

New larger sample of SNRs in NGC 7793, using MUSE IFS

Maria Kopsacheili

SUPERNOVA REMNANTS III
AN ODYSSEY IN SPACE AFTER STELLAR DEATH



GOBIERNO
DE ESPAÑA

MINISTERIO
DE CIENCIA
E INNOVACIÓN



CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Collaborators: Jiménez-Palau C., Galbany L., Boumis P.,
González-Díaz R.

Institute of
Space Sciences

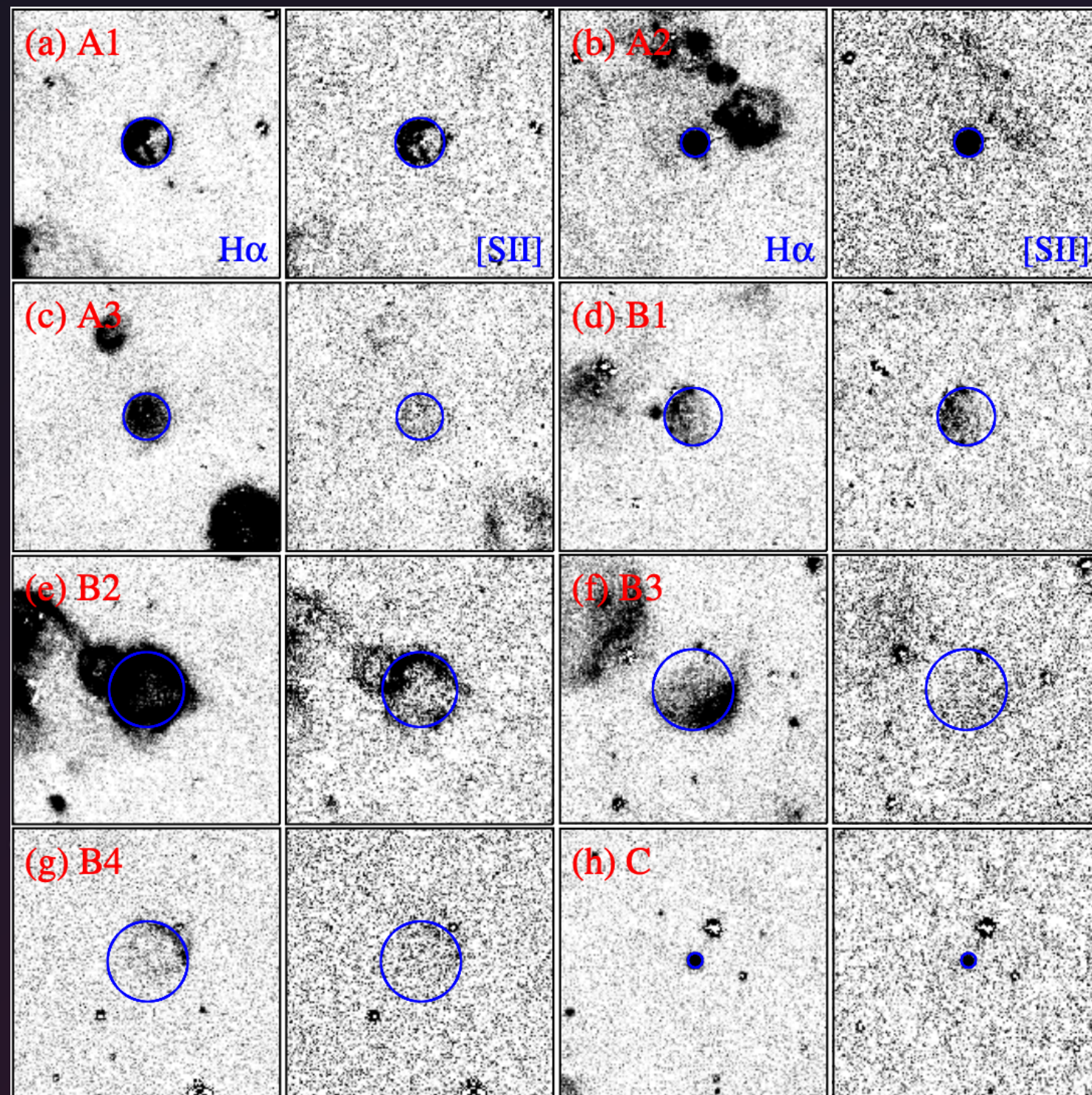


EXCELENCIA
MARÍA
DE MAEZTU

Optical Identification of SNRs: Traditional Diagnostic

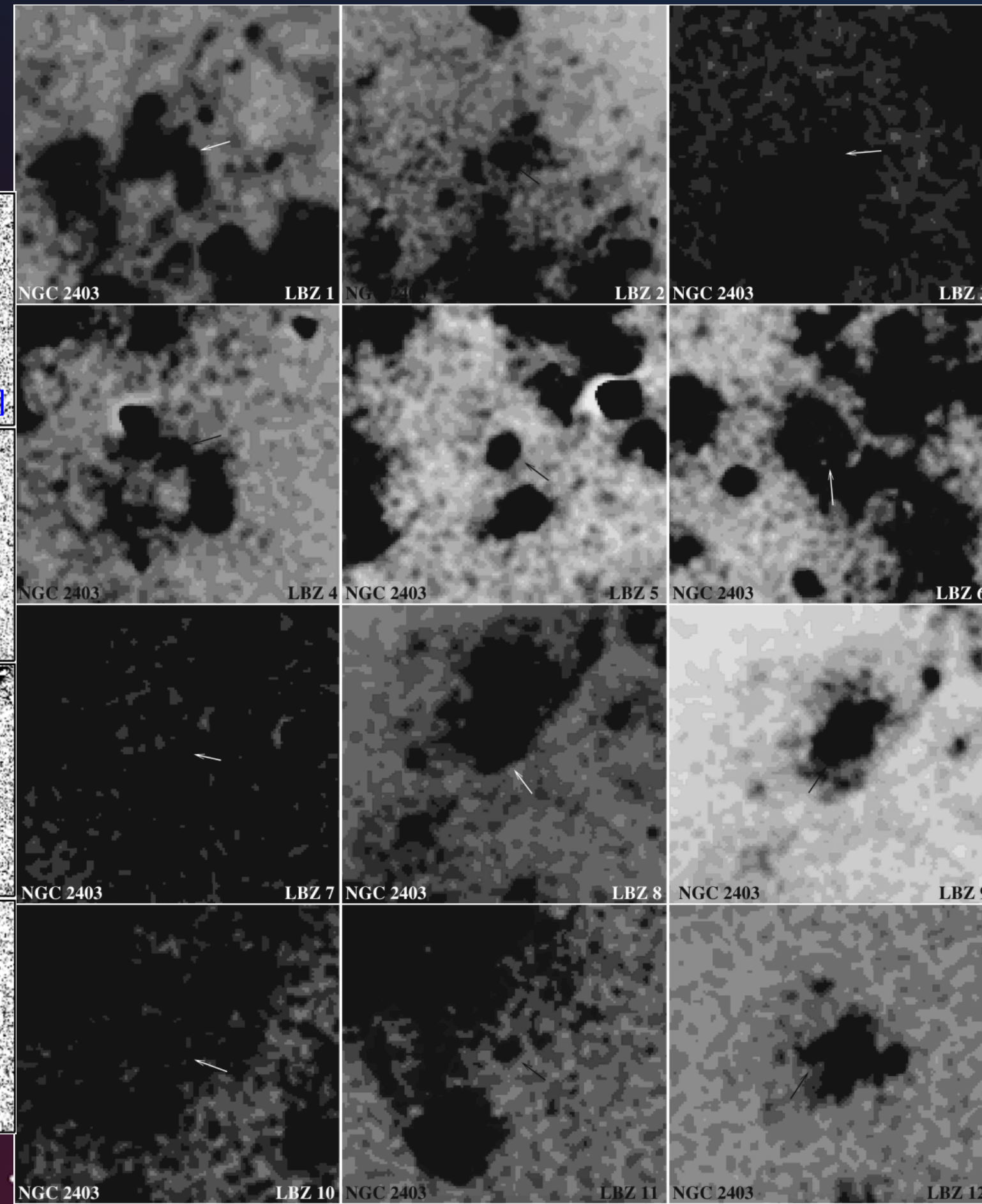
$[S II]/H\alpha > 0.4$

(Mathewson & Clarke 1973,
Dopita et al. 1977
Dodorico et al., 1978)

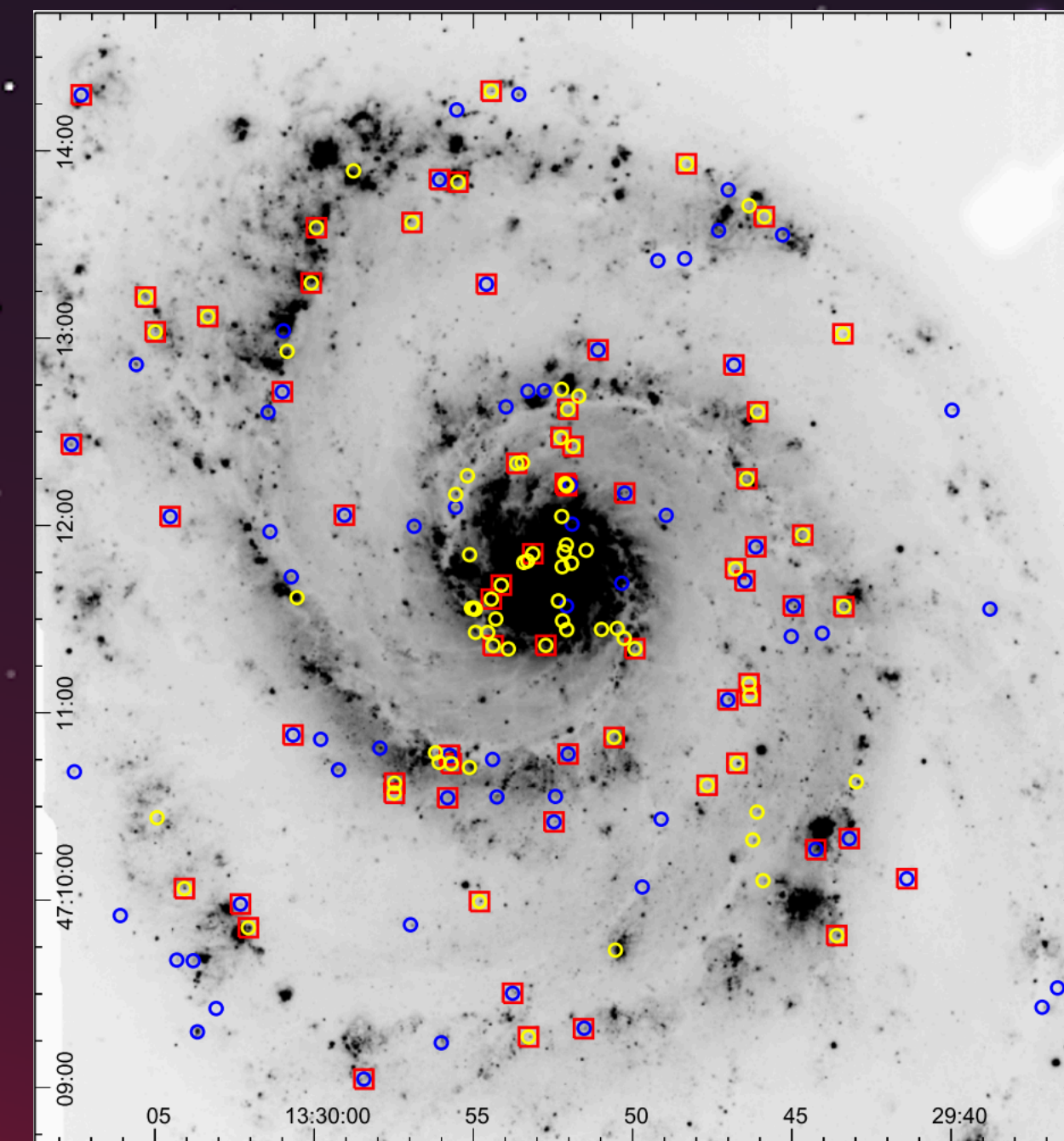
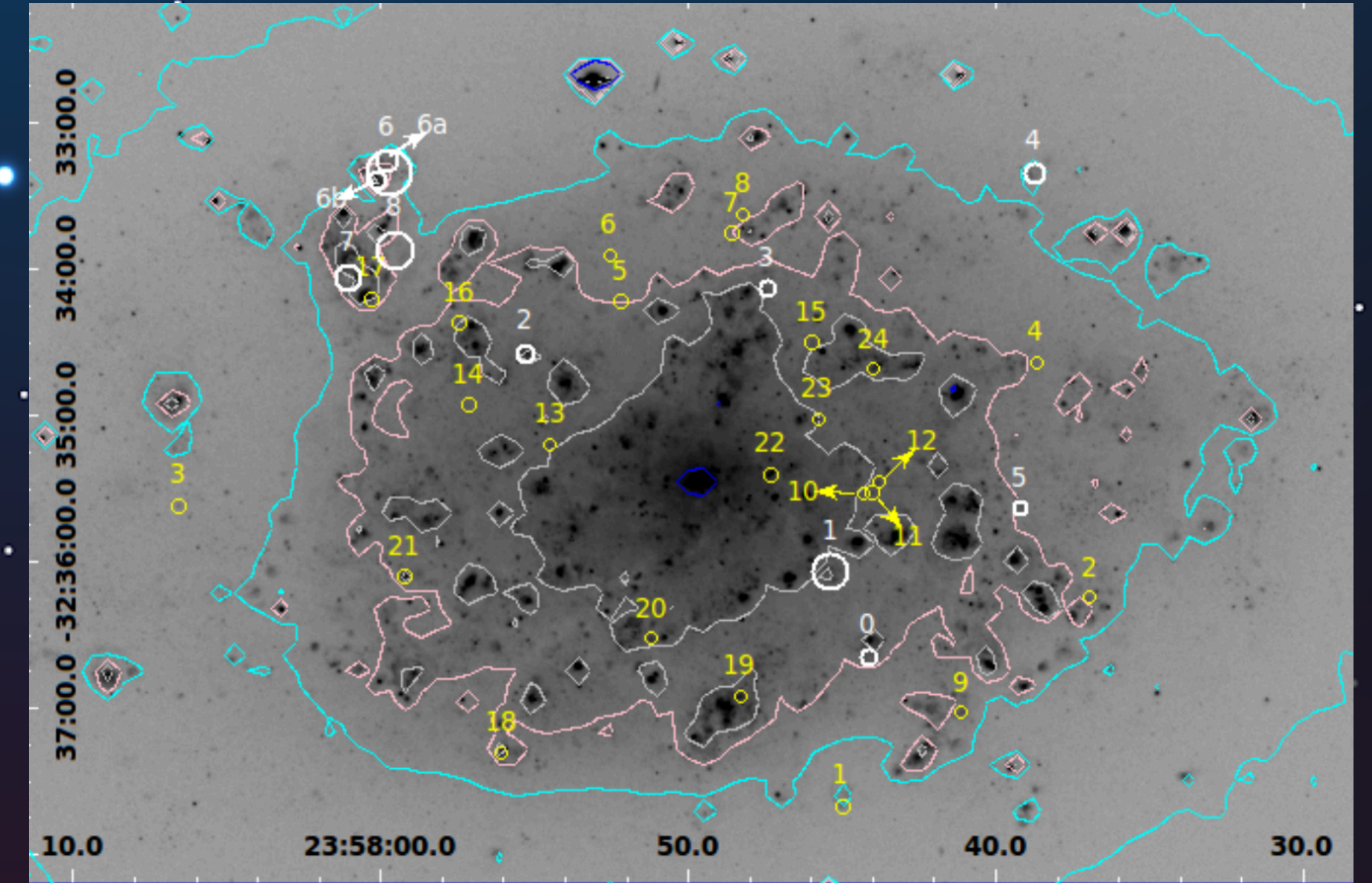


M31: Lee & Lee 2014

NGC 7793:
Kopsacheili et al.,
2021



NGC 2403: Leonidaki et al. 2013



M51:
Winkler et al.
2021

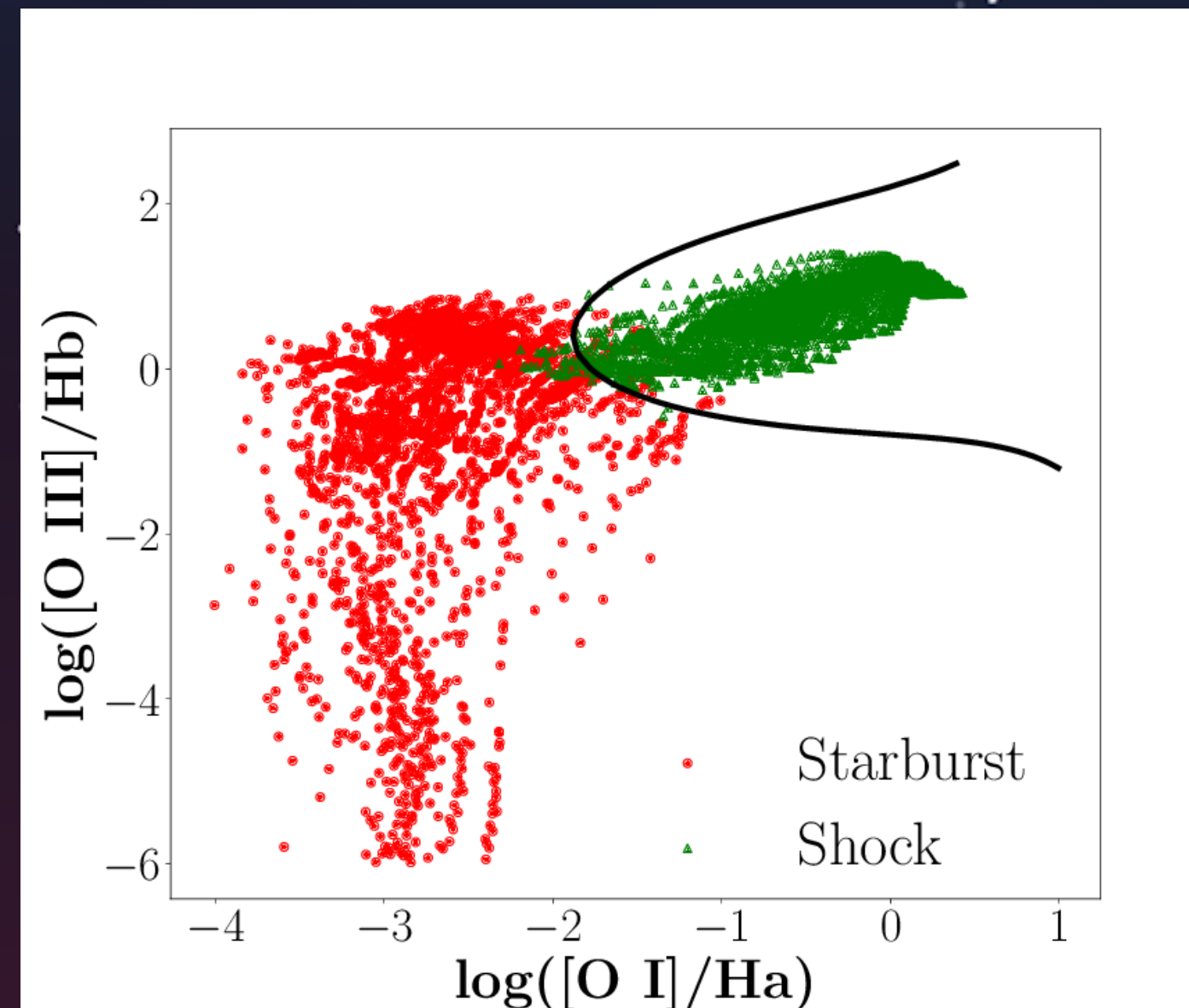
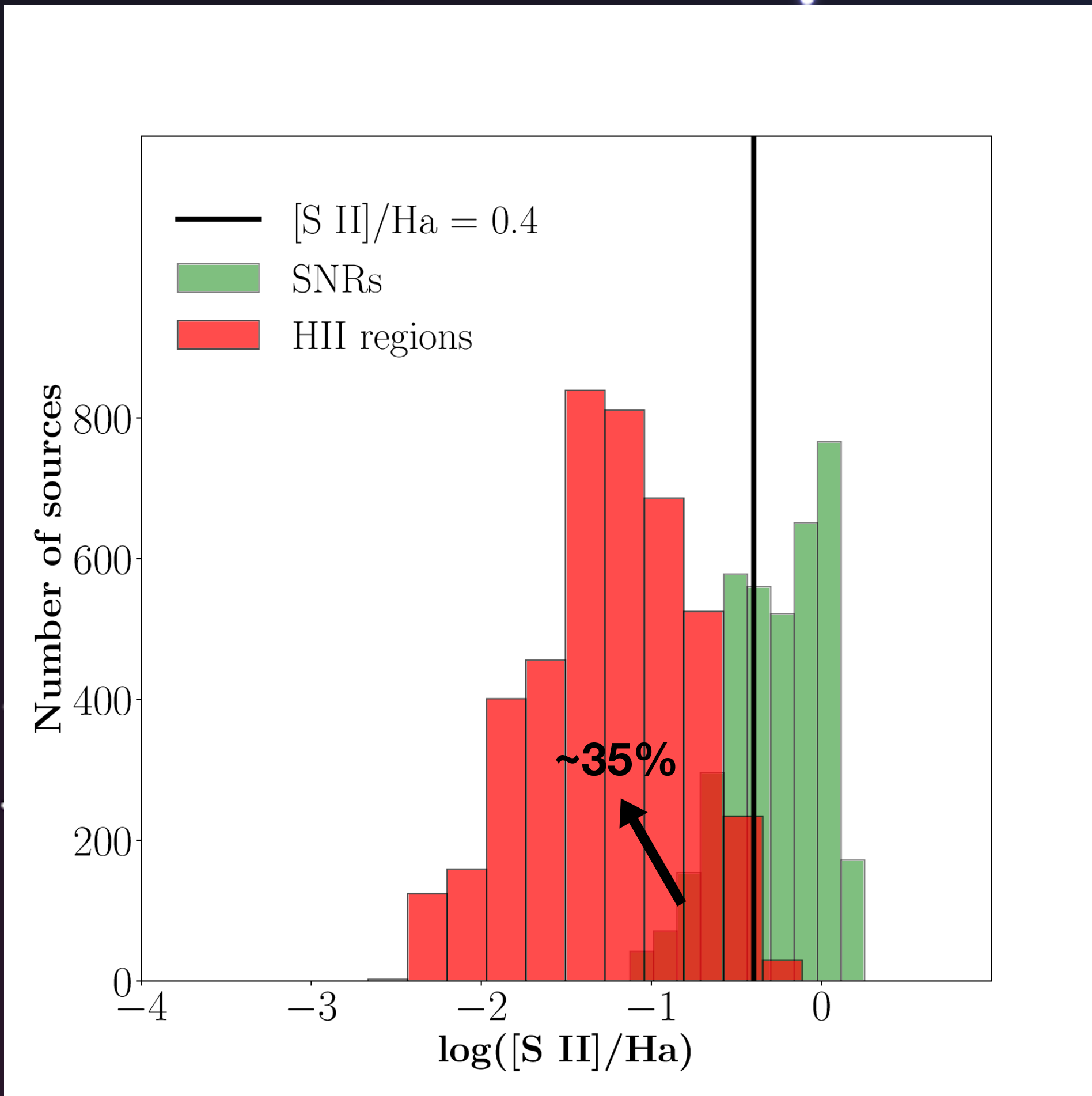
Multi-line diagnostics for the optical identification of SNRs

Shock and photoionization models from MAPPINGS III

New diagnostics: 2D and 3D

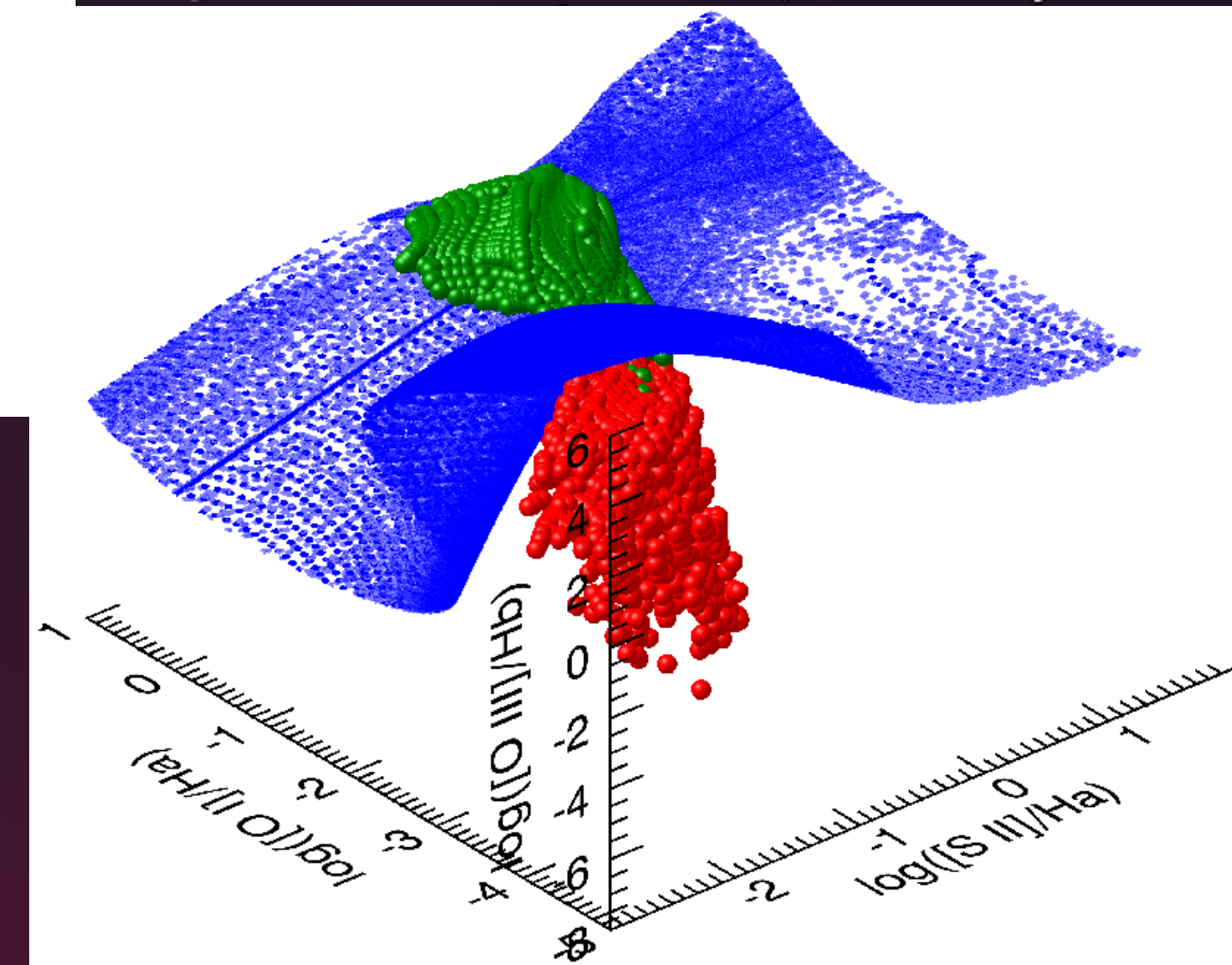
Shock → SNRs, Photoionization → HII regions

$\frac{[\text{N II}]}{\text{H}\alpha}$, $\frac{[\text{S II}]}{\text{H}\alpha}$, $\frac{[\text{O I}]}{\text{H}\alpha}$, $\frac{[\text{O II}]}{\text{H}\beta}$, $\frac{[\text{O III}]}{\text{H}\beta}$ + Support Vector Machine



Completeness > 98%
Contamination < 2%

Completeness > 90%
Contamination < 6%



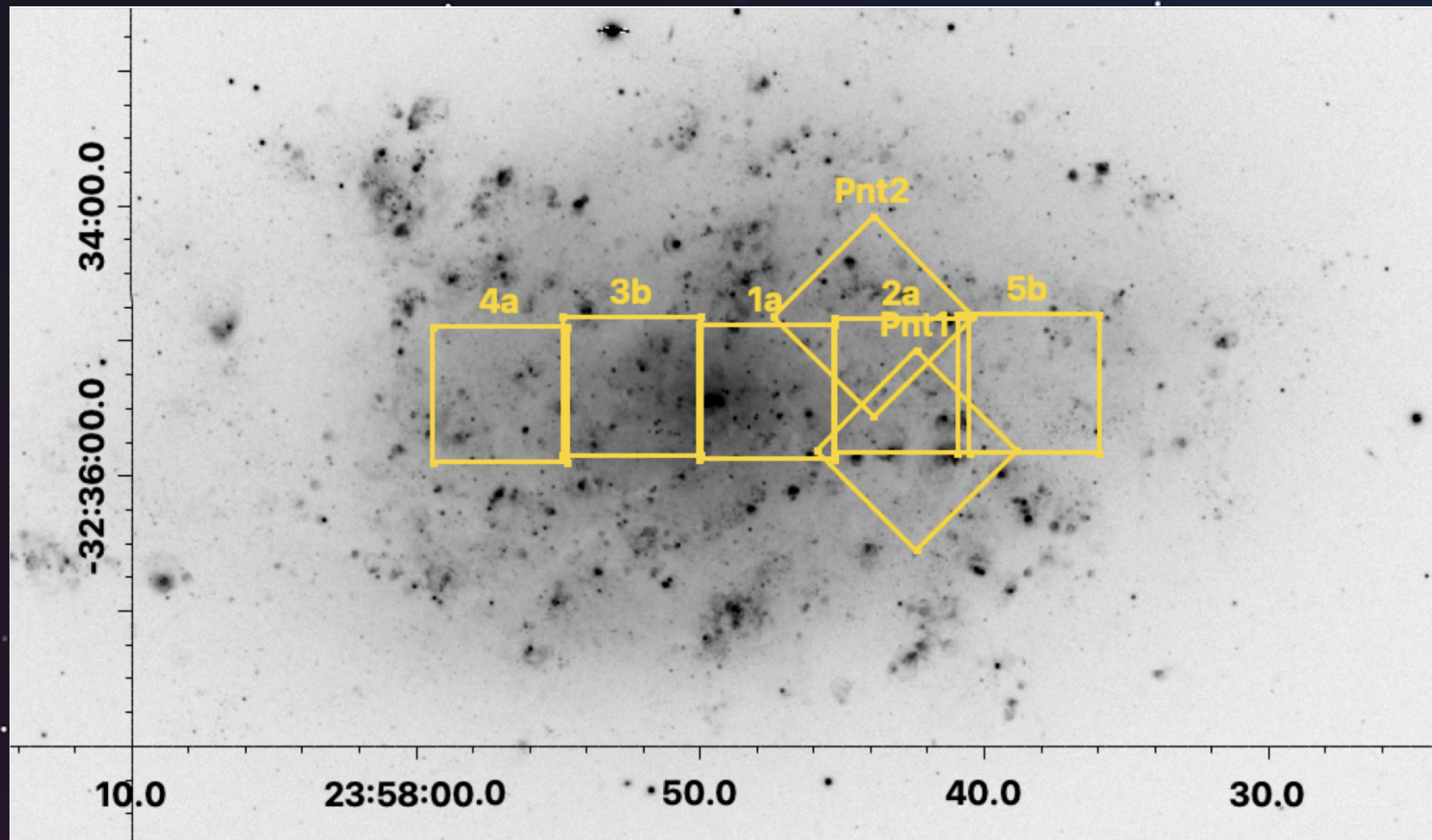
More studies on the optical identification of SNRs

- Velocity broadening (Points et al. 2019)

- $\xi = \sigma \frac{[\text{S II}]}{\text{H}\alpha}$ (Sébastien Vicens-Mouret et al. 2023)

- Combination of emission line ratios: Sabbadin plots and BPT diagrams, traditional diagnostic (Moumen et al. 2019, Congiu et al. 2023) with velocity dispersion (Jing Li et al. 2024)

MUSE data - SNRs in NGC 7793



H α + [N II] image obtained by 4m Blanco telescope at CTIO

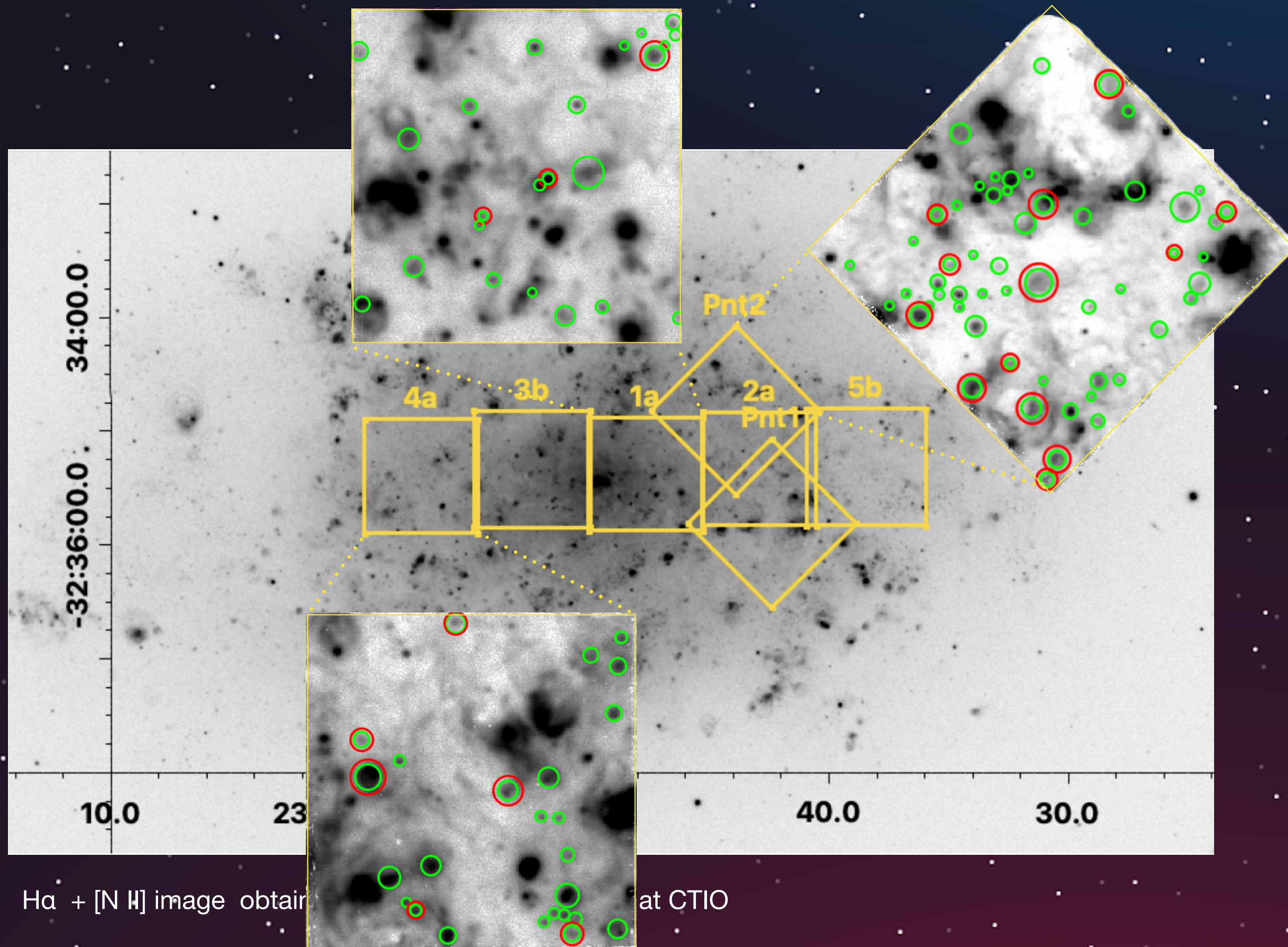
$$1. \frac{[\text{S II}]}{\text{H}\alpha} - \frac{[\text{N II}]}{\text{H}\alpha} \quad 3. \frac{[\text{N II}]}{\text{H}\alpha} - \frac{[\text{O III}]}{\text{H}\beta}$$

$$2. \frac{[\text{S II}]}{\text{H}\alpha} - \frac{[\text{O III}]}{\text{H}\beta} \quad 4. \frac{[\text{S II}]}{\text{H}\alpha} > 0.4$$

$$5. \frac{[\text{N II}]}{\text{H}\alpha} - \frac{[\text{S II}]}{\text{H}\alpha} - \frac{[\text{O III}]}{\text{H}\beta}$$

~~[O I], [O II]~~

Recent study - SNRs in NGC 7793



$$\frac{[\text{S II}]}{\text{H}\alpha} > 0.4$$

Multi-line diagnostics

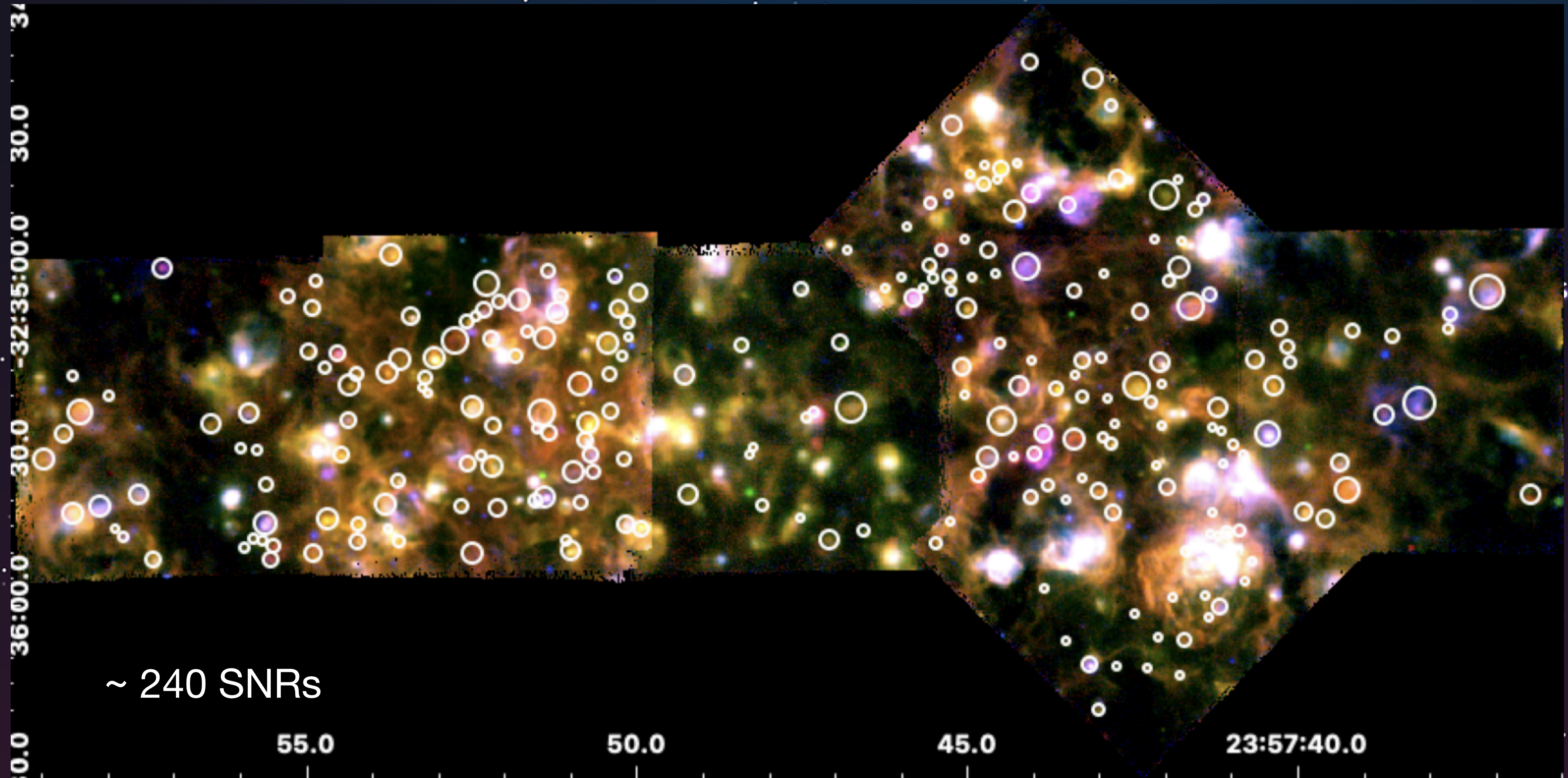
Increase the number of SNRs by a factor of 2

Final sample:

Combination of all the diagnostics

Emission lines and emission line ratios $> 3\sigma$.

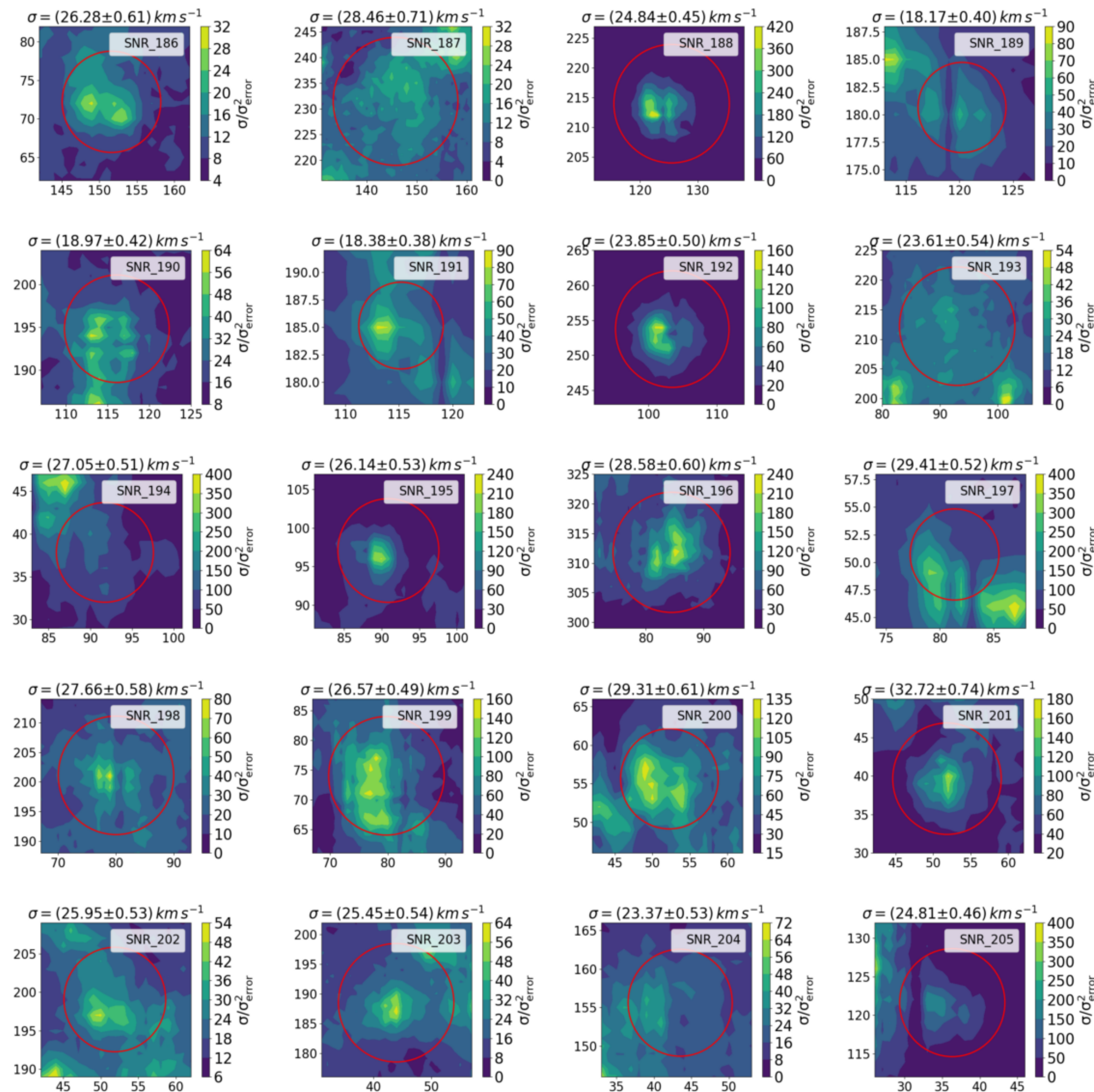
Supernova Remnants in NGC 7793



[S II] $\lambda\lambda 6717, 6731$
H α $\lambda 6563$
[O III] $\lambda 5007$

Kopsacheili et al. 2024

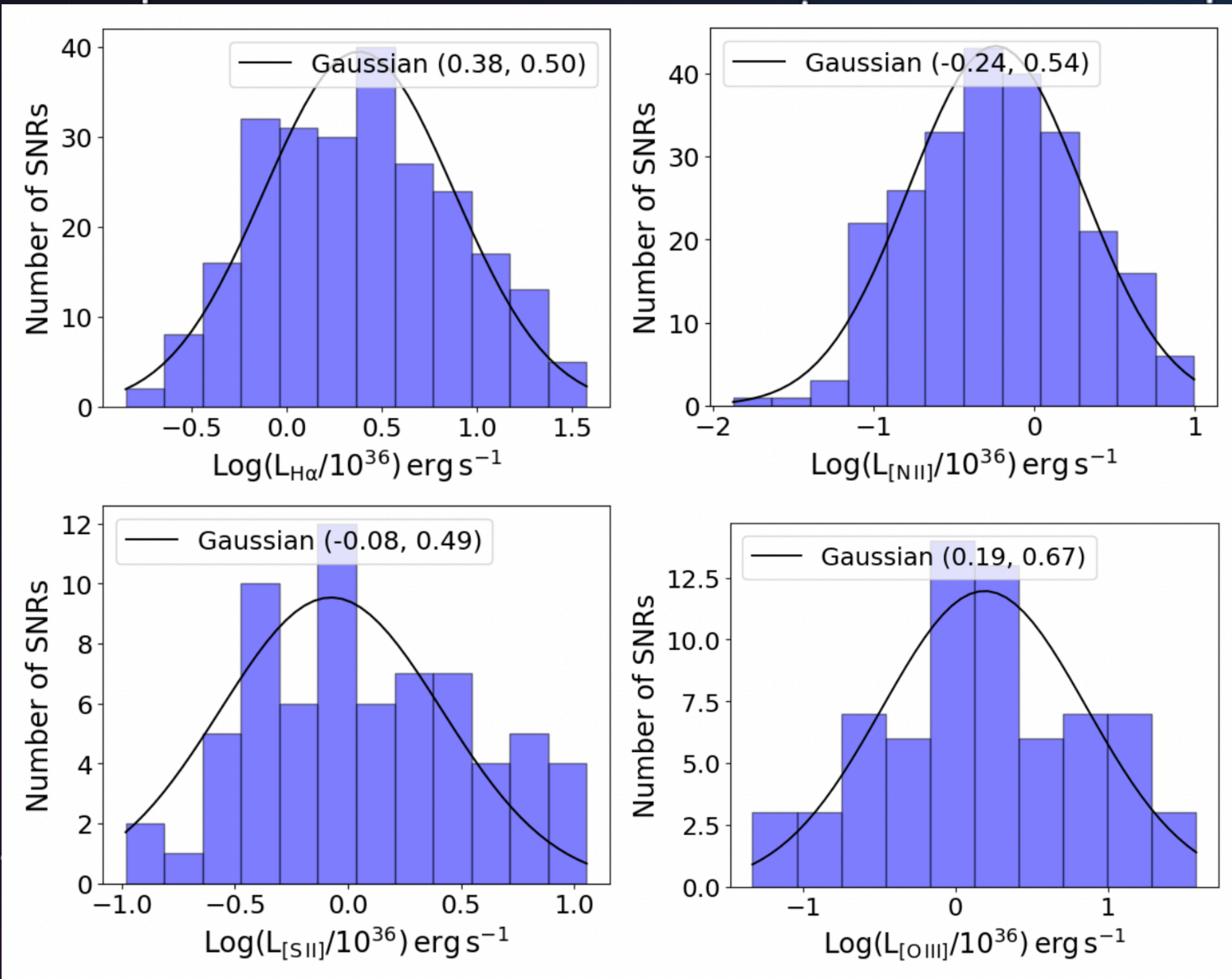
Velocity Dispersion



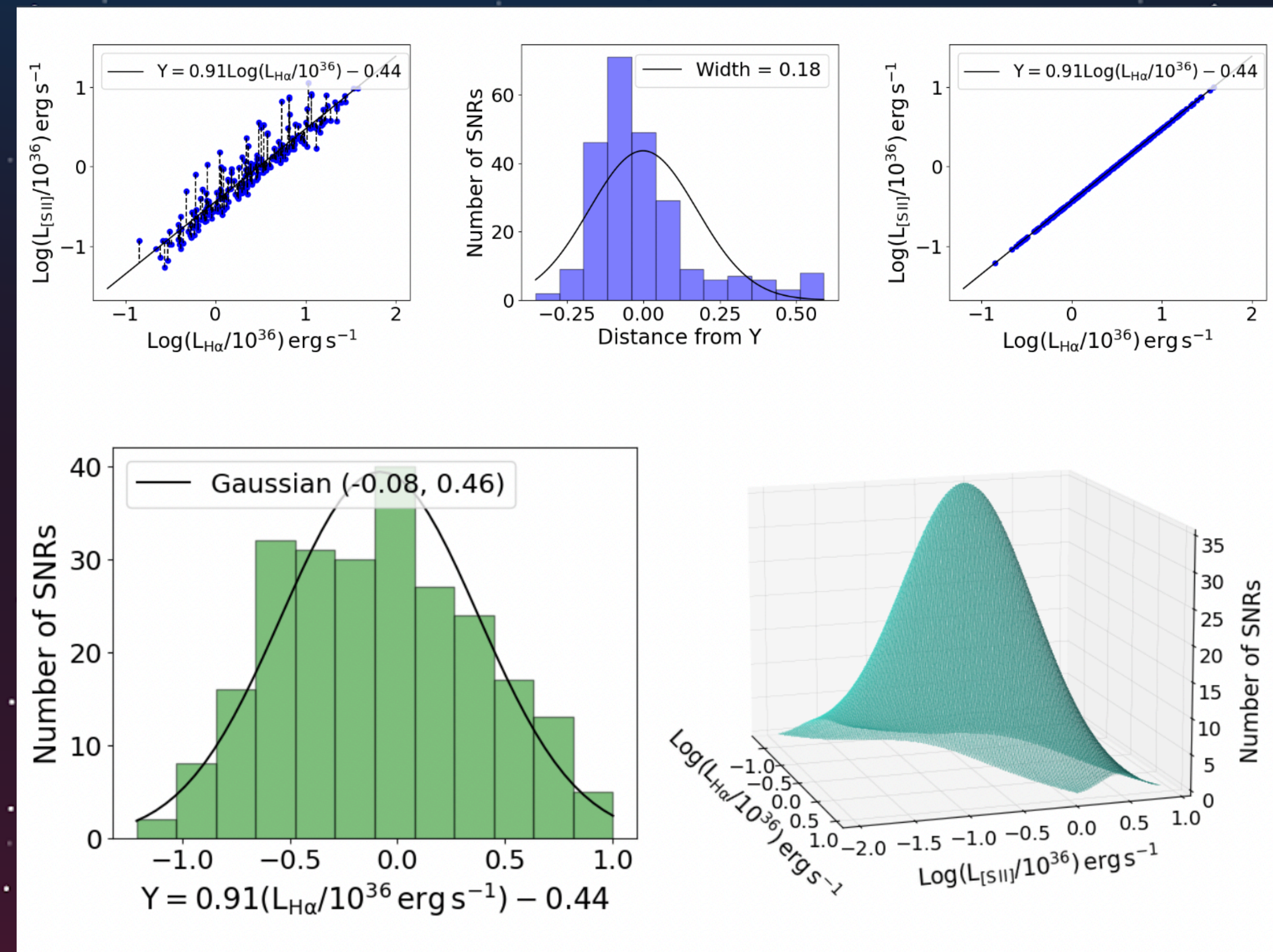
15 - 70 km s^{-1}
(mean: 27 km s^{-1})

- ★ 9 candidates out of the range suggested by Points et al. 2019 (19 - 110 km s^{-1})
- ★ Velocities between 18-19 km s^{-1}
- ★ Mean values $>$ not excluded

Luminosity Functions of SNRs

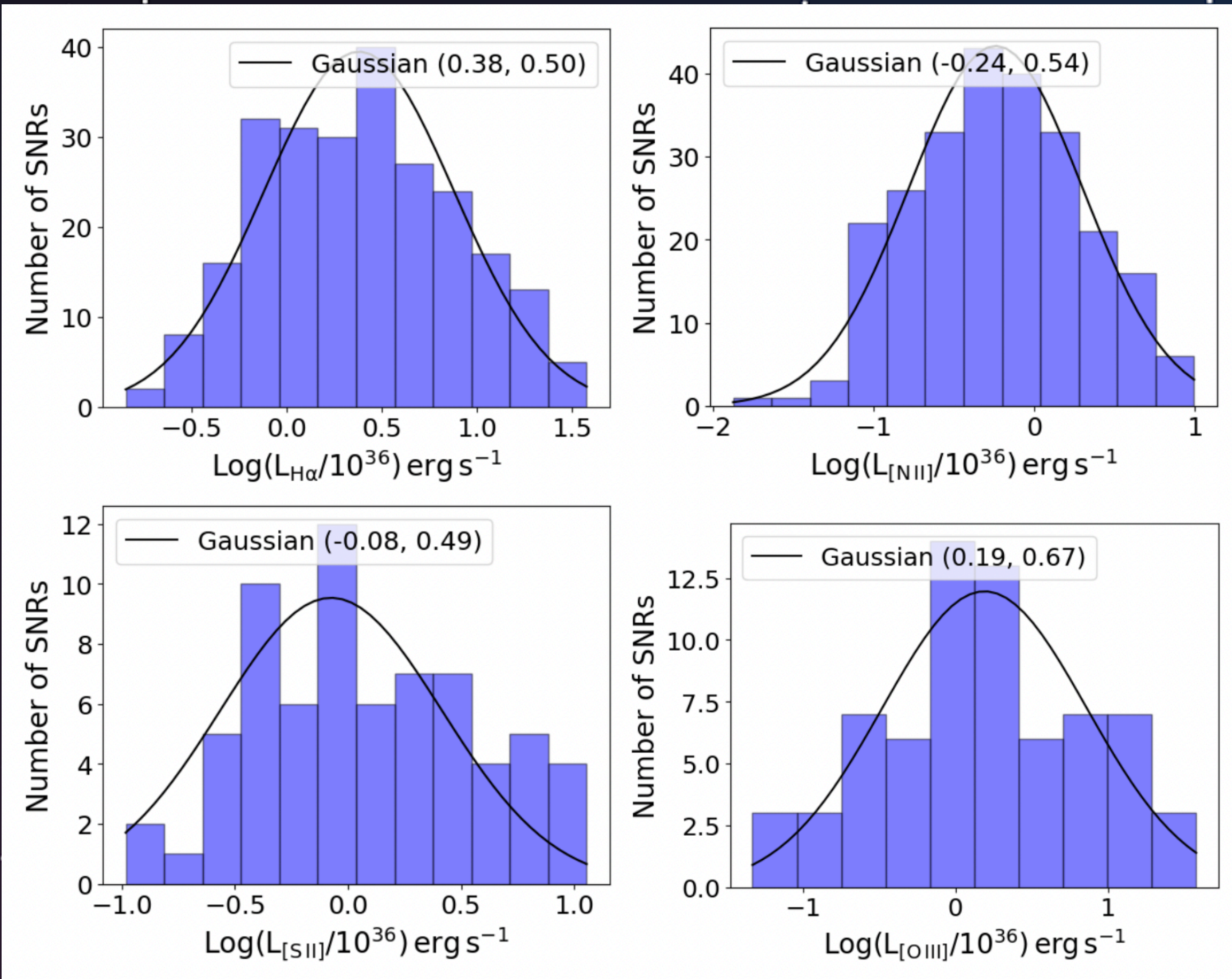


1D Luminosity Functions

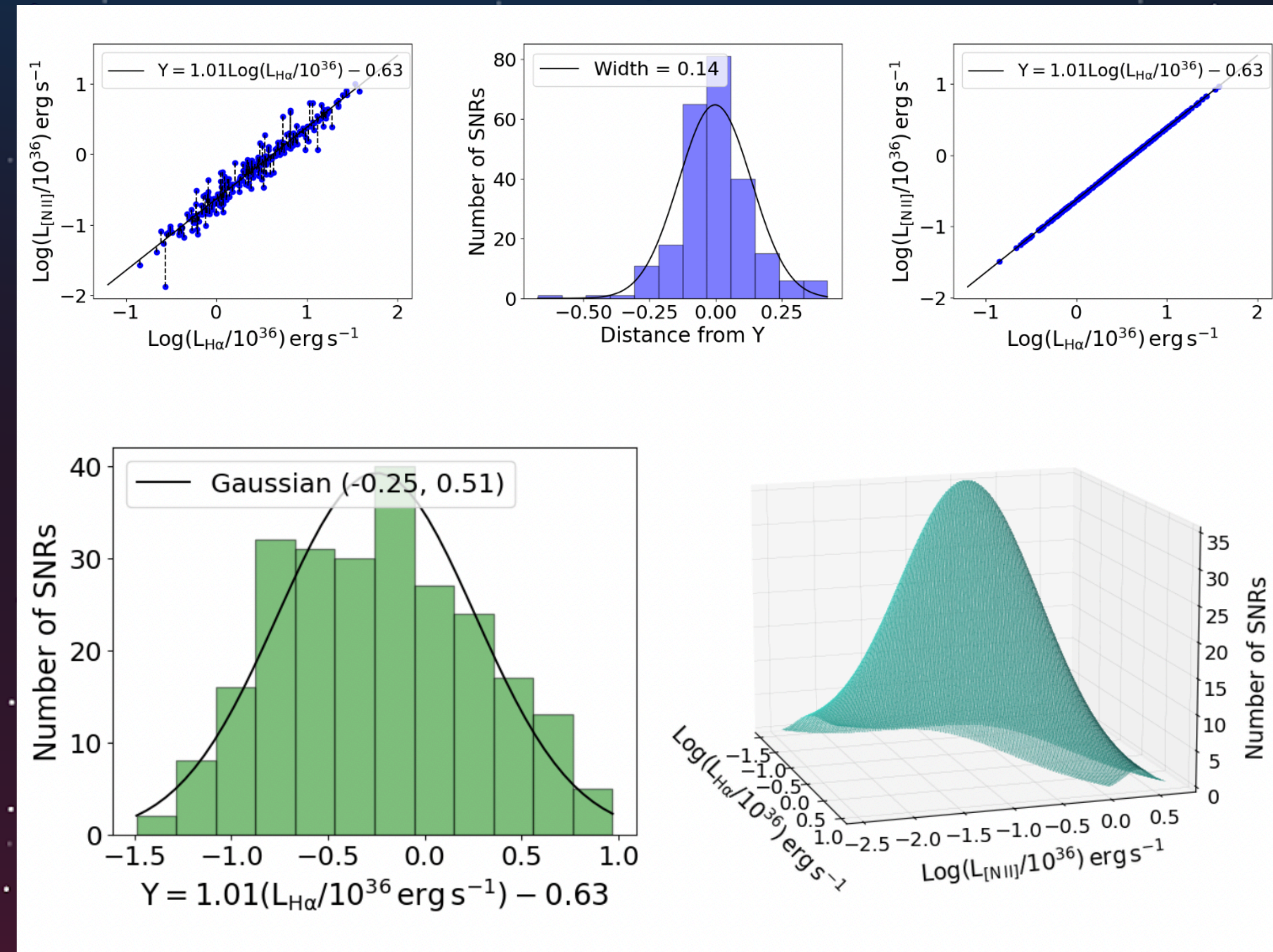


2D [S II]-Ha Luminosity Function

Luminosity Functions of SNRs

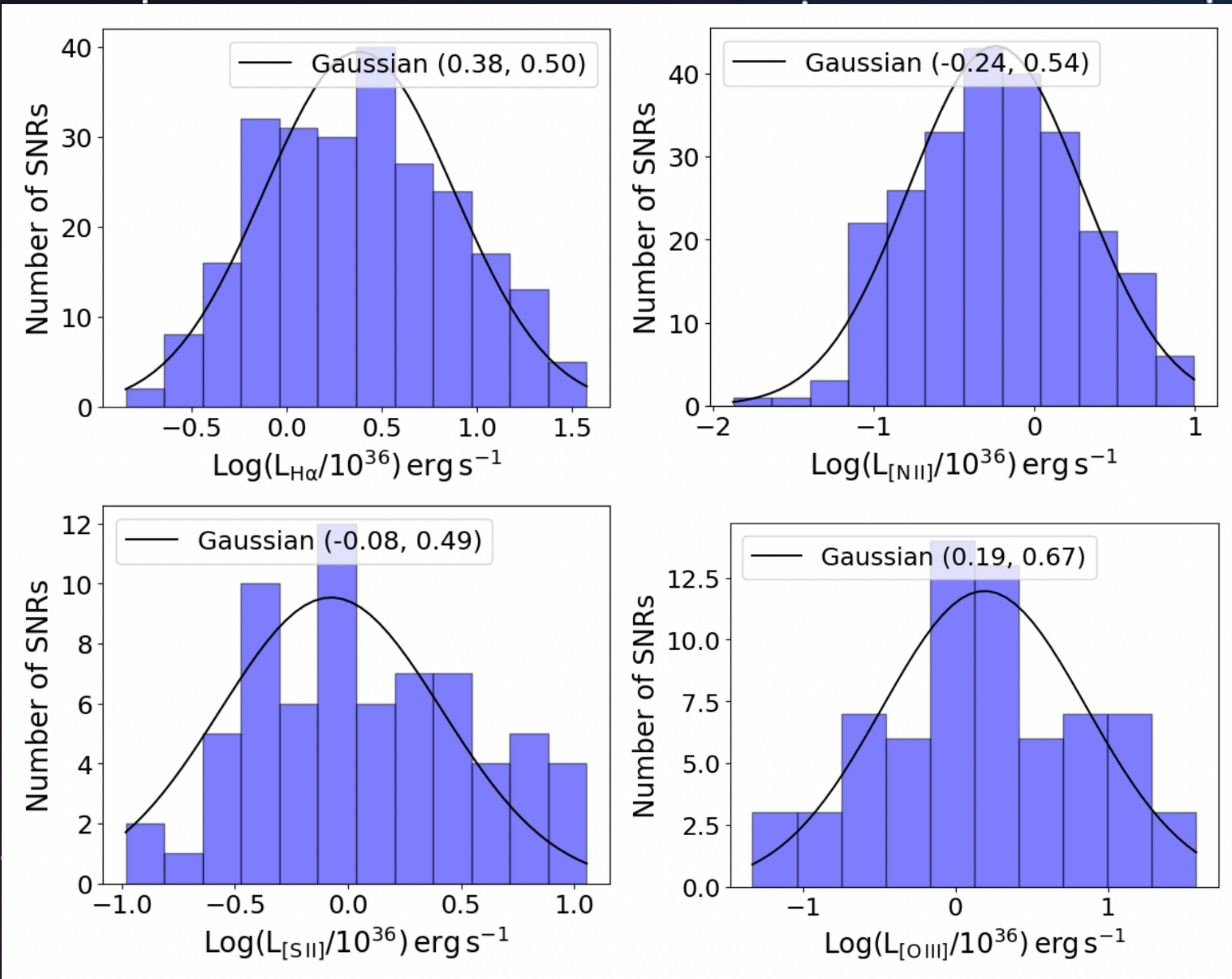


1D Luminosity Functions

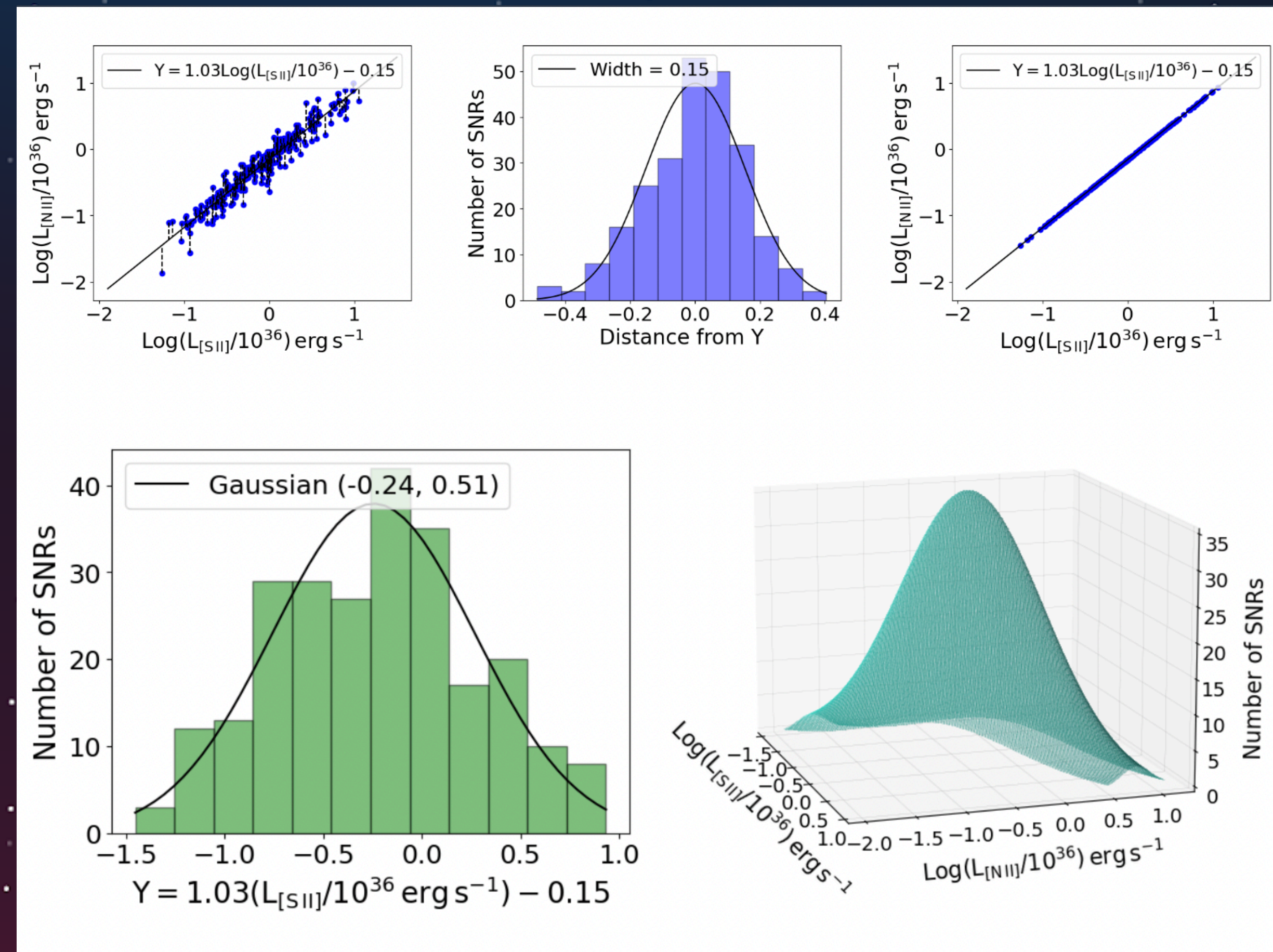


2D [N II]-Ha Luminosity Function

Luminosity Functions of SNRs

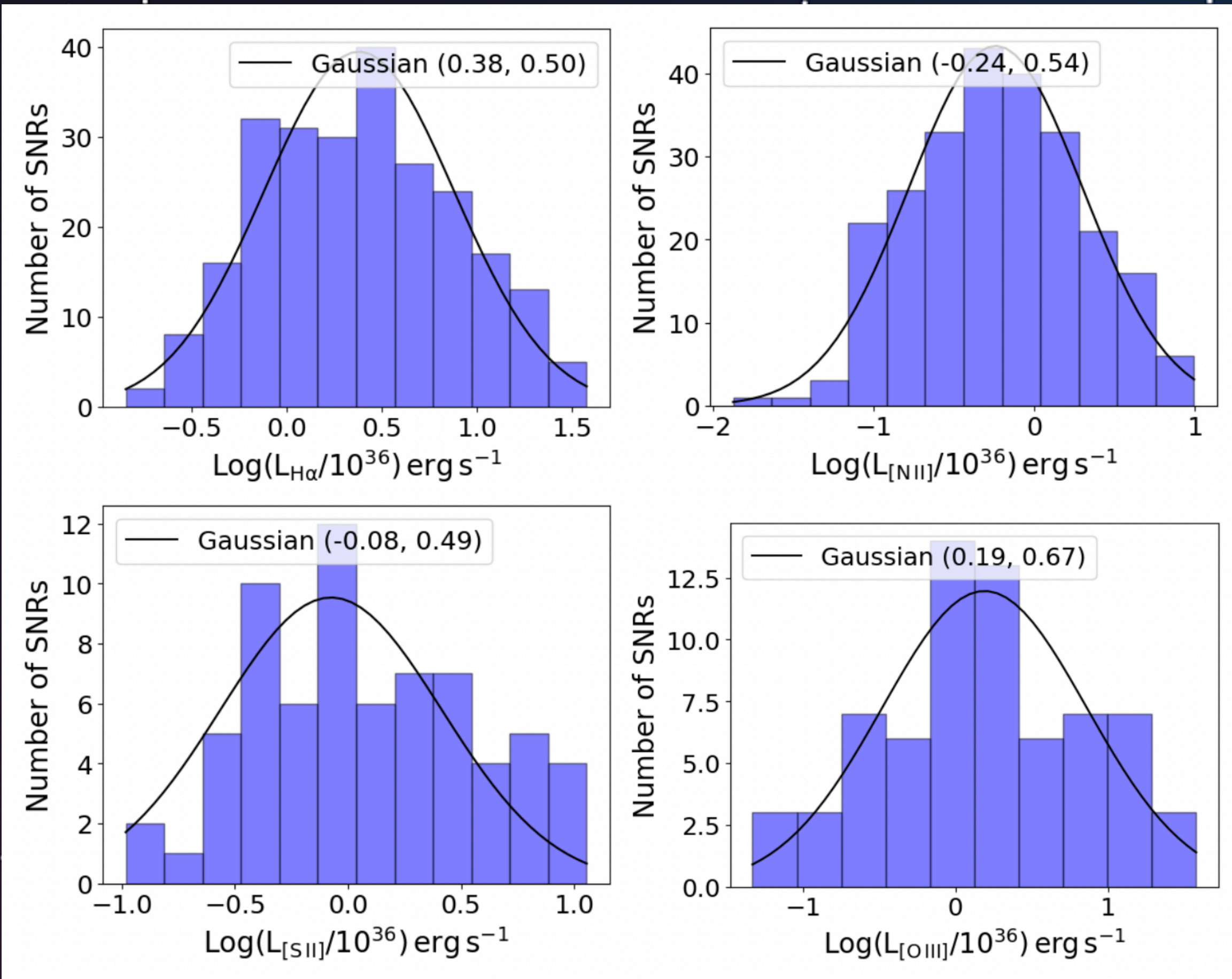


1D Luminosity Functions

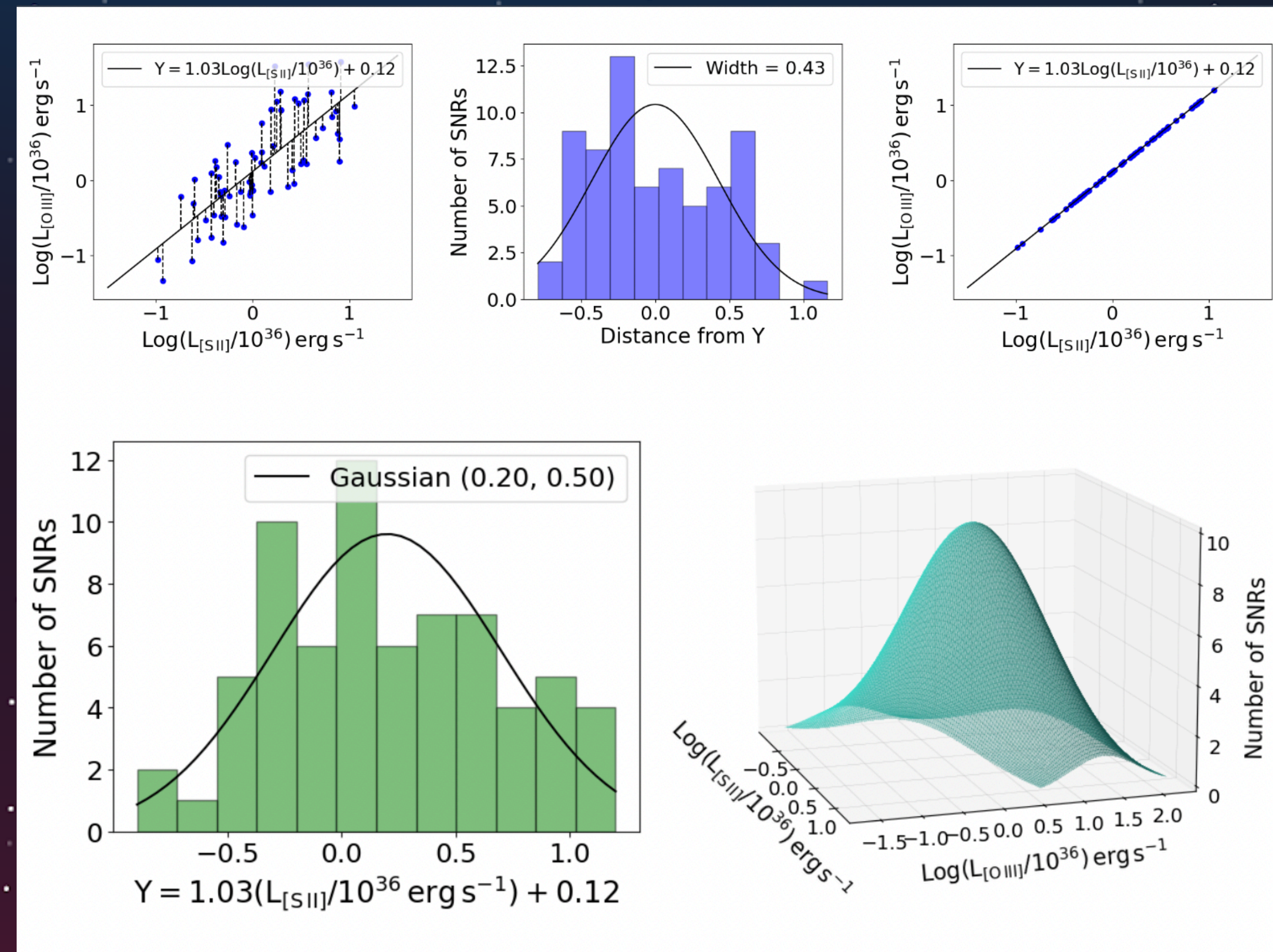


2D [N II]-[S II] Luminosity Function

Luminosity Functions of SNRs

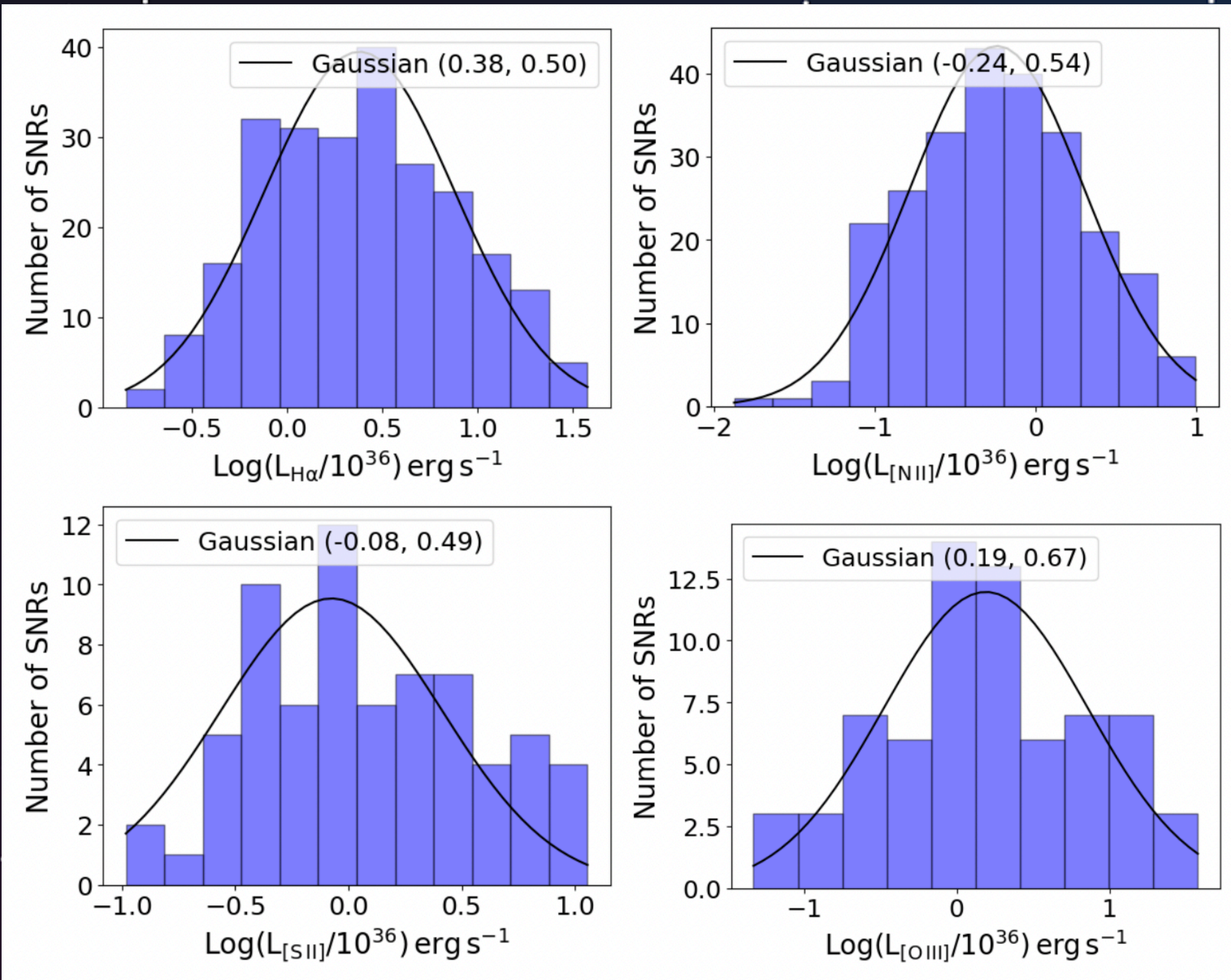


1D Luminosity Functions

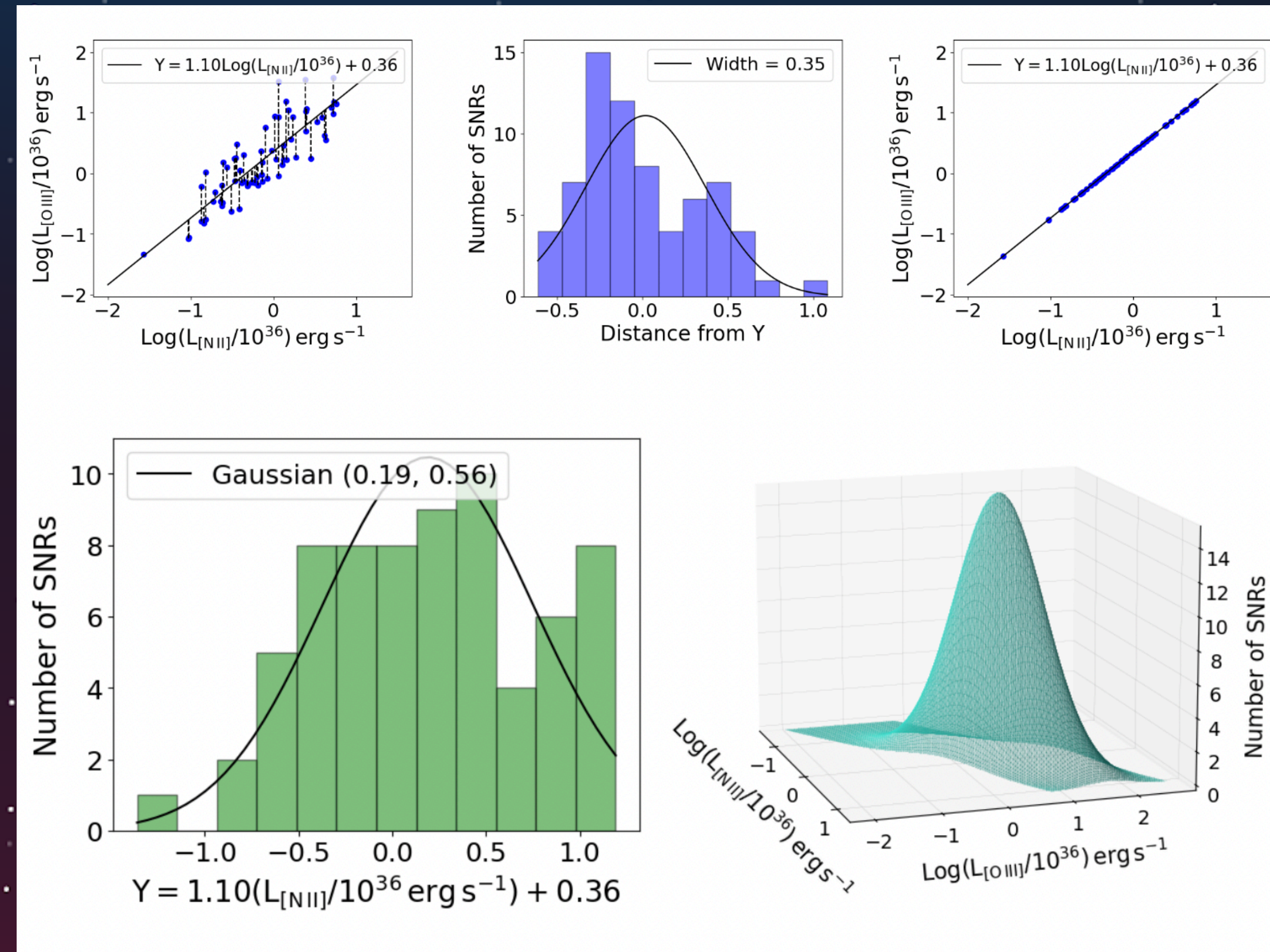


2D [O III]-[S II] Luminosity Function

Luminosity Functions of SNRs

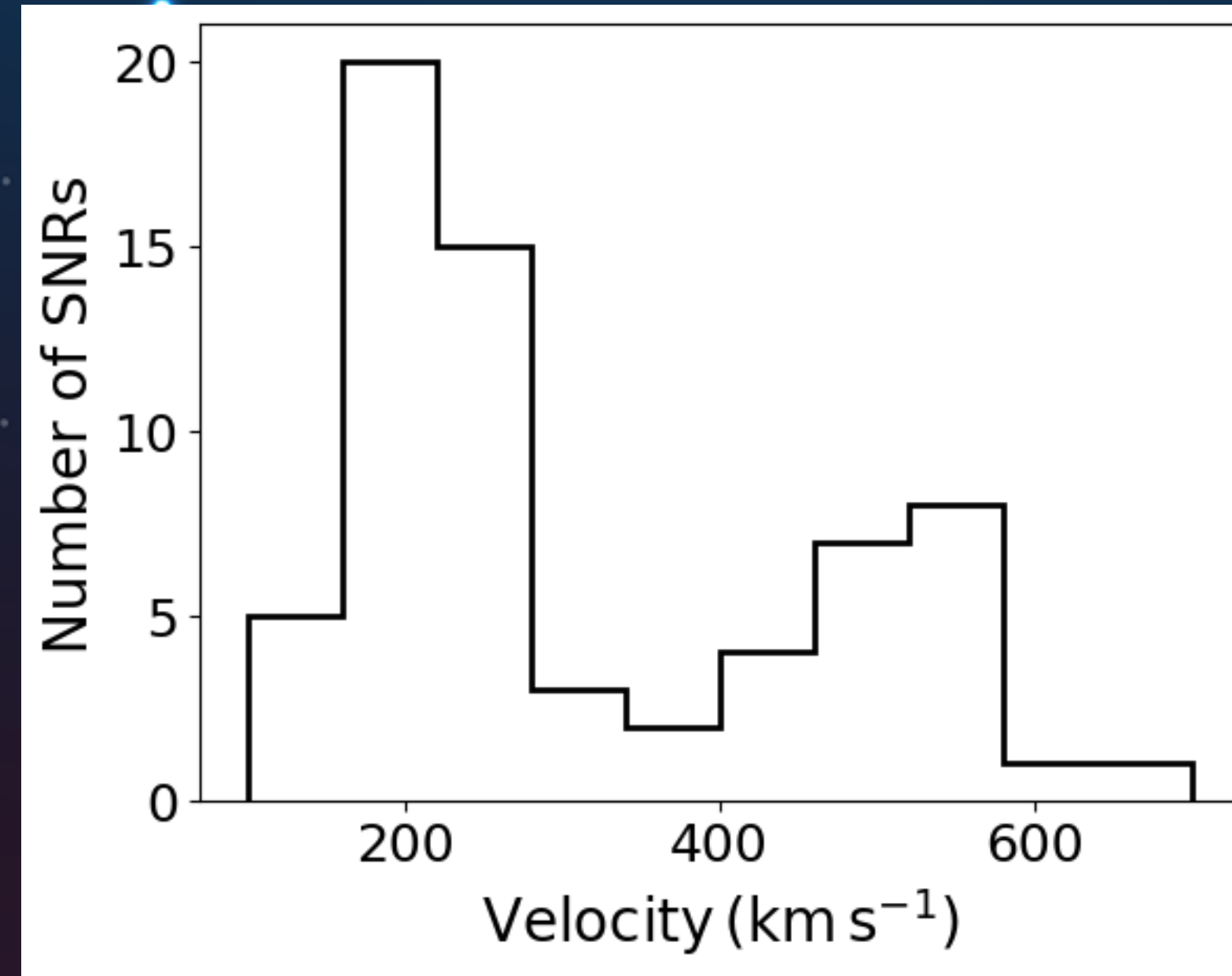
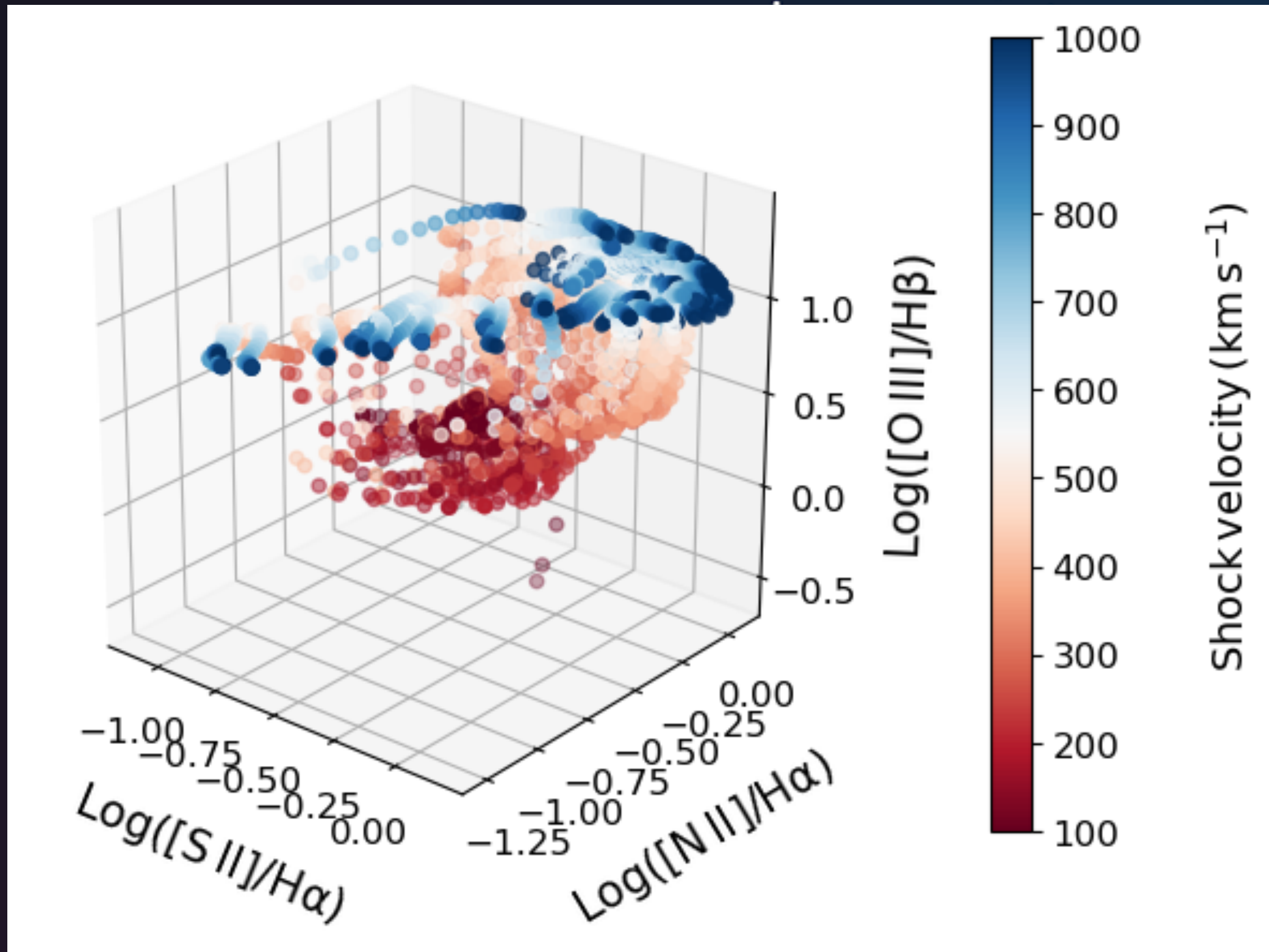


1D Luminosity Functions



2D [O III]-[N II] Luminosity Function

Shock Velocities



Shock Velocity distribution of SNRs
 (~ 34% of the sample)

Constructed using shock models from
 MAPPINGS III (Allen et al., 2008)

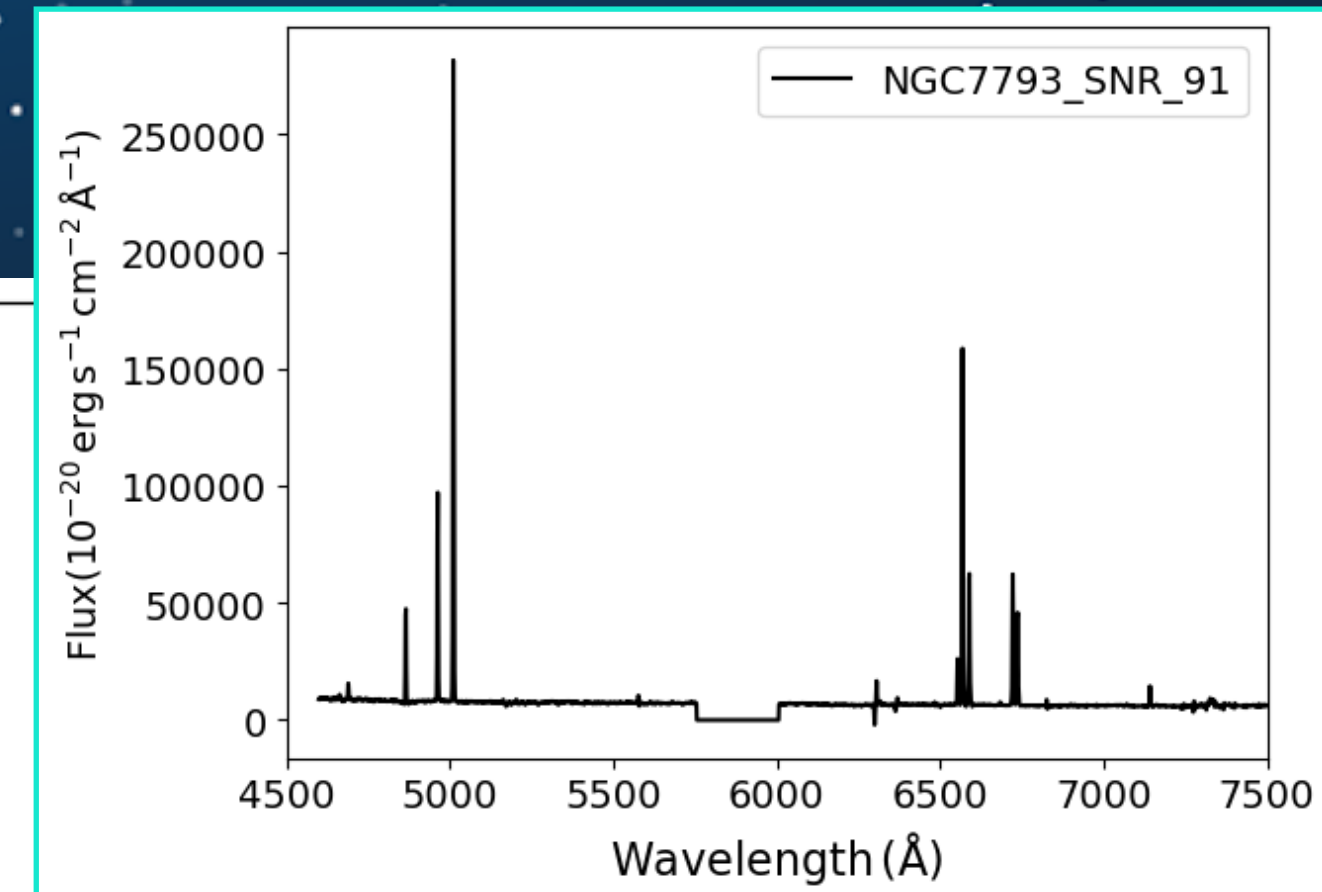
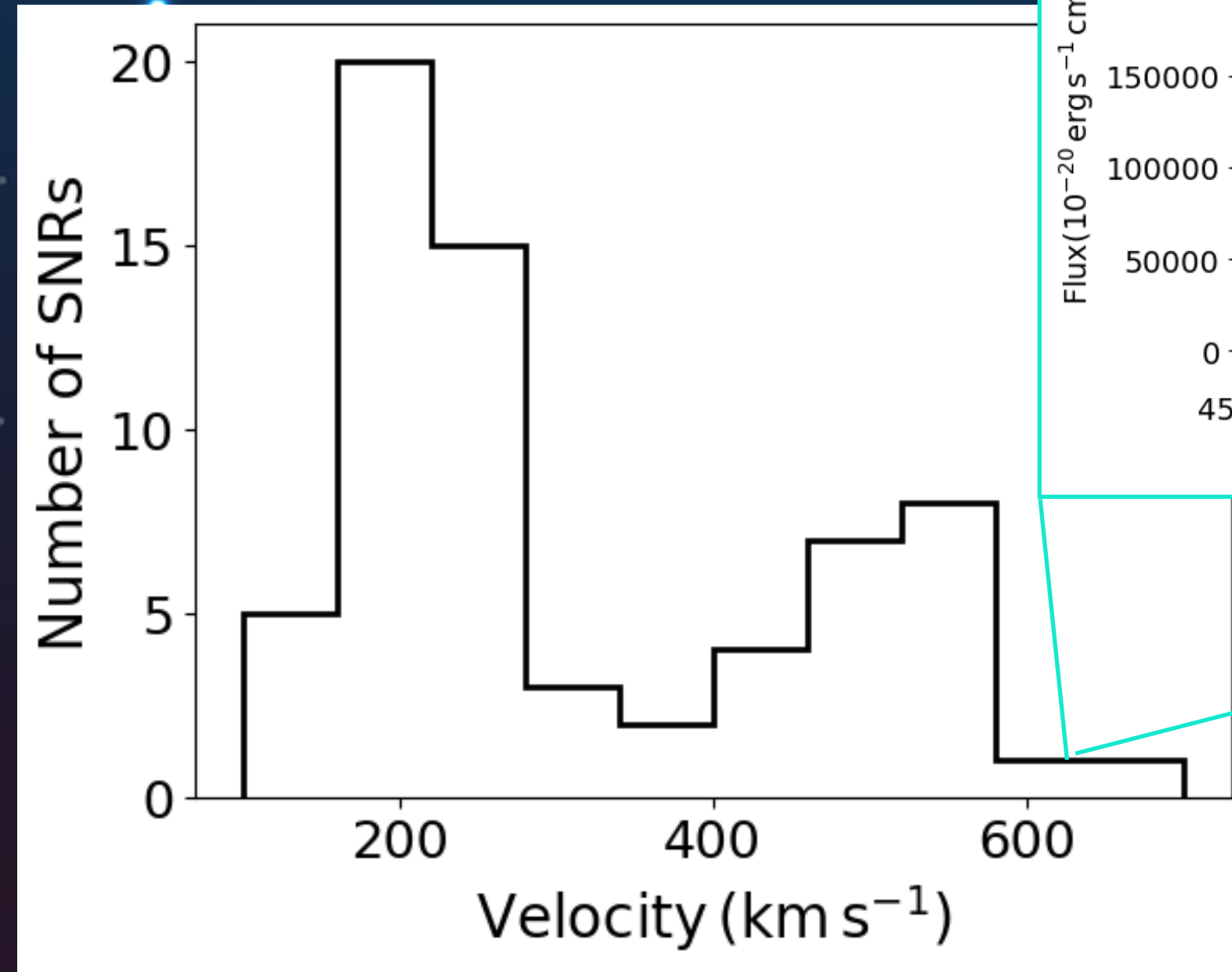
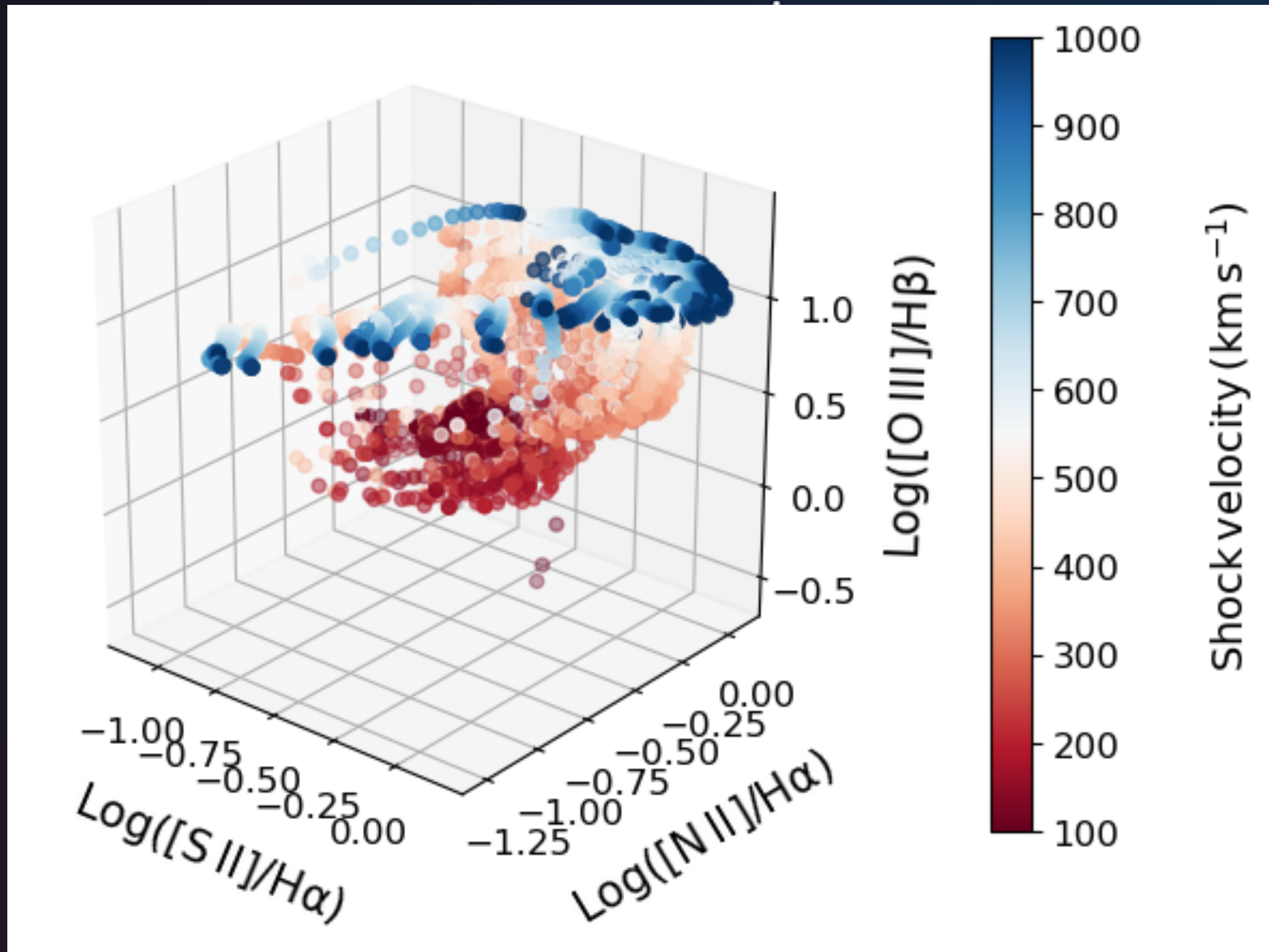
★ ~ 70% < 300 km/s

Observed emission line ratios:
 Interpolation in Shock models

$$\frac{[\text{S II}]}{\text{H}\alpha}, \frac{[\text{N II}]}{\text{H}\alpha}, \frac{[\text{O III}]}{\text{H}\beta}$$

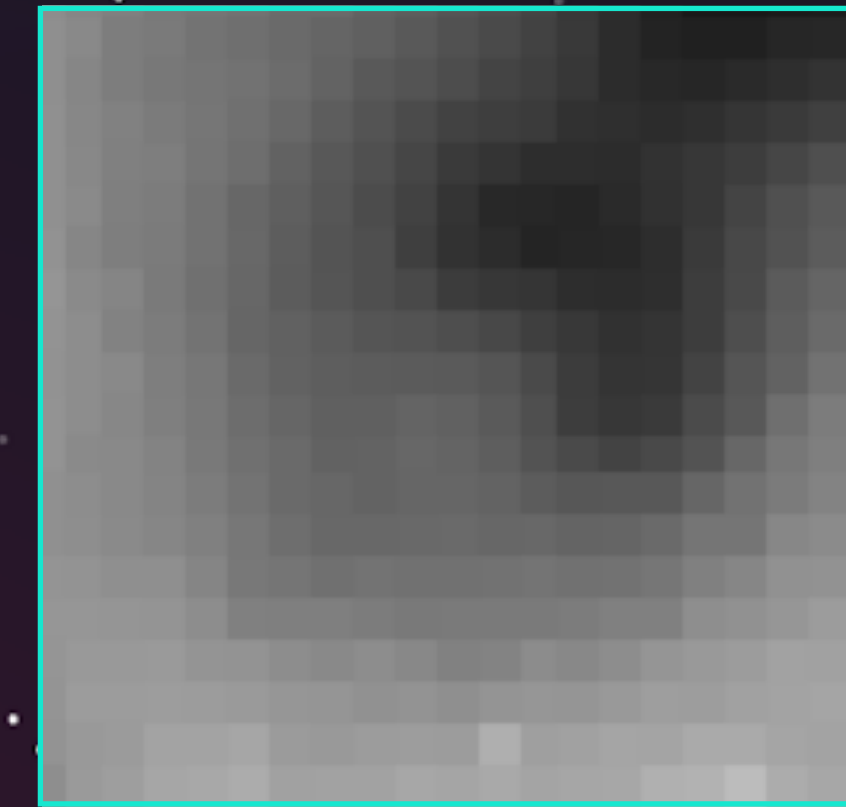
Shock Velocities

Shock Velocities



Shock Velocity distribution of SNRs
(~ 34% of the sample)

★ ~ 70% < 300 km/s



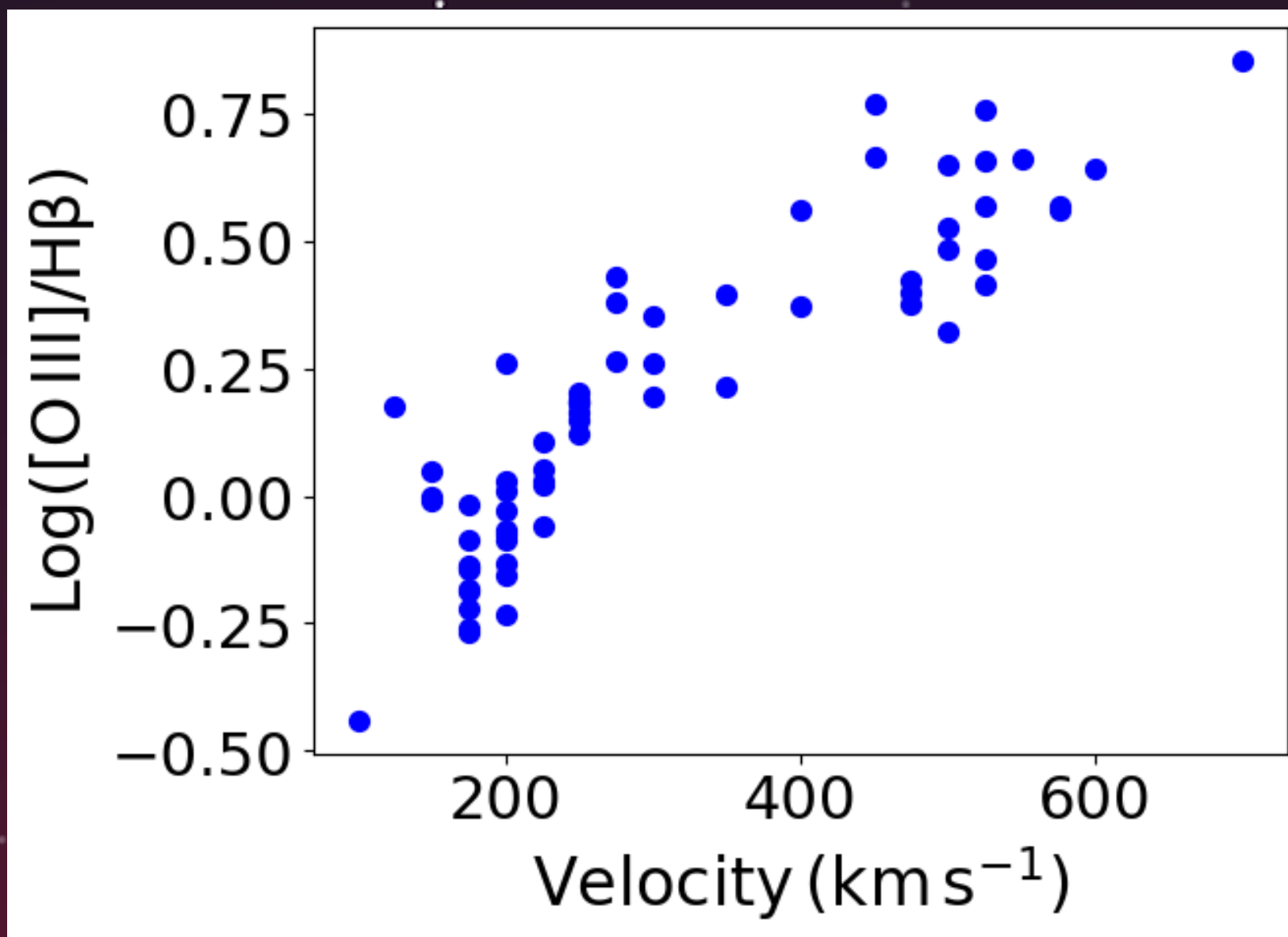
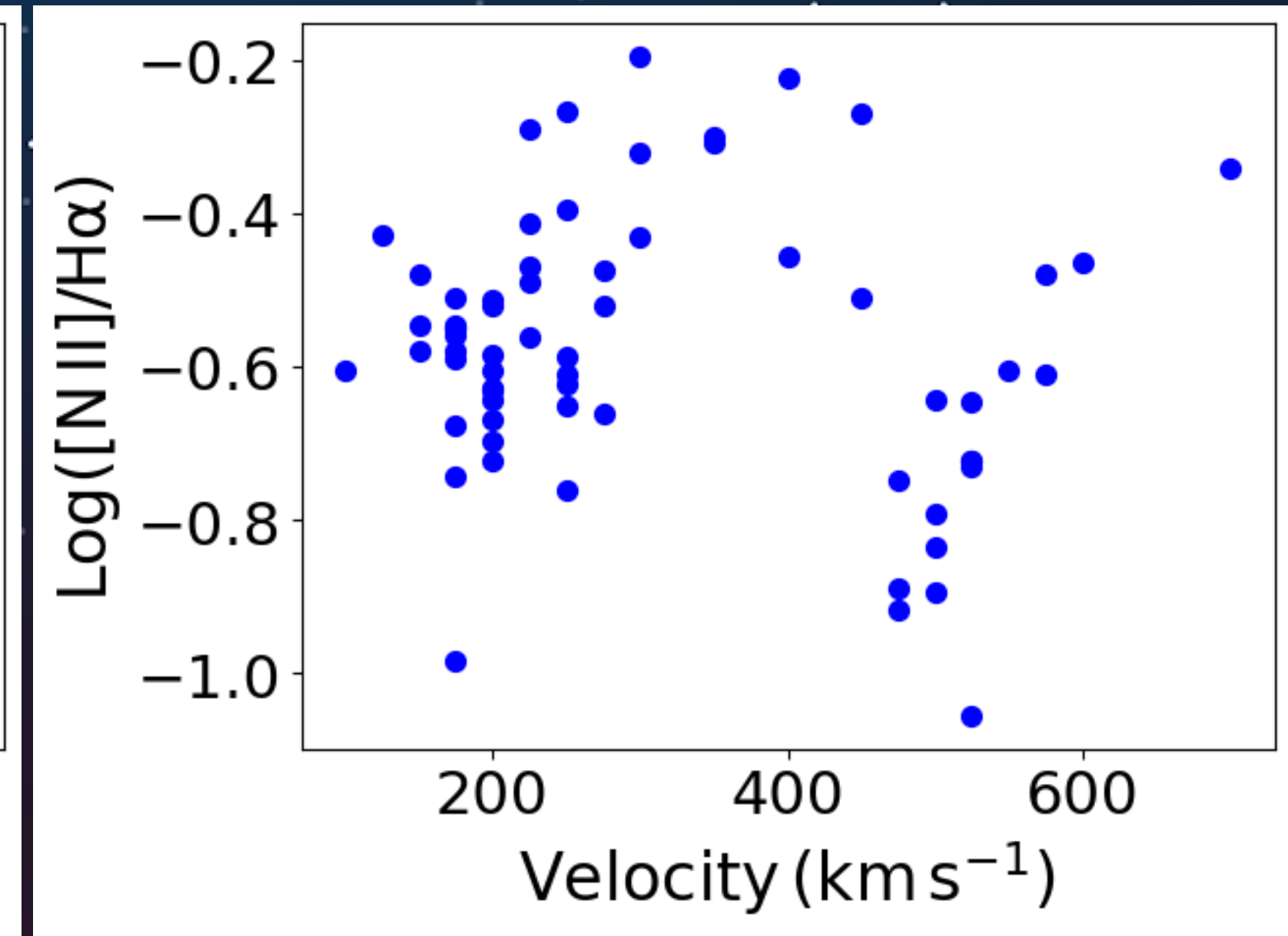
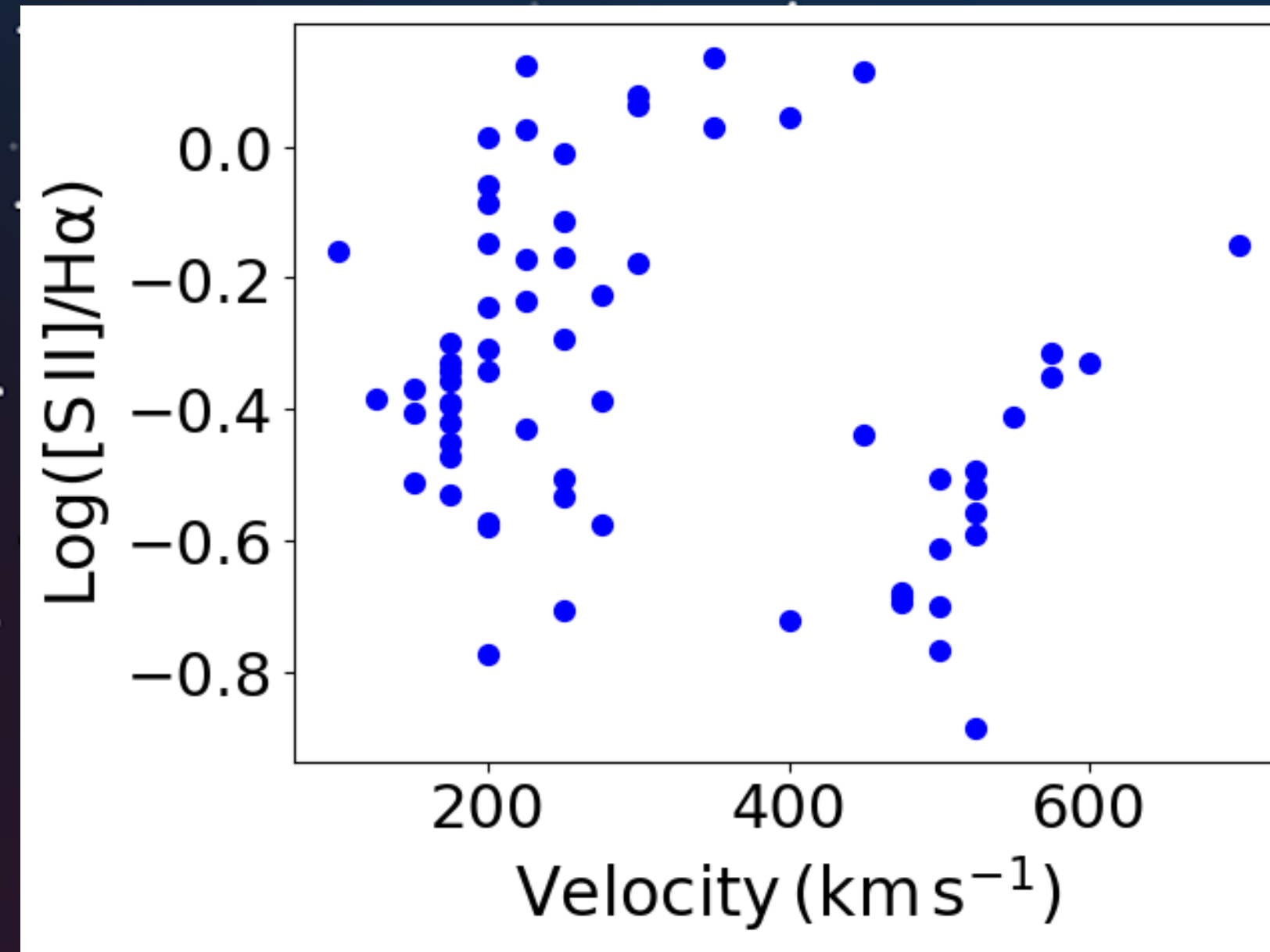
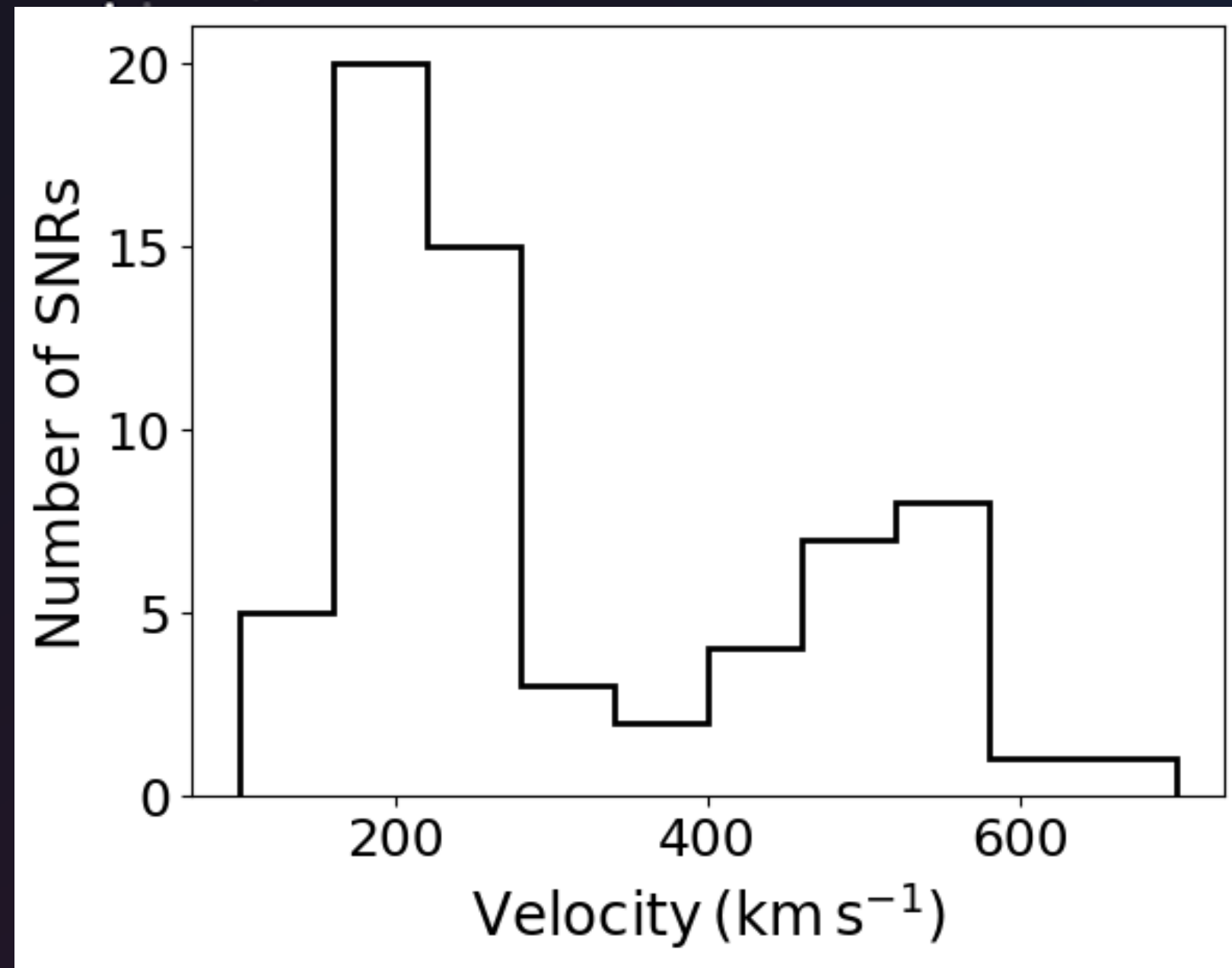
Constructed using shock models from
MAPPINGS III (Allen et al., 2008)

Observed emission line ratios:
Interpolation in Shock models

$$\frac{[\text{S II}]}{\text{H}\alpha}, \frac{[\text{N II}]}{\text{H}\alpha}, \frac{[\text{O III}]}{\text{H}\beta}$$

Shock Velocities

Shock Velocities

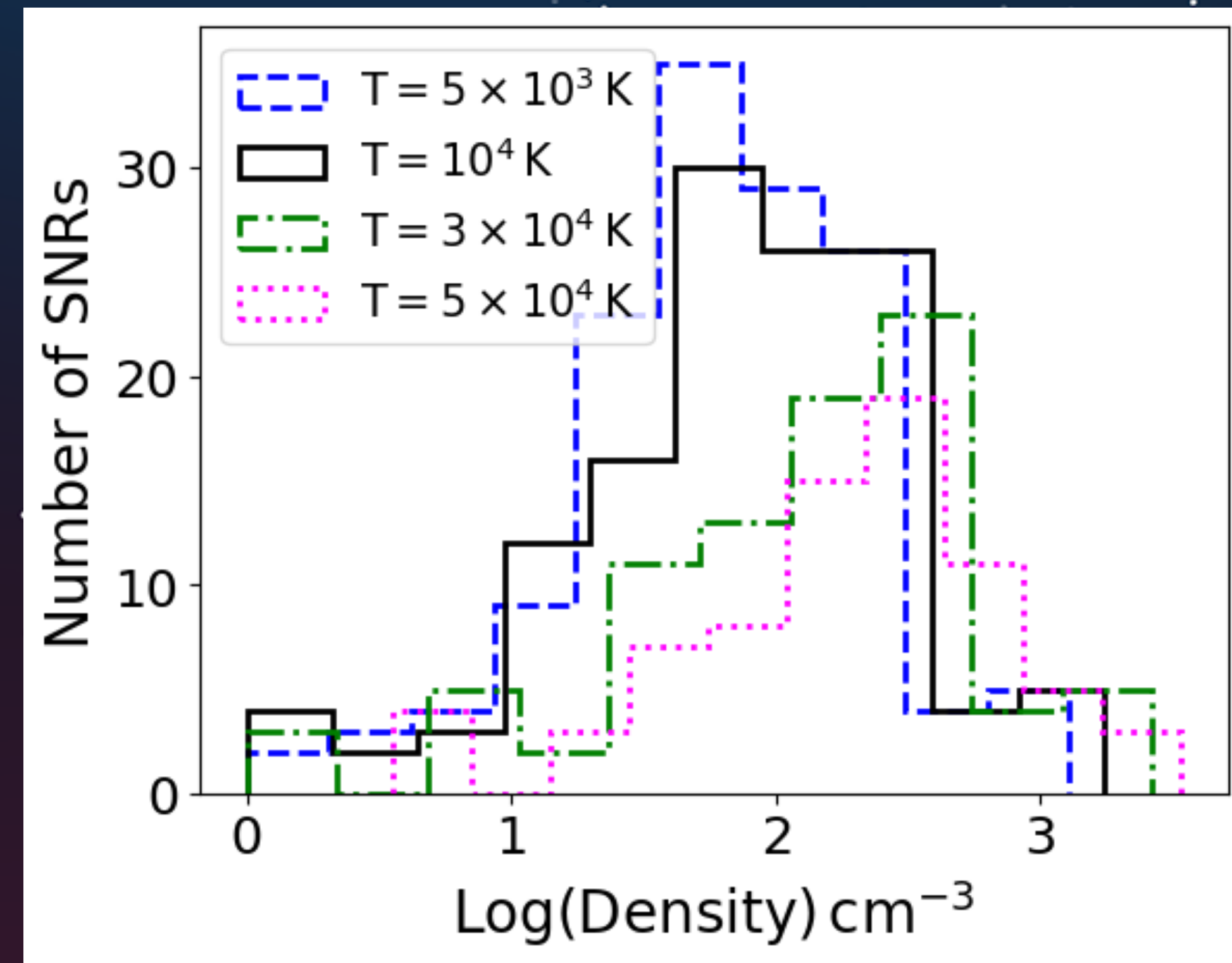
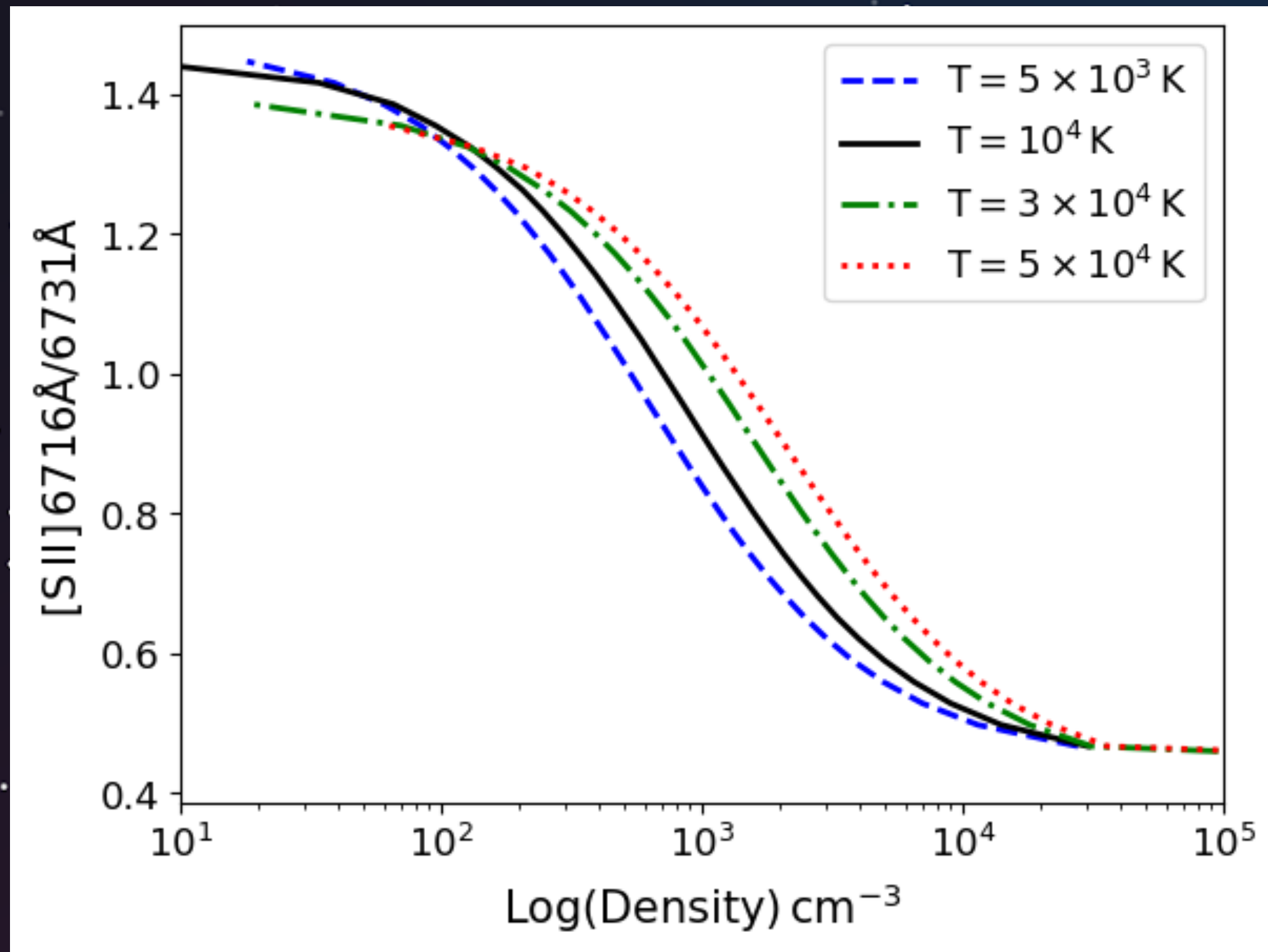


Shock Velocity distribution of SNRs

~ 70% < 300 km/s

[O III] is affected more directly by temperature...

Pre-shock Densities



[S II] 6716/6731 → Density

PYNEB

Input:

observed [S II] 6716/6731 + Temperature

Output:

Density

Median values:

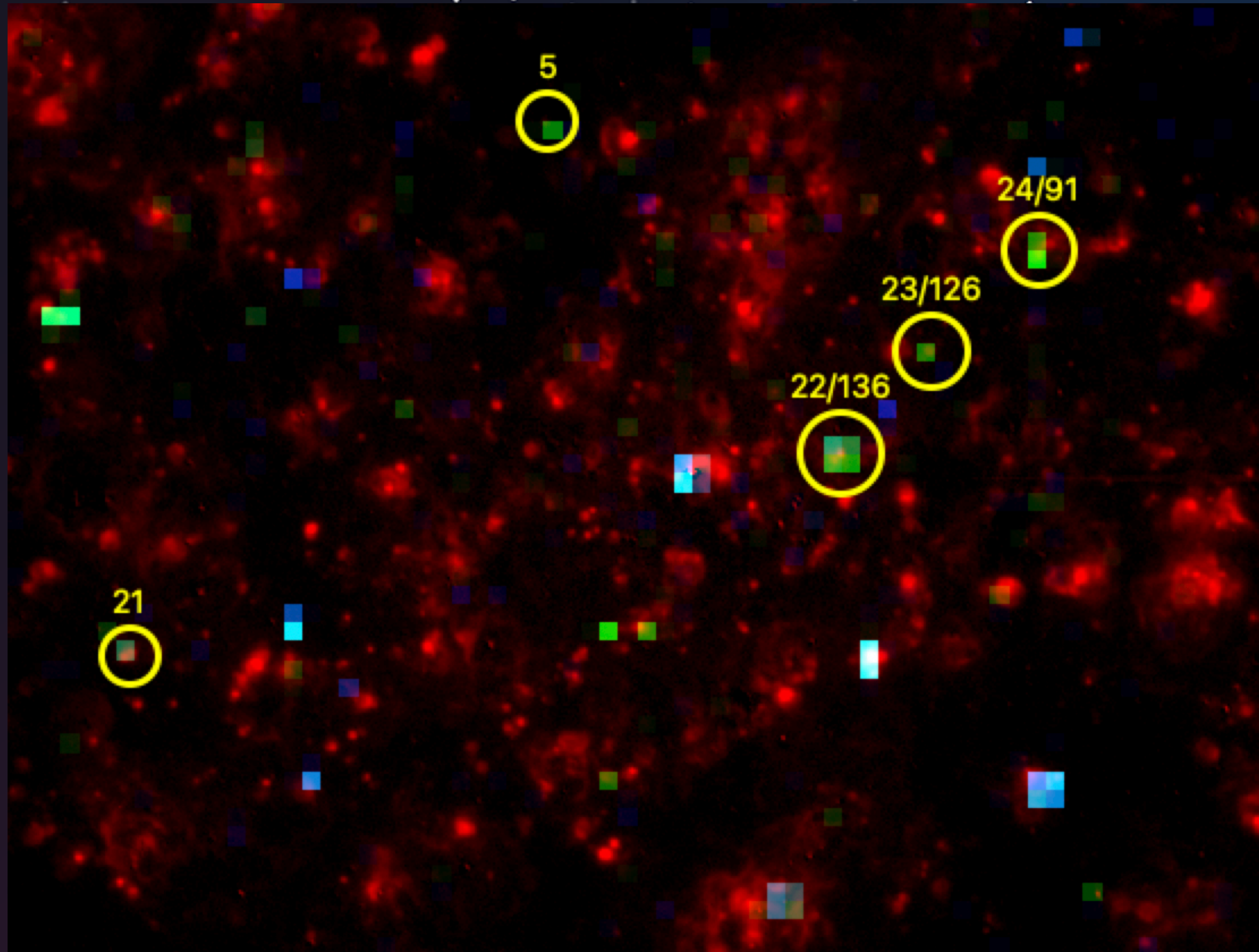
T = 5 × 10³ K → ~ 70 cm⁻³

T = 1 × 10⁴ K → ~ 80 cm⁻³

T = 3 × 10⁴ K → ~ 160 cm⁻³

T = 5 × 10⁴ K → ~ 240 cm⁻³

X-ray candidate SNRs in NGC 7793



H α + [N II] (Blanco 4m telescope)

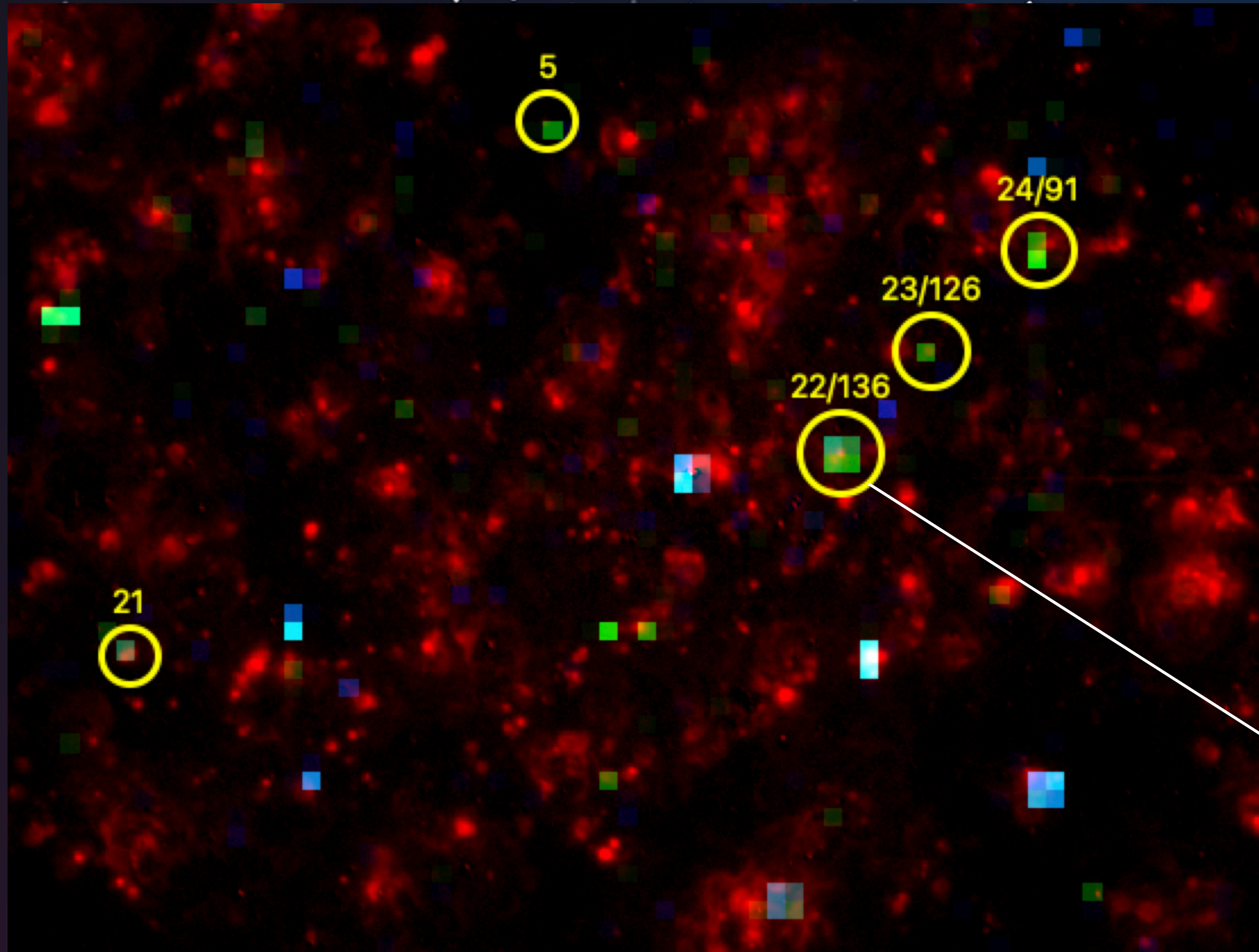
0.5-1.2 keV (Chandra)

1.2-2.0 keV (Chandra)

Archival *Chandra* data

OBS ID	Exp. (ks)	PI	RA (J2000)	DEC (J2000)	Start Date
3954	48.94	Pannuti	23:57:49.8	-32:35:29.5	2003-09-06
14231	58.84	Soria	23:57:59.9	-32:33:20.9	2011-08-13
13439	57.77	Soria	23:57:59.9	-32:33:20.9	2011-12-25
14378	24.71	Soria	23:57:59.9	-32:33:20.9	2011-12-30
23266	29.69	Walton	23:57:51.0	-32:37:26.6	2020-06-04
27481	9.95	Brightman	23:57:49.9	-32:35:27.7	2022-10-27

X-ray candidate SNRs in NGC 7793



Ha+[N II] (Blanco 4m telescope)
0.5-1.2 keV (Chandra)
1.2-2.0 keV (Chandra)

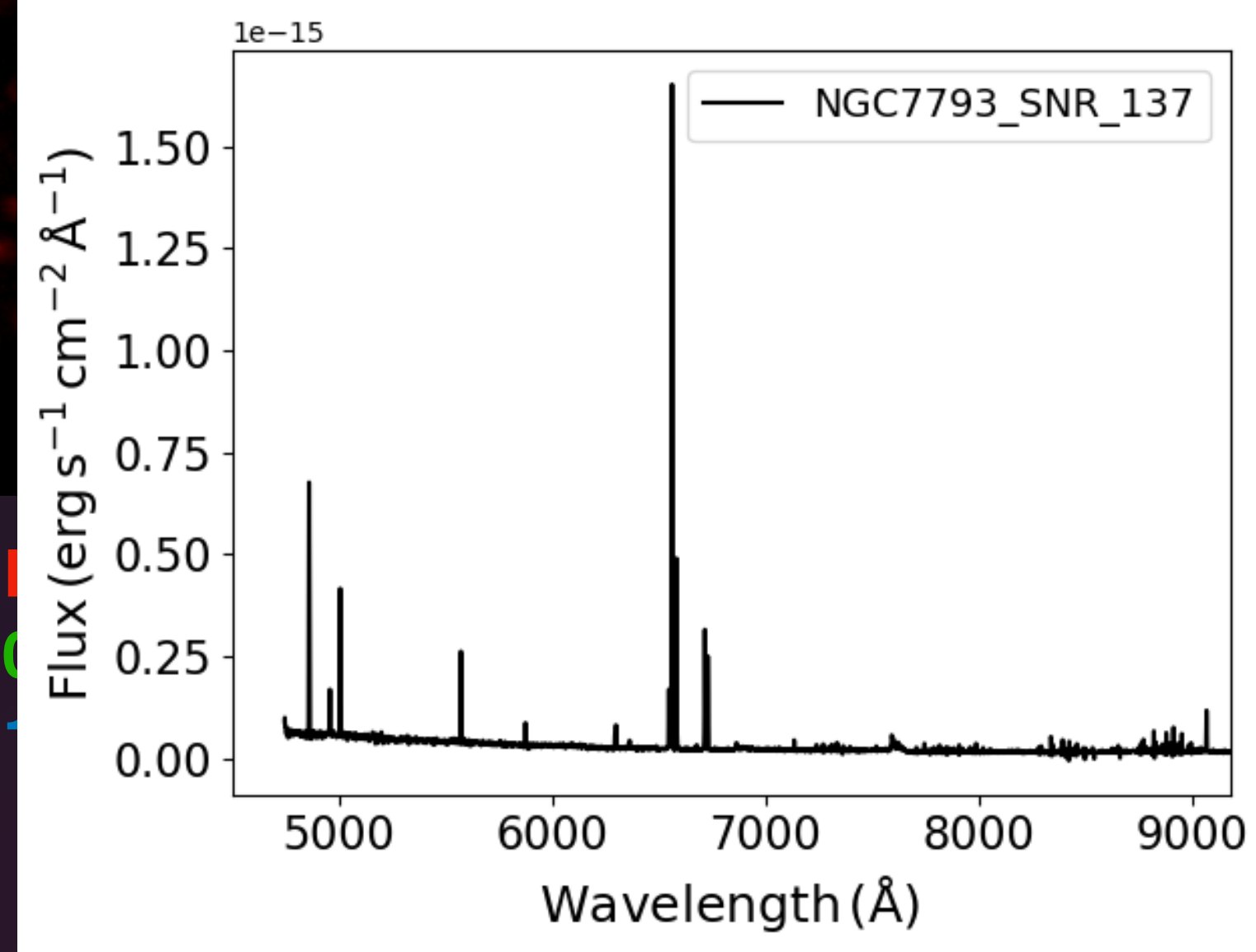
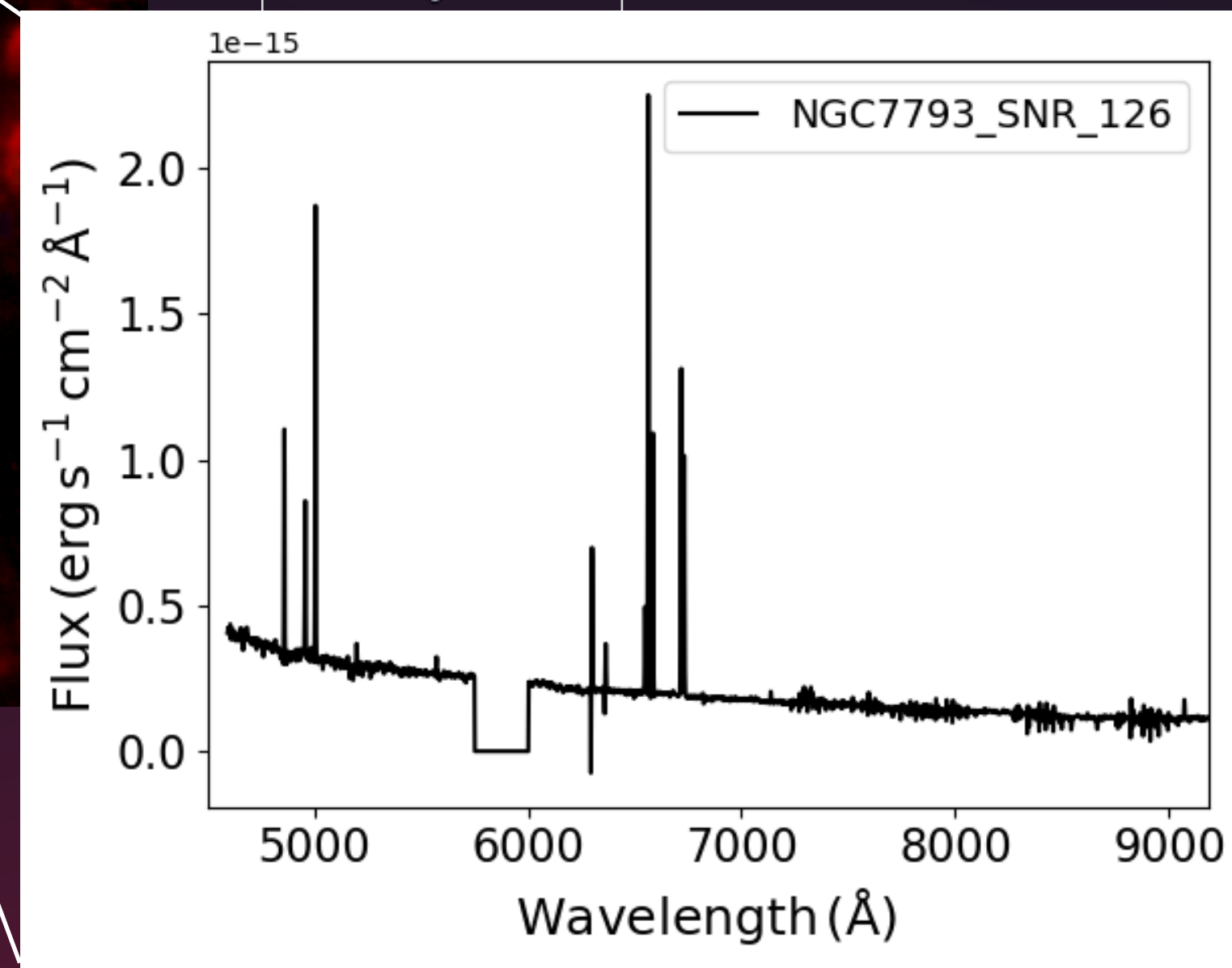
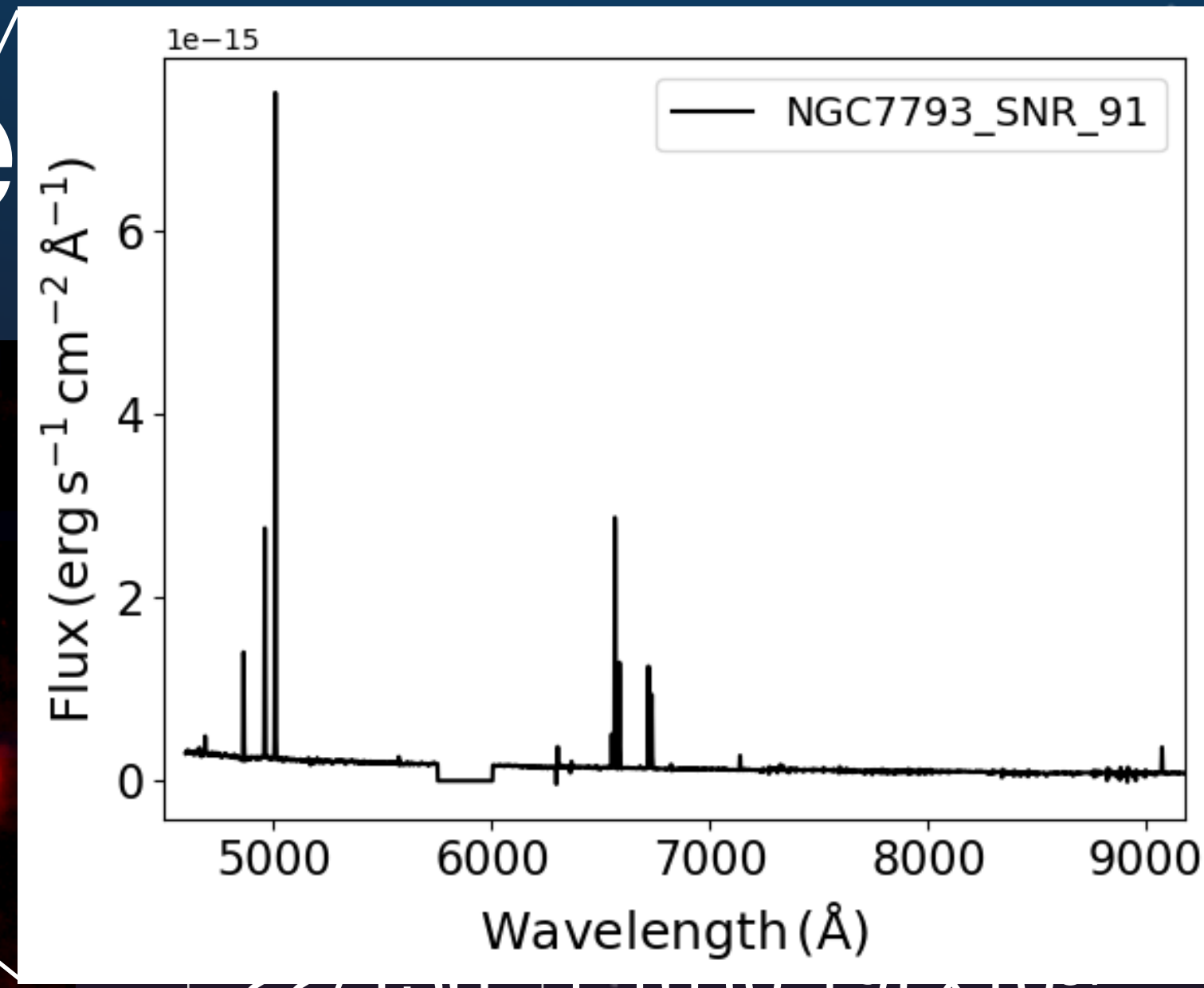
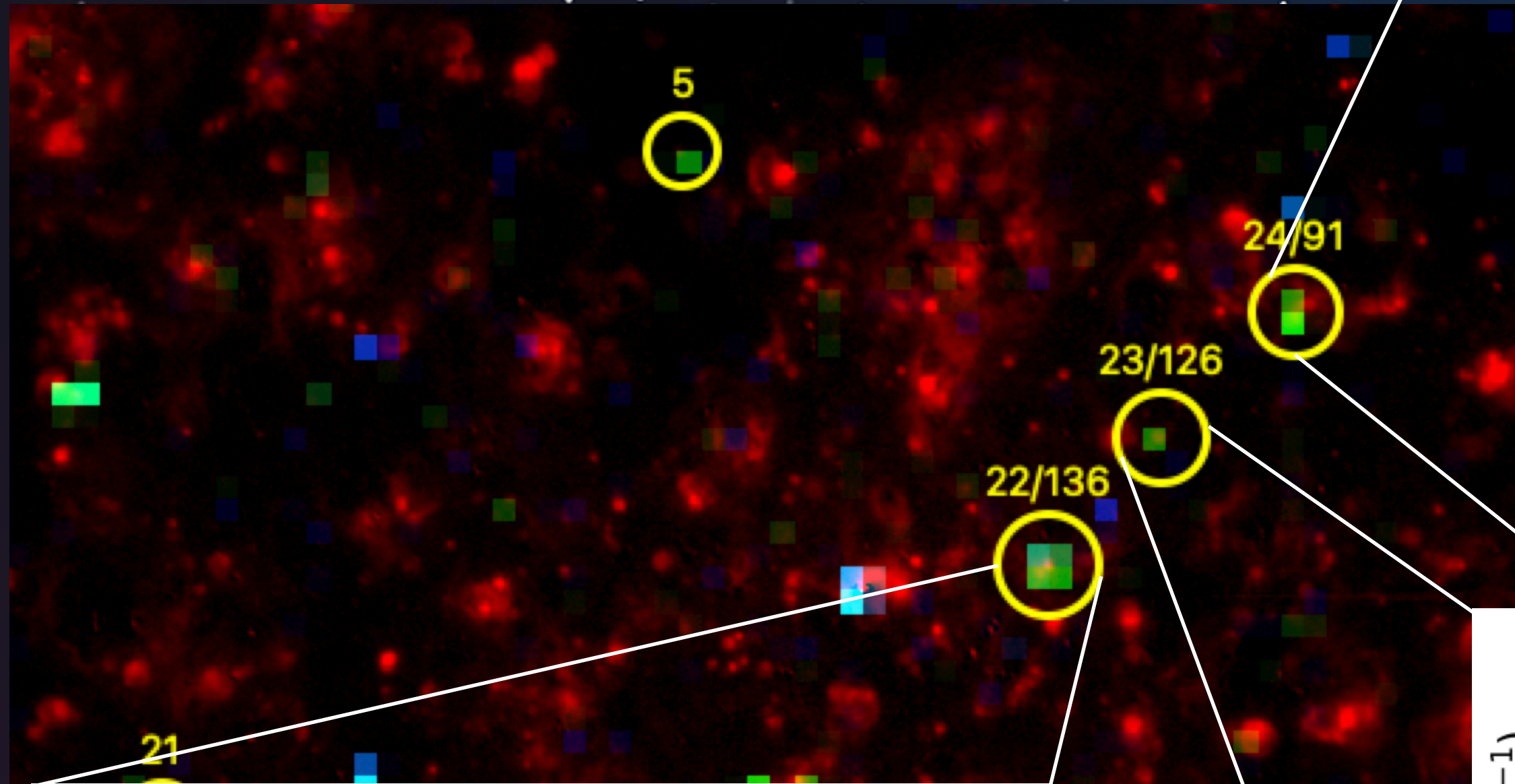
ID	L_{broad} (erg s ⁻¹)	S/N _{broad} *	S/N _{soft} **
5	3.43 (0.93) x10 ³⁶	2.43	2.29
21	2.85 (0.90) x10 ³⁶	2.14	1.48
22/136	1.16 (0.19) x10 ³⁷	5.09	5.05
23/126	1.69 (0.86) x10 ³⁶	1.23	1.12
24/91	8.47 (1.60) x10 ³⁶	4.39	4.2

*broad: 0.5-7.0 keV, **soft: 0.5 - 1.2 keV

Optical: Blair & Long (1997)
Kopsacheili et al. (2021, 2024)
Xrays: Pannuti et al. (2011)
Radio: Pannuti et al. (2002); Galvin et al. 2014

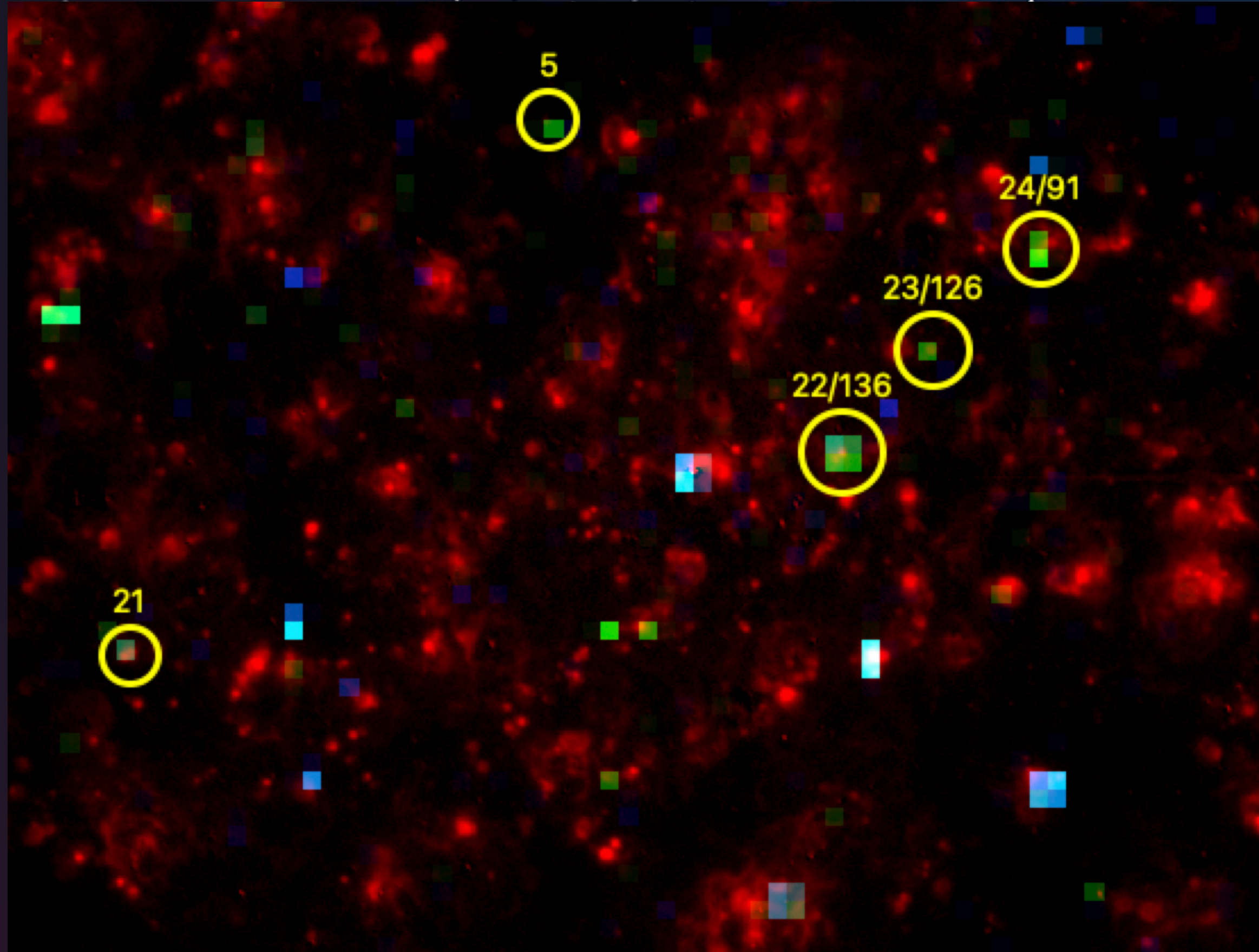
X-ray candidate

NGC 7793



	S/N _{broad} *	S/N _{soft} **
5	2.43	2.29
21	2.14	1.48
22/136	5.09	5.05
23/126	1.23	1.12
24/91	4.39	4.2

X-ray candidate SNRs in NGC 7793



H α + [N II] (Blanco 4m telescope)
0.5-1.2 keV (Chandra)
1.2-2.0 keV (Chandra)

Looking for correlations...

ID	L _{broad} ($\times 10^{36}$ erg s ⁻¹)	L _{Hα} ($\times 10^{36}$ erg s ⁻¹)	L _[O III] ($\times 10^{36}$ erg s ⁻¹)
5	3.43	1.64	
21	2.85	22.9	42.8
22/136	1.16	6.56	4.18
23/126	1.69	10.6	9.59
24/91	8.47	11.6	37.7

Spectroscopy: Kopsacheili et al. 2024

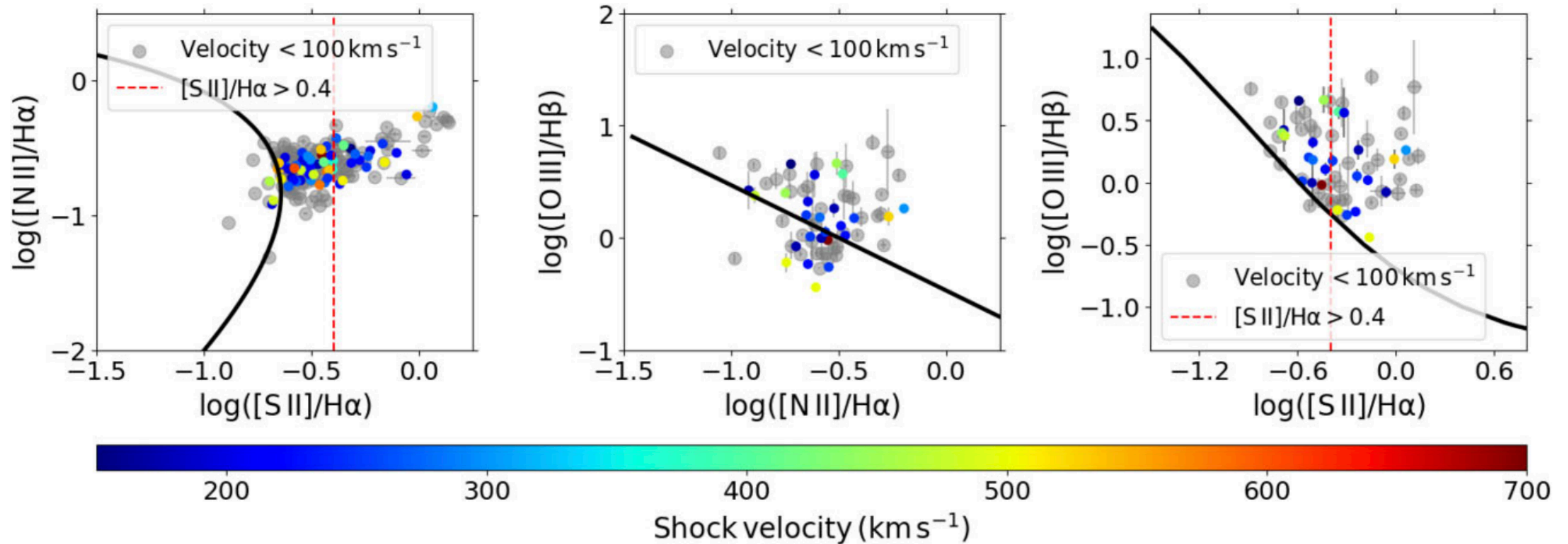
Blair & Long 1997

Photometry: Kopsacheili et al. 2021

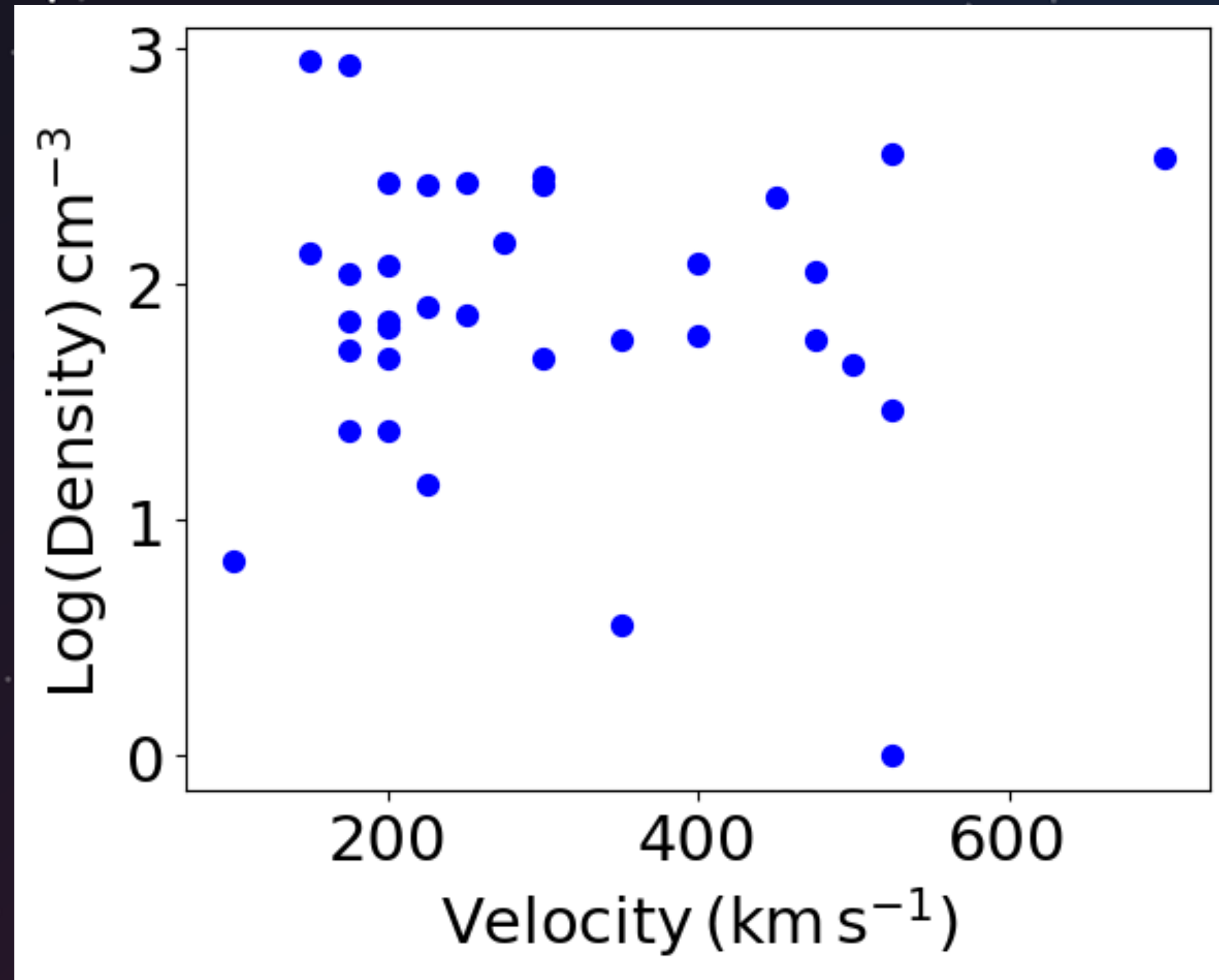


Thank you !

Multi-line diagnostics

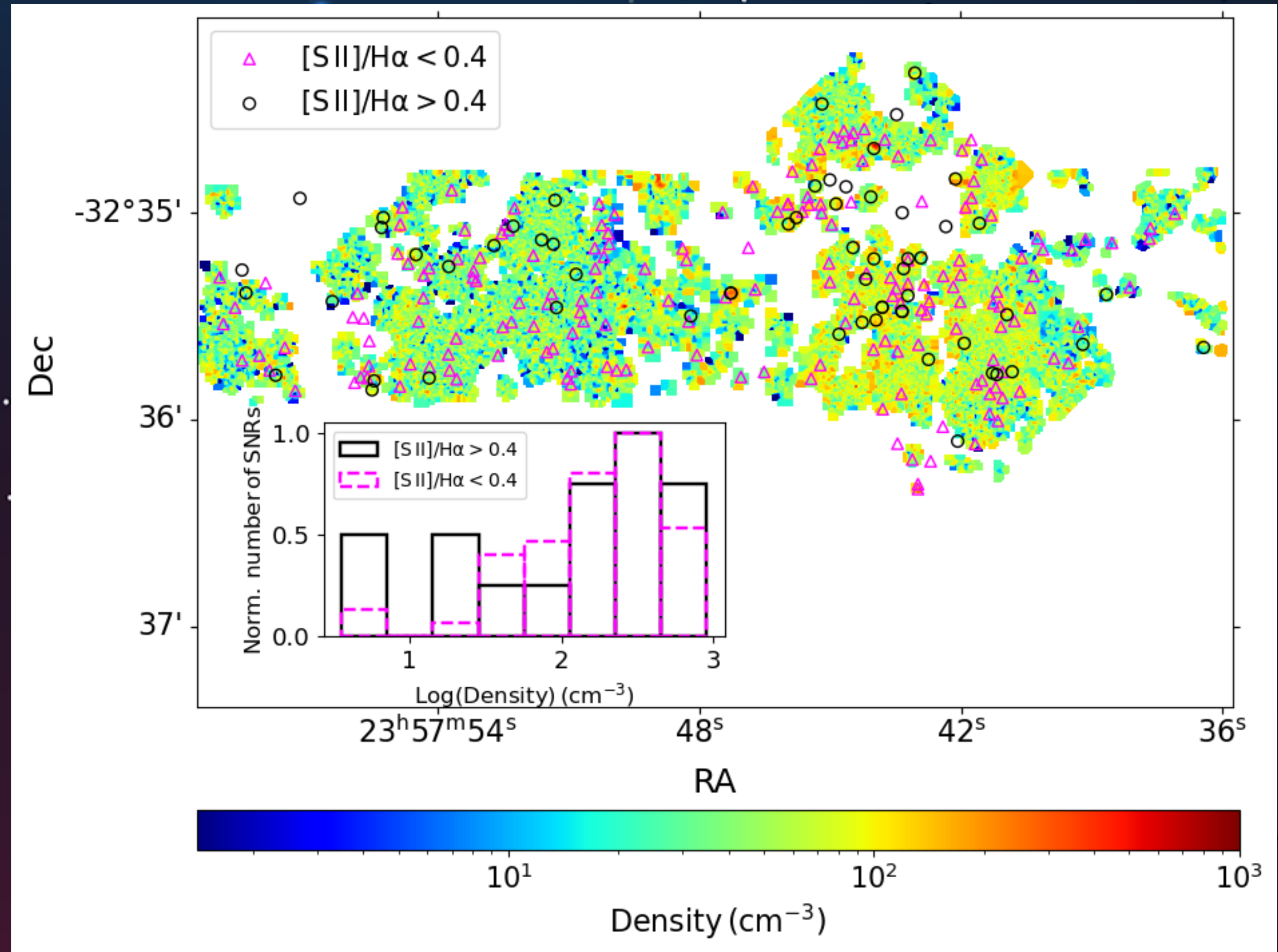


Correlation between density and shock velocity?



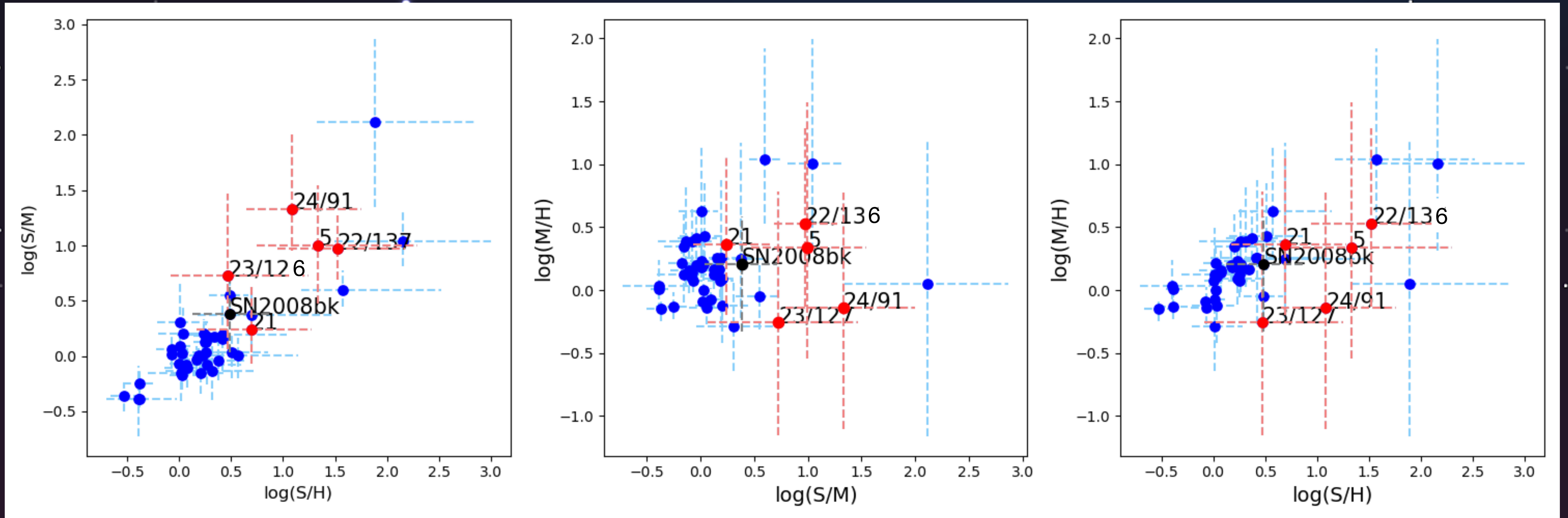
Slight or no correlation between shock velocity and density.

Correlation between density and [S II]/H α ratios?



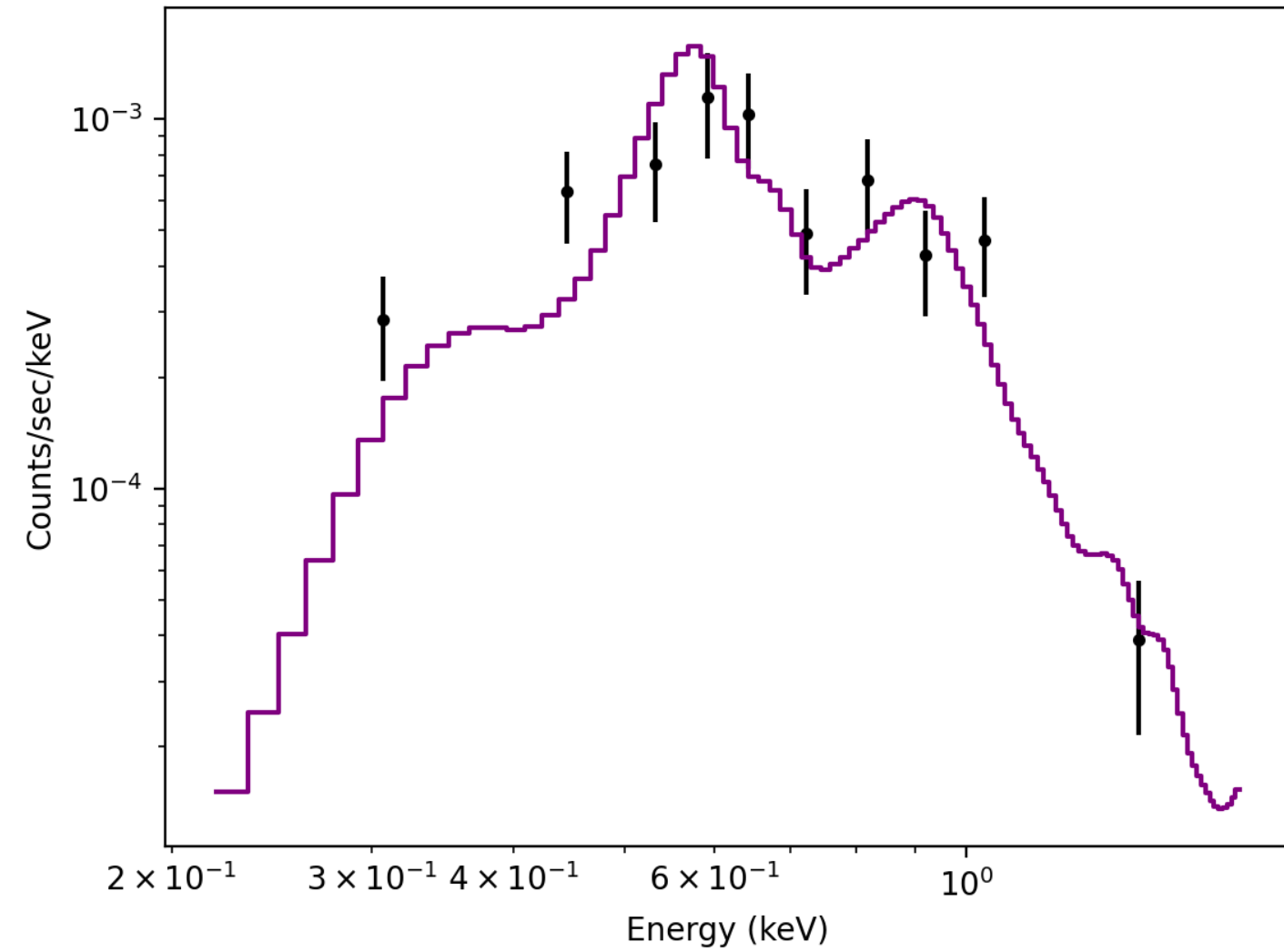
No obvious correlation between density and [S II]/H α ratio

Hardness ratios - Color color diagrams



X-ray candidate SNRs

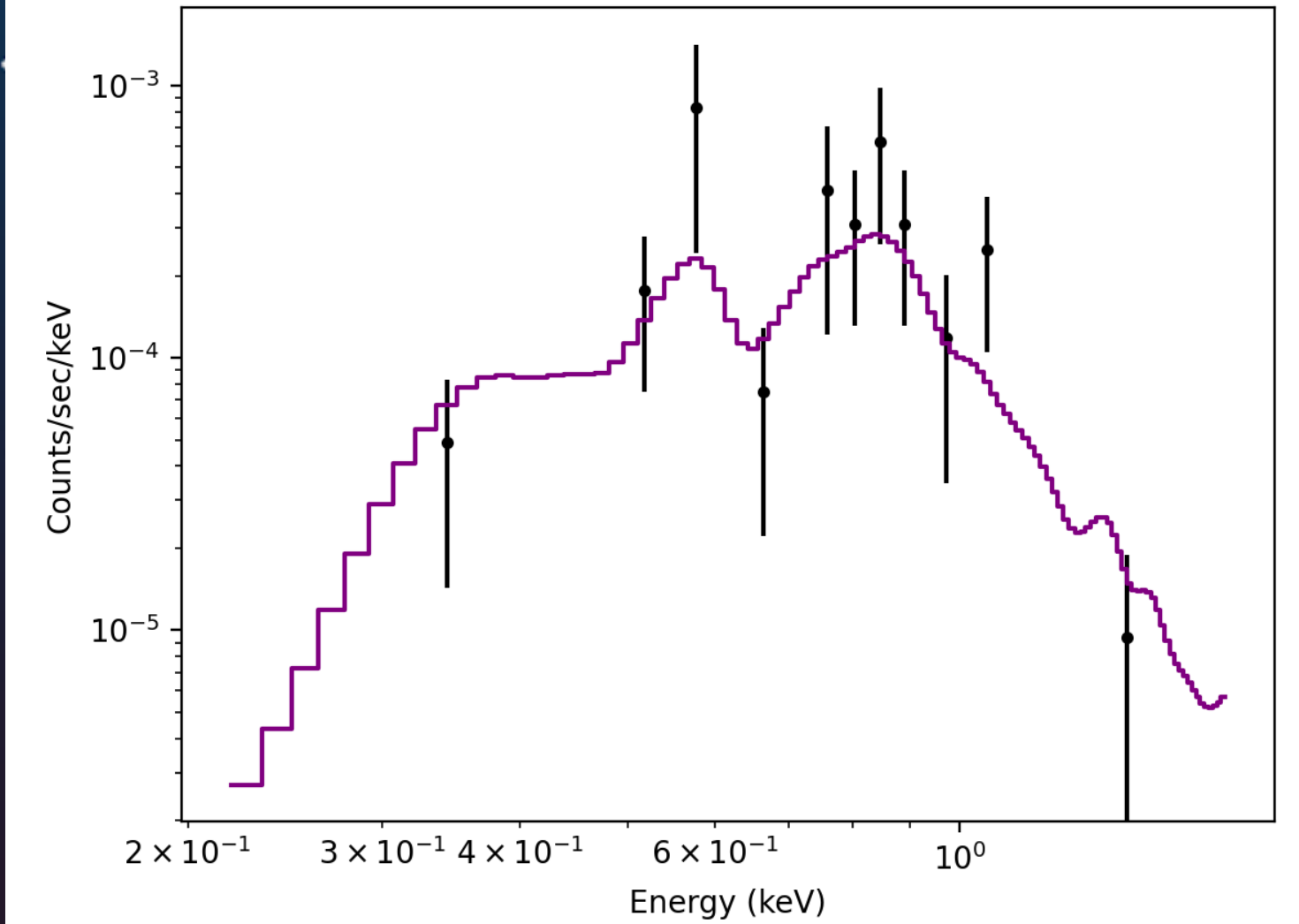
../All_detection_20_11_23/group_combined.pi



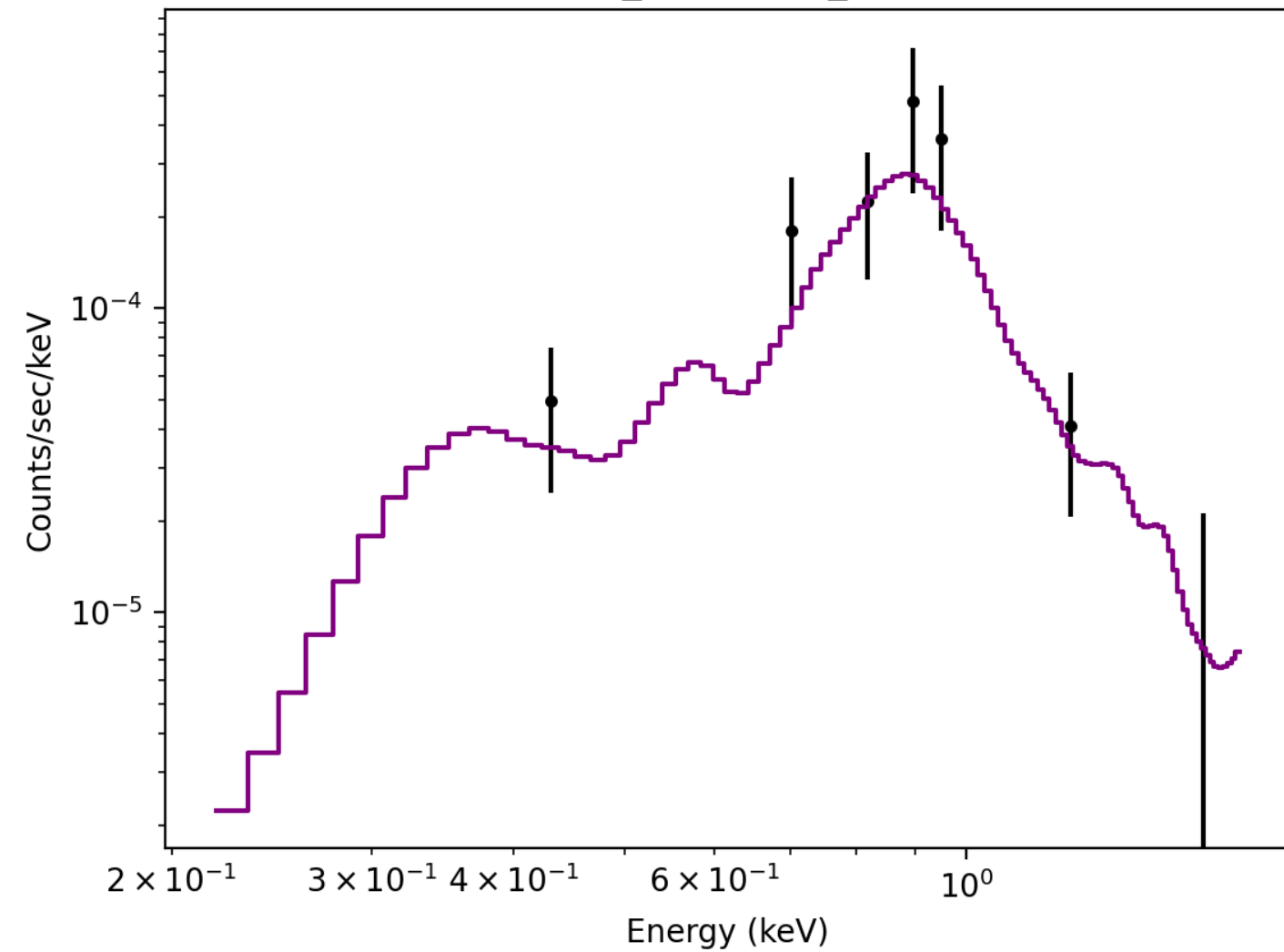
kT1 = 0.83
kT2 = 0.15

kT1 = 0.64
kT2 = 0.10

group_combined_5.pi



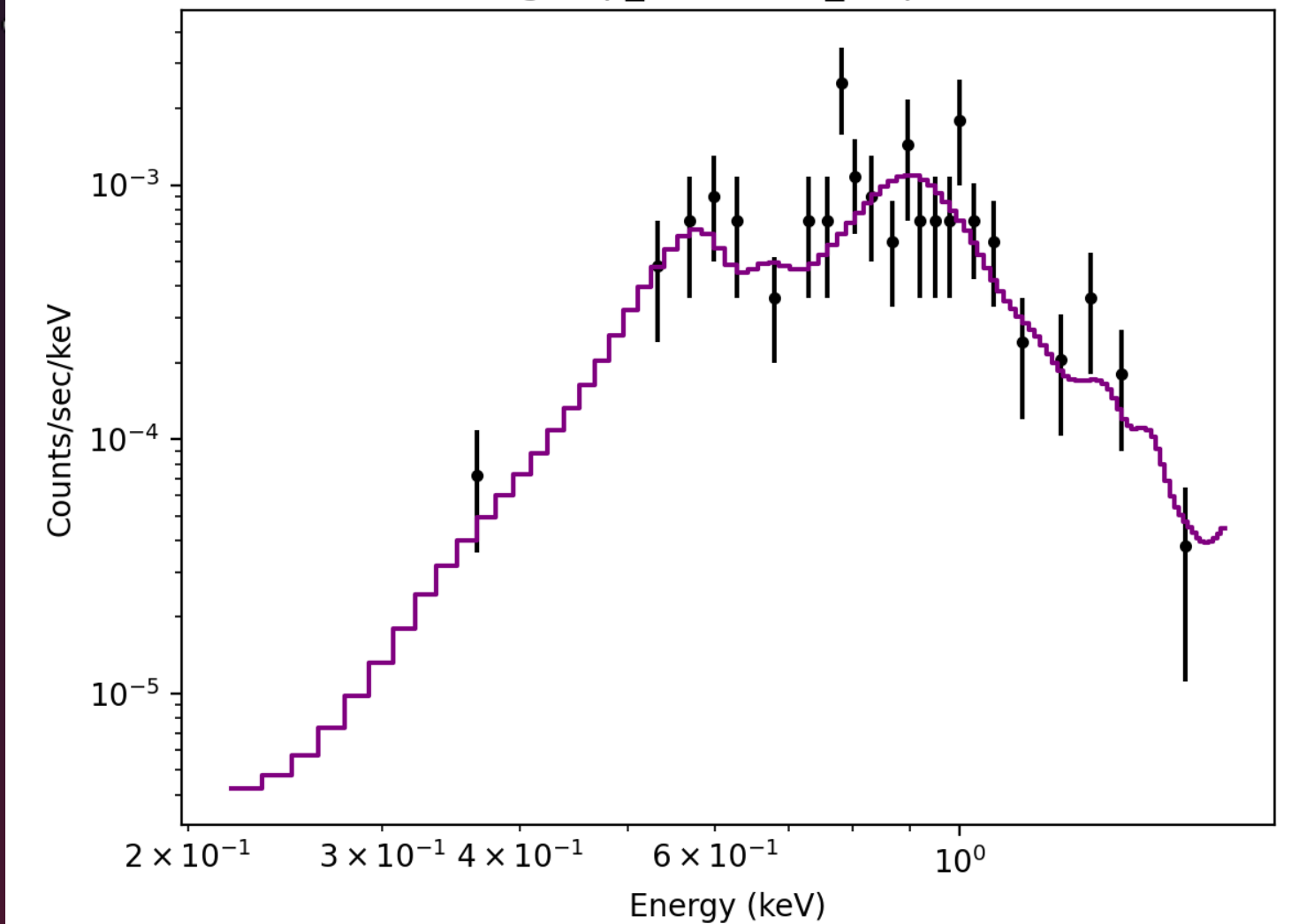
group_combined_23.pi



kT1 = 0.80
kT2 = 0.09

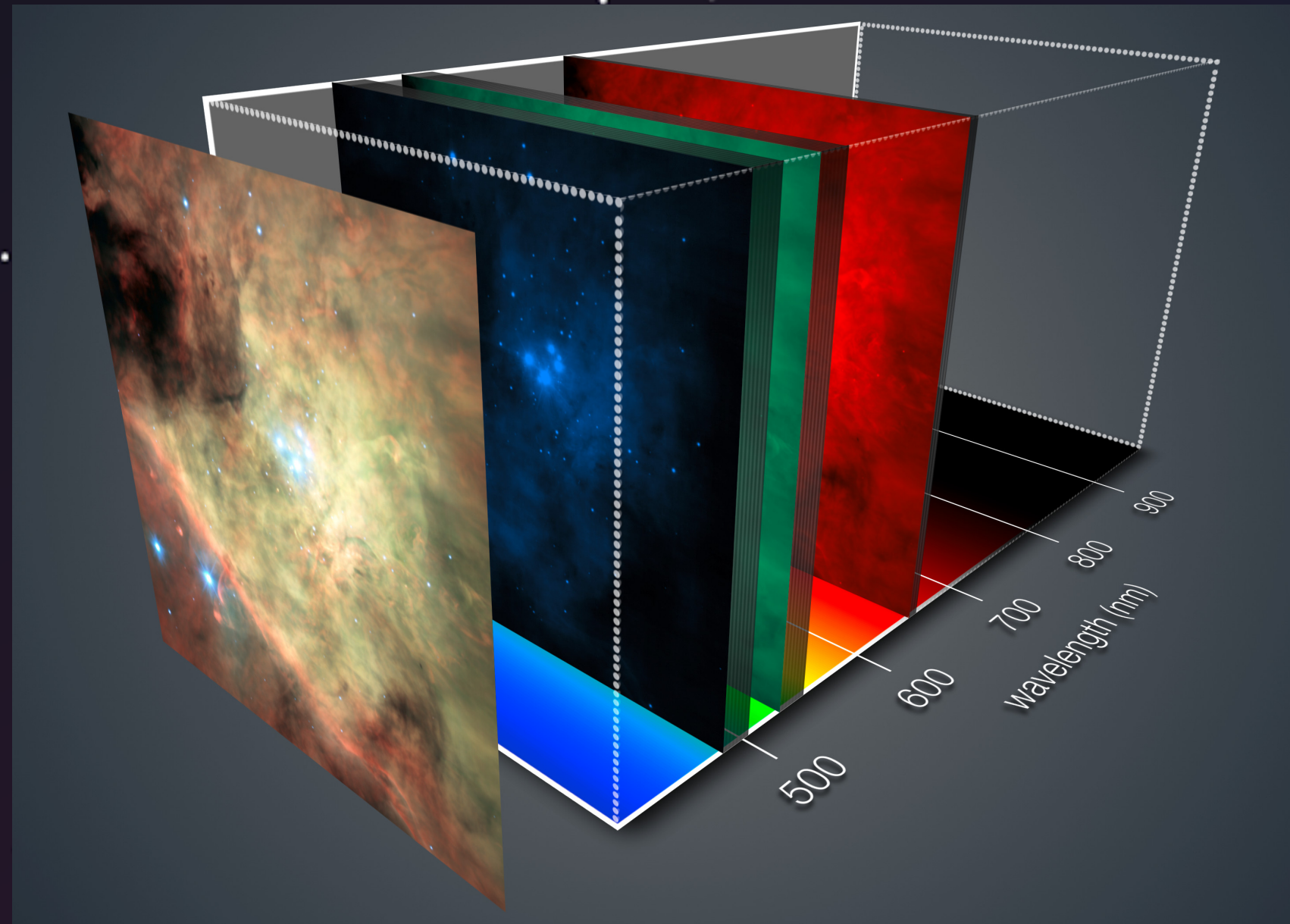
kT1 = 0.82
kT2 = 0.15

group_combined_22.pi



Useful Data for the new diagnostics

Integral Field Spectroscopy (IFS)



2D field of view + 1D wavelength

VLT MUSE:

FOV: 59.9" x 60.0"

Spatial Sampling: 0.2"/pixel

Resolving Power: 1770 (480 nm) - 3590 (930 nm)