Spectroscopy technique

2018 October 4

Preparation

- [6months-1year] Based on your research objective, let's design the observation plan and write proposal to an observatory/telescope
  - Scientific significance, uniqueness, feasibility, usage of the telescope
  - S/N ratio, wavelength resolution, and restriction on the exposure time

- Determine the instrumental setting, which includes a disperser, slit (width), order-sorting filter

- [>1month] Make a concrete plan for observations of your target(s), standard stars, and other calibration data (flat, bias or dark, comparison lamp)

- [>1month] Close communication with support scientists, experts of the telescope/ instruments

- Narrower slits do not always work fine. → go to next slides

Atmospheric dispersion (1)

- A difference in the atmospheric refraction results in deflection, which depend on wavelength.

- This effect means that positions of celestial bodies are dependent on observed wavelength (more severe for shorter wavelengths).

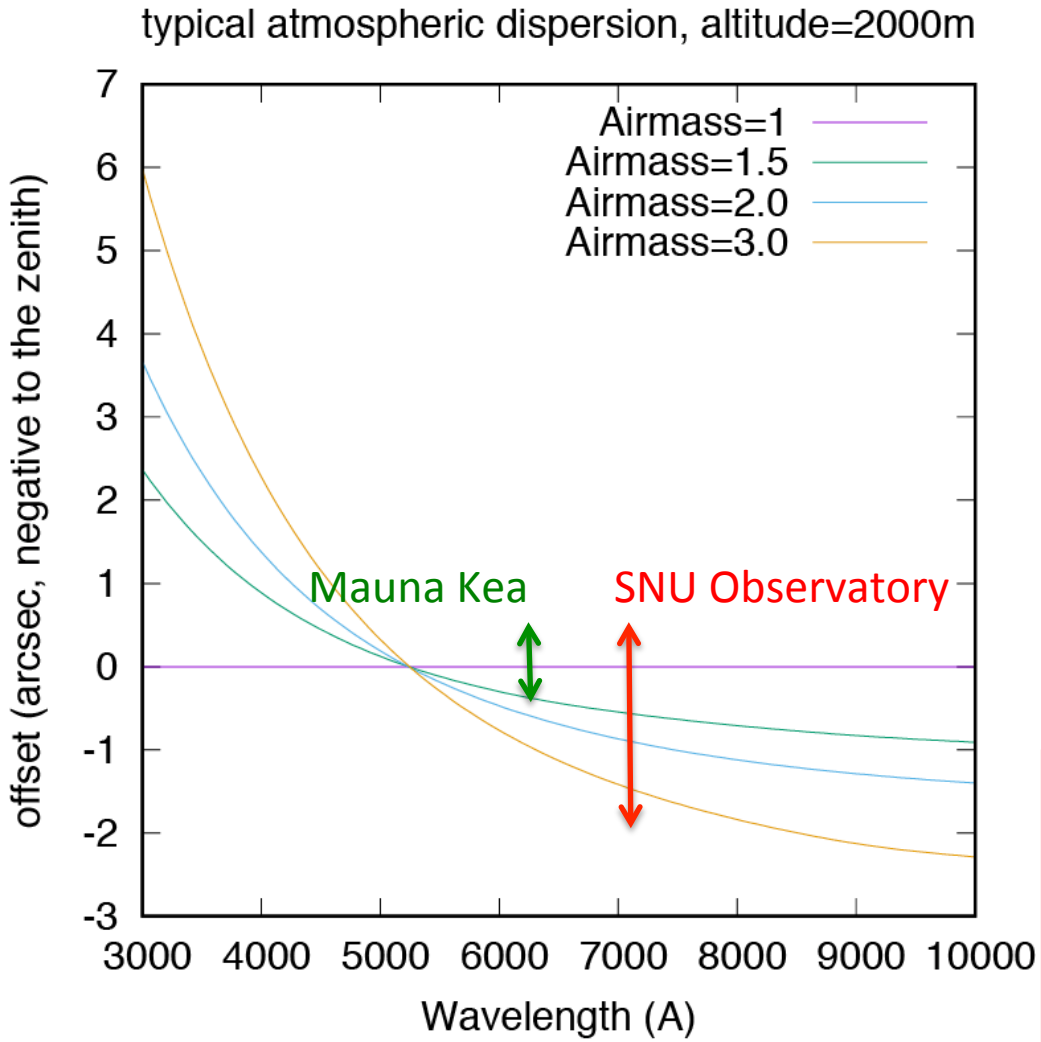
- The offset is aligned along zenith—horizon direction.

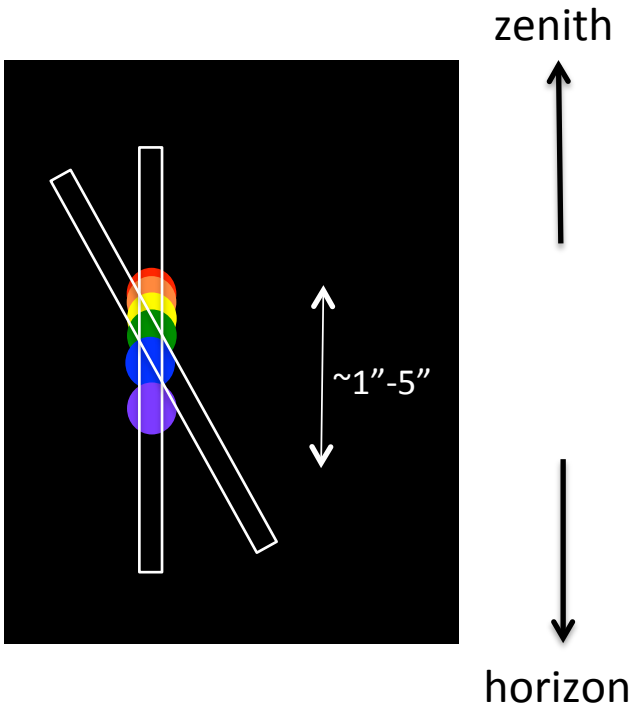
Atmospheric differential refraction at an altitude of 2 km (arcseconds)

	Wavelength (Ångstroms)													
Sec z	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.05	0.68	0.38	0.20	0.08	0.00	-0.06	-0.11	-0.14	-0.17	-0.19	-0.21	-0.23	-0.24	-0.25	-0.26
1.10	0.97	0.55	0.29	0.12	0.00	-0.09	-0.15	-0.20	-0.24	-0.28	-0.30	-0.32	-0.34	-0.36	-0.37
1.15	1.20	0.68	0.36	0.15	0.00	-0.11	-0.19	-0.25	-0.30	-0.34	-0.38	-0.40	-0.42	-0.44	-0.46
1.20	1.40	0.80	0.42	0.17	0.00	-0.13	-0.22	-0.30	-0.35	-0.40	-0.44	-0.47	-0.50	-0.52	-0.54
1.25	1.59	0.90	0.48	0.20	0.00	-0.14	-0.25	-0.33	-0.40	-0.45	-0.50	-0.53	-0.56	-0.59	-0.61
1.30	1.76	1.00	0.53	0.22	0.00	-0.16	-0.28	-0.37	-0.44	-0.50	-0.55	-0.59	-0.62	-0.65	-0.67
1.35	1.92	1.09	0.58	0.24	0.00	-0.17	-0.30	-0.40	-0.48	-0.55	-0.60	-0.64	-0.68	-0.71	-0.73
1.40	2.07	1.18	0.62	0.26	0.00	-0.19	-0.33	-0.44	-0.52	-0.59	-0.65	-0.69	-0.73	-0.77	-0.79
1.45	2.22	1.26	0.67	0.28	0.00	-0.20	-0.35	-0.47	-0.56	-0.63	-0.69	-0.74	-0.79	-0.82	-0.85
1.50	2.37	1.34	0.71	0.29	0.00	-0.21	-0.37	-0.50	-0.60	-0.68	-0.74	-0.79	-0.84	-0.87	-0.91
1.55	2.51	1.42	0.75	0.31	0.00	-0.23	-0.40	-0.53	-0.63	-0.72	-0.78	-0.84	-0.89	-0.93	-0.96
1.60	2.64	1.50	0.80	0.33	0.00	-0.24	-0.42	-0.56	-0.67	-0.75	-0.83	-0.88	-0.93	-0.98	-1.01
1.65	2.78	1.58	0.84	0.34	0.00	-0.25	-0.44	-0.59	-0.70	-0.79	-0.87	-0.93	-0.98	-1.03	-1.06
1.70	2.91	1.65	0.88	0.36	0.00	-0.26	-0.46	-0.61	-0.73	-0.83	-0.91	-0.97	-1.03	-1.07	-1.11
1.75	3.04	1.73	0.92	0.38	0.00	-0.27	-0.48	-0.64	-0.77	-0.87	-0.95	-1.02	-1.07	-1.12	-1.16
1.80	3.17	1.80	0.95	0.39	0.00	-0.29	-0.50	-0.67	-0.80	-0.90	-0.99	-1.06	-1.12	-1.17	-1.21
1.85	3.29	1.87	0.99	0.41	0.00	-0.30	-0.52	-0.69	-0.83	-0.94	-1.03	-1.10	-1.16	-1.22	-1.26
1.90	3.42	1.94	1.03	0.42	0.00	-0.31	-0.54	-0.72	-0.86	-0.98	-1.07	-1.14	-1.21	-1.26	-1.31
1.95	3.54	2.01	1.07	0.44	0.00	-0.32	-0.56	-0.75	-0.89	-1.01	-1.11	-1.19	-1.25	-1.31	-1.36
2.00	3.67	2.08	1.10	0.45	0.00	-0.33	-0.58	-0.77	-0.92	-1.05	-1.15	-1.23	-1.30	-1.35	-1.40
2.10	3.91	2.22	1.18	0.48	0.00	-0.35	-0.62	-0.82	-0.99	-1.12	-1.22	-1.31	-1.38	-1.44	-1.50
2.20	4.15	2.36	1.25	0.51	0.00	-0.37	-0.66	-0.87	-1.05	-1.18	-1.30	-1.39	-1.47	-1.53	-1.59
2.30	4.38	2.49	1.32	0.54	0.00	-0.40	-0.69	-0.92	-1.11	-1.25	-1.37	-1.47	-1.55	-1.62	-1.68
2.40	4.62	2.62	1.39	0.57	0.00	-0.42	-0.73	-0.97	-1.16	-1.32	-1.44	-1.55	-1.63	-1.70	-1.77
2.50	4.85	2.75	1.46	0.60	0.00	-0.44	-0.77	-1.02	-1.22	-1.38	-1.52	-1.62	-1.71	-1.79	-1.86
2.60	5.08	2.88	1.53	0.63	0.00	-0.46	-0.80	-1.07	-1.28	-1.45	-1.59	-1.70	-1.80	-1.88	-1.94
2.70	5.31	3.01	1.60	0.66	0.00	-0.48	-0.84	-1.12	-1.34	-1.51	-1.66	-1.78	-1.88	-1.96	-2.03
2.80	5.54	3.14	1.67	0.69	0.00	-0.50	-0.88	-1.17	-1.40	-1.58	-1.73	-1.85	-1.96	-2.04	-2.12
2.90	5.76	3.27	1.74	0.71	0.00	-0.52	-0.91	-1.21	-1.45	-1.64	-1.80	-1.93	-2.04	-2.13	-2.20
3.00	5.99	3.40	1.80	0.74	0.00	-0.54	-0.95	-1.26	-1.51	-1.71	-1.87	-2.00	-2.12	-2.21	-2.29
3.10	6.21	3.53	1.87	0.77	0.00	-0.56	-0.98	-1.31	-1.57	-1.77	-1.94	-2.08	-2.19	-2.29	-2.38
3.20	6.44	3.65	1.94	0.80	0.00	-0.58	-1.02	-1.36	-1.62	-1.84	-2.01	-2.15	-2.27	-2.38	-2.46
3.30	6.66	3.78	2.00	0.83	0.00	-0.60	-1.05	-1.40	-1.68	-1.90	-2.08	-2.23	-2.35	-2.46	-2.55
3.40	6.88	3.91	2.07	0.85	0.00	-0.62	-1.09	-1.45	-1.73	-1.96	-2.15	-2.30	-2.43	-2.54	-2.63
3.50	7.10	4.03	2.14	0.88	0.00	-0.64	-1.12	-1.50	-1.79	-2.03	-2.22	-2.38	-2.51	-2.62	-2.72
3.60	7.32	4.16	2.20	0.91	0.00	-0.66	-1.16	-1.54	-1.85	-2.09	-2.29	-2.45	-2.59	-2.70	-2.80
3.70	7.54	4.28	2.27	0.94	0.00	-0.68	-1.19	-1.59	-1.90	-2.15	-2.36	-2.52	-2.66	-2.78	-2.88
3.80	7.76	4.41	2.34	0.96	0.00	-0.70	-1.23	-1.64	-1.96	-2.21	-2.42	-2.60	-2.74	-2.86	-2.97
3.90	7.98	4.53	2.40	0.99	0.00	-0.72	-1.26	-1.68	-2.01	-2.28	-2.49	-2.67	-2.82	-2.95	-3.05
4.00	8.20	4.66	2.47	1.02	0.00	-0.74	-1.30	-1.73	-2.07	-2.34	-2.56	-2.74	-2.90	-3.03	-3.14
4.10	8.42	4.78	2.53	1.04	0.00	-0.76	-1.33	-1.77	-2.12	-2.40	-2.63	-2.82	-2.97	-3.11	-3.22
4.20	8.64	4.90	2.60	1.07	0.00	-0.78	-1.37	-1.82	-2.18	-2.46	-2.70	-2.89	-3.05	-3.19	-3.30
4.30	8.85	5.03	2.67	1.10	0.00	-0.80	-1.40	-1.87	-2.23	-2.53	-2.77	-2.96	-3.13	-3.27	-3.39
4.40	9.07	5.15	2.73	1.12	0.00	-0.82	-1.44	-1.91	-2.29	-2.59	-2.83	-3.04	-3.21	-3.35	-3.47
4.50	9.29	5.27	2.80	1.15	0.00	-0.84	-1.47	-1.96	-2.34	-2.65	-2.90	-3.11	-3.28	-3.43	-3.55
4.60	9.51	5.40	2.86	1.18	0.00	-0.86	-1.51	-2.00	-2.40	-2.71	-2.97	-3.18	-3.36	-3.51	-3.64
4.70	9.72	5.52	2.93	1.21	0.00	-0.88	-1.54	-2.05	-2.45	-2.77	-3.04	-3.25	-3.44	-3.59	-3.72
4.80	9.94	5.64	2.99	1.23	0.00	-0.90	-1.57	-2.09	-2.51	-2.84	-3.10	-3.33	-3.51	-3.67	-3.80
4.90	10.15	5.77	3.06	1.26	0.00	-0.92	-1.61	-2.14	-2.56	-2.90	-3.17	-3.40	-3.59	-3.75	-3.88

Filippenko, A. PASP 94, 715, 1982

Atmospheric dispersion (2)

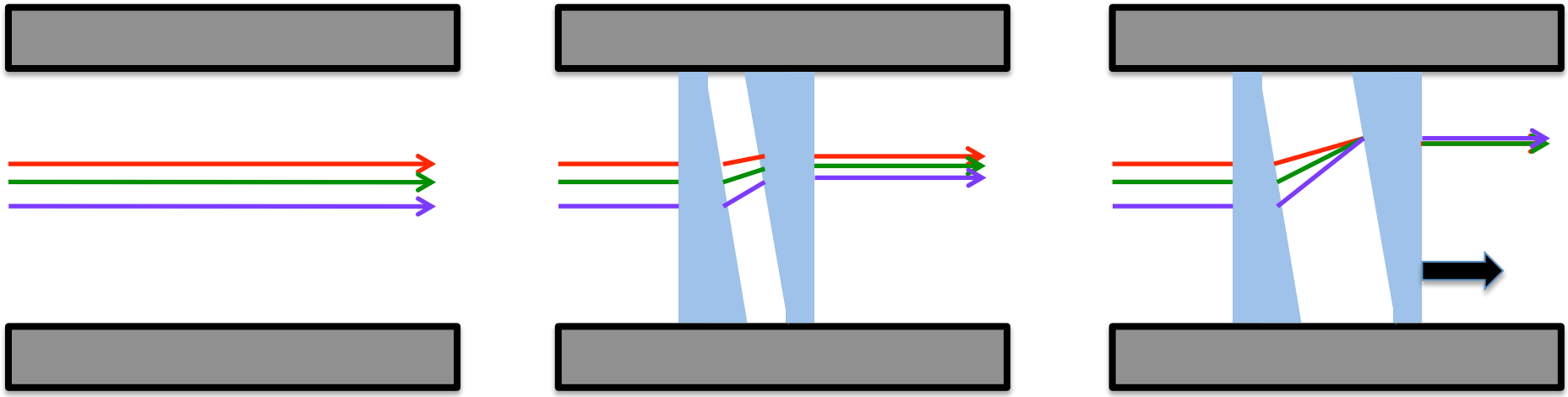




It is recommended (but not always) that the position angle of the slit is aligned parallel to parallactic angle.

The effect can be eliminated by using atmospheric dispersion corrector (ADC).

ADC: Separating prisms design

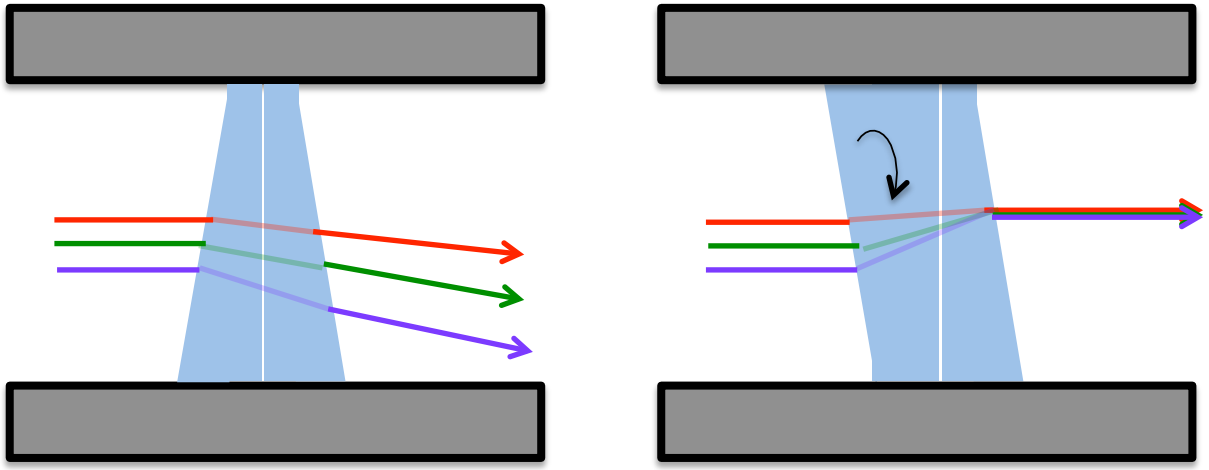


Without ADC

With ADC

After tuning the separation

ADC: Rotating prisms



After rotating 1st unit

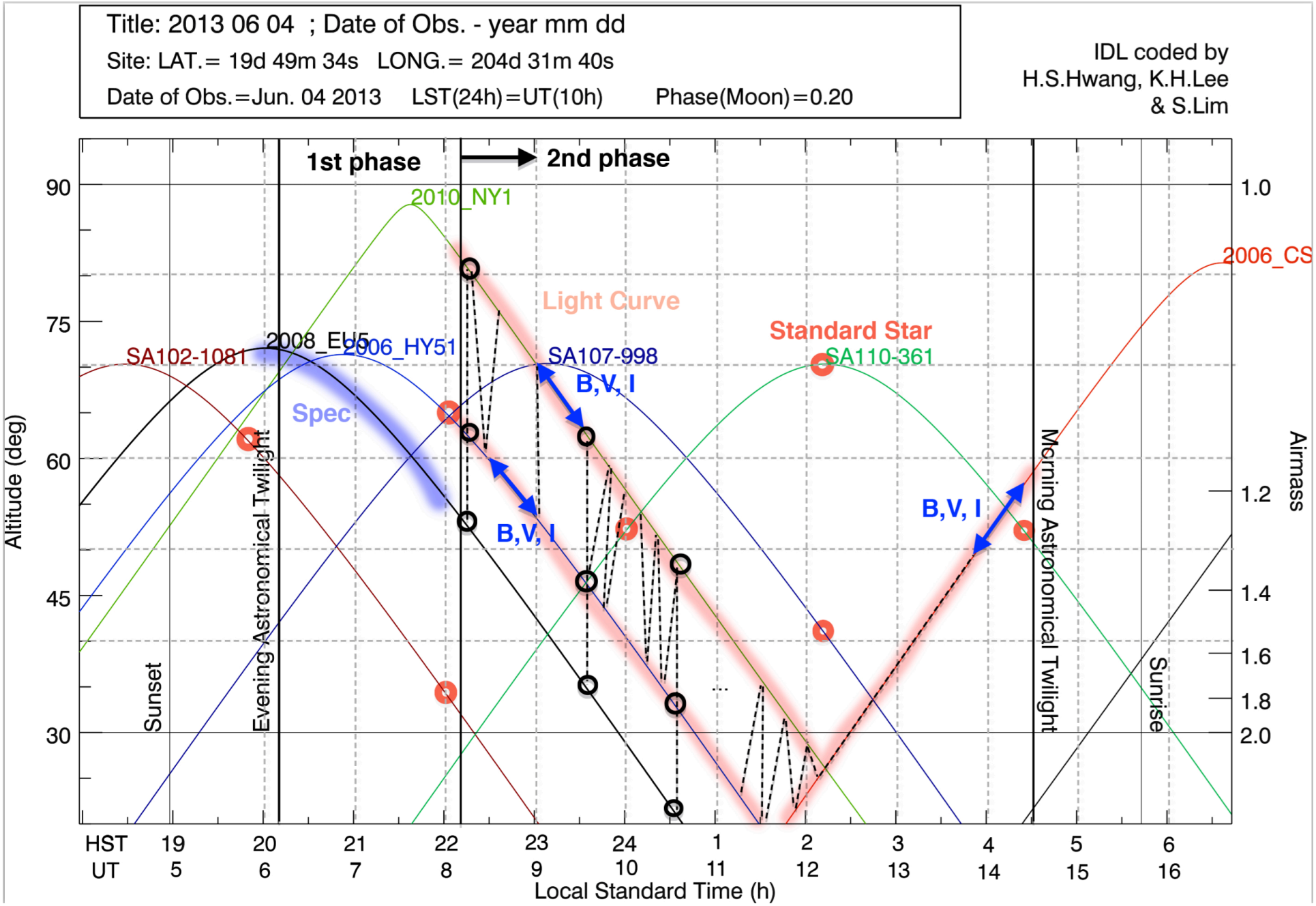
Effect of slit-loss

- We usually set our target on the center of a slit, illuminating the slit uniformly.

- An imperfect setting/guiding result in shifts of the projected spectrum in both spatial and dispersion direction.

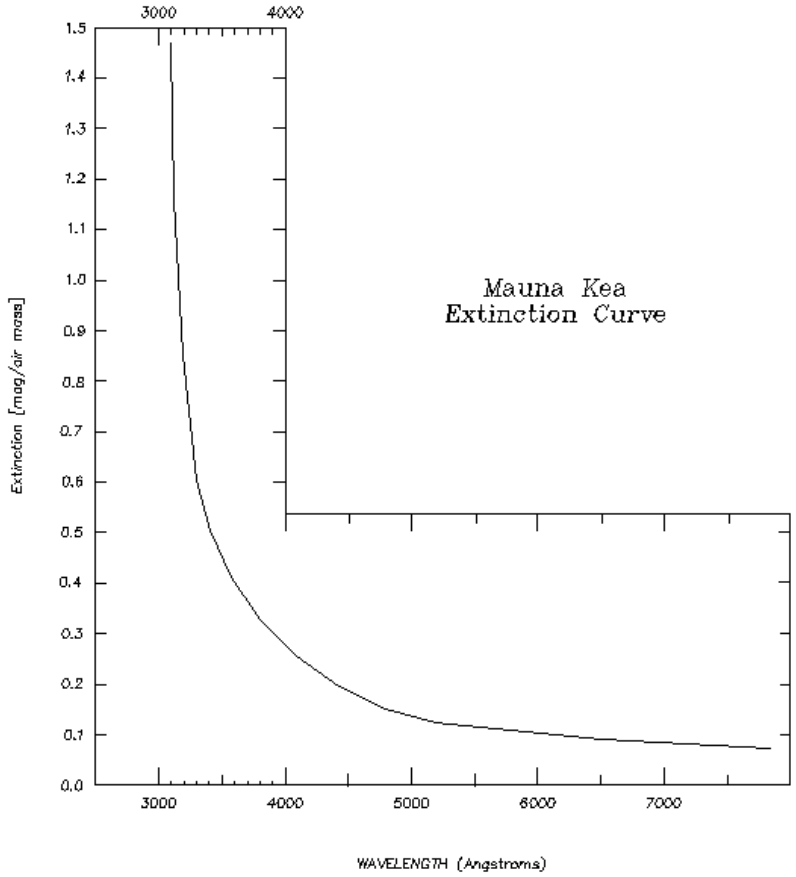
Observation Planning

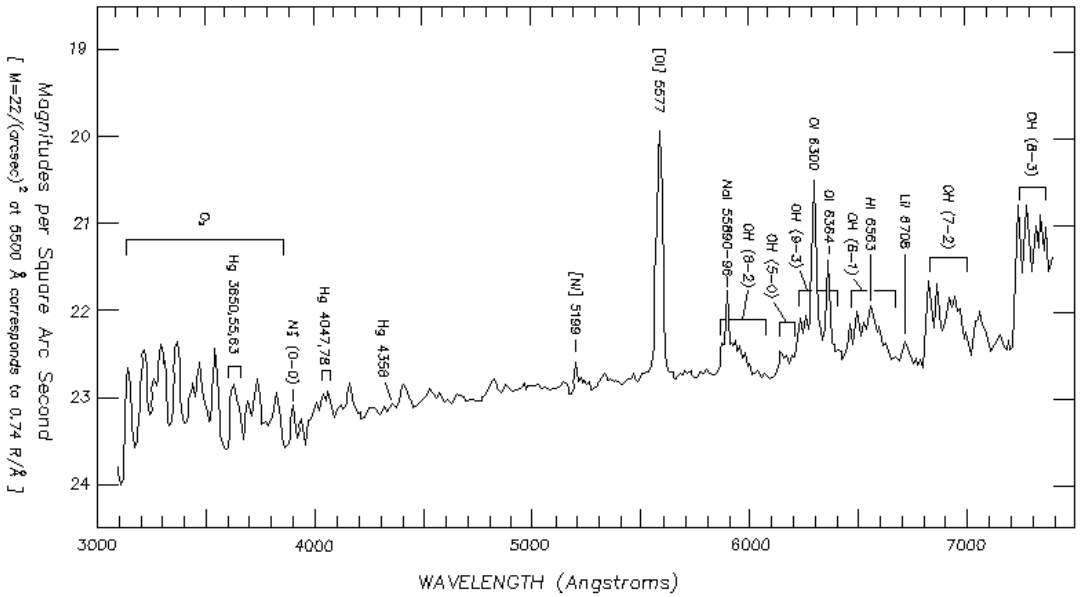
- Choose standard stars
- Exposure time (usually long exposure for your targets)
- Make an airmass plot (an example, next page)
- Backup plan (if you consider observation of objects not listed in the proposal, you should ask the observatory if it is acceptable or not)
- Do not forget about flat, dark or bias, and comparison lamp data acquisition



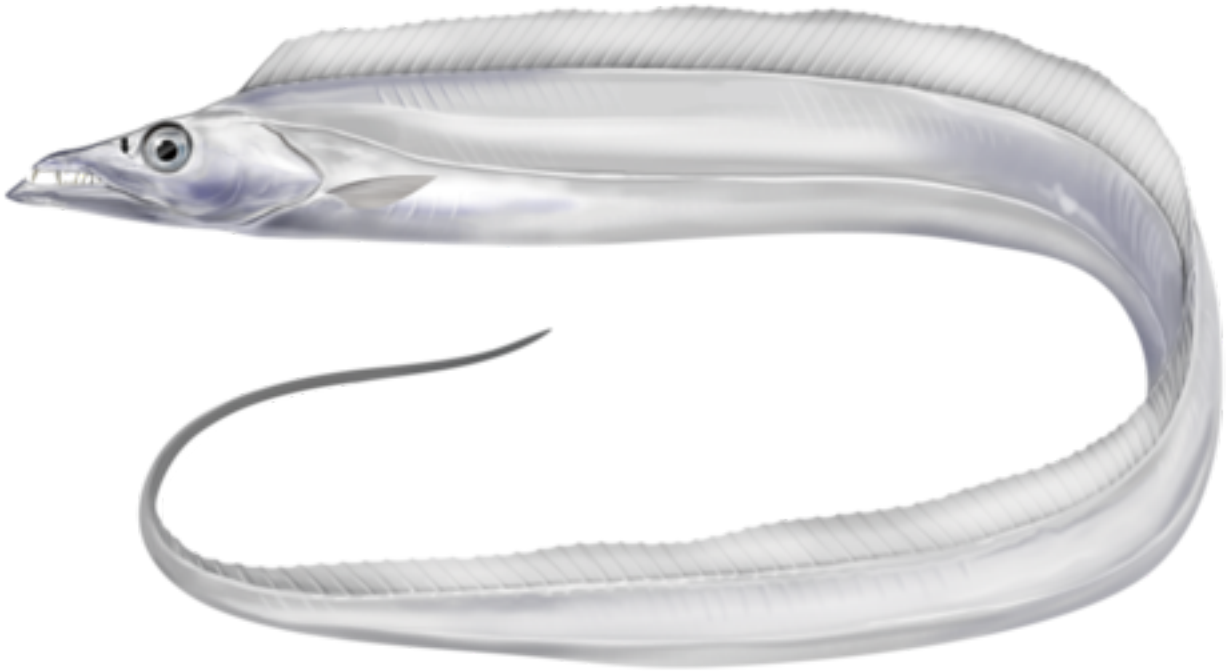
Courtesy of Dr. Yoonyoung Kim

- Observed signal signal: $S(\lambda) = I_{obj}(\lambda) p(\rho, \lambda) + I_{sky}(\lambda)$

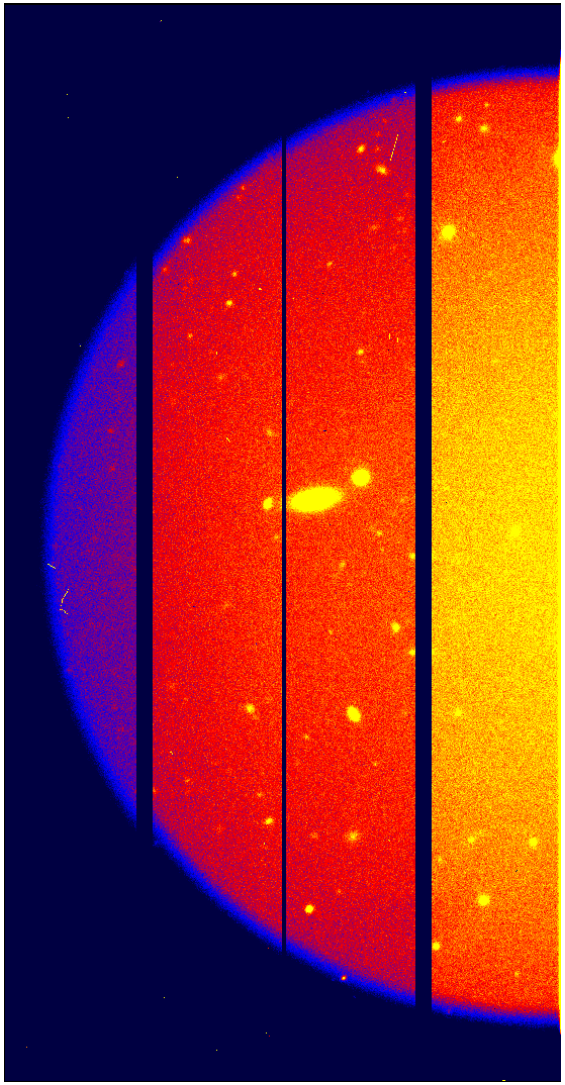




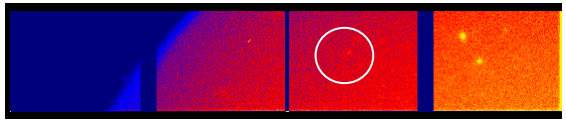
http://www.cfht.hawaii.edu/I



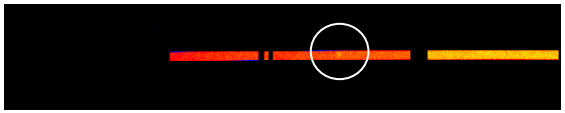
Observations (1)



1. After pointing, take a snapshot image to confirm the location of your target.

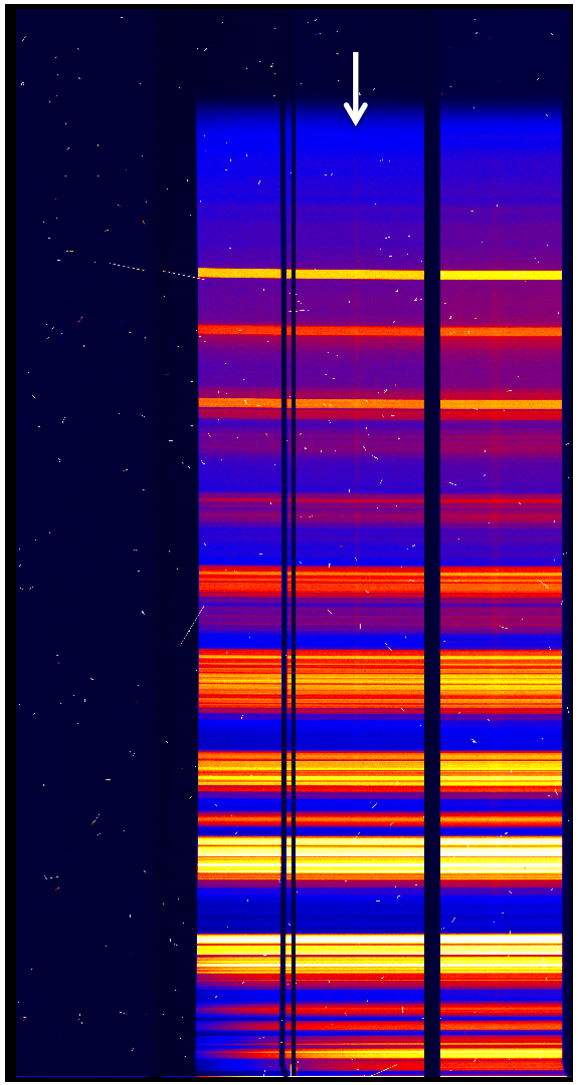


2. After giving an offset to set the location of your target on the slit position, take another image. The above is the example (readout only the central region).

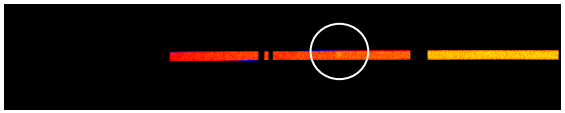


3. After inserting a slit, take an exposure to confirm the location. Once you confirm the location and set up the disperser, start exposure for the spectroscopy (usually with a long exposure time)

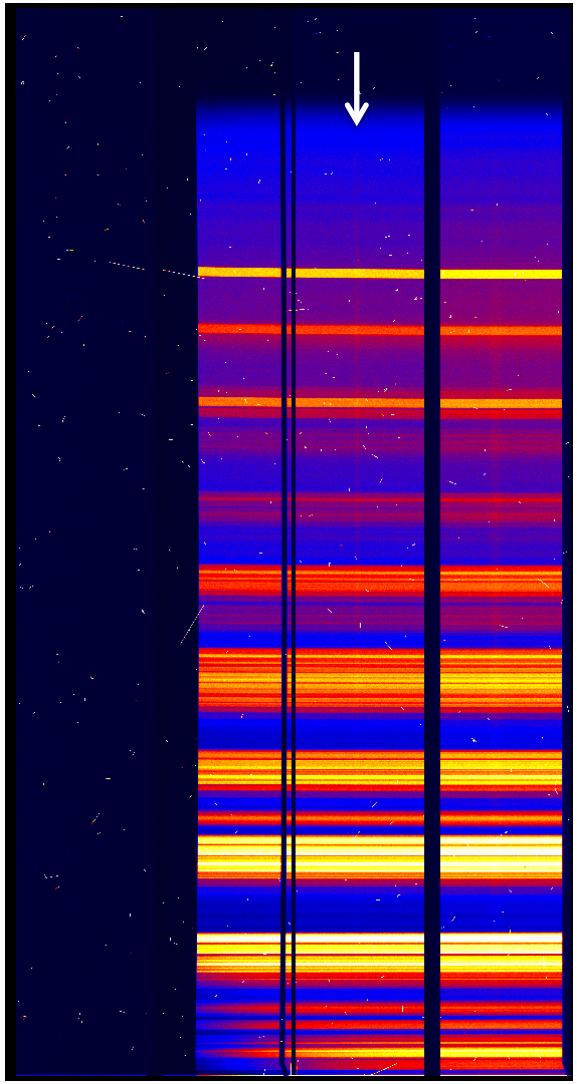
Observations (2)



4. Confirm the obtained spectrum.

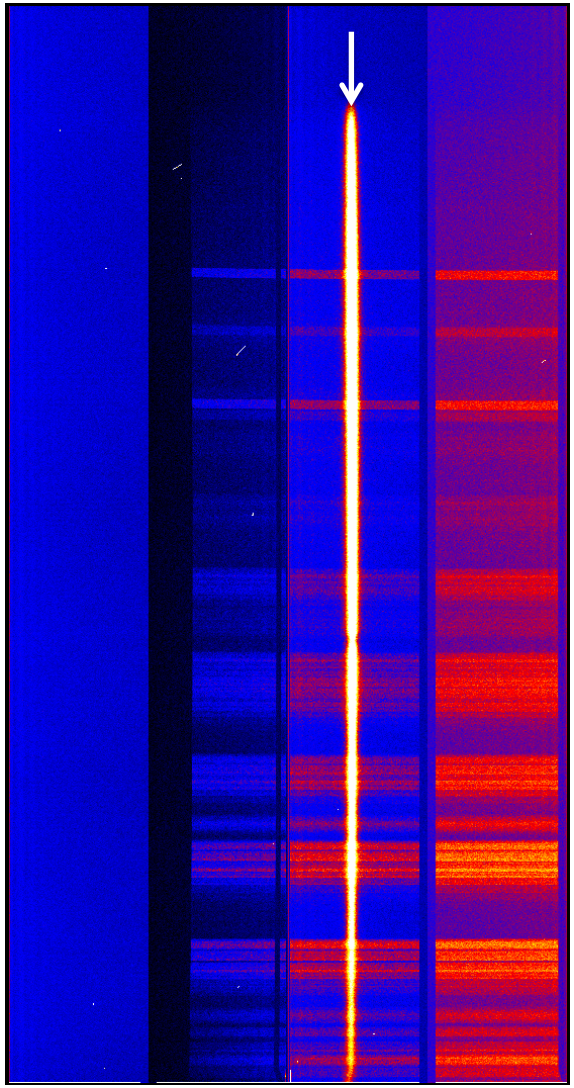


5. Check the location of your target. If it is not on the slit, repeat from 2. You may take spectra again.

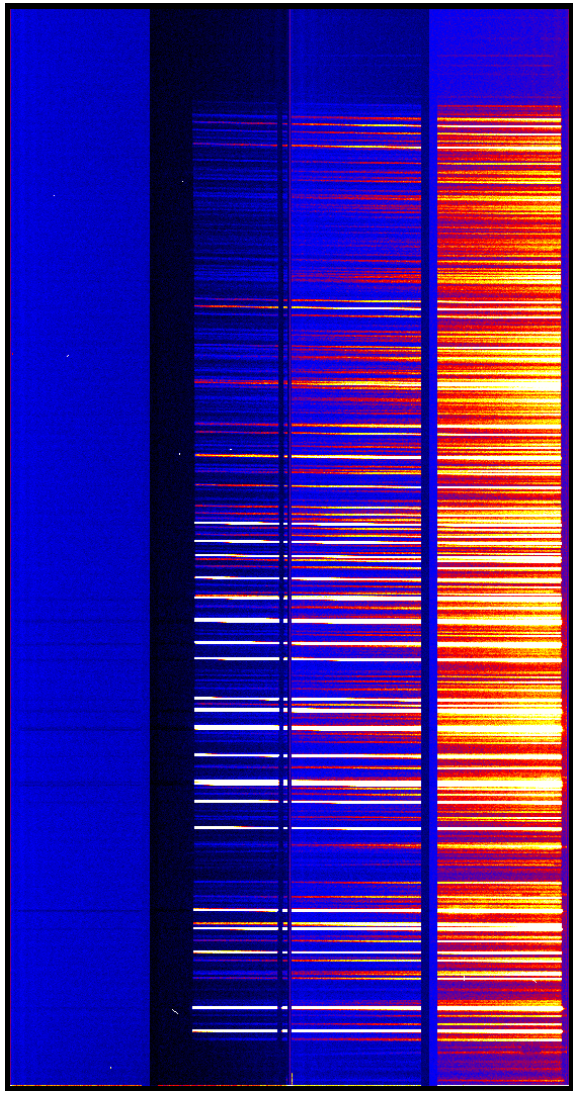


6. Take second and third …. spectra

Observations (3)



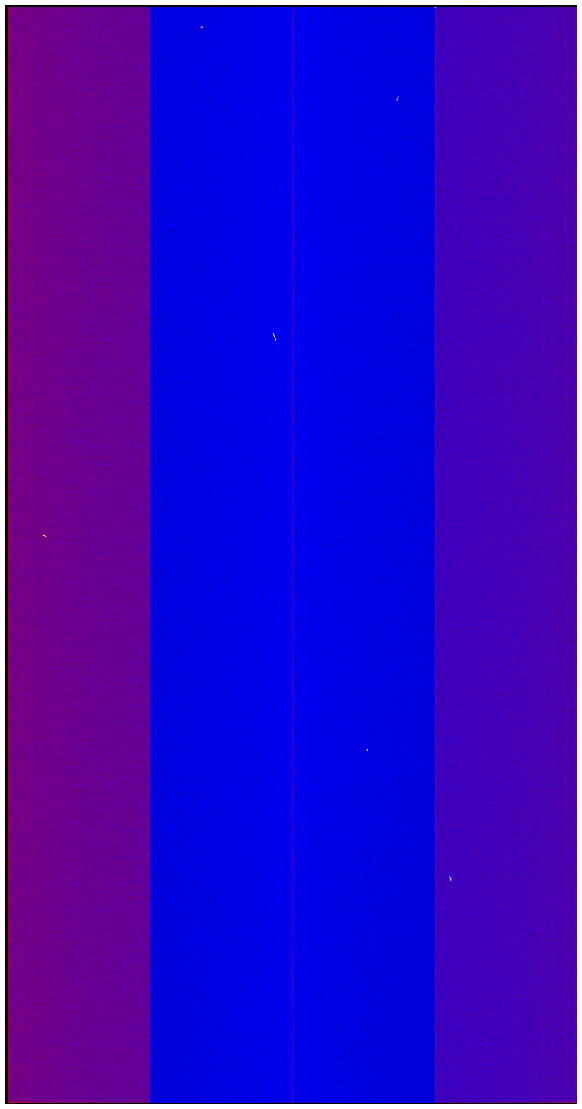
7. Take spectra of standard star(s). It usually complete in a short exposure time.



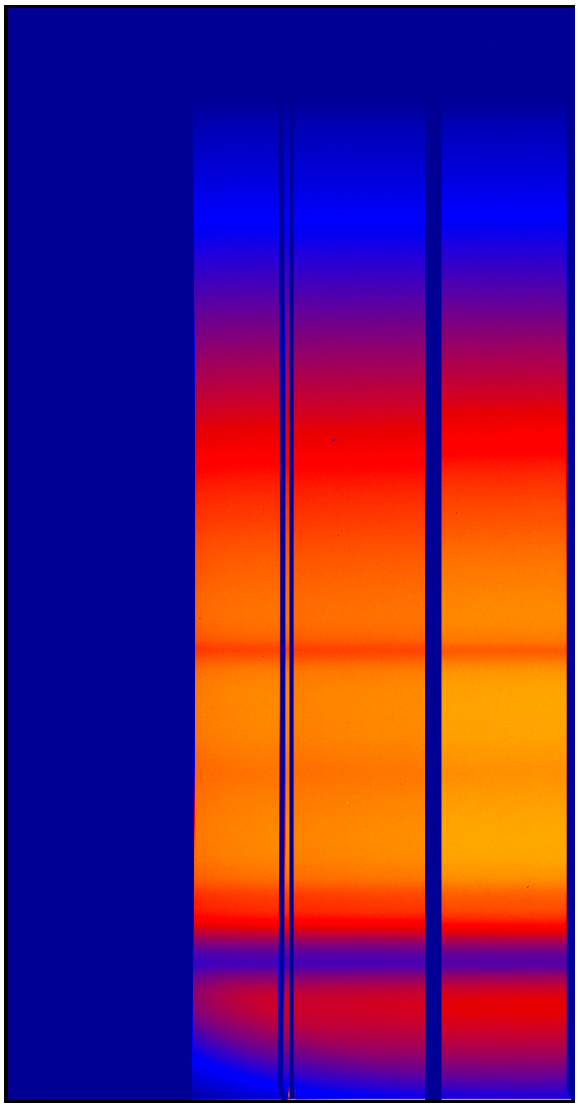
8. Take spectra of a comparison lamp (for wavelength identification)

You may also utilize background emissions of either artificial light or natural airglow for wavelength identification.

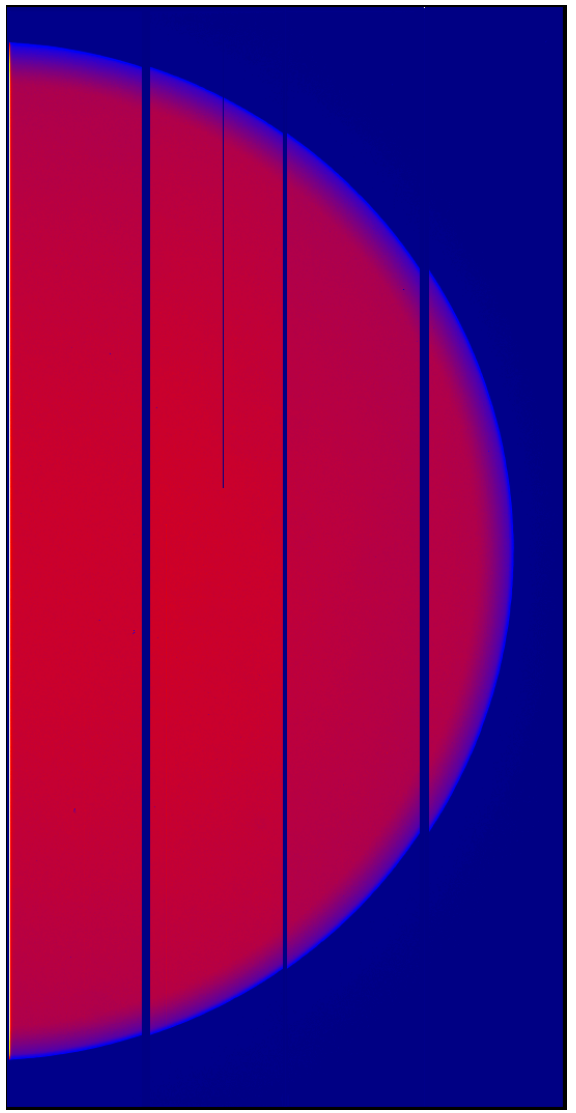
Observations (4)



9. Take bias or dark, depending on the temperature of the detector.



10. Take flat spectra in the same configuration as you took your object

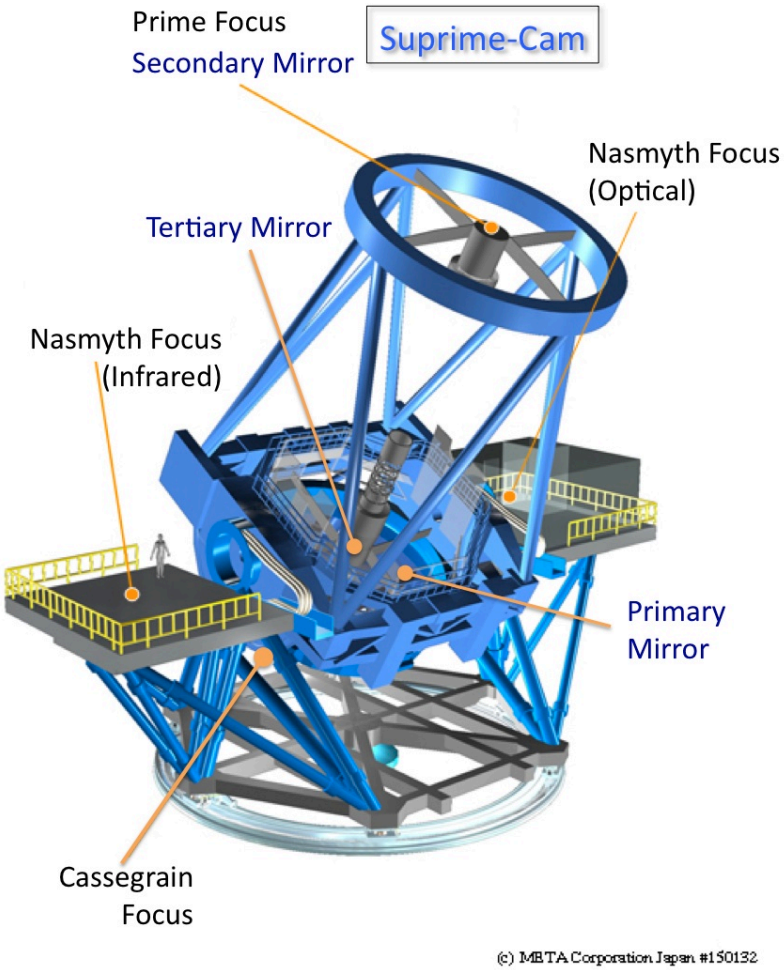


11. Do not forget about flat images

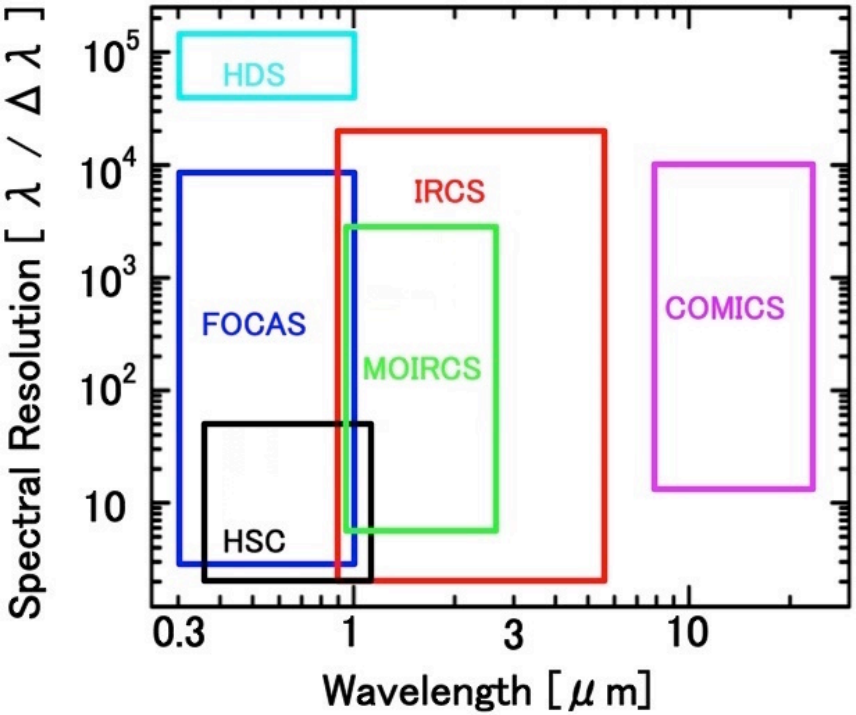
Data Reduction

- The detailed instruction will be given by TA
- Preprocess (i.e., bias/dark and flat)
  - Correction for bias or dark is basically in the same manner as for imaging
  - Regarding the flat-fielding, it is required to illuminate light along slit direction using a light source having smooth SED (e.g. tungsten and halogen)
- Correction for distortion
- Wavelength calibration
- Sky subtraction and extraction of spectra
- Flux calibration
- The order of these workflows can be changed

Data for practice



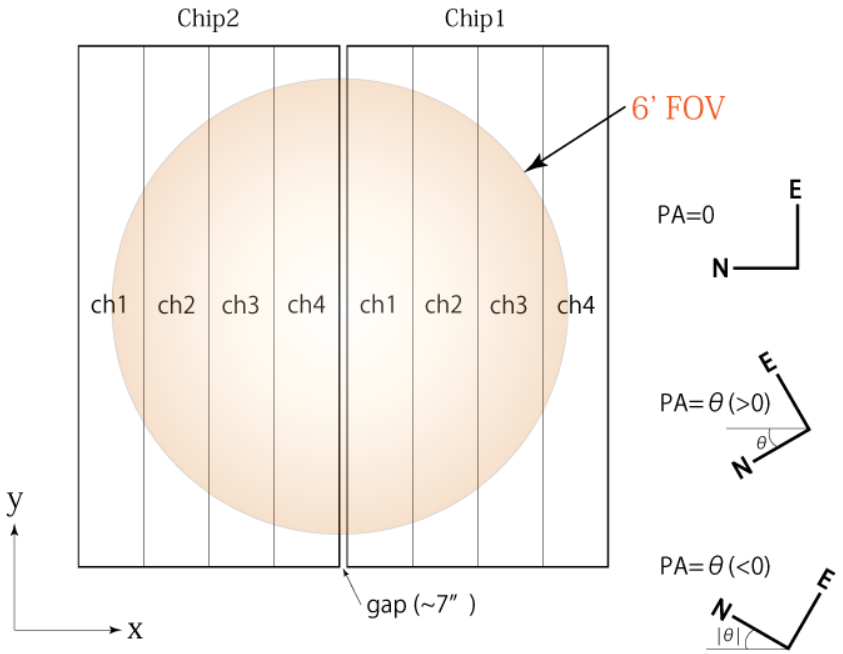
Subaru Telescope

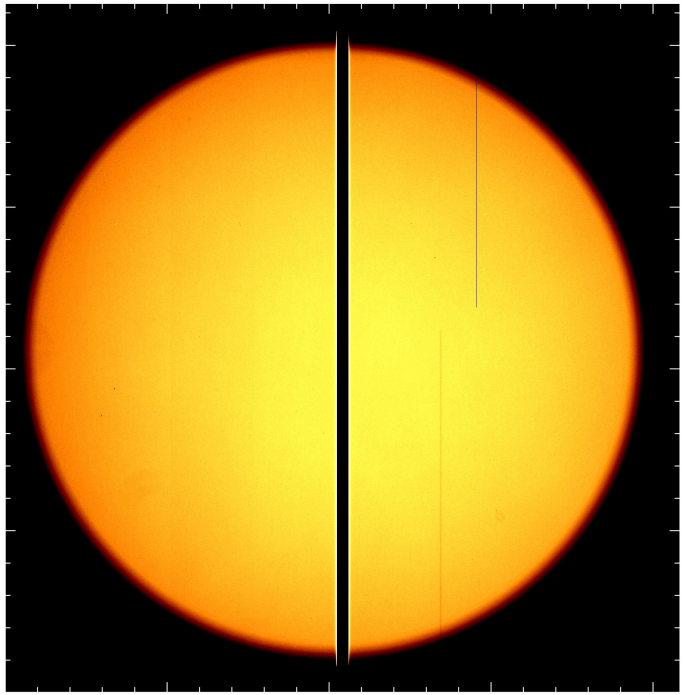


https://www.naoj.org

FOCAS

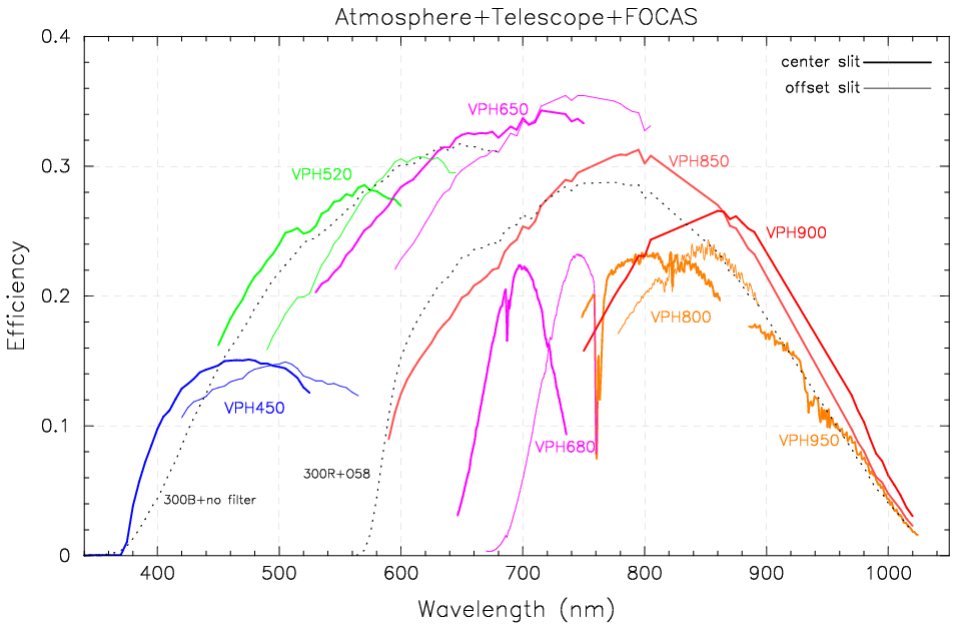
The Faint Object Camera and Spectrograph (FOCAS) is a versatile optical imaging and spectroscopy unit which can be installed at the Cassegrain focus of Subaru Telescope. FOCAS uses refracting optics for both the collimator and camera and uses grisms to achieve high throughput optimized for the wavelength range of 3700-10000 A. It has four operating modes: imaging, spectroscopy (long slit and multi-slit), polarimetry, and spectropolarimetry, and covers a circular 6' field of view. The atmospheric dispersion corrector (ADC) installed in the telescope Cassegrain unit will be used in most FOCAS observation (from the website).

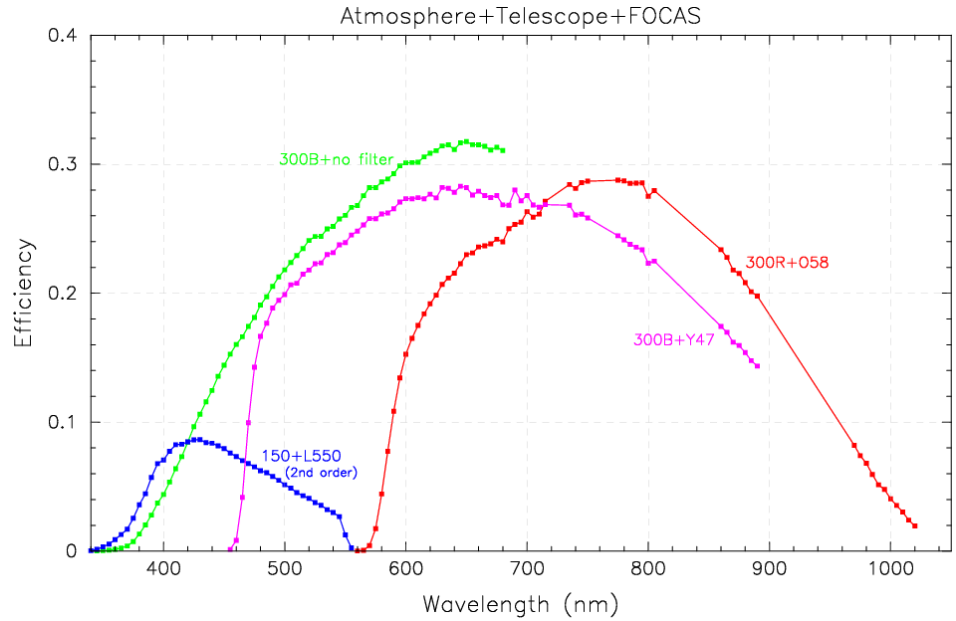




https://www.naoj.org/Observing/Instruments/FOCAS/index.html

Grating	Blaze (A)	Order	Filter	Range of operation (A)	Dispersion (A/pixel)	Resolution (0.4'' slit)	Sensitivity (mag)
75	6500	1	SY47	4700 - 9100	-5.90	250	*V*=24.6, *R*=24.4, *I*=23.8
		1	SO58	5800 - 10000			*R*=24.4, *I*=23.8
150	6500	1	SY47	4700 - 9100	-2.83	500	*V*=23.4, *R*=23.6, *I*=22.9
		1	SO58	5800 - 10000			*R*=23.6, *I*=22.9
		2	L550	3400 - 5500	-1.41	700	*U*=20.5
300B	5500	1	SY47	4700 - 9100	-1.34	1000	*V*=23.1, *R*=22.9, *I*=22.1
		1	L600	3700 - 6000			*B*=23.0, *V*=22.9
300R	7500	1	SY47	4900 - 9100	-1.34	1000	*V*=22.3, *R*=22.5, *I*=22.0
		1	SO58	5800 - 10000			*R*=22.6, *I*=22.1, *z'*=21.7
		2	L600	3700 - 5950	-0.64	2000	*B*=22.6, *V*=21.5
		2	L550	3400 - 5250			*U*=19.0, *B*=22.6, *V*=21.5
Echelle	9720	2	*I*	7300 - 8700	0.98	2500	*I*=20.7
		2	SDSS-z'	8300 - 10000			
VPH grisms							shift(**)
VPH450	4000(*)	1	none	3800 - 5250	-0.37	3000	*B*=22.2	+16
VPH520	5200	1	none	4450 - 6050	-0.39	3000	*V*=22.2	-47
VPH650	6500	1	SY47	5300 - 7700	-0.60	2500	*V*=22.1, *R*=22.0, *I*=21.3	+222
VPH850	8000	1	SO58	5800 - 10350	-1.17	1500	*R*=22.5, *I*=22.1, *z'*=21.8	-6
VPH900	9000	1	SO58	7500 - 10450	-0.74	3000	*I*=21.7, *z'*=21.6	-120
High Dispersion VPH grisms							
VPH680	6800	1	SY47	6450 - 7350	-0.22	7500	*R*=20.5	+41
VPH800	8000	1	SY47	7500 - 8600	-0.28	7000	*I*=20.3	-27
VPH950	9500	1	O58	8850 - 10000	-0.35	5500	*AB*(8900A)=18.0,*AB*(9700A)=17.2	-190





https://www.naoj.org/Observing/Instruments/FOCAS/index.html