Thermodynamics of HII regions: SITELLE SV Results

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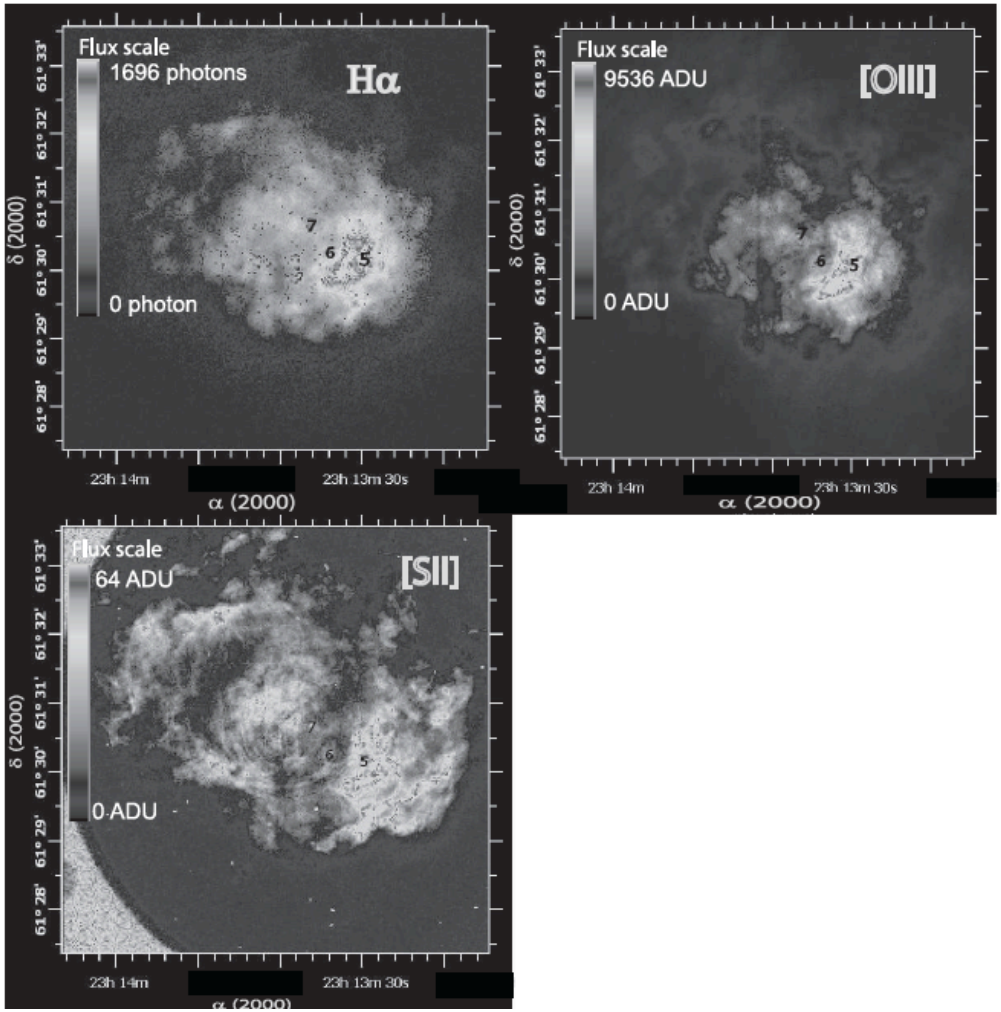
Université Laval

Part I: The astrophysical justification

Part II: Preliminary results from the Orion nebula and the battle ahead

What is an HII region

- Ionic structure



Marten et al. (1997)

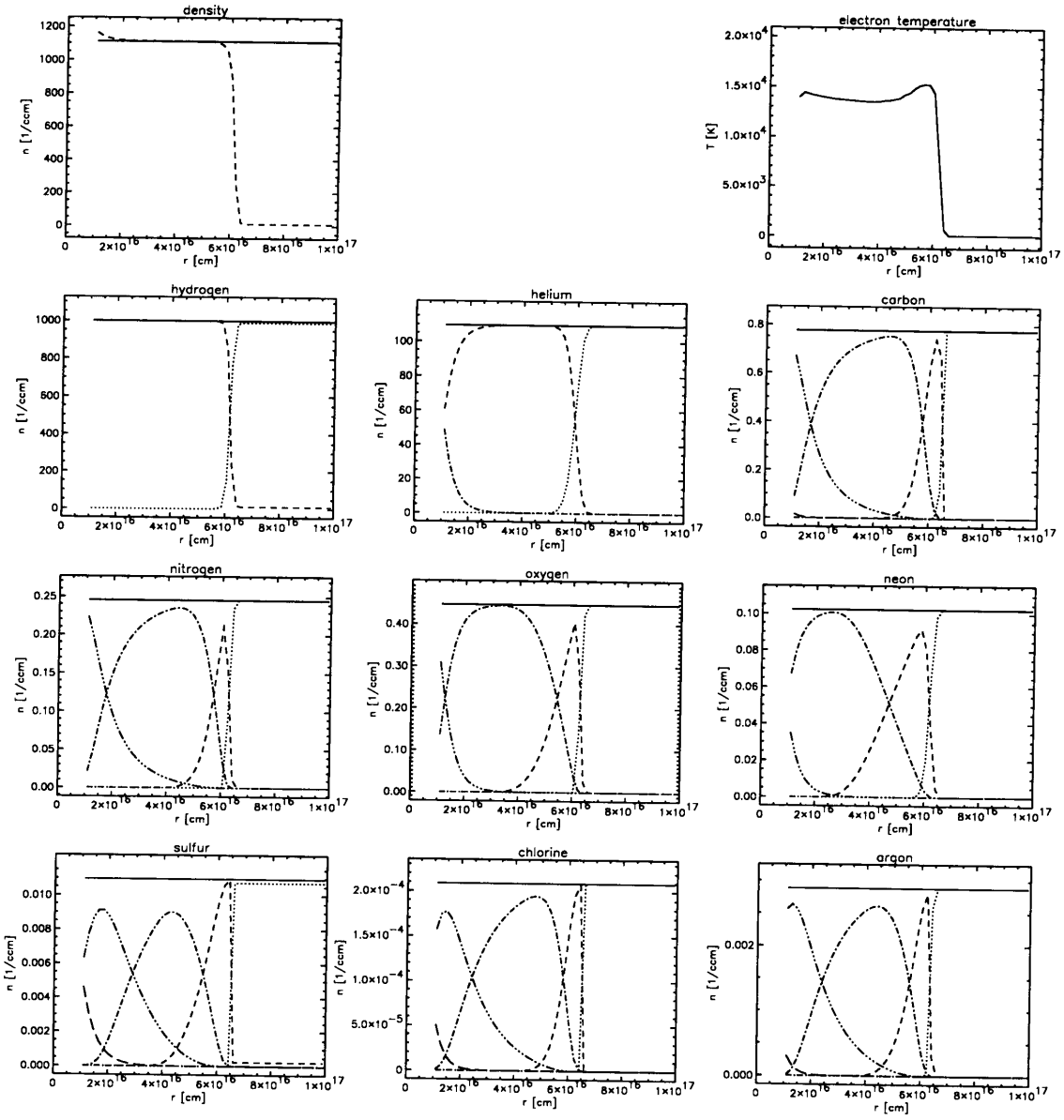


Fig. 2. Radial distribution of the total number density (top left, solid line), of the electron number density (top left, dashed line), of the temperature (top right) and of the number densities of all ions for the model sequence with 50 radial mesh points (RES 50) at an evolutionary age of about $2.15 \cdot 10^6$ sec. In each plot of a single element, the designation is: total number density of the respective element (solid line), number density of the I-ion (dotted), of the II-ion (short dashed), of the III-ion (dash-dotted), of the IV-ion (dash–three dots) and of the V-ion (long dashed)

What is an HII region

Kinematical structure

- Gas flows
- Stellar winds, H-H Objects, etc.
- …Turbulence

Moral of the story:

The structure of the HII region will vary according to the

- Abundance (metallicity)
- Type and location of ionizing star(s)
- Age
- Geometry

Diagnostic lines

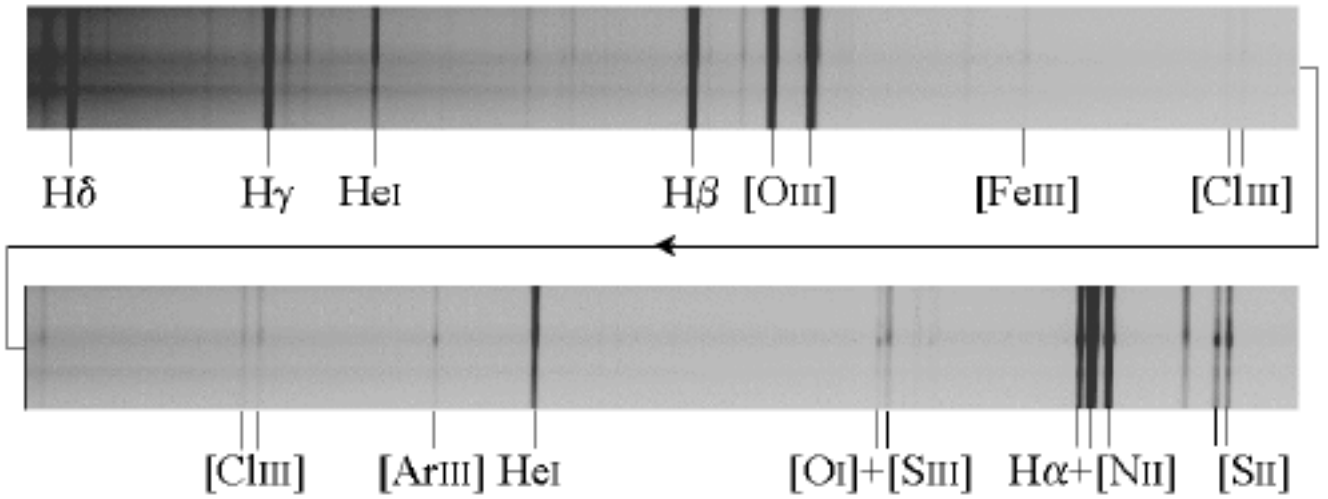


Figure III-11: Long-slit spectrum of the Orion Nebula taken in the region of the "Orion Bar" [1.8m Perkins Telescope, R. Pogge & S.R. Benfer]

Diagnostic lines

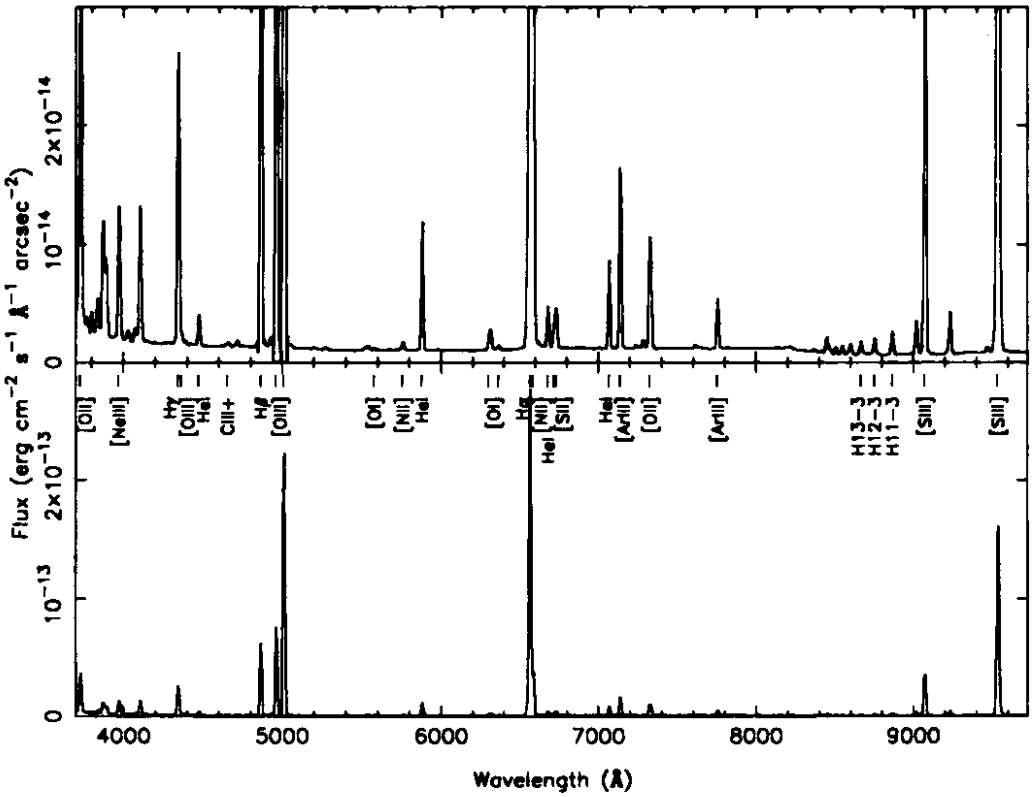


FIG. 1.—Typical spectrum of the Orion Nebula, here the surface brightness at the innermost synthesized slit position (position 1).

Diagnostic lines

- Extinction
- Ionization
- Shocks
- Abundances (recombination vs forbidden)

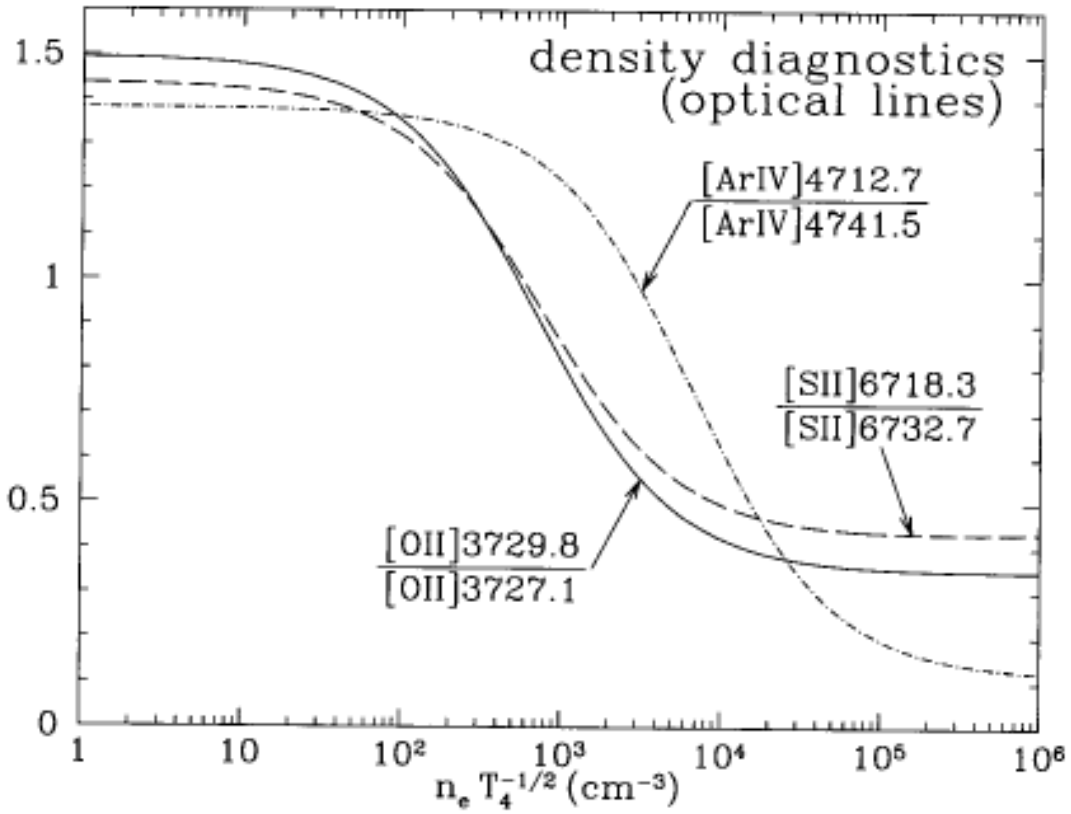
BEWARE : Systematic uncertainties due to ill-calculated atomic parameters

Diagnostic lines

Thermodynamic data

- Density

$$\frac{j(2\rightarrow 0)}{j(1\rightarrow 0)} = \frac{\Omega_{20}}{\Omega_{10}}\frac{E_{20}}{E_{10}}e^{-E_{21}/kT} \approx \frac{\Omega_{20}}{\Omega_{10}}$$



Diagnostic lines

Thermodynamic data:

- Temperature

[OIII] Lines (Measures T_e in O^{++} Zone):

$$R_{[OIII]} = \frac{I(4959)+I(5007)}{I(4363)} \approx \frac{7.73e^{32900/T_e}}{1+4.5\times10^{-4}(n_e/T_e^{1/2})}$$

[NII] Lines (Measures T_e in N^{+} Zone):

$$R_{[NII]} = \frac{I(6548)+I(6583)}{I(5755)} \approx \frac{6.91e^{25000/T_e}}{1+2.5\times10^{-3}(n_e/T_e^{1/2})}$$

Diagnostic lines

- Ionic volume data

Ionization potential(ev):	-	10.4	13.6	14.5	23.5	35.1
Temperature:	OI	SII	OII	NII	SIII	OIII
Density:	OI	SII	OII	-	ClIII	-

OI: 555.7, 630.0, 636.4 nm	1.6, 5.5, 1.3	
SII: 406.9, 407.6, 671.6, 673.1 nm	1.7, 0.78, 5, 6	
OII: 372.6, 372.9, 732.4 nm	70, 70, 6	
NII: 575.5, 654.8, 658.4 nm	15, 15, 45	Hβ = 100
SIII: 631.2, 906.9, 953.2 nm	14, 24, 56	Hα = 350
ClIII: 551.8, 553.8 nm	6, 15	
OIII: 436.3, 495.9, 500.7 nm	1.7, 112, 335	

Diagnostic lines

Using T[OIII] for both low and high stages of ionization implies an overestimate for (O/H) of 40-60%.

Ill-Understood microphysics due to HII region peculiarities

- Velocity fluctuations (turbulence)
- Density fluctuations (turbulence, irregular boundaries…?)
- Temperature fluctuations
- Abundance Discrepancy Problem

Abundance Discrepancy Problem

- The key problem in photoionized nebulae physics!
- At constant temperature, ionic abundances from CEL are half (1.3-2.8) those derived from recombination lines. It is worst for planetary nebulae.
- Cause unknown and hotly debated

Temperature fluctuations

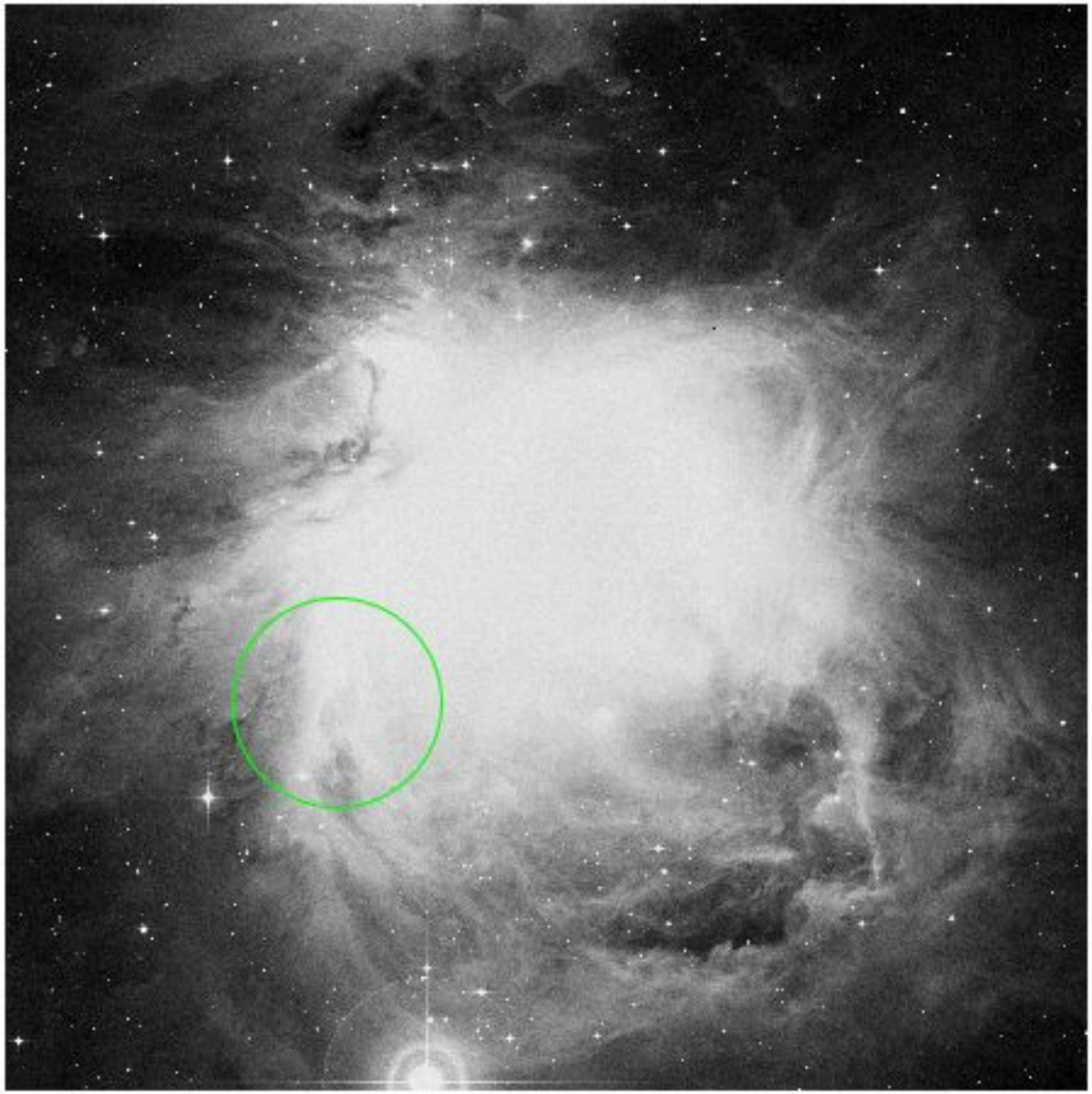
- Targeted as the culprit for the ADP from the beginning (Peimbert 1967)
- …quite debated now:

  cold gas

  H-H objects, proplyds

  scattered light

  high Z droplets from halo
- Density, chemical inhomogeneities and turbulence



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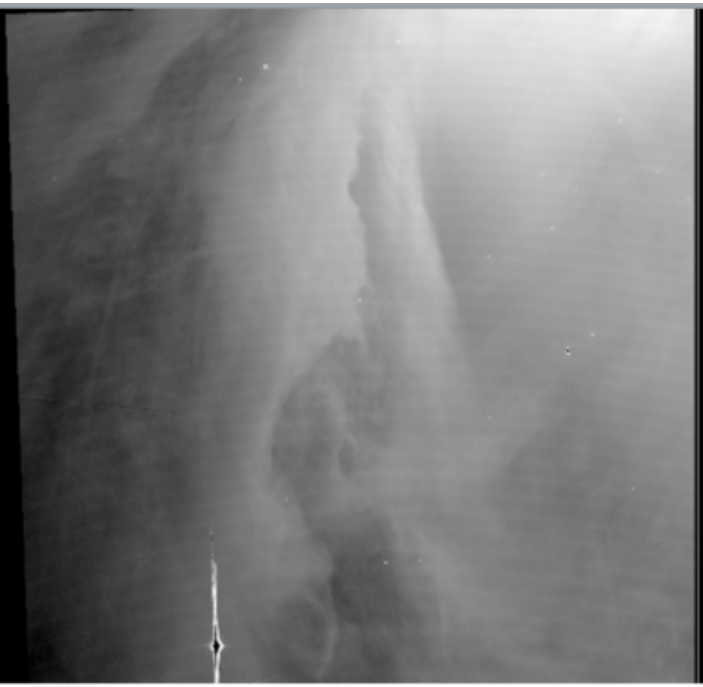
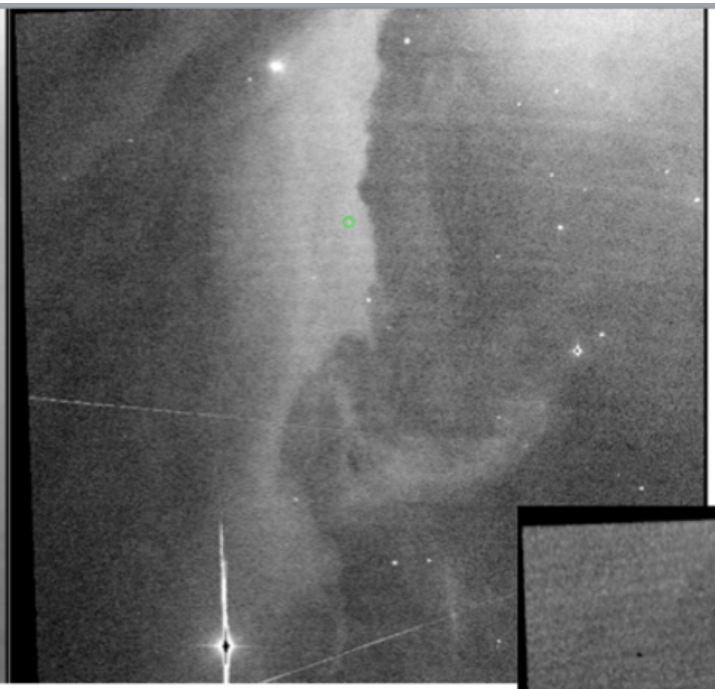
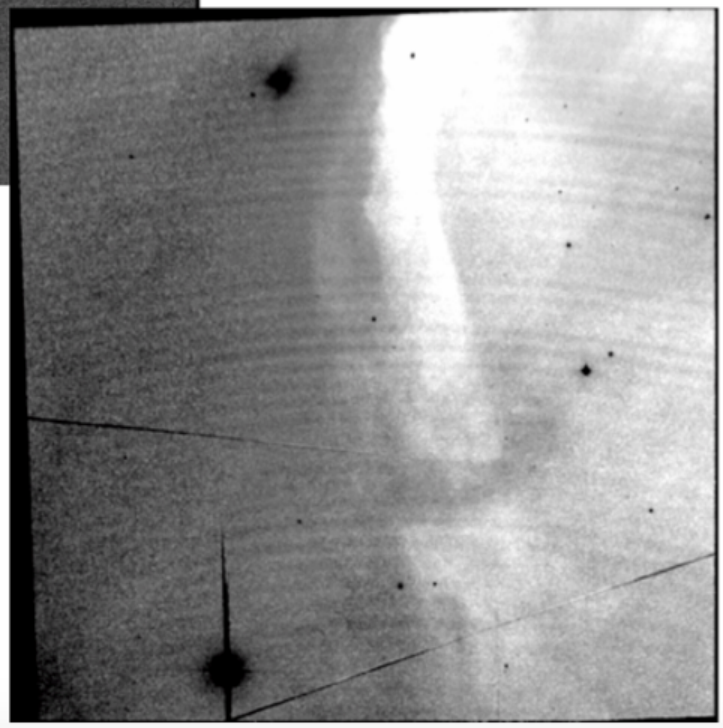




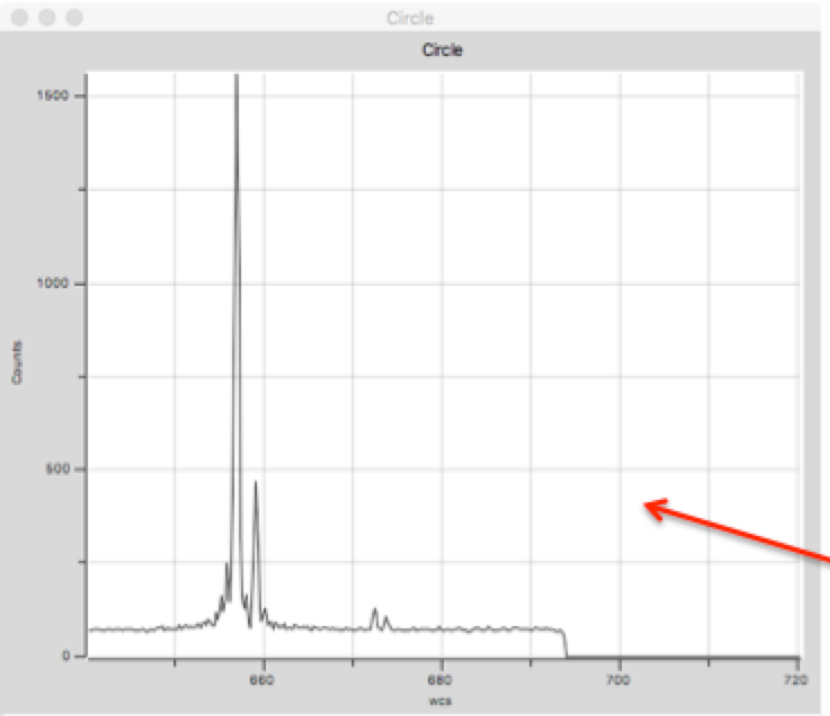
Hel 4471

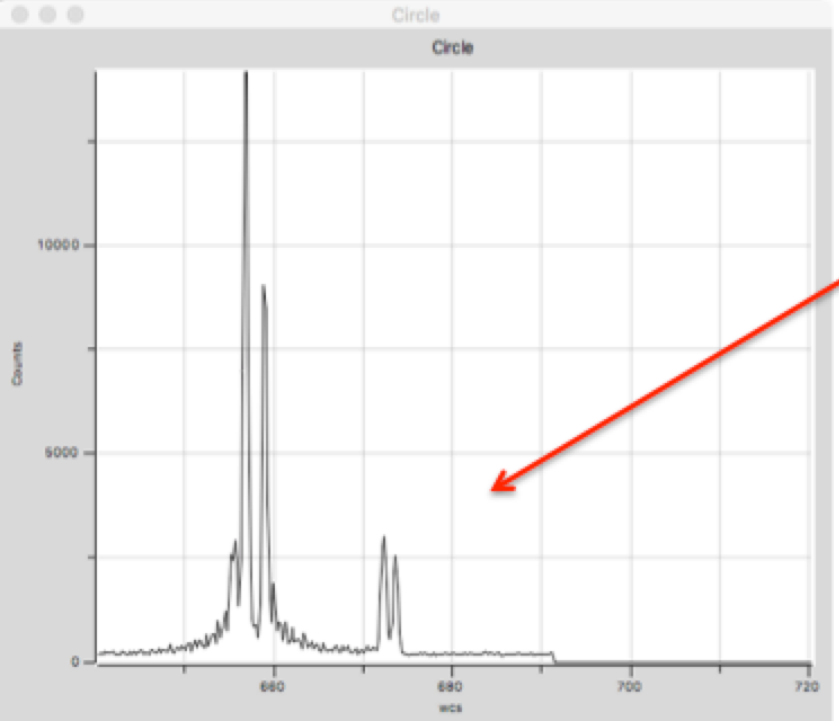
Hbeta

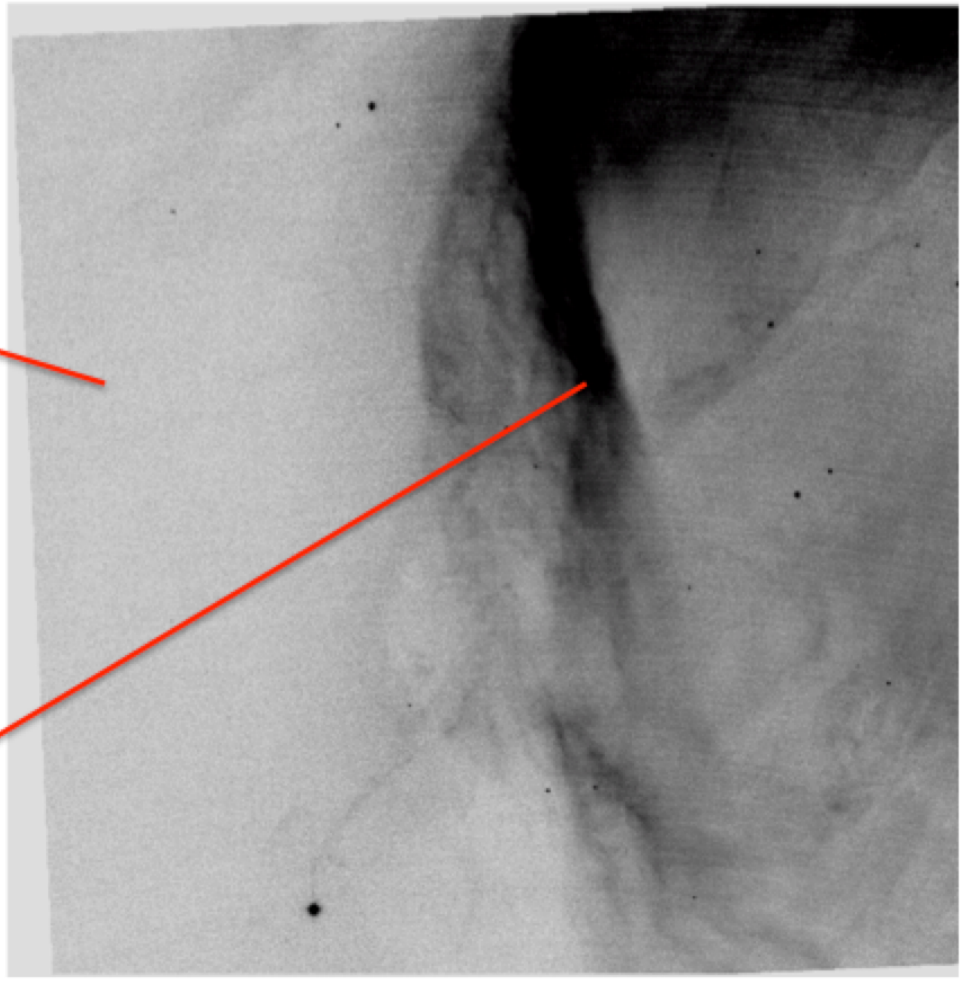


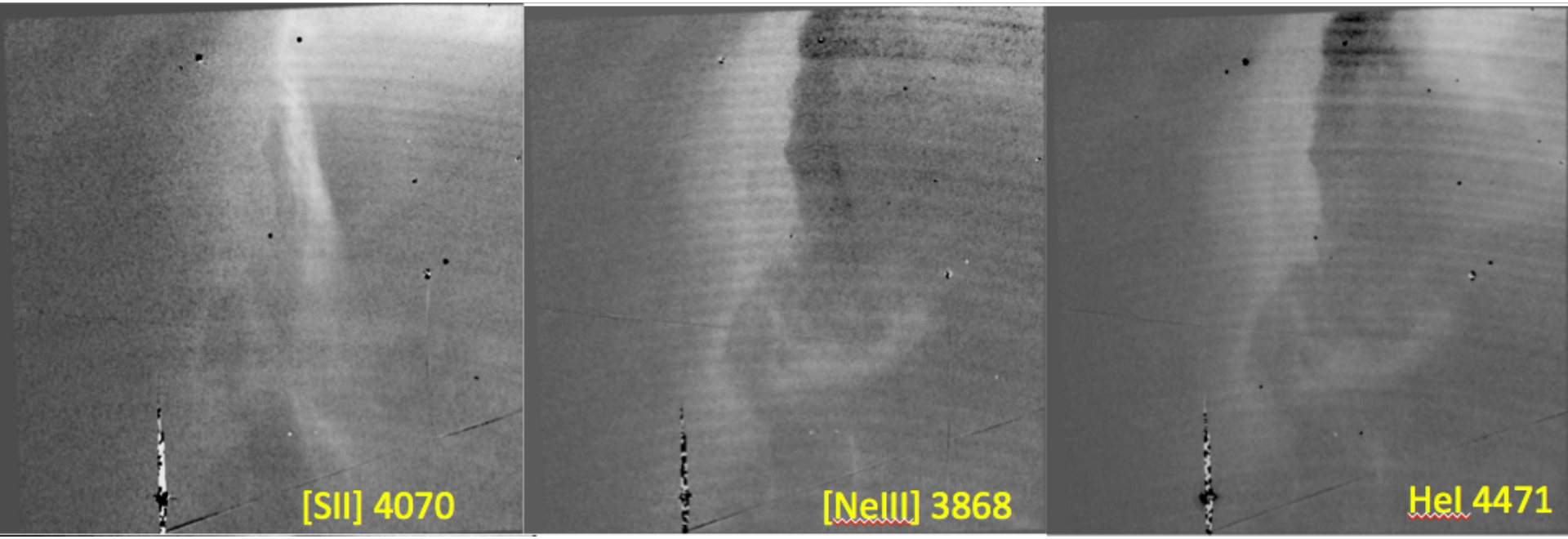
Hbeta/Hel

Orion-F1: [SII] 6717

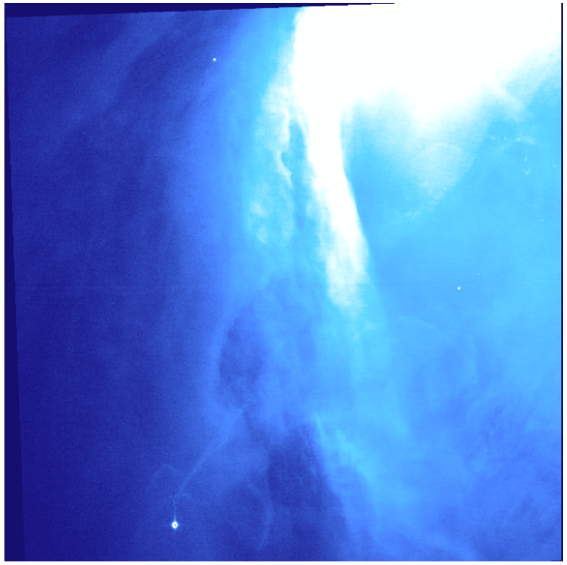


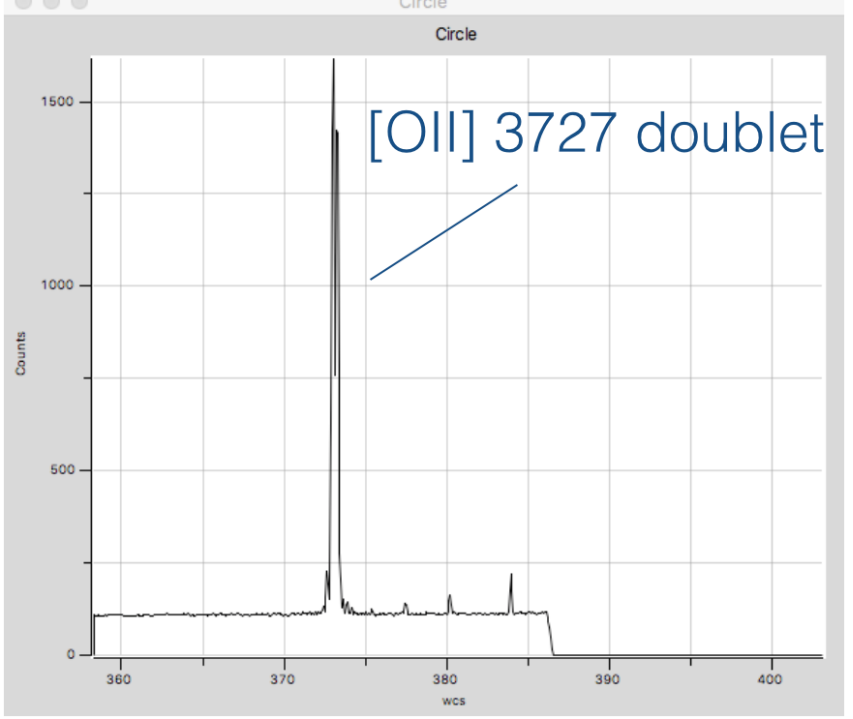


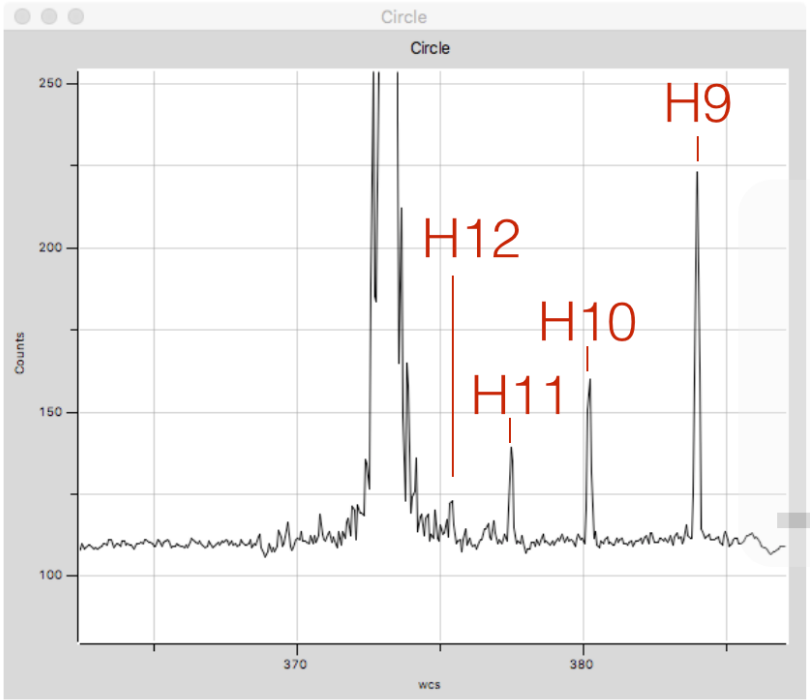


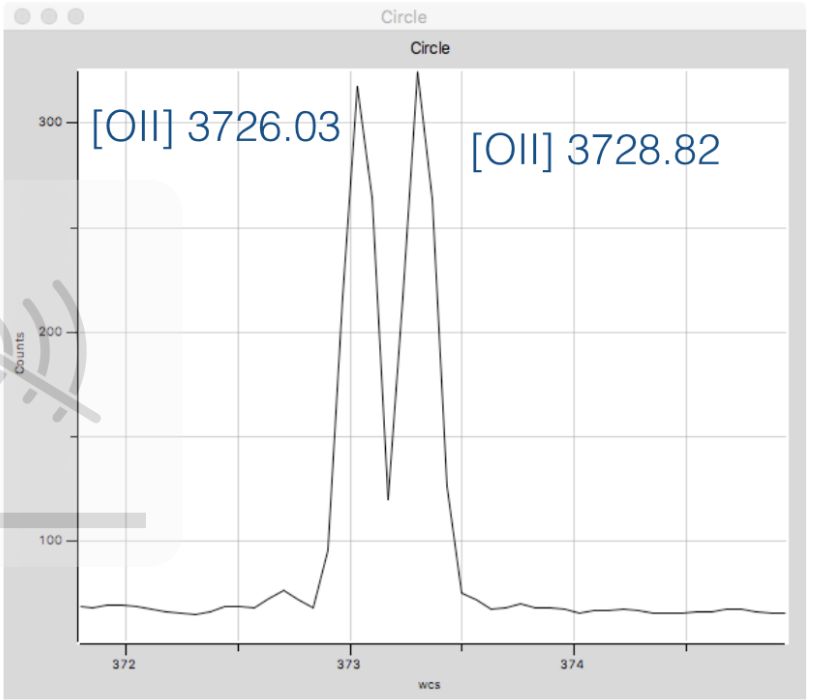

[SII] 4070
[NeIII] 3868
HeI 4471

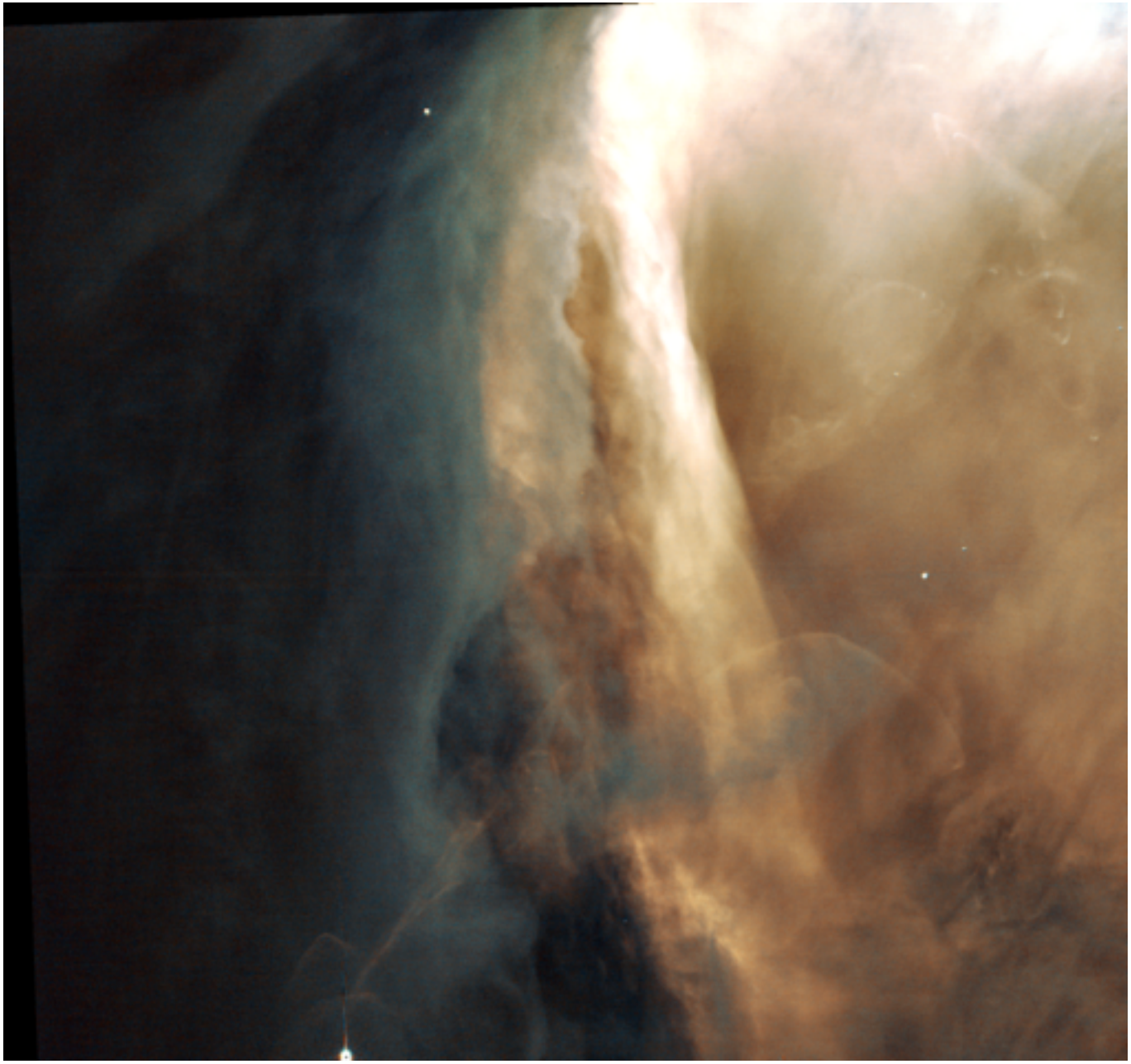
Orion-F1, SN1

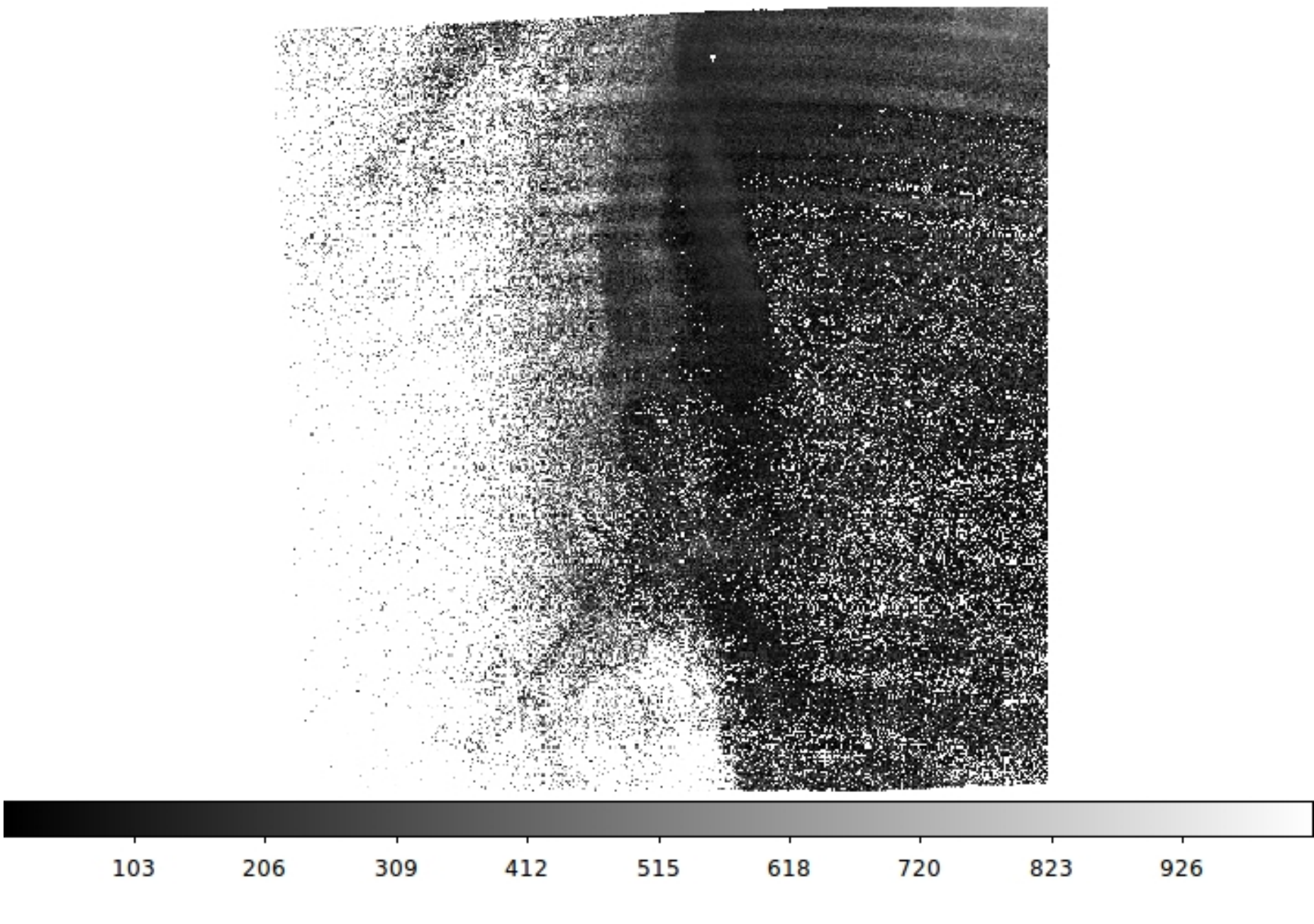


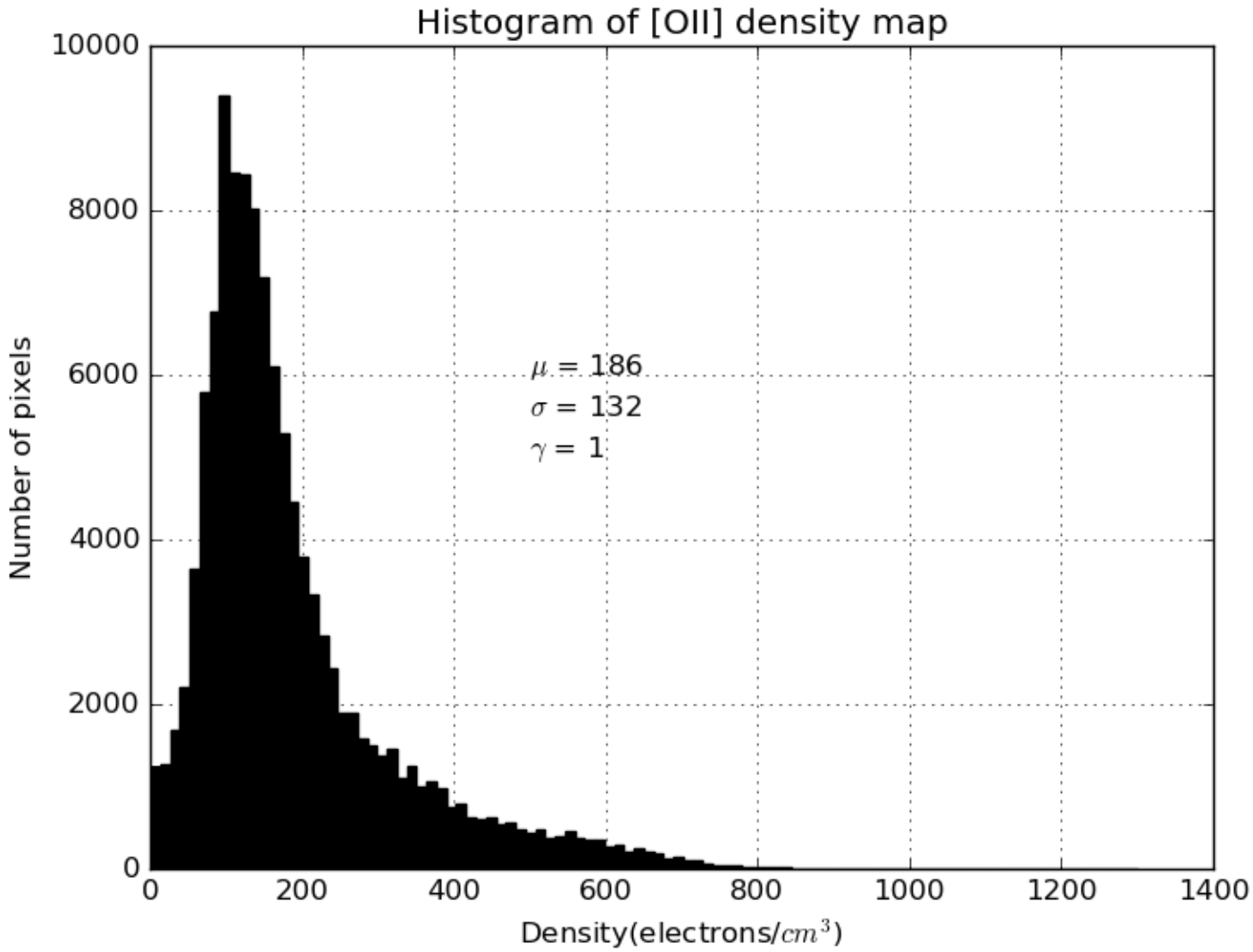

Circle
[OII] 3727 doublet
Counts
wcs

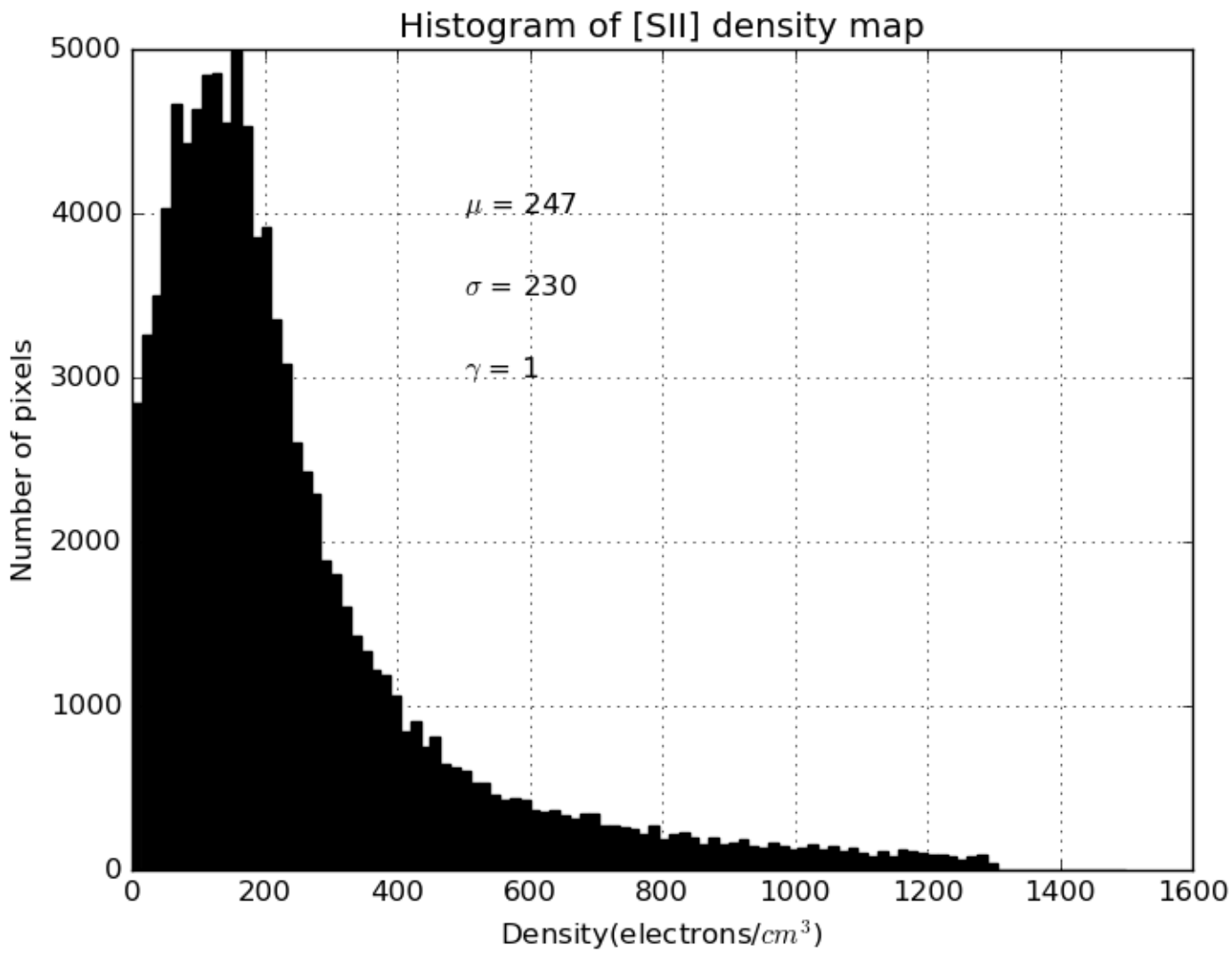

Circle
Circle
H9
H12
H10
H11
Counts
wcs


Circle
Circle
[OII] 3726.03
[OII] 3728.82
Counts
wcs




103
206
309
412
515
618
720
823
926


Histogram of [OII] density map
Number of pixels
Density(electrons/cm^3)
μ = 186
σ = 132
γ = 1
0
2000
4000
6000
8000
10000
0
200
400
600
800
1000
1200
1400


Histogram of [SII] density map
μ = 247
σ = 230
γ = 1
Number of pixels
Density(electrons/cm^3)
0
1000
2000
3000
4000
5000
0
200
400
600
800
1000
1200
1400
1600

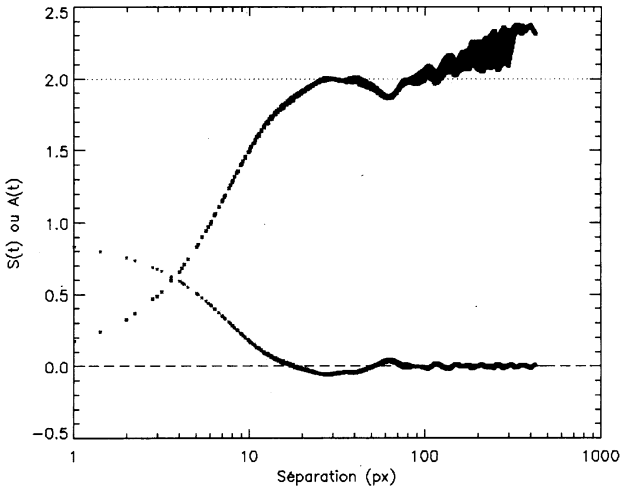
Conclusion

➔HII regions are far from being simple objects!

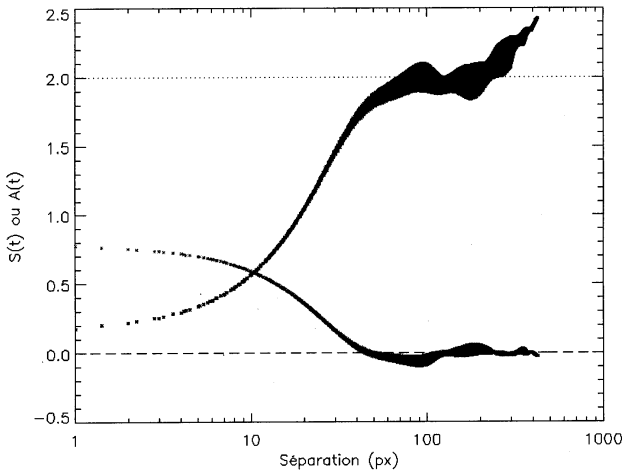
☑ When using SITELLE make sure you leave with all the proper calibrations!

Orion: Turbulence

Hα



[OIII]



[SII]