Bulge formation from z=4 to 1

Collaborators:
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Analysis of ART simulations.

1. AMR simulation hydro ART (Kratsov, Klypin), zoom-in simulations of high redshift galaxies.
   - ~ 33 (27 reach z=2) spatial with resolution 35-70 pc $\simeq 50$ pc.
   - ~ 30 (14 analyzed, 16 on the way) pairs with resolution 17-35 pc, $\simeq 25$ pc
2. Main focus:
   - VDI (N. Mandelker)
   - disc/bulge evolution (D. Tweed)
   - blue/red nuggets (A. Zolotov)
   - Inflow/outflow (H. House, M. Danovich)

DC's 1st generation simulation sample

#	Galaxy ID	Halo Mass [$M_\odot$/h]	Box Size [Mpc/h]	Status	a final	snapshot Δa
1	MW01	1.07 10^{12} (z=1)	20	Stopped.	0.42	0.01-0.02
2	MW02	0.85 10^{12} (z=1)	20	Stopped.	0.34	0.02
3	MW03	1.35 10^{12} (z=1)	20	Stopped.	0.42	0.01-0.02
4	MW04	2.81 10^{12} (z=1.1)	40	Stopped.	0.38	0.01-0.02
5	MW05	7.26 10^{12} (z=1)	80	Stopped.	0.25	0.01
6	MW06	2.86 10^{12} (z=0)	40	Complete.	0.5	0.01
7	MW07	1.19 10^{12} (z=0)	40	Stopped.	0.40	0.01
8	MW08	0.99 10^{12} (z=0)	40	Stopped.	0.45	0.01
9	MW09	0.77 10^{12} (z=0)	40	Complete.	0.5	0.01
10	MW10†	1.07 10^{12} (z=1)	20	Complete.	0.5	0.01
11	MW11†	1.00 10^{12} (z=1)	20	Stopped.	0.4	0.01
12	MW12†	1.18 10^{12} (z=1)	40	Stopped.	0.39	0.01
13	SFG1	2.31 10^{12} (z=1)	40	Stopped.	0.38	0.01
14	SFG2	1.24 10^{13} (z=1)	80	Stopped.	0.22	0.005
15	SFG3	0.075 10^{13} (z=1)	80	Stopped.	0.075	0.005
16	SFG4	2.30 10^{12} (z=1)	40	Stopped.	0.38	0.01
17	SFG5	2.33 10^{12} (z=1)	40	Stopped.	0.40	0.01
18	SFG6	1.56 10^{13} (z=1)	80	Stopped.	0.09	0.005
19	SFG7	1.12 10^{13} (z=1)	80	Stopped.	0.22	0.005
20	SFG8	4.61 10^{12} (z=1)	80	Stopped.	0.35	0.005
21	SFG9	3.62 10^{12} (z=1)	80	Stopped.	0.486	0.005

#	Galaxy ID	Halo Mass [$M_\odot$/h]	Box Size [Mpc/h]	Status	a final	snapshot Δa
22	VL01	1.40 10^{12} (z=1)	40	Complete.	0.37	0.01
23	VL02	1.40 10^{12} (z=1)	40	Complete.	0.50	0.01
24	VL03	1.43 10^{12} (z=1)	40	Complete.	0.33	0.01
25	VL04	1.44 10^{12} (z=1)	40	Complete.	0.42	0.01
26	VL05	1.40 10^{12} (z=1)	40	Complete.	0.41	0.01
27	VL06	1.41 10^{12} (z=1)	40	Complete.	0.50	0.01
28	VL07	1.83 10^{12} (z=1)	80	Complete.	0.34	0.01
29	VL08	1.86 10^{12} (z=1)	80	Stopped.	0.46	0.01
30	VL09	1.81 10^{12} (z=1)	80	Stopped.	0.34	0.01
31	VL10	1.81 10^{12} (z=1)	80	Complete.	0.50	0.01
32	VL11	1.85 10^{12} (z=1)	80	Complete.	0.50	0.01
33	VL12	1.83 10^{12} (z=1)	80	Complete.	0.50	0.01

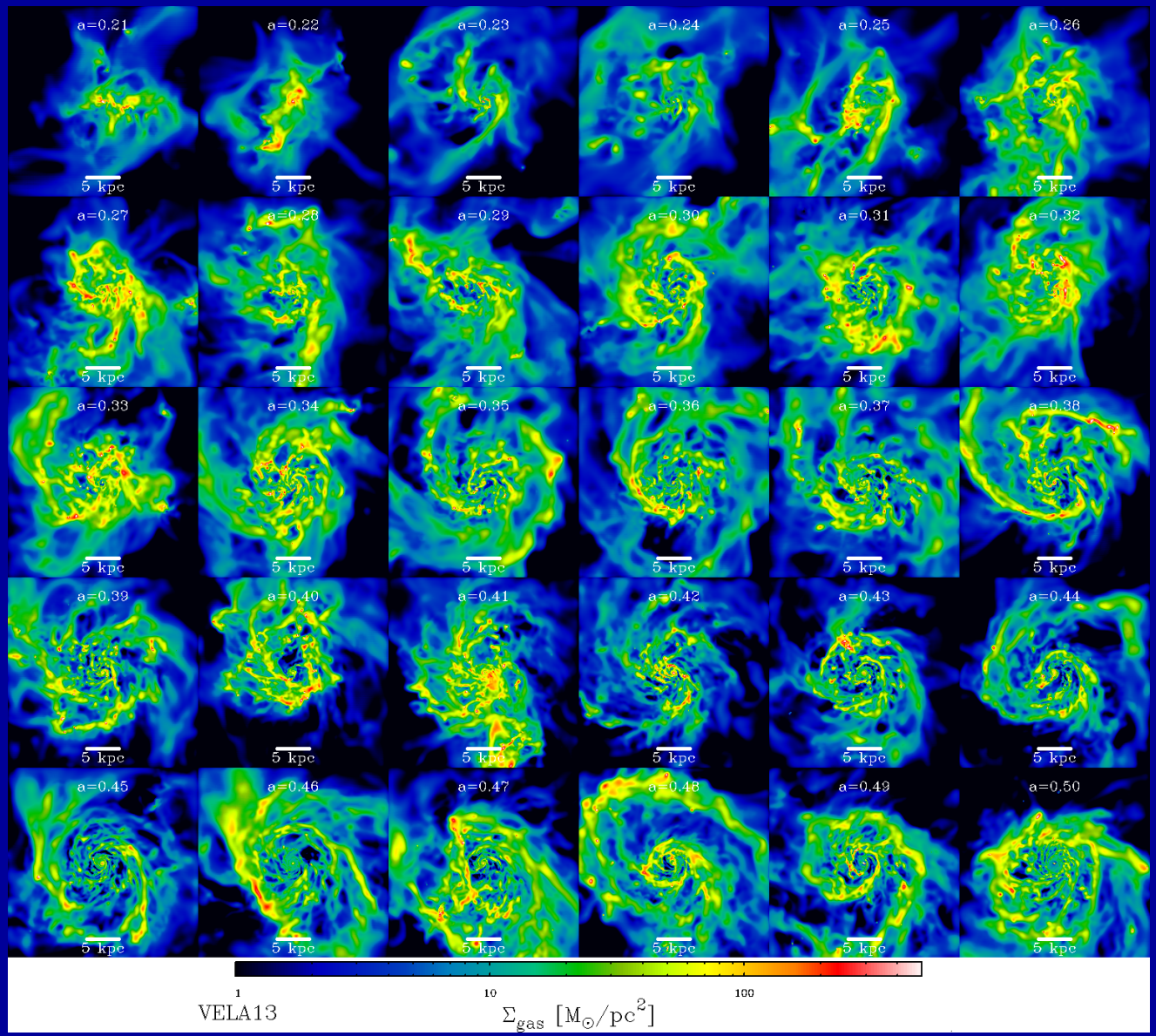
- Resolution: 35-70 pc
- Thermal feedback

DC's 2nd and 3rd generation simulation sample

#	Galaxy ID	Halo Mass [$M_\odot$/h]	Box Size [Mpc/h]	Status	a final	snapshot Δa
1	VELA01	4.74 10^{11} (z=1)	10	Complete.	0.50	0.01
2	VELA02	3.75 10^{11} (z=1)	10	Complete.	0.50	0.01
3	VELA03	3.17 10^{11} (z=1)	10	Complete.	0.50	0.01
5	VELA05	1.69 10^{11} (z=1)	10	Complete.	0.50	0.01
6	VELA06	1.19 10^{12} (z=0.8)	40	Running.	0.30	0.01
7	VELA07	1.00 10^{12} (z=0.8)	40	Running.	0.35	0.01
8	VELA11	6.30 10^{11} (z=0.8)	40	Complete.	0.50	0.01
9	VELA12	5.11 10^{11} (z=0.8)	40	Complete.	0.50	0.01
10	VELA13	2.79 10^{11} (z=0.8)	40	Complete.	0.40	0.01
11	VELA14	3.15 10^{11} (z=0.8)	40	Running.	0.37	0.01
12	VELA15	2.29 10^{11} (z=0.8)	40	Complete.	0.50	0.01
1b	VELA_v2_01	4.74 10^{11} (z=1)	10	Complete.	0.50	0.01
2b	VELA_v2_02	3.75 10^{11} (z=1)	10	Complete.	0.50	0.01
3b	VELA_v2_03	3.17 10^{11} (z=1)	10	Complete.	0.50	0.01
4b	VELA_v2_04	1.91 10^{11} (z=1)	10	Complete.	0.50	0.01
5b	VELA_v2_05	1.69 10^{11} (z=1)	10	Complete.	0.50	0.01
6b	VELA_v2_06	1.19 10^{12} (z=0.8)	40	Running.	0.28	0.01
7b	VELA_v2_07	1.00 10^{12} (z=0.8)	40	Running.	0.30	0.01
8b	VELA_v2_11	6.30 10^{11} (z=0.8)	40	Complete.	0.50	0.01
9b	VELA_v2_12	5.11 10^{11} (z=0.8)	40	Complete.	0.50	0.01
10b	VELA_v2_13	2.79 10^{11} (z=0.8)	40	Complete.	0.40	0.01
11b	VELA_v2_14	3.15 10^{11} (z=0.8)	40	Running.	0.37	0.01
12b	VELA_v2_15	2.29 10^{11} (z=0.8)	40	Complete.	0.50	0.01

- Resolution: 17-35 pc
- Improved star formation recipe
- Feedback
- Generation 2: Thermal feedback
- Generation 3: Radiative feedback

Gas mosaics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a=0.47
a=0.48
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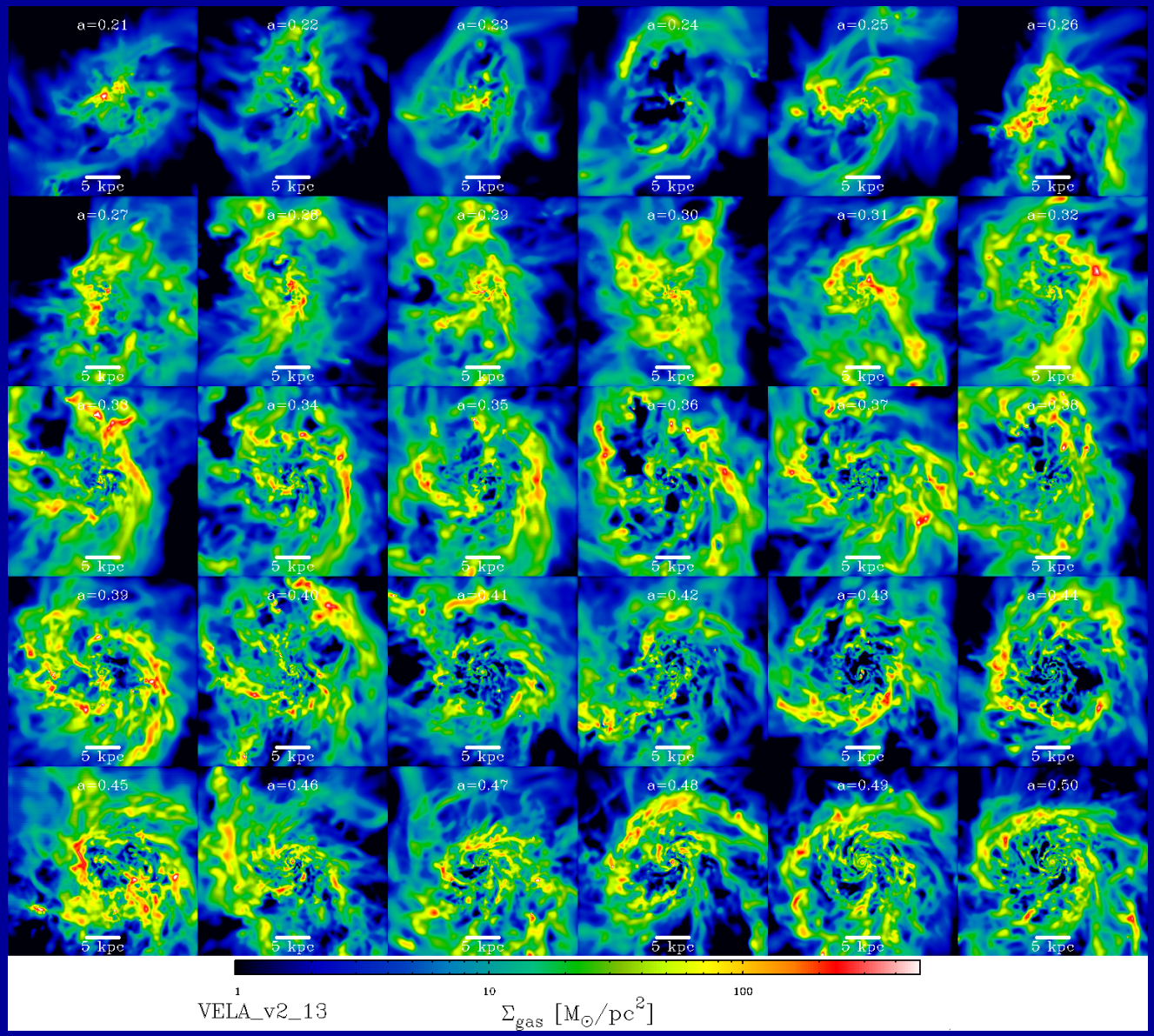
5 kpc
1
10
100
VELA13
Σ_{gas} [$M_\odot/pc^2$]

Gas mosaics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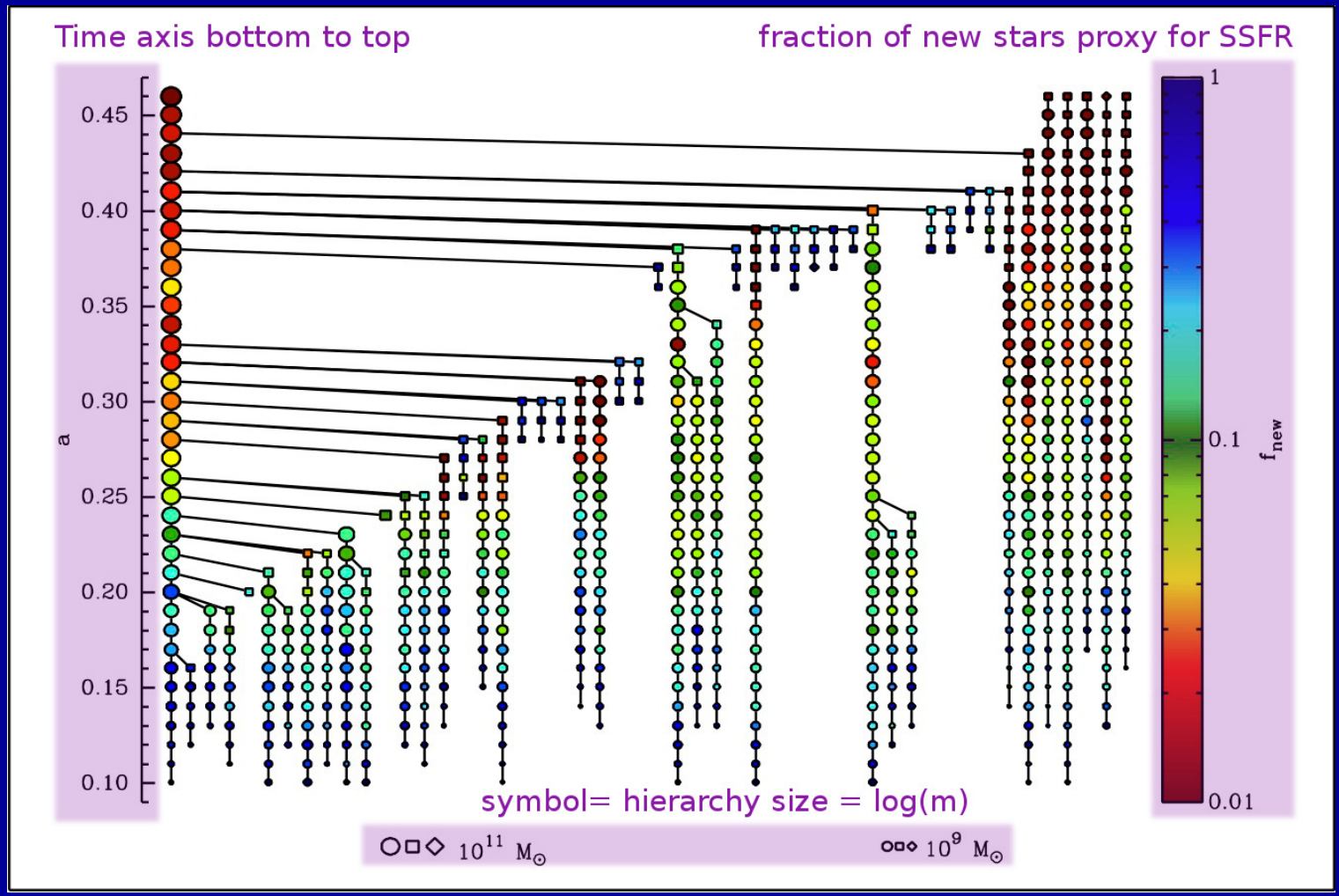
a=0.47
a=0.48
a=0.49
a=0.50
5 kpc
1
10
100
VELA_v2_13
Σ_{gas} [$M_\odot/pc^2$]

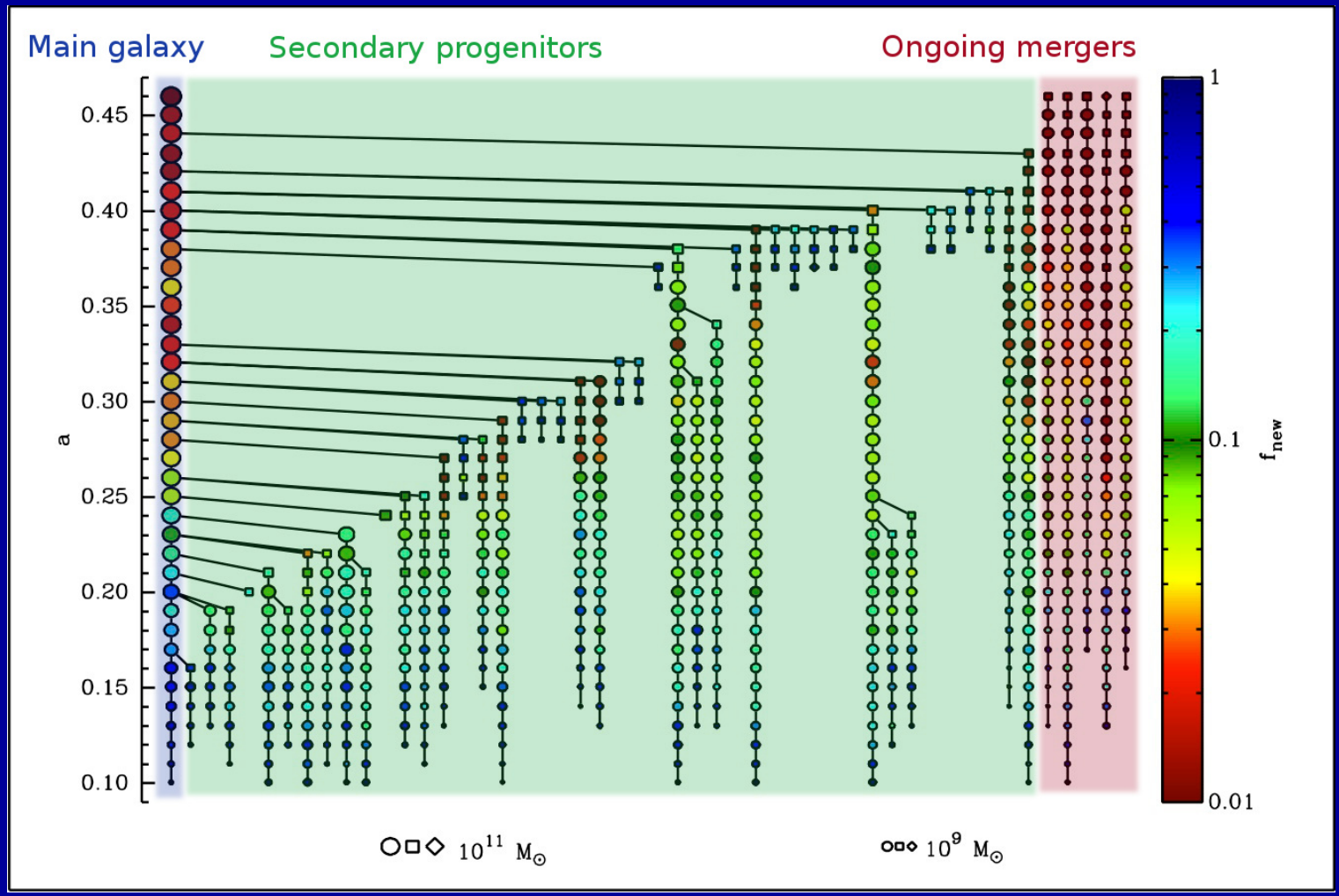
Pipeline

1. Group finding on stellar component with AdaptaHOP: Galaxies, clumps.
2. Stellar Merger trees: stars used as tracer particles.
3. Clump extraction:
   - In-situ: VDI
   - Ex-situ: Mergers/interactions
4. Analysis:
   - Galaxy properties
   - Galaxy evolution
   - Origin of the stellar population
   - Age Metallicity relation

Visualisation



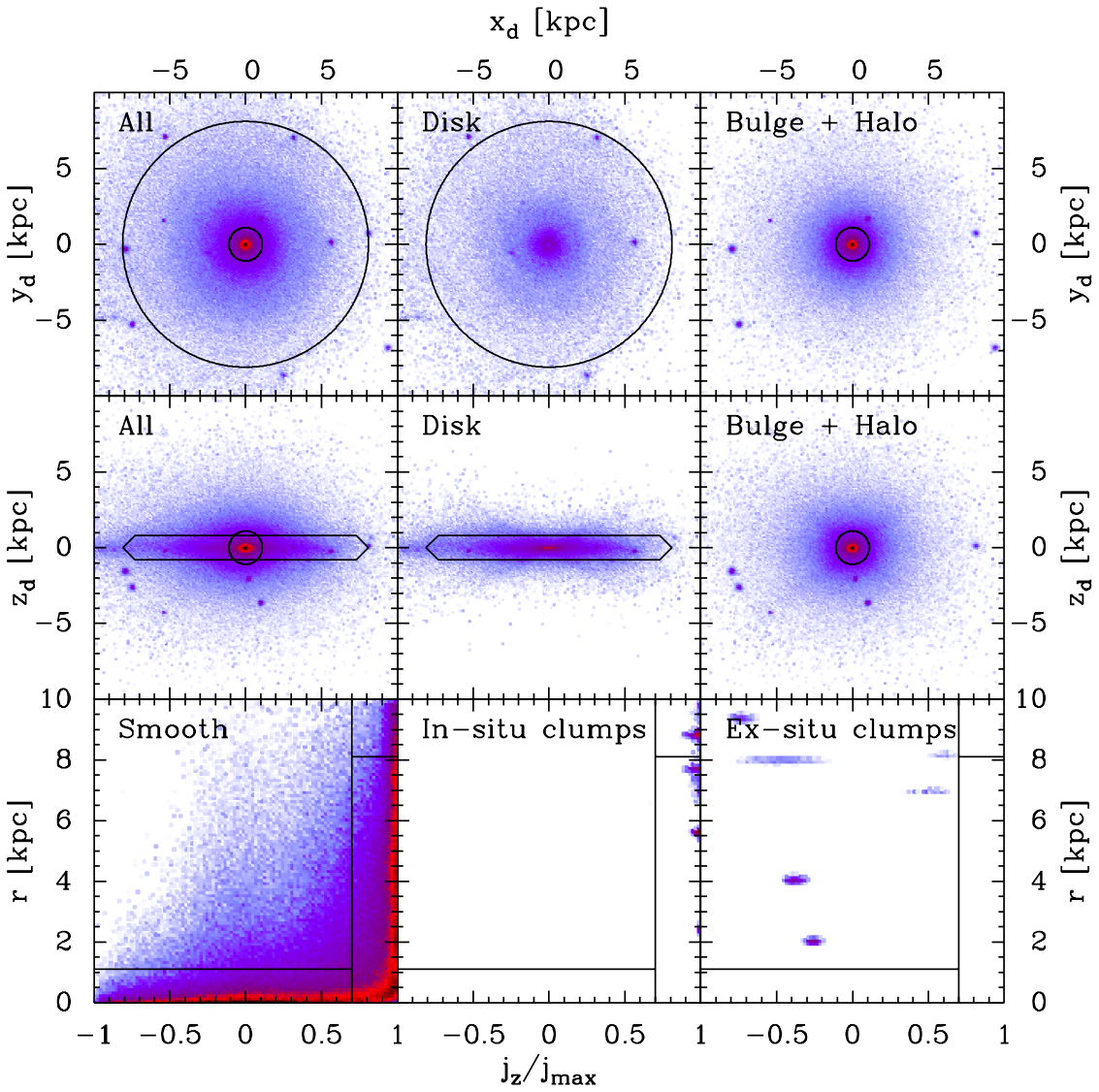
Visualisation



Question

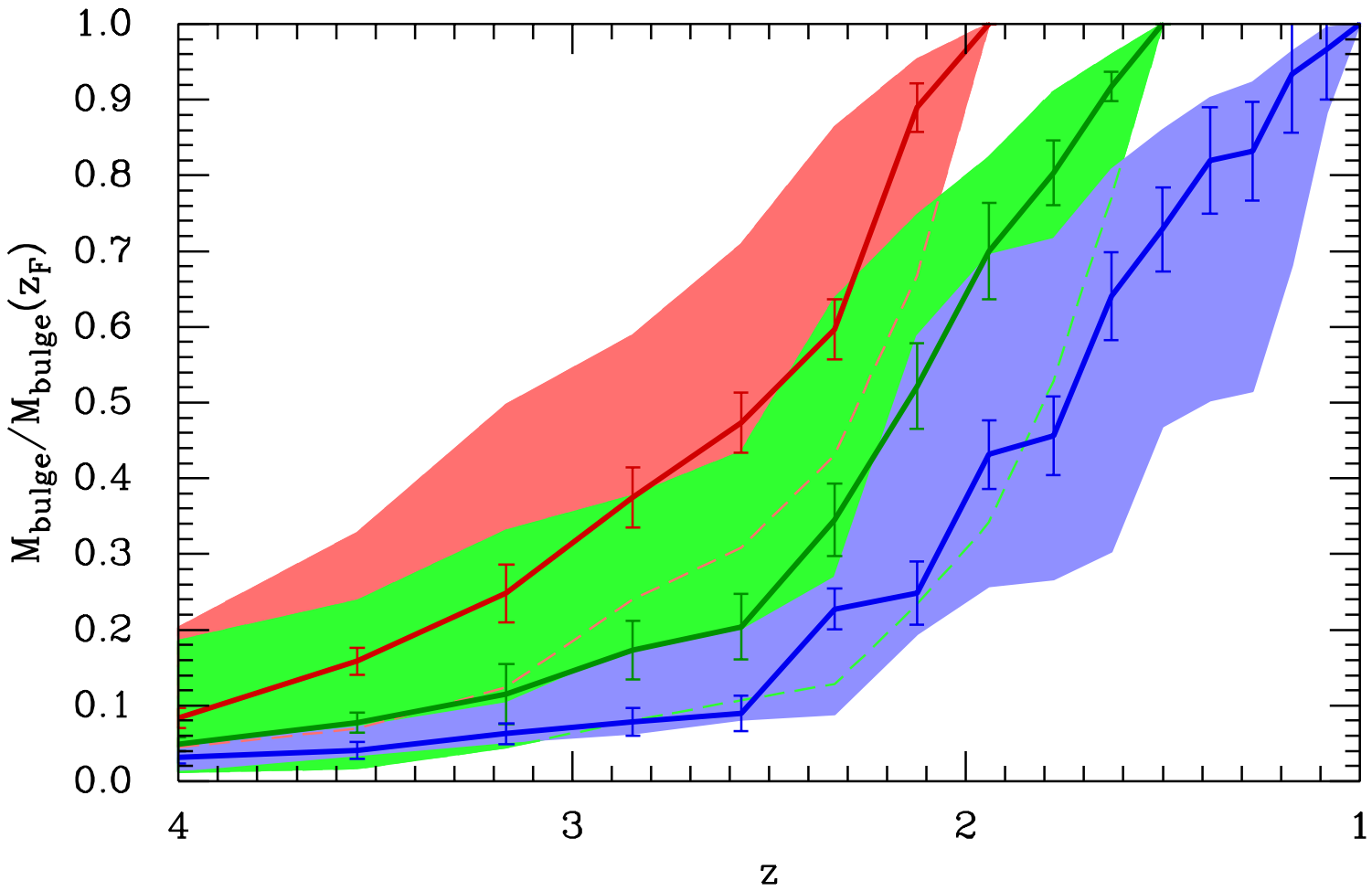
1. How is the stellar bulge built up? (Tweed, Zolotov et al. in prep)
   - We can track the whole galaxy in time.
   - Let's divide the galaxy as 3 kinematic components. Disc, Bulge, Halo

Decomposition



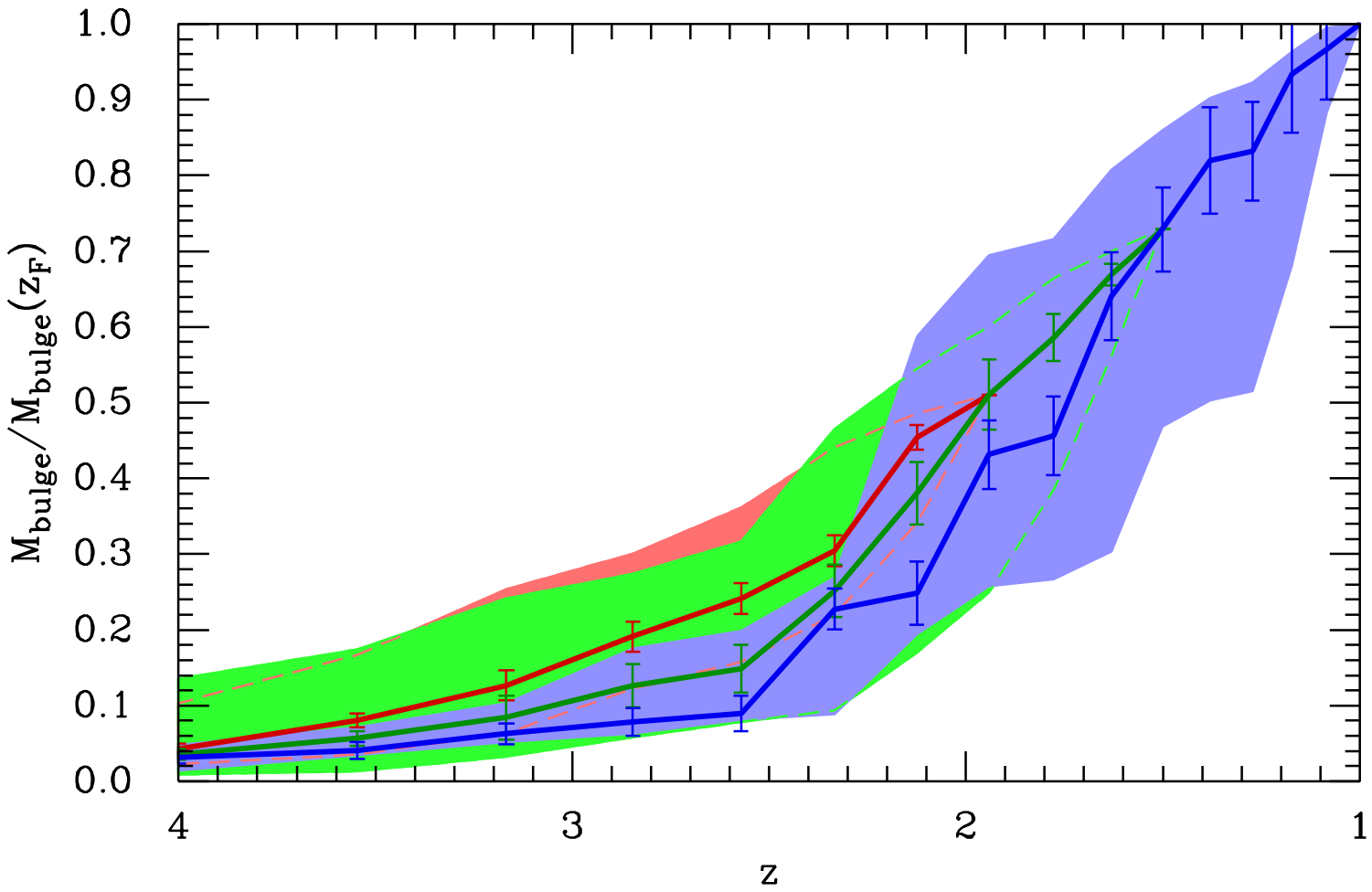
Tweed, Zolotov et al. (in prep)

Mass growth of the bulges



Tweed, Zolotov et al. (in prep)

Mass growth of the bulges

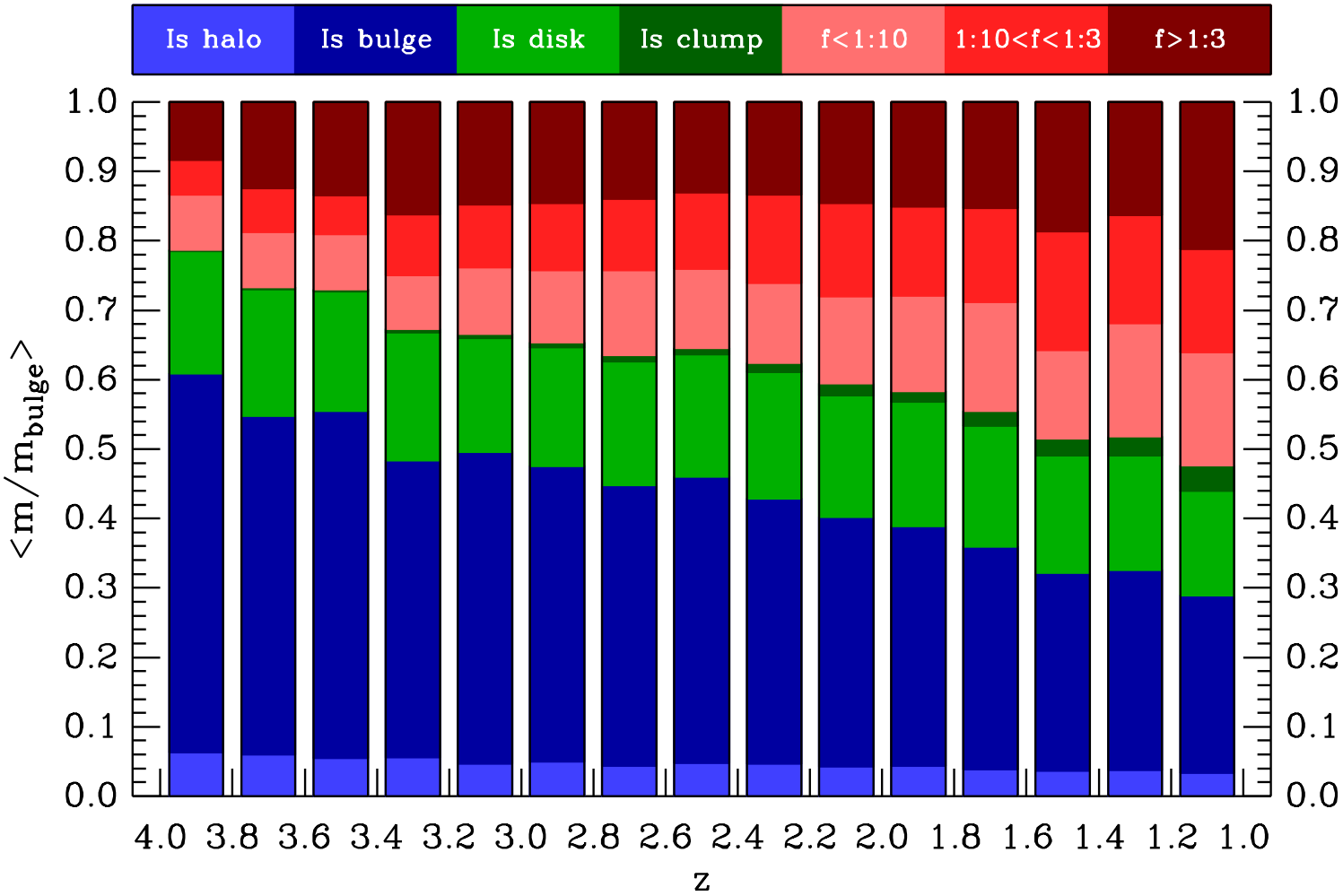


Tweed, Zolotov et al. (in prep)

Back to the question

1. How is the stellar bulge built up? (Tweed, Zolotov et al. in prep)
   - We can track the galactic bulge in time.
2. What is the origin of the stellar population within the bulge? (Tweed, Zolotov et al. in prep)
   - Let's use the merger tree..
   - ...Track each star according to the branch or
   - ...according to the kinematic component

Origin of the stellar bulge, stacked 1st gen



Tweed, Zolotov et al. (in prep)

Back to the future question

1. How is the stellar bulge built up? (Tweed, Zolotov et al. in prep)
   - We can track the galactic bulge in time.
2. What is the origin of the stellar population? (Tweed, Zolotov et al. in prep)
   - We trace the stars in the stellar bulge
3. Ok, in-situ star formation is important, where does the gas comes from?
   VDI, diffuse accretion, cold streams, wet mergers.
   - Not easy to trace gas with AMR simulation without tracers
   - Still we might cook up a good estimate

Summary

1. Simulations
   - Large sample of zoom-in simulations
   - 2 resolution, and feedback recipes.
   - ~ 30 1^{st} generation, ~ 10 pairs 2^{nd} generation, ~ 10 pairs 2^{nd} generation to be analyzed
2. Analysis (Tweed, Zolotov et al 2013 in prep, p)
   - High redshift compact bulges form initially in-situ Blue nuggets? see Adi Zolotov talk (Zolotov, Tweed et al 2013 in prep)
   - At lower redshift mergers participate to a more rapid built up of the stellar bulge.
3. Undergoing work
   - Effect of resolution and feedback (2^{nd} and 3^{rd} generation)
   - Origin of the gas.