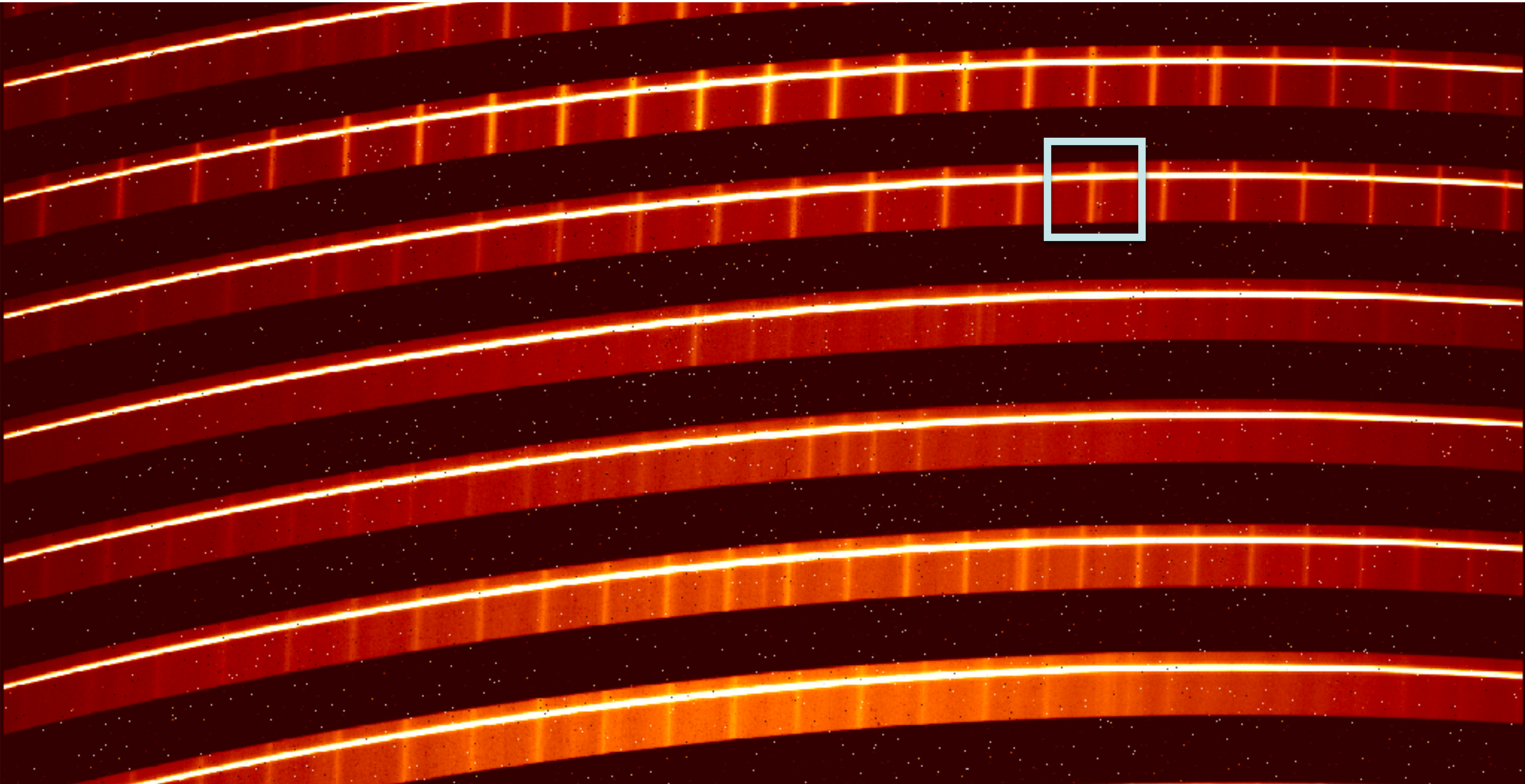
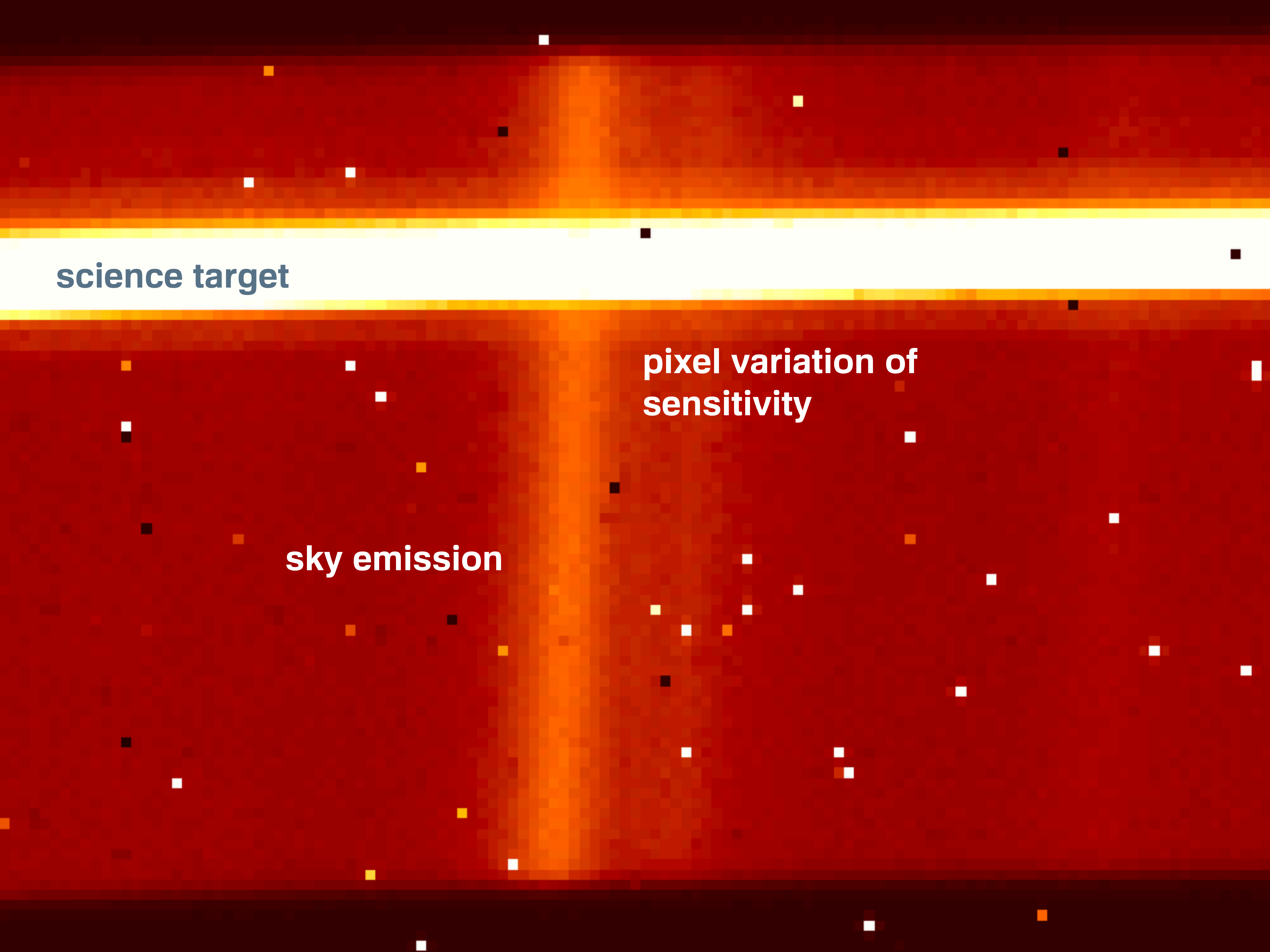
Data reduction / calibration

what is in the data?

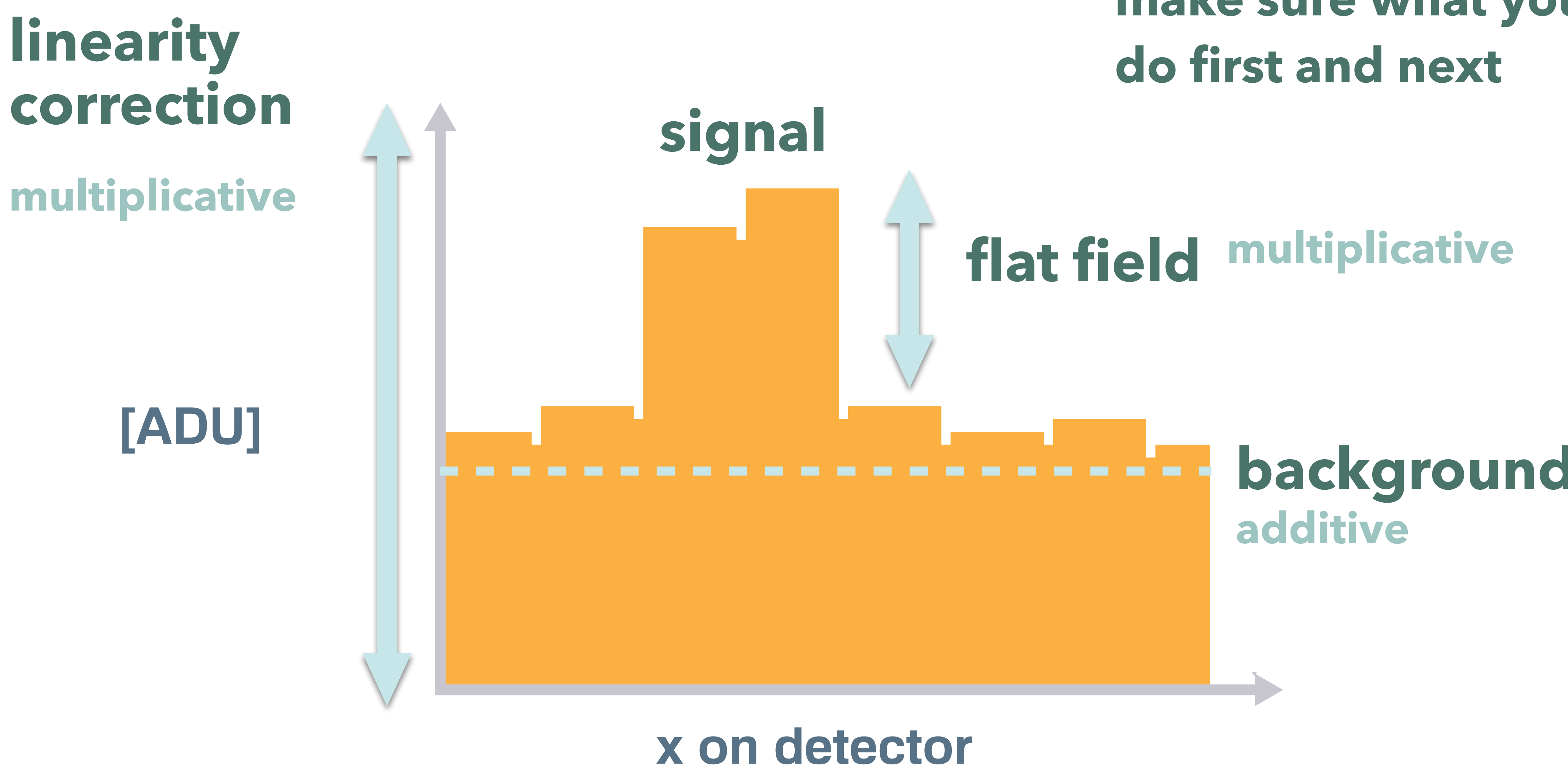
IRTF / iSHELL
L band
3.9 μm
R = 75,000



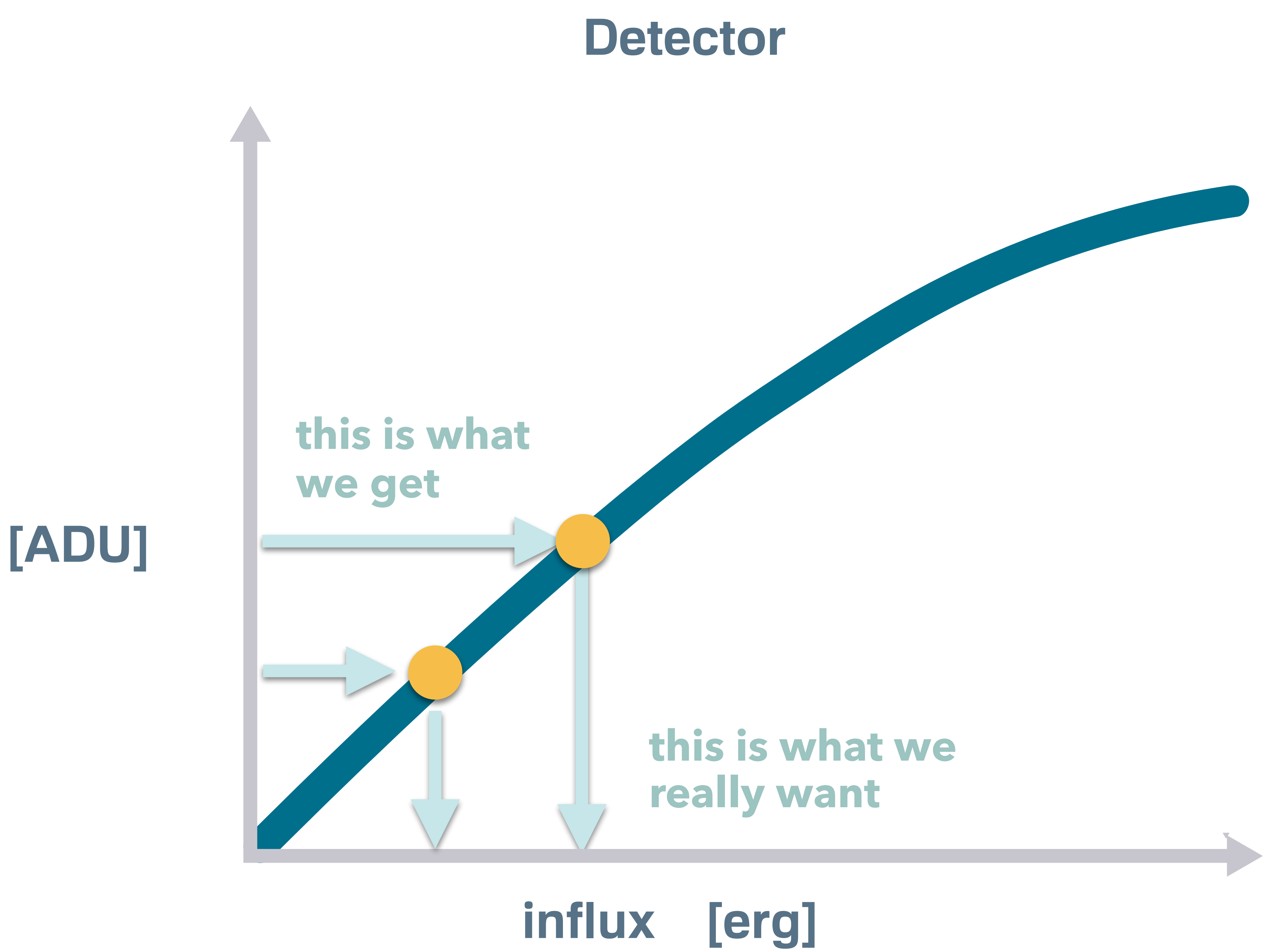

science target
pixel variation of
sensitivity
sky emission

1. linearity
2. background subtraction
3. flat field

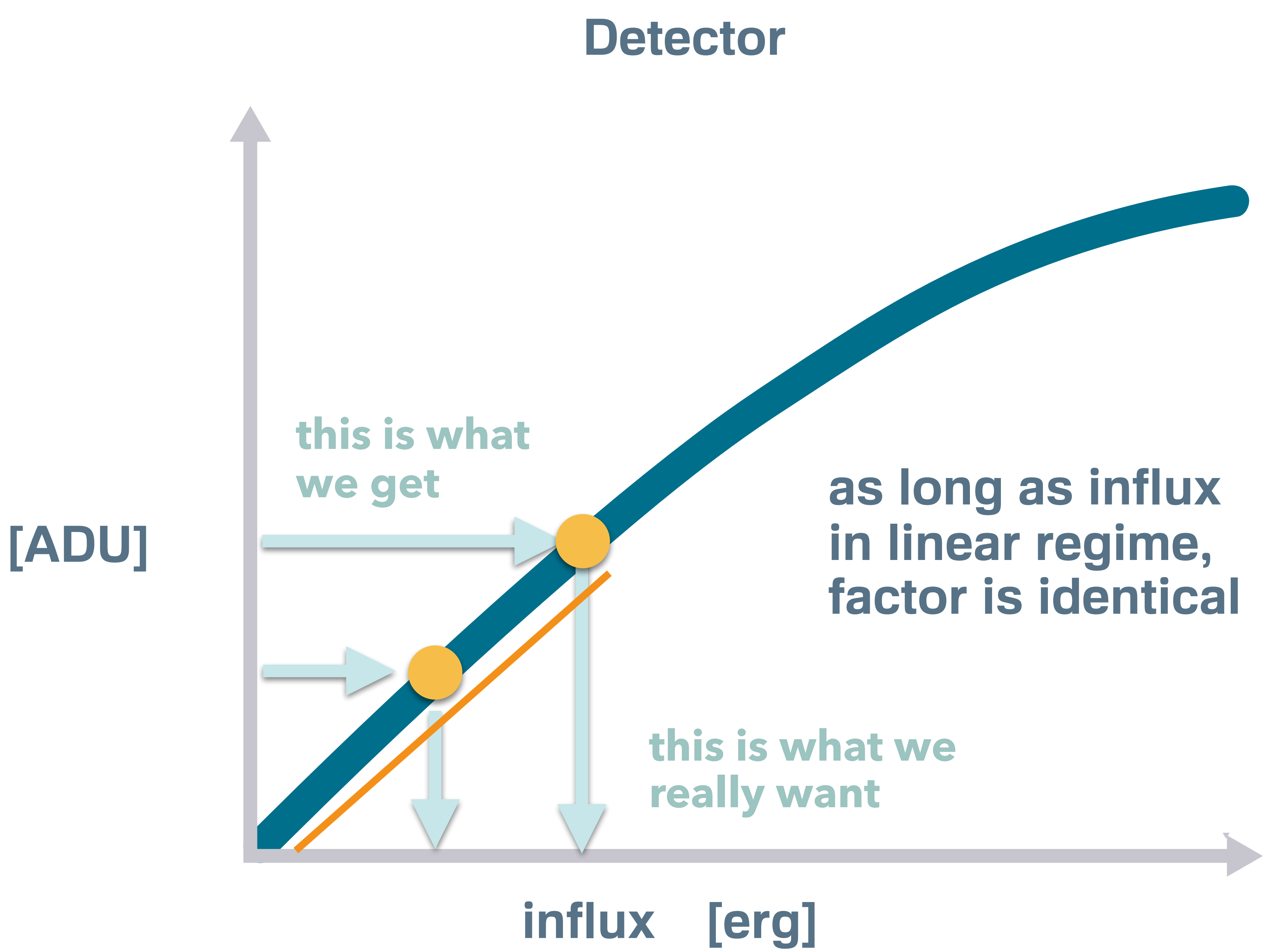
make sure what you do first and next



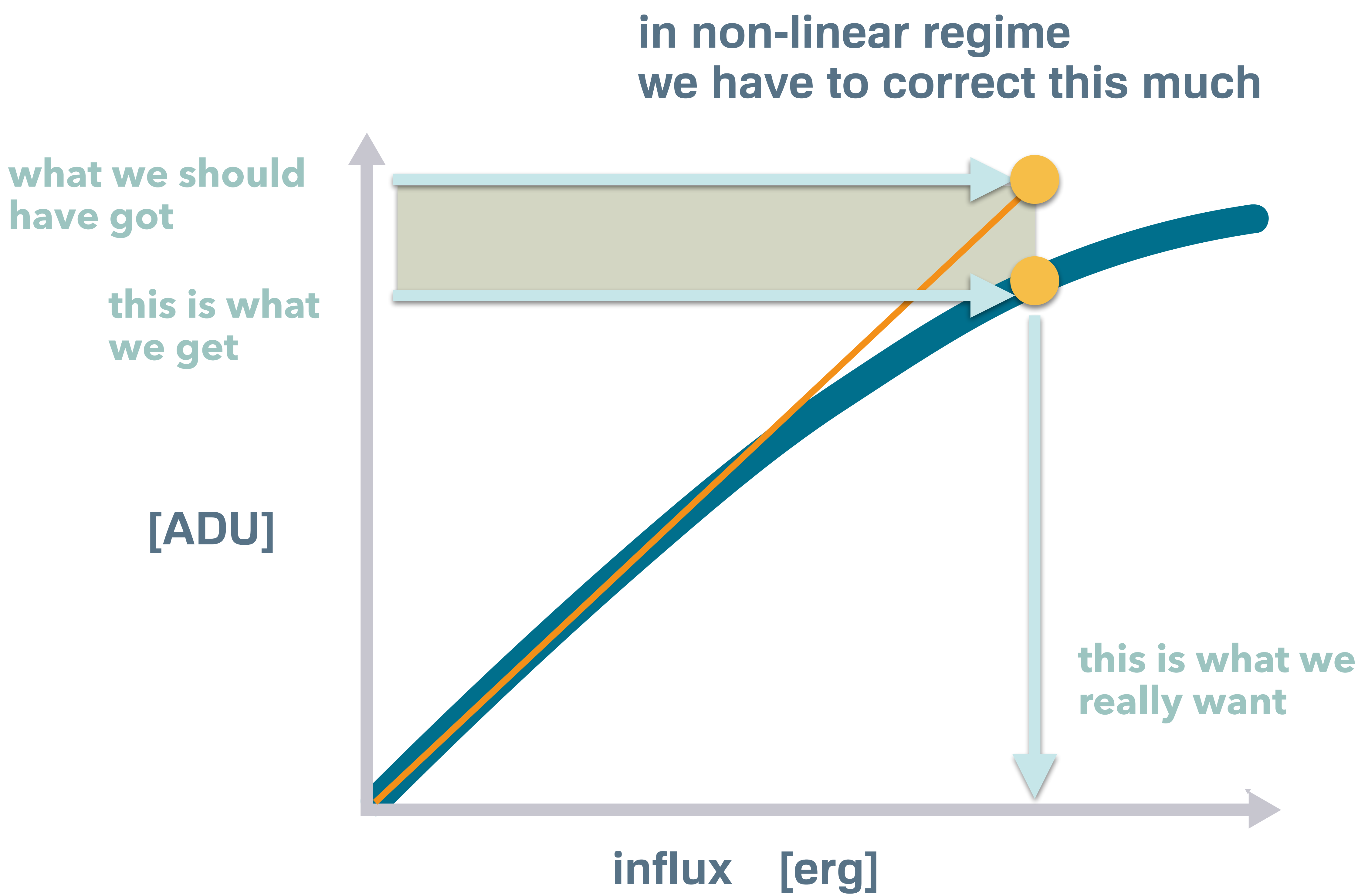
1 linearity correction



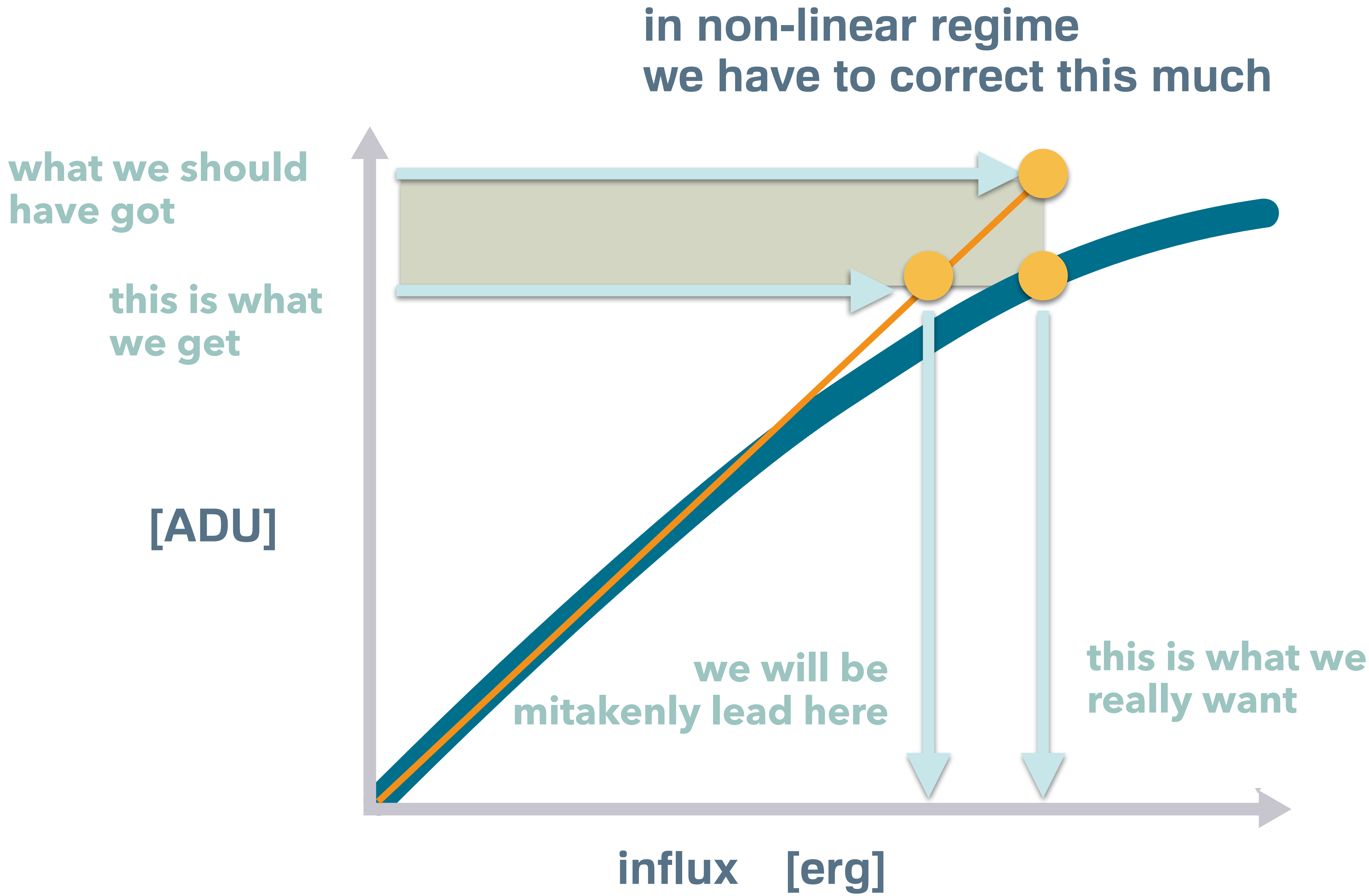
1 linearity correction



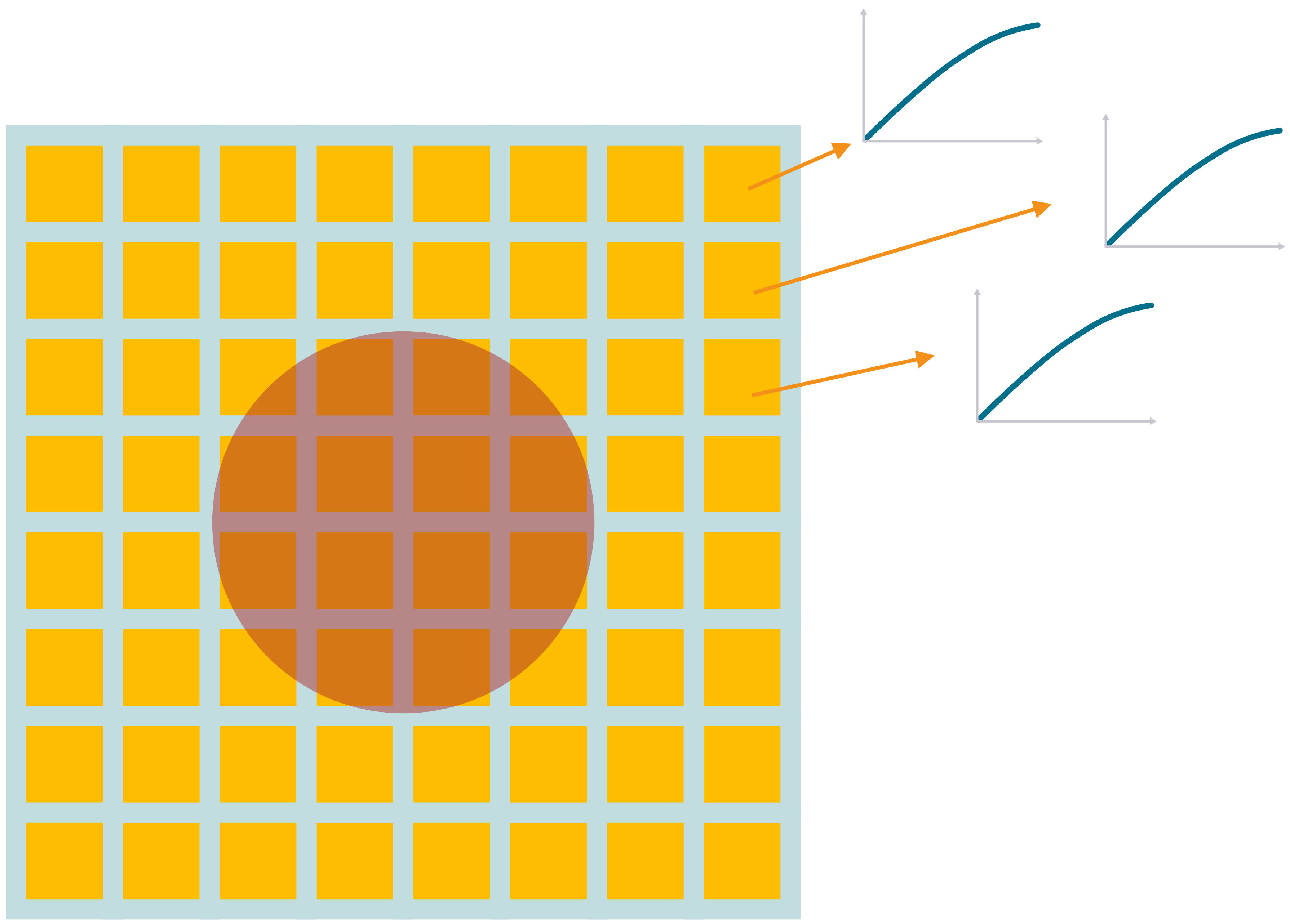
1 linearity correction



1 linearity correction



linearity curve differs pixel by pixel



$f(x) = a + bx + cx^2$

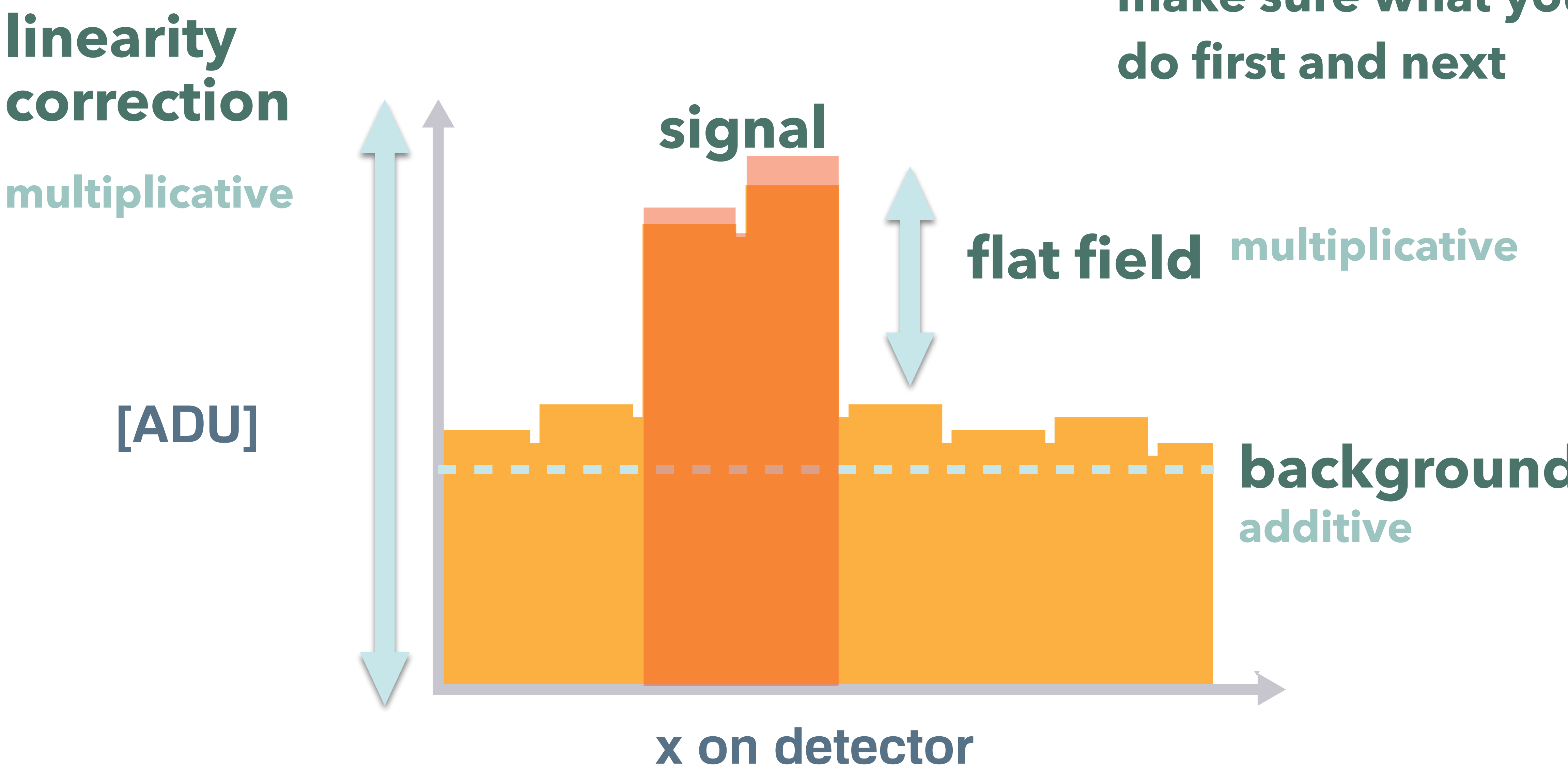
coefficients [a,b,c] are stored

1 linearity

2 background subtraction

3 flat field

make sure what you do first and next



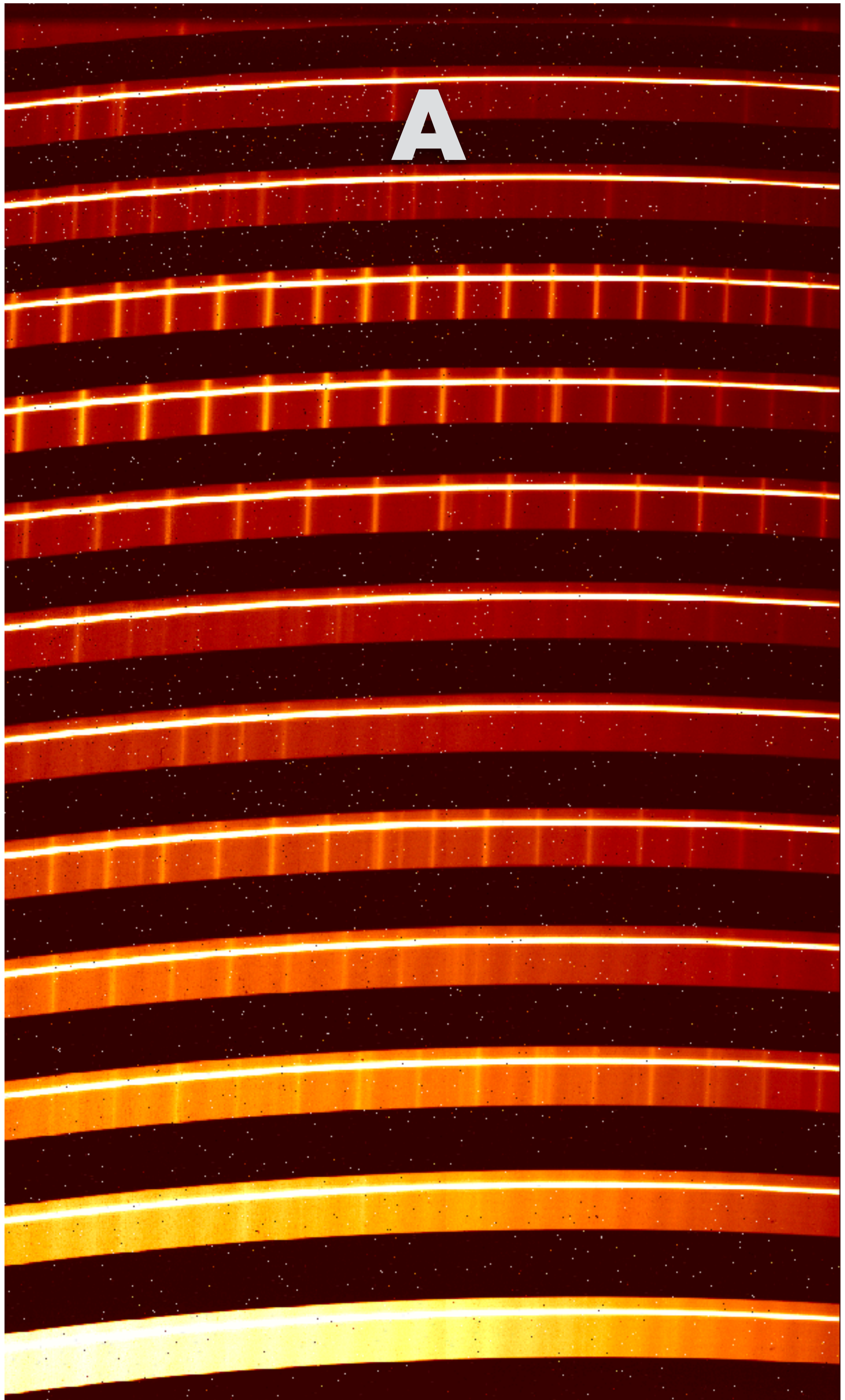
2 background subtraction

what is difference?

same source

same exposure time

same wavelength



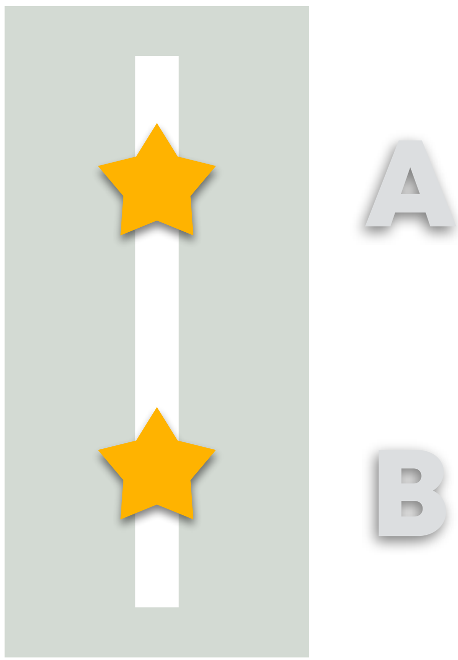
2 background subtraction

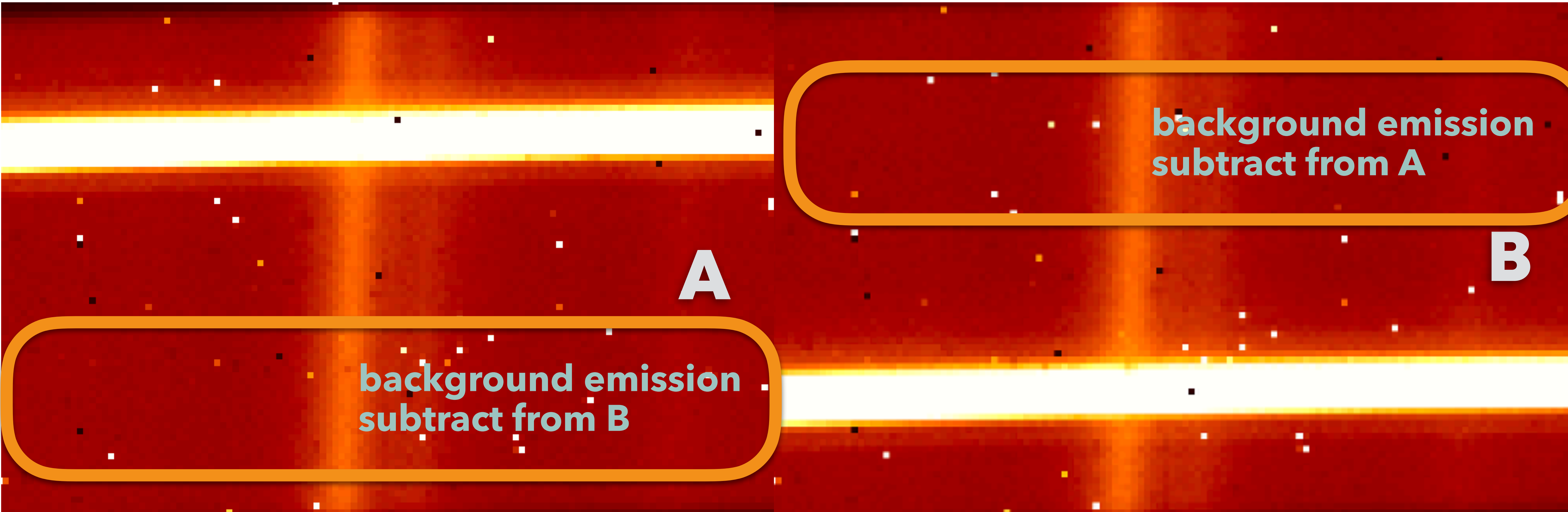
what is difference?

same source

same exposure time

same wavelength





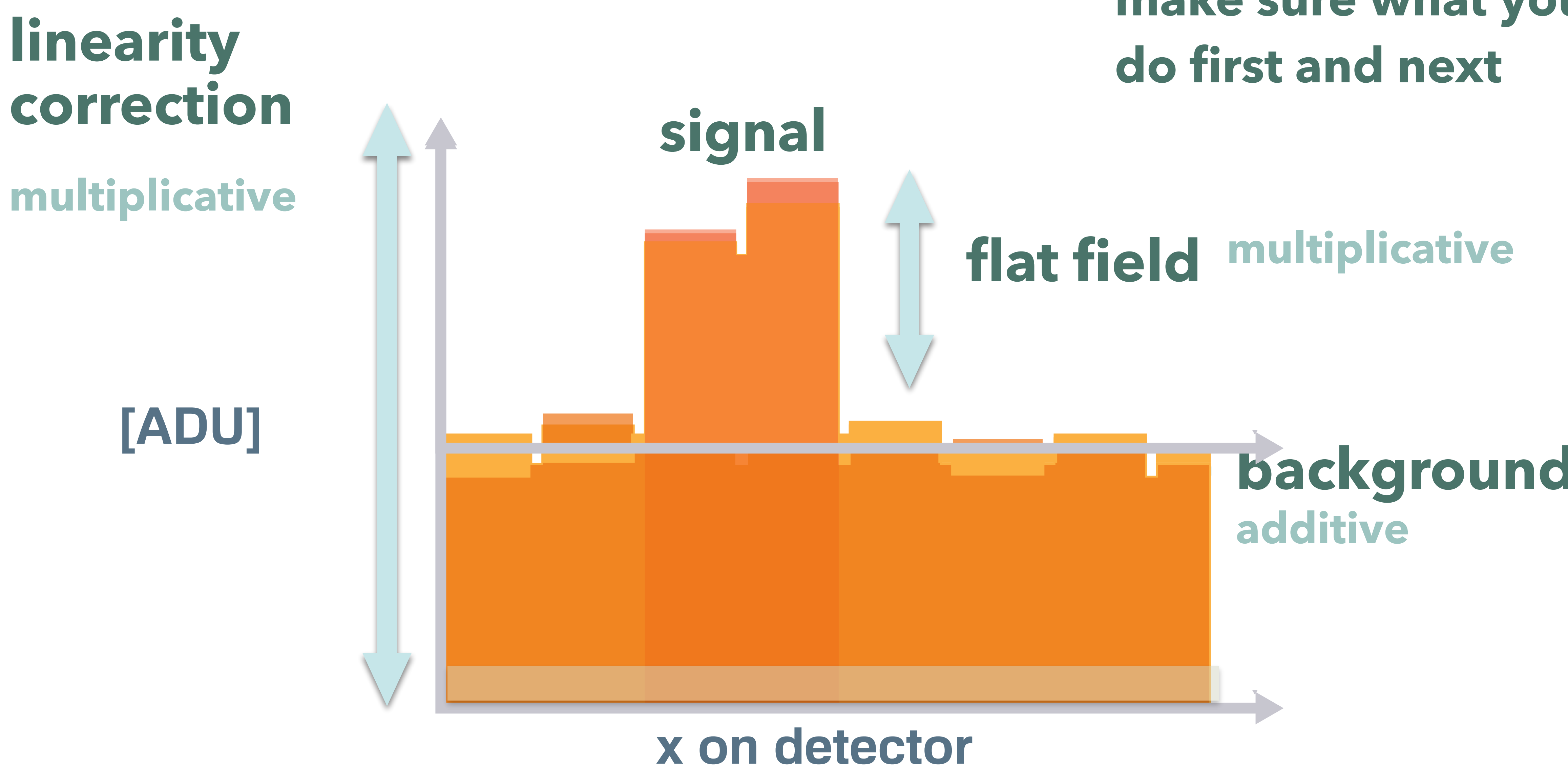

A-B

1 linearity

2 background subtraction

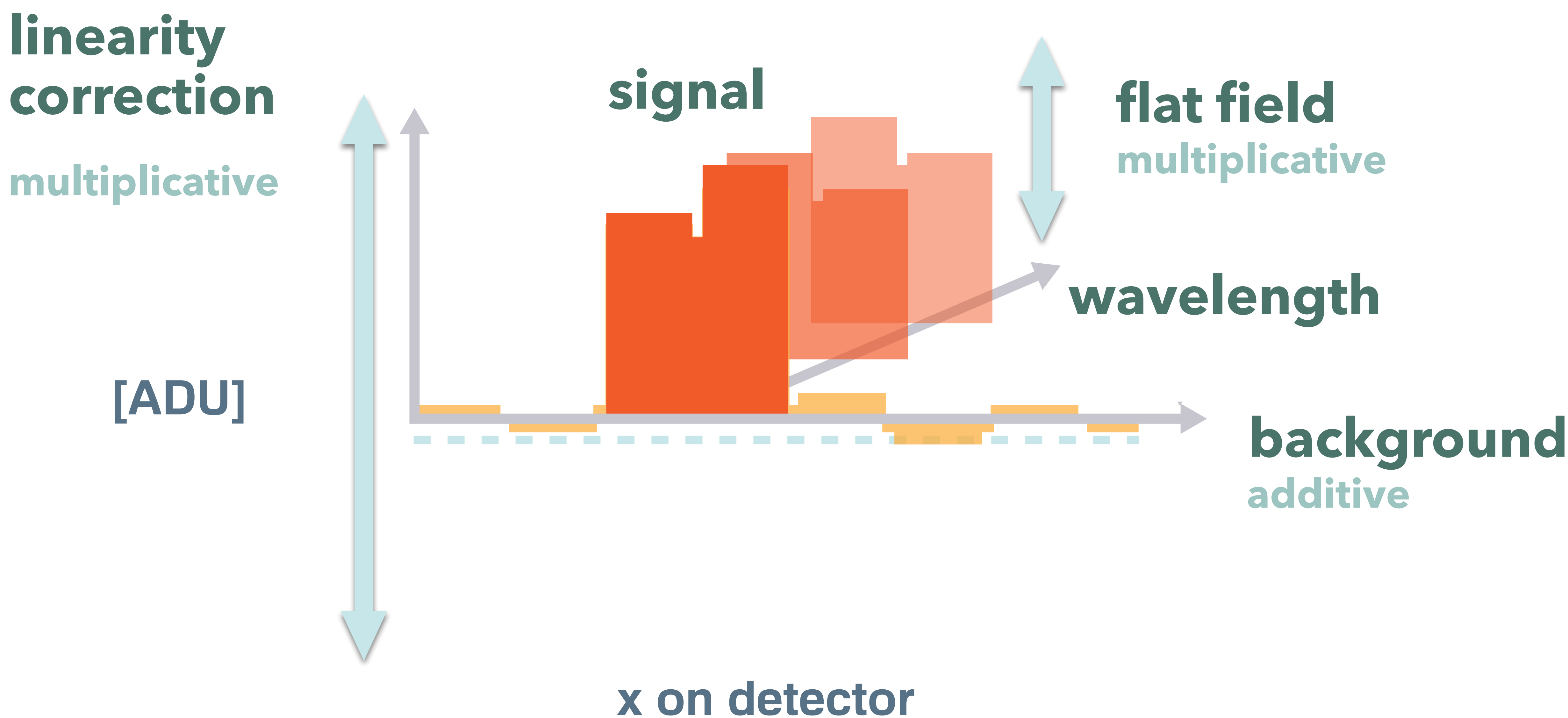
3 flat field

make sure what you do first and next

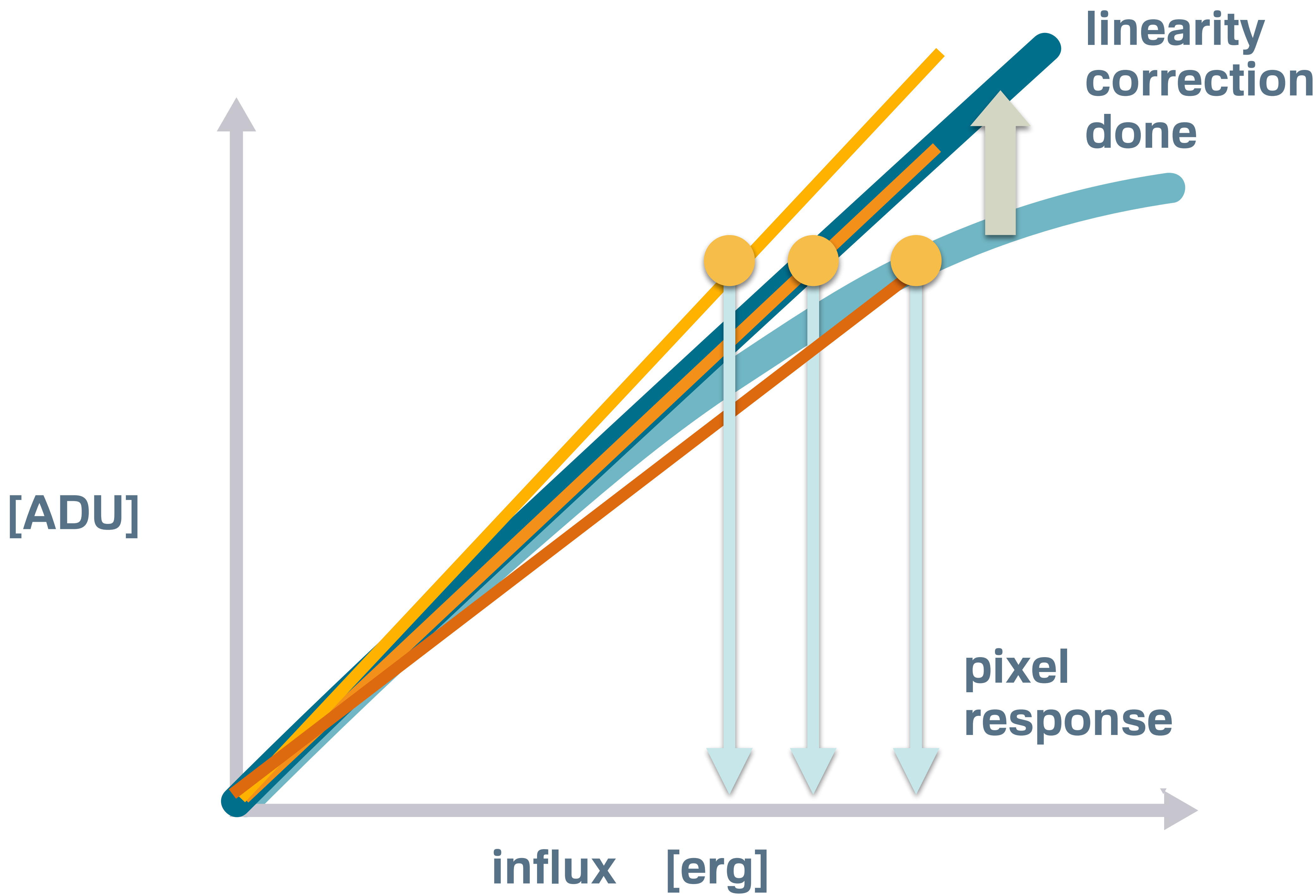


*** dark current subtracted in same time

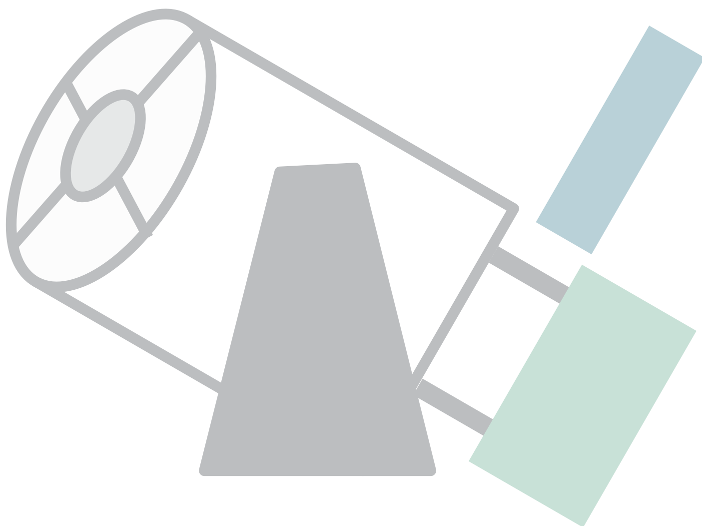
3 flat field


linearity correction
multiplicative
[ADU]
signal
flat field
multiplicative
wavelength
background
additive
x on detector

3 flat field



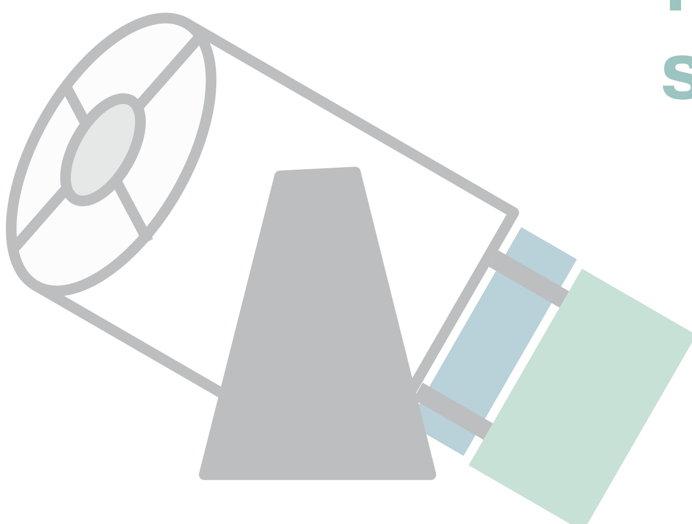
3 flat field



3 flat field

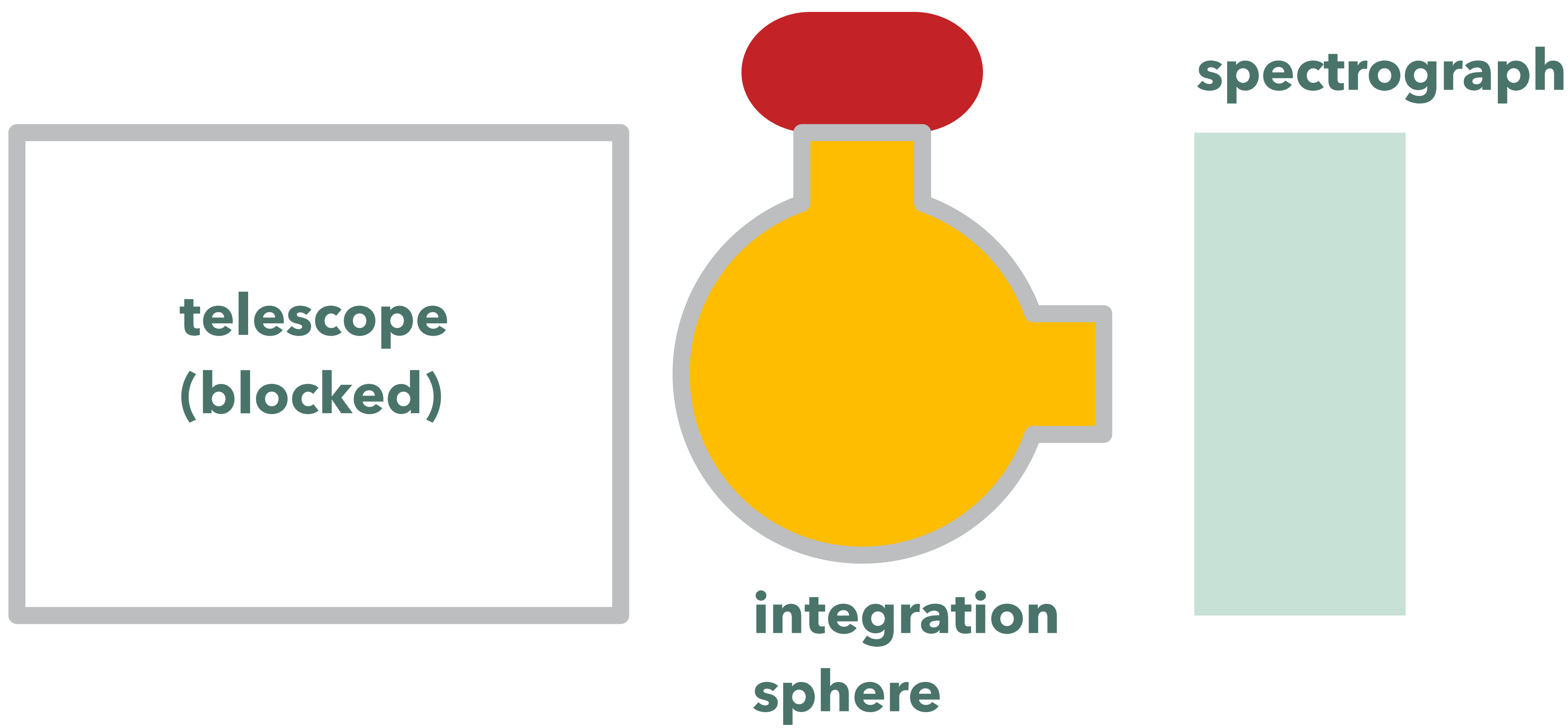
need

- clean
- featureless
- strong continuum source

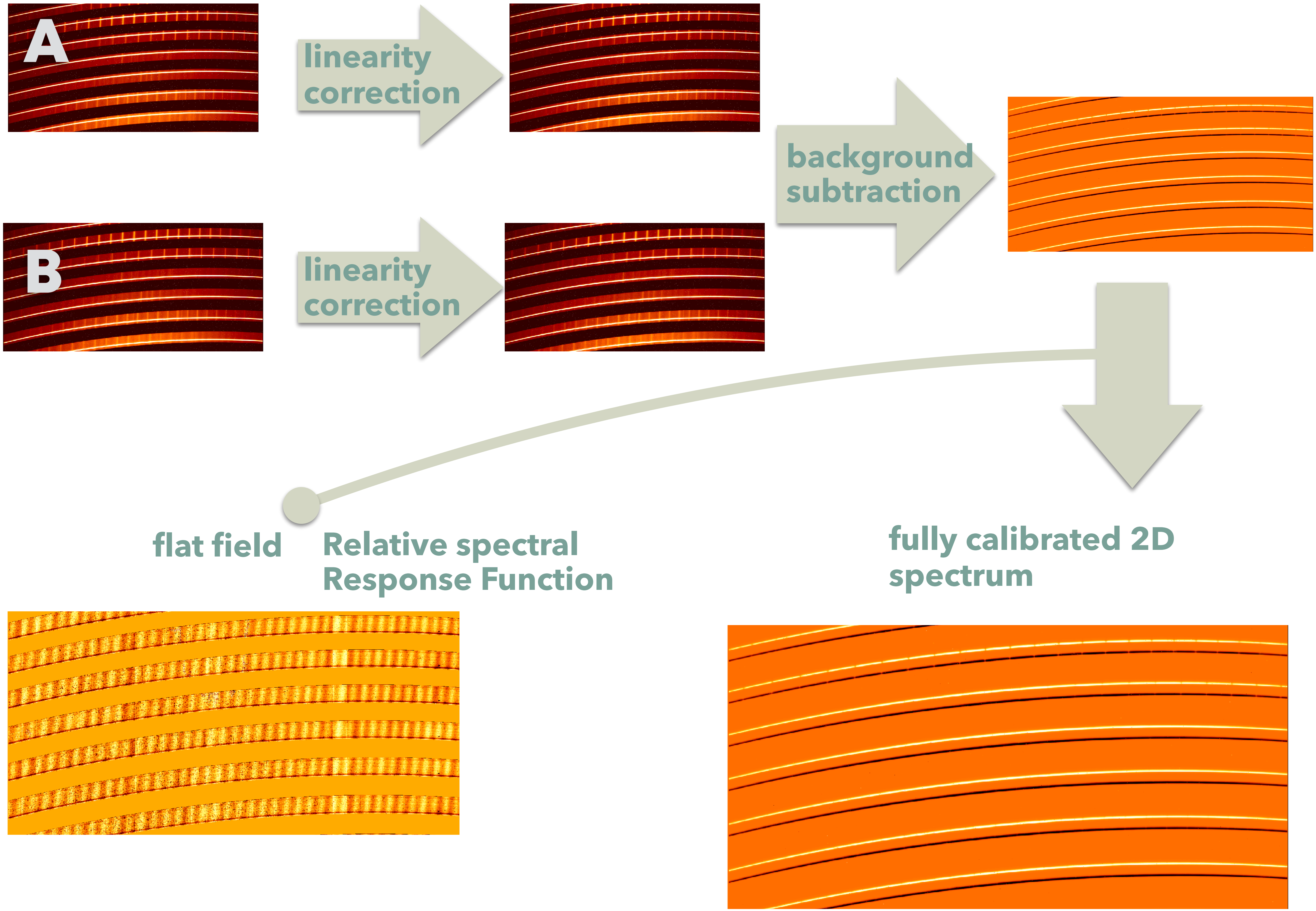


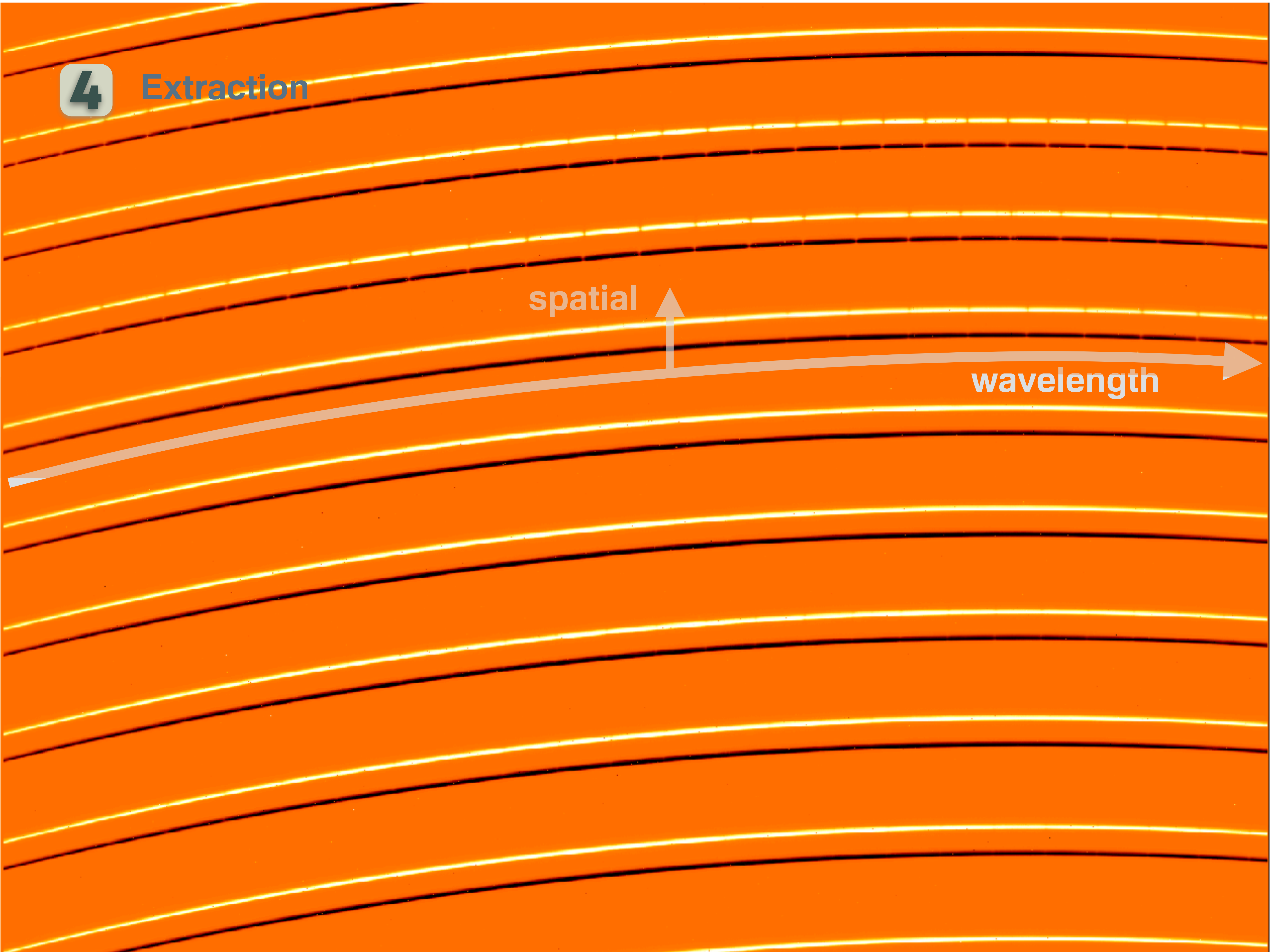
blackbody source

heater (~1000K)

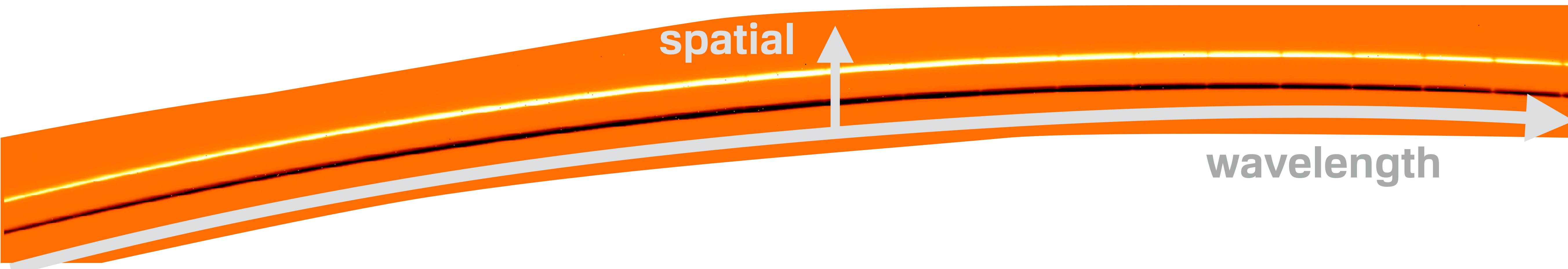


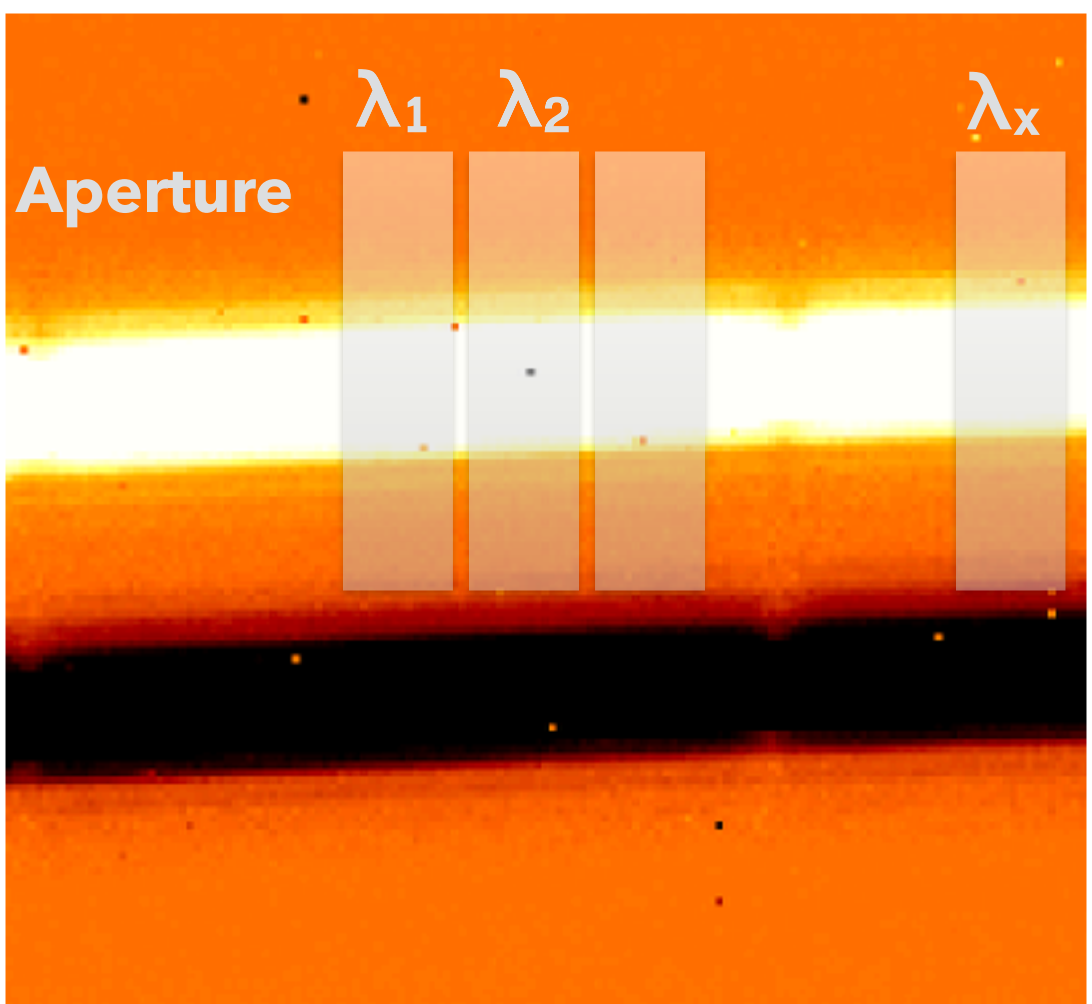
Blackbody lamp


A
linearity correction
B
linearity correction
background subtraction
flat field
Relative spectral Response Function
fully calibrated 2D spectrum


4
Extraction
spatial
wavelength

4 Extraction



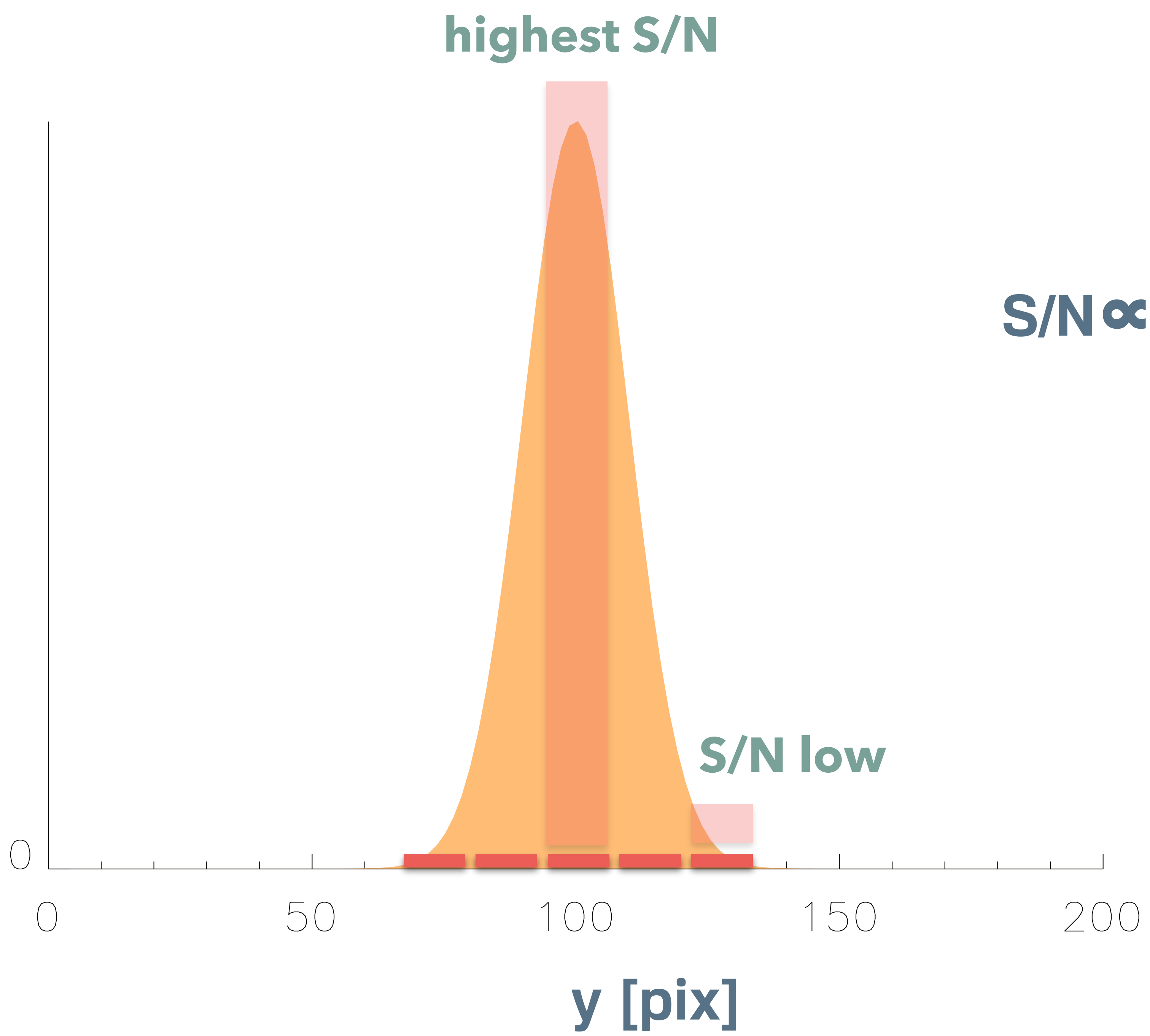


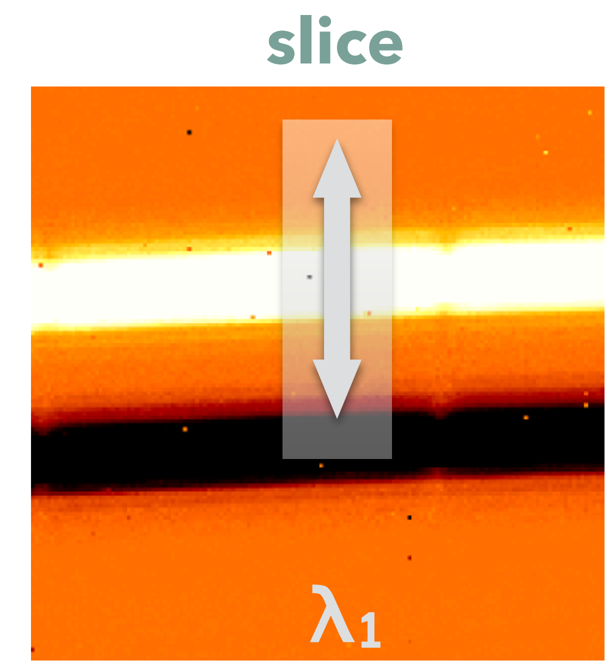
Aperture extraction

sum up all counts inside aperture

just like photometry

Optimal Extraction





$S/N \propto S$

to get highest S/N

high S/N pixel must have highest weight

$\Sigma D_i \omega_i$

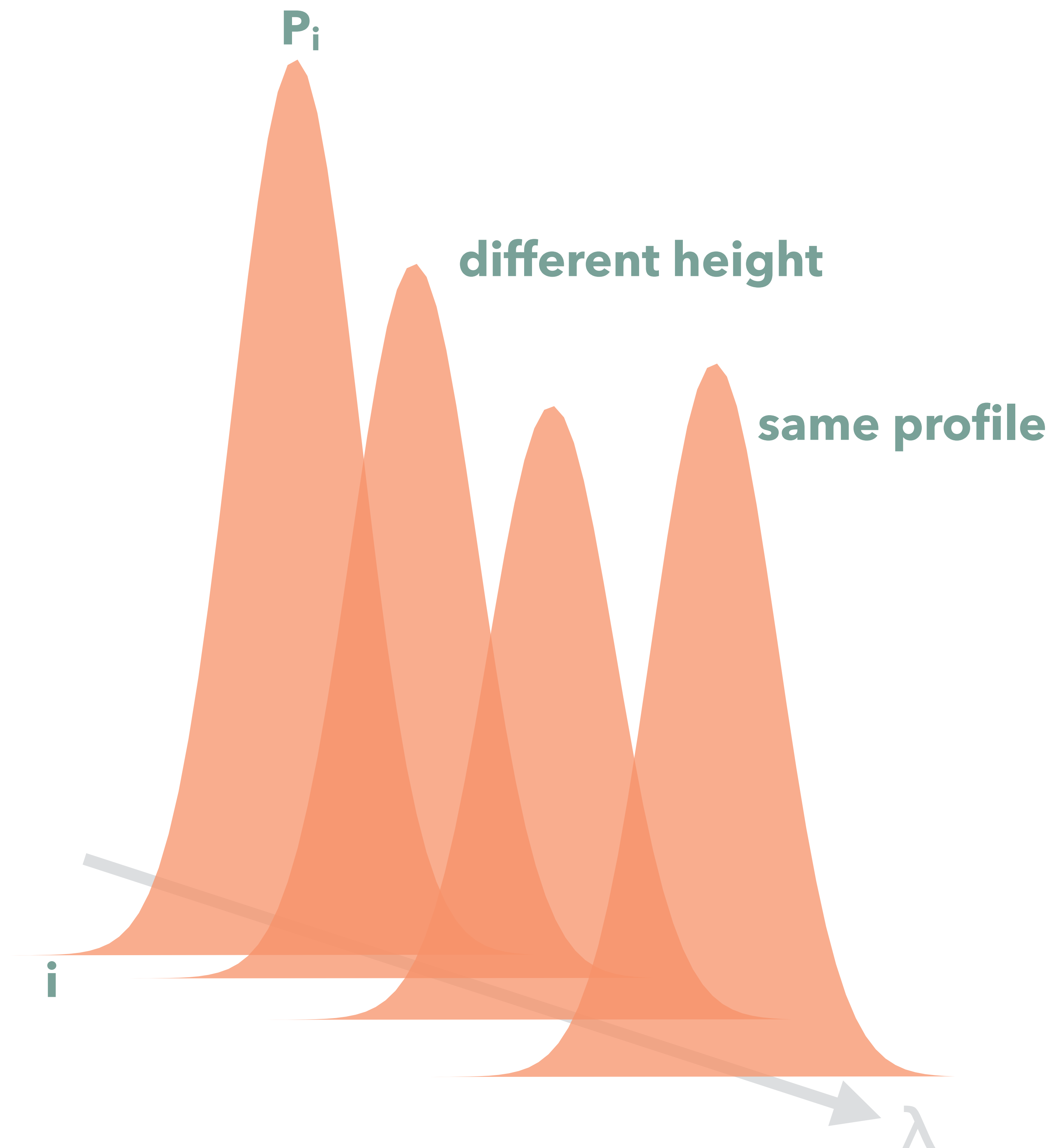
$\omega_i \propto P_i / \sigma_i^2$

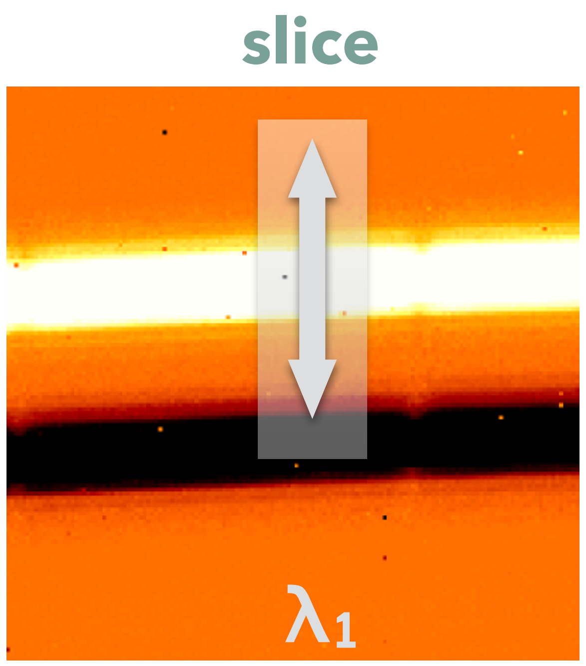
P_i : reconstructed profile

Horne (1986) PASP, 98, 609

Marsh (1989) PASP, 101, 1032

reconstructed profile





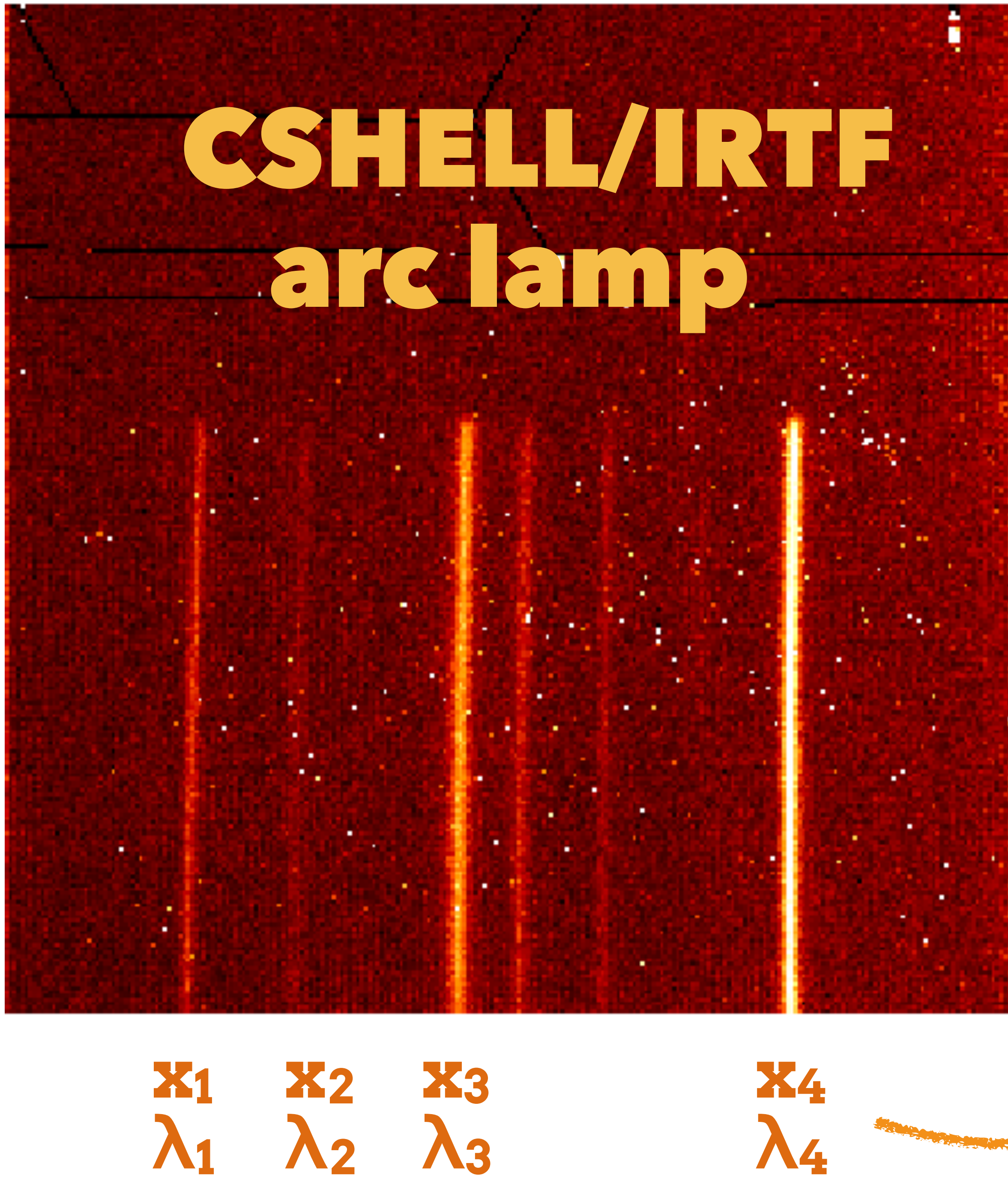
Point source only!

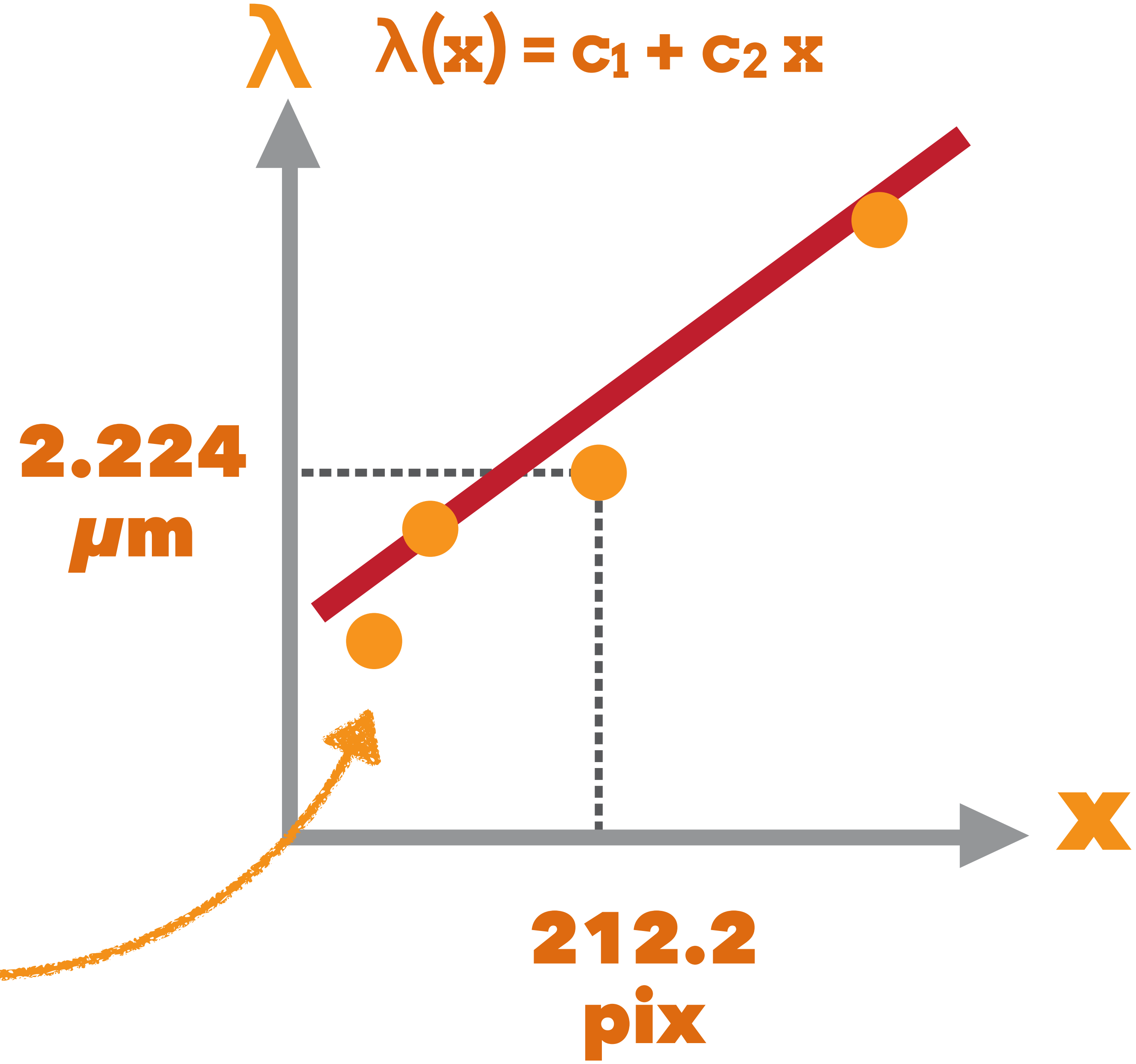
P_i can be assumed all same at different wavelength

emission lines

disks

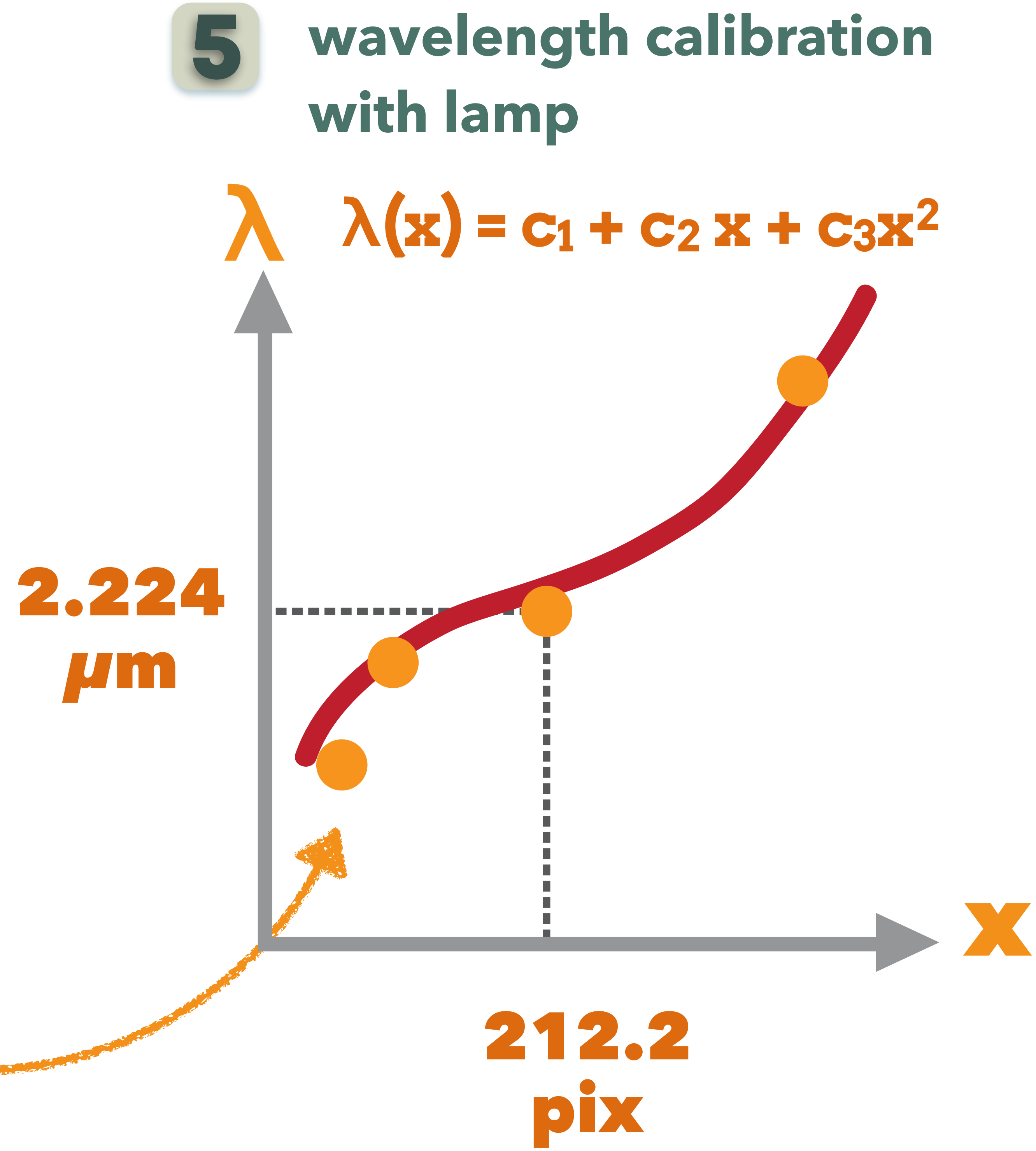
5 wavelength calibration with lamp





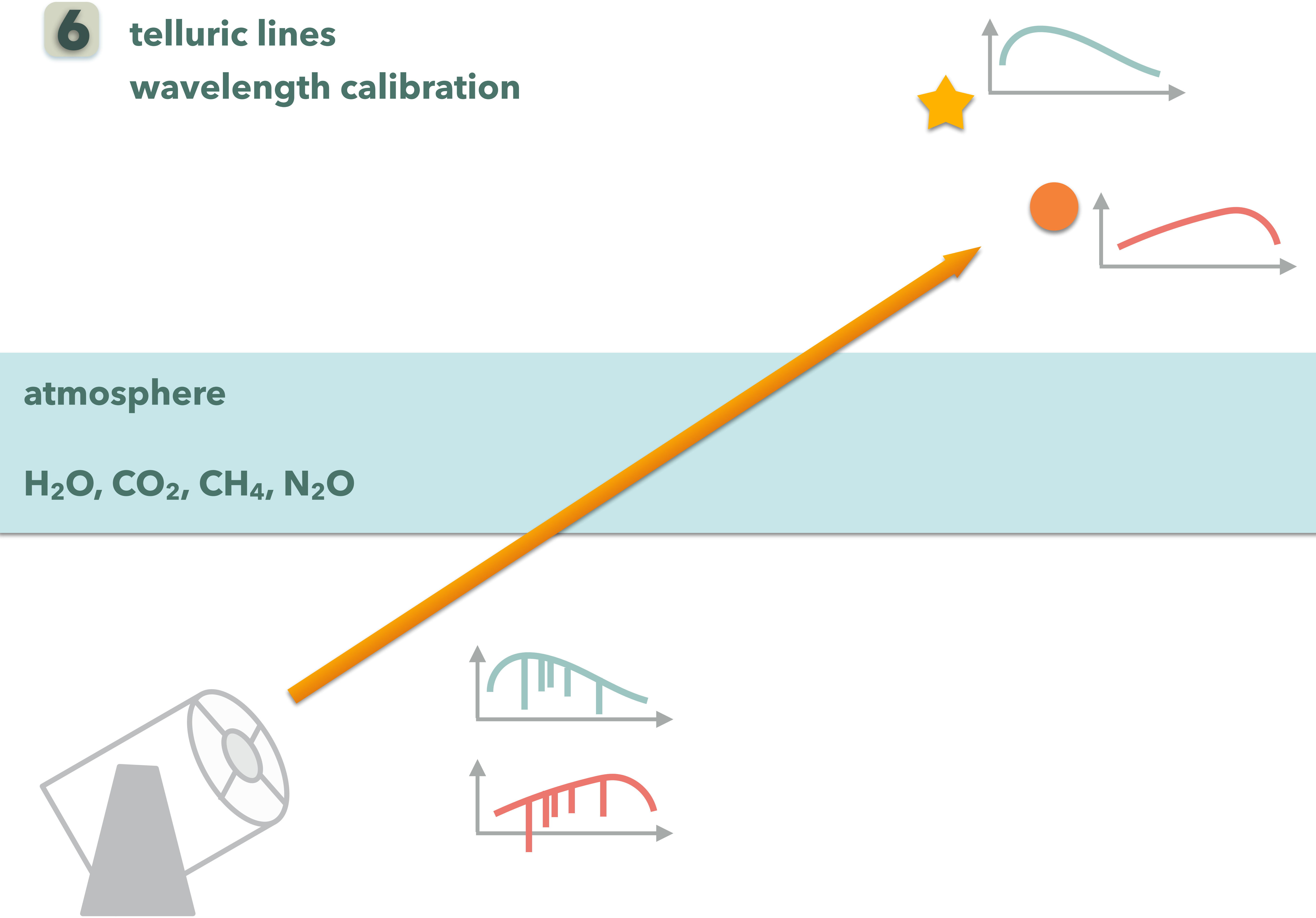
wavelength calibration

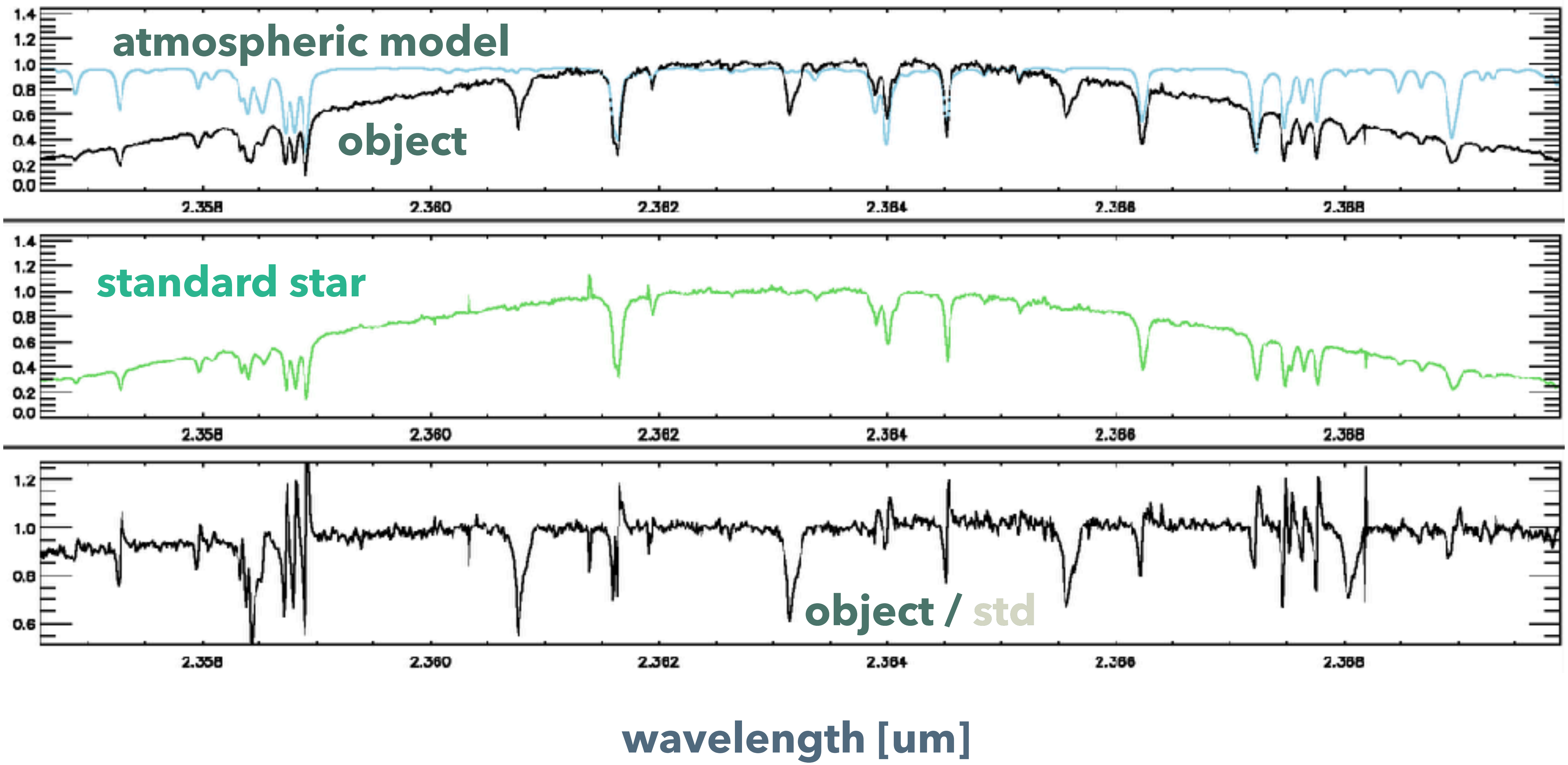
= to determine c_1, c_2

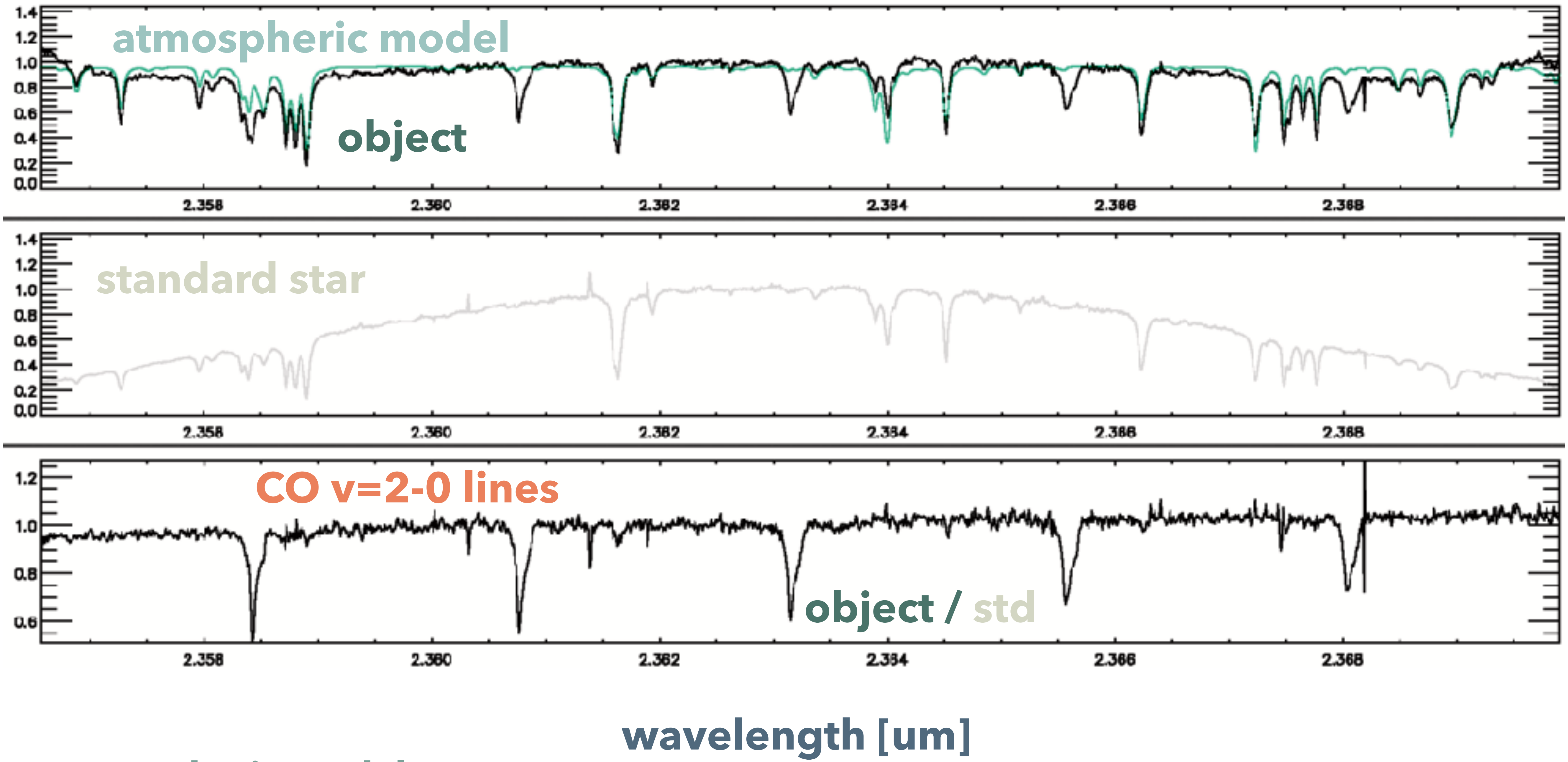


wavelength calibration

= to determine c_1, c_2, c_3


6
telluric lines
wavelength calibration
atmosphere
H₂O, CO₂, CH₄, N₂O


atmospheric model
object
standard star
object / std
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2.358
2.360
2.362
2.364
2.366
2.368
wavelength [um]

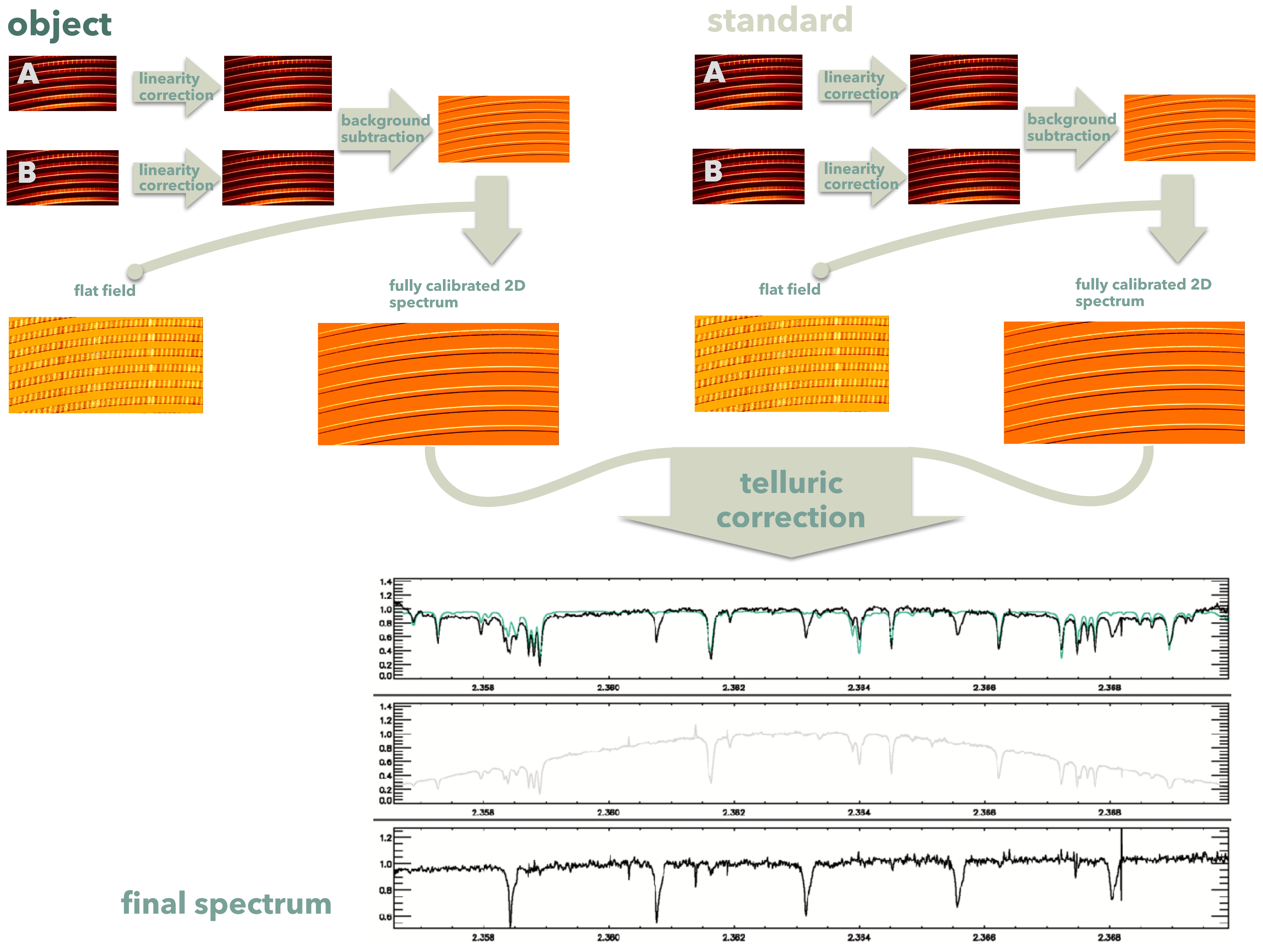


Atmospheric models

ATRAN

molecfit

xtellcore_model

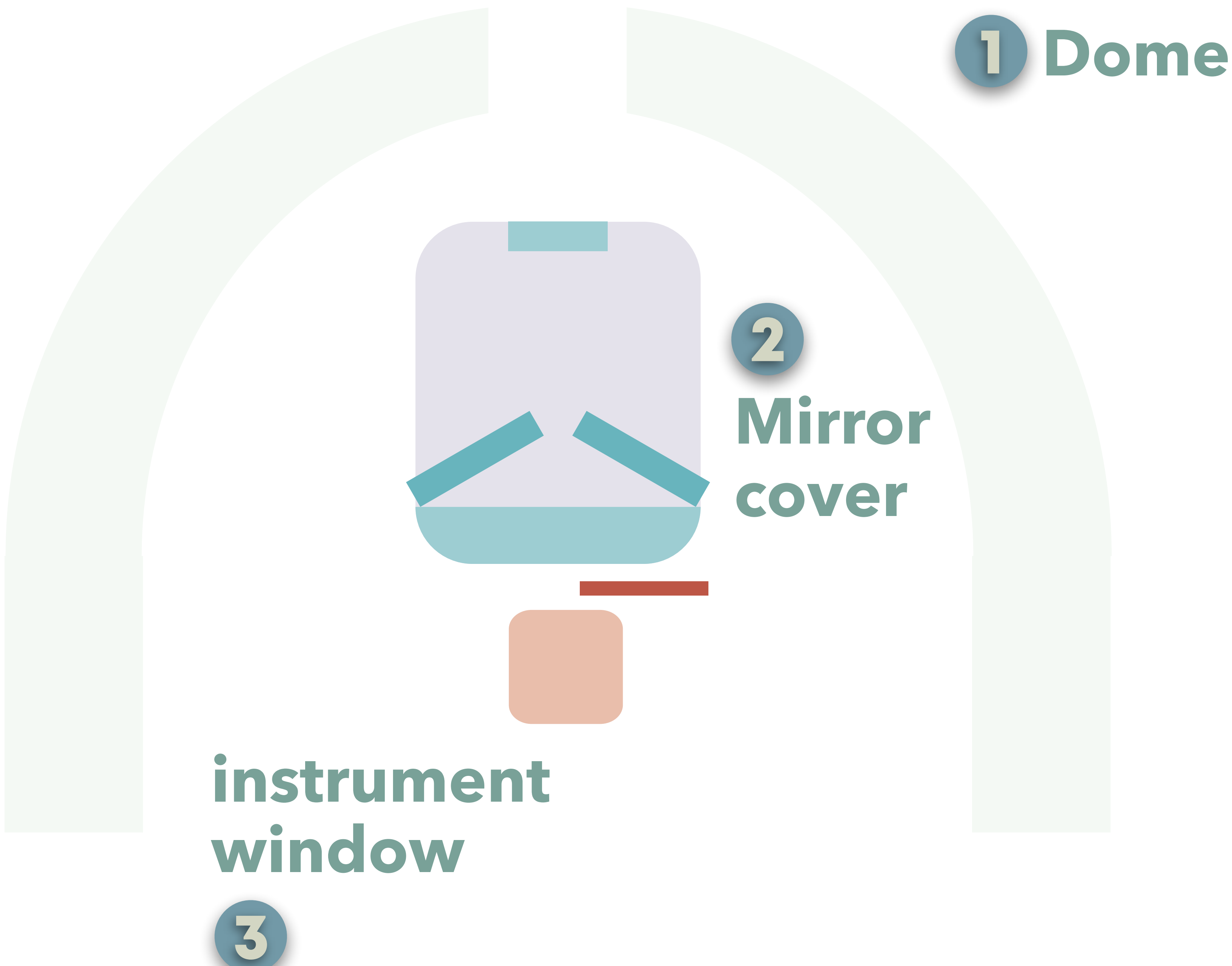


object
standard
A
B
linearity correction
background subtraction
flat field
fully calibrated 2D spectrum
telluric correction
final spectrum

How an actual observation goes?

1. Open dome / Mirror cover / Instrument window
2. Focus telescope / instrument
3. Slew telescope to target
4. Acquisition
5. Fix exposure time
6. Start integration
7. Calibration
8. Standard star 3 – 7
9. Close

1 Open dome / Mirror cover / Instrument window



2 Focus telescope / instrument

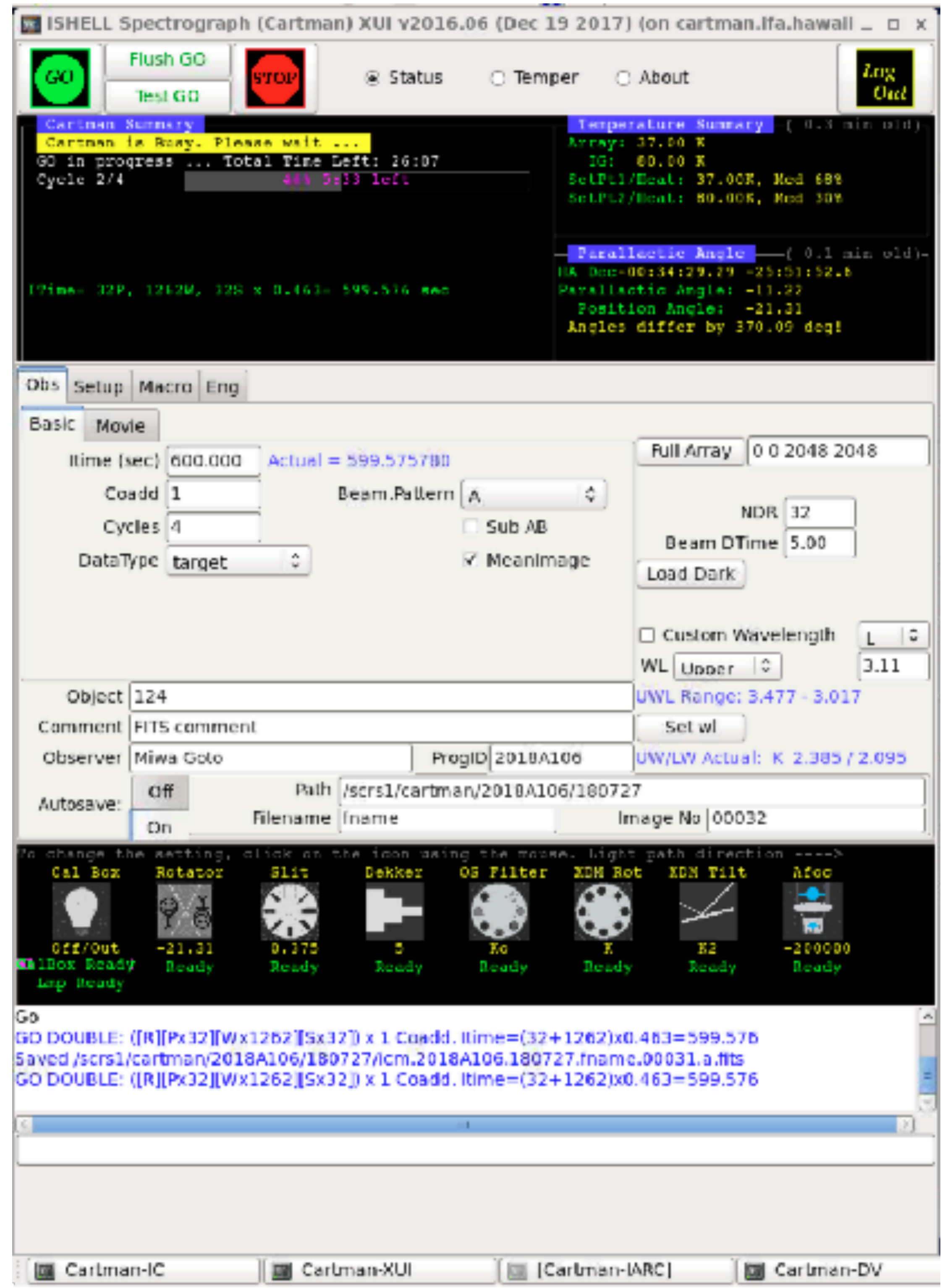
pointing check

3 Slew telescope to target

Instrument setup

rotator
slit width
wavelength

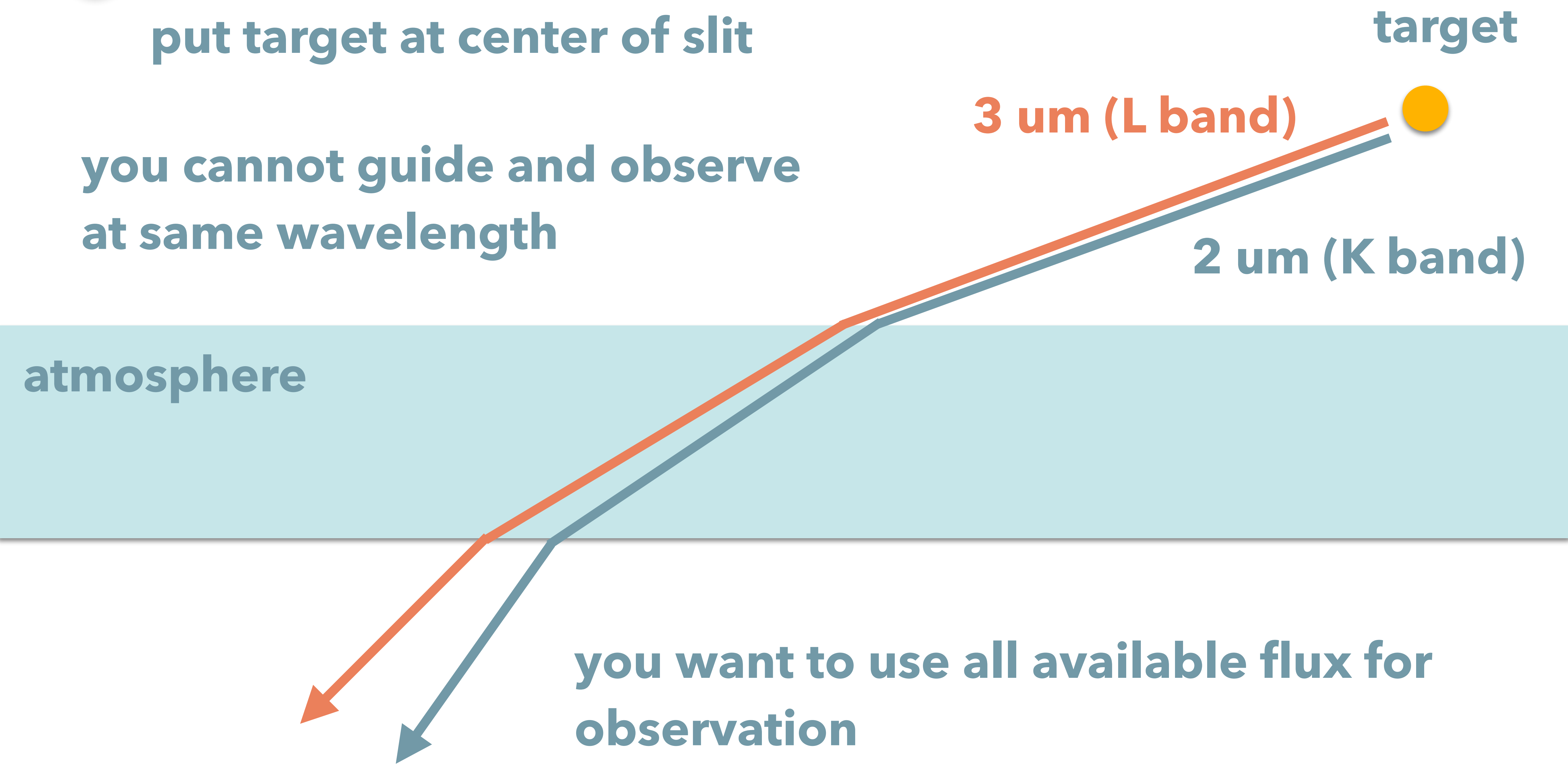
Parallactic angle



4 Acquisition

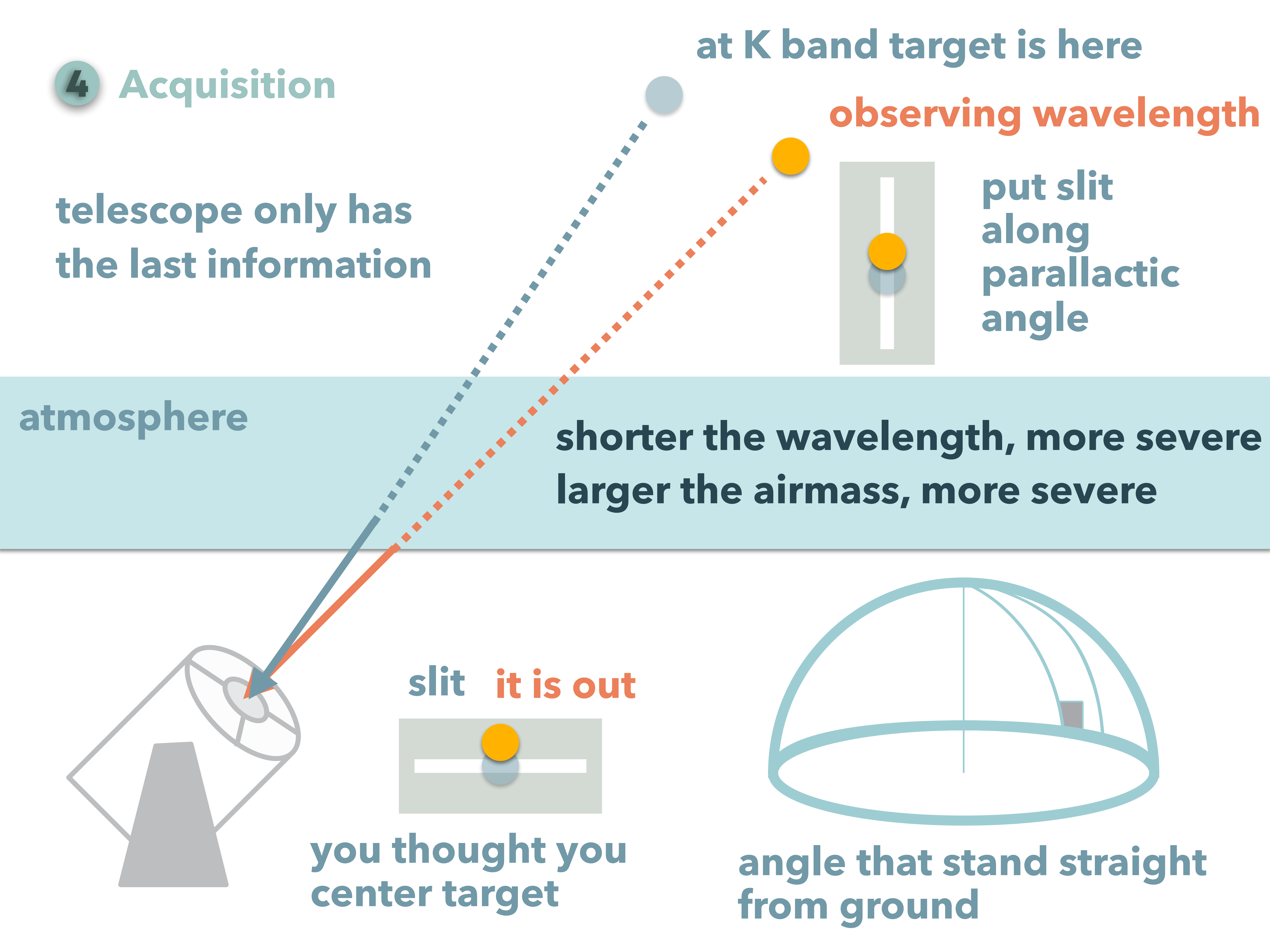
put target at center of slit

you cannot guide and observe at same wavelength



you want to use all available flux for observation

light bends more at short wavelength


4 Acquisition
at K band target is here
observing wavelength
telescope only has
the last information
put slit
along
parallactic
angle
atmosphere
shorter the wavelength, more severe
larger the airmass, more severe
slit
it is out
you thought you
center target
angle that stand straight
from ground

5

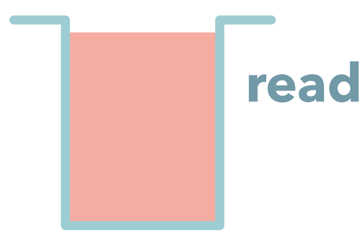
1 minimize noise

each readout costs noise
fill to linearity limit

linearity limit

Don't

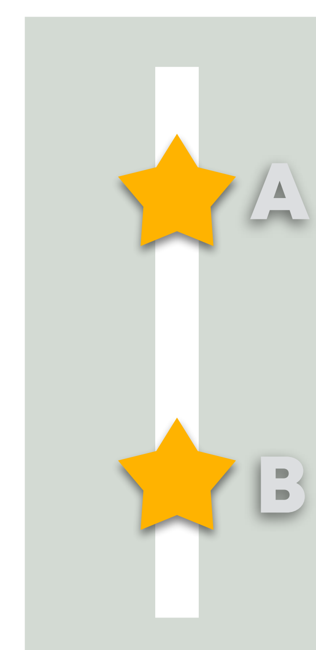
Do



linearity limit	20000 ADU
test exposure 1 sec	100 ADU
integration time	200 sec

2 sky variation

longer wavelength
more sky emission
faster sky variation



J/H/K band	(1-2 um)	5 - 15 min
L/M band	(3-5 um)	30 - 120 sec

5 Fix exposure time

example 1. J/H/K band (1-2 um) 5 - 15 min

linearity limit	20000 ADU	* coadd
test exposure 1 sec	1000 ADU	readouts are added on chip
single integration time	20 sec	faster than writing on disk
coadd	*15	
1 frame	300 sec	read out margin

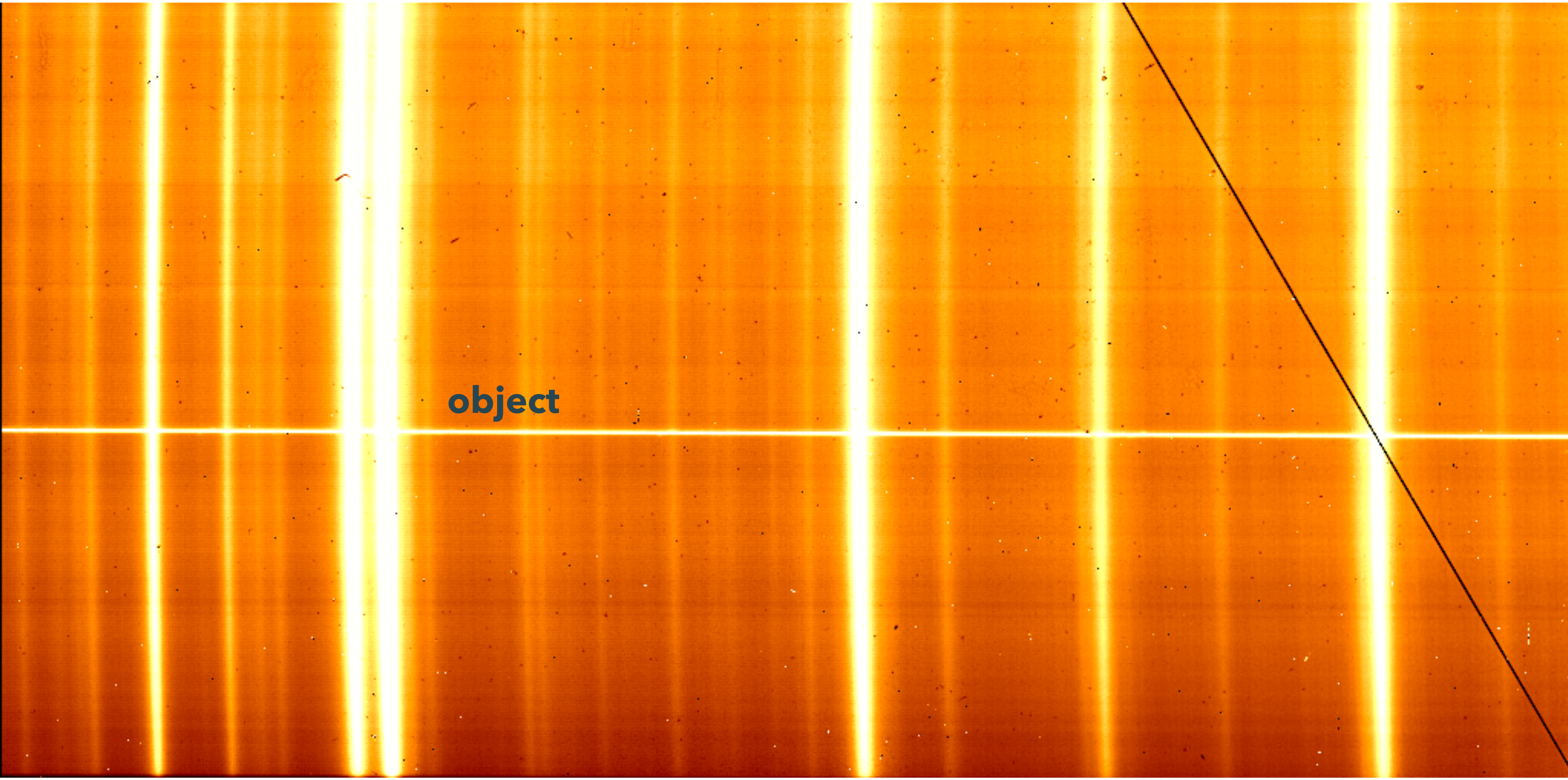
example 2. J/H/K band (1-2 um) 5 - 15 min

linearity limit	20000 ADU	
test exposure 1 sec	10 ADU	
single integration time	600 sec	sky variation limit
coadd	1	
1 frame	600 sec	

5 Fix exposure time

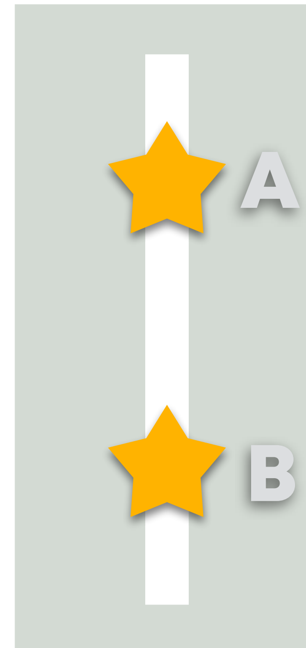
sky emission lines

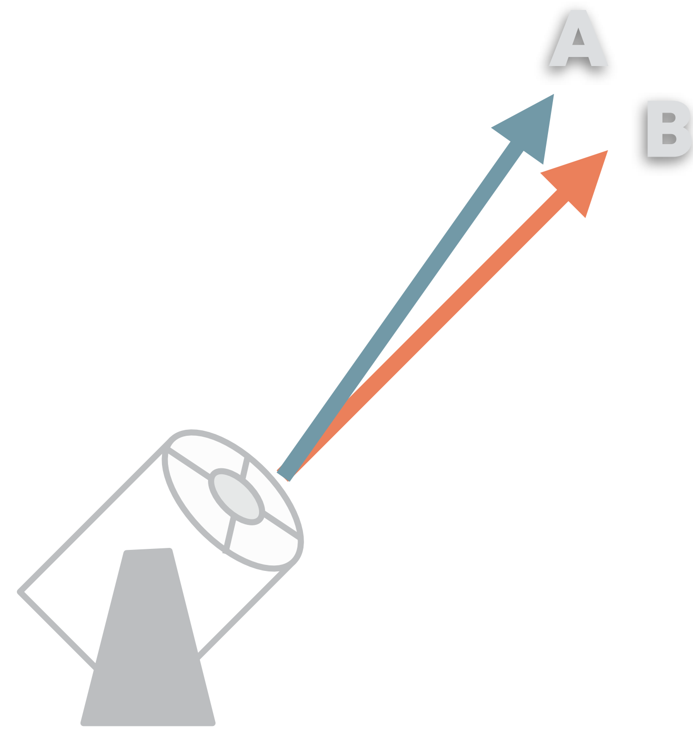
can saturate if you do not use this particular wavelength



6 Start integration

nodding





Don't

sky sample interval — sky sample interval

A → B → A → B

sky for B — sky for A — sky for B — sky for A

Do

A → B → B → A

nodding costs time
save it.

7 Calibration

flat field

- can take in the morning as well
- instrument stability

arc lamp

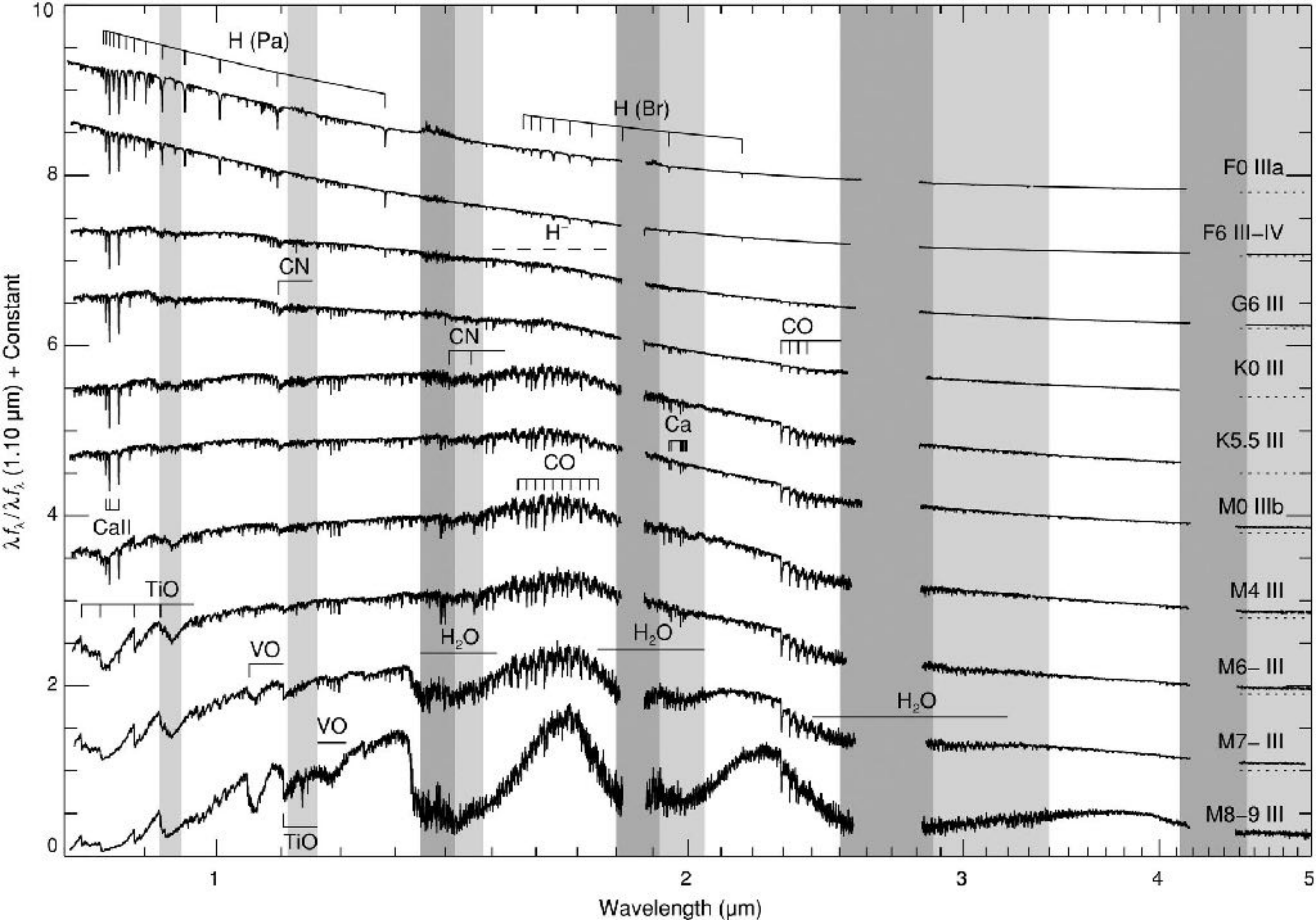
- can skip if enough sky lines

8 Standard star 3 – 7

what standard star best?

- few photospheric lines → early type A-B
- lines are narrow → class I better than V

  pressure broadening



Rayner et al. 2009, ApJ, 185, 289

8 Standard star 3 – 7

what standard star are best?

- few photospheric lines → early type A-B

low T_{eff}

molecule can be present (not dissociate)

high T_{eff}

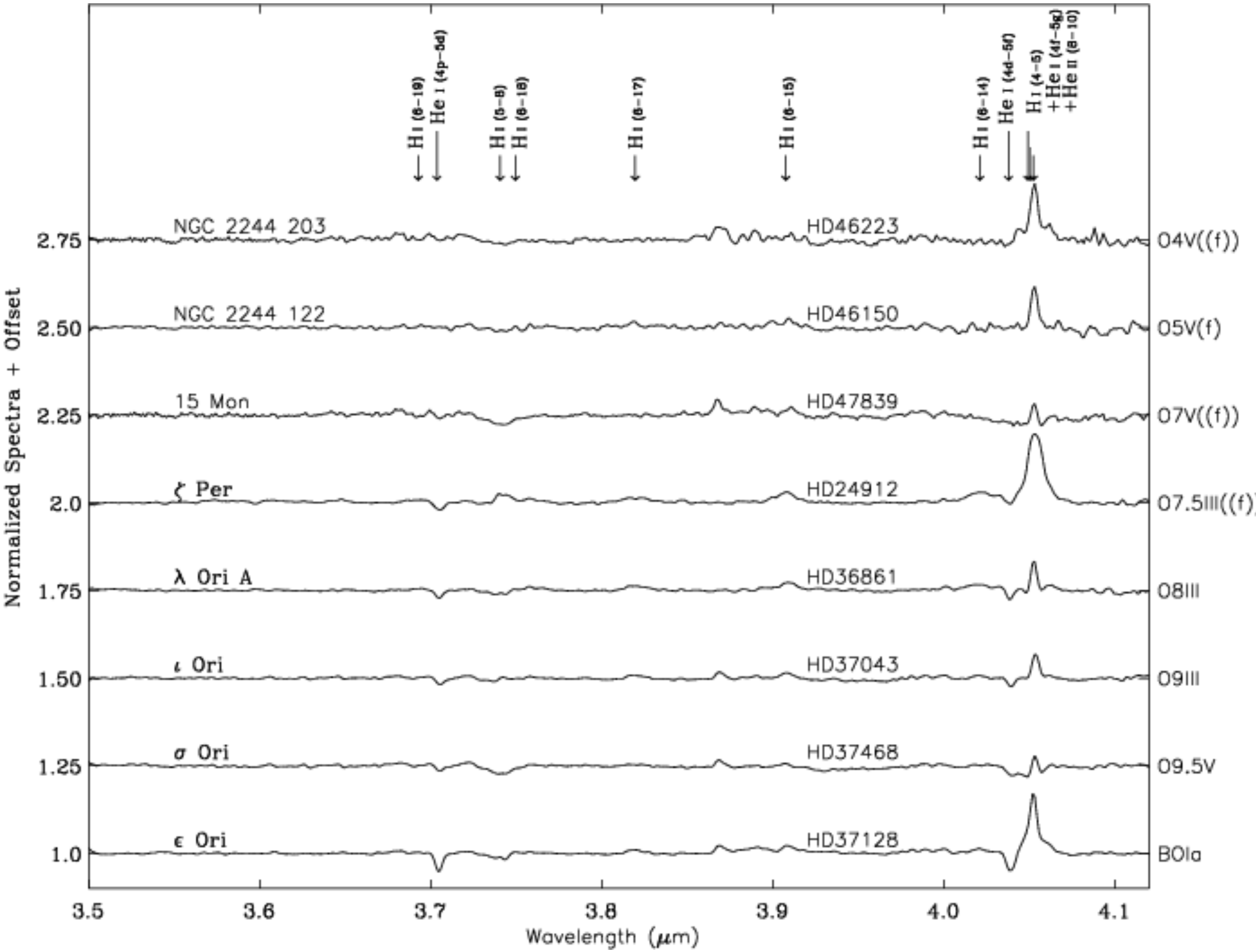
still HI lines have to be removed

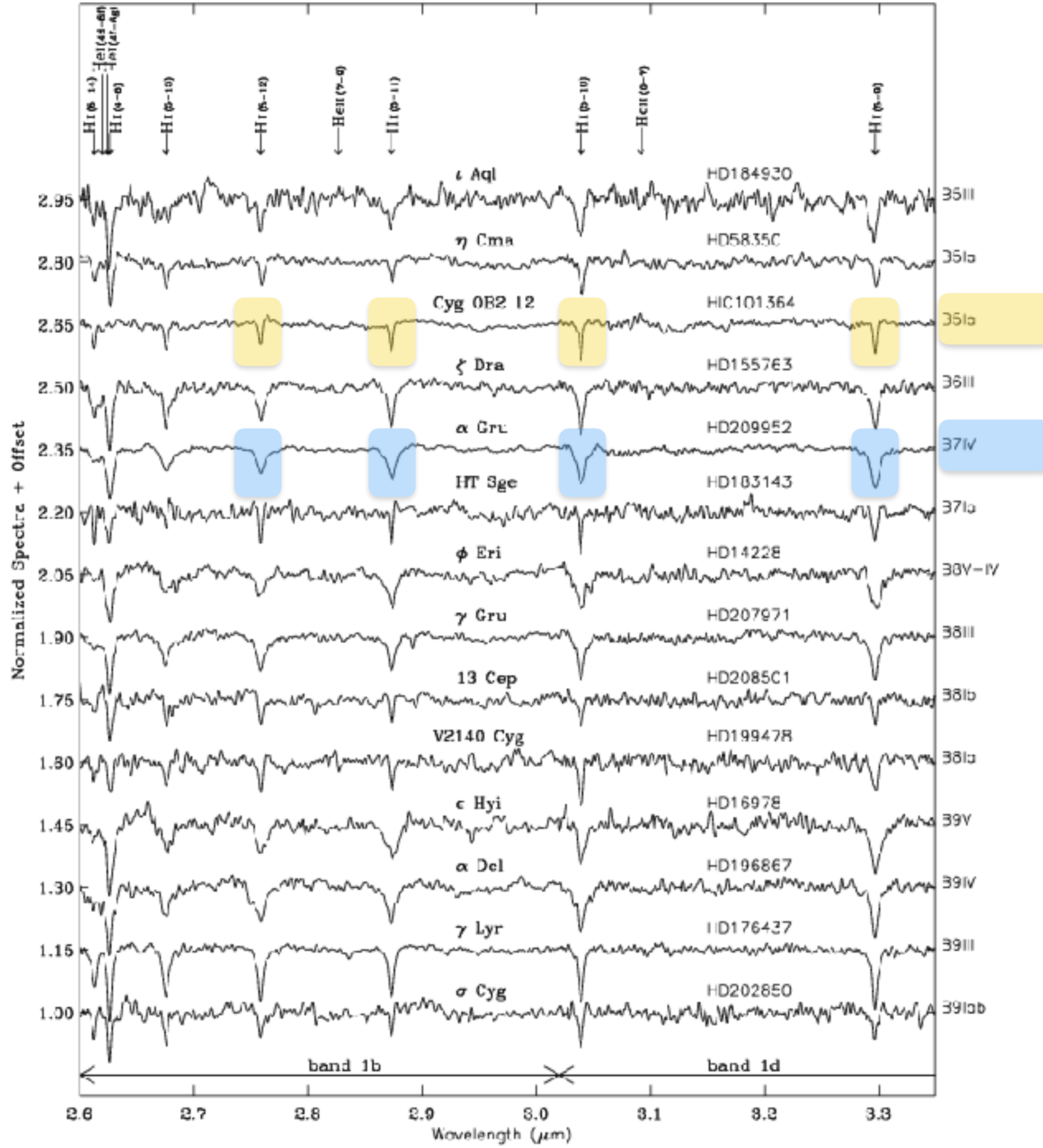
O type

even better but

very few

circumestellar envelope → emission lines


H I (6–19)
He I (4p–5d)
H I (5–8)
H I (6–18)
H I (6–17)
H I (6–15)
H I (6–14)
He I (4d–5f)
H I (4–5)
+He I (4f–5g)
+He II (8–10)
NGC 2244 203
HD46223
O4V((f))
NGC 2244 122
HD46150
O5V(f)
15 Mon
HD47839
O7V((f))
ζ Per
HD24912
O7.5III((f))
λ Ori A
HD36861
O8III
ι Ori
HD37043
O9III
σ Ori
HD37468
O9.5V
ϵ Ori
HD37128
B0Ia
Normalized Spectra + Offset
Wavelength (μm)
2.75
2.50
2.25
2.0
1.75
1.50
1.25
1.0
3.5
3.6
3.7
3.8
3.9
4.0
4.1



Lenorzer et al. 2002 A&A 384, 473

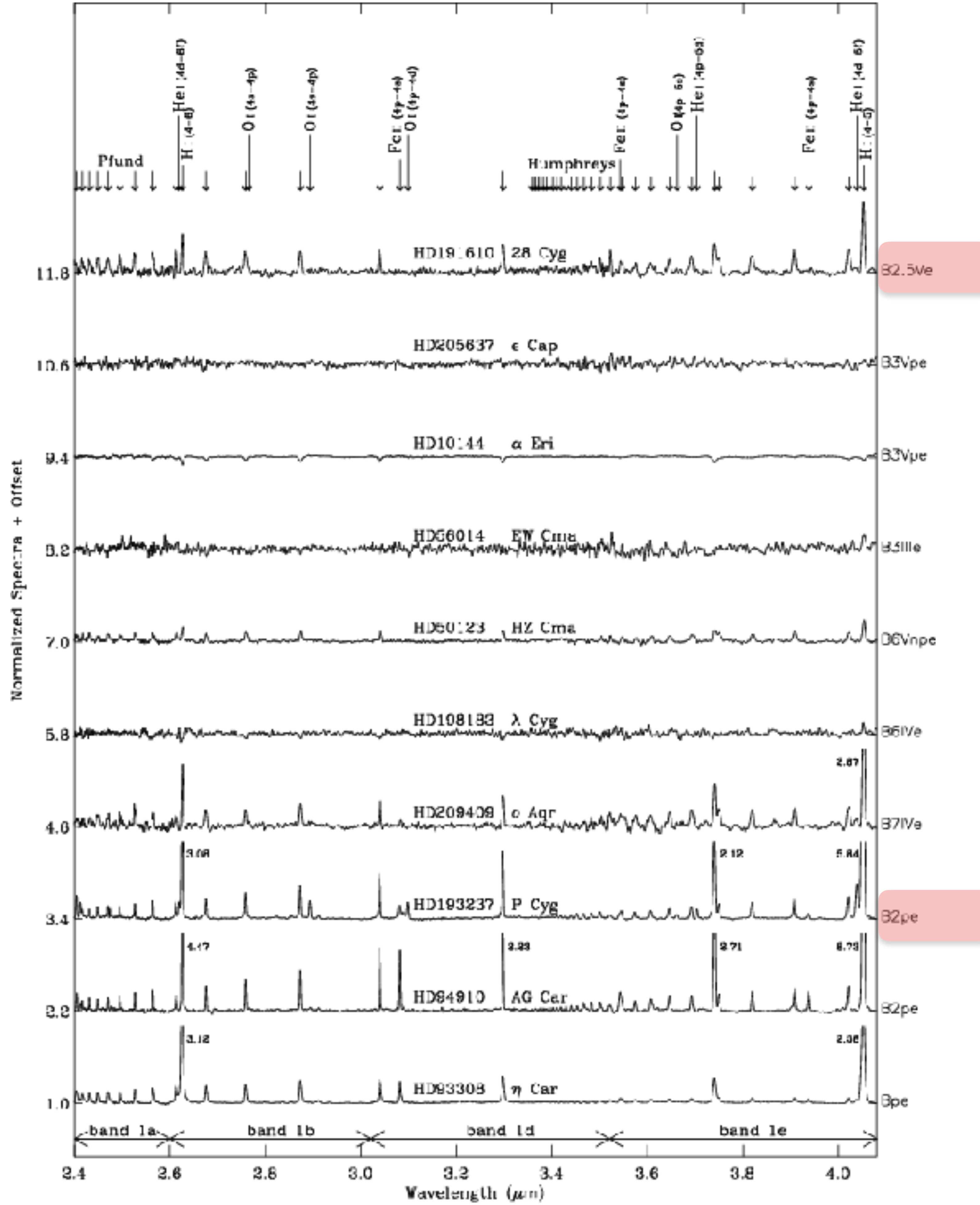
8 Standard star 3 – 7

what standard star best?

- few photospheric lines → early type A-B
- lines are narrow → I better than V
- no peculiar lines → no *e, no *p

Lenorzer et al. 2002
A&A 384, 473

not usable



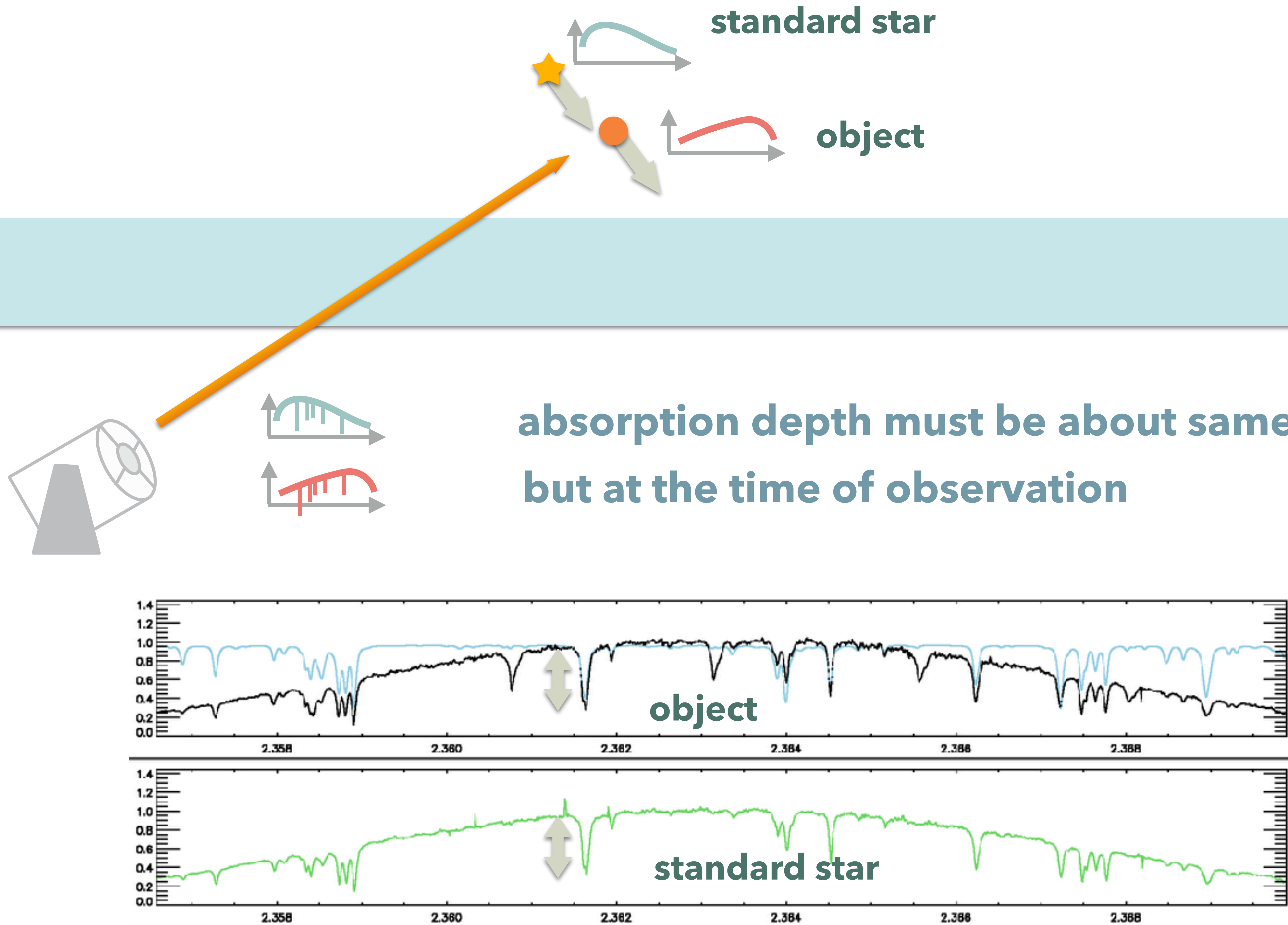
8 Standard star 3 – 7

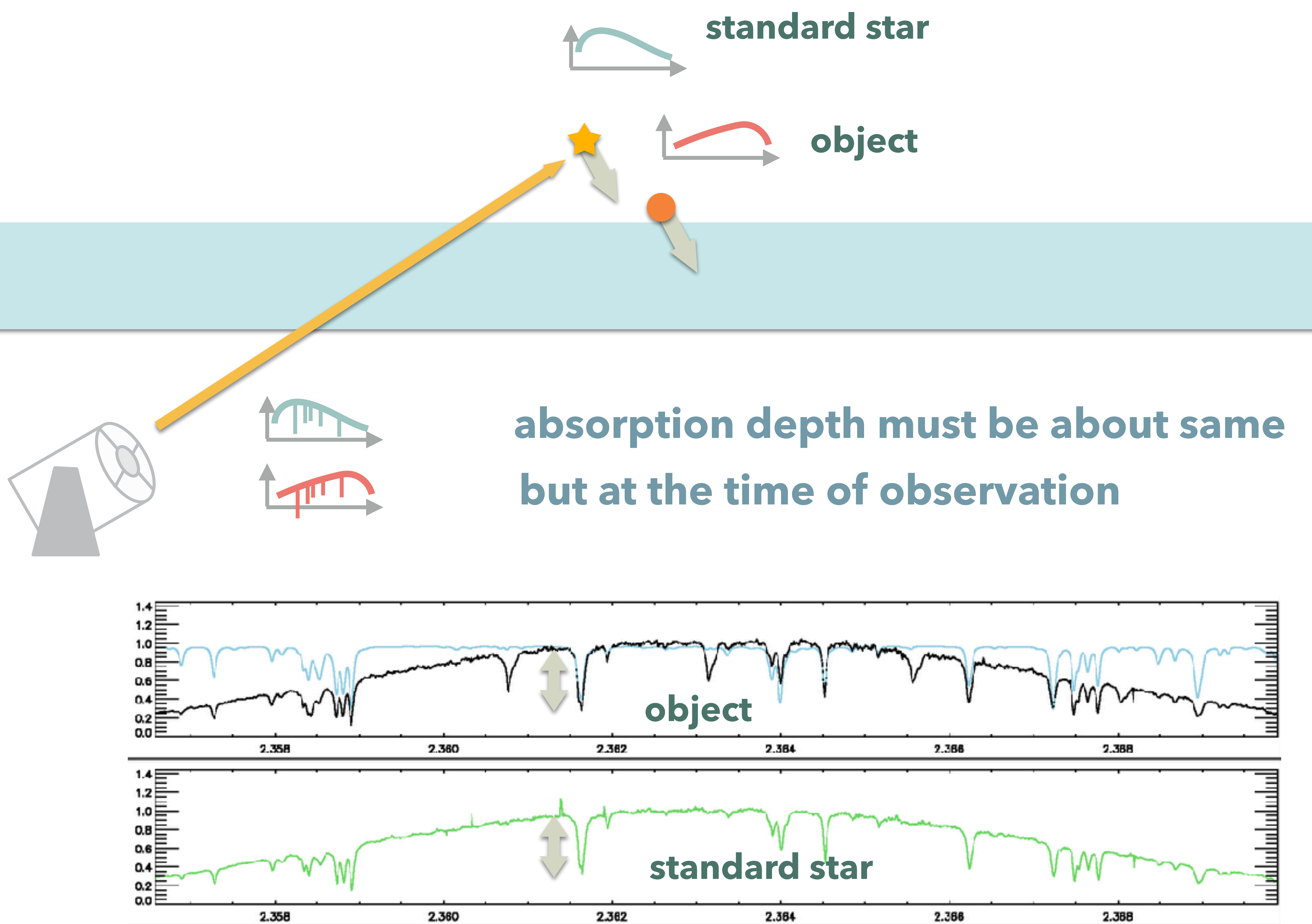
what standard star best?

- few photospheric lines → early type A-B
- lines are narrow → I better than V
- no peculiar lines → no *e, no *p
- no binary → no *+*
- bright → but does not saturate

look good STD that have been used by others

- right position → plan


standard star
object
absorption depth must be about same
but at the time of observation
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2.358
2.360
2.362
2.364
2.366
2.368
object
standard star

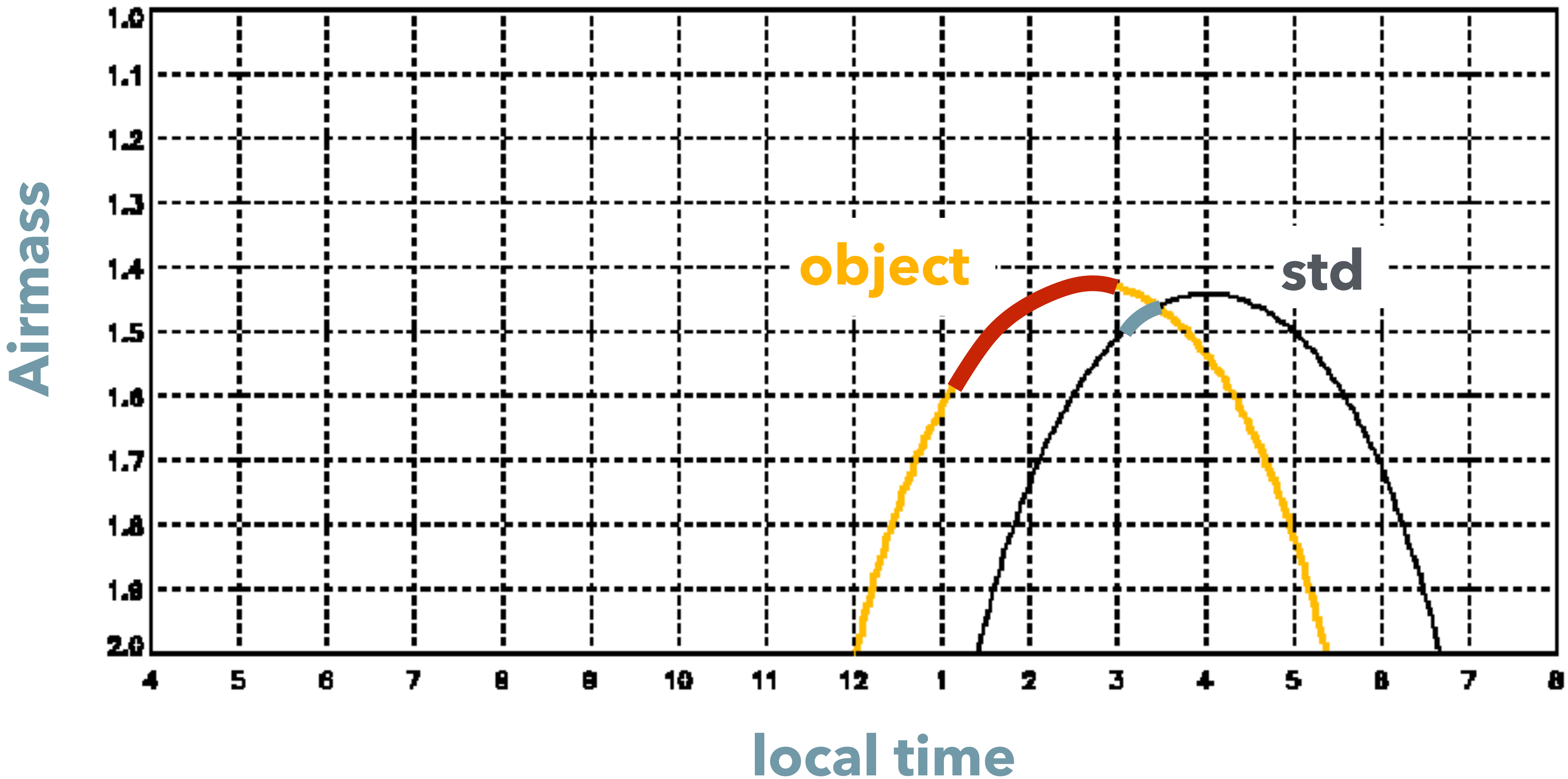

standard star
object
absorption depth must be about same
but at the time of observation
object
standard star
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2.358
2.360
2.362
2.364
2.366
2.368

you observe object

at 1 am to 3 am at airmass 1.6 - 1.4

you observe standard

at 3 am to 3:30 am at airmass ~1.5

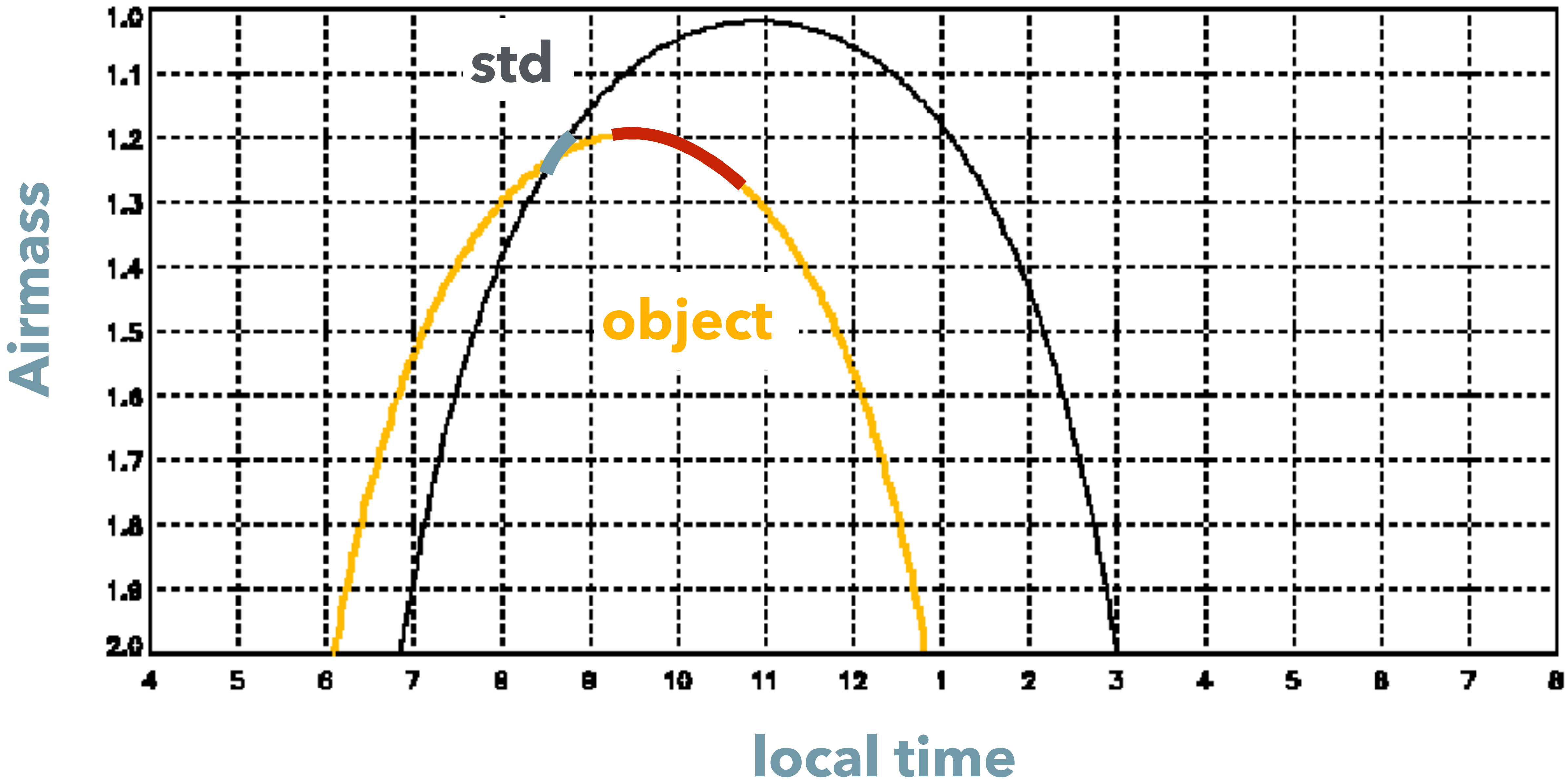


you observe standard

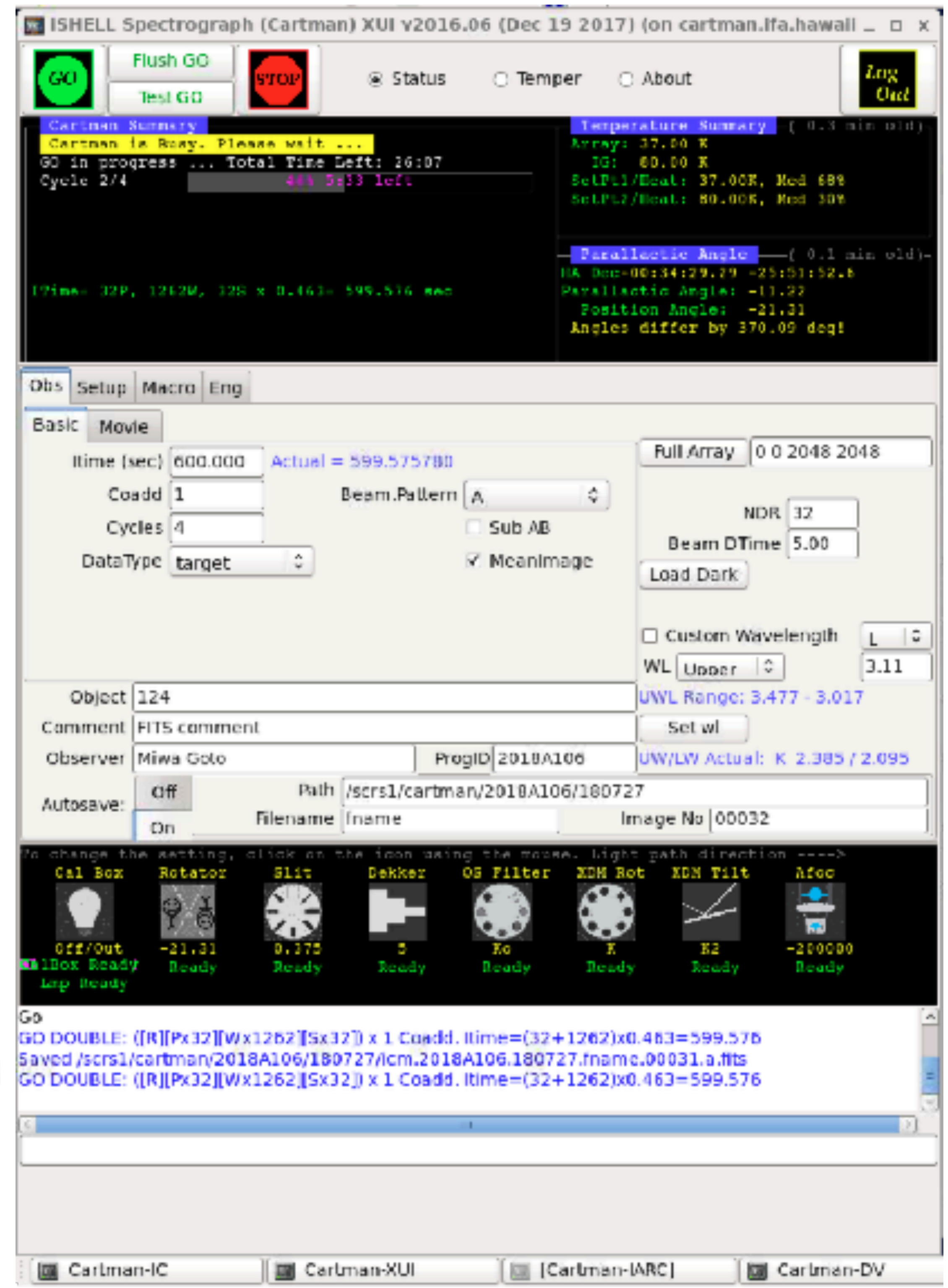
at 8:30 pm to 8:45 am at airmass 1.25-1.20

you observe object

at 9:00 pm to 10:30 pm at airmass 1.20-1.25



9 Close



blank out filters

Troubles

bad weather

- cloudy
- high humidity
- strong wind
- bad seeing

hurricanes

flood

snow evacuation order (no one reply call)

technical trouble

- dome
- telescope
- instrument

slit does not open

dome rotation stuck

does not point (specification)

adaptive optics does not close loop

IRTF May 10, 2019 day 1 second half

600 x 9 frames = 90 min

12:05 remotely connected to IRTF
12:10 calibration started => window was closed
12:15 telescope motor drive trouble
1:00 telescope focusing

1:10 slew to target 1
1:17 target 1 integration
2:50 lost
2:55 calibration started

3:01 slew to standard star 1
3:05 integration started
3:20 calibration

3:25 slew to template star 1
3:30 integration
3:35 calibration

600 x 9 frames = 90 min

3:45 back to target 1
3:50 integration
5:20 calibration

5:32 slew to standard star 2
5:40 closing instrument

total 3 hr on source
5 hr 35 telescope time