Introduction of near-infrared (NIR) spectroscopy

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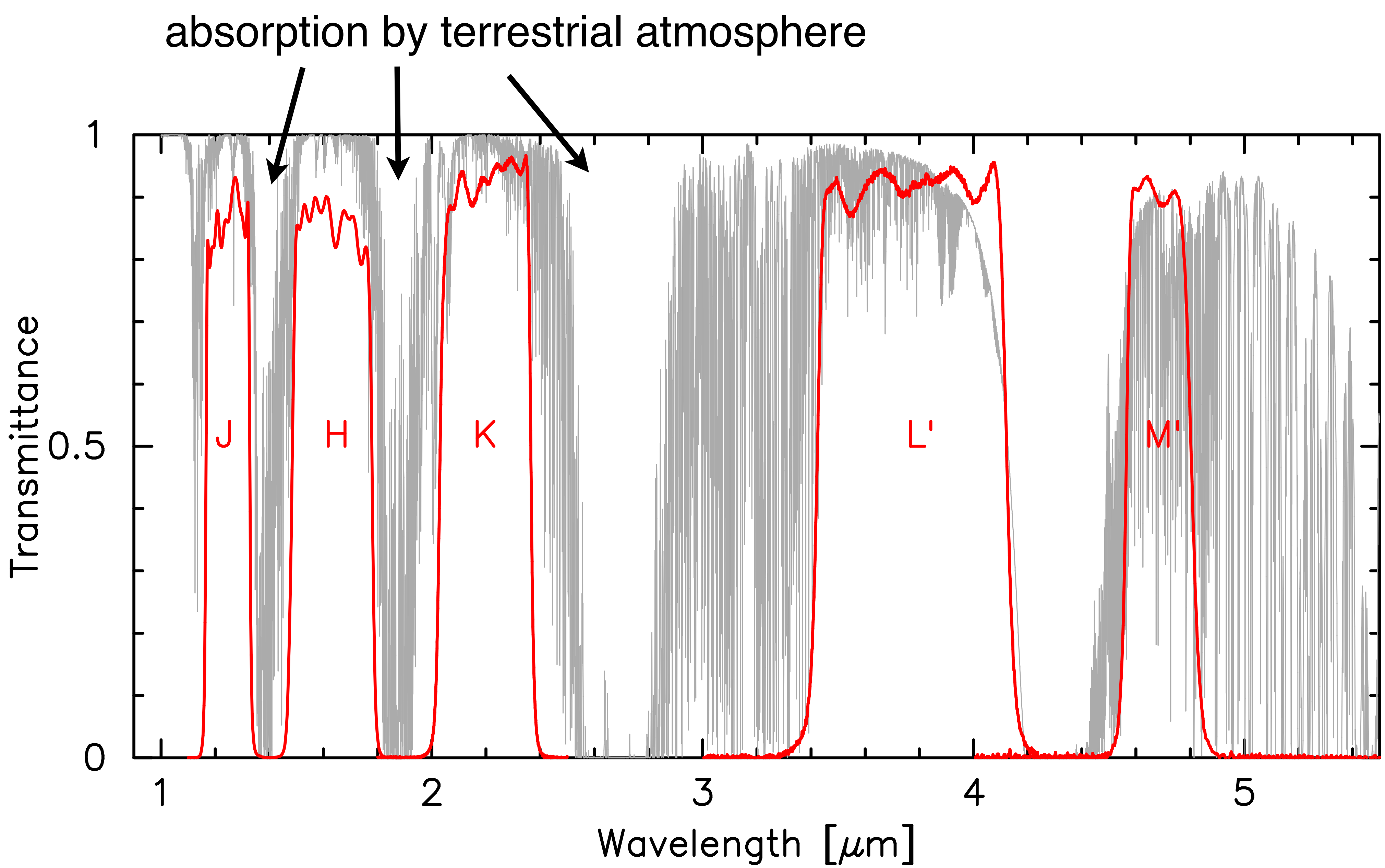
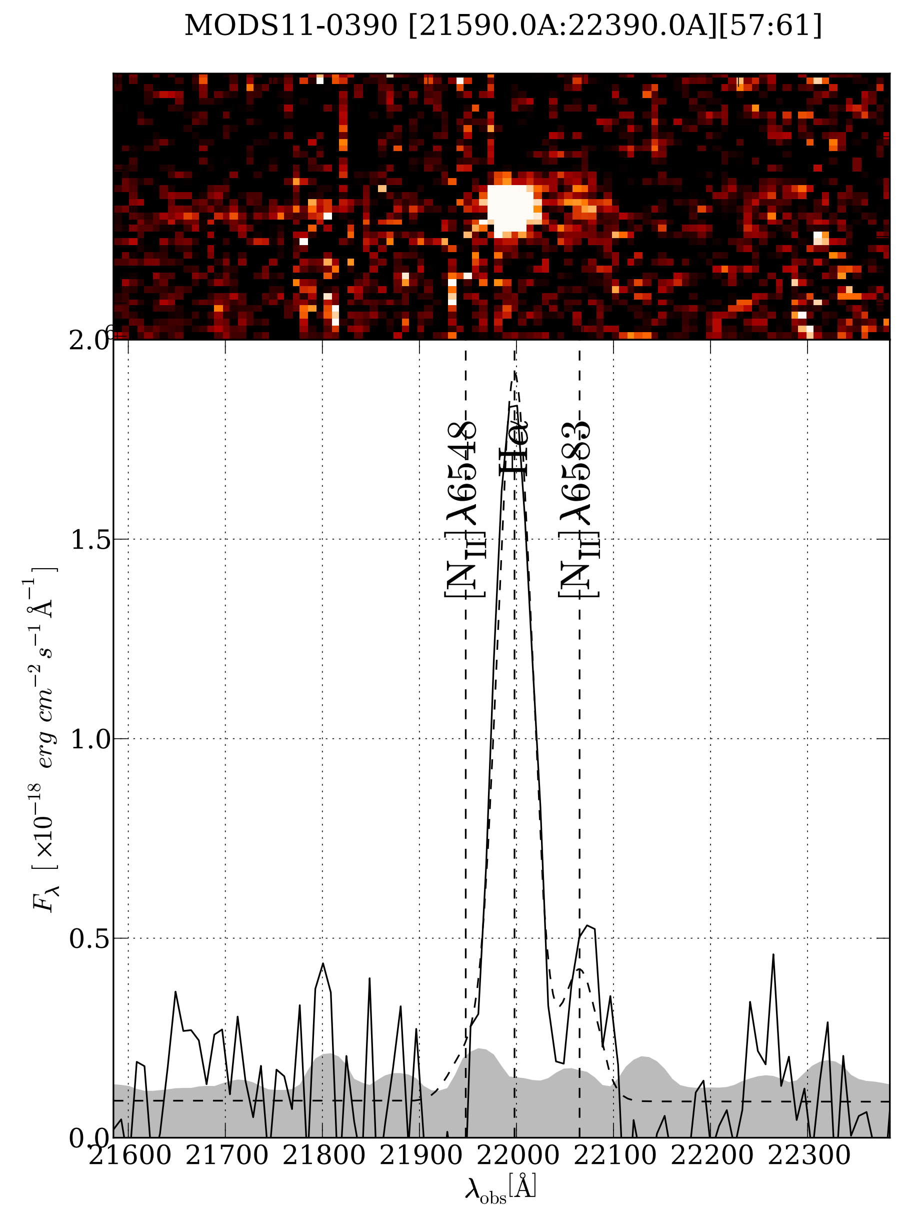
Near-infrared in astronomy



- wavelength range of 1-5 um
- observable windows are limited (J, H, K, L’, M’)

Science case 1 in near-infrared astronomy

- high-redshift galaxies
e.g. Hα emission line at z>1, Lyα at z>7



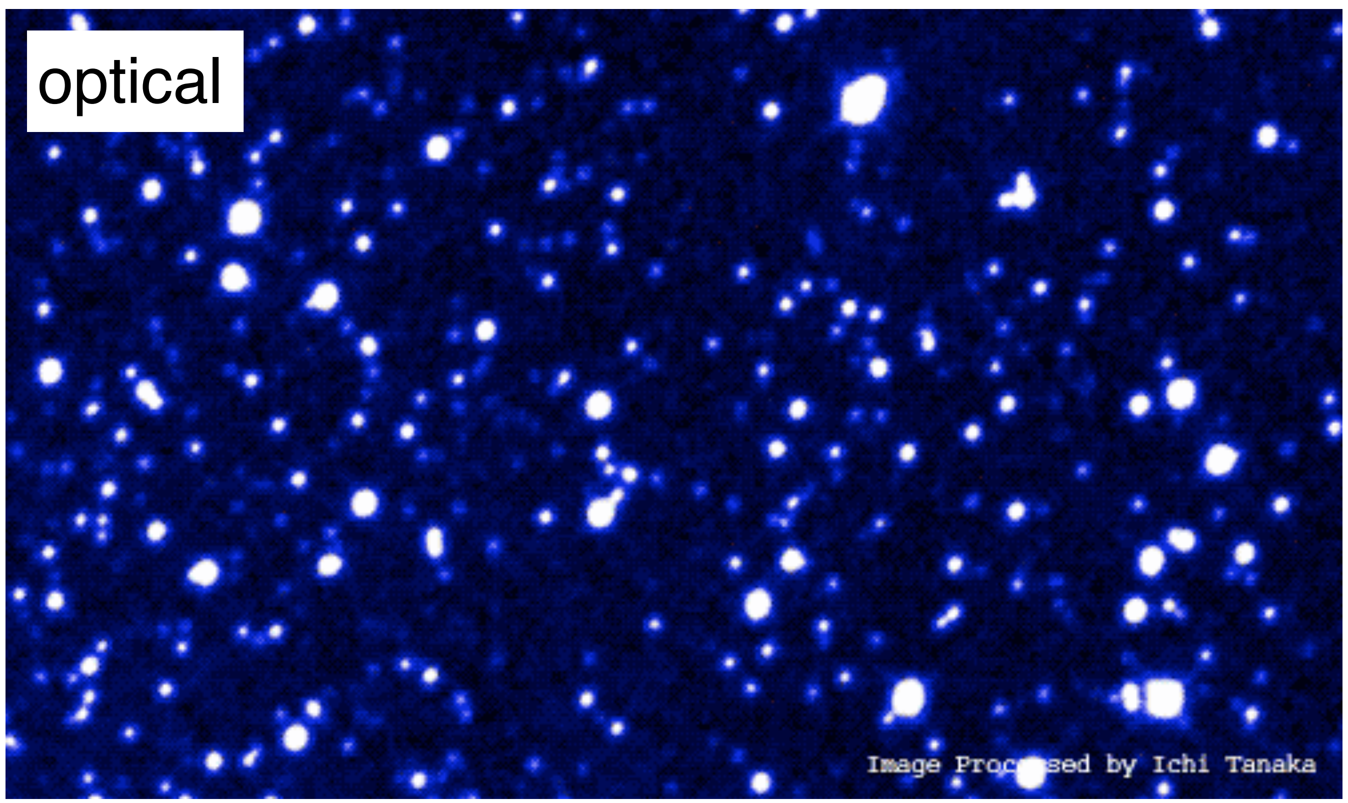
Hα emission line in the rest-frame (z=0)
-> λ_{rest} = 0.6563 um (optical)

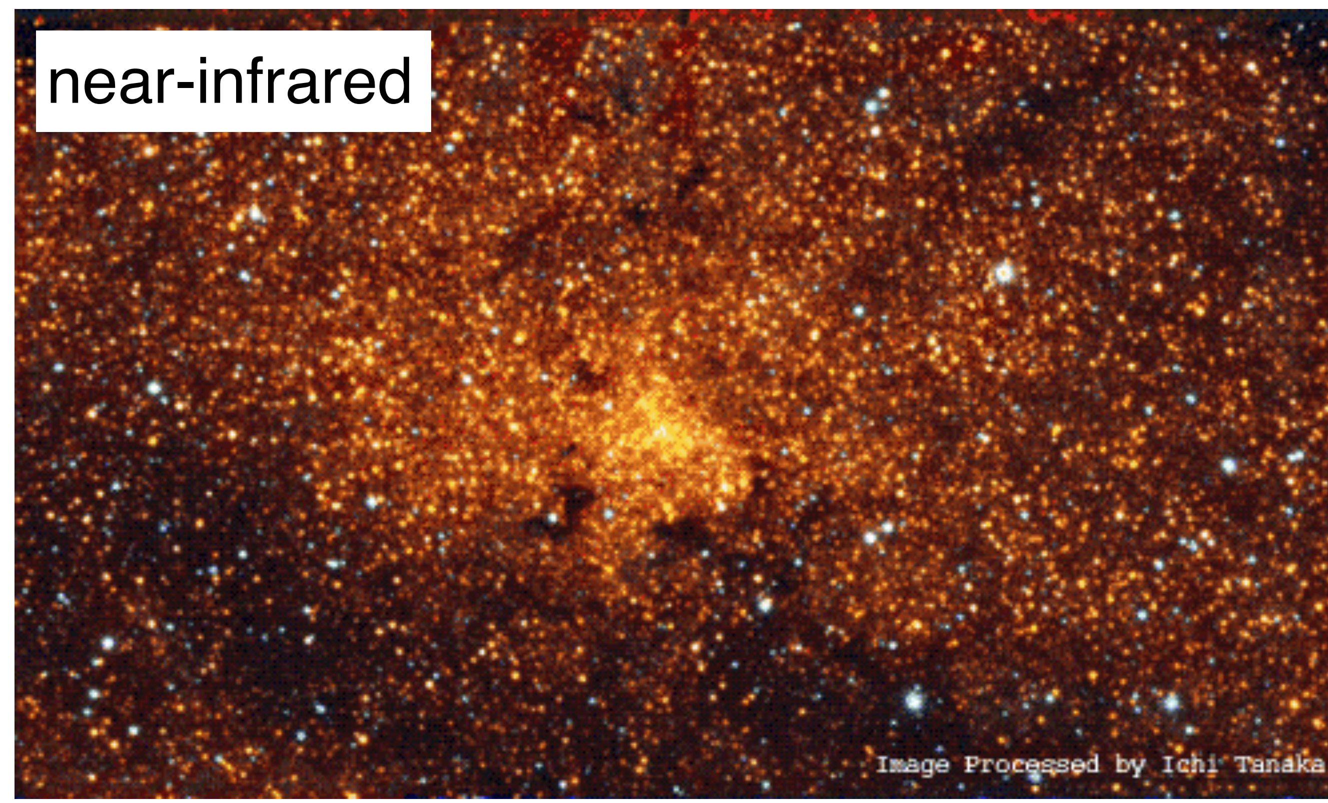
Hα emission line at z=2.35
-> $\lambda_{obs} = \lambda_{rest}(1+z)$
= 2.2 um (near-infrared)

Yoshikawa et al. 2010

Science case 2 in near-infrared astronomy

- dust obscured objects
e.g. Galactic center, star-forming regions

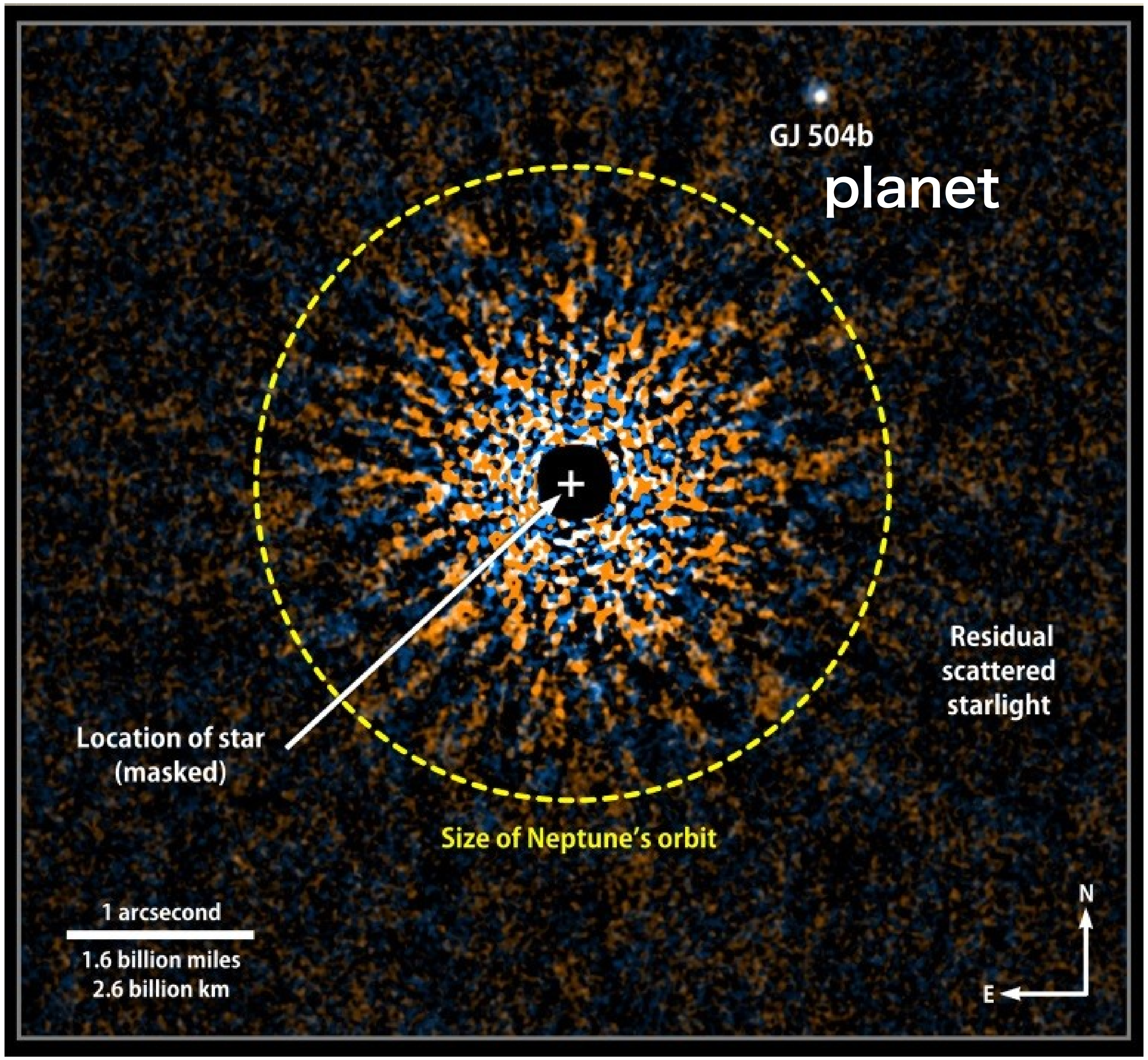




created by Ichi Tanaka

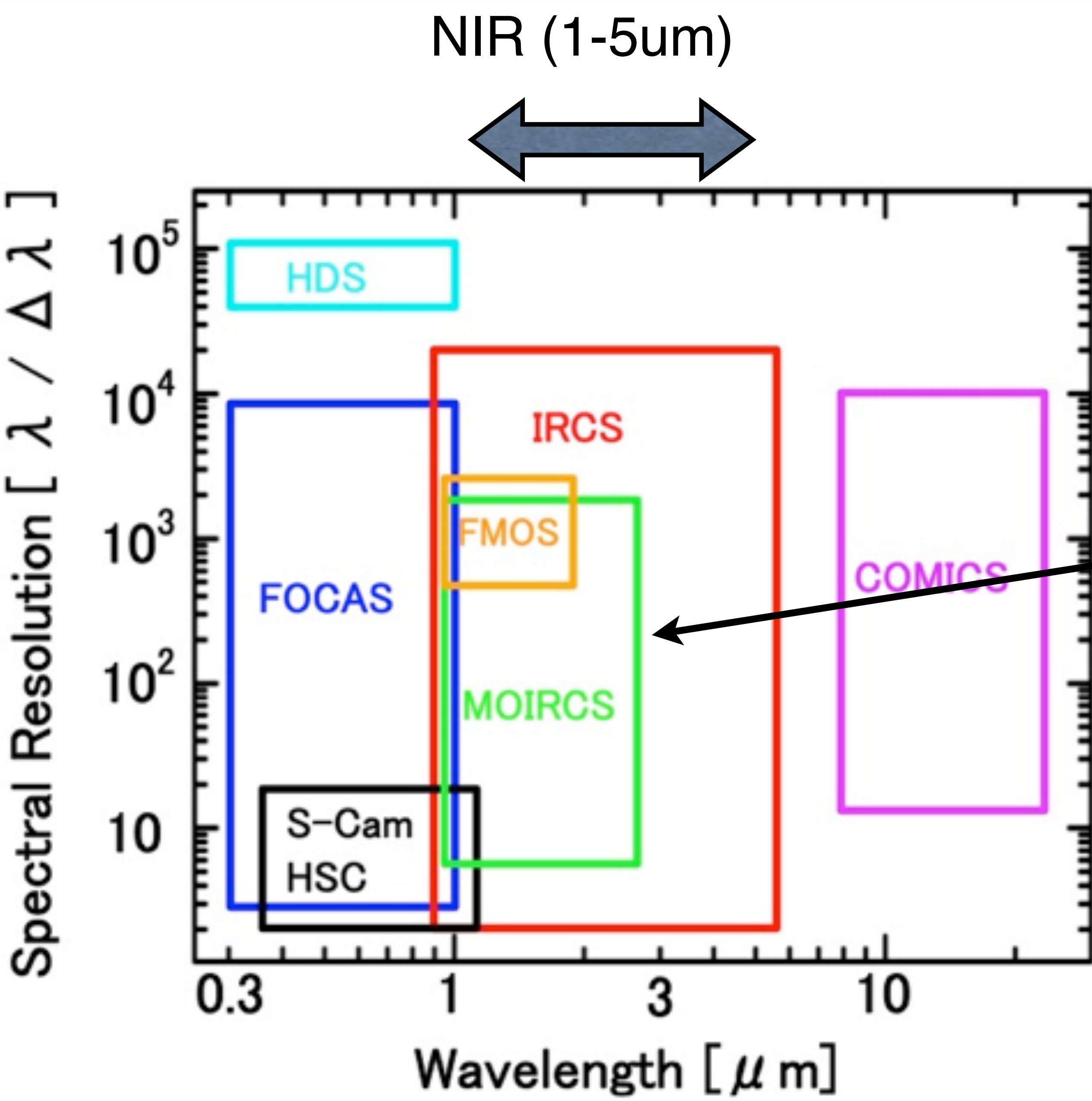
Science case 3 in near-infrared astronomy

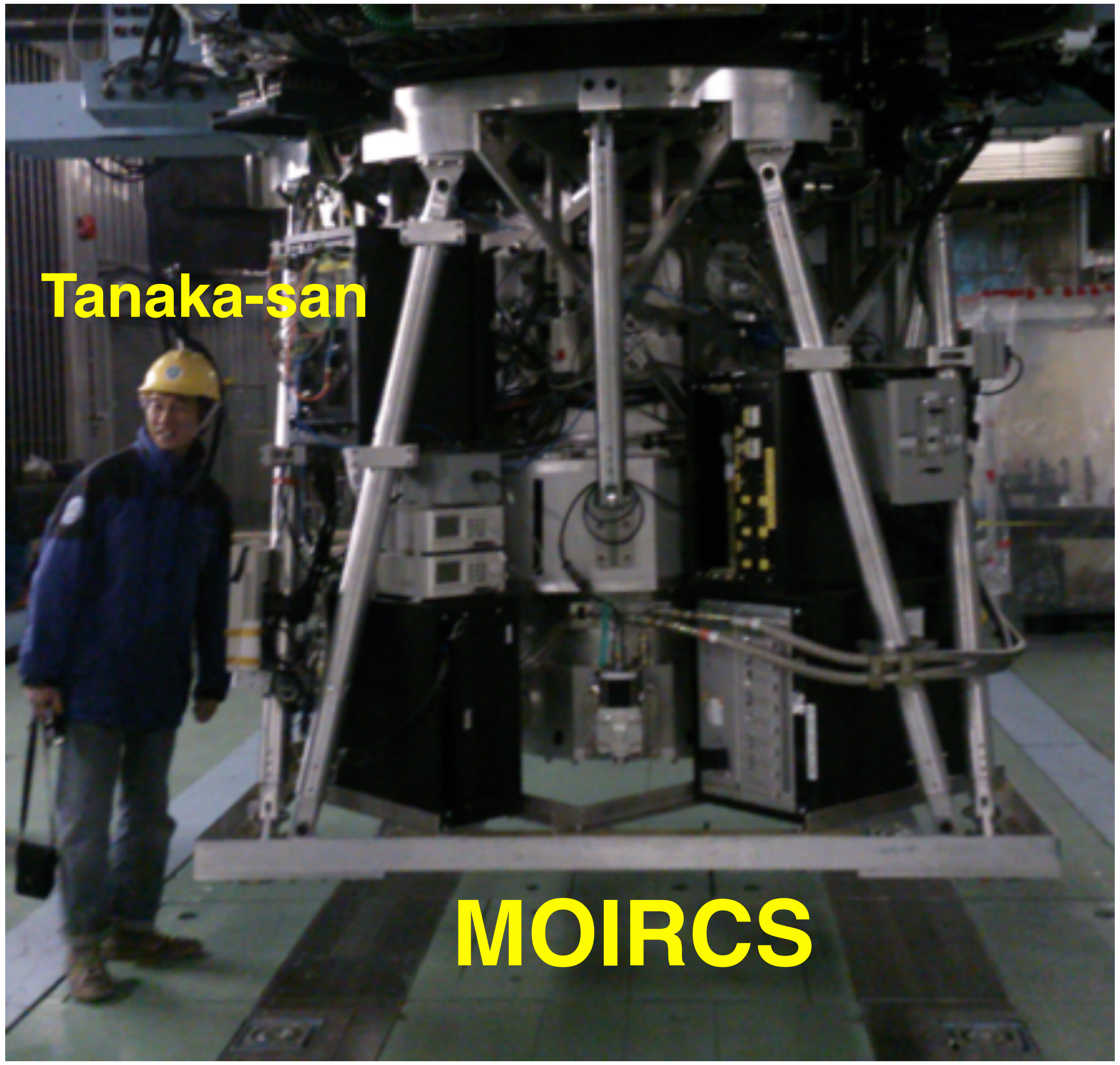
- cool objects
e.g. brown dwarfs, young gas planet



Kuzuhara et al. 2013

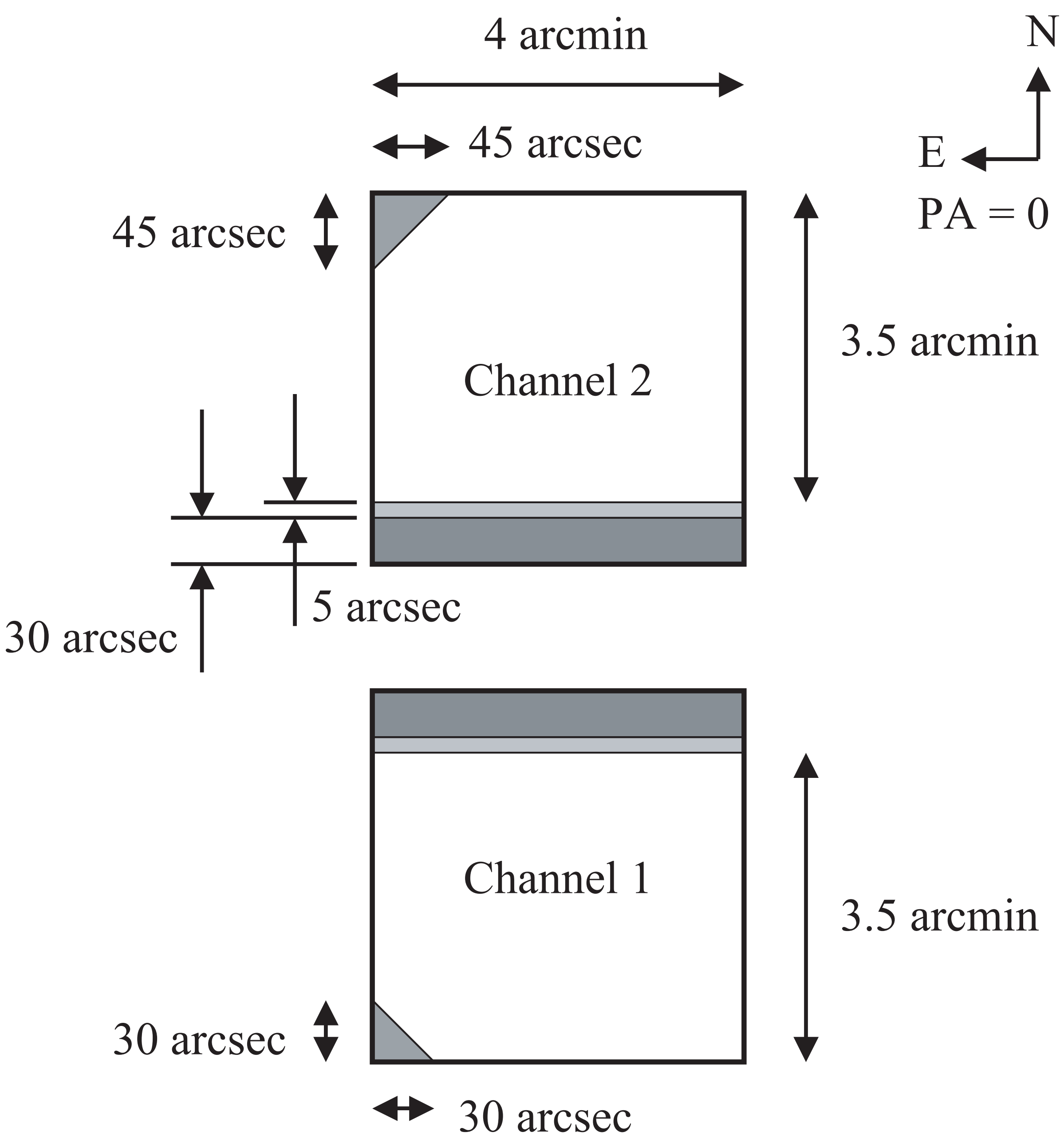
NIR instruments of Subaru telescope



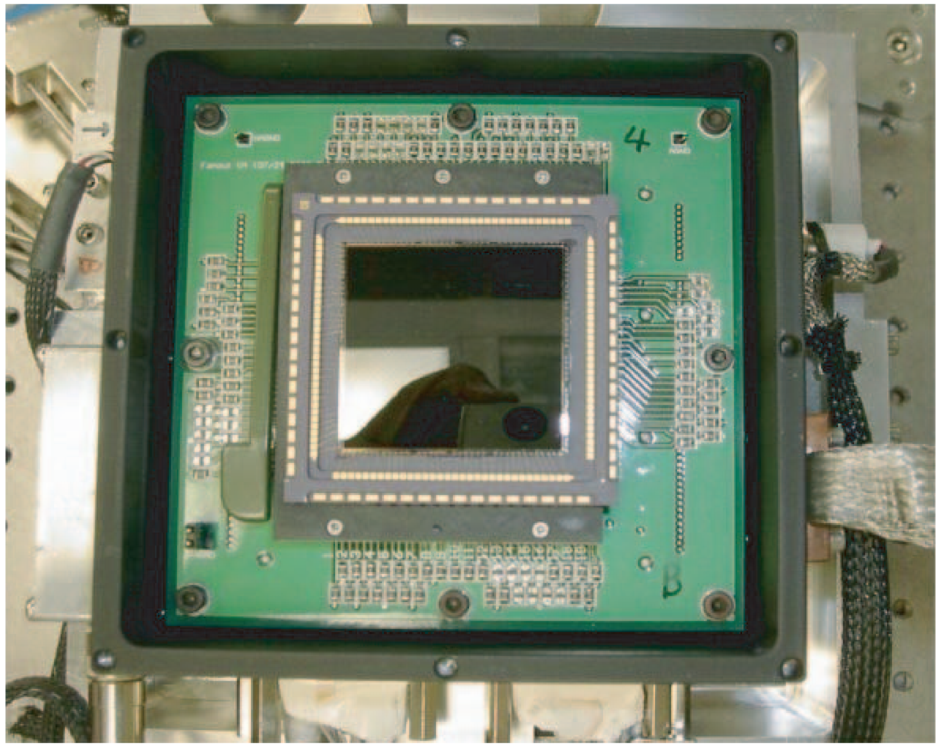


- Subaru telescope has three NIR instruments.
- MOIRCS is mounted on the Cassegrain focus.

Multi-Object InfraRed Camera and Spectrograph



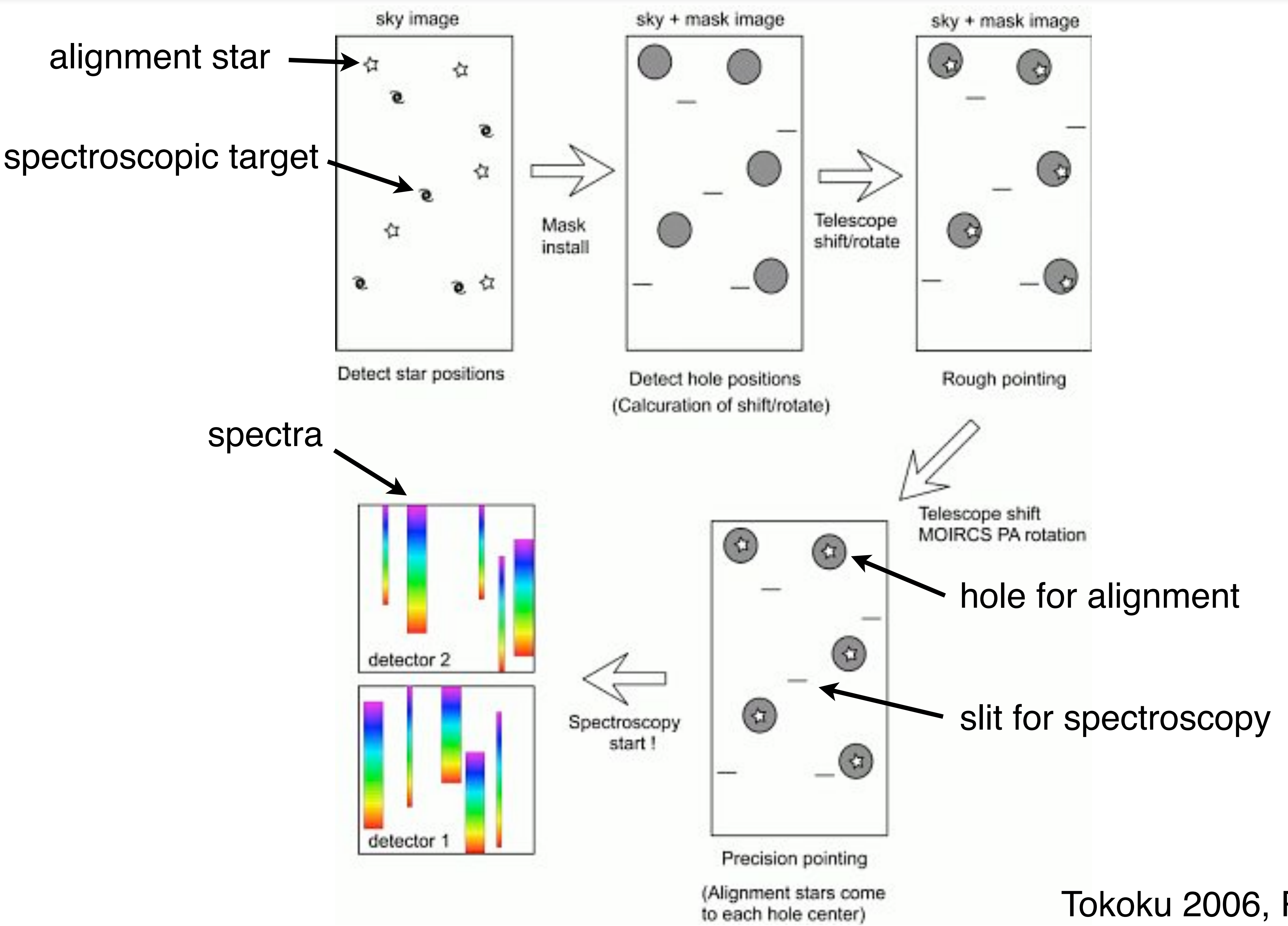
HAWAII-2 detecter (HgCdTe)



Suzuki et al. 2008

- MOIRCS has two detecters, providing a FoV of 4′×7′
- imaging mode and spectroscopy mode

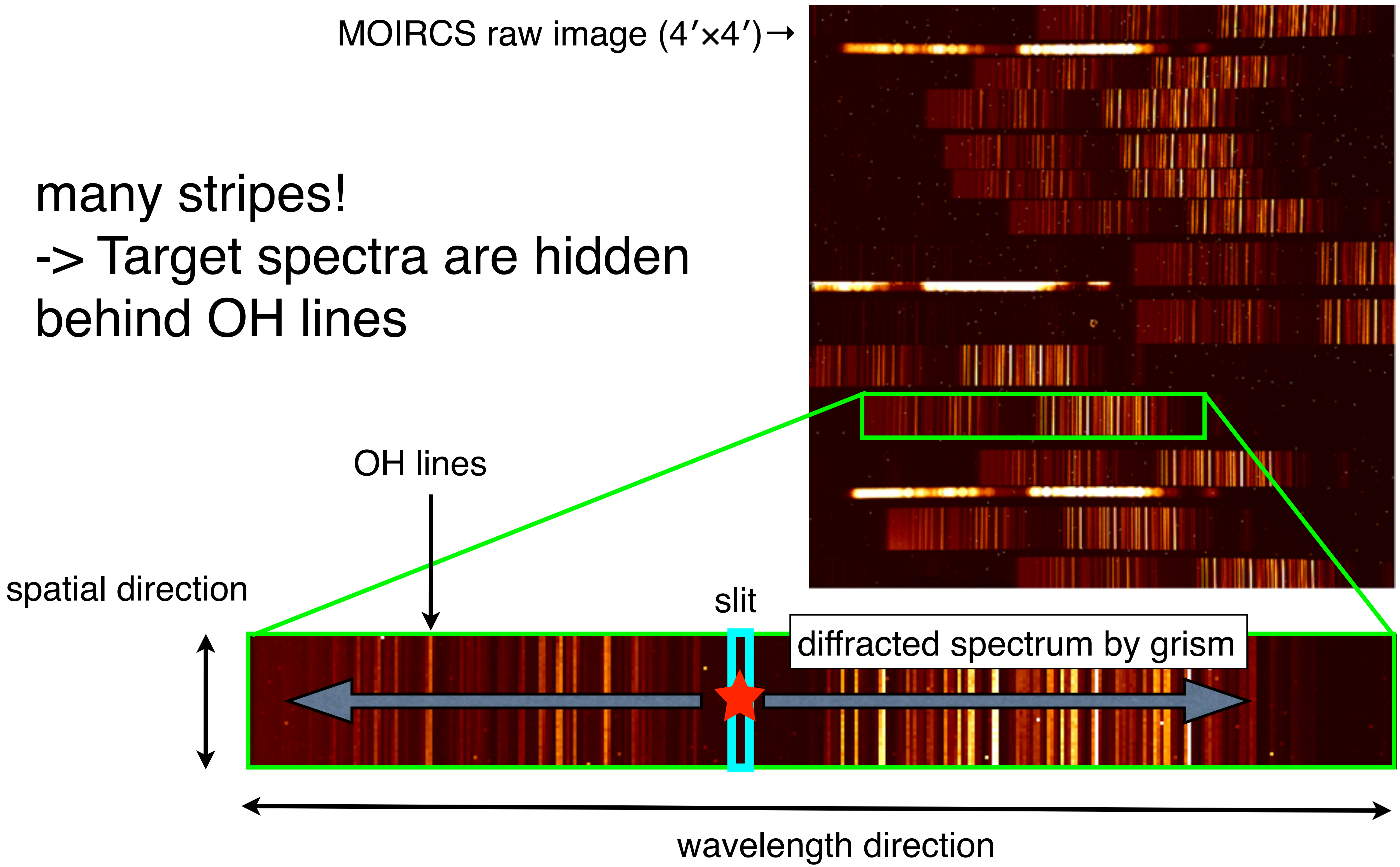
Multi-object spectroscopy mode



Tokoku 2006, PhD thesis

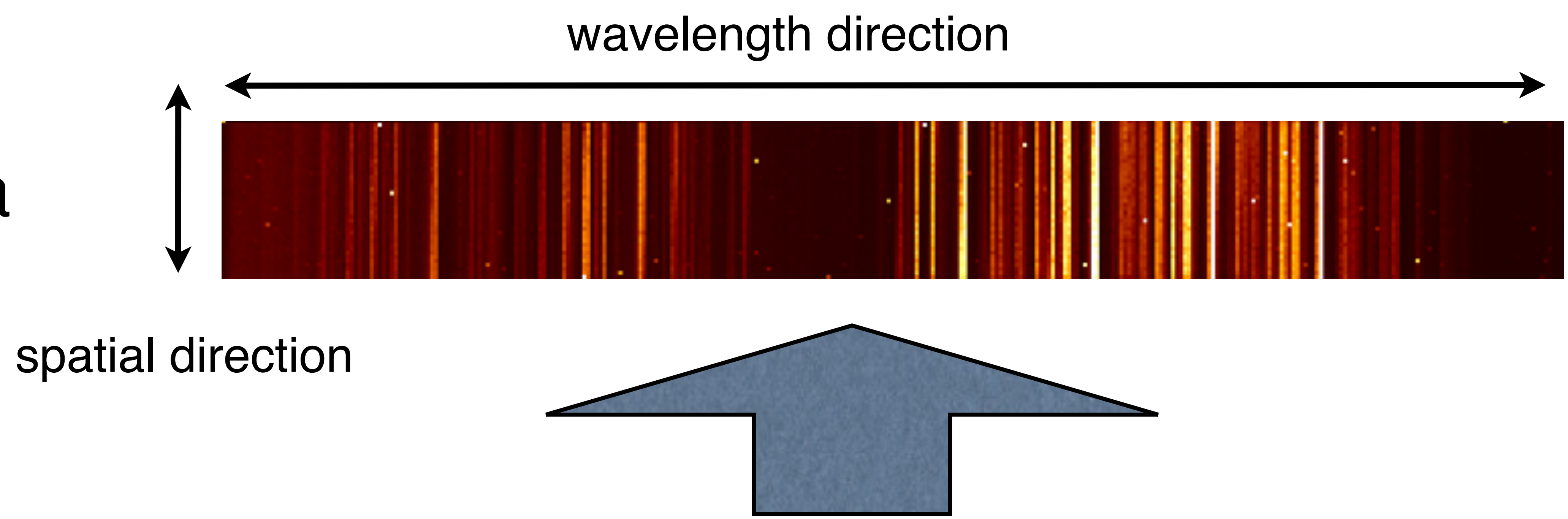
Multi-object spectroscopy mode

many stripes!
-> Target spectra are hidden behind OH lines

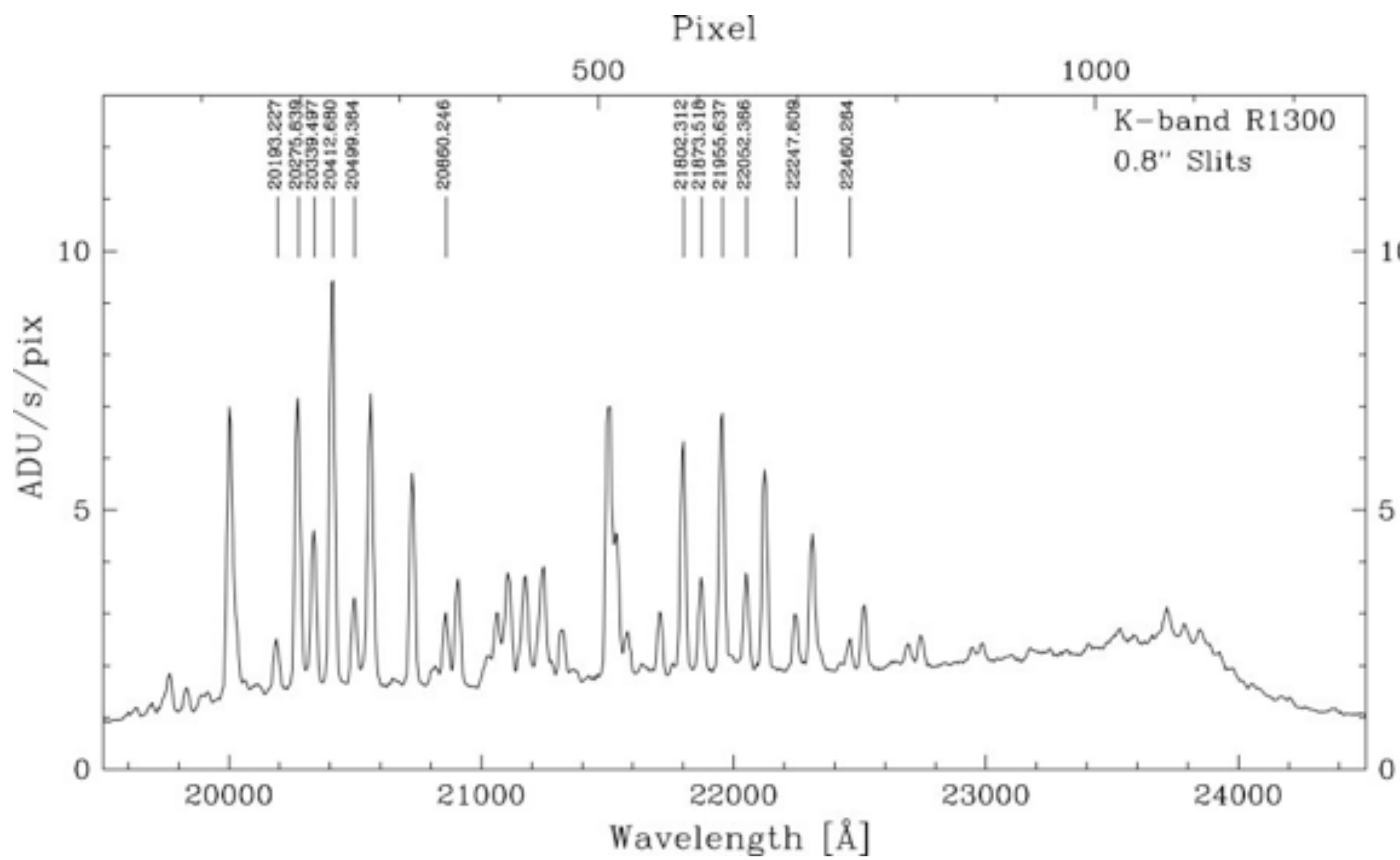


2D spectra and 1D spectra

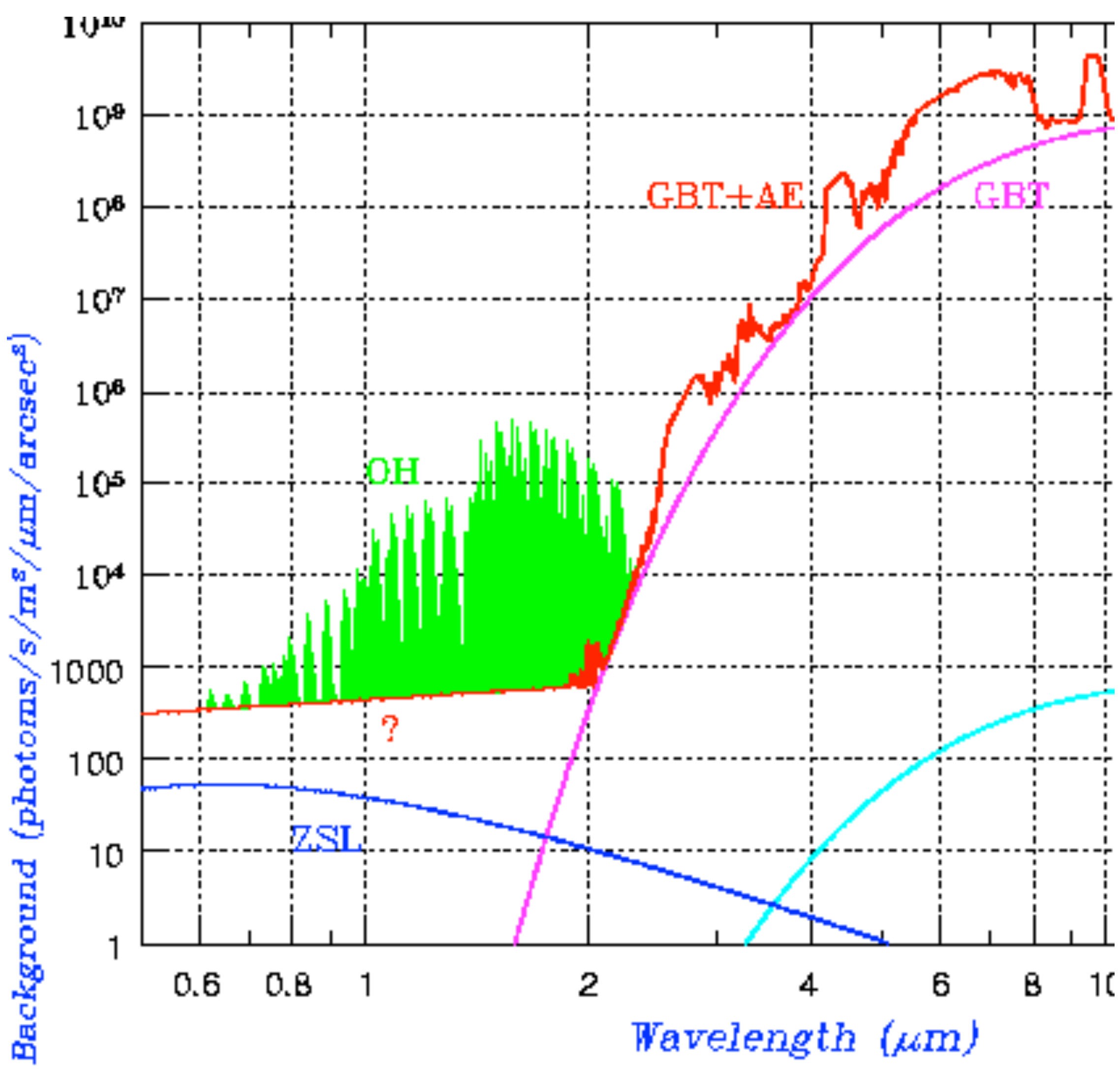
2D spectra



1D spectra



Sky is bright in near-infrared

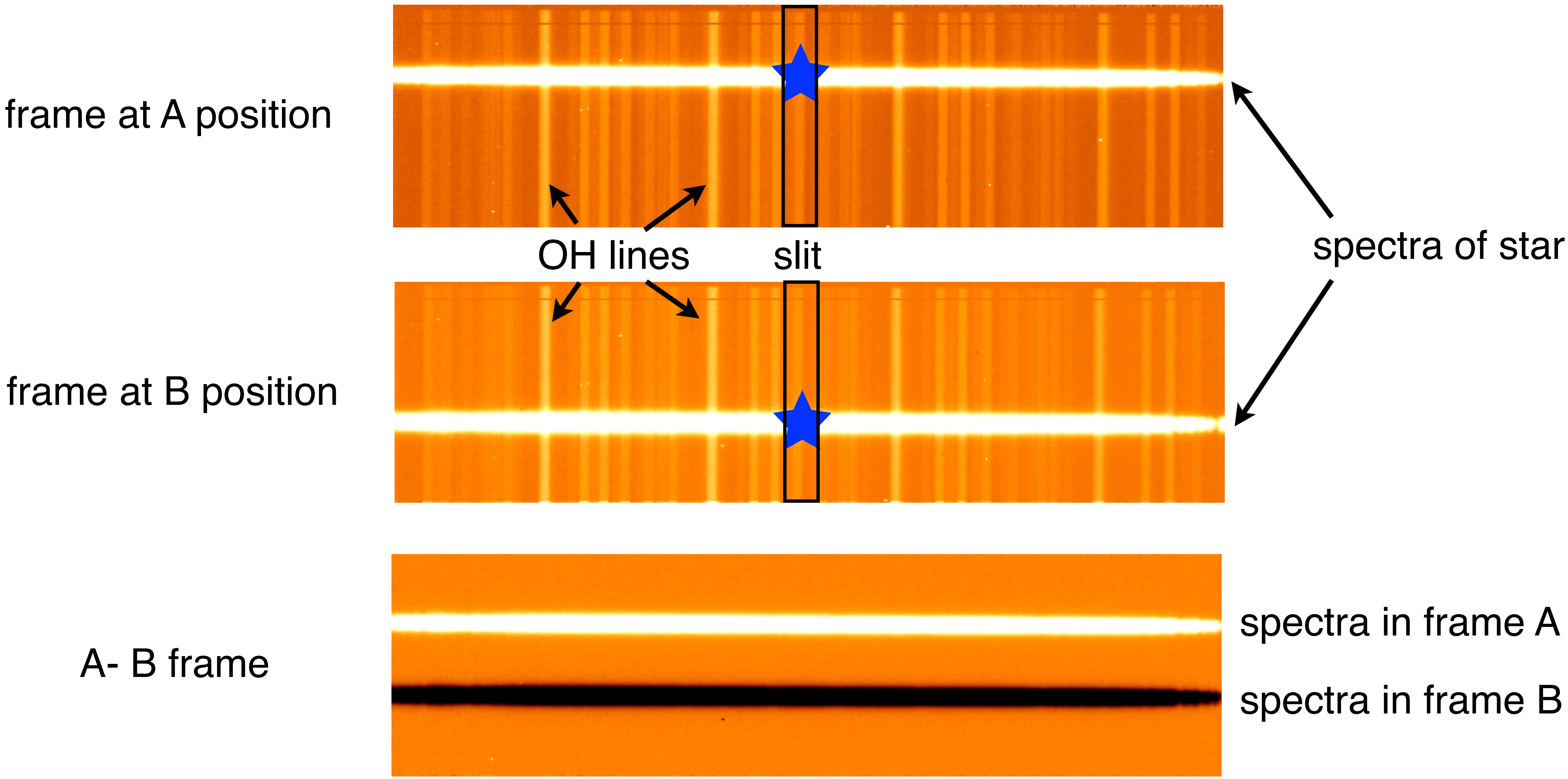


Reference: lecture note by Iwamuro-san
(http://www.kusastro.kyoto-u.ac.jp/ iwamuro/LECTURE/OBS/)

$\lambda < 2.2\mu m$:
OH lines dominate (green line)
$\lambda > 2.2\mu m$:
thermal radiation from telescope dominate (pink line)

- sky emission should be subtracted

A-B sky subtraction



- sky emission is roughly subtracted
- but sky emission is time variable

signal to noise ratio (S/N)

$$S/N = \frac{\text{object} \times t}{\sqrt{(\text{object} + \text{sky}) \times t + \text{readout noise}}}$$

if sky × t << readout noise
 $S/N \propto 1 / t$
if sky × t >> readout noise
 $S/N \propto 1 / \sqrt{t}$
 -> background limit

from MOIRCS website

Grism	Saturation magnitude				Max exposure time (s)(2)(3)	Min BLIP time (s)
	15 s	60 s	300 s	600 s		
zJ500-J	9.8	11.3	13.0	13.8	800	300
HK500-H	9.4	10.9	12.9	13.9	600	50
HK500-K	8.4	9.9	11.7	12.5	600	200
R1300-J	6.8	8.3	10.1	10.8	TBD	4200
R1300-H	7.3	8.8	10.6	11.3	2800	300
R1300-K	7.3	8.8	10.5	11.3	2500	500

- integration time should be longer than the background limit

MOIRCS Grisms

from MOIRCS website

Grism name	Operating range [um]	Resolution (0.5'' slit)	Dispersion [A/pixel]	Sensitivity (Vega magnitude) [mag/arcsec^2]
*zJ*500	0.9-1.78 (*3)	700 @ *J*	5.57	*J*=19.2
*HK*500	1.3-2.5 (*4)	640 @ *H* 820 @ *Ks*	7.72	*H*=17.8 *K*=17.6
*R*1300 (*1)	1-2.5(*5)	1300 @ ch1 ~1100 @ ch2(*2)	1.91 @ *J* 2.61 @ *H* 3.88 @ *K*	*J*=17.8 *H*=16.7 *K*=17.1

spectral resolving power: $R=\lambda / \Delta\lambda$

in the case of the HK500 grism
$R=820$ and $\lambda=22000$Å -> spectral resolution $\Delta\lambda=22000$Å$/820\sim27$Å

- use the appropriate grism for your science case
- resolution depends on the slit width

Procedures of data reduction

0. raw data
1. flat fielding
2. Interpolation of cosmic ray and bad pixel
3. A-B sky subtraction
4. distortion correction
5. slit extraction
6. wavelength calibration
7. residual sky subtraction
8. combine frames
9. telluric correction and flux calibration

From raw image to reduced image

extract the object information from raw data including noises

raw data= gain(x,y) × (object + sky + cosmicray + bad pixel)

①. flat fielding (=gain map)

rawdata / gain(x,y) = object + sky + cosmicray + bad pixel

②. interpolation of cosmicray and bad pixel

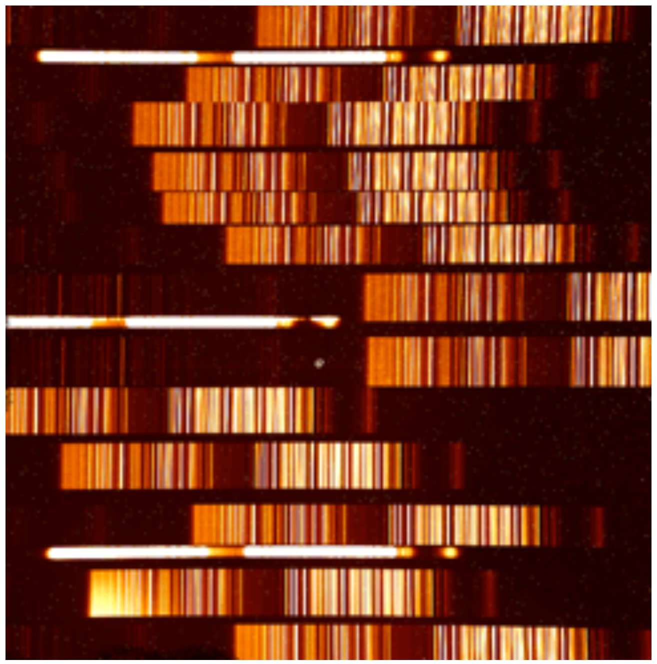
① - cosmicray - bad pixel = object + sky

③. sky subtraction

② - sky = object

1. flat fielding

rawdata



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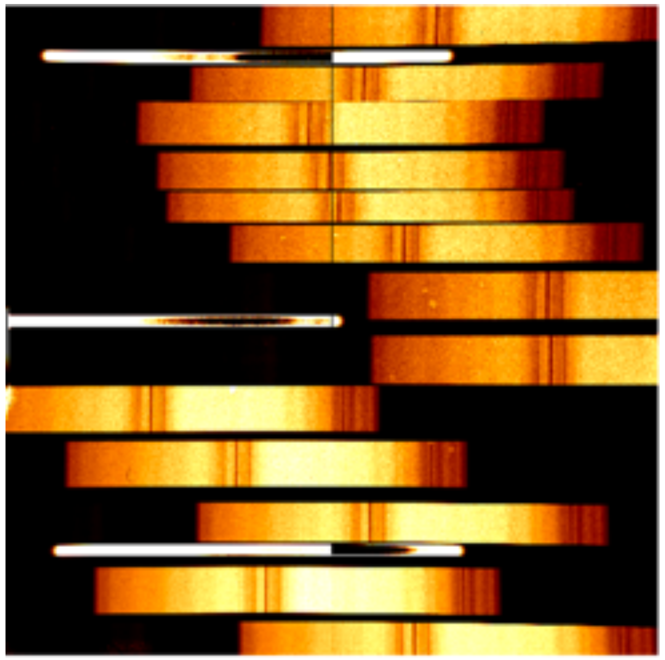
domeflat



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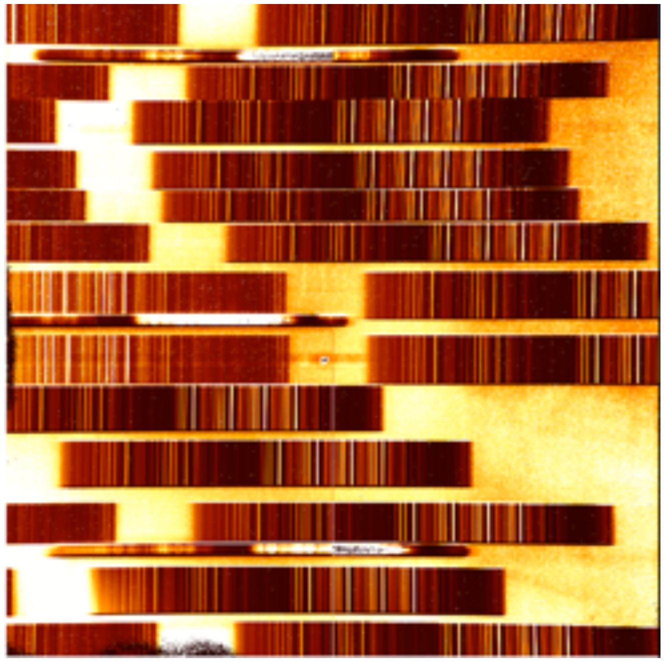
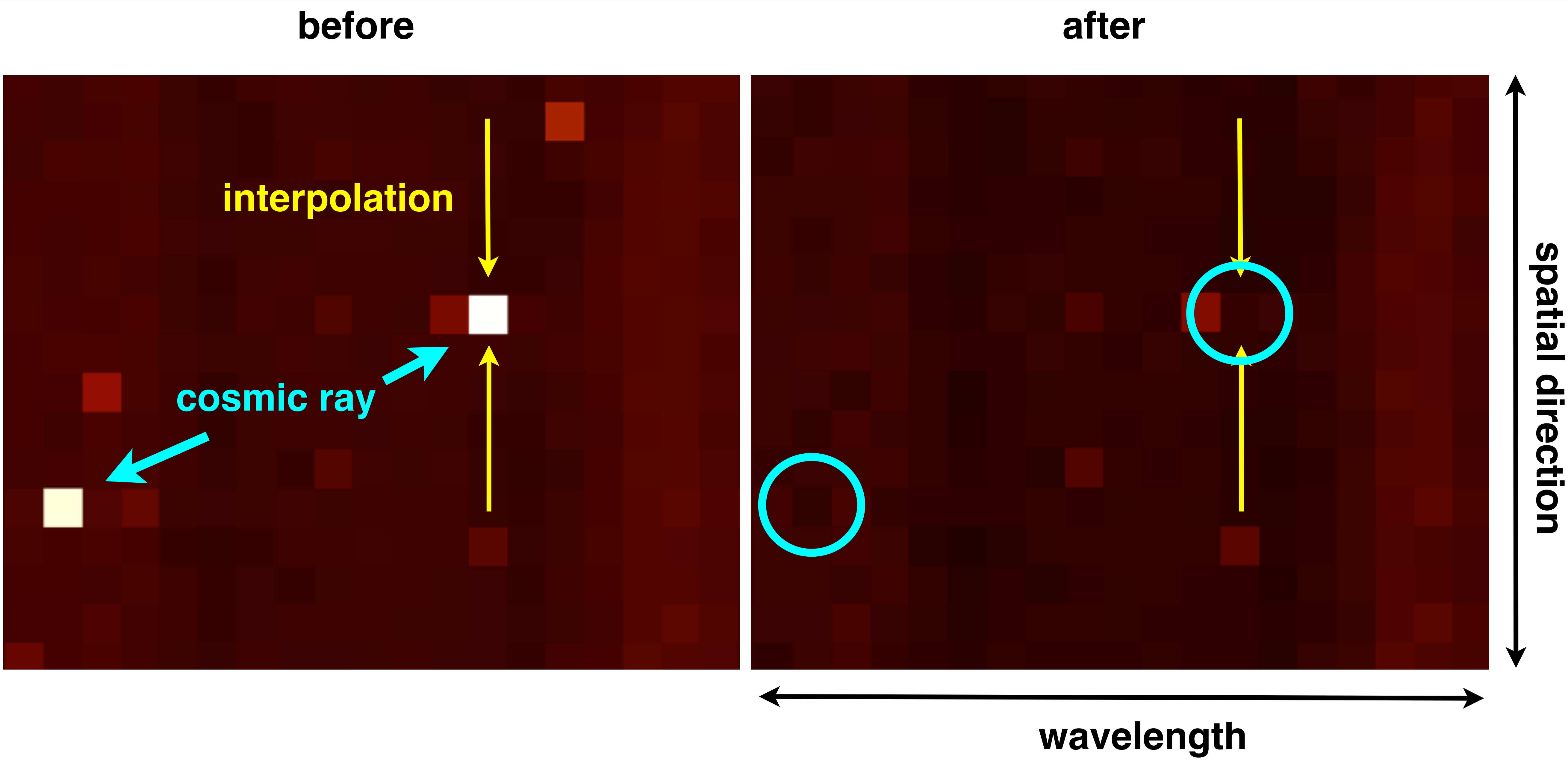
after flat fielding



correct the inequity of sensitivity between detector pixels

rawdata / gain(x,y) = object + sky + cosmicray + bad pixel

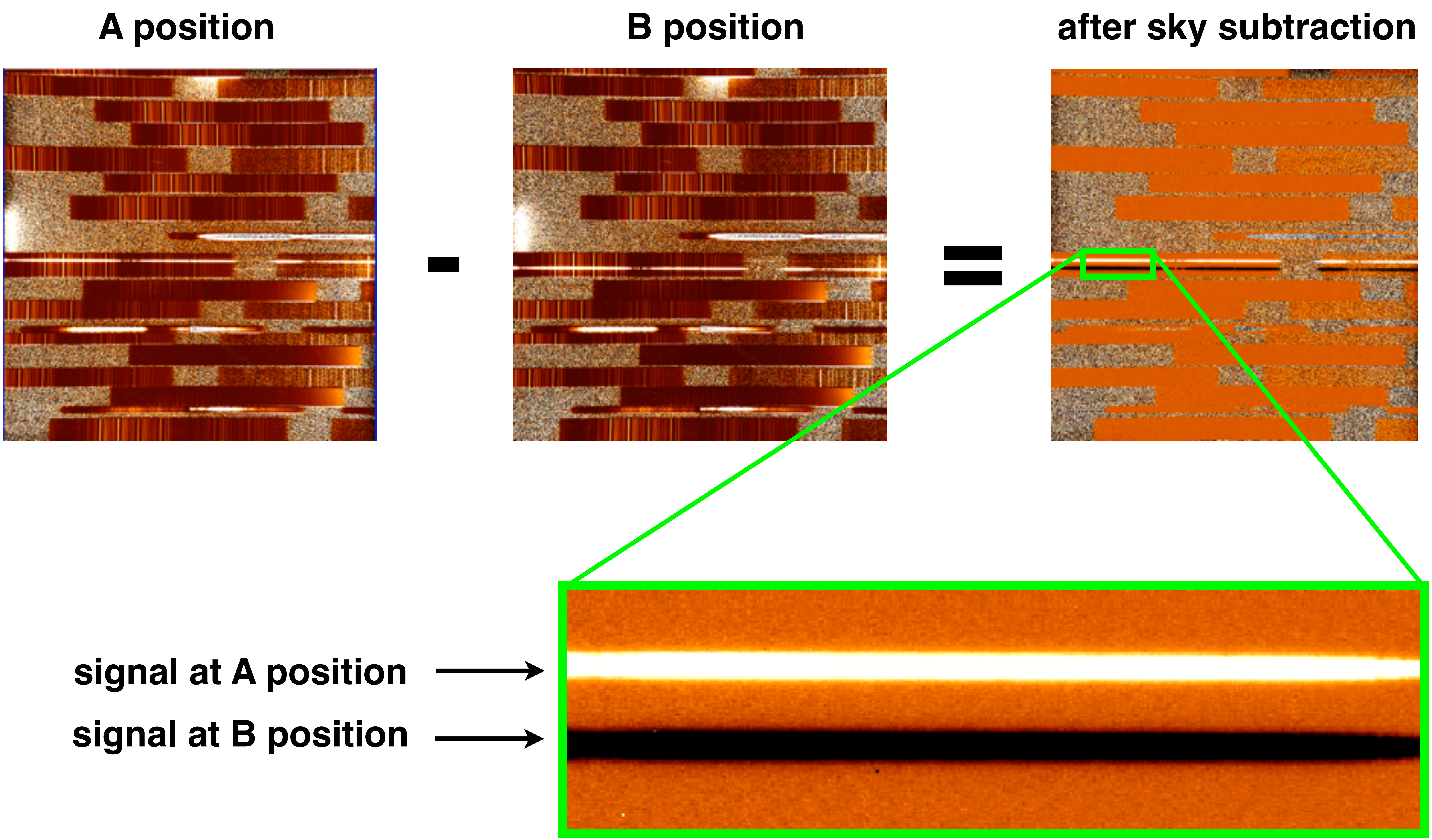
2. interpolation of cosmic rays/bad pixel



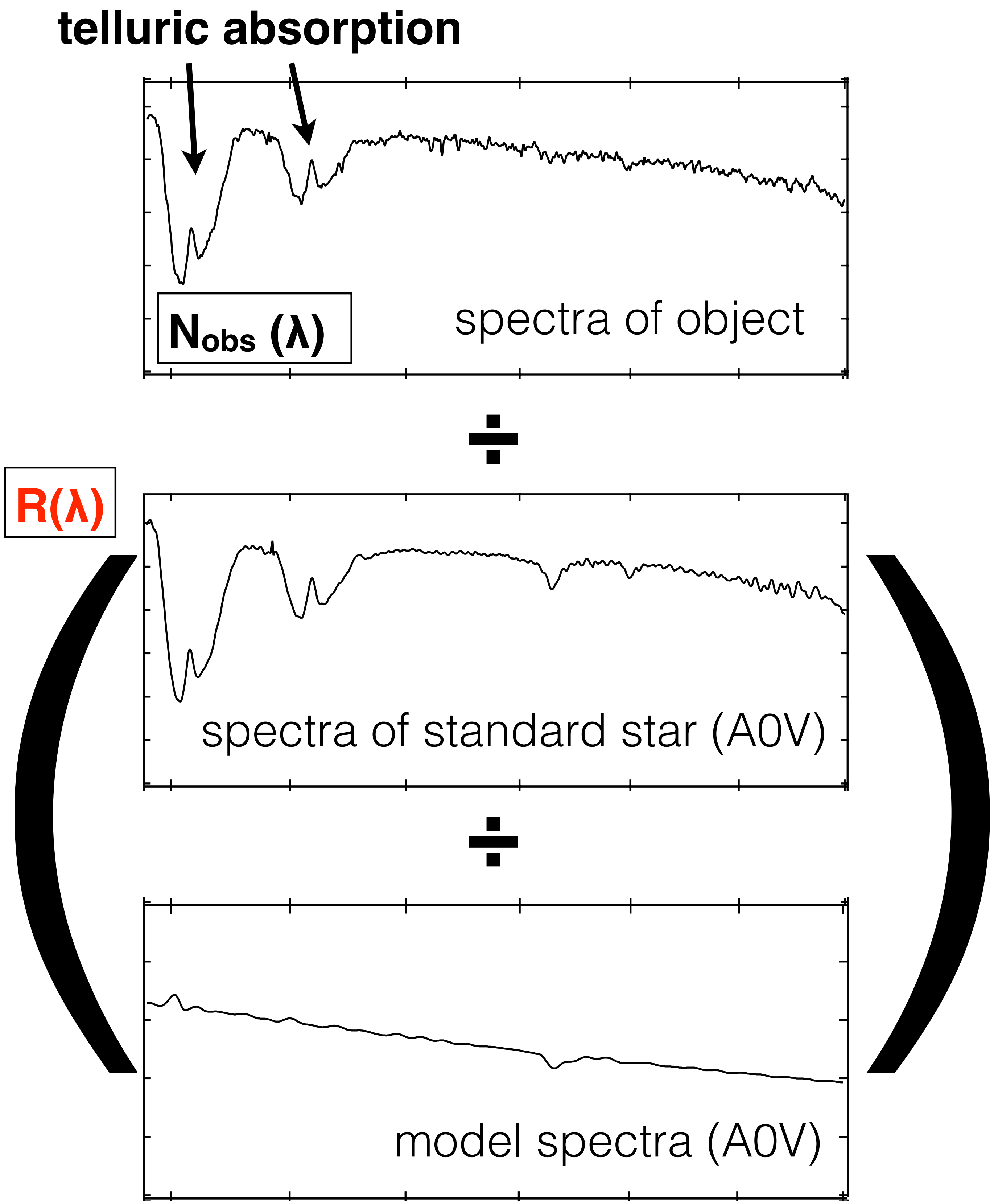
interpolate the pixel value along spatial direction

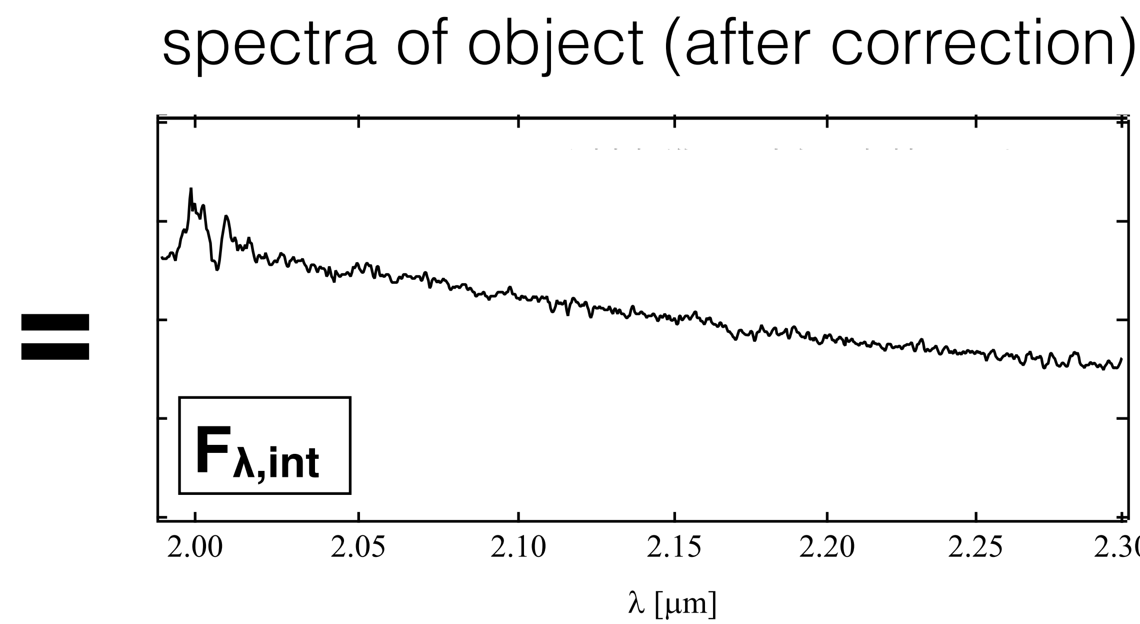
① - cosmicray - bad pixel = object + skynoise

3. A-B sky subratction



9. telluric correction and flux calibration



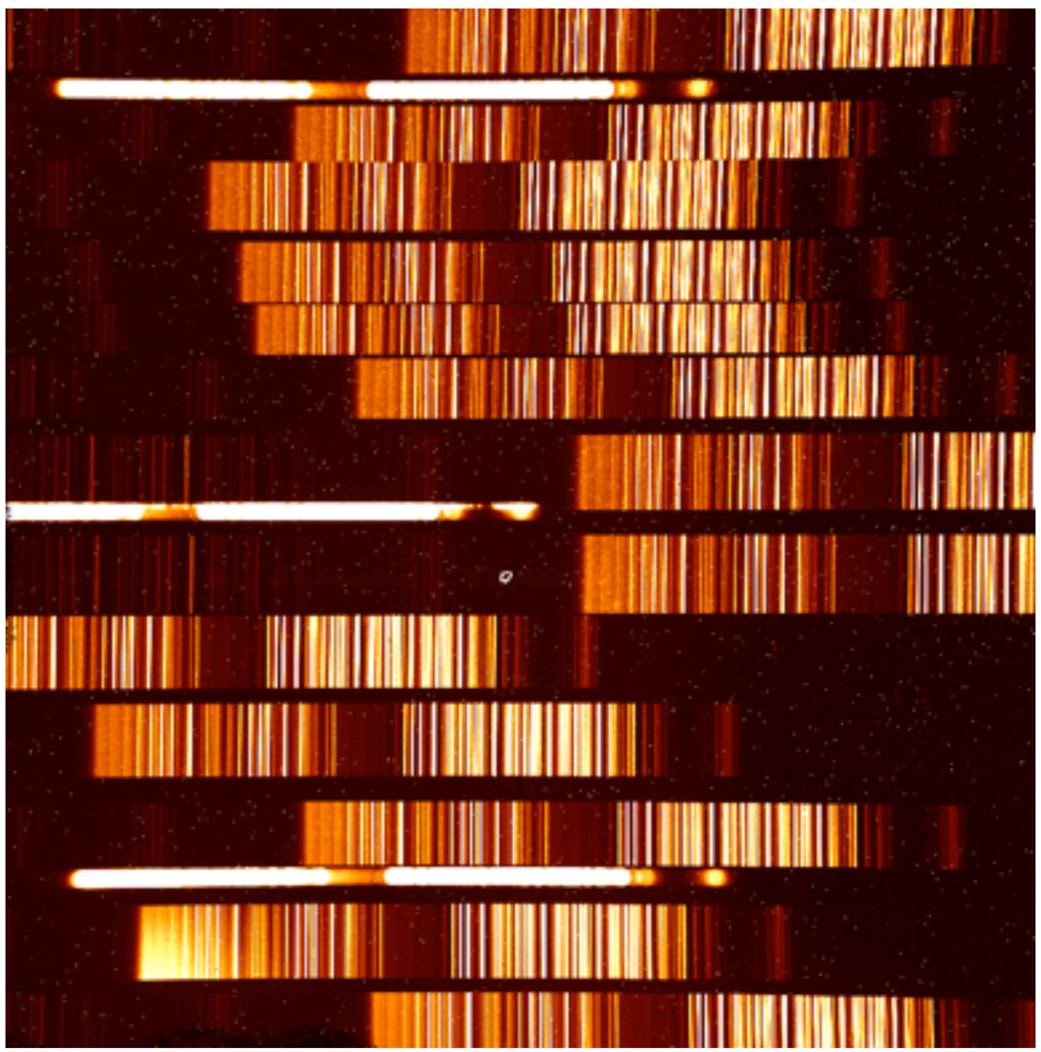


$N_{obs}(\lambda) = R(\lambda) \times F_{\lambda,int}$

$N_{obs}(\lambda)$: observed count
$R(\lambda)$: efficiency of atmosphere/telescope/instrument
$F_{\lambda,int}$: intrinsic flux

From raw image to reduced spectra

raw data



reduced spectrum