ASTRONOMICAL DATA REDUCTION PHOTOMETRY & SPECTROSCOPY

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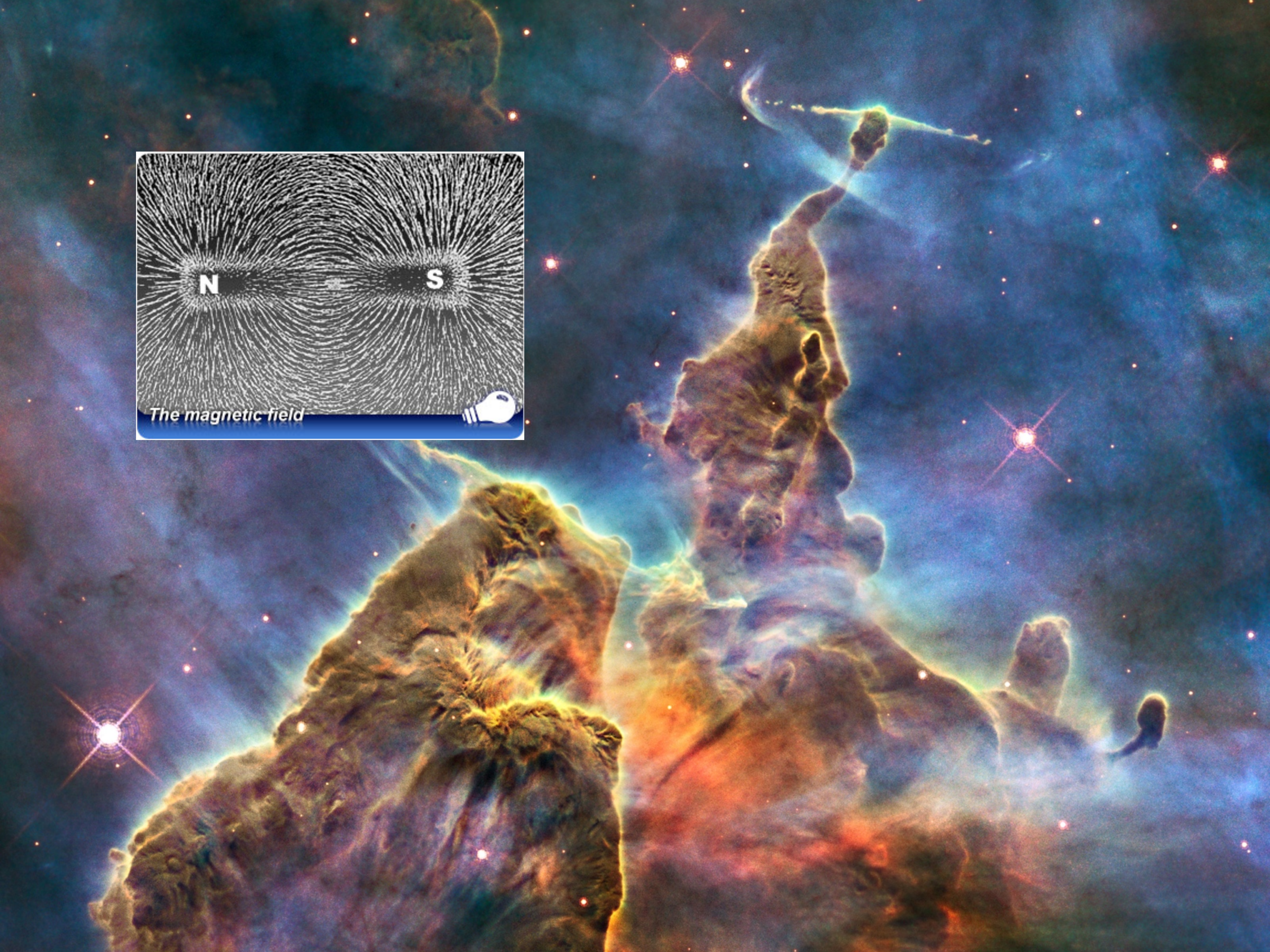
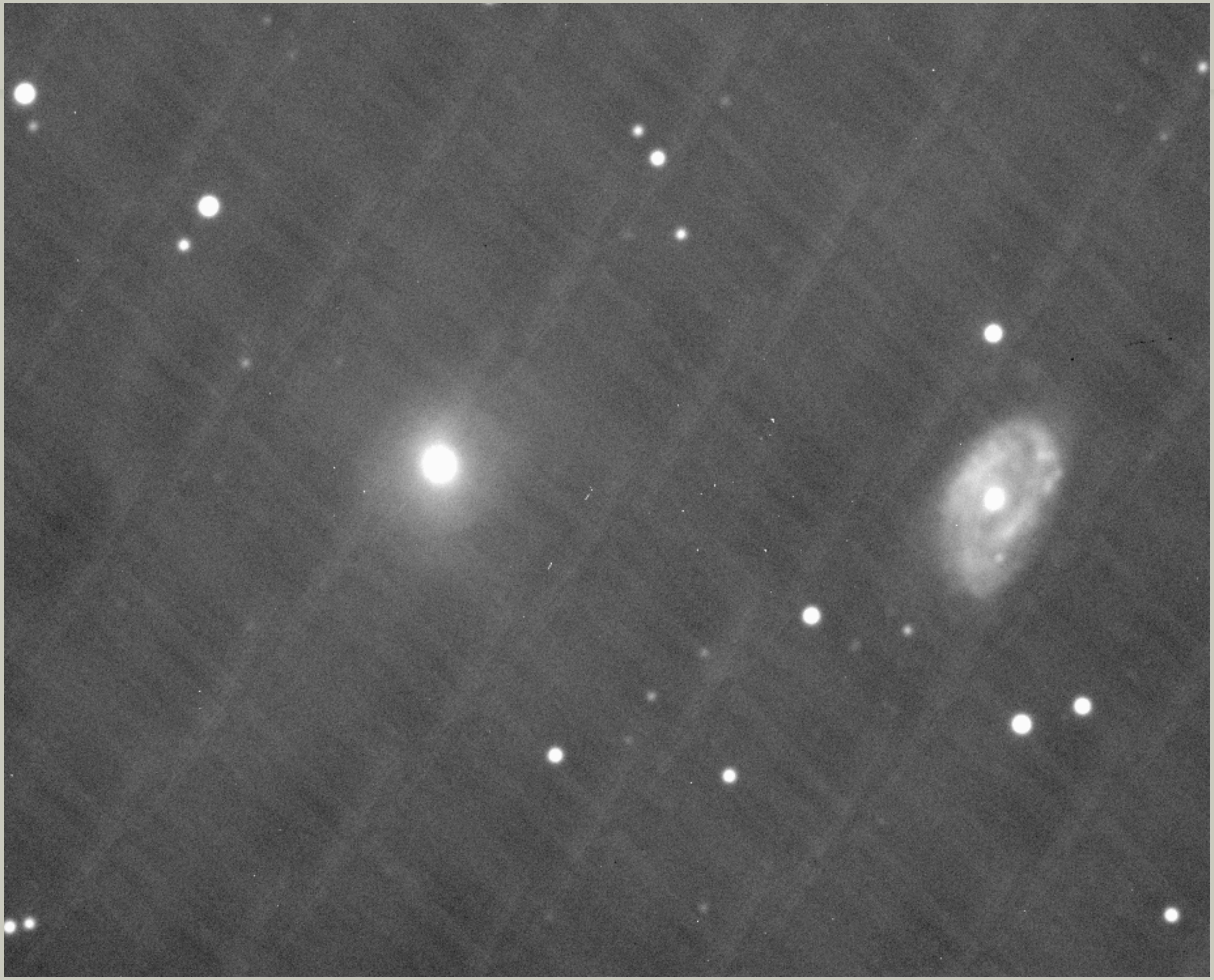
OBSERVATOIRE ASTRONOMIQUE
DE STRASBOURG

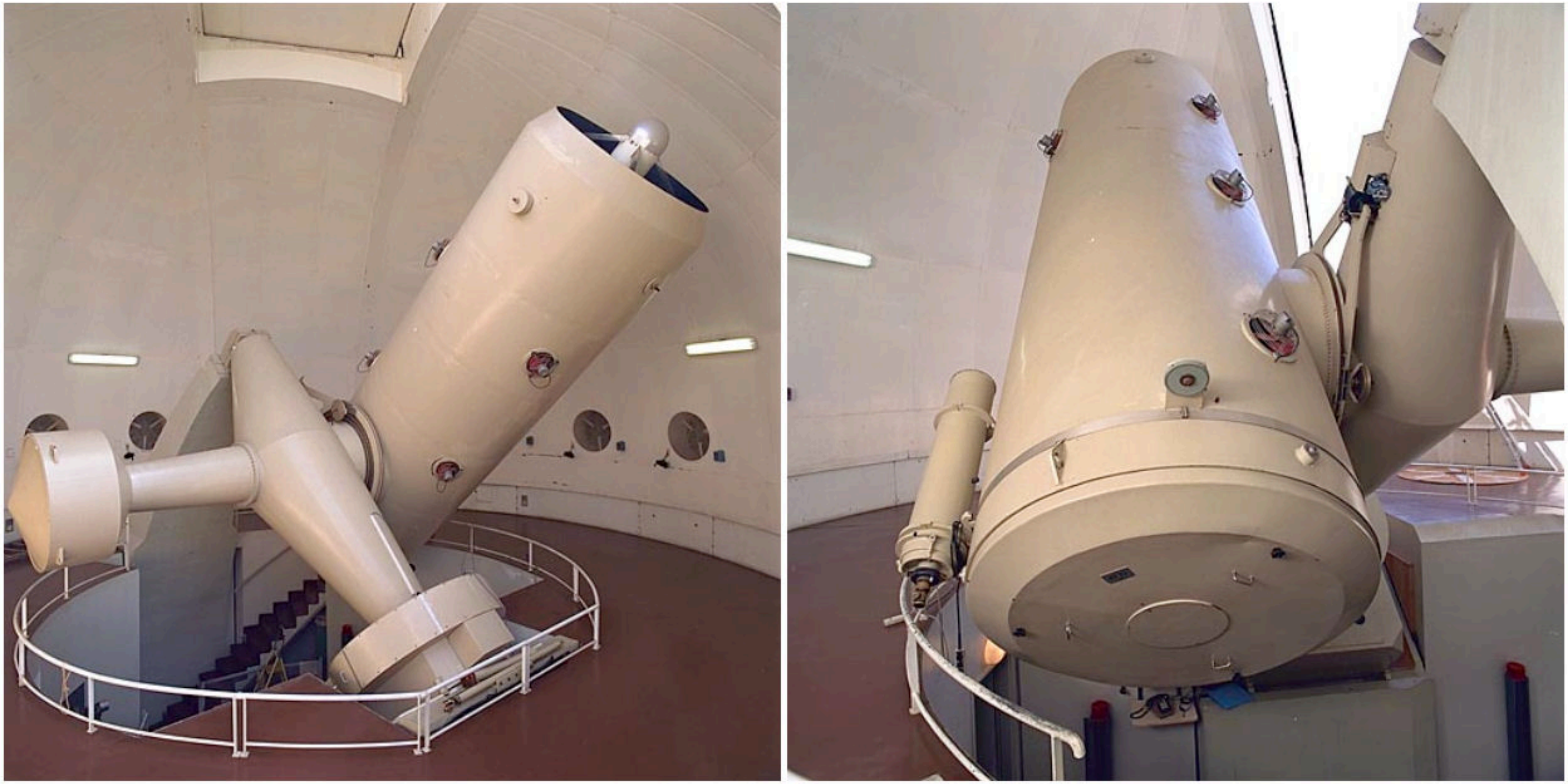
SUMMARY

- GOAL: TO BE OPERATIONAL AT 2T36 AND OHP
- 6X2H (THIS + NEXT WEEK) + OHP (11-15 DEC. 2023)
  - OPTICAL DATA ACQUISITION
  - DATA REDUCTION
    - PRINCIPLES AND ALGORITHMICS
    - ~~IRAF: INTRODUCTION AND TUTORIAL~~
    - PYTHON NOTEBOOKS
    - EXERCISES
  - PREPARATION OHP


N
S
The magnetic field

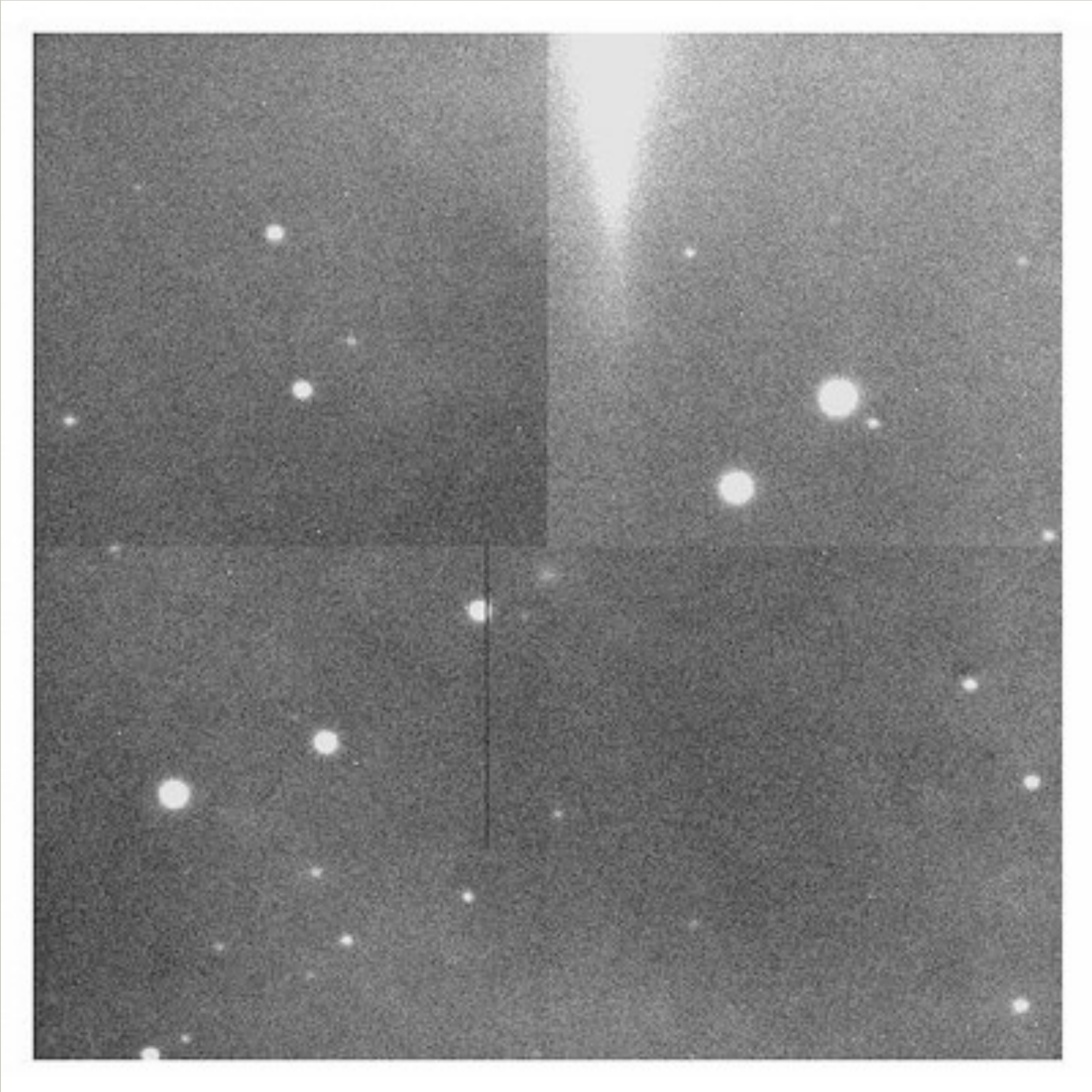
E STRASBOURG



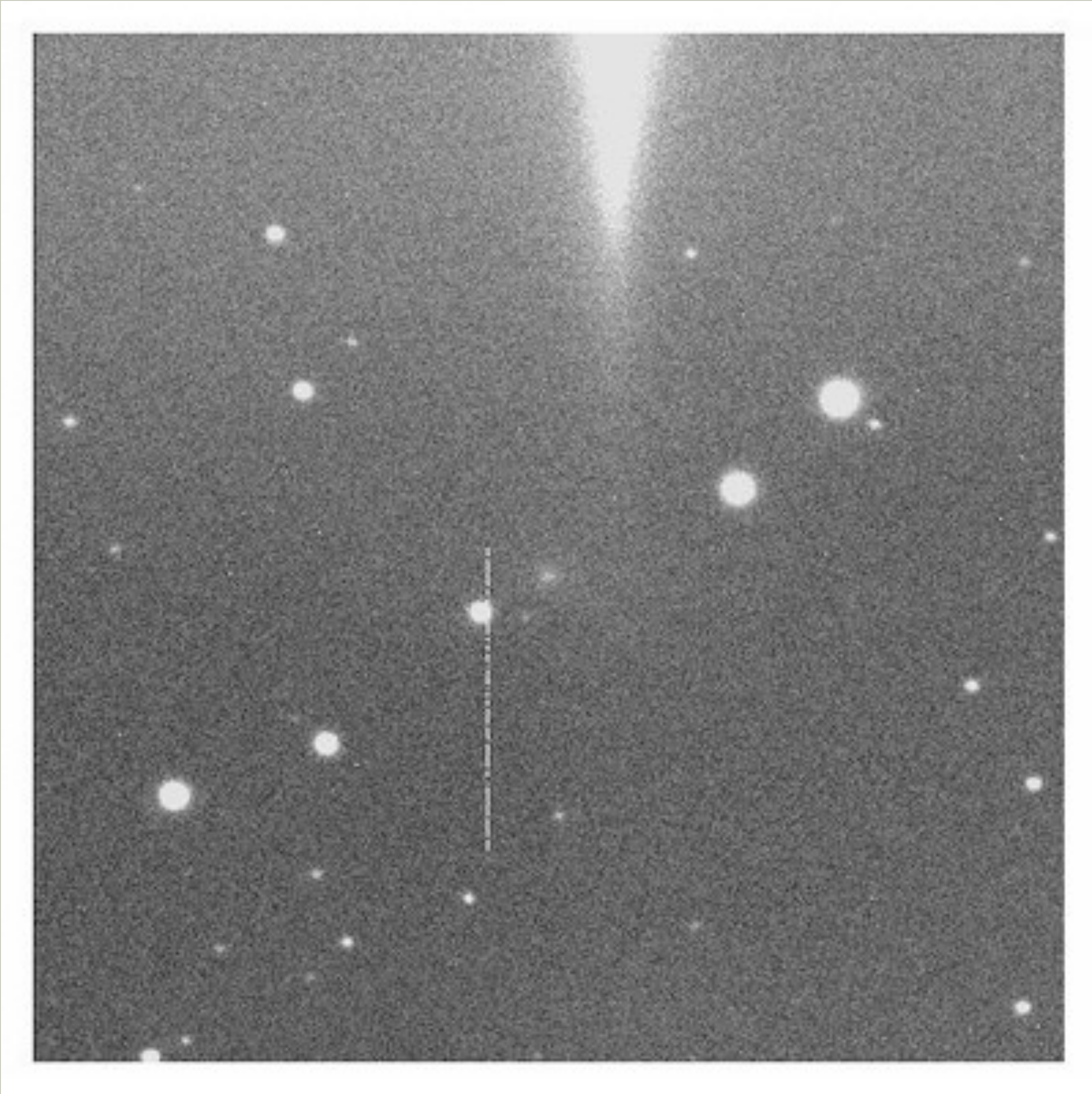


T 152

DATA REDUCTION?



RAW

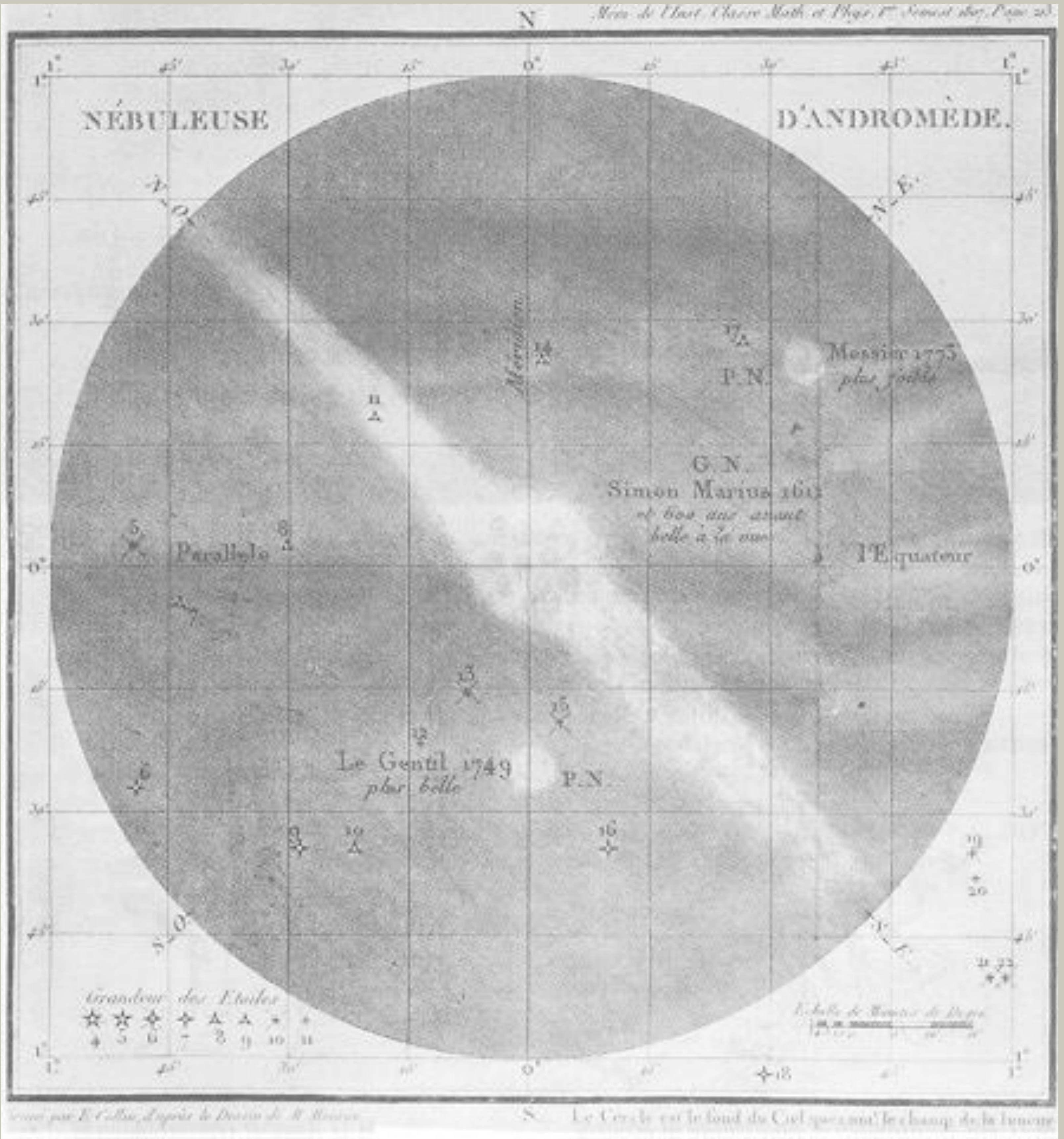


REDUCED

TODAY'S SESSION'S SUMMARY

- 1 - OBSERVATION TECHNIQUES (CCD)
- 2 - PROCESSES ALTERING THE IMAGE
- 3 => CORRECTIONS = DATA REDUCTION
  - IMAGING
  - SPECTROSCOPY

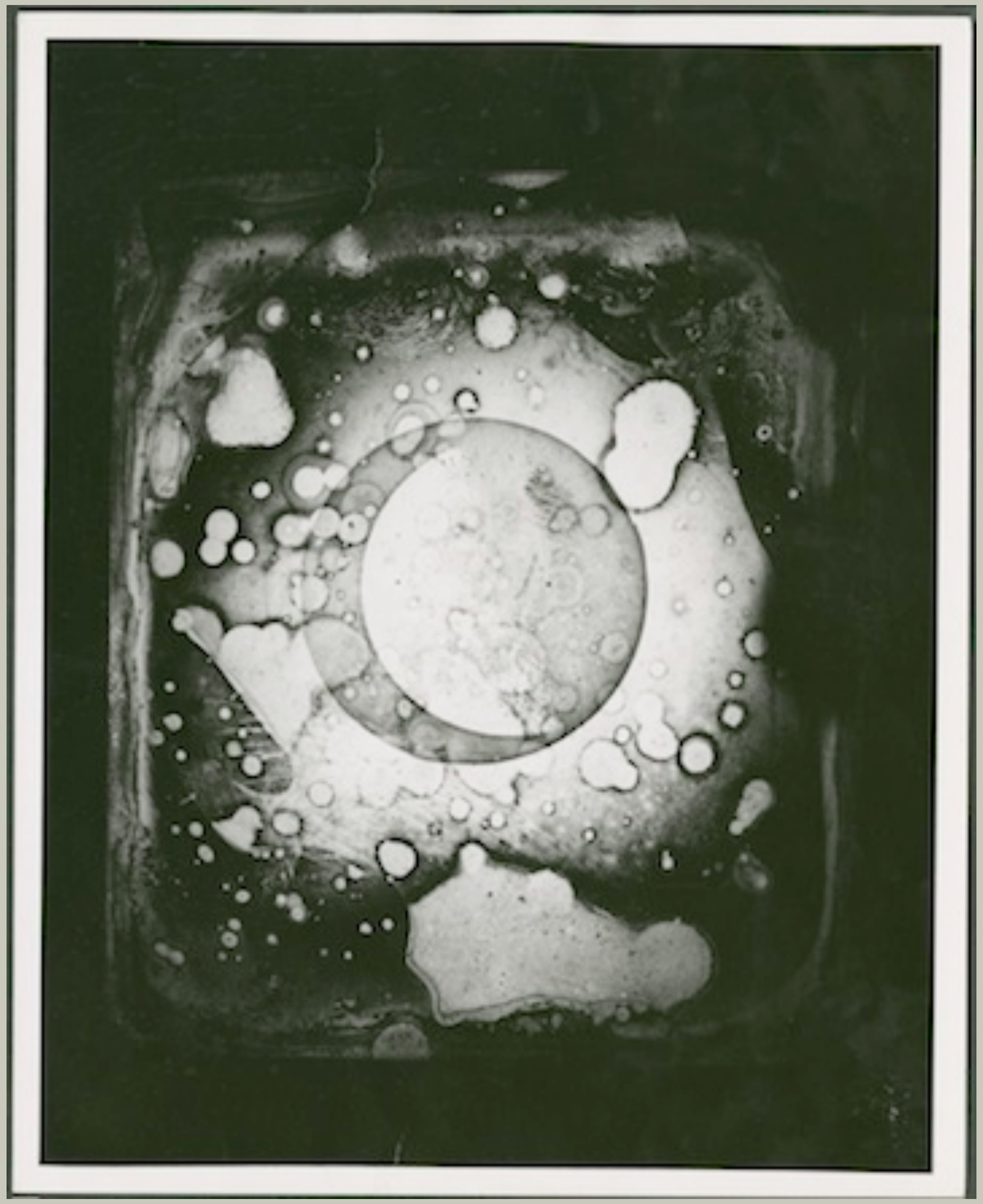
BEFORE THE CCD (1)



M31 (ANDROMEDE)

CHARLES MESSIER
1730-1817

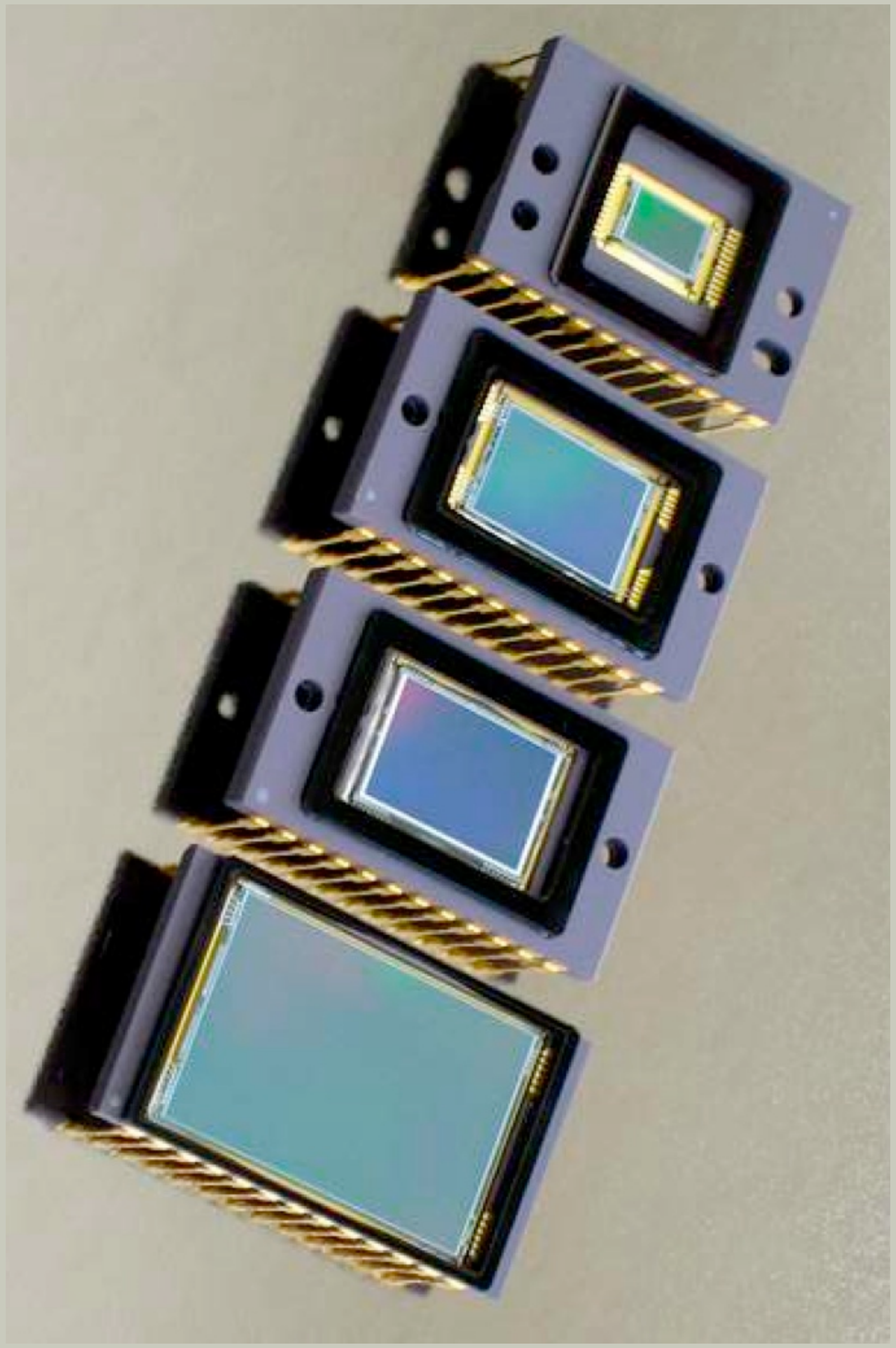
BEFORE THE CCD (2)



- 1839: 1ST ASTRONOMICAL CHEMICAL PHOTOGRAPHY (J. DRAPER)

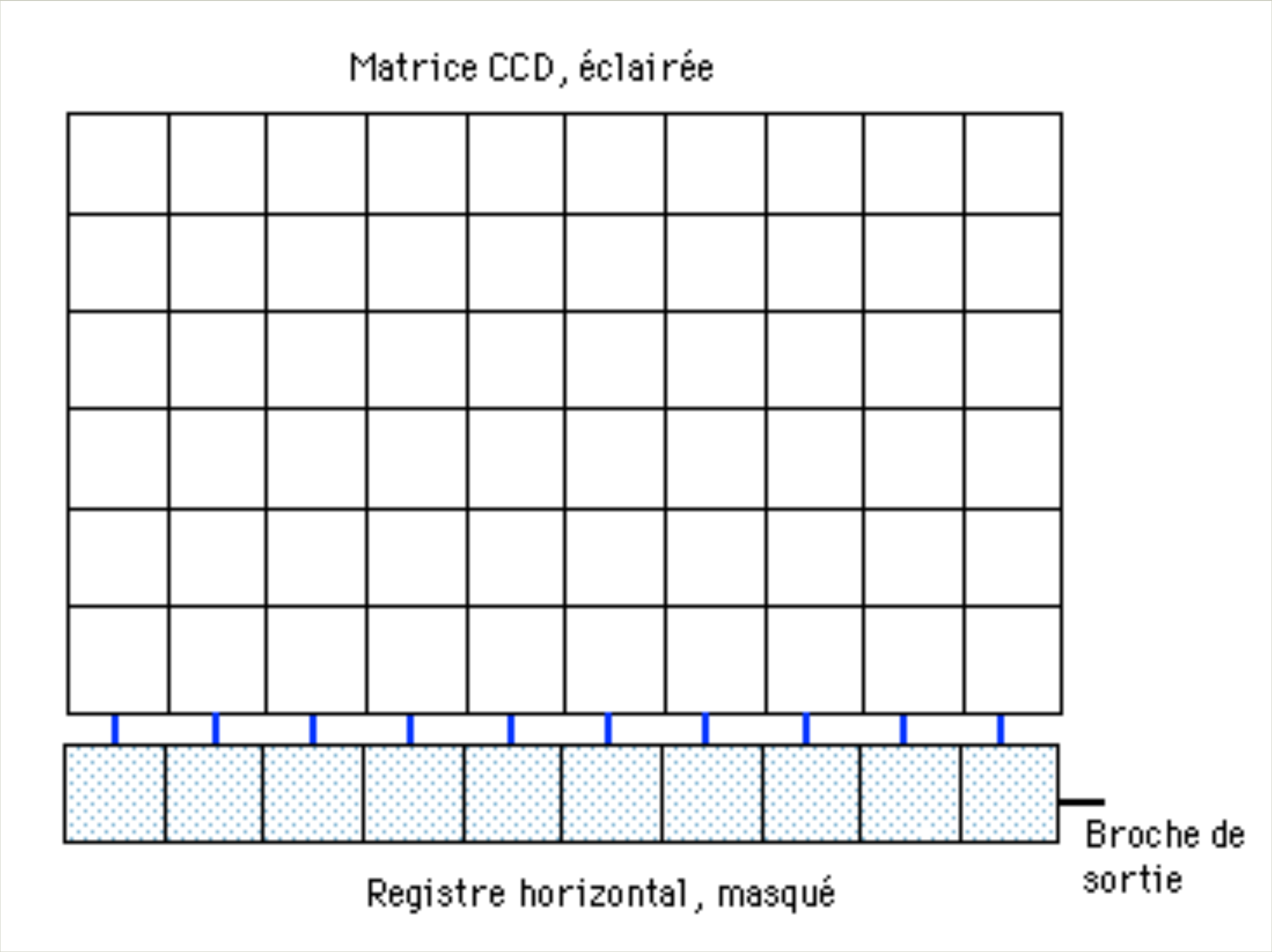
- 1883: ORION NEBULA
- ANDREW AINSLIE COMMON

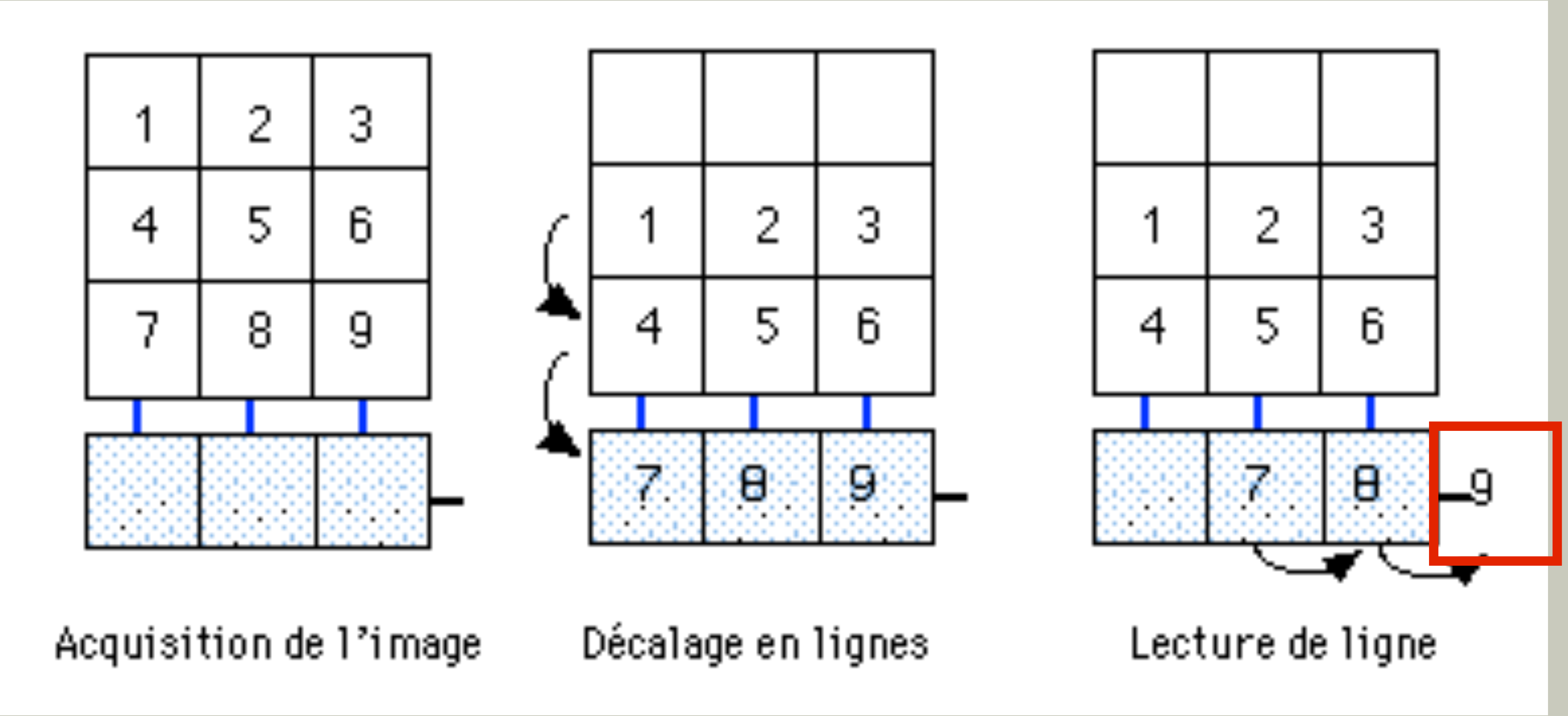
THE CCD (1)



- CHARGE COUPLED DEVICE
- 1969 AT&T (BOYLE & SMITH)
- SEMI-CONDUCTOR
- PHOTO-ELECTRIC EFFECT
- ADVANTAGES:
  - DIGITAL=> AUTOMATISATION
  - QUANTUM EFFICIENCY >80% (2-3% FOR PHOTO)
  - => + ACCURATE + DEEPER

THE CCD (2): PRINCIPLES





- ONLY 1 READOUT REGISTRY => CHEAPER, LESS COMPLEXITY
- SLOW READOUT (UP TO 1 MINUTE, DEPENDING ON TARGET NOISE LEVEL)
- LOW NOISE (READOUT ONLY)
- WIDELY ADOPTED TECH BUT NOT UNIQUE (SEE NIR, X-RAY)

2 - IMAGE ALTERATIONS

- INSIDE THE CCD
- OPTICAL SYSTEM (TELESCOPE)
- ATMOSPHERE

CCD PROPERTIES

- SENSITIVITY = F(LAMBDA)
- BIAS/OFFSET
- DARK CURRENT
- NON-UNIFORM SENSITIVITY
  - FRINGING
- TRANSFER INEFFICIENCY
- READOUT NOISE

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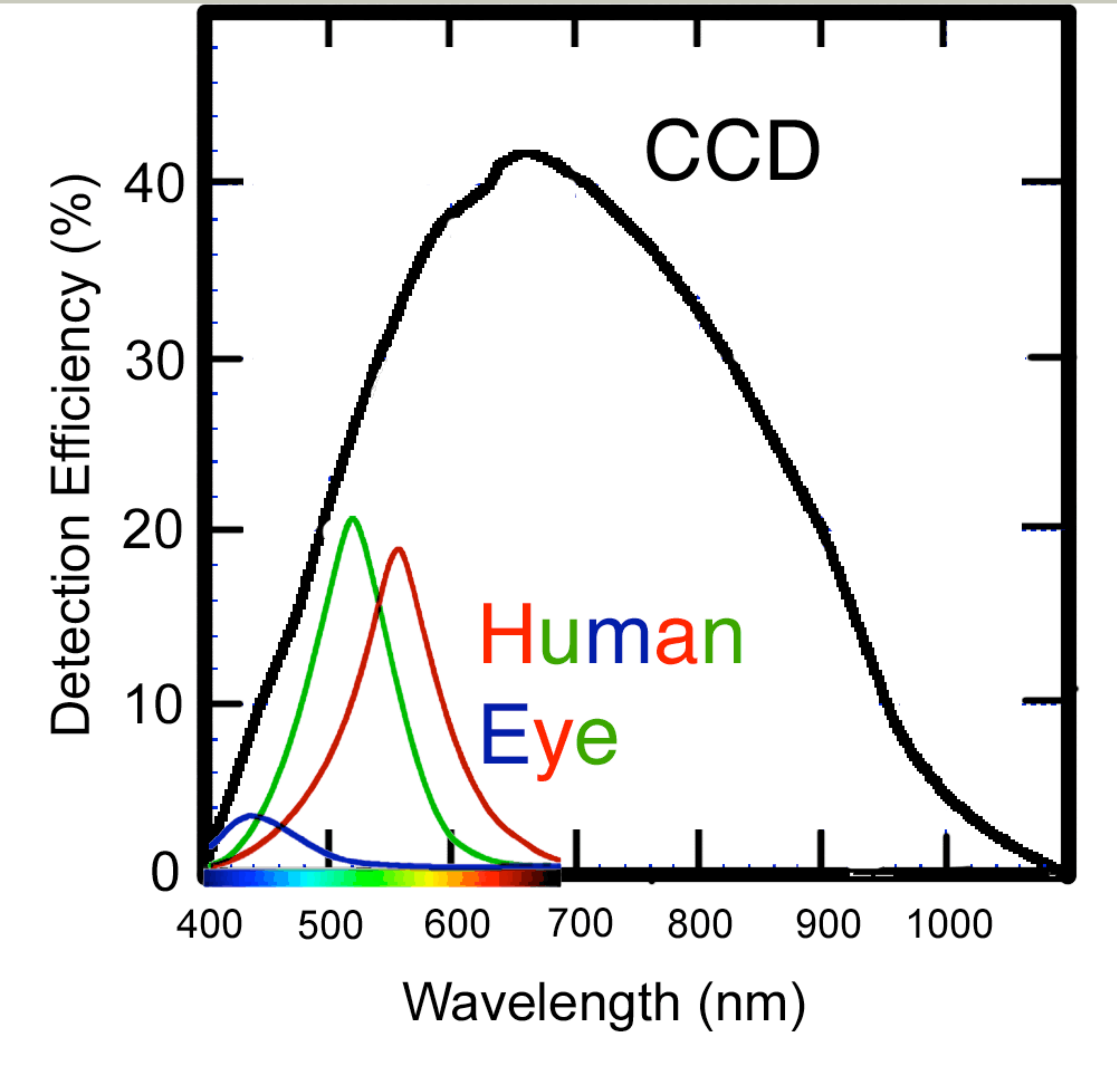

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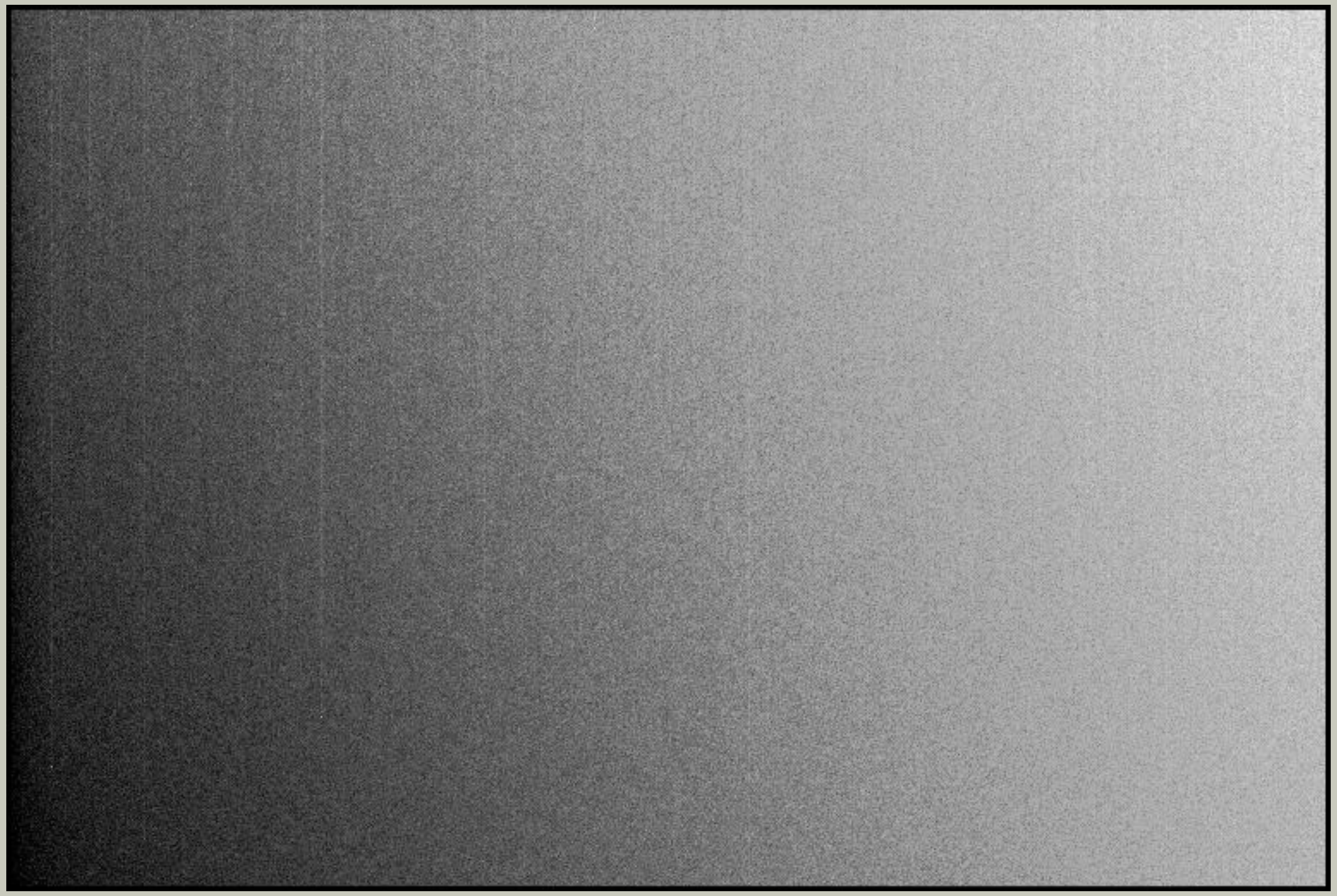

- 0-LEVEL OF CCD
- (GUARANTEES SIGNAL > 0)
- STATIONARY (NO TIME VARIATION)
- POSSIBLY NON UNIFORM

CCD PROPERTIES

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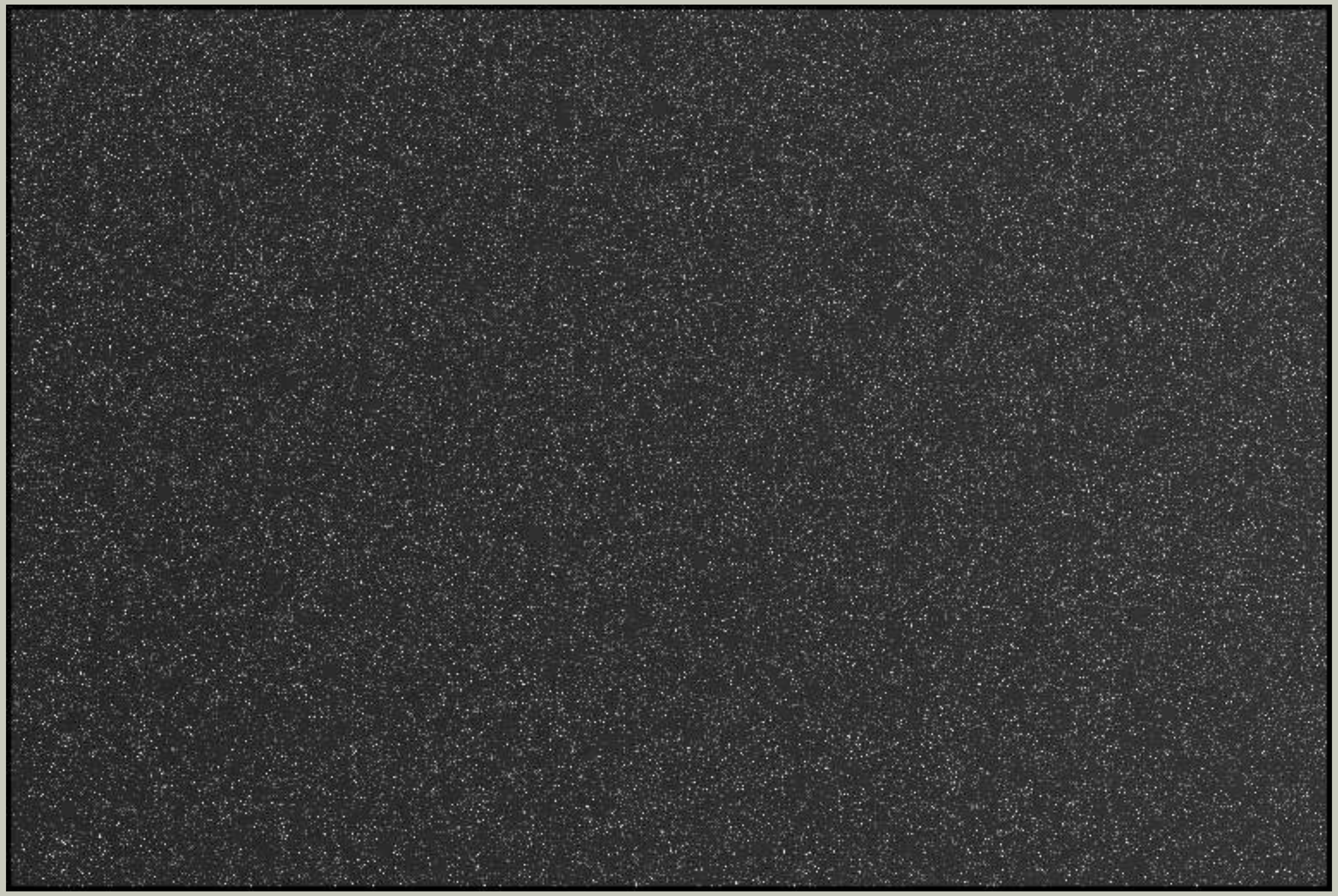

- THERMAL MOTIONS => CHARGE CREATION
- =>F(TEMP,TEXP)
- ~UNIFORM?

CCD PROPERTIES

- SENSITIVITY = F(LAMBDA)
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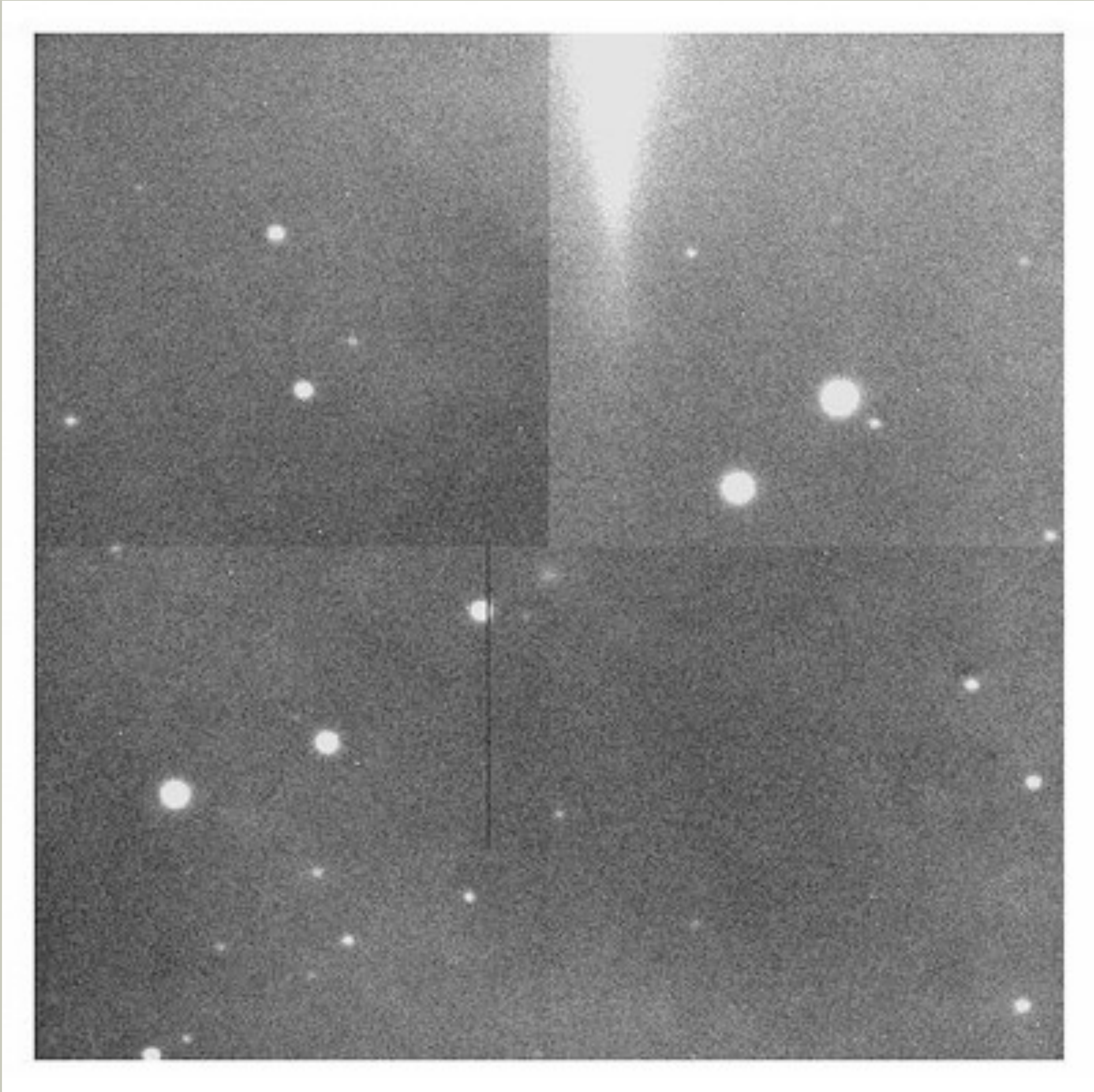

- PIXEL NON-UNIFORMITY
- NON-UNIFORM ILLUMINATION (DUE TO MIRROR IMPERFECTIONS)

CCD PROPERTIES

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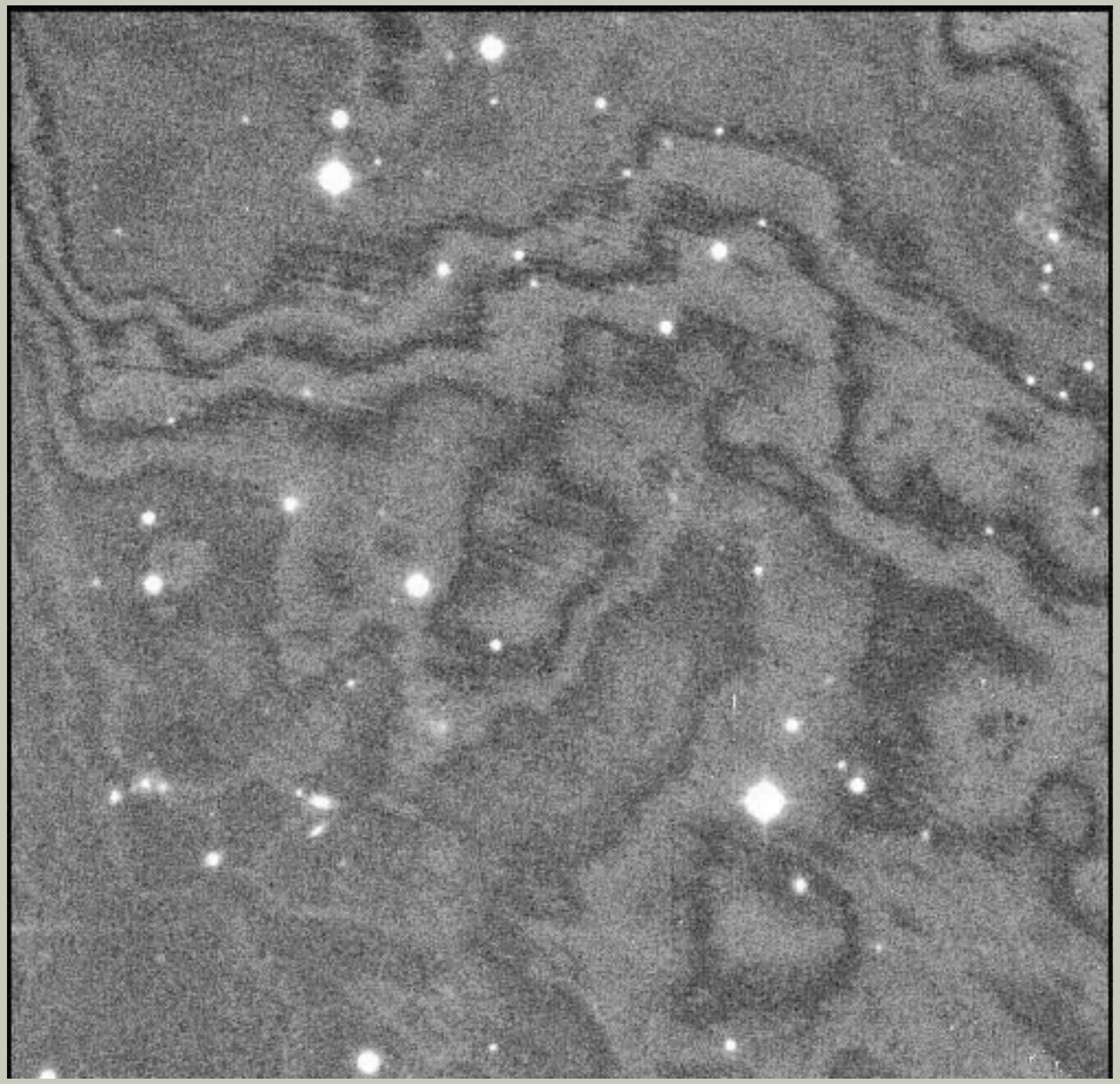

- LAMBDA ~ PIXEL THICKNESS
- => INTERFERENCE PATTERN
- (~THIN FILM)

CCD PROPERTIES

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CORRECTIBLE!!!

CCD PROPERTIES

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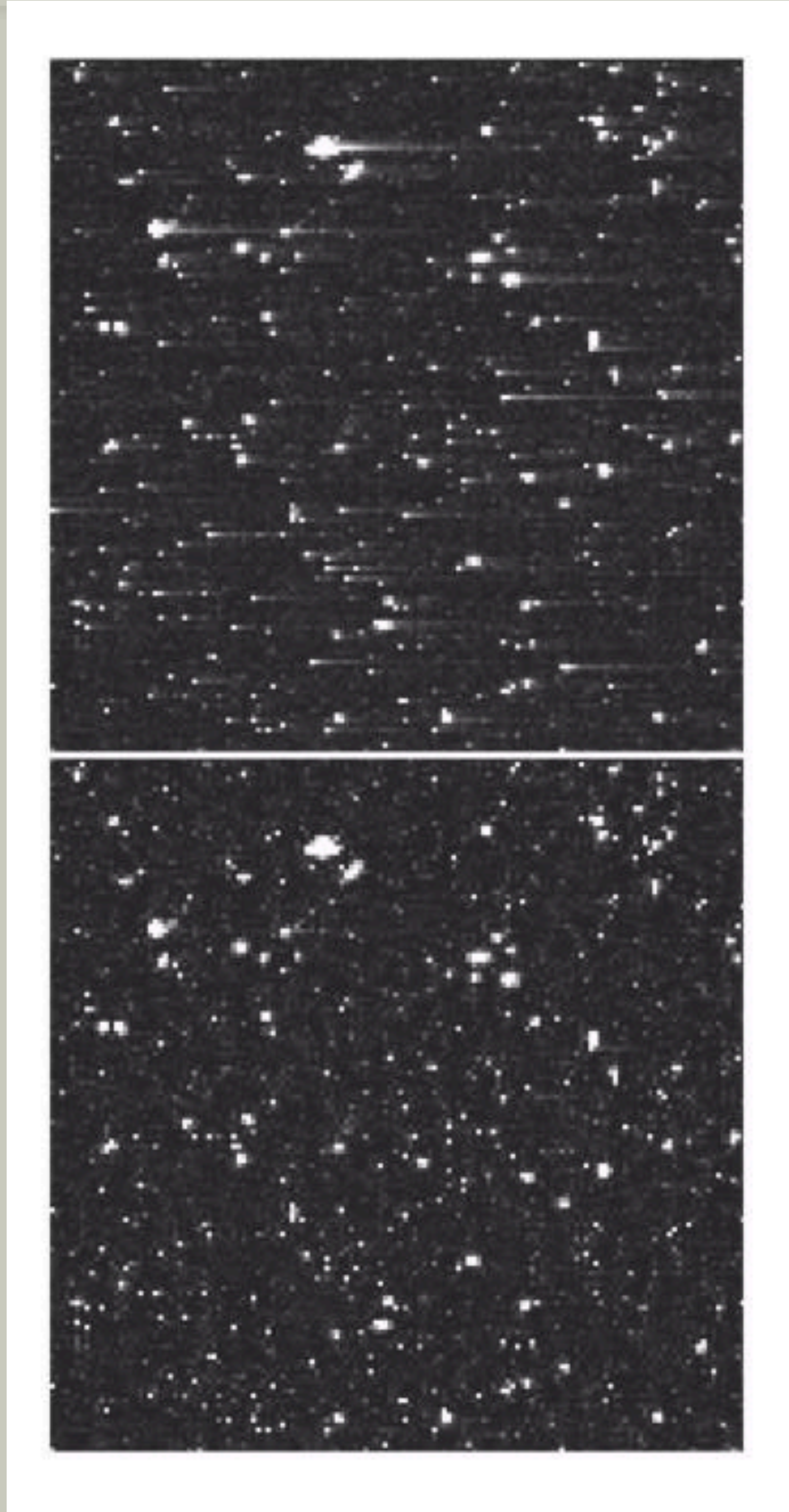
- READOUT NOISE

TAKEN FROM HST ACS DATA HANDBOOK

RAW

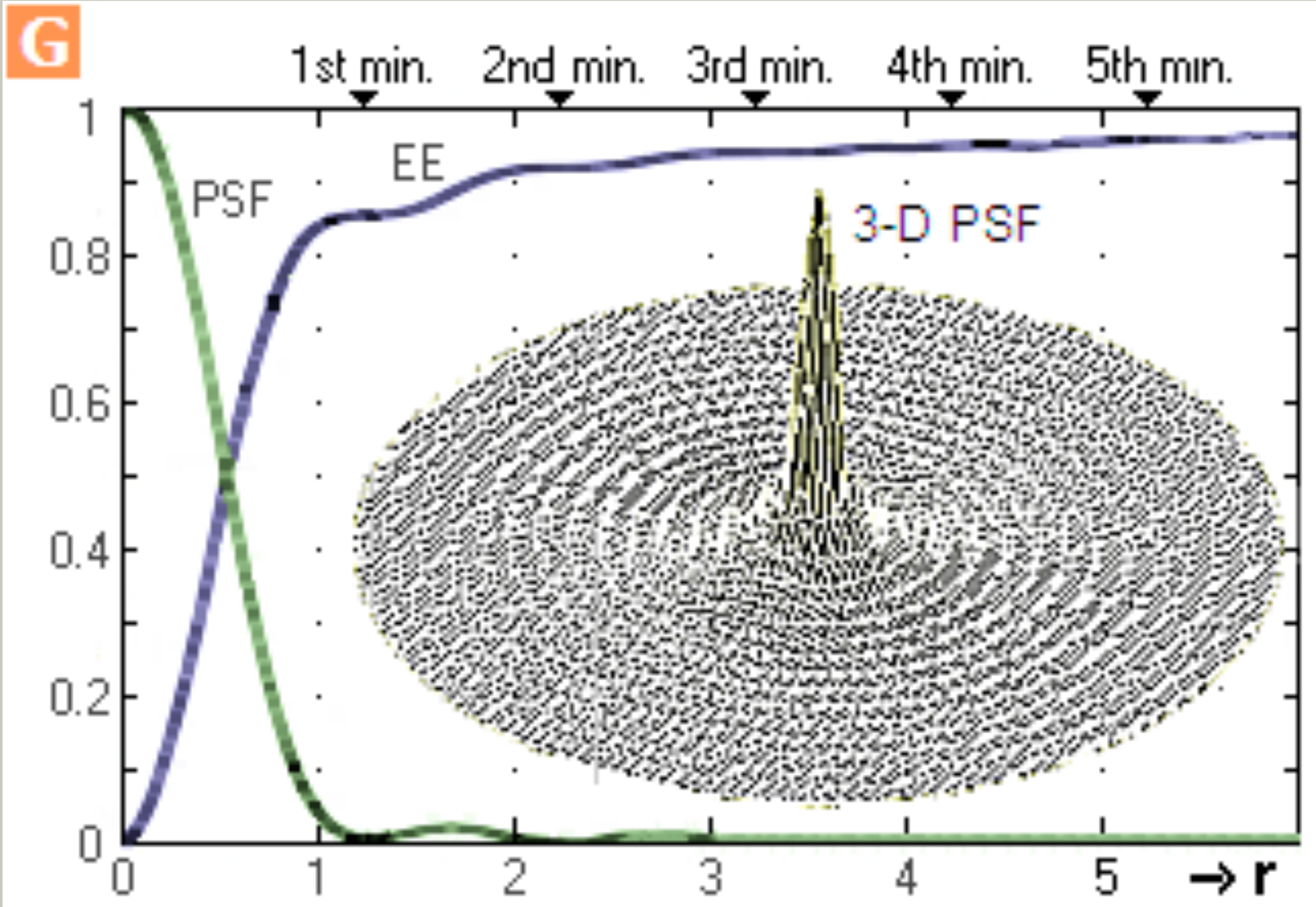
CORRECTED

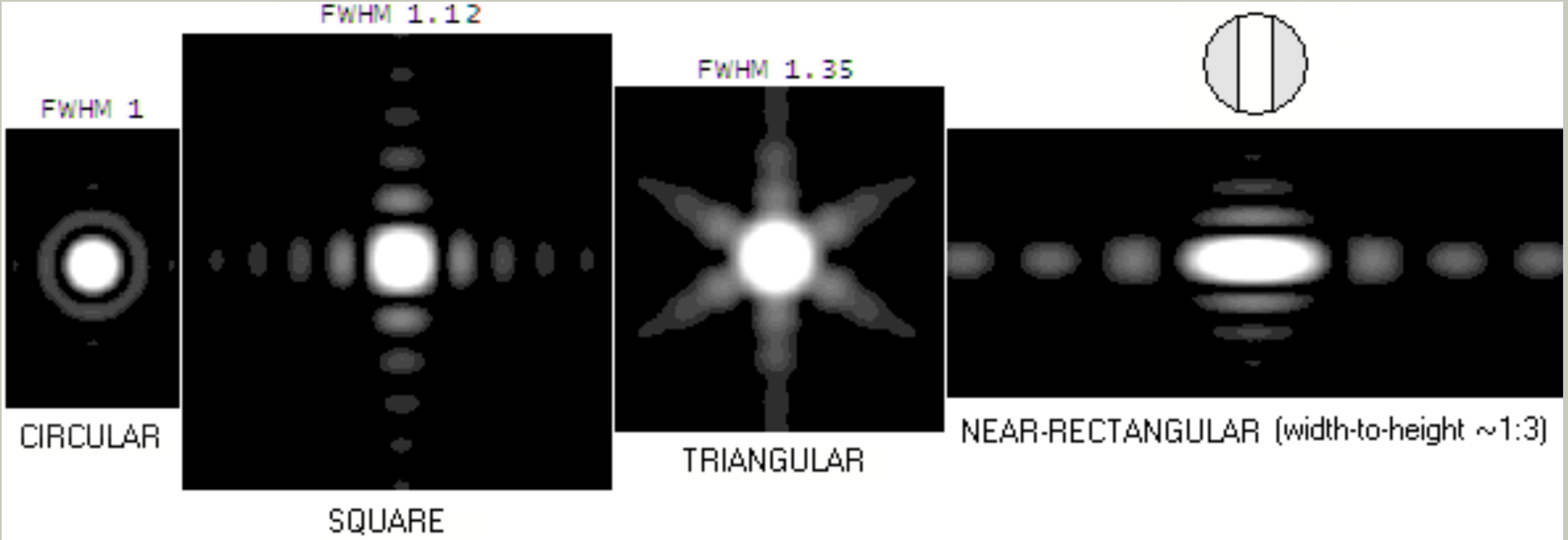


CTI (CHARGE TRANSFER INEFFICIENCY) IS AGGRAVATED BY RADIATION DAMAGE

OPTICAL SYSTEM (TELESCOPE)

- DIFFRACTION: AIRY DISC FWHM ~ 0.05 ARCSEC => **PSF**
- SINC=> THETA=1.22 LAMBDA/D
- EMISSION (MIRROR = BLACK BODY=>NIR-FIR, OPTICAL = OK)





SYTEME OPTIQUE (TELESCOPE)

- DIFFRACTION: AIRY DISC FWHM ~ 0.05 ARCSEC => **PSF**
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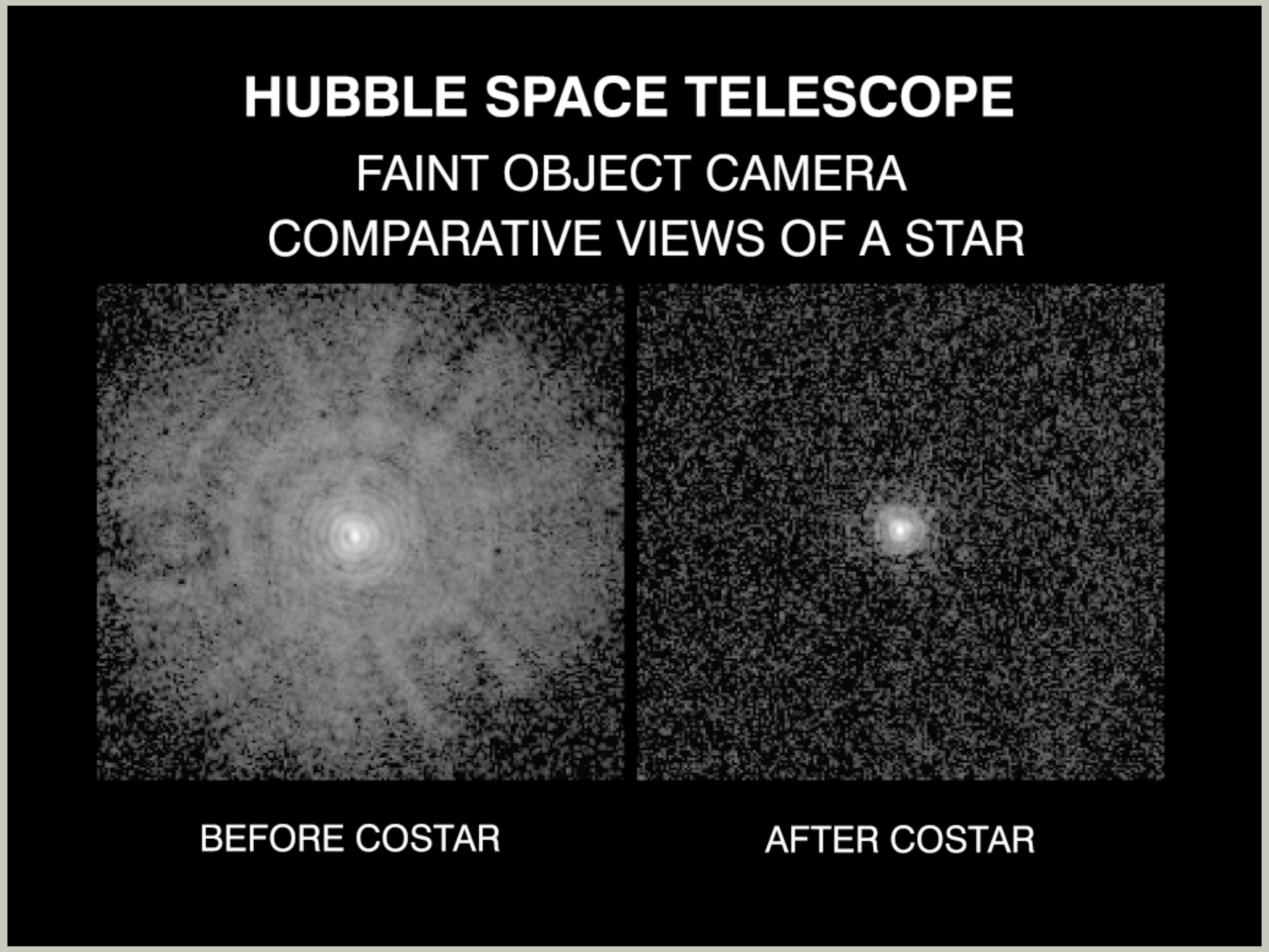
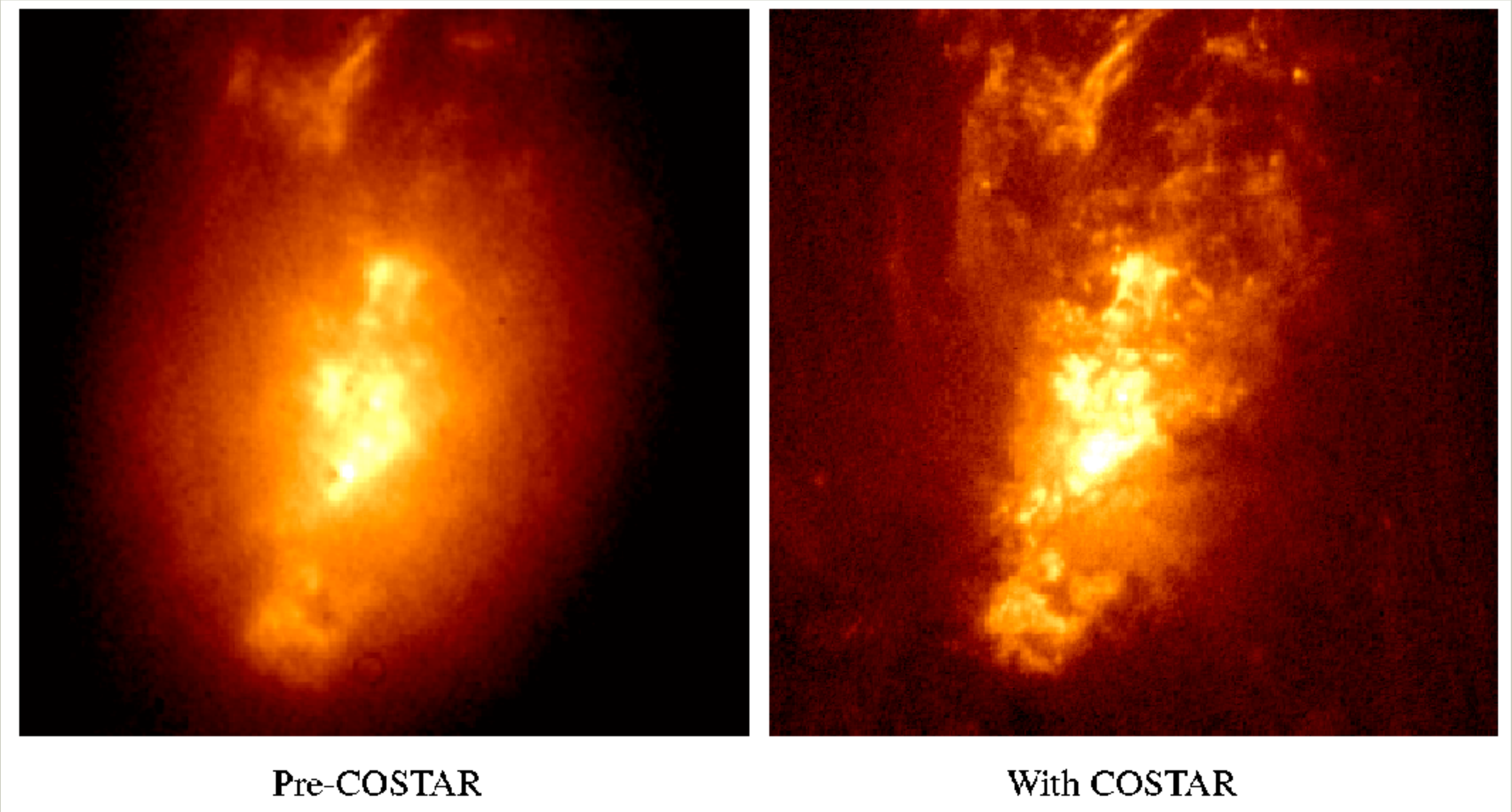
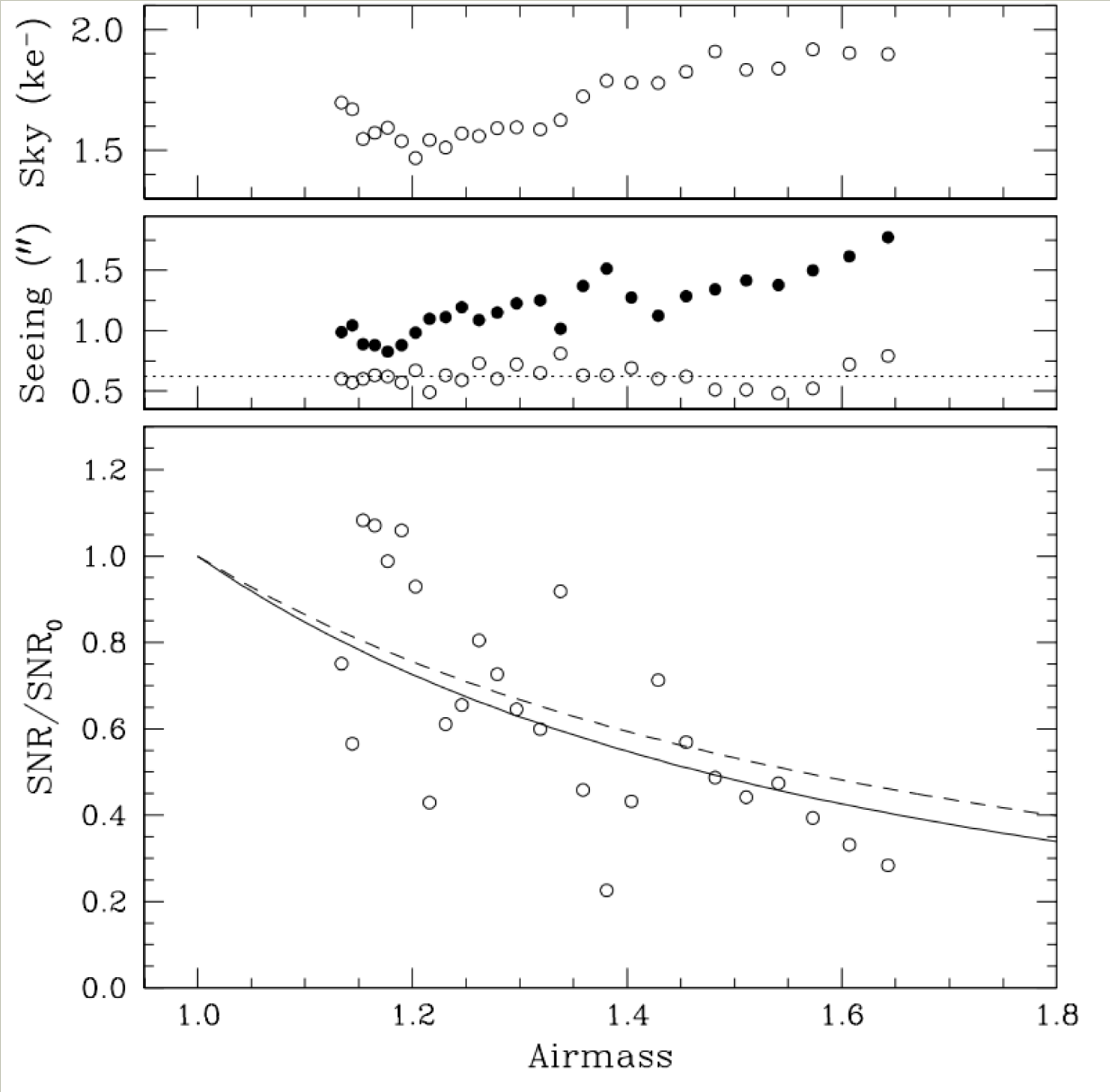




ATMOSPHERE

- SKY BACKGROUND (=F(AIRMASS, TIME, MOON, CLOUDS))
- TURBULENCE
  - => SEEING (~1 ARCSEC A PARANAL)
  - => DIFFRACTION TEL NEGLIGEABLE (0.05 ARCSEC)
- REFRACTION DIFFERENTIELLE (=F(LAMBDA)
- DIFFUSION OF SOURCE PHOTONS



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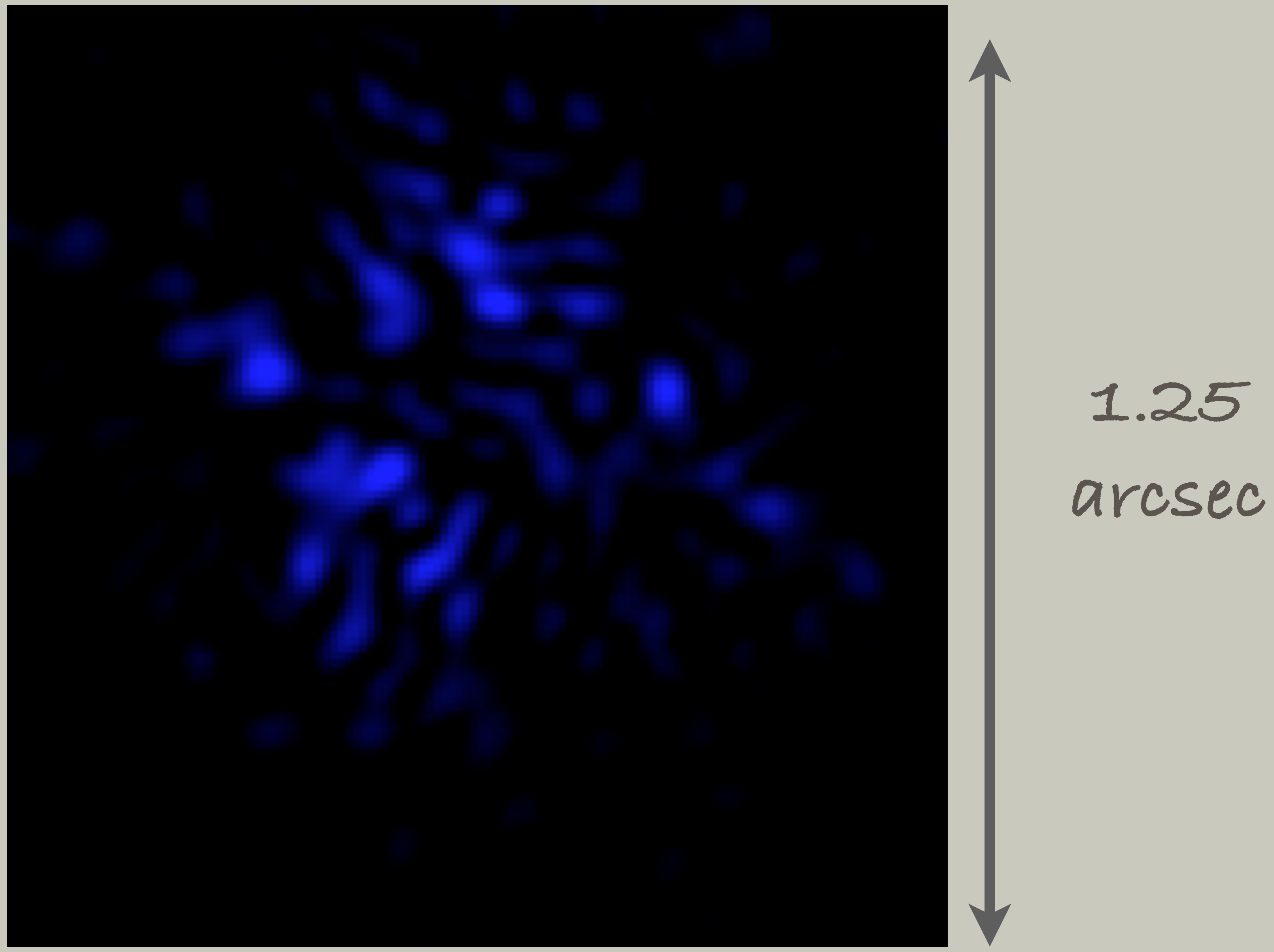

(NICK KAISER, 8000 ANGSTROM)

SLOWDOWN X 100

ATMOSPHERE AND BEYOND

- PLANES
- SATELLITES
- COSMIC RAYS
- PHOTON SHOT NOISE

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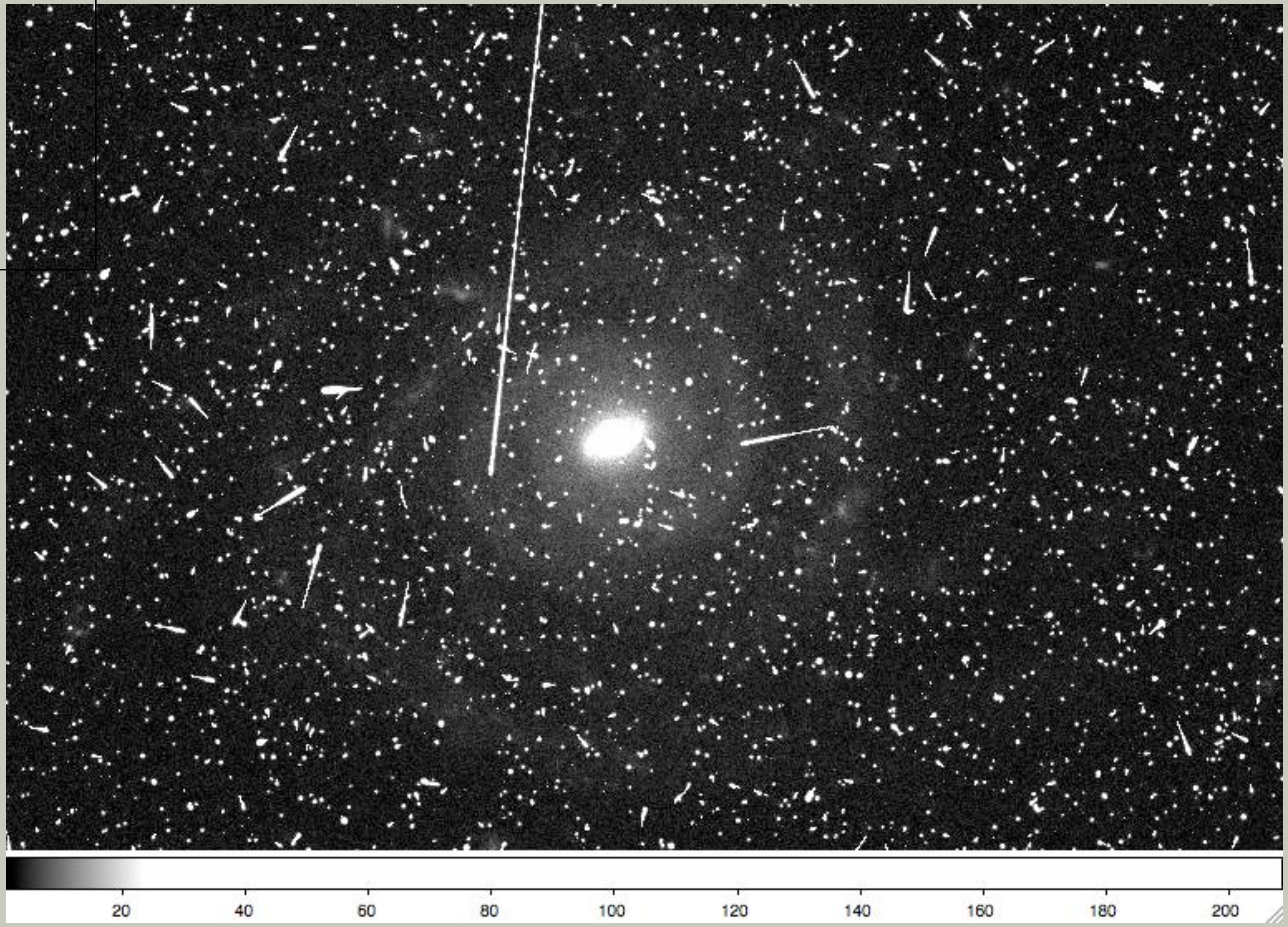

ATMOSPHERE AND BEYOND

- PLANES
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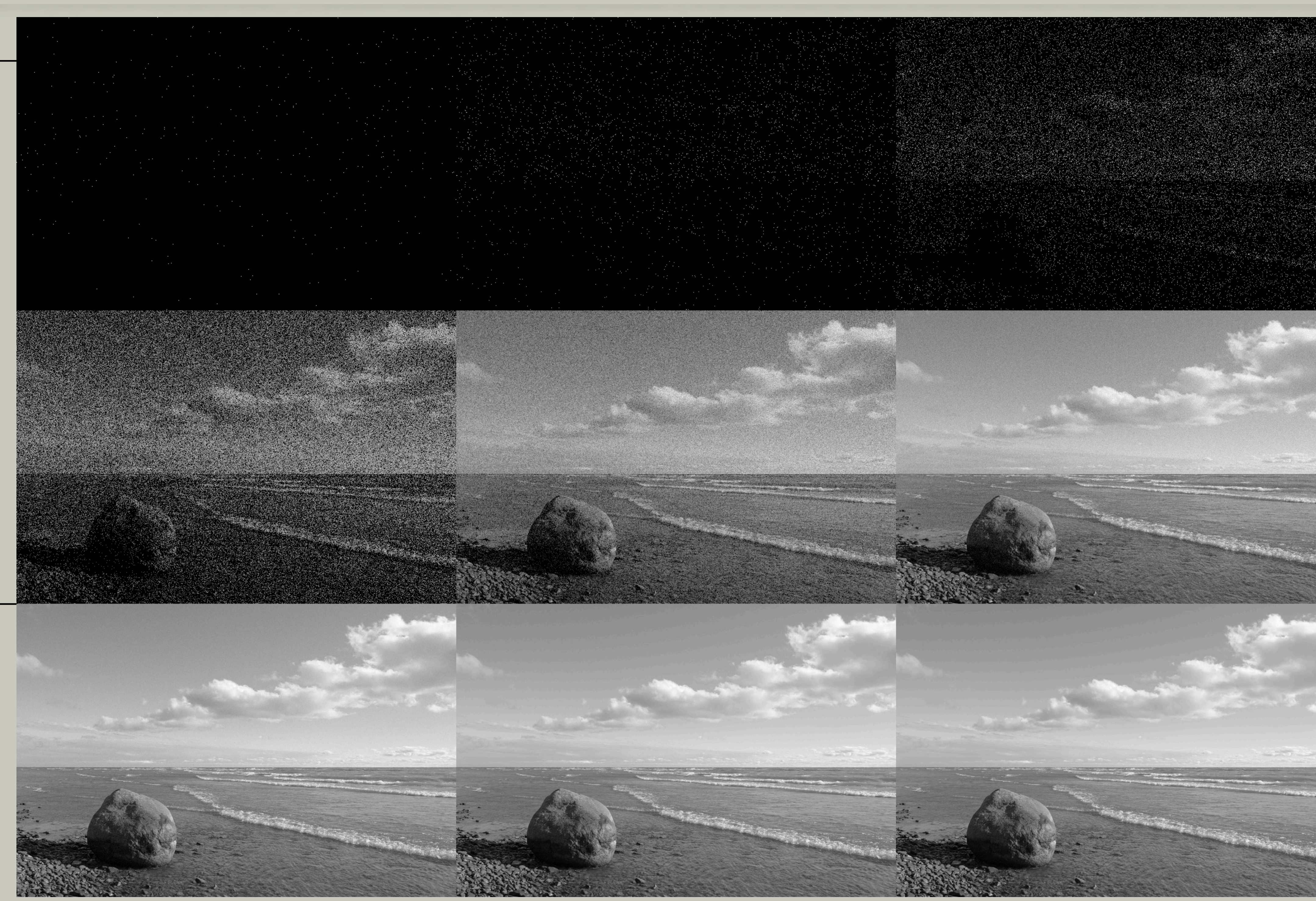
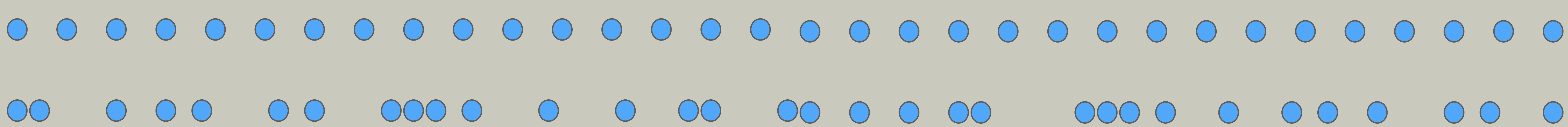


PHOTON EMISSION PROCESSES ARE INHERENTLY RANDOM
=> RANDOMNESS ALSO IN ARRIVAL TIMES



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- SATELLITES
- COSMIC RAYS
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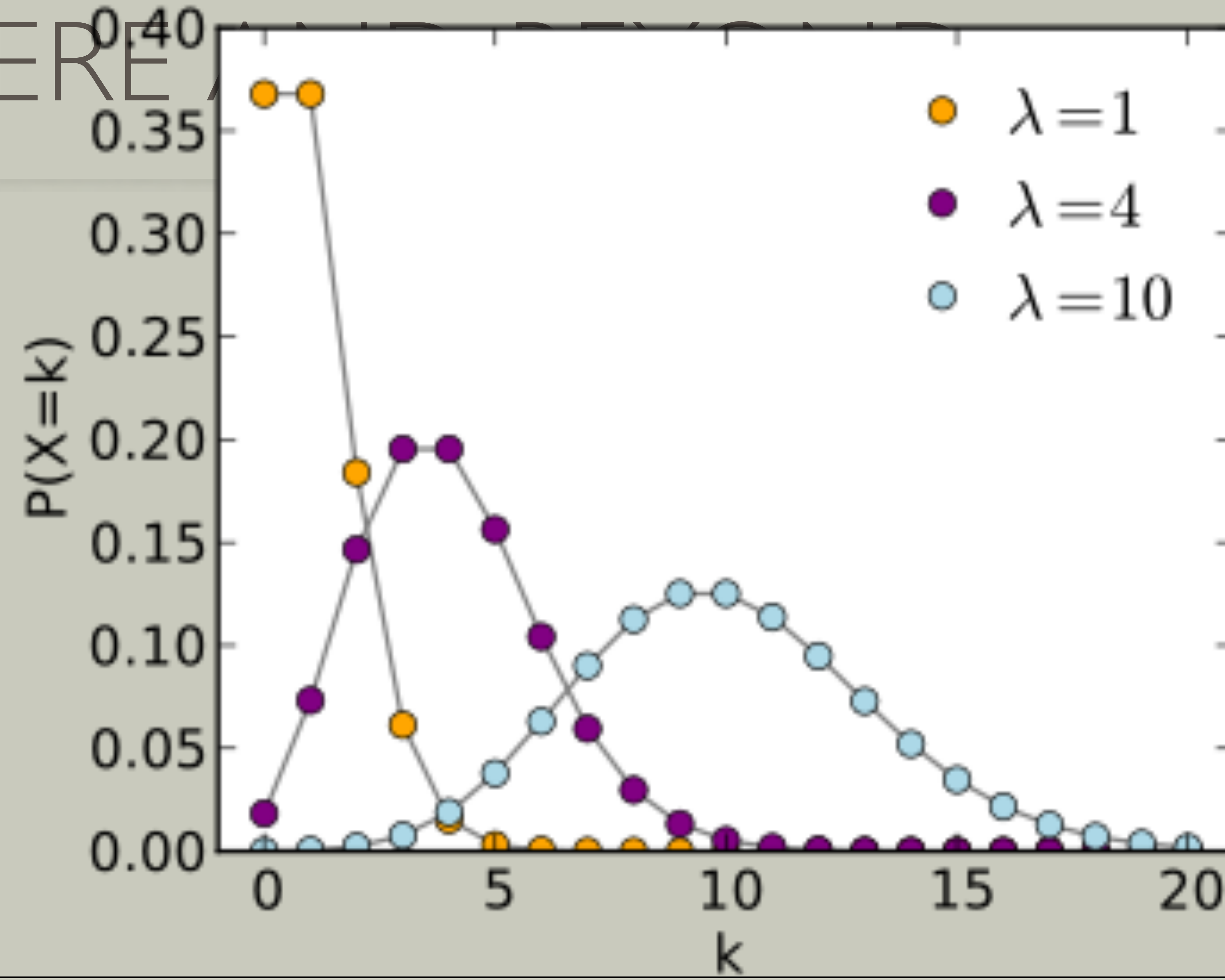

- THE PHOTON SHOT NOISE FOLLOWS A **POISSON** DISTRIBUTION OF PARAMETER N THE AVERAGE NUMBER OF PHOTONS EMITTED => SIGMA = SQRT(N)
- IN OPTICAL REGIME, N VERY LARGE => INDISTINGUISHABLE FROM GAUSSIAN
- => PROPERTIES OF PHOTON NOISE <=> NORMAL LAW (N, SQRT(N))
- => SIGNAL TO NOISE RATIO S/N=N/SQRT(N) = SQRT(N)

IMAGE ALTERATIONS, SUMMARY

- CCD:
    - READ OUT NOISE
    - NON-UNIFORMITY
    - BIAS/OFFSET
    - DARK CURRENT

- PHOTONS SHOT NOISE
- COSMICS

- OPTICS/TELESCOPE:
    - DIFFRACTION / PSF
    - NON-UNIFORMITY

- ATMOSPHERE
    - TURBULENCE
    - PLANES, SATELLITES
    - SKY

ALTERATIONS, SOMMAIRE

- CCD:
  - READ OUT NOISE
  - NON-UNIFORMITY
  - BIAS/OFFSET
  - DARK CURRENT

- PHOTONS SHOT NOISE
- COSMICS

- OPTICS/TELESCOPE:
  - DIFFRACTION / PSF
  - NON-UNIFORMITY "*"

- ATMOSPHERE
  - TURBULENCE
  - PLANES, SATELLITES
  - SKY

ALTERATIONS, SOMMAIRE

- CCD:
  - READ OUT NOISE
  - NON-UNIFORMITY
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"+"

- OPTICS/TELESCOPE:
  - DIFFRACTION / PSF
  - NON-UNIFORMITY

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- ATMOSPHERE
  - TURBULENCE
  - PLANES, SATELLITES
  - SKY

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- PHOTONS SHOT NOISE
- COSMICS

ALTERATIONS, SOMMAIRE

- CCD:
  - READ OUT NOISE
  - NON-UNIFORMITY
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- ATMOSPHERE
  - TURBULENCE
  - PLANES, SATELLITES
  - SKY

"+"

- PHOTONS SHOT NOISE
- COSMICS

"STATISTICAL" CORRECTION

3 - DATA REDUCTION

- PRINCIPLES
- APPLICATION TO PHOTOMETRY
- APPLICATION TP SPECTROSCOPY
- DATA REDUCTION / ANALYSIS SOFTWARE

BASIC PRINCIPLES

IMAGE ALTERATION PROCESSES INTERVENE IN THE SOURCE=> CCD ORDER DURING LIGHT PROPAGATION AND COLLECTION. CORRECTIONS ARE APPLIED IN THE **REVERSE** ORDER.

- 1 - CORRECTION OF ADDITIVE COMPONENTS BIAS, DARK
- 2 - CORRECTION OF MULTIPLICATIVE NON-UNIFORMITY COMPONENTS: “FLAT-FIELDING”
- 3 - SKY CORRECTION, ADDITIVE

DETERMINATION OF ADDITIVE COMPONENTS

BIAS / OFFSET

- GOAL: DETERMINE THE 0-LEVEL OF THE CCD
- METHOD: SERIES OF 0 SECONDS EXPOSURES, SHUTTER CLOSED.
  AVERAGE OR MEDIAN => <BIAS> (~200 E IN OUR CASE)

DARK CURRENT

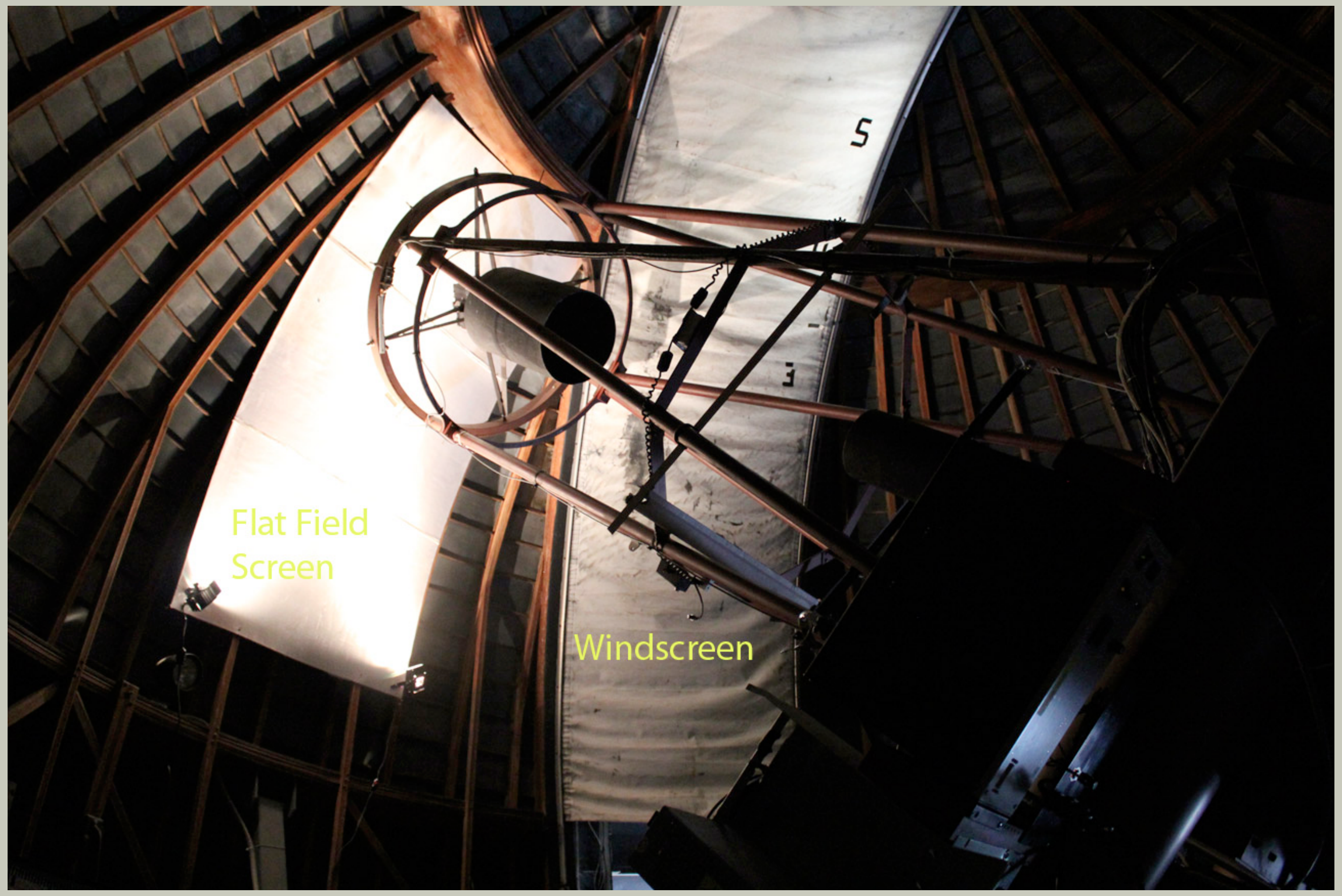
- GOAL: DETERMINE THE CCD'S THERMAL NOISE LEVEL
- METHOD: SERIES OF EXPOSURES OF SIMILAR DURATION TO THE SCIENCE FRAMES, SHUTTER CLOSED.
  AVERAGE OR MEDIAN => <DARK>

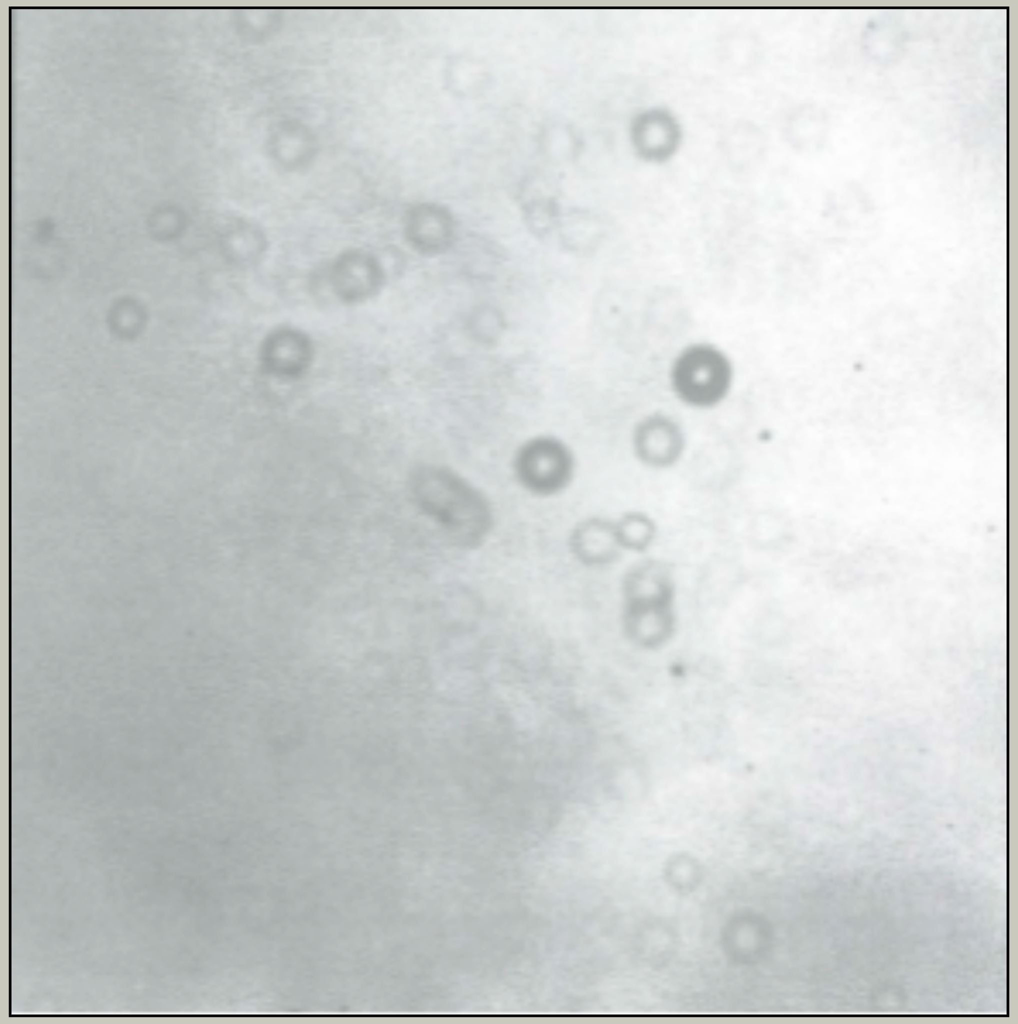
DETERMINATION OF MULTIPLICATIVE COMPONENTS

FLATFIELD

- GOAL: CORRECT THE SPATIAL VARIATIONS OF ILLUMINATION AND CCD SENSITIVITY
- METHOD: SERIES OF EXPOSURES OF UNIFORM FIELDS, (WHITE SCREEN OR DAWN/DUSK SKY)
  AVERAGE OR MEDIAN => <FLAT>

MT HAMILTON





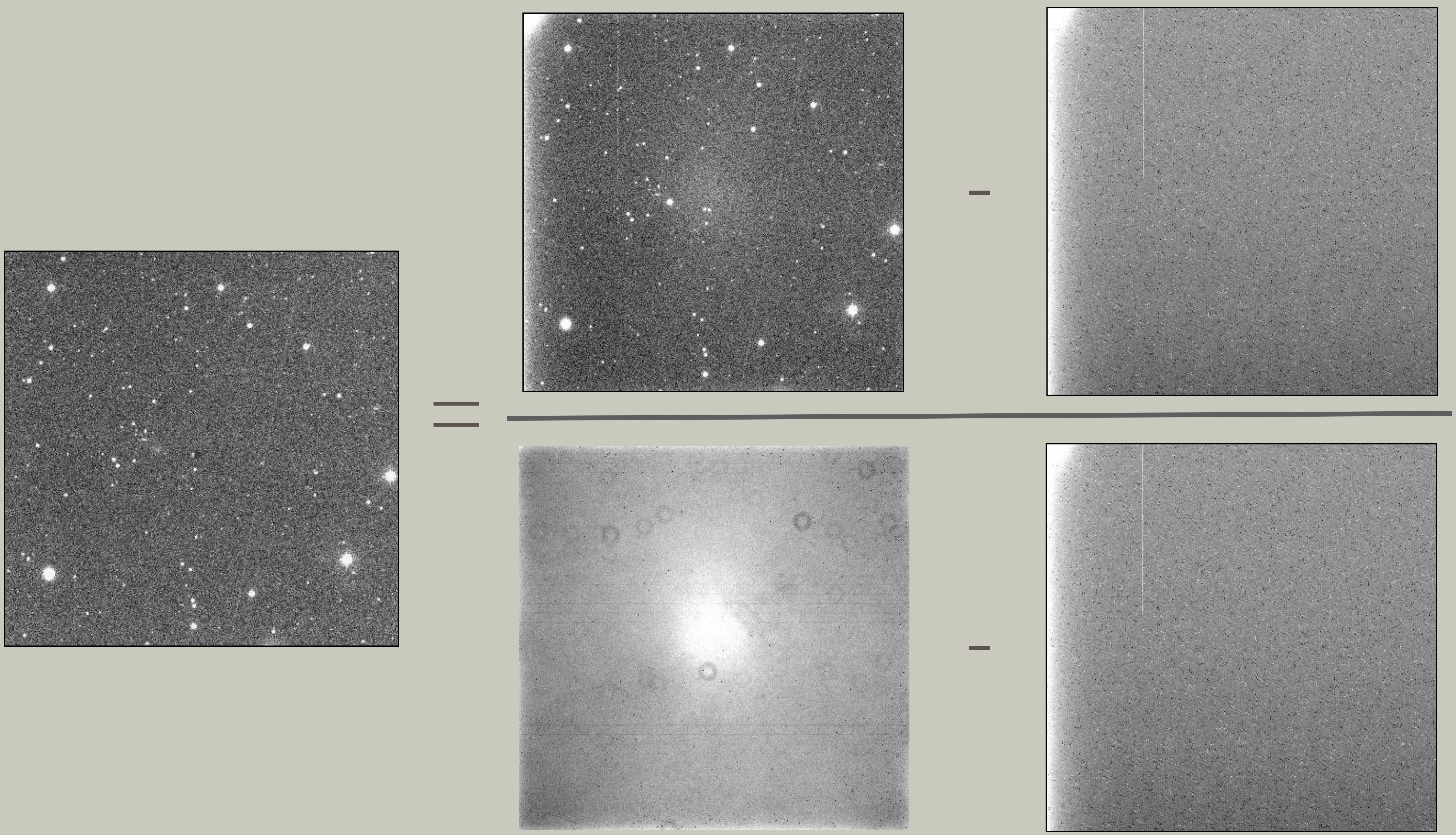
DETERMINATION OF SKY CONTAMINATION

SKY

- GOAL: EVALUATE THE ADDITIVE CONTRIBUTION DUE TO THE SKY
- METHOD: SERIES OF EXPOSURES ON EMPTY FIELDS.
  AVERAGE OR MEDIAN => <SKY>

REDUCED IMAGE

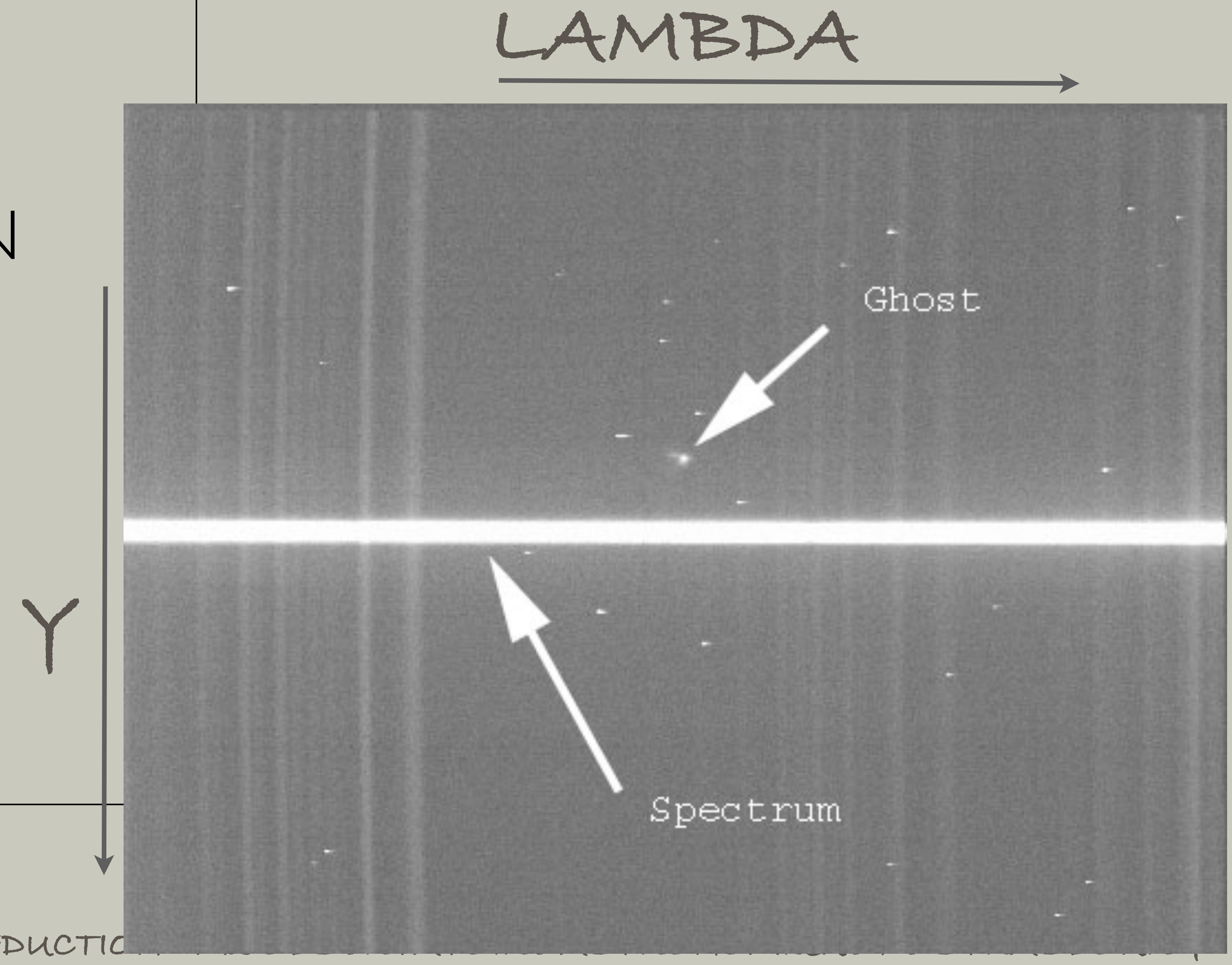
$$\texttt{Image réduite} = \frac{\texttt{Image brute} - <BIAS> - <DARK>}{<FLAT> - <BIAS> - <DARK>}$$



APPLICATION TO SPECTROSCOPY

LONG SLIT SPECTROSCOPY

- RAW IMAGE = 2D, X <= LAMBDA
- SIMILAR STEPS (BIAS,FLAT)
- + WAVELENGTH CALIBRATION
- + TELLURIC ABSORPTION CORRECTION
- + FLUX CALIBRATION

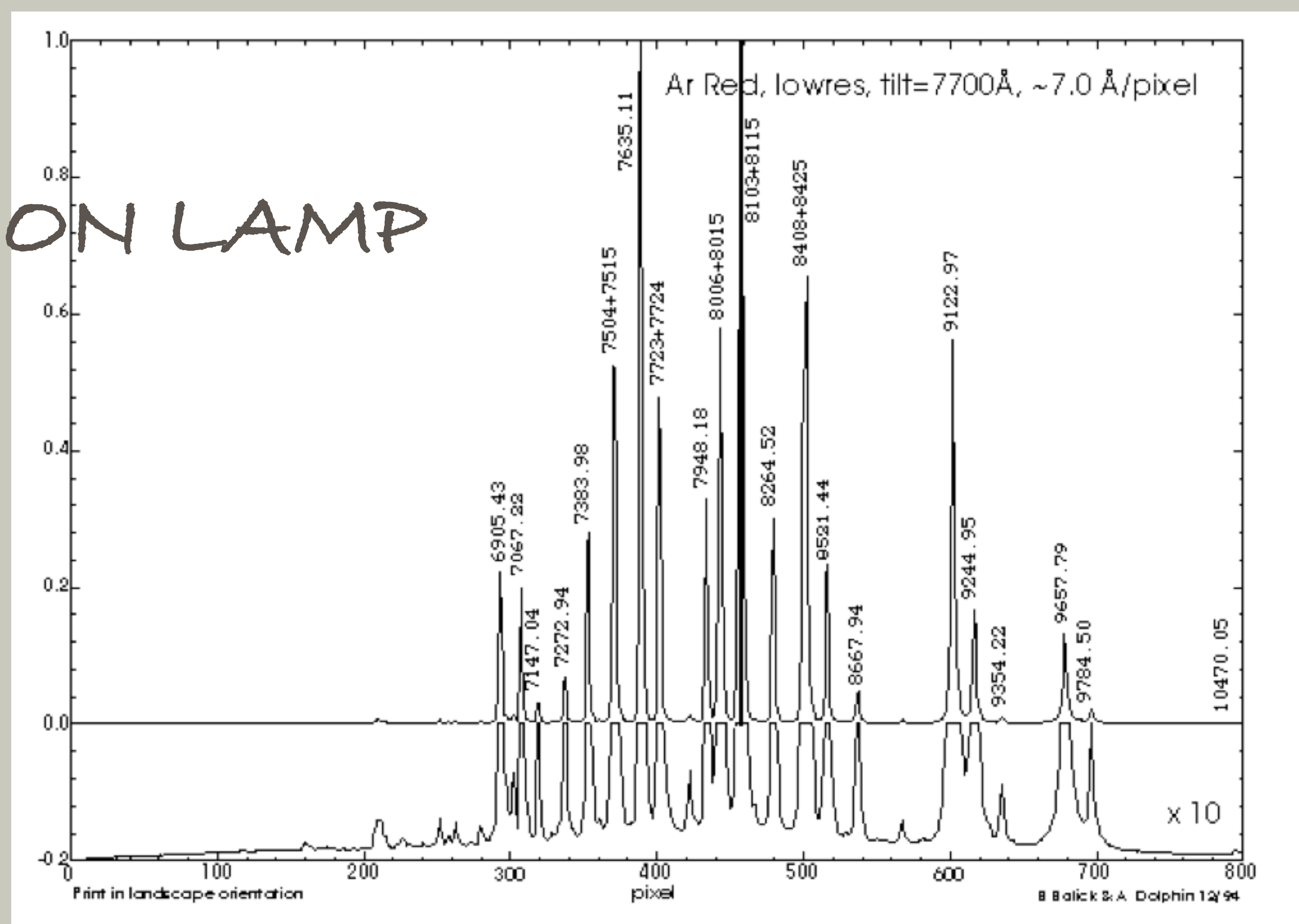


WAVELENGTH CALIBRATION

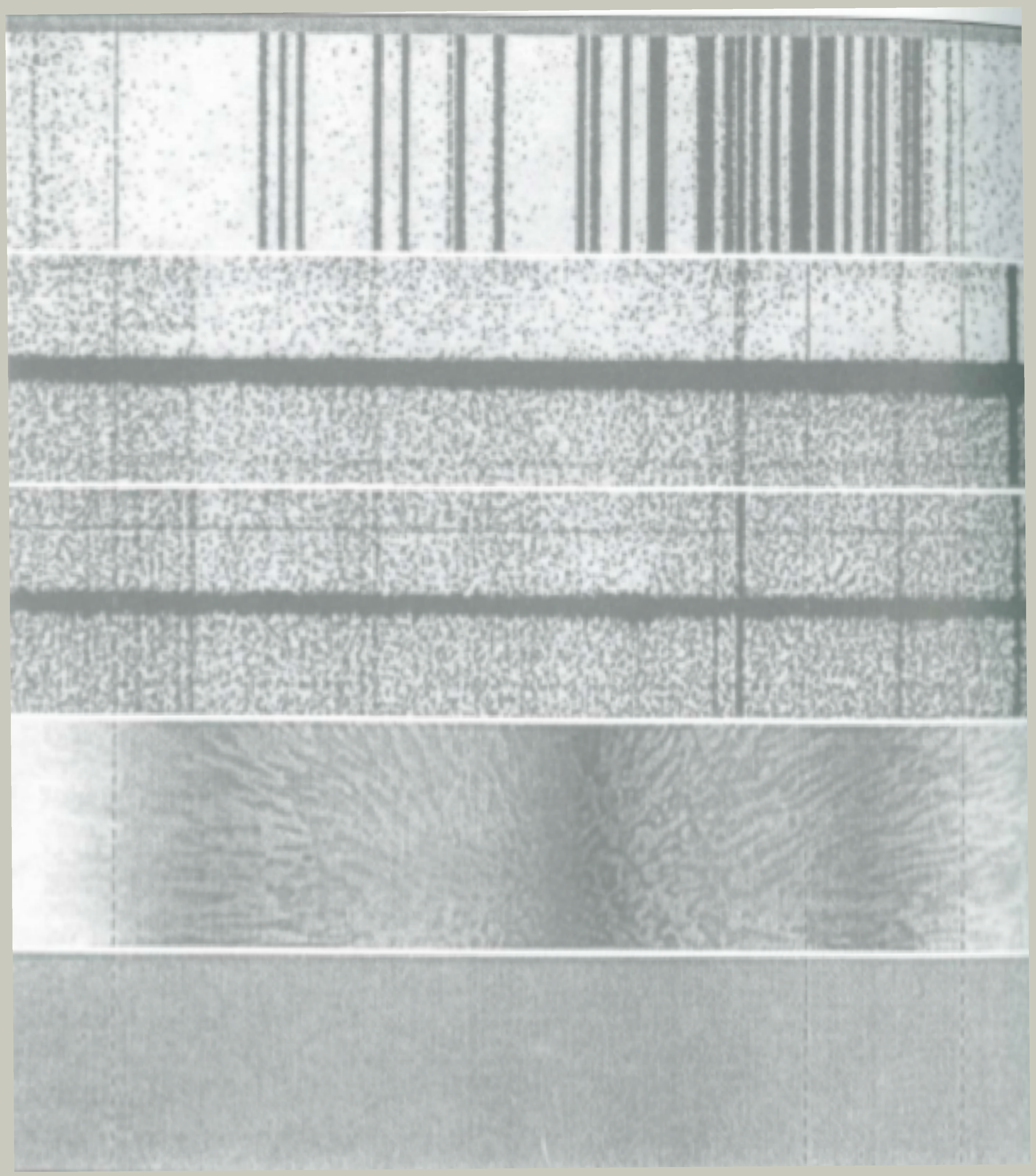
PRINCIPLE

- USE OF A SPECTRAL LAMP TO ESTABLISH A X <=> LAMBDA SCALE

ARGON LAMP



SPECTROSCOPY, SUMMARY



LAMBDA

LAMP	X=>LAMBDA
STANDARD	COUNTS=>FLUX
OBJECT	SCIENCE
FLAT	SENSITIVITY
BIAS	OFFSET

DATA REDUCTION SOFTWARE

- HISTORICALLY: GENERAL PURPOSE SOFTWARE
- MIDAS (ESO)
- IRAF: IMAGE REDUCTION AND ANALYSIS FACILITY (NOAO, TUCSON)
- NOWADAYS: SPECIALIZED
  - MOST INSTRUMENTS / OBSERVATORIES HAVE THEIR OWN DEDICATED DATA REDUCTION PIPELINES AVAILABLE FOR DOWNLOAD
- FOR THIS COURSE: PYTHON NOTEBOOKS!

SETTING UP THE TUTORIAL

- log into your astromas workstation
- Have a look at:
  - https://github.com/pocvirk/astronomical_data_reduction
- On astromas:
  - git clone https://github.com/pocvirk/astronomical_data_reduction
  - cd astronomical_data_reduction
- launch jupyter notebook
  - jupyter notebook

SETTING UP THE TUTORIAL

- Another useful tool: ds9
- Try it out:
  - cd data/photo/M1
  - ds9
  - open an image
  - play with scalings (log vs linear, cuts etc…)

4 - TP/TD DATA REDUCTION

WARNING: THERE ARE STILL SOME IRAF RELICS IN THIS DOCUMENT

- IMAGING
  - INGREDIENTS
  - EXERCISES
- SPECTROSCOPY:
  - INGREDIENTS
  - EXERCISES

DATA REDUCTION - IMAGING

A typical night:

- CCD bias acquisition (multiple)
- Dark current acquisition (multiple)
- Flatfield acquisition (multiple, all filters)
- Science frames (multiple, various filters)
- Re-acquisition of bias, dark, flat-field

DATA REDUCTION - IMAGING

Why multiple bias/dark/flat frames?

- Reduction of read out noie ($\sigma_b = \sigma_{RON}/\sqrt{n}$)
- Cosmic rays correction

=>Question:

Are the statistical properties of the bias frame compatible with Gaussian noise? (hint: Pr(X>5 sigma) < 10^{-6} for a normal law)

- Check stats offsets:

ecl> imstat photo/offsets/*

IMAGE	NPIX	MEAN	STDDEV	MIN	MAX
p43955f1.fits	1048576	226.1	5.539	216.	2976.
p43956f1.fits	1048576	226.2	4.111	216.	1313.
p43957f1.fits	1048576	226.5	6.029	216.	3823.
p43958f1.fits	1048576	226.	5.395	215.	3415.
p43959f1.fits	1048576	225.4	3.737	215.	1576.

DATA REDUCTION - IMAGING

Why multiple bias/dark/flat frames?

- Reduction of read out noise ($\sigma_b = \sigma_{RON}/\sqrt{n}$)
- Cosmic rays correction

=>Exercise:

display and examine offset/bias frames, find a high variance region

- Check stats offsets:

ecl> imstat photo/offsets/*

IMAGE	NPIX	MEAN	STDDEV	MIN	MAX
p43955f1.fits	1048576	226.1	5.539	216.	2976.
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p43957f1.fits	1048576	226.5	6.029	216.	3823.
p43958f1.fits	1048576	226.	5.395	215.	3415.
p43959f1.fits	1048576	225.4	3.737	215.	1576.

DATA REDUCTION - IMAGING

Why multiple bias / flat / dark ?

- Reduce readout noise ($\sigma_b = \sigma_{RON}/\sqrt{n}$)
- Correct cosmic rays

Solution: median (bias)

- Generation of **master_bias** (I) = median (bias)

IMAGE	NPIX	MEAN	STDDEV	MIN	MAX
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p43956f1.fits	1048576	226.2	4.111	216.	1313.
p43957f1.fits	1048576	226.5	6.029	216.	3823.
p43958f1.fits	1048576	226.	5.395	215.	3415.
p43959f1.fits	1048576	225.4	3.737	215.	1576.
photo/master_bias.fits	1048576	226.	1.325	220.	236.

DATA REDUCTION - IMAGING

What does a flat field look like?

Display a flat field frame in python or with ds9

DATA REDUCTION - IMAGING

Generation of **master_flat. Goal**:

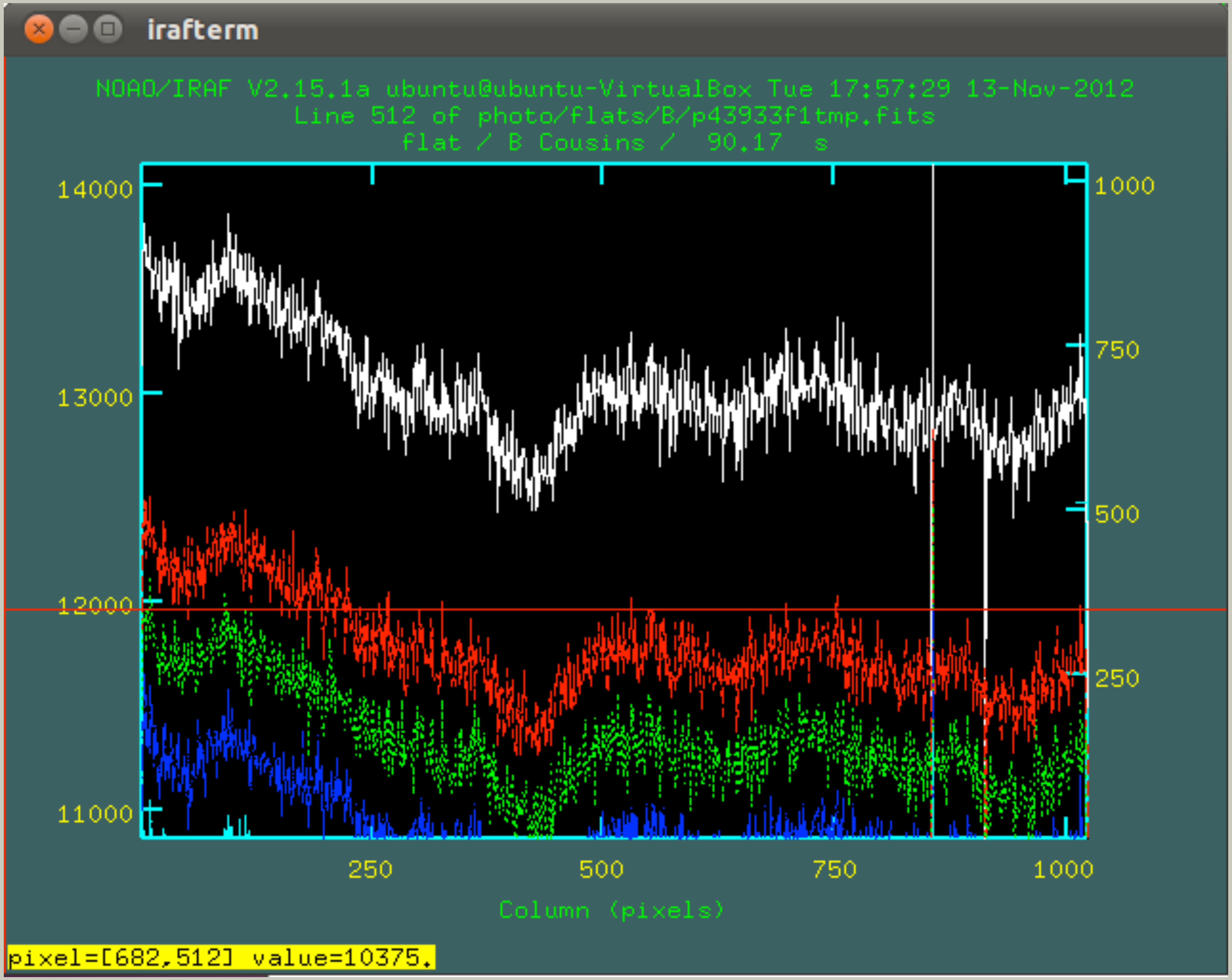
- Reduce the read out noise and photon shot noise (√electrons)
- Correct for cosmic rays

Same problems as bias => same solution?

Not necessarily: lets look at corrected flats:

- Correct the flats by removing the bias:
- Plot the corrected flats together in the same graphic window:

DATA REDUCTION - IMAGING



REMINDER:

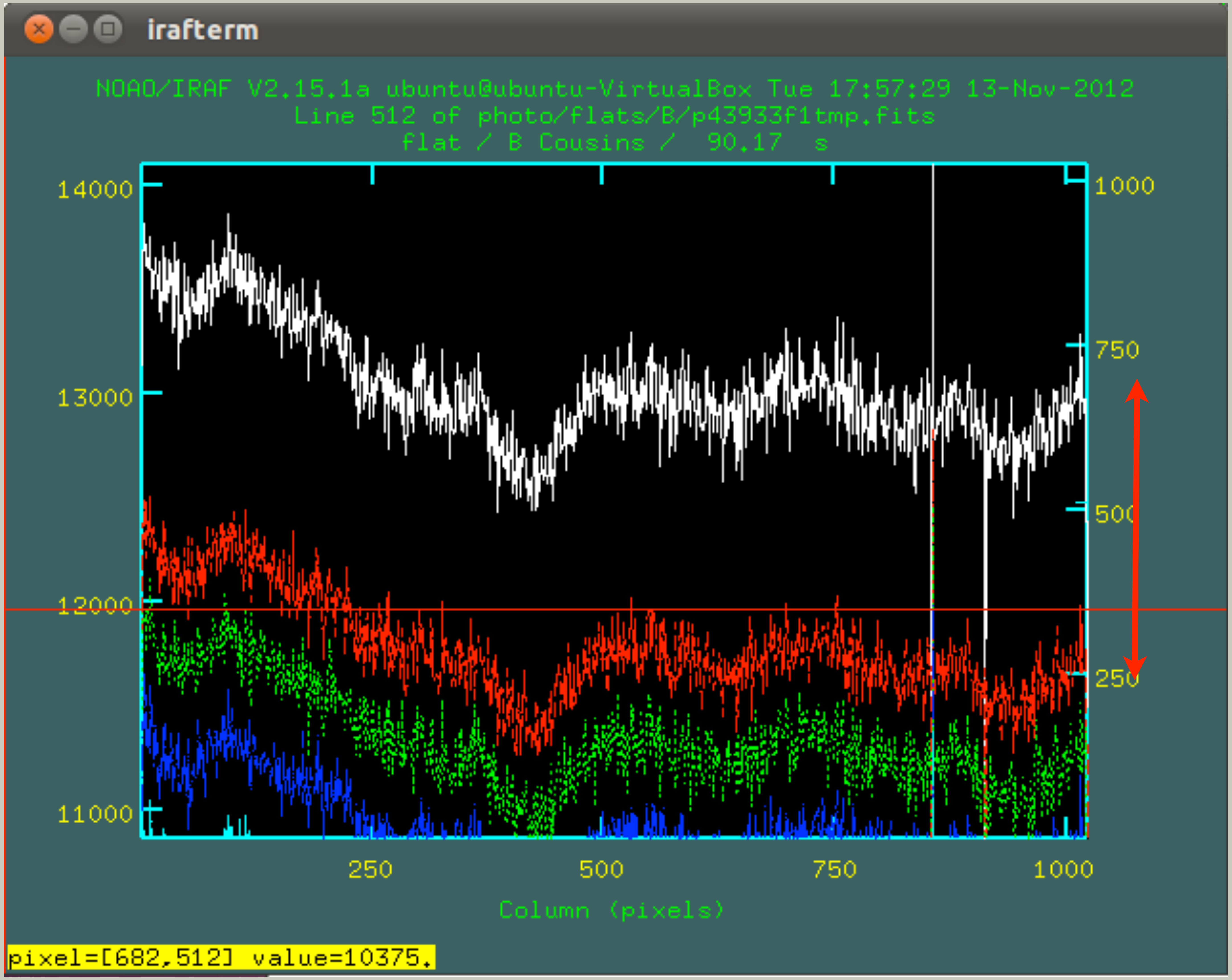
FOR A POISSON LAW :

STD = SQRT(MEAN)

MEAN ~ 10 000

=> PHOTON NOISE ~ 100 ADU

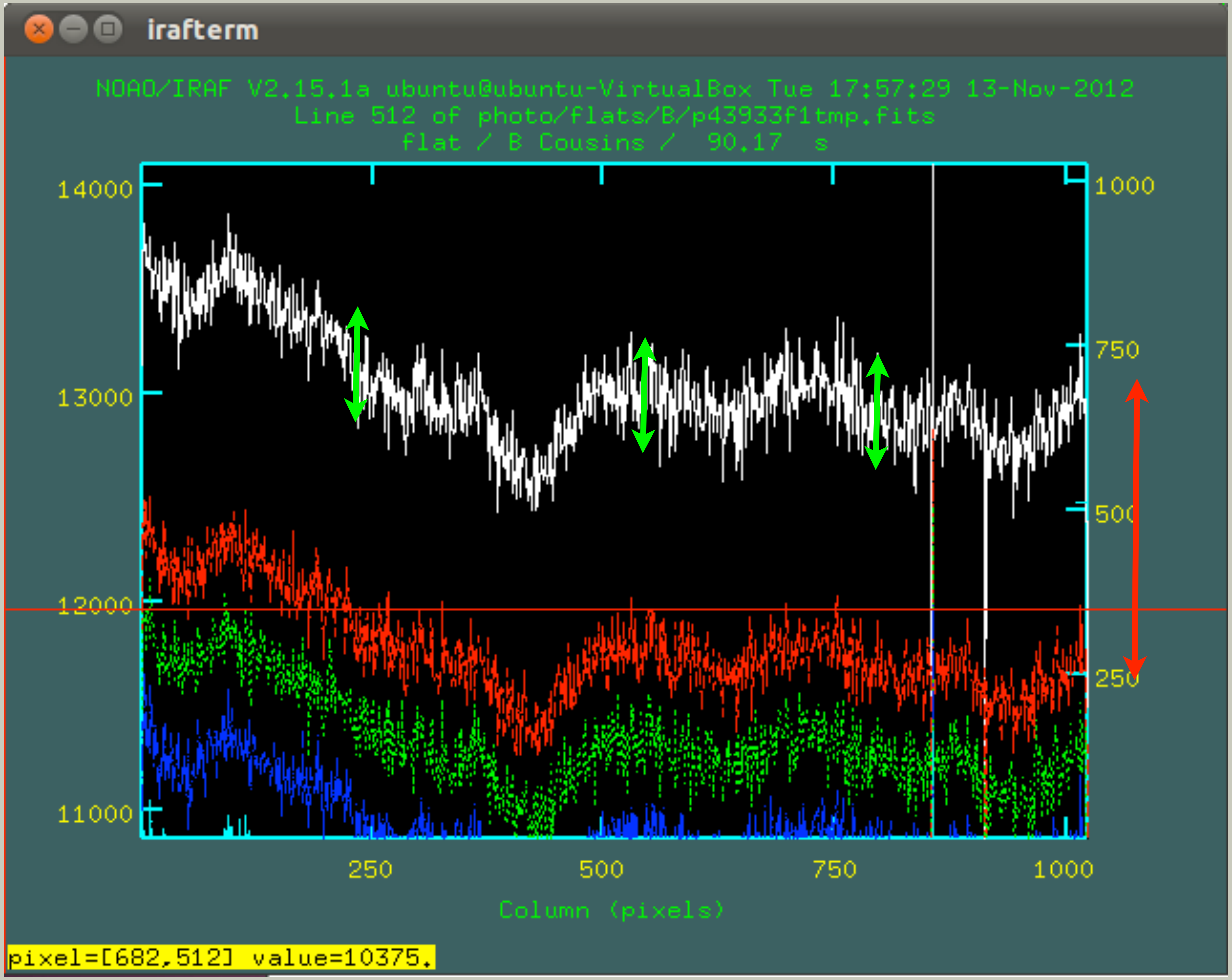
DATA REDUCTION - IMAGING



REMINDER:
FOR A POISSON LAW :
STD
=
SQRT(MEAN)

???

DATA REDUCTION - IMAGING



REMINDER:

FOR A POISSON LAW :

STD

=

SQRT(MEAN)

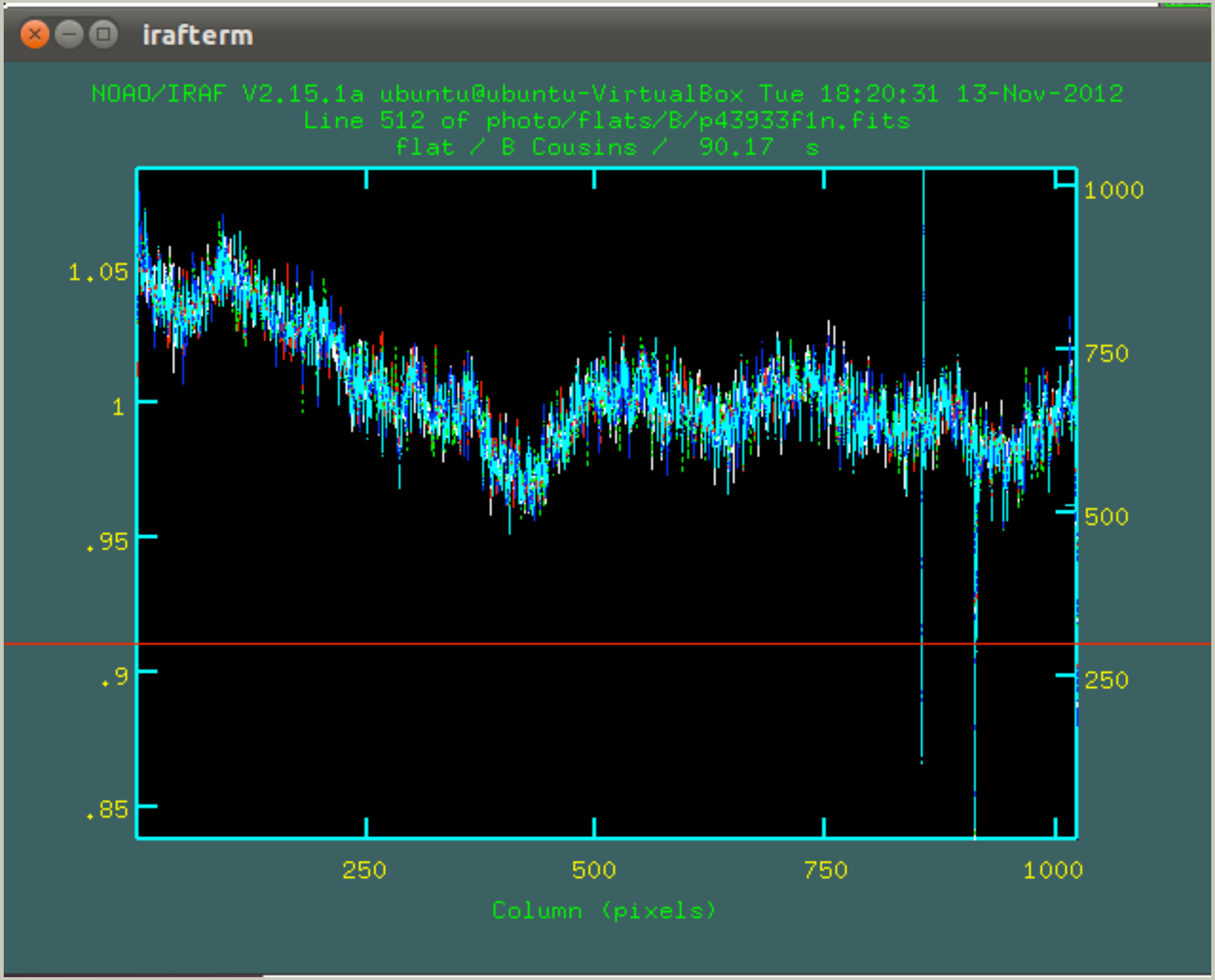
??? ≫ σ_{phot}

DATA REDUCTION - IMAGING

Generate the **master_flat**:

- Correct flats by subtracting the bias:
- Compute median of each corrected flat
- Divide each flat by its median (normalisation)
- Plot normalised flats

DATA REDUCTION - IMAGING



DATA REDUCTION - IMAGING

Generate the **master_flat**:

- Correct flats by subtracting the bias:
- Compute the mean of each corrected flat:
- Divide each flat by its mean (normalize)
- Plot normalised flats
- Combine the flats by medianing for a given filter

DATA REDUCTION - IMAGING

Science frames reduction (poses uniques)

- Subtract bias from all images:
- Make sure to check which frame corresponds to which filter:
  - by checking the header for instance
- Divide each image by the corresponding master_flat (Pay attention to the filters!)

DATA REDUCTION - IMAGING

Science frames reduction (mutlipe exposures per filter)

- Subtract bias from all images
- Check filter for each image
- Combine multiple exposures
  - Normalise images corresponding to each filter
  - Check normalisation
  - Combine images in the same filter (will correct cosmic and improve noise)
- Divide resulting image by the master flat (pay attention to filter)

DATA REDUCTION - IMAGING

Summary:

- master_bias = median (bias)
- master_flat = median(norm_flat)
  - norm_flat = (debiased_flat)/mean(debiased_flat)
  - debiased_flat = flat - master_bias
- => reduced_i = (raw - master_bias)/master_flat
- reduced_combined=median(reduced_i)

DATA REDUCTION - IMAGING

Exercise:

- M1 (crab nebula): B,V,R,OIII,Halpha
- M42 (Orion nebula): BVR OIII Halpha
- M51 (Whirlpool galaxy): BVR, **Halpha** (3 exposures)
- NGC2392 (eskimo nebula): V, OIII, Halpha

- Then try RGB composition with ds9:
  - Example M1 with following filter assignment:
  - R<=Halpha, G<=OIII, B<=B

DATA REDUCTION - IMAGING

Astrometric calibration

Goal: go from (x,y) to (RA, DEC) (celestial coords system).

Motivation: allows for multi-night stacking, multi-lambda and variability studies

Tool: Aladin astrometric calibration.

- load image to calibrate
- Load dss image around our object
- image -> properties -> astrometry -> New -> By star matches
- select one by one the reference stars in the 2 images
- Create, Apply, Save

Back in iraf, apply this calibration to other exposures, if relevant:

cl> wcscopy <targetimages> <referenceimage>

To check the headers and see the new keywords

imheader <targetimages> l+

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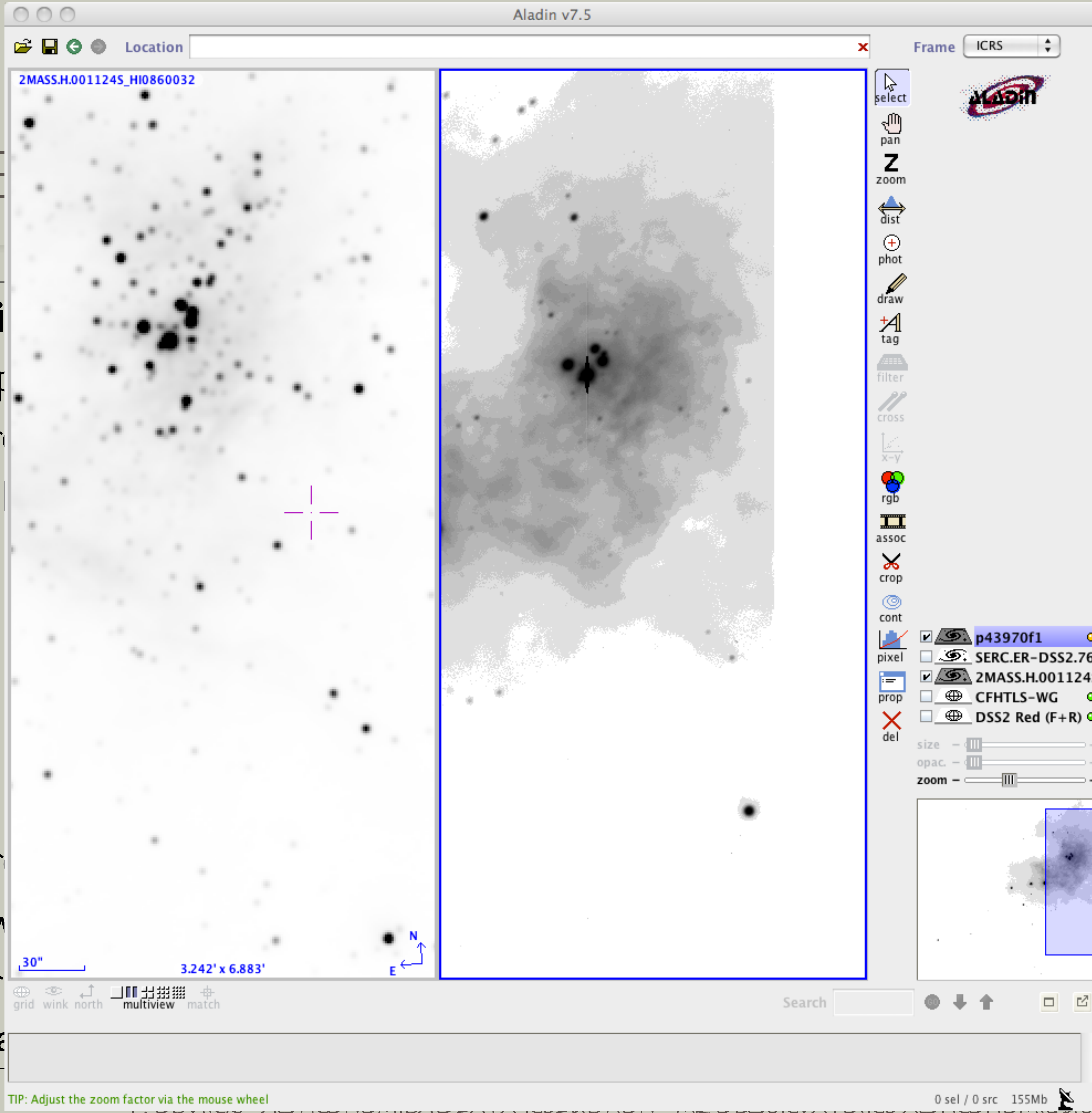

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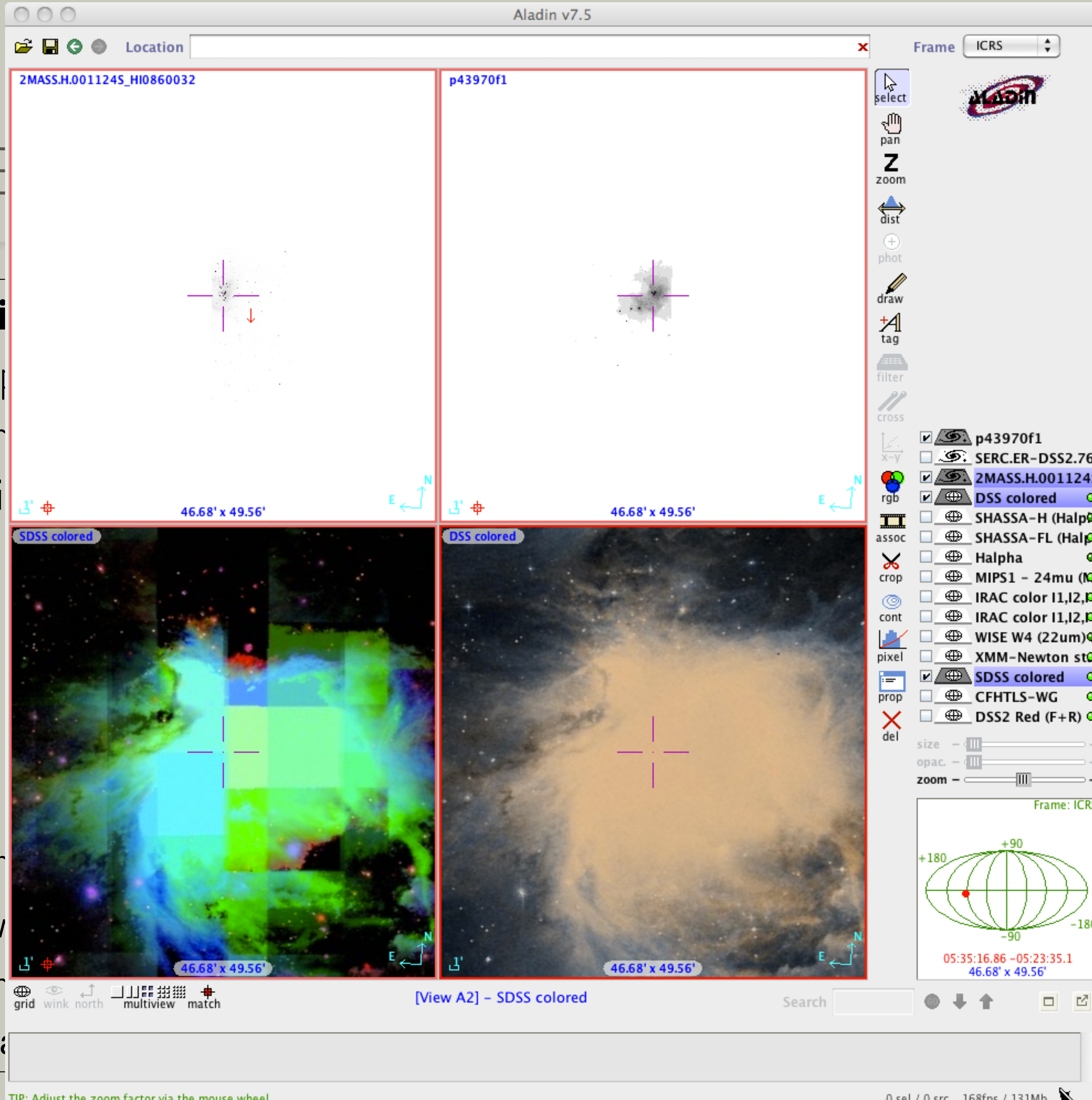


DATA REDUCTION - IMAGING

RGB composition of images: 2 ways:

With ds9 (better to launch it from outside iraf)

- New RGB frame
- Load 3 images for M1 (R,V,B,Halpha,OIII)
- Set dynamics (think about log)

OR

With Aladin (requires astrometric reduction)

- Load images
- Optional: Download images from other missions/archives (HST, VLA,Chandra...)
- Use RGB

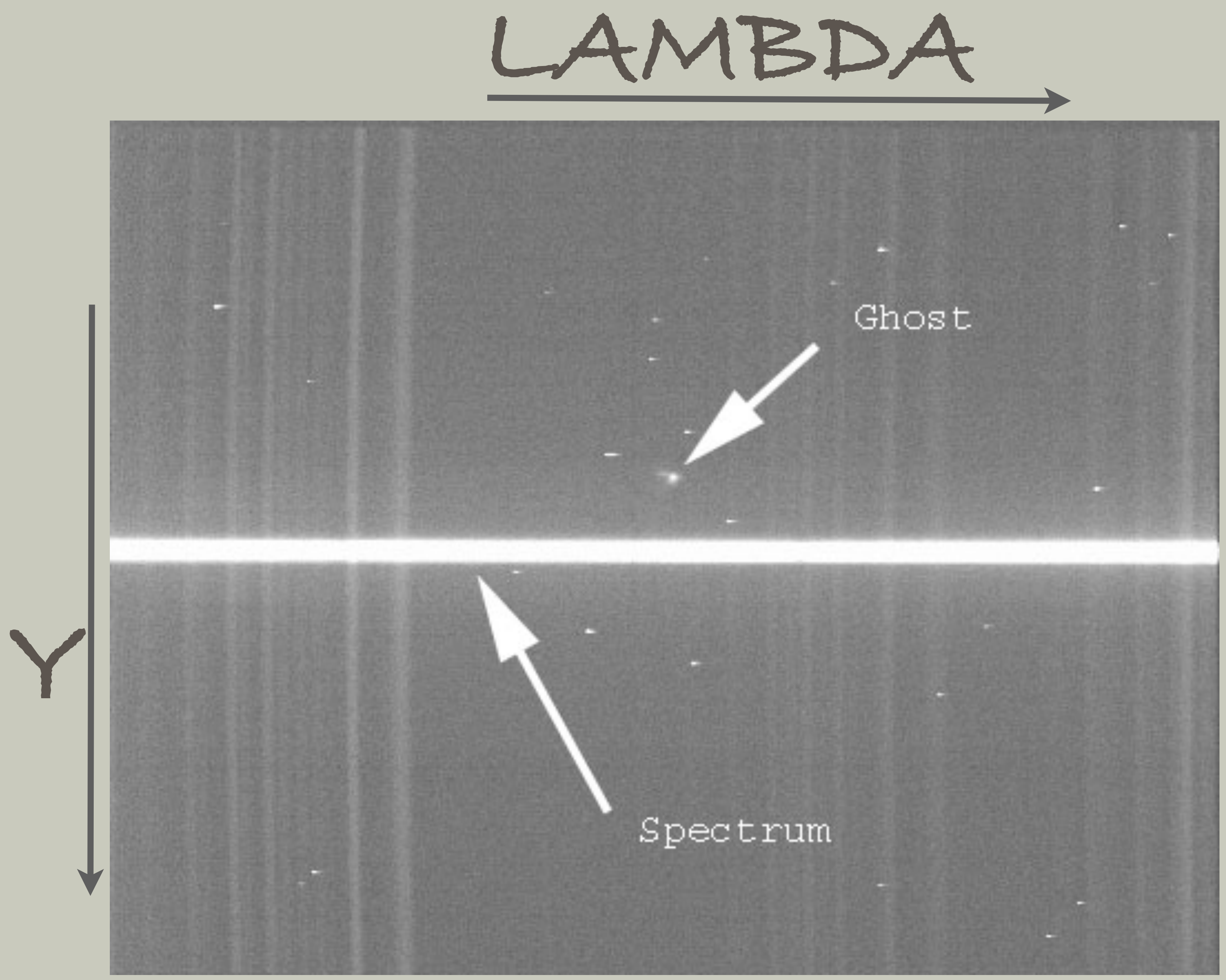
ASTROALIGN IN PYTHON

- v_al, footprint=astroalign.register(np.float32(v),np.float32(b))
- it may work without the np.float32 but Ive seen astroalign crash when v or b is a numpy array of float64
- SEE NOTEBOOK

4 - TP/TD DATA REDUCTION - SPECTROSCOPY

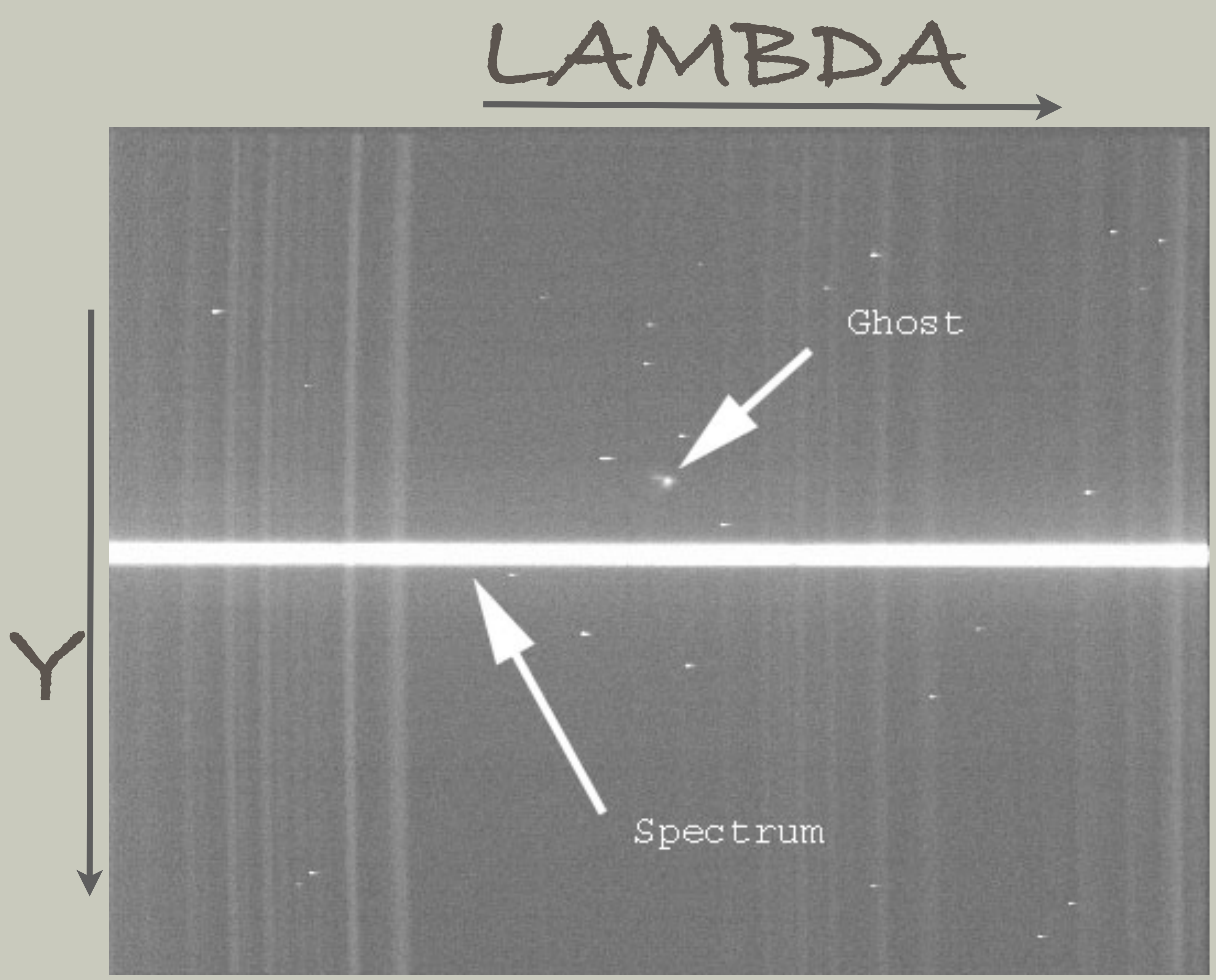
- TECHNIQUES
- ACQUISITION
- REDUCTION
- CALIBRATION
- EXERCISES

TECHNIQUES OF SPECTROSCOPY



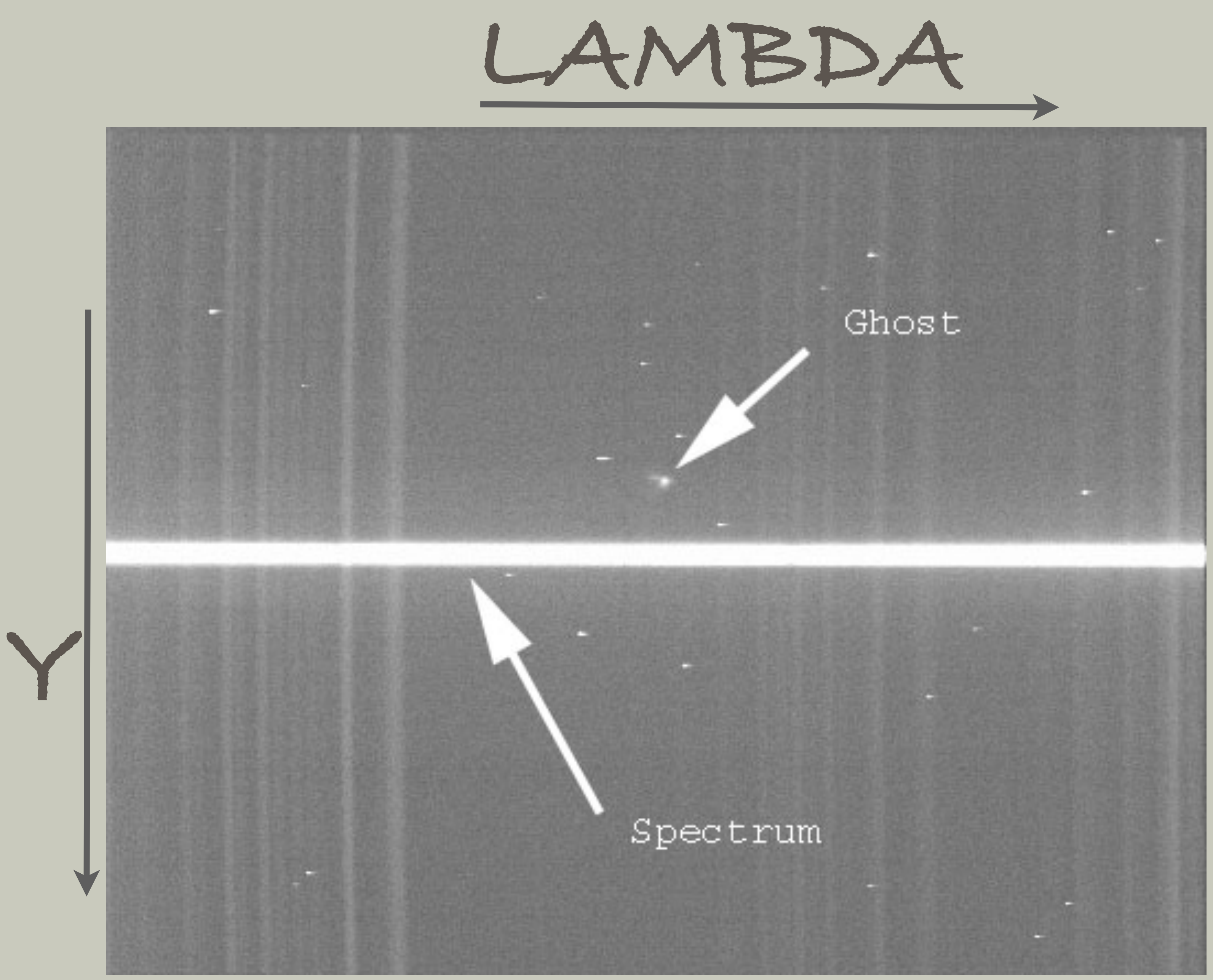
Long slit:
1 reflection on 1 grism
(grism = grating + prism)

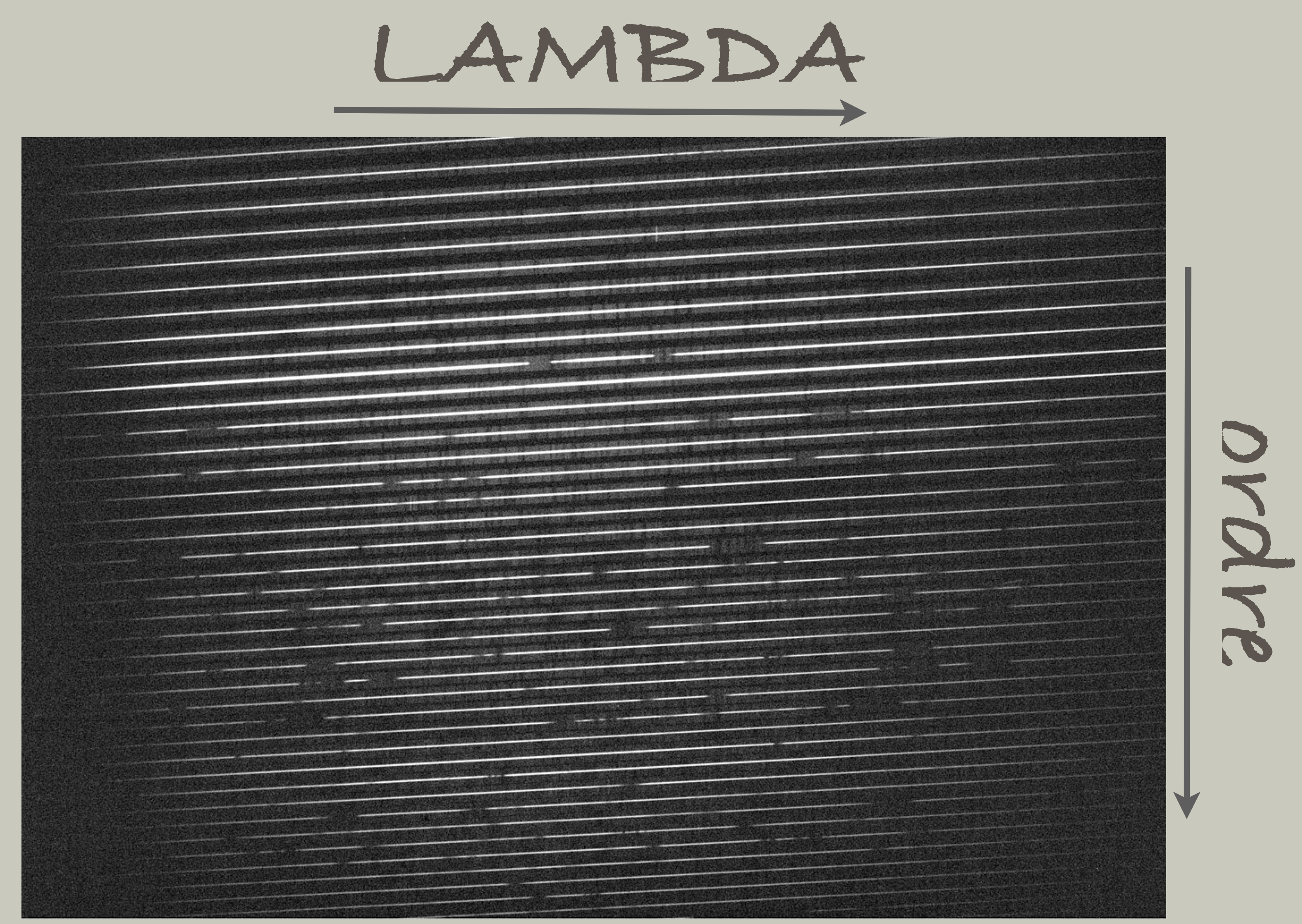
TECHNIQUES OF SPECTROSCOPY



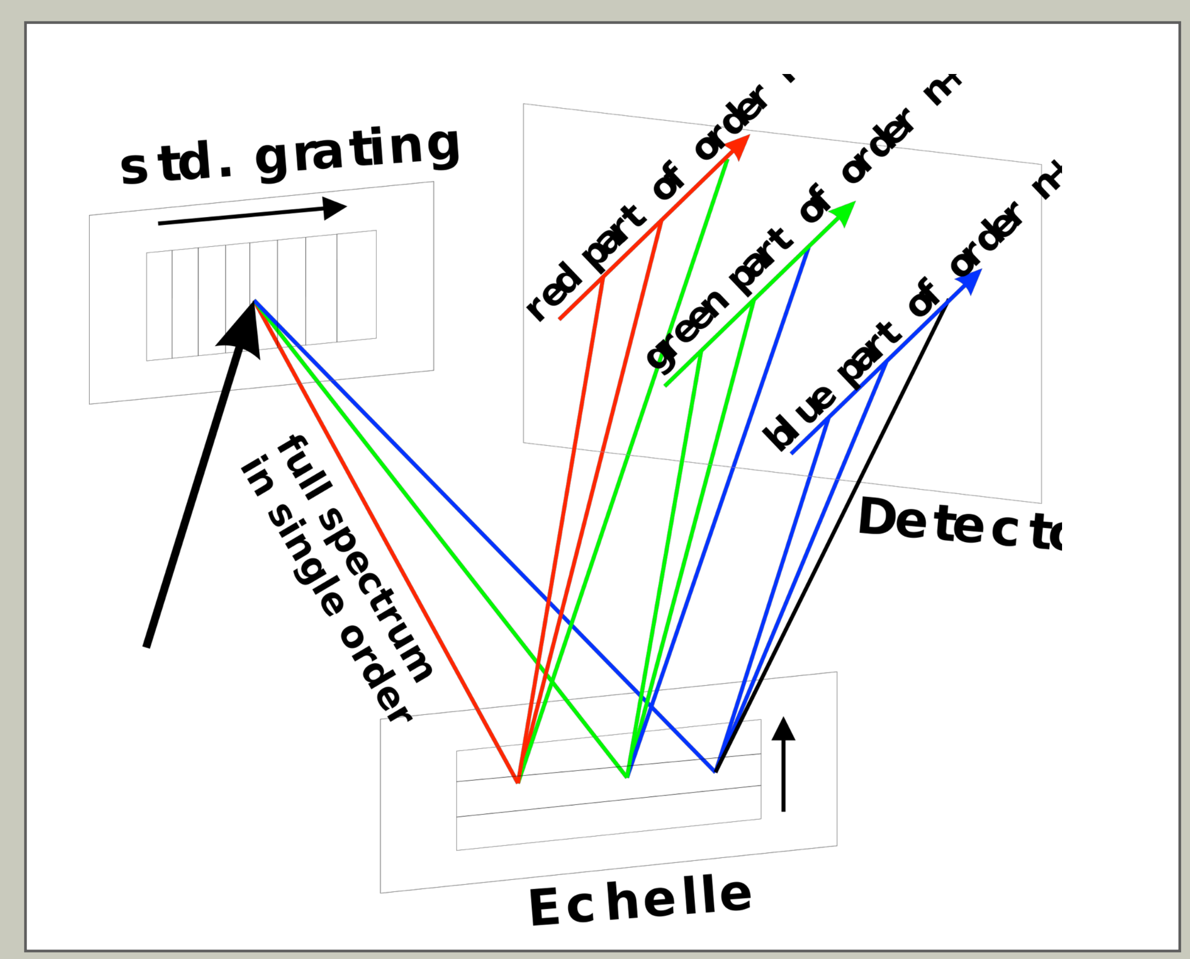
Long slit:
1 reflection on 1 grism
(grism = grating + prism)

TECHNIQUES OF SPECTROSCOPY





Long slit:
1 reflection on 1 grism
(grism = grating + prism)



Echelle

DATA REDUCTION - SPECTROSCOPY

A typical night in spectroscopy

- CCD bias/offset acquisition (multiple)
- Dark current acquisition (multiple)
- Flatfield acquisition (multiple, all filters)
- Science frames (multiples, science)
- Re-acquisition of biais, dark, flatfield

DATA REDUCTION - SPECTRO

A spectrum is an image recorded by a CCD

=> same basic principles as photometry

A typical night in spectroscopy

- CCD bias acquisition (multiple)
- Dark current acquisition (multiple)
- Flatfield acquisition (multiple, all filters)
- Science frames (multiple, on the sky)
- Acquisition of one or more standard stars
- Acquisition spectral lam spectra
- Re-acquisition of bias, dark, flatfield

→ Reduction
(correction artefacts instrumentaux)

→ Calibration
(Passage aux unites physiques)

DATA REDUCTION - SPECTRO

A spectrum is an image recorded on a CCD. (1D on OHP/Aurelie)

=> same basic principles as photometry.

1 - Generation of master_bias

- Medianing of bias/offset

2 - Generation of master_flat

- Subtract master_bias from each flatfield
- Normalise each flat
- Combine by medianing

3 - Reduction of spectra

- Subtract master_bias
- Divide by master_flat

DATA REDUCTION - SPECTRO

Generation of **master_bias**:

- load spectro 1d environment: cl> onedspec
- Combine bias by medianing

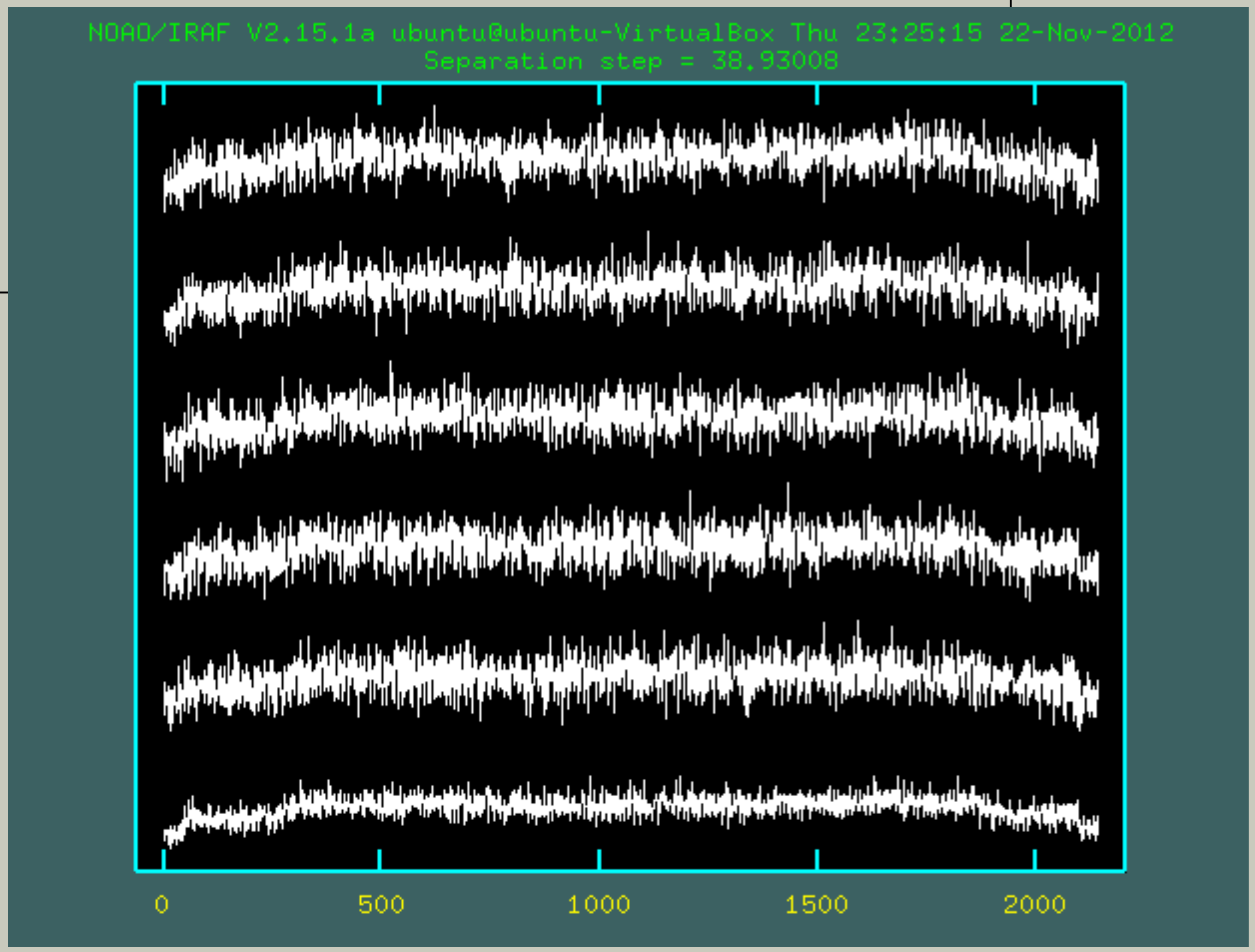
cl> imcombine t152_spectro/offsets/* t152_spectro/offsets/master_bias.fits combine="median"

cl> splot t152_spectro/offsets/master_bias.fits

cl> specplot t152_spectro/offsets/*.fits

splot basic commands:

a, b, c



GENERATION OF MASTER_FLAT - 1

- Subtract master_bias from each flat:

cl> imarith t152_spectro/flats/* - t152_spectr/offsets/master_bias t152_spectro/flats/*//tmp

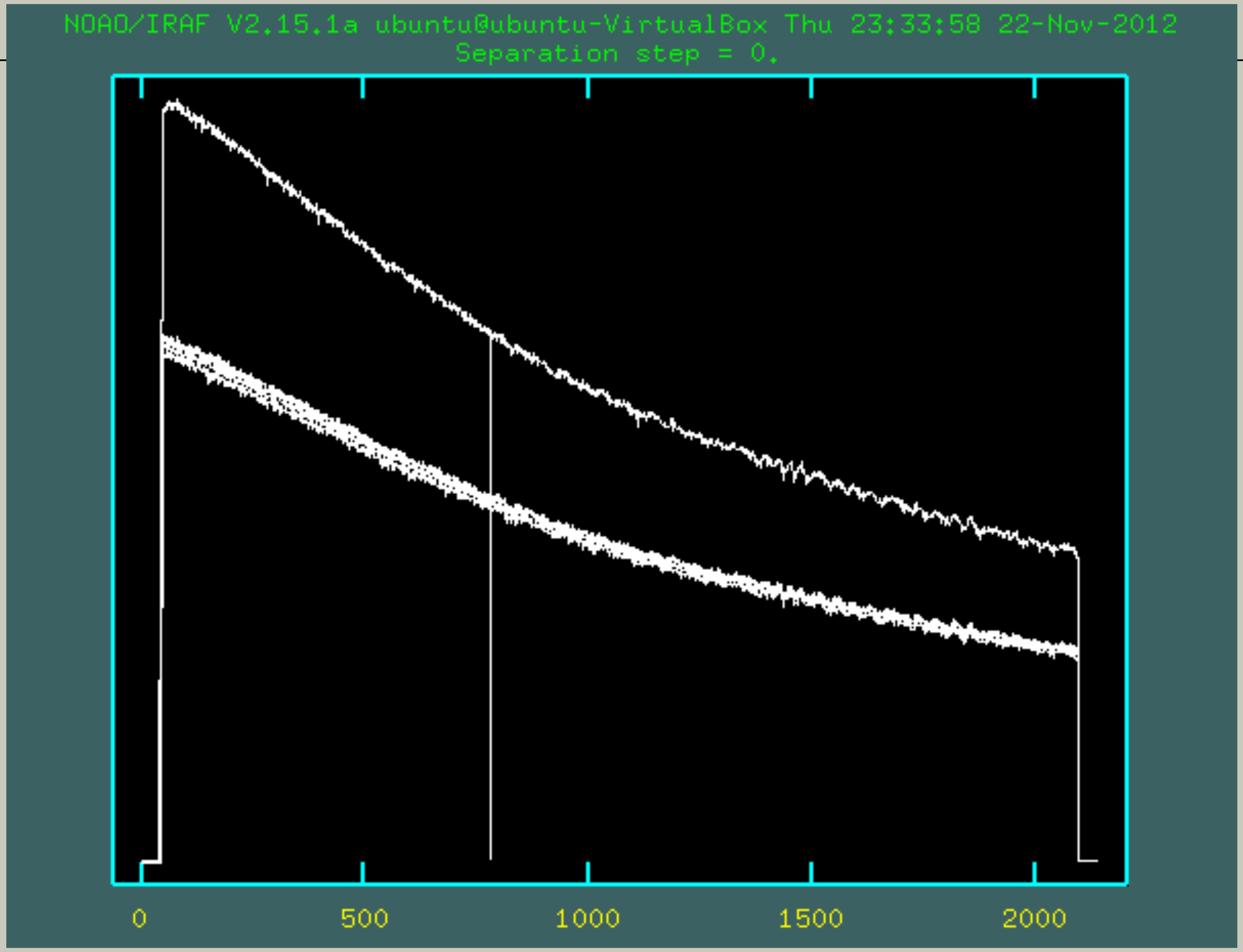
cl> specplot t152_spectro/flats/* step=0 autolayout-

Tips

- Colors in specplot: in the graphics window

:color[1] 3 f(colore le spectre 1 en couleur 3)

r (redessine la figure en prenant en compte la couleur)



FASTER: IMCOMBINE SCALE=MEDIAN AND THEN

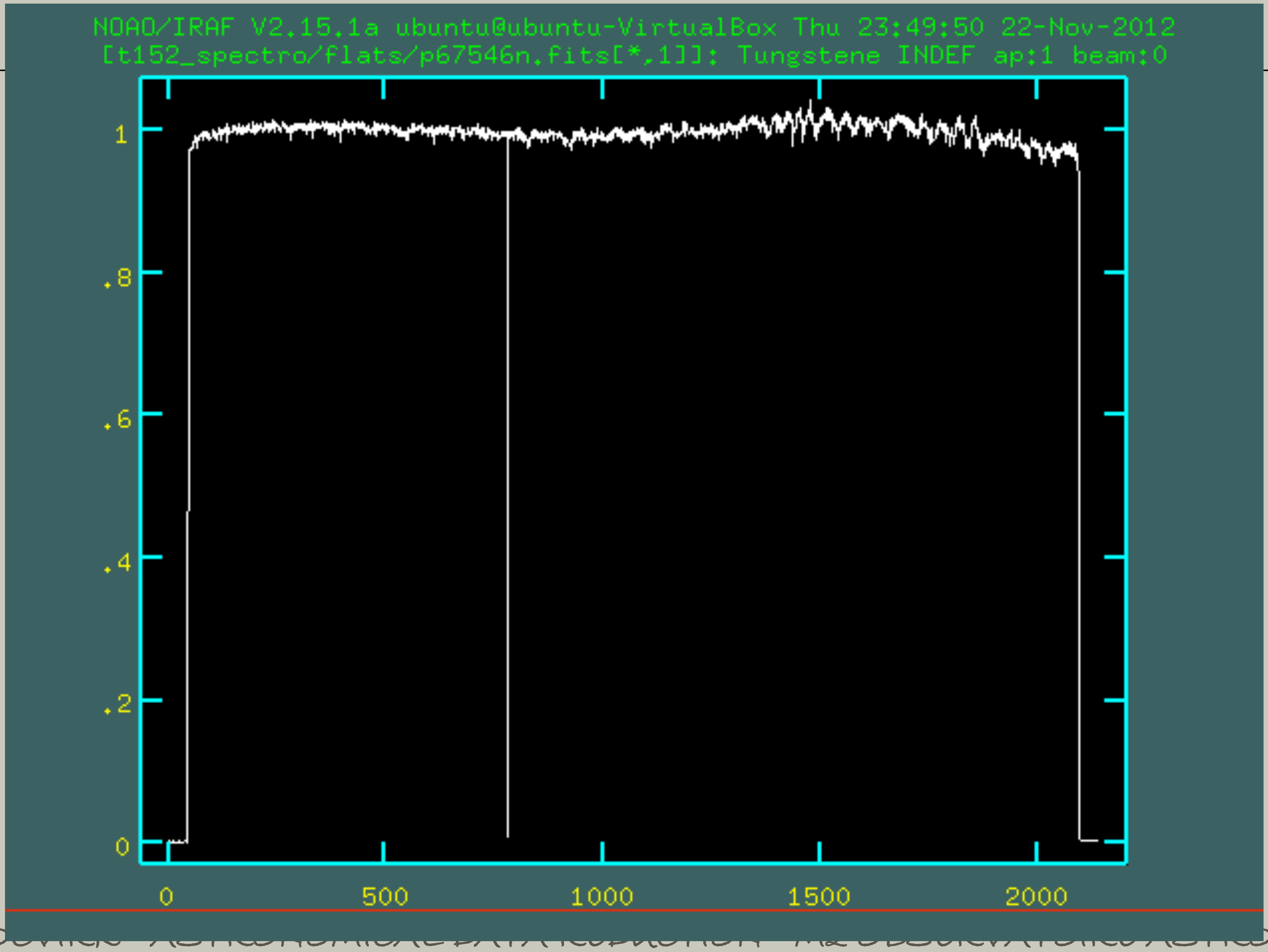
FASTER: IMCOMBINE SCALE=MEDIAN AND THEN CONTINUUM ON COMBINED SPECTRUM

GENERATION OF MASTER_FLAT -2

- Divide each flat by its low frequency continuum (normalisation)

cl> unlearn continuum (NO NEED to type this the first time you run continuum)

cl> continuum t152_spectro/flats/p67546tmp.fits t152_spectro/flats/p67546n.fits type=”ratio” naverag=1 function=”legendre” order=3



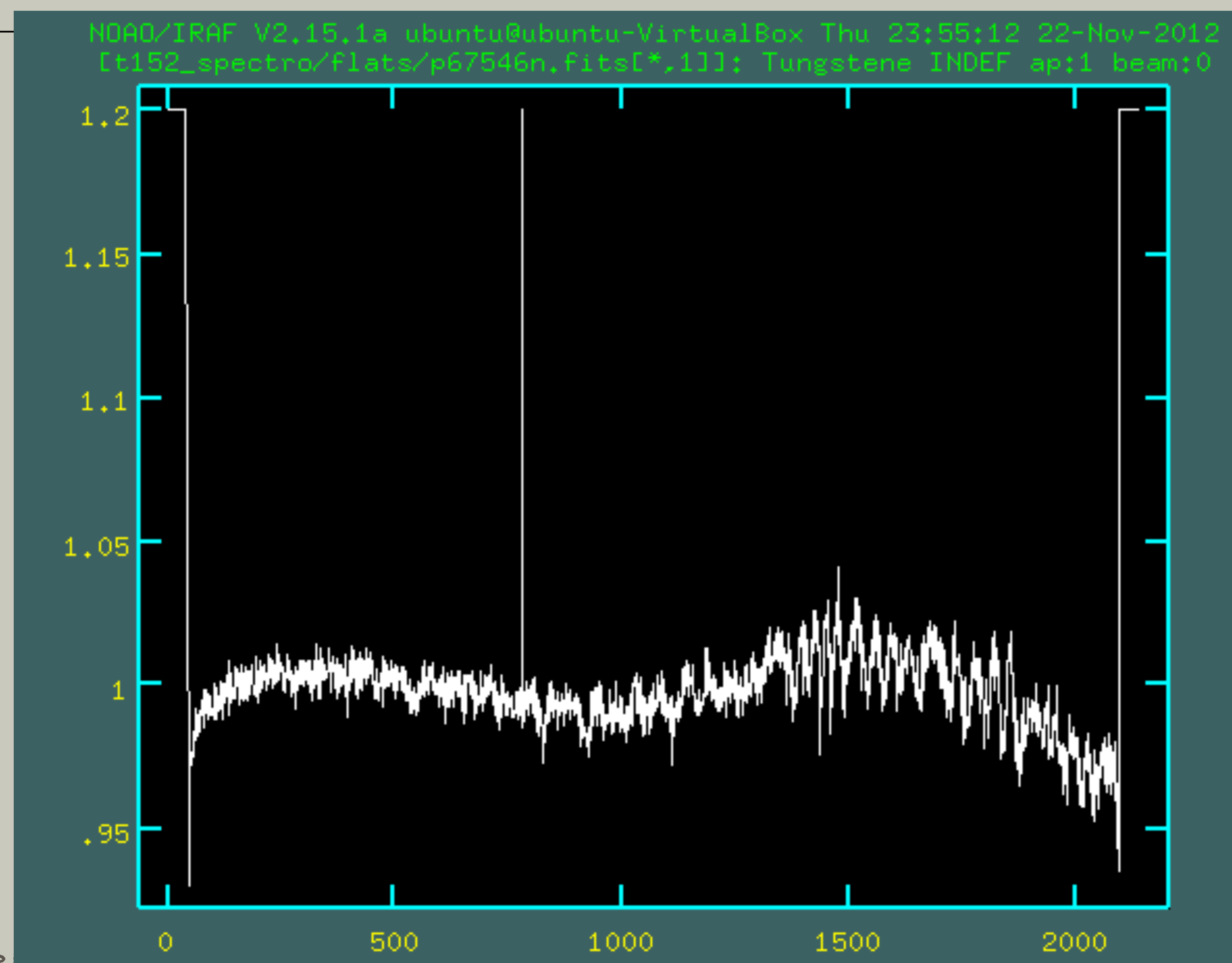
GENERATION OF MASTER_FLAT -3

- Combine normalised flats by medianing

cl> imcombine t152_spectro/flats/*n.fits t152_spectro/flats/master_flat.fits combine="median"

- Change 0 values (pour eviter la division par 0)

cl> imreplace t152_spectro/flats/master_flat 1.2 upper=0.5



OBSERVED SPECTRUM REDUCTION

- Subtract master_bias from each observation

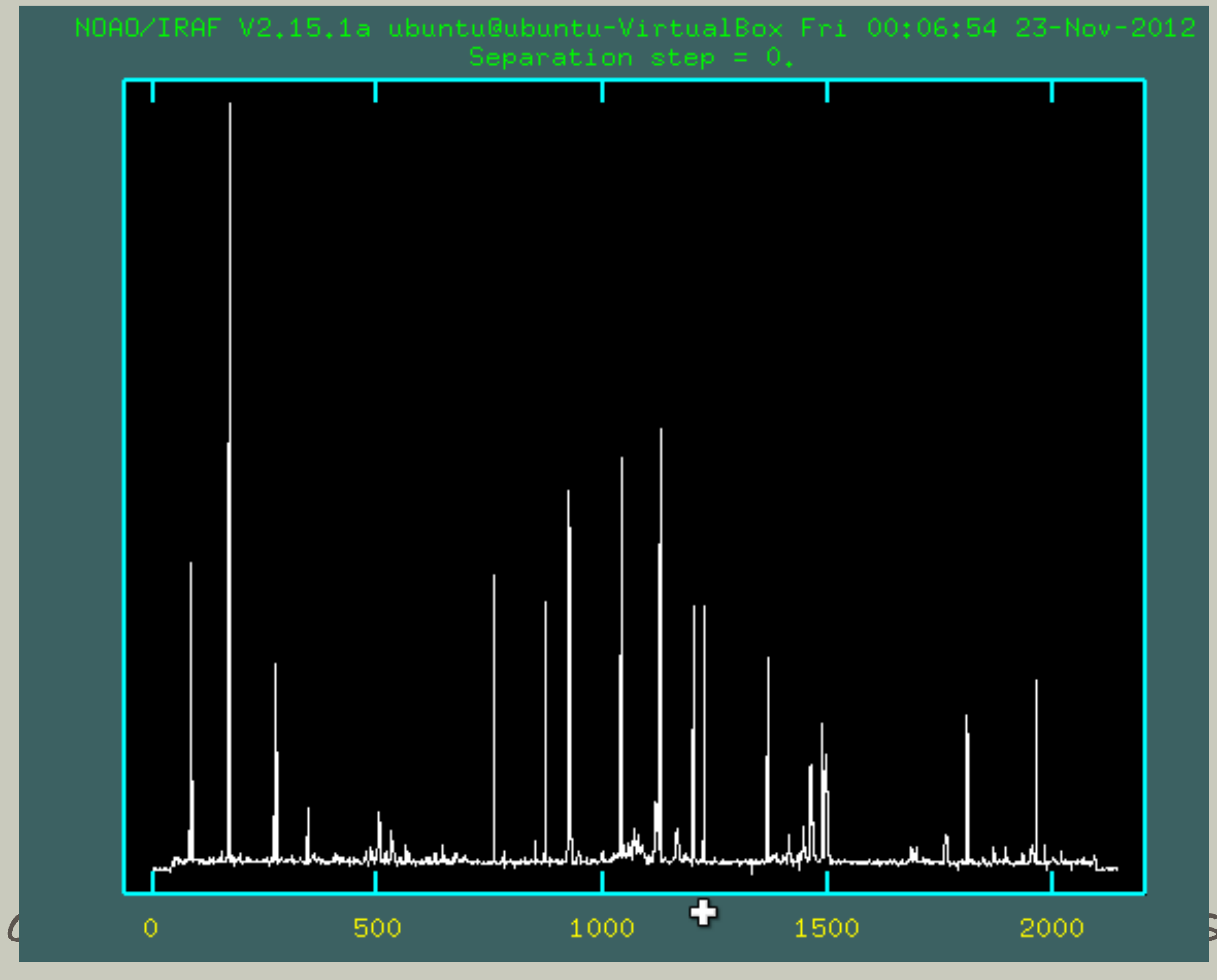
cl> imarith t152_spectro/M1/* - t152_spectro/offsets/master_bias t152_spectro/M1/*//tmp

- Divide by master_flat => REDUCED SPECTRUM

cl> imarith t152_spectro/M1/p*tmp.fits / t152_spectro/flats/master_flat.fits t152_spectro/M1/p*tmp.fits//n

- (If you have several spectra from the same region, combine them by first normalising by median of the [1600,1700] section:)

cl> imcombine t152_spectro/M1/<spectres.fits> t152_spectro/M1/spcombine.fits scale="median" statsec=[1600:1700] combine="median"

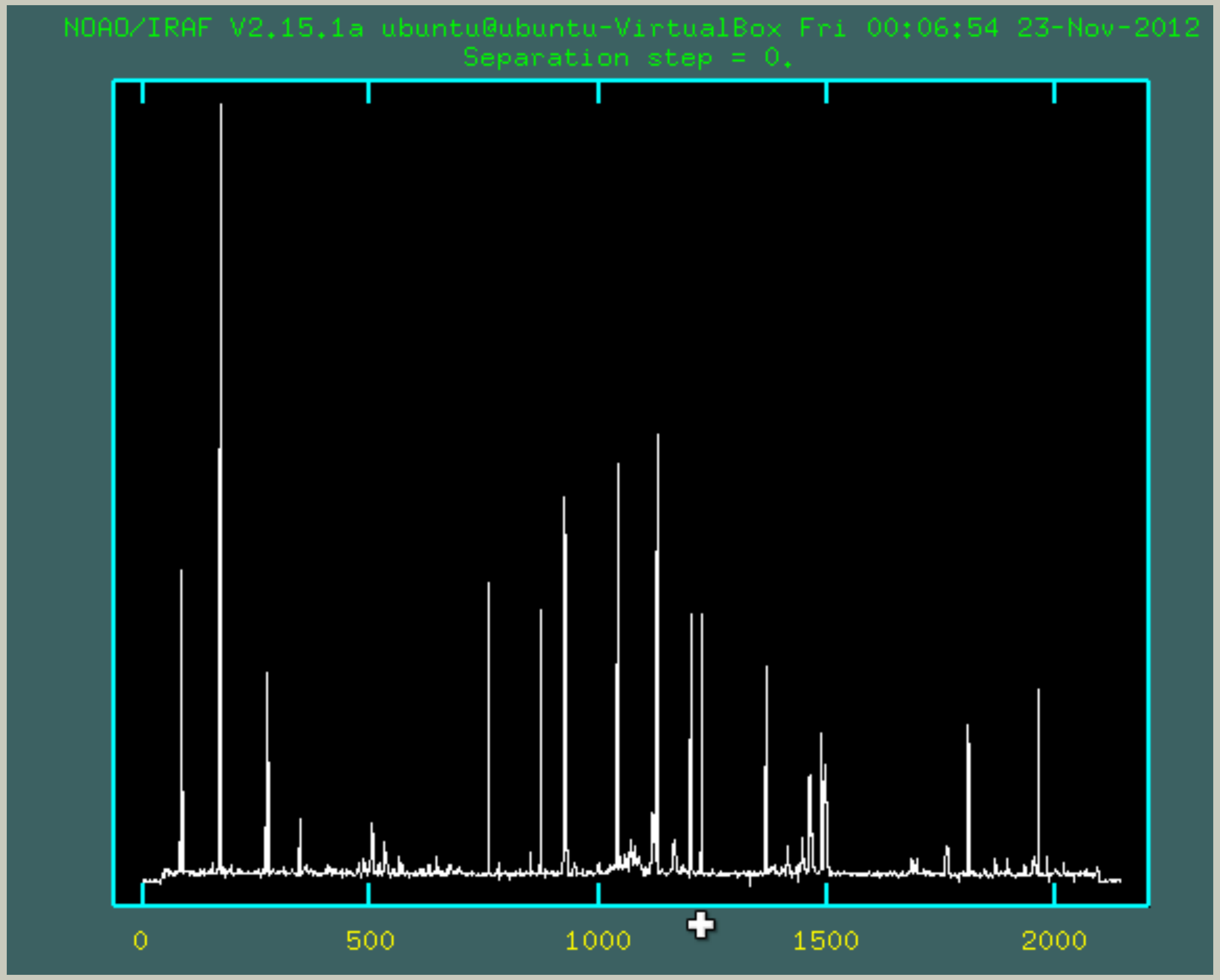


WAVELENGTH CALIBRATION

- Reduction of Thorium Argon lamp spectrum

cl> imcombine t152_spectro/lamp_thar/* t152_spectro/lamp_thar/tharavg.fits combine="median"

cl> imexp '(a-b)/c' t152_spectro/lamp_thar/thar.fits t152_spectro/lamp_thar/tharavg.fits t152_spectro/offsets/master_bias.fits t152_spectro/flats/master_flat.fits (files in order: result, a, b, c)



L

- Identification of lines in lamp spectrum
- Caution: execute within directory t152_spectro/lamp_thar/

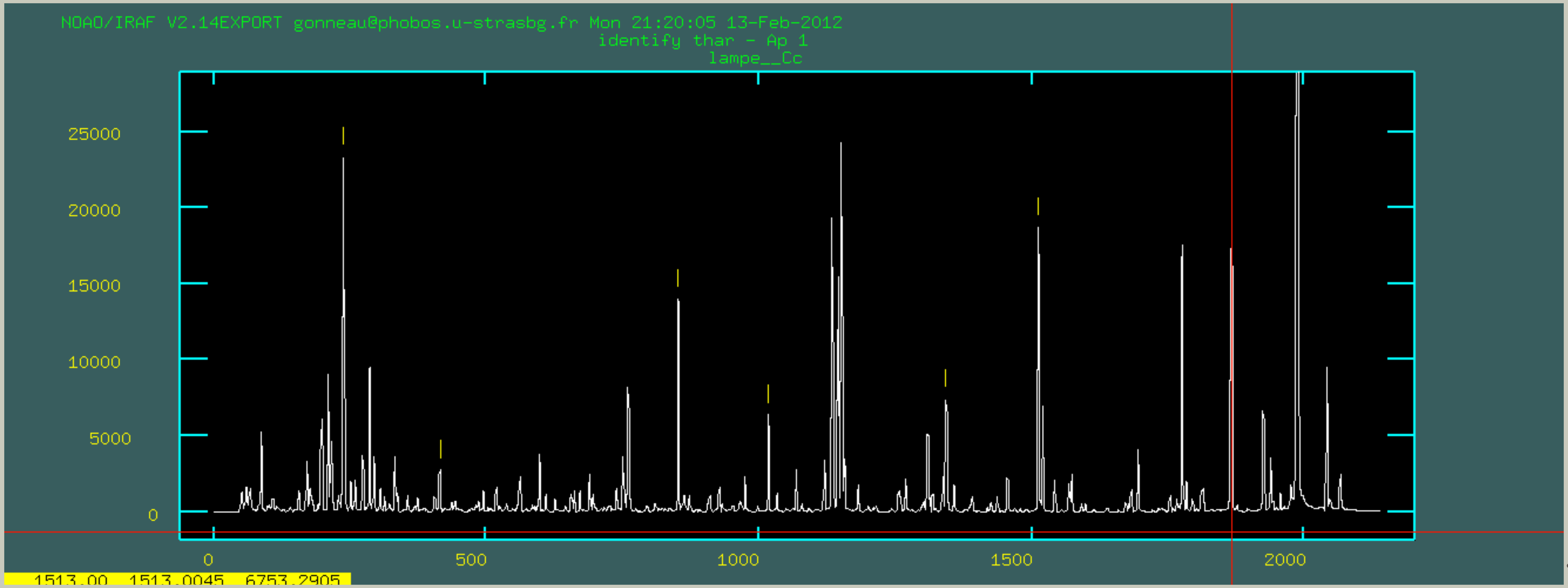
cl>cd t152_spectro/lamp_thar/

cl>identify thar.fits databas=database coordli=linelists$thar.dat fwidth=6. function=" legendre" order=3

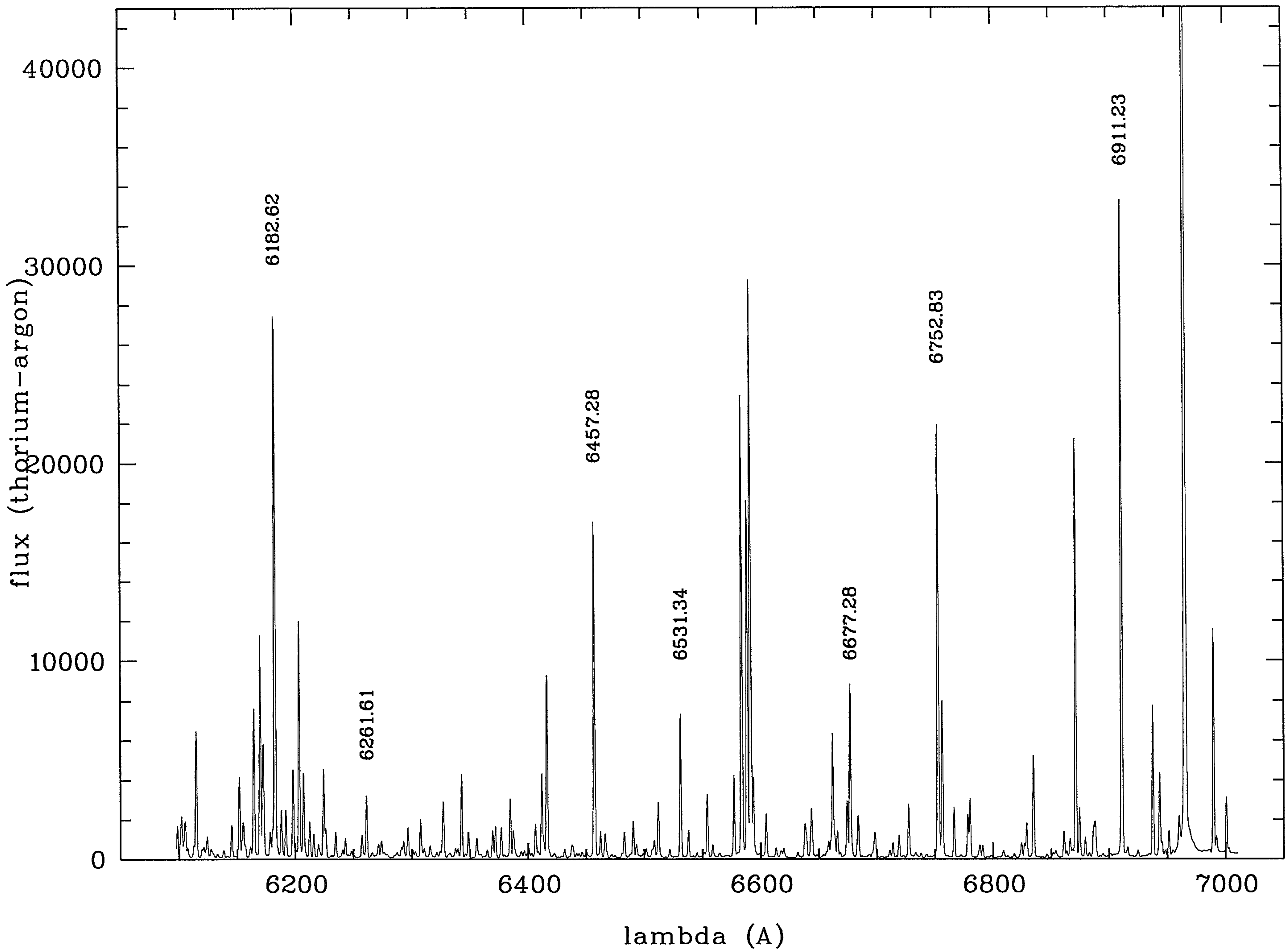
m: assign a wavelength to a line

d: suppress a line ID

(l: automatic line ID: only after a number of lines have been identified manually.)



STRASBOURG



6182.62
6261.61
6457.28
6531.34
6677.28
6752.83
6911.23
40000
30000
20000
10000
0
6200
6400
6600
6800
7000
flux (thorium-argon)
lambda (A)

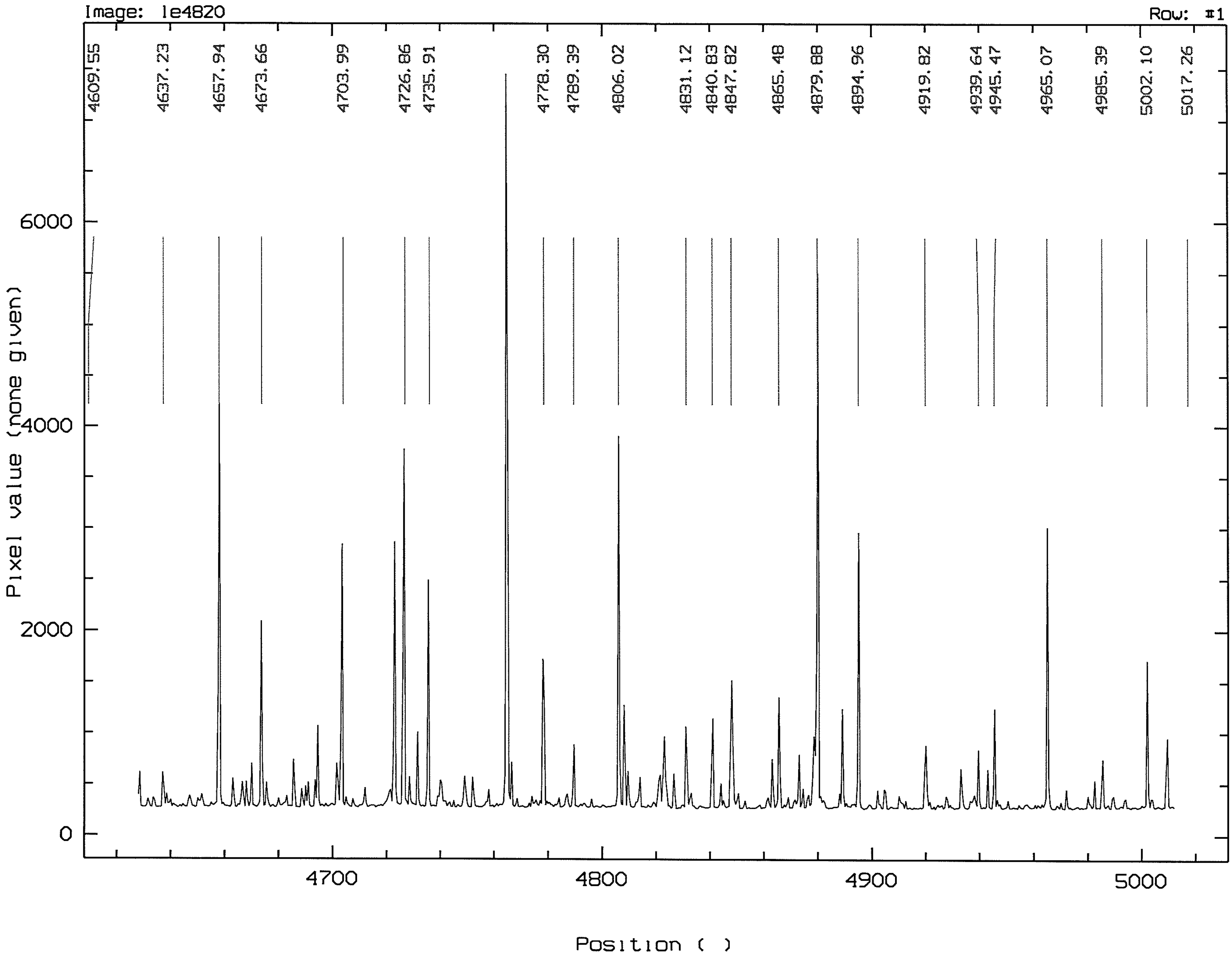


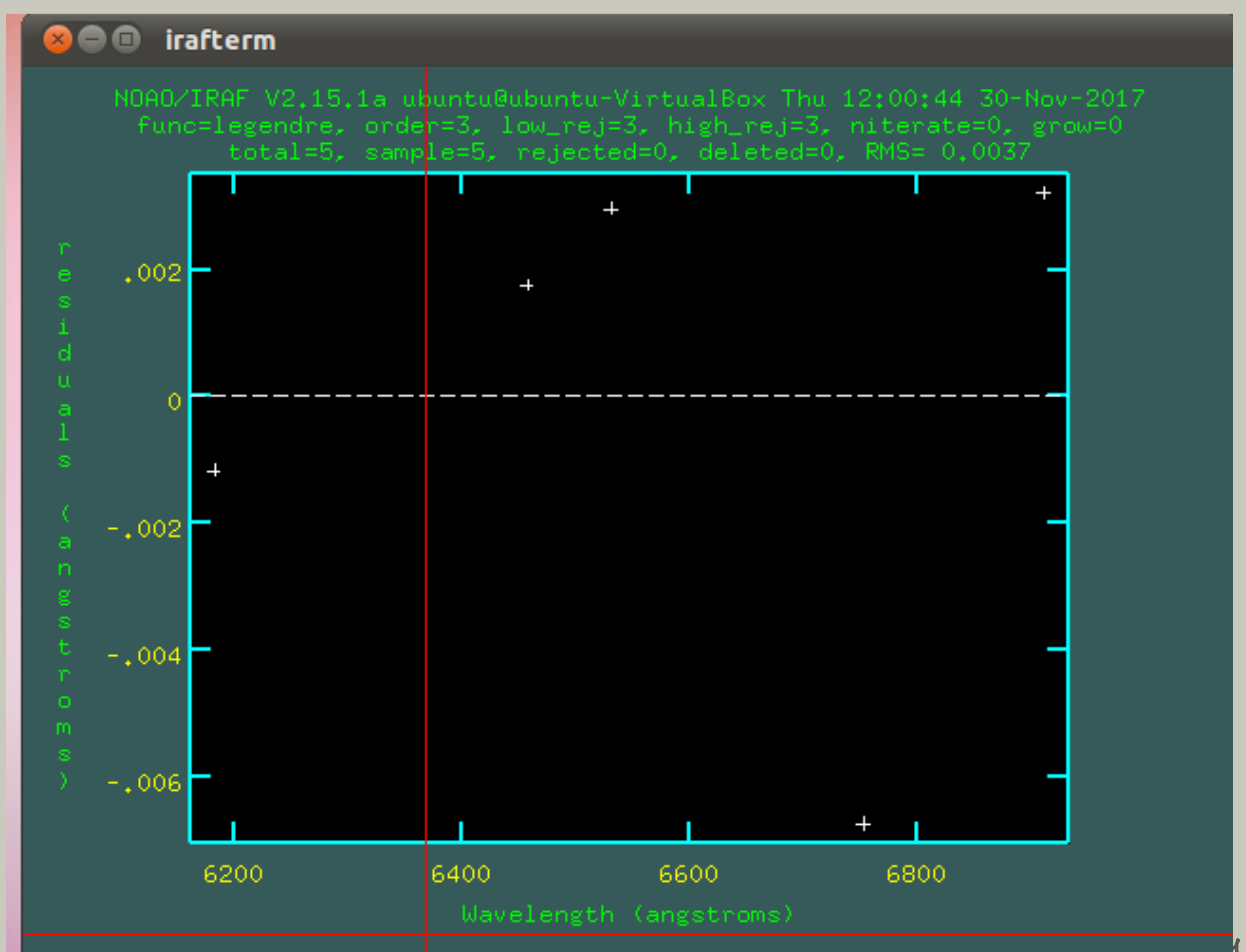
Image: le4820
Row: #1
4609.55
4637.23
4657.94
4673.66
4703.99
4726.86
4735.91
4778.30
4789.39
4806.02
4831.12
4840.83
4847.82
4865.48
4879.88
4894.96
4919.82
4939.64
4945.47
4965.07
4985.39
5002.10
5017.26
Pixel value (none given)
0
2000
4000
6000
4700
4800
4900
5000
Position ( )

IMPROVING THE WAVELENGTH CALIBRATION

- Still in identify window, launch the pixel-wavelength fit (pressing "f" produces the figure below) VERY IMPORTANT: without this step, calibration will not be obtained
- **Note the RMS=** on the top right of the window. This number is super important: it is the accuracy of the wavelength calibration. It has direct implications for the accuracy of your Doppler shift measurements as deltav = c * delta_lambda / lambda
- If you have a big outlier, you can remove the line from the calibration by pressing "d" (for delete) on it, and then press f again. => the excluded point will appear as a cross (while the other points are "+")
- You can also go back to the line marking window by pressing q once. For instance if one of your atlas lines is wrong you can delete (d) it and mark (m) its value again, corrected.

WAVELENGTH CALIBRATION

- Still in identify window, launch the pixel-wavelength fit (pressing "f" produces the figure below) VERY IMPORTANT: without this step, calibration will not be obtained
- type q q in the graphical window to recover control in the terminal
- answer yes to save the calibration parameters into the database.



- Amplitude of residuals ~0.002 Angstrom

WAVELENGTH CALIBRATION

- What is the result of the identify command?
  - generation of directory t152_spectro/lamp_thar/database
  - containing file idthar containing the calibration parameters computed by identify.
  - The field "features" corresponds to coords (x,λ) of lines flagged by user
  - The header of thar.fits contains a new keyword "REFSPEC1" which points to the file containing the calibration parameters (**imheader <img> l+**)

```
ubuntu@ubuntu-VirtualBox: ~/iraf/t152_spectro/lamp_thar/database
File Edit View Search Terminal Help
ubuntu@ubuntu-VirtualBox:~/iraf/t152_spectro/lamp_thar/database$ ls
idthar
ubuntu@ubuntu-VirtualBox:~/iraf/t152_spectro/lamp_thar/database$ more idthar
# Wed 11:15:35 28-Nov-2012
begin   identify thar - Ap 1
        id      thar
        task    identify
        image   thar - Ap 1
        aperture        1
        aplow   1.
        aphigh  1.
        units   Angstroms
        features        2
                238.92  6199.9375  6199.9375    6.0 1 1
               1867.09   6902.667   6902.667    6.0 1 1
        function legendre
        order 3
        sample *
        naverage 1
        niterate 0
        low_reject 3.
        high_reject 3.
```

```
onedspec> imheader thar.fits l+
thar.fits[2142,1][real]: lampe__Cc
No bad pixels, min=0., max=0. (old)
IMCMB002= 'p67508.fits'
IMCMB003= 'p67509.fits'
IMCMB004= 'p67520.fits'
IMCMB005= 'p67521.fits'
NCOMBINE=                    5
REFSPEC1= 'thar    '
```

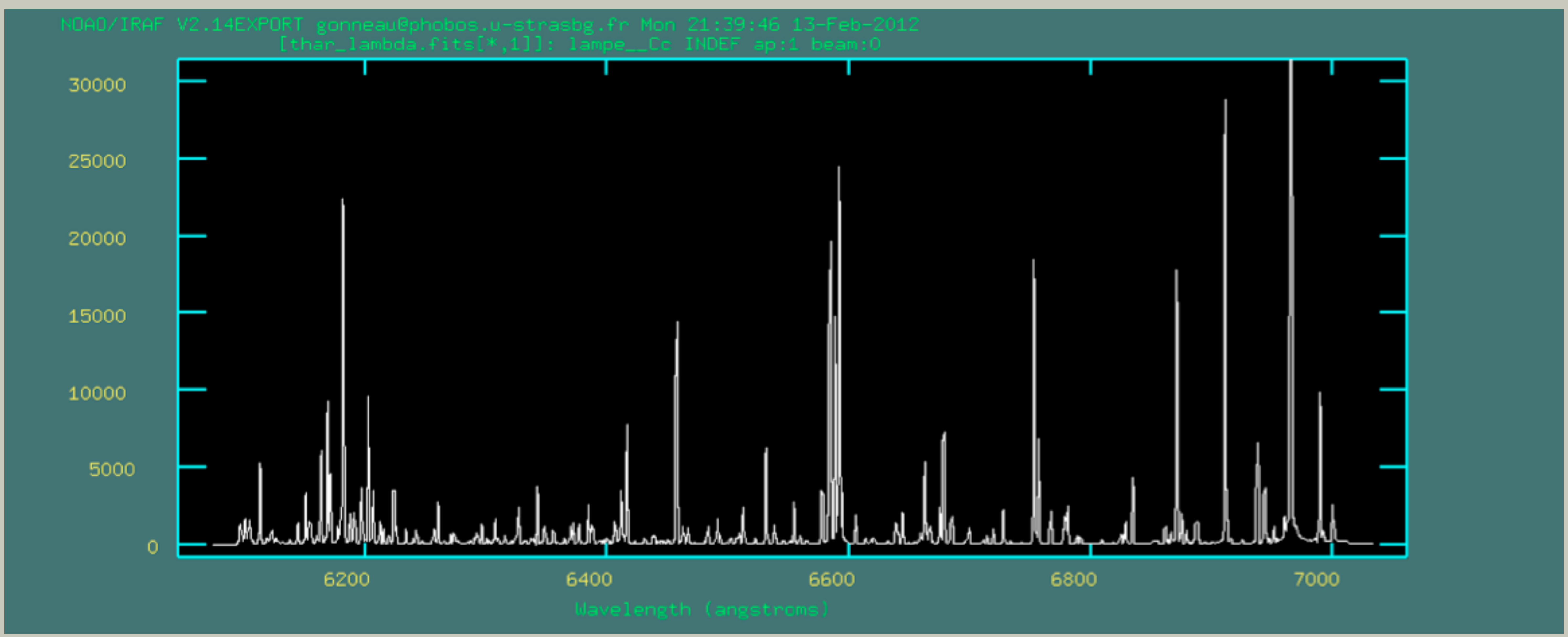
WAVELENGTH CALIBRATION

- calibrate the lamp spectrum (resampled)

cl> dispcor t152_spectro/lamp_thar/thar.fits t152_spectro/lamp_thar/thar_lambda.fits databas=t152_spectro/lamp_thar/database

cl> splot t152_spectro/lamp_thar/thar_lambda.fits

cl> imheader t152_spectro/lamp_thar/thar_lambda.fits l+ (see new keywords!!)




```
APNUM1  = '1 0 1.00 1.00'
DC-FLAG =                    0
WCSDIM  =                    2
CTYPE1  = 'LINEAR  '
CTYPE2  = 'LINEAR  '
CRVAL1  =     6097.70725595451
CRPIX1  =                   1.
CDELT1  =    0.429927894950191
CDELT2  =                   1.
CD1_1   =    0.429927894950191
CD2_2   =                   1.
LTM1_1  =                   1.
LTM2_2  =                   1.
WAT0_001= 'system=equispec'
WAT1_001= 'wtype=linear label=Wa
WAT2_001= 'wtype=linear'
DCLOG1  = 'REFSPEC1 = p67520'
onedspec> 
```

WAVELENGTH CALIBRATION OF SCIENCE FRAMES

- update the keyword REFSPEC1 in the science spectra

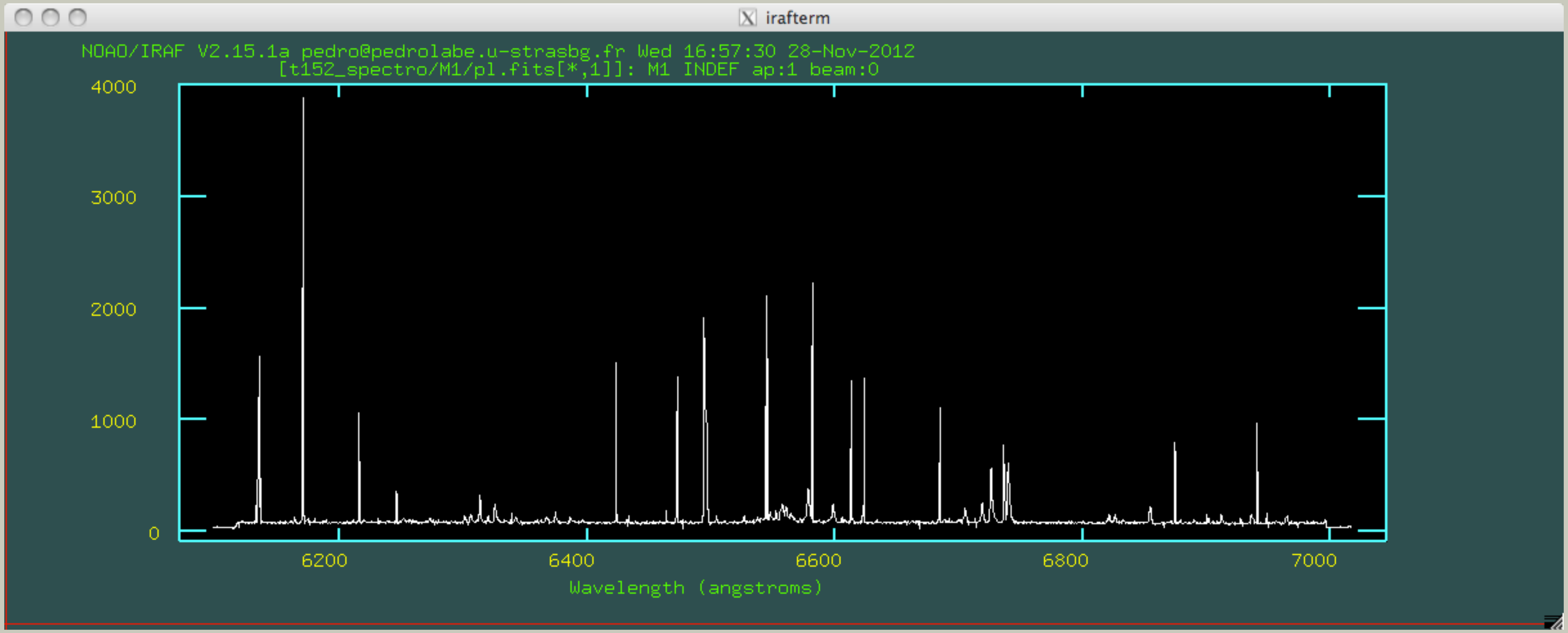
cl> hedit t152_spectro/M1/p*tmpn.fits REFSPEC1 thar add+

- Check the the REFSPEC1 has indeed been added to the headers

cl> imheader t152_spectro/M1/p*tmpn.fits l+

- relaunch the calibration/resampling

cl> dispcor t152_spectro/M1/p*tmpn.fits t152_spectro/M1/p*tmpn.fits//_lambda databas=t152_spectro/lamp_thar/database



DATA REDUCTION - SPECTRO

Exercise:

- M1(crab nebula)
- M42 (Orion nebula)
- M51 (Whirlpool galaxy)
- NGC2392 (Eskimo nebula)

PREPARATION OF OBSERVATIONS

- Objects visibility
    - http://catserver.ing.iac.es/staralt/index.php
- Exposure time estimation => ETC
    - http://www.eso.org/observing/etc/ (exemple)
- Finding charts => Aladin
- Check OHP website for more information

PREPARATION OF OBSERVATIONS

A list of interesting objects, and 3 questions:

- Can they be observed during our stay at ohp? (decembre)
- Which parts of the object should we observe?
- In which order should we observe these objects?

- NGC40
- M77
- NGC1275
- M42
- CQ_Tau
- T_Tau
- HD53367
- M1
- SH2-247
- SH2-257
- NGC2273
- NGC2392
- MRK710
- M81
- M82
- MRK35
- NGC4258
- M87
- MRK59
- NGC6543
- WR137
- SH2-125
- NGC7027

5 - ANALYSE SPECTRO

- LINE MEASUREMENTS:
- IN SPLOT:
- ZOOM COMMANDS: A, W, K, J
- LINE FITTING: K K
- GAUSSIAN FIT: G G
- GEOCENTRIC VELOCITY (A L'OHP)

5 - ANALYSE SPECTRO

- LINE MEASUREMENTS:
- IN SPLOT:
- ZOOM COMMANDS: A,W, K, J
- LINE FITTING: K K
- GAUSSIAN FIT: G G
- WHATS A REAL LINE? WHATS NOISE?

6 - TIPS & TRICKS

- PHOTOMETRY: SHIFT IMAGE AROUND
- IMALIGN:HTTP://CASA.COLORADO.EDU/~GINSBURA/DS9_IMALIGN.HTM

TIPS AND TRICKS: SHARED FOLDERS IN VIRTUALBOX

- **On guest**, in ubuntu virtualbox, install GuestAdditions:
  - right click on the CD (menu at bottom right screen corner)
  - choose VBoxGuestAdditions.iso (use "locate" on host if needed or download from: http://download.virtualbox.org/virtualbox/)
  - popup => run, authenticate
  - It runs for a while, entry at the end.
- **On host:** create a directory ~/share
- **On guest** (ubuntu virtual box), Right click shared folders (menu bottom right corner of screen)
- New shared folder
- Choose directory ~/share of host, choose as name "share" (not host)
- (if field "Mount point" exists, => "share")
- click "Auto-mount"
- Create a shared directory on guest: mkdir ~/host
- sudo mount -t vboxsf -o uid=1000,gid=1000 share /home/ubuntu/host
- You may need to reboot the virtual box.
- The share on the host directory and the host on guest should have the same content (y mettre un fichier quelconque pour tester (touch myfile))

SHARE FOLDER TROUBLESHOOTING

- **if you get: mounting failed: no such device:**

```
cd /opt/VBoxGuestAdditions-*/init
sudo ./vboxadd stop
sudo ./vboxadd setup
```

then redo the mount command

STUFF TO TRY/EXPERIMENT

- SIRIL?
- **jskycalc : planning tool for observations**
- **for wavelength calibration in python:** https://pydis.readthedocs.io/index.html **or**
- **RASCAL https://arxiv.org/abs/1912.05883**
- nova.astrometry.net **: automatic astrometric calibration**
- **align images with astroimageJ. Use images from OHP or:**
- astro.u-strasbg.fr/~ocvirk/M20_R.tar
- **Also check astralign python module https://astroalign.readthedocs.io/en/latest/**
- **Follow steps given in**

http://www.astrofriend.eu/astronomy/tutorials/tutorial-astroimagej/tutorial-aij-06-align-rggb-files.html

MORE ON SHARED FOLDERS

Depuis la console guest, taper
sudo apt install build-essential dkms linux-headers-$(uname -r)
puis cliquer sur périphériques en haut de la fenêtre, insérez le CD, accepter l'installation, etc.
Ensuite, redémarrer la Vbox, et à l'allumage normalement on peut changer l'échelle de la Vbox sans que la qualité d'image baisse

ou plutot (depuis virtualbox6?):
=> virtual screen => 200%

HEDIT DISPLAY ONLY

Sometimes you just want to get one specific keyword from all file headers in a list. There is a specific hedit syntax for that:

example below for EXPOSURE

- hedit file EXPOSURE .
- the . tells hedit to just print the value of the keyword
- file can be a list of files (*)

MEASURING THE SIZE OF A GALAXY/OBJECT

Note the apparent size of an extended object depends on your cuts! The deeper the image, the larger the object seems to be. For galaxies, R_{25} was often used … EXPLAIN.

What to do: find the cut where the galaxy has its max size before seeing only the sky. => means we have reached the sky mag, which is given on OHP website.

PUT URL HERE

If sky mag is 19mag/arcsec^2, that means you hvae determined R_{19}

- hedit file EXPOSURE .
- the . tells hedit to just print the value of the keyword

NOUVEAU PLAN COURS

- ☐ USE NIST TO FIGURE OUT WHAT ELEMENT LINES WE HAVE
- ☐ DONT FORGET TO REJECT/ MASK BAD LINES
- ☐ MANIPULATION DES HEADERS
- ☐ ALTERNATIVE FOR SPECTRAL CALIB: CROSS-CORRELATION BETWEEN CALIBRATED AND RAW LAMP SPECTRUM?
- ☐ EXPLAIN ROLE / AMPLITUDE OF HIGHER ORDER TERMS IN DISPERSION LAW