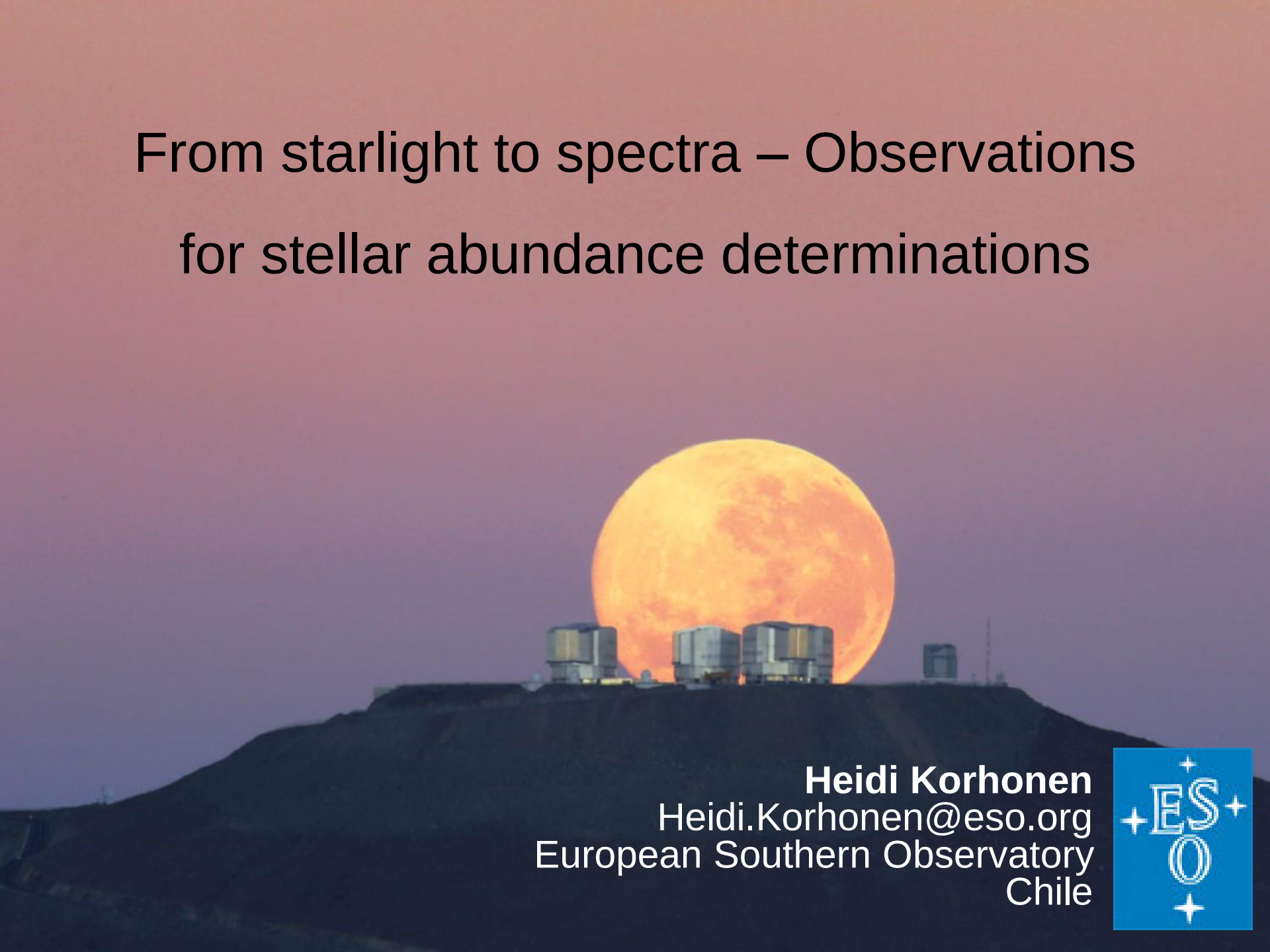


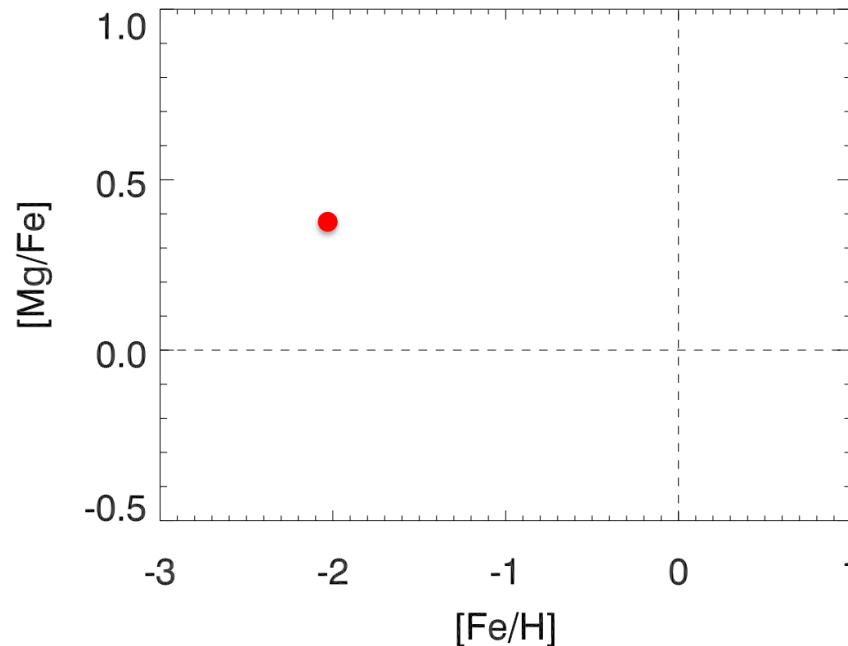
From starlight to spectra – Observations for stellar abundance determinations



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How to get an abundance ?

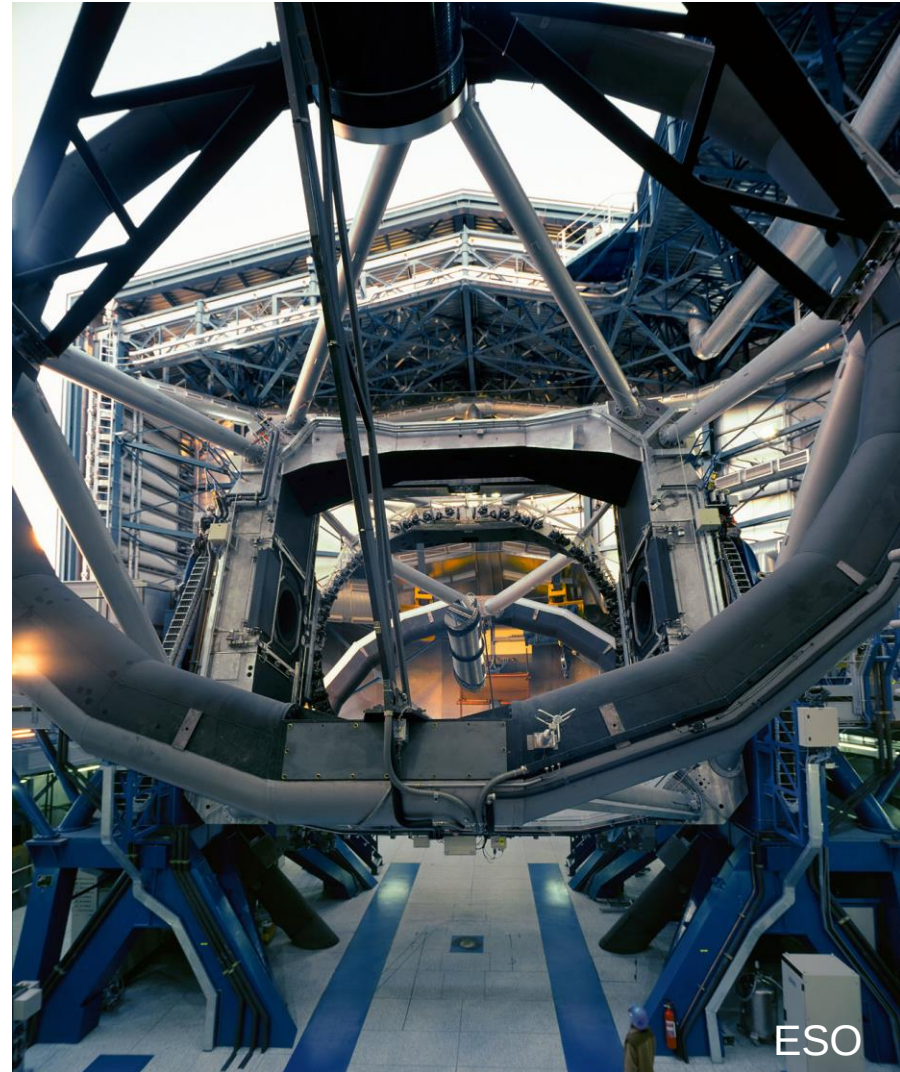


Input needed for that one dot alone:

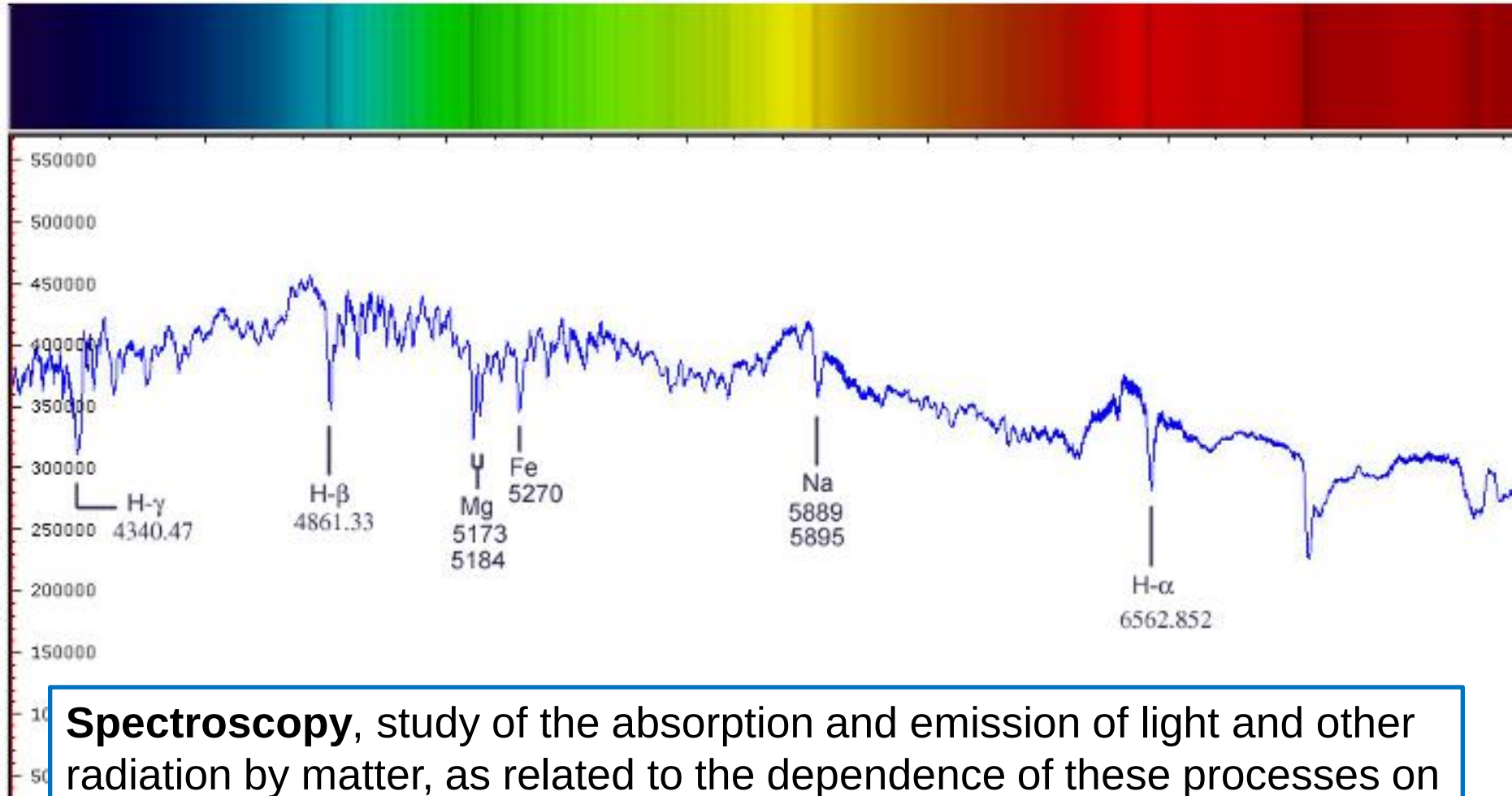
- Spectra
- Atomic data
- Spectrum synthesis codes
- Stellar atmospheres

Outline

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



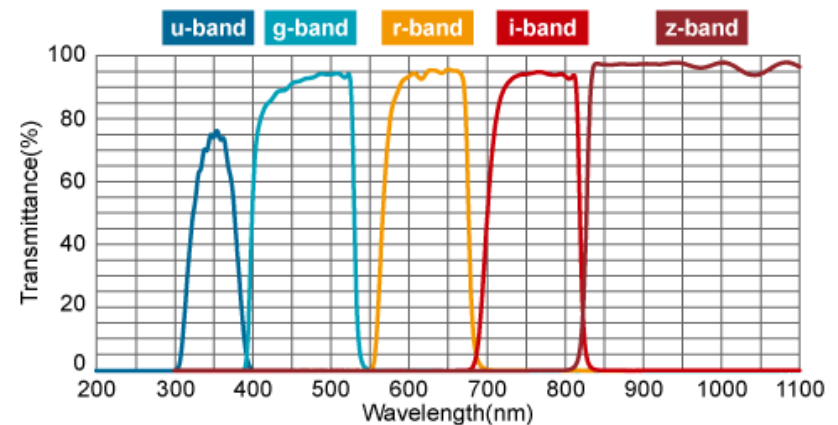
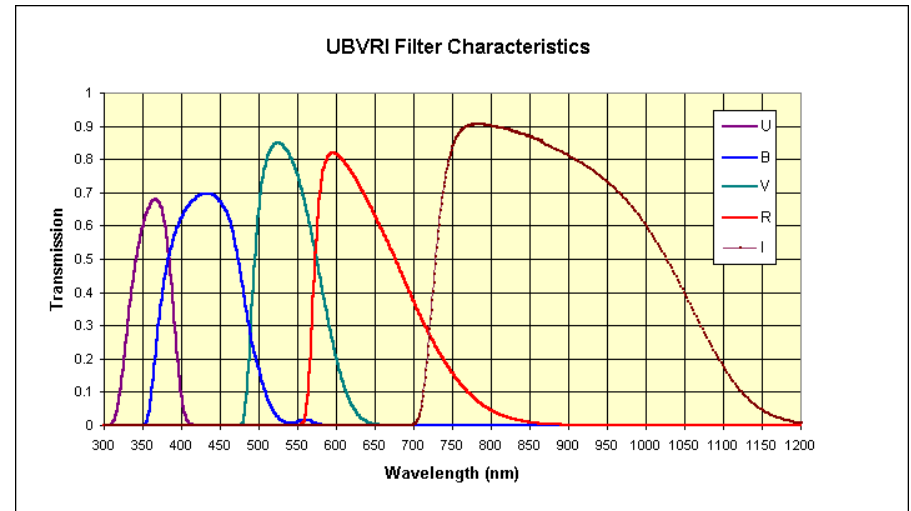
What is spectroscopy?



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)

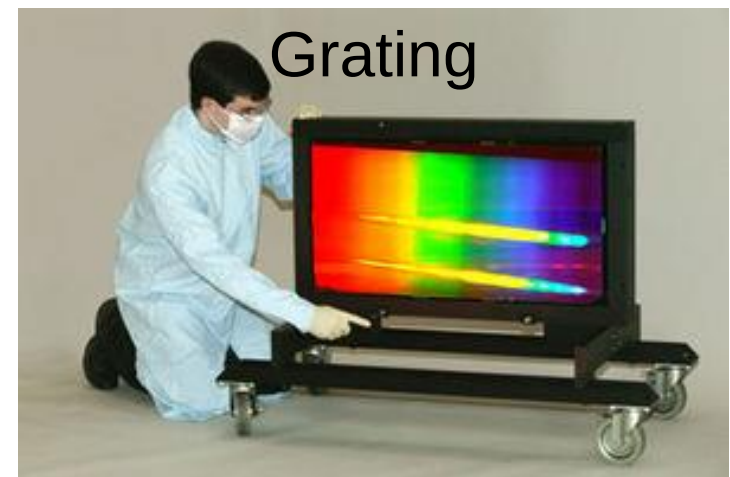
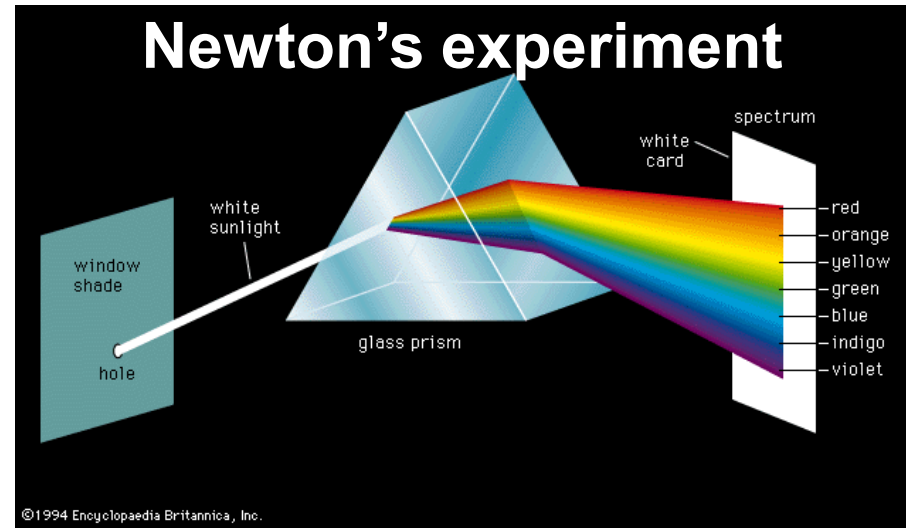
Spectroscopy

- 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

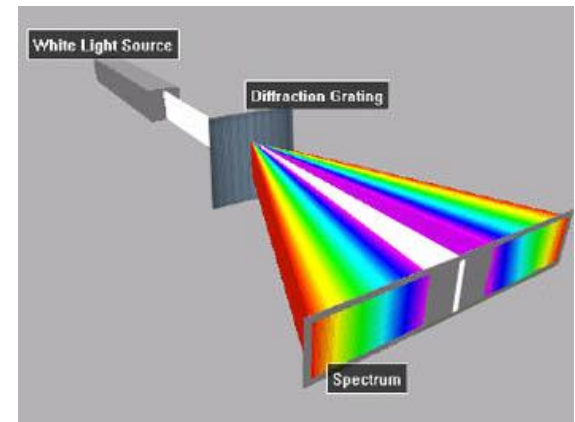
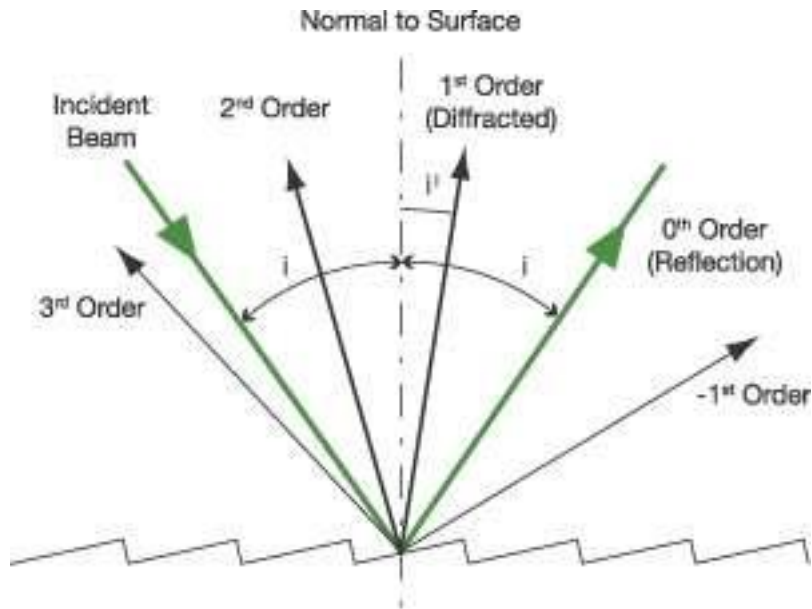


Dispersive elements

- 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**

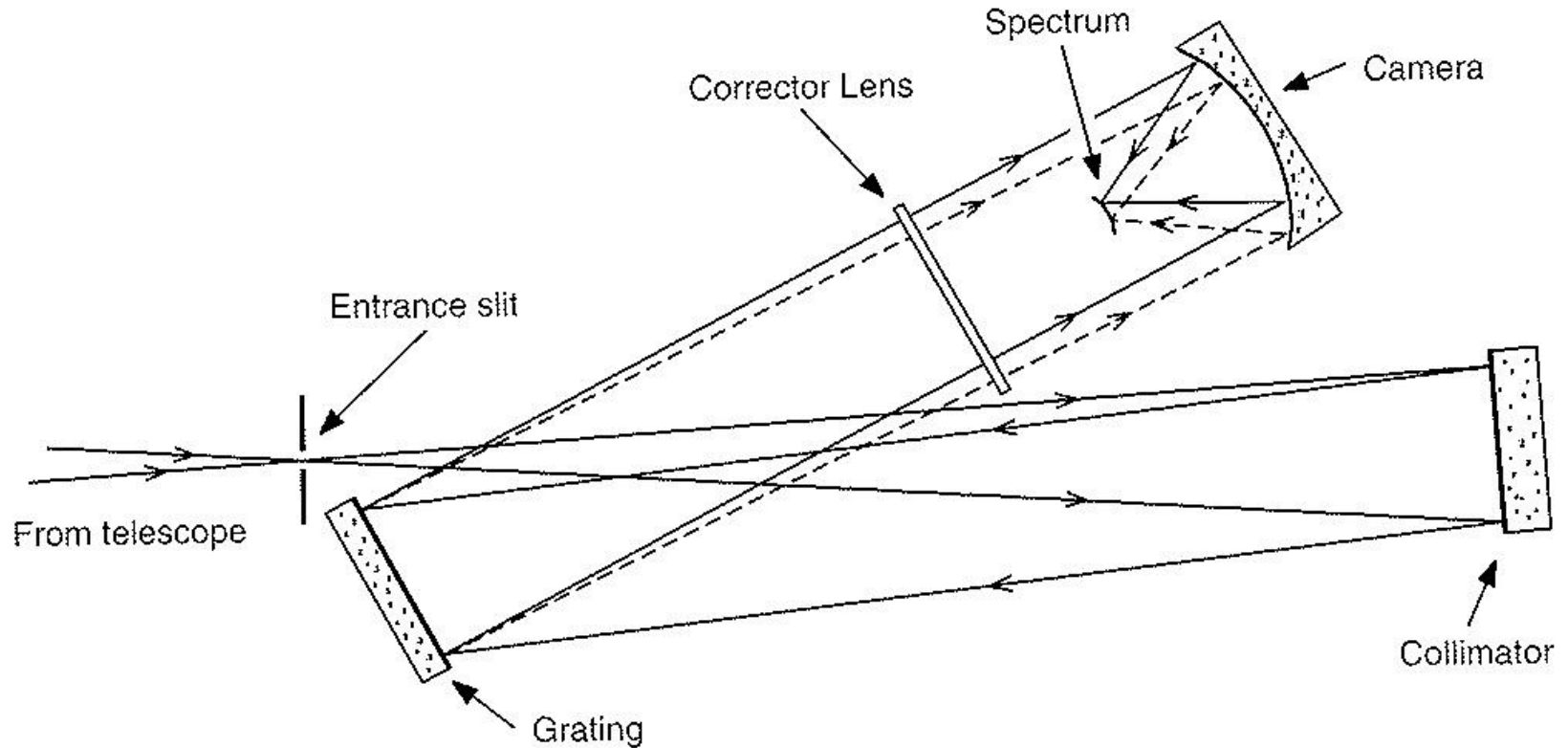


Gratings



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

Spectrograph

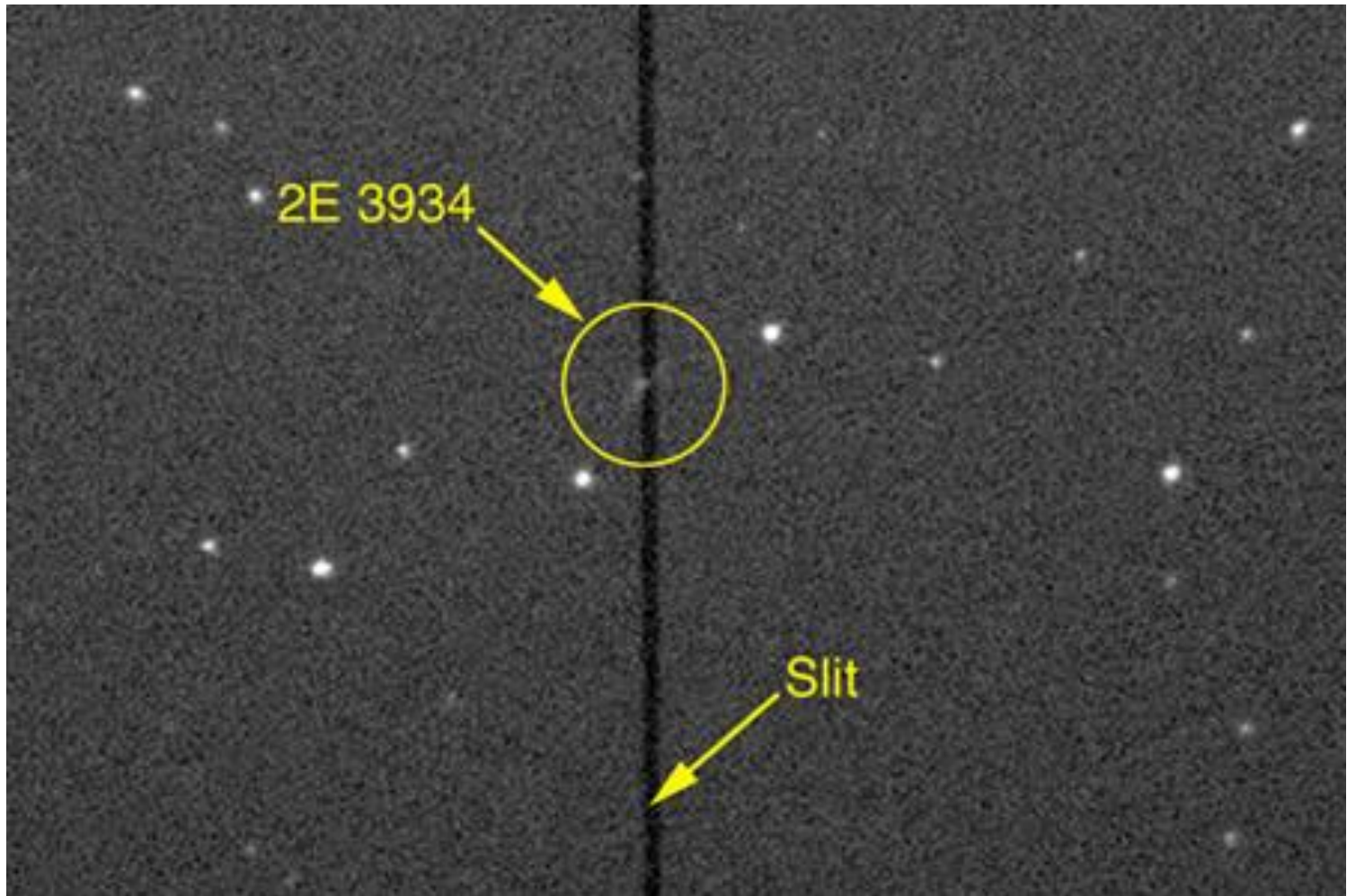


Collimator makes the rays parallel

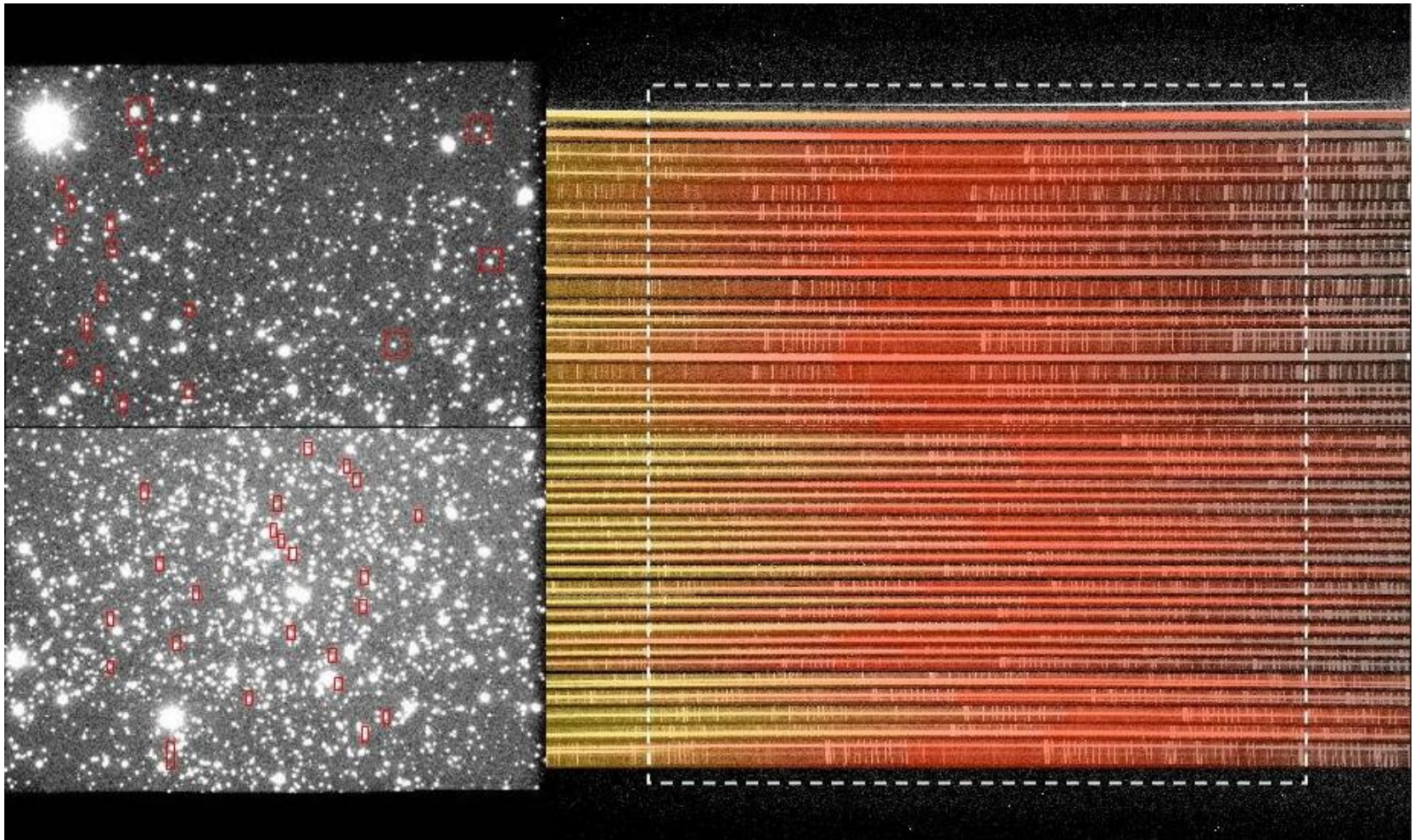
Grating disperses the light into colours

Camera re-images the rays onto a CCD or infra-red detector

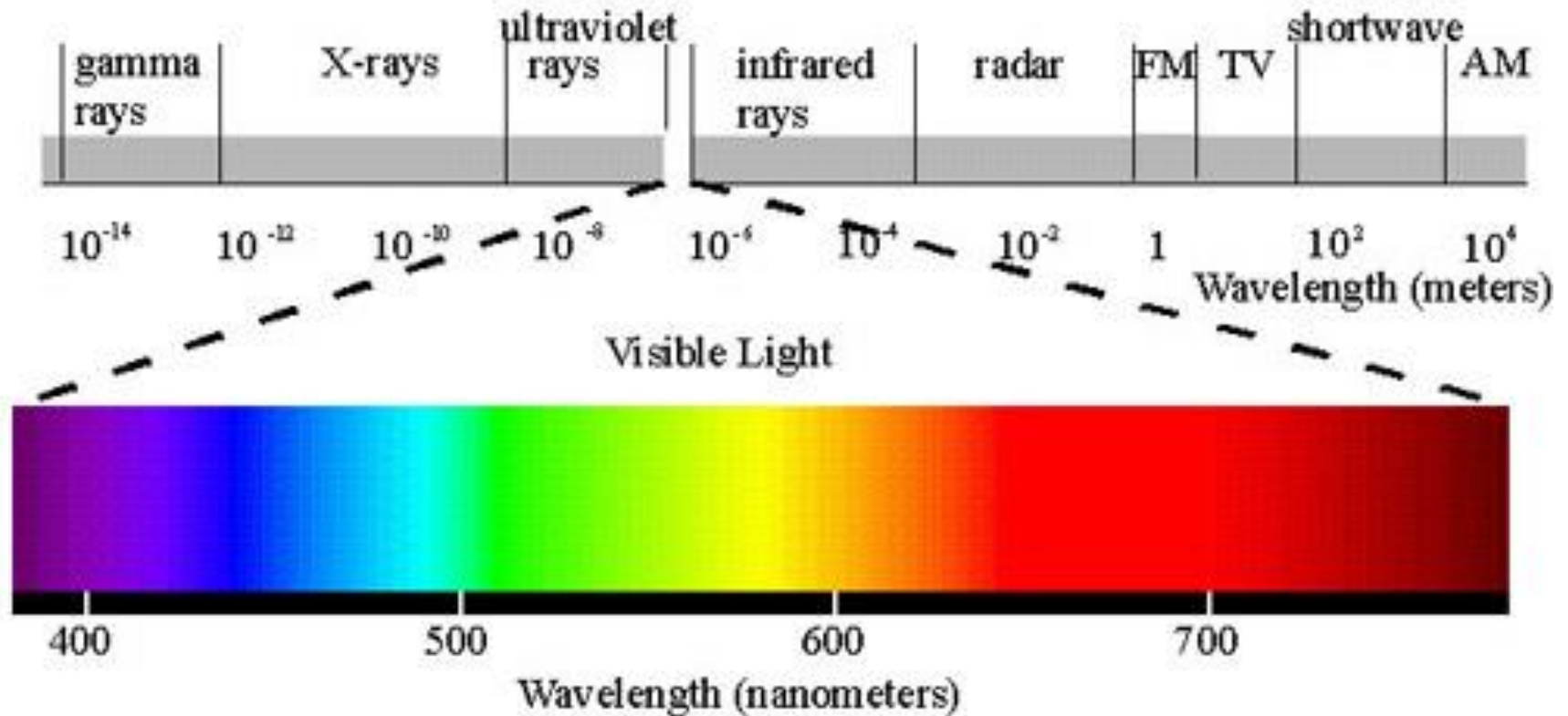
Why to use slit?



Multi-object spectroscopy



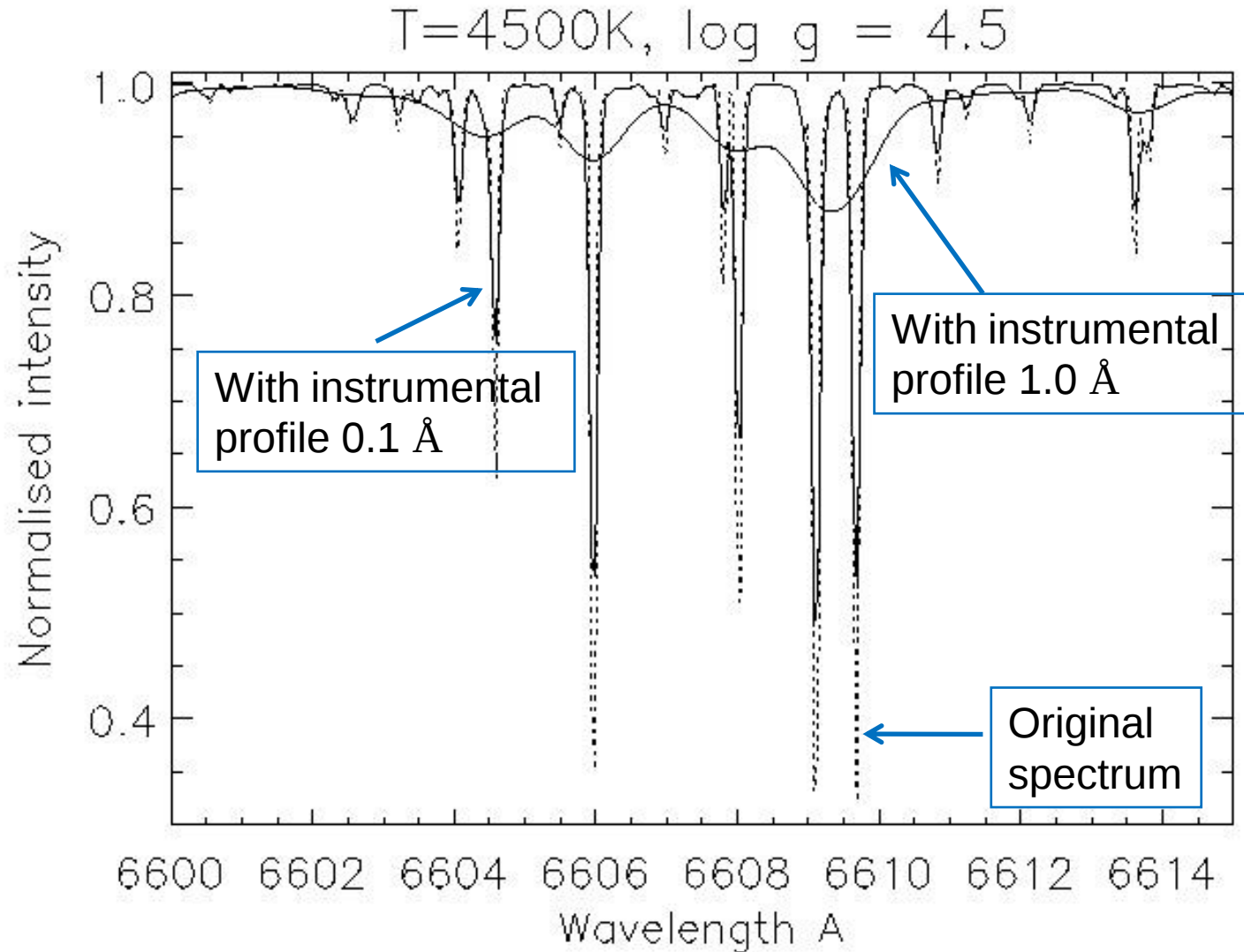
Resolving power



Resolving power

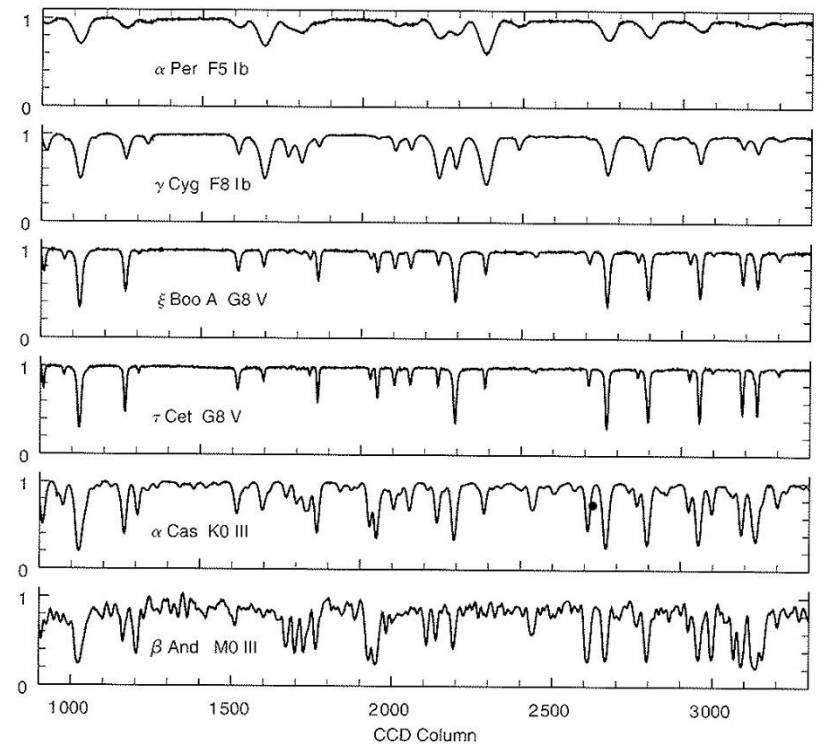
- Resolving power (R) tells how small details we can resolve in the spectrum
- It is defined as $\lambda/\Delta\lambda$
- So for example:
 - R=1000 at 6500 Å gives $\Delta\lambda=6.5$ Å or ~ 300km/s
 - R=10 000 at 6500 Å gives $\Delta\lambda=0.65$ Å or ~30km/s
 - R=100 000 at 6500 Å gives $\Delta\lambda=0.065$ 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

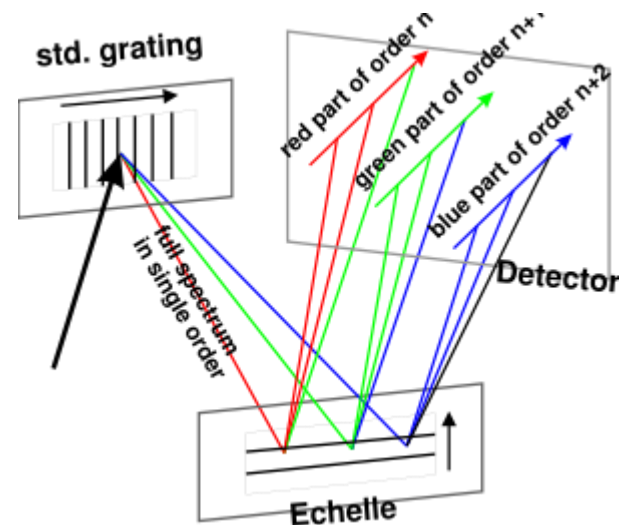
- For seeing detailed structures in our spectra one resolution element has to be small, i.e., the spectral resolution has to be high
- With high spectral resolution we can for example study in detail the composition of stellar atmospheres



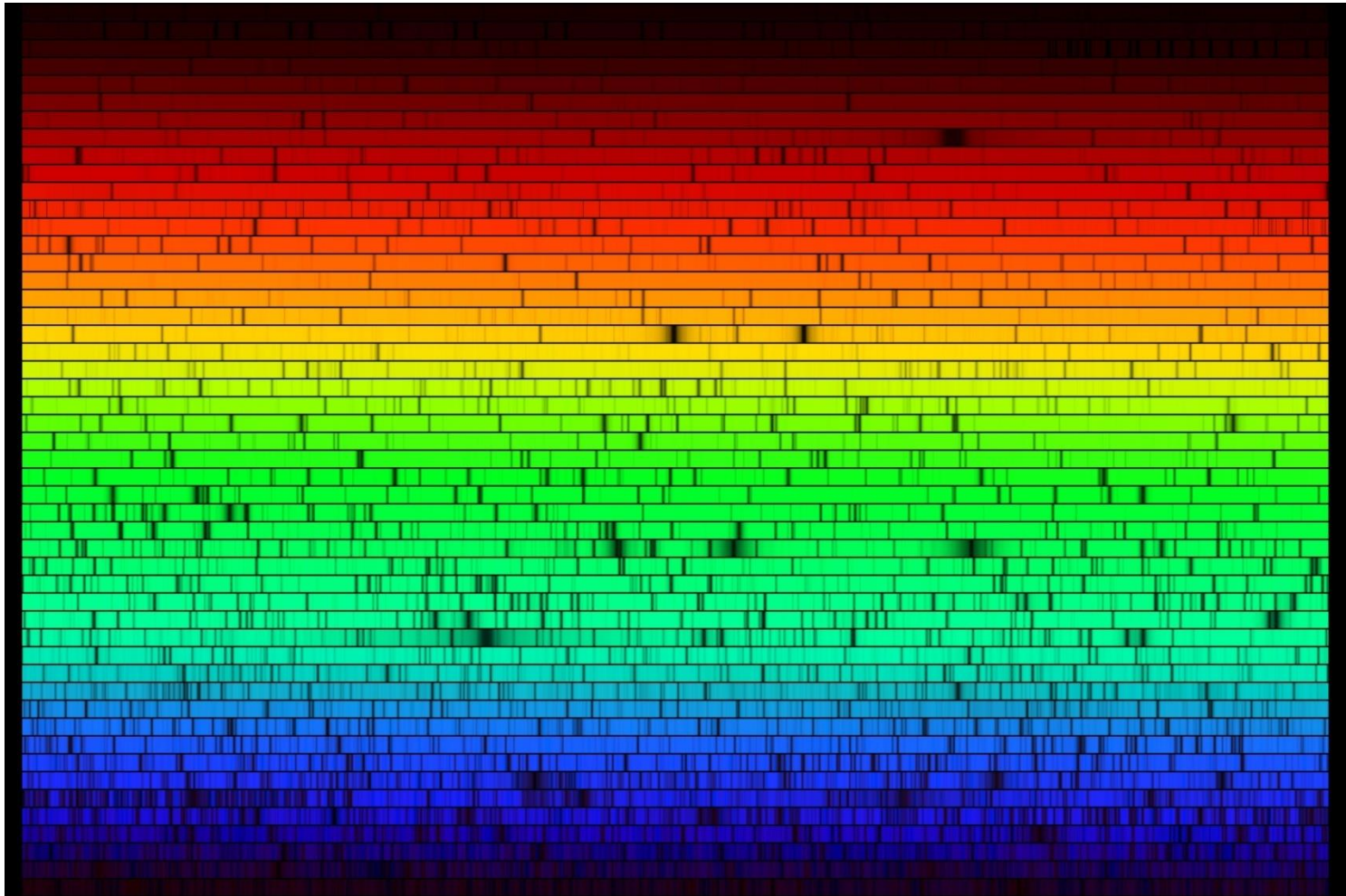
23Å of stellar spectra centered at $\lambda 6245\text{\AA}$

Échelle gratings

- For high resolution astronomical work échelle is the preferred choice 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



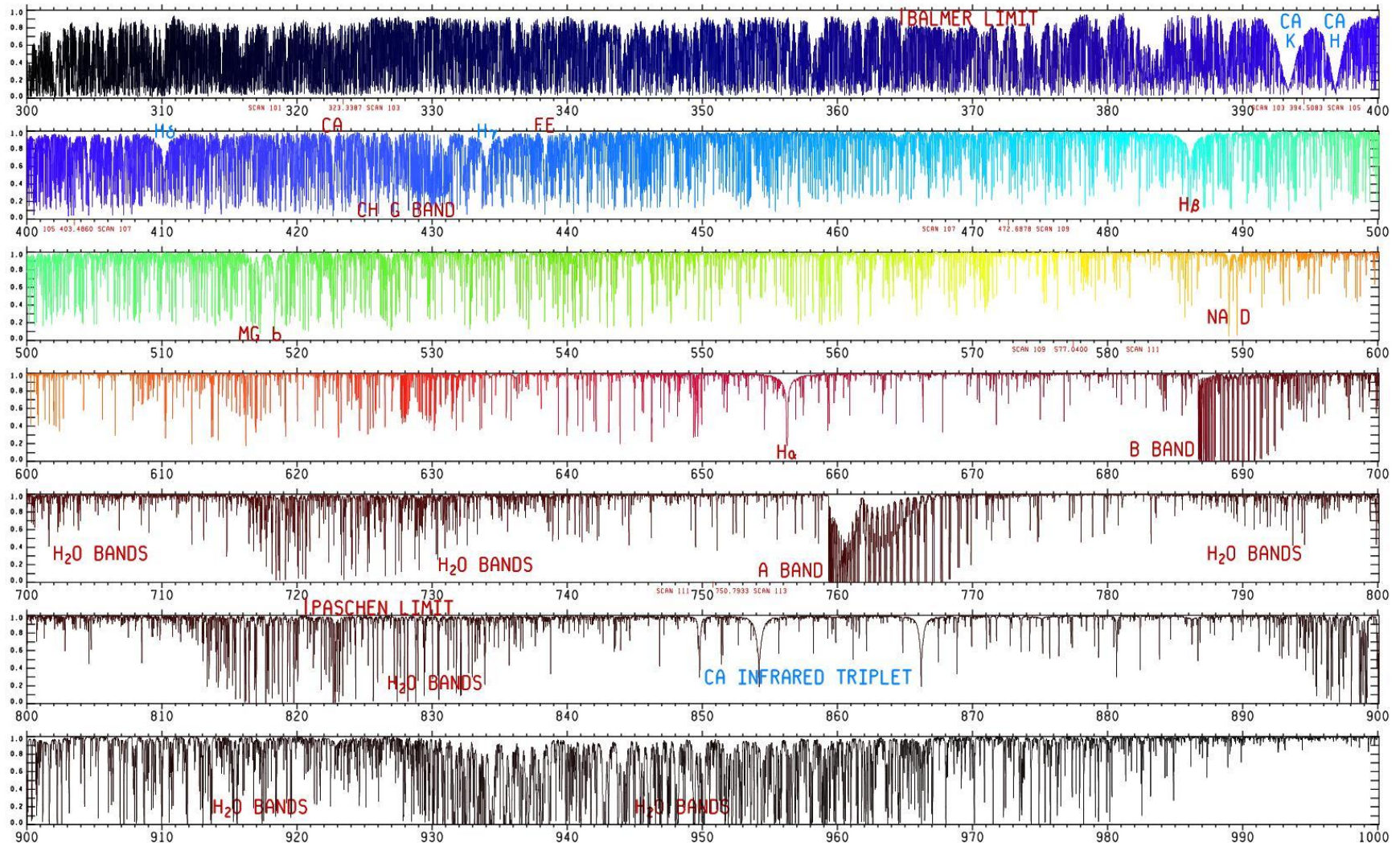
Échelle spectrum



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

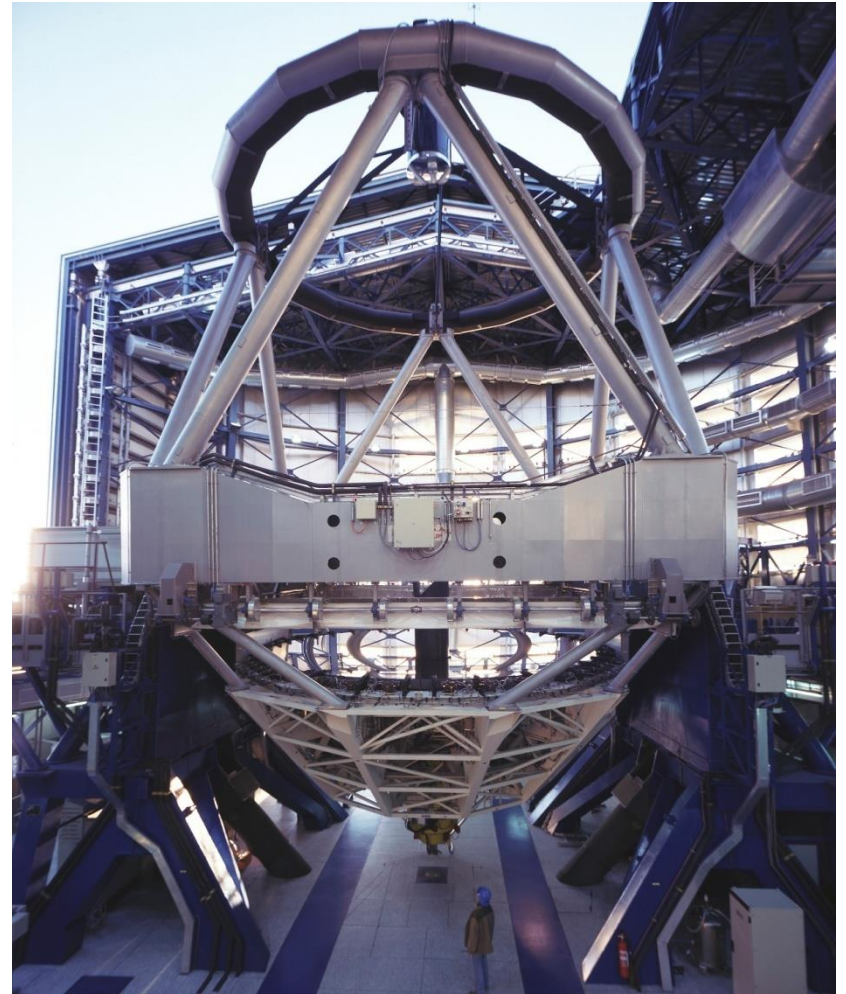
And when unstacked

KITT PEAK SOLAR FLUX ATLAS (KURUCZ, 2005) RESIDUAL, AIR WL IN NM, 300-400 NM UNCERTAIN, REVISED FROM (KURUCZ, FURENLID, BRAULT, AND TESTERMAN 1984)

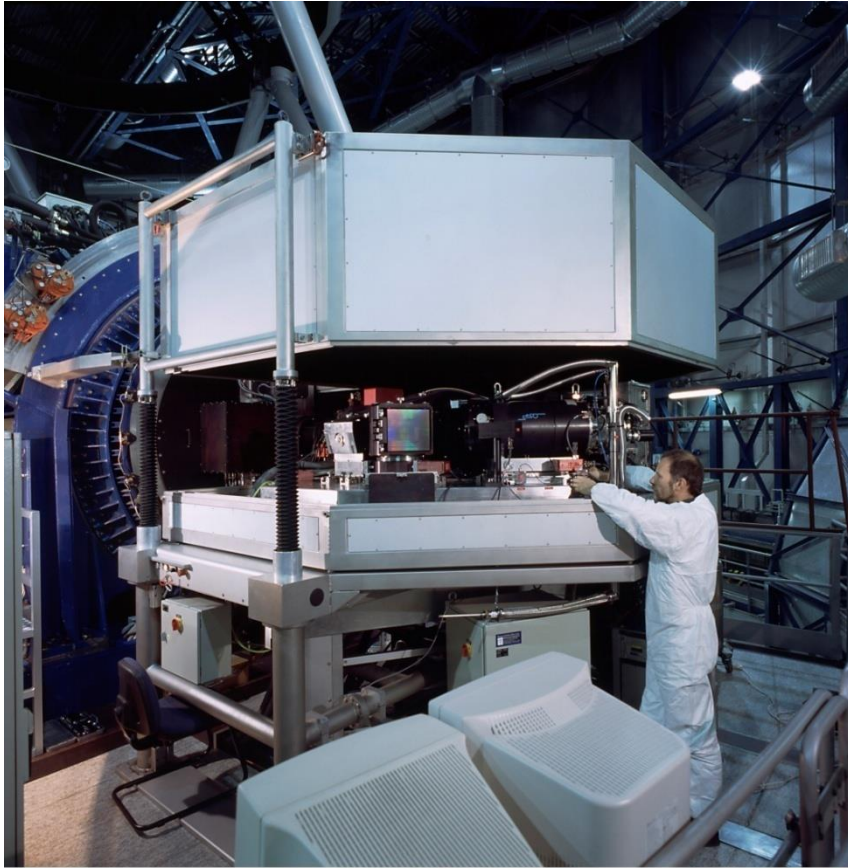


Kitt Peak Solar Flux Atlas, Kurucz 2005

UVES at ESO's VLT



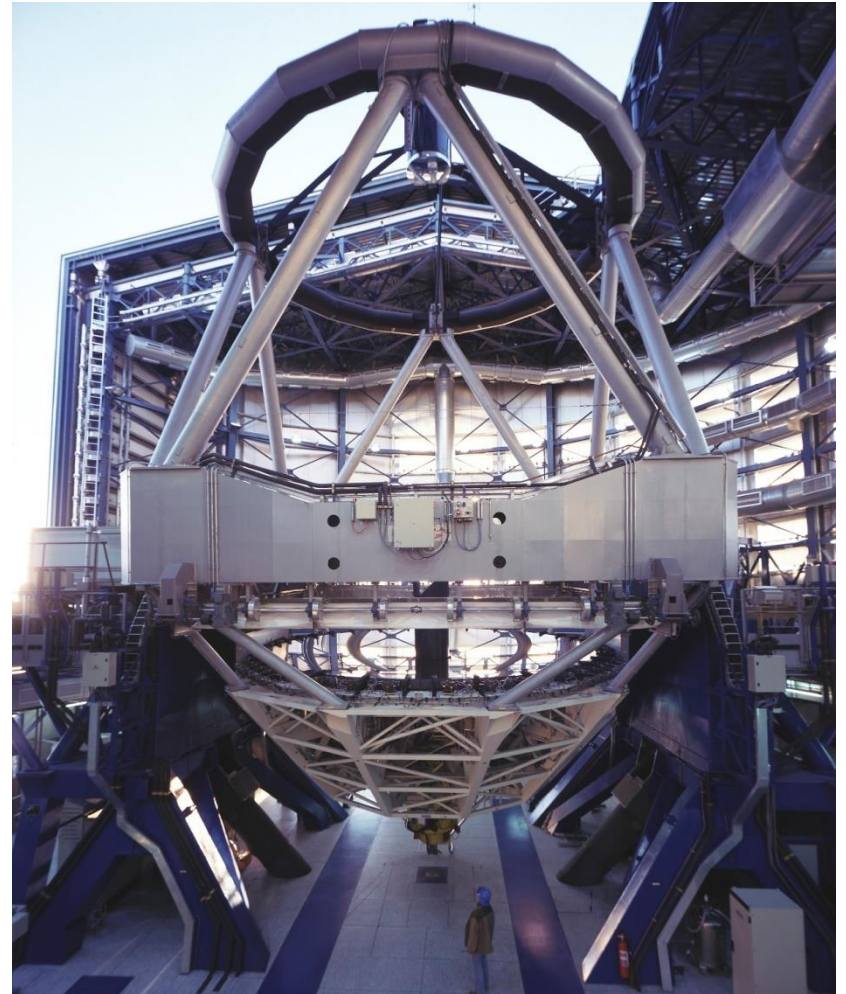
UVES at ESO's VLT



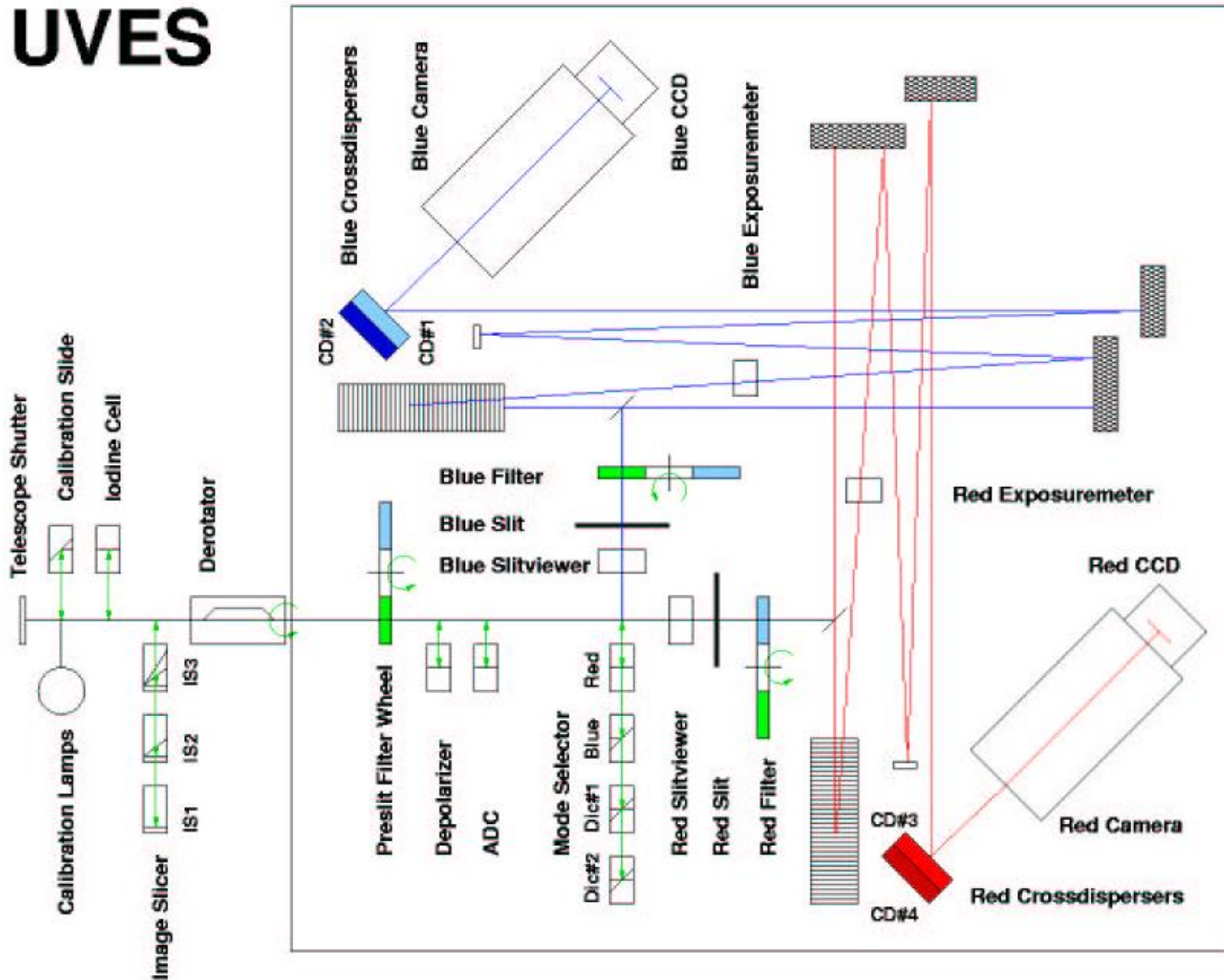
UVES at Kueyen

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

© European Southern Observatory



UVES

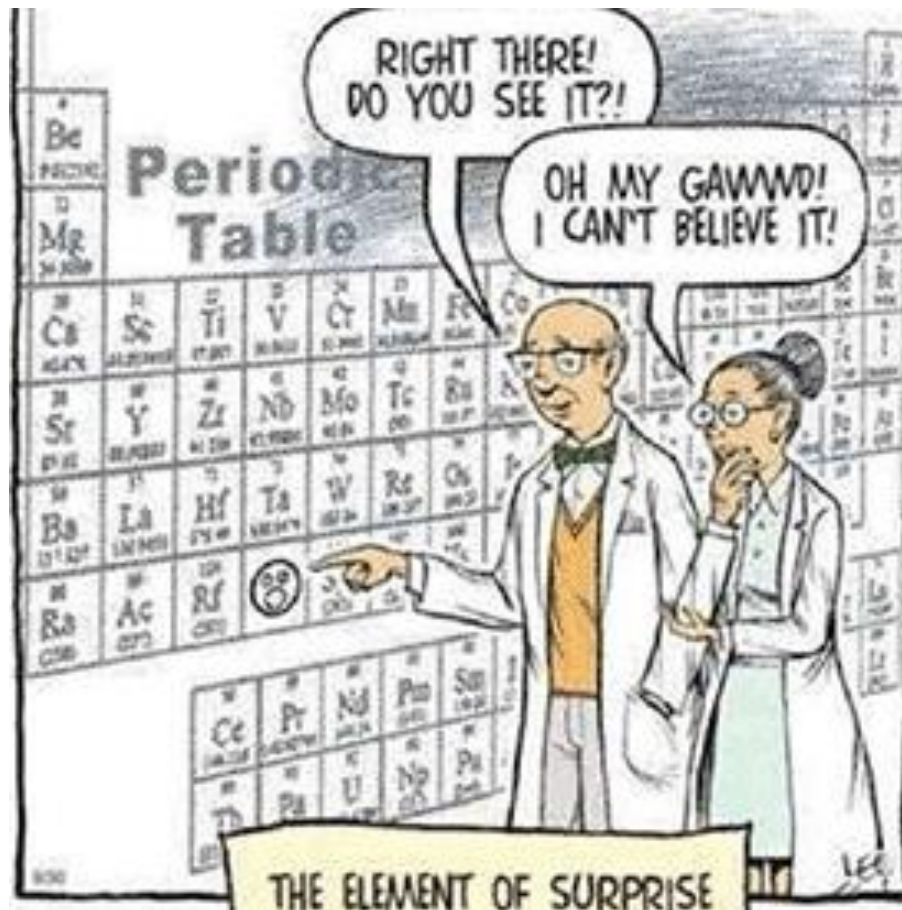


Take home messages - 1

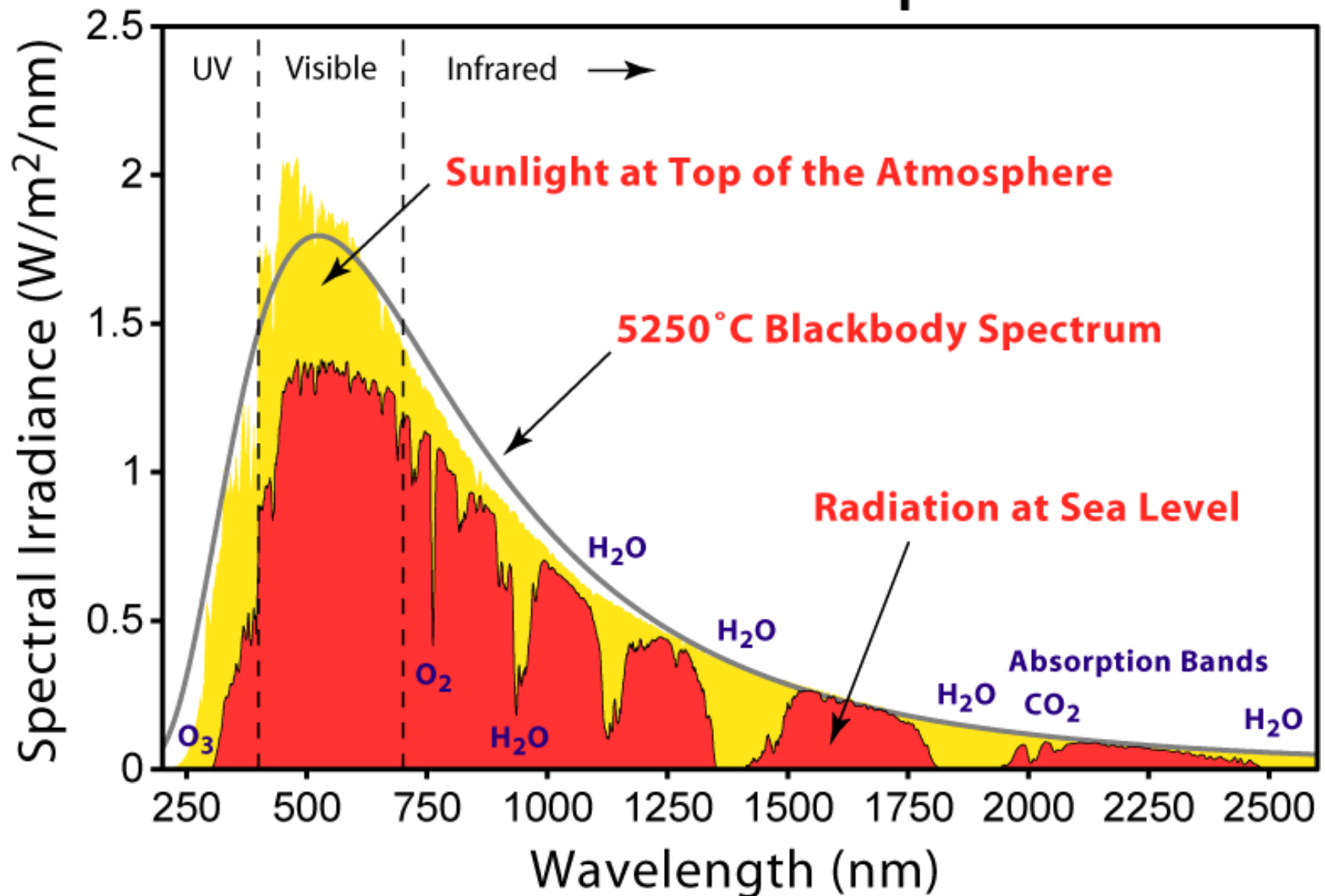
Choose your instrument wisely. For a single object quite high spectral resolution (up to 250,000) is possible. If you want more objects at the same time you are limited by your detector area and need to sacrifice resolution and/or wavelength coverage

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)

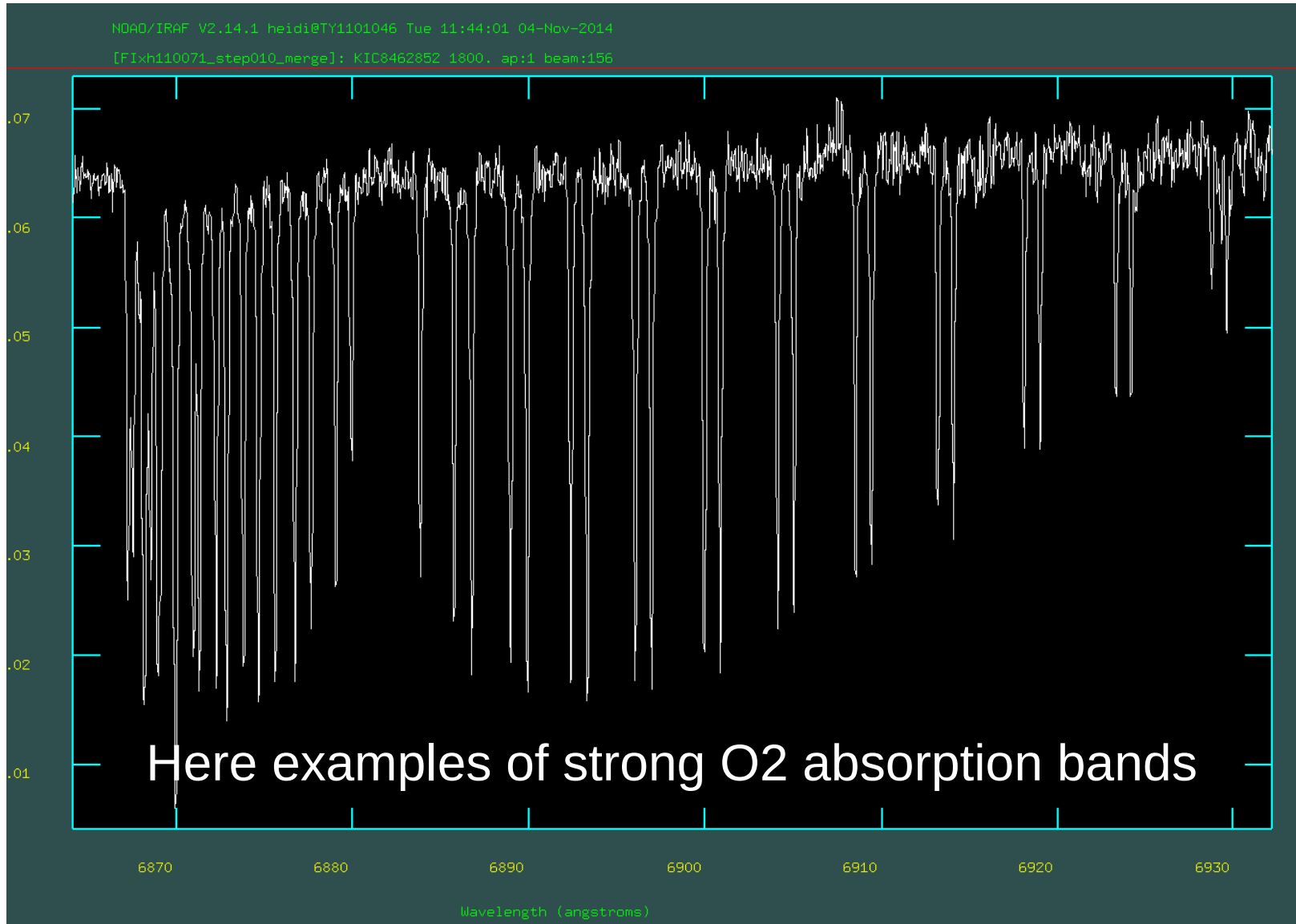
Some effects in your spectra

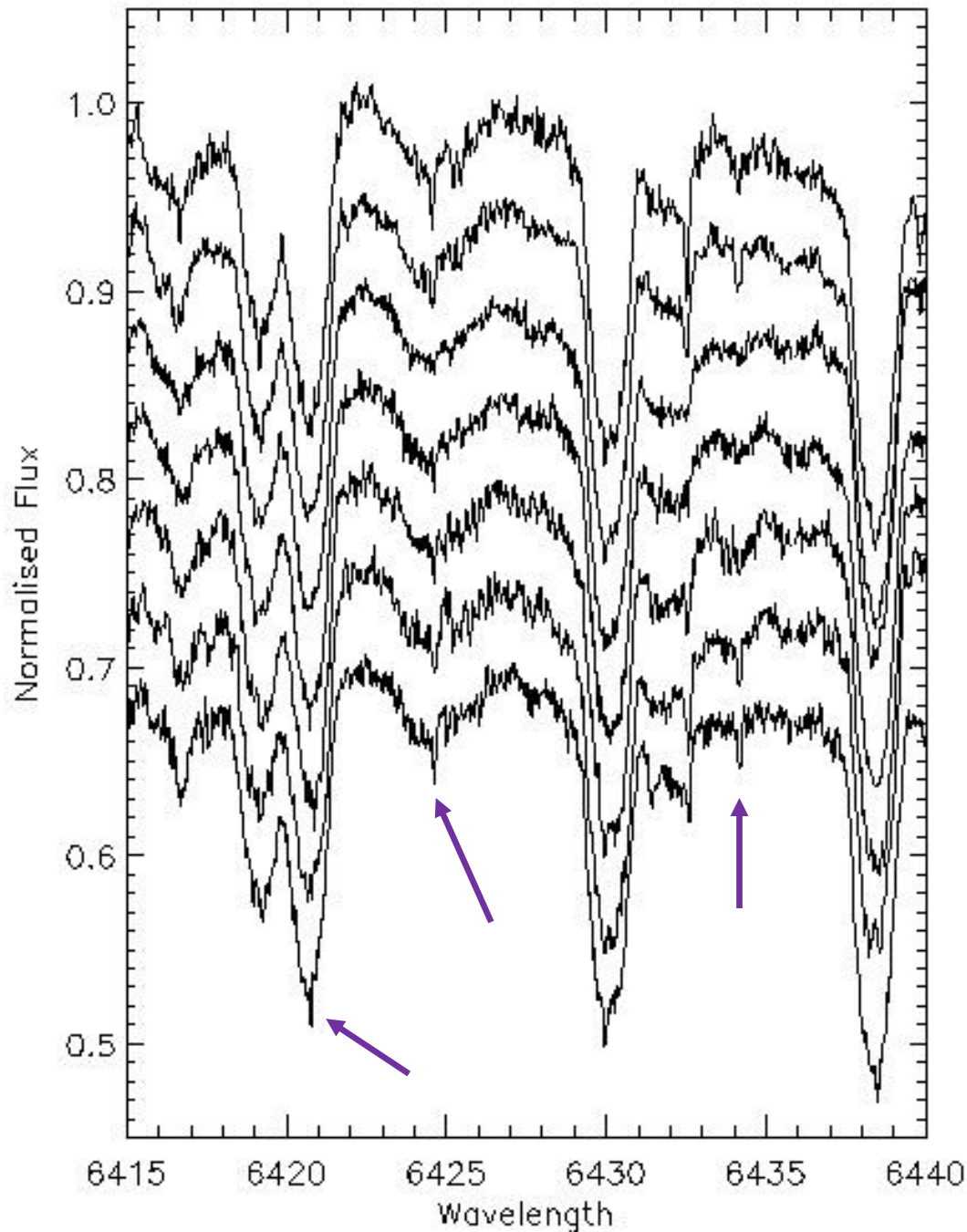


Solar Radiation Spectrum



Absorption lines



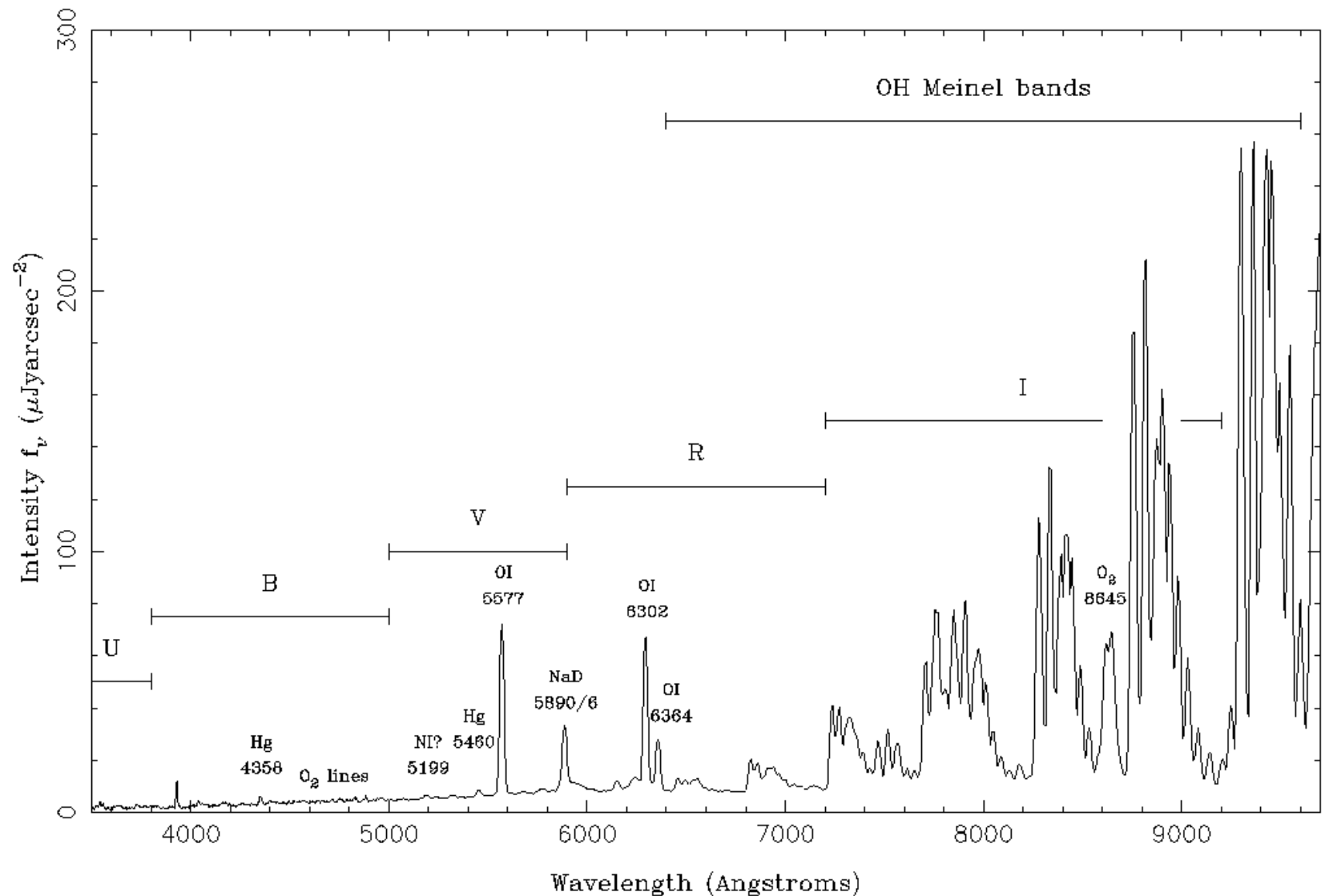


Also much weaker atmospheric absorption lines exist, but they are often only detectable with high spectral resolution

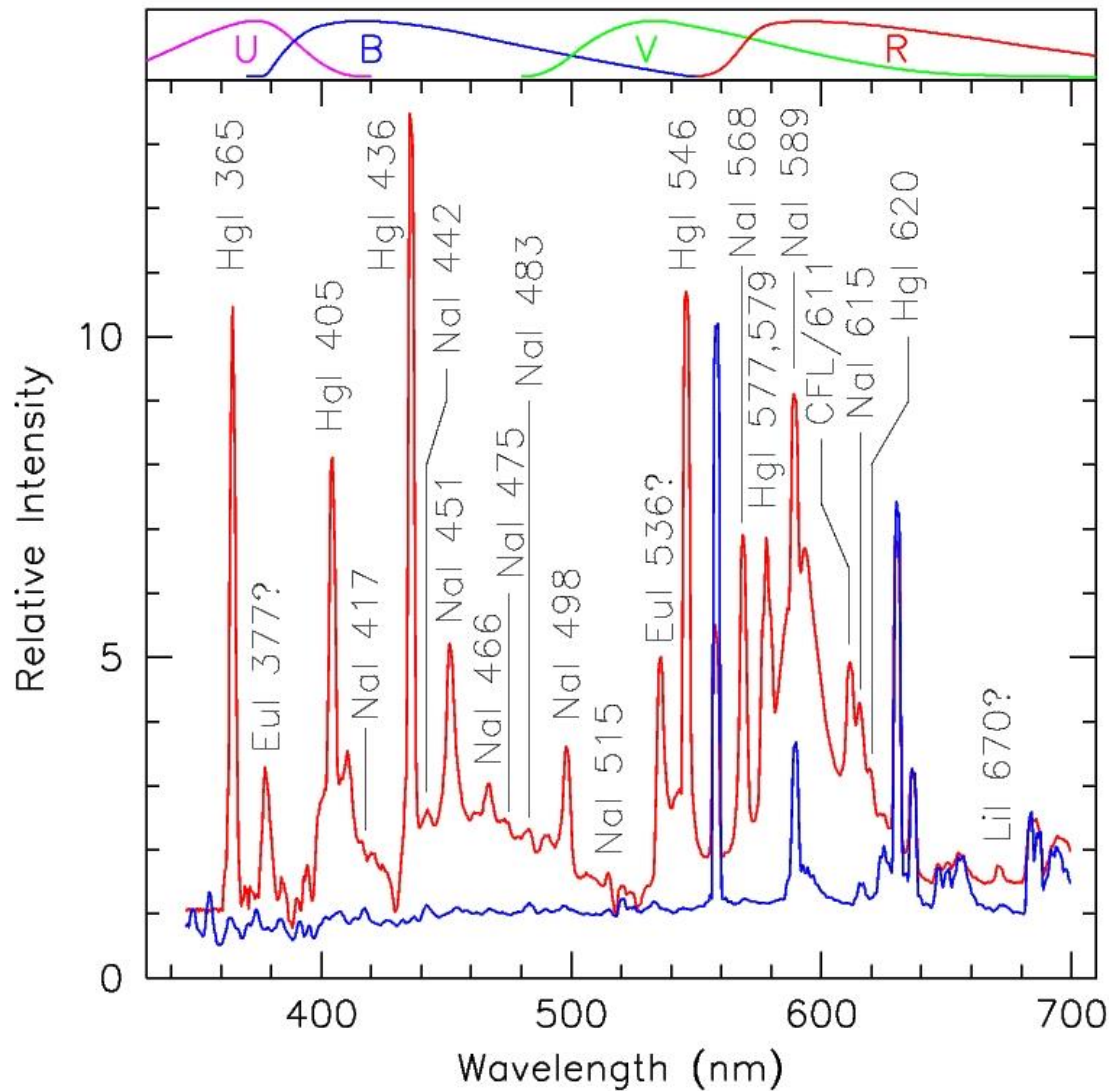
Here some water lines, which also change strength night to night, depending on how much water is in the atmosphere

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

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

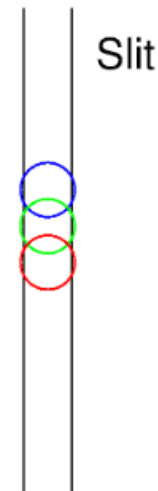
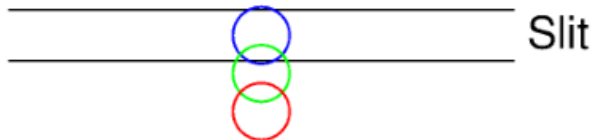
The appearance of intense emission lines of neutral potassium at $\lambda\lambda$ 7665, 7699 on coudé spectrograms of three stars obtained at the Haute-Provence Observatory has prompted us to conduct a survey of 162 bright stars for emission at λ 7699, using a photoelectric scanner. No definite potassium 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.

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.



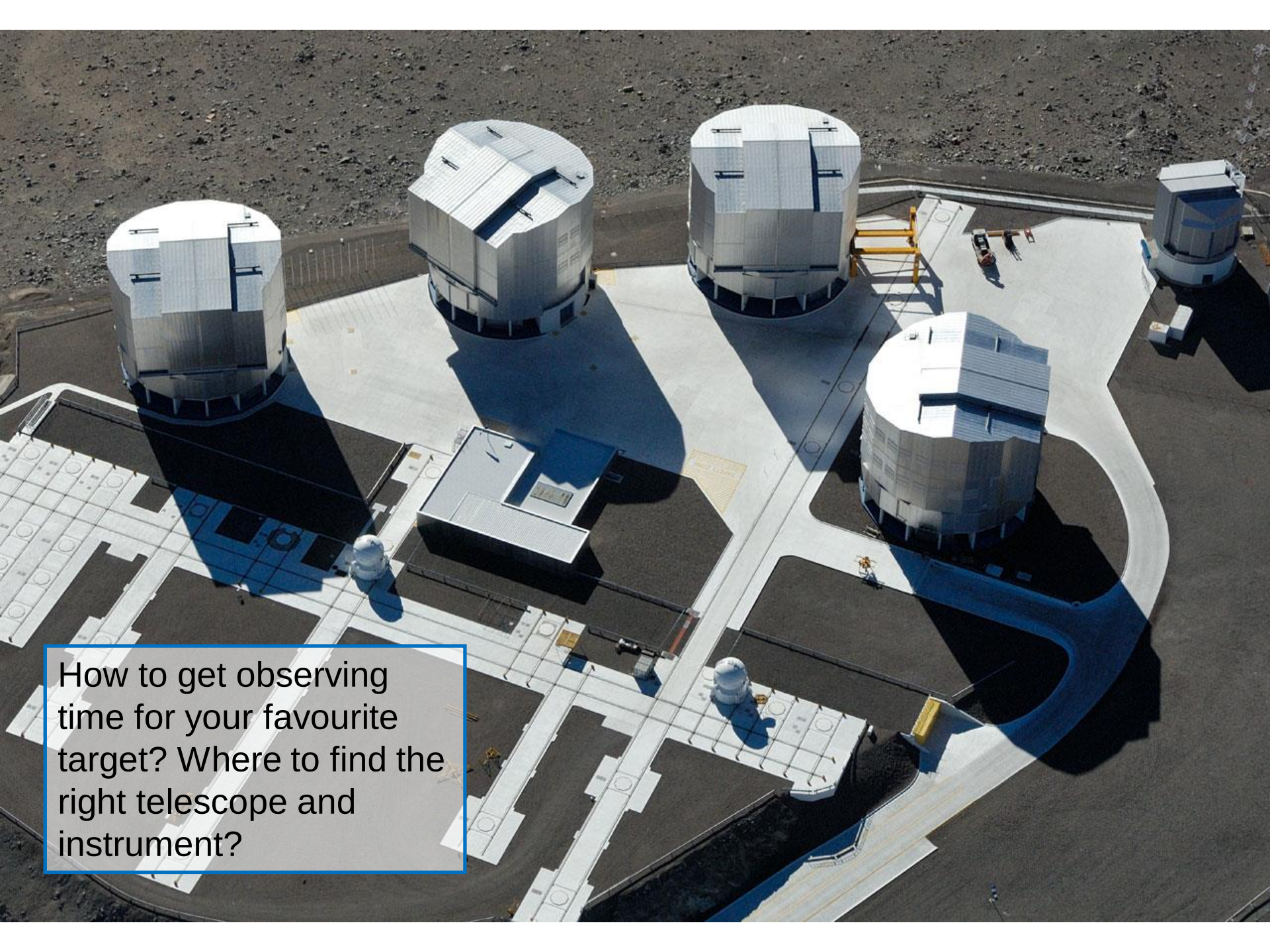
Reducing spectra

- 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: 1994

Inspiration Notice:
By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the content of the proposal and the agreement to not submitting a second proposal for the same project.

1. Title: **Category:** D-3
Resolving surface on two structures by combining Doppler imaging and telluric and astronomical imaging

2. Abstract / Text Time Request:
Total Amount of Time: 10 nights (10 x 2 hours 00)
One recent astronomical image of the K giant 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 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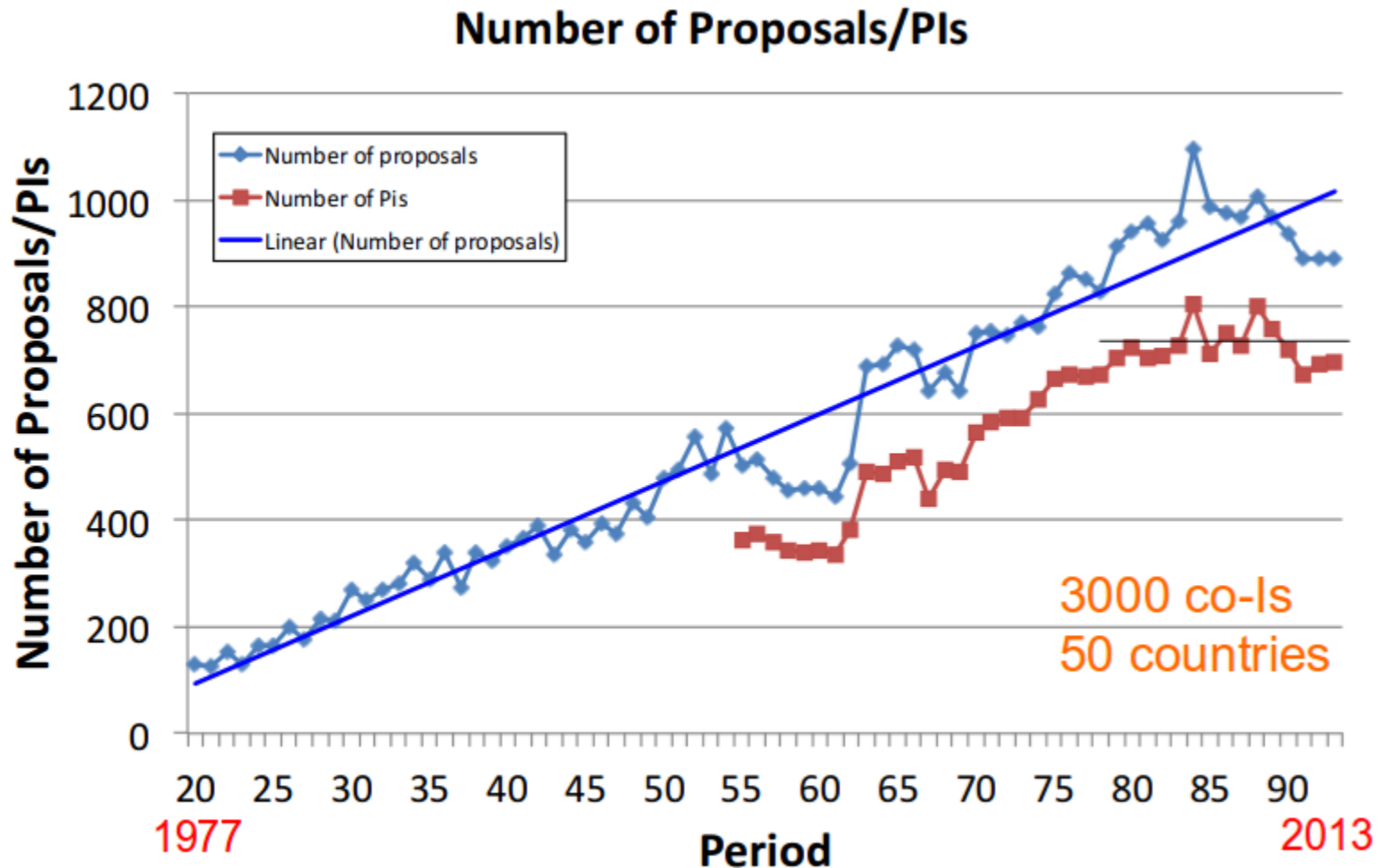
Where to get observing time?

- [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



ESO Call for Proposals – P103
Proposal Deadline: 27 September 2018, 12:00 noon CEST

Number of proposals - ESO



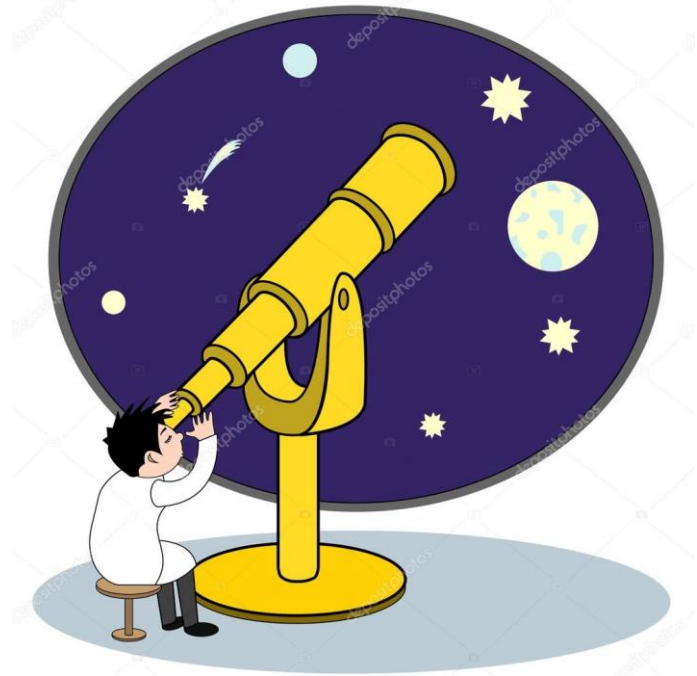
Service vs visitor



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

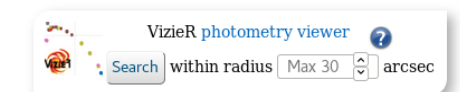
Parallaxes (mas): 4.6102 [0.0446] A 2018yCat.1345....0G

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



When is your target observable?

Mode	Staralt v
Night	08 v April v 2021 v or date when the local night starts. <i>Staralt, Startrack only.</i>
Observatory	Roque de los Muchachos Observatory (La Palma, Spain) v Select one above or specify your own site with this format: Longitude(°E) Latitude(°N) Altitude(metres) UT-offset(hours) Ex.: 289.2767 -30.2283 2725 -4
Coordinates	Formats can be any of these: name hh mm ss ±dd mm ss name hh:mm:ss ±dd:mm:ss name ddd.ddd dd.ddd name must be a single word with no dots, avoid using single numbers. Every entry must be in the same format, do not use different formats with different entries. We recommend a maximum of 100 targets per submission. FKCom 13 30 47 +24 13 58 Alternatively, you can upload a file with coordinates. You can use the same format as in the TCS catalog . Target names must be single words with no dots. Browse... No file selected.
Options	v Moon distance v Included on plot. Moon coordinates at ~02:00 UT. <i>Staralt only.</i> v 10°, X=5.8 v Min. elevation (or max. airmass X). <i>Starobs, Starmult only.</i> v GIF [inline] v Output format
Submit	Retrieve Help

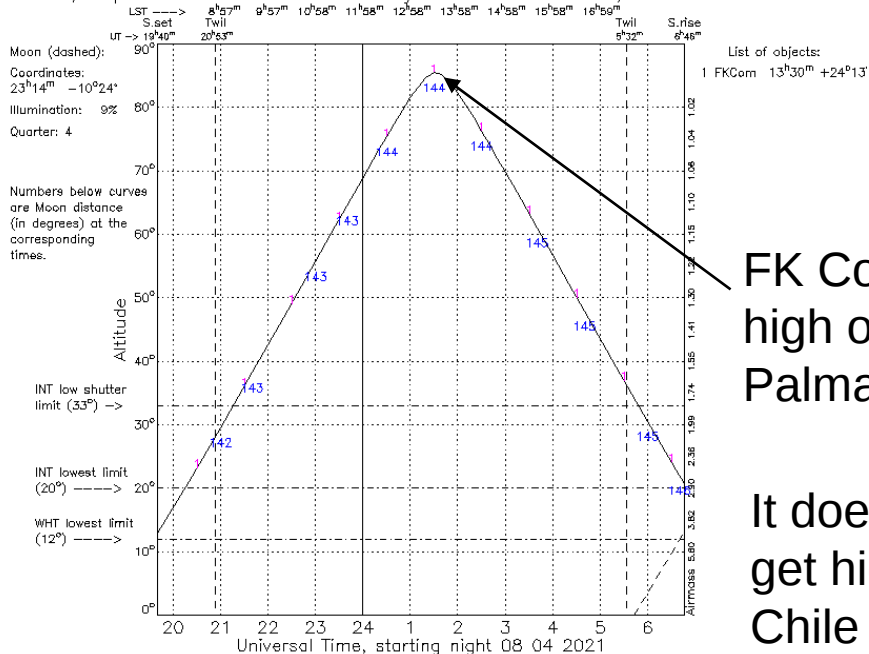
- There is a lot of software available for plotting visibilities of targets
- Most large observatories have their own
- I like [Staralt](#) because of the many pre-defined observatories and you can even put in your own

Visibility of FK Com in La Palma and Chile

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

FK Com on La Palma April 8

Altitudes, Roque de los Muchachos Observatory 342.1184E 28.7606N, 2326 m above sea level

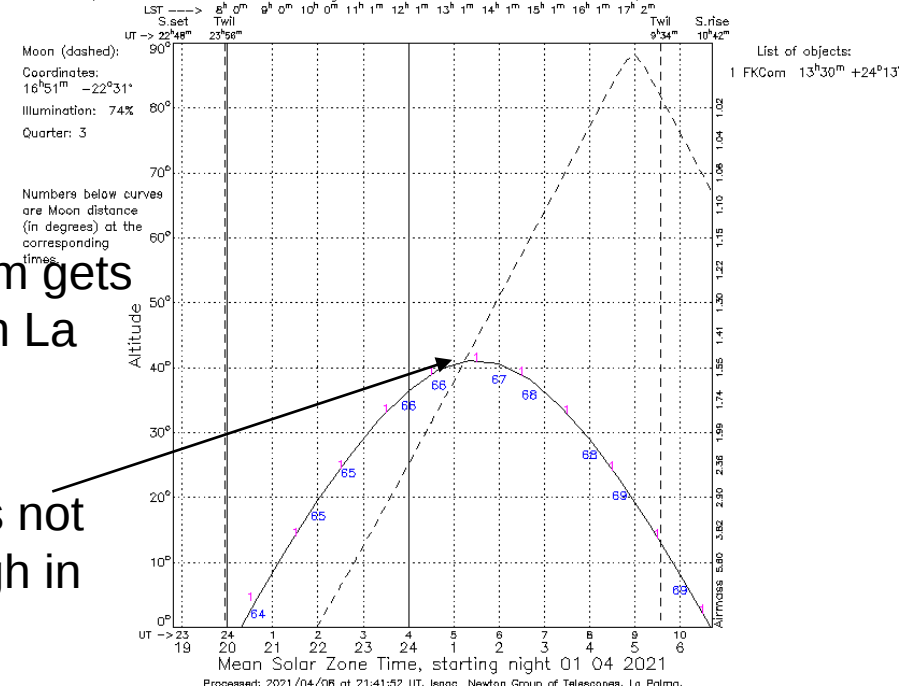


FK Com gets high on La Palma

It does not get high in Chile

FK Com in Chile April 1

Altitudes, Cerro Paranal Observatory 289.5972E -24.6253N, 2635 m above sea level

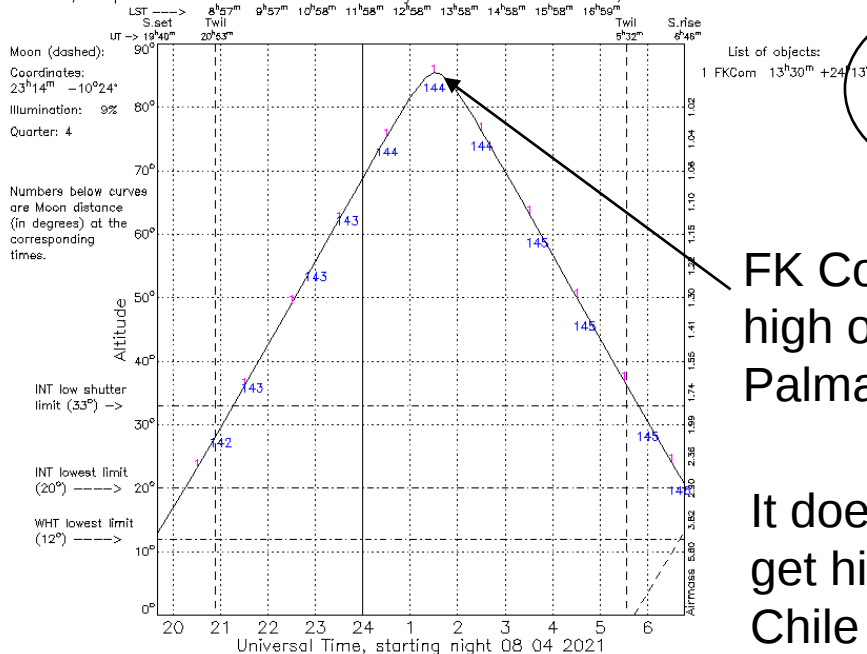


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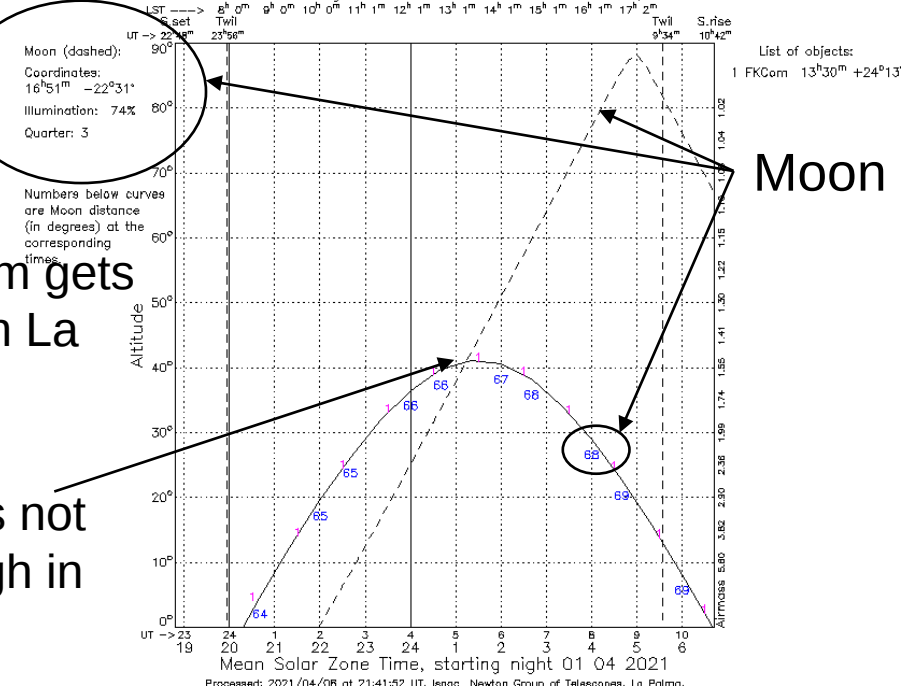


FK Com gets high on La Palma

It does not get high in Chile

FK Com in Chile April 1

Altitudes, Cerro Paranal Observatory 289.5972E -24.6253N, 2635 m above sea level



Moon

Exposure Time Calculator (ETC)

- Most larger observatories have exposure time calculators for their instruments
- [ESO ETC](#)

Target Input Flux Distribution

☒ Template Spectrum	G0 (Pickles) ▾	Redshift z = 0.00	Target Magnitude and Mag.System: V ▾ = 7.900 ☒ Vega ☐ AB
☐ MARCS Stellar Model	Teff=4000 log(g)=-0.5 [Fe/H]= 0 M= 1 ▾		
☐ Upload Spectrum	Select...	Magnitudes are given per arcsec ² for extended sources	
☐ Blackbody	Temperature: K		
☐ Power Law	Index: $F(\lambda) \propto \lambda^{\text{index}}$		
☐ Emission Line	Lambda: nm Flux: 10 ⁻¹⁸ ergs/s/cm ² (per arcsec ² for extended sources) FWHM: nm		

Spatial Distribution: ☒ Point source ☐ Extended source

Instrument Setup

Pre slit optics: ADC ▾ Image slicer: IS#3 ▾ Slit width: 0.3 ▾ arcsec

☐ Free template: Central wavelength: 520.000 nm Camera Tilt: 0.000 pixels

☒ Standard template: Dic 1, Red Arm, CD3, [450-750] free template only ▾

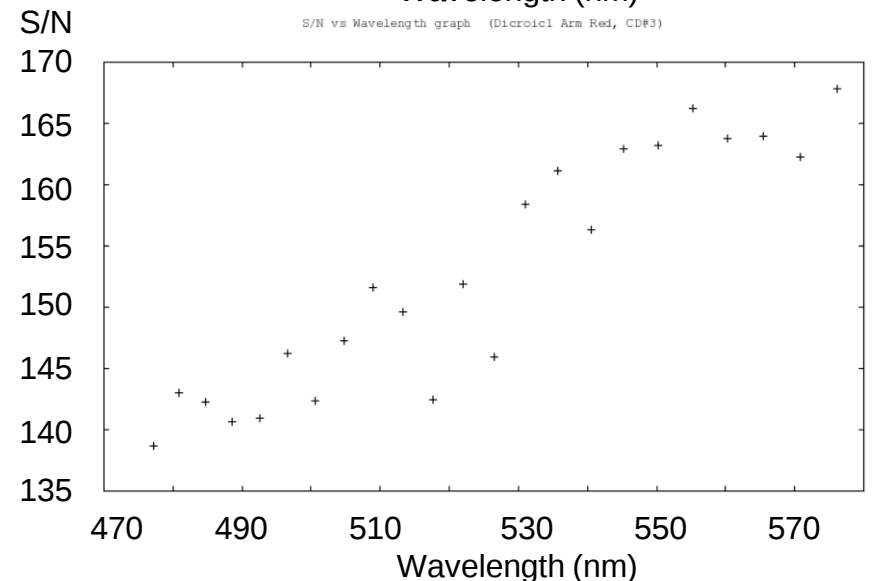
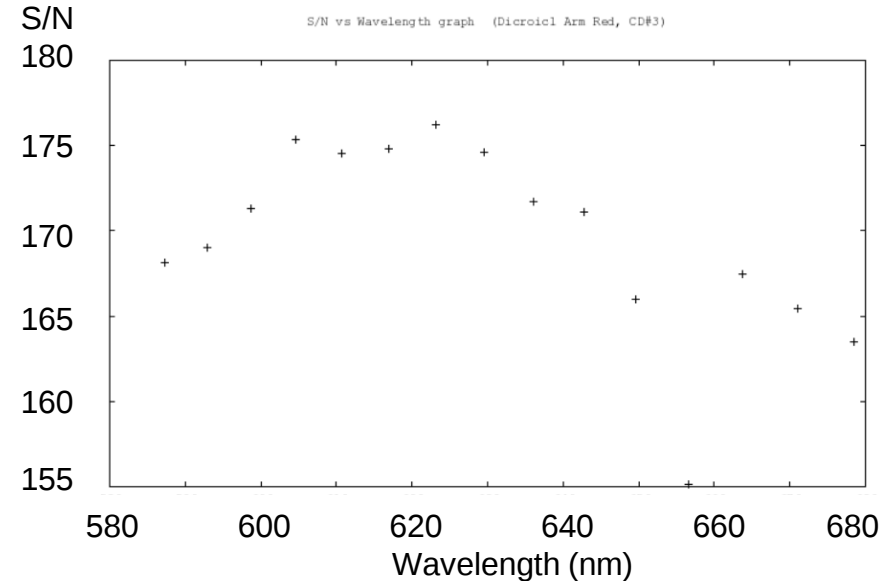
For standard templates, only the central wavelength in parenthesis () can be selected. For free templates, the user can enter values in the range indicated square brackets []

Below slit filter: None ▾

CCD binning: 1x1 (Fast Readout, Low Gain) ▾

In the binning, the second value refers to the direction of the dispersion in the spectra

Exposure time: 60.000



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 spectrographs)

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)

<u>HRS</u>	wl = 370 - 550 nm & 550 - 890nm	R=14,000 – 65,000	Needs three obs for full coverage	Access: Institutes and <u>ORP</u>
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Very Large Telescope of ESO – 4 x 8.2m – Cerro Paranal, Chile

<u>CRIRES+</u>	wl = ~950 – ~5000nm	R=50,000 or 100,000	Being commisisoned	Access: <u>ESO</u>
<u>ESPRESSO</u>	wl = 380 – 788nm	R=70,000 – 190,000	can be used on a single 8m telescope or combining light from all four	Access: <u>ESO</u>
<u>FLAMES</u>	wl = 370 - 950 nm (~100nm per obs)	R=7,000 – 47,000	Some 130 objects at a time	Access: <u>ESO</u>
<u>UVES</u>	wl = 300 – 1100nm	R~40,000 – 110,000	Needs two obs for full coverage	Access: <u>ESO</u>
<u>X-Shooter</u>	wl = 300 – 2500nm	R~ 3,000 – 19,000		Access: <u>ESO</u>

Telescopes with main mirror >8m

Subaru – 8.2m – Mauna Kea, Hawaii, USA

<u>HDS</u>	wl = 300 – 1000nm	R up to 160,000		Access: National, institutes and <u>international</u>
<u>IRD</u>	wl = 970 – 1750nm	R~70,000	<u>Visitor instrument</u>	Access: National, institutes and <u>international</u>

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)

<u>GRACES</u>	wl = 400 – 1000nm	R~40,000 or 60,000	Visitor instrument (not always available)	Access: institutes and <u>NOIRLab</u>
<u>MAROON-X</u>	wl = 500 – 920nm	R~80,000	Visitor instrument (not always available)	Access: institutes and <u>NOIRLab</u>

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

<u>ESPaDOnS</u>	wl = 370 – 1050nm	R ~68,000 or 81,000	Includes spectro-polarimetry	Access: National, institutes, <u>ORP</u>
<u>SPIRou</u>	wl = 950 – 2350nm	R ~75,000	Includes spectro-polarimetry	Access: National, institutes, <u>ORP</u>

ESO 3.6m at ESO – 3.57m – Cerro Paranal, Chile

<u>HARPS</u>	wl = 383 – 691 nm	R ~115,000	High percision, includes spectro-polarimetry	Access: <u>ESO</u>
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CAHA 3.5 – 3.5m – Calar Alto, Spain

<u>CARMENES</u>	wl = 520 - 960nm & 960 - 1710nm	R~80,000 – 100,000	High radial velocity precision	Access: National, institutes and <u>ORP</u>
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