

Bulge ART

Introduction

Stellar clumps and
merger history

Merger tree
Kinematic structure

Analysis

Method
Origin of the Bulge

Conclusion

The origin of bulges in cosmological simulations

Collaborators:

Adi Zolotov, Daniel Ceverino, Avishai Dekel.

Dylan Tweed

dylan.tweed@googlemail.com

Racah Institute of Physics, HUJI, Jerusalem

UCSC Galaxy Formation Workshop - UCSC -
August 13th – 17th 2012

Analysis of ART simulations.

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion

- Work in collaboration with:
Daniel Ceverino, Nir Mandelker, Adi Zolotov, Marcello Cacciatto, Loren Hoffman, Avishai Dekel, Joel Primack.
- AMR simulation hydro ART, (Kratsov, Klypin), 30 zoom-in simulations of high redshift galaxies, spatial resolution 35-70 pc.
- Main focus, VDI, disc evolution, bulge formation.

High resolution AMR zoom-in $z > 1$ simulations

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion

Daniel Ceverino's 1st simulations sample

Galaxy	Target M_v $10^{12} M_\odot$	R_v kpc	M_v $10^{12} M_\odot$	M_{star} $10^{11} M_\odot$	M_g $10^{11} M_\odot$	a_{fin}
MW01	1.53	102	0.81	0.72	0.57	0.42
MW02	1.21	105	0.89	2.56	1.12	0.34
MW03	1.93	099	0.73	0.60	0.51	0.42
MW04	4.01	123	1.42	1.41	0.89	0.42
MW06	40.9	106	0.92	1.06	0.49	0.50
MW07	1.70	073	0.30	0.30	0.22	0.50
MW08	1.41	071	0.28	0.28	0.15	0.50
MW09	1.10	059	0.16	0.19	0.08	0.50
MW10	1.53	102	0.82	0.72	0.44	0.50
MW11	1.42	088	0.53	0.51	0.28	0.40
MW12	1.69	130	1.70	2.06	1.01	0.48
VL01	2.00	117	1.23	1.54	0.75	0.37
VL02	2.00	101	0.81	0.89	0.46	0.50
VL03	2.04	117	1.22	1.44	0.76	0.33
VL04	2.06	109	1.01	1.33	0.51	0.50
VL05	2.00	118	1.28	1.29	0.75	0.41
VL06	2.01	099	0.75	0.94	0.32	0.50
VL07	2.61	129	1.66	2.15	0.82	0.35
VL08	2.66	112	1.09	1.35	0.46	0.50
VL09	2.59	086	0.49	0.61	0.24	0.34
VL10	2.59	102	0.81	0.95	0.44	0.50
VL11	2.64	130	1.73	2.02	0.81	0.50
VL12	2.61	105	0.90	0.96	0.51	0.50
SFG1	3.30	129	1.66	2.10	0.87	0.46
SFG4	3.29	112	1.09	1.16	0.66	0.42
SFG5	3.33	123	1.38	1.52	0.78	0.50
SFG8	6.59	121	1.38	1.70	0.72	0.35
SFG9	5.17	135	1.89	2.44	1.22	0.49

Table : Target mass is at $z=1$, virial measurement are at $z=2$.

Gas mosaics

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

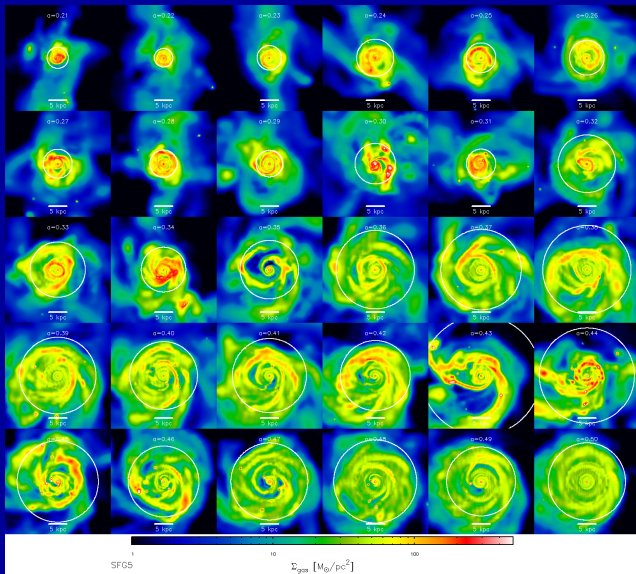
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Gas mosaics

Bulge ART

Introduction

Stellar clumps and merger history

Merger free

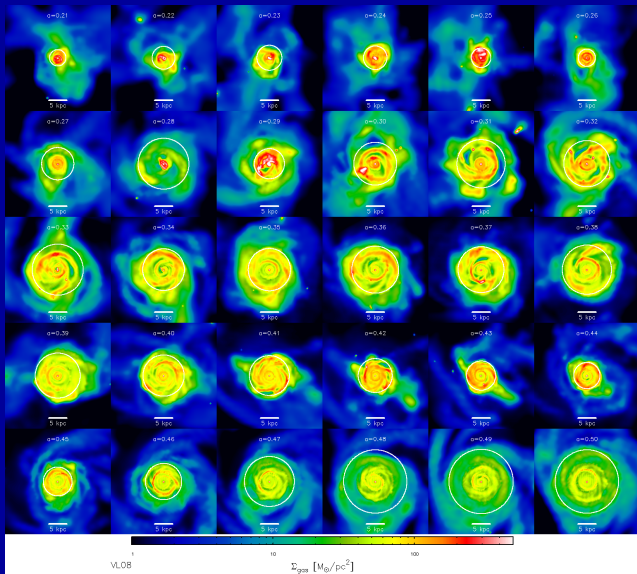
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Pipeline

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion

- 1 Group finding on stellar component with AdaptaHOP: Galaxies, clumps.
- 2 Stellar Merger trees: stars used as tracer particles .
- 3 Analysis: Galaxy evolution, In-situ clump, Ex-situ clump (mergers/interactions)

Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

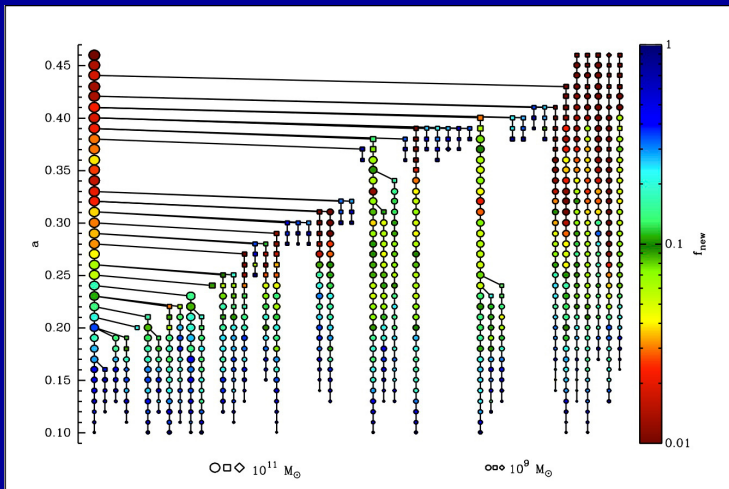
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

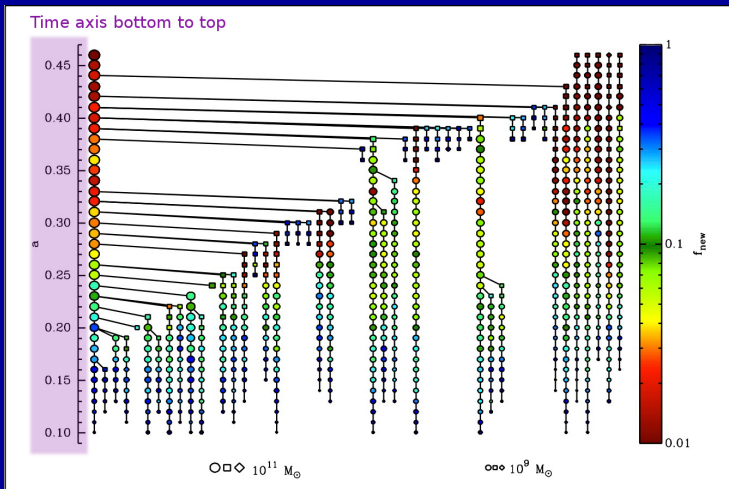
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

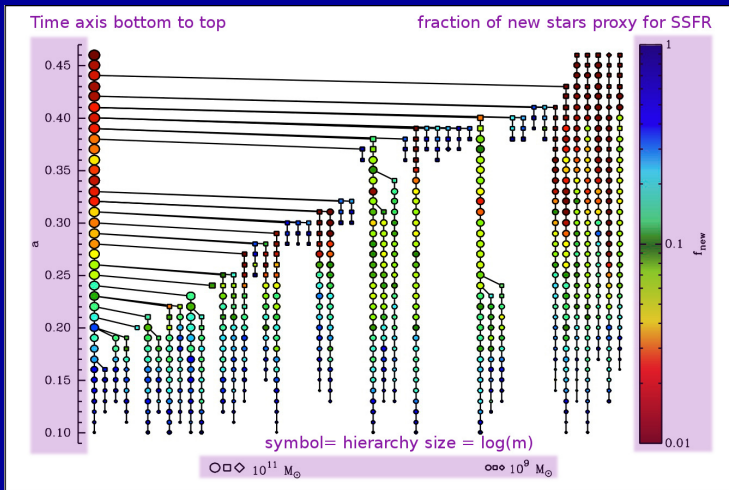
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

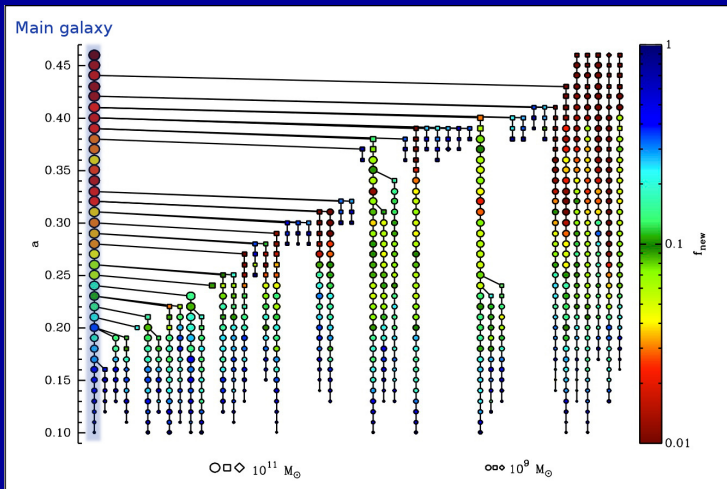
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

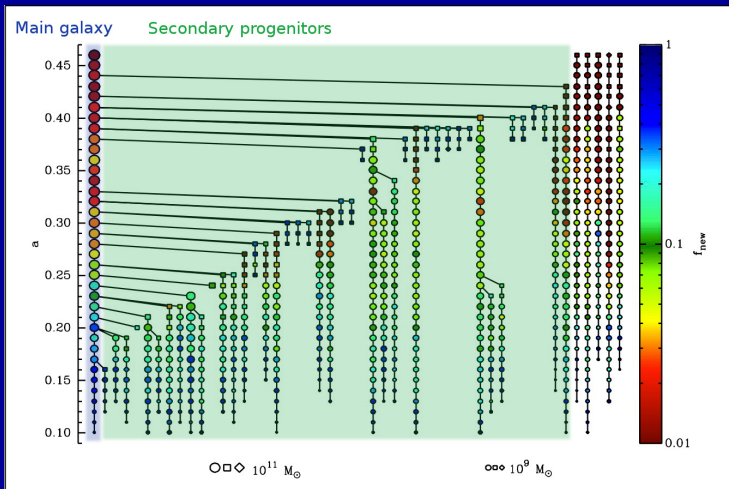
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

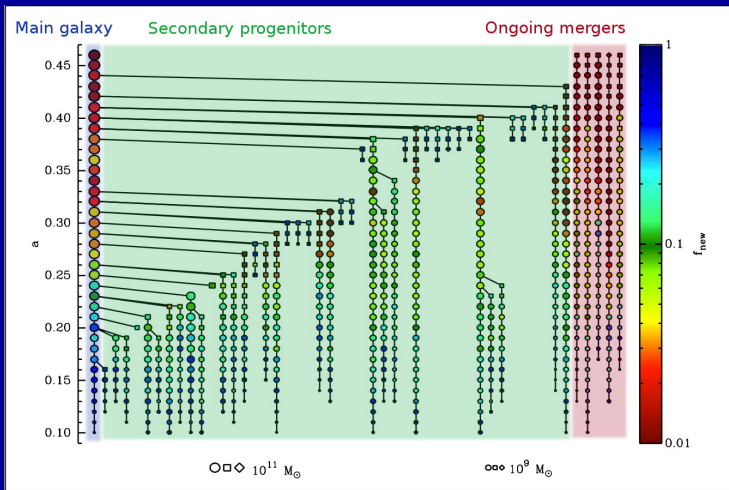
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

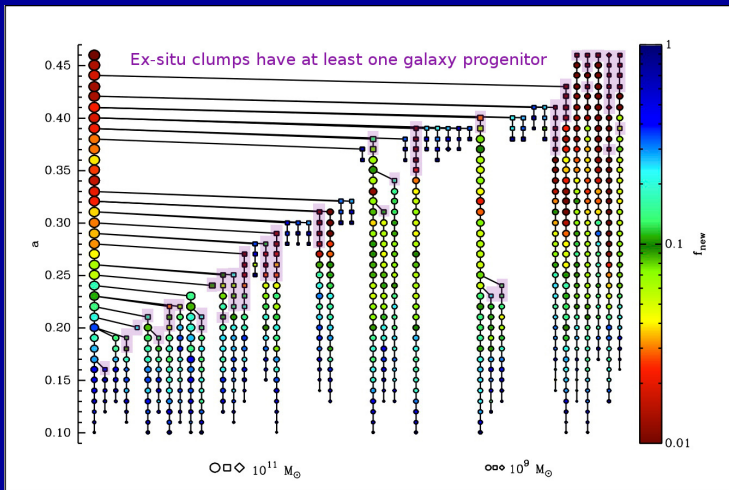
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Visualisation

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

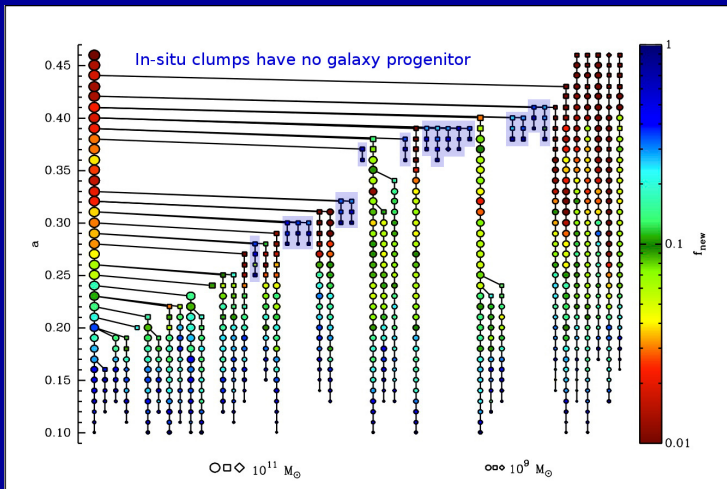
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Clumps co-rotating with the disc.

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

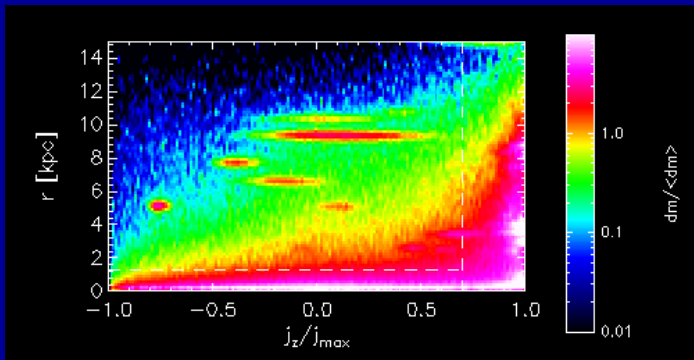
Analysis

Method

Origin of the Bulge

Conclusion

Visualization in the rotation frame of the galaxy¹



Smooth component + In-situ clumps + Ex-situ clumps

$$^1 j_z = \mathbf{L}_{\text{star}} \cdot \mathbf{L}_{\text{gal}} \text{ and } j_{\text{max}} = |r_{\text{star}}| * |v_{\text{star}}|$$

Clumps co-rotating with the disc.

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

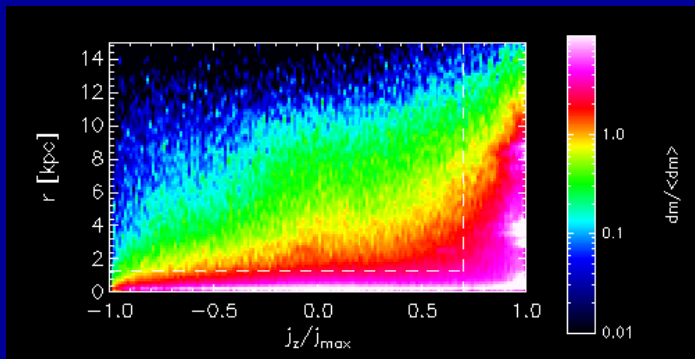
Analysis

Method

Origin of the Bulge

Conclusion

Visualization in the rotation frame of the galaxy¹



Smooth component + In-situ clumps

$$^1 j_z = \mathbf{L}_{\text{star}} \cdot \mathbf{L}_{\text{gal}} \text{ and } j_{\text{max}} = |r_{\text{star}}| * |v_{\text{star}}|$$

Clumps co-rotating with the disc.

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

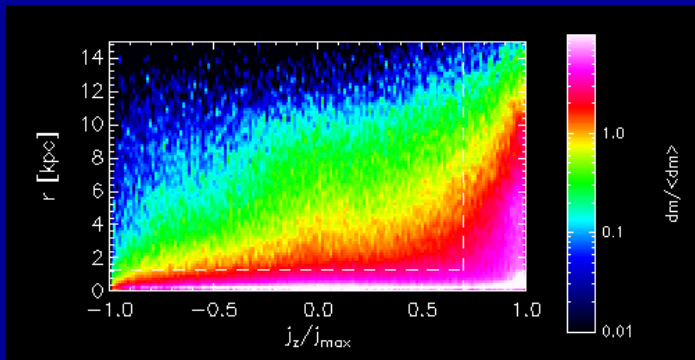
Analysis

Method

Origin of the Bulge

Conclusion

Visualization in the rotation frame of the galaxy¹



Smooth component

$$^1 j_z = \mathbf{L}_{\text{star}} \cdot \mathbf{L}_{\text{gal}} \text{ and } j_{\text{max}} = |r_{\text{star}}| * |v_{\text{star}}|$$

Question

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion

- 1 How is the stellar bulge built up? (Zolotov & Tweed 2012 in prep)
- 2 Can we understand the build up of the Galaxy with this merger trees?
 - We can quantify the evolution of global properties of the whole galaxy.
 - We can define the galaxy as 3 kinematic components.
- 3 Is it enough to understand the build up of one component?
 - No.
 - Let's track the stars which build up each component.

3 criteria classification

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion

- 1 Structural decomposition: AdaptaHOP, smooth, In-situ clumps, Ex-situ clumps
- 2 Kinematic decomposition: stellar halo, stellar bulge, stellar disc.
- 3 Stellar origin: where the star was born in the merger tree and kinematic component.

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

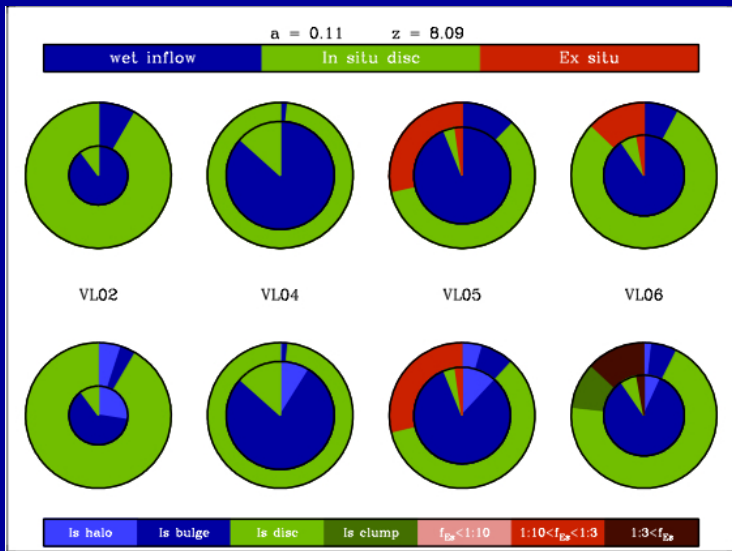
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

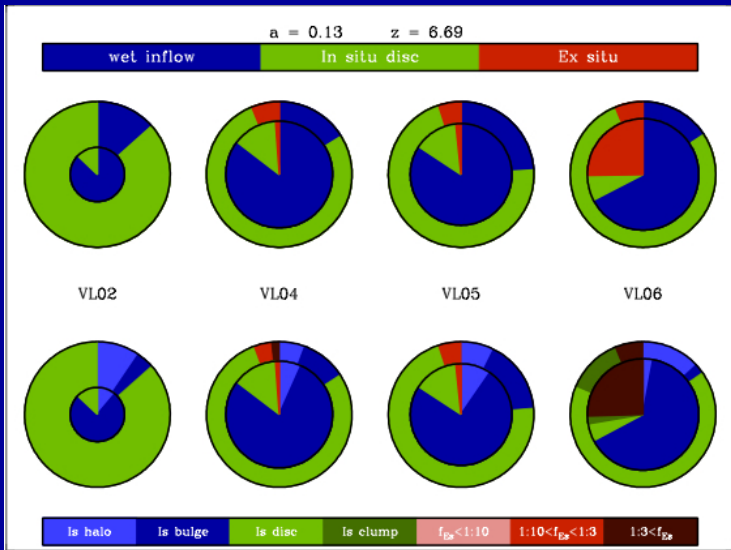
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

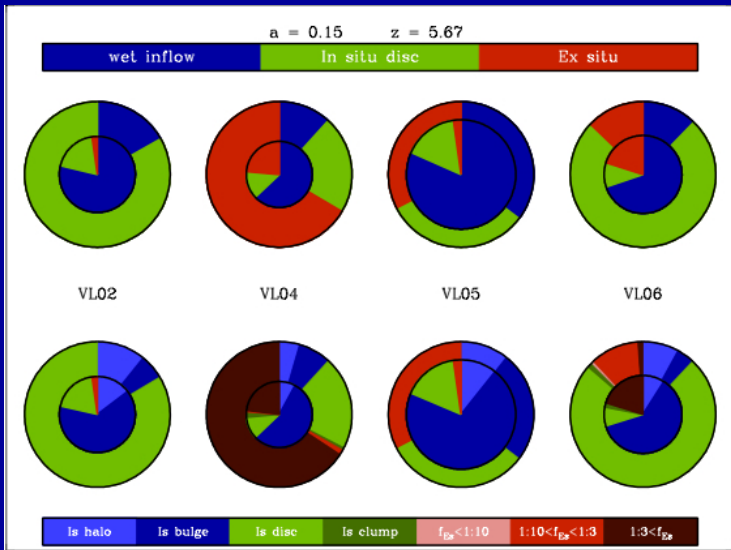
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

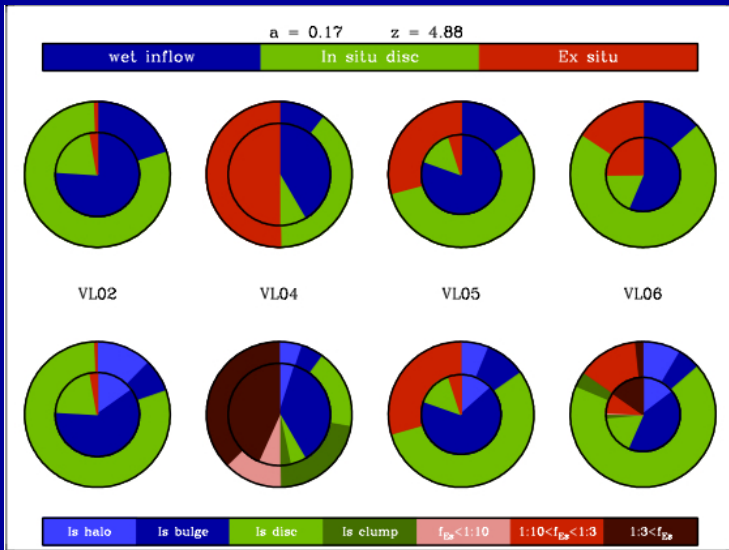
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

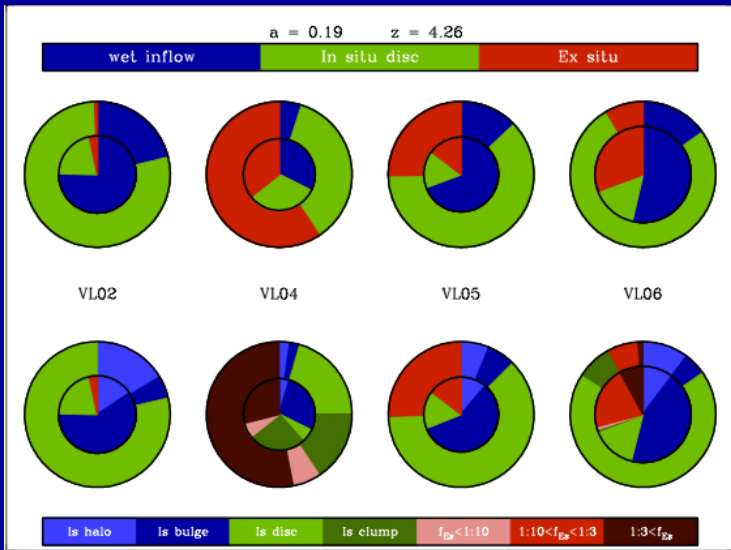
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

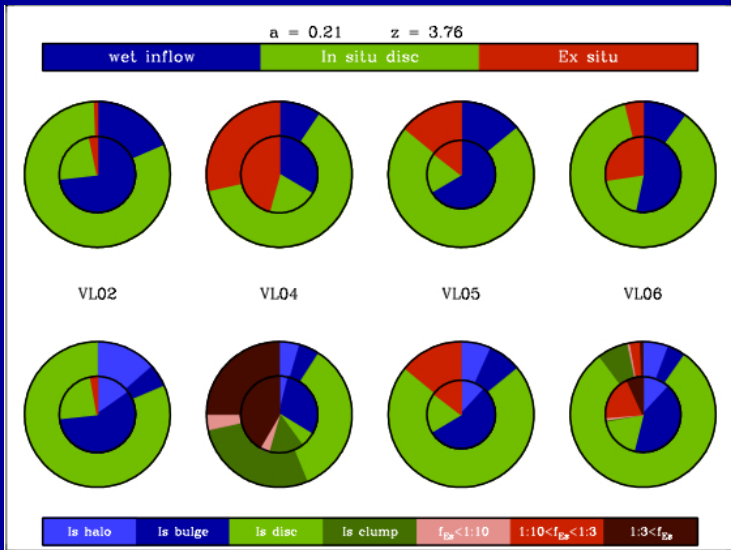
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

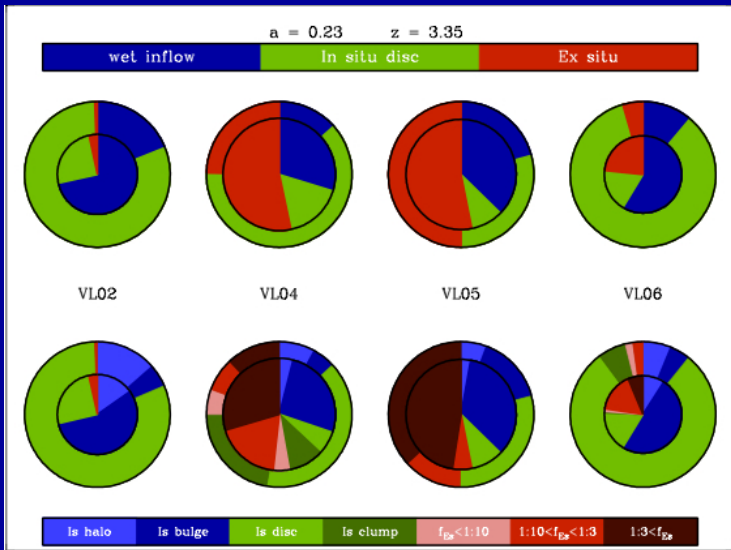
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

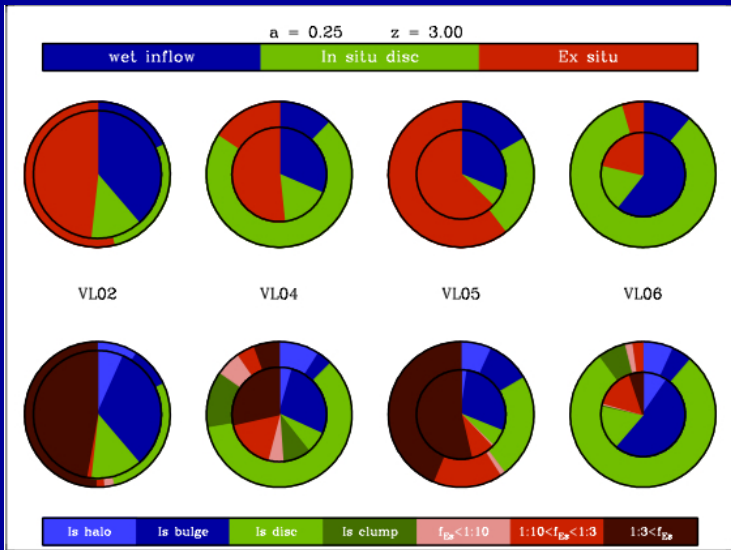
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

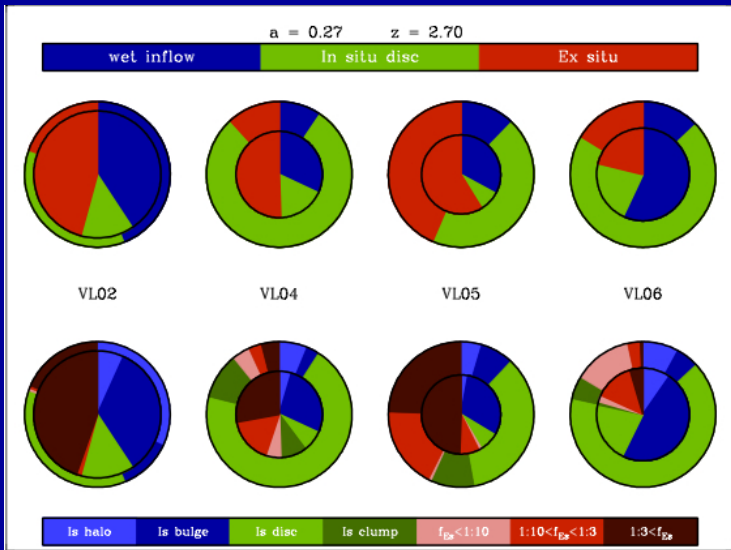
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

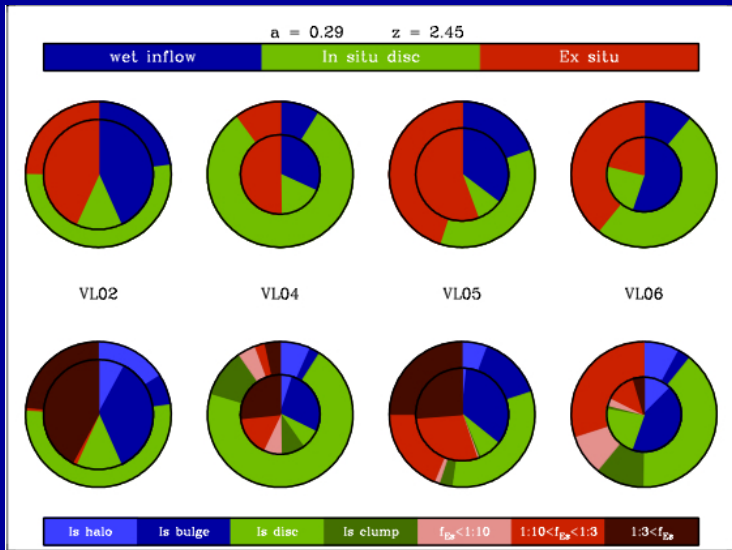
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

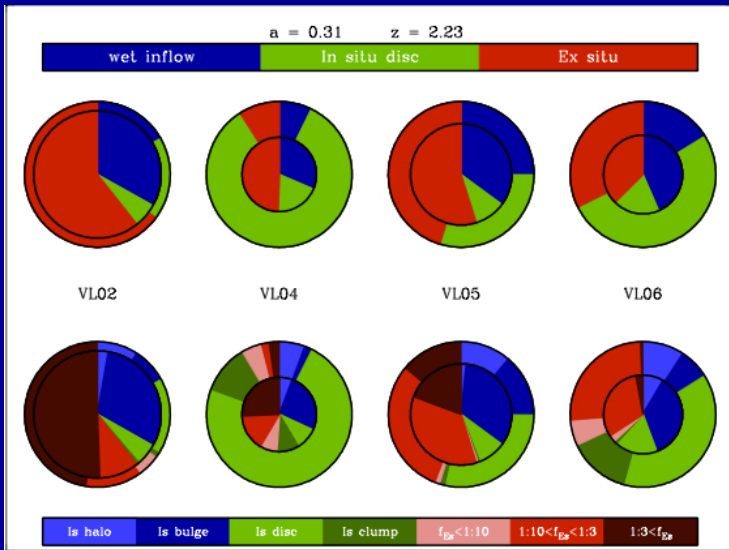
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

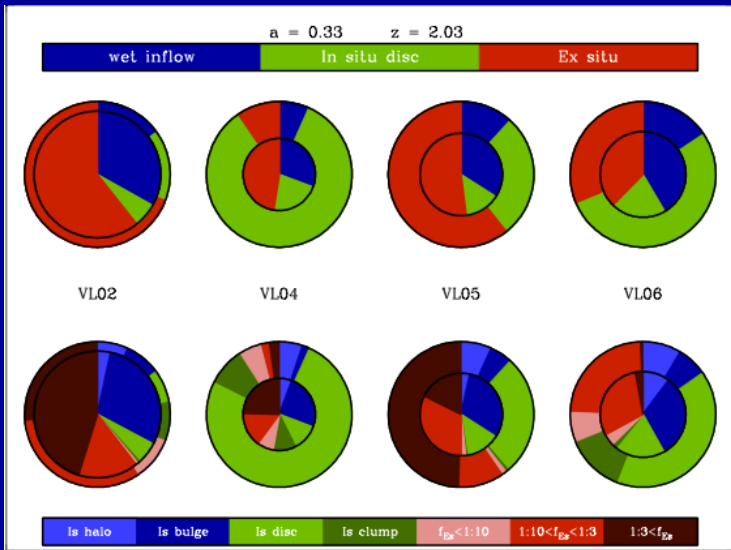
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

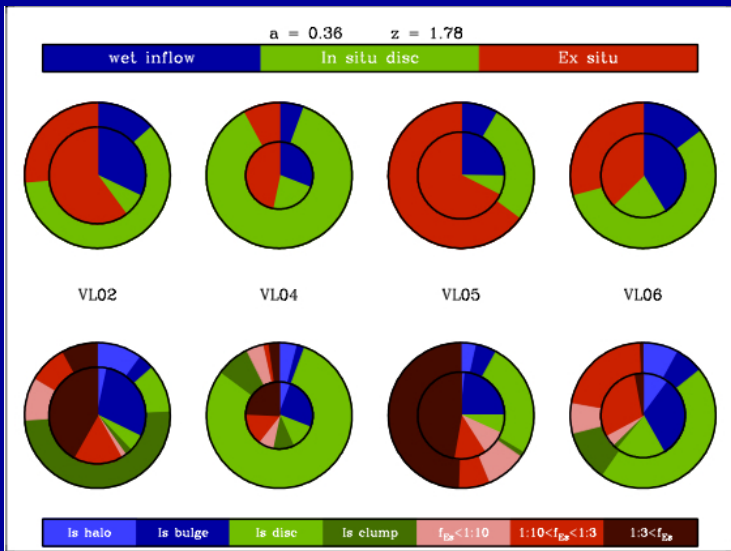
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

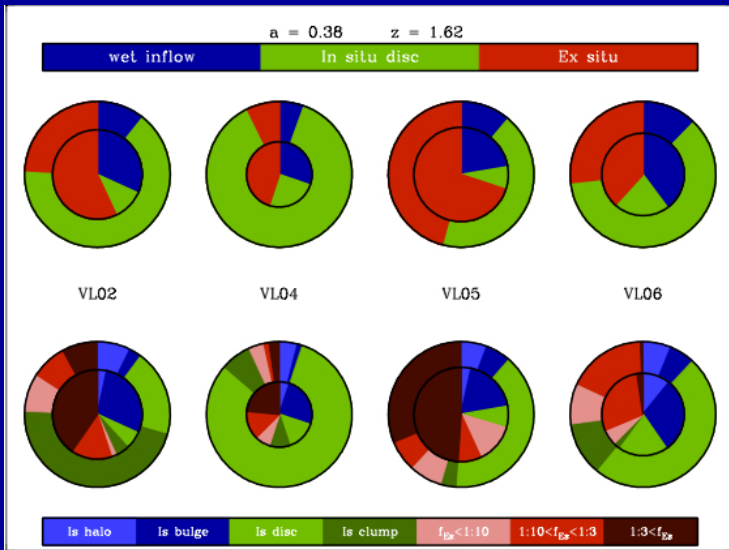
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

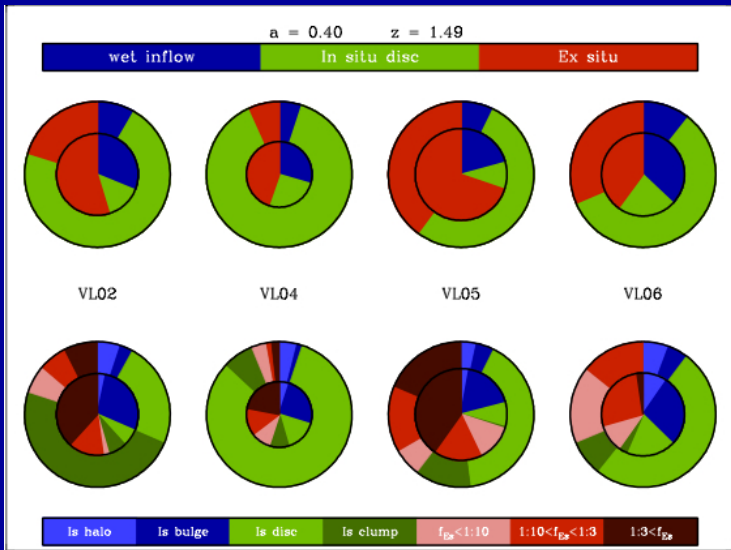
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

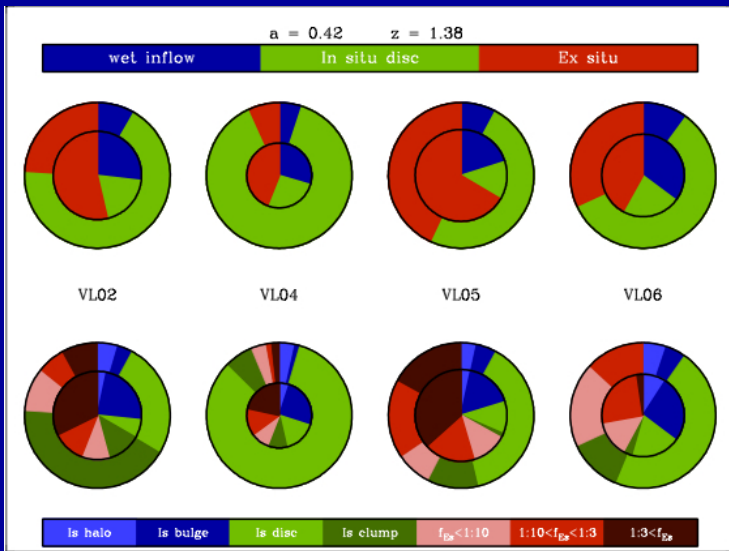
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

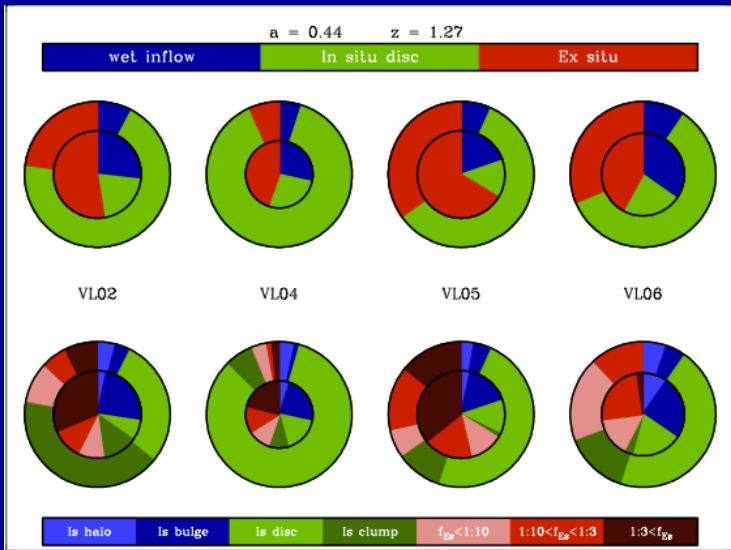
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

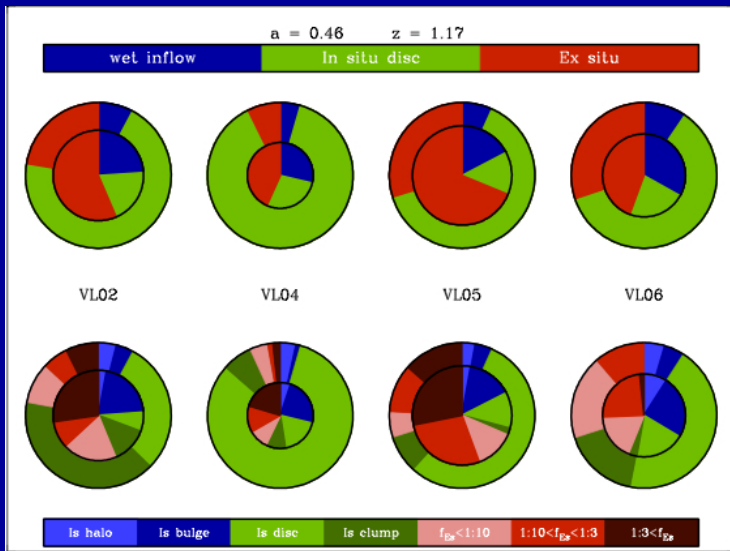
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

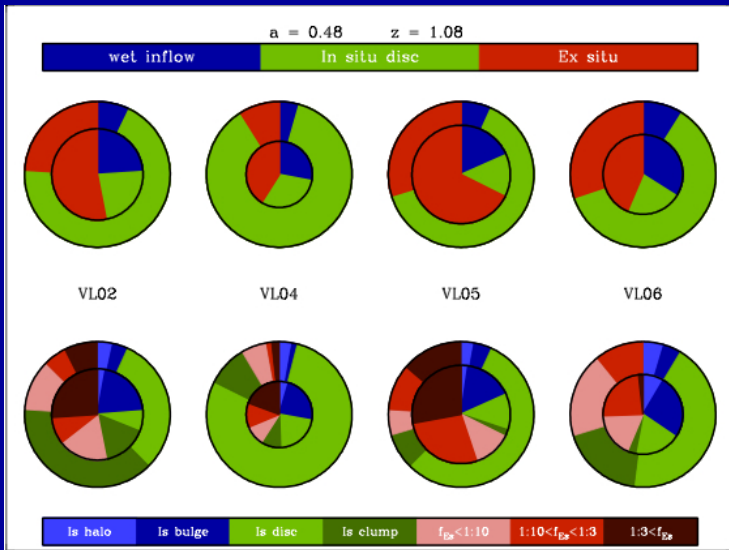
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Exemples: Build up of the discs and the bulges

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

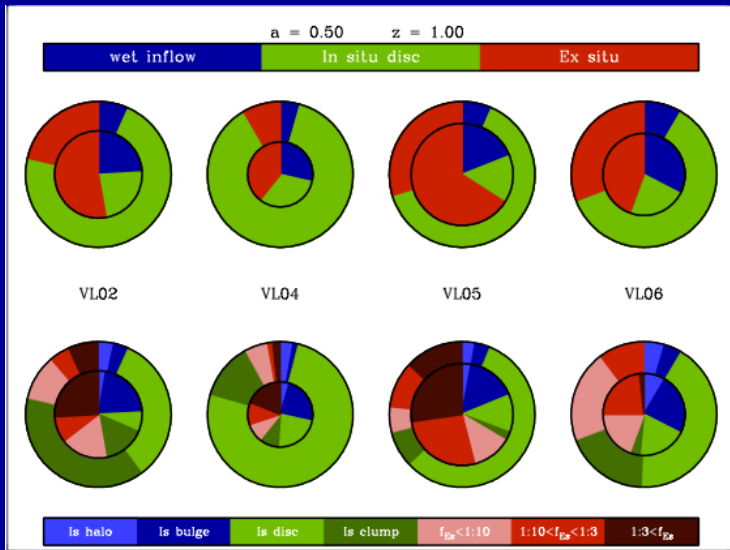
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Stacked evolution

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

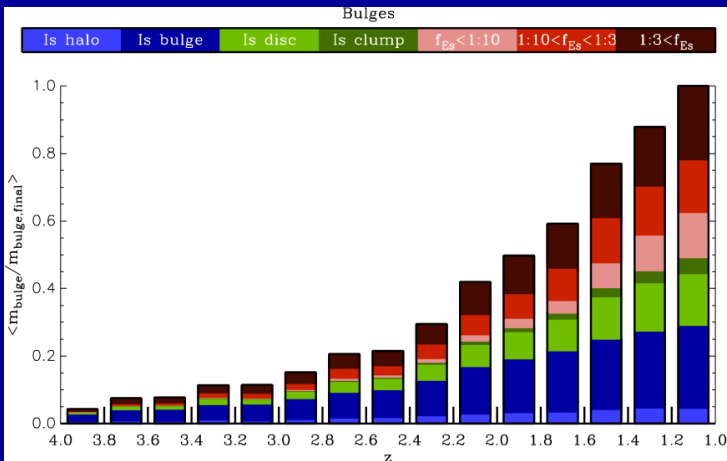
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Stacked evolution

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree

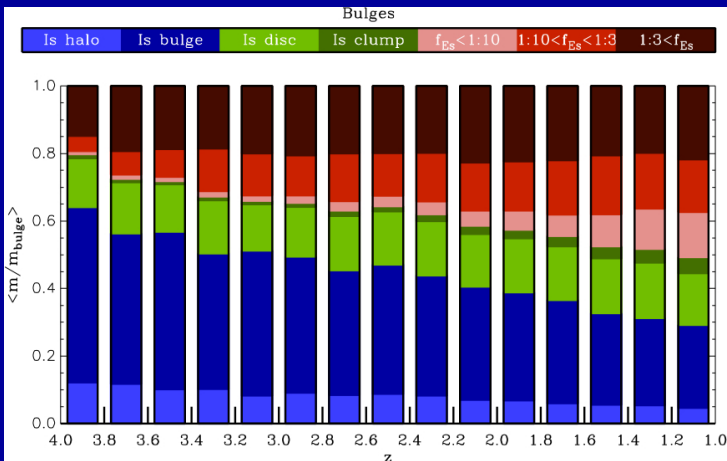
Kinematic structure

Analysis

Method

Origin of the Bulge

Conclusion



Zolotov, Tweed et al. (in prep)

Conclusion

Bulge ART

Introduction

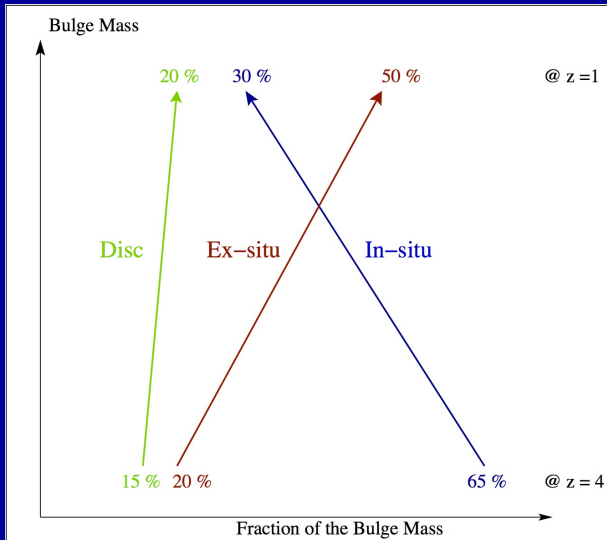
Stellar clumps and merger history

Merger tree
Kinematic structure

Analysis

Method
Origin of the Bulge

Conclusion



Conclusion

Bulge ART

Introduction

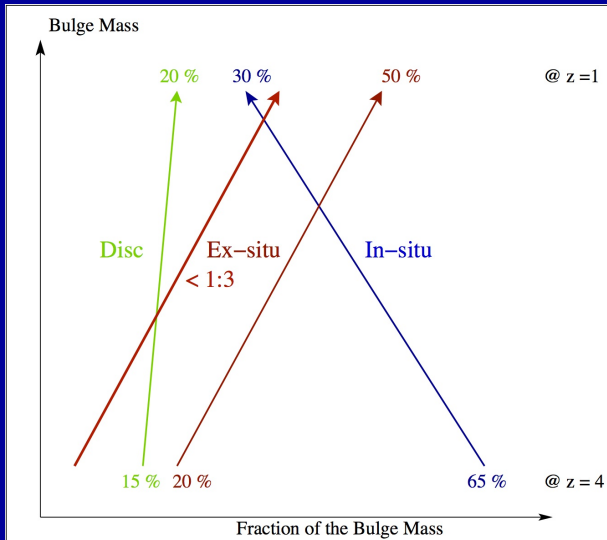
Stellar clumps and merger history

Merger tree
Kinematic structure

Analysis

Method
Origin of the Bulge

Conclusion



Conclusion

Bulge ART

Introduction

Stellar clumps and merger history

Merger tree
Kinematic structure

Analysis

Method
Origin of the Bulge

Conclusion

