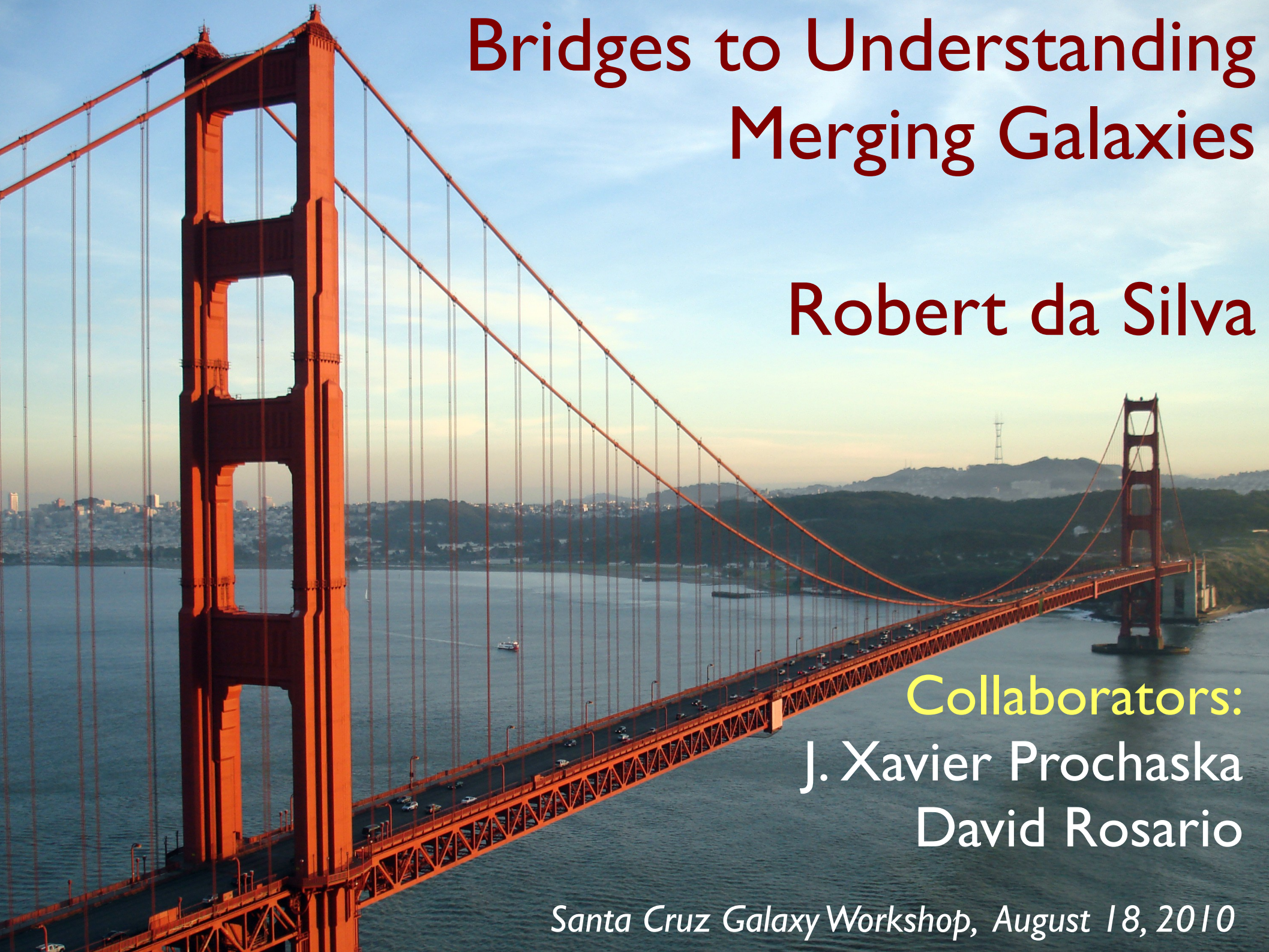
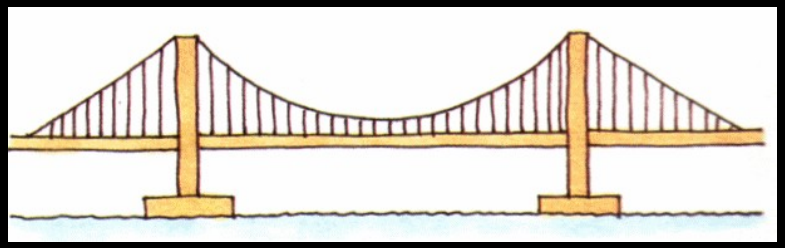


Bridges to Understanding Merging Galaxies

Robert da Silva

Collaborators:
J. Xavier Prochaska
David Rosario

Santa Cruz Galaxy Workshop, August 18, 2010



Theory

Observations

Goals

- To study gas in mergers at high ($z>0.1$) redshift
  -Measure kinematics, column density, volume density and metallicity to later compare with simulations

- To study the triggering of quasars and further evolution

- To study and quantify the quasar sphere of influence
  -how long?
  -how far?
  -how isotropic?

Challenges

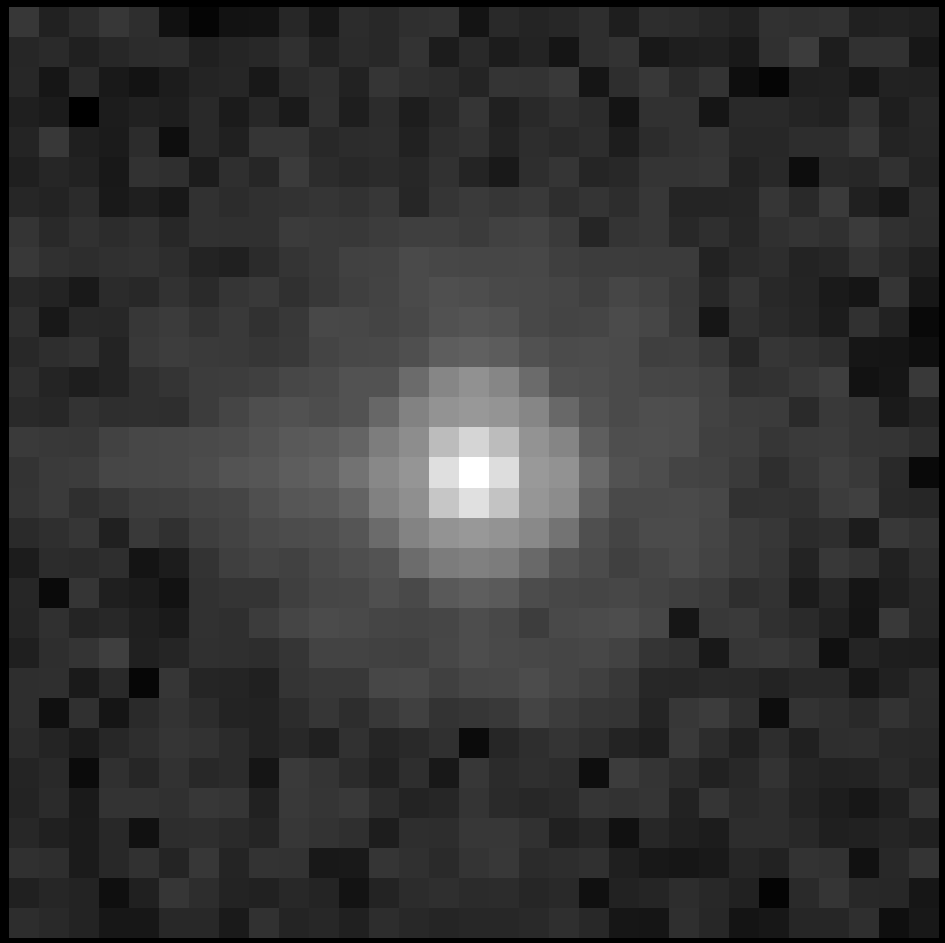
- Faintness of tidal features

Challenges

- Faintness of tidal features
- Unclear merger stage

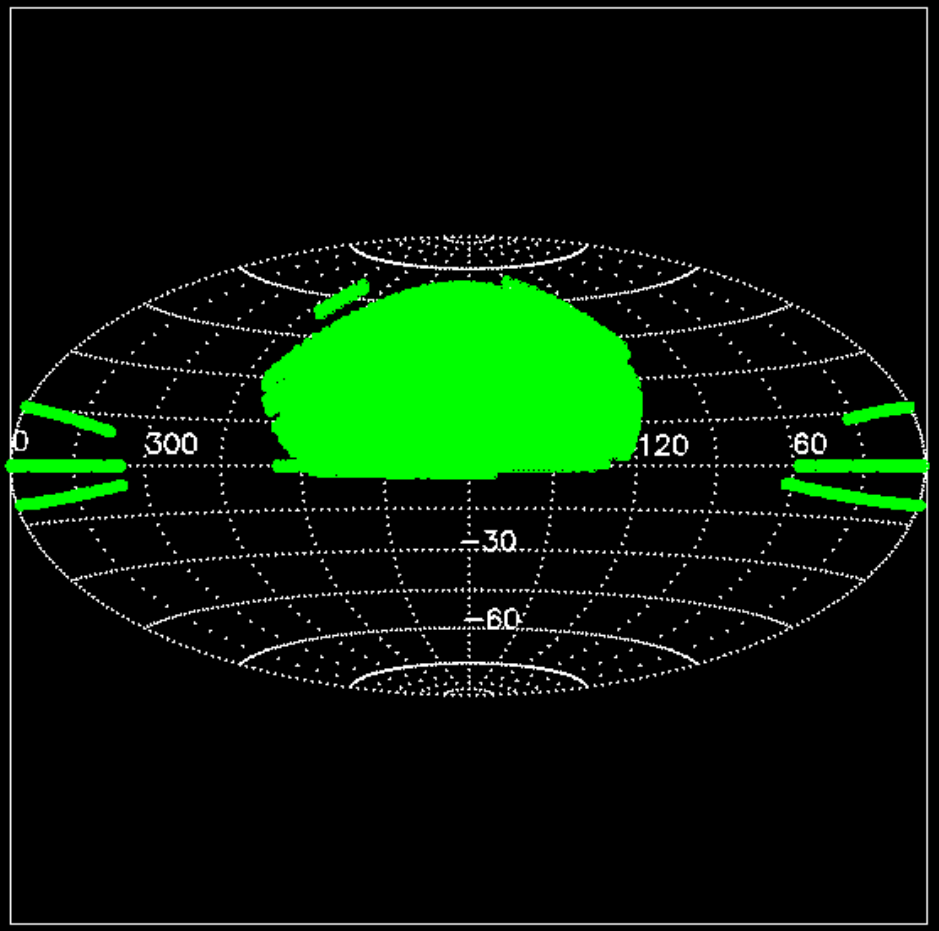
Challenges

- Faintness of tidal features
- Unclear merger stage
- Quasars outshine companion galaxies at high redshift



Challenges

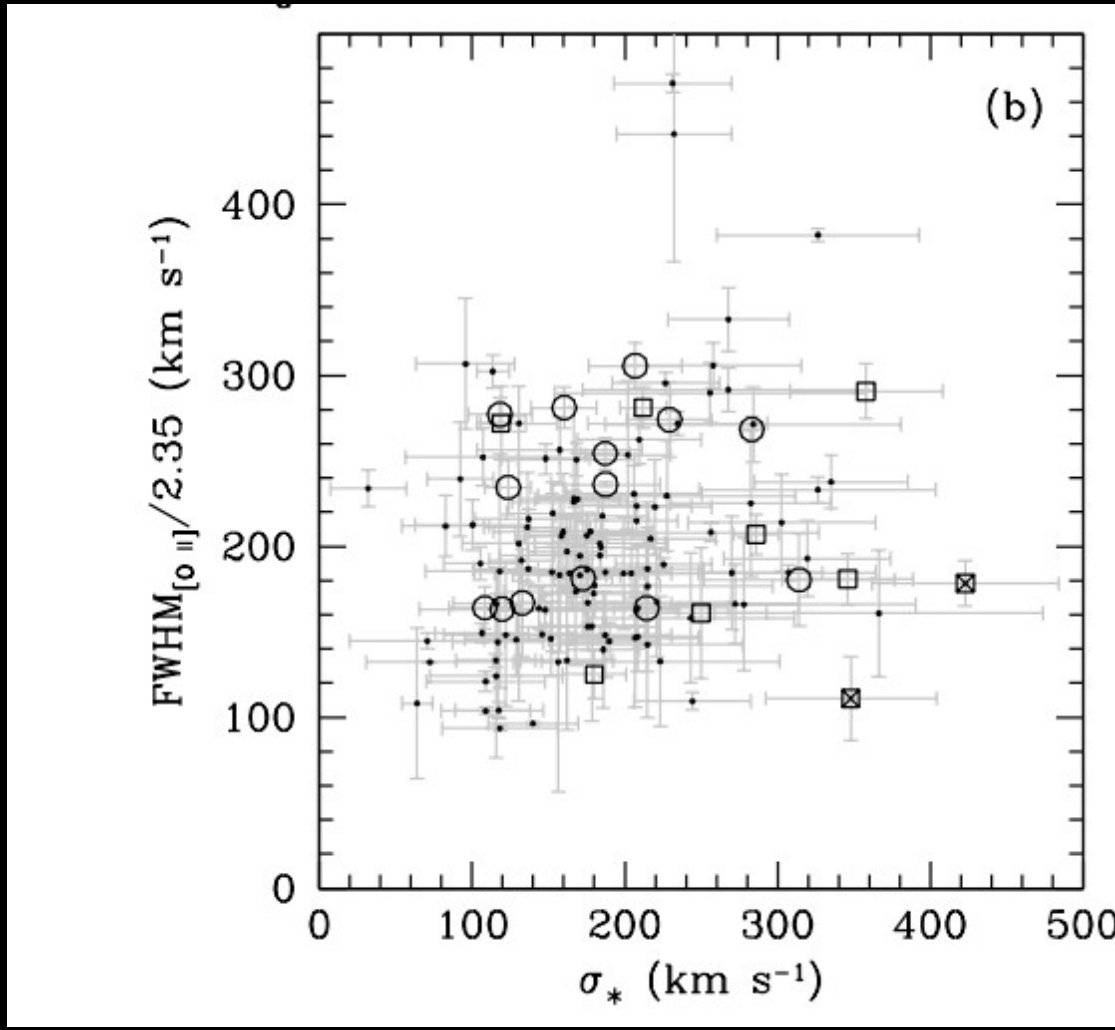
- Faintness of tidal features
- Unclear merger stage
- Quasars outshine companion galaxies at high redshift
- Quasars are relatively rare



SDSS DR7 Spectral Footprint

Challenges

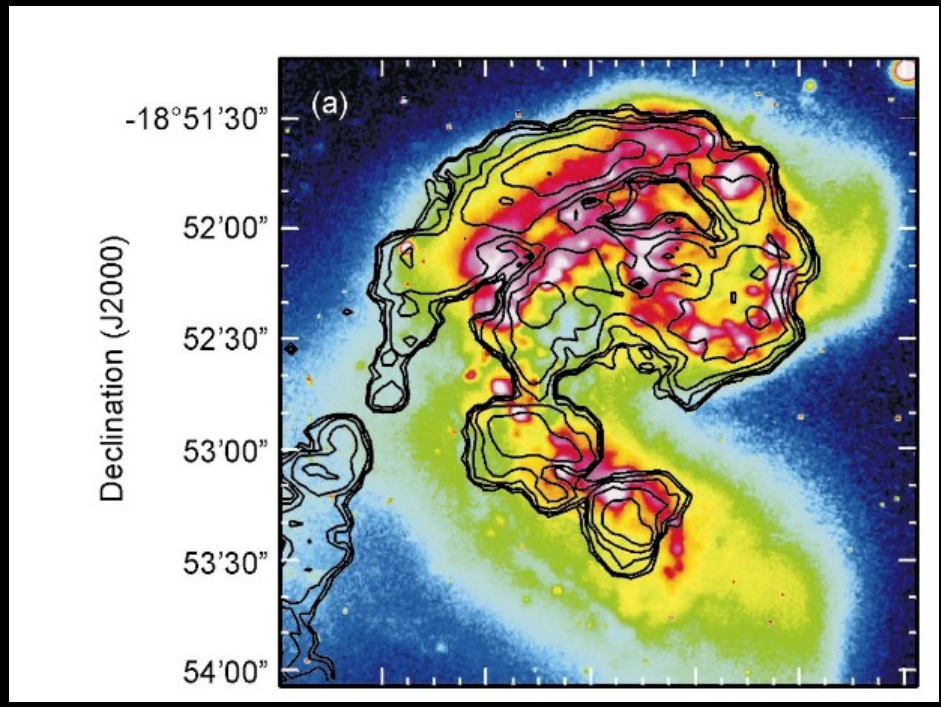
- Faintness of tidal features
- Unclear merger stage
- Quasars outshine companion galaxies at high redshift
- Quasars are relatively rare
- Gas kinematics are not the same as stellar kinematics



Greene et al 2009

Challenges

- Faintness of tidal features
- Unclear merger stage
- Quasars outshine companion galaxies at high redshift
- Quasars are relatively rare
- Gas kinematics are not the same as stellar kinematics
- 21cm is nearly impossible for anything with cosmological redshift (z>0.1)



Hibbard et al 2001

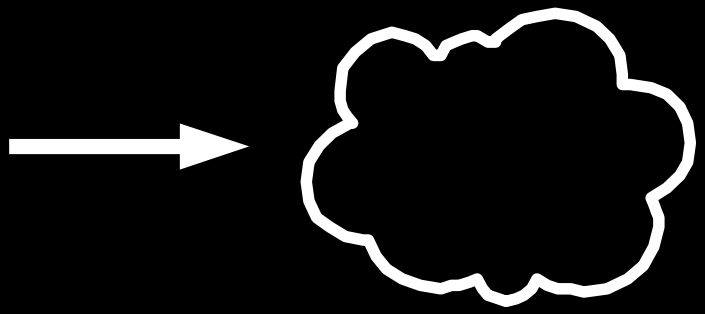
$$S \lesssim 10^{57} s^{-1}$$

$$\frac{S}{S_{O3V}} \sim 10^{7}$$

Quasar emits ionizing photons

$$S \lesssim 10^{57} s^{-1}$$

$$\frac{S}{S_{O3V}} \sim 10^{7}$$

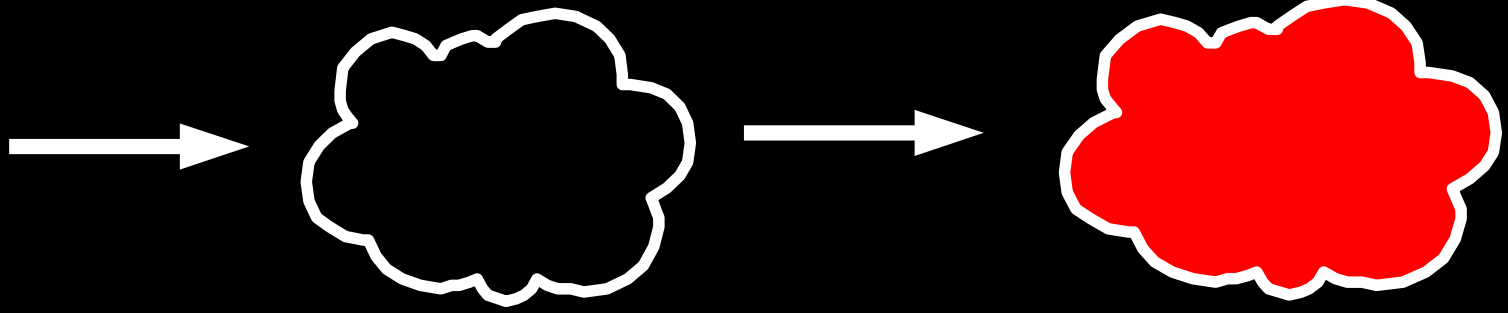


Quasar emits ionizing photons

Invisible Gas absorbs photons, heating and ionizing the gas

$$S \lesssim 10^{57} s^{-1}$$

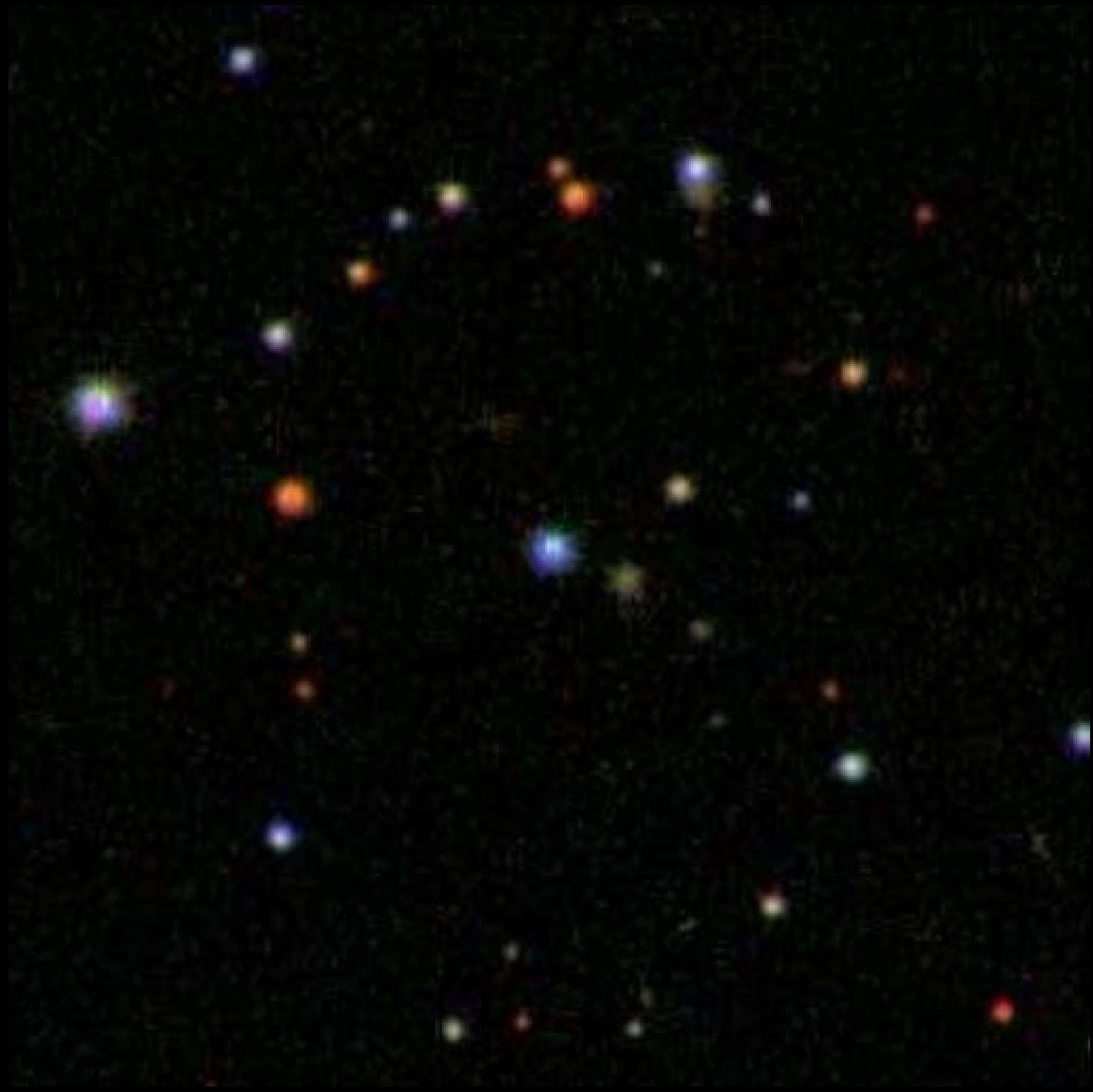
$$\frac{S}{S_{O3V}} \sim 10^{7}$$

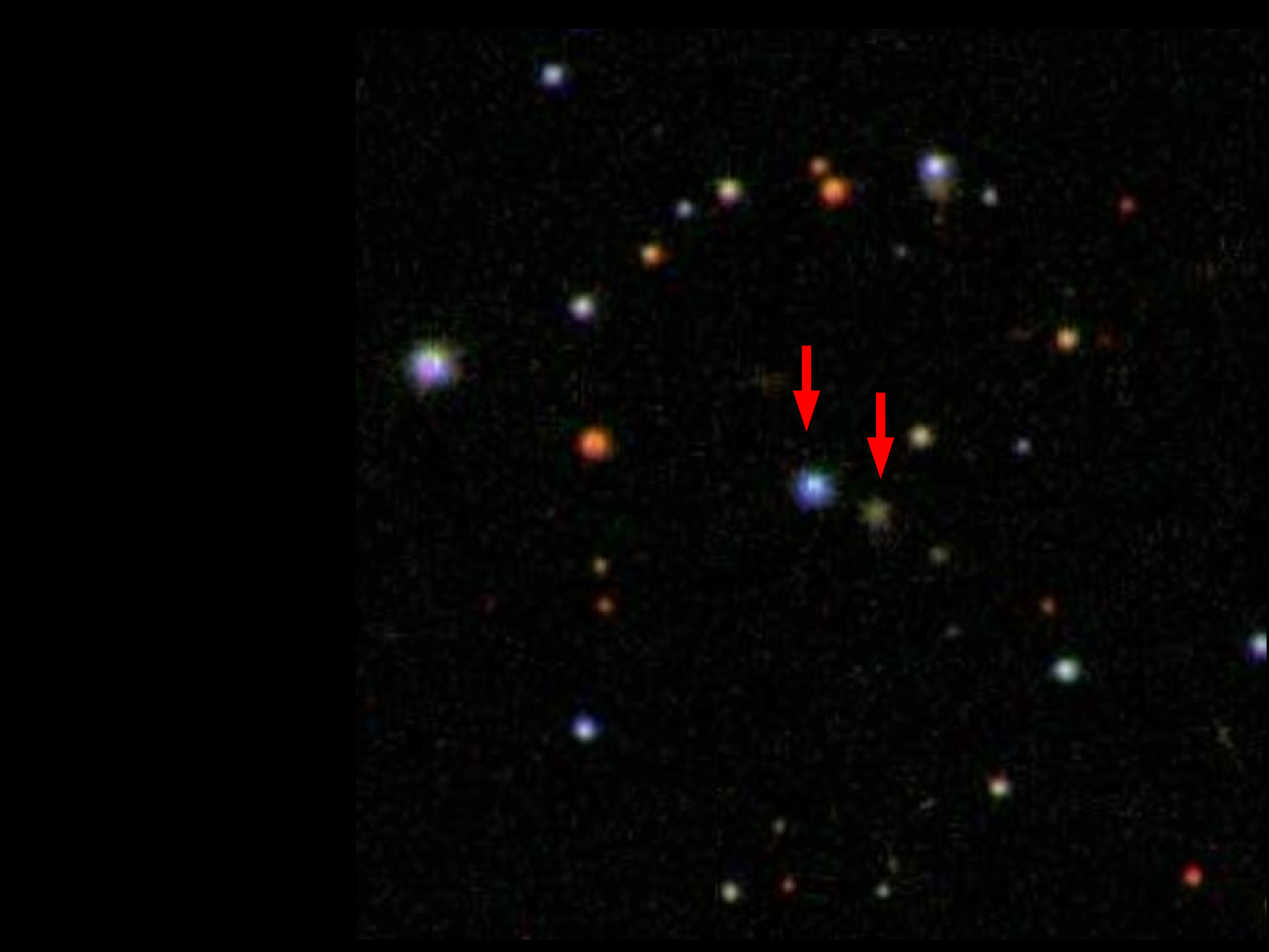


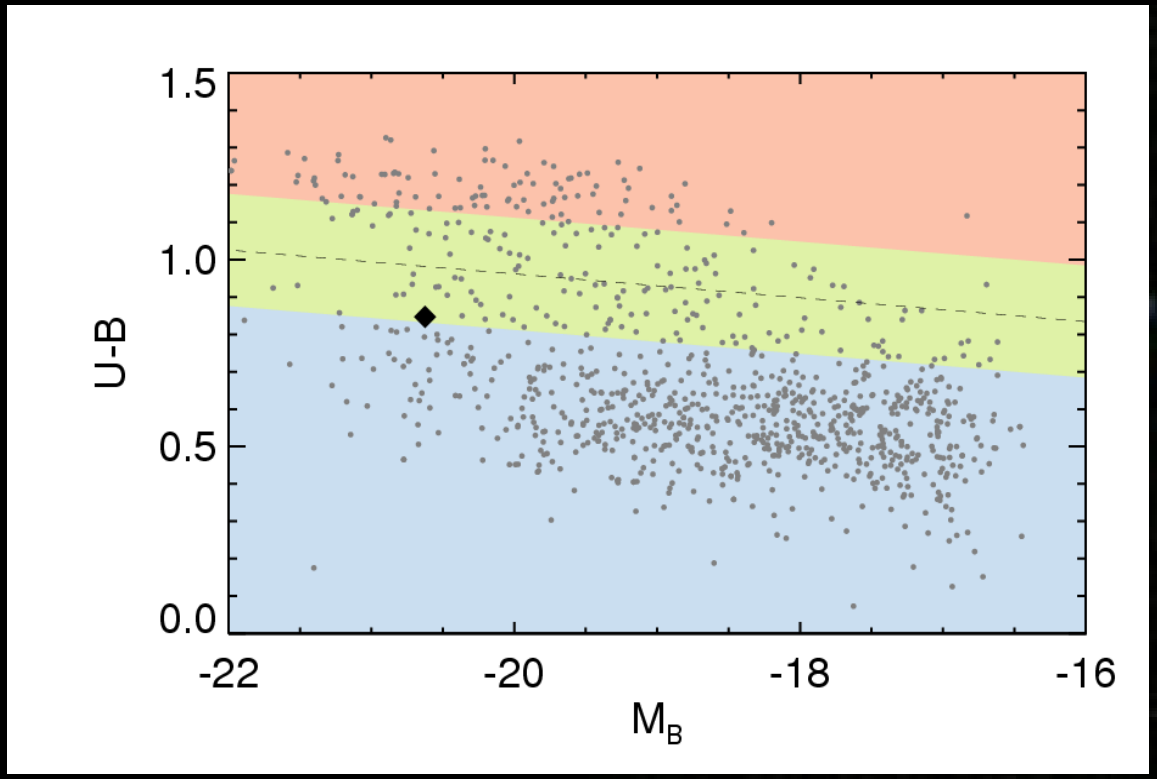
Quasar emits ionizing photons

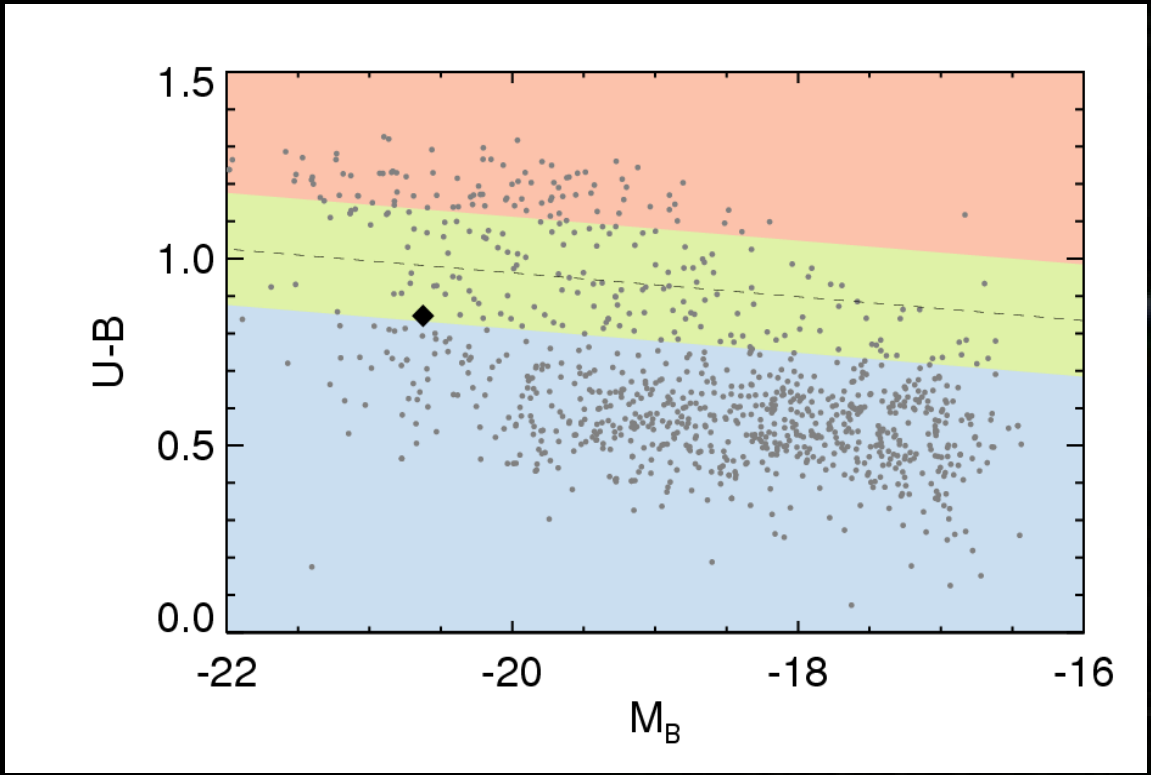
Invisible Gas absorbs photons, heating and ionizing the gas

Recombination and collisionally excited emission lines render the gas observable





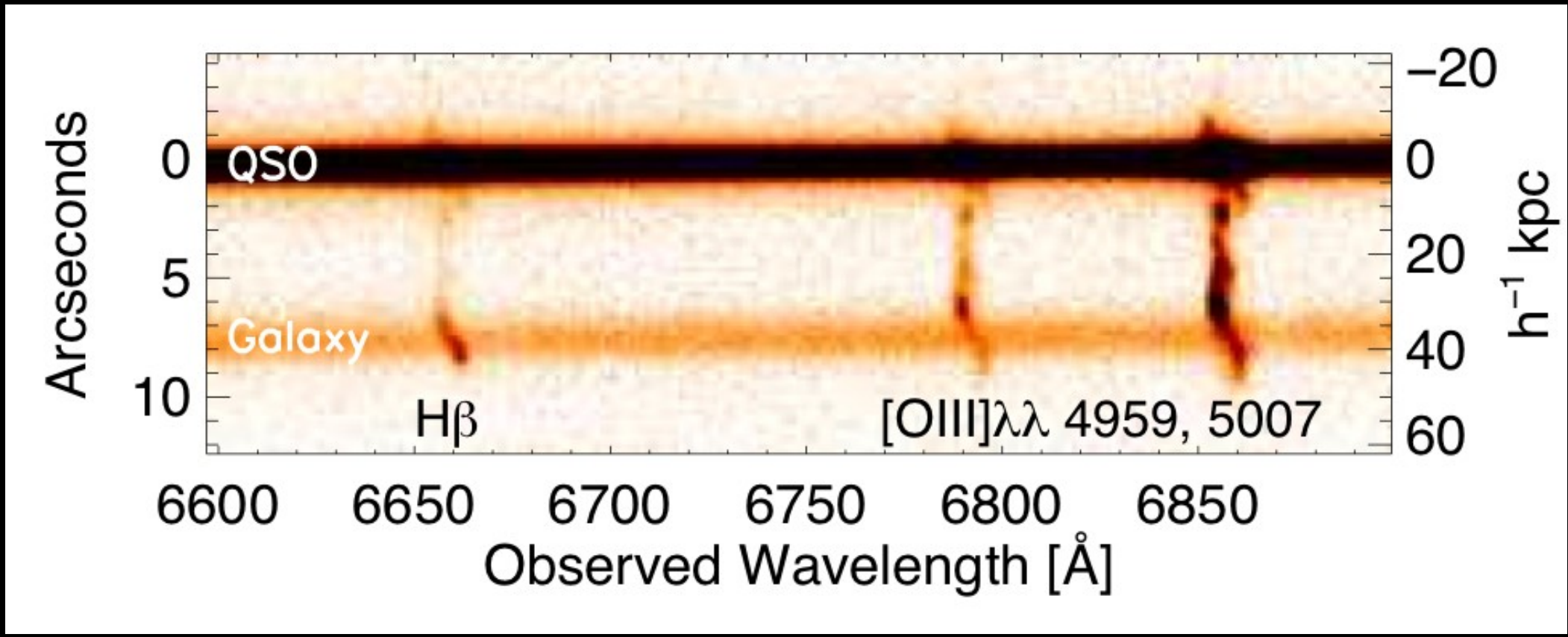

1.5
1.0
0.5
0.0
U-B
-22
-20
-18
-16
M_B

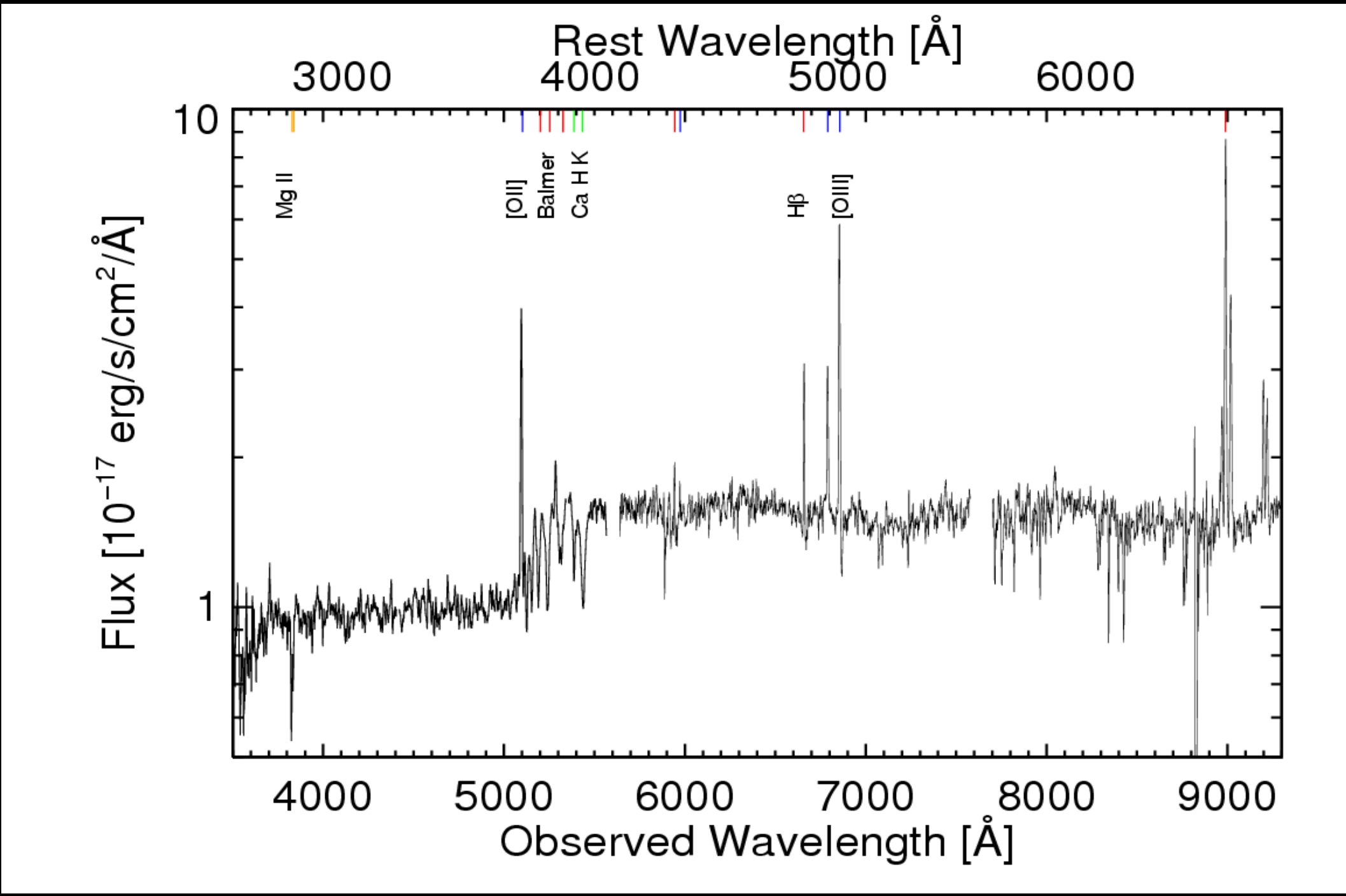

1.5
1.0
0.5
0.0
U-B
-22
-20
-18
-16
M_B

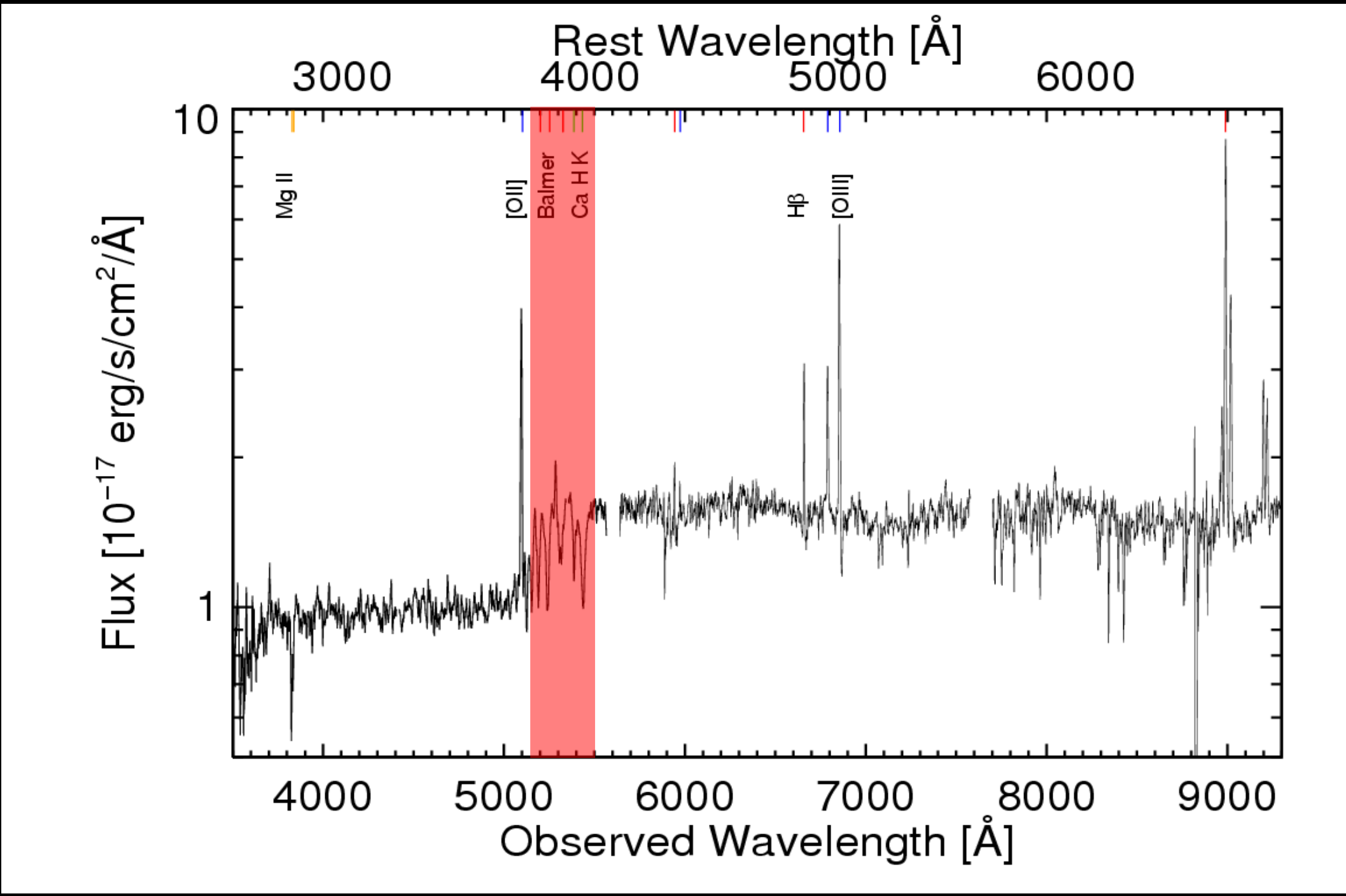
$z = 0.3693$

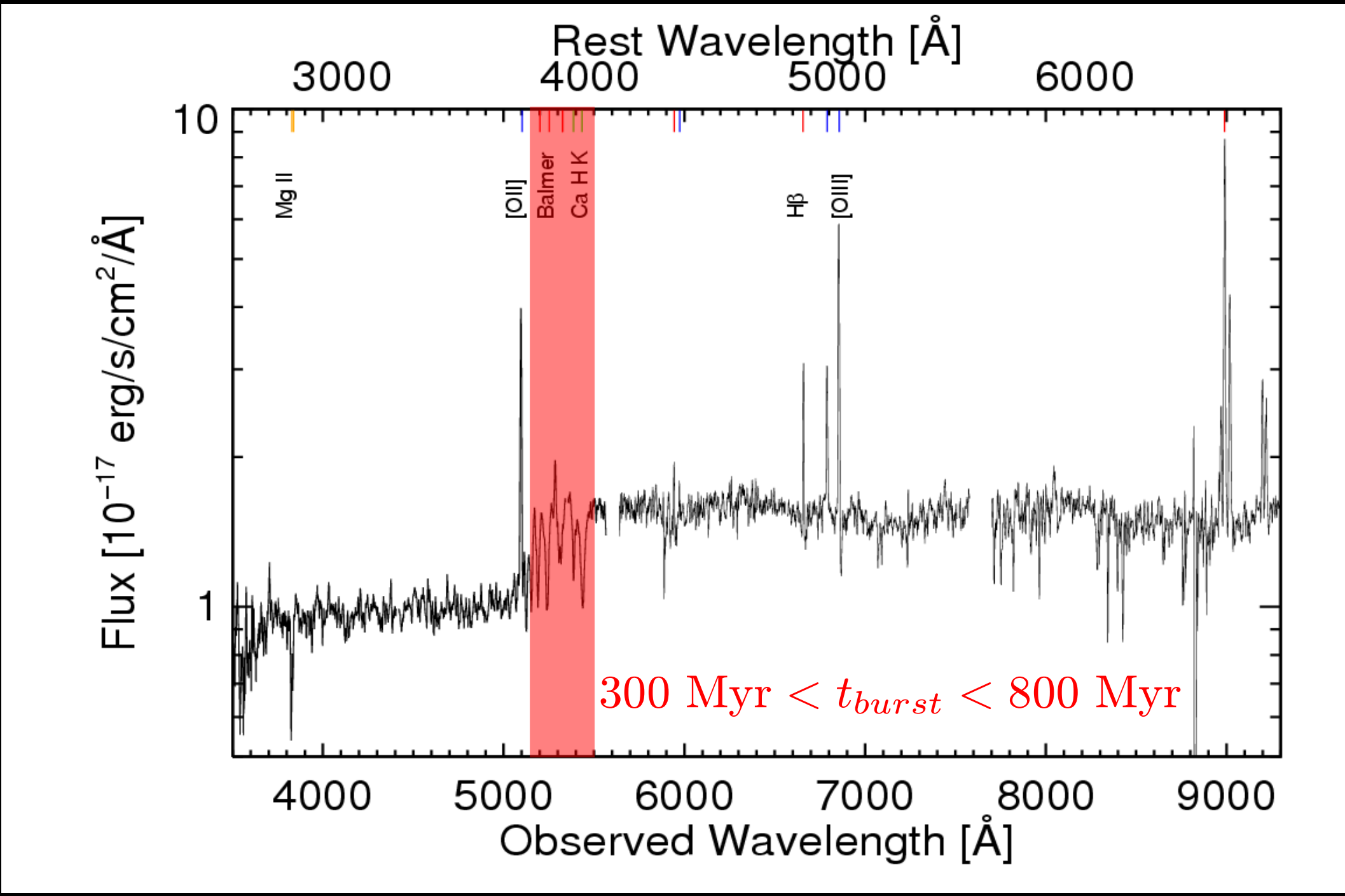
$\Delta v = 159 \pm 20$ km/s

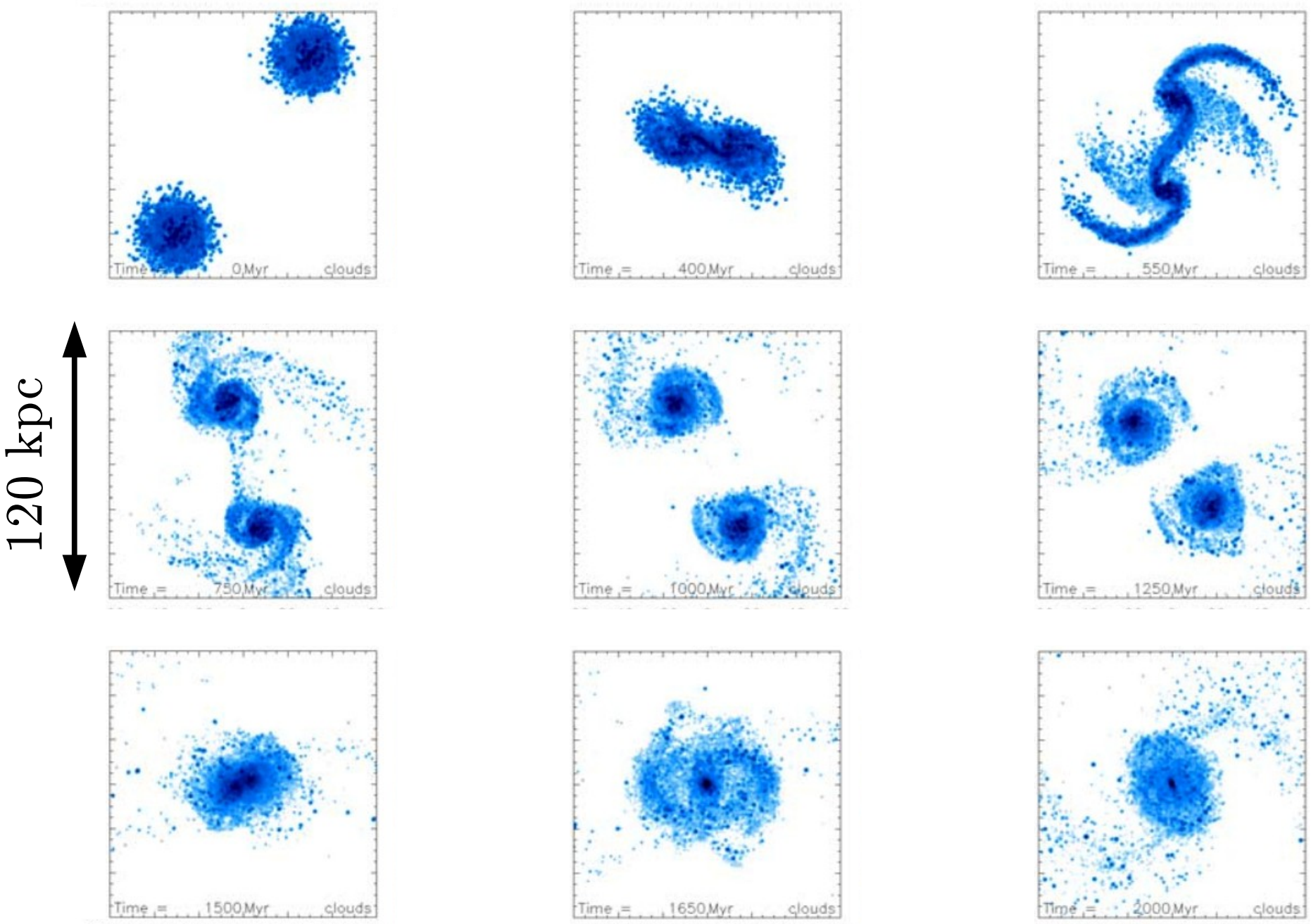
$b = 38$ kpc



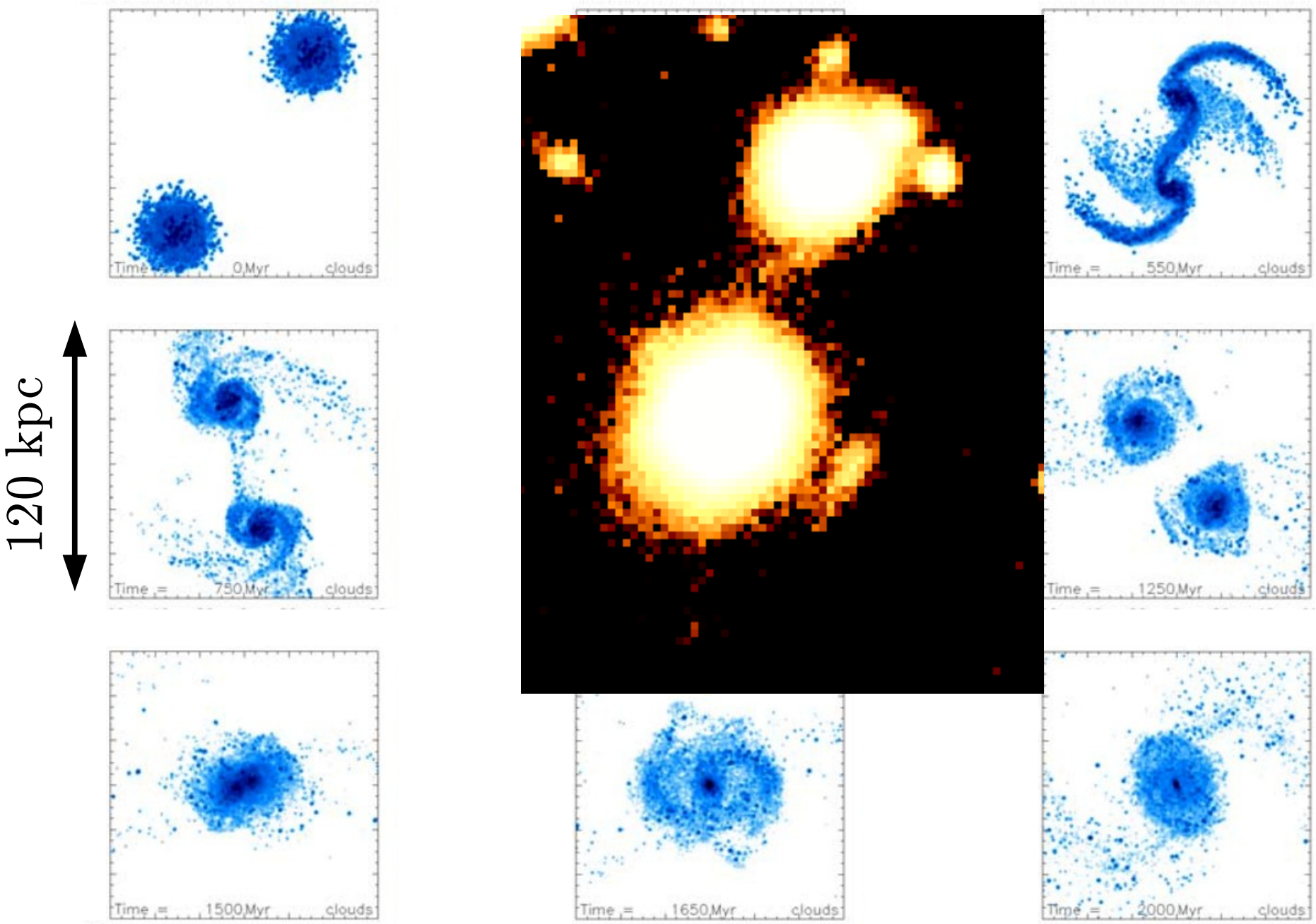

Rest Wavelength [Å]
3000
4000
5000
6000
10
1
Mg II
[OII]
Balmer
Ca H K
Hβ
[OIII]
Flux [10^-17 erg/s/cm^2/Å]
4000
5000
6000
7000
8000
9000
Observed Wavelength [Å]


Rest Wavelength [Å]
3000
4000
5000
6000
10
1
Mg II
[OII]
Balmer
Ca H K
Hβ
[OIII]
Flux [10^-17 erg/s/cm^2/Å]
4000
5000
6000
7000
8000
9000
Observed Wavelength [Å]

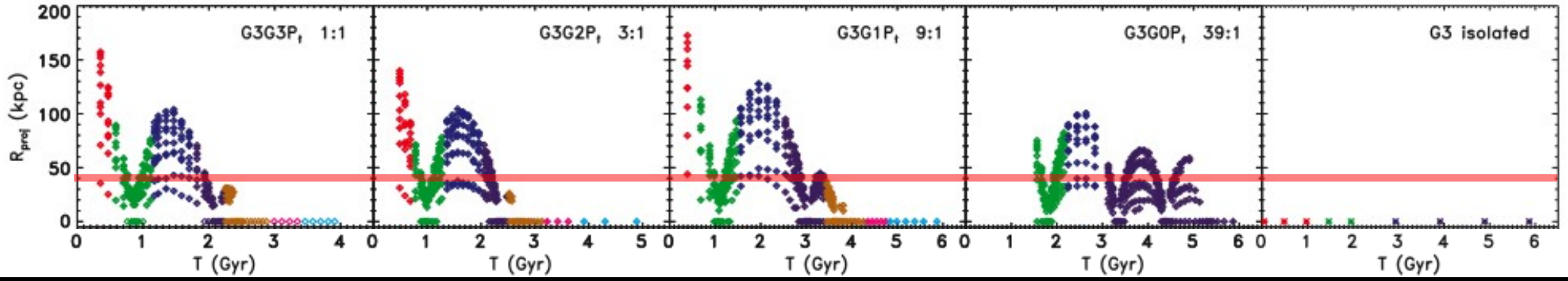

Rest Wavelength [Å]
3000
4000
5000
6000
10
1
Mg II
[OII]
Balmer
Ca H K
Hβ
[OIII]
Flux [10^-17 erg/s/cm^2/Å]
300 Myr < t_burst < 800 Myr
4000
5000
6000
7000
8000
9000
Observed Wavelength [Å]



Weniger+2009



Weniger+2009



Lotz+2010a

Merger Stage

- Before first passage there is no tidal bridge connecting the two galaxies
- Current separation is 38 h^{-1} kpc
- This large separation rules out any merger stage after second passage for any major merger
- This is nearly independent of gas fraction (Lotz+2010b)
- Thus we know the merger stage to be sometime between first and second passage

Well-Characterized Merger System

Quasar

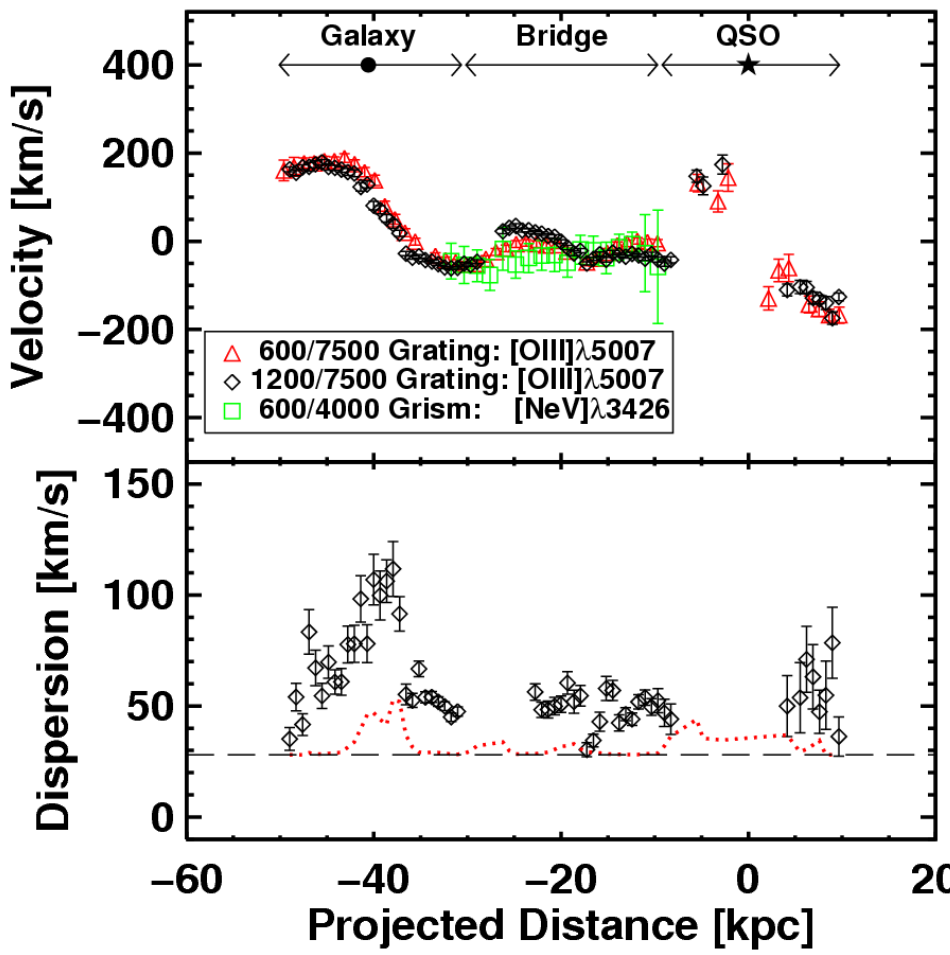
$L_{\rm bol}$	$10^{45.7}$ erg s^{-1} *
M_{BH}	$10^{8.74} M_\odot$ *
$L_{\rm Bol}/L_{\rm Edd}$	0.07 *
Spectral Index	-0.35 ± 0.06
S	$10^{56.5\pm0.1\pm0.4}$ s^{-1}
$\Gamma(H^0)$	$10^{38.4\pm0.05\pm0.4}$ s^{-1} cm^2
M_{DM}	$> 8.8 \times 10^{11} M_\odot$
$t_{\rm QSO}$	$\gtrapprox 8 \times 10^{4\pm0.4} (\mathcal{R}/{\rm kpc})^{-1}$ yr

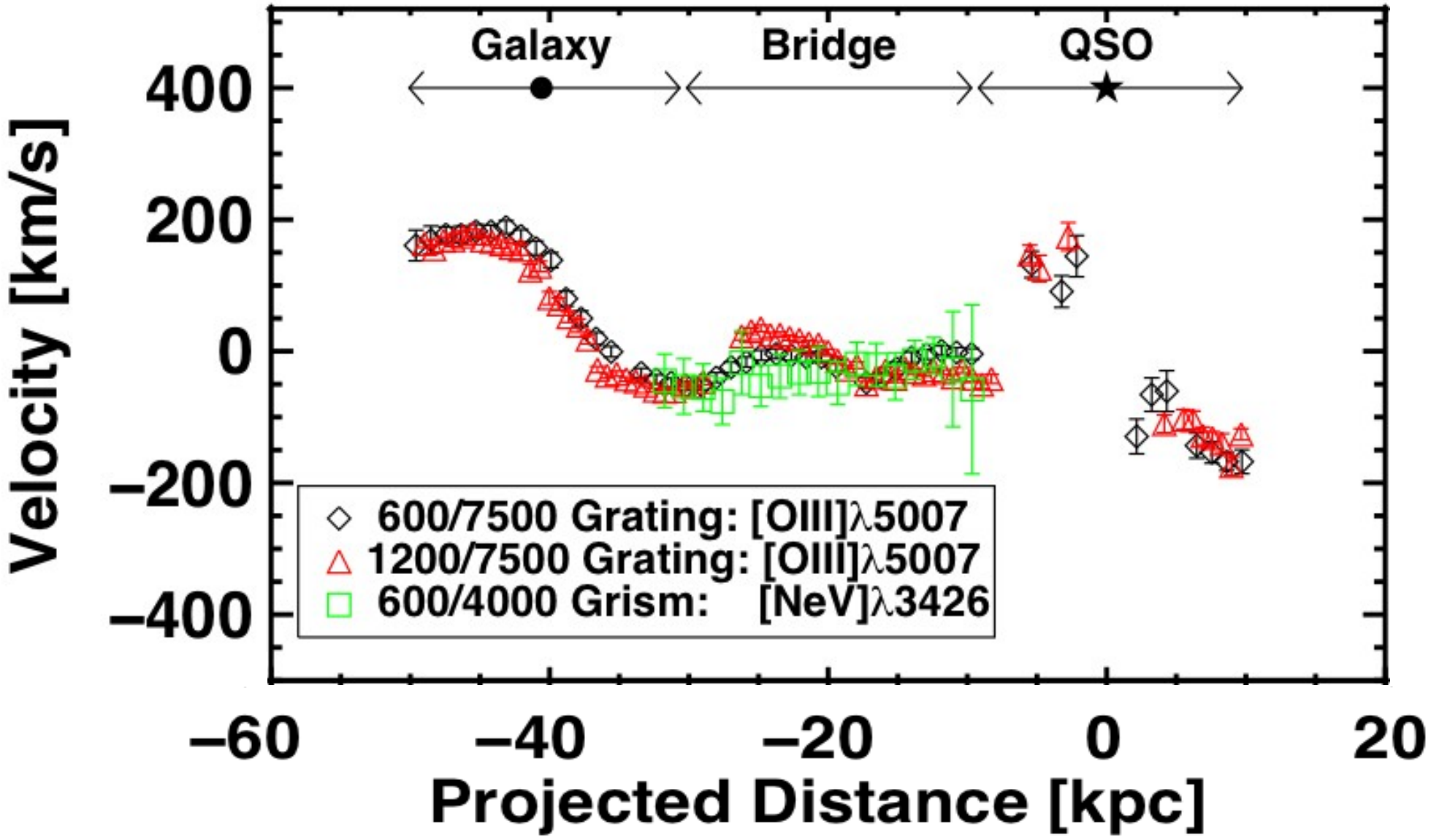
Galaxy

$12 + \log(O/H)$	8.66 ± 0.1**
SFR	$1.78 \pm 0.04\ M_\odot$ yr^{-1}
$t_{\rm burst}$	300-800 Myr
M_{DM}	$> 2.1 \times 10^{11} M_\odot$

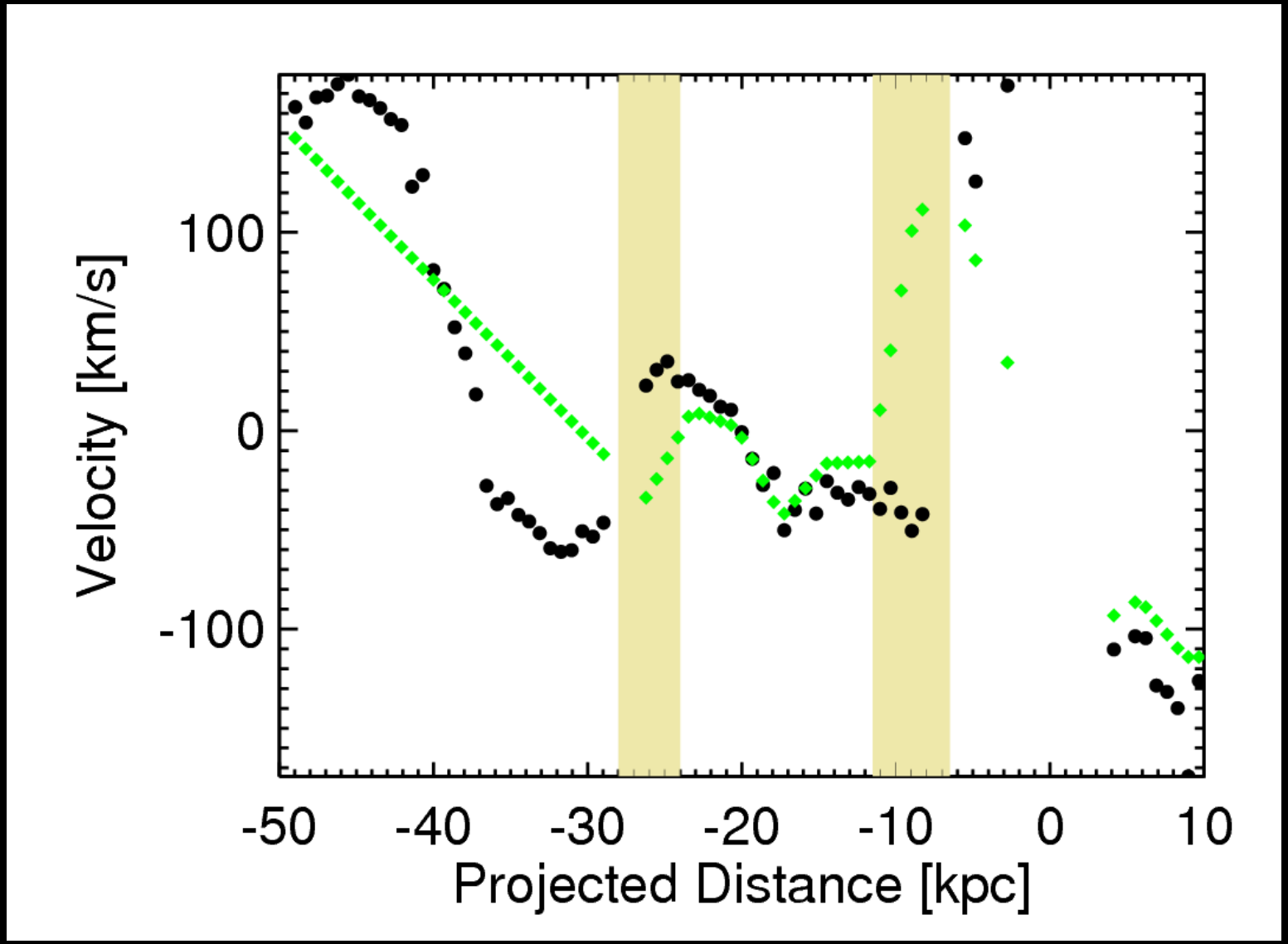
Bridge

Kinematics	(see plot)
$M_{\rm bridge}$	$\approx 3(\mathcal{R}/{\rm kpc})^{-1} 10^8 M_\odot$
$\log U$	$-2.425^{+0.024}_{-0.012} \pm 0.05$
$N_{H,Obs}$	$\approx 10^{21}$ cm^{-2}
$N_{H,QSO}$	$\approx (r/\mathcal{R}) 10^{21}$ cm^{-2}
n	$\gtrapprox 0.1$ cm^{-3}
T	$< 7 \times 10^4$ K



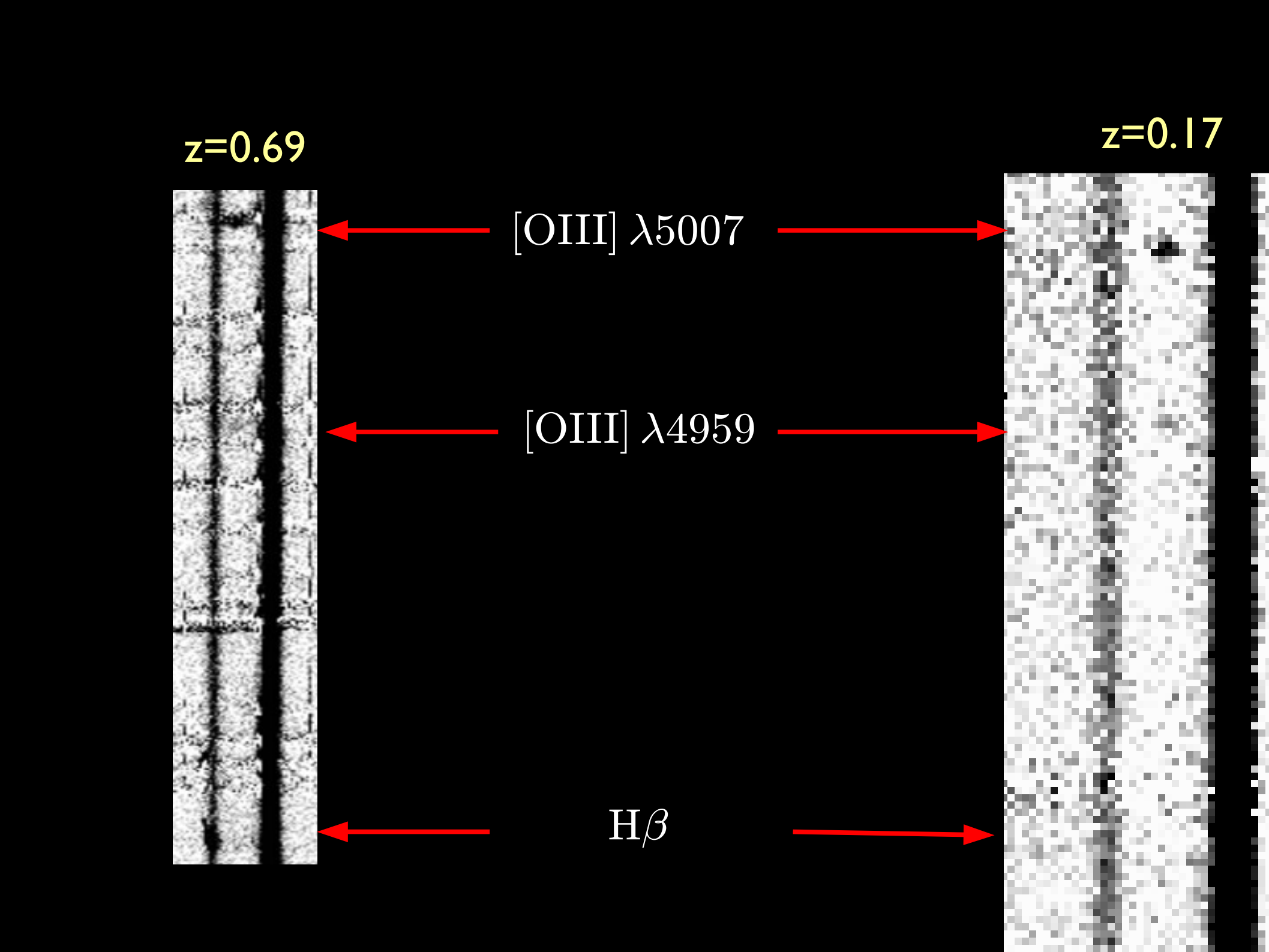

Galaxy
Bridge
QSO
400
200
0
−200
−400
Velocity [km/s]
600/7500 Grating: [OIII]λ5007
1200/7500 Grating: [OIII]λ5007
600/4000 Grism: [NeV]λ3426
−60
−40
−20
0
20
Projected Distance [kpc]

Testing the Merger Model



Future Work

- Space based imaging and integral field spectroscopy will allow us to tighten constraints on QSO-Host relations
  - do they grow lock step along these relations?
- What fraction of QSOs are first-passage QSOs vs. final coalescence?
- Learn about QSO properties:
  - feedback on companion galaxy
  - isotropy
  - lifetime
  - variability on kyr timescales
- Search for more such pairs...


z=0.69
z=0.17
[OIII] λ5007
[OIII] λ4959
Hβ

Quasar		
	$L_{\rm bol}$	$10^{45.7}$ erg s^{-1} *
	M_{BH}	$10^{8.74} M_\odot$ *
	$L_{\rm Bol}/L_{\rm Edd}$	0.07 *
	Spectral Index	-0.35 ± 0.06
	S	$10^{56.5\pm0.1\pm0.4}$ s^{-1}
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Galaxy		
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Bridge		
	Kinematics	(see plot)
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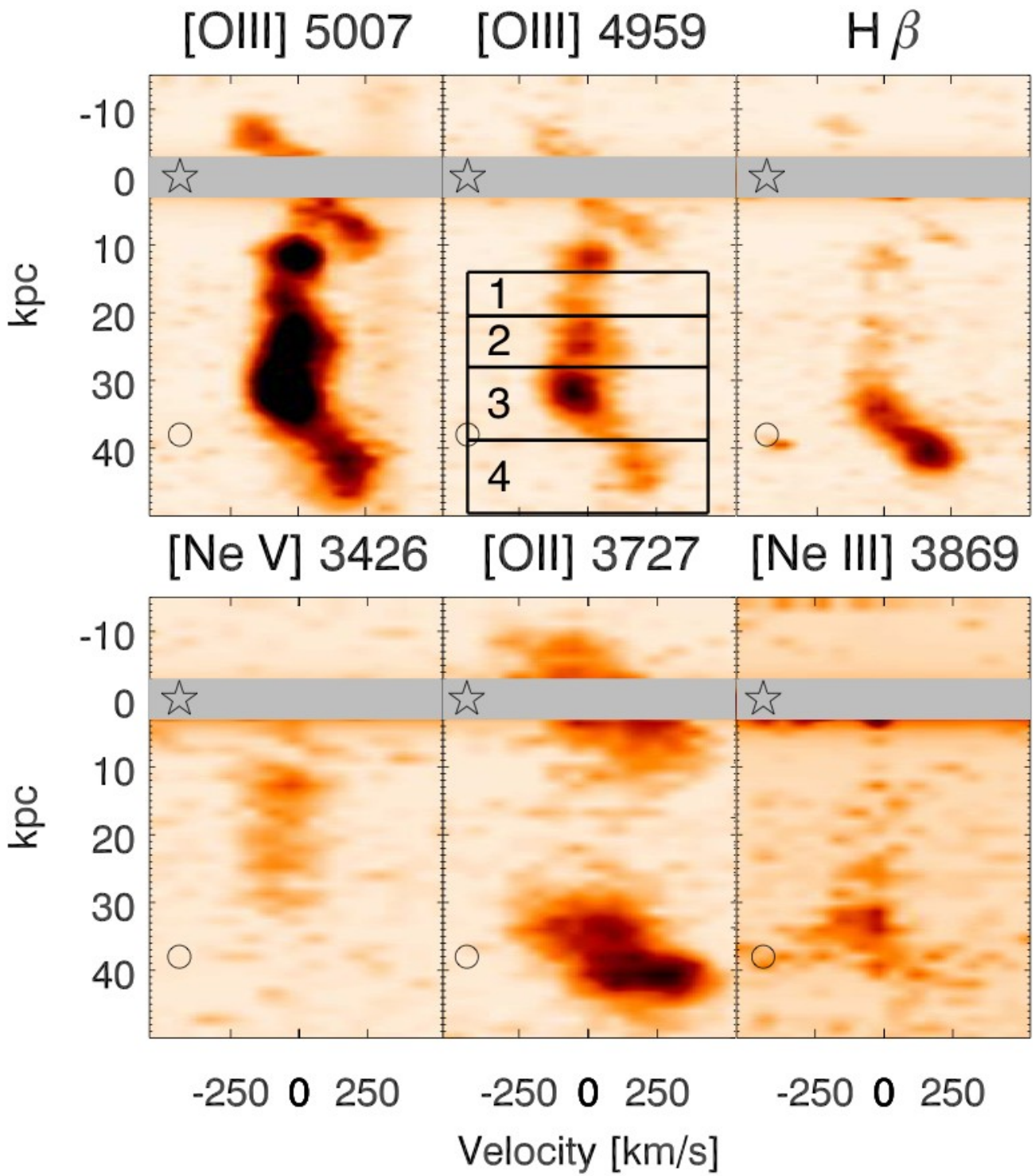
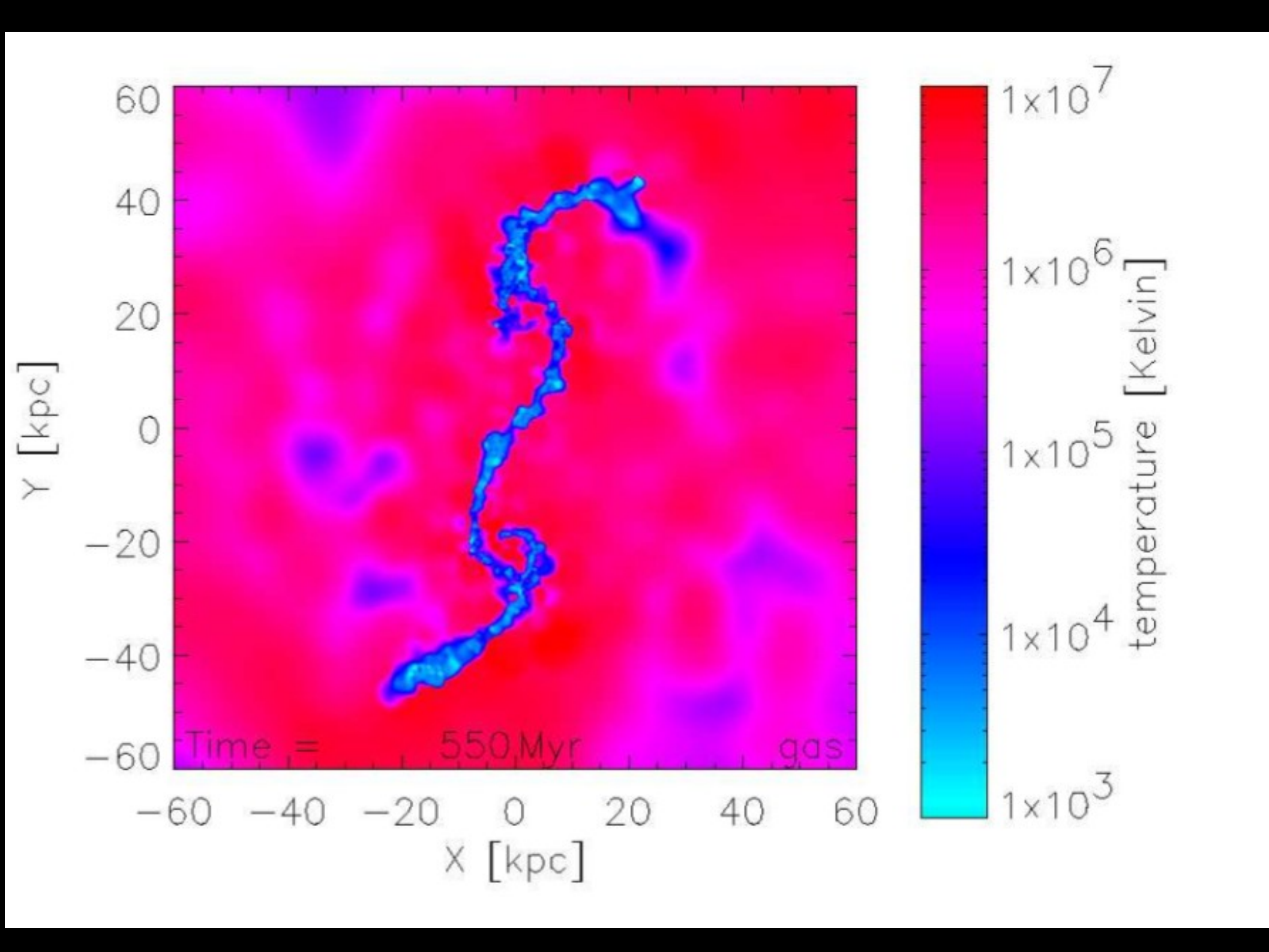
	n	$\gtrapprox 0.1$ cm^{-3}
	T	$< 7 \times 10^4$ K

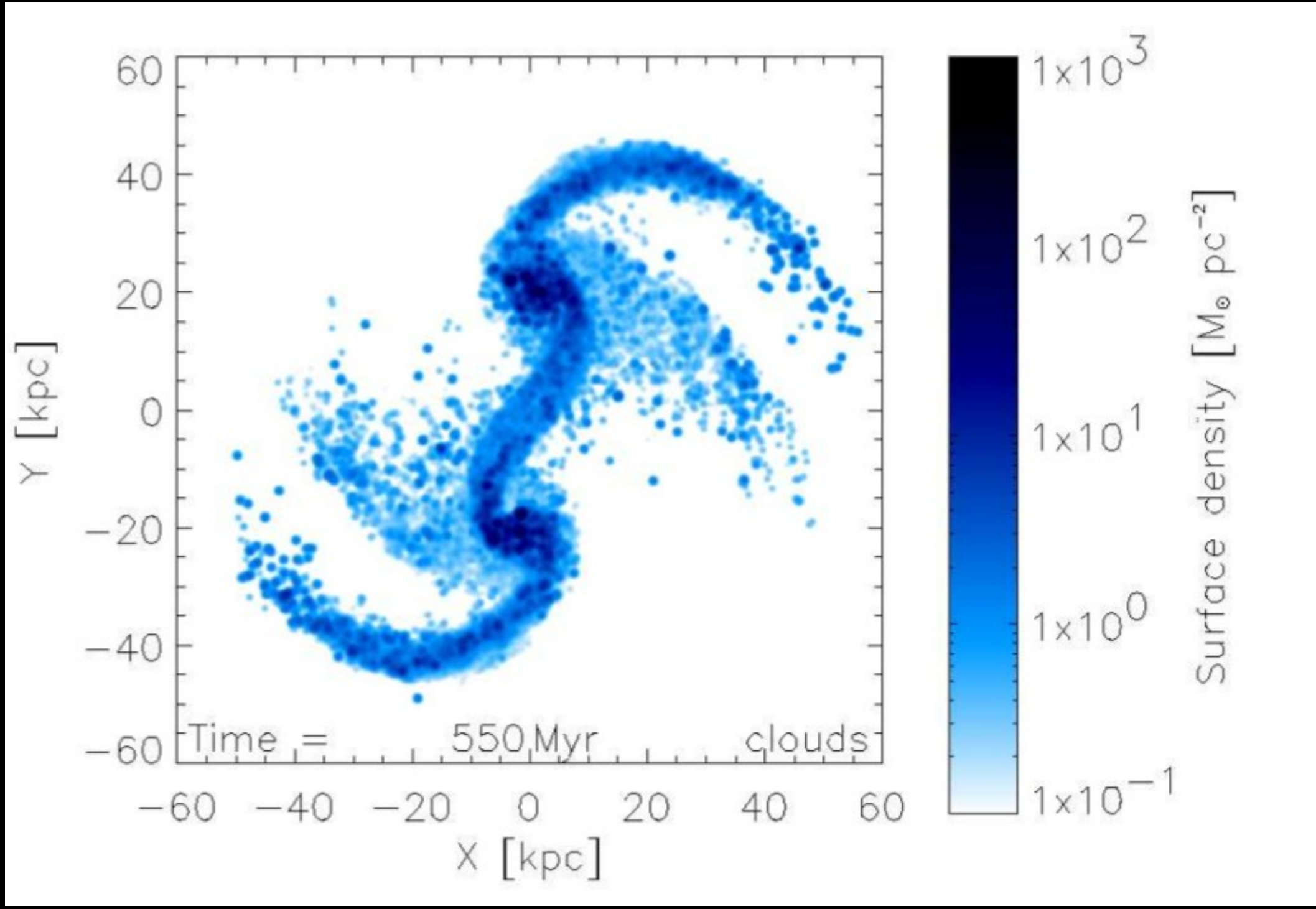
Summary

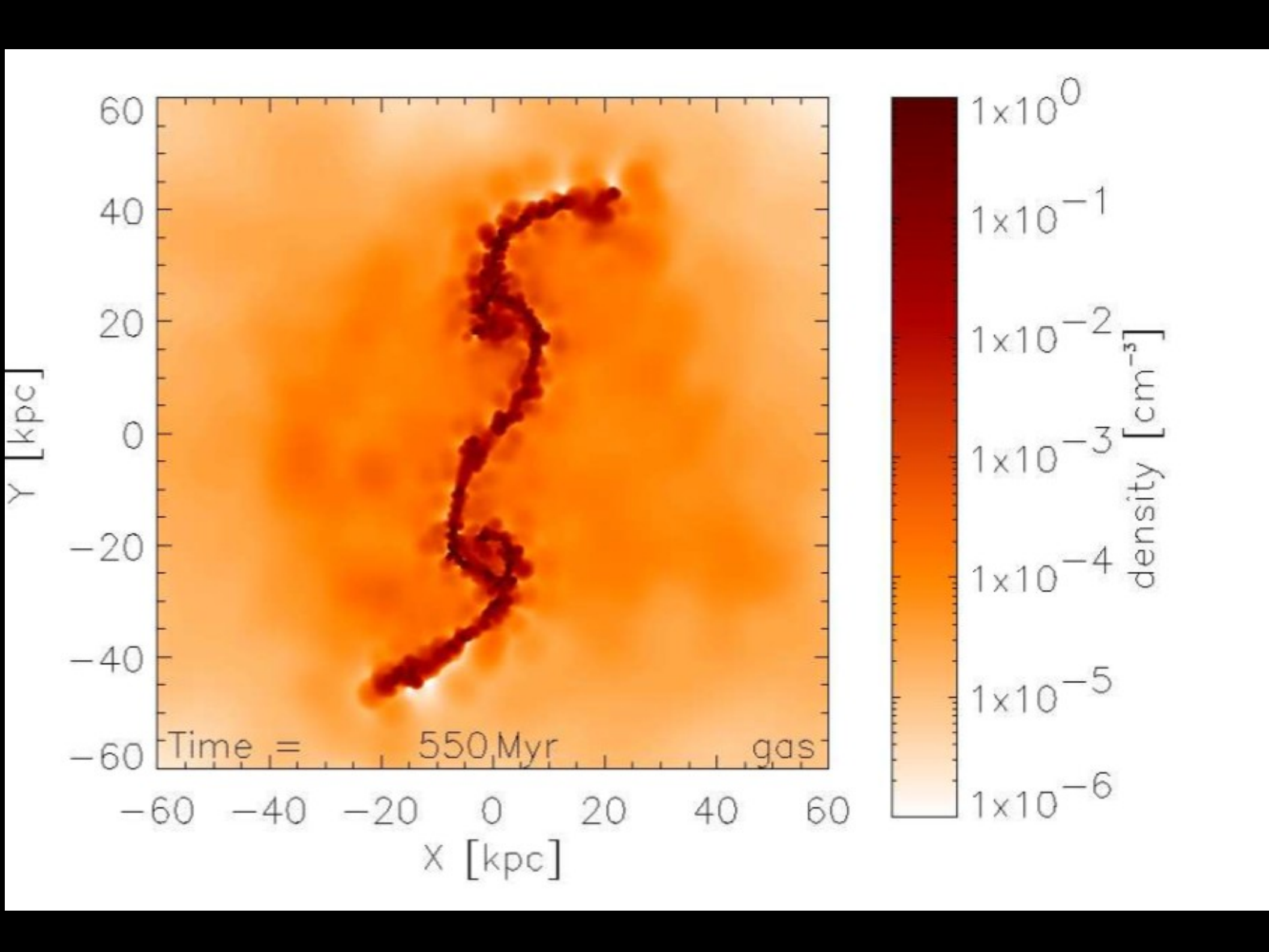
- J2049 is an interacting pair of galaxies with an emission line bridge photoionized by a QSO in one of the galaxies
- Merger models are able to reproduce the kinematics of the system and constrain initial conditions
- This offers a new laboratory to study QSOs and galaxy mergers

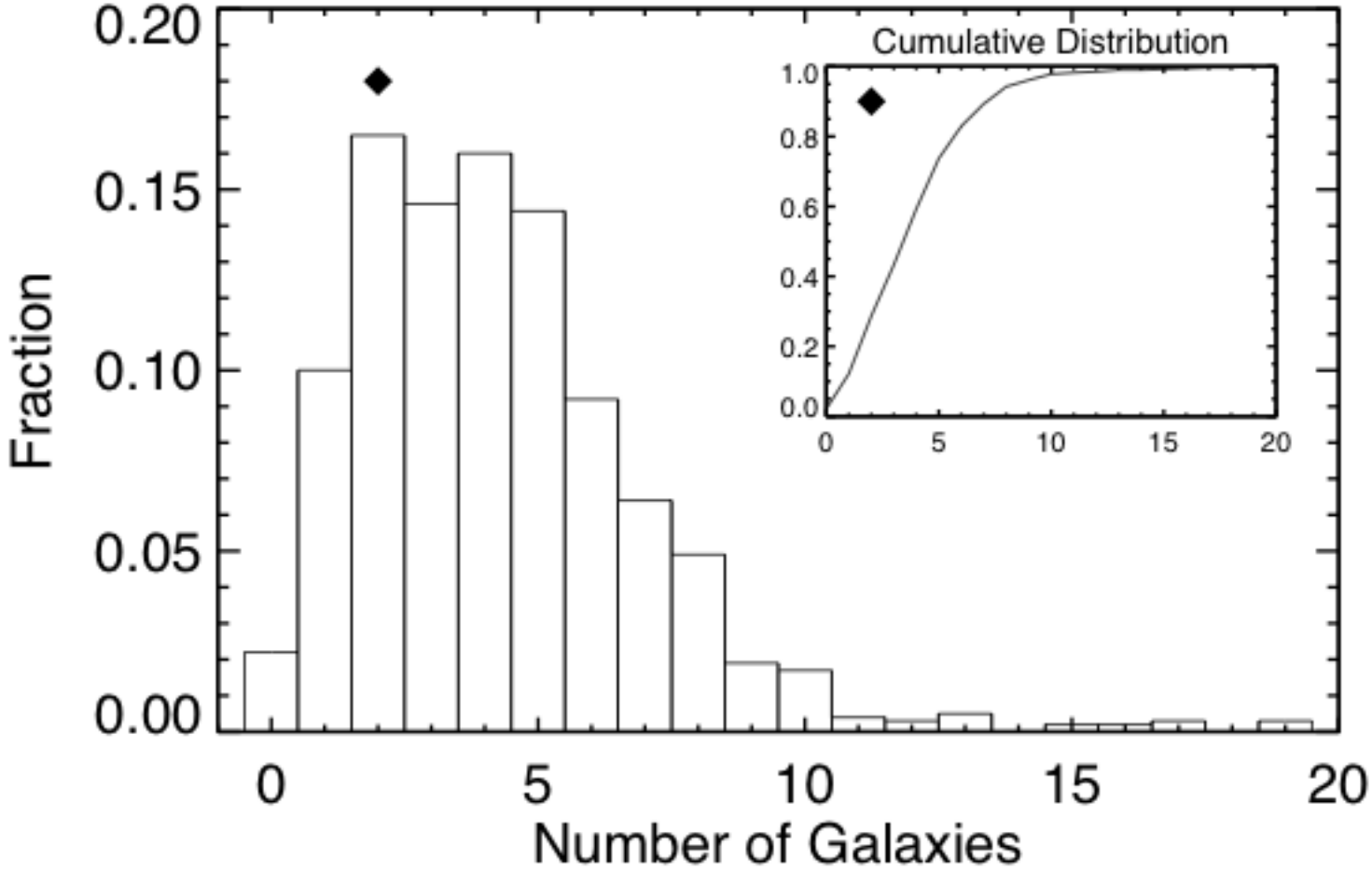
Thank You


[OIII] 5007
[OIII] 4959
H β
[Ne V] 3426
[OII] 3727
[Ne III] 3869
-10
0
10
20
30
40
kpc
1
2
3
4
-250 0 250
Velocity [km/s]


60
40
20
0
−20
−40
−60
Y [kpc]
−60 −40 −20 0 20 40 60
X [kpc]
Time = 550 Myr
gas
1x10^7
1x10^6
1x10^5
1x10^4
1x10^3
temperature [Kelvin]


60
40
20
0
−20
−40
−60
Y [kpc]
Time = 550 Myr
clouds
−60 −40 −20 0 20 40 60
X [kpc]
1x10^3
1x10^2
1x10^1
1x10^0
1x10^−1
Surface density [M⊙ pc^−2]


60
40
20
0
−20
−40
−60
Y [kpc]
−60 −40 −20 0 20 40 60
X [kpc]
Time = 550 Myr
gas
1x10^0
1x10^−1
1x10^−2
1x10^−3
1x10^−4
1x10^−5
1x10^−6
density [cm^−3]


Fraction
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
Number of Galaxies
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20

Quasars are Bright!

A quasar emits S ionizing photons/sec

$$S \lesssim 10^{57} s^{-1} \qquad \frac{S}{S_{O3V}} \sim 10^7$$

We can quantify the influence of photoionization by a dimensionless U parameter

$$U(n, r, S) = \frac{\#\ \text{Ionizing Photons}}{\#\ \text{hydrogen atoms}} = \frac{S/(4\pi r^2 c)}{n}$$

We see that a quasar can render a region of $\log U \sim$ -2 (typical of HII regions) out to 60 kpc

Credits

Thanks to:
Gabor Worseck, Michele Fumagalli, Greg Bryan, T.J. Cox, Phil Hopkins, Patrik Jonsson, Bill Matthews, Joe Miller, John O'Meara, Joel Primack, Enrico Ramirez-Ruiz, and Greg Shields,