

Trivia

in **Infrared** spectroscopy

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Max Planck Institute for Extraterrestrial Physics (MPE)

Plan

- 0 IR spectroscopy in low water vapor**
- 1 wavelength calibration**
- 2 flux calibration**
- 3 astrometric calibration**

it all started here

Monthly Notices

of the

ROYAL ASTRONOMICAL SOCIETY



MNRAS **439**, 247–255 (2014)

doi:10.1093/mnras/stt2404

Advance Access publication 2014 January 28

An episode of extremely low precipitable water vapour over Paranal observatory

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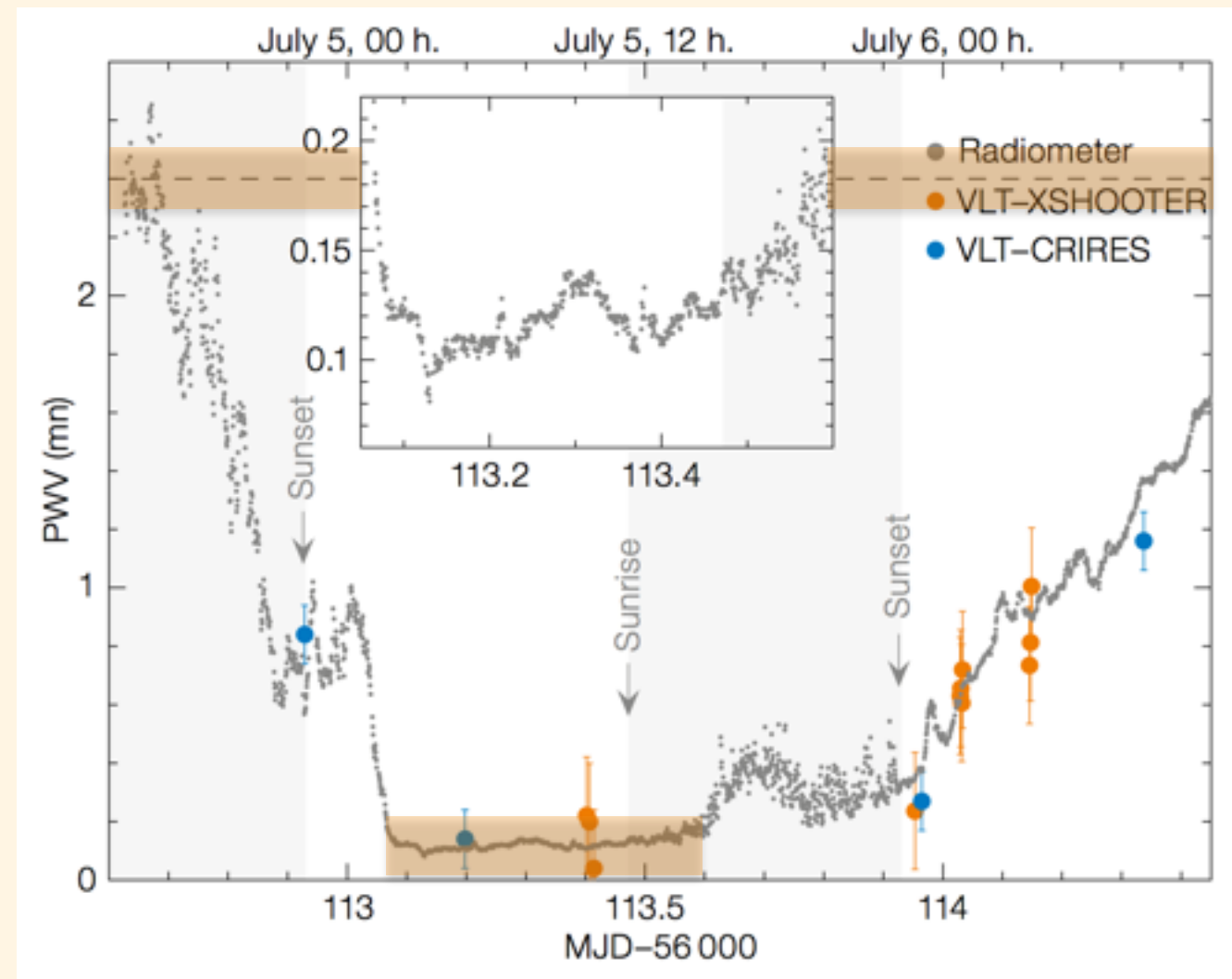
Precipitable water vapor
2.4 mm → 0.1 mm

2500 μm : Mauna Kea
150 μm : Paranal dry
5-20 μm : SOFIA

observationally
speaking,

***VLT* can** (almost) **fly**

8 m telescope outside the atmosphere
window opens on 2-3 nights / yr



what do you do **if *VLT* can fly?**

1

Cosmological

deuterium as Baryon meter

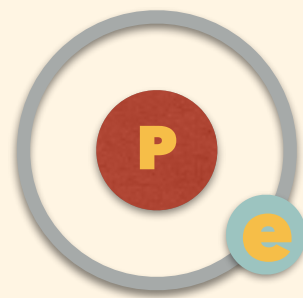
2

Astrochemical

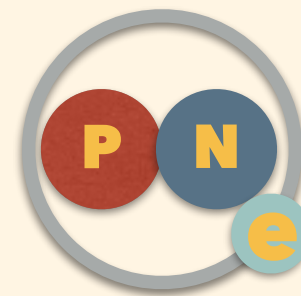
**deuteration in the ISM
origin of water in Earth**

Deuterium

Hydrogen

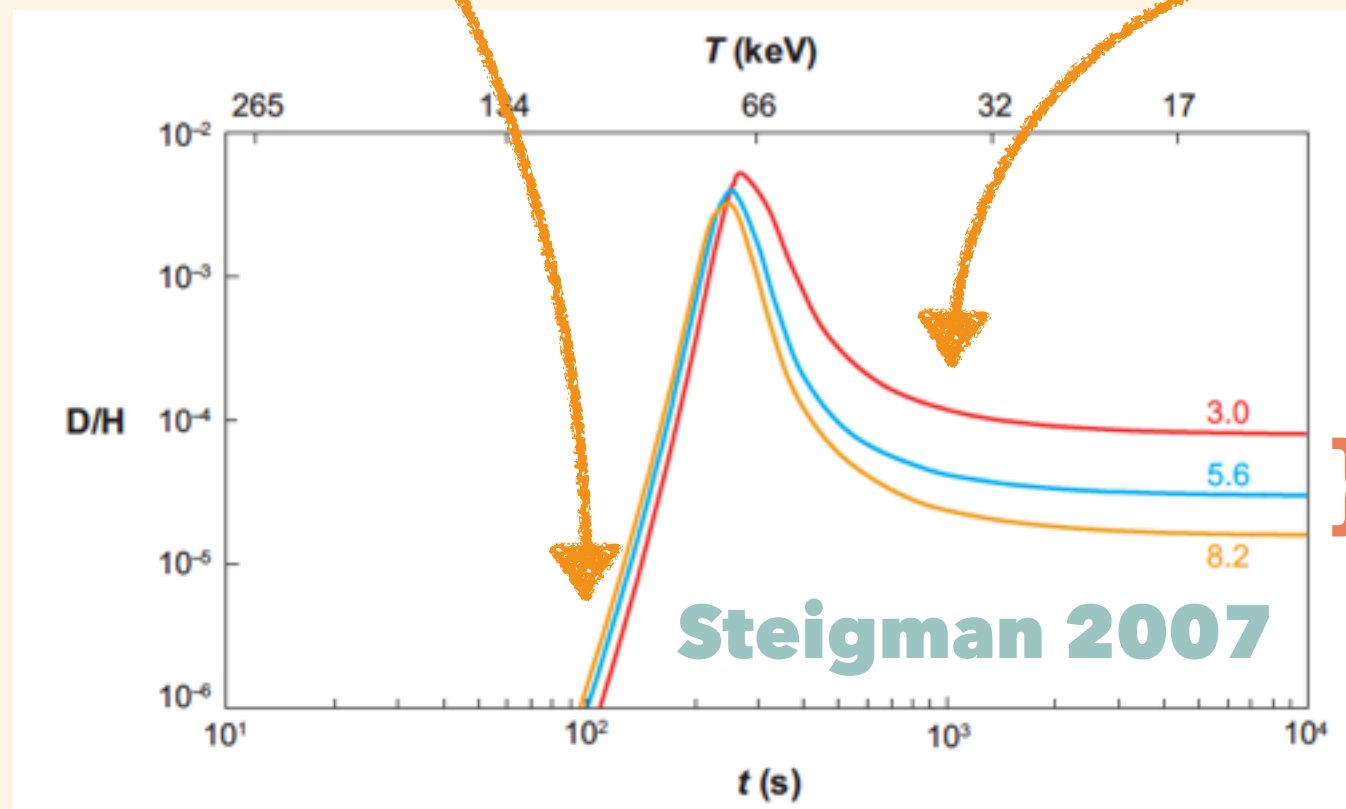


Deuterium
(D, or ^2H)



started forming
at **2 min** after Big Bang

stopped forming
at **20 min** after Big Bang

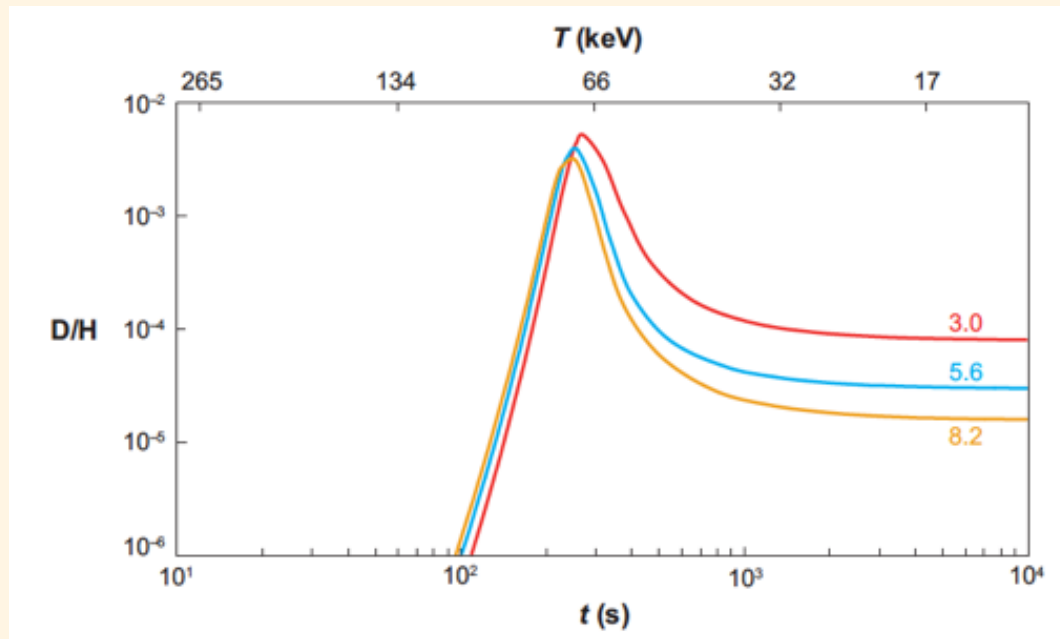


$$\text{D/H} = 2.7 \times 10^{-5}$$

$$\eta_{10} = 10^{10} \frac{\text{nucleons}}{\text{CMB photons}}$$

Baryon abundance

D/H = Baryon meter



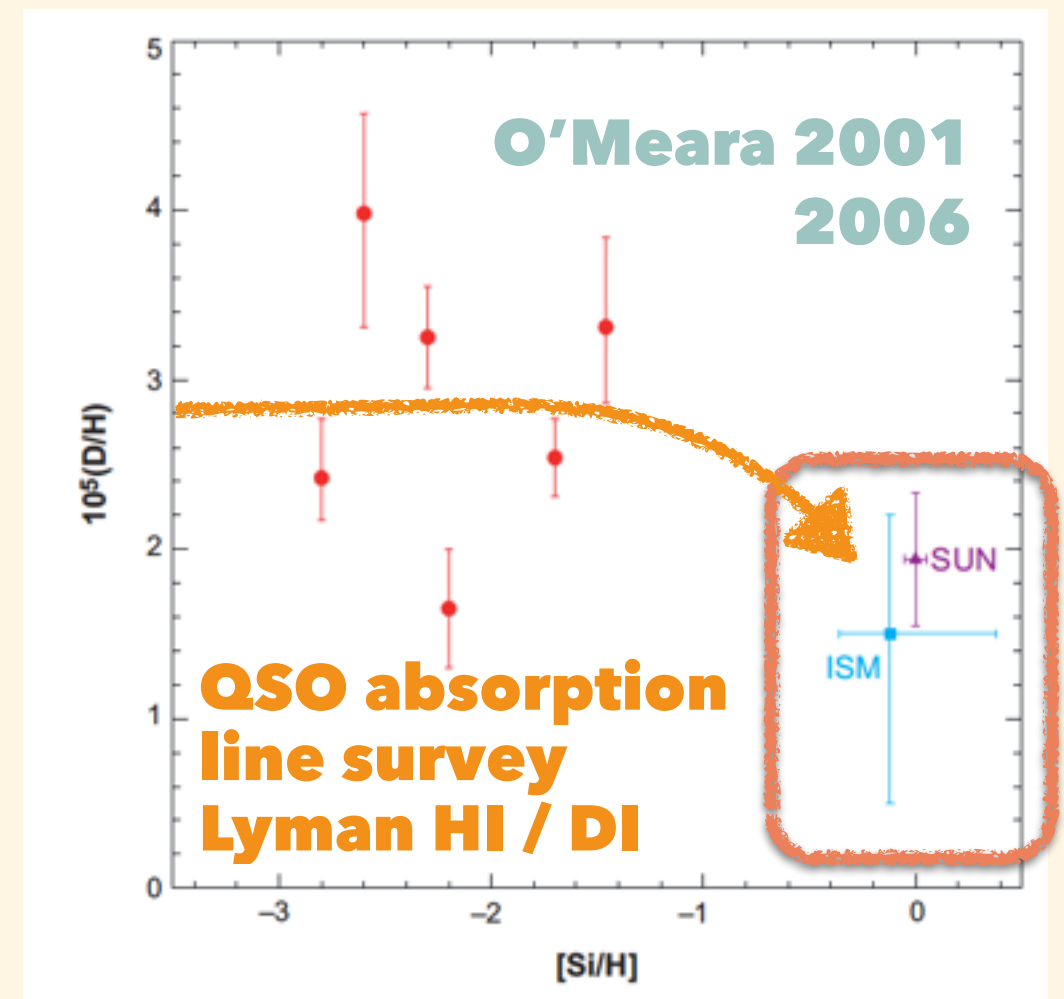
$$D/H = 2.7 \times 10^{-5}$$



destroyed
in stellar nuclear fusion
past 13 Gyrs

$$D/H \sim 1.5 \times 10^{-5}$$

how much do we know about
D/H in local ISM?



History of Observations

FUSE

HI / DI Lyman α absorption

ISO / SWS

HD $v=0-0$ R(5) 19 μm

Spitzer

HD $v=0-0$ R(3), R(4) 23, 28 μm

Herschel

HD $J=1-0$ 112 μm

SOFIA/GREAT

HD $J=1-0$ 112 μm

$D/H = 2.7 \times 10^{-5}$ (primordial)

$D/H = 1.5 \times 10^{-5}$ (HI/DI)

$D/H = 7.5 \times 10^{-6}$

Neufeld 2006 (star forming regions)



History of Observations

UKIRT / CGS4

HD v=1-0 R(5)

from ground

	H	HD
<i>n</i>	10 ⁵	1
<i>A</i> (v=1-0)	10 ⁻⁷	10 ⁻⁵
<i>nA</i>	10 ⁻²	10 ⁻⁵
line intensity	1000	1

D/H = 2.7 x 10⁻⁵

(primordial)

D/H =1.5 x 10⁻⁵

(ISM, HI/DI)

D/H = 7.5 x 10⁻⁶

(star forming regions, jets)

D/H = (5+-2) x 10⁻⁶

(Orion Peak 1)

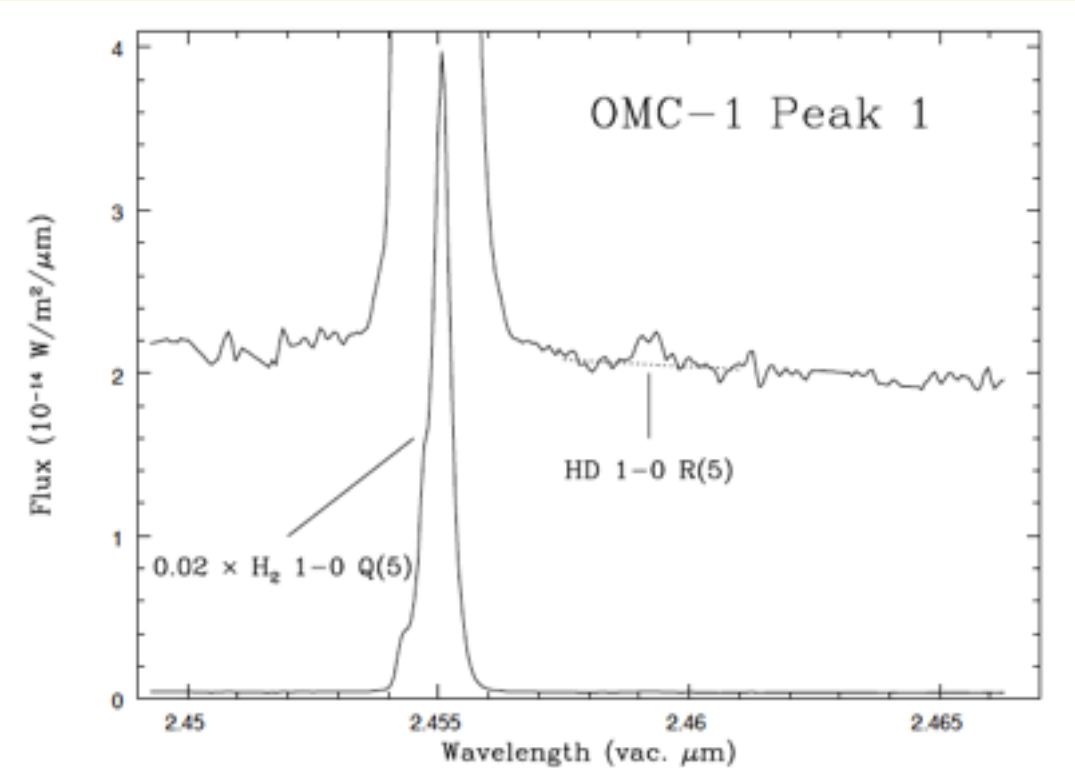


FIG. 1.—Spectrum of a 0".82 × 7".28 (NS x EW) area of OMC-1 Peak 1 near 2.46 μm is shown in expanded form to reveal the HD line, and also compressed by a factor of 50 to the peak intensity of the H₂ 1-0 Q(5) line. Spectrum is a co-addition of the eight brightest rows of H₂ line emission. H₂ and HD lines are indicated. The assumed continuum, used to calculate the flux in the HD line, is also shown. Line flux was estimated by fitting the continuum and integrating over a 0.0012 μm interval centered on the line.

Ramsay et al. 2002

History of observation

single line observation
constraining temperature tough

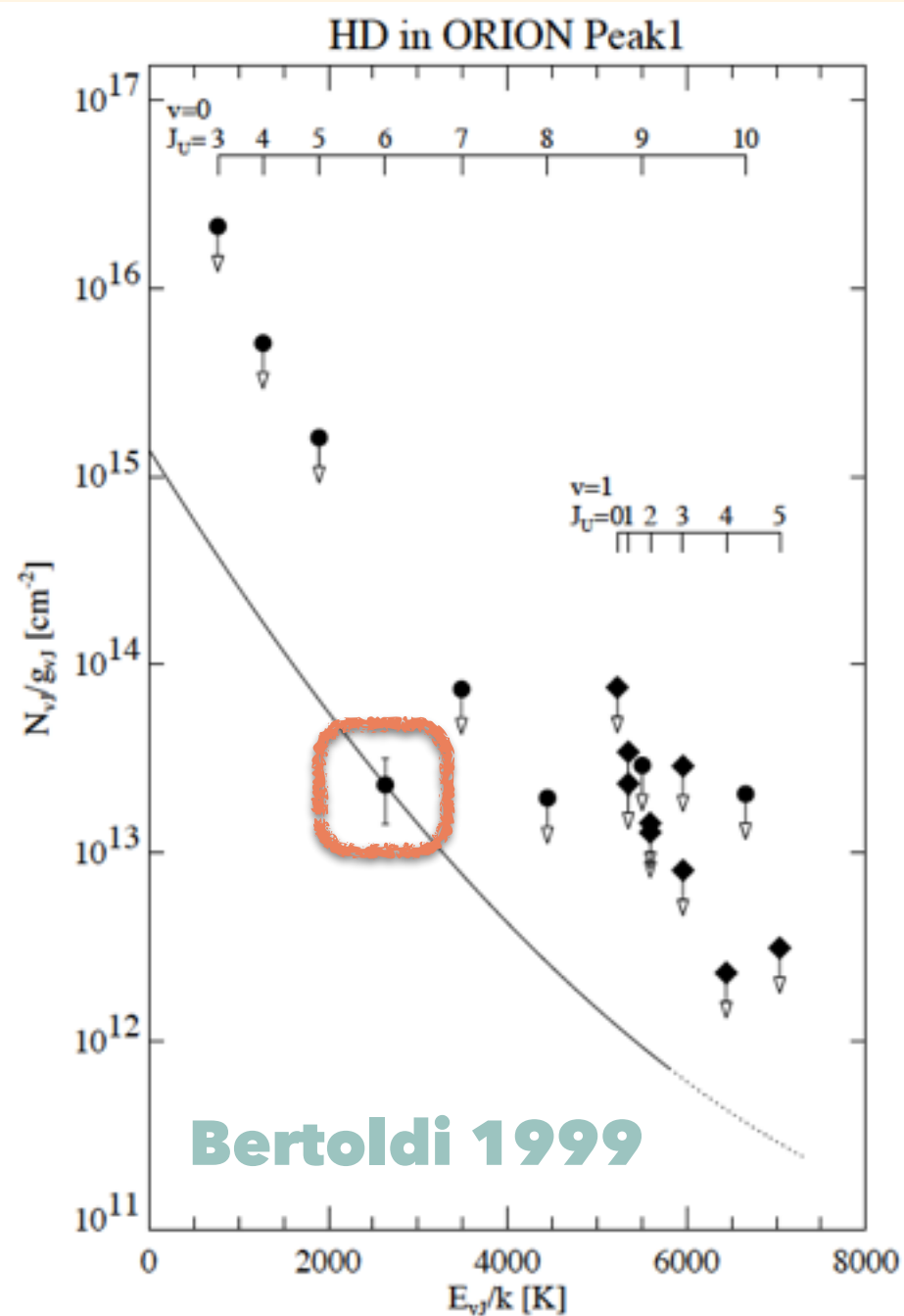
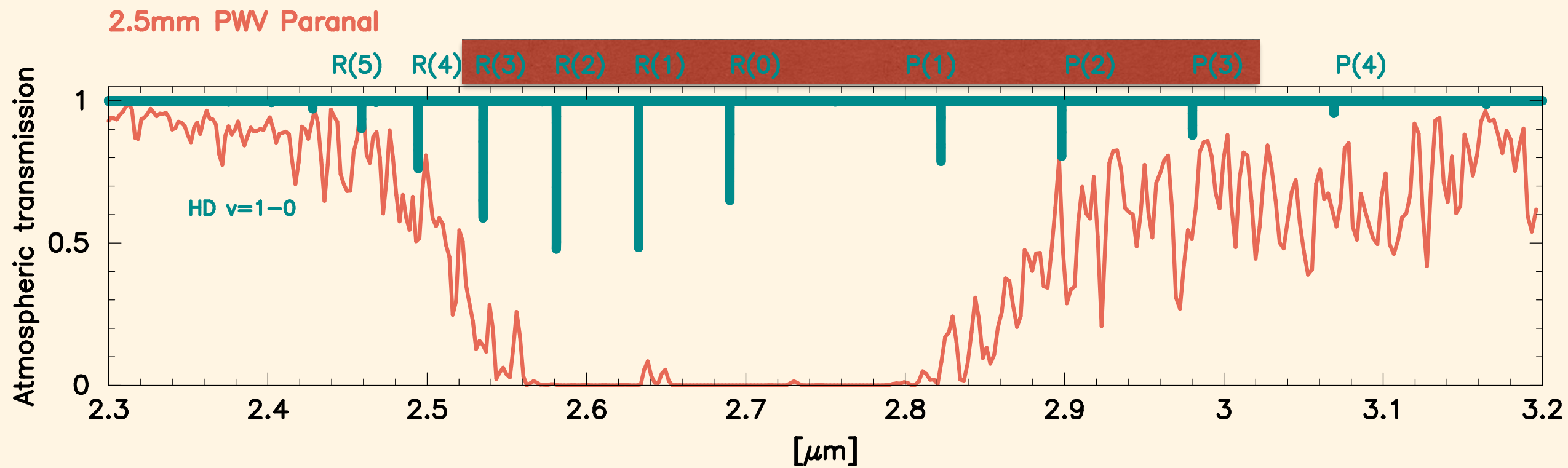
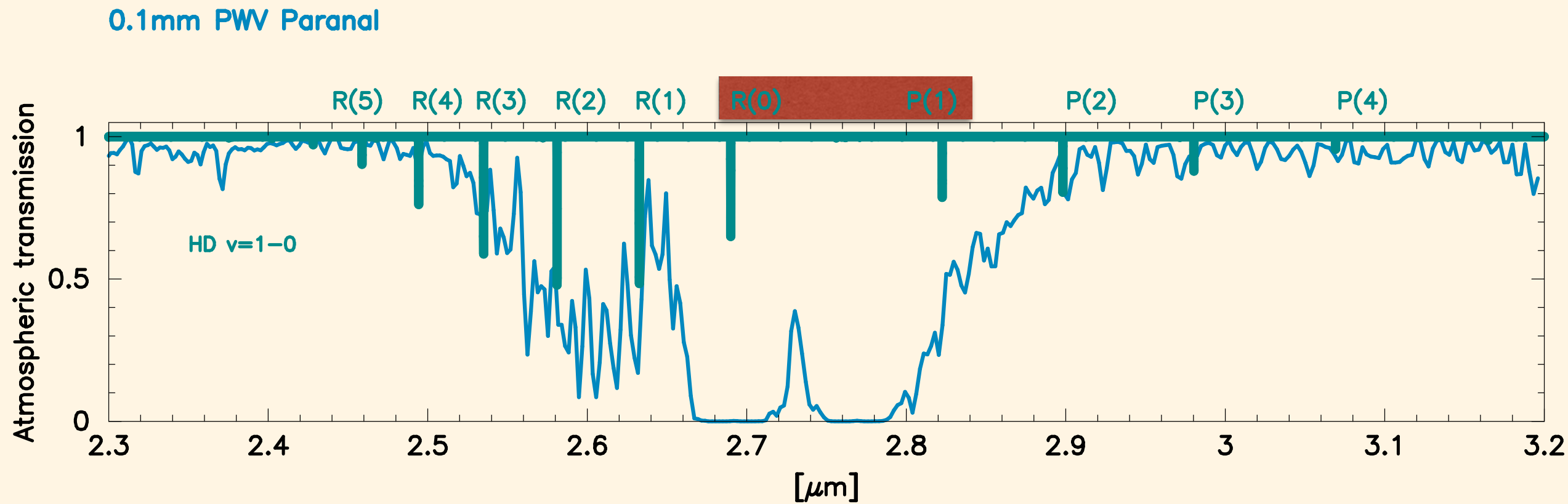
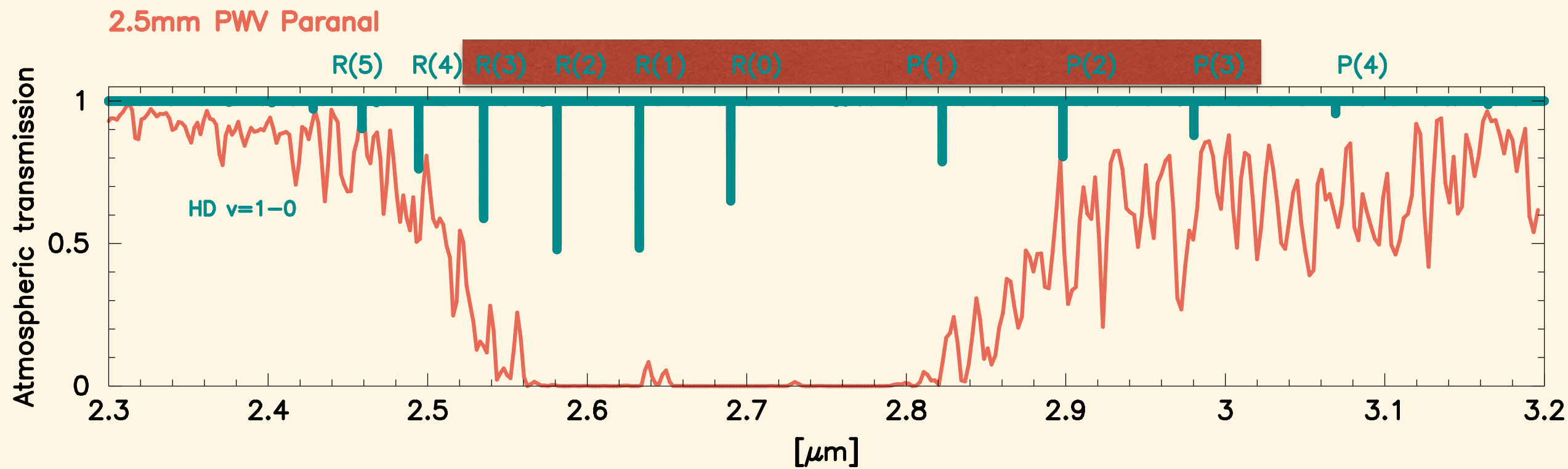


Fig. 6. HD excitation diagram. Pure rotational transitions are denoted by dots, and $v = 1-0$ transitions by diamonds. The line represents the fit Eq. (6). The error of the 0-0 R(5) line is computed from spectral noise (22%) and uncertainties in the flux calibration (11%) and the extinction at $19.4 \mu\text{m}$ ($\simeq 14\%$).





- 1 nearby star forming regions**
- 2 Galactic Center**
- 3 Outer Galactic Disk**
- 4 Small/Large Magellanic clouds**

Spectrograph needed

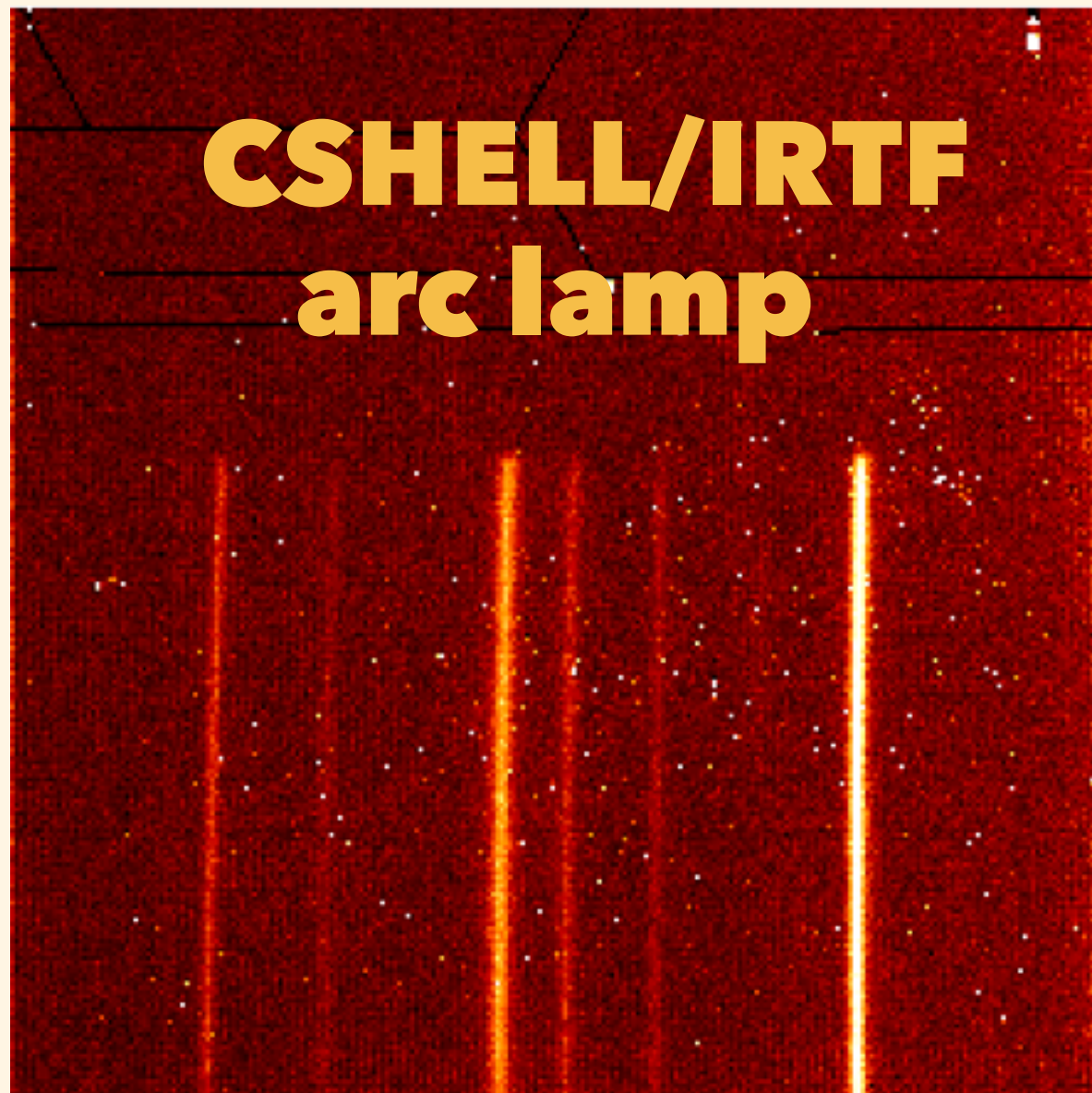
- 1 no cut off filter at 2.5 μm**
- 2 detector sensitivity cut off**

Trivia

in Infrared spectroscopy

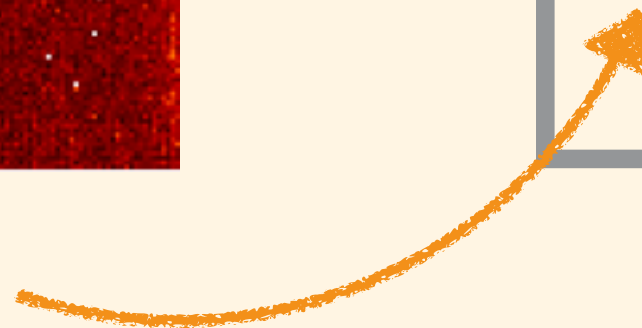
- 1 wavelength calibration**
- 2 resampling is a sin**
- 3 tricky linearity correction in IR**
- 4 why filling slit is important**
- 5 spectroastronomy**
- 6 do not correct bad pixel at bad pix correction**

CSHELL/IRTF arc lamp



x_1 x_2 x_3
 λ_1 λ_2 λ_3

x_4
 λ_4



$$\lambda(x) = c_1 + c_2 x$$

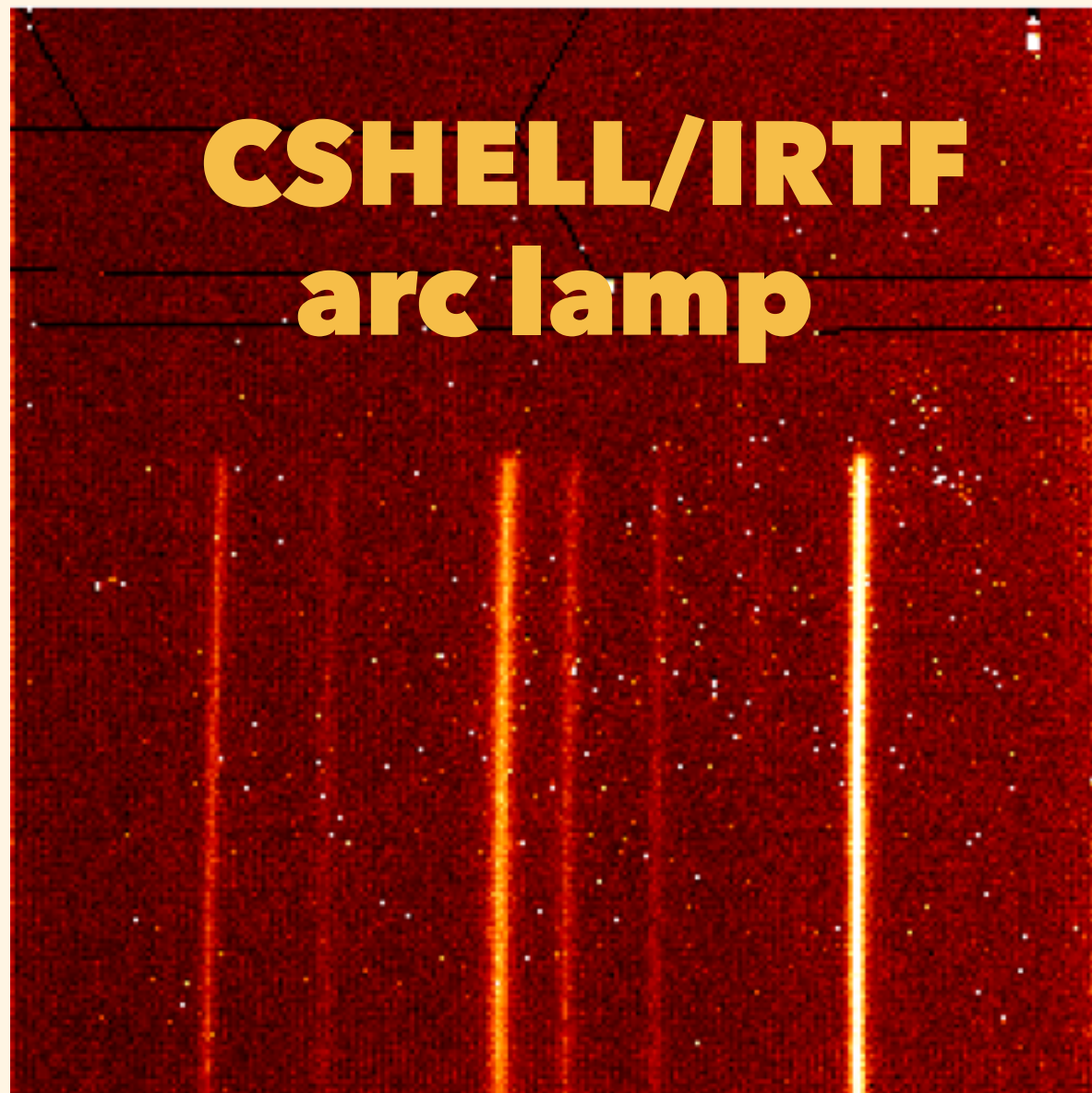
2.224
 μm

212.2
pix

wavelength calibration

= to determine c_1, c_2

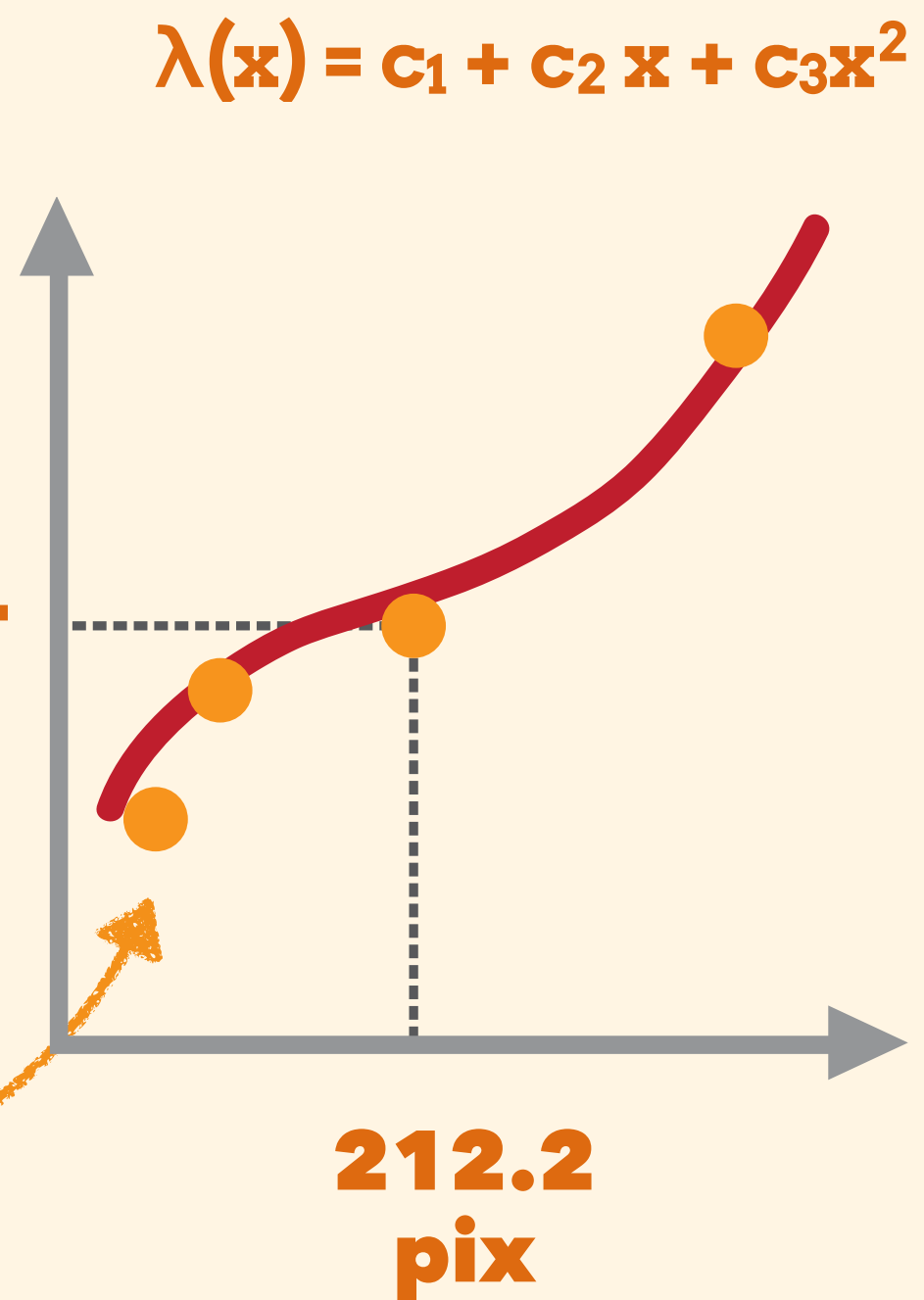
CSHELL/IRTF arc lamp



x_1 x_2 x_3
 λ_1 λ_2 λ_3

x_4
 λ_4

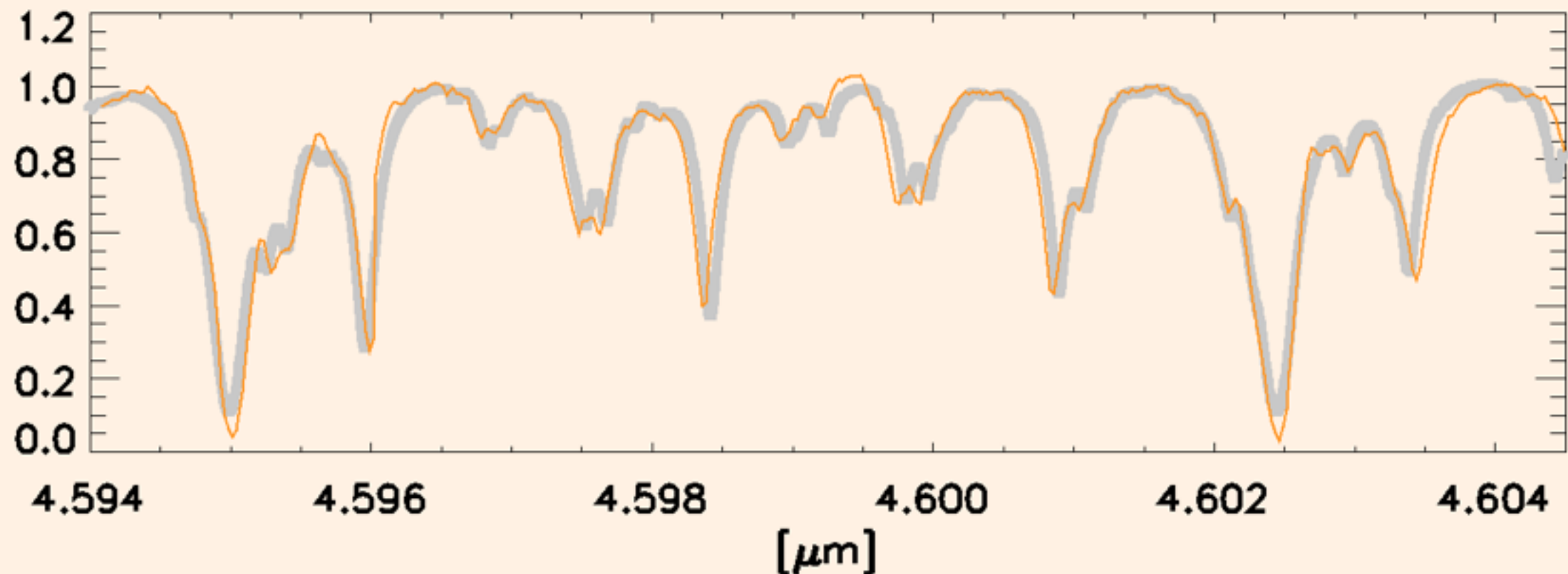
2.224
 μm



wavelength calibration

= to determine c_1, c_2, c_3

atmospheric lines



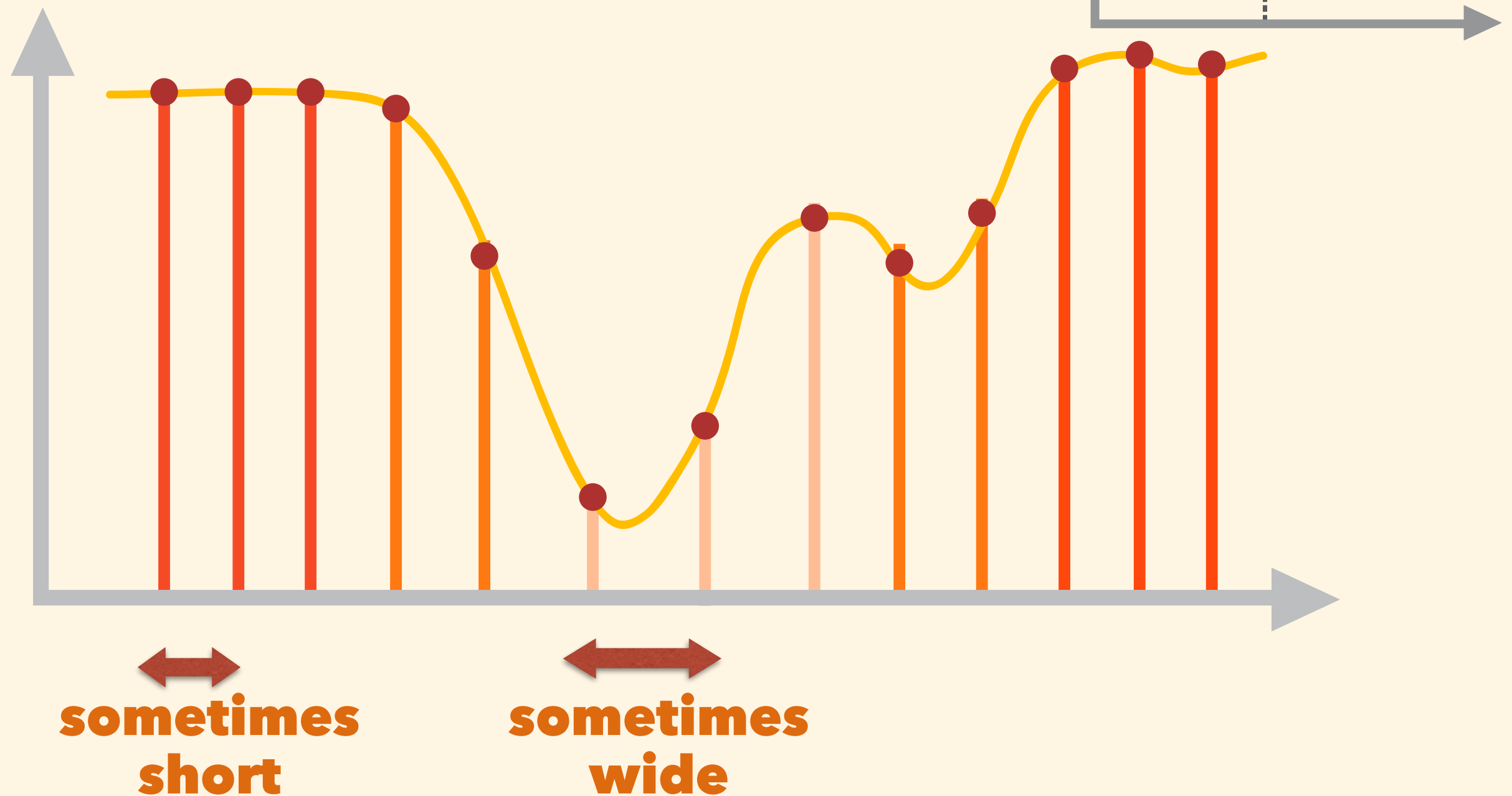
$$\lambda(\mathbf{x}) = c_1 + c_2 \mathbf{x} + c_3 \mathbf{x}^2$$

machine tries combination of c_1, c_2, c_3

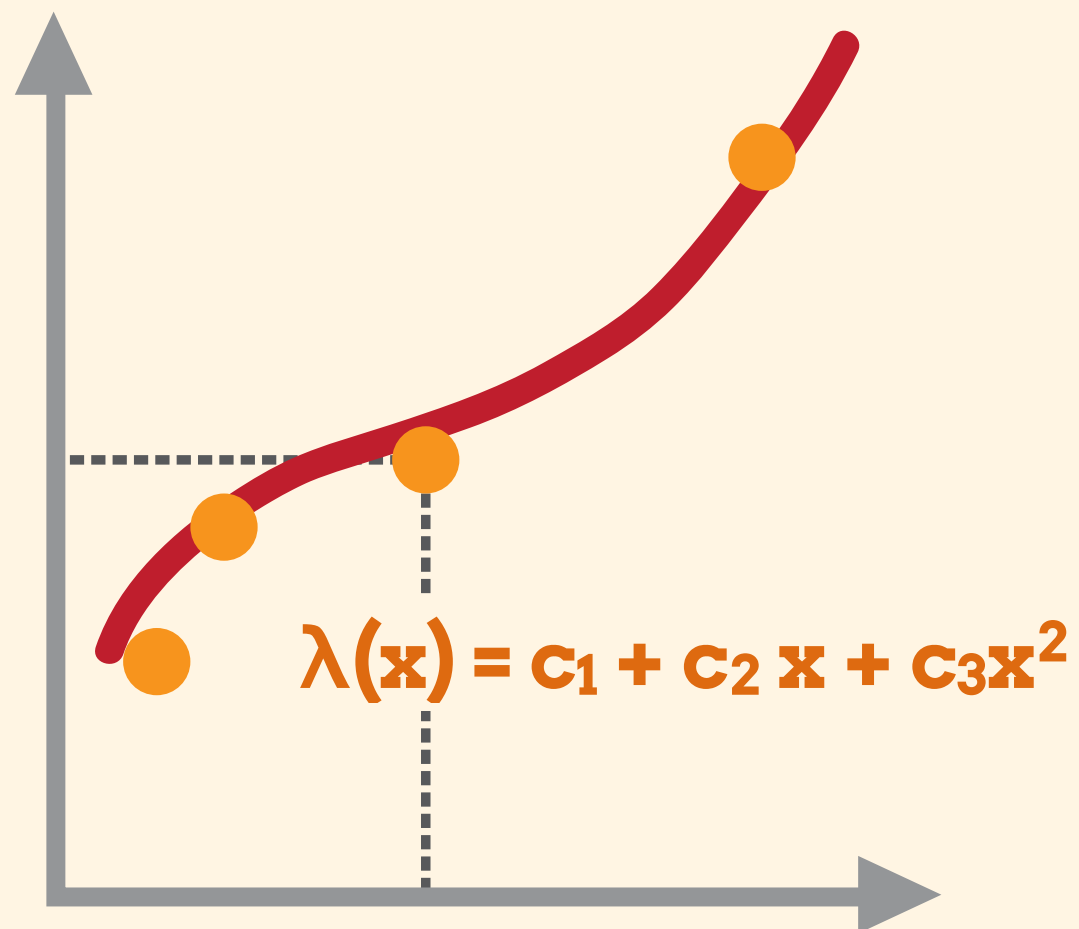
to make difference smallest

all data points (shoulders, skews) counts

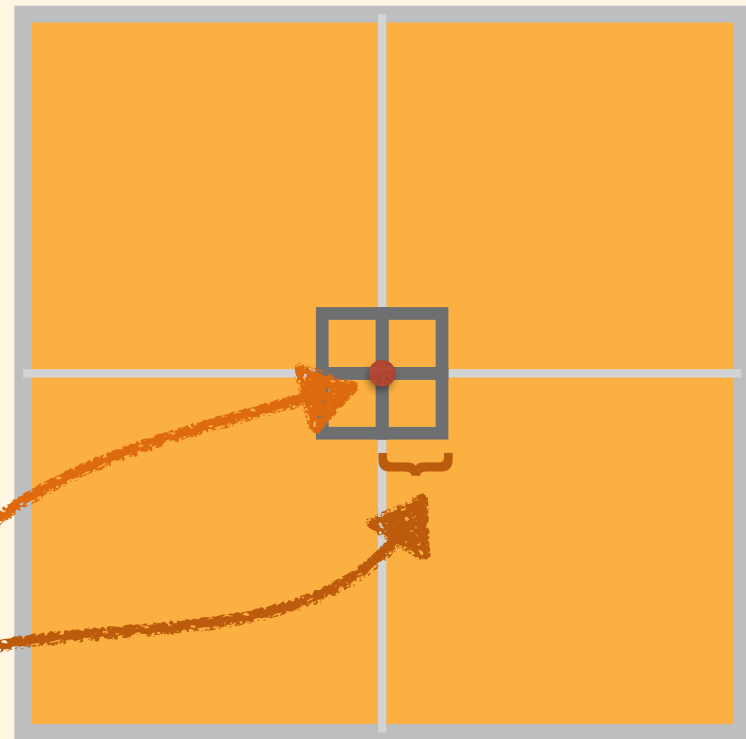
irregularly sampled



Resampling = Sin



imaging
fits header entry



CRPIX1 = 512.5

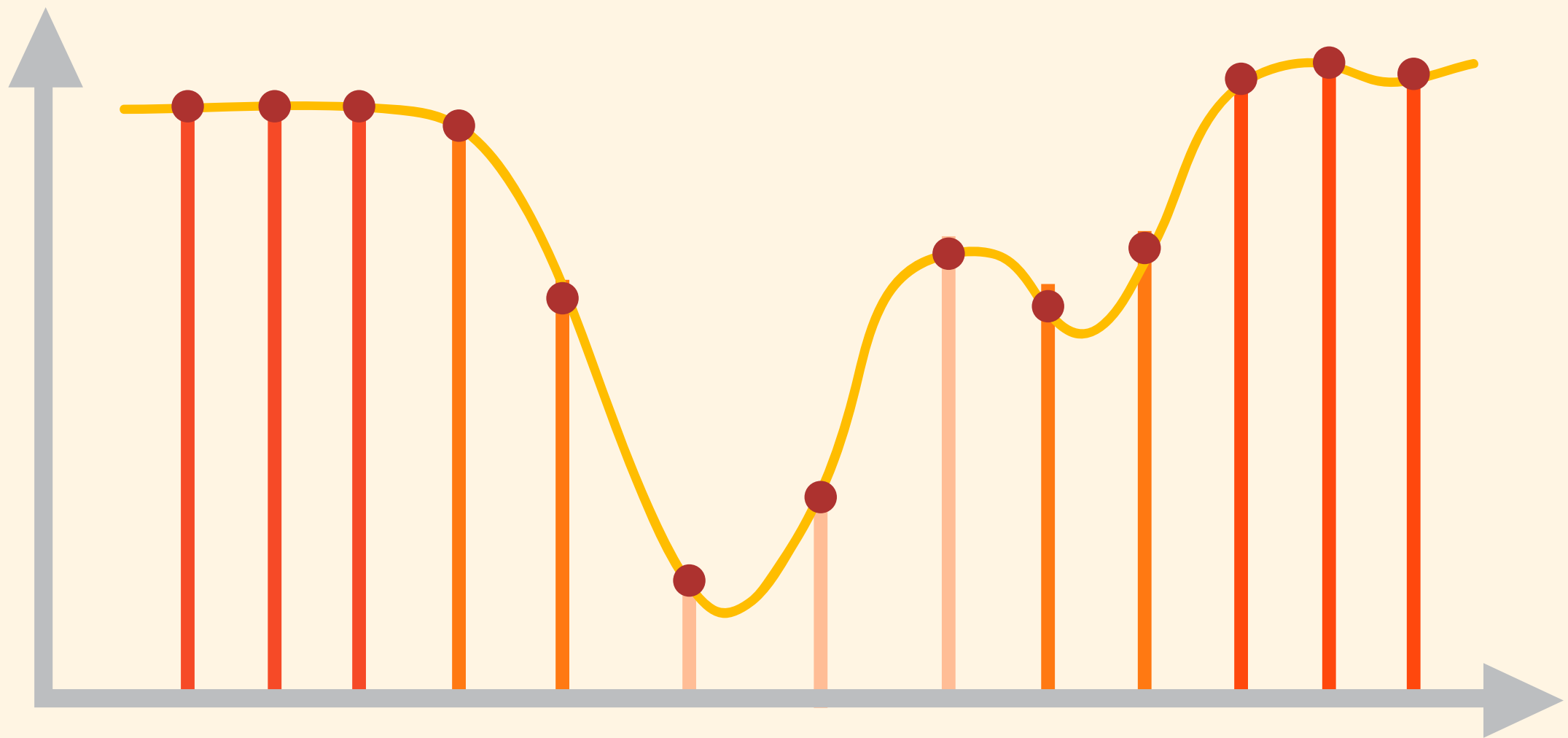
CDELT1 = 0.0003194

it would be cute if

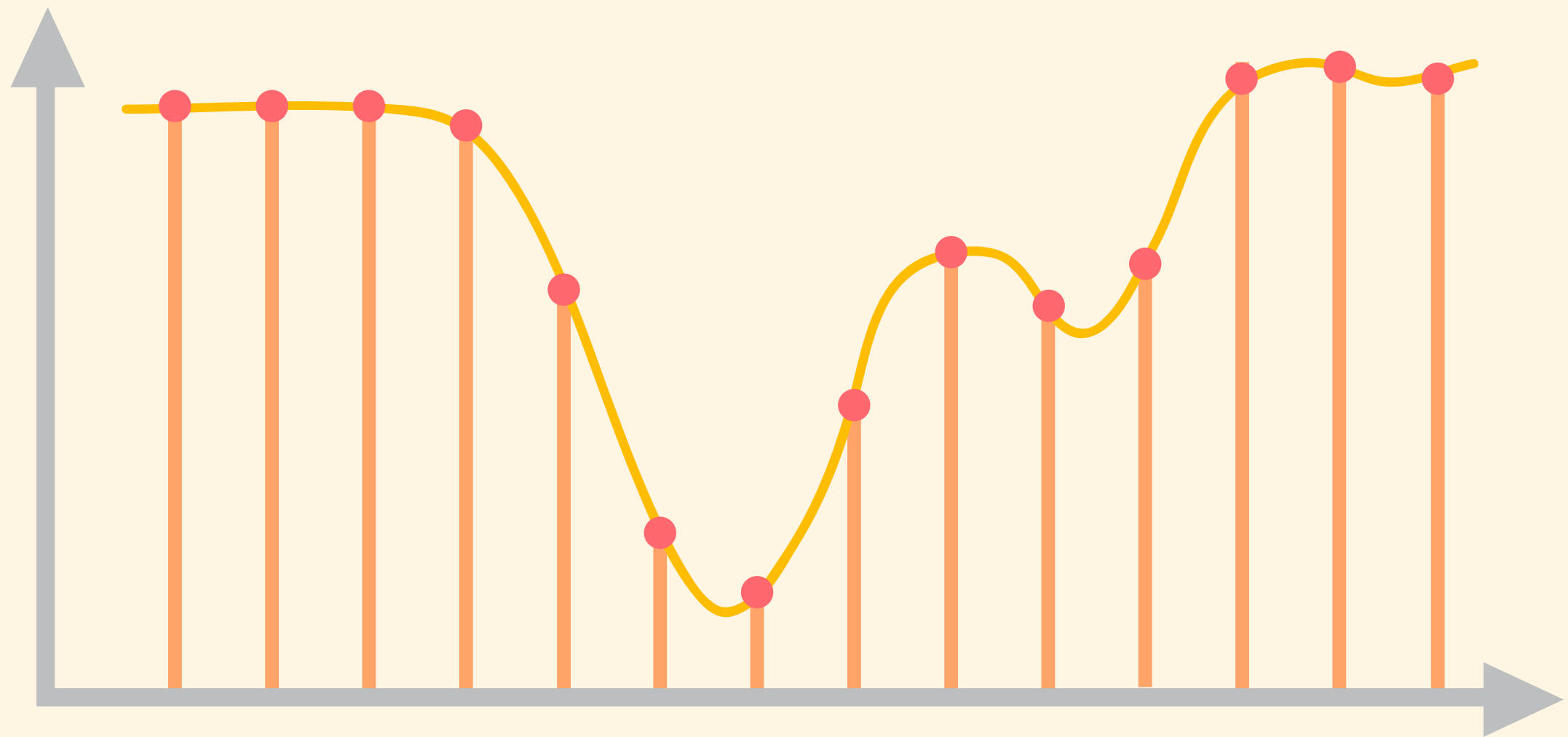
one pixel has fixed wavelength span...

we can put them fits header entry...

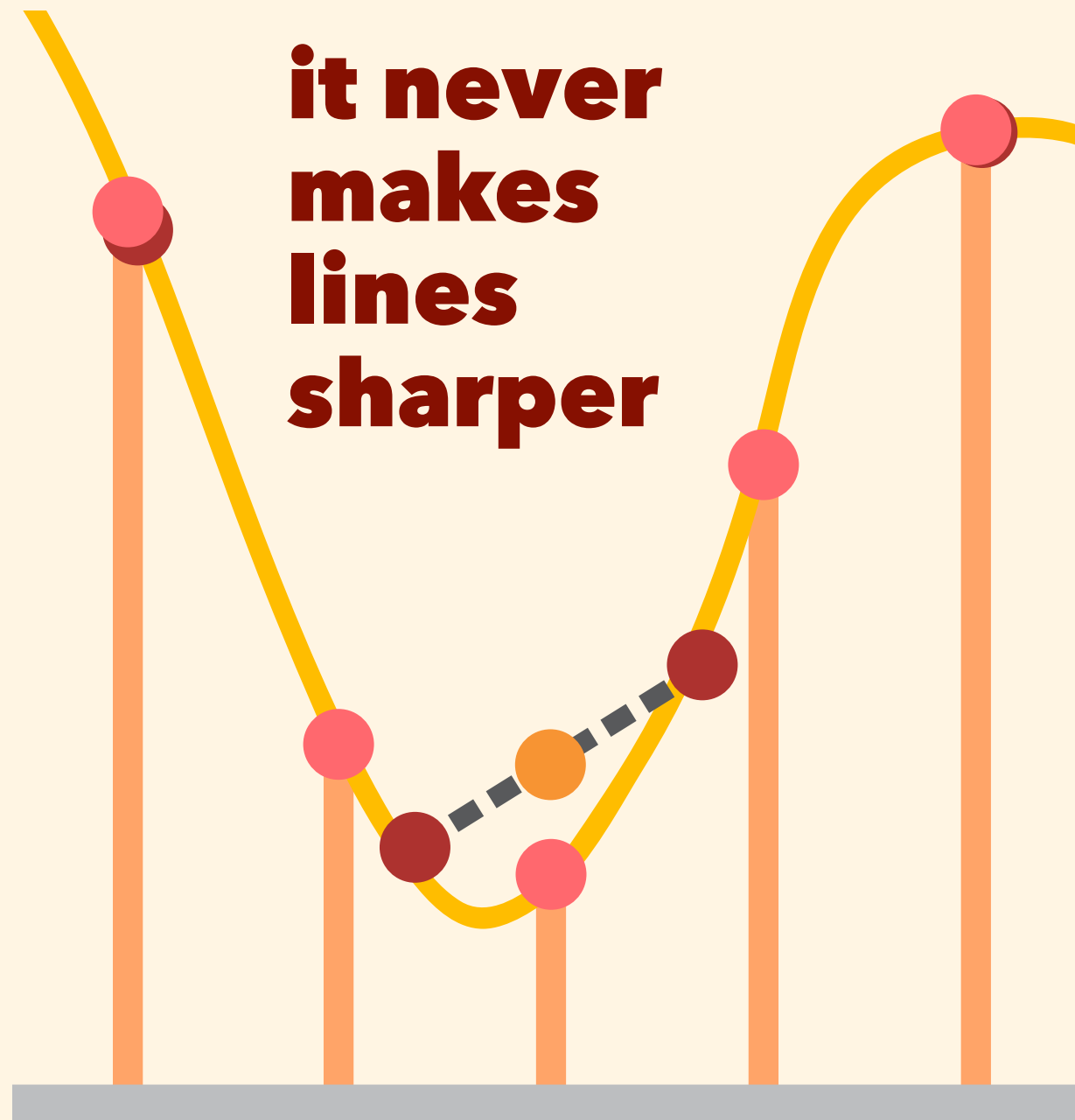
he is ugly



he is cute!



linear interpolation is **guaranteed** to do
harm

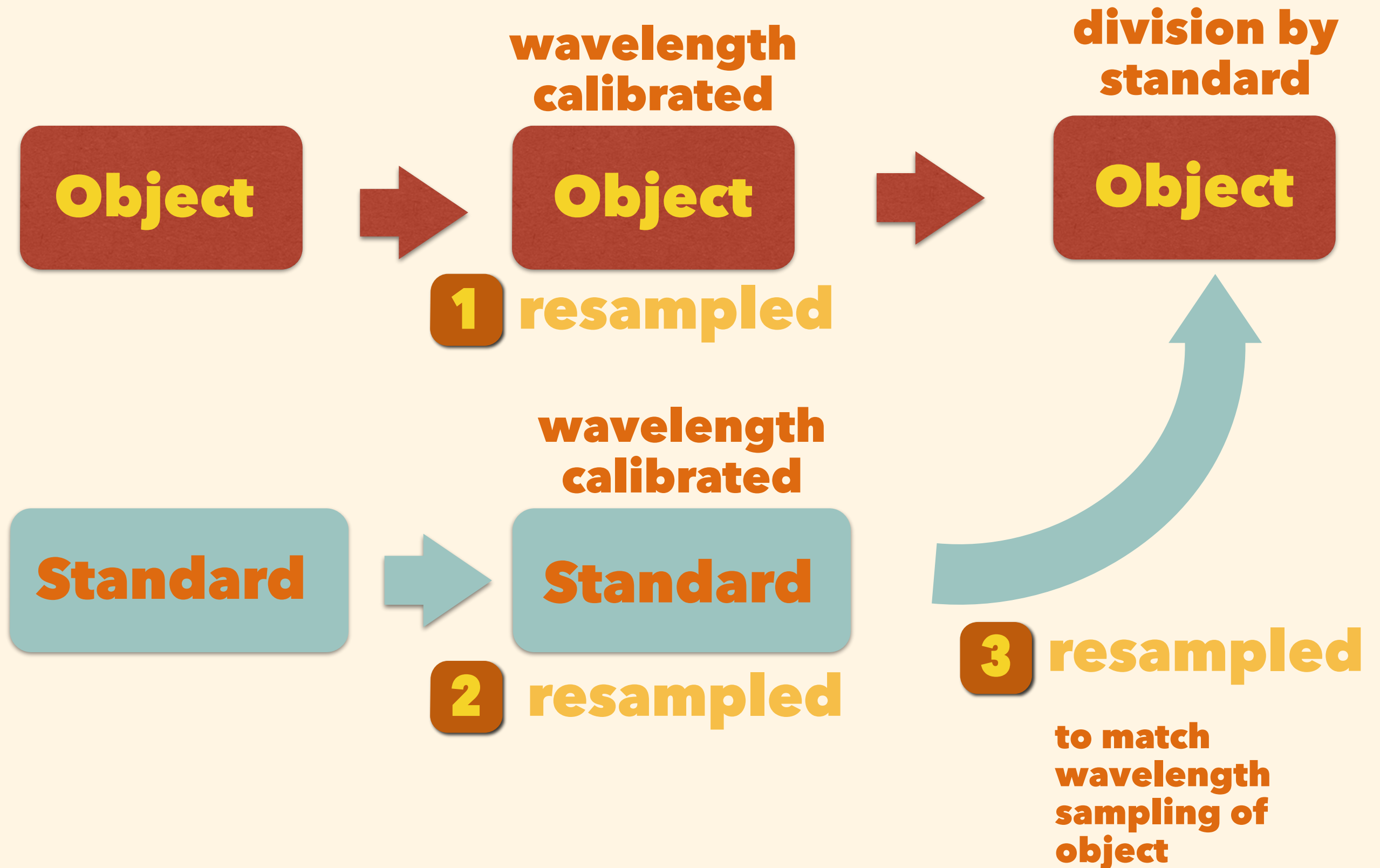


cubic interpolation
not guaranteed to do harm

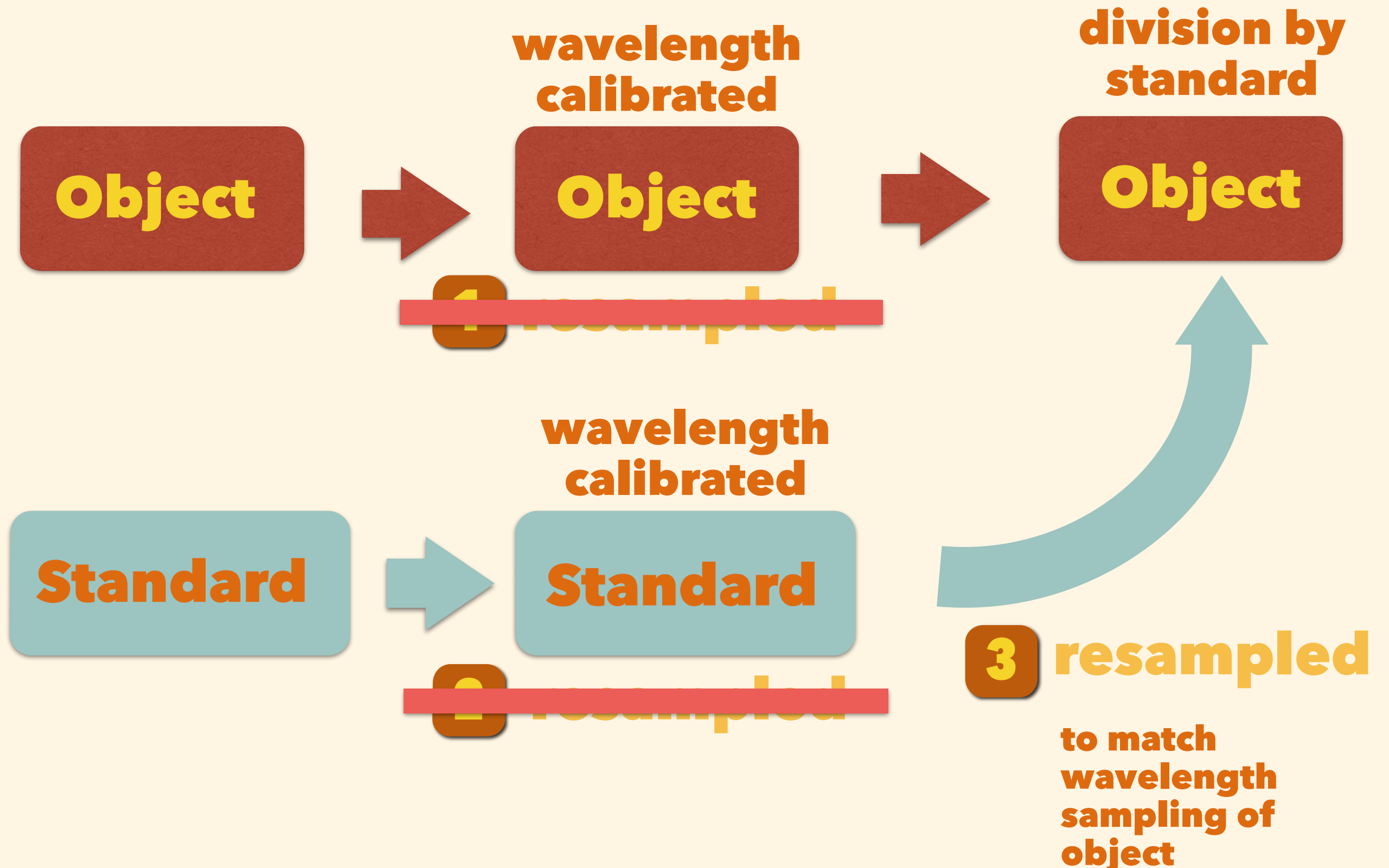
**but results could be
unexpected**

Worse

resampling = sin

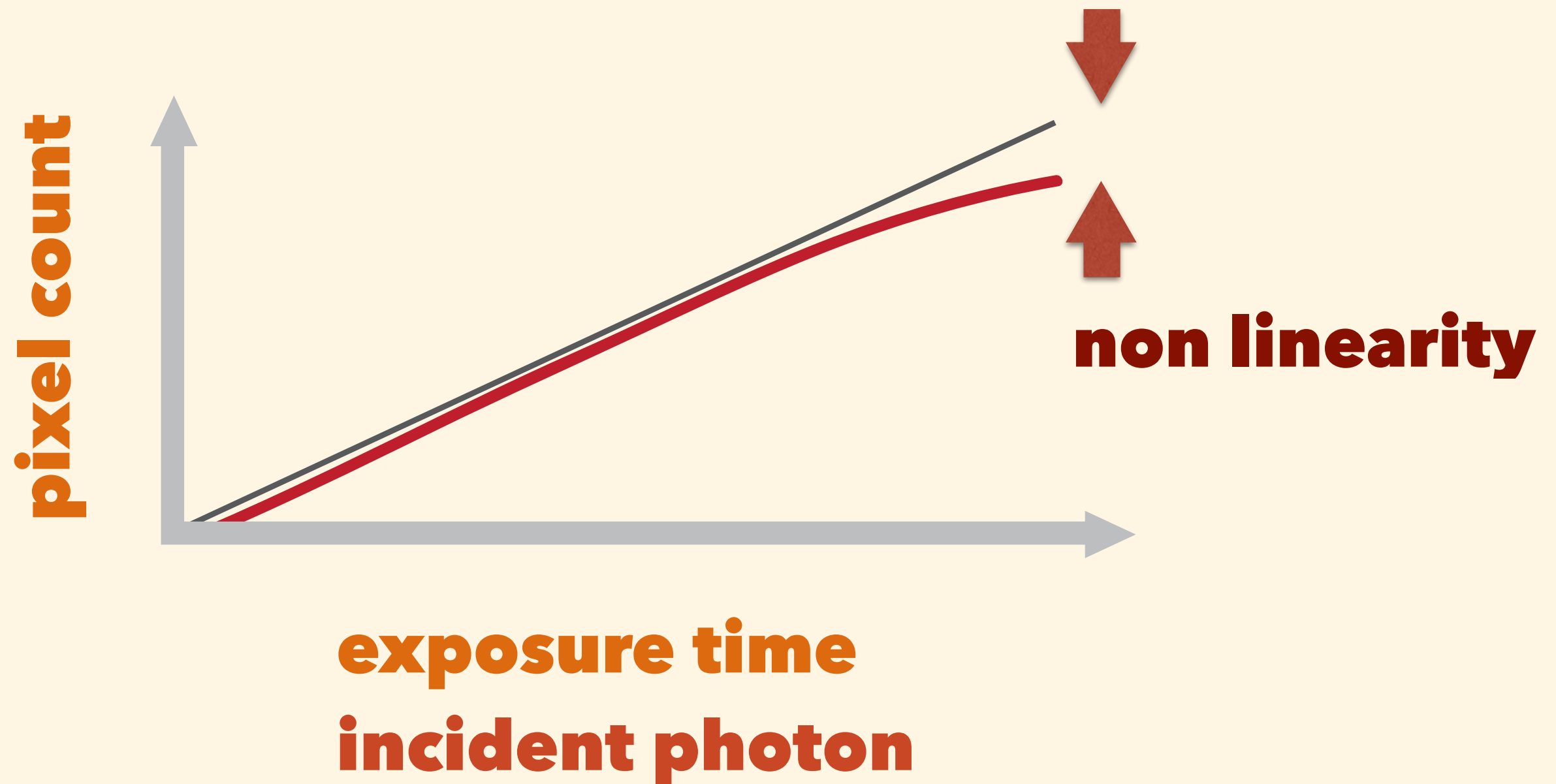


resample = sin

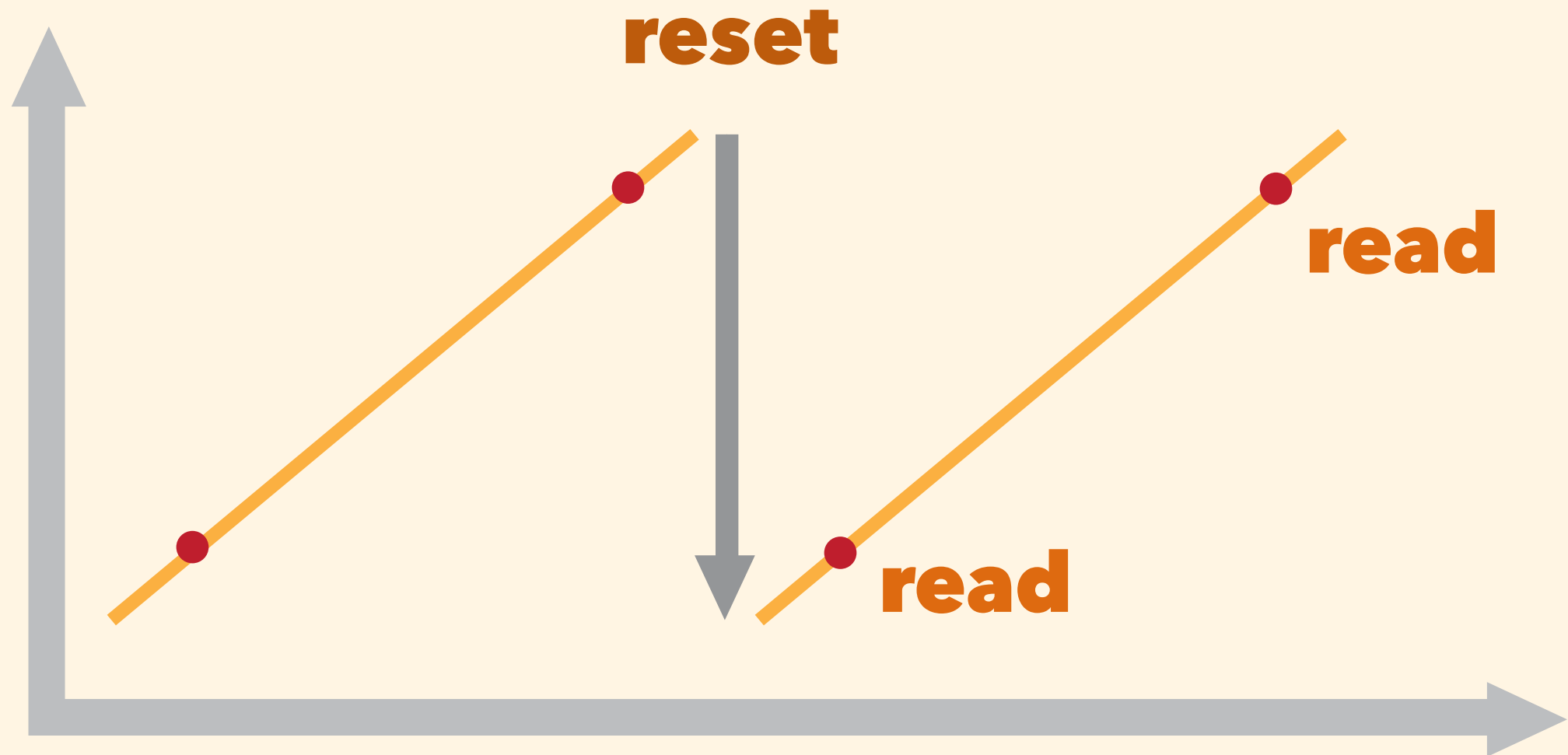


Flux calibration

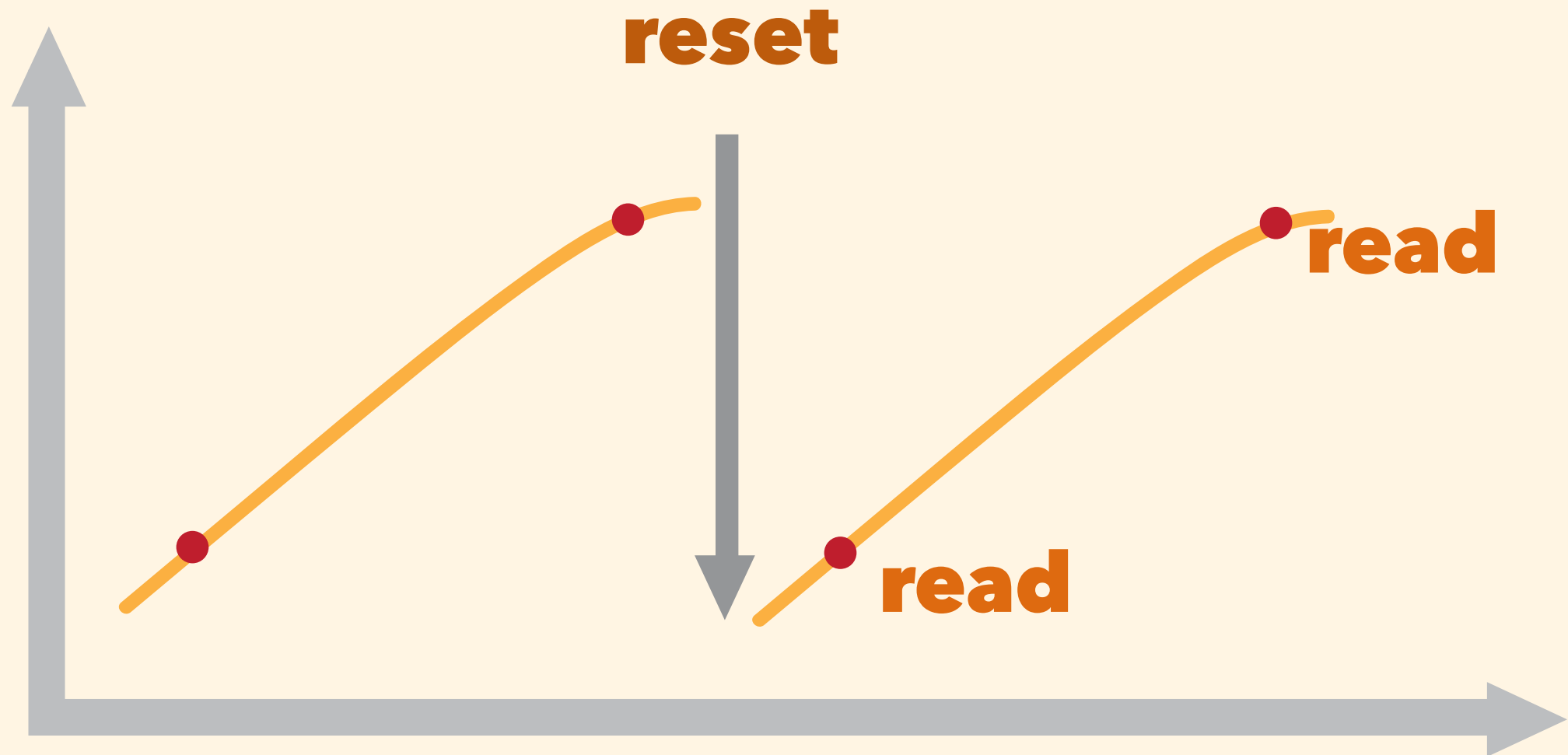
or linearity correction

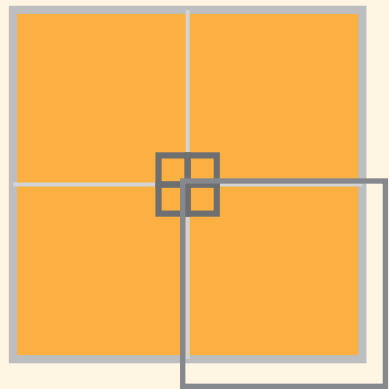


How a pixel is read?

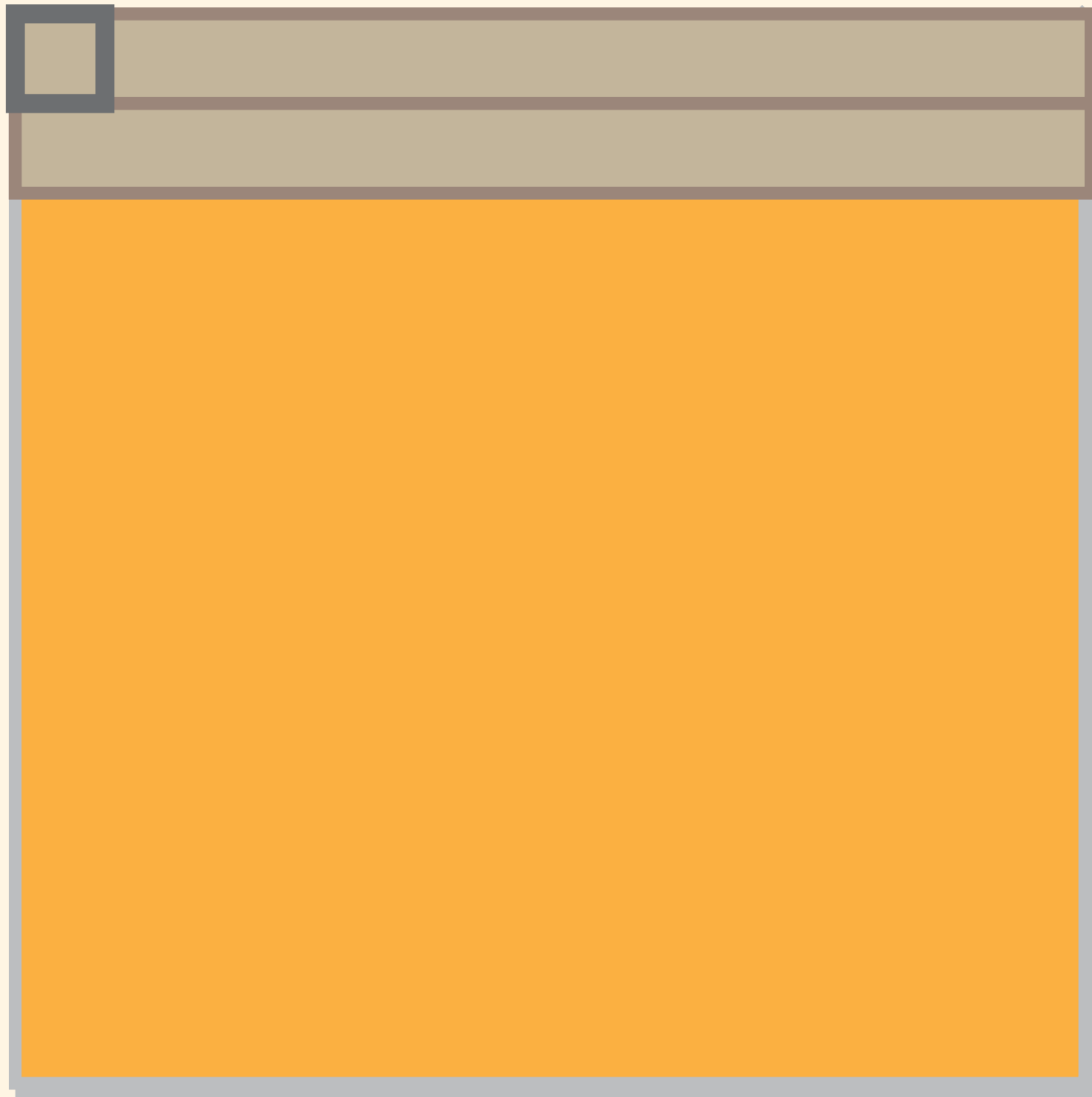


How a pixel is read?





reset



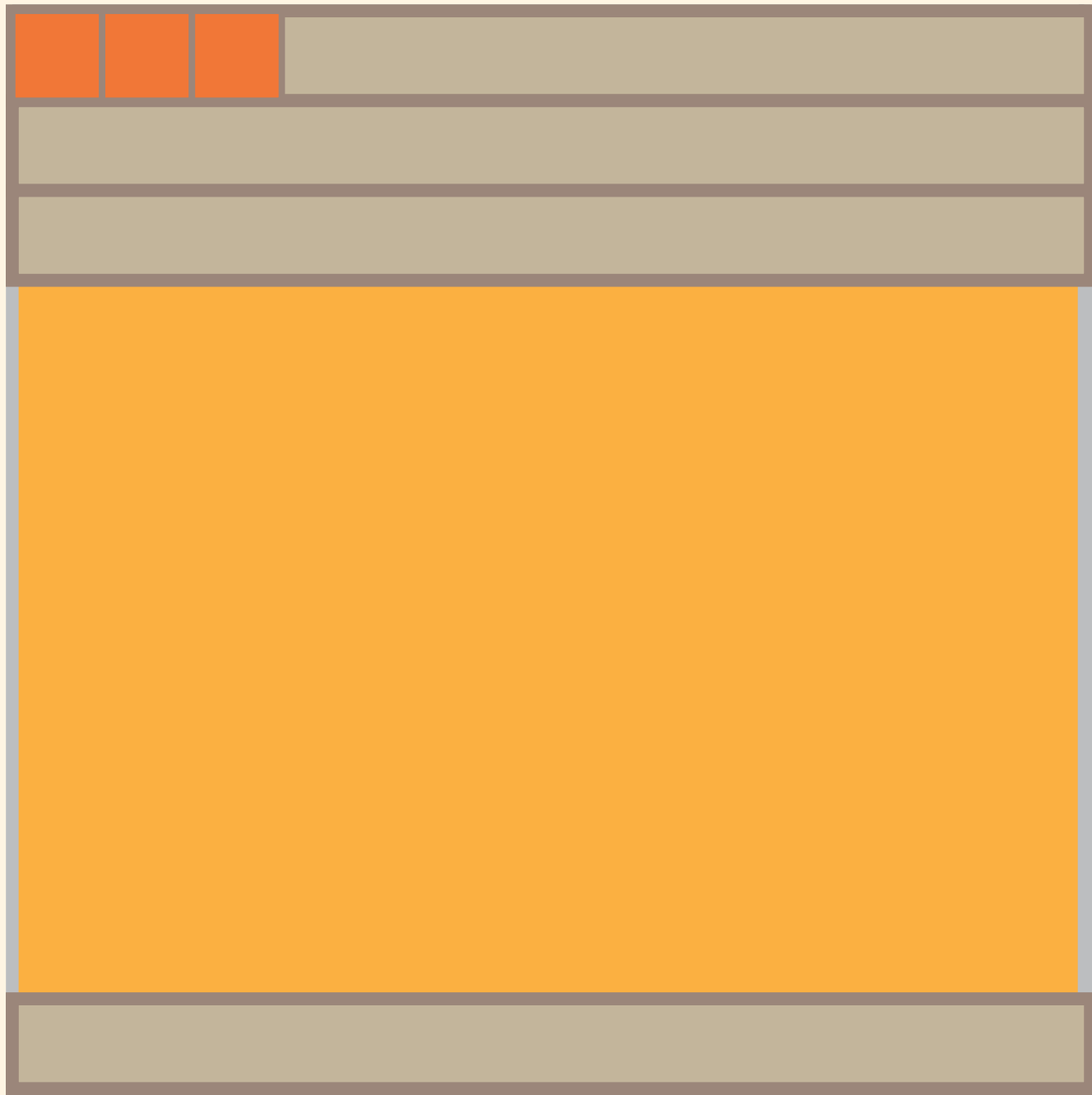
← **row by row reset**



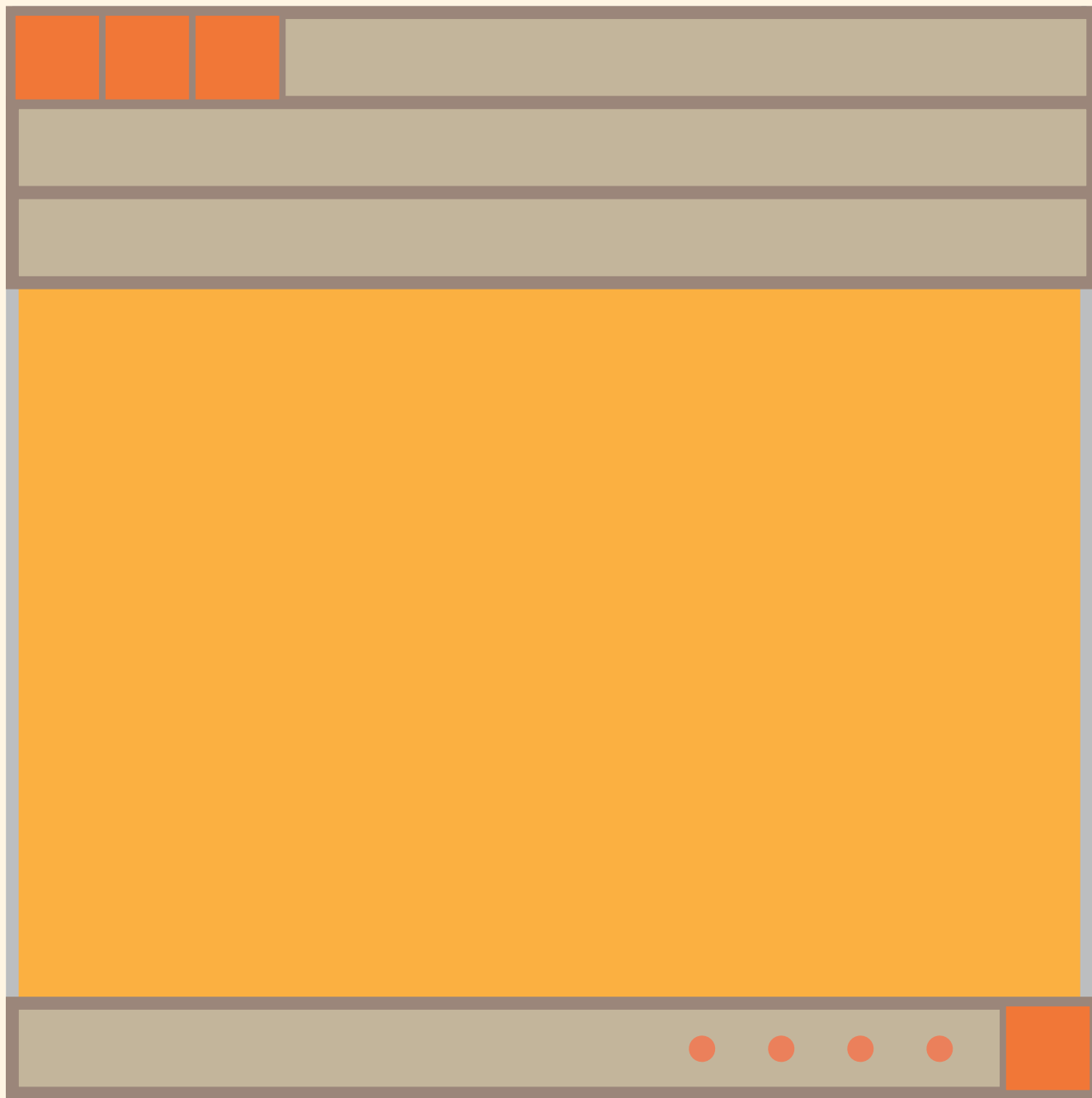
**x 512 times
faster than
pixel by pixel reset**

after a reset

pixel by pixel read #1



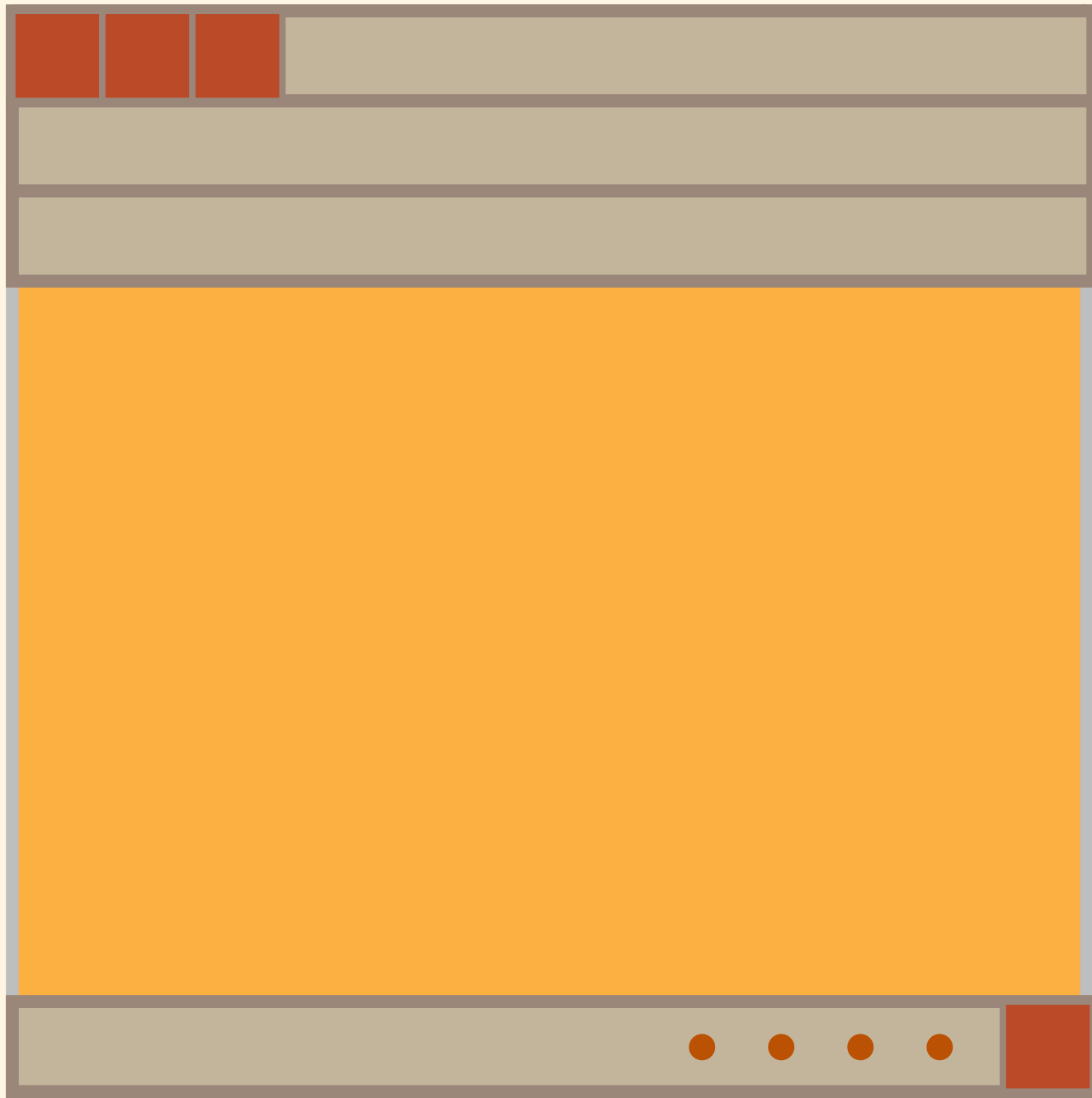
pixel by pixel read #1



**it takes long
until last pixel
is read**

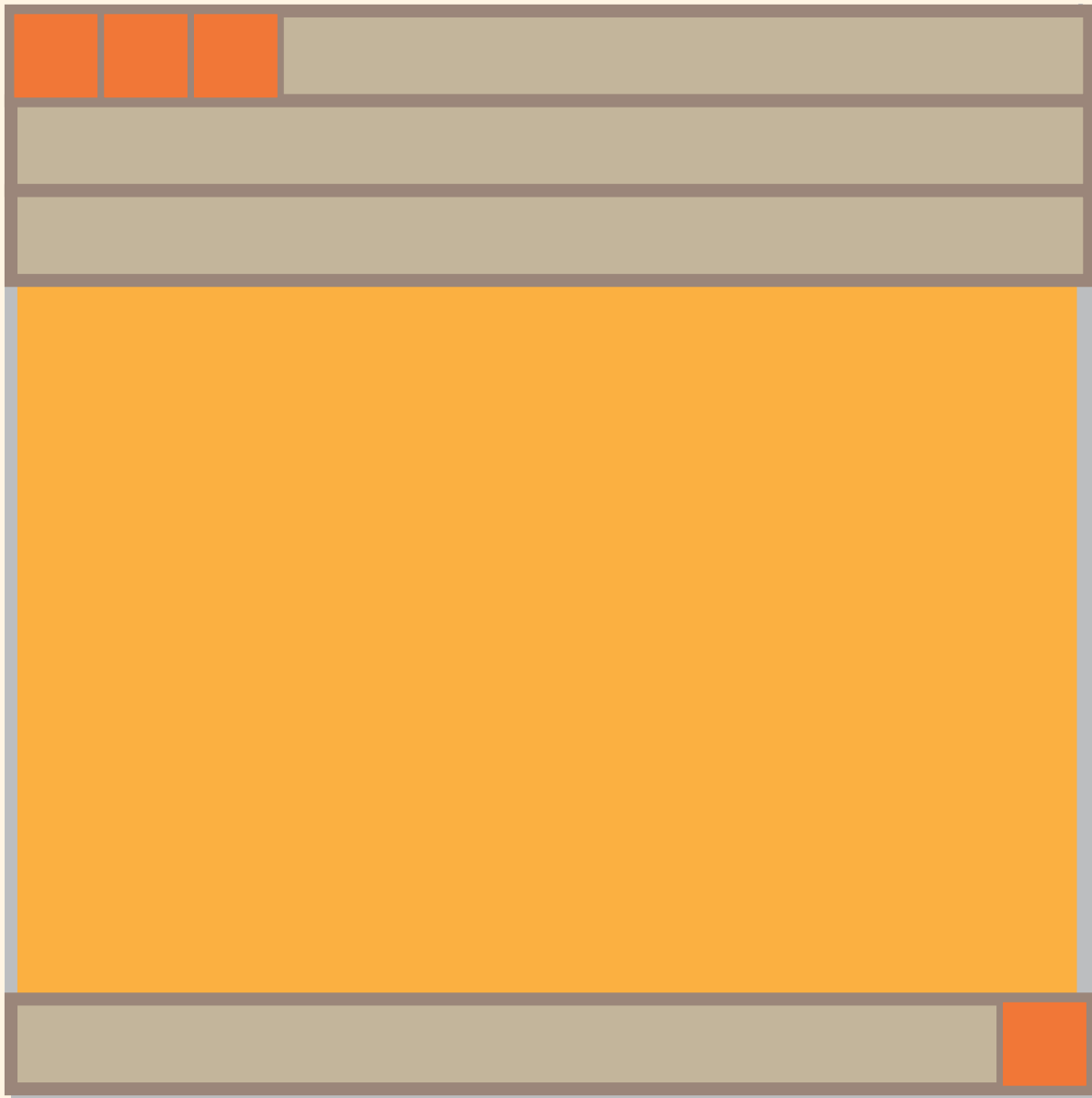
2nd readout

pixel by pixel read 2



Two problems

- 1 high flux at thermal IR:**
minimum integration time 0.1-0.4s

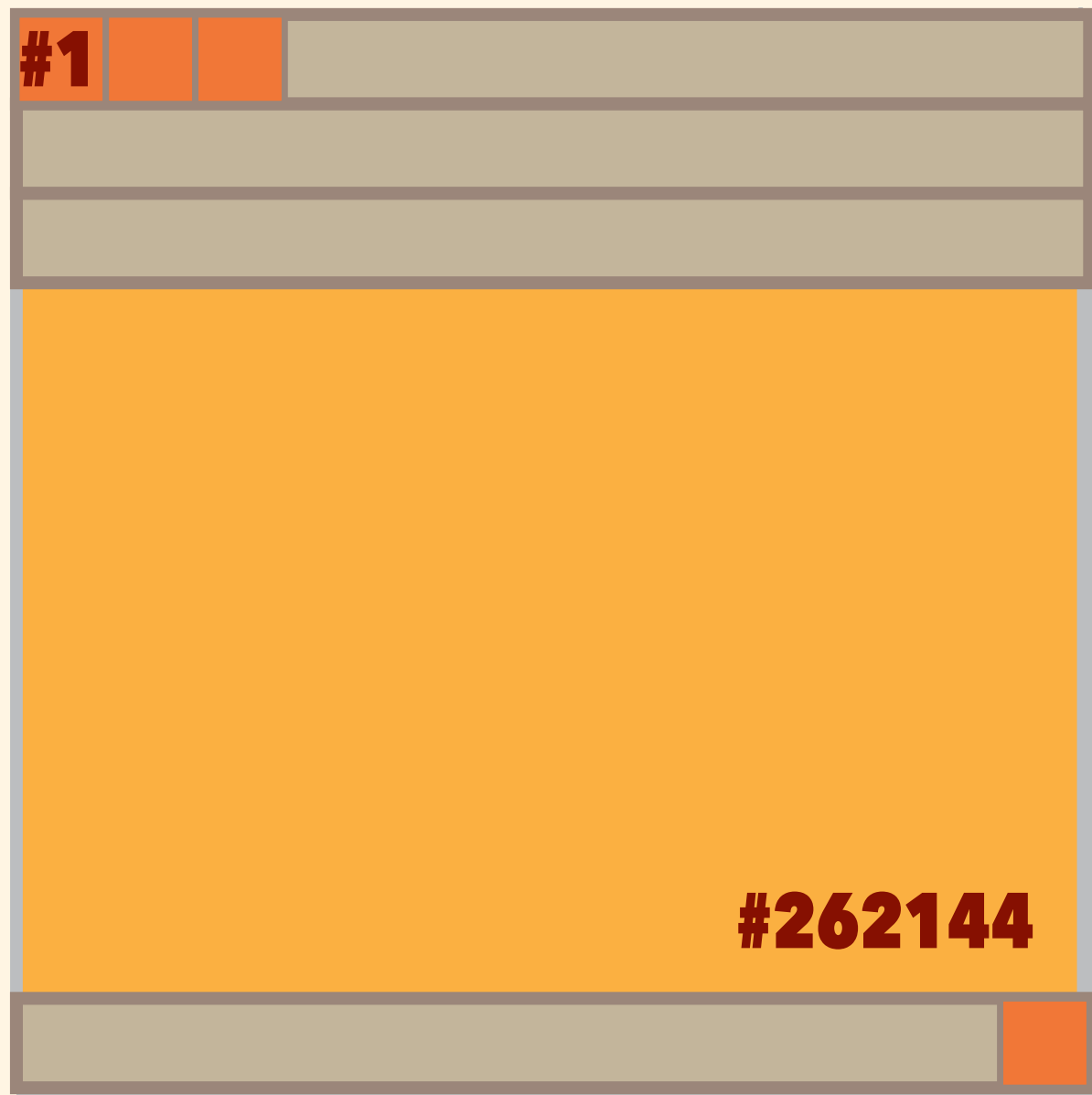


**at the 1st read out
already high counts**

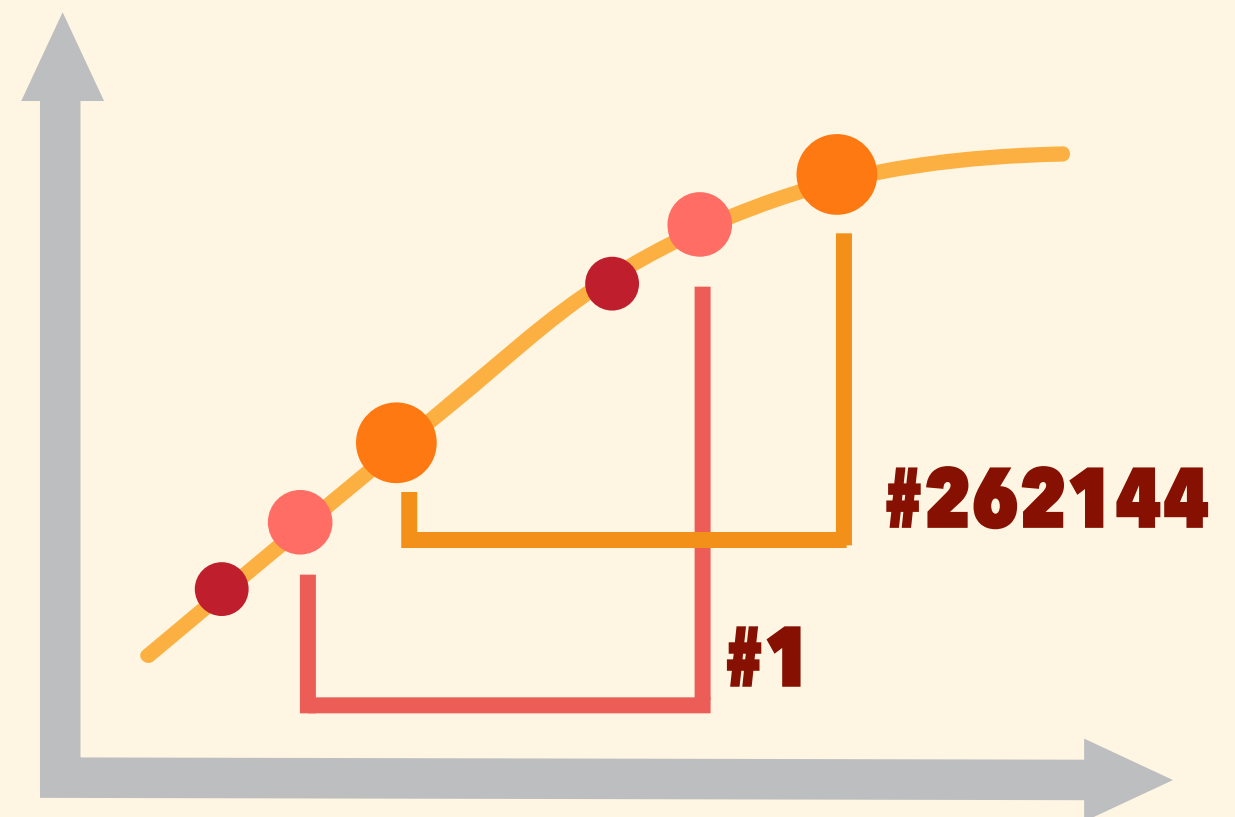


Two problems

2 reset is instant. read takes much longer



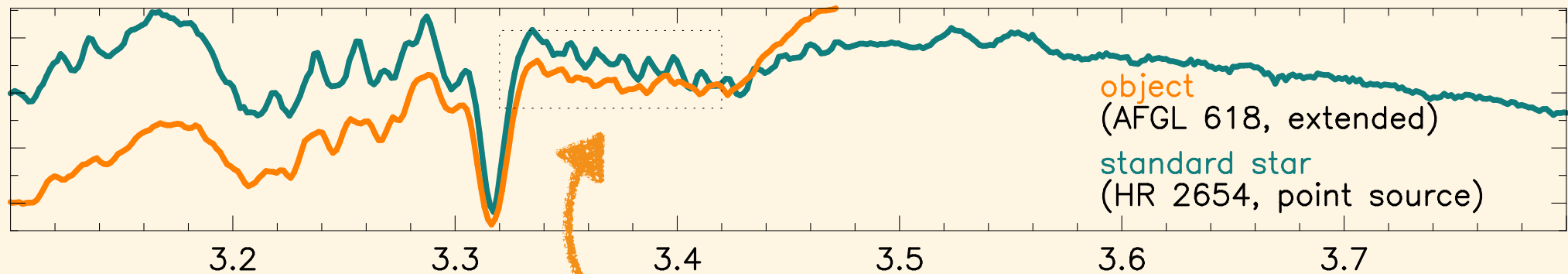
last pixel has
higher signal offset than #1



linearity correction is a function of
position + influx

why filling slit so important

● aliasing

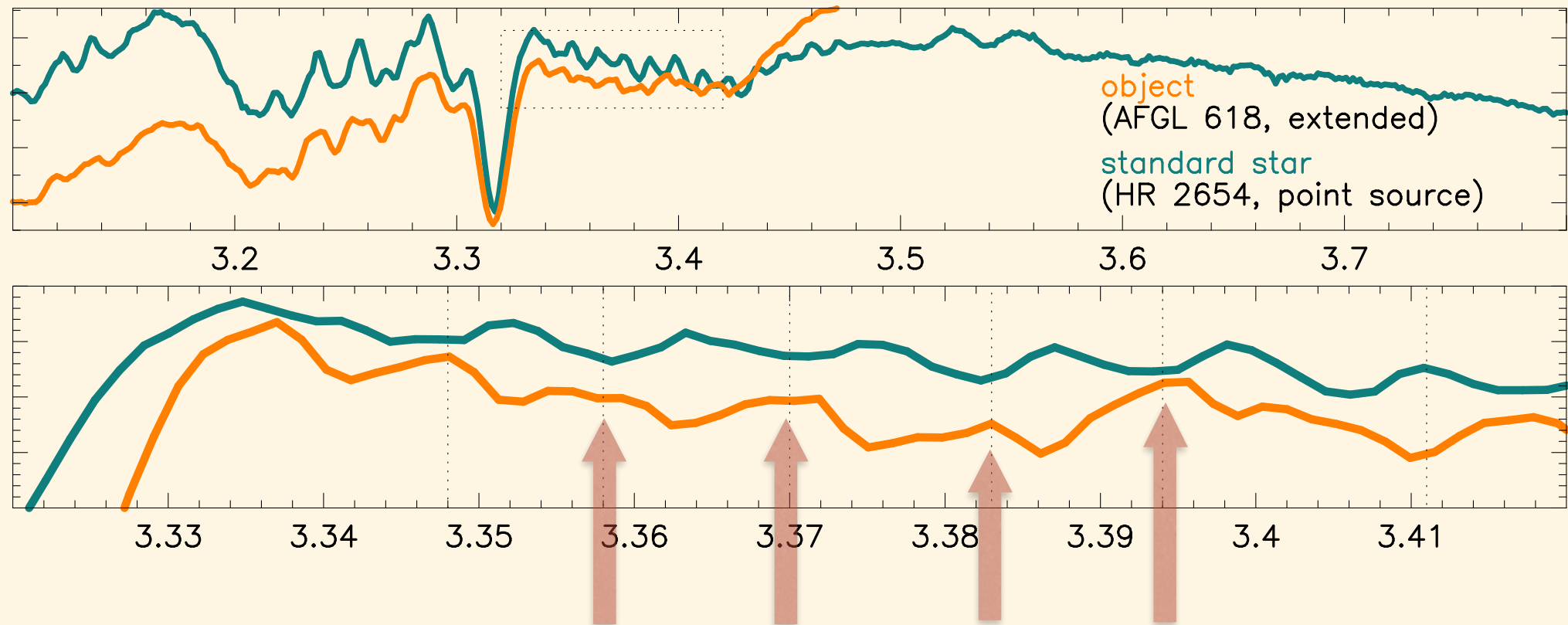


something
strange here

normal
medium resolution ($R=2000$)
L-band spectra

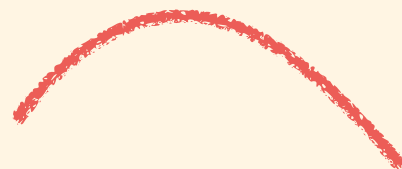
why filling slit so important

● aliasing



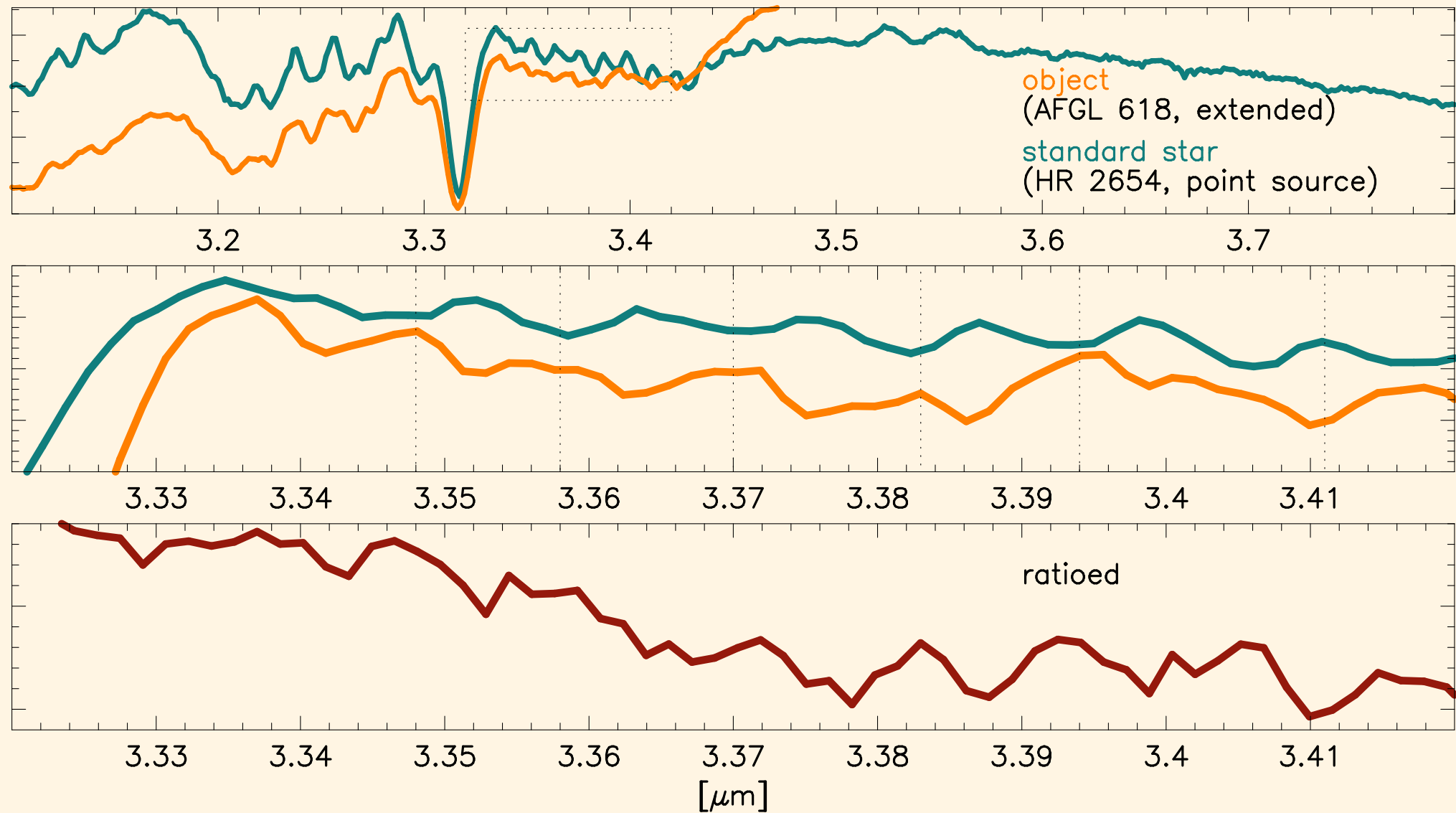
Blow-up

Dents and Bumps
are opposite in **Std** and **Obj**



why filling slit so important

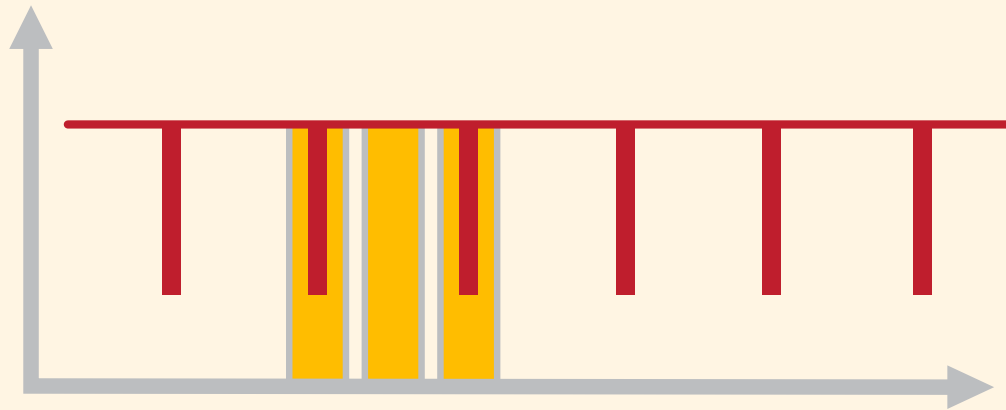
● aliasing



if you divide **ugly result**

why this happened?

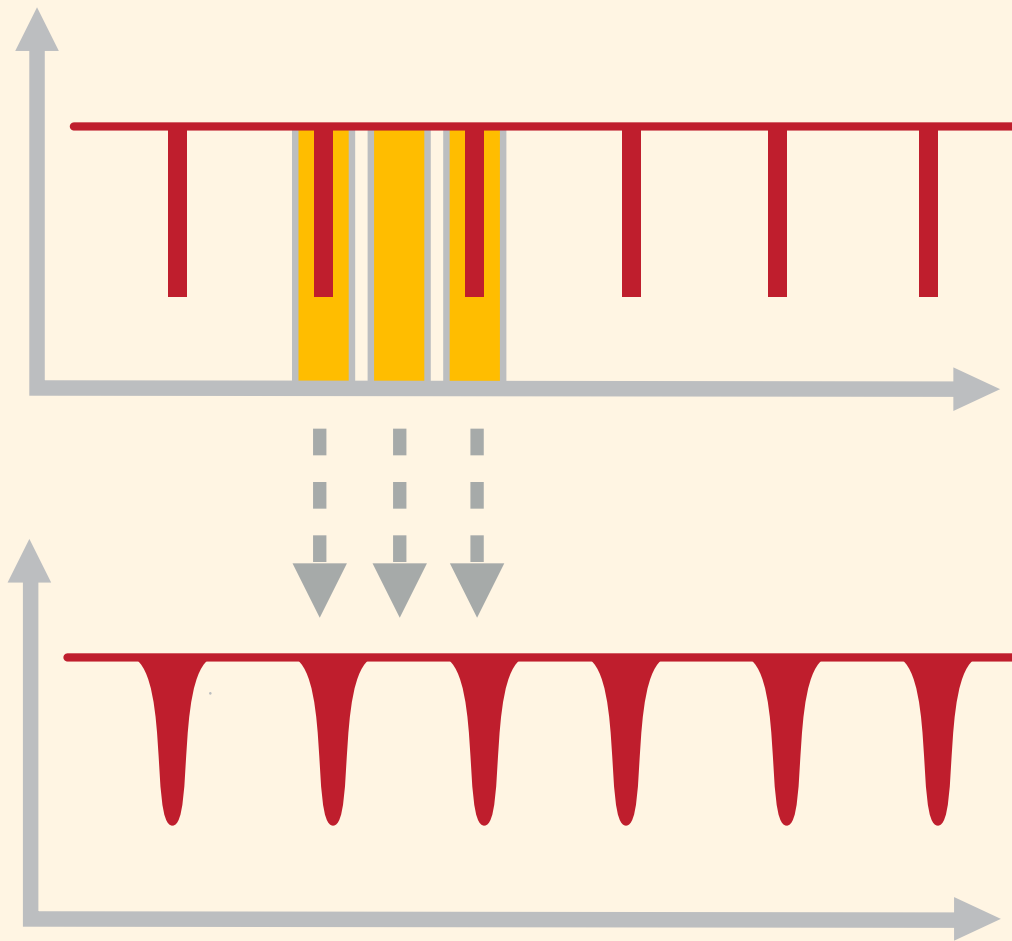
you have series of sharp absorption lines



**use
a narrow slit**

why this happened?

you get this.



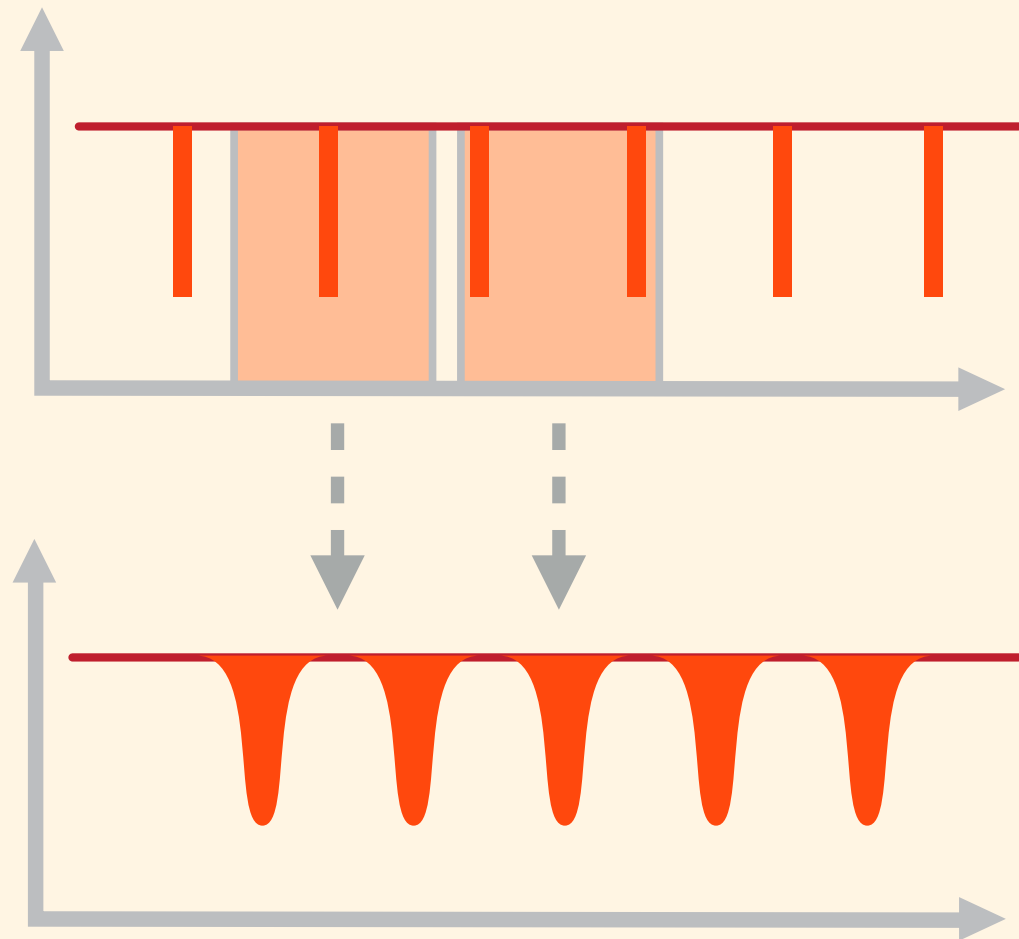
**you have dents
at the position of absorption lines**

why this happened?

but if you use a slit
about the size of
line separation

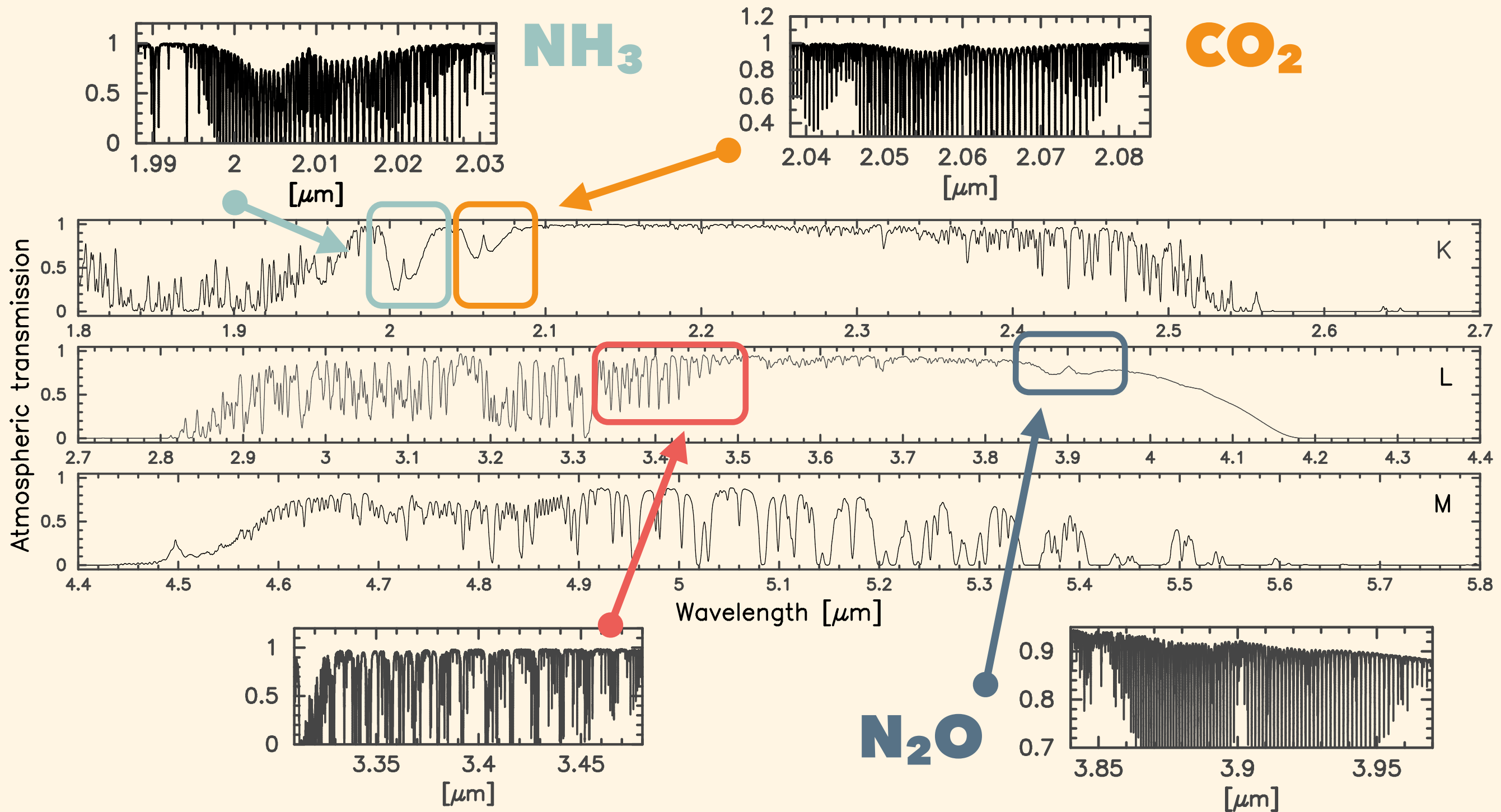
two lines **can** be
in the slit

then, dents are deepest
at the **middle** of
two lines



when this happens,
large telescope does not help

Does this happens?



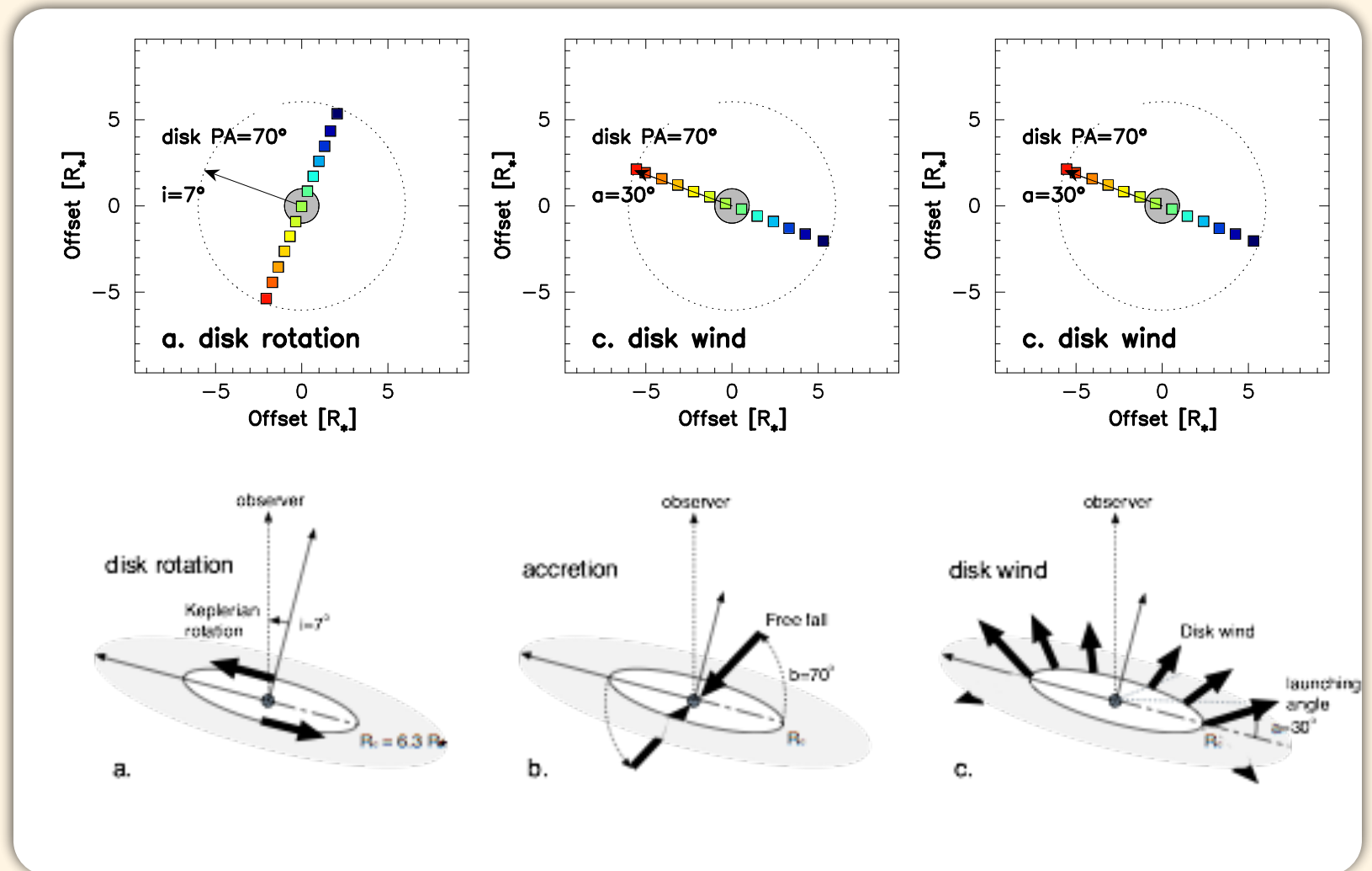
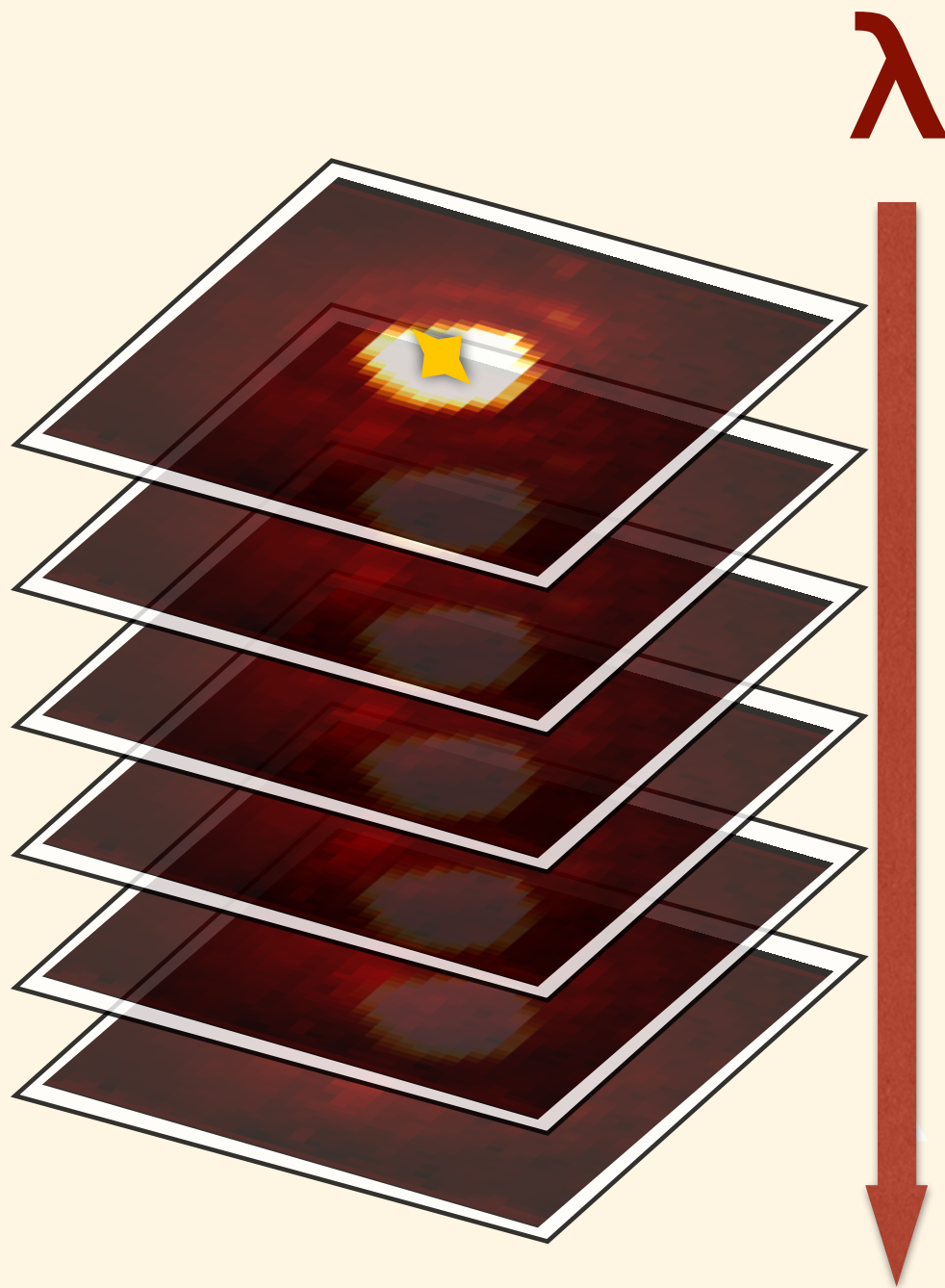
unfortunately.

The problem was

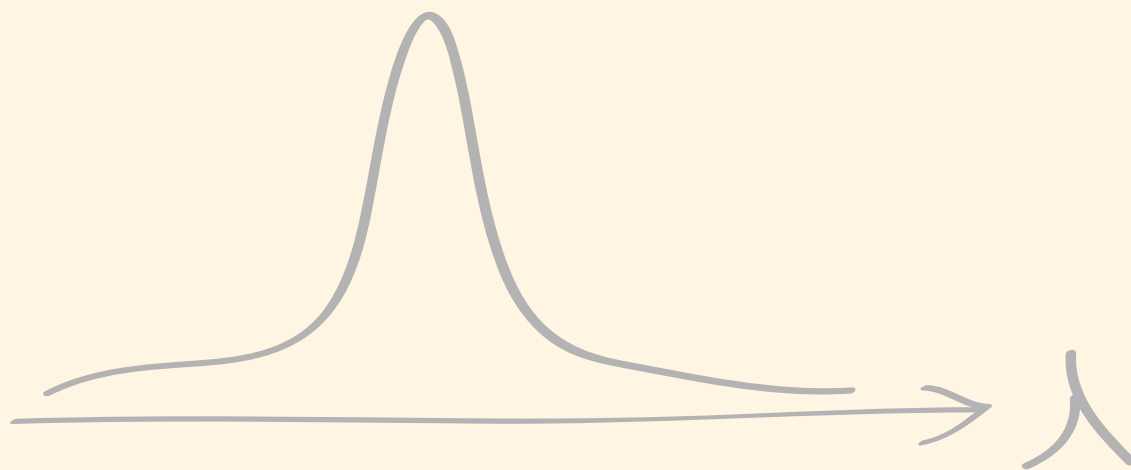
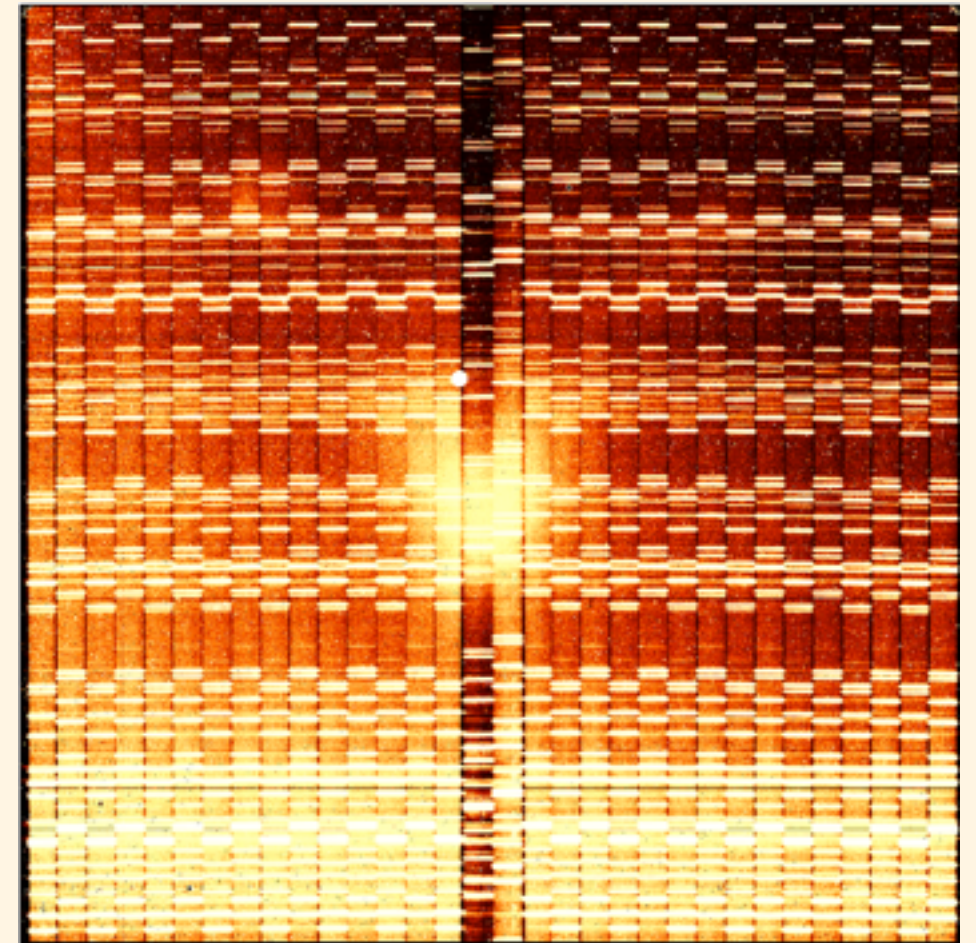
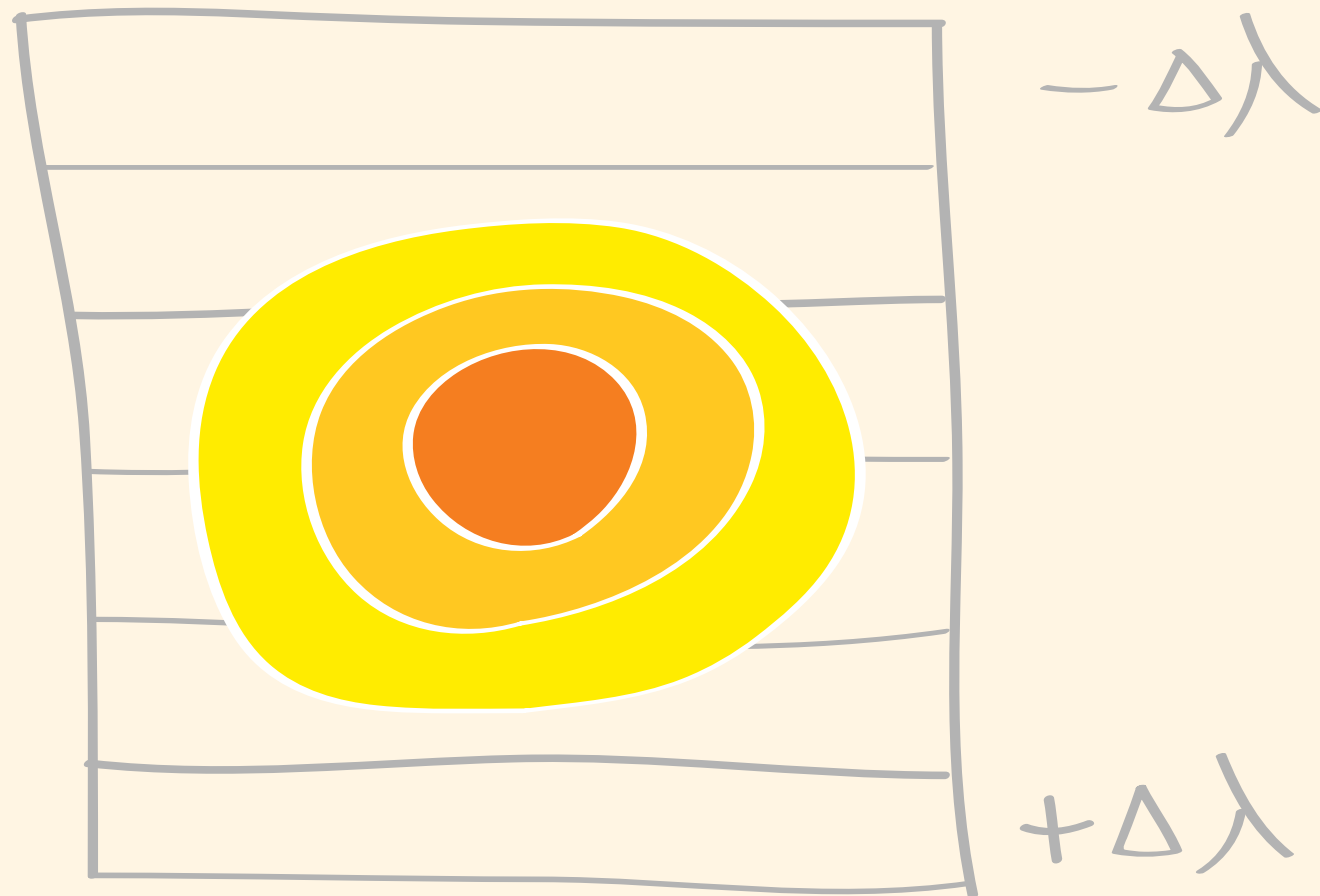
- 1** object was extended
standard was a point source
- 2** standard spectroscopy dose not fill slit
spectral resolution was higher.
- 3** this pitfall is larger, when we use AO

→ **Fill the slit!**

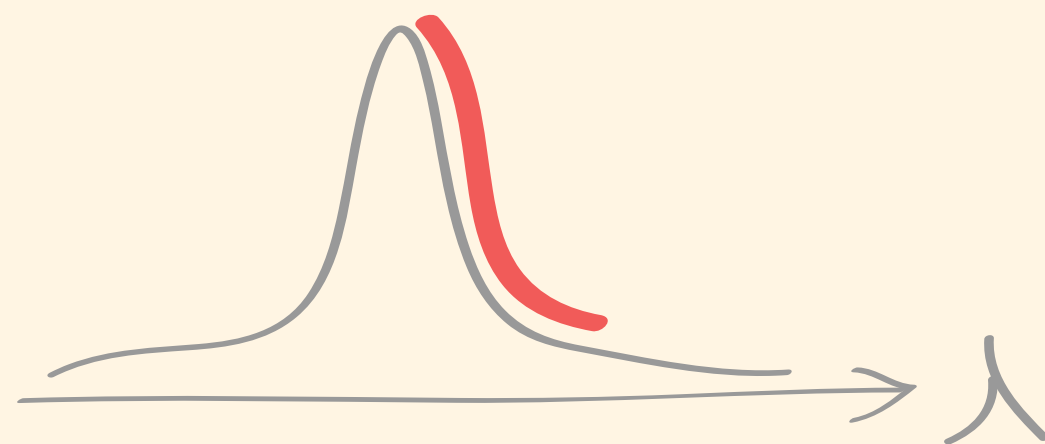
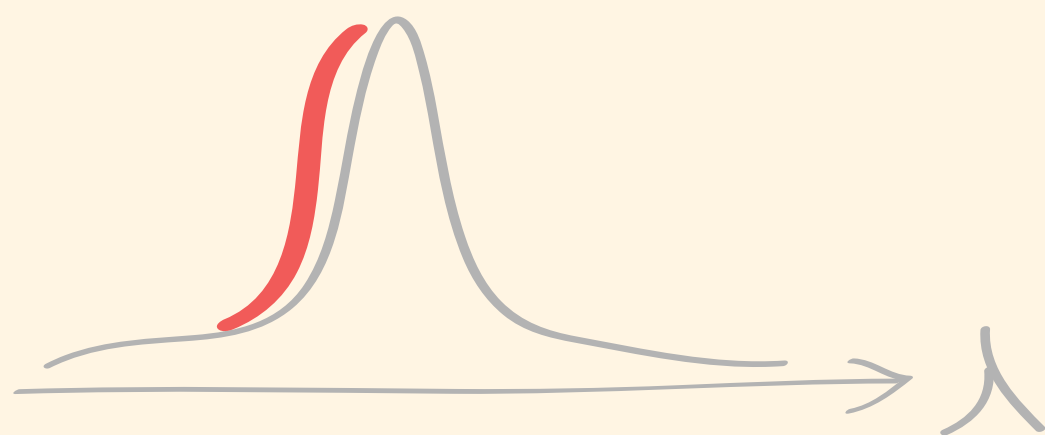
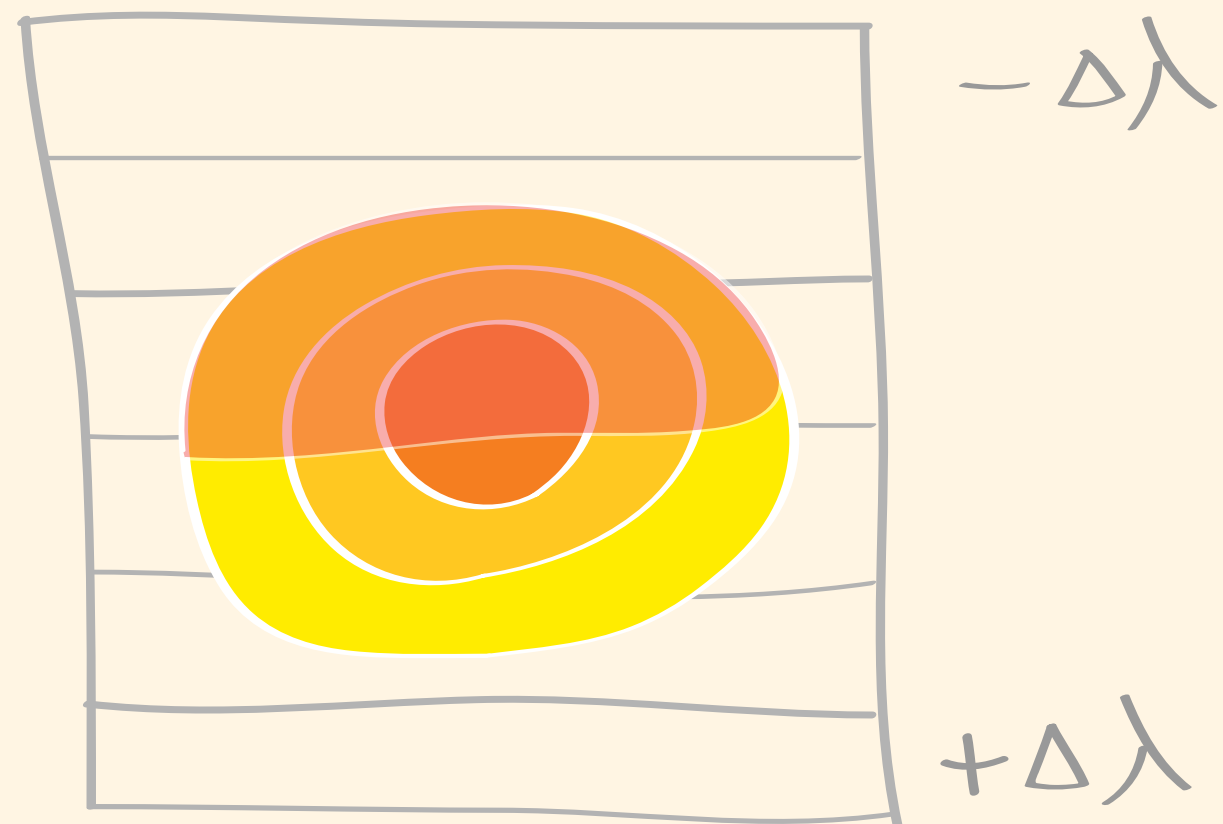
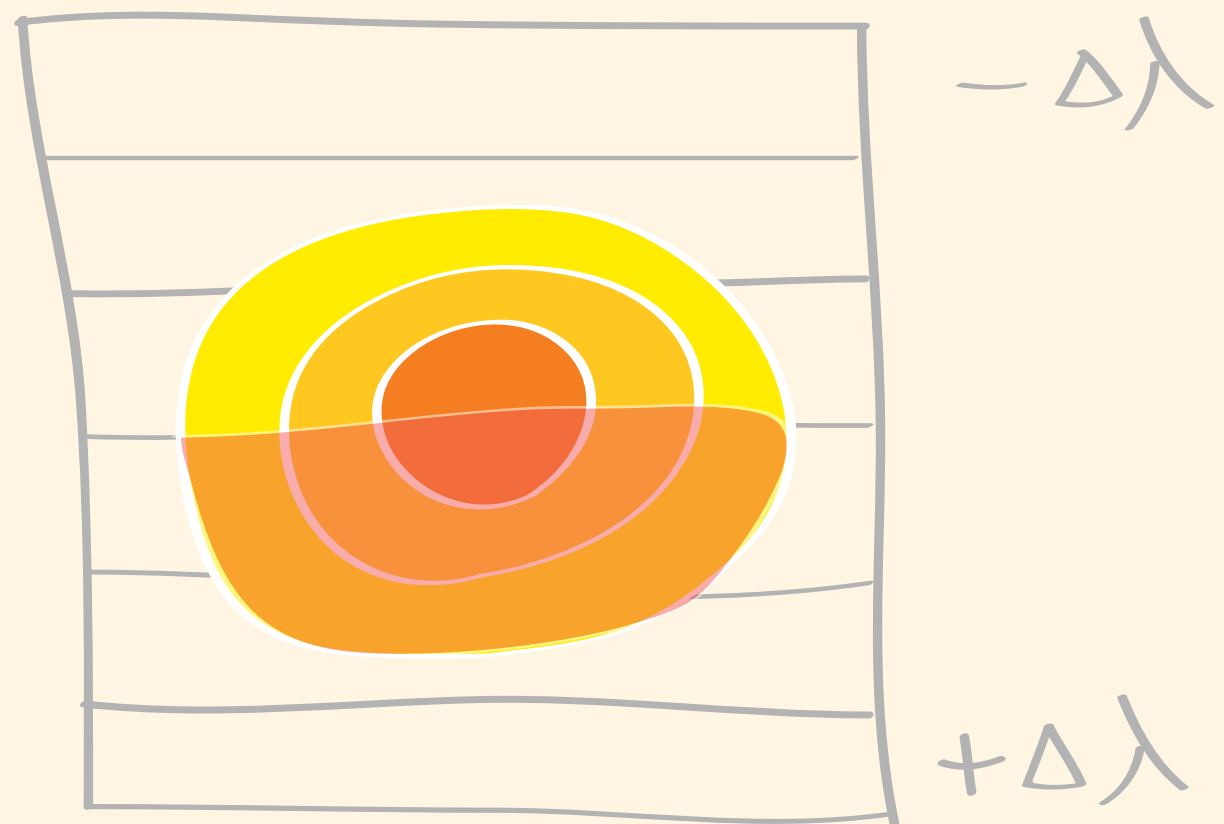
spectroAstrometric precision



is wavelength calibration
precision



SINFONI
raw spectrum



perfect case

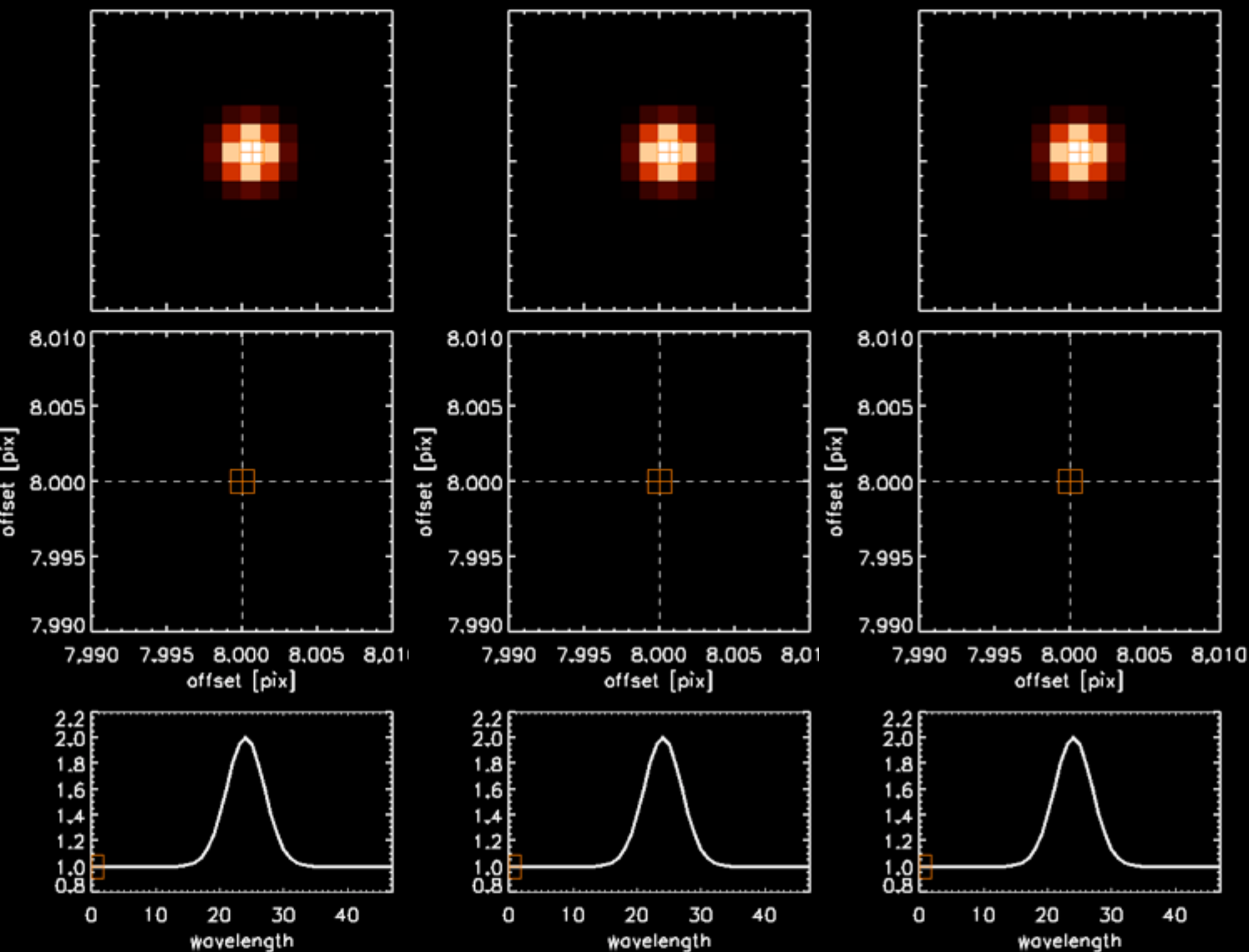
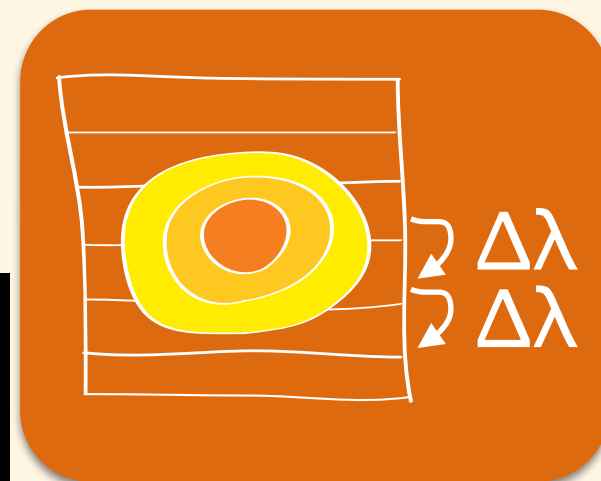
$\Delta\lambda=0.00$ spu

bad

$\Delta\lambda=0.01$ spu

worse

$\Delta\lambda=0.05$ spu



Astrometric precision

**is wavelength
calibration precision**

- 1 before claiming astrometric precision**
- 2 check wavelength offsets among spaxels first**

Bad pixel correction

principle:

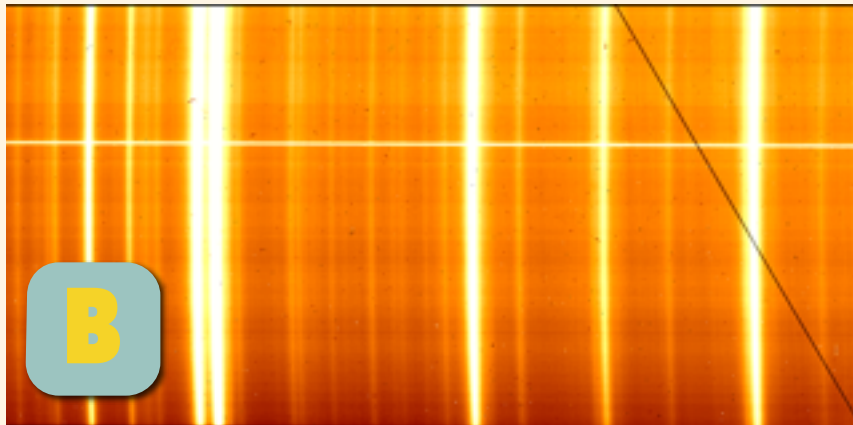
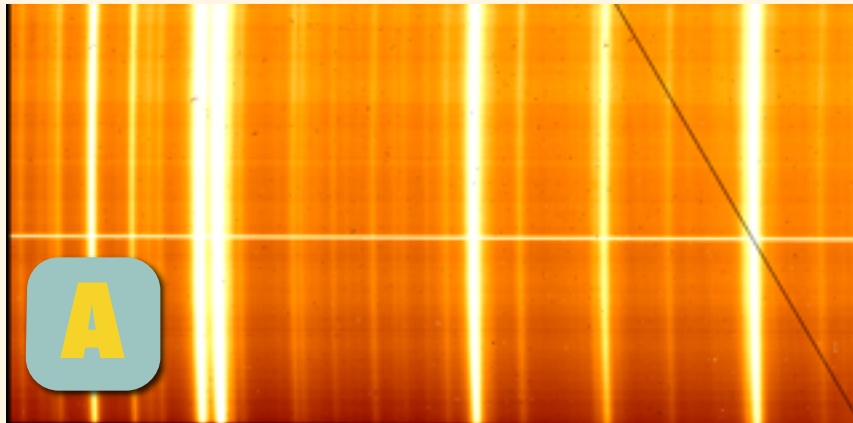
- 1 Do not correct.**
- 2 mark up, and**
- 3 do not use**

detector #2, CRIRES

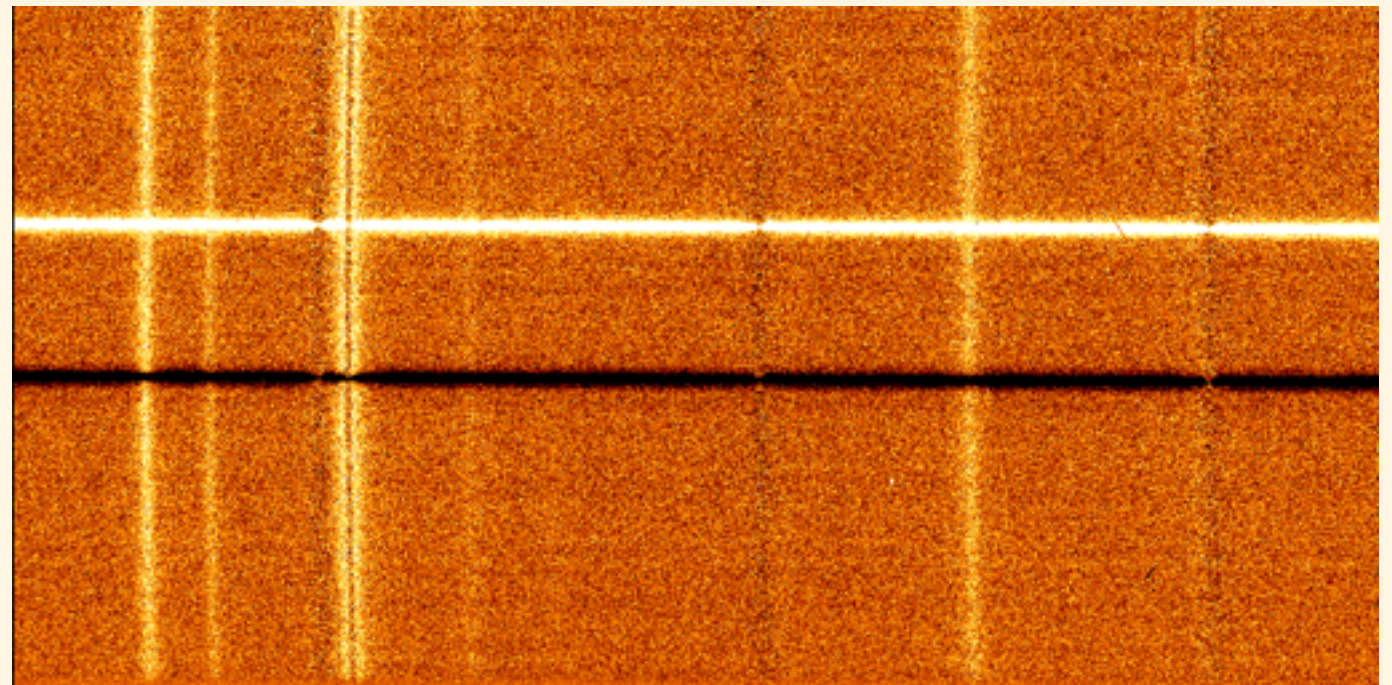
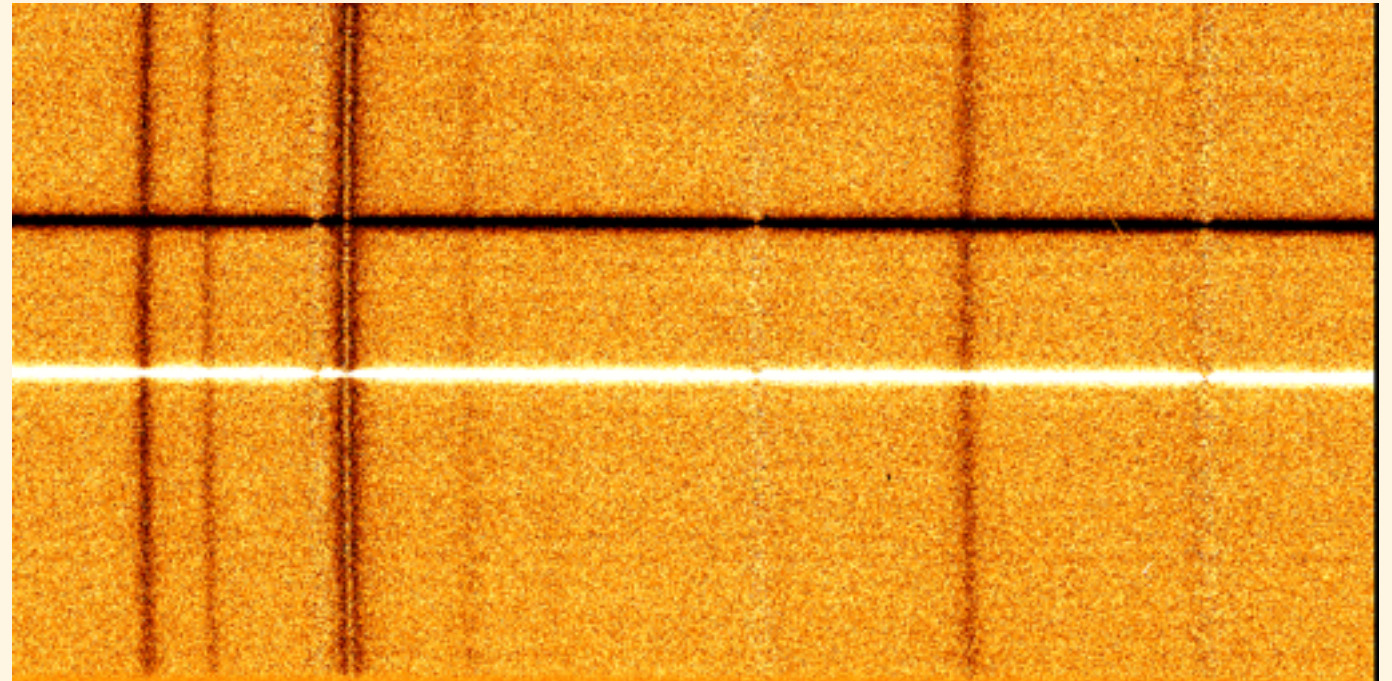


nice double scar

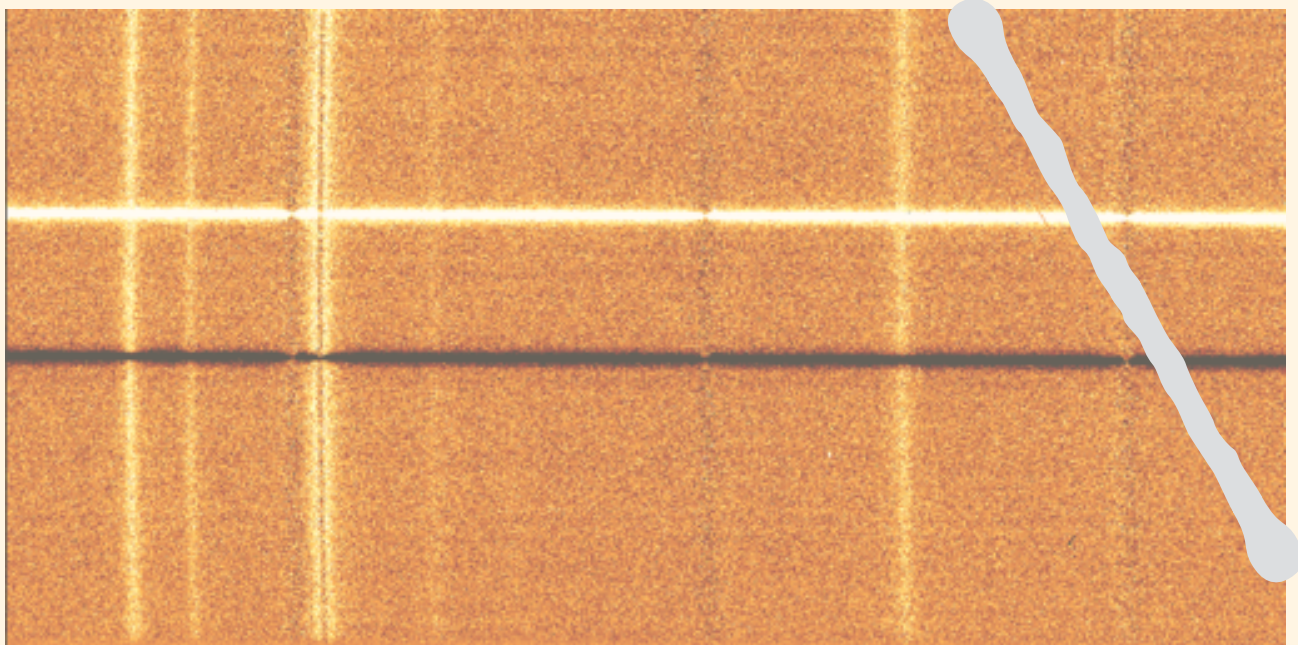
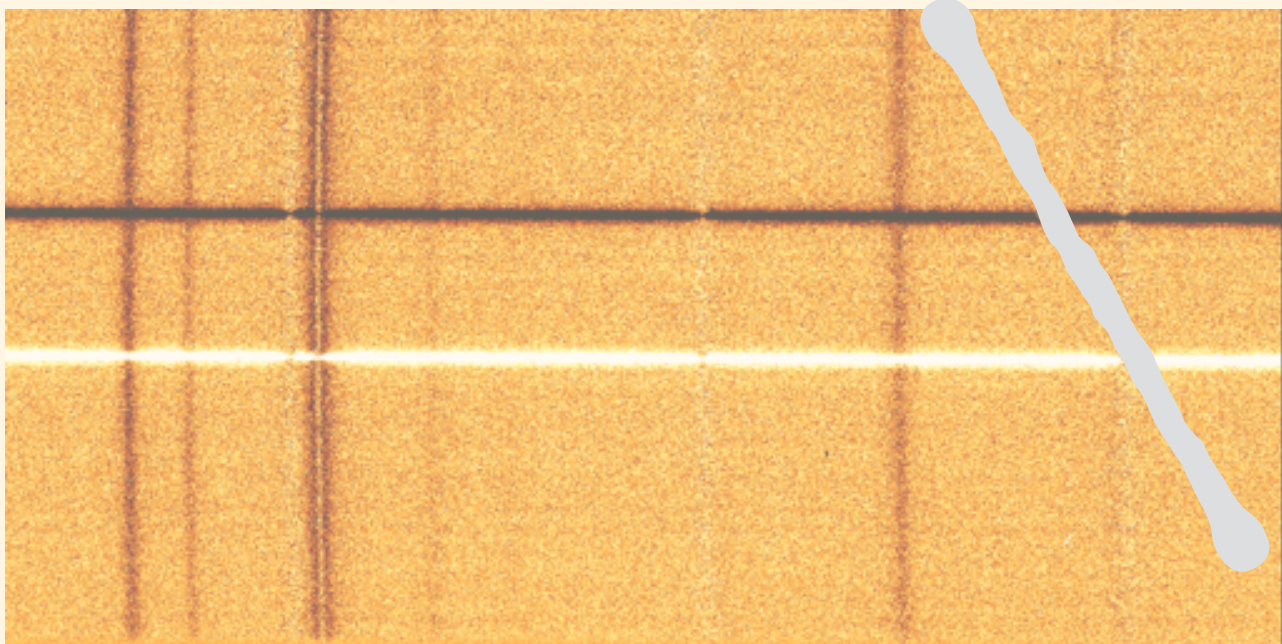
1 raw



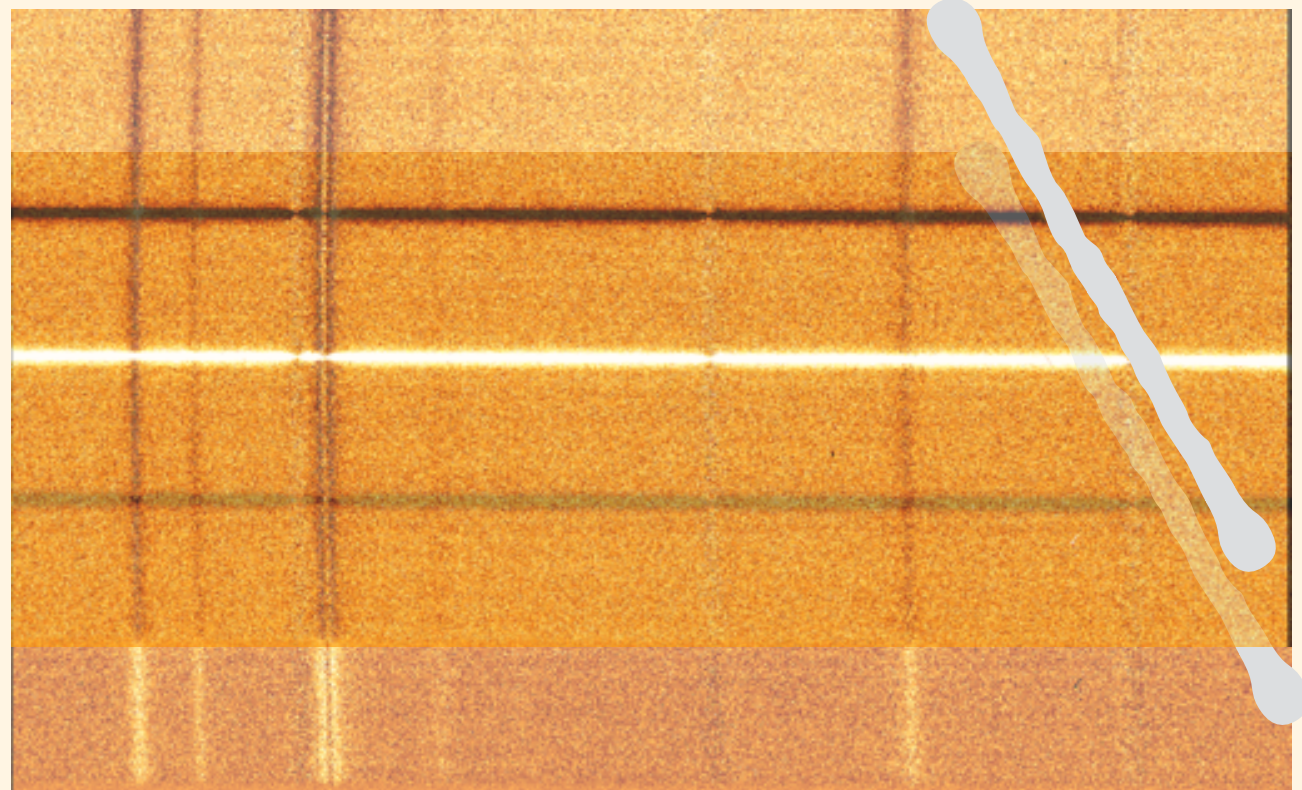
2 sky subtracted



③ offset



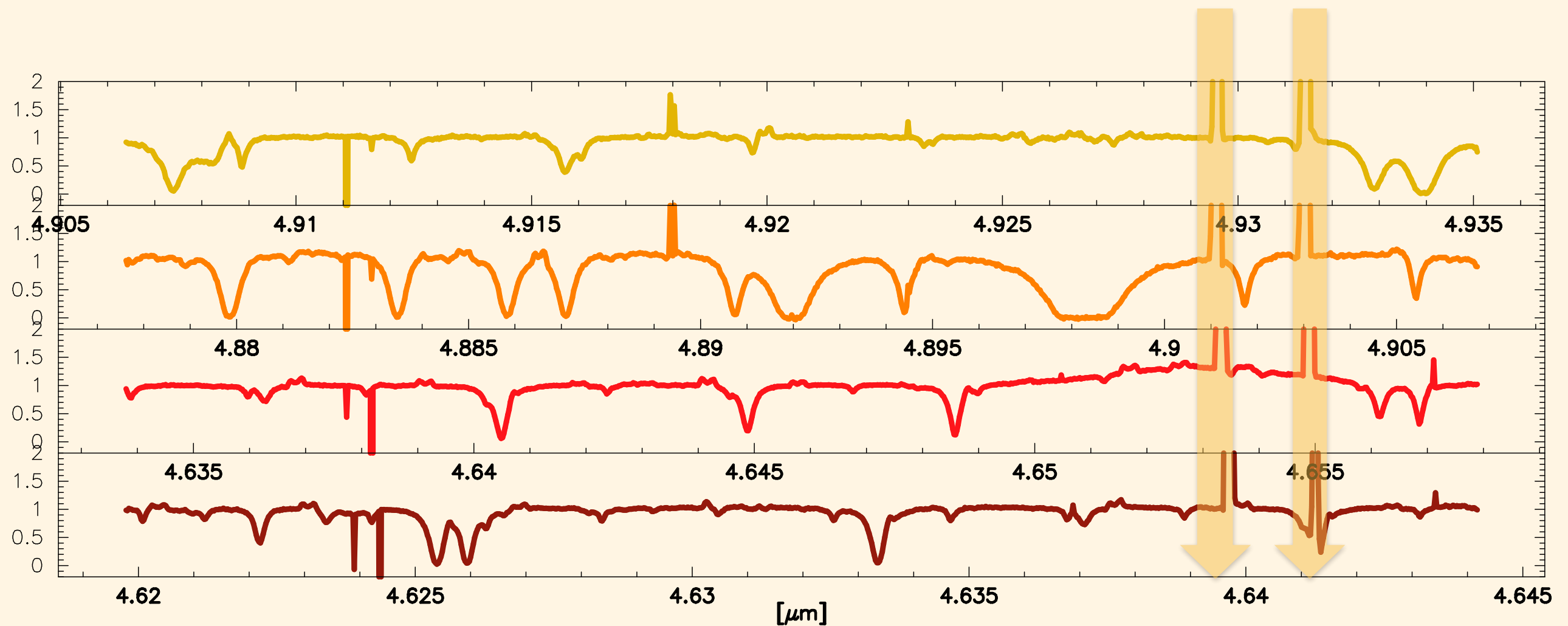
④ add



⑤ ... double scar

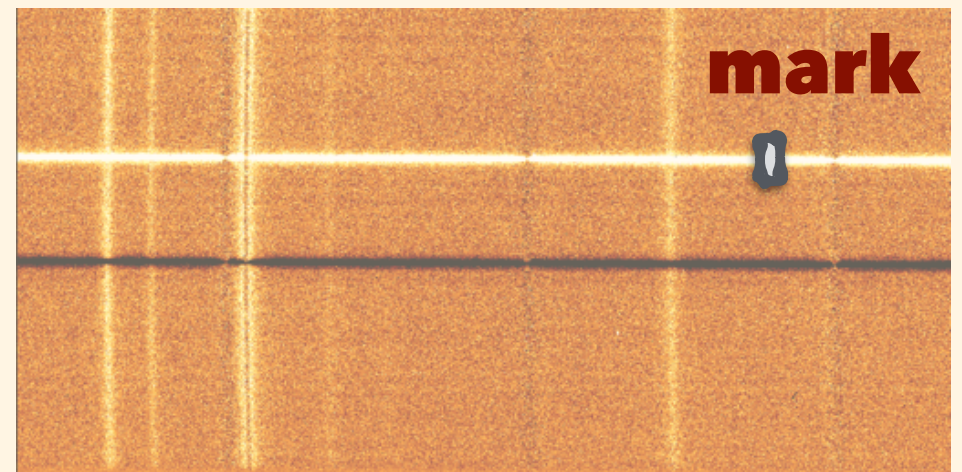
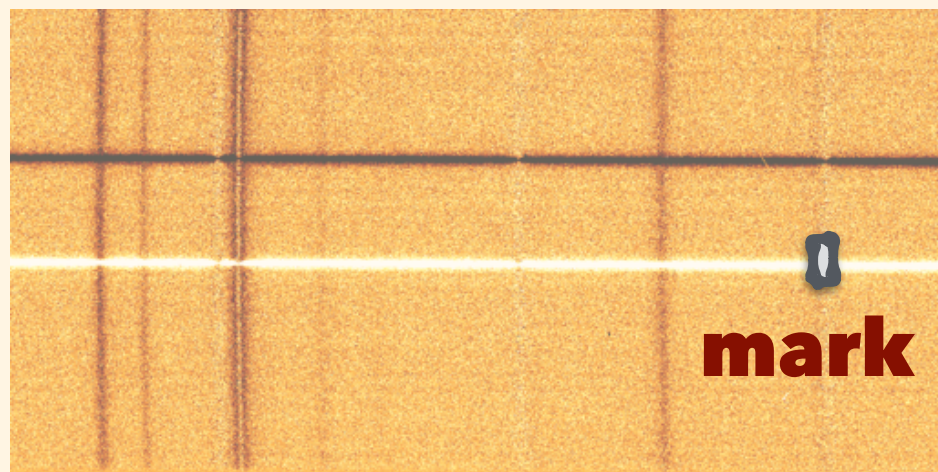


whatever the grating setting is
always large chunk of pixels unusable

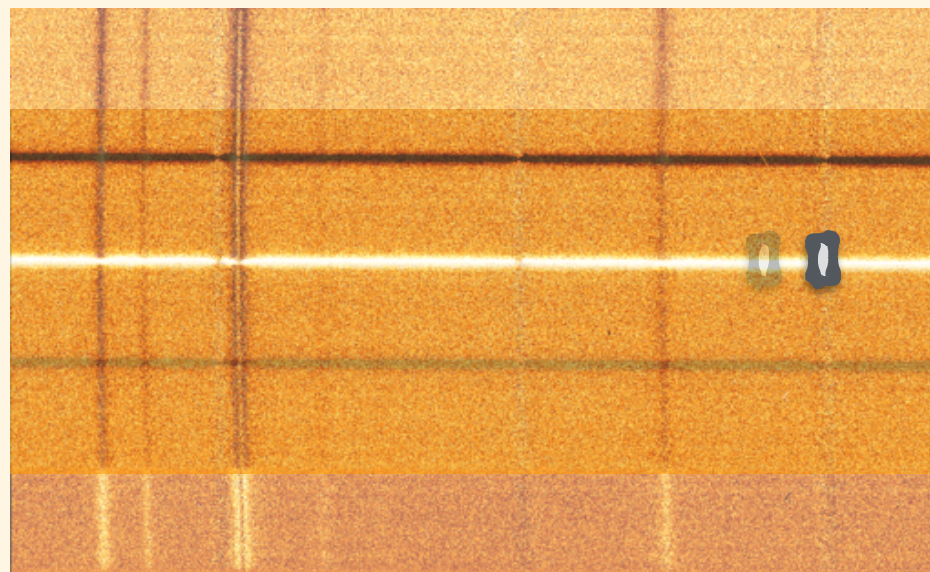


principle:

- 1** Do not correct
- 2** mark up



- 3** add

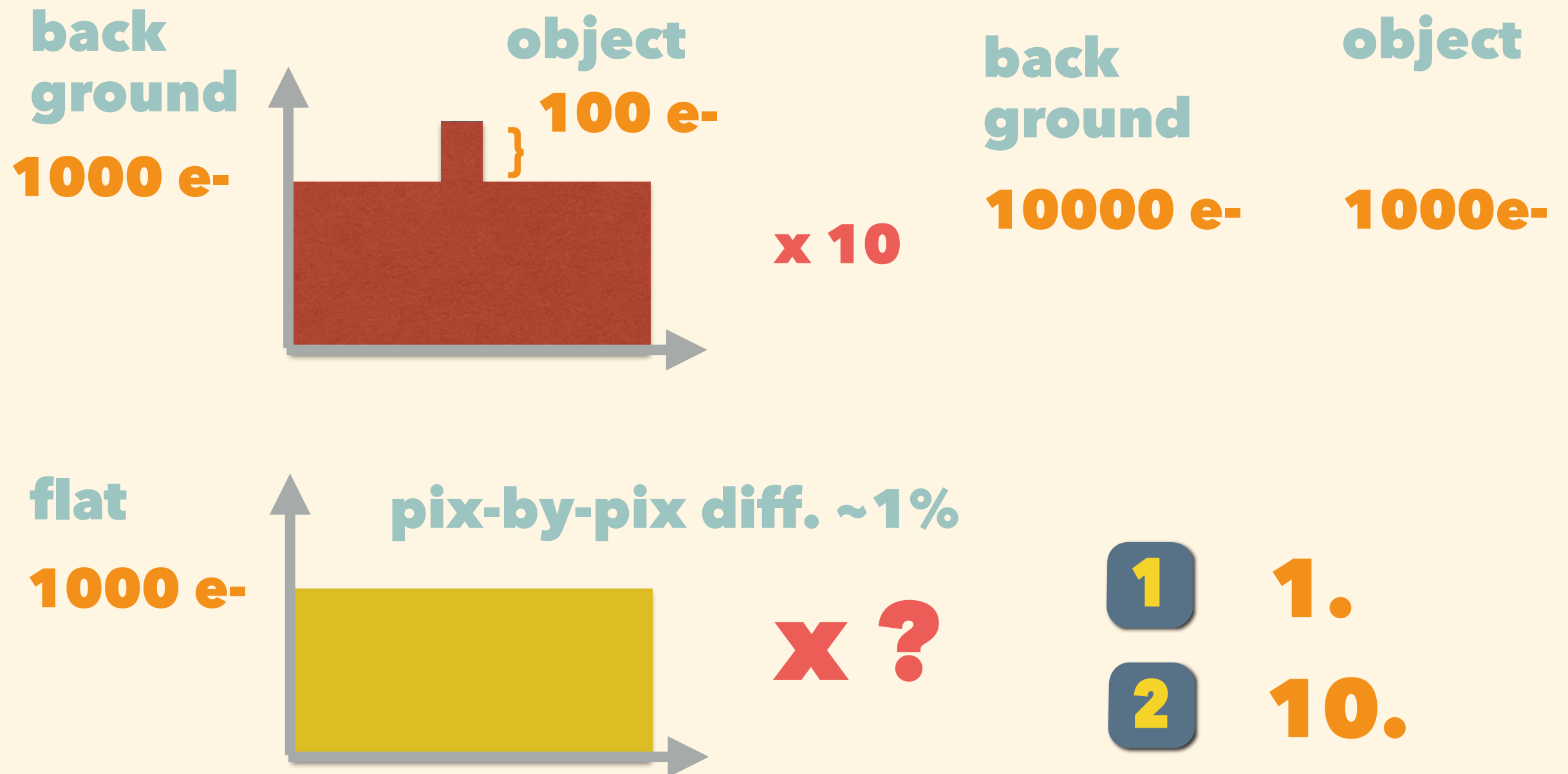


without using
marked pixels

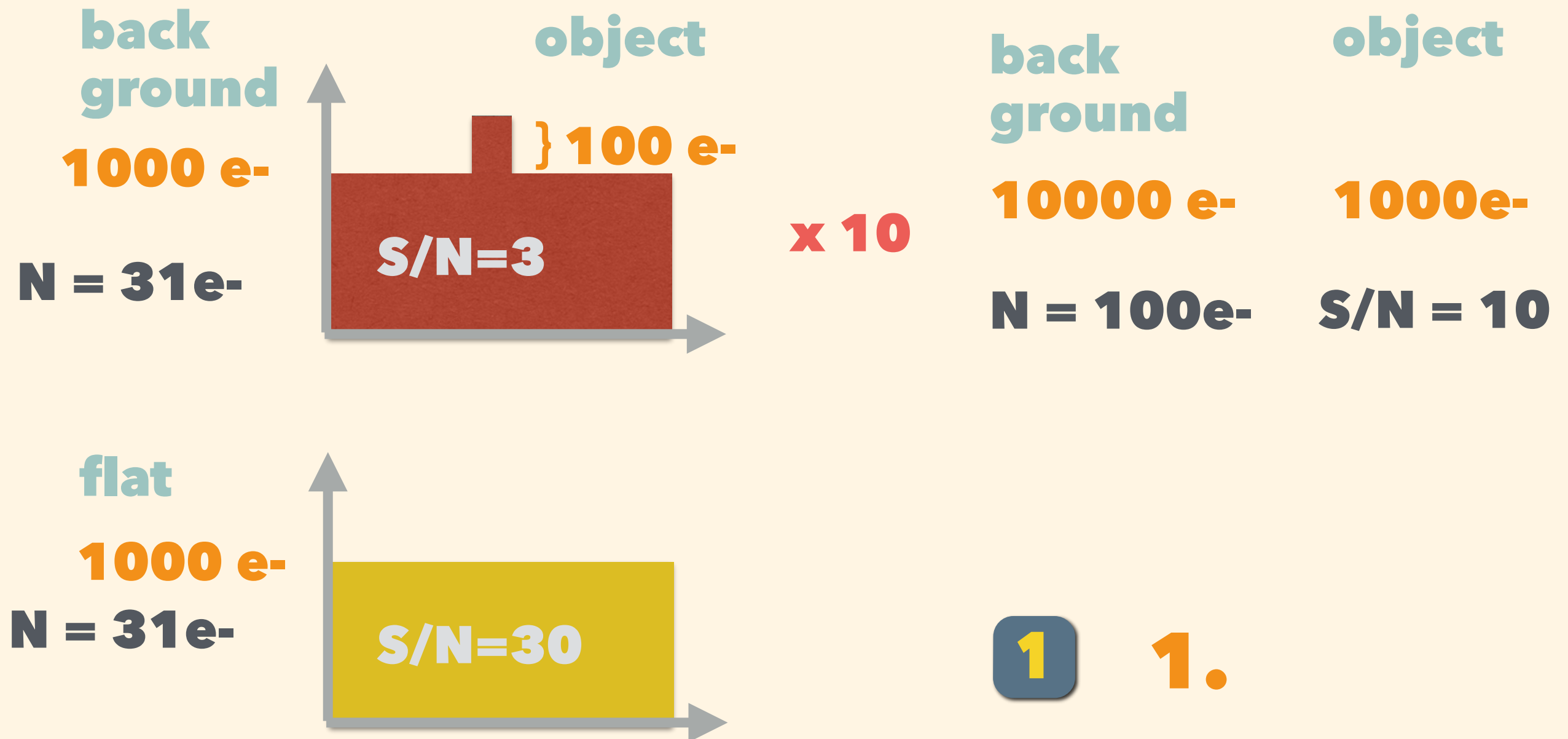
**Thank you
for your attention.**

Appendix

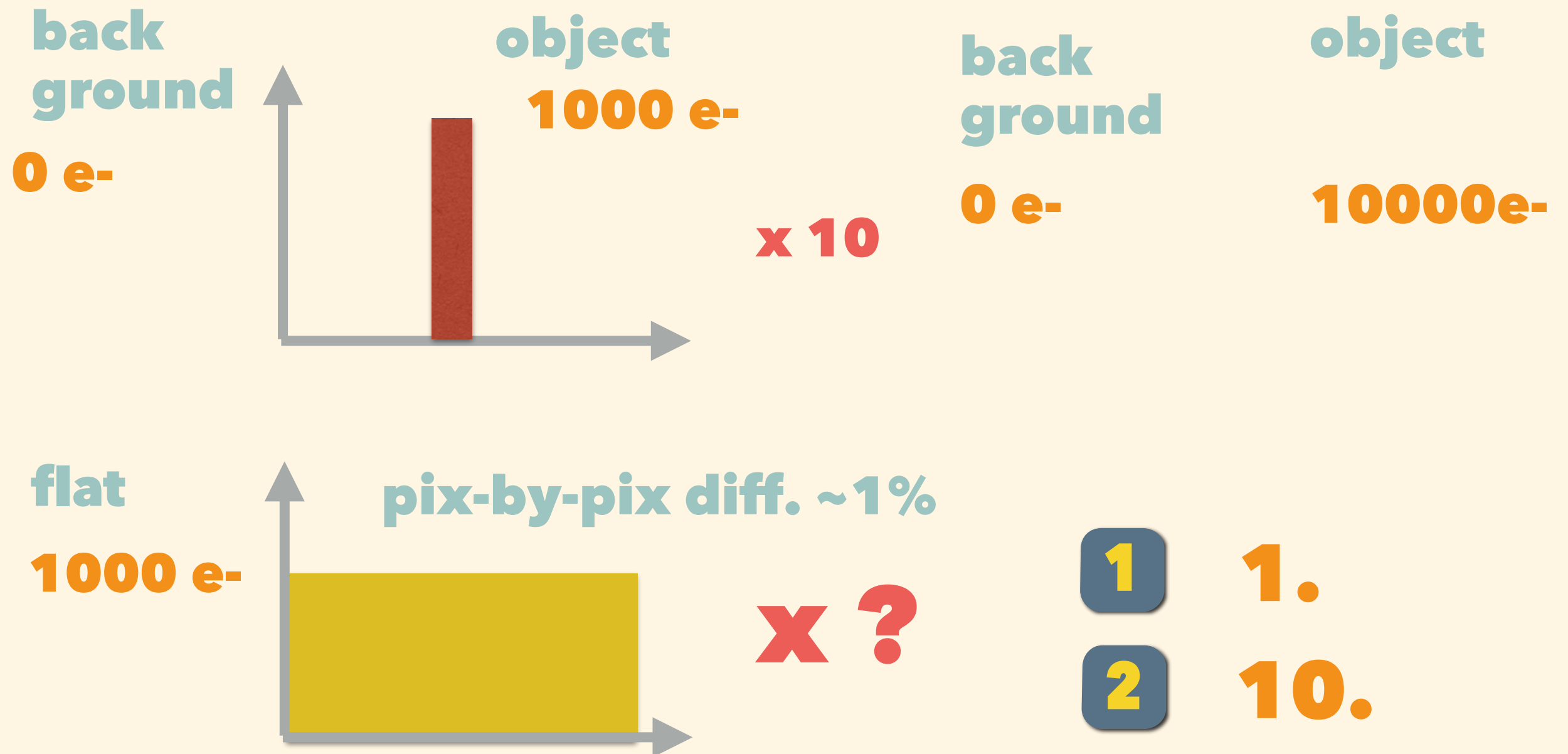
How many flats do we need?



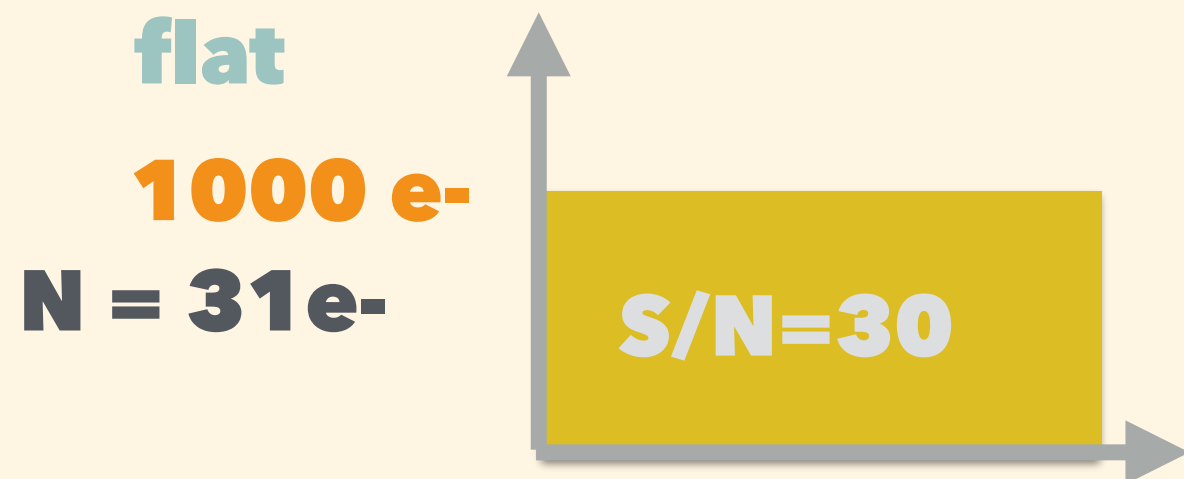
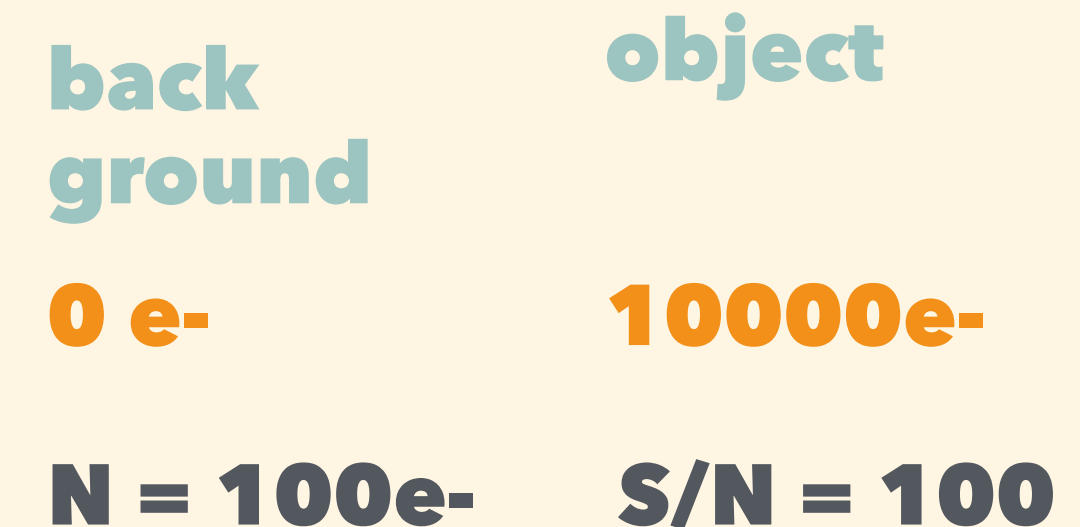
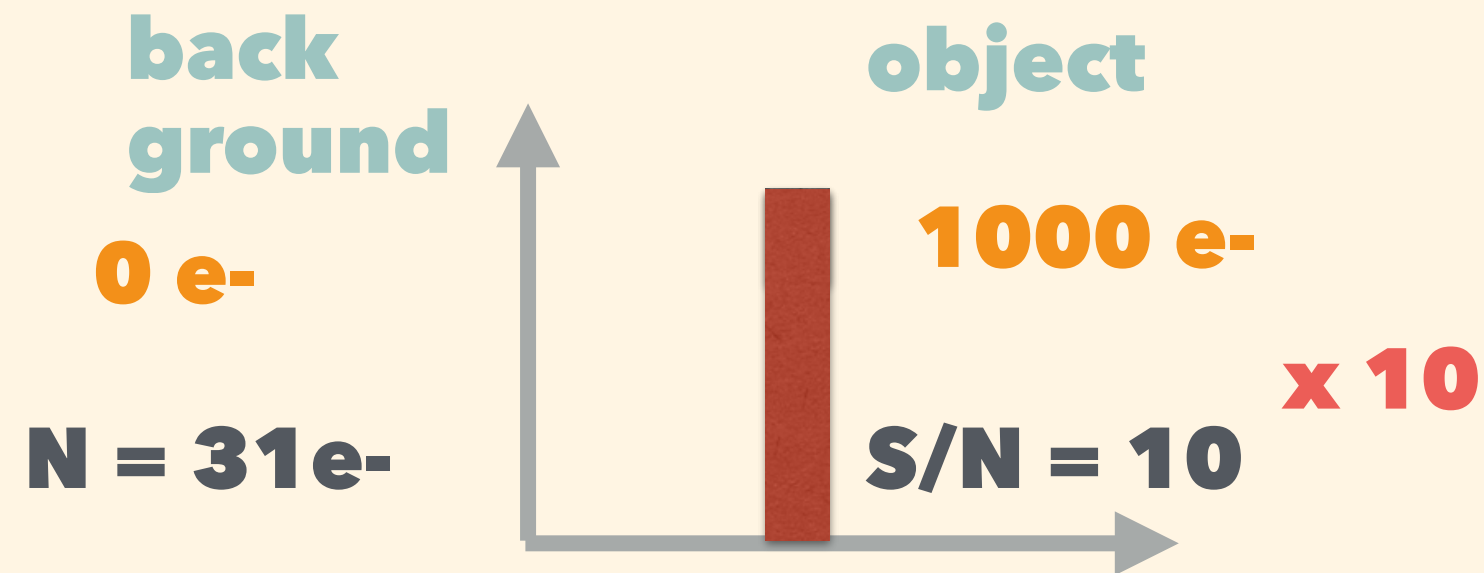
How many flat do we need?



How many flats do we need?

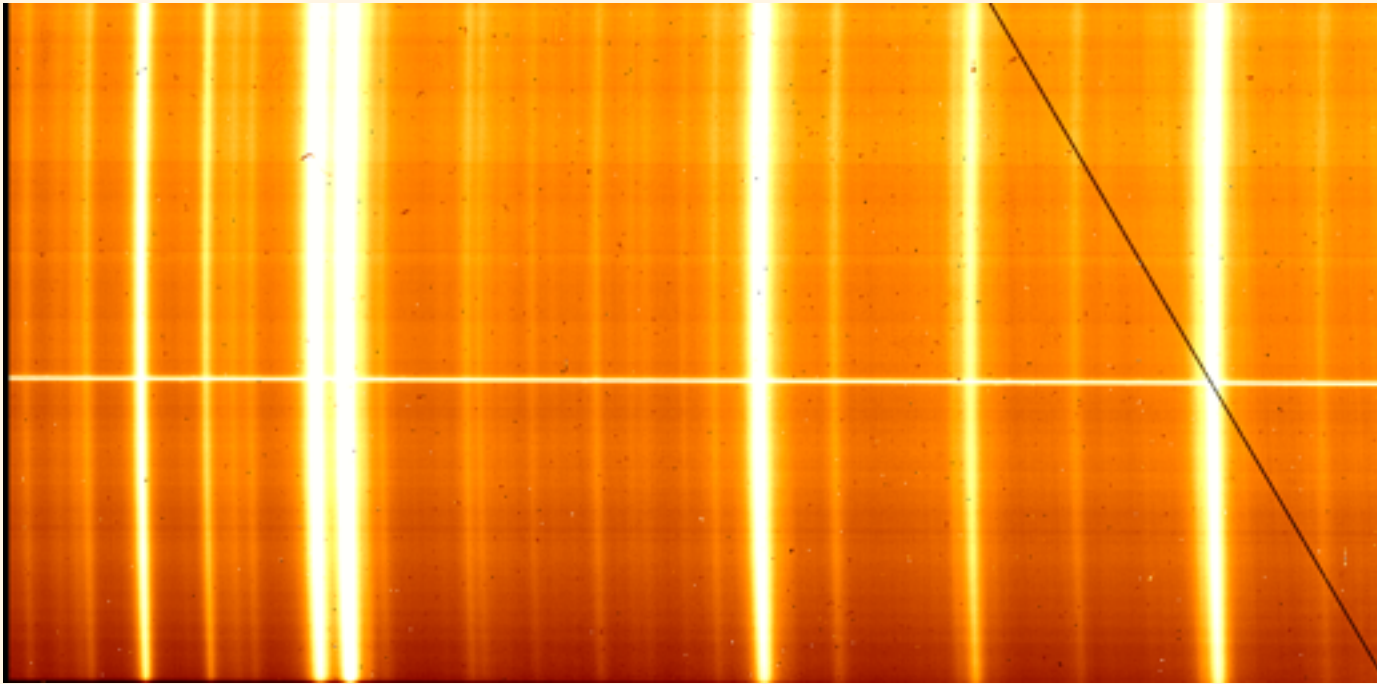


How many flat do we need?



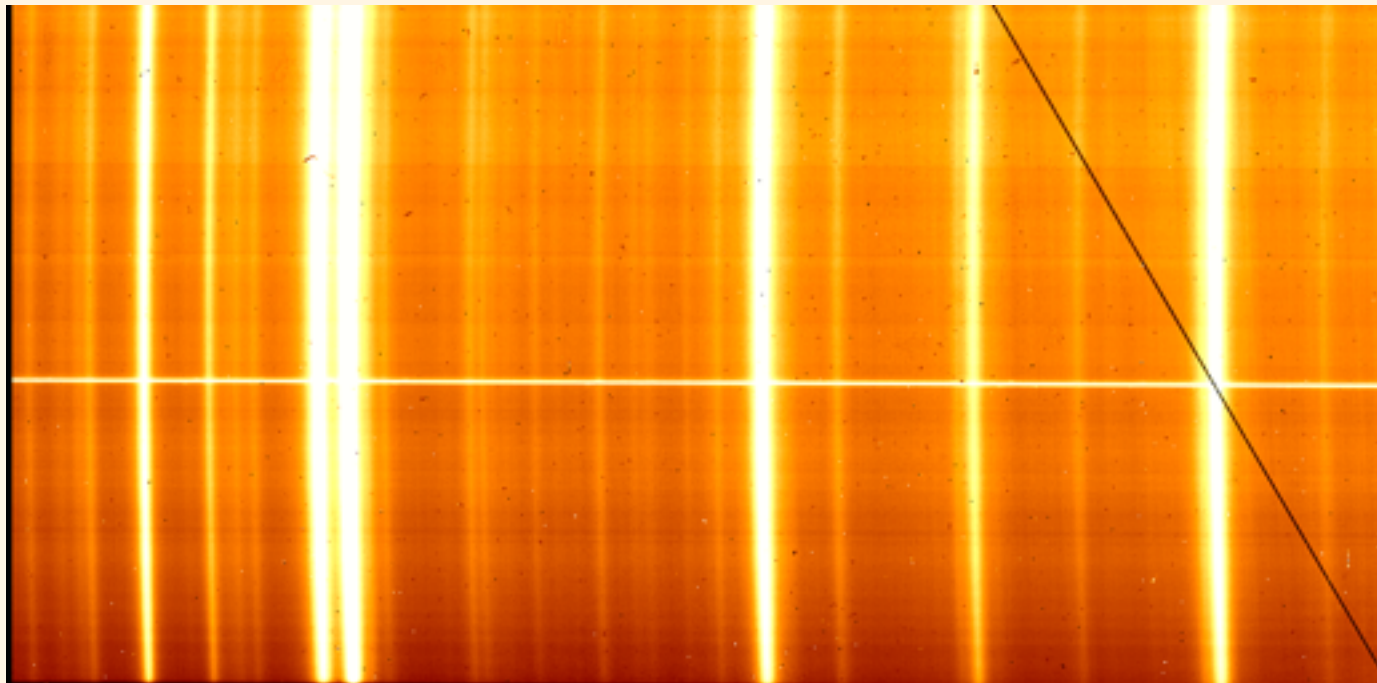
2 10.

if you see spectrum in raw frame,



is the case

if you see spectrum in raw frame,



is the case

2

DIT x NDIT x Ncycle

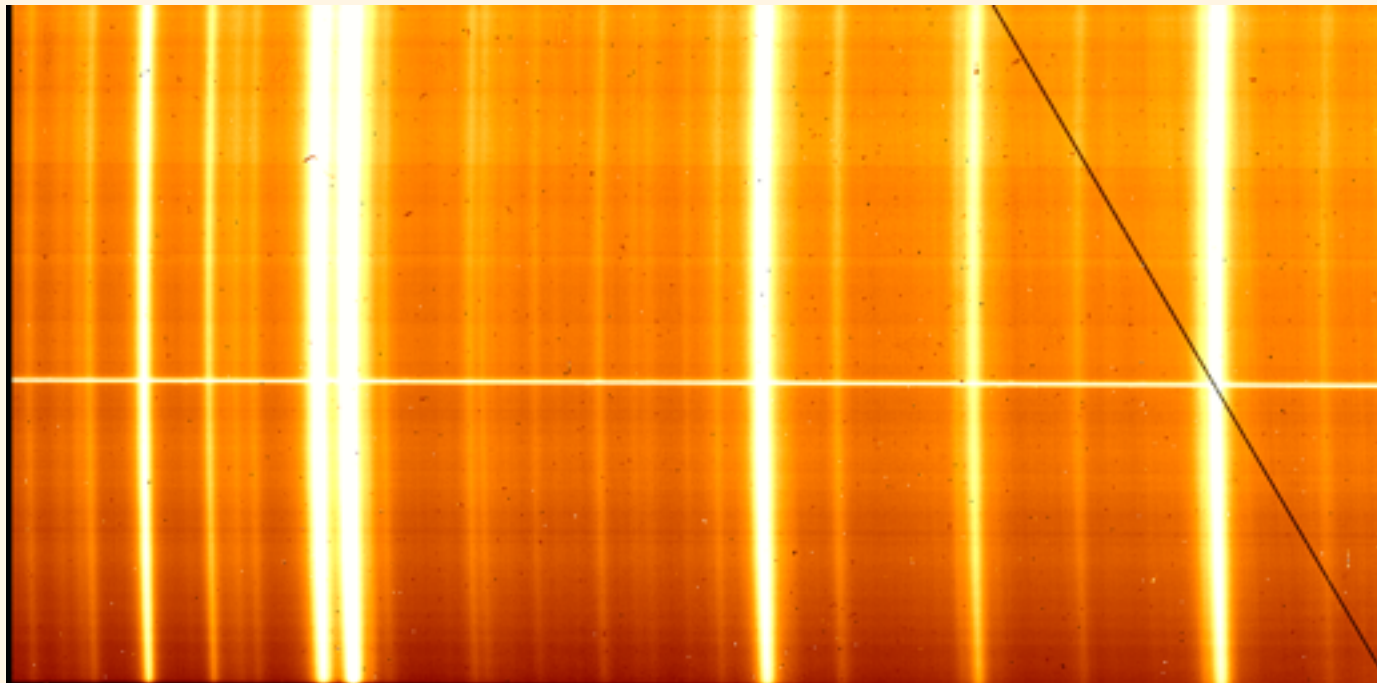
10s x 6 x (4 x 4) = 960

**16 min of
exposure**

6 x 16 = 96 frames of flats

if 1s x 60 x (4 x 4), 960 frames

if you see spectrum in raw frame,



is the case

2

DIT x NDIT x Ncycle

10s x 6 x (4 x 4) = 960

**16 min of
exposure**

6 x 16 = 96 frames of flats

and std as well.