Green Pea galaxies seen with MUSE/VLT and HST

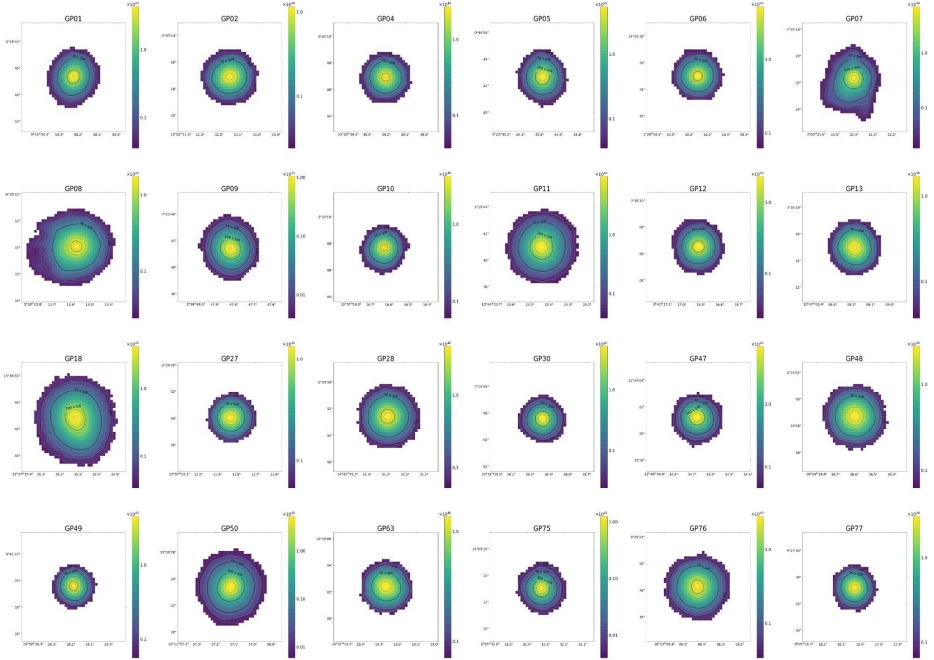
Antonio Arroyo Polonio

Jorge Iglesias Páramo, Carolina Kehrig, Jose M. Vílchez, Enrique Pérez Montero, Ricardo Amorín…

IAA INSTITUTO DE ASTROFÍSICA DE ANDALUCÍA
EXCELENCIA SEVERO OCHOA
CSIC

Introduction

Hα maps



Arroyo-Polonio et al. (2023)
Observations PI: Matthew Hayes

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

-Discovered by galaxy zoo volunteers.

-Size of 10 kpc in HST images (32% 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 stellar mass of ~3,200 million M⊙,
star formation rate of ~20 M⊙/yr
and thus a depletion time of 160 Myr.

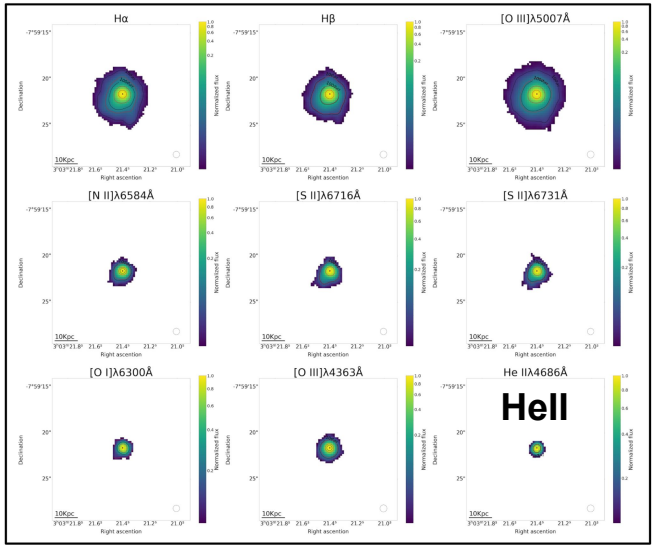
-Most of them are Lyα emitters and there are some confirmed LyC leakers among the GPs.

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

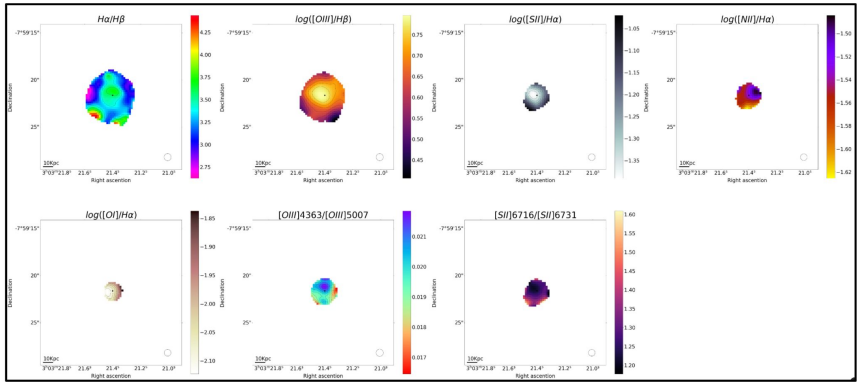
A MUSE/VLT spatially resolved study of the emission structure of GPs

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

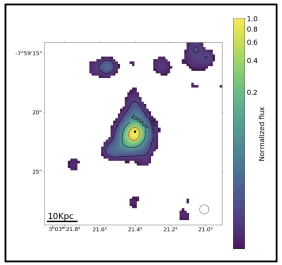
-**Emission line** maps



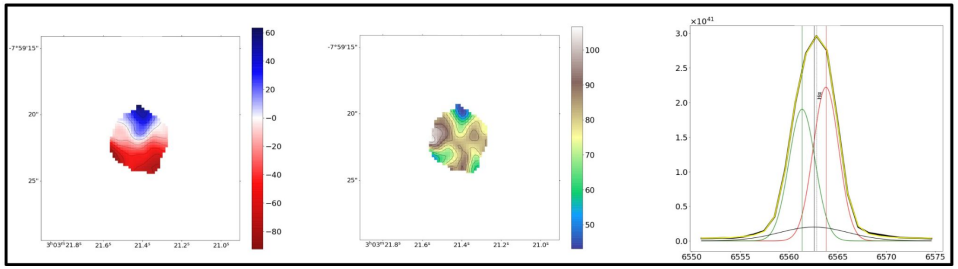
-**Emission line ratios** maps (e.g. Hα/Hβ, [SII]/Hα).



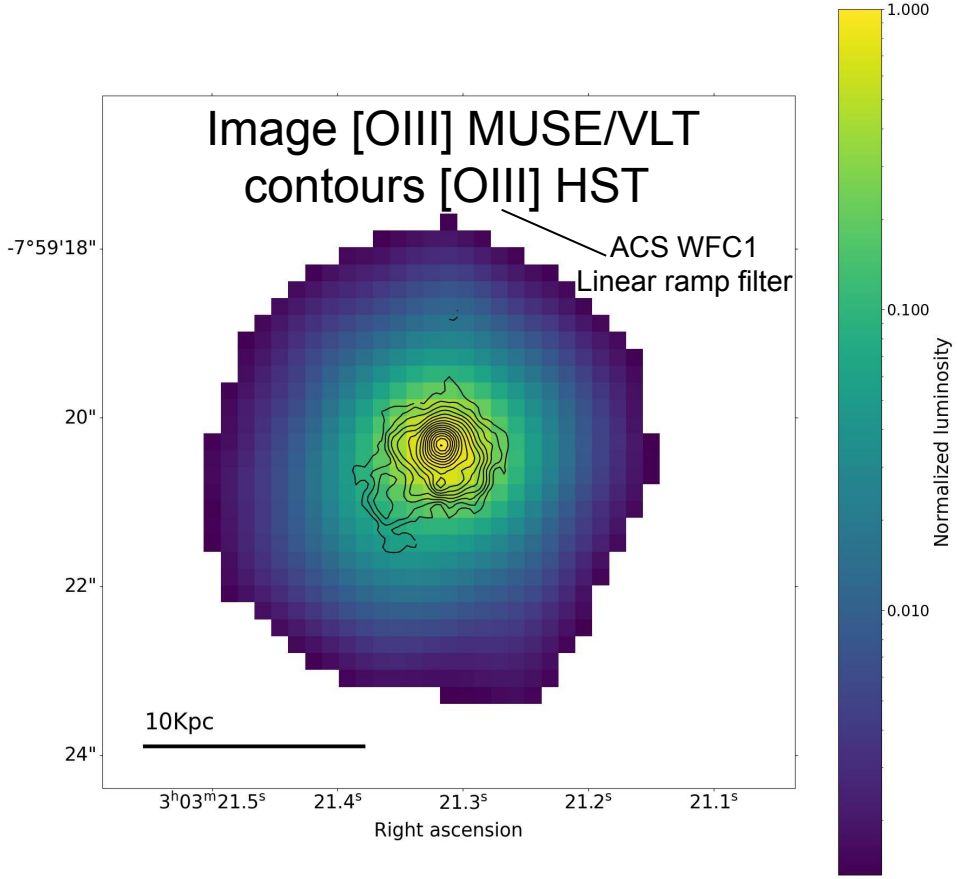
-Maps of the **continuum**.

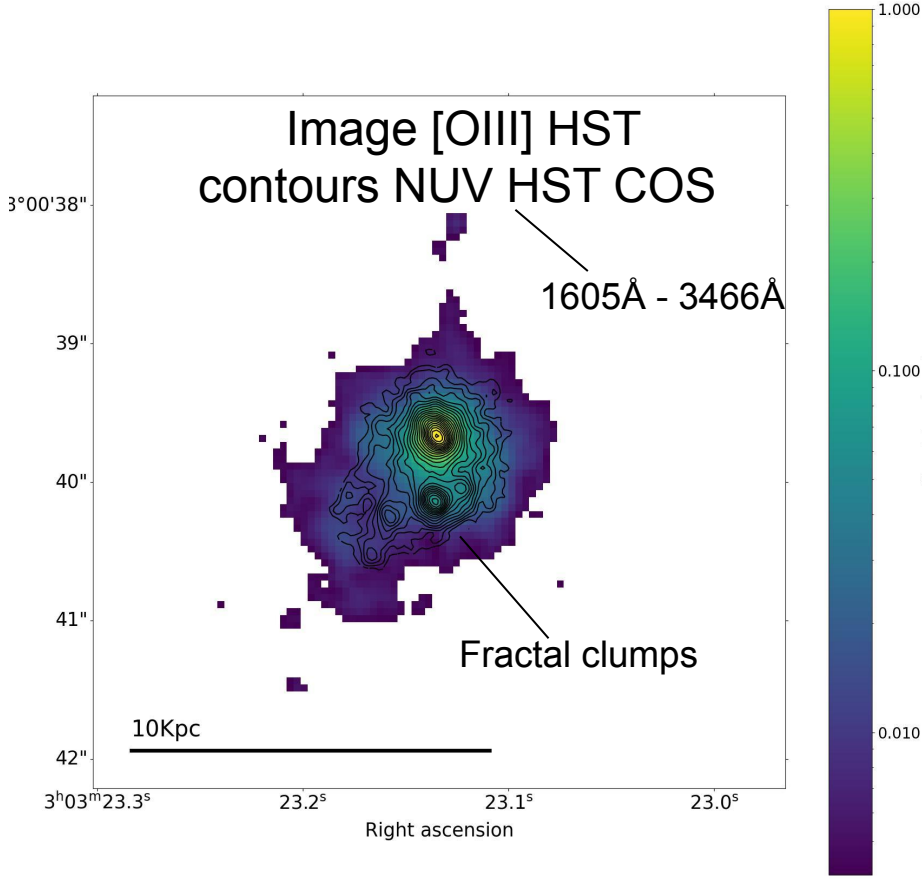


-**Kinematics**: Velocity and dispersion maps.
Multi-gaussian fit to emission line profile.



GP06 structure





Lyman continuum escape in GP06

-[OIII/OII] = 9
-12 + log(O/H) = 7.9
-[OIII] EW = ~700Å

-**2% Lyα escape.**
-**Optically thick, neutral outflow aligned with the LOS.**
Jaskot & Oey (2014)

but

high ionising photon production efficiency

$$\log_{10}(\xi_{\rm ion}^{\rm HII}/{\rm erg}^{-1}{\rm Hz}) = 25.5$$

Boyyet, K. et al. (2024)

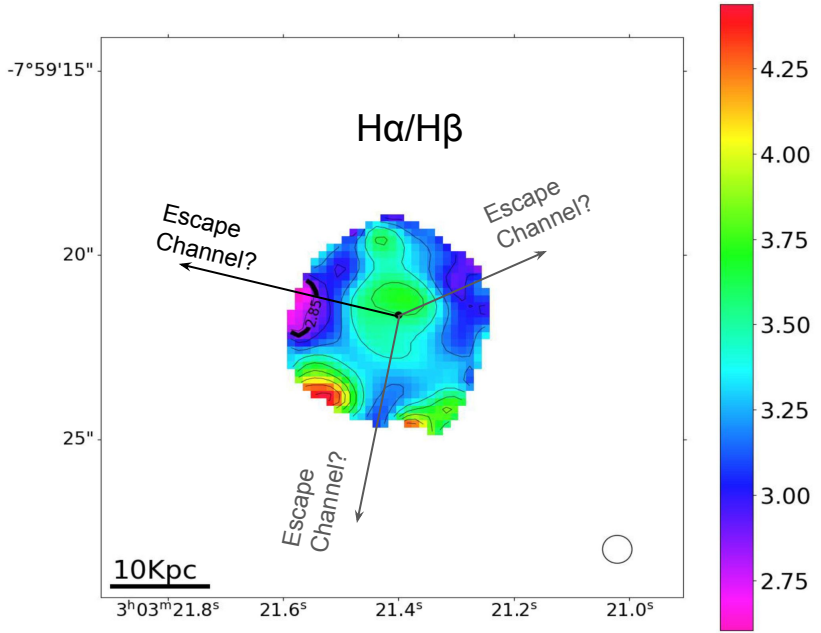
What about **perpendicular channels respect to the LOS**?

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

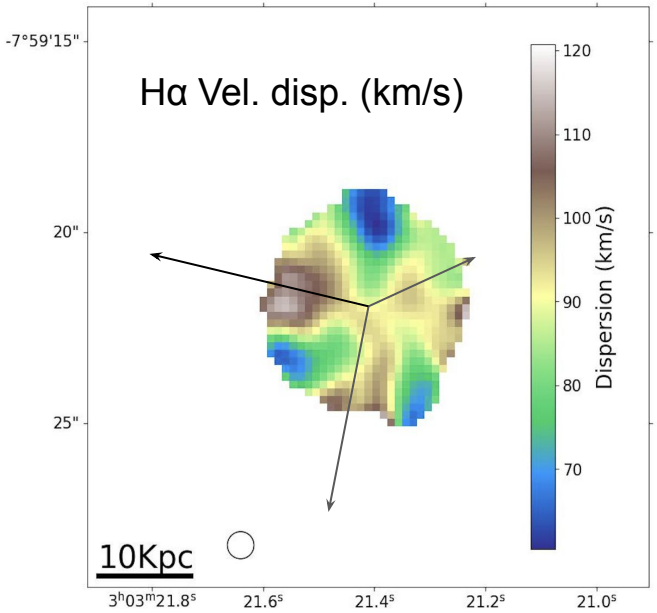
-**High ionization** ([OIII]/[OII], [OIII]/Hβ)
-**Low extinction** (Hα/Hβ)
-Disturbed / **complex kinematics** (Velocity dispersion)
-**Density-bounded** tracers ([SII]/Hα, [OI]/Hα)
-Detectable **brightness** of the **ionized gas** in zones far away from central ionizing object (as seen in Hα and [OIII]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

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

Lyman continuum escape in GP06

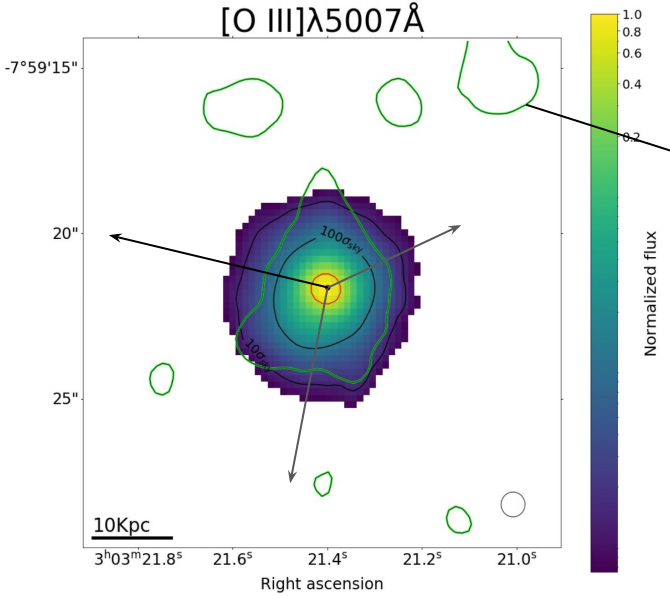


Lowest extinction



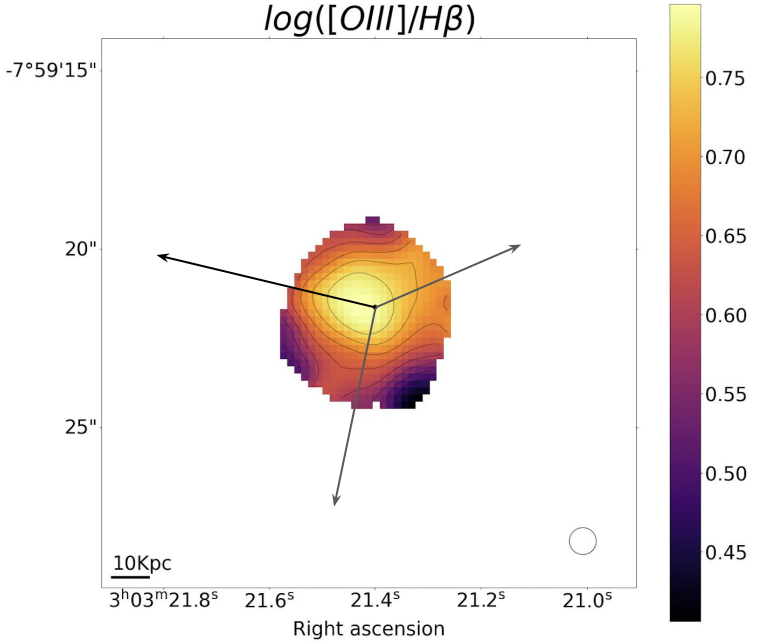
>100 km/s high vel. disp.

Lyman continuum escape in GP06



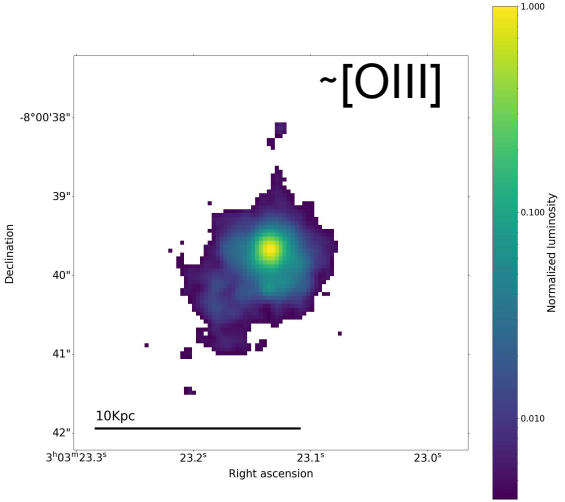
Green contours: Continuum 4154Å-7026Å rest frame

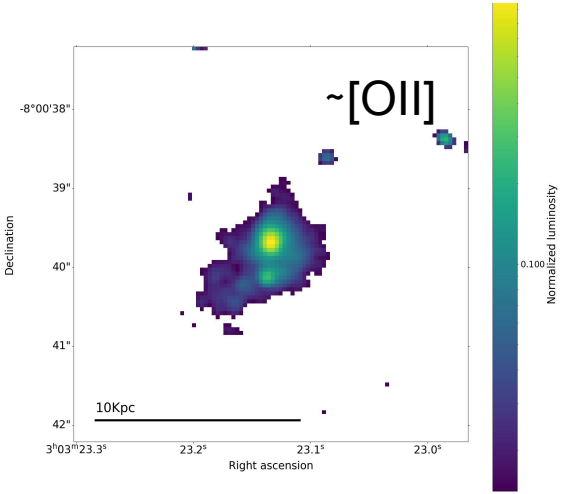
Ionized gas more extended than stellar continuum

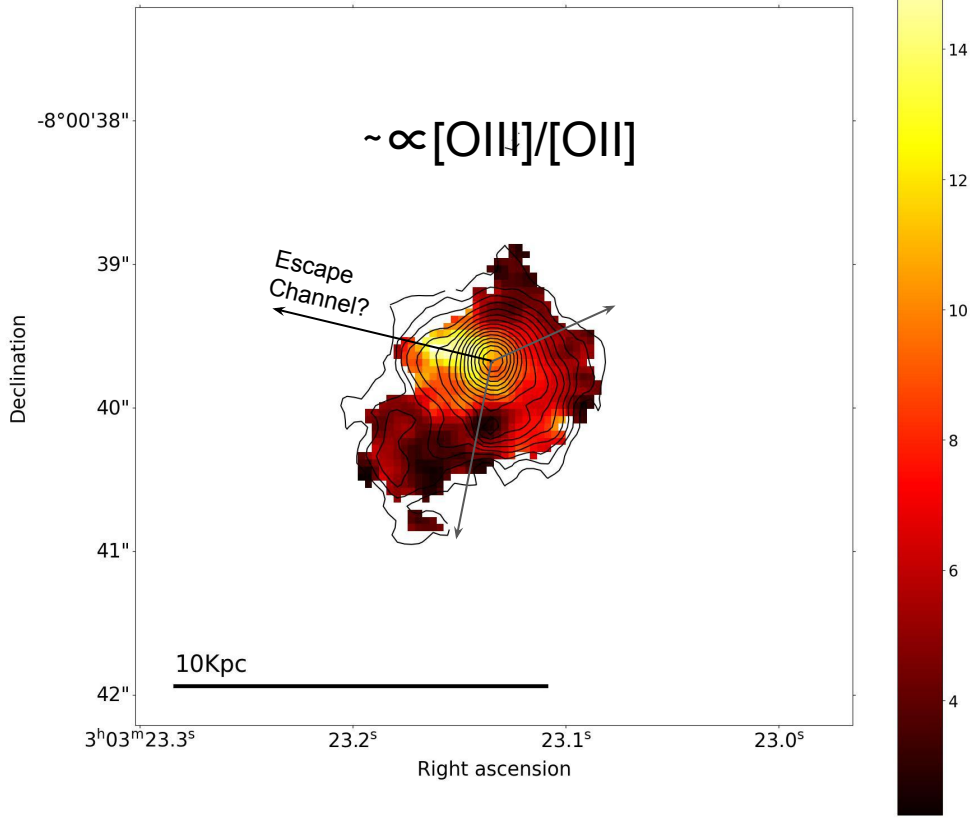


Lower gradient in ionization

Ionization tracer with HST

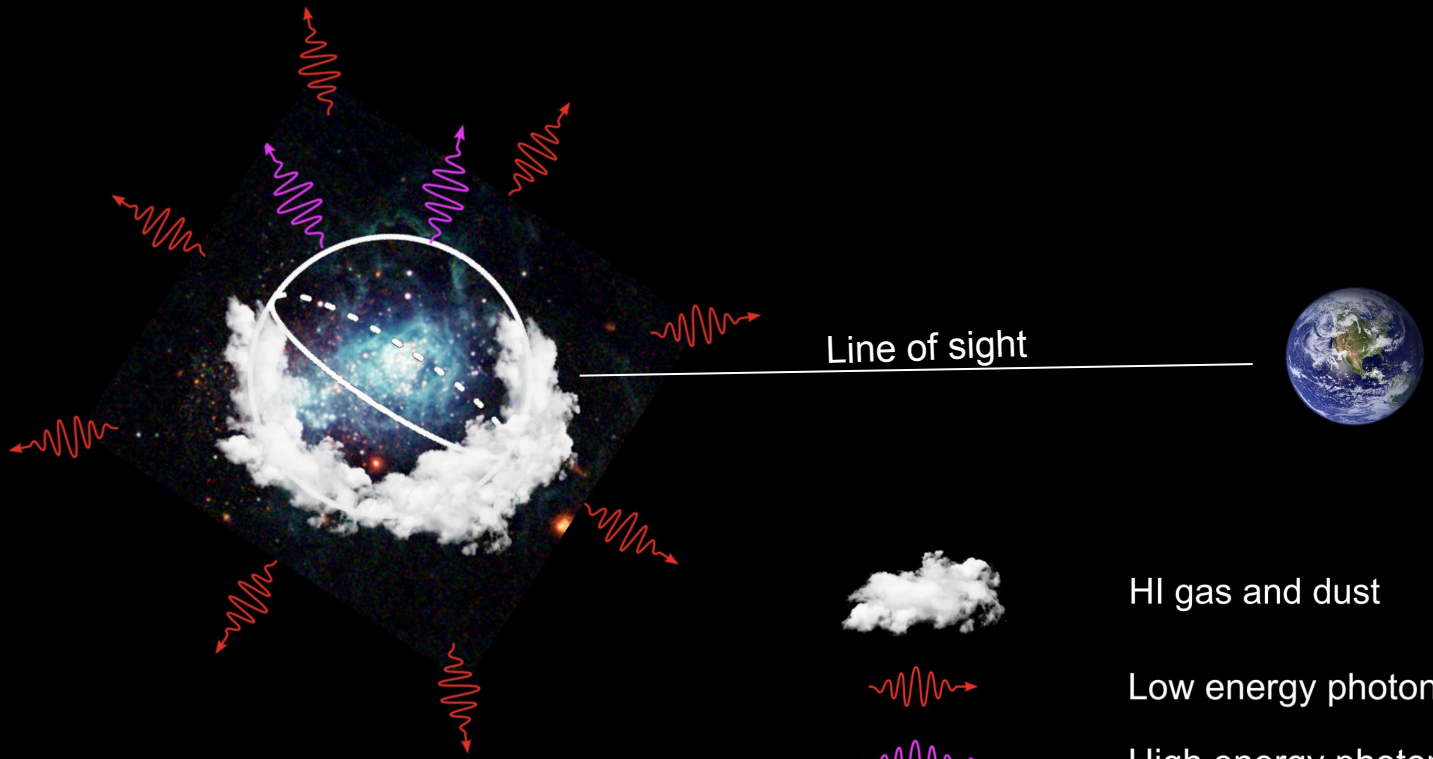






Highest ionization in one the channels

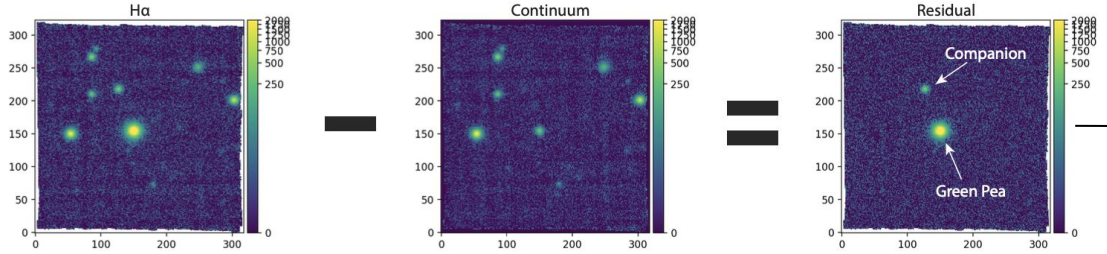
GP06 case?


Line of sight
HI gas and dust
Low energy photons
High energy photons

Green Pea companions

On the triggering of extreme starburst events in low-metallicity galaxies: a deep search for companions of Green Peas

Lauren Laufman,[1] Claudia Scarlata,[1] Matthew Hayes,[2] and Evan Skillman[1]

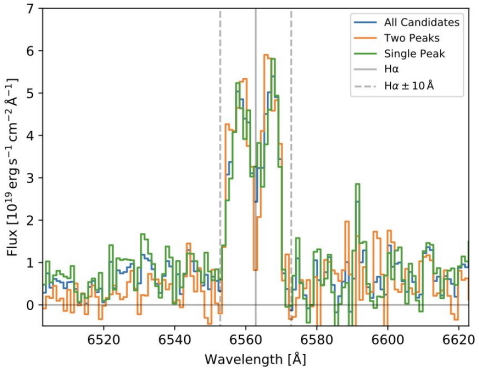


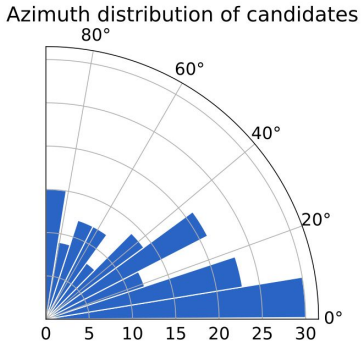
What if we do
Hα + Hβ + [OIII] stacking?

4+3 companions
in 24 GPs

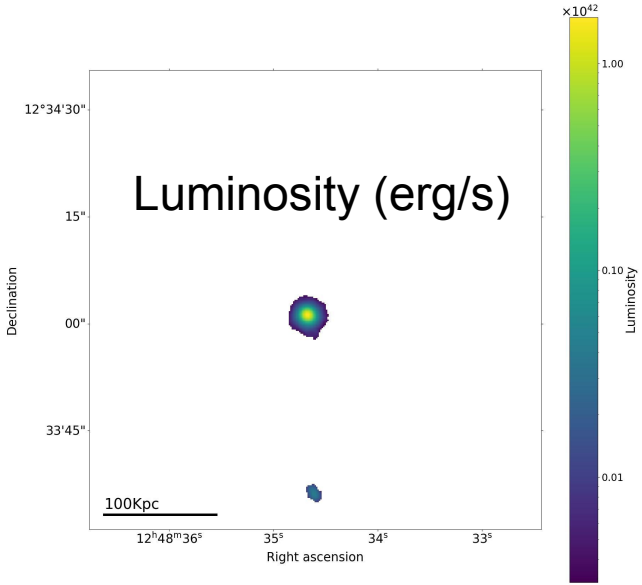
Discovery of Faint Double-peak Hα Emission in the Halo of Low Redshift Galaxies

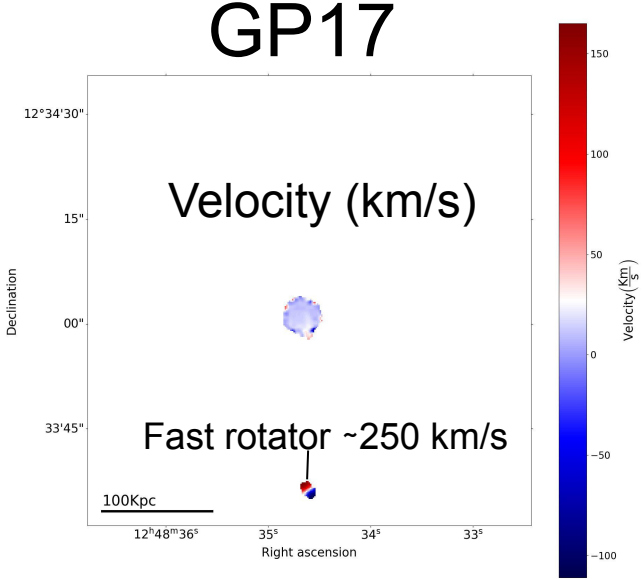
J. Sánchez Almeida[1,2], J. Cąlhau[1,2], C. Muñoz-Tuñón[1,2], A. L. González-Morán[1,2], and J. M. Rodríguez-Espinosa[1,2,3]

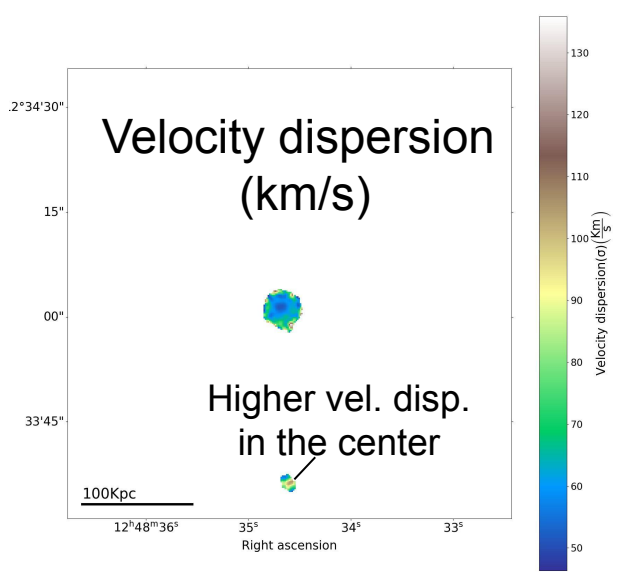




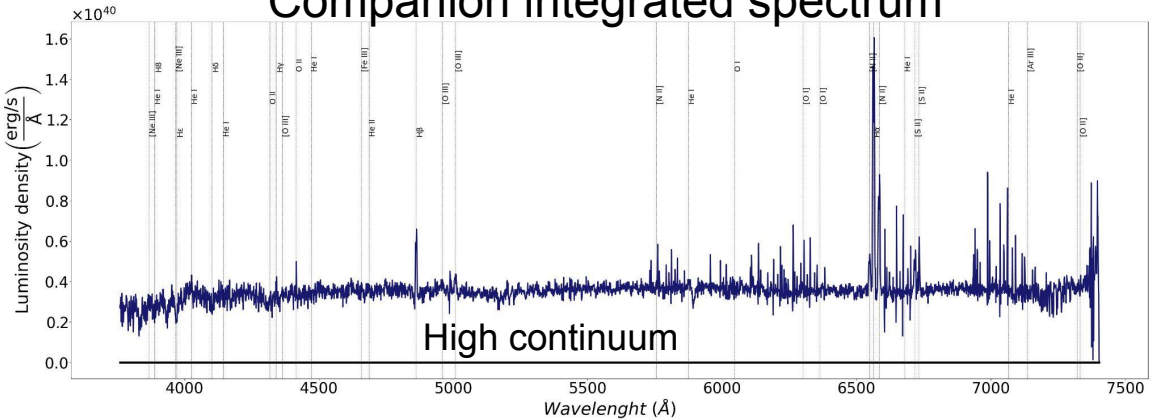
GP17



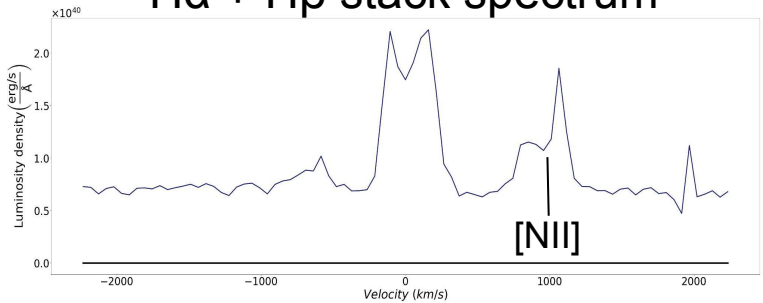




Companion integrated spectrum

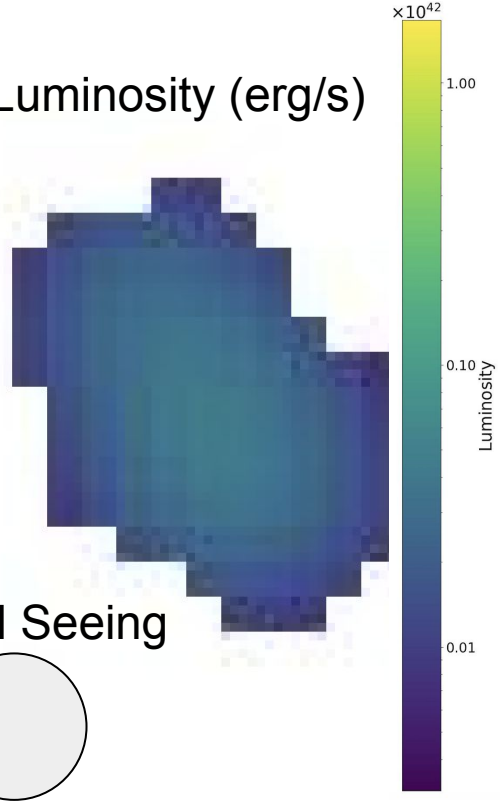


Hα + Hβ stack spectrum

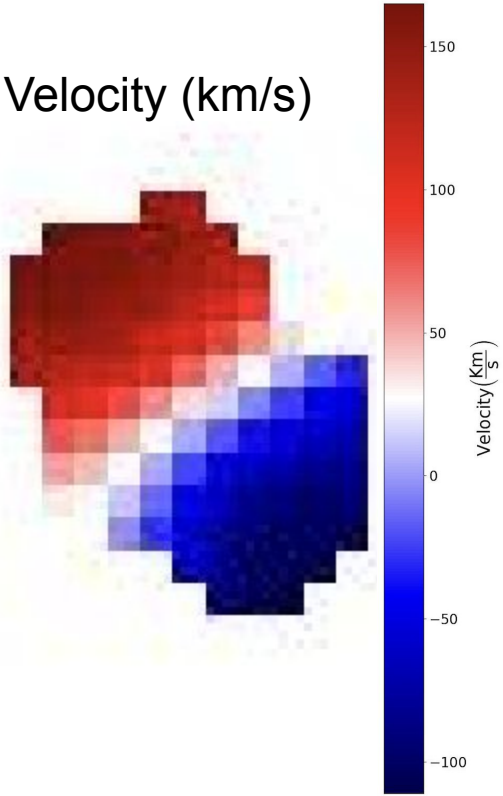


GP17 companion

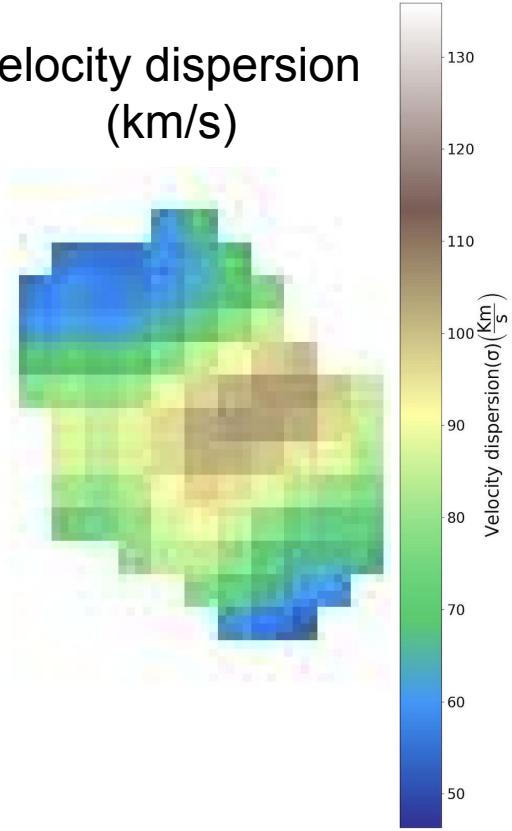
Luminosity (erg/s)



Velocity (km/s)

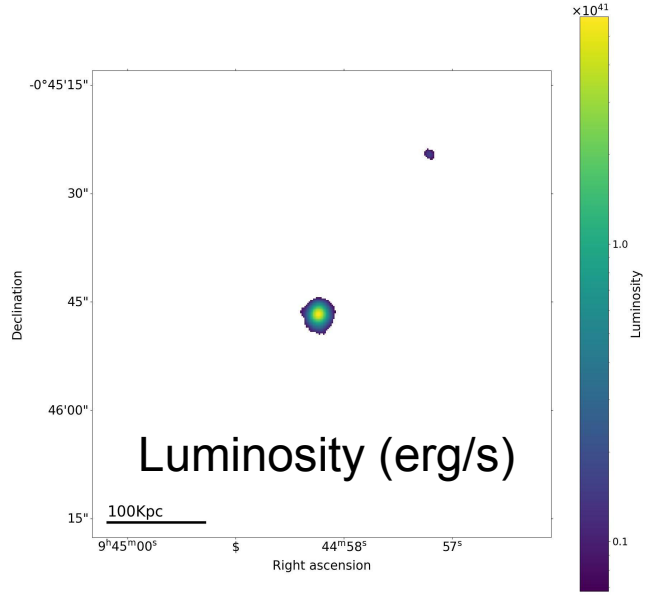


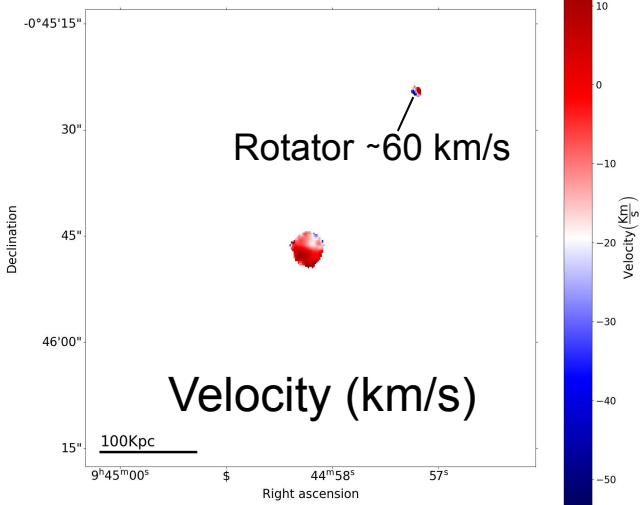
Velocity dispersion (km/s)

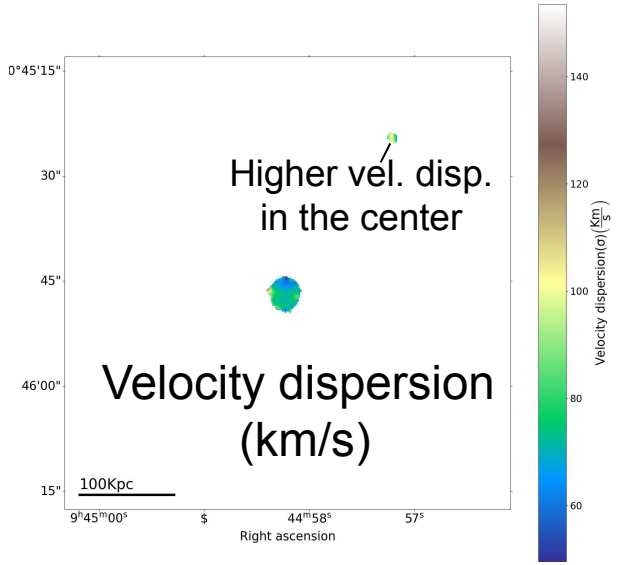


FWHM Seeing

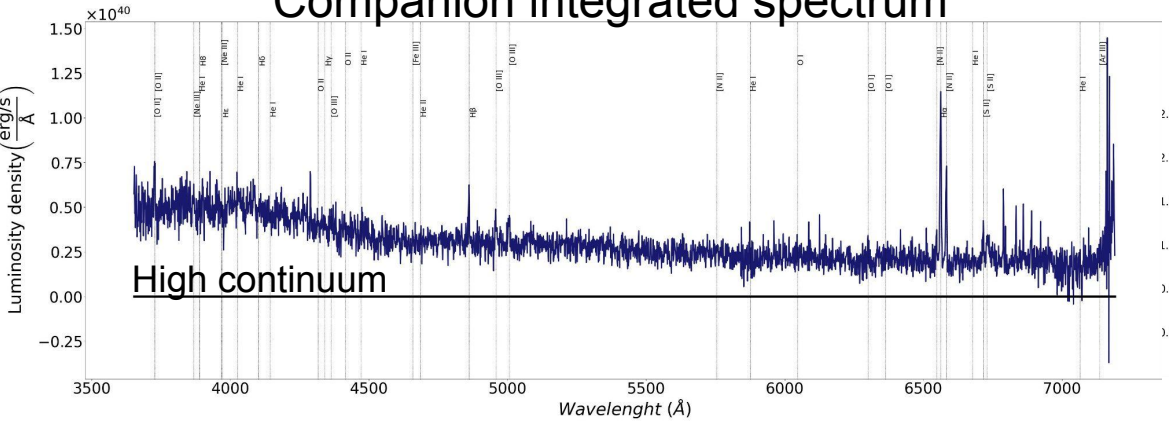
GP01



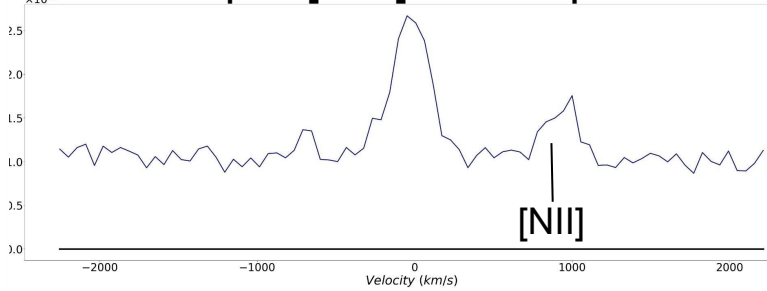




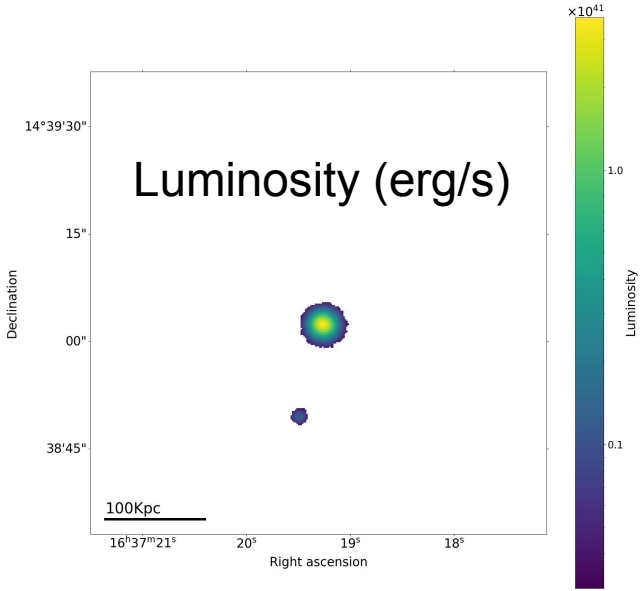
Companion integrated spectrum

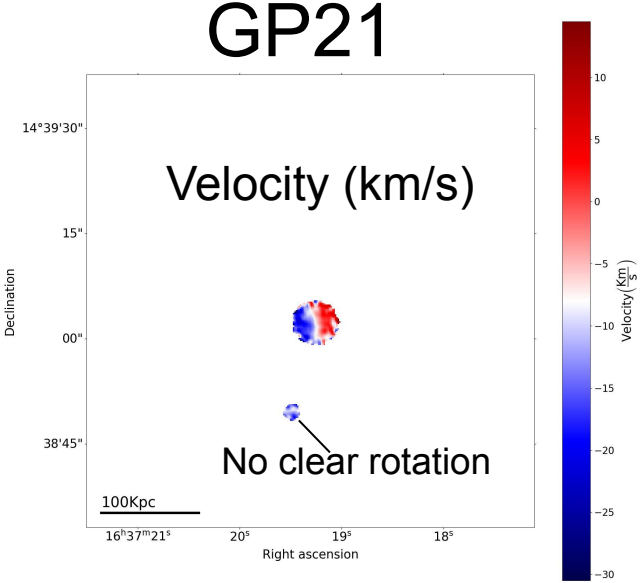


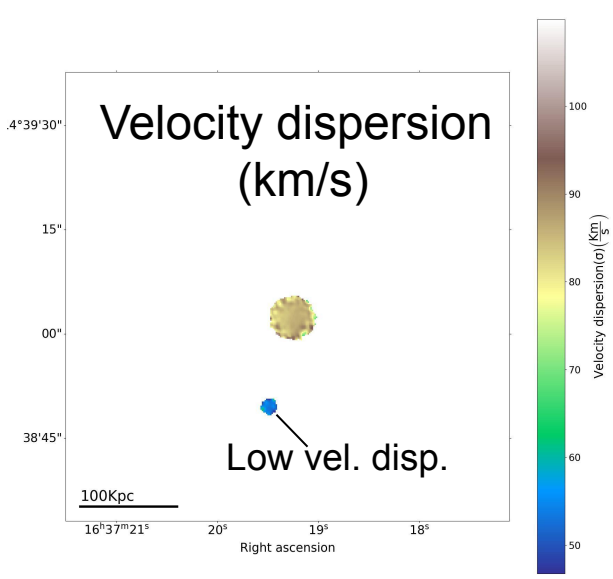
Hα + Hβ + [OIII] stack spectrum



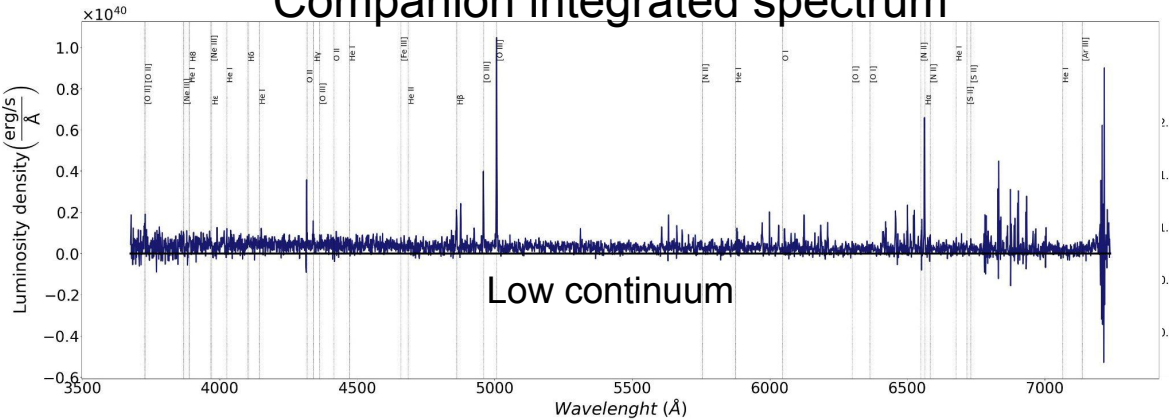
GP21



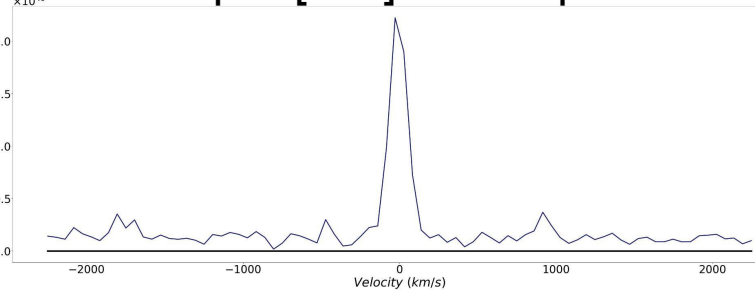




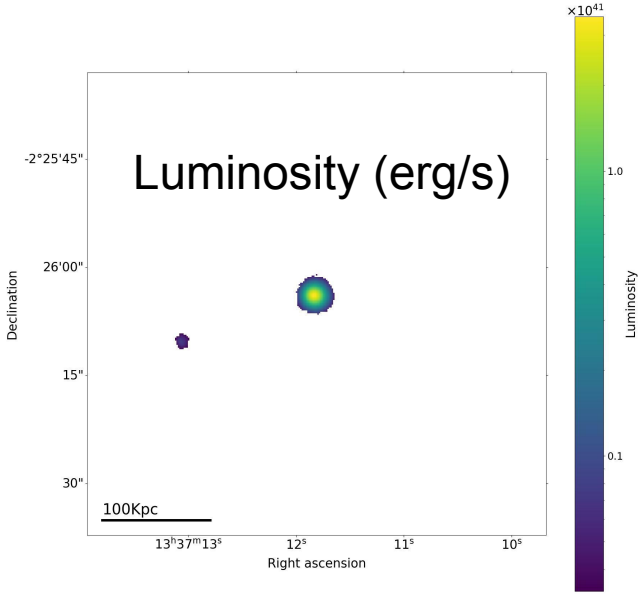
Companion integrated spectrum

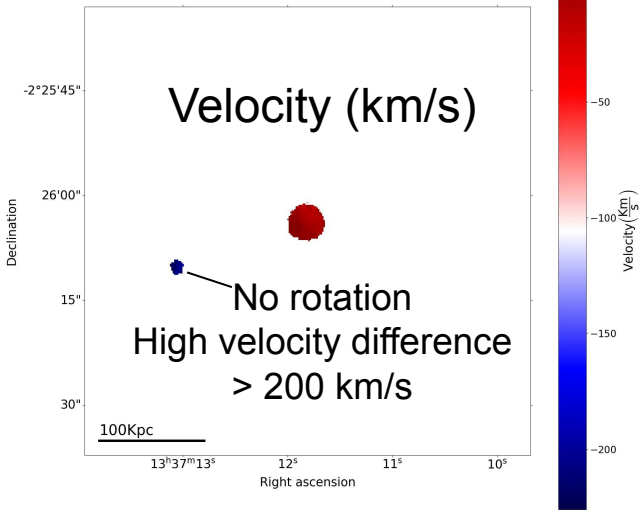


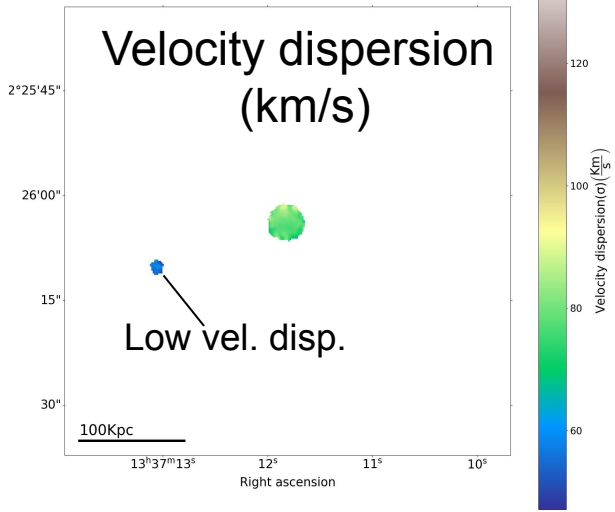
Hα + Hβ + [OIII] stack spectrum

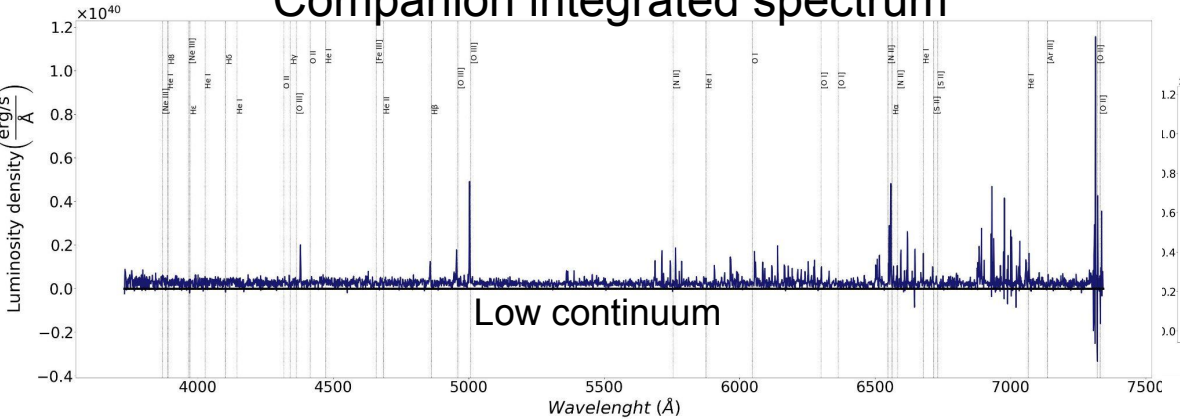


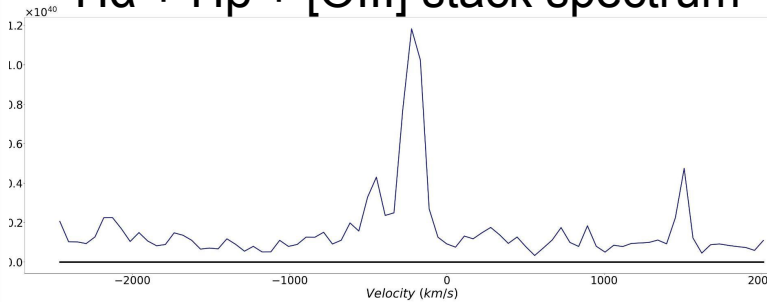
GP14


Luminosity (erg/s)
×10^41
Luminosity
1.0
0.1
Declination
-2°25'45"
26'00"
15"
30"
100Kpc
13h37m13s
12s
11s
10s
Right ascension

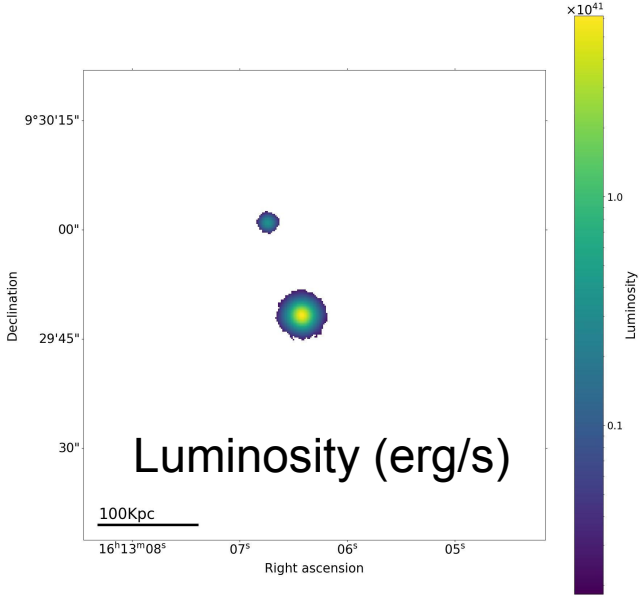

Velocity (km/s)
No rotation
High velocity difference
> 200 km/s
Velocity (km/s)
0
−50
−100
−150
−200
Declination
-2°25'45"
26'00"
15"
30"
100Kpc
13h37m13s
12s
11s
10s
Right ascension

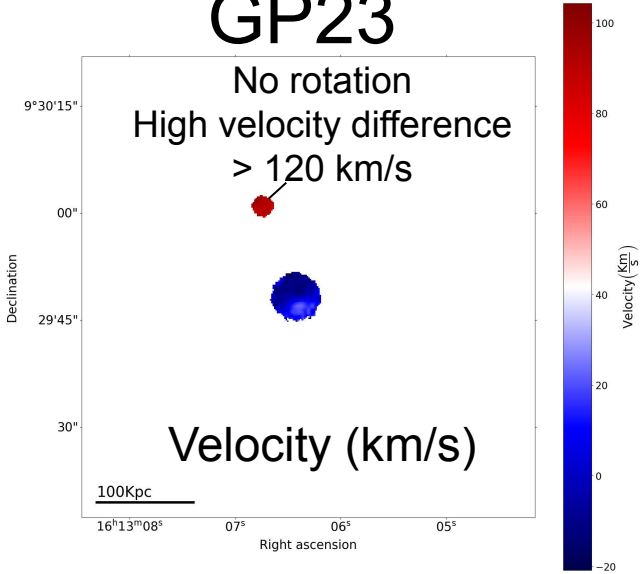

Velocity dispersion
(km/s)
Low vel. disp.
Velocity dispersion(σ) (km/s)
120
100
80
60
2°25'45"
26'00"
15"
30"
100Kpc
13h37m13s
12s
11s
10s
Right ascension

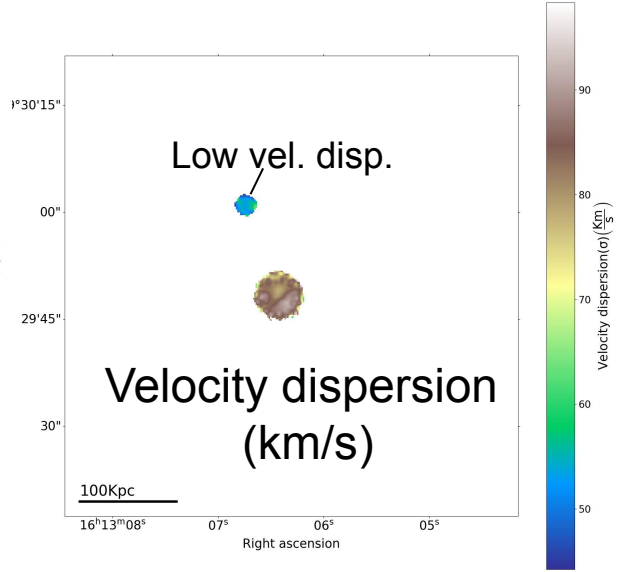

Companion integrated spectrum
×10^40
Luminosity density (erg/s/Å)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
[Ne III]
He I
Hβ
Hε
[Ne III]
He I
Hδ
He I
O II
Hγ
[O III]
O II
He I
[Fe III]
He II
Hβ
[O III]
[O III]
[N II]
He I
O I
[O I]
[O I]
[N II]
Hα
[N II]
He I
[S II]
[S II]
He I
[Ar III]
[O II]
[O II]
4000
4500
5000
5500
6000
6500
7000
7500
Wavelenght (Å)
Low continuum


Hα + Hβ + [OIII] stack spectrum
×10^40
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−2000
−1000
0
1000
2000
Velocity (km/s)

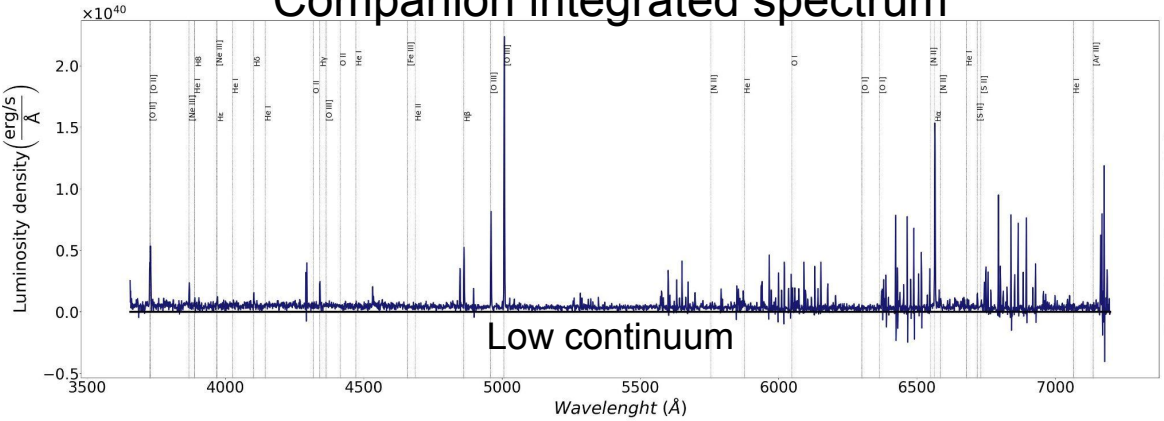
GP23



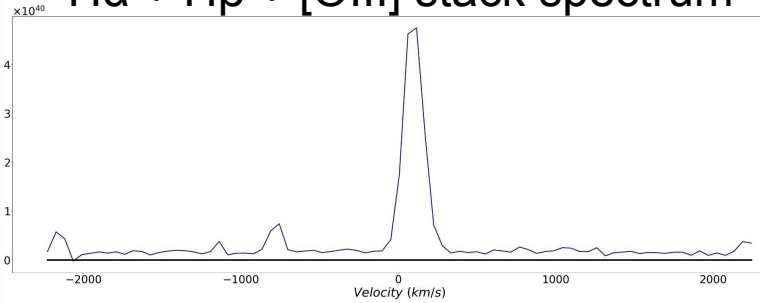




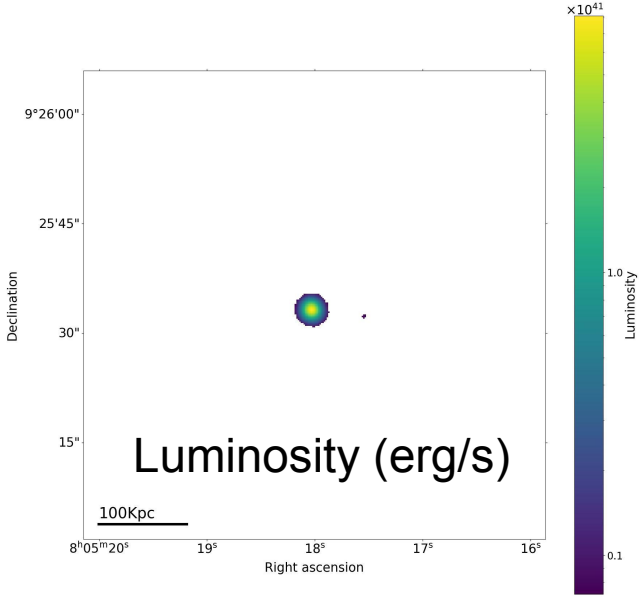
Companion integrated spectrum

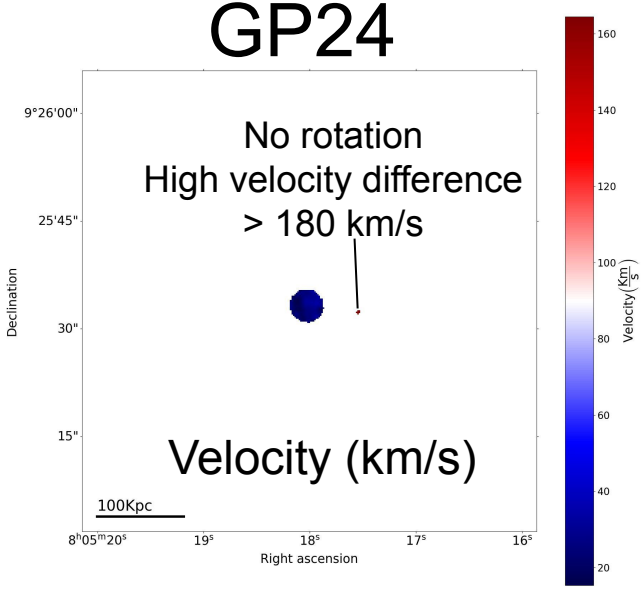


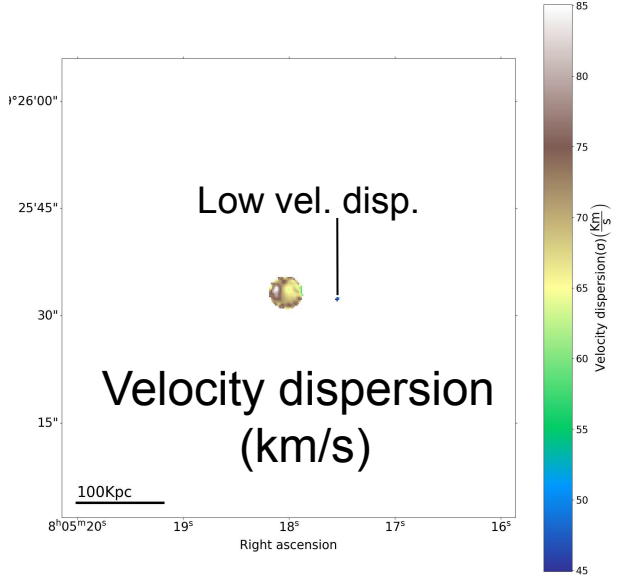
Hα + Hβ + [OIII] stack spectrum



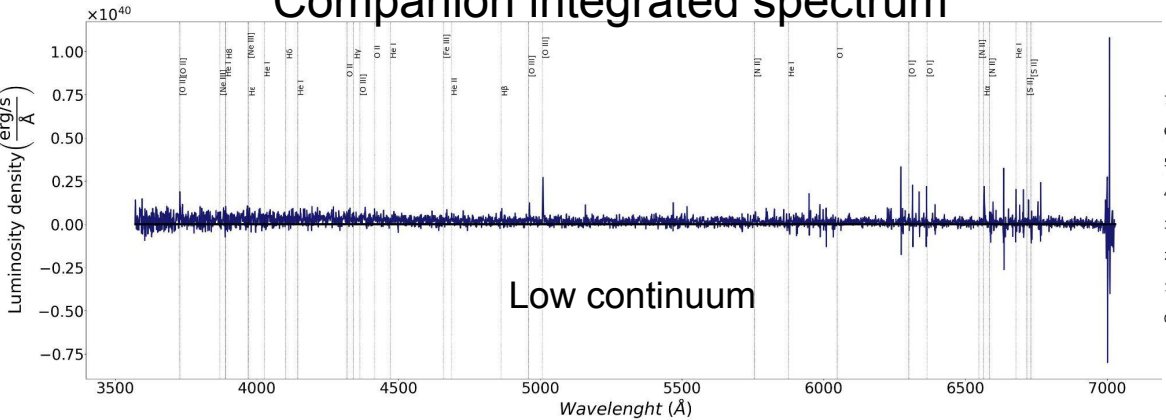
GP24



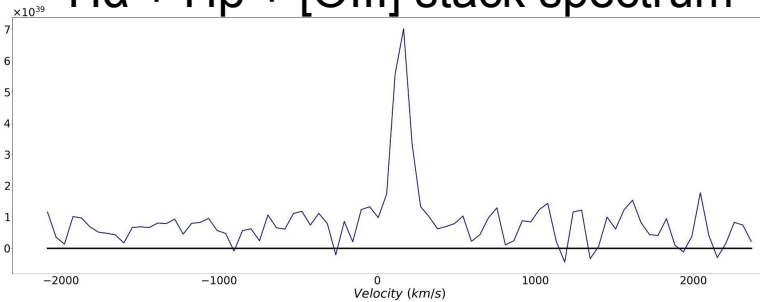




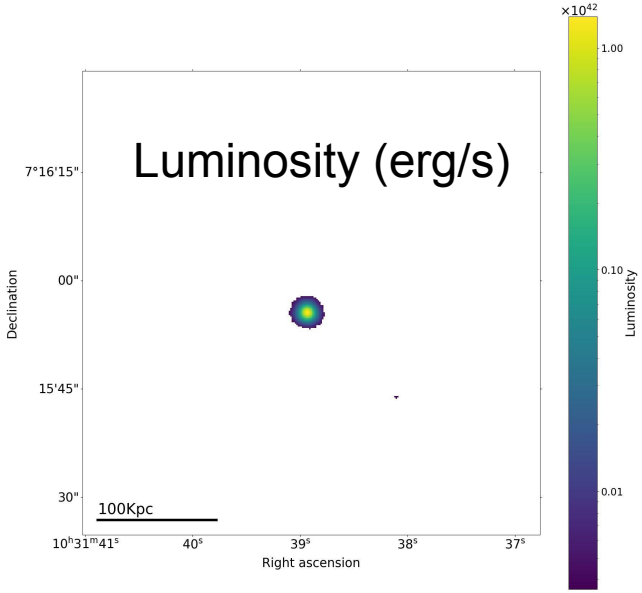
Companion integrated spectrum

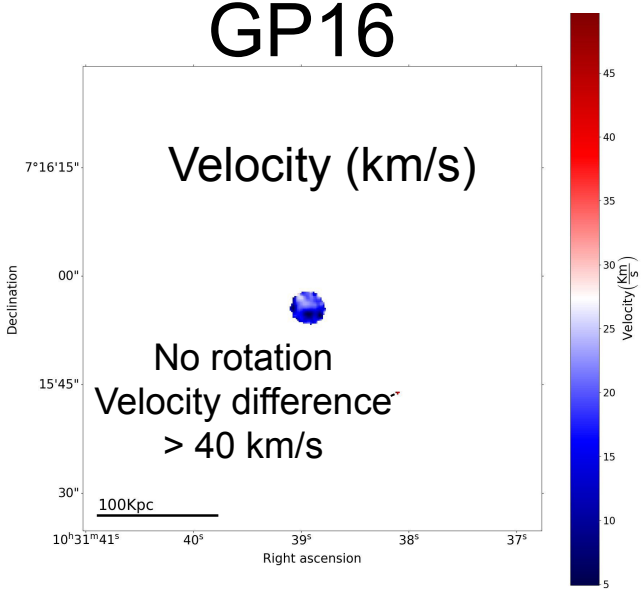


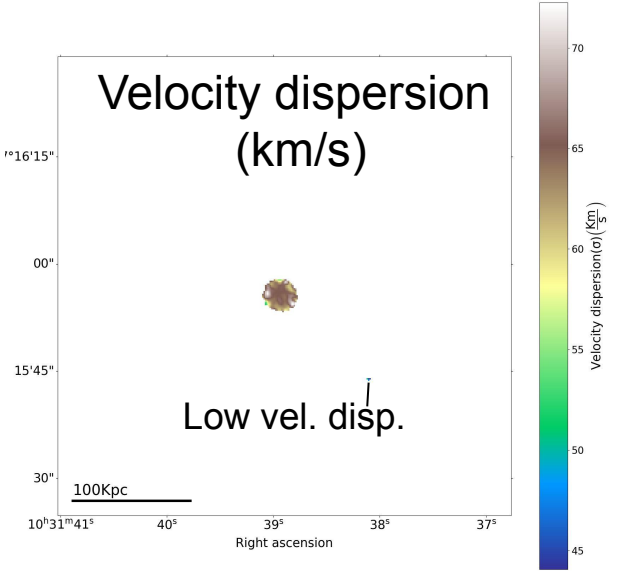
Hα + Hβ + [OIII] stack spectrum

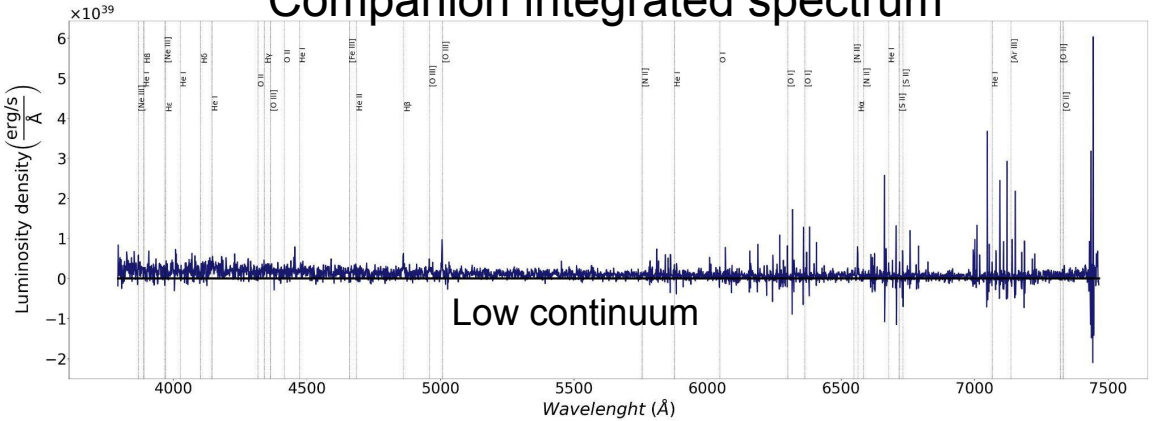


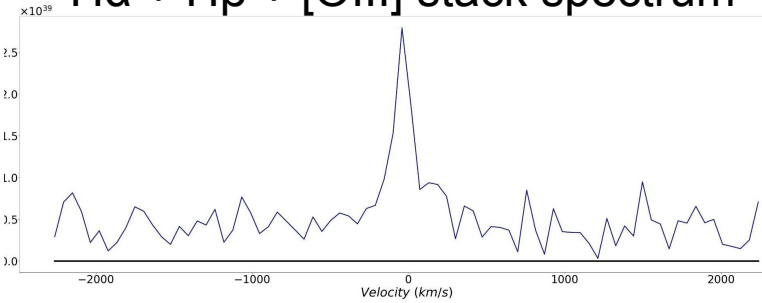
GP16


Luminosity (erg/s)
×10^42
1.00
0.10
0.01
Luminosity
Declination
7°16'15"
00"
15'45"
30"
100Kpc
10h31m41s
40s
39s
38s
37s
Right ascension

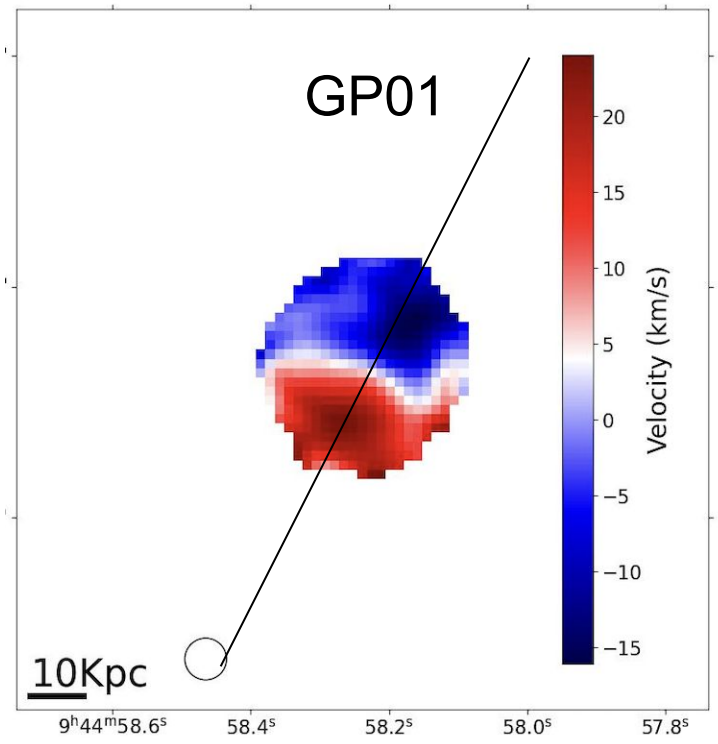

Velocity (km/s)
No rotation
Velocity difference
> 40 km/s
Velocity (Km/s)
45
40
35
30
25
20
15
10
5
Declination
7°16'15"
00"
15'45"
30"
100Kpc
10h31m41s
40s
39s
38s
37s
Right ascension

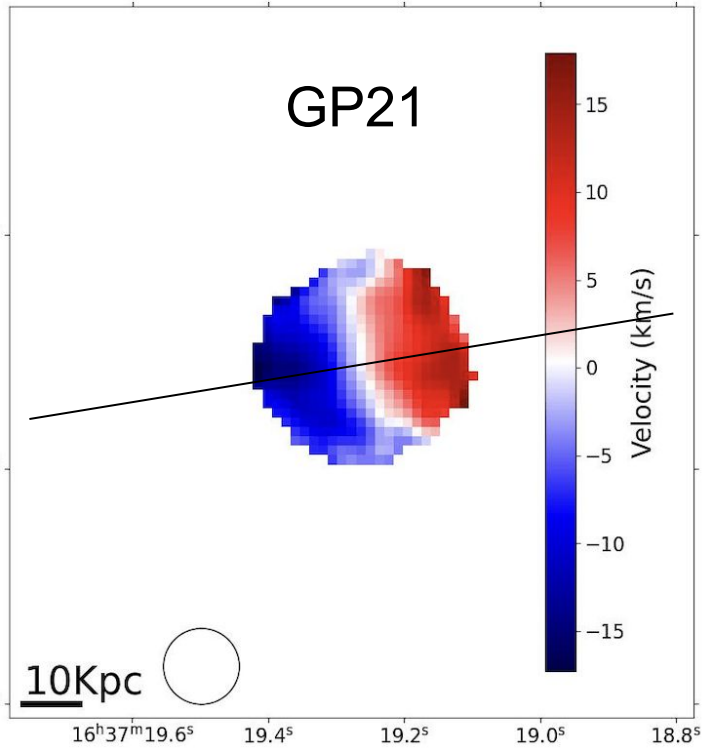

Velocity dispersion
(km/s)
Low vel. disp.
Velocity dispersion(σ) (Km/s)
70
65
60
55
50
45
7°16'15"
00"
15'45"
30"
100Kpc
10h31m41s
40s
39s
38s
37s
Right ascension


Companion integrated spectrum
×10^39
Luminosity density (erg/s/Å)
Low continuum
[Ne III]
He I
Hδ
[Ne III]
He I
Hε
He I
Hδ
O II
Hγ
[O III]
O II
He I
[Fe III]
He II
Hβ
[O III]
[O III]
[N I]
He I
O I
[O I]
[O I]
[N II]
Hα
[N II]
[S II]
He I
He I
[Ar III]
[O II]
[O II]
4000
4500
5000
5500
6000
6500
7000
7500
Wavelenght (Å)


Hα + Hβ + [OIII] stack spectrum
×10^39
2.5
2.0
1.5
1.0
0.5
0.0
−2000
−1000
0
1000
2000
Velocity (km/s)

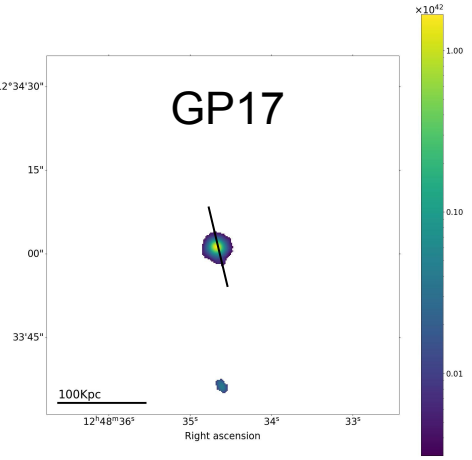
Companion orientation

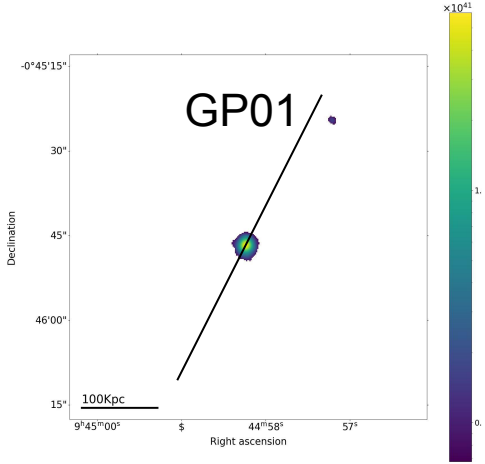


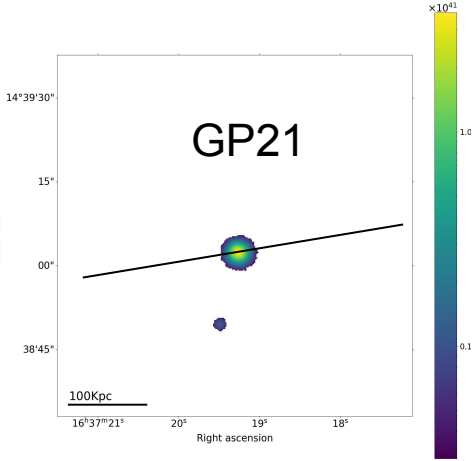


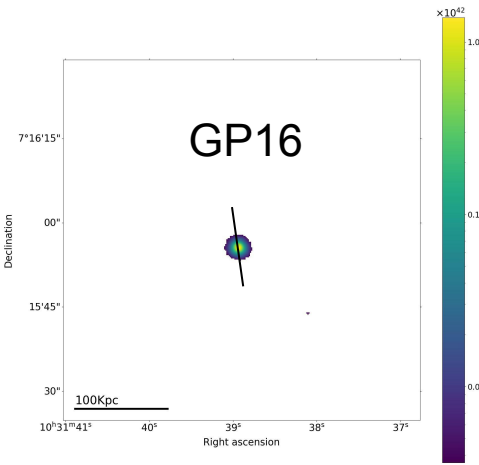
Disk orientation of GPs

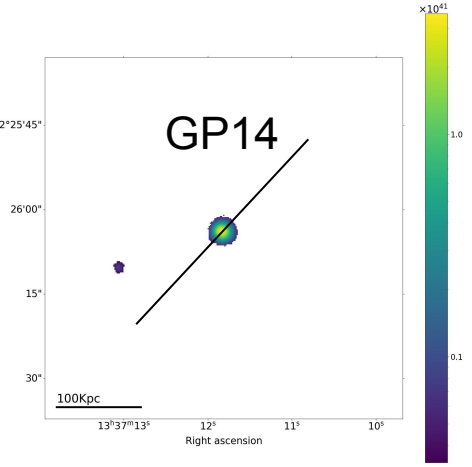
Companion orientation

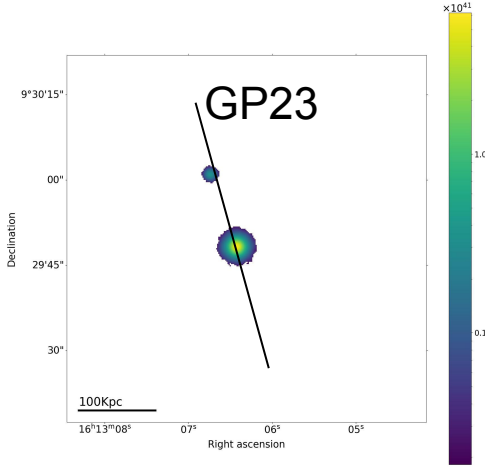


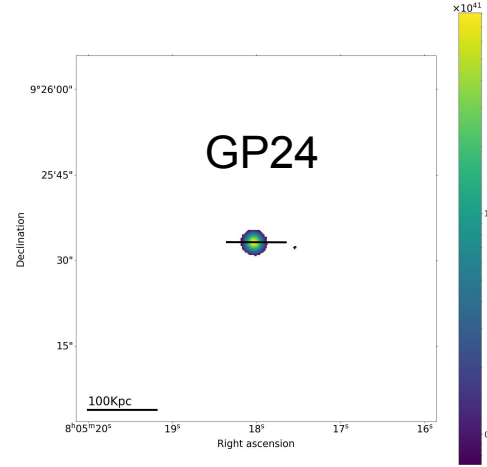










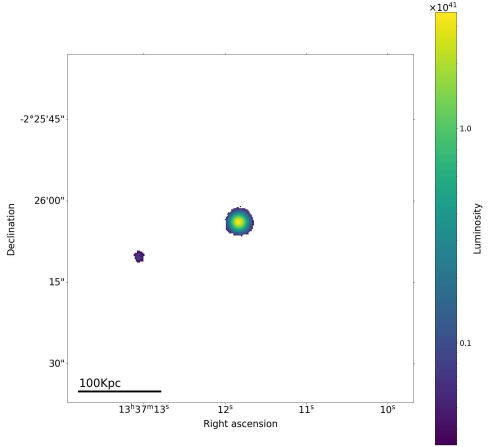


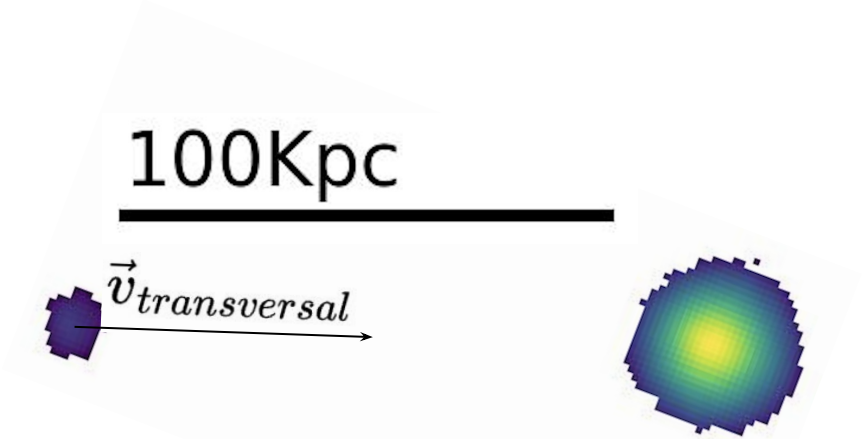
Tend to be aligned

↓

Memory of past interaction?

Companion and triggering of SF in GPs





$T_{SB} \sim sSFR^{-1} \sim 100$ Myr

Pretty rough estimation! → $v_{transversal}$ ~1000 km/s → Too high

Radial velocity difference ~ 40,180,200,120 km/s

Conclusions

-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.

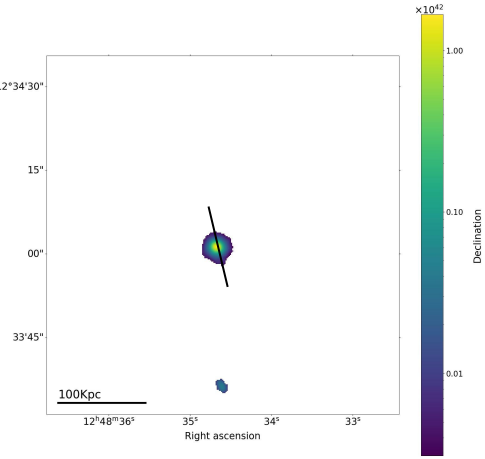
-GP06 may have very low / no LyC escape in the line of sight but could potentially present channels perpendicular to it.

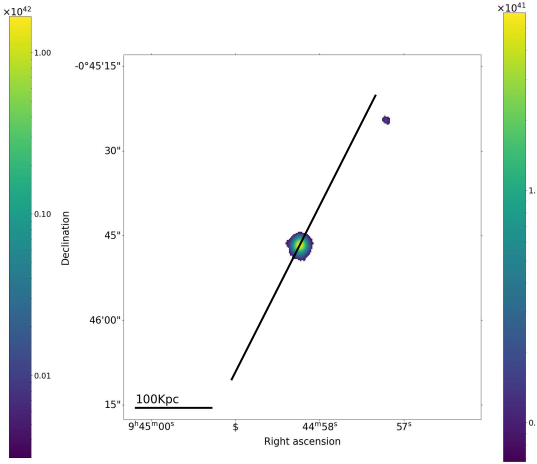
-30% of the GPs in our sample presents companions. 2 of them are chemically evolved rotating disk galaxies with higher stellar continuum and mass, 5 of them are low mass gas dominated systems.

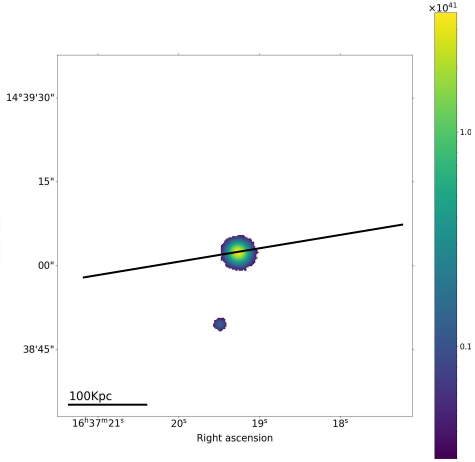
-The companions tend to be in the direction of the rotation of the GPs, indicating a sort of memory of a past interaction. Nevertheless companions are pretty far away to be considered triggers of the SF in GPs.

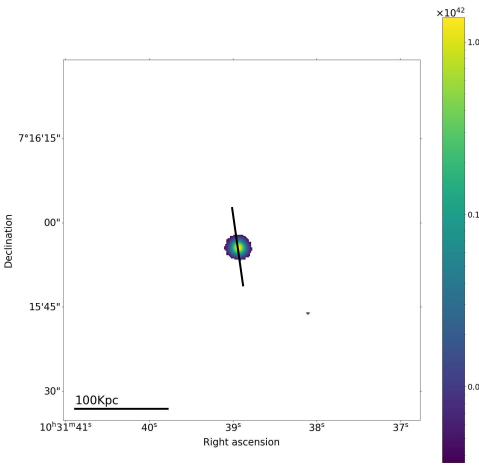
Thank you for your attention

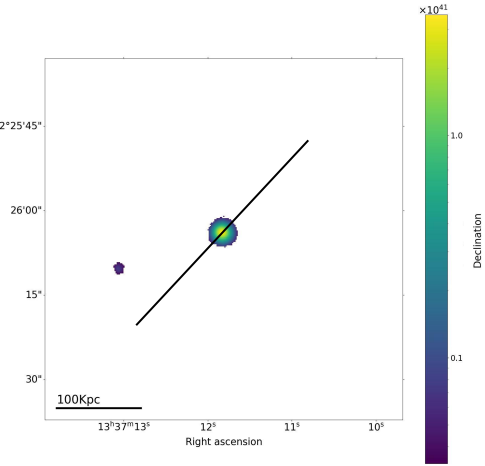
Companion orientation

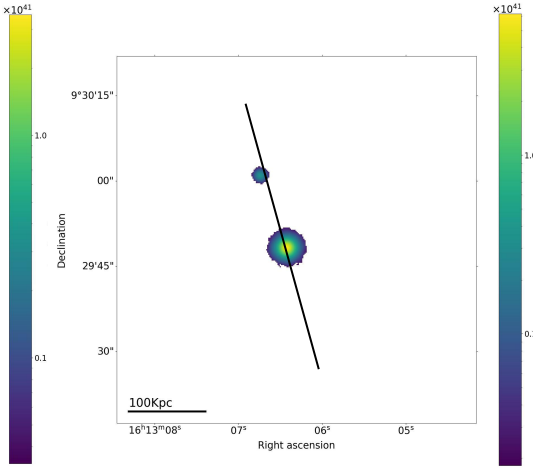


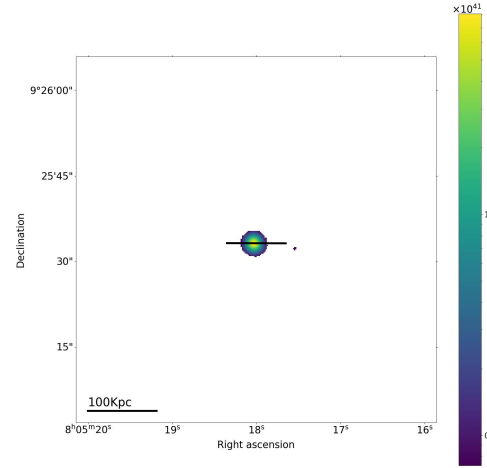








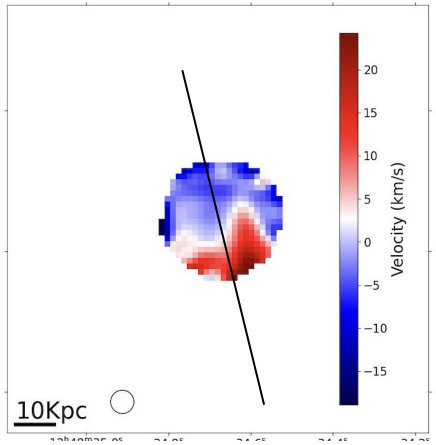


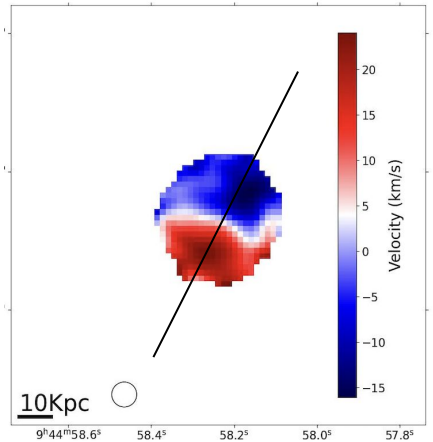


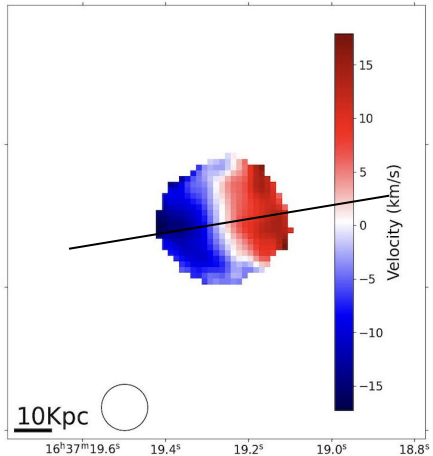
Tend to be aligned

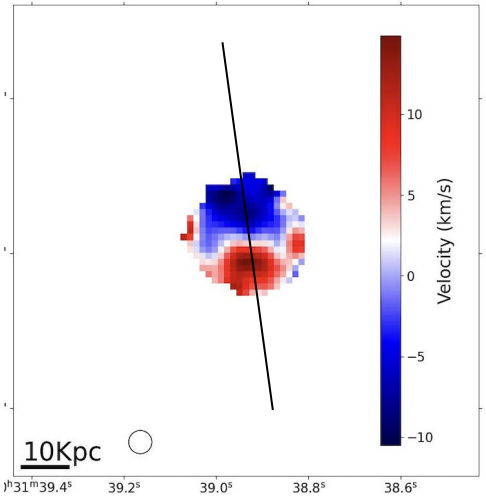
↓

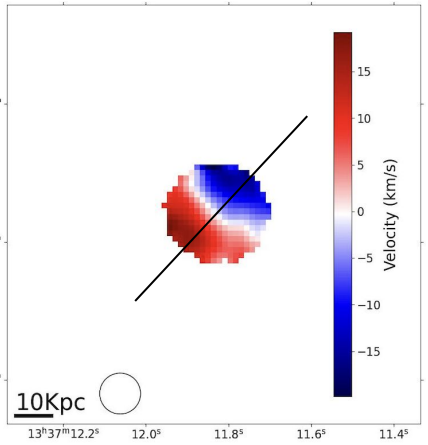
Memory of past interaction?

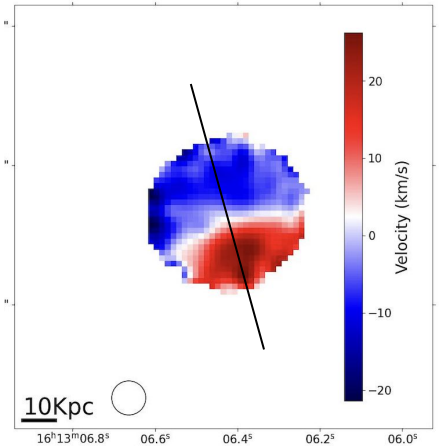

10Kpc
Velocity (km/s)
20
15
10
5
0
−5
−10
−15

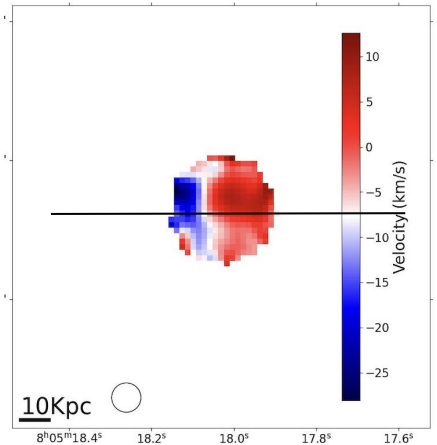

10Kpc
Velocity (km/s)
20
15
10
5
0
−5
−10
−15
9h44m58.6s
58.4s
58.2s
58.0s
57.8s


10Kpc
Velocity (km/s)
15
10
5
0
−5
−10
−15
16h37m19.6s
19.4s
19.2s
19.0s
18.8s


10Kpc
Velocity (km/s)
10
5
0
−5
−10
h31m39.4s
39.2s
39.0s
38.8s
38.6s

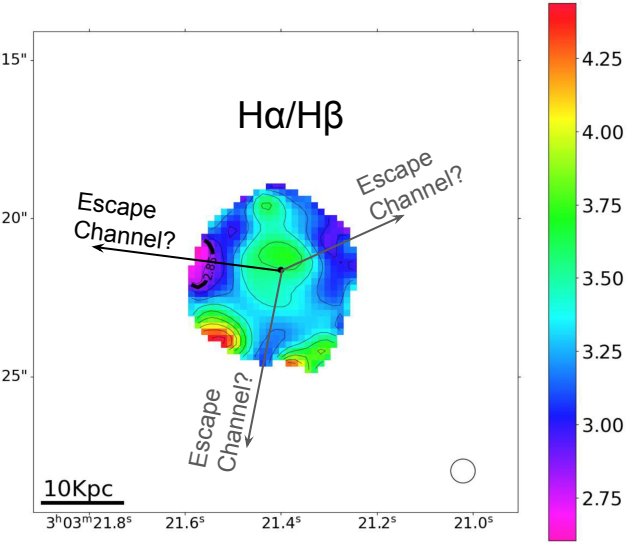

10Kpc
Velocity (km/s)
15
10
5
0
−5
−10
−15
13h37m12.2s
12.0s
11.8s
11.6s
11.4s


10Kpc
Velocity (km/s)
20
10
0
−10
−20
16h13m06.8s
06.6s
06.4s
06.2s
06.0s

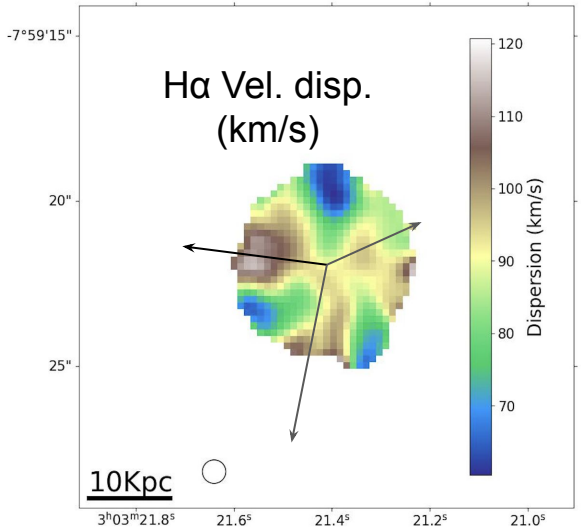

10Kpc
Velocity (km/s)
10
5
0
−5
−10
−15
−20
−25
8h05m18.4s
18.2s
18.0s
17.8s
17.6s

Lyman continuum escape in GP06

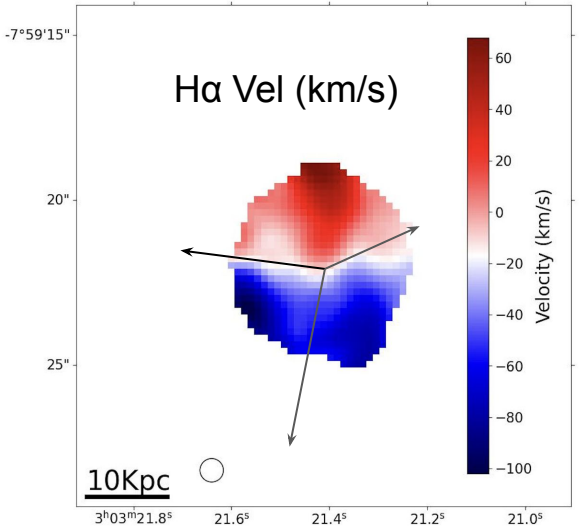
100 kpc a 100 km/s se tarda 1Gyr
sSFR^-1 GP 10Myr - 1Gyr



Lowest extinction



>100 km/s high vel. disp.



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