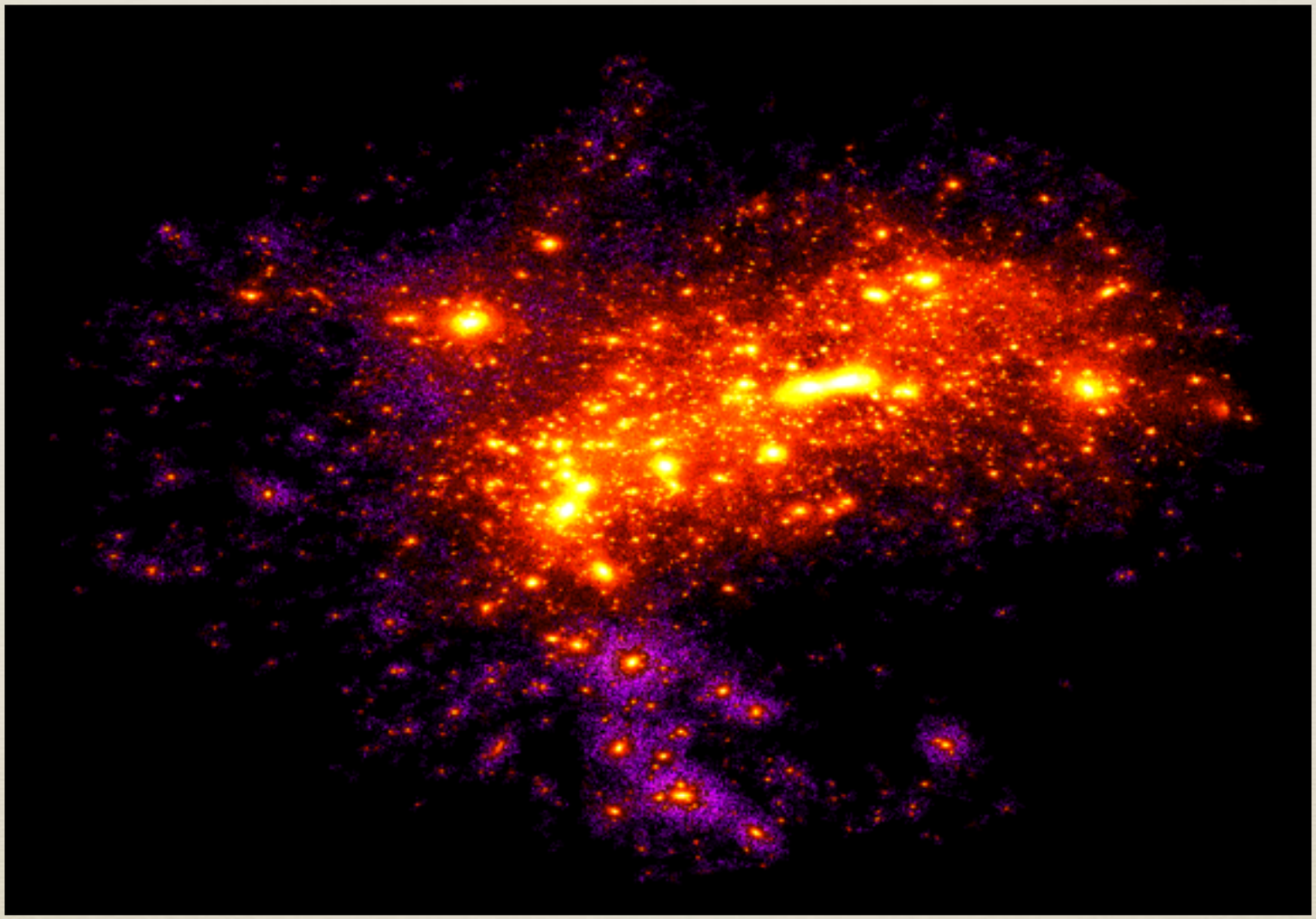
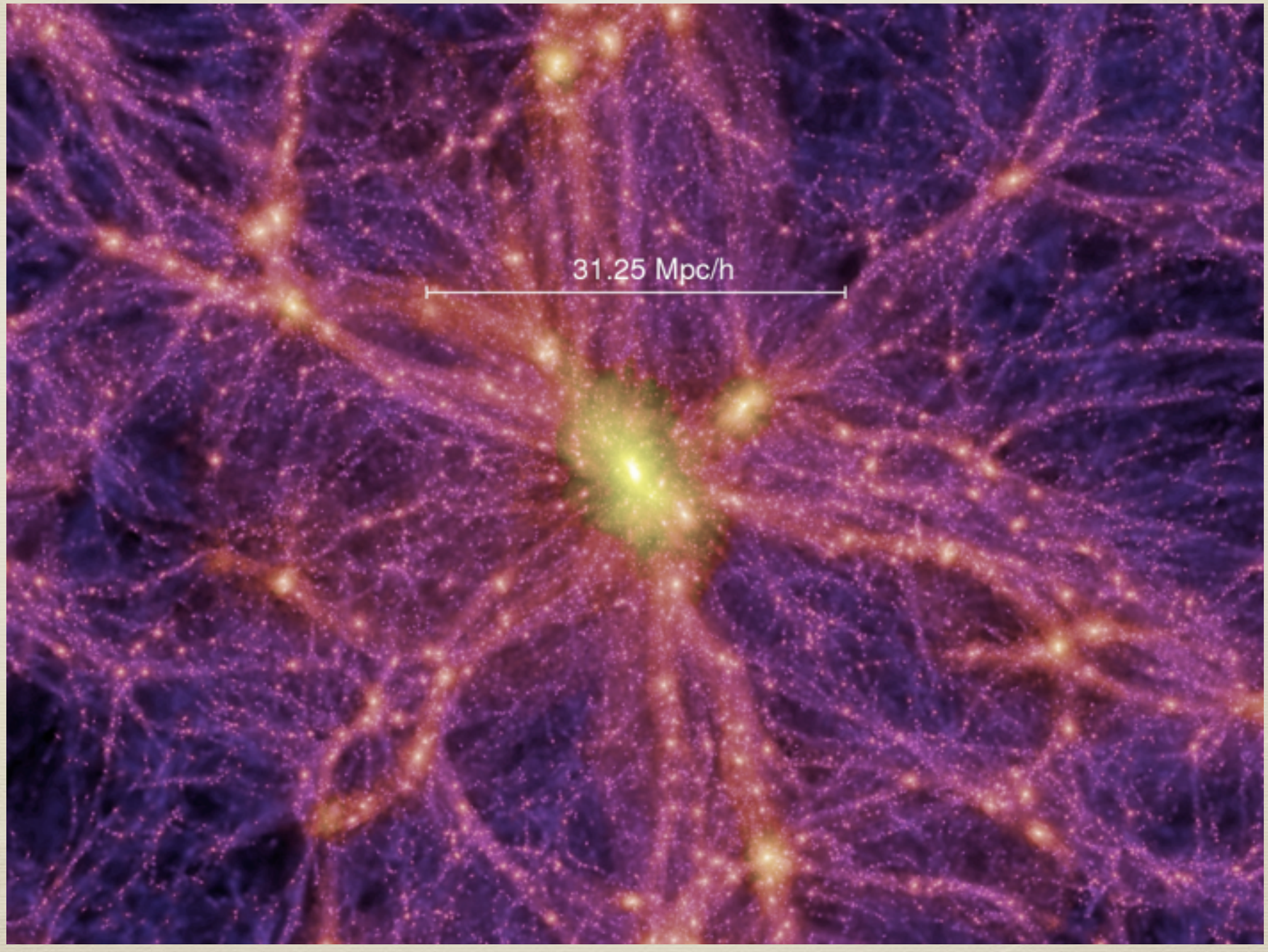
ADVANCES IN PHASE-SPACE

For Halo and Galaxy Finding



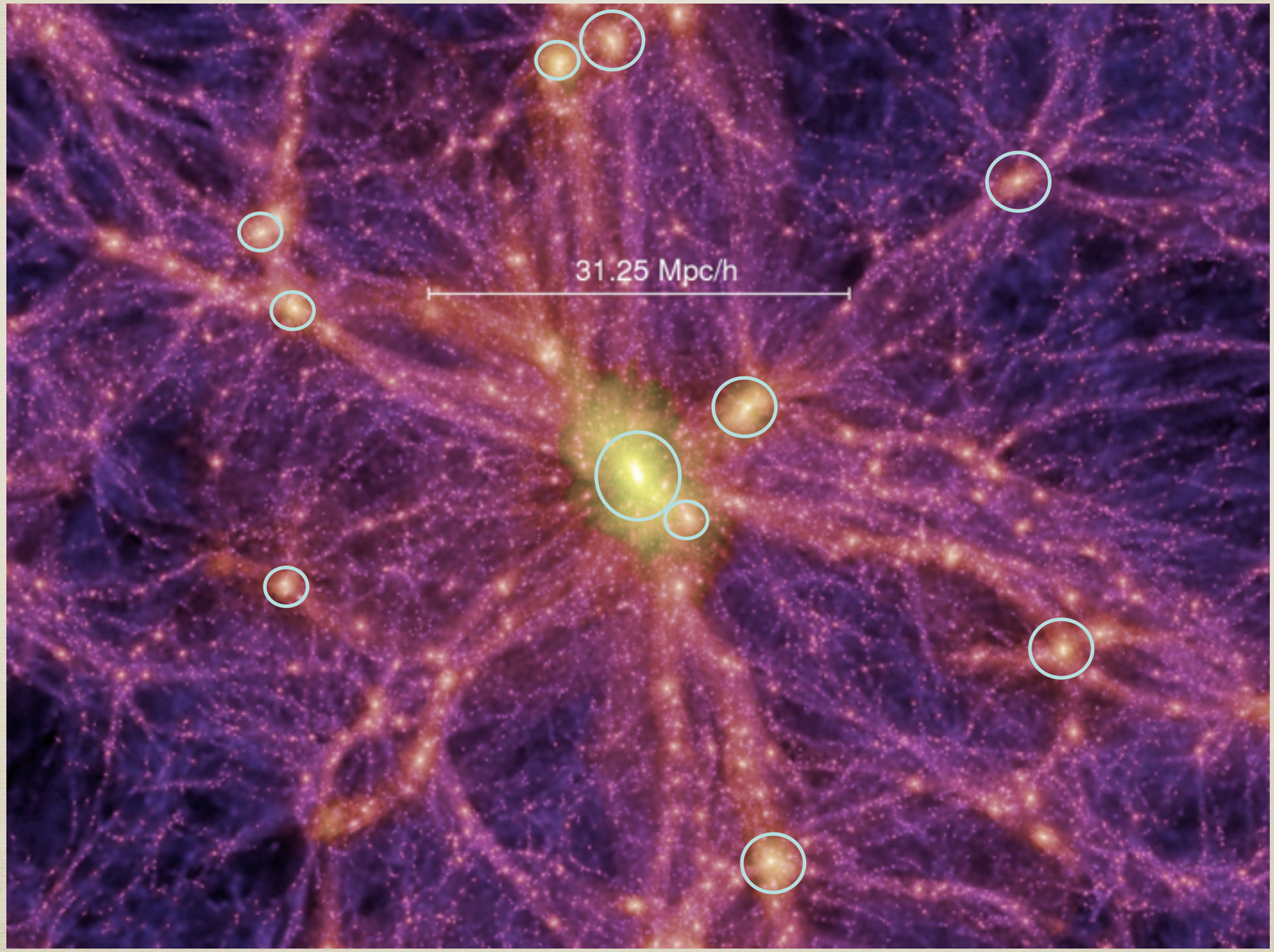
Peter Behroozi, STScI
+Risa Wechsler, Hao-Yi Wu, Lauren Anderson, Fabio Governato
ICTP, 5/14/15

What's a Halo Finder?



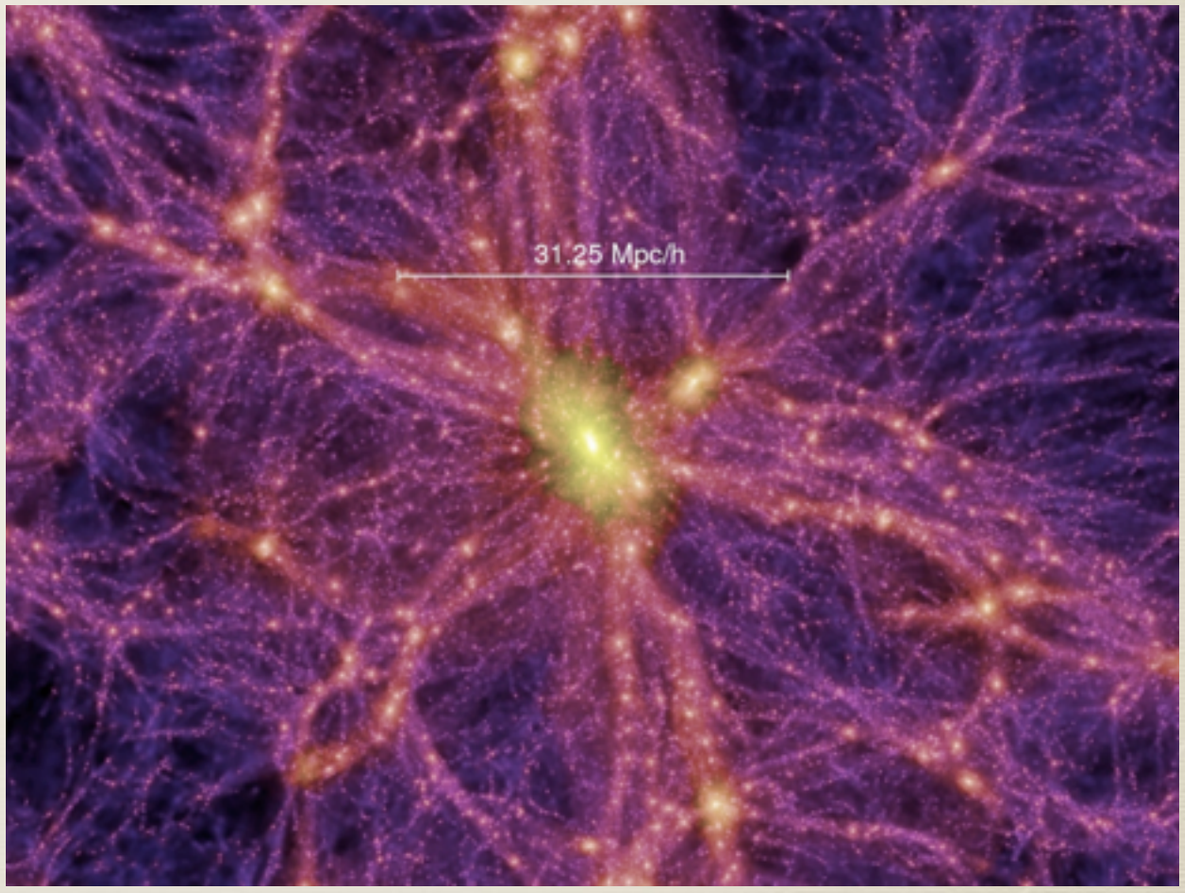
Springel et al. (2005)

What's a Halo Finder?



Springel et al. (2005)

Where does it fit in?



Springel et al. (2005),
Klypin et al. (2011),
...

N-Body Simulations

Lambda CDM

Where does it fit in?

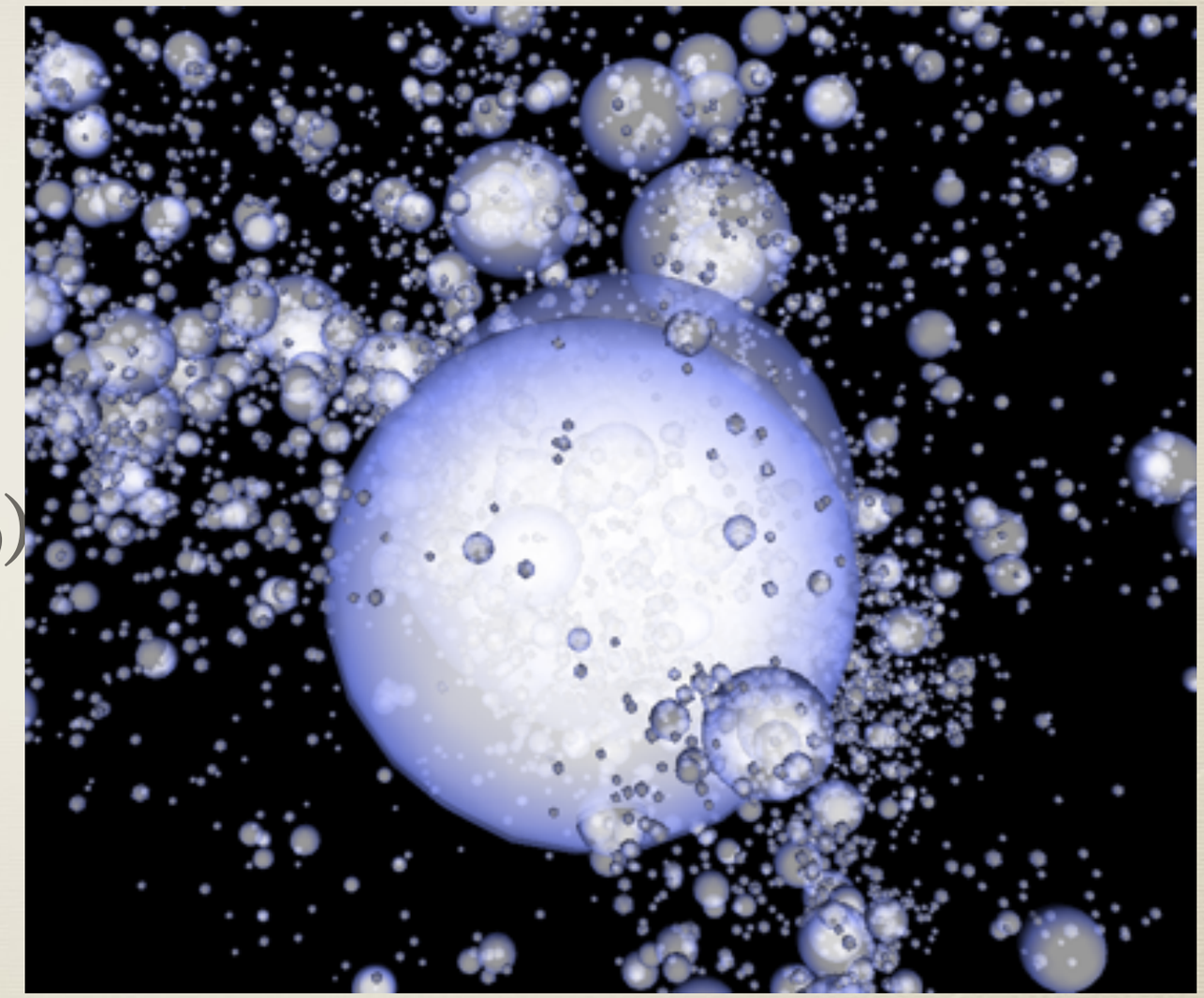
Behroozi et al. (2013a,b),
Knollmann & Knebe (2009)

...

Halos + Merger Trees

N-Body Simulations

Lambda CDM



Where does it fit in?

Conroy et al. (2006),
Behroozi et al. (2010),
Moster et al. (2010),
...

Galaxies

Halos + Merger Trees

N-Body Simulations

Lambda CDM

Credit: M101, Robert Gendler

Where does it fit in?

Conroy & Wechsler (2008),
Behroozi et al. (2013c,d),
Moster et al. (2013),
...

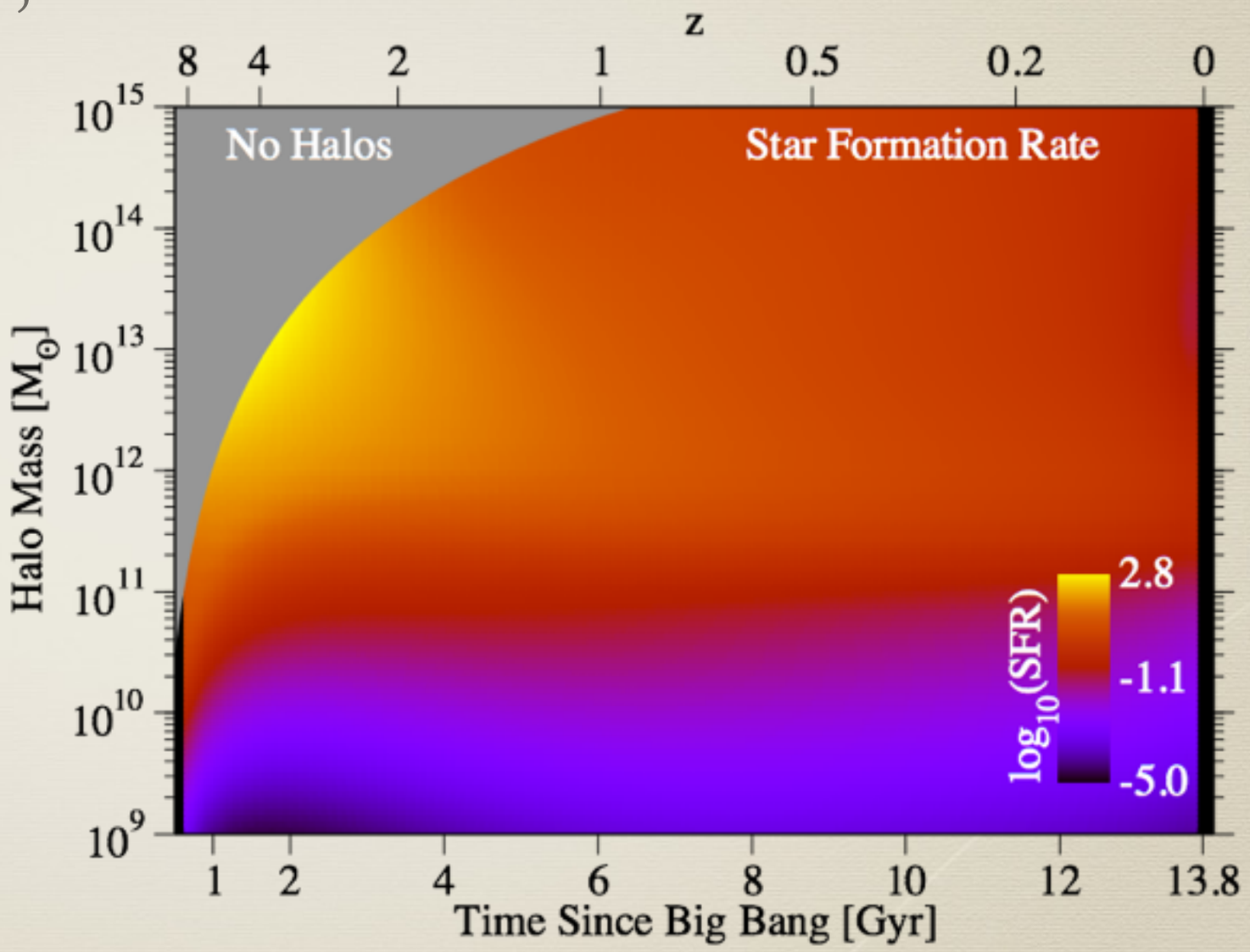
Star Formation

Galaxies

Halos + Merger Trees

N-Body Simulations

Lambda CDM



Where does it fit in?

Star Formation

Galaxies

Halos + Merger Trees

N-Body Simulations

Lambda CDM

Gas (Cold and Hot) Popping, PB+ (2015)

Metals / Outflows Peeples, PB+ (prep.)

Quenching PB, Zhu+ (2015)

Black Hole Growth PB, Silk+ (prep.)

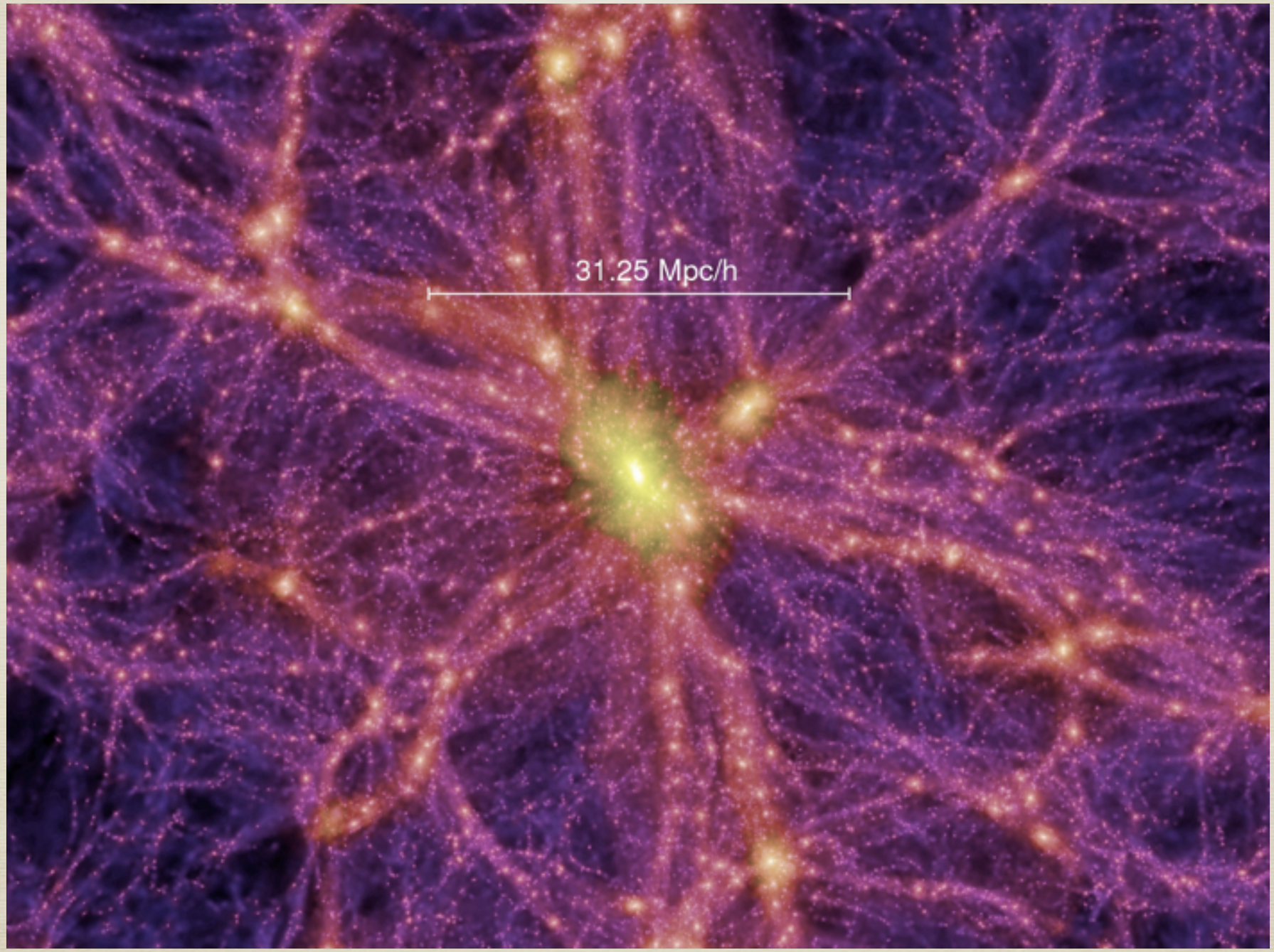
BH Merger Rates Watson, PB+ (prep.)

Supernovae Hosts PB+ (prep.)

GRB Hosts PB, R-Ruiz+ (2014)

Planets PB, Peeples (2015)

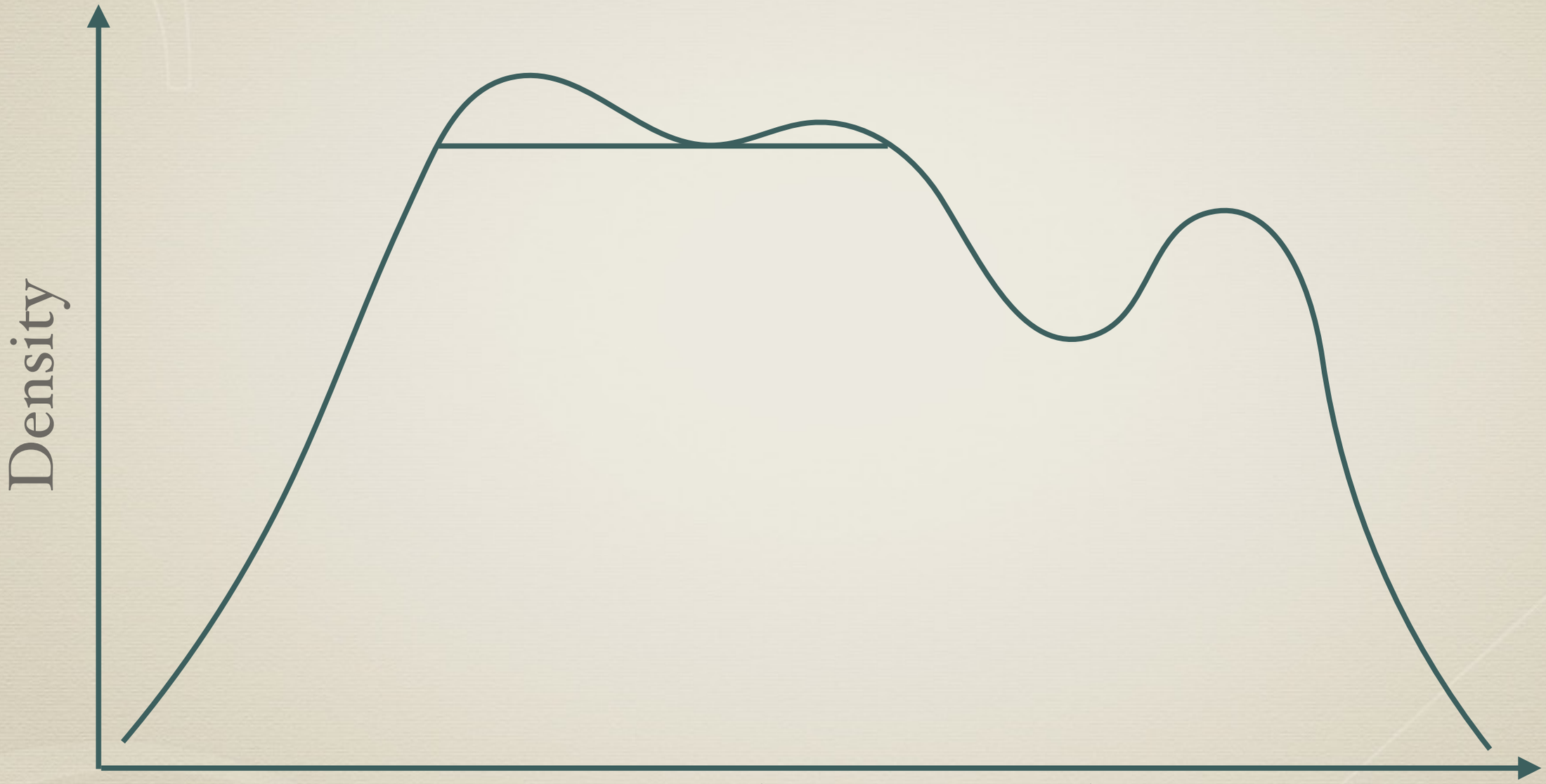
Structure Classification



Watershed Theory

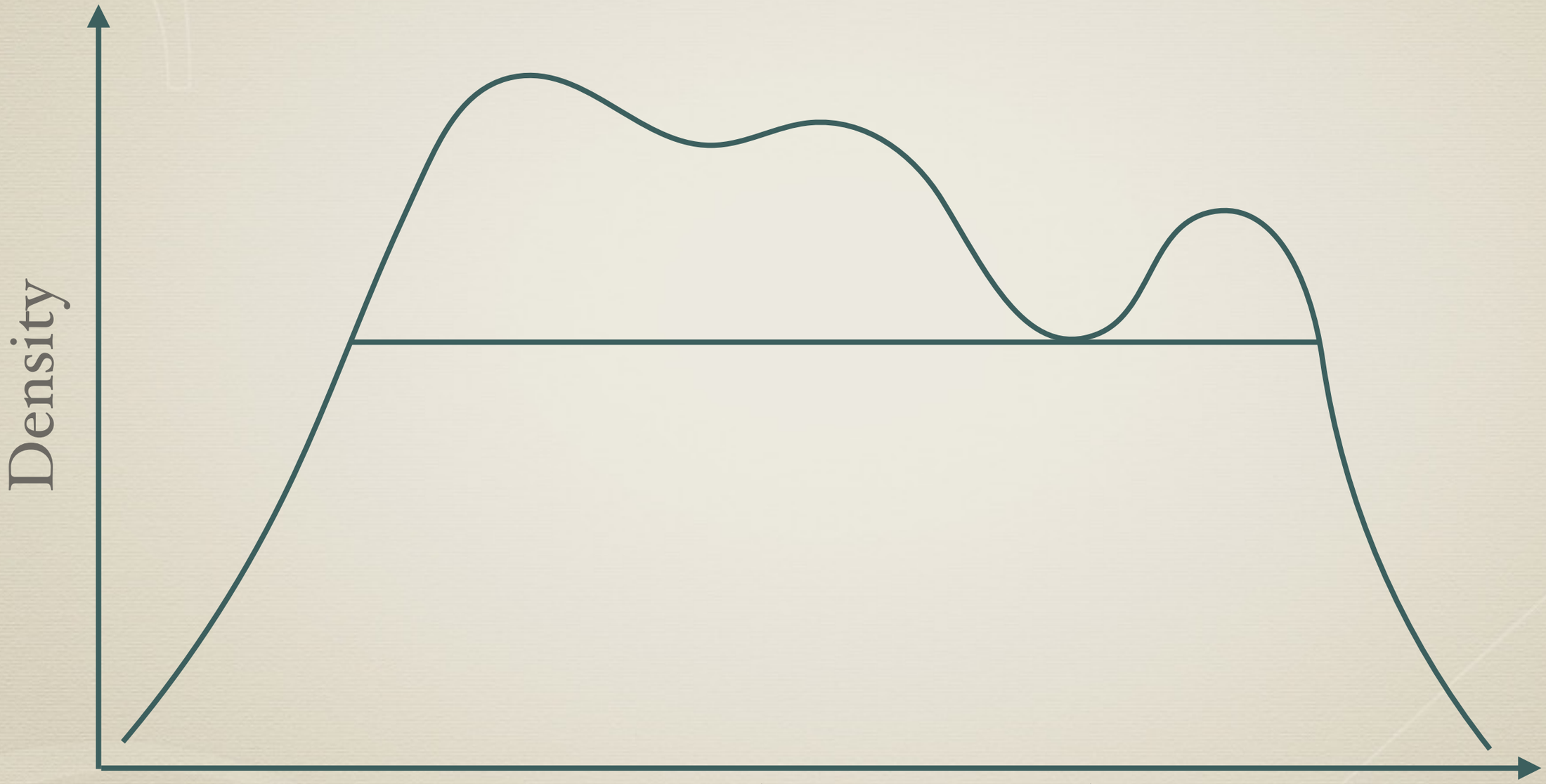
For Halos

Watershed Theory



For Halos

Watershed Theory



For Halos

Watershed Theory

For Halos

Rockstar

Robust Overdensity Calculation using K-Space Topologically Adaptive Refinement

Rockstar

Robust Overdensity Calculation using K-Space Topologically Adaptive Refinement

Freely Available

http://www.peterbehroozi.com/code.html

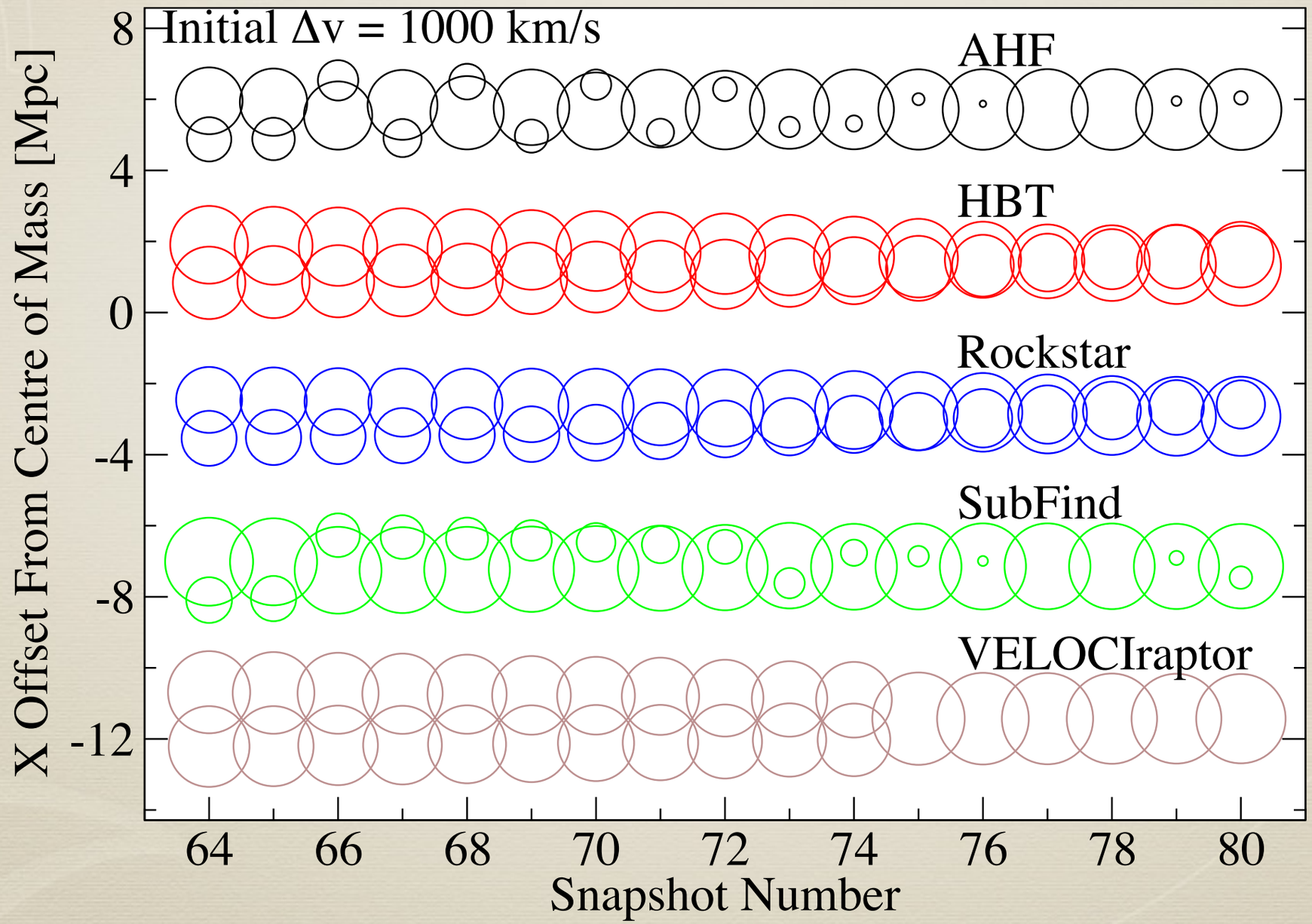
Fast, Memory Efficient

Small fraction of simulation runtime; massively parallel

Phase Space+Time (7D), Accurate & Consistent Recovery

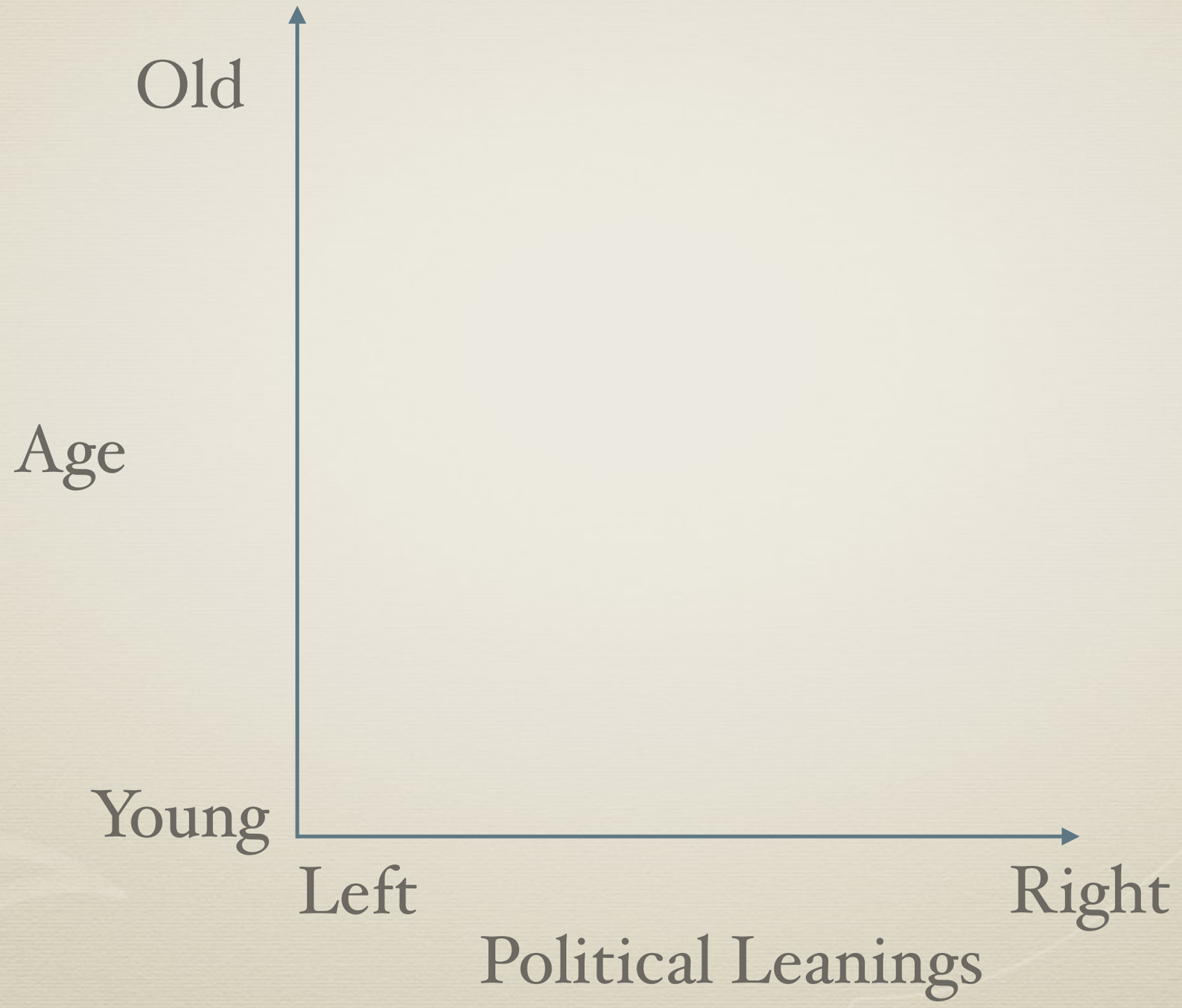
PB, Wechsler, Wu (2013)
Knebe+ (2011, 2013), Onions+ (2012,2013), Srisawat+ (2013), ...

Why Phase-Space?



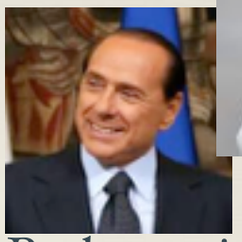
PB, Knebe, et al. in prep.

How to Find Structures?



How to Find Structures?


Francis


Berlusconi


Benedict XVI

Old

Age

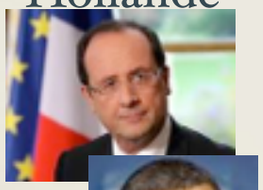
Young

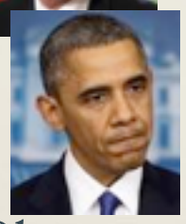
Left

Right

Political Leanings

Hollande




Obama

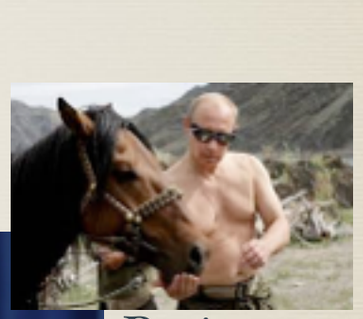

Clinton


Renzi


Merkel


Cameron

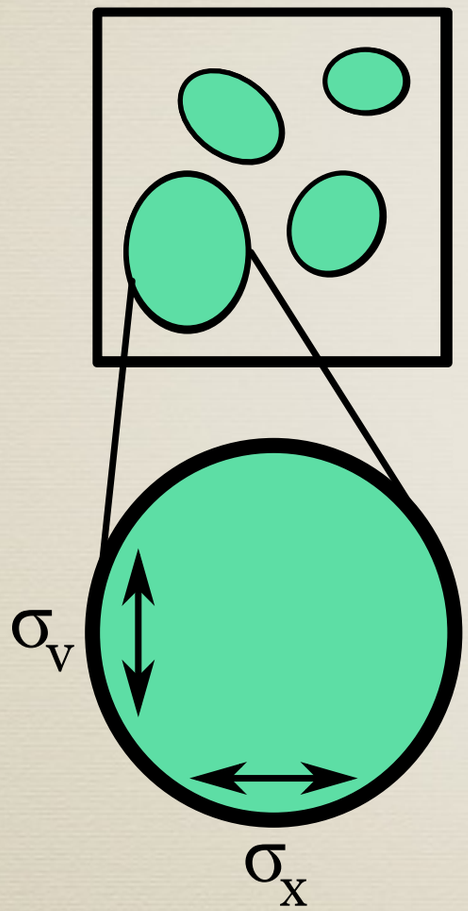

Abe


Putin


Kim

Rockstar

Robust Overdensity Calculation using K-Space Topologically Adaptive Refinement



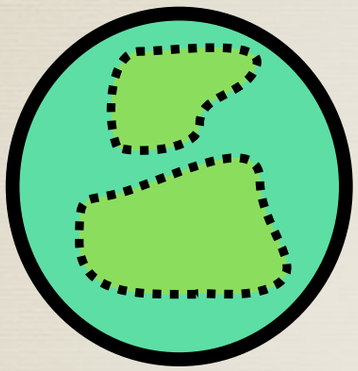
The simulation is divided into FOFs for easy parallelization.

For each group, particle positions and velocities are normalized by the group position and velocity dispersions, giving a natural phase-space metric.

Behroozi, Wechsler, Wu (2013)

Rockstar

Robust Overdensity Calculation using K-Space Topologically Adaptive Refinement

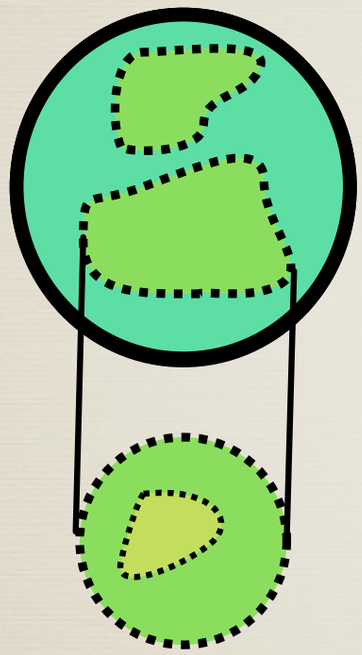


A phase space linking length is chosen adaptively such that 70% of the group's particles are linked together.

Behroozi, Wechsler, Wu (2013)

Rockstar

Robust Overdensity Calculation using K-Space Topologically Adaptive Refinement



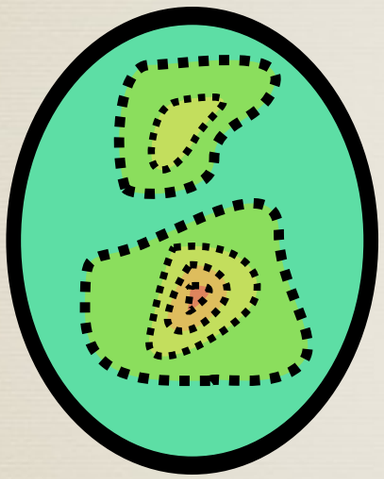
A phase space linking length is chosen adaptively such that 70% of the group's particles are linked together.

The process repeats for each subgroup: renormalization, a new linking length, and a new substructure level calculated.

Behroozi, Wechsler, Wu (2013)

Rockstar

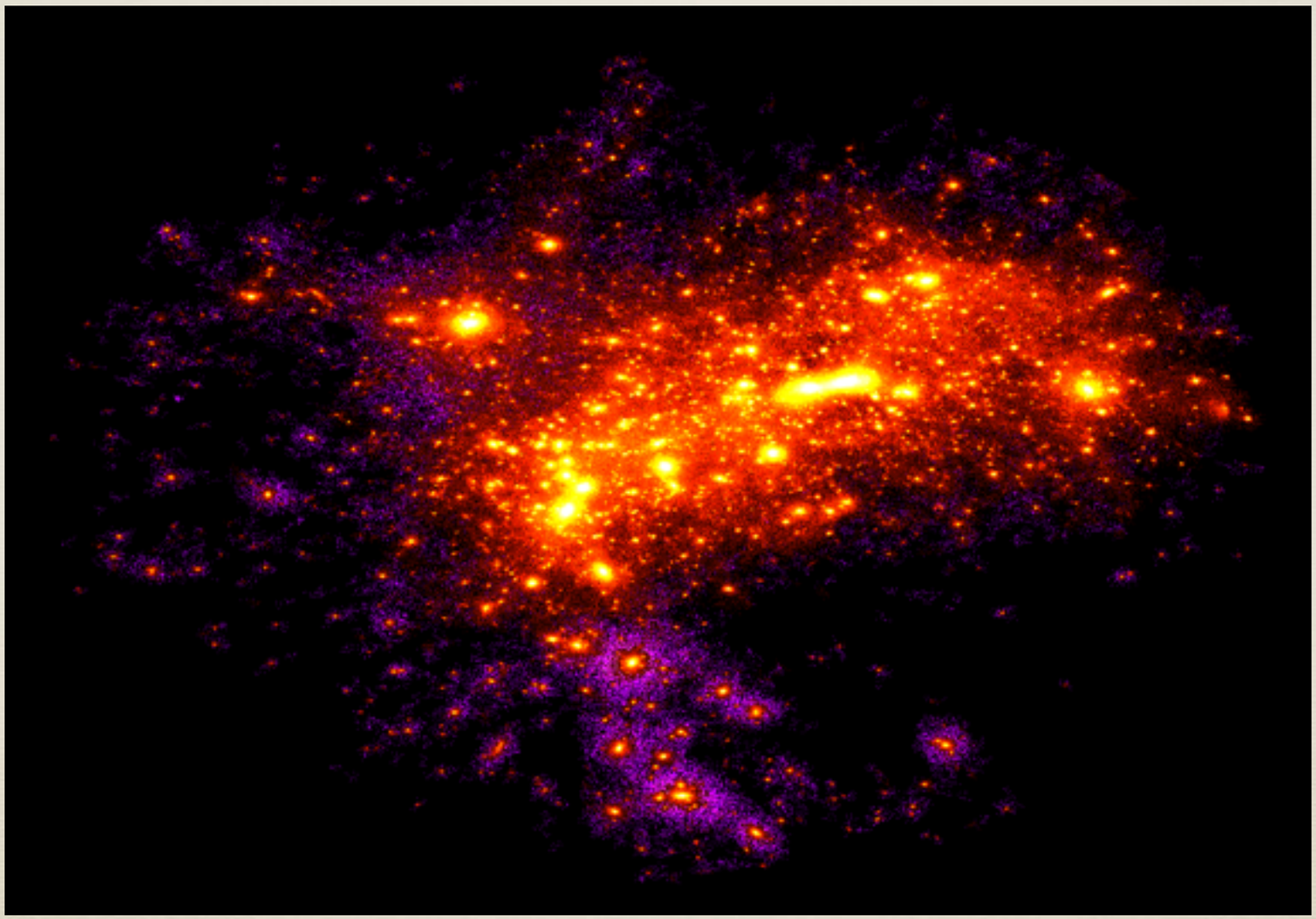
Robust Overdensity Calculation using K-Space Topologically Adaptive Refinement



Once all levels of substructure are found, seed halos are placed at the deepest substructure levels and particles are assigned hierarchically to the closest seed halo in phase space.

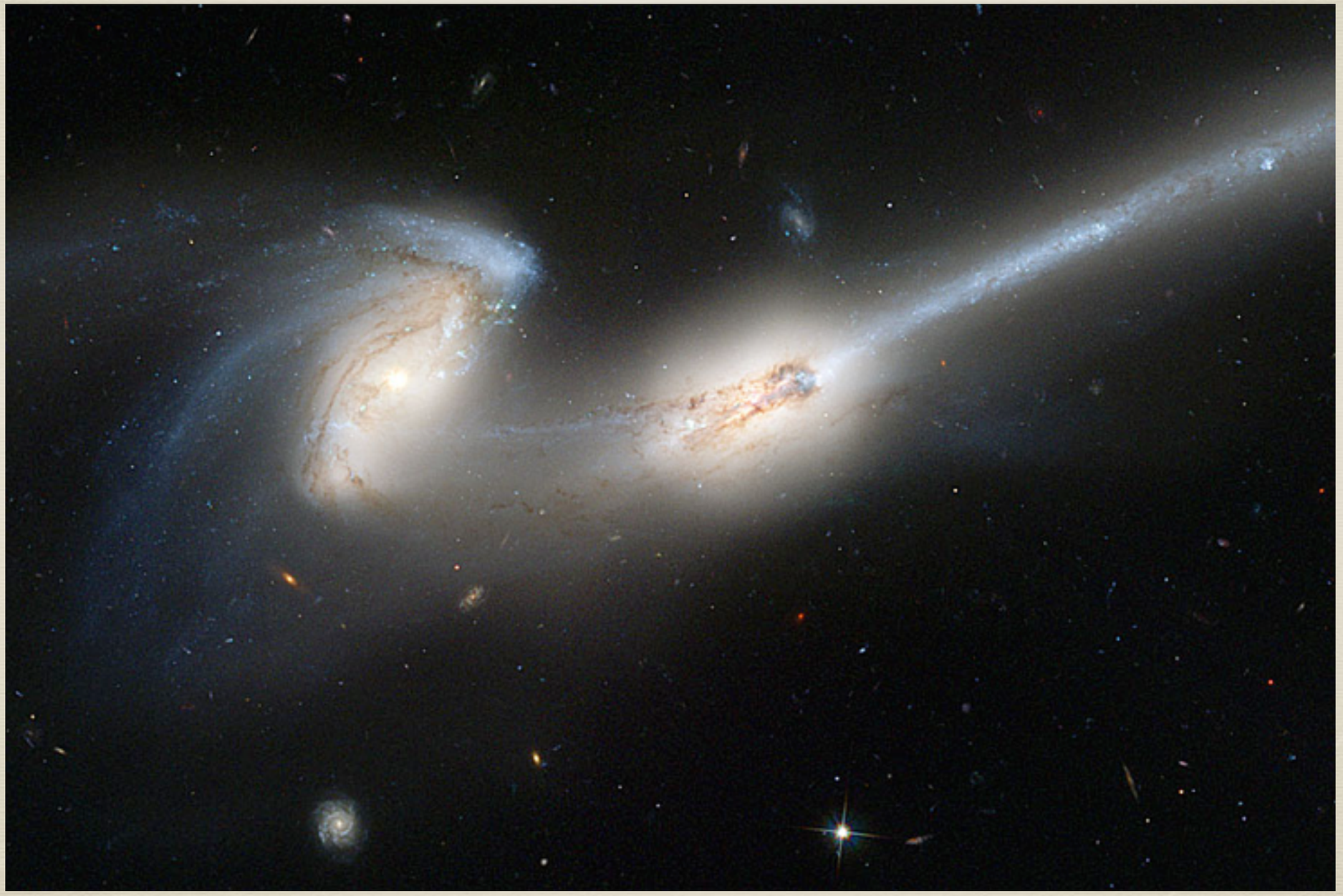
Behroozi, Wechsler, Wu (2013)

How does it work?



Behroozi, Wechsler, Wu (2013)

Next Frontier



Credit: NGC 4676; NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M.Clampin (STScI),
G. Hartig (STScI), the ACS Science Team, and ESA

Automated Classification of Galaxies in Simulations

Next Frontier

Credit: M101, Robert Gendler

Automated Classification of Galaxies in Simulations

Watershed Theory

For Spiral Galaxies

Watershed Theory

For Spiral Galaxies

Summary

Using Position + Velocity information improves stability of halo classification

Rockstar Algorithm can be applied to find hierarchical structure in arbitrary-dimensional spaces

Future applications to merging galaxies for IFU observations

`http://code.google.com/p/rockstar`