ICRAR

International Centre for Radio Astronomy Research

A census of galactic winds in the local universe

Ed Elson
ed.elson@icrar.org

Curtin University

The Government of Western Australia

The University of Western Australia
Achieve International Excellence

Collaborators

- Gerhardt Meurer (ICRAR-UWA)
- Tim Heckman (Johns Hopkins)

Introduction

- Arguably, the universe becomes increasingly complex at smaller scales.
- Various important physical processes govern galaxy evolution:
  - star formation
  - Interaction with environment
  - Feedback activity

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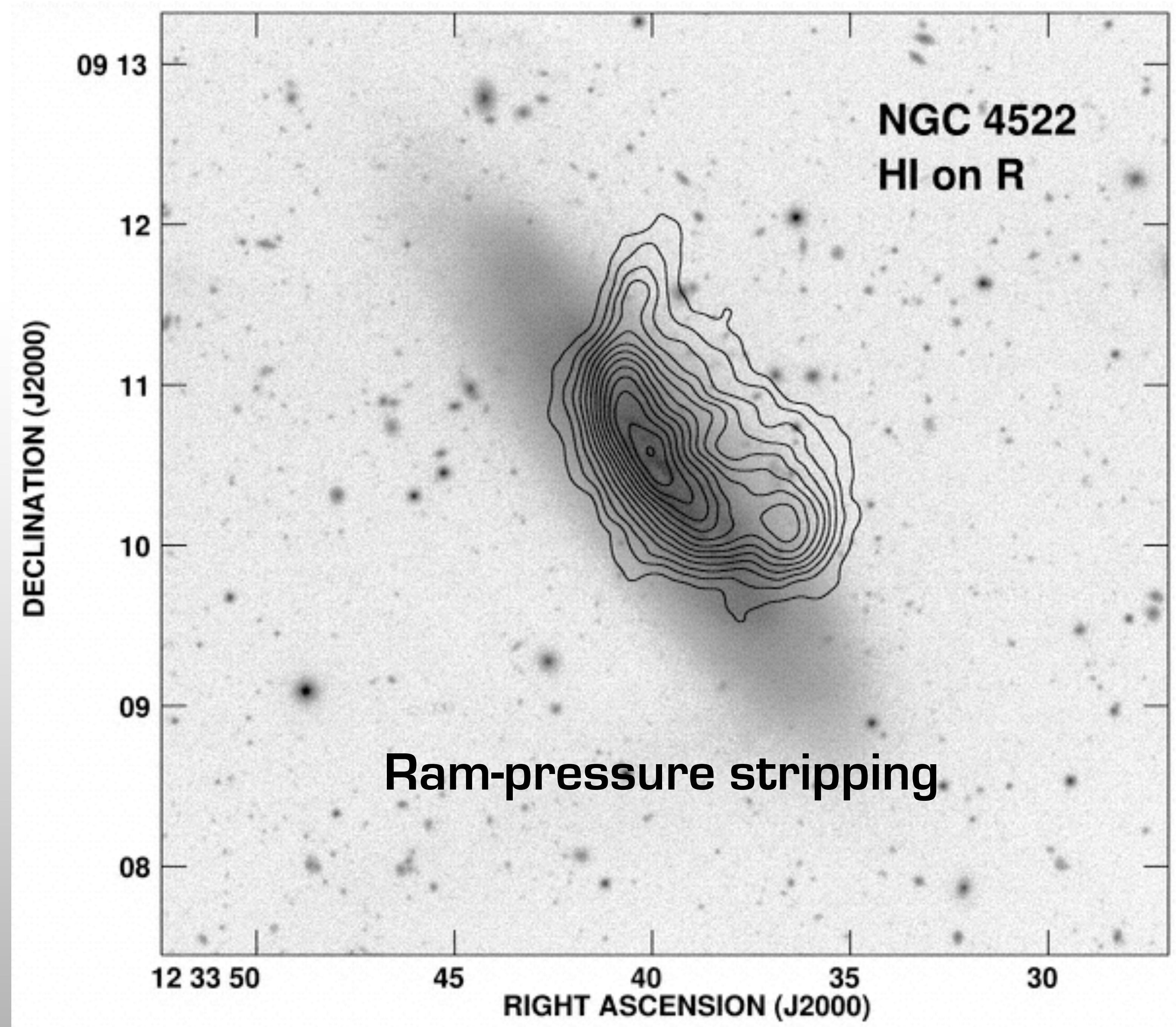

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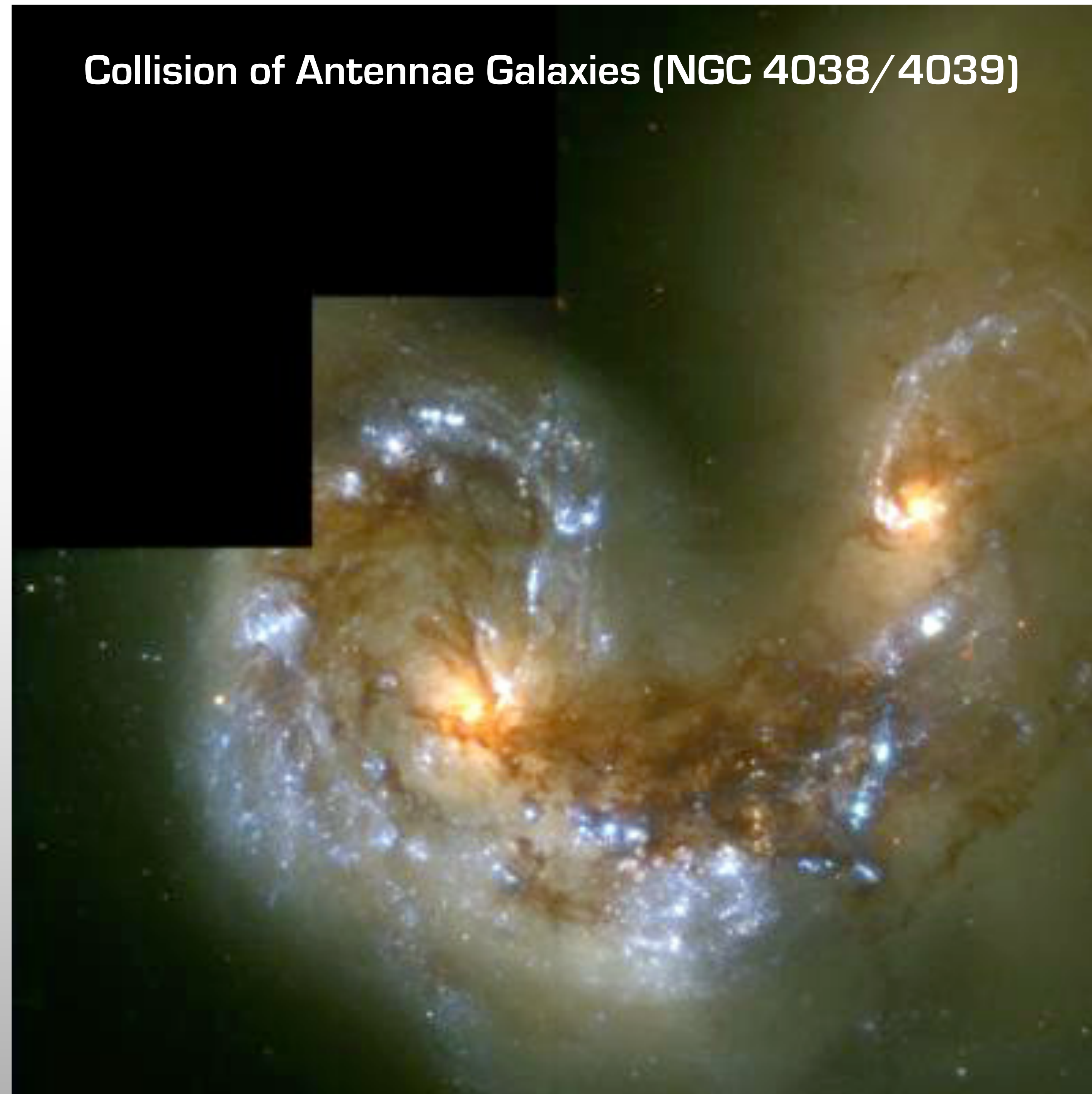


Image source: http://hubblesite.org/gallery/album/entire/pr1997034d/web/

Galactic super winds

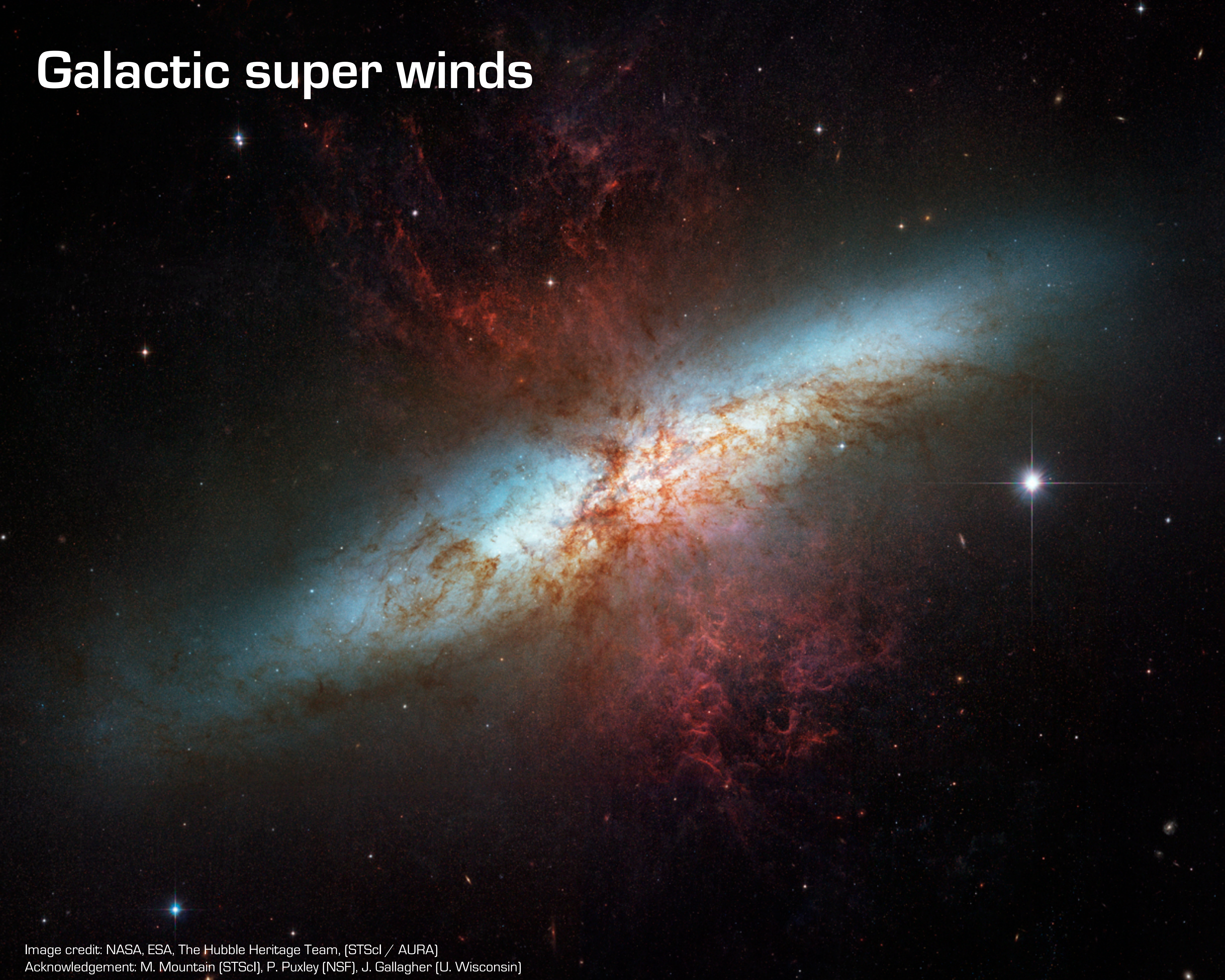
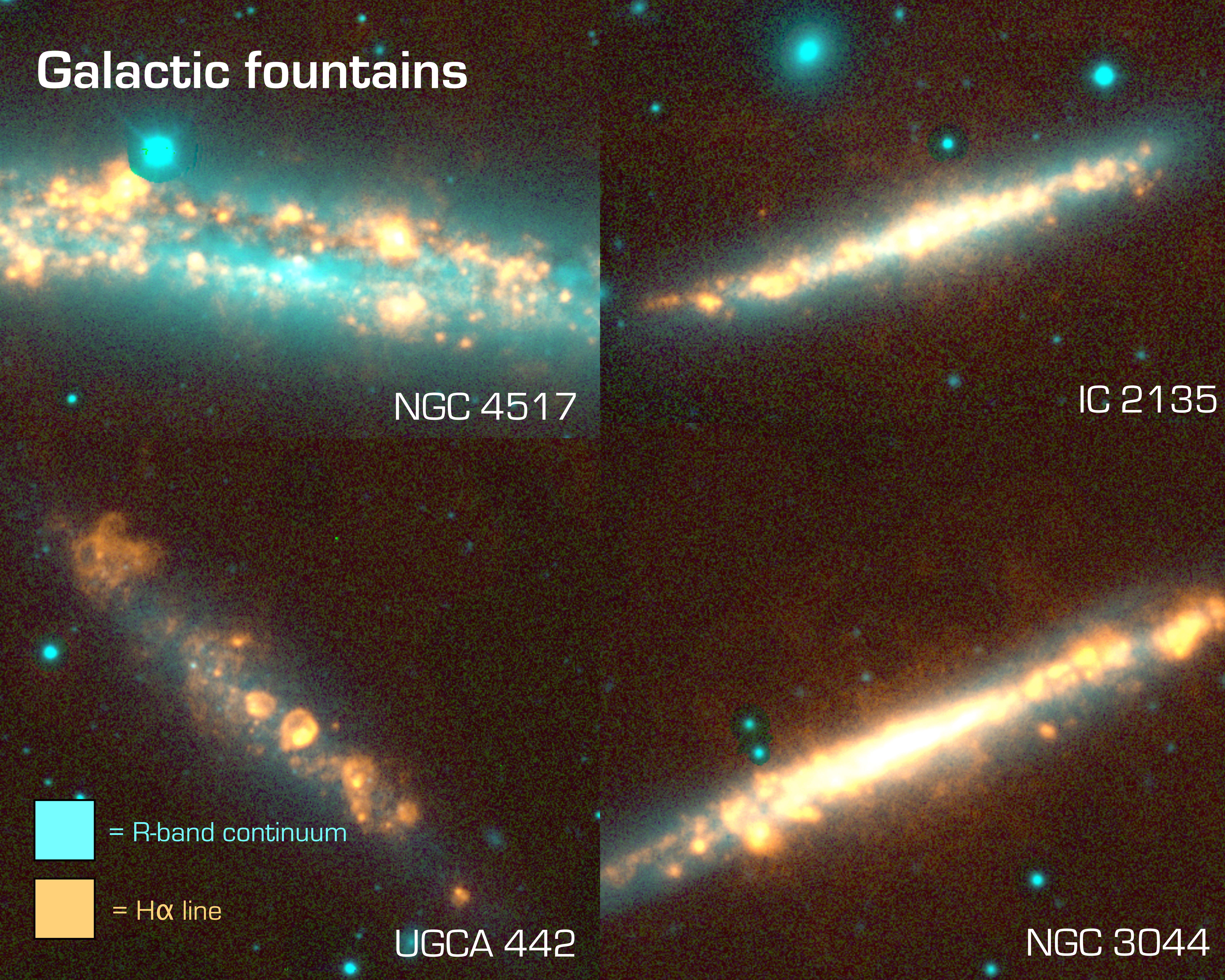


Image credit: NASA, ESA, The Hubble Heritage Team, (STScI / AURA)
Acknowledgement: M. Mountain (STScI), P. Puxley (NSF), J. Gallagher (U. Wisconsin)


Galactic fountains
NGC 4517
IC 2135
UGCA 442
NGC 3044
= R-band continuum
= Hα line

Galactic fountains

- Regardless of its specific nature, feedback is an important evolutionary driver in many ways:
  - controls the cycle of energy between the stars and the ISM
  - regulates the chemical composition of the ISM
  - shapes the bulge, disk and halo components
  - chemically enriches the IGM

= R-band continuum

= Hα line

Galactic fountains

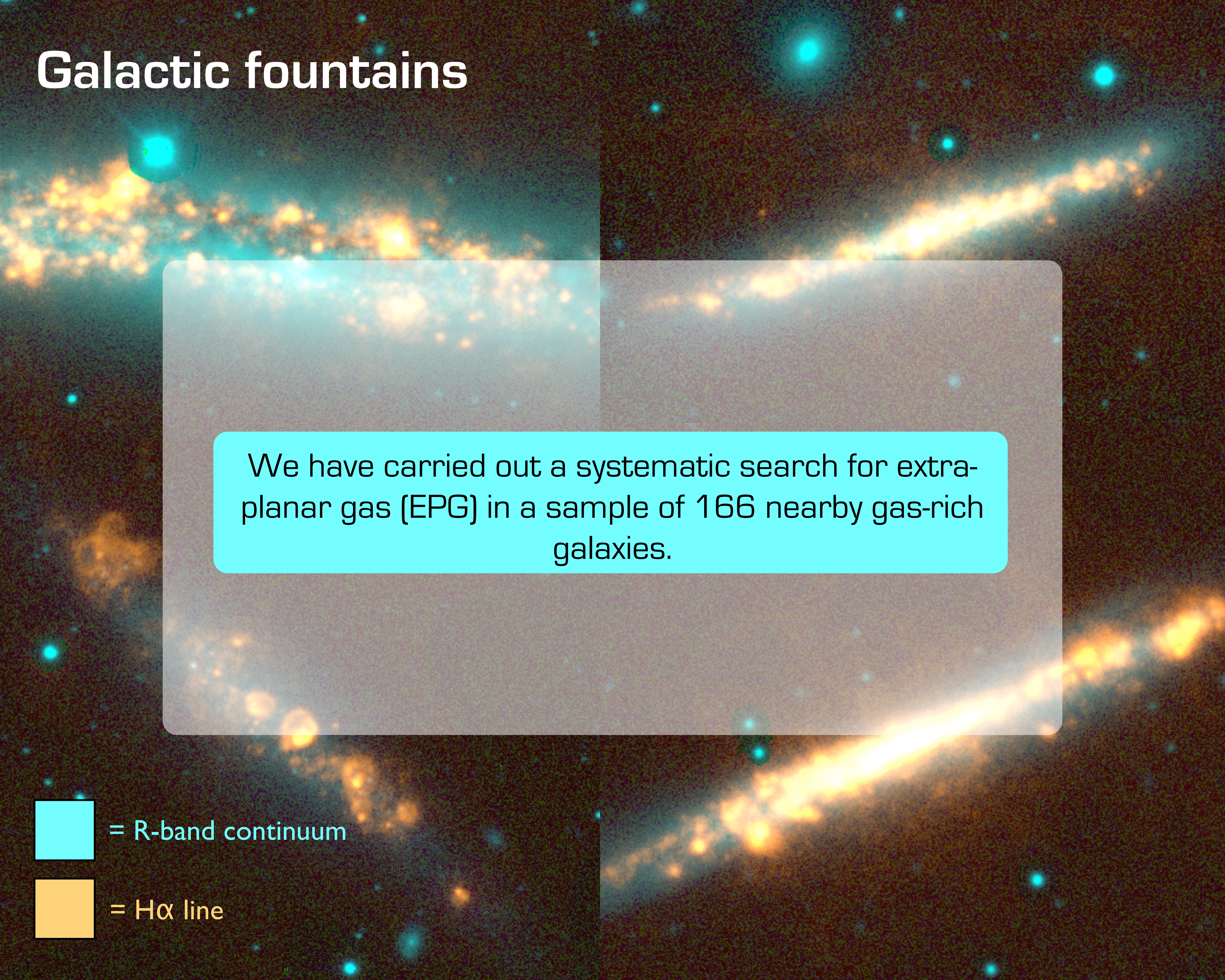
- Some important questions regarding feedback that need answering:
  - How common is it?
  - How does it influence the intergalactic environment?
  - How is it triggered/powered?

= R-band continuum

= Hα line

Galactic fountains

We have carried out a systematic search for extra-planar gas (EPG) in a sample of 166 nearby gas-rich galaxies.



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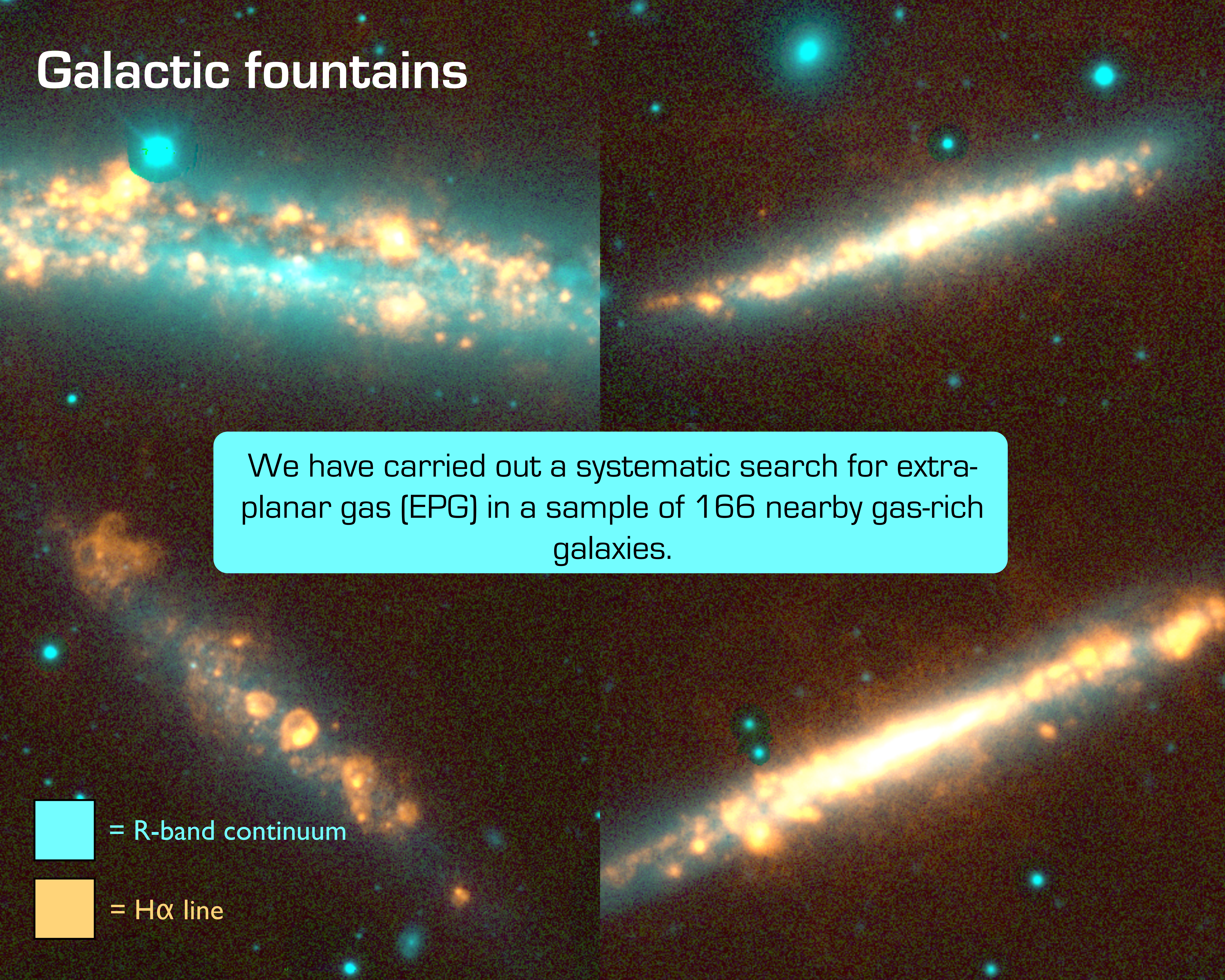

Introducing SINGG

- SINGG = Survey for Ionized Neutral Gas Galaxies (Meurer et al. 2006)
  - 412 HI-selected galaxies from HIPASS
  - Uniform sample of star-forming galaxies
  - Hα and R-band imaging using CTIO 1.5 m telescope
  - Provides unbiased view of local SF demographics…
  - …and associated processes/activities

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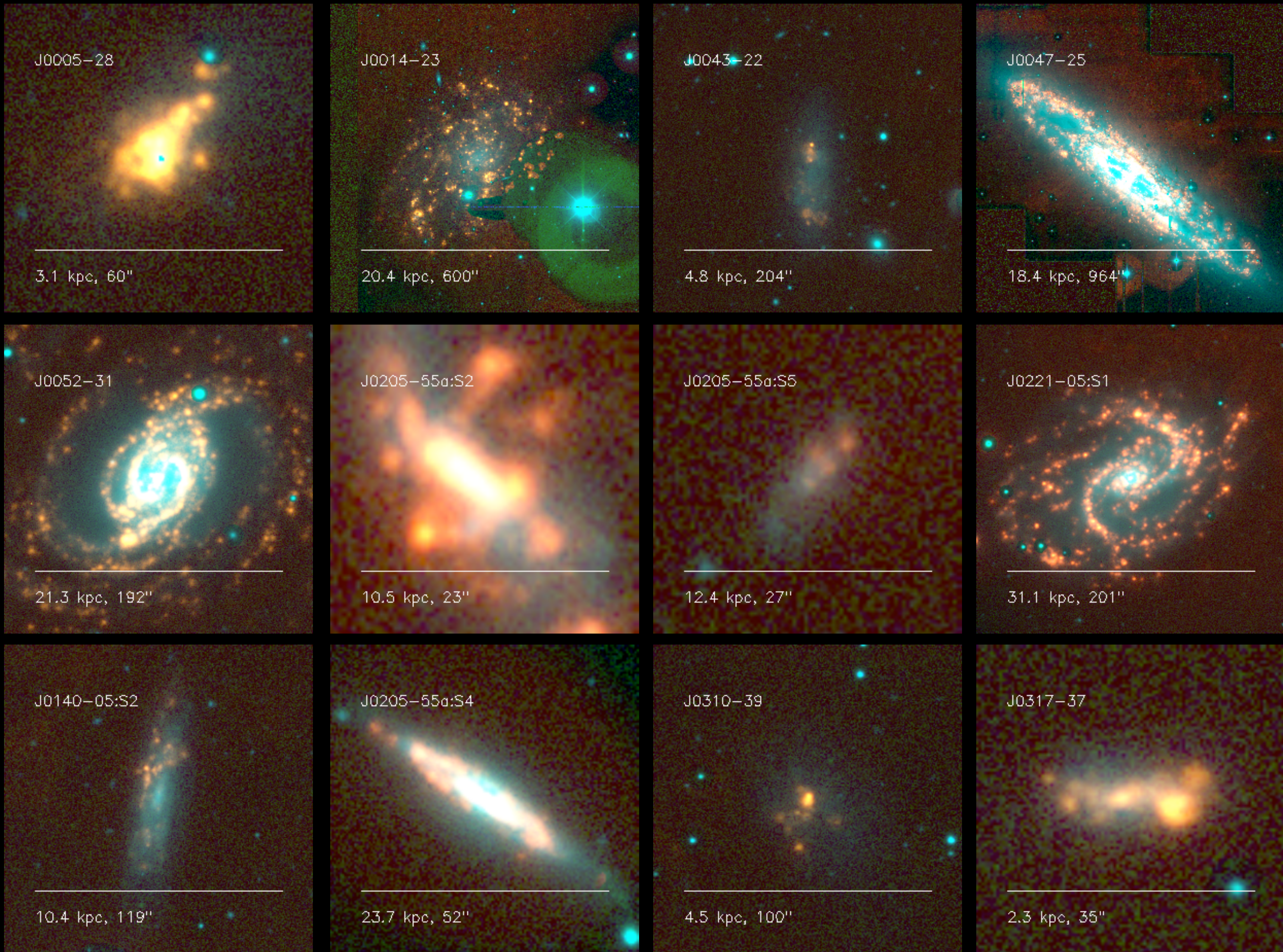
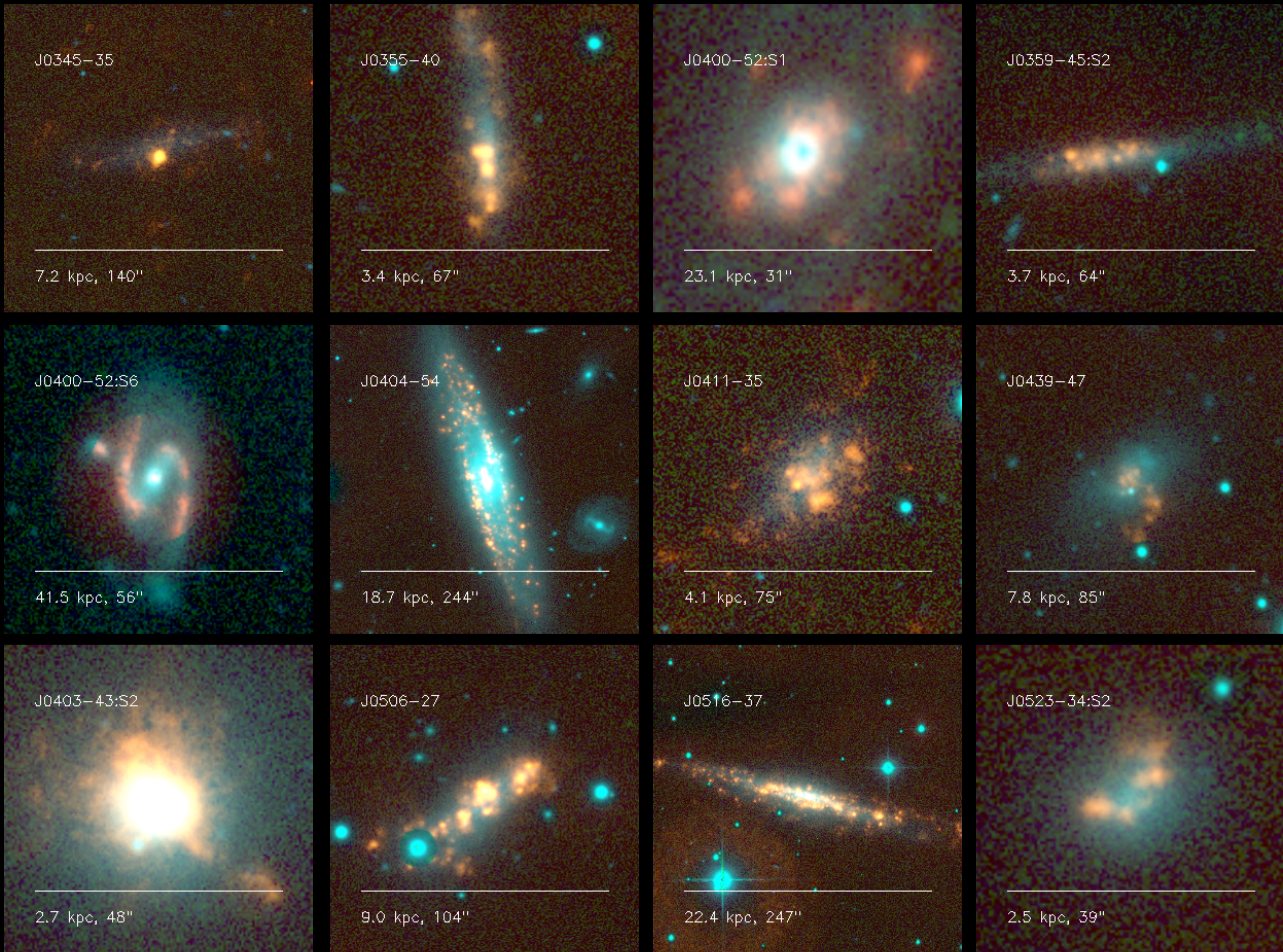
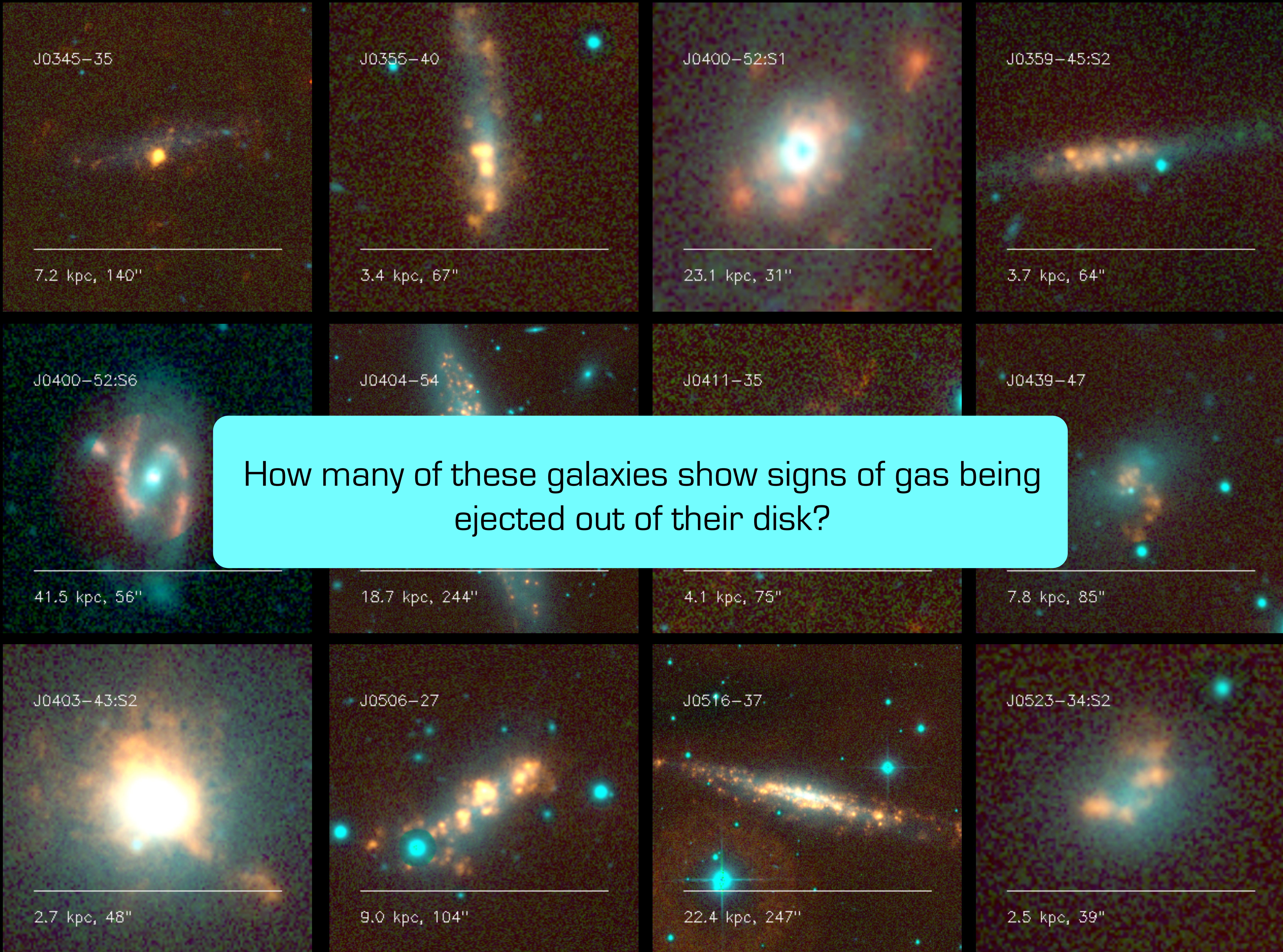
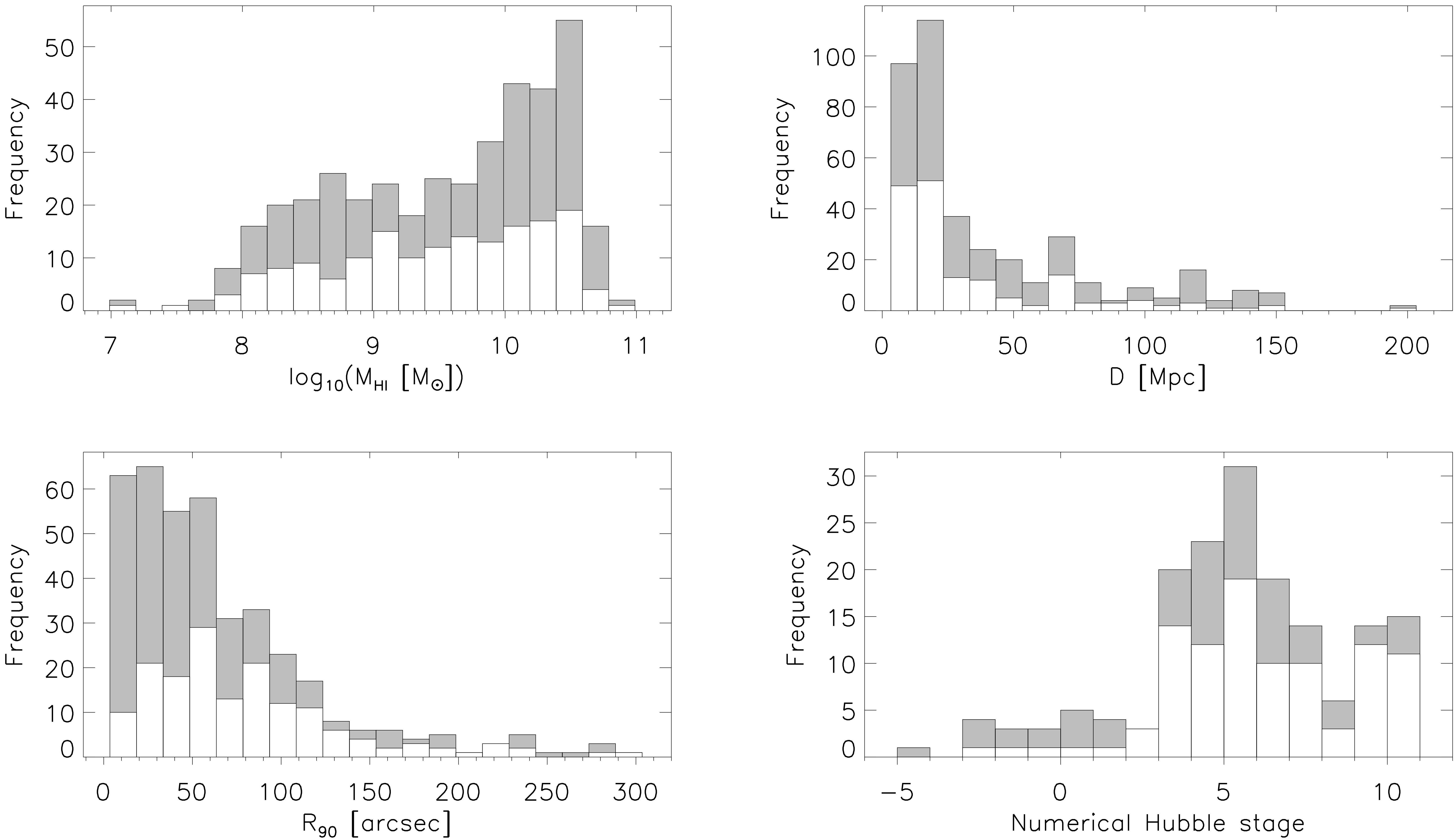

J0005−28
3.1 kpc, 60''
J0014−23
20.4 kpc, 600''
J0043−22
4.8 kpc, 204''
J0047−25
18.4 kpc, 964''
J0052−31
21.3 kpc, 192''
J0205−55a:S2
10.5 kpc, 23''
J0205−55a:S5
12.4 kpc, 27''
J0221−05:S1
31.1 kpc, 201''
J0140−05:S2
10.4 kpc, 119''
J0205−55a:S4
23.7 kpc, 52''
J0310−39
4.5 kpc, 100''
J0317−37
2.3 kpc, 35''


J0345−35
7.2 kpc, 140"
J0355−40
3.4 kpc, 67"
J0400−52:S1
23.1 kpc, 31"
J0359−45:S2
3.7 kpc, 64"
J0400−52:S6
41.5 kpc, 56"
J0404−54
18.7 kpc, 244"
J0411−35
4.1 kpc, 75"
J0439−47
7.8 kpc, 85"
J0403−43:S2
2.7 kpc, 48"
J0506−27
9.0 kpc, 104"
J0516−37
22.4 kpc, 247"
J0523−34:S2
2.5 kpc, 39"



How many of these galaxies show signs of gas being ejected out of their disk?



= Full SINGG sample

= EPG sub sample

Apply i > 60° cut to SINGG sample

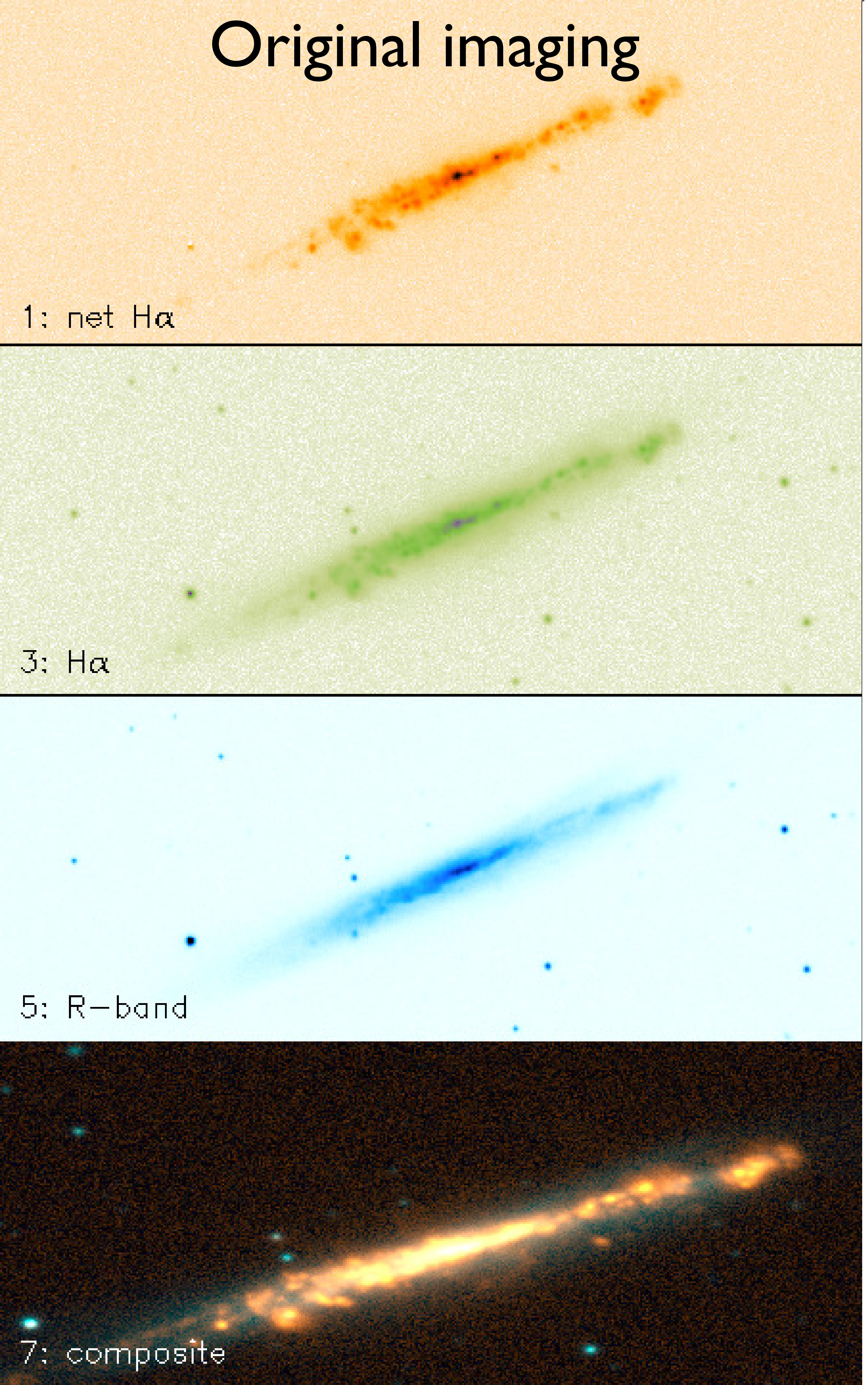
↓

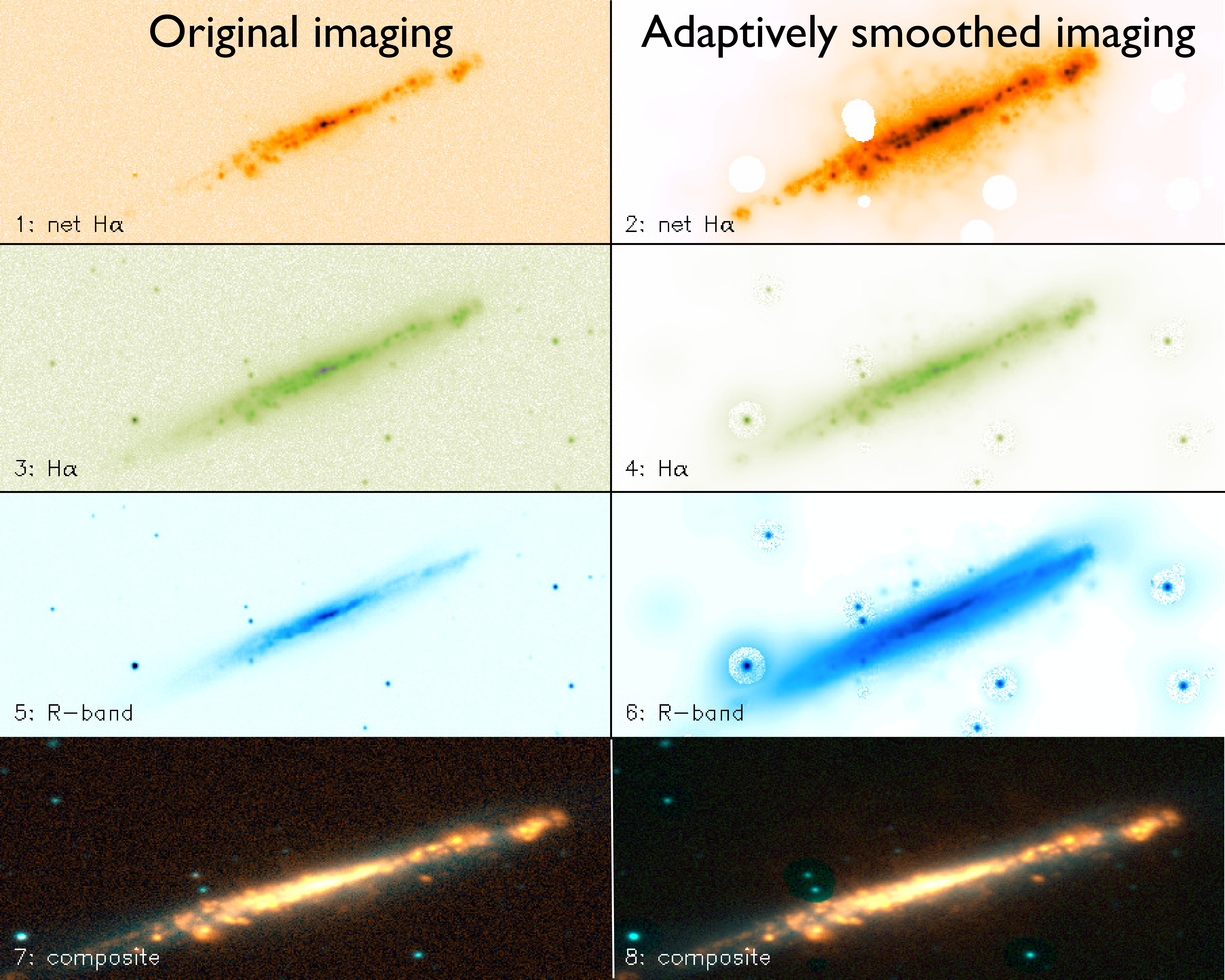
166 galaxies in EPG sample

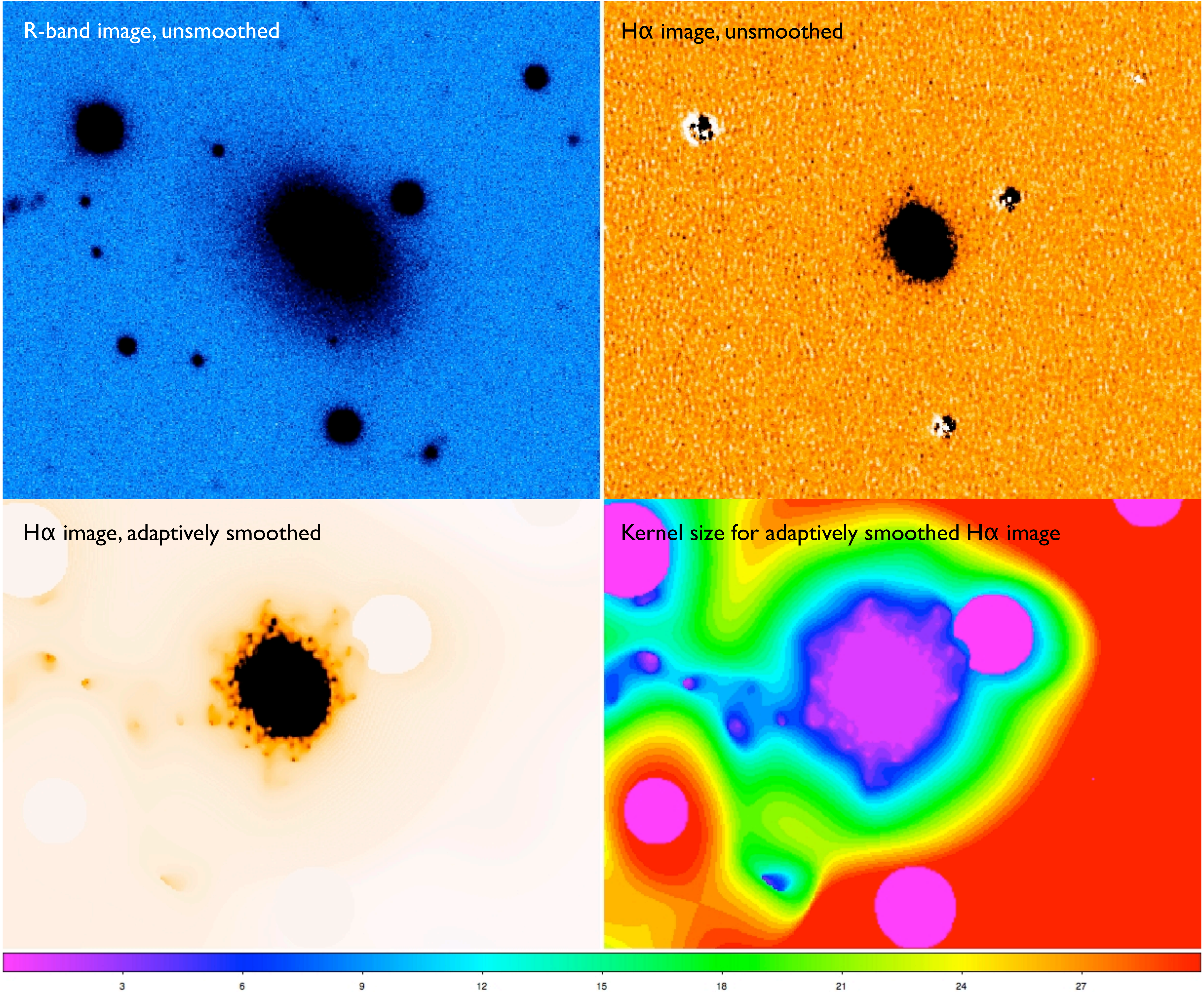
Adaptive smoothing

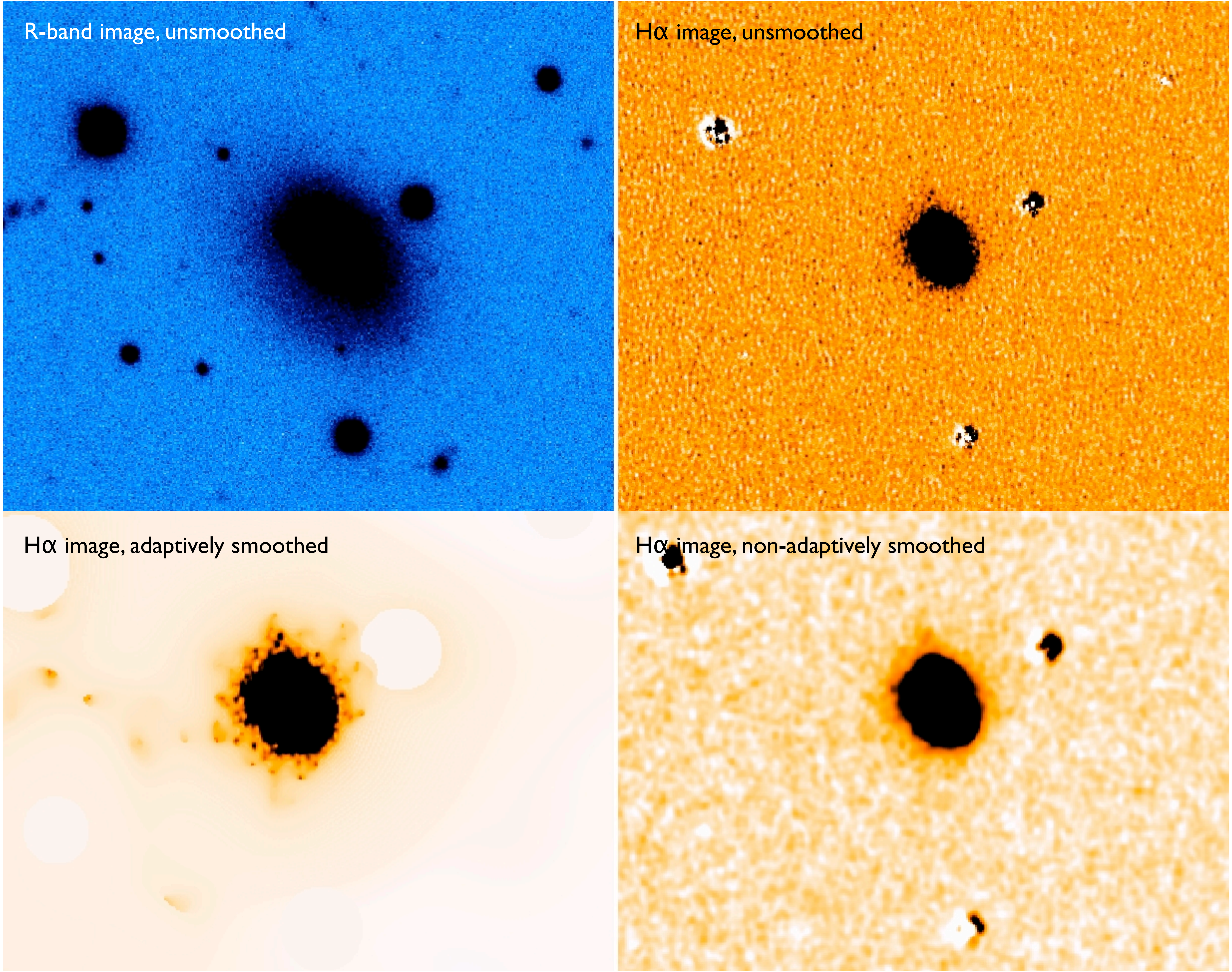
- All Hα images were adaptively smoothed in order to enhance low-level diffuse emission.
- Adaptive smoothing: size of convolution kernel is varied over image to ensure ~ constant SNR.

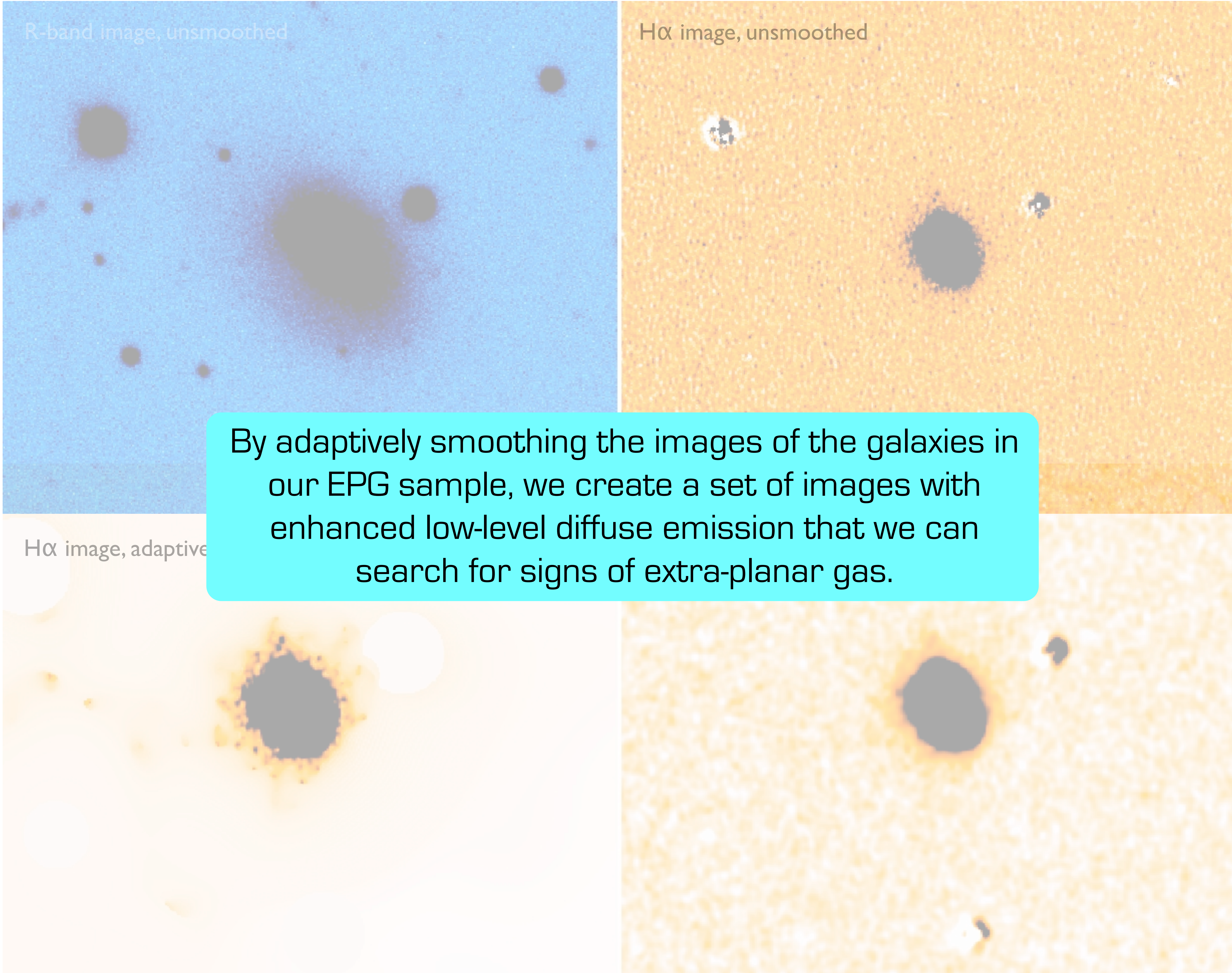
Original imaging



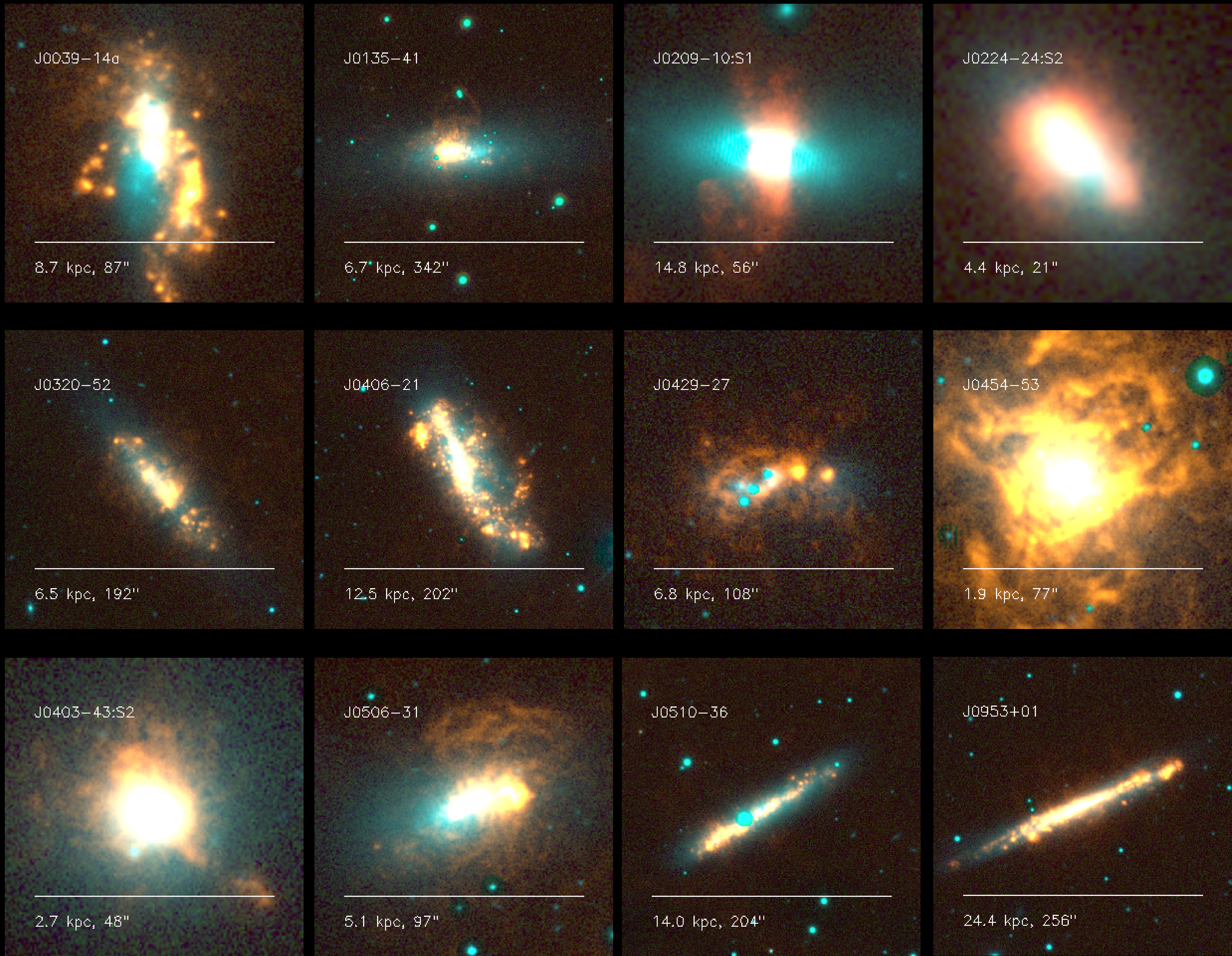

Original imaging
Adaptively smoothed imaging
1: net Hα
2: net Hα
3: Hα
4: Hα
5: R-band
6: R-band
7: composite
8: composite


R-band image, unsmoothed
Hα image, unsmoothed
Hα image, adaptively smoothed
Kernel size for adaptively smoothed Hα image
3
6
9
12
15
18
21
24
27


R-band image, unsmoothed
Hα image, unsmoothed
Hα image, adaptively smoothed
Hα image, non-adaptively smoothed



By adaptively smoothing the images of the galaxies in our EPG sample, we create a set of images with enhanced low-level diffuse emission that we can search for signs of extra-planar gas.


J0039−14a
8.7 kpc, 87"
J0135−41
6.7 kpc, 342"
J0209−10:S1
14.8 kpc, 56"
J0224−24:S2
4.4 kpc, 21"
J0320−52
6.5 kpc, 192"
J0406−21
12.5 kpc, 202"
J0429−27
6.8 kpc, 108"
J0454−53
1.9 kpc, 77"
J0403−43:S2
2.7 kpc, 48"
J0506−31
5.1 kpc, 97"
J0510−36
14.0 kpc, 204"
J0953+01
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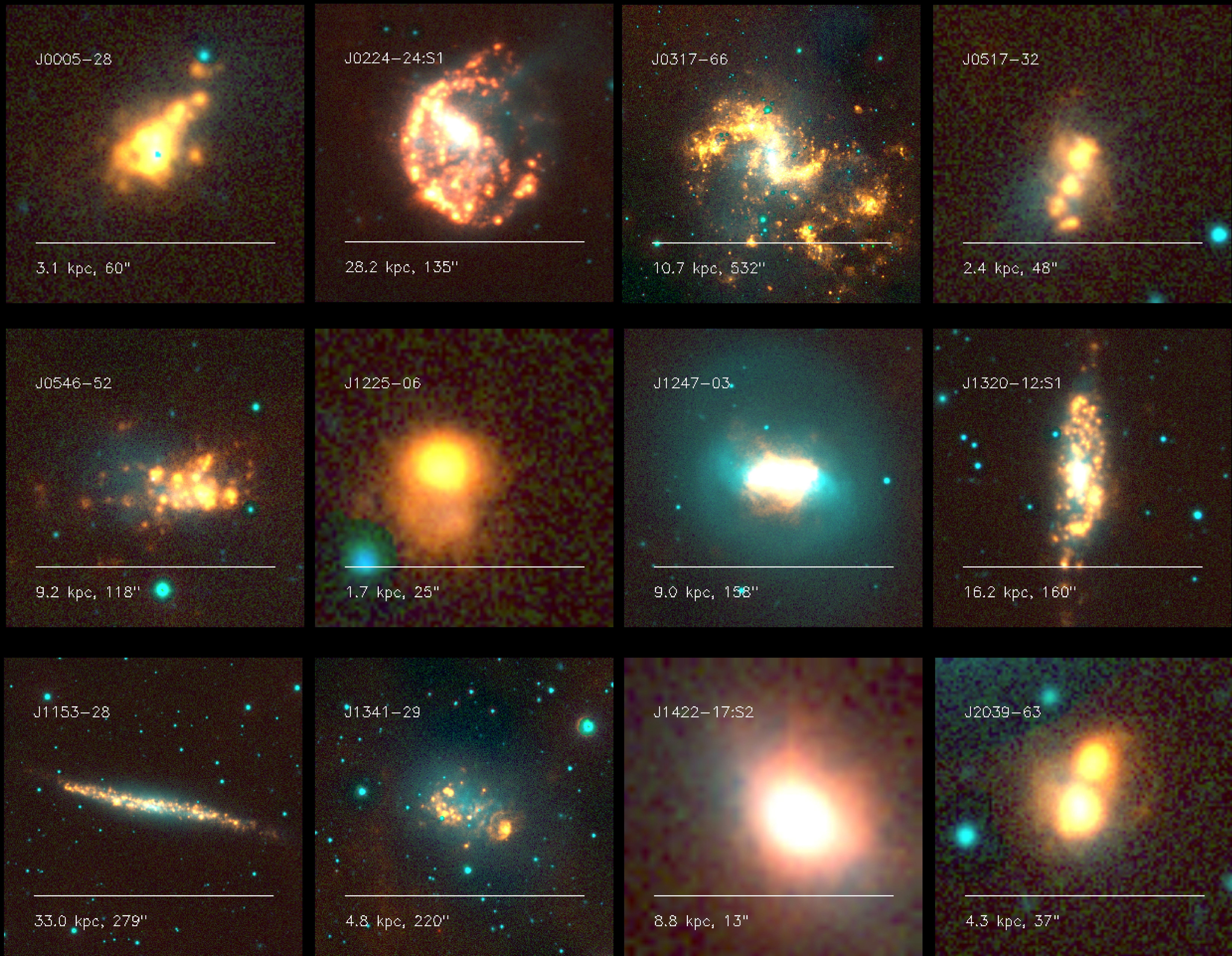

J0005−28
3.1 kpc, 60"
J0224−24:S1
28.2 kpc, 135"
J0317−66
10.7 kpc, 532"
J0517−32
2.4 kpc, 48"
J0546−52
9.2 kpc, 118"
J1225−06
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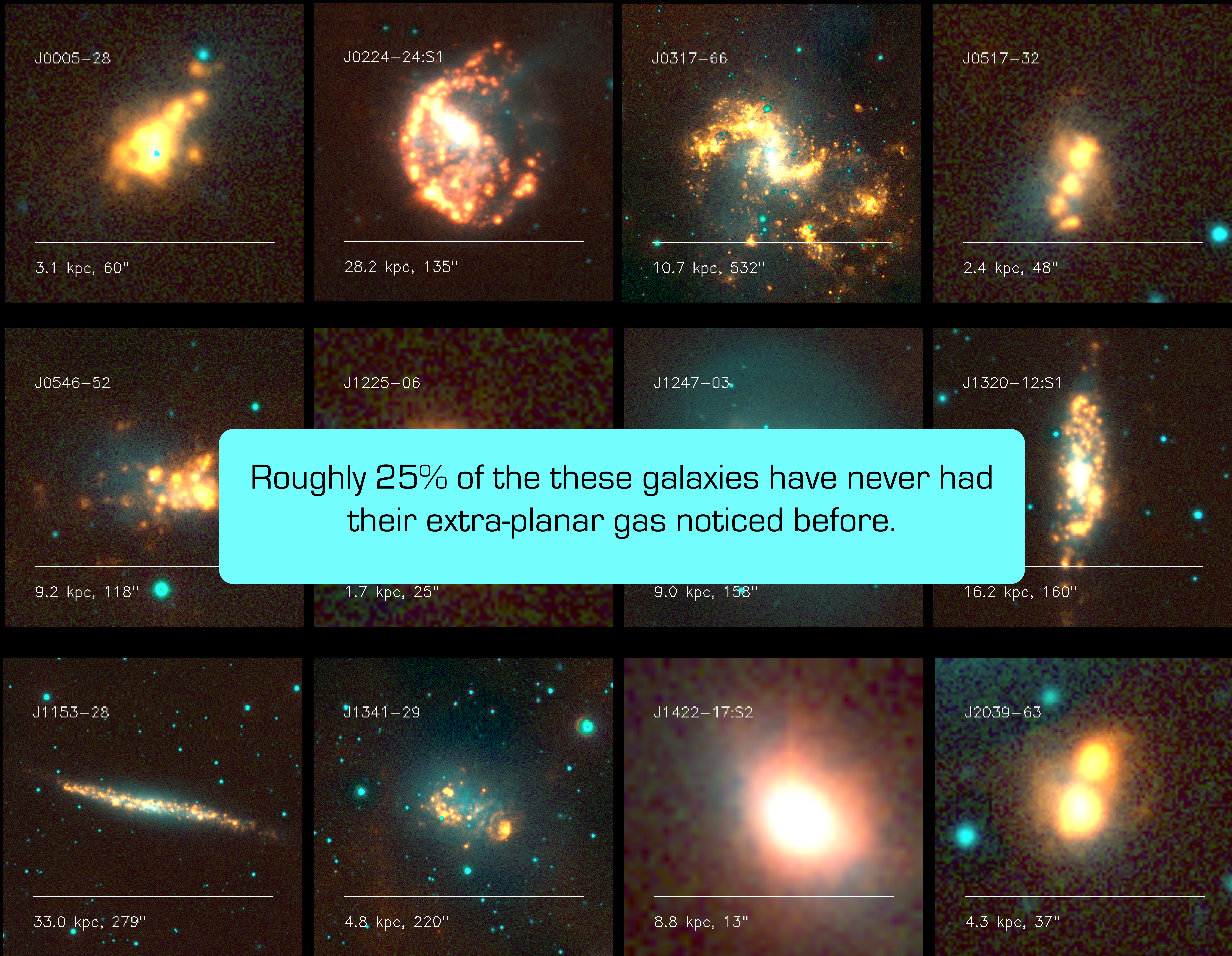


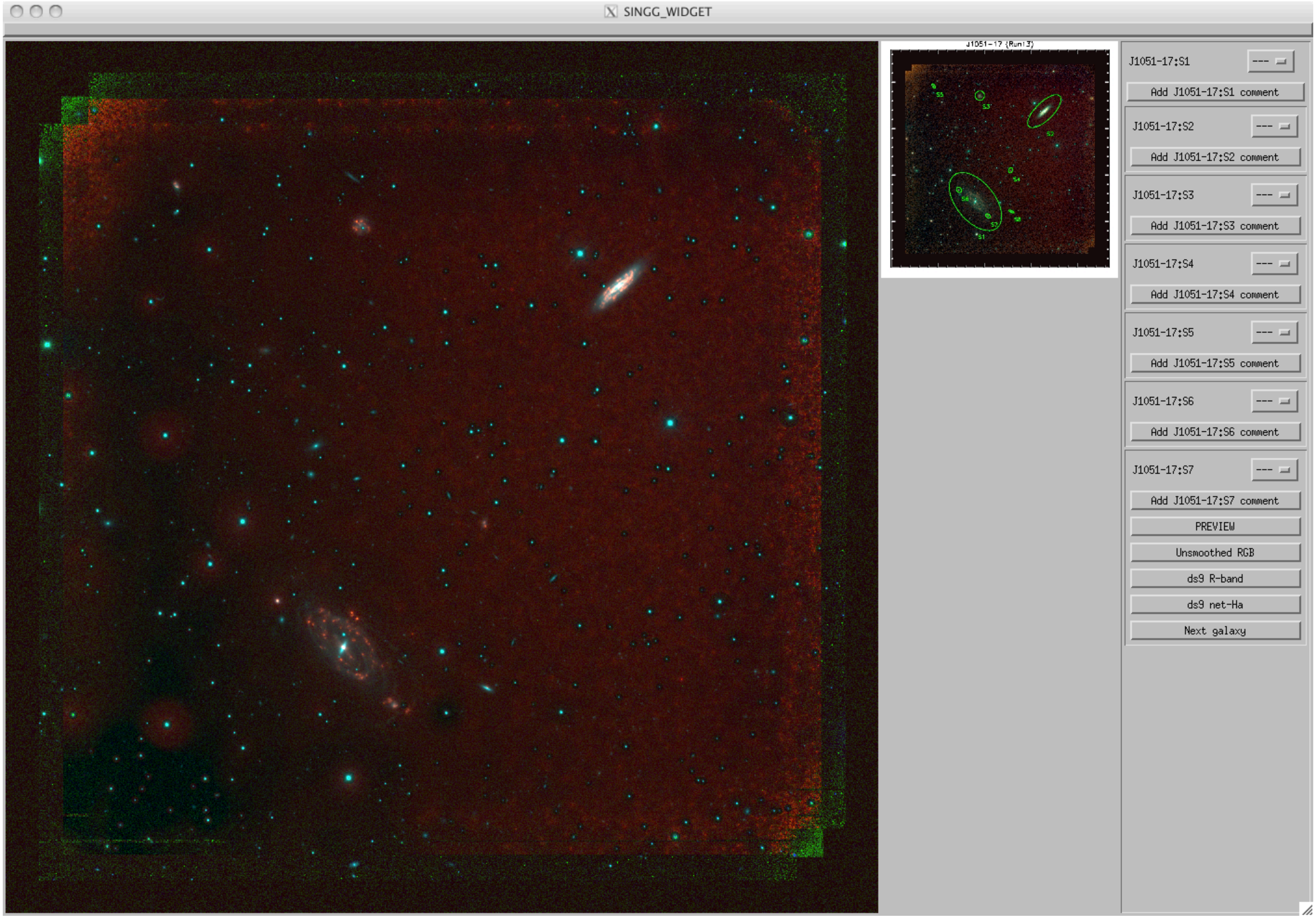
Roughly 25% of the these galaxies have never had their extra-planar gas noticed before.

We can use our uniform data set to produce a set of unbiased characterisations of the galaxies and their feedback activity.

Classifying the EPG

- All adaptively smoothed images were visually inspected by several people for signs of EPG.

 ed.elson@icrar.org


SINGG_WIDGET
J1051-17:S1

Add J1051-17:S1 comment
J1051-17:S2

Add J1051-17:S2 comment
J1051-17:S3

Add J1051-17:S3 comment
J1051-17:S4

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J1051-17:S5

Add J1051-17:S5 comment
J1051-17:S6

Add J1051-17:S6 comment
J1051-17:S7

Add J1051-17:S7 comment
PREVIEW
Unsmoothed RGB
ds9 R-band
ds9 net-Ha
Next galaxy

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  - EPG = 2 → Unambiguous evidence for EPG

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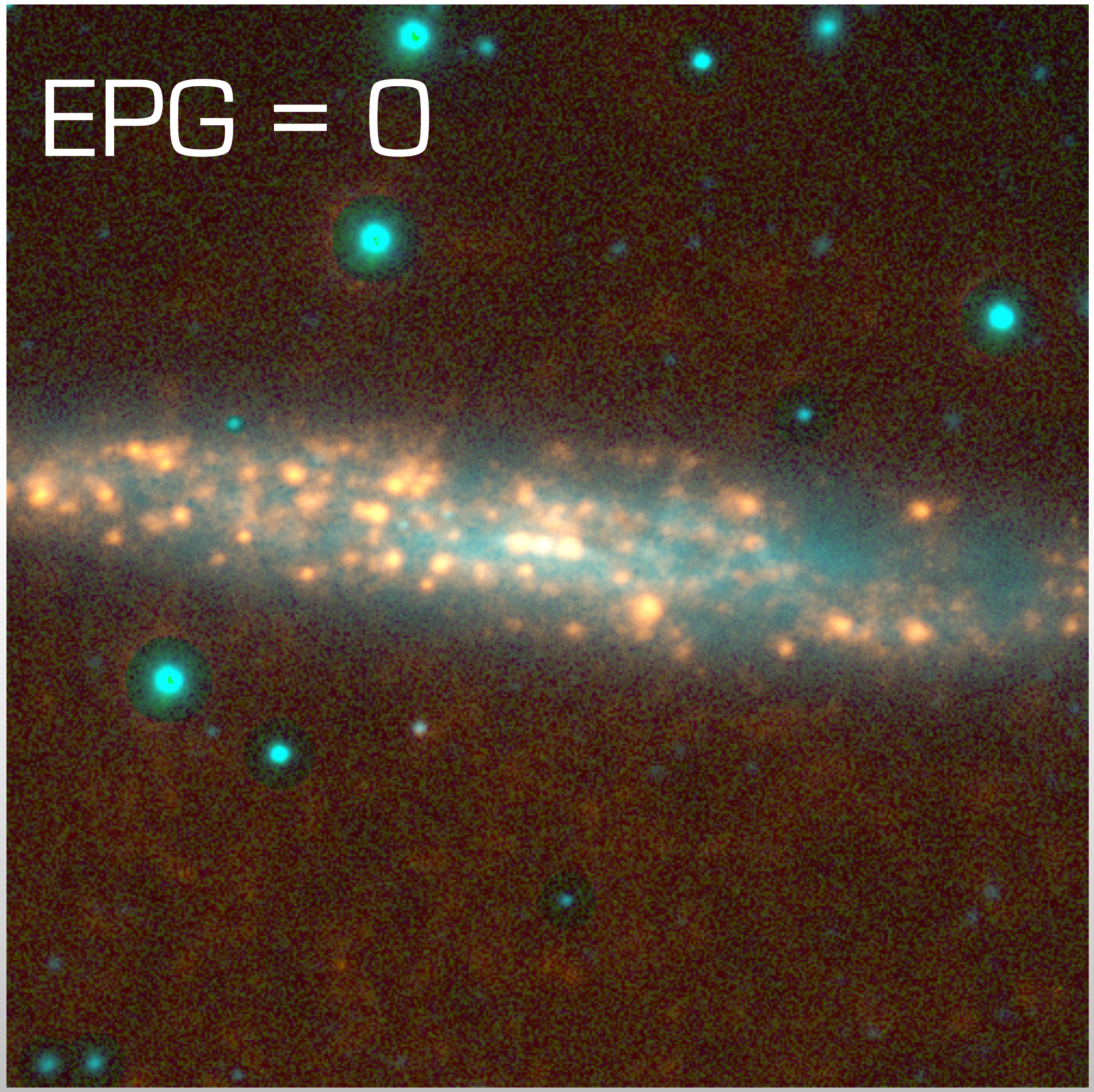

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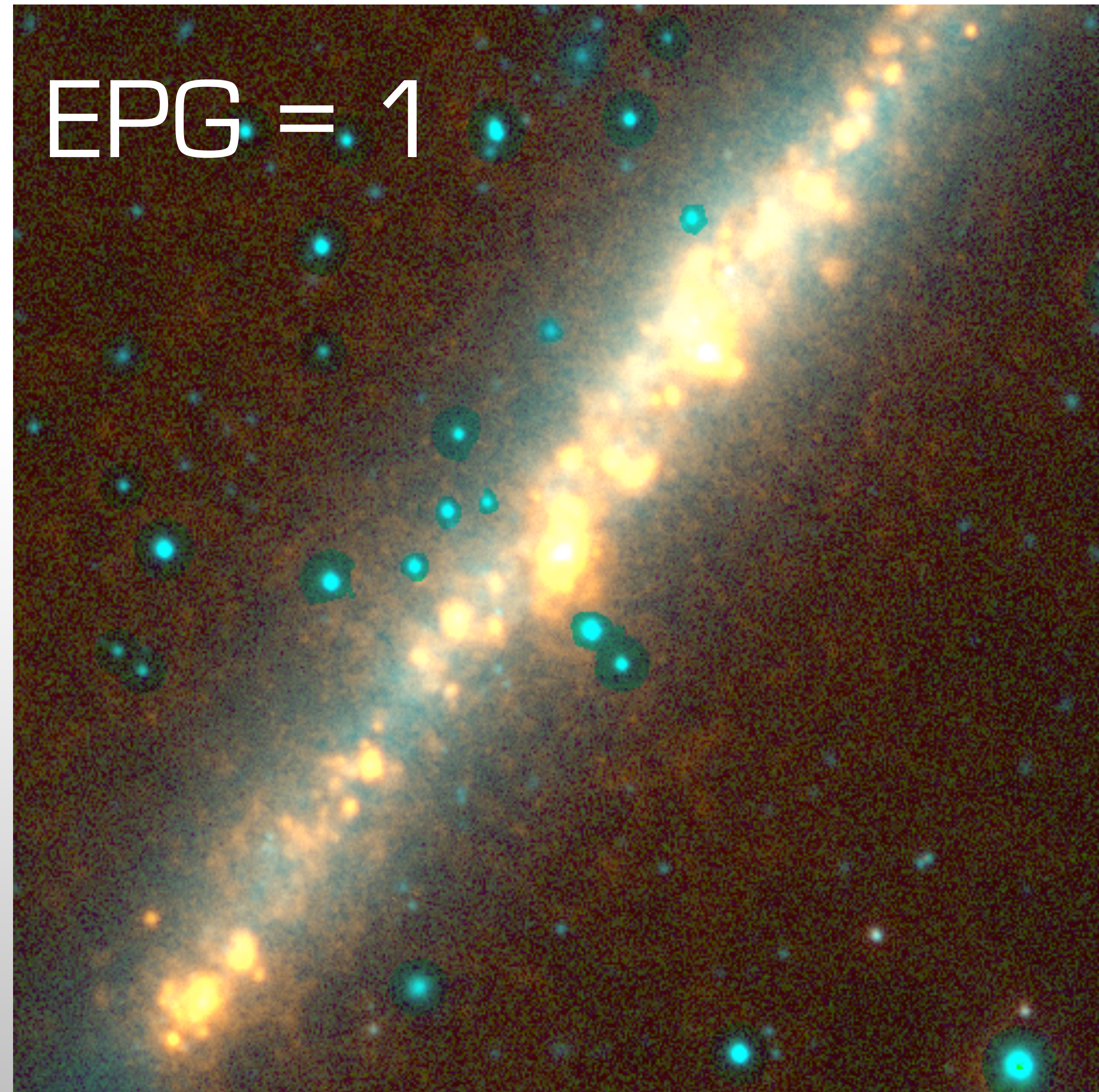

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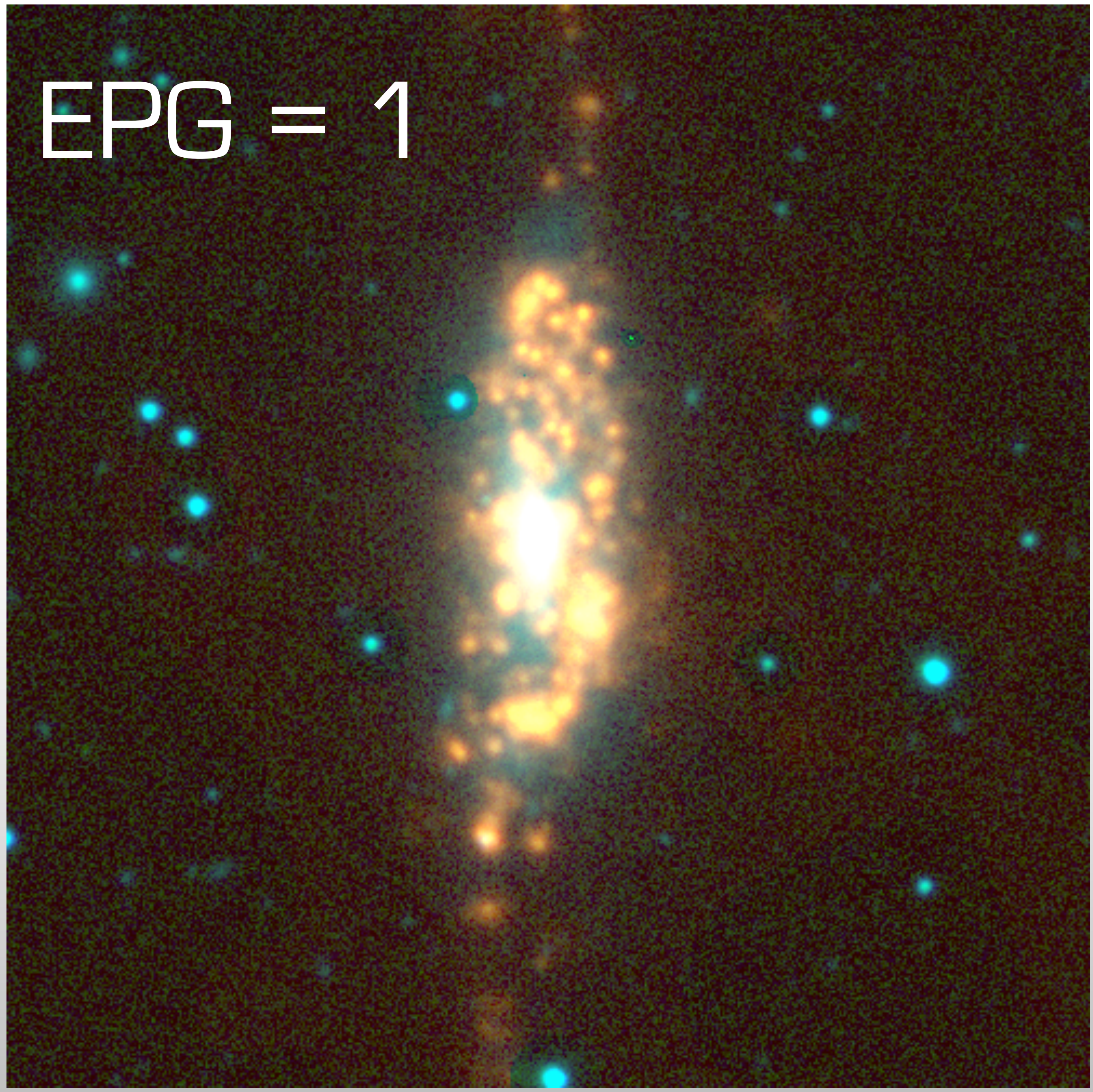

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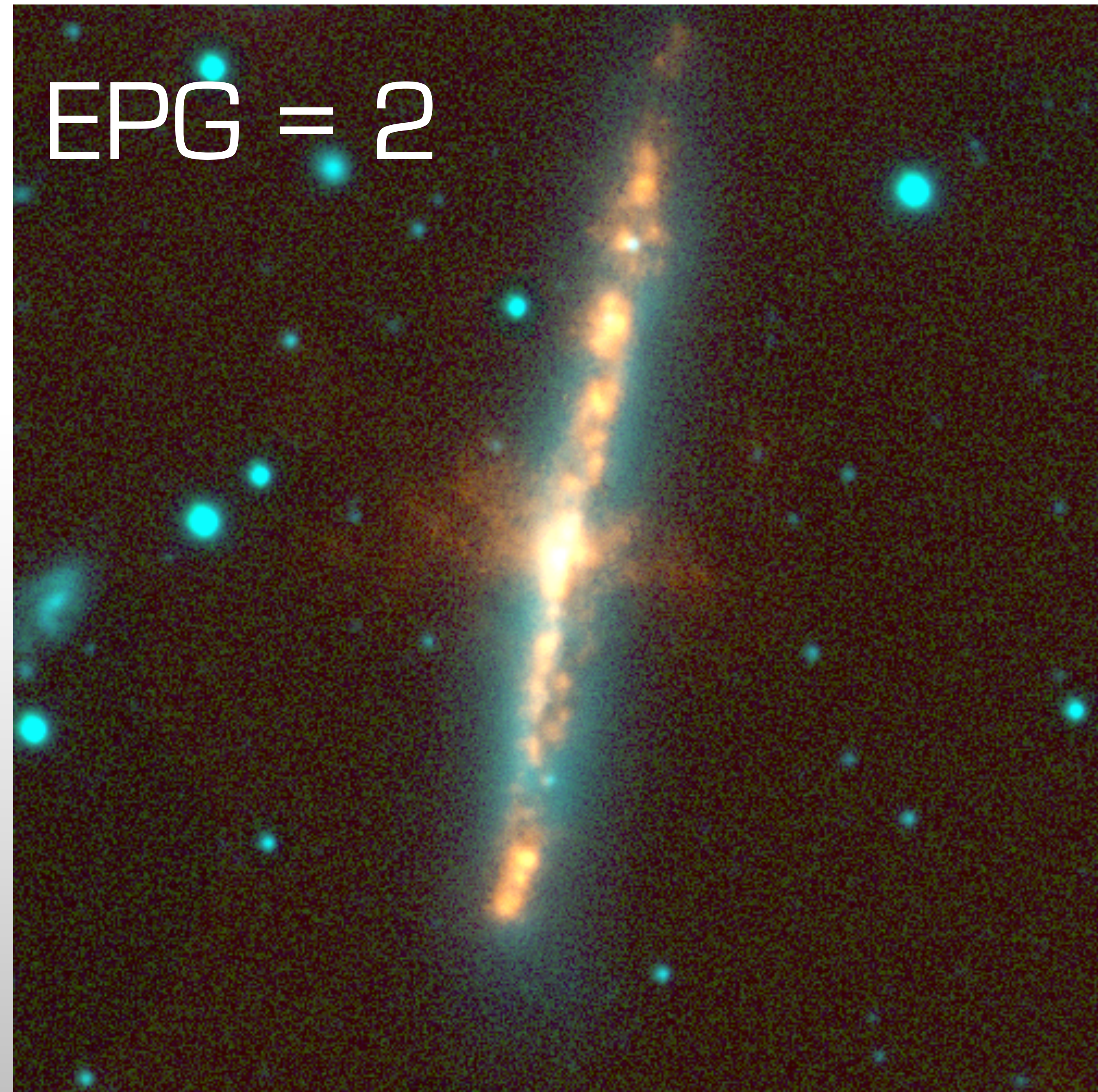

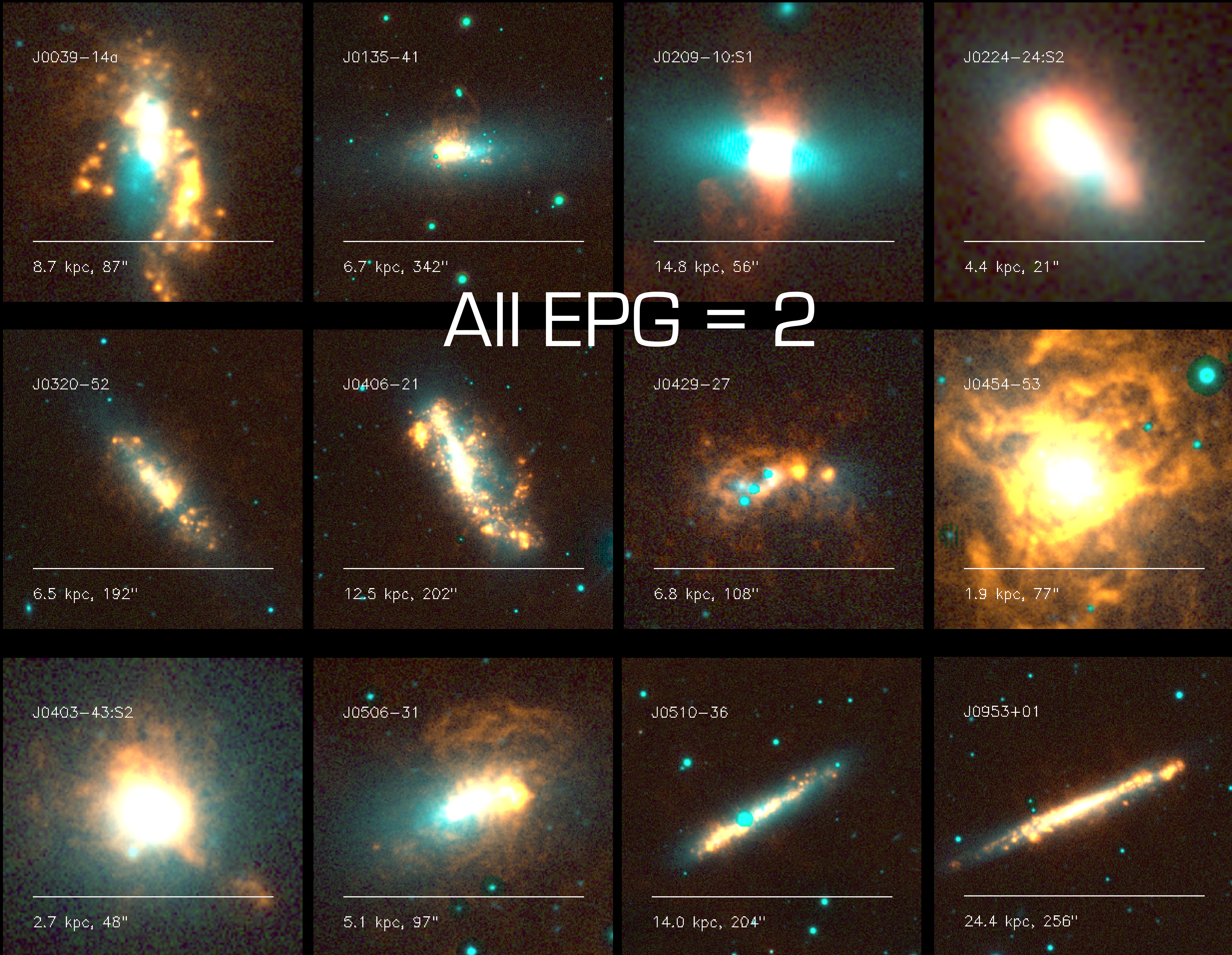
All EPG = 2
J0039−14a
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6.7 kpc, 342"
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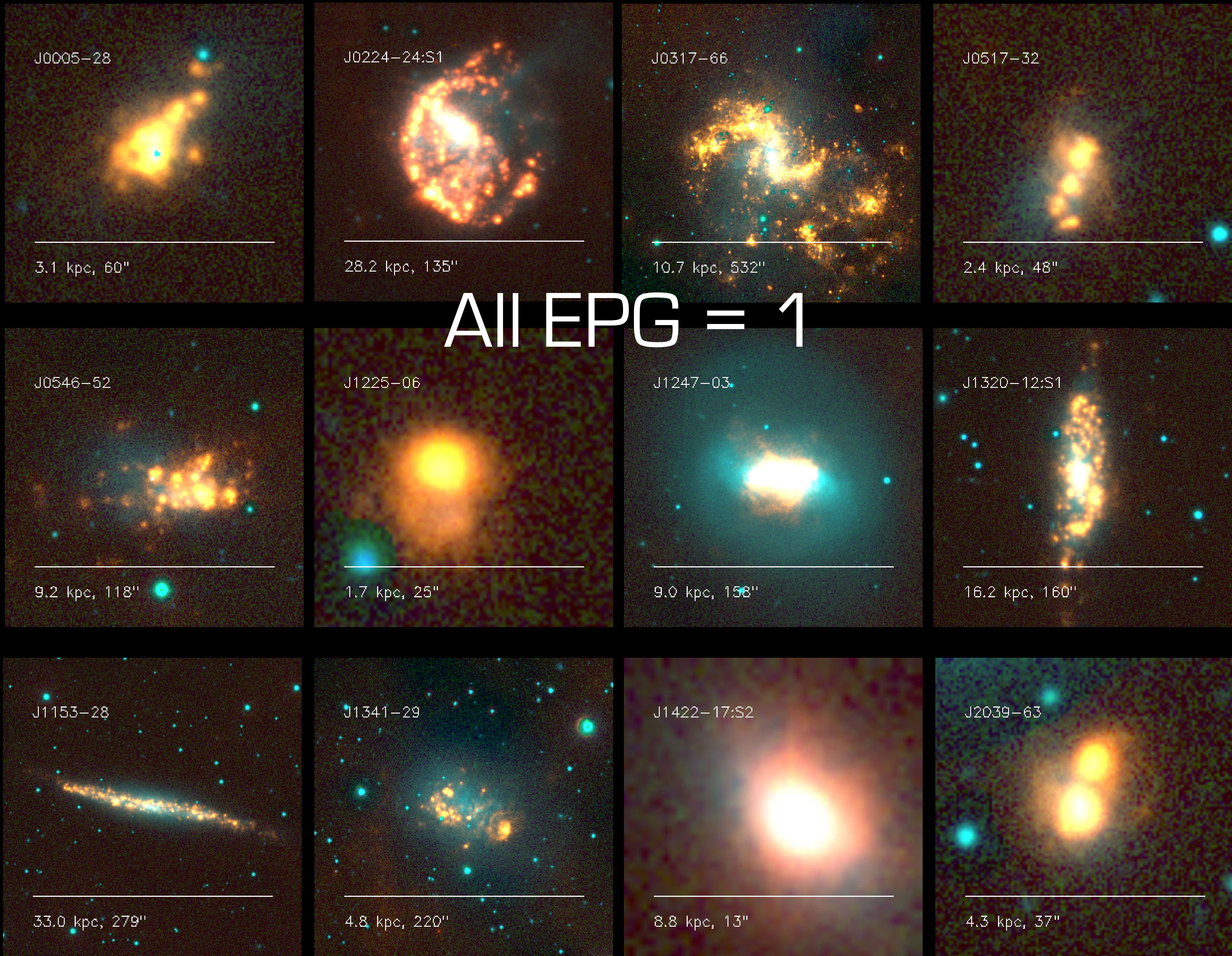
All EPG = 1
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3.1 kpc, 60"
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The big question...

- Out of the 166 galaxies in the EPG sample, how many have at least some evidence for extra-planar gas?

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- Out of the 166 galaxies in the EPG sample, how many have at least some evidence for extra-planar gas?

Answer: 37 are EPG = 2 → 22%

21 are EPG = 1 → 12.6%

35% of EPG galaxies have at least some evidence of feedback activity

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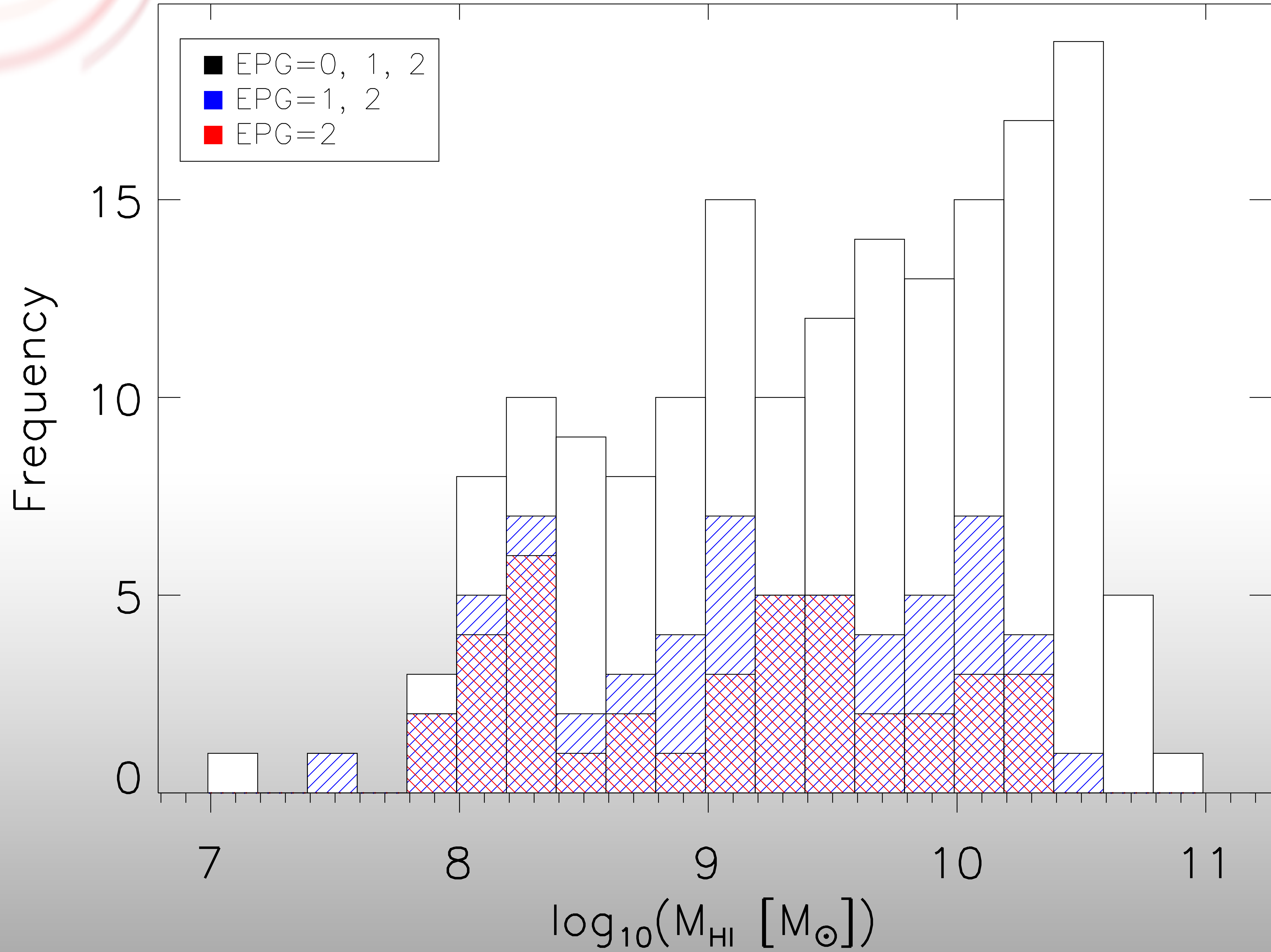
Dependence of EPG on HI mass...



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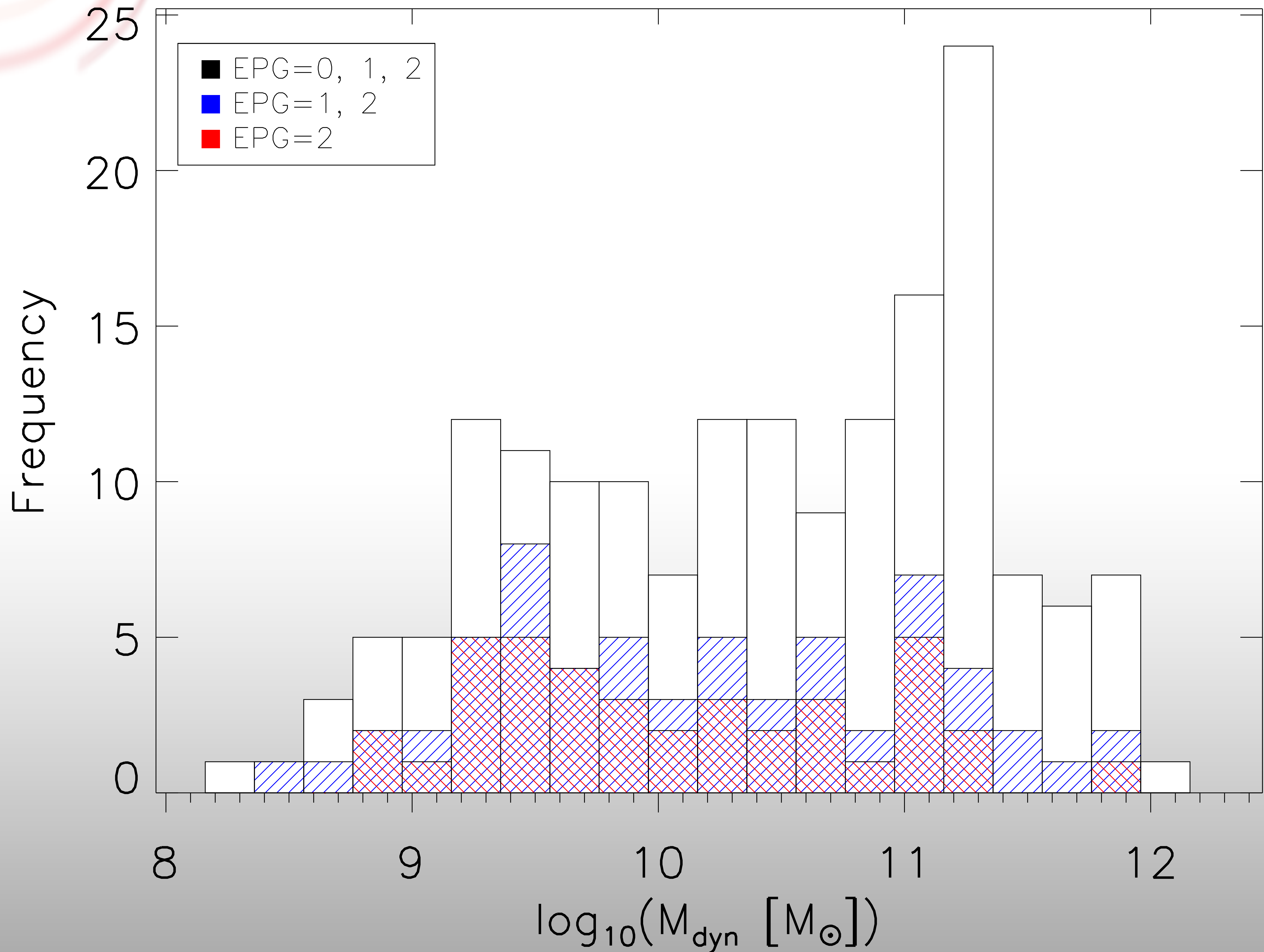

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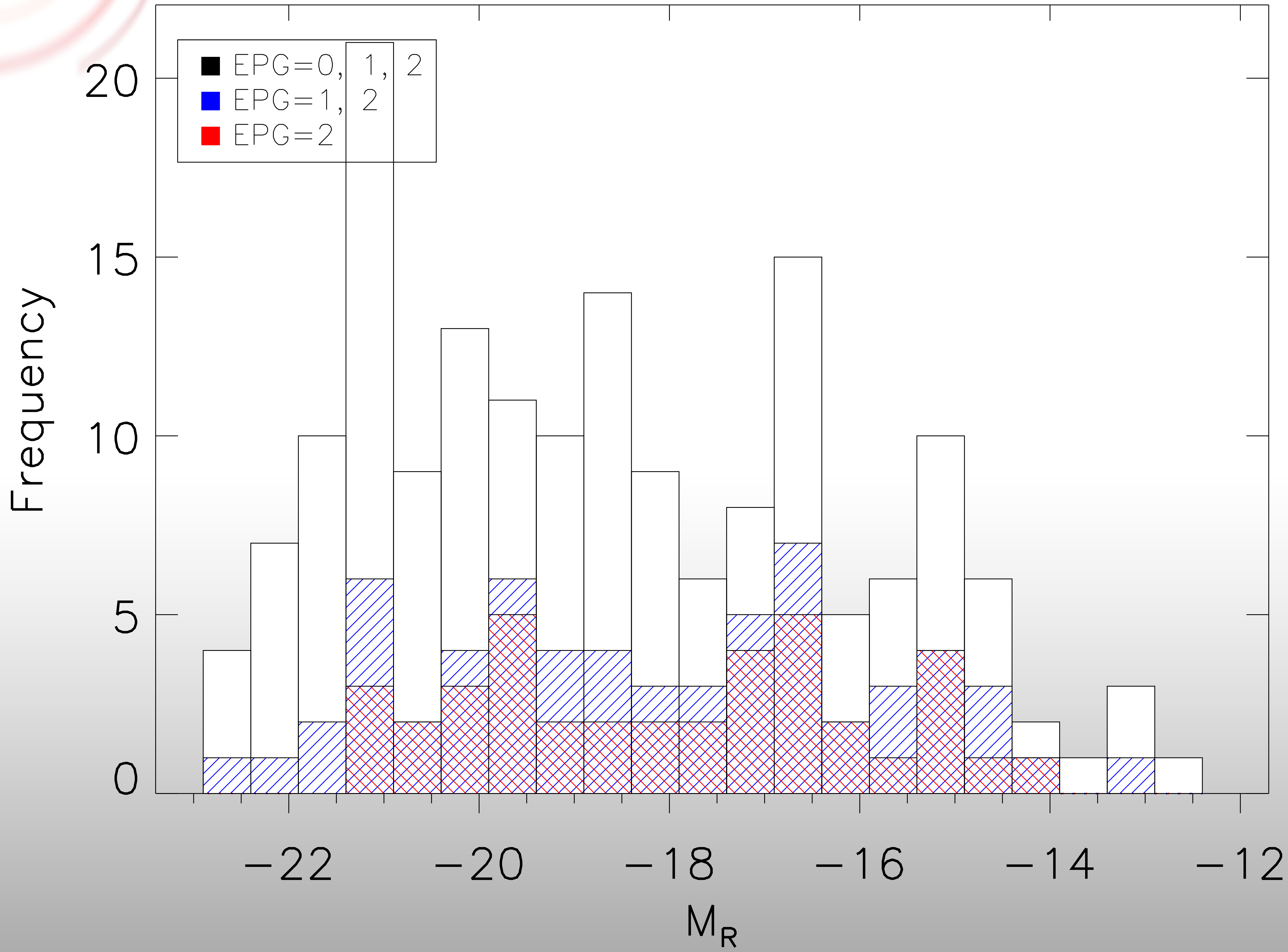
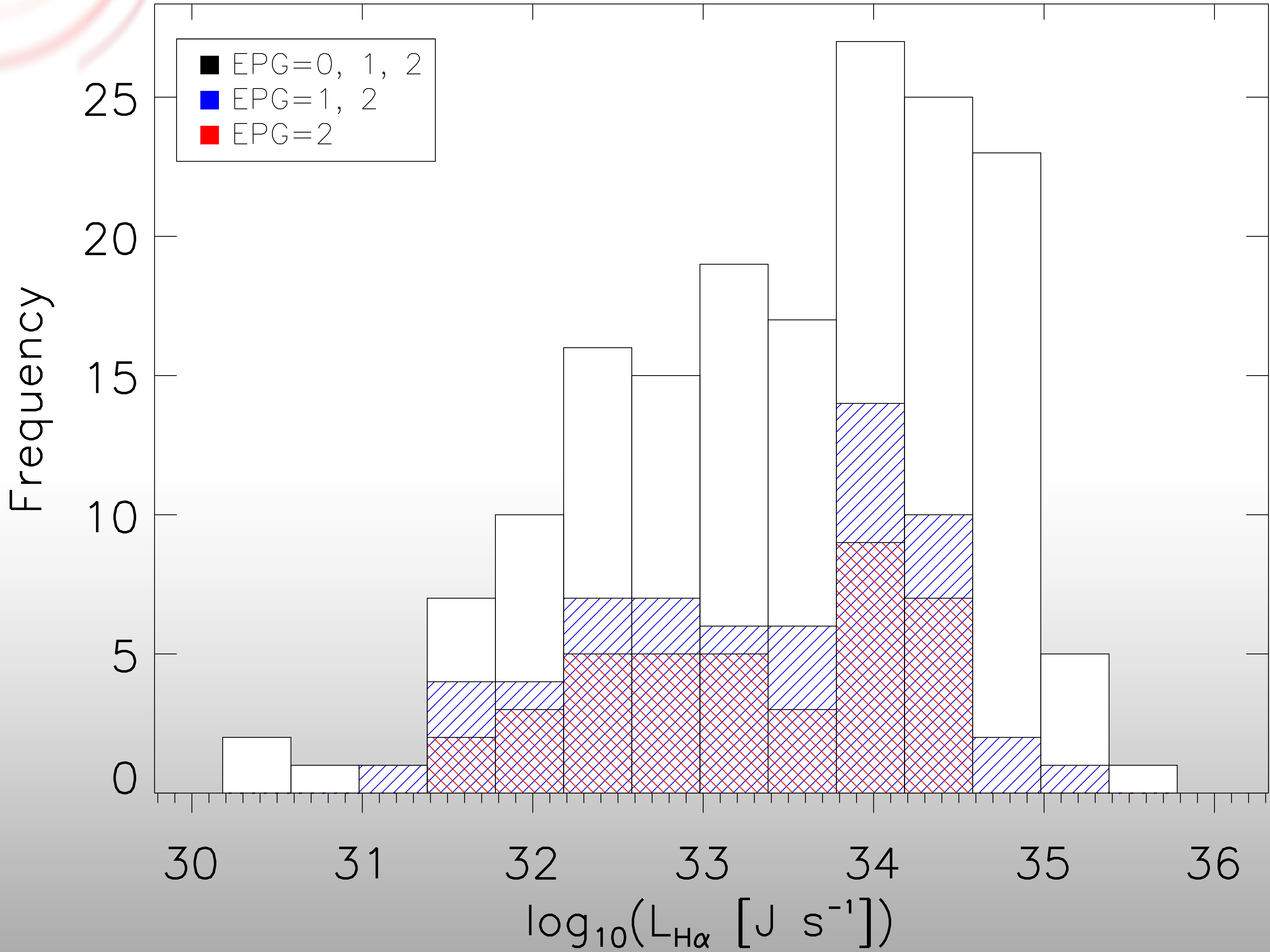
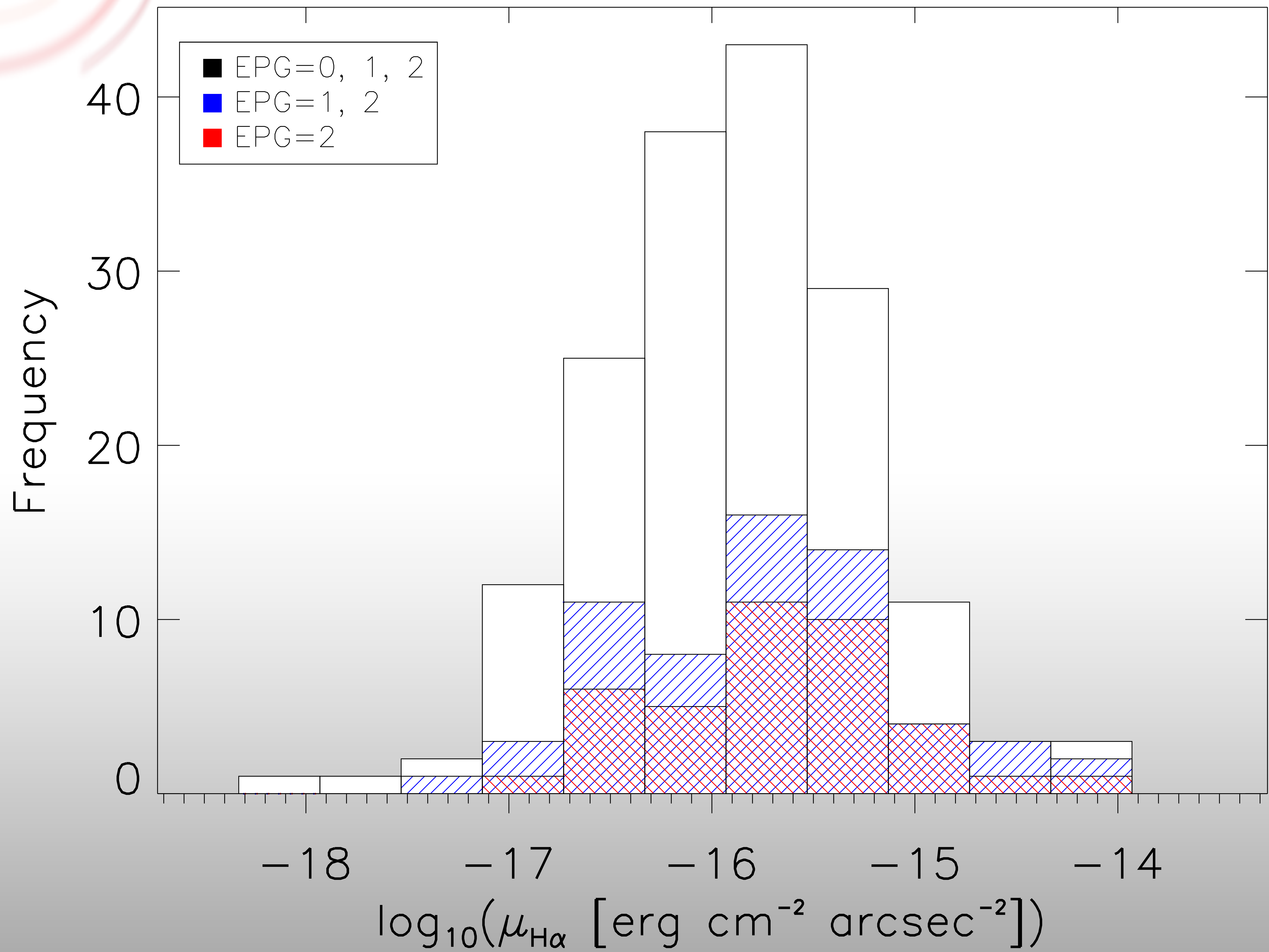


Dependence of EPG on Hα luminosity...



Dependence of EPG on Hα surface brightness...



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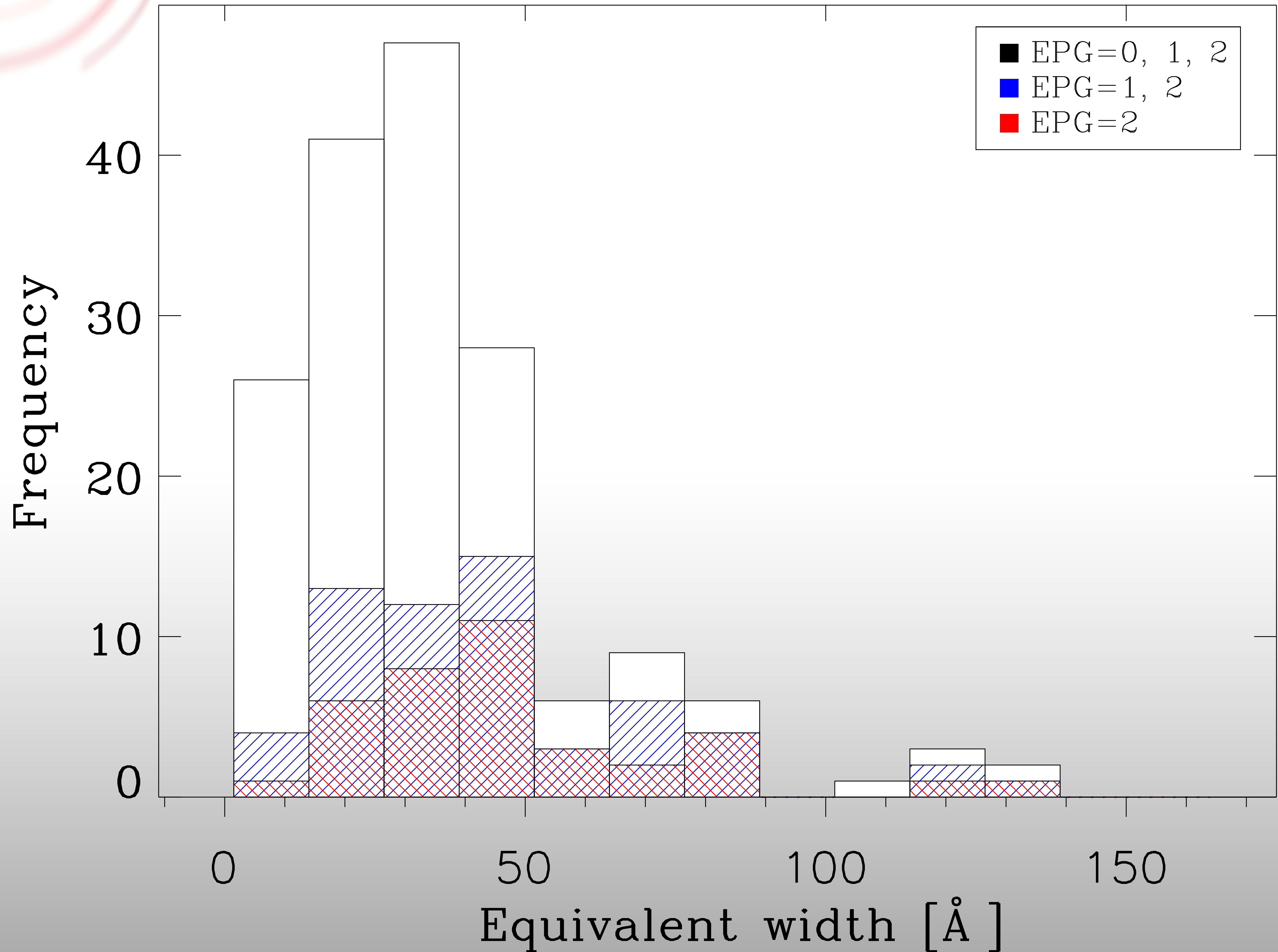
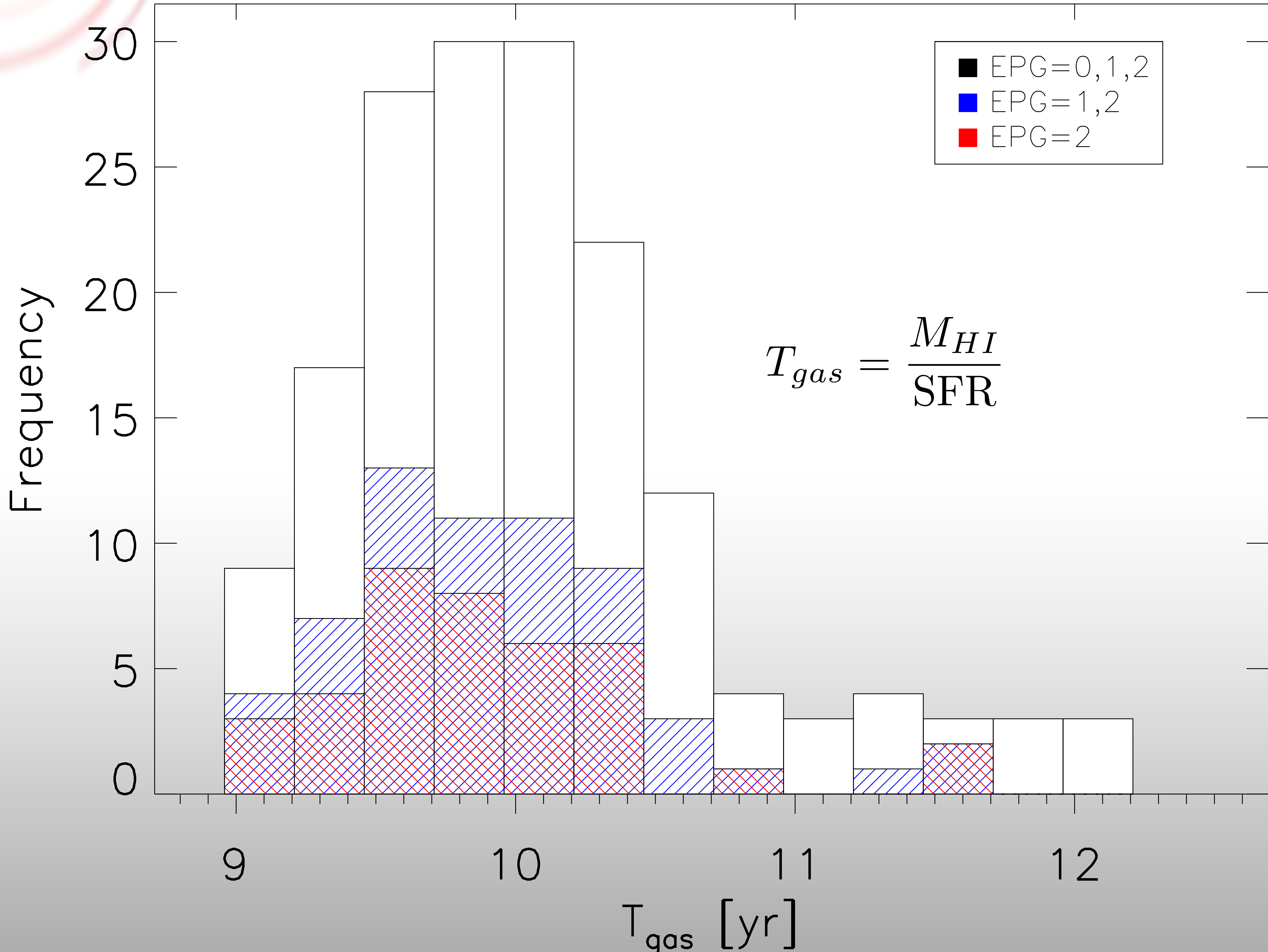
Dependence of EPG on Hα equivalent width…

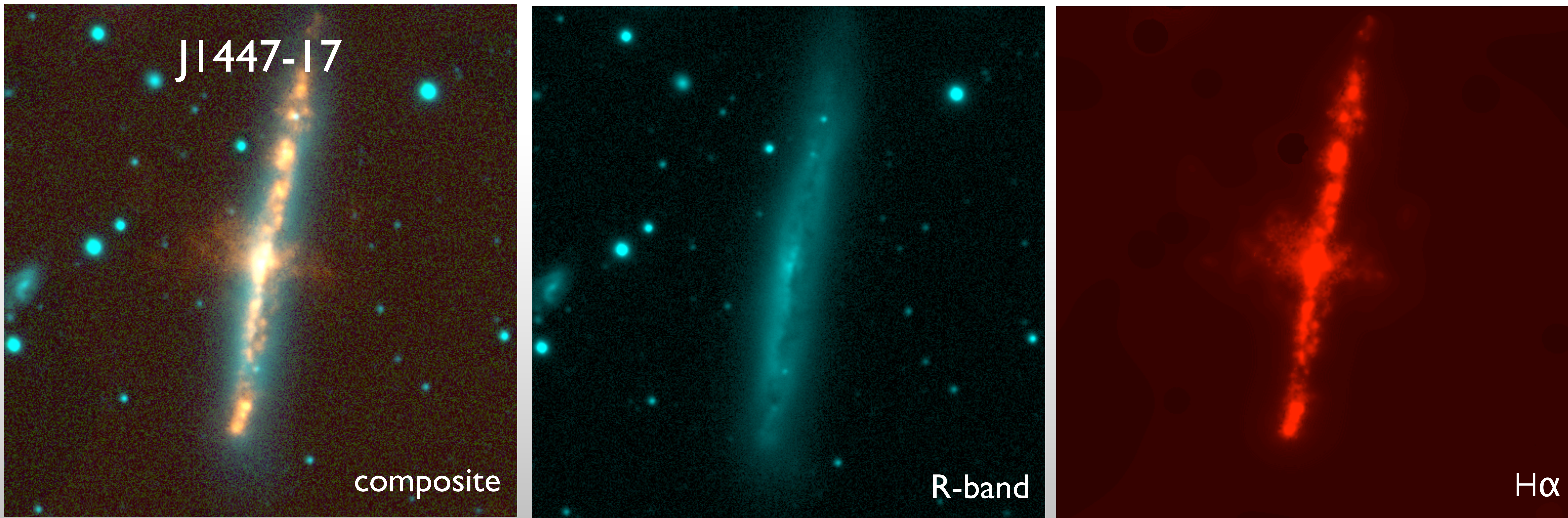


Dependence of EPG on HI consumption time...



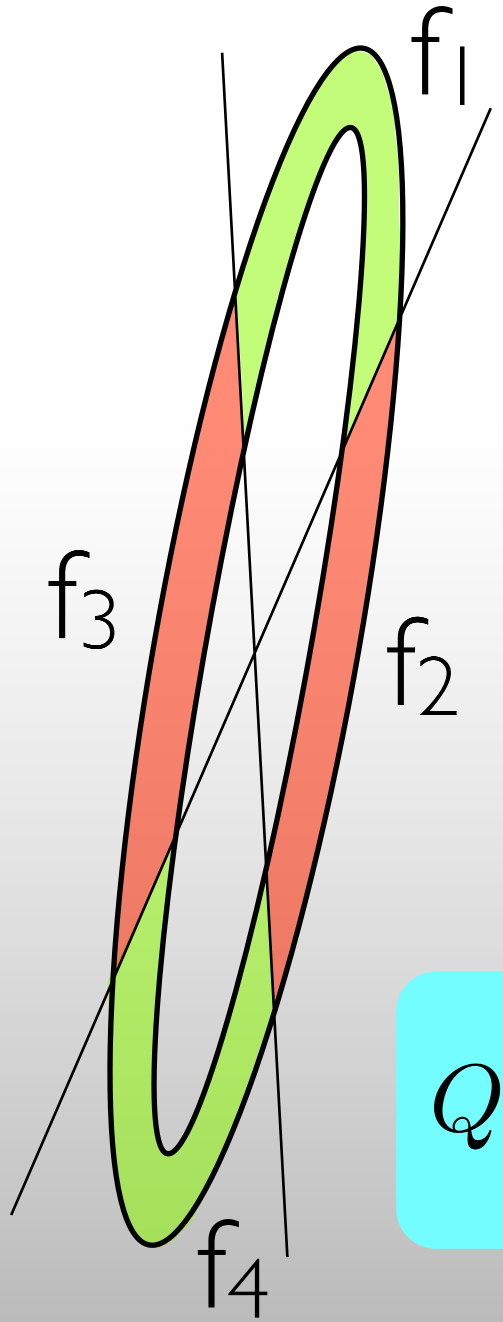
Minor axis “excess” of EPG

- Prediction of theory of starburst-driven outflows: gas should expand preferentially along minor axis.
- Expect distribution of Hα to be more extended along minor axes than continuum light.

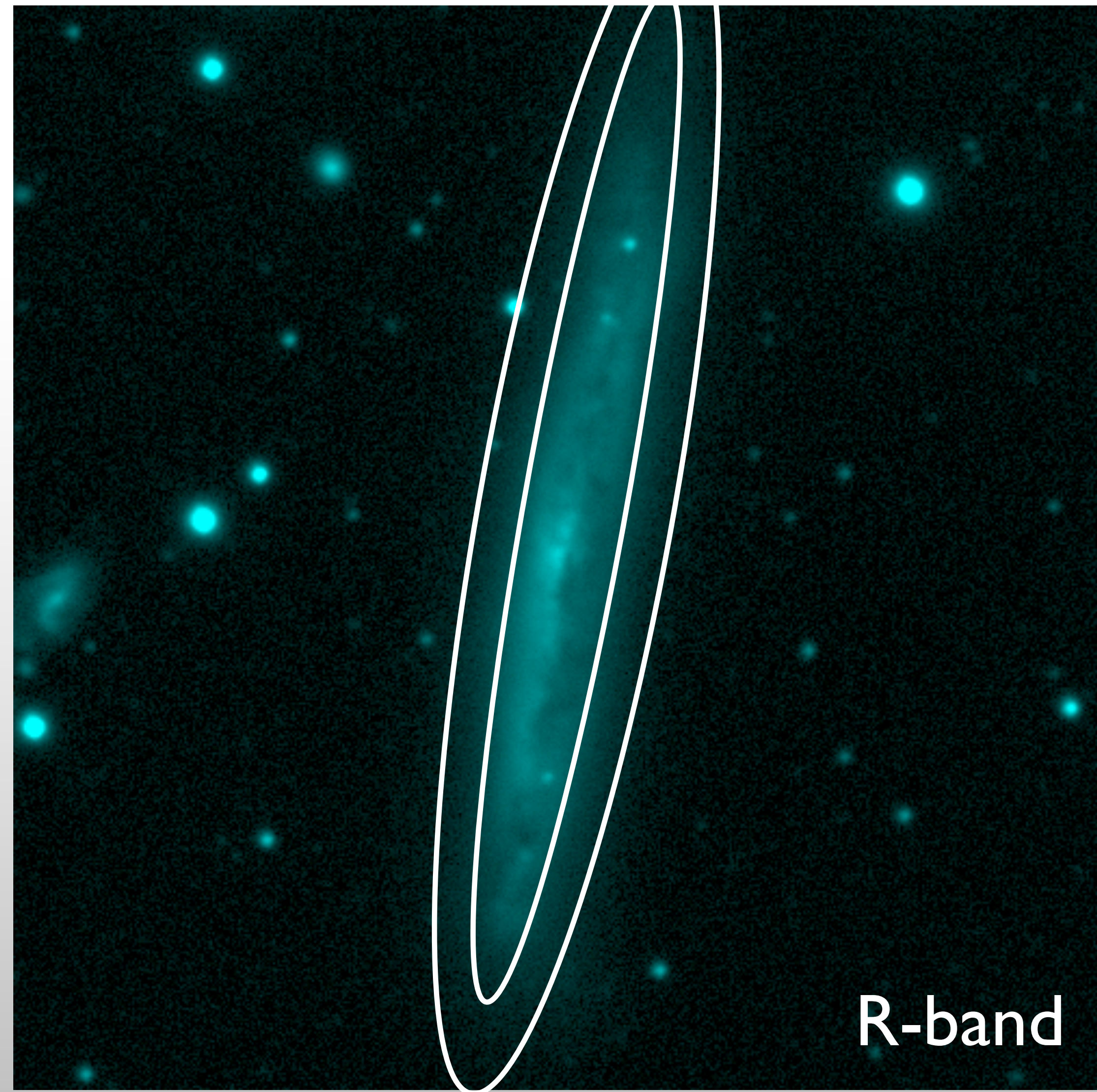


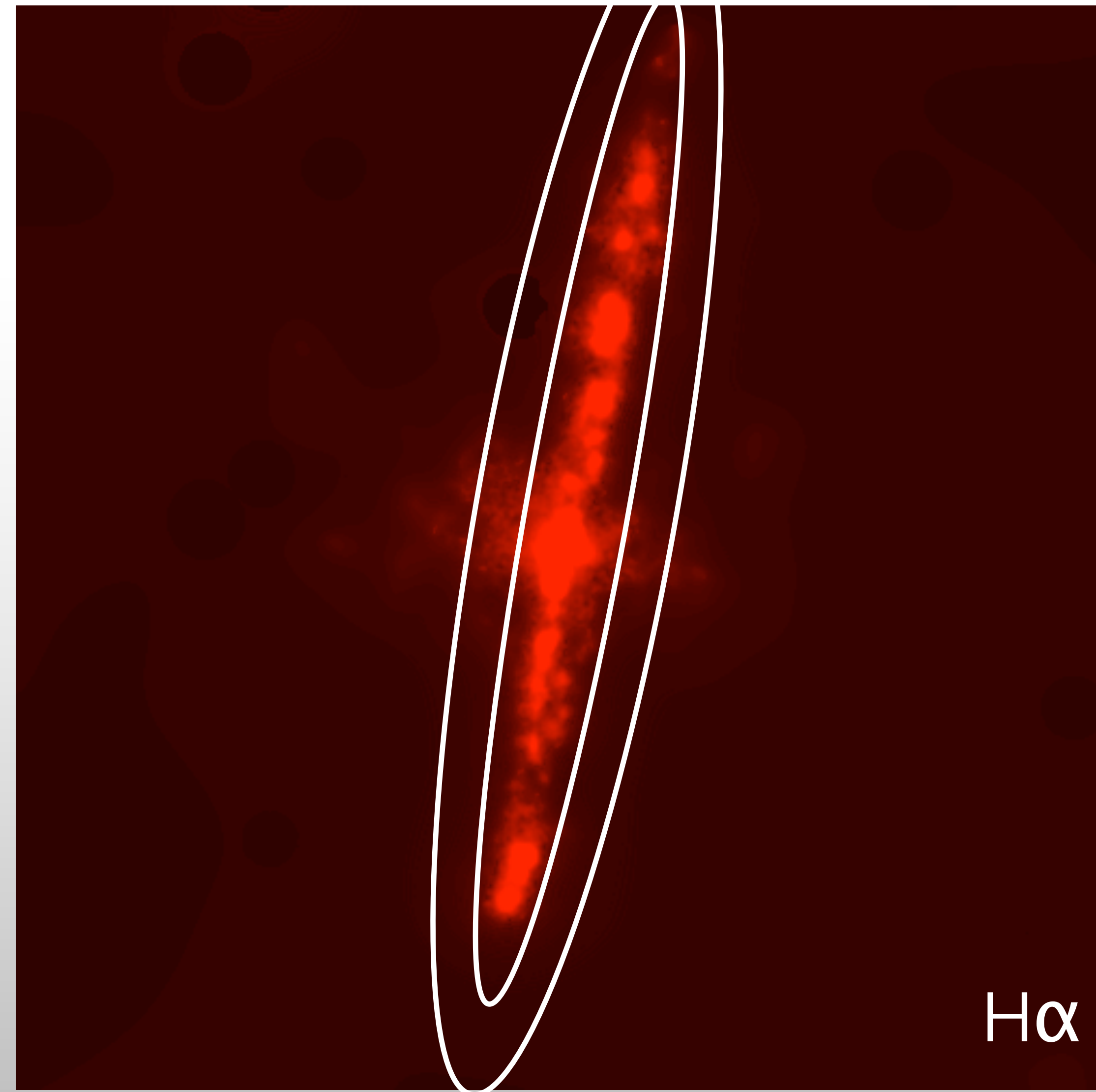
Minor axis "excess" of EPG

- Prediction of theory of starburst-driven outflows: gas should expand preferentially along minor axis.
- Expect emission line morphologies of galaxies to be more extended along minor axes than continuum light.



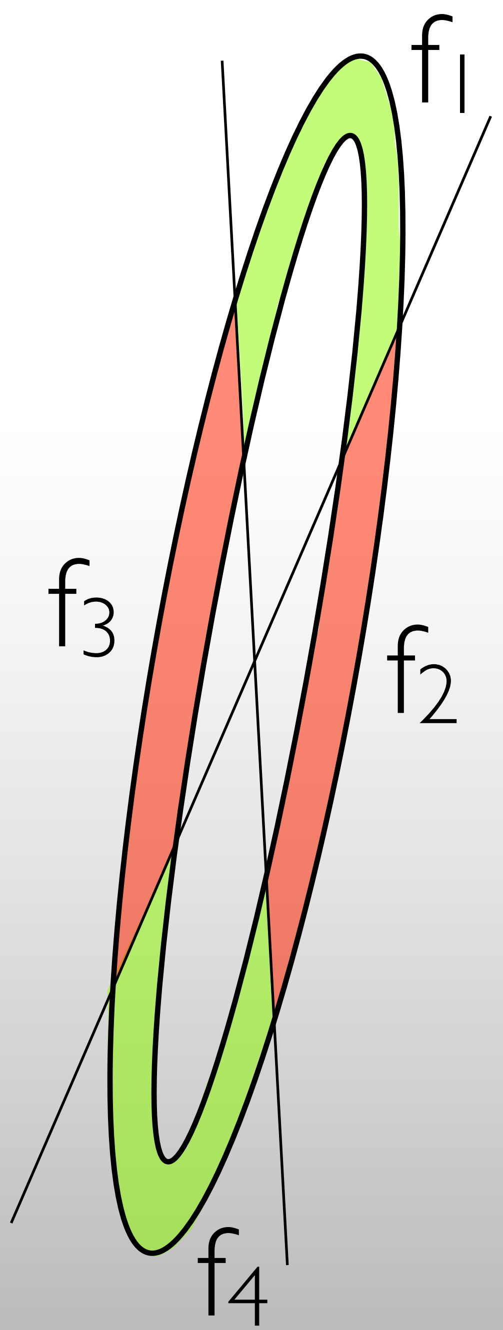
$$Q = \frac{f_2 + f_3}{f_1 + f_4}$$





Minor axis "excess" of EPG

- Statistically, the galaxies with outflows have their extra-planar gas component aligned with the minor axis in a way that is not associated with the normal emission from the tilted galaxy disk.



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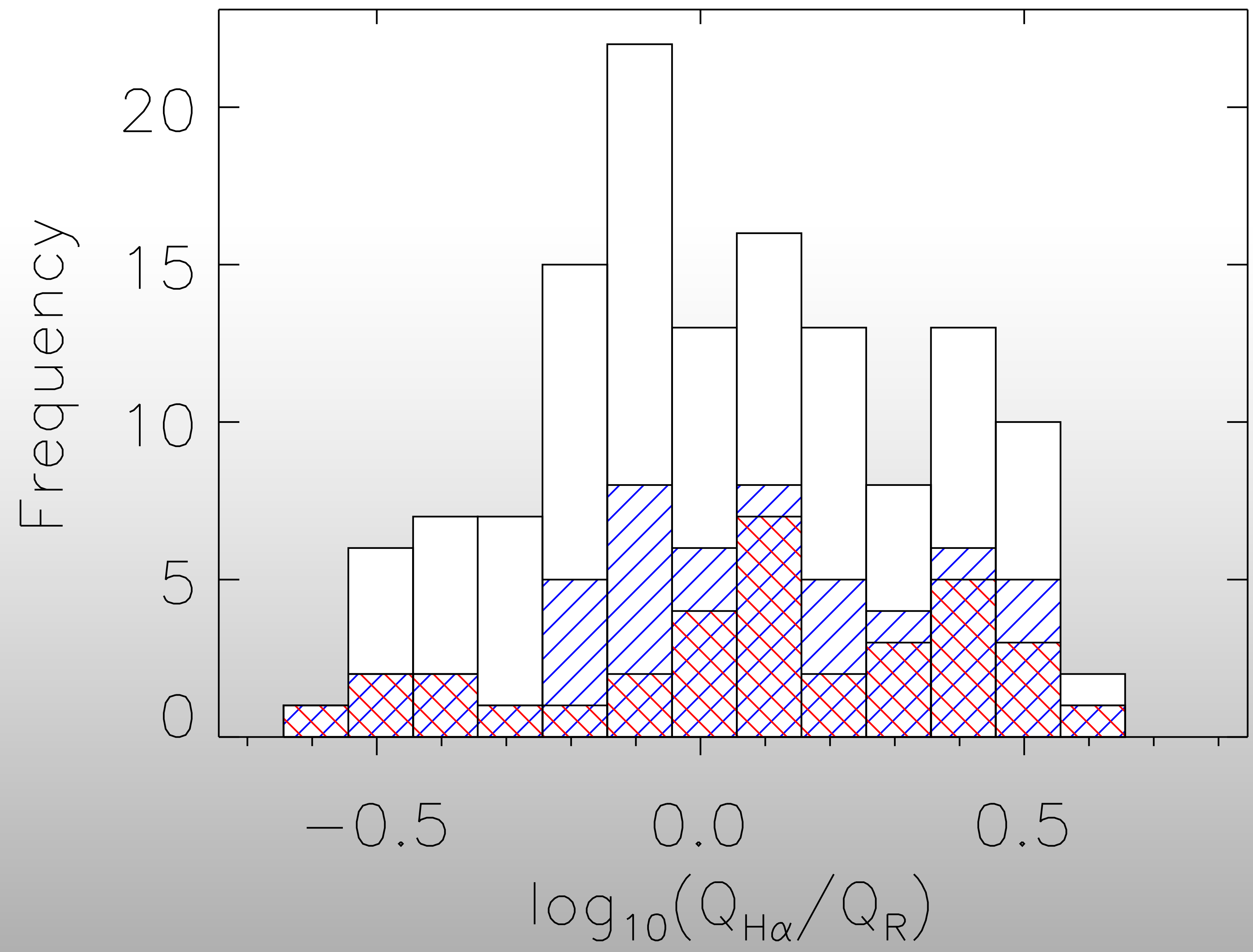
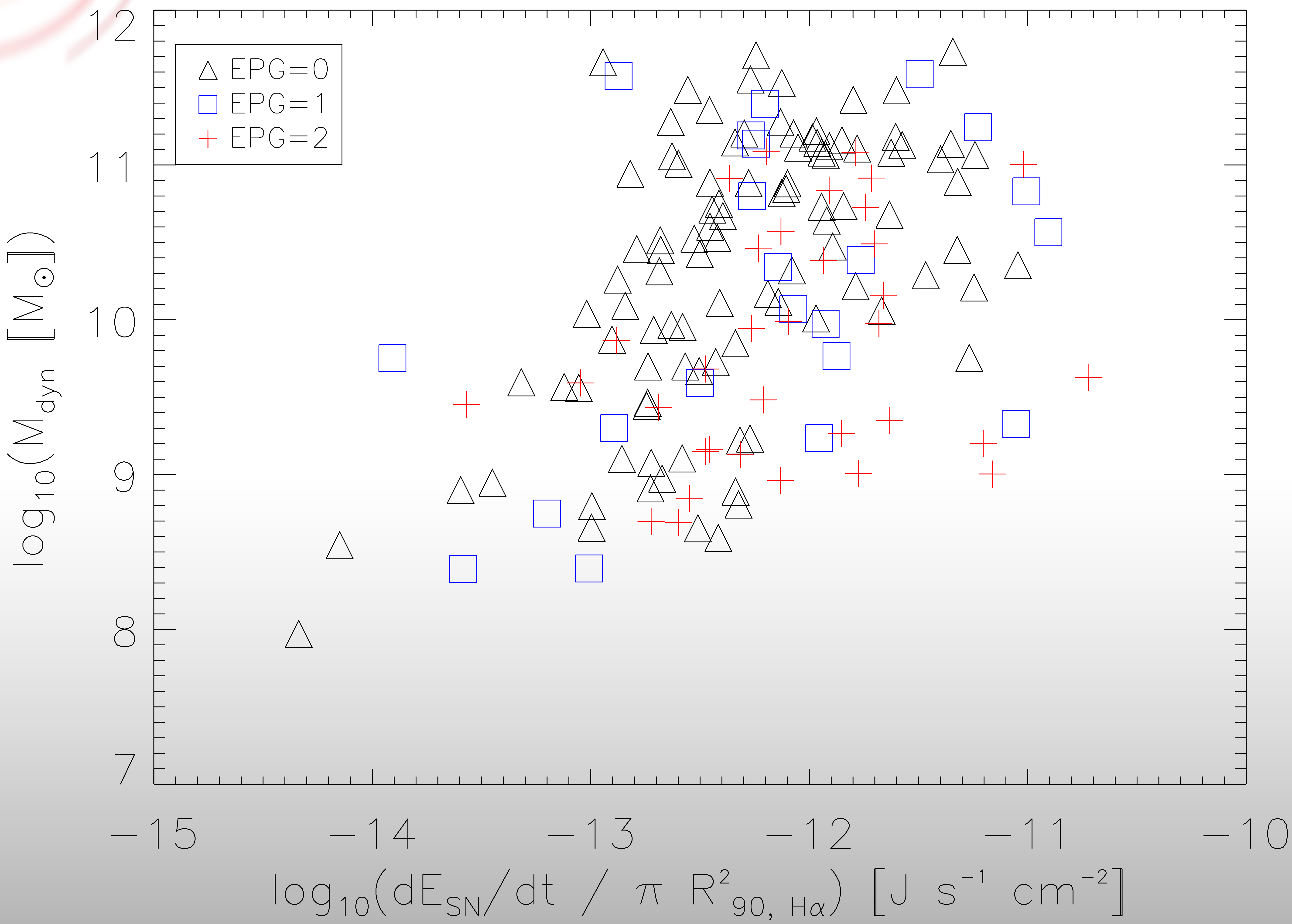


Ejection conditions



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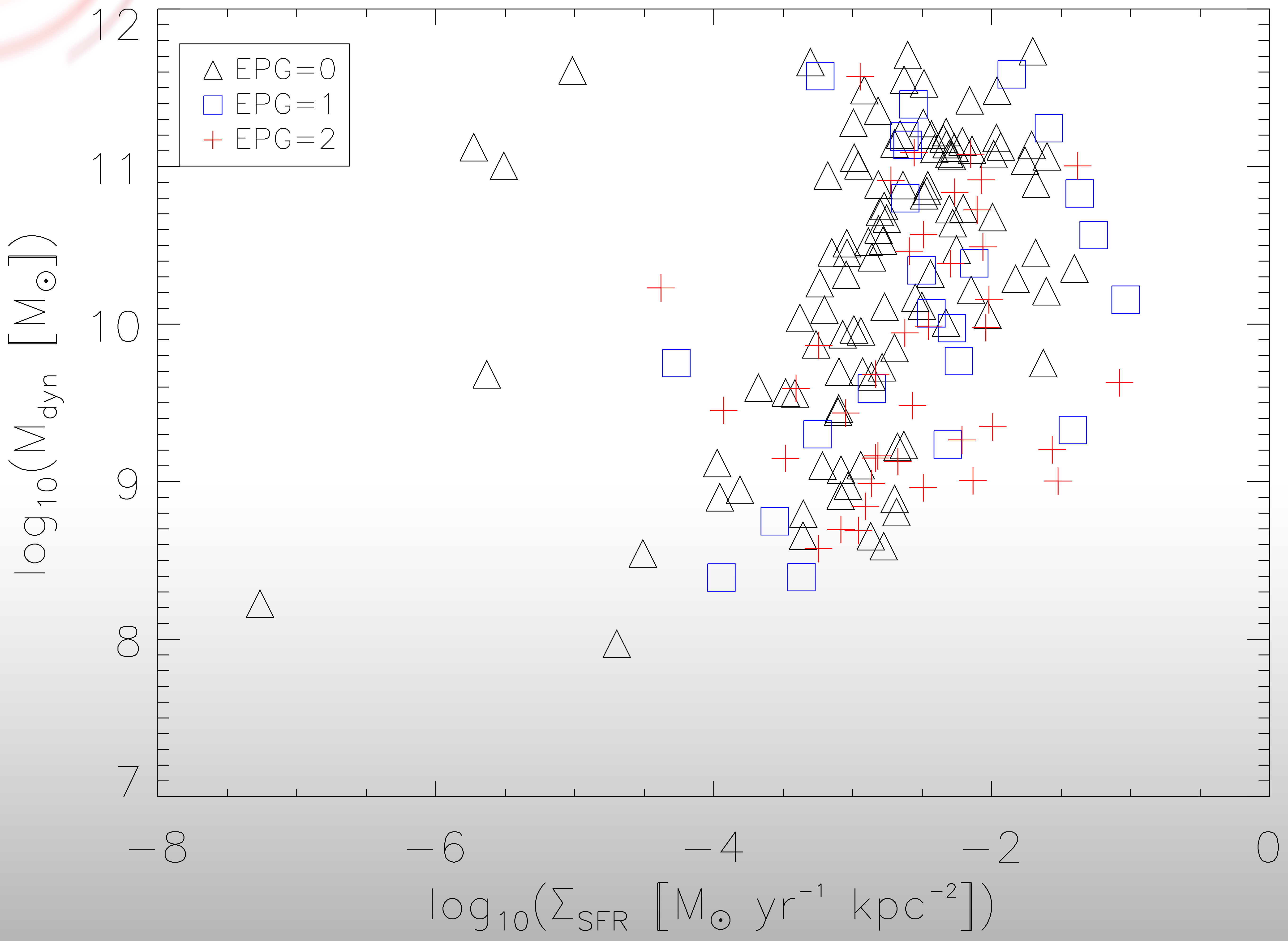

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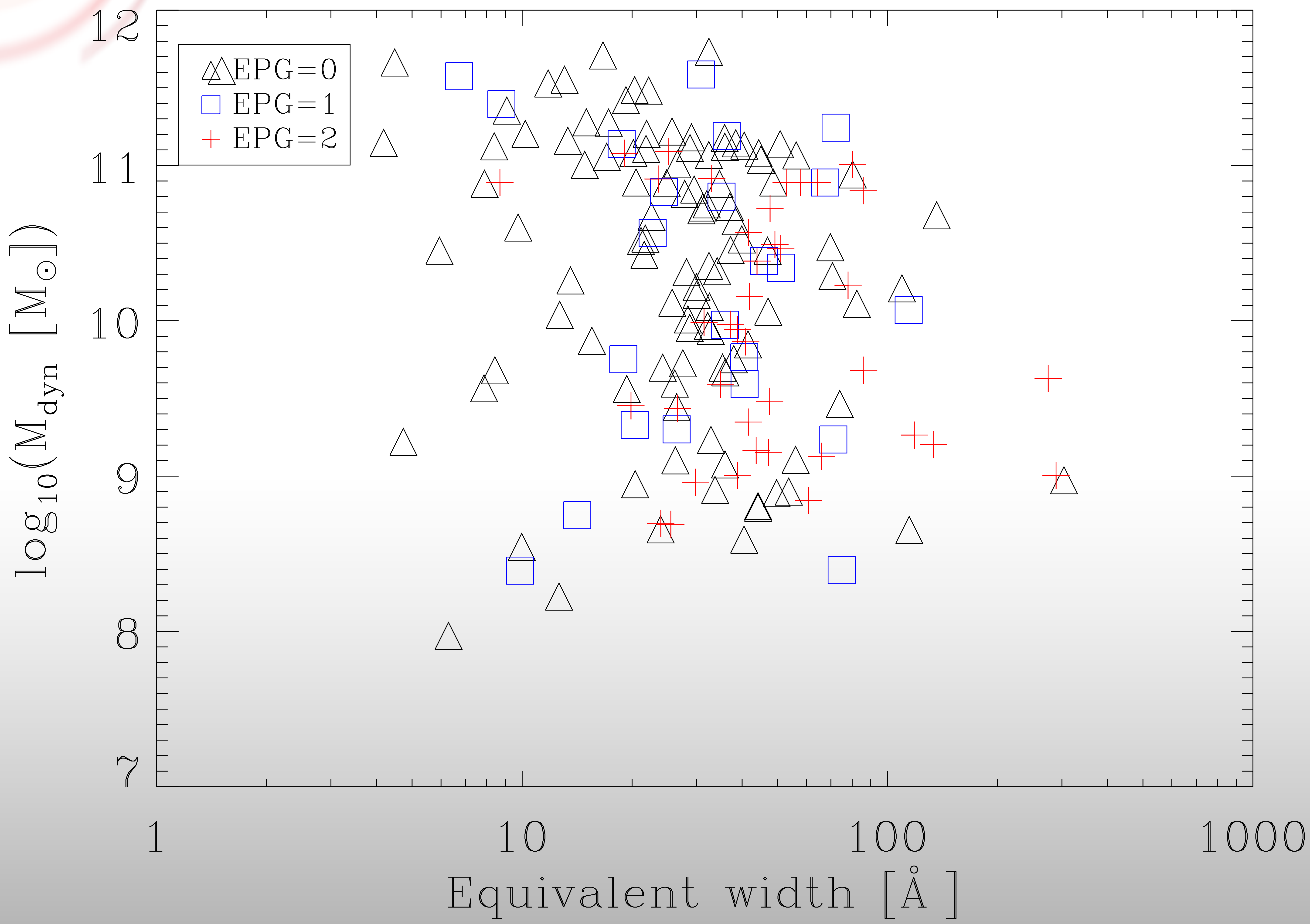

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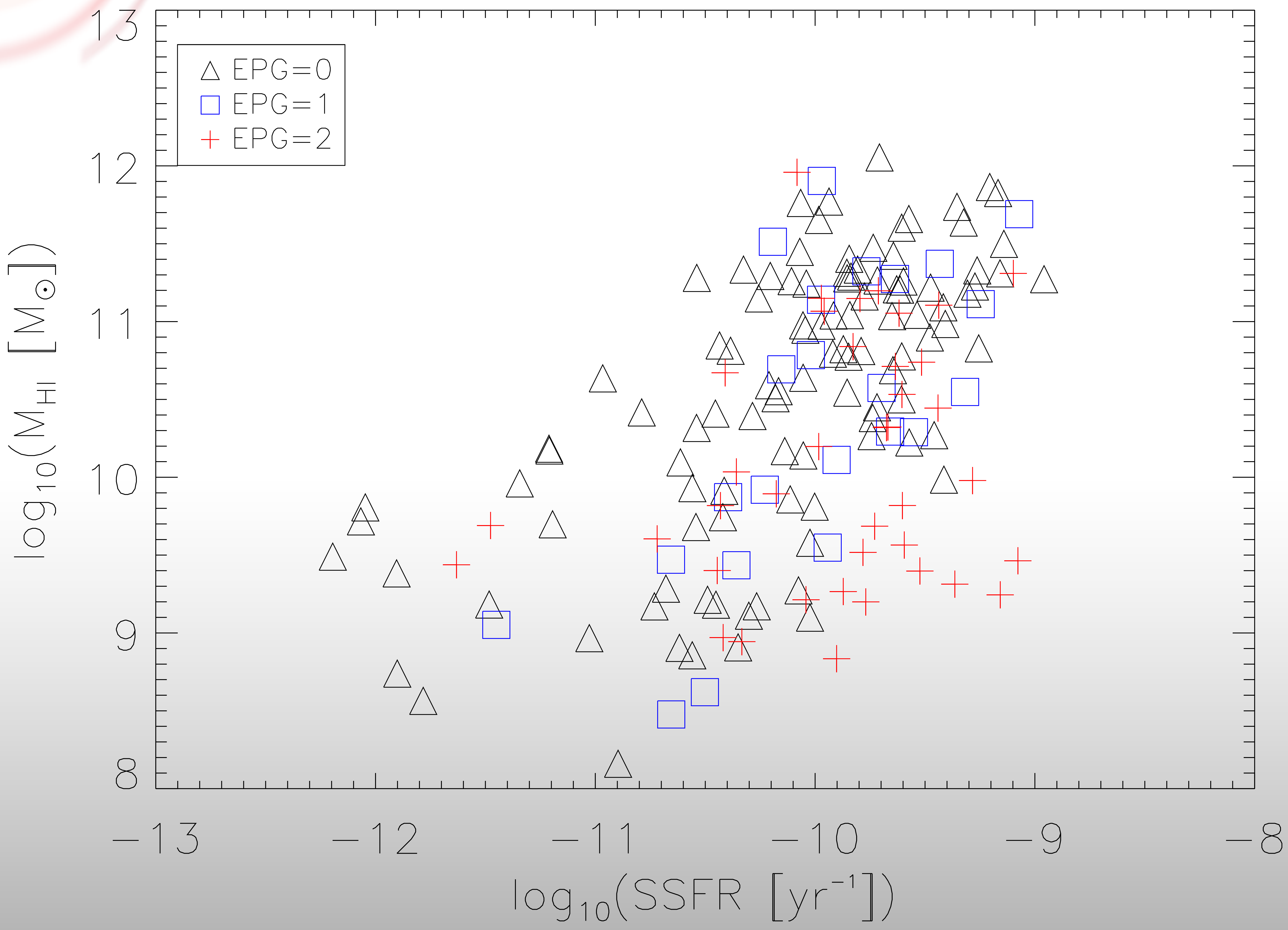

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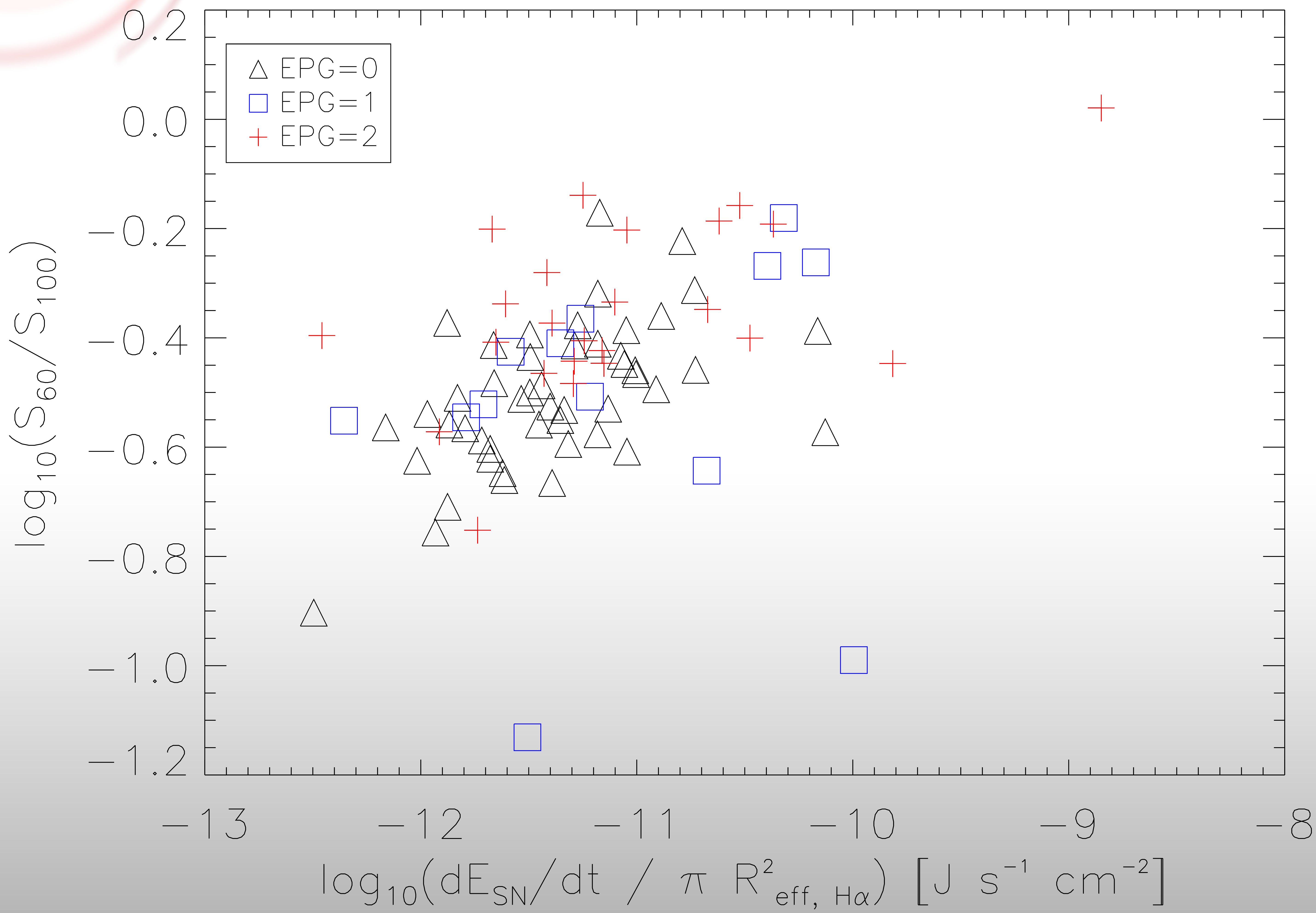

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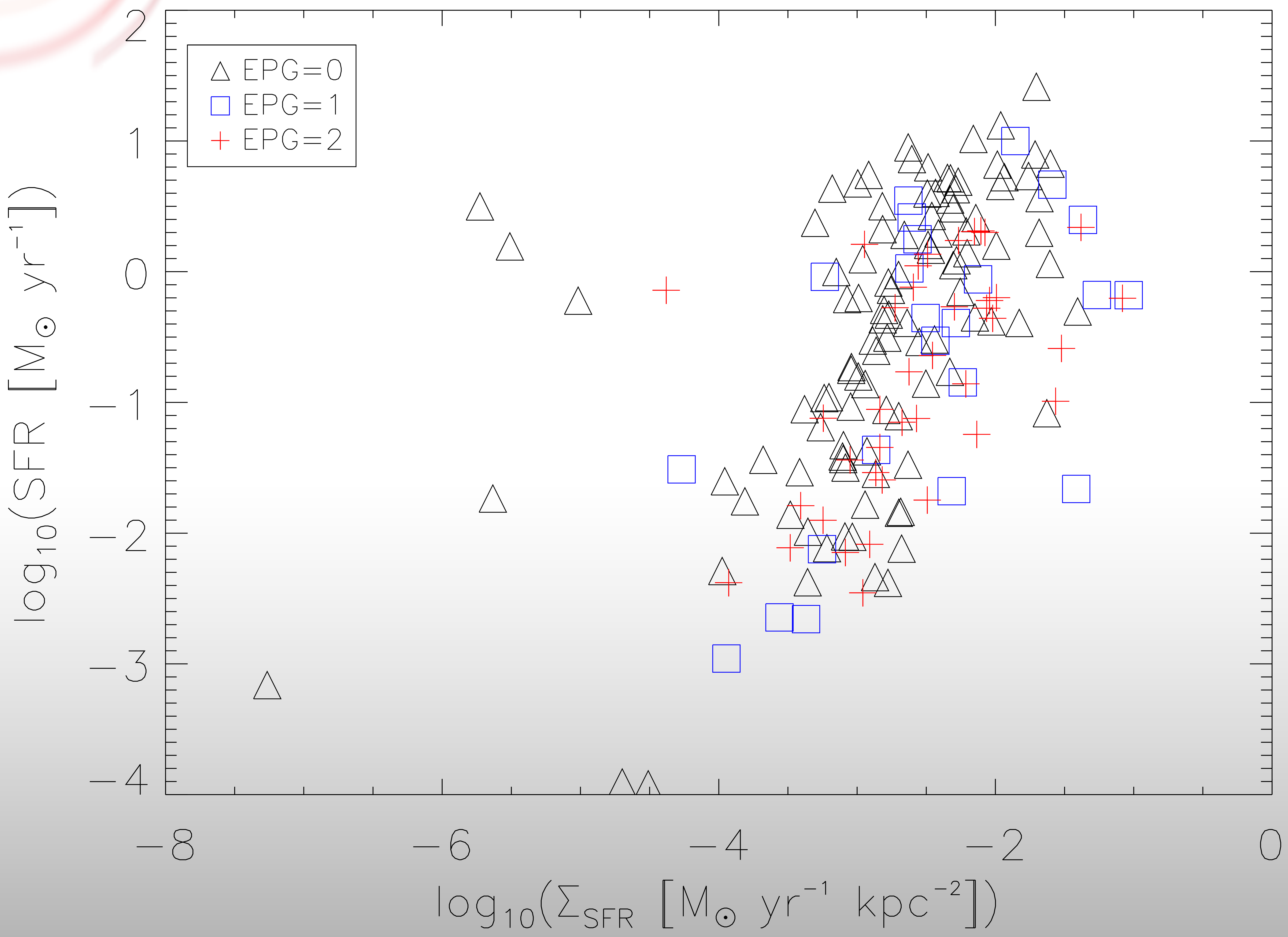

Summary

- We have used Hα and R-band imaging from SINGG to search for galaxies with extra-planar gas.

- Images were adaptively smoothed in order to enhance diffuse Hα emission.

- Ubiquity of EPG: 58/166 galaxies show evidence for EPG, i.e. 35% of all galaxies in our sample.

- All EPG activity classified.

- Started checking dependence of EPG on various global galaxy properties, e.g. EW, T_{gas}, etc.

- Statistically, galaxies with outflows have an extra-planar gas component aligned with the minor axis.

Summary

- Started identifying the physical conditions necessary for feedback, e.g. lower dynamical masses combined with higher energy input rates.

Near-future work

- Assimilate the many results
- Estimates masses of ejected gas
- Estimate rate of chemical enrichment of ISM
- Calculate concentration parameters. EPG=2 more concentrated than EPG=1?
- Parameterise R-band surface brightness profiles
- Classify the morphologies and linear extents of EPG
- Obtain kinematic data for at least some of the galaxies
- Obtain HI line data for some EPG=2 galaxies