From starlight to spectra – Observations for stellar abundance determinations

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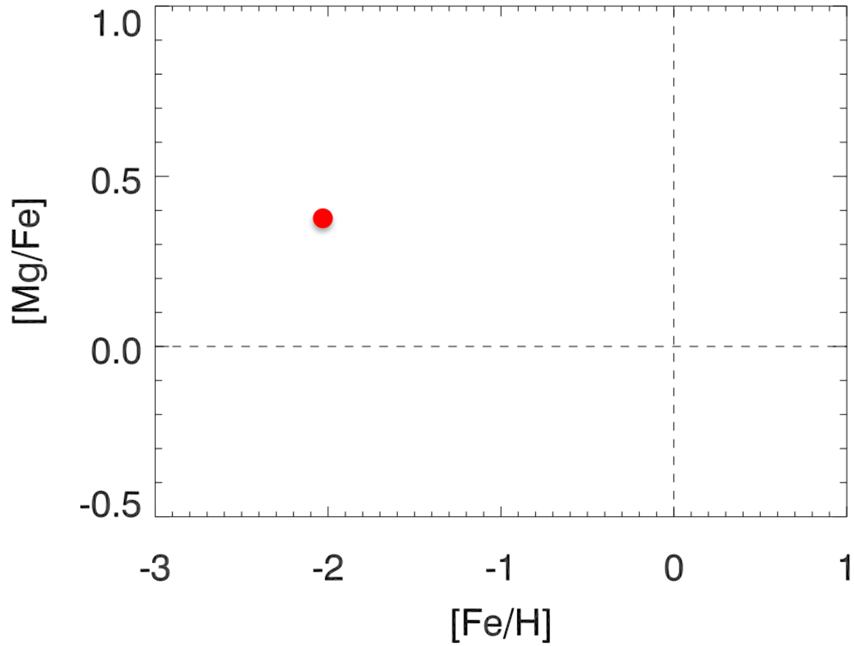
How to get an abundance ?

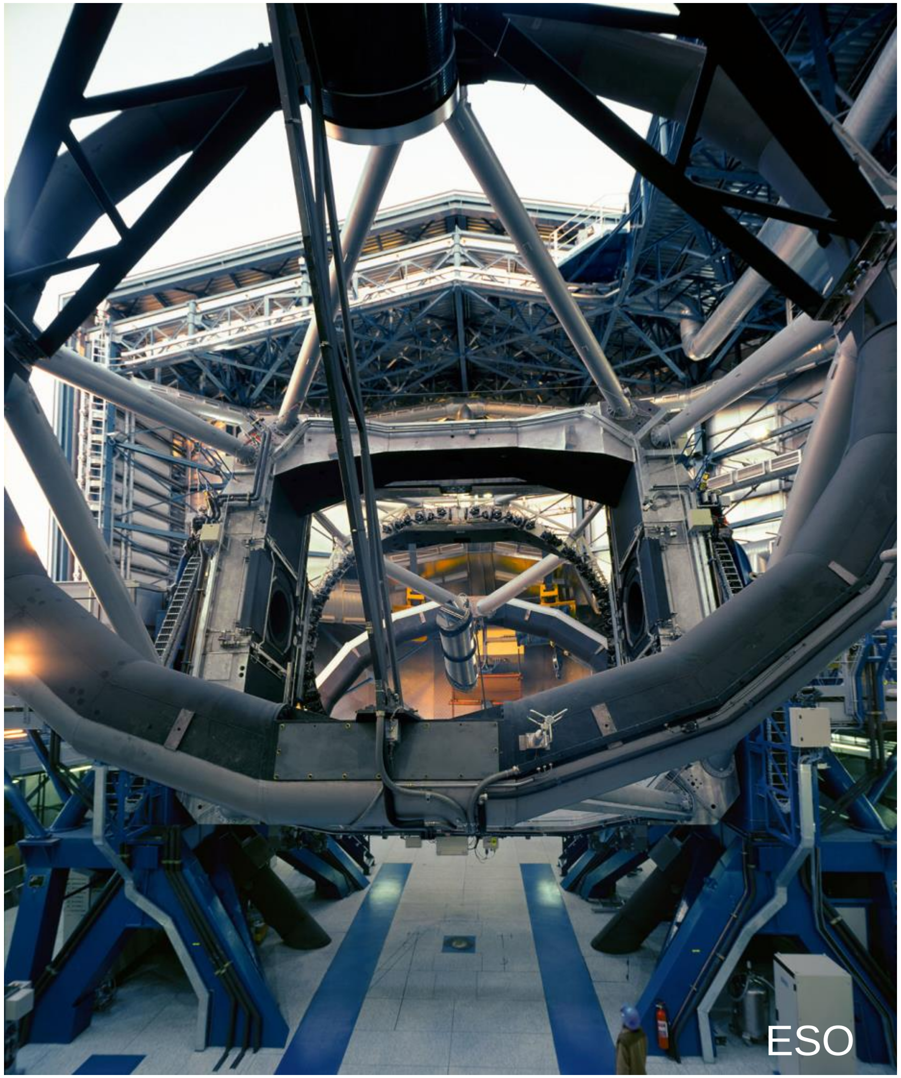


Input needed for that one dot alone:

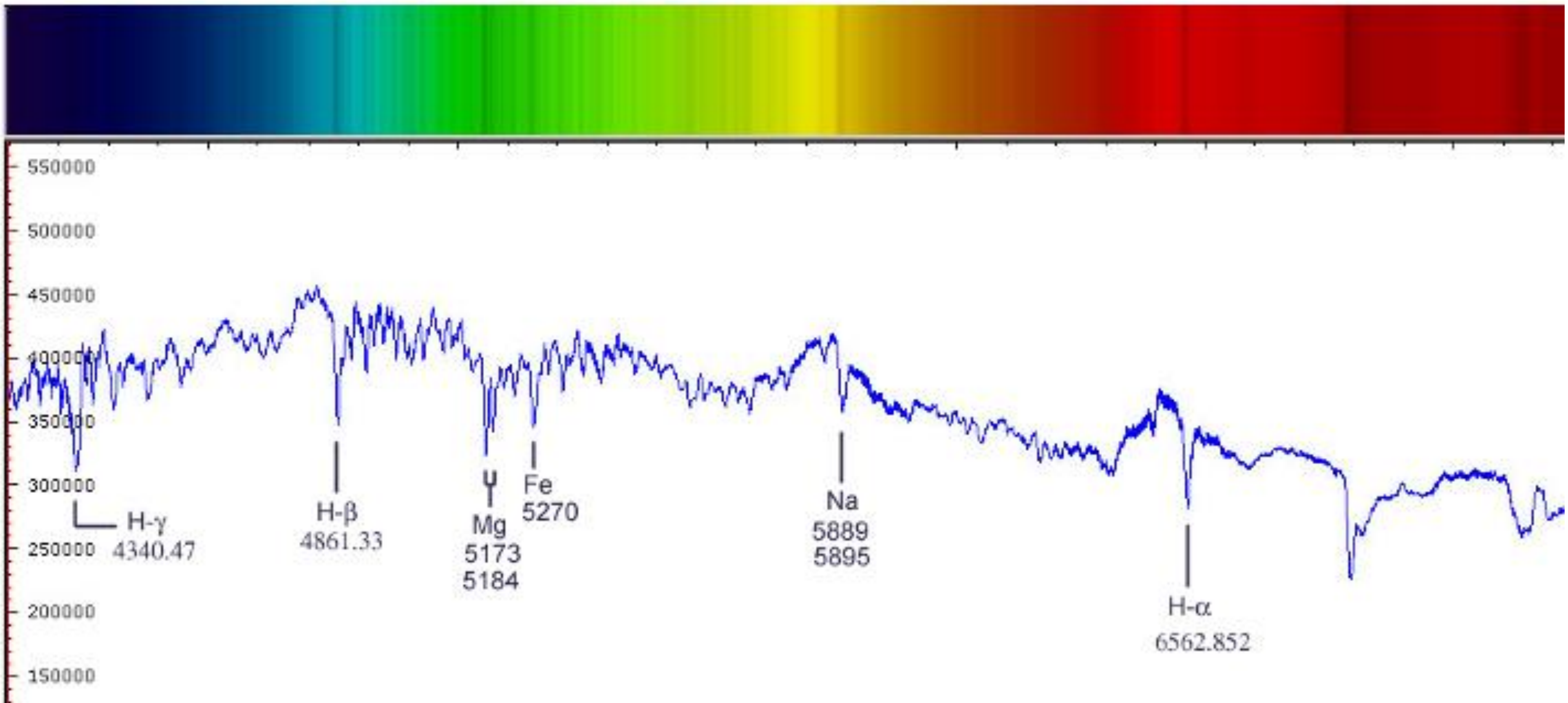
- Spectra
- Atomic data
- Spectrum synthesis codes
- Stellar atmospheres

Outline

- Introduction to spectroscopy and spectrographs
- Spectral resolution
- Effects of the Earth‘s atmosphere
- How and from where to obtain observations



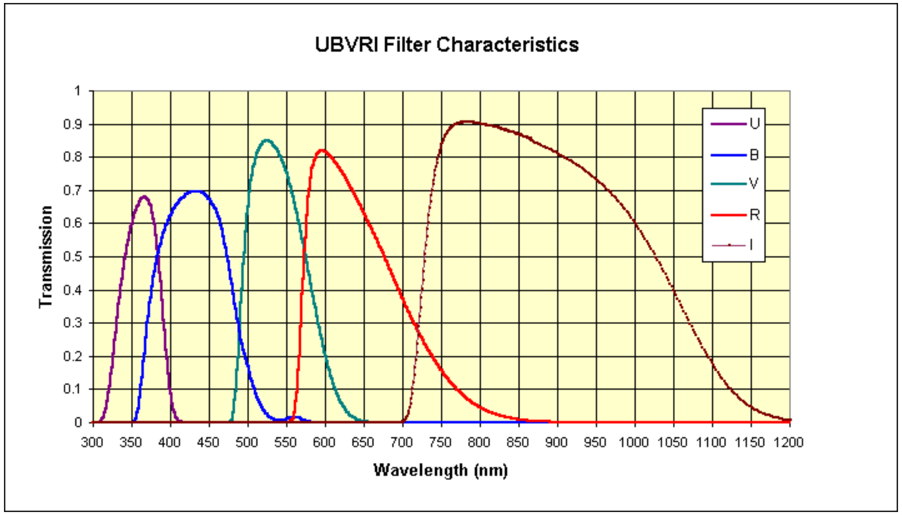
What is spectroscopy?

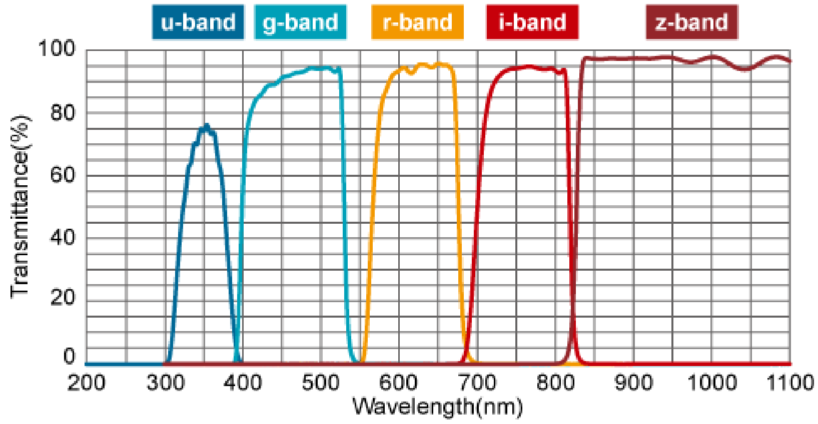


Spectroscopy, study of the absorption and emission of light and other radiation by matter, as related to the dependence of these processes on the wavelength of the radiation. (from Encyclopaedia Britannica)

Spectroscopy

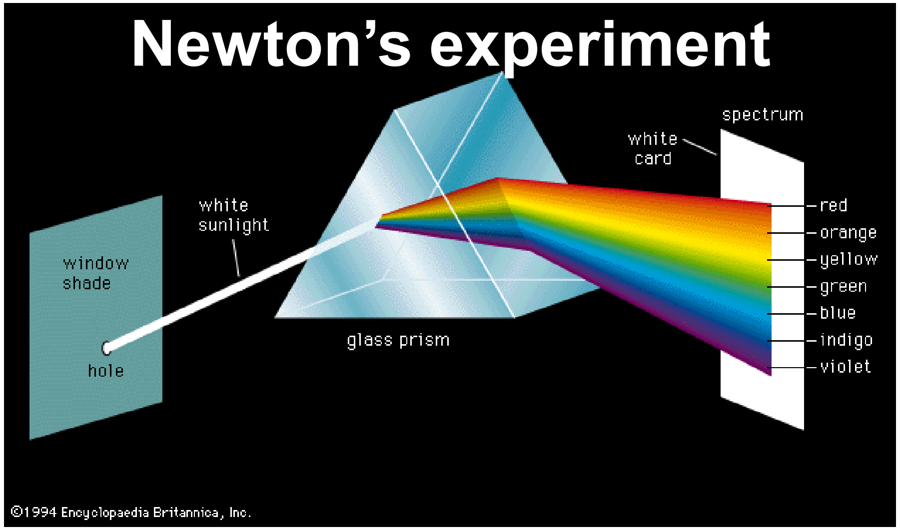
- Spectral analysis is probably the most important method for learning about the physics of astronomical sources
- Simplest method to get spectral information is using filters
- In this case the size of the spectral element we can resolve is the width of the filter
- More detailed information is obtained if the light is sent through a dispersive element

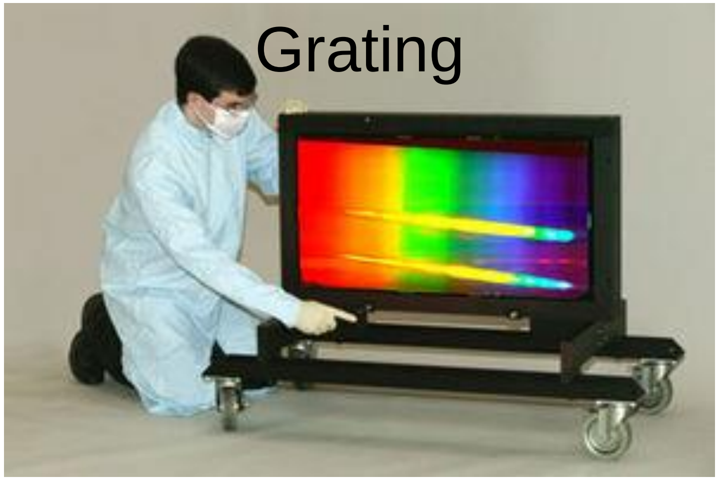




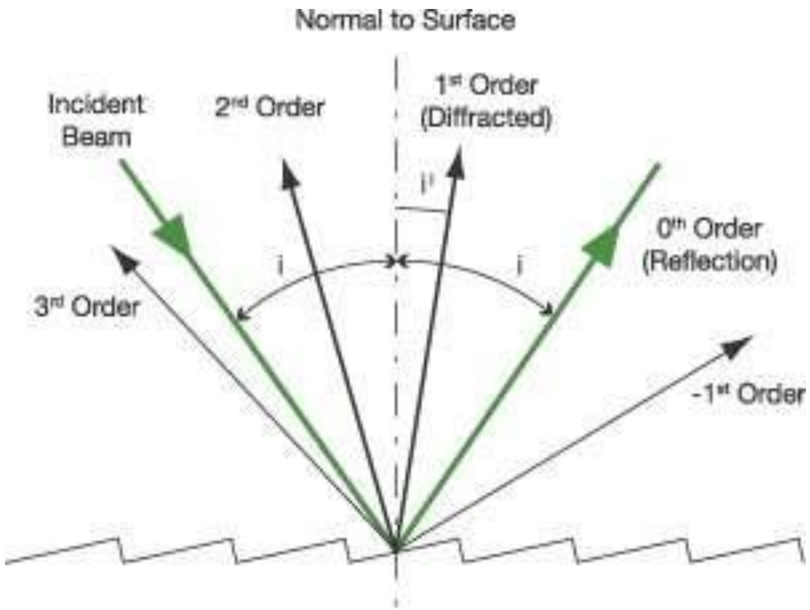
Dispersive elements

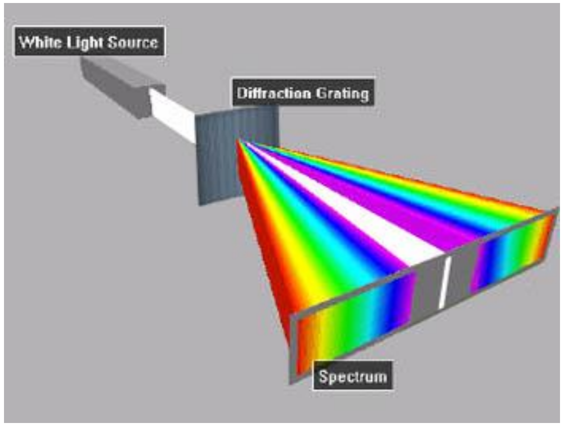
- The core optical element of an astronomical spectrograph is its dispersive element
- With a dispersive element, the angle at which the light leaves it, is wavelength dependent.
- There are two kinds of dispersive elements:
  - **Prisms**
  - **Grating**





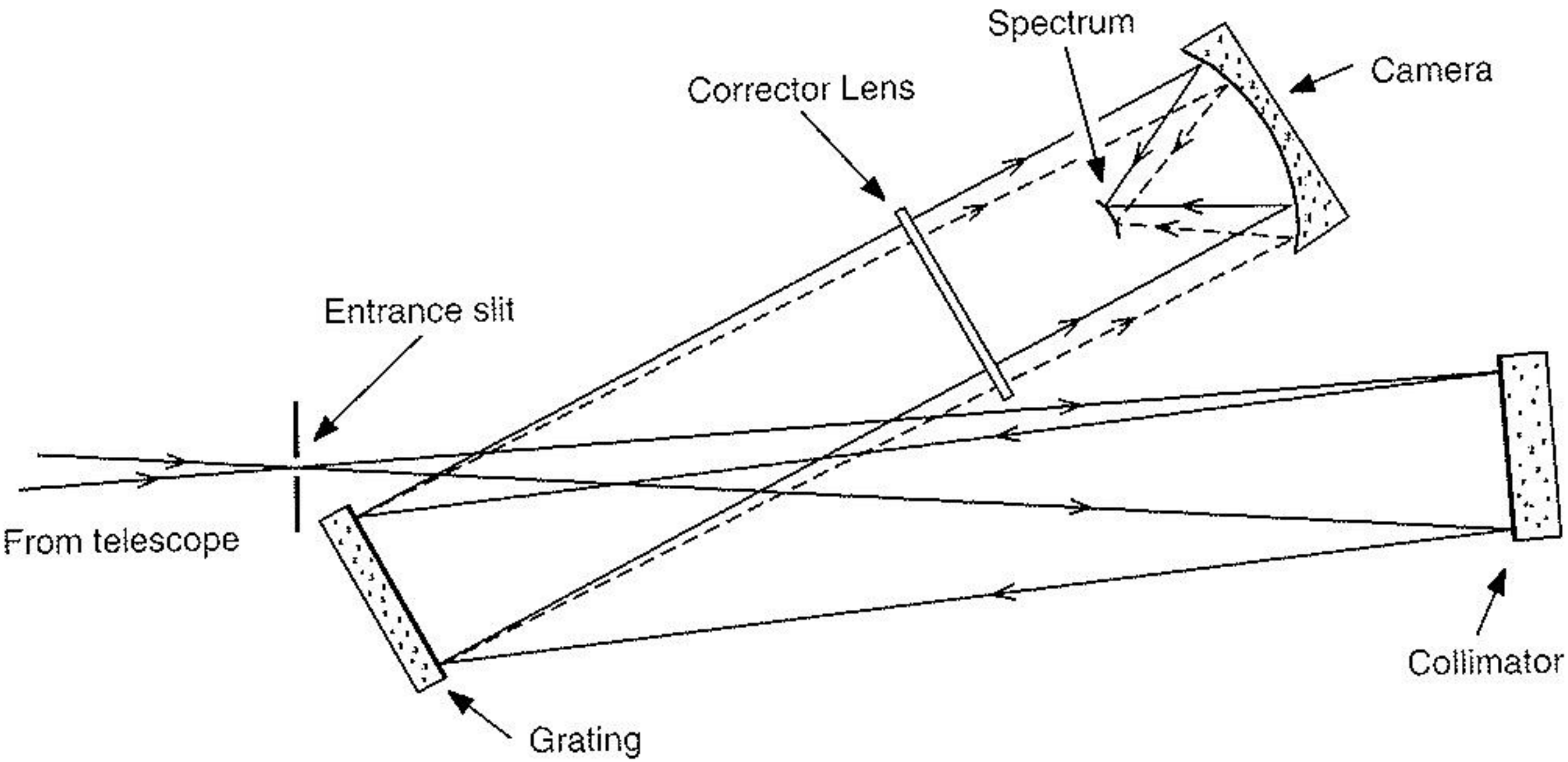
Gratings





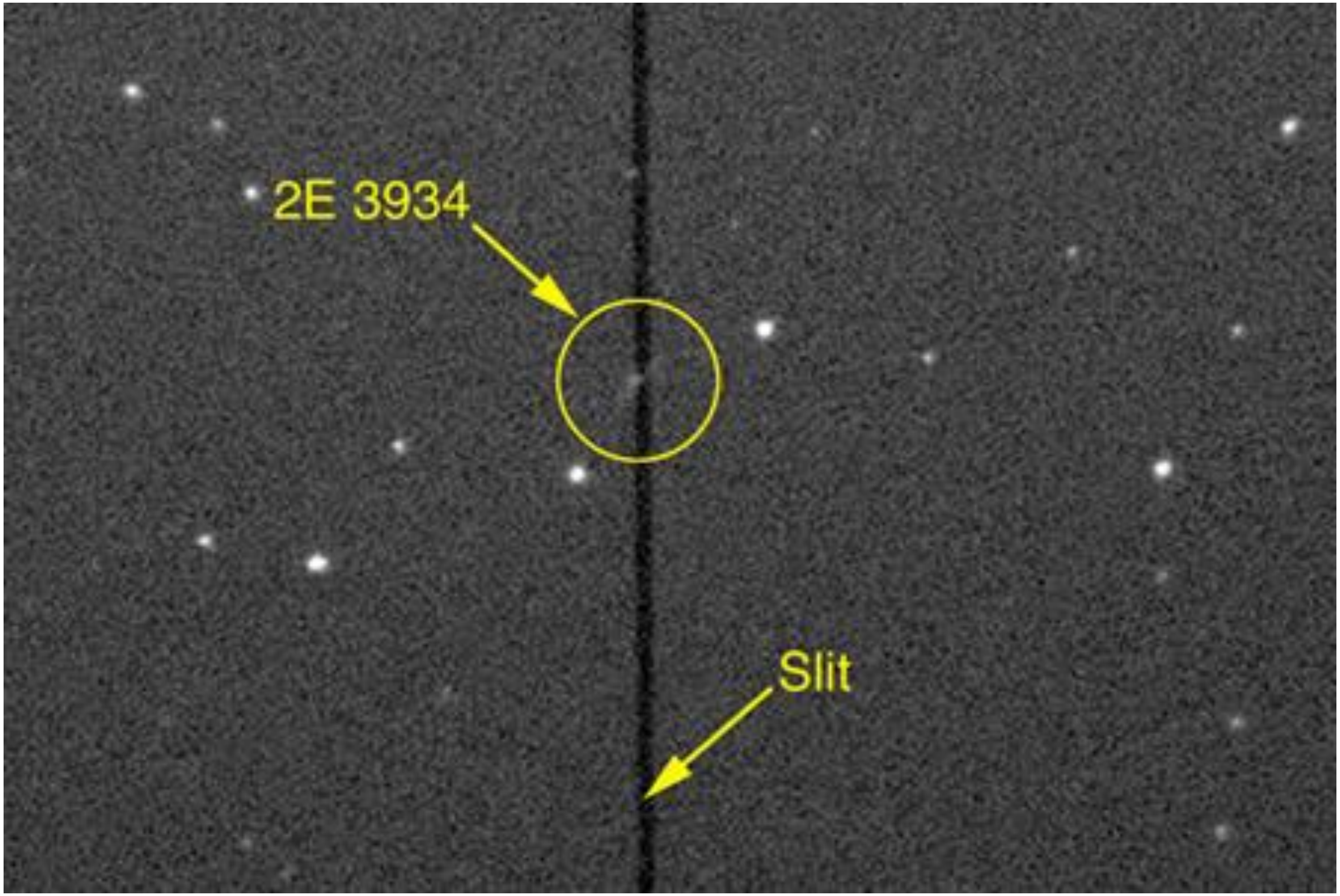
The spectrum is repeated in the different orders of diffraction.
Only the zeroth order spectrum is pure white light.

Spectrograph

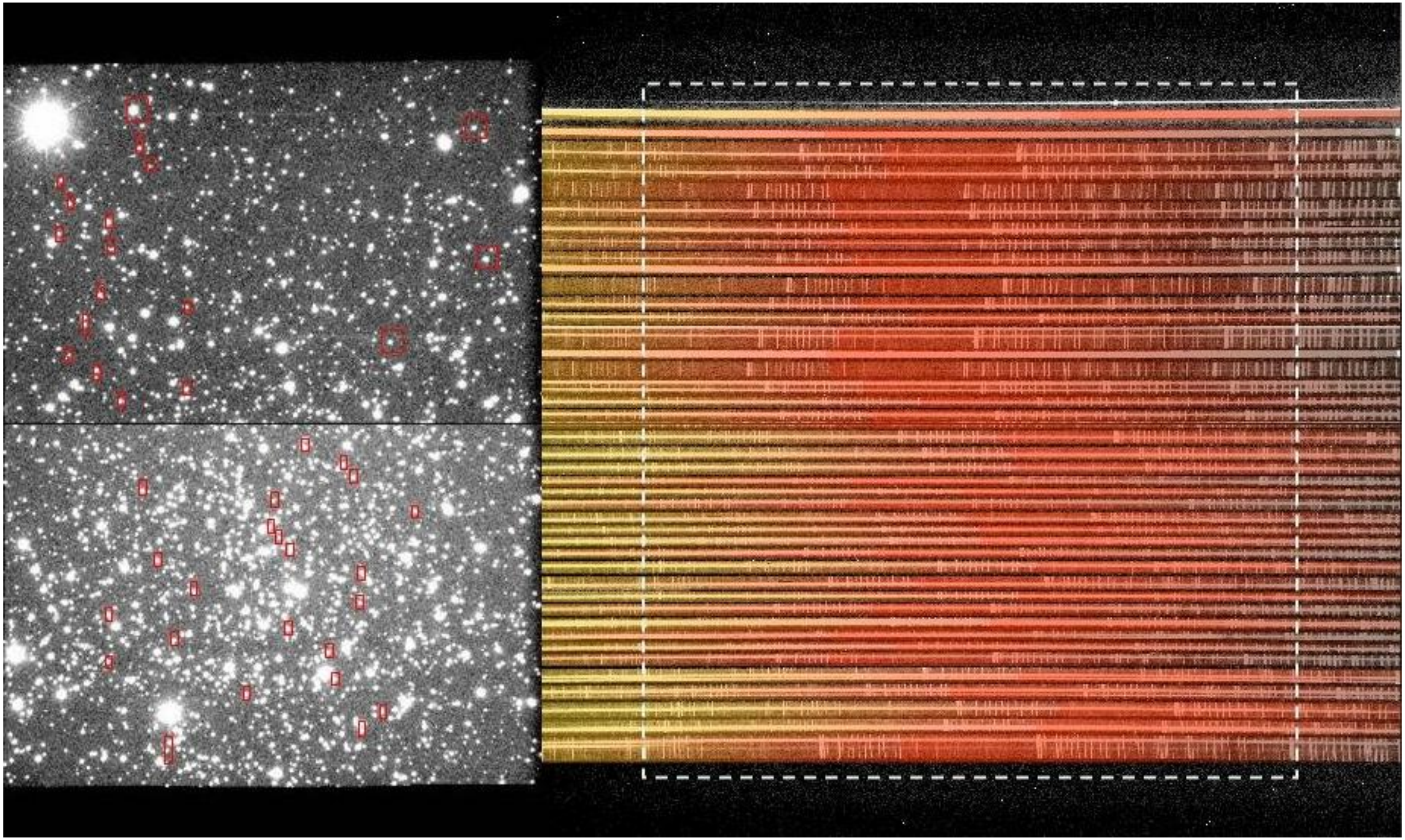


Collimator makes the rays parallel
Grating disperses the light into colours
Camera re-images the rays onto a CCD or infra-red detector

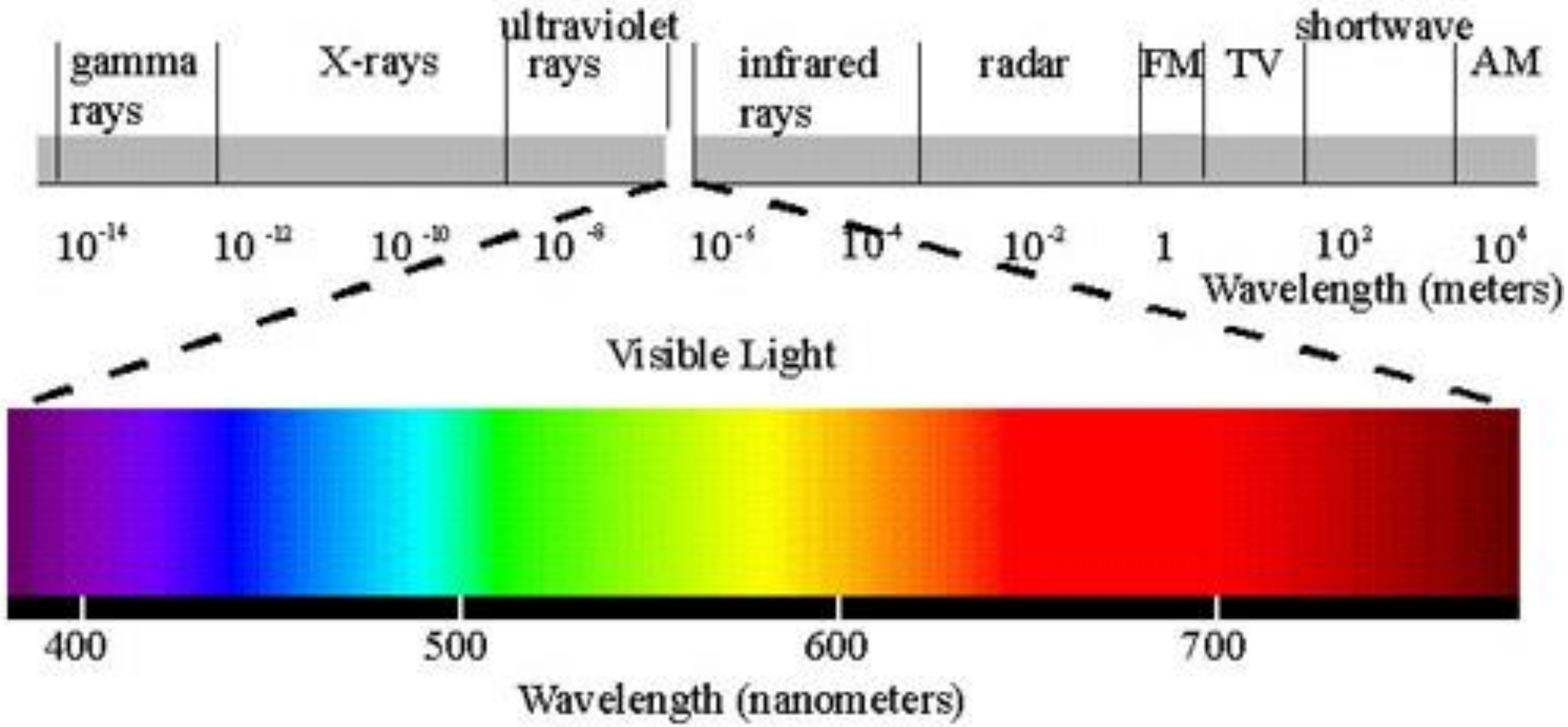
Why to use slit?



Multi-object spectroscopy



Resolving power



Resolving power

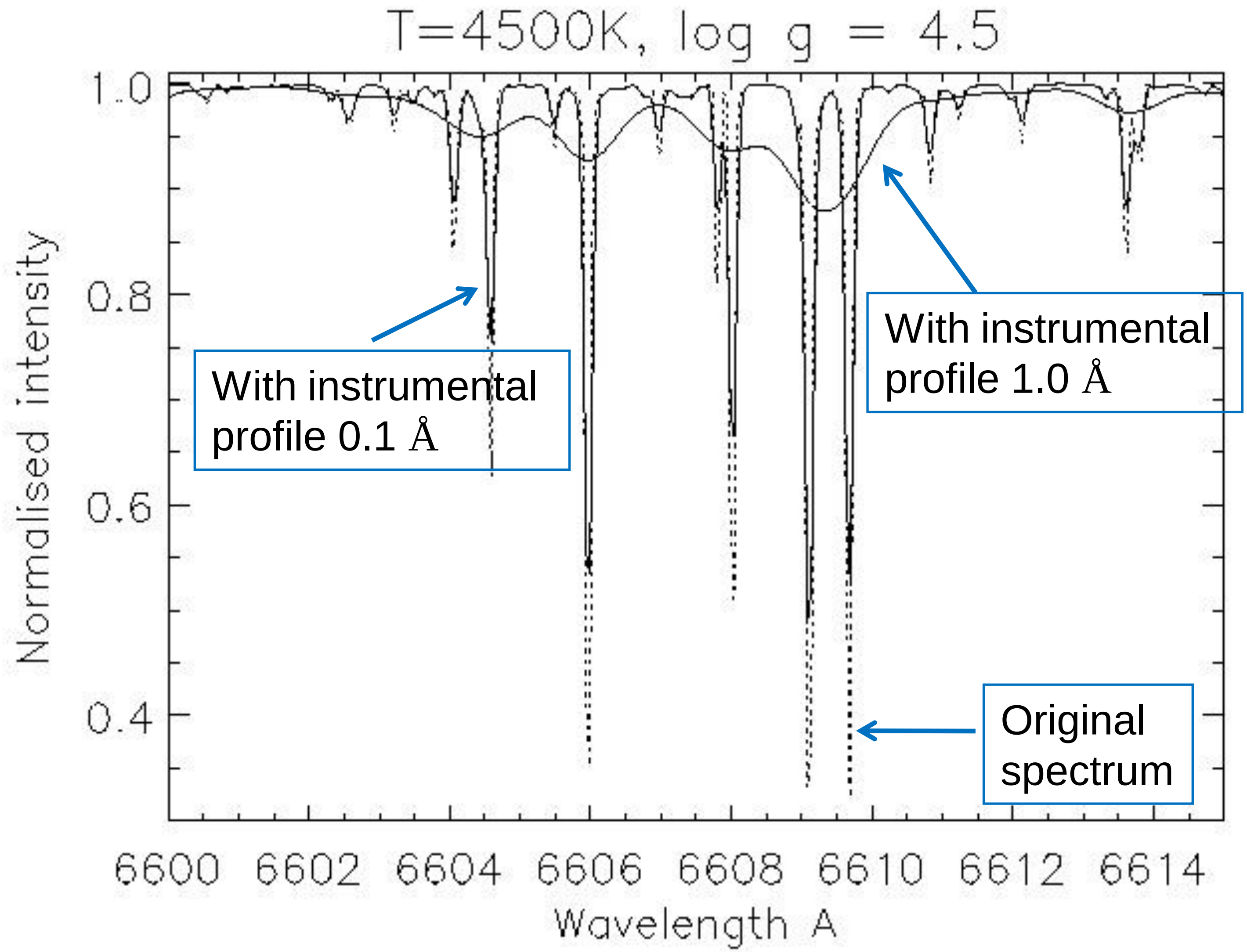
- Resolving power (R) tells how small details we can resolve in the spectrum

- It is defined as $\lambda/\Delta\lambda$

- So for example:
  - R=1000 at 6500 Å gives $\Delta\lambda$=6.5 Å or ~ 300km/s
  - R=10 000 at 6500 Å gives $\Delta\lambda$=0.65 Å or ~30km/s
  - R=100 000 at 6500 Å gives $\Delta\lambda$=0.065 Å or ~3km/s

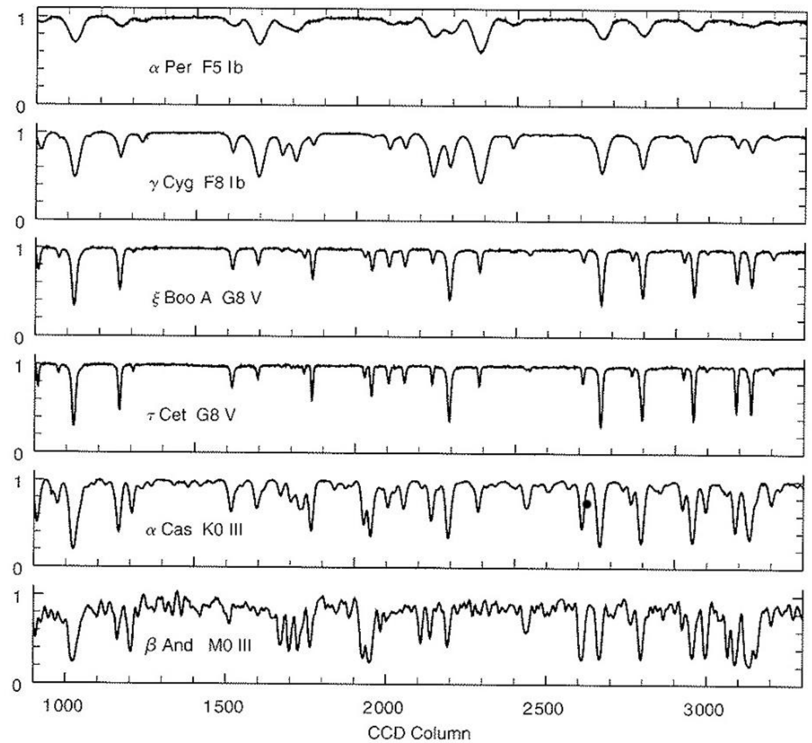
- At a given R, the resolution in velocity does not change with wavelength:
  - $R=\lambda/\Delta\lambda=c/\Delta v$

Lines get “diluted” by low resolution



High resolution spectroscopy

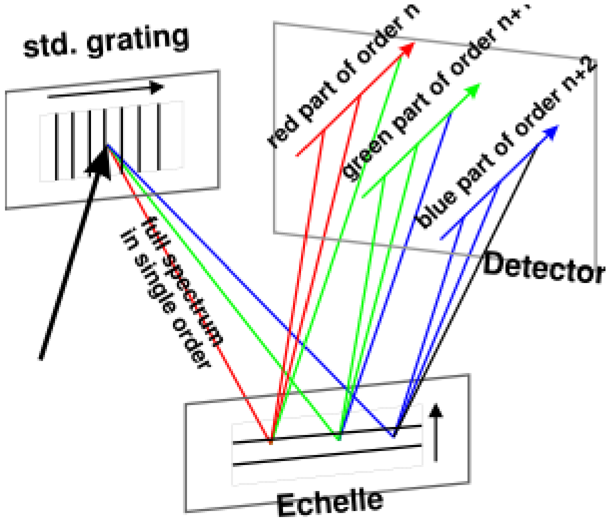
- For seeing detailed structures in our spectra one resolution element has to be small, i.e., the spectral resolution has to be high
- With high spectral resolution we can for example study in detail the composition of stellar atmospheres



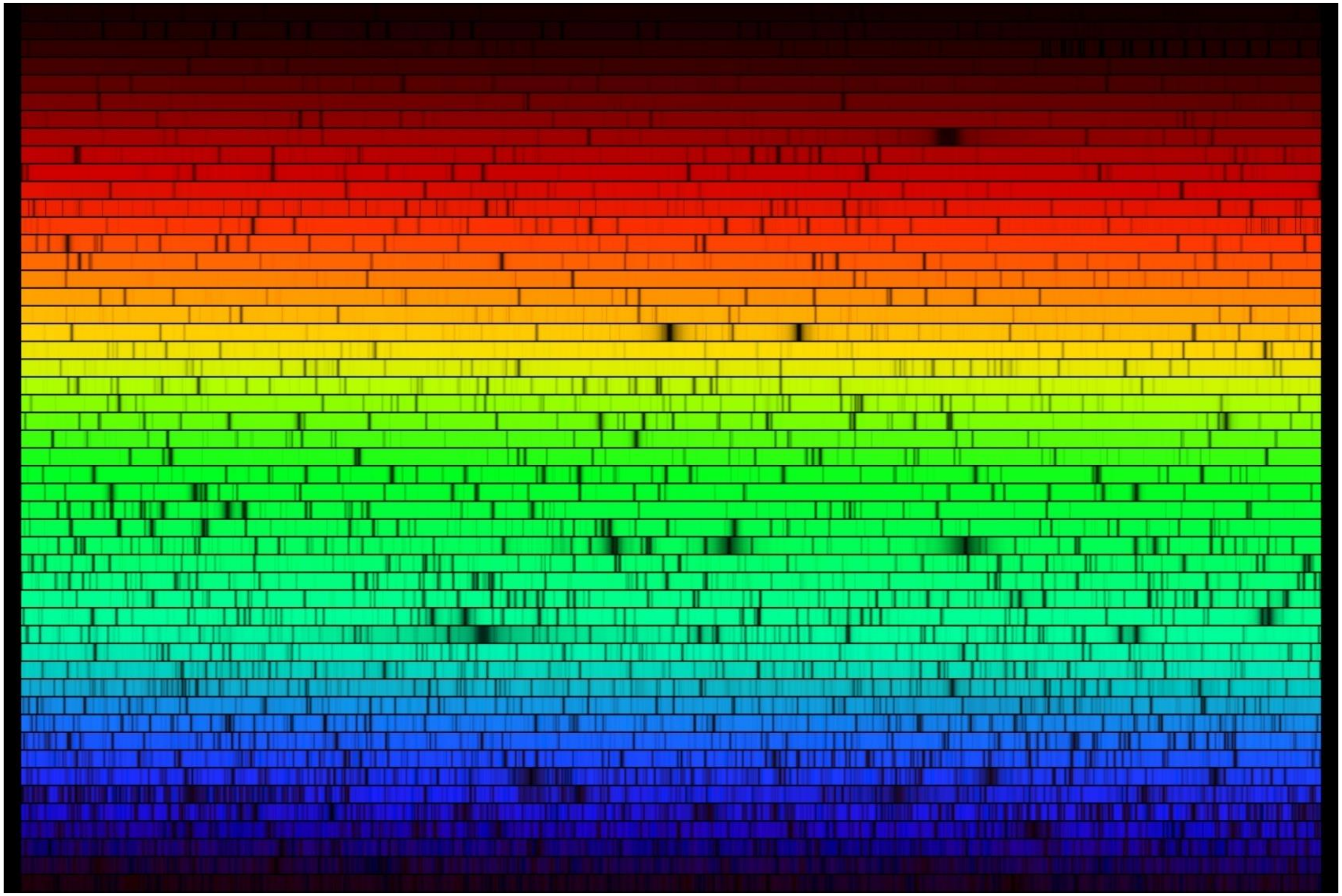
23Å of stellar spectra centered at λ6245Å

Échelle gratings

- For high resolution astronomical work échelle is the preferred choise over a grating used in low order
- The reasons for this are:
  - Two dimensional format that permits broad spectral coverage
  - Allows compact spectrograph design
- Échelle has a large groove spacing and is used at high order number, thus it is necessary to use a cross-disperser to separate the orders, or to use a filter to isolate a single order

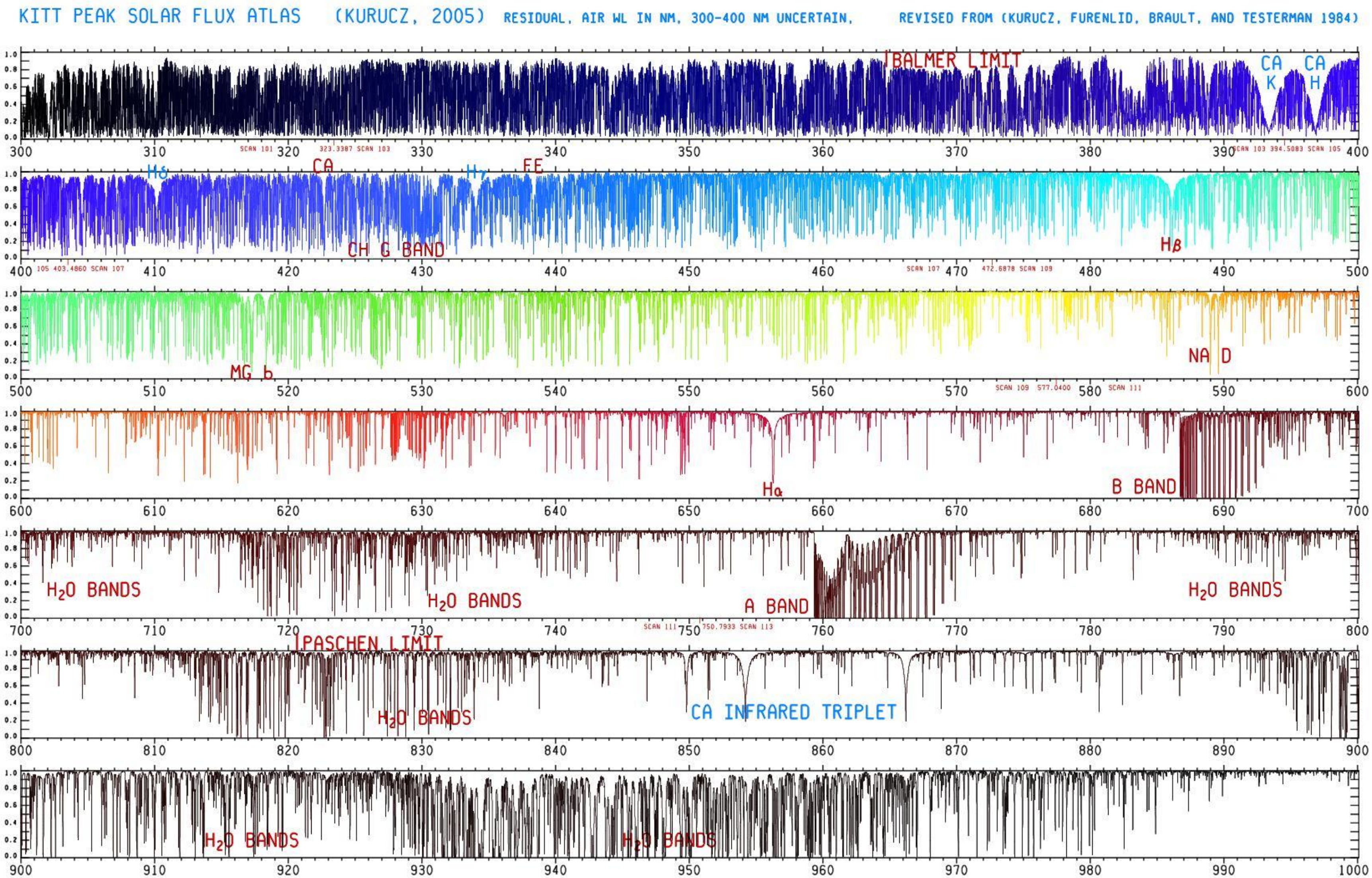


Échelle spectrum



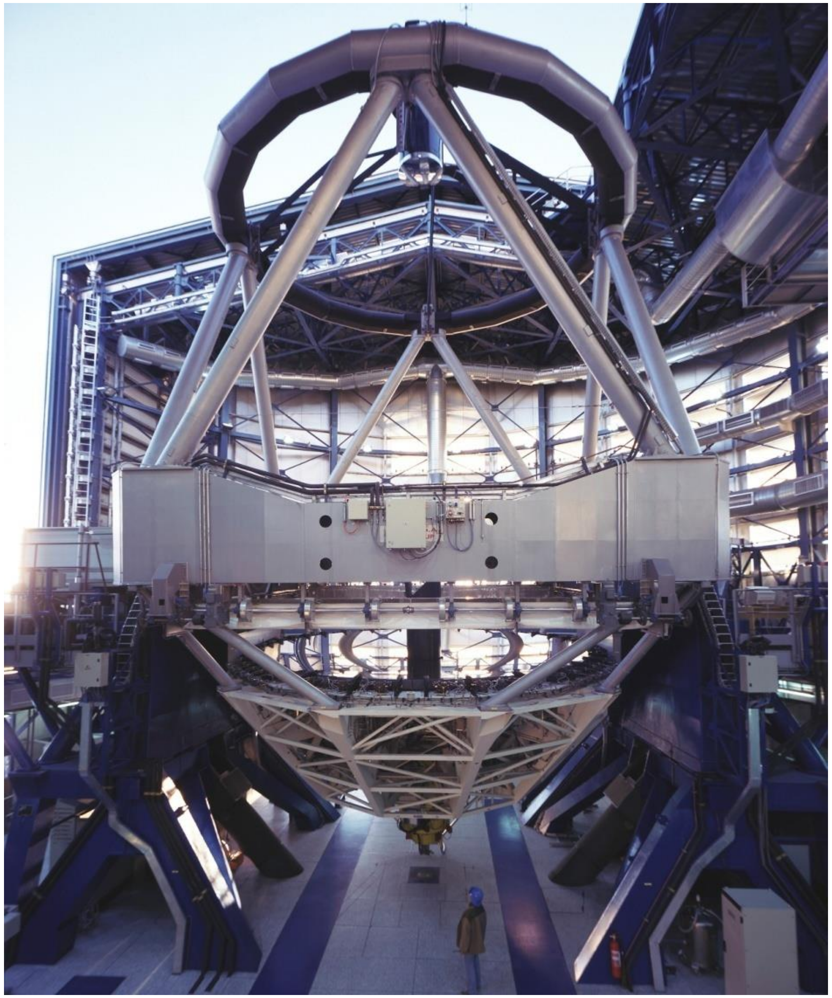
N.A.Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF

And when unstacked

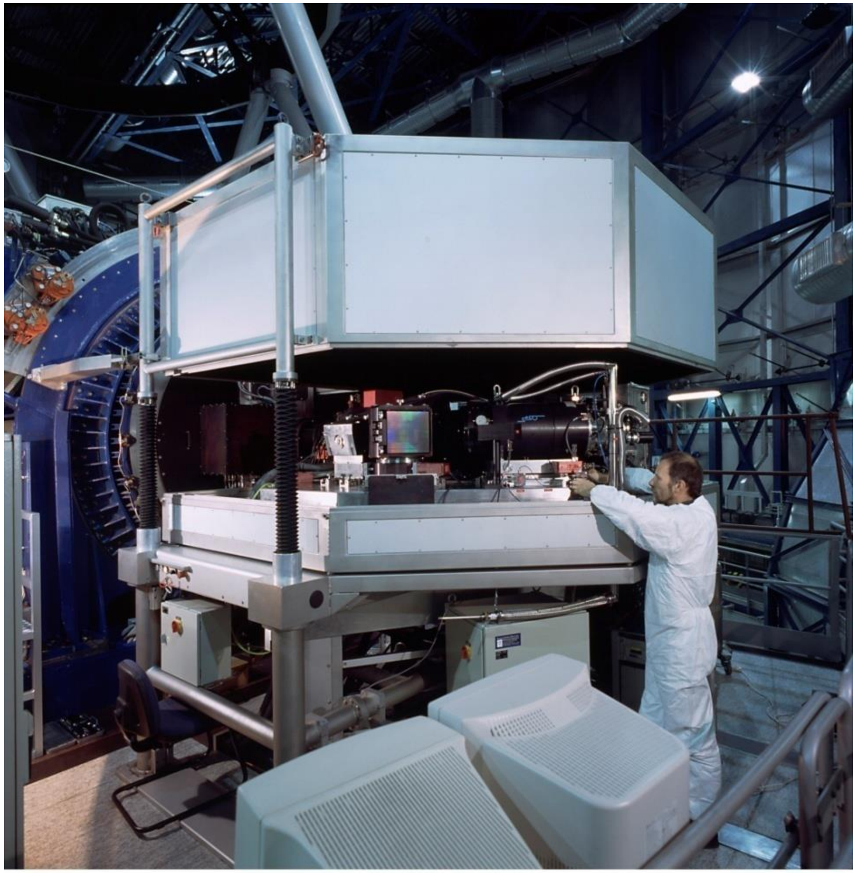


Kitt Peak Solar Flux Atlas, Kurucz 2005

UVES at ESO’s VLT

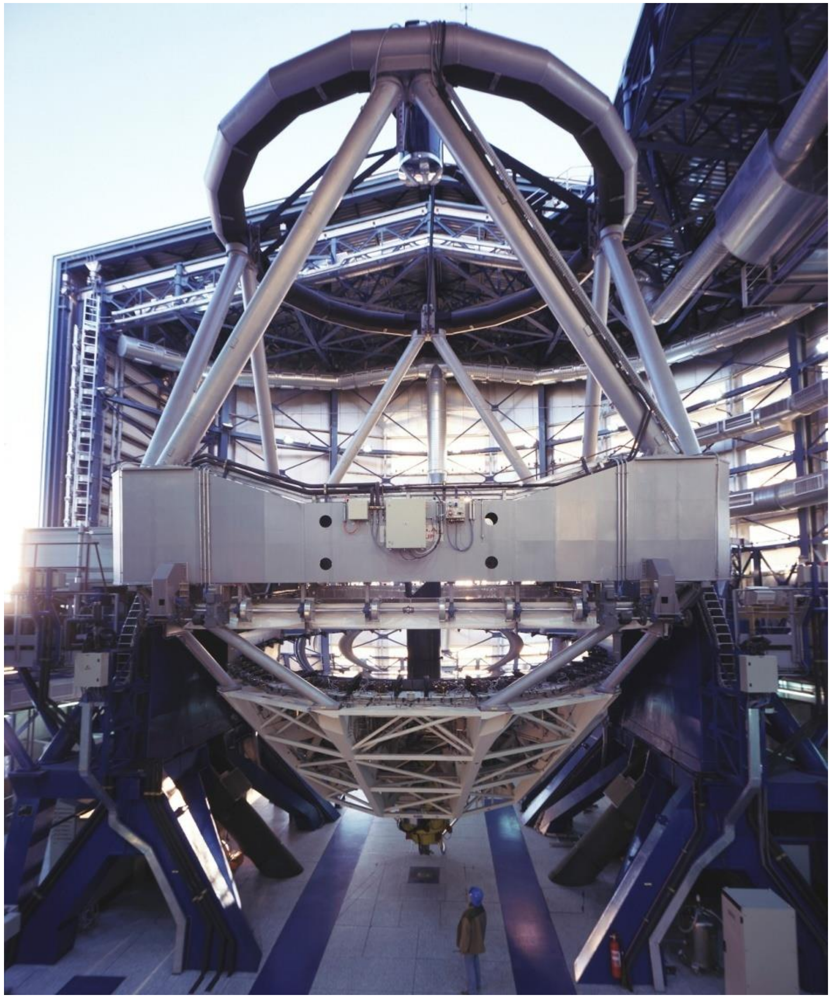


UVES at ESO's VLT

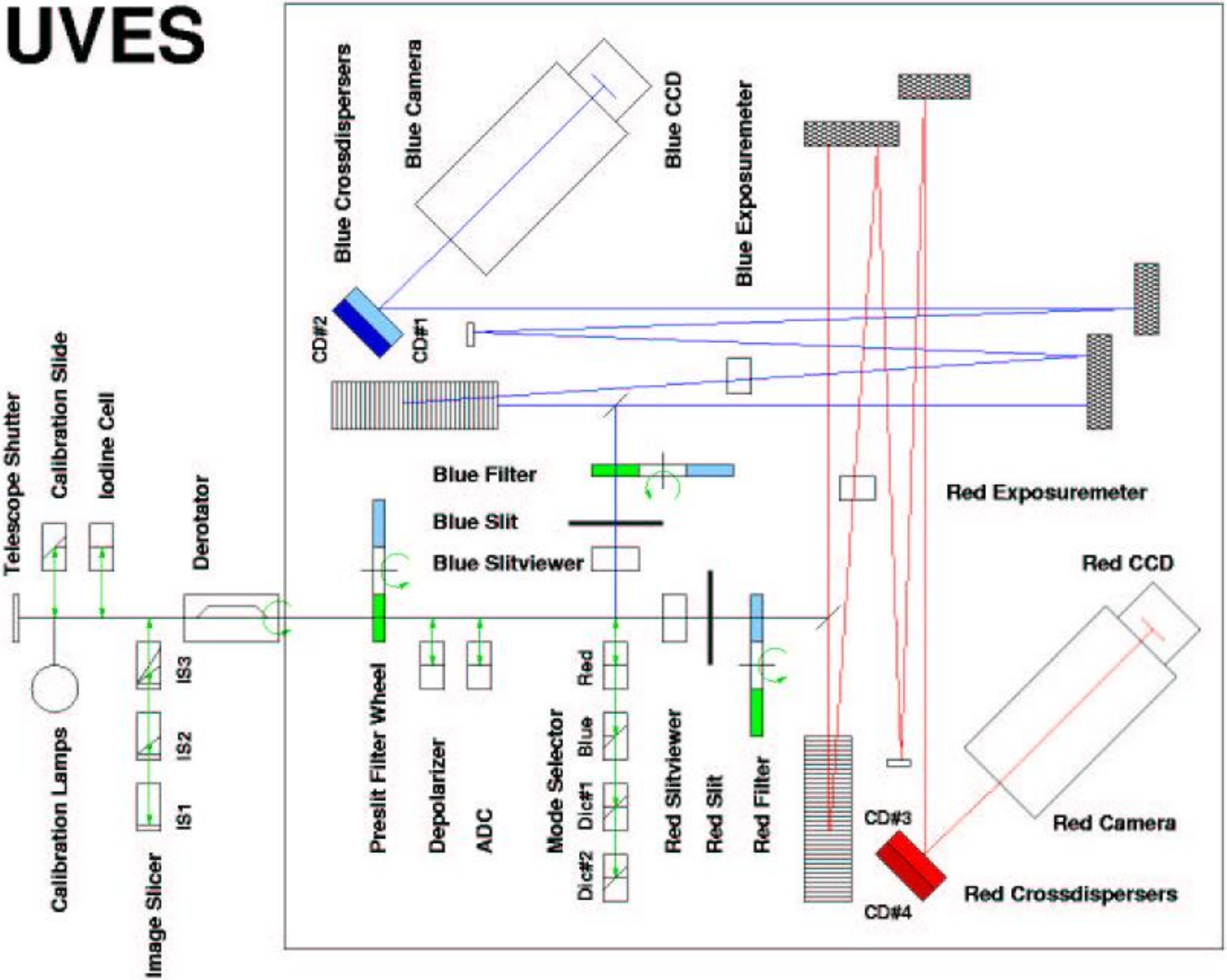


UVES at Kueyen

ESO PR Photo 43e/99 (8 December 1999)



UVES

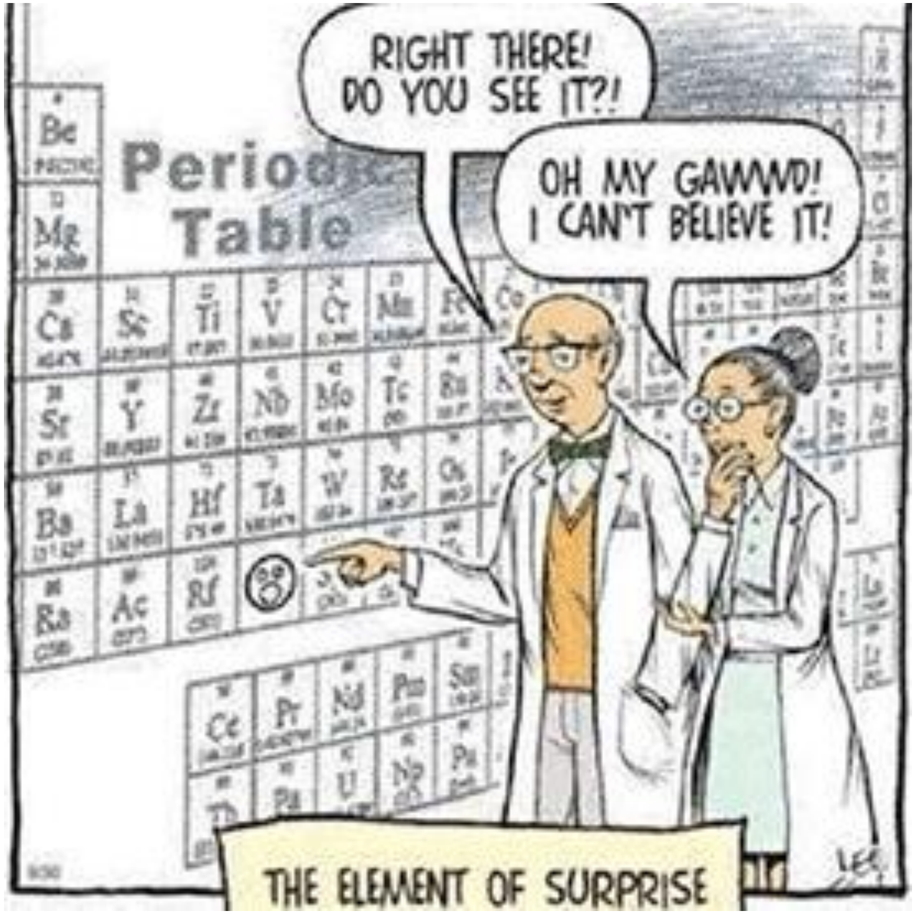

Blue Crossdispersers
Blue Camera
Blue CCD
Blue Exposuremeter
CD#2
CD#1
Telescope Shutter
Calibration Slide
Iodine Cell
Derotator
Blue Filter
Blue Slit
Blue Slitviewer
Red Exposuremeter
Red CCD
Calibration Lamps
Image Slicer
IS3
IS2
IS1
Preslit Filter Wheel
Depolarizer
ADC
Mode Selector
Red
Blue
Dic#1
Dic#2
Red Slitviewer
Red Slit
Red Filter
CD#3
CD#4
Red Camera
Red Crossdispersers

Take home messages - 1

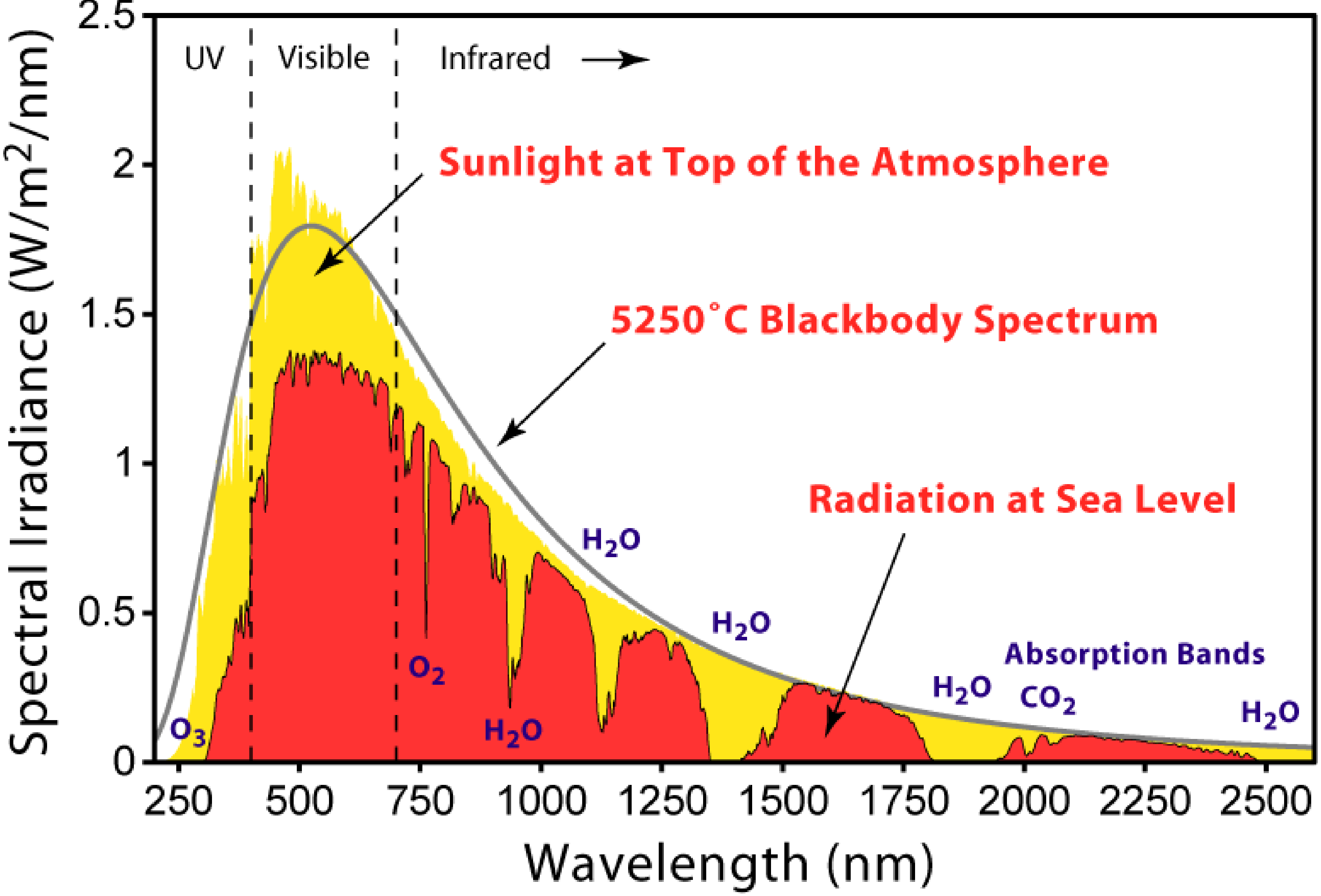
Choose your instrument wisely. For a single object quite high spectral resolution (up to 250,000) is possible. If you want more objects at the same time you are limited by your detector area and need to sacrifice resolution and/or wavelength coverage

In high spectral resolution you are dividing the photons coming from your target into smaller and smaller wavelength bins. Therefore you are often limited to **bright targets** (or need a larger telescope)

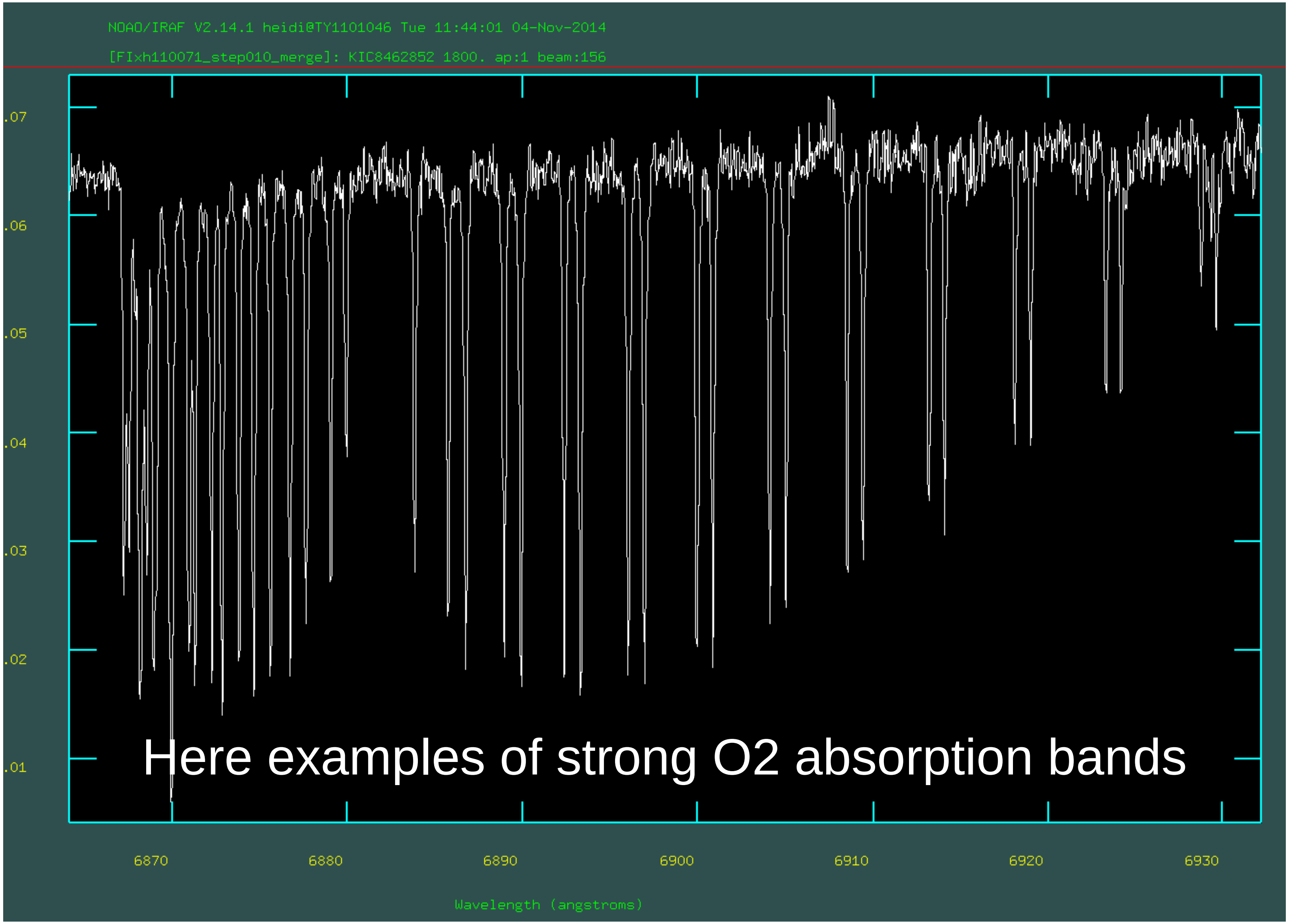
Some effects in your spectra

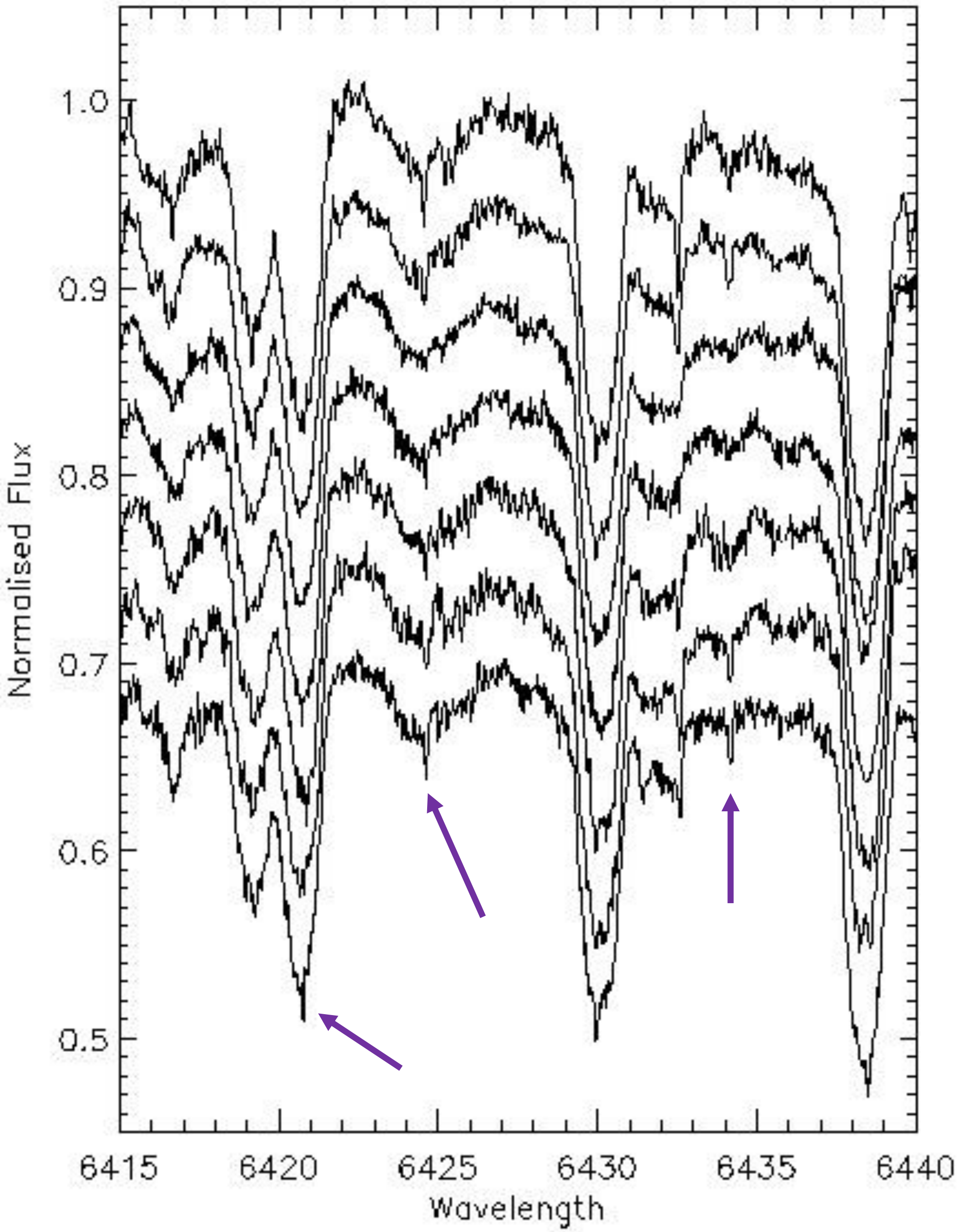


Solar Radiation Spectrum



Absorption lines



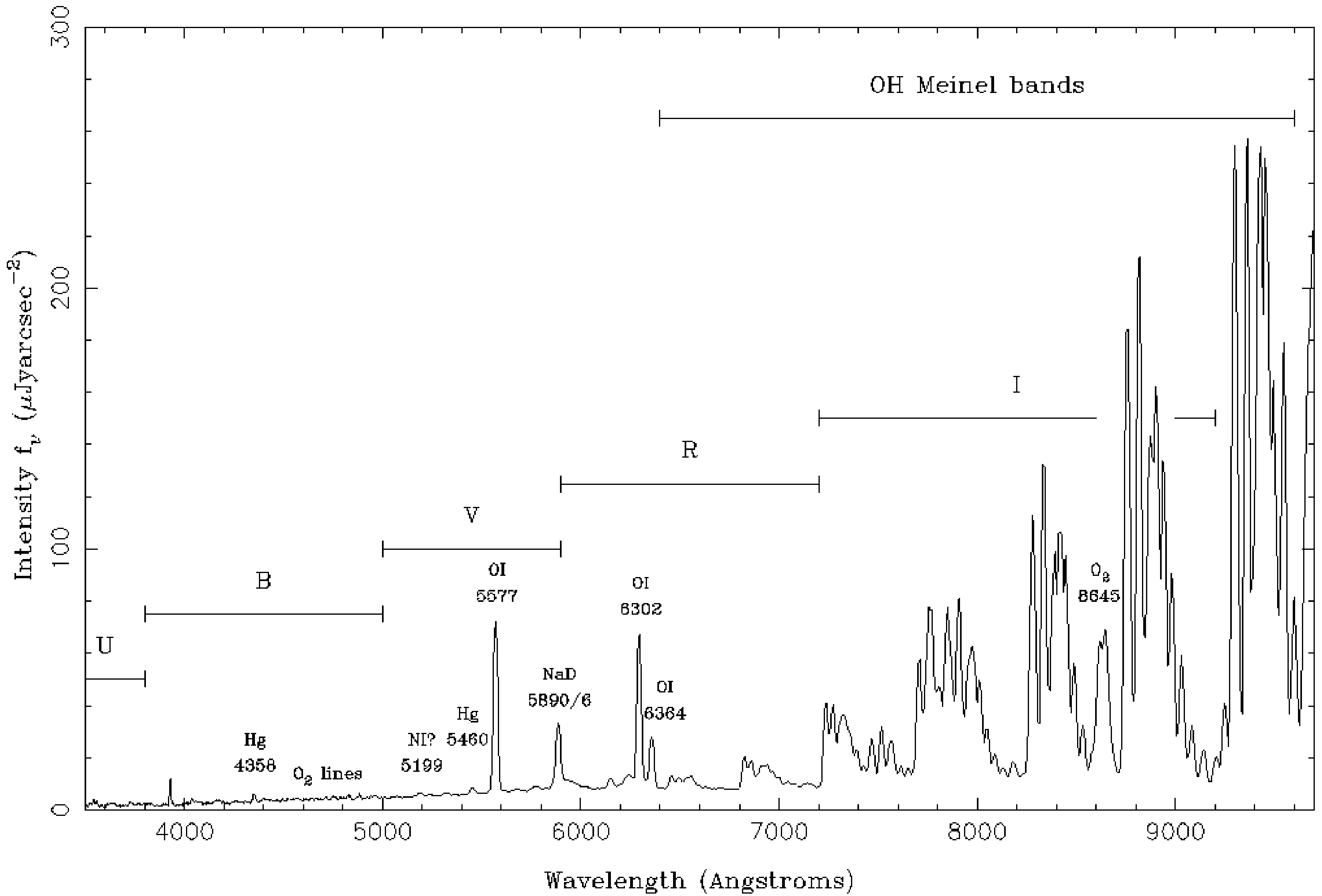


Also much weaker atmospheric absorption lines exist, but they are often only detectable with high spectral resolution

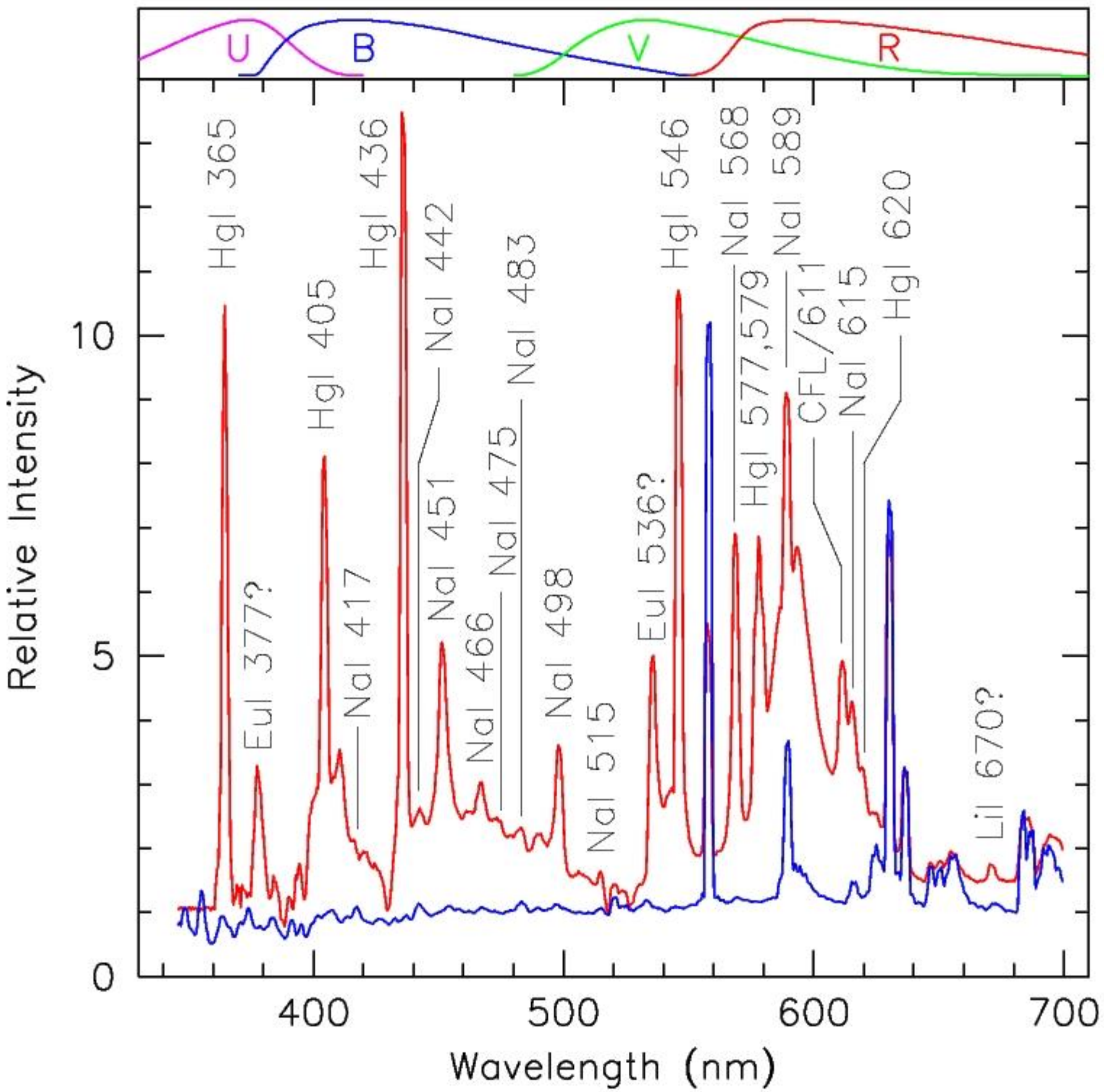
Here some water lines, which also change strength night to night, depending on how much water is in the atmosphere

Atmospheric absorption lines can be modelled quite well, though and there are tools for removing them, e.g., ESO's Molecfit

Night sky emission in optical



Light pollution



Dark site

Light polluted site

Credit: Nando Patat (ESO)

And don't smoke at the telescope

POTASSIUM FLARES

ROBERT F. WING, MANUEL PEIMBERT, AND
HYRON SPINRAD
Berkeley Astronomy Department
University of California

Received April 14, 1967

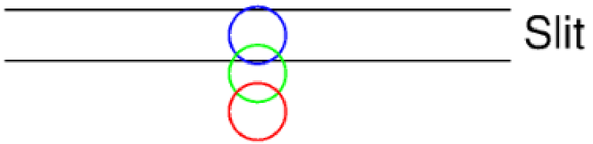
The appearance of intense emission lines of neutral potassium at λλ 7665, 7699 on coudé spectrograms of three stars obtained at the Haute-Provence Observatory has prompted us to conduct a survey of 162 bright stars for emission at λ 7699, using a photoelectric scanner. No definite potassium flares were observed. We discuss the advantages of using a scanner for such a survey and for measuring potassium absorption in late-type dwarfs.

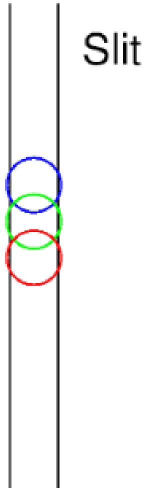
An artificial origin of the emission lines is suggested by the fact that the infrared resonance lines of K I are by far the strongest features in the spectra of matches. Experiments at the Lick and Haute-Provence coudé spectrographs have shown that if a match is struck at certain positions in the coudé room during the exposure of an infrared spectrogram, the resulting potassium emission lines can appear very similar to those previously observed.

1967, PASP, 79, 351

Atmospheric dispersion

- Causes mainly problems for spectroscopy in the form of *slit losses*, which stem from the fact that bluer wavelengths are more strongly refracted.
- Can be avoided by placing the slit in the *parallactic angle*, i.e. perpendicular to the horizon.





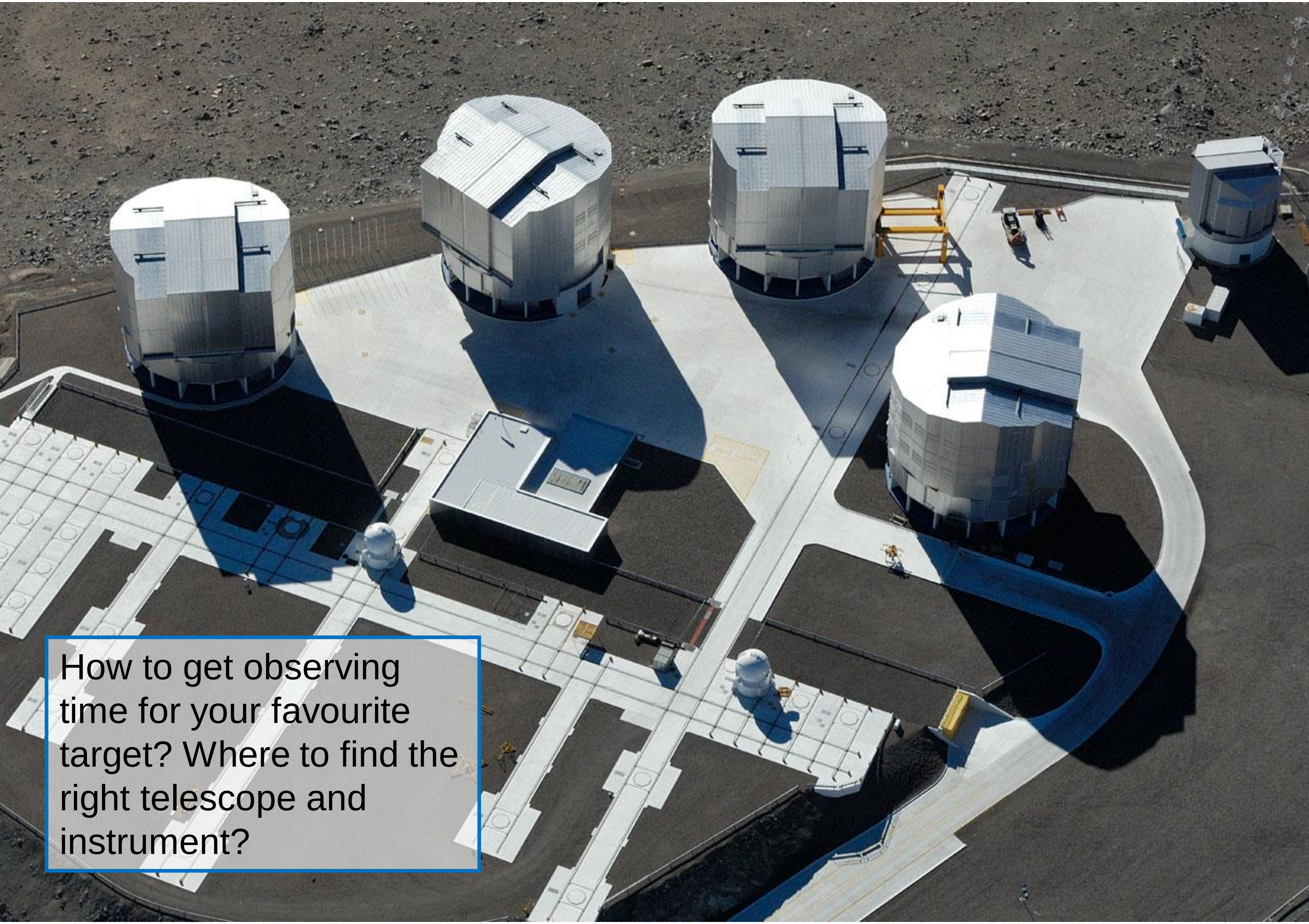
Reducing spectra

- Reducing spectra is more complicated than reducing images, because higher number of calibrations are needed
- In addition to the science frames you will need:
  - Bias frames for removing the constant offset applied to detectors (in order not to have negative counts)
  - A continuum lamp image for removing non-uniform illumination due to optics and removal of pixel-to-pixel variations.
  - A line lamp (so-called arc) frame for wavelength calibration
  - A standard star spectrum for flux calibration (often not used for high resolution spectroscopy)
- Usually the continuum and line lamps are inside the instrument in a special calibration unit.

Take home messages - 2

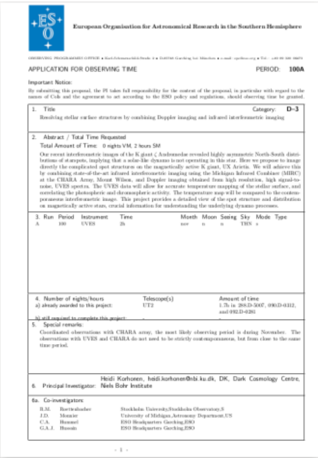
Only a fraction of the light from the target arriving at Earth reaches your detector

If you see stange features in your spectra, do not immediatelly write a Nature paper.



How to get observing time for your favourite target? Where to find the right telescope and instrument?

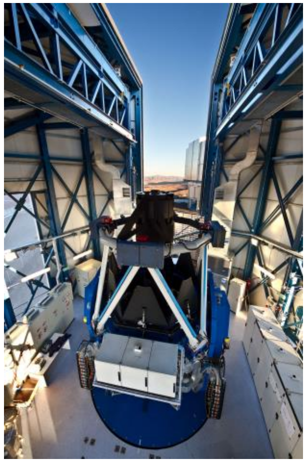
Proposal: from idea to science


European Organisation for Astronomical Research in the Southern Hemisphere

APPLICATION FOR OBSERVING TIME

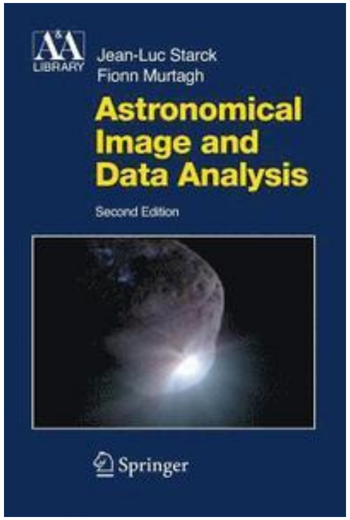
PERIOD: 100A

Important Notice:



CASA

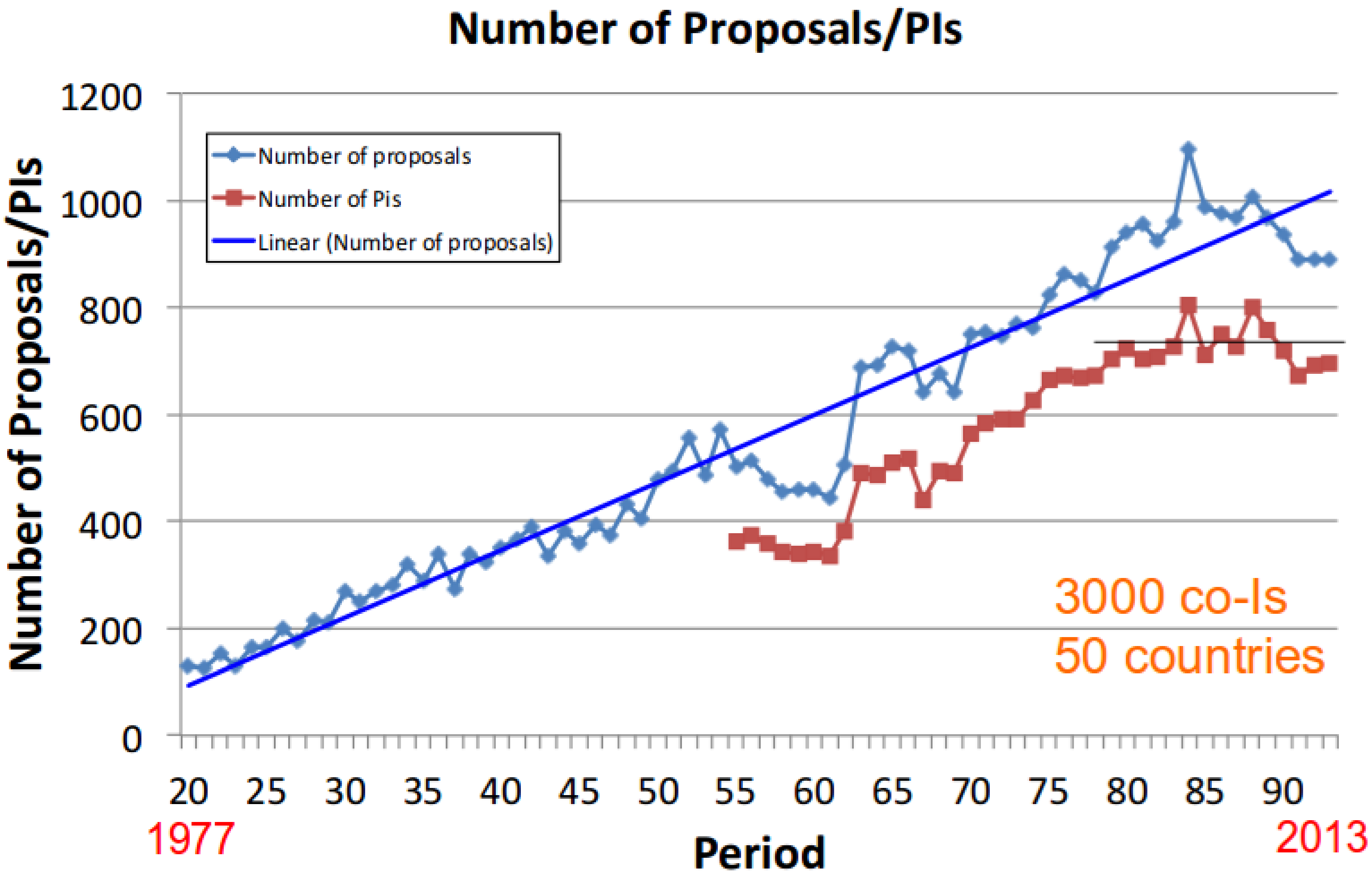
Common Astronomy Software Applications



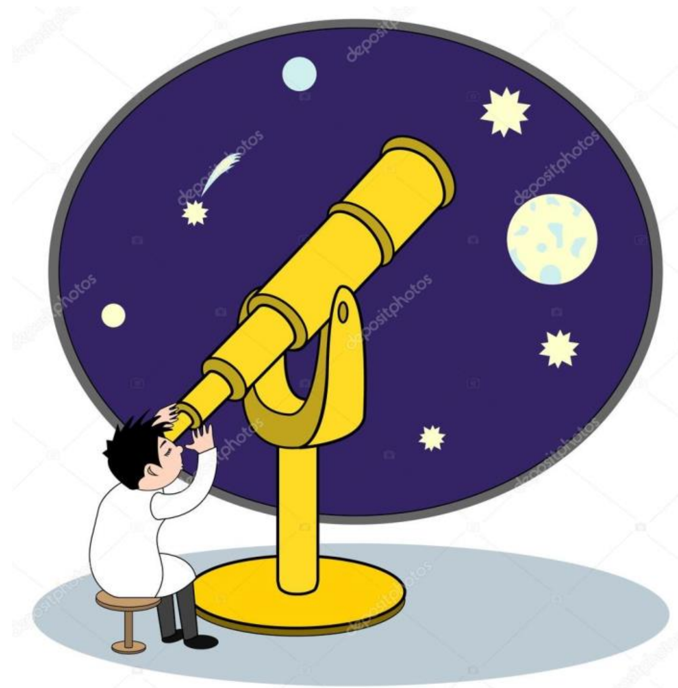
Where to get observing time?

- ESO – Anyone can apply
- ORP/OPTICON (EU funded) – Anyone can apply
- NOIRLab (NSF funded) – Anyone can apply
- National/institute facilities – usually only people working in the institute/country can apply

Number of proposals - ESO



Service vs visitor



In **service mode** the observatory does the observations for you when the conditions are best for your programme

PROs: You will get the observations in optimal conditions

CONS: Predefined observations

In **visitor mode** you go to the observatory and do the observations

PROs: You can change your observations on the fly

CONs: Weather is what it is

Finding information on your target

- For stars: SIMBAD
- For extra-galactic objects: NED

SIMDAB query result for FK Com:

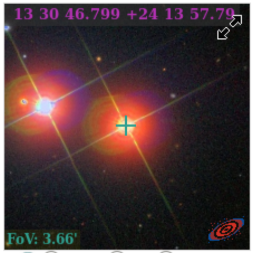
Basic data :

V* FK Com -- Rotationally variable Star

Other object types:	* (HD,AG,...), X (2015A&A,2E,...), ** (**,ADS,...), V* (2012ApJ,ASAS,...), Ae* (1999AJ), PM* (2018yCat), Ro* (2009yCat), Rad (FIRST), IR (2MASS)
ICRS coord. *(ep=J2000)* :	13 30 46.7993742986 +24 13 57.786184235 (Optical) [0.0318 0.0223 90] A 2018yCat.1345....0G
FK4 coord. *(ep=B1950 eq=1950)* :	13 28 24.7543213278 +24 29 25.373558198 [0.0318 0.0223 90]
Gal coord. *(ep=J2000)* :	017.0211082191669 +80.6785094749651 [0.0318 0.0223 90]
Proper motions *mas/yr* :	-51.969 -22.262 [0.085 0.040 90] A 2018yCat.1345....0G
Radial velocity / Redshift / cz :	V(km/s) -21.00 [5.8] / z(~) -0.000070 [0.000019] / cz -21.00 [5.80] D 2007AN....328..889K
Parallaxes *(mas)*:	4.6102 [0.0446] A 2018yCat.1345....0G
Spectral type:	G4III C 2009A&ARv..17..251S
Fluxes (12) :	B 9.04 [~] E ~ V 8.245 [0.067] C 2012AcA....62...67K G 7.9082 [0.0017] C 2018yCat.1345....0G I 7.204 [0.040] C 2012AcA....62...67K J 6.541 [0.021] C 2003yCat.2246....0C H 6.089 [0.018] C 2003yCat.2246....0C K 5.997 [0.015] C 2003yCat.2246....0C u (AB) 13.823 [0.011] D 2009yCat.2294....0A g (AB) 13.123 [0.008] C 2009yCat.2294....0A r (AB) 12.559 [0.01] C 2009yCat.2294....0A i (AB) 12.329 [0.011] D 2009yCat.2294....0A z (AB) 7.759 [0.001] C 2009yCat.2294....0A

SIMBAD query around with radius 2 arcmin

Interactive AladinLite view

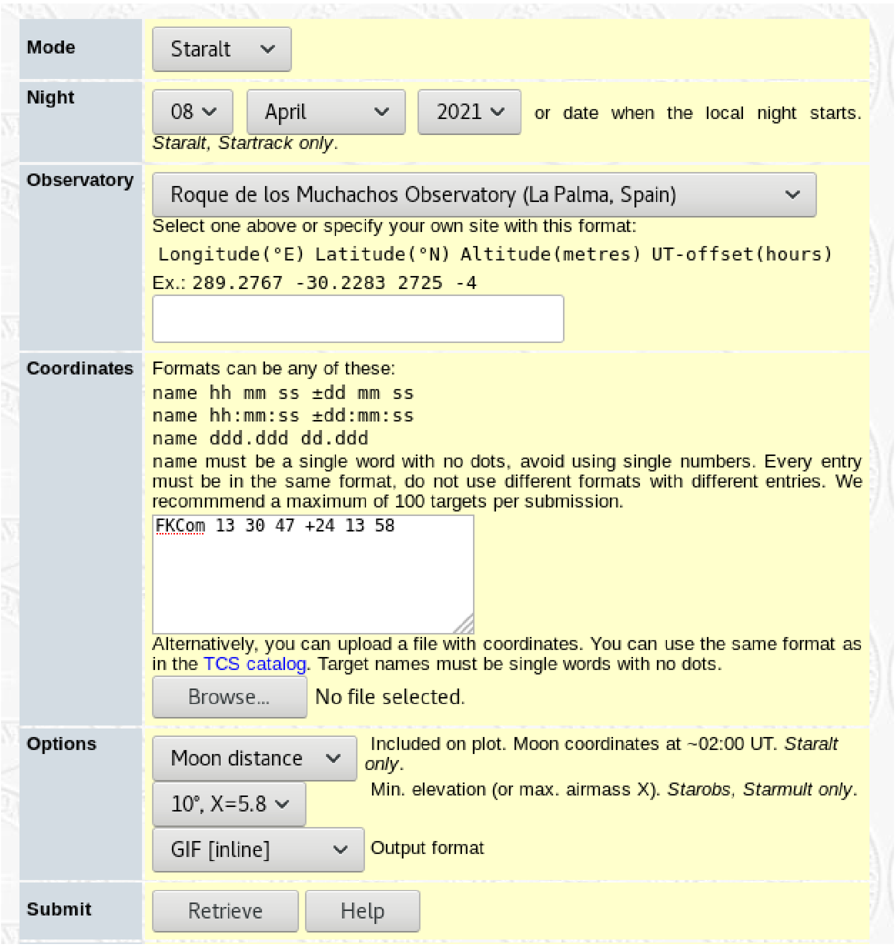


2MASS DSS SDSS

VizieR photometry viewer

Search within radius Max 30 arcsec

When is your target observable?

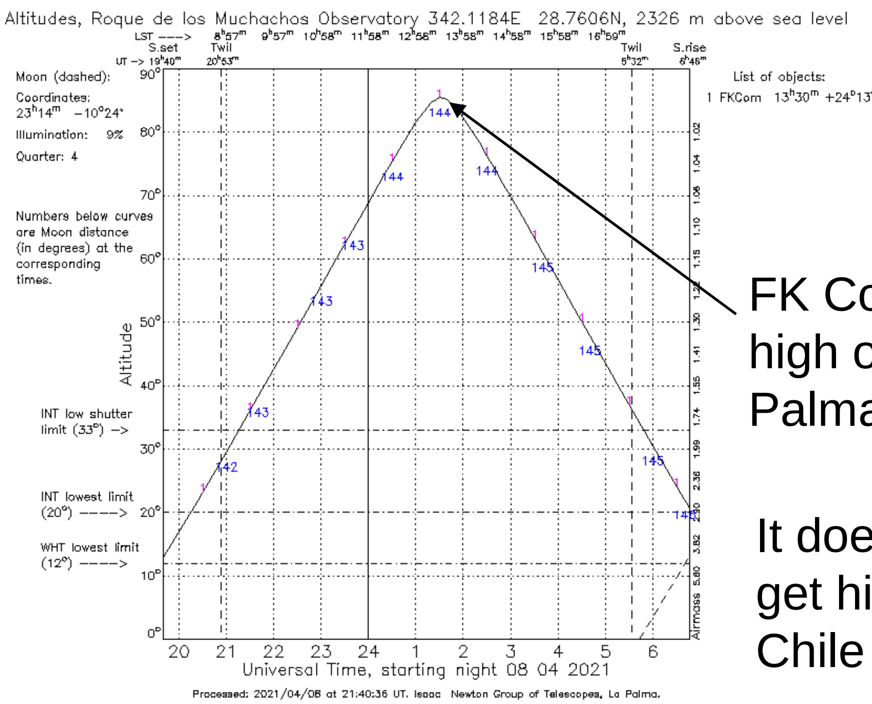


- There is a lot of software available for plotting visibilities of targets
- Most large observatories have their own
- I like Staralt because of the many pre-defined observatories and you can even put in your own

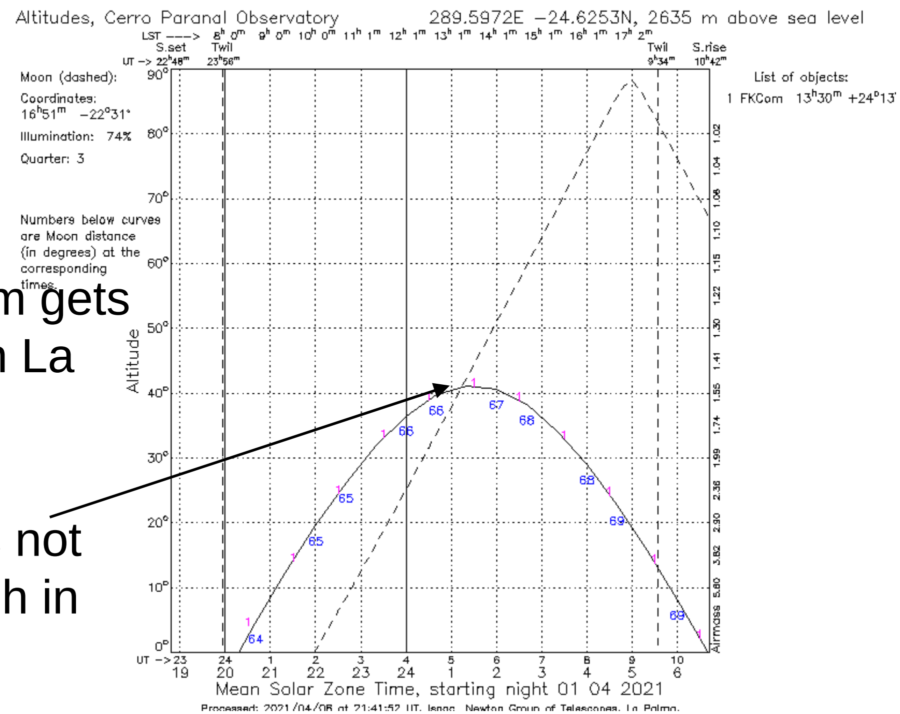
Visibility of FK Com in La Palma and Chile

- FK Com has declination +24 it is a northern hemisphere target
- It has right assencion of 13 hours, meaning it is best visible during the northern hemisphere spring

FK Com on La Palma April 8



FK Com in Chile April 1



FK Com gets high on La Palma

It does not get high in Chile

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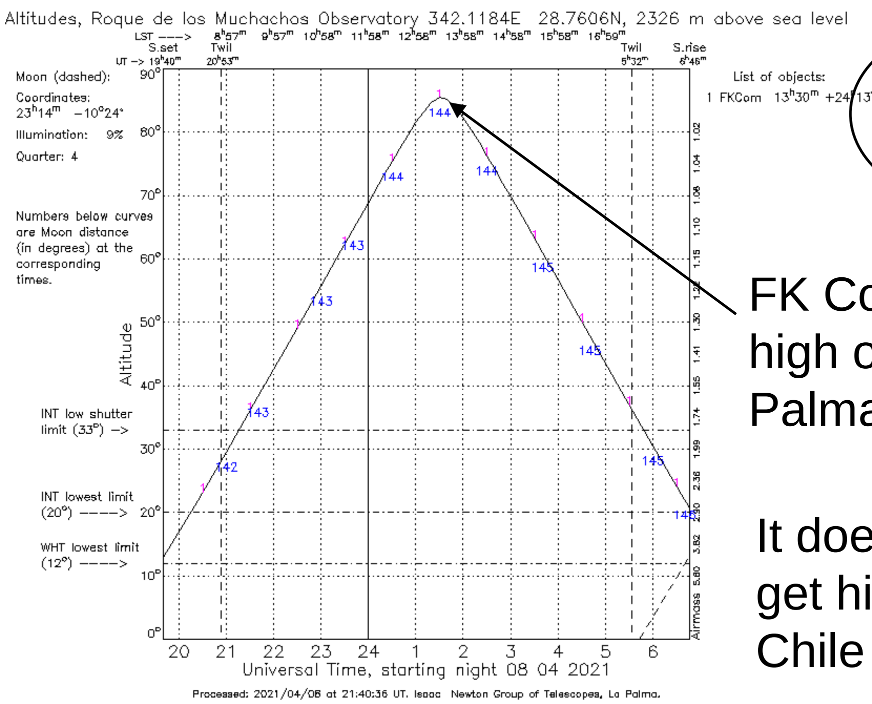
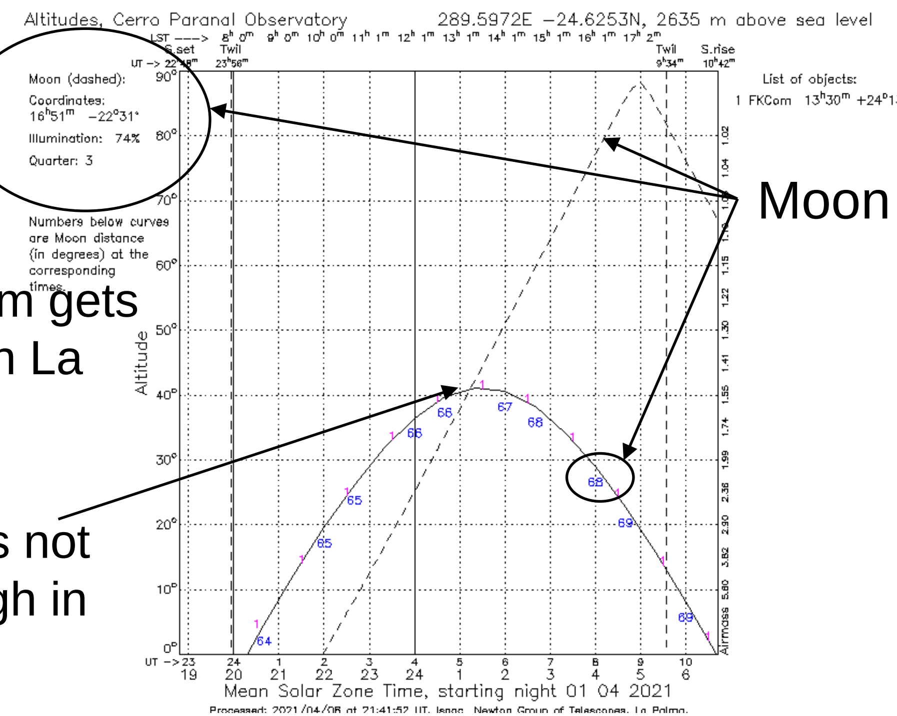


FK Com in Chile April 1



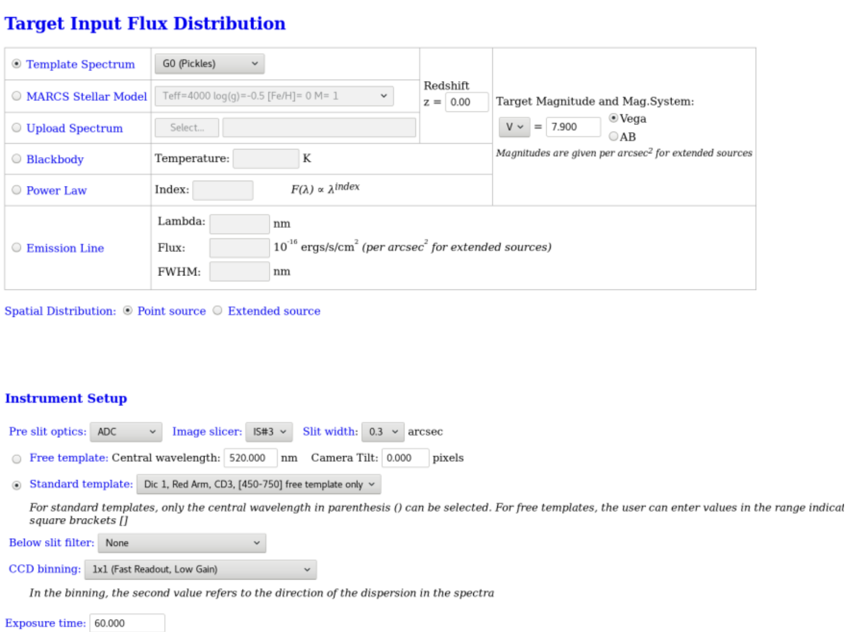
FK Com gets high on La Palma

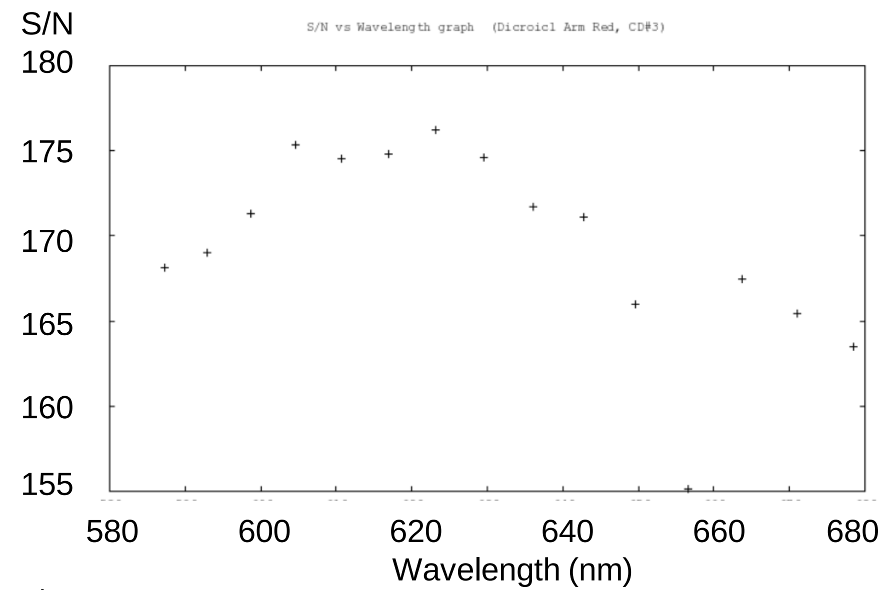
It does not get high in Chile

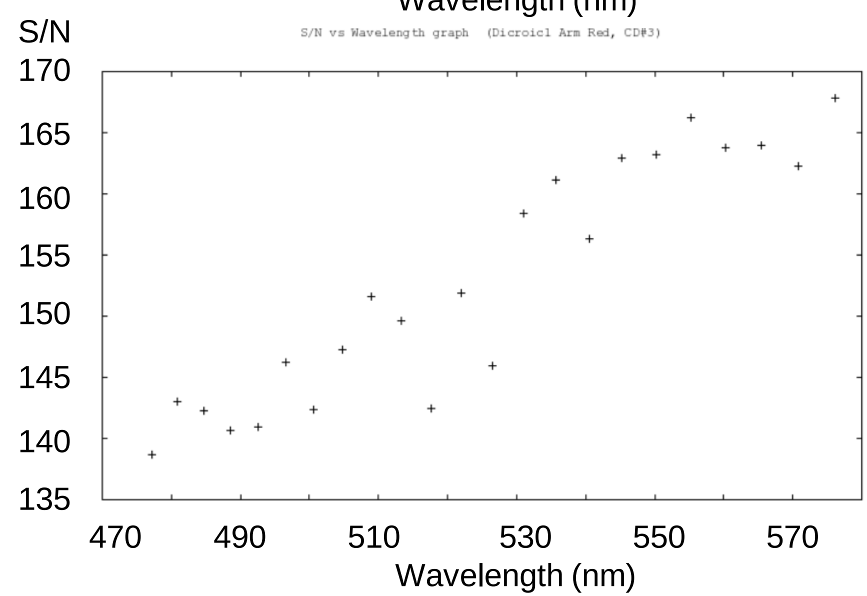
Moon

Exposure Time Calculator (ETC)

- Most larger observatories have exposure time calculators for their instruments
- ESO ETC







Take home messages - 3

Anyone can apply observing time from:

- ESO
- ORP/OPTICON (Note that the website might change as OPTICON is ending and ORP is starting)
- NOIRLab

Plan your observations well. **Telescope time is expensive!**

2m class telescope costs ~3,000EUR/night

4m class telescope costs ~12,000 EUR/night

8m class telescope costs ~35,000 EUR/night (~1EUR/sec!)

Telescopes with main mirror >8m

Large Binocular Telescope (LBT) – 2 x 8.4m – Mt. Graham, Arizona, USA (effective aperture 11.9m)				
PEPSI	wl = 383 – 907nm	R=50,000 – 250,000	Needs three exposures for the full coverage	Access: Institutes
Gran Telescopio Canarias (GTC) – 10.4m – La Palma, Spain (no high resolution spectrogpraphs)				
Hobby Eberly Telescope (HET) – 10m – McDonald Observatory, Texas, USA (altitude fixed to 55 degrees)				
HPF	wl = 810 – 1280nm	R~53,000	Needs two exposures for the full coverage	Access: Institutes
Keck 1 & 2 – 10m – Mauna Kea, Hawaii, USA				
HIRES	wl = 300 – 1000nm	R~25,000 – 85,000		Access: institutes and NOIRLab
NIRSPEC	wl = 950 – 5000nm	R~ 25,000		Access: institutes and NOIRLab

Telescopes with main mirror >8m

Southern African Large Telescope (SALT) – 9.2m – Sutherland, South Africa (altitude fixed to 55 degrees, like HET)				
HRS	wl = 370 - 550 nm & 550 - 890nm	R=14,000 – 65,000	Needs three obs for full coverage	Access: Institutes and ORP
Very Large Telescope of ESO – 4 x 8.2m – Cerro Paranal, Chile				
CRIRES+	wl = ~950 – ~5000nm	R=50,000 or 100,000	**Being commisisoned**	Access: ESO
ESPRESSO	wl = 380 – 788nm	R=70,000 – 190,000	can be used on a single 8m telescope or combining light from all four	Access: ESO
FLAMES	wl = 370 - 950 nm (~100nm per obs)	R=7,000 – 47,000	Some 130 objects at a time	Access: ESO
UVES	wl = 300 – 1100nm	R~40,000 – 110,000	Needs two obs for full coverage	Access: ESO
X-Shooter	wl = 300 – 2500nm	R~ 3,000 – 19,000		Access: ESO

Telescopes with main mirror >8m

Subaru – 8.2m – Mauna Kea, Hawaii, USA				
HDS	wl = 300 – 1000nm	R up to 160,000		Access: National, institutes and international
IRD	wl = 970 – 1750nm	R~70,000	Visitor instrument	Access: National, institutes and international
Gemini North and Gemini South – 2 x 8.1m – Mauna Kea, Hawaii, USA and Cerro Pachon, Chile (the instruments mentioned below are at Gemini North)				
GRACES	wl = 400 – 1000nm	R~40,000 or 60,000	Visitor instrument (not always available)	Access: institutes and NOIRLab
MAROON-X	wl = 500 – 920nm	R~80,000	Visitor instrument (not always available)	Access: institutes and NOIRLab

Other telescopes of interest: at least 3.5m diameter mirror and universal access

William Herschel Telescope (WHT) – 4.2m – La Palma, Spain				
WEAVE	wl = 404 – 465nm, 473 – 545nm, and 595 – 685 nm (with some small gaps)	R up to 20,000	1000 objects over 2 square degree field, **being commissioned**	Access: National (mostly for predefined surveys), ORP?
VISTA at ESO – 4.1m – Cerro Paranal, Chile				
4MOST	wl = 392.6 – 435.5nm, 516 – 573nm, and 610 – 679 nm	R up to ~20,000	2400 objects over 4 square degree field, **being built**	Access: ESO
TNG – 3.58m – La Palma, Spain				
HARPS-N	wl = 383 – 693nm	R~115,000	High radial velocity precision	Access: National, institutes and ORP

Other telescopes of interest: at least 3.5m diameter mirror and universal access

Canada-France-Hawaii-Telescope (CFHT) – 3.58m – Mauna Kea, Hawaii, USA				
ESPaDOnS	wl = 370 – 1050nm	R ~68,000 or 81,000	Includes spectro-polarimetry	Access: National, institutes, ORP
SPIRou	wl =950 – 2350nm	R ~75,000	Includes spectro-polarimetry	Access: National, institutes, ORP
ESO 3.6m at ESO – 3.57m – Cerro Paranal, Chile				
HARPS	wl = 383 – 691 nm	R ~115,000	High percision, includes spectro-polarimetry	Access: ESO
CAHA 3.5 – 3.5m – Calar Alto, Spain				
CARMENES	wl = 520 - 960nm & 960 - 1710nm	R~80,000 – 100,000	High radial velocity precision	Access: National, institutes and ORP