Title: Star-Formation in the local Universe and high-resolution imaging spectroscopy.

Speakers: Laurie Rousseau-Nepton
Date: September 27, 2023 - 11:00 AM

URL: https://pirsa.org/23090101

Abstract: This seminar will be divided in two segments: 1) New Instrumentation for Astronomy and 2) the SIGNAL-Survey of Star-forming regions in Nearby Galaxy.

1) Evolution of technologies and optics manufacturing technics are providing new interesting options for the design of astronomical instruments to increase precision and add new capabilities. In this presentation, I will discuss my new laboratory plan at the University of Toronto to include Micro-kinetic inductance detector arrays and meta-surface optics to a Fourier Transform Imaging spectrograph design. The goal is to reach high-spectral resolution (R:15,000 to 80,000) over a large field-of-view, while keeping high sensitivity.

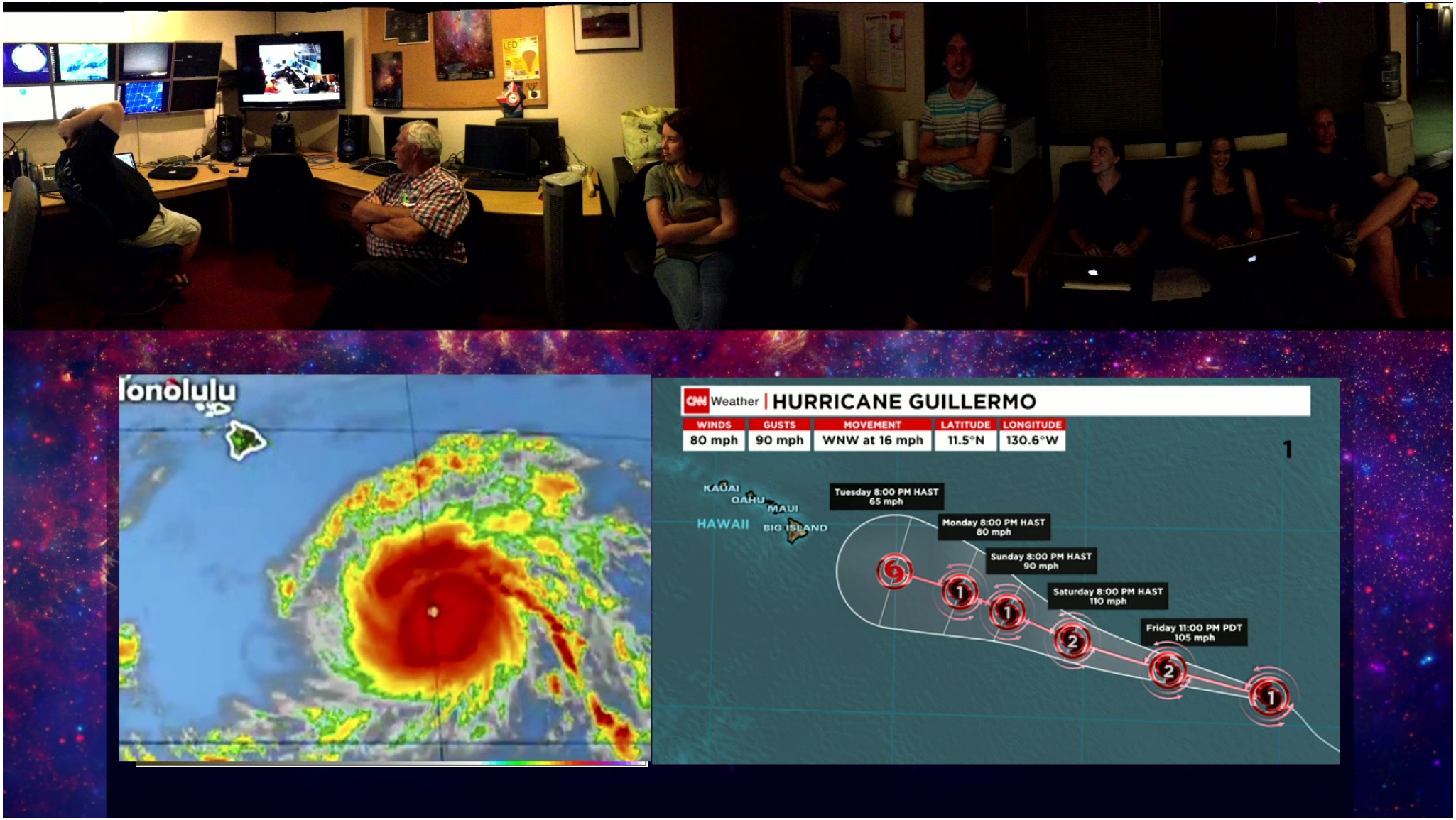
2) SIGNALS stands for the Star formation, Ionized Gas, and Nebular Abundances Legacy Survey. Using a Fourier Transform Imaging Spectrograph SITELLE, at the Canada-France-Hawaii Telescope, we observed 40 nearby galaxies and covered over 50,000 star-forming regions in different environment at a spatial resolution from 0.5 to 40 pc. Covering several emission line spectral features including Halpha (at R: 5,000), the survey aims at characterizing the star-forming sites and their environments to produce the most complete and well resolved database on star formation.

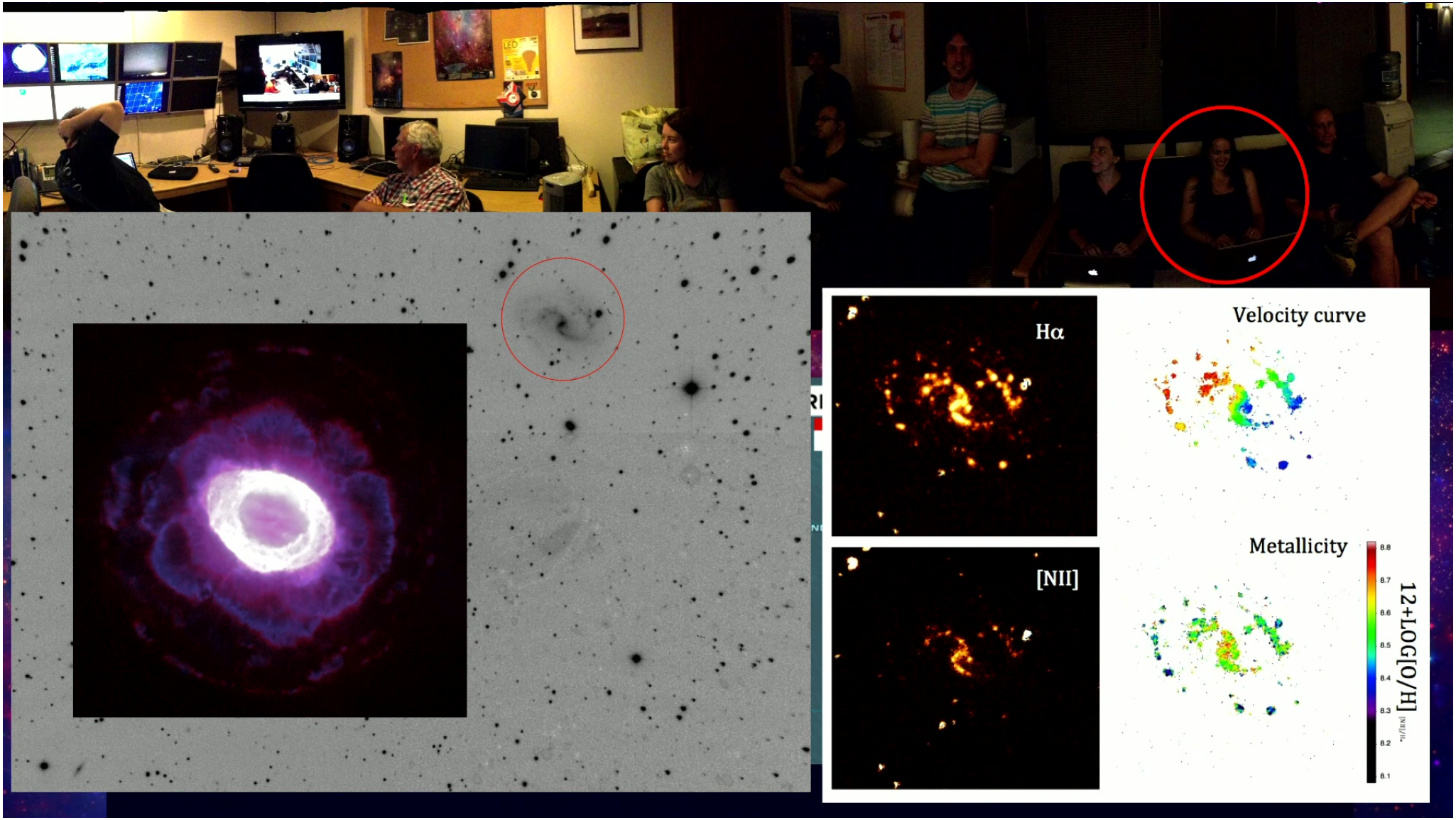
Zoom link https://pitp.zoom.us/j/94273599584?pwd=TUY3UFpVa20wbkJUcEdoTmlYUzlQUT09

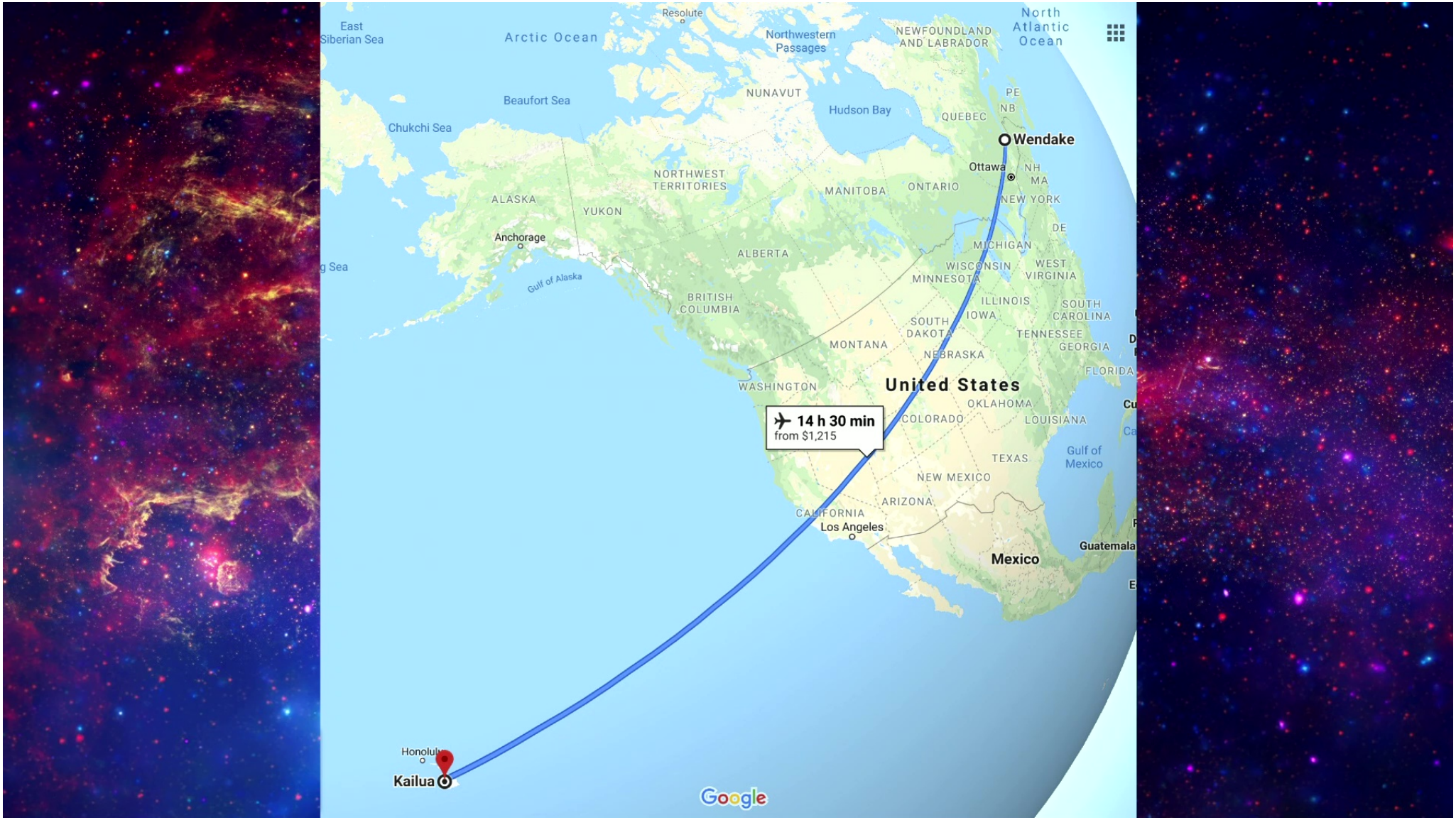
Bio:

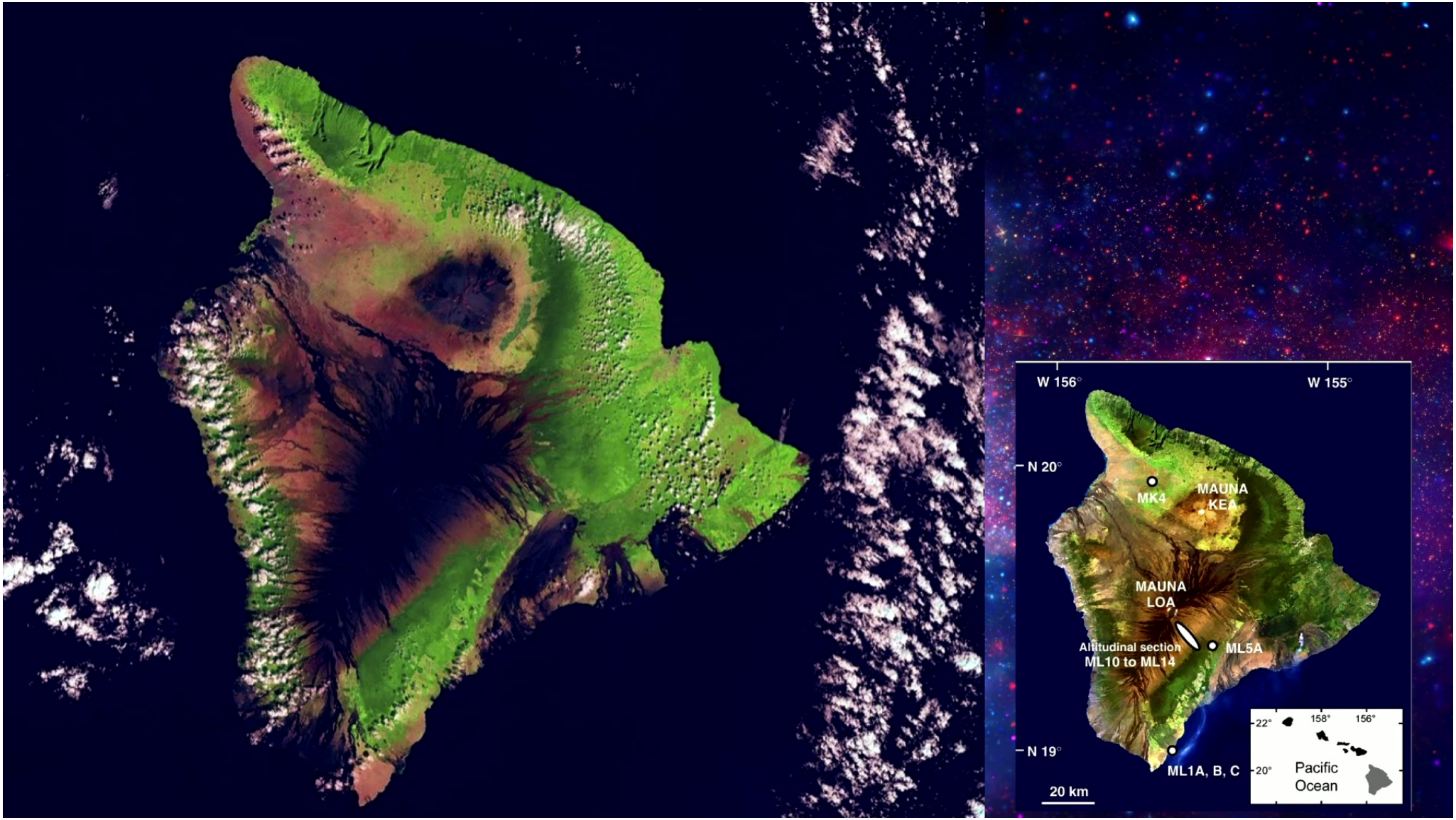
Laurie Rousseau-Nepton is a new faculty at the University of Toronto and the Dunlap Institute for Astronomy and Astrophysics. She comes with six years of experience working as a resident astronomer at the Canada-France-Hawaii Observatory supporting various instruments including wide-field cameras, high-resolution spectrographs, Fourier Transform Spectro-imager. She received her diploma from Université Laval by studying regions of star formation in spiral galaxies and helping with the development of two Fourier Transform Spectro-imagers, SpIOMM and SITELLE. She is now leading an international project called SIGNALS, the Star formation, Ionized Gas, and Nebular Abundances Legacy Survey, which sampled with the SITELLE instrument more than 50,000 of star-forming regions in 40 nearby galaxies to understand how the local environment affect the young star clusters characteristics.


SIGNALS
ITELLE
CFH
SIGNALS: A Survey of Star-Forming Regions in the Local Universe
Laurie Rousseau-Nepton, PhD
Assistant Professor UoT

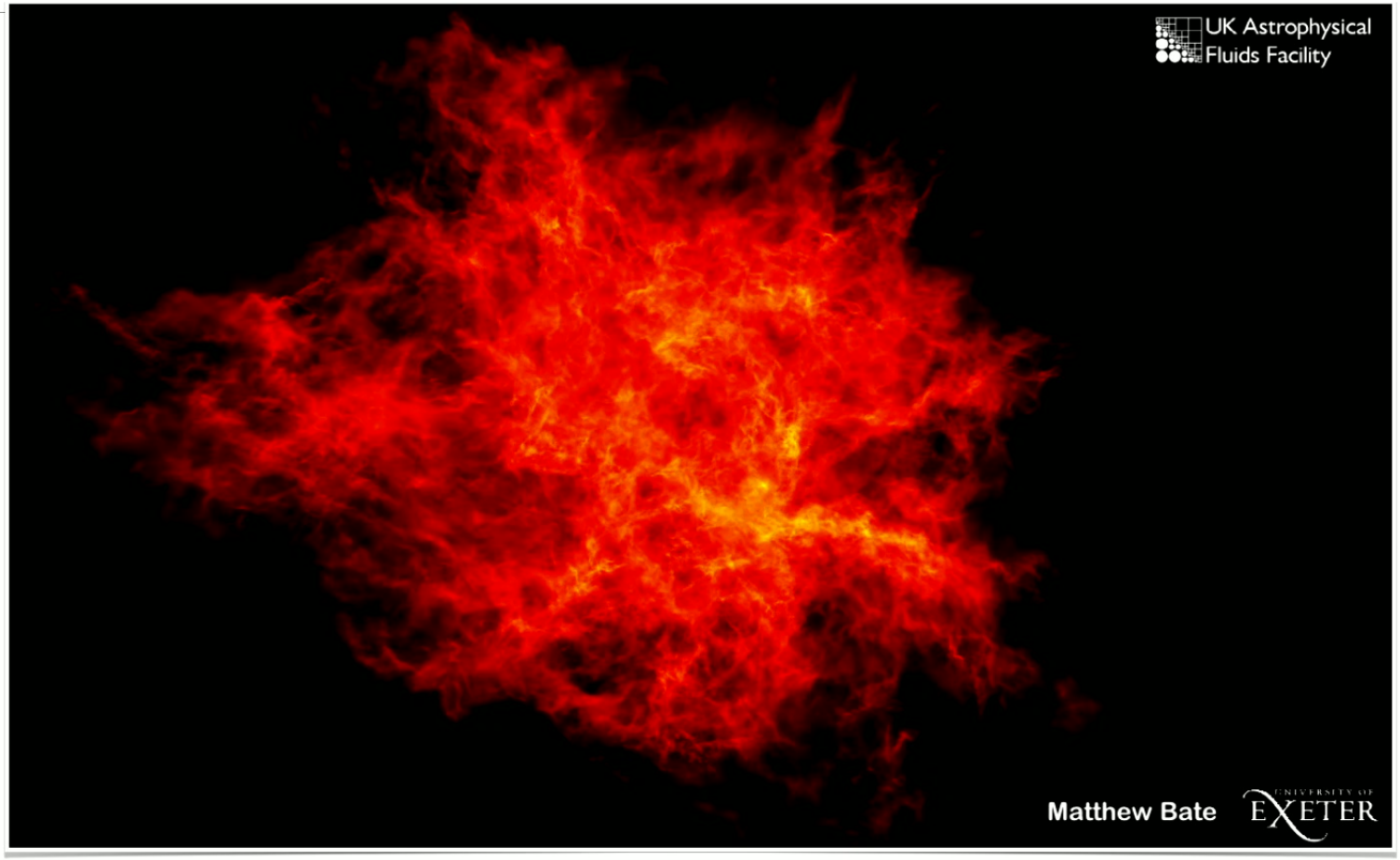

Honolulu
CNN Weather | HURRICANE GUILLERMO
WINDS
80 mph
GUSTS
90 mph
MOVEMENT
WNW at 16 mph
LATITUDE
11.5°N
LONGITUDE
130.6°W
KAUAI
OAHU
MAUI
HAWAII
BIG ISLAND
Tuesday 8:00 PM HAST
65 mph
Monday 8:00 PM HAST
80 mph
Sunday 8:00 PM HAST
90 mph
Saturday 8:00 PM HAST
110 mph
Friday 11:00 PM PDT
105 mph

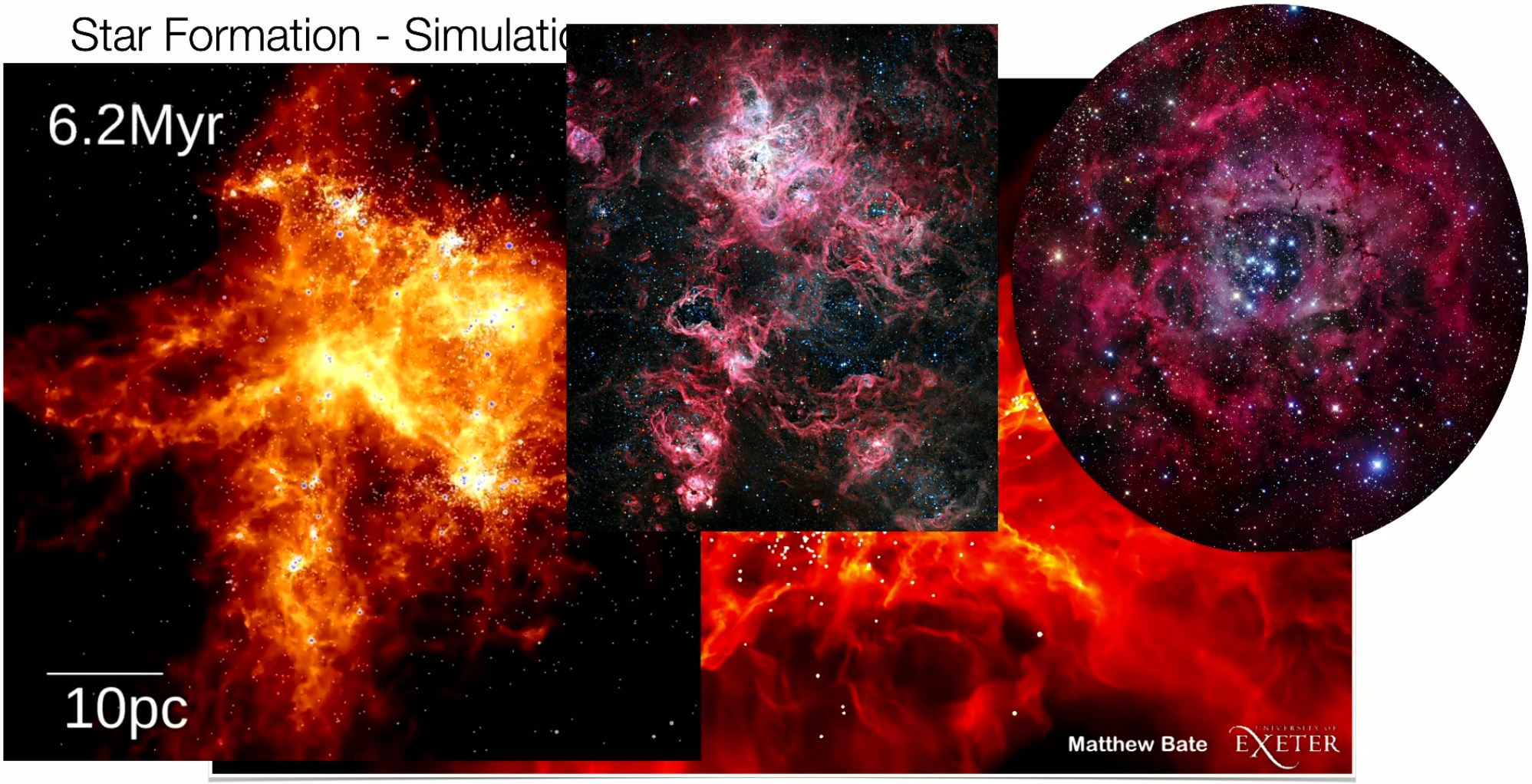

Hα
[NII]
Velocity curve
Metallicity
12+LOG[O/H]
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1


Resolute
East Siberian Sea
Arctic Ocean
Northwestern Passages
NEWFOUNDLAND AND LABRADOR
North Atlantic Ocean
Beaufort Sea
NUNAVUT
Hudson Bay
PE
NB
QUEBEC
Chukchi Sea
Wendake
Ottawa
NH
MA
NORTHWEST TERRITORIES
MANITOBA
ONTARIO
NEW YORK
ALASKA
YUKON
DE
Anchorage
MICHIGAN
ALBERTA
WISCONSIN
WEST VIRGINIA
MINNESOTA
Gulf of Alaska
BRITISH COLUMBIA
ILLINOIS
SOUTH CAROLINA
IOWA
SOUTH DAKOTA
TENNESSEE
MONTANA
GEORGIA
NEBRASKA
FLORIDA
WASHINGTON
United States
OKLAHOMA
14 h 30 min
from $1,215
COLORADO
LOUISIANA
Gulf of Mexico
TEXAS
NEW MEXICO
ARIZONA
CALIFORNIA
Los Angeles
Guatemala
Mexico
Honolulu
Kailua
Google

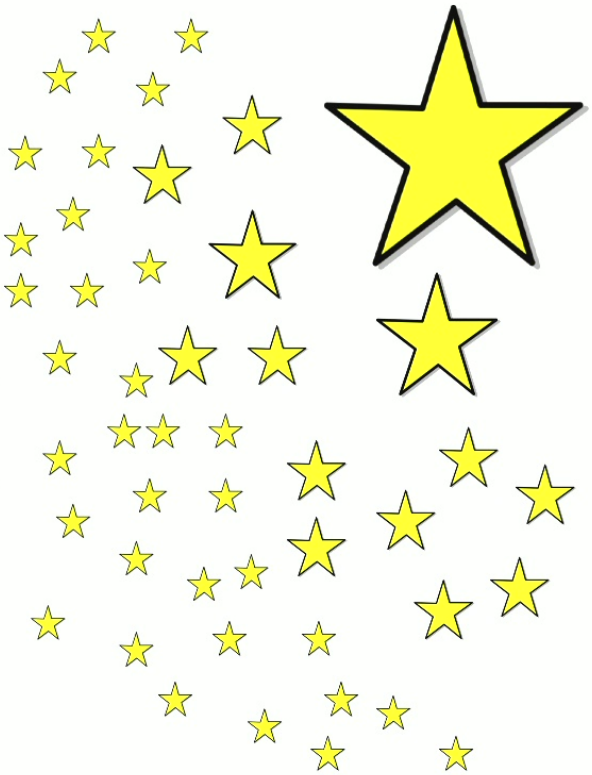

W 156°
W 155°
N 20°
N 19°
MK4
MAUNA KEA
MAUNA LOA
Altitudinal section ML10 to ML14
ML5A
ML1A, B, C
20 km
22°
20°
158°
156°
Pacific Ocean

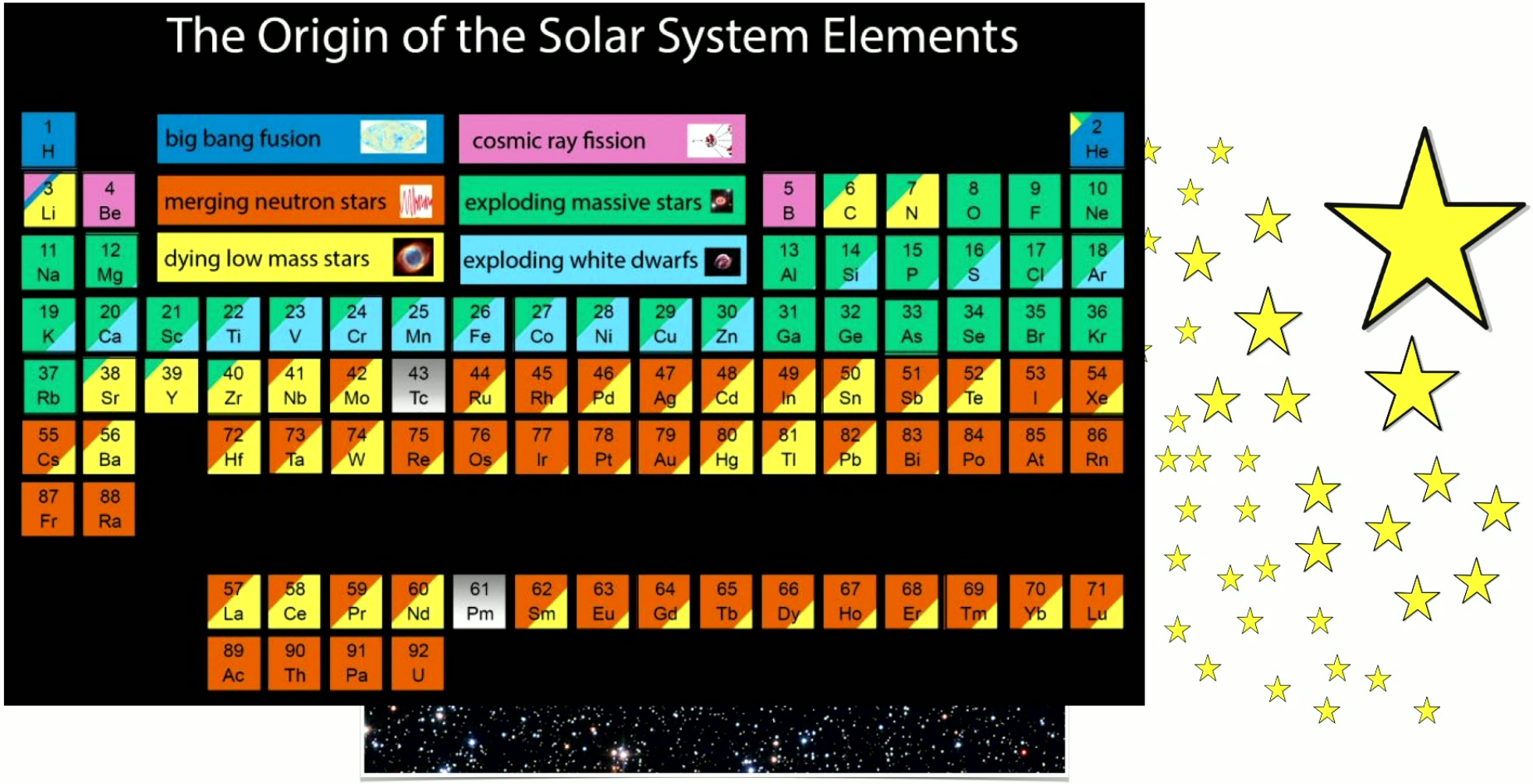
Star Formation - Simulation

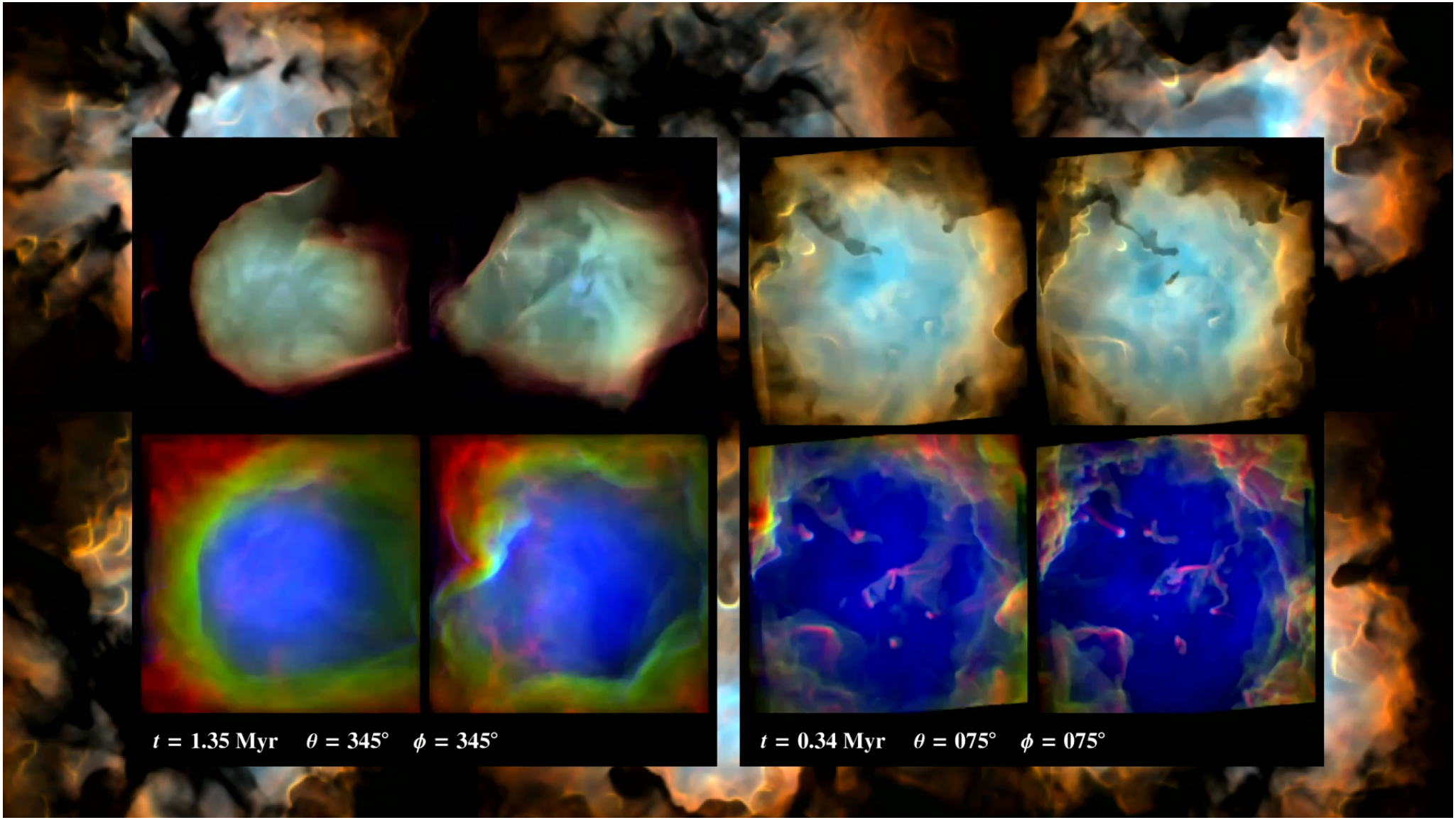



Star Formation - Simulatio
6.2Myr
10pc
Matthew Bate
EXETER

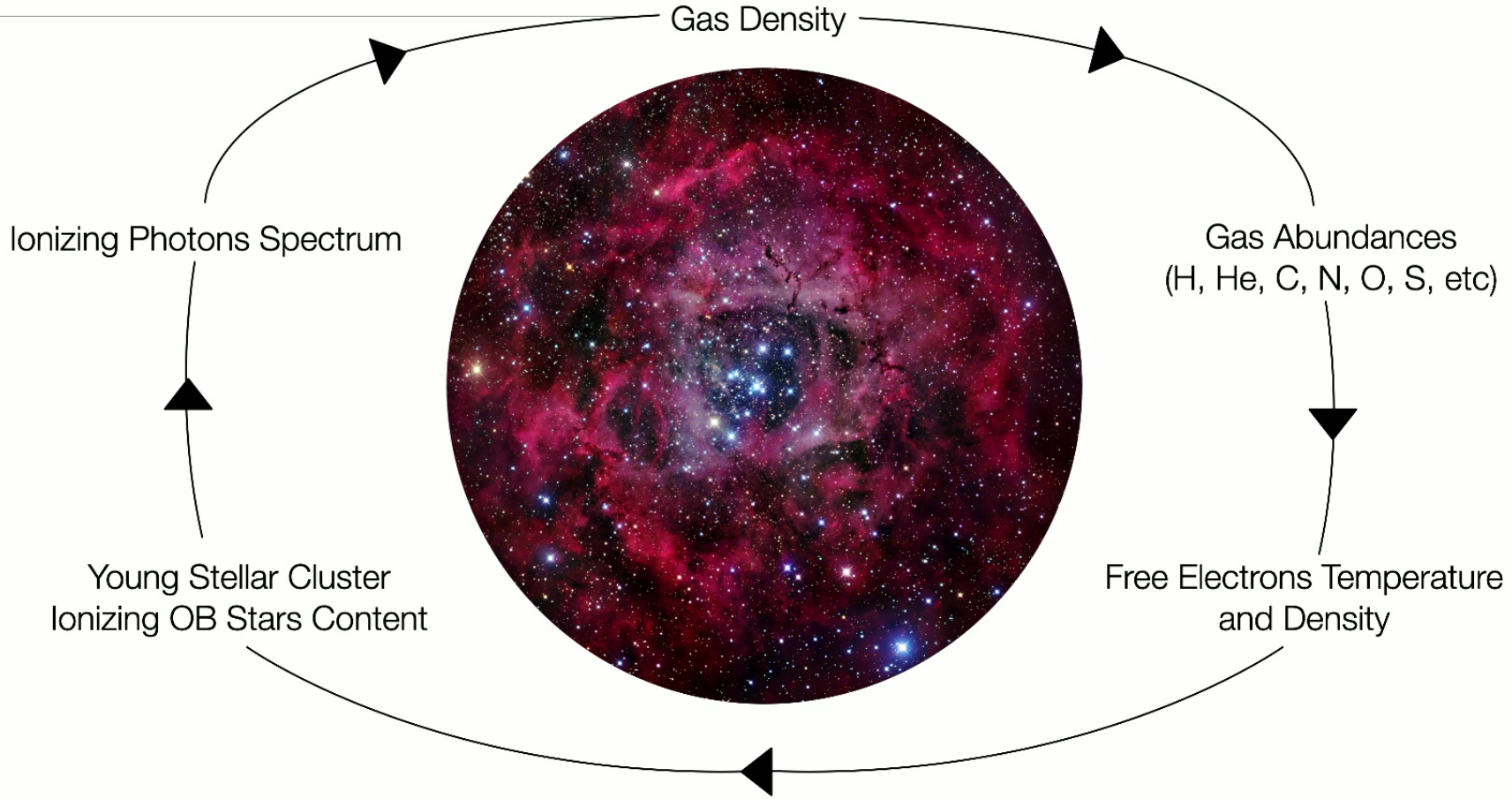
Star Formation - Initial Mass Function




The Origin of the Solar System Elements
big bang fusion
cosmic ray fission
merging neutron stars
exploding massive stars
dying low mass stars
exploding white dwarfs
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U

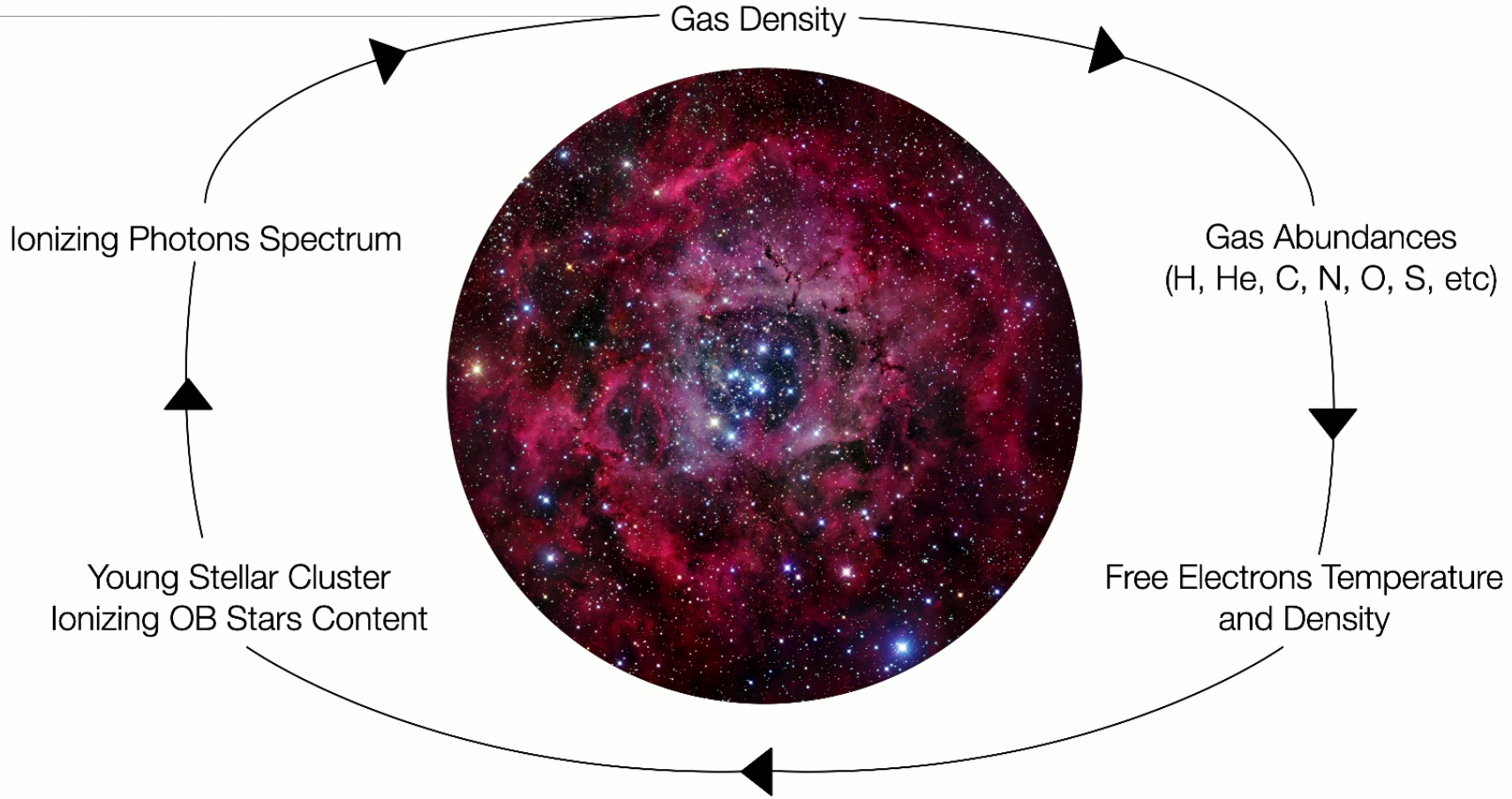

t = 1.35 Myr θ = 345° ϕ = 345°
t = 0.34 Myr θ = 075° ϕ = 075°

Star Forming Regions Physics



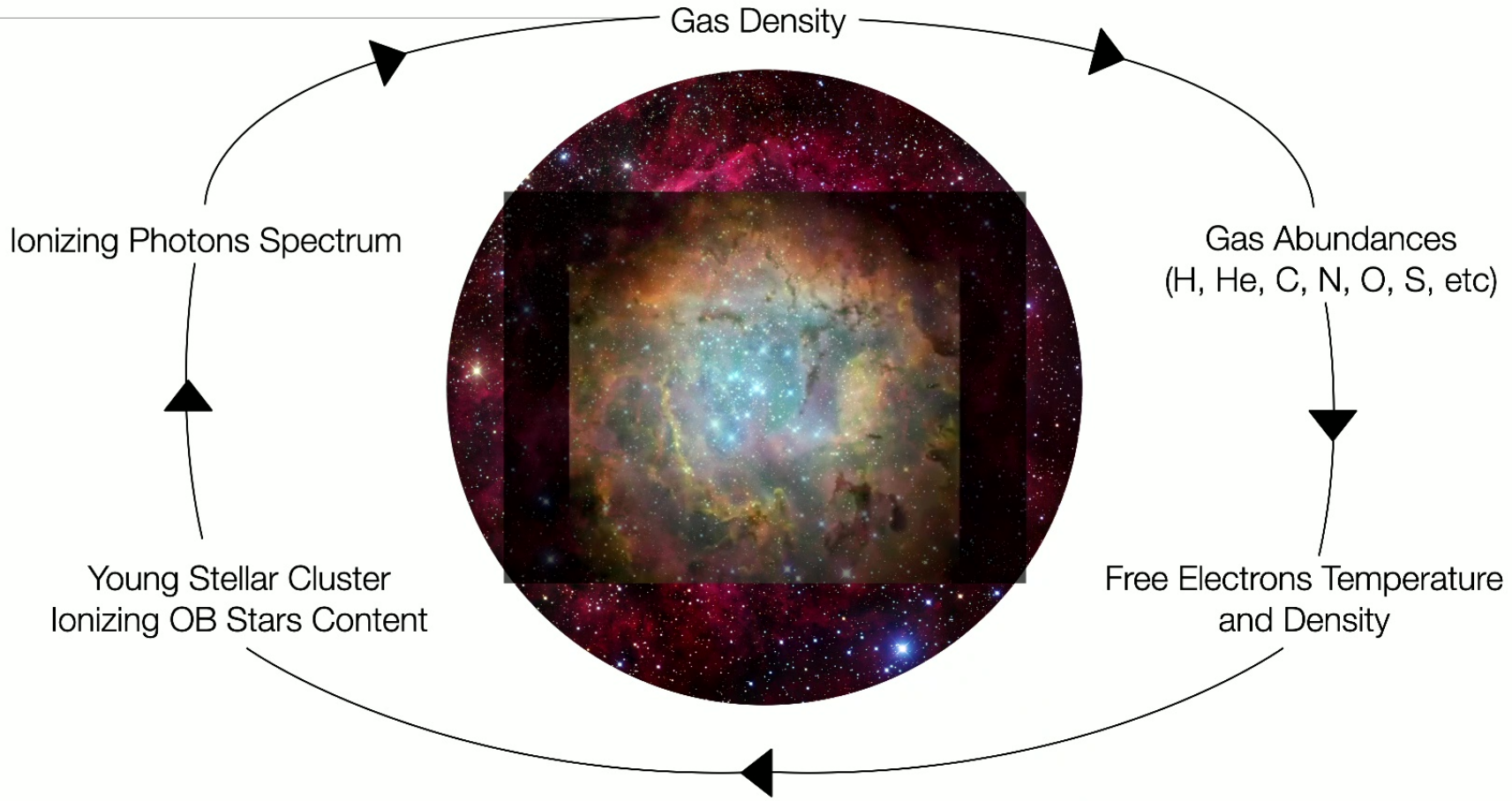
Star Forming Regions Physics

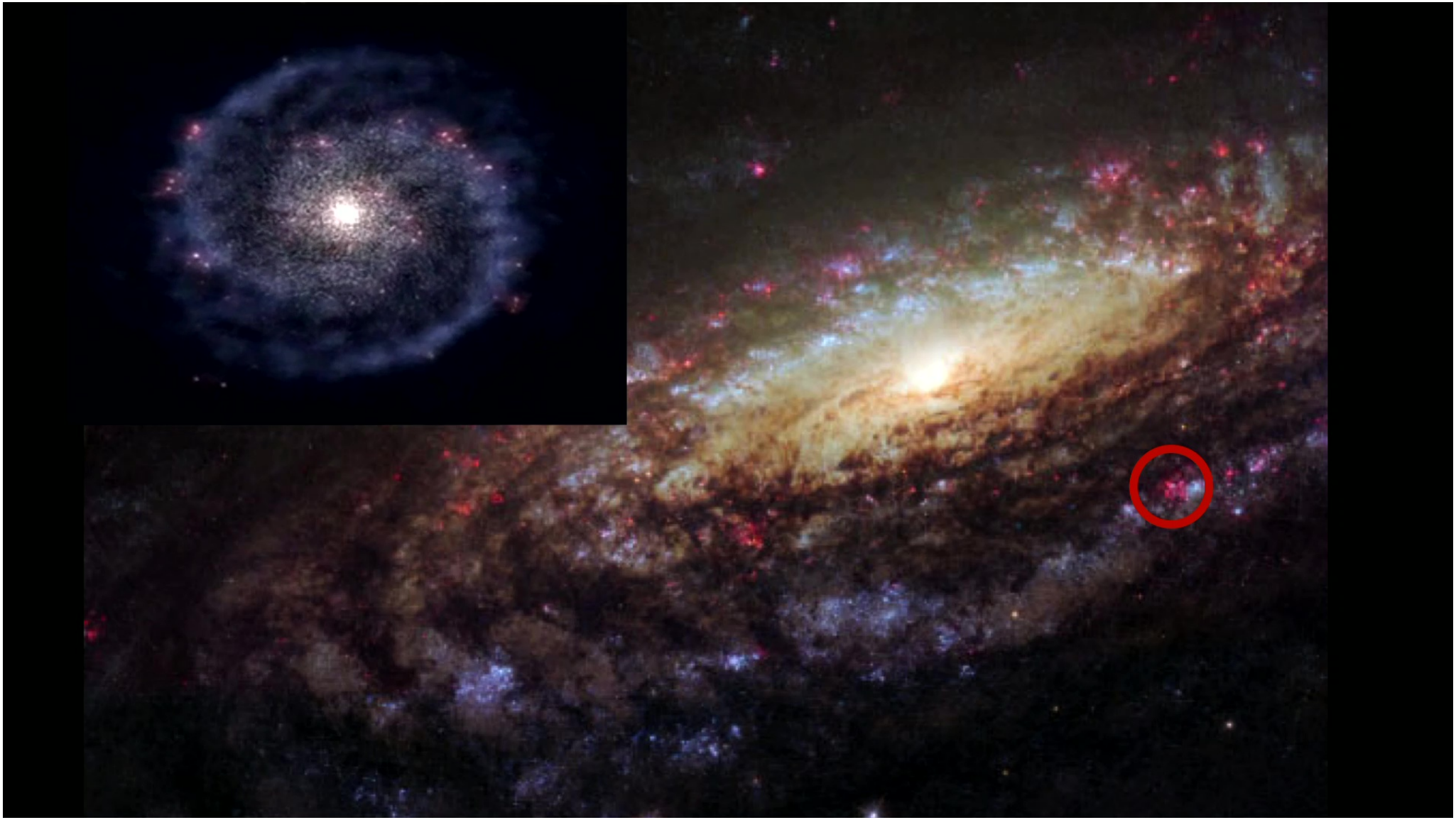
Collision Lines (i.e. [NII], [OII], [OIII], [SII], etc)
Recombinaison Lines (i.e. Hα, Hβ, Metals, etc)



Star Forming Regions Physics

Collision Lines (i.e. [NII], [OII], [OIII], [SII], etc)
Recombinaison Lines (i.e. Hα, Hβ, Metals, etc)



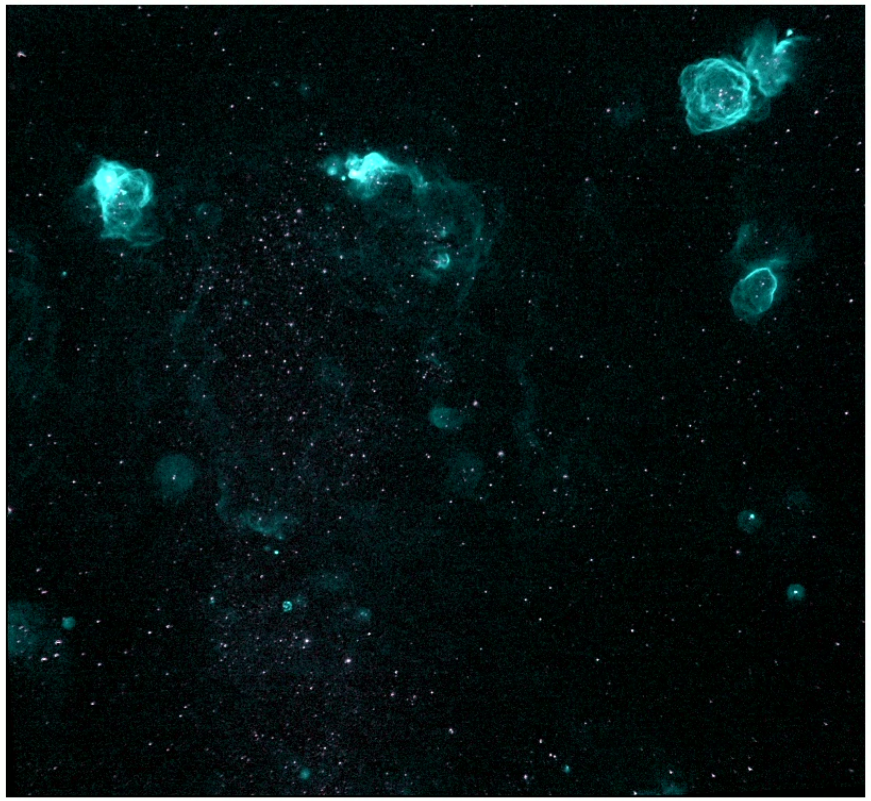


How Well do we see Stars Forming?

M42 (Orion: HST)
Distance = 412 pc

~4.0 pc

NGC6822 (SITELLE)
Distance = 0.5 Mpc



How Well do we see Stars Forming?

M42 (Orion: HST)
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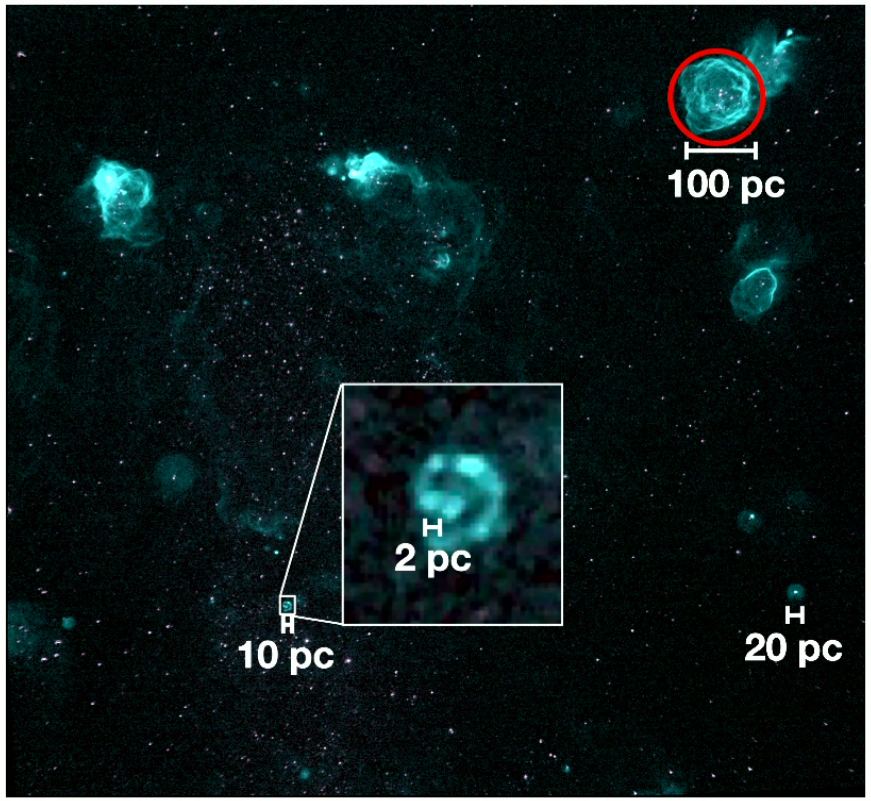
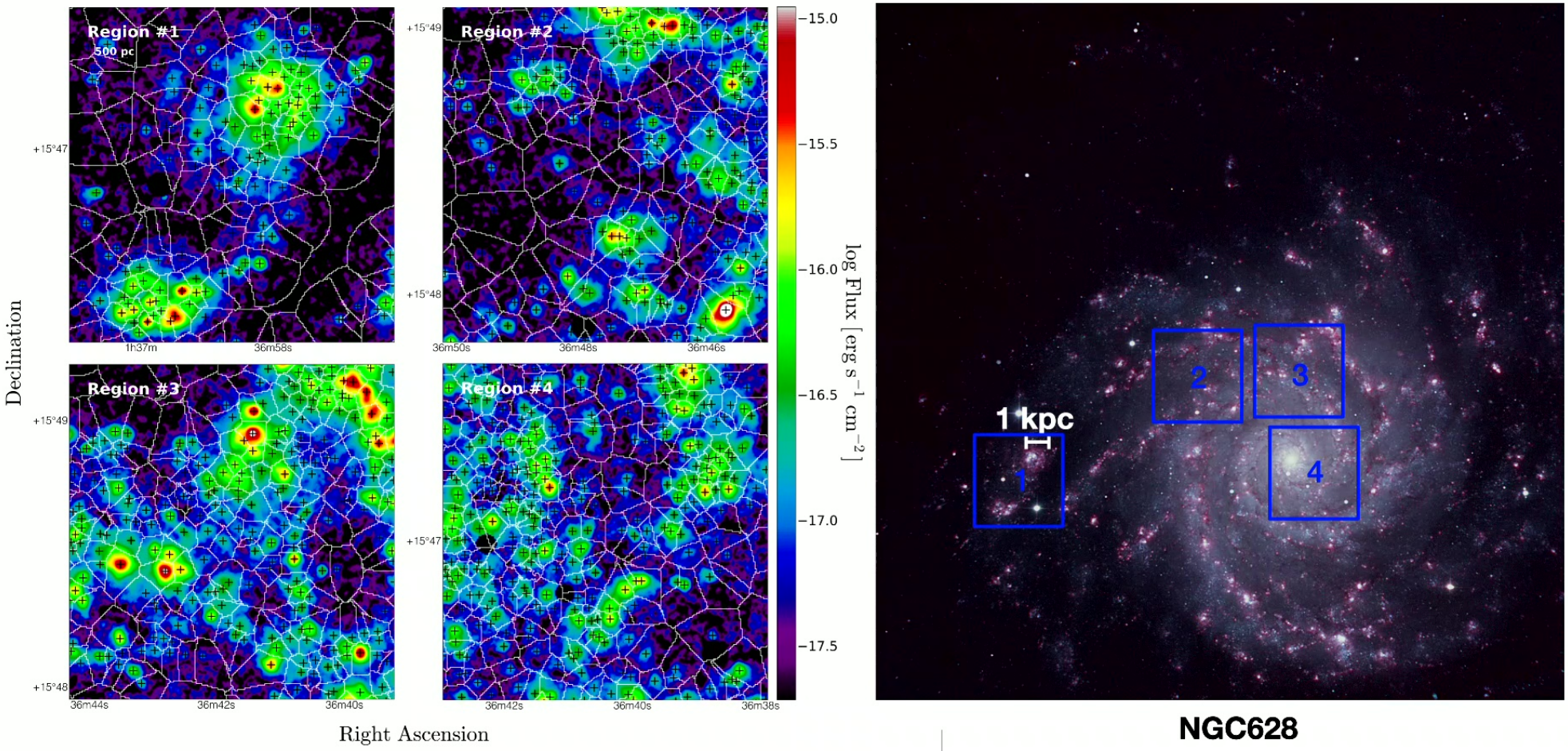
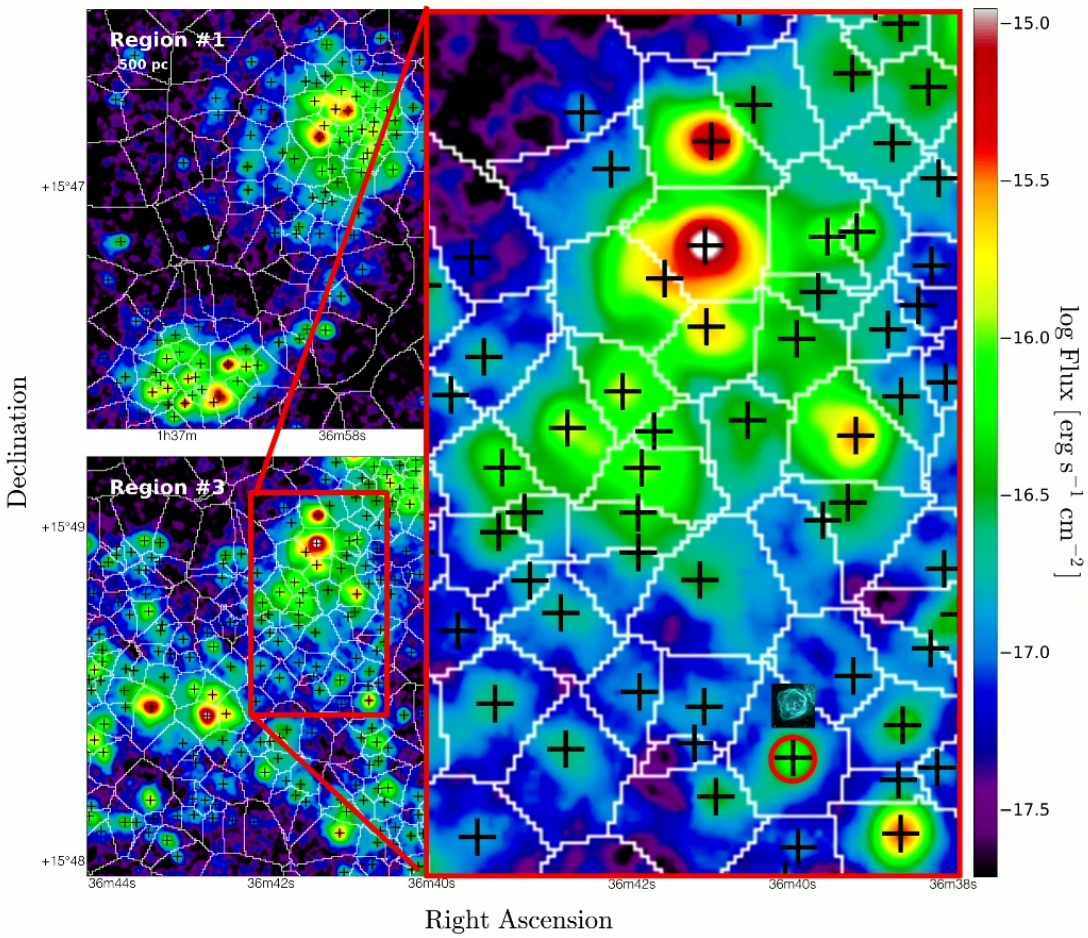
NGC6822 (SITELLE)
Distance = 0.5 Mpc

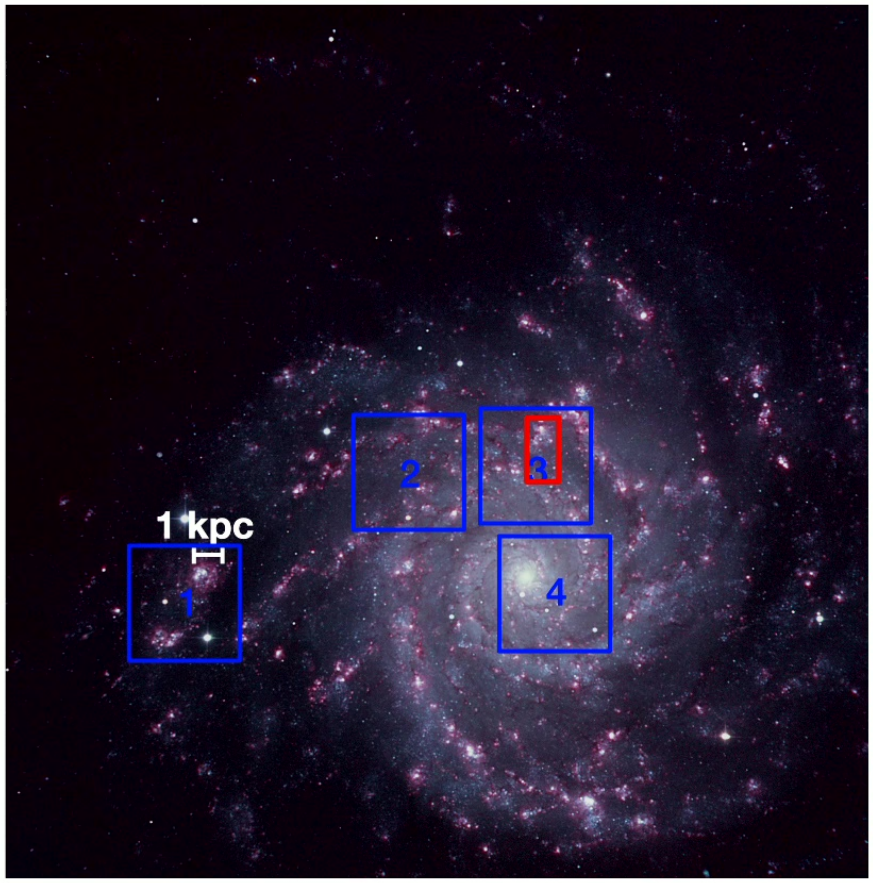




NGC628
Distance = 9.0 Mpc

Scales of Star Formation

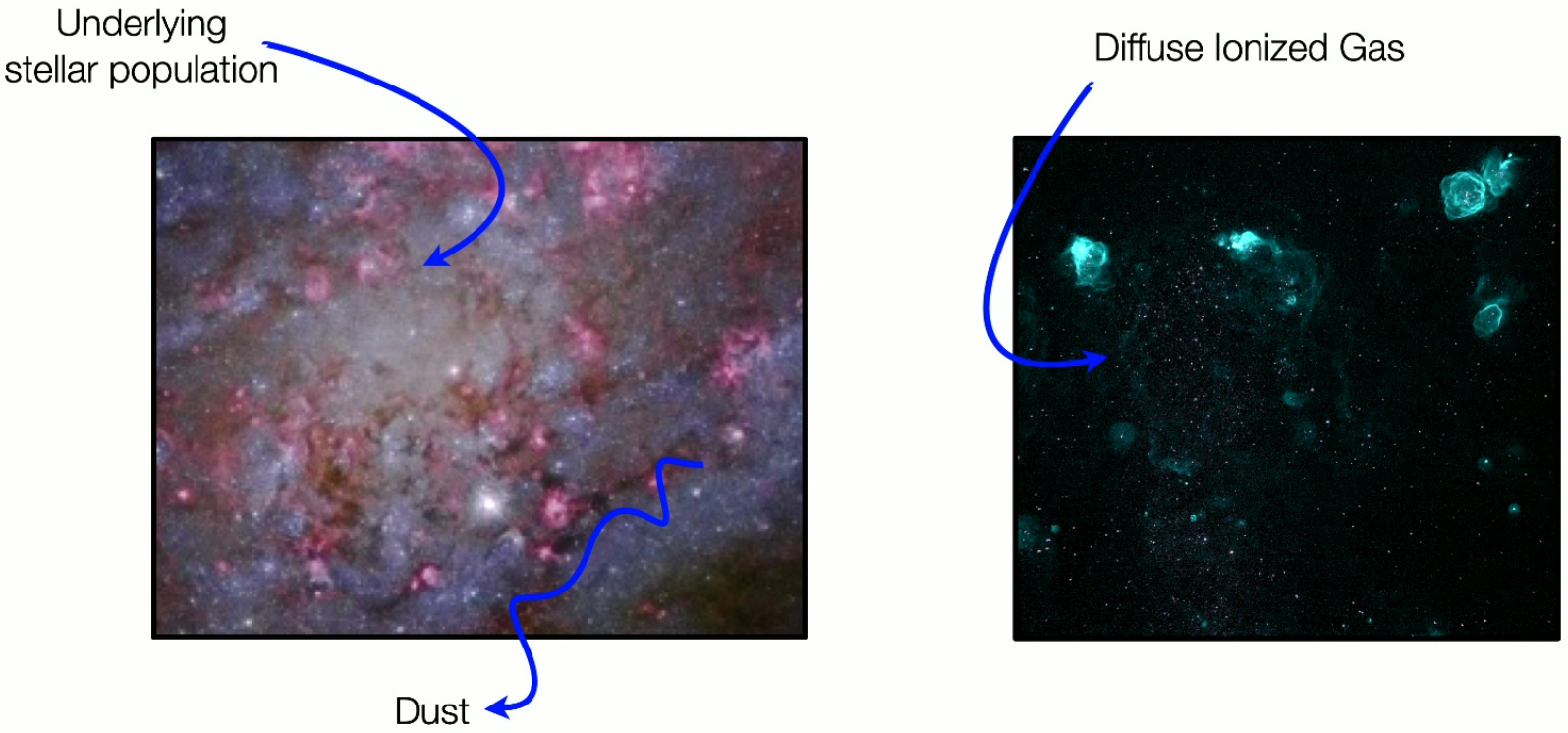


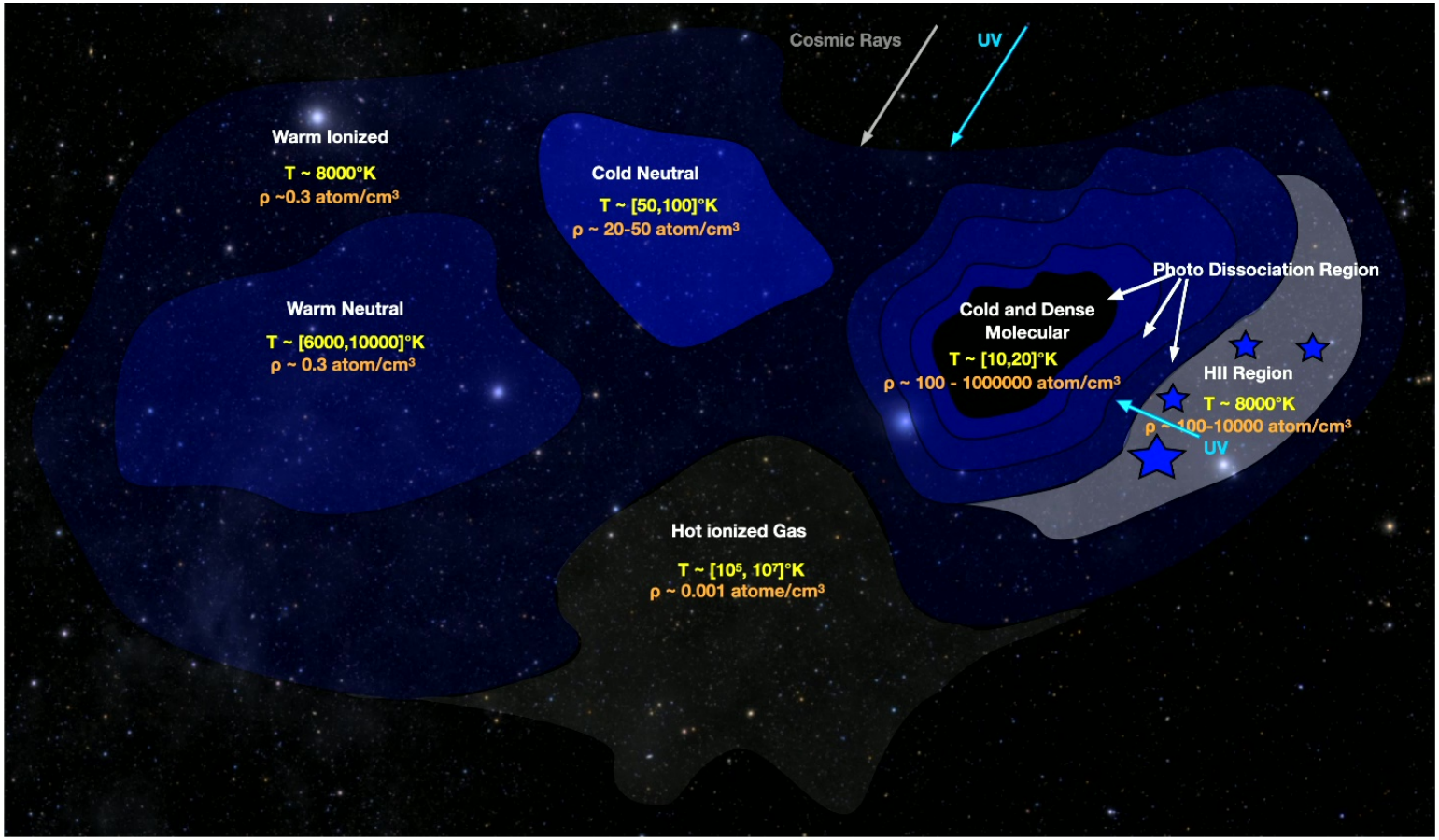


NGC628
Distance = 9.0 Mpc

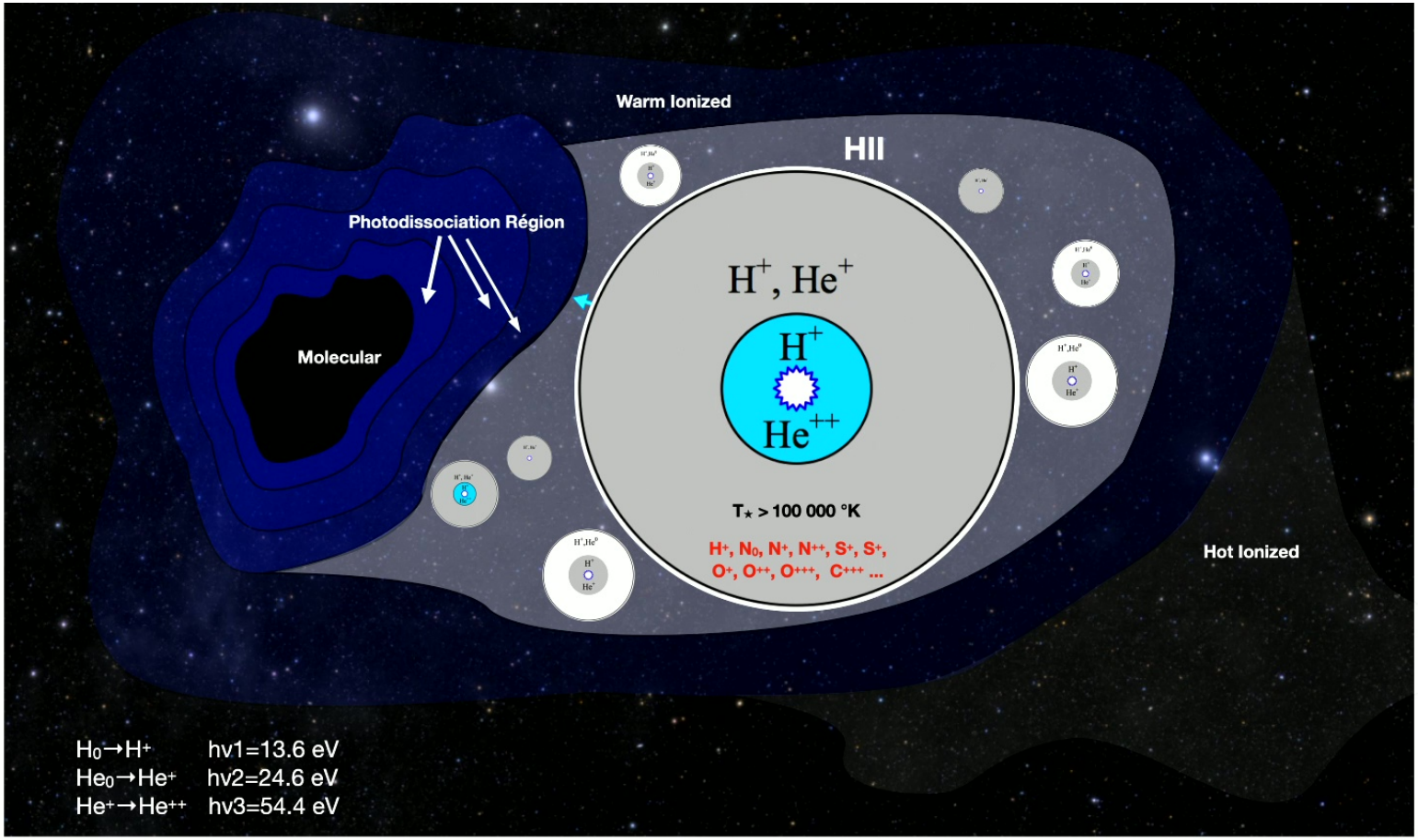
Scales of Star Formation

Star Forming Regions Environment (Swimming in...)





The interstellar Medium



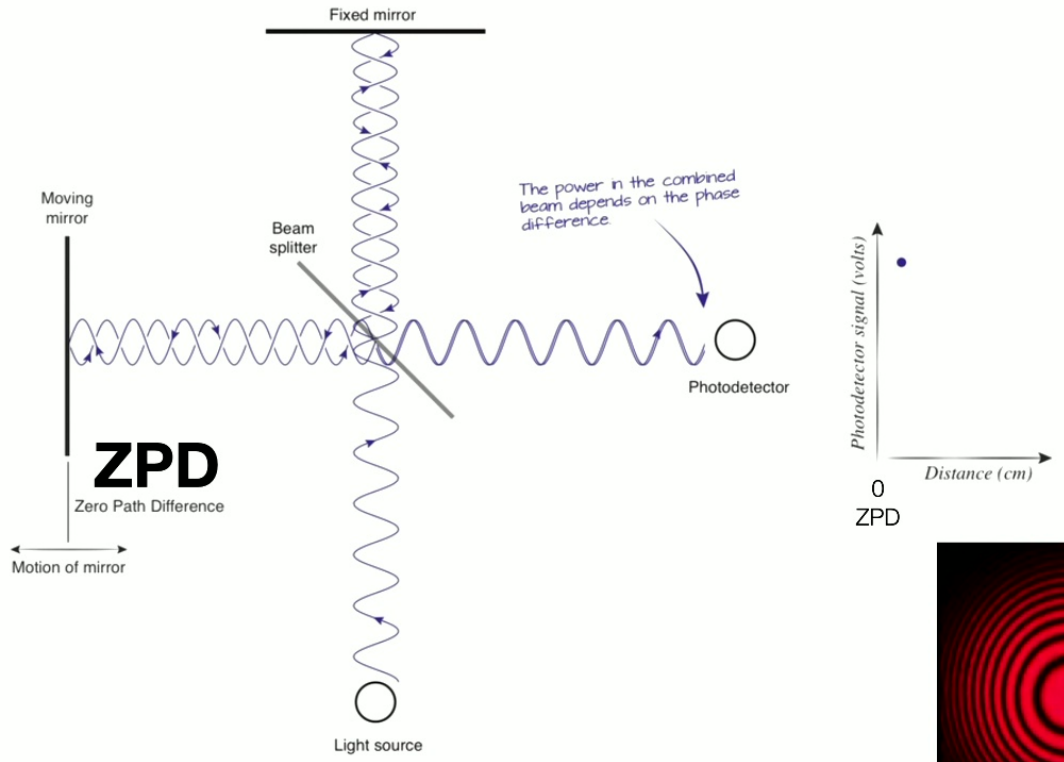
The Massive Stars

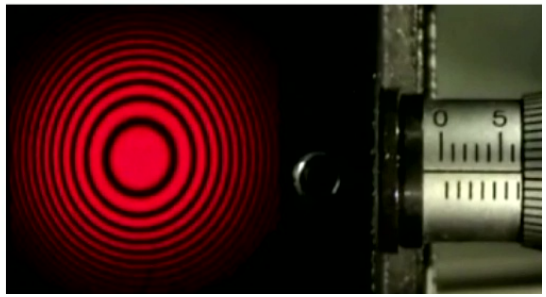
SITELLE
IFTS

Attribute	SITELLE
FOV	11' x 11’
Pixels FOV	0.32”
Bandwidth Covered	350-930 nm
Spectral Resolution	1 - 20 000 (Selectable)
Multiplex Capacity	2048 x 2064 4.2Million Spectra

The heart of the IFTS

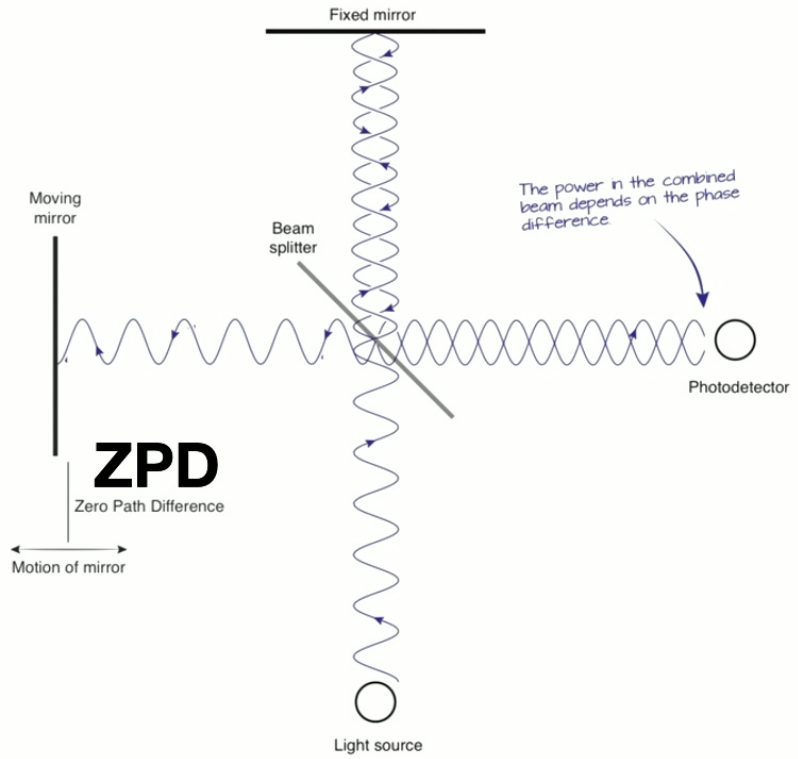
- The Michelson Interferometer

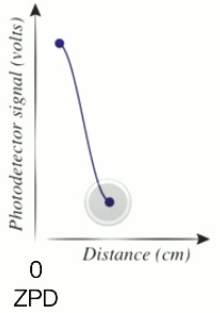


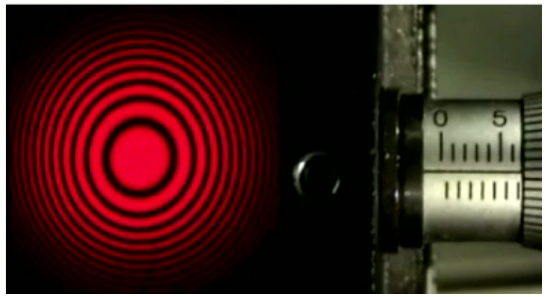


The heart of the IFTS

- The Michelson Interferometer

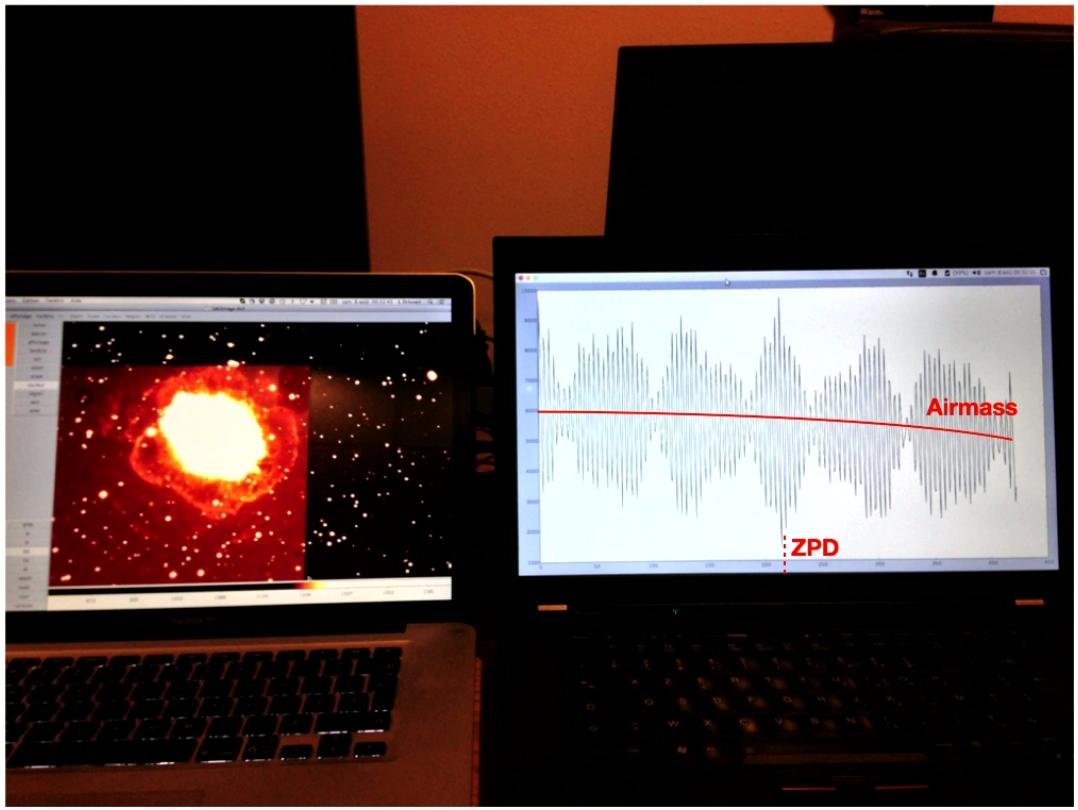






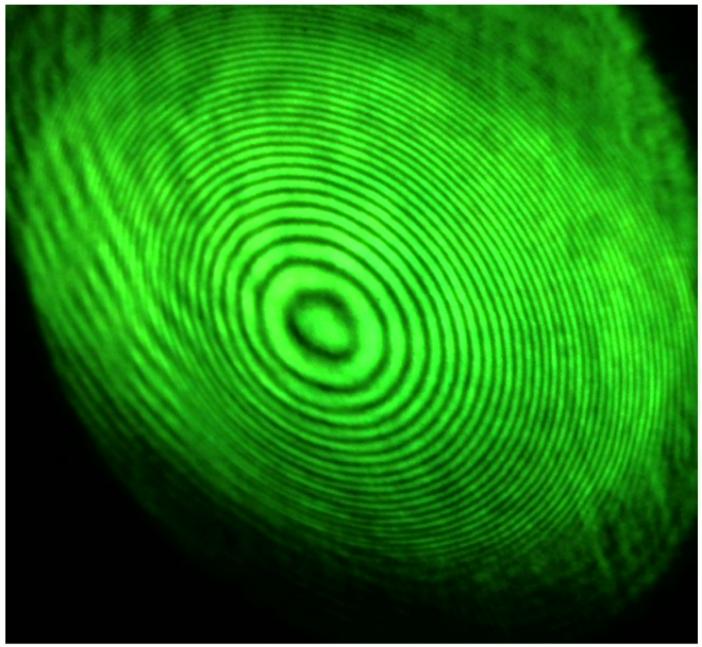
The heart of the IFTS

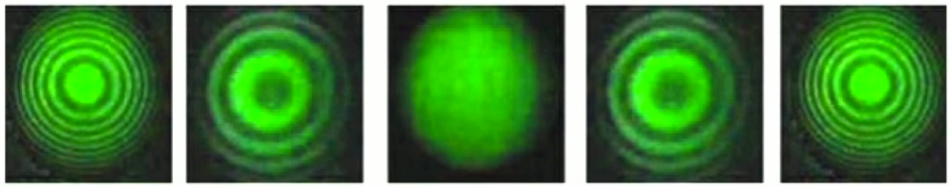
- Interferogram of emission lines source



The heart of the IFTS

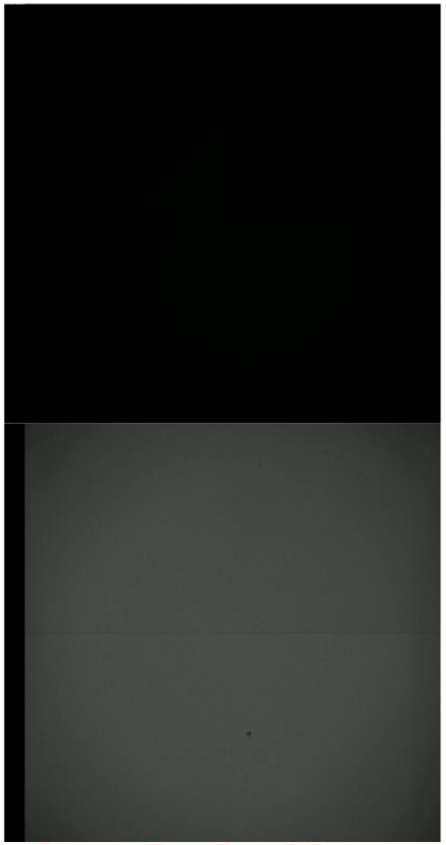
- Tilted Michelson



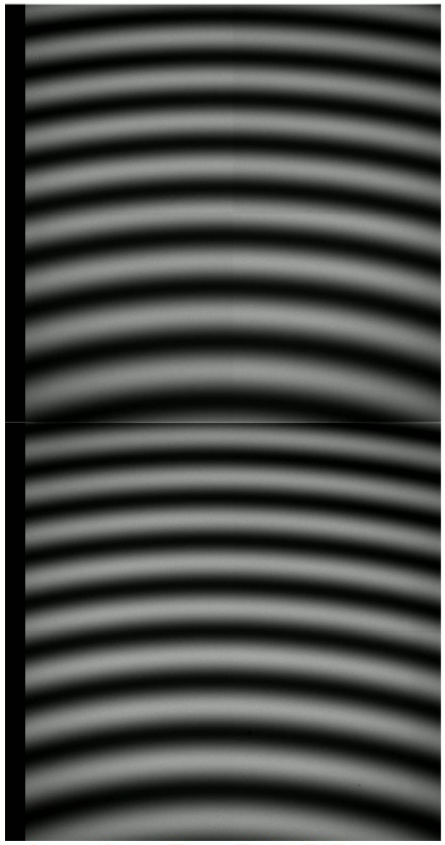


Away from ZPD ← Close to Zero Path Difference → Away from ZPD

IFTS
Laser interferogram

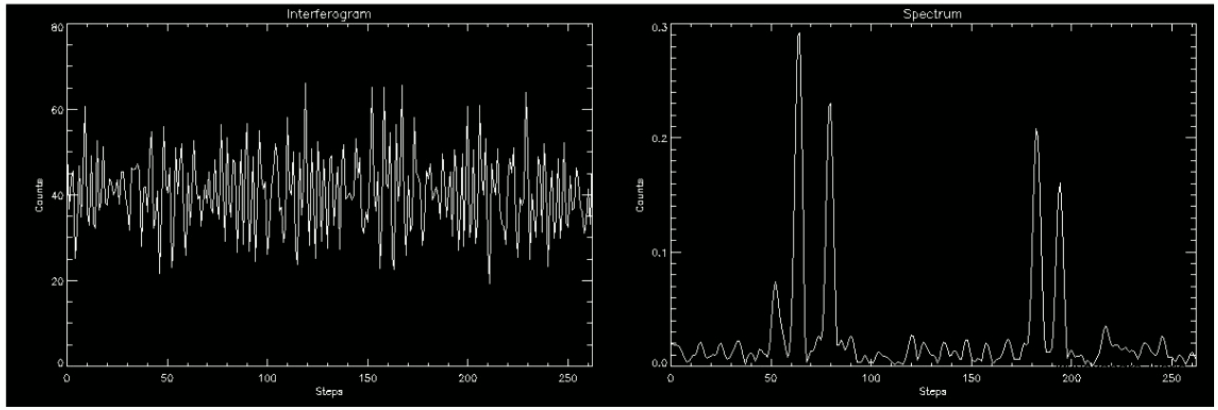


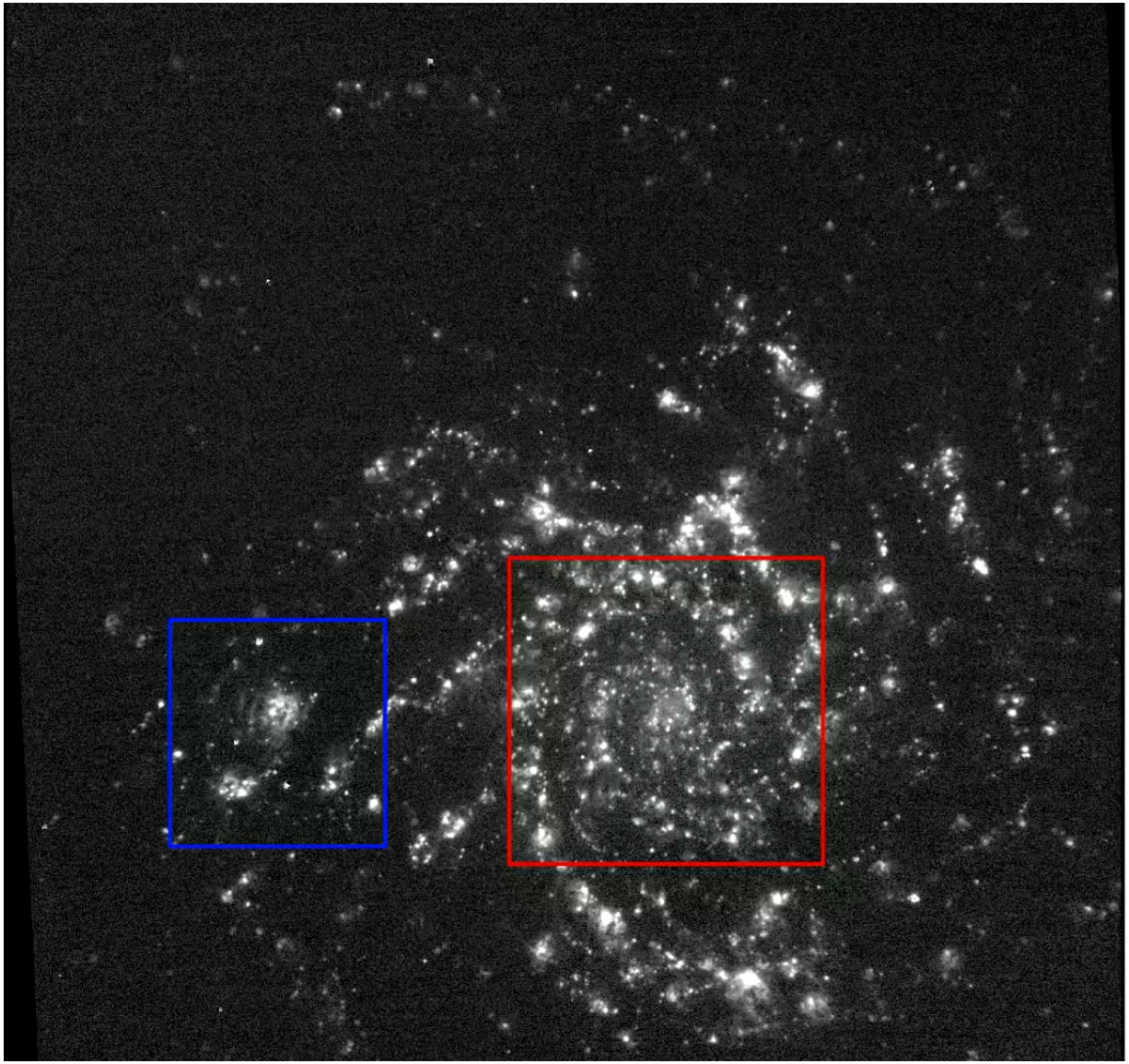
Close to Zero Path Difference

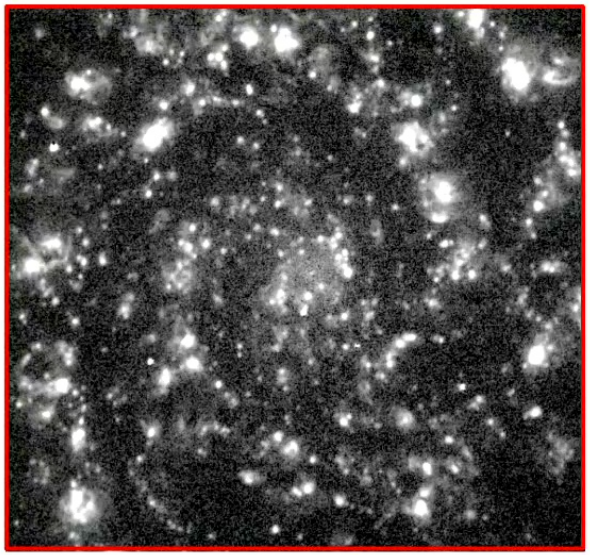


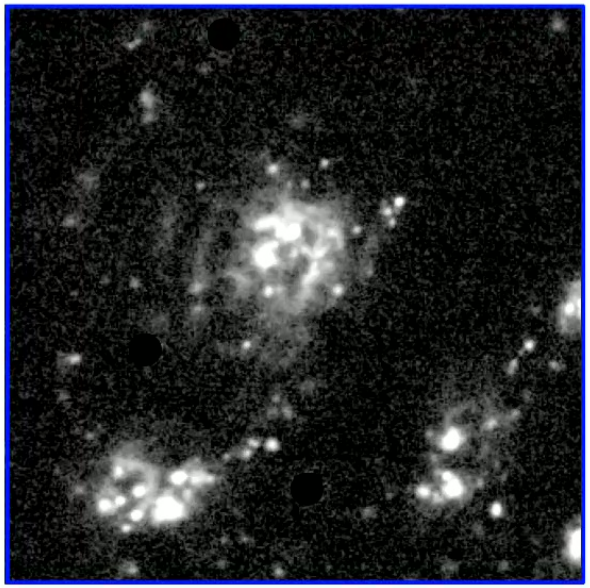
Away from Zero Path Difference

IFTS
Spectral Resolution

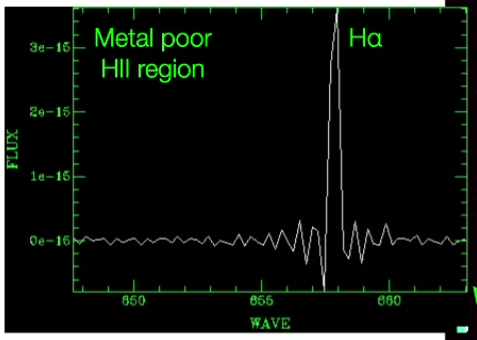


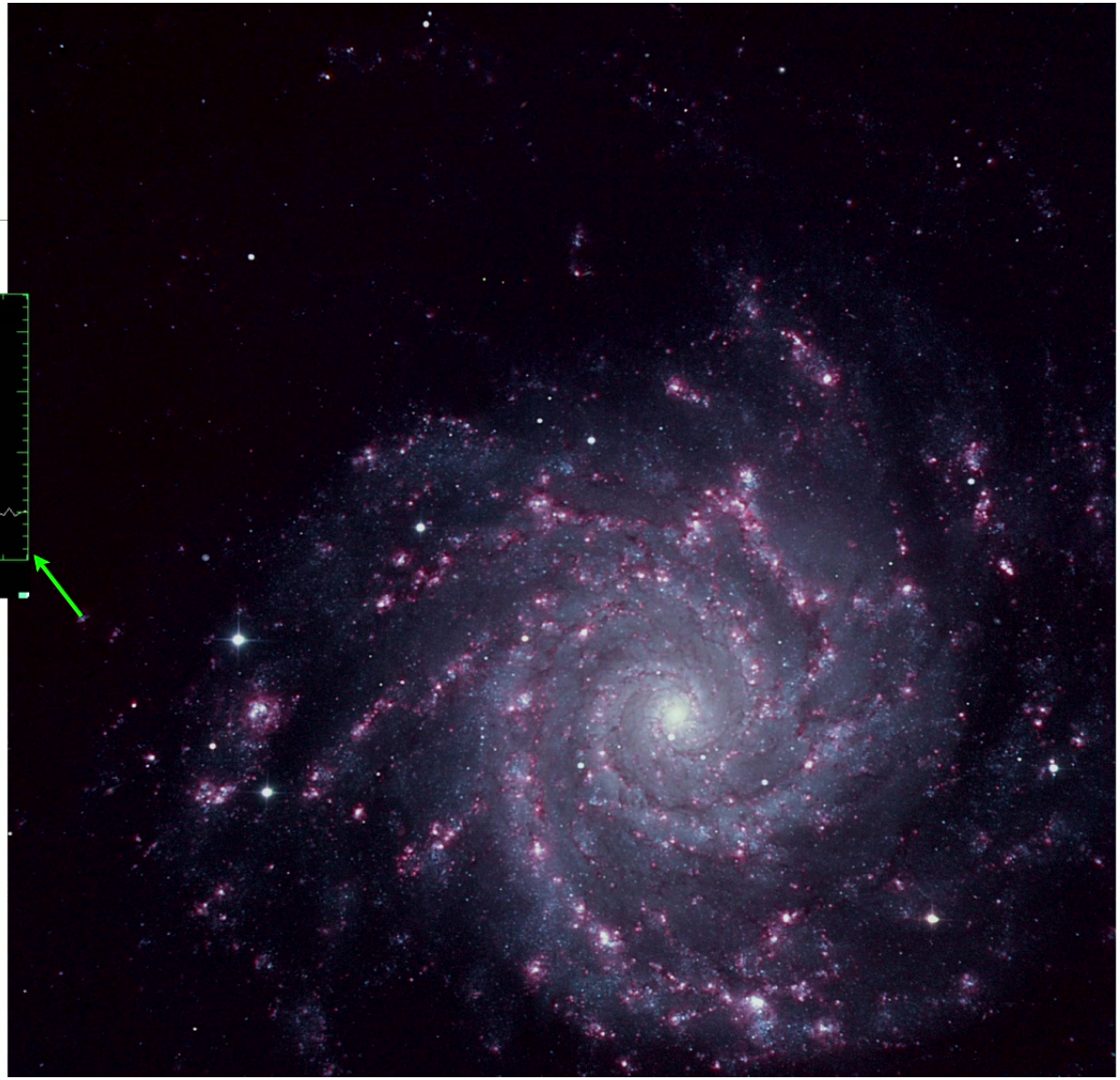




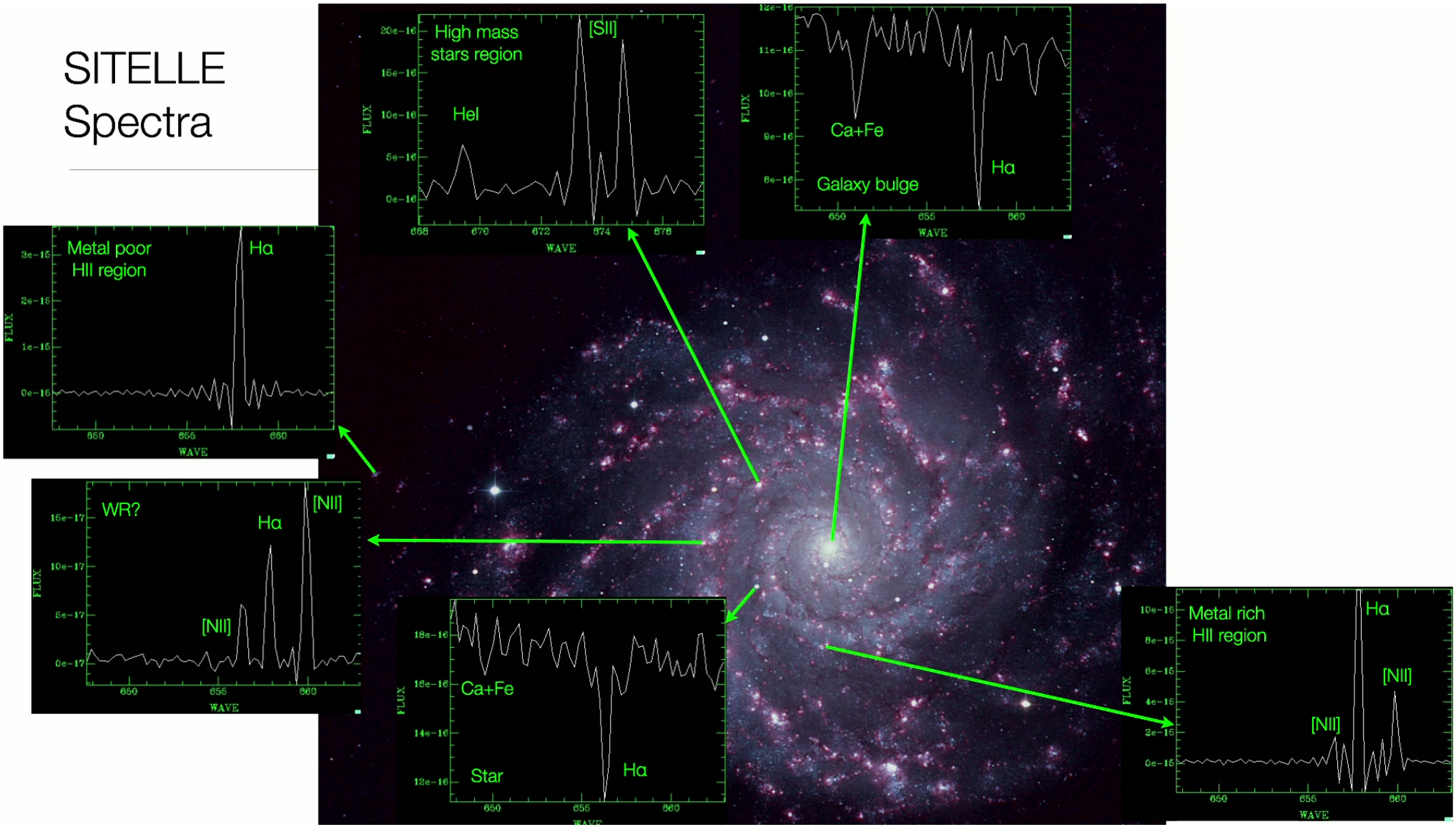


SITELLE Spectra





SITELLE Spectra



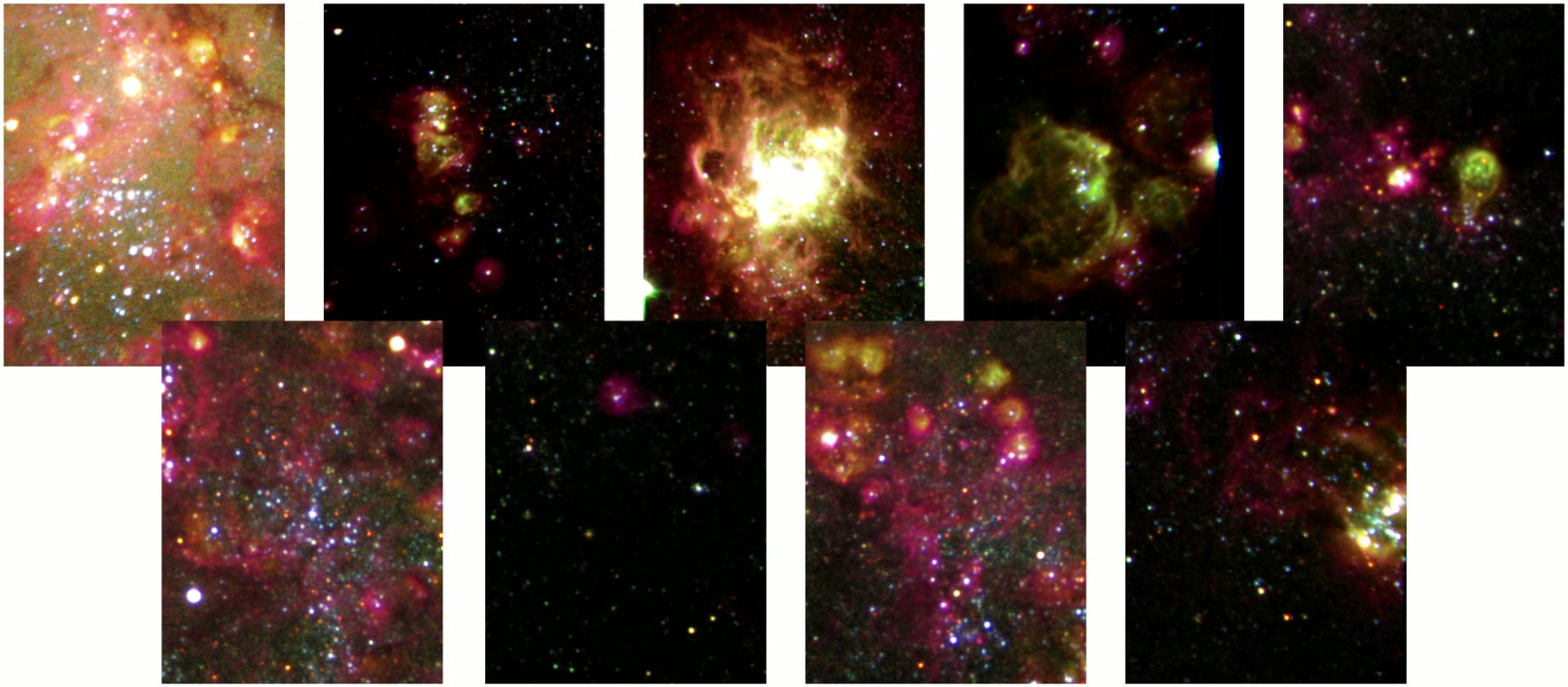
The Star formation and Nebular Abundance Survey




Laurie Rousseau-Nepton, R. Pierre Martin, Carmelle Robert, Laurent Drissen, Philippe Amram and the SIGNALS Collaborations

SIGNALS

The Star formation, Ionized Gas, and Nebular Abundances Legacy Survey



SIGNALS

The Star formation, Ionized Gas, and Nebular Abundances Legacy Survey

1 - Star Formation Process at the Scale of an HII Region

- Star Formation Rate and Resolved Star Formation Law
- HII Region Characteristics:
  - Gas Conditions, Photoionization, and Ionized Gas Models
  - Massive Stars Content and IMF Variations
- Star Formation Efficiency - Ionized vs Neutral Gas Component
- Ionizing Photons: HII Regions vs DIG

2 - Feedback Processes

- Mass and Energy Returned into the ISM by Stars

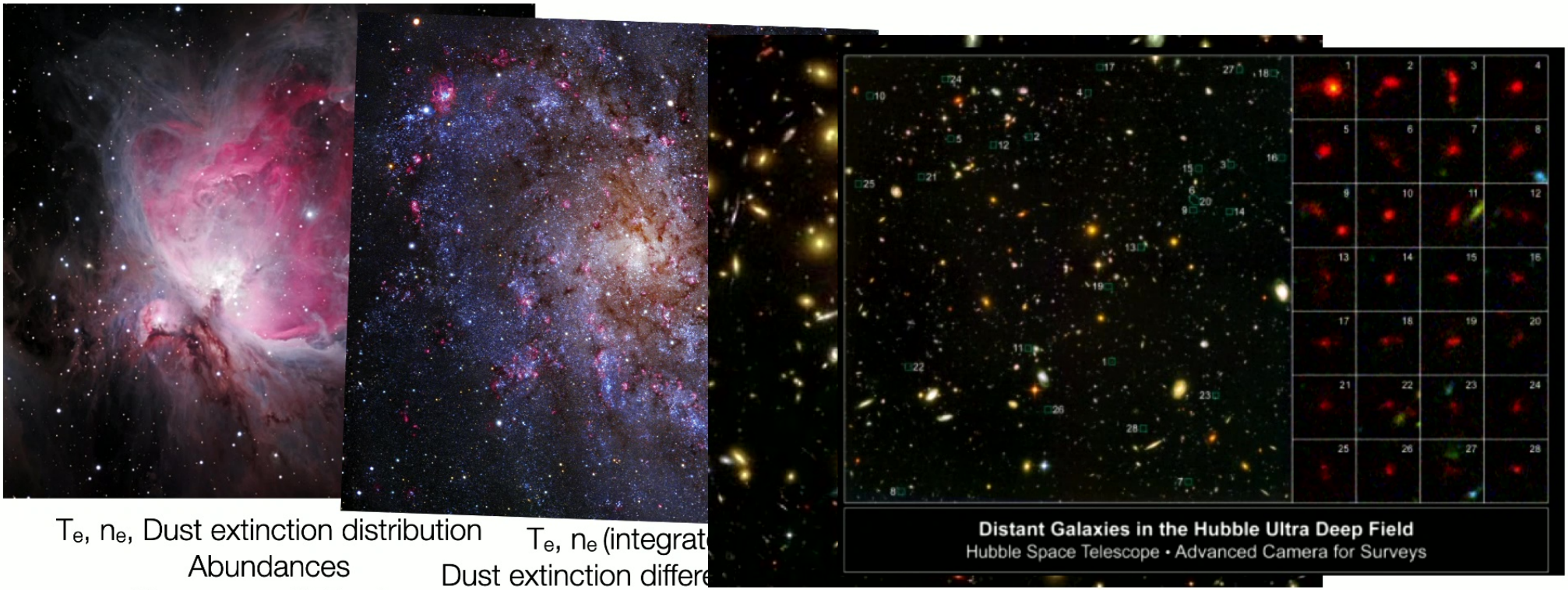
3 - Small Scale Dynamics

4 - Local Environment Influence

T_e, n_e, Dust extinction distribution
Abundances
Stars mass, SED, etc.

T_e, n_e (integrated)
Dust extinction differential effet
Global Abundances
Clusters mass,
~SED (IMF assumption), etc.

Spatial Resolution Through Cosmic Time



T_e, n_e, Dust extinction distribution
Abundances
Stars mass, SED, etc.

T_e, n_e (integrat
Dust extinction differe
Global Abundances
Clusters mass,
~SED (IMF assumption), etc.

~~T_e, n_e integrated~~
~~Dust extinction differential effect~~
Global Abundances
Cluster mass (integrated),
~SED (IMF assumption), etc.

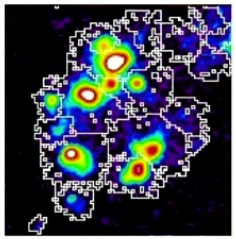
Spatial Resolution Through Cosmic Time

SITELLE

High spatial resolution

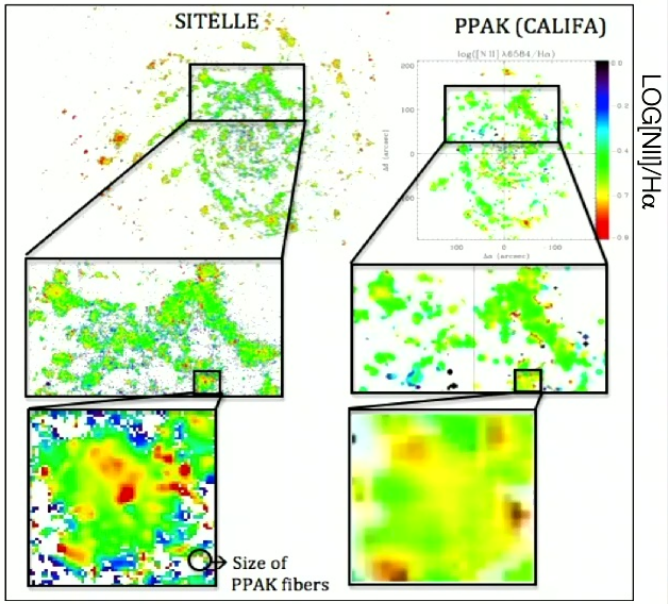
SITELLE

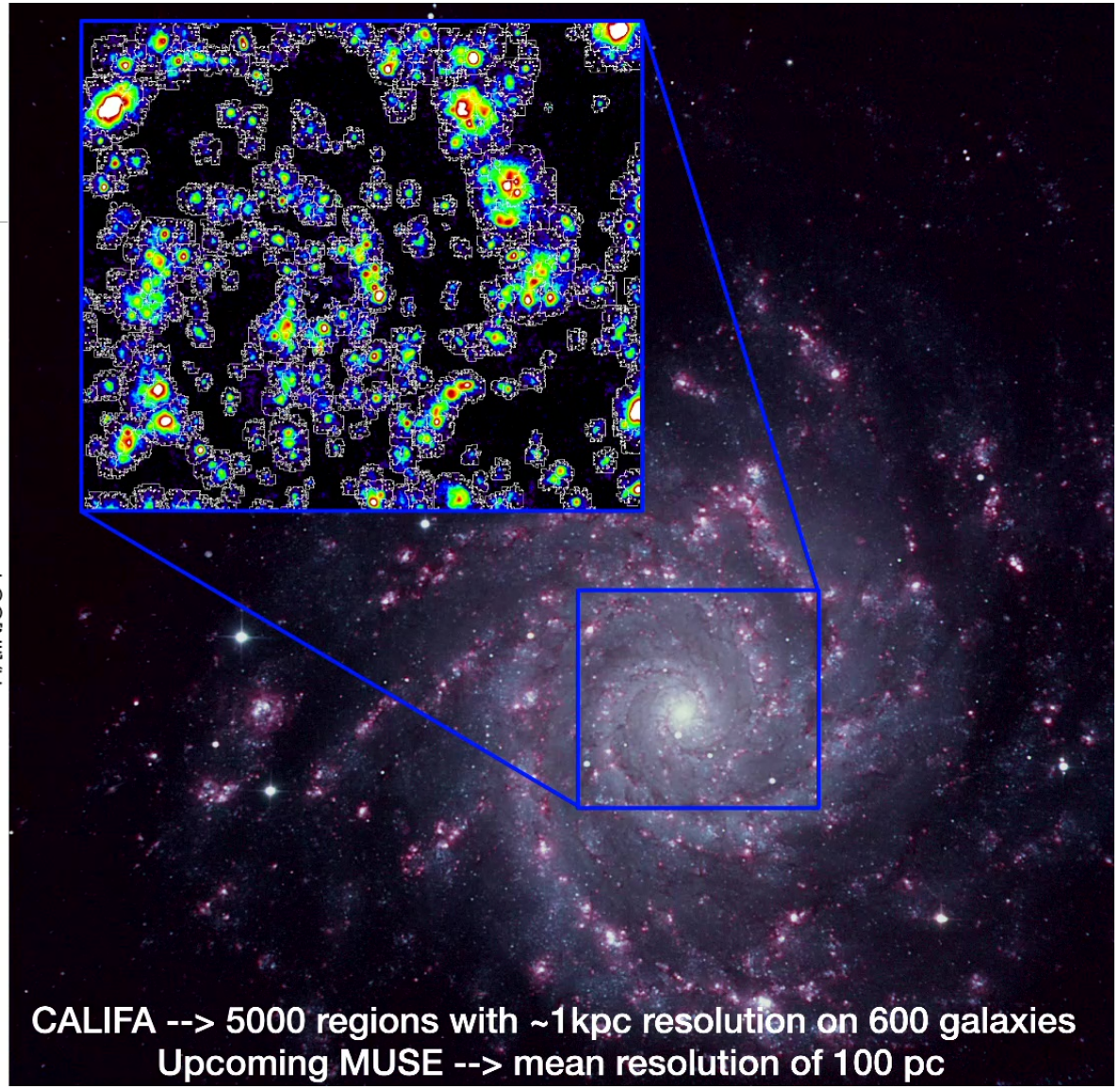
HII regions definiton on Hα ~25 pc



~3500 regions

Resolved Ionization Structures



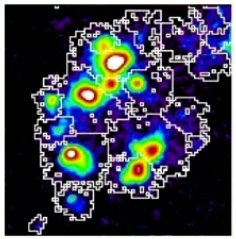


SITELLE

High spatial resolution

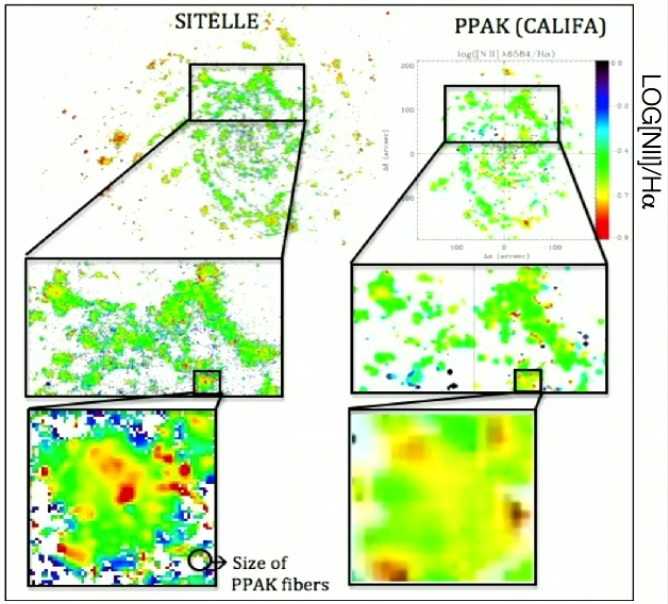
SITELLE

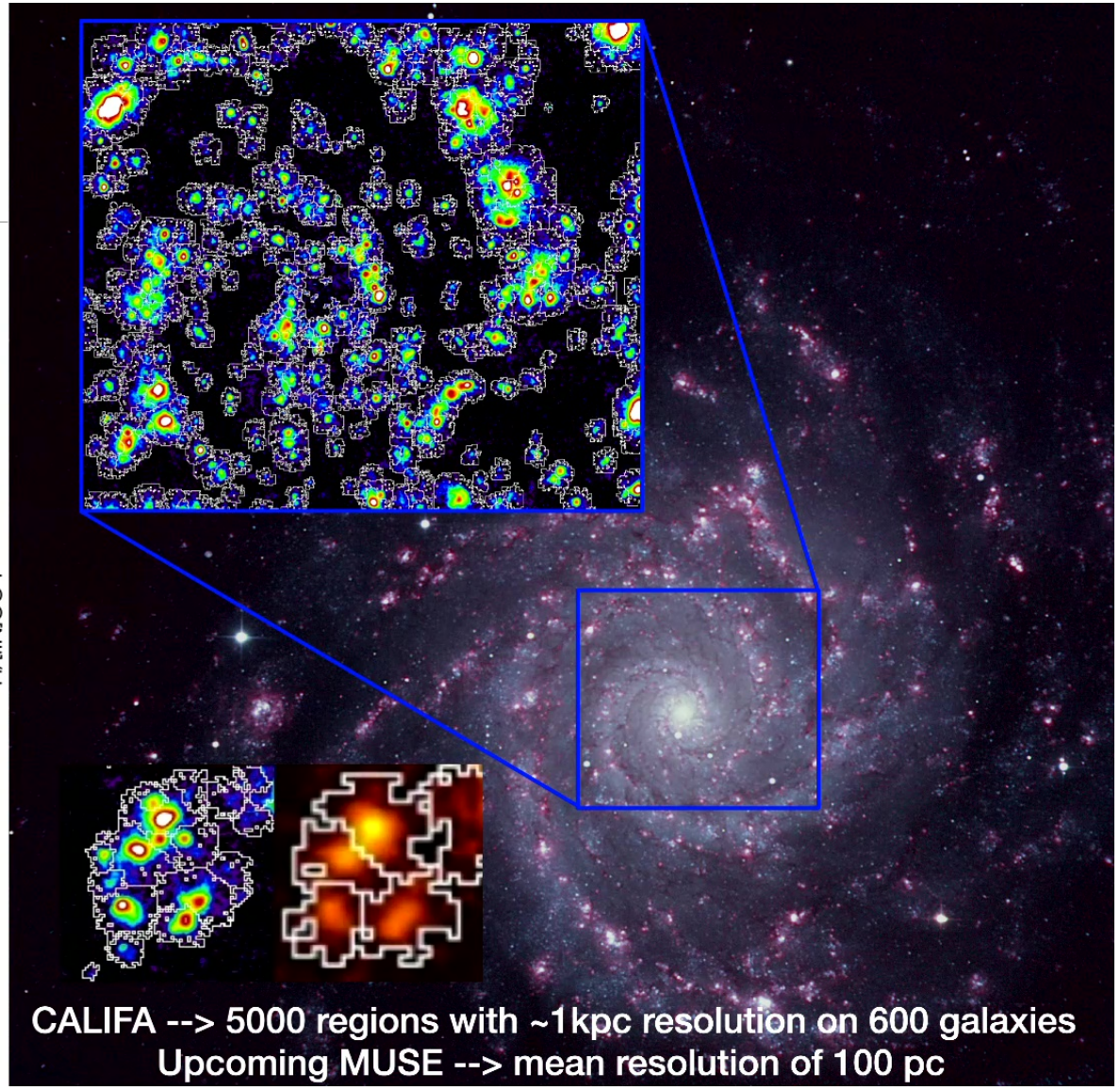
HII regions definiton on Hα ~25 pc



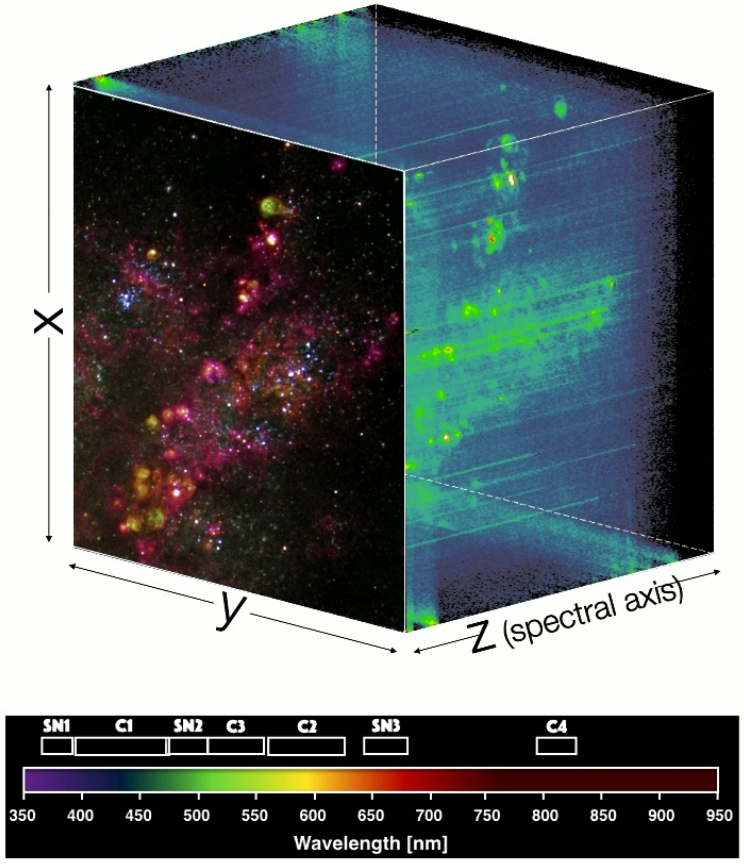
~3500 regions

Resolved Ionization Structures

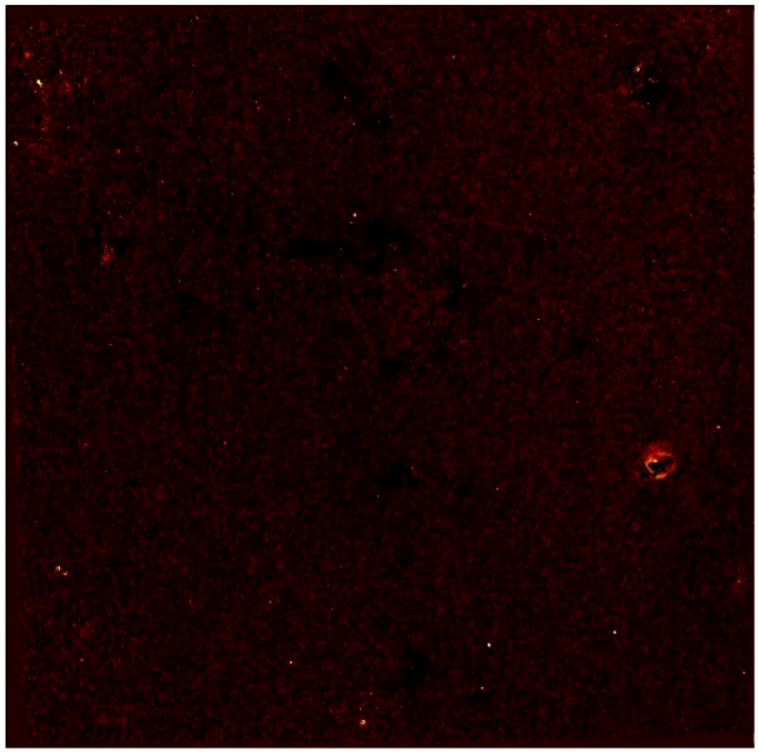


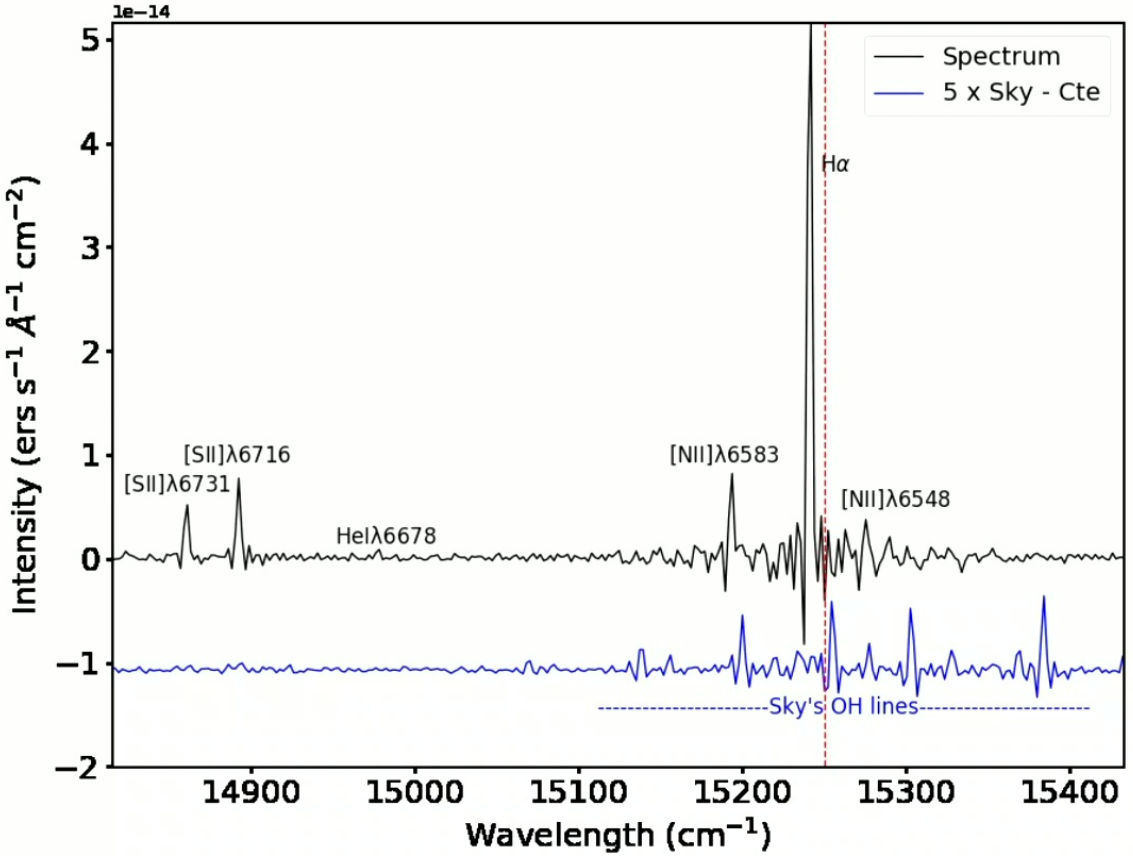


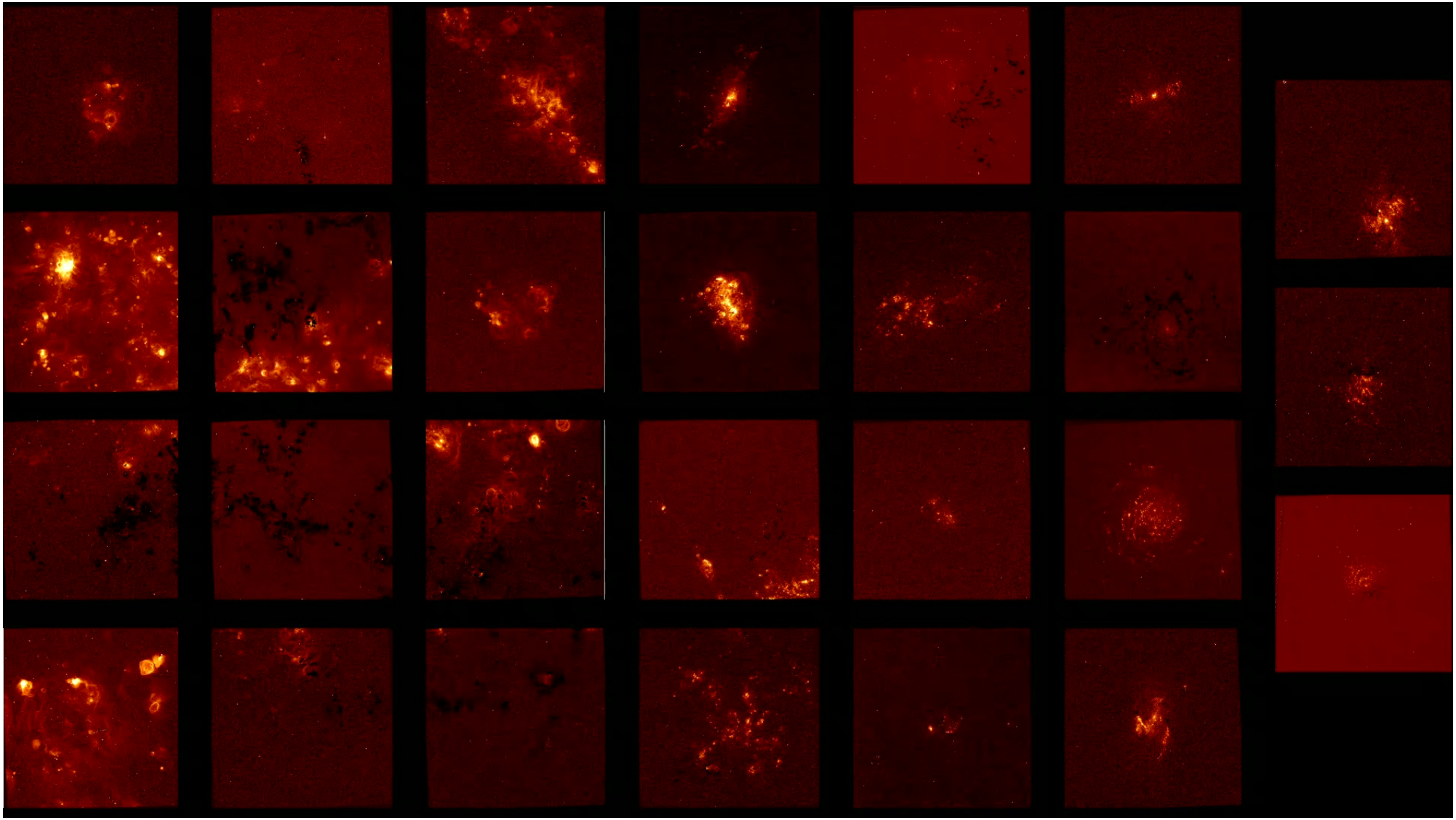
Instrument configuration for SIGNALS

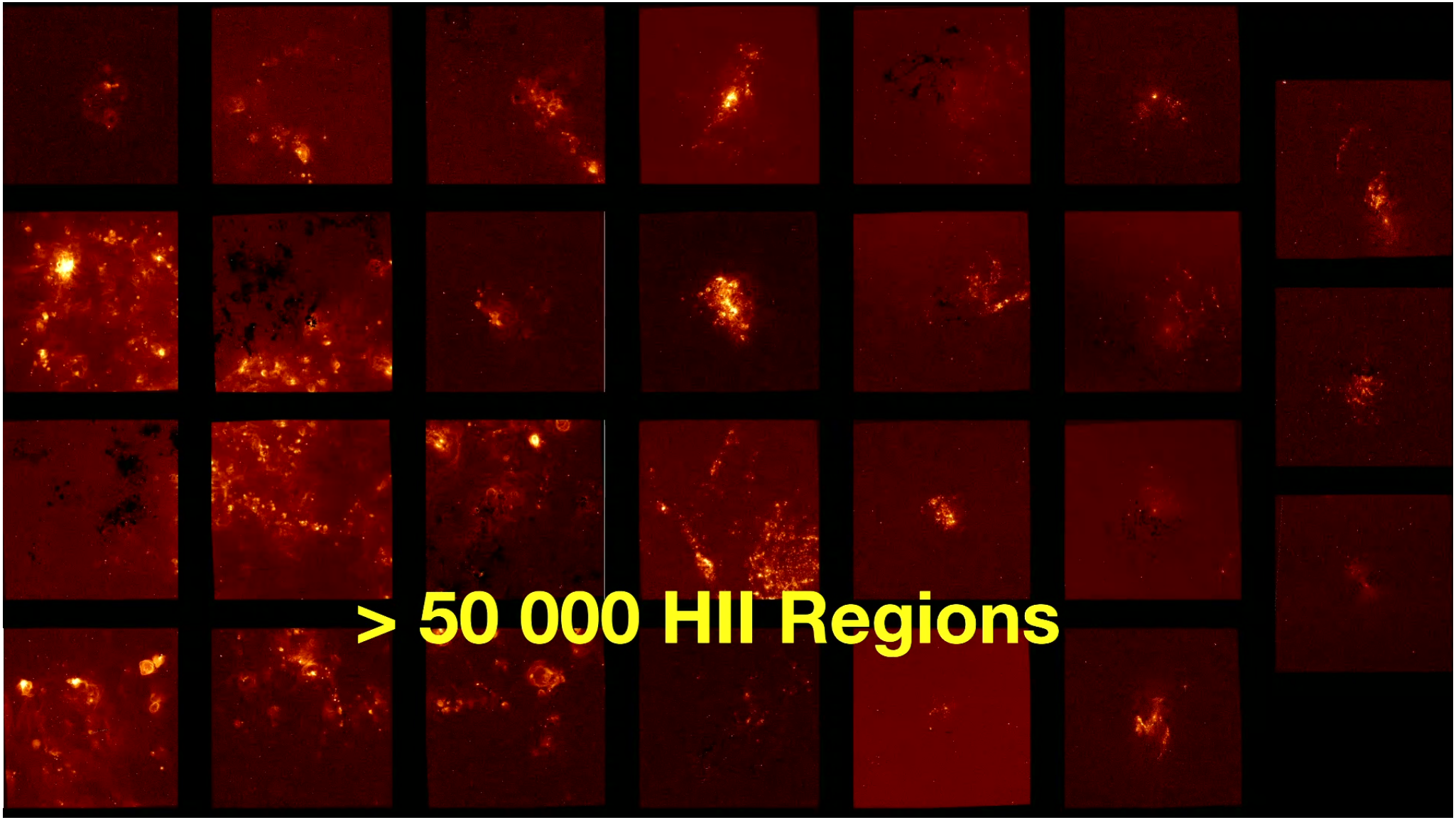


M33 Field #7 SN3 Full Datacube

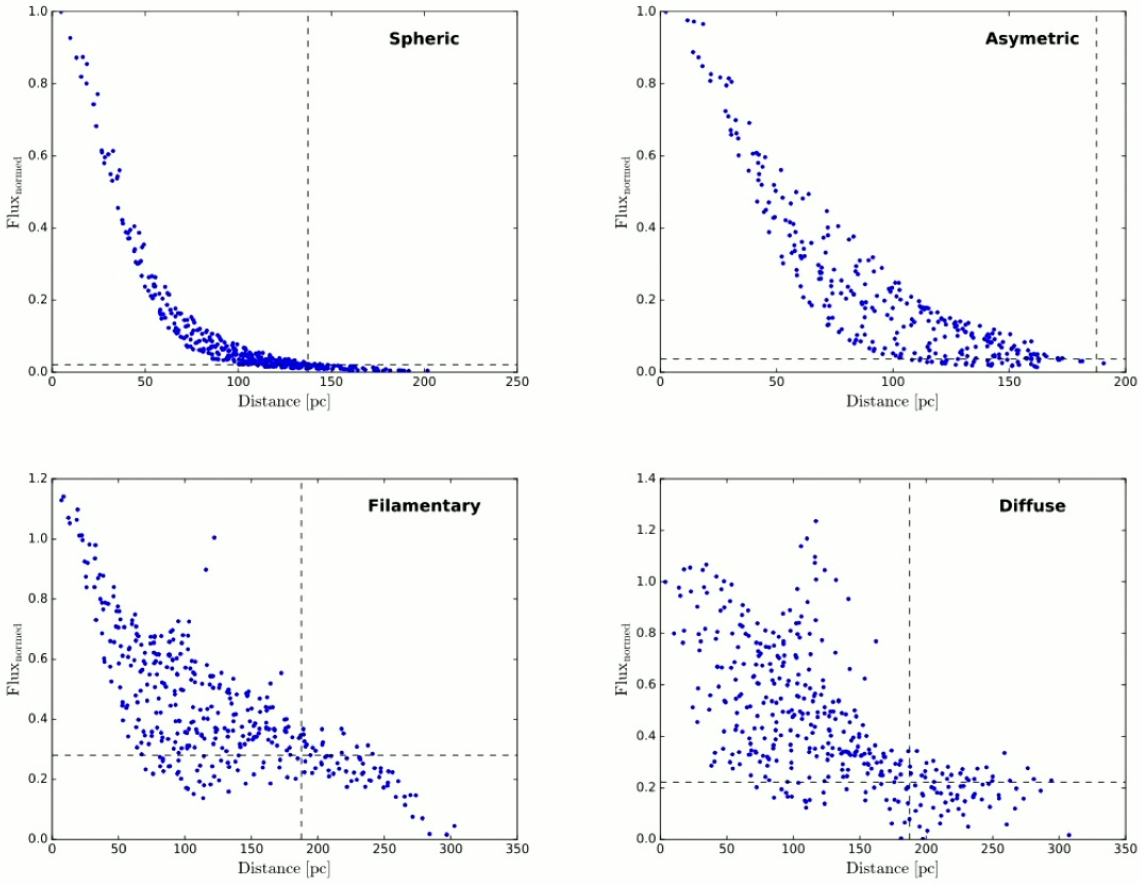


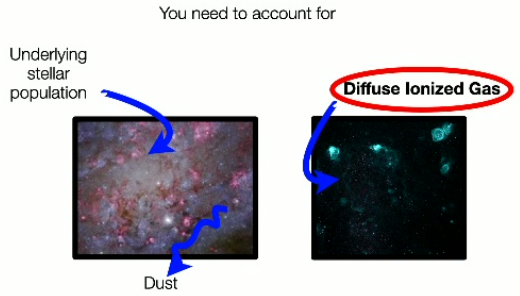


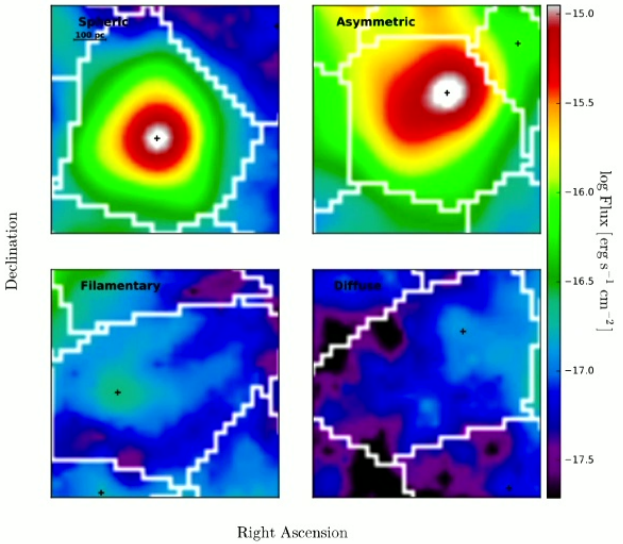



> 50 000 HII Regions

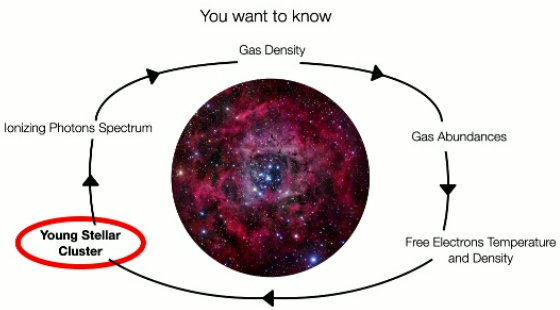
Diffuse Ionized Gas

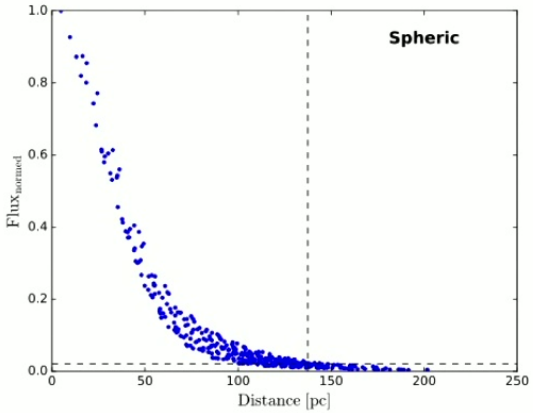


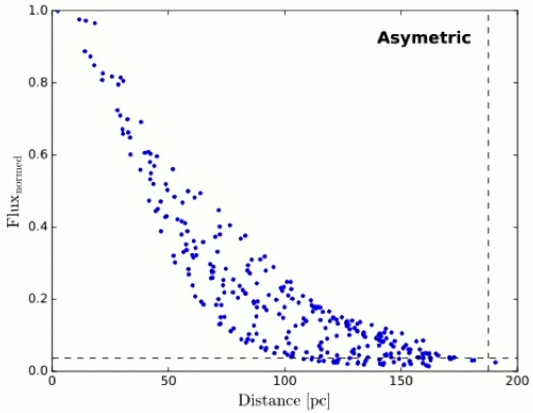




Young Stellar Clusters

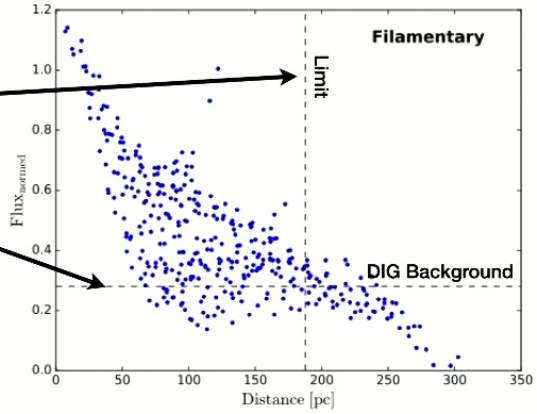


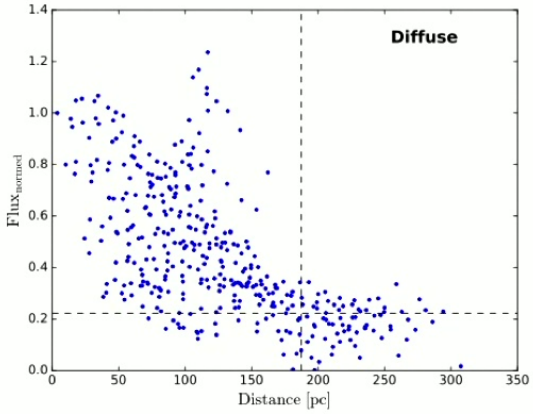




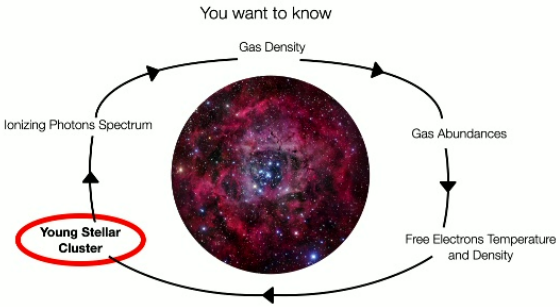
This Procedure Enable to:

- Recovers Lines Profiles
- Define the Limits of the Regions
- Define the Level of DIG
- Evaluate the Total Flux
- Evaluate the Size of the Regions





Young Stellar Clusters



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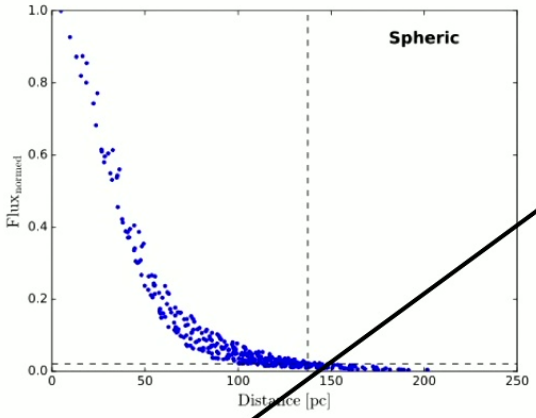
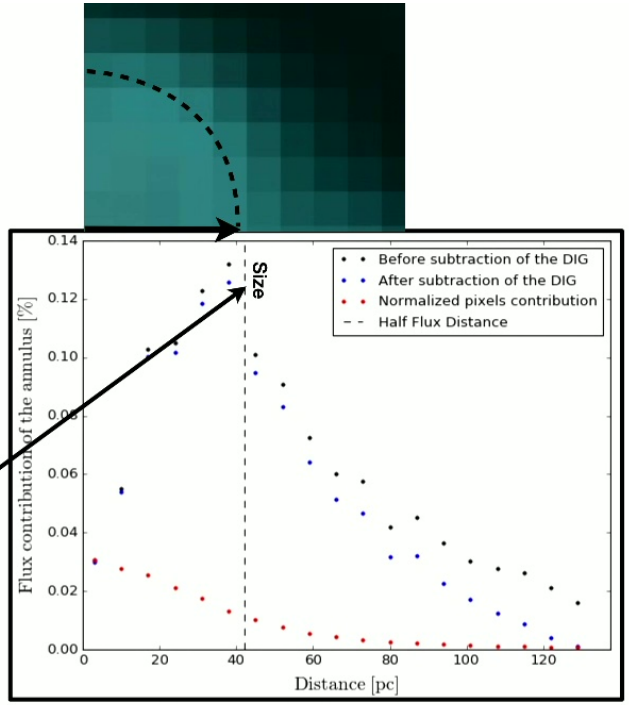
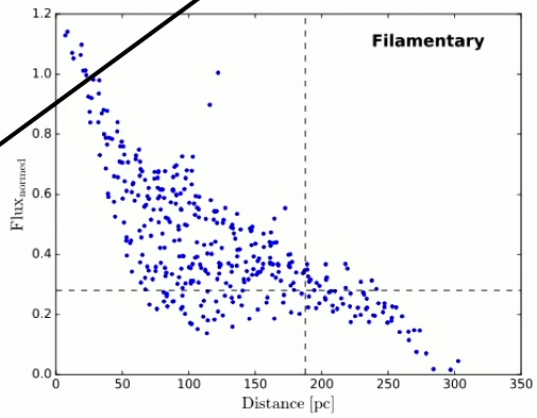
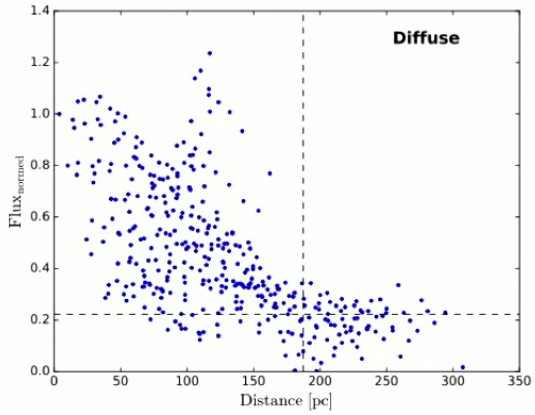
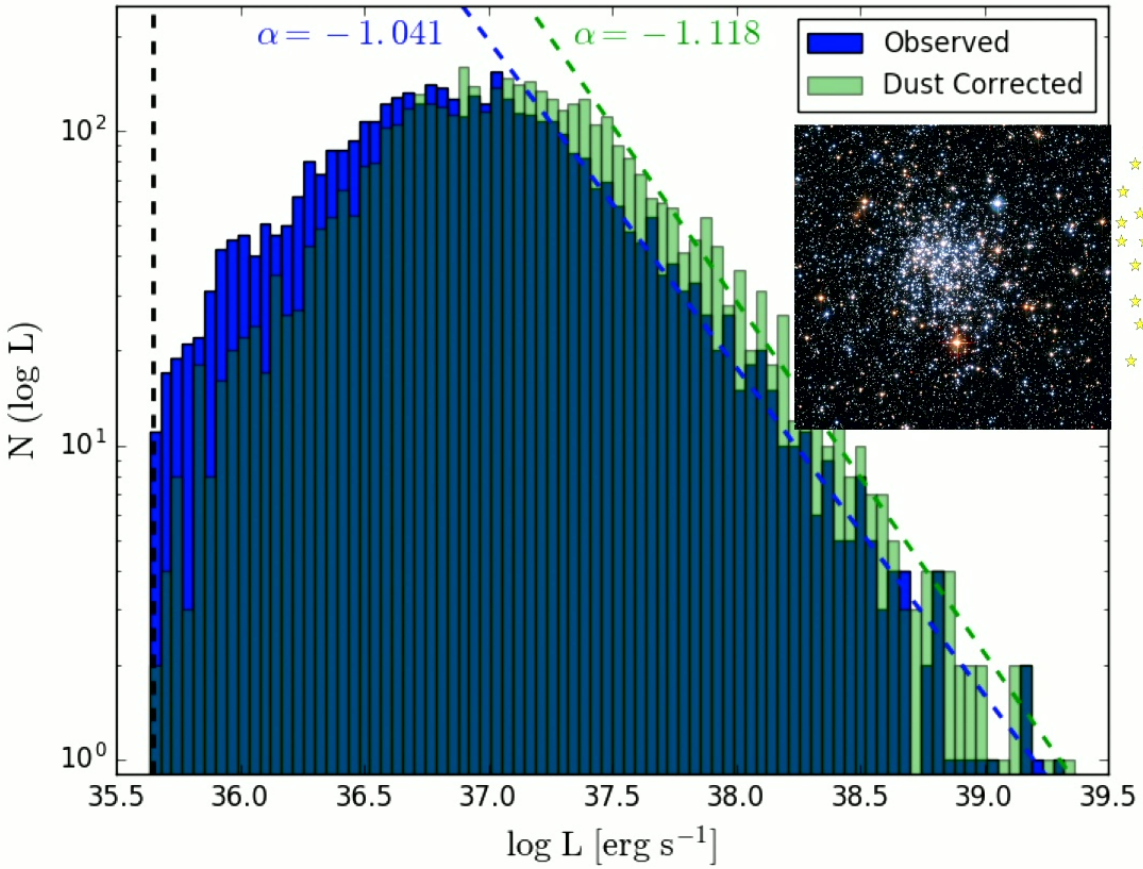


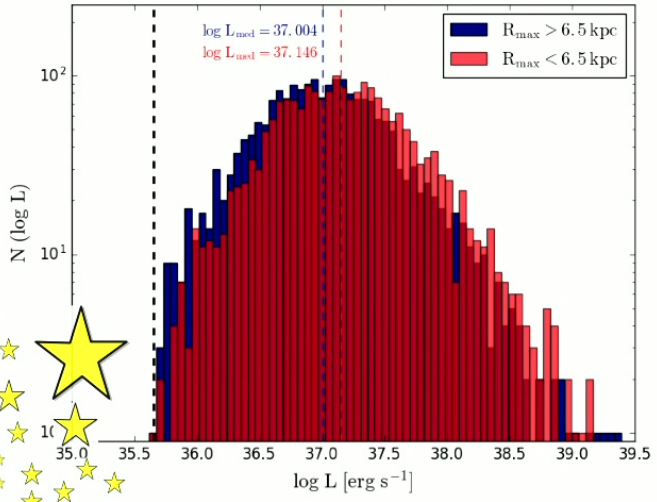


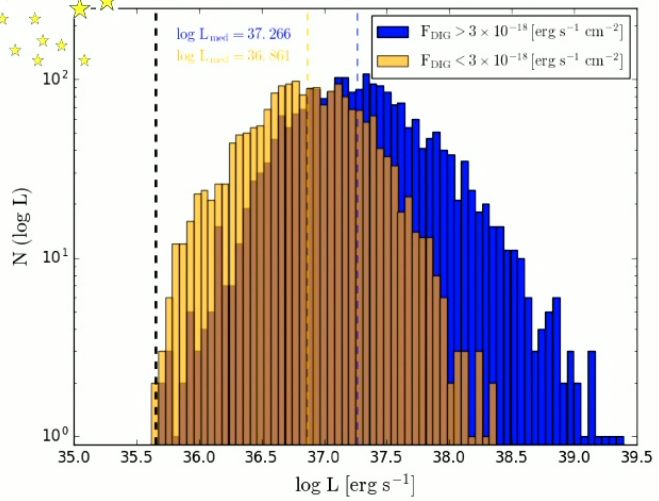


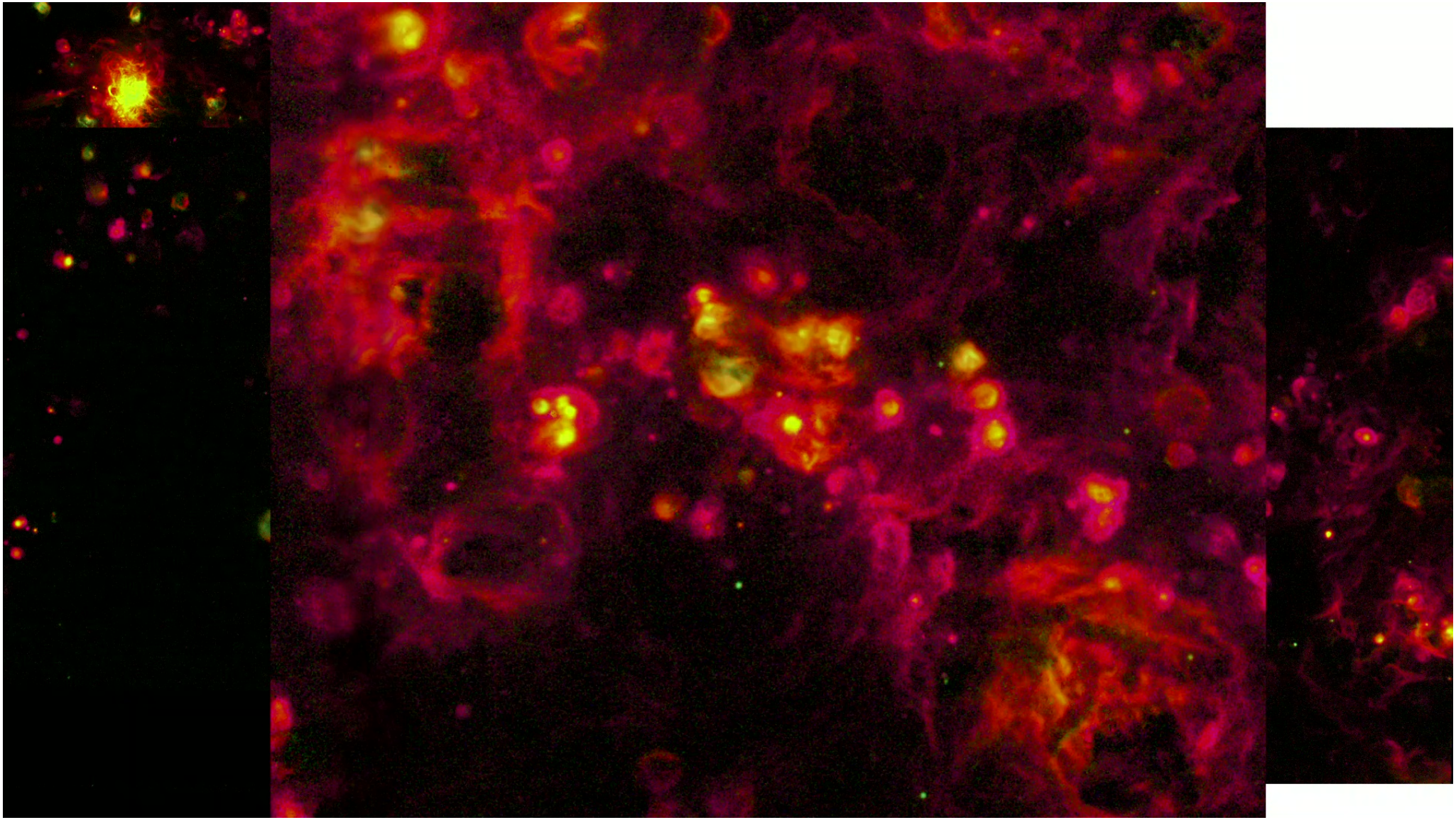


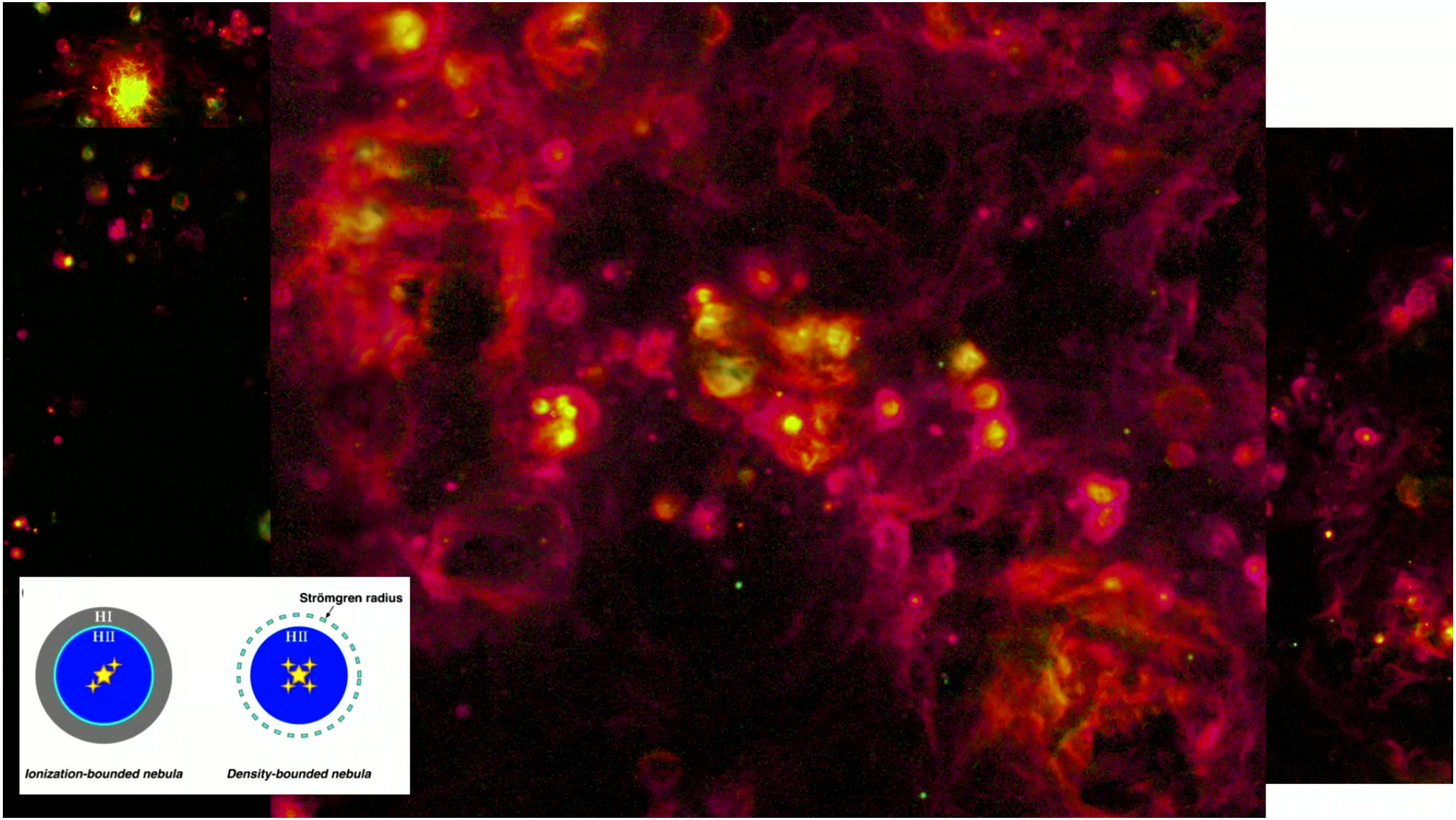
Highly Defined Luminosity Function of the HII regions



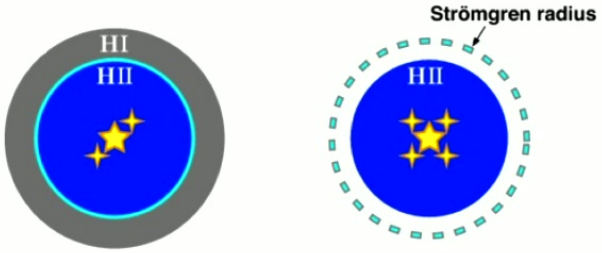




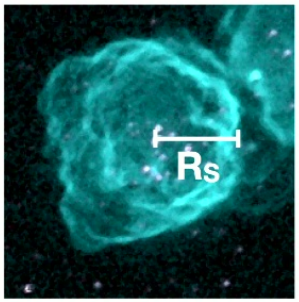



HI
HII
Strömgren radius
HII
Ionization-bounded nebula
Density-bounded nebula

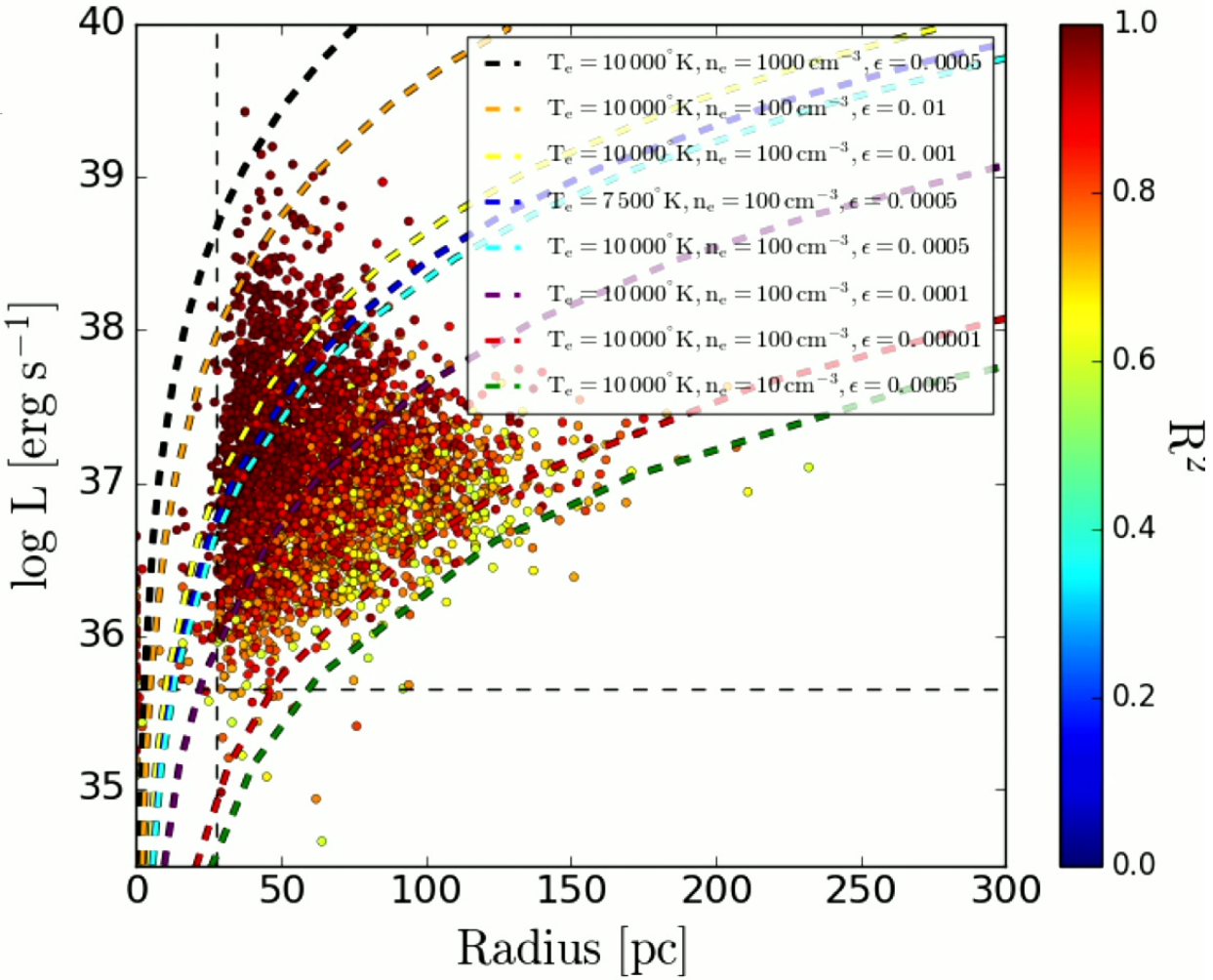
Size of the Ionized Sphere



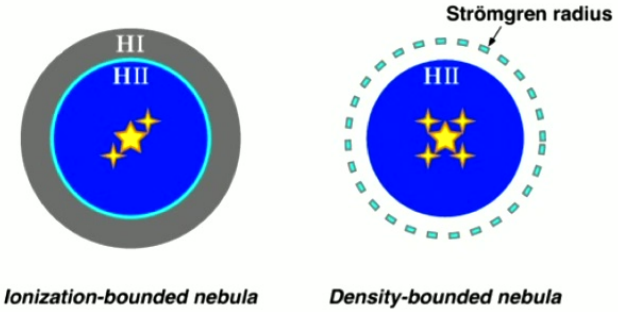
Ionization-bounded nebula *Density-bounded nebula*

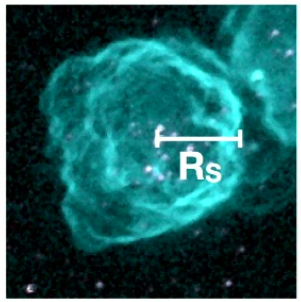


$$R^3_{\text{Strömgren}} = \frac{3Q_H}{4\pi\,\varepsilon\,n_e^2\,\alpha_B(H,T_e)}$$



Size of the Ionized Sphere





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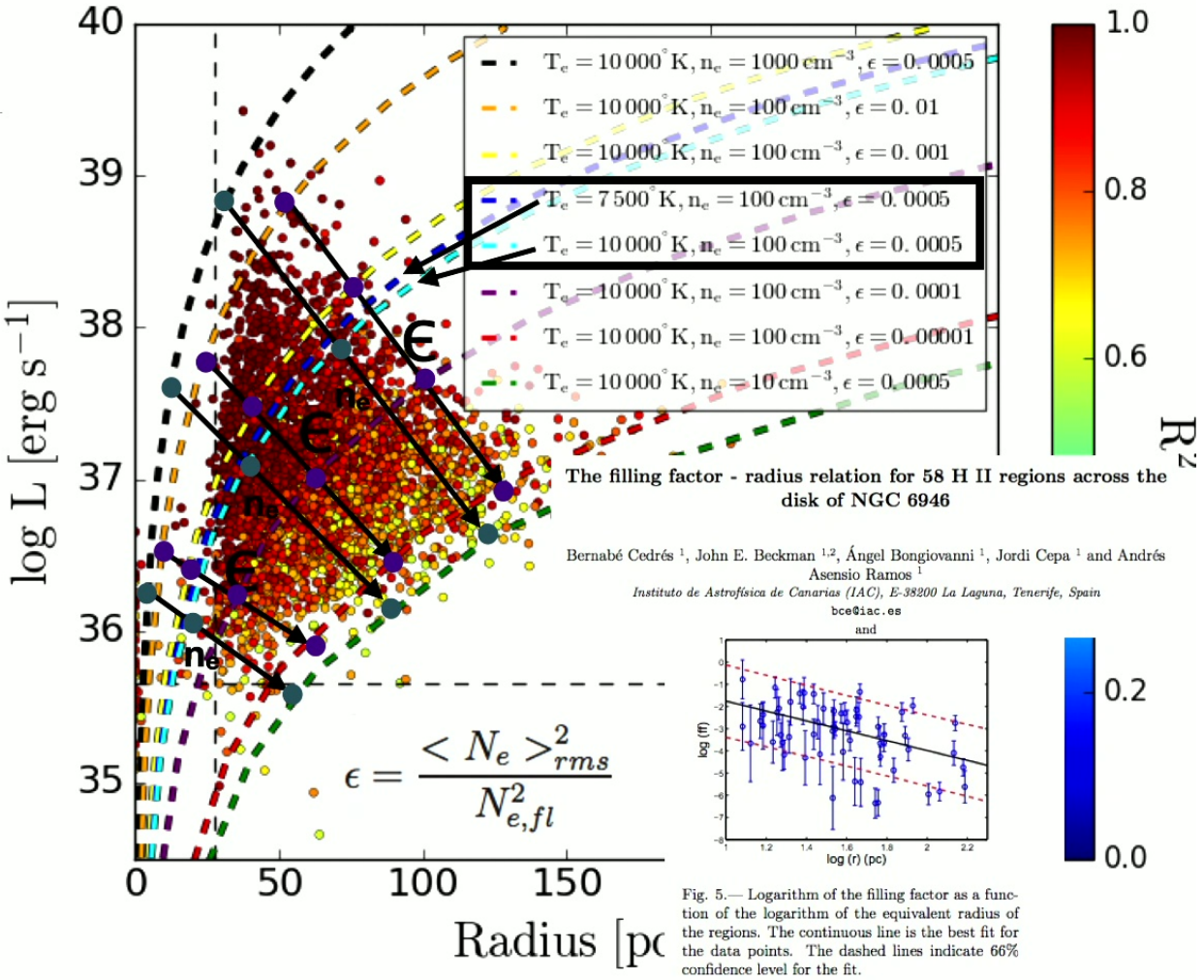
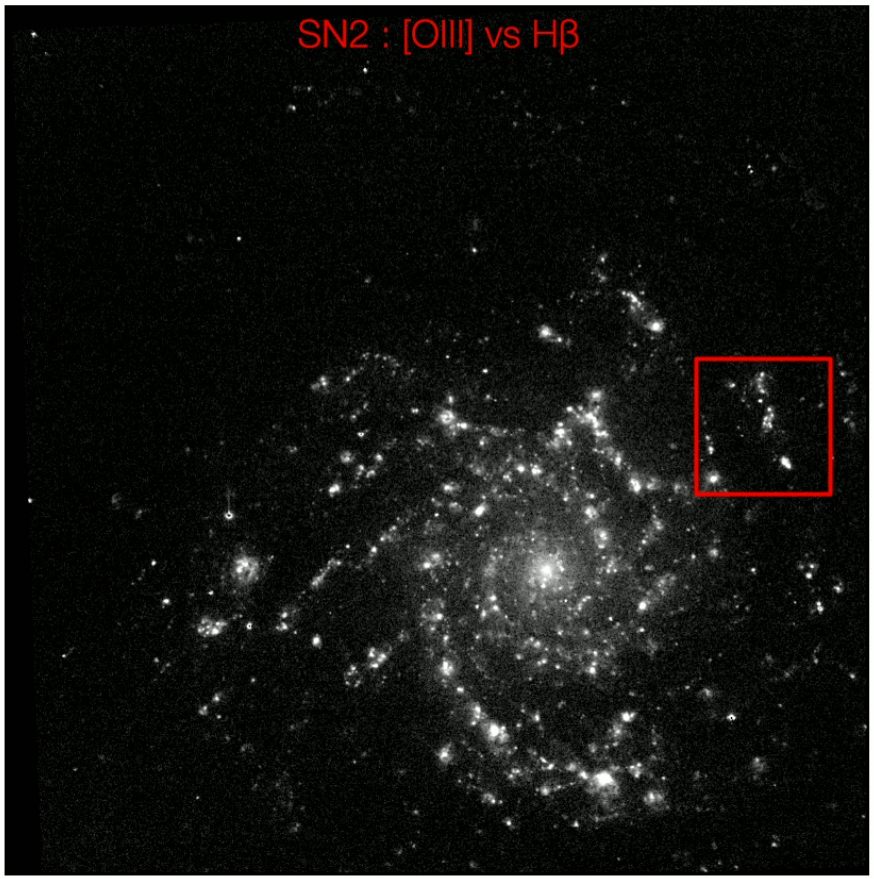


The filling factor - radius relation for 58 H II regions across the disk of NGC 6946

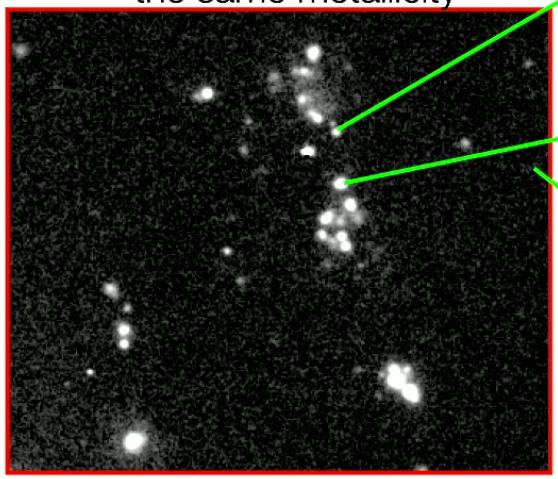
Bernabé Cedrés [1], John E. Beckman [1,2], Ángel Bongiovanni [1], Jordi Cepa [1] and Andrés Asensio Ramos [1]
Instituto de Astrofísica de Canarias (IAC), E-38200 La Laguna, Tenerife, Spain
bce@iac.es
and

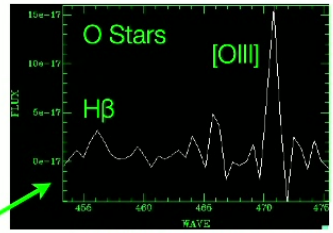
Fig. 5.— Logarithm of the filling factor as a function of the logarithm of the equivalent radius of the regions. The continuous line is the best fit for the data points. The dashed lines indicate 66% confidence level for the fit.

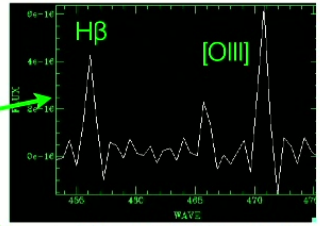
Line Ratios are affected by The Young Stellar Cluster Properties

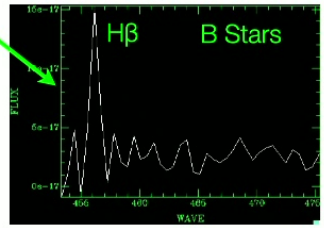


Group of regions with
~ the same metallicity









O stars vs B stars

Massive Region vs Less Massive Region

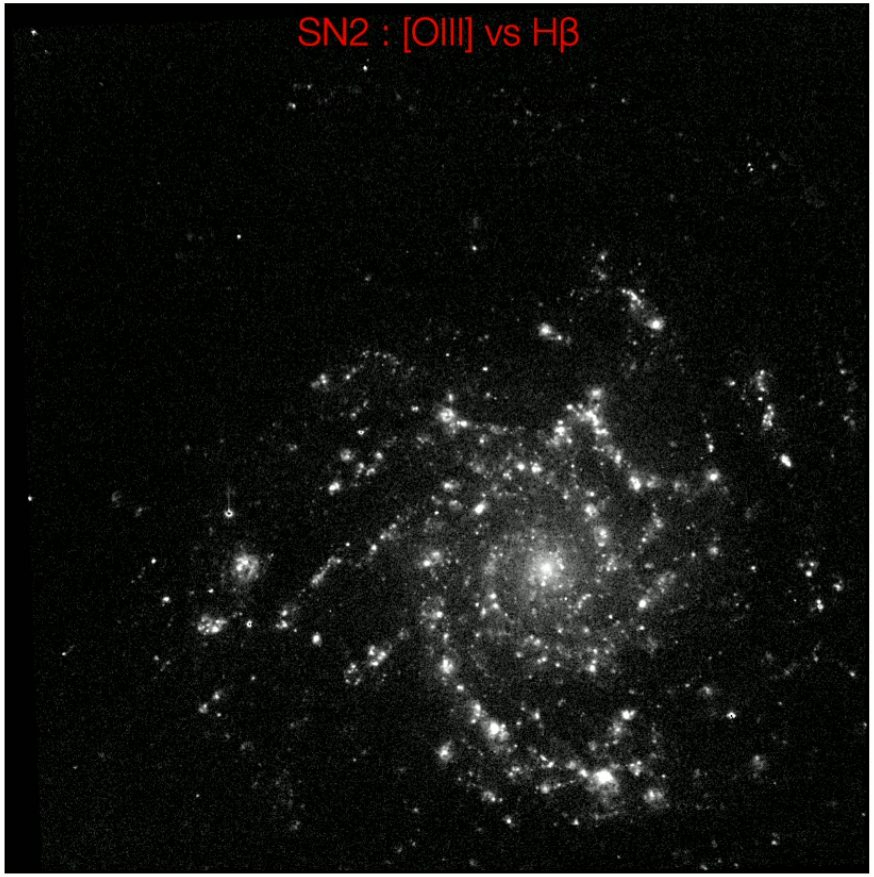
Young Region vs Older Region

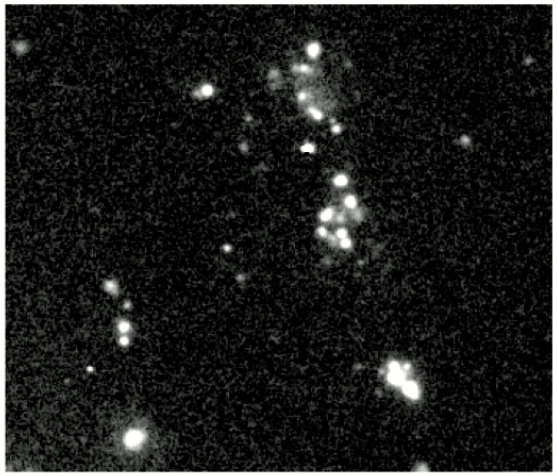
or Stochastic Sampling of the IMF

with a lot of regions

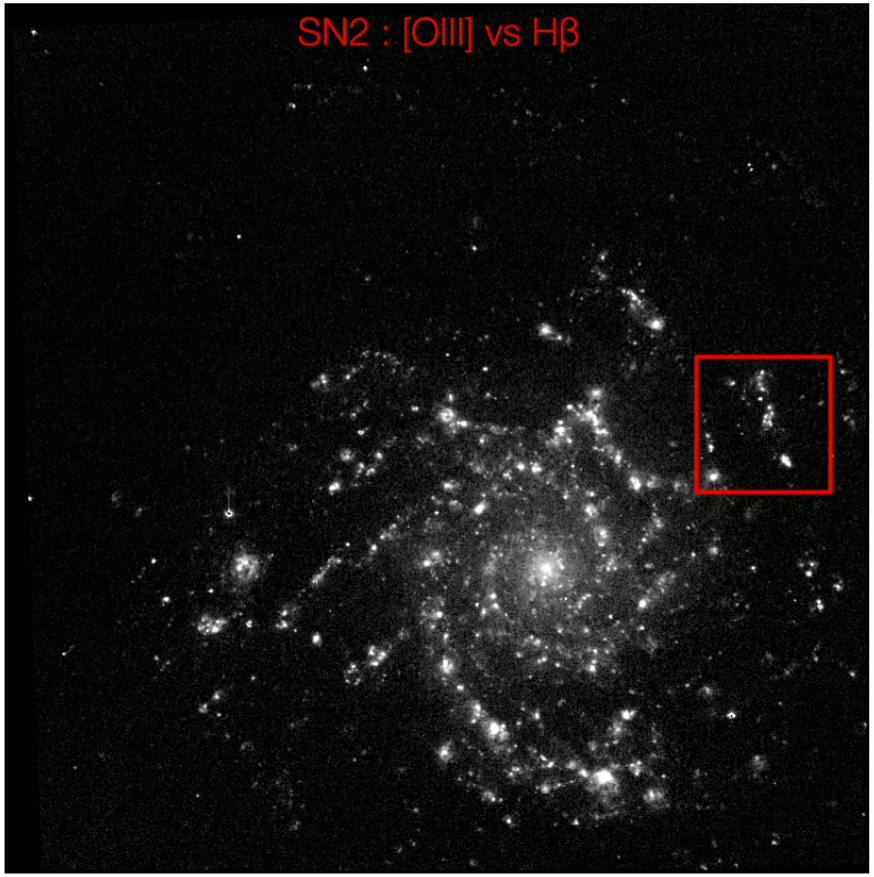
Variations of the IMF in different environments

Line Ratios are affected by The Young Stellar Cluster Properties

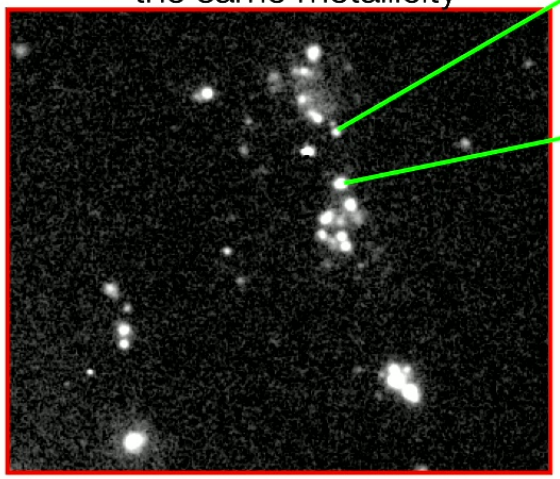


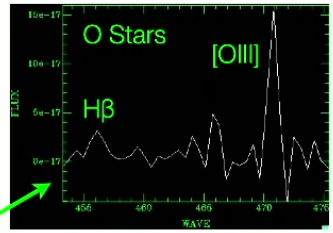


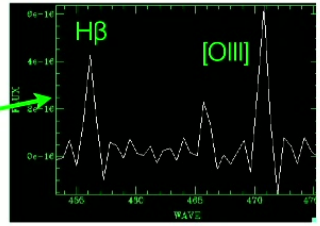
Line Ratios are affected by The Young Stellar Cluster Properties



Group of regions with
~ the same metallicity

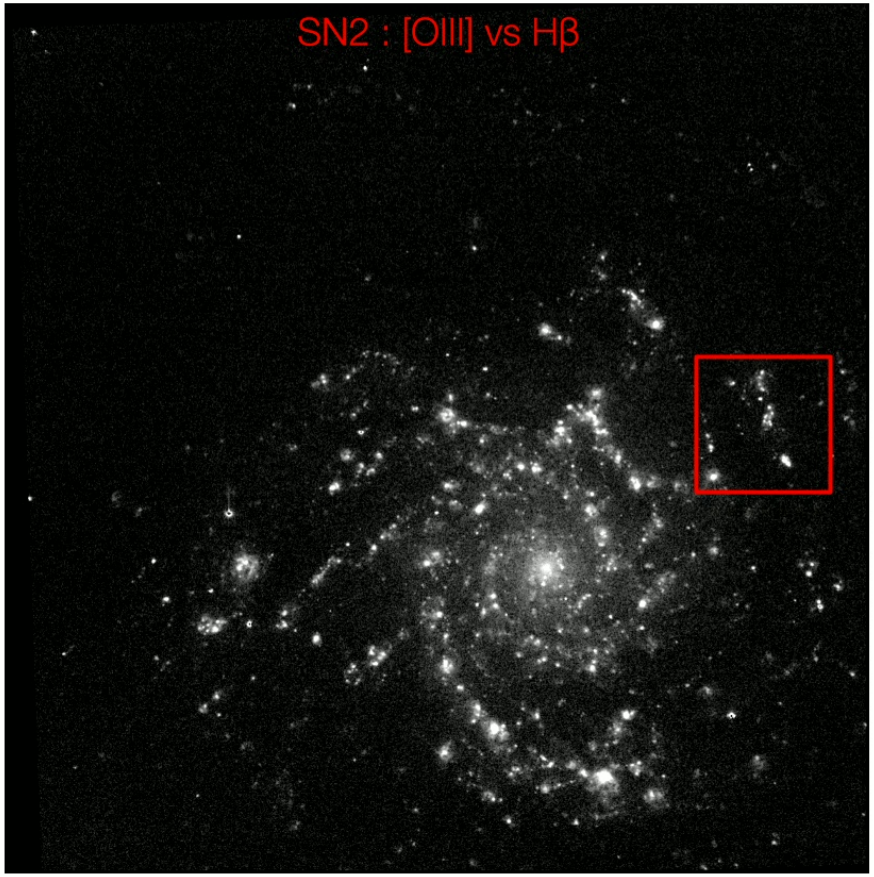






O stars vs B stars

Line Ratios are affected by The Young Stellar Cluster Properties



Group of regions with
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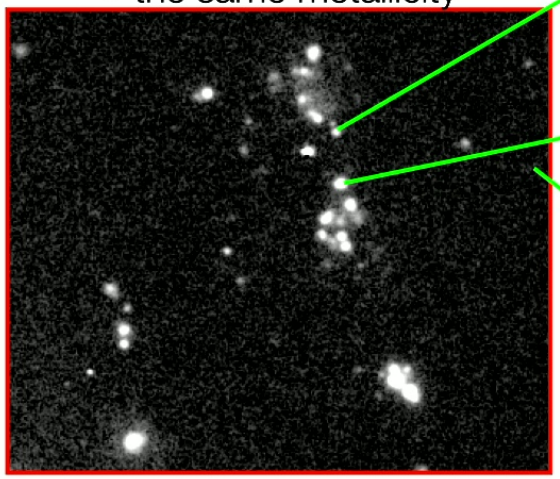
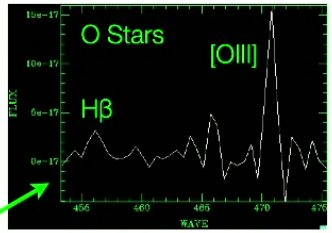
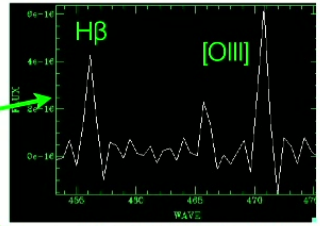
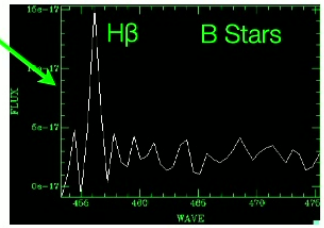








O stars vs B stars

Massive Region vs Less Massive Region

Young Region vs Older Region

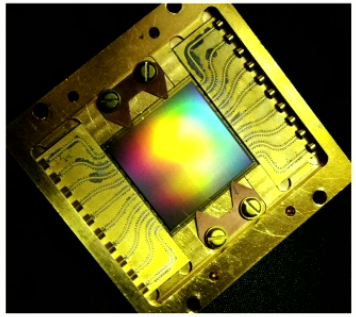
or Stochastic Sampling of the IMF

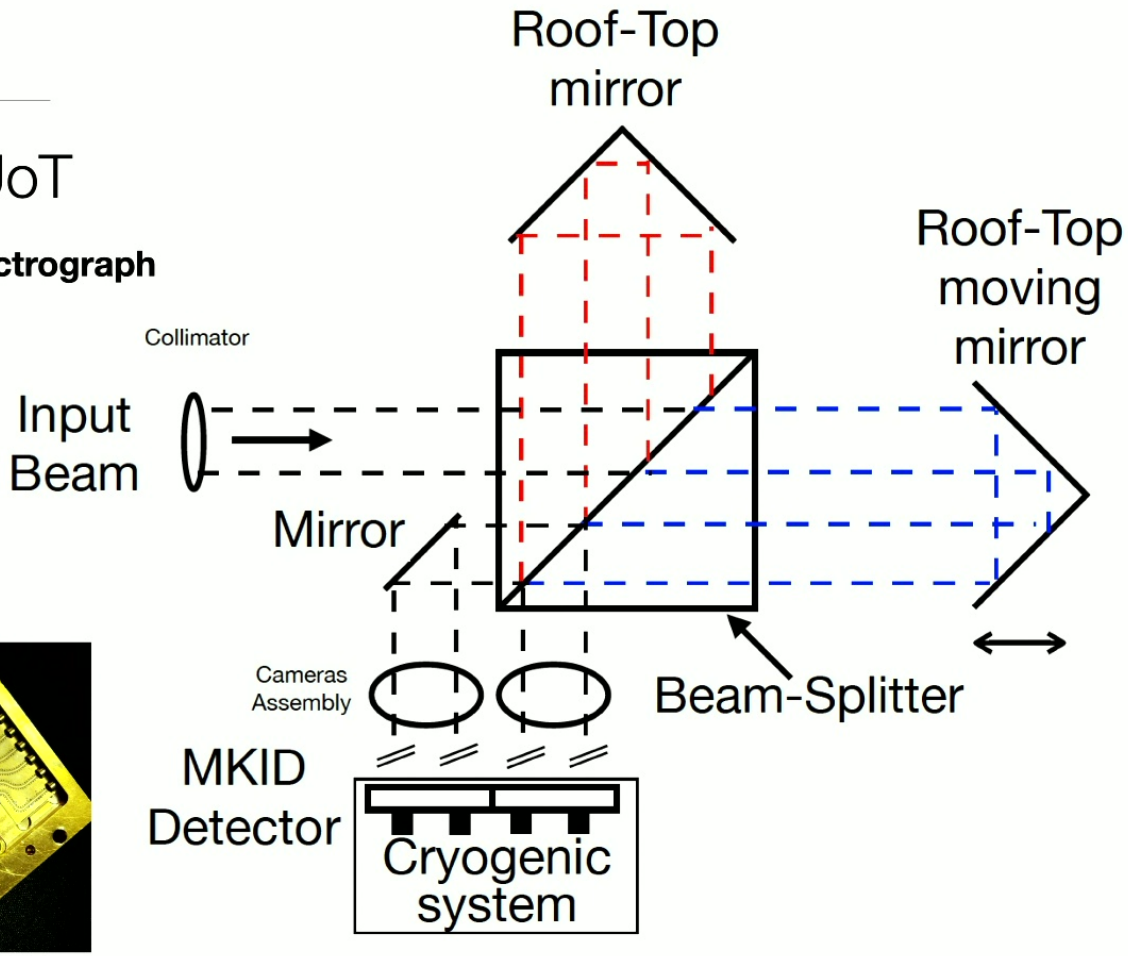
Multiplexing

Instrumentation Project at UoT

Developing a High-resolution Imaging Spectrograph

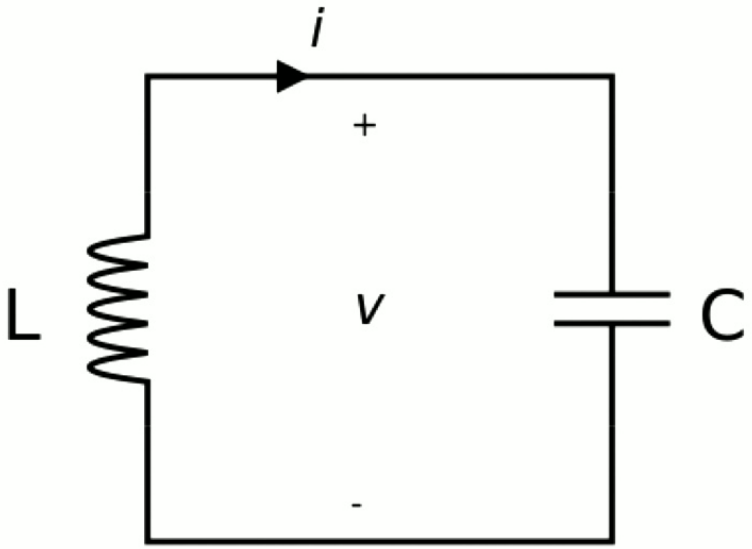
- No Need for filters
- Broad Band from 300nm to 1.5um
- No read out noise
- No dark current
- On-axis for better efficiency

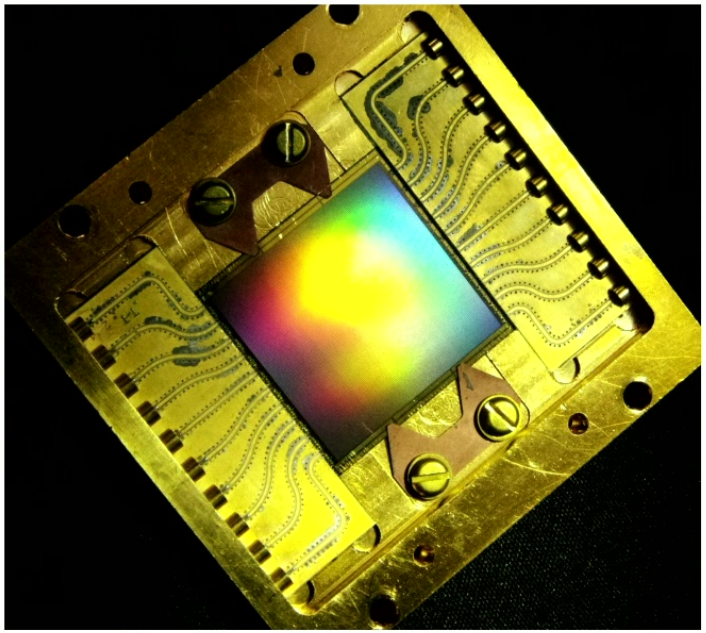




Low temperature superconducting resonant LC circuits

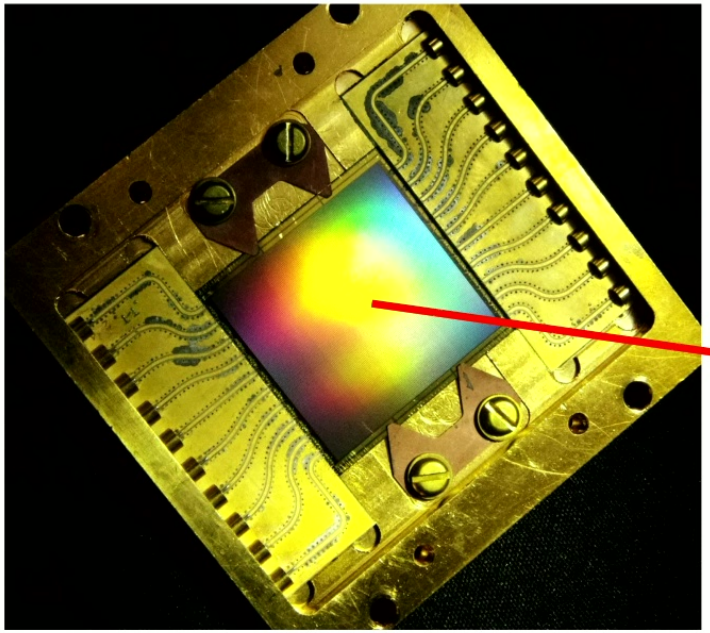
An LC circuit (**Resonant circuit**) is consisting of an inductor, represented by the letter L, and a capacitor, represented by the letter C, connected together. The circuit can act as an electrical resonator, an electrical analogue of a tuning fork, storing energy oscillating at the circuit's resonant frequency.





Superconductor

Dilution Refrigerator



MKIDs working principle: Incident photons change the surface impedance of a superconductor through the kinetic inductance effect.

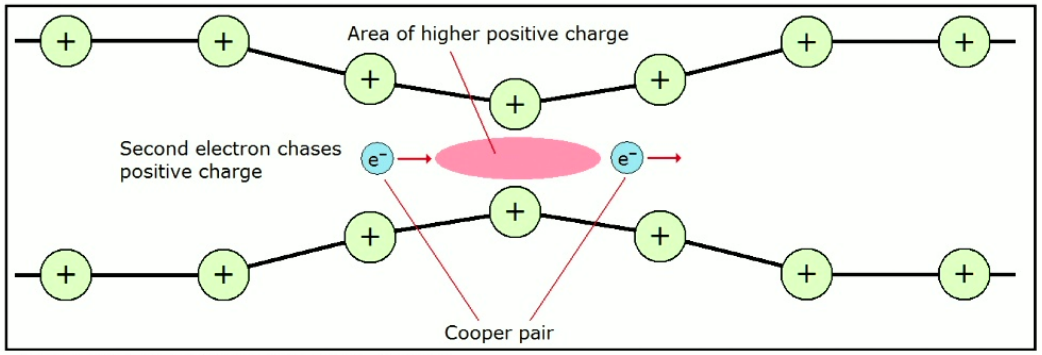
Impedance is the opposition to alternating current presented by the combined effect of resistance and reactance in a circuit.

Assuming a two-terminal circuit element with impedance Z is driven by a sinusoidal voltage or current:

$$V = IZ = I|Z|e^{j\arg(Z)}$$

The magnitude of the impedance |Z| acts just like resistance, giving the drop in voltage amplitude across an impedance Z for a given current I. The phase factor tells us that the current lags the voltage by a phase of θ=arg(Z) (i.e., in the time domain, the current signal is shifted T*θ/2π later with respect to the voltage signal).

The **kinetic inductance effect** occurs because energy can be stored in the super current (the flow of Cooper Pairs) of a superconductor.



https://dc.edu.au/wp-content/uploads/cooper-pair-phonon.png

The rigorous quantum mechanical explanation shows that the effect is due to electron–phonon interactions, with the phonon being the collective motion of the positively-charged lattice.

How do we measure the photons E and t?

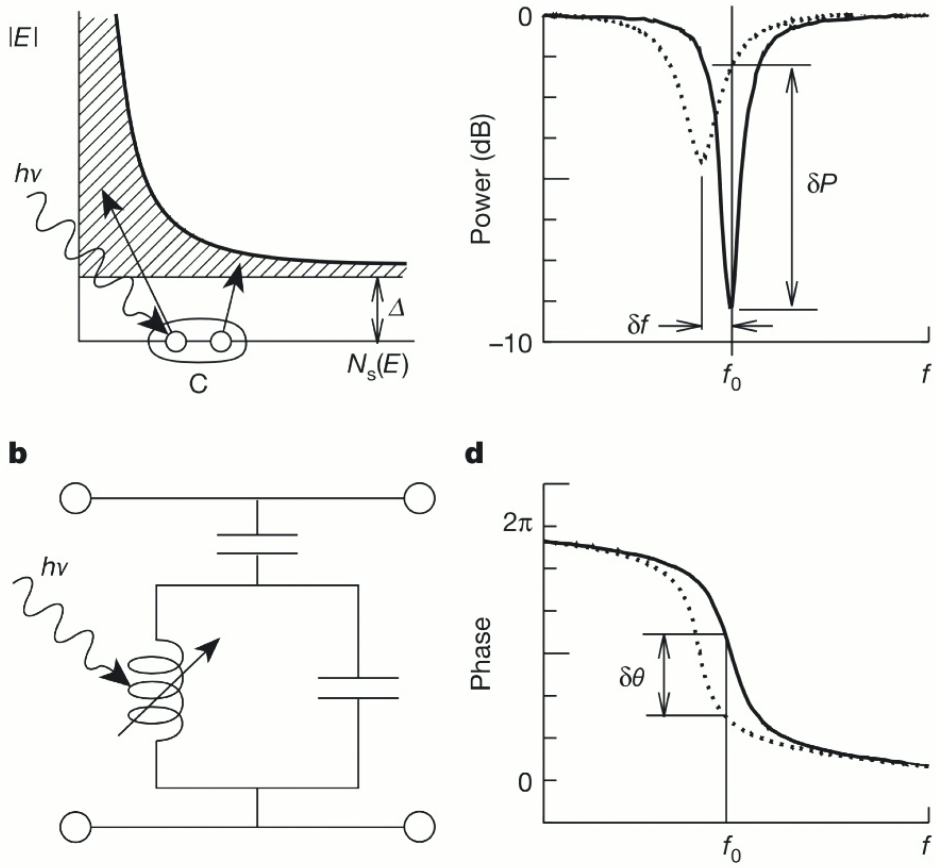
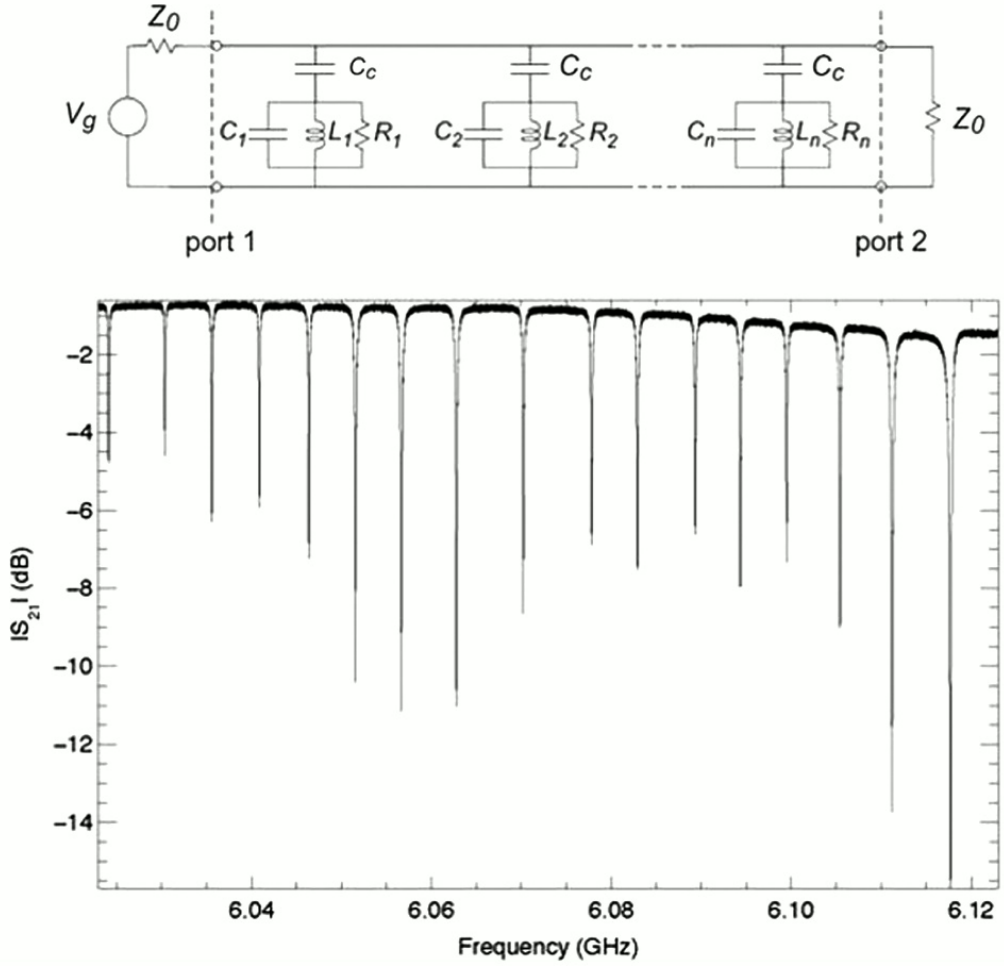


Figure 1.10 The basic operation of an MKID, from Day et al. (2003). (a) Photons with energy $h\nu$ are absorbed in a superconducting film producing a number of excitations called quasiparticles. (b) To sensitively measure these quasiparticles the film is placed in a high frequency planar resonant circuit. The amplitude (c) and phase (d) of a microwave excitation signal sent through the resonator. The change in the surface impedance of the film following a photon absorption event pushes the resonance to lower frequency and changes its amplitude. If the detector (resonator) is excited with a constant on-resonance microwave signal, the energy of the absorbed photon can be determined by measuring the degree of phase and amplitude shift.

Since the quality factor, Q, of the resonators is high, and their transmission off resonance is nearly perfect, multiplexing can be accomplished by tuning each pixel to a different resonant frequency with lithography during device fabrication.



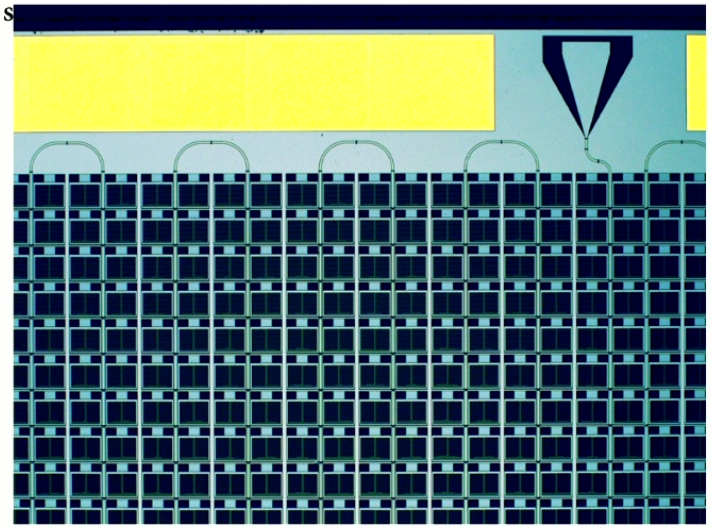


Figure 6. An optical microscope picture of part of a 10 kpix MKID array.

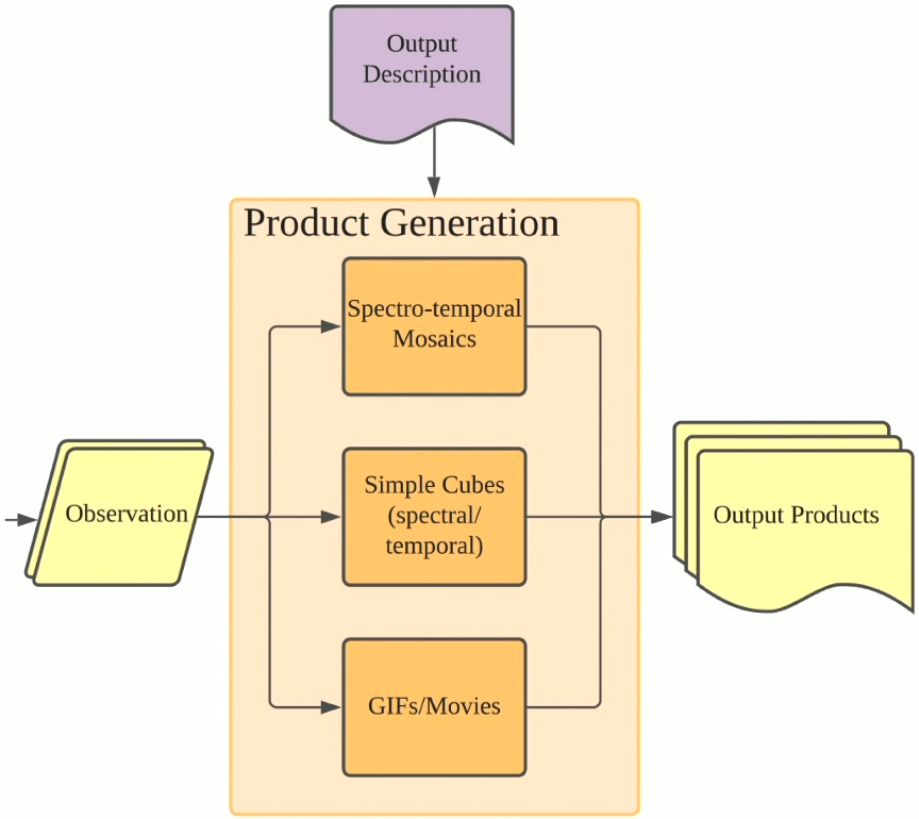
Data output

The MKID Pipeline: A Data Reduction and Analysis Pipeline for UVOIR MKID Data

Sarah Steiger [1,*] John I. Bailey, III [1,*] Nicholas Zobrist [1] Noah Swimmer [1] Rupert Dodkins,[1] Kristina K. Davis [1] and Benjamin A. Mazin [1]

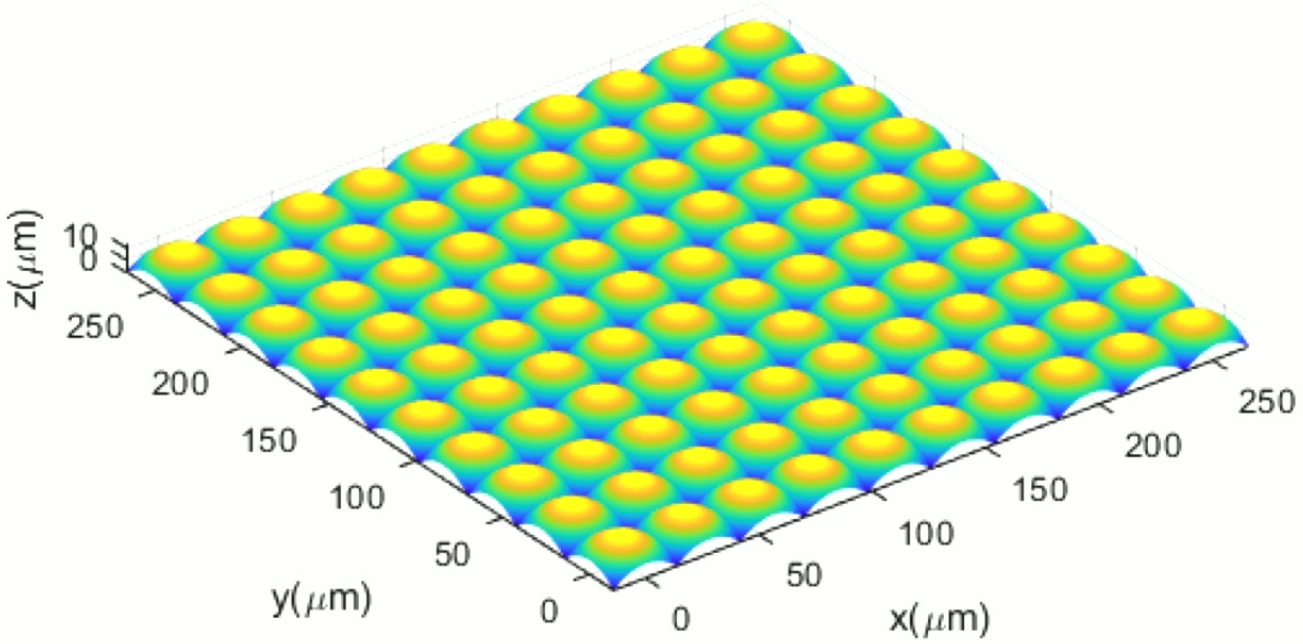
- Photons table
- 64bits words for every photons:

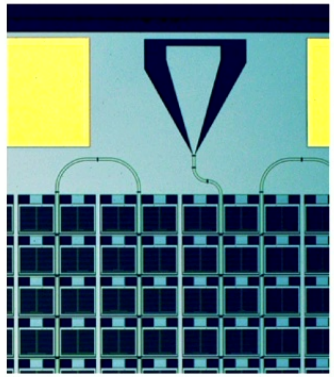
  pixelsID (position), energy, time
- Terabites of data every night



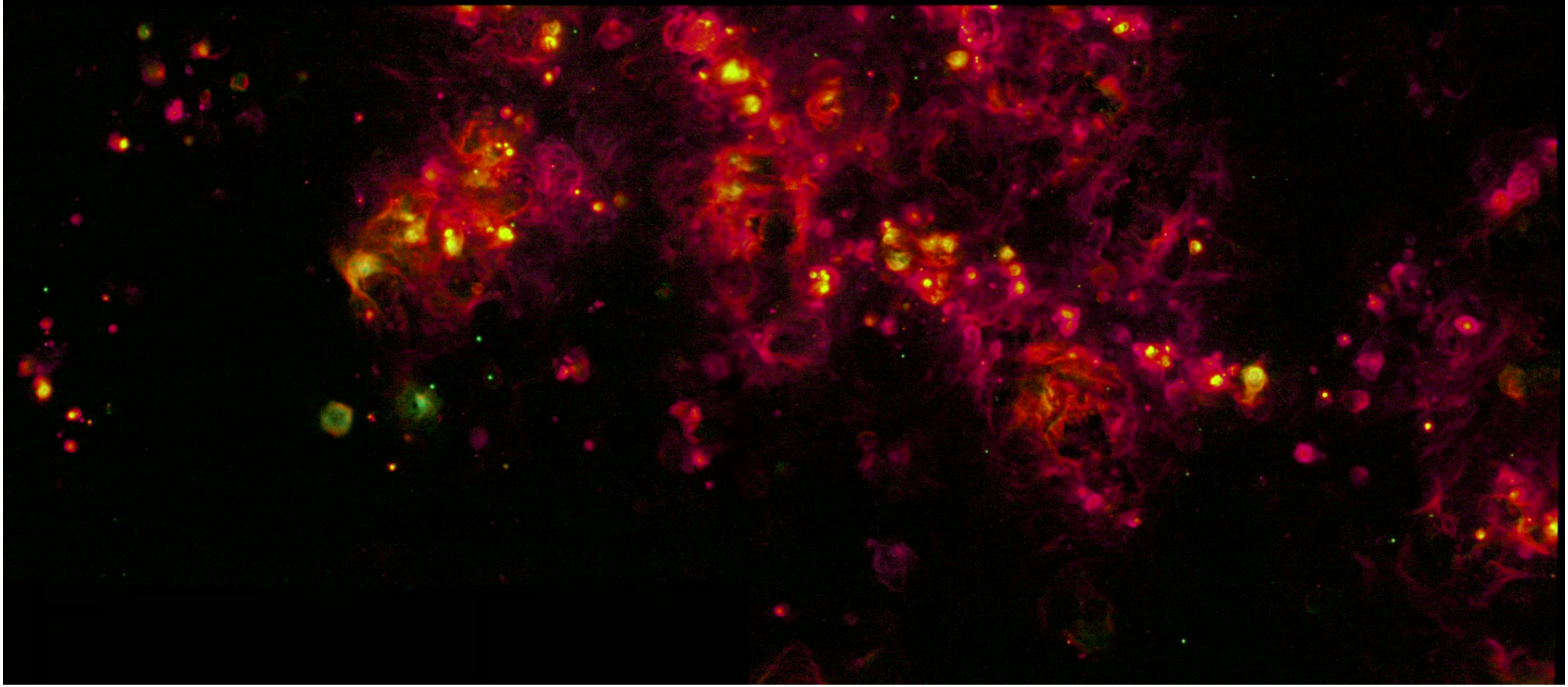
Array of micro lenses to increase QE (99% filling)

150um size pixels with gaps





Concluding Remarks and Questions?



The heart of the IFTS

- Tilted Michelson