Suppressing star formation in quiescent galaxies with supermassive black hole winds

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Kevin Bundy
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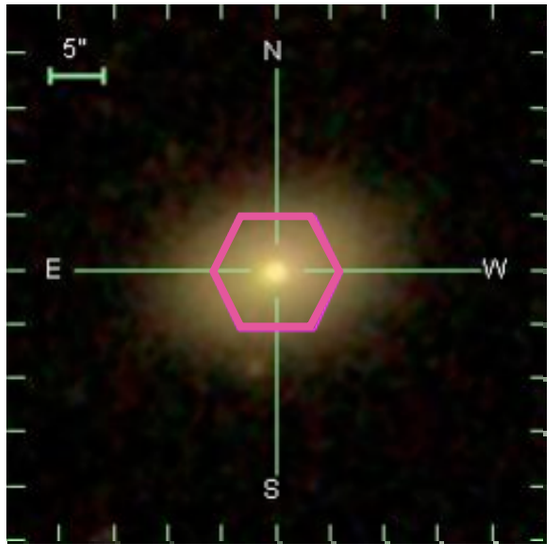
& MaNGA team

(Kavli IPMU)

The Interplay
Between Local and
Global Processes
in Galaxies

April 12, 2016


5"
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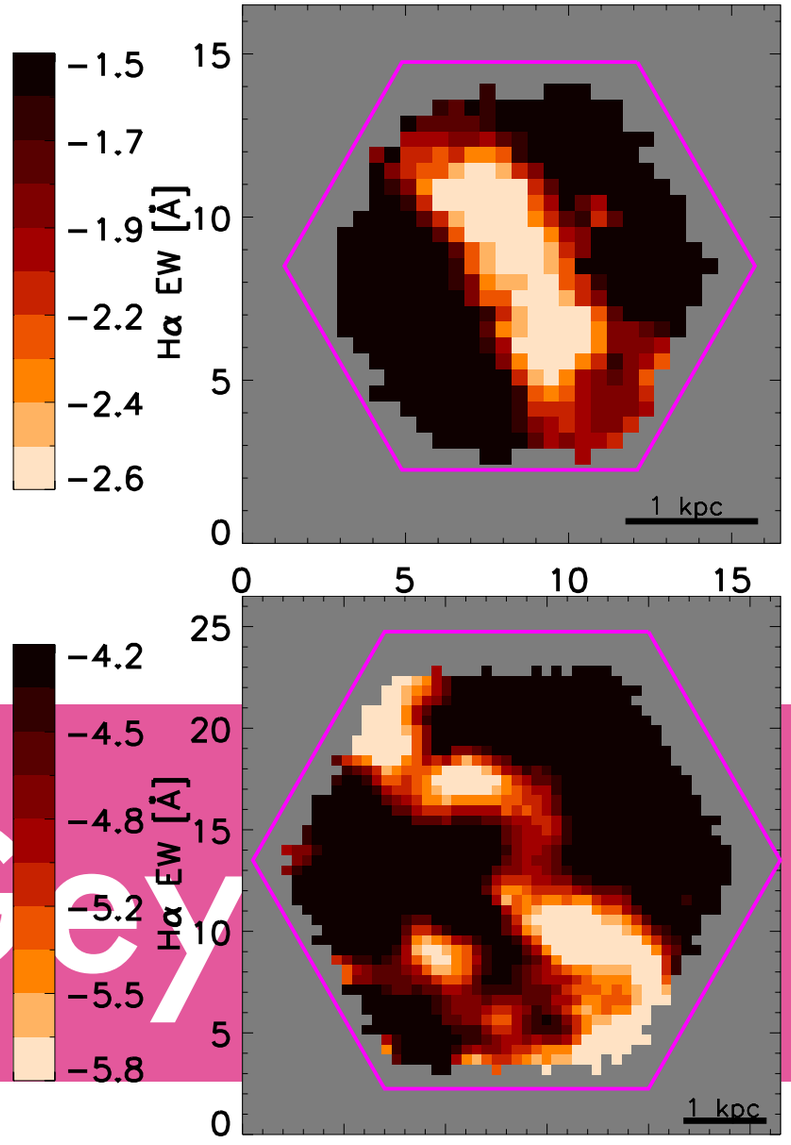
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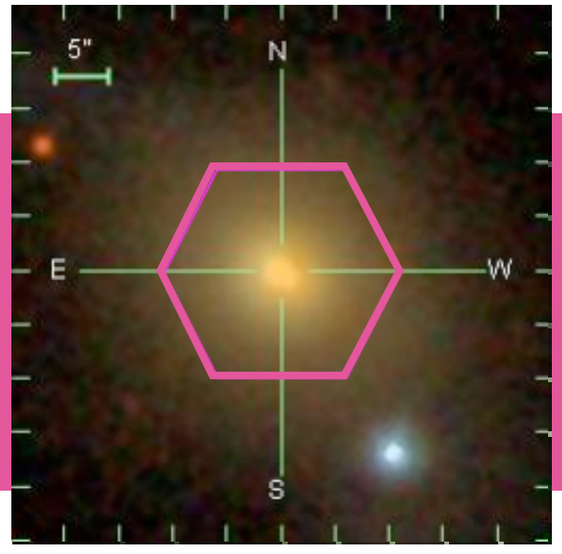
Hα EW [Å]
0
5
10
15
1 kpc


5"
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−4.2
−4.5
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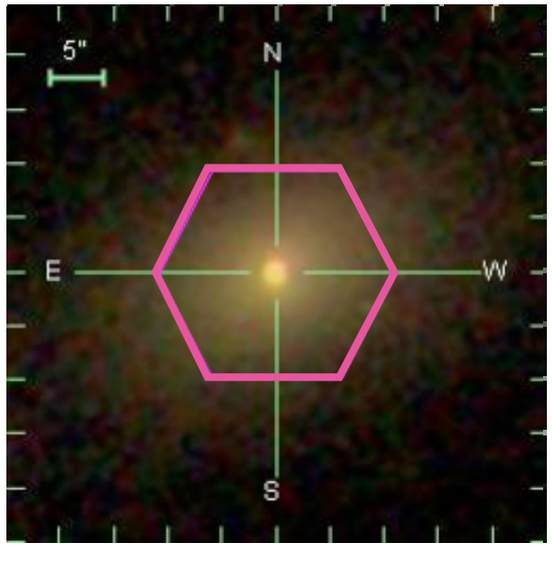
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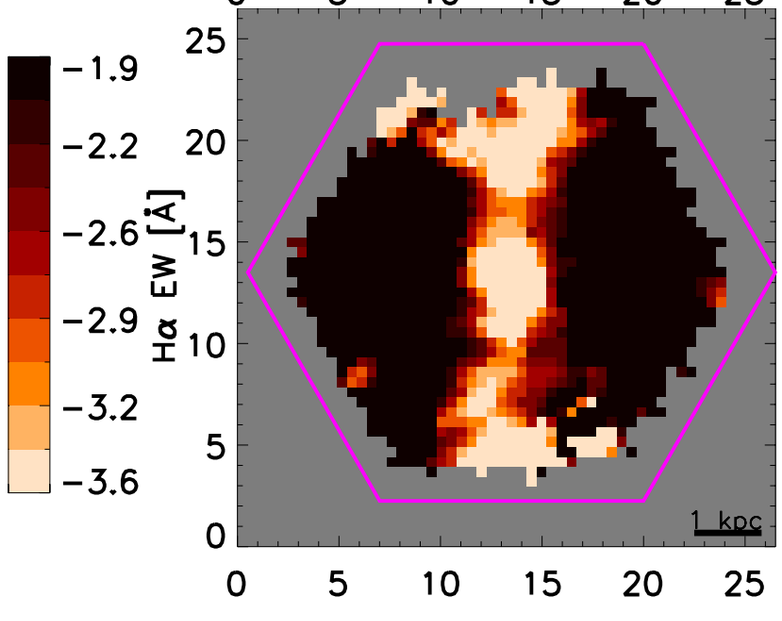
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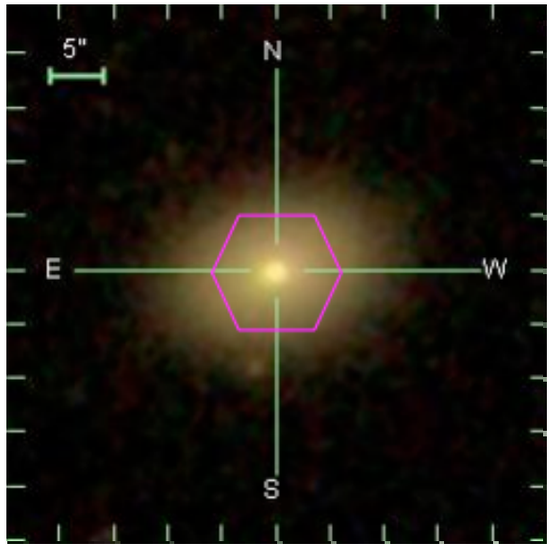
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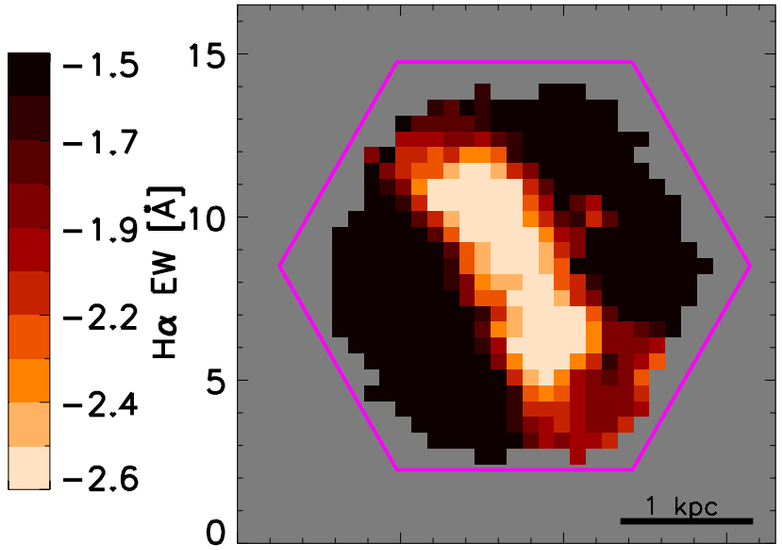
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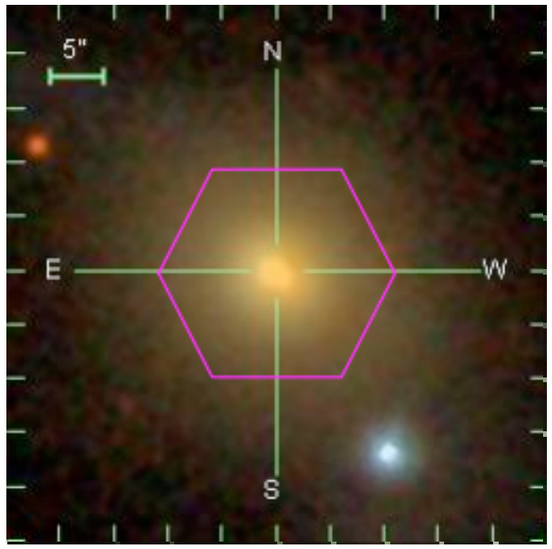
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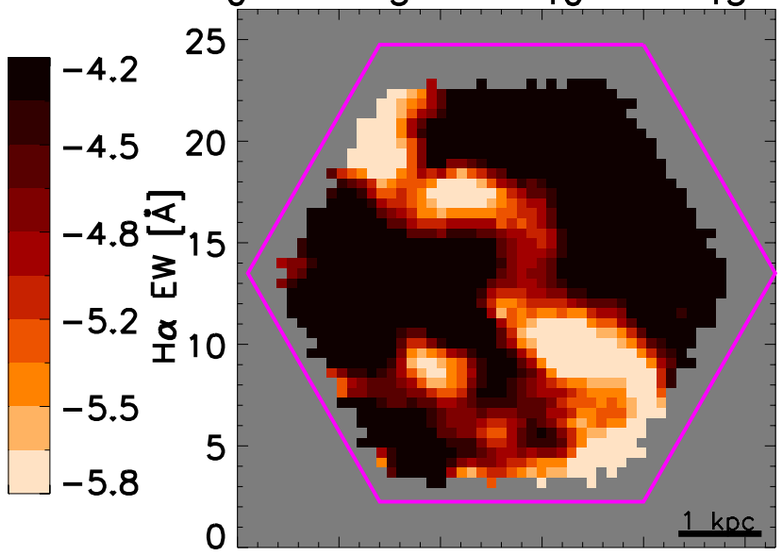
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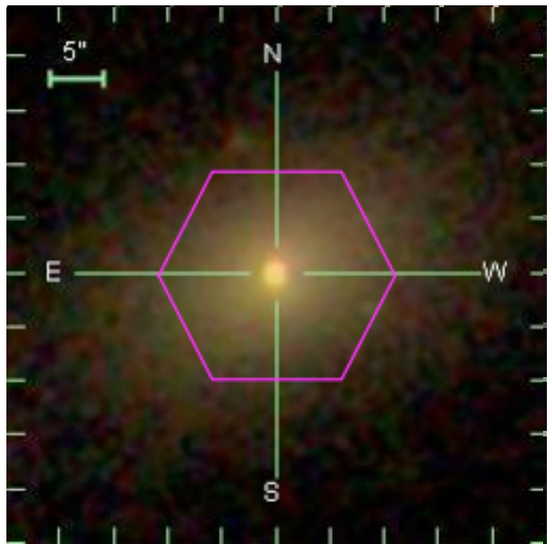
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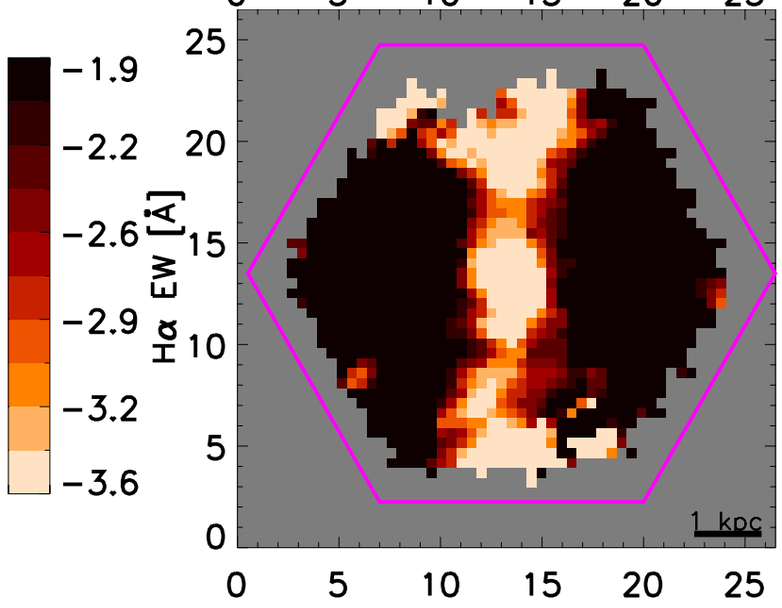
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Red Geysers

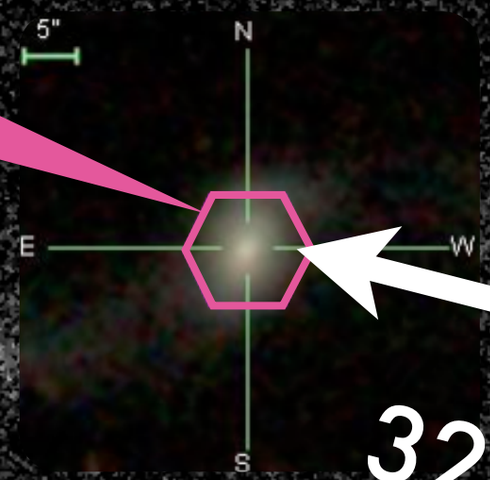
Cheung, Bundy, et al.
Nat

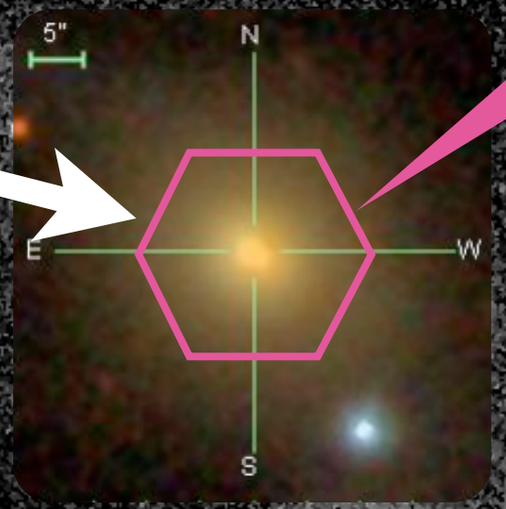
"Tetsuo"

"Akira"

19 fibers
12″ diameter

61 fibers
22″ diameter





32 kpc
67″

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Nature, in press

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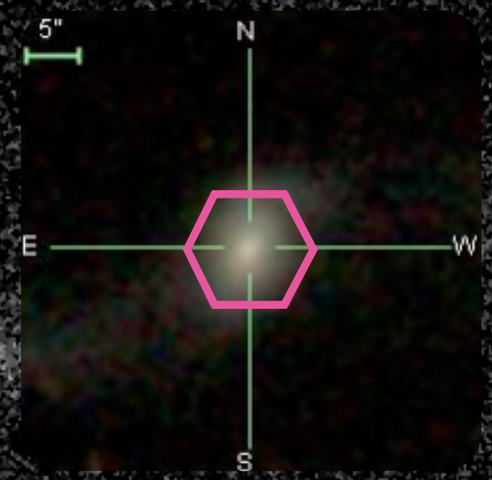
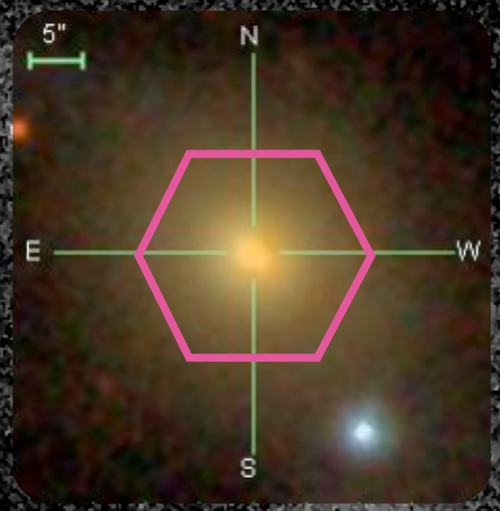
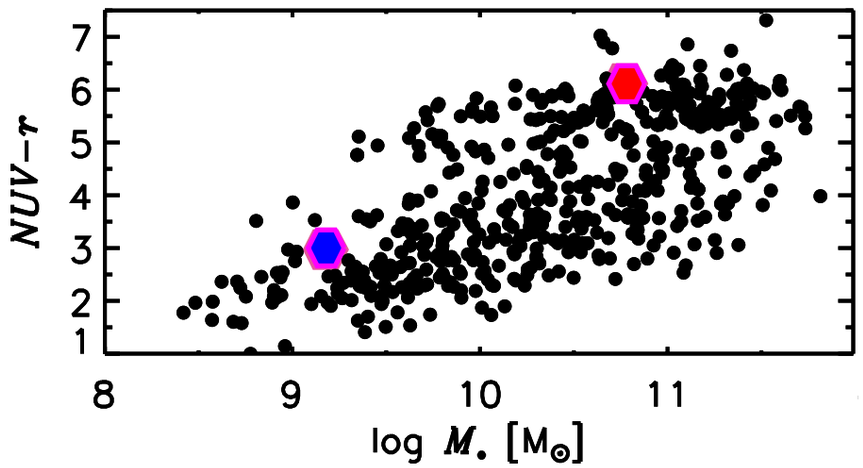


"Akira"



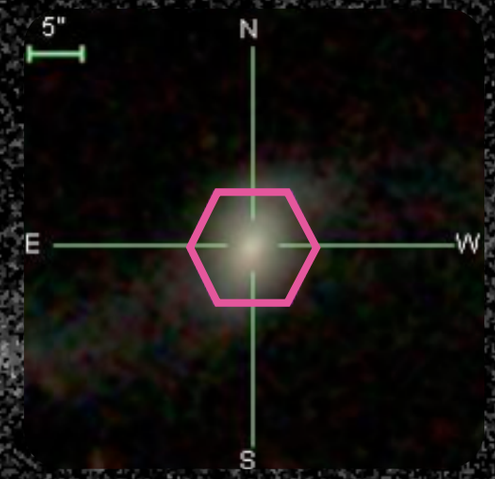


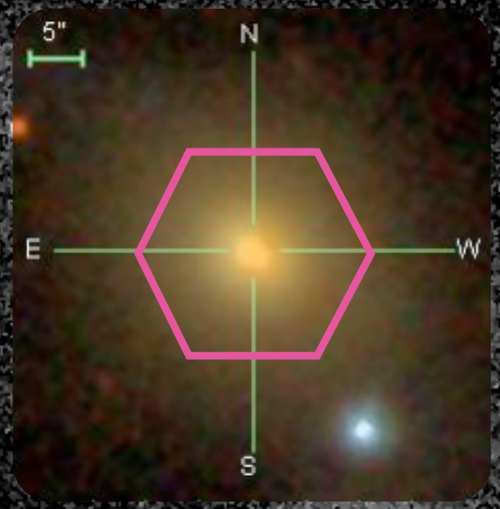
- Akira is a typical quiescent galaxy

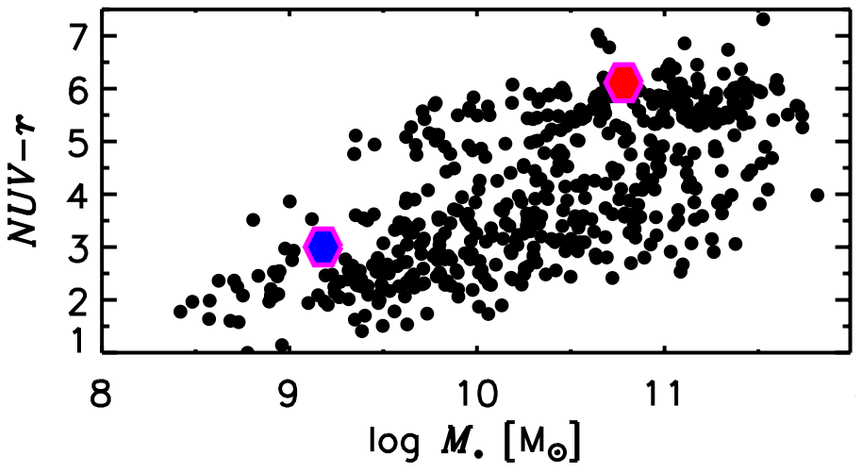
“Tetsuo”

“Akira”

Cheung, Bundy, et al.
Nature, in press







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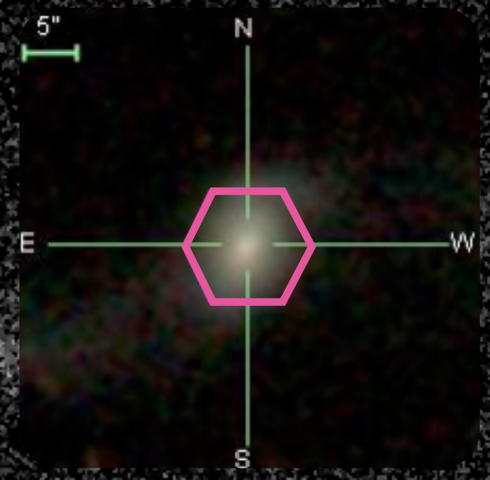

“Akira”

Cheung, Bundy, et al.
Nature, in press

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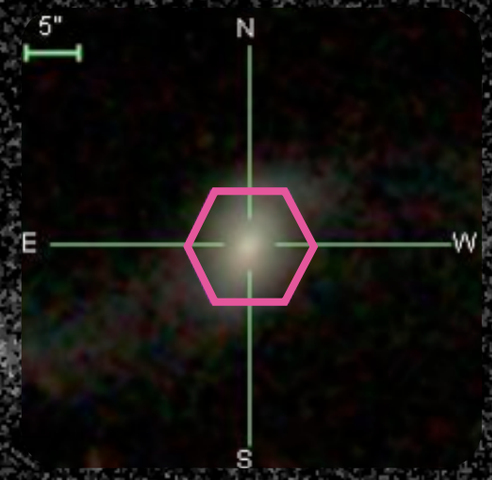

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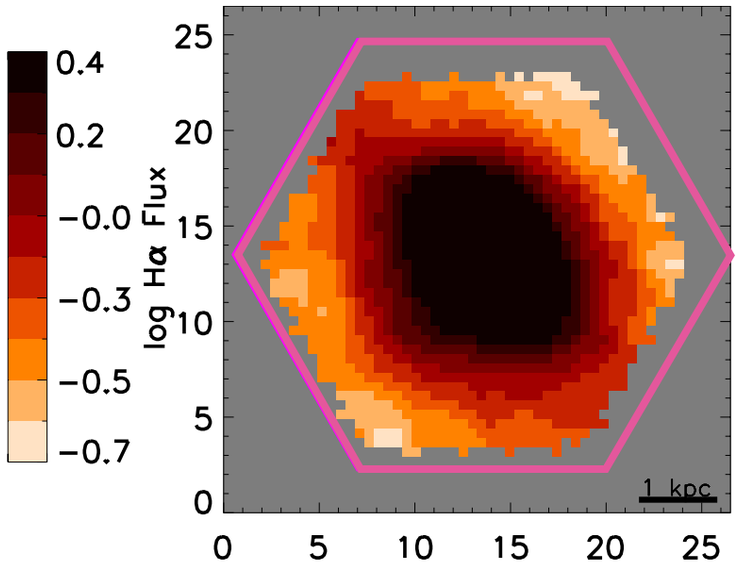
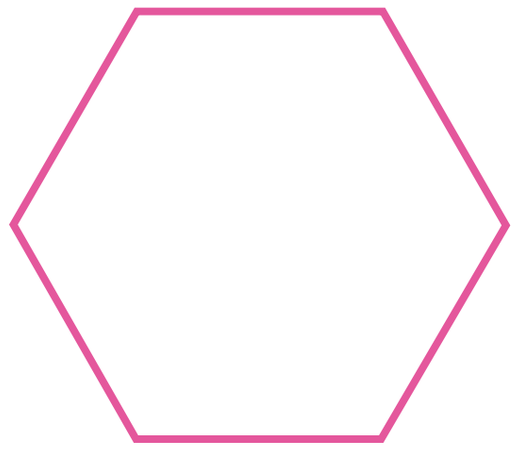
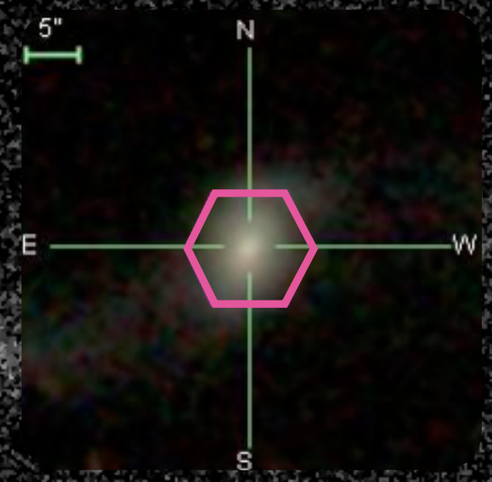




- Extensive ionized gas
- Narrow, bisymmetric EW pattern

“Tetsuo”

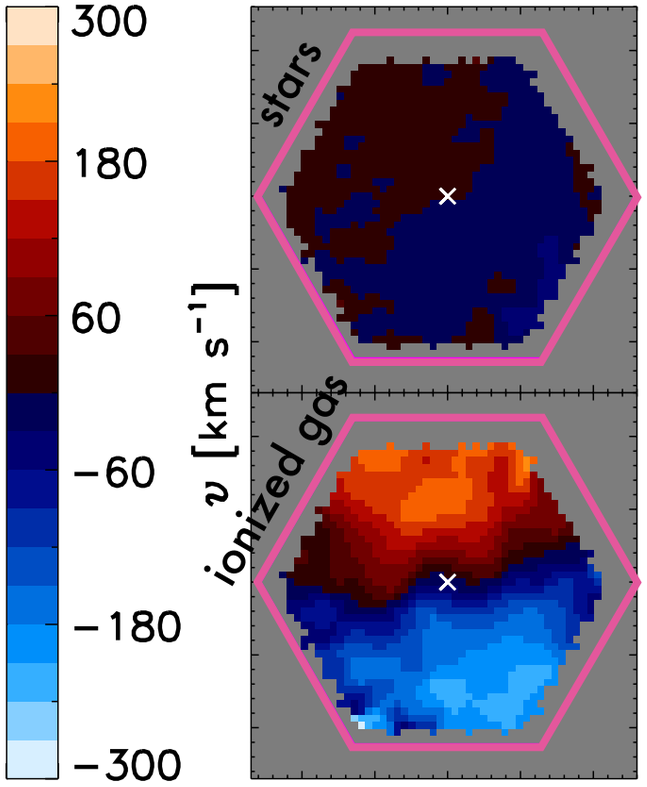


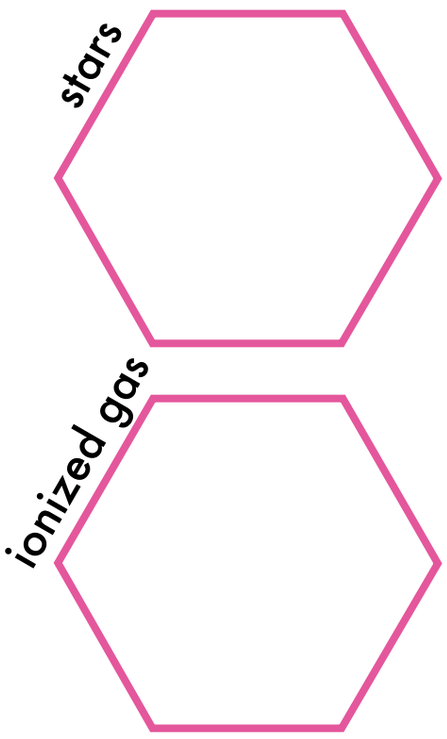
“Akira”

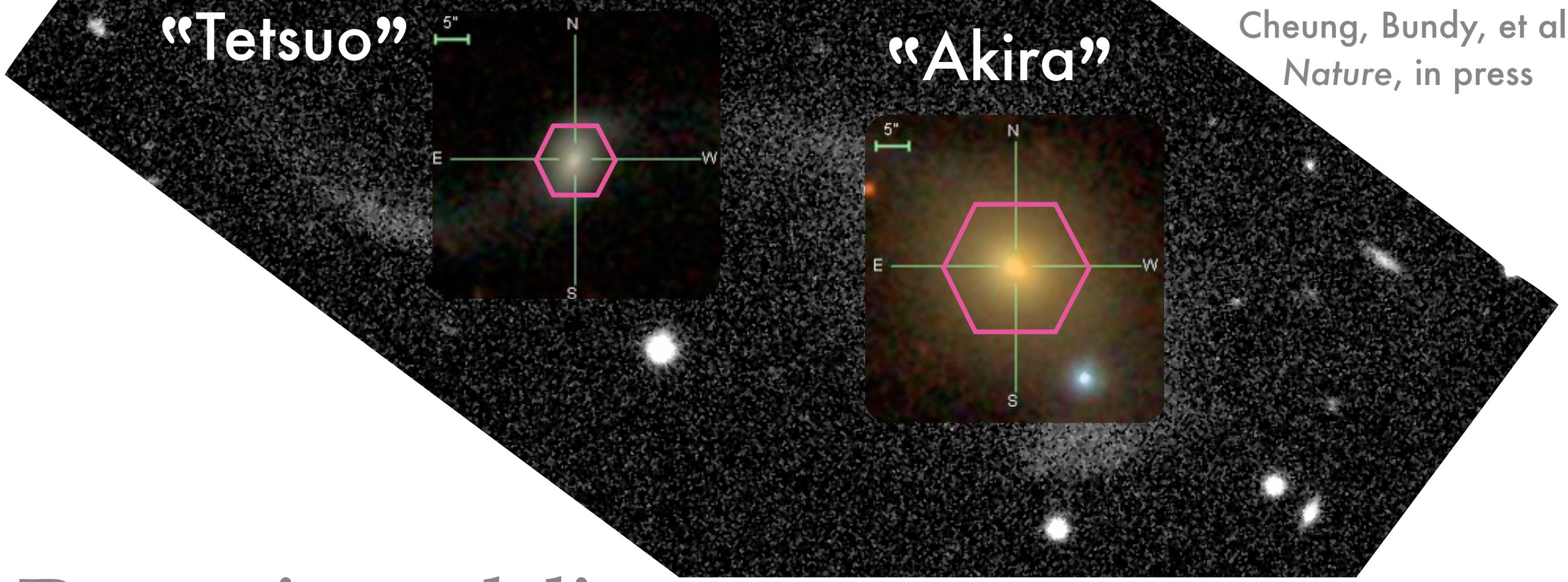
Cheung, Bundy, et al.
Nature, in press

- $v_{\text{ionized gas}} >> v_{\text{stars}}$
- Position angles of these velocity fields are offset by ~25°
- $\sigma_{\text{ionized gas}}$ is asymmetric and complex

➡ Ionized gas is decoupled from stars



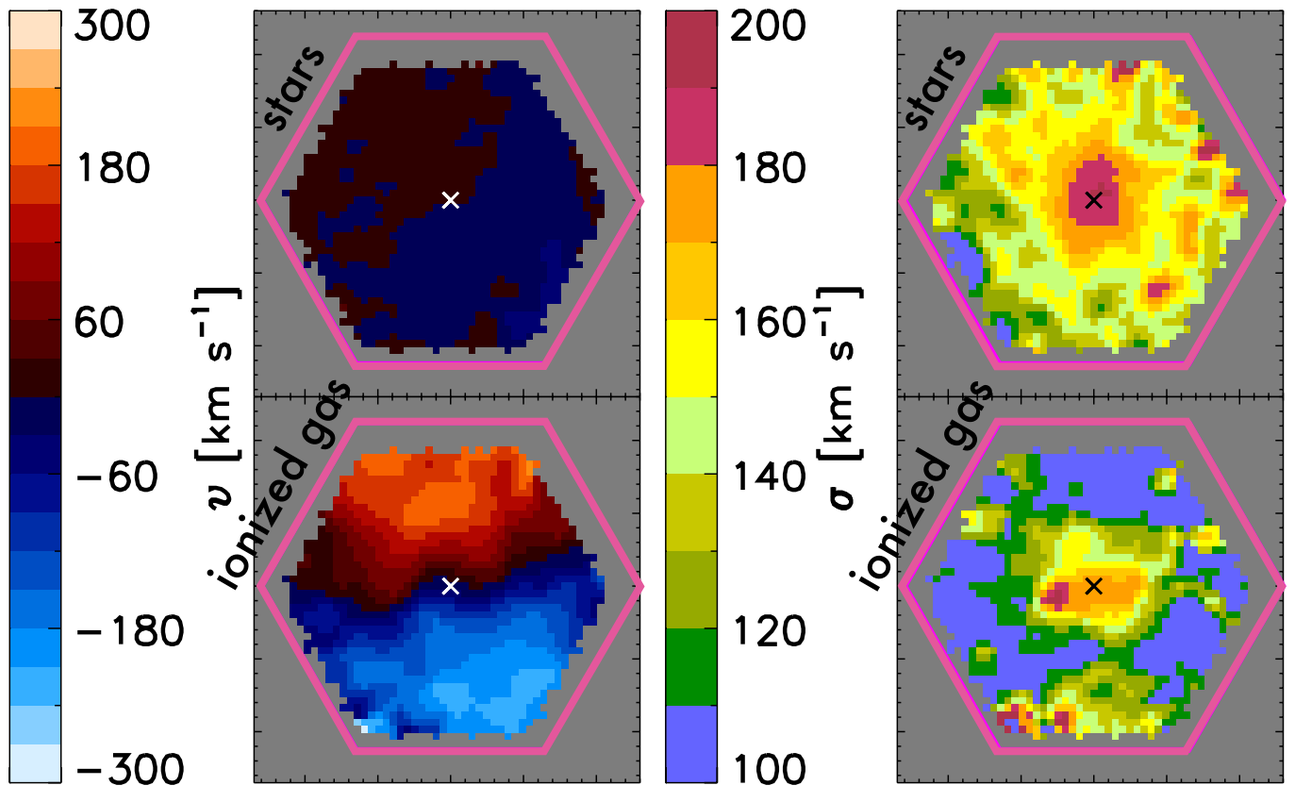




Cheung, Bundy, et al.
Nature, in press

Dynamic modeling

- Model the gravitational potential with Akira's stellar dynamics
- Predict the second velocity moments of the ionized gas
  - $V_{\rm rms} \equiv [v_{\rm gas}^2 + \sigma_{\rm gas}^2]^{1/2}$



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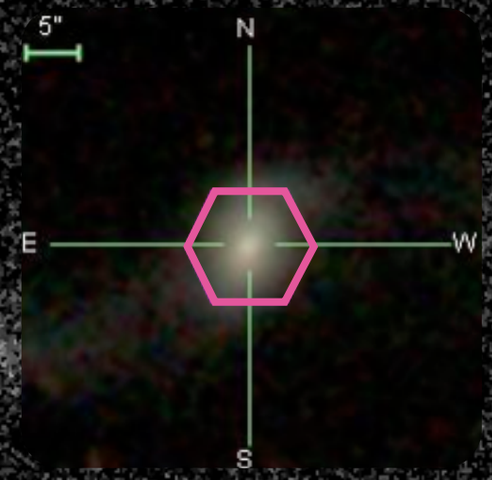

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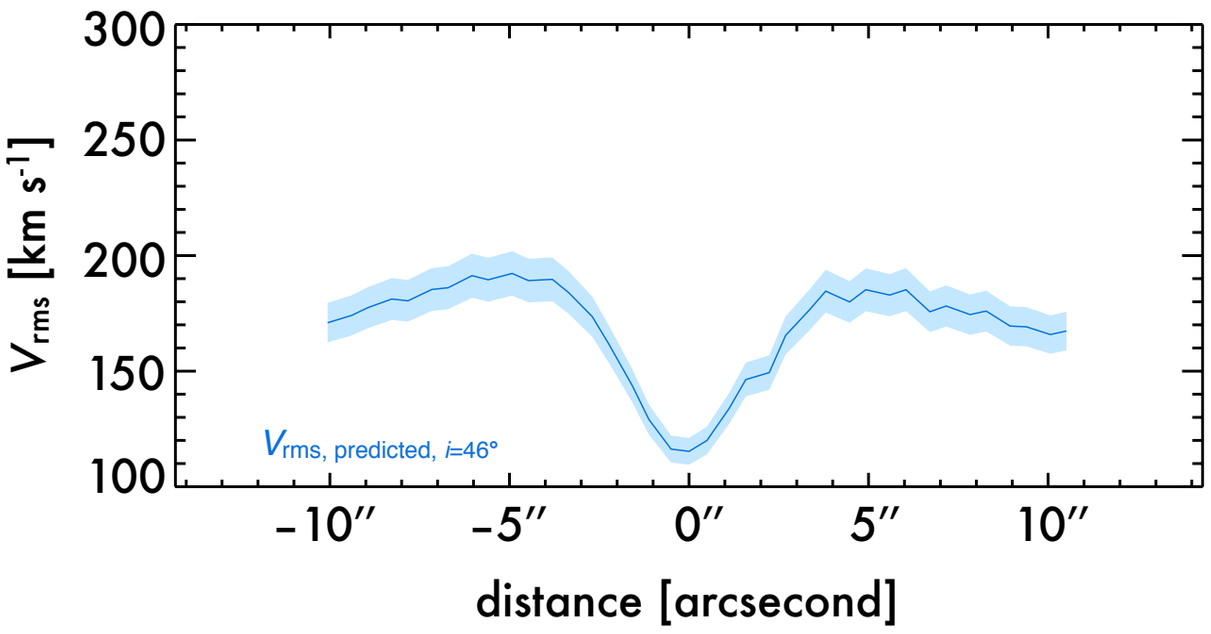

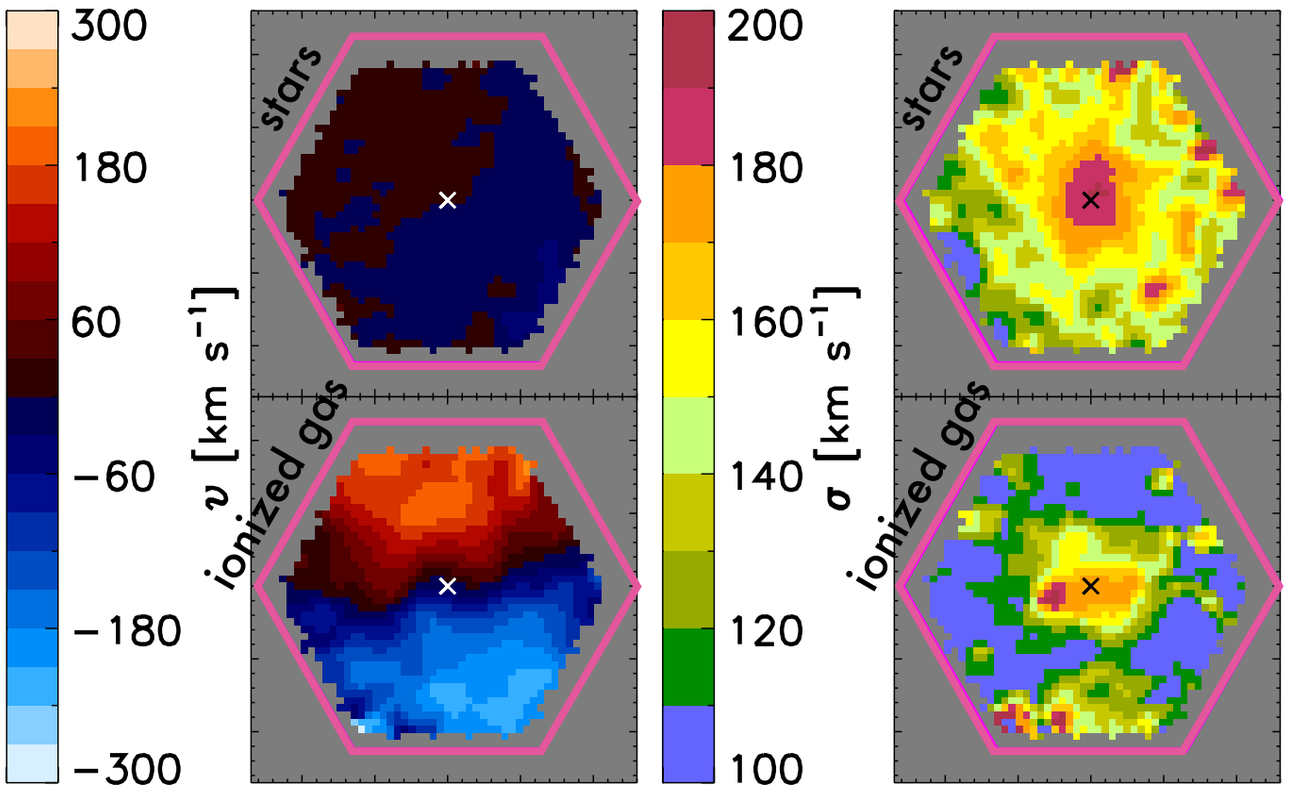

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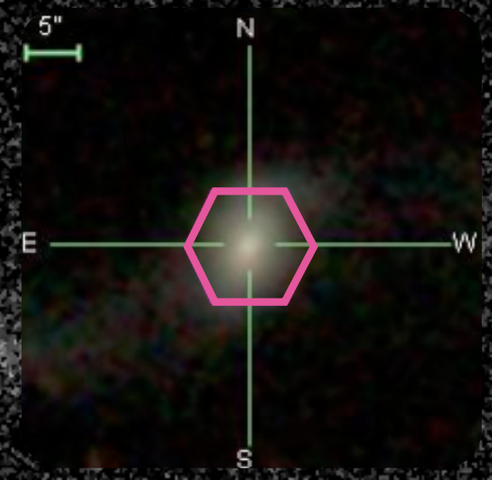

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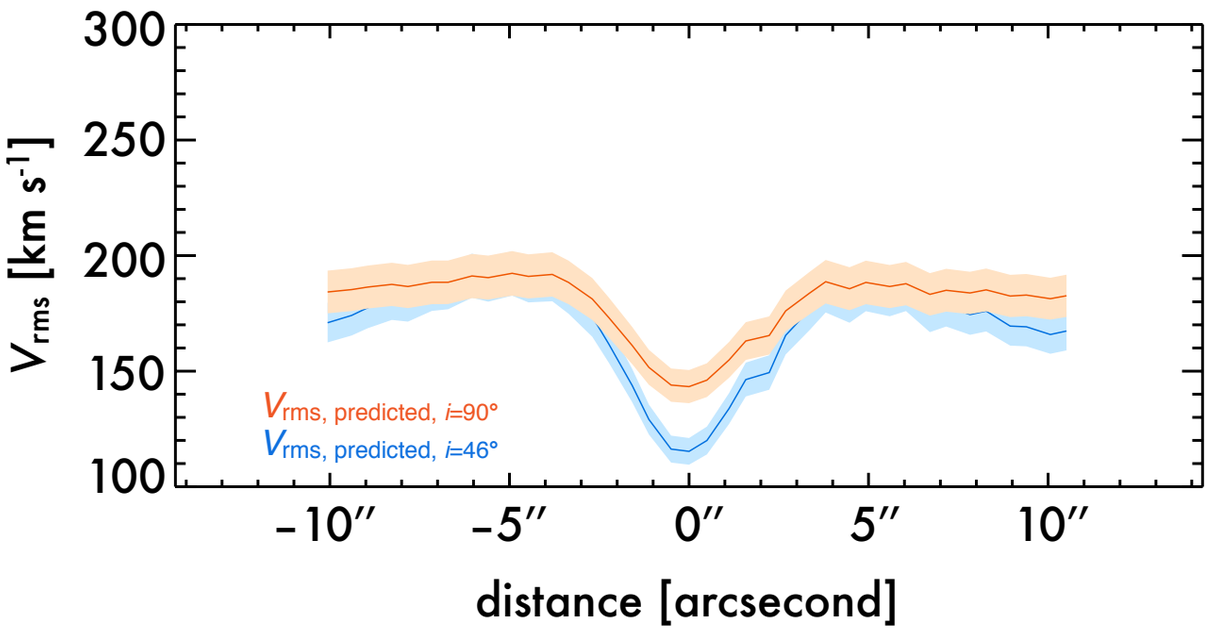

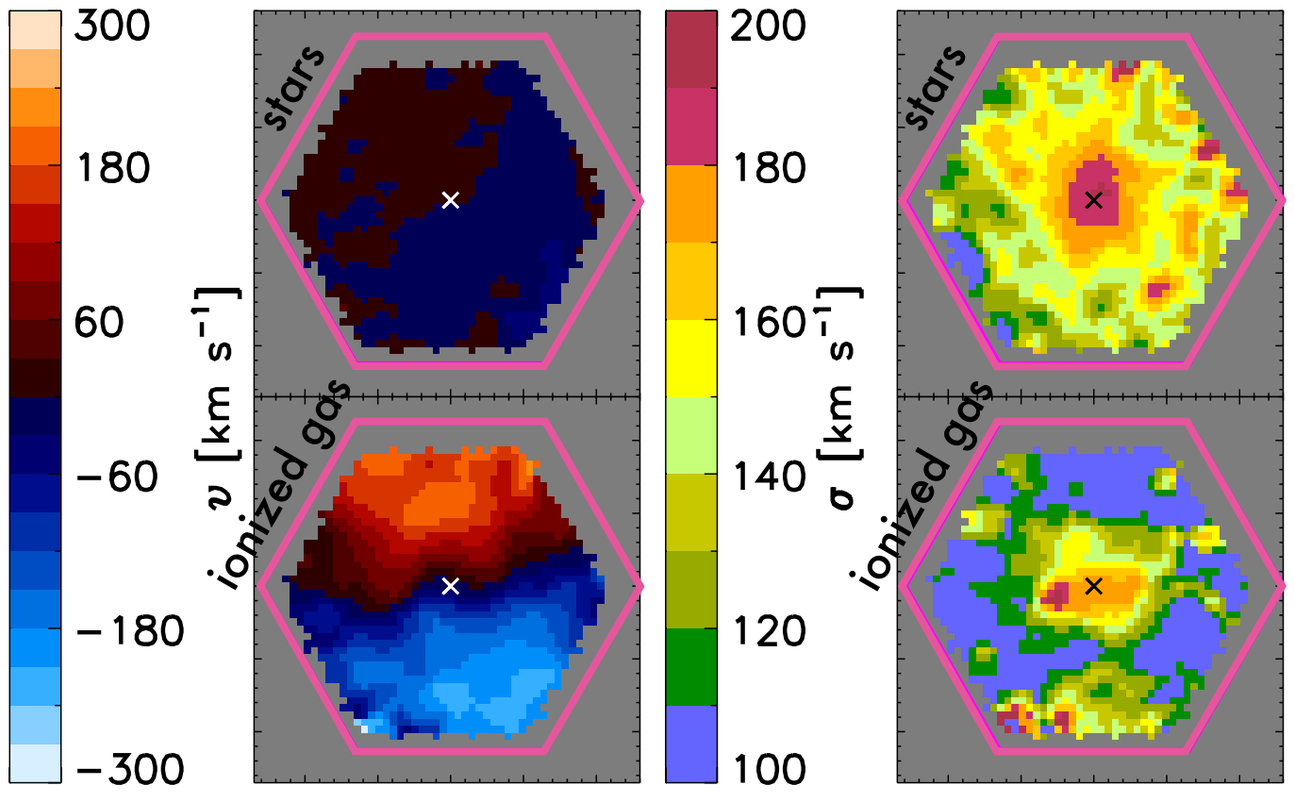

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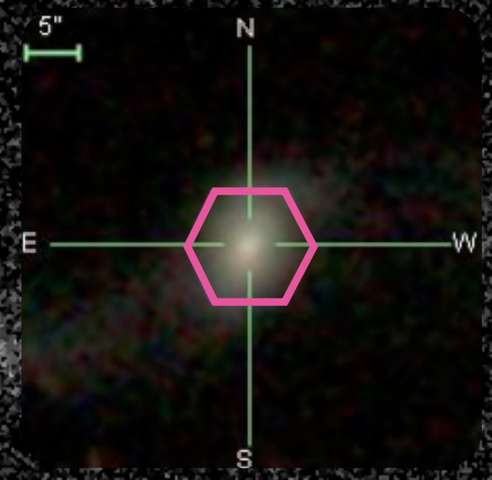

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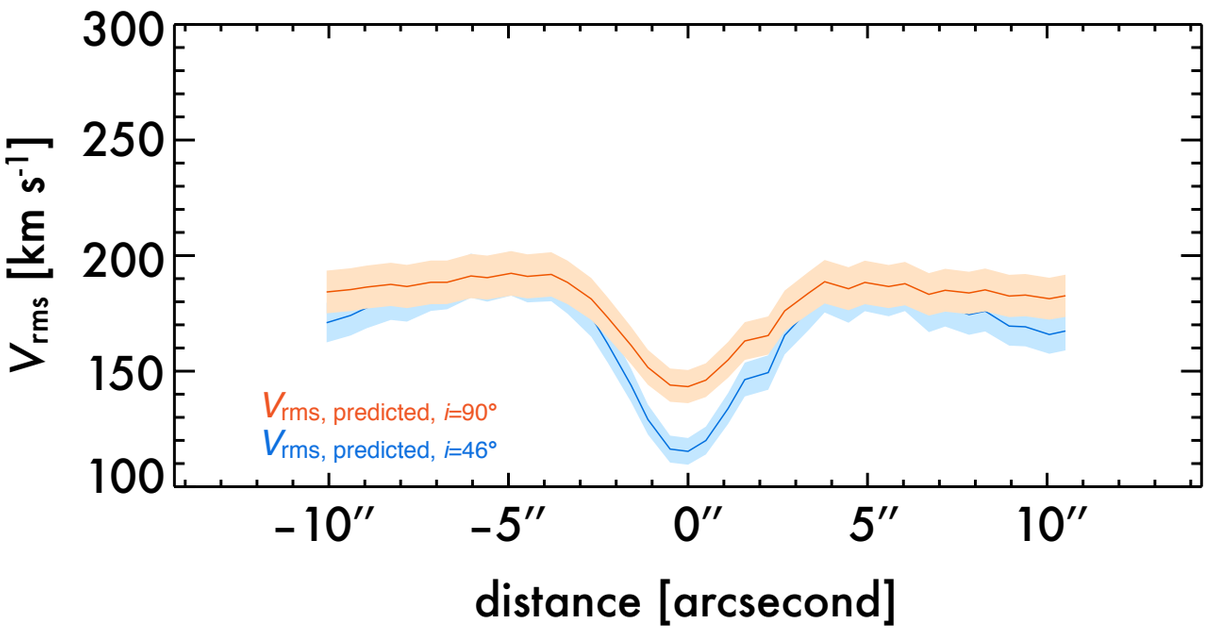

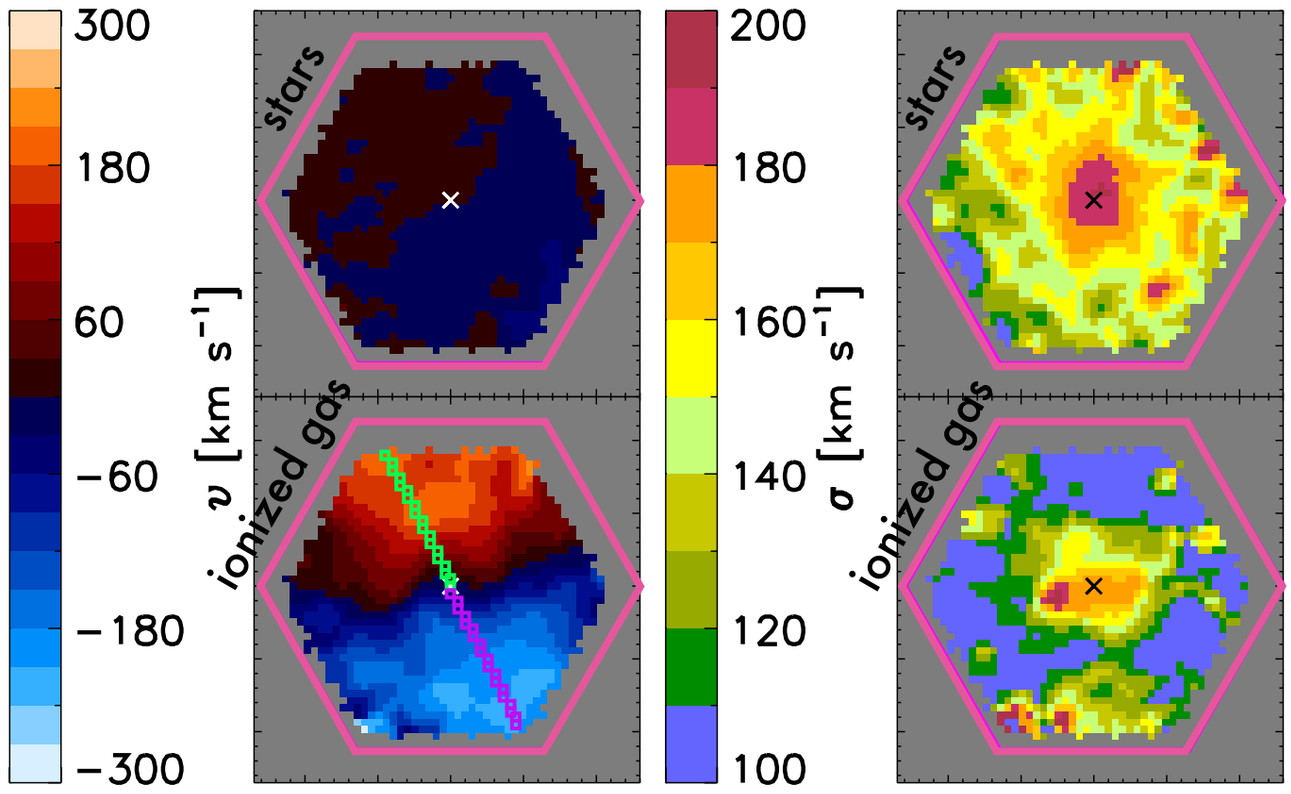

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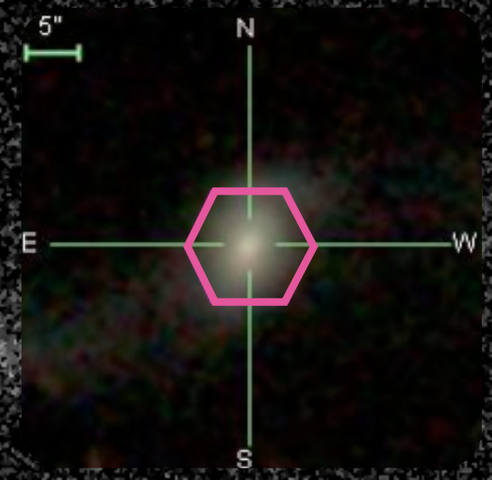

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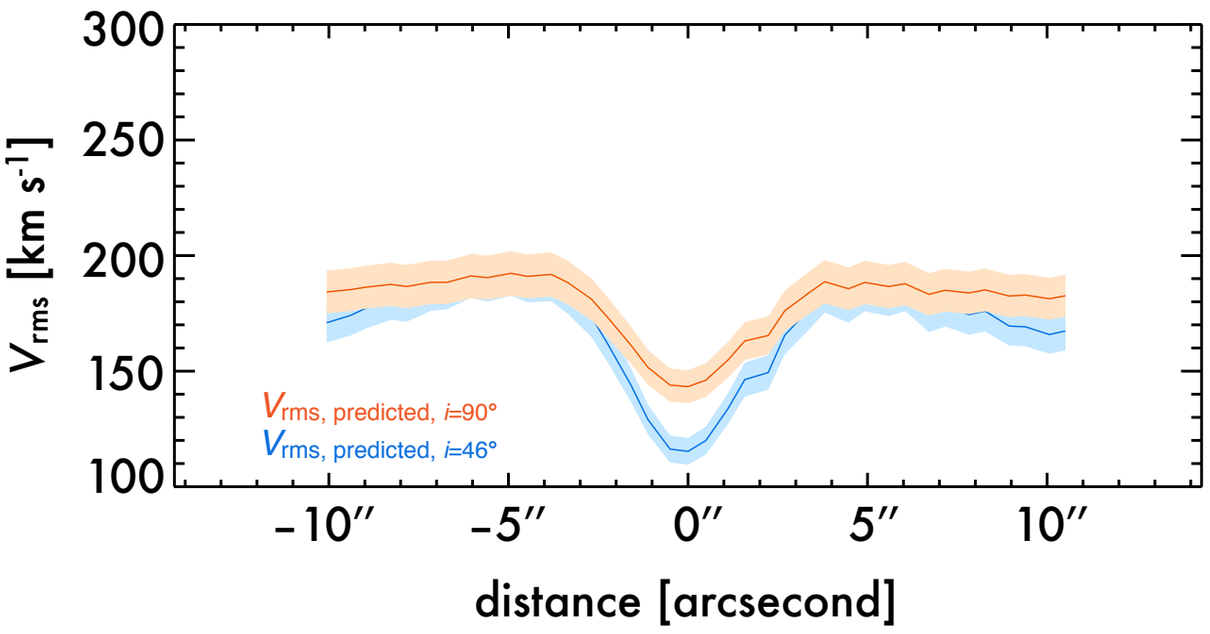

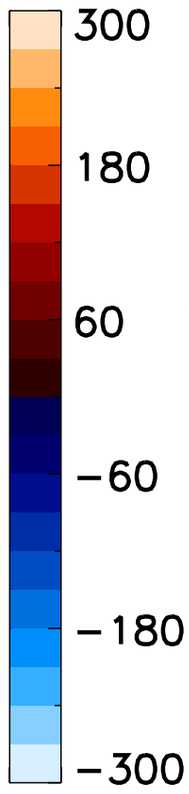

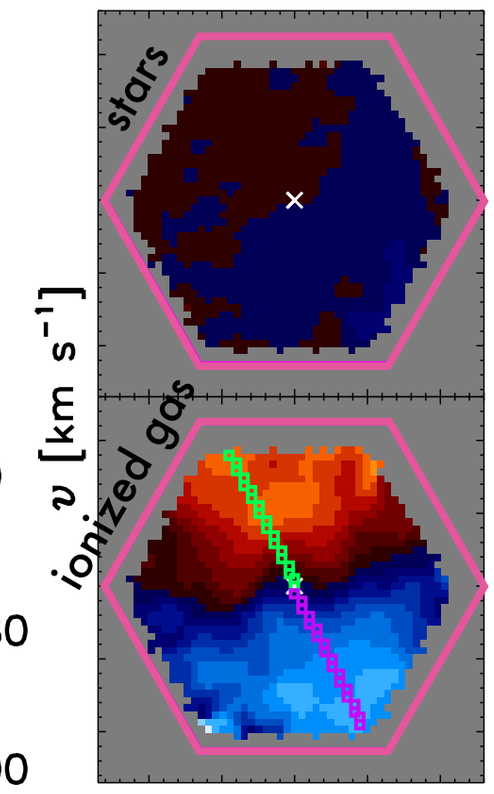

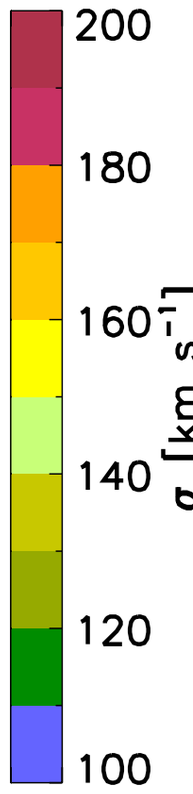

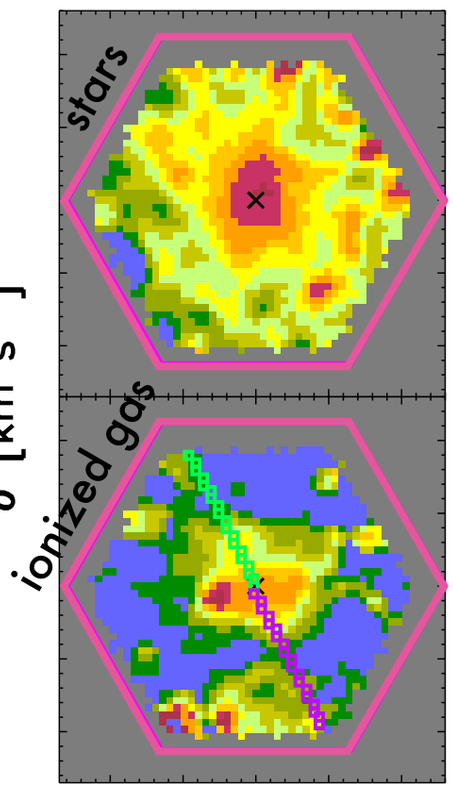

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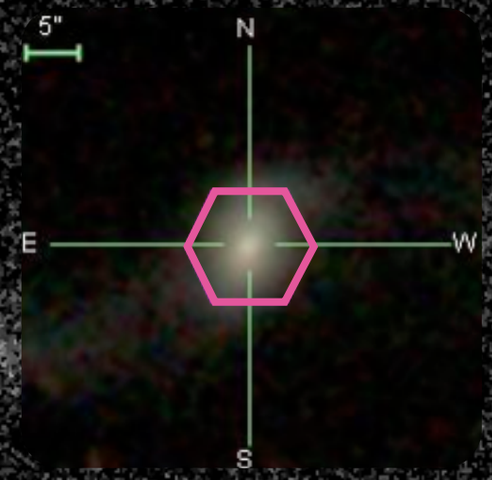

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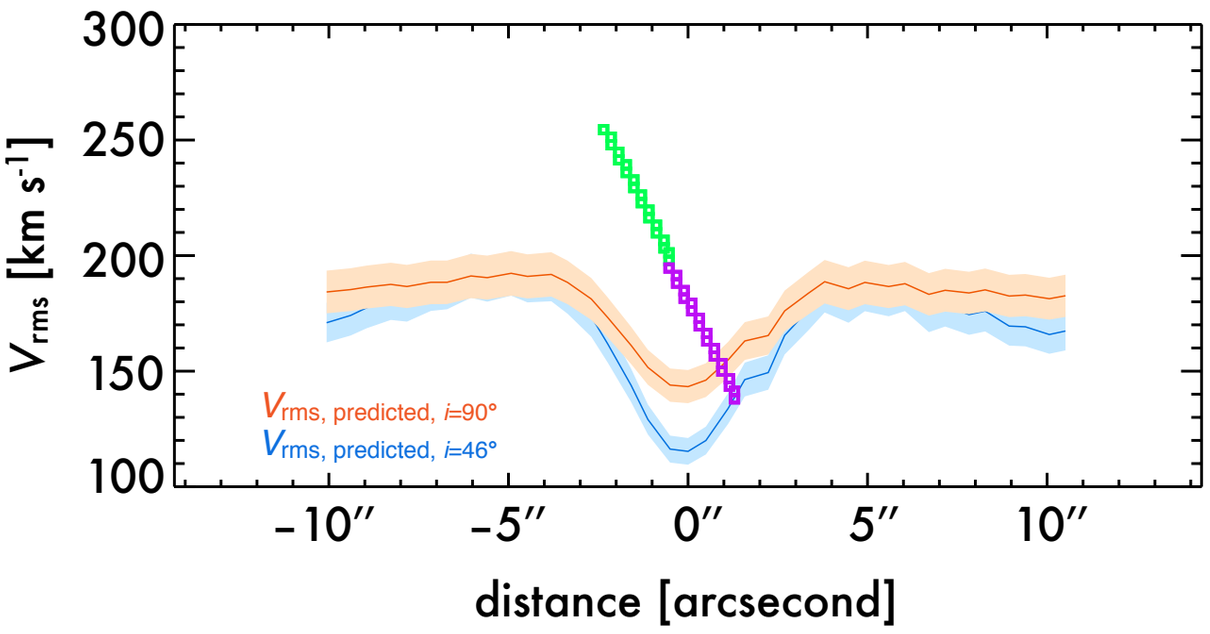

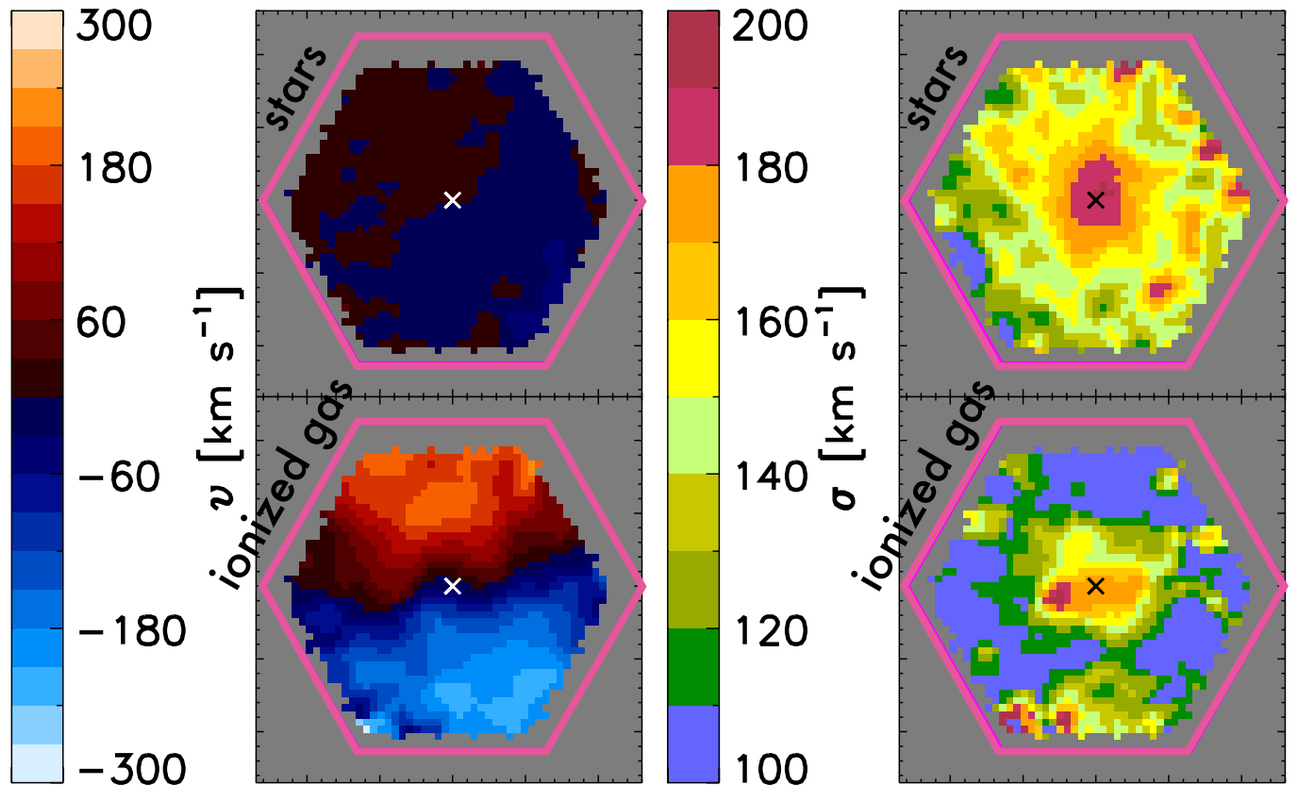

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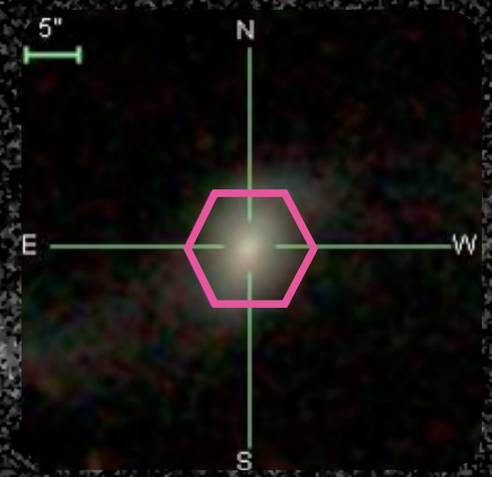

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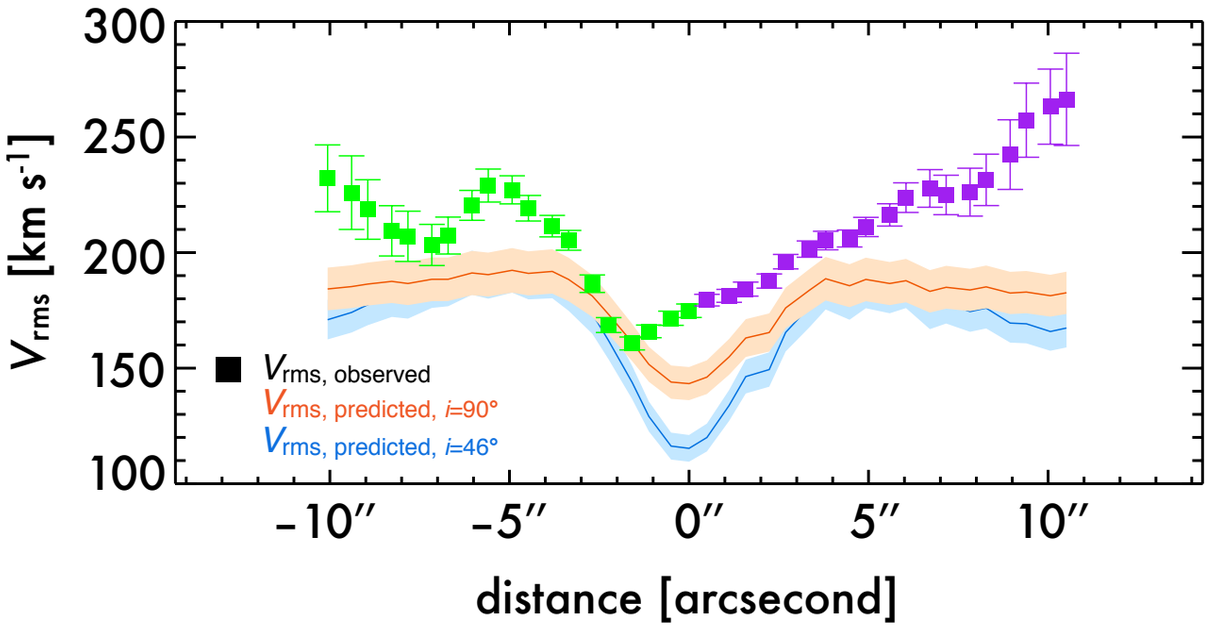
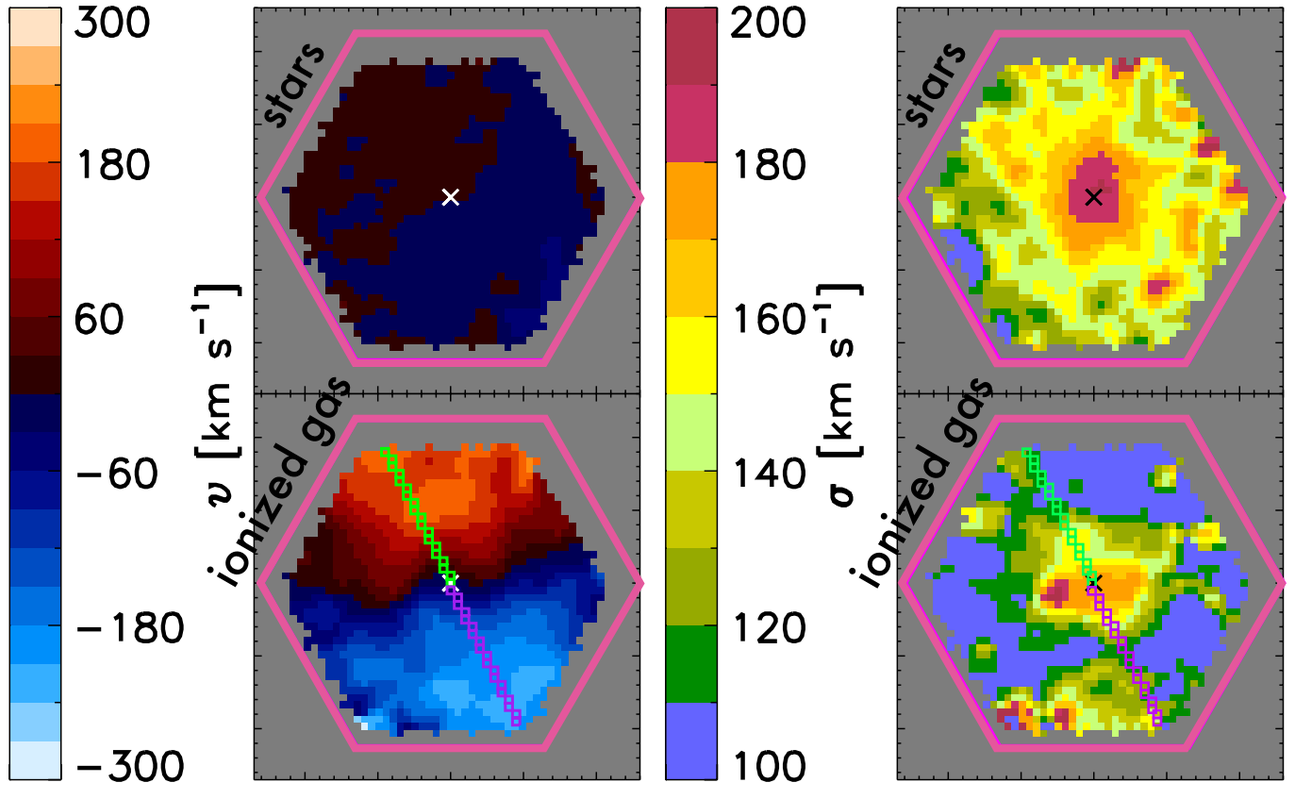
Nature, in press

- $V_{\mathrm{rms,\,observed}}$ far exceeds $V_{\mathrm{rms,\,predicted}}$
  - ➡ Ionized gas is not moving under the influence of gravity alone





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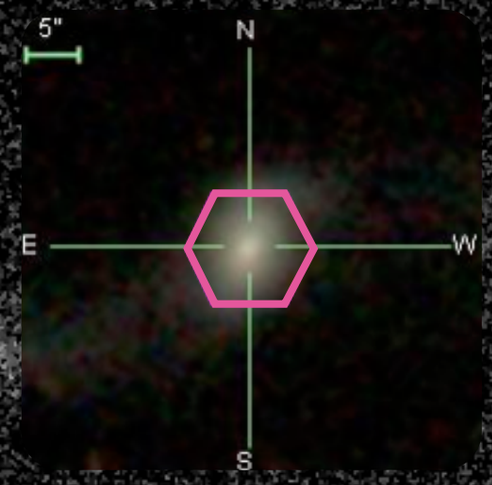
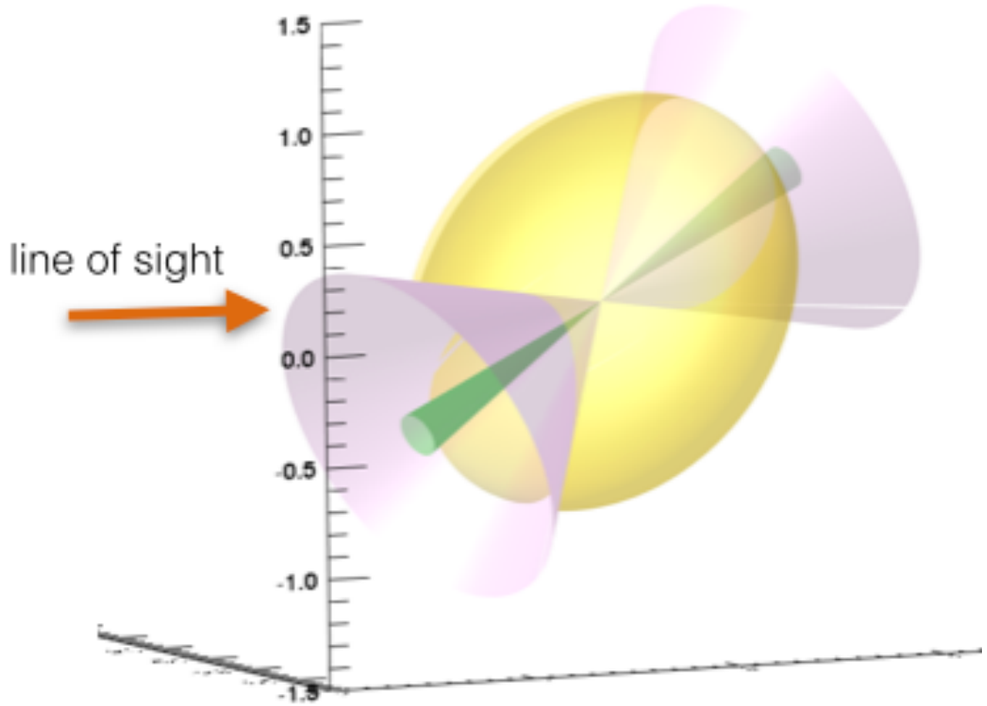
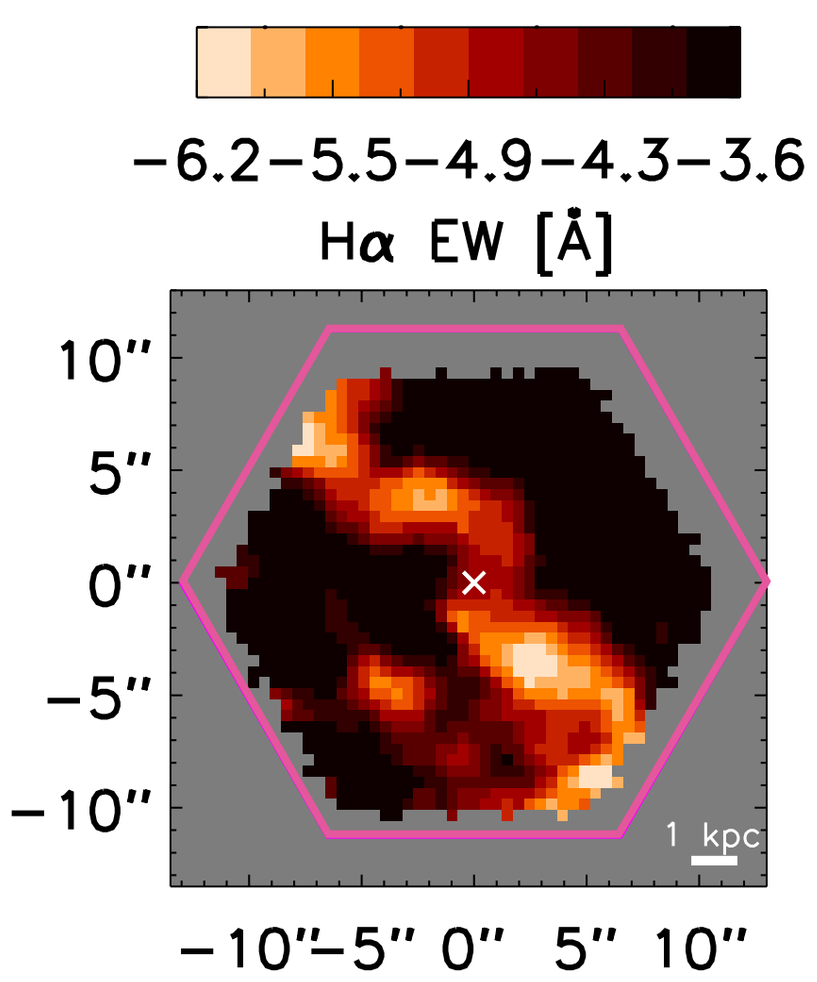


"Akira"

- Wind model
  - ➡ reproduces many qualitative features of data





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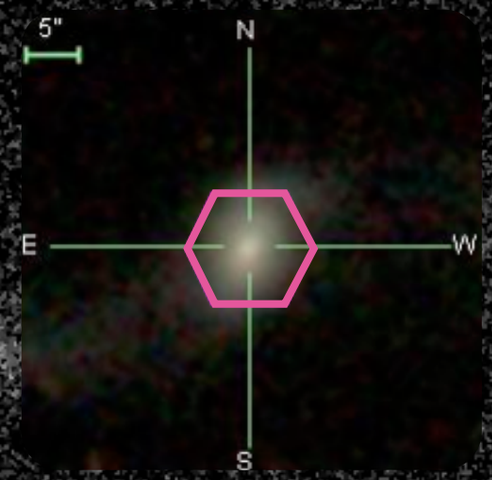

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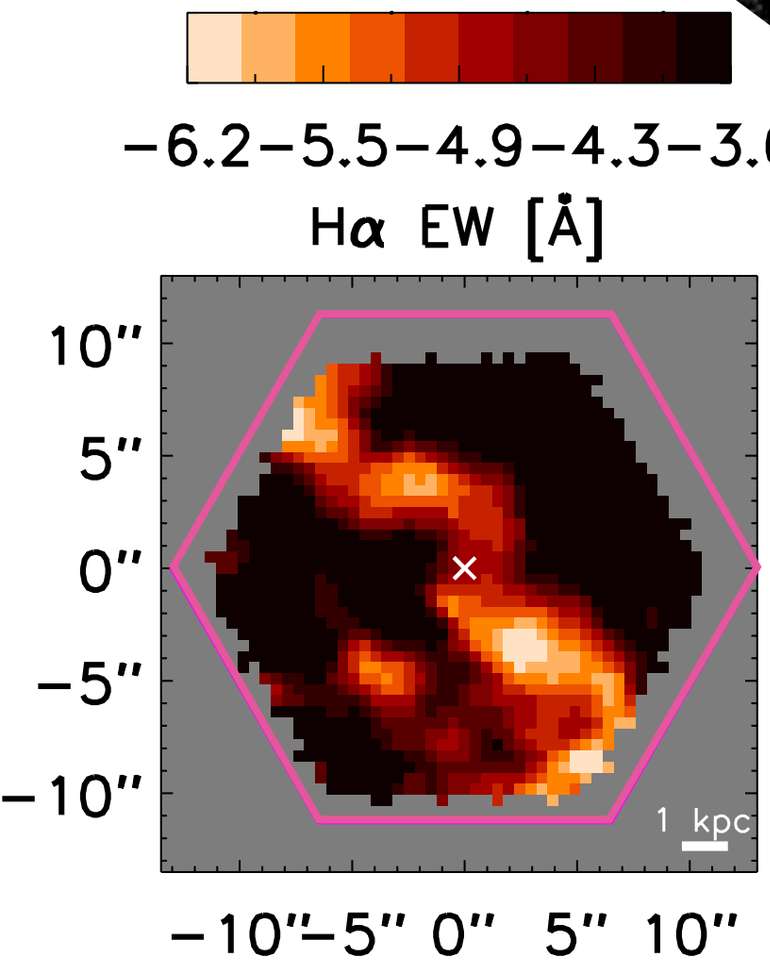
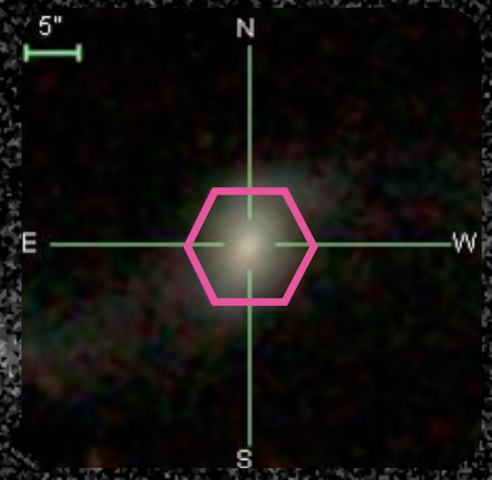


- Central radio source
  - ➡ AGN
  - ➡ small-scale jets (<1 kpc) or uncollimated winds
- Eddington ratio ≈ 10^{-4}
  - ➡ low accretion rate or radiatively inefficient accretion flow
  - ➡ i.e., radio mode, kinetic mode, jet mode, maintenance mode

“Tetsuo”



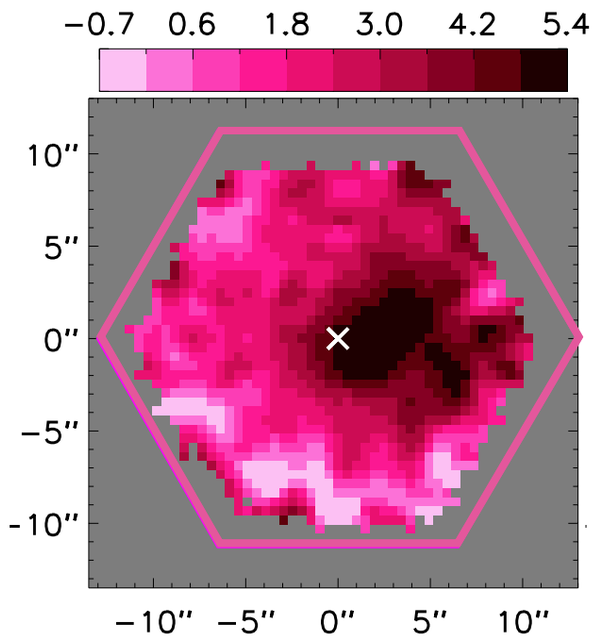
“Akira”

Cheung, Bundy, et al.
Nature, in press

- Inflowing cool material
- SFR$_{Akira}$ ~ 10$^{-1.5}$ $M_\odot$ yr^{-1}
- SFR$_{Akira}$ ~ 10$^{-1.5}$ $M_\odot$ yr^{-1}

Why is Akira still quiescent?

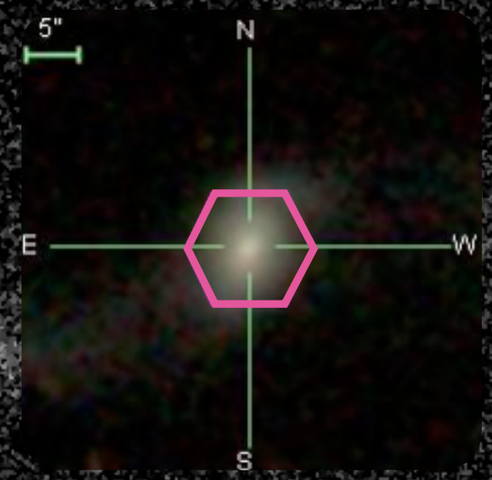
Na D EW [Å]



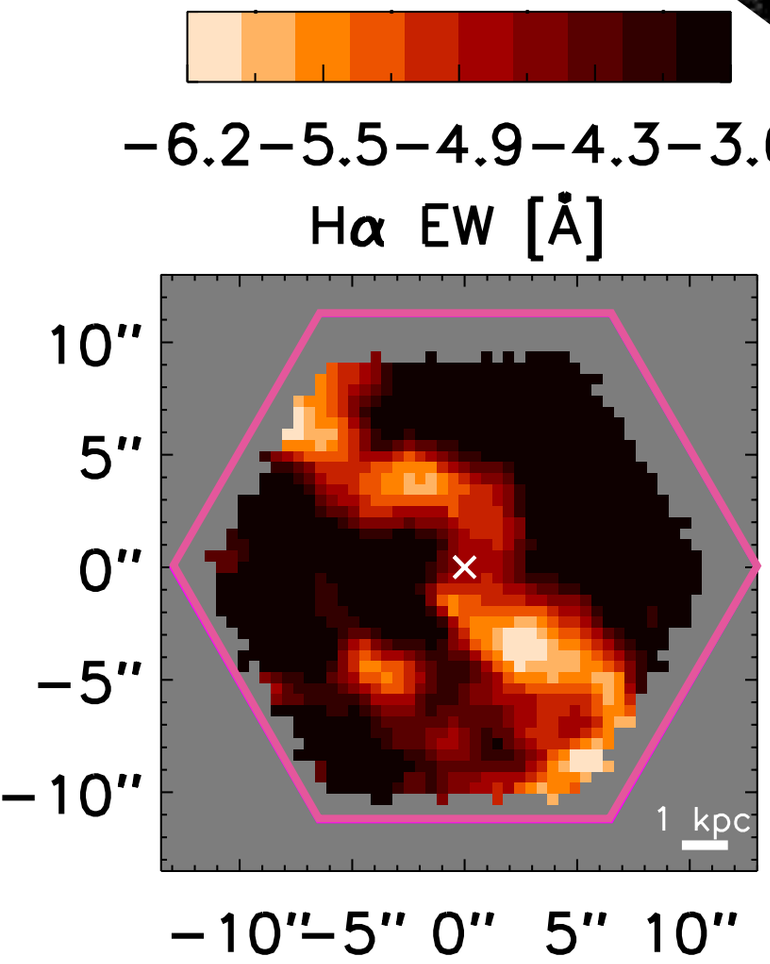
$v_{Na\ D}$ [km s^{-1}]

Cheung, Bundy, et al.
Nature, in press

"Tetsuo"



"Akira"

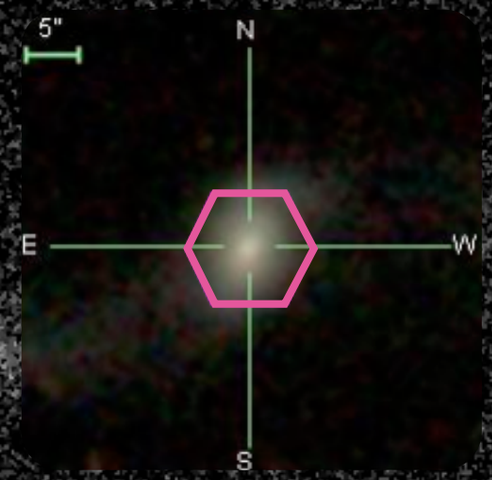


- Wind power ≈ 10^{39} erg s^{-1}
- Cooling rate of ionized gas ≈ 10^{38} erg s^{-1}
- Cooling rate of cool gas ≈ 10^{39} erg s^{-1}

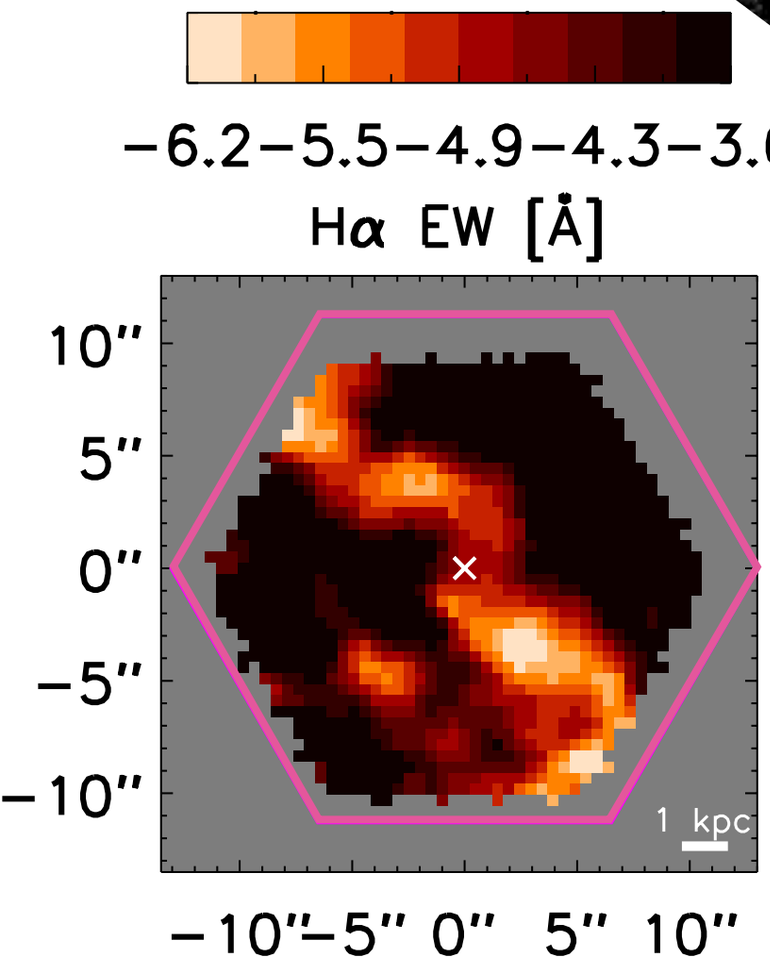
➡ wind can balance cooling and thus maintain quiescence

Cheung, Bundy, et al.
Nature, in press

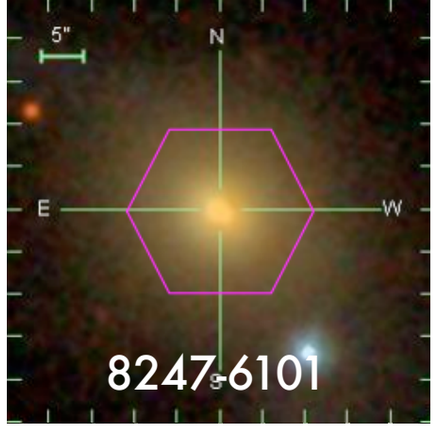
"Tetsuo"

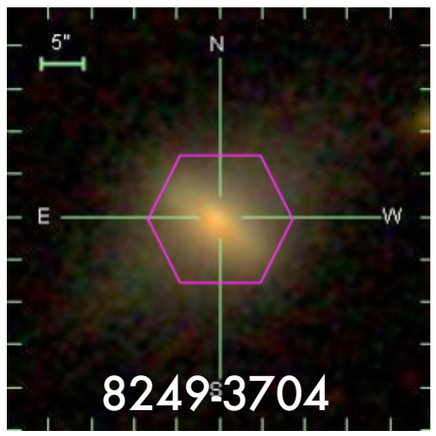


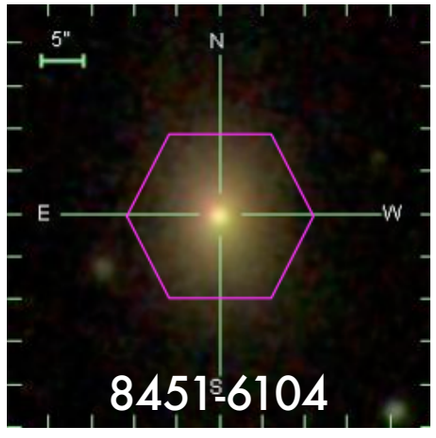
"Akira"

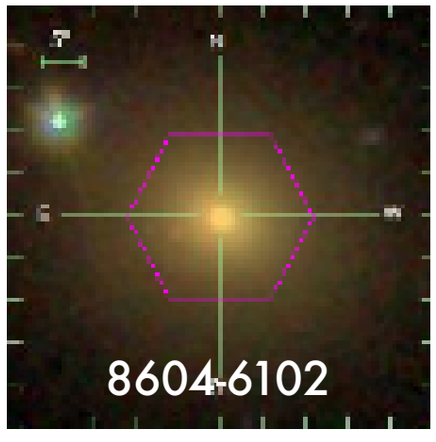


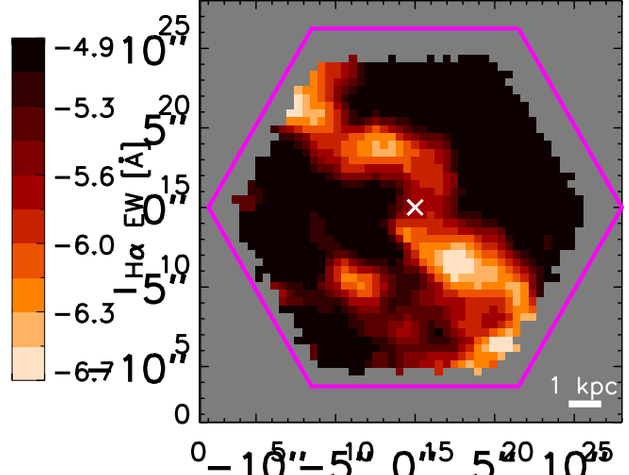
- Akira may represent how typical quiescent galaxies maintain their quiescence

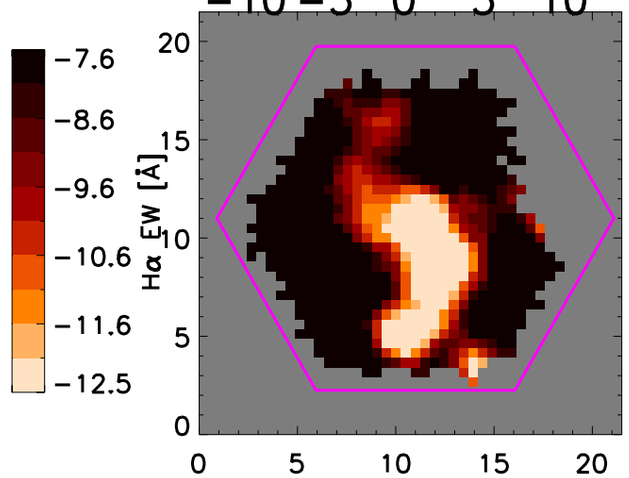

5"
N
E
W
S
8247-6101

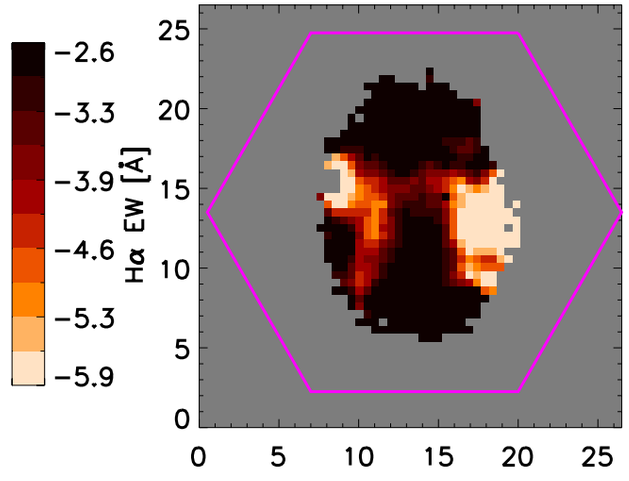

5"
N
E
W
S
8249-3704

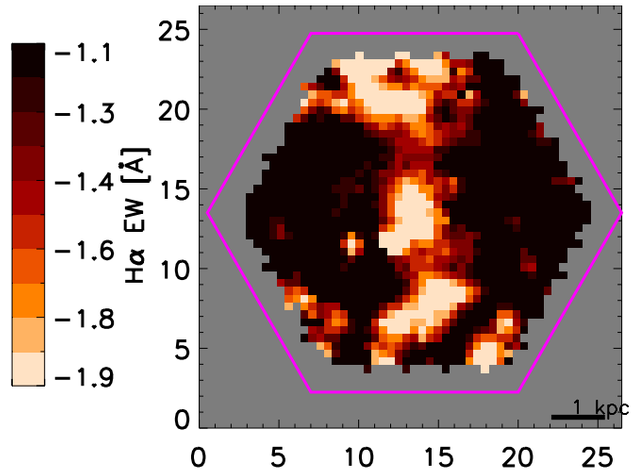

5"
N
E
W
S
8451-6104

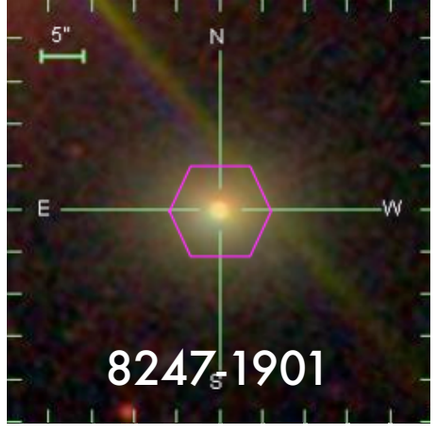

N
S
8604-6102

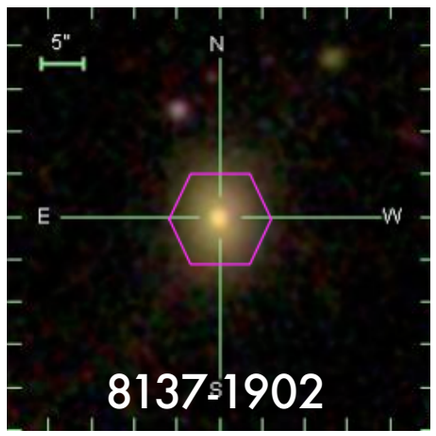

−4.9
−5.3
−5.6
−6.0
−6.3
−6.7
Hα EW [Å]
1 kpc

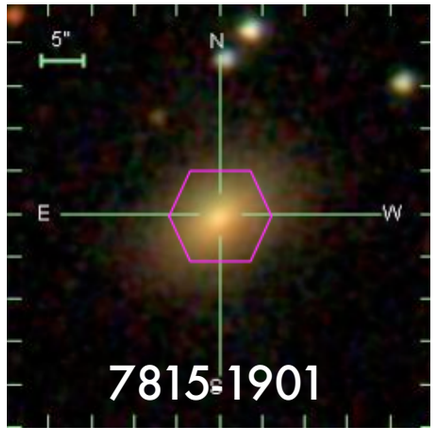

−7.6
−8.6
−9.6
−10.6
−11.6
−12.5
Hα EW [Å]

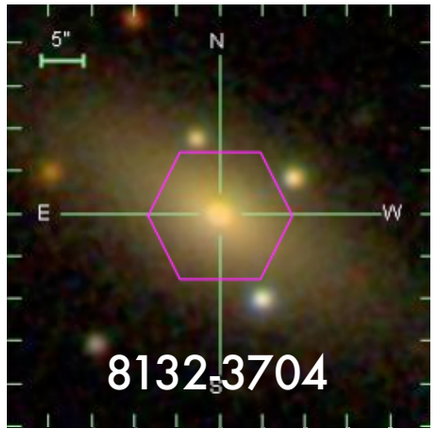

−2.6
−3.3
−3.9
−4.6
−5.3
−5.9
Hα EW [Å]

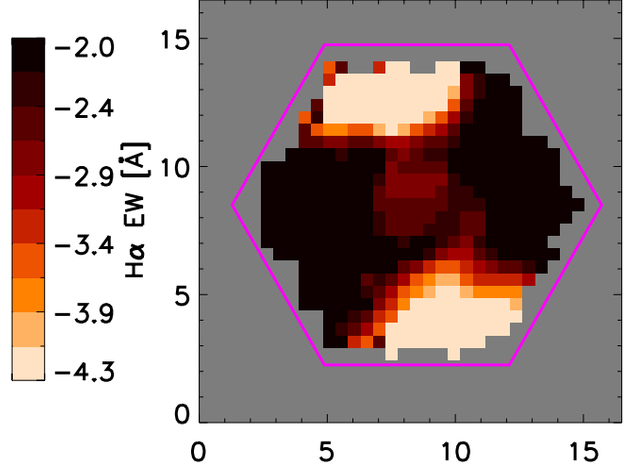

−1.1
−1.3
−1.4
−1.6
−1.8
−1.9
Hα EW [Å]
1 kpc

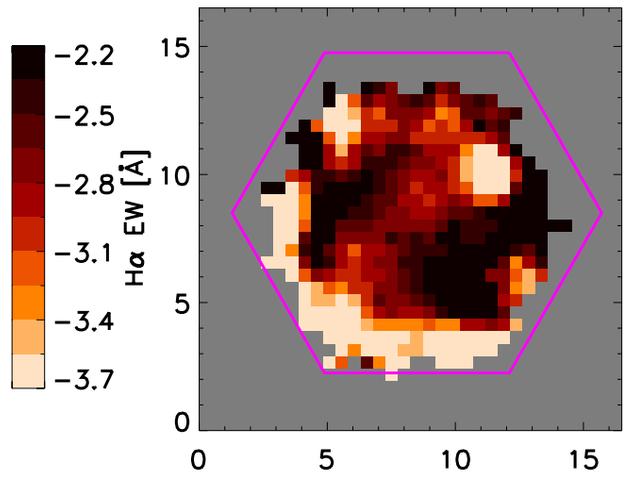

5"
N
E
W
8247-1901

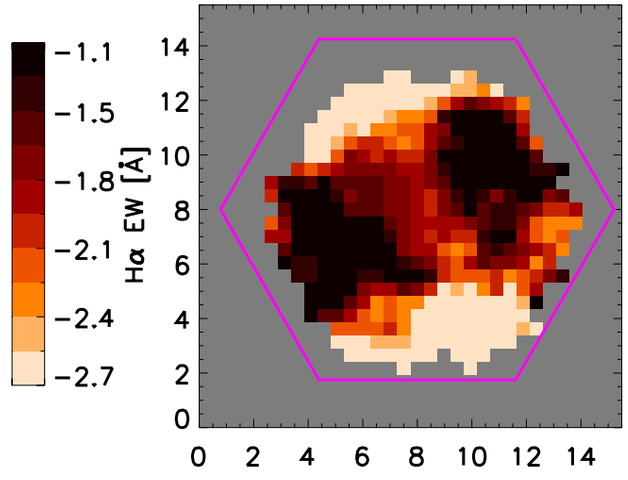

5"
N
E
W
8137-1902

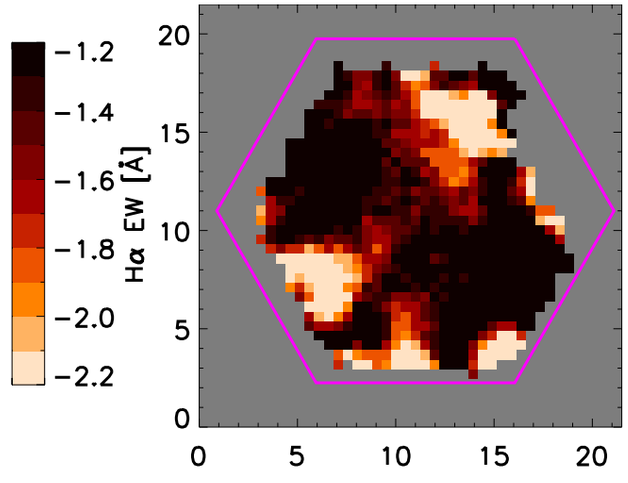

5"
N
E
W
7815-1901

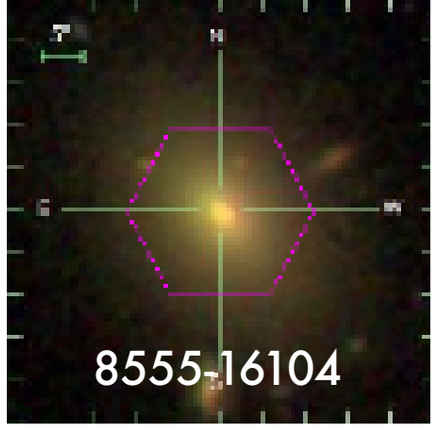

5"
N
E
W
8132-3704

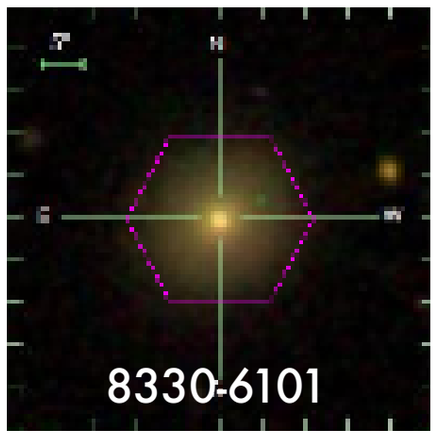

−2.0
−2.4
−2.9
−3.4
−3.9
−4.3
Hα EW [Å]
0
5
10
15

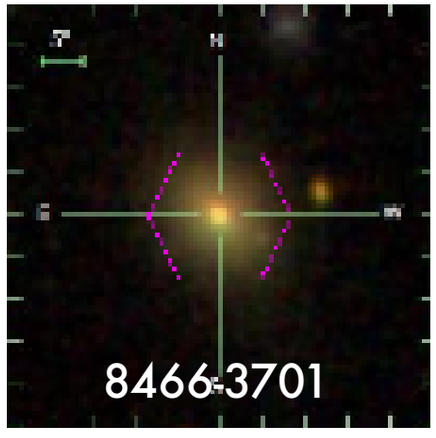

−2.2
−2.5
−2.8
−3.1
−3.4
−3.7
Hα EW [Å]
0
5
10
15

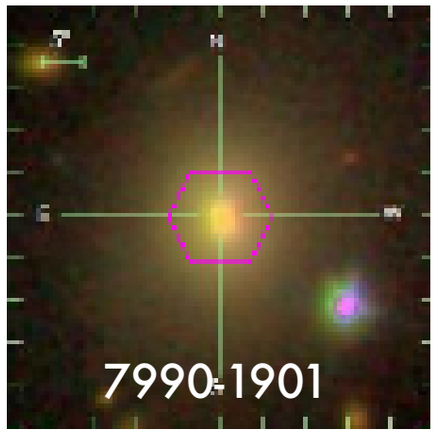

−1.1
−1.5
−1.8
−2.1
−2.4
−2.7
Hα EW [Å]
0
2
4
6
8
10
12
14

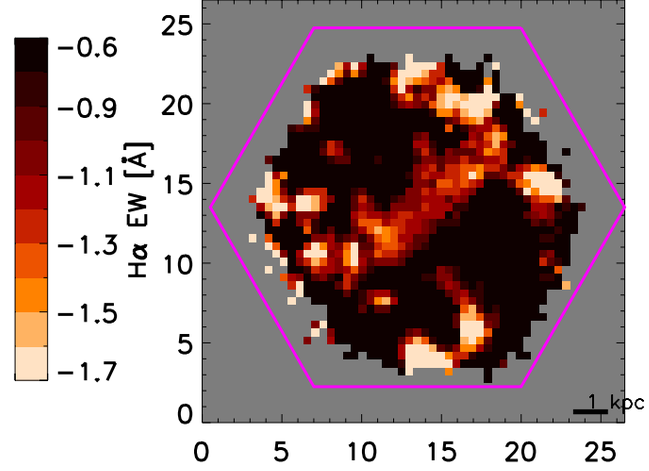

−1.2
−1.4
−1.6
−1.8
−2.0
−2.2
Hα EW [Å]
0
5
10
15
20

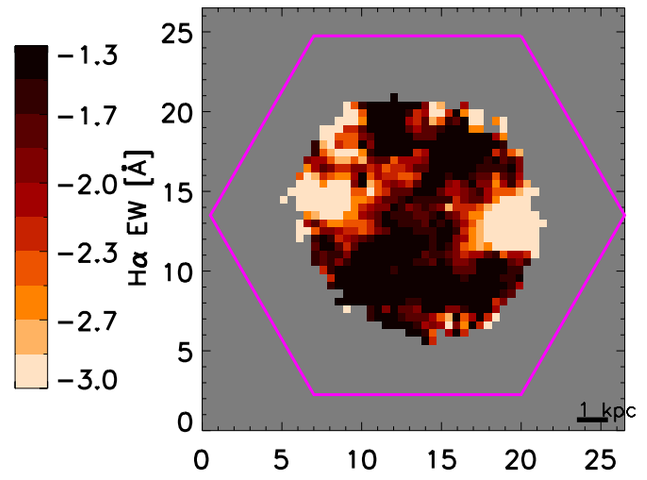

8555-16104

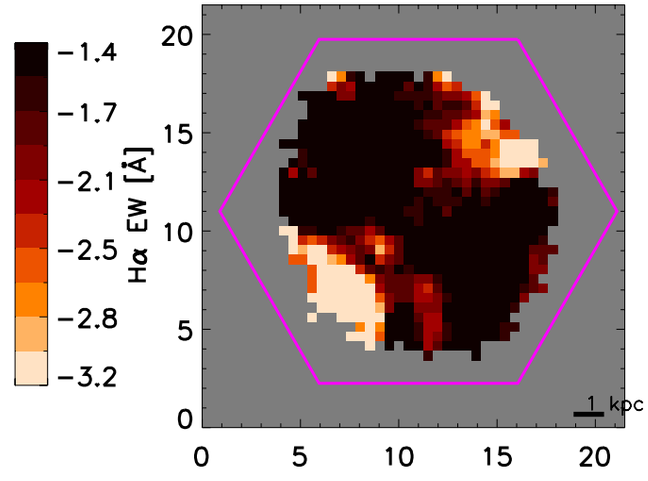

8330-6101

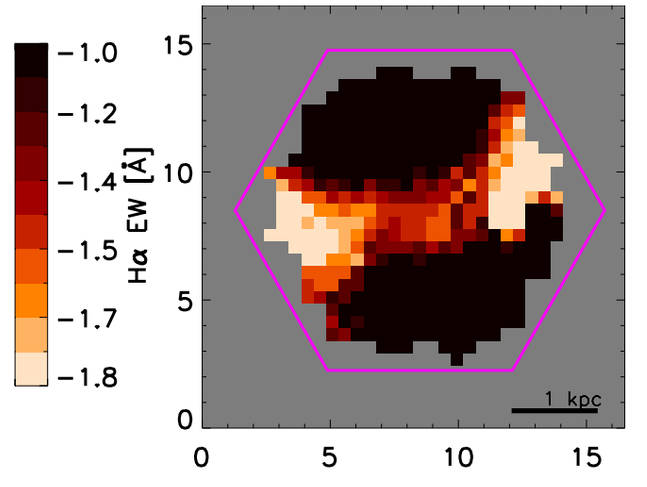

8466-3701

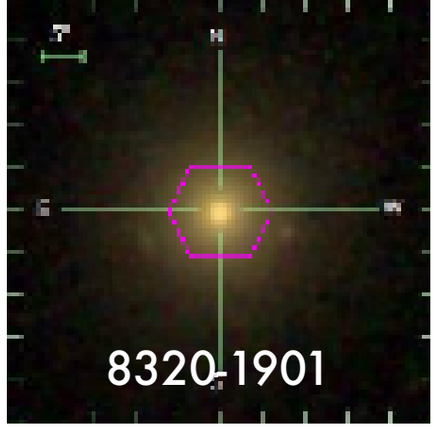

7990-1901

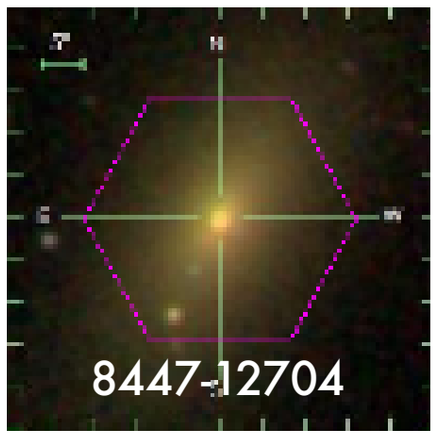

−0.6
−0.9
−1.1
−1.3
−1.5
−1.7
Hα EW [Å]
1 kpc

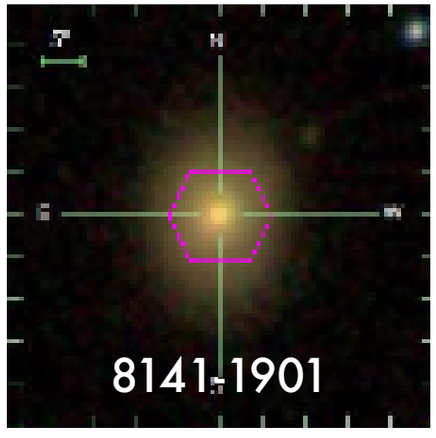

−1.3
−1.7
−2.0
−2.3
−2.7
−3.0
Hα EW [Å]
1 kpc

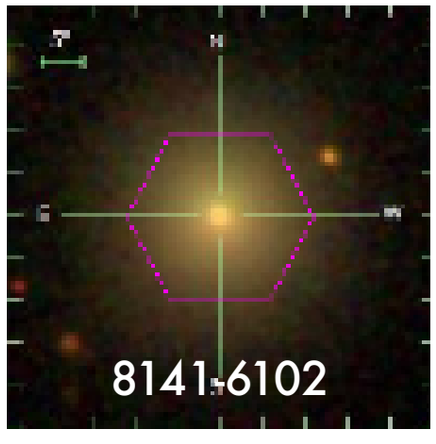

−1.4
−1.7
−2.1
−2.5
−2.8
−3.2
Hα EW [Å]
1 kpc

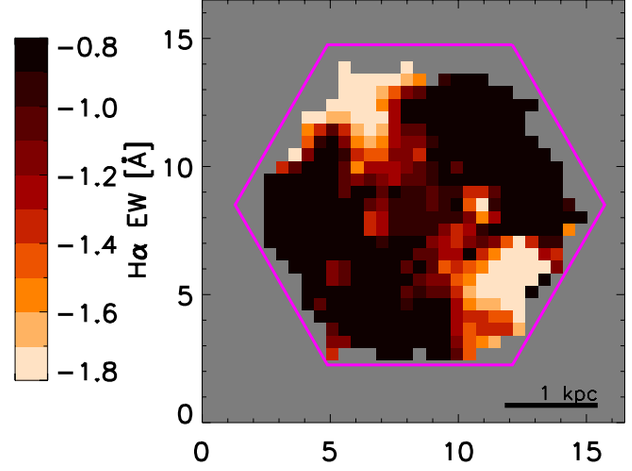

−1.0
−1.2
−1.4
−1.5
−1.7
−1.8
Hα EW [Å]
1 kpc

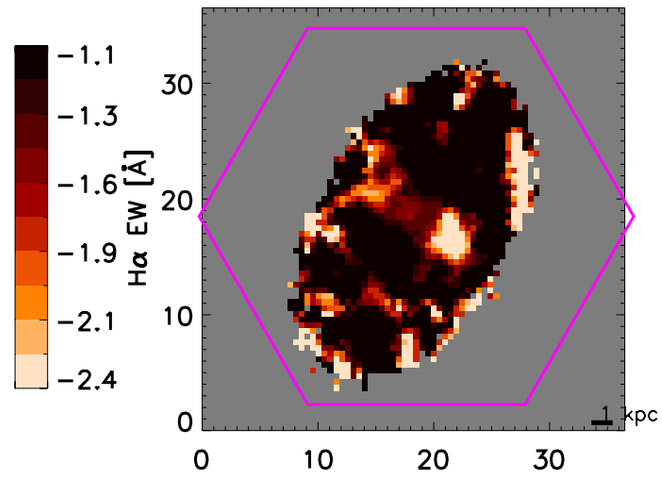

N
E
W
8320-1901

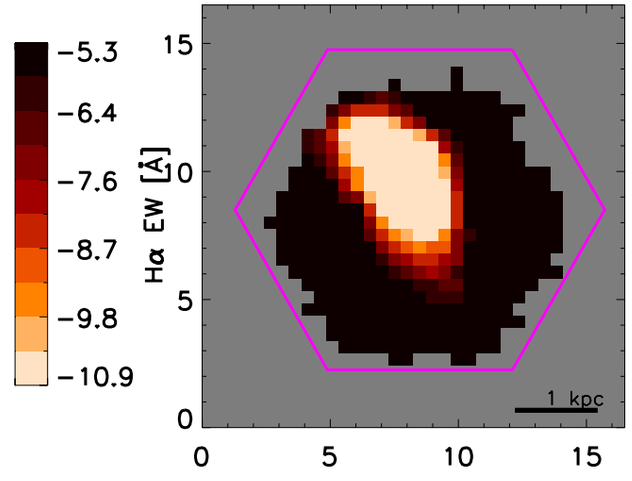

N
E
W
8447-12704

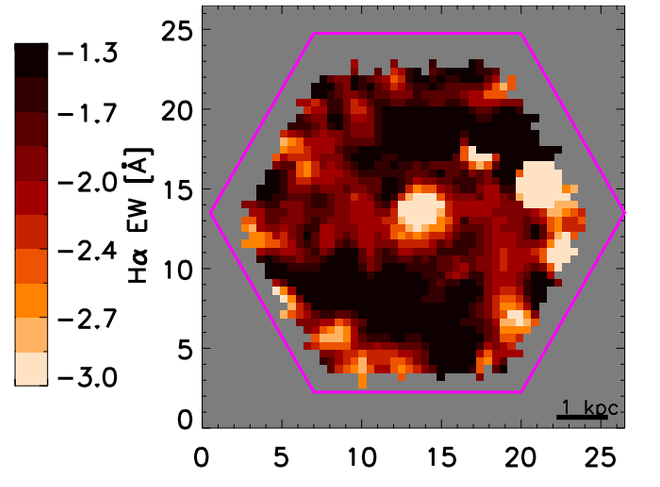

N
E
W
8141-1901

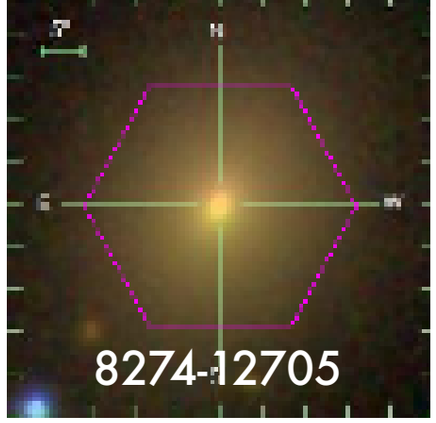

N
E
W
8141-6102

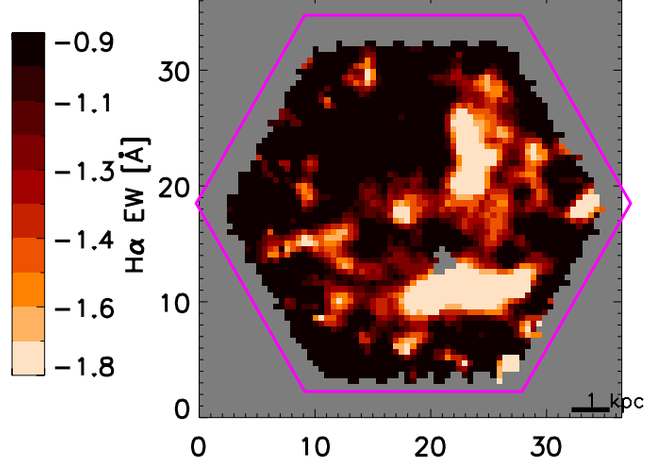

−0.8
−1.0
−1.2
−1.4
−1.6
−1.8
Hα EW [Å]
0
5
10
15
1 kpc

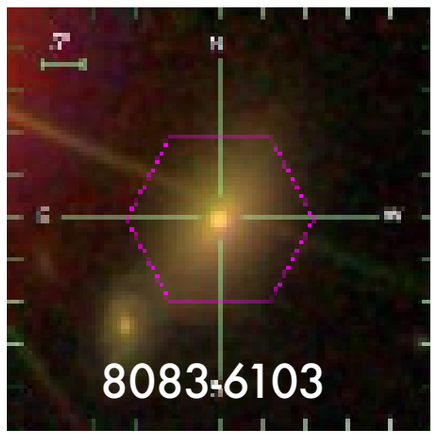

−1.1
−1.3
−1.6
−1.9
−2.1
−2.4
Hα EW [Å]
0
10
20
30
1 kpc

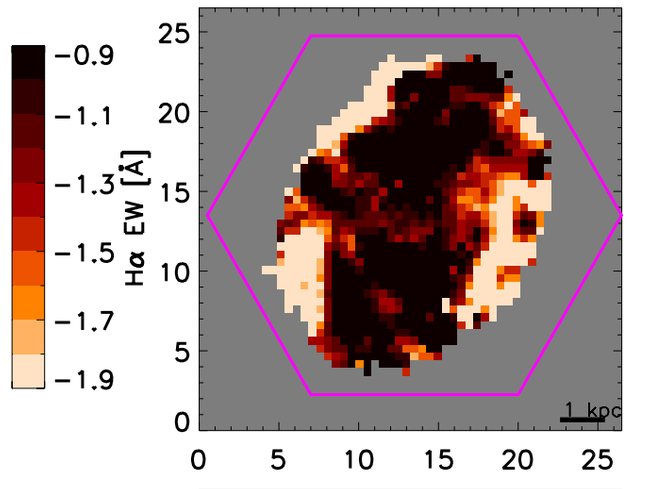

−5.3
−6.4
−7.6
−8.7
−9.8
−10.9
Hα EW [Å]
0
5
10
15
1 kpc

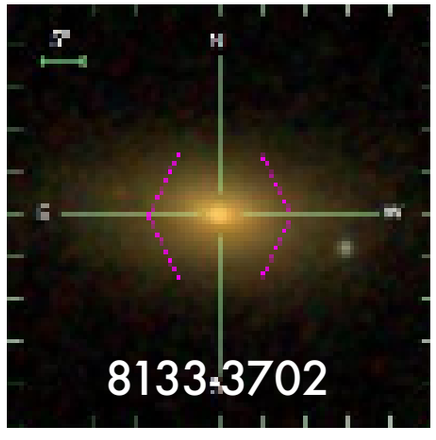

−1.3
−1.7
−2.0
−2.4
−2.7
−3.0
Hα EW [Å]
0
5
10
15
20
25
1 kpc

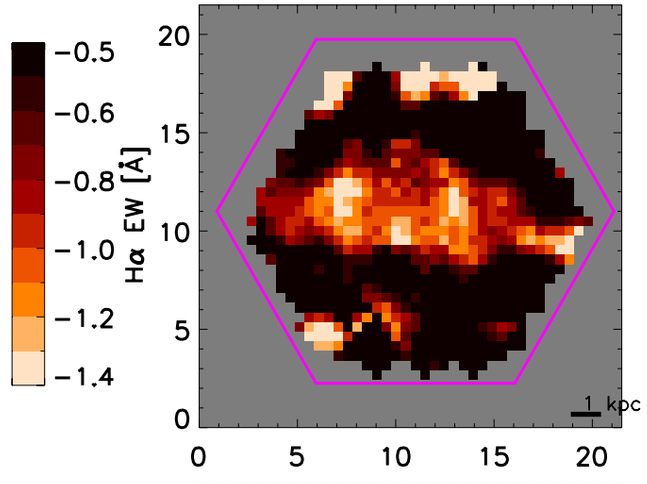

8274-12705

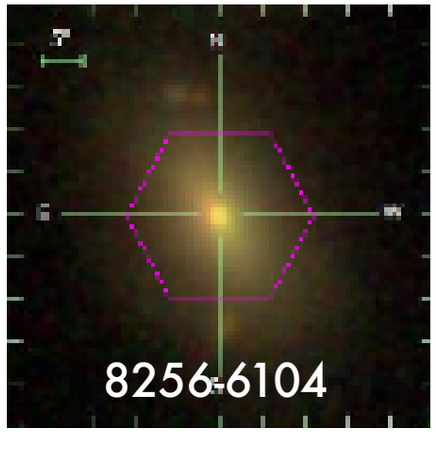

−0.9
−1.1
−1.3
−1.4
−1.6
−1.8
Hα EW [Å]
0
10
20
30
1 kpc

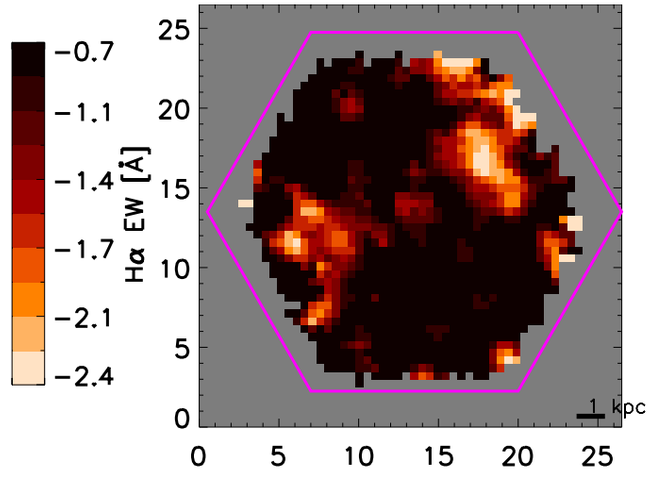

8083-6103

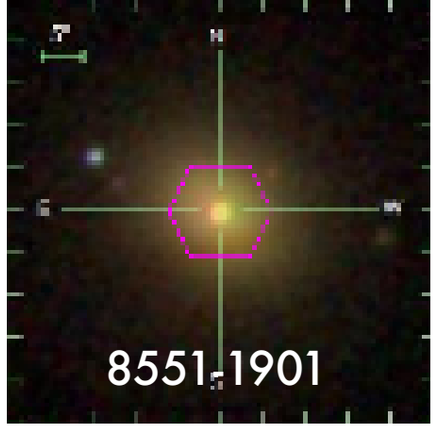

−0.9
−1.1
−1.3
−1.5
−1.7
−1.9
Hα EW [Å]
0
5
10
15
20
25
1 kpc

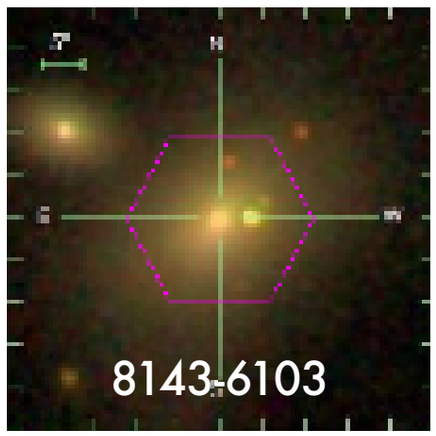

8133-3702

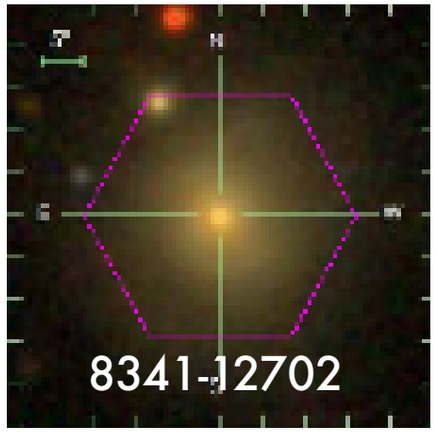

−0.5
−0.6
−0.8
−1.0
−1.2
−1.4
Hα EW [Å]
0
5
10
15
20
1 kpc

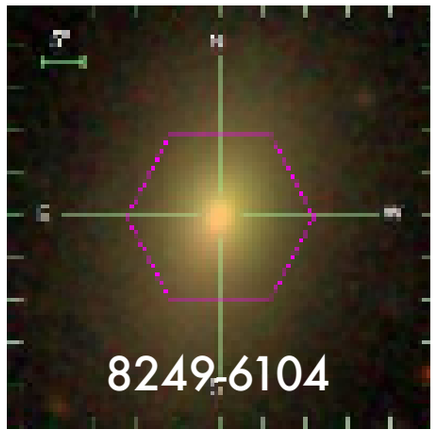

8256-6104

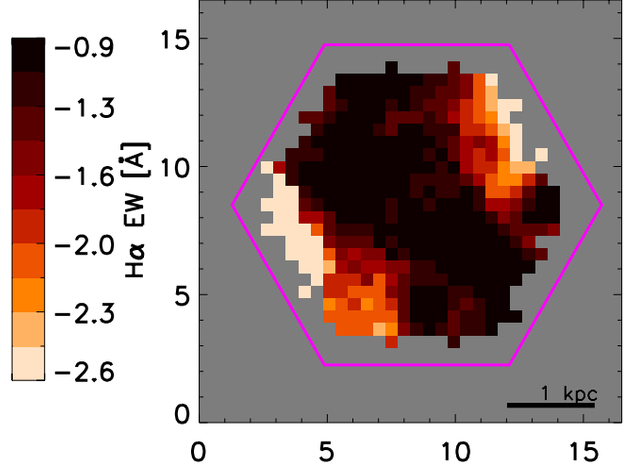

−0.7
−1.1
−1.4
−1.7
−2.1
−2.4
Hα EW [Å]
0
5
10
15
20
25
1 kpc

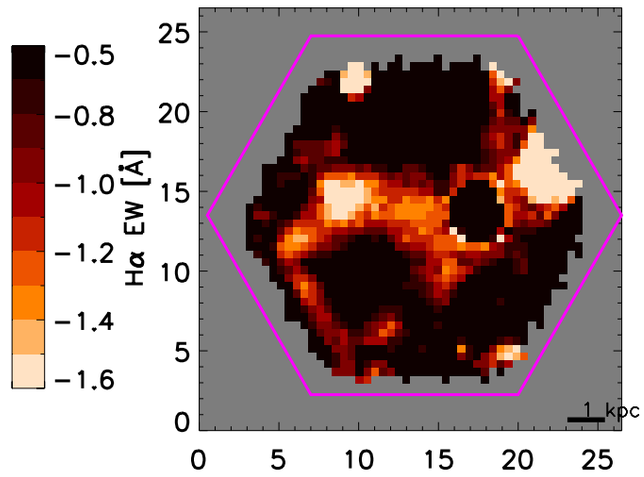

8551-1901

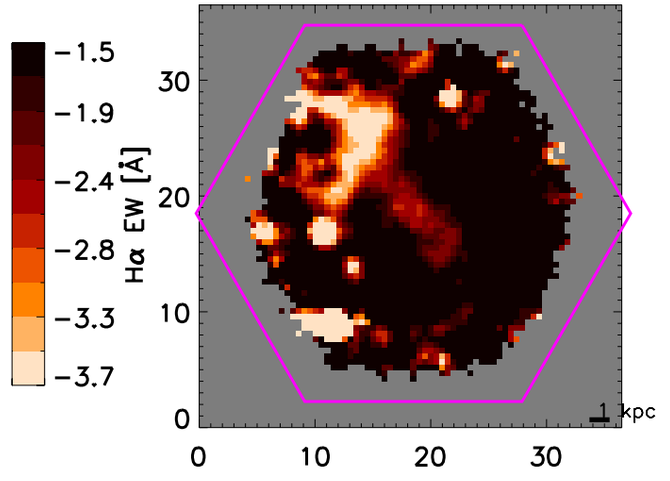

8143-6103

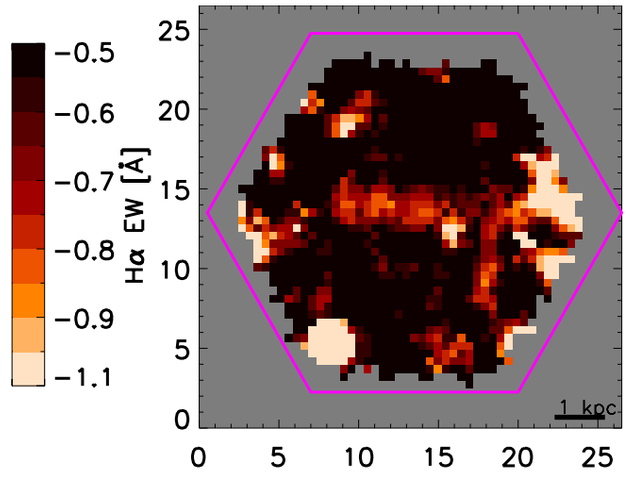

8341-12702

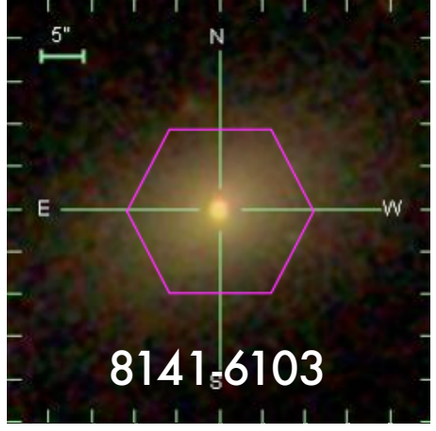

8249-6104

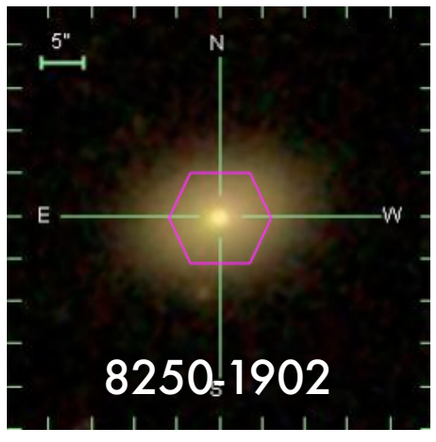

−0.9
−1.3
−1.6
−2.0
−2.3
−2.6
Hα EW [Å]
0
5
10
15
1 kpc

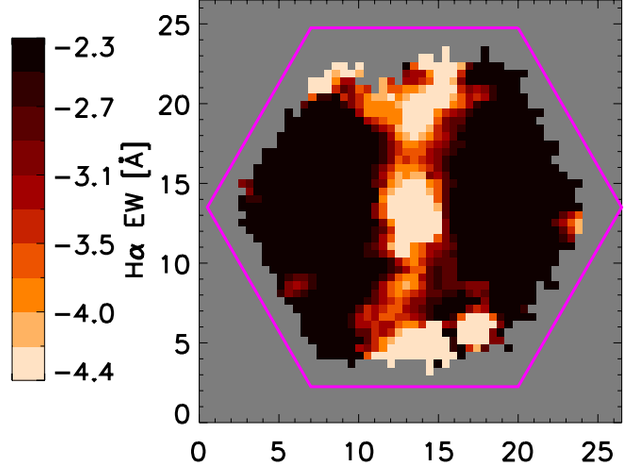

−0.5
−0.8
−1.0
−1.2
−1.4
−1.6
Hα EW [Å]
0
5
10
15
20
25
1 kpc

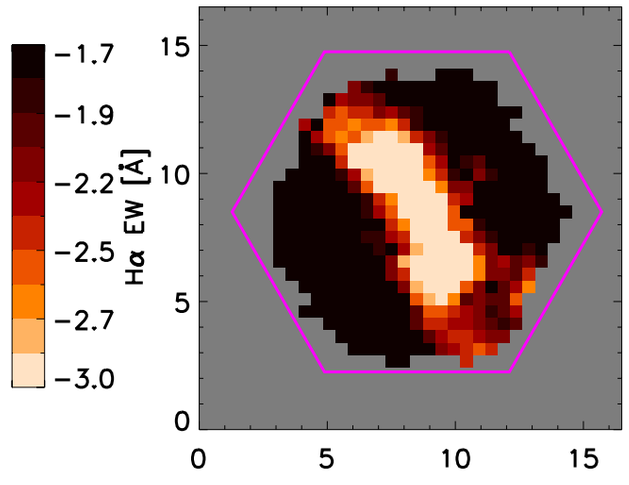

−1.5
−1.9
−2.4
−2.8
−3.3
−3.7
Hα EW [Å]
0
10
20
30
1 kpc


−0.5
−0.6
−0.7
−0.8
−0.9
−1.1
Hα EW [Å]
0
5
10
15
20
25
1 kpc

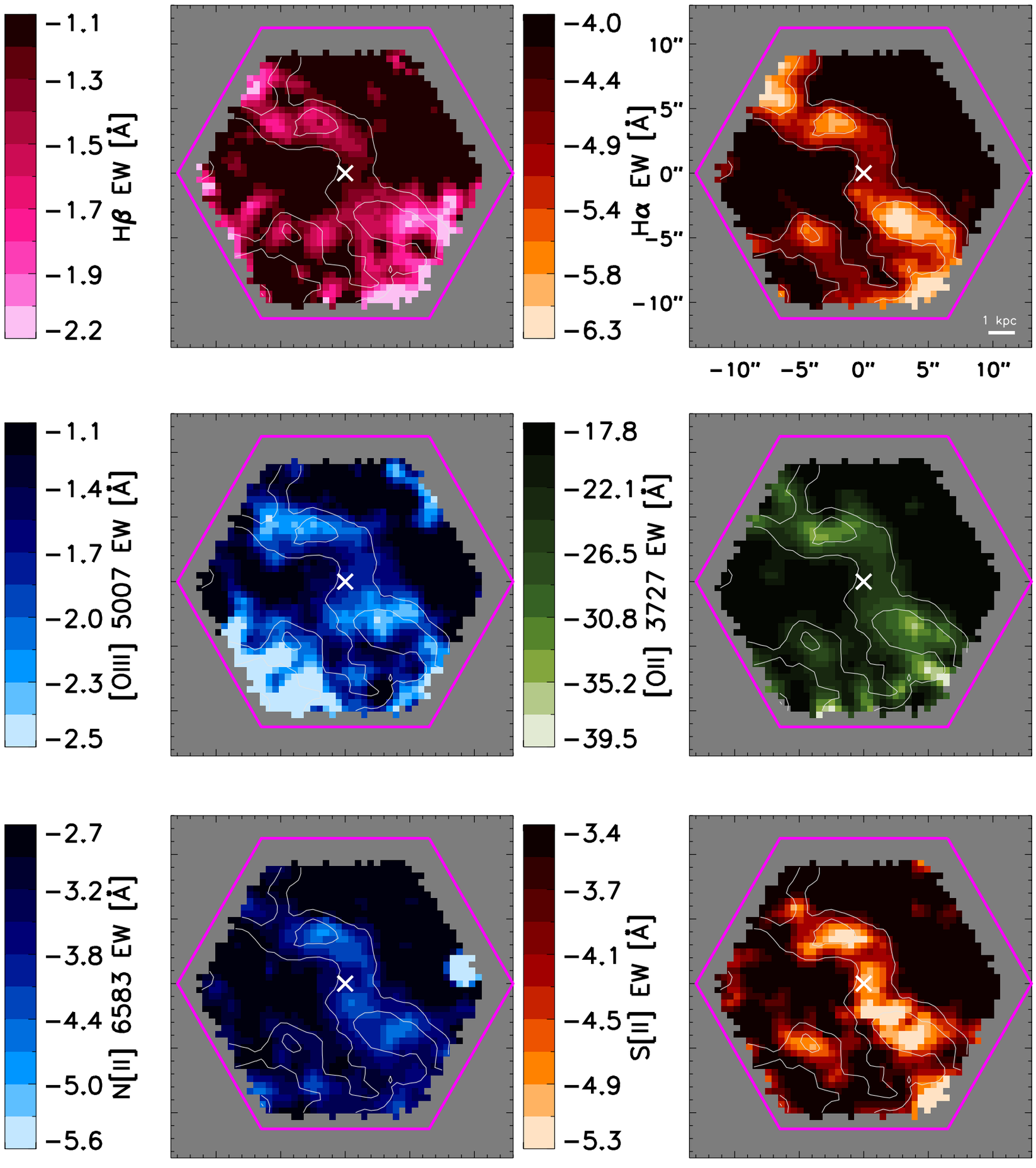

5"
N
E
W
8141_6103

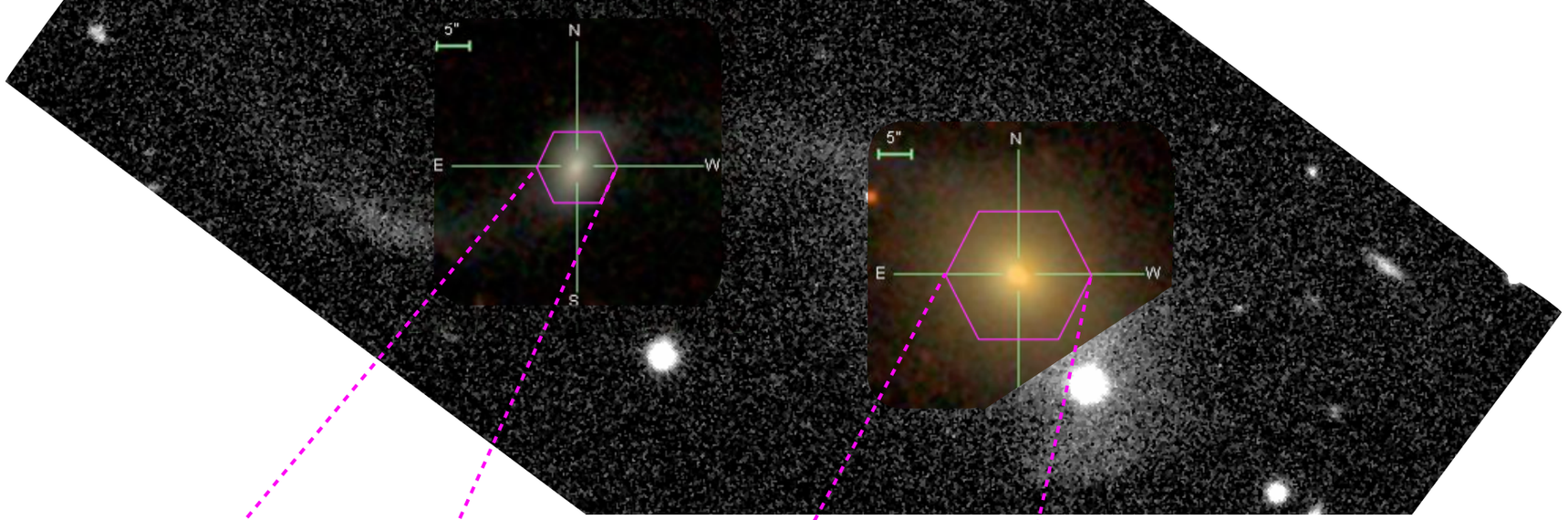

5"
N
E
W
8250_1902

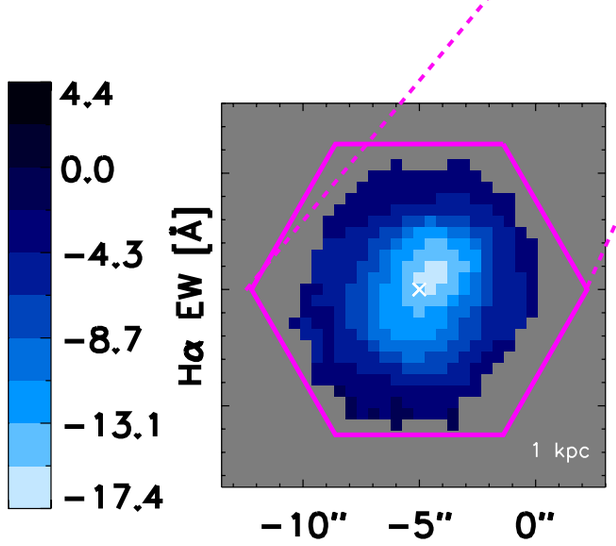

−2.3
−2.7
−3.1
−3.5
−4.0
−4.4
Hα EW [Å]
0
5
10
15
20
25

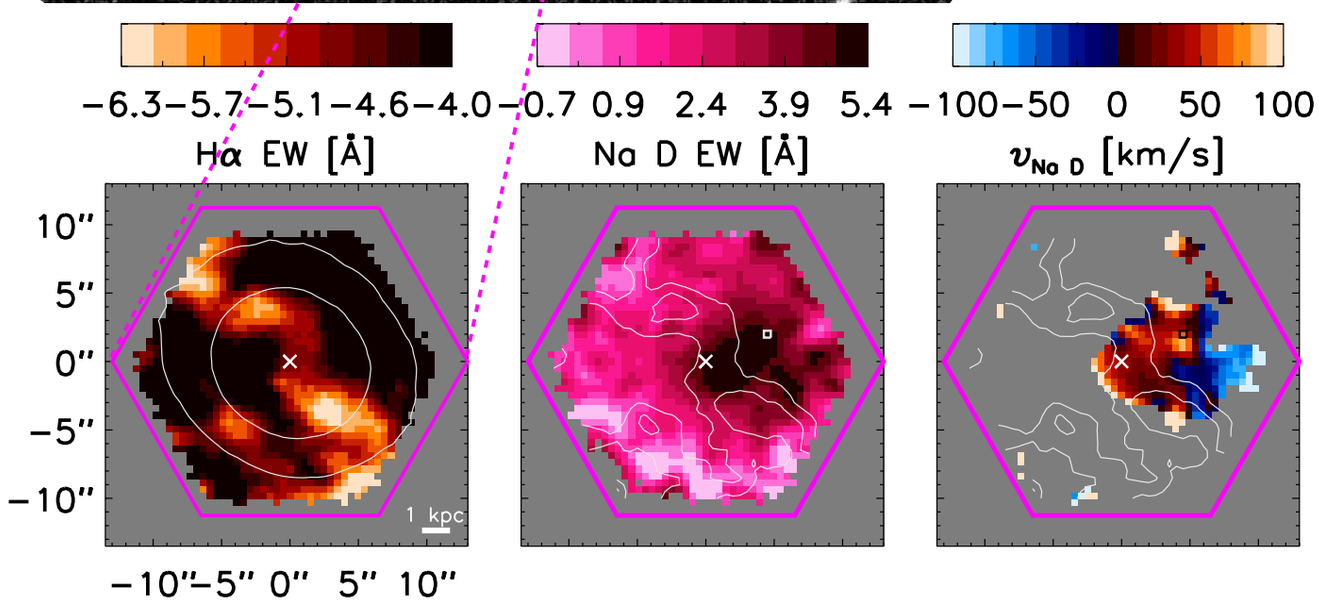

−1.7
−1.9
−2.2
−2.5
−2.7
−3.0
Hα EW [Å]
0
5
10
15

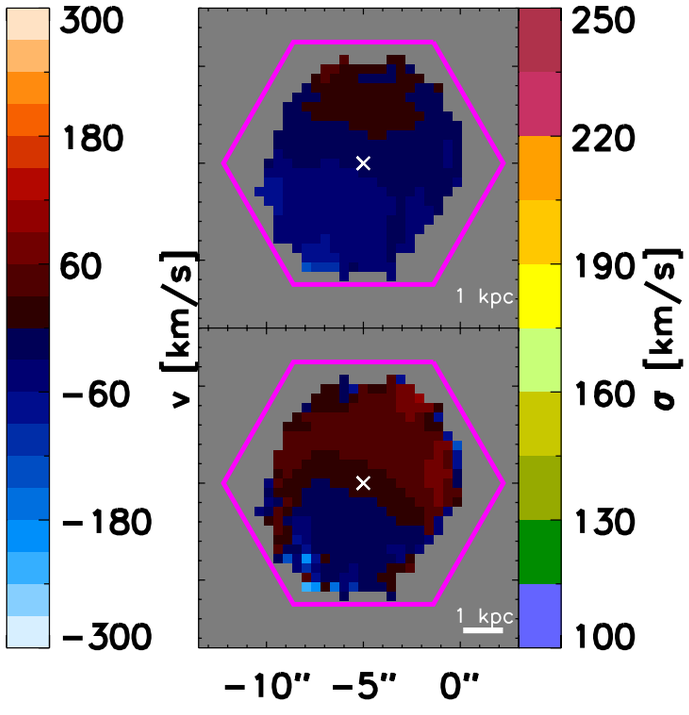
Red Geysers

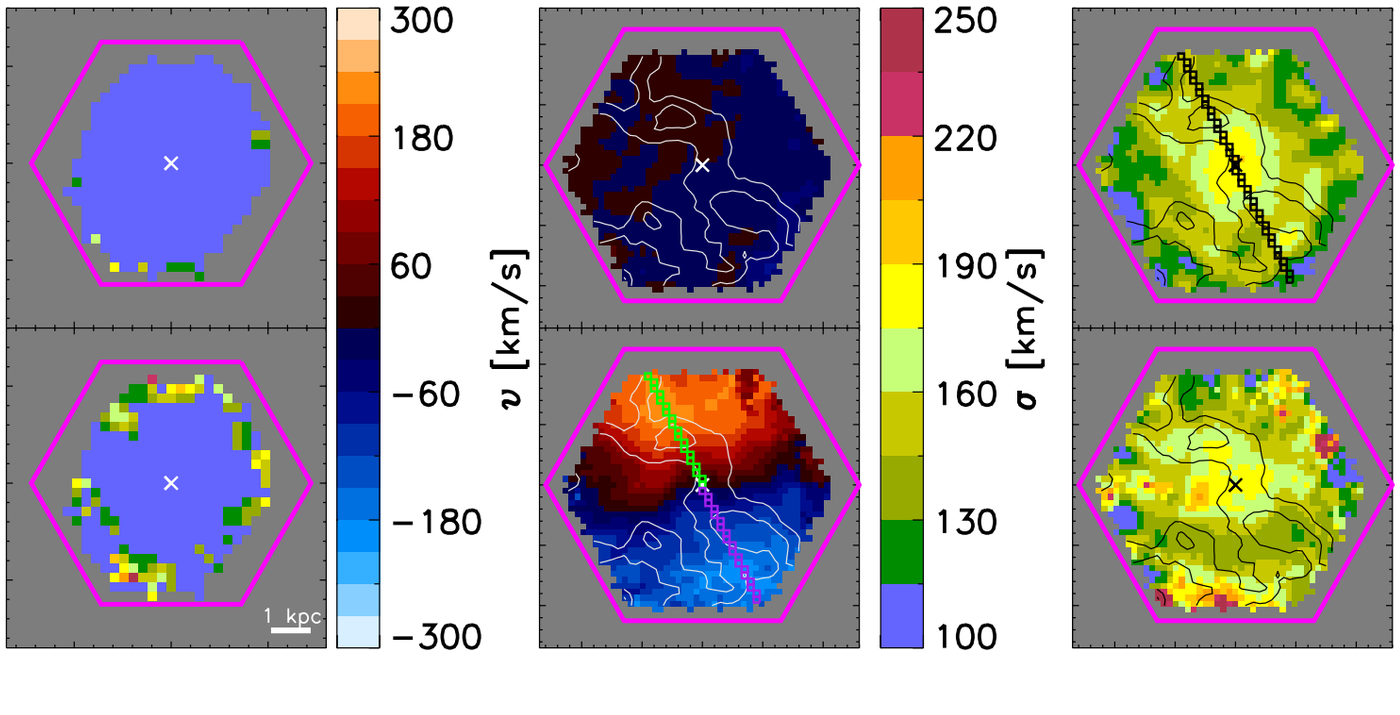

−1.1
−1.3
−1.5
−1.7
−1.9
−2.2
Hβ EW [Å]
−4.0
−4.4
−4.9
−5.4
−5.8
−6.3
Hα EW [Å]
10"
5"
0"
−5"
−10"
1 kpc
−10" −5" 0" 5" 10"
−1.1
−1.4
−1.7
−2.0
−2.3
−2.5
[OIII] 5007 EW [Å]
−17.8
−22.1
−26.5
−30.8
−35.2
−39.5
[OII] 3727 EW [Å]
−2.7
−3.2
−3.8
−4.4
−5.0
−5.6
N[II] 6583 EW [Å]
−3.4
−3.7
−4.1
−4.5
−4.9
−5.3
S[II] EW [Å]

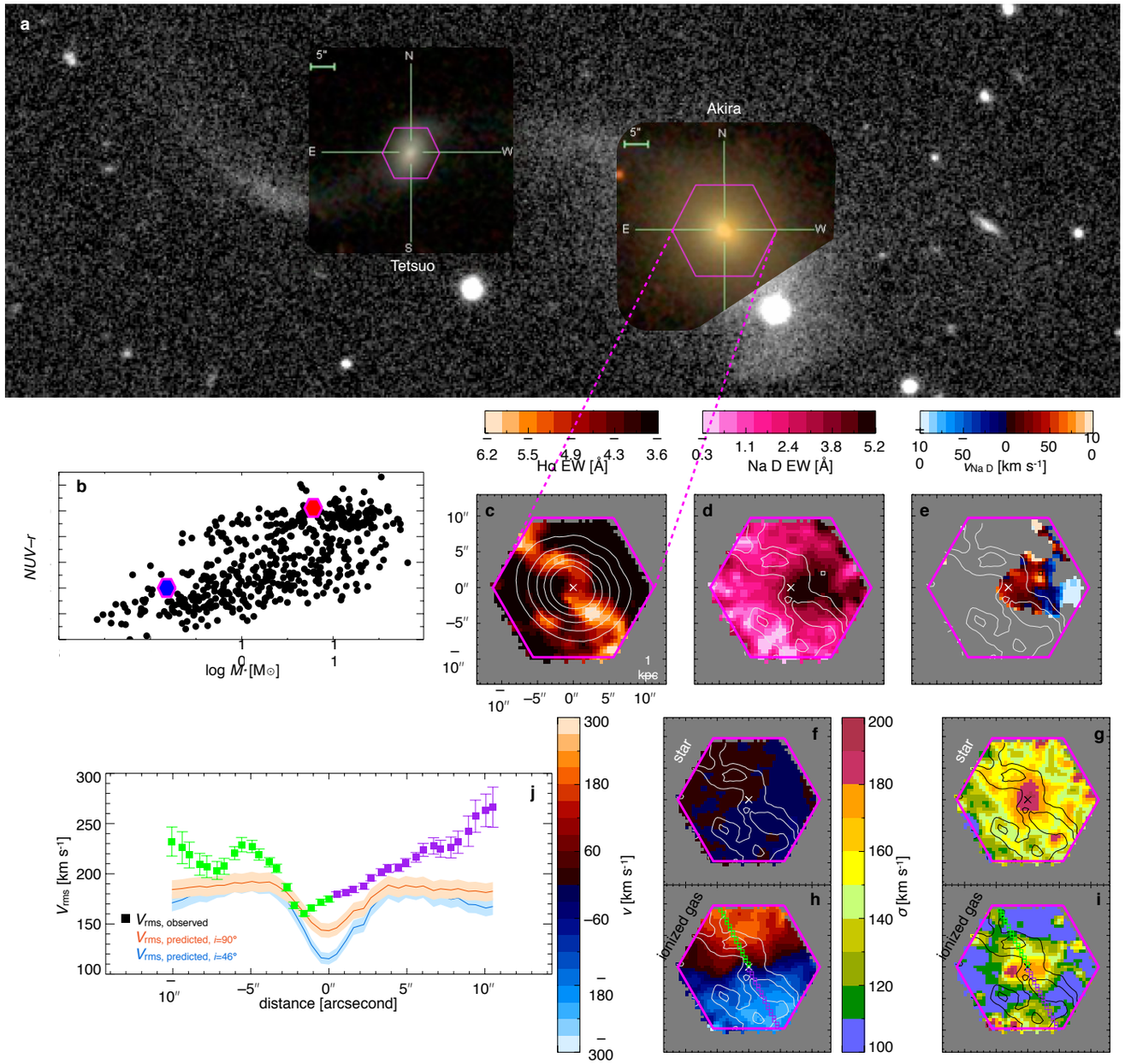

5"
N
E
W
S
5"
N
E
W

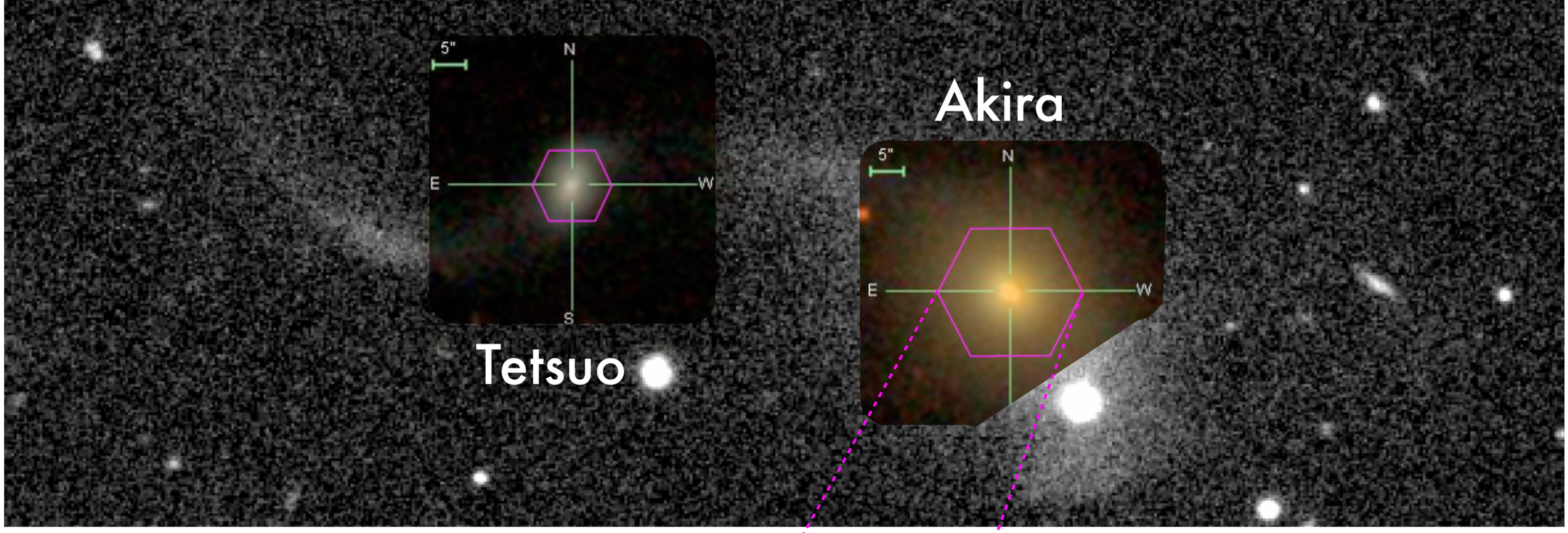

4.4
0.0
−4.3
−8.7
−13.1
−17.4
Hα EW [Å]
1 kpc
−10″
−5″
0″

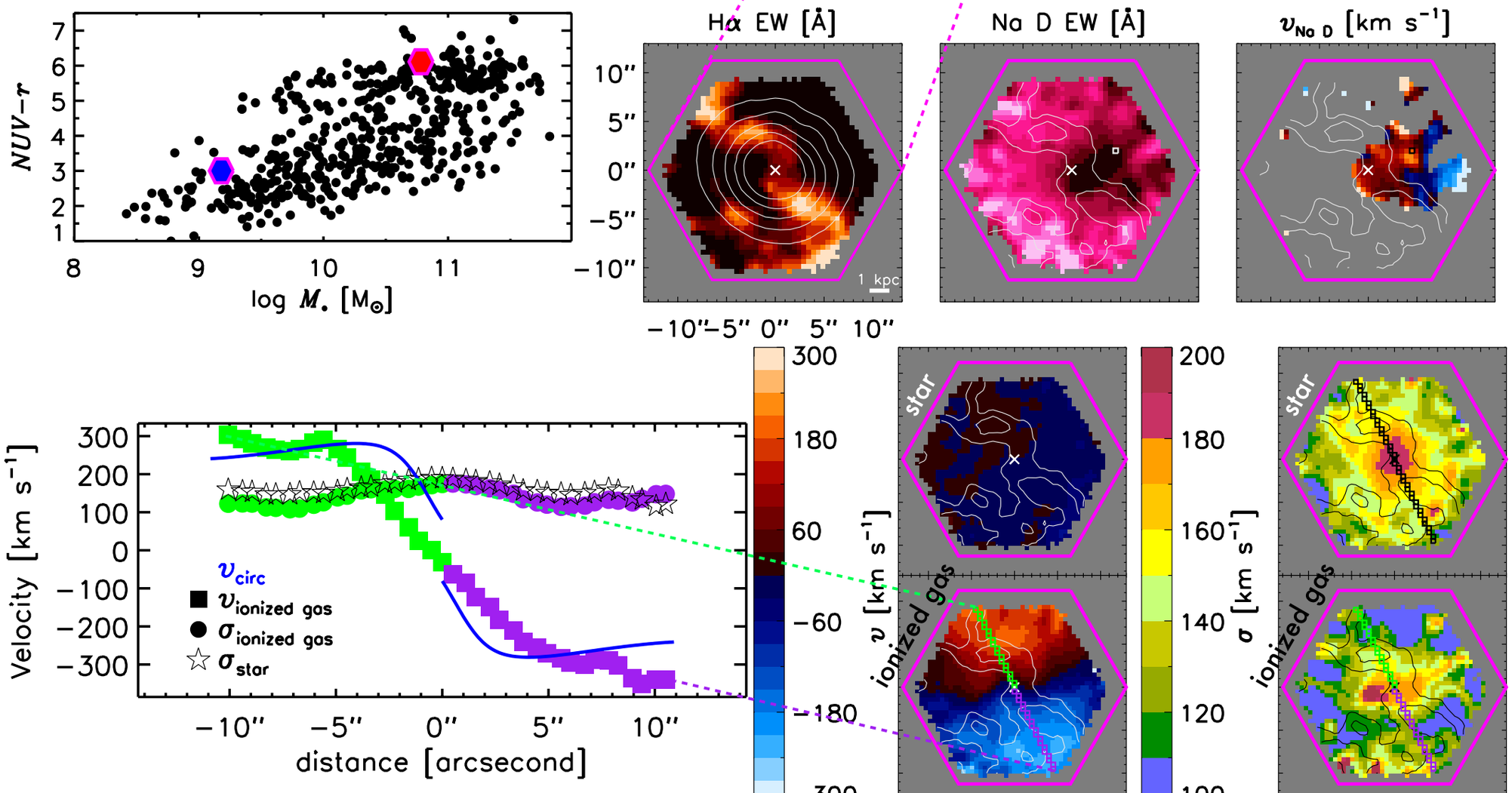

−6.3 −5.7 −5.1 −4.6 −4.0
Hα EW [Å]
−0.7 0.9 2.4 3.9 5.4
Na D EW [Å]
−100 −50 0 50 100
$v_{Na\ D}$ [km/s]
10″
5″
0″
−5″
−10″
1 kpc
−10″ −5″ 0″ 5″ 10″

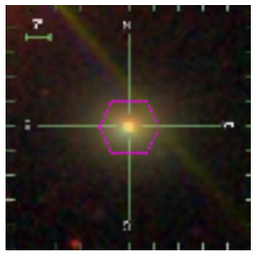

300
180
60
−60
−180
−300
v [km/s]
250
220
190
160
130
100
σ [km/s]
1 kpc
−10″ −5″ 0″

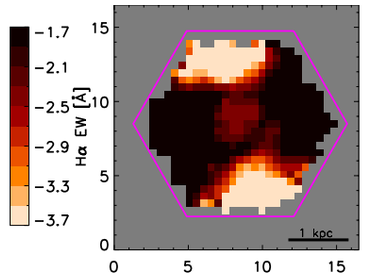

300
180
60
−60
−180
−300
v [km/s]
250
220
190
160
130
100
σ [km/s]
1 kpc

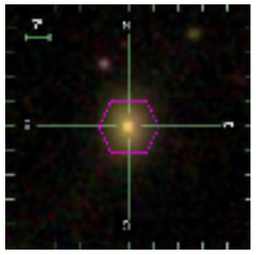

a
5″
N
E
W
S
Tetsuo
Akira
5″
N
E
W
6.2 5.5 4.9 4.3 3.6
Hα EW [Å]
0.3 1.1 2.4 3.8 5.2
Na D EW [Å]
100 50 0 50 100
vNa D [km s-1]
b
NUV–r
log M* [M⊙]
c
d
e
10″
5″
0″
–5″
–10″
1 kpc
–10″ –5″ 0″ 5″ 10″
300 180 60 –60 –180 –300
v [km s-1]
j
Vrms [km s-1]
Vrms, observed
Vrms, predicted, i=90°
Vrms, predicted, i=46°
distance [arcsecond]
f
star
h
ionized gas
200 180 160 140 120 100
σ [km s-1]
g
star
i
ionized gas

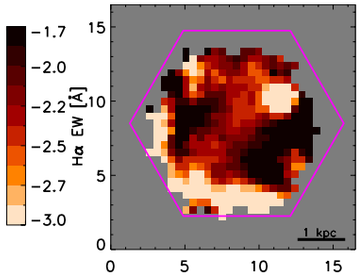

5"
N
E
W
S
Tetsuo
Akira
5"
N
E
W

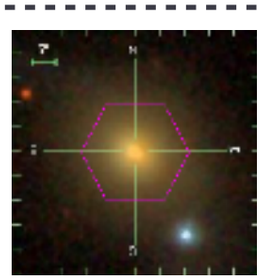

NUV−r
log M* [M⊙]
−6.4 −5.8 −5.2 −4.6 −4.0 −0.8 0.8 2.3 3.8 5.4
Hα EW [Å]
Na D EW [Å]
−100 −50 0 50 100
v_Na D [km s⁻¹]
10″
5″
0″
−5″
−10″
1 kpc
−10″ −5″ 0″ 5″ 10″
Velocity [km s⁻¹]
v_circ
v_ionized gas
σ_ionized gas
σ_star
distance [arcsecond]
300
180
60
−60
−180
−300
star
ionized gas
v [km s⁻¹]
200
180
160
140
120
100
σ [km s⁻¹]

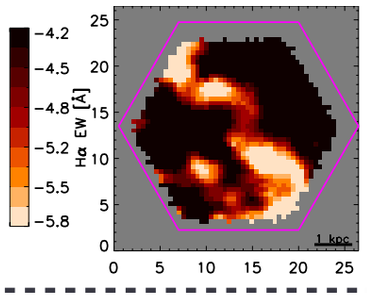


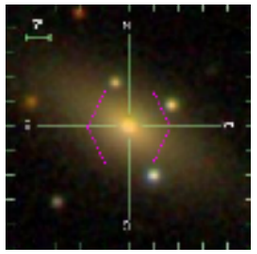

−1.7
−2.1
−2.5
−2.9
−3.3
−3.7
Hα EW [Å]
1 kpc

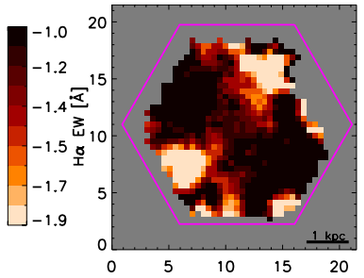


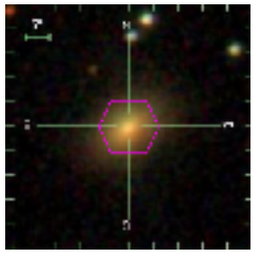

−1.7
−2.0
−2.2
−2.5
−2.7
−3.0
Hα EW [Å]
1 kpc

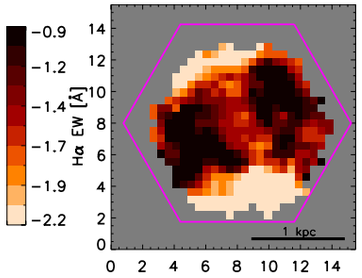


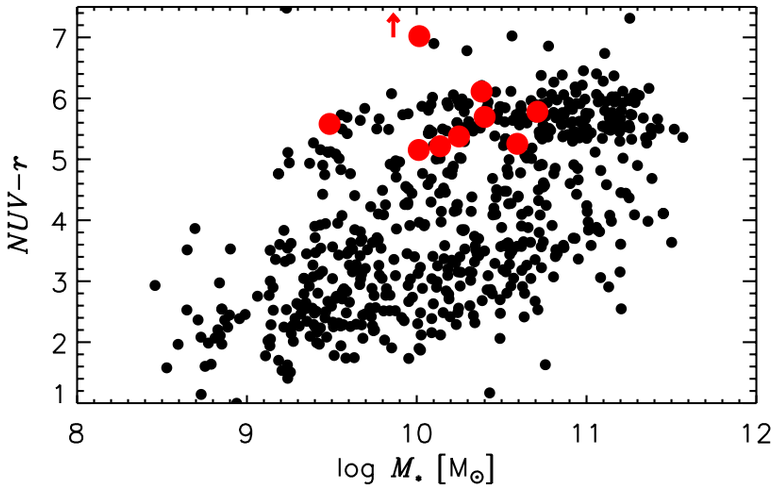

−4.2
−4.5
−4.8
−5.2
−5.5
−5.8
Hα EW [Å]
1 kpc

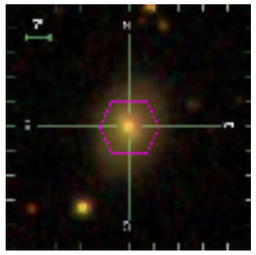


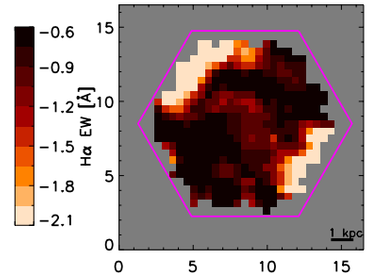

−1.0
−1.2
−1.4
−1.5
−1.7
−1.9
Hα EW [Å]
1 kpc

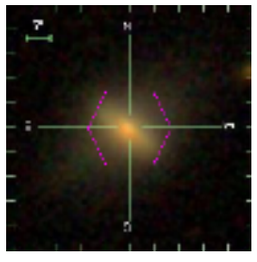


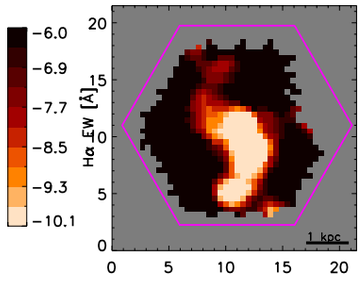

−0.9
−1.2
−1.4
−1.7
−1.9
−2.2
Hα EW [Å]
1 kpc

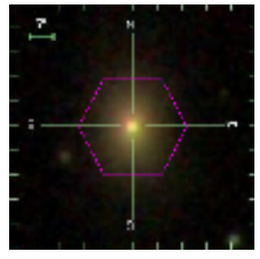

NUV−r
log M* [M⊙]

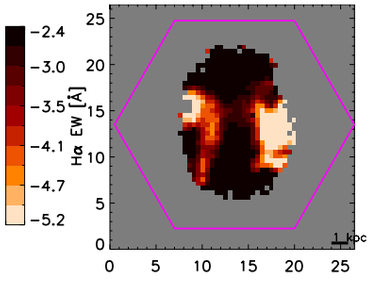


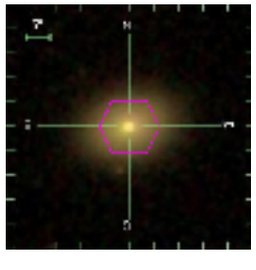

−0.6
−0.9
−1.2
−1.5
−1.8
−2.1
Hα EW [Å]
1 kpc

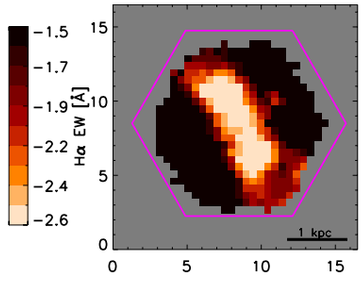


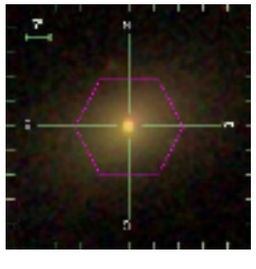

−6.0
−6.9
−7.7
−8.5
−9.3
−10.1
Hα EW [Å]
1 kpc

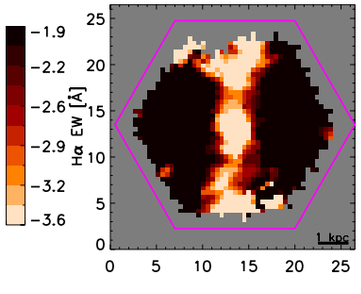


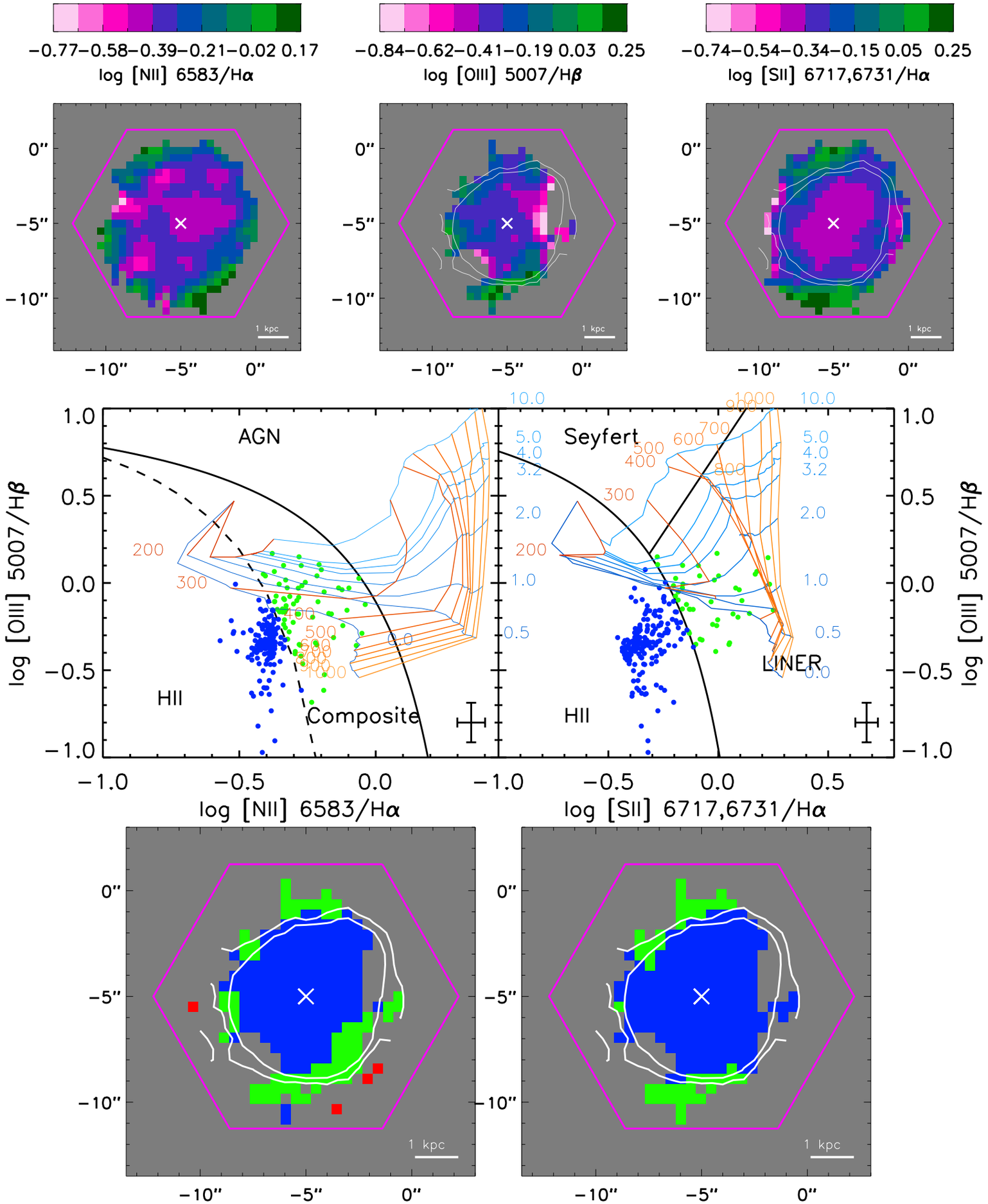

−2.4
−3.0
−3.5
−4.1
−4.7
−5.2
Hα EW [Å]
1 kpc

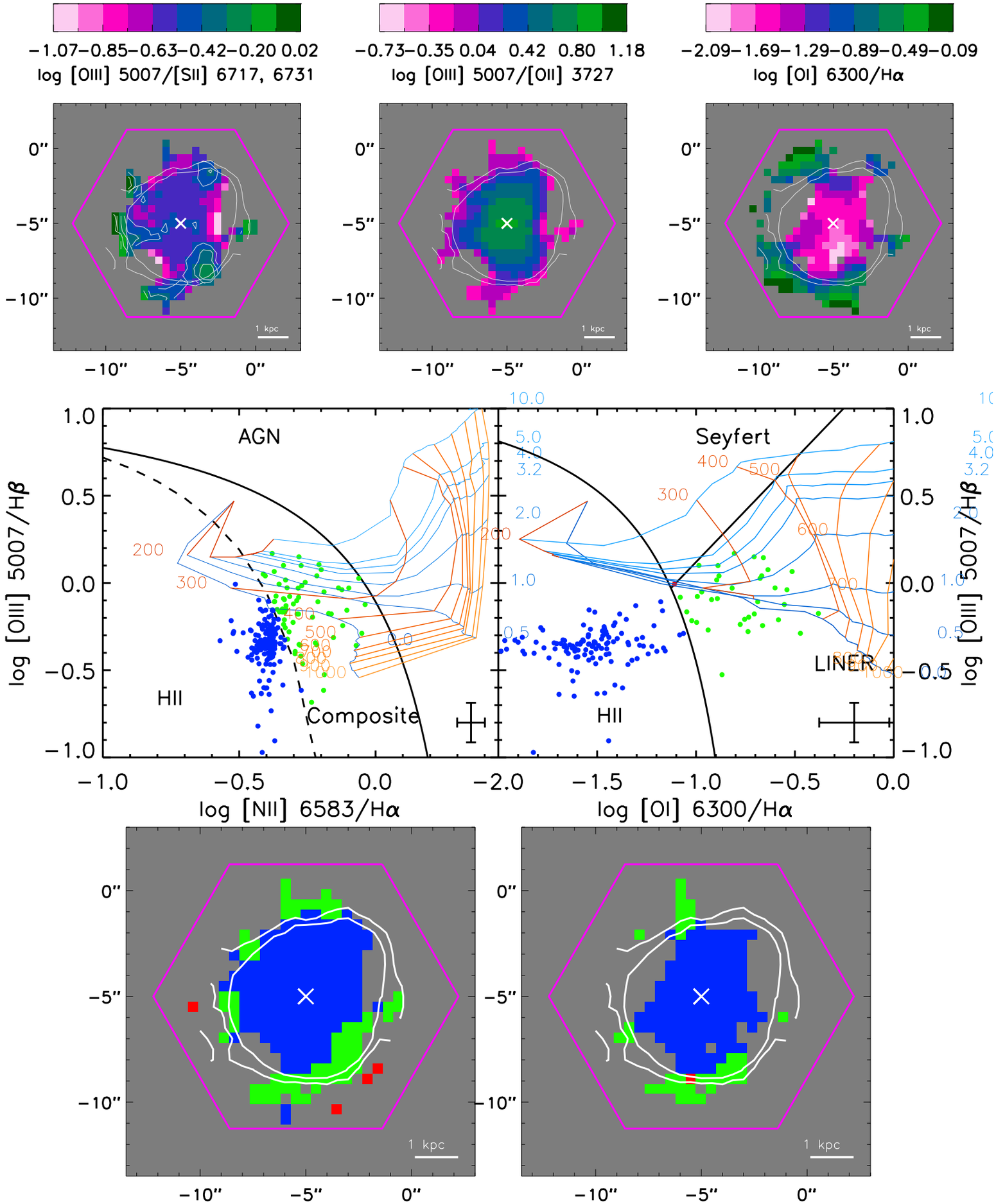



−1.5
−1.7
−1.9
−2.2
−2.4
−2.6
Hα EW [Å]
1 kpc




−1.9
−2.2
−2.6
−2.9
−3.2
−3.6
Hα EW [Å]
1 kpc


−0.77 −0.58 −0.39 −0.21 −0.02 0.17
log [NII] 6583/Hα
−0.84 −0.62 −0.41 −0.19 0.03 0.25
log [OIII] 5007/Hβ
−0.74 −0.54 −0.34 −0.15 0.05 0.25
log [SII] 6717,6731/Hα
0″
−5″
−10″
1 kpc
AGN
Seyfert
LINER
HII
Composite
log [OIII] 5007/Hβ
log [NII] 6583/Hα
log [SII] 6717,6731/Hα


−1.07 −0.85 −0.63 −0.42 −0.20 0.02
log [OIII] 5007/[SII] 6717, 6731
−0.73 −0.35 0.04 0.42 0.80 1.18
log [OIII] 5007/[OII] 3727
−2.09 −1.69 −1.29 −0.89 −0.49 −0.09
log [OI] 6300/Hα
0″
−5″
−10″
1 kpc
AGN
Seyfert
LINER
HII
Composite
log [OIII] 5007/Hβ
log [NII] 6583/Hα
log [OI] 6300/Hα
200
300
400
500
600
10.0
5.0
4.0
3.2
2.0
1.0
0.5