

Integral Field Spectroscopy

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Institute of
Space Sciences

IEEC^R **CSIC**
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



MINISTERIO
DE CIENCIA
E INNOVACIÓN



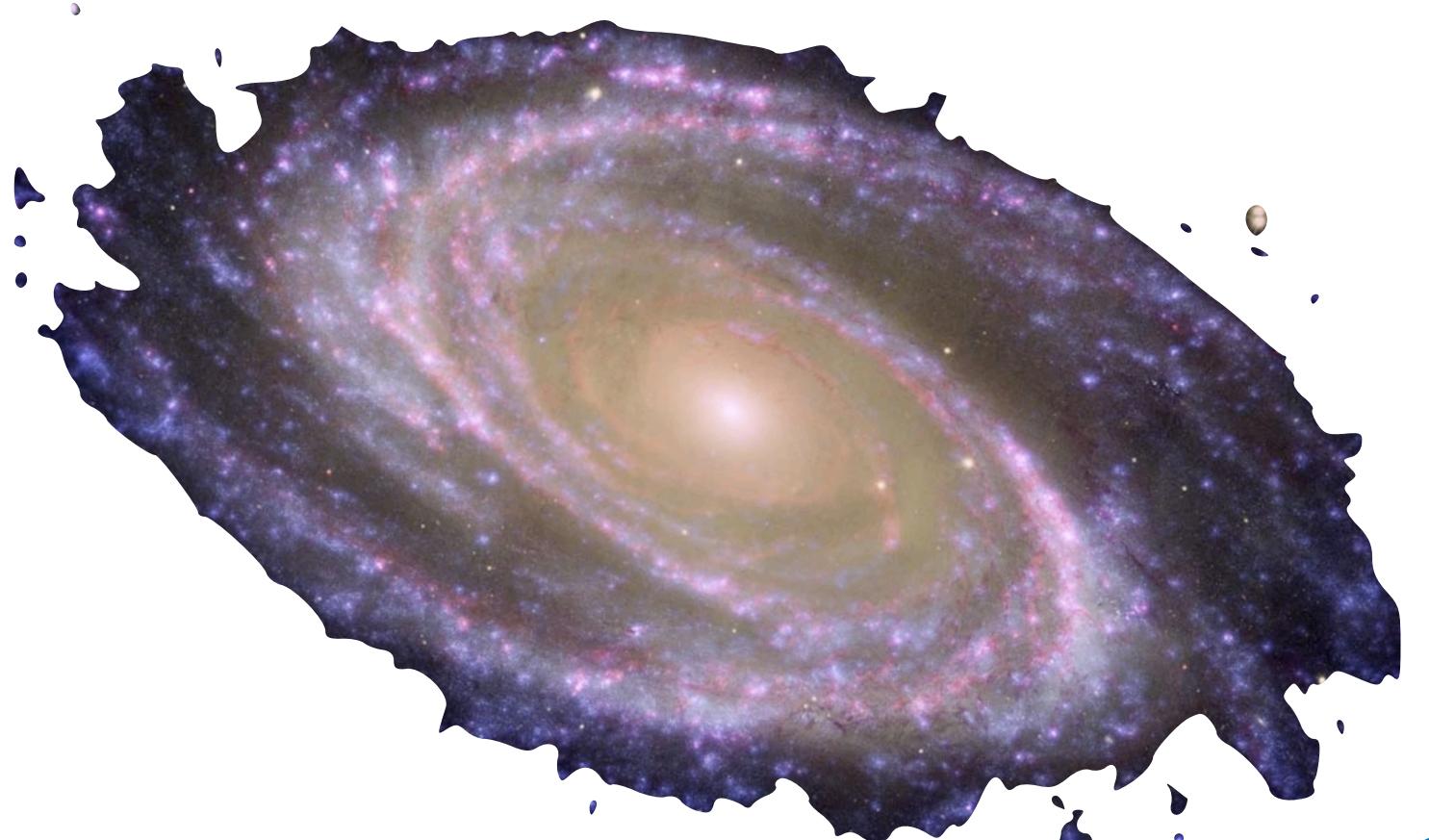
UNIÓN EUROPEA
Fondo Social Europeo
El FSE invierte en tu futuro



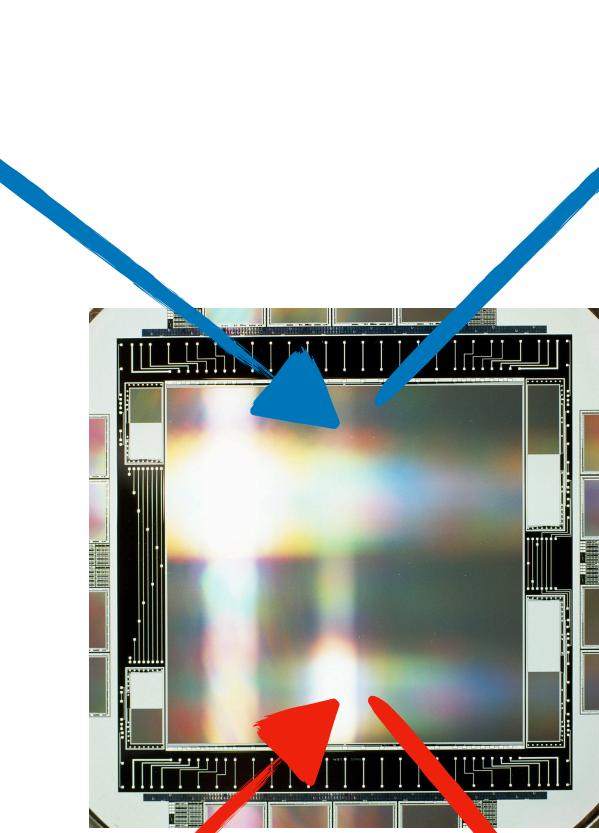
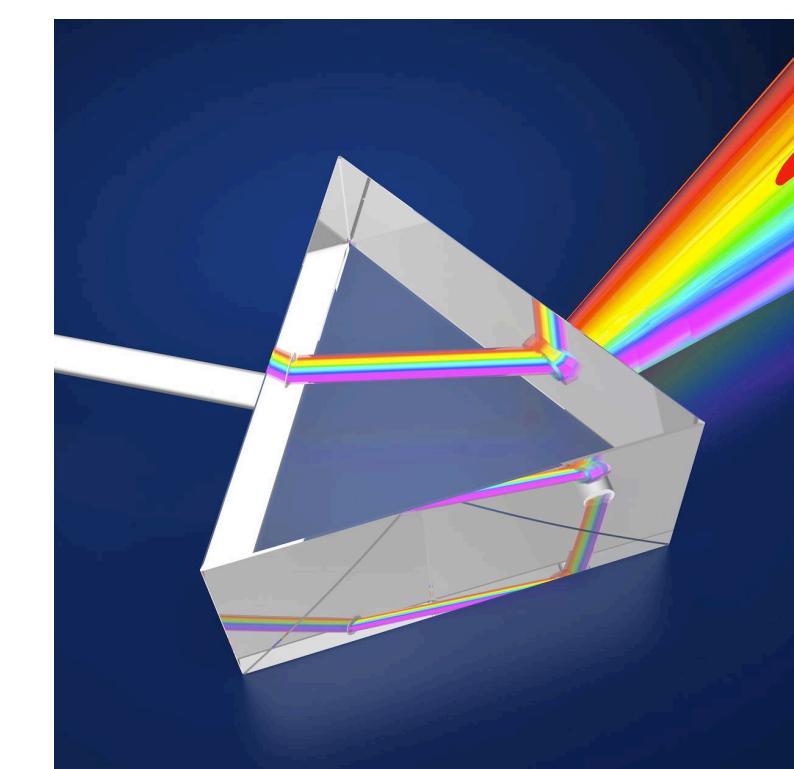
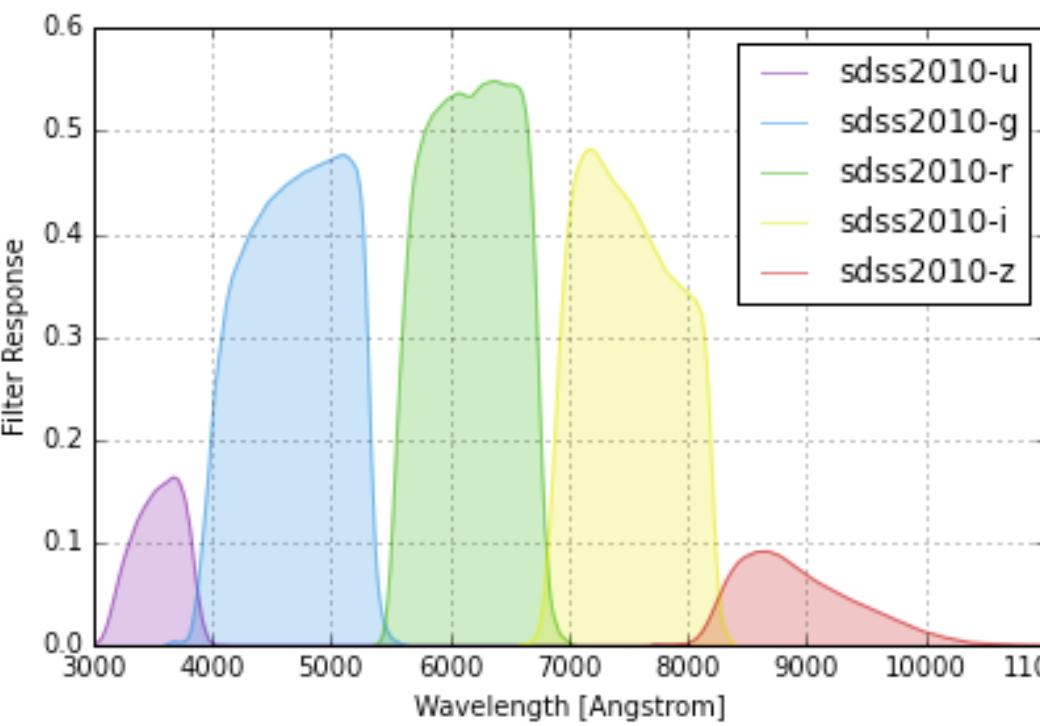
AGENCIA
ESTATAL DE
INVESTIGACIÓN

Spectroscopy

Basics

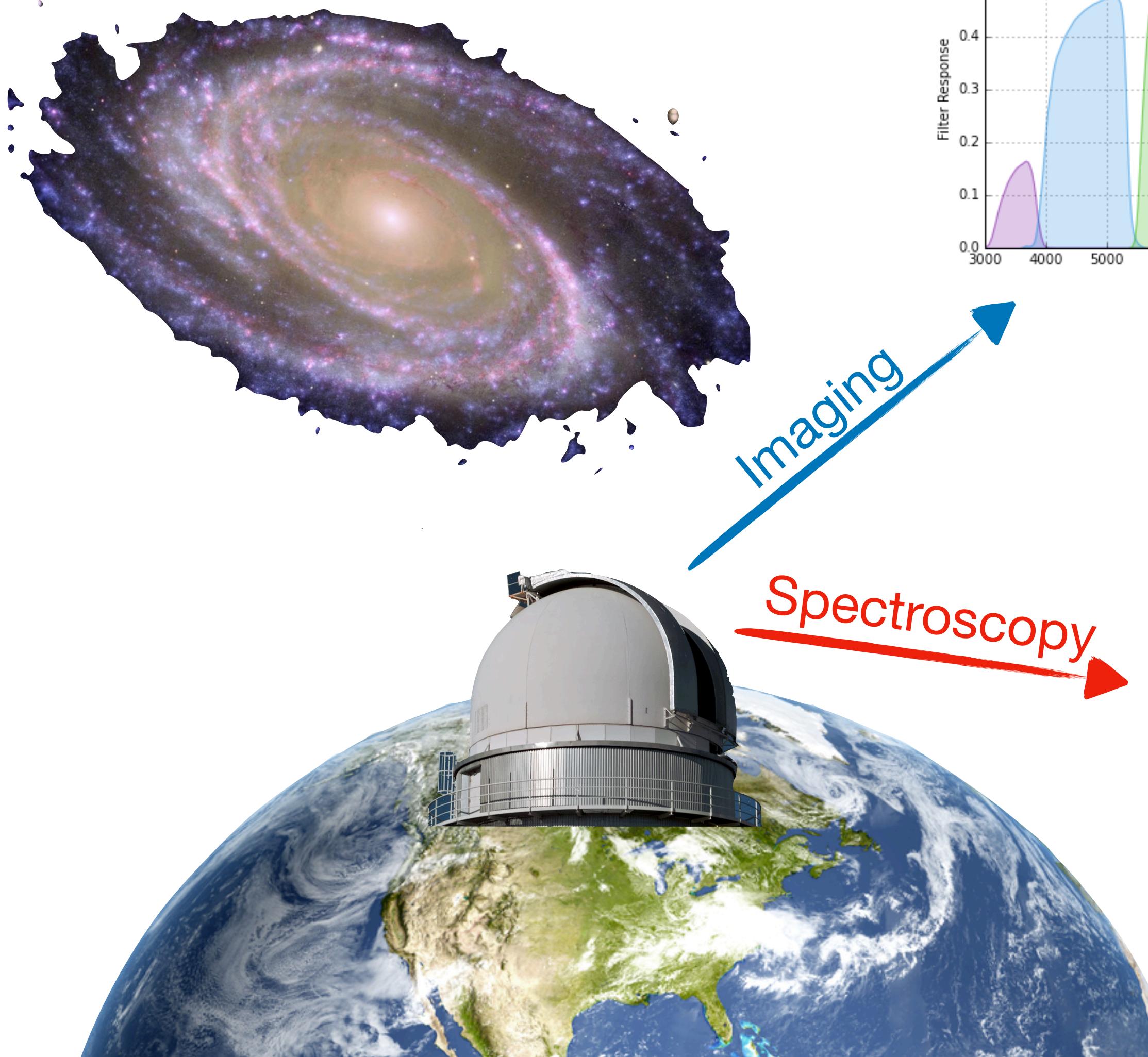


Imaging
Spectroscopy

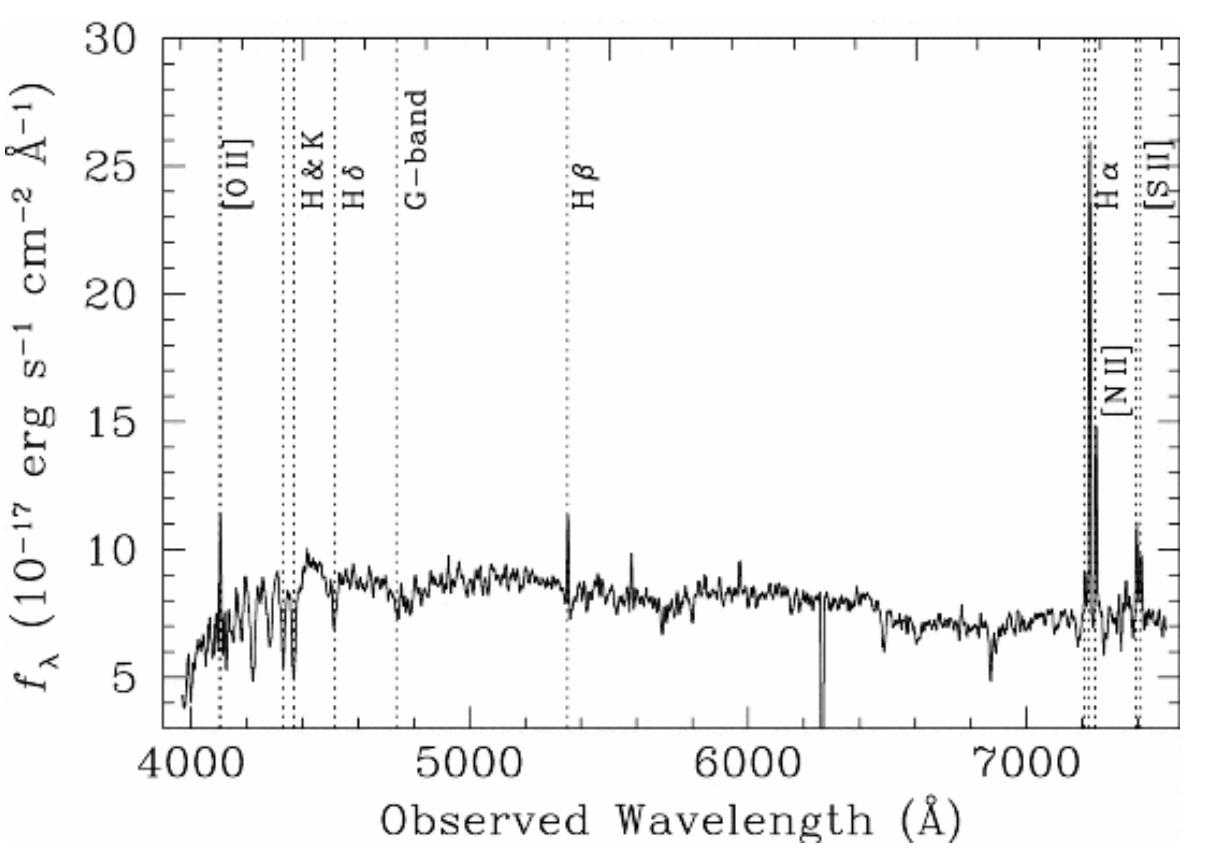
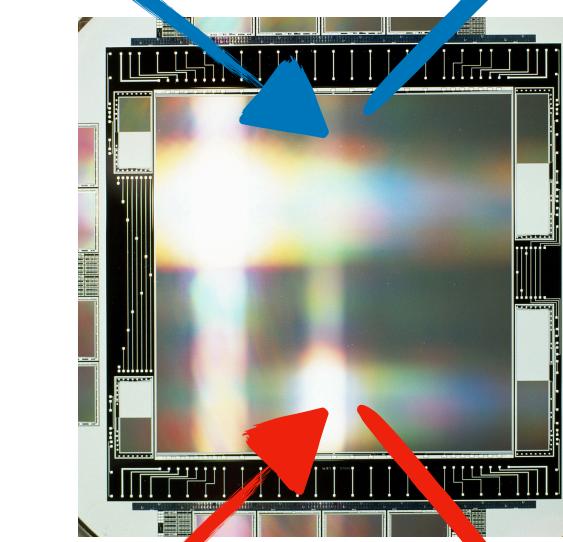
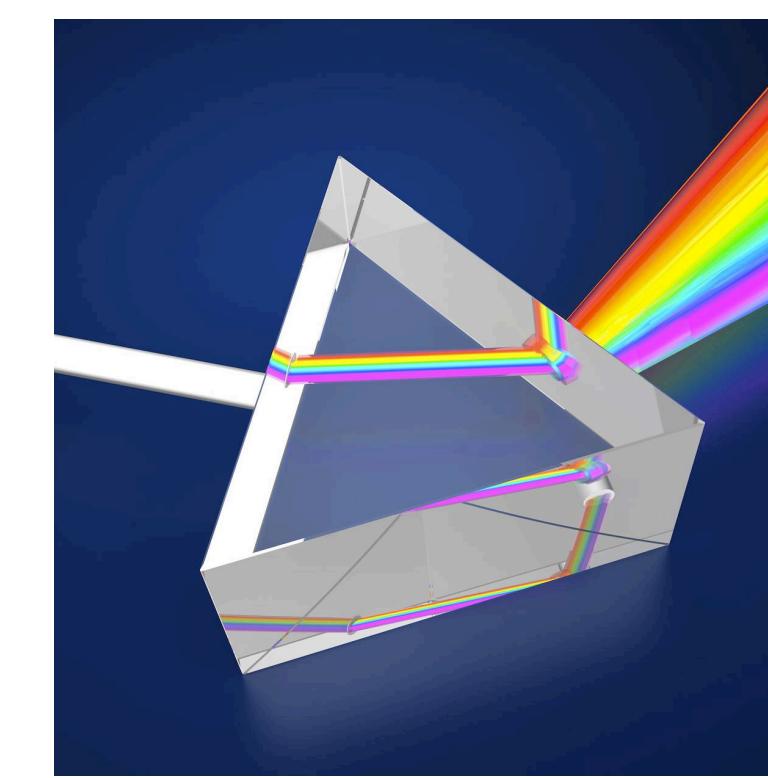
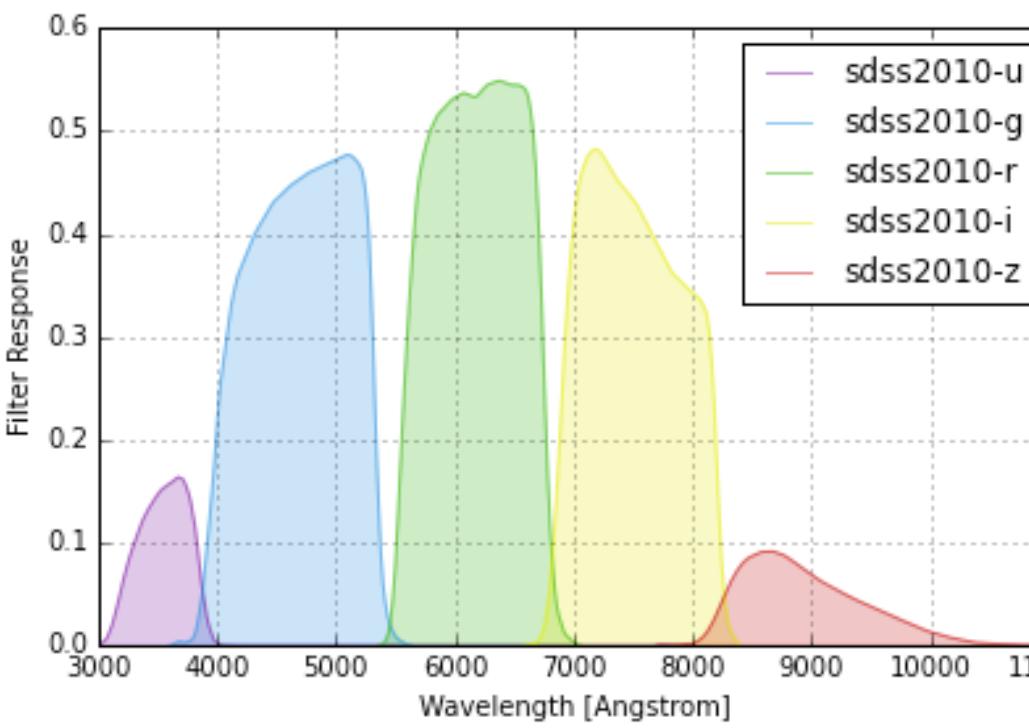


Spectroscopy

Basics



Imaging
Spectroscopy



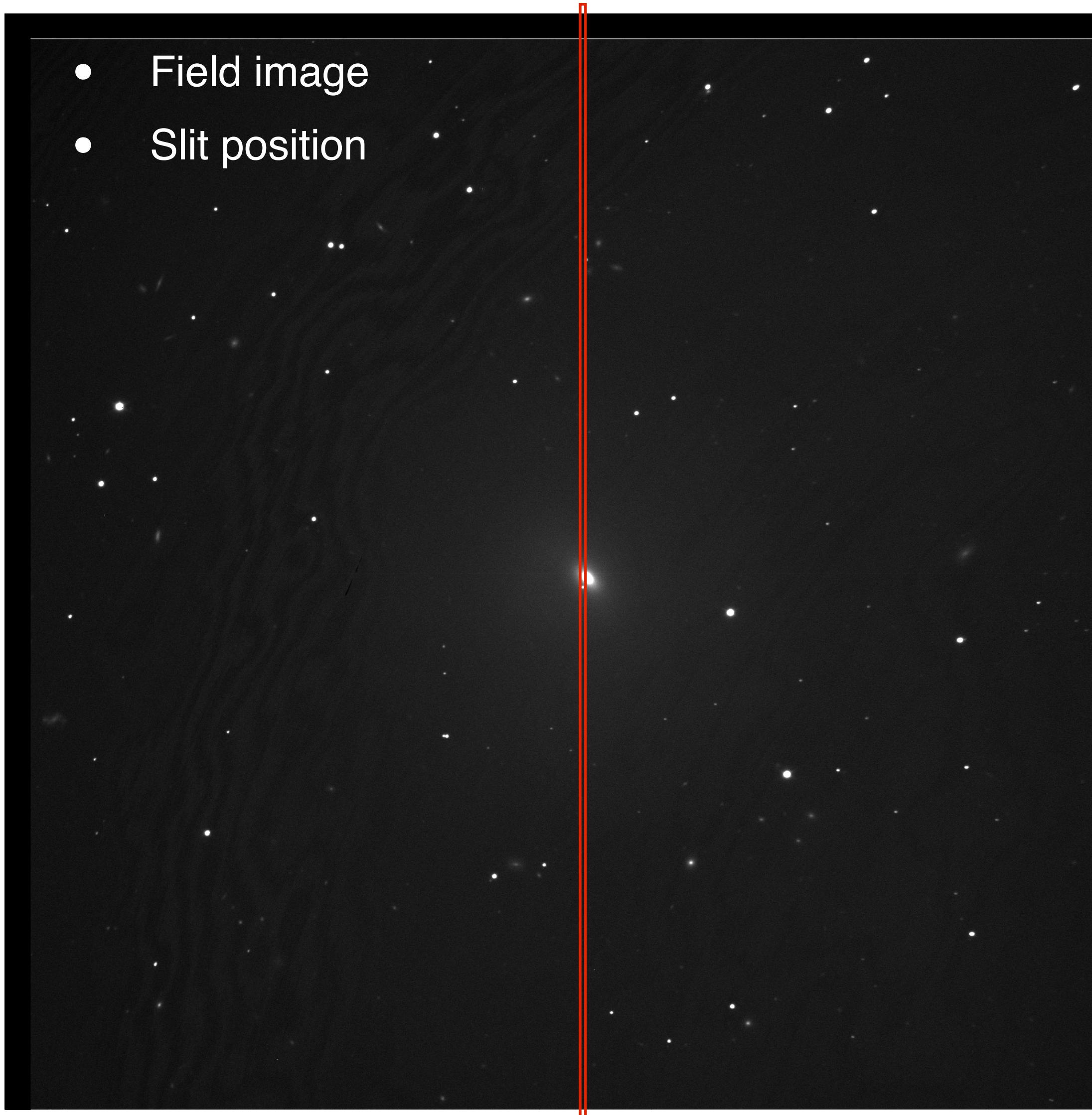
(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)



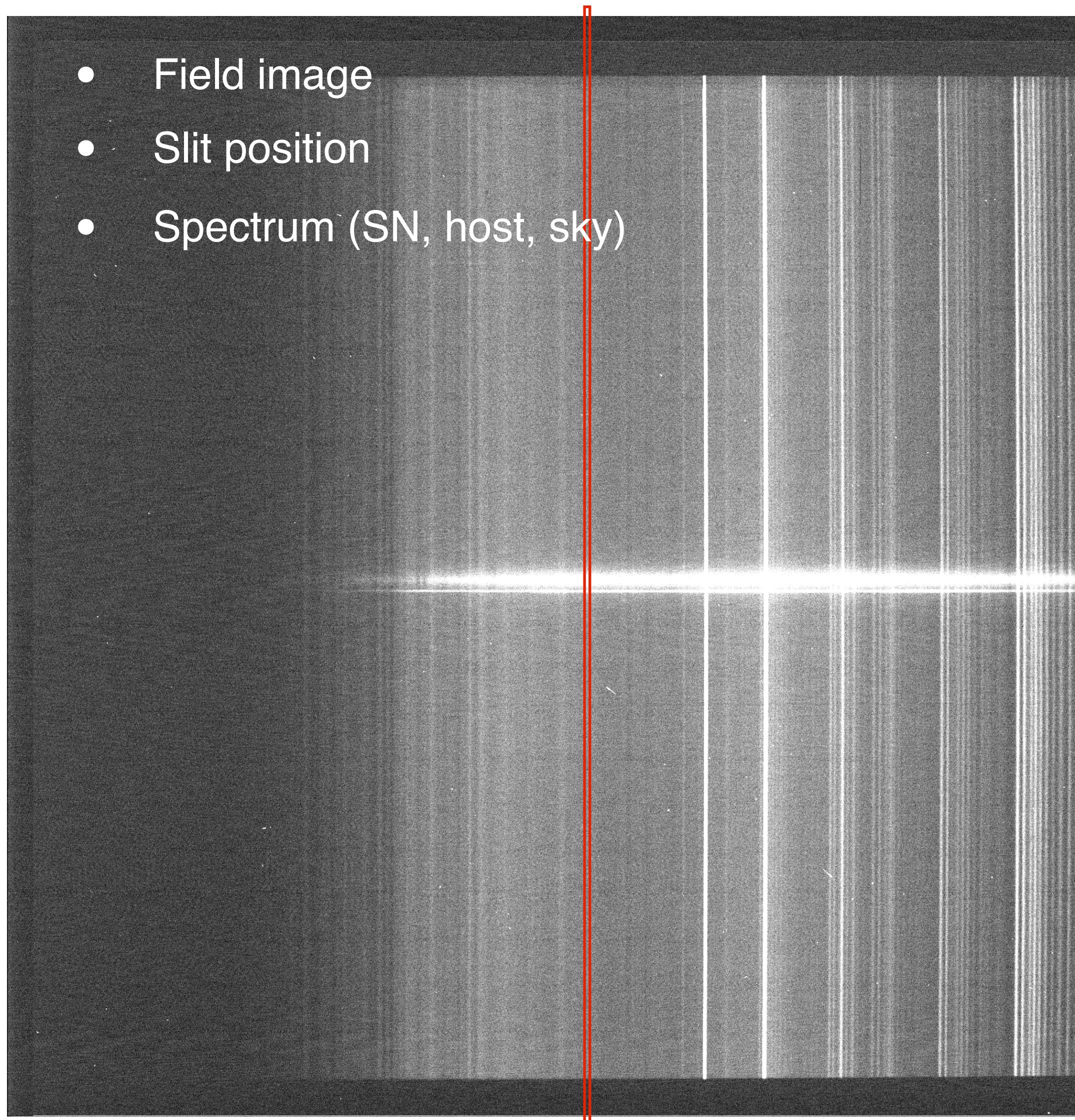
(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)



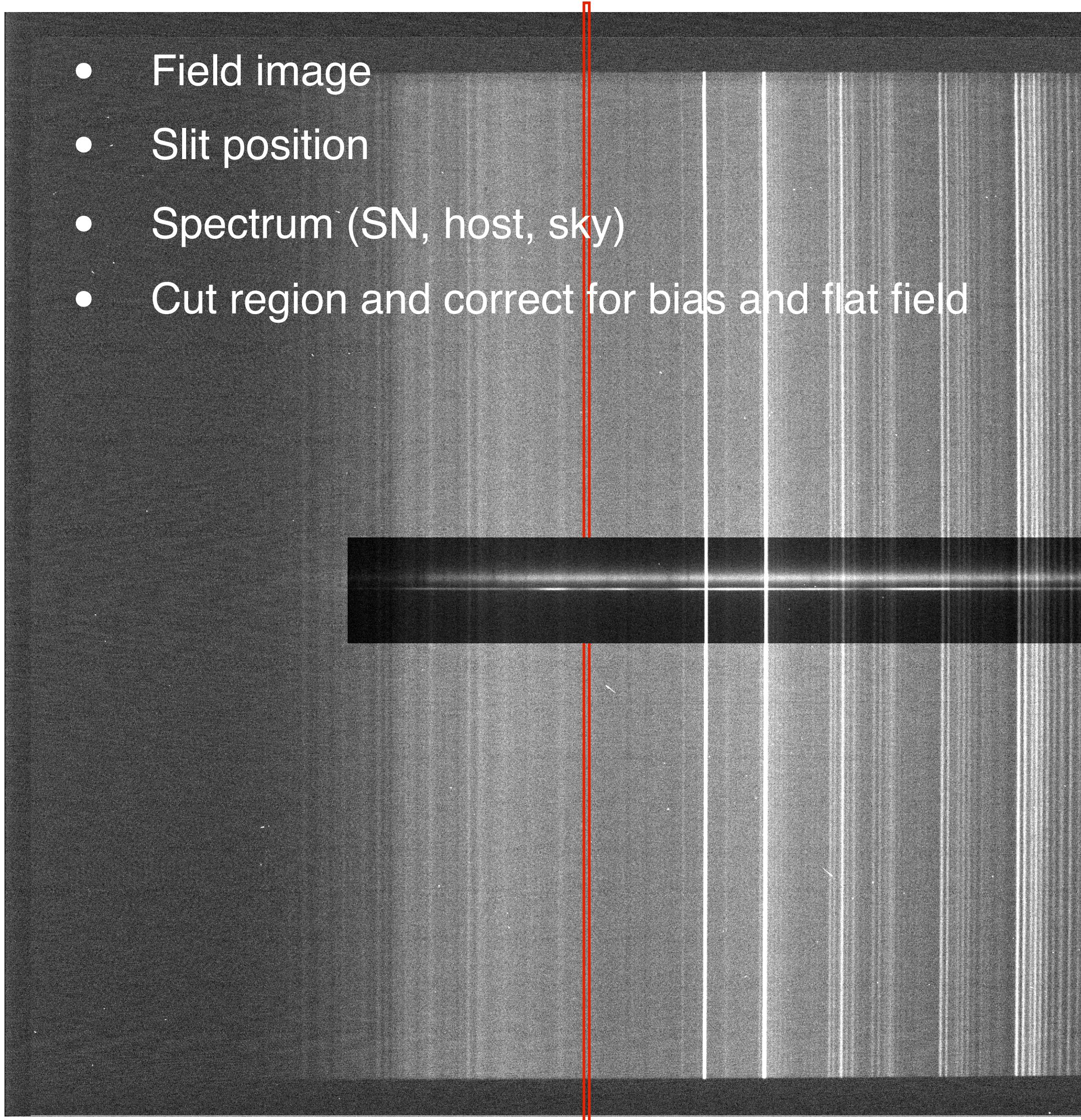
(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)



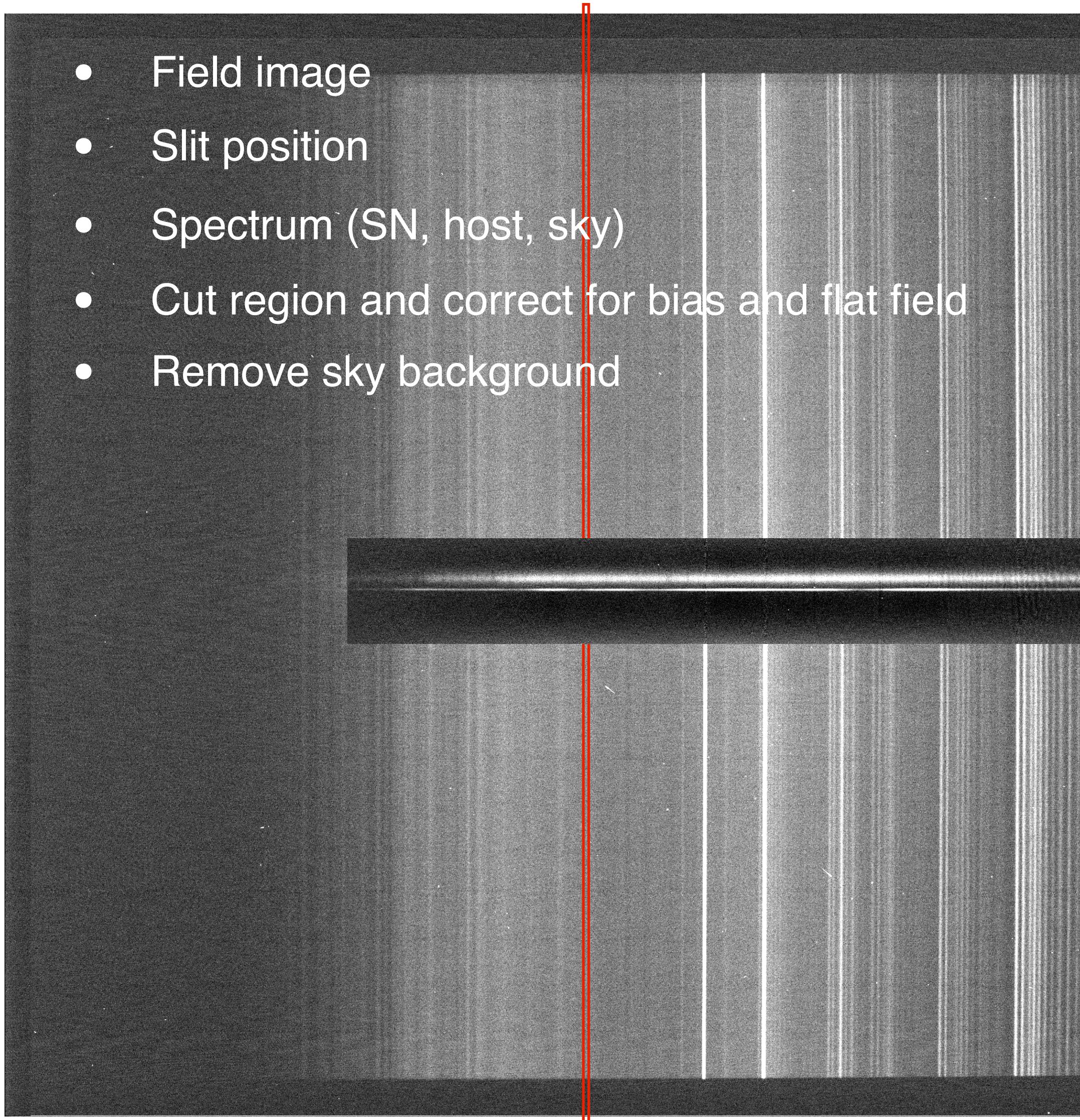
(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)



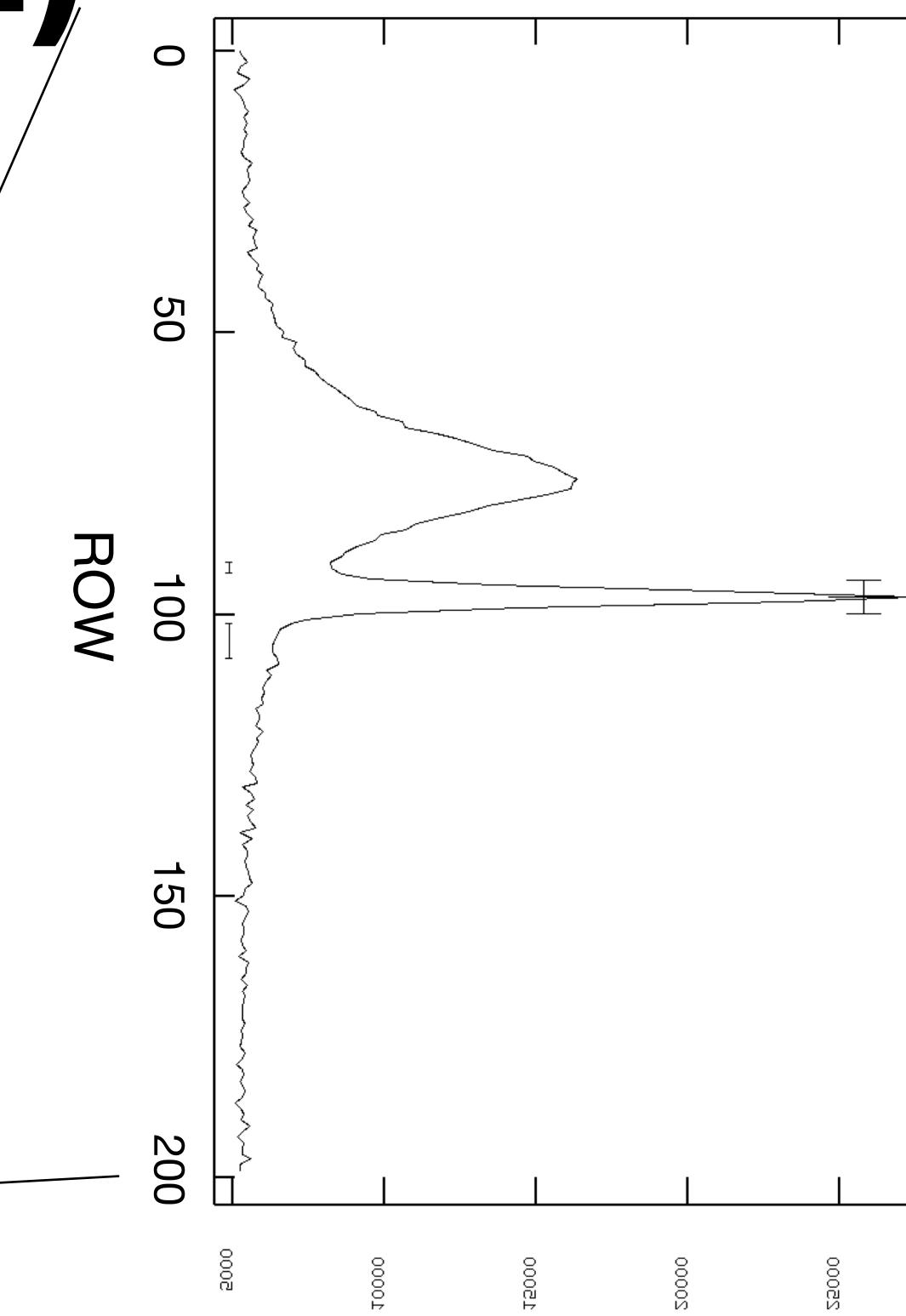
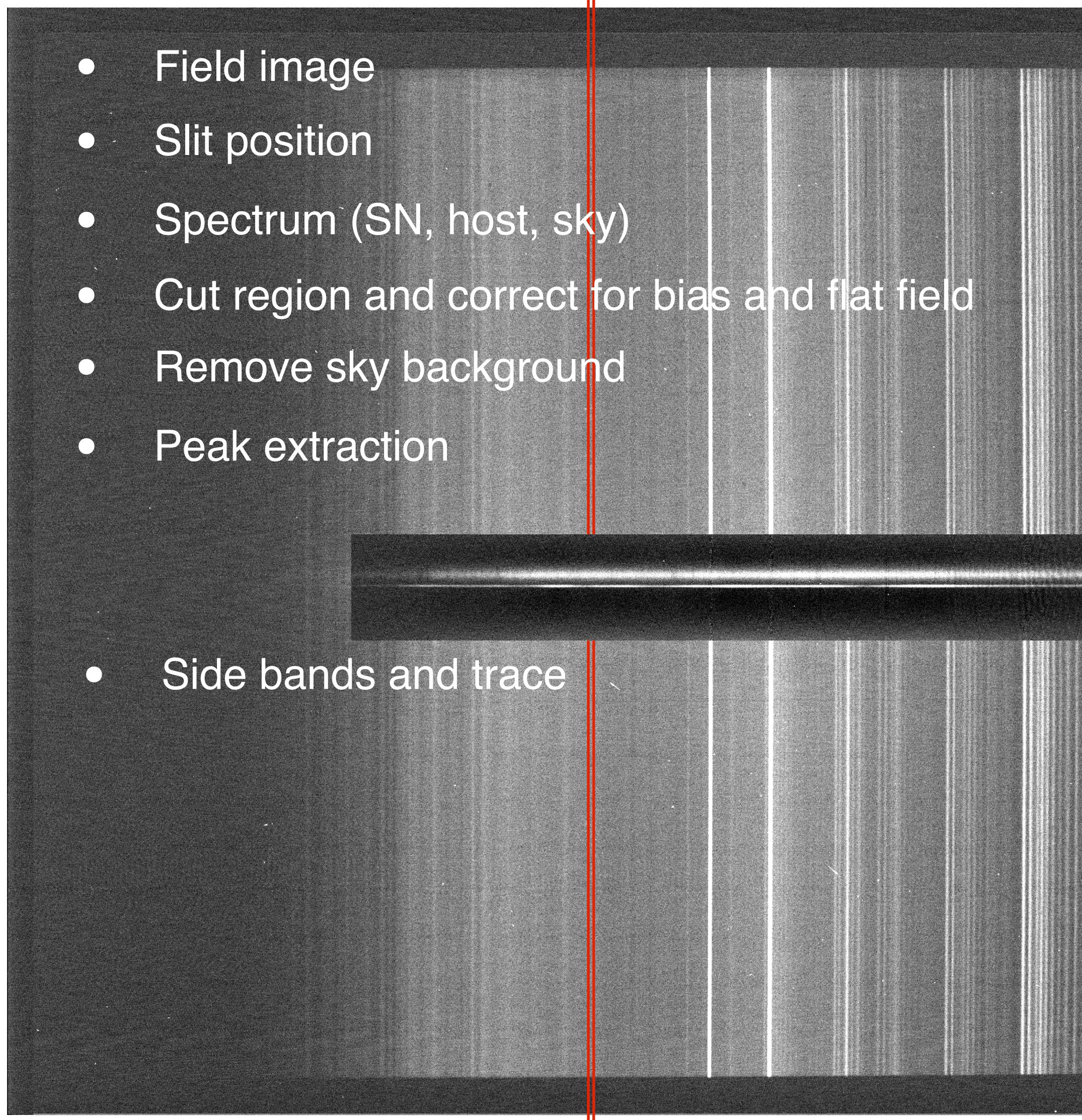
(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)



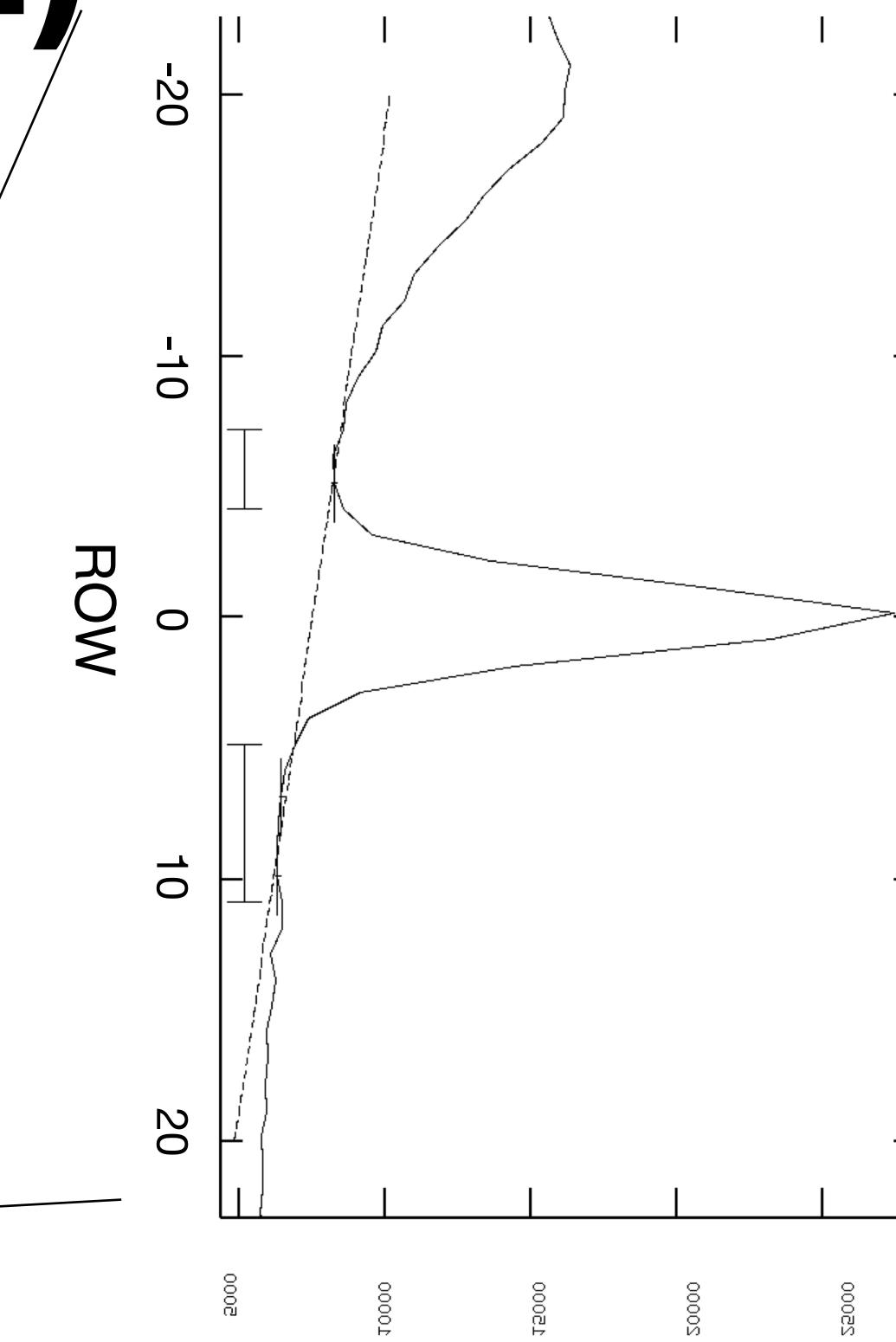
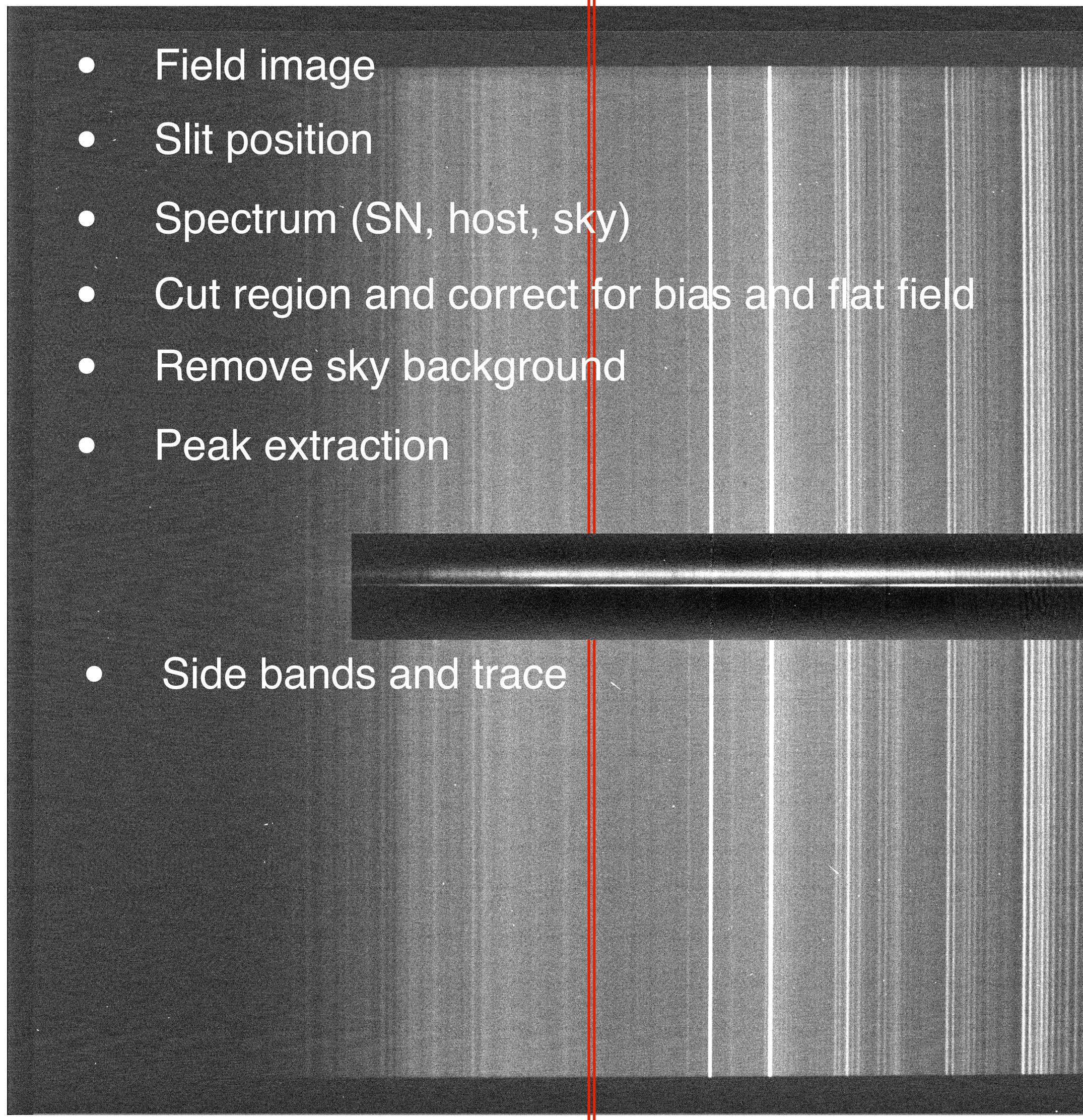
(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)



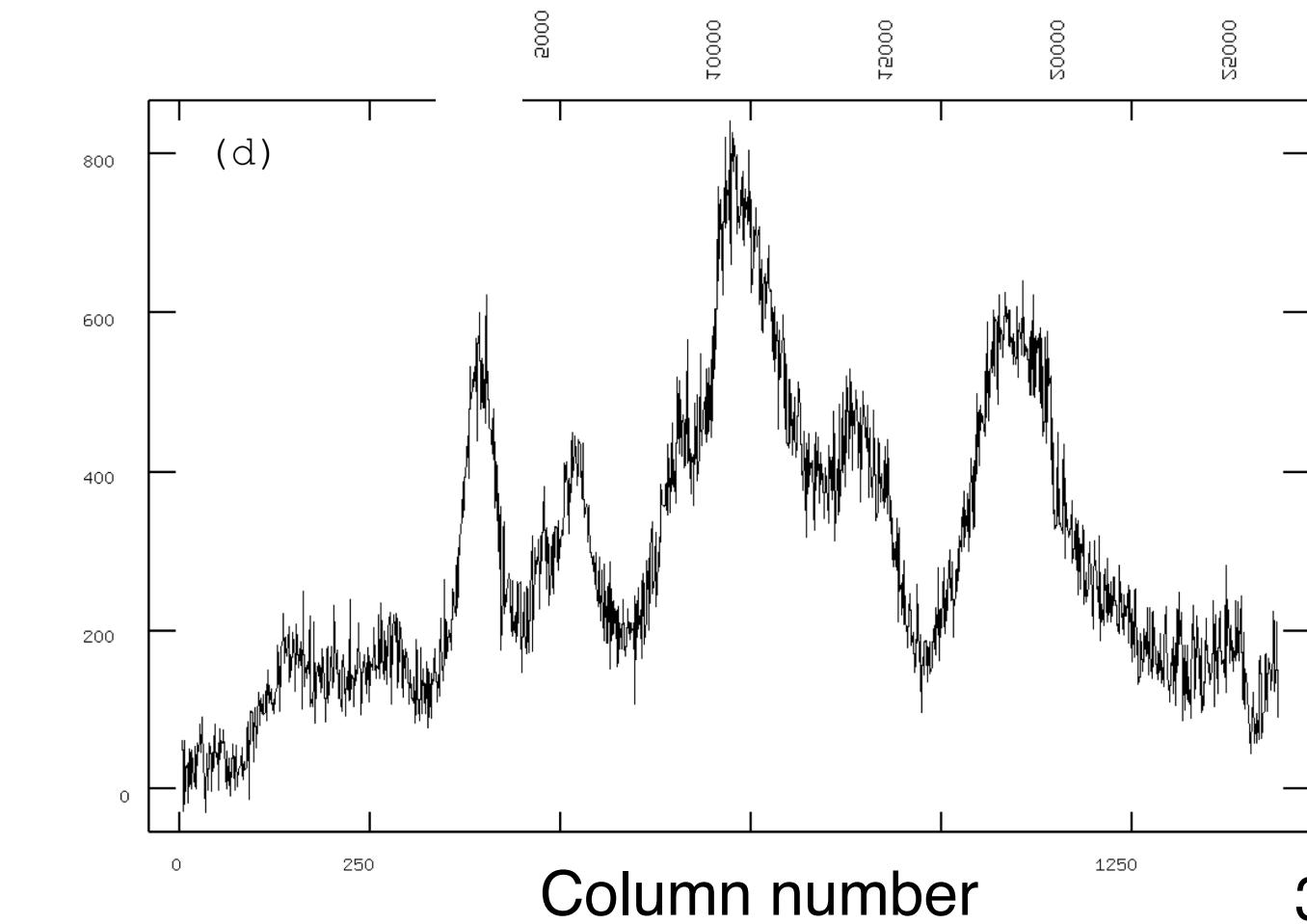
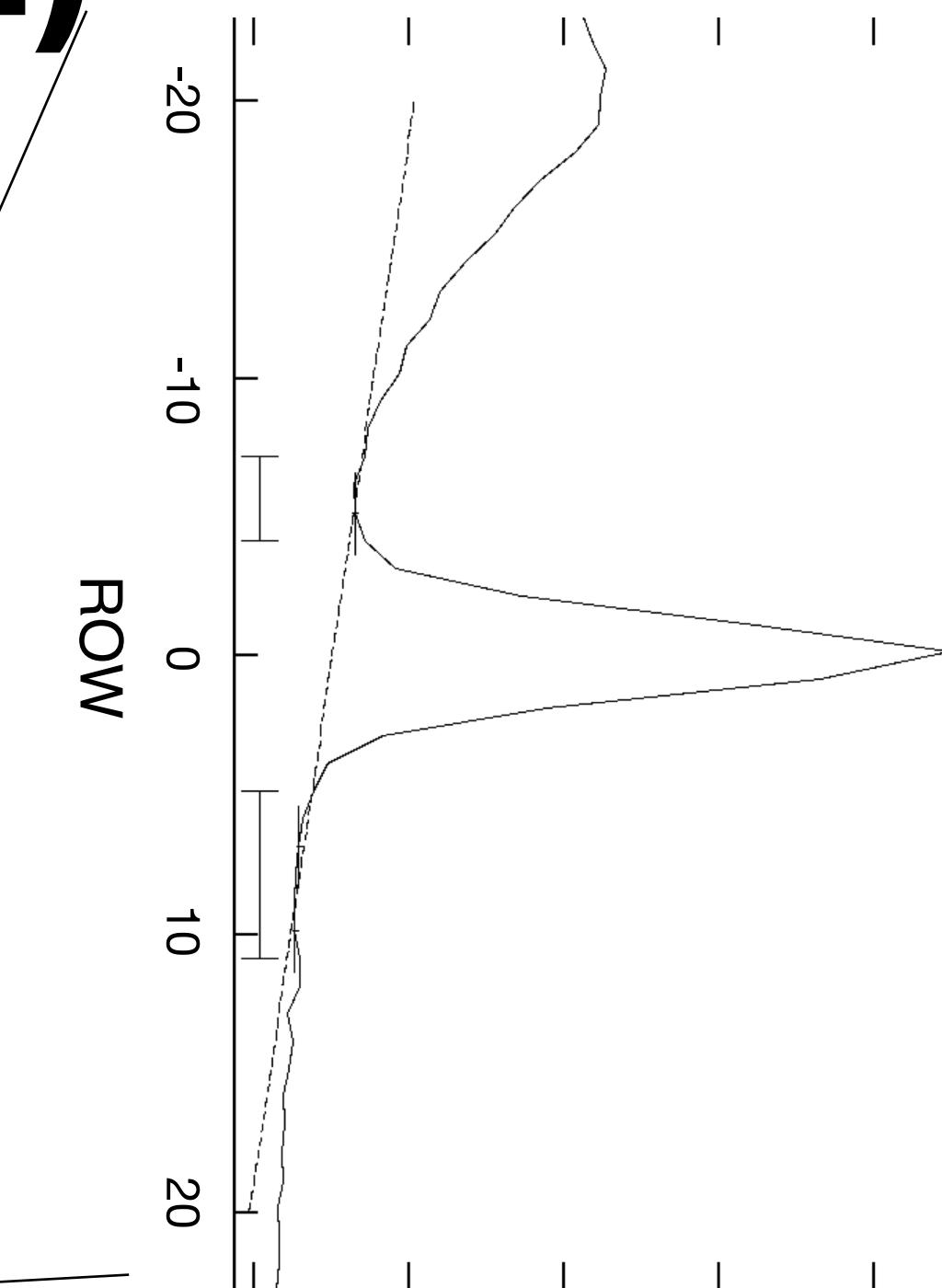
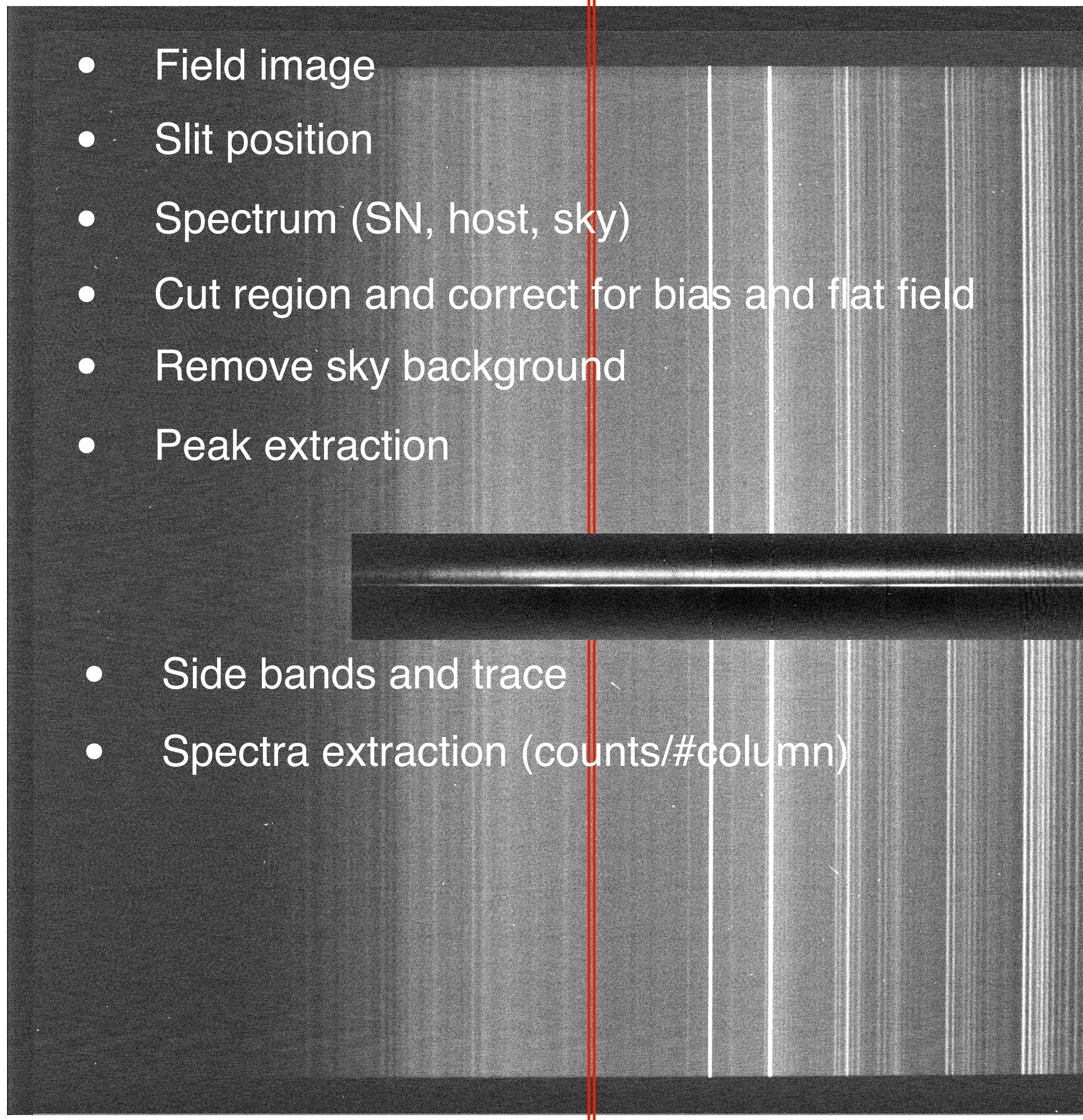
(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)

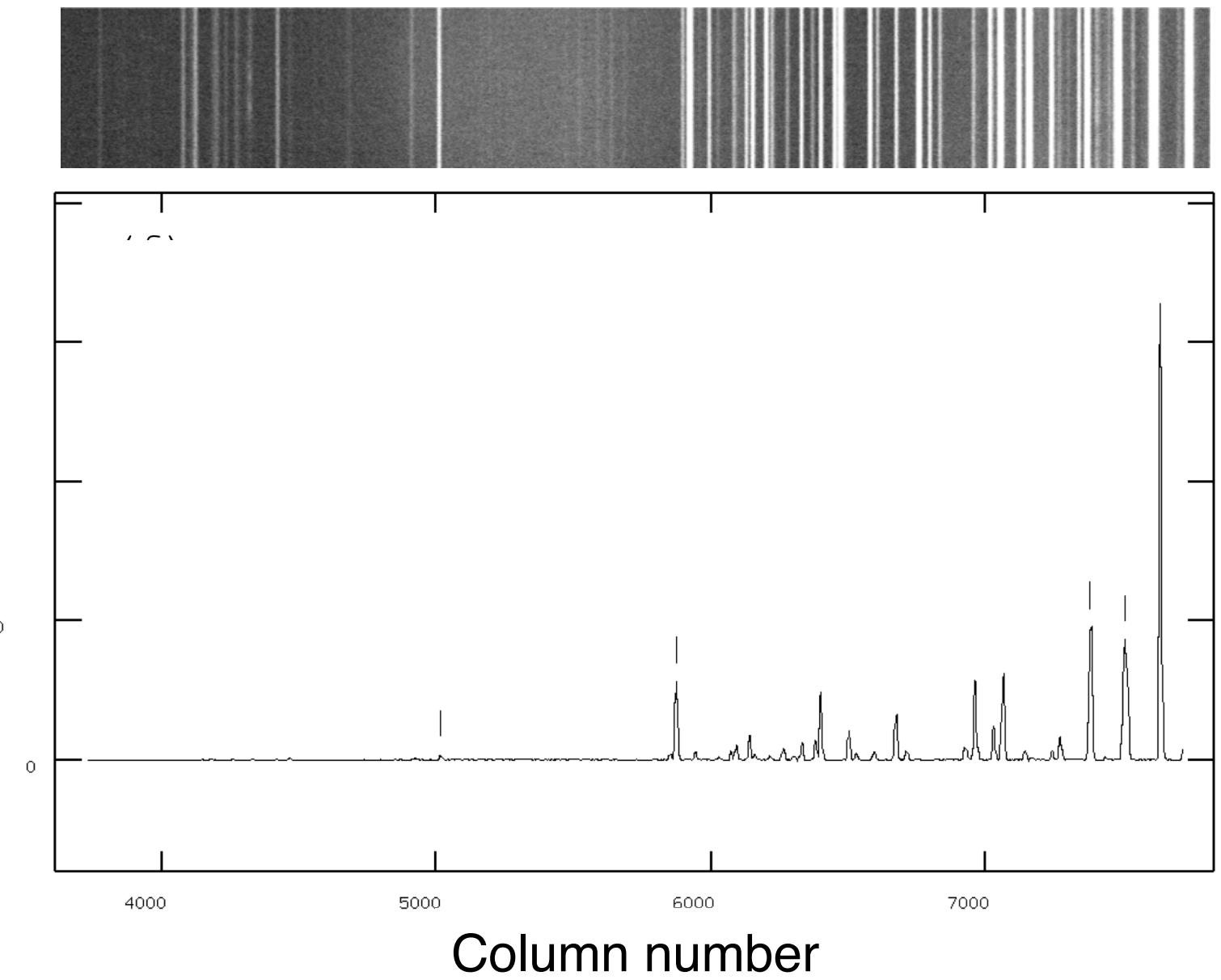
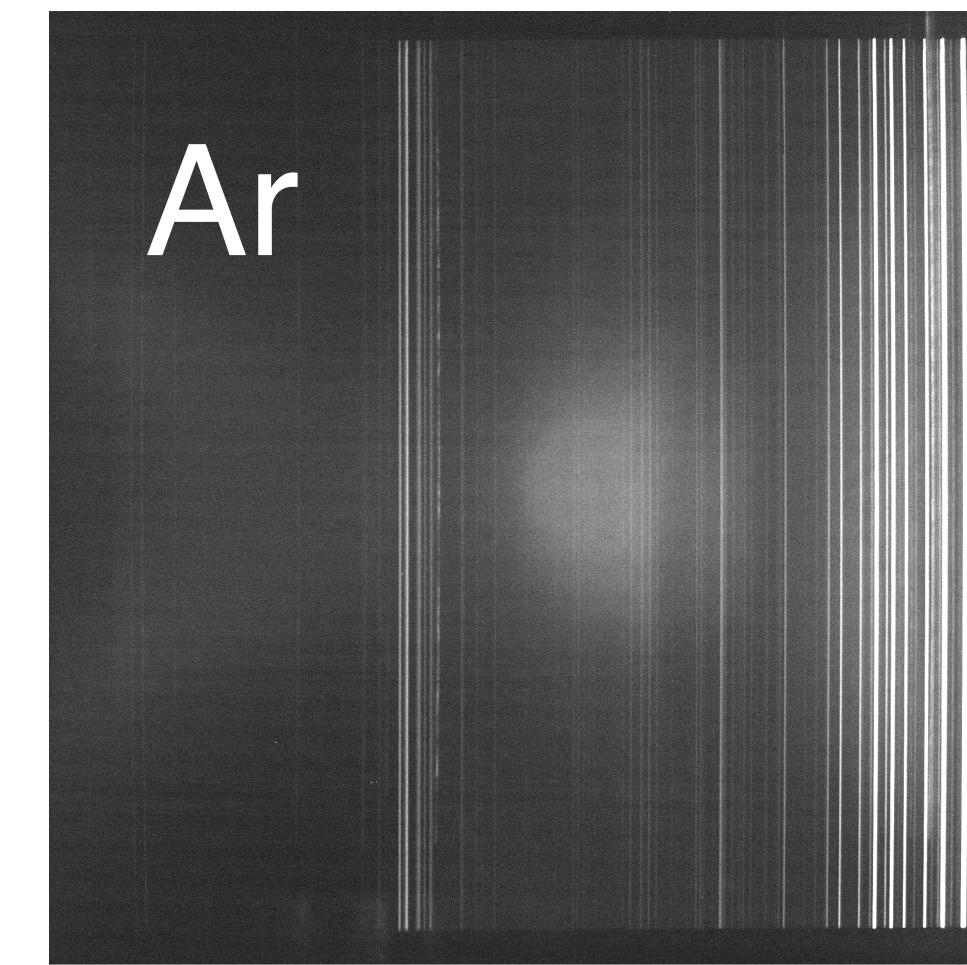
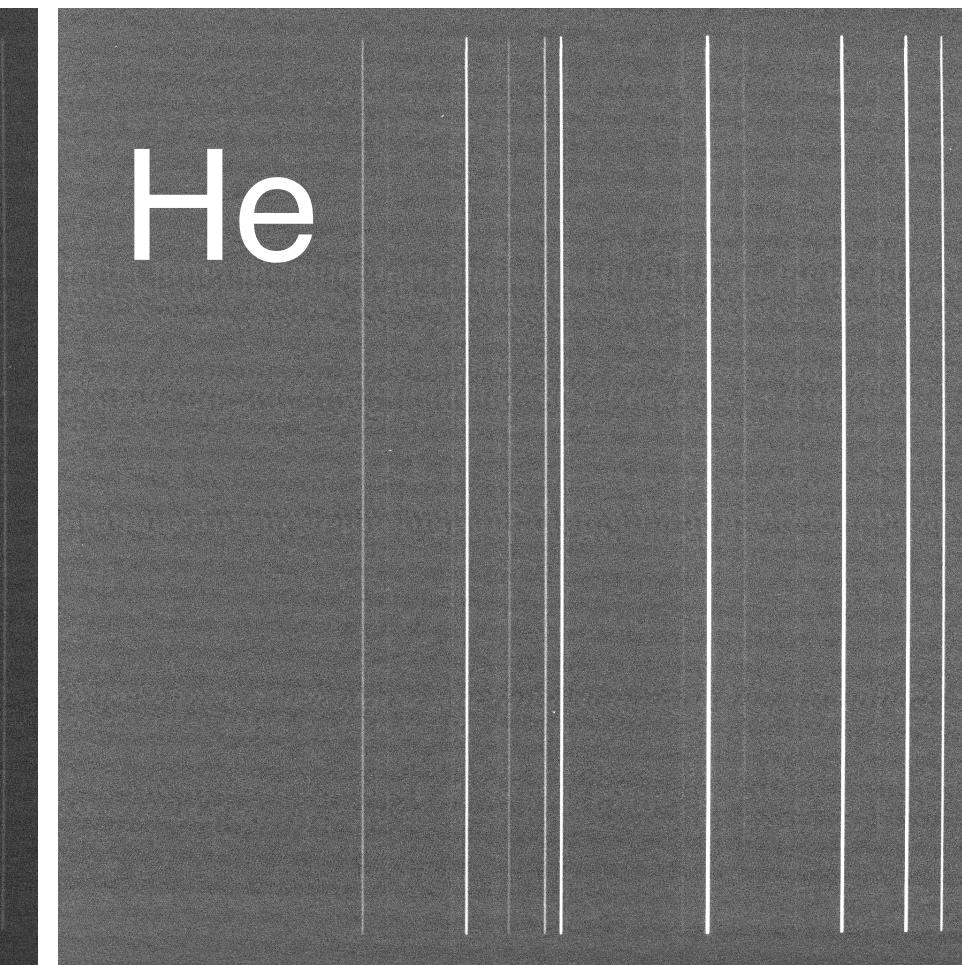
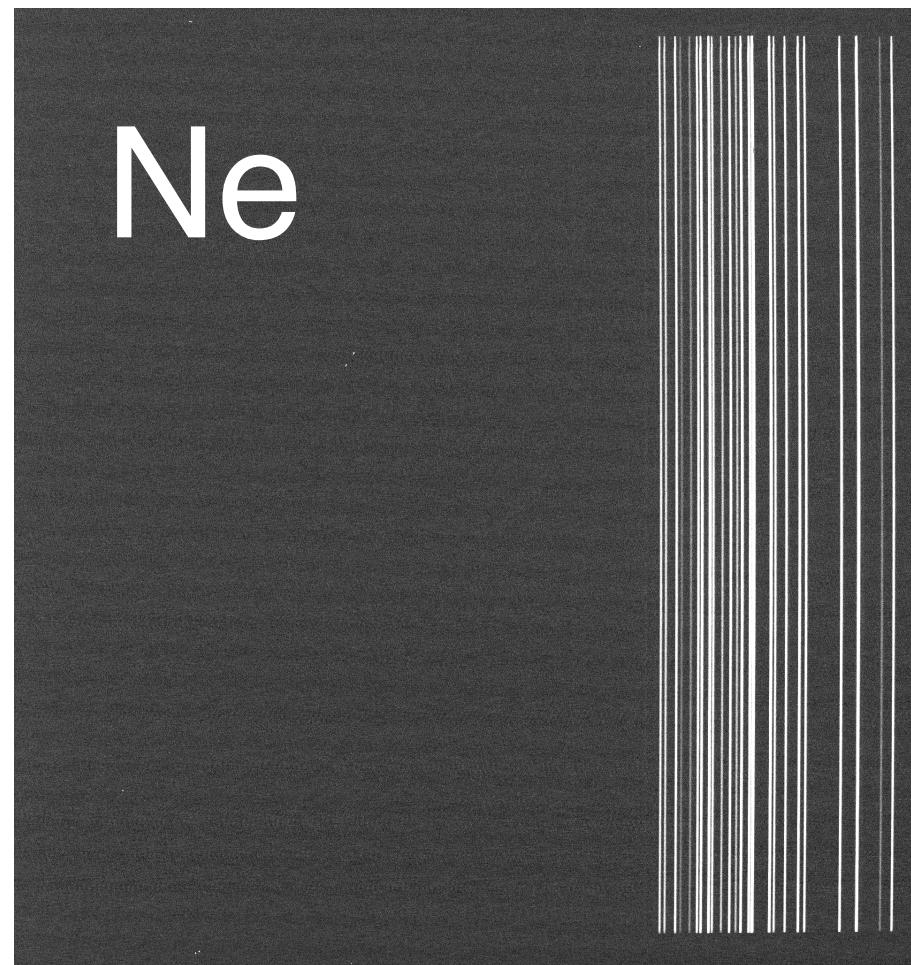


(But also with an optic fiber instead!)

Long-slit example (SN 2007jh)

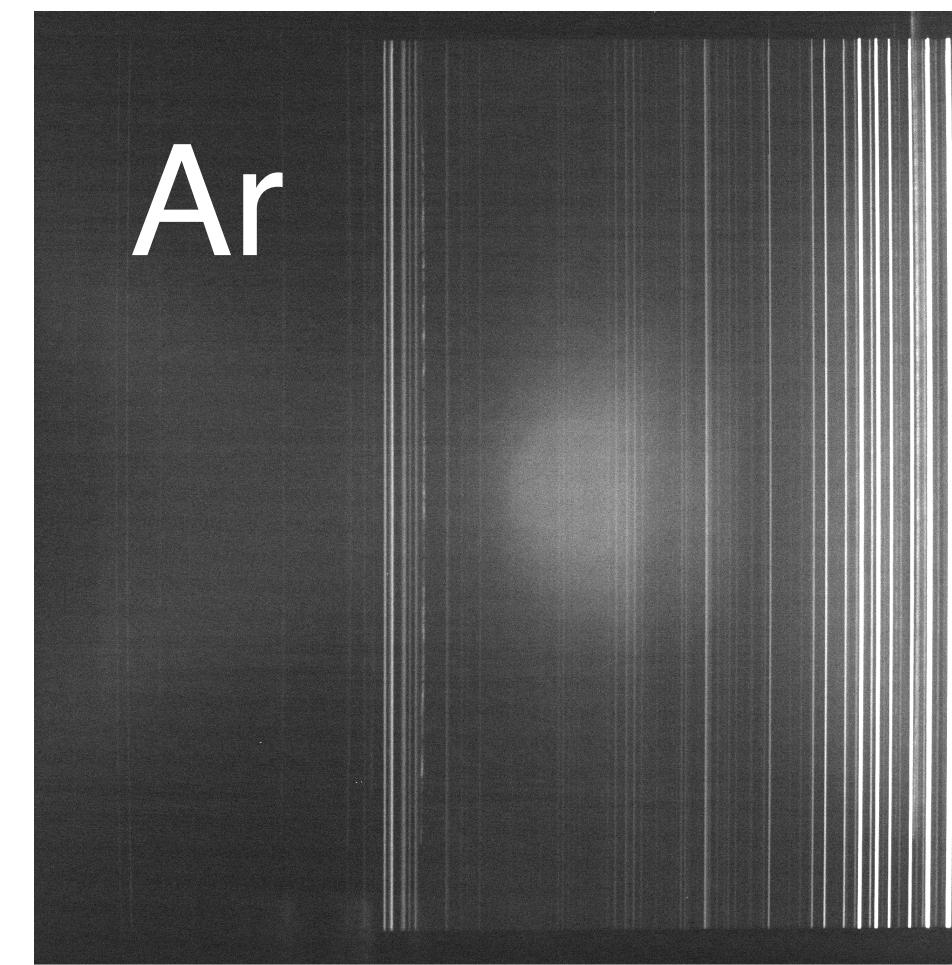
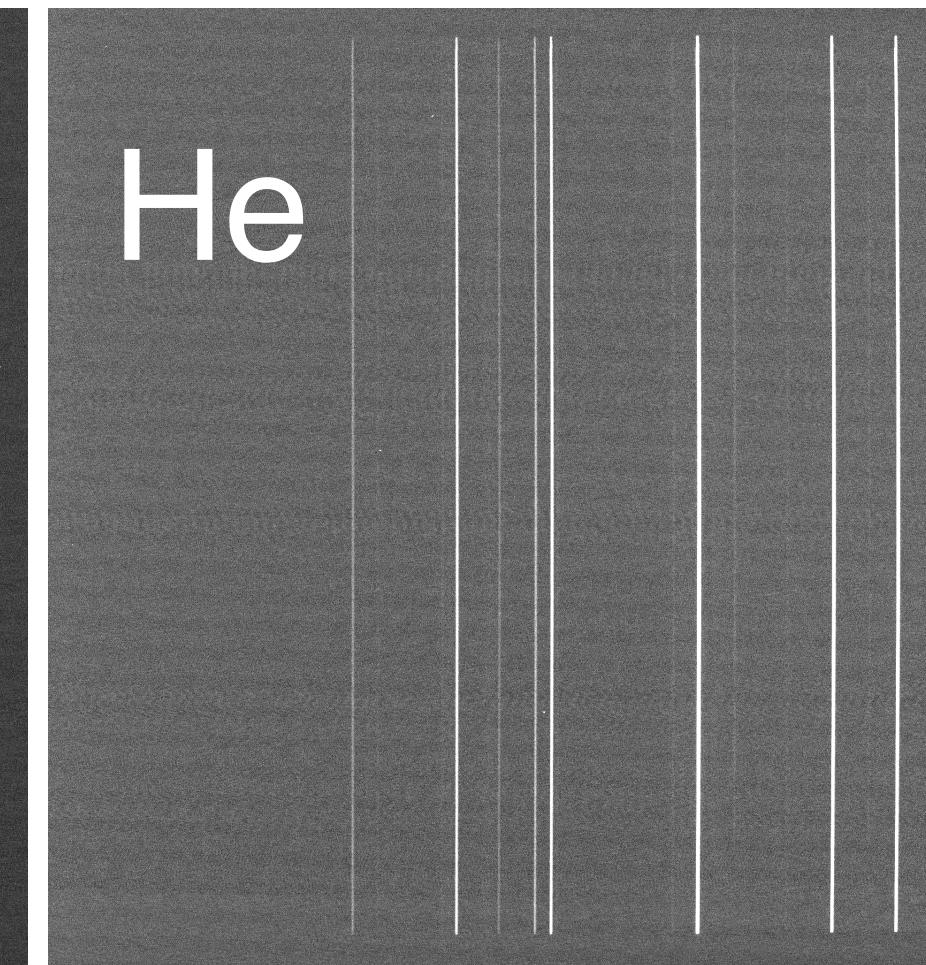
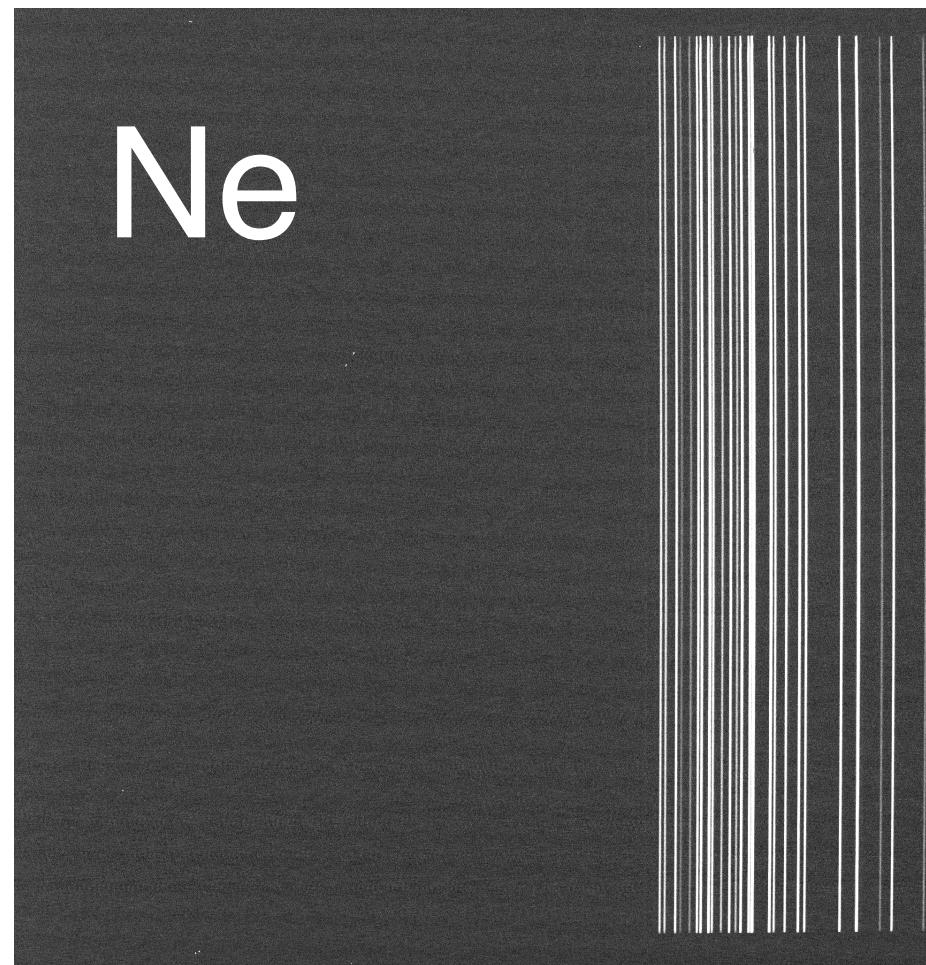


Long-slit example (SN 2007jh)

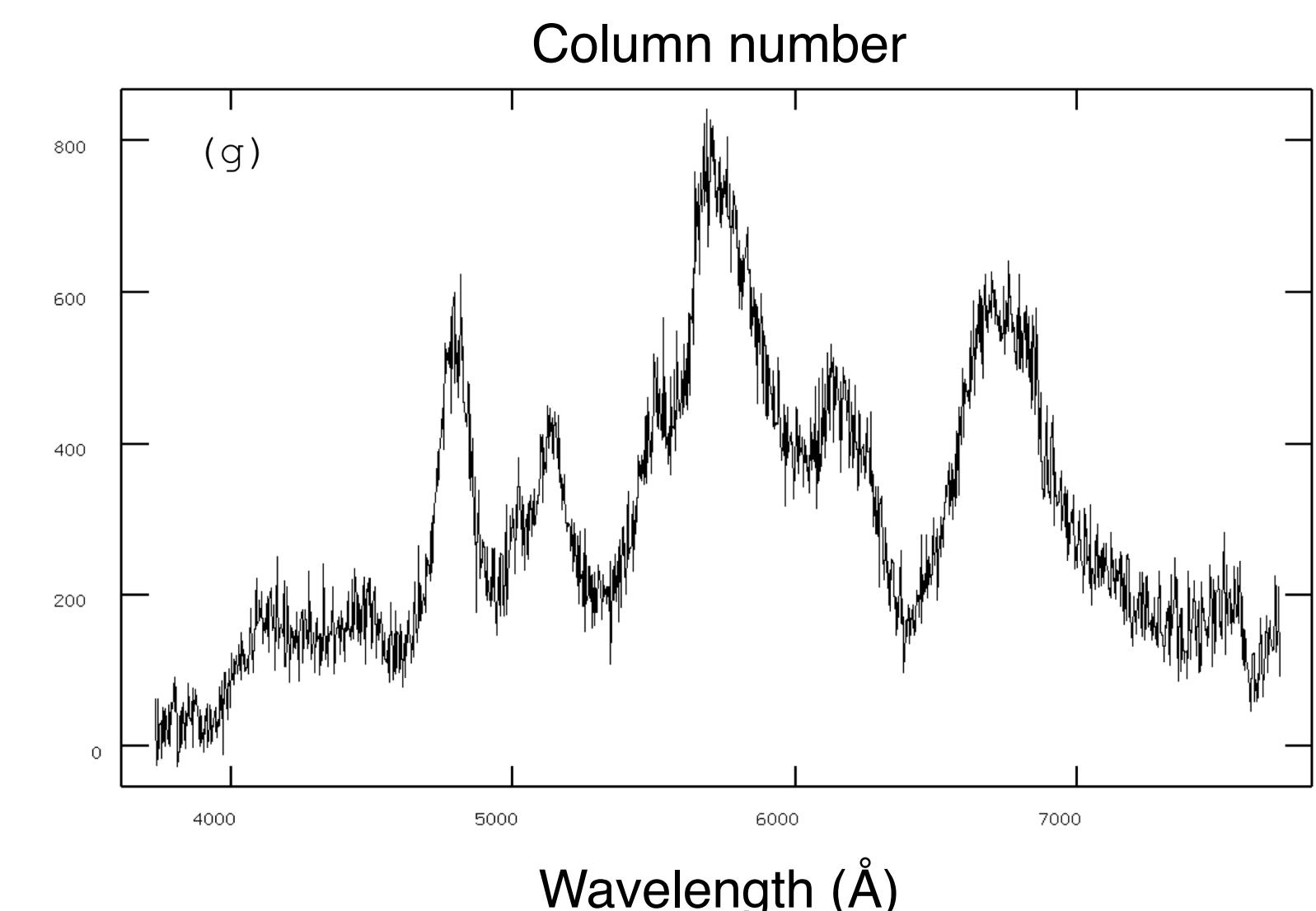
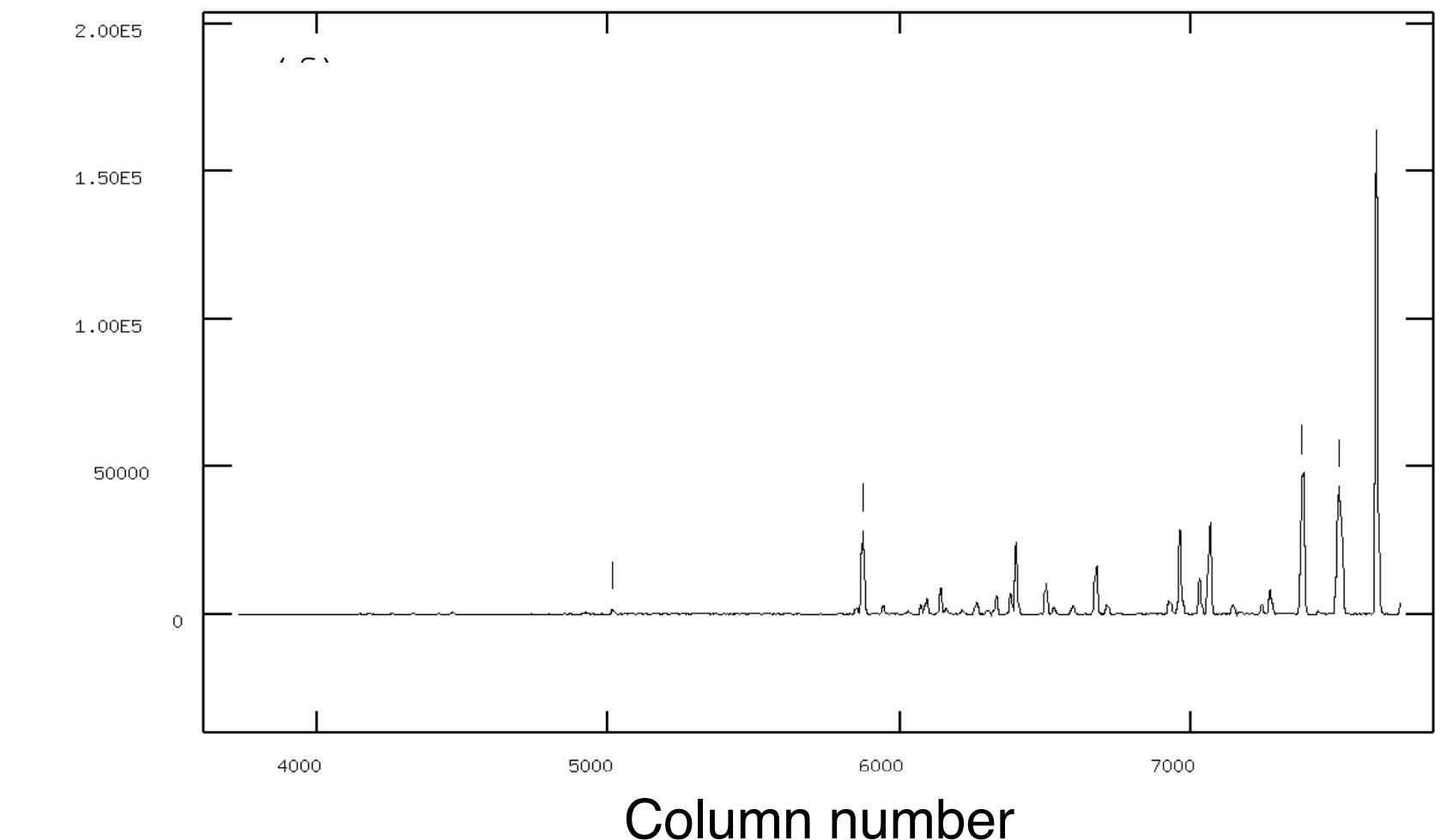
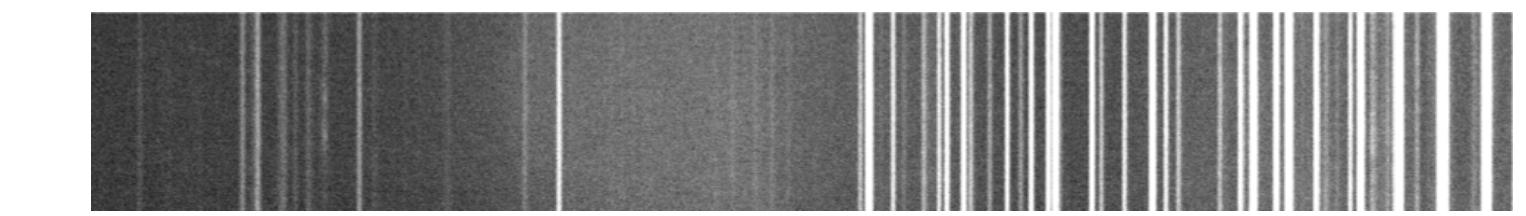


Arc lamps used for wavelength calibration

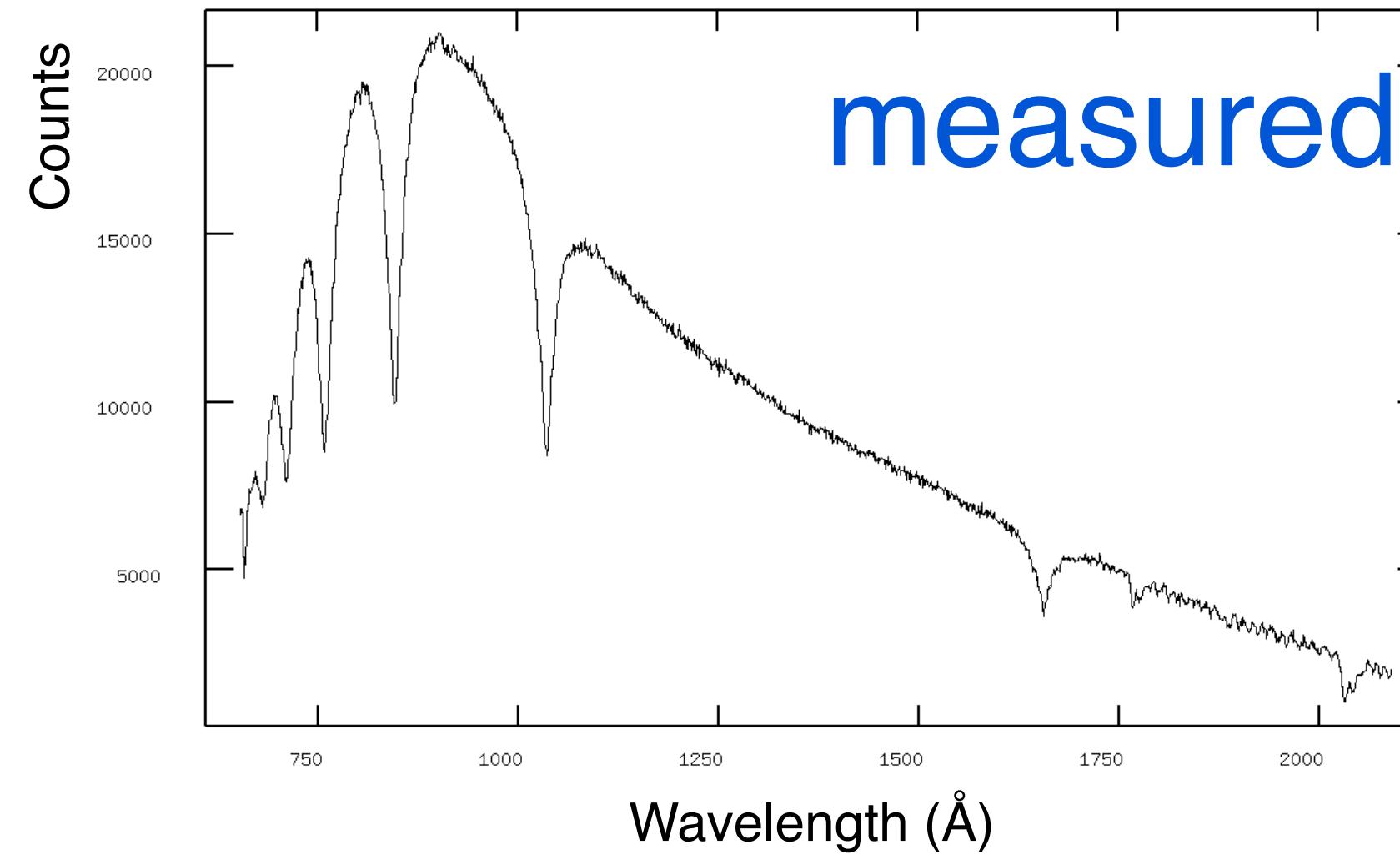
Long-slit example (SN 2007jh)



Arc lamps used for wavelength calibration

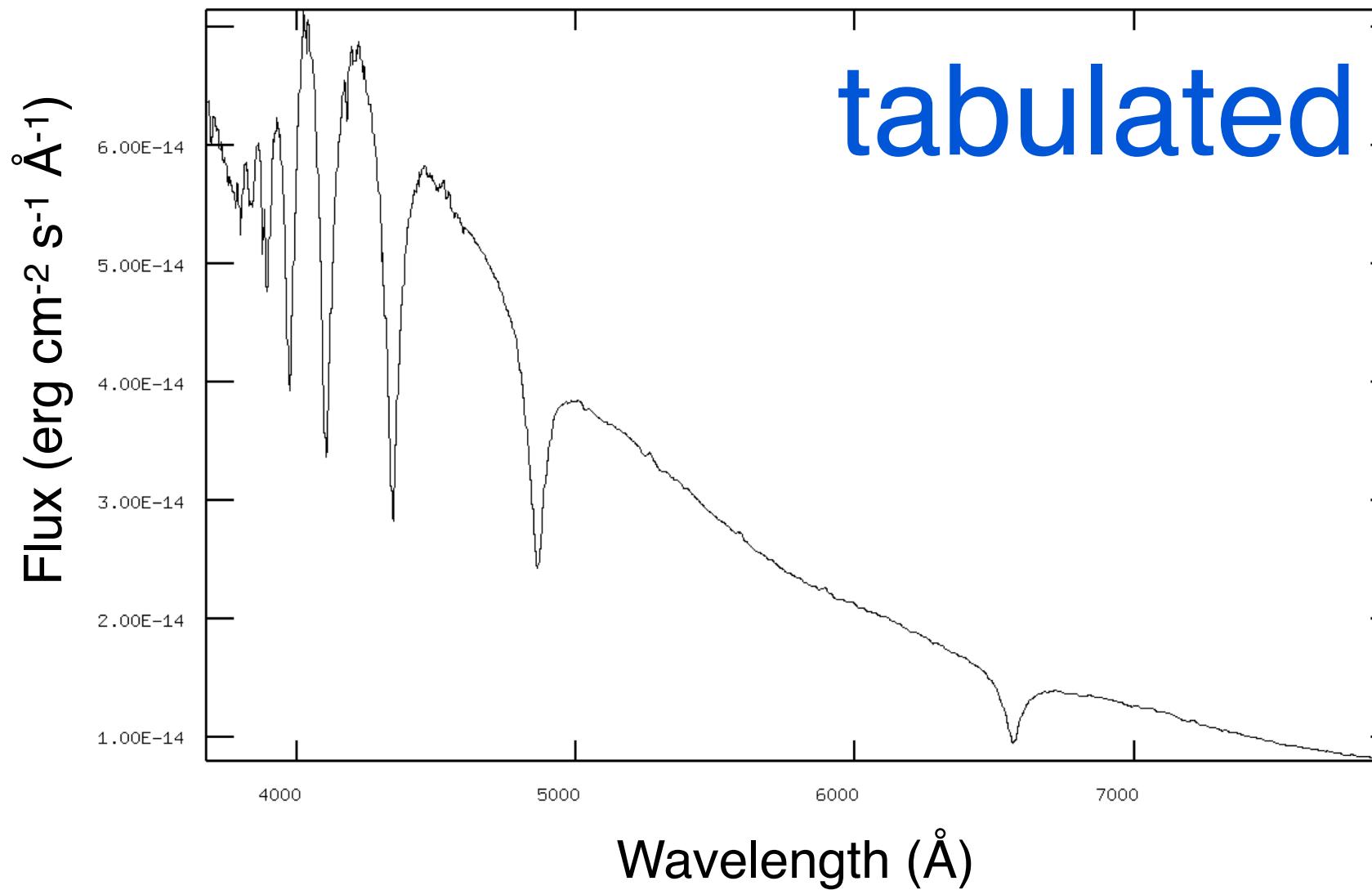


Long-slit example (SN 2007jh)

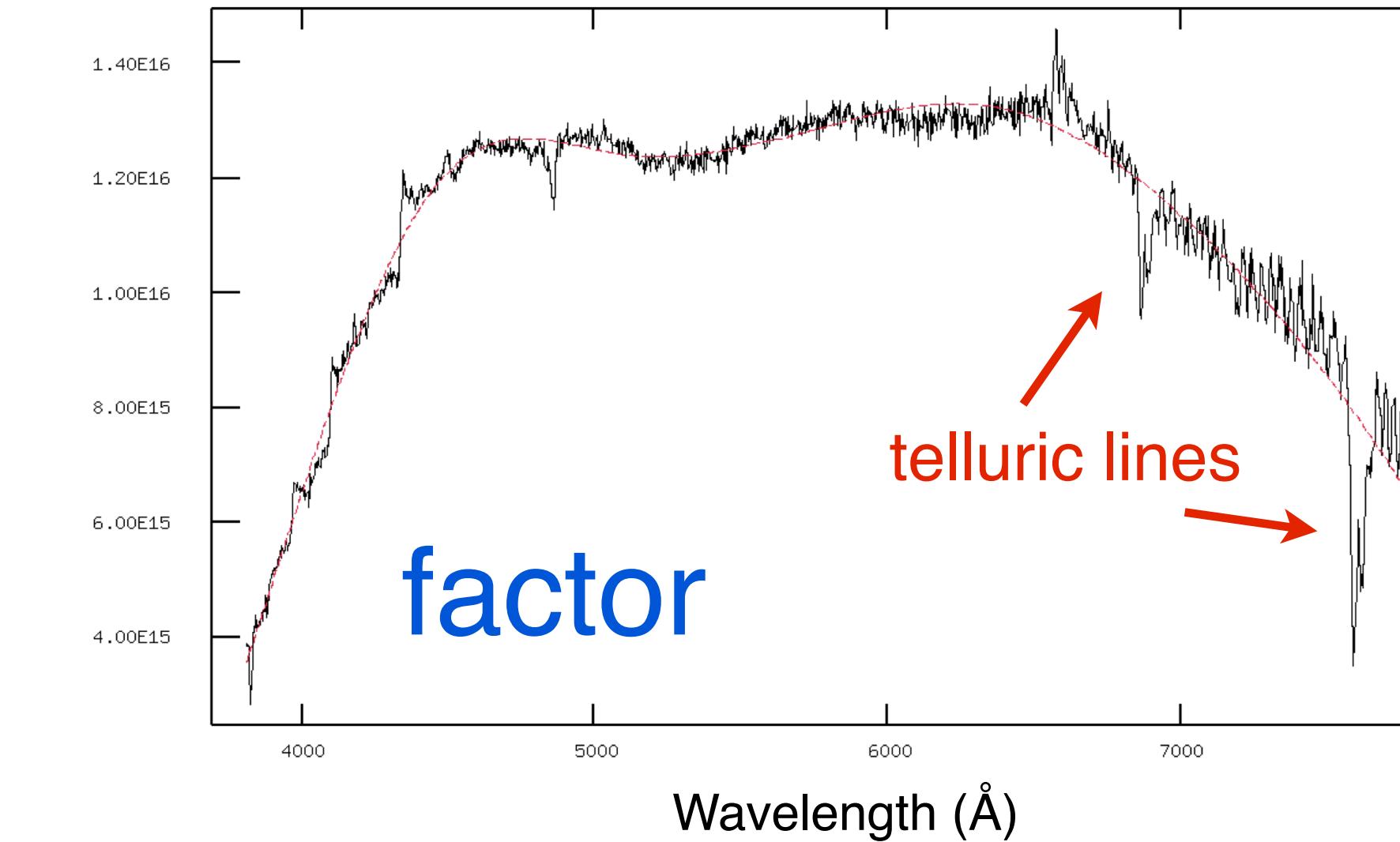


measured

- Measure spectrum of some standard stars
- Apply wavelength calibration
- Divide by the tabulated spectrum
- Obtain the flux calibration factor

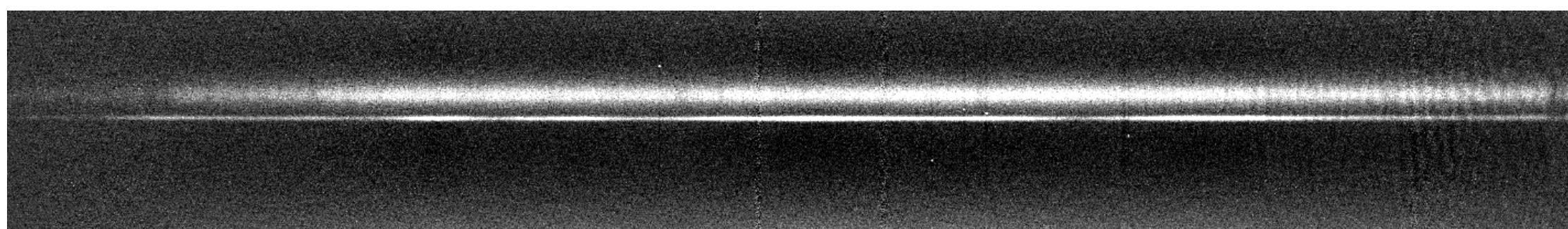
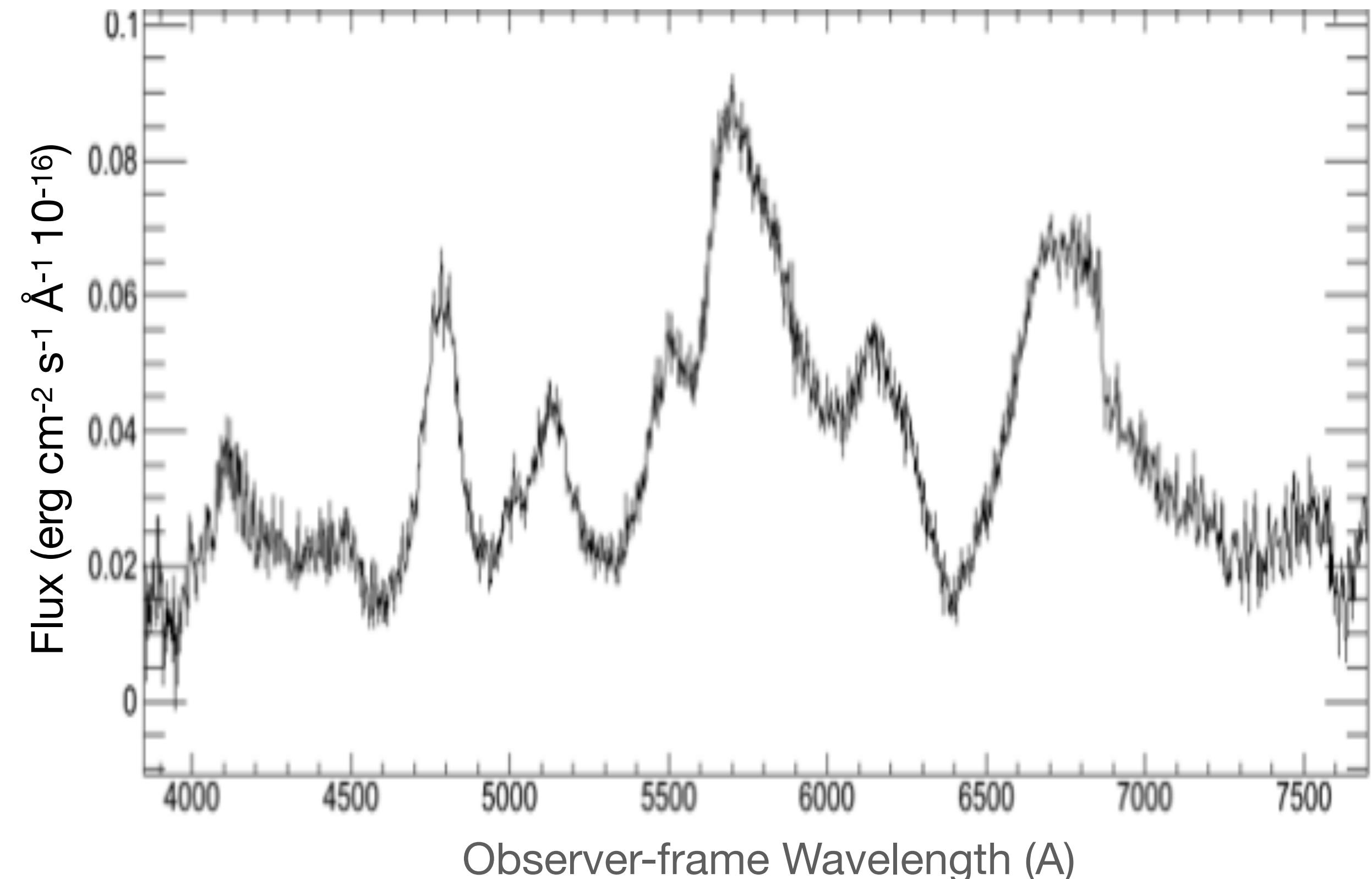
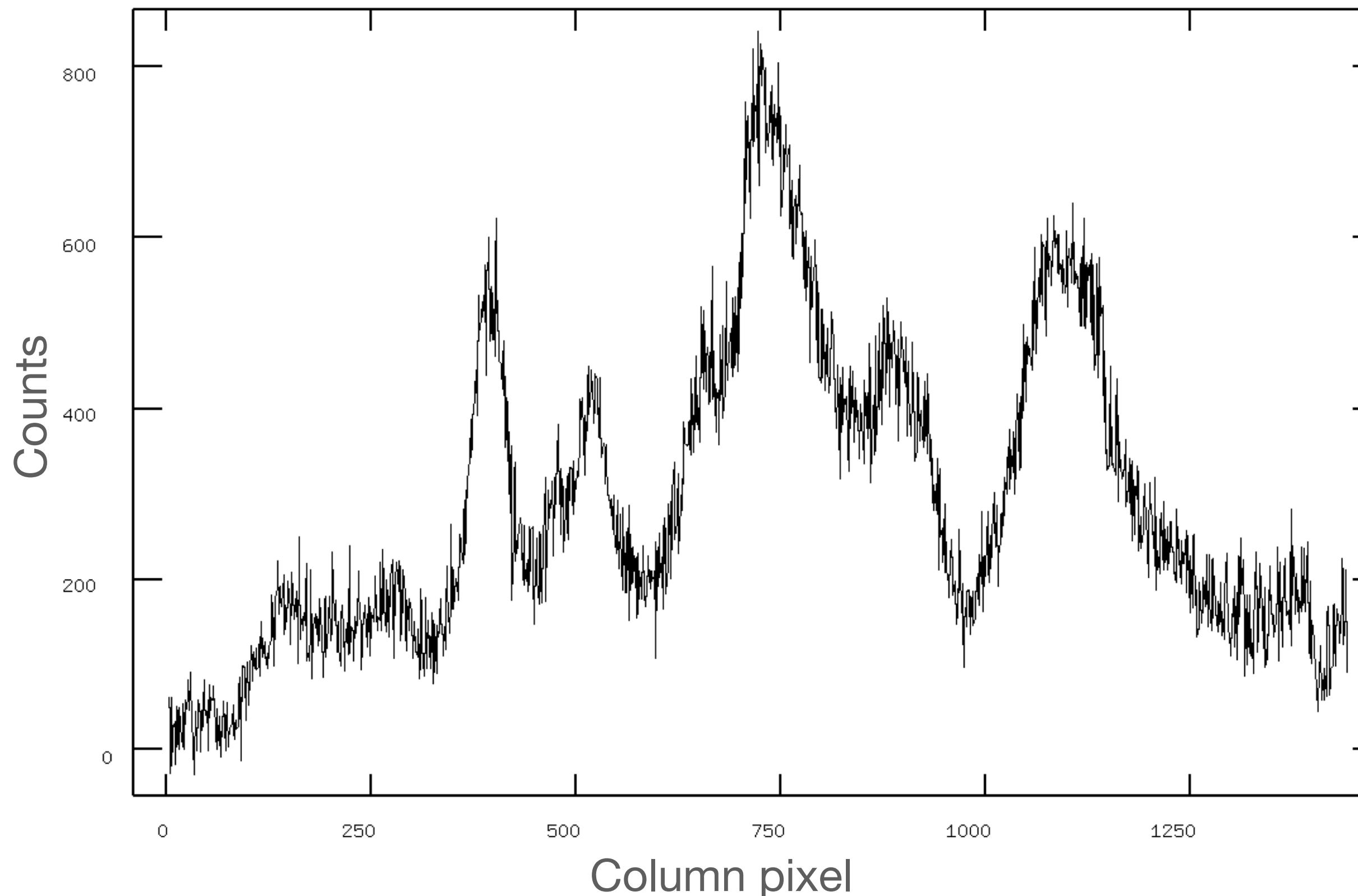


tabulated

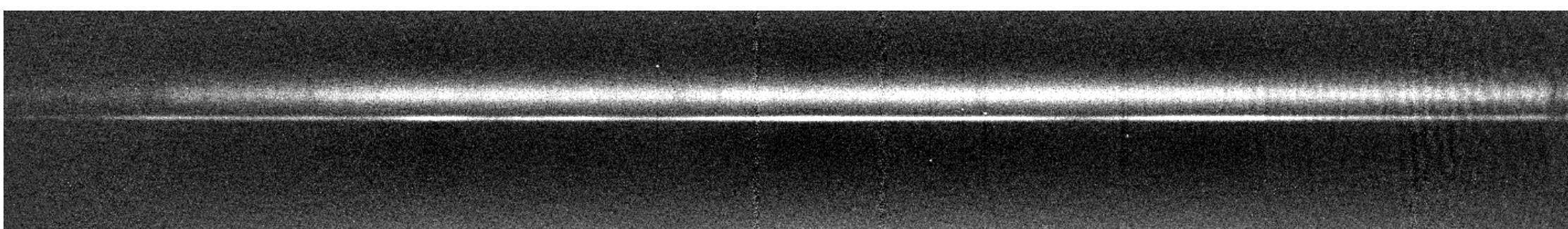
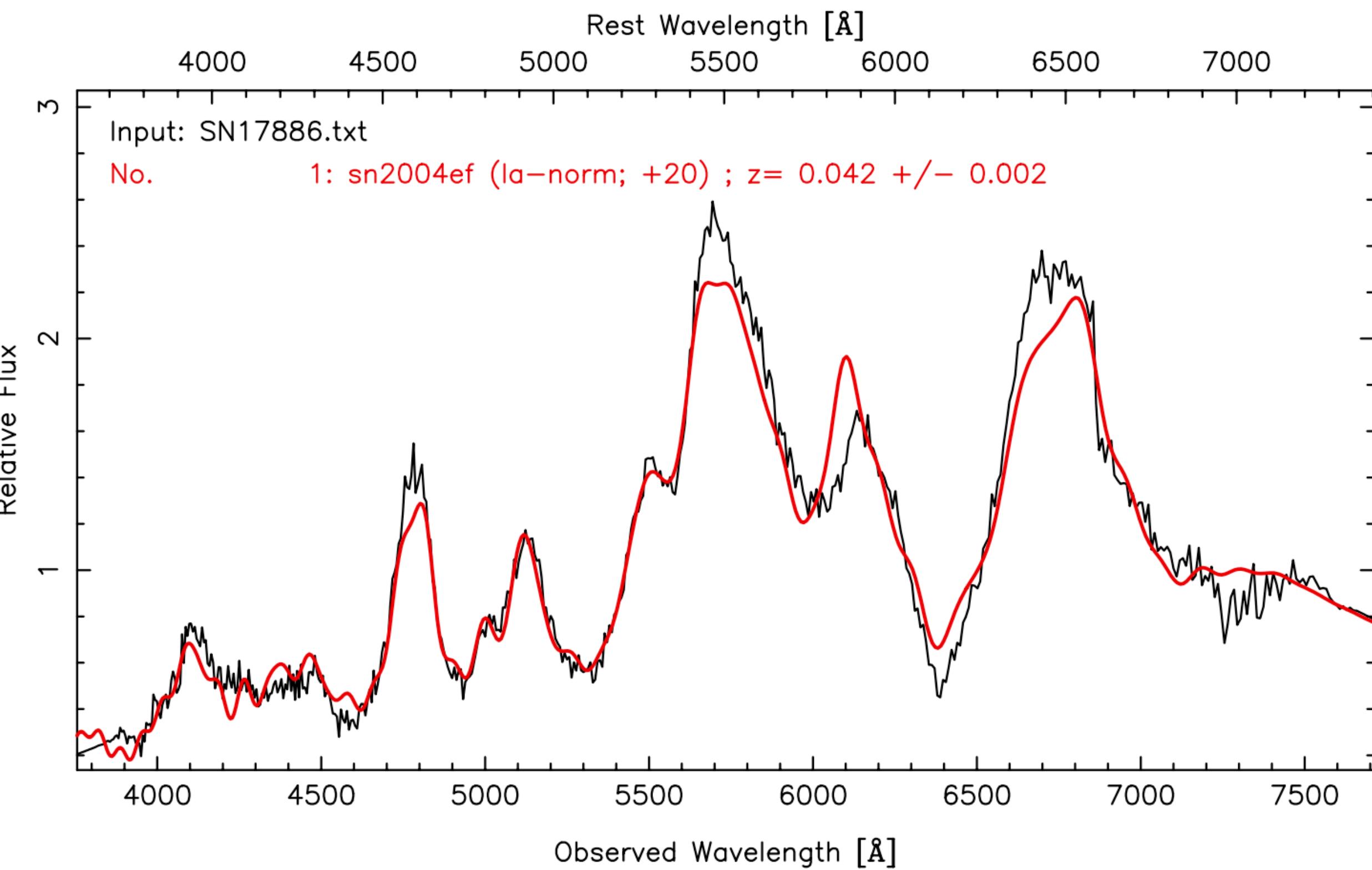
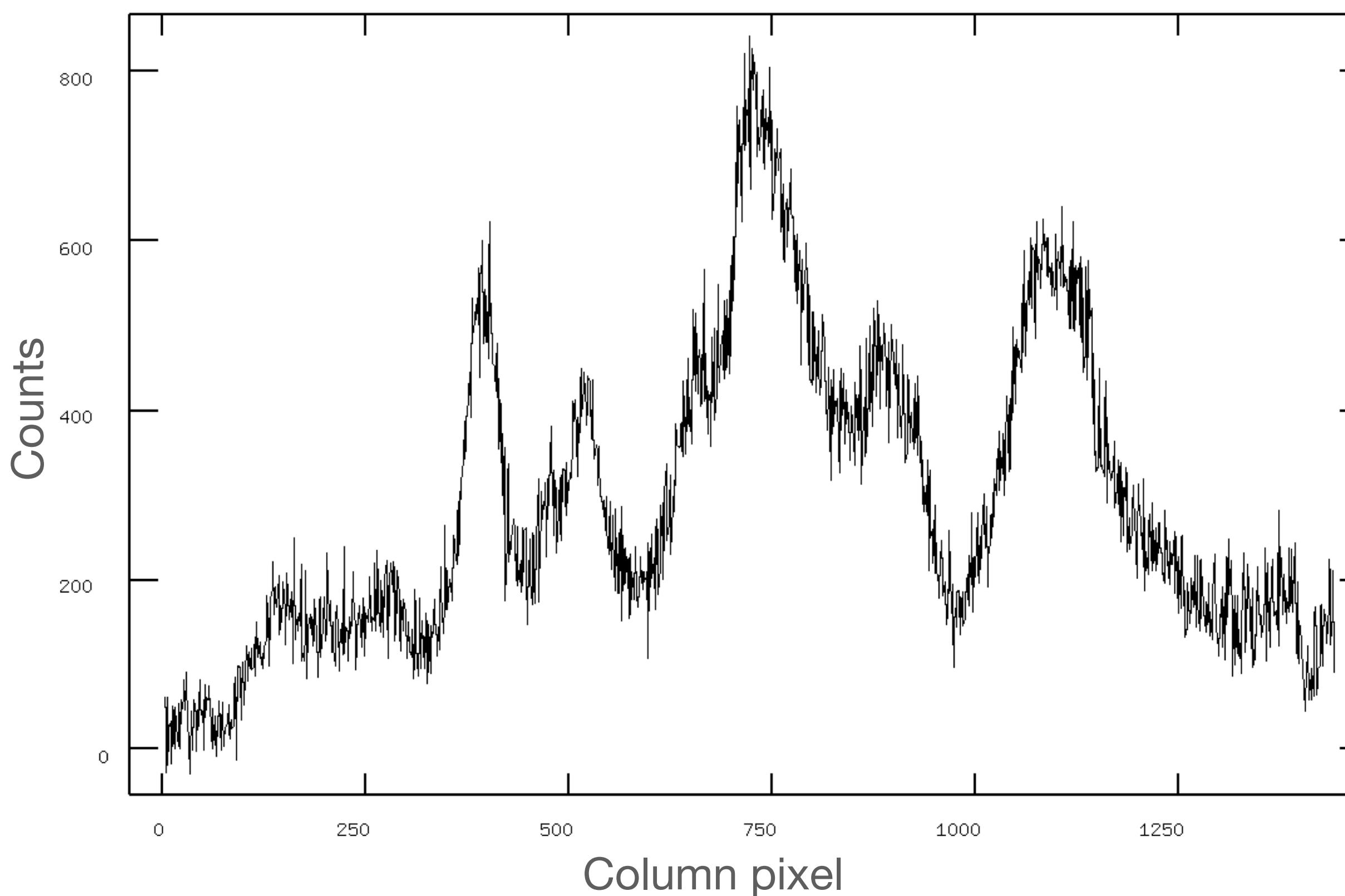


factor

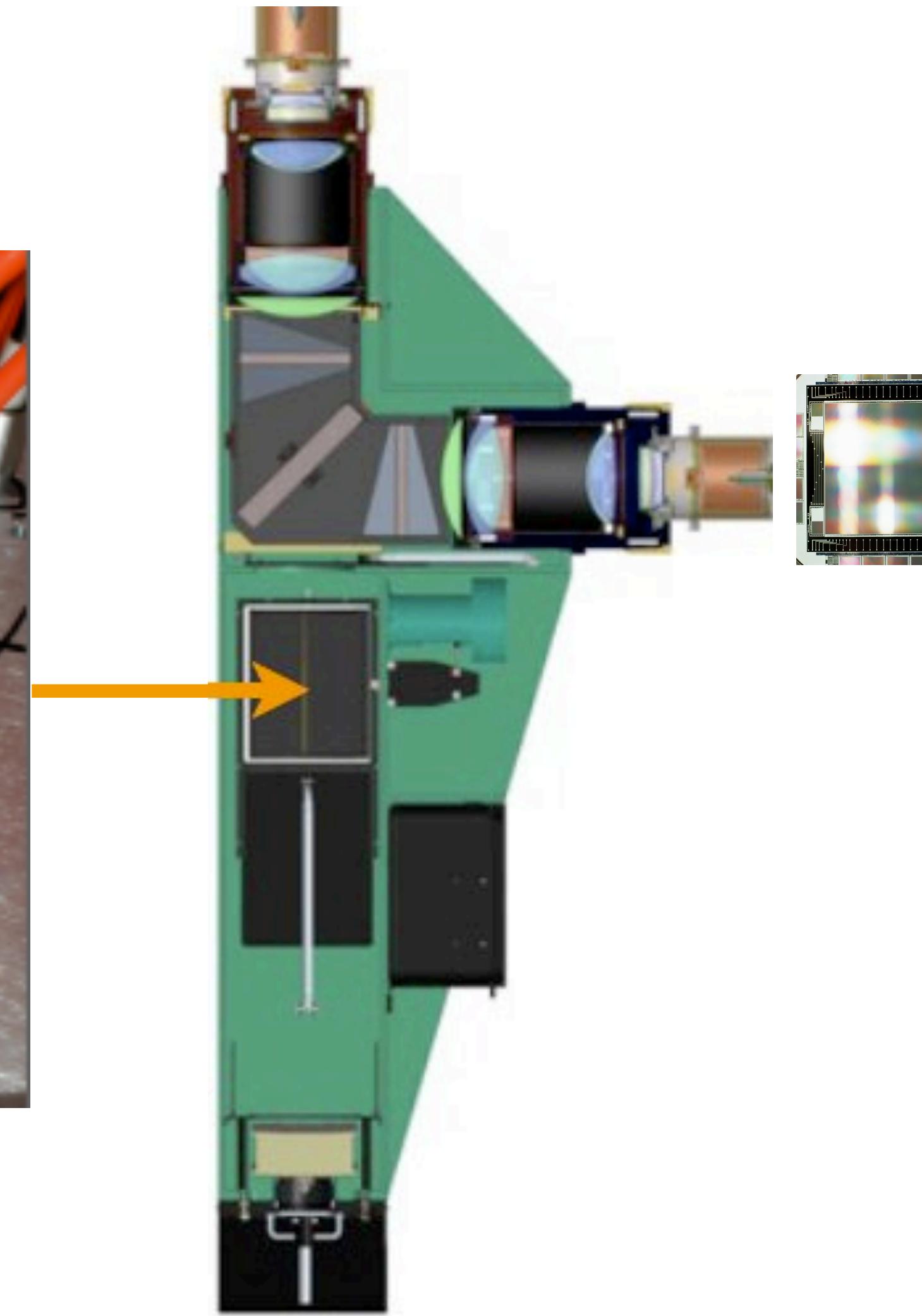
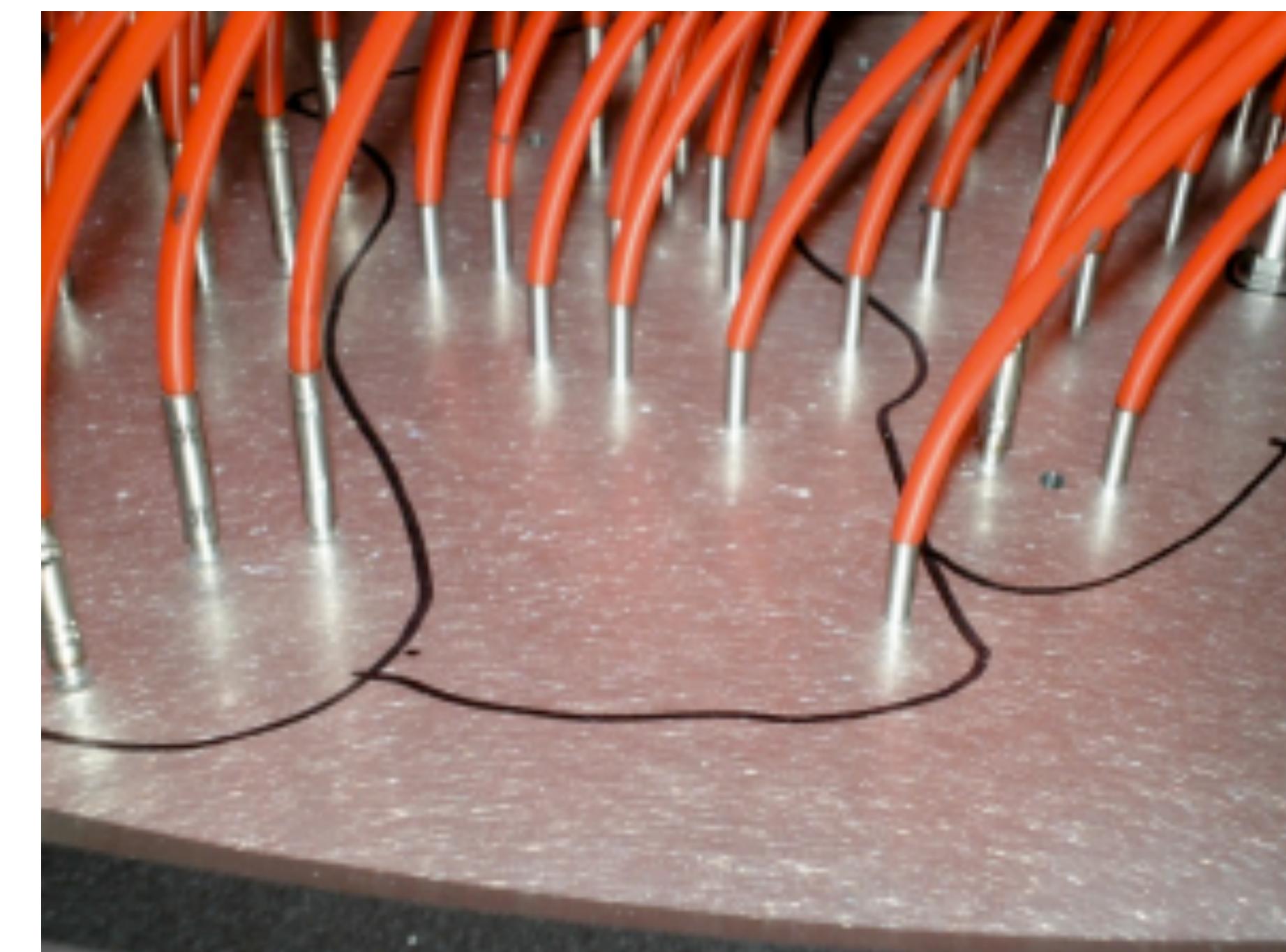
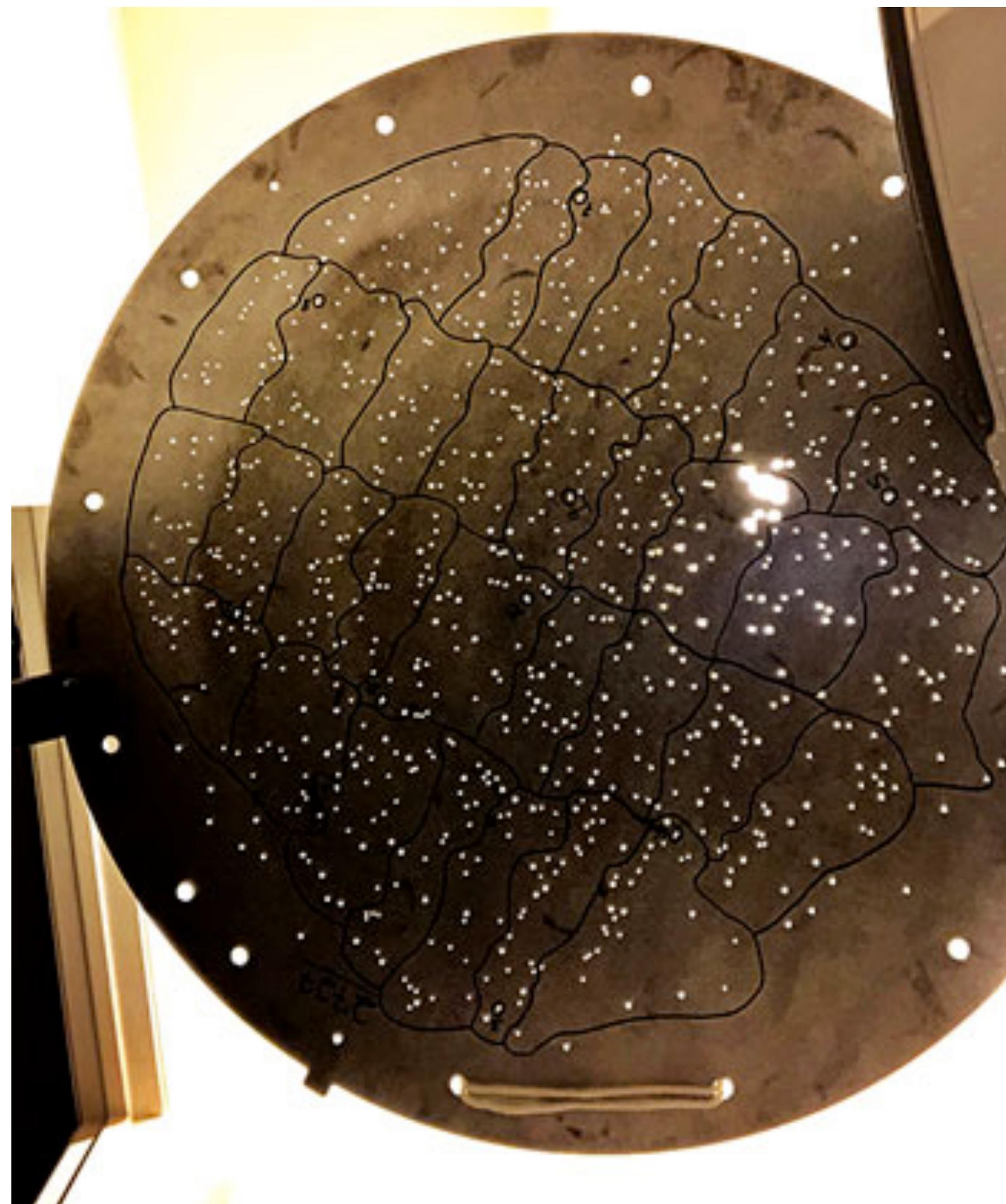
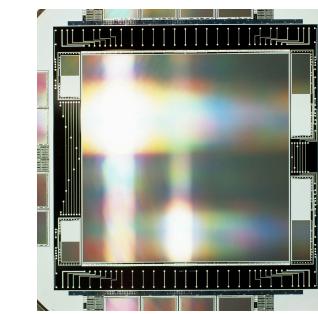
Magic (SN 2007jh)



Magic (SN 2007jh)

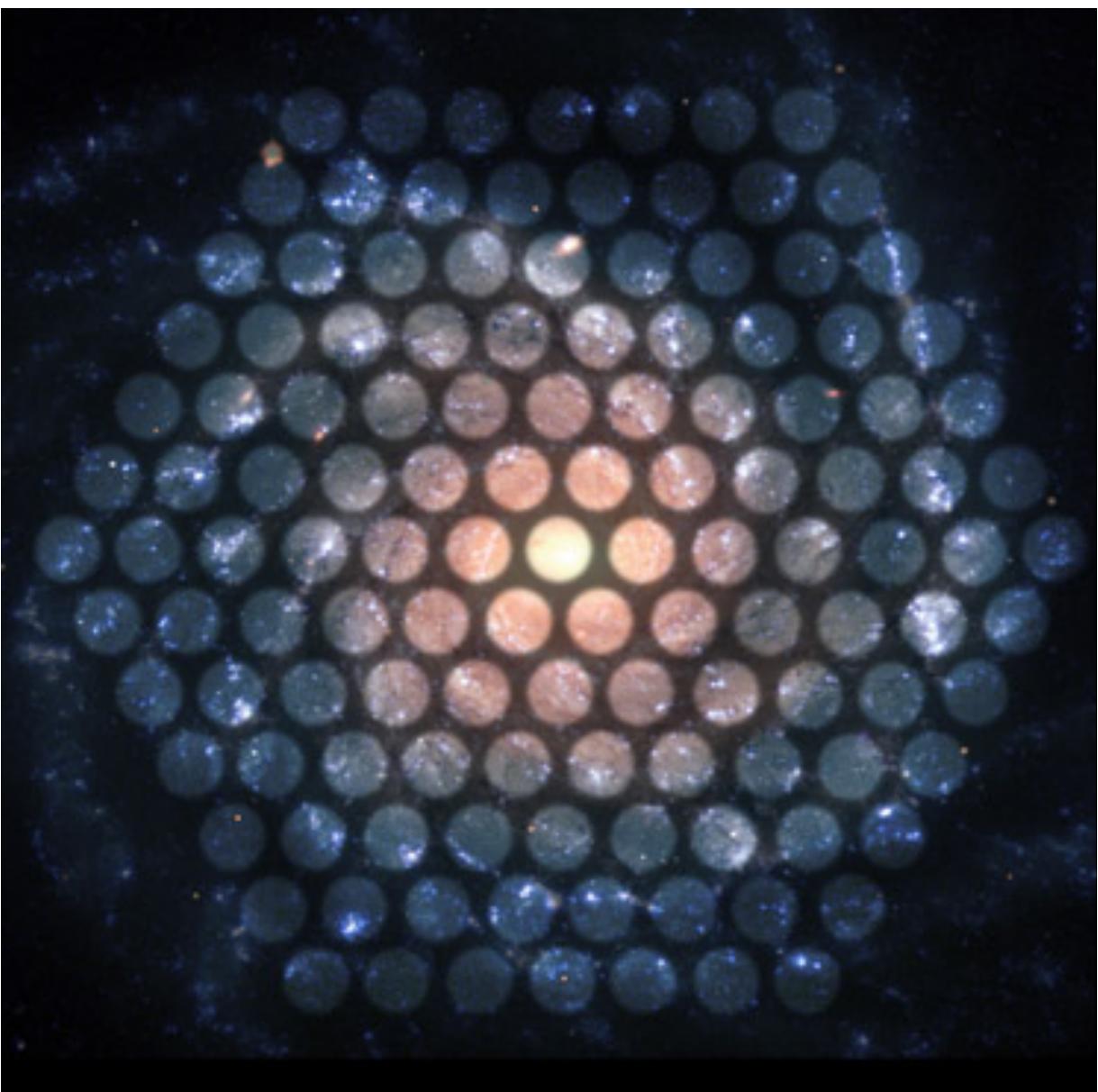


Fiber-fed spectrograph (e.g. SDSS)

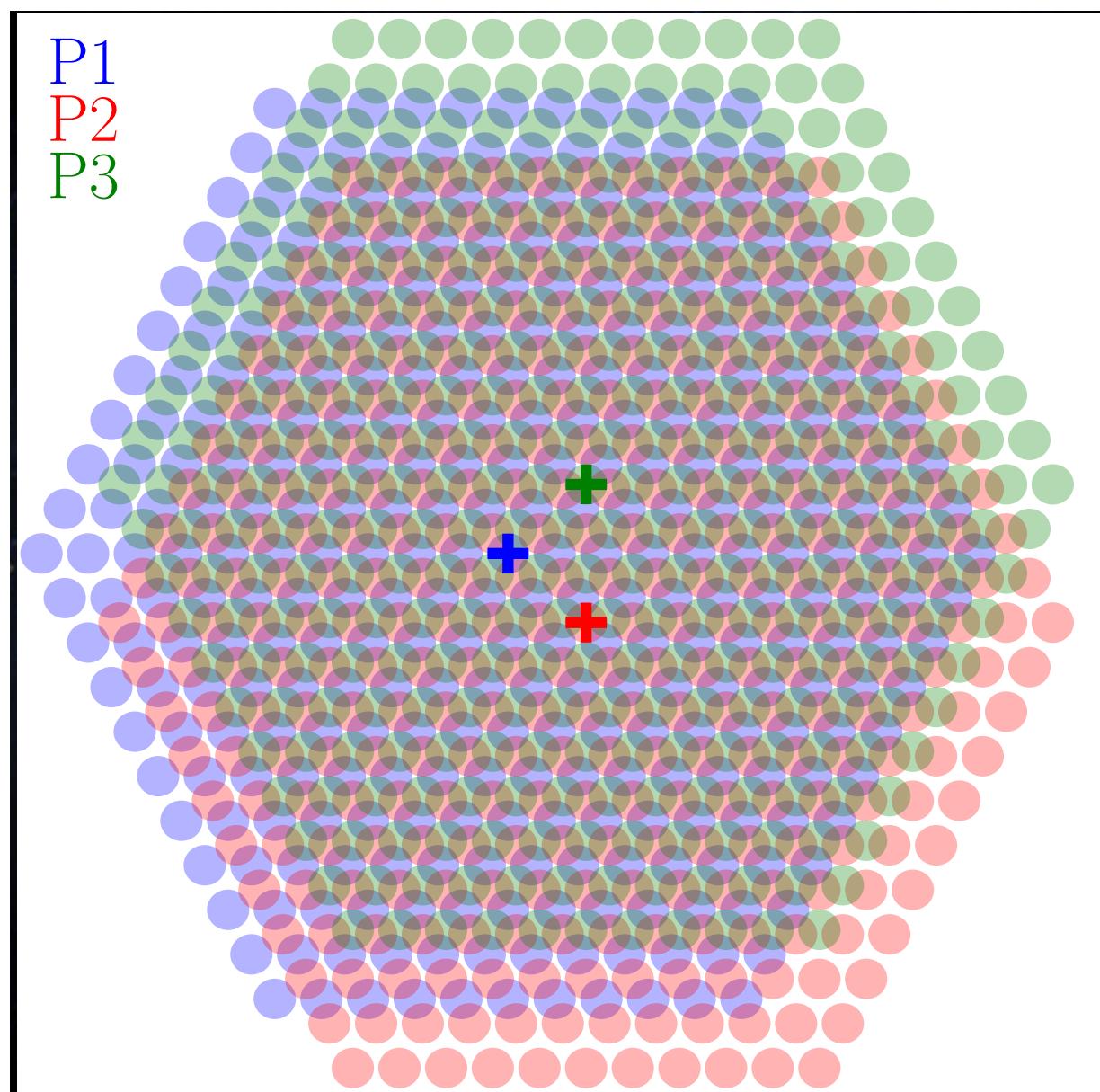


Optical system

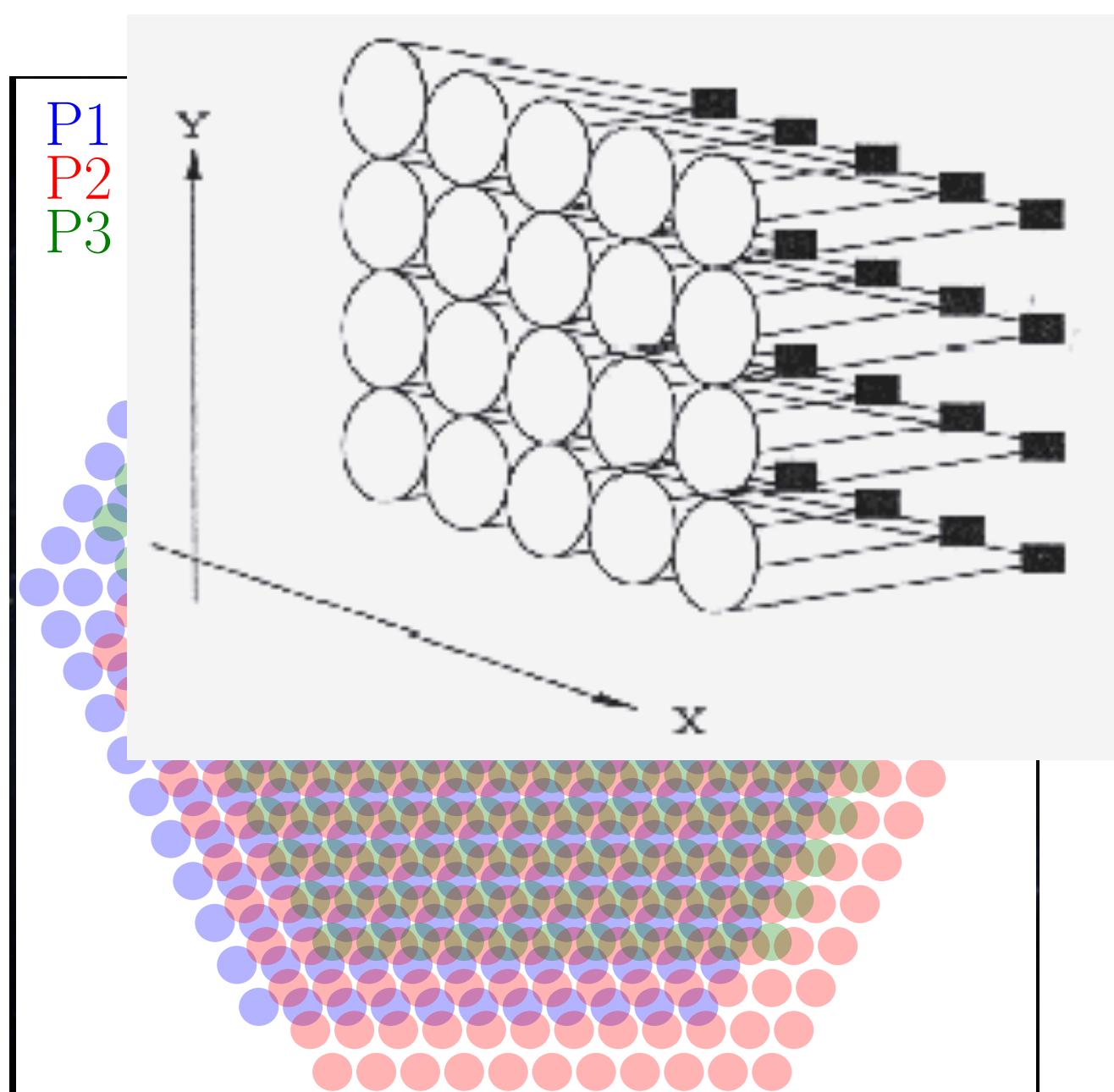
Integral Field Spectroscopy



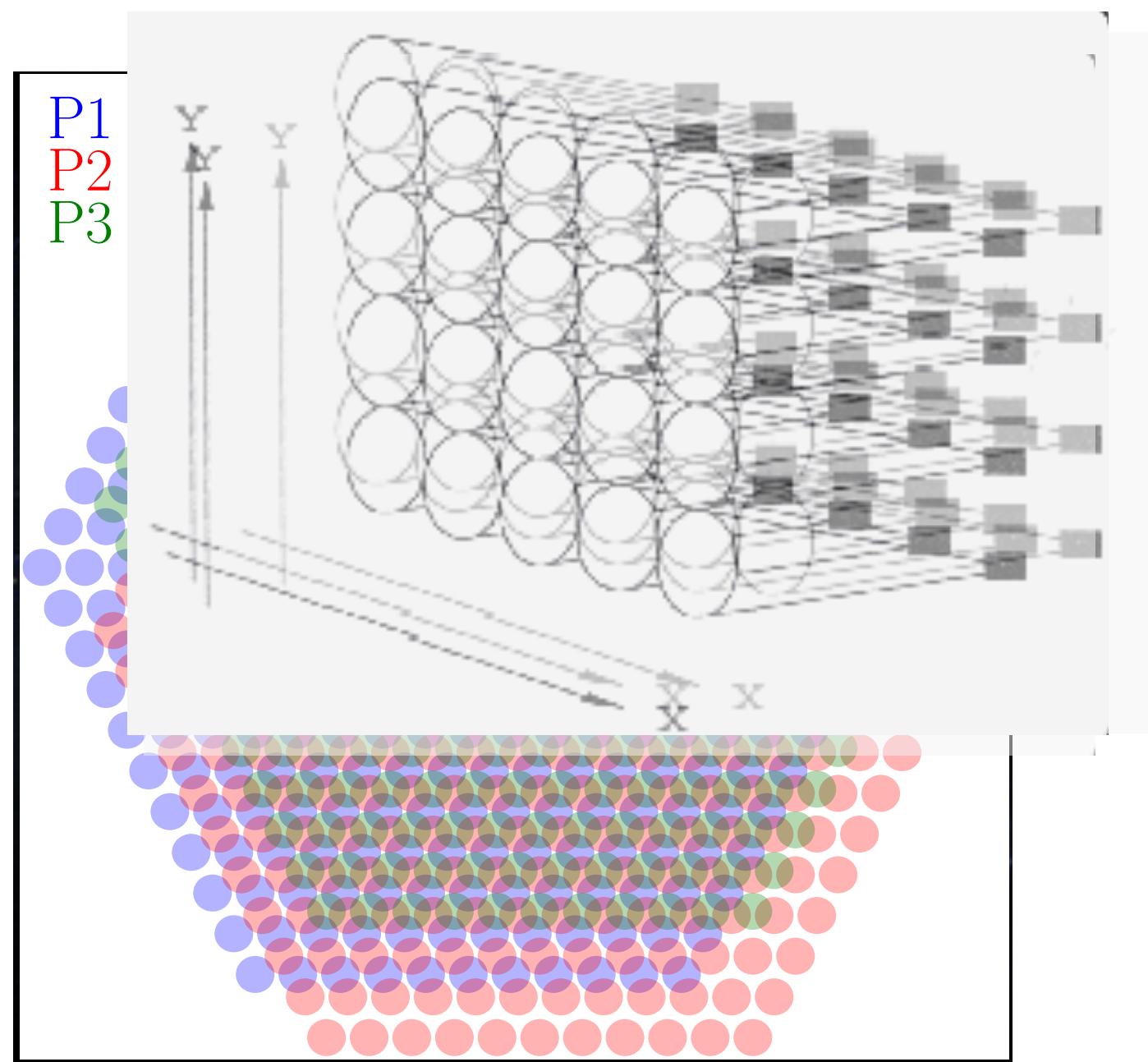
Integral Field Spectroscopy



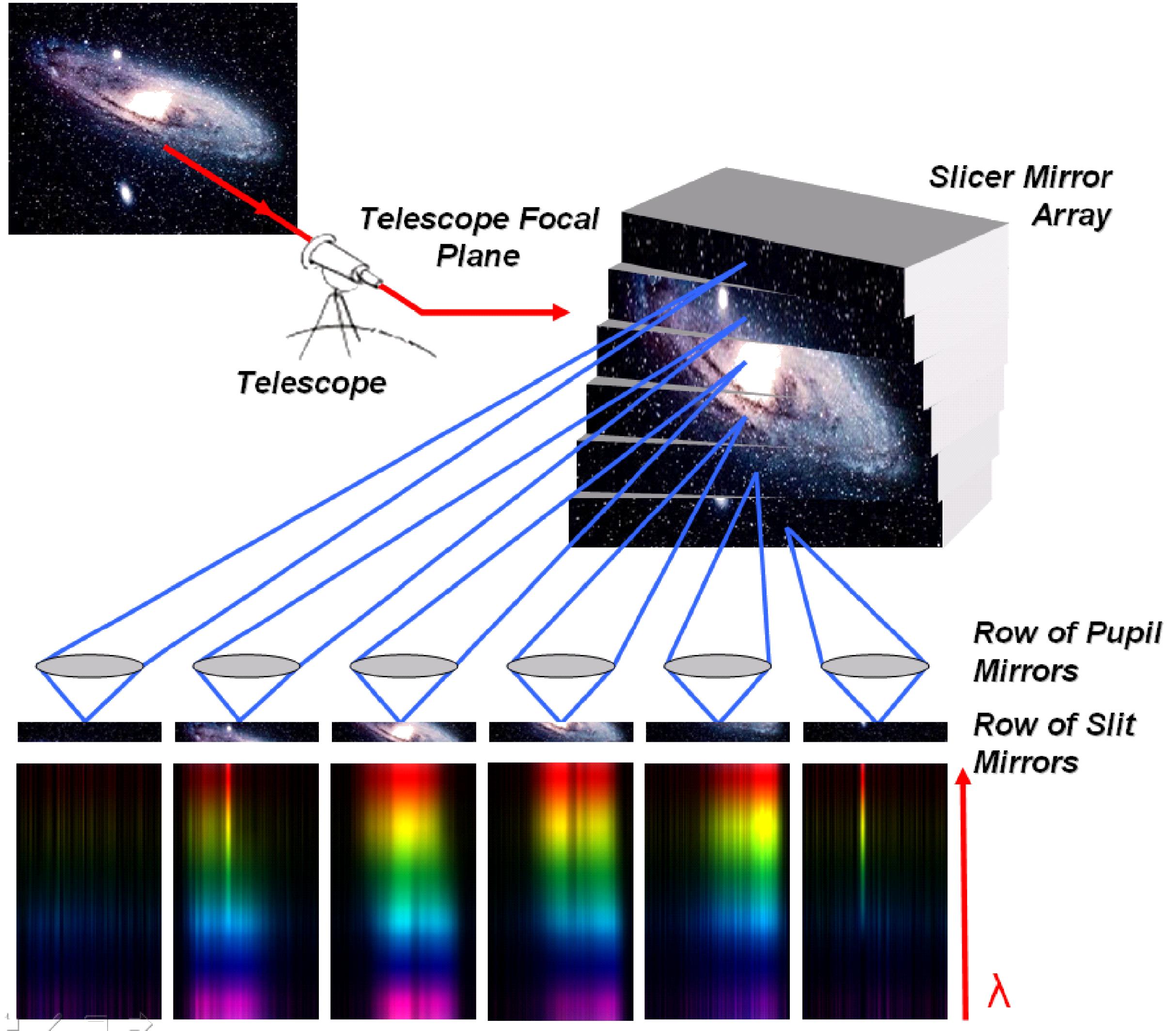
Integral Field Spectroscopy



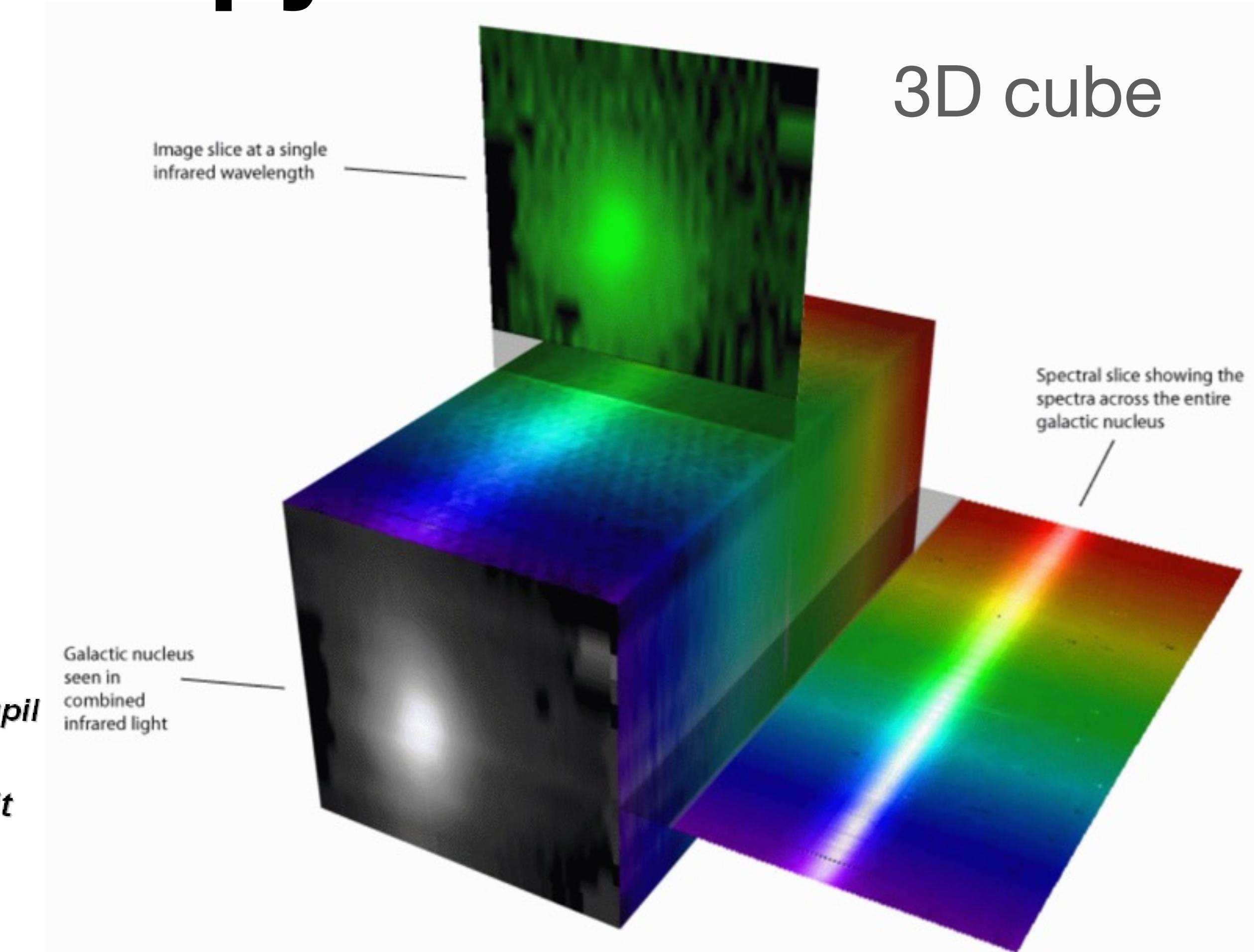
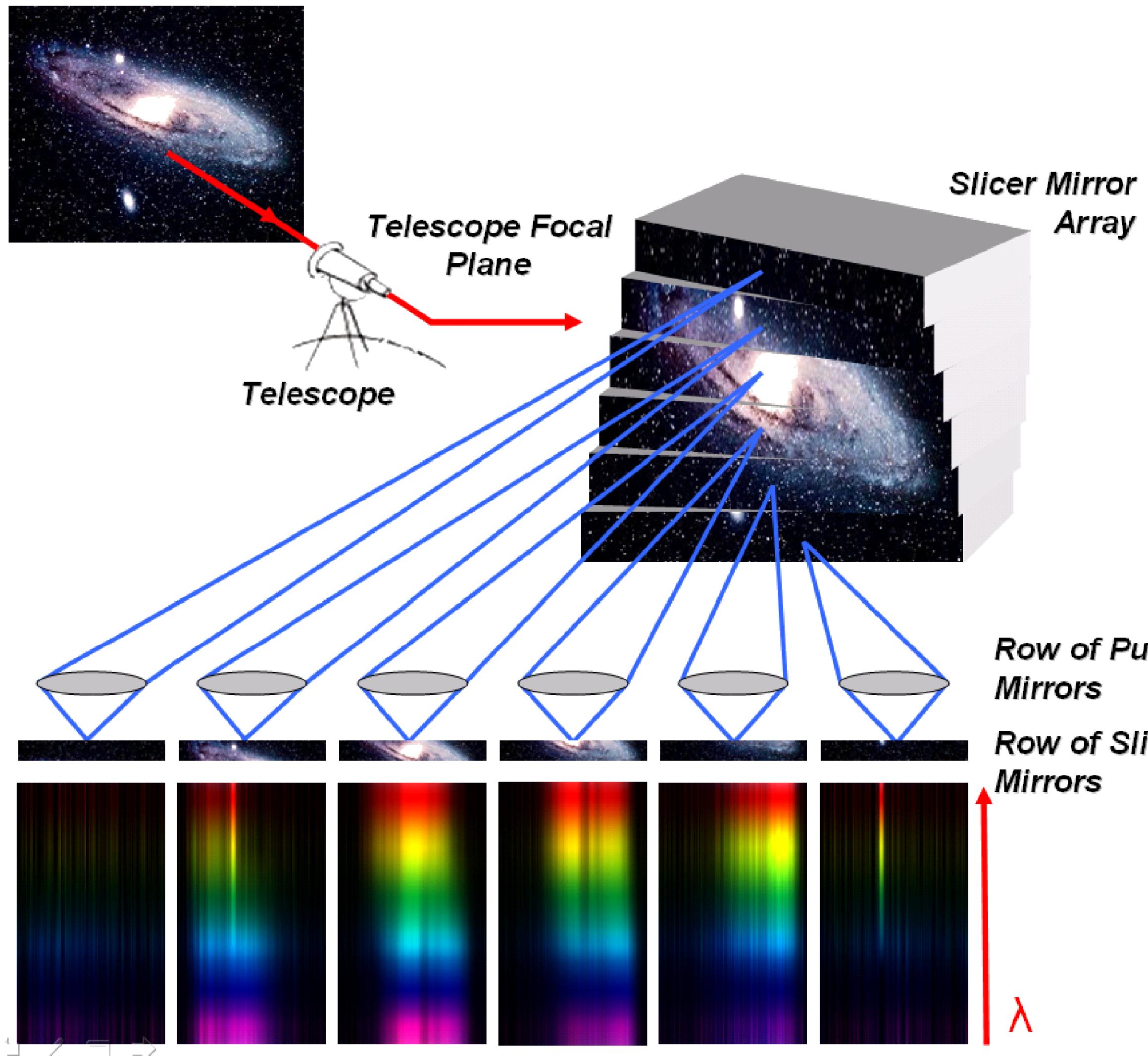
Integral Field Spectroscopy



Integral Field Spectroscopy

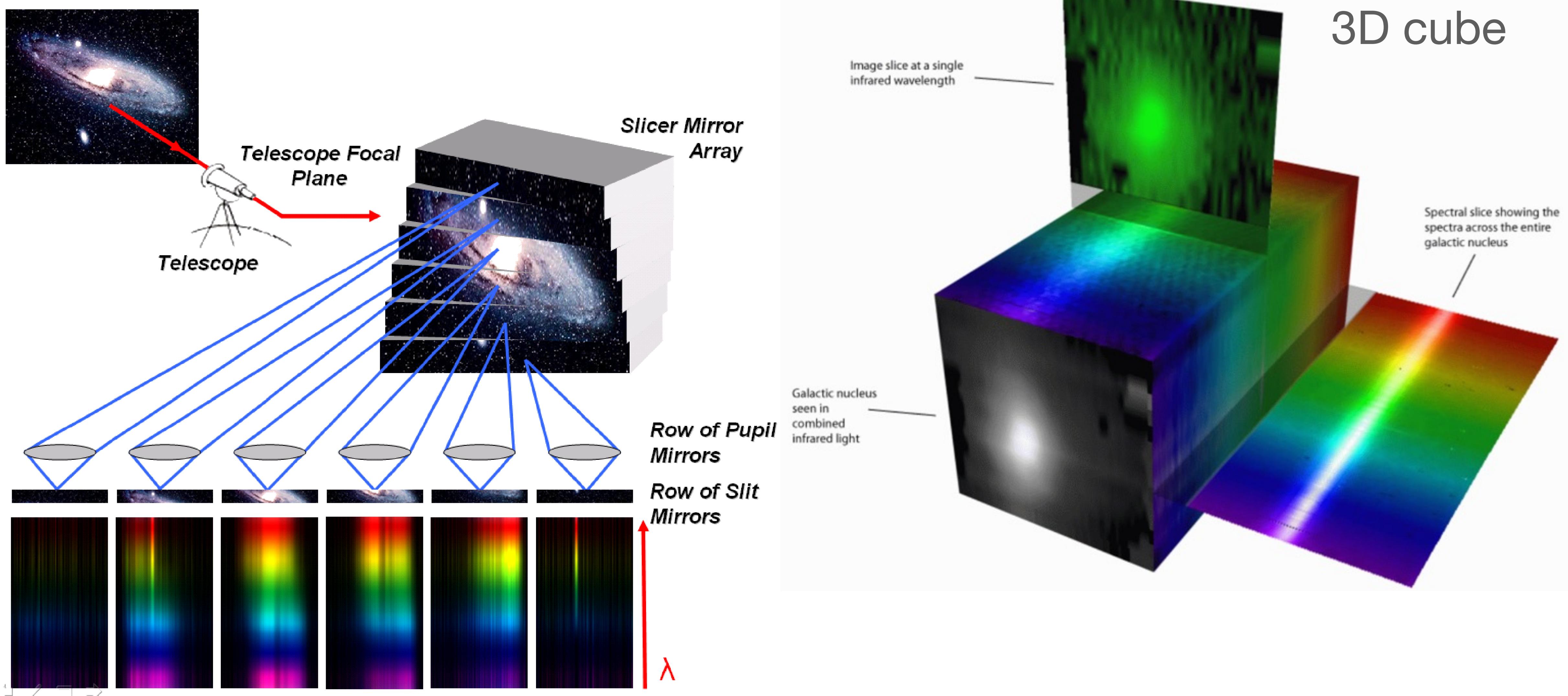


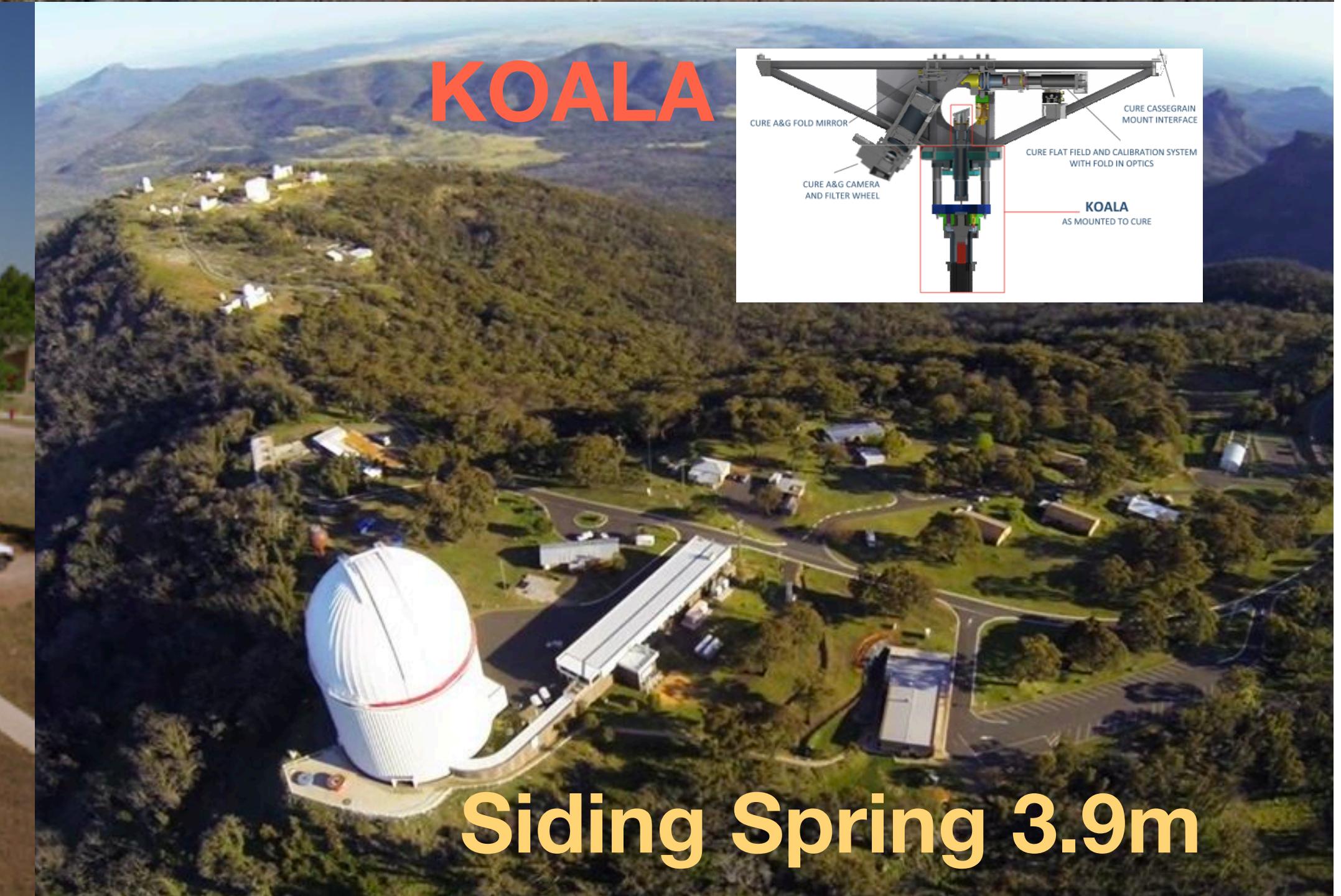
Integral Field Spectroscopy



3D cube

Integral Field Spectroscopy

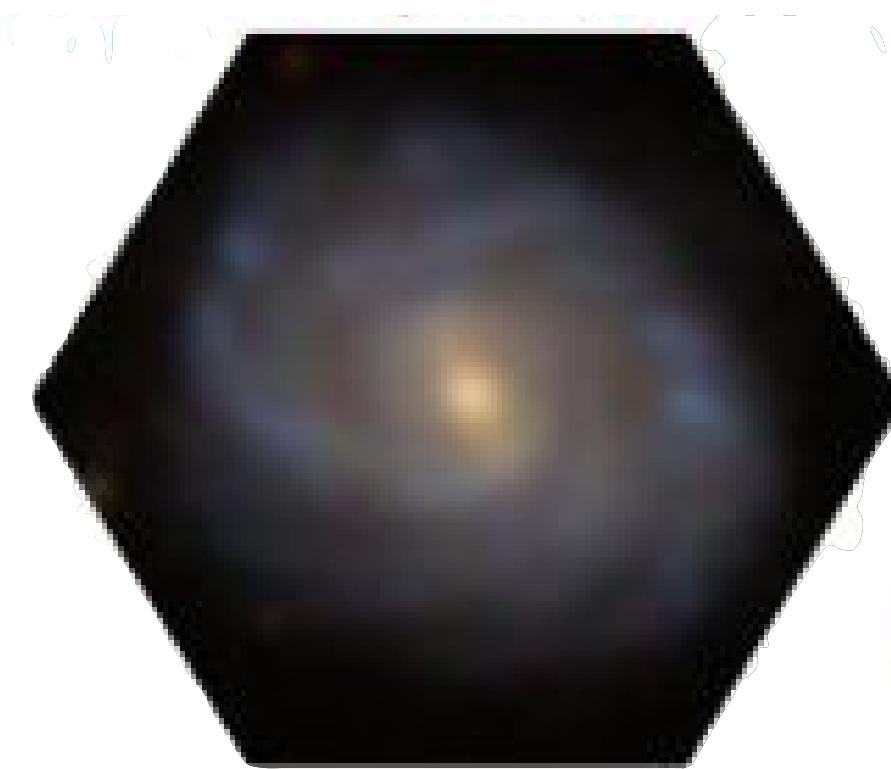




Integral Field Units (IFU)

PMAS

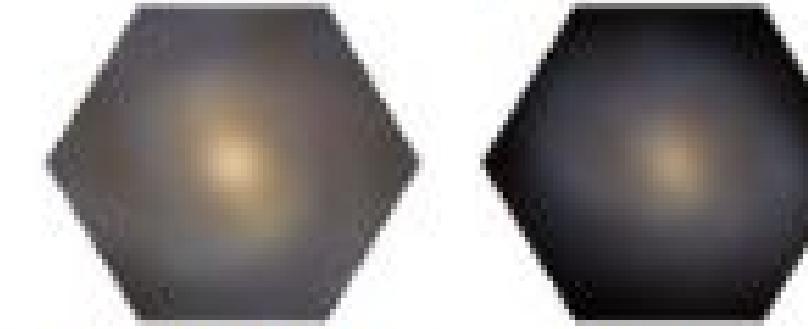
Field of view	70" \times 70"
Spectral Resolution	R~500-1200
Number of spectra	\sim 5,000 sp
Spatial Resolution	1"/spaxel
Wavelength coverage	3700-7500



Includes CALIFA DR3
and unpublished extensions,
archival data, and **PISCO**

MaNGA

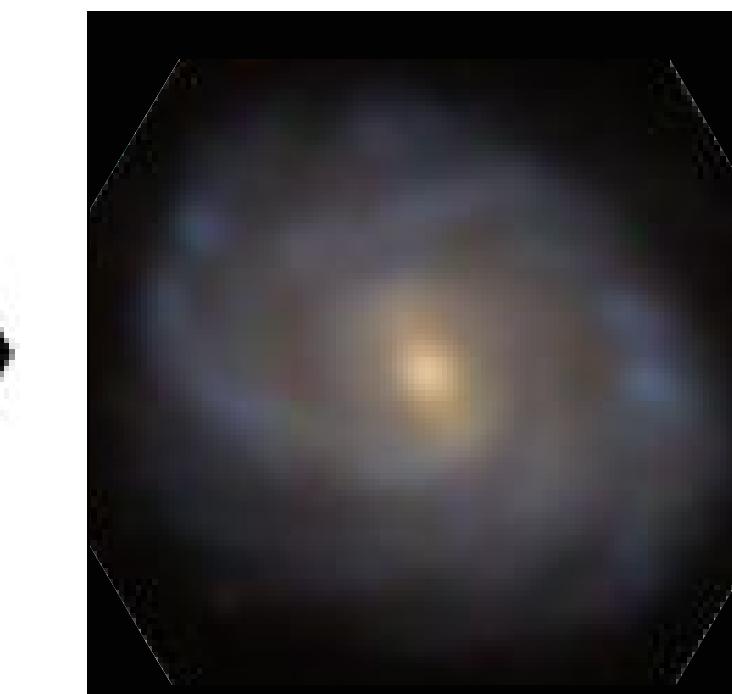
Field of view	30" \times 30"
Spectral Resolution	R~2000
Number of spectra	\sim 2,000 sp
Spatial Resolution	0.5"/spaxel
Wavelength coverage	3600-10000



FoV \sim 1.5Re ~2.5Re

MUSE

Field of view	60" \times 60"
Spectral Resolution	R~1700-3500
Number of spectra	\sim 90,000 sp
Spatial Resolution	0.2"/spaxel
Wavelength coverage	4650-9300



MaNGA public data,
ancillary program
for SN host galaxies
(PI Galbany)

AMUSING survey
and archival data

KOALA

Field of view	30" \times 60"
Spectral Resolution	R~1300-3700
Number of spectra	\sim 1,000 sp
Spatial Resolution	0.5"/spaxel
Wavelength coverage	3700-8000



Includes Hi-KIDS
and 1 (18A)
semester data

MUSE facts

Multi-Unit Spectroscopic Explorer

8.2m-UT4, VLT, Cerro Paranal (Chile)

the most efficient sp @paranal

24 IFS + AO system (GALACSI)

*secondary adaptative mirror
(currently installed)*

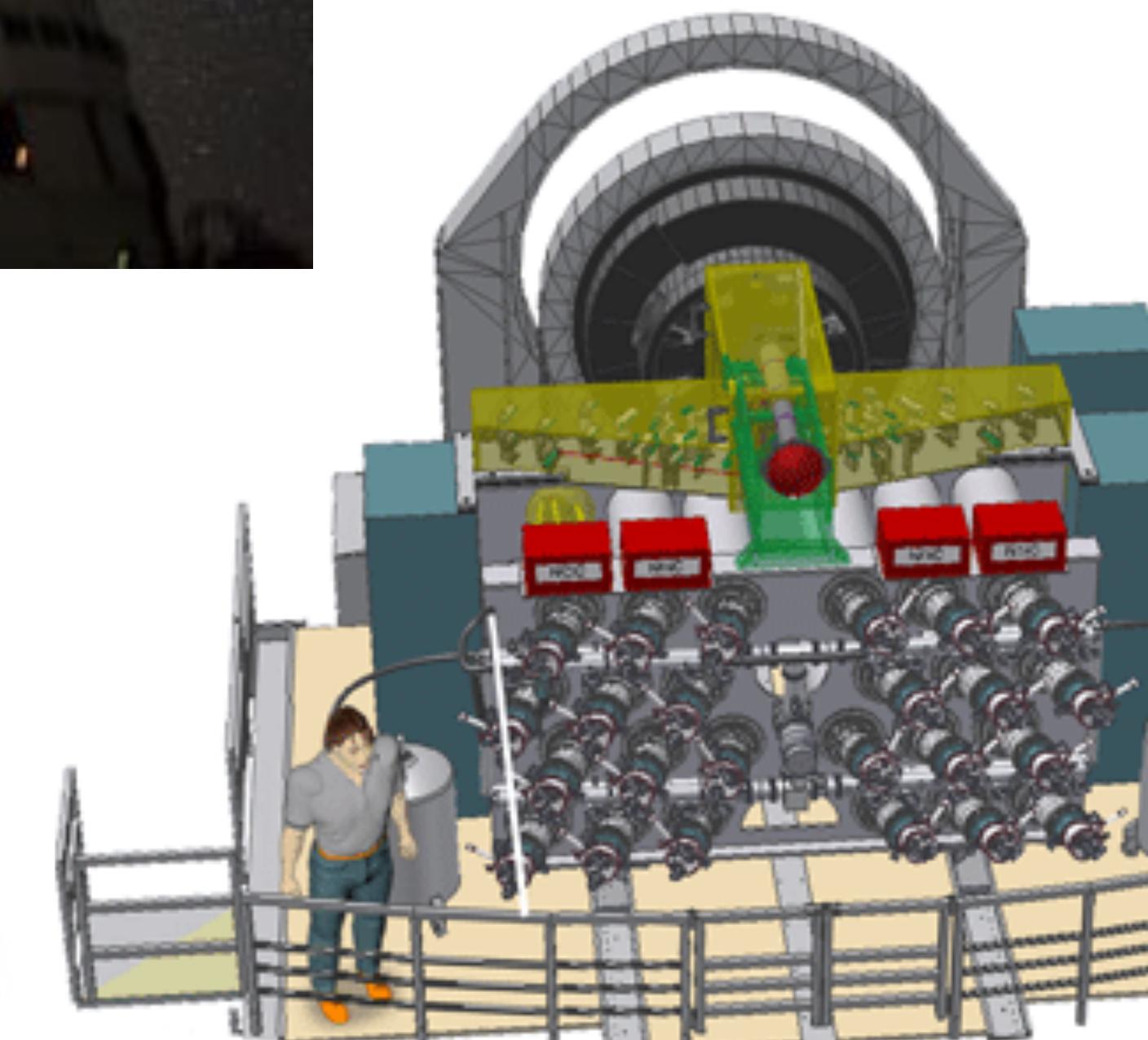
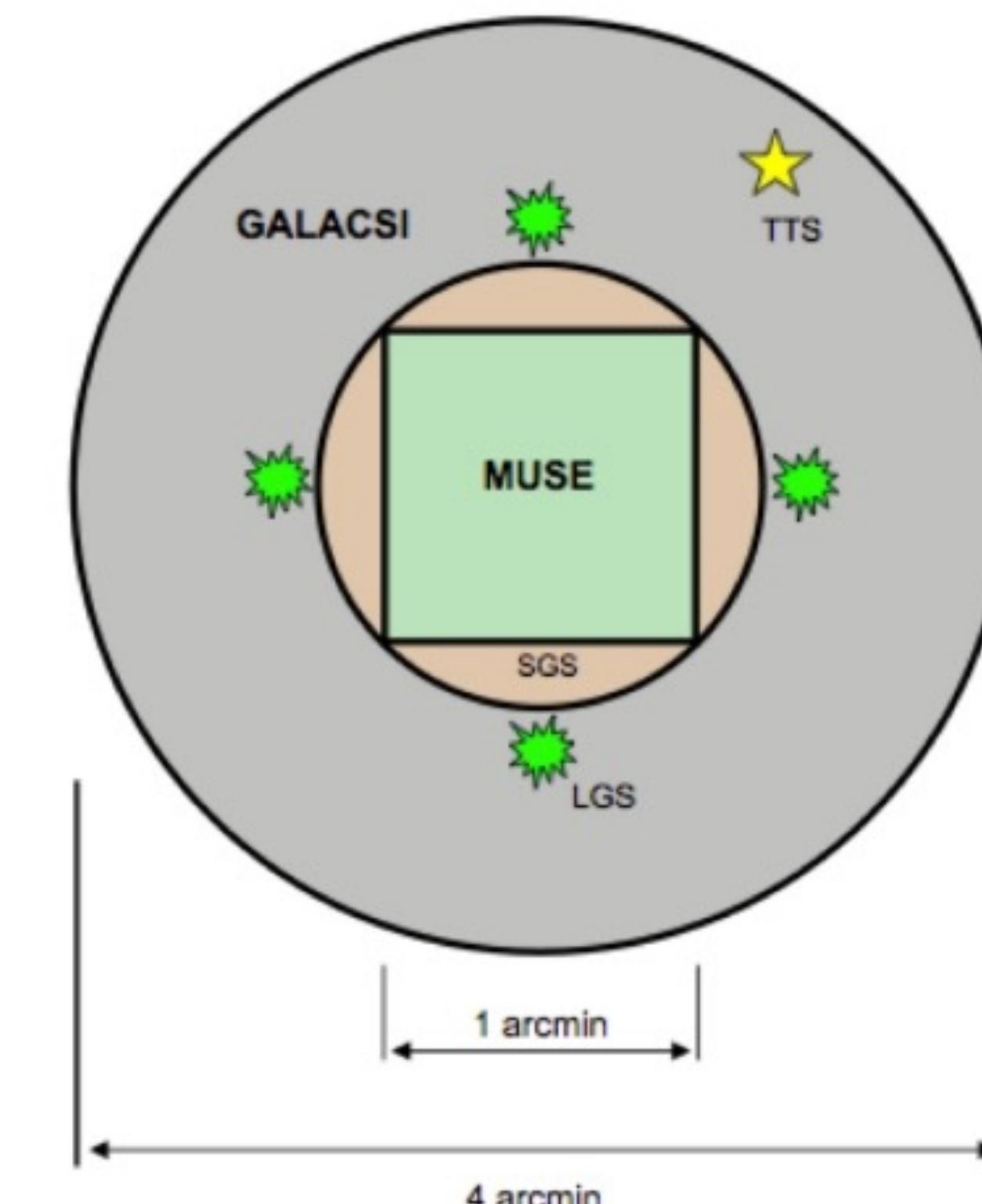
*lasers -> fake stars
(Na layer 100km)*

FoV of $60'' \times 60''$

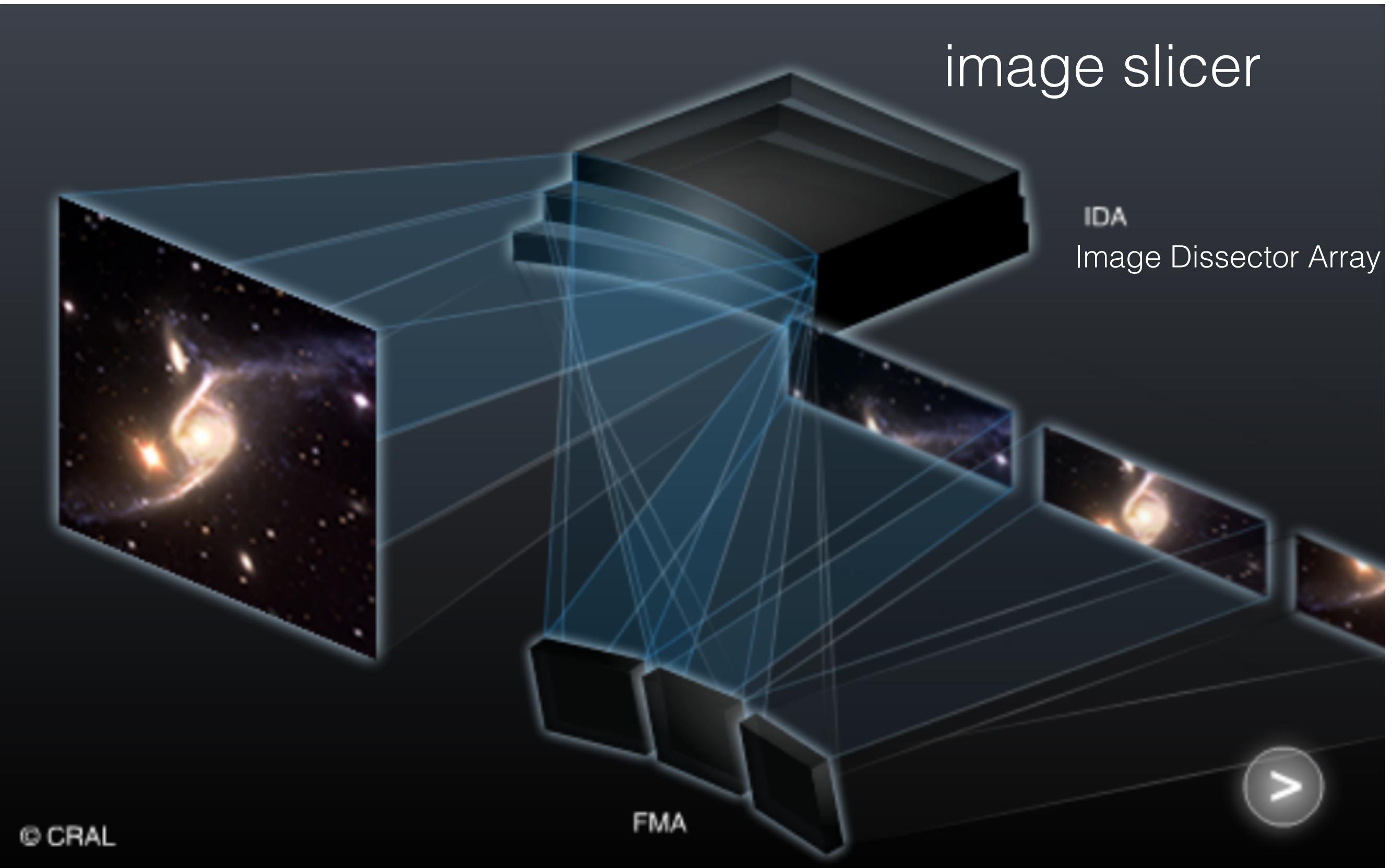
$0.2'' \times 0.2''$ spaxel size

seeing limited (spatial res $\sim 0.4\text{-}0.5''$)

all these for the WFM



Nasmyth B



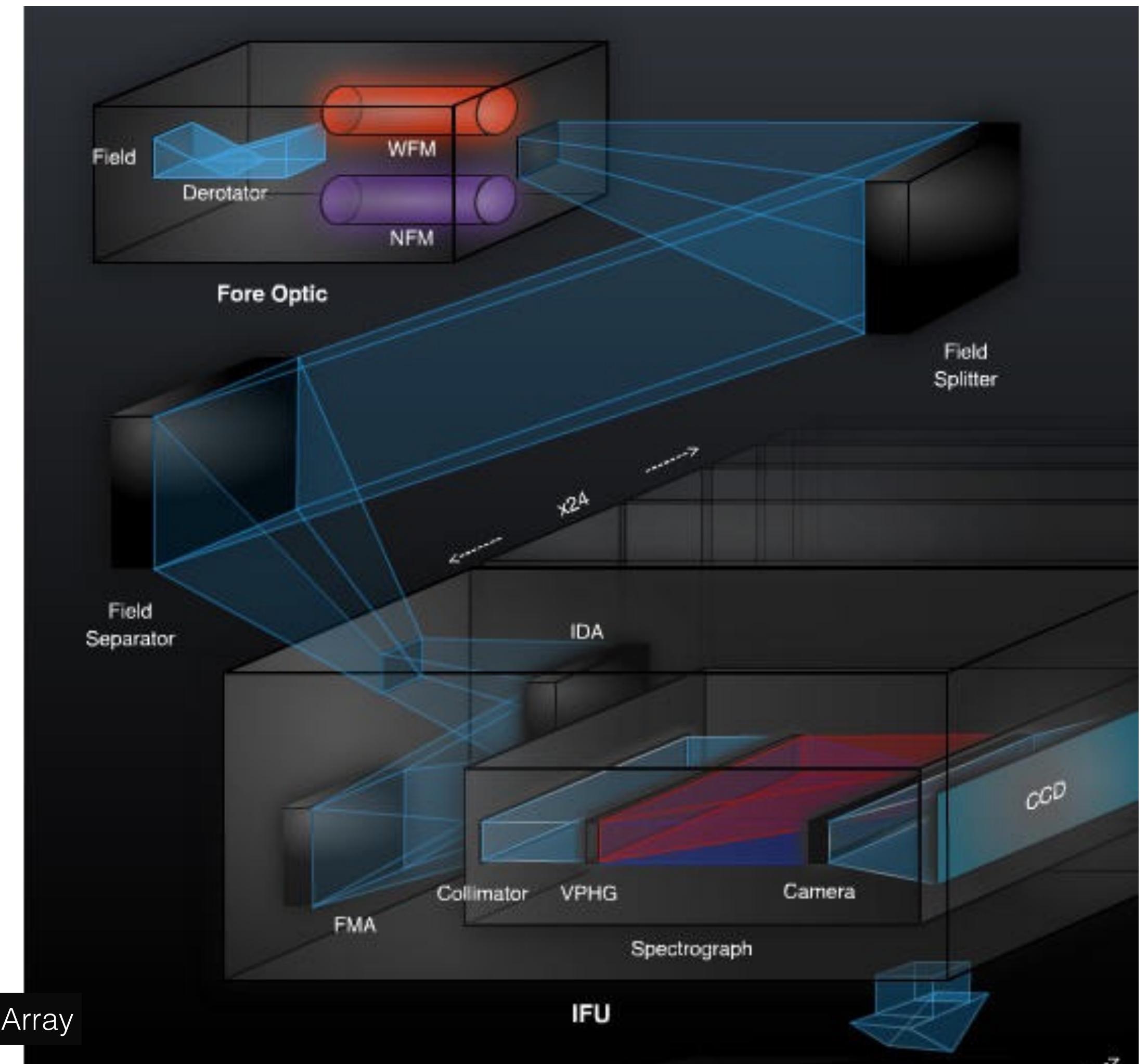
~100% FoV coverage
(but CCD gaps)

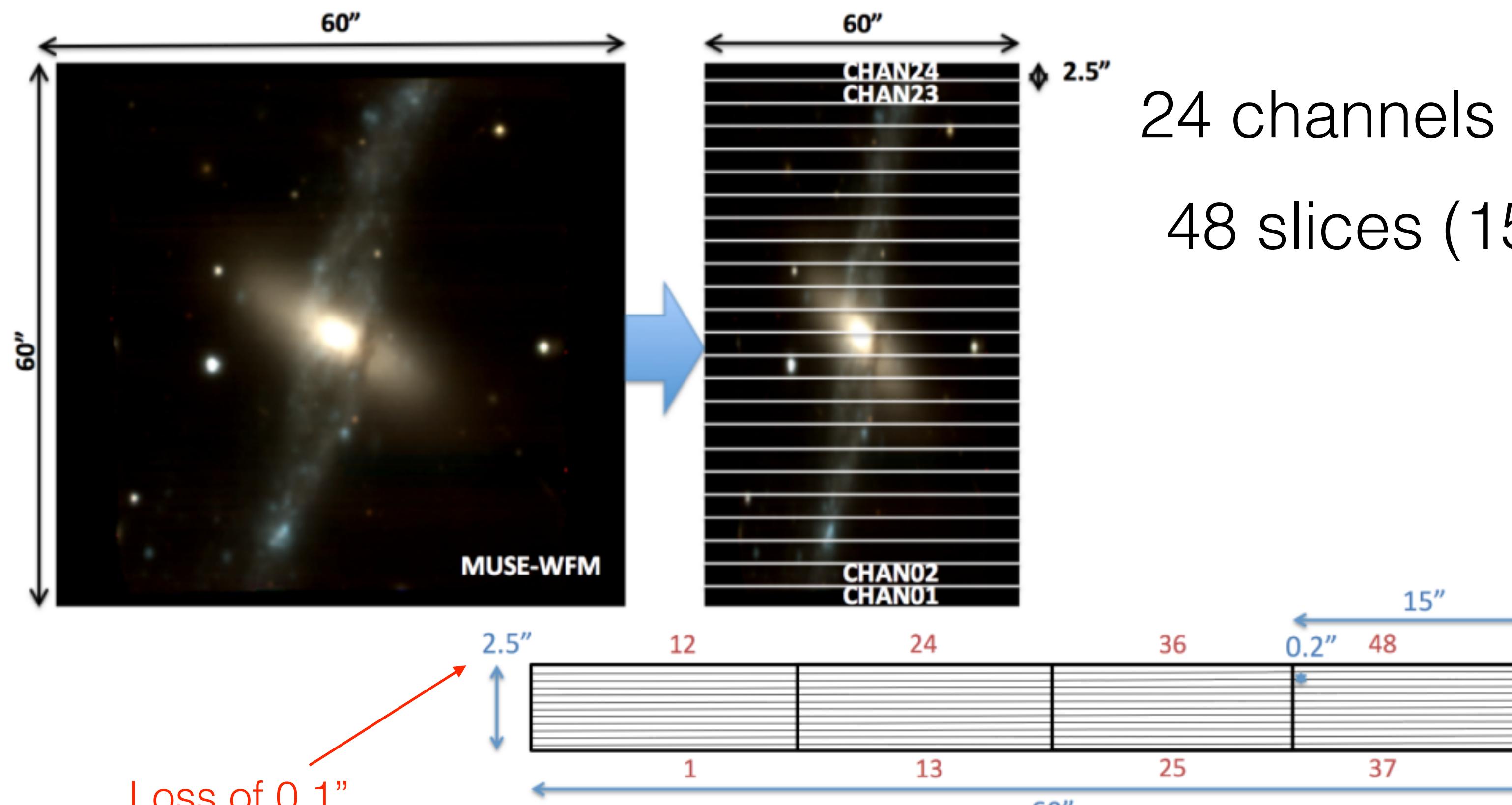
4 obs. 90deg, 2" N-E shift

24 channels (60" x 2.5")

48 slices (15" x 0.2")

Focusing Mirrors Array





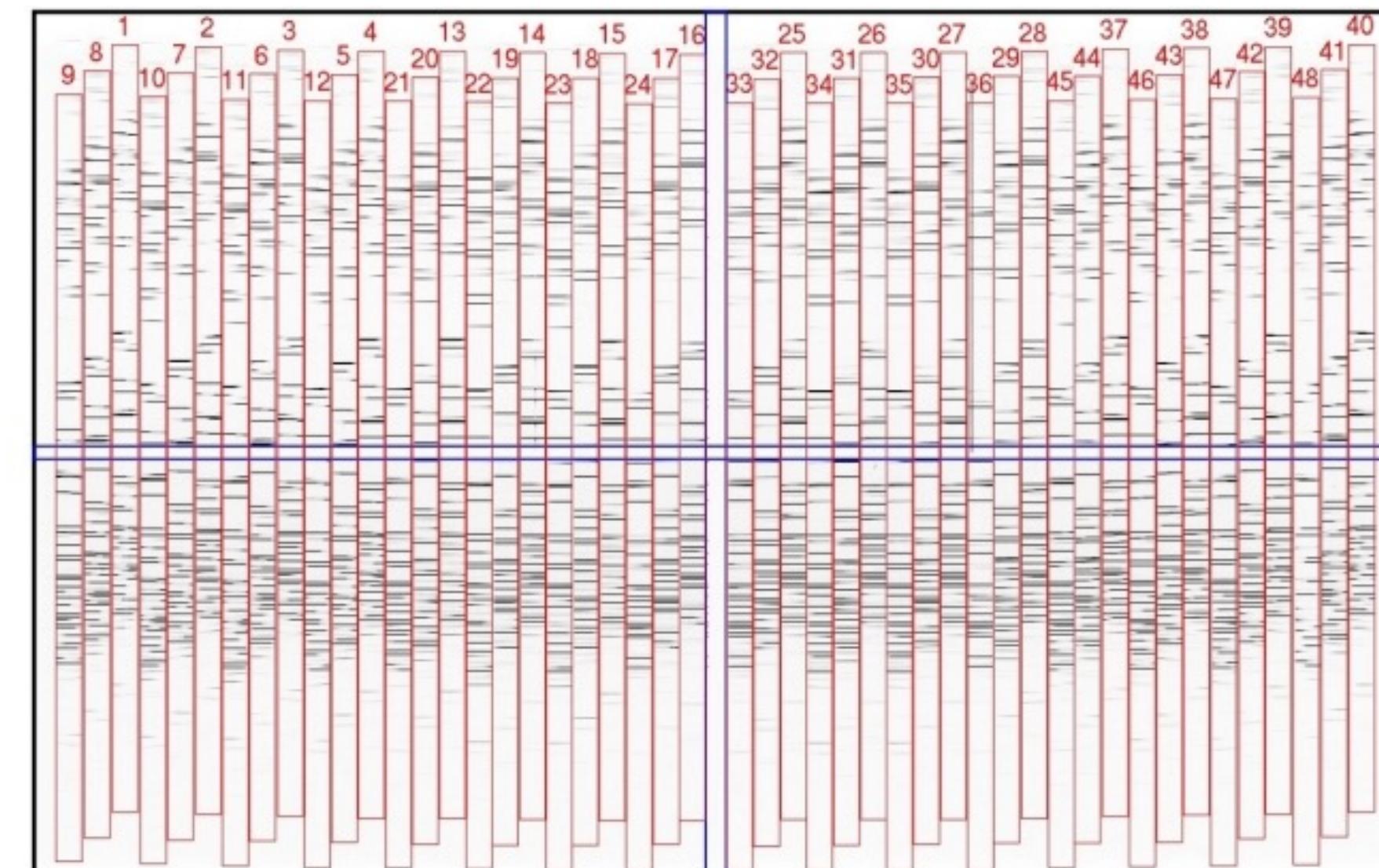
24 channels (60" x 2.5")
48 slices (15" x 0.2")

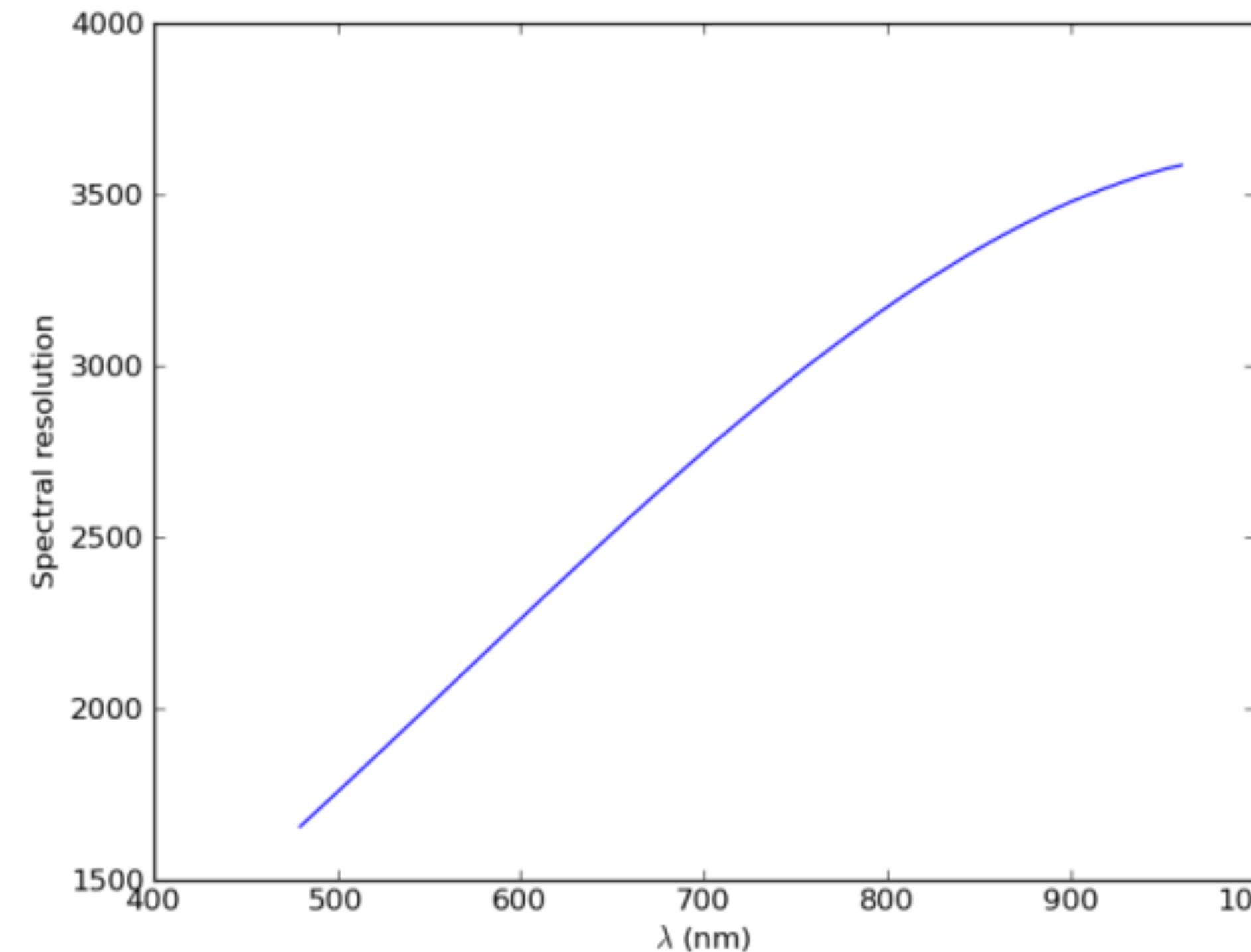
$15/0.2 * 48 * 24 = 86400$
 $60/0.2 * 60/0.2 = 90000$

96%

~100% FoV coverage
(but CCD gaps)

4 obs. 90deg, 2" N-E shift

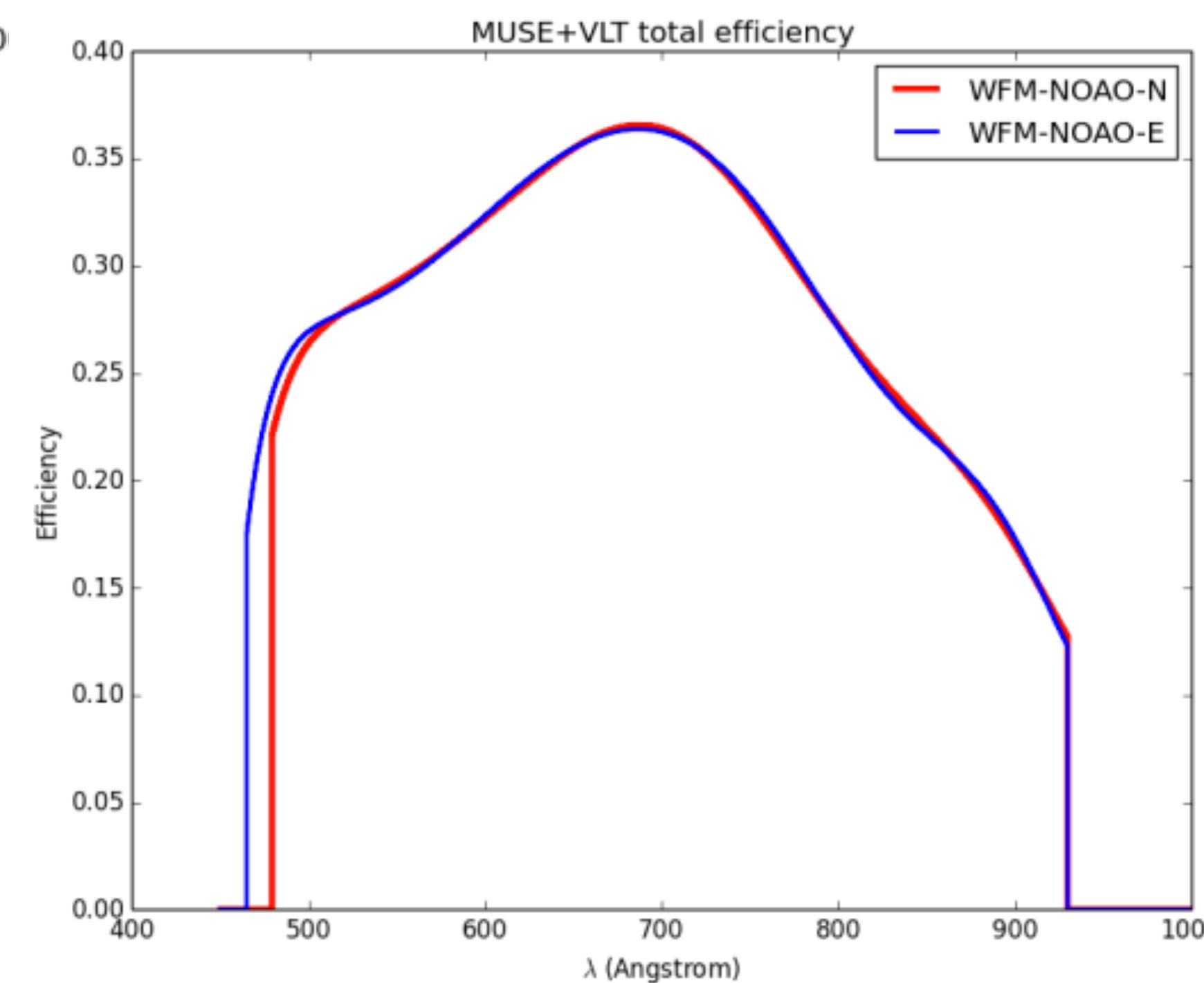




24 channels (60" \times 2.5")
48 slices (15" \times 0.2")

\sim 100% FoV coverage
(but CCD gaps)

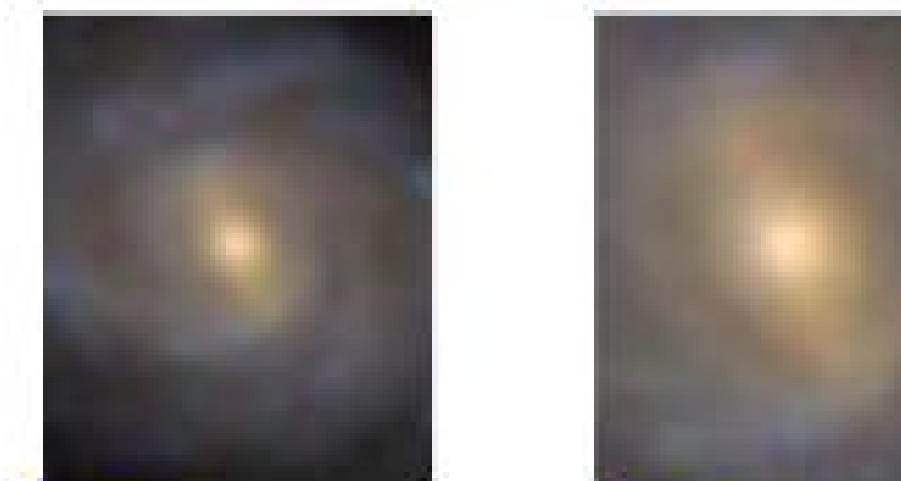
4 obs. 90deg, 2" N-E shift



SDSS 90''x90'' image



Atlas3D



Z~Z
califa Z~Z
Atlas3D

R~500/1200 CALIFA ~70''x70''

2x3x331 spaxels; 2.7''/spaxel

600 galaxies of any type

~1.200.000 spec.; 3700-7500 Å

Atlas3D ~30''x60''

1577 spaxels; 0.94''/spaxel

260 ETGs

~400.000 spectra; 4810-5350 Å

R~1400-2200 MaNGA ~30''x30''

3x(19-127) spaxels; 2''/spaxel

7000 gal. of any type (~1.5Re)

2000 gal. of any type (~2.5Re)

1000 gal. of any type (any Re)

~800.000 spec.; 3550-10000 Å

CALIFA (V500/V1200)



MUSE

60''x60''
R~1700-3500
~90.000 sp
0.3-0.5''/spaxel
4650-9300

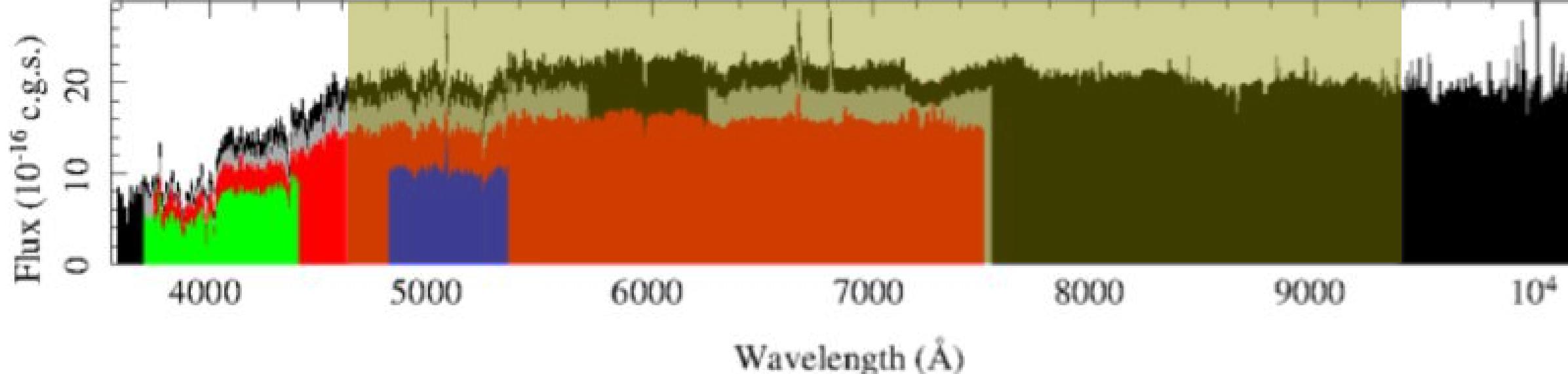
FoV~1.5Re

~2.5Re

SAMI

Z~Z
califa

Z~Z
SAMI



R~1730-4500 SAMI 20''x20''

9x61 spaxels; 1.6''/spaxel

3400 galaxies of any type

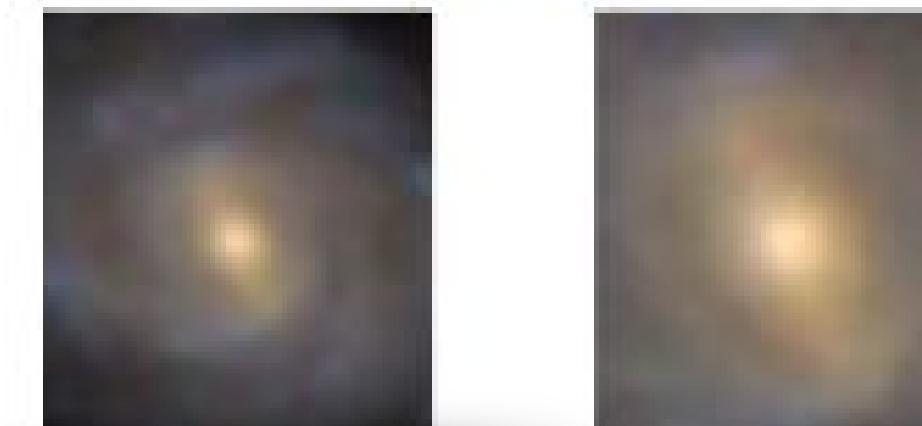
~1.900.000 spec.; 3700-7500 Å

from Sánchez

SDSS 90''x90'' image



Atlas3D



R~500/1200 CALIFA ~70''x70''

2x3x331 spaxels; 2.7''/spaxel

600 galaxies of any type

~1.200.000 spec.; 3700-7500 Å

Atlas3D ~30''x60''

spaxels; 0.94''/spaxel

10 ETGs

spectra; 4810-5350 Å

MaNGA ~30''x30''

spaxels; 2''/spaxel

any type (~1.5Re)

any type (~2.5Re)

any type (any Re)

spec.; 3550-10000 Å

MUSE cubes notes:

units: 10^{-20} erg/s/cm 2 /Å

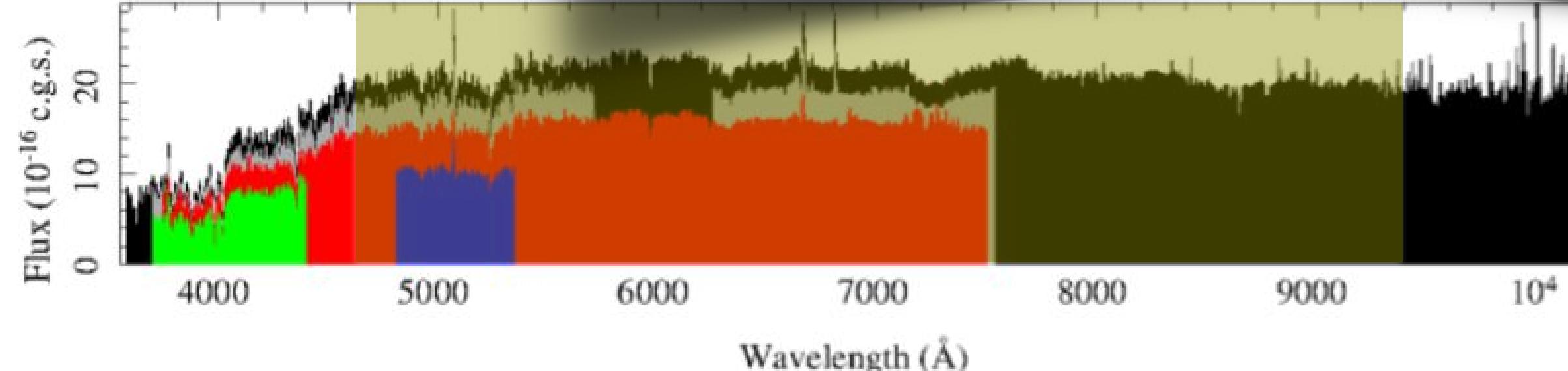
info (header) in the primary

flux in the 1st extension

error in the 2nd extension

wavelength step 1.25 Å

CALIFA (V500/V)



R~1730-4500 SAMI 20''x20''

9x61 spaxels; 1.6''/spaxel

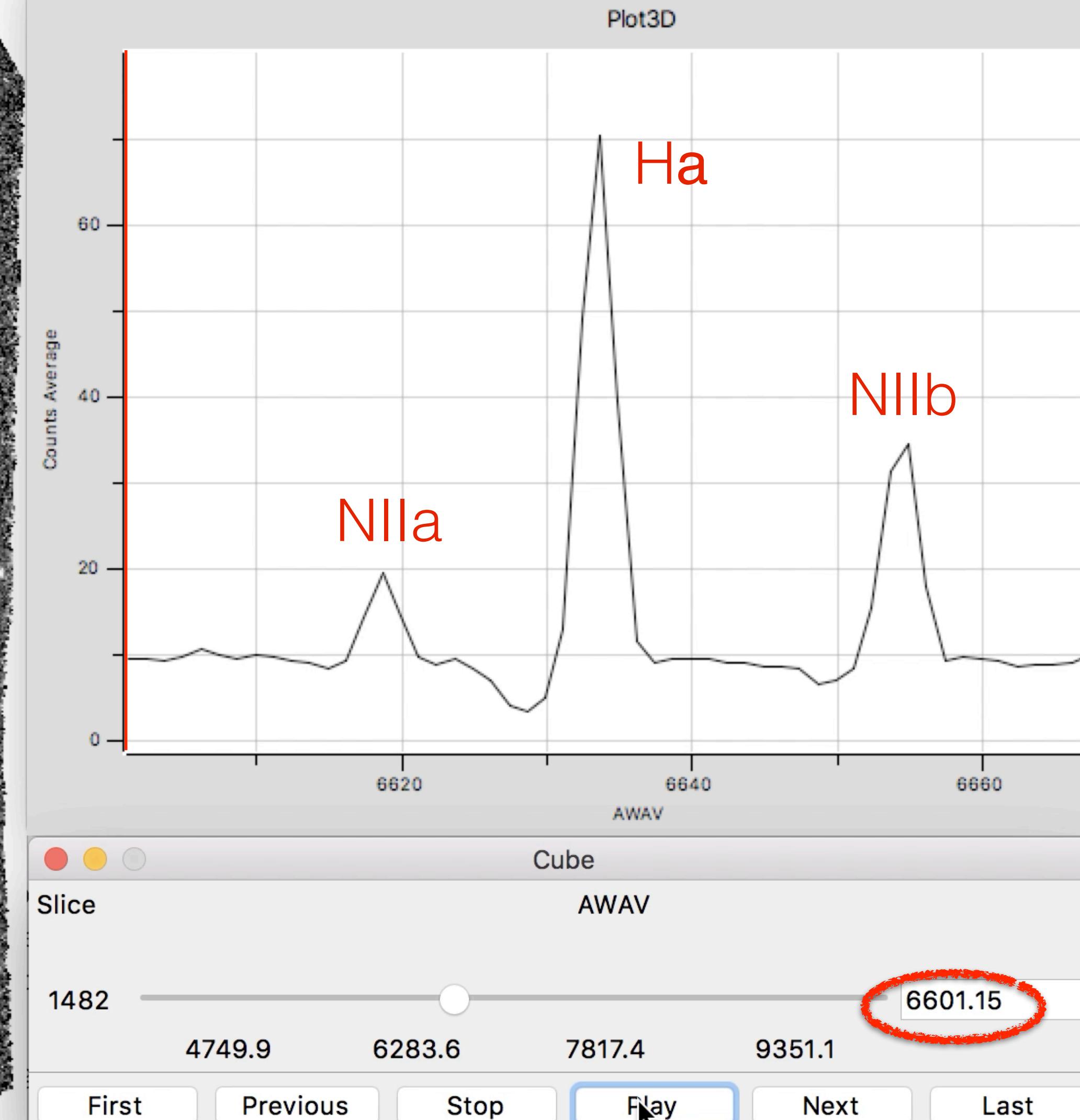
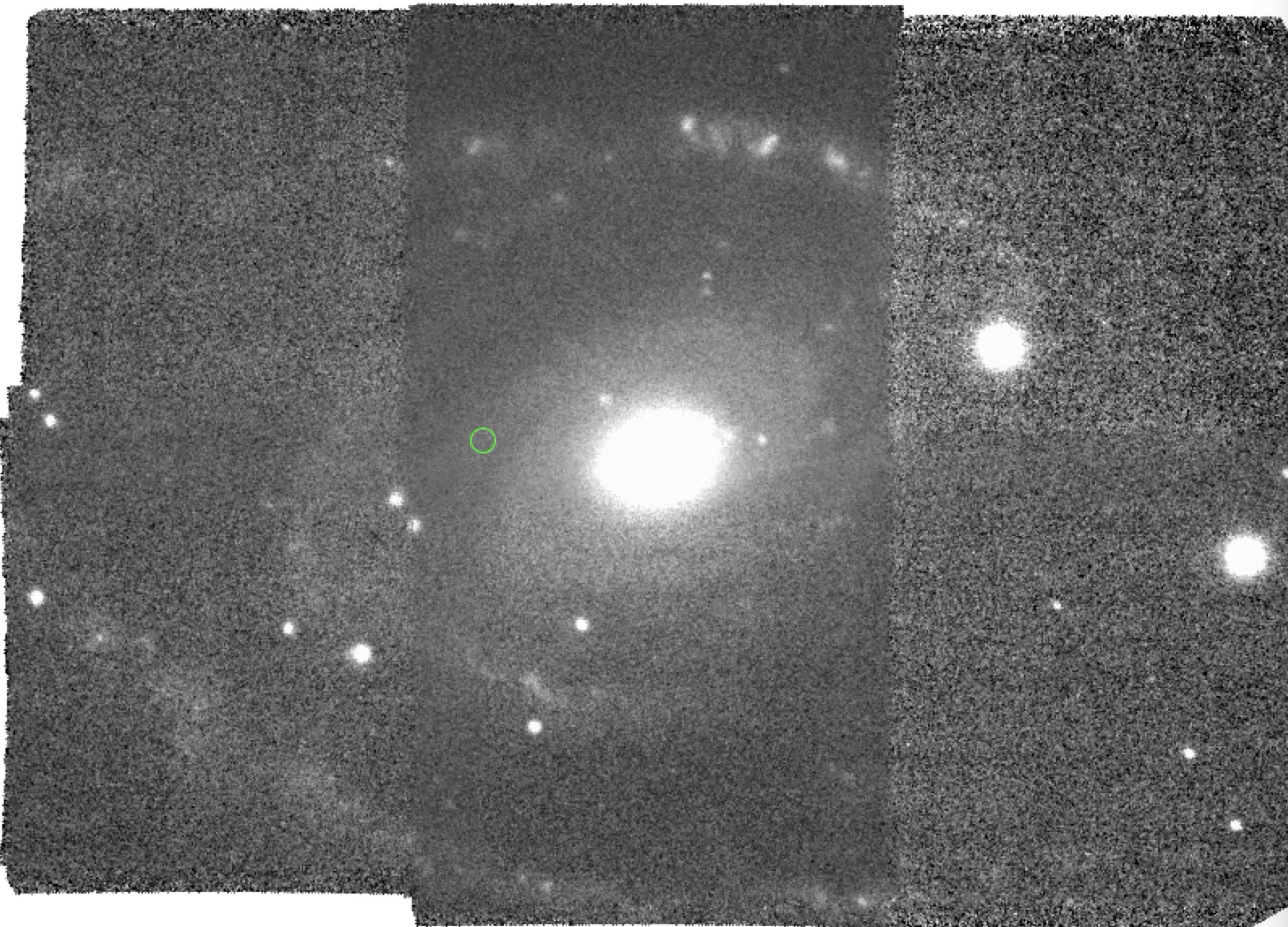
3400 galaxies of any type

~1.900.000 spec.; 3700-7500 Å

from Sánchez

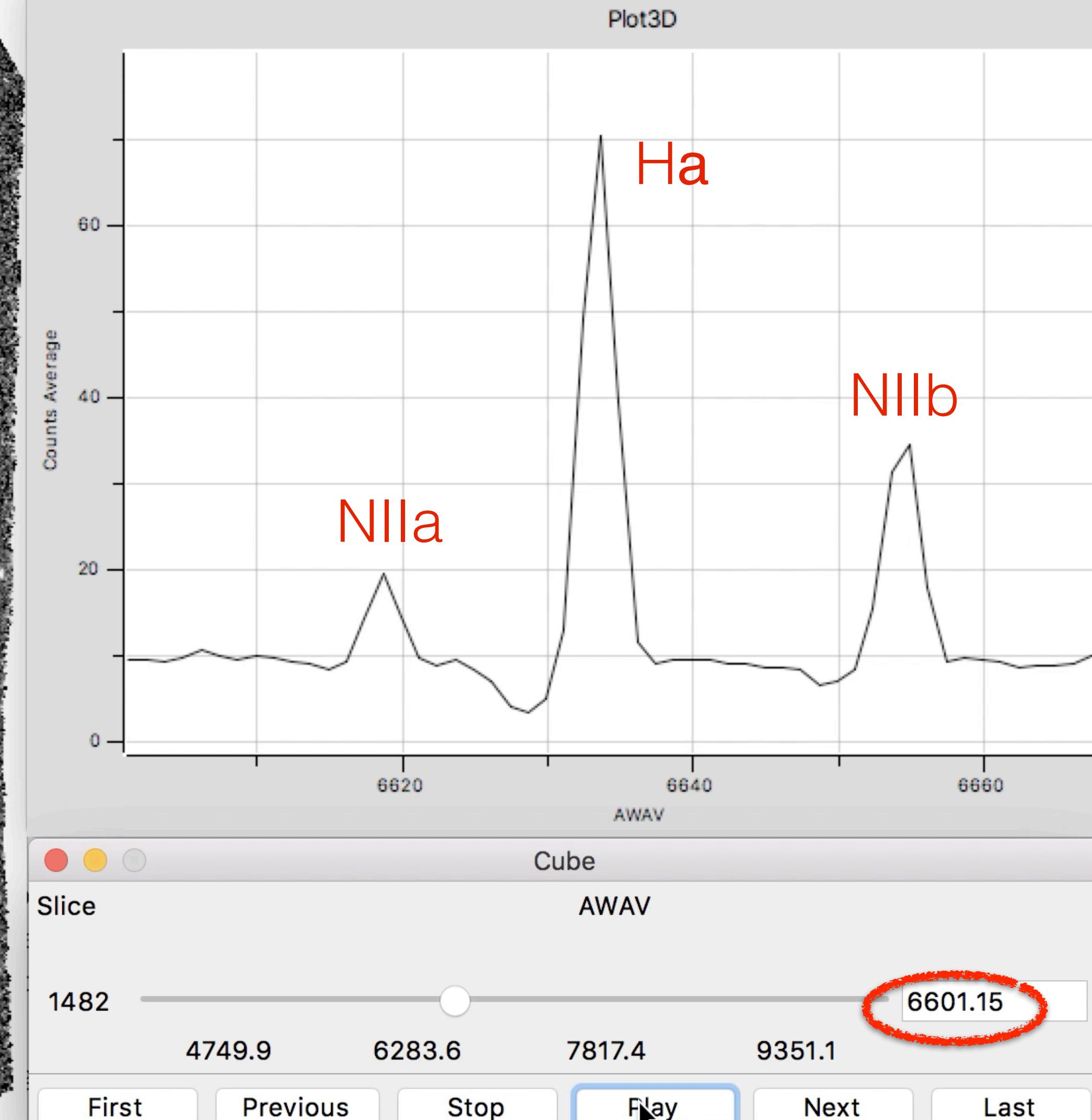
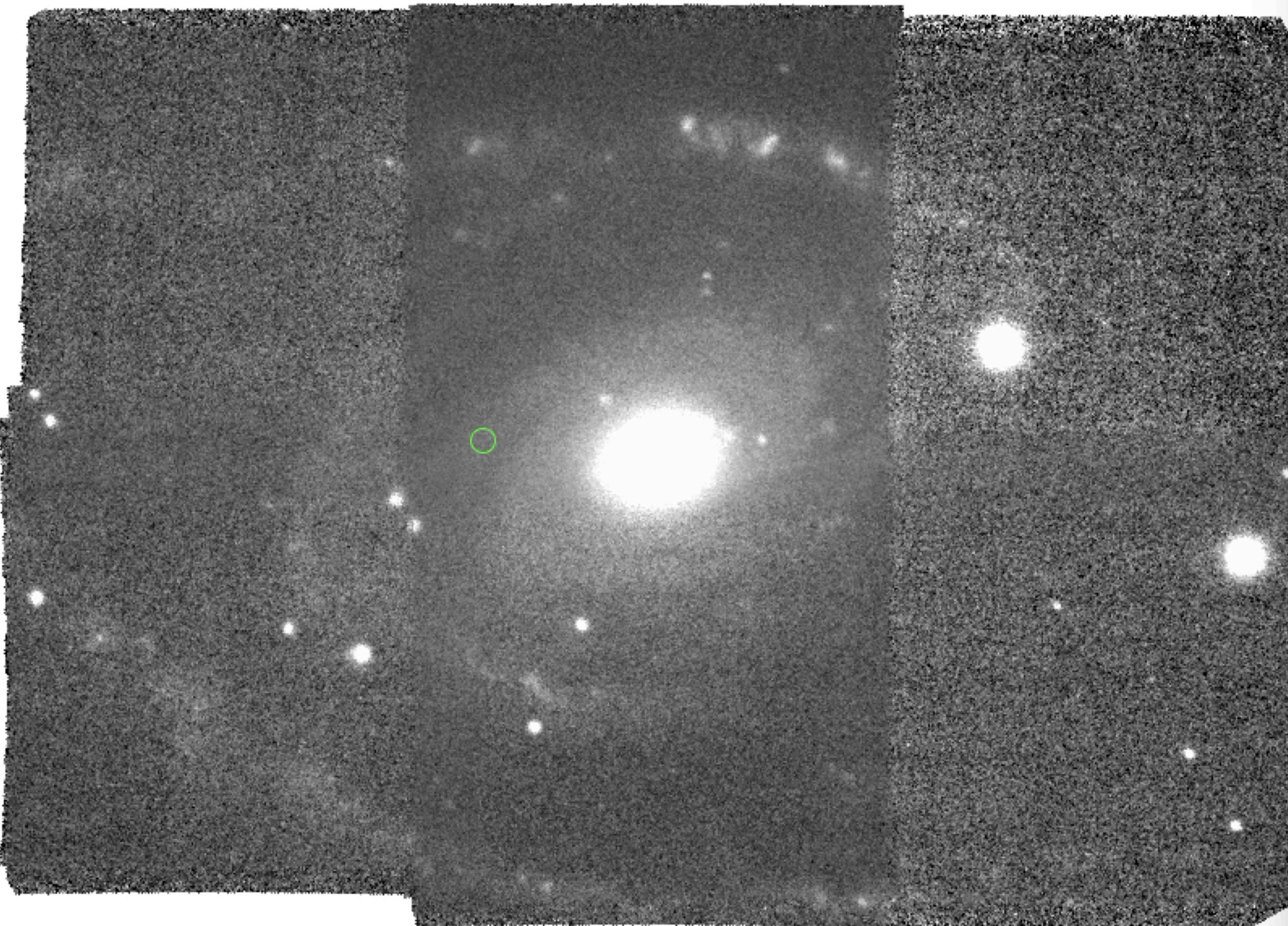
MUSE example

6600 to 6670 Å (obs. frame) in steps of 1.25 Å

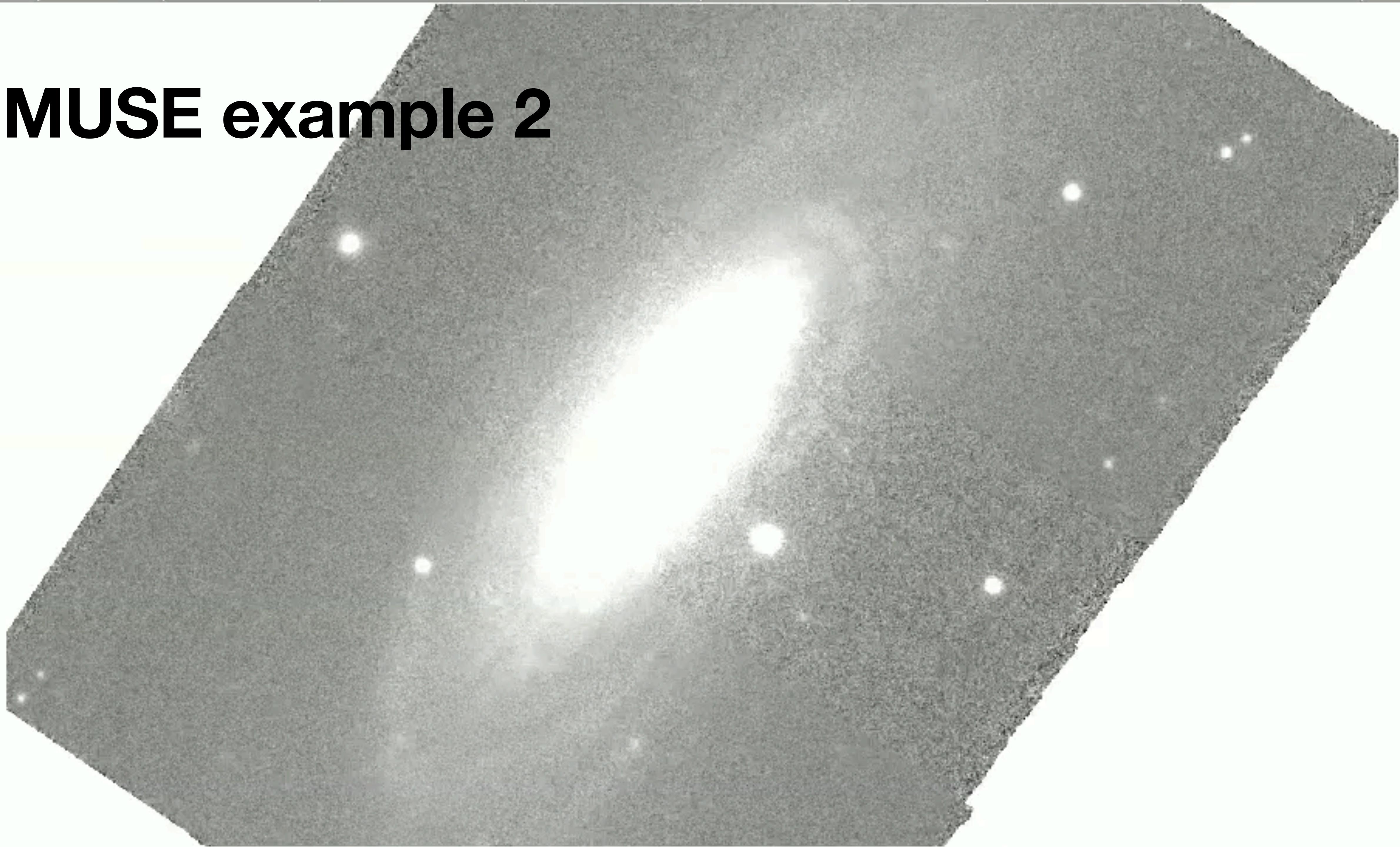


MUSE example

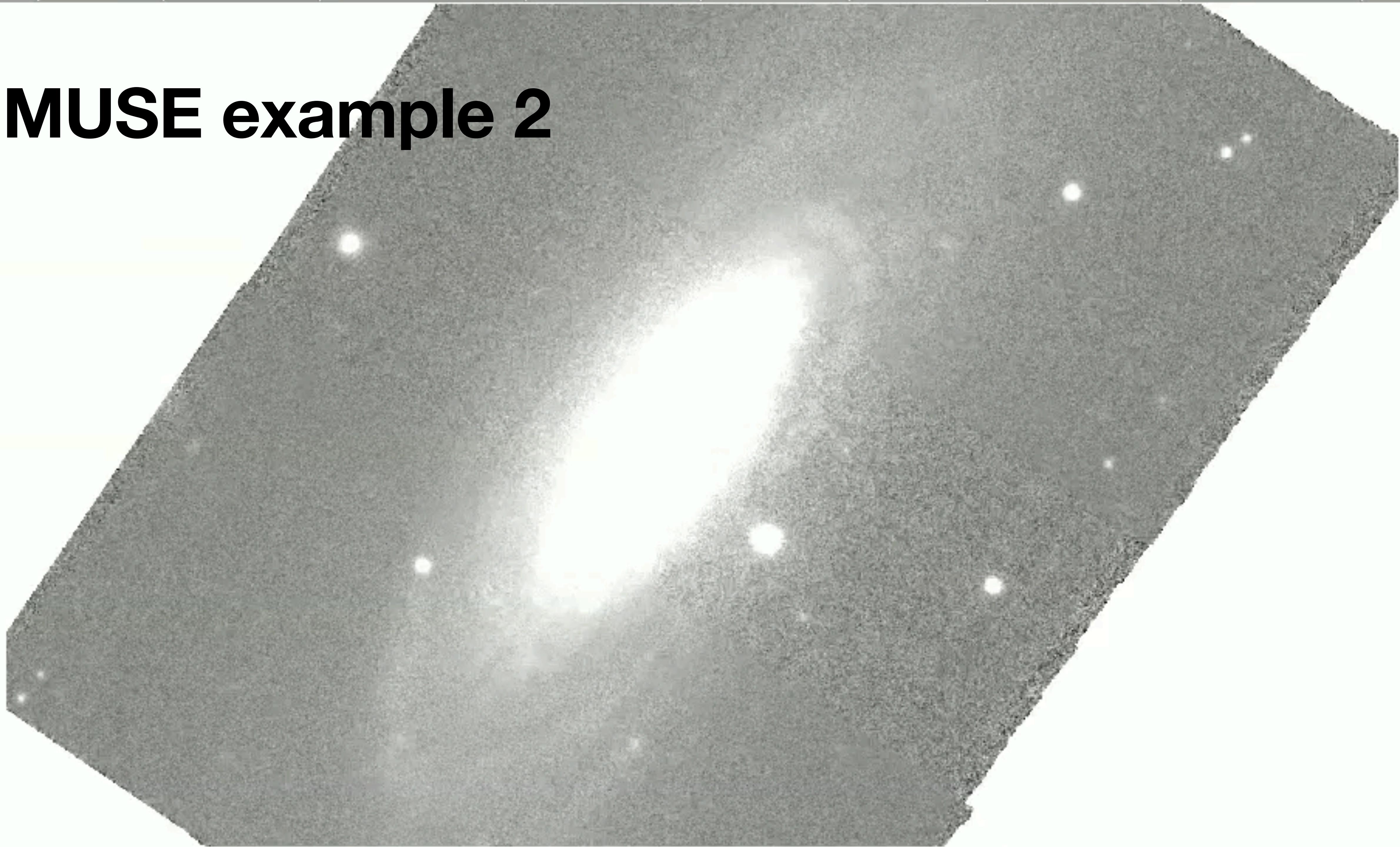
6600 to 6670 Å (obs. frame) in steps of 1.25 Å



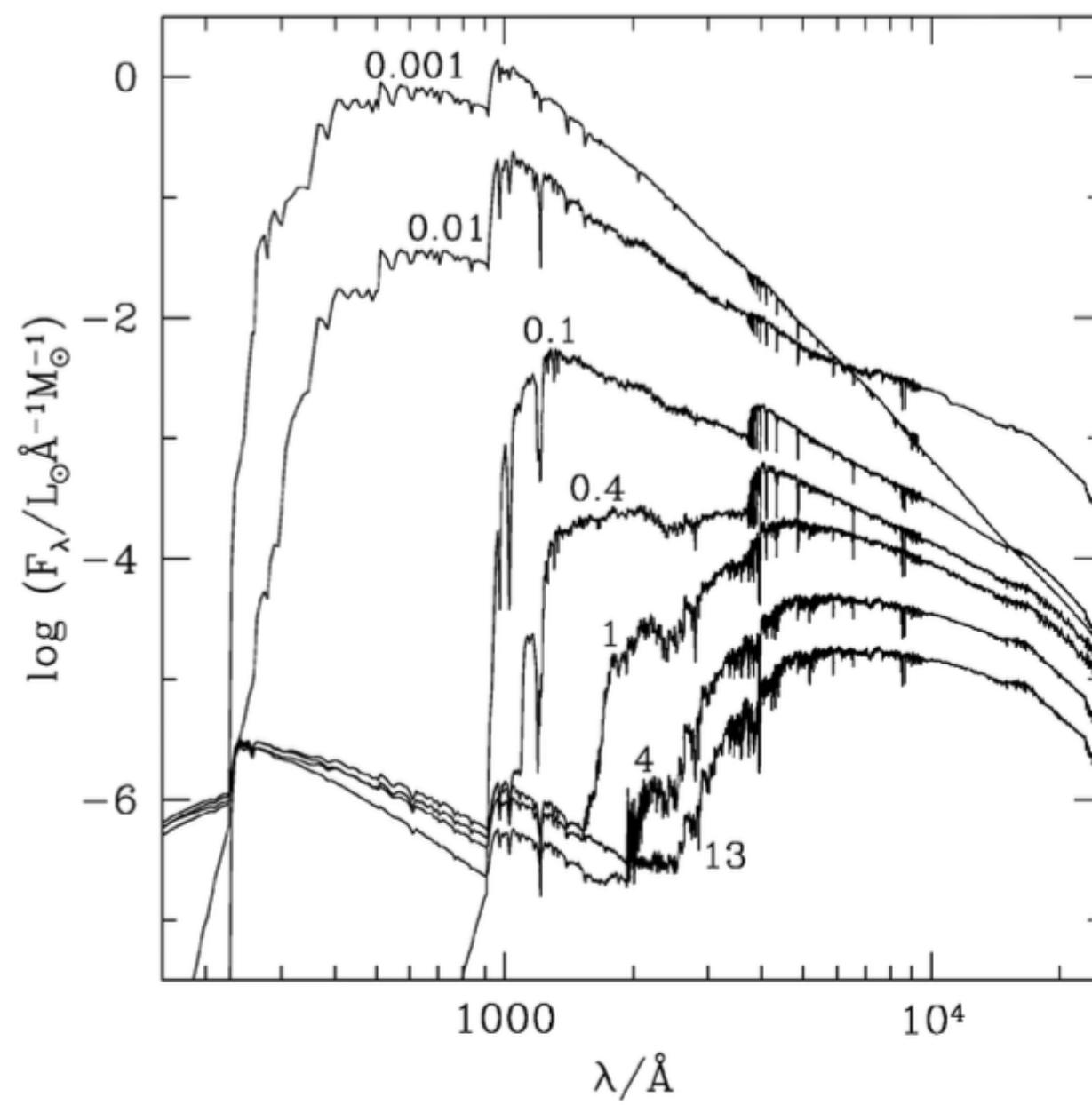
MUSE example 2



MUSE example 2



Analysis



1- fit to the continuum using a base of single stellar population (SSP) models and STARLIGHT: **Cid Fernandes+15**

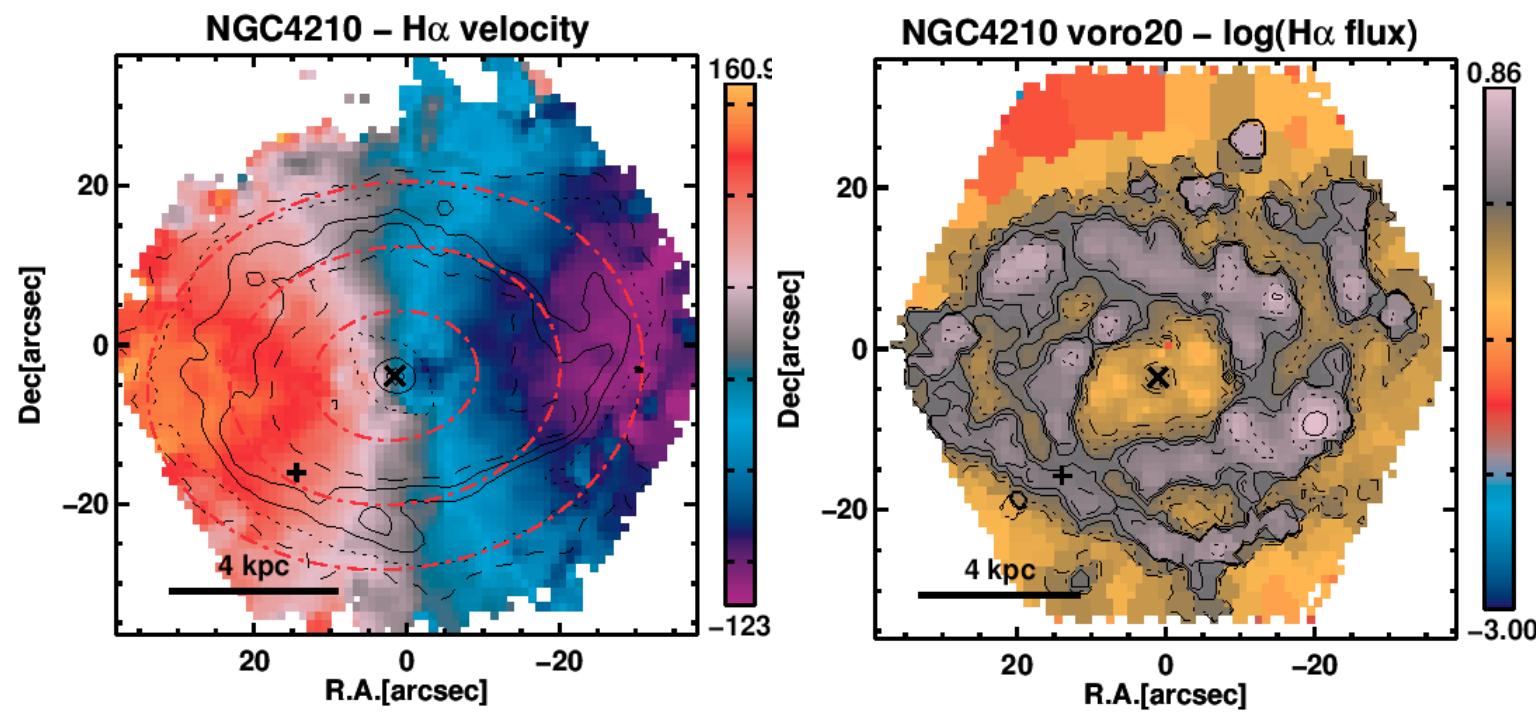
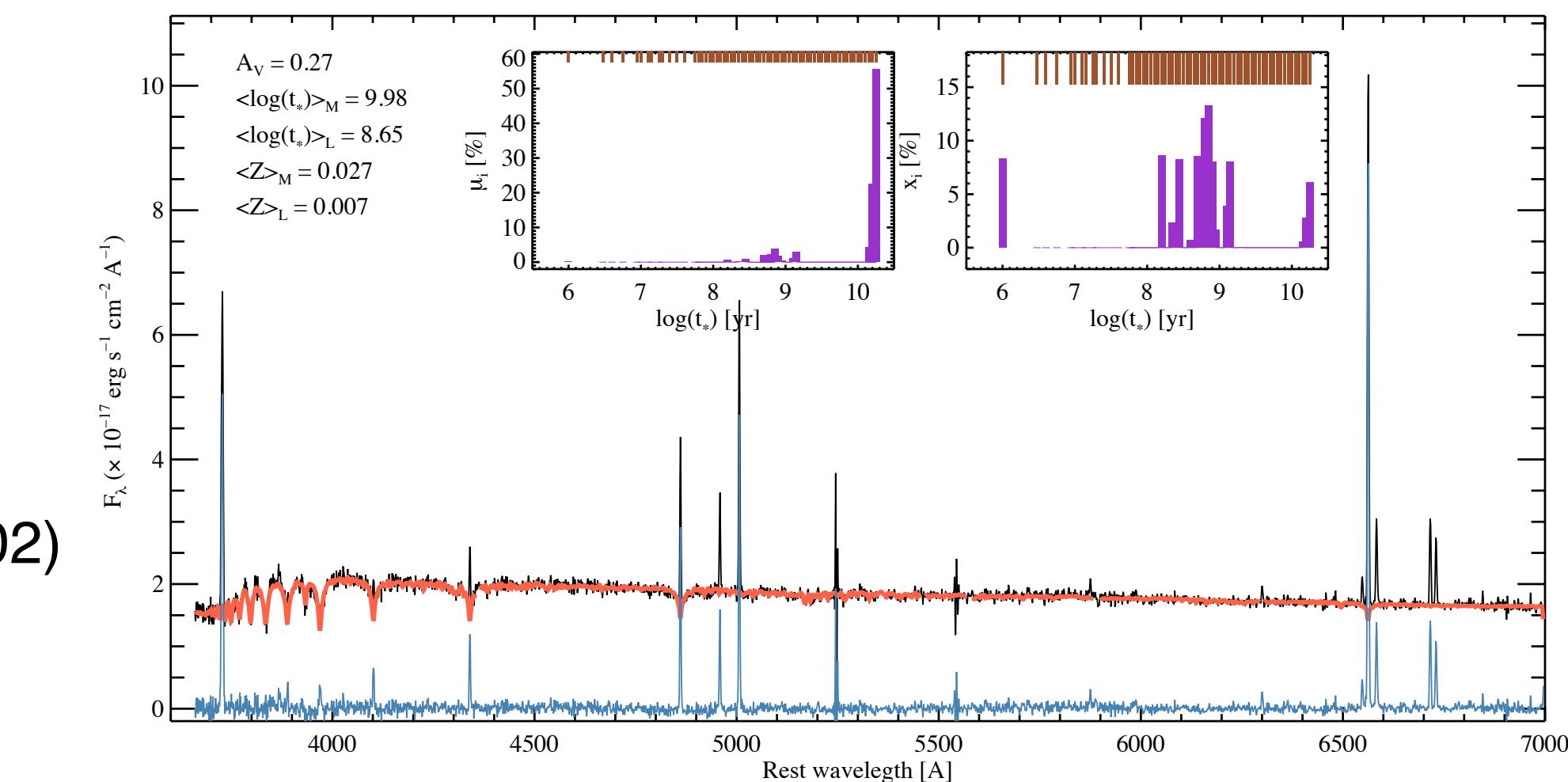
CB07:

17 Ages 10^6 to $1.8 \cdot 10^{10} M_\odot$

4 metallicities 0.004, 0.05, 0.2, 2.5 Z_\odot ($Z_\odot = 0.02$)

S/N window: [4580:4640] Å

Fit range: [3660:7000] Å



2- construct strong line emission maps by fitting gaussians to the pure emission spectra

[O II]	$\lambda 3727$	[Ne I]	$\lambda 4931$	[O I]	$\lambda 6364$
[Ne III]	$\lambda 3868$	[O III]	$\lambda 4959$	[N II]	$\lambda 6548$
H ϵ	$\lambda 3970$	[O III]	$\lambda 5007$	H α	$\lambda 6563$
H δ	$\lambda 4102$	[O I]	$\lambda 5577$	[N II]	$\lambda 6583$
H γ	$\lambda 4340$	[He I]	$\lambda 5875$	[S II]	$\lambda 6716$
[O III]	$\lambda 4363$	[O I]	$\lambda 6300$	[S II]	$\lambda 6731$
H β	$\lambda 4861$	[S III]	$\lambda 6312$		

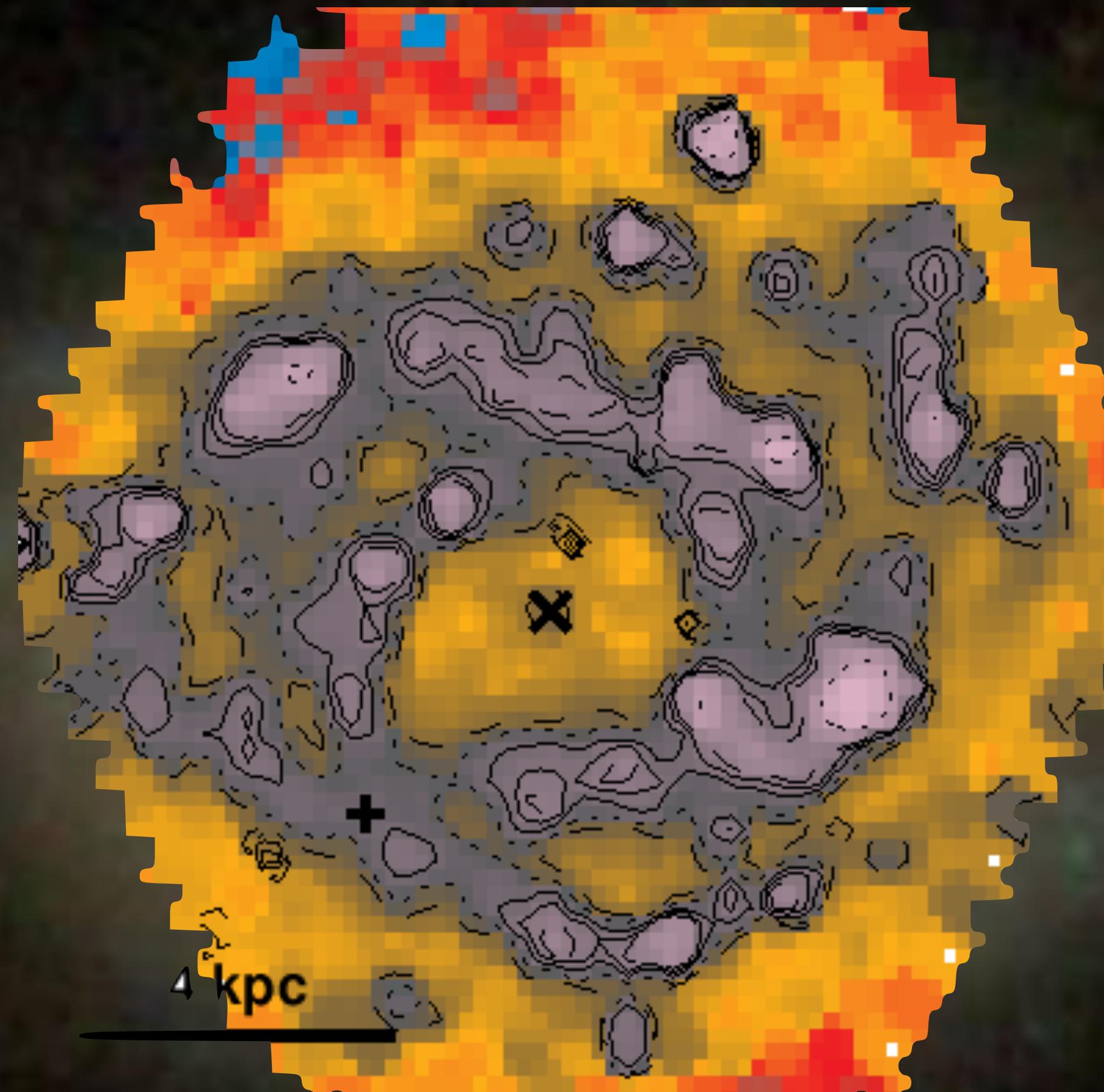
PMAS



NGC 4210

PMAS

$F_{\text{H}\alpha}$

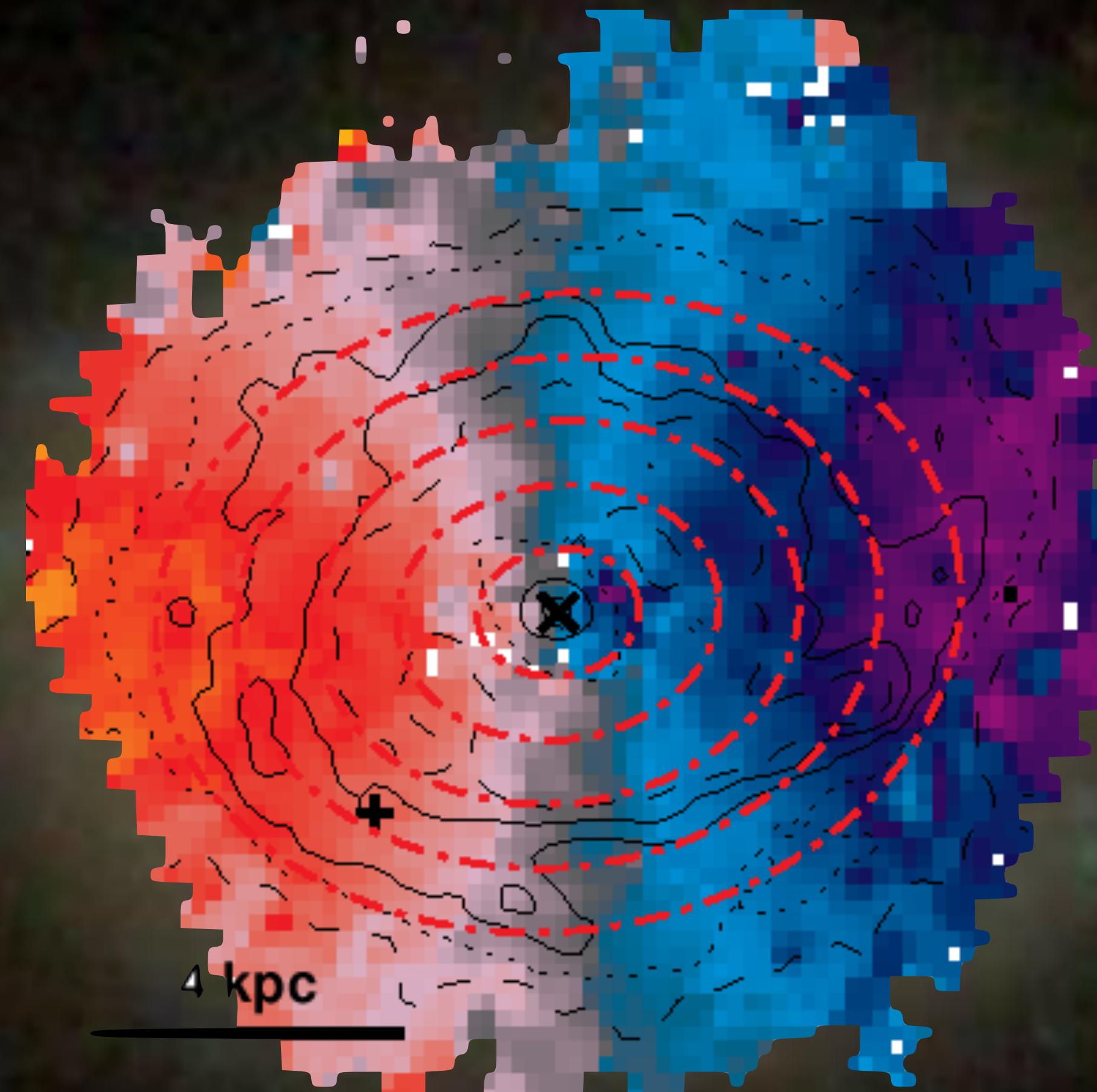


NGC 4210

PMAS

$F_{\text{H}\alpha}$

$V_{\text{H}\alpha}$



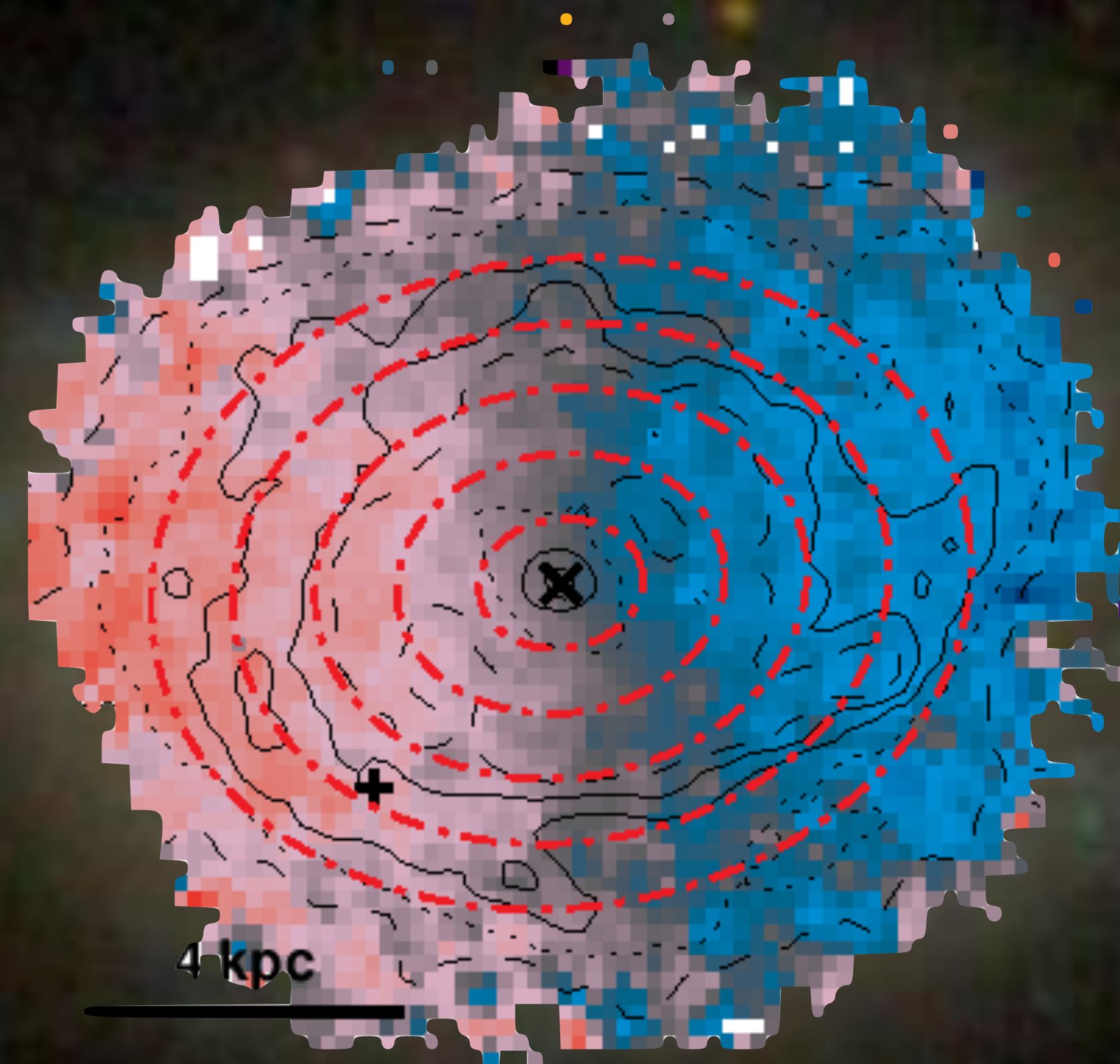
NGC 4210

PMAS

$F_{\text{H}\alpha}$

$V_{\text{H}\alpha}$

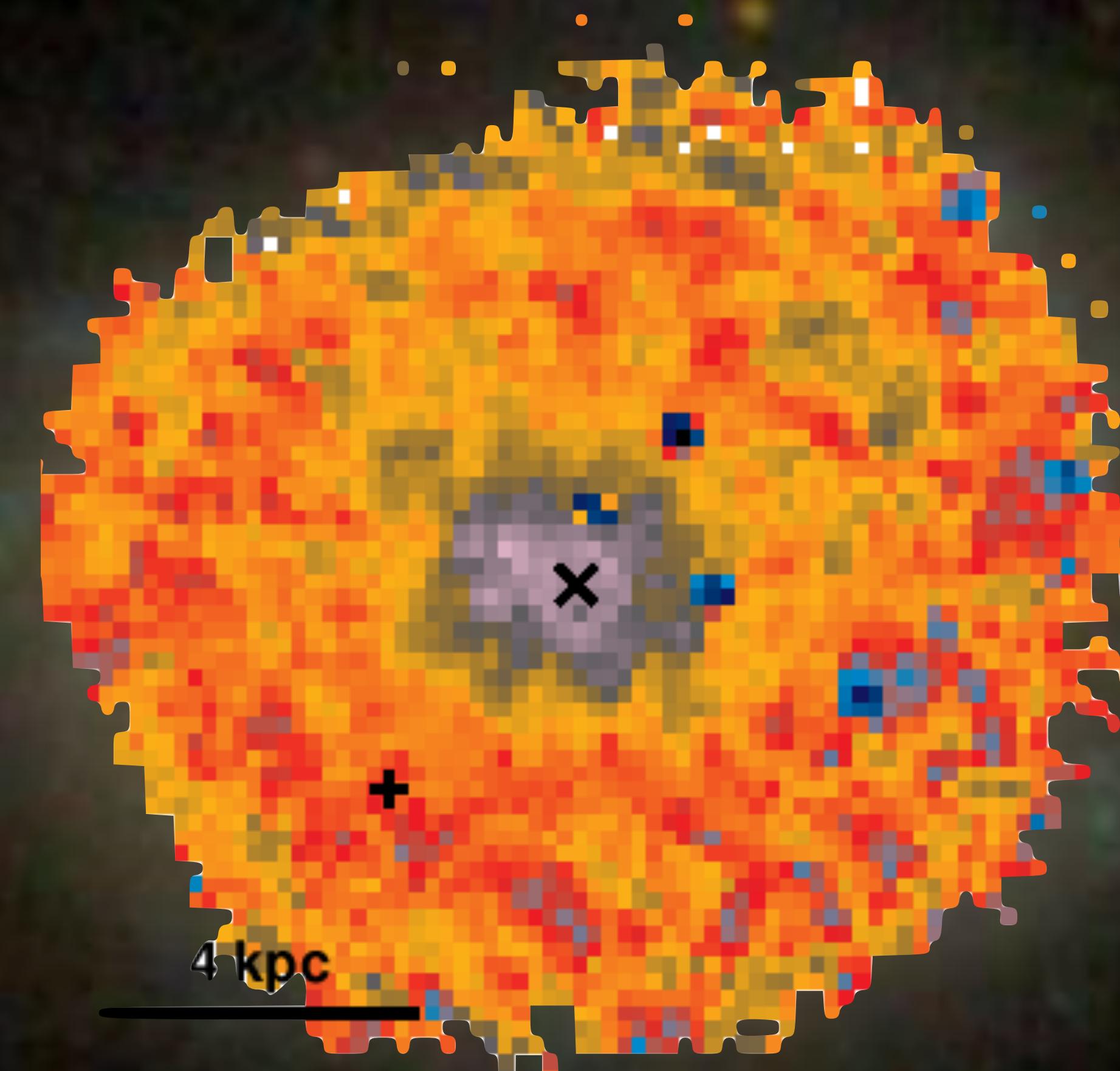
V^*



NGC 4210

PMAS

$F_{\text{H}\alpha}$
 $V_{\text{H}\alpha}$
 V^*
 $\langle t^* \rangle$



NGC 4210

PMAS

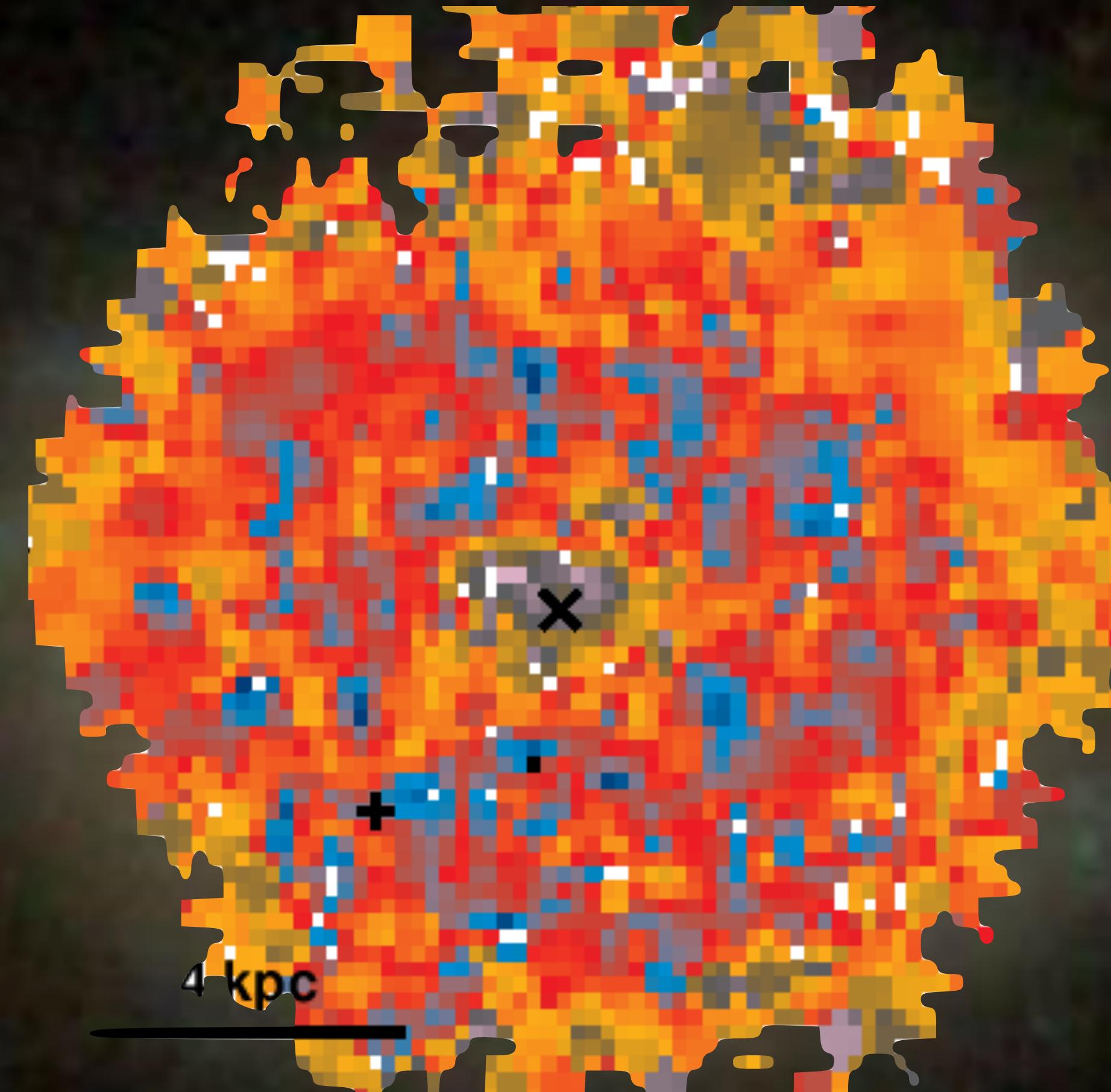
$F_{\text{H}\alpha}$

$V_{\text{H}\alpha}$

V^*

$\langle t^* \rangle$

OIII/Hb



NGC 4210

PMAS

$F_{\text{H}\alpha}$

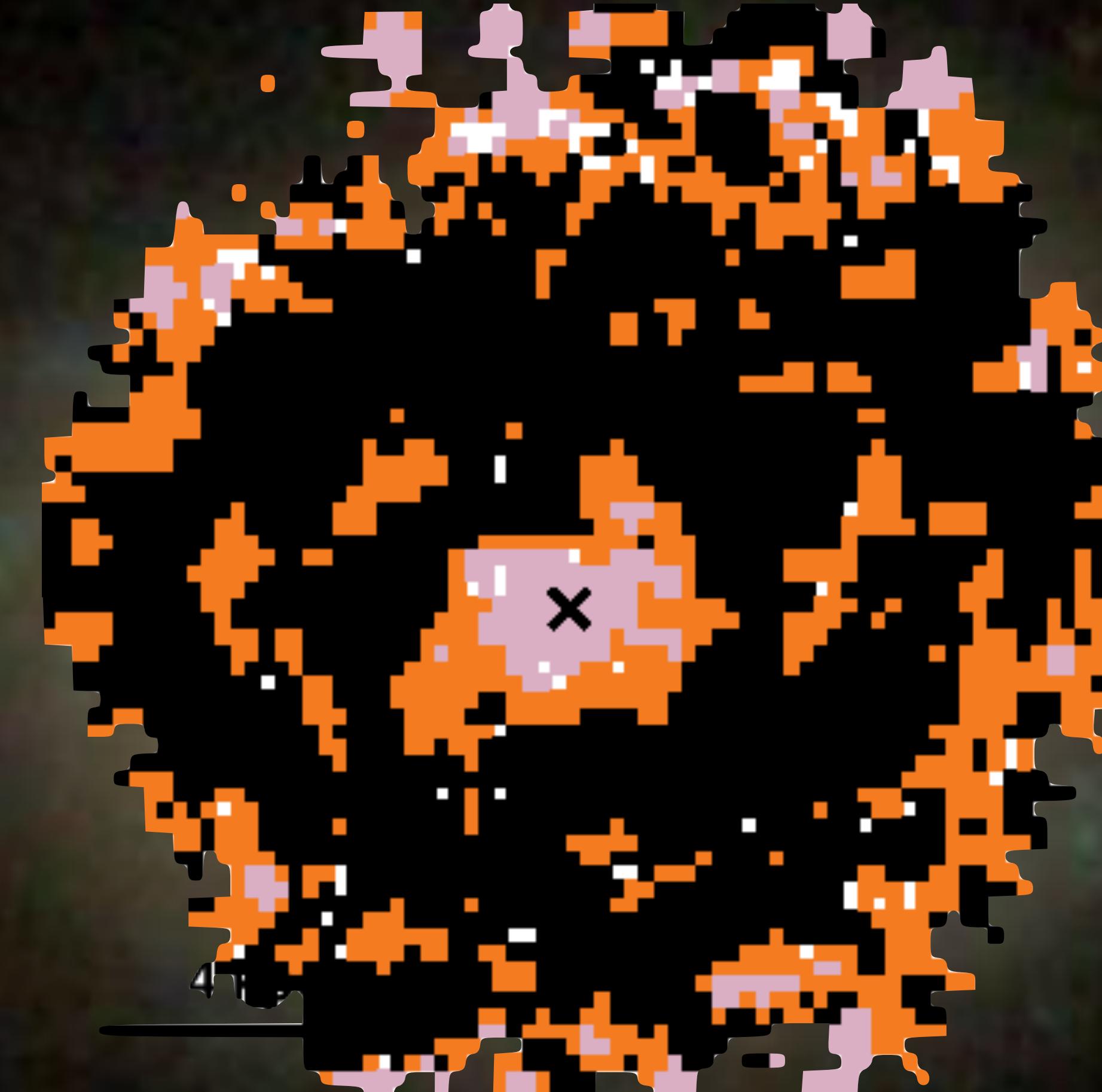
$V_{\text{H}\alpha}$

V^*

$\langle t^* \rangle$

OIII/H β

BPT



NGC 4210

PMAS

$F_{\text{H}\alpha}$

$V_{\text{H}\alpha}$

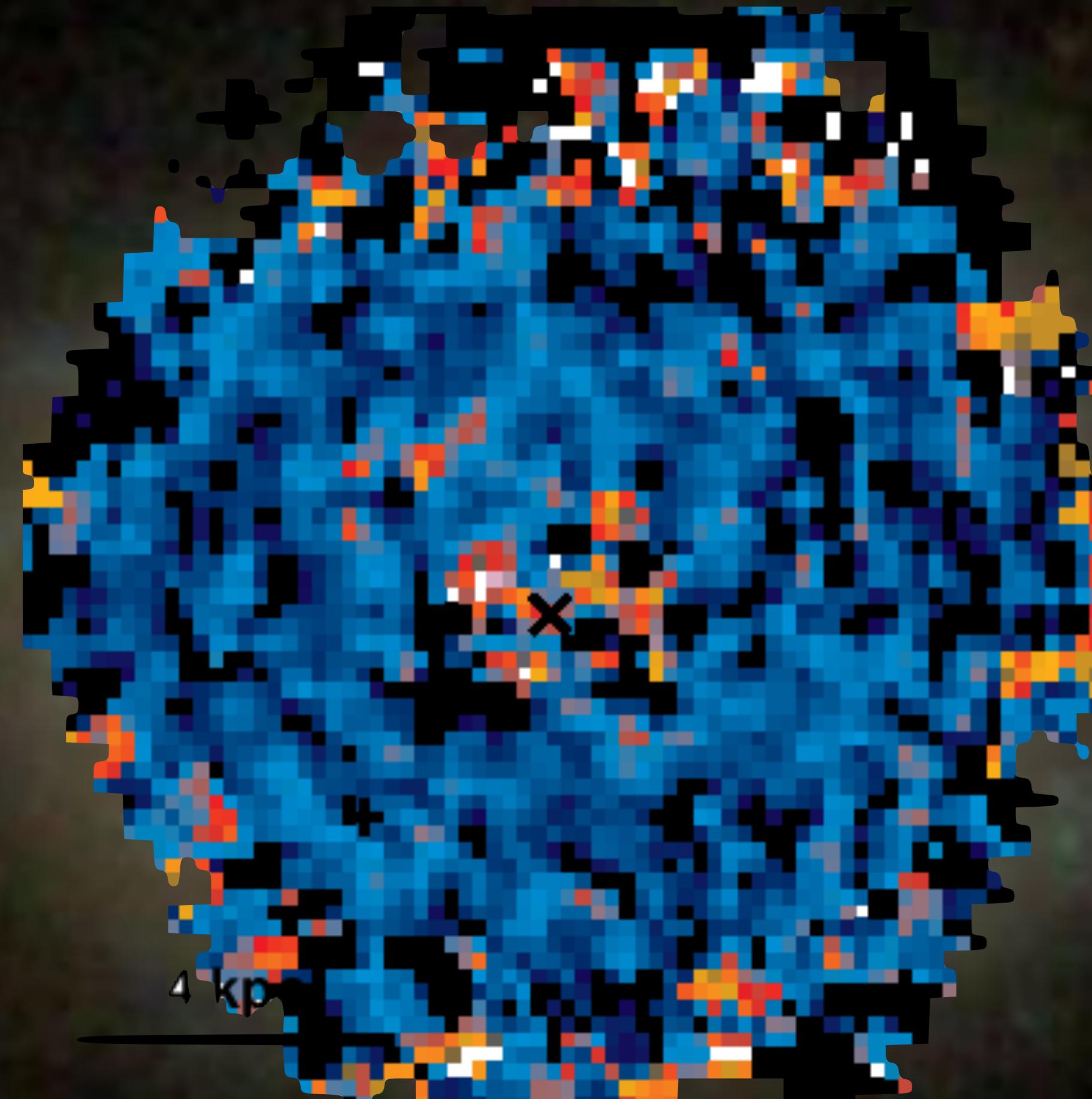
V^*

$\langle t^* \rangle$

OIII/Hb

BPT

A_V



NGC 4210

PMAS

$F_{\text{H}\alpha}$

$V_{\text{H}\alpha}$

V^*

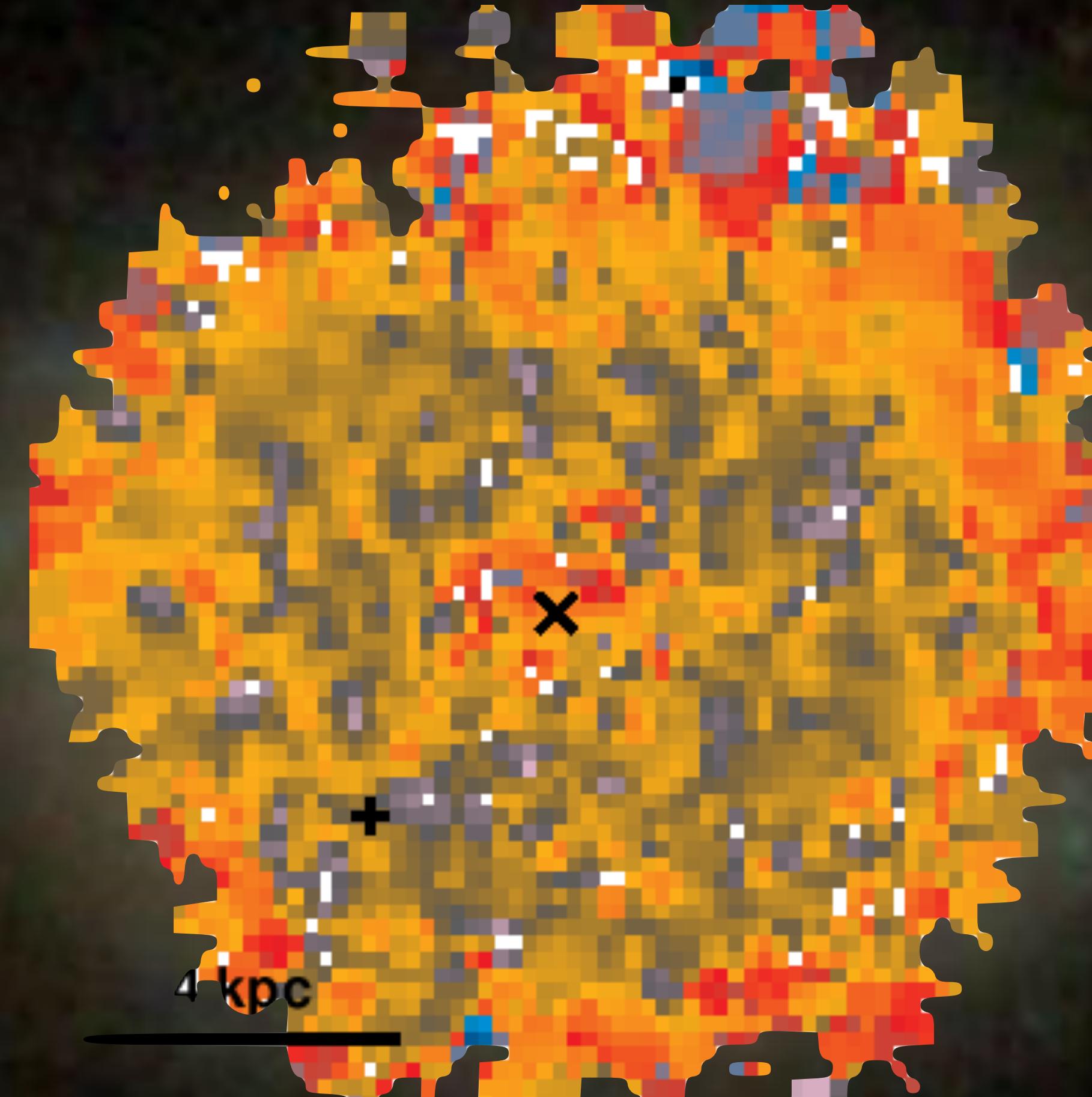
$\langle t^* \rangle$

OIII/Hb

BPT

A_V

O/H



NGC 4210

PMAS

$F_{\text{H}\alpha}$

$V_{\text{H}\alpha}$

V^*

$\langle t^* \rangle$

OIII/H β

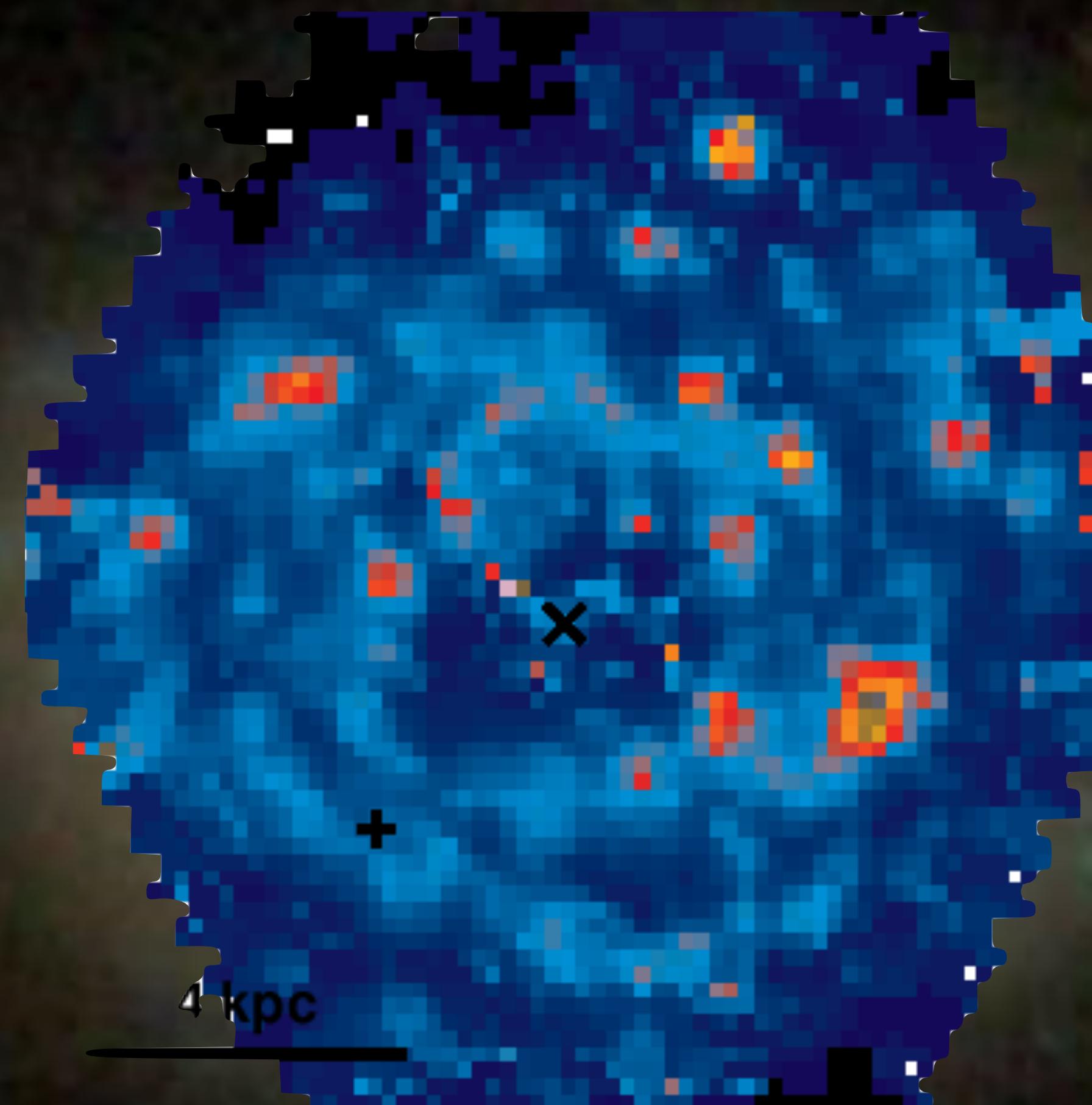
BPT

A_V

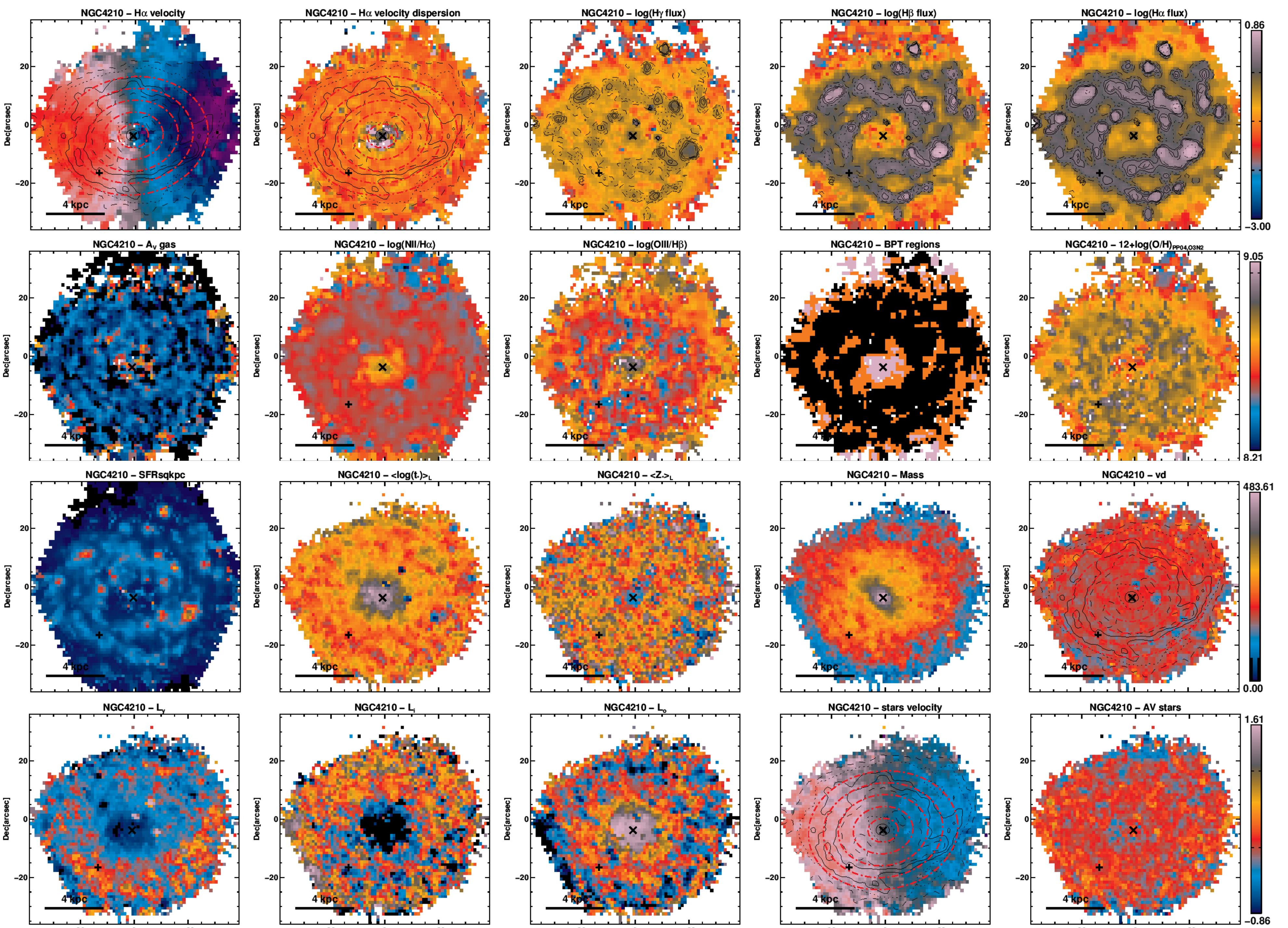
O/H

ESFR

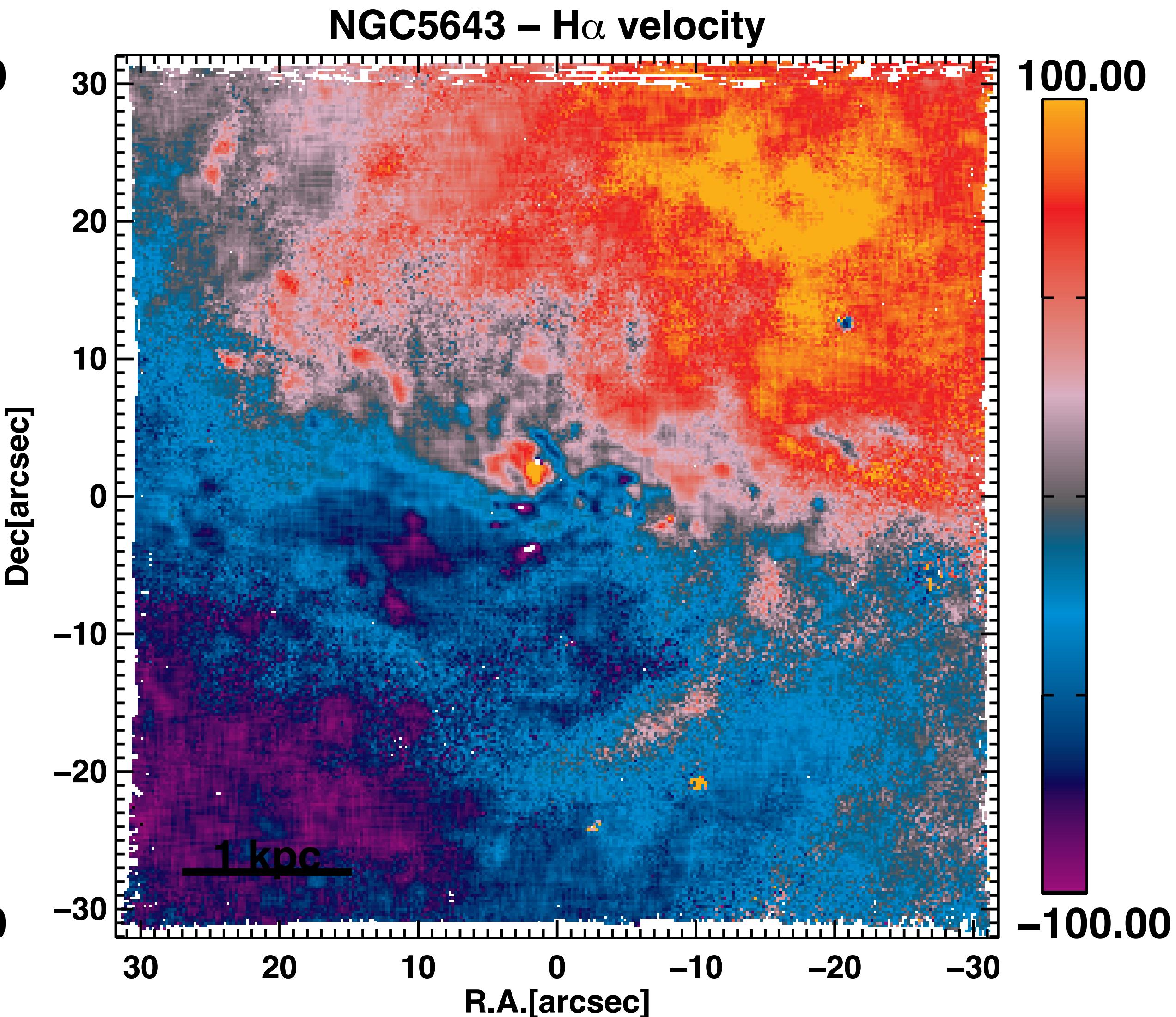
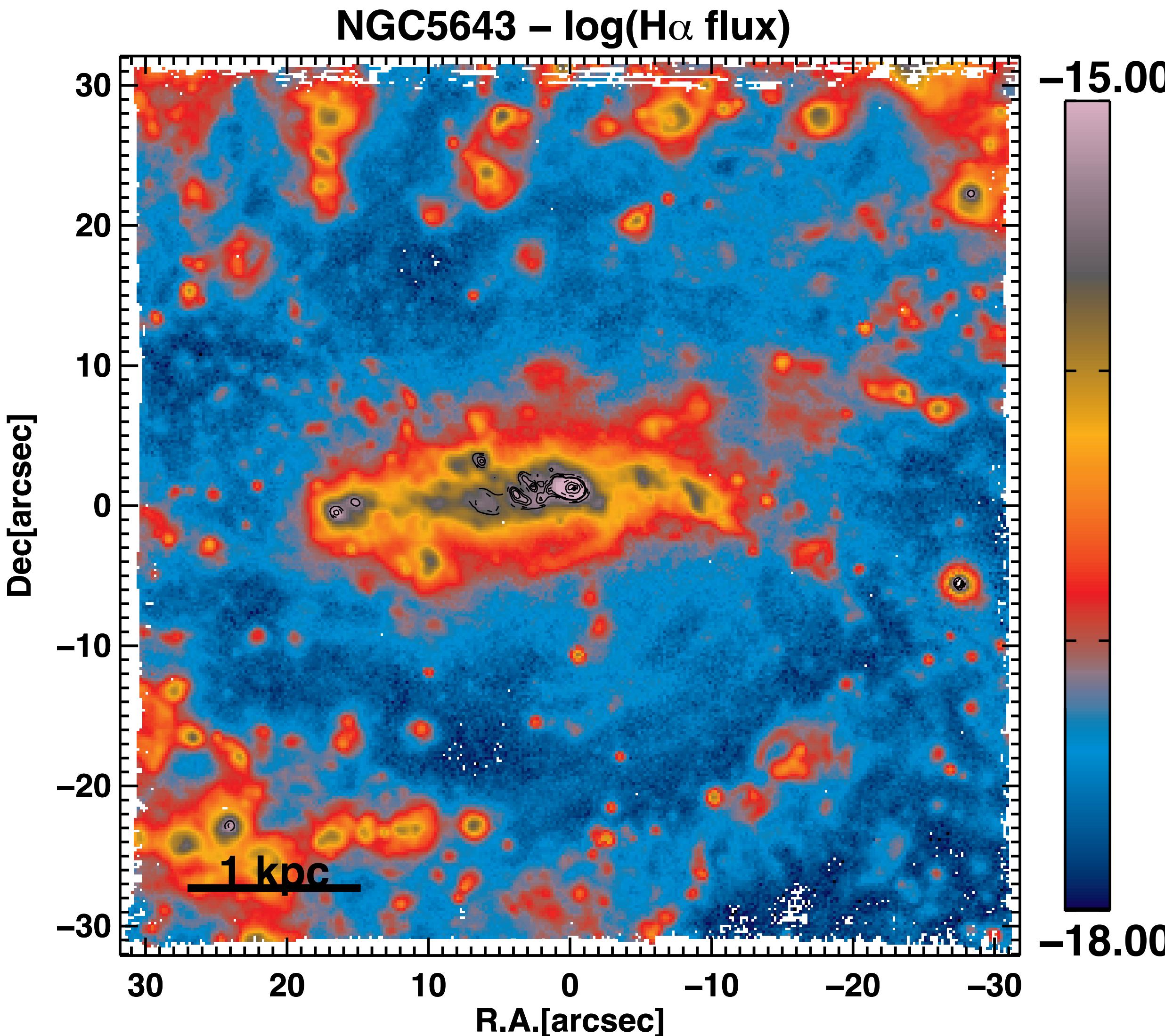
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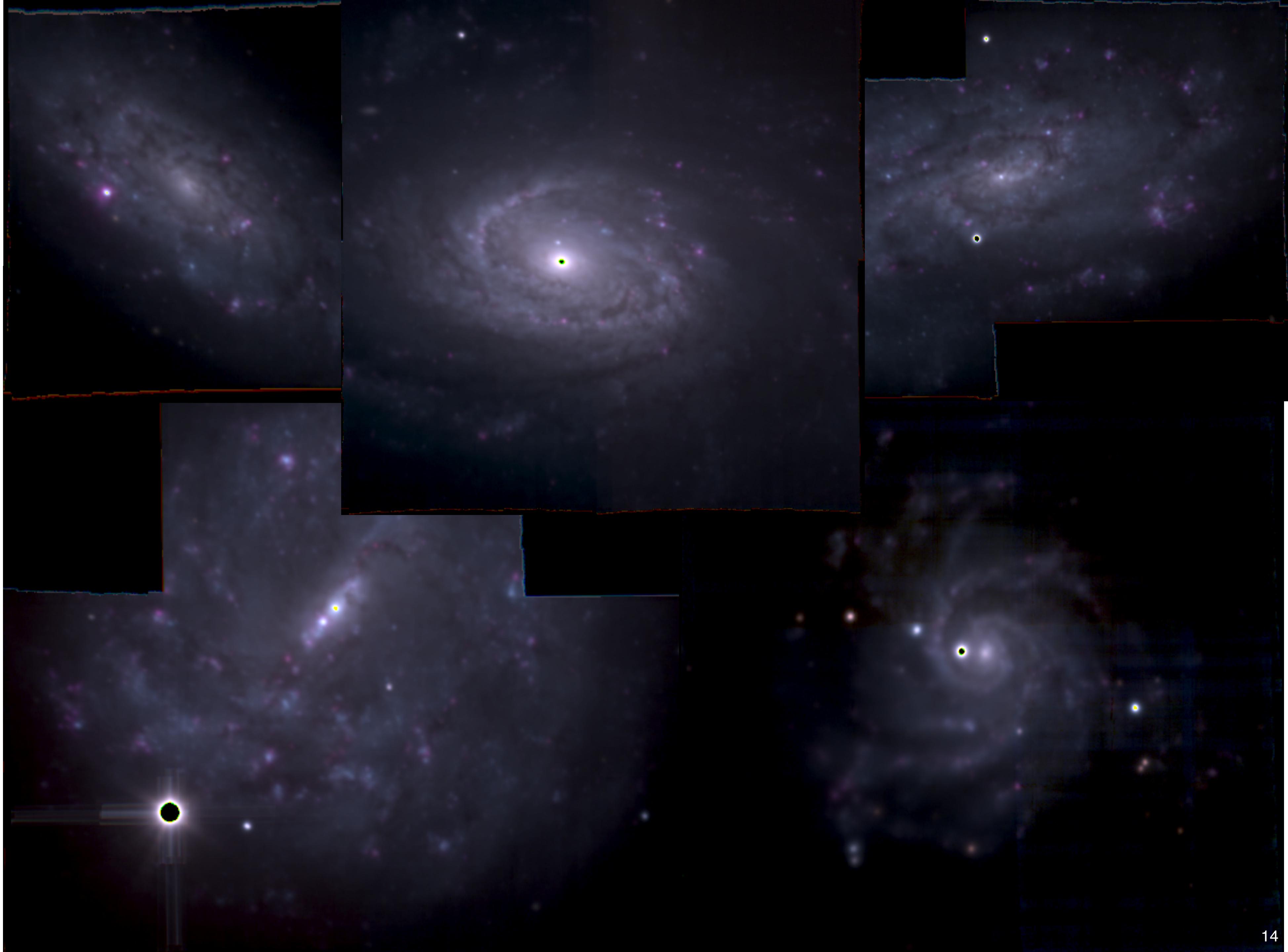


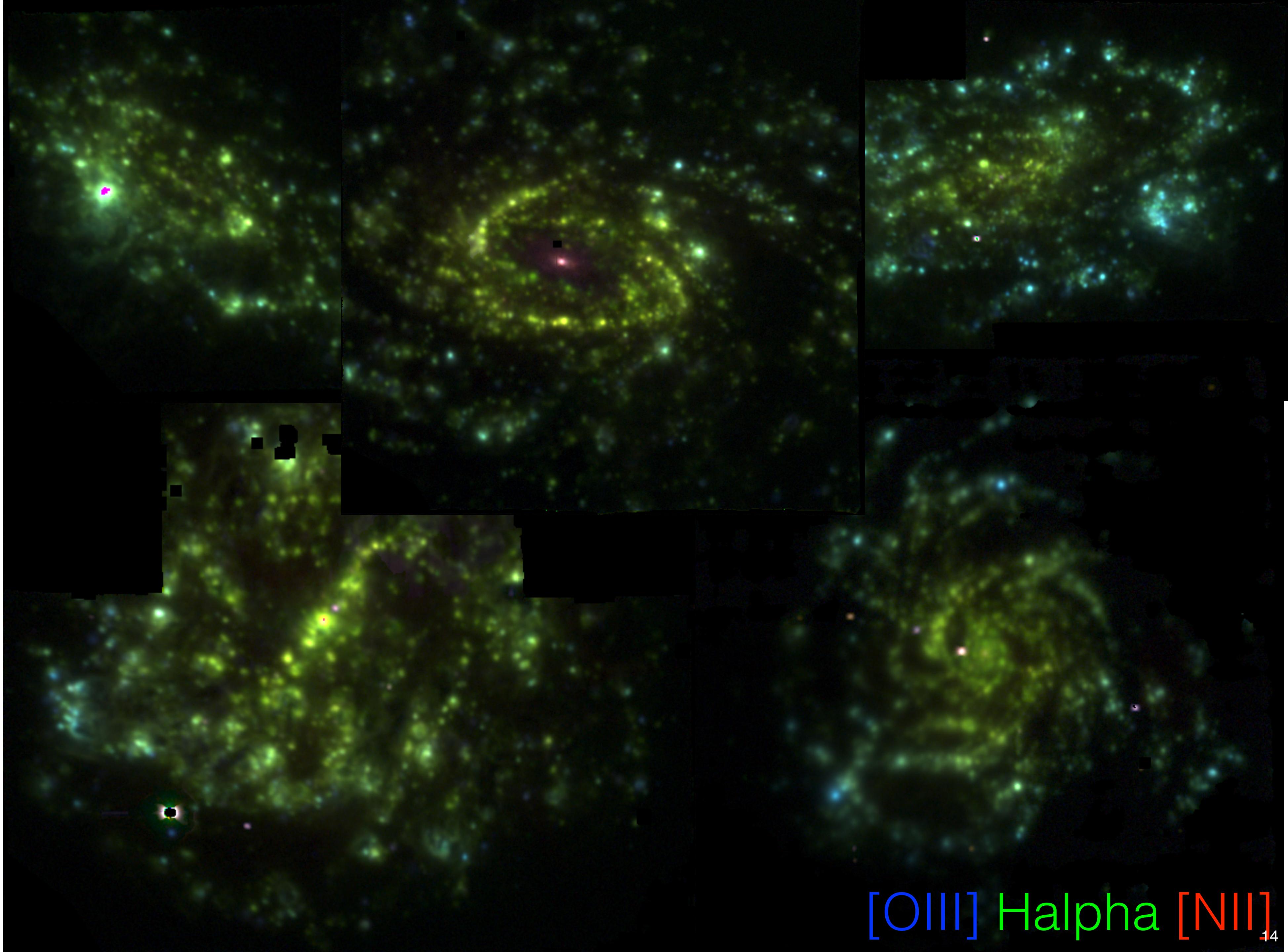
NGC 4210



...and MUSE







[OIII] Halpha [NII]

Do not say hostless, say:

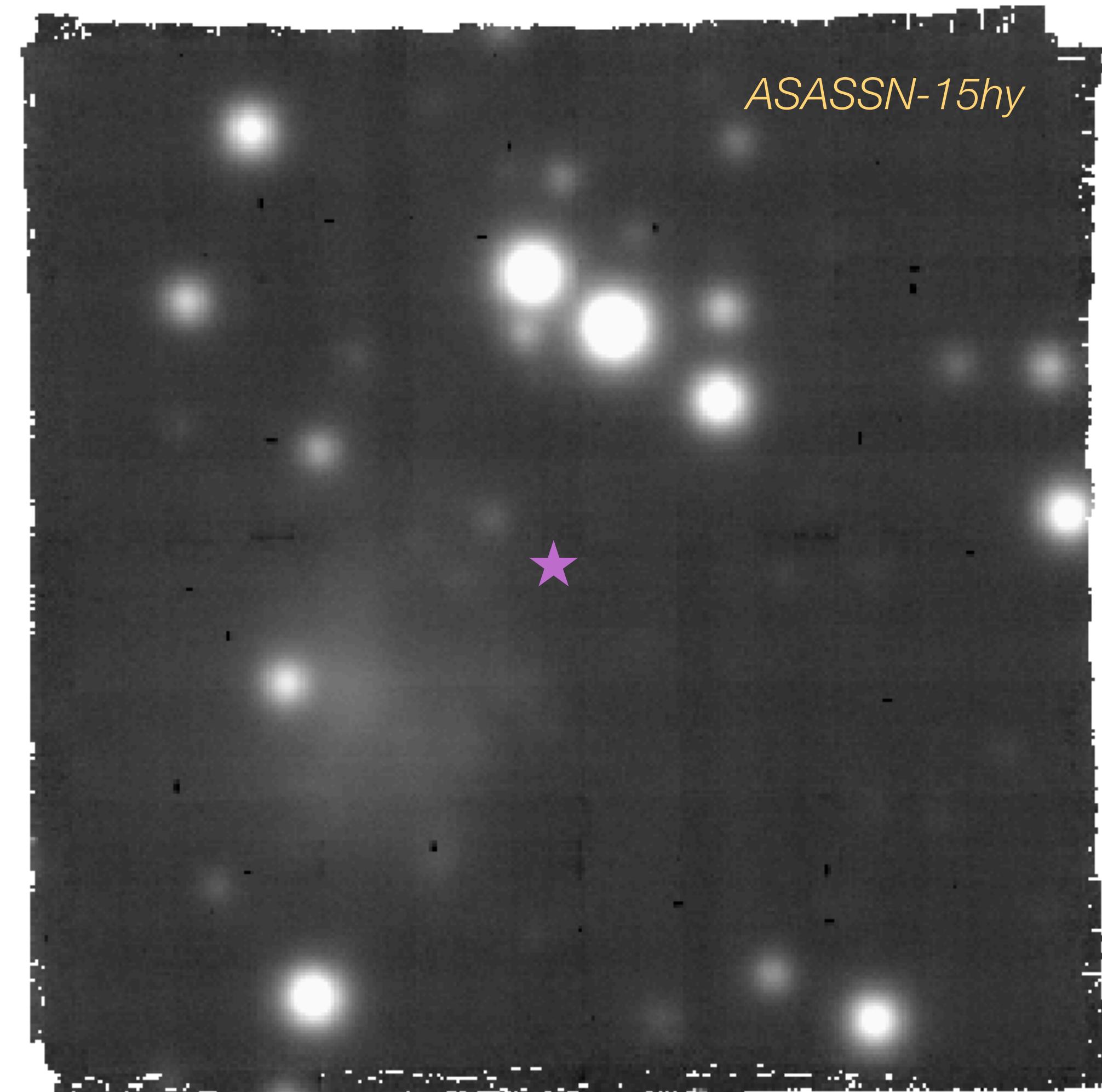
“my observations are not deep enough”

“the instrument is not sensitive enough”

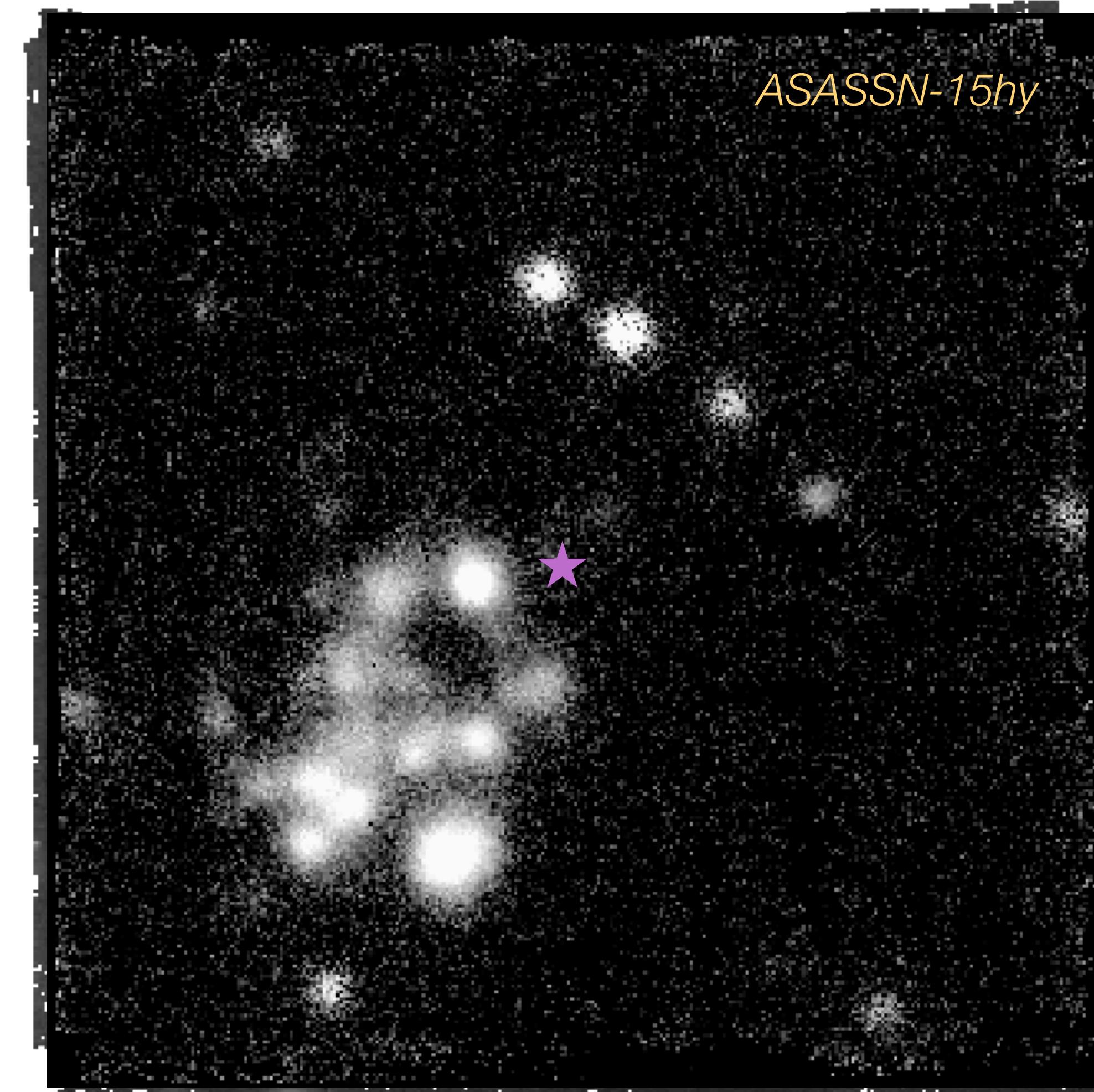
“I do not care, I just want to submit the paper”



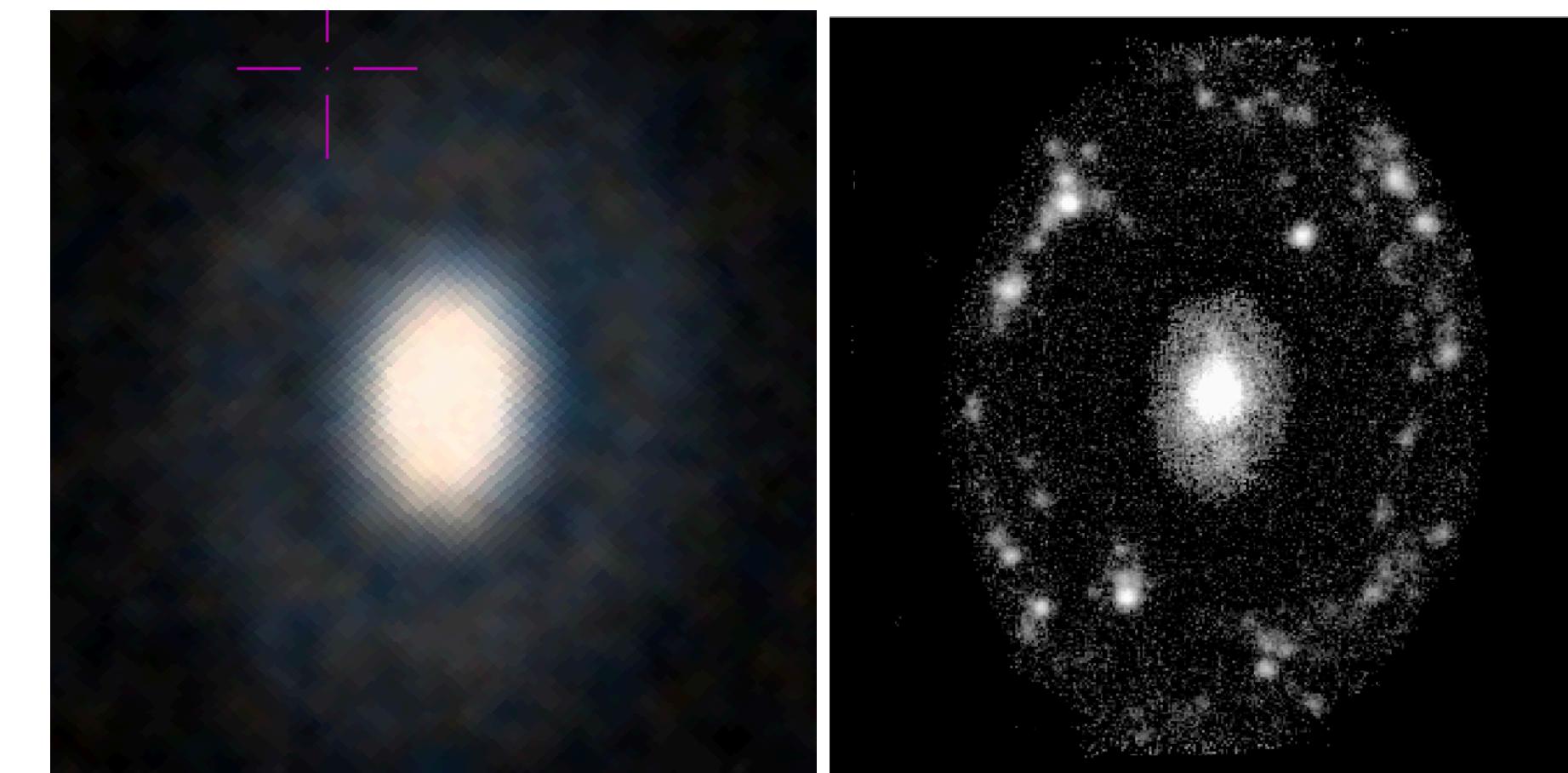
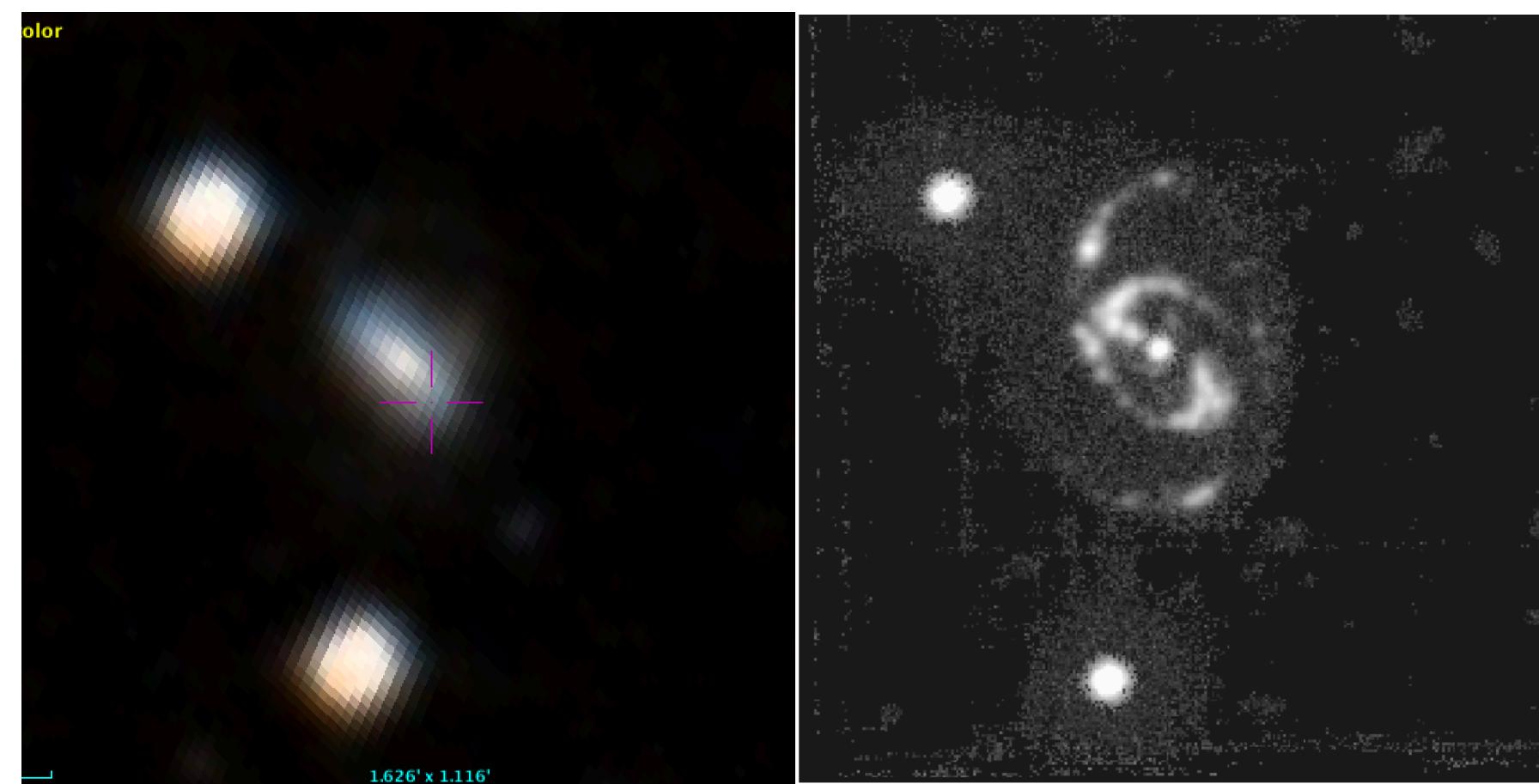
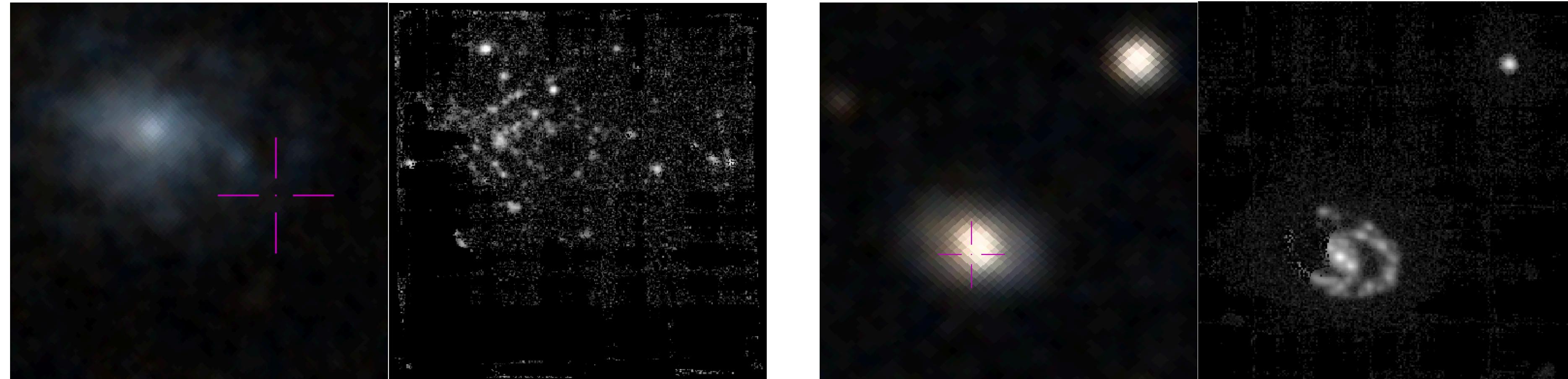
Do not say hostless, say: “my observations are not deep enough”
“the instrument is not sensitive enough”
“I do not care, I just want to submit the paper”



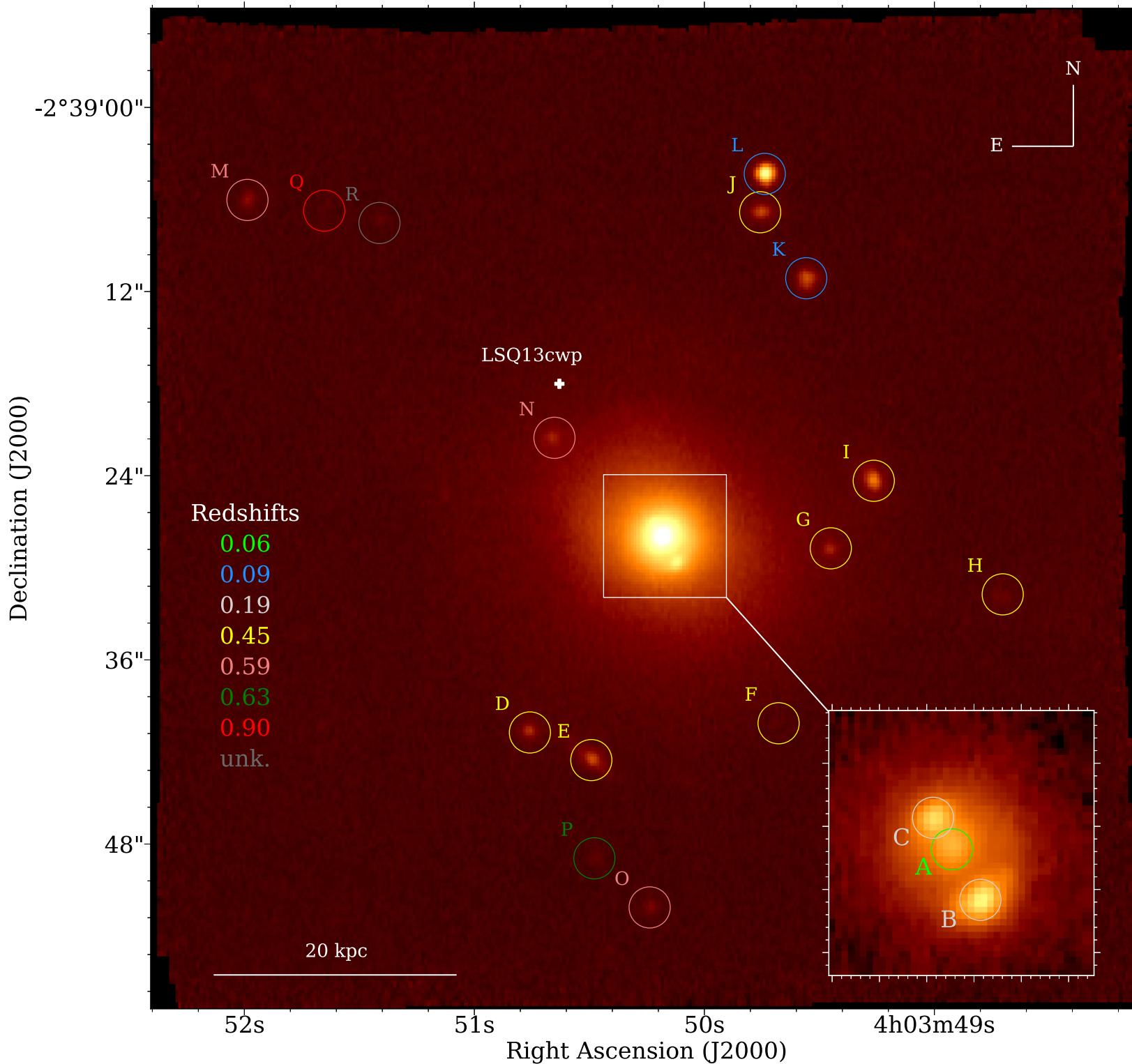
Do not say hostless, say: “my observations are not deep enough”
“the instrument is not sensitive enough”
“I do not care, I just want to submit the paper”



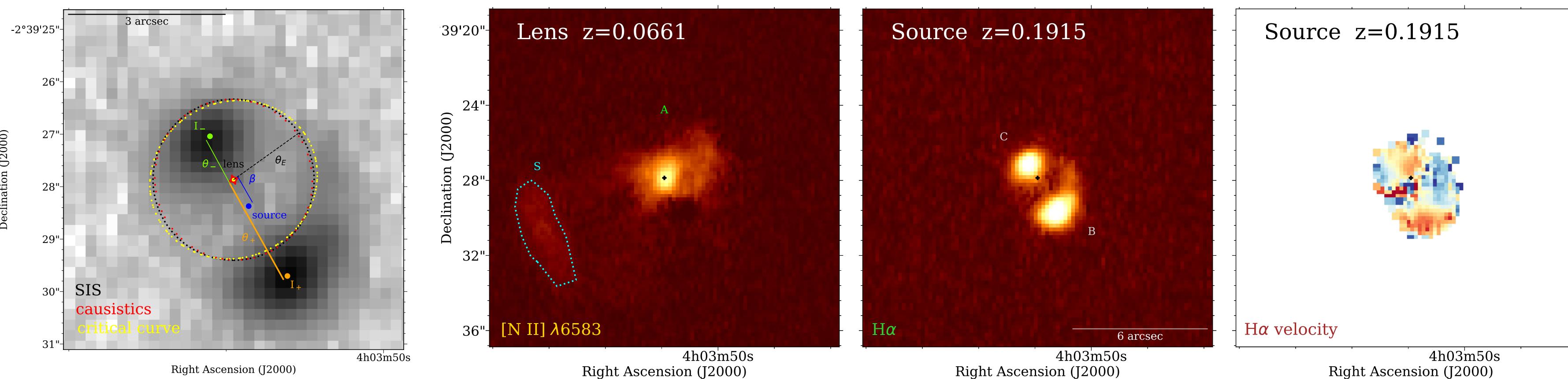
“I've seen things you people wouldn't believe“



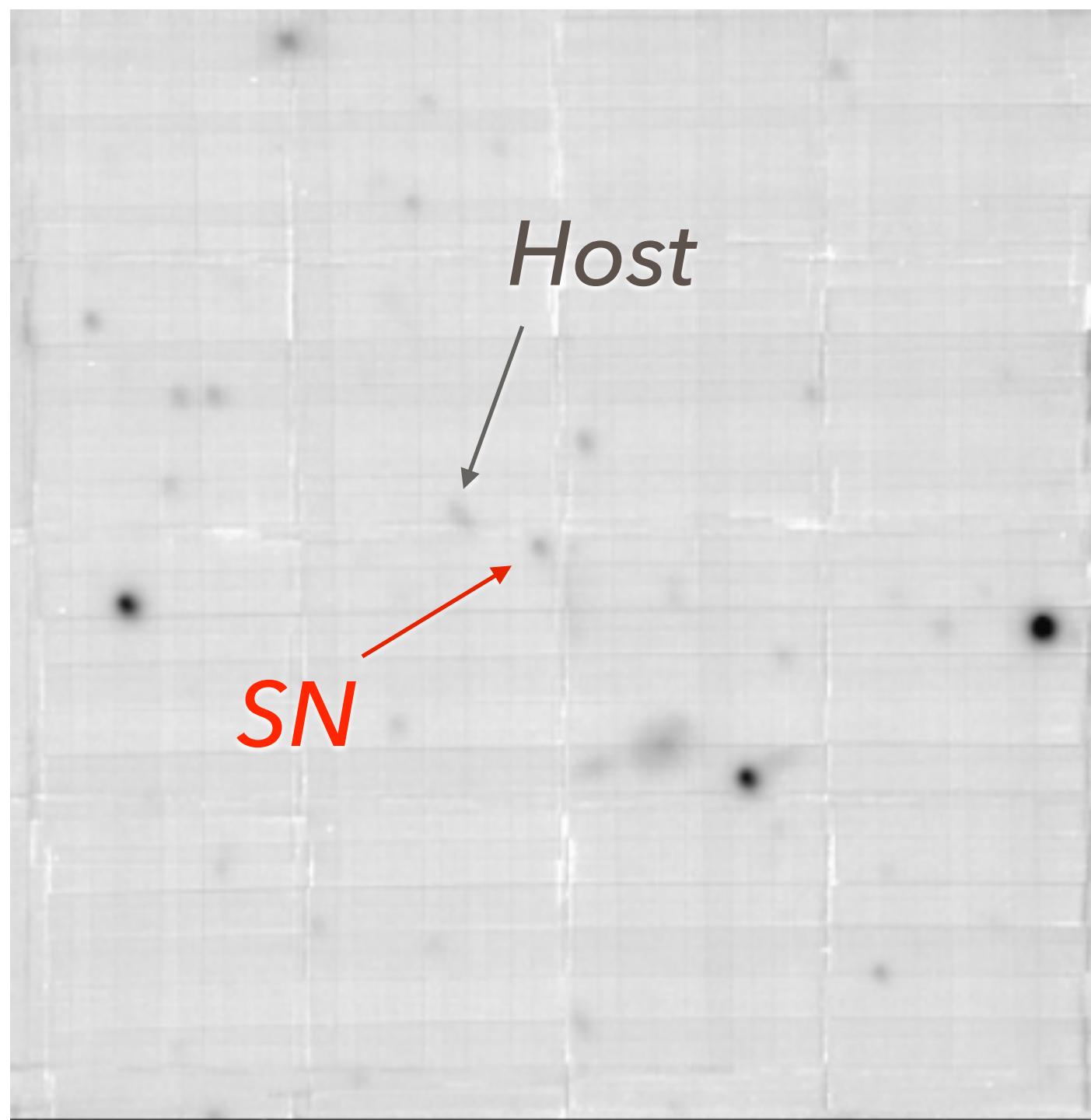
Discovery of a strong lensed galaxy in IFS data



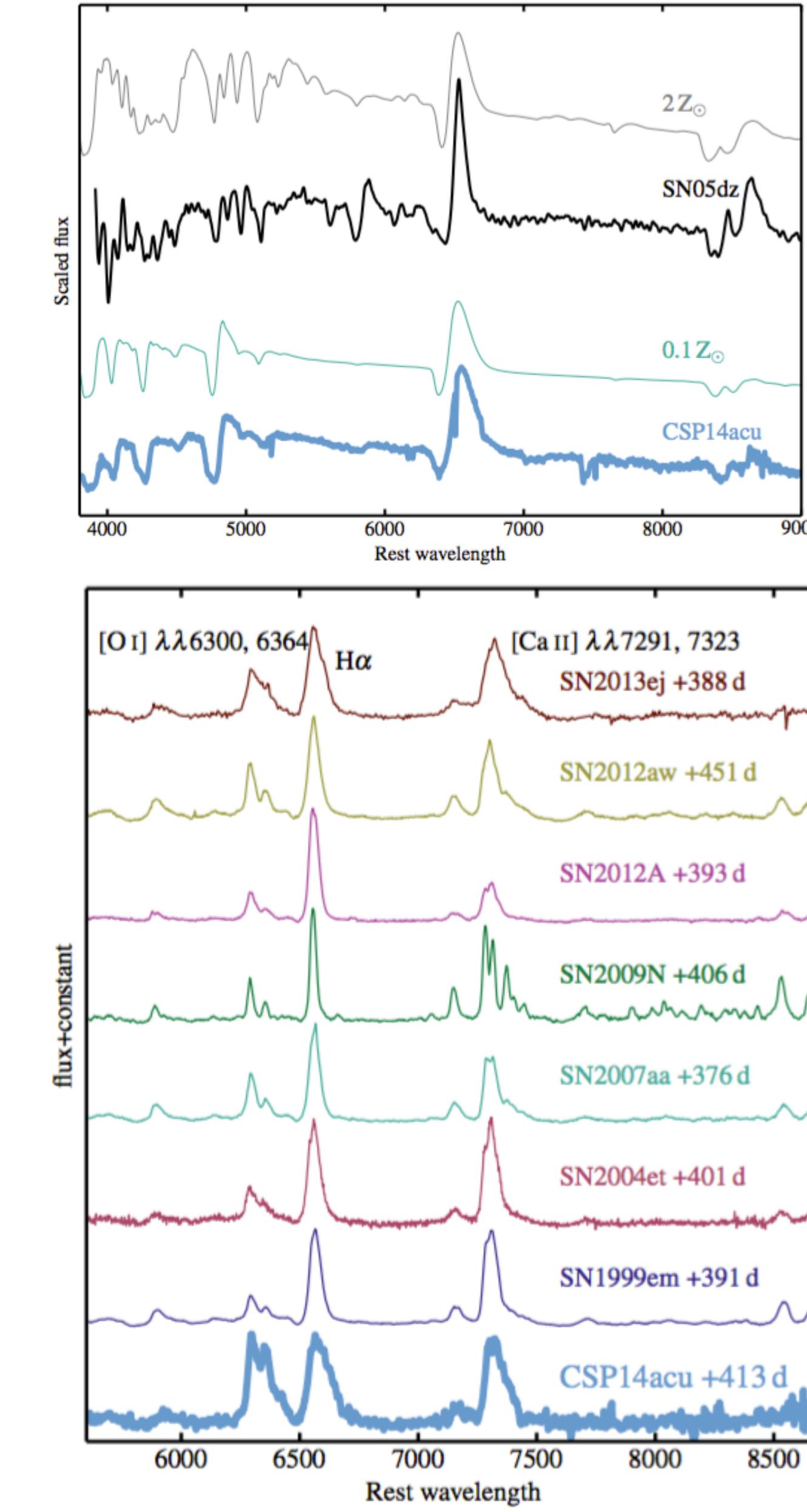
- Report the discovery of a background lensed galaxy at redshift 0.1915
- plus other 15 background galaxies at redshifts ranging from $z=0.09$ to 0.9
- Einstein radius of $1.45 \pm 0.04''$, which corresponds to 1.9 kpc
- dark matter fraction of $18 \pm 8\%$ within the Einstein radius.



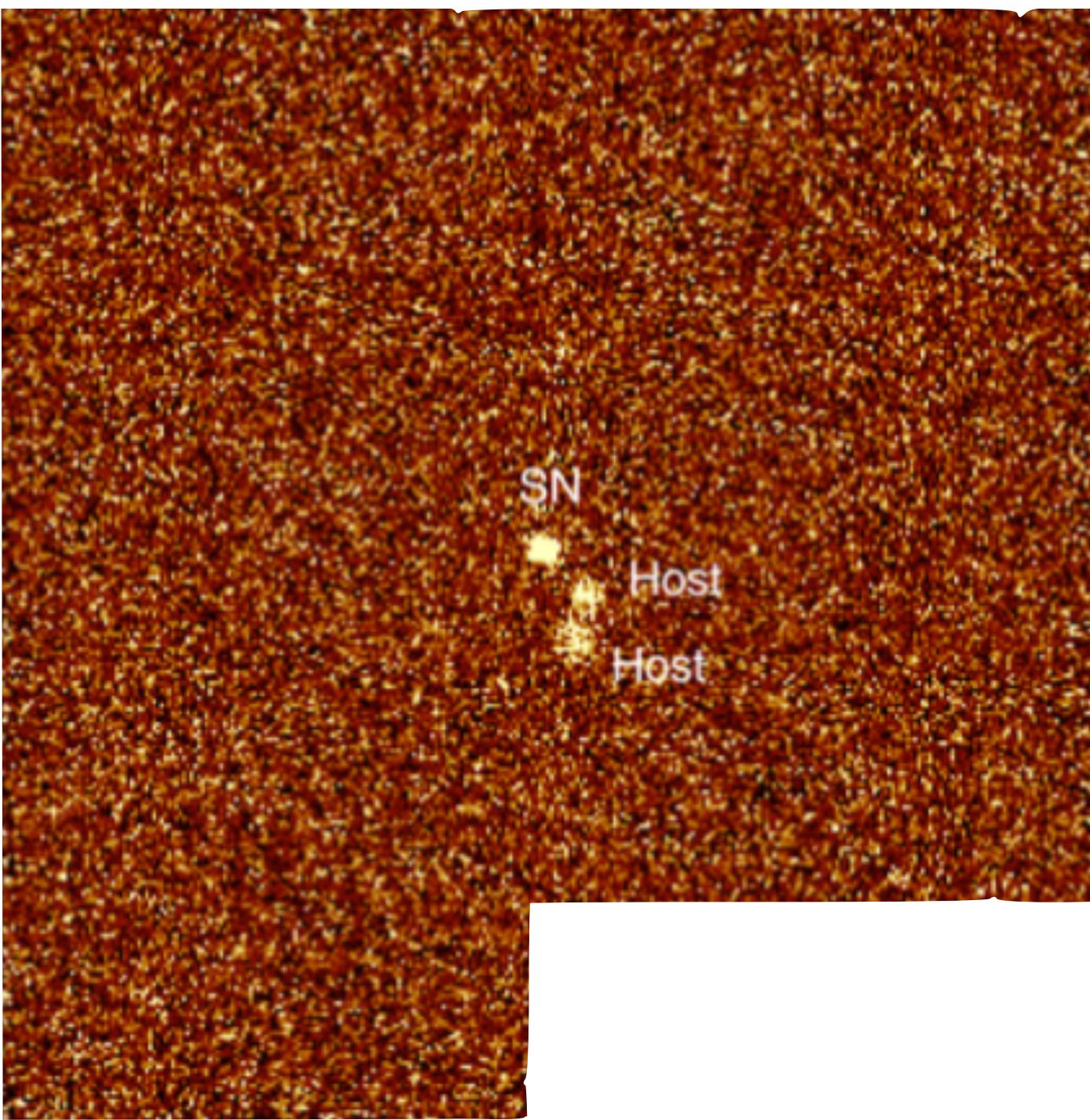
CSP14acu: high-M low-Z progenitor



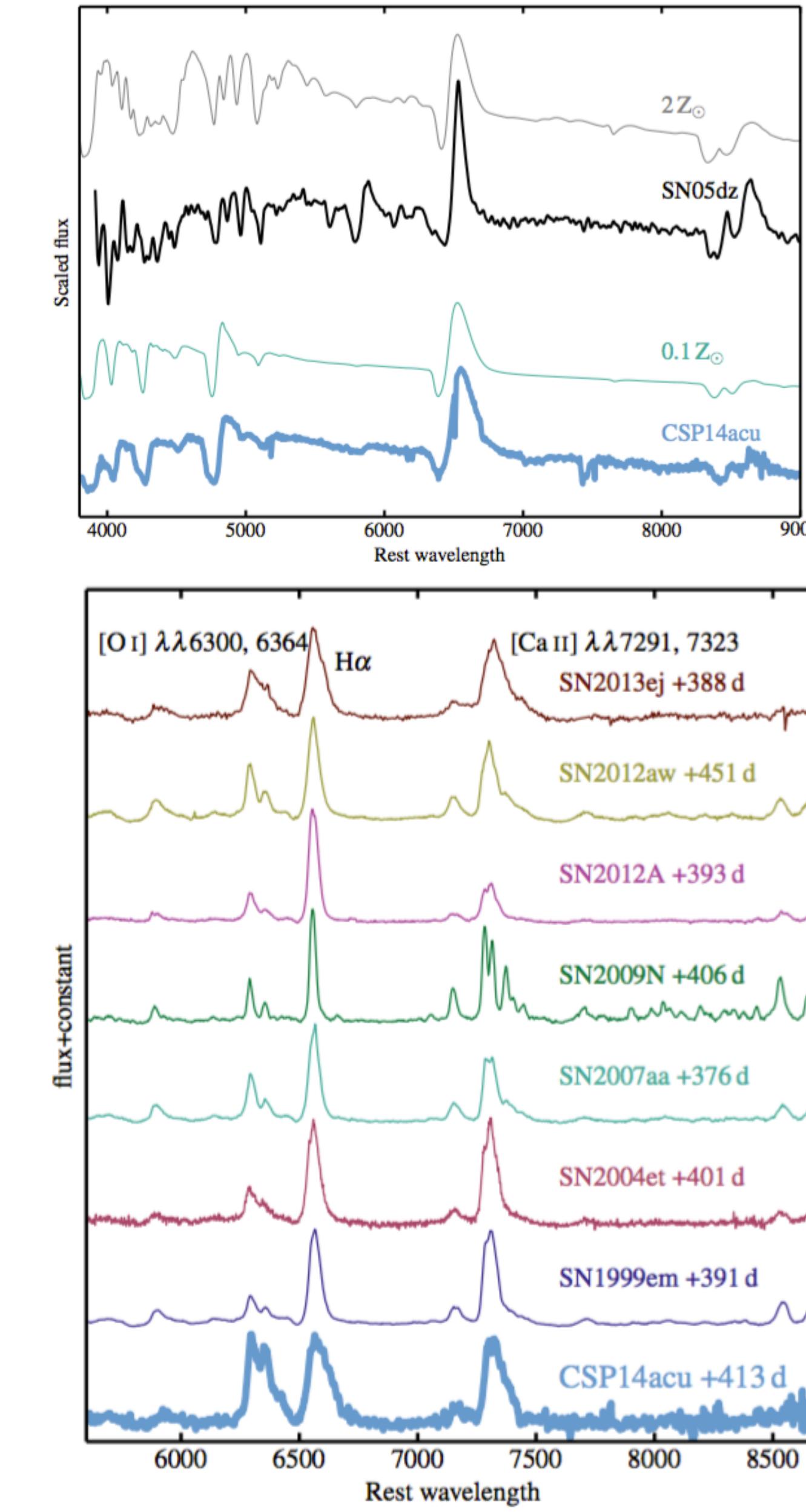
- MUSE constrained its host galaxy
- the SNI^I with the lowest Z to date
- strong [OI] w.r.t Ha (very broad) and [CaII], which means more massive He;lium core and more massive initial progenitor mass



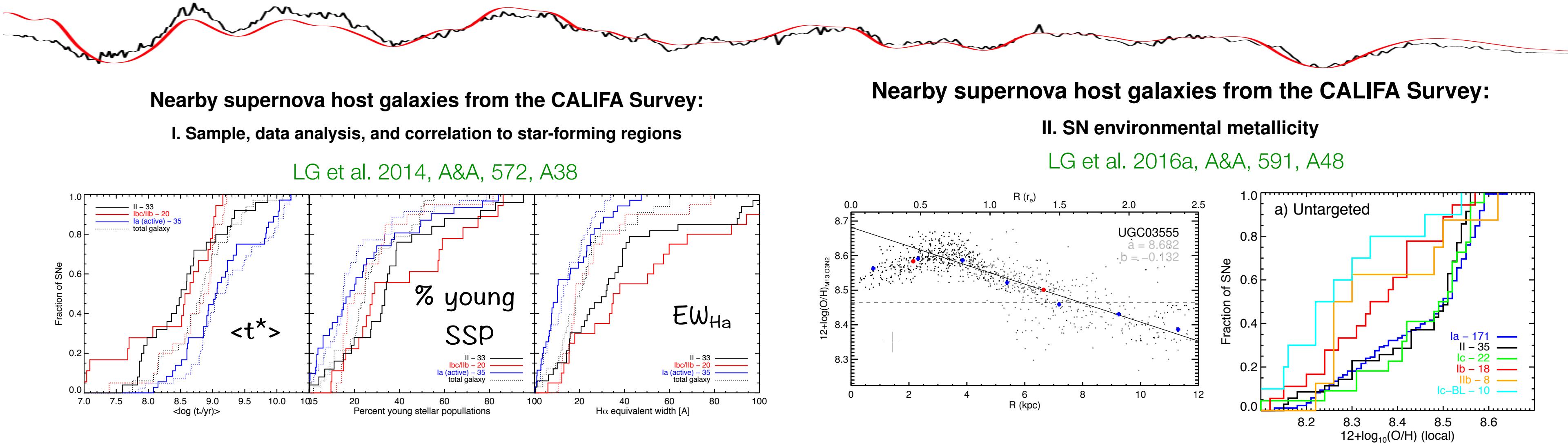
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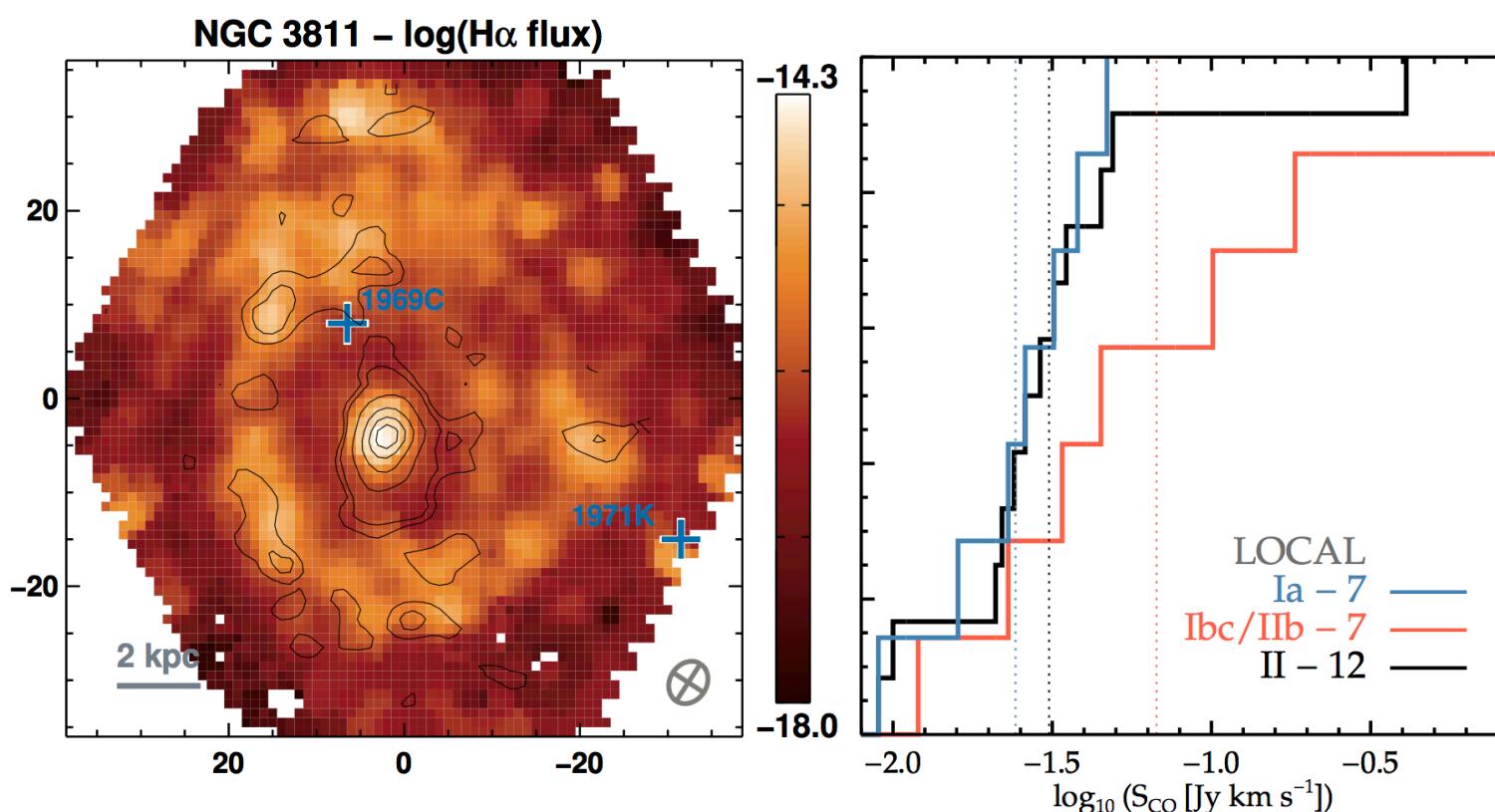


PISCO results



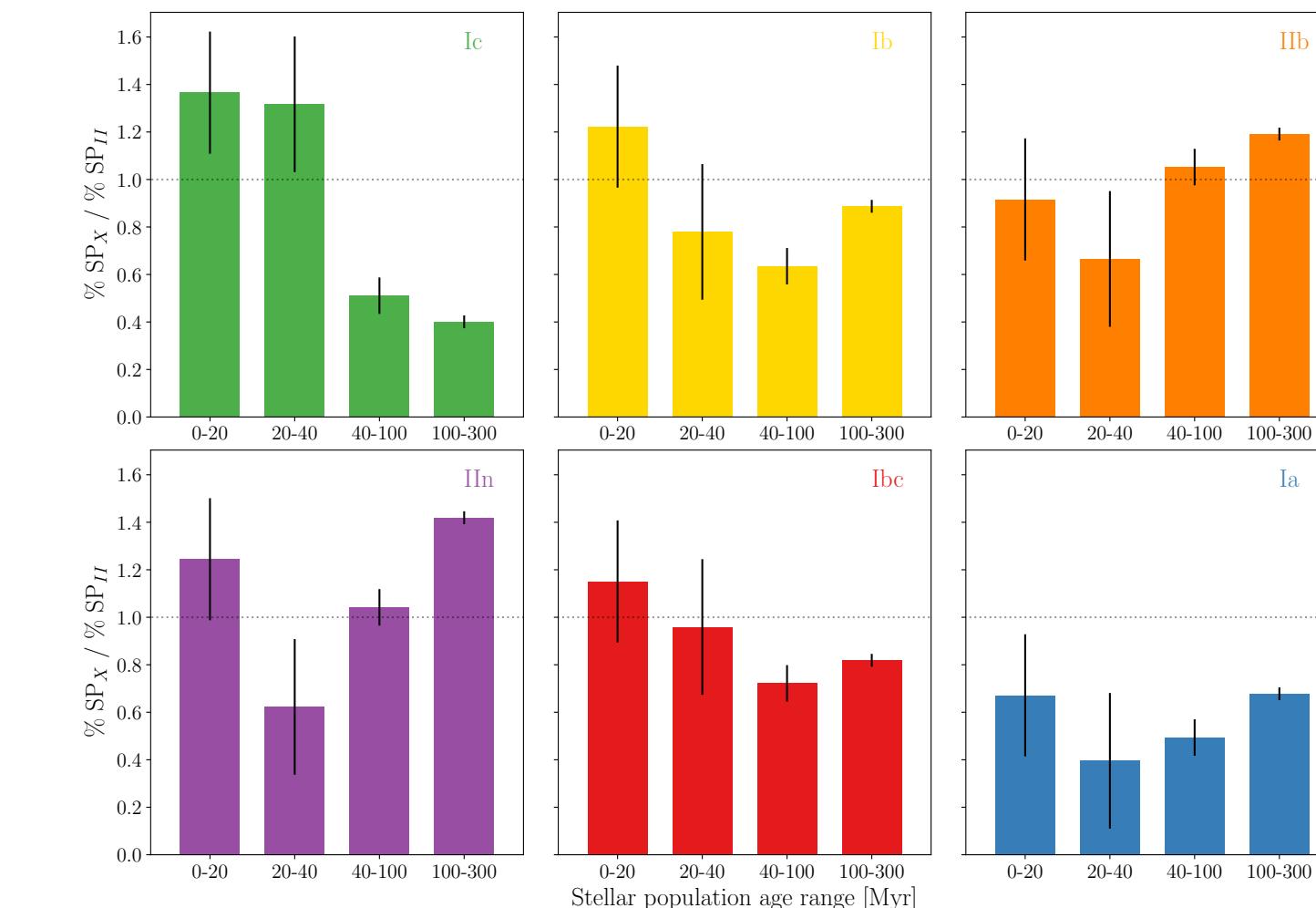
Molecular gas in supernova local environments unveiled by EDGE

LG et al. 2017, MNRAS, 468, 628

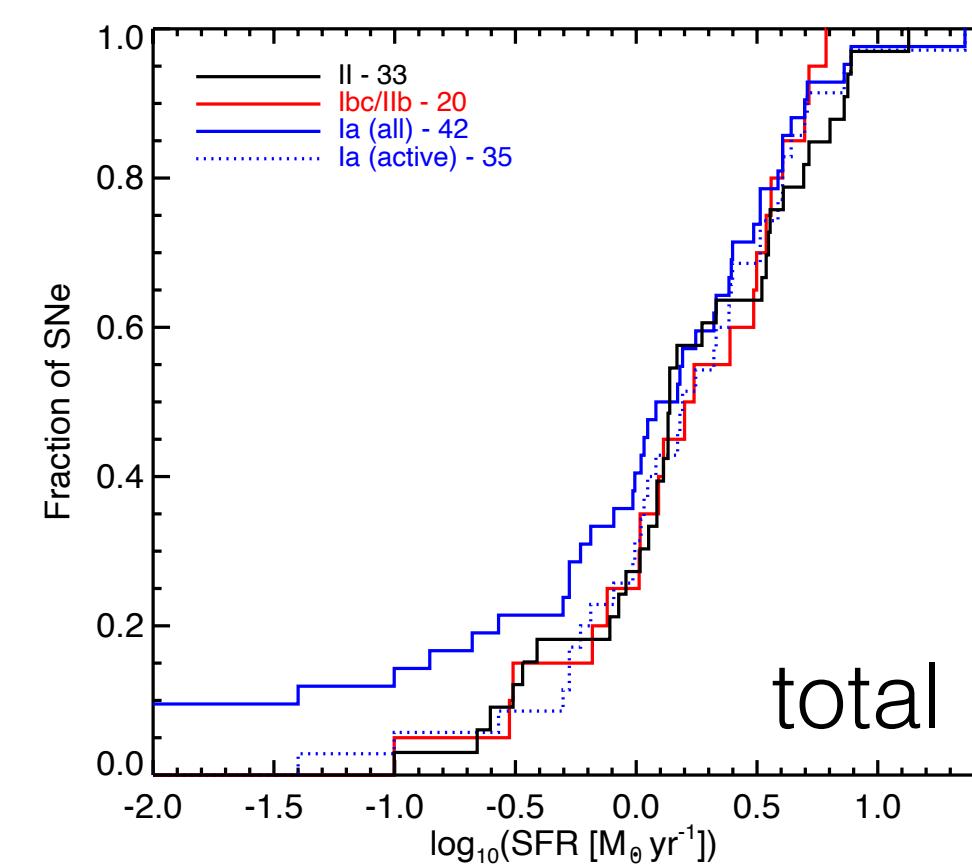


PISCO: The PMAS/PPak Integral-field Supernova Hosts Compilation

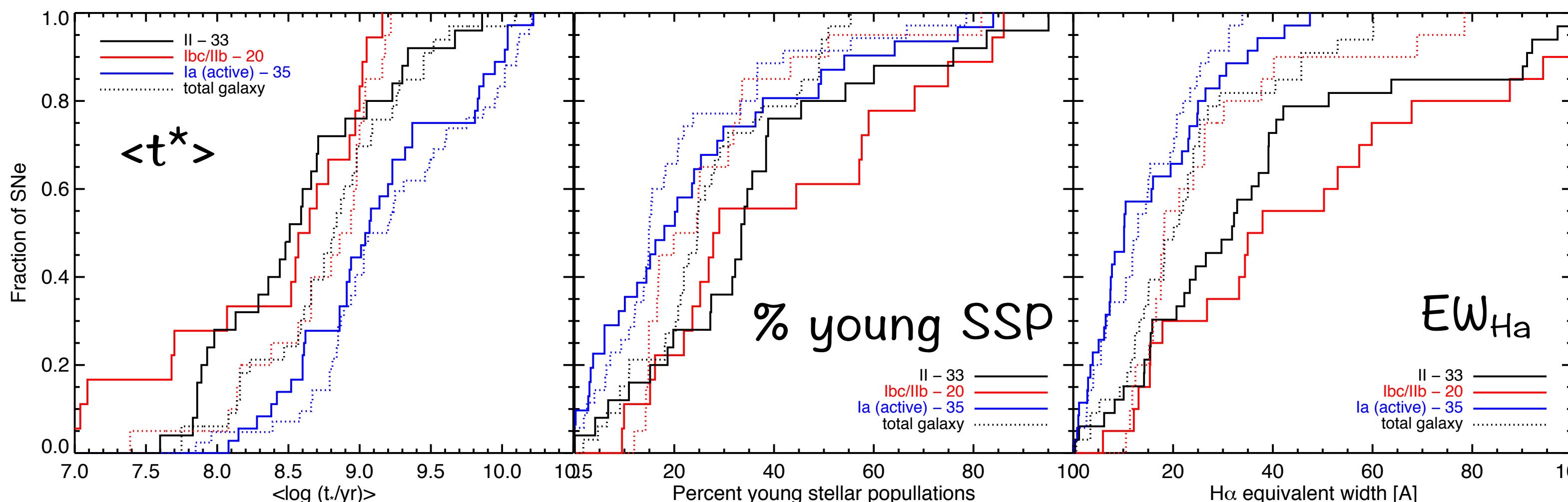
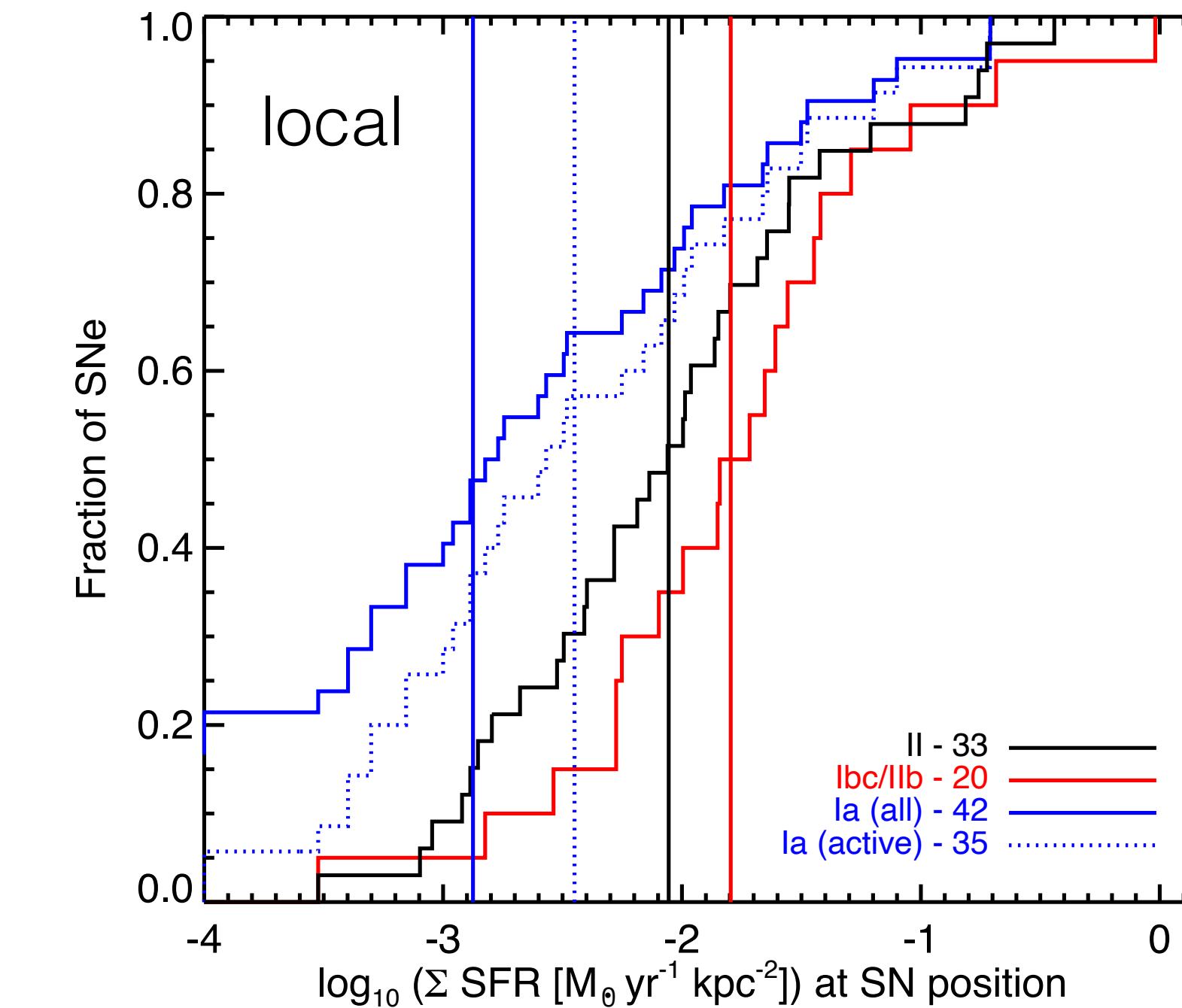
LG et al. 2018, ApJ, 855, 107



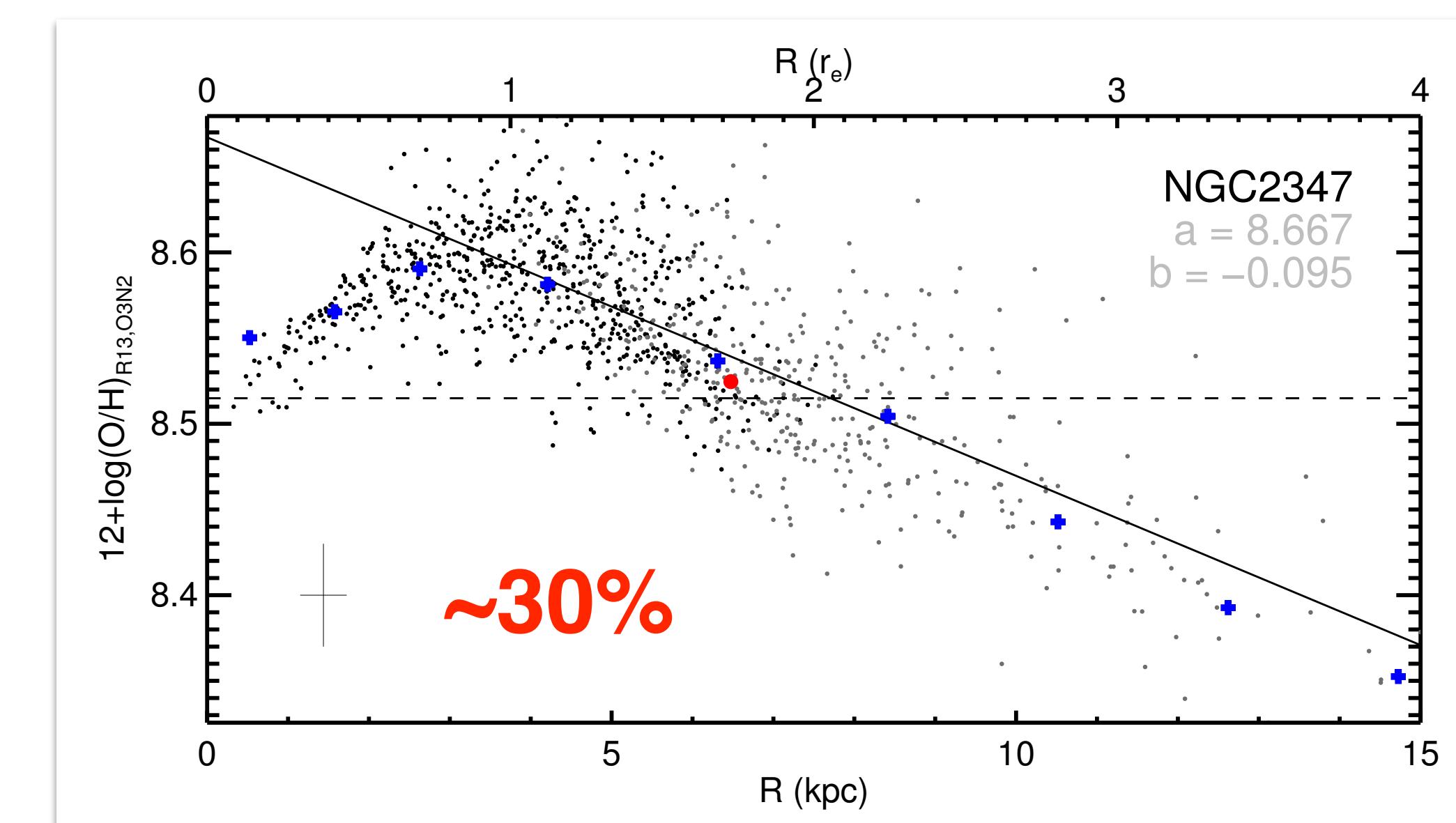
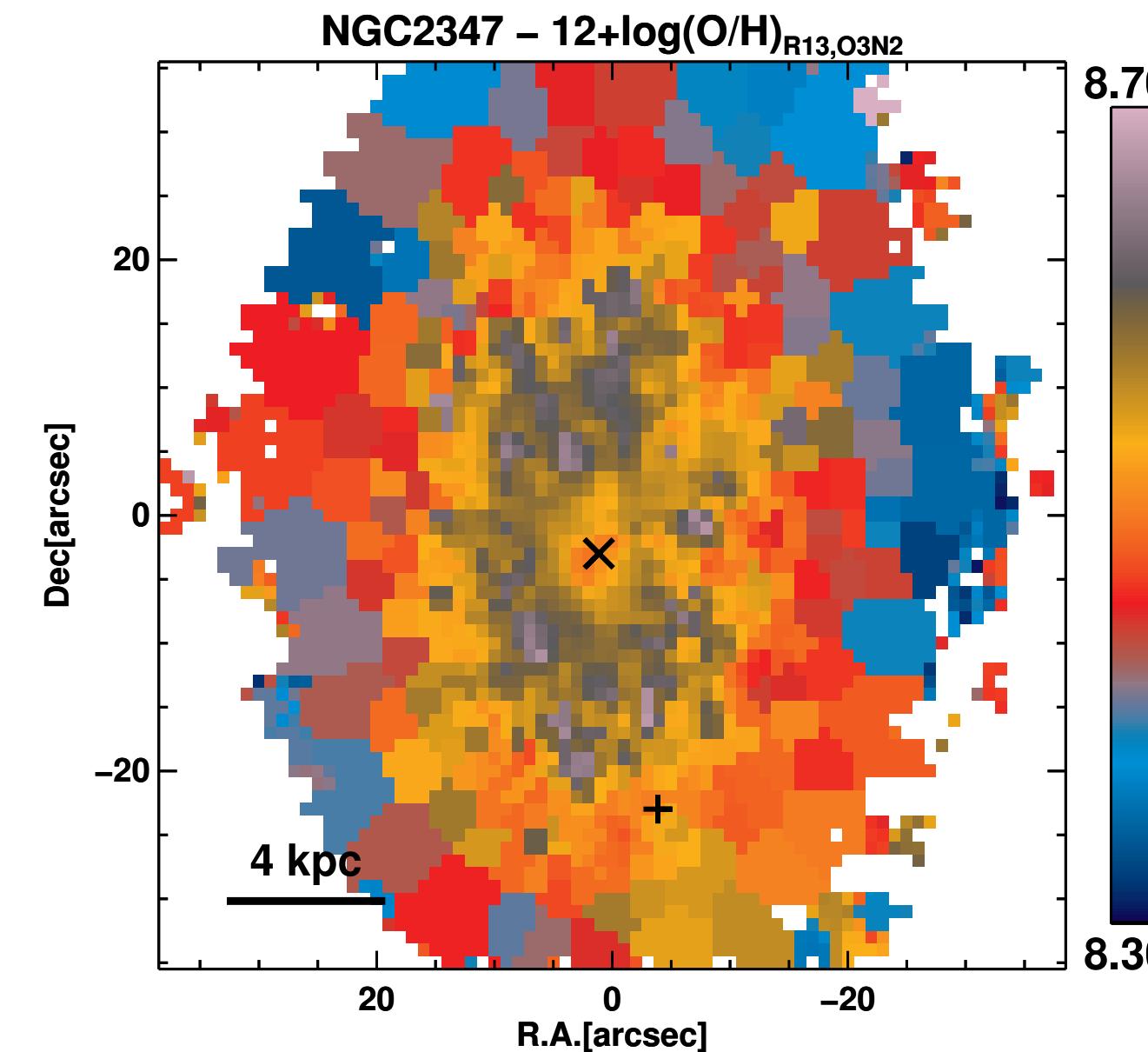
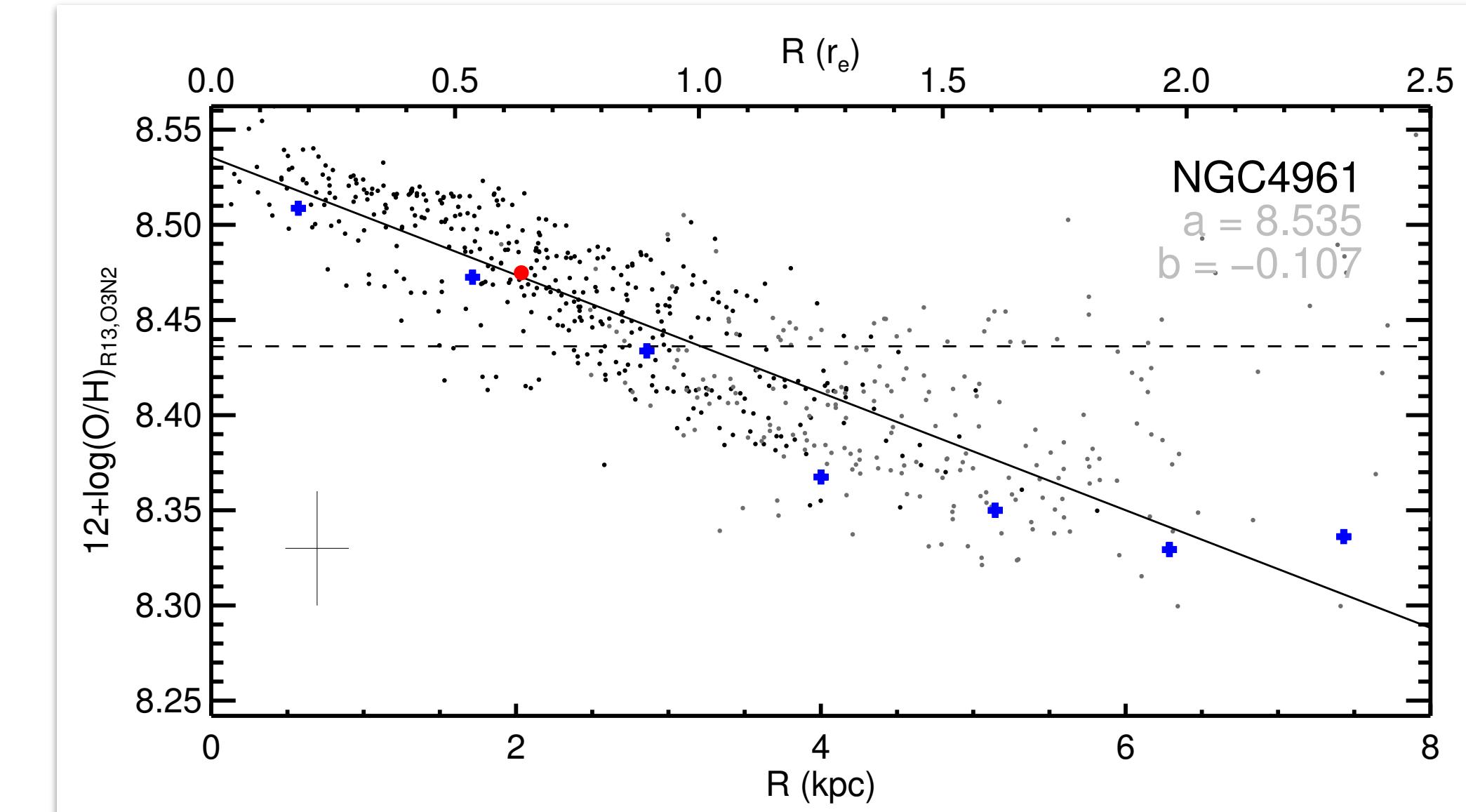
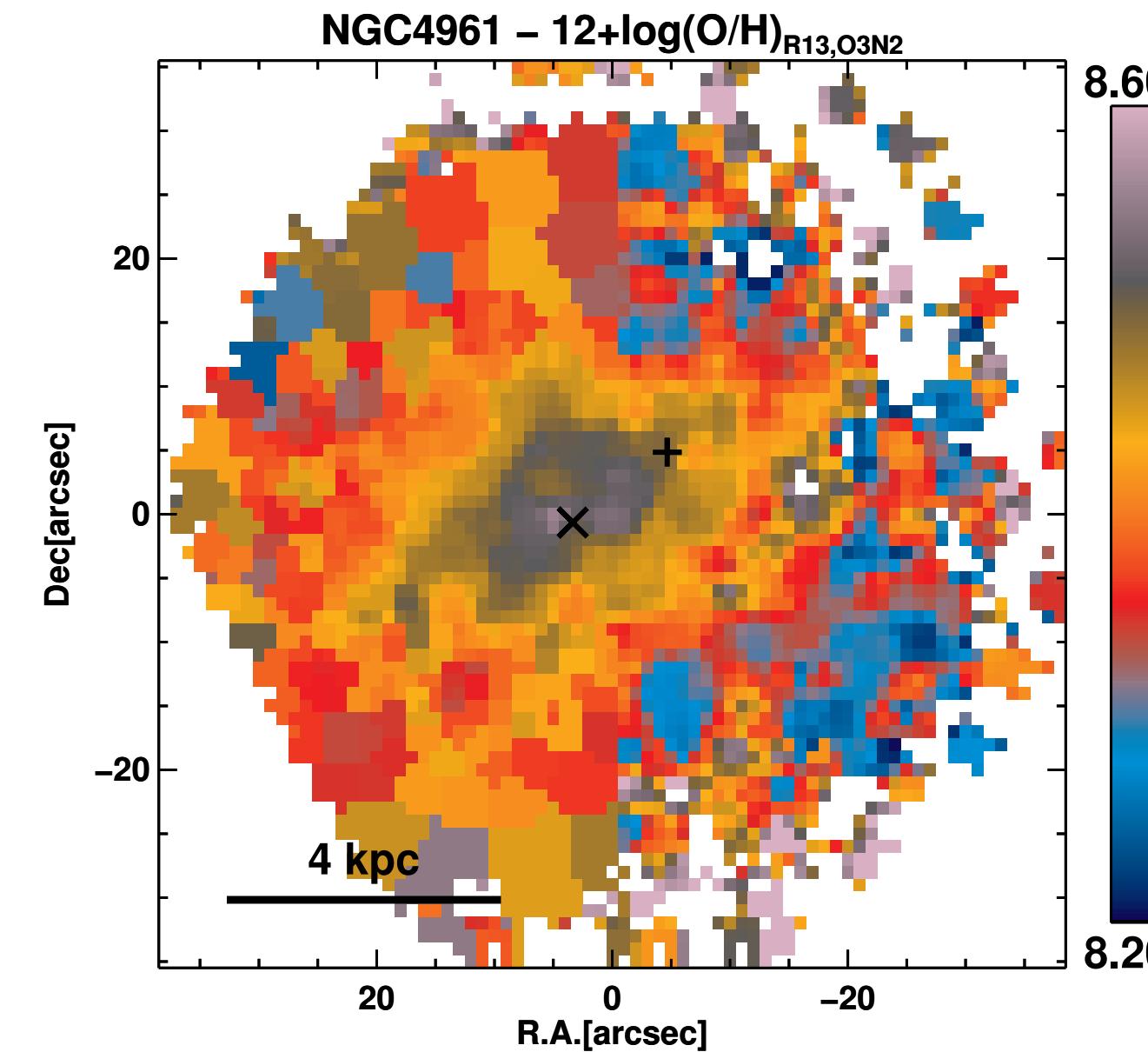
Star formation rate at SN locations



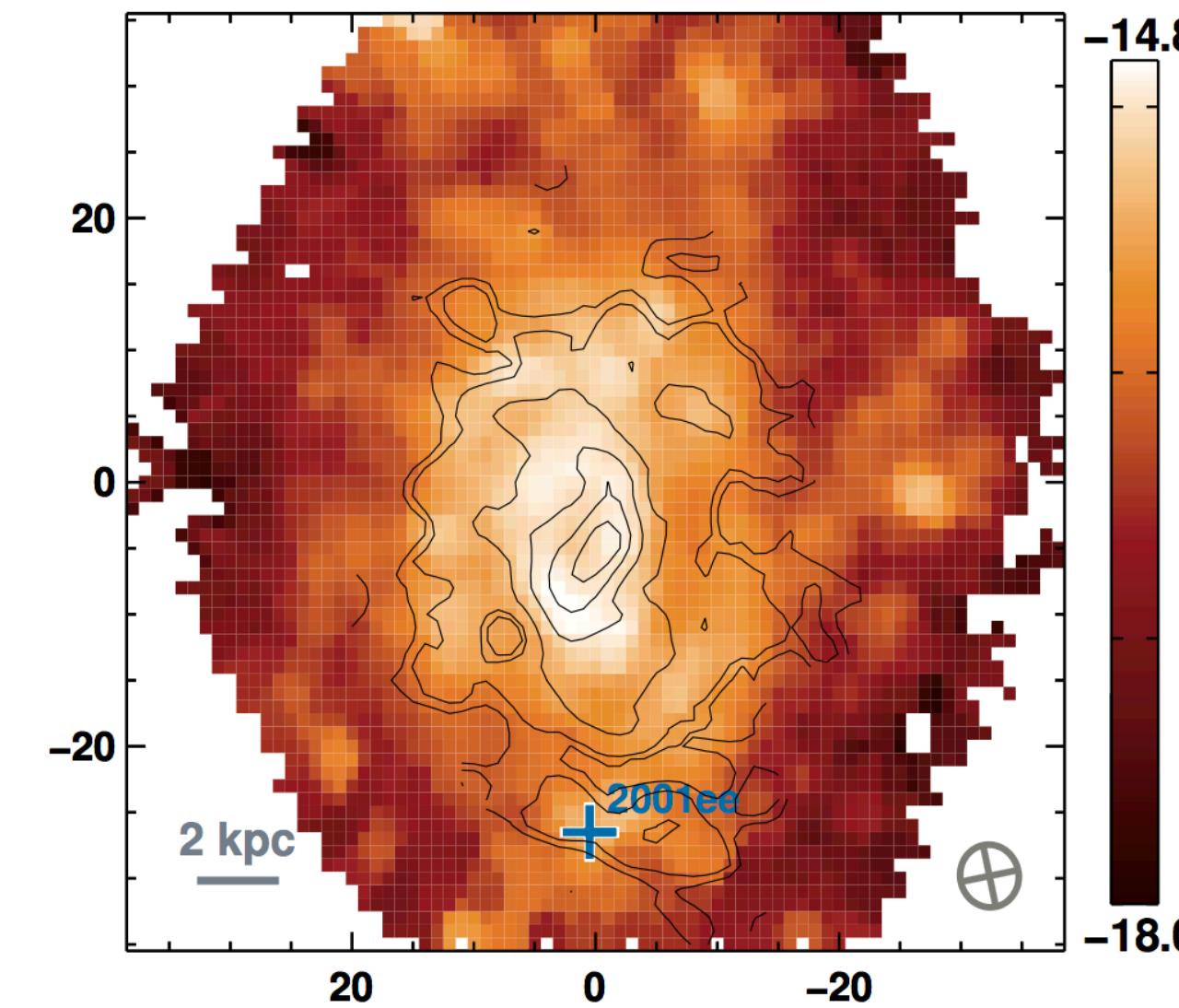
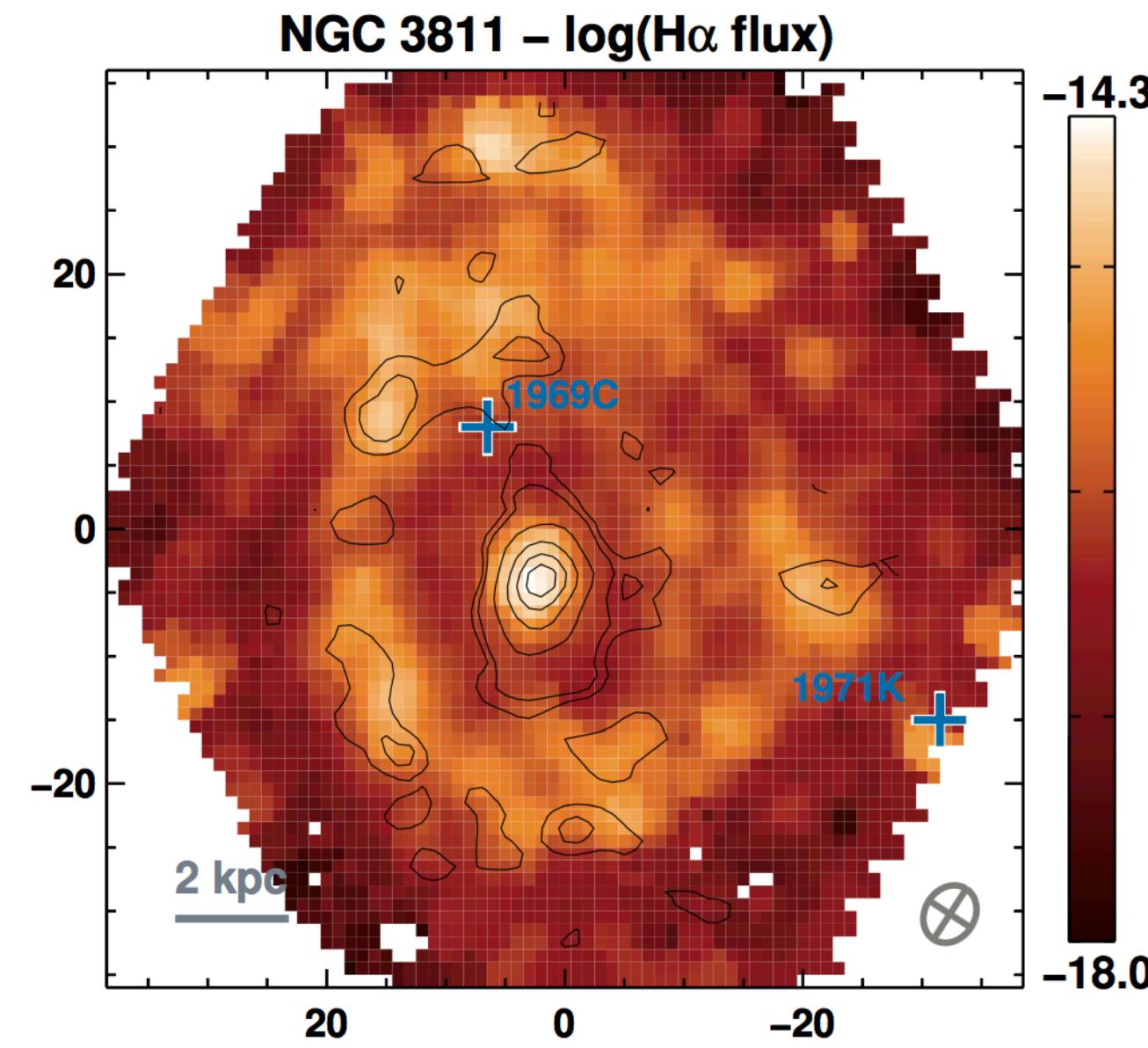
Even in galaxies with similar SFR, **Ibc/IIB** tend to explode in higher ESFR regions than **II** and **Ia**



Metallicity gradients



SN environments in the submillimeter



EDGE survey

CO observations of 175 CALIFA galaxies using CARMA with 2 configurations D+E

CO \rightleftharpoons 0 (2.6mm) intensity maps

23 SN host galaxies (26 SNe)

SNe Ibc occur at places with more SF, but also with more molecular H₂ content

