AN INTERACTING GALAXY PAIR AT THE ORIGIN OF A *LIGHT ECHO*

Paola Merluzzi
INAF - Osservatorio di Capodimonte

G. Busarello (INAF-OACN)
M. A. Dopita, A. D. Thomas (ANU, AU)
C. P. Haines (INAF-OABM)
A. Grado, L. Limatola, A. Mercurio (INAF-OACN)

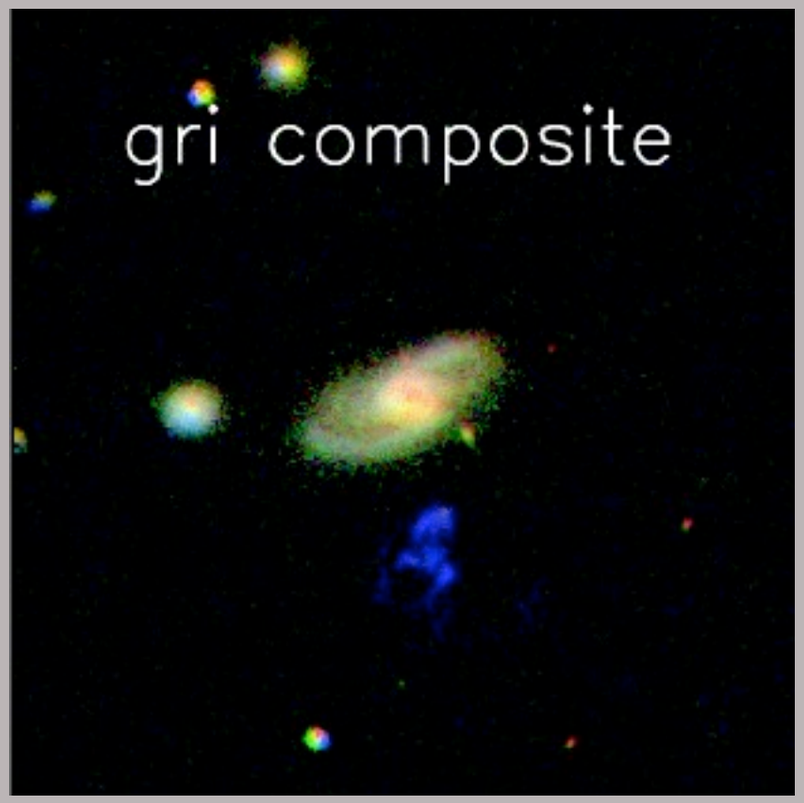
ongoing transformation ⟺ extraplanar gas ⟺

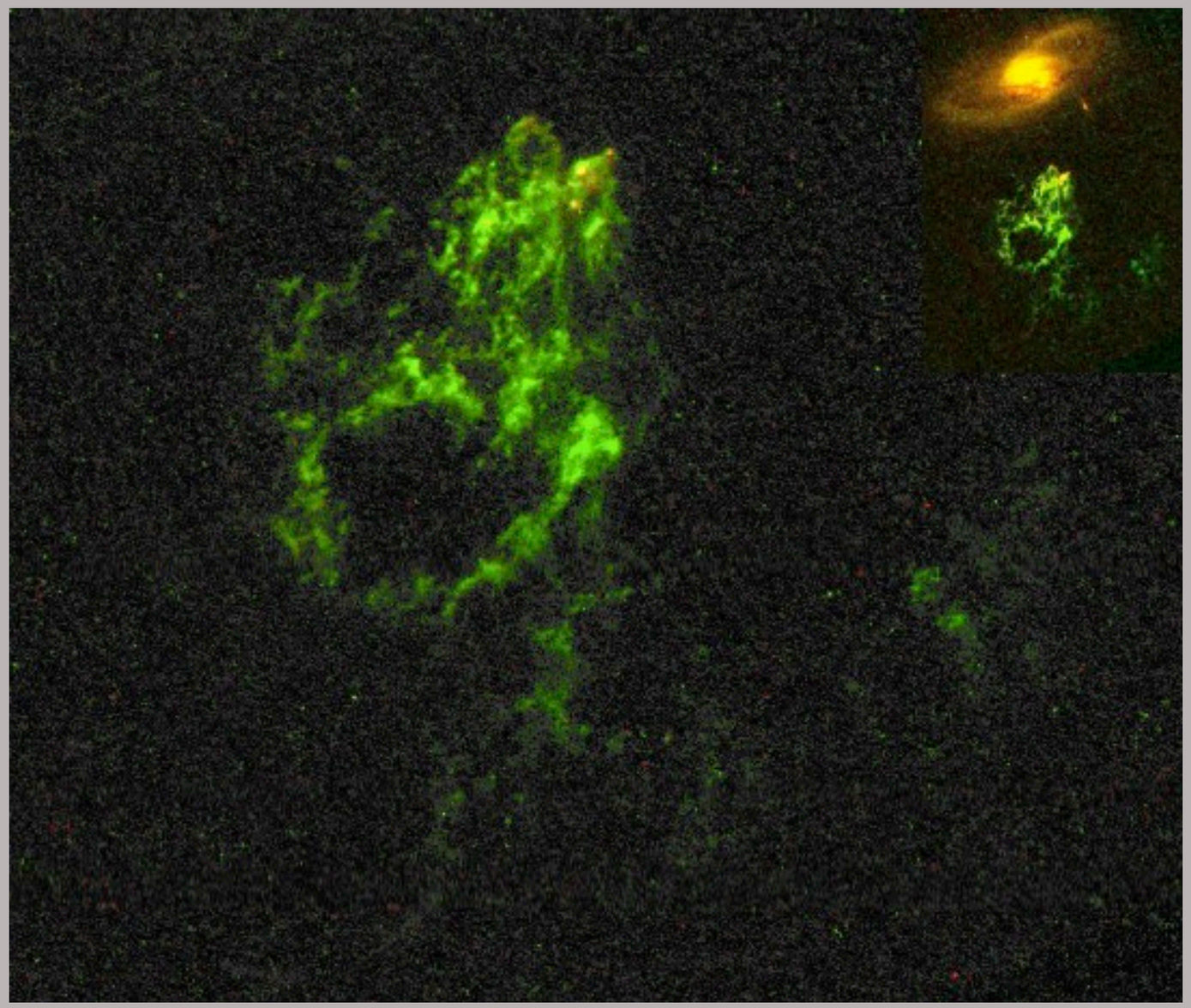
- **ram-pressure stripping**
- **galaxy interaction**
- **star formation**
- **nuclear activity**

NLR EELR

Hanny's voorwerp (z=0.05)

Lintott+ 2009





discrepancy between the level of the cloud ionization and the AGN luminosity

Rampadarath+ 2010, Keel+2012a, Sartori+2016

HV is a *light echo* ionized by an AGN faded within the last 10^5yr

HV-like trought the Galaxy Zoo

Keel+ 2012b

From SDSS DR7 a sample of potential AGN at $z < 0.1$

[OIII]/Hβ and [NII]/Hα
Veron-Cetty & Veron (2010)

⬇

18116 objects

Galaxy Zoo

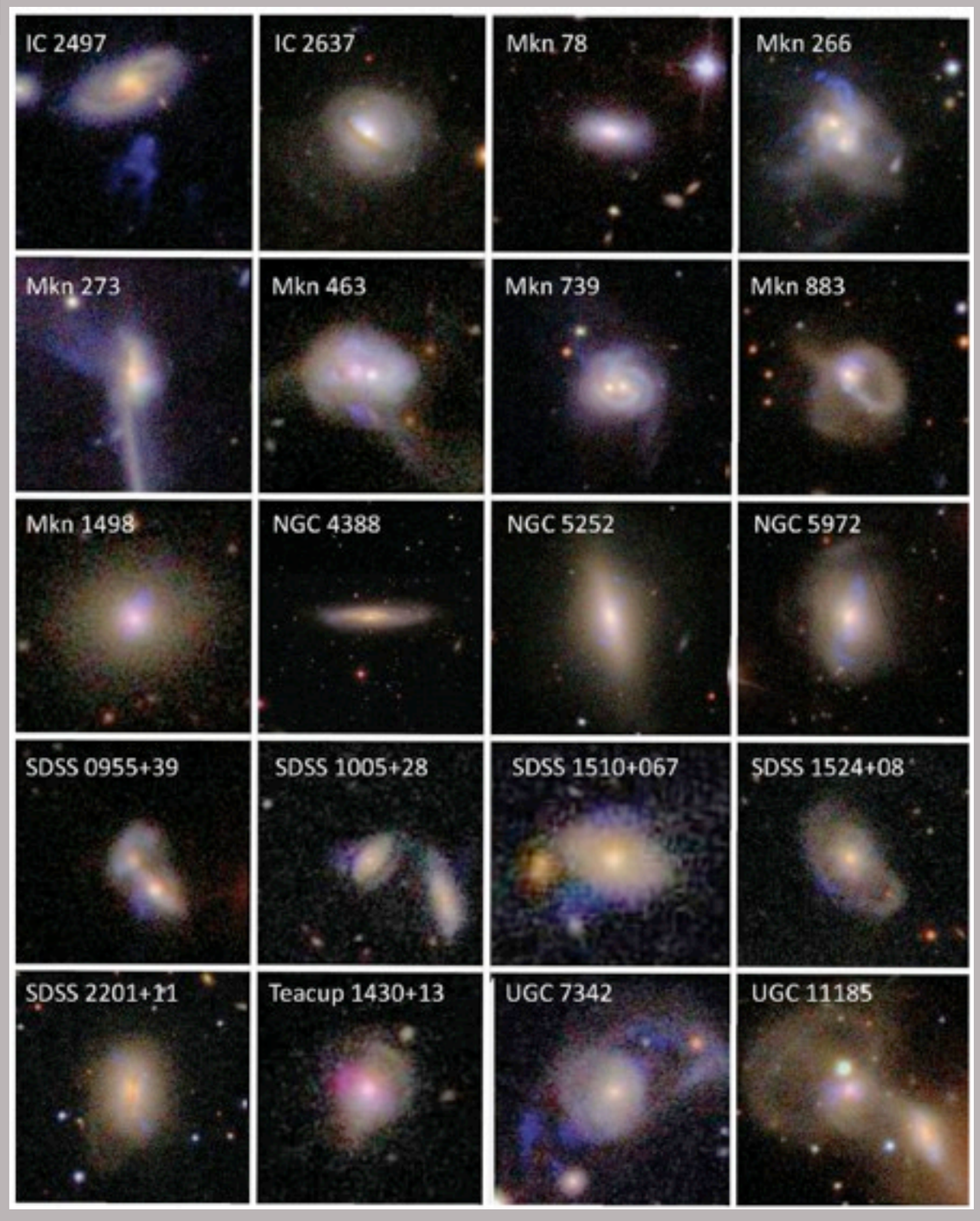
⬇

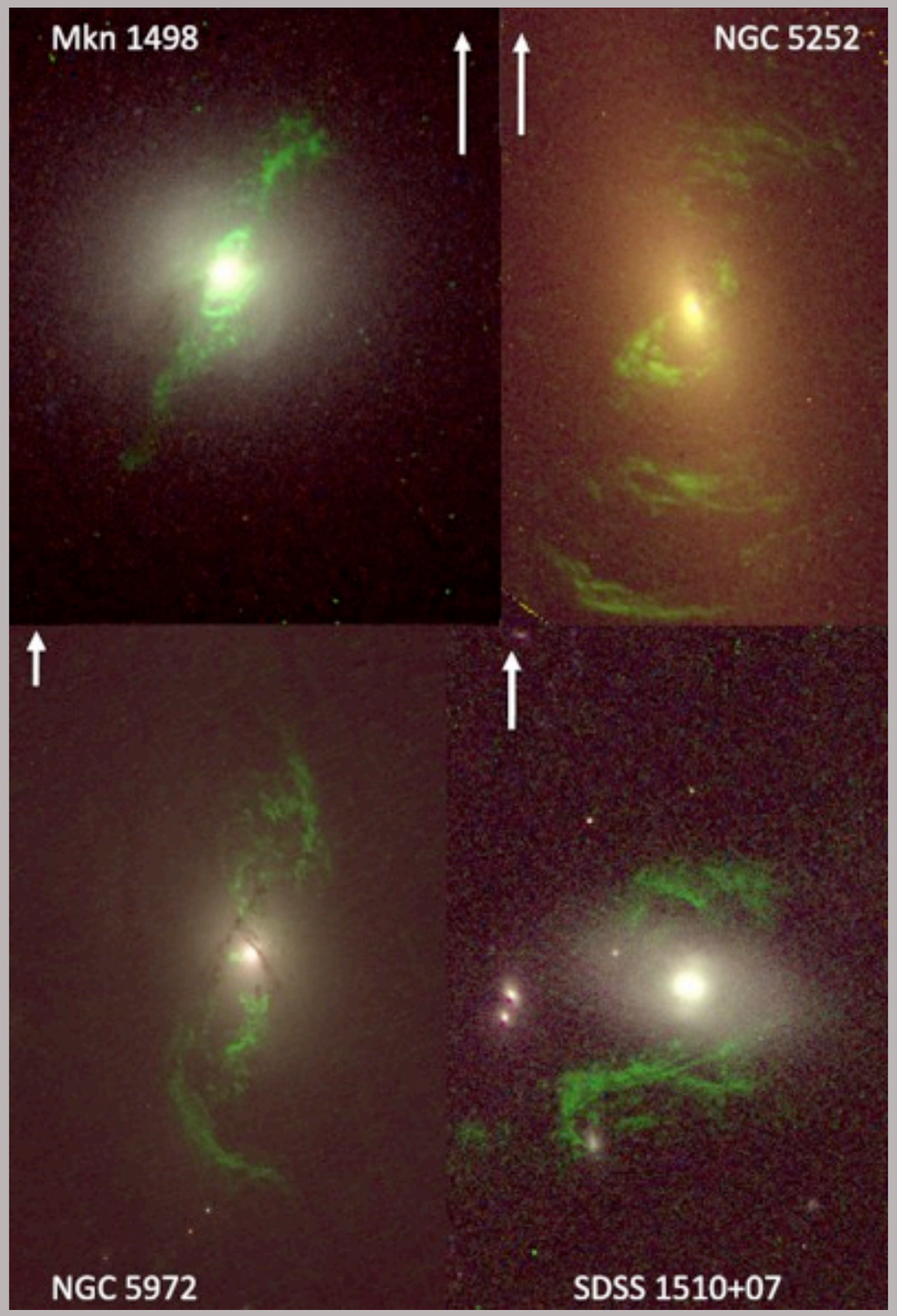
19 galaxies with AGN-ionized region
at a projected radii r > 10 kpc

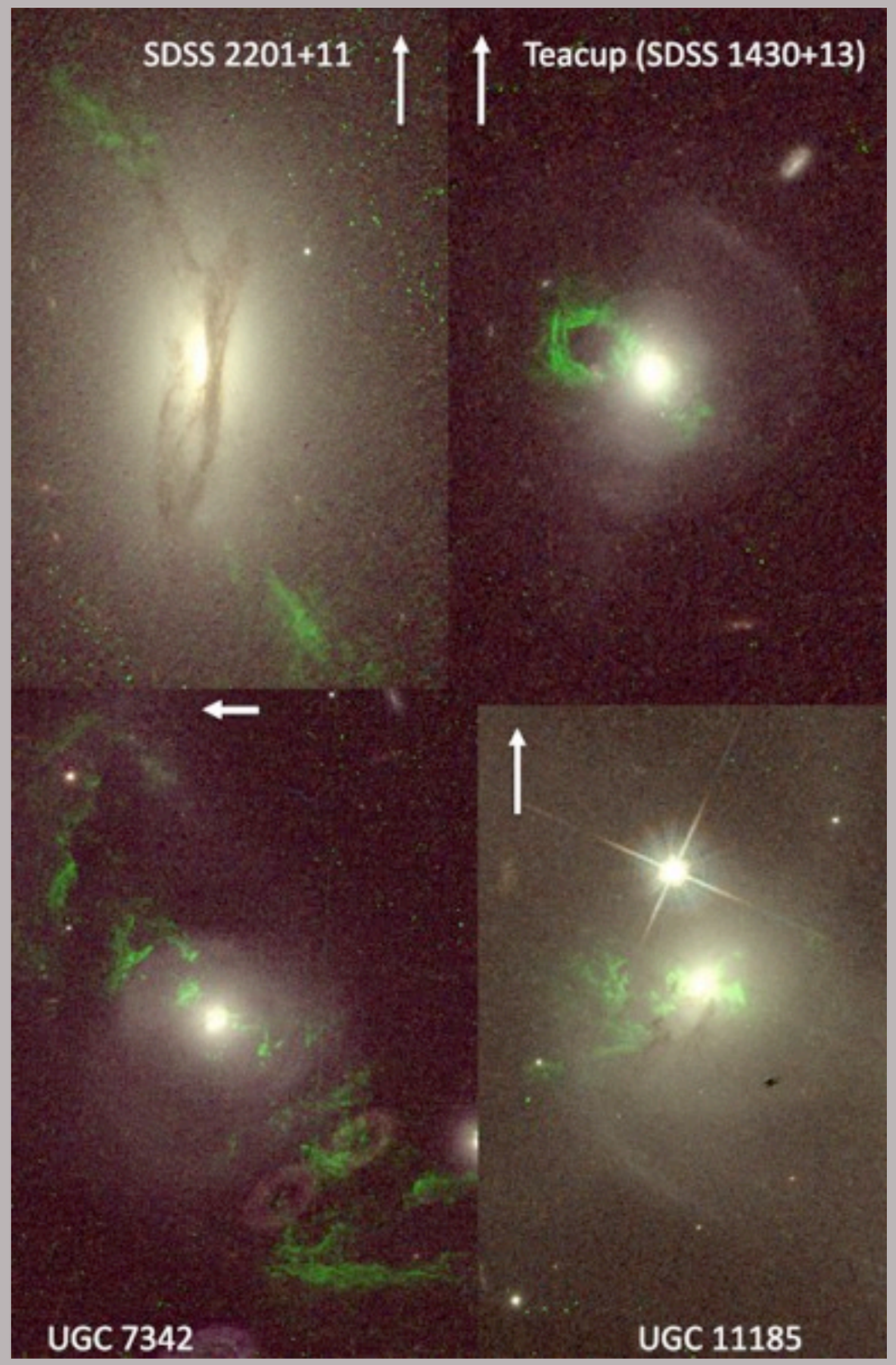
[OIII] vs. L_{FIR}

⬇

8 strong deficit in ionizing luminosity and no evidence of obscured AGN







EELR are largely phoionized tidal debris

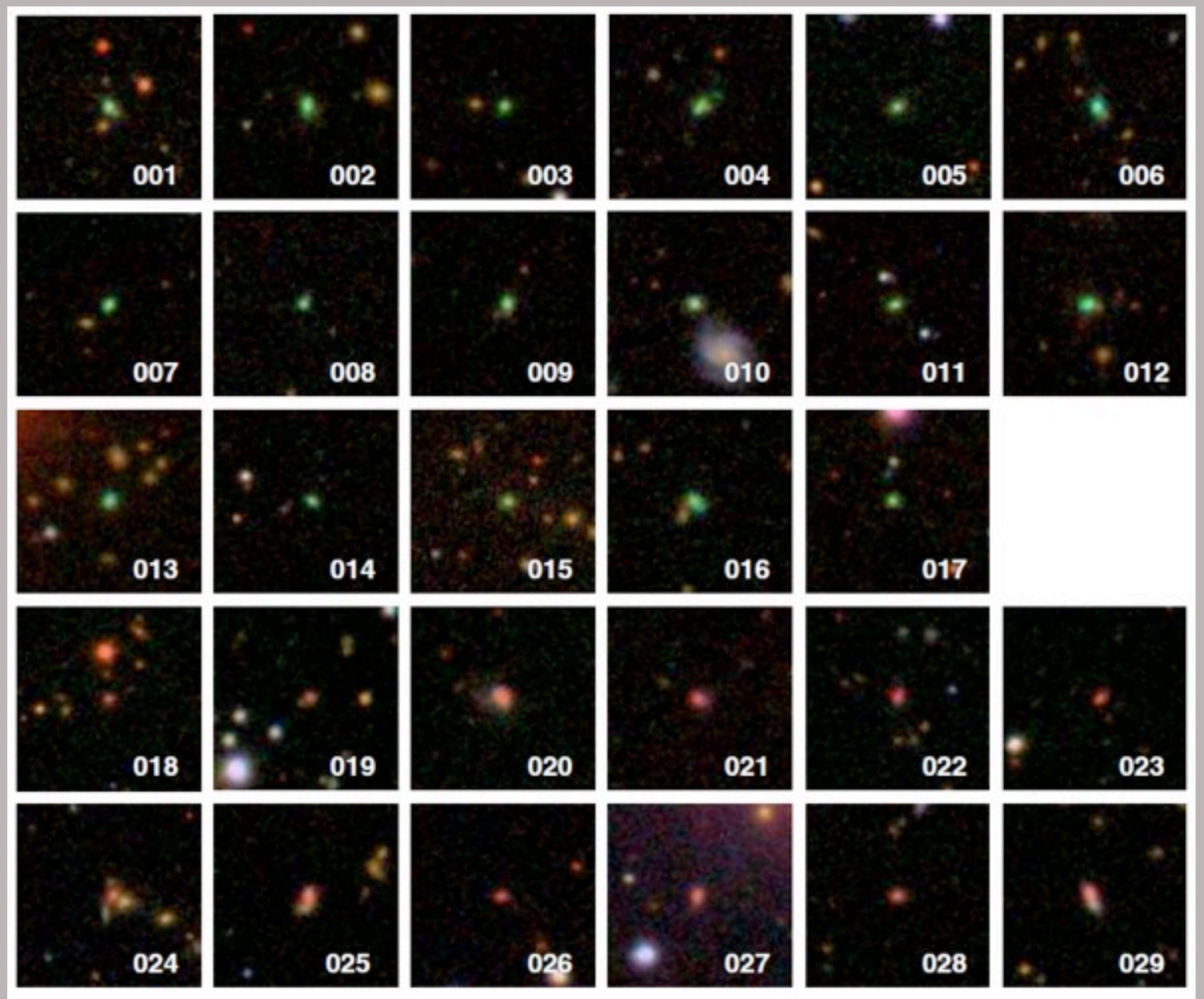
Green Bean sample

Schirmer+ 2013

From SDSS DR8 a sample of 29 Seyfert-2 at z = 0.2 - 0.6

g-r >1
0.12 < z < 0.35

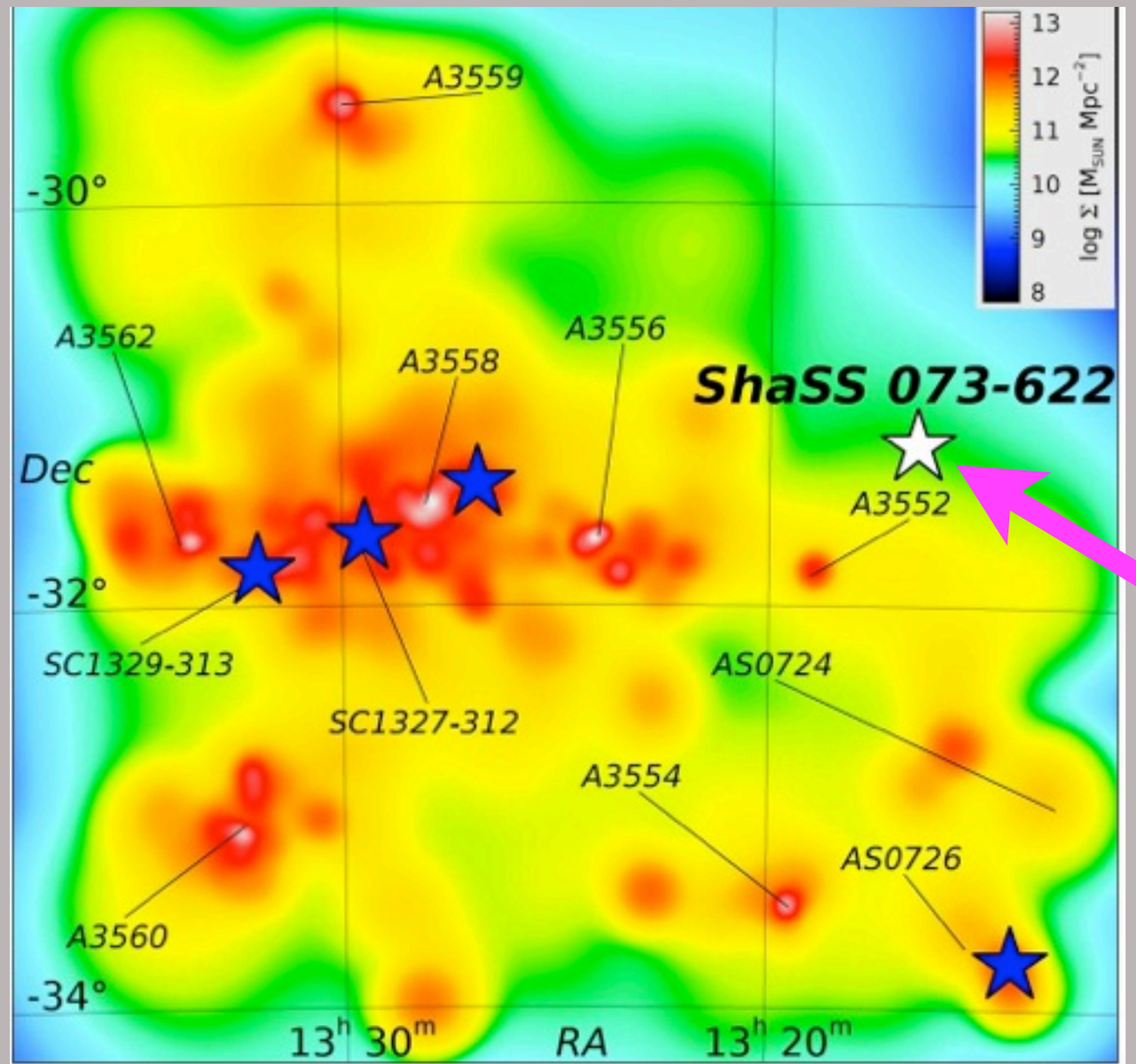
r-i > 1
0.39 < z < 0.69



[OIII] vs. $L_{24\mu m}$ ➡ AGN luminosity is insufficient to power the EELR [OIII] flux

Shapley Supercluster Survey

stellar mass surface density map



Merluzzi+ 2015

ShaSS-073_622

ShaSS-073

Seyfert-2 **Veron-Cetty & Veron 2001**

Bar and external ring: (R)SB0a

$M^* = 5.7 \times 10^{10} M_\odot$

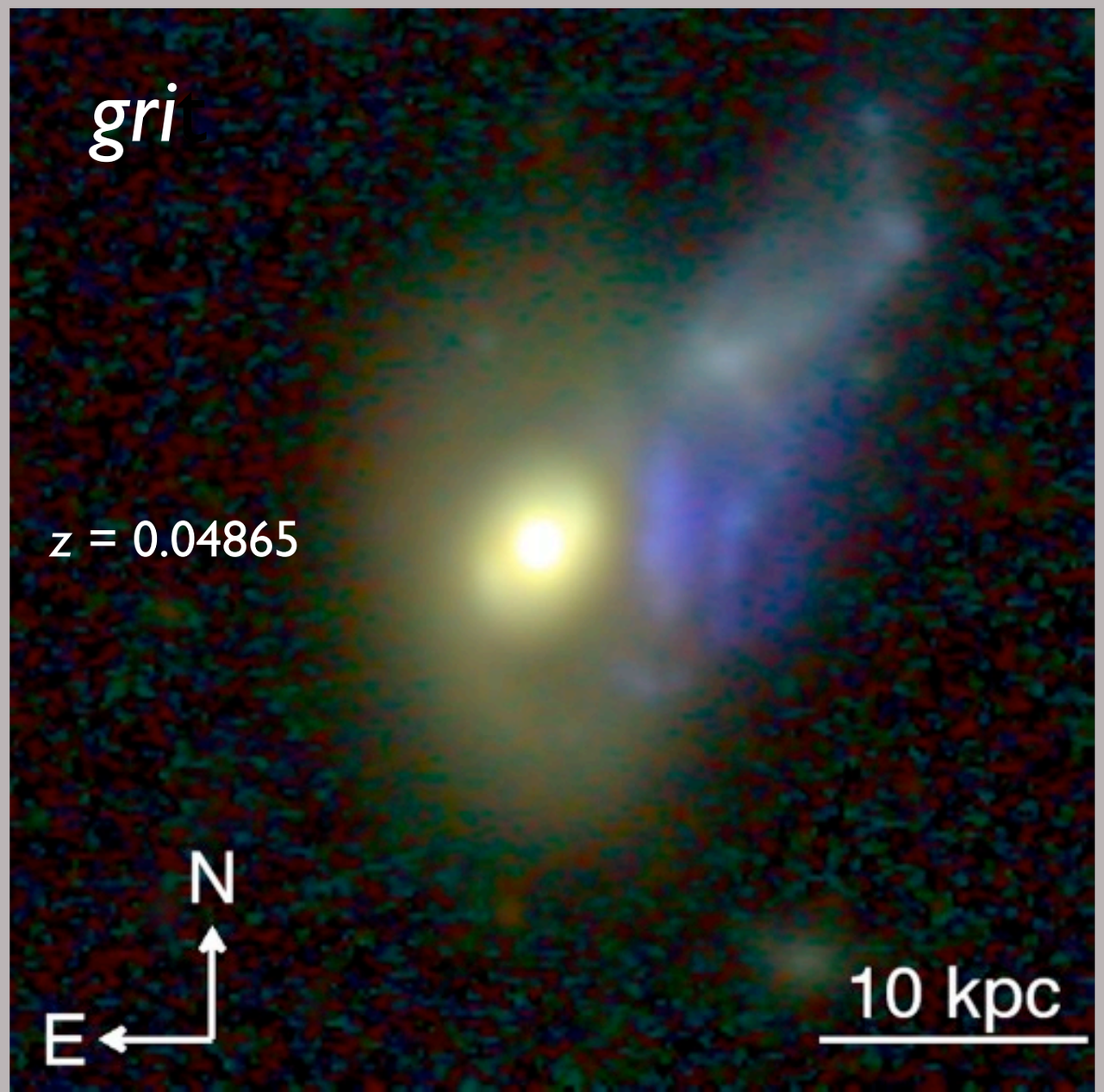
ShaSS-622

probably was Sb/Sbc

$\Delta V = 130$ km s^{-1}

$M^*_{073}/M^*_{622} = 10$

minor or intermediate merger



ShaSS-073_622

ShaSS-073

Seyfert-2 **Veron-Cetty & Veron 2001**

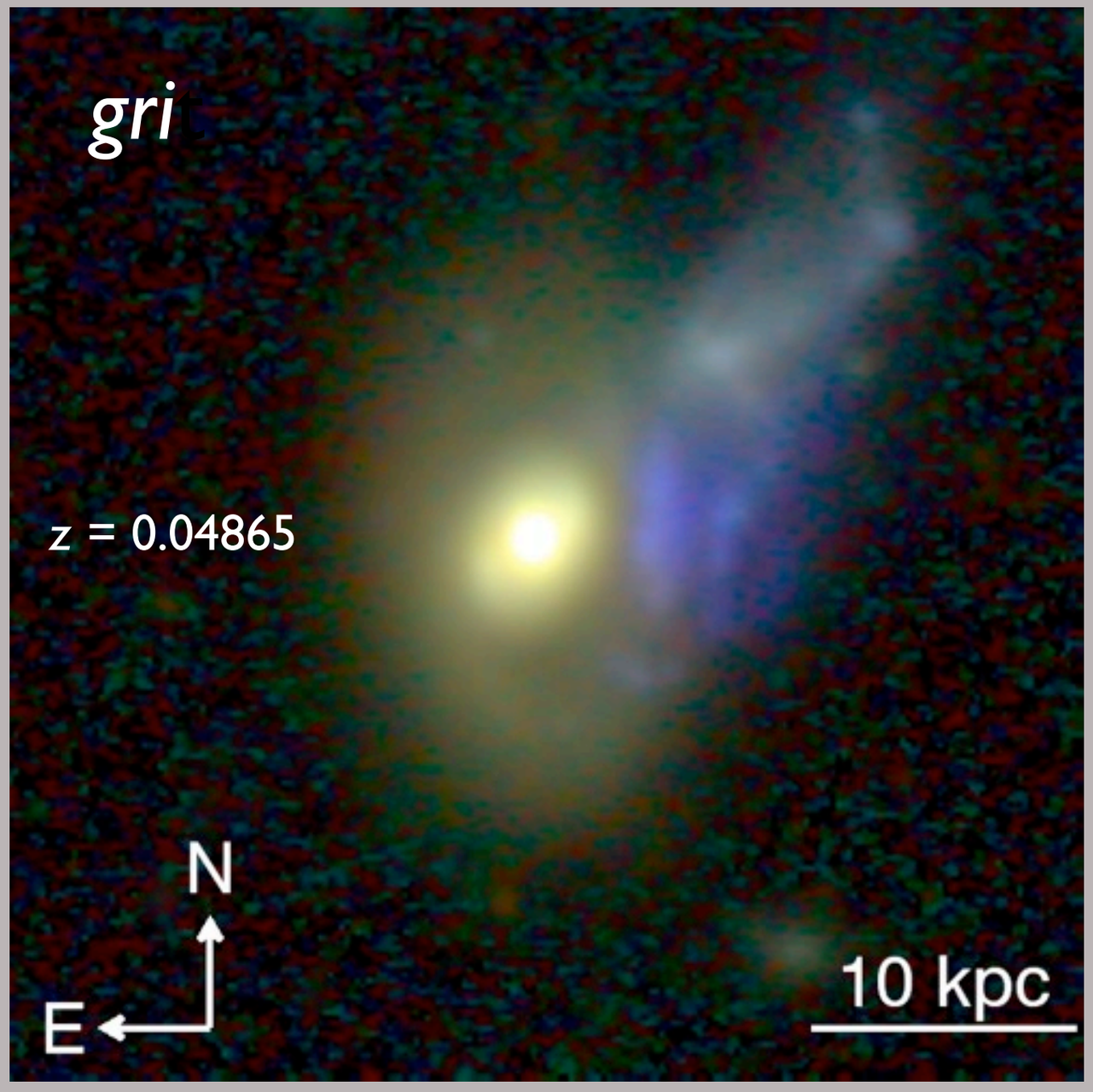
Bar and external ring: (R)SB0a

$M^* = 5.7 \times 10^{10} M_\odot$

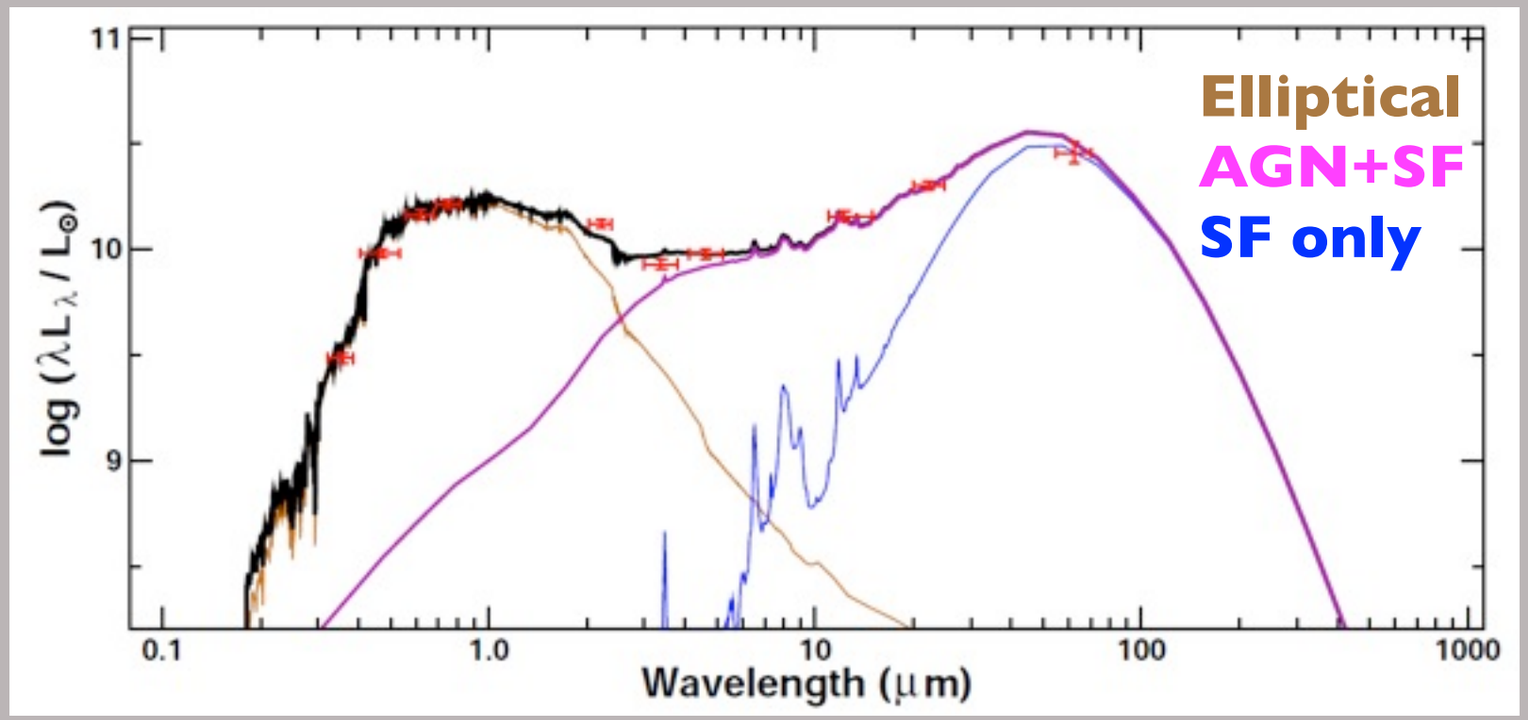
ShaSS-622

probably was Sb/Sbc

Property	ShaSS 423045073	ShaSS 423045622
Coordinates[1,2] (J2000)	13 16 32.58 -31 12 18.5	13 16 32.02 -31 12 11.5
Magnitudes[3,4,5]		
$u^{(a)}$	17.70±0.04	17.68±0.04
$g^{(a)}$	16.20±0.02	16.64±0.02
$r^{(a)}$	15.47±0.02	16.87±0.02
$i^{(a)}$	15.11±0.02	17.03±0.02
$K^{(a)}$	12.22±0.03	14.95±0.03
$W1^{(b)}$	11.69±0.02[(c)]	
$W2^{(b)}$	10.59±0.02[(c)]	
$W3^{(b)}$	7.19±0.02[(c)]	
$W4^{(b)}$	4.79±0.03[(c)]	
$F_{60\mu m}$	0.40±0.05 Jy[(c)]	
$F_{1.4GHz}$	3.9±0.6 mJy[(c)]	
$L_{1.4GHz}$	2.2×10^{22} WHz^{-1}	



SED of ShaSS-073



Polletta+ 2007

Dale+ 2014

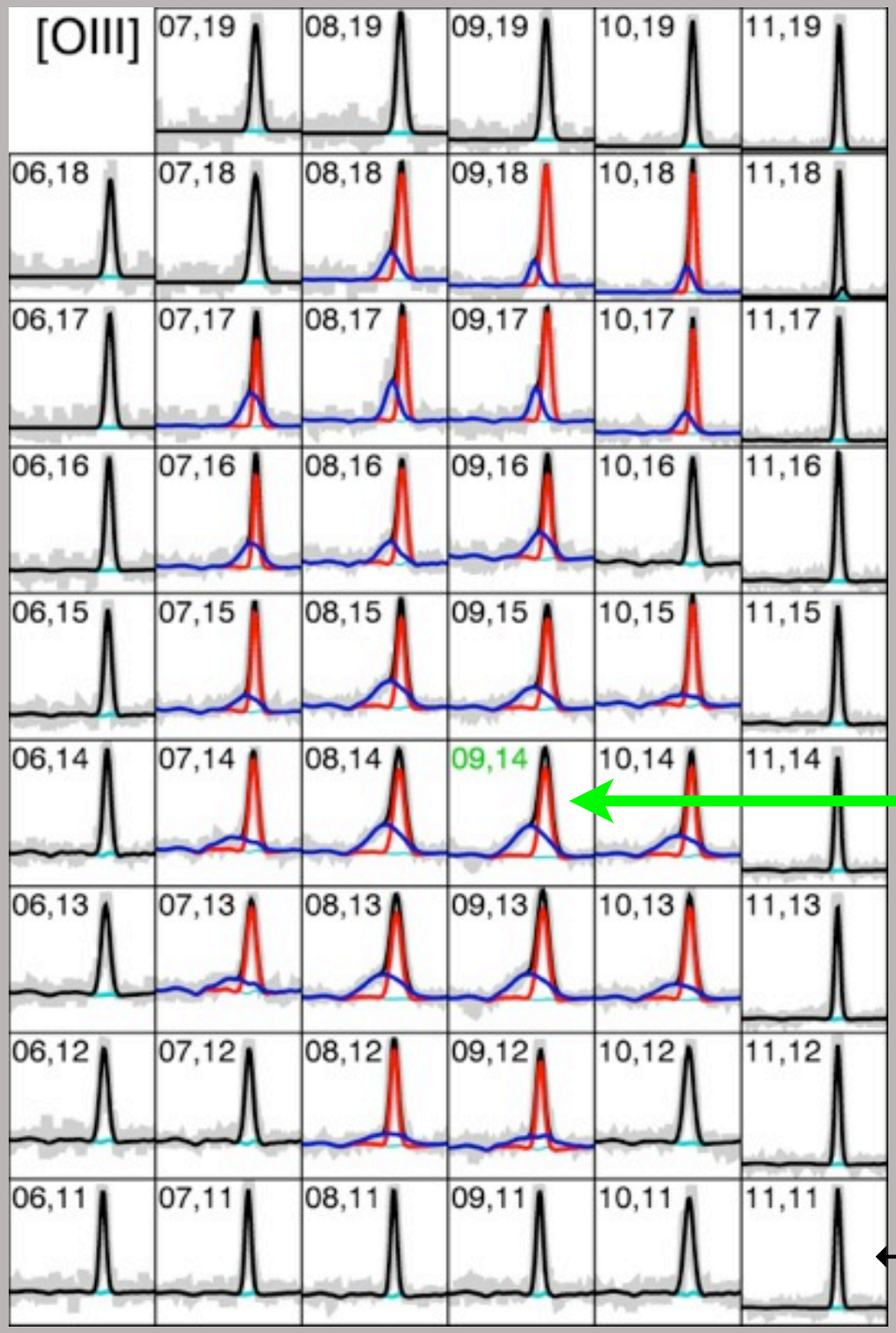
3-60μm: 85% AGN and 15% SF

emission from a torus of hot dust is required to produce the observed SED over 2–30μm

AGN contribution at 5μm: 3.09×10^{43} erg s^{-1}

AGN bolometric luminosity: 2.47×10^{44} erg s^{-1} **Lacy+2015**

Kinematics of the gas



Structure of the [OIII] λ5007 emission line around the AGN of ShaSS-073 (6x9 arcsec^2)

gray: observed spectrum

cyan: continuum

black: one-component fit

red+blue: two-component fit

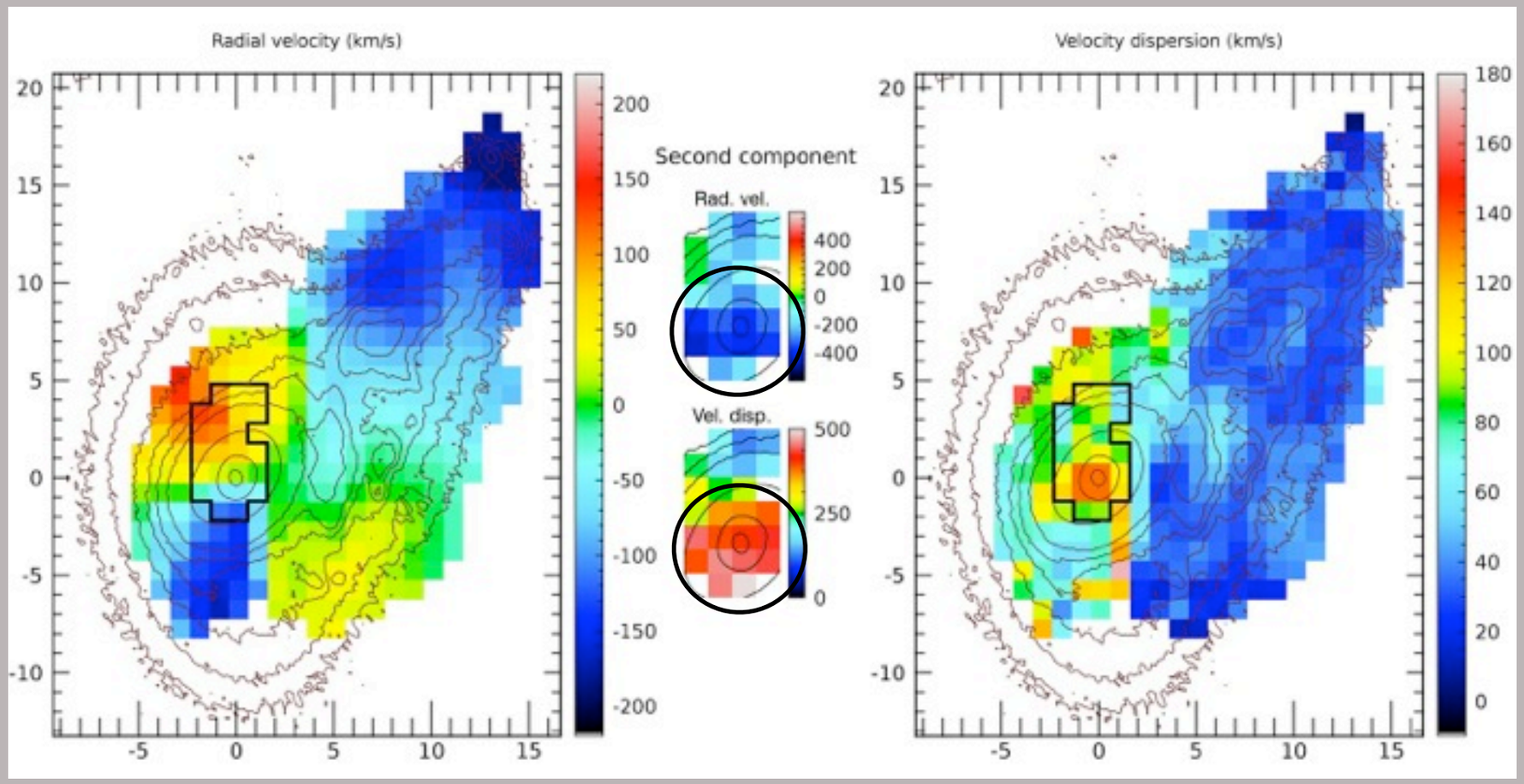
main component: continuum distribution in width and redshift with the rest of the galaxy

second component: blue shifted and generally much wider

center (AGN)

←1Å~1 arcsec^2 spaxel (WiFeS@ANU2.3m)

Kinematics of the gas

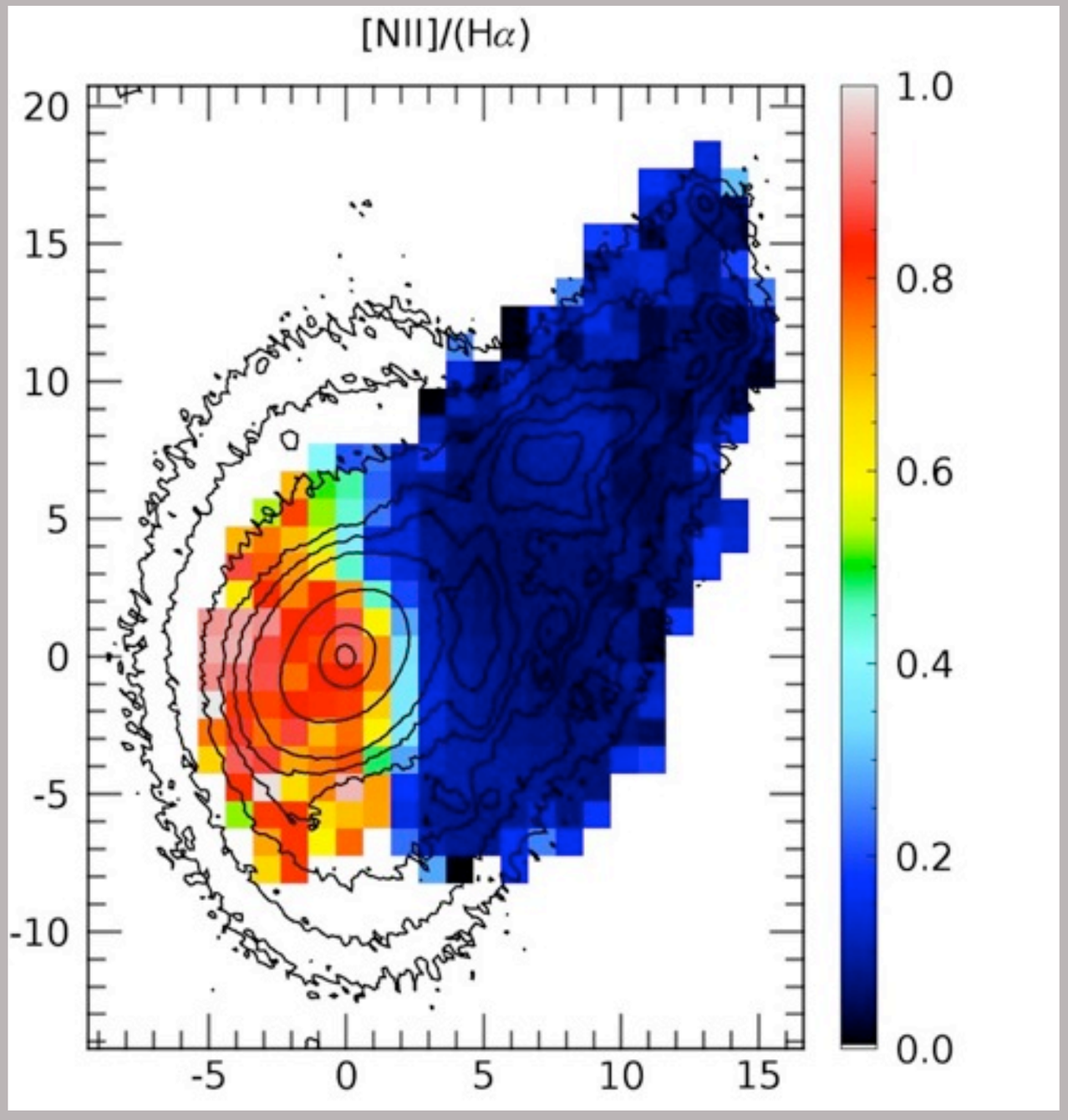


The radial velocity field of the main gas component is fairly consistent with rotation in the disks of both galaxies → **evidence that the interaction between the two galaxies is at its starting phase**

The second gas component blue-shifted with respect to the disk of ShaSS-073 and with a higher velocity dispersion:
circum-nuclear (r<2-3 kpc) region **σ > 360 km s^{-1}** →
radial velocity down to **-440 km s^{-1}**
northern area with more moderate values

AGN outflow

Metallicity helps!



ShaSS-622: [NII]/Hα <0.2

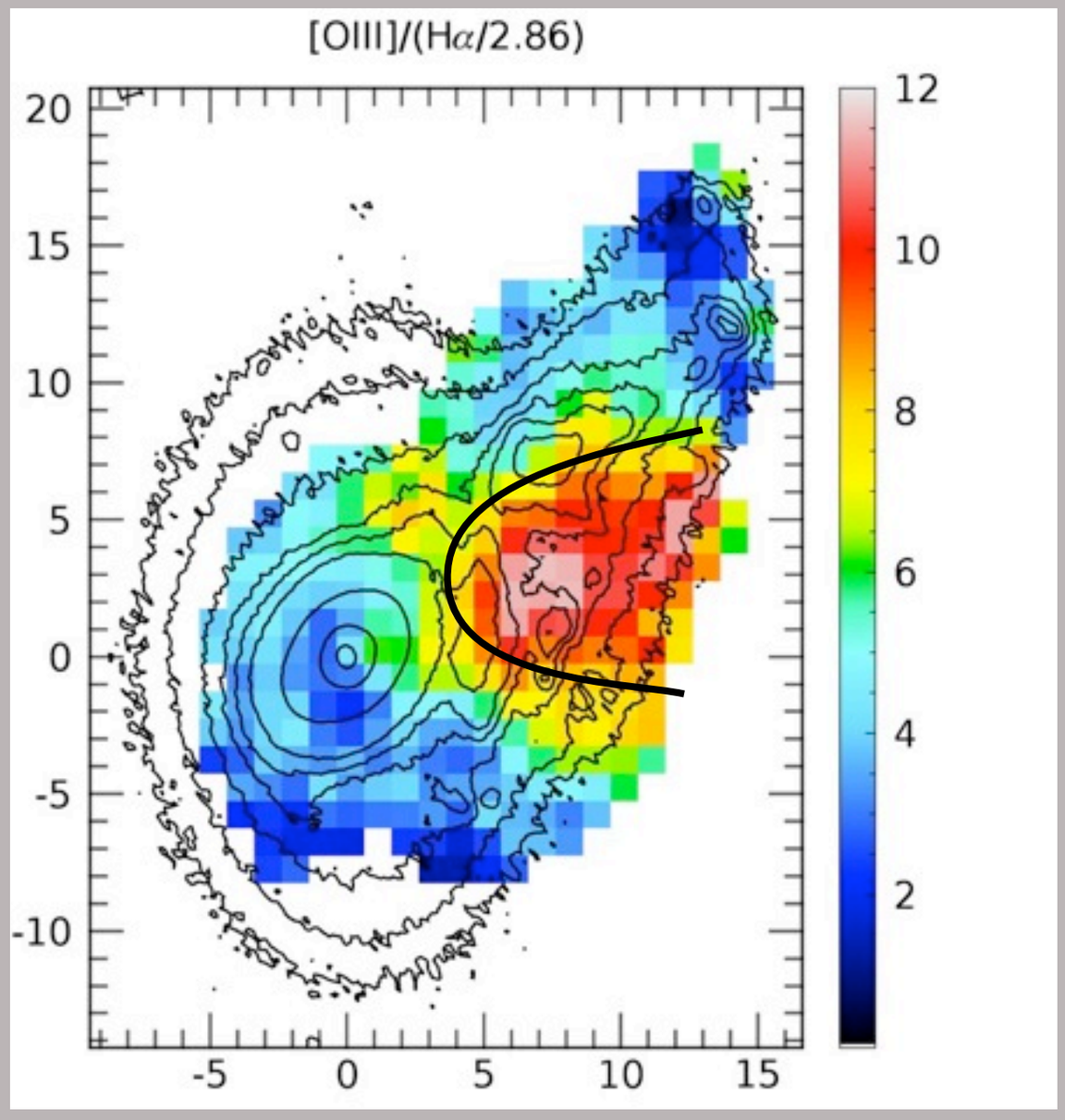
ShaSS-073: [NII]/Hα >0.6

⬇

the gas of the two galaxies can be easily distinguished

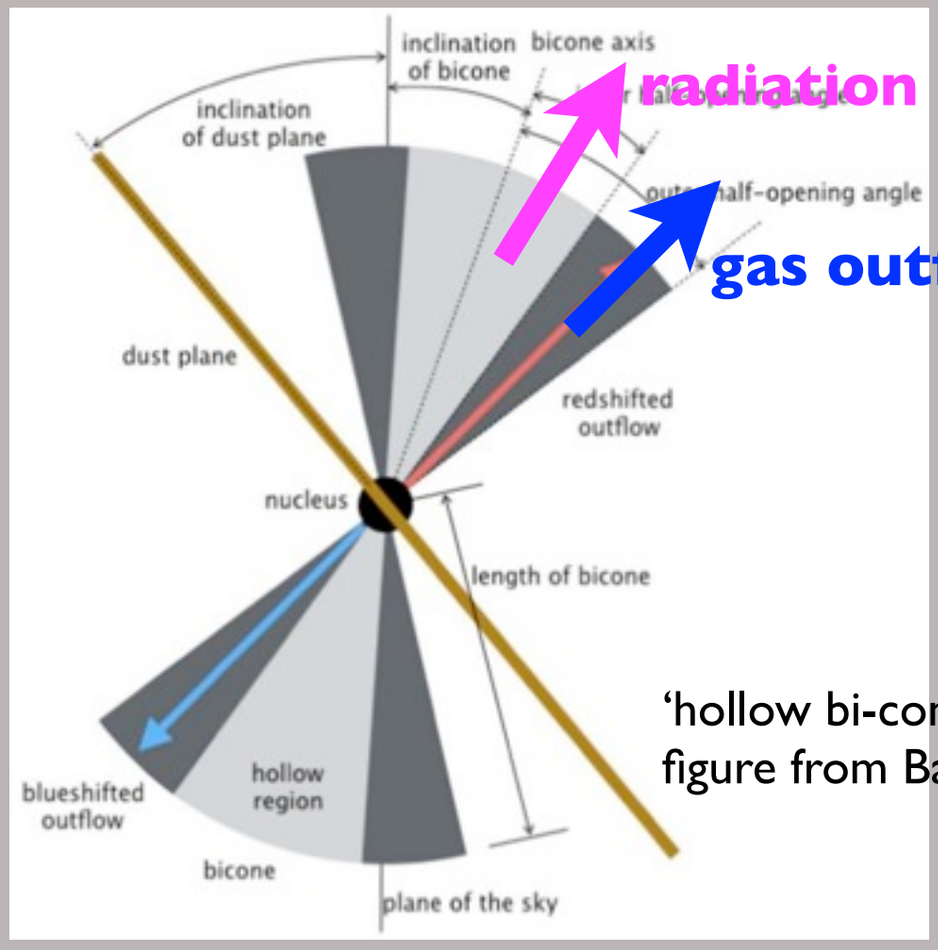
Revealing the ionization cone

a proxy for the ionization parameter for regions excited by an AGN



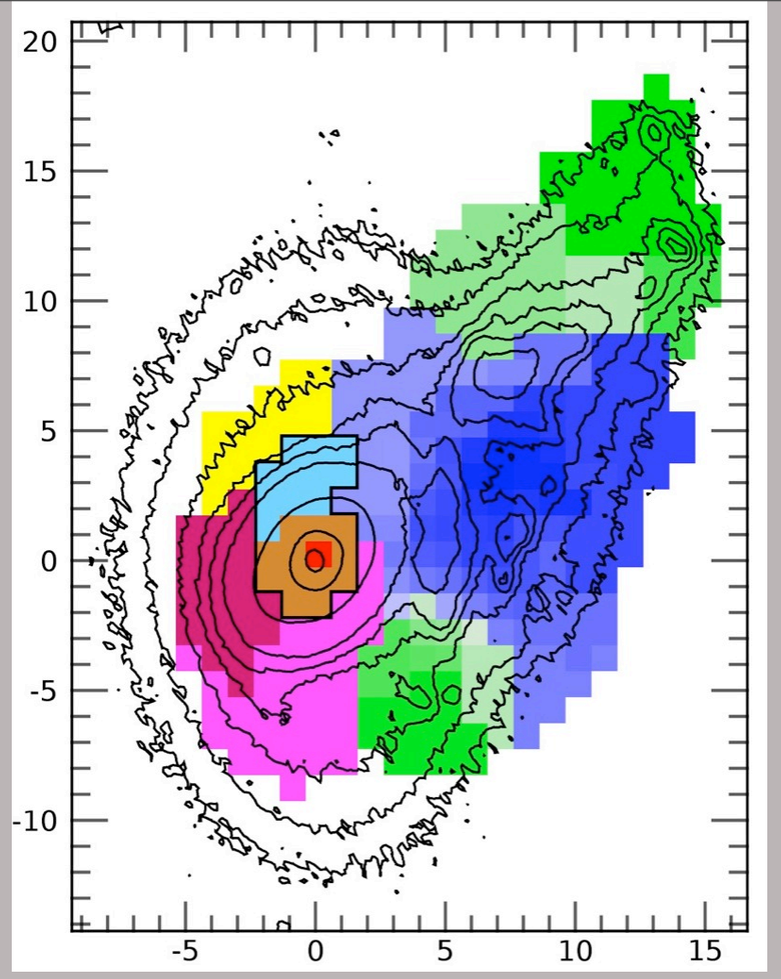
- region of very strong [OIII] emission in ShaSS-622
- border of highly ionized area resembling a conic section

intersection of the ionization cone from the AGN with the gas disk of ShaSS-622



'hollow bi-cone' figure from Bae+2016

Physical properties of the gas



SNR=150 for the Hα line

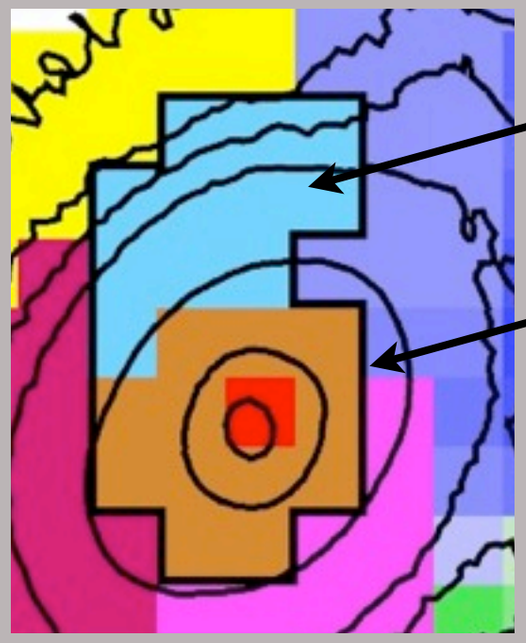
Weighted Voronoi Tessellation

73 regions

ShaSS-622: [OIII]/Hβ **decreasing ratios**

ShaSS-073: 3 disk regions, **centre** and 2 regions with the second component (**σ > 360 km s^{-1}**)

Area with 2 spectral components



'northern area': disk+blue-shifted gas

circum-nuclear: AGN+outflow

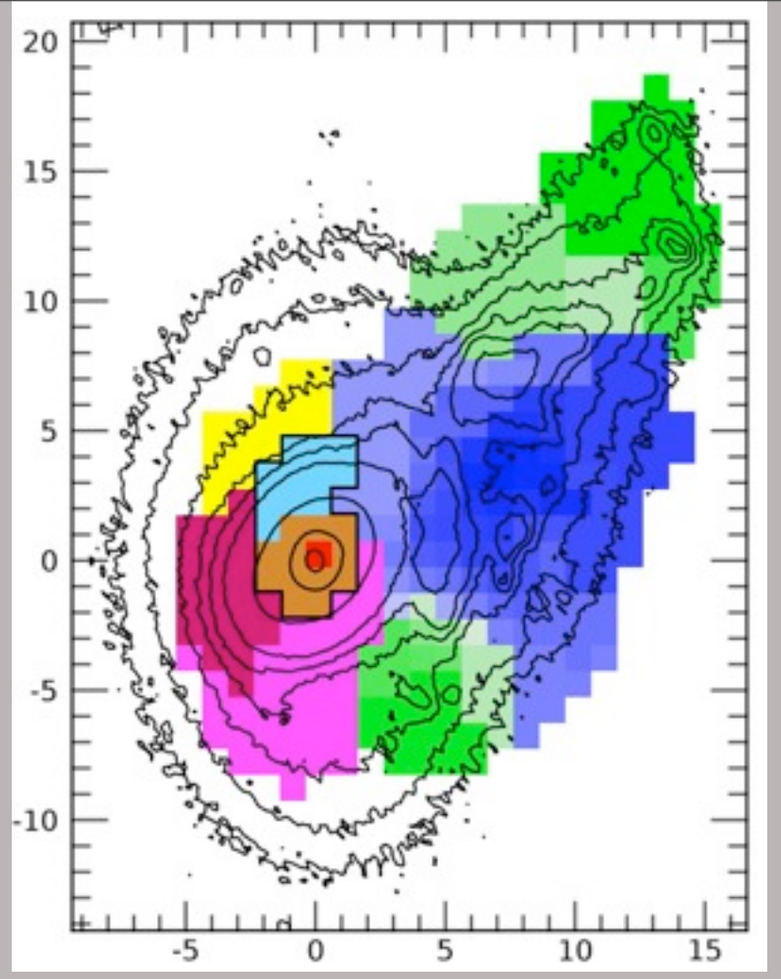
Physical properties of the gas

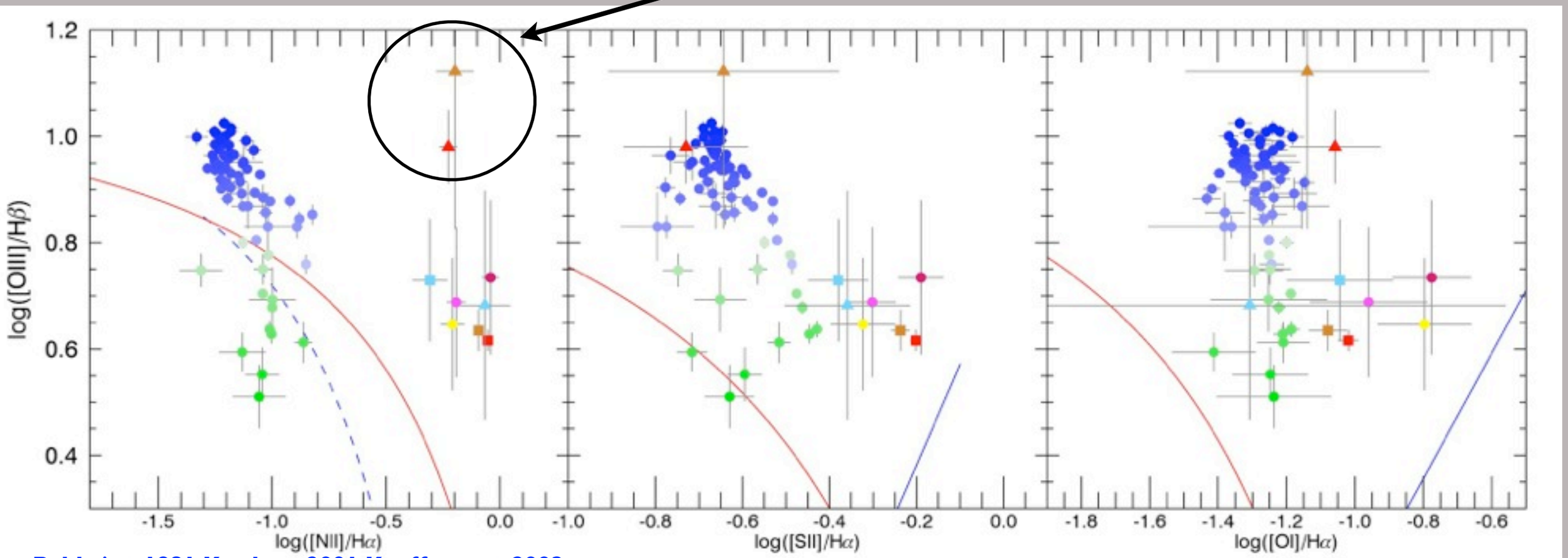
regions separate into distinct groups:

- regions of gas photoionized by star formation
- regions within the ionization cone in ShaSS-622 (log([OIII]/Hβ)~1)
- regions of ShaSS-073
  (□ main component, Δ second component)

Gas in ShaSS-073 is generally characterized by a lower excitation than the ionization cone...

with the notable exception of the gas in the outflow.

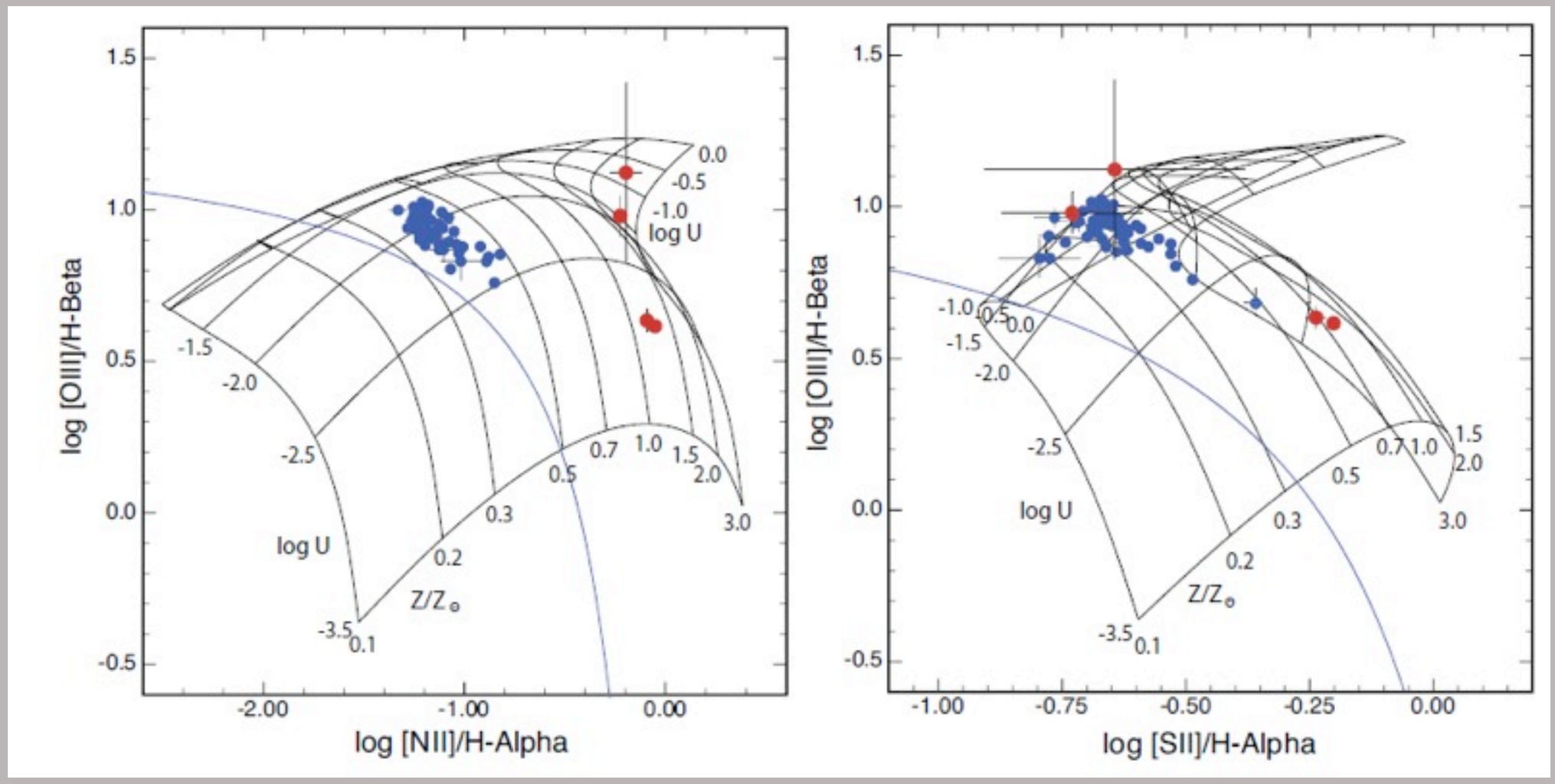




Baldwin+ 1981 Kewley+ 2001 Kauffmann+ 2003

Photoionization modelling

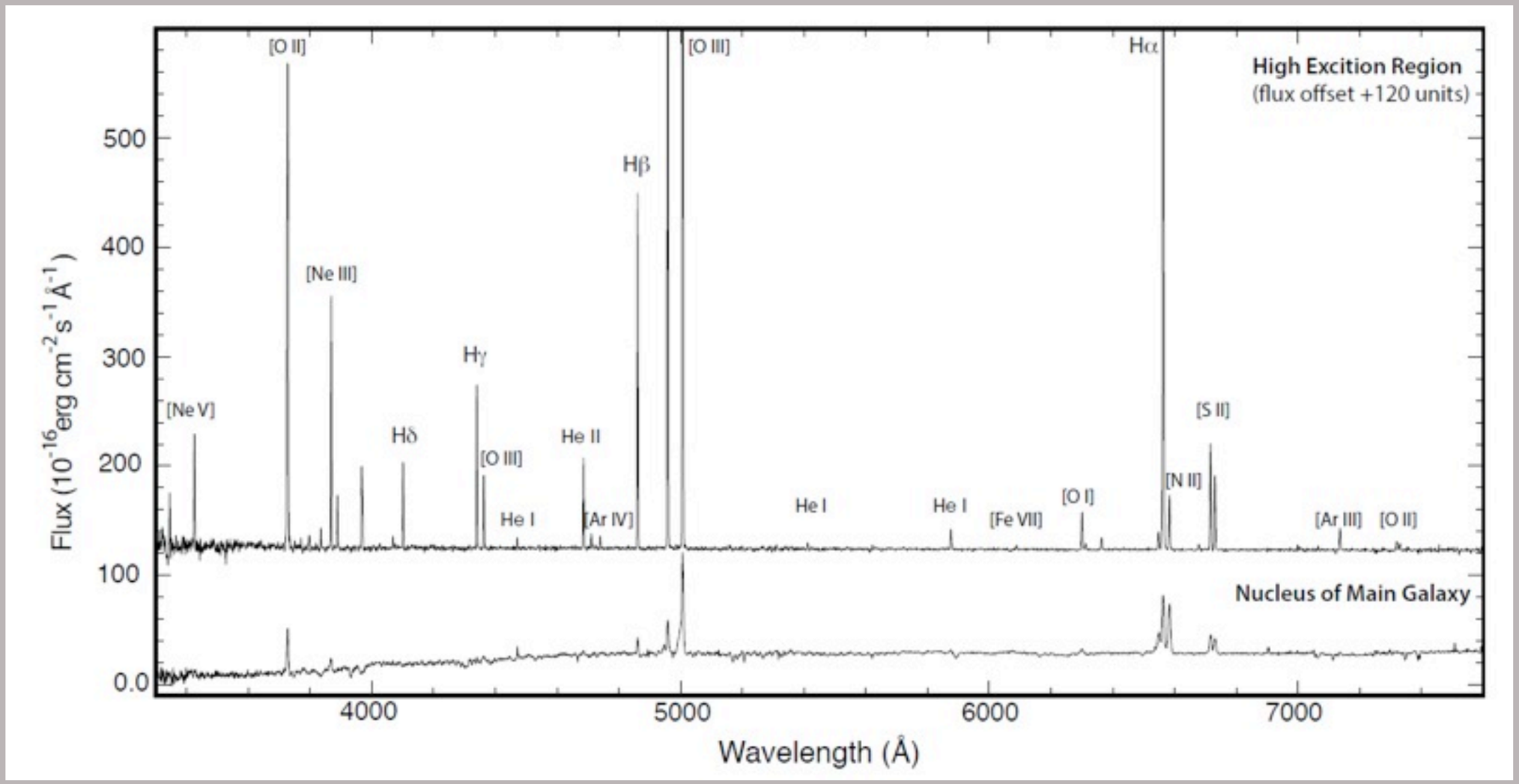
Theoretical AGN grid of models **Davies+ 2016**



ionization cone in ShaSS-622
AGN and outflow in ShaSS-073

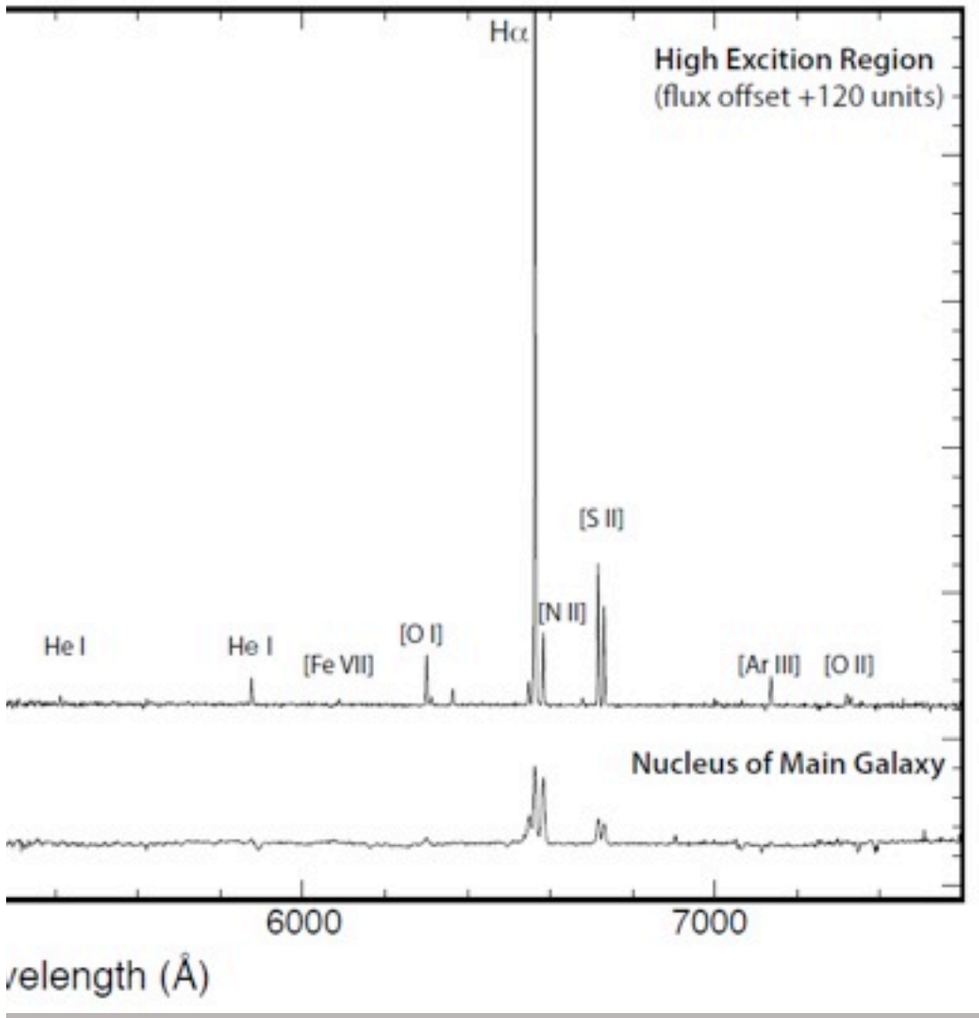
Confirming the different abundances in the two galaxies
ShaSS-073 1.5 solar
ShaSS-622 0.4 solar

Photoionization modelling



nization modelling

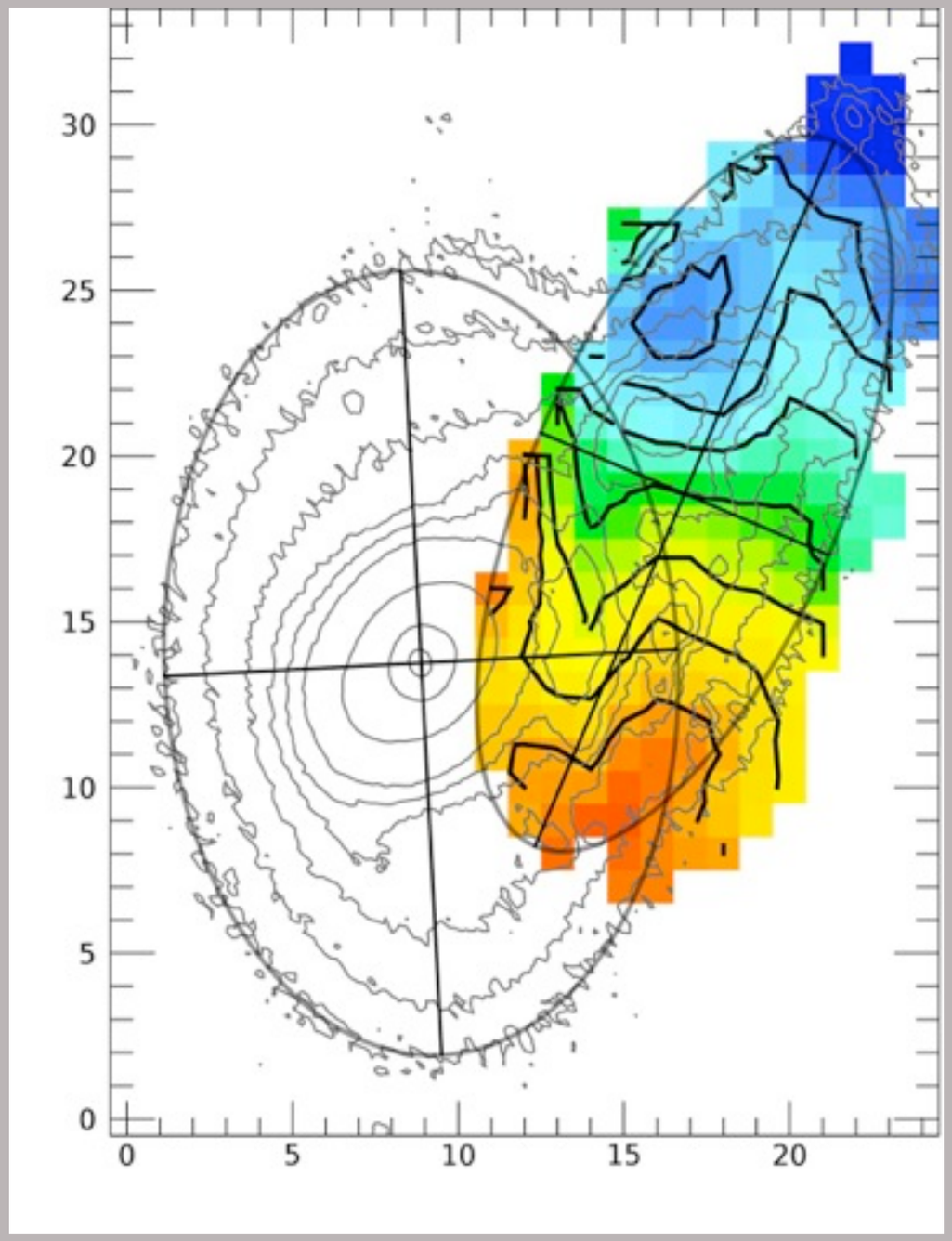
λ (Å)	Line ID	Ionization cone		H II regions		
		Observed	Model	H II #1	H II #2	Model
3346	[Ne V]	13.19 ± 0.30	8.39			
3426	[Ne V]	35.50 ± 0.41	23.50			
3729	[O II]			252.7 ± 6.5	201.5 ± 3.2	355.0
3738	[O II]	240.8 ± 1.6	160.84			
3869	[Ne III]	73.07 ± 1.13	84.67	21.8 ± 3.3	26.0 ± 1.4	52.9
3889	Hζ			13.1 ± 1.8	12.8 ± 1.7	10.5
3967	[Ne III]	24.42 ± 0.63	25.51			
3970	Hε	14.82 ± 1.96	15.40			
3889	Hζ			13.1 ± 1.8	12.8 ± 1.7	10.5
4068	[S II]	3.1 ± 0.53	1.80			
4076	[S II]	1.0 ± 0.50	0.58			
4102	Hδ	24.48 ± 1.60	25.20	29.8 ± 1.5	23.8 ± 1.2	25.8
4340	Hγ	45.96 ± 0.11	46.74	48.7 ± 1.9	42.2 ± 1.6	47.0
4363	[O III]	21.31 ± 0.17	20.65	8.7 ± 3.4	0.4 ± 0.4	4.2
4471	He I	2.80 ± 0.17	2.81			
4686	He II	26.4 ± 0.39	33.58			
4711	[Ar IV]	4.12 ± 0.13	5.73			
4740	[Ar IV]	3.45 ± 0.20	4.34			
4861	Hβ	100 ± 0.80	100	100.0 ± 2.4	100.0 ± 2.6	100.0
4959	[O III]	292.3 ± 0.55	331.0	116.4 ± 2.4	109.2 ± 2.6	120.2
5007	[O III]	876.3 ± 0.70	956.7	349.1 ± 4.5	327.5 ± 5.4	347.4
5200	[N I]	1.25 ± 0.60	2.85			
5876	He I	7.49 ± 0.10	7.30	8.4 ± 1.3	14.2 ± 2.1	11.5
6087	[Fe VII]	1.45 ± 0.26	0.44			
6300	[O I]	14.43 ± 1.07	12.19	10.0 ± 2.0	7.1 ± 3.9	5.6
6312	[S III]	2.89 ± 0.69	8.42			
6364	[O I]	4.56 ± 0.36	3.90	6.4 ± 1.6	3.3 ± 0.9	1.8
6548	[N II]	7.26 ± 0.65	5.11	4.1 ± 2.3	7.4 ± 3.5	7.1
6563	Hα	285.8 ± 0.30	293.8	286.0 ± 4.5	286.0 ± 5.5	285.5
6583	[N II]	21.27 ± 0.96	15.09	12.2 ± 3.0	22.1 ± 3.0	20.2
6678	He I	2.13 ± 0.50	2.06	4.9 ± 2.0	7.0 ± 3.5	3.2
6716	[S II]	39.65 ± 0.43	26.58	33.9 ± 3.5	48.9 ± 4.5	23.3
6731	[S II]	27.81 ± 0.35	18.84	22.9 ± 2.6	35.2 ± 3.5	19.7
7136	[Ar III]	8.80 ± 0.61	10.06			
7319	[O II]	3.54 ± 0.99	2.50			
7329	[O II]	2.34 ± 1.05	2.02			
7751	[Ar III]	1.89 ± 0.15	2.41			



Best fit model for the gas in the ionization cone:

- gas pressure of log(P/k) = 6. 2 cm^{-3} K
- ionization parameter log U = −2. 2
- recombination time-scale of 2500 yr for H and 23 yr for [OIII]

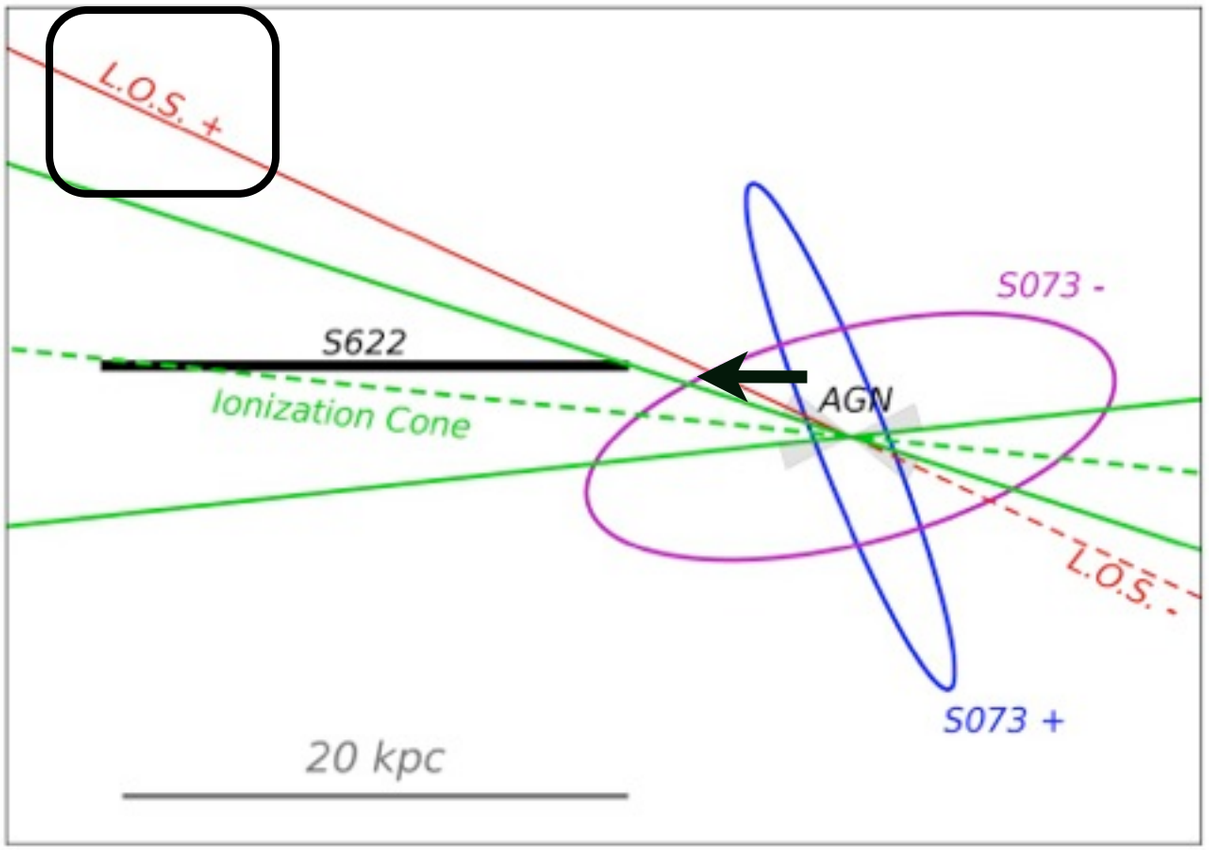
Structure of the ShaSS-073_622 system



unperturbed gas velocity field → the gas still lies in the galactic plane → **flat projection screen**

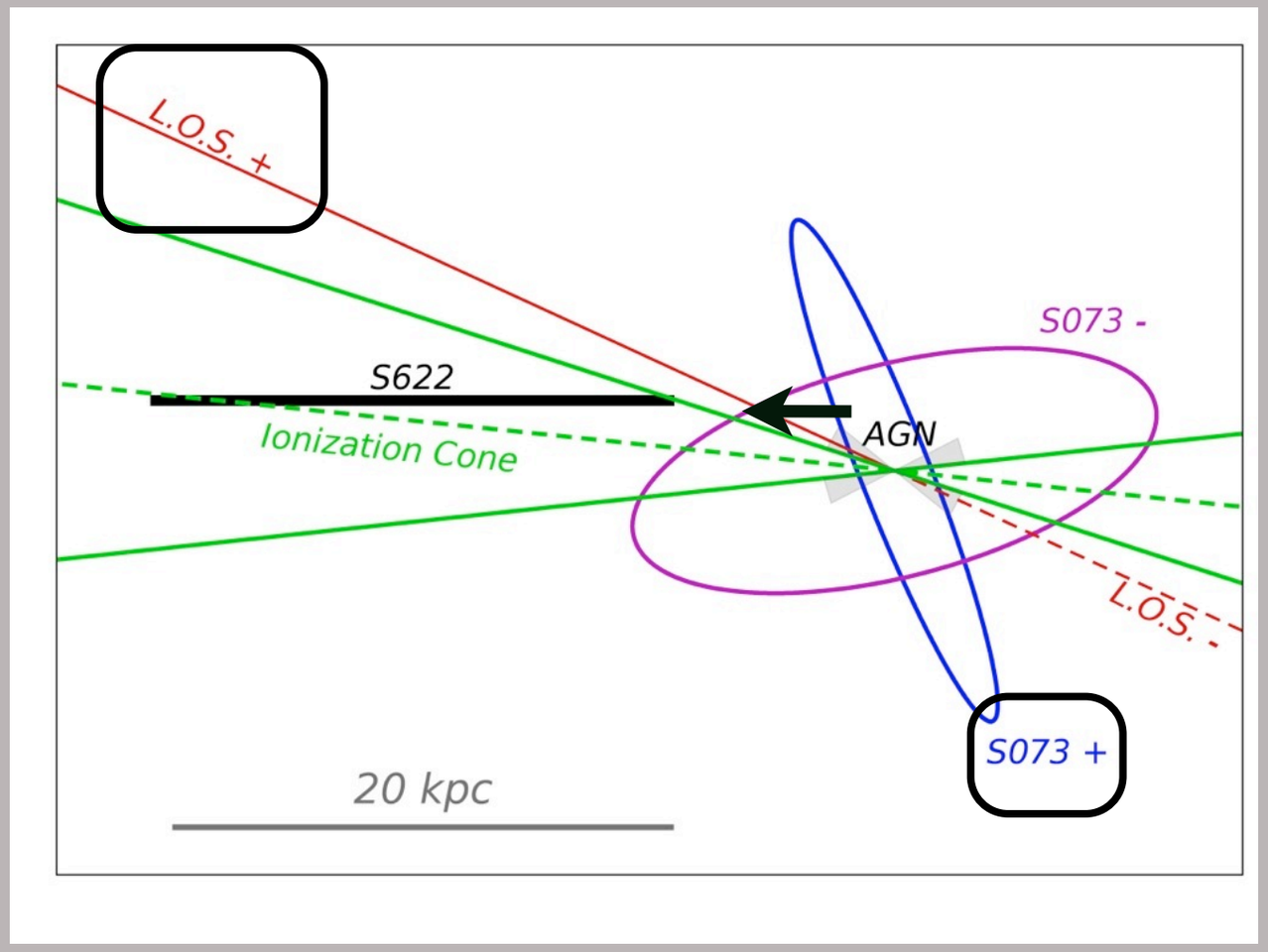
Properties of the disks + shape of the illuminated area in ShaSS-622 → direction of the AGN

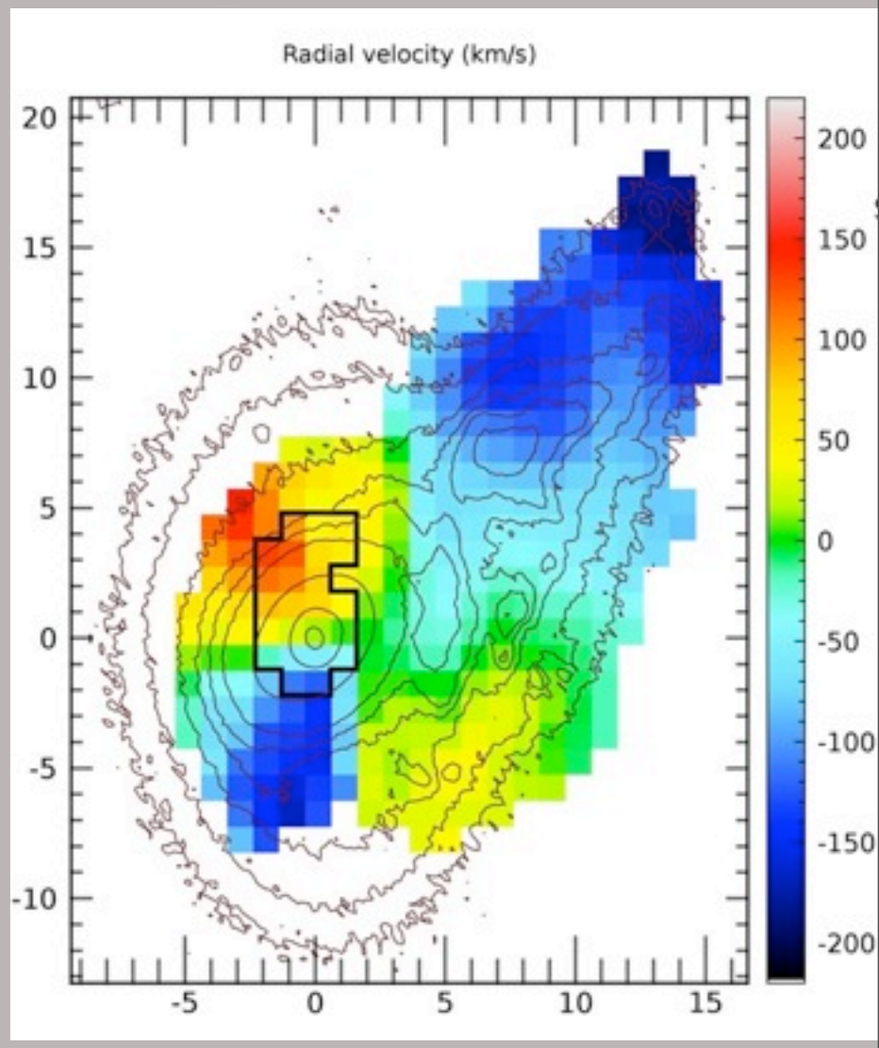
Structure of the ShaSS-073_622 system

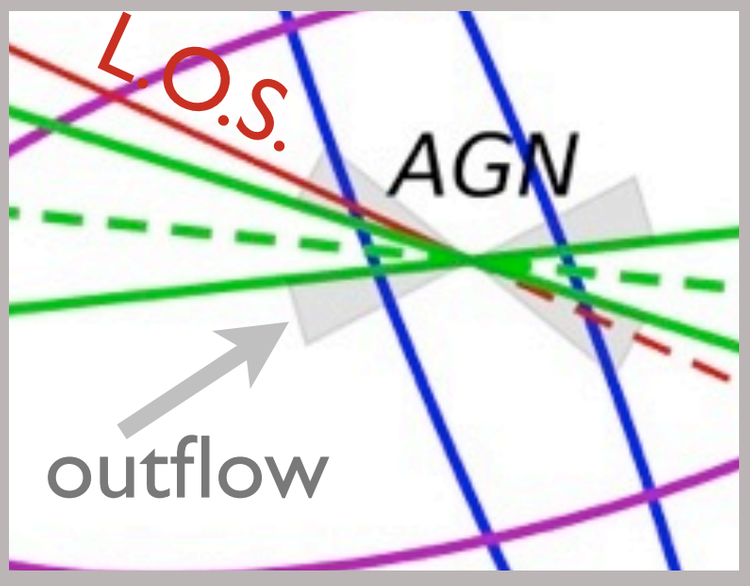


	$k_7 = -1$		$k_7 = +1$
distance between the centers of the galaxies		21 kpc *[19-24]*	
distance along the line of sight		19 kpc *[17-22]*	
angle between their disks	27° *[22-32]*		69° *[63-75]*
semi-aperture of ionization cone		12° *[12-15]*	
angle between ShaSS 073 axis and cone axis	71° *[66-78]*		28° *[21-34]*
angle between cone axis and line of sight		22° *[20-25]*	
angle between the cone axis and the disk of ShaSS 622		6° *[2-10]*	

Structure of the ShaSS-073_622 system







	$k_7 = -1$	$k_7 = +1$
distance between the centers of the galaxies	21 kpc *[19-24]*	
distance along the line of sight	19 kpc *[17-22]*	
angle between their disks	27° *[22-32]*	69° *[63-75]*
semi-aperture of ionization cone	12° *[12-15]*	
angle between ShaSS 073 axis and cone axis	71° *[66-78]*	28° *[21-34]*
angle between cone axis and line of sight	22° *[20-25]*	
angle between the cone axis and the disk of ShaSS 622	6° *[2-10]*	

Allocating the AGN radiation power

Can the AGN ionize the gas in ShaSS-622 at the observed level?

[OIII] in the ionization cone to estimate the AGN luminosity

⬇

integrated [OIII] λ5007 flux in the ionization cone region: **2.25×10^{42} erg s^{-1}**

⬇

geometric model: **Ω=0.0686**

⬇

total omnidirectional [OIII] flux: **4.12×10^{44} erg s^{-1}**

●

[OIII] line is 8.87% of the bolometric flux

⬇

requested luminosity of the AGN: **log L = 45.66 erg s^{-1}**

to compare with log L = 44.39 erg s^{-1}

Conclusions

AGN luminosity required to ionize the gas in the ShaSS-622 disk
vs.
bolometric luminosity given by the SED fit

⬇

the AGN radiation required to excite the gas inside the ionization cone in ShaSS-622 is ~20 times the current luminosity of the AGN

the light travel time from the AGN to the disk of ShaSS-622 is ~3 x10^4 yr
+
the gas recombination time is very short compared to the light travel time

⬇

AGN luminosity has dropped by a factor 20 within the last ~3 x10^4 yr

First light echo between galaxies

→ **EELRs around local AGNs are tidal debris**
→ **is ShaSS_073-622 the progenitor of a GB and HV-like object?**

Merluzzi+ 2017 ApJ, in press