The physical origin for the faint double-peak Ha emission detected in the halo of low redshift galaxies

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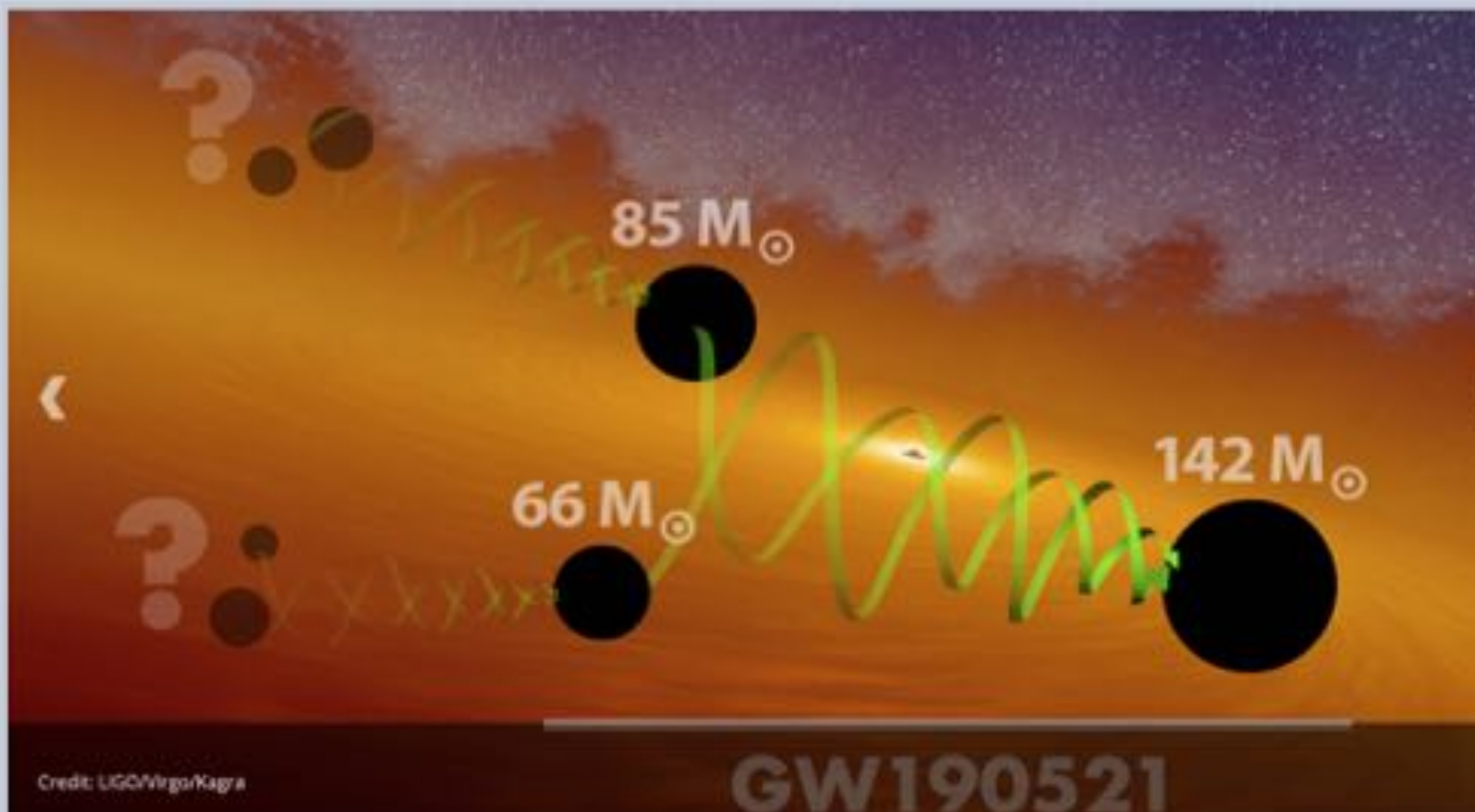
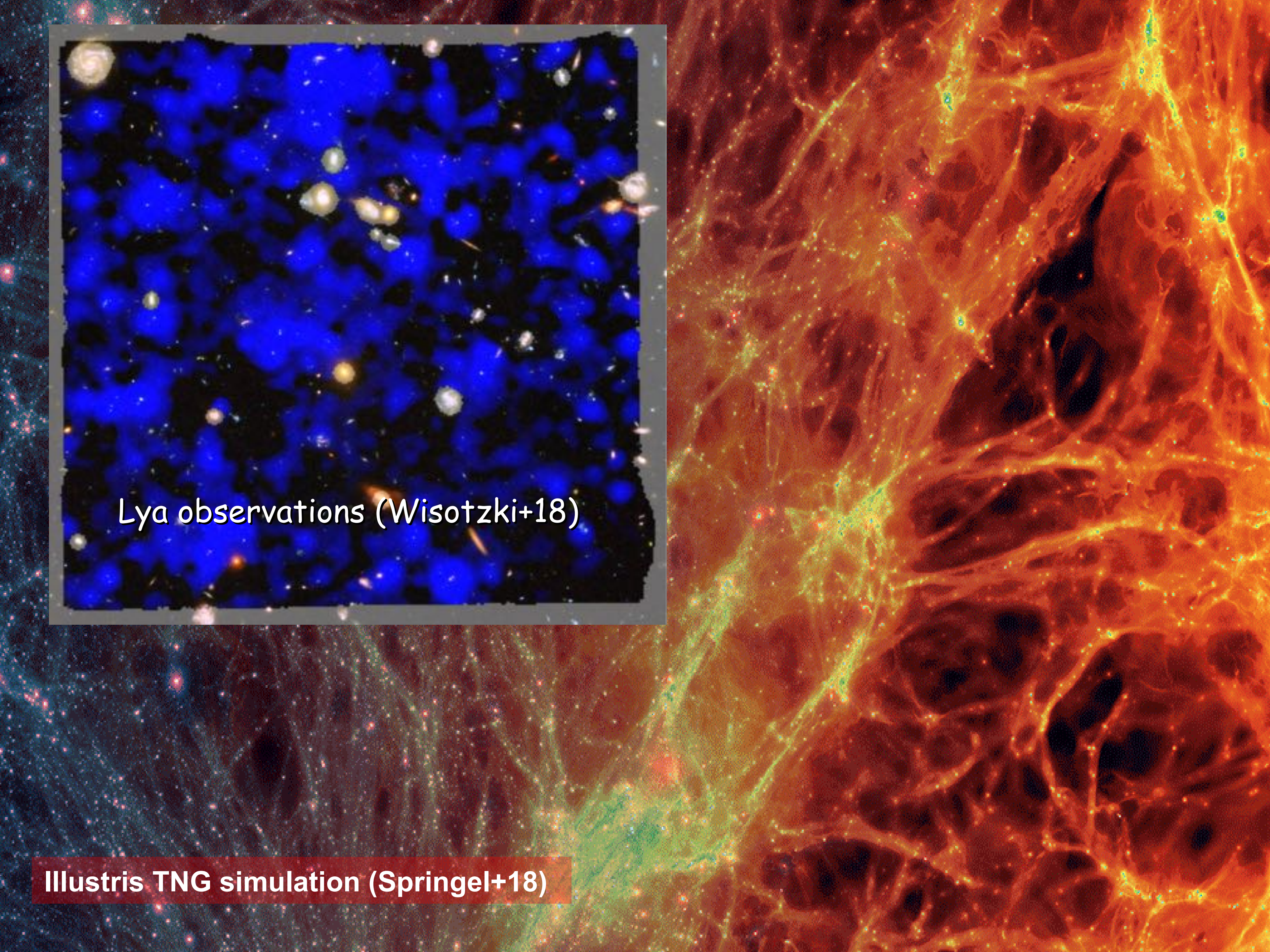
- Ana Luisa Gonzalez (post Doc)

- Casiana Muñoz Tuñon.

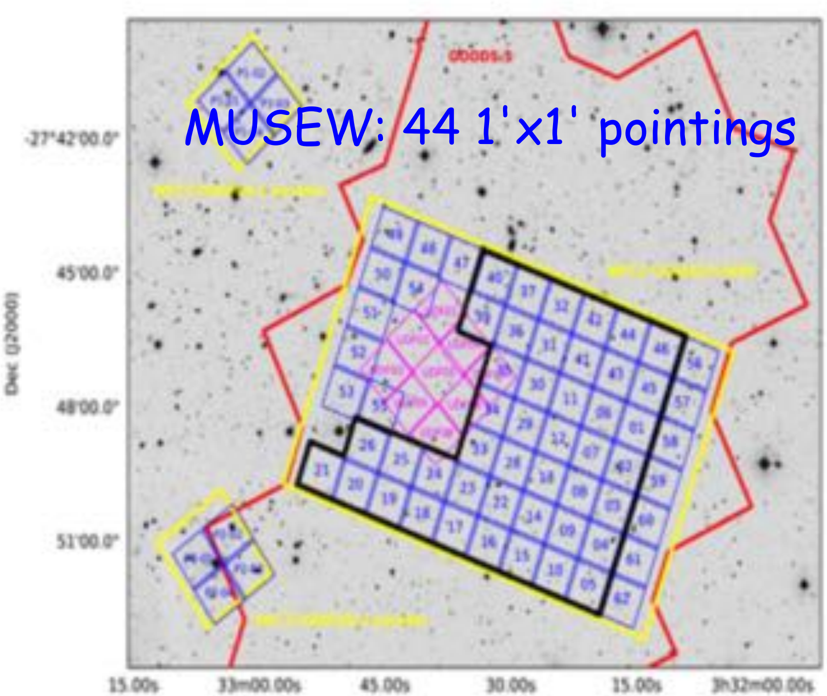
- Jose Miguel Rodriguez Espinosa

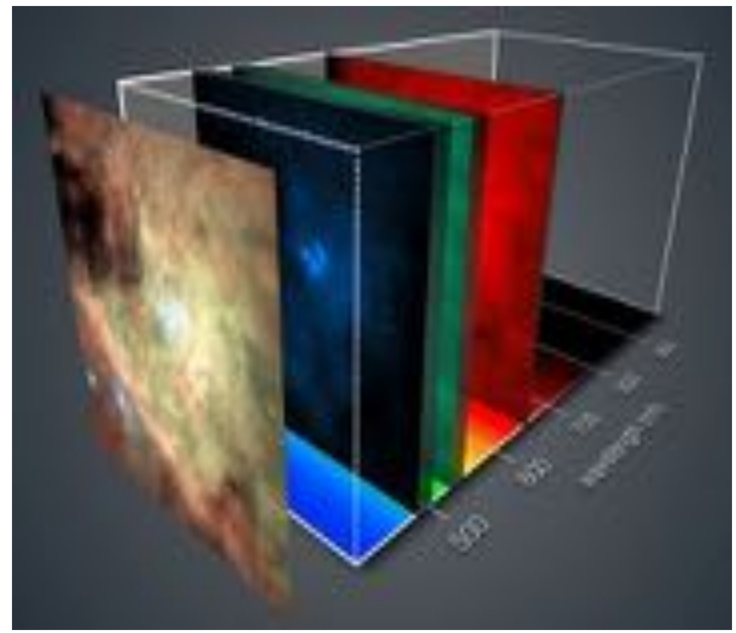
INTERMEDIATE-MASS BLACK HOLES: NEW SCIENCE FROM STELLAR EVOLUTION TO COSMOLOGY




Lya observations (Wisotzki+18)
Illustris TNG simulation (Springel+18)

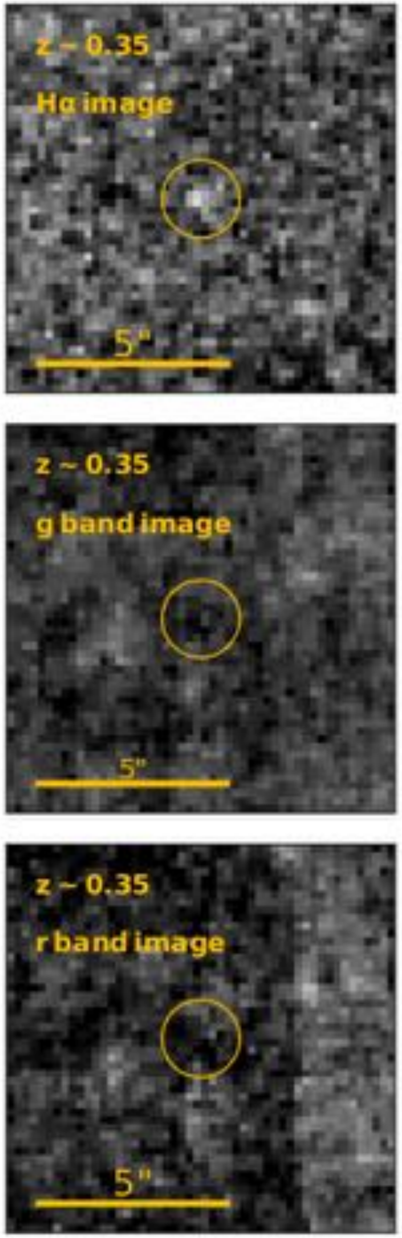
We tried to detect the gas in the circum-galactic medium (CGM) and inter galactic medium (IGM) in the nearby Universe in Ha using MUSE Wide public datacubes (Urrutia+19)



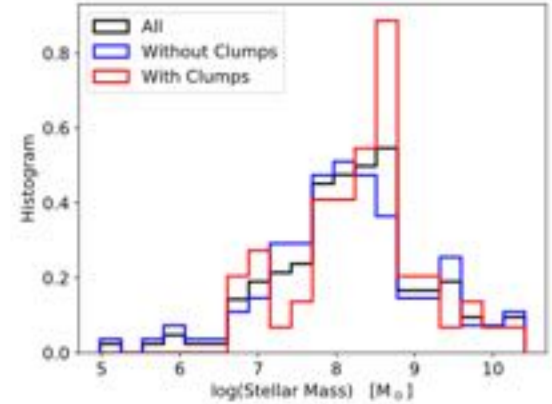


Spectral range (simultaneous)	0.465-0.93 μm
Resolving power	2000@0.46 μm
	4000@0.93 μm
Wide Field Mode (WFM)	
Field of view	1x1 arcmin^2
Spatial sampling	0.2x0.2 arcsec^2
Spatial resolution (FWHM)	0.3-0.4 arcsec

MUSE@VLT: Bacon+14,15



- search around all 164 galaxies with redshift small enough (<0.42) to have Ha within the MUSE wavelength coverage.

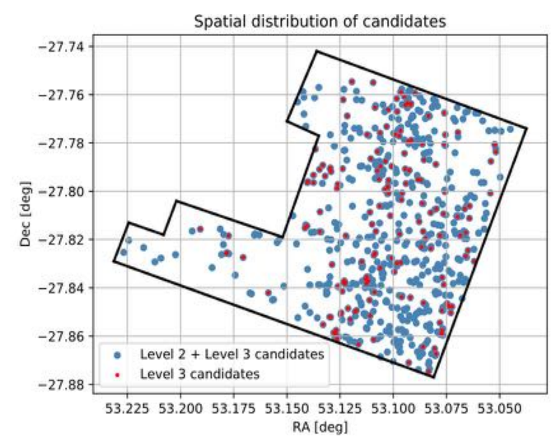


- from the MUSE spectra, construct Ha images tuned to each galaxy, and also broad band images.

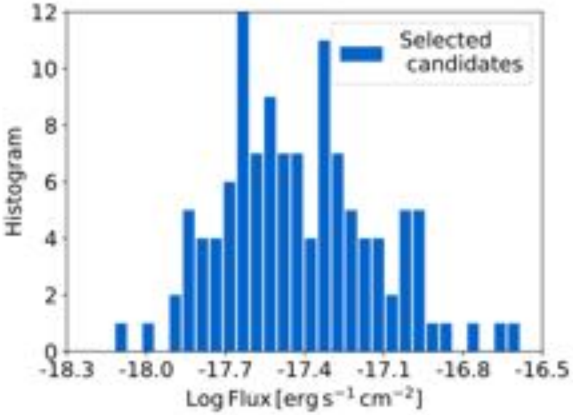
- huge searching area; ~100 effective radii around each galaxy

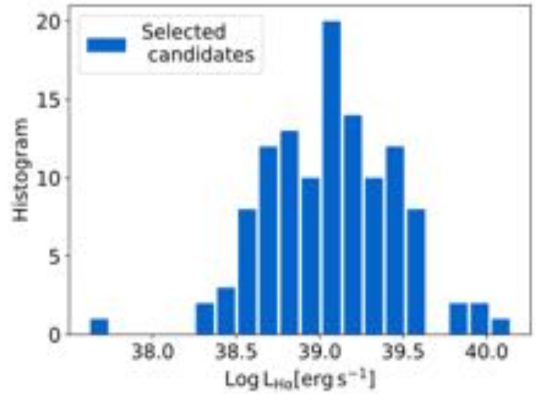
- select those places with Ha signal and without continuum signal

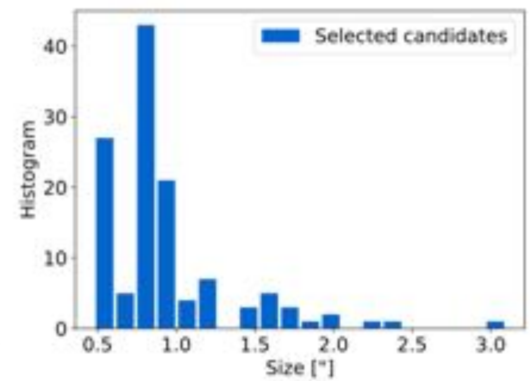
- all in all, we selected 118 such Ha emitting clumps

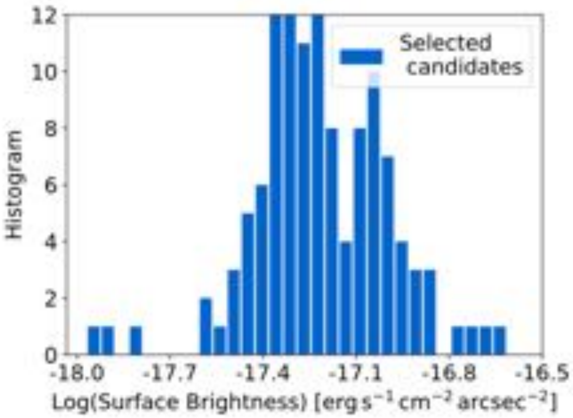


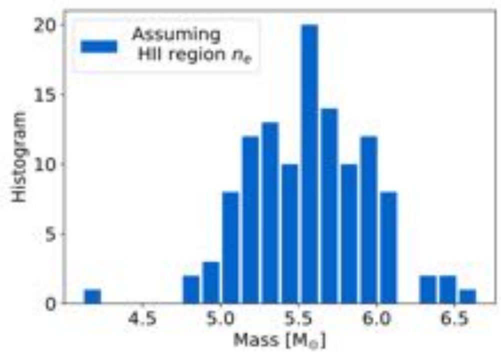
Properties of the Ha emitting clumps

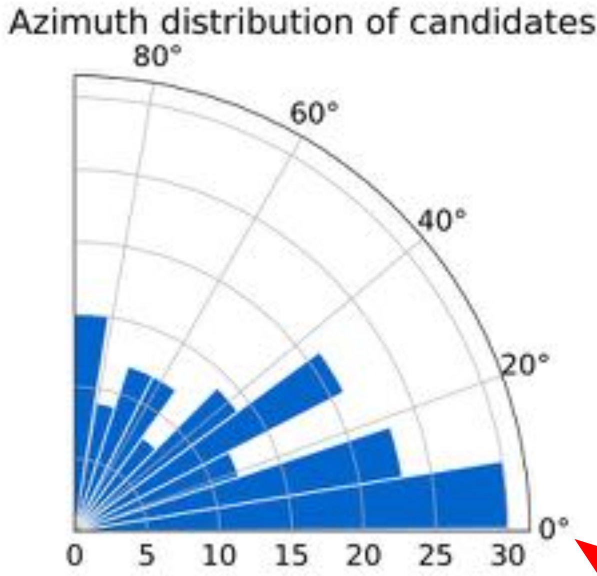


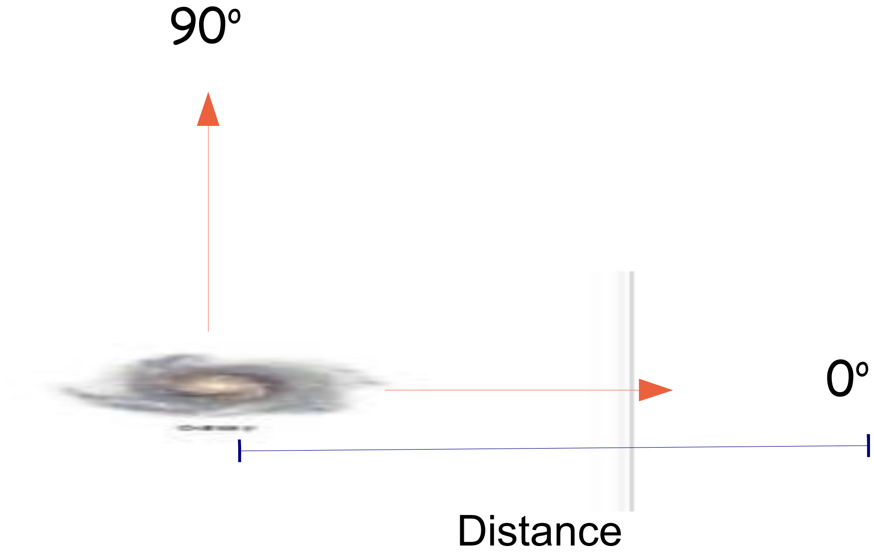




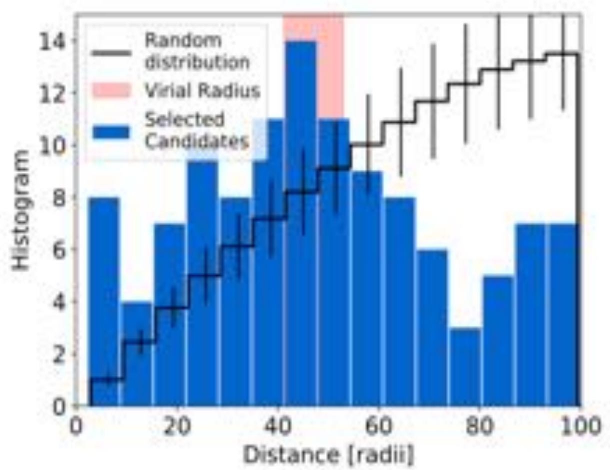








The Ha emitting clumps prefer the plane of the galaxy



The Ha emitting clumps appear within the virial radius (Rvir ~50 radii; e.g., Kratsov 13).

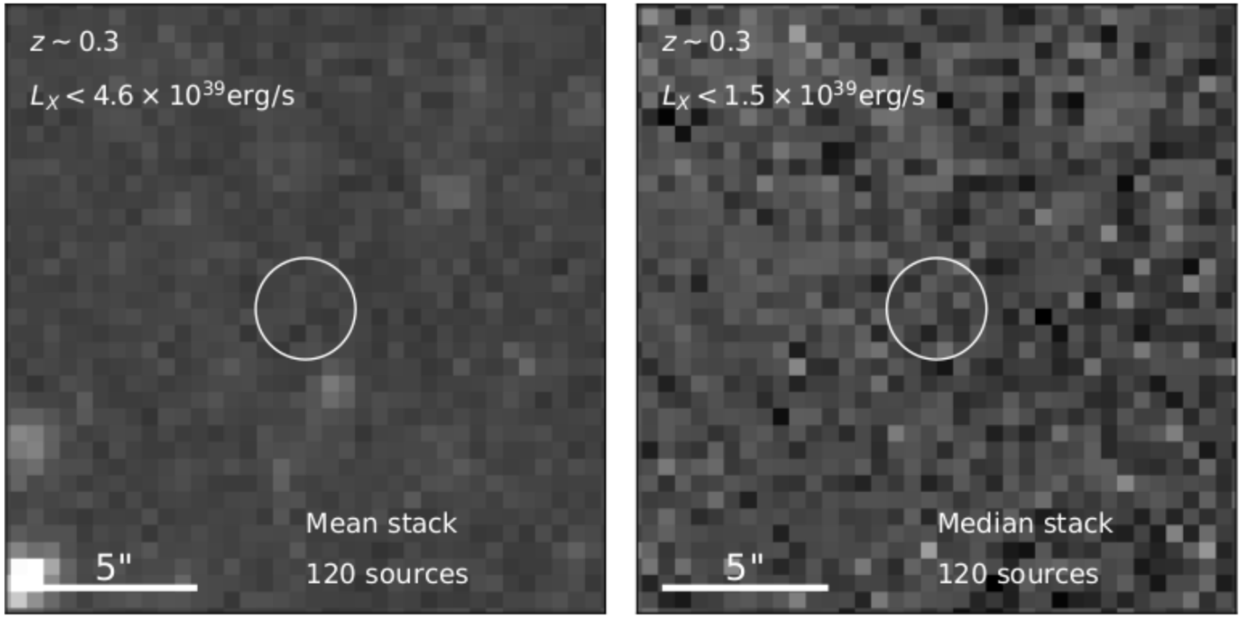
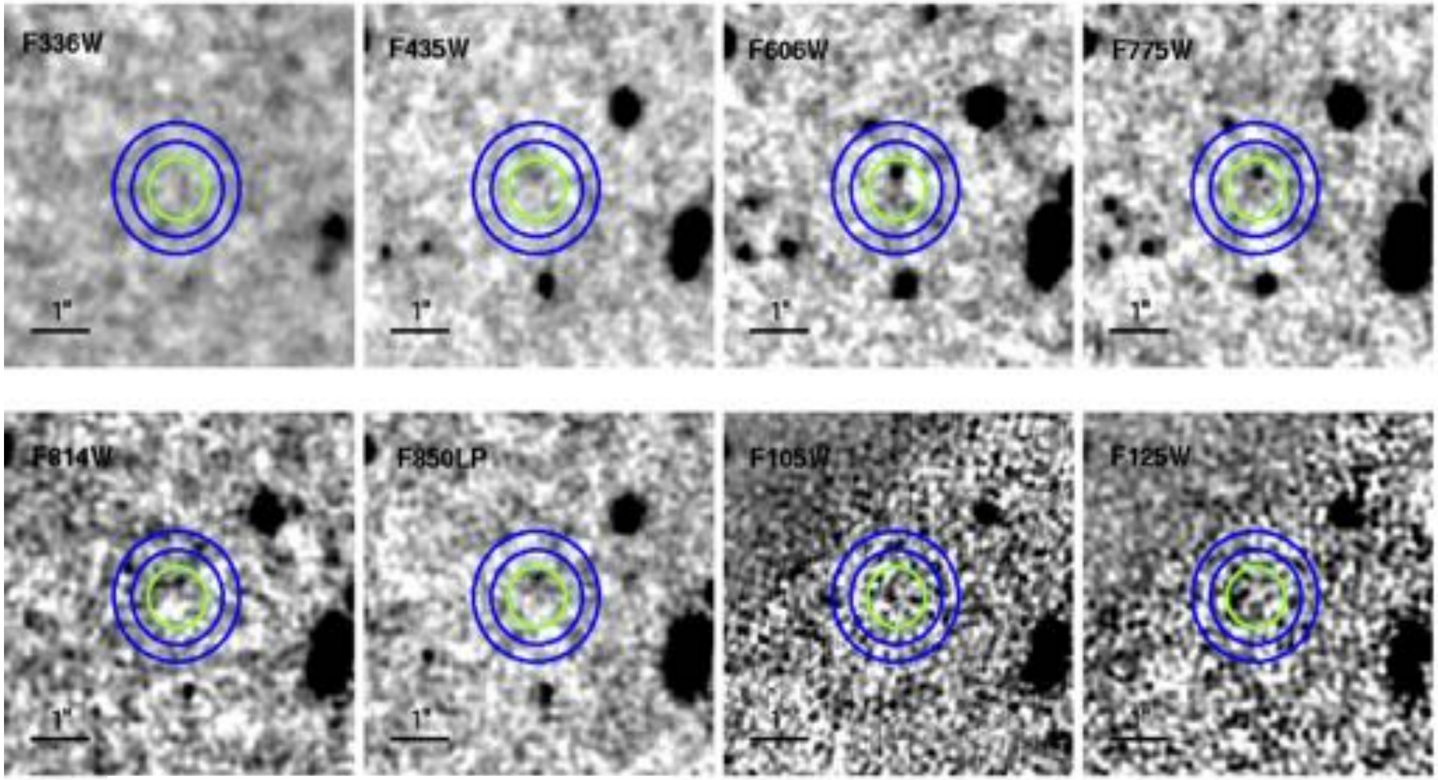
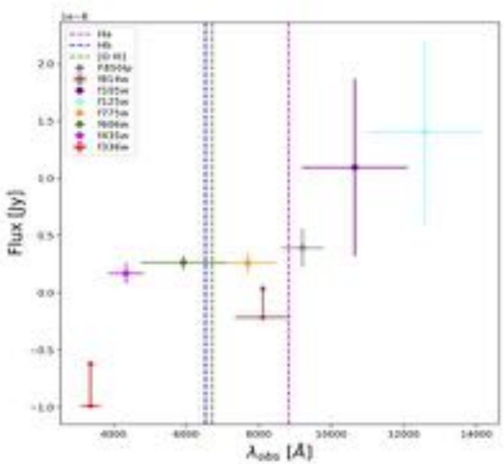


Figure 18. The result of stacking our candidates in full band (0.5-7 keV) 7Ms X-ray Chandra images. The left panel shows mean stacking whereas the right panel shows median stacking. The mean stacking reveals the presence of some clear sources, likely in the vicinity of several of our clumps, but no actual detection in the position of our candidates (marked with a circle), a lack of signal also supported by the median stack. Our mean stacking reveals an X-ray non-detection with an upper limit luminosity of $L_X < 4.6\times10^{39}$ erg s^{-1}. The images have been scaled to their minimum (black) and 0.85 × maximum (white) values.

- No match in X-ray full band 7Ms X-ray Chandra images.

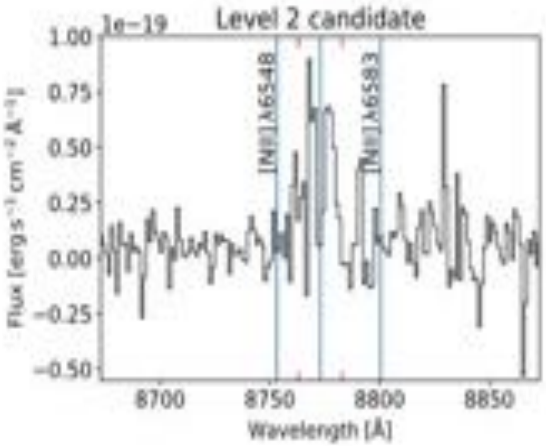
- No counterpart in radio : with the Very Large Array (VLA) 1.4 GHz survey for the Extended Chandra Deep Field South (E-CDFS; Kellermann et al. 2008; Miller et al. 2013). The second data release goes down to an average depth of ħ 7μJy.

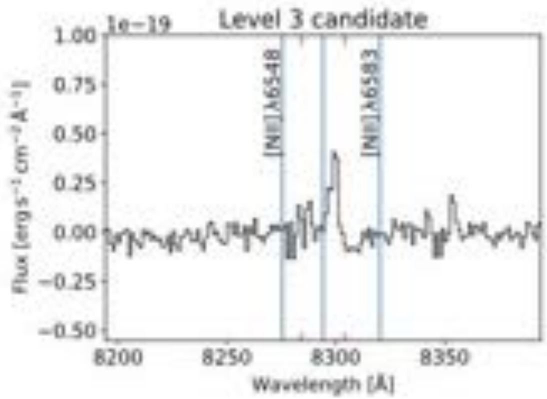




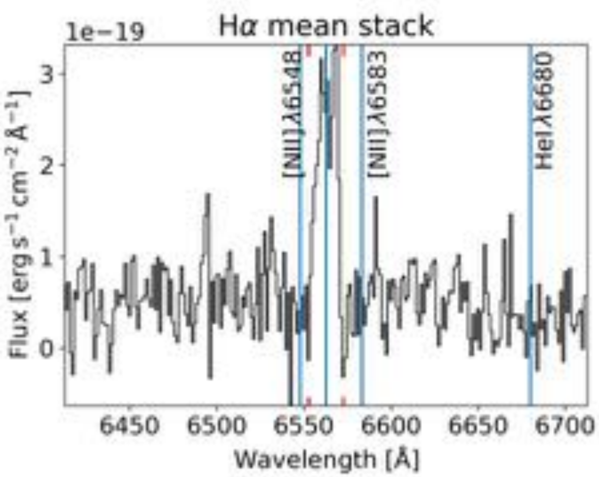
HST images & SEDs

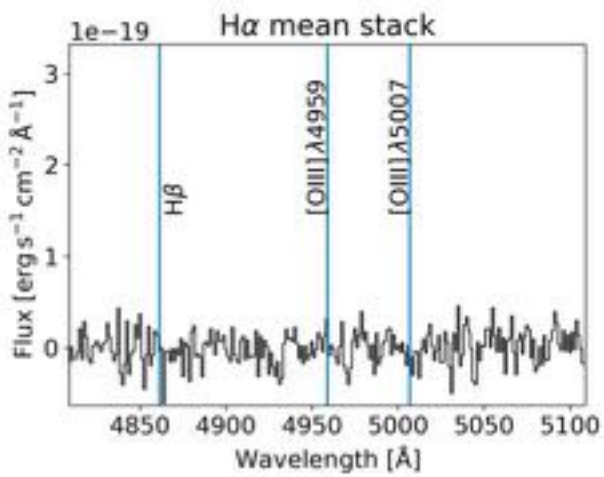
Ha often show two peaks + weak continuum



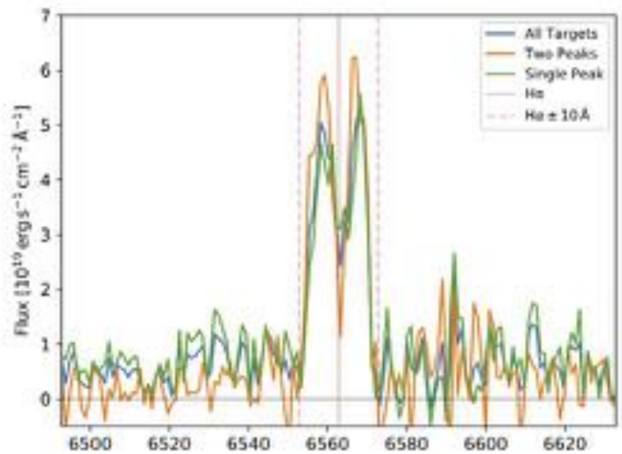


Individual spectra



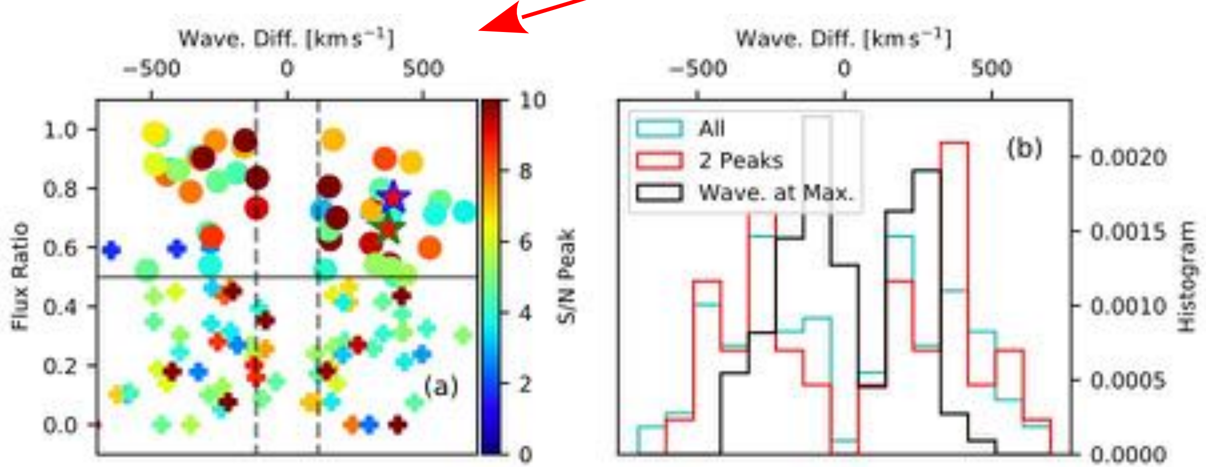


Stacked spectra:
Ha has two peaks
No Hb or [OIII]
emission



Stacked spectra

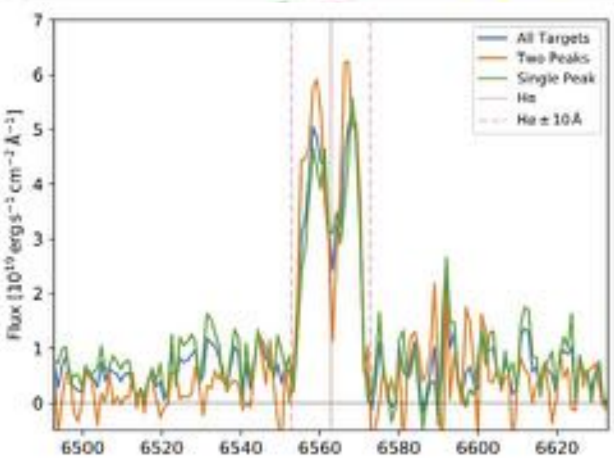
38% two peaks



± 175 km/s

Possible Physical Origin of the Hα emission

Mechanism (1)	Surface Brightness (2)	Number Density (3)	Double Peak (4)	Central Drop (5)	Hβ/Hα (6)	No Continuum (7)	Size (8)	Spatial Distribution (9)
Accretion disks (IMBH)	✓	✓	✓	✓	?	✓	✓	✓
Expanding bubbles (SN)	✓	✓	✓	✓	?	✓	✓	✗
Cosmological gas	✓	✓	?	?	✗	✓	✓	✓
Planetary nebulae	✗	✓	✓	✓	?	✓	✓	?
X-ray binaries	✗	✓	✓	✓	?	✓	✓	?
Shocks	?	✓	✓	✗	?	✓	?	✓
Galaxy outflows	✓	✓	✓	✗	✓	✓	?	✗
Tidal disruption events	?	✗	✓	✓	?	✓	✓	✗
Interlopers	✓	✗	?	✗	✓	✓	?	✗
Jets	?	?	✓	✓	?	?	?	✗



The spatial distribution discards telluric line contamination

Possible Physical Origin of the Hα emission

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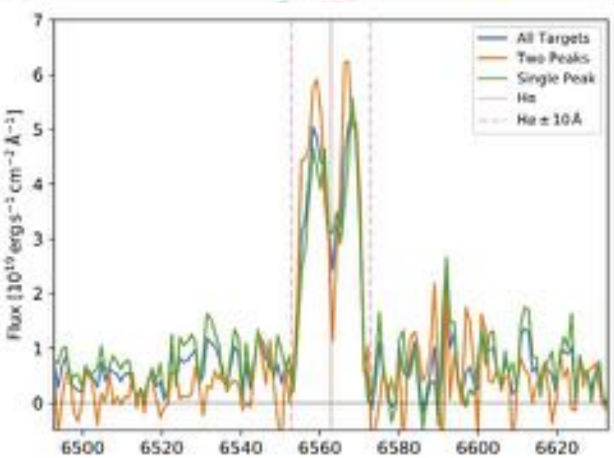
Accretion disks (IMBH)	✓	✓	✓	✓	?	✓	✓	✓
Expanding bubbles (SN)	✓	✓	✓	✓	?	✓	✓	✗
Cosmological gas	✓	✓	?	?	✗	✓	✓	✓
Planetary nebulae	✗	✓	✓	✓	?	✓	✓	?
X-ray binaries	✗	✓	✓	✓	?	✓	✓	?
Shocks	?	✓	✓	✗	?	✓	?	✓
Galaxy outflows	✓	✓	✓	✗	✓	✓	?	✗
Tidal disruption events	?	✗	✓	✓	?	✓	✓	✗
Interlopers	✓	✗	?	✗	✓	✓	?	✗
Jets	?	?	✓	✓	?	?	?	✗



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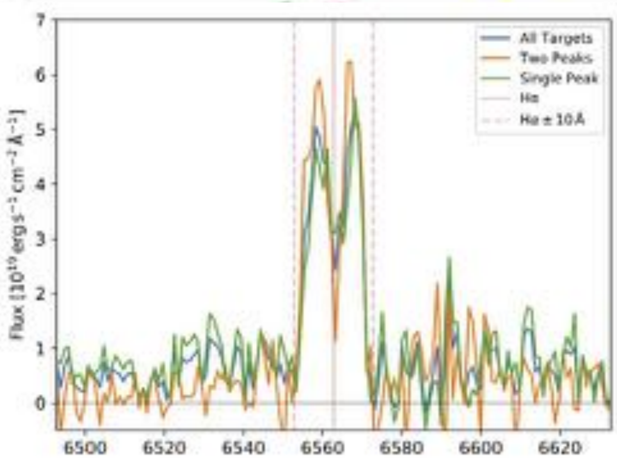
Accretion disks (IMBH)	✓	✓	✓	✓	?	✓	✓	✓
Expanding bubbles (SN)	✓	✓	✓	✓	?	✓	✓	✗
~~Cosmological gas~~	✓	✓	?	?	✗	✓	✓	✓
Planetary nebulae	✗	✓	✓	✓	?	✓	✓	?
X-ray binaries	✗	✓	✓	✓	?	✓	✓	?
~~Shocks~~	?	✓	✓	✗	?	✓	?	✓
Galaxy outflows	✓	✓	✓	✗	✓	✓	?	✗
Tidal disruption events	?	✗	✓	✓	?	✓	✓	✗
Interlopers	✓	✗	?	✗	✓	✓	?	✗
Jets	?	?	✓	✓	?	?	?	✗



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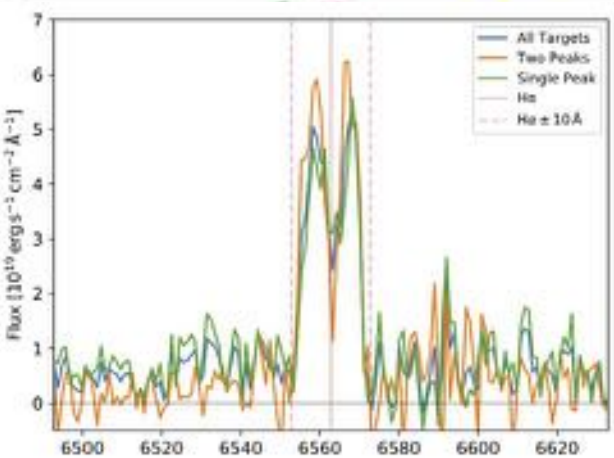
Expanding bubbles (SN)	✓	✓	✓	✓	?	✓	✓	✗
~~Cosmological gas~~	✓	✓	?	?	✗	✓	✓	✓
Planetary nebulae	✗	✓	✓	✓	?	✓	✓	?
X-ray binaries	✗	✓	✓	✓	?	✓	✓	?
~~Shocks~~	?	✓	✓	✗	?	✓	?	✓
Galaxy outflows	✓	✓	✓	✗	✓	✓	?	✗
Tidal disruption events	?	✗	✓	✓	?	✓	✓	✗
~~Interlopers~~	✓	✗	?	✗	✓	✓	?	✗
Jets	?	?	✓	✓	?	?	?	✗



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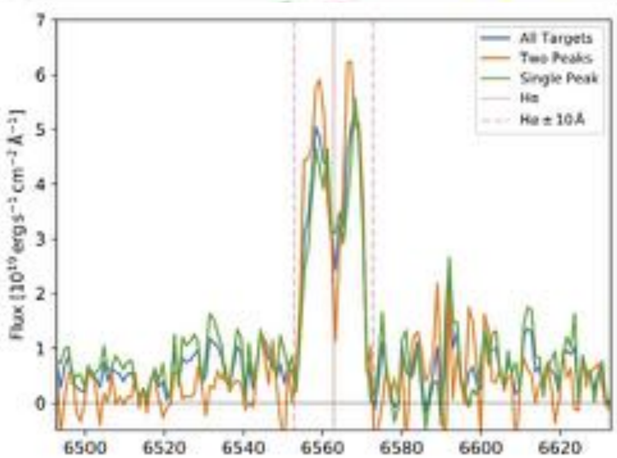
~~Cosmological gas~~	✓	✓	?	?	✗	✓	✓	✓
Planetary nebulae	✗	✓	✓	✓	?	✓	✓	?
X-ray binaries	✗	✓	✓	✓	?	✓	✓	?
~~Shocks~~	?	✓	✓	✗	?	✓	?	✓
~~Galaxy outflows~~	✓	✓	✓	✗	✓	✓	?	✗
Tidal disruption events	?	✗	✓	✓	?	✓	✓	✗
~~Interlopers~~	✓	✗	?	✗	✓	✓	?	✗
Jets	?	?	✓	✓	?	?	?	✗



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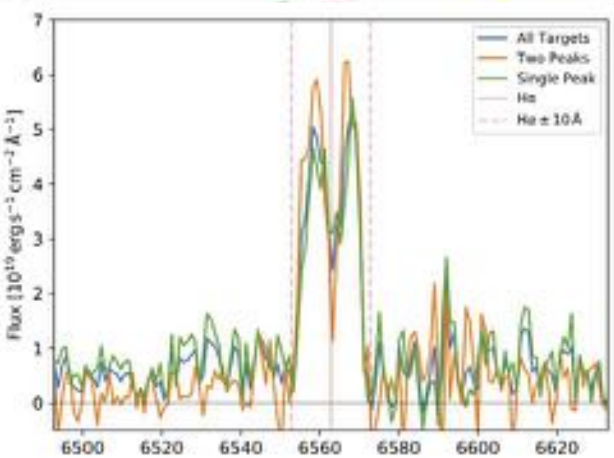
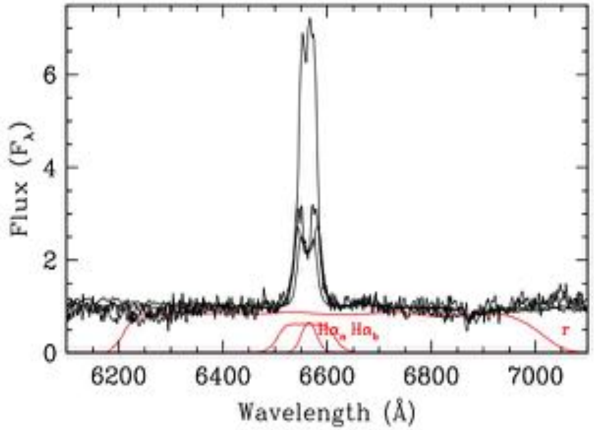
Cosmological gas	✓	✓	?	?	✗	✓	✓	✓
Planetary nebulae	✗	✓	✓	✓	?	✓	✓	?
X-ray binaries	✗	✓	✓	✓	?	✓	✓	?
Shocks	?	✓	✓	✗	?	✓	?	✓
Galaxy outflows	✓	✓	✓	✗	✓	✓	?	✗
Tidal disruption events	?	✗	✓	✓	?	✓	✓	✗
Interlopers	✓	✗	?	✗	✓	✓	?	✗
Jets	?	?	✓	✓	?	?	?	✗



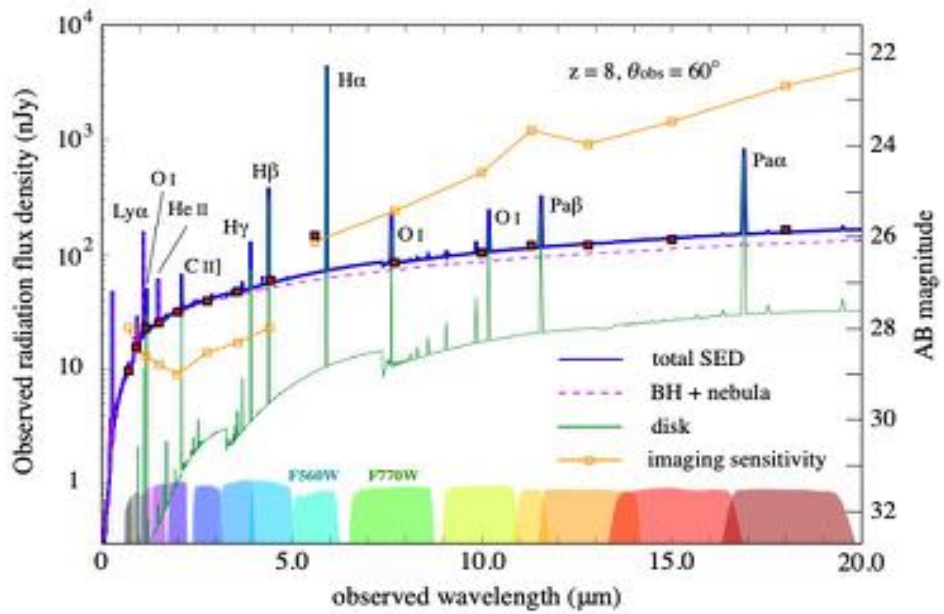
The spatial distribution discards telluric line contamination



- black hole X-ray binaries (BHXBs) Ha spectra have 2 peaks (e.g., Casares & Torres, 2018.

- Why IMHBs? Scaling with the observed Ha Luminosities with BH mass to match the luminosities in BHXBs, our signals could be produced by compact objects with mass between 10^3 and 10^6 M, i.e., in the realm of the IMBHs

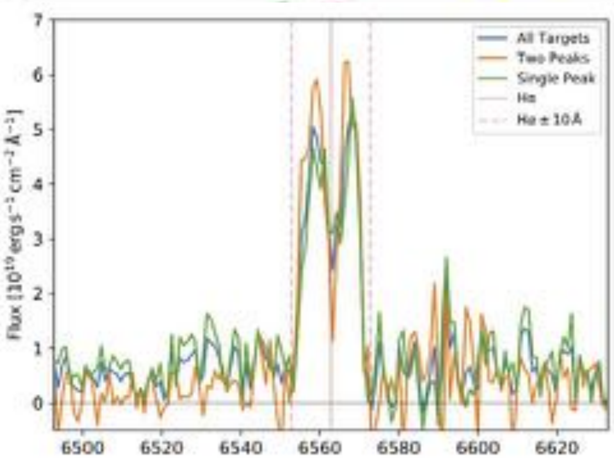
- Ha >> Hb? Maybe.



Synthetic SED of the first massive BHs (Inayoshi+22, ApJL, submitted).

Possible Physical Origin of the Hα emission

Mechanism	Surface Brightness	Number Density	Double Peak	Central Drop	Hβ/Hα	No Continuum	Size	Spatial Distribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Accretion disks (IMBH)	✓	✓	✓	✓	?	✓	✓	✓
Expanding bubbles (SN)	✓	✓	✓	✓	?	✓	✓	✗
Cosmological gas	✓	✓	?	?	✗	✓	✓	✓
Planetary nebulae	✗	✓	✓	✓	?	✓	✓	?
X-ray binaries	✗	✓	✓	✓	?	✓	✓	?
Shocks	?	✓	✓	✗	?	✓	?	✓
Galaxy outflows	✓	✓	✓	✗	✓	✓	?	✗
Tidal disruption events	?	✗	✓	✓	?	✓	✓	✗
Interlopers	✓	✗	?	✗	✓	✓	?	✗
Jets	?	?	✓	✓	?	?	?	✗



The spatial distribution discards telluric line contamination

Summary:

SA+22, ApJ, submitted

◊ Aiming at the detection of cosmological gas, we examined the Ha emission in the halo of 164 galaxies in the field of view of MUSEW (redshift < 0.42).

◊ We found 118 reliable Ha emitting gas clouds.

◊ Surface brightness of $10^{-17.3\pm0.3}$ erg s^{-1} cm^{-2} $arcsec^{-2}$.

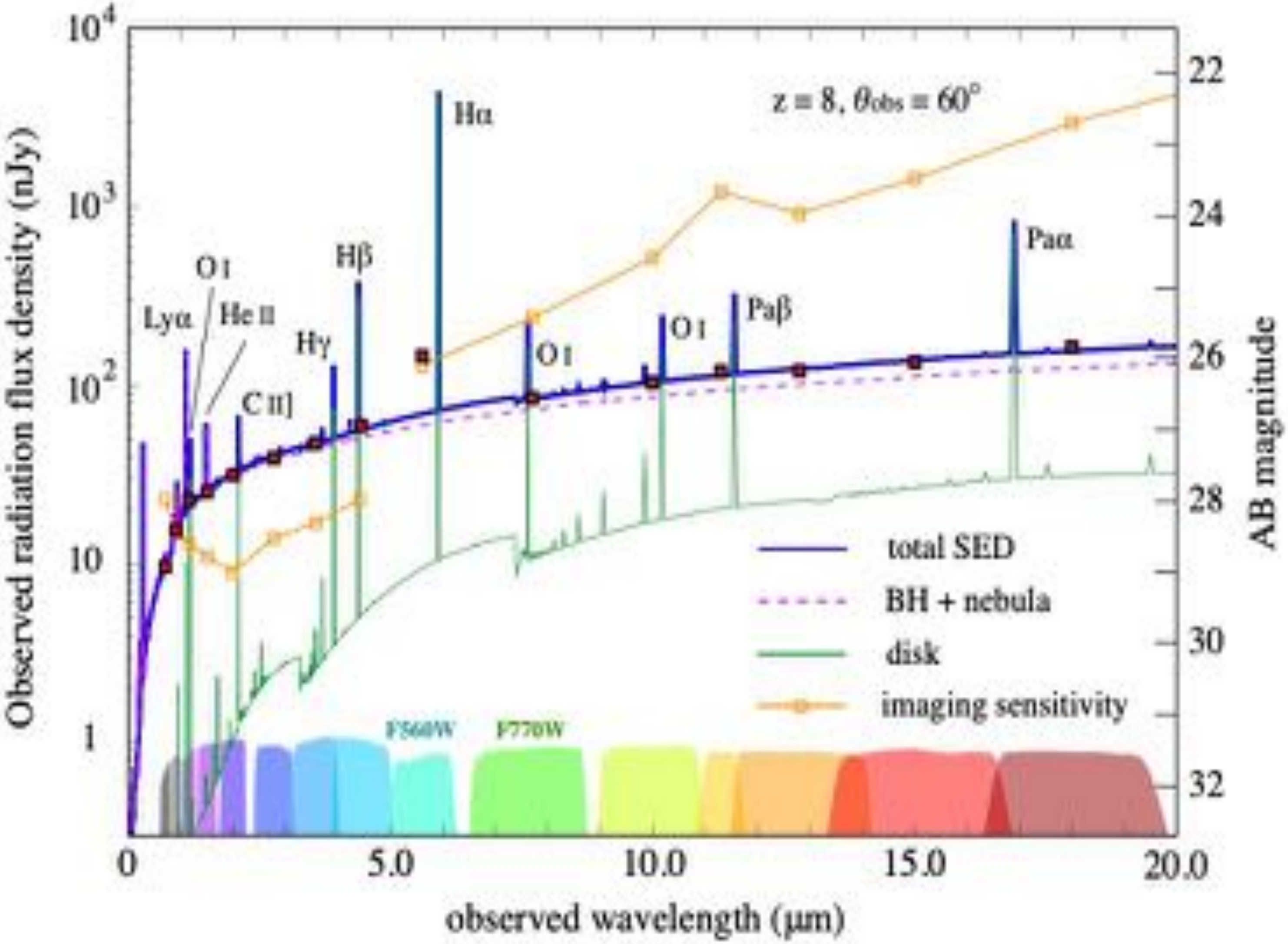
◊ They are not created by instrumental artifacts, telluric line residuals, or high redshift interlopers.

◊ 40 % of the Ha line profile shows a double peak with the drop at the rest-frame of the central galaxy, and with a typical peak-to-peak separation of ±175 km s^{-1} .

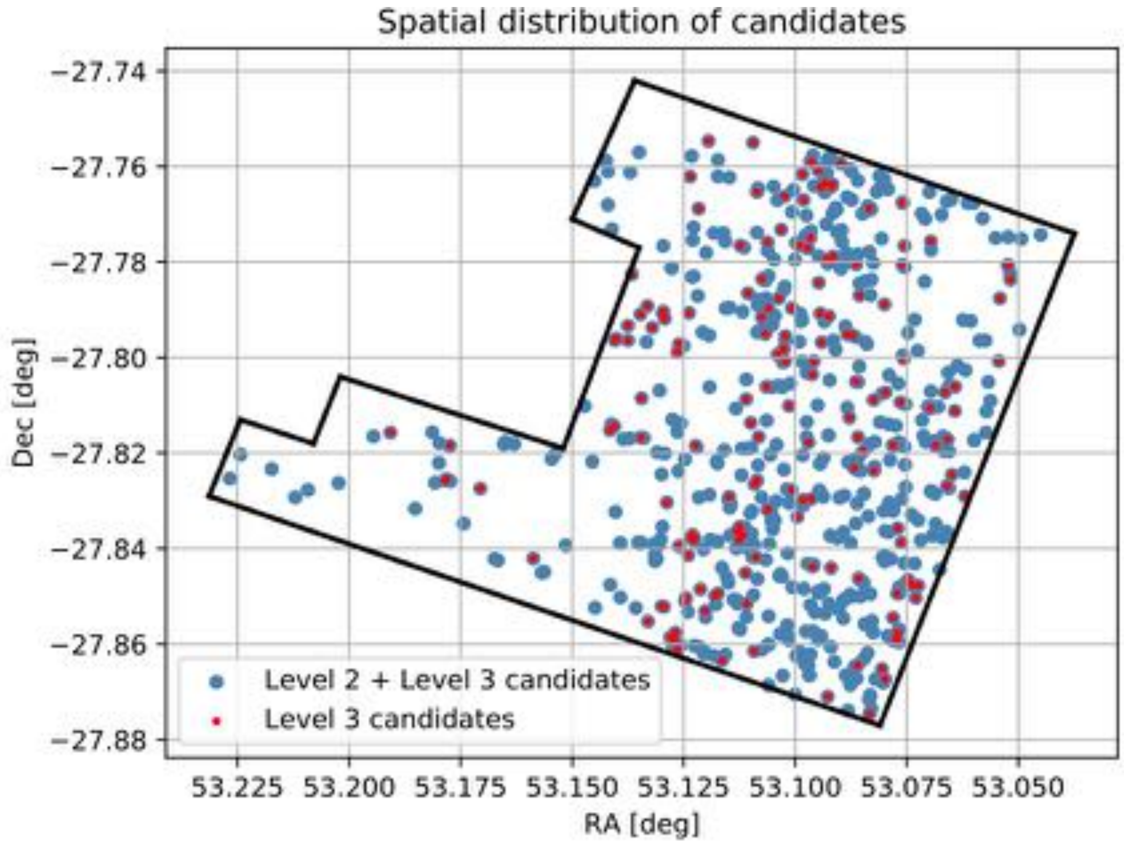
◊ Most line emission clumps are spatially unresolved (1").

◊ The signals are not uniformly distributed; their azimuth tends to be aligned with the major axis of the galaxy and their presence drops at a distance corresponding to the virial radius of the central galaxy.

◊ We explore several physical scenarios, among which accretion disks around rogue intermediate mass black holes fit the observations best.



Synthetic SED of the first massive BHs (Inayoshi+22, ApJL, submitted).


Spatial distribution of candidates
−27.74
−27.76
−27.78
−27.80
−27.82
−27.84
−27.86
−27.88
Dec [deg]
53.225
53.200
53.175
53.150
53.125
53.100
53.075
53.050
RA [deg]
Level 2 + Level 3 candidates
Level 3 candidates

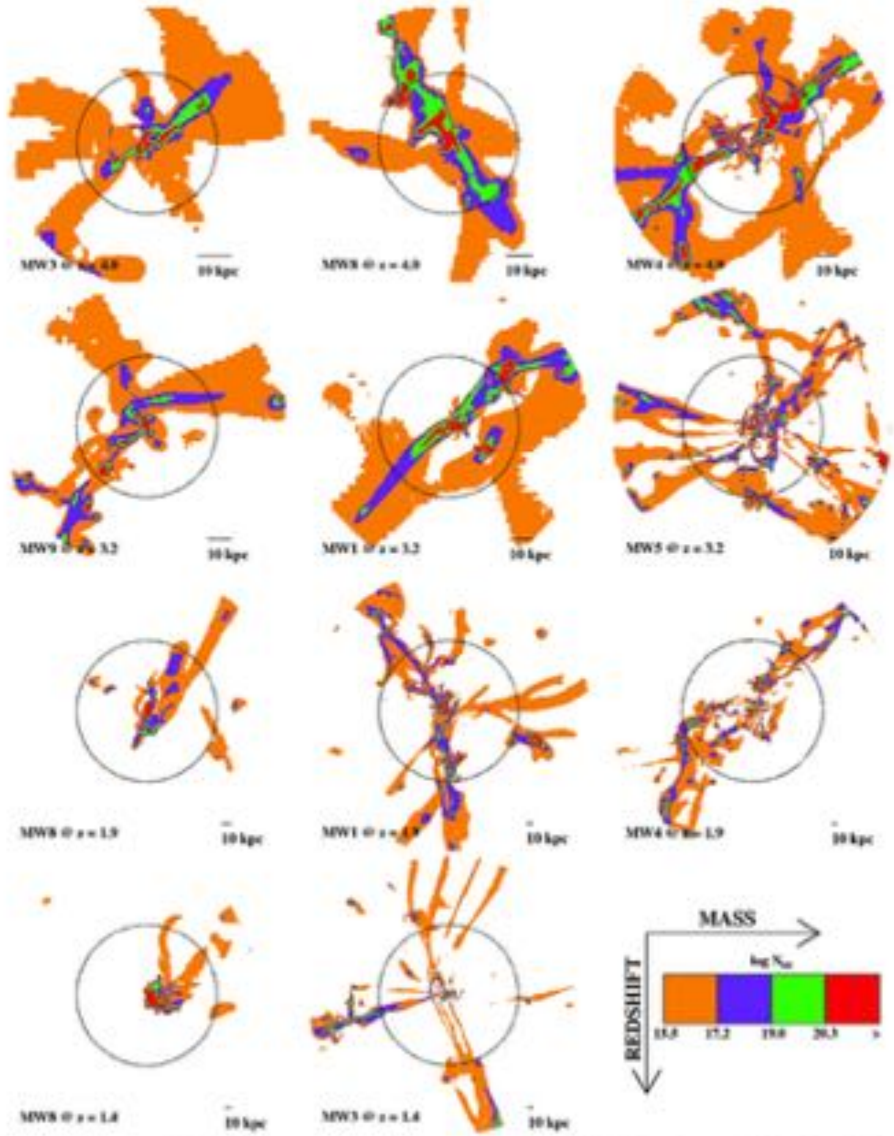
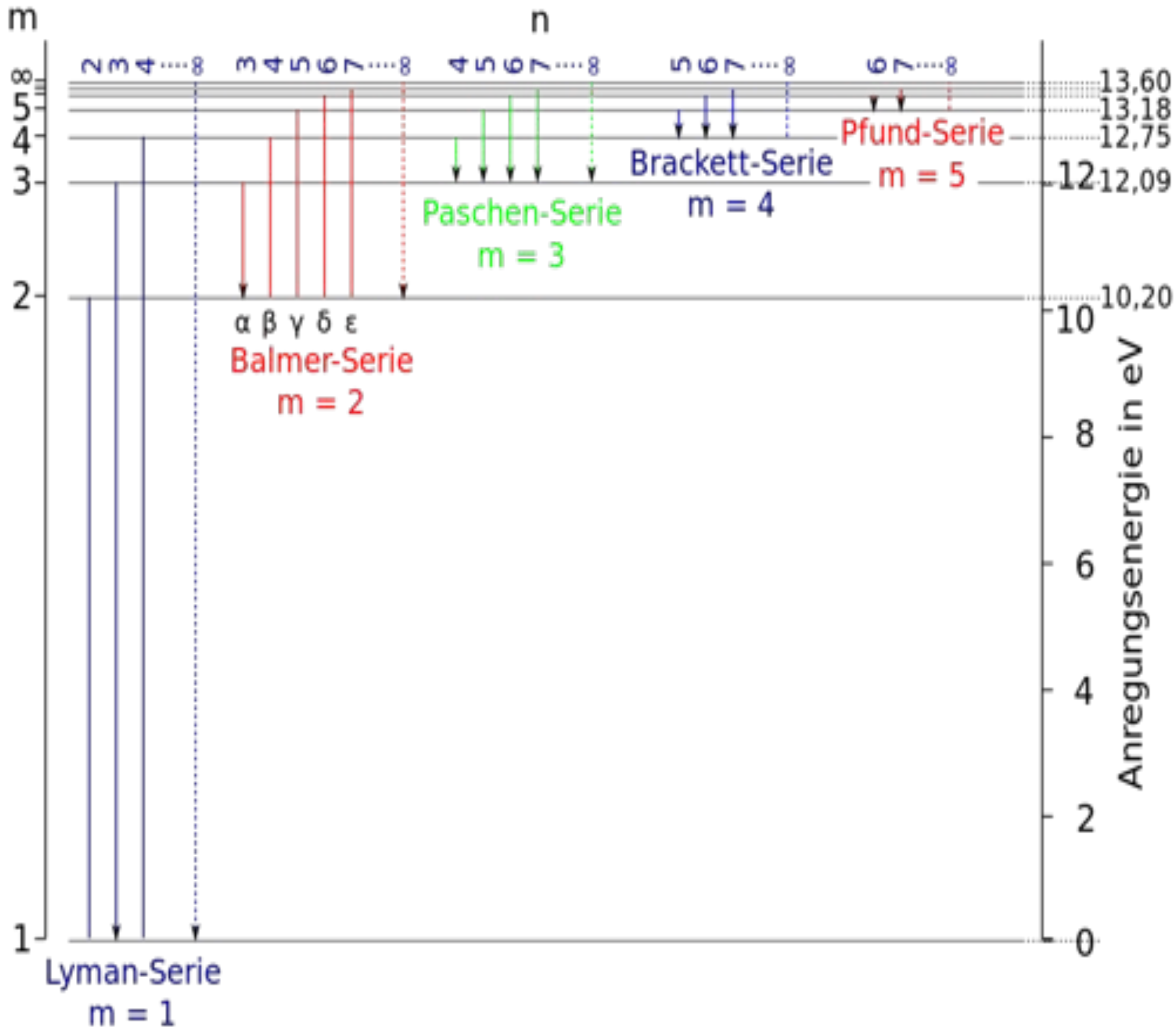
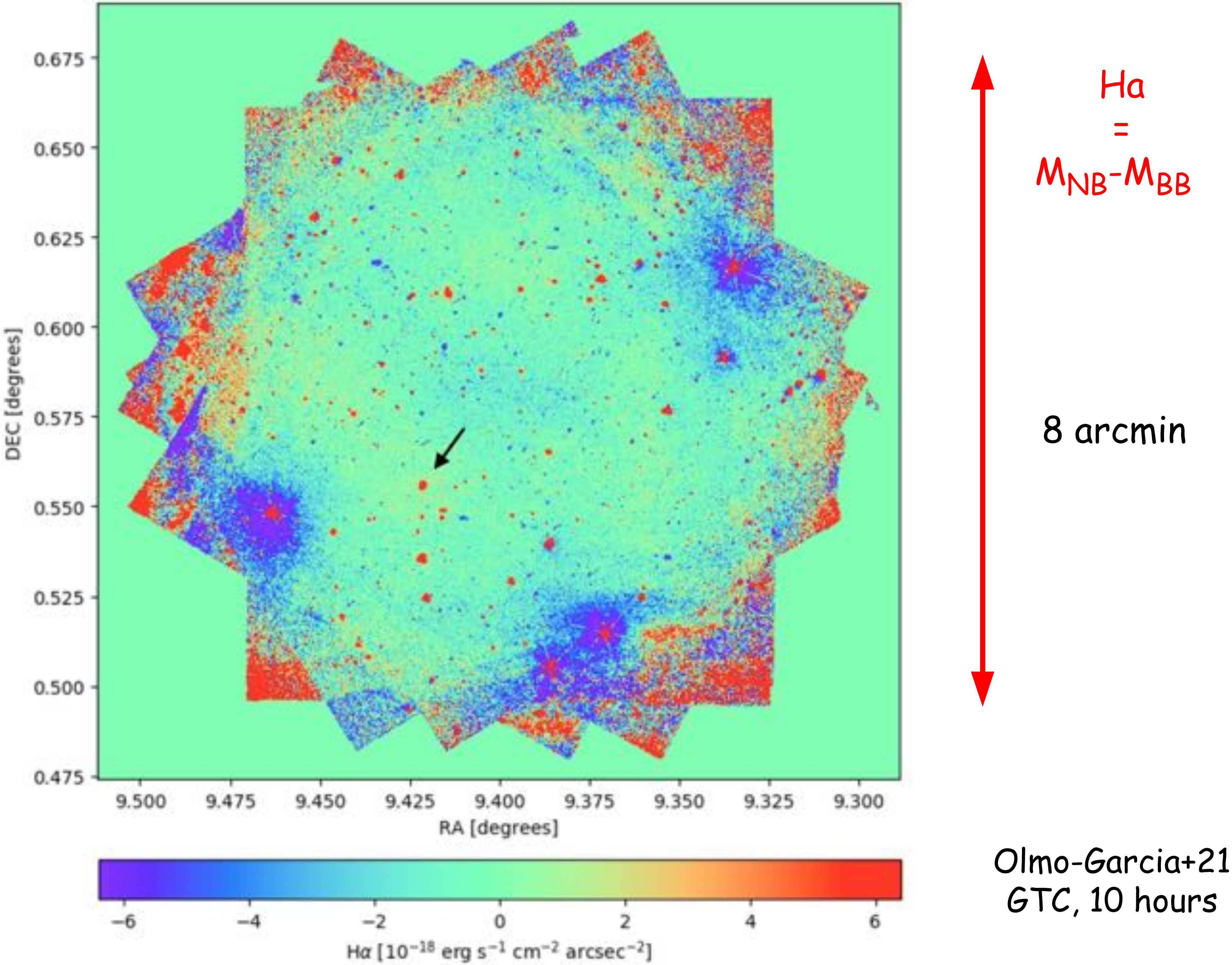


Fig. 4 HI column densities in the cosmic web for a number of model galaxies in cosmological simulations as worked out by Fumagalli et al. (2011b). Color codes four intervals of column density including LLSs (in *blue*) to DLAs (in *red*). Redshift is decreasing from *top* to *bottom*, and virial mass is increasing from *left* to *right*. The *dotted circles* mark the virial radius. The cold streams are very patchy, with pockets of neutral gas immersed in an ionized medium


m
n
Lyman-Serie
m = 1
Balmer-Serie
m = 2
α β γ δ ε
Paschen-Serie
m = 3
Brackett-Serie
m = 4
Pfund-Serie
m = 5
13,60
13,18
12,75
12,09
10,20
Anregungsenergie in eV


0.675
0.650
0.625
0.600
0.575
0.550
0.525
0.500
0.475
DEC [degrees]
9.500
9.475
9.450
9.425
9.400
9.375
9.350
9.325
9.300
RA [degrees]
−6
−4
−2
0
2
4
6
Hα [10−18 erg s−1 cm−2 arcsec−2]
Hα
=
MNB-MBB
8 arcmin
Olmo-Garcia+21
GTC, 10 hours

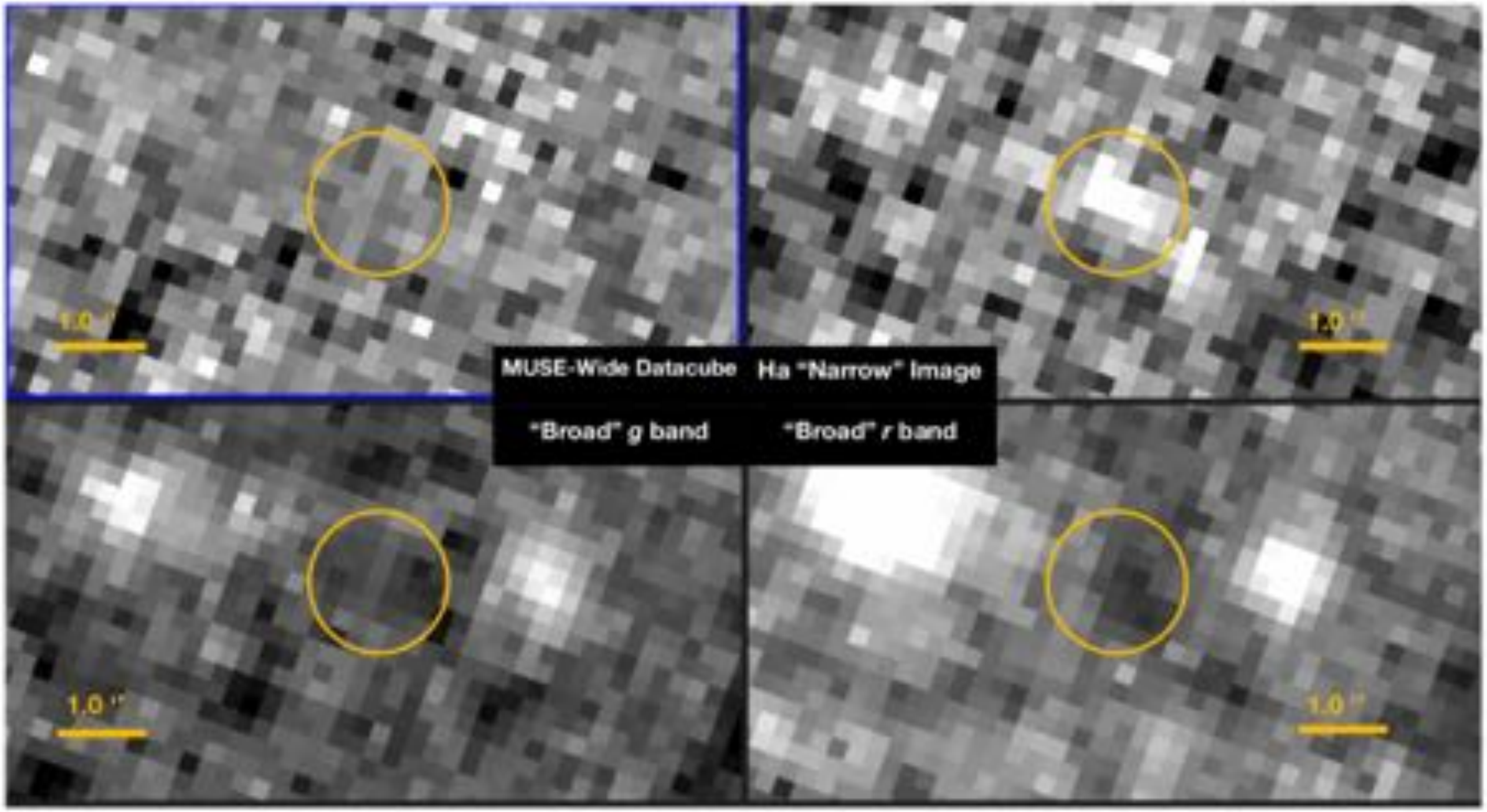


Figure 1. The process of selecting candidates. The first panel shows a wavelength slice as seen in the data cube itself. The yellow circle marks the region where the candidate is expect to be and the size assigned to it from the inspection of the collapsed Hα image. The upper right panel shows the Hα narrow band image. Candidates need to have a distinguishable emission in this band in order to be considered for selection. The lower panels show the broad band images of the r and g bands, respectively. A valid candidate will have negligible or no emission in these bands. The yellow band shows the length corresponding to $1.0''$, the average resolution achieved in MUSE-Wide due to seeing constraints.