SITELLE

au Télescope Canada-France-Hawaii

Thomas Martin (Université Laval)
PI: Laurent Drissen (Université Laval)

SITELLE in a nutshell

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(Sittelle = Nuthatch)

Imaging Fourier Transform Spectrometer

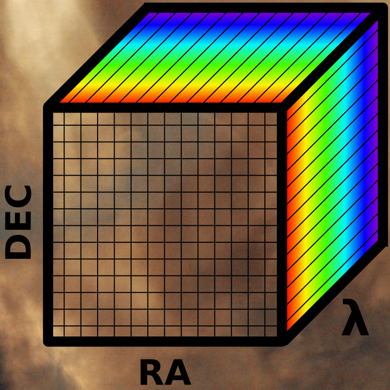
FoV: 11x11 arcminutes

R=1~20 000

350nm - 950 nm

2048x2048 pixels, 0.32"

4.3 millions spectra



Orion [0II] 3726,3729 composite image by SITELLE (Drissen, Alarie)

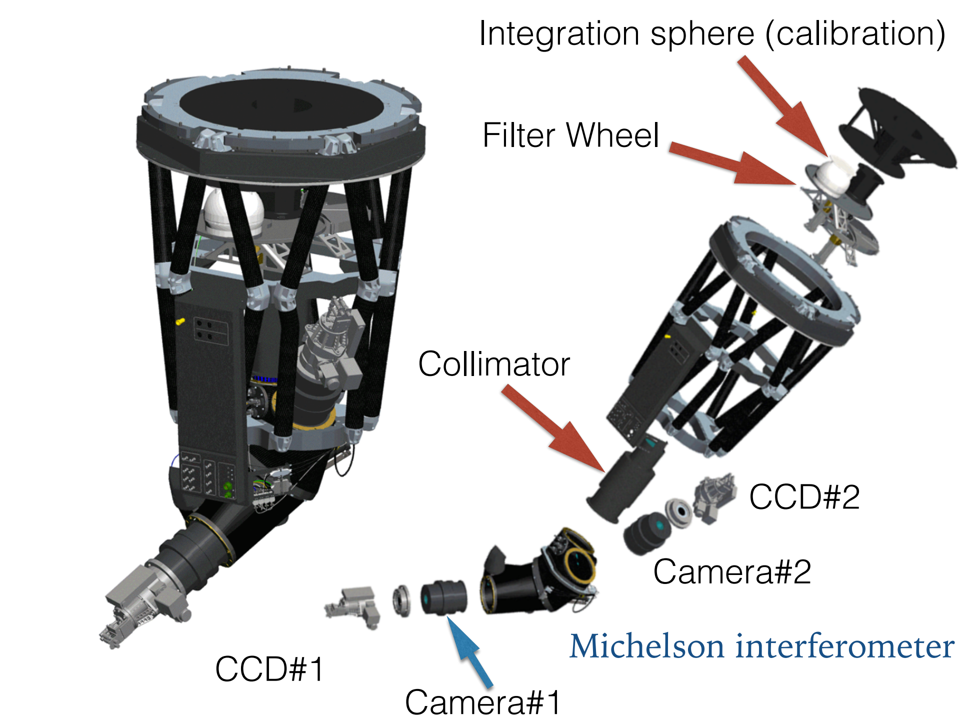
PI: Laurent Drissen

Structure + interferometer + electronics

Optics: Simon Thibault

Detectors: Marc Baril

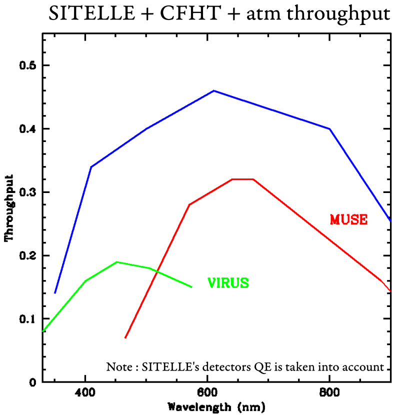
Reduction software: Thomas Martin



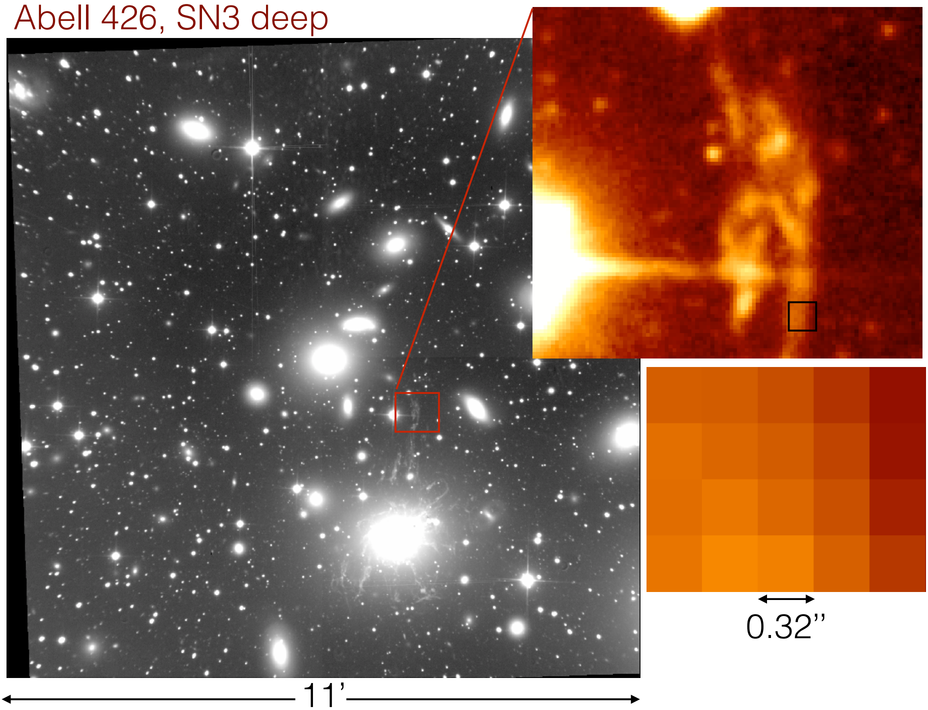
Integration sphere (calibration)
Filter Wheel
Collimator
CCD#2
Camera#2
Michelson interferometer
CCD#1
Camera#1

SITELLE as an imager

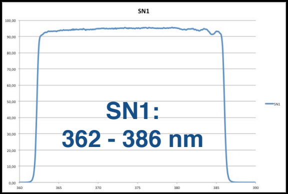
Throughtput

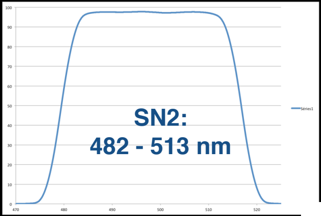


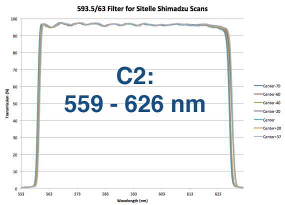
SITELLE's throughput is very high compared to dispersive-based techniques.

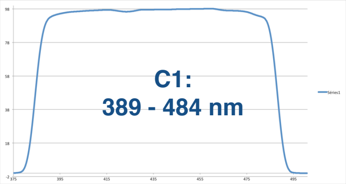

Abell 426, SN3 deep
0.32''
11'

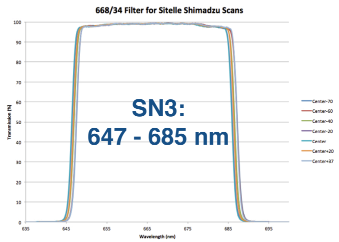
Available filters

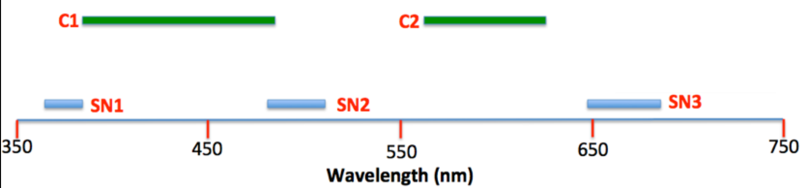






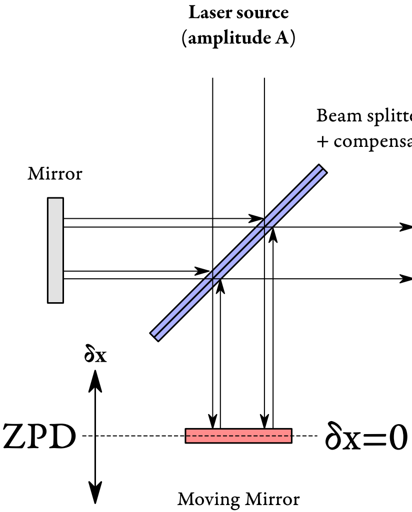


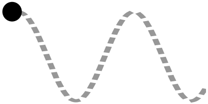




At the core of SITELLE: an interferometer

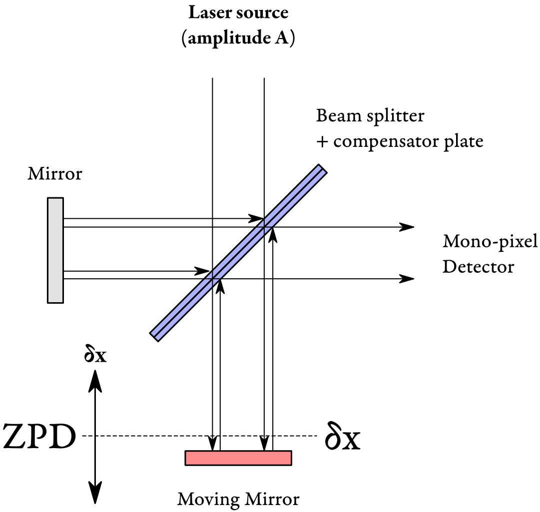
How does it work ?

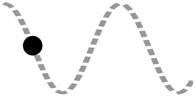




Measured intensity

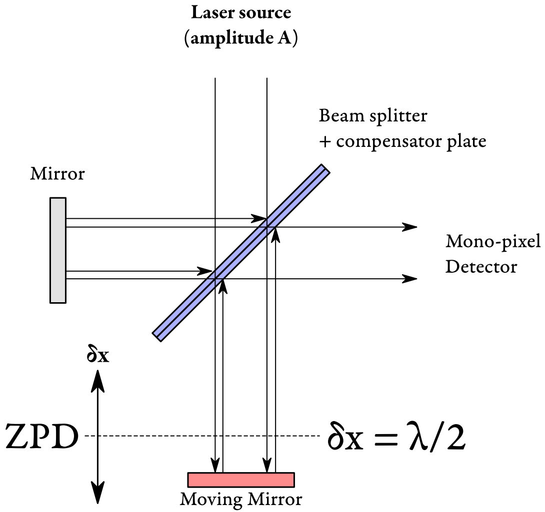
How does it work ?

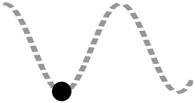




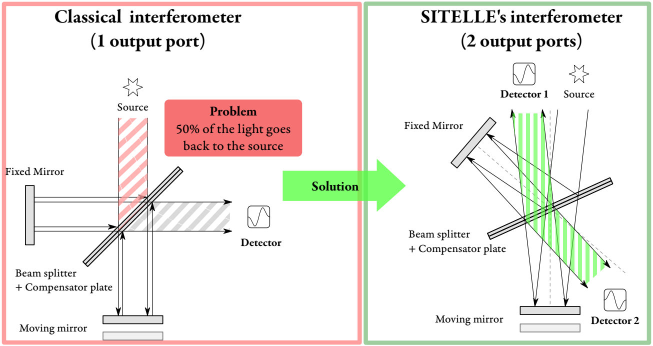
Measured intensity

How does it work ?





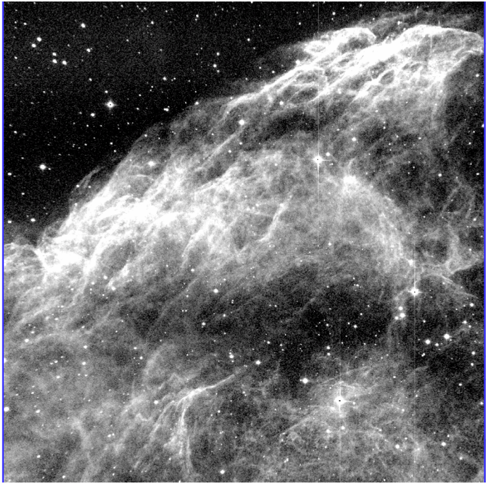
Measured intensity

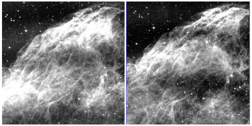


- Collect 100% of the incoming light instead of 50%
- Correct for sky transmission variations
- Remove scattered-light

Camera#1

Camera#2



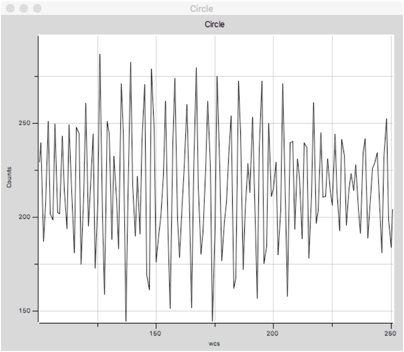


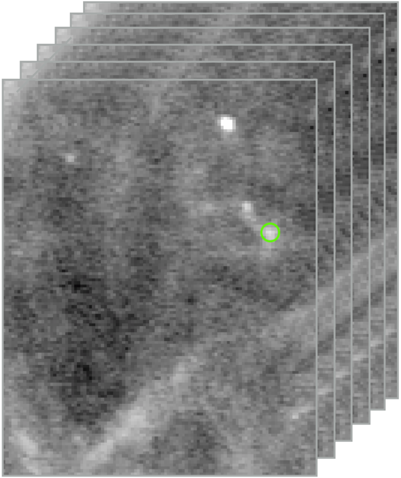
Technical challenges

For a **very good interference** at all wavelength (down to 350 nm) (i.e. a good modulation efficiency) we need:

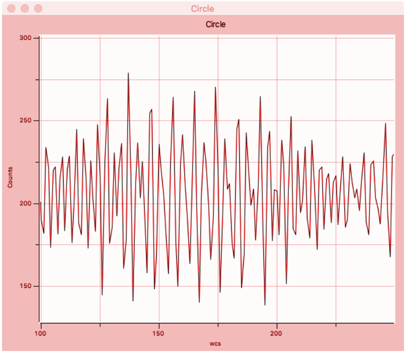
- A very good **optical flatness** ($\lambda/30$) on large optics (more than 12 cm).
- A **precisely known and stable position and angle of the mirrors** (~ 10 nm) : **servo control loop** based on 3 IR lasers which measure the position of the mirror in real time.
- a stable alignment of all the optics: **athermal** structure based on carbon fibre tubes.

Camera#1





Interferometric cube



Camera#2

ORBS is the data reduction software of SITELLE.

Fully **automated** and **robust**

Parallelized at **90%**

Easy to use (one command line to run it)

Scalable, works on any modern computer

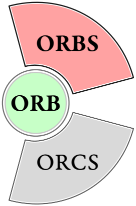
Process 64 Gb of row data in < 7 hours

General architecture

Data reduction module
(13 000 lines)

Core module
(23 000 lines)

Data analysis tools
(4 000 lines)



Written in **Python**

Free software

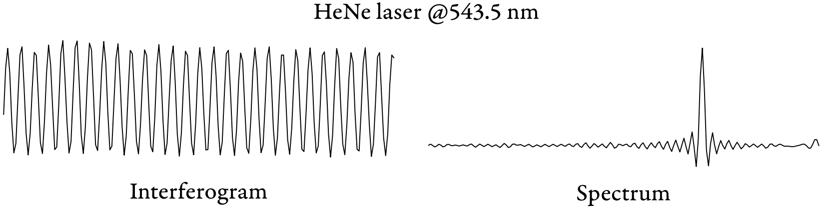
Object-oriented

Fully **documented**

sources @ https://sourceforge.net/u/thomasorbs/profile/

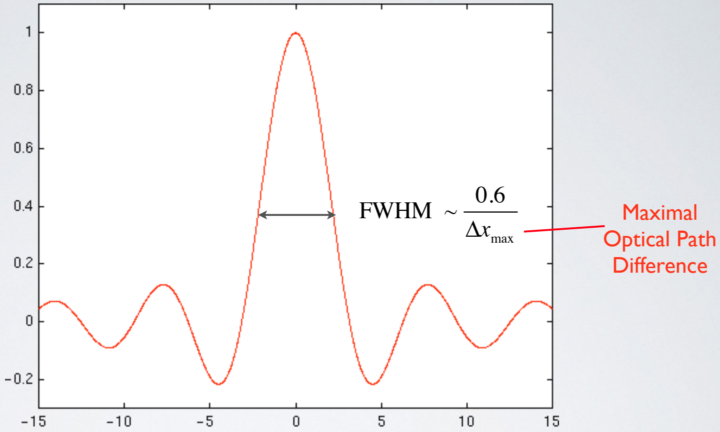
SITELLE as a spectrograph

Instrumental Line Shape (ILS)



- Natural ILS of Fourier transformed spectrum is a **sinc** not a gaussian. (i.e. strange wiggles near the lines are not noise).

$$\text{Instrument function} = FT\left[boxcar(x)\right] = 2d\,\frac{\sin(\omega d)}{\omega d}$$



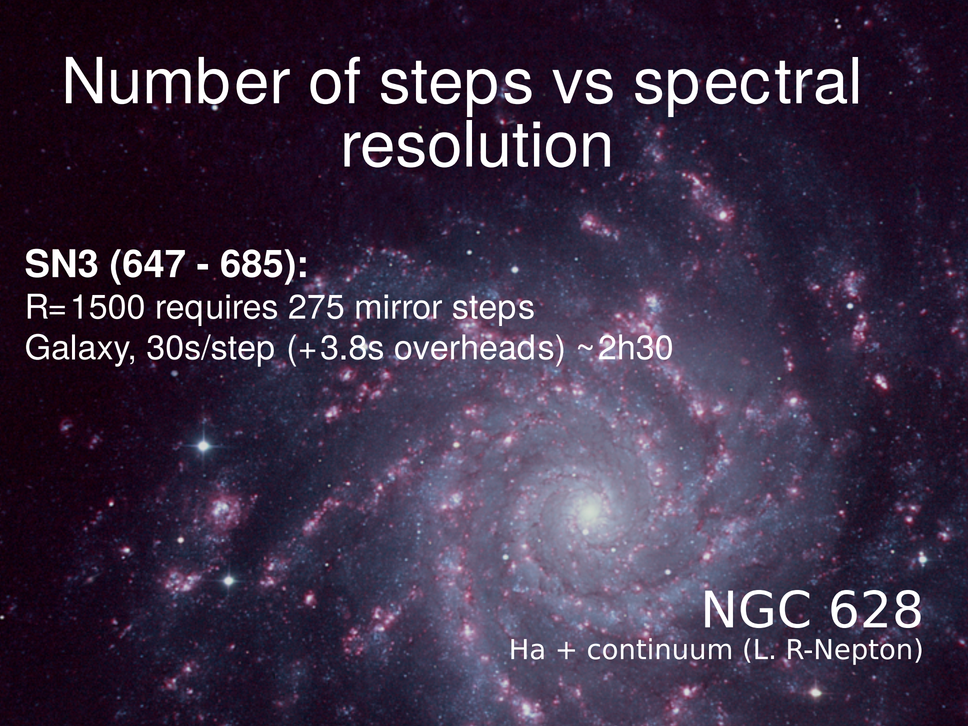
Spectral resolution is directly proportional to the total optical path difference (properly) sampled by the Michelson

Number of steps vs spectral resolution

SN3 (647 - 685):

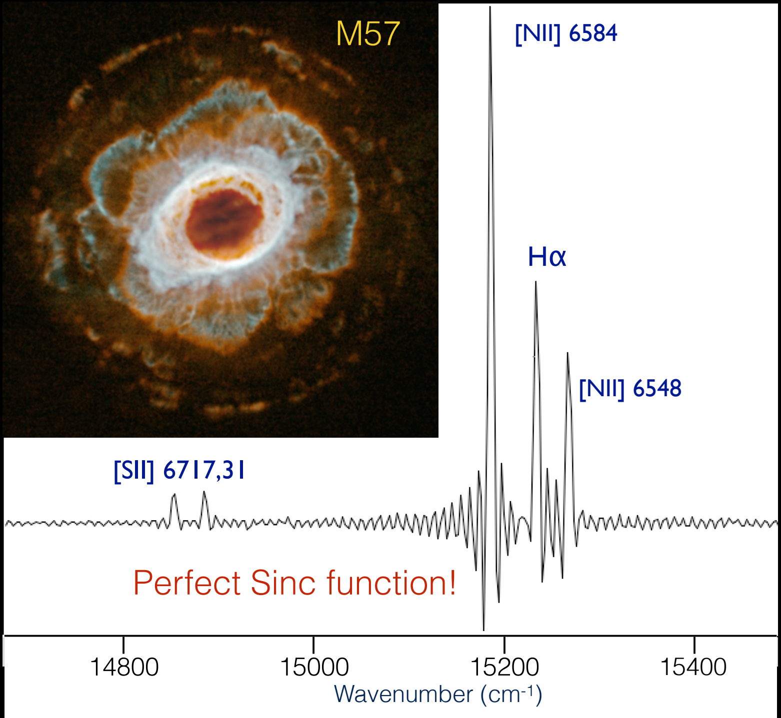
R=1500 requires 275 mirror steps

Galaxy, 30s/step (+3.8s overheads) ~2h30



NGC 628

Ha + continuum (L. R-Nepton)


M57
[NII] 6584
Hα
[NII] 6548
[SII] 6717,31
Perfect Sinc function!
14800
15000
15200
15400
Wavenumber (cm-1)

Data extraction: ORCS

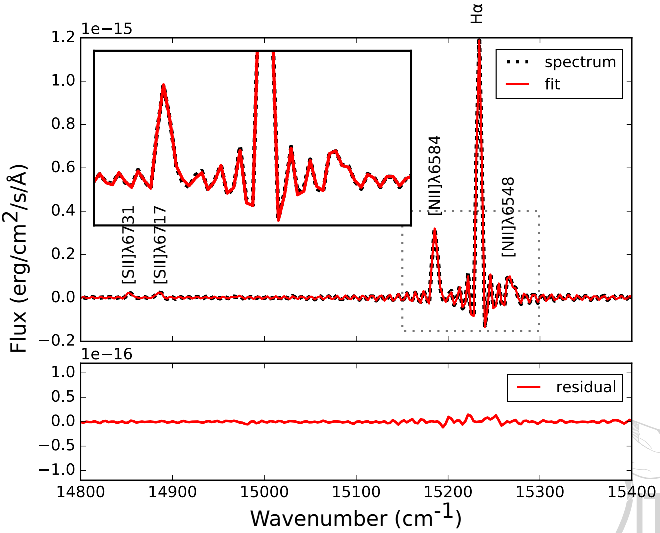
ORCS is a fitting engine for SITELLE.

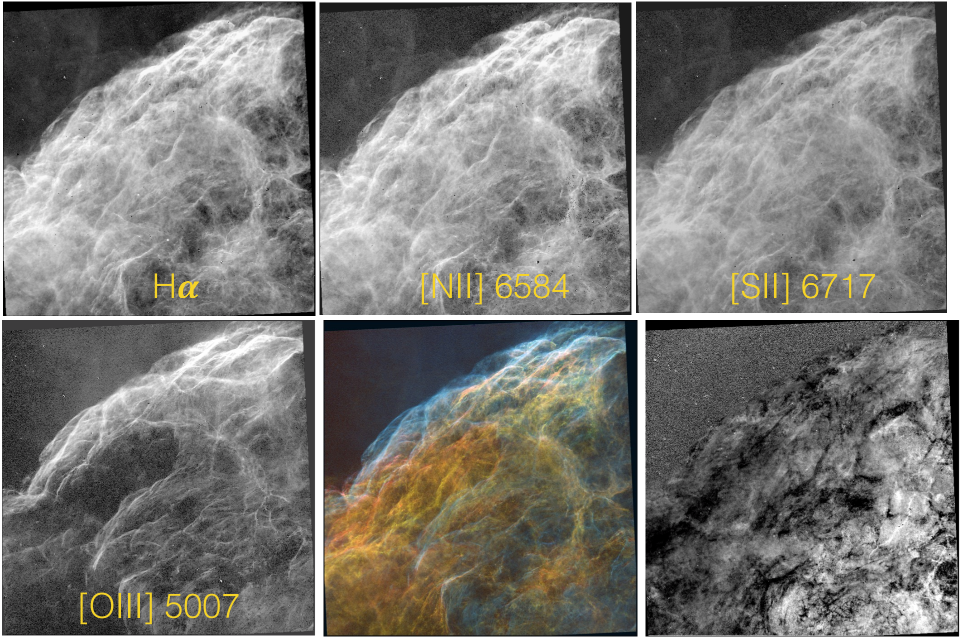
A wide variety of models
- emission lines
- continuum
- filter
- model grids

Multiply constrained

Parallelized at 100%

Example of a fit on one M57 spectrum





Line ratios

Doppler

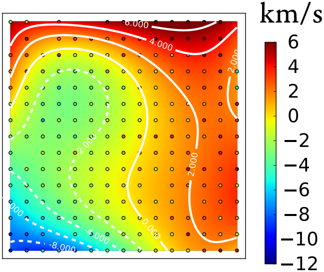
Data release 1: calibration checks

Wavelength calibration

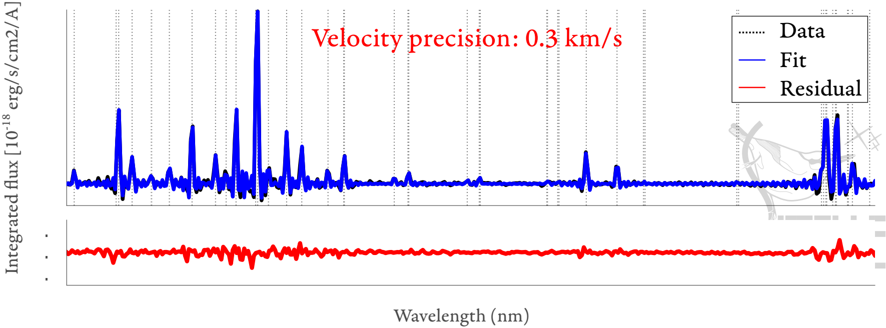
On Fourier transform spectra the velocity zero point is the only uncertainty.

Absolute calibration is done via the observation of a laser source.

It can be improved up to a **precision of 0.3 km/s by fitting sky lines (@R=5000, much better at higher resolution)**



Relative velocity map



Data Release 1 — Flux calibration

NGC3344 (Rousseau-Nepton et al.)	Hα vs SpIOMM	-4% ±2%
	Hα + [NII]λ6584 vs SpIOMM	-4% ±3%
M1-71	Hα vs Wright (2005)	-7% ±3%
	[NII]λ6584 vs Wright (2005)	-11% ±3%
NGC628	SN1 vs CALIFA	-6% ±6%
	SN2 vs CALIFA	-7% ±6%
	SN3 vs CALIFA	-9% ±6%
HETDEX Field (Drissen et al.)	Lyα flux of ~20 high redshift galaxies	-5%±7%

Flux « bias » has been corrected in the most recent version of ORBS -flux uncertainty ~ 5%

What about absorption lines?

4 - What about absorption lines?

Spectrographe **I**mageur à **T**ransformée de Fourier

pour l'**E**tude en **L**ong et en **L**arge de raies d'**E**mission

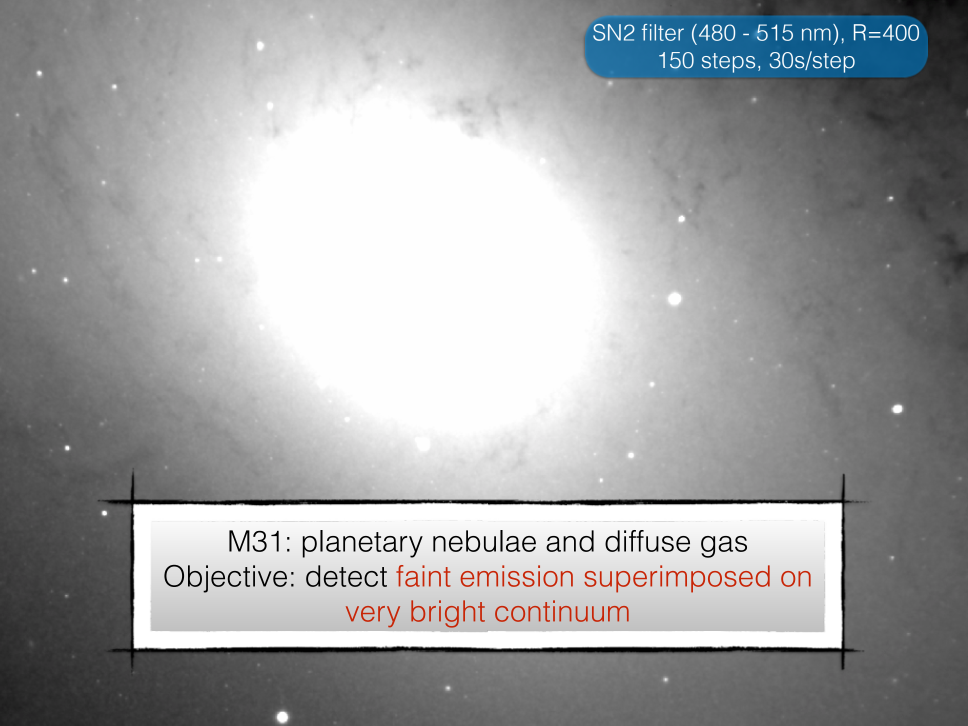
NGST Science and Technology Exposition
ASP Conference Series, Vol. 207, 2000
E. P. Smith, and K. S. Long, eds.

A Comparison of Imaging Spectrometers

Charles L. Bennett

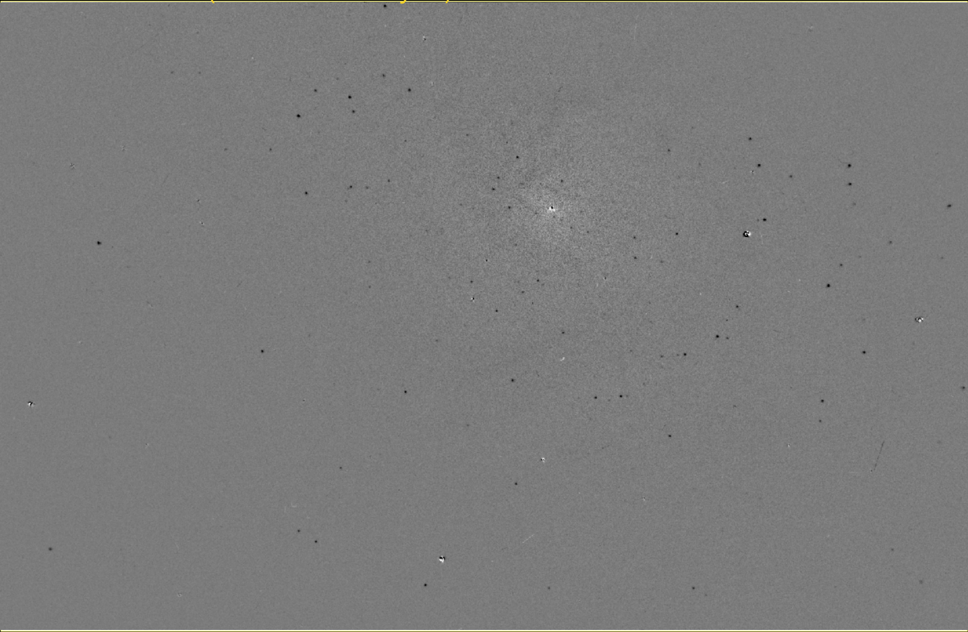
L-43, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California, 94550

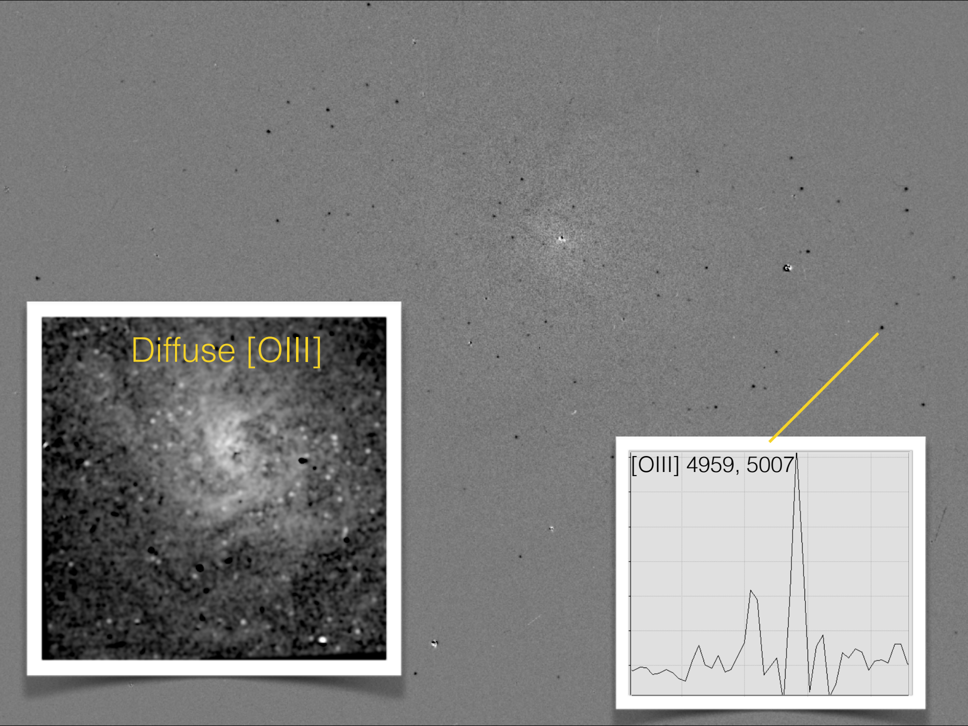
Abstract. Realistic signal to noise performance estimates for the various types of instruments being considered for NGST are compared, based on the point source detection values quoted in the available ISIM final reports. The corresponding sensitivity of the various types of spectrometers operating in a full field imaging mode, for both emission line objects and broad spectral distribution objects, is computed and displayed. For the purpose of seeing the earliest galaxies, or the faintest possible emission line sources, the imaging Fourier transform spectrometer emerges superior to all others, by orders of magnitude in speed.

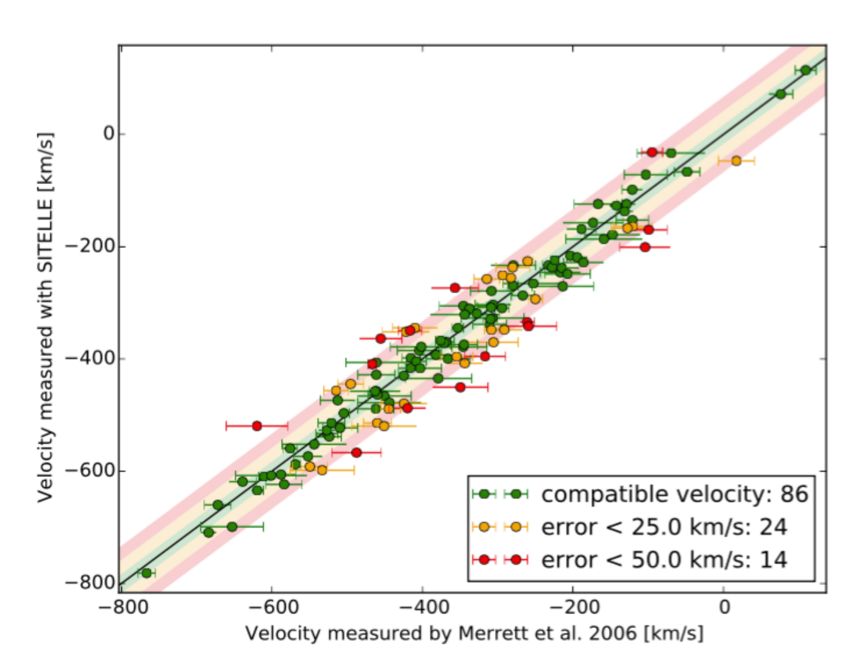

SN2 filter (480 - 515 nm), R=400
150 steps, 30s/step
M31: planetary nebulae and diffuse gas
Objective: detect faint emission superimposed on very bright continuum

Continuum (+ cosmic rays!)

[OIII] 5007

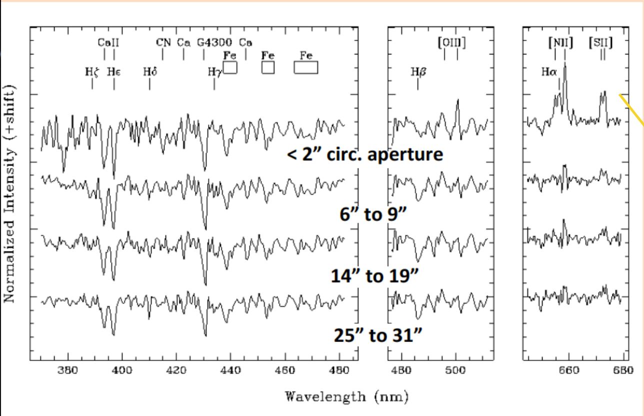



Diffuse [OIII]
[OIII] 4959, 5007

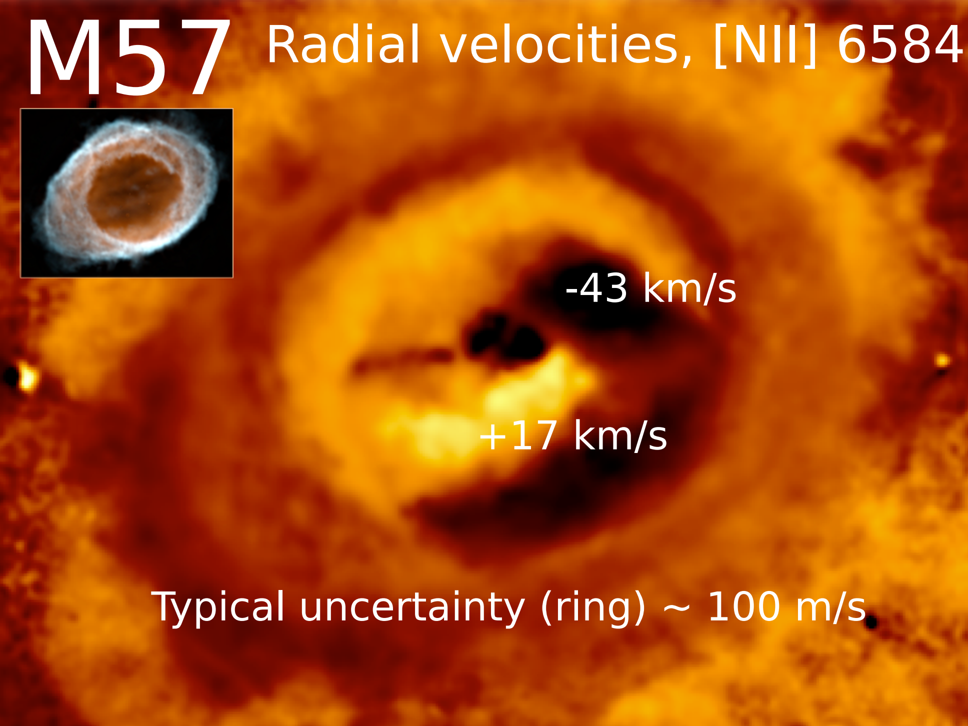


Velocity measured with SITELLE [km/s]
Velocity measured by Merrett et al. 2006 [km/s]
0
−200
−400
−600
−800
compatible velocity: 86
error < 25.0 km/s: 24
error < 50.0 km/s: 14

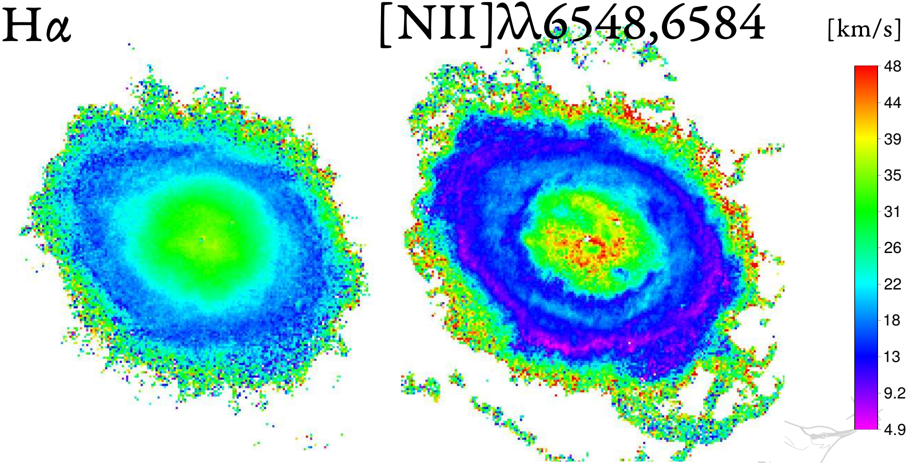
Arp 94
PI: C. Robert



Science teasers

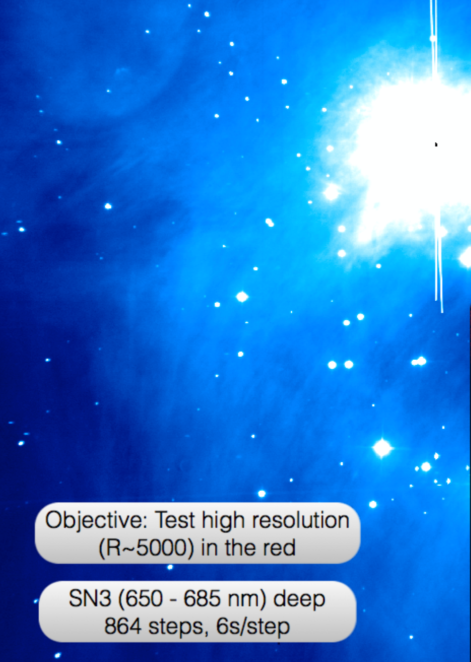

M57
Radial velocities, [NII] 6584
-43 km/s
+17 km/s
Typical uncertainty (ring) ~ 100 m/s

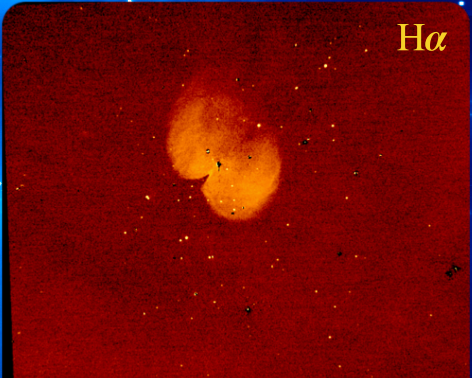
M57 velocity dispersion



We have measured the line broadening of Hα and the [NII] lines. The smoothness of the hydrogen bubble is due to its homogeneous distribution whereas the very thin [NII] shell reflects the geometry of the PDR.

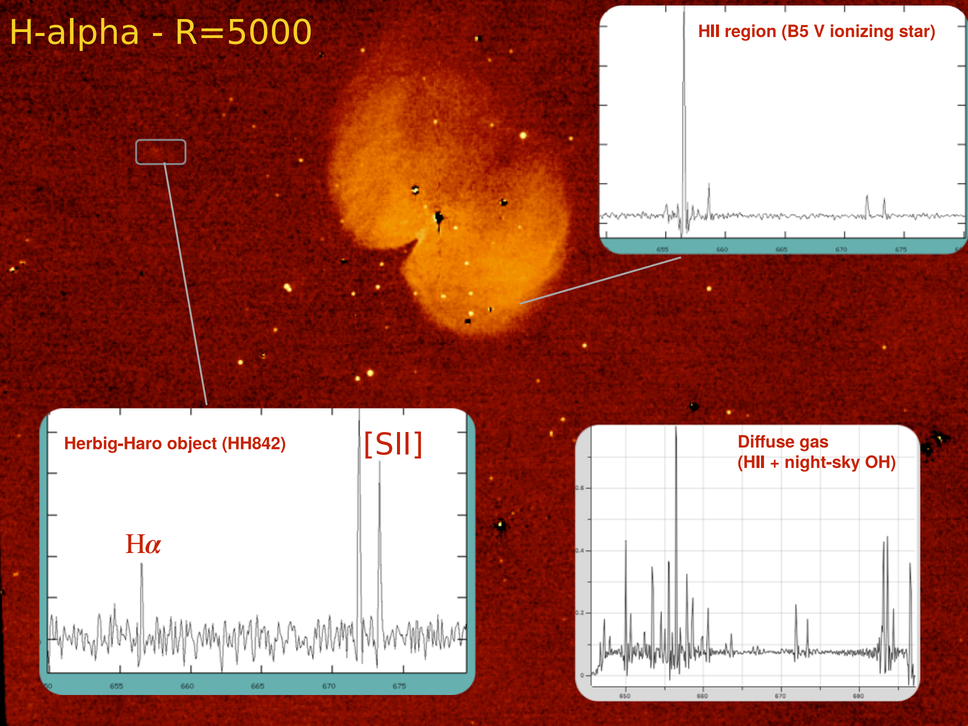
IC 348 (PI: Gregory Herczeg, Peking University)





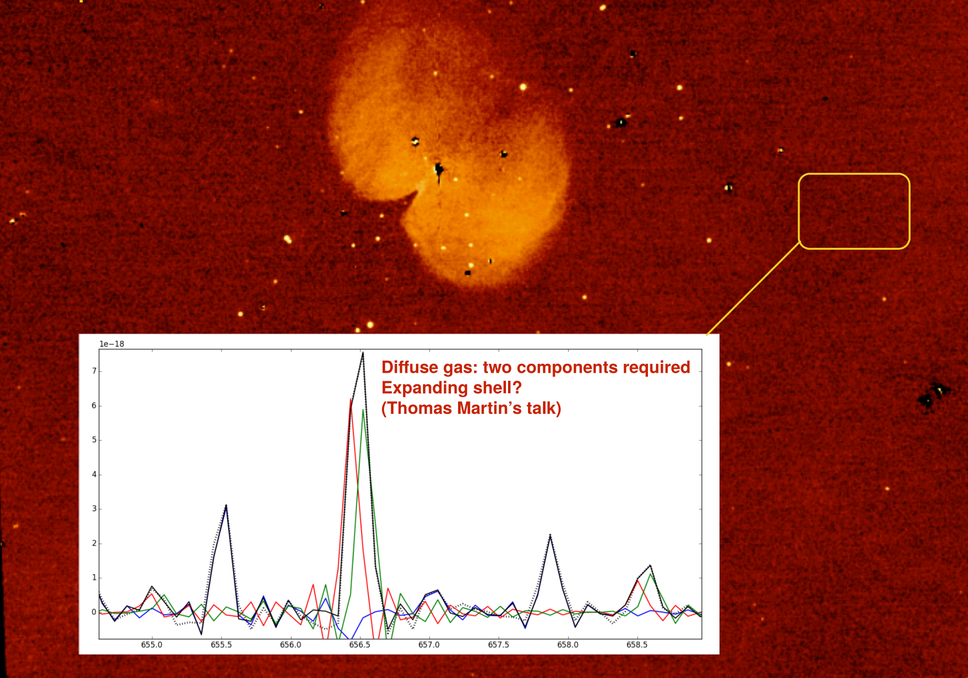
Objective: Test high resolution (R~5000) in the red

SN3 (650 - 685 nm) deep
864 steps, 6s/step

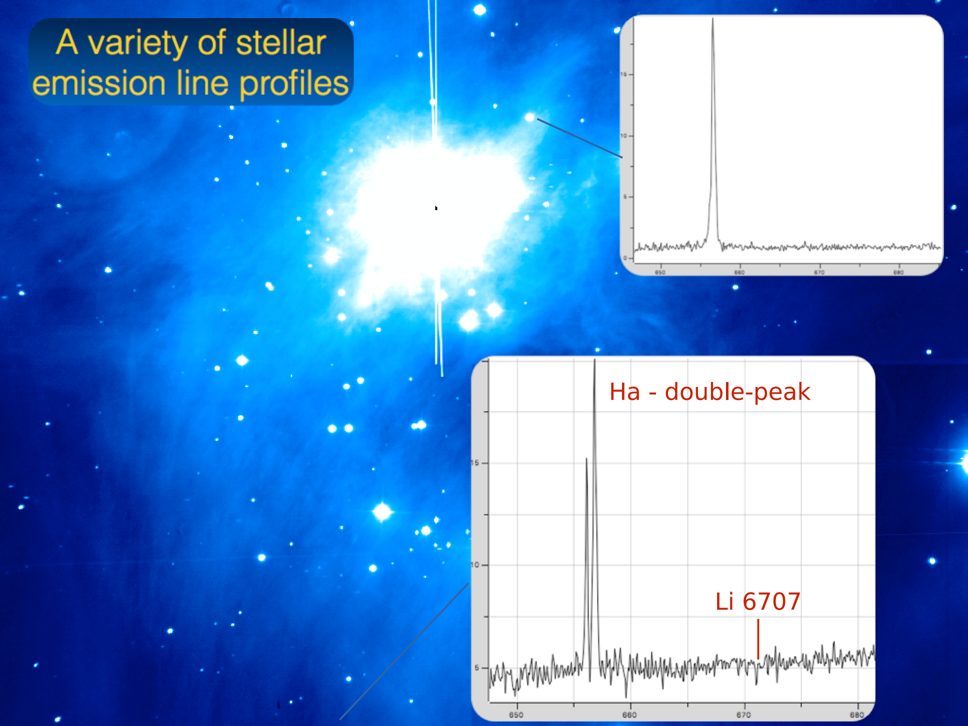


H-alpha - R=5000
HII region (B5 V ionizing star)
655
660
665
670
675
Herbig-Haro object (HH842)
[SII]
Hα
655
660
665
670
675
Diffuse gas
(HII + night-sky OH)
0.6
0.4
0.2
0
650
660
670
680

H-alpha - R=5000

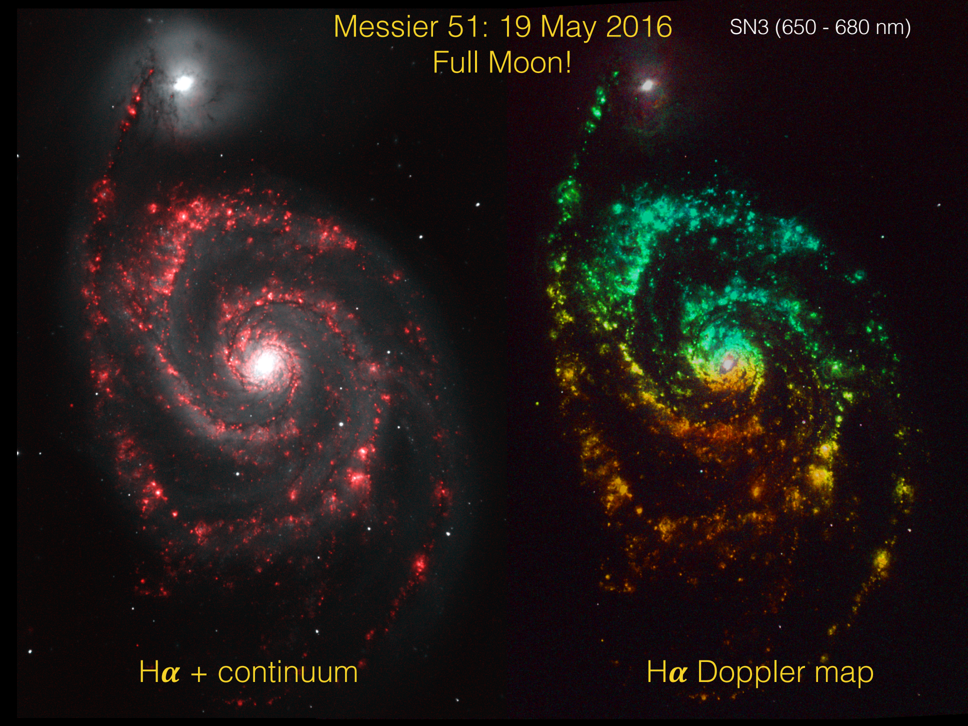


A variety of stellar emission line profiles

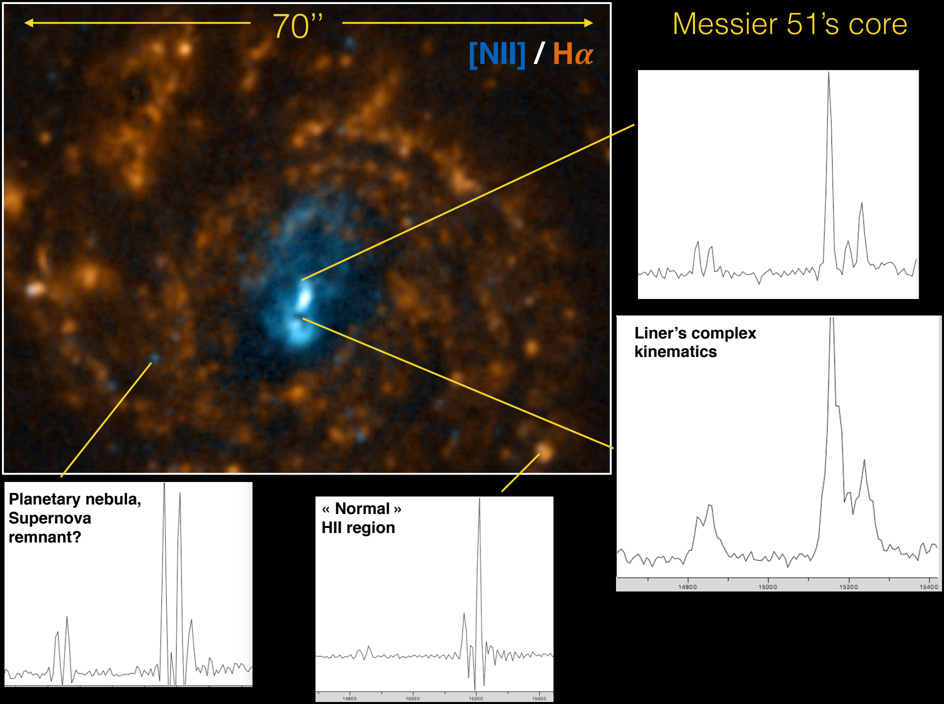


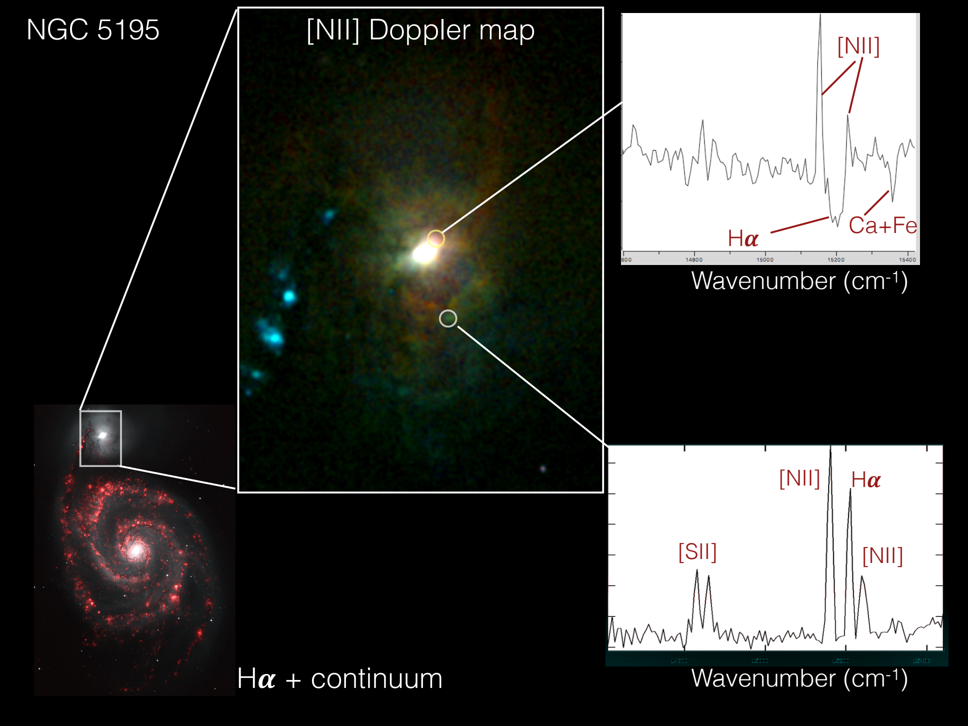
Science teasers

- Galactic science
- Nearby galaxies
- Galaxy clusters

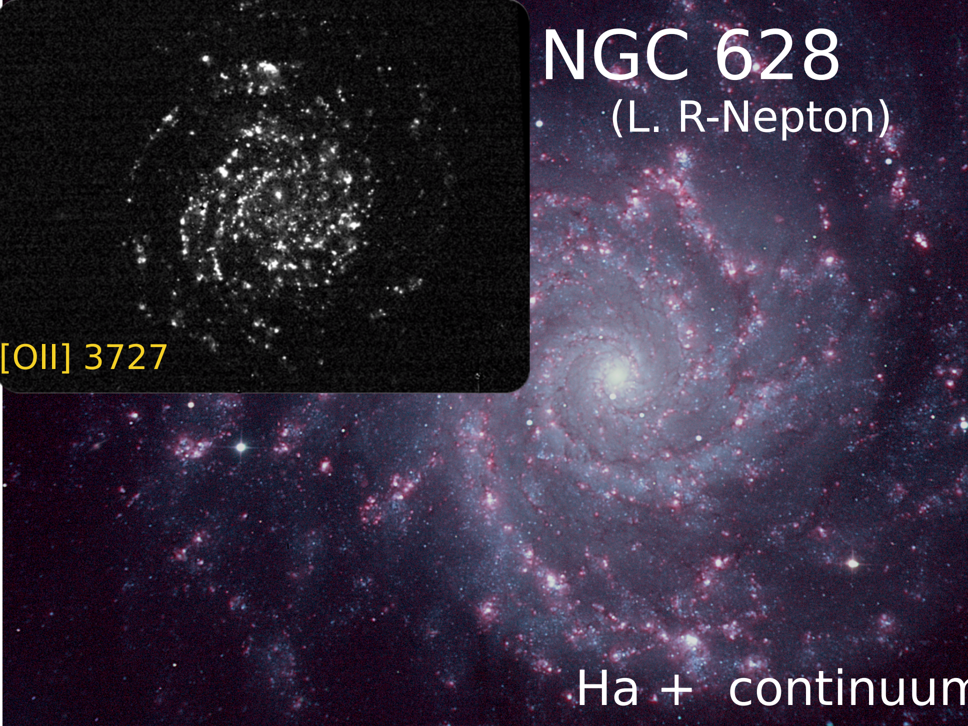

Messier 51: 19 May 2016
Full Moon!
SN3 (650 - 680 nm)
Hα + continuum
Hα Doppler map

Messier 51's core



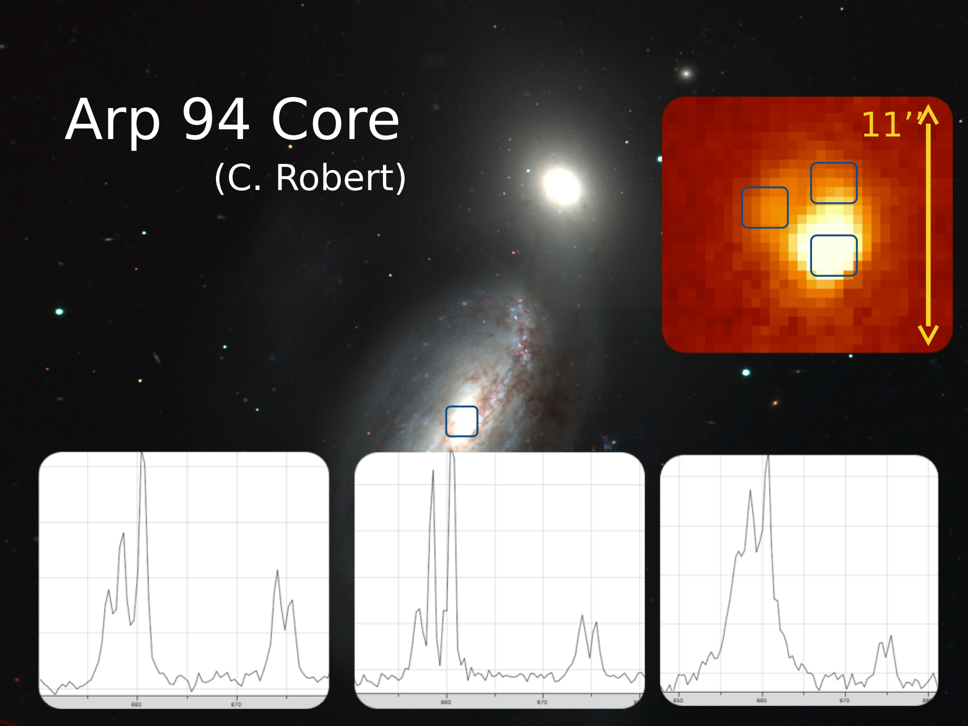


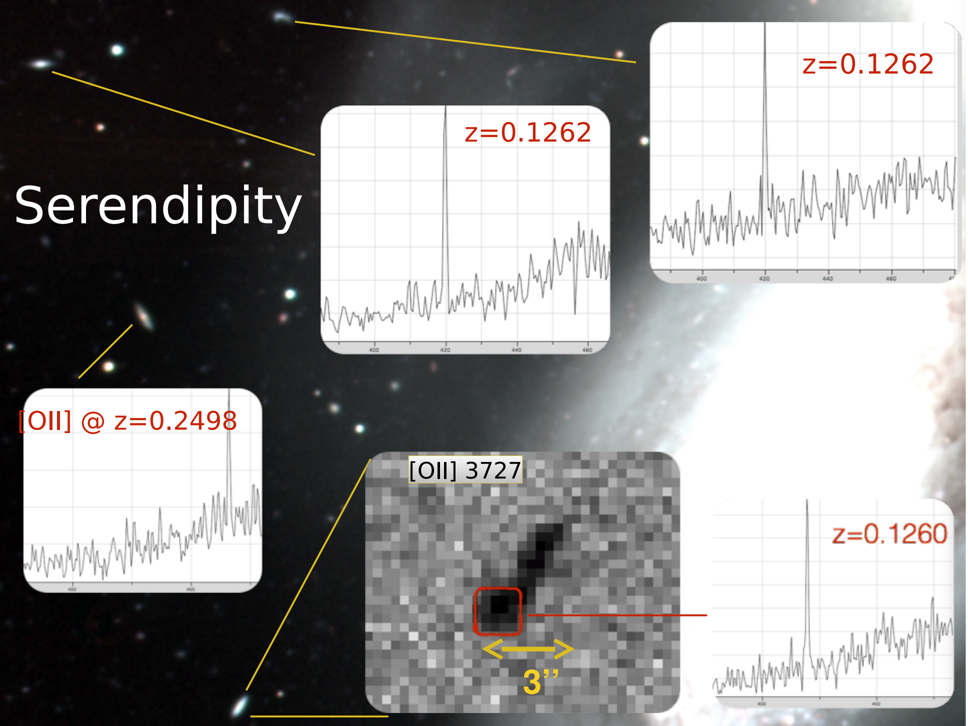
NGC 5195
[NII] Doppler map
[NII]
Hα
Ca+Fe
14800
15000
15200
15400
Wavenumber (cm-1)
[SII]
[NII]
Hα
[NII]
Wavenumber (cm-1)
Hα + continuum


NGC 628
(L. R-Nepton)
[OII] 3727
Ha + continuum

Arp 94 Core

(C. Robert)





Serendipity
z=0.1262
z=0.1262
[OII] @ z=0.2498
[OII] 3727
3''
z=0.1260

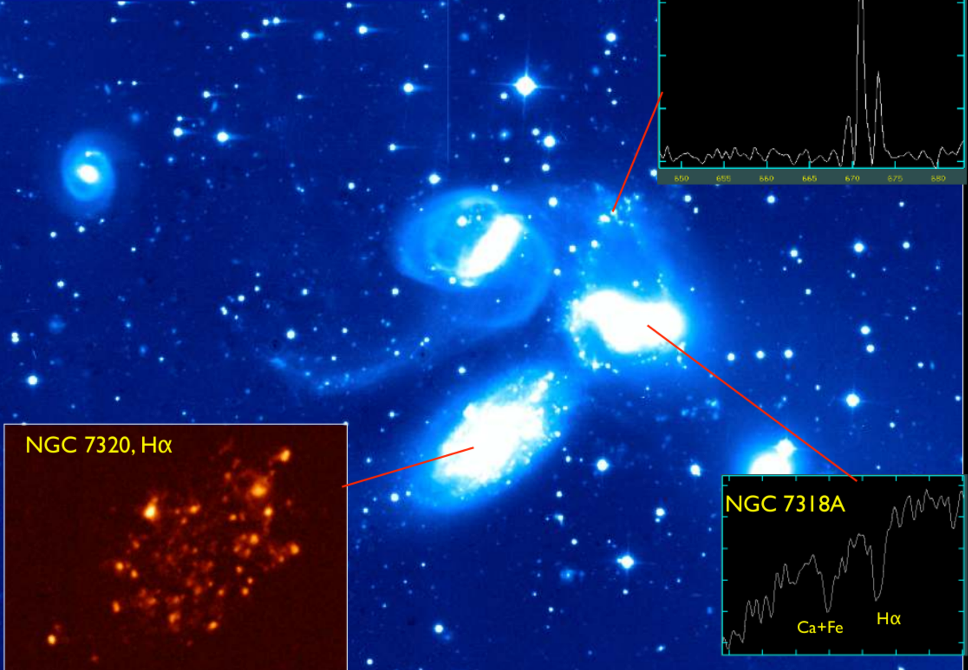
NGC 1275

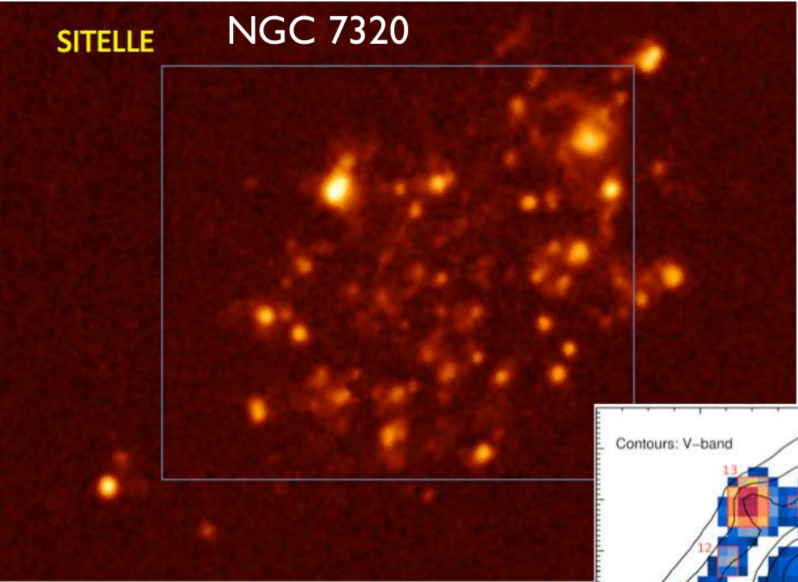
videos/N1275movie.mov

Science teasers

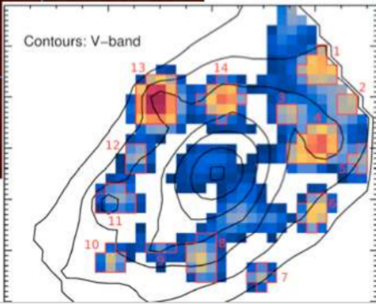
- Galactic science
- Nearby galaxies
- Galaxy clusters

Stephan's quintet



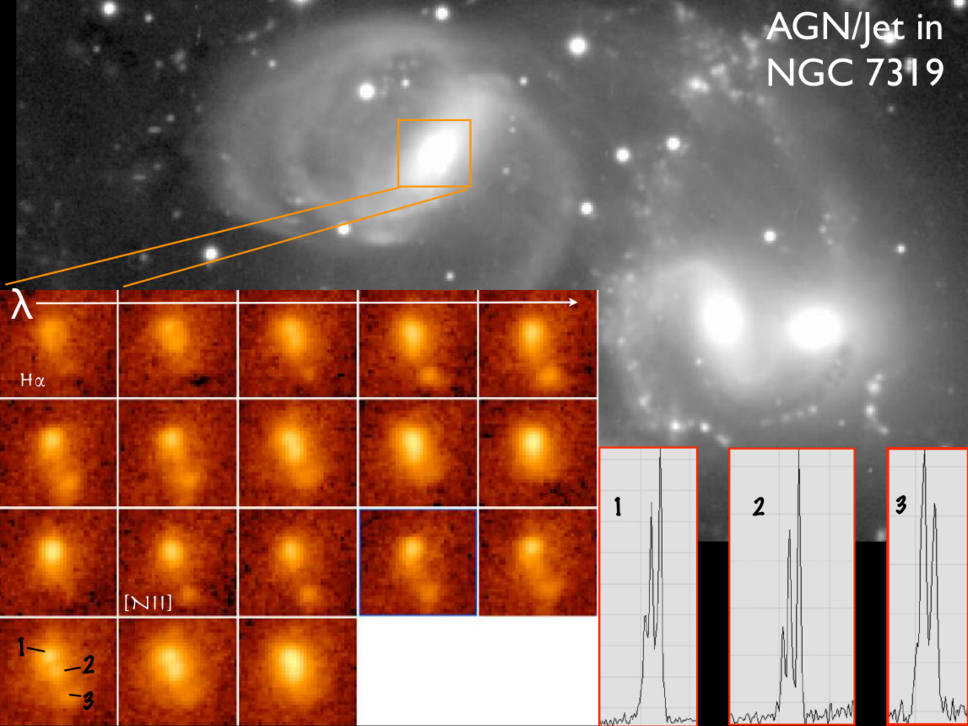


PPAK



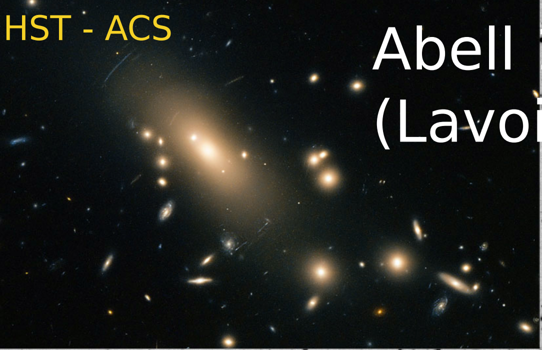
A study of the ionized gas in Stephan's Quintet from integral field spectroscopy observations*

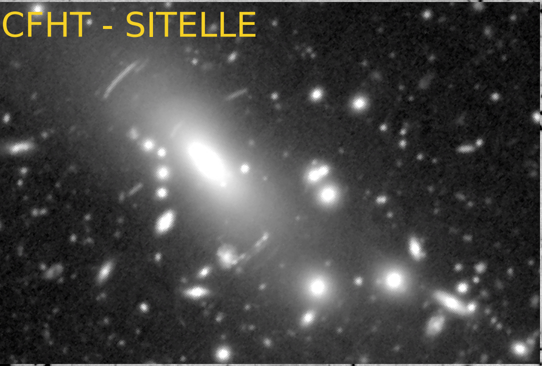
M. Rodríguez-Baras[1]†, F. F. Rosales-Ortega[2,1], A. I. Díaz[1], S. F. Sánchez[3,4], A. Pasquali[5]

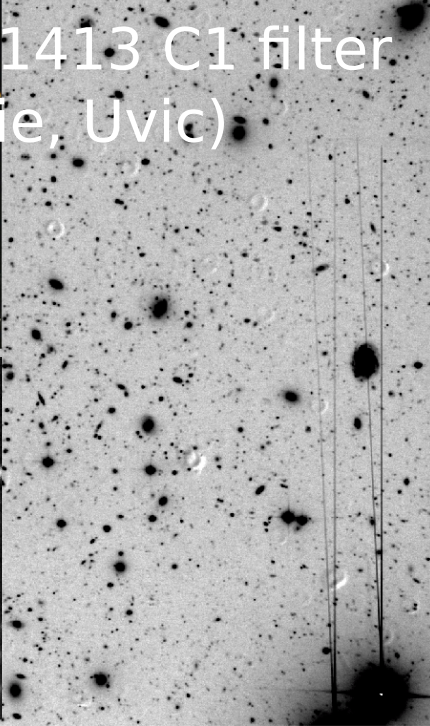


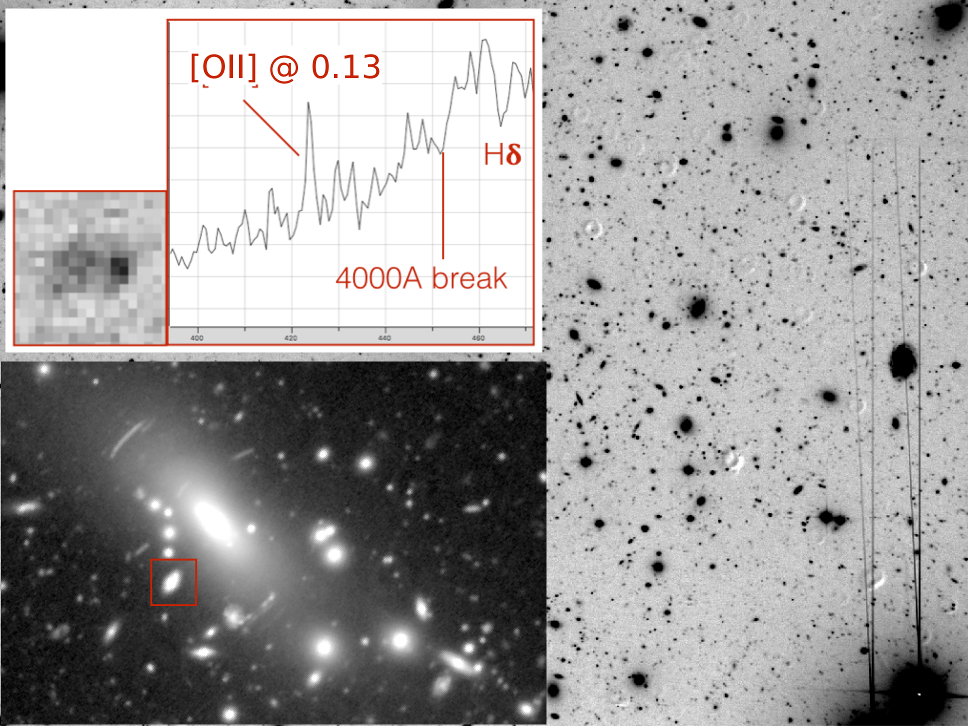
AGN/Jet in NGC 7319
λ
Hα
[NII]
1
2
3
1
2
3

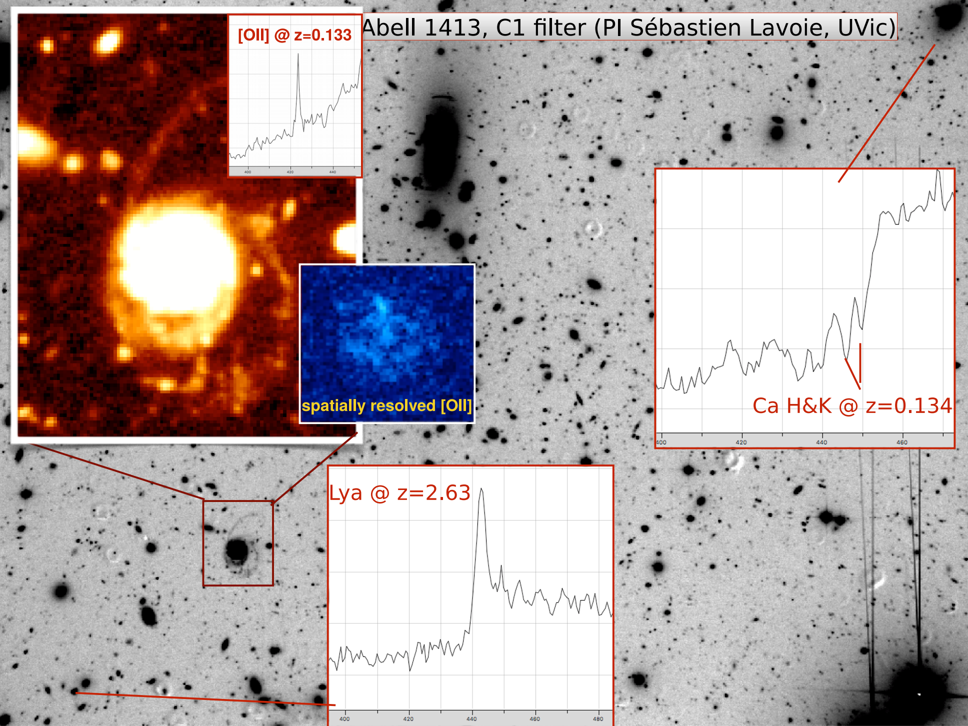
Abell 1413 C1 filter (Lavoie, Uvic)

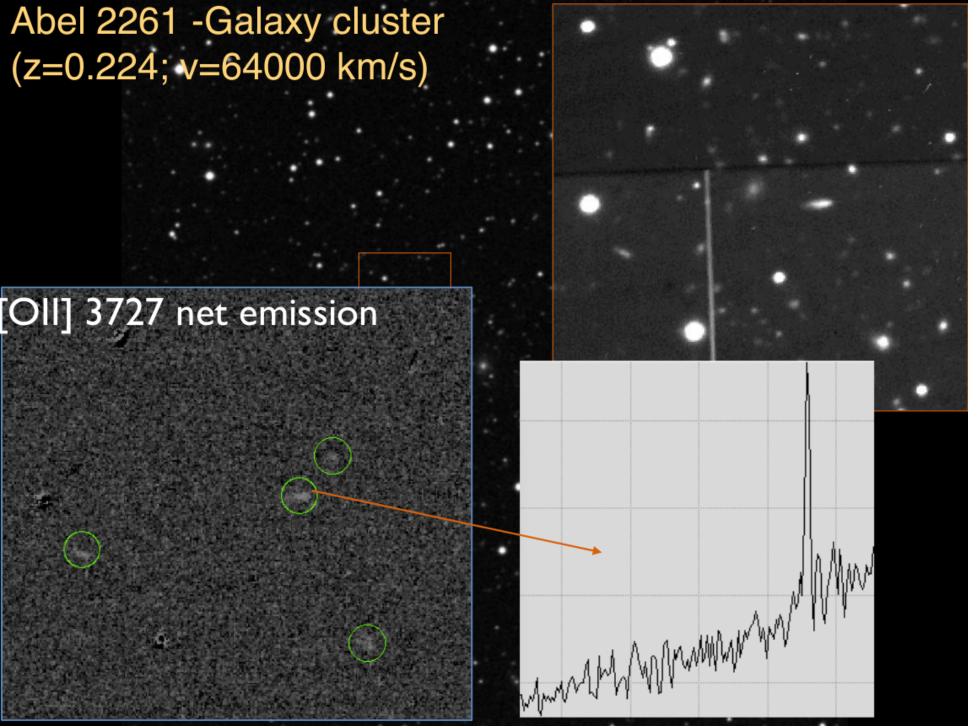






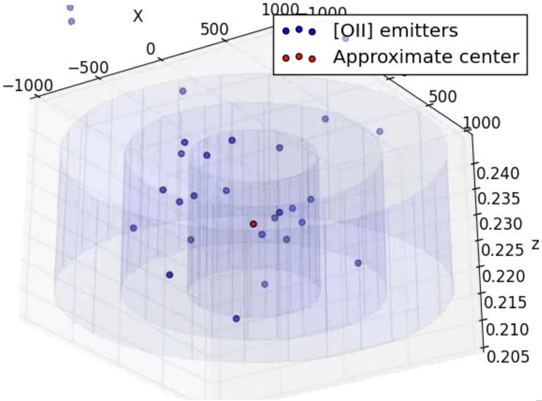

[OII] @ 0.13
Hδ
4000A break
400
420
440
460


Abell 1413, C1 filter (PI Sébastien Lavoie, UVic)
[OII] @ z=0.133
400
420
440
spatially resolved [OII]
Ca H&K @ z=0.134
400
420
440
460
Lya @ z=2.63
400
420
440
460
480



Abel 2261 -Galaxy cluster
(z=0.224; v=64000 km/s)
[OII] 3727 net emission

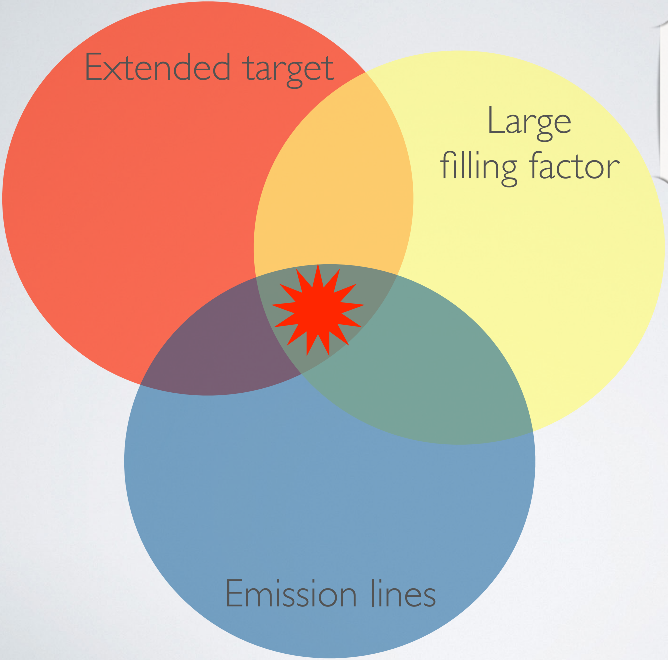
Abell2261 - newly detected [0II] emitters

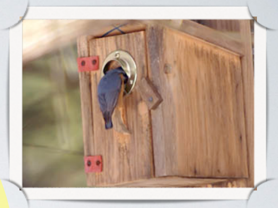


30 new [OII]3727 emitters in A2261 with redshifts around 0.2 (Lavoie et al.)

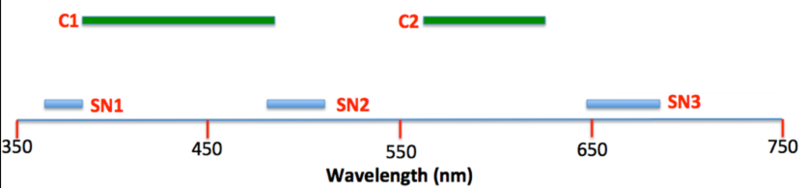
Conclusion

A niche for SITELLE





Need for more filters?



* Narrow band for high resolution?
* Filters in the red (Ca triplet)?
* Special purpose (absorption lines in galaxies)?

SITELLE is available to the French community!
Don't hesitate to ask if you would like to use it!

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ITELLE

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