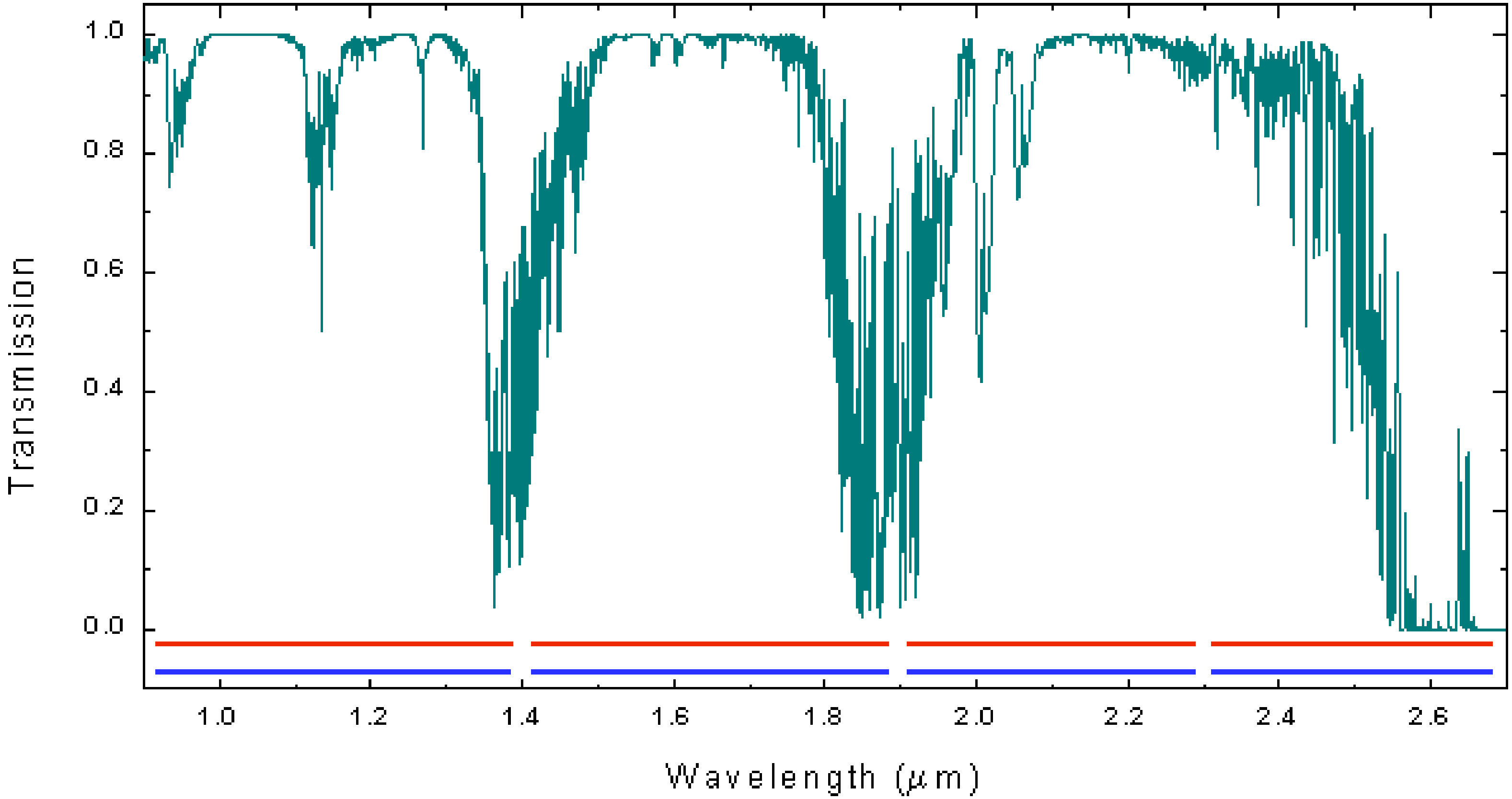
- Detection

- Peak and width determination

- Noise determined by “background” : sky background, weak absorption line on the continuum component

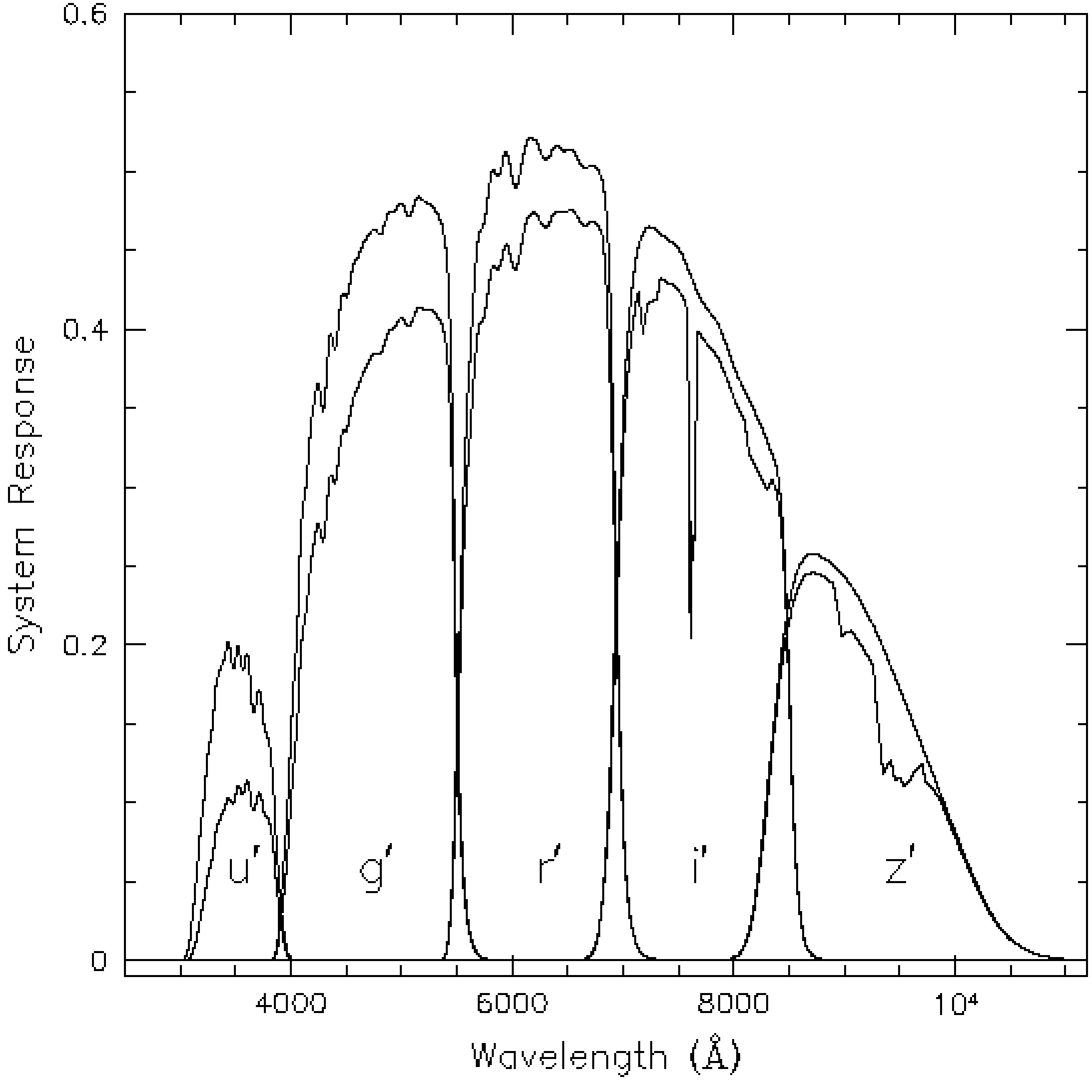
tau in NIR

- H2O absorption bands



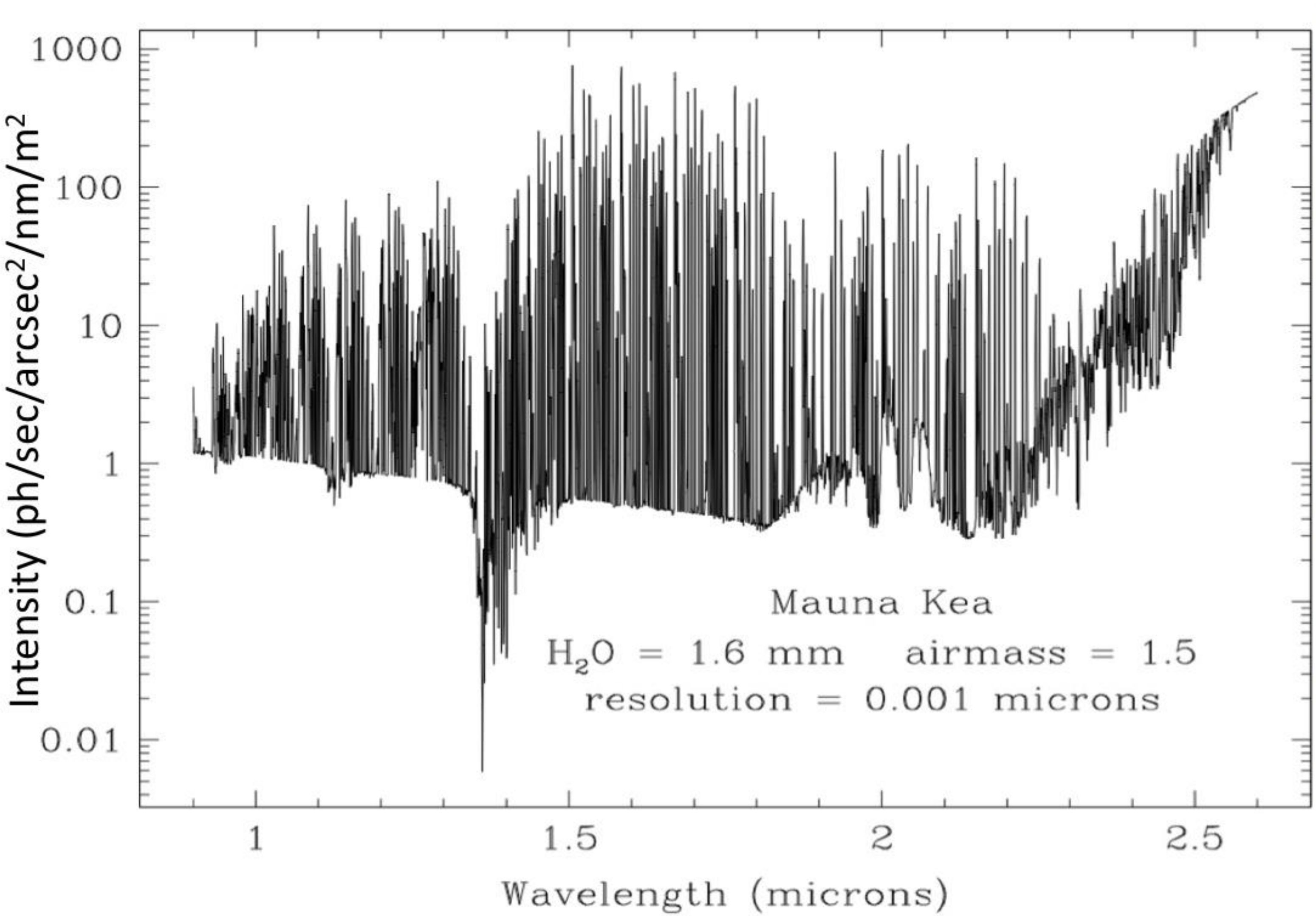
From http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-transmission-spectra

eta and tau in visible



eta for the Sloan Digital Sky Survey (SDSS) imaging camera
Bottom lines for eta x tau

n_sky



From http://www.gemini.edu/sciops/telescopes-and-sites/observing-condition-constraints/ir-background-spectra

n_background

- n_background coming from telescope/dome structure and inside instrument.

- Typically you can ignore n_background in the visible instrument.

- You need to design an IR instrument such that n_background is negligible compared to $A \tau$ n_sky >> n_background .

n_object and ADU

- AB magnitude system : 3631 Jy as zero-magnitude
-
- Astronomical Data Unit
  - Usually 1 count in the final image does not represent 1 electron (1 photon).
  - Usually set to 1ADU~RON
  - Conversion GAIN factor in the detector readout.
    - Amplification in the readout
    - Analog to Digital conversion

Comparison

- Comparison between the components. 8m aperture telescope.

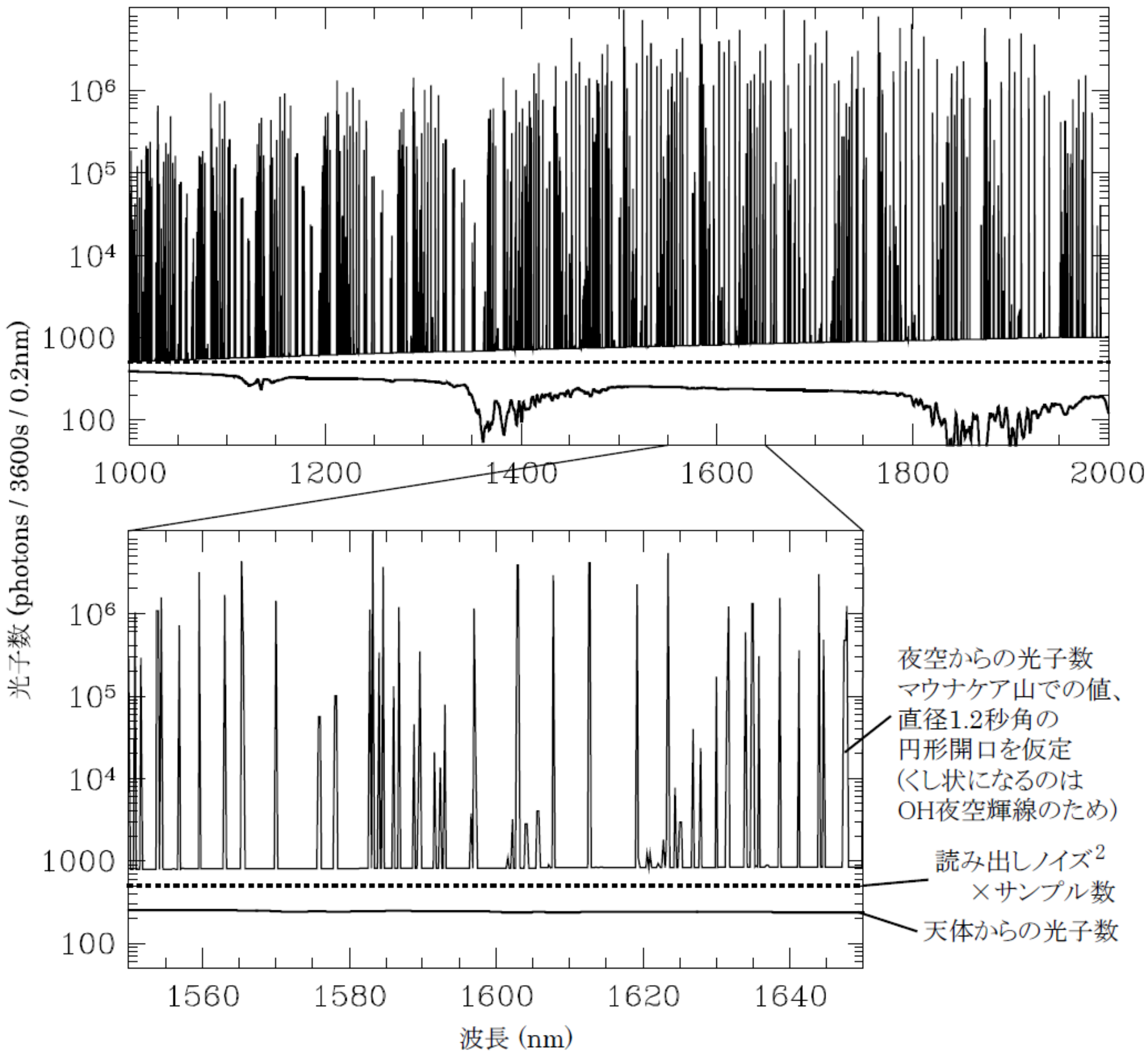
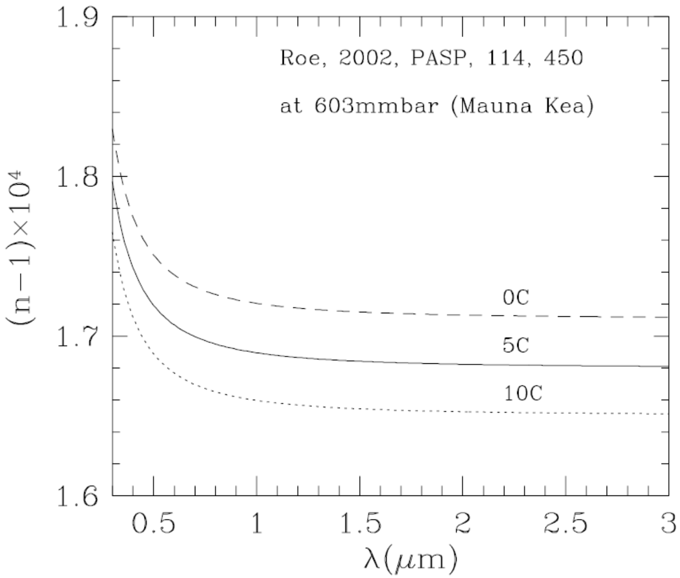


図1　近赤外線での天体からの光子数，夜空からの光子数，読み出しノイズの比較

AB=21mag

Atmospheric Refraction

- Refraction index of the air



AOinst/refraction_index/refraction_index.pdf

- Image upward-shift due to the atmospheric refraction

	400nm	600nm	1200nm	1600nm	2200nm
0 deg	0	0	0	0	0
30 deg	20.7″	20.3″	20.1″	20.0″	20.0″
45 deg	35.9″	35.2″	34.7″	34.7″	34.7″
60 deg	62.2″	60.9″	60.1″	60.0″	60.0″

Atmospheric Refraction

- Image upward-shift due to the atmospheric refraction
- ZD=zenith distance

ZD	400nm	600nm	1200nm	1600nm	2200nm
0 deg	0	0	0	0	0
30 deg	20.7″	20.3″	20.1″	20.0″	20.0″
45 deg	35.9″	35.2″	34.7″	34.7″	34.7″
60 deg	62.2″	60.9″	60.1″	60.0″	60.0″

- Atmospheric Dispersion : difference between different wavelength

- Differential Atmospheric Refraction : difference inside FoV