Shapley Supercluster Survey:

observing transformations of galaxies in a stormy environment

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with

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candidate selection + IFS + multi-λ data + models

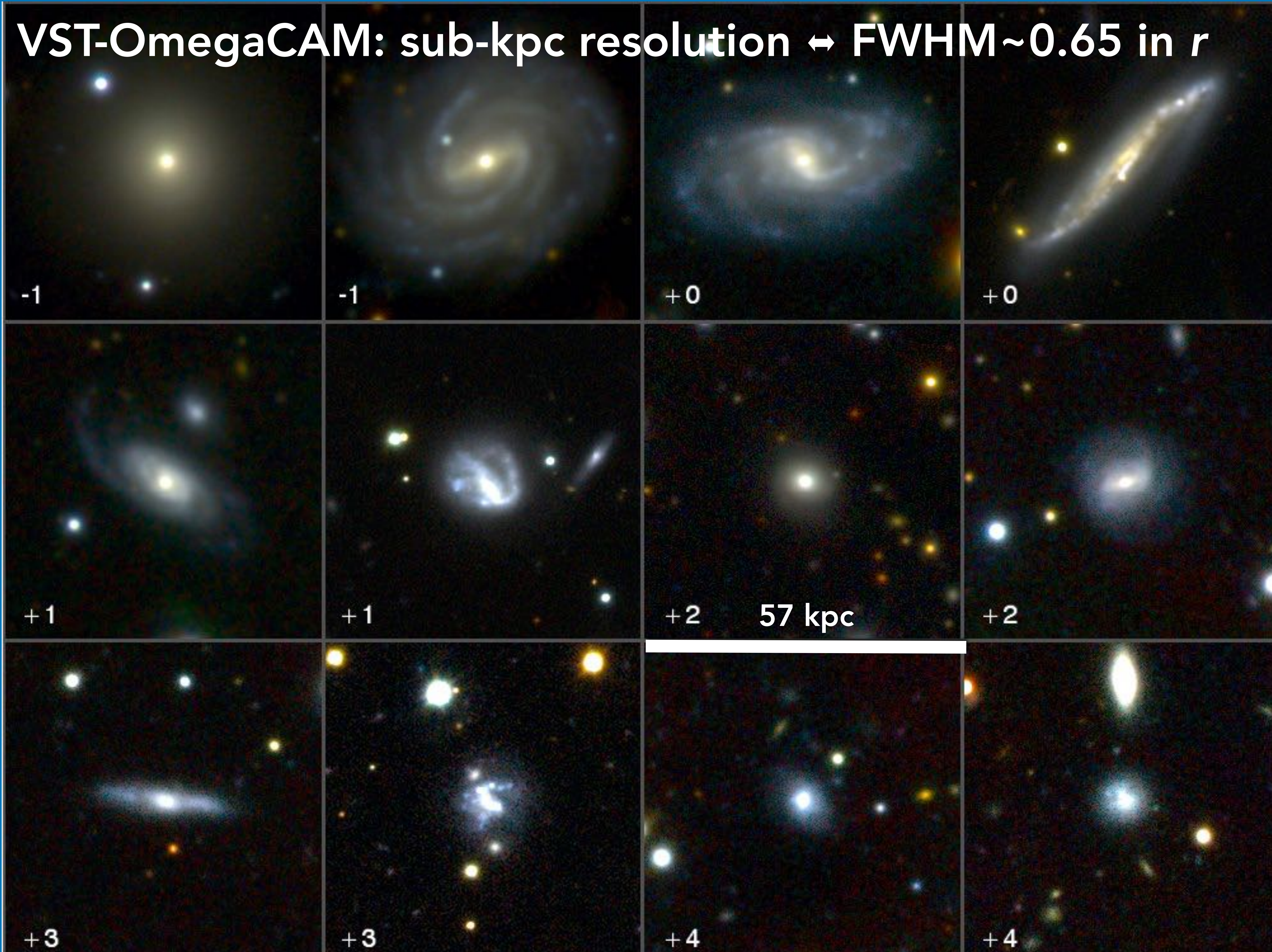
↓

interpretation

to investigate the role of cluster-scale mass assembly on galaxy evolution

to map the effects of the environment out to the cluster outskirts and along the filaments

VST-OmegaCAM: sub-kpc resolution ↔ FWHM~0.65 in *r*



Ram-pressure stripping: how and where

beyond Gunn & Gott (1972)

- immediately removes the gas halo
- low-mass galaxies in poor environments
- truncates, but also bends the gas disc of massive spirals
- efficiently contributes to transform galaxies outside the cluster core
- compresses and shocks the ISM temporarily enhancing star formation both in the disc and in the tail
- acts in different phases

e.g. Roediger & Hensler 2005 **-** Kronberger et al. 2007-2008 **-** Roediger & Brügger 2008
Kapferer et al. 2008-2009 - Jáchym et al. 2007-2009 - Tonnesen & Bryan 2008-2012
Bekki 2009, 2014 - Bekki & Couch 2010 - Book & Benson 2010
Steinhauser et al. 2012 - Roediger et al. 2014 - Bischko et al. 2015 - Quilis et al. 2017
Ramos-Martínez et al. 2018...

Ram-pressure stripping: how and where

open issues

- how many cluster galaxies and how differently are affected by RPS?
- does the cluster mass or the cluster dynamics matter?
- where do the cluster galaxies feel the ram-pressure: falling in the clusters from the filaments, crossing cold fronts?

observational bias

- geometry
- timing
- sensitivity

disentangle between RPS and tidal interaction (TI)

Ram-pressure stripping candidates

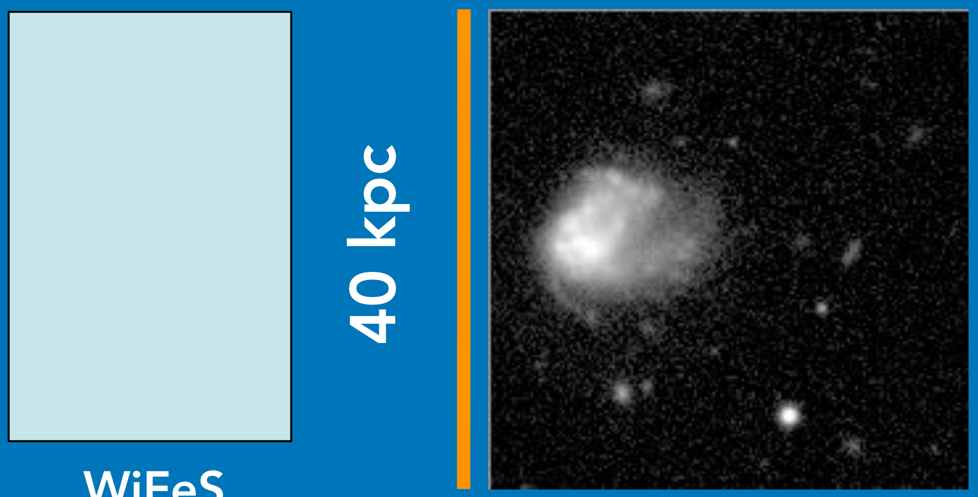
Ebeling et al. (2014) criteria:

- disturbed morphology indicative of an unilateral external force
- brightness knots and colour gradients suggesting bursts
- evidence of tails

80 out of 2700 members satifying at least two of the three criteria of Ebeling et al. 2014

WiFeS observations:

Dual beam image-slicing integral field spectrograph
Spectral range: 3300 – 9800 Å
fov: 25 x 38 arcsec → 950 spectra



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WiFeS observations:

gas and stellar kinematics

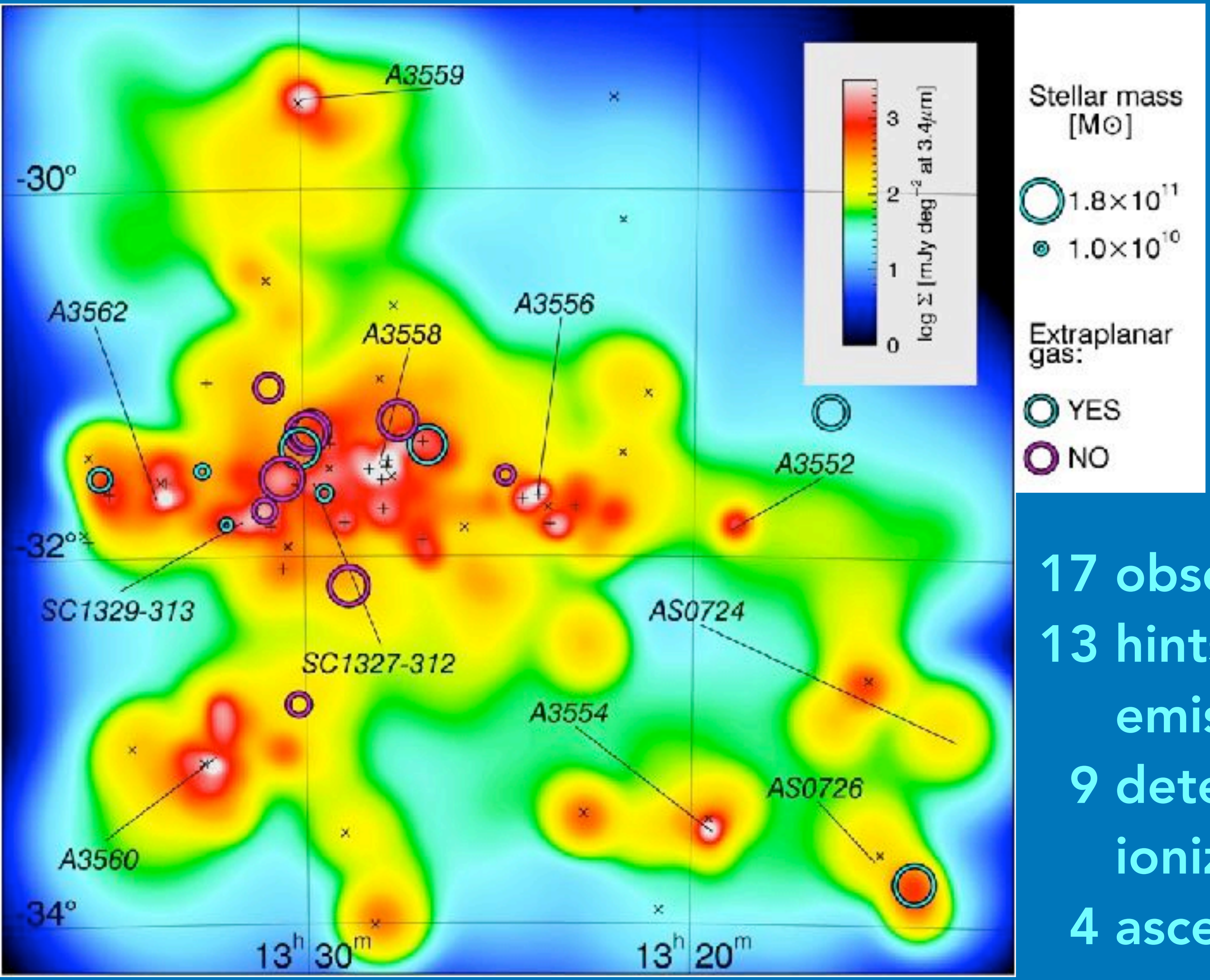
nature of the gas emission

star formation across the galaxy

abundances

dust attenuation

W1 flux density map



17 observed with WiFeS

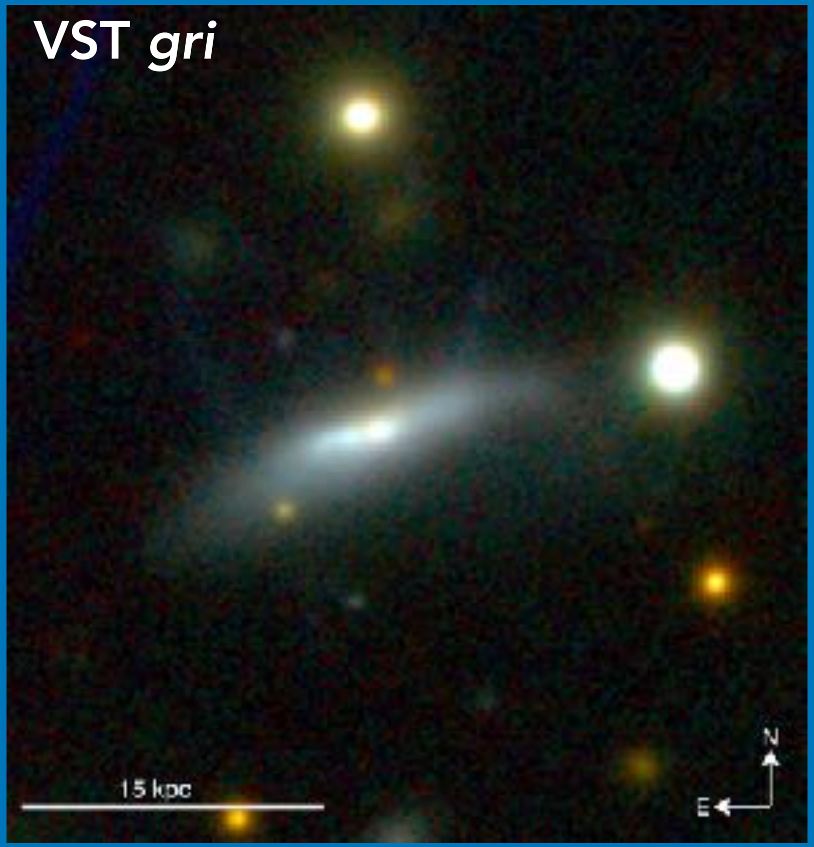
13 hints of extraplanar emission

9 detected outflowing ionized gas

4 ascertained ongoing RPS

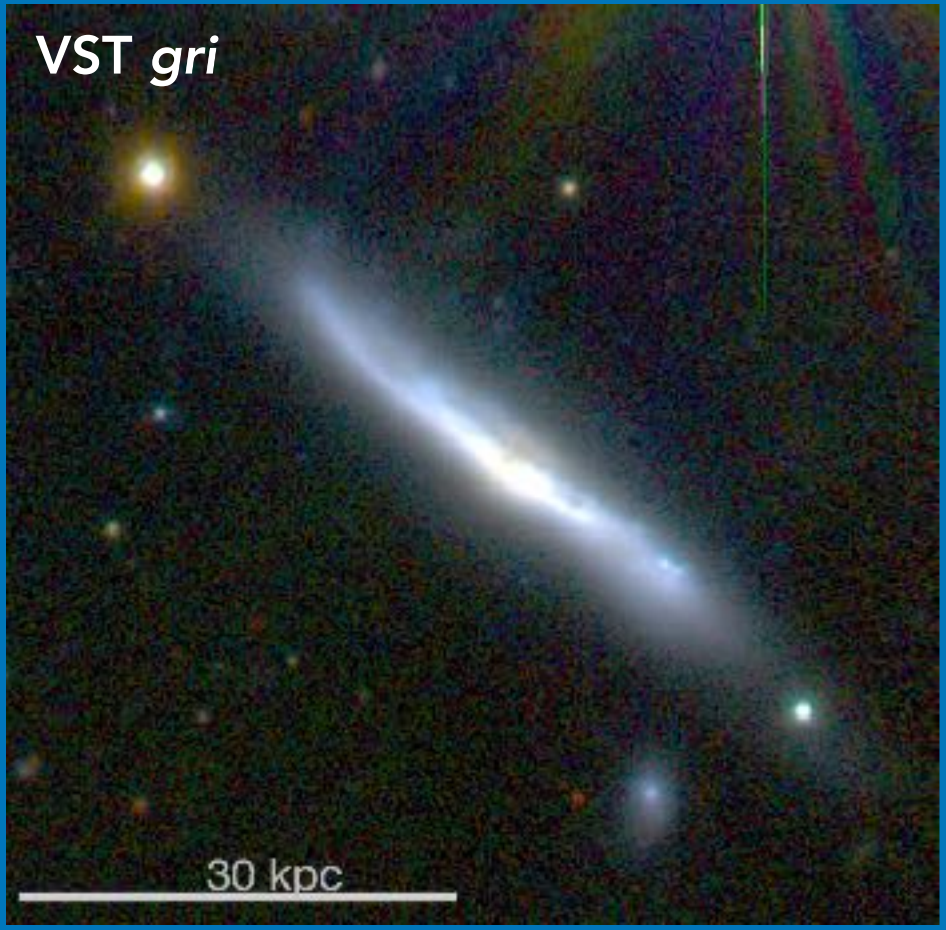
Extraplanar emission: RPS or TI?

ShaSS-403015754



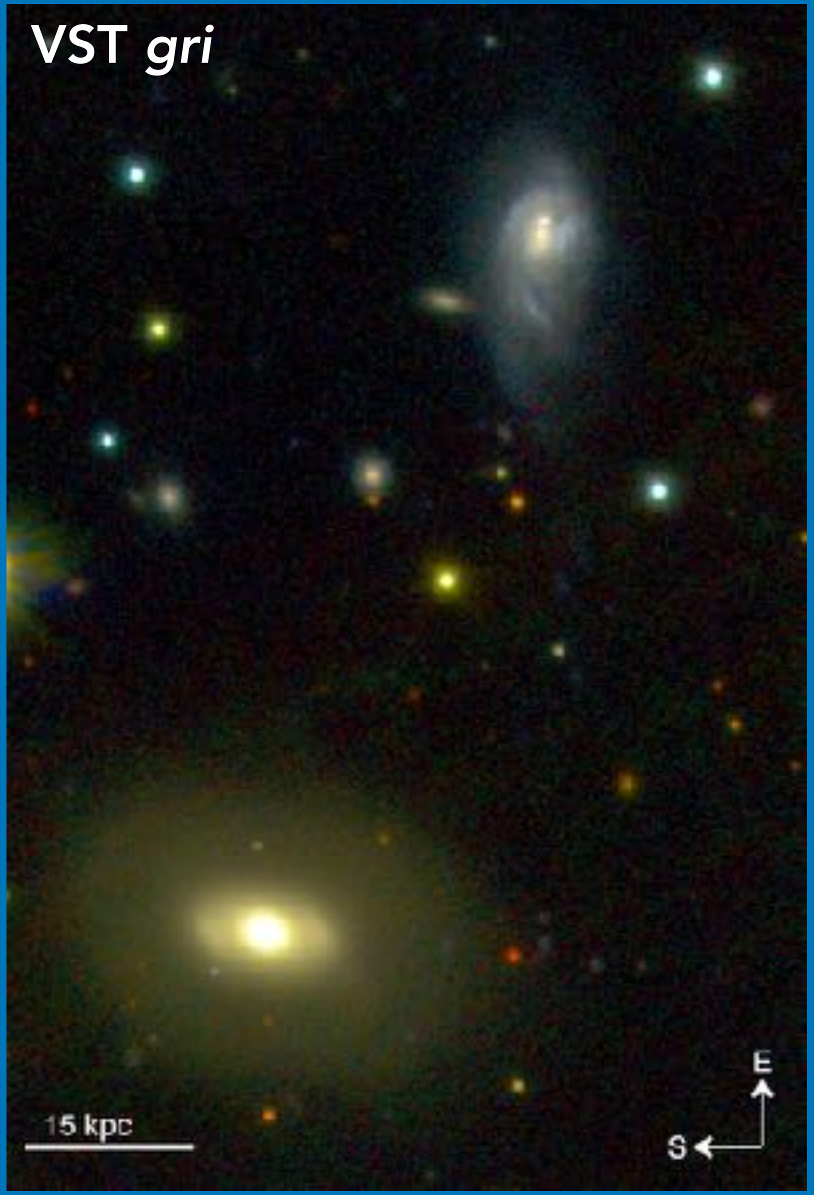
$M_{star} \approx 3.6\times10^{9}\ M_{\odot}$
$SFR_{UV+FIR} \approx 1.4\ M_{\odot}\ yr^{-1}$

ShaSS-408053060



$M_{star} \approx 6\times10^{10}\ M_{\odot}$
$SFR_{UV+FIR} \approx 8.5\ M_{\odot}\ yr^{-1}$

ShaSS-408053848



$M_{star} \approx 1.0\times10^{10}\ M_{\odot}$
$SFR_{UV+FIR} \approx 2.5\ M_{\odot} yr^{-1}$

Merluzzi+2013,2016

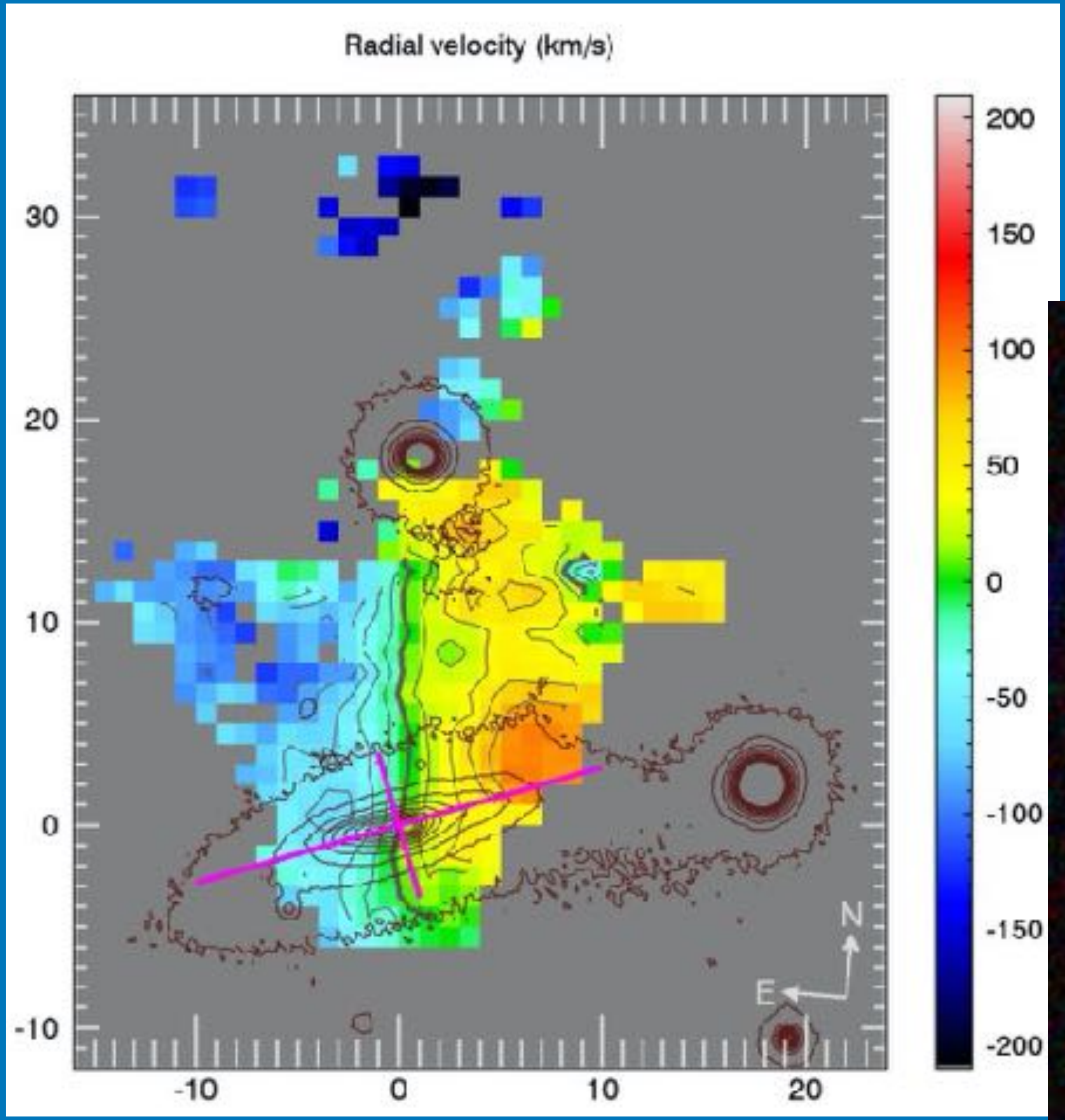
Extraplanar emission: RPS or TI?

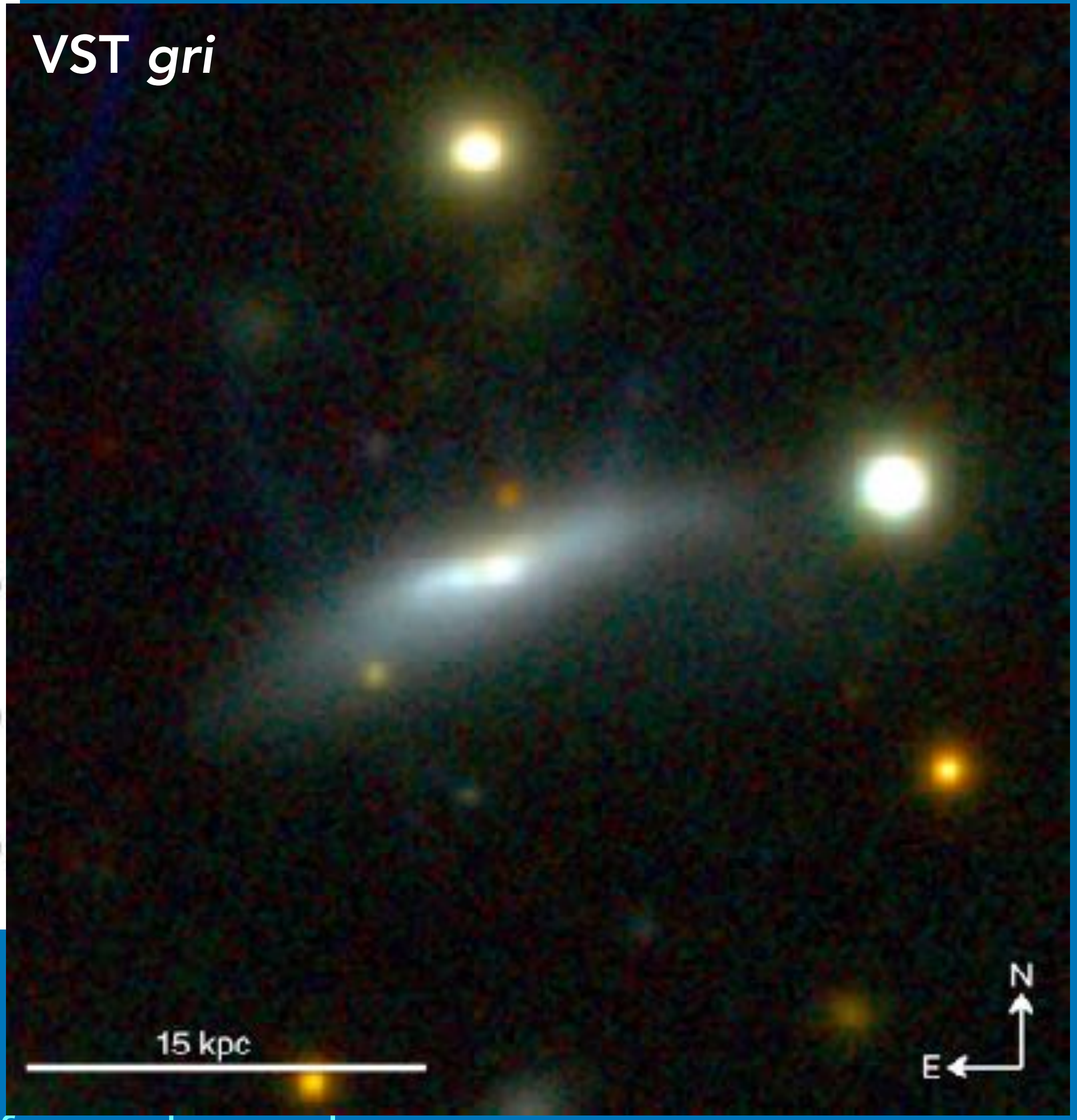
ShaSS-421015419

$M_{star} \approx 1.6 \times 10^{11}\ M_{\odot}$

SFR $\approx 6\ M_{\odot}\ yr^{-1}$

ShaSS-403015754: ionized gas velocity field





Ionized gas:

- gas extending up to 30 kpc in projection from the galaxy centre
- truncated disc and large-scale regular motion up to 11-12 kpc

ShaSS-403015754: RPS vs. TI

- companion ~17 kpc in projection and $\Delta V \sim 300$ km s^{-1}
- extraplanar emission toward the companion, but with extraplanar ionized gas extending further in projection
- truncated gas disc
- rotational component is preserved into the extraplanar ionized gas
- asymmetric velocity profile of the gas
- fairly symmetric stellar velocity profile
- gas e stellar velocity components are decoupled
- peak of star formation in the centre dominated by a young (< 1 Gyr) stellar component
- star formation knots out of the disc
- the gas is photoionized

$$\rho_{ICM} V^2 = 2\pi\, G\, \Sigma_{ISM}\, \Sigma_{*} \cos\beta$$

$$V > 480 \text{ km s}^{-1} \text{ (face-on)}$$

ShaSS-403015754: simulations

AREPO: *sator arepo tenet opera rotas* **(Springel 2010)**

2×10^5 particles/cells for the stellar and gas disc

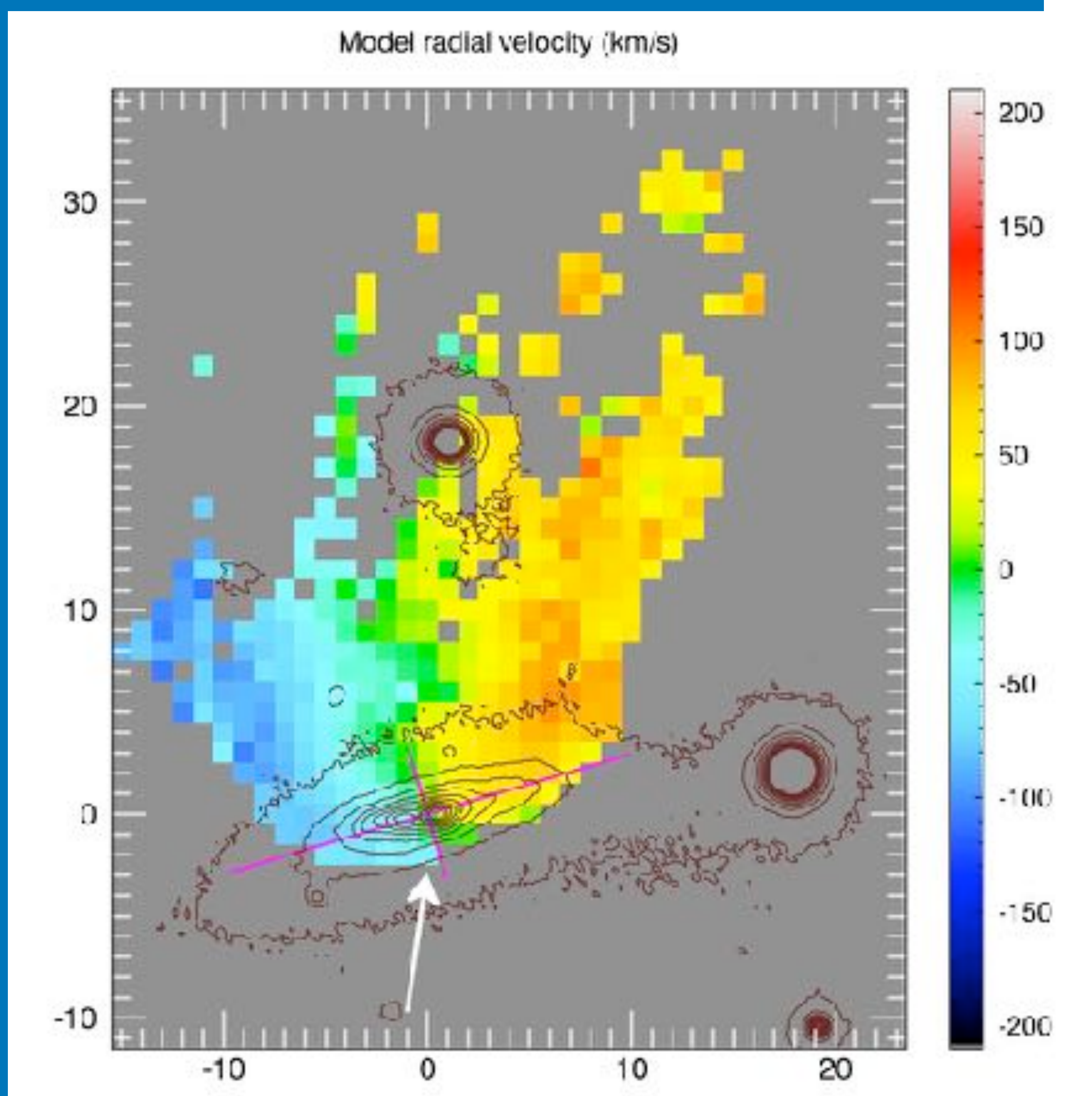
5×10^4 particles for the stellar bulge

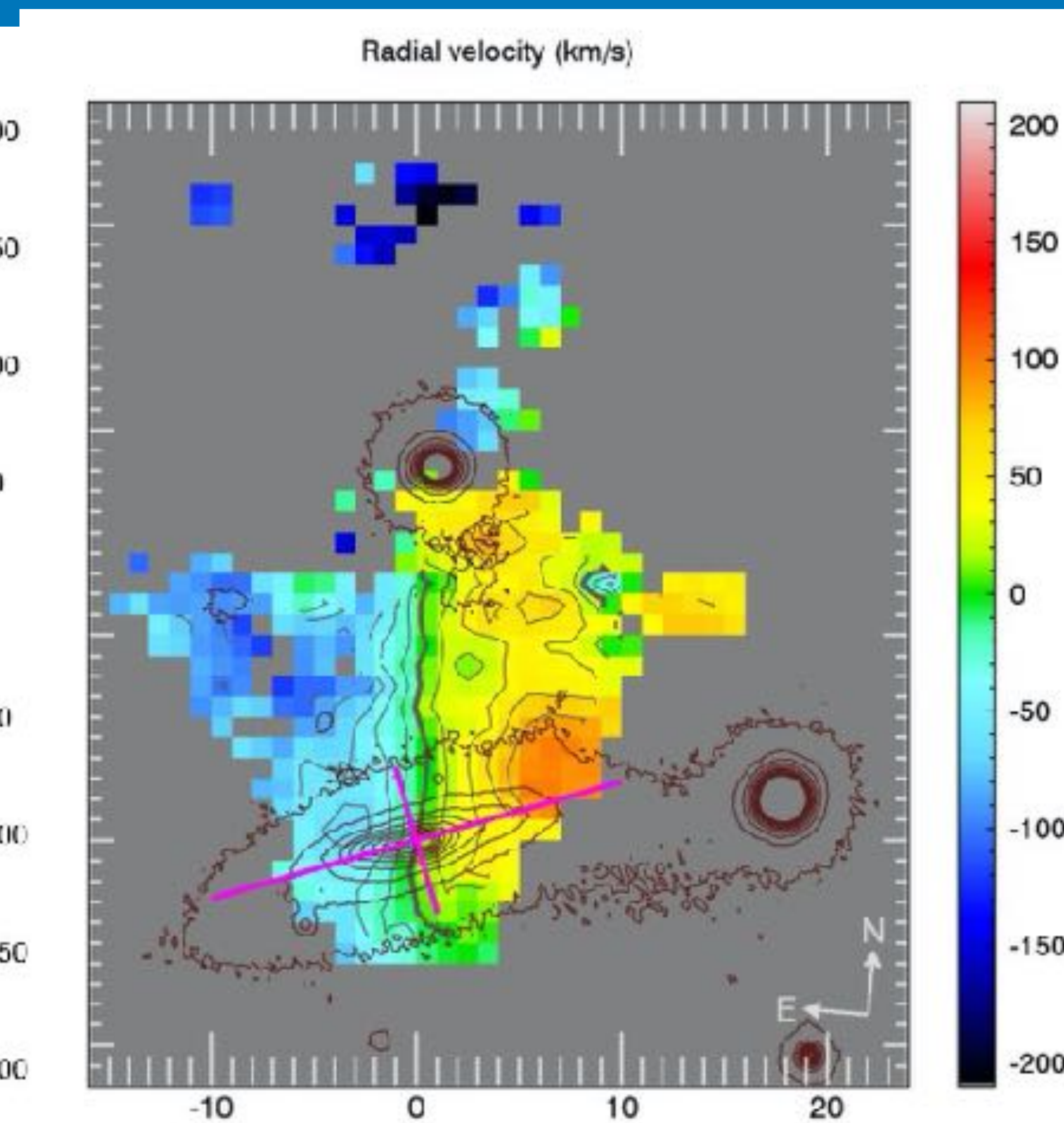
wind-tunnel contains on average 450000 gas cells

V_w = 500, 750, 1000, 1500 km s^{-1}

β = 10° - 80°

ρ_{ICM} = 3-5×10^{-28} gcm^{-3}

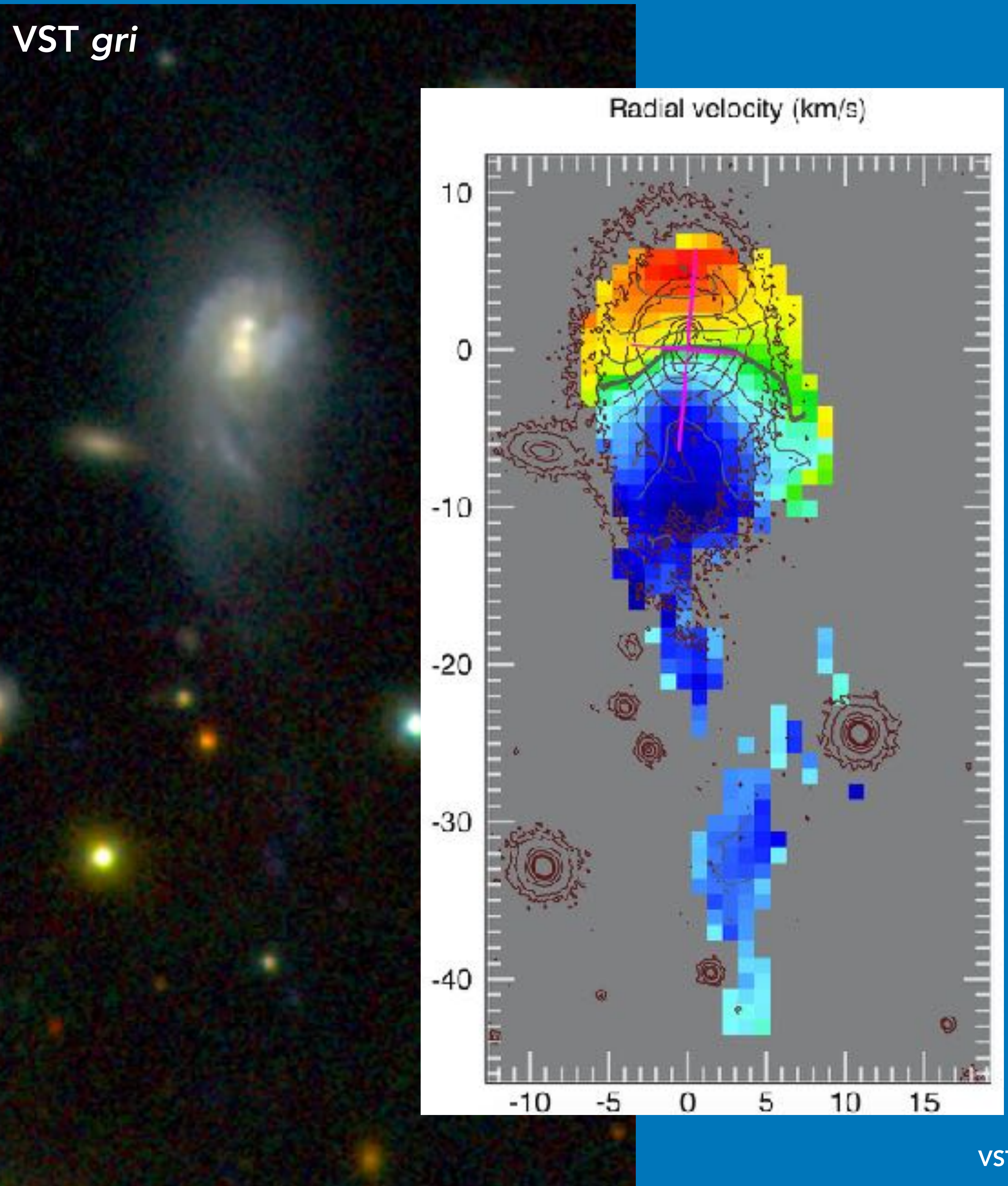




model: V_w = 750 km s^{-1} β= 30° ρ_{ICM} = 5×10^{-28} gcm^{-3} 240 Myr

star formation history → 2× SFR ~200 Myr ago

ShaSS-408053848: ionized gas velocity field



Ionized gas:

- gas tail up to 42-43 kpc
- truncated gas disc

ShaSS-408053848: RPS vs. TI

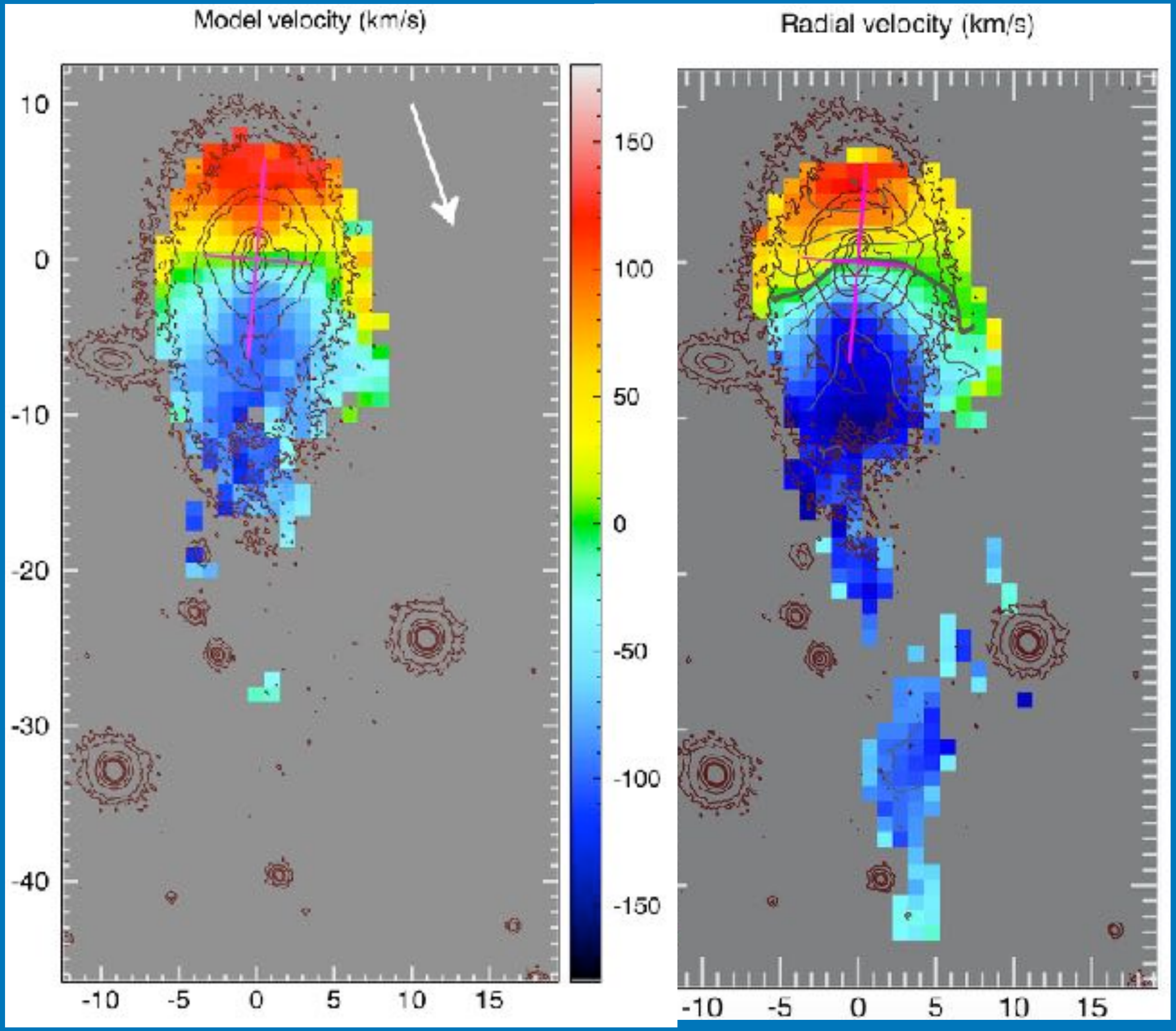
- 4-5× more massive companion ~68 kpc in projection and $\Delta V \sim 320$ km s^{-1} in redshift
- extraplanar emission toward the companion with emission connecting the two galaxies barely detected
- truncated gas disc
- the gas tail follows the galaxy rotation
- the star formation is asymmetric
- fairly symmetric stellar velocity profile
- the gas and stellar velocity profiles are decoupled in the external disc, but both are U-shaped

$$\rho_{ICM} V^2 = 2\pi\, G\, \Sigma_{ISM}\, \Sigma_{*} \cos\beta$$

$$V > 650 \text{ km s}^{-1} \text{ (face-on)}$$

ShaSS-408053848: simulations

V_w = 500, 1000 km s^{-1}
β = 20° - 80°
ρ_{ICM} = 5-9×10^{-28} gcm^{-3}



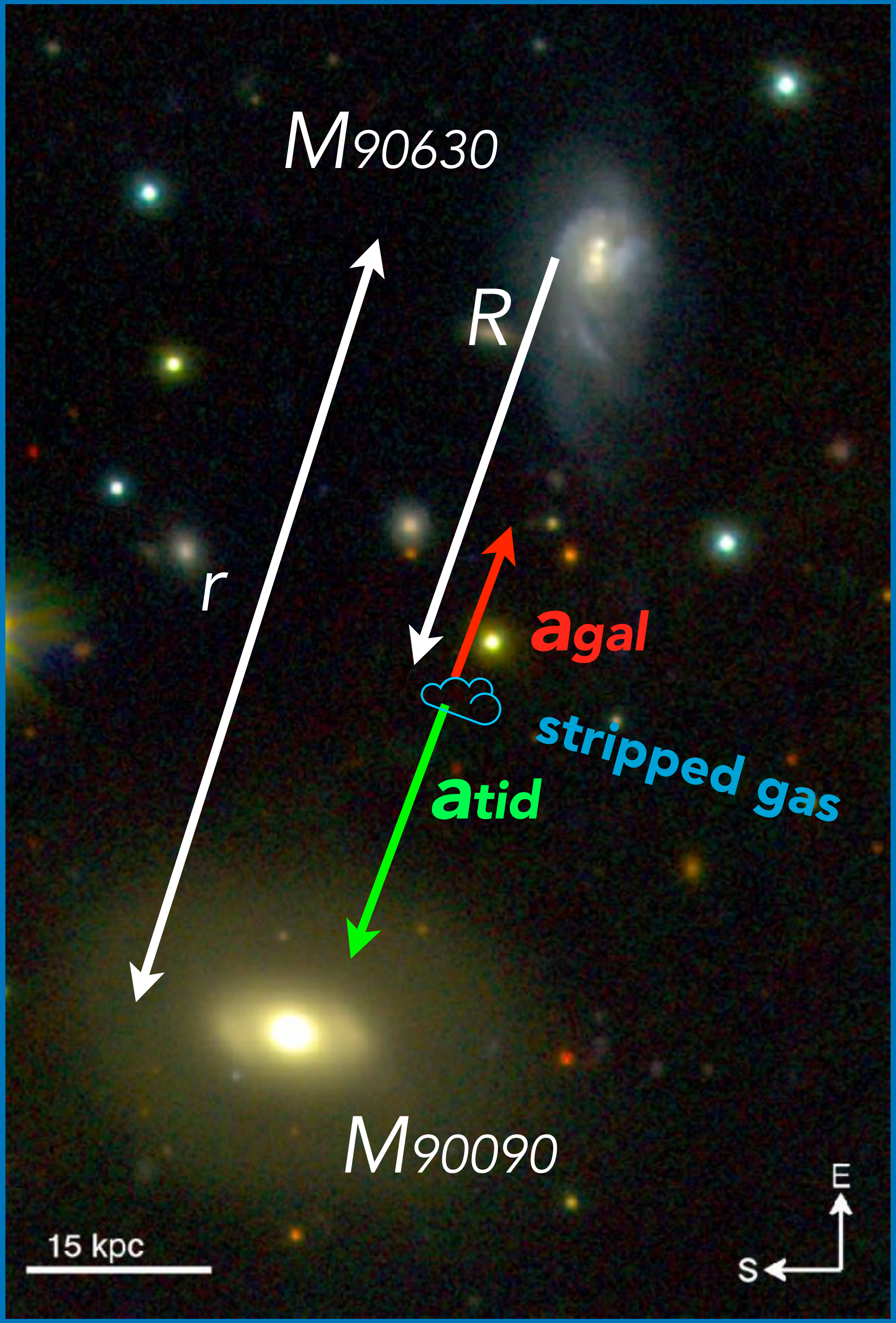
model:
V_w = 500 km s^{-1}
β = 80°
ρ_{ICM} = 5×10^{-28} gcm^{-3}
t = 400 Myr

ShaSS-408053848: RPS vs. TI

Balance between tidal and `restoring' forces:

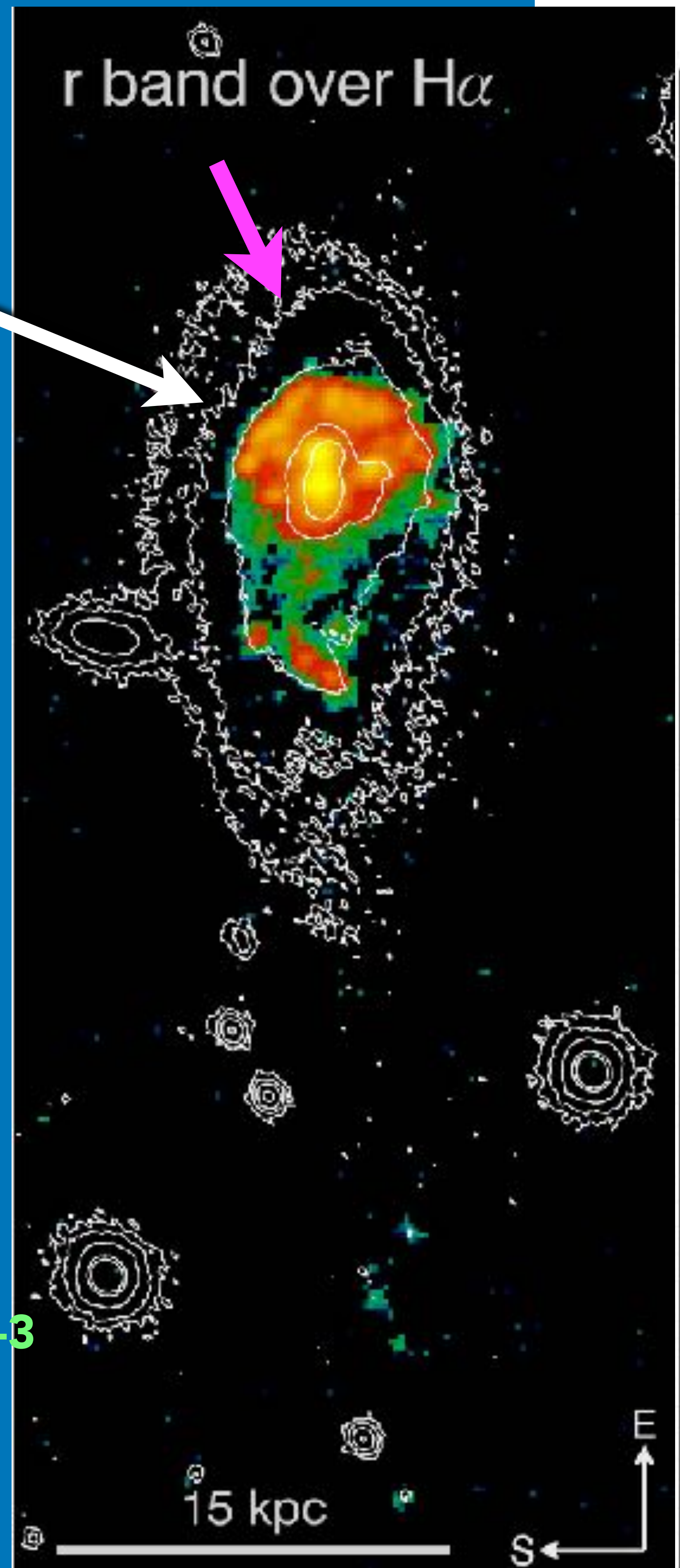
$$\frac{a_{tid}}{a_{gal}} = \frac{M_{90090}}{M_{90630}} \frac{R^2}{(r-R)^2}$$

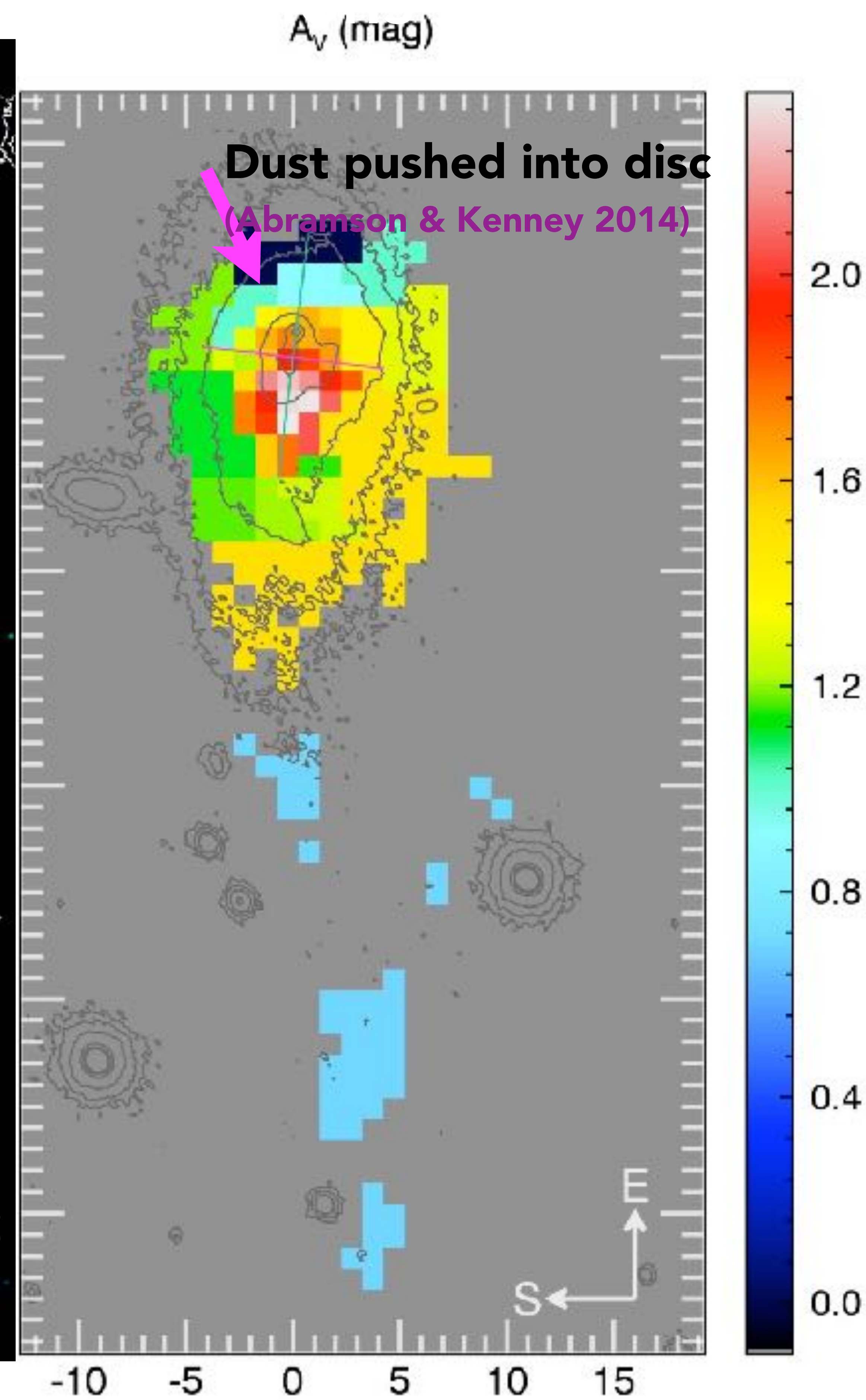
Vollmer et al. 2005



ShaSS-4080538

current SF





model:

V_w = 500 km s^{-1}

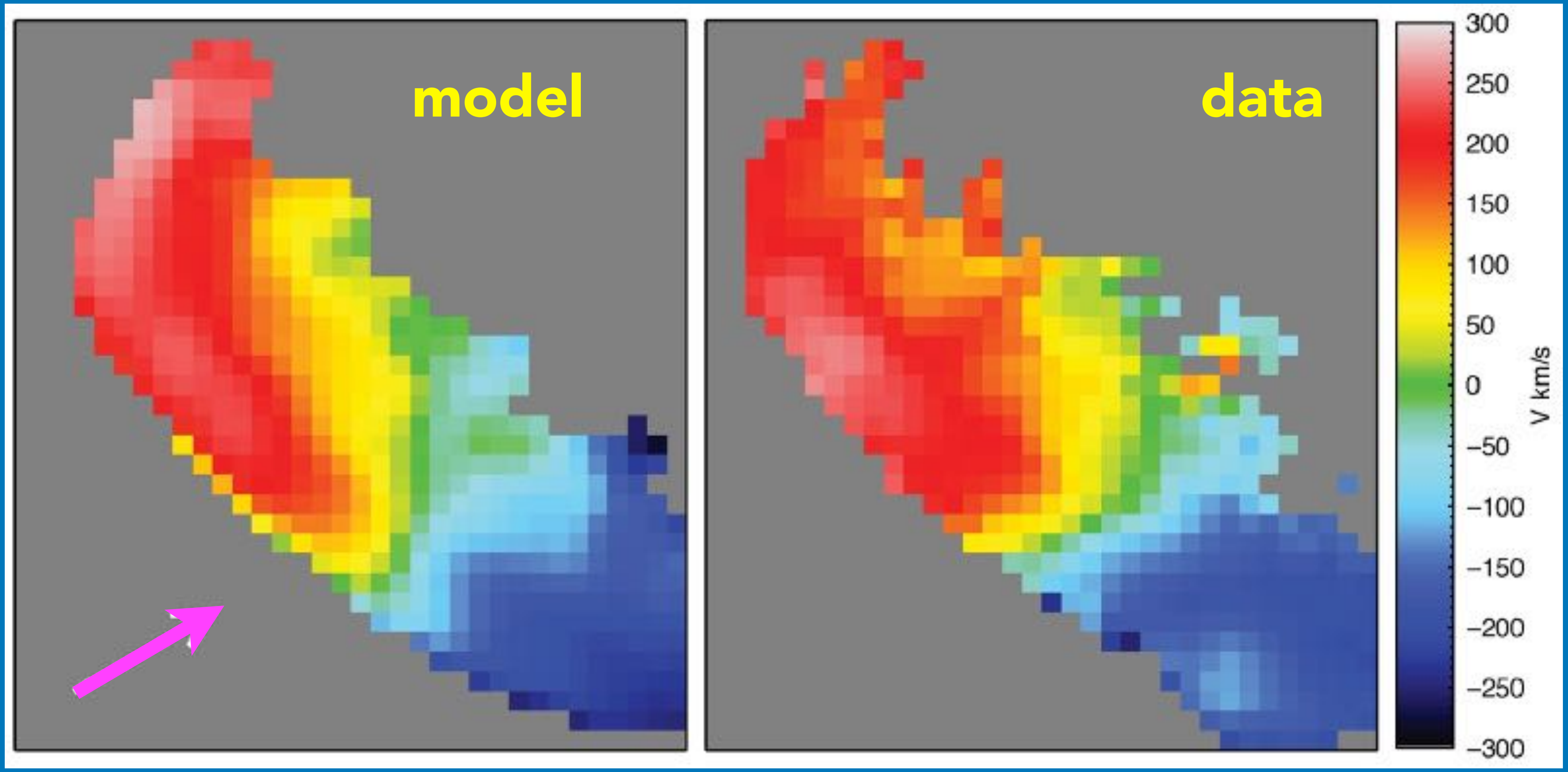
β = 80°

ρ_{ICM} = 5×10^{-28} gcm^{-3}

t = 400 Myr

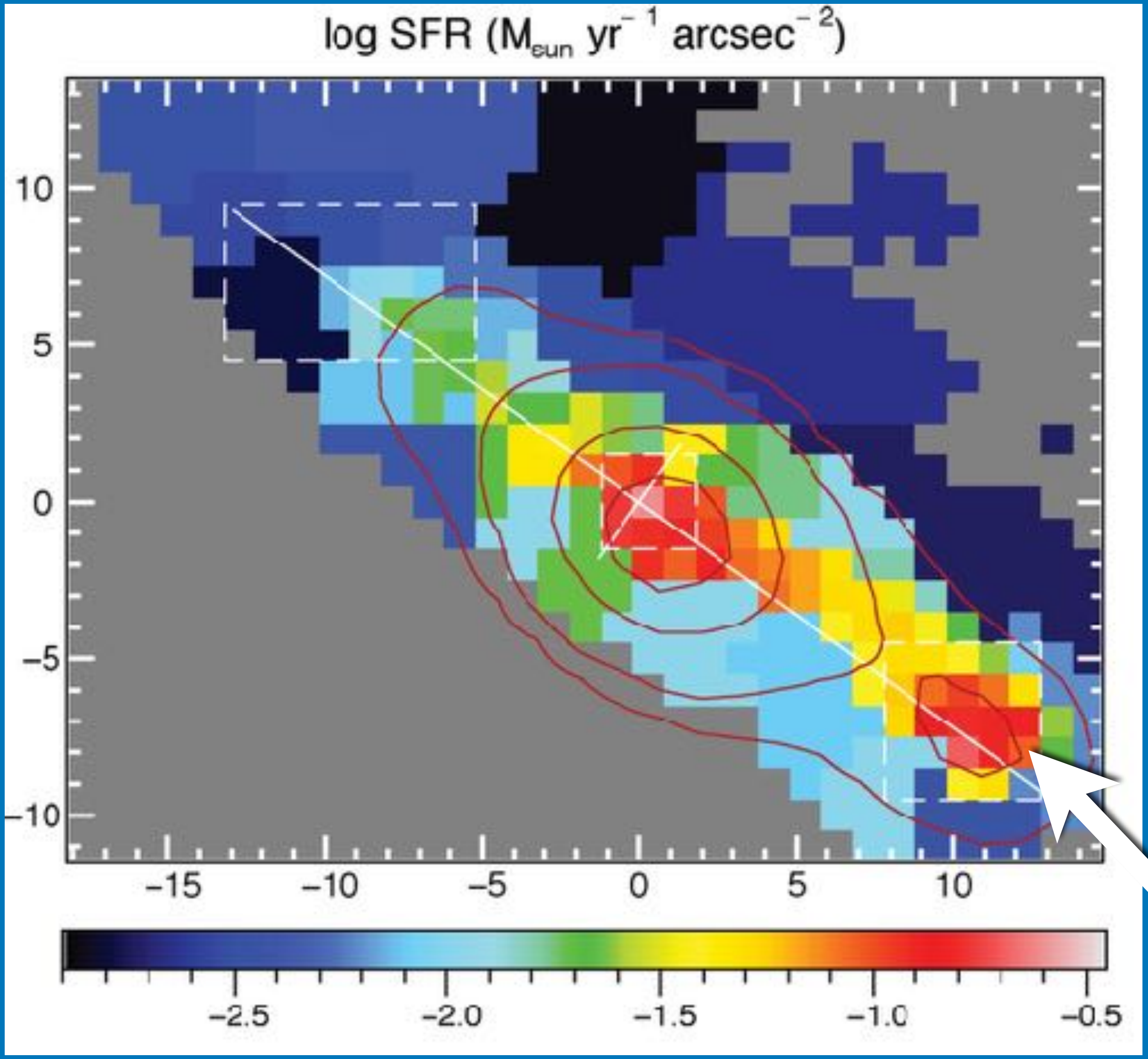
ShaSS-408053060: ionized gas velocity field

V_w = 830 - 2600 km s^{-1}
β = 15° - 85°
ρ_{ICM} = 1.3×10^{-28} gcm^{-3}



β = 45° **V_{wind} = 1400 km s^{-1}** **t ~ 60 Myr**

ShaSS-408053060: star formation



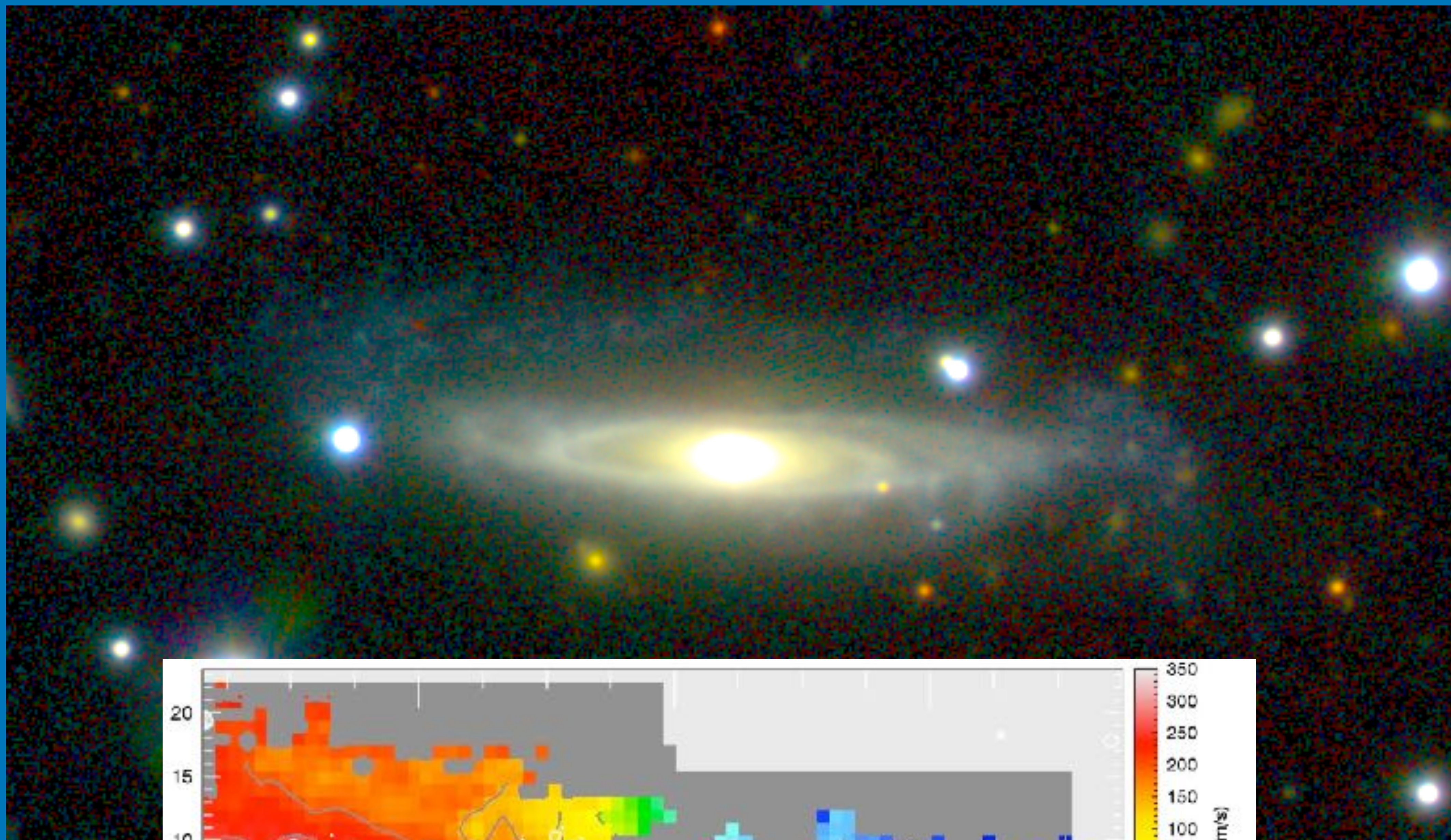
a starburst with 5x increase in SFR over the last 100 Myr (SW disc)

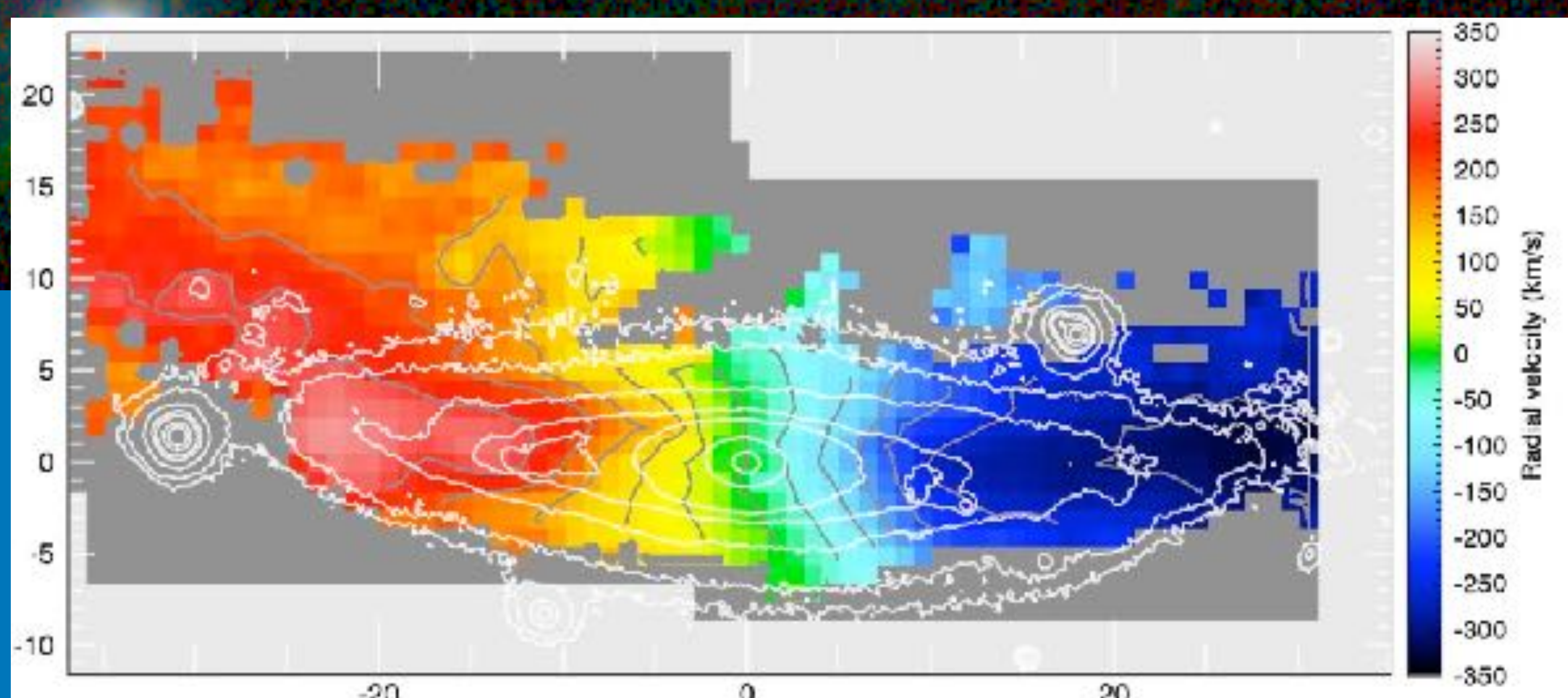
i = i* - 1

$M_{star} \approx 1.6 \times 10^{11}\ M_{\odot}$

SFR $\approx 6\ M_{\odot}\ yr^{-1}$

ShaSS-421015419

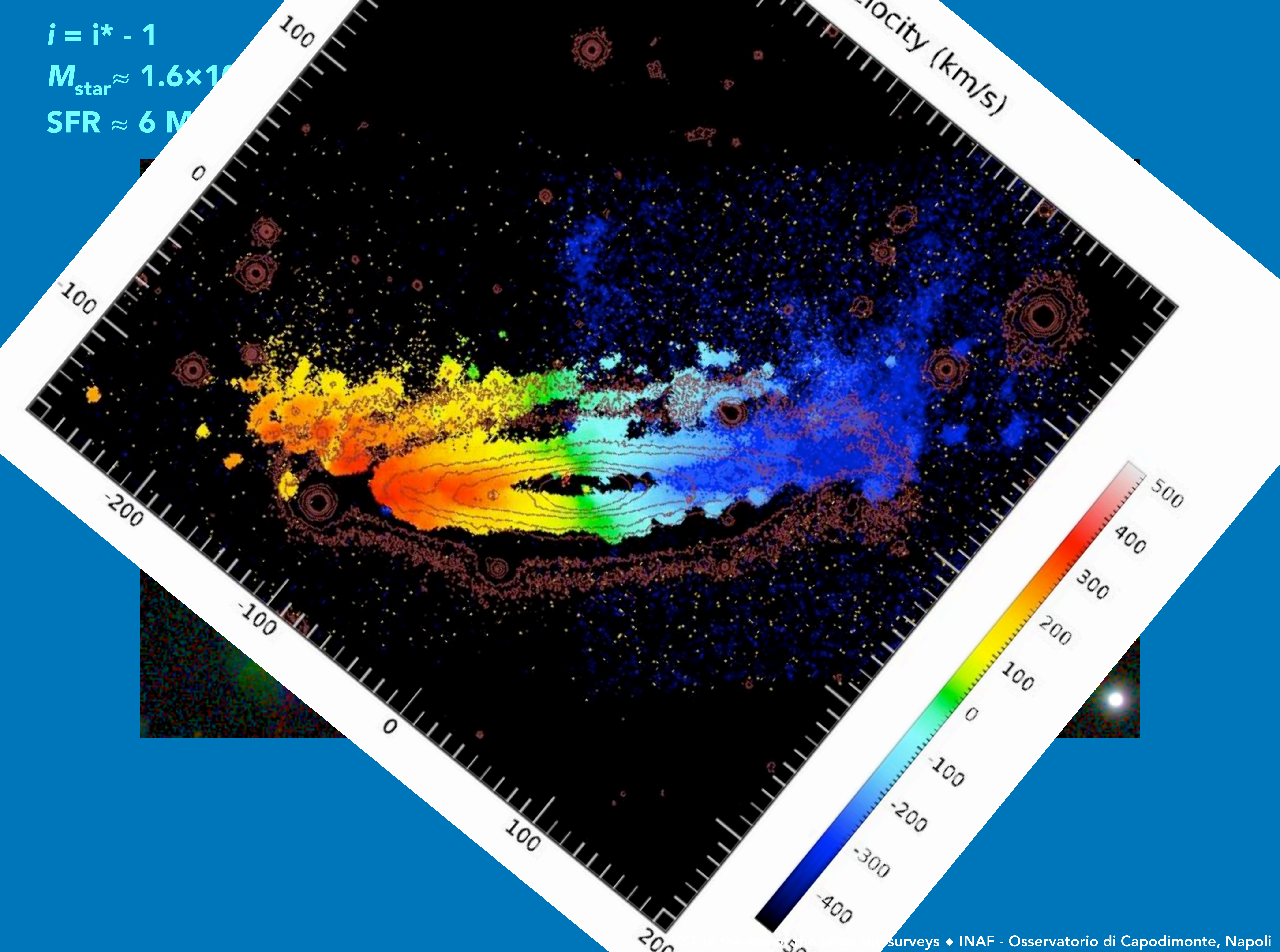




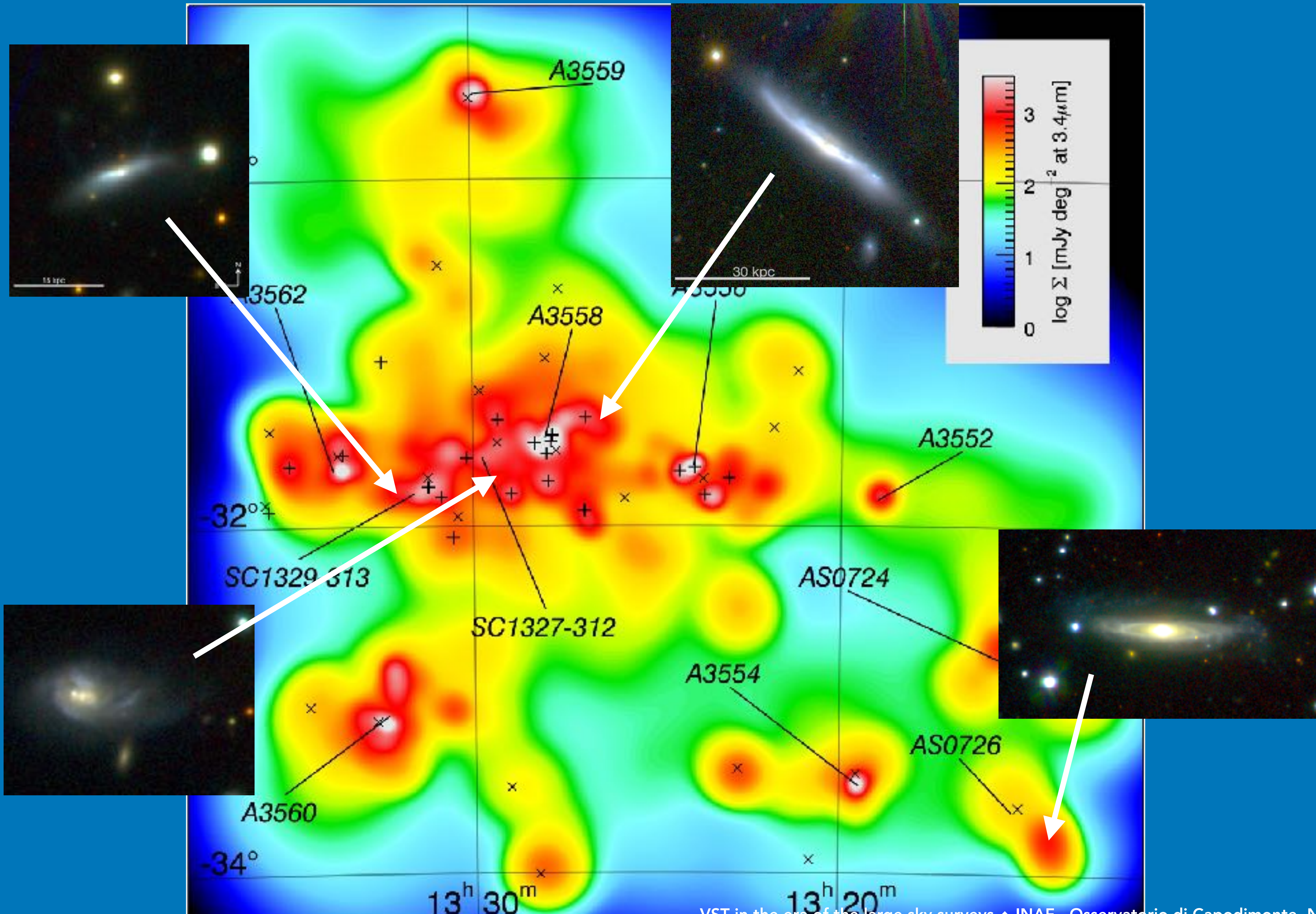
i = i* - 1

$M_{star} \approx$ 1.6×1

SFR ≈ 6 M



Where are the *bona fide* RPS galaxies?



- RPS (+ TI + merging + …): multi-band data + IFS + simulations

  (e.g. Vollmer et al. 2005, Cortese et al. 2006-2007, Cortés et al. 2015)

- RPS often temporarily enhances SF also in the disc

  (e.g Kromberger et al. 2008, Merluzzi et al. 2013)

- RPS can take place everywhere and affect any cluster/group galaxy

BUT

13 galaxies: possible extraplanar gas ➜ detected in 9

➜ RPS in 4

⬇

0.5%

supercluster members

ongoing RPS examples
not census