Intergalactic sites of star formation in the vicinity of interacting galaxies

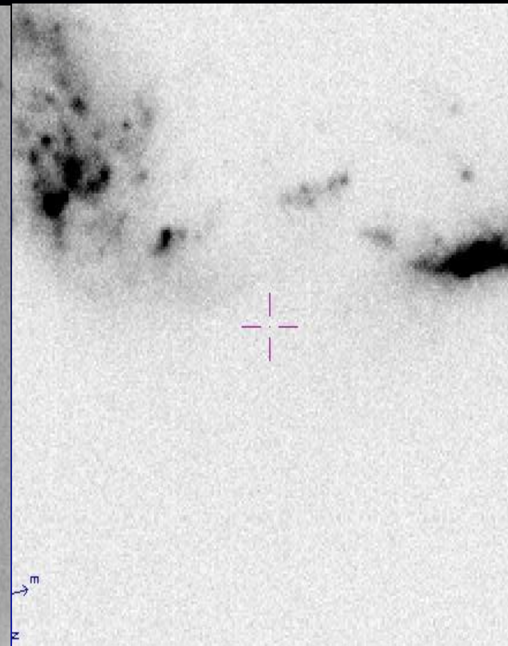
- **A.V.Zasov**

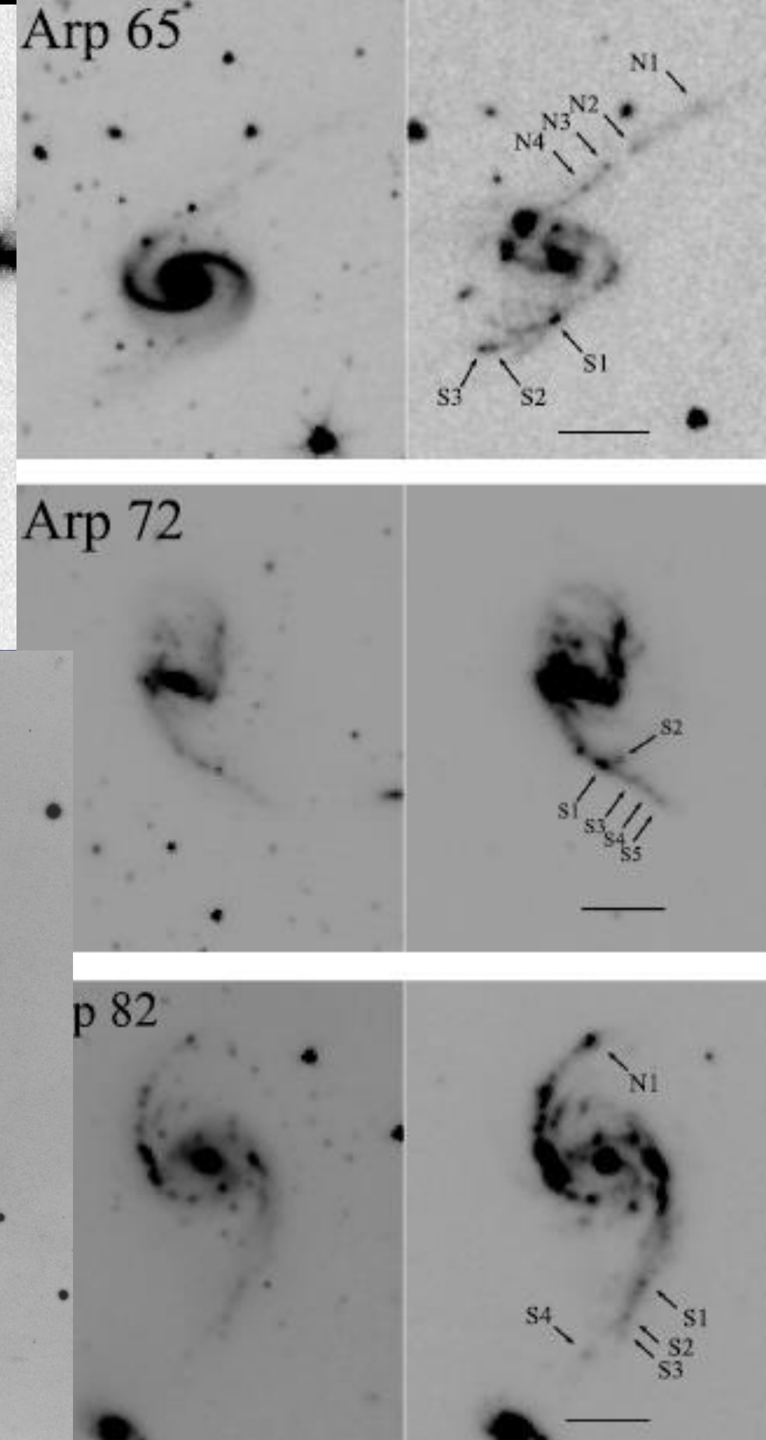
in collaboration with

A.S.Saburova, I.Katkov, O.Egorov, R.Uklein, V.Afanasiev.

Topics

1. Different types of extragalactic sites of star formation in the interacting systems.
2. A study of tidal dwarfs candidates and their fate : systems Arp270, Arp194 and NGC4631+UVdwarf.
3. Some general conclusions.




Arp 65
N1
N2
N3
N4
S1
S3
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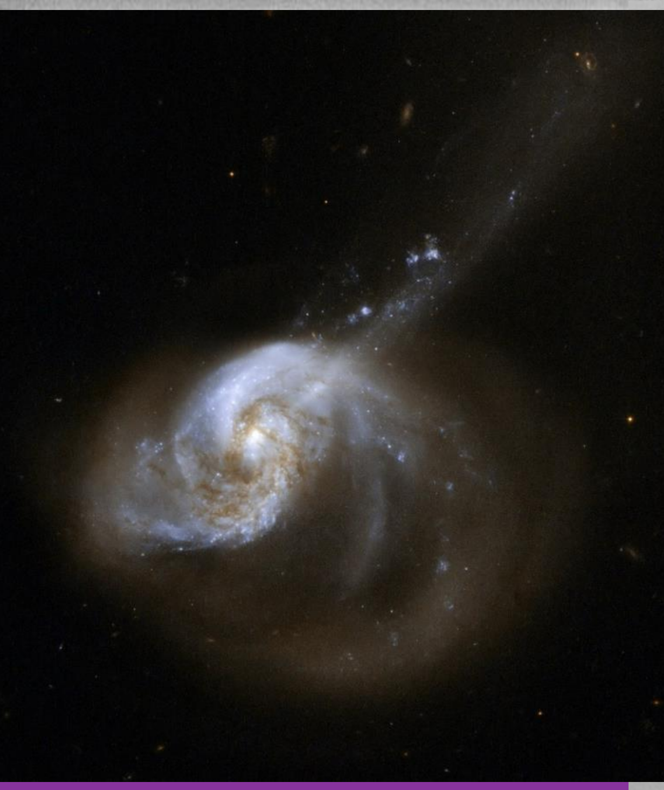
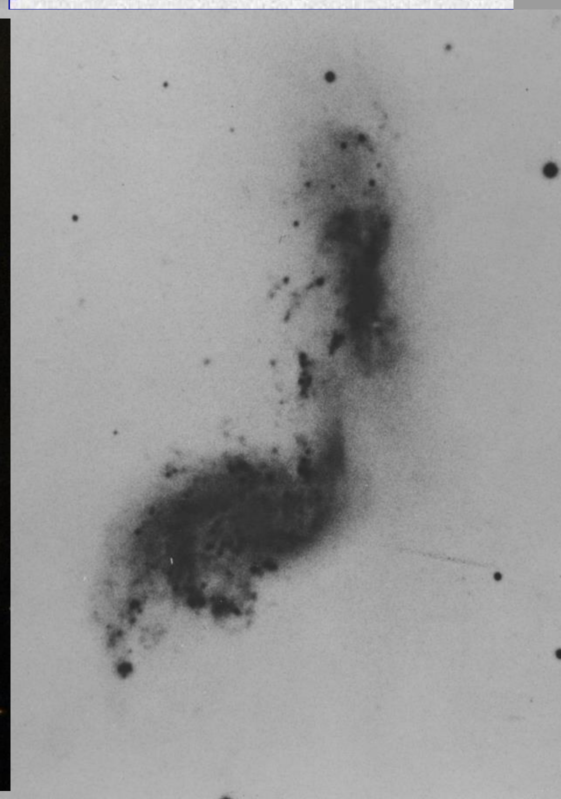
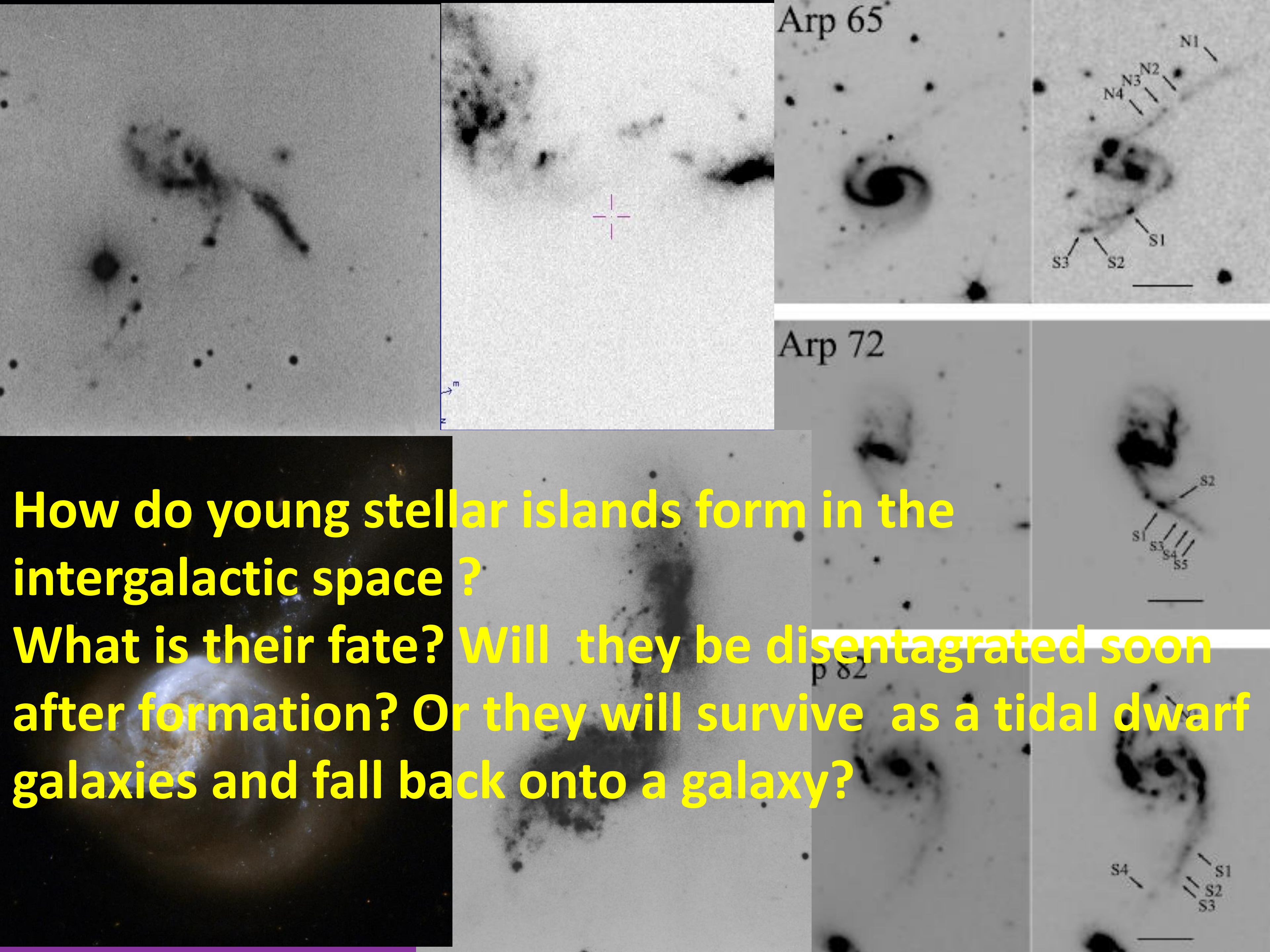
Arp 72
S2
S1
S3
S4
S5
p 82
N1
S4
S1
S2
S3







How do young stellar islands form in the intergalactic space ?
What is their fate? Will they be disentagrated soon after formation? Or they will survive as a tidal dwarf galaxies and fall back onto a galaxy?

Mechanisms stimulating the extragalactic star formation:

1. Gravitational condensation of gas , tidally thrown away from a galaxy.

Mean gas density is too low. Hightly inhomogeneous medium is needed.

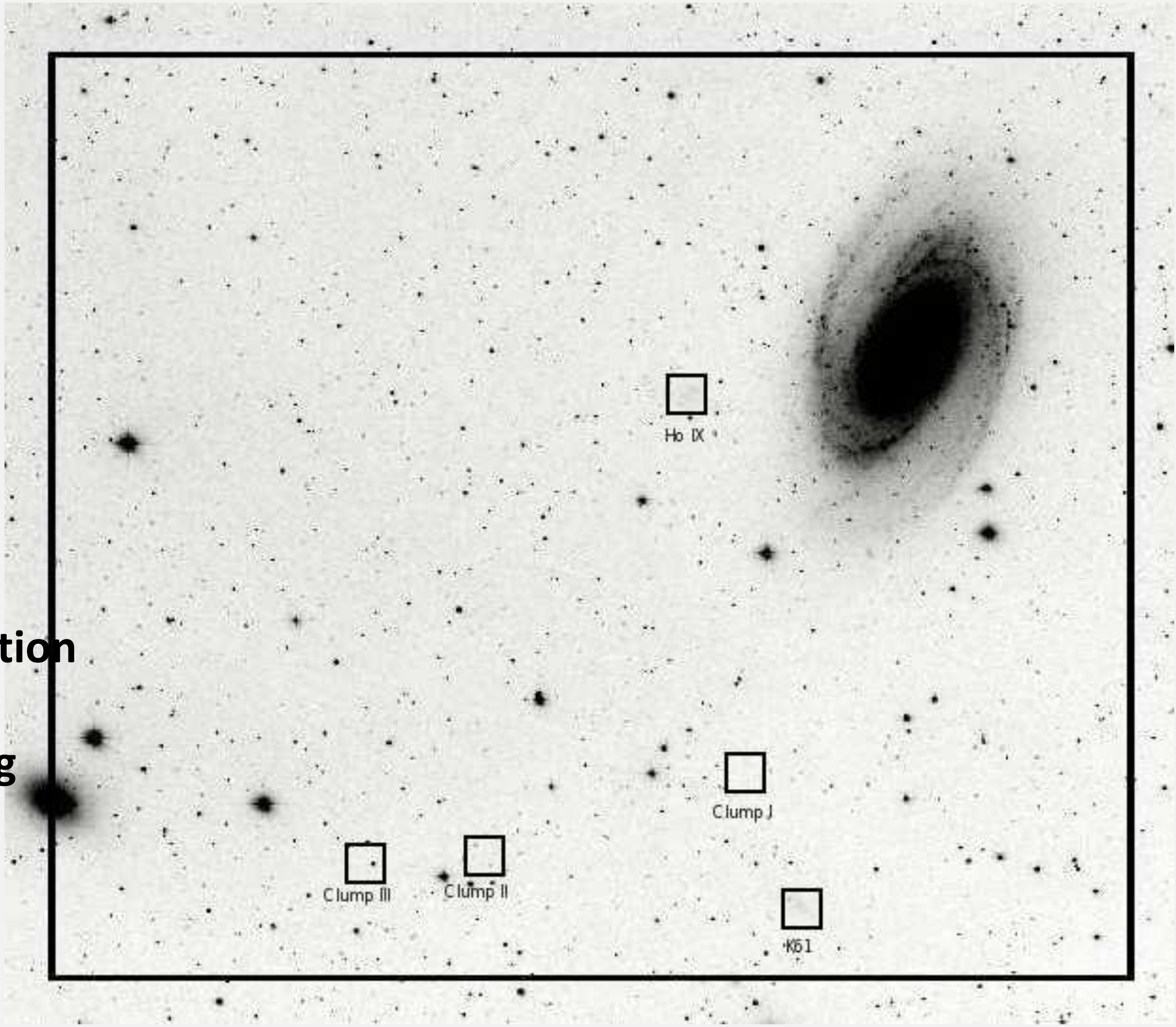
2. Delayed star formation inside of long -lived clouds, tidally separated from a galaxy

Good to explain small single spots of SF separated from a galaxy.

3. Shock waves: a collision of gas flows (caustics?) or the interaction between the expelled gas and halo gas.

This is the most probable mechanism of intergalactic star formation we observe.

Type 1
Isolated emission knots: tiny areas of SF

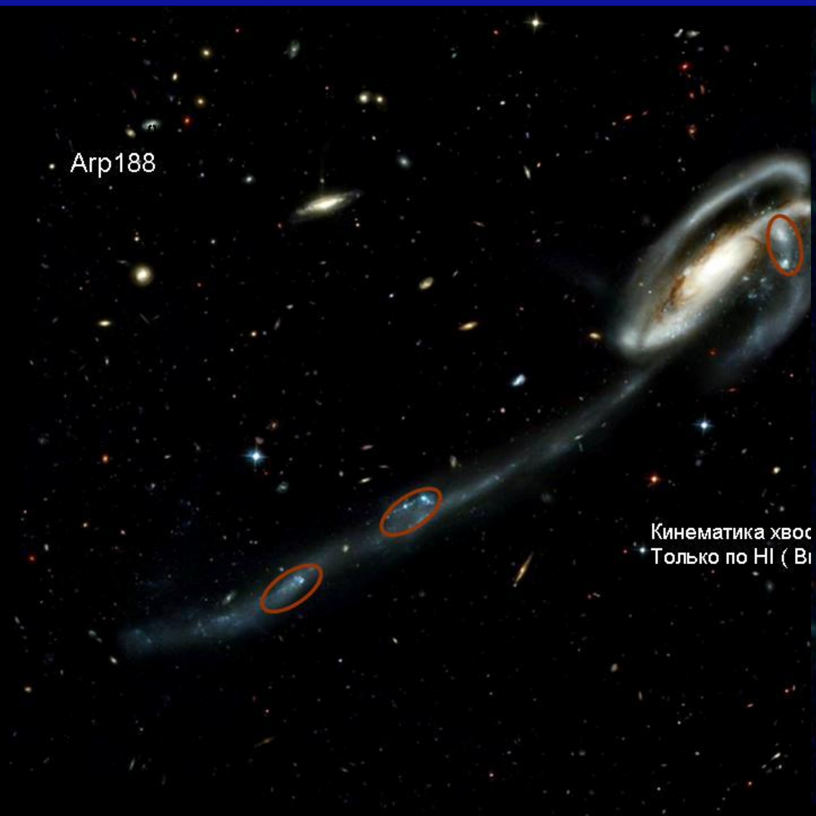


Taken from:
Karachentsev et al.,2011

A delay time of star formation ~ 10^8 -10^9 yr (otherwise some triggering mechanism is needed).

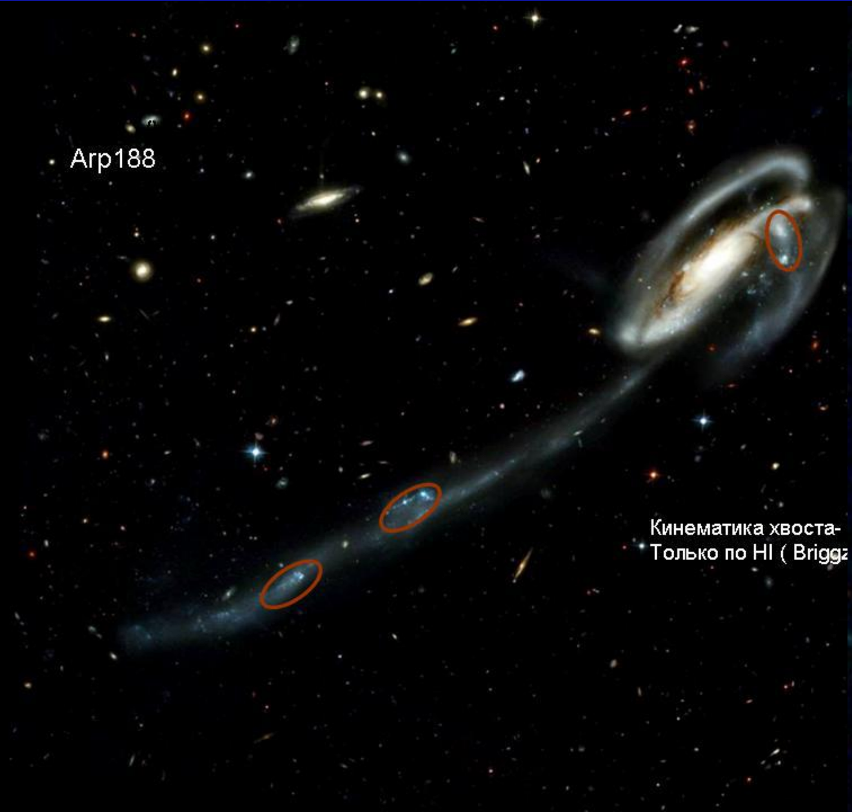
Type 2
SF sites in the extended tidal tails

- Gravitational instability may work only in the most dense regions of gaseous tails (such regions are really observed)
- Surface density of gas in the region of the obserbed SF is $\Sigma HI \geq 10^{21}$ cm^{-2},
- Velocity dispersion of HI : C ≥ 10 km/s (Mullan et al, 2013)



Type 2
SF sites in the extended tidal tails

$t_{ff} \geq 10^8$ yr, $M_J \geq 10^8 M_{sun}$,
which is compatible with observational data

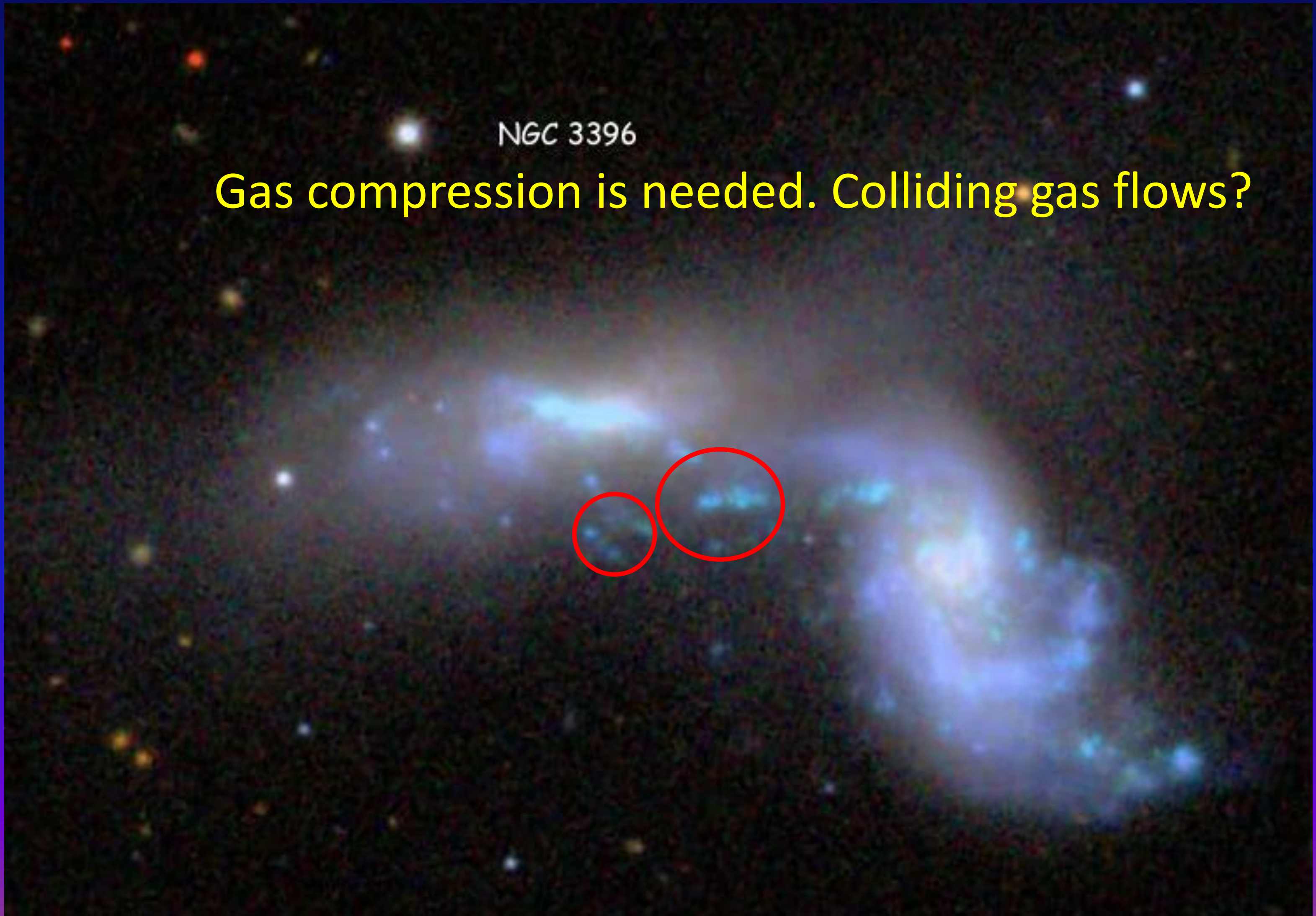


Type 3

kpc-size islands of young stars between galaxies

Type 3

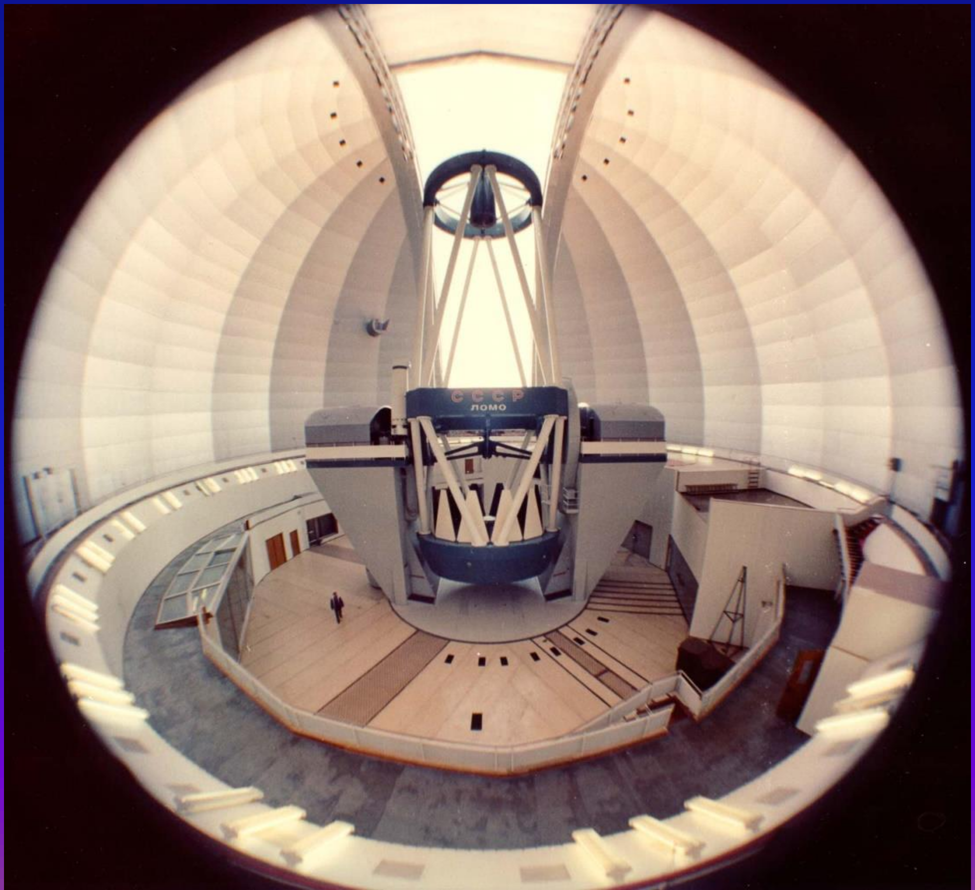
kpc-size islands of young stars between galaxies



OBSERVATIONS

BTA, Special Astrophysical Observatory
long-slit mode
Spectral camera/optical reducer
SCORPIO 1-2 in the main focus of BTA

Data processing:
see f.e.
A. Zasov, A. Saburova, I. Katkov,
O. Egorov, V. Afanasiev,
MNRAS, 2015
Observers:
V.Aafanasiev, S.Dodonov,
R.Uklein (SAO RAN), I.Katkov (SAI).

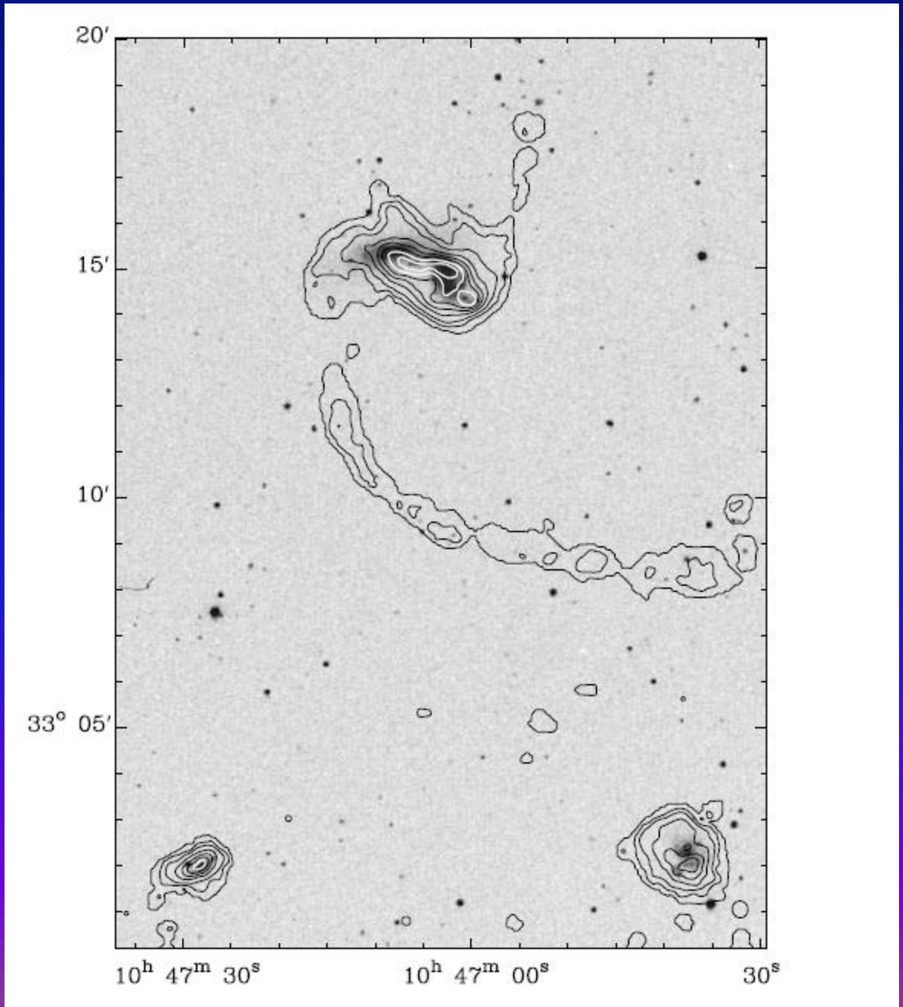


OBSERVATIONS.

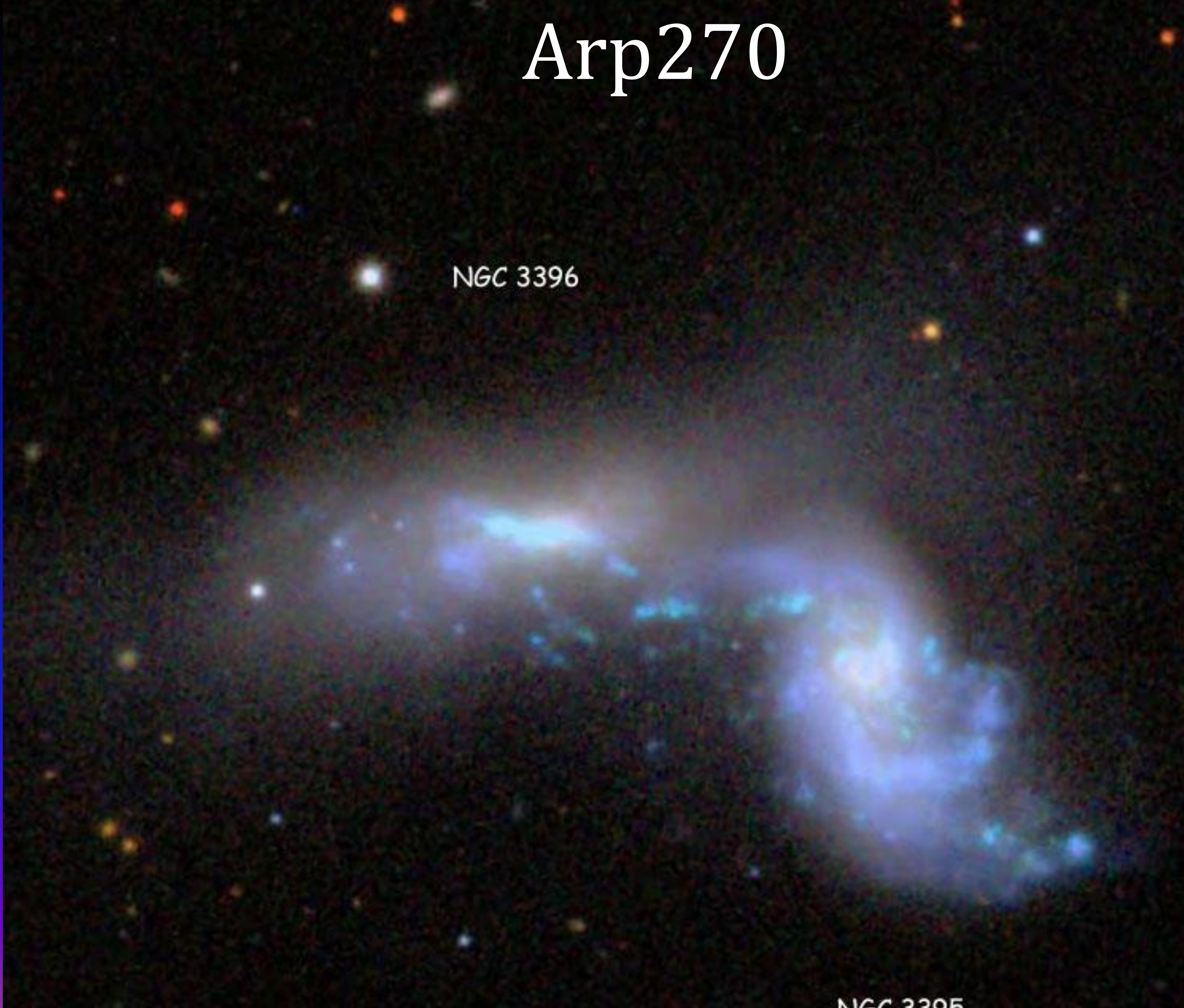
I. Interacting system Arp270

Clemens et al, 1999

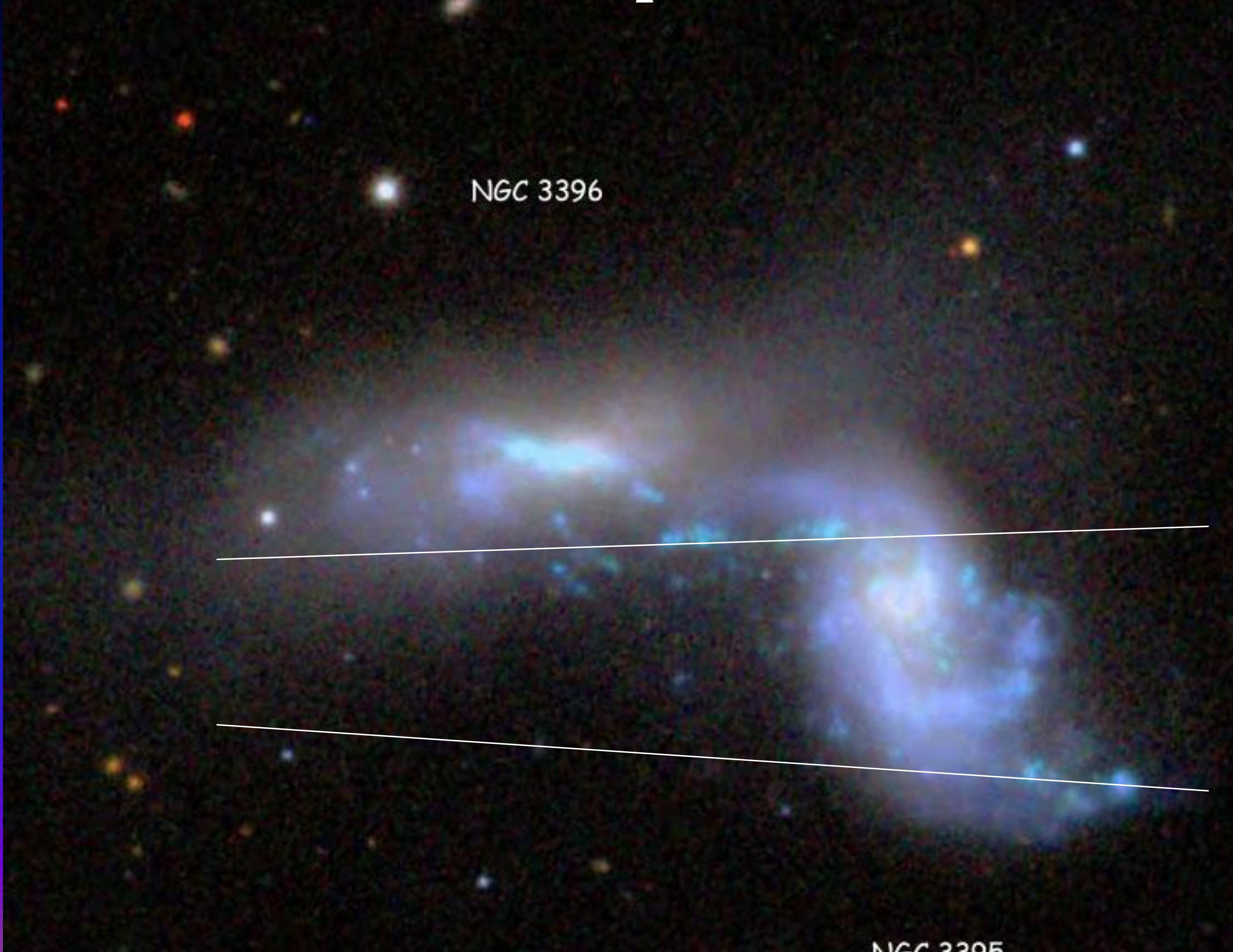
This system have already experienced a strong tidal interaction~ $5 \cdot 10^8$ yr ago.

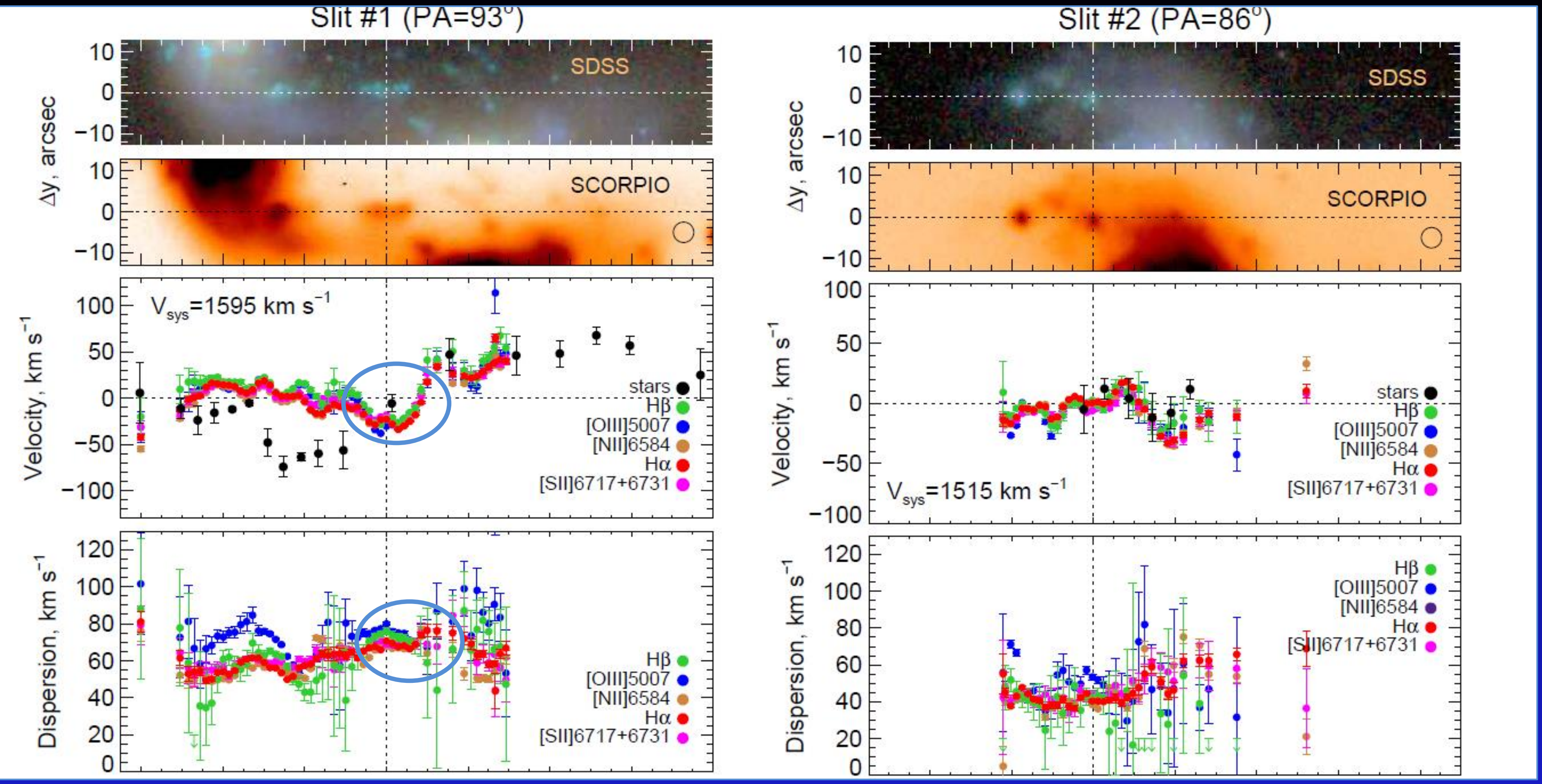


Arp270



Arp270

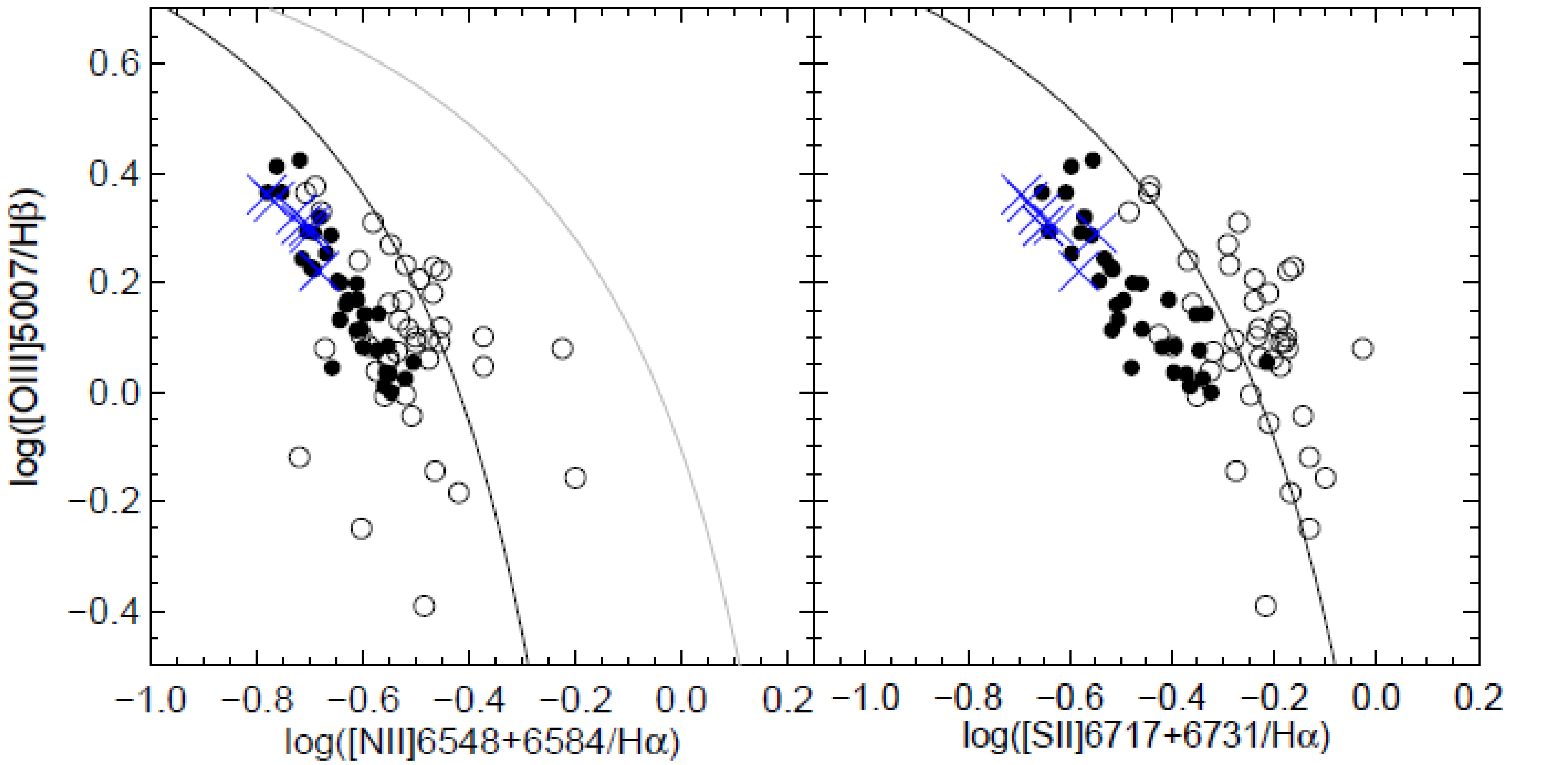




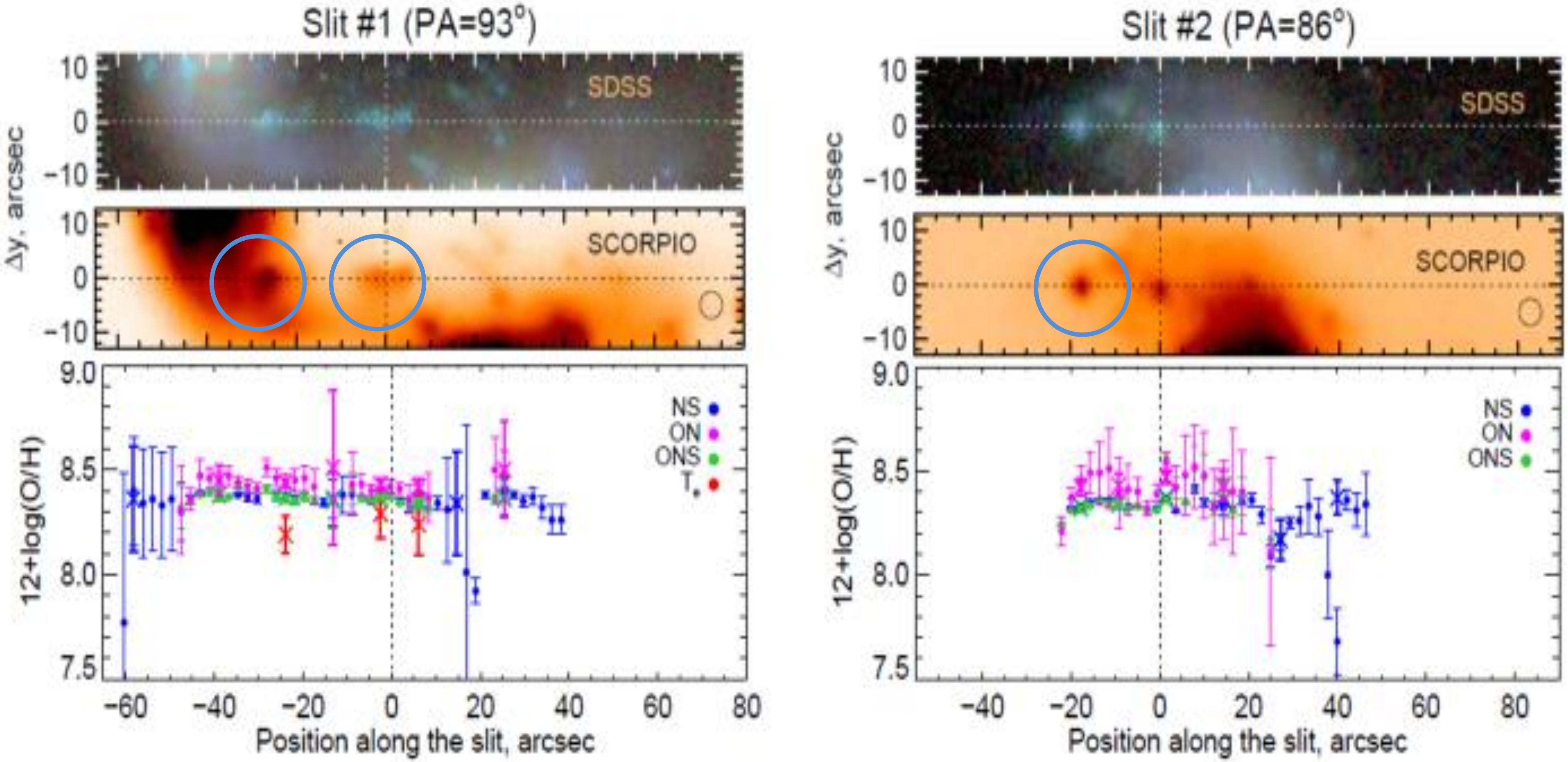
Velocity dispersion of emission gas remains high even in the low intensity regions, which evidences a strong turbulent gas motion between galaxies.

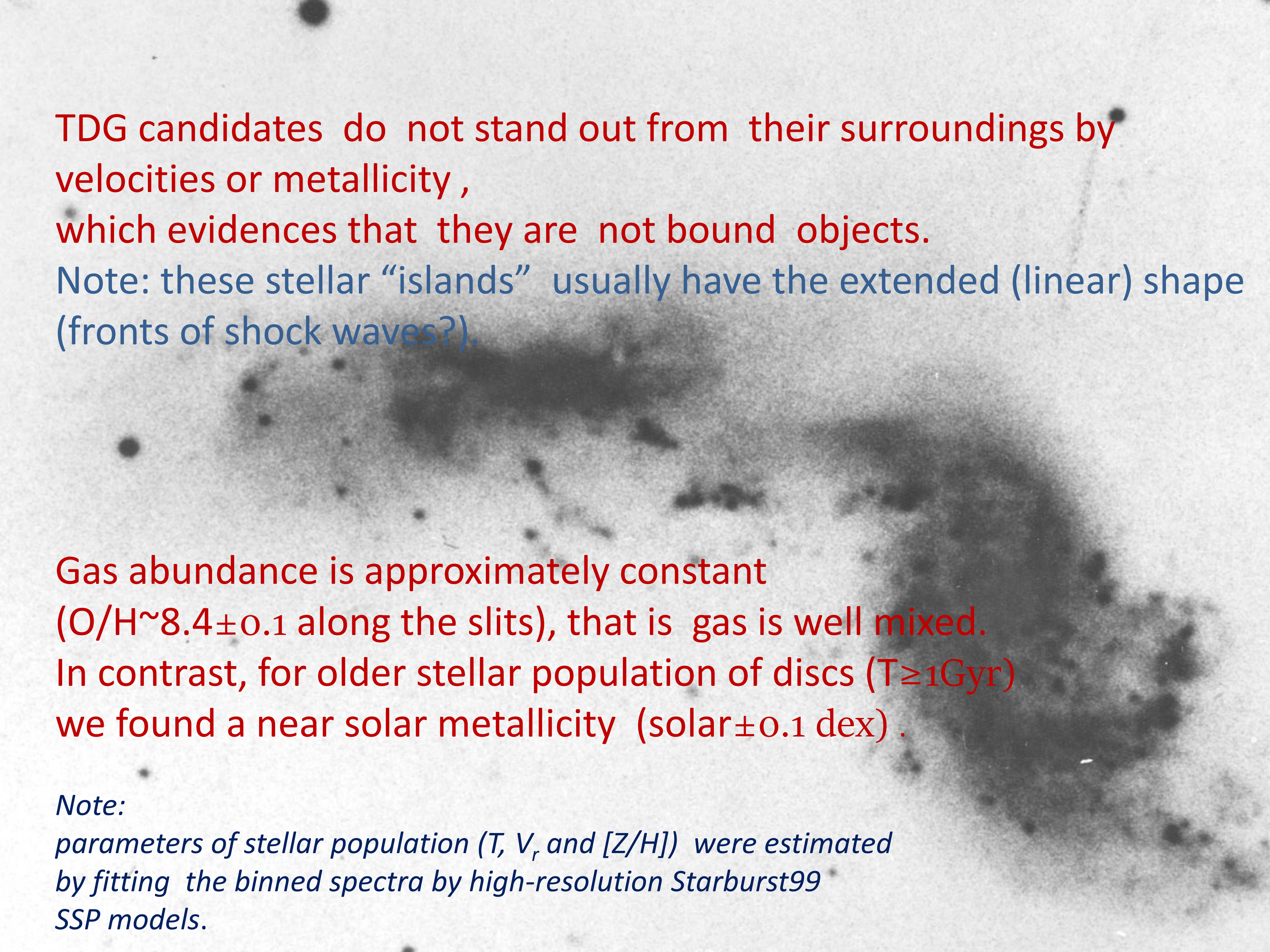
The largest TDG lays near the border separated gas systems of two galaxies.

Diagnostic diargams for ARP270



Circles denote “faint beams”


Slit #1 (PA=93°)
SDSS
SCORPIO
Δy, arcsec
12+log(O/H)
NS
ON
ONS
Tₑ
Position along the slit, arcsec
Slit #2 (PA=86°)
SDSS
SCORPIO
Δy, arcsec
12+log(O/H)
NS
ON
ONS
Position along the slit, arcsec



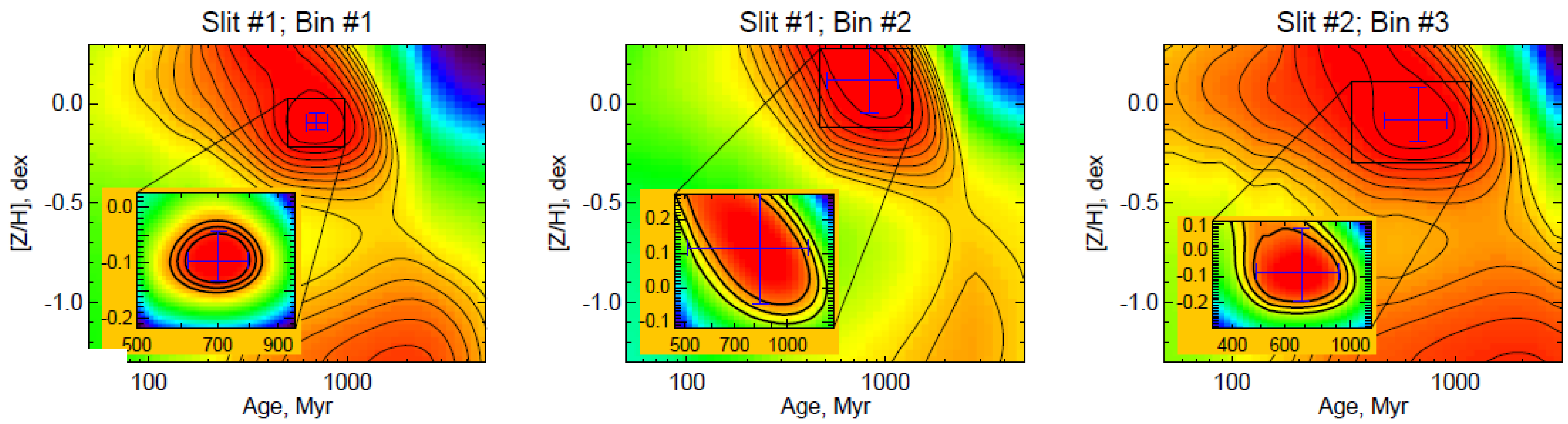
TDG candidates do not stand out from their surroundings by velocities or metallicity ,
which evidences that they are not bound objects.

Note: these stellar "islands" usually have the extended (linear) shape (fronts of shock waves?).

Gas abundance is approximately constant
(O/H~8.4±0.1 along the slits), that is gas is well mixed.
In contrast, for older stellar population of discs (T≥1Gyr)
we found a near solar metallicity (solar±0.1 dex) .

Note:
parameters of stellar population (T, V_r and [Z/H]) were estimated by fitting the binned spectra by high-resolution Starburst99 SSP models.

χ2-map in the plane “age-metallicity”



χ^2-maps in the age-metallicity plane for different binned regions along slits. Black contours at the zoomed subregion of χ^2 espond to 1σ, 2σ, 3σ confidence levels. Blue error bars in both maps are computed by using 1σ level contour.

. Stellar population properties

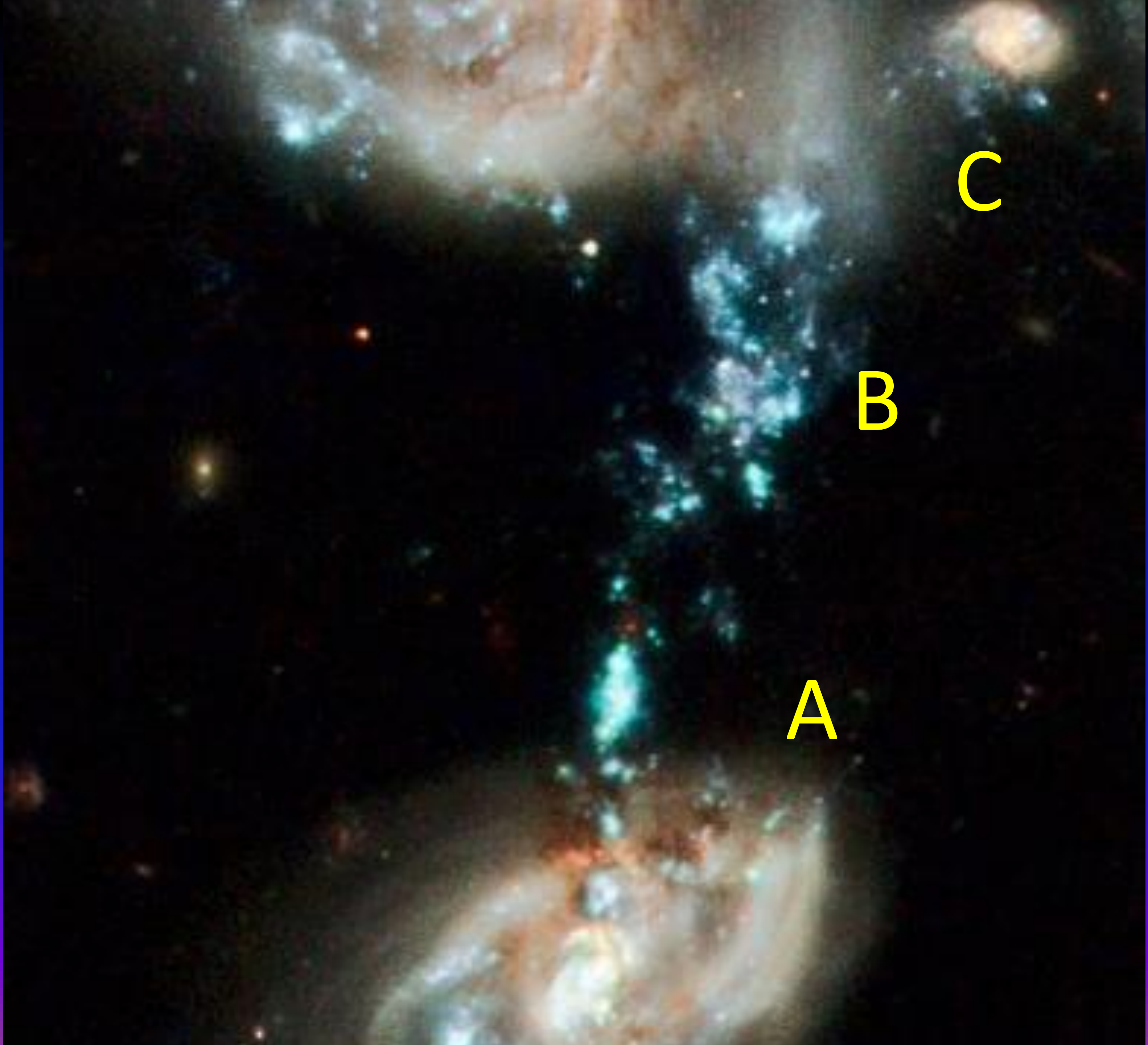
Slit	Bin	Position (arcsec)	S/N	T_{SSP} (10^6 yr)	$[Z/H]_{SSP}$ (dex)
№ 1 (PA=93°)	№ 1	[-52,-16]	20.3	702^{+93}_{-82}	$-0.10^{+0.05}_{-0.04}$
№ 1 (PA=93°)	№ 2	[16, 77]	5.5	832^{+326}_{-325}	$0.12^{+0.19}_{-0.16}$
№ 2 (PA=86°)	№ 3	[-22, 31]	7.0	683^{+235}_{-199}	$-0.08^{+0.17}_{-0.11}$

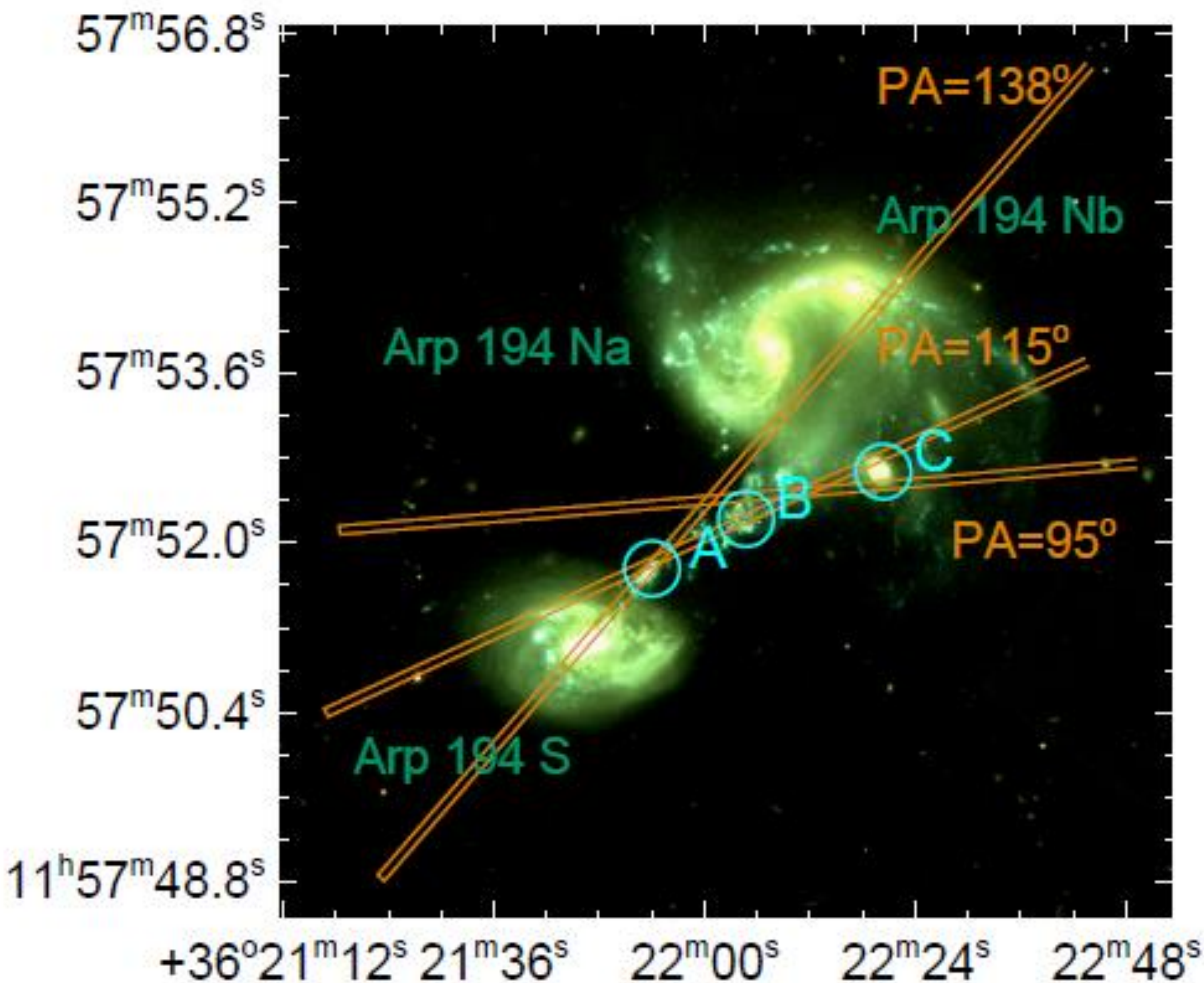
Paired galaxies may share a common halo (see f.e. Holmberg' effect).

The metallicity of gas in ARP270 is found to be lower than that of old stars!

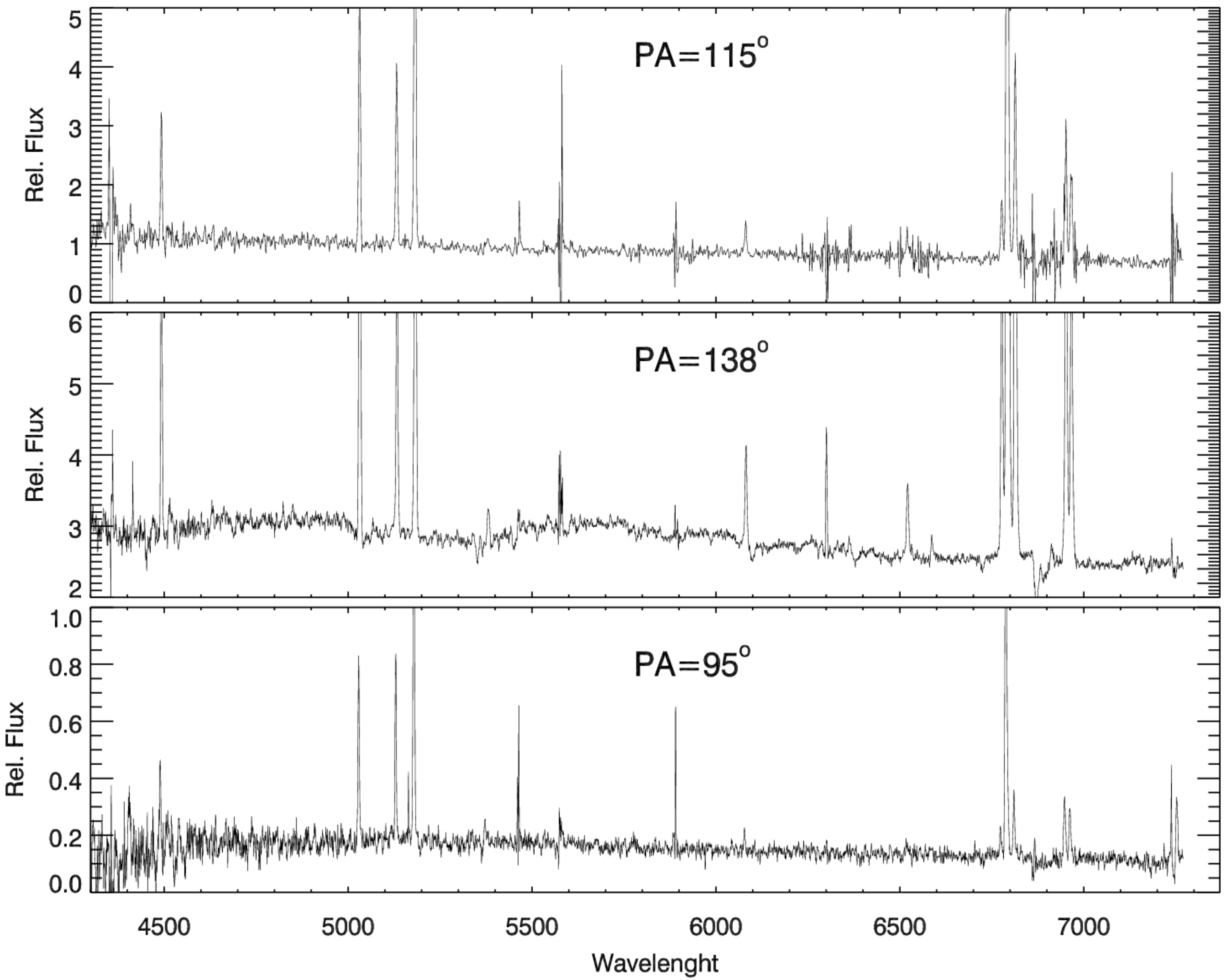
It is natural to propose that both galaxies have experienced the accretion of metal-deficient halo gas which have diluted the gas left in galaxies.

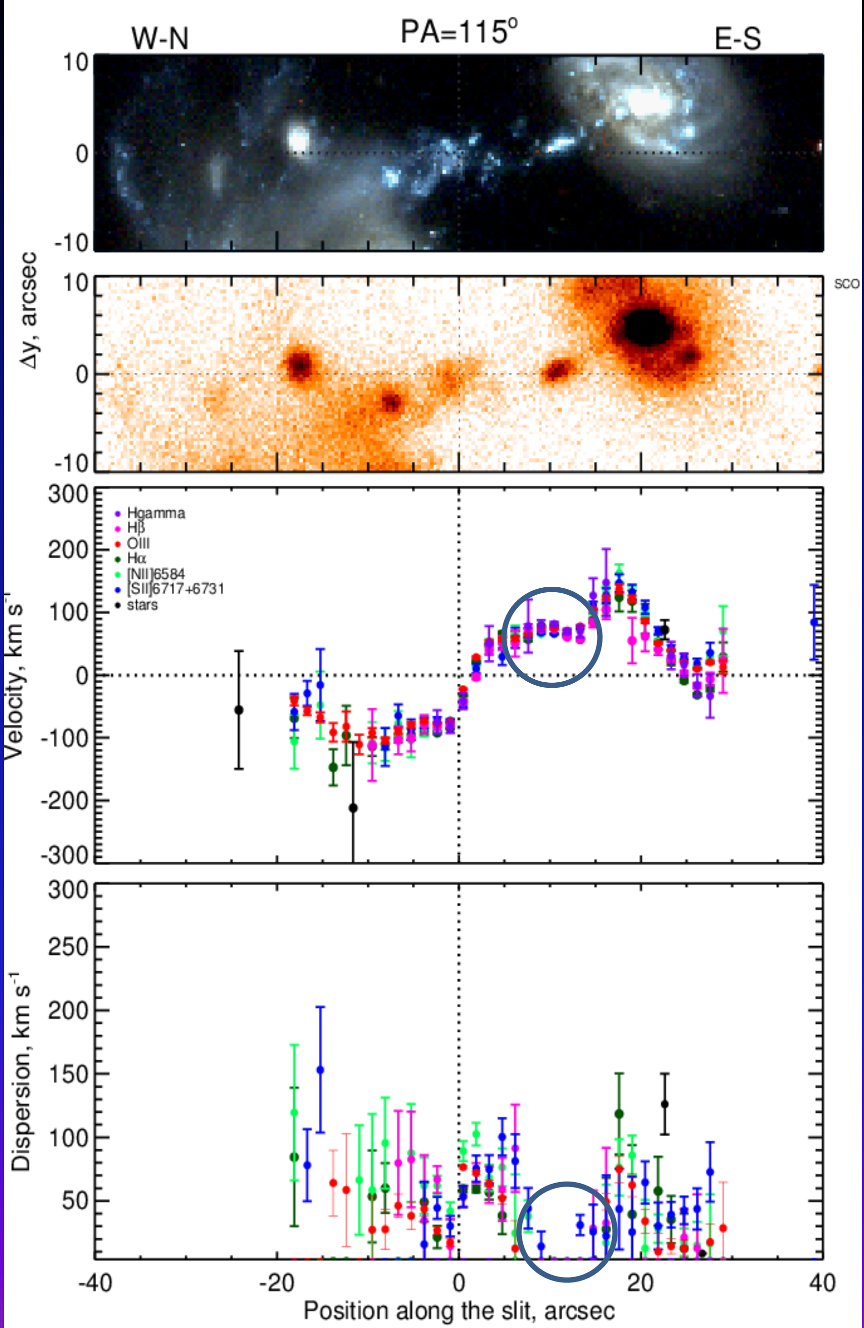
II. Interacting system Arp194

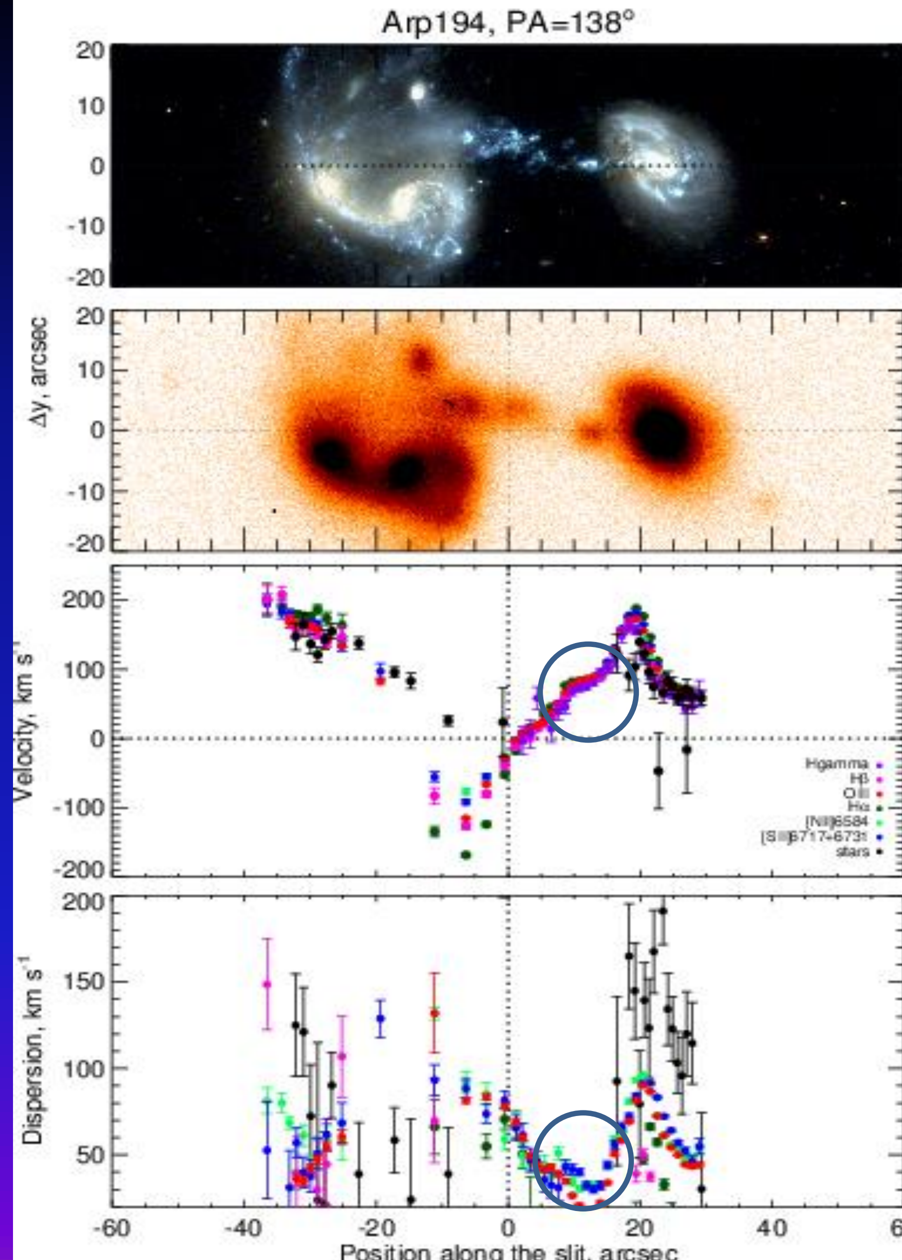

C
B
A

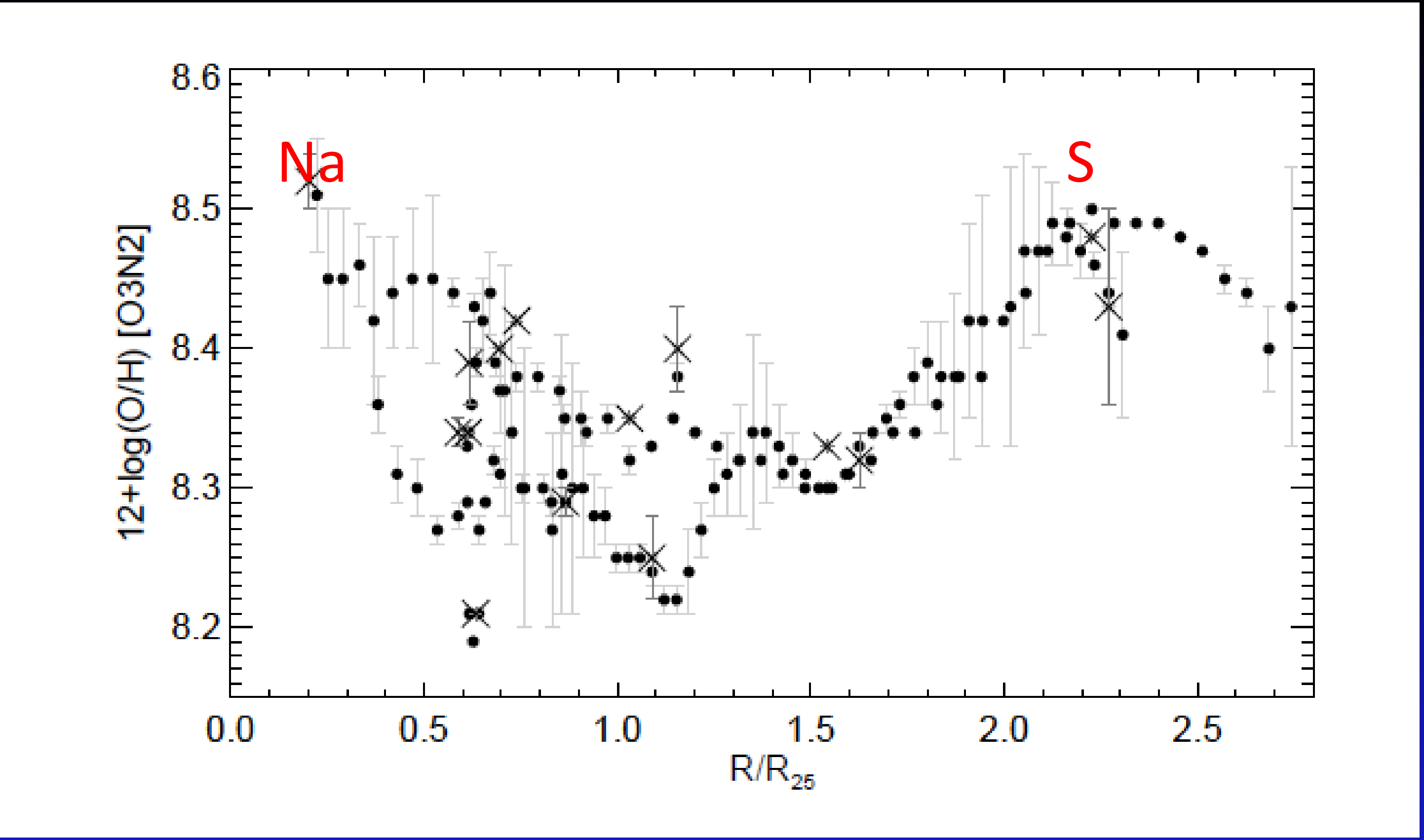

PA=138°
Arp 194 Nb
Arp 194 Na
PA=115°
C
B
A
PA=95°
Arp 194 S
57m56.8s
57m55.2s
57m53.6s
57m52.0s
57m50.4s
11h57m48.8s
+36°21m12s
21m36s
22m00s
22m24s
22m48s

SPECTRA OF ARP 194
intergated along the slits

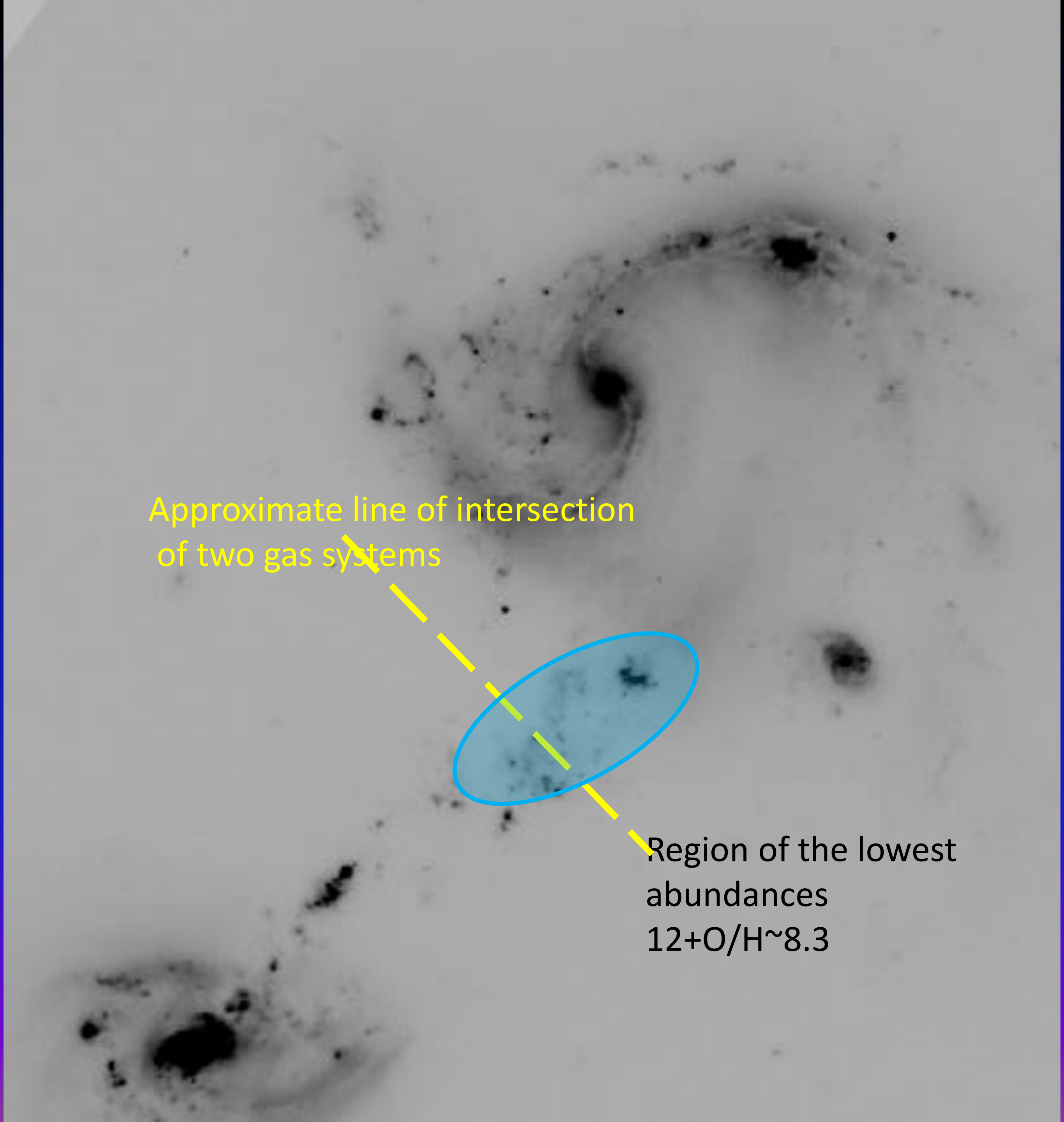



W-N
PA=115°
E-S
Δy, arcsec
Hgamma
Hβ
OIII
Hα
[NII]6584
[SII]6717+6731
stars
Velocity, km s^{-1}
Dispersion, km s^{-1}
Position along the slit, arcsec


Arp194, PA=138°
Δy, arcsec
Velocity, km s^{-1}
Hgamma
Hβ
OIII
Hα
[NII]6584
[SII]6717+6731
stars
Dispersion, km s^{-1}
Position along the slit, arcsec

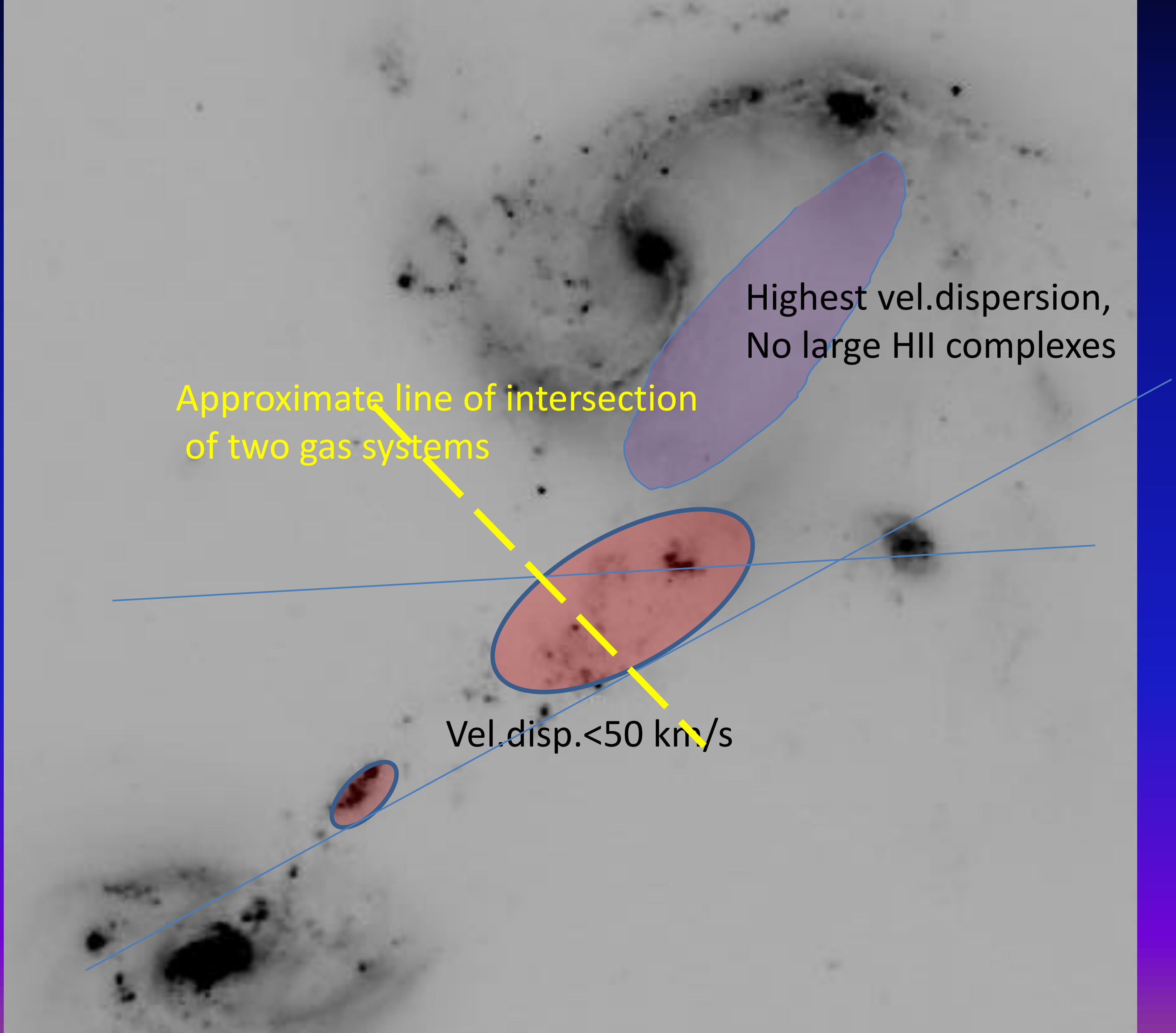


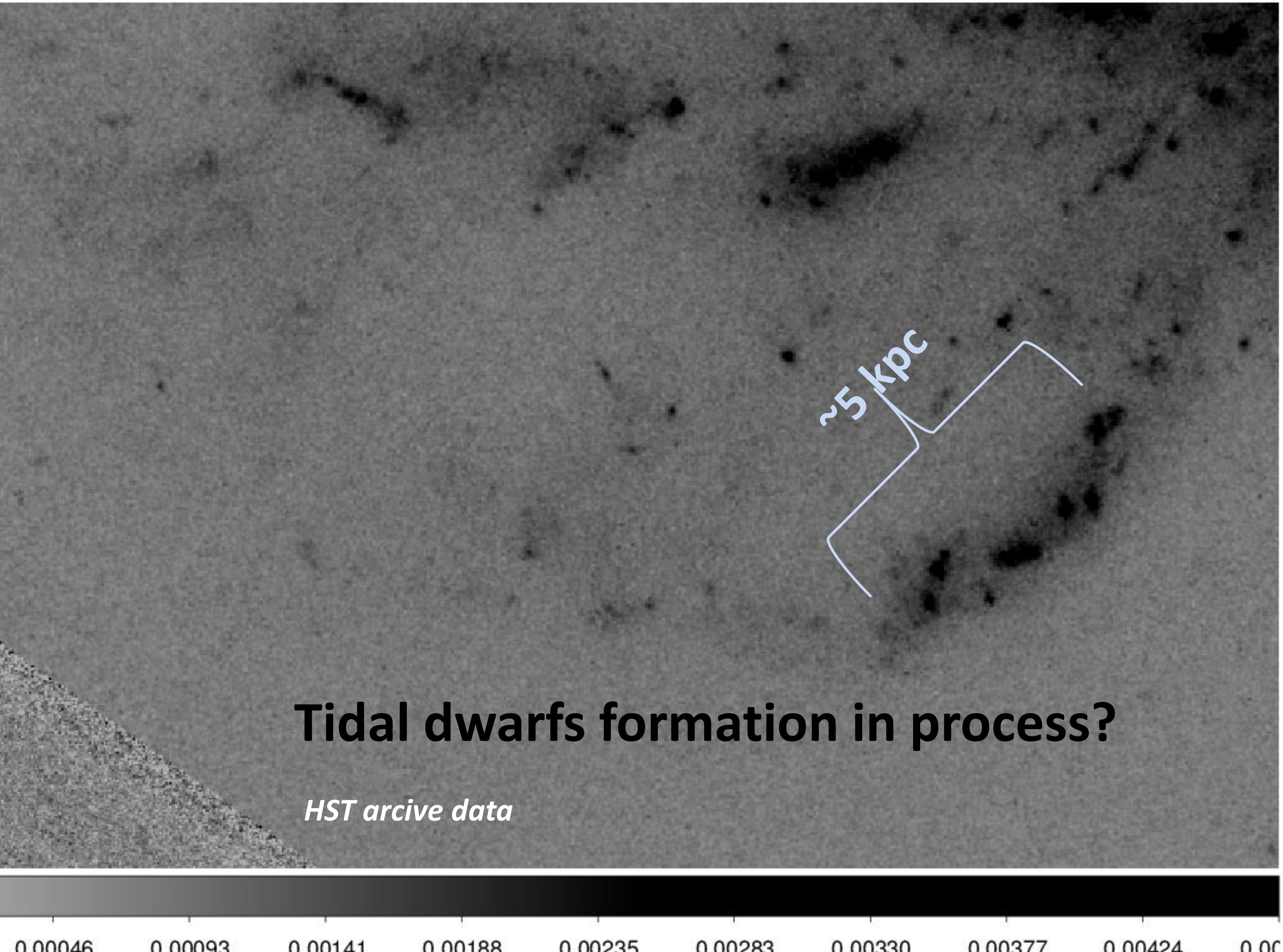
Variation of oxygen abundance estimated by O3N2 method with
the distance from Na-galaxy along all three slits. As a zero-point at the
x-axis we took the centre of Na galaxy, the radial scale is normalized to the
photometric radius of Na galaxy R_{25} = 19 kpc

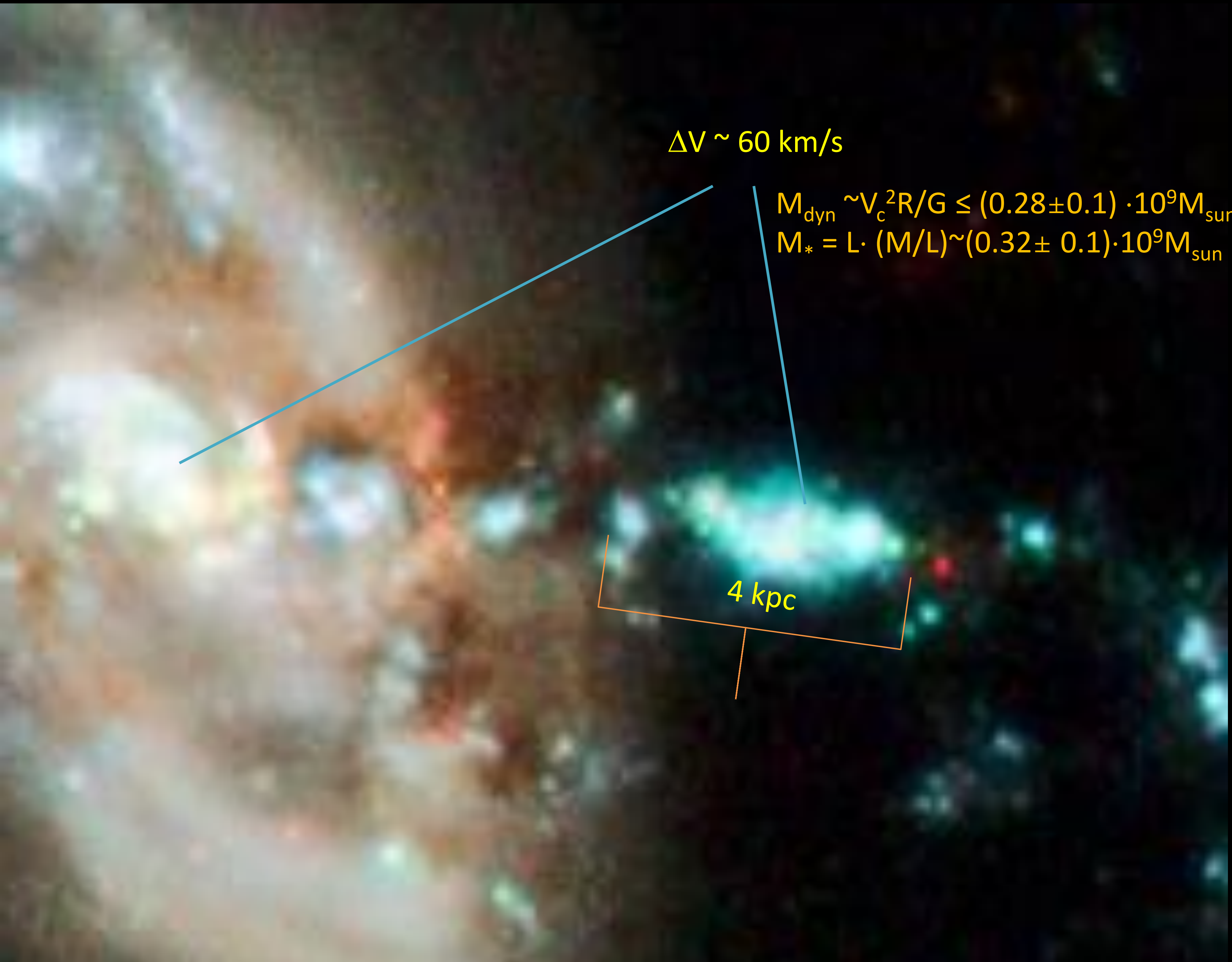


Approximate line of intersection
of two gas systems
Region of the lowest
abundances
12+O/H~8.3

Gas velocity dispersion does not correlate, or rather anticorrelates with the intensity of emission lines




~5 kpc
Tidal dwarfs formation in process?
HST arcive data
0.00046
0.00093
0.00141
0.00188
0.00235
0.00283
0.00330
0.00377
0.00424

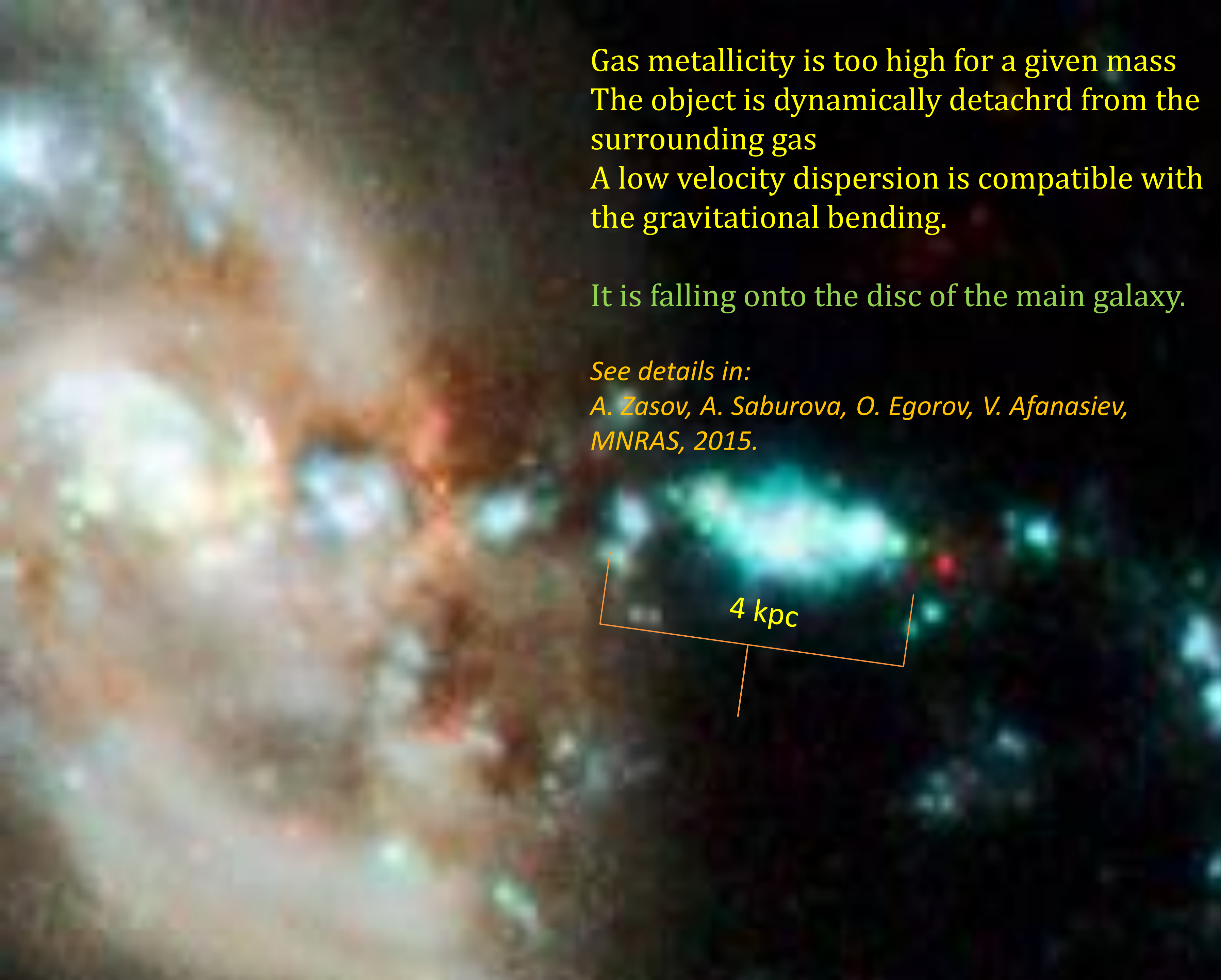


$\Delta V \sim 60$ km/s
$M_{dyn} \sim V_c^2 R/G \leq (0.28\pm0.1) \cdot 10^9 M_{sun}$
$M_* = L\cdot (M/L) \sim (0.32\pm 0.1)\cdot 10^9 M_{sun}$
4 kpc

Gas metallicity is too high for a given mass
The object is dynamically detachrd from the surrounding gas
A low velocity dispersion is compatible with the gravitational bending.

It is falling onto the disc of the main galaxy.

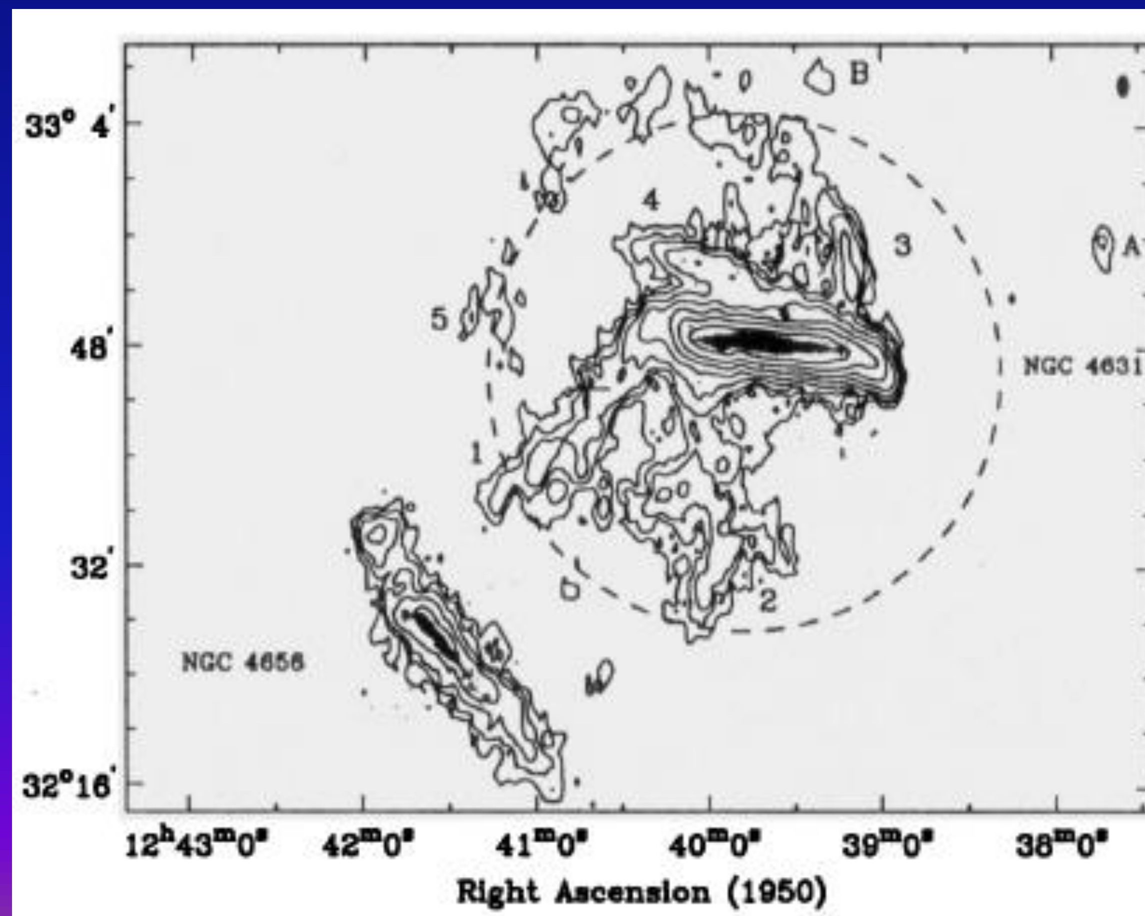
See details in:
A. Zasov, A. Saburova, O. Egorov, V. Afanasiev, MNRAS, 2015.



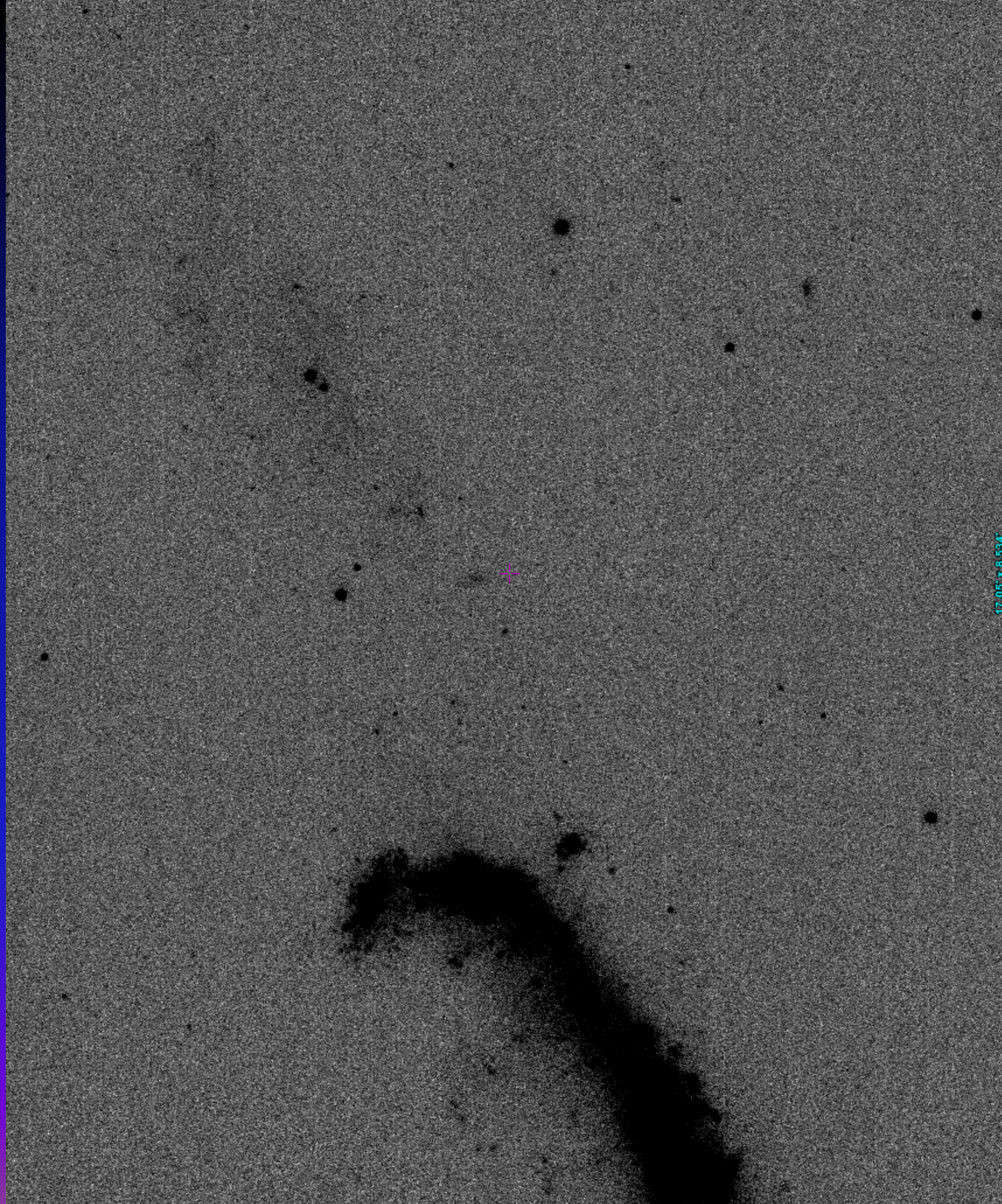
III. INTERACTING SYSTEM NGC4631/4656

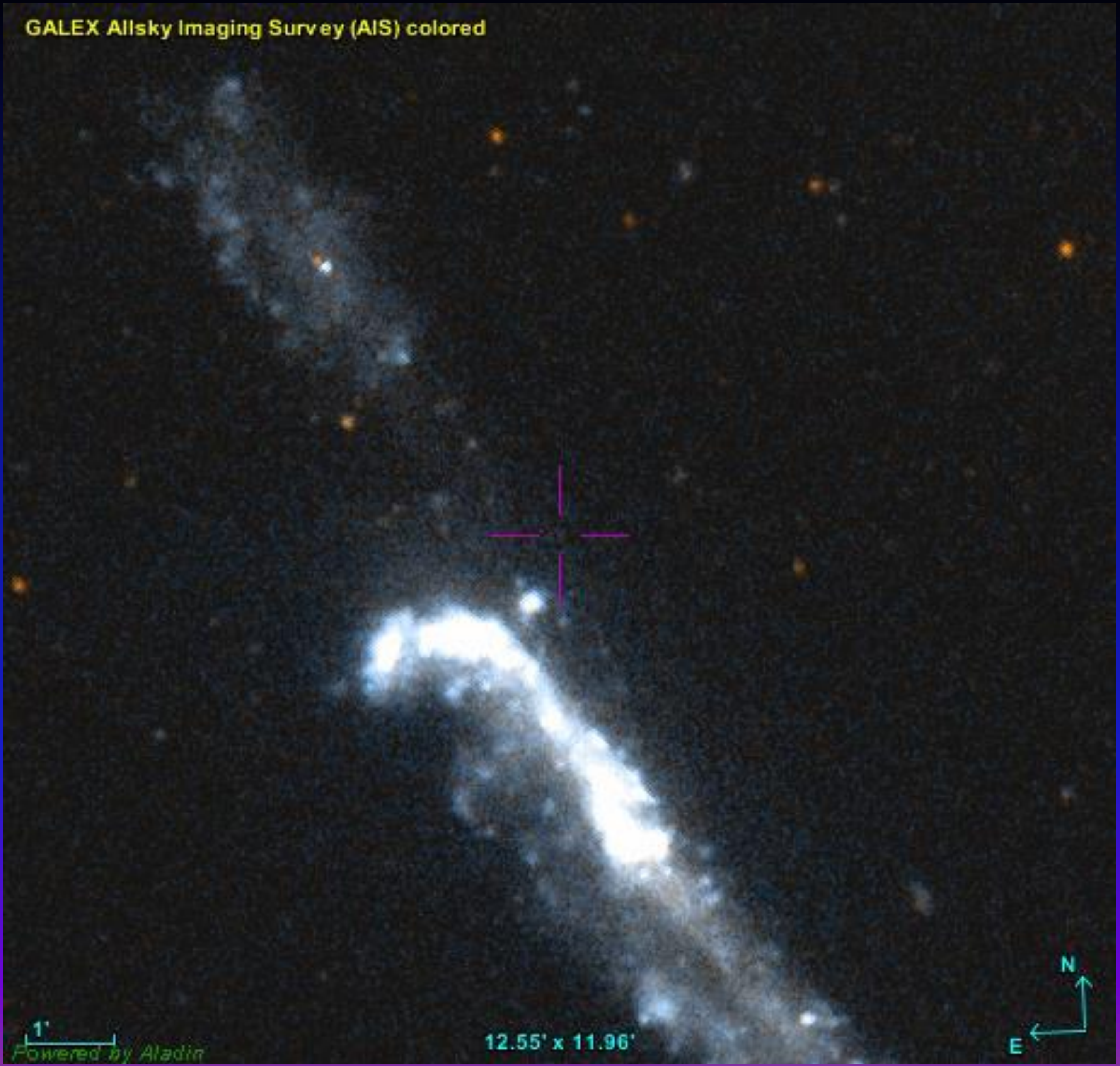
(Zasov, et al., in preparation)

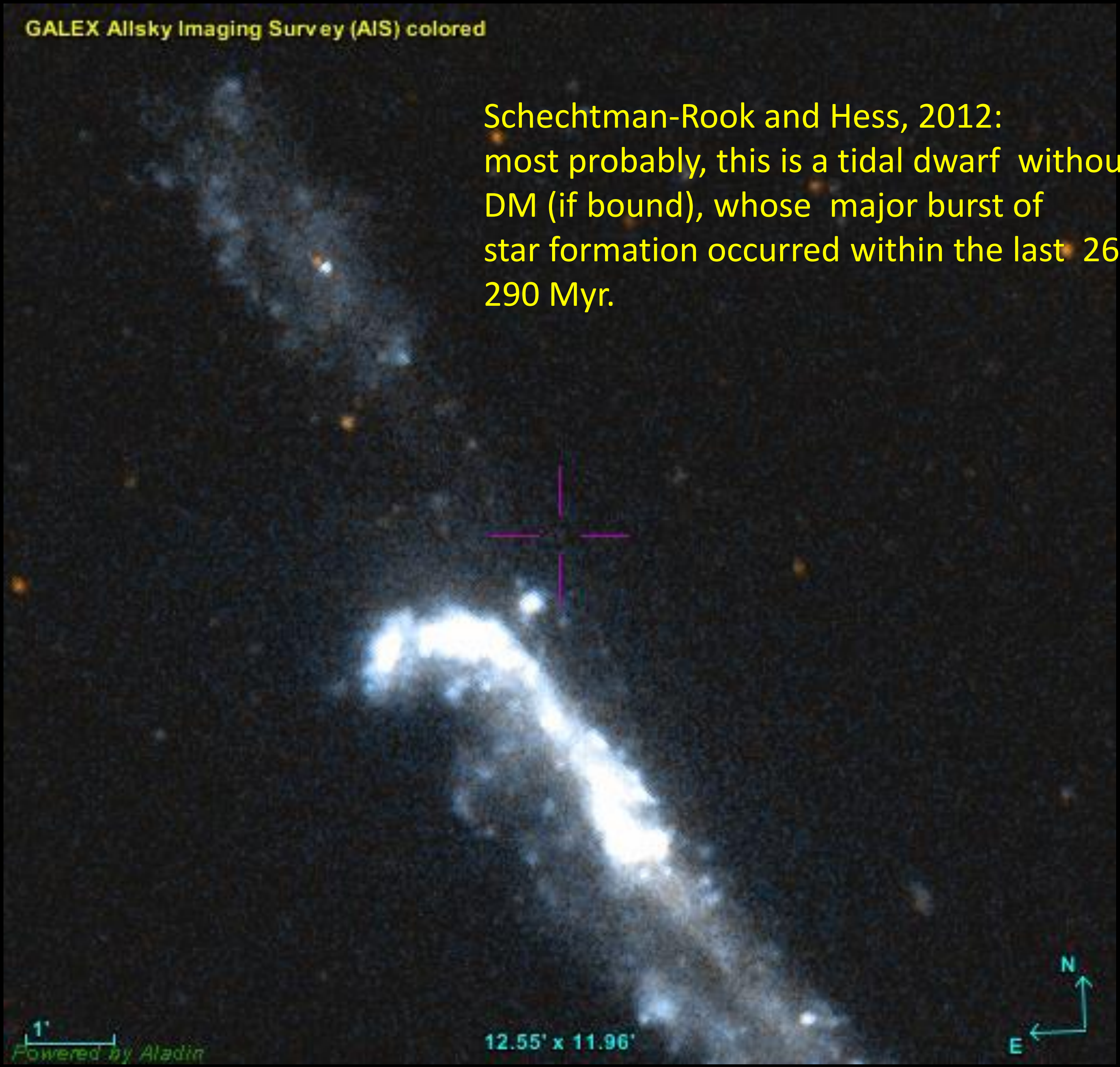
HI: Rand 1994



SDSS (u)

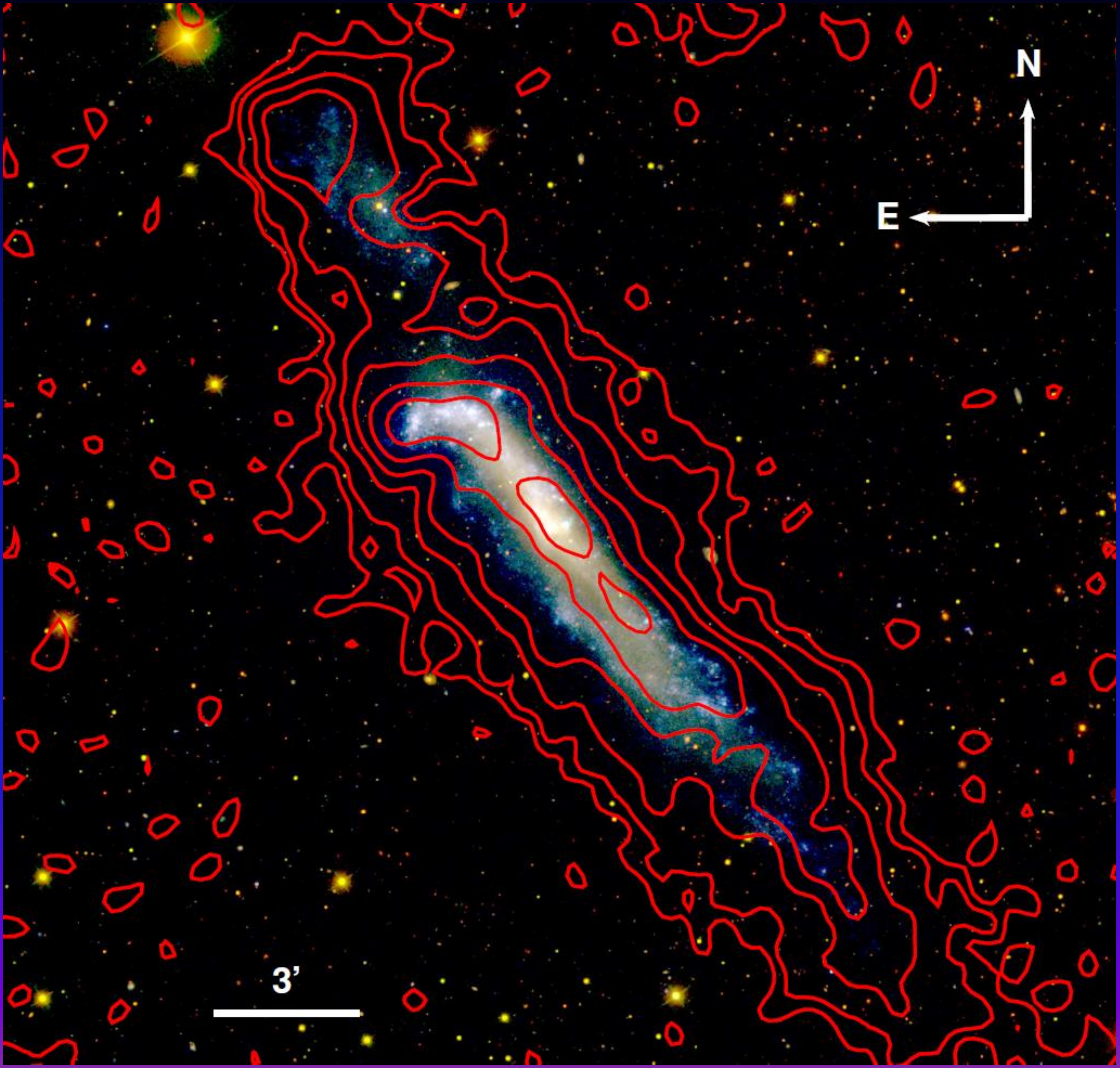



GALEX Allsky Imaging Survey (AIS) colored
1'
Powered by Aladin
12.55' x 11.96'
N
E



Schechtman-Rook and Hess, 2012:
most probably, this is a tidal dwarf without DM (if bound), whose major burst of star formation occurred within the last 260 – 290 Myr.

Schechtman-Rook and Hess, 2012



Projected distance from the center of NGC4656 ~20 kp

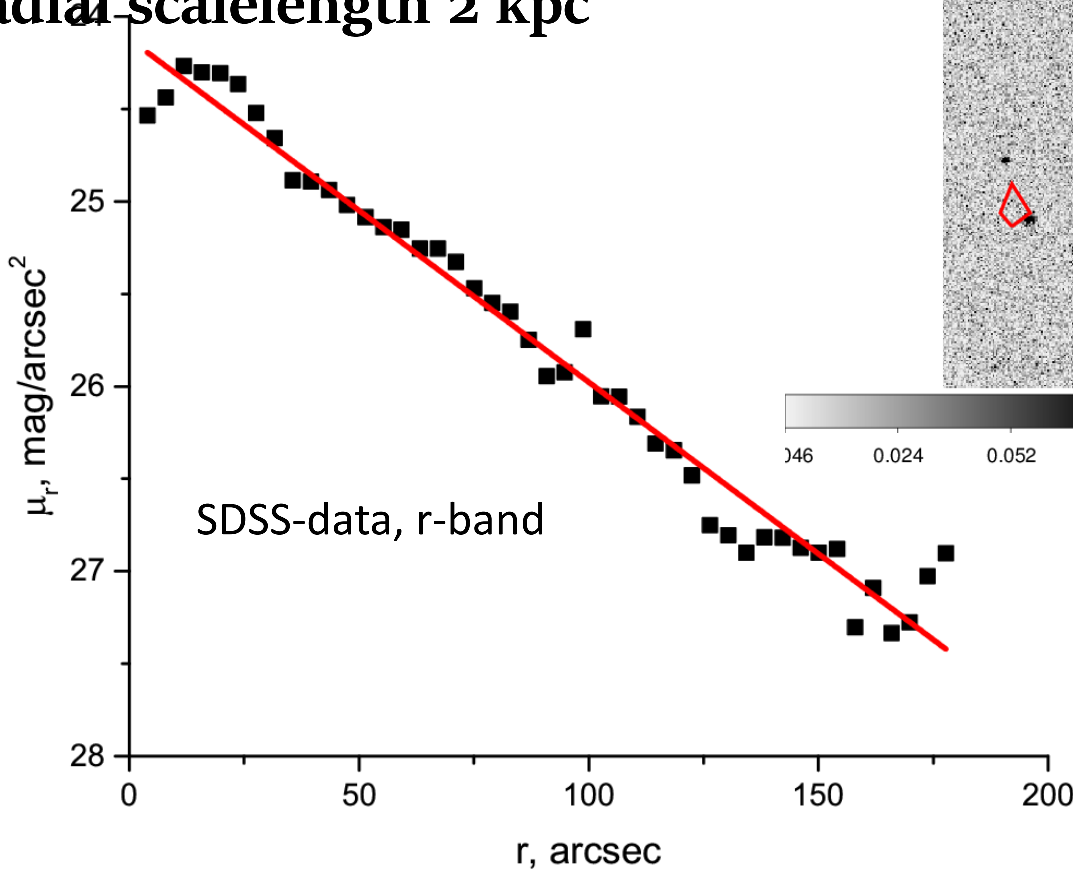
Visible diameter ~5’ ≅ 10 kpc

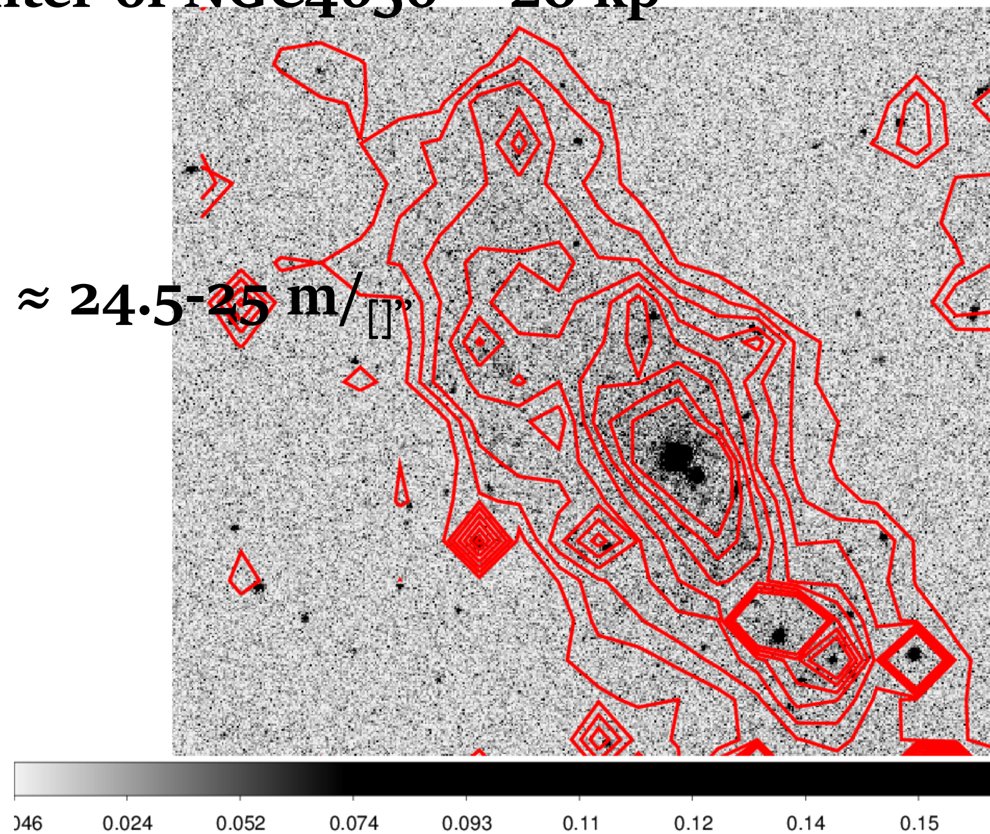
m_r 13.6

L_R $2\cdot10^8 L_{sun}$

Mean surface brightness $\langle\mu_r\rangle \approx$ 24.5-25 m/[]”

Radial scalelength 2 kpc

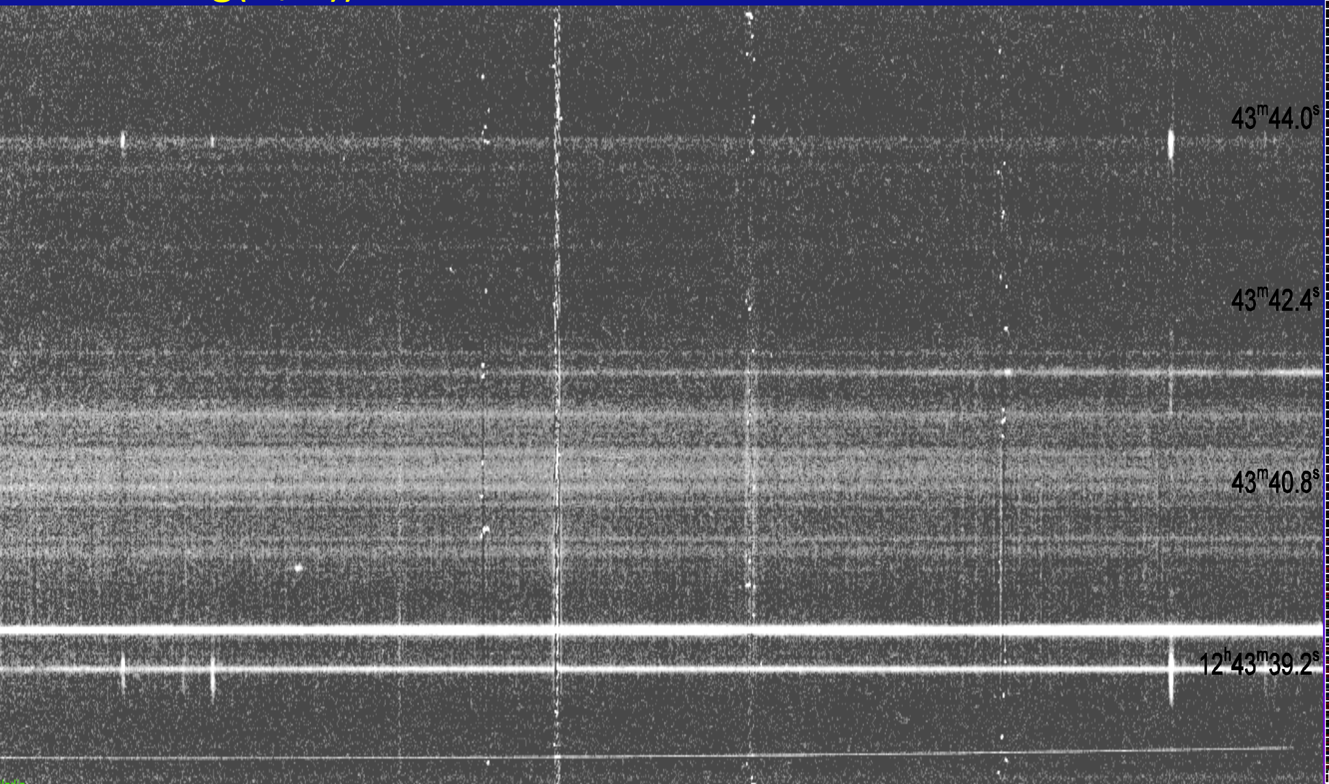


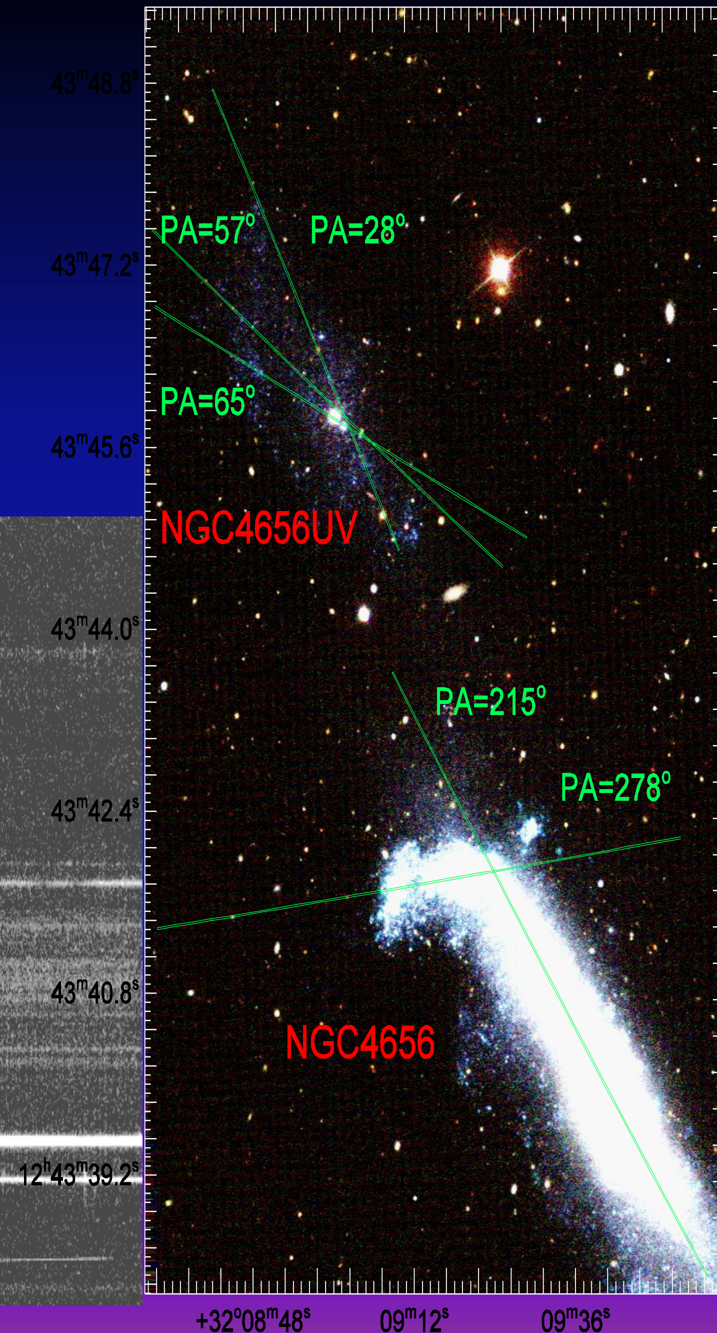


NGC4656UV

Sky-subtracted spectrum of NGC4656UV, PA=28^0

This is metal-poor dwarf.
Method IZI (Blanc et al,2015) gives
12+log(O/H)) m= 7.8 -7.9

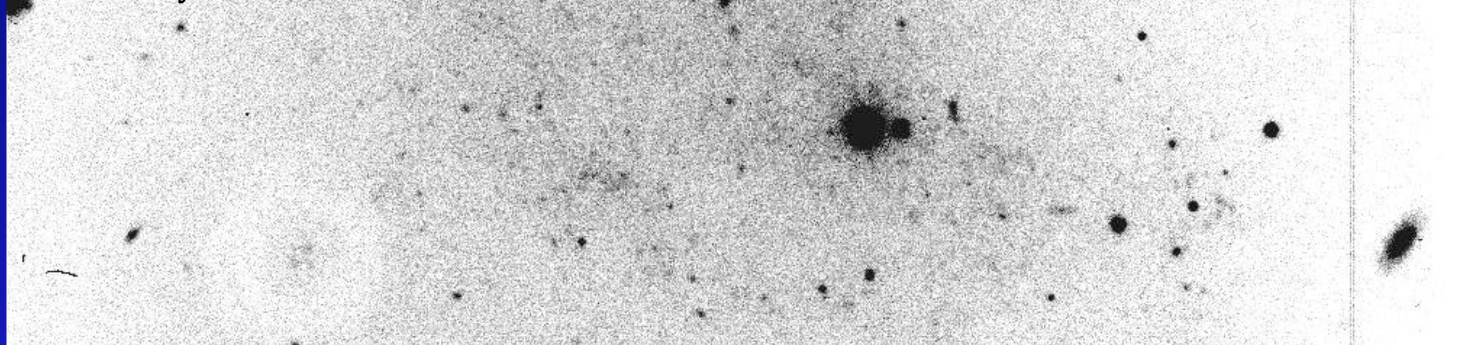


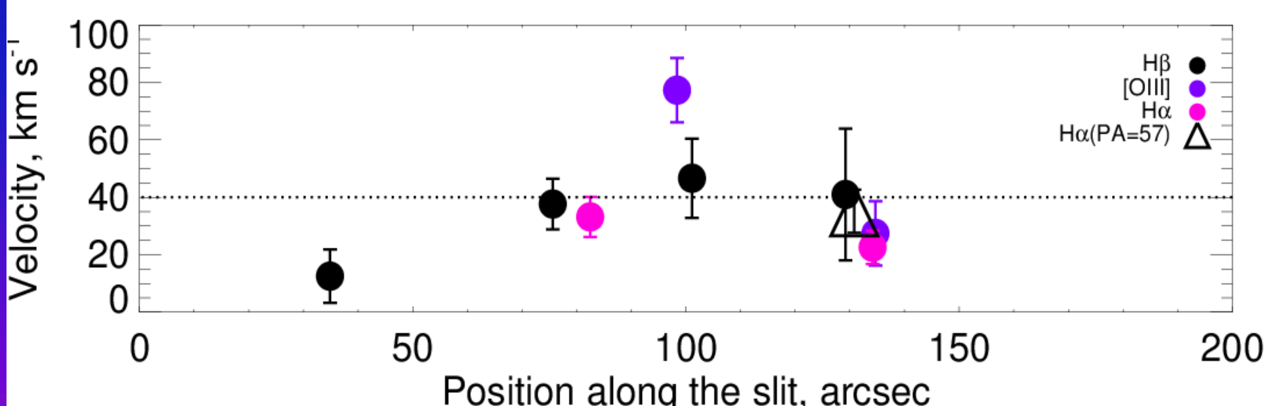


$(V_{rot})_{max}$ = 40±10 km/s (not corrected for asymmetric drift).

Dynamical mass (2.4±0.9)·$10^9 M_{sun}$

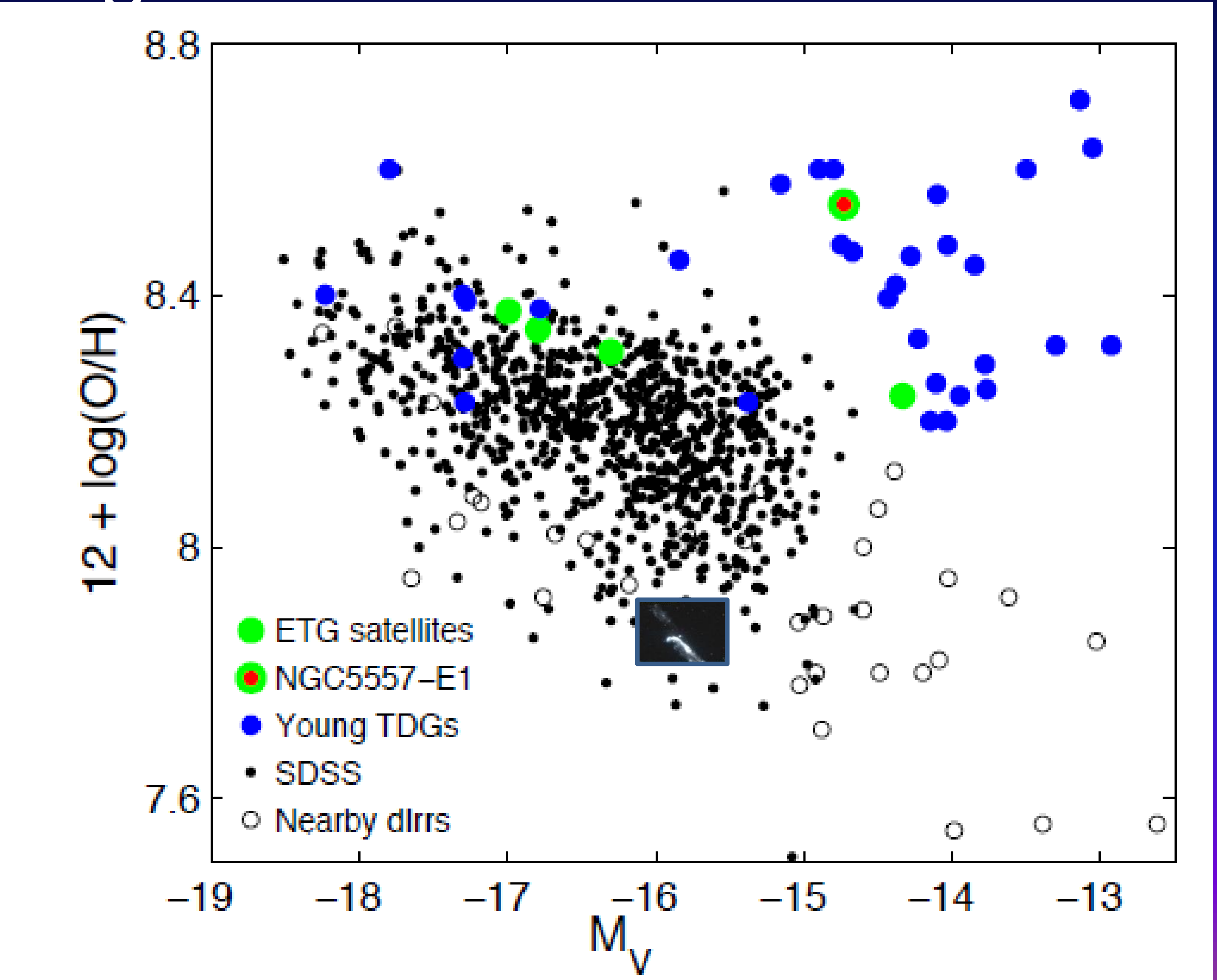
M_{dyn}/L_r = 13±6 solar units



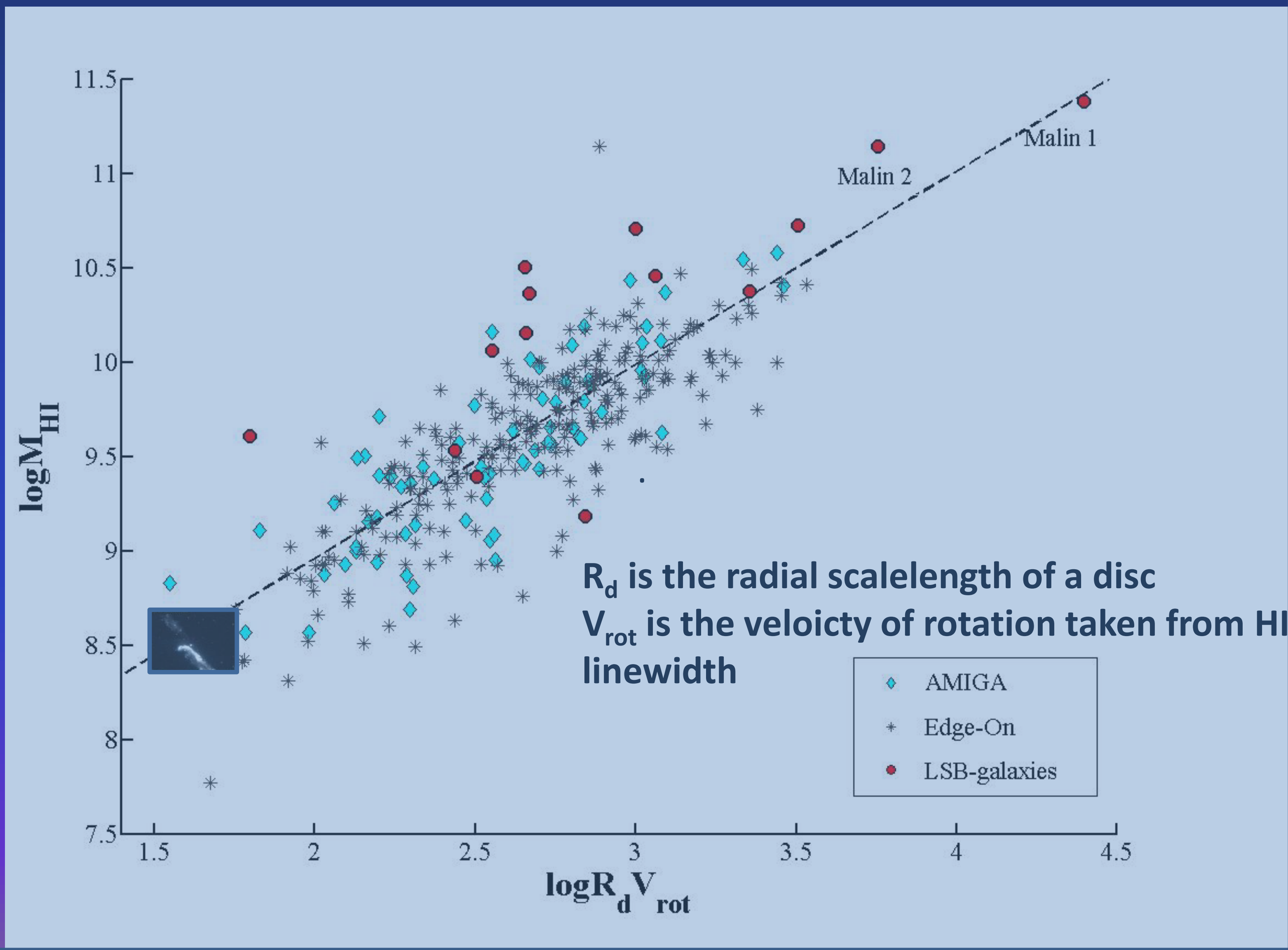


A comparison of NGC4656UV with dIrr galaxies and tidal dwarfs

Duc et al, 2014



The empirical relationship berween the hydrogen mass and specific angular momentum of galaxies



R_d is the radial scalelength of a disc

V_{rot} is the veloicty of rotation taken from HI linewidth

Main conclusions

- The mechanisms of formation of the extended stellar islands in the intergalactic space we observed is different, as well as their properties, including the gravitational bending.
- Some tidal dwarf candidates we studied appear to be short-lived objects or substantive galaxies (as in the case of a strange galaxy NGC4656UV , a real tidal dwarf Arp194-A, or a background galaxy Arp194-C).
- In Arp270 gas metallicity is found to be lower than stellar one, also being lower than it is expected judging from the relative mass of gas. It allows to propose that the gas in both galaxies in this system is diluted and well mixed by accretion of low-abundant halo gas.
- Paired galaxies may share a common dark halo. Its role in the gas exchange and gas accretion, inspired by tidal interactions, deserves serious consideration.

THANK YOU!