Tracing escape channels for LyC photons in EELGs

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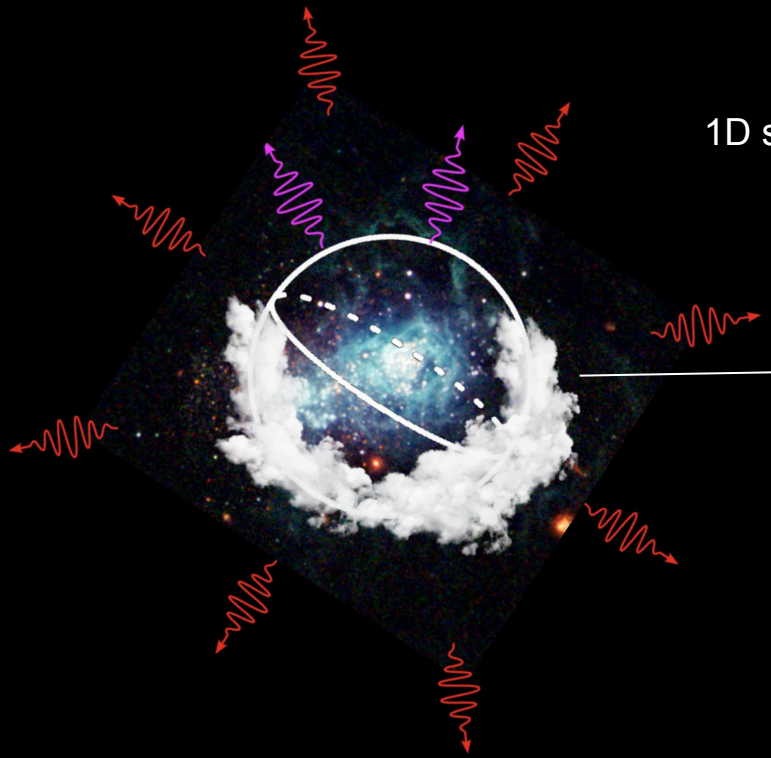
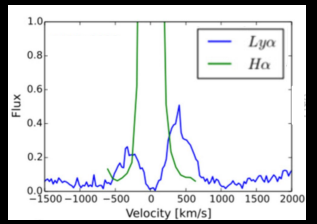
EXCELENCIA SEVERO OCHOA
CSIC

Escape of high energy photons scenario



1D spectroscopy

High [OIII]/[OII] (ext.cor.)
High extinction
Low escape
Low turbulence?



Yang et al. (2016)

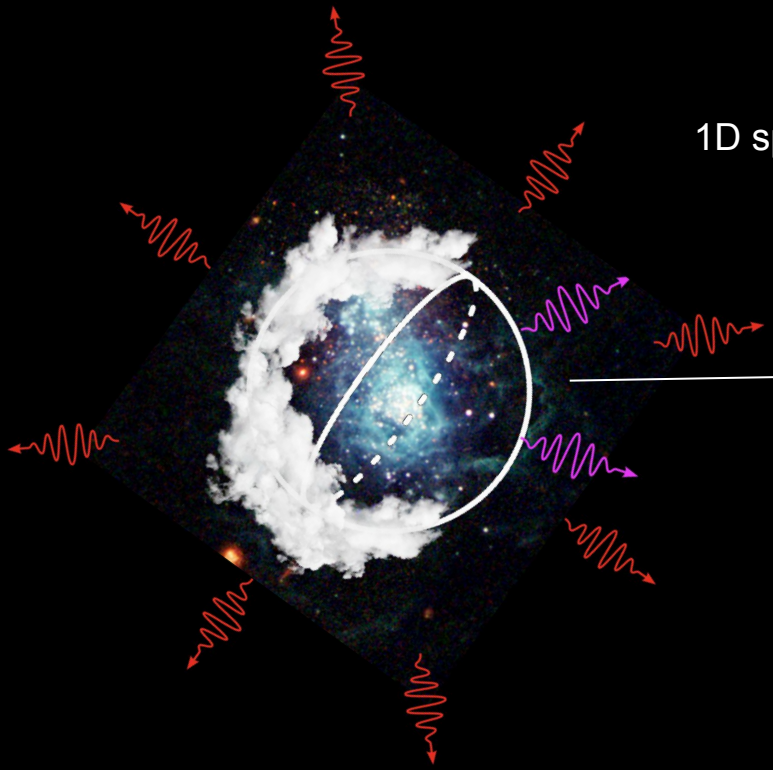
Line of sight

HI gas and dust

Low energy photons

High energy photons

Escape of high energy photons scenario



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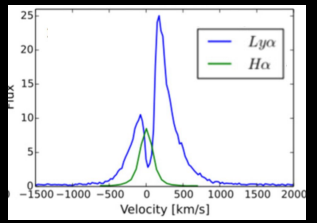

Yang et al. (2016)

Line of sight

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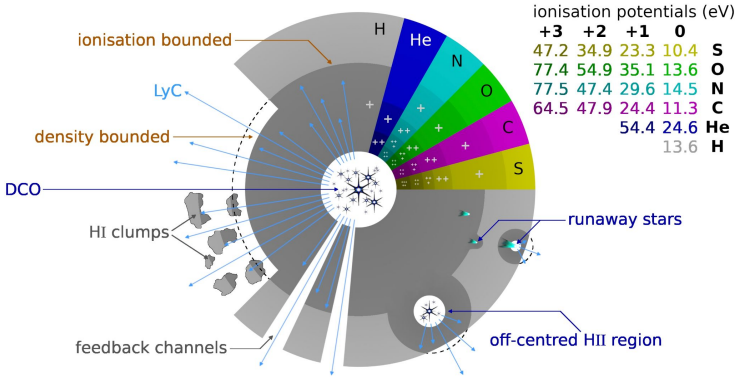
Low energy photons

High energy photons

Importance of 2D spectroscopy

The **total** intrinsic (solid angle integration) **escape fraction** of a galaxy **does not depends on orientation** but **line of sight measurement** of escape fraction **does.**

Geometry of **HI gas** and **dust** is key in understanding the **escape** of high energy photons.



Enders et al. (2023)

High [OIII]/[OII] is a **necessary** but **not sufficient** condition for **escaping ionizing radiation**. [OIII]/[OII] depends also on U and metallicity.

e.g. Izotov et al. (2018)

Geometry and **orientation** also determine it.

Izotov et al. (2021)

To take into account the **orientation** of the galaxy we can not wait for the galaxy to rotate over itself.

Statistic

2D spectroscopy

Ionized gas in escape channels / regions

-No UV IFS so far.
-**Optical IFS** gives us information about the **ionized gas** in galaxies.

What are the **properties** of the **ionized gas** that we expect where **high energy photons** are **escaping**?

-**High ionization** ([OIII]/[OII], [OIII]/Hβ)
-**Low extinction** (Hα/Hβ)
-Disturbed / **complex kinematics** (Velocity dispersion)
-**Density-bounded** tracers ([SII]/Hα, [OI]/Hα)
-Detectable **brightness** of the **ionized gas** in zones far away from central ionizing object (as seen in Hα and [OIII] maps)

e.g.: T. M. Heckman et al. (2011),
Herenz et al. (2017), Izotov et al. (2018),
Vanzella et al. (2018)

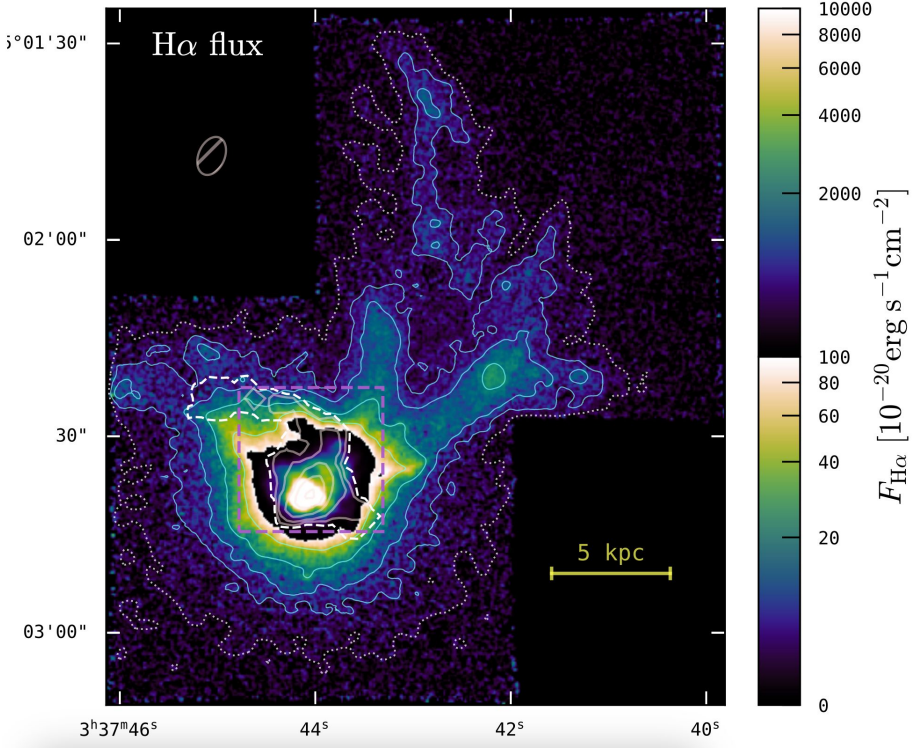
Previous studies on tracing escape channels

SBS 0335-052E has a **[OIII]/[OII] ~ 15** and shows **very strong Lyα absorption** indicating an **extremely high neutral hydrogen column density along the line of sight.**

Thuan & Izotov (1997), Izotov et al. (2017)

-**Brightness** in the **ionized gas** in form of **filaments** in the outer part of the galaxy.
-The **filament** exhibit unusual **low Hα/Hβ** ~ 2.4.

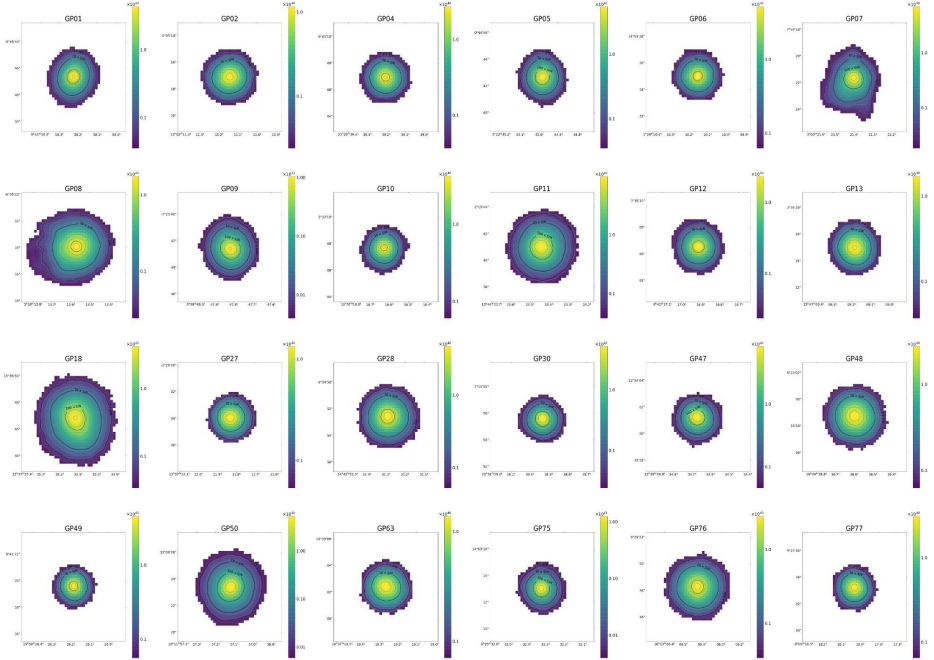
Herenz et al. (2023)



See also e.g.: V. Menacho et al. (2019), A. Bik et al. (2015), M. S. Westmoquette et al. (2008)

Green Peas seen with MUSE/VLT

Hα maps



Arroyo-Polonio et al. (submitted)
Observations PI: Matthew Hayes

-Green Peas are galaxy starburst at z=0.112-0.360.

-Discovered by galaxy zoo volunteers.

-Upper size limit of 5000 pc in HST images (16% Milky way diameter).

-Reside in low density environments.

-Low metallicity 12+log(O/H) = 7.6-8.4 (~1 O atom - 1000 H atoms).

-Average mass of ~3,200 million M⊙,
star formation rate of ~20 M⊙/yr
and thus a depletion time of 160 Myr.

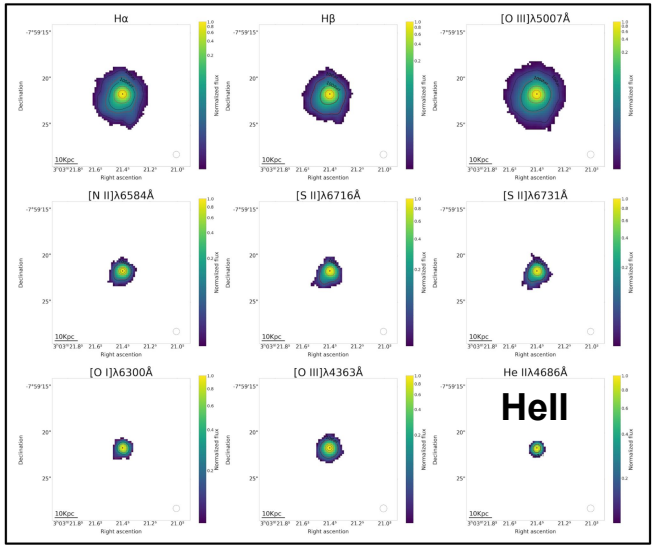
-Most of them are Lyα emitters and there are some confirmed LyC leakers among the GPs.

C. Cardamone et al. (2009), R. O. Amorín et al. (2010),
A. Jaskot et al. (2014), H. Yang et al. (2017)

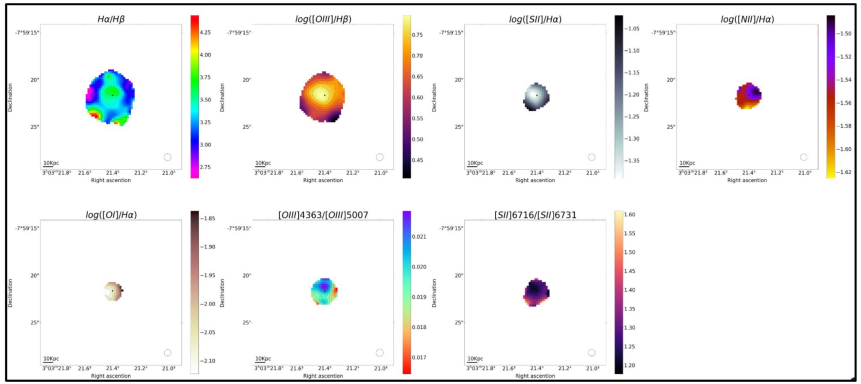
Green Peas seen with MUSE/VLT

-**Limit of spatial resolution**.
Various criteria to determine **spatial extension** (**core** and **low surface brightness regions**).
-Atmosphere Rayleigh scattering correction.

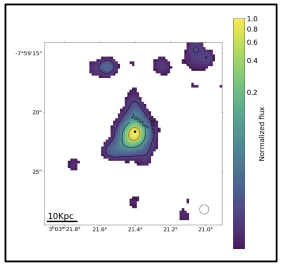
-**Emission line** maps



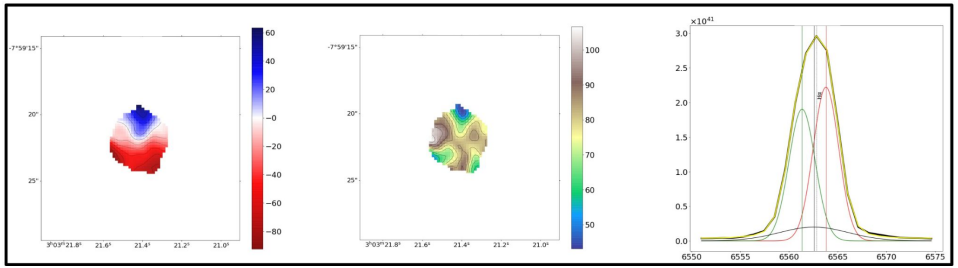
-**Emission line ratios** maps (e.g. Hα/Hβ, [SII]/Hα).



-Maps of the **continuum**.

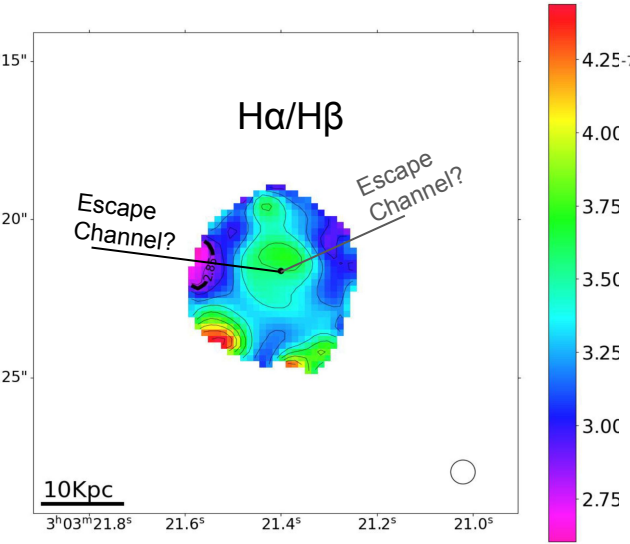


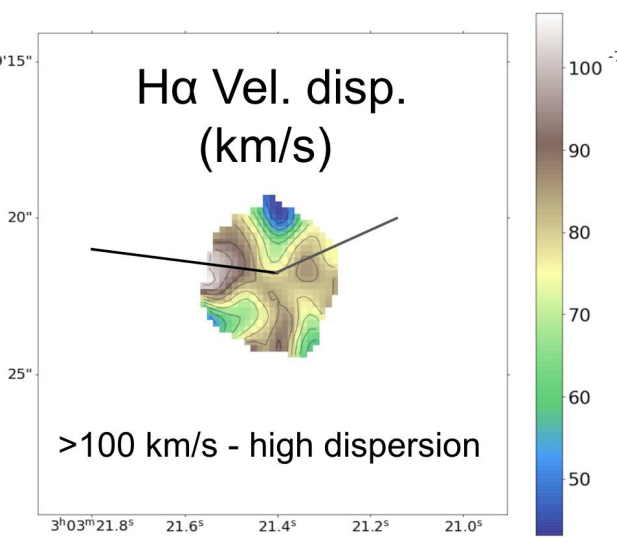
-**Kinematics**: Velocity and dispersion maps.
Multi-gaussian fit to emission line profile.

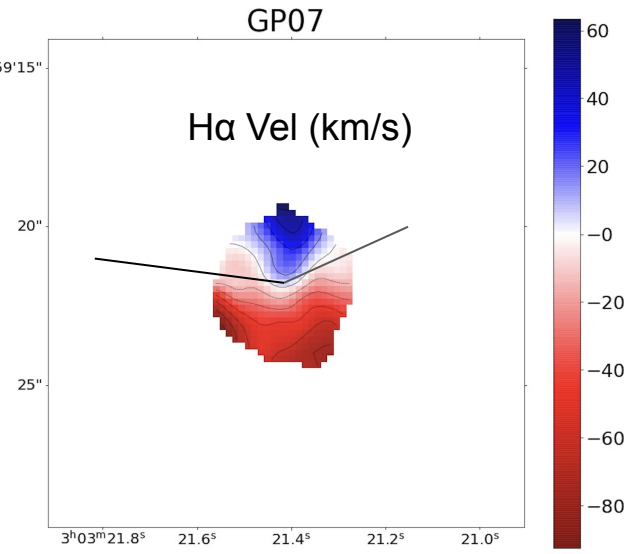


GP06 / J030321.41−075923.2

[OIII/OII] = 9
12 + log(O/H) = 7.9







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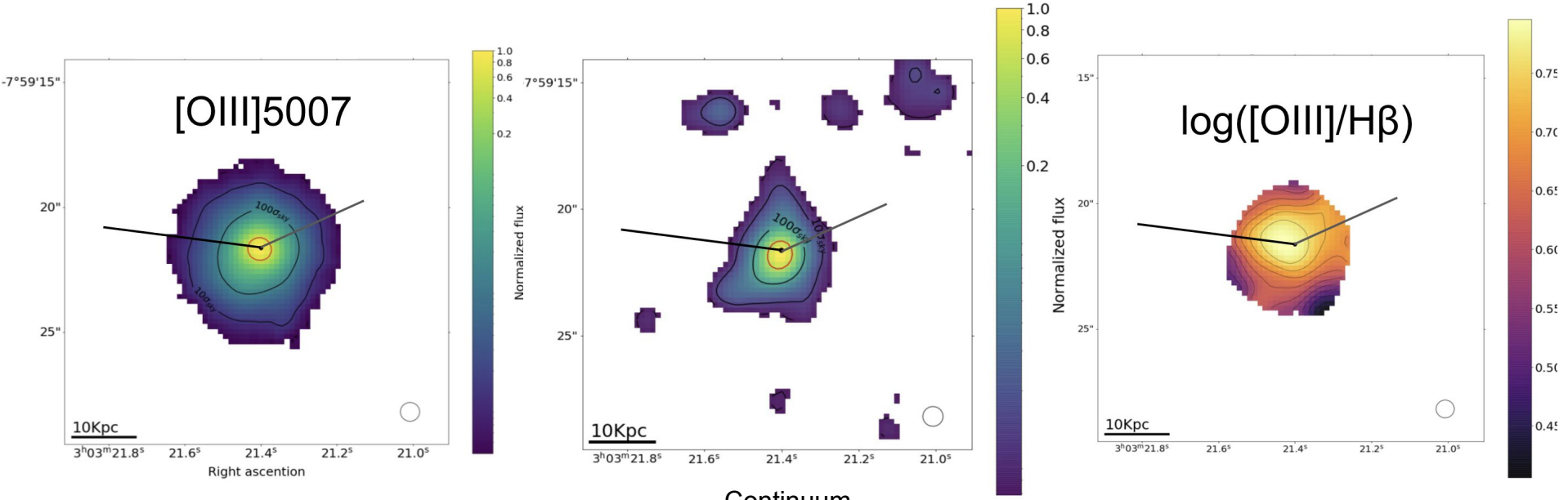
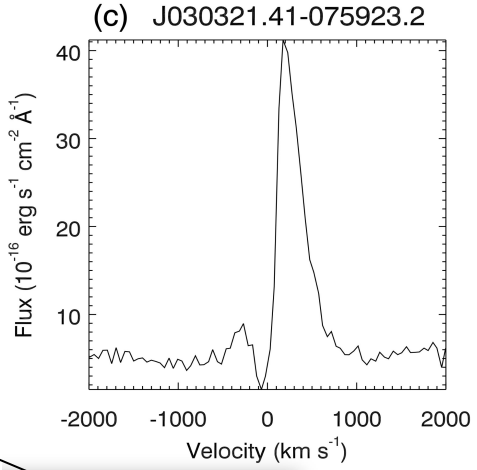


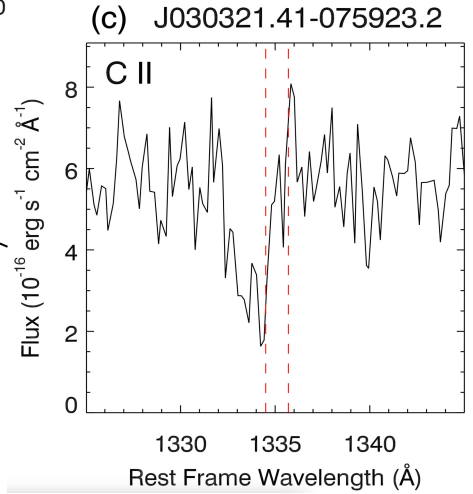
Continuum
4154Å-7026Å rest frame

GP06 / J030321.41−075923.2

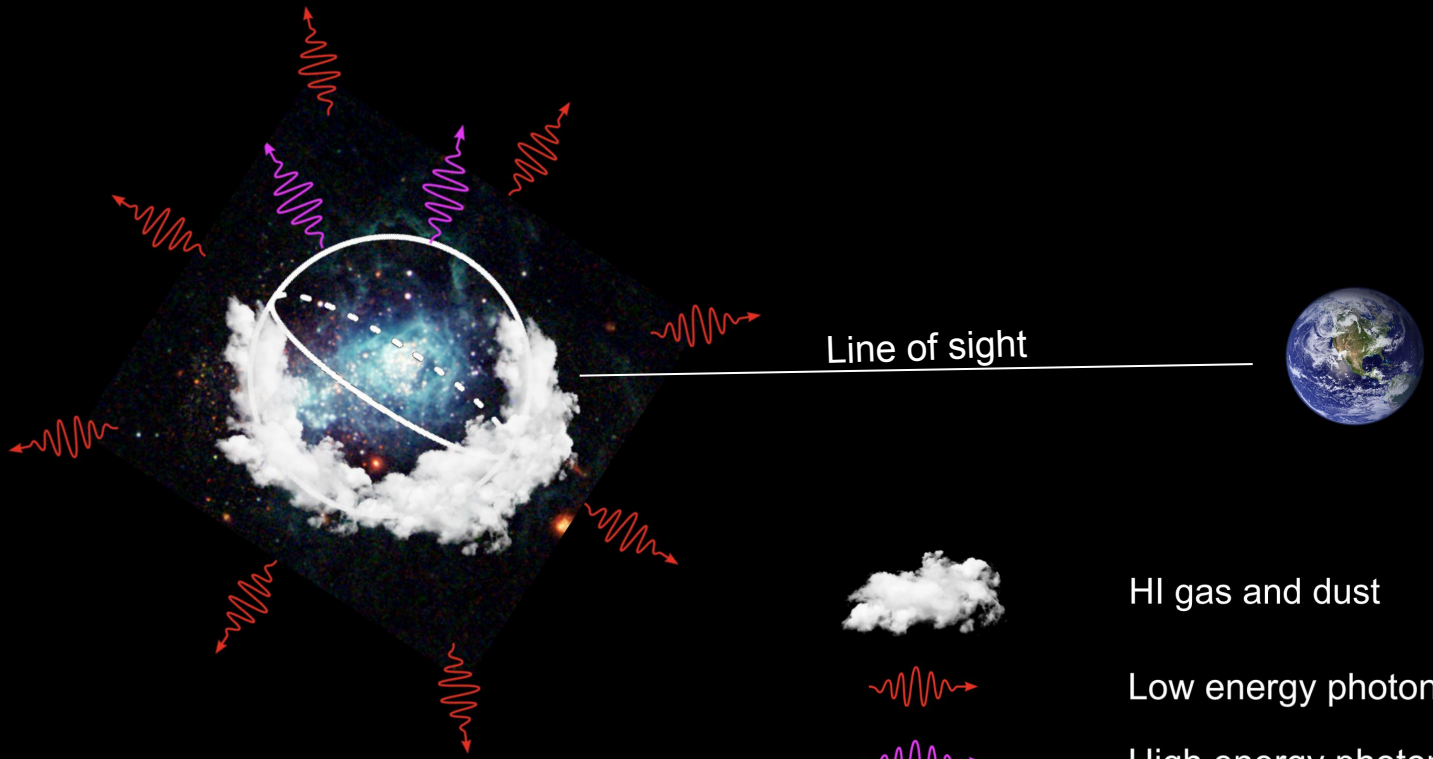
-**2% Lyα escape.**
-**High optical depth** (P-cygni Lyα profile and high vel. sep. between peaks).
-CII blueshifted and broad absortion + low extinction:
Neutral outflow aligned with the LOS.
-Conclusion: **Optically thick, neutral outflow along the LOS.**

Jaskot & Oey (2014)





SBS 0335-052E and GP06 case?



Conclusions

-Our study of Green Pea galaxies using the MUSE / VLT data cubes has provided valuable insights into their ionized gas properties, revealing information about the ionization structure and kinematics.

-IFS UV would be the best tool to trace LyC escape channels. Map of the velocity separation between peaks in Lyα line.

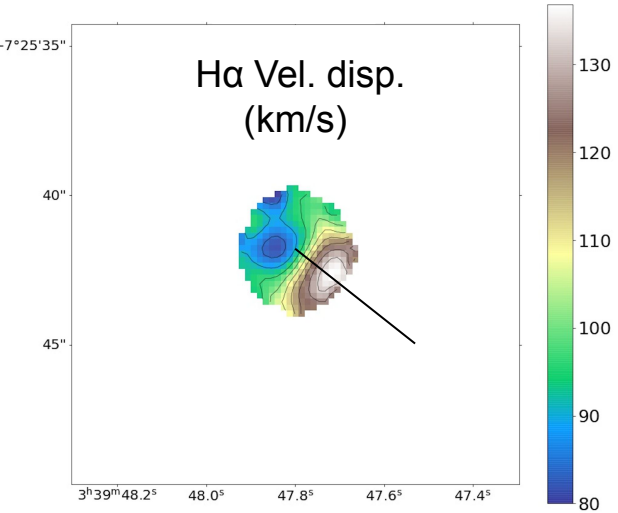
-Optical IFS may bring some clues about regions / channels where the high energy photons can escape. Ionized gas through which these photons travel likely exhibits specific properties, such as low extinction, high ionization, and high velocity dispersion.

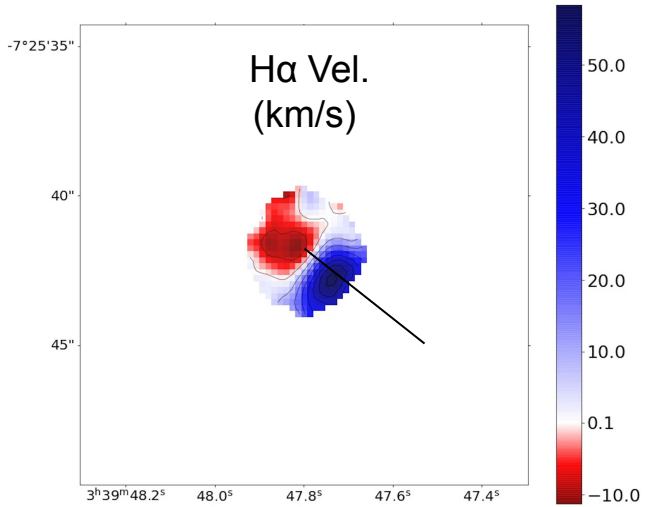
-The orientation of the galaxy and the geometry of the HI gas and dust are essential factors that influence the measurement of the LyC escape fraction.

-Galaxies such as SBS 0335-052E and GP06 may have very low / no LyC escape in the line of sight but could potentially present channels perpendicular to it.

Thank you for your attention

GP08


Hα Vel. disp.
(km/s)
-7°25'35"
40"
45"
3h39m48.2s
48.0s
47.8s
47.6s
47.4s
130
120
110
100
90
80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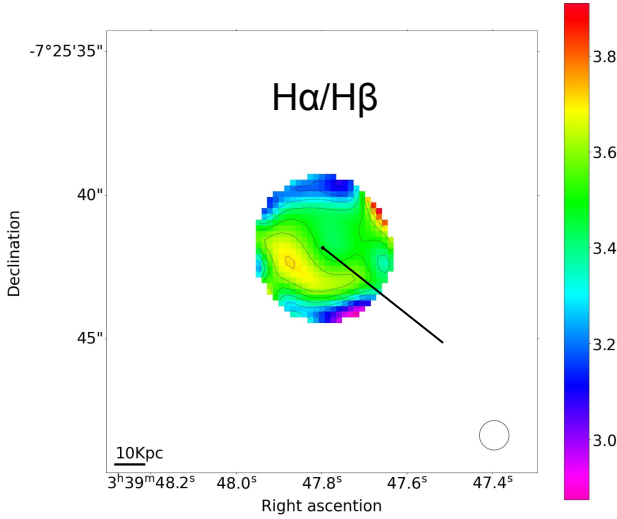
40.0
30.0
20.0
10.0
0.1
−10.0


Hα/Hβ
-7°25'35"
40"
45"
Declination
10Kpc
3h39m48.2s
48.0s
47.8s
47.6s
47.4s
Right ascention
3.8
3.6
3.4
3.2
3.0

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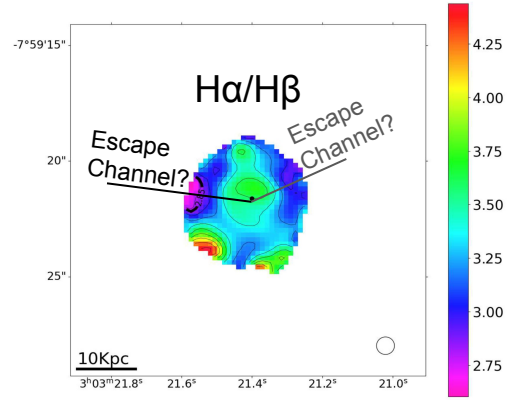

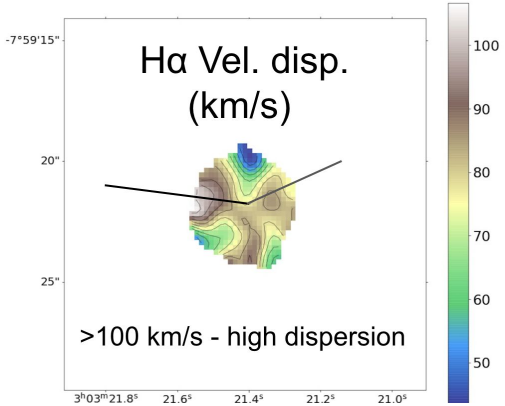

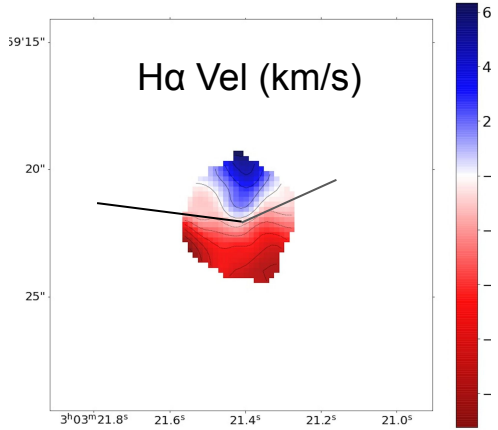

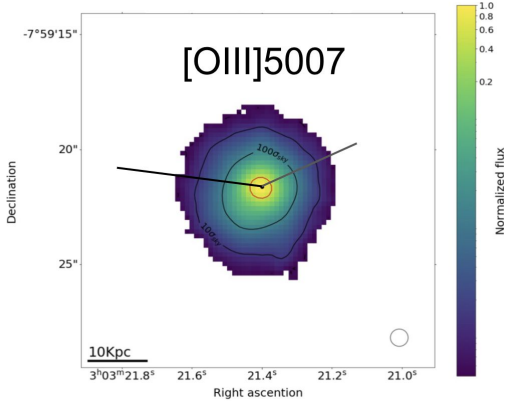

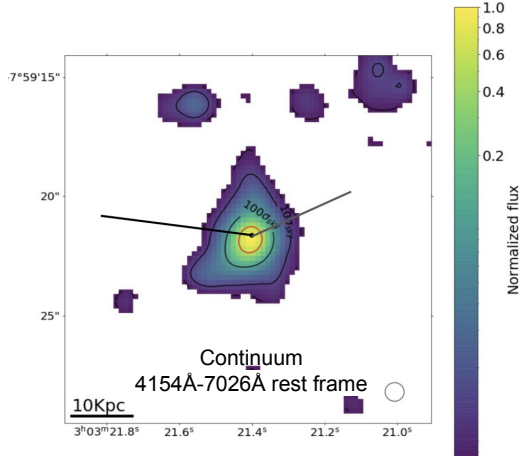

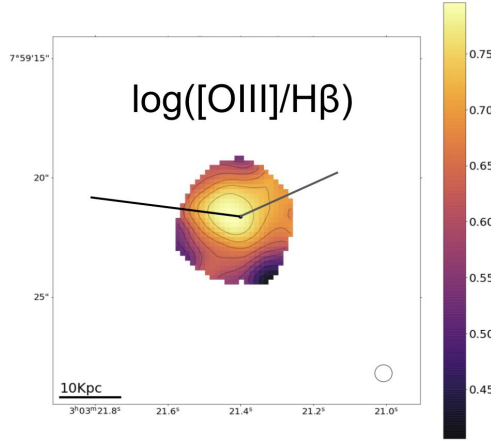

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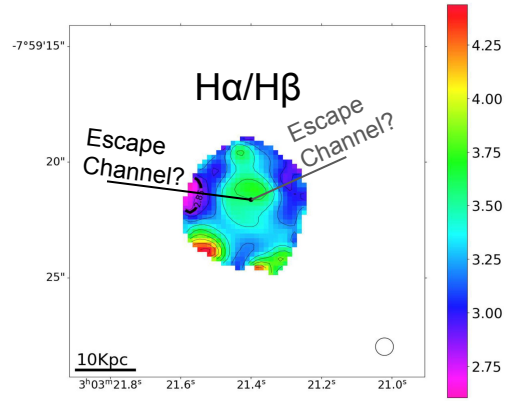
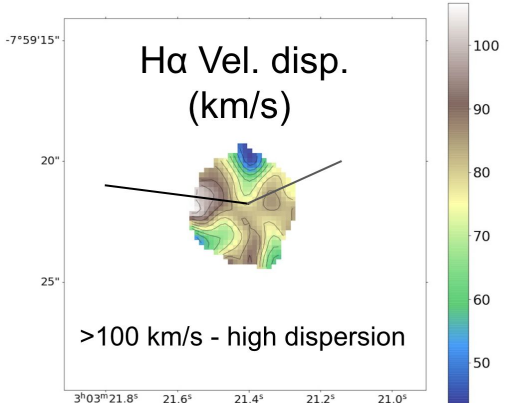
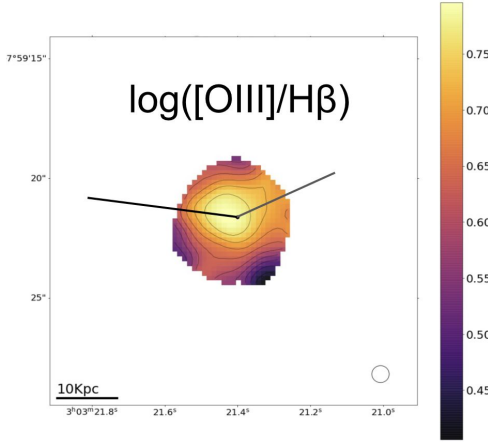
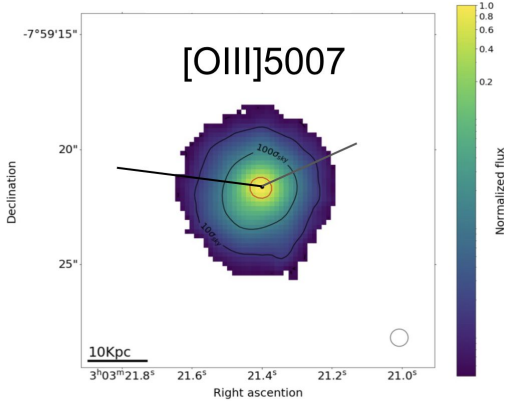
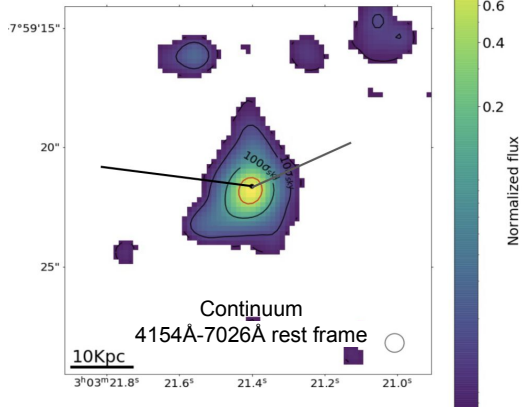
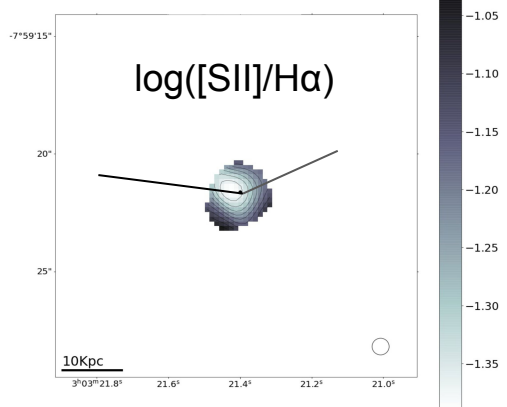






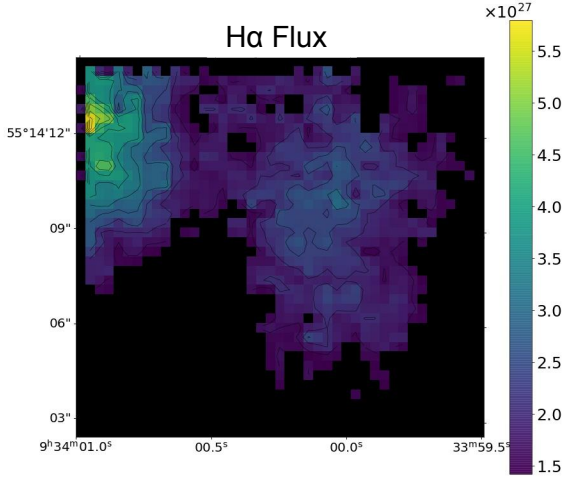




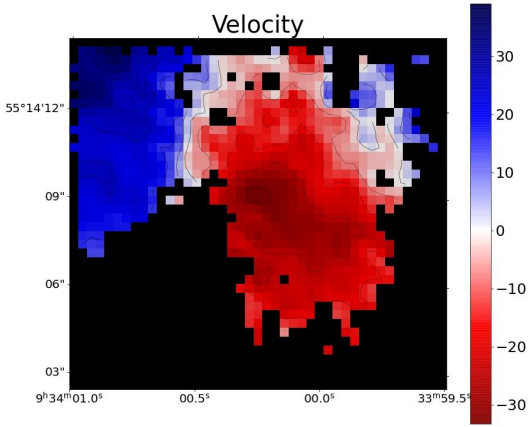


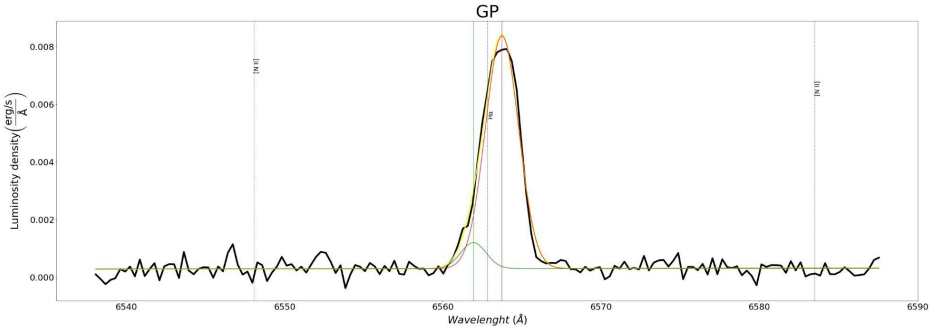
Thank you for your attention

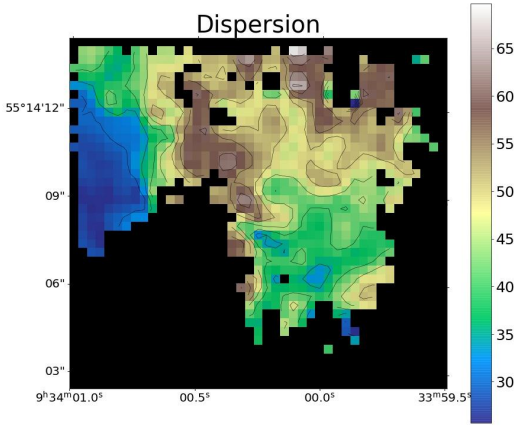
Other work regarding my thesis



IZw18 halo kinematics



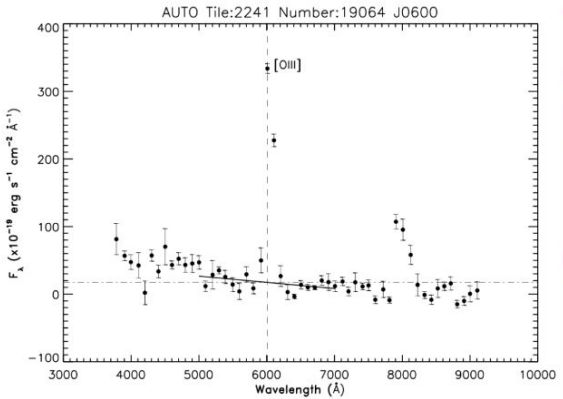


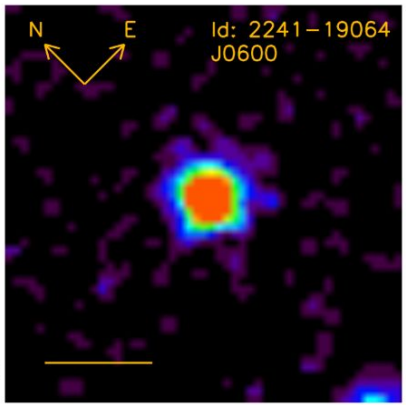


Other work regarding my thesis

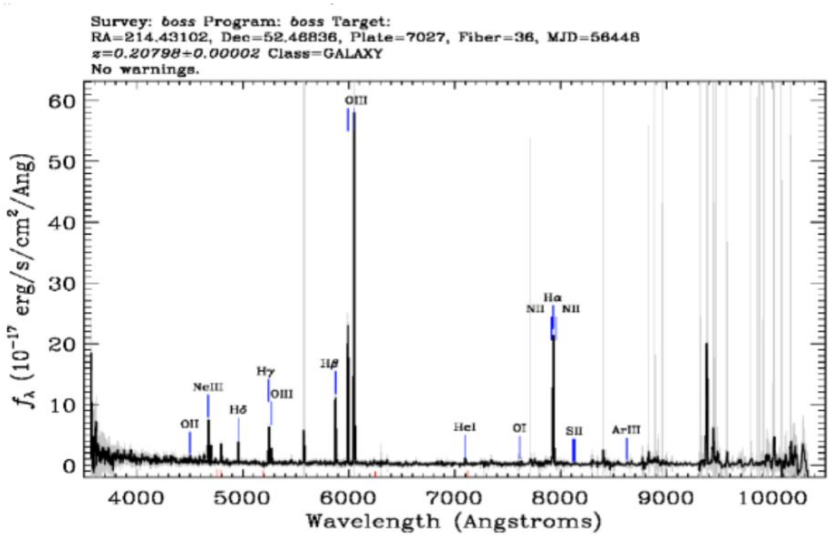
Searching for
EELGs in JPAS

JPAS photospectrum

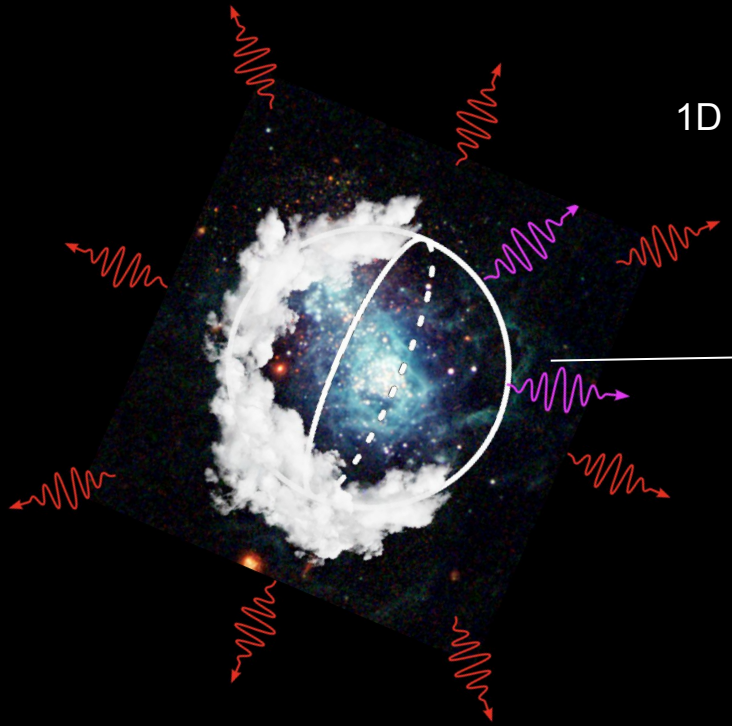




SDSS spectrum



Escape of high energy photons scenario



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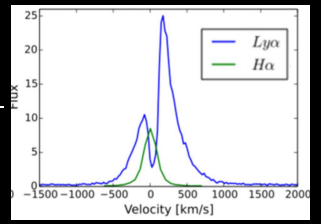

Credit: Yang et al 2016

Line of sight

HI and gas

Low energy photons

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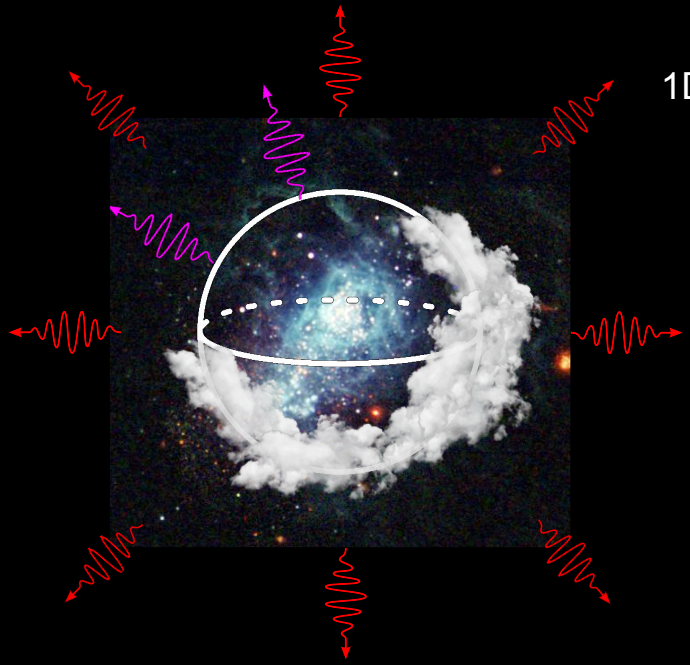

1D spectroscopy

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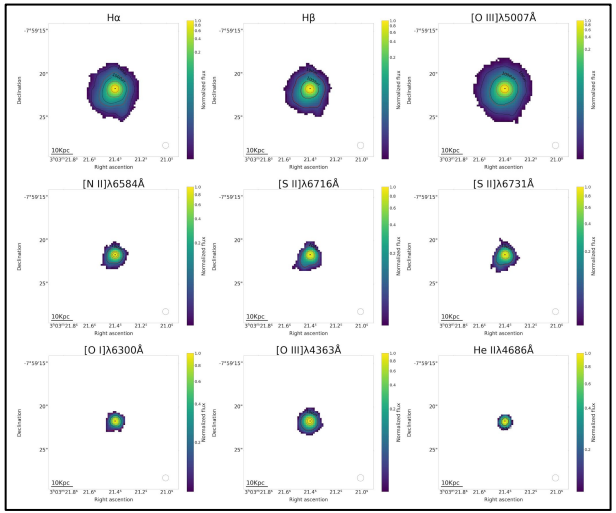
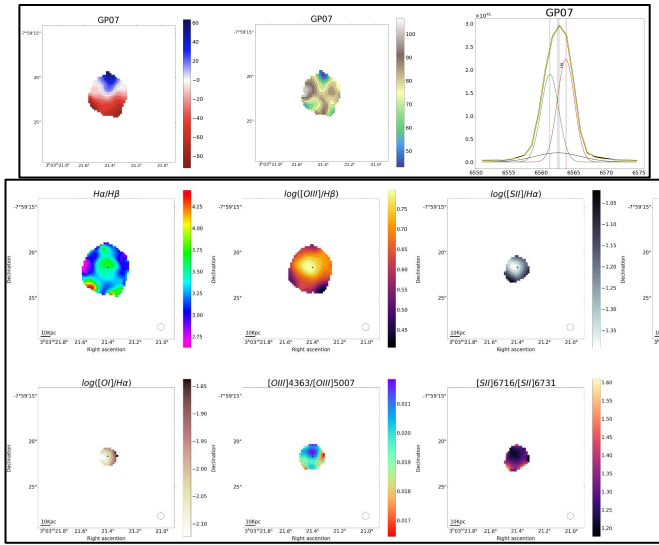
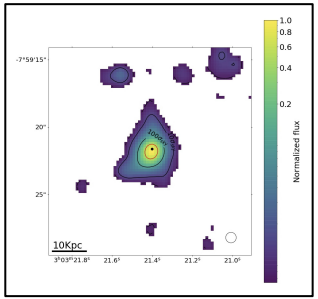
-**Limit of spatial resolution**. Various criteria to determine **spatial extension** (**core** and **low surface brightness regions**)
-Atmosphere Rayleigh scattering correction

-**Emission line** maps and **emission line ratios** maps (e.g. Hα/Hβ, [OIII]/[OII])
-Maps of the **continuum**.
-**Kinematics**: Velocity and dispersion maps. Multi-gaussian fit to emission line profile
-3 GPs present nebular **Hell emission**

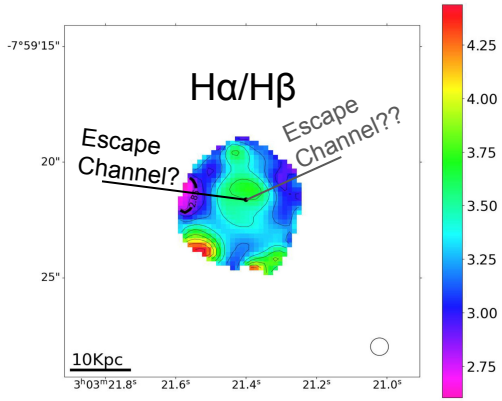


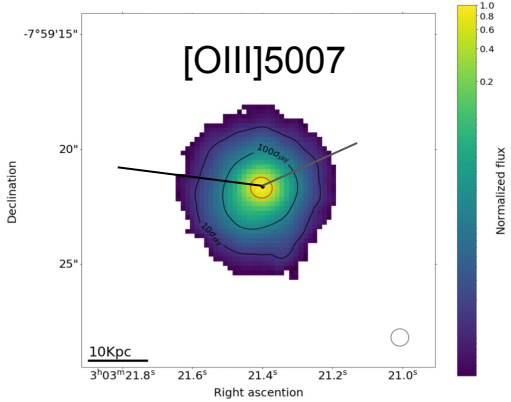




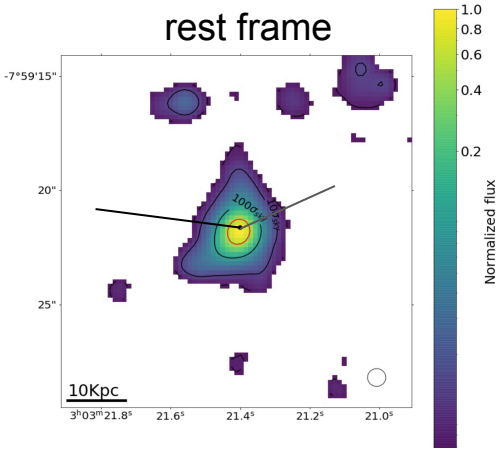
GP06 / J030321.41−075923.2

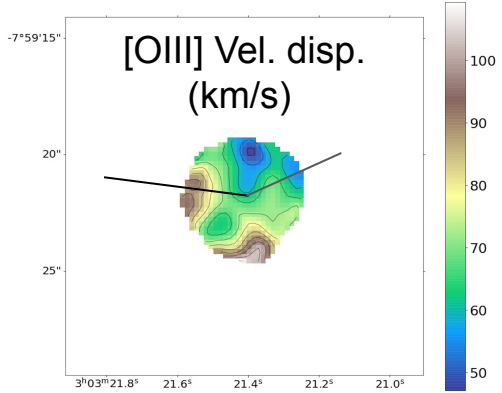
[OIII/OII] = 9
12 + log(O/H) = 7.9

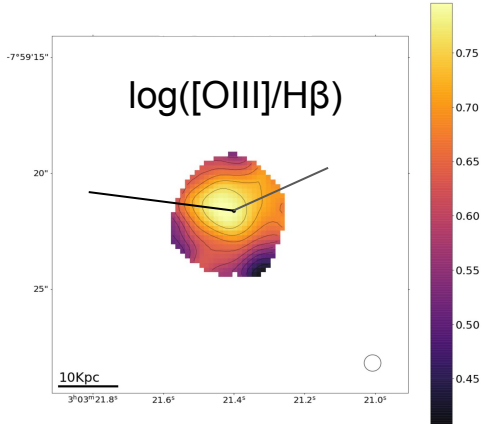


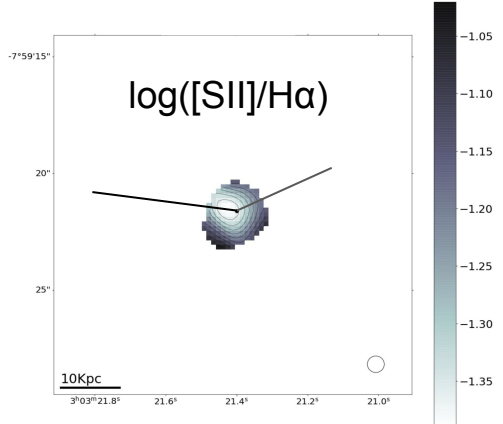


Continuum
4154Å-7026Å
rest frame

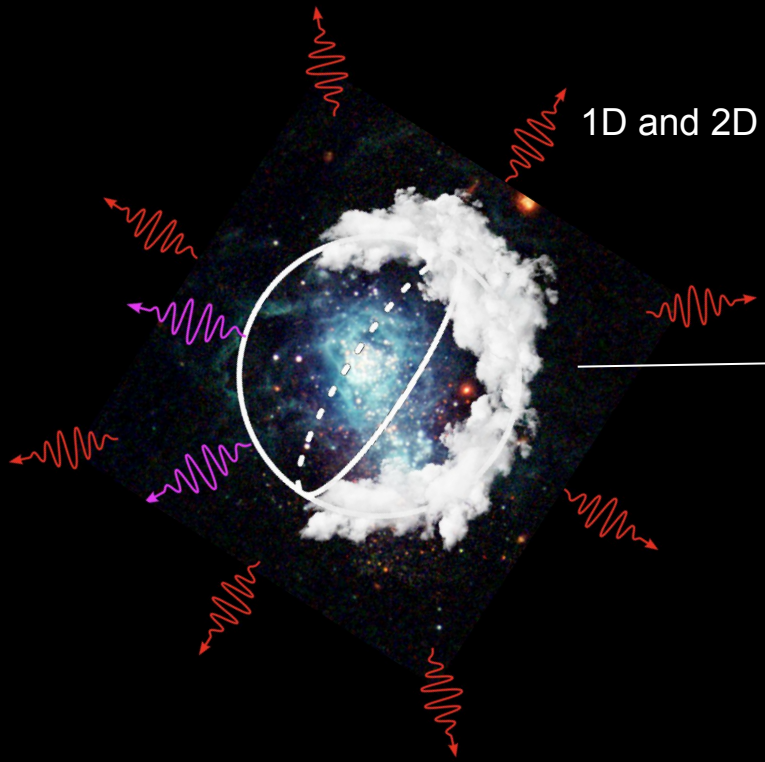






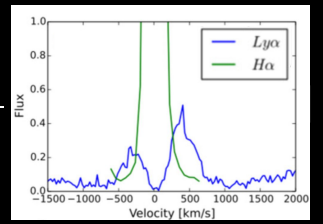


2D spectroscopy restrictions



1D and 2D spectroscopy

High [OIII]/[OII]
High extinction
Low escape
Low turbulence?



Yang et al (2016)

Line of sight

HI gas and dust

Low energy photons

High energy photons