



Mechanisms that shape star formation: a study on metallicity and HI holes

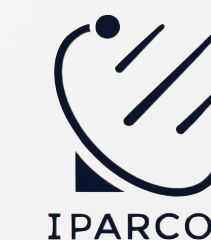
Guillermo Valé Arteaga

METAL-THINGS

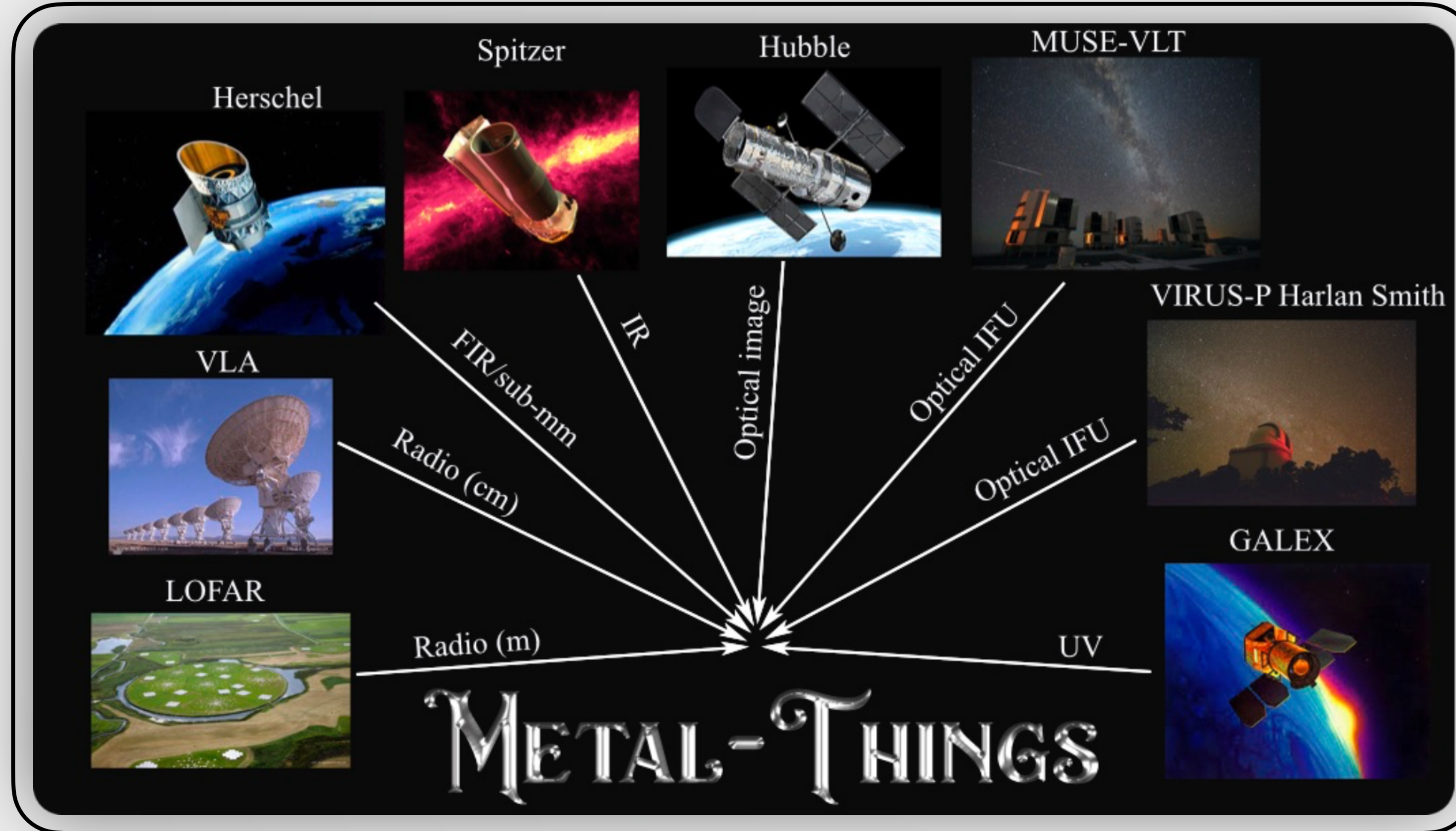
PhD supervisors:

Maritza Arlene Lara López

Shane P. O'Sullivan



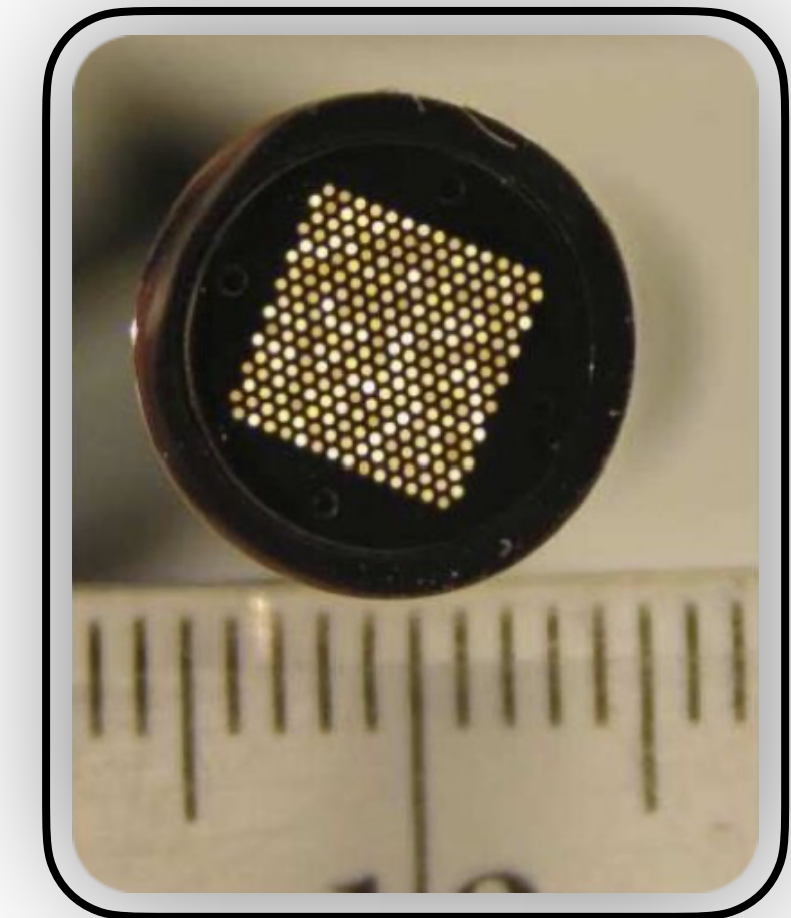
1. The Metal-THINGS survey



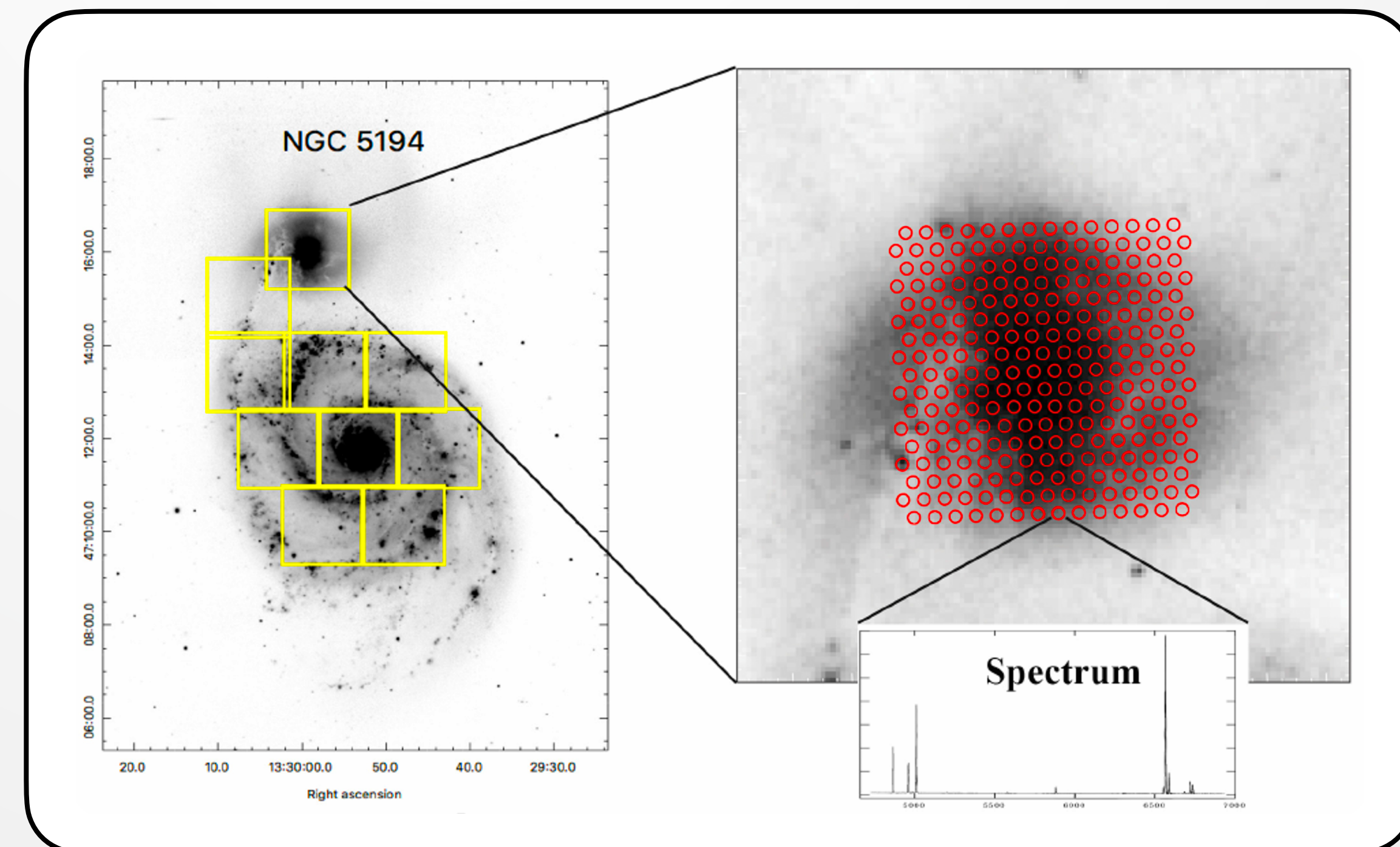
- Resolved IFU data for a sample of 35 nearby galaxies.
- Aims to identify the main drivers in the evolution of galaxies combining information at multiple wavelengths.

1. The Metal-THINGS survey: Key instrument

- George and Cynthia Mitchell Spectrograph (VIRUS-P).
- 2.7m Harlan J. Smith Telescope, McDonald Observatory.
- VIRUS-P FoV: $100'' \times 102''$.
- 246 fibers in a fixed pattern with 1/3 fill factor.
- Full range coverage: 3400 – 6850 Å.



Credit: Blanc (2013)



2. Main objectives of the PhD project

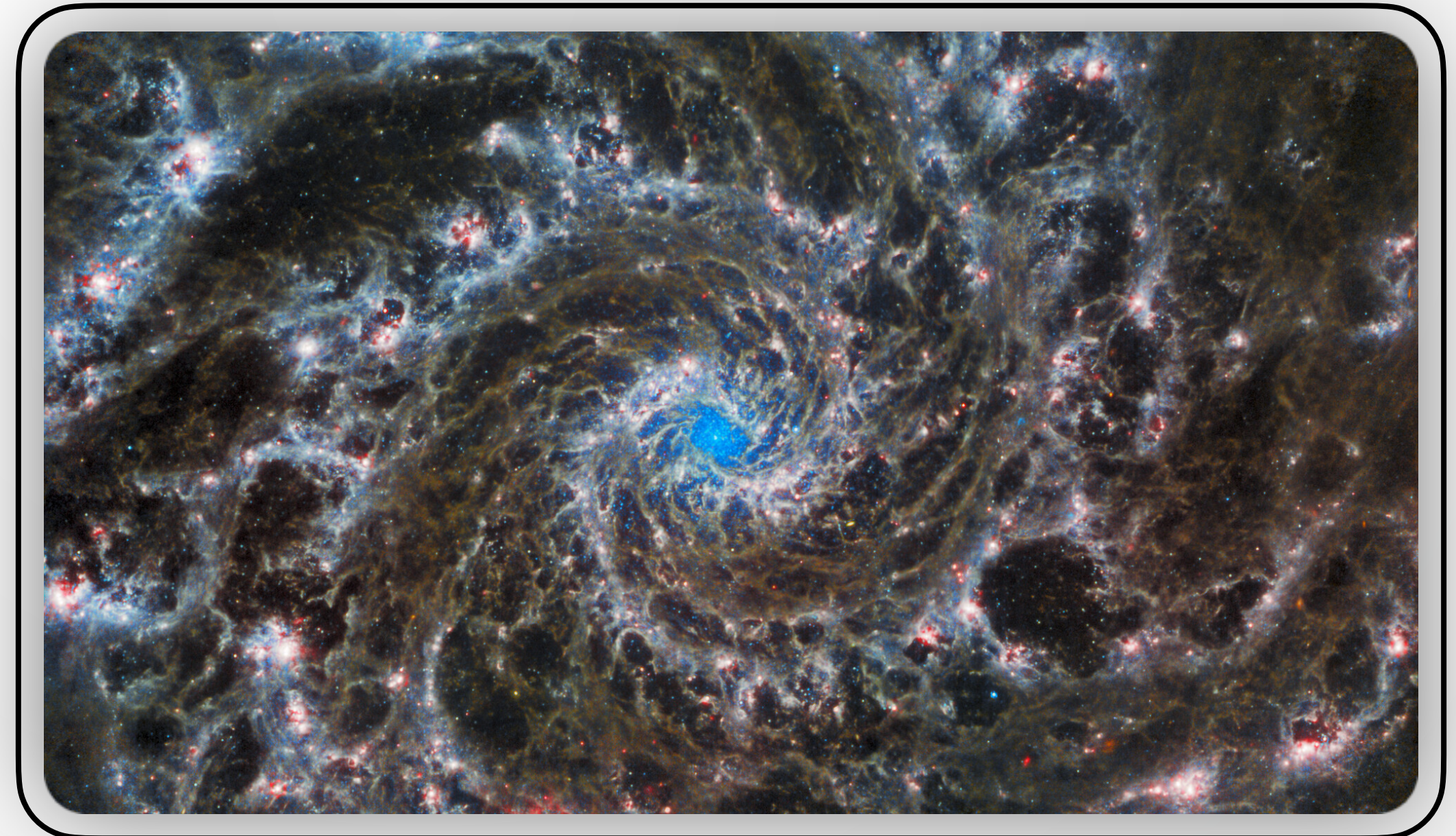
Project divided into two main parts:

1. Analysis of metallicity gradients in a sample from the Metal-THINGS survey.

Abundance distribution is influenced by processes such as star death.

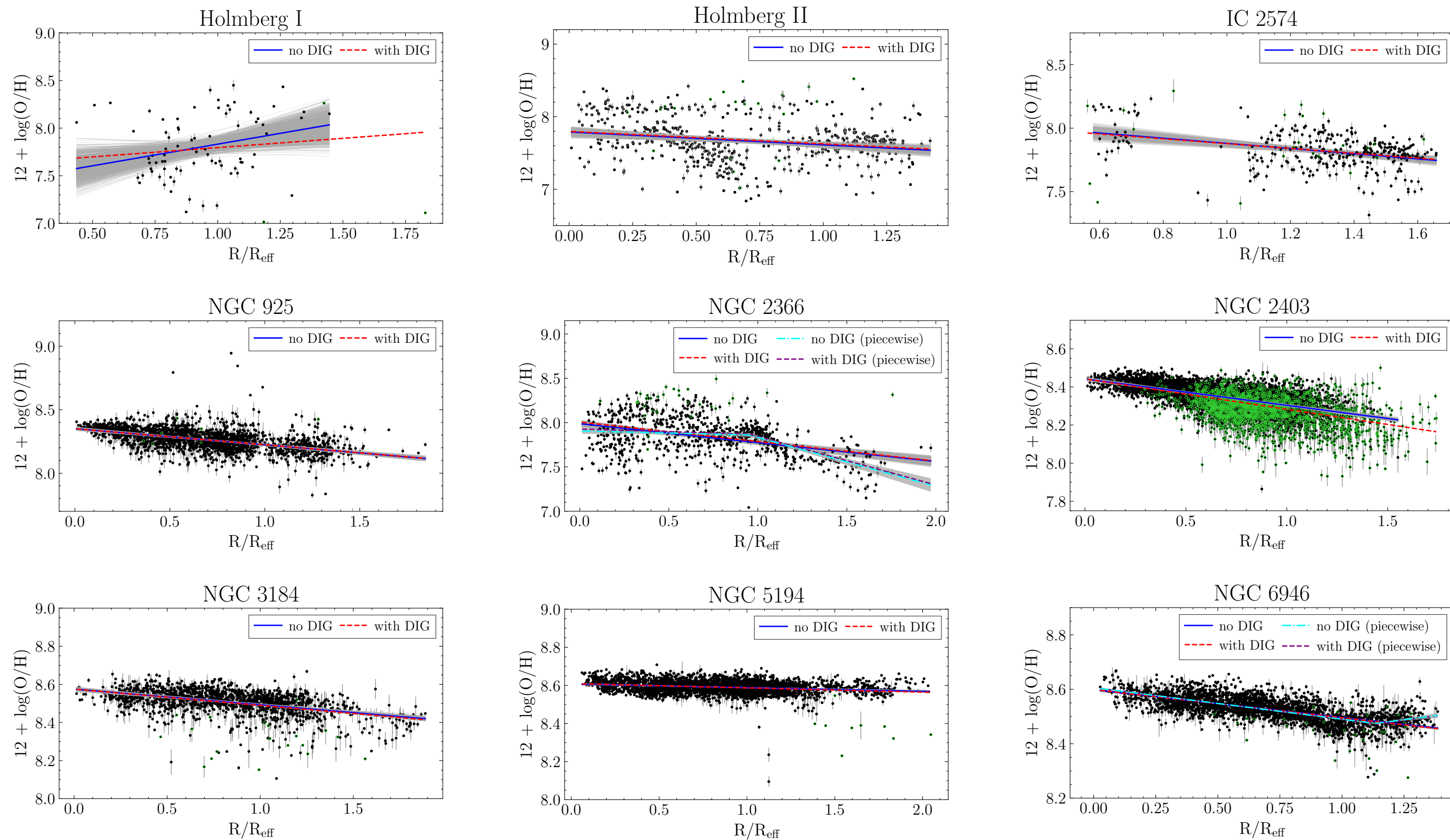
2. Machine Learning techniques will be used to identify and characterize HI holes.

Main focus of today's talk.



Credit: NASA/ESA/CSA JWST
Visible holes in the H I distribution.

3. First results: metallicity gradients



and 16 more...

Metal-THINGS: Gas metallicity gradients in nearby galaxies

G. Valé^{1,2,*}, M. A. Lara-López^{1,2}, M. Valerdi^{3,4}, I. Zinchenko^{5,6}, S. P. O'Sullivan^{1,2}, L. S. Pilyugin^{6,7}, J. Cepa^{8,9}, V. Casasola¹⁰, M. E. De Rossi^{11,12}, S. Dib¹³, J. Fritz¹⁴, J. Gallego^{1,2}, L. E. Garduño¹, O. López-Cruz³, V. Tailor^{10,15}, and J. Zaragoza-Cardiel¹⁶

- ¹ Departamento de Física de la Tierra y Astrofísica, Fac. de C.C. Físicas, Universidad Complutense de Madrid, E-28040 Madrid, Spain
- ² Instituto de Física de Partículas y del Cosmos, IPARCOS, Fac. C.C. Físicas, Universidad Complutense de Madrid, E-28040 Madrid, Spain
- ³ Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), Luis E. Erro No. 1, Sta. Ma. Tonantzintla, Puebla, C.P. 72840, Mexico
- ⁴ Consejo Nacional de Humanidades, Ciencias y Tecnologías, Av. Insurgentes Sur 1582, 03940, Ciudad de México, Mexico
- ⁵ Faculty of Physics, Ludwig-Maximilians-Universität, Scheinerstr. 1, 81679 Munich, Germany
- ⁶ Main Astronomical Observatory, National Academy of Sciences of Ukraine, 27 Akademika Zabolotnoho St, 03680 Kiev, Ukraine
- ⁷ Institute of Theoretical Physics and Astronomy, Vilnius University, Sauletekio av. 3, 10257 Vilnius, Lithuania
- ⁸ Instituto de Astrofísica de Canarias, 38205 La Laguna, Tenerife, Spain
- ⁹ Departamento de Astrofísica, Universidad de La Laguna (ULL), 38205 La Laguna, Tenerife, Spain
- ¹⁰ INAF – Istituto di Radioastronomia, Via Piero Gobetti 101, 40129, Bologna, Italy
- ¹¹ Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales y Ciclo Básico Común, Buenos Aires, Argentina
- ¹² CONICET-Universidad de Buenos Aires, Instituto de Astronomía y Física del Espacio (IAFE), Buenos Aires, Argentina
- ¹³ Max-Planck-Institut für Astronomie, Königstuhl 17, 69117, Heidelberg, Germany
- ¹⁴ Instituto de Radioastronomía y Astrofísica, Universidad Nacional Autónoma de México, Morelia, Michoacán 58089, Mexico
- ¹⁵ Dipartimento di Fisica e Astronomia, Alma Mater Studiorum Università di Bologna, via Piero Gobetti 93/2, I-40129, Bologna, Italy
- ¹⁶ Centro de Estudios de Física del Cosmos de Aragón (CEFCA), Plaza San Juan 1, 44001 Teruel, Spain

Received 20 January 2025 / Accepted 11 July 2025

ABSTRACT

Aims. This paper explores and analyses the gas metallicity gradients in a sample of 25 nearby galaxies using new integral field spectroscopy observations from the Metal-THINGS survey, for a total of 102 individual pointings. We derive and analyse the resolved diffuse ionised gas content, Baldwin, Phillips, & Terlevich diagrams, and gas metallicities for our entire sample, at spatial resolutions of 40–300 pc. Gas metallicity gradients are studied as a function of the galaxy's stellar mass, H I gas fraction, and diffuse ionised gas content, and using different parametric length scales for normalisation.

Methods. The metallicity gradients are analysed using Bayesian statistics based on data from the Metal-THINGS survey. Bayesian MCMC models are developed to explore how metallicity gradients vary with a galaxy's mass and how they correlate with properties such as the stellar mass or the atomic gas fraction. Additionally, we compare and contrast our results with those from other works that use the same metallicity calibration.

Results. For our sample, we find that the metallicity typically decreases with galactic radius, consistent with inside-out galaxy growth. We find a trend dependent on the stellar mass, with a break at $\log(M_{\text{star}}/M_{\odot}) \approx 9.5$, and another between the metallicity gradients and the atomic gas fraction ($f_{\text{e,H I}}$) of a galaxy at $f_{\text{e,H I}} \approx 0.75$, indicating shallower gradients for lower gas fractions. These results are consistent with previous studies on galaxies with comparable stellar mass regimes and morphologies. We find that normalisation using NUV-band effective radii is preferable for galaxies with a higher atomic gas content and lower stellar masses, while r-band radii are better suited for those with lower atomic gas fractions and more massive ones.

Conclusions. Our results highlight a strong connection between gas content, stellar mass, and metallicity gradients. The breaks at $\log(M_{\text{star}}/M_{\odot}) \approx 9.5$ and $f_{\text{e,H I}} \approx 0.75$ mark shifts in chemical enrichment behaviour, with low-mass galaxies showing greater sensitivity to gas processes. Overall, this points to gas accretion and removal as key drivers of chemical evolution in low-mass systems.

Key words. galaxies: abundances – galaxies: ISM – galaxies: statistics

1. Introduction

The interstellar medium (ISM) is a complex environment that plays a crucial role in shaping the dynamics and evolution of galaxies. The metal content and its distribution in galaxies result from the complex interplay of various processes that affect the ISM, including: (i) gas infall, which dilutes the ISM but can

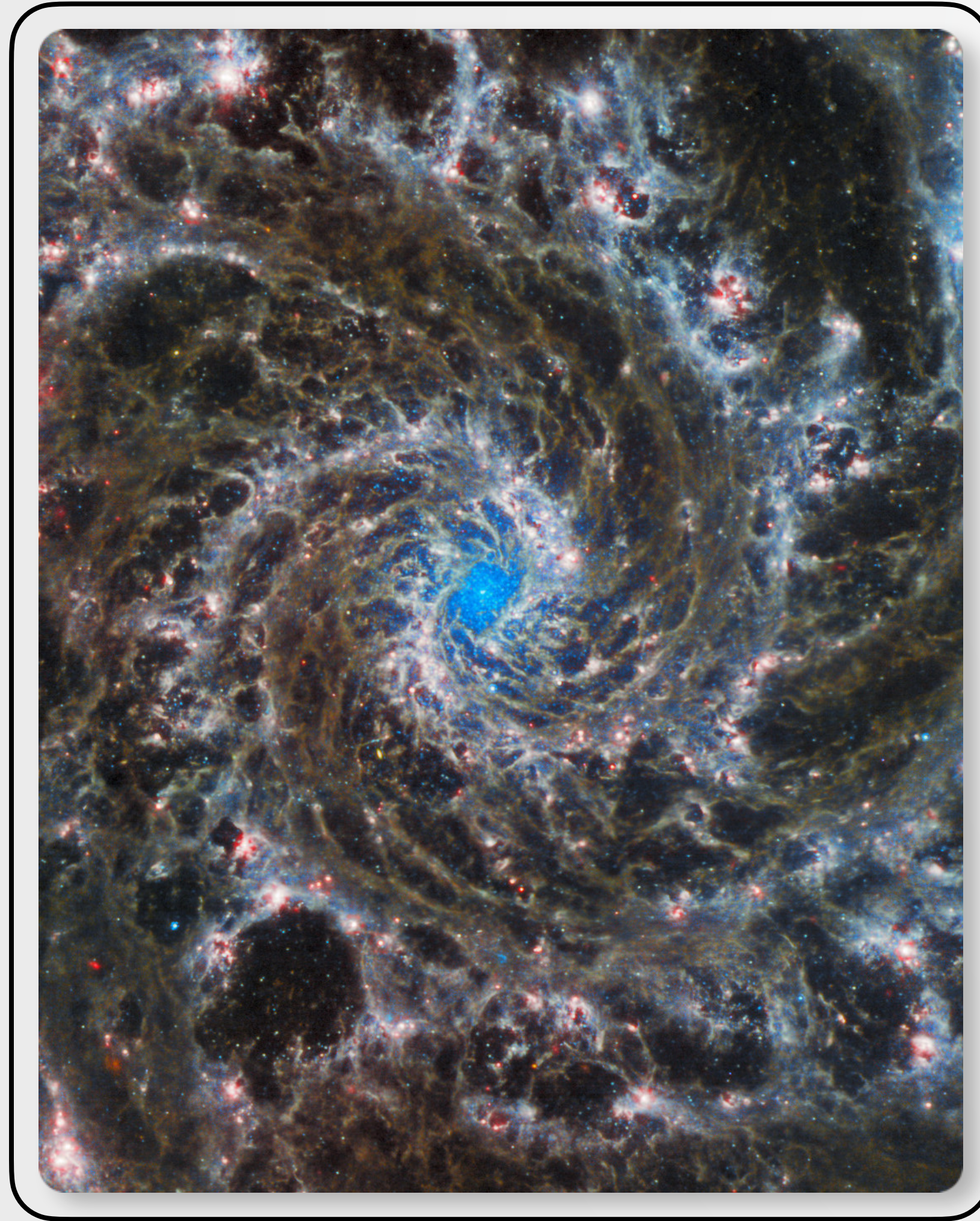
also trigger star formation (e.g. Mollá et al. 2016); (ii) feedback from active galactic nuclei (AGNs), star formation, and stellar evolution, driving outflows that redistribute or expel enriched gas (e.g. Villar Martín et al. 2024); (iii) metal injection into the ISM through stellar evolution (e.g. Cousin et al. 2016); (iv) turbulence leading to metal-mixing (e.g. Petit et al. 2015); and (v) galaxy interactions and mergers, which can trigger enhanced star formation rates (SFRs) up to starbursts, AGN activity, or tidal perturbations (e.g. Casasola et al. 2004; Mo et al. 2010). Many

* Corresponding author.

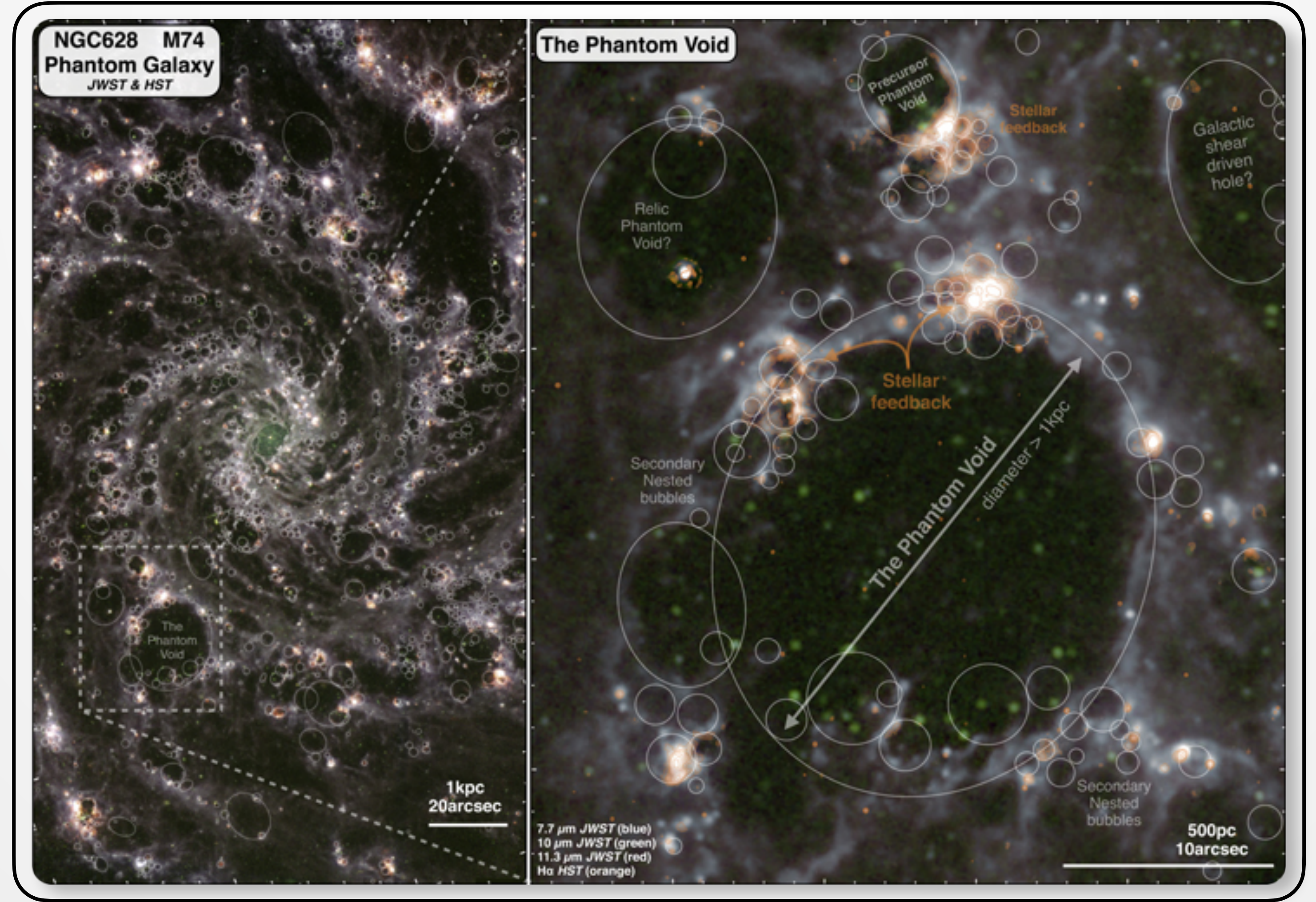
Credit: Valé et al. (2025)

Paper published on A&A on September 2025.

4. HI holes



Credit: NASA/ESA/CSA JWST

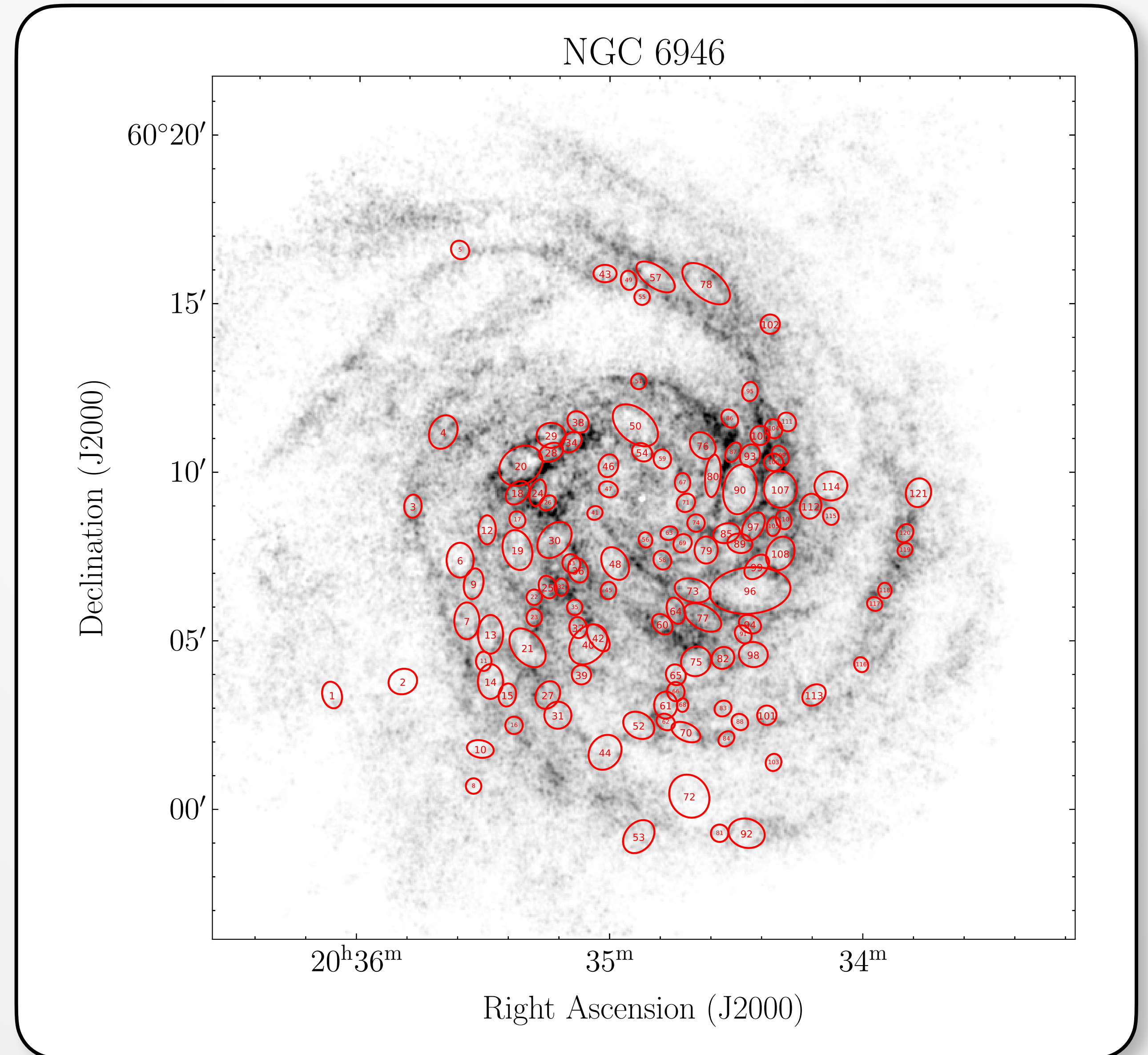


Credit: Barnes et al. (2023)

4. HI holes

Rense Boomsma's thesis (2007).

- Identifies 121 HI holes in NGC 6946 (Fireworks galaxy).



Credit: Boomsma (2007)

4. HI holes

Rense Boomsma's thesis (2007).

- Identifies 121 HI holes in NGC 6946 (Fireworks galaxy).
- Explains:
 - Formation.

HI holes form from stellar feedback and episodes of numerous SN explosions but also from turbulence.

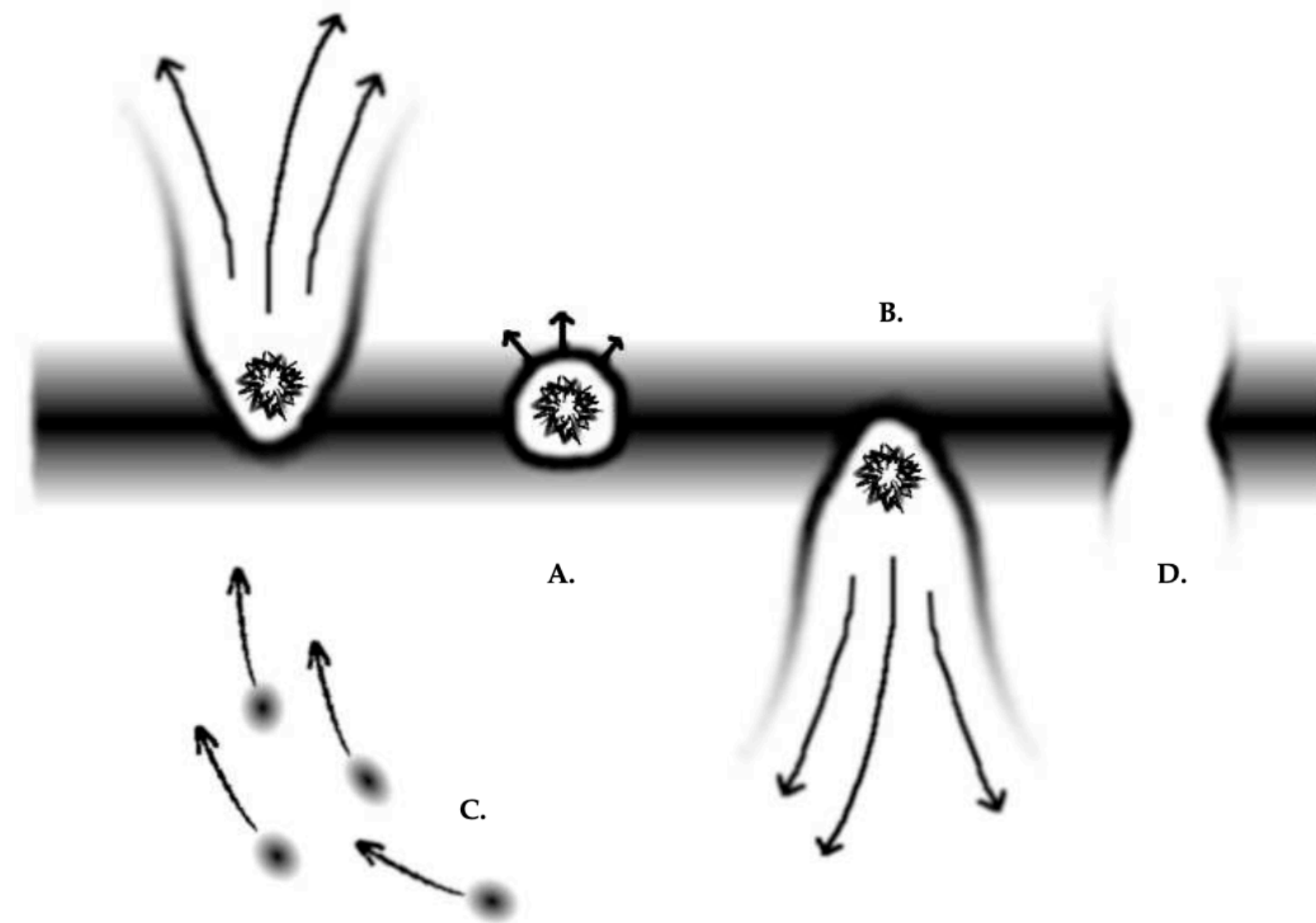


Figure 4– A sketch of a galaxy disk showing several stages of the galactic fountain and the formation of HI holes. *A)* stars and SNe have blown a bubble in the ISM which is still expanding; *B)* the bubble has broken out and the hot interior is blown away from the disk; *C)* the gas cools in the halo and rains as high-velocity clouds back onto the disk; *D)* broken bubbles that form a tunnel through the disk will appear as empty holes when viewed from outside.

Credit: Boomsma (2007)

4. HI holes

Rense Boomsma's thesis (2007).

- Identifies 121 HI holes in NGC 6946 (Fireworks galaxy).
- Explains:
 - Formation.
 - The hole-type identification scheme.

Type classification based on the velocity of the gas in the environment of the hole.

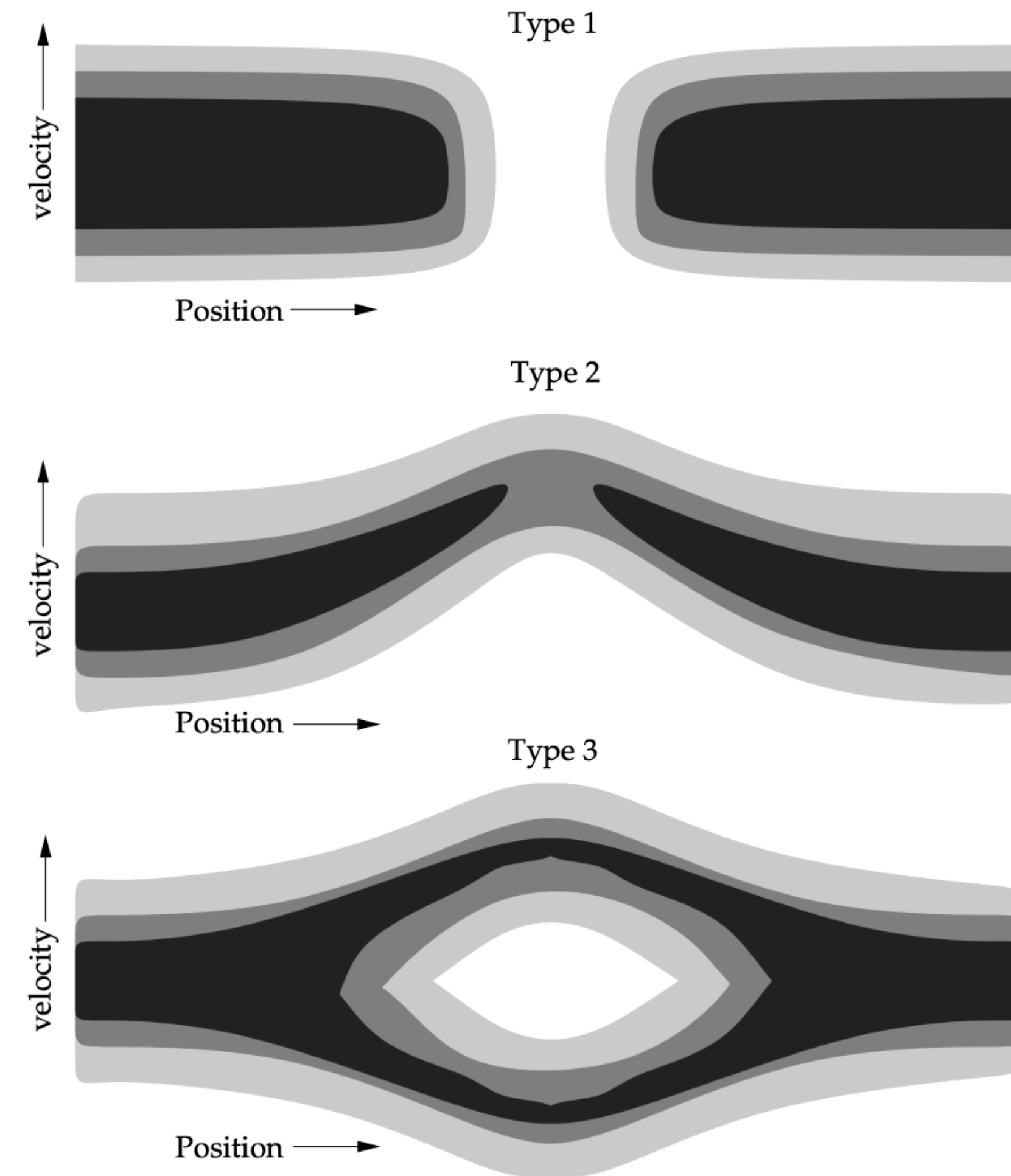
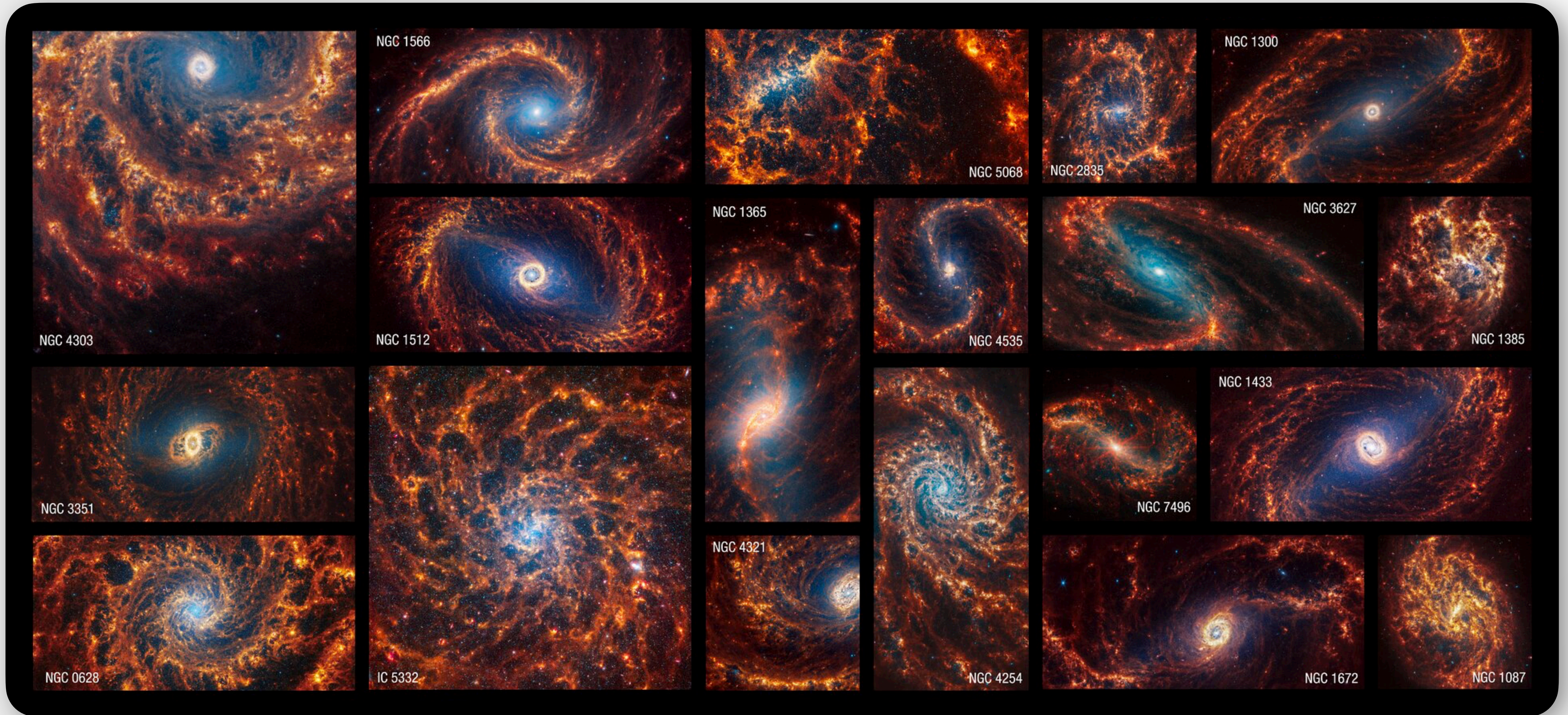


Figure 4.1- The three types of HI holes (Brinks & Bajaja 1986).

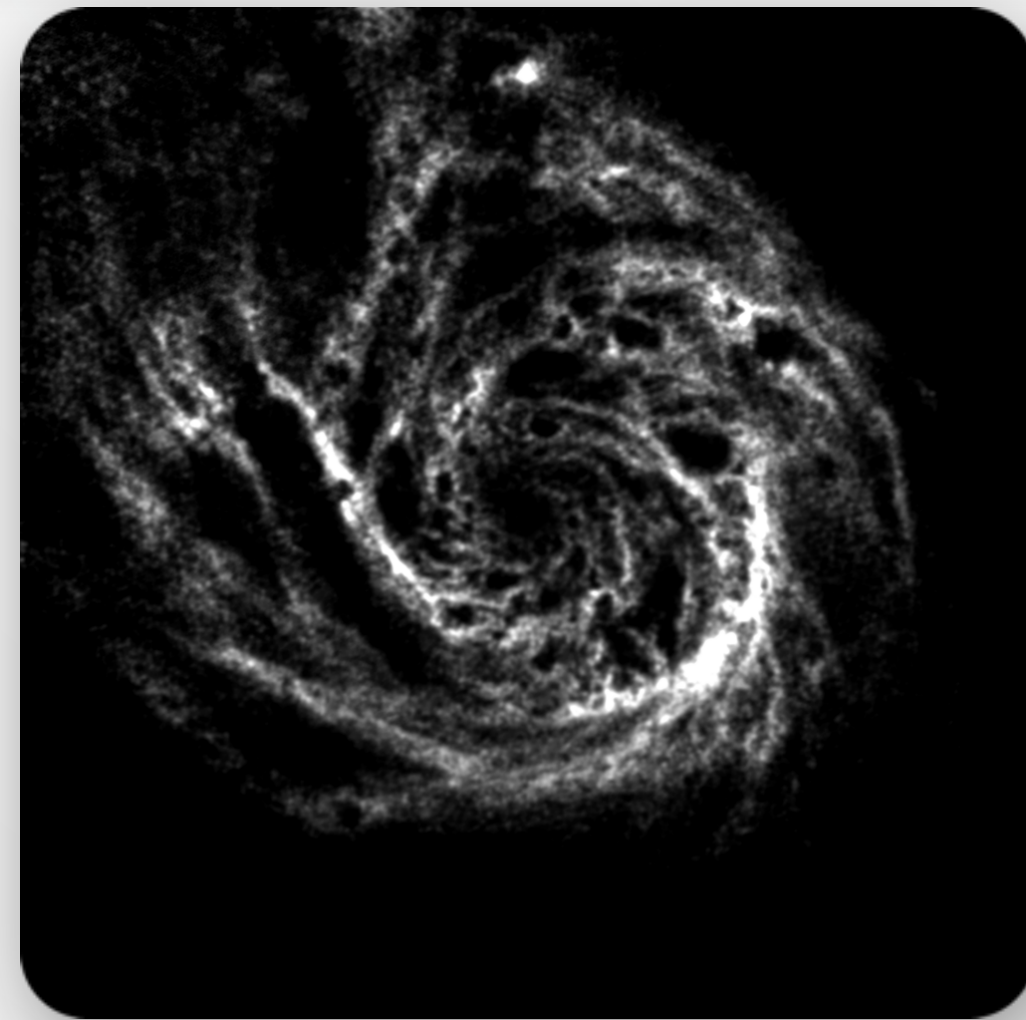
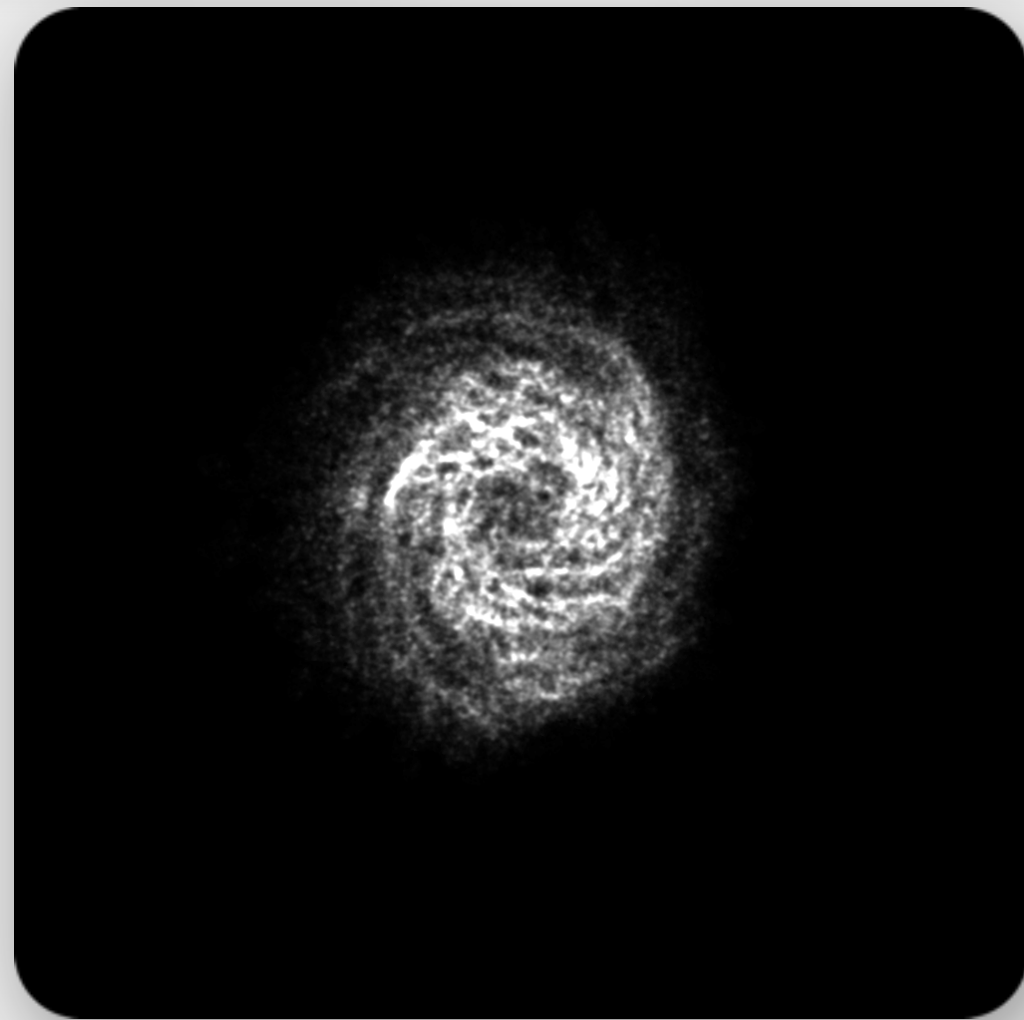
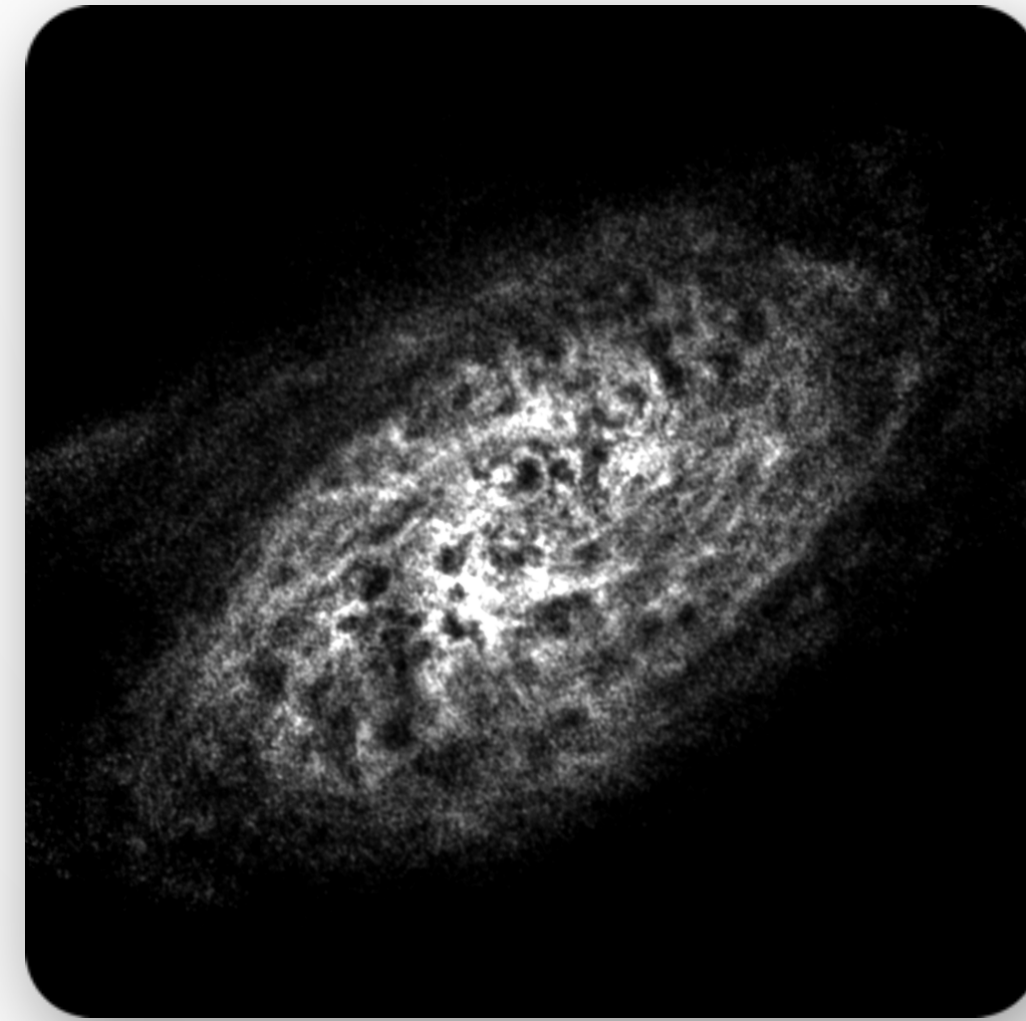
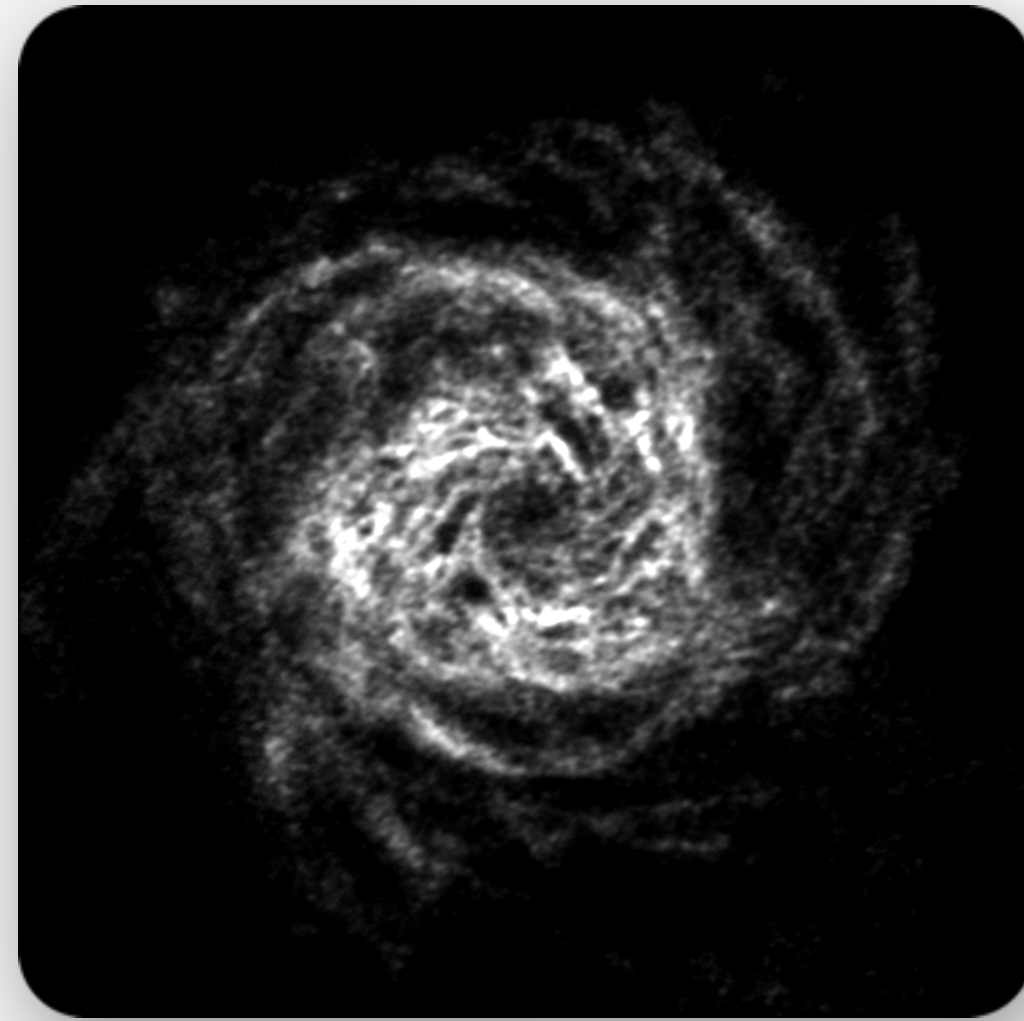
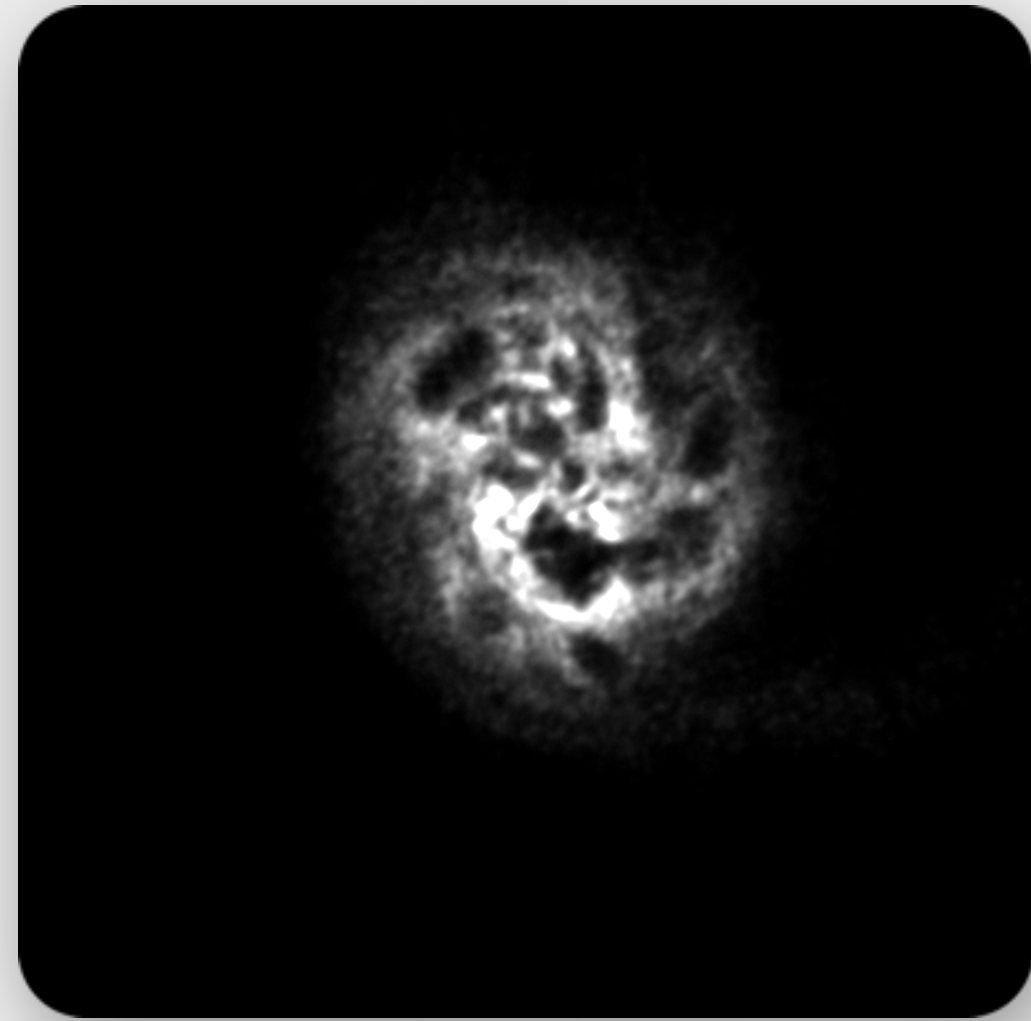
Credit: Boomsma (2007)

4. HI holes



Credit: Bethany Downer (ESA)

5. Machine learning to detect HI holes: The data

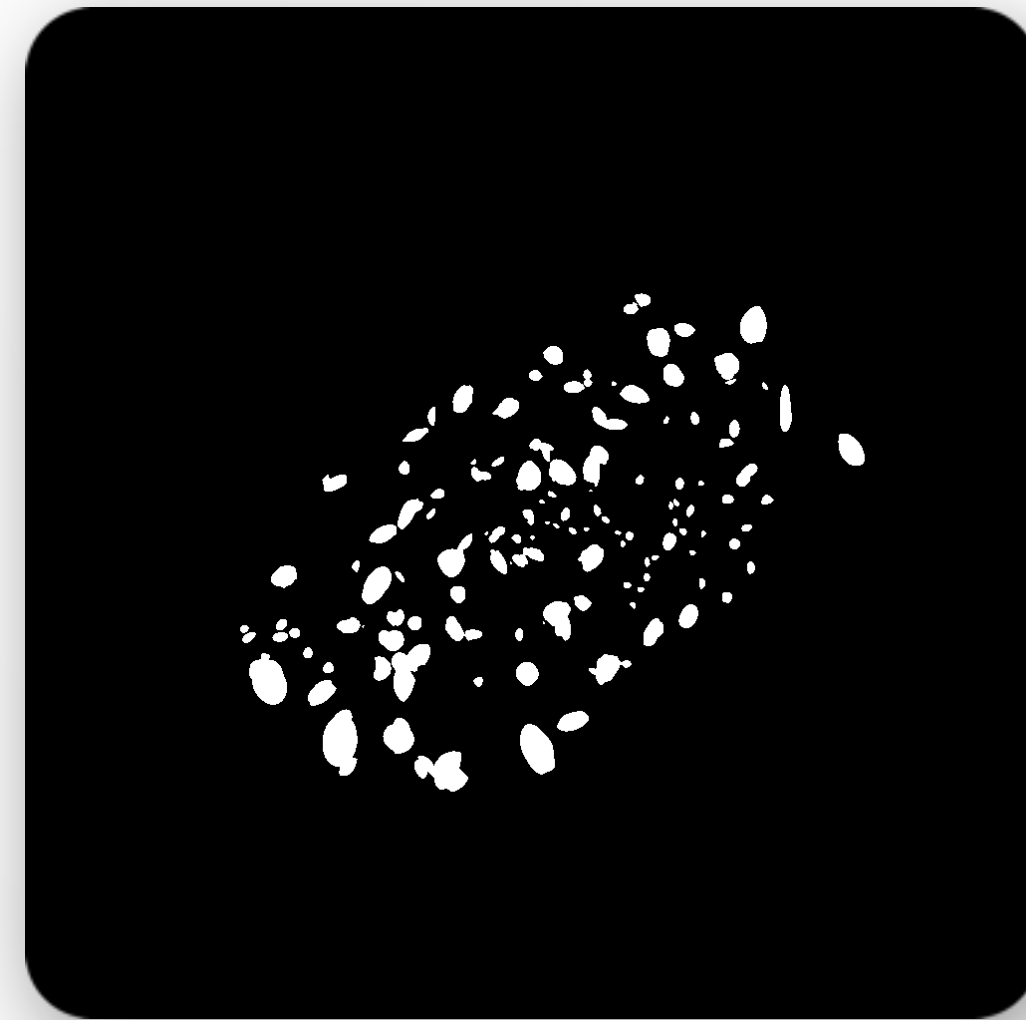
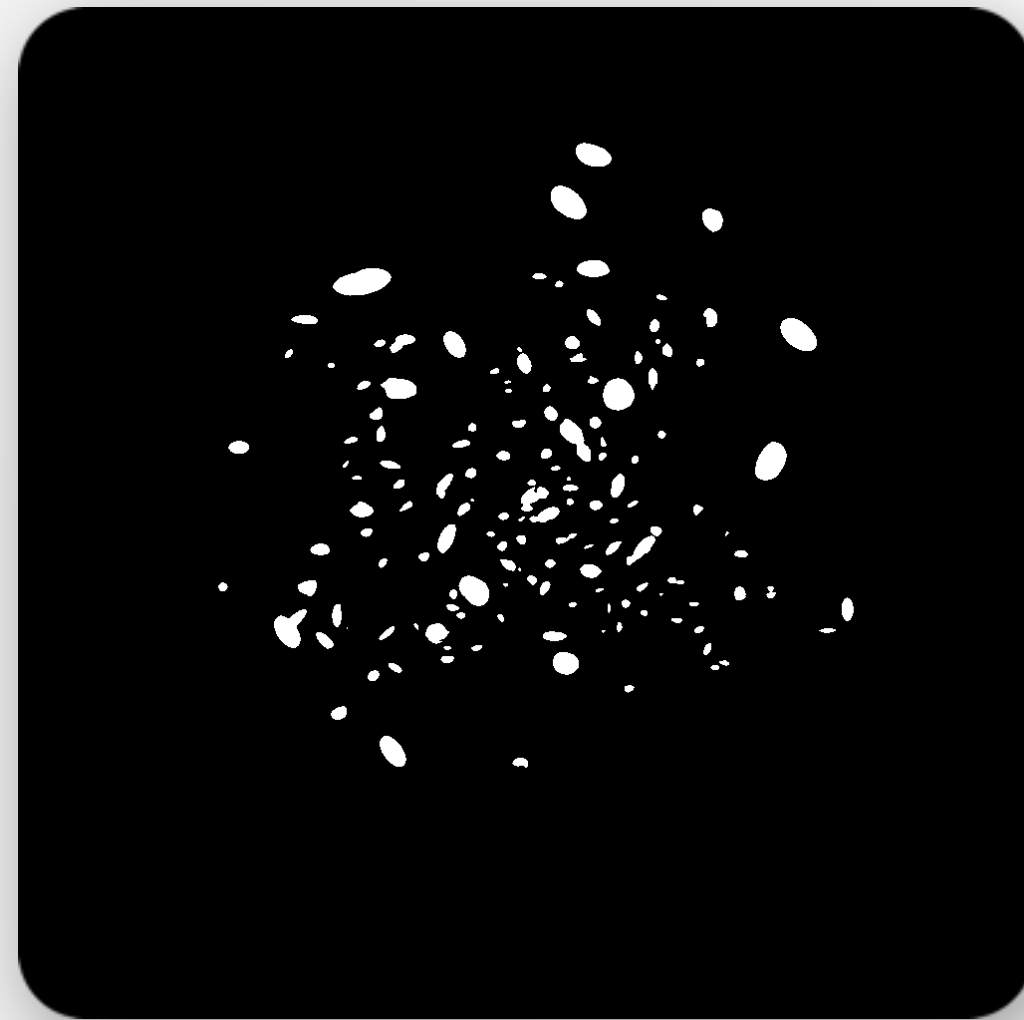
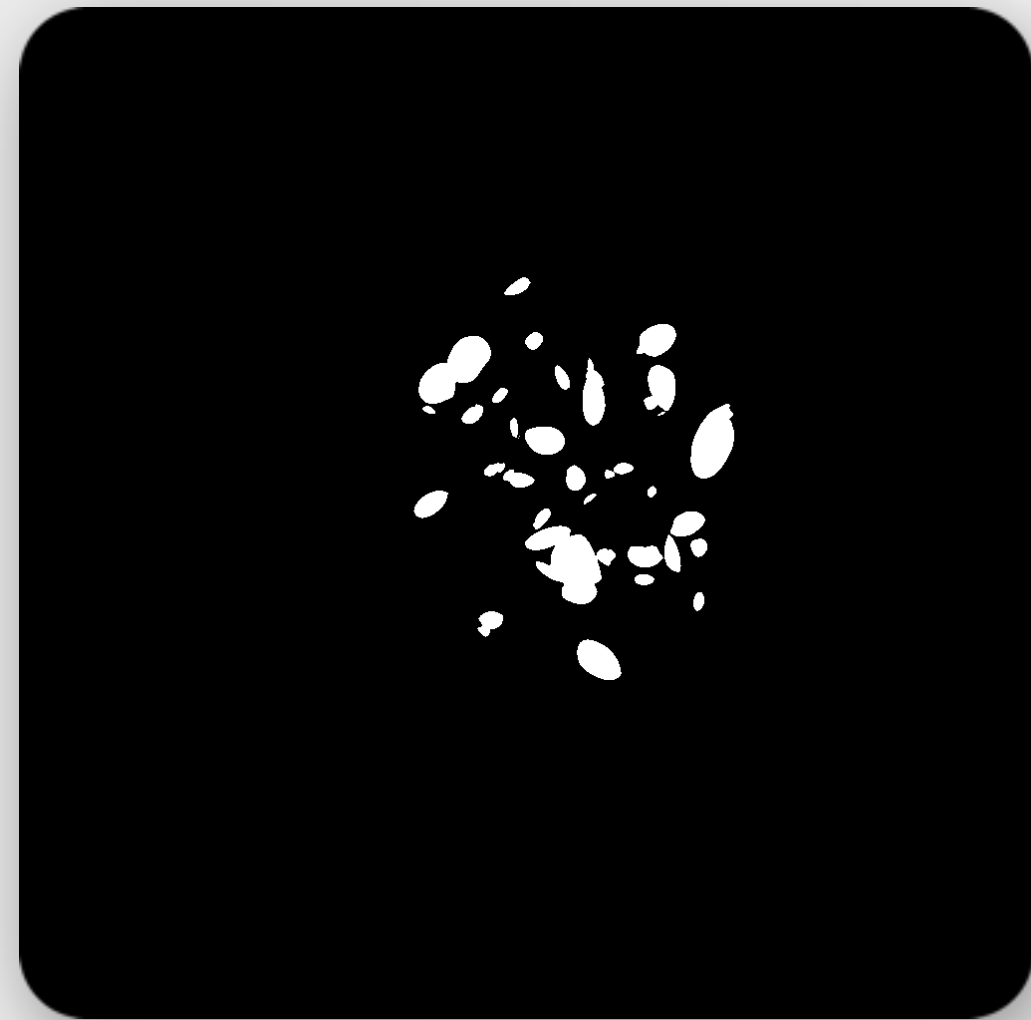


HI data from the
THINGS survey.

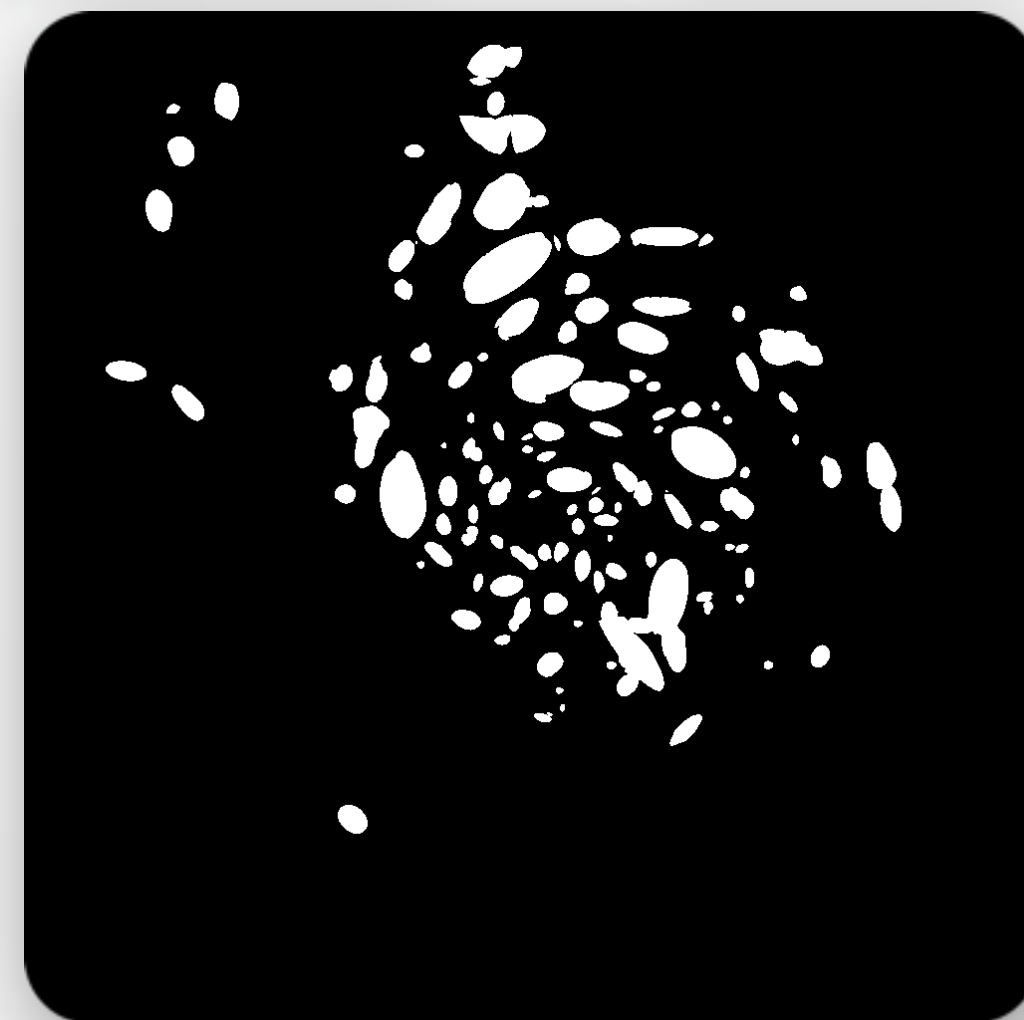
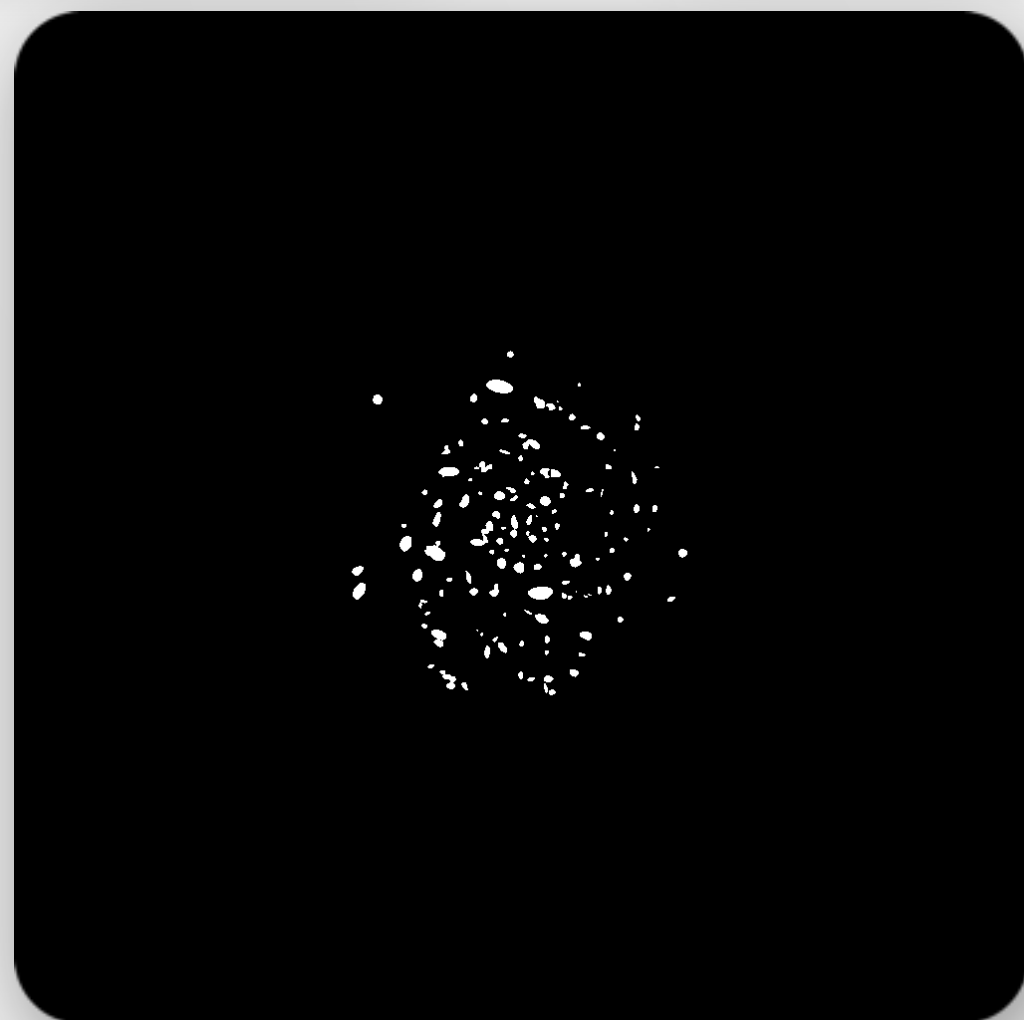
**Training
galaxies:**

- Holmberg II
- NGC 628
- NGC 2403
- NGC 3184
- NGC 5457

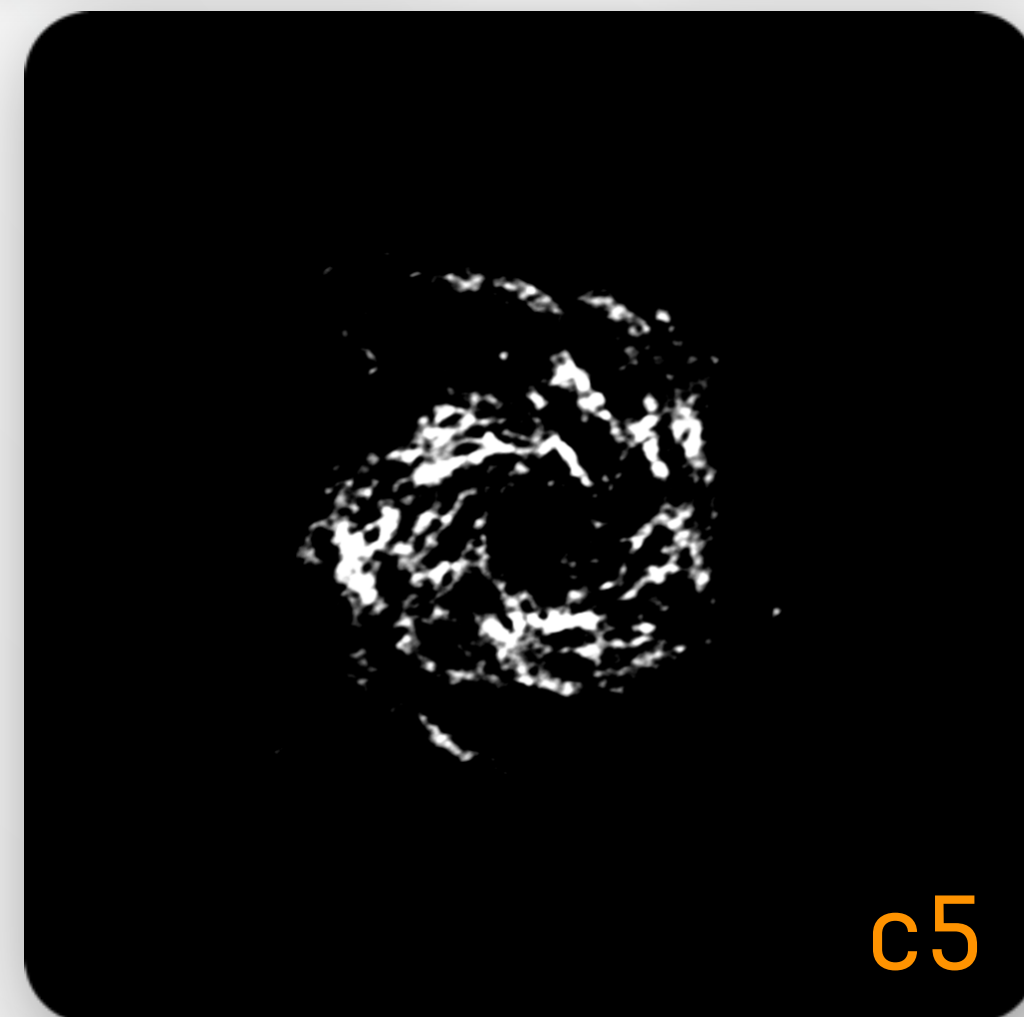
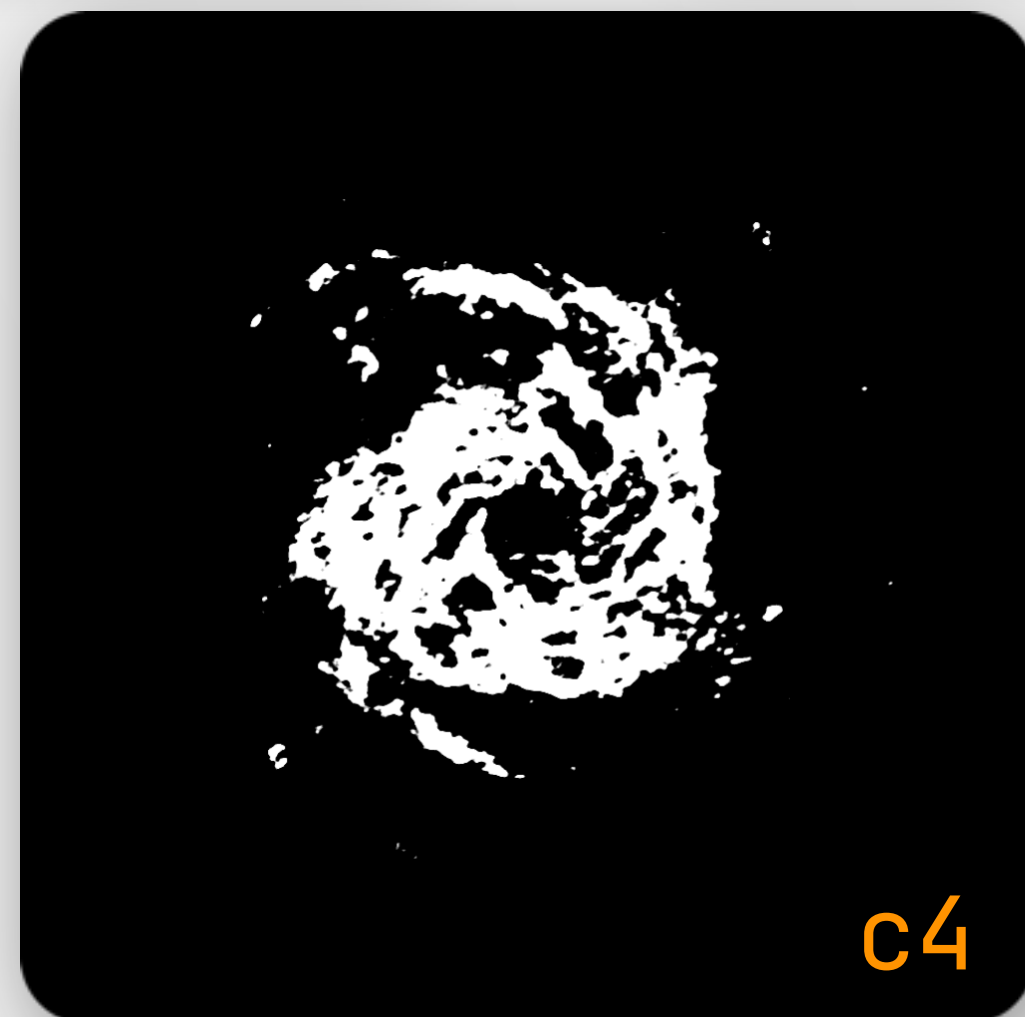
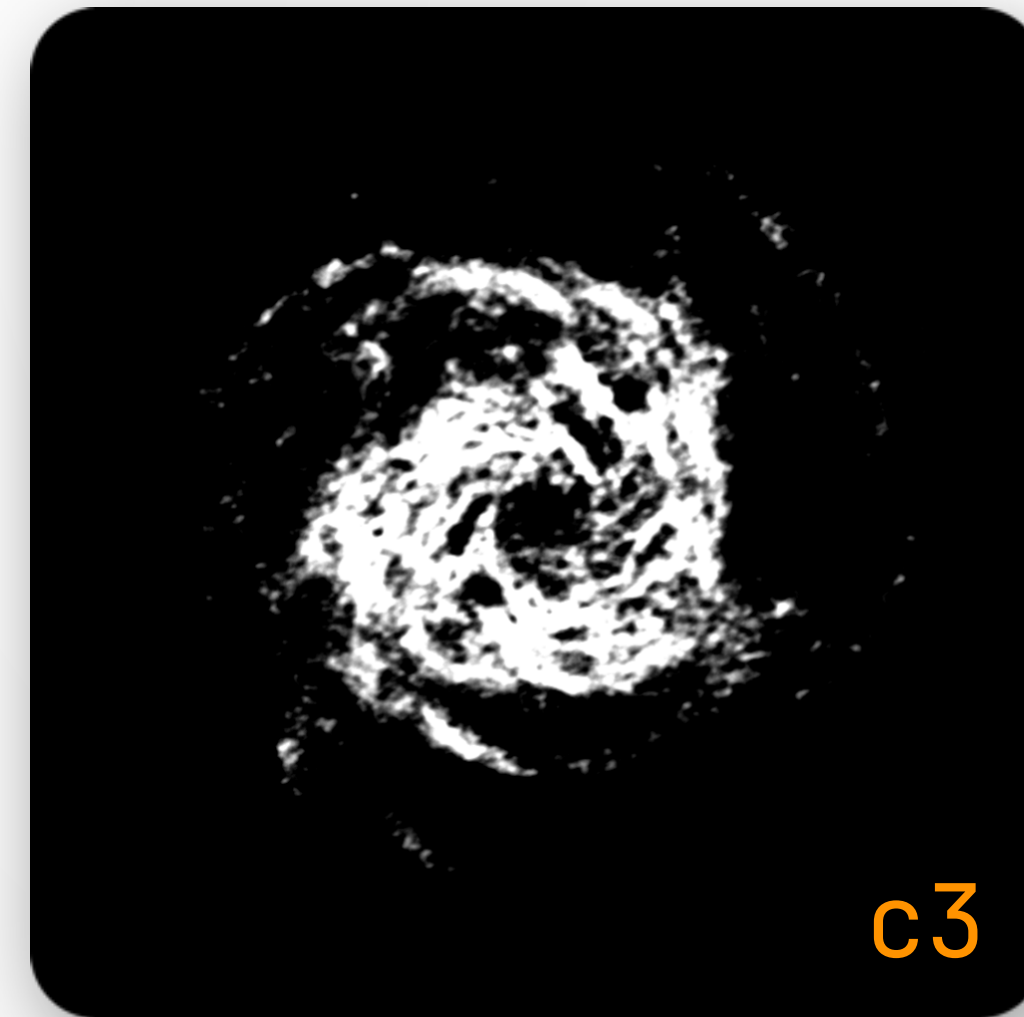
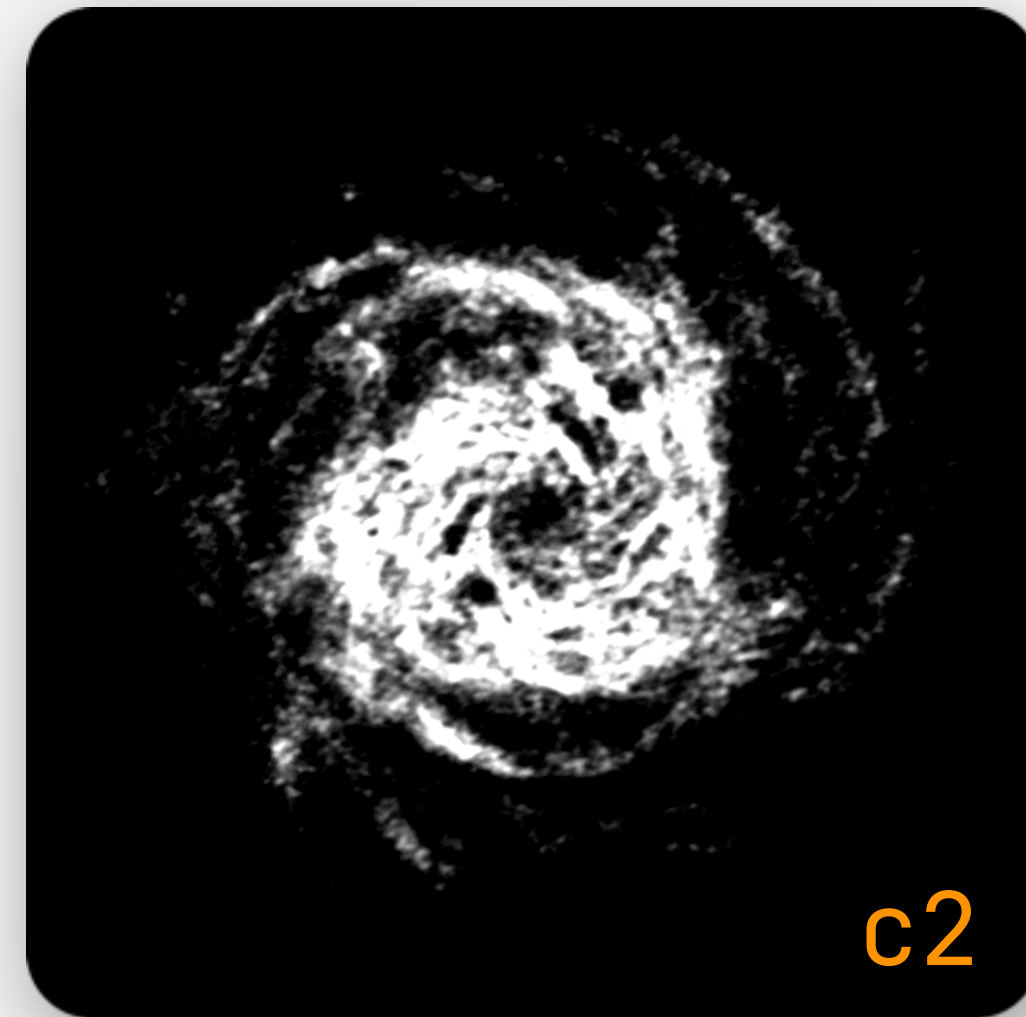
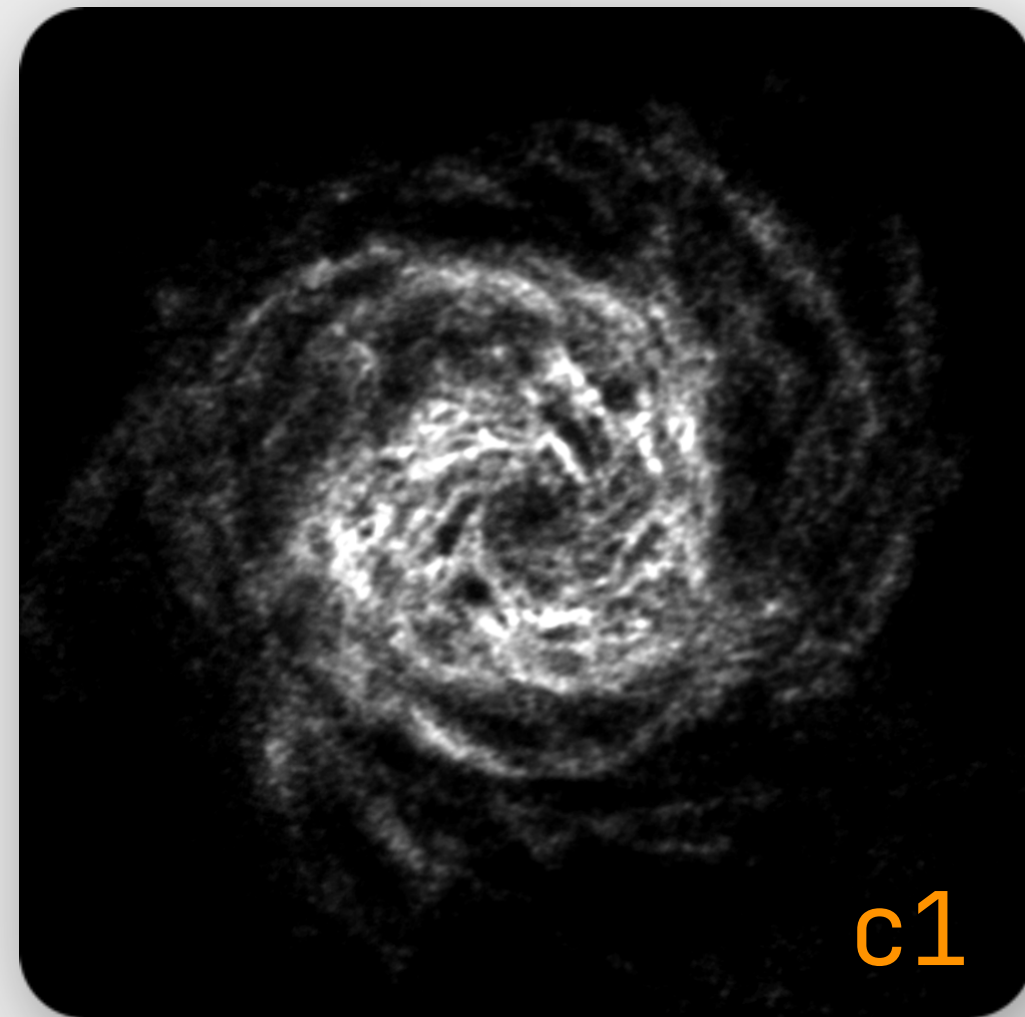
5. Machine learning to detect HI holes: The data



Each galaxy
has a
corresponding
mask showing
its HI holes.



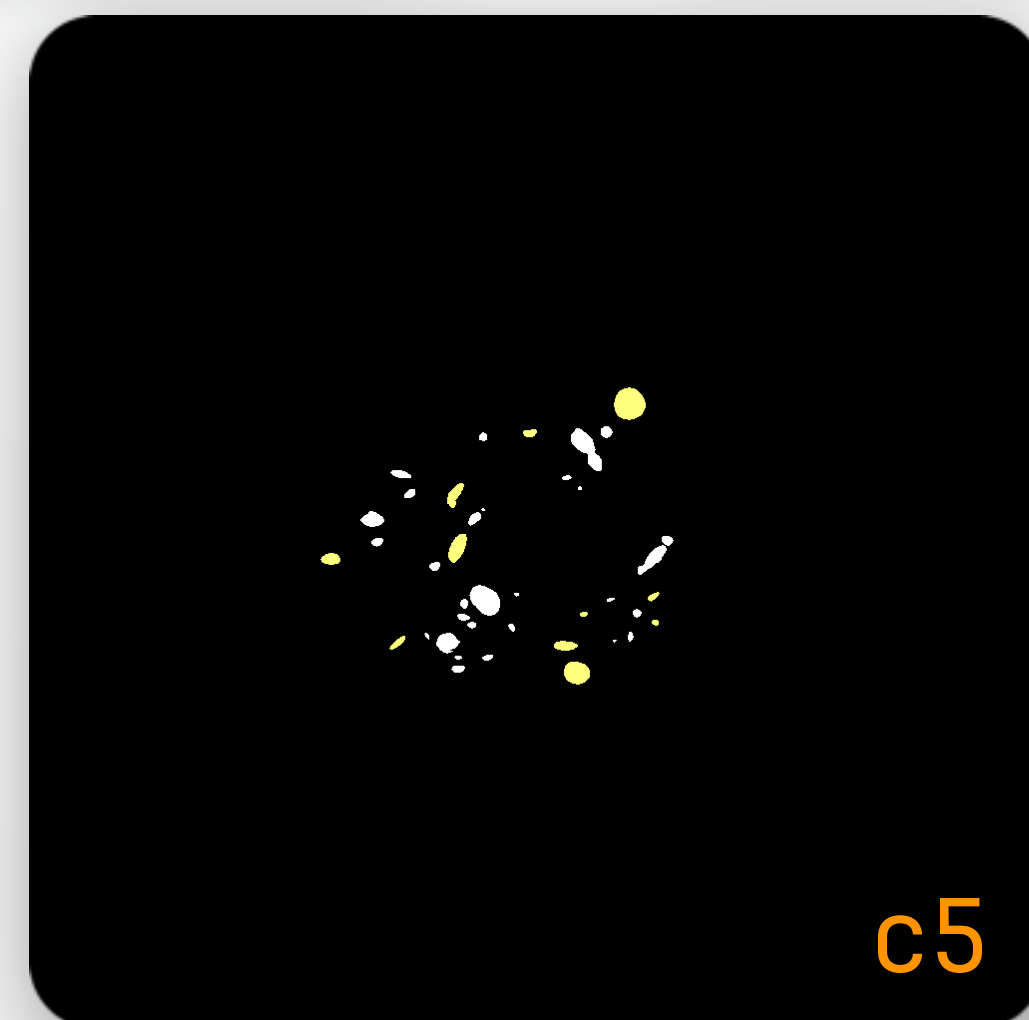
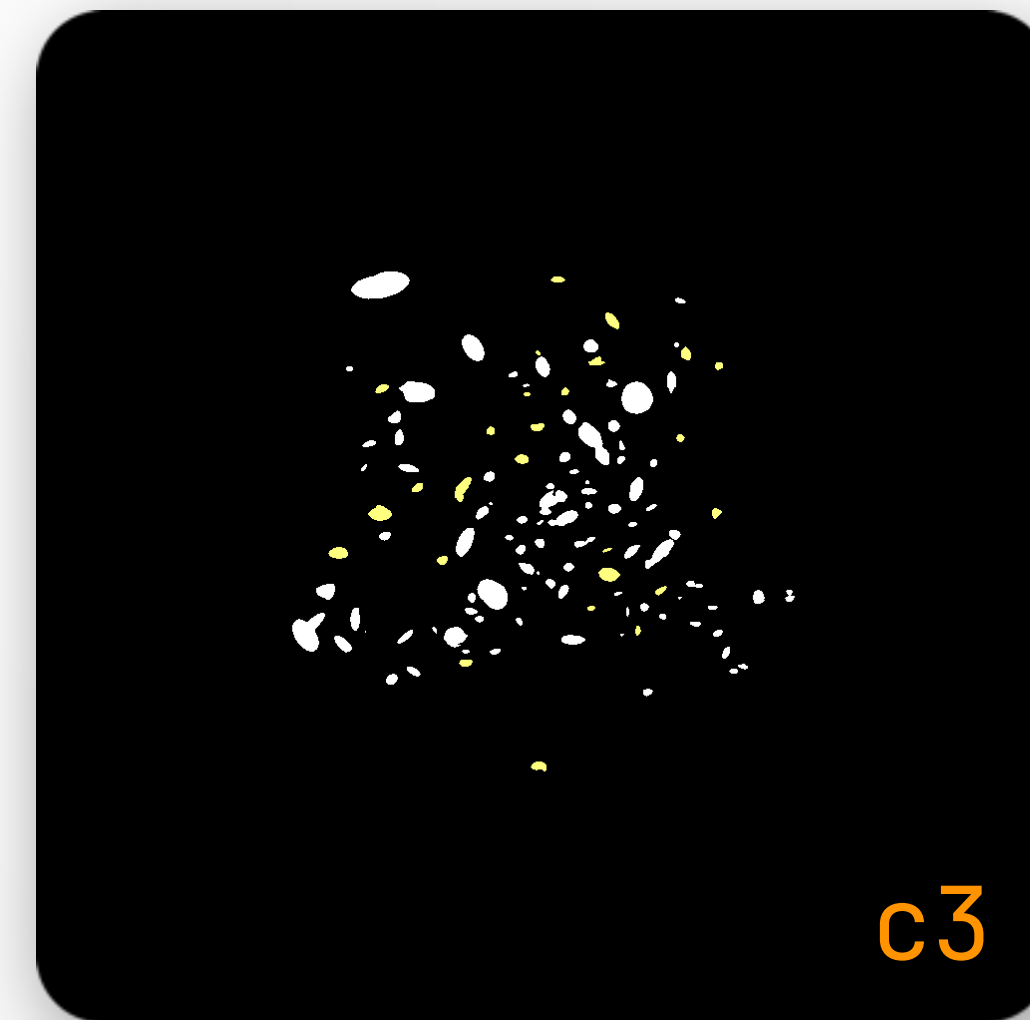
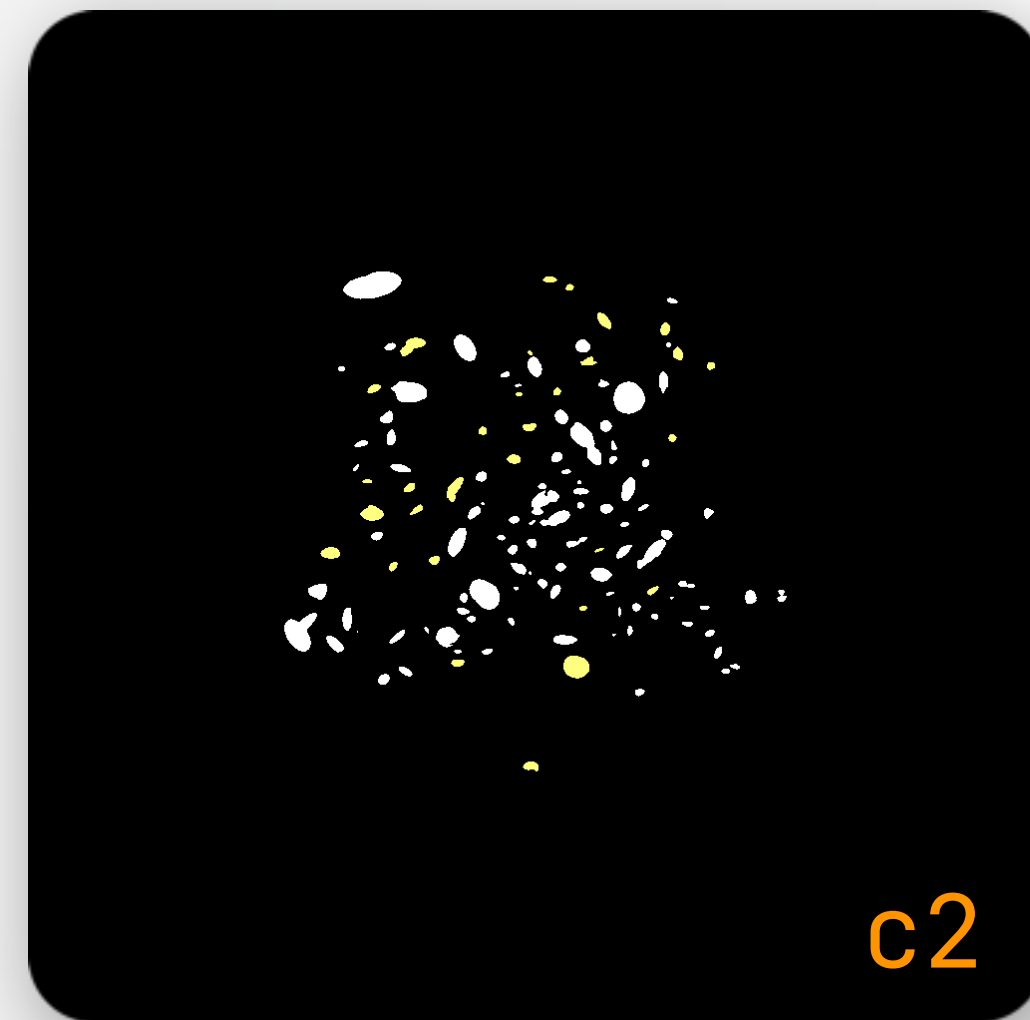
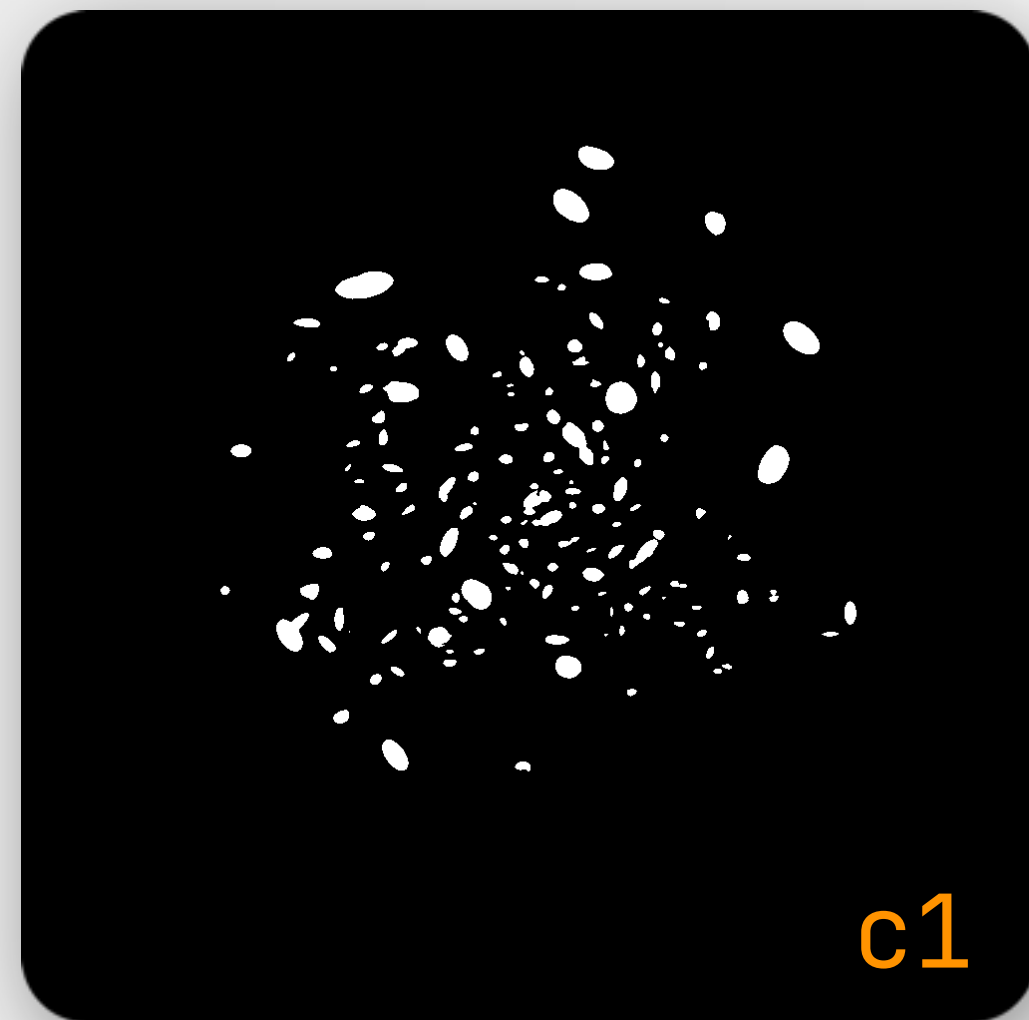
5. Machine learning to detect HI holes: The data



I am using
different
contrast
levels
for each
galaxy.

Artificially
increases
training
dataset

5. Machine learning to detect HI holes: The data



Each contrast level has its own mask.

White:
fully visible holes.

Yellow:
partially visible holes.

5. Machine learning to detect HI holes: Convolutional Neural Network

Convolutional Neural Network (CNN) designed for image segmentation.

Introduced by Ronnenberger et al. in 2015 for biomedical images.

Left side compresses image into features and right side reconstructs it to pixel-level predictions.

There are possibly useful variants.



Example of an U-net

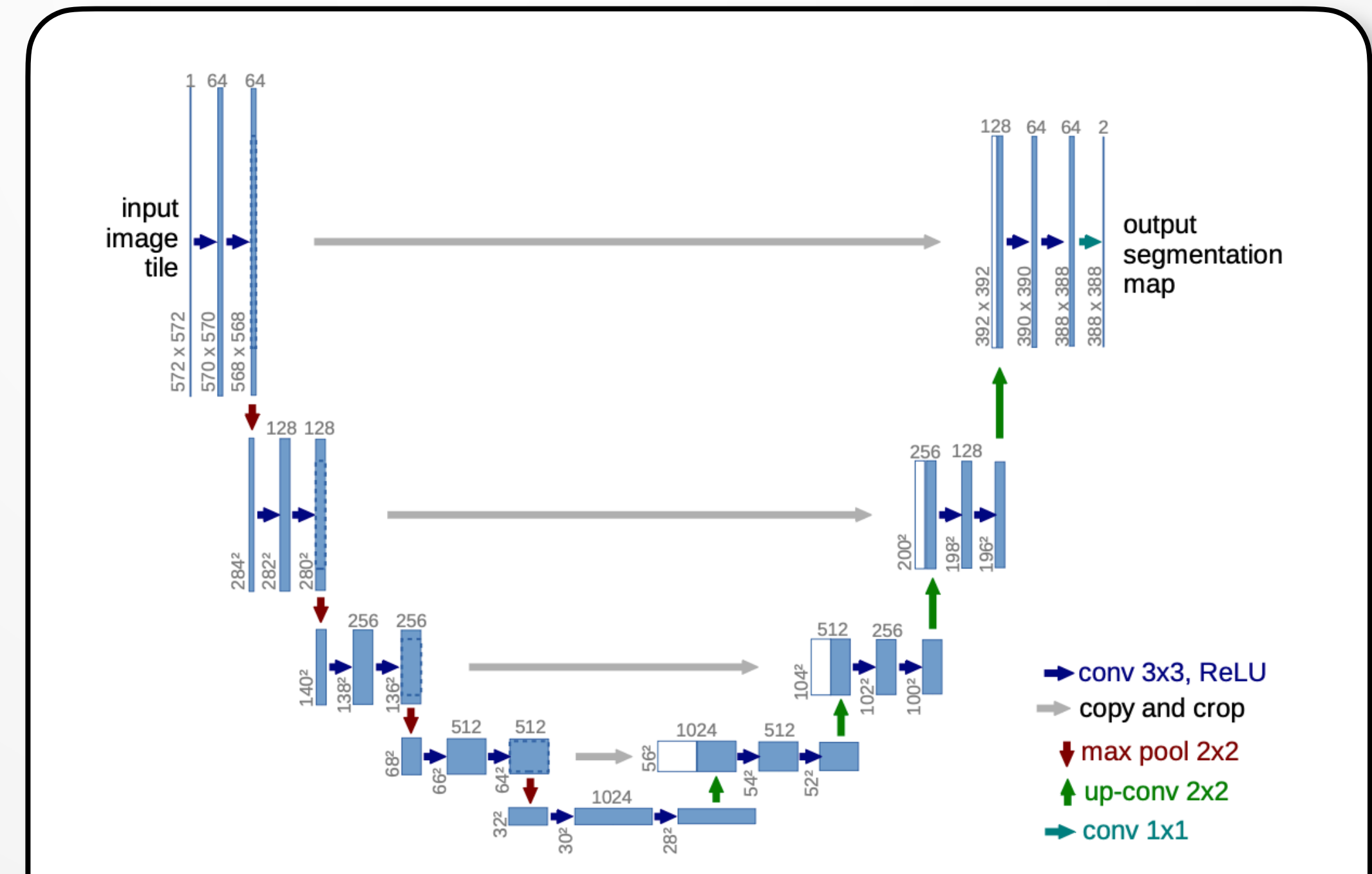
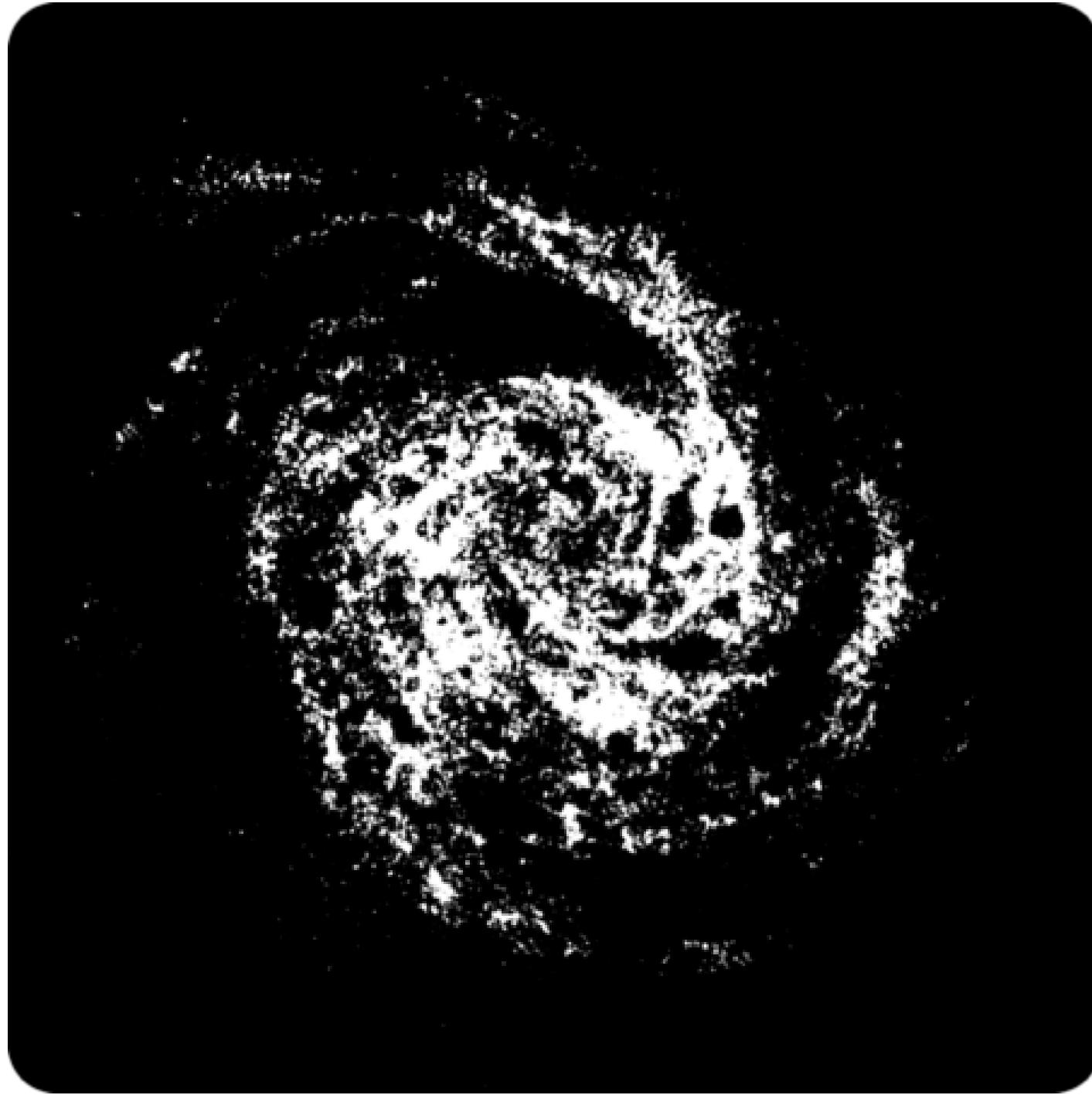


Fig. 1. U-net architecture (example for 32x32 pixels in the lowest resolution). Each blue box corresponds to a multi-channel feature map. The number of channels is denoted on top of the box. The x-y-size is provided at the lower left edge of the box. White boxes represent copied feature maps. The arrows denote the different operations.

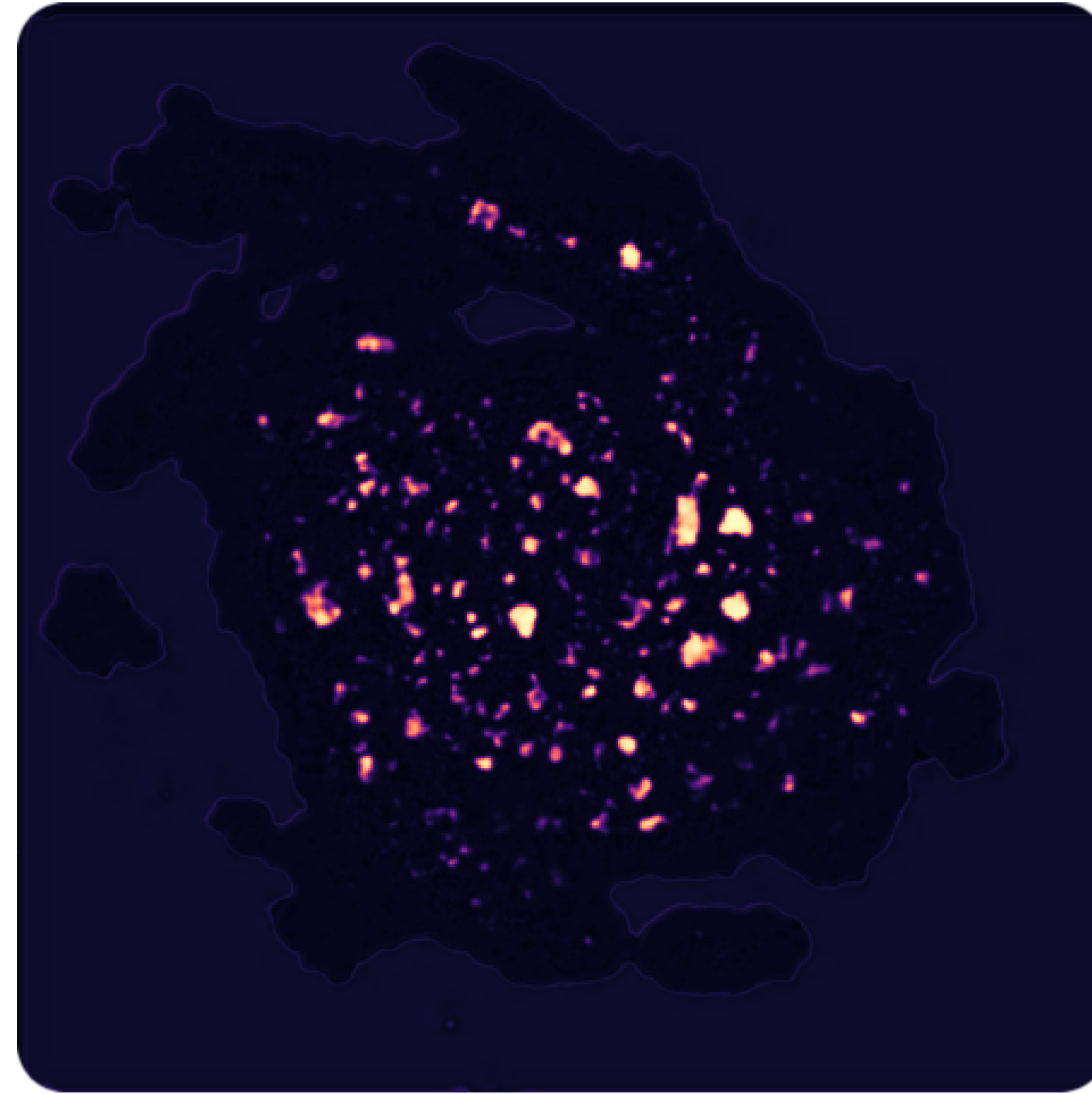
Credit: Ronneberger et al. (2015)

5. Machine learning to detect HI holes: Current state

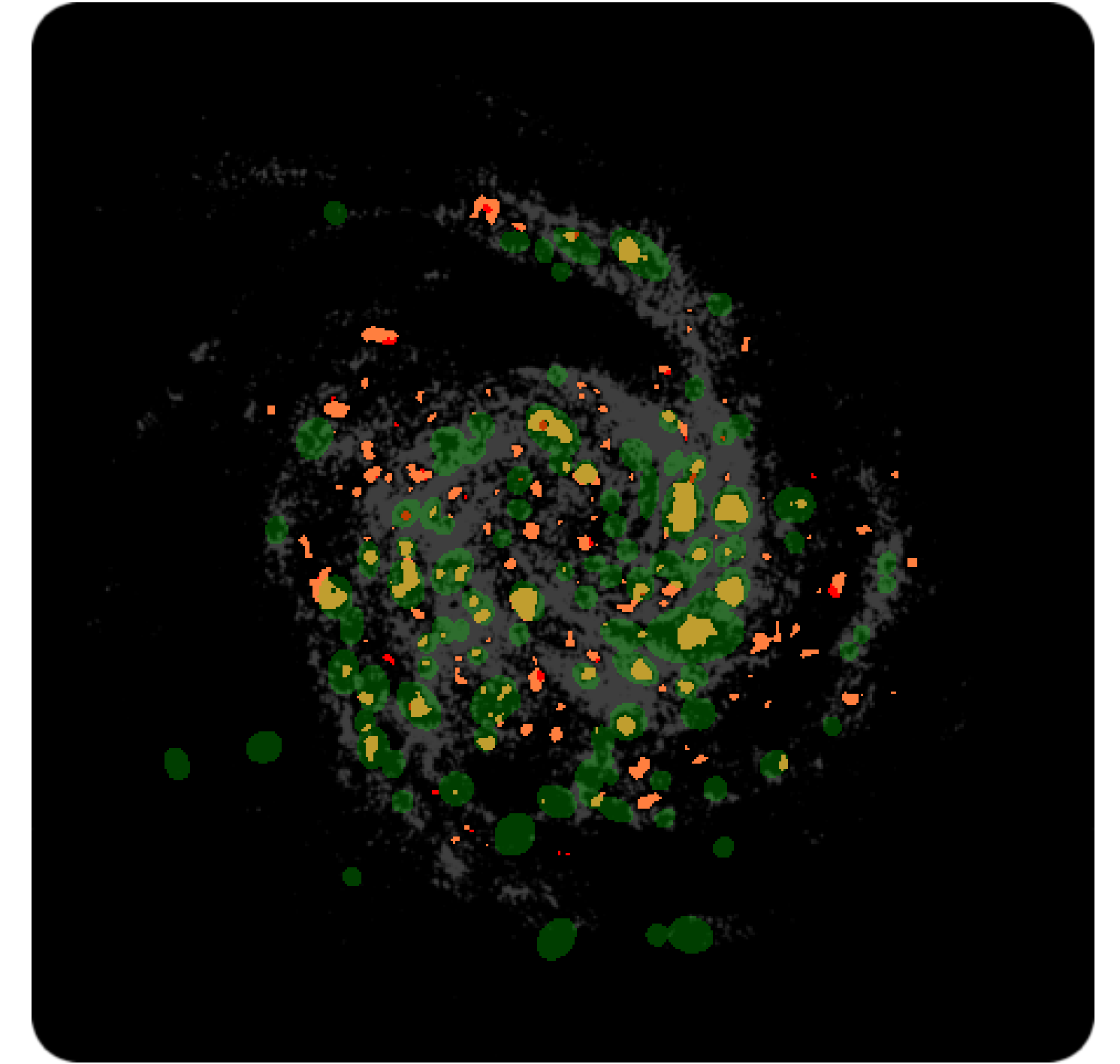
Original HI map



HI holes mask prediction

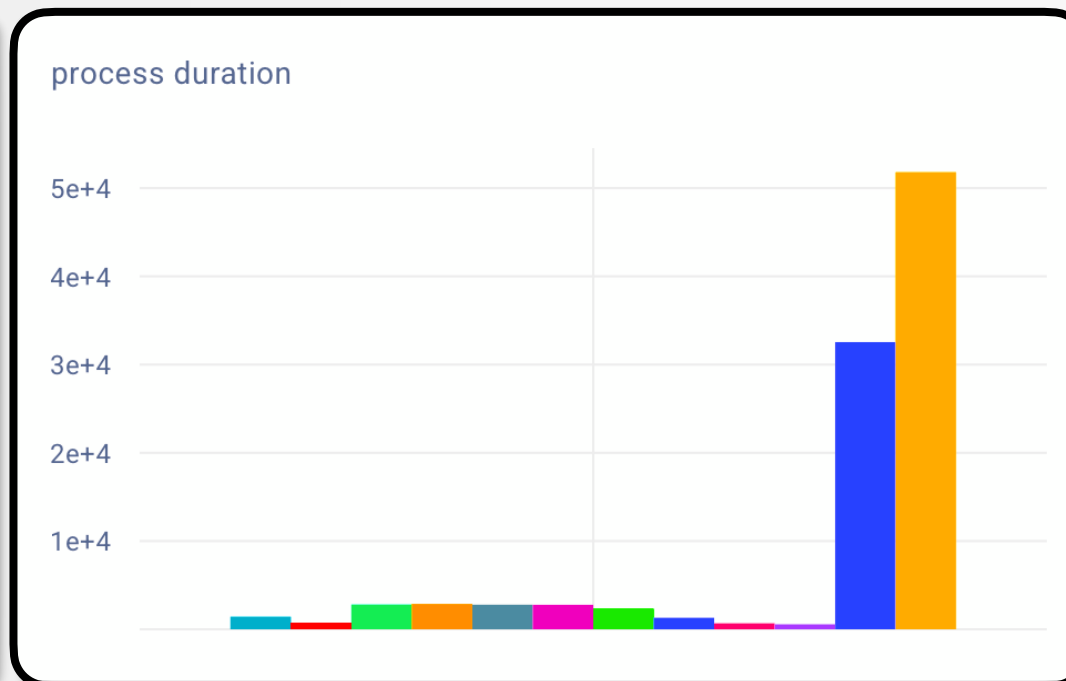
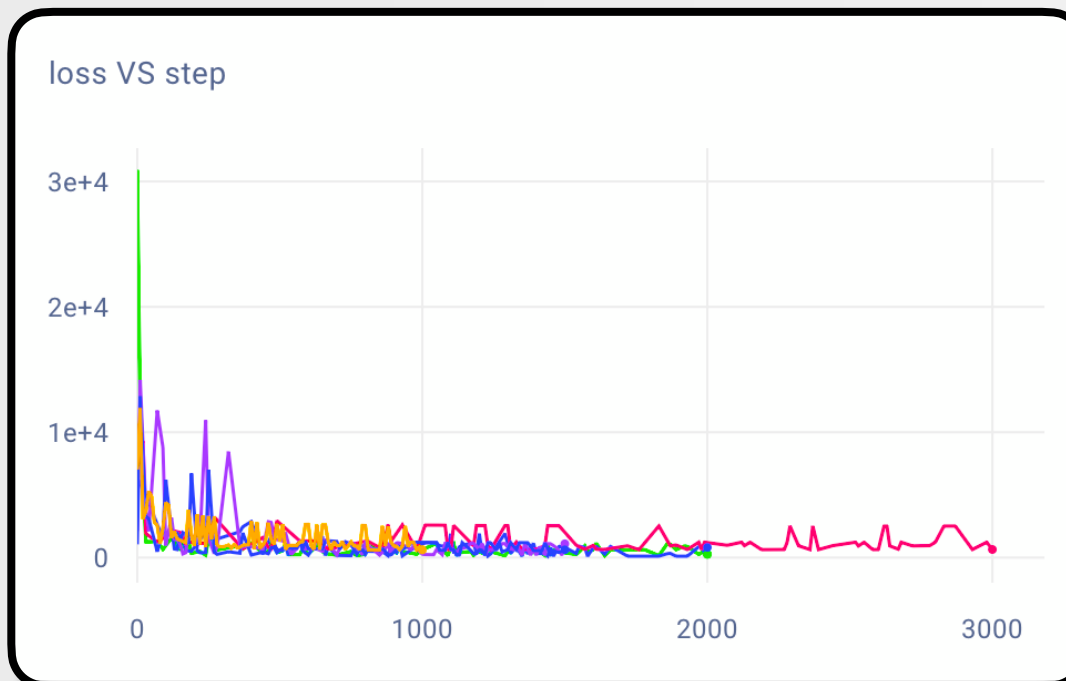


Final HI holes mask



* I am still working on the metrics to analyze different models.

5. Machine learning to detect HI holes: Current state

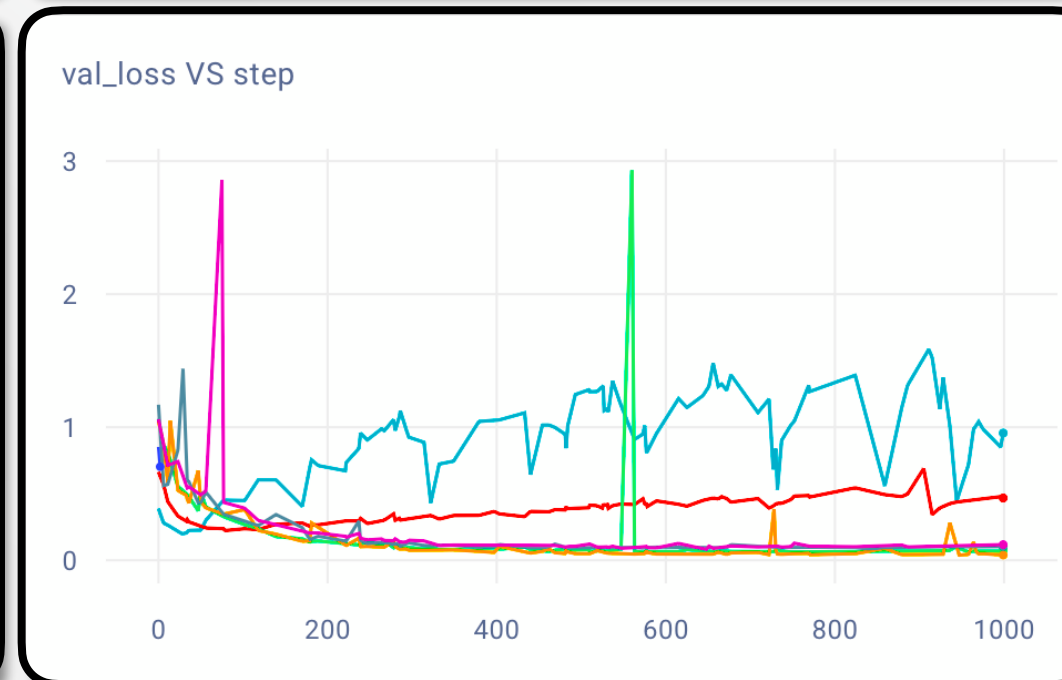
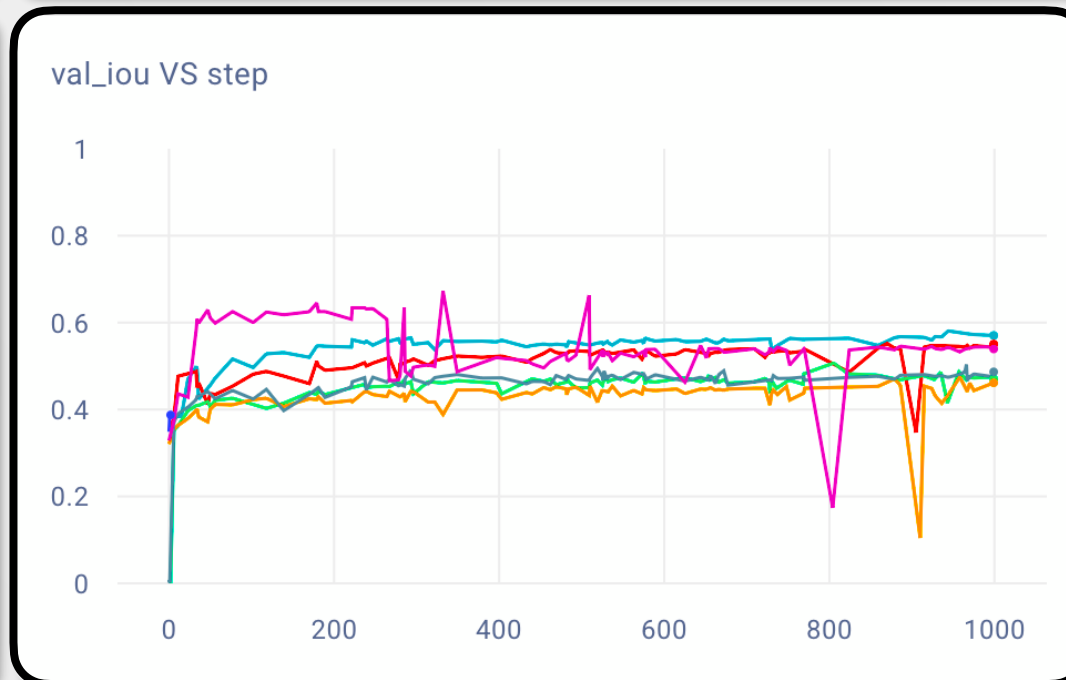
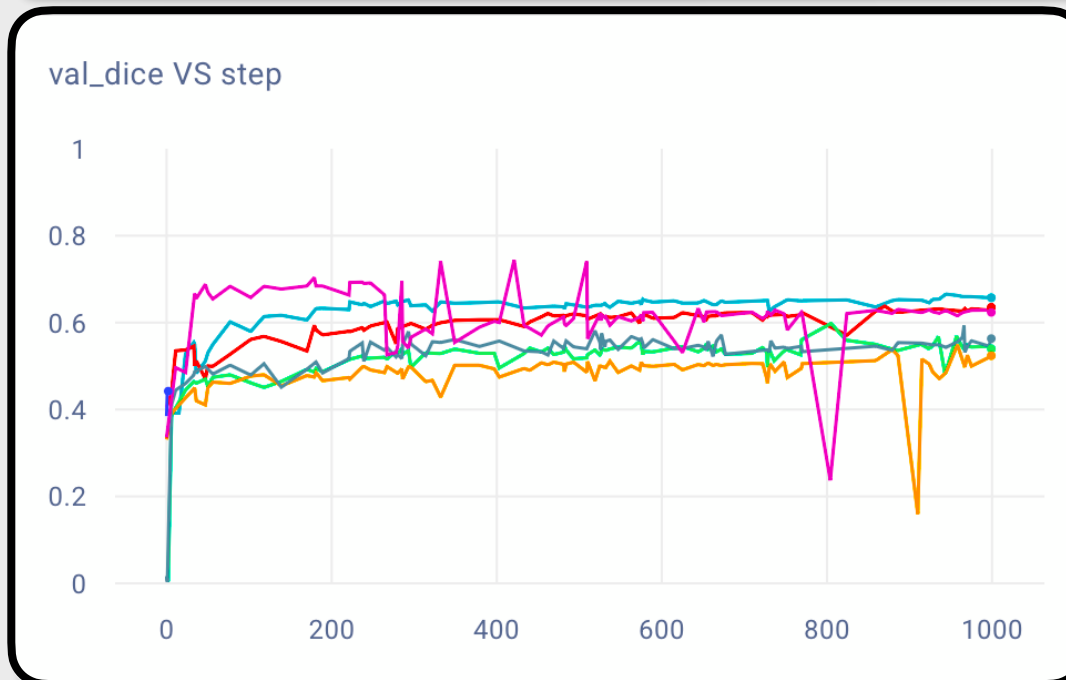
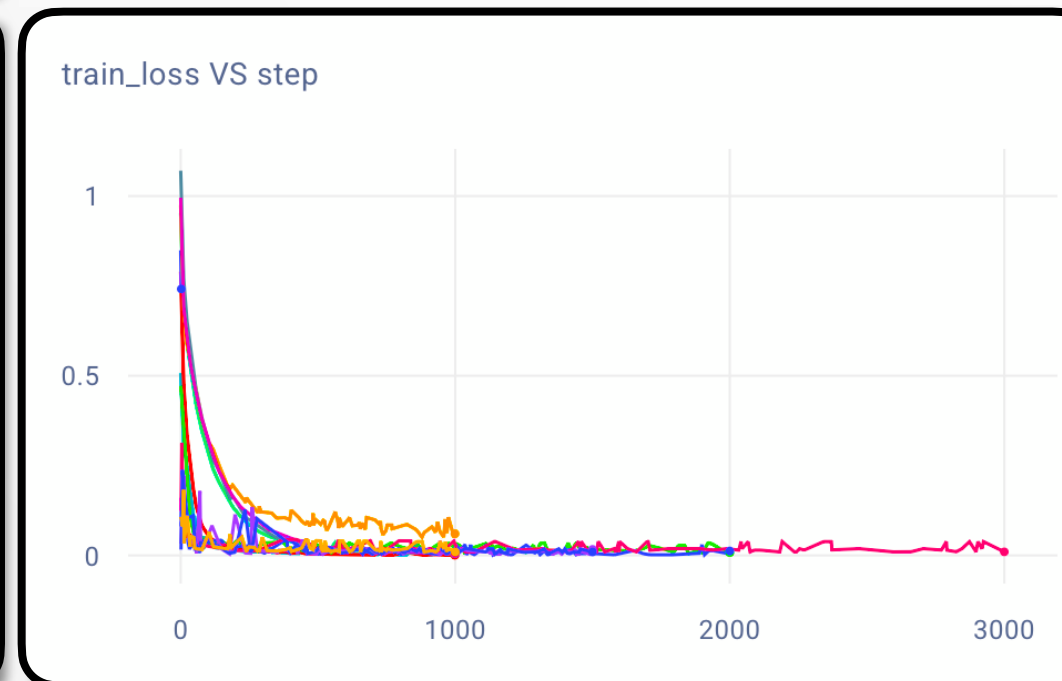
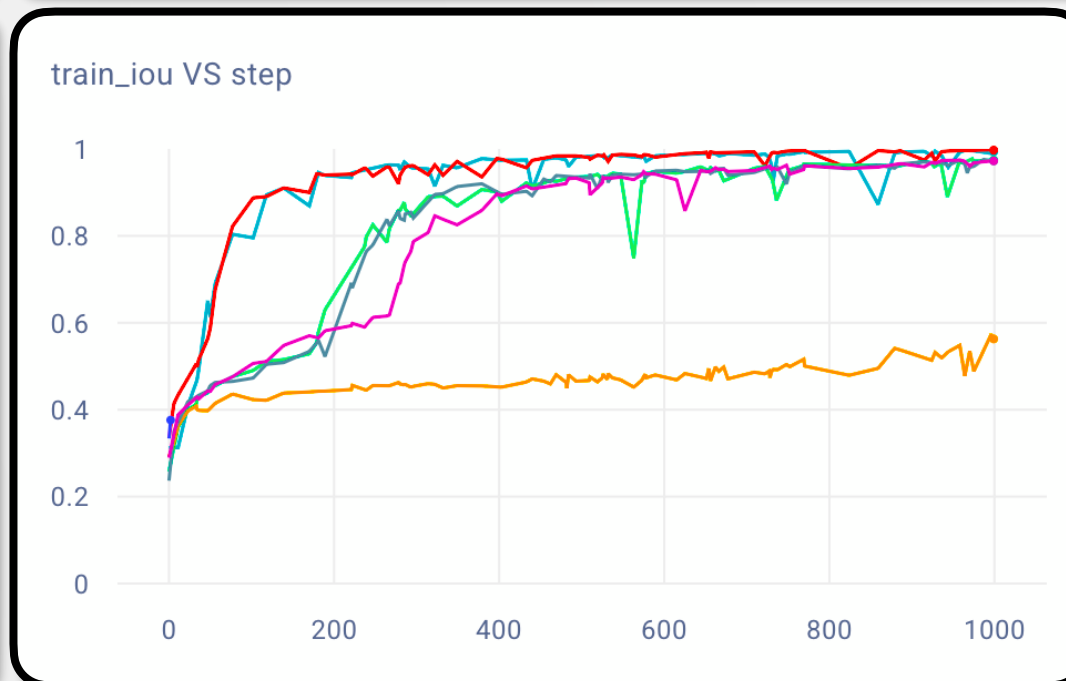
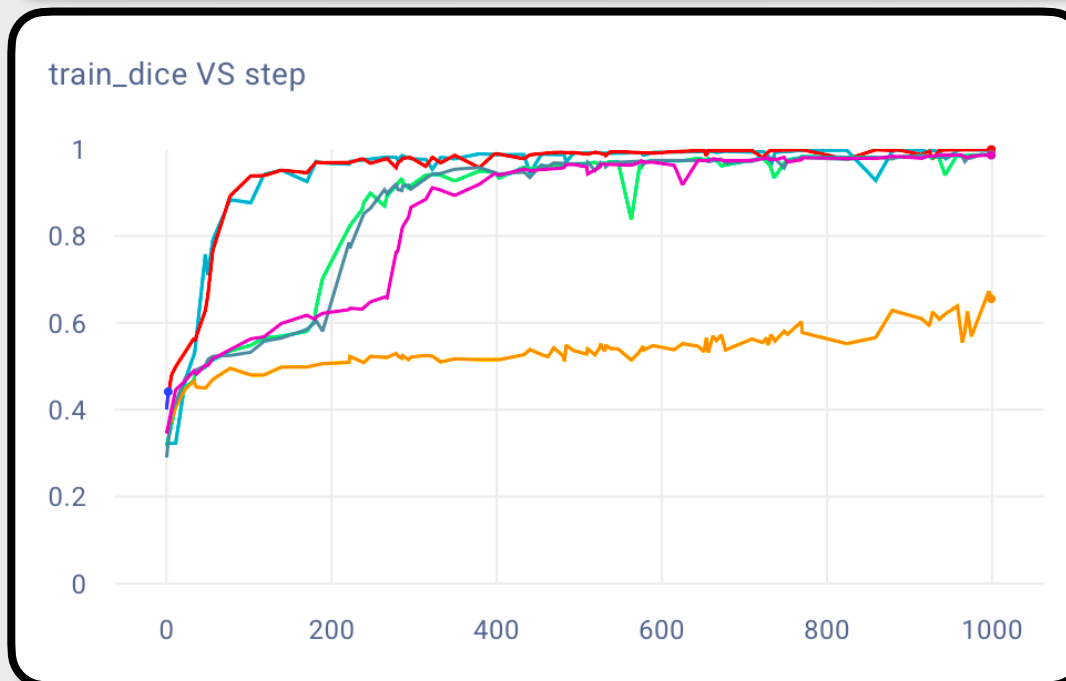


IoU (Intersection over Union) to measure accuracy.

Dice accuracy is less harsh on small imperfections.

Problems reaching high accuracy in validation dataset.

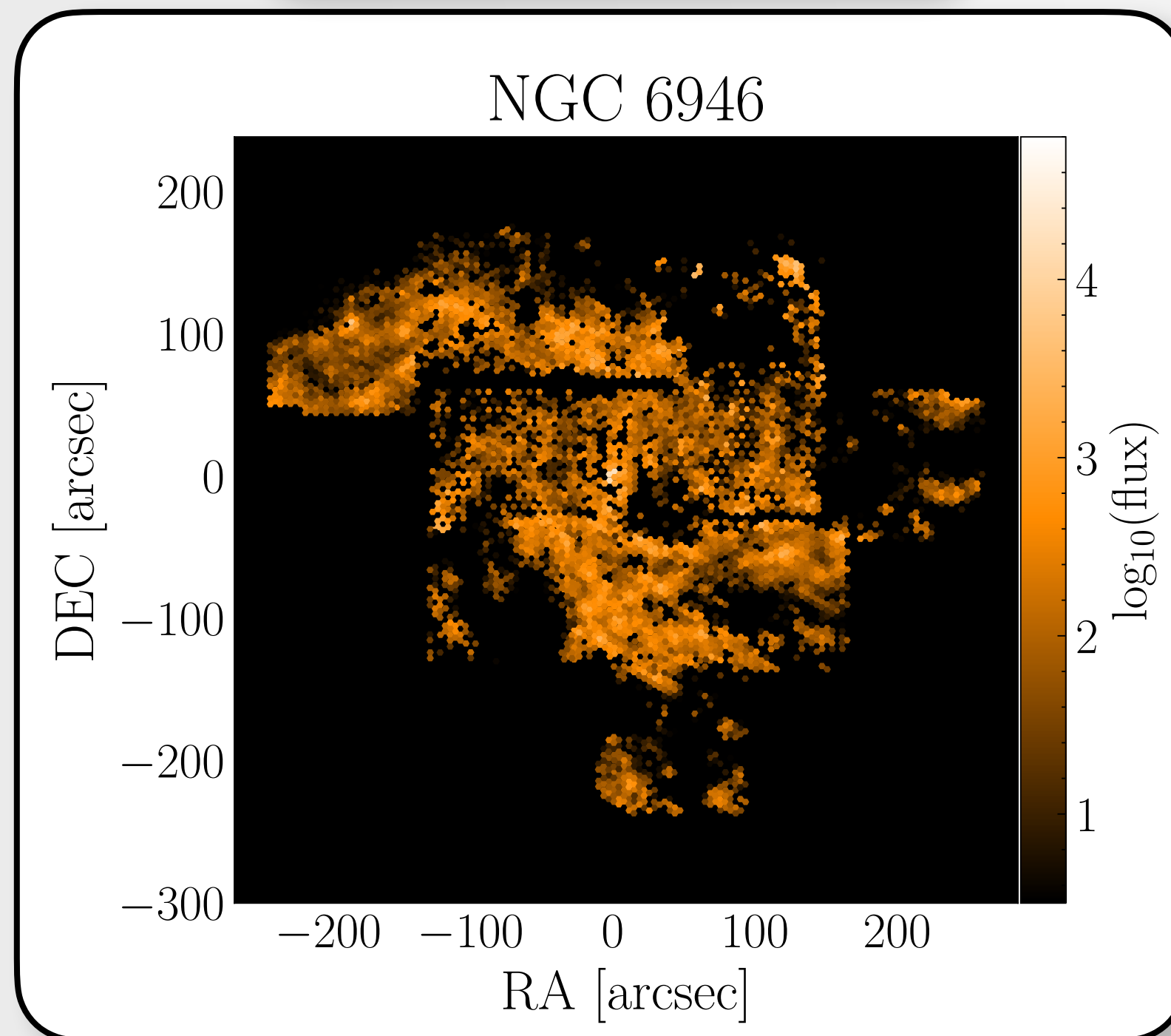
Possible symptoms of overfitting.



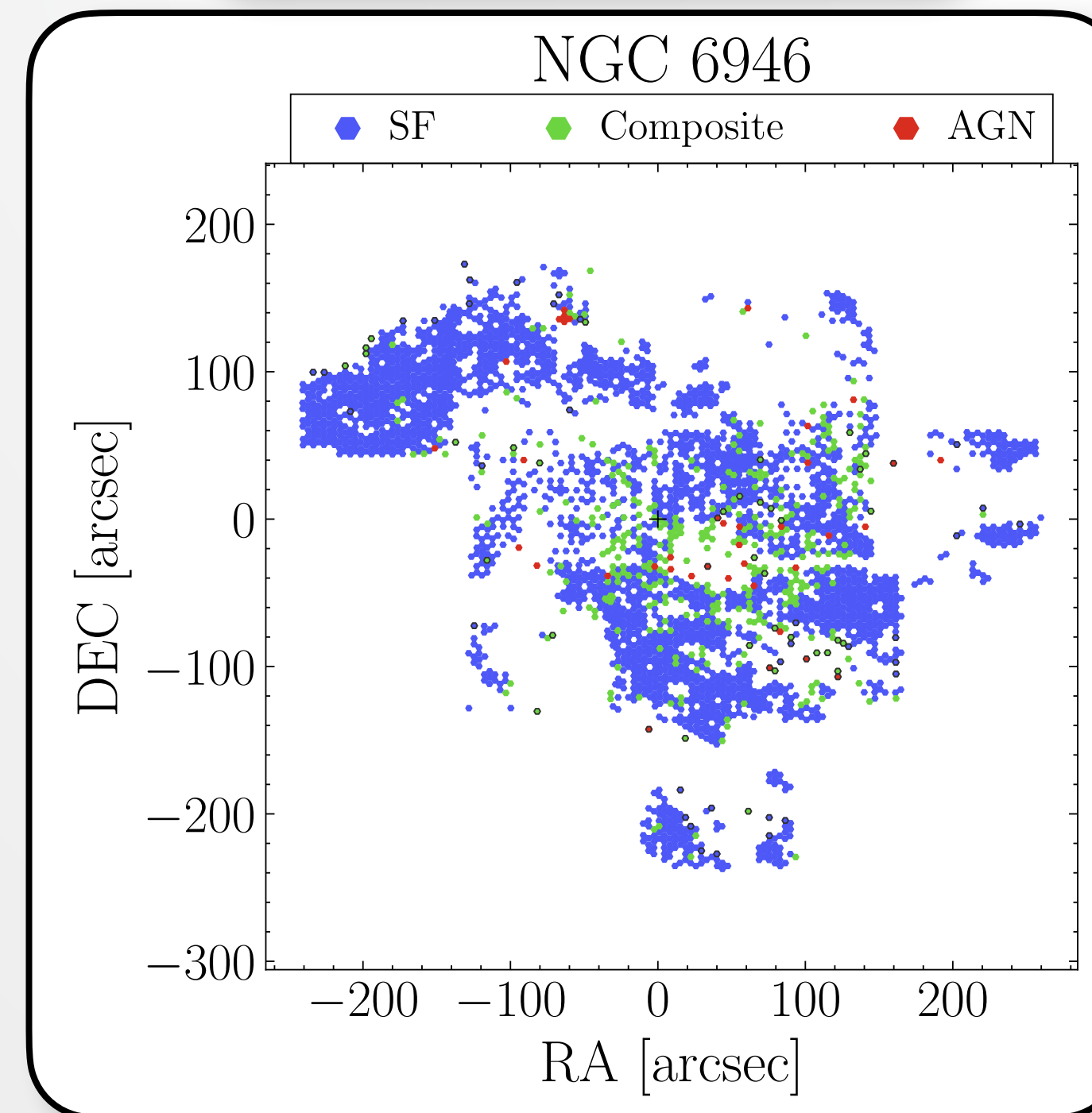
5. Machine learning to detect HI holes

The final objective is to study the physical properties of the surrounding regions of HI holes in the Metal-THINGS galaxies.

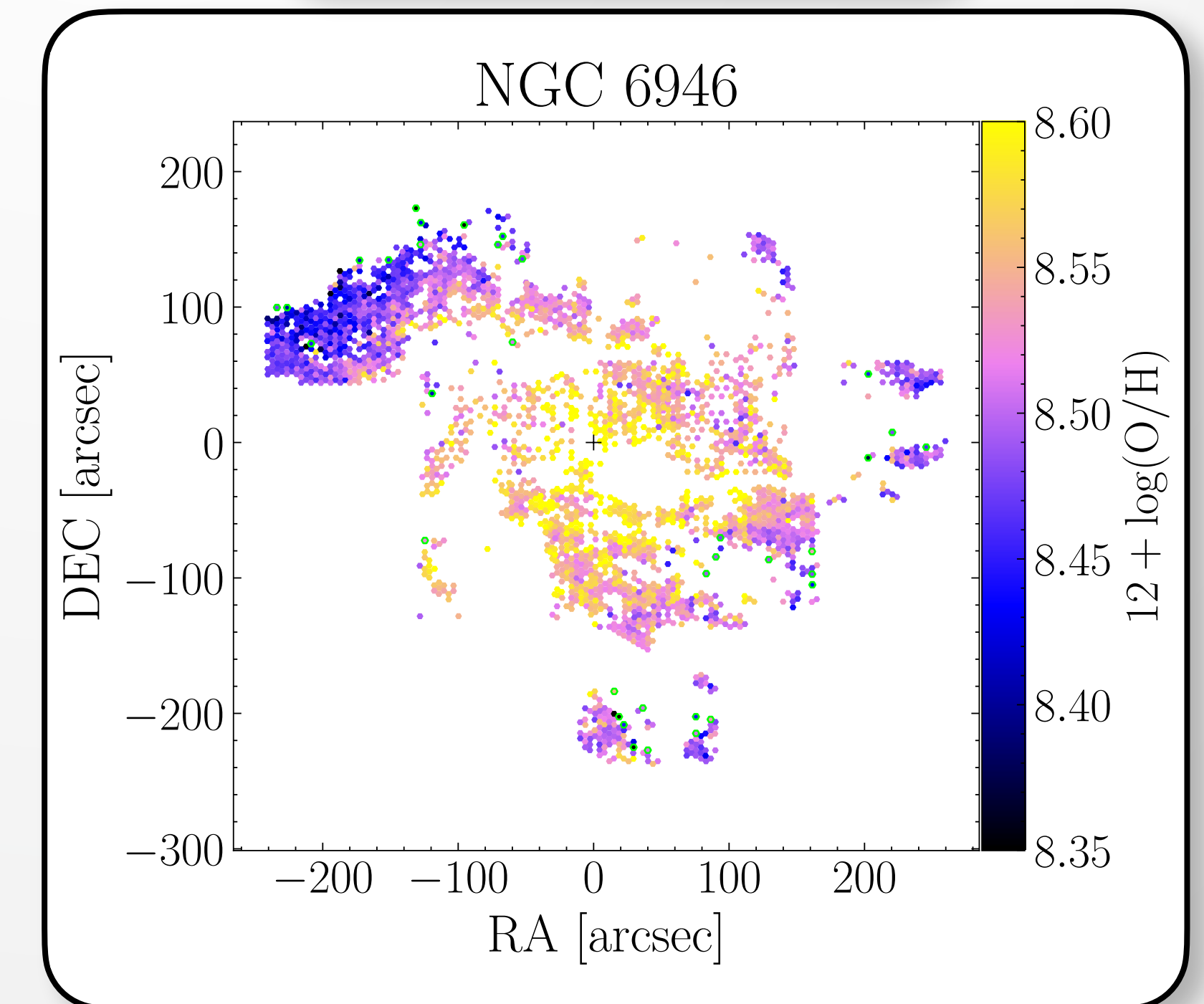
Flux



BPT regions



Metallicity



Key points

- Paper on metallicity gradients published in September 2025.
- HI holes form from SN activity and gas turbulence.
- U-net architecture used for segmenting holes from HI maps of galaxies.
- Facing overfitting issues and studying solutions.
- End goal is to study properties of the environment of HI holes.

**Mechanisms that shape
star formation:
a study on metallicity
and HI holes**



THANK YOU

Guillermo Valé Arteaga

PhD supervisors:

Maritza Arlene Lara López

Shane P. O'Sullivan

Contact info:

guivale@ucm.es