The interaction between stars and the ISM on “cloud scales”

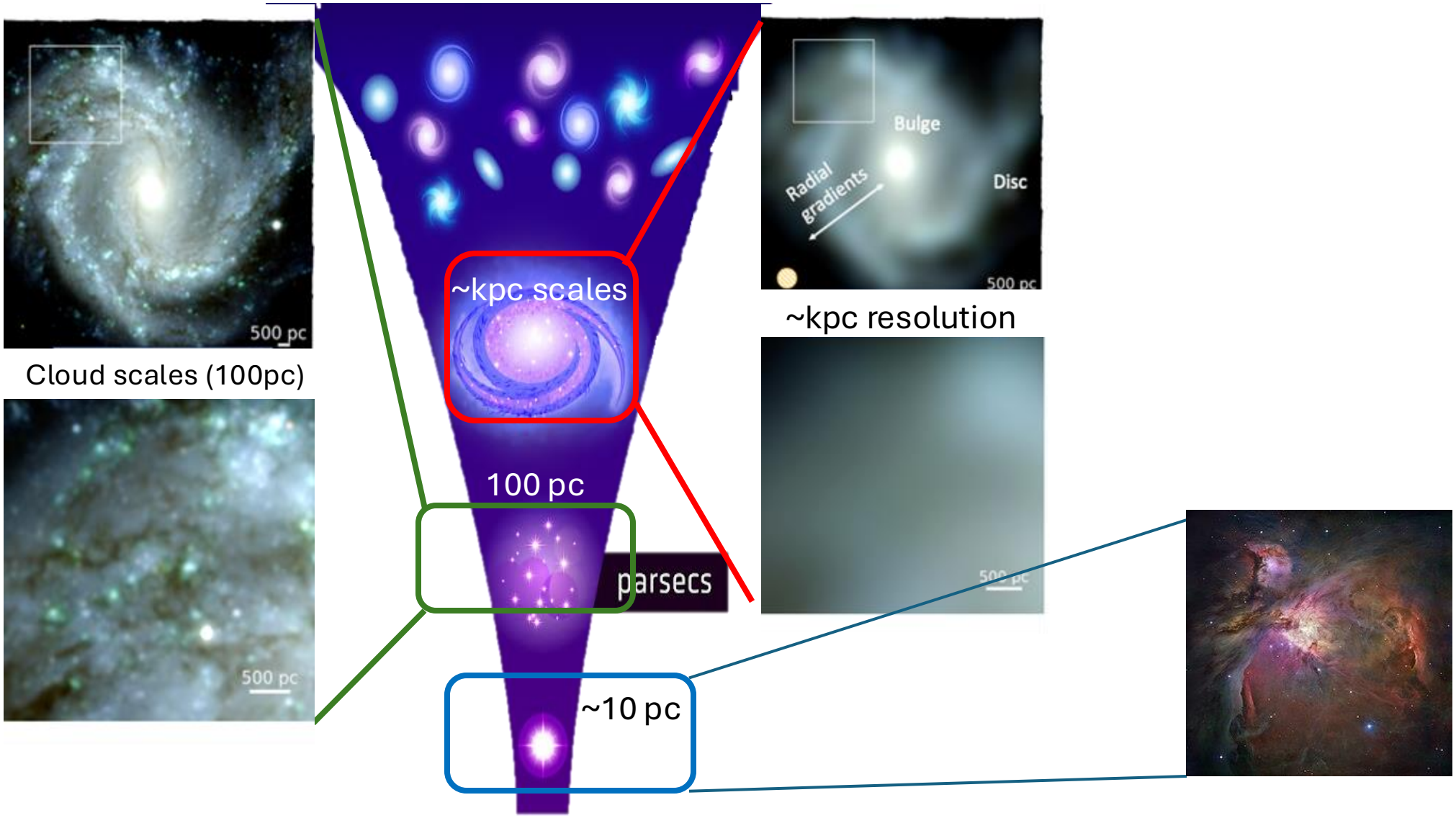
Francesco Belfiore

INAF – Arcetri Astrophysical Observatory
&
ESO Garching (from September 1st)

AIP Thinkshop, 14 July 2025

In collaboration with: the PHANGS team & the Arcetri Extragalactic Group

Motivation: an observer's view



Outline


Anna Feltre


Caterina Bracci


Bianca Moreschini

Cloud-scale science (<100pc)

HII region scales (<10pc)

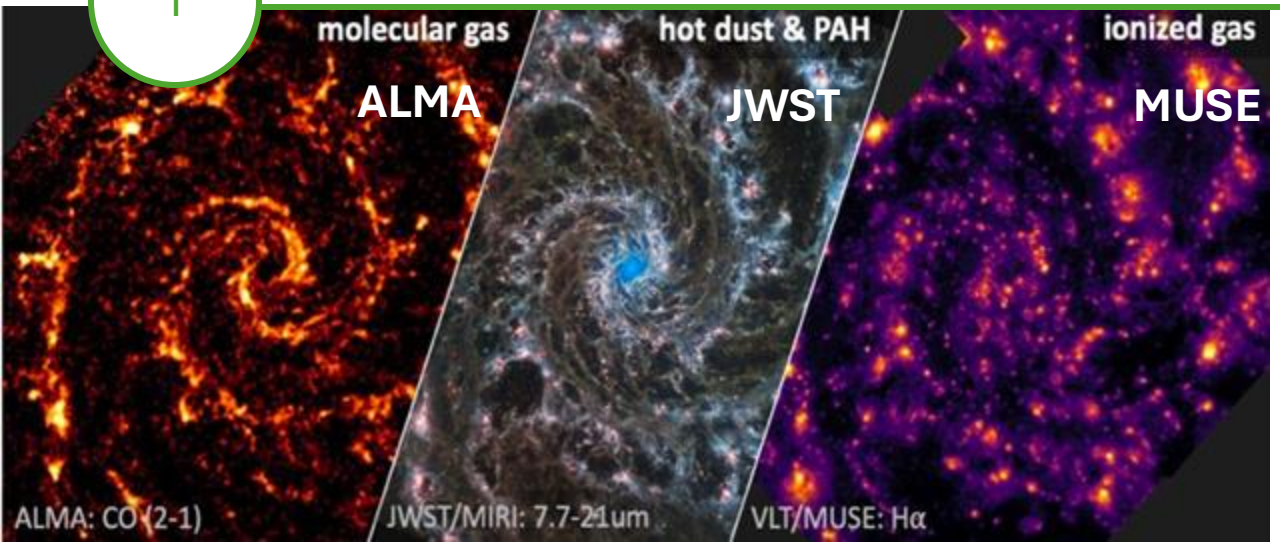
1 How does ionizing radiation shape the ISM?

2 Linking nebulae and ionizing sources (using machine learning)

3 ISM diagnostics and chemical abundances

Leveraging a multi-wavelength view

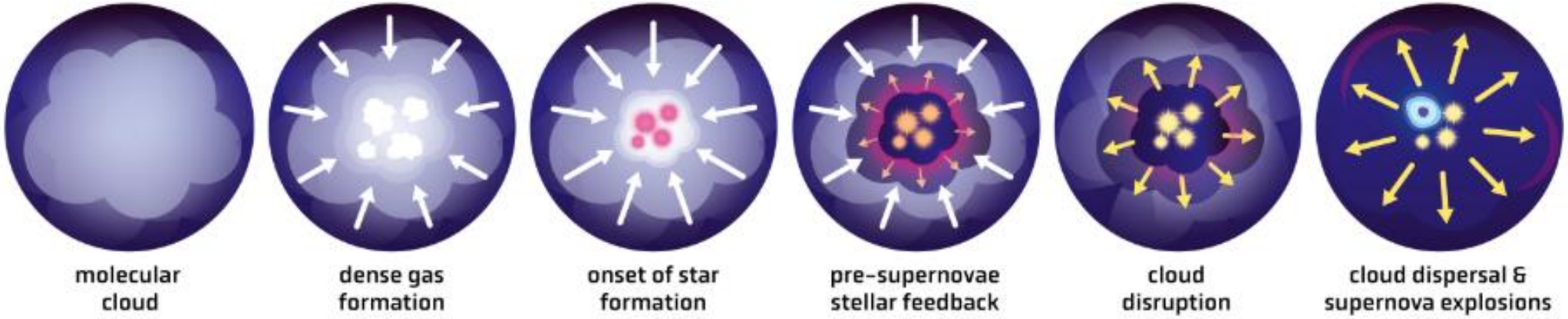
1

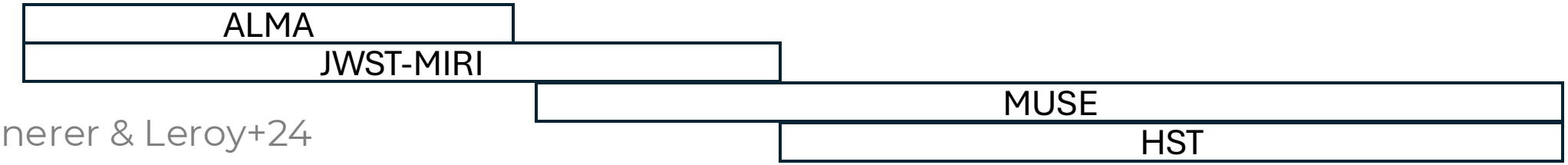


Resolve the fundamental units of the star formation cycle: **GMCs, HII regions, star clusters**

The **PHANGS** survey studies ~90 nearby main sequence galaxies with ALMA, HST, JWST and MUSE (only partially)

Leroy+21, Emsellem+22, Lee+23a,b



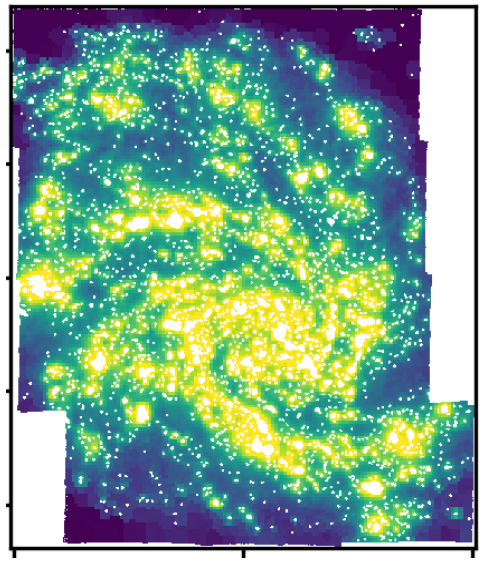


Schinnerer & Leroy+24

See Lise's talk!

The escape of ionizing radiation

log(Hα observed)

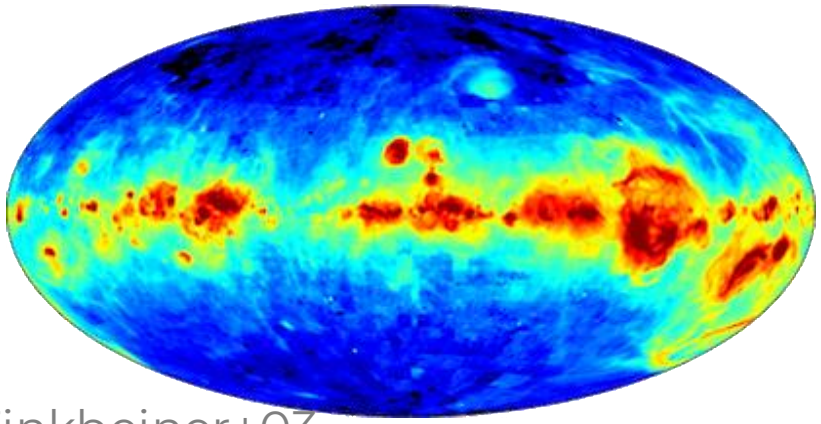


FB+22, 23

What fraction of ionising radiation escapes HII regions?

How far does ionizing radiation travel?

What ionises the diffuse ionised gas (DIG)?

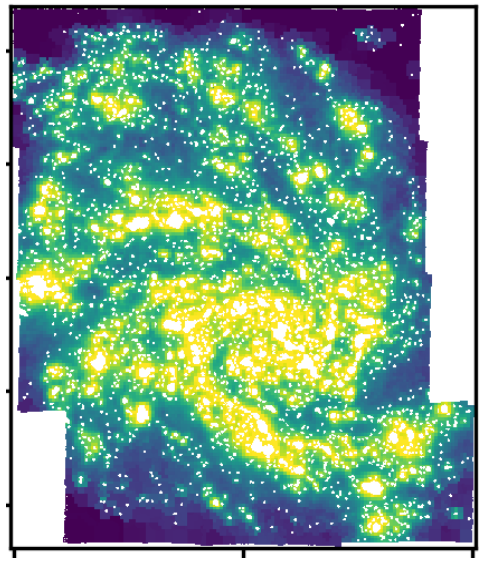


Finkbeiner+03

The escape of ionizing radiation

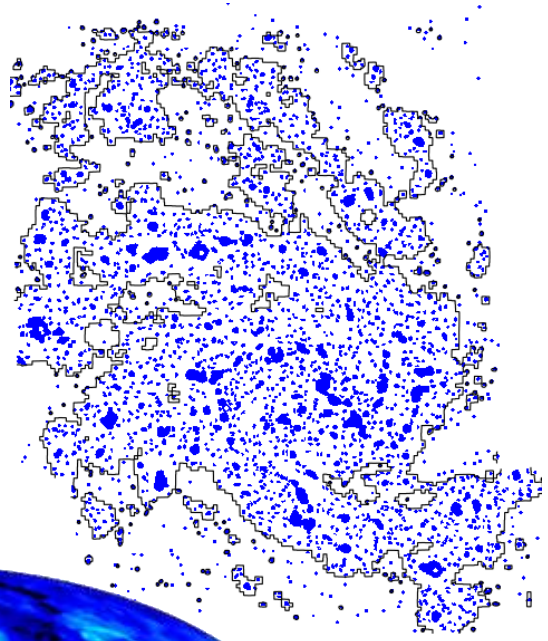
1

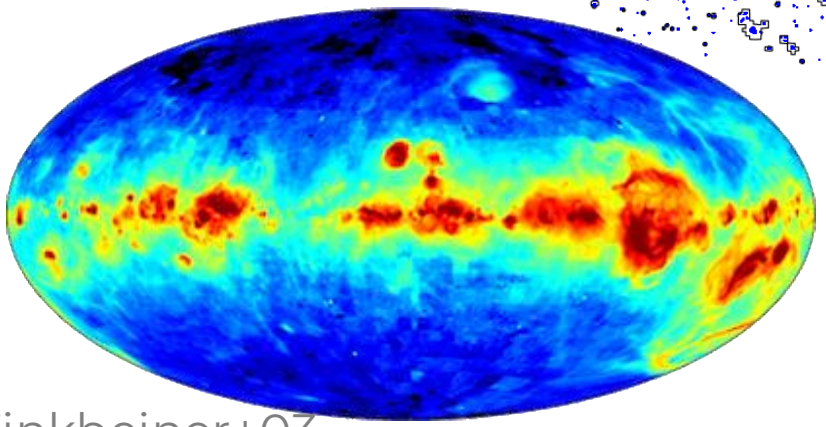
log(Hα observed)



FB+22, 23

HII regions





Finkbeiner+03

What fraction of ionising radiation escapes HII regions?

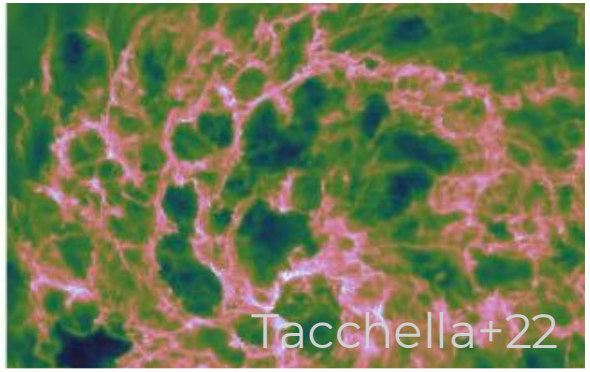
Median escape fraction ~40%

How far does ionizing radiation travel?

Ionizing radiation travels around ~1-2 kpc, simulations indicate this is mostly perpendicular to the disc

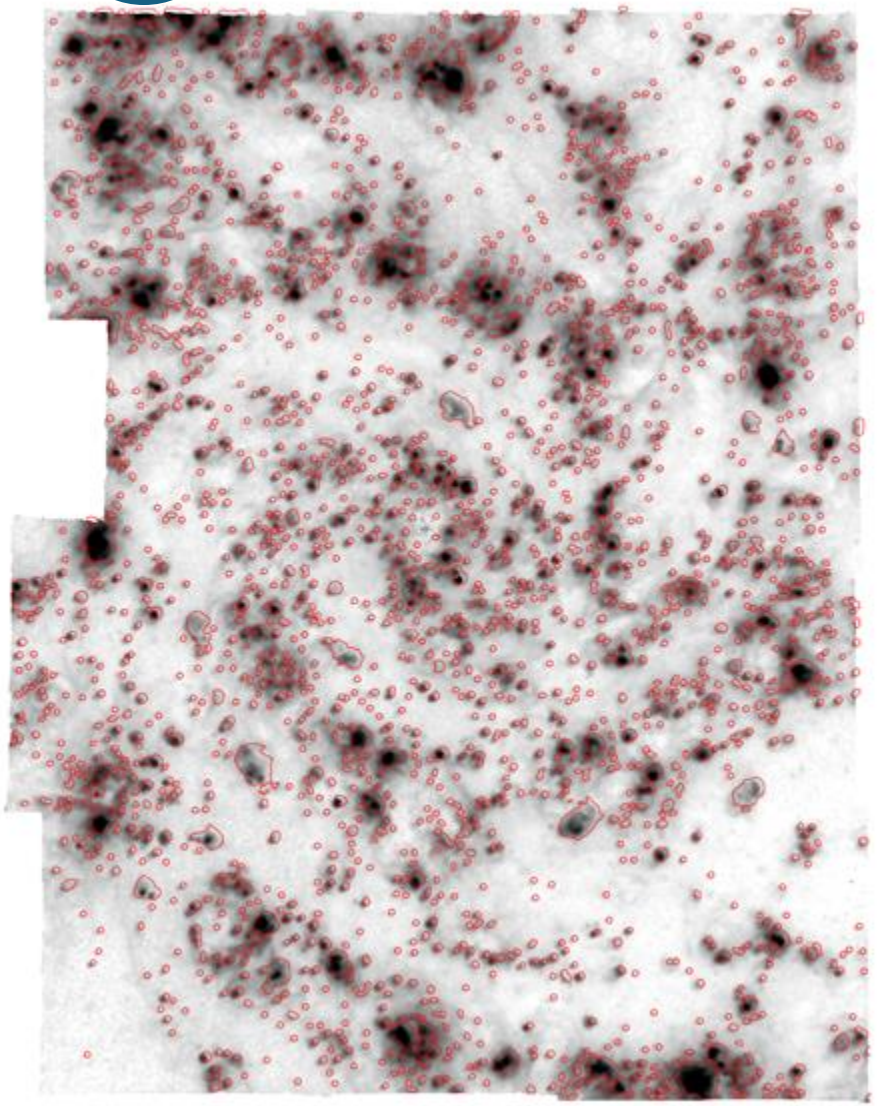
What ionises the diffuse ionised gas (DIG)?

>90% of the Ha emission in the DIG is ionised by leaking radiation, the rest from old stars



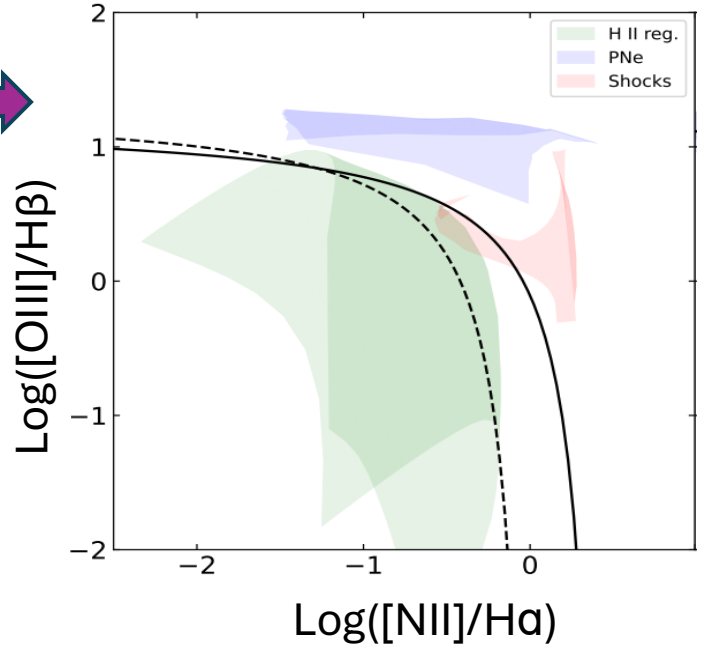
Tacchella+22

Classifying nebulae: the classical approach



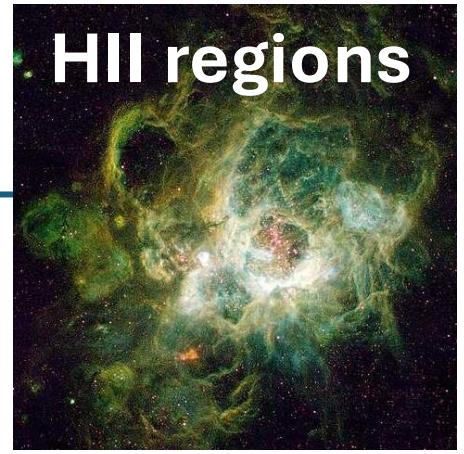
Santoro+22, Groves_23, Congiu+23

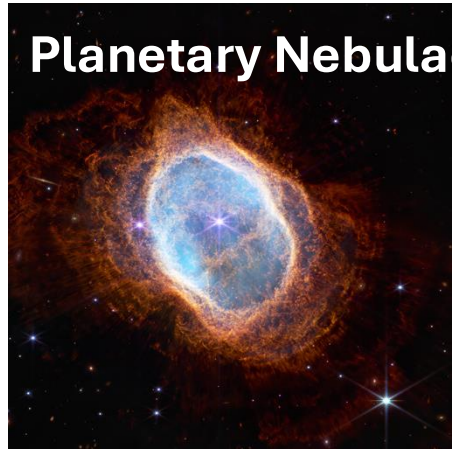
Photoionisation models

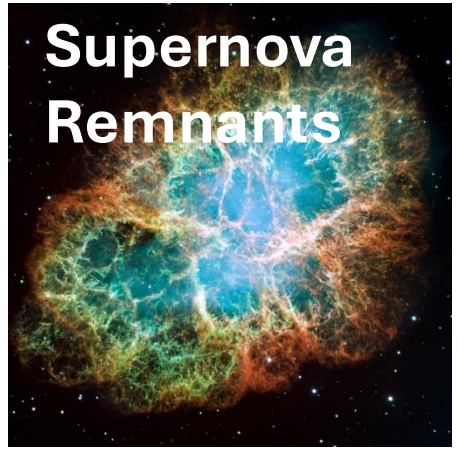


LIMITATIONS

- We are not using the 3D nature of the data to find sources.
- Boundaries are painfully arbitrary





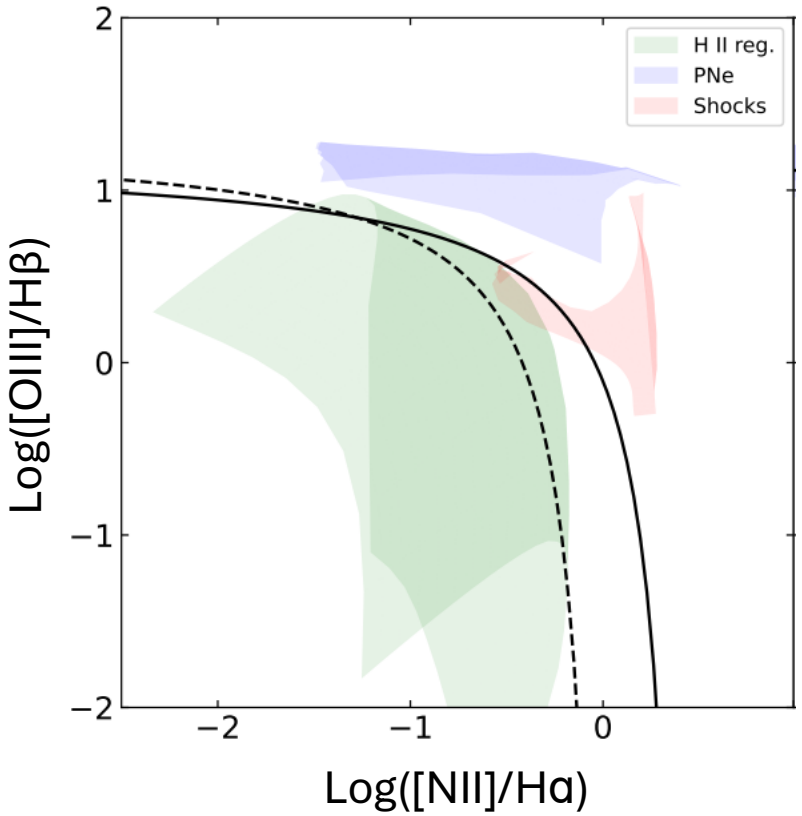


Classifying nebulae: using Machine Learning

2

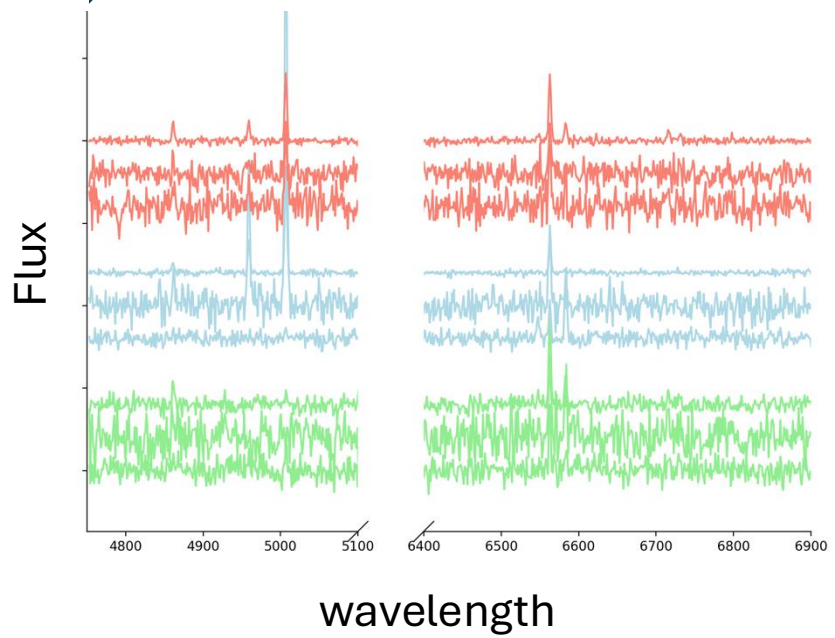
Generate models

Predictions from photoionisation model calculations (CLOUDY, MAPPINGS)



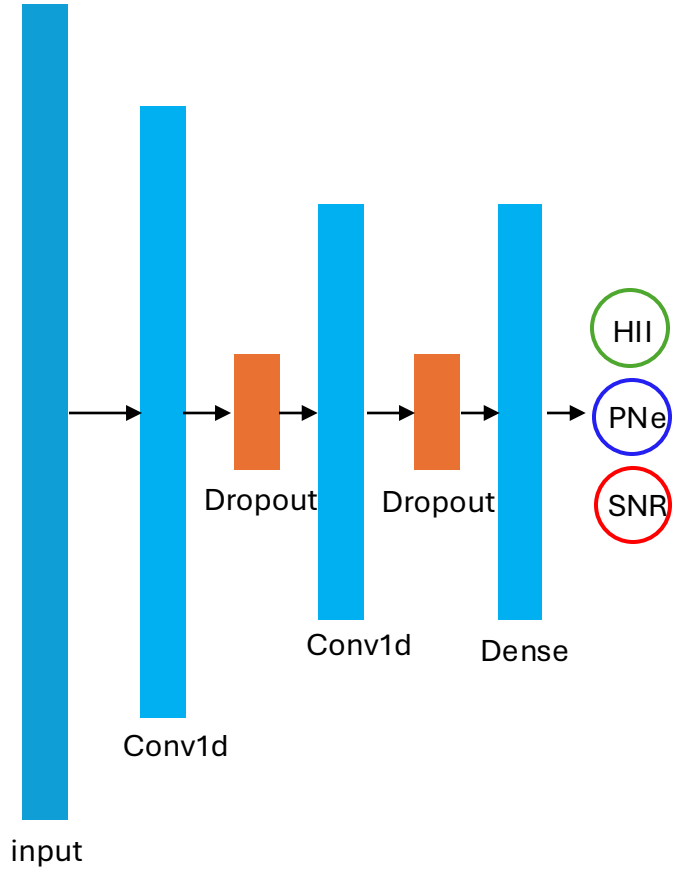
Simulate spectra

with observational characteristics (noise, instrument line spread function, etc)



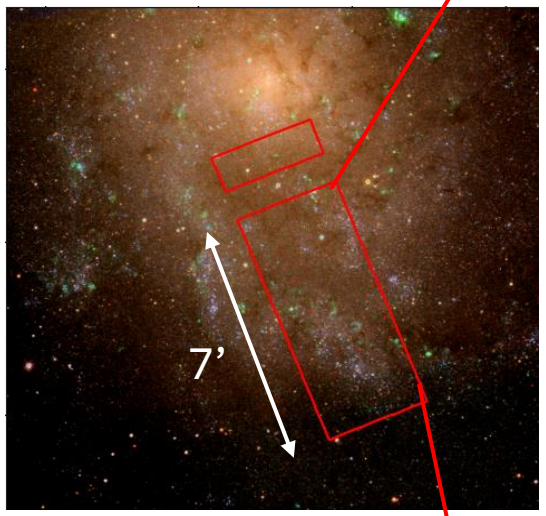
Train a network

to classify spectra in MUSE cubes



Bracci+25, FB+25

2

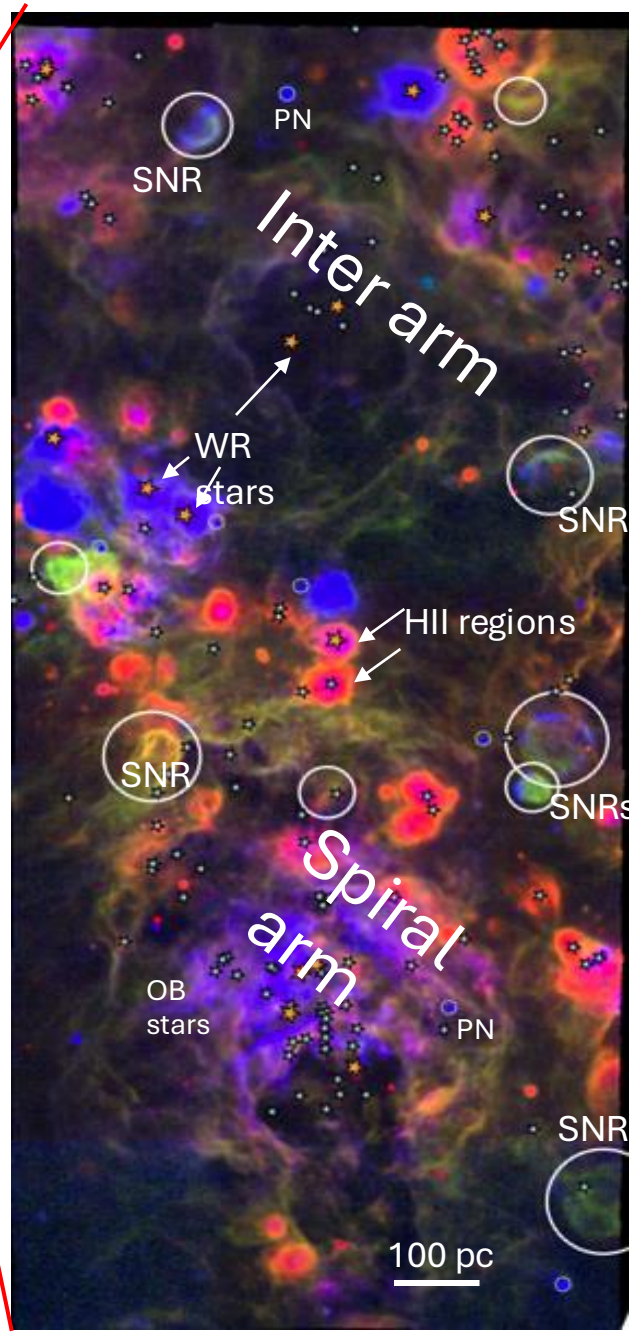


Bracci+25

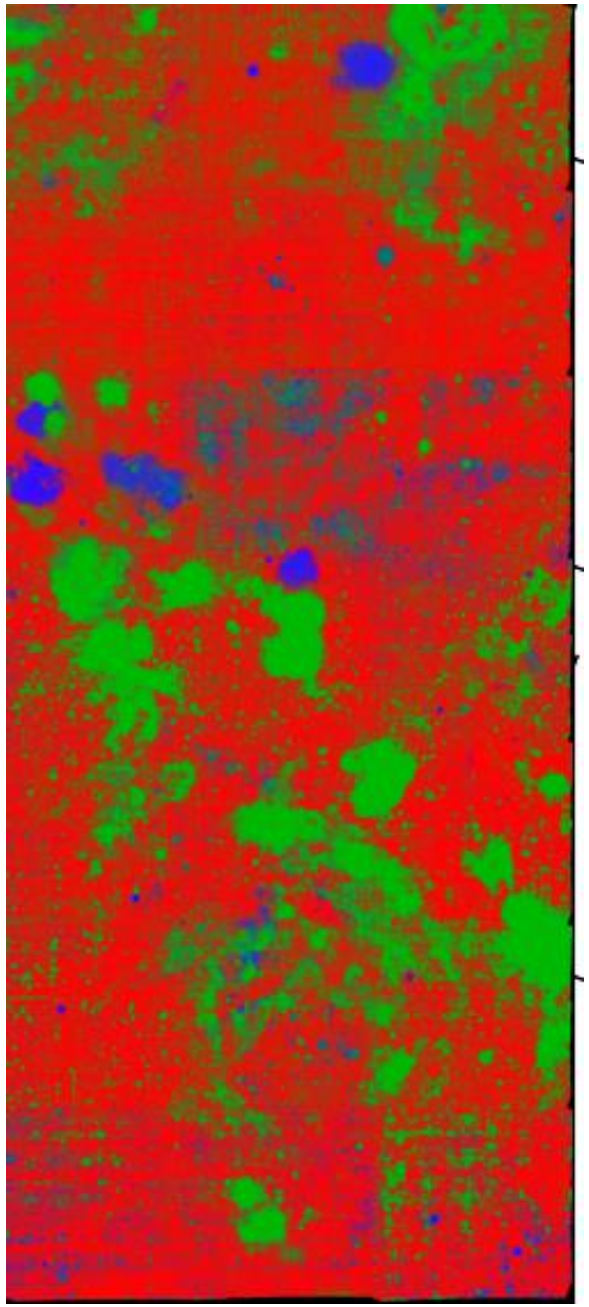
Local Group galaxy M33
24 MUSE pointings
(**PI: Cresci**)

- 2×10^6 spectra
- ~4pc resolution

MUSE data, Ha [SII] [OIII]



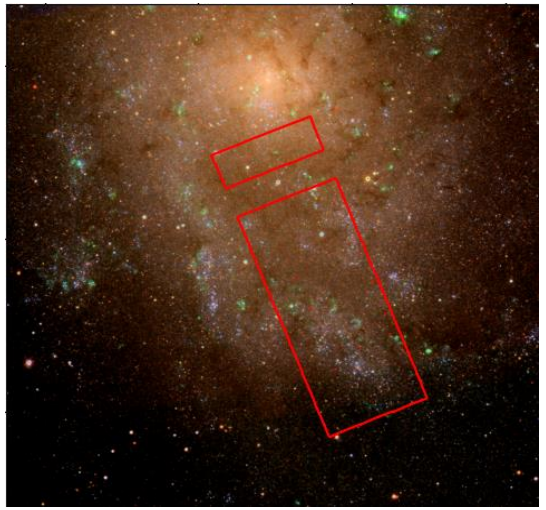
ML predictions



HII regions

Planetary Nebulae

Shocks/Supernova Remnants



Bracci+25

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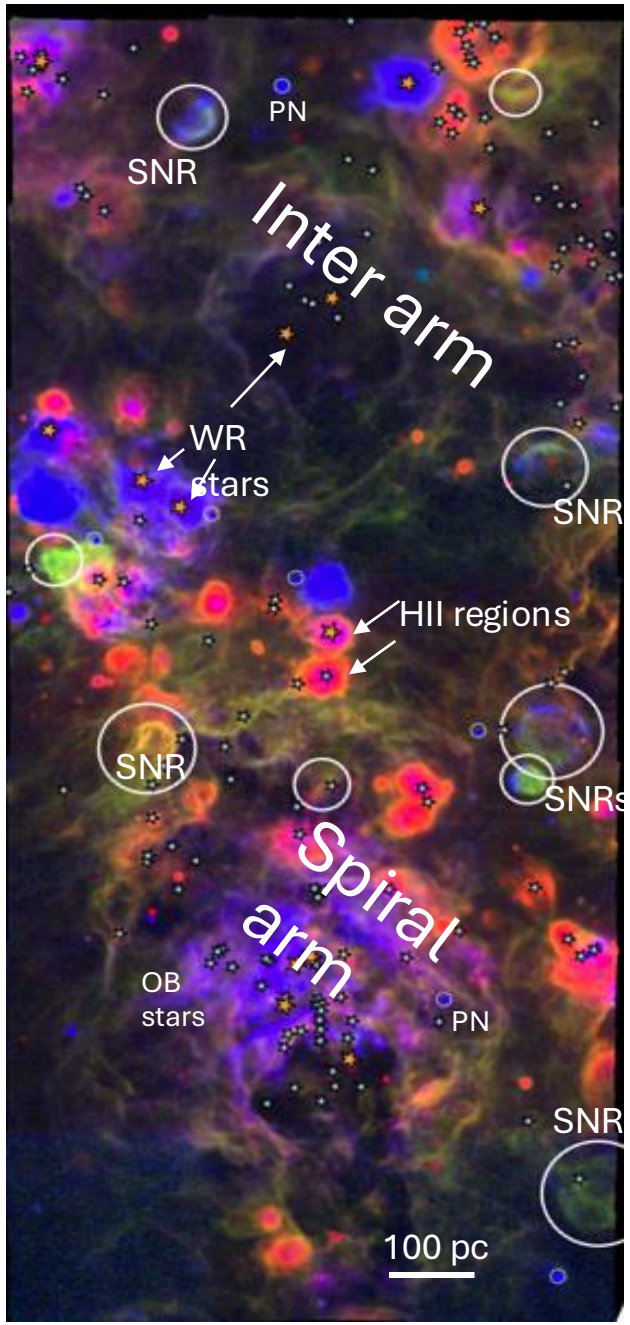
MUSE data, Ha [SII] [OIII]



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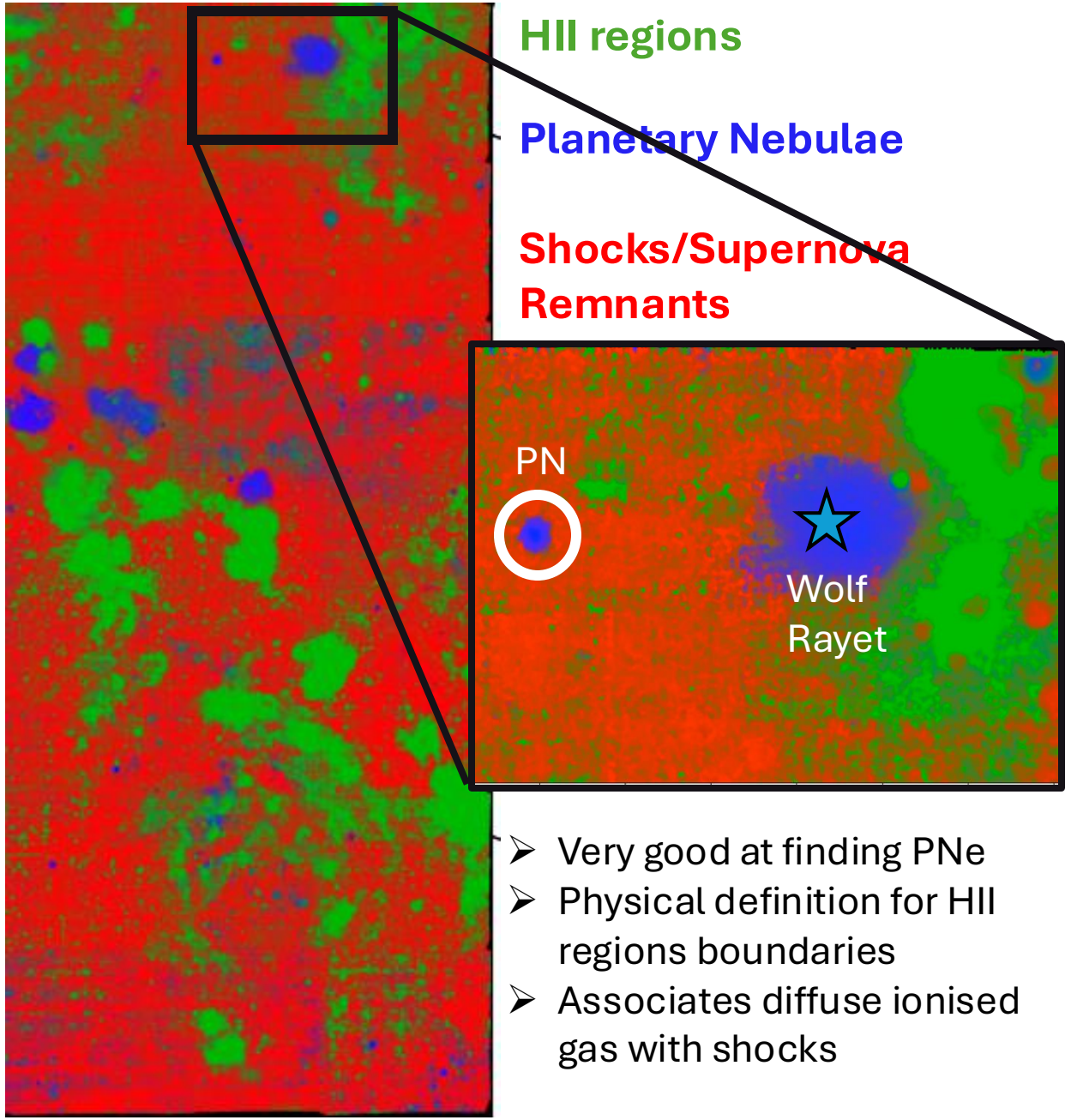
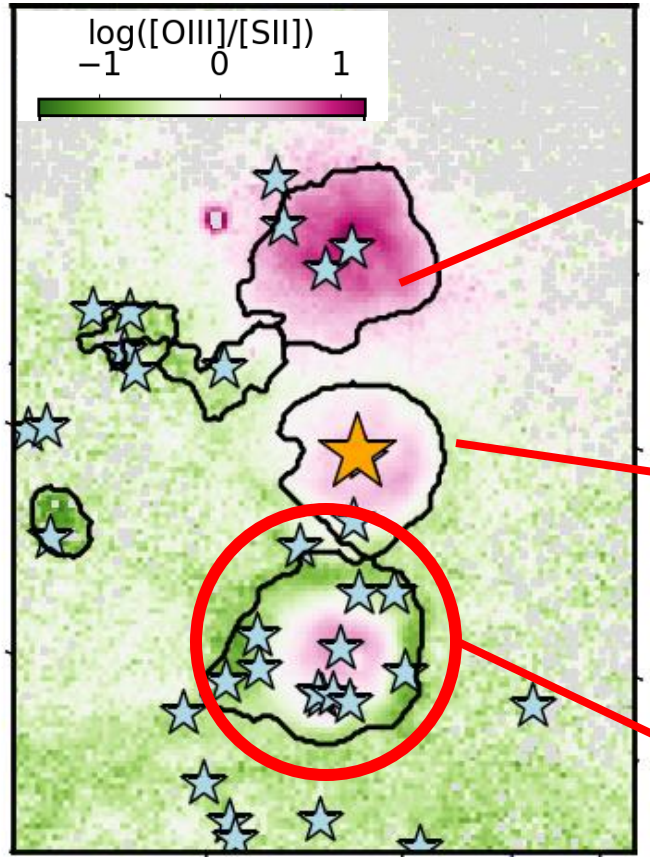


- Very good at finding PNe
- Physical definition for HII regions boundaries
- Associates diffuse ionised gas with shocks

A diversity of ISM conditions

Three HII regions in M33



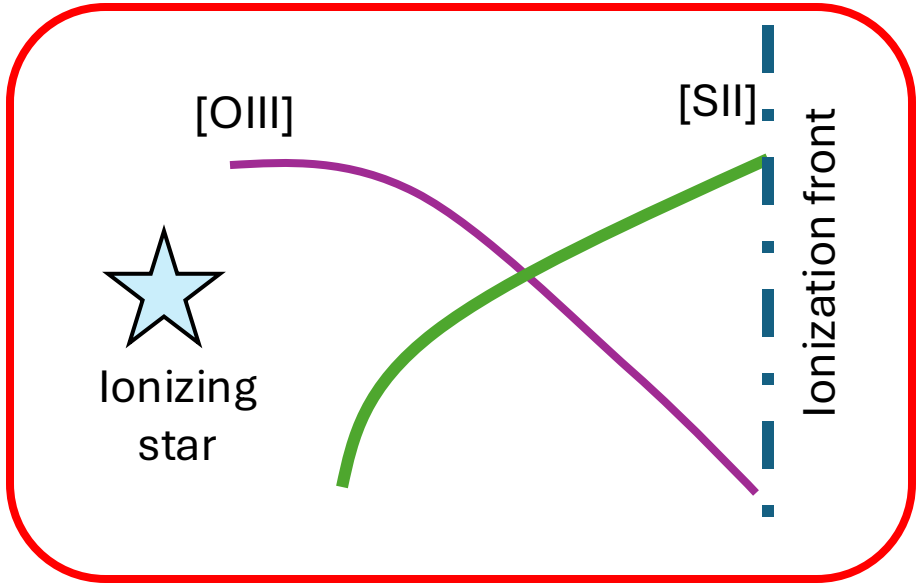
Feltre, FB+in prep

Matter-bounded HII regions: no clear ionization front
→ escaping photons ionize the DIG

A **Wolf-Rayet** star: harder ionization field, local enrichment?

A classical, **ionization-bounded** HII region

Photoionization cartoon

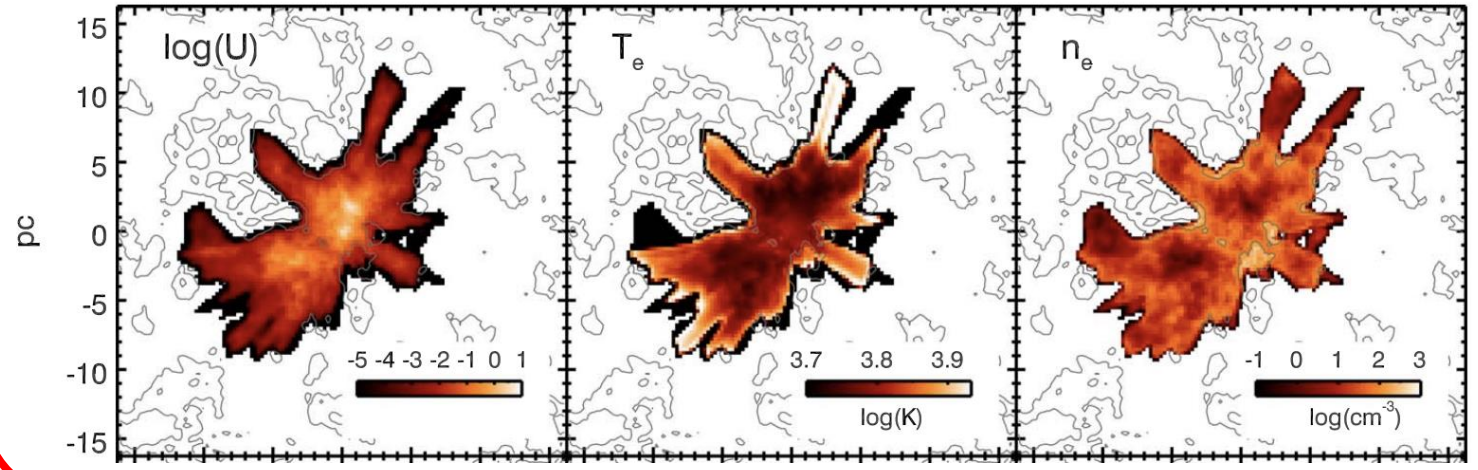


Temperature and density fluctuations

→Biases in measurements of e.g. metallicity

→But … with proper modelling one can use spectra to access sub-resolution physics!

3D photoionization simulation



Jin+22

Our Approach

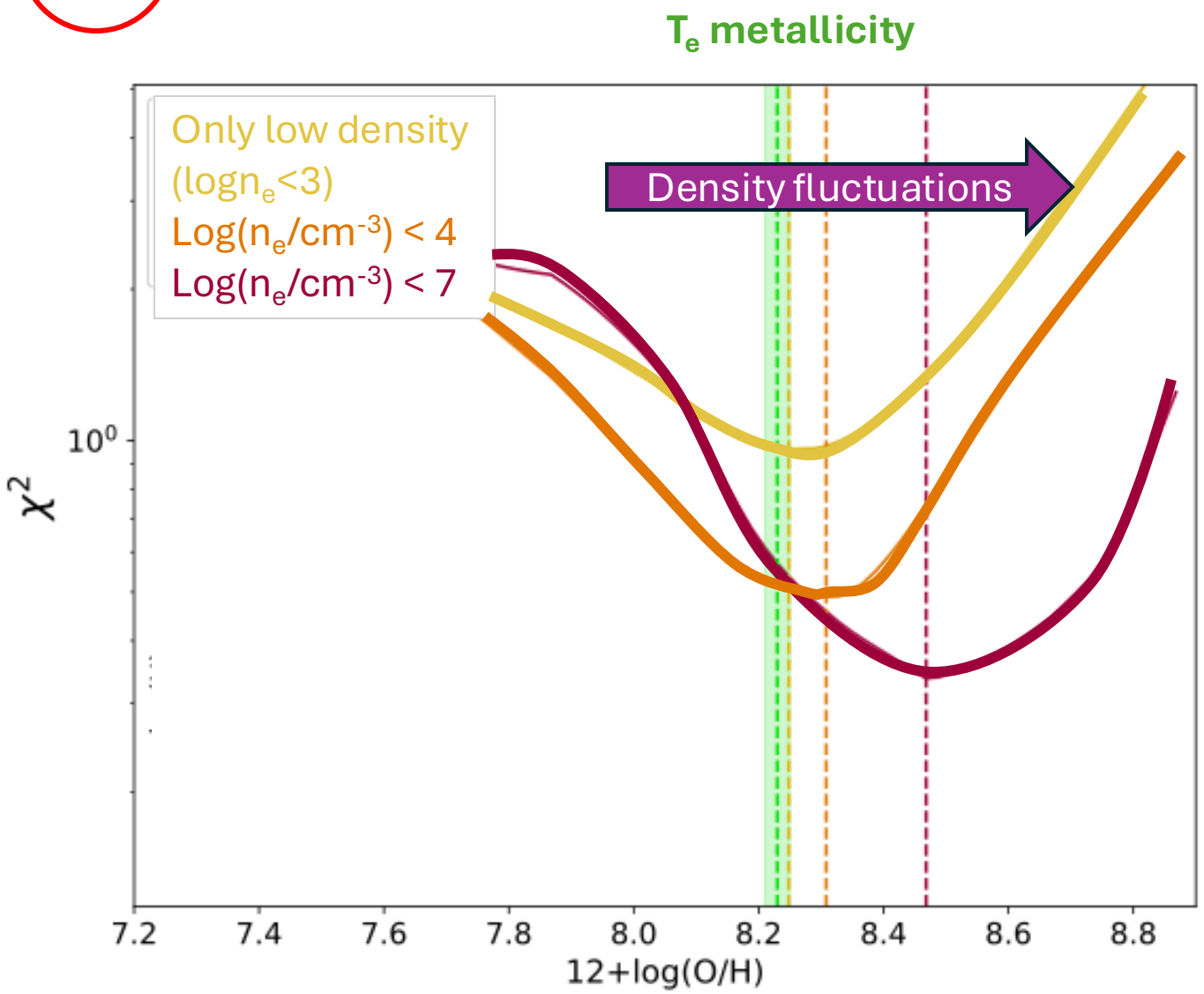
$$= \sum_{i=0}^{n}$$

Clouds with different conditions and weights

Marconi+2024

Temperature and density fluctuations

Work in Progress



Fitting the line fluxes from a local HII region (not M33 yet)

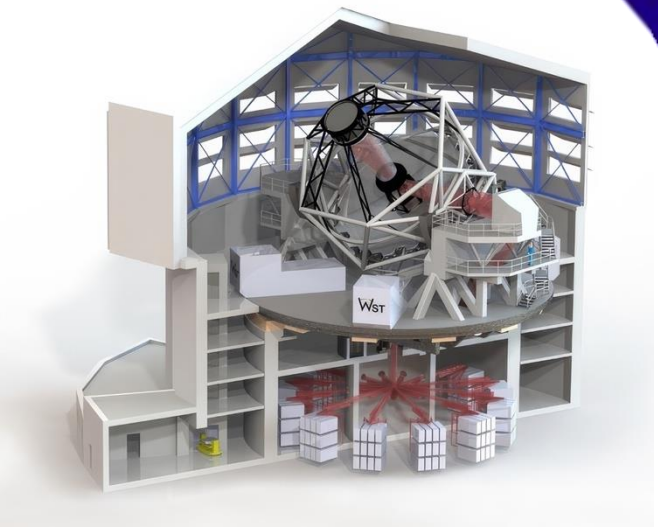
→ Density measured from optical lines (e.g. [SII] ratio) is ~200 cm^{-3}.

→ A small amount of flux in **high-density regions** can lead to a large underestimation of metallicity.

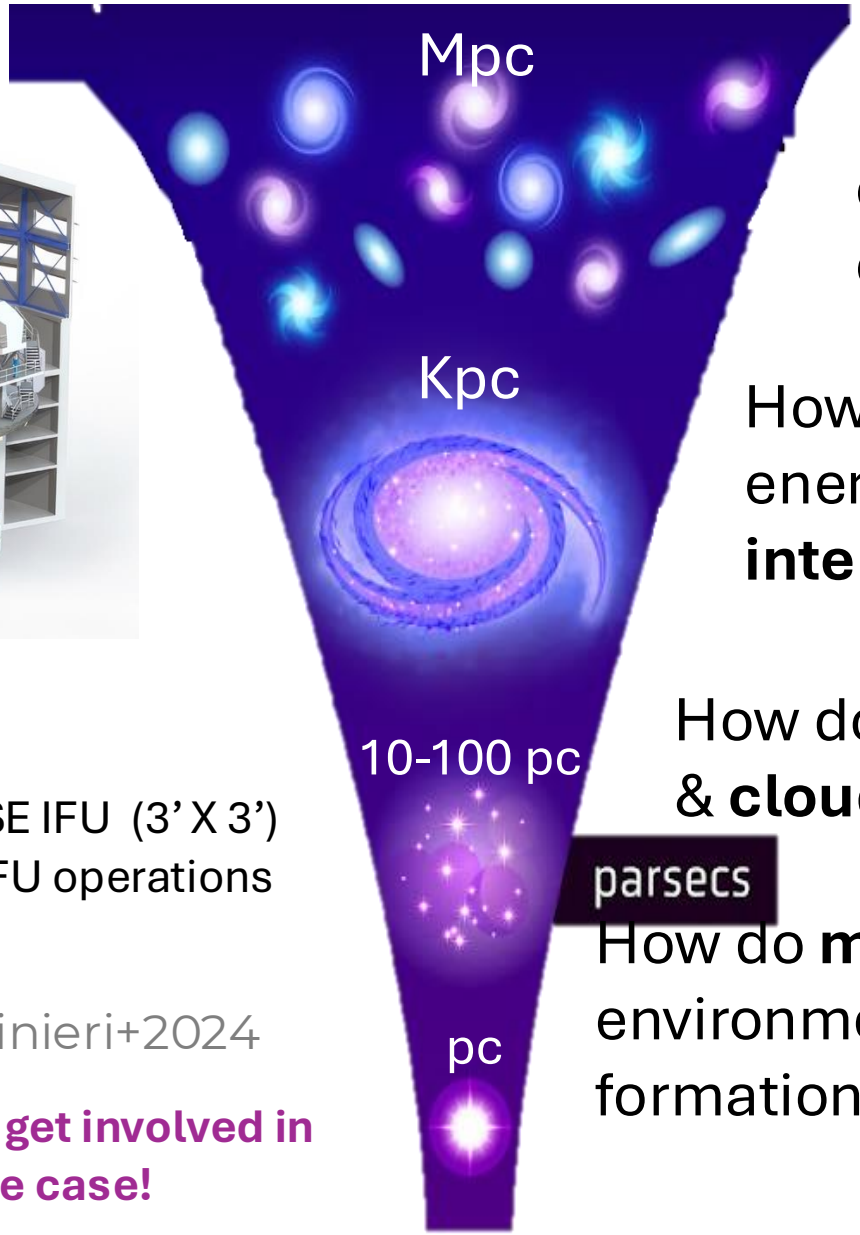
→ The higher metallicity is consistent with metallicity derived from metal **recombination lines**

Credit: Bianca Moreschini

The Wide-field Spectroscopic Telescope



- 12m optical telescope
- Large FoV (3deg^2)
- MOS (30k) + superMUSE IFU (3' X 3')
- Simultaneous MOS + IFU operations



How does the **Cosmic Web** impact the evolution of galaxies from the peak epoch of star formation to now?

How do galaxies exchange matter and energy with the **circum- and intergalactic** medium?

How does feedback set the state of the ISM & **cloud-scale** efficiency of star formation?

How do **massive stars** shape their local environment and how does feedback affect the formation of **planetary systems**?

Mainieri+2024

Feel free to reach out to get involved in the extragalactic science case!

Summary

We are building observations of a representative dataset of galaxies at **cloud scales** and moving towards samples of **resolved HII regions**

1. Typical HII regions in galaxy discs have ~40% escape fraction. These photons are the main ionizing sources for the DIG and travel ~kpc scales.

2. Machine Learning offers a very promising avenue for classifying and segmenting ionized nebulae in large IFU surveys.

3. Multi-cloud photoionization models offer a promising avenue for interpreting complex ionization conditions found in real nebulae.

WST Get involved in shaping the science case!