Mass assembly survey with SINFONI in VVDS

Massiv Assembly Survey with SINFONI in VVDS

Philippe AMRAM

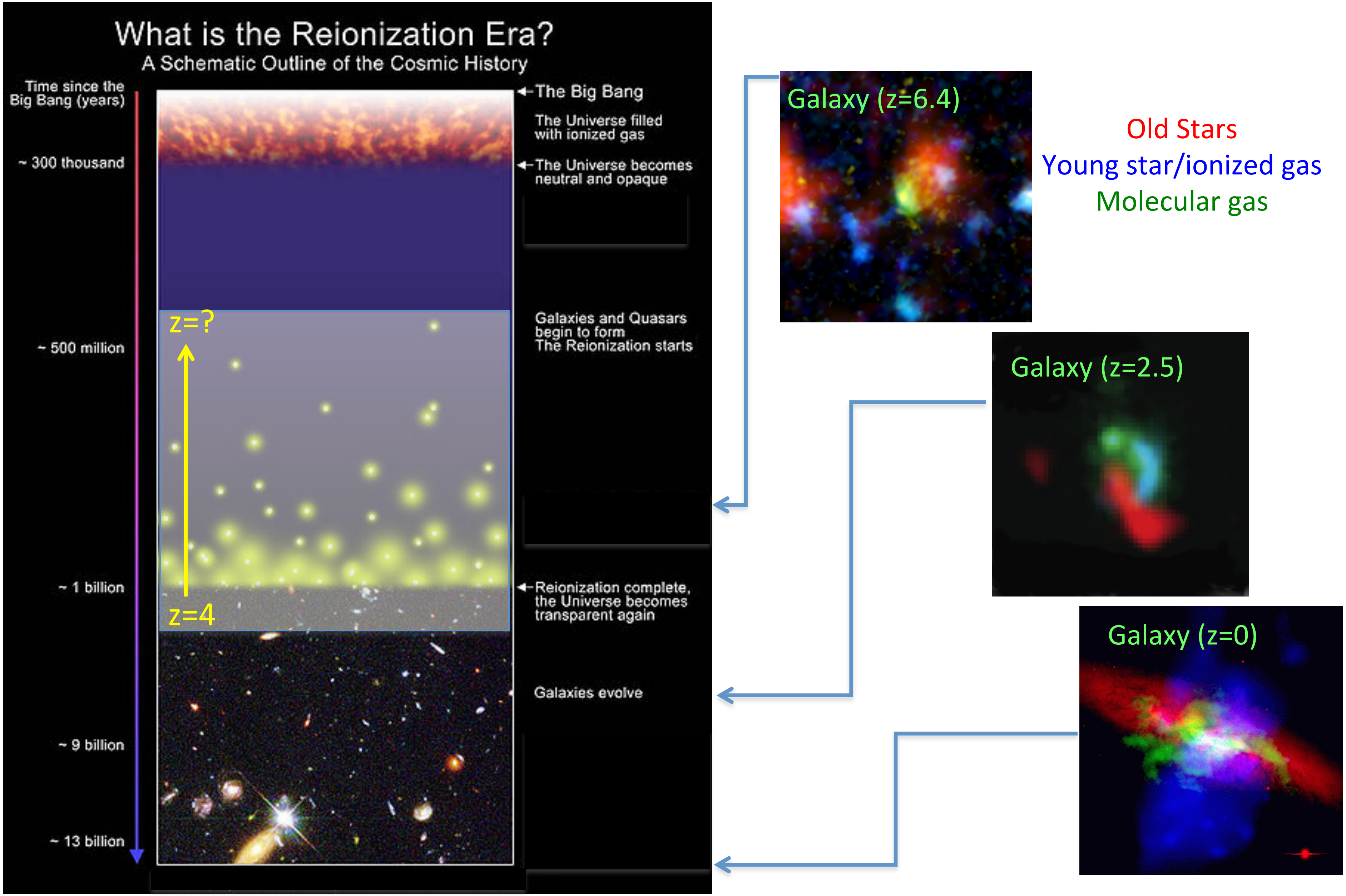
LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

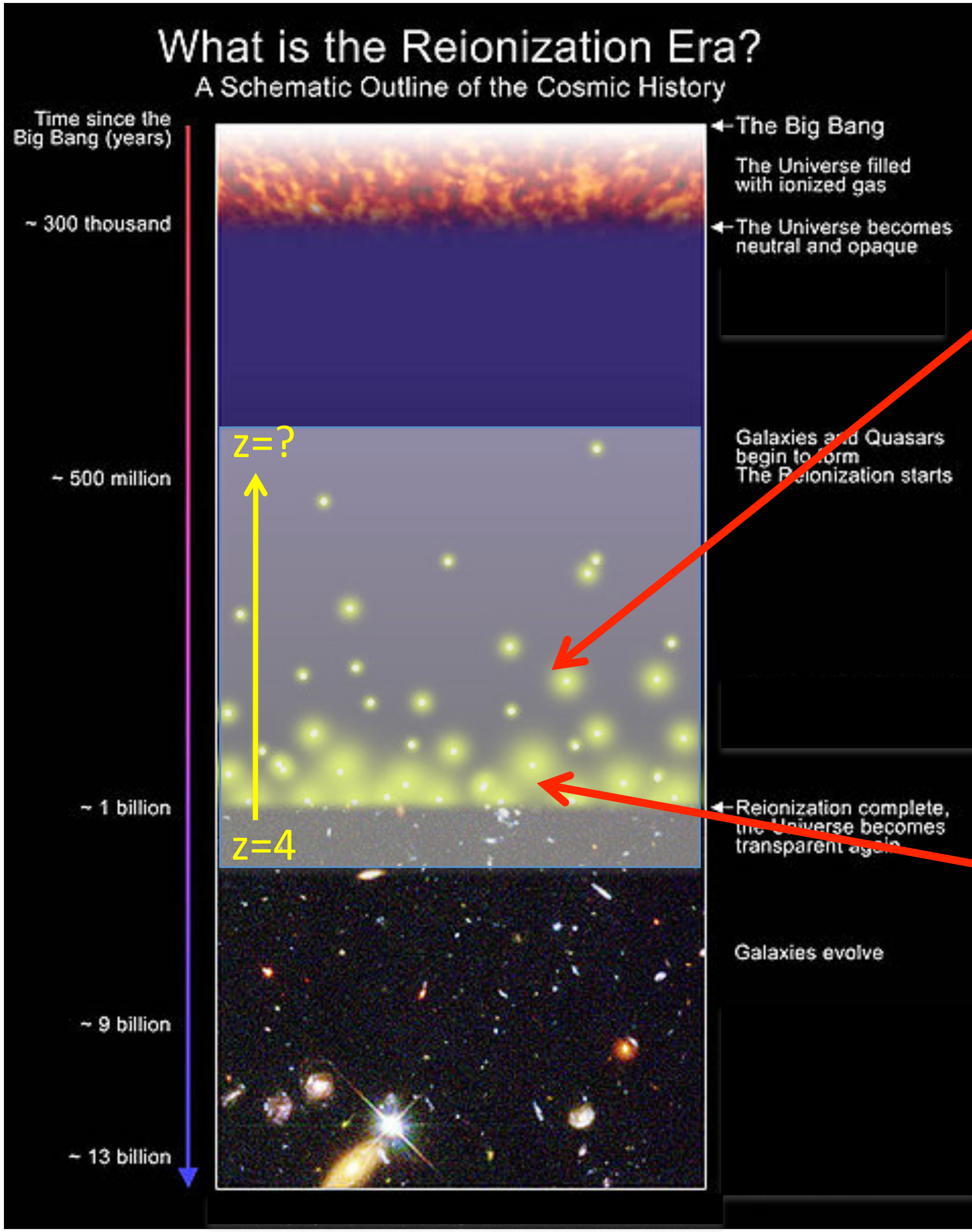
on behalf of the MASSIV team

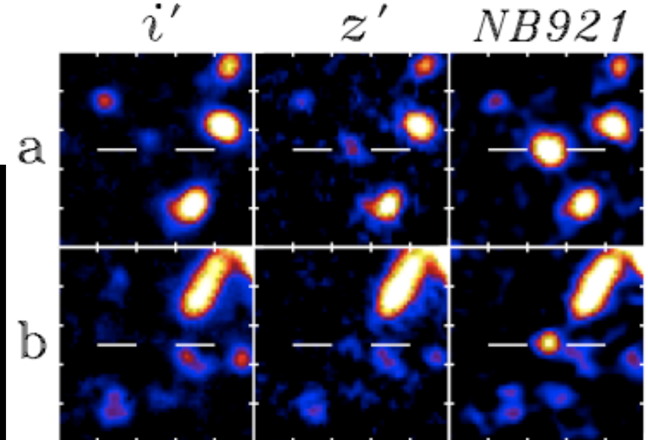
SFP- Marseille 2013

Mass Assembly of Galaxies

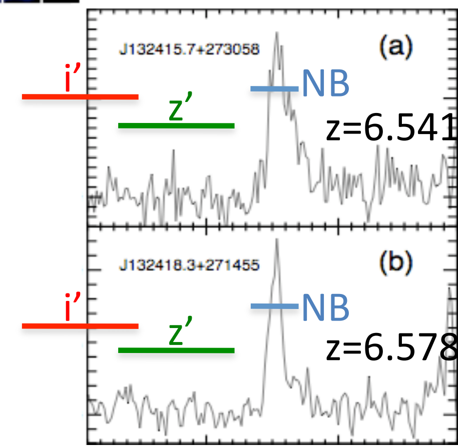
Cosmic History

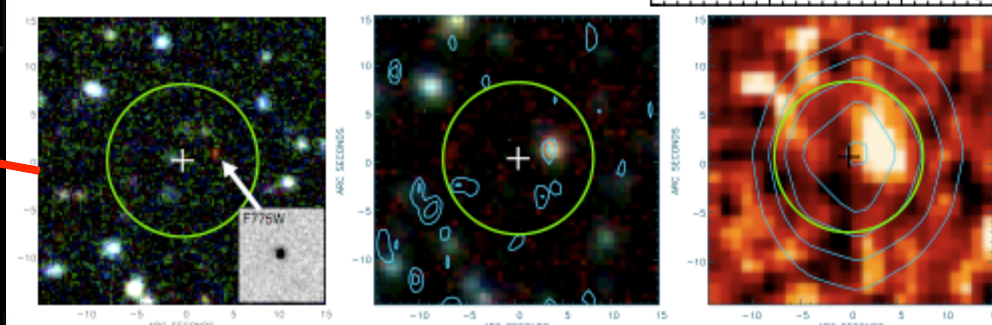






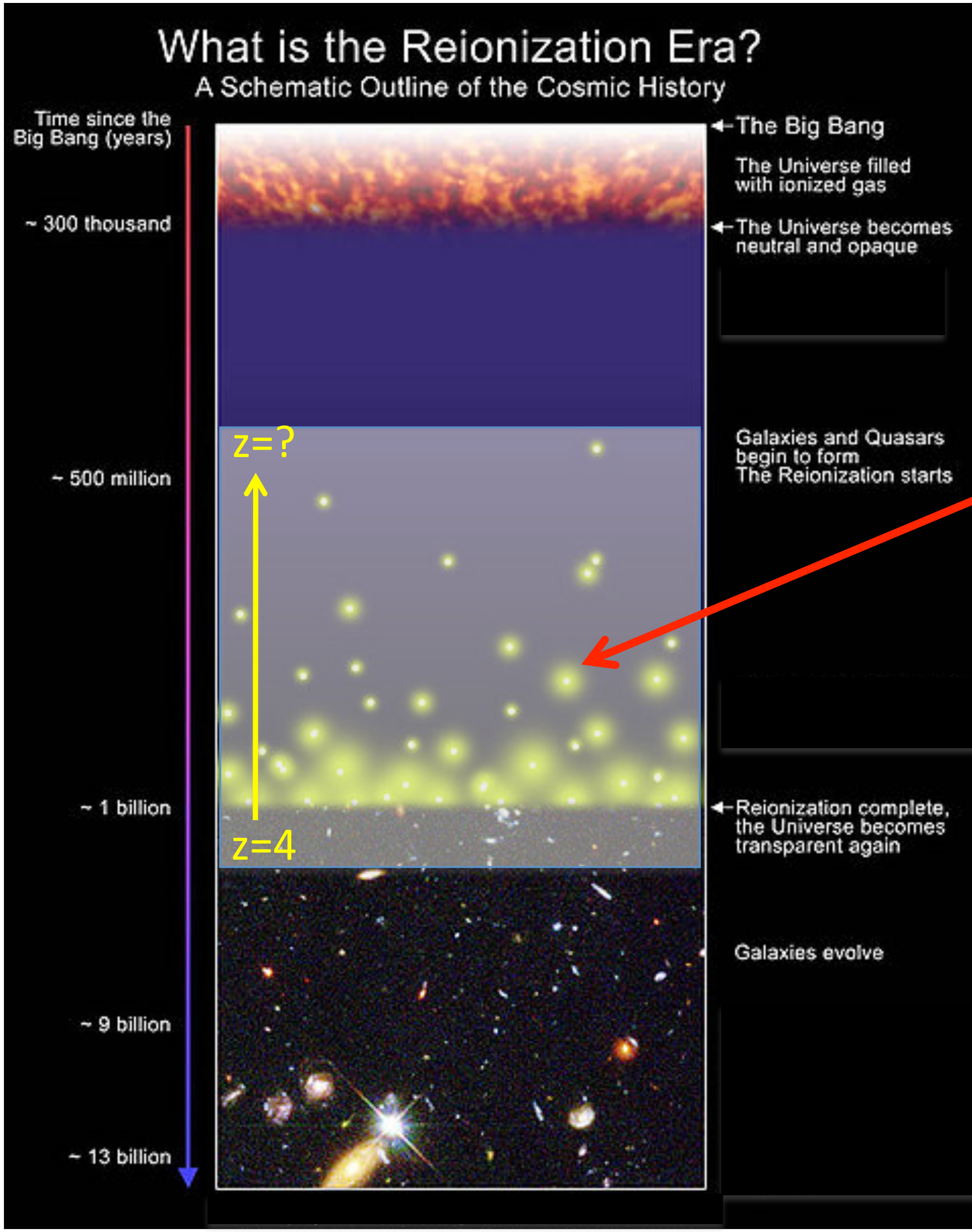
Lyα recombination line
Kodaira et al. (2003)

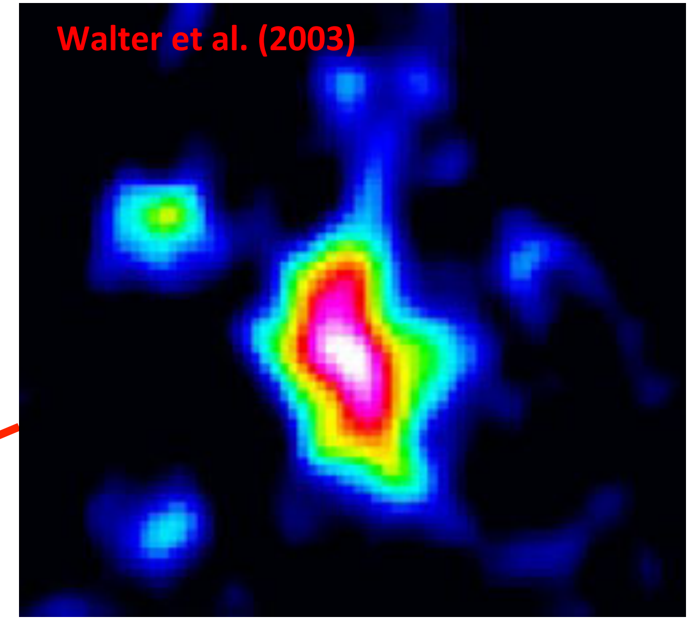




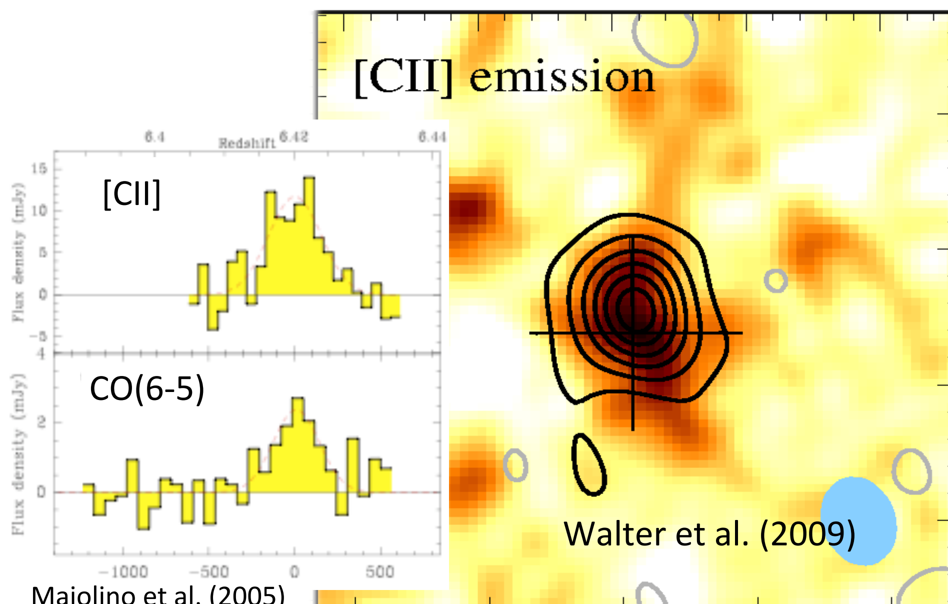
z=4.76 submm-selected source not associated with a QSO
Coppin et al. (2009) - 870μm APEX/LABOCA Survey

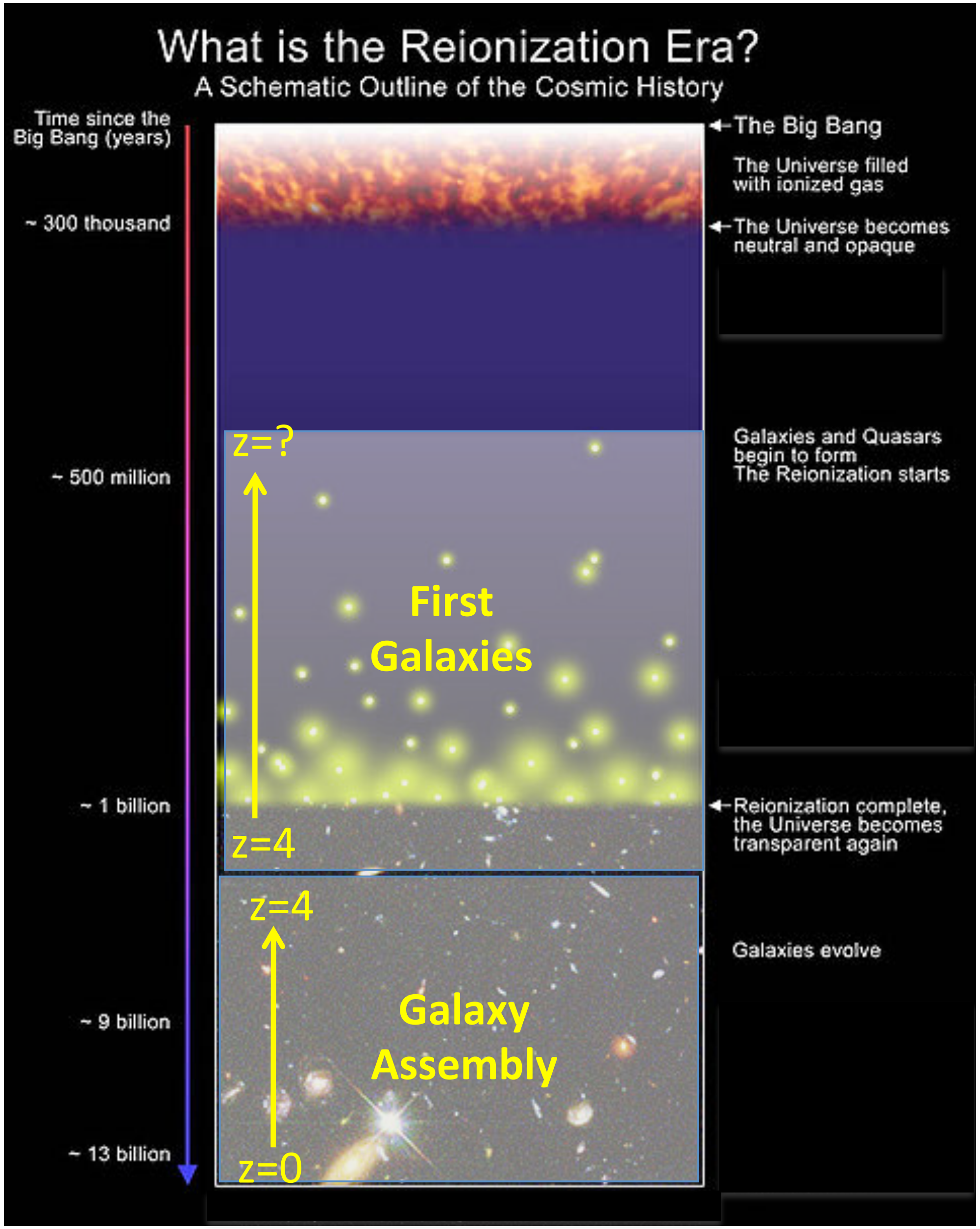
CO 3-2 in SDSSJ1148+5152 (z=6.42)





The highest CO detection to date
Universe was 1/16 of its current age





Key questions to be addressed in the coming decade:

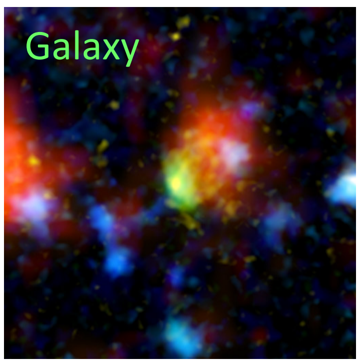
- When did the EoR start?
- How and when did the first supermassive black holes form?
- What was the inter-relationship between supermassive black hole and host galaxy growth at these early epochs?
- Process of galaxy mass assembly at early epochs?
- Role of violent mergers vs. smooth gas accretion?
- Impact of feedback (SNe, AGNs, ...)?
- Influence of environment?

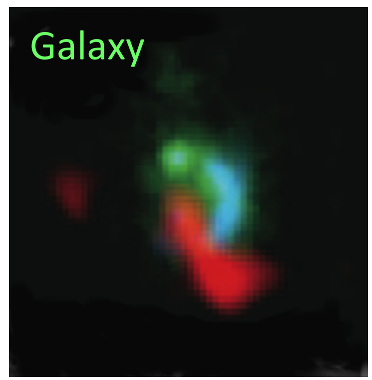
The role of gas in galaxy formation and evolution

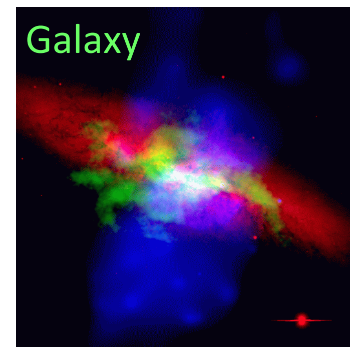
The gravitational hierarchical build-up of dark matter structures provides the framework for galaxy formation and evolution

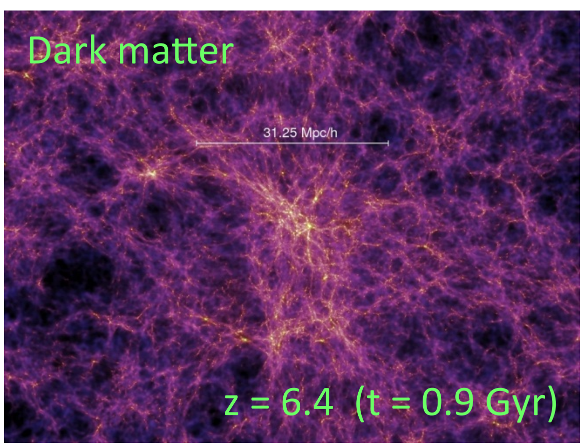
The interstellar medium (gas and dust) is a key ingredient in galaxy formation and evolution as it provides the 'fuel' for star formation and supermassive black hole accretion

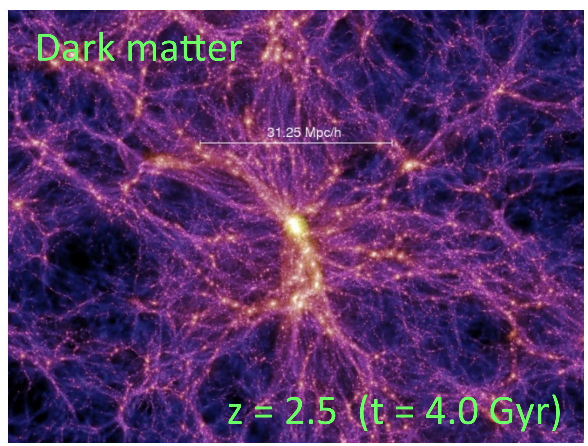
Understanding the physical properties of the interstellar medium (ISM) in distant galaxies is fundamental to our picture of galaxy formation and evolution

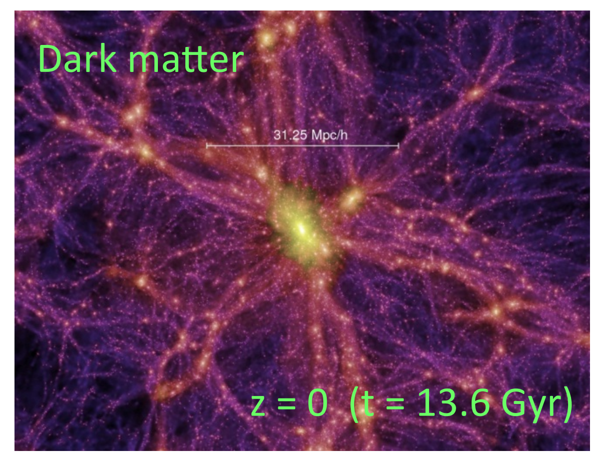










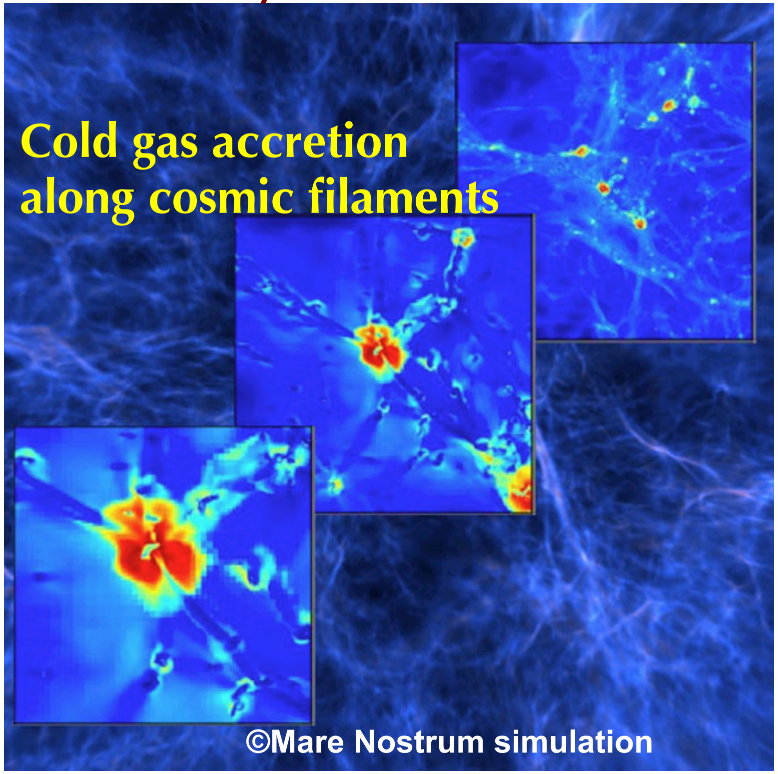


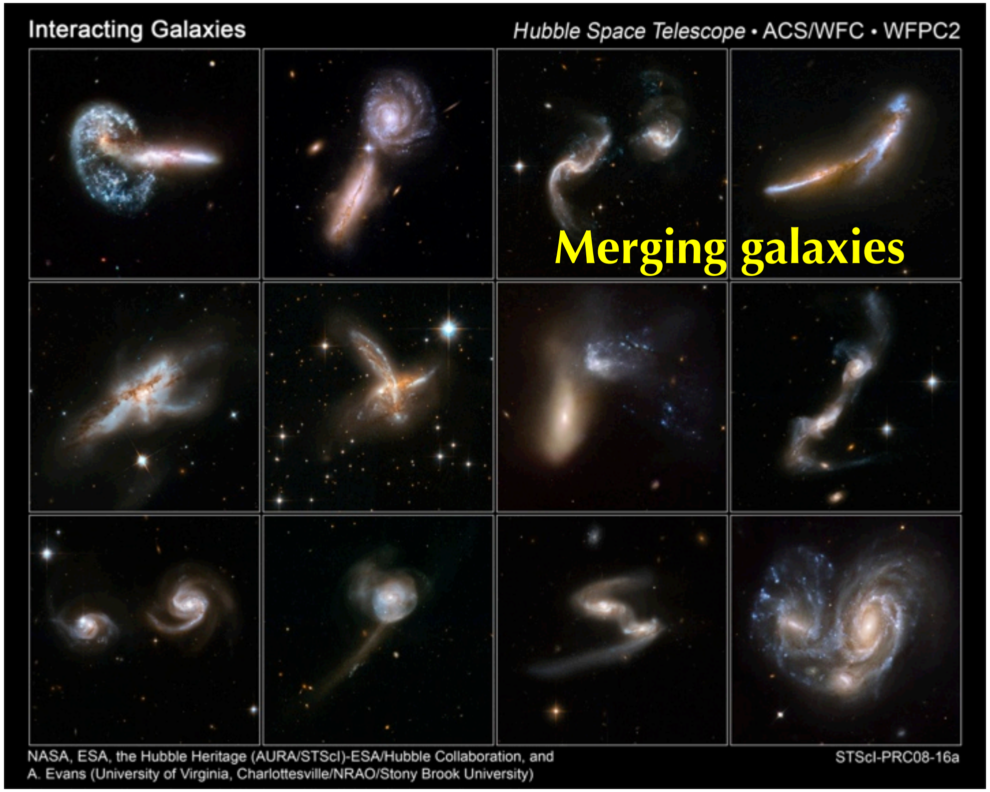
Springel et al. (2006), Nature

Open issues in galaxy evolution

Physical parameters to constrain galaxy assembly

- **Mass**: stars + gas + DM
- **Dynamics**: rotation vs. dispersion
- **Metallicity**: global + spatially-resolved
- **Activity**: star formation, AGN, …
- **Morphology**
- **Density field**





z~2-4 galaxies

Samples are (strongly?) biased due to the **colour** (LBG, BzK, etc) **pre-selection**

z~1-2 galaxies

A **crucial epoch in galaxy evolution** corresponding to:

- The peak of the cosmic **star formation activity**
- The transition between the **morphological diversity** observed @ z~3-4 and the modern-day Hubble sequence

Offering well defined parent samples for IFU studies

MASSIV
Mass assembly survey with SINFONI in VVDS

ESO *"Large Program"* (200h - 2008-11)

SINFONI observations @ VLT

Sample: **85 VVDS star-forming galaxies @ 1 < z < 2**

- **representative** of the « normal » galaxy population
- Spanning a **wide range of stellar masses** log(M*)=[9,12]

J *or* ***H*** *band to* ***target*** *redshifted*
Hα *bright emission line*
High spatial resolution *(<0.8")*
- partly with AO

MASSIV
Mass assembly survey with SINFONI in VVDS

People & Places

About 15 astronomers located in
France, Italy, Germany and Spain
are involved in the MASSIV project

IRAP – Toulouse (F)
T. Contini (PI)
J. Moultaka
J. Queyrel
F. Boone

LAM – Marseille(F)
P. Amram
B. Epinat
O. Le Fèvre
V. Perret
L. Tasca
L. Tresse

INAF – Milano(I)
B. Garilli
L. Paioro

CEFCA – Teruel(S)
C. Lopez-Sanjuan

IAA – Granada(S)
E. Perez-Montero

INAF – Bologna(I)
D. Vergani

Gemini – (US)
M. Kissler-Patig

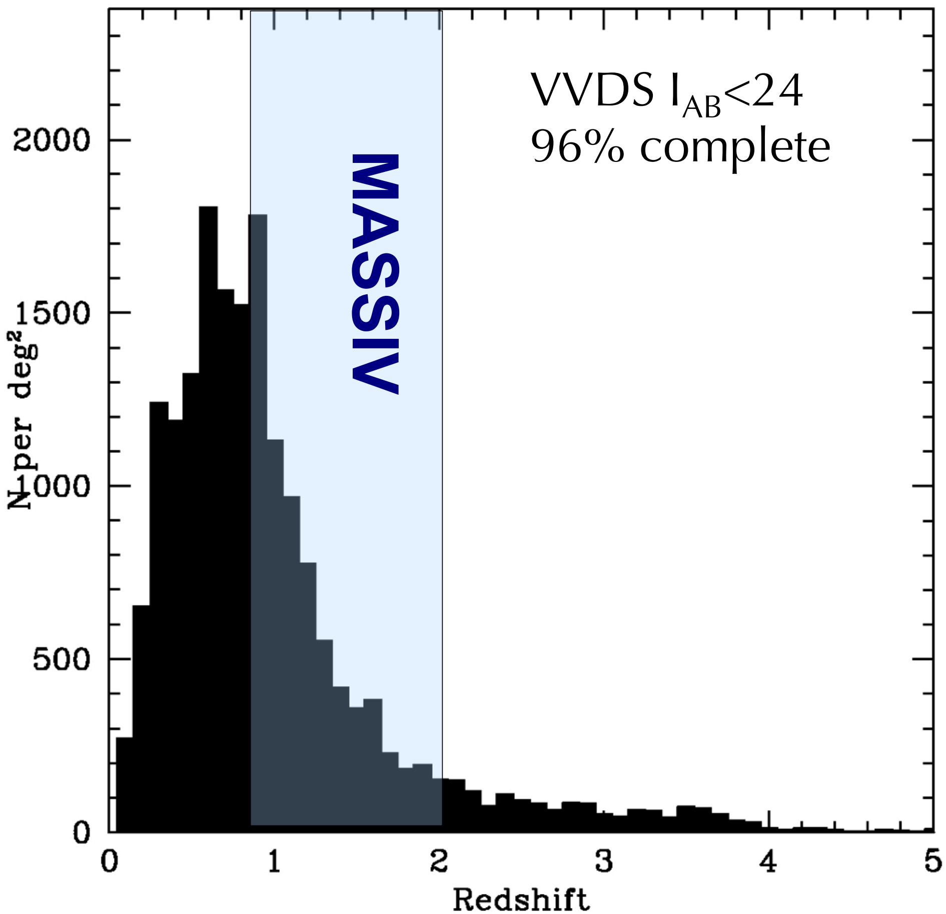
CEA – Saclay(F)
F. Bournaud

Staff – Postdoc – PhD student – Database manager - Associate

The parent sample

VLT/VISMOS (visible wide field imager and multi- object spectrograph)

The **VIMOS-VLT Deep Survey (VVDS)**, a comprehensive imaging and redshift survey of the deep universe based on more than 150,000 redshifts in four 4 sq.-degree fields.
(Le Fèvre et al., 2005, A&A, 439, 877)



VVDS offers the best suited parent sample to select high-z galaxies for NIR 3D spectroscopic follow-up

- Well-defined & **minimal bias**
- Complete & **representative**
- **Accurate** spectroscopic **redshifts**

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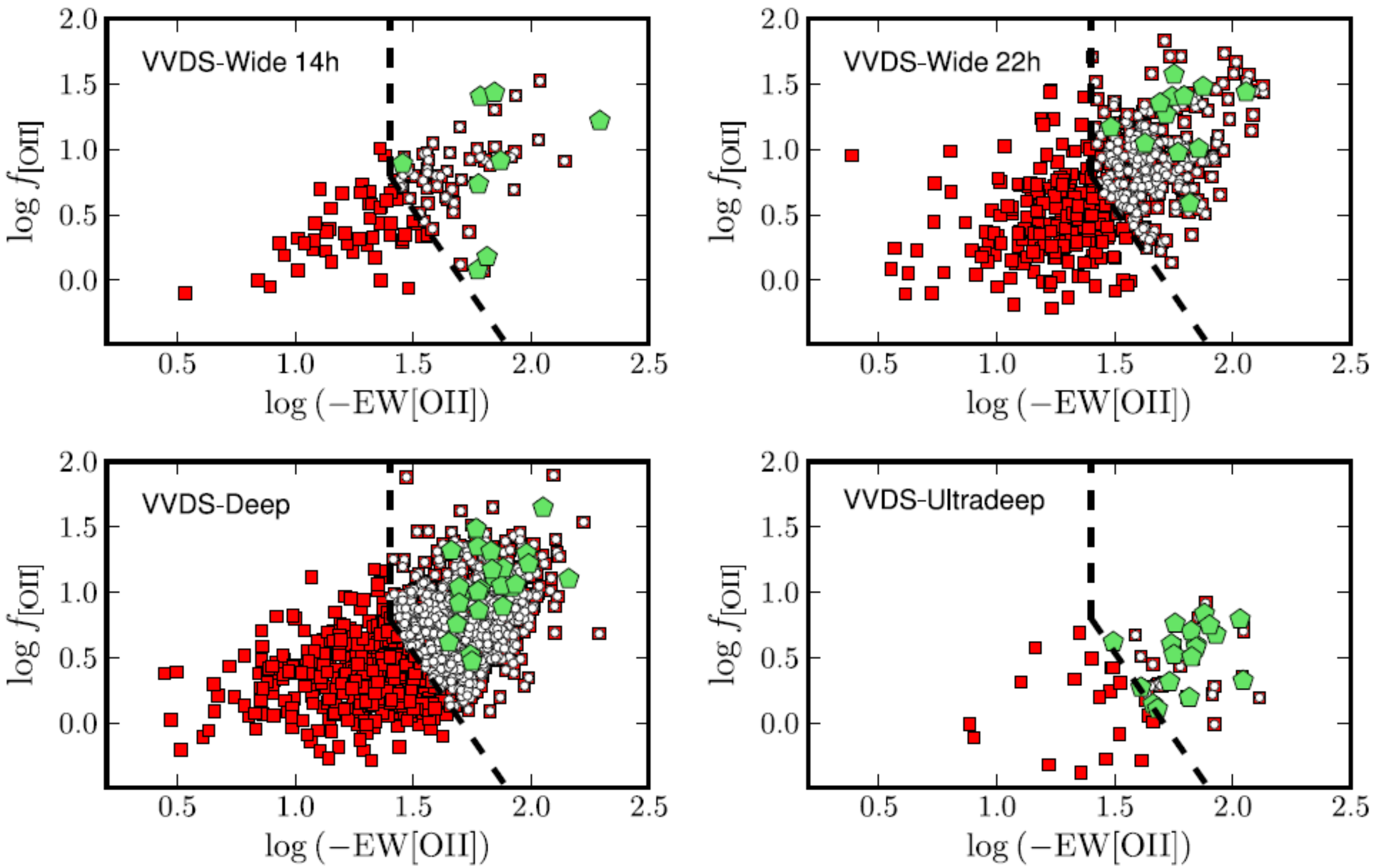
Mass assembly survey with SINFONI in VVDS

Selection criteria

Contini et al. 2012
Lopez-Sanjuan et al. 2012

Star-forming galaxies

***z < 1.46*: [OII]3727 strength**
z > 1.46: UV slope + abs. lines



[OII]3727 Flux

[OII]3727 EW

+

- Ha free of bright OH lines
- Bright star close enough for **AO/LGS** observations

Three fields:
F02 **deep** (I_{AB}<24) & **ultra-deep** (I_{AB}<24.75)
F14 & F22 **wide** (I_{AB}<22.5)

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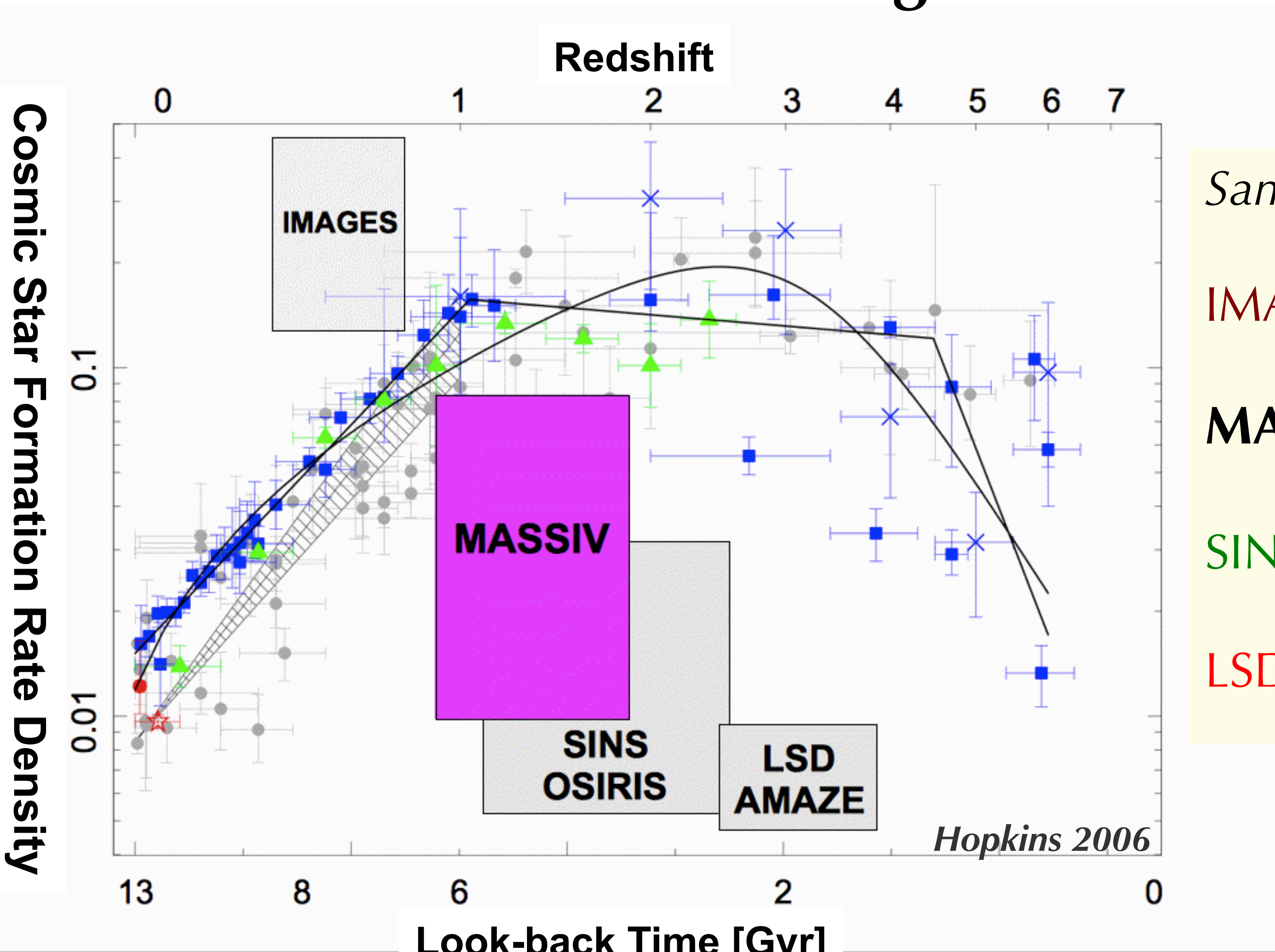
Mass assembly survey with SINFONI in VVDS

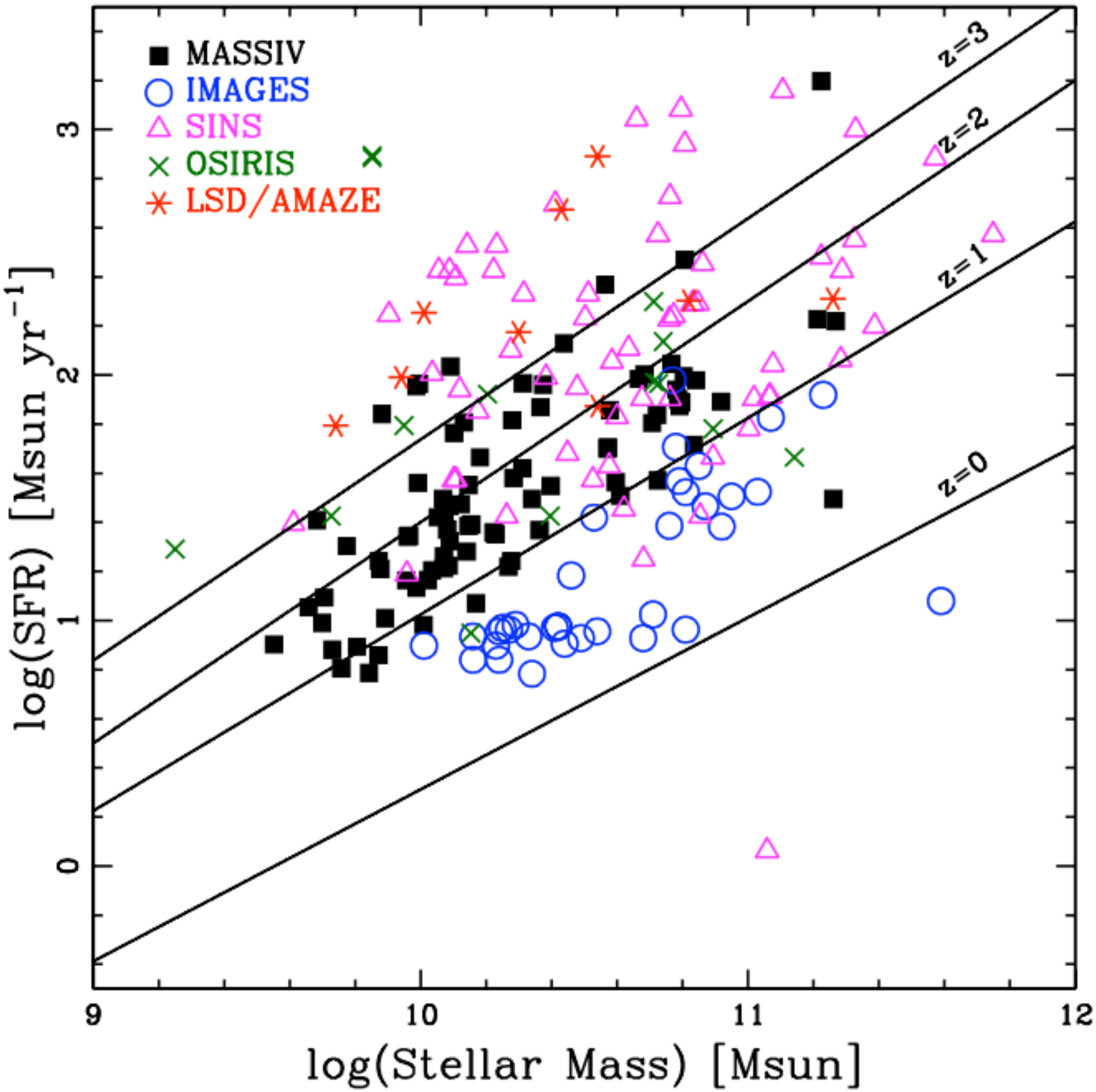
MASSIV vs other high-z IFU surveys



Sample	*N*	*<z>*
IMAGES	63	0.60
MASSIV	**85**	**1.33**
SINS+OSIRIS	100+	2.17
LSD/AMAZE	18	3.29

Contini et al. 2012

SED-derived star formation rate



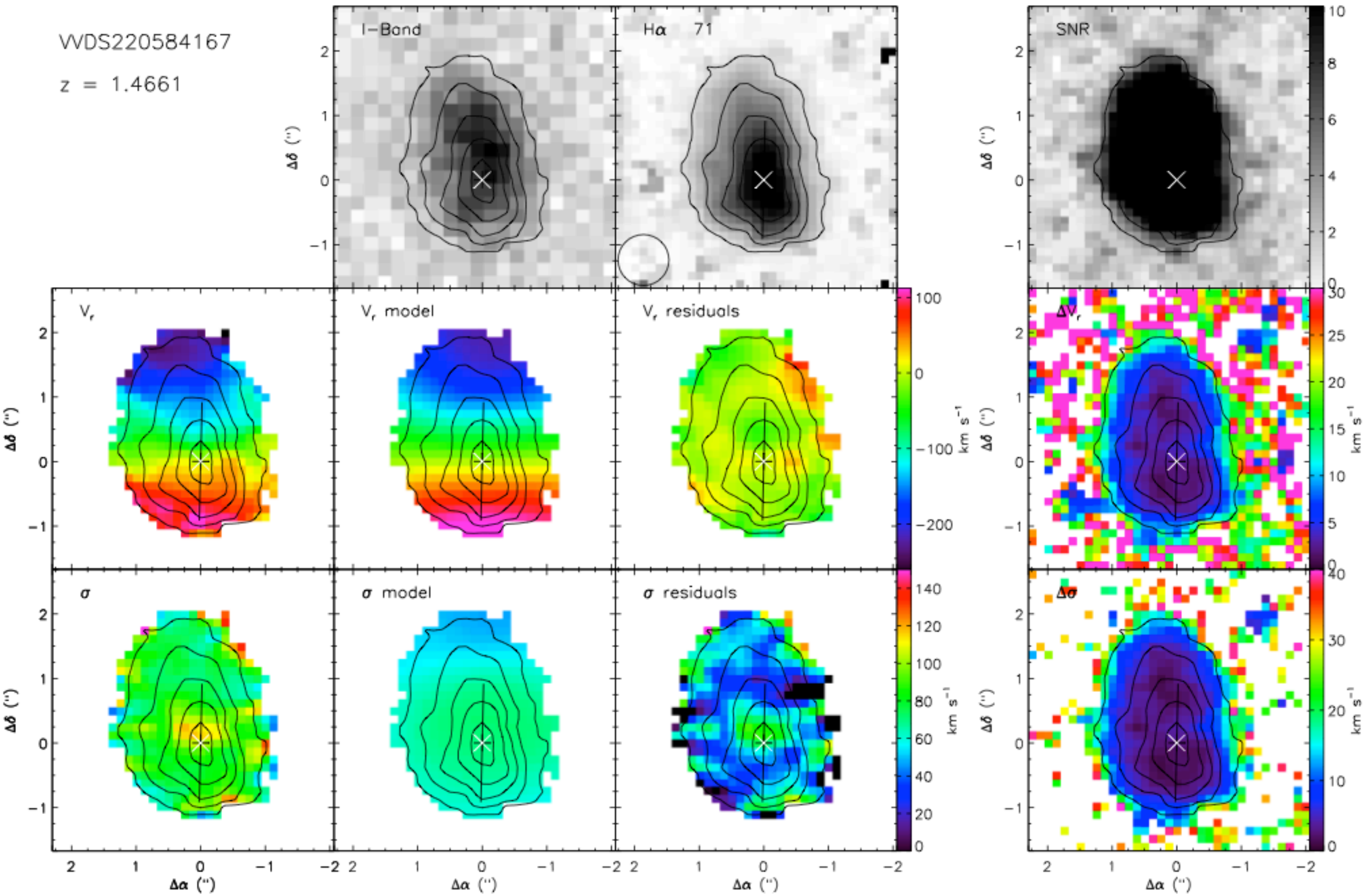
Lines @z=0-3
Empirical relations from
Bouché et al.+10

IMAGES 0.4 < z < 07
MASSIV 0.9 < z < 1.8
SINS 1.4 < z < 2.6
OSIRIS 1.5 < z < 3.3
LSD/AMAZE 2.6 < z < 3.8

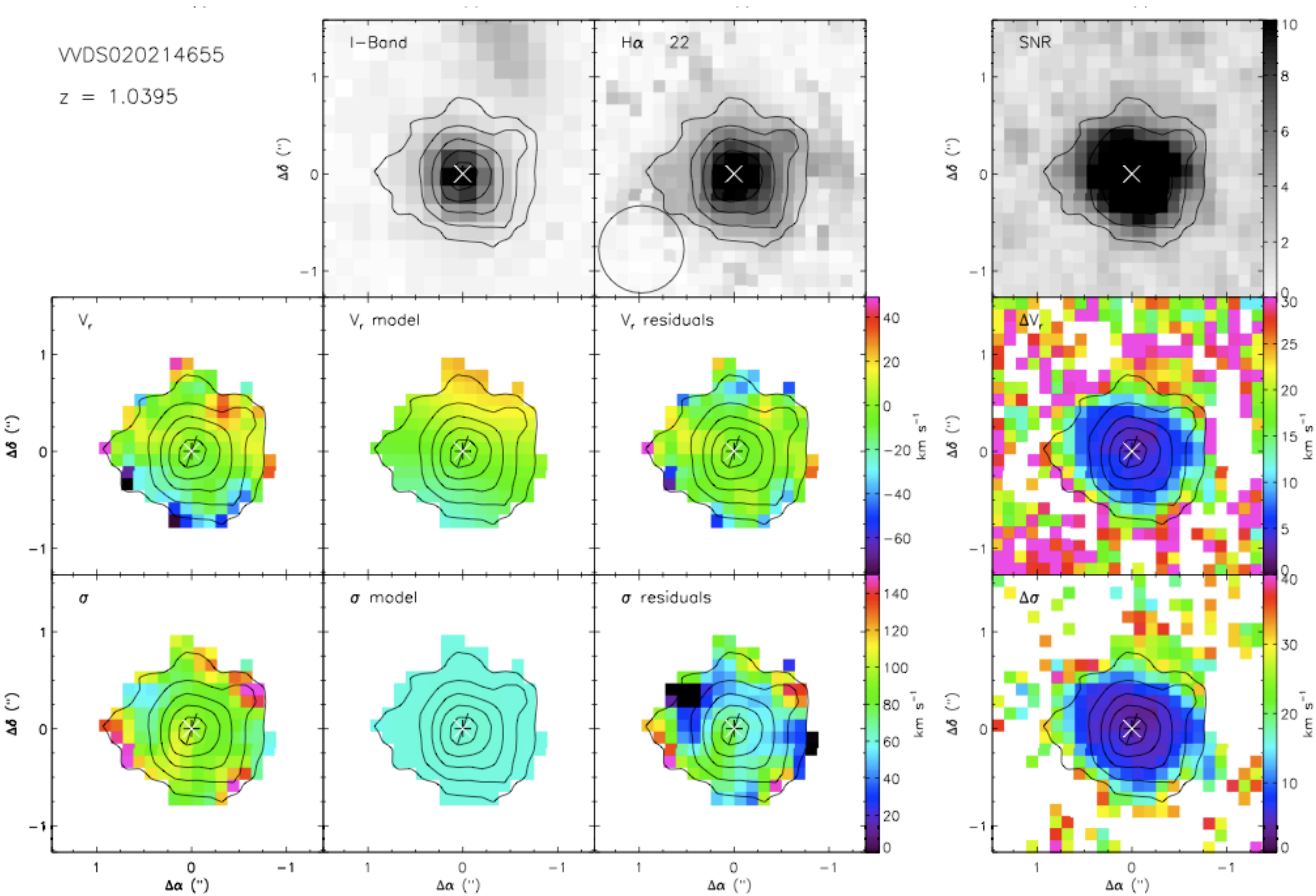
scaling factor of +0:25 dex

Contini et al+12

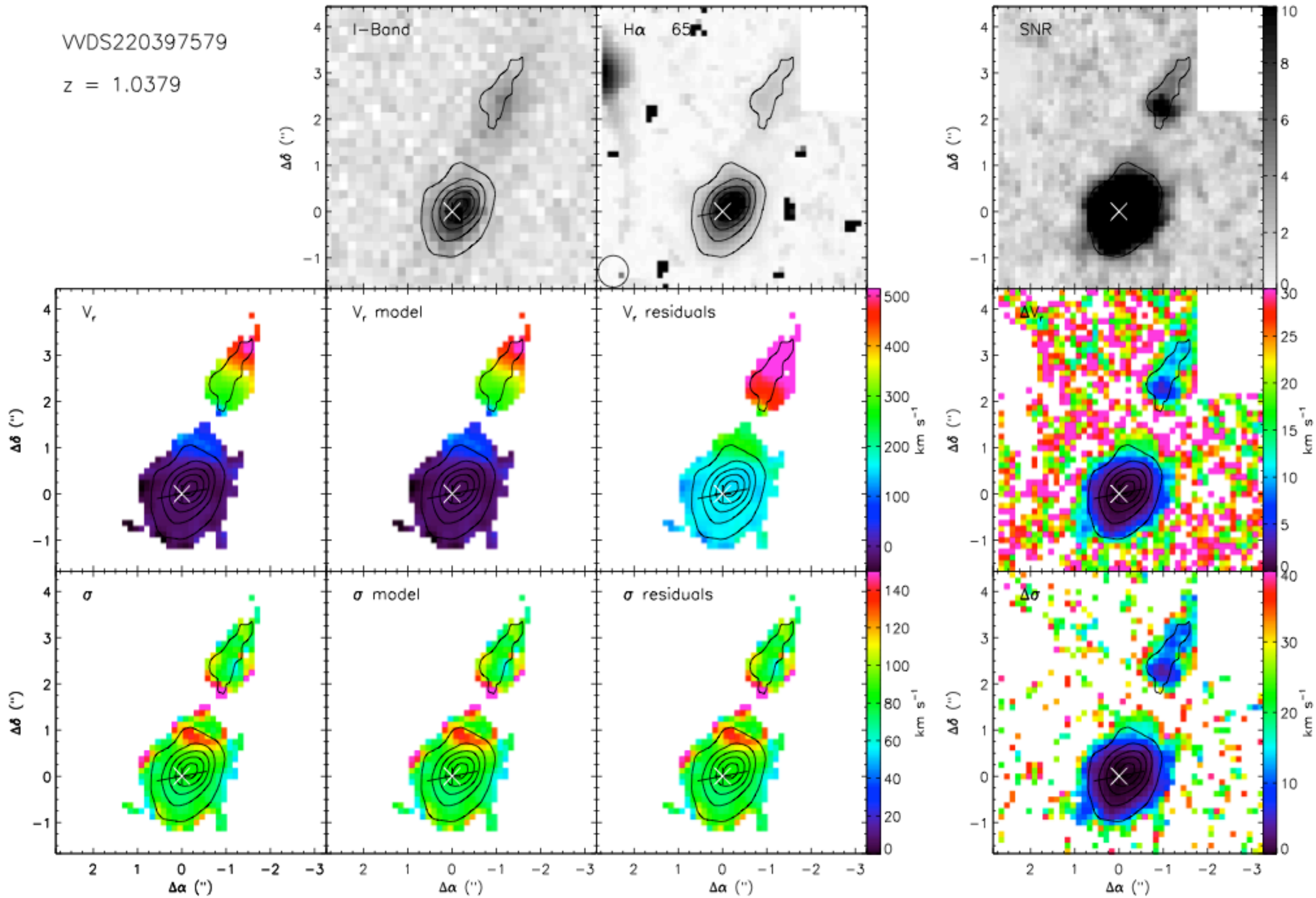
Isolated galaxy
Fast rotating (V_{max}~200 km/s) **disk**



Isolated galaxy
Slowly rotating (V_{max} < 50 km/s) **disk**

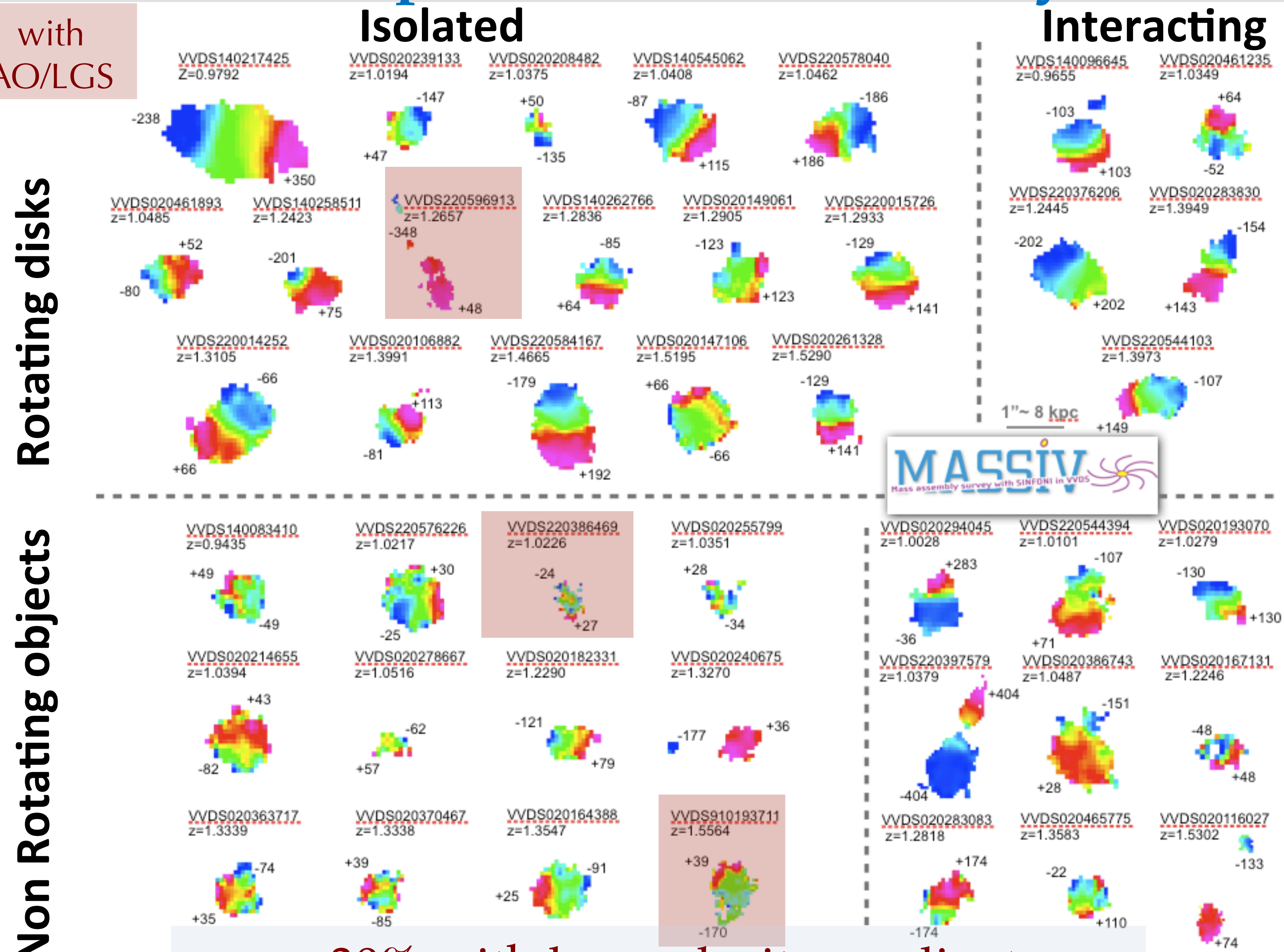


Interacting galaxies with a **fast rotating component** and another **without rotation**



The first epoch MASSIV velocity fields

with AO/LGS

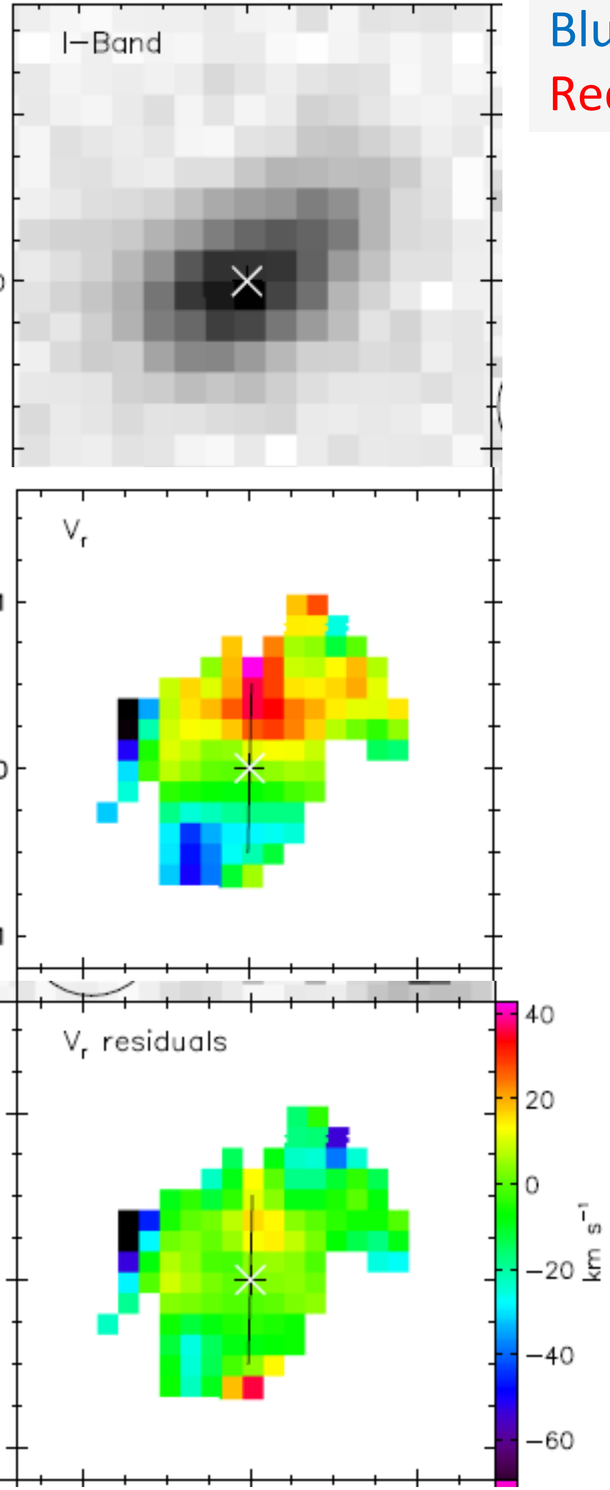


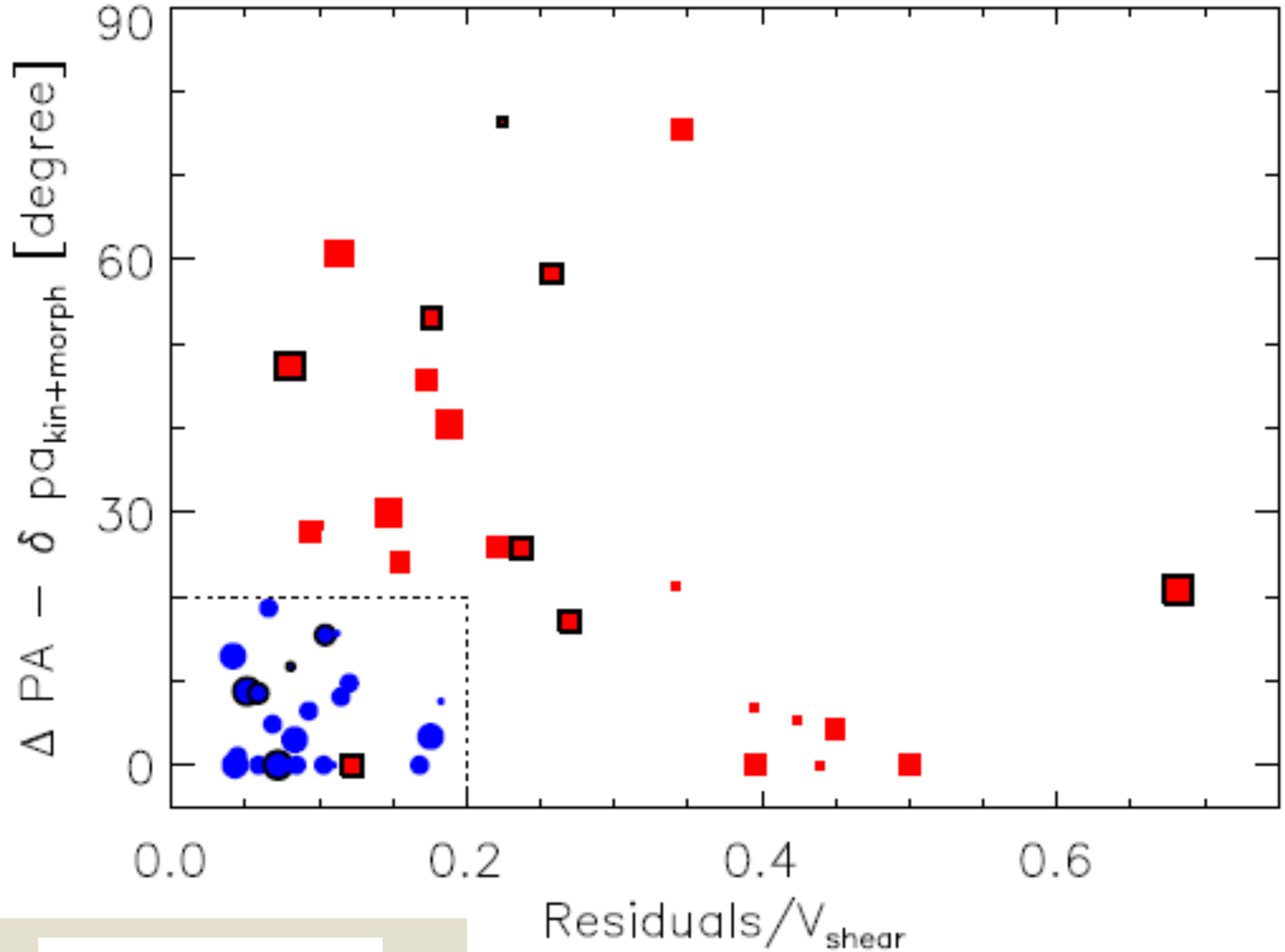
~30% interacting systems

~30% with low velocity gradient

Blue circles : fast rotators
Red squares : slow rotators

Large symbols : SNR > 10
Medium symbols : 5 < SNR < 10
Small symbols : SNR < 5





e.g. VVDS020283083

z = 1.2818

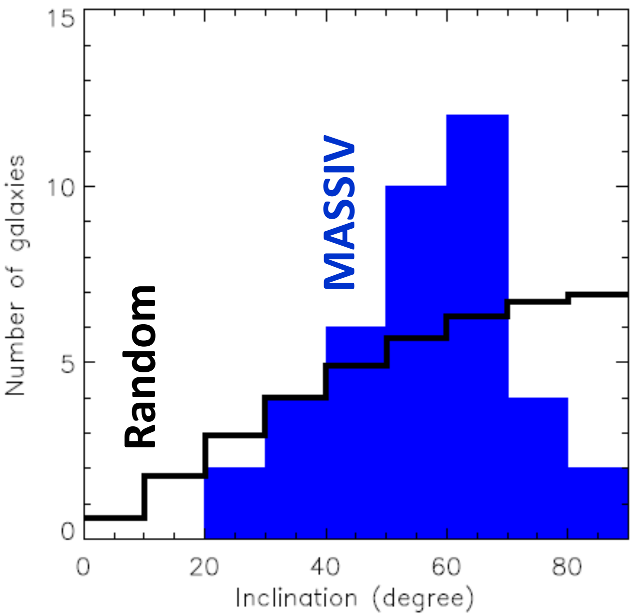
$PA_{kin} - PA_{Morph} = 58°$

$Residual/V_{shear} = 0.18$

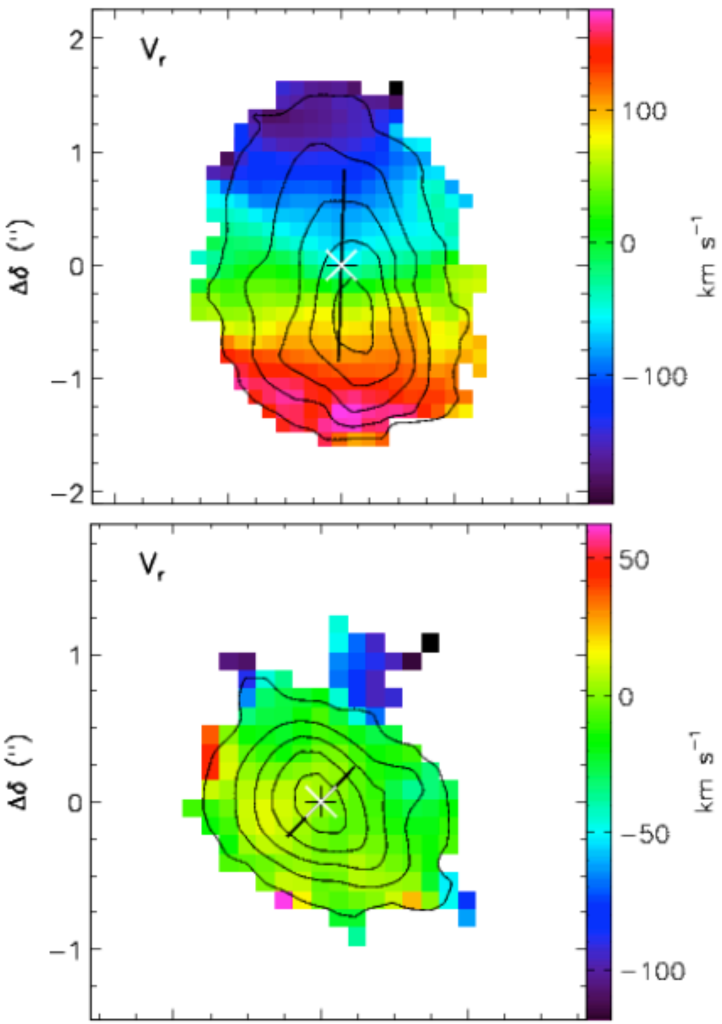
Epinat+12
First Epoch Sample

Do galaxies rotate?

Epinat+12



Two broad classes
- Amplitude of the velocity shear
- Threshold at $\Delta V = 50$ km/s



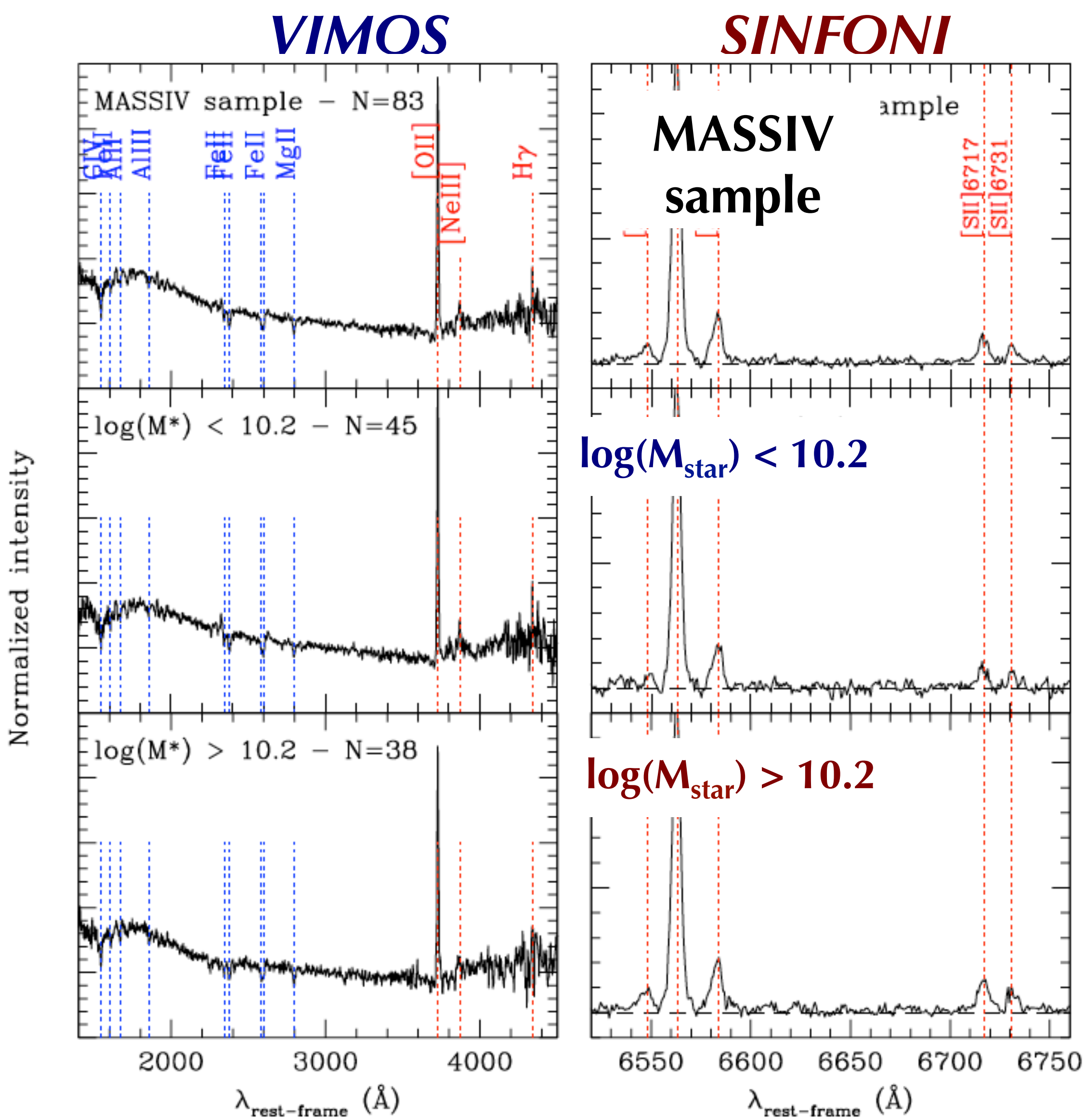
Nature of **large V-shear** galaxies
- Mainly rotating disks
- But also interacting/merging systems

Nature of **low V-shear** galaxies
- Face-on disks?
- Spheroïds?
- On-going mergers in transcient state?

Metals @ z~1-1.5

Contini et al. 2012

Composite spectra



- O/H from [NII]/Hα
- N/O from [NII]/[SII]

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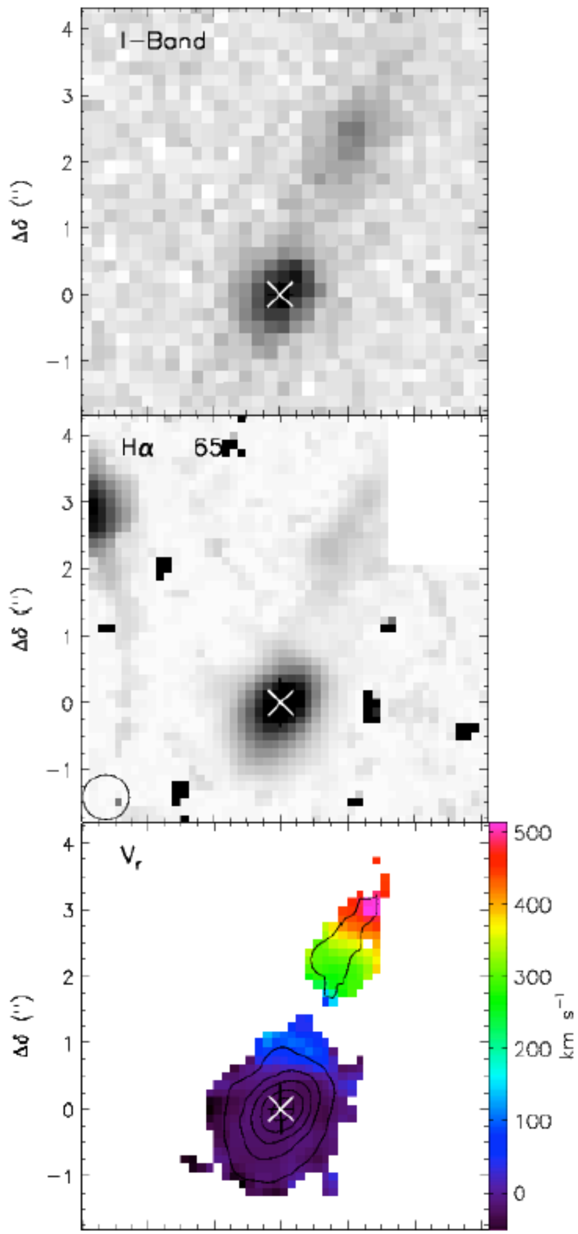
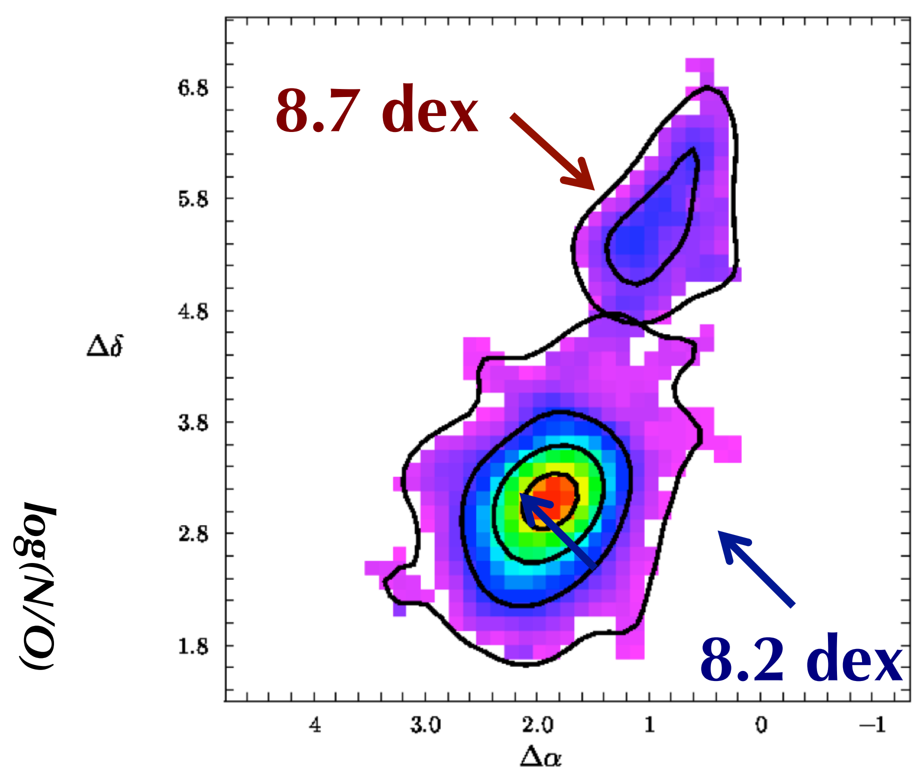
Metals @ z~1-1.5

Epinat et al. 2012

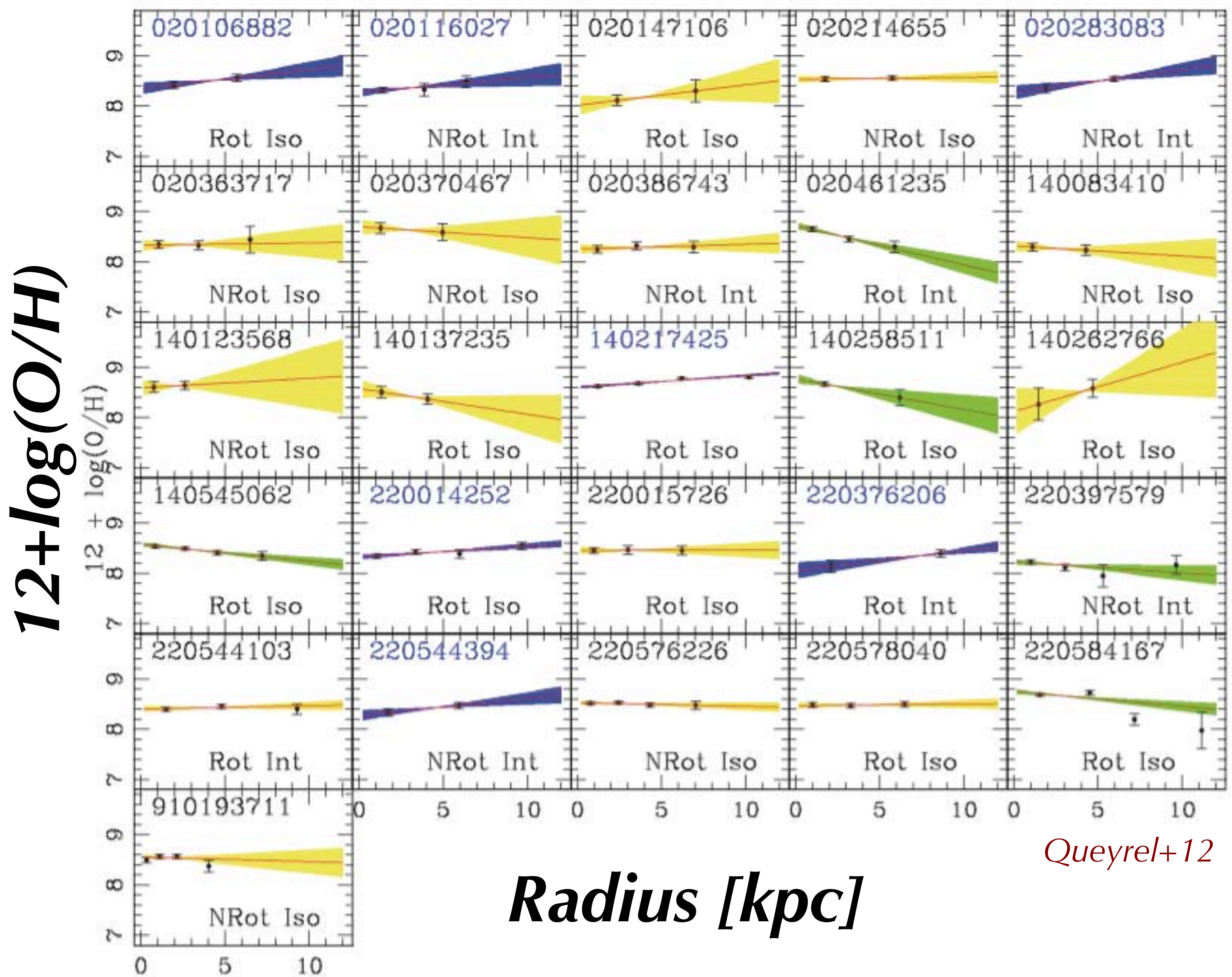


Contini et al. 2012

VVDS220397579 z=1.04

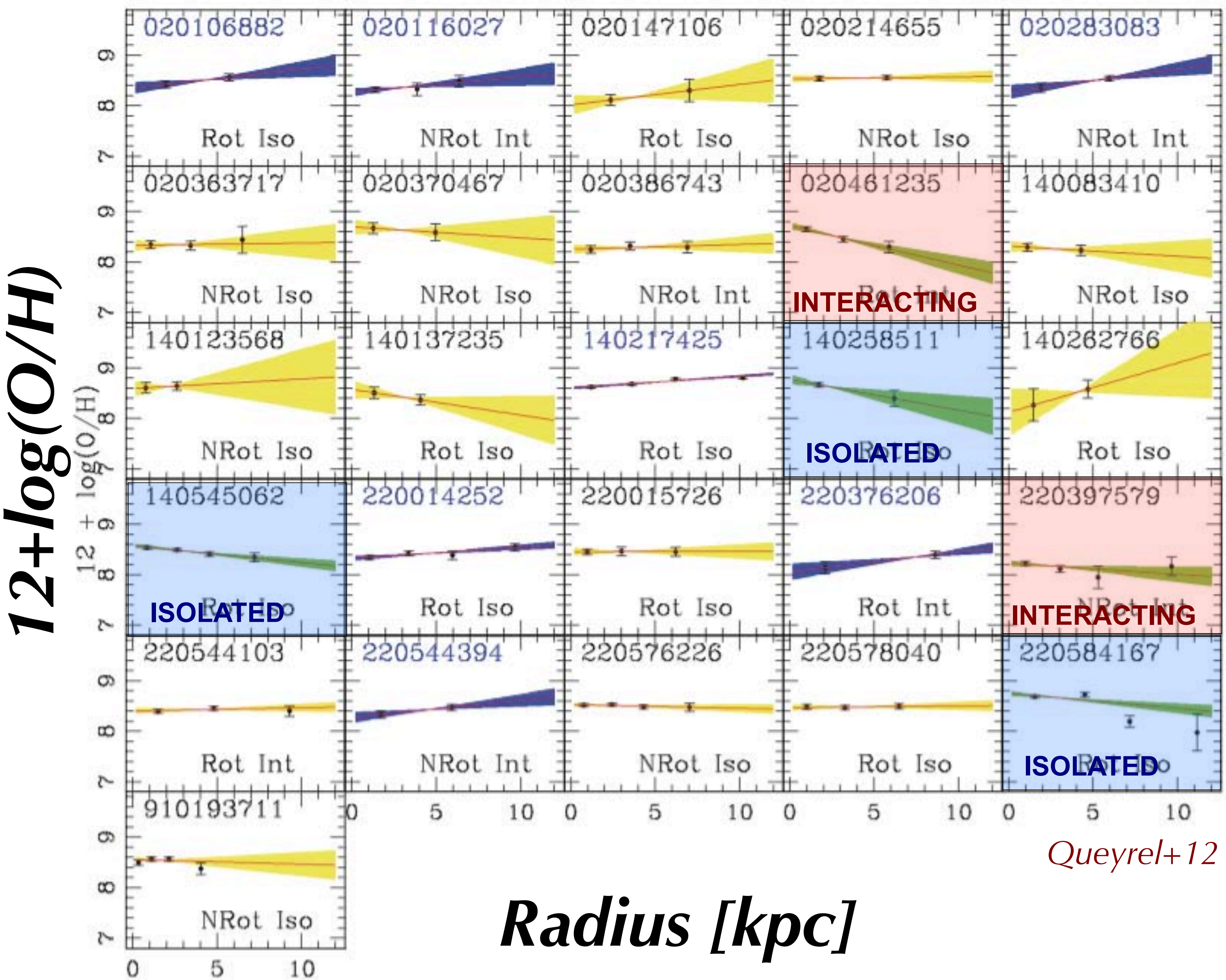


Metallicity gradients



Metallicity gradients for **29 MASSIV galaxies**

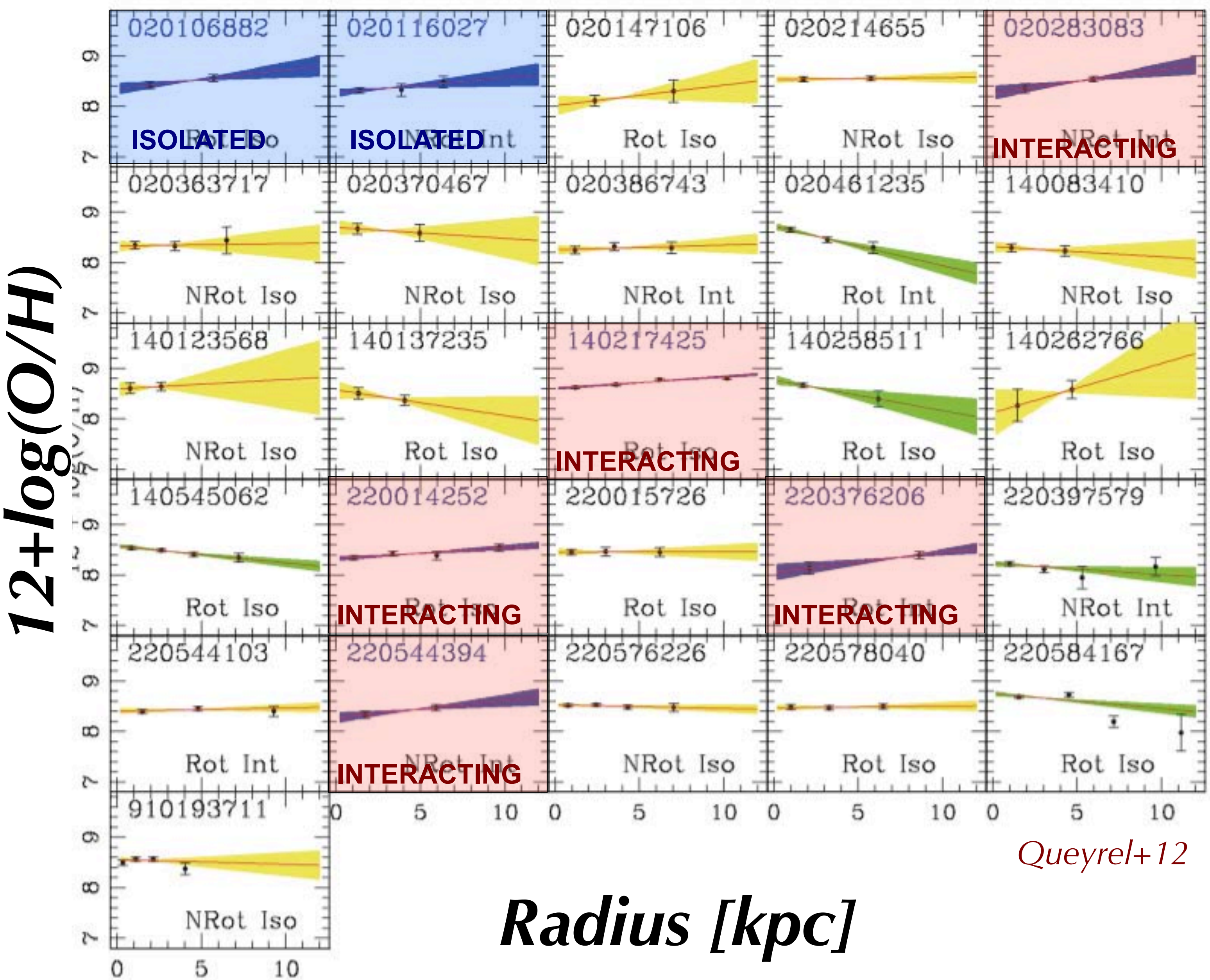
Metallicity gradients



Five secure **NEGATIVE** gradients

3/5 are **isolated** galaxies

Metallicity gradients



Seven secure **POSITIVE** gradients

5/7 are **interacting** galaxies

Interactions or cold gas accretion might be responsible for shallowing and even inverting the abundance gradient ?

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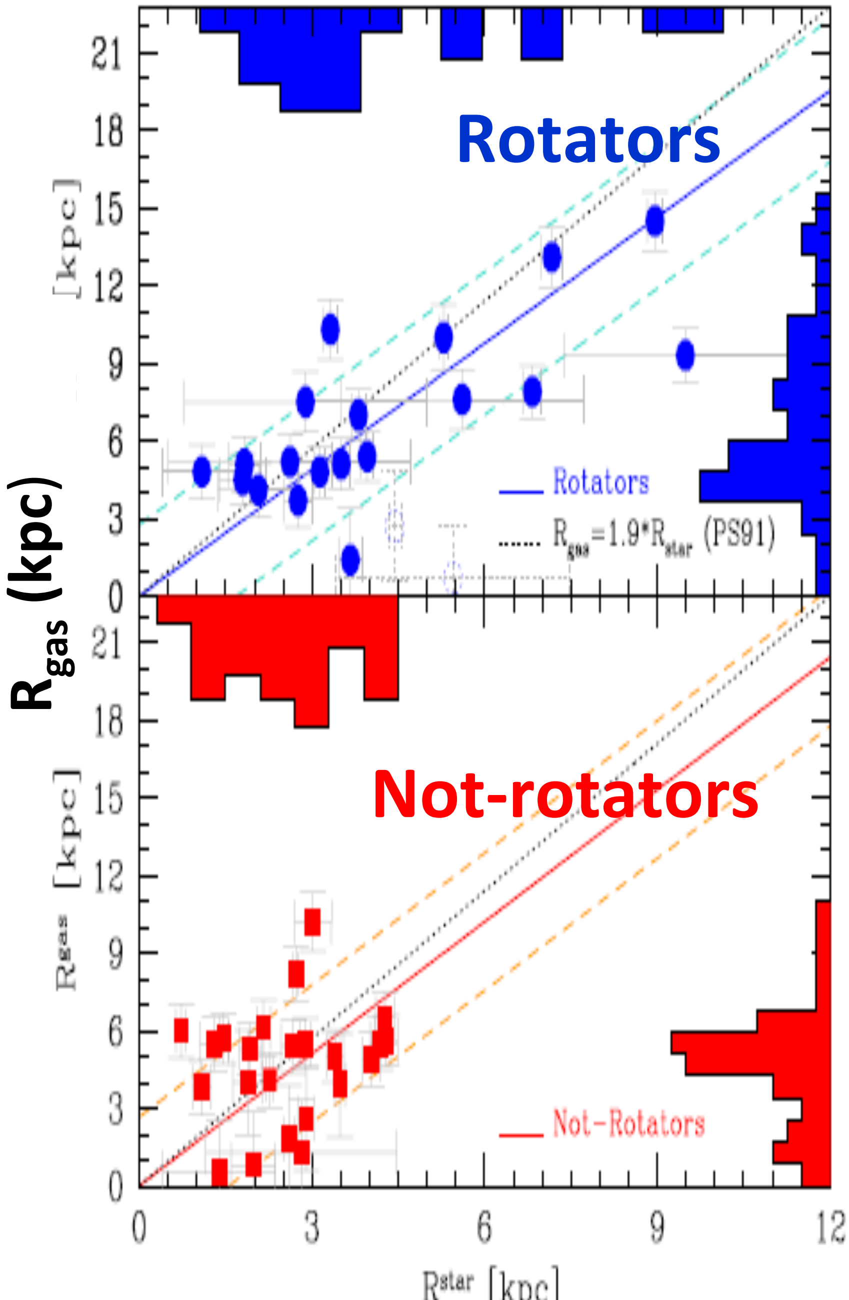
Disk size



R_{Star} (kpc) I-band

	Rotators	Non Rotators
<Rgas>	5.4 kpc	5.5 kpc
<Rstar>	3.5 kpc	2.7 kpc
Rgas =	1.63+-0.14 Rstar	1.70+-0.21 Rstar

Non-rotating galaxies are
- **more compact in their extent of the stellar component than rotators but**
- **not statistically different in their gas extent.**

Masses
Velocities

Marginal evolution in the
- **size - stellar mass** and
- **size - velocity** relations

Vergani et al. 2012

Stellar Tully-Fisher relation

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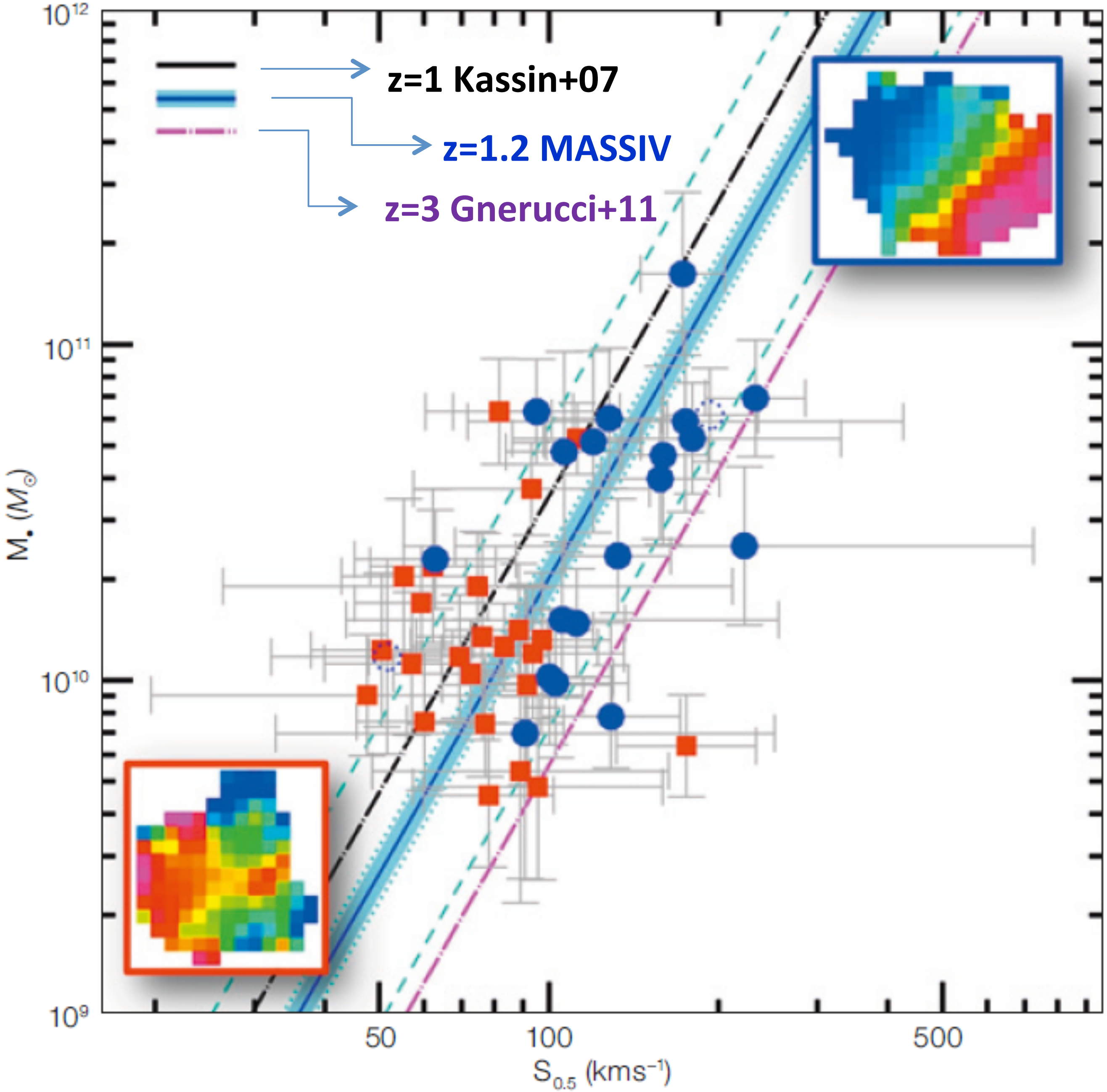
Mstar



Blue circles : fast rotators

Red squares : slow rotators

$$S_{05} = \sqrt{(0.5 \times v_{rot}^2 + \sigma_0^2)}$$

Vergani et al. 2012

The major merger rate @ 0.9<z<1.7 from MASSIV close pairs

Lopez-Sanjuan et al. , 2013

Close pairs in projection:

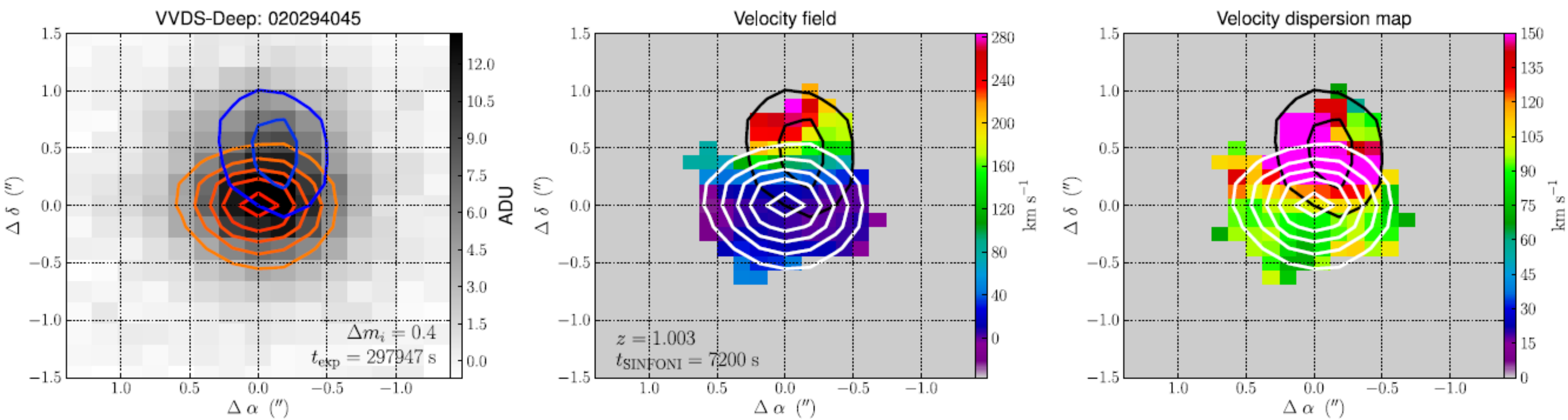
$r_p^{min} = 0 < r_p < r_p^{max} = 20h^{-1}kpc$

$\Delta v < \Delta v^{max} = 500$ km/s

N_P major close pairs : $L_2/L_1 > 1/4$

minor close pairs : $L_2/L_1 < 1/4$

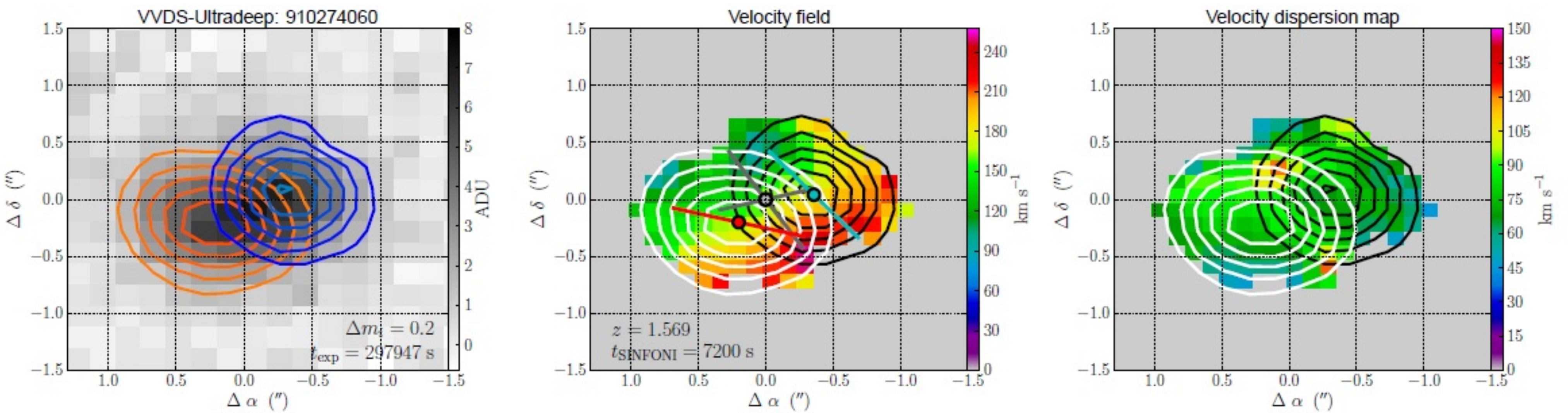
$f_{Major\ Merger} = N_P/N$ + corrections for completeness



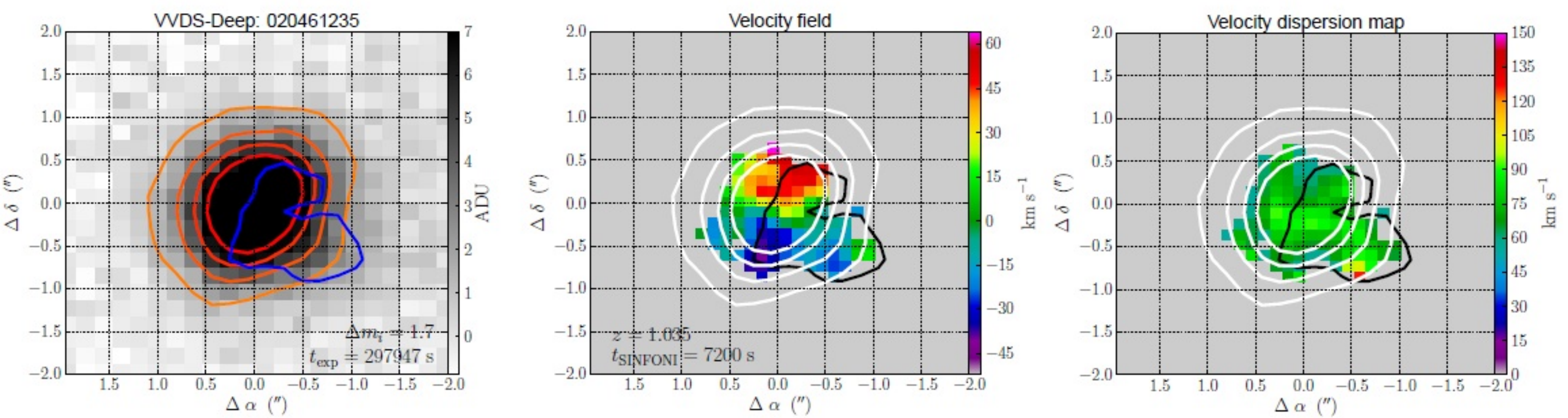
Example of a major merger

$10^9 < M^* < 10^{11}$
20 close pairs
13 major mergers, 7 minor mergers

Other example of a major merger



Example of a minor merger



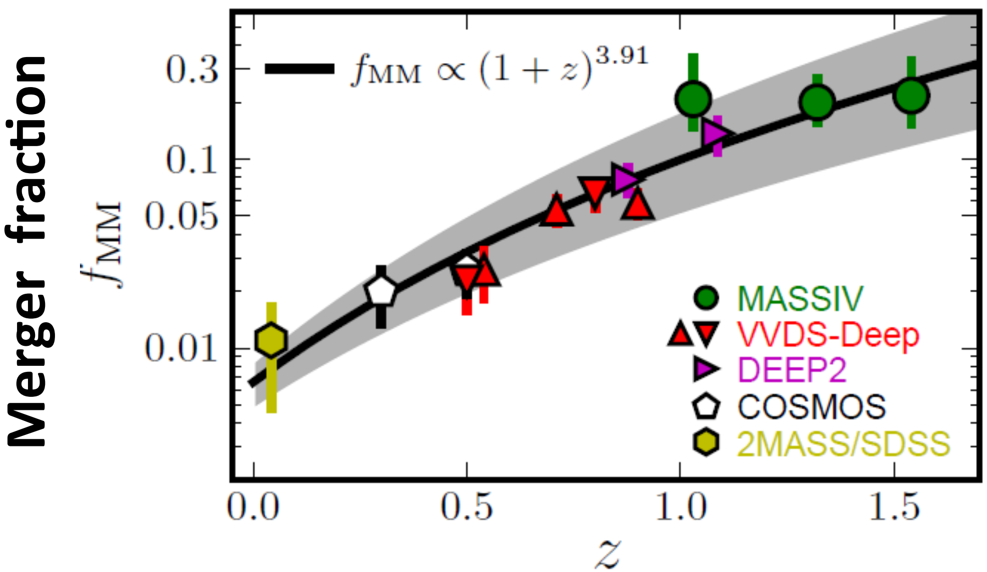
The merger fraction f_{MM} @ z>1 is higher by an order of magnitude than in the local universe

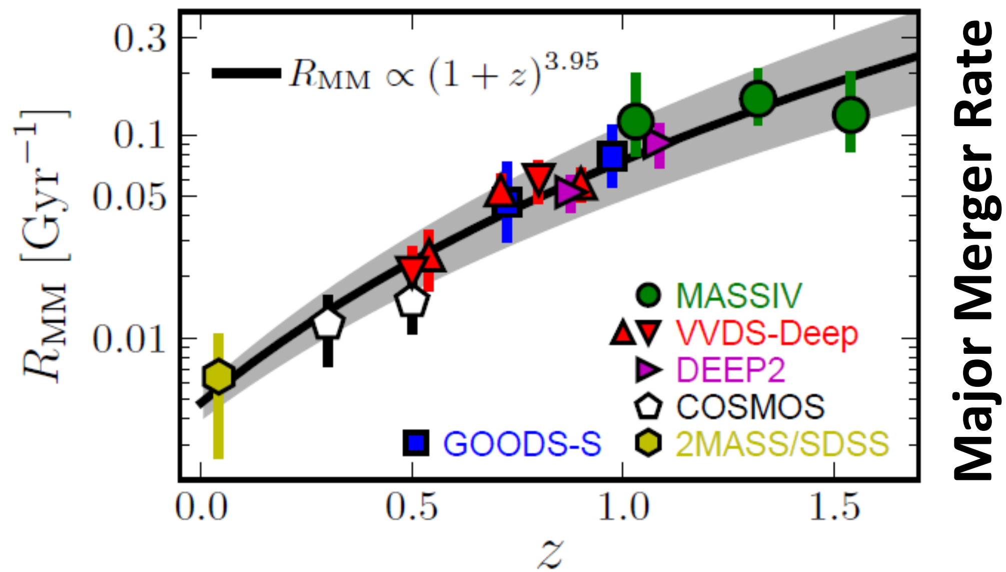
The major merger rate

$R_{MM} \propto f_{MM} / T_{MM}$

T_{MM} : Merger time scale from the Millennium simulation

T_{MM} = 1.80 Gyr (0.94 < z < 1.06)
T_{MM} = 1.37 Gyr (1.20 < z < 1.50)
T_{MM} = 2.54 Gyr (1.50 < z < 1.80)



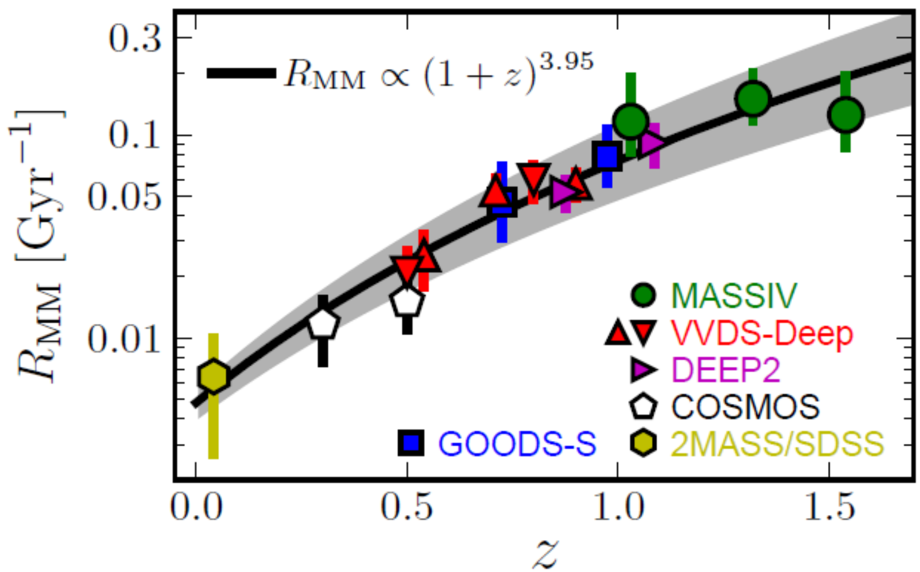


Lopez-Sanjuan et al. , 2013

$$N_{\rm MM}(z_1, z_2) = \int_{z_1}^{z_2} \frac{R_{\rm MM}\, {\rm d}z}{(1+z) H_0 E(z)}$$

The average number of major gas-rich mergers per star-forming galaxy between z_2 and z_1

$M_*=10^{10}$-10^{11} M_o
star forming galaxies underwent
~0.4 major mergers since z~1.5



Major Merger Rate

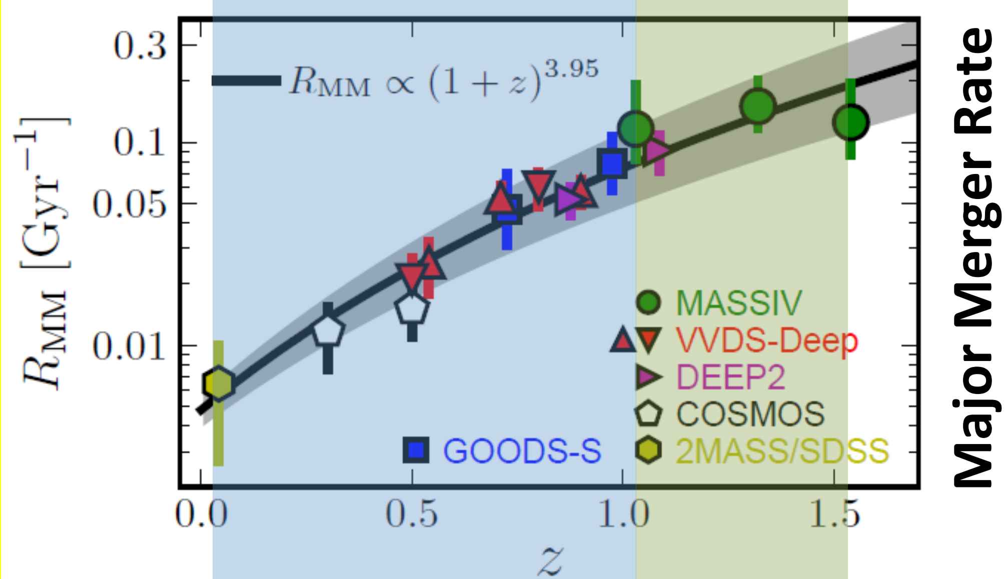
Lopez-Sanjuan et al. , 2013

Half of the merger activity occurs between

z=1 and 0

z=1.5 and 1

$M_{*}=10^{10}$-10^{11} M_{o}
star forming galaxies underwent
~0.4 major mergers since z~1.5

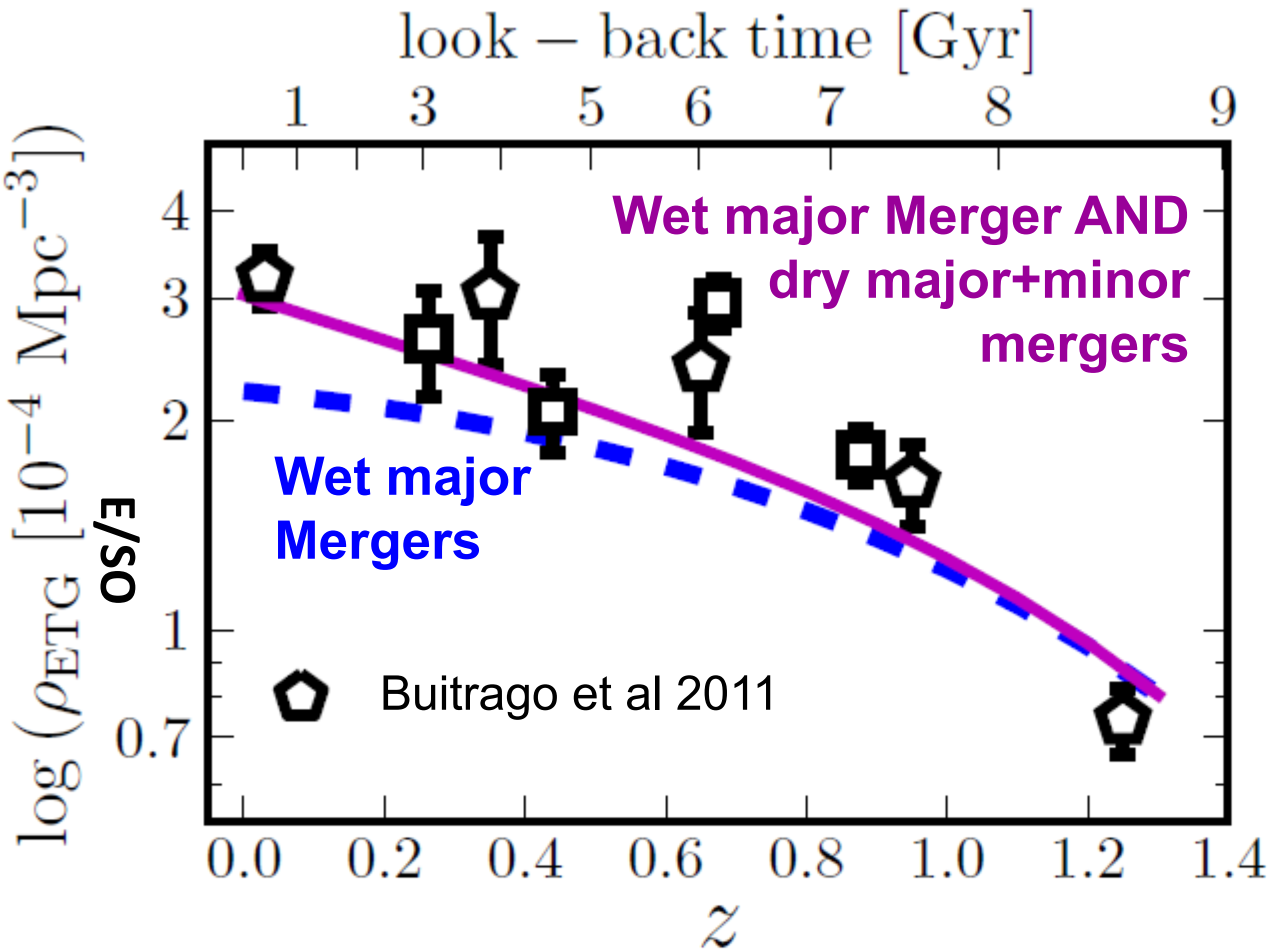


Lopez-Sanjuan et al. , 2013

Look back time (Gyr)

$$\rho_{\rm wet}(z_{\rm min}, z_{\rm max}, M_{\star,\rm lim}) = \int_{z_1}^{z_2}\int_{-\infty}^{\infty} \Phi\, R_{\rm MM} E(1, 1/4)\, f_{\rm LTG}\, {\rm d}M_{\star}\, {\rm d}z$$

ϕ : Schechter function
R_{MM}: gas-rich major merger rate
E: merger efficiency



Lopez-Sanjuan et al. , 2013

The combined effect of gas-rich and dry mergers $f_{tot} = f_{wet} + f_{dry}$ is able to explain the evolution in Early Type Galaxies since z ~ 1.3, with gas rich merger accounting for 2/3.

Assumptions:

- Wet major mergers produce fast rotators
- Dry major mergers produce slow rotators
- Dry minor mergers do not change the kinematical state of ETGs
- All ETGs at z=1.3 are fast rotators

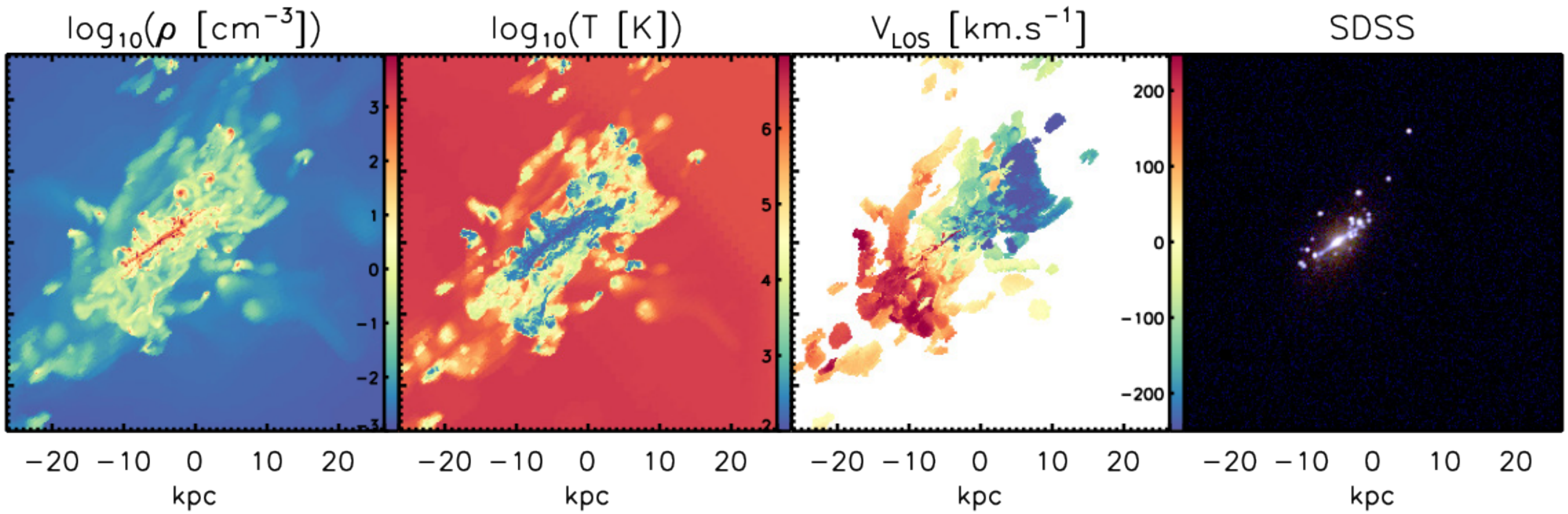
$F_{slow\ rotator}$ ~ 55%

$F_{slow\ rotator}$ ~47-75% for $M_{dyn} > 10^{11.25}\ M_O$ - ATLAS 3D (Ensellem et al 2011)

Merging is a major process driving mass assembly into the red sequence galaxies.

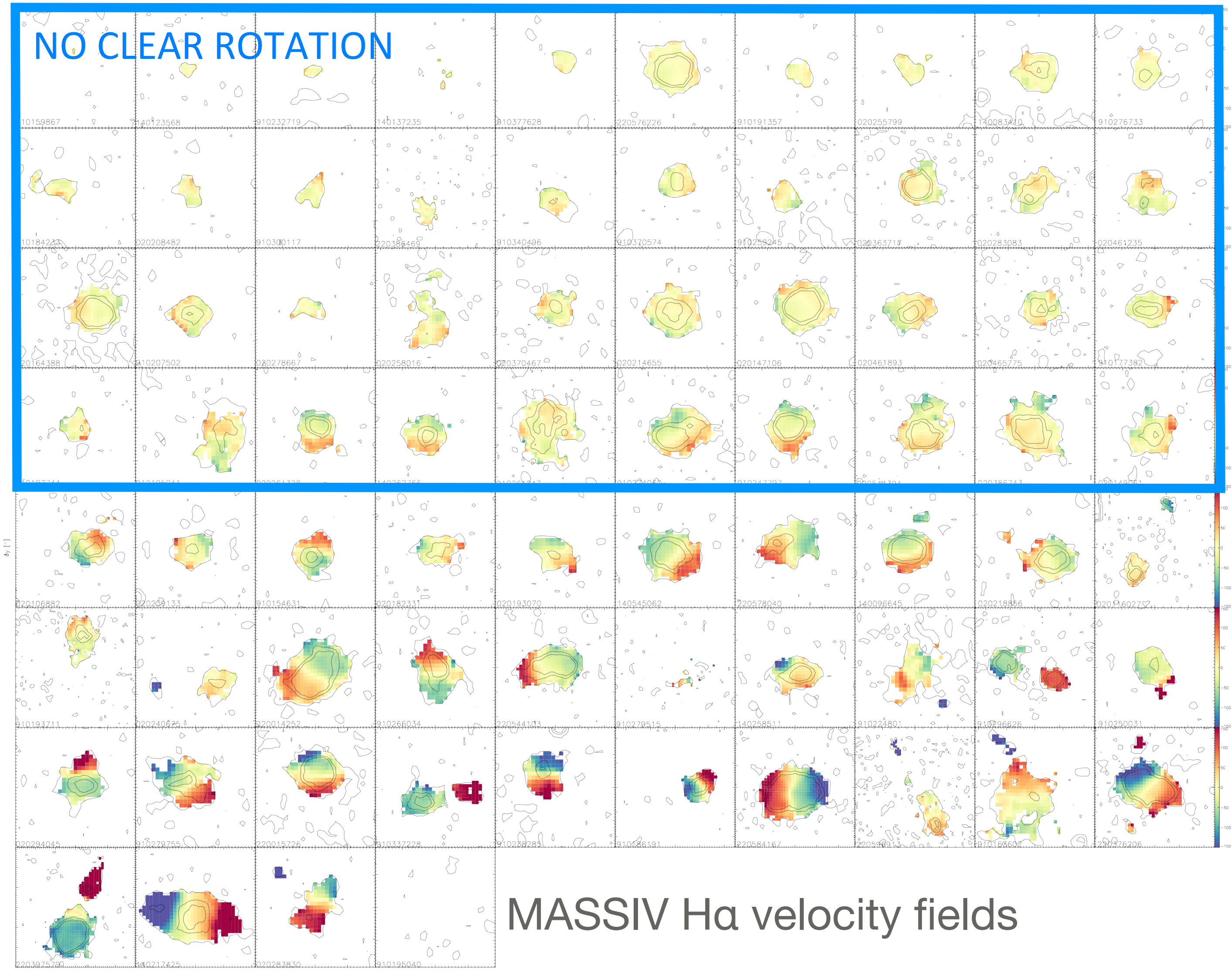
Minor merger is definitively present in the MASSIV sample but due to incompleteness we are not able to assess a minor merger rate.

•High-z Merger Idealized Simulations Library



V. Perret (PhD)

Simulating High-z galaxies: motivations

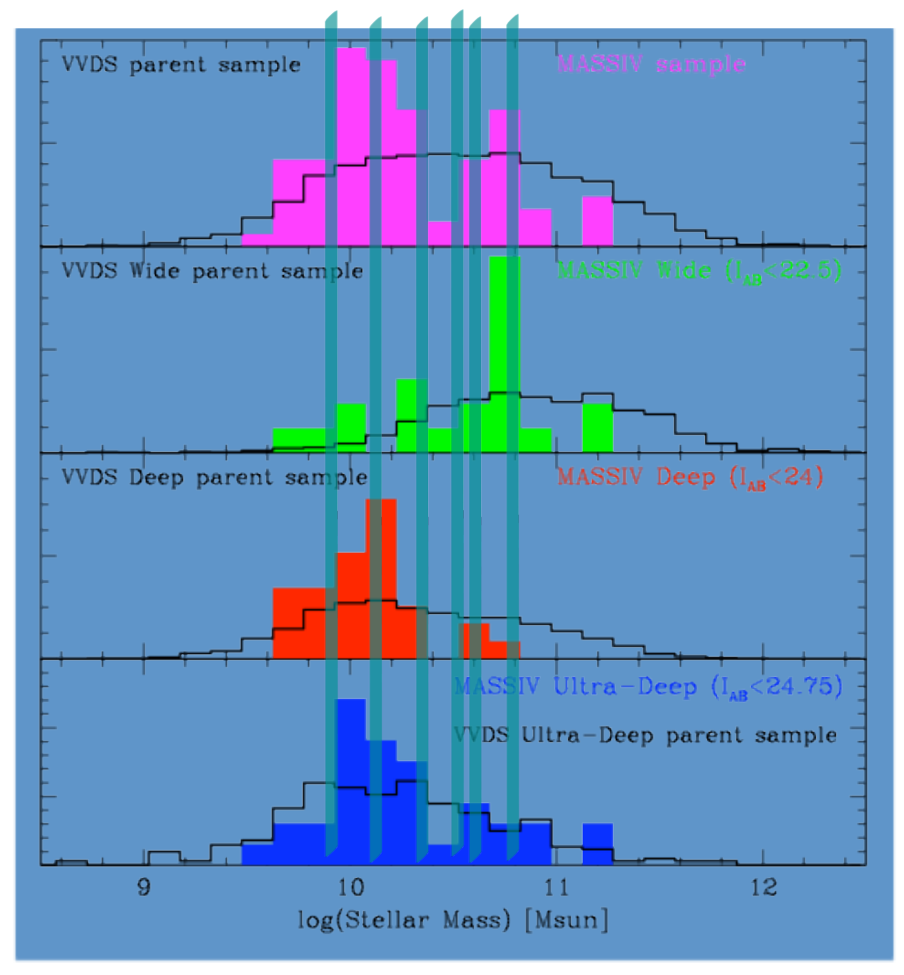


MASSIV Hα velocity fields

Simulating High-z galaxies: sample building

- "Toy" scenario: the merger consumes 25% of the gas, and eject 20% of the stars out of the optical radius of the remnant, within a Gyr
- 3 models: the following masses cover well the MASSIV stellar mass distribution
  - log(M*)=9.8
  - log(M*)=10.2
  - log(M*)=10.6
- Toy scenario over all possible mass ratios produces stellar masses:

  [10.04,10.28,10.44,10.69,10.75,10.94]

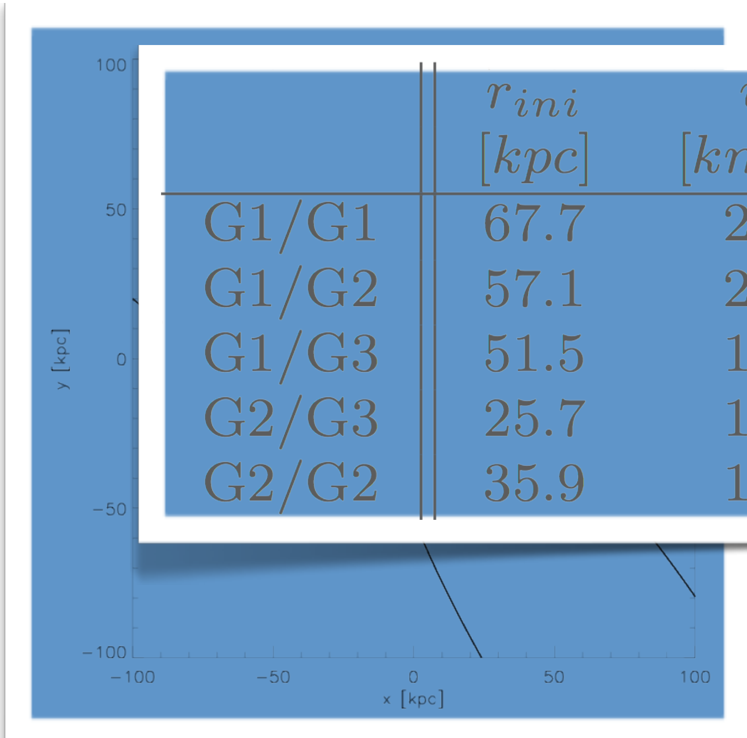


Initial Conditions parameters

		G1	G2	G3
	Virial quantities			
1	$log(M_\star)$	10.60	10.20	9.80
2	R_{200} $[kpc]$	99.8	73.4	54.0
3	M_{200} $[10^{10} M_\odot]$	102.4	40.8	16.2
4	V_{200} $[km.s^{-1}]$	210.1	154.6	113.7
	Scalelength			
5	$r_\star$ $[kpc]$	2.28	1.62	1.15
6	r_{gas} $[kpc]$	3.71	2.64	1.88
7	$h_\star$ $[kpc]$	0.46	0.32	0.23
8	h_{gas} $[kpc]$	0.19	0.13	0.09
9	r_{metal} $[kpc]$	3.71	2.64	1.88
10	c		5	
	Mass fractions			
11	f_g		0.65	
12	f_b		0.10	
13	m_d		0.10	
	Collisionless particles			
14	N_{disk} $[10^6]$	2.00	0.80	0.32
15	N_{halo} $[10^6]$	2.00	0.80	0.32
16	N_{bulge} $[10^6]$	0.22	0.09	0.04
	Various quantites			
17	Q_{min}		1.5	
18	Z_{core}	0.705	0.599	0.479

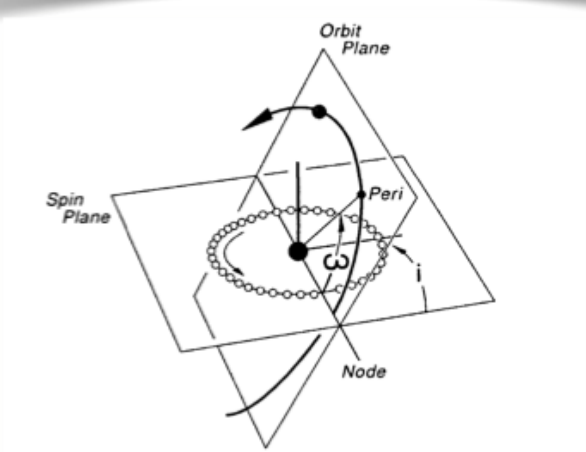
- ICs generated with **DICE**
- Idealized initial conditions mimicking z≃2 galaxies20 mergers simulations
- 3 isolated disks simulations
- Integrated over 800 Myrs
- Library is sampling disks orientations & mass ratios
- Initial metallicity profile following the radial gas density profile
- Total disk Z assumed to be half the Erb et al. 2006 mass-metallicity relation
- Halo & Bulge following a Hernquist profile

Mergers orbital configurations



	r_{ini} $[kpc]$	v_{ini} $[km.s^{-1}]$	r_{peri} $[kpc]$	e	E $[10^4 kg.km^2.s^{-2}]$
G1/G1	67.7	236.5	21.8	0.67	-63.1
G1/G2	57.1	203.6	19.1	0.61	-38.0
G1/G3	51.5	183.3	16.8	0.59	-18.2
G2/G3	25.7	172.6	13.6	0.31	-15.1
G2/G2	35.9	166.8	15.5	0.42	-25.1

PERICENTRAL DISTANCE

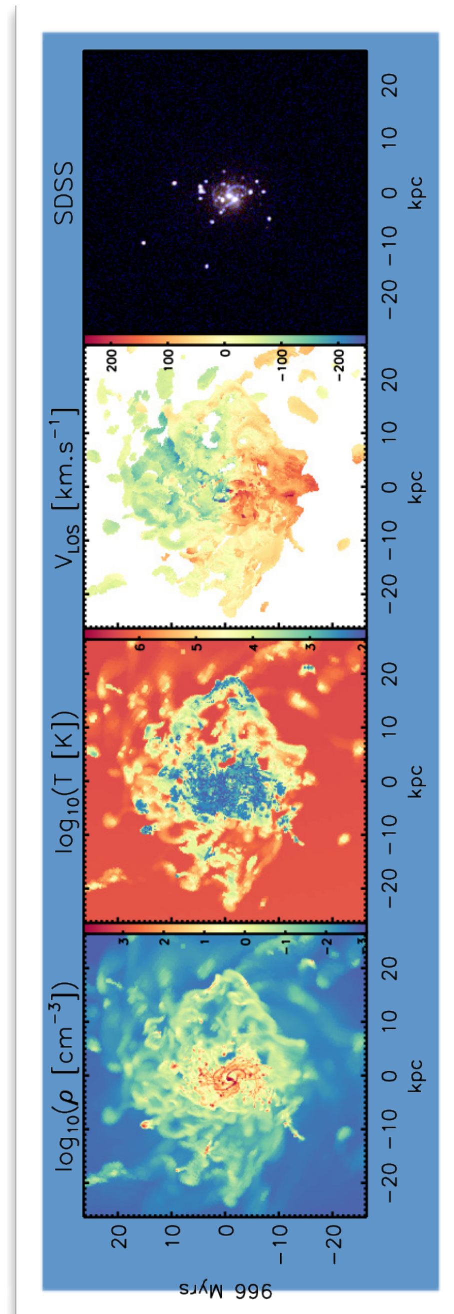


- We want to explore probable configurations: Khochfar & Burquert 2006 (Cosmological DM only simulation analysis)Keplerian trajectories hypothesisOrientation angles of the system are uncorrelated (spin vectors embedded in the orbital plane are more probable)We choose orbital timescales short enough to preserve gas fraction in the remnant:

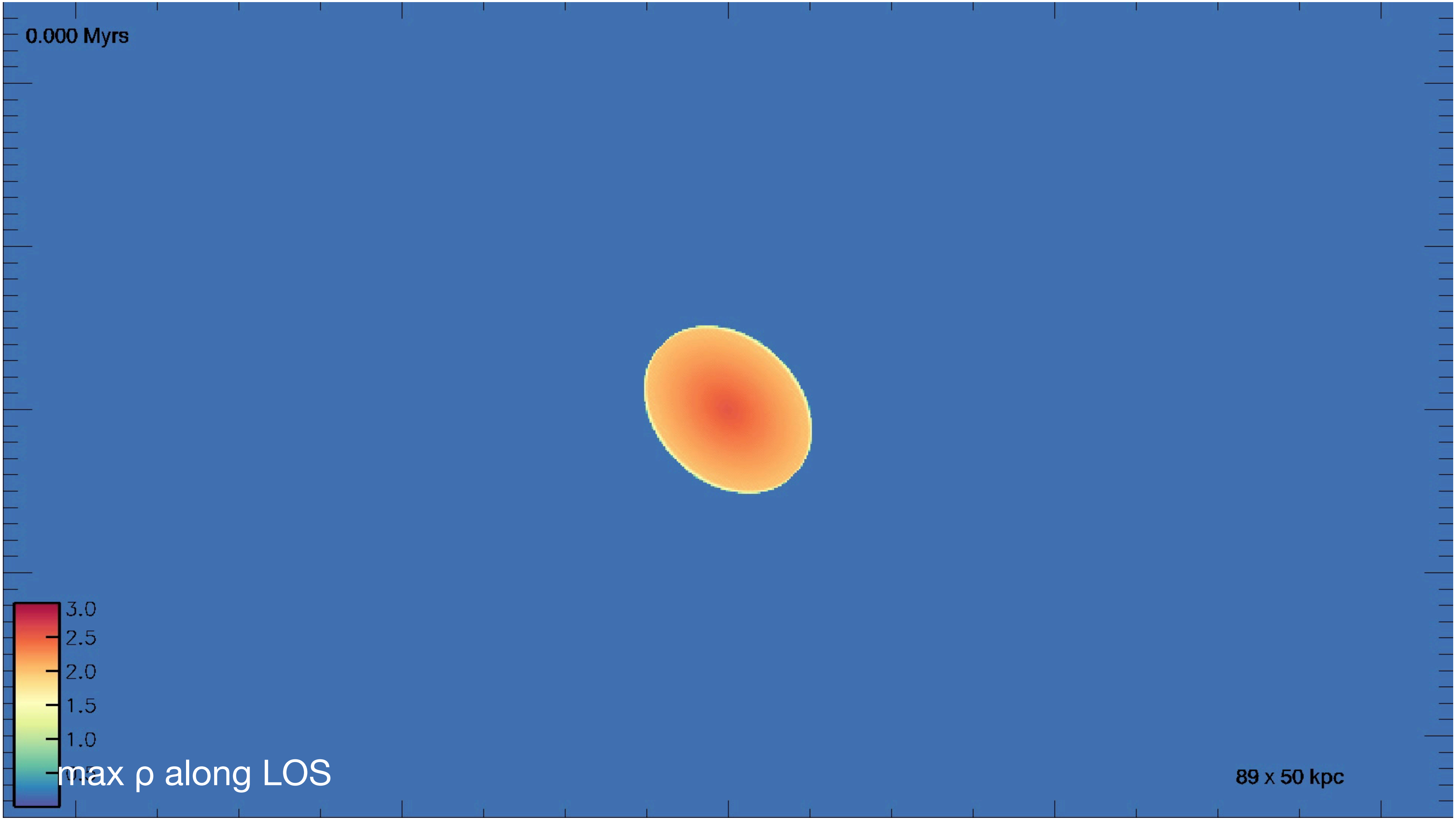
- pericentral time = 250 Myrs

Simulations: numerical recipes

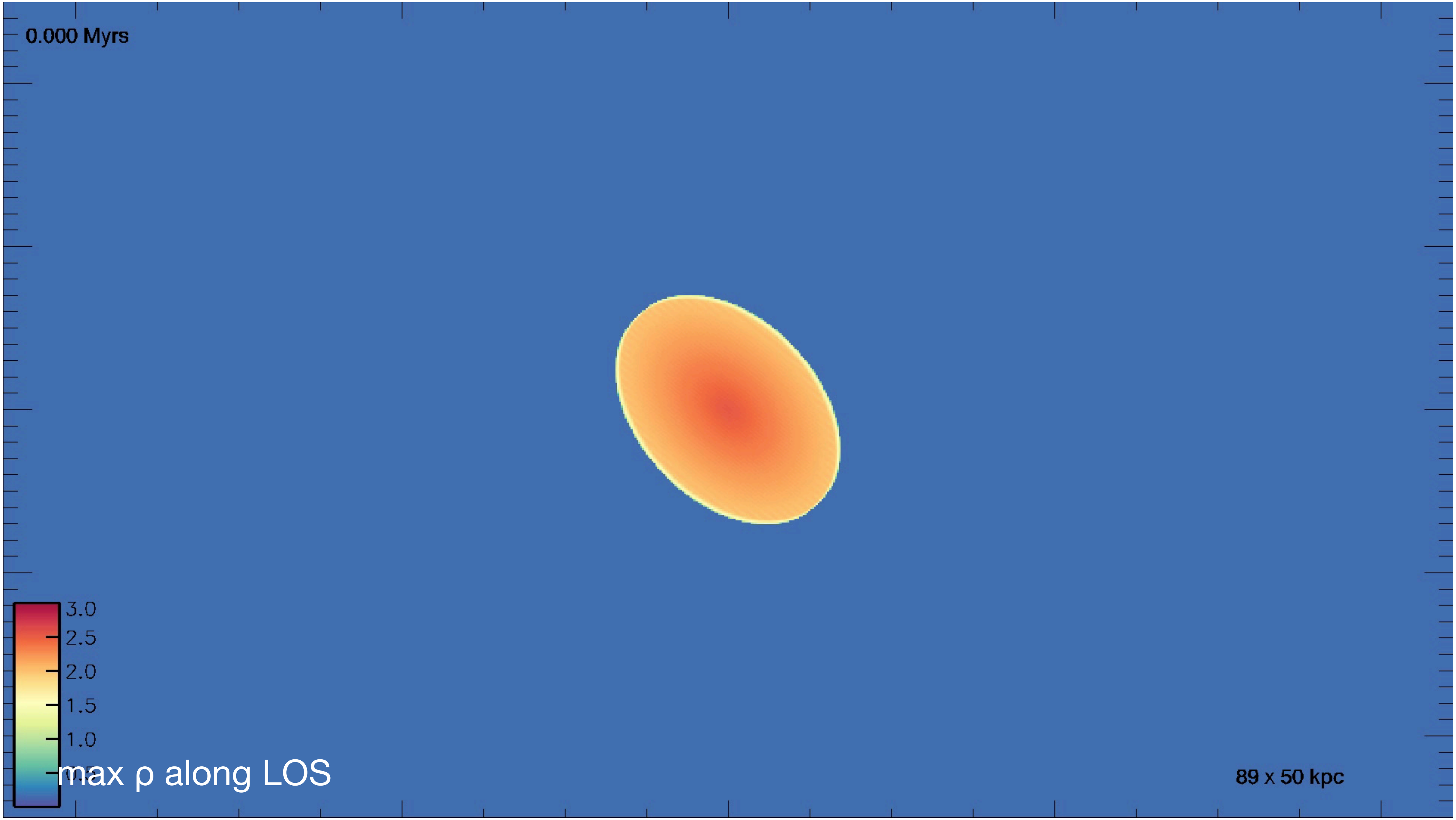
- We use the RAMSES code with the following physics recipesStar formation: efficiency=1%, SF trigger $n_* = 100cm^{-3}$
- Supernova thermal feedback: 2E51 erg.s^-1 per 10 solar mass for $\eta_{sn} = 0.20$ injected in the NGP leaf cell
- Metal lines cooling down to 300 K
- Metallicity: metals fraction passively advected
- Delayed cooling: cooling switch passively advected with $t_{delay} = 3Myrs$
- AMR boxlen = 240 kpc, lmax=15 i.e. 7.3 parsec physical resolution
- Jeans polytrope ensures that 6 Jeans length are always resolved
- OB stars photo-ionization: THII = 1E4 K
- OB stars radiative pressure: velocity kick computed so that each photon is scattered 5 times @ 100% efficiency



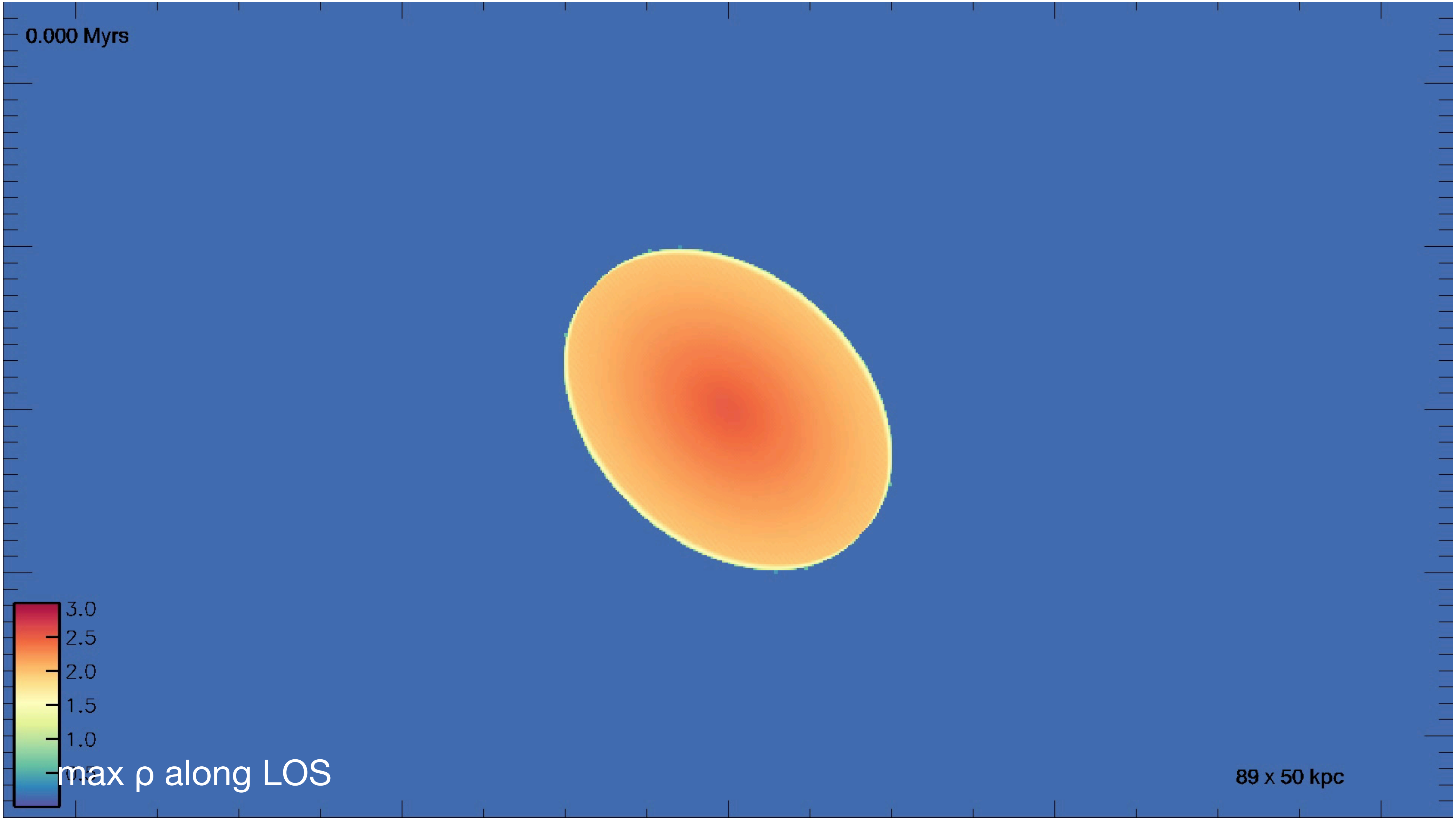
G3 disk log(M*)=9.8



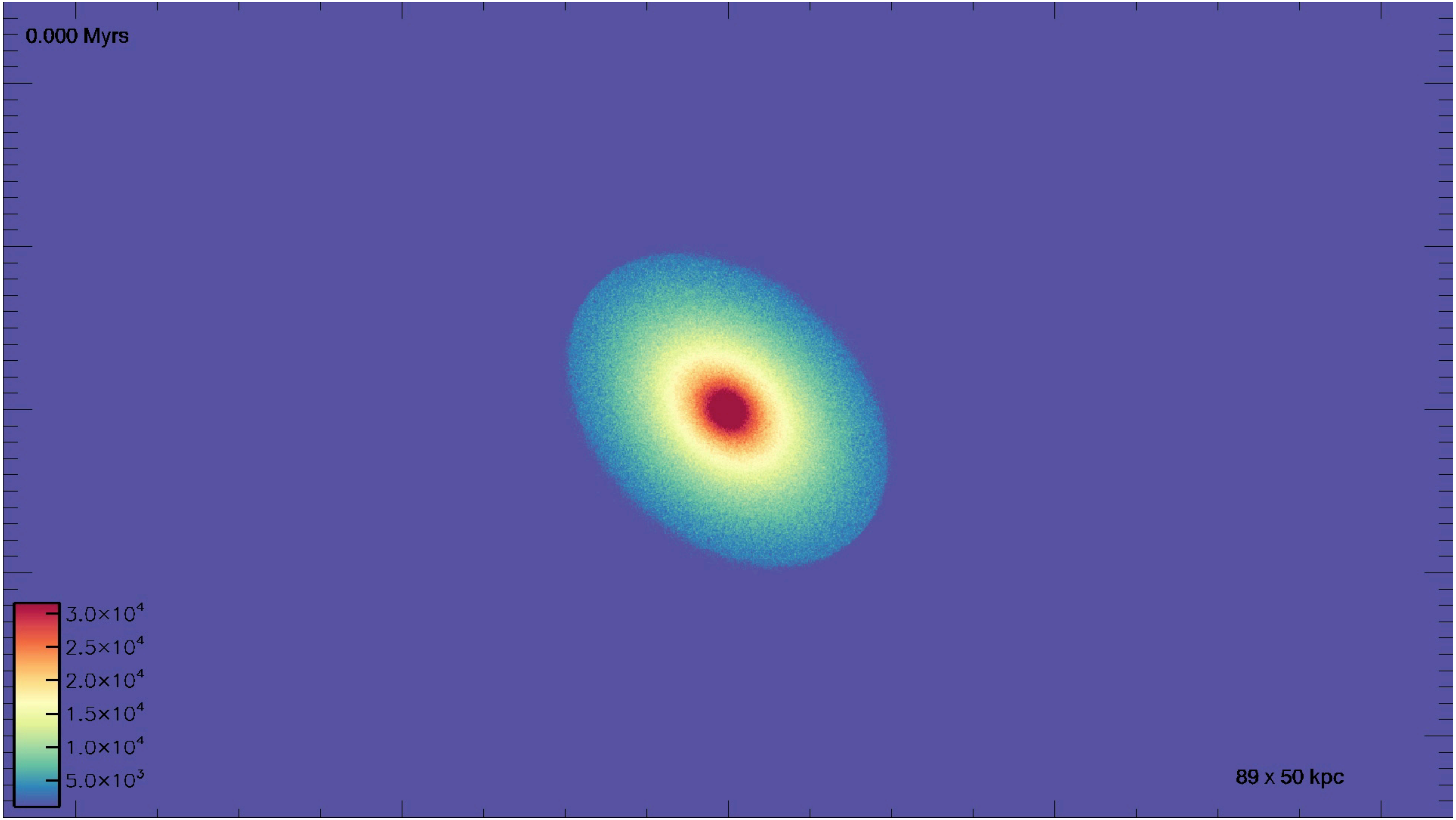
G2 disk log(M*)=10.2



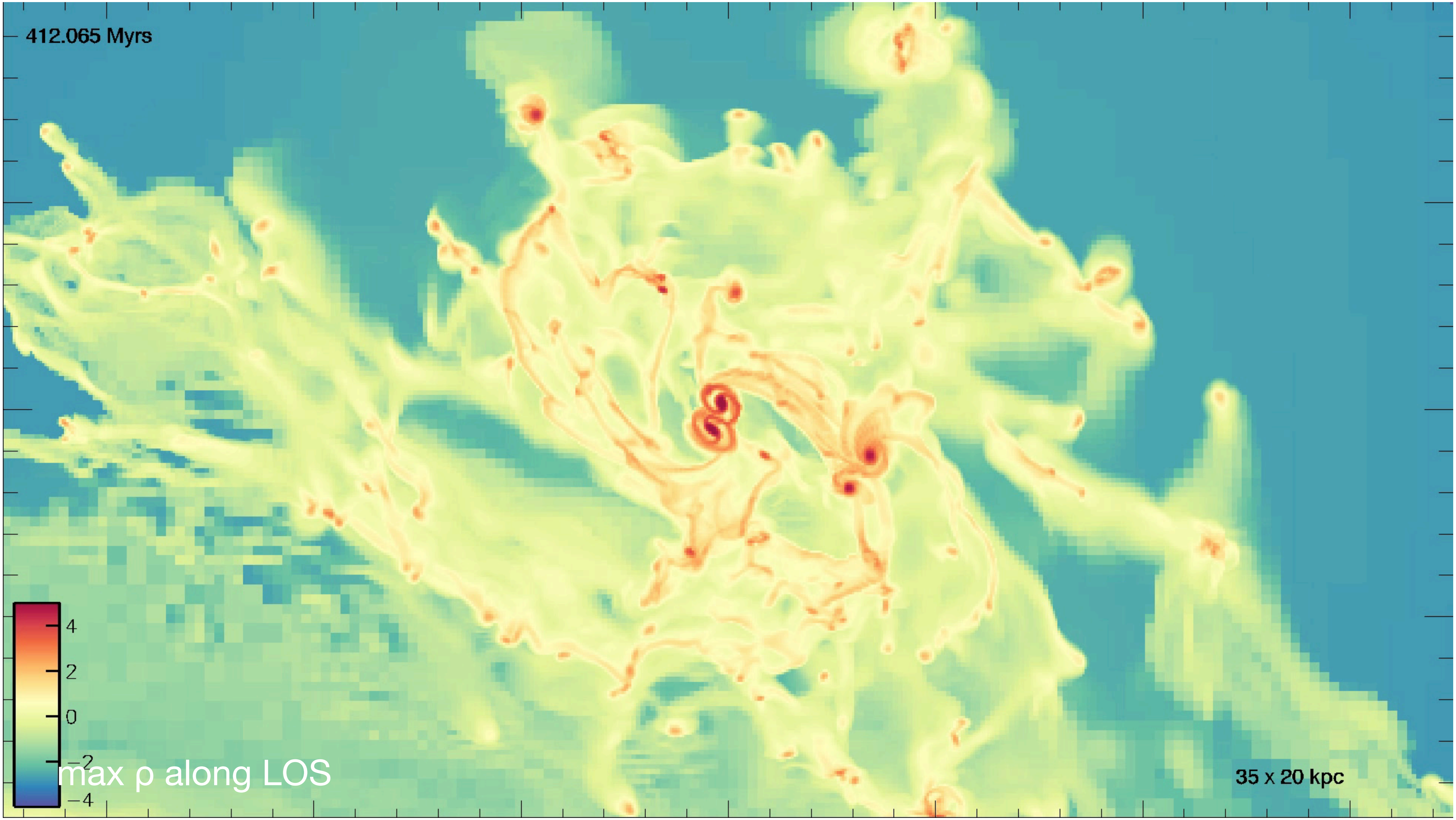
G1 disk log(M*)=10.6



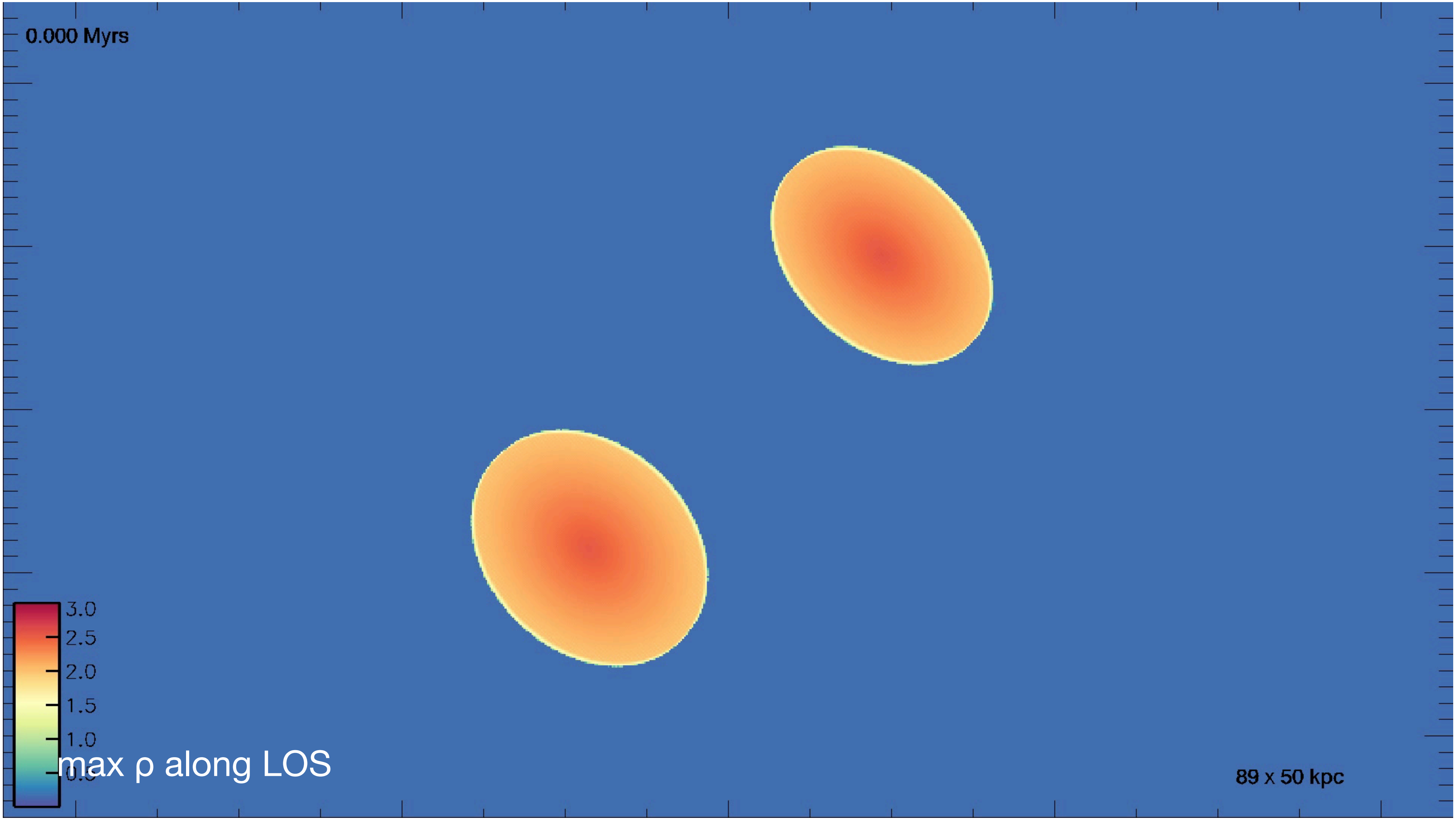
G1 disk log(M*)=10.6



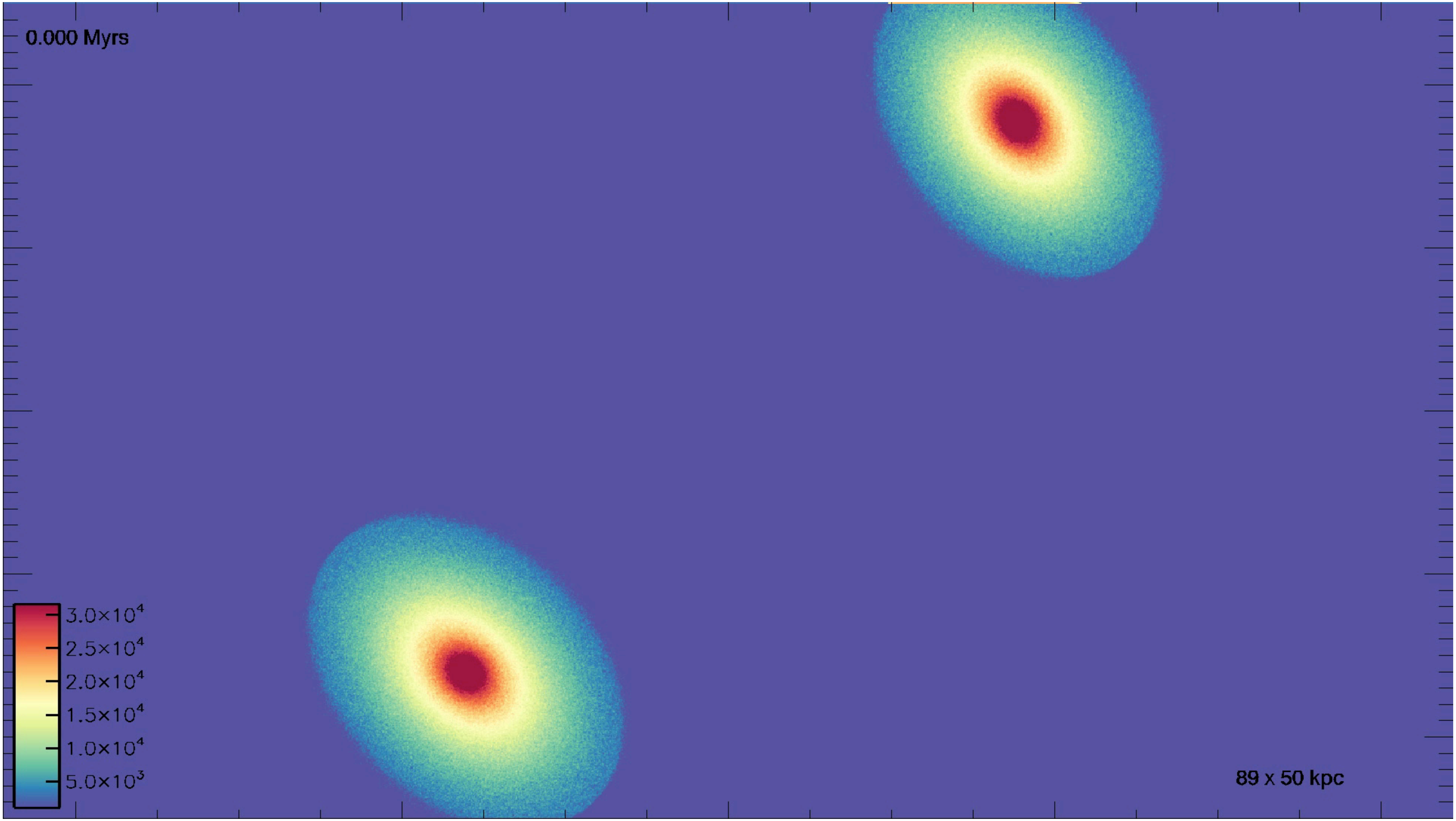
.G1 disk: clumps coalescence



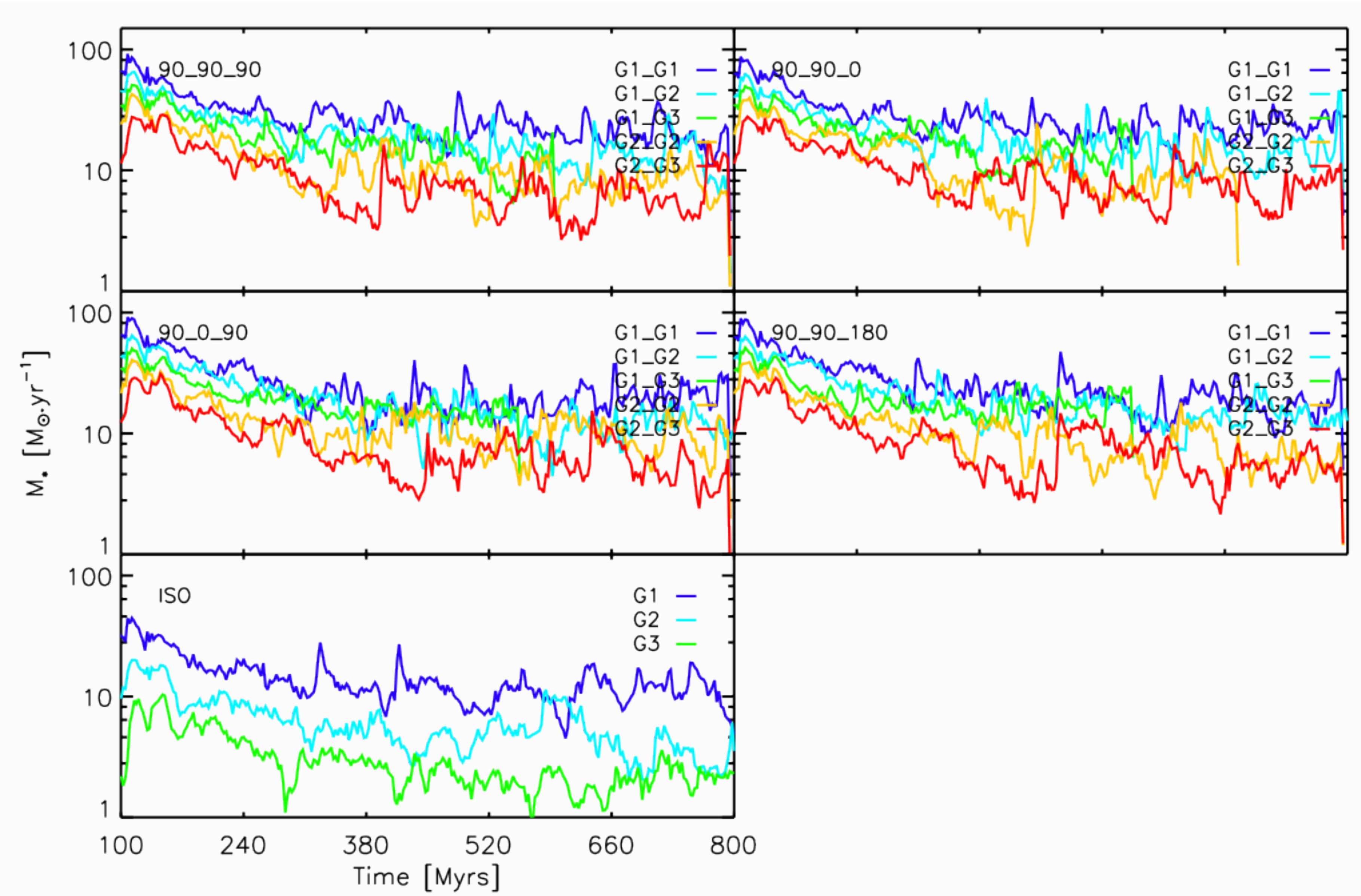
G2/G2 (quiet) merger



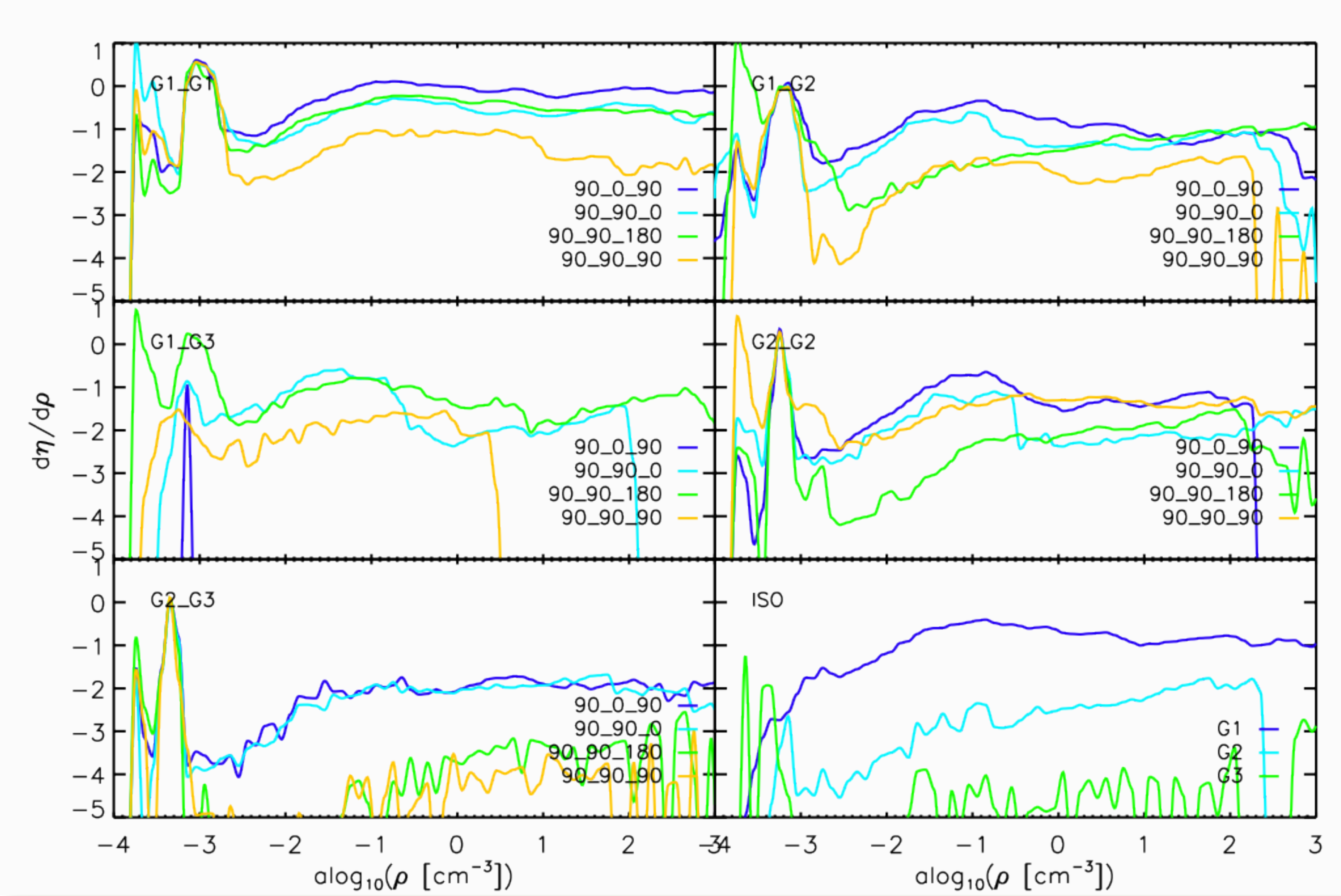
.G1/G1 merger



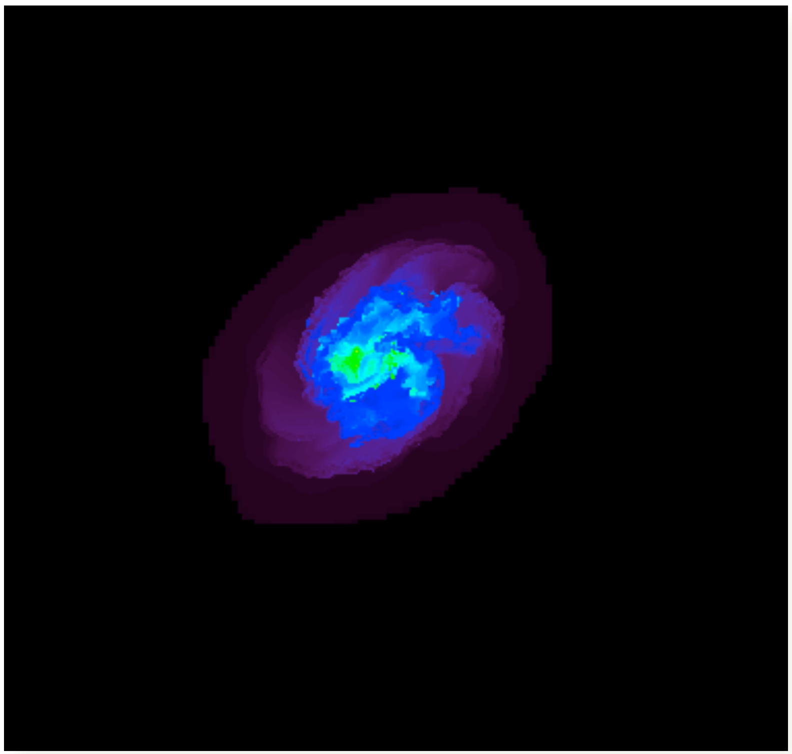
Preliminary results: SFR

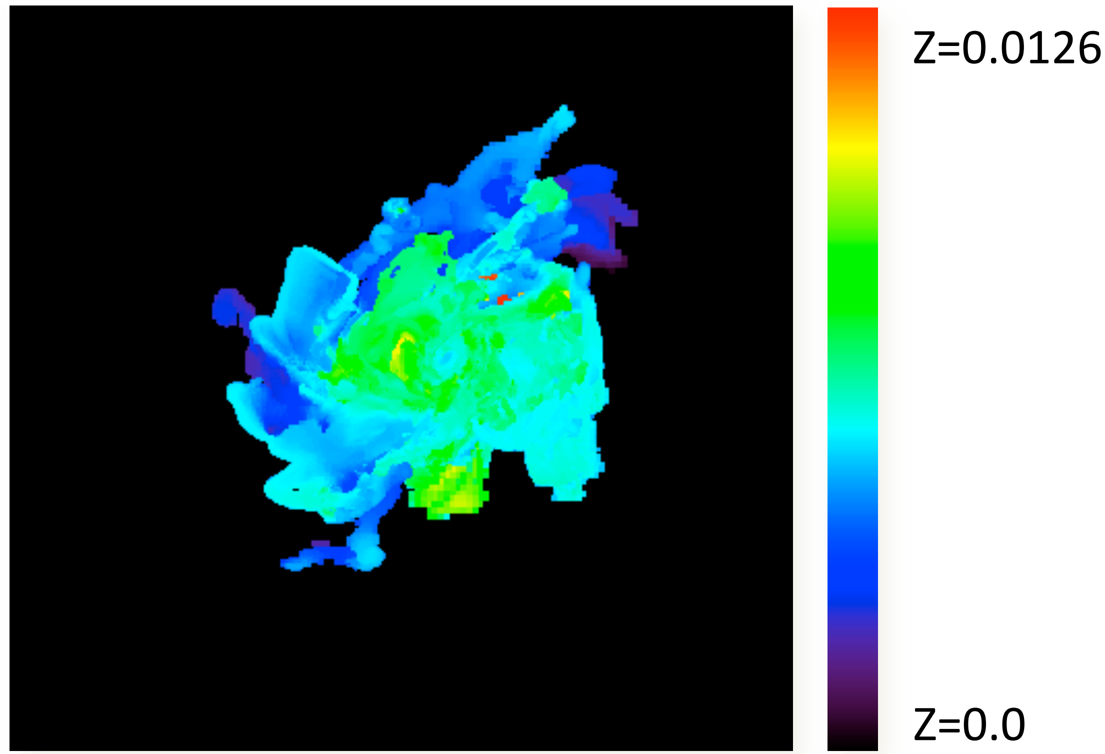


•Preliminary results: outflow rate



Preliminary results: metallicity gradients

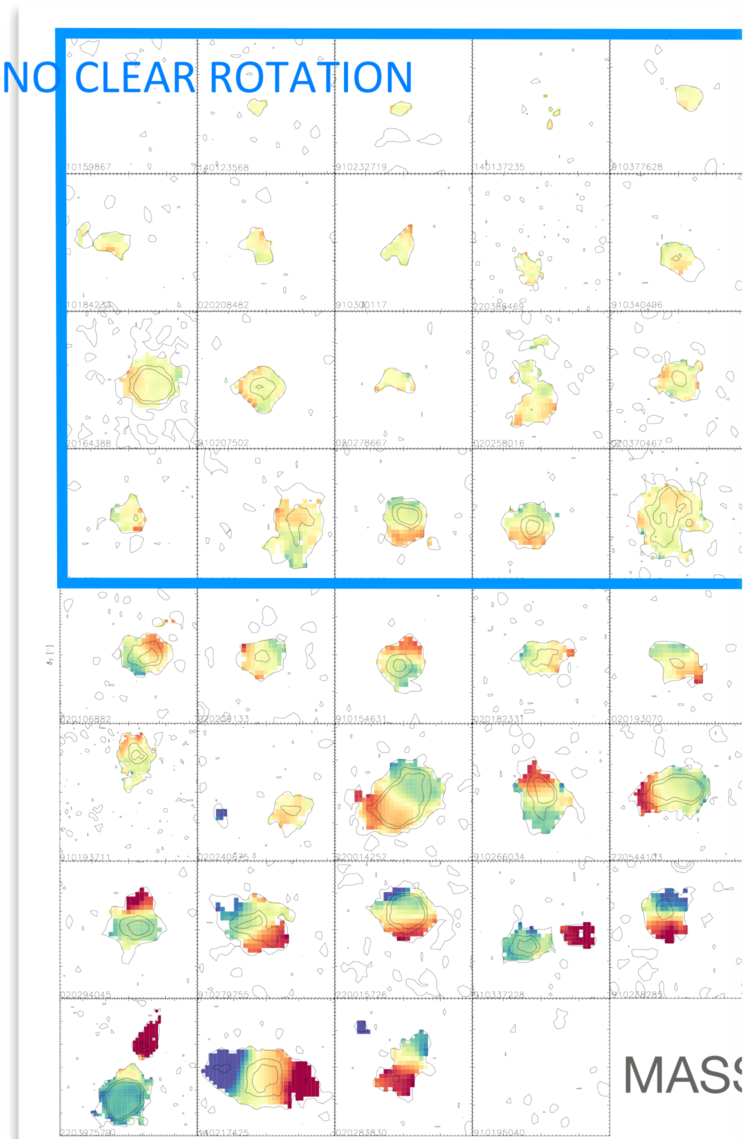


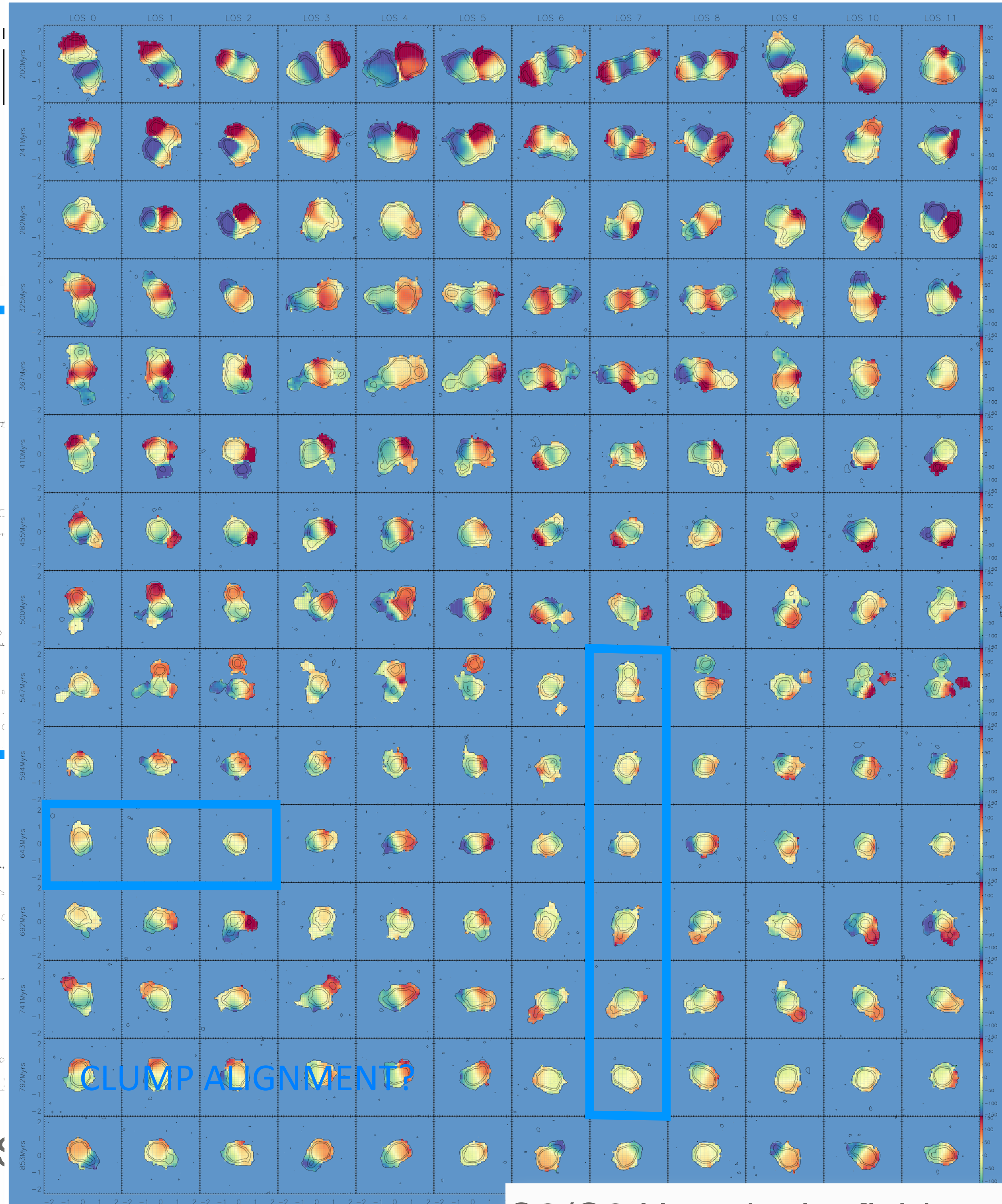


T=136 MYRS

T=634 MYRS

.Simulati





G2/G2 Hα velocity fields

SUMMARY

Environment

- High fraction (~1/3) of interacting/merging galaxies

Disks formation

- High (gaseous) velocity dispersion (decreasing continuously from z=3 to 0)
- ~ 1 galaxy over 2 is non-rotating (Vmax /σ > 1) – Are massive disks are in place @ z ~ 1.5 ?
- Non-rotating galaxies: stellar disk more compact; less massive than rotators
- Marginal evolution in size-stellar mass and size velocity relations

Metallicity

- Positive metallicity gradients in high-z disks - Evidence for gas inflows / interaction ?

Tully-Fisher

- The scatter in the TF decreases with S05 - turbulent motions - intrinsic complex physical m.

Merger Rate

- the gas-rich major merger rate evolves as $(1 + z)^n$, with n = 3.95 ± 0.12, up to z = 1.5
- Almost constant merger fraction f_{MM} =0.20 @ 1 < z < 1.6.

  This merger fraction at z @ 1 is higher by an order of magnitude than in the local universe
- Major merger rate R_{MM} = (0.12 Gyr^{-1} @z=1); (0.15 @ *z=1.3) and (0.13* @ z=1.54).
- ~ 35% of the star-forming galaxies with stellar masses $M_\star = 10^{10} - 10^{10.5}\ M_\odot$ have undergone a major merger since z ~ 1.5.
- The combined effect of gas-rich and dry mergers is able to explain the evolution in the nb density in ETG since z = 1.5 with gas rich merger rate accounting for 2/3 of this evolution.
- Merging of star-forming galaxies is frequent at around the peak in star formation activity and on gas-rich mergers provide an important contribution on the built-up of the red sequence