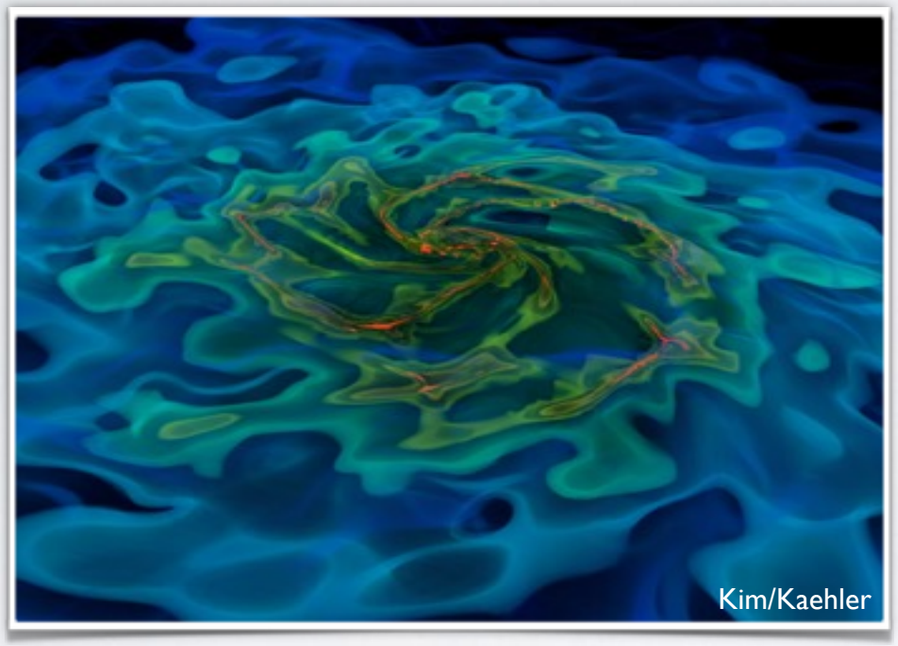
Upcoming New Era in Numerical Galaxy Formation:

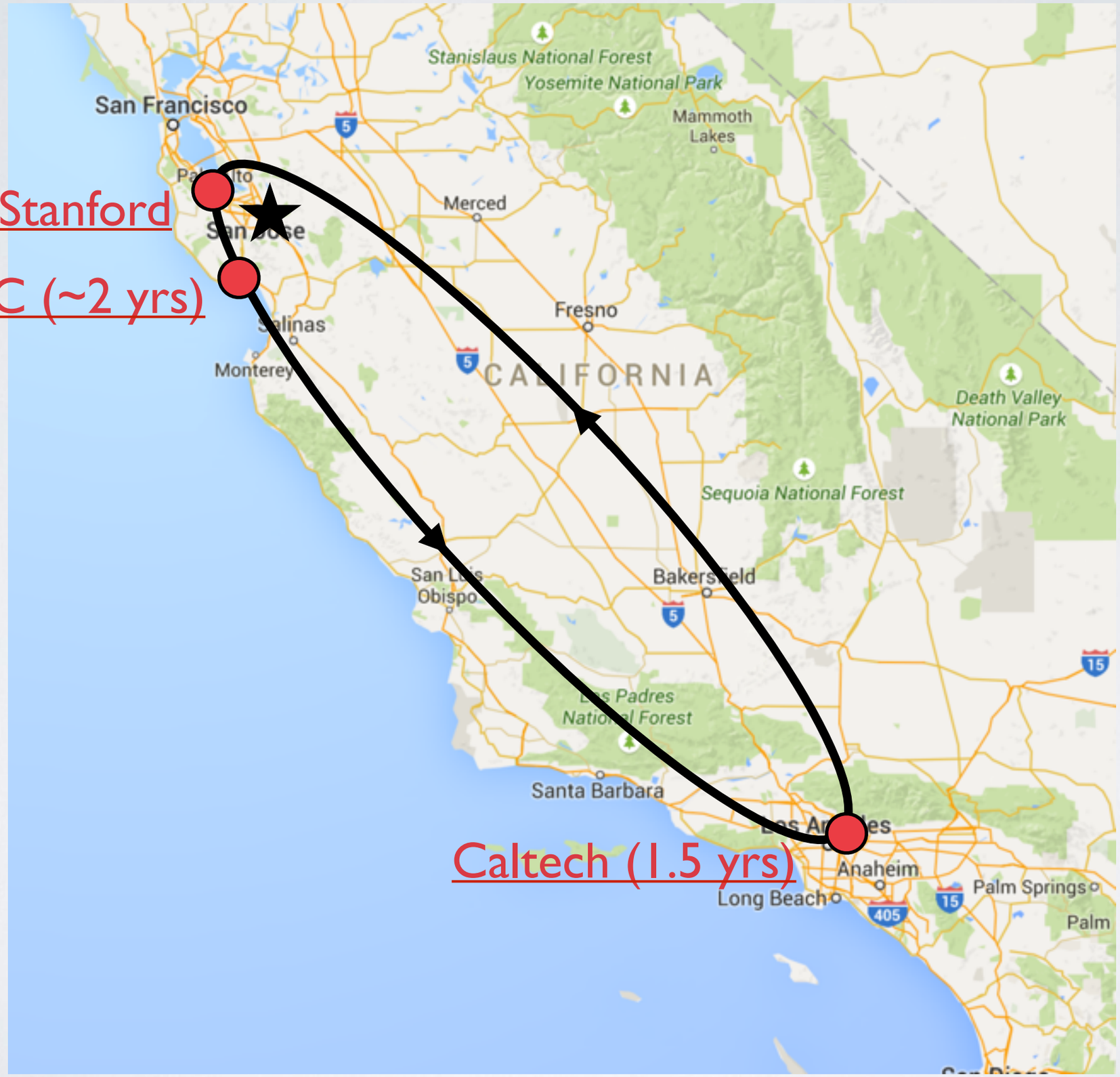
New Possibilities and Challenges



Ji-hoon Kim (SLAC/Stanford University)

Mentors: T. Abel (Stanford), P. Hopkins (Caltech), M. Krumholz, J. Primack (UCSC)

The Orbit


Stanford
UCSC (~2 yrs)
Caltech (1.5 yrs)
San Francisco
Stanislaus National Forest
Yosemite National Park
Mammoth Lakes
Merced
Fresno
Monterey
CALIFORNIA
Death Valley National Park
Sequoia National Forest
Bakersfield
Santa Barbara
Anaheim
Long Beach
Palm Springs
Palm
5
15
405

Upcoming New Era in Numerical Galaxy Formation:

New Possibilities and Challenges

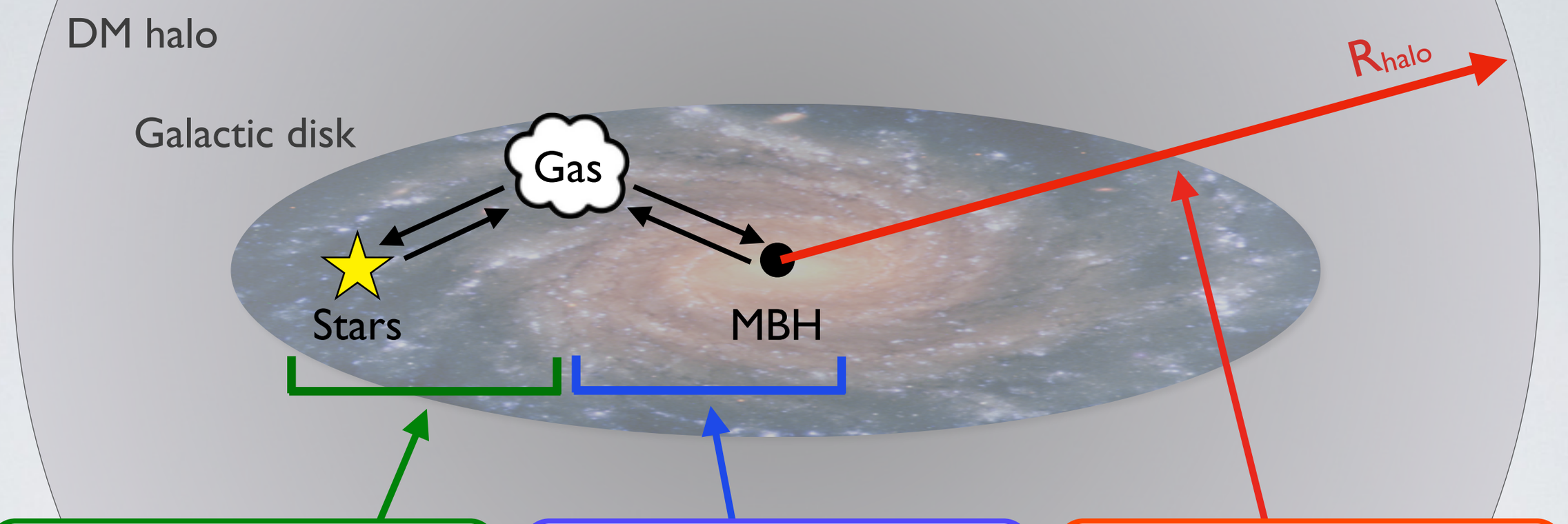
- New Possibilities:

  1. What is to come and what will be possible?

- New Challenges:

  2. What are we doing to tackle the challenges?

Galaxy Formation: Multi-scale Nonlinearity

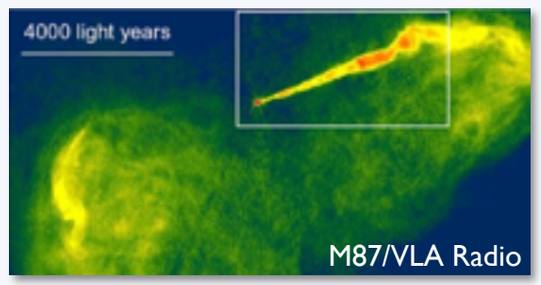


Star Cluster or GMC Formation & Feedback

$R_{GMC} \sim 10$ pc

Massive Black Hole (MBH) Accretion & Feedback

$R_{Bondi} \sim$ pc
$R_{Schw.} \sim$ AU



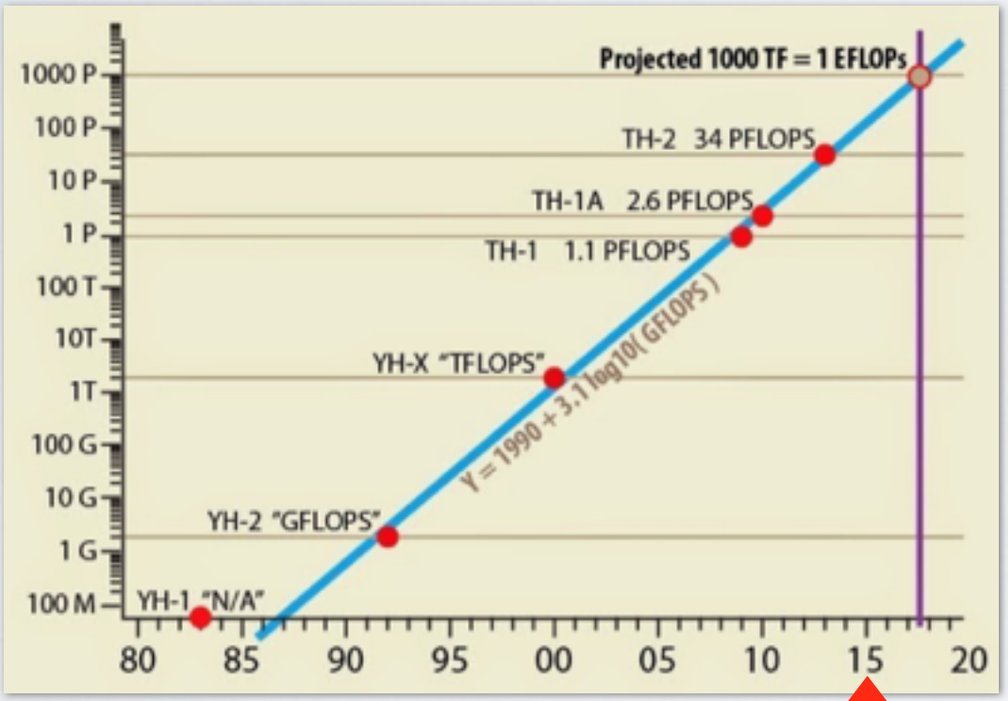
(Inter-)Galactic Dynamics & Interaction

$R_{halo} \sim 100$ kpc

Numerical Experiment: Tools

- Tools of numerical experiments have evolved exponentially

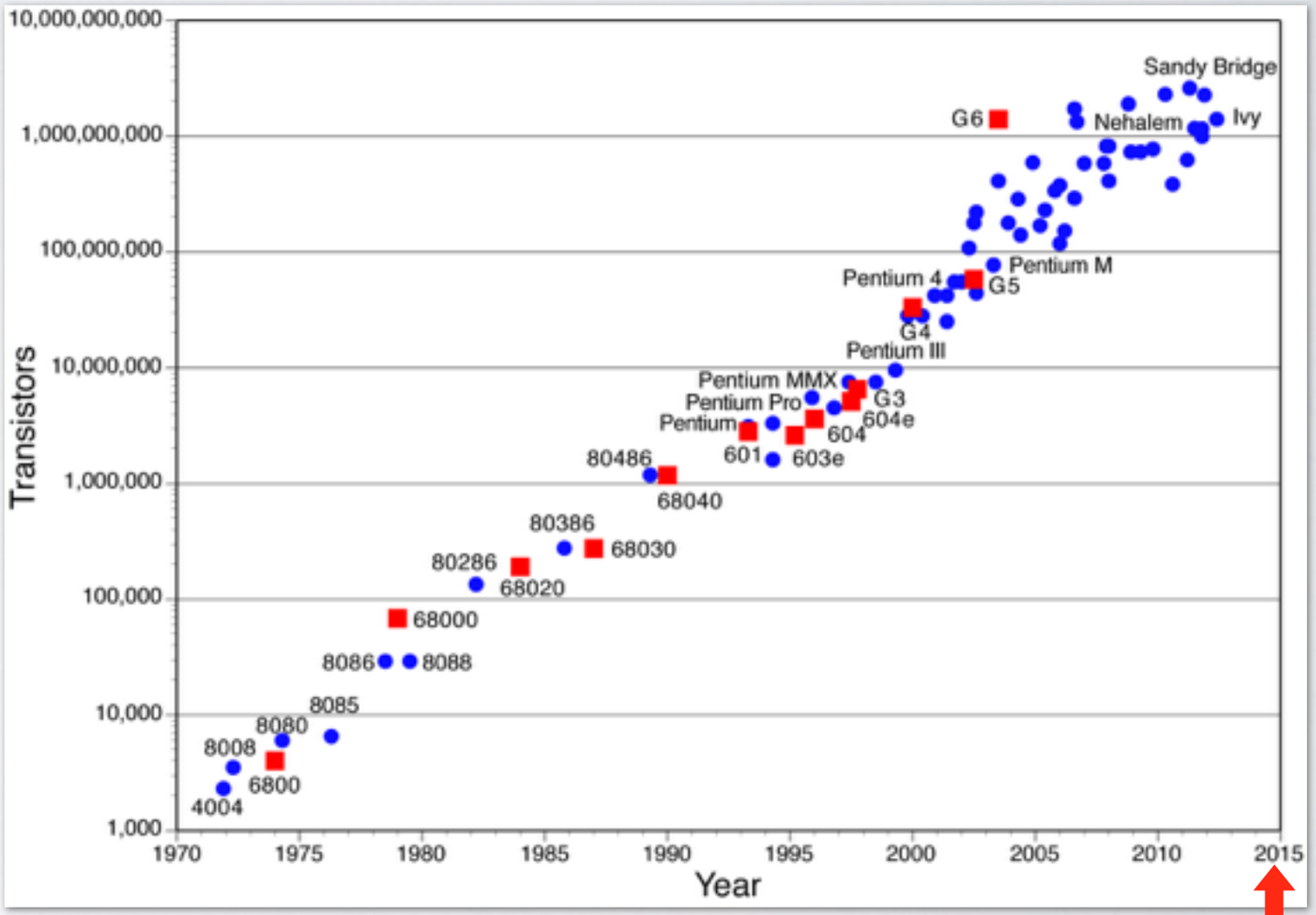
Supercomputing FLOPS vs. Year



nextbigpicture.com

2015

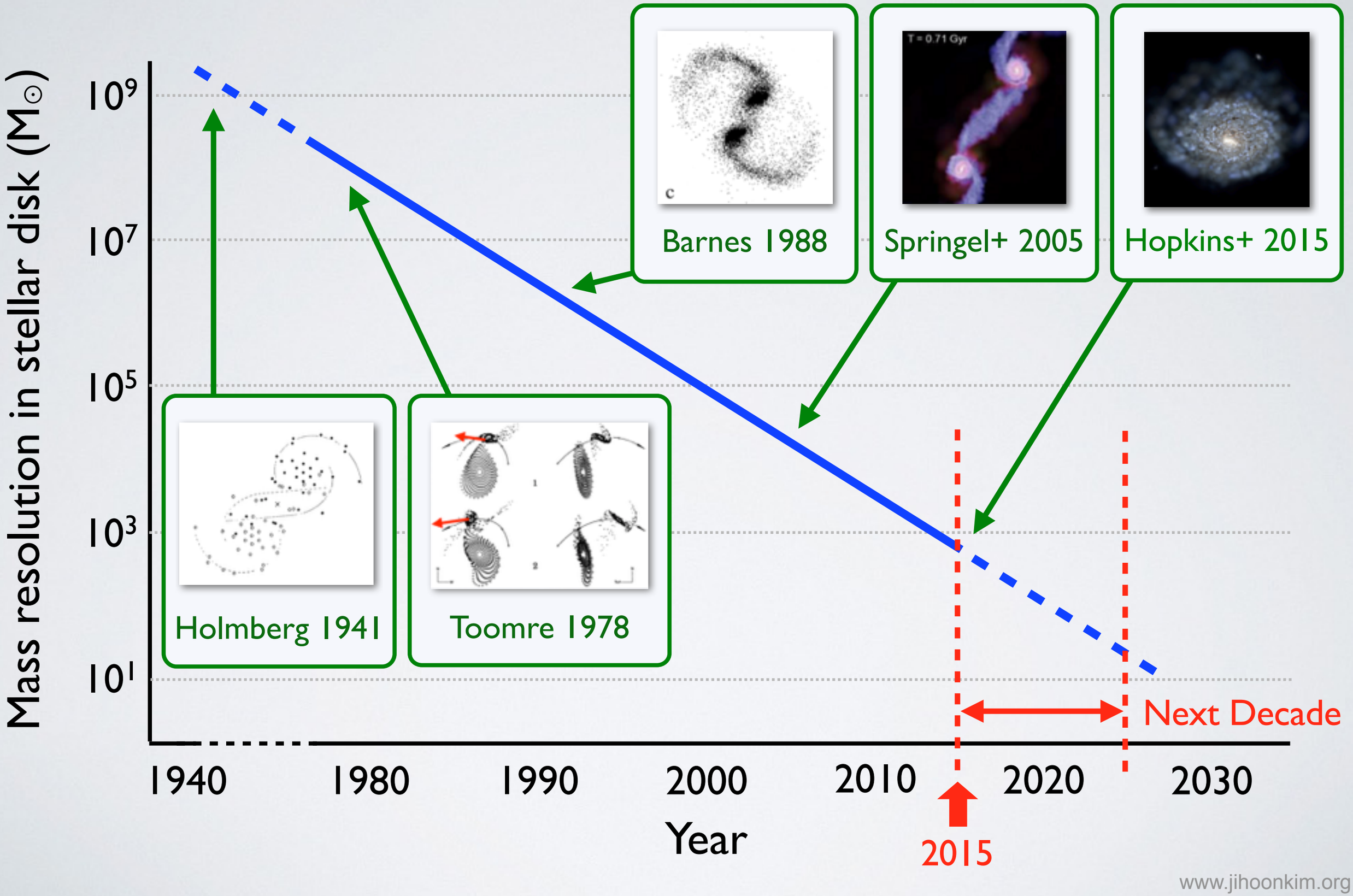
Transistor Counts on IC vs. Year



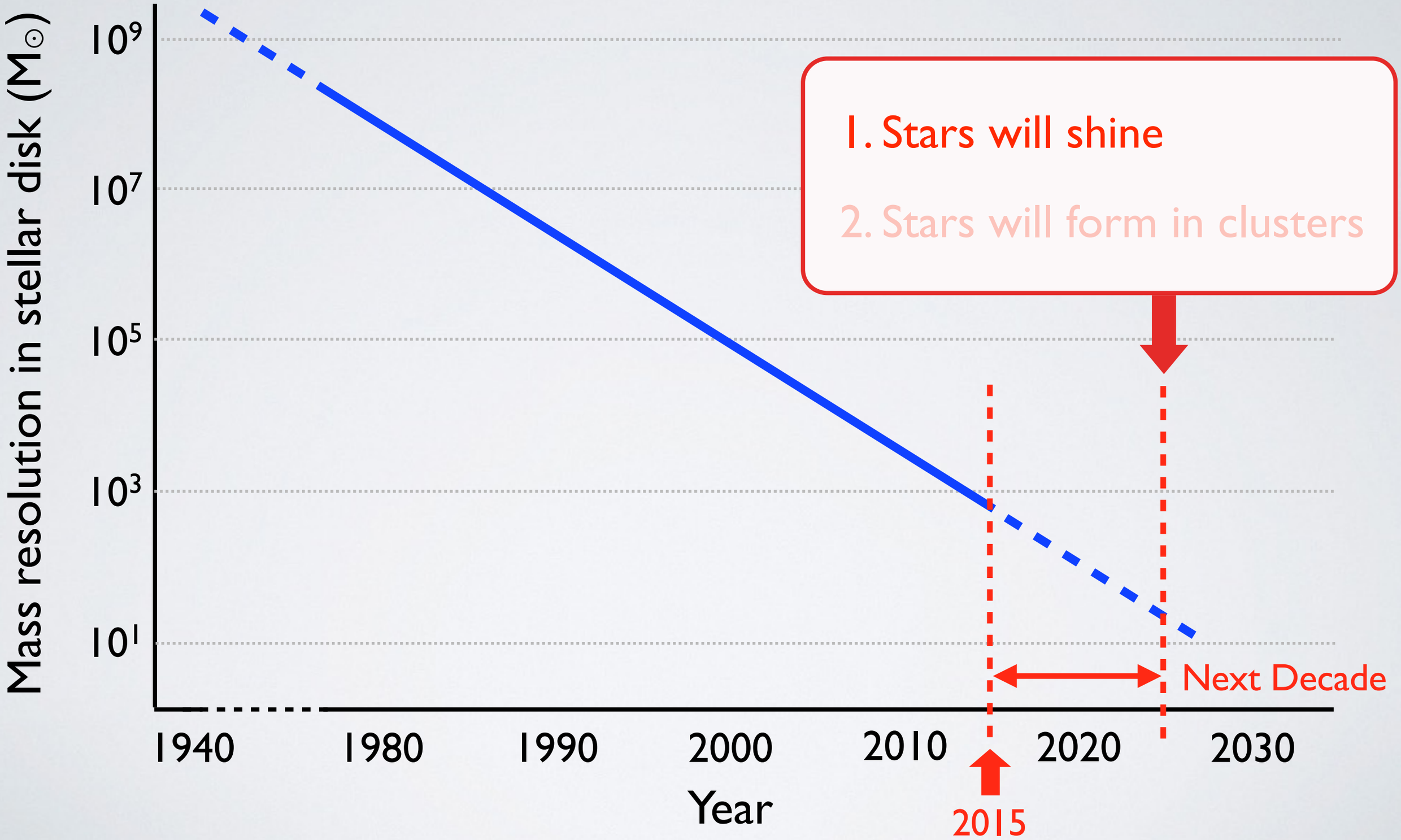
techinvestingdaily.com

2015

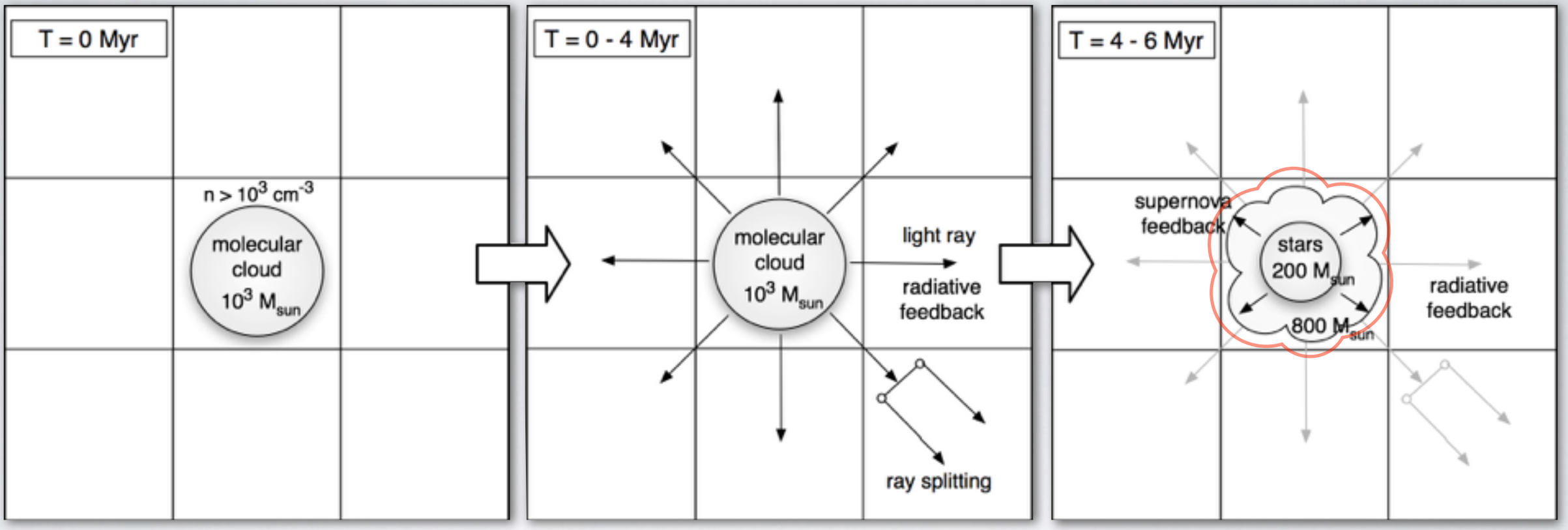
Numerical Galaxy Formation: Upcoming Era



Numerical Galaxy Formation: Upcoming Era



Stellar Feedback Resolved in Time

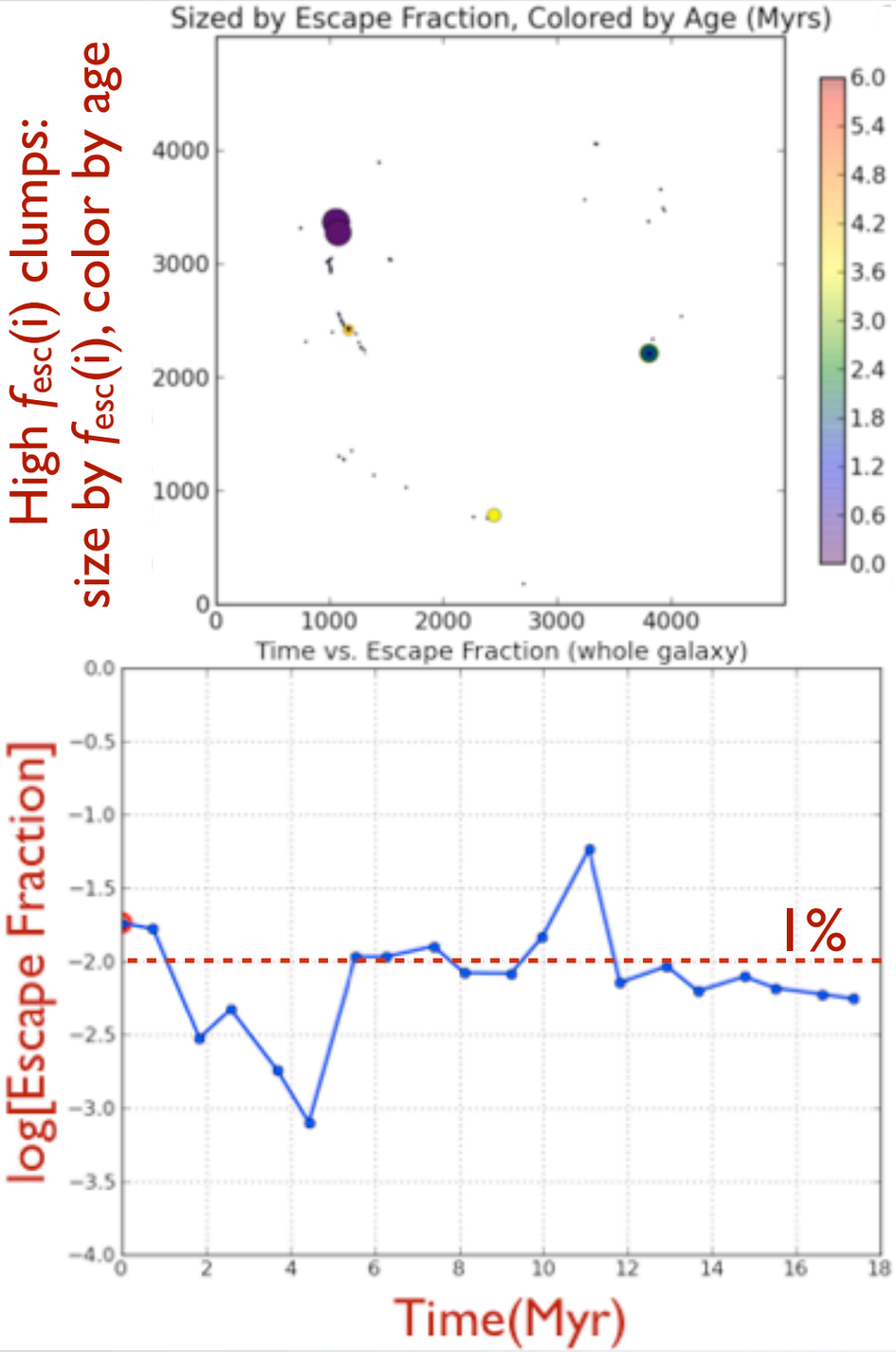


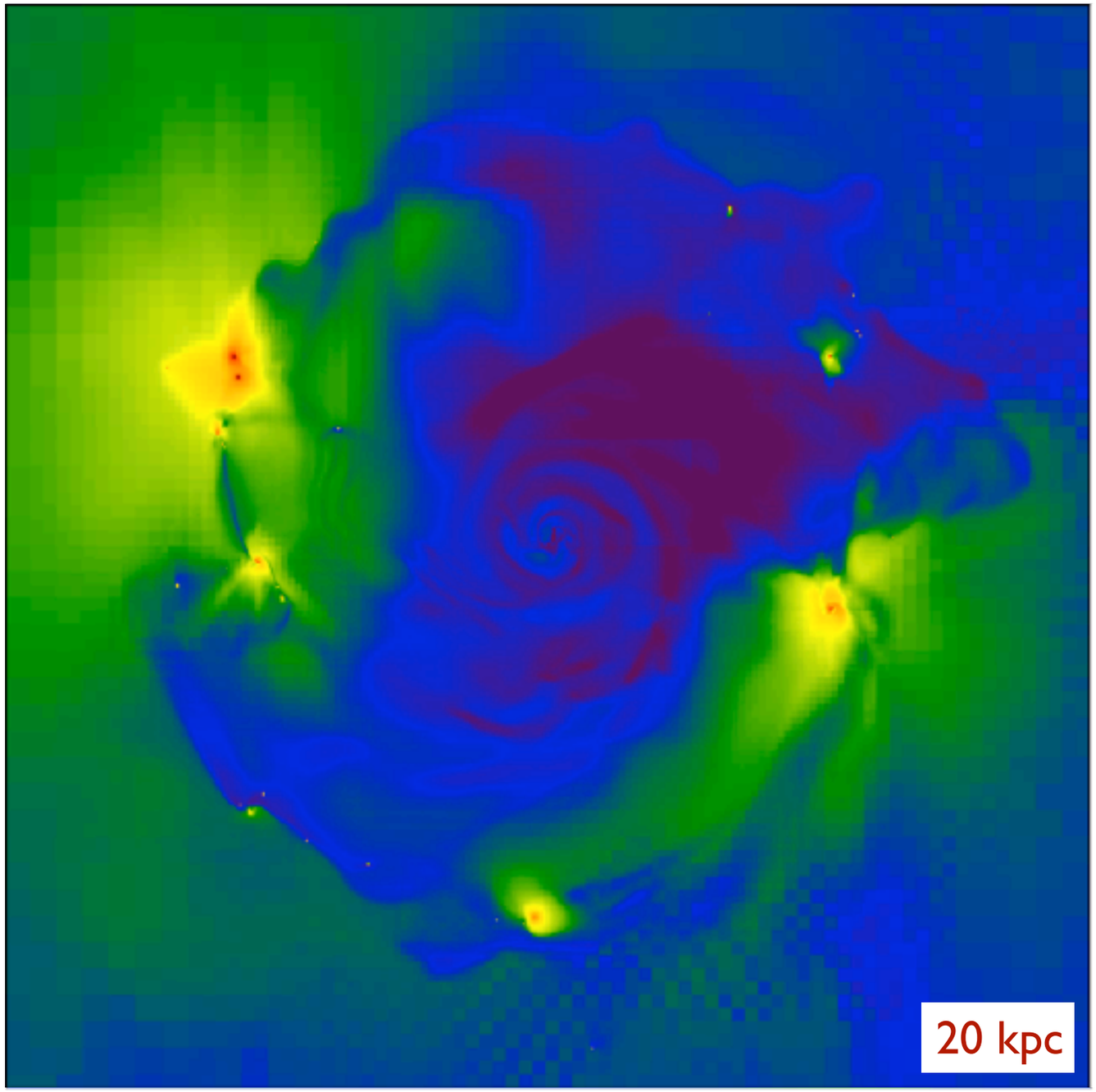
- Before the supernova goes off at T = 5 Myr, ultraviolet photons from stars (GMCs) are considered via radiation transport

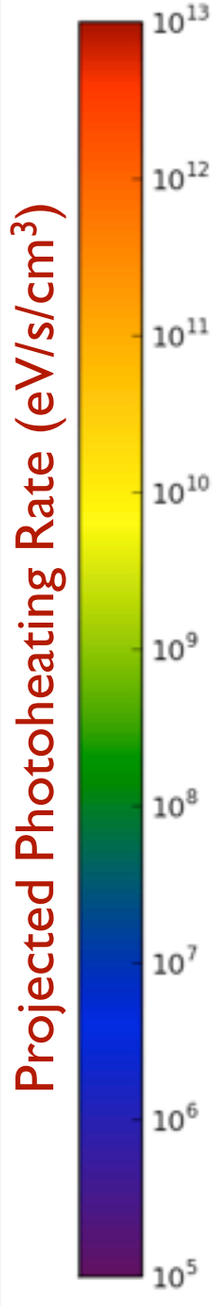
  - Photoionization + Photoheating (interacting with H, no IR radiation pressure)
  - Early stellar feedback important (e.g. Stinson et al. 2012)

Galactic Escape Fraction f_{esc}

- Galactic f_{esc} stays at around 1% with a few SCs with high f_{esc}(i)

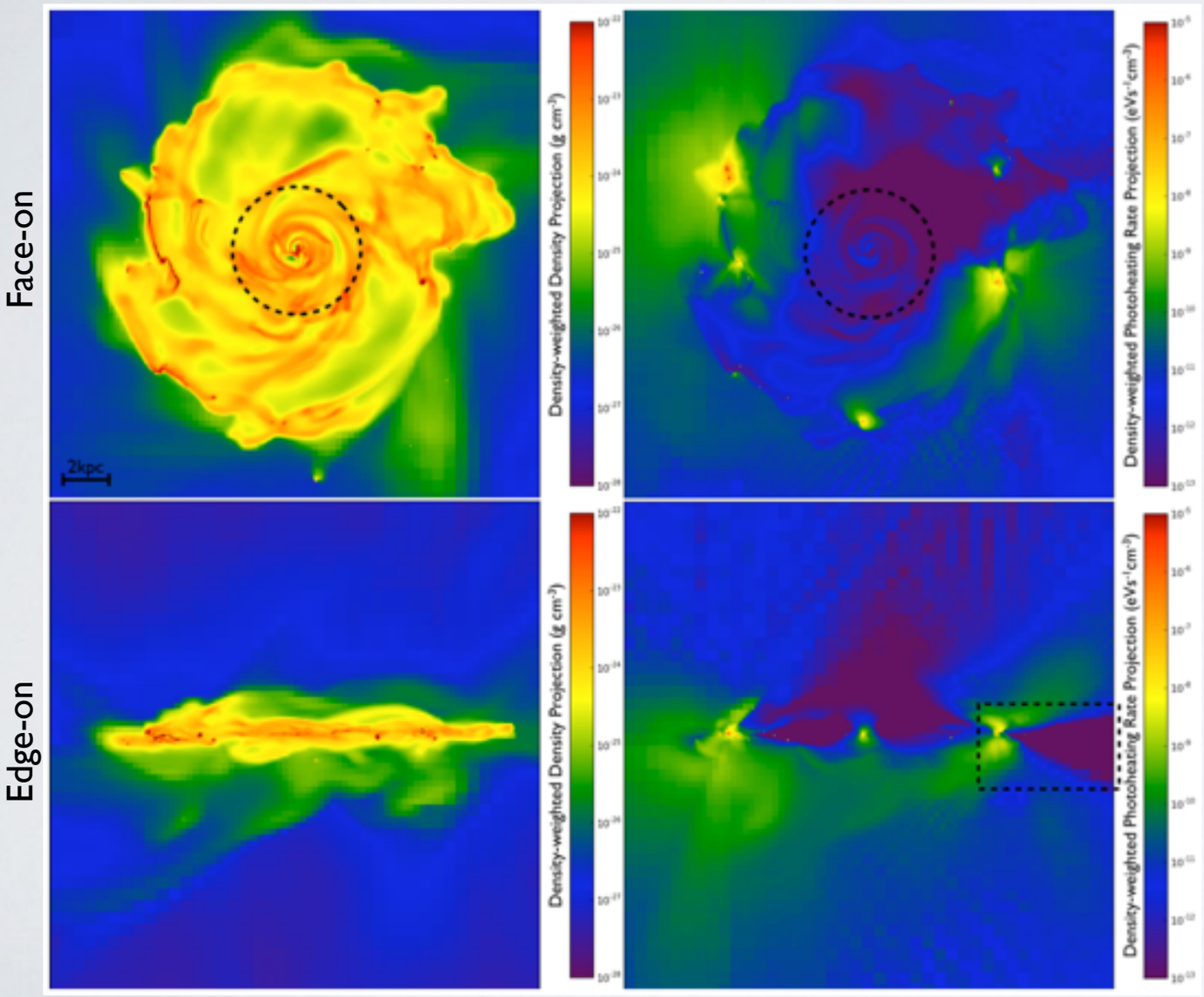




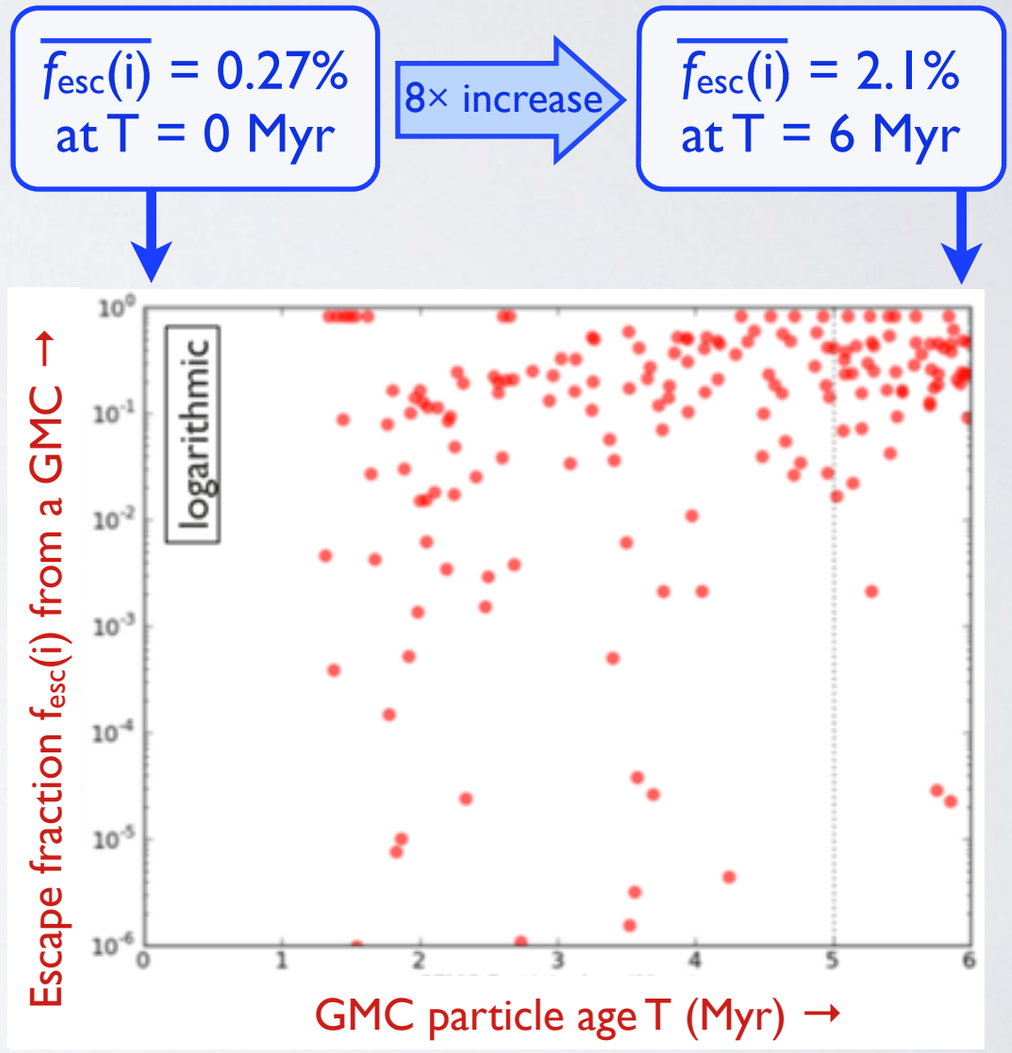


Radiating Star Clusters: Escape Fraction

- Photons escape easily from old star-forming clumps
  → old clumps dominate galactic escape fraction (Kim et al. 2013a)



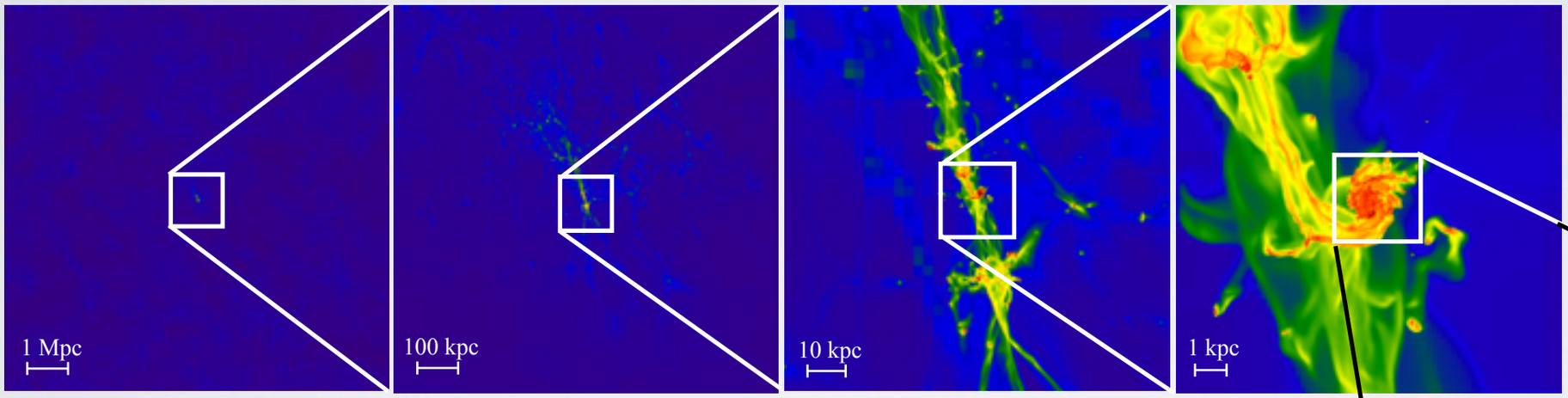
Projected density Projected photoheating rate (eV s^{-1} cm^{-3})

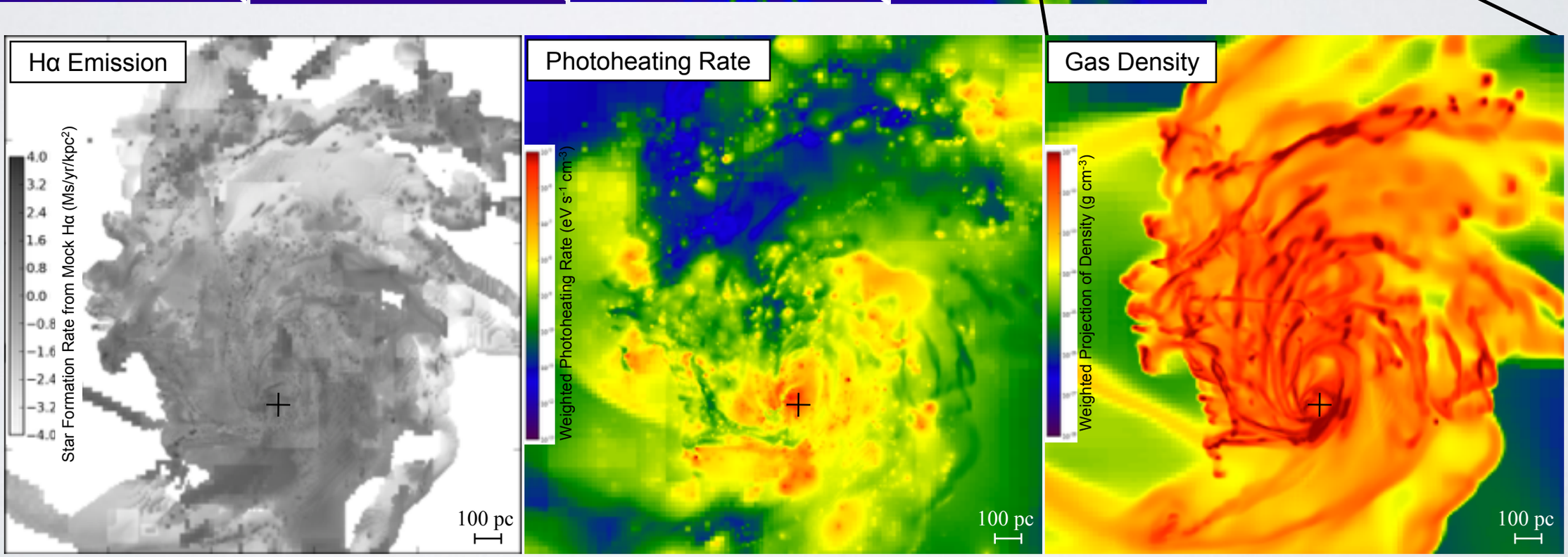


2.3×10^{11} $M_\odot$ halo, 3.8 pc resolution, ENZO. Kim et al. (2013a)

z~7 Quasar-hosts with Radiating GMCs

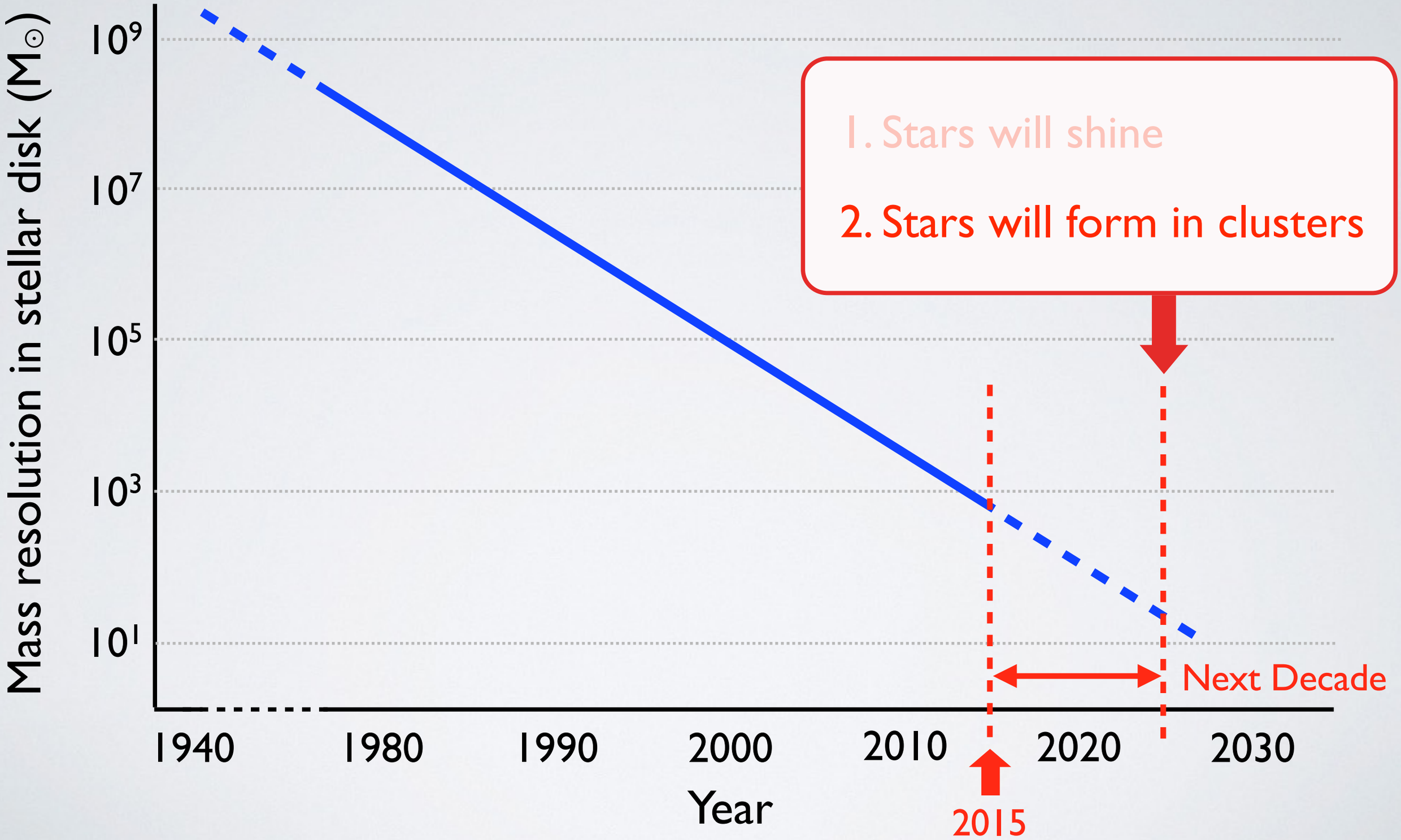
- ~10^{11} $M_\odot$ quasar-host at ~5 pc resolution (Kim et al. 2015a in prep.)





Kim et al. 2015a in prep.

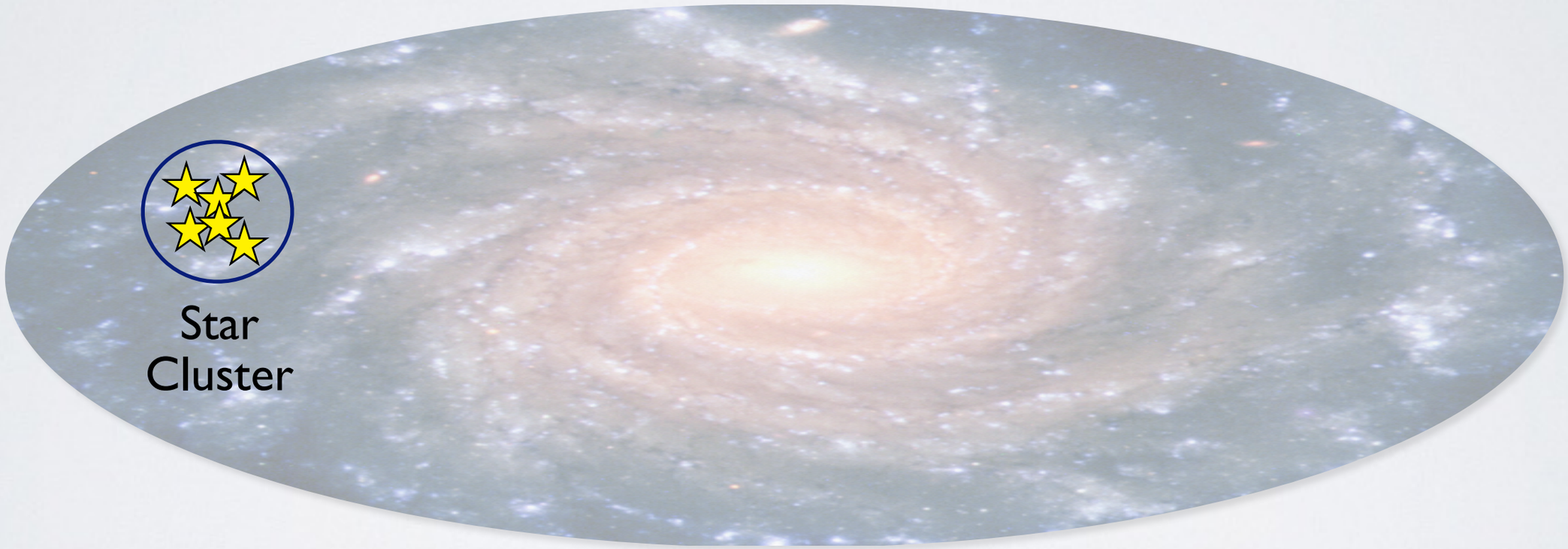
Numerical Galaxy Formation: Upcoming Era



Star Cluster Simulation in Galactic Context?

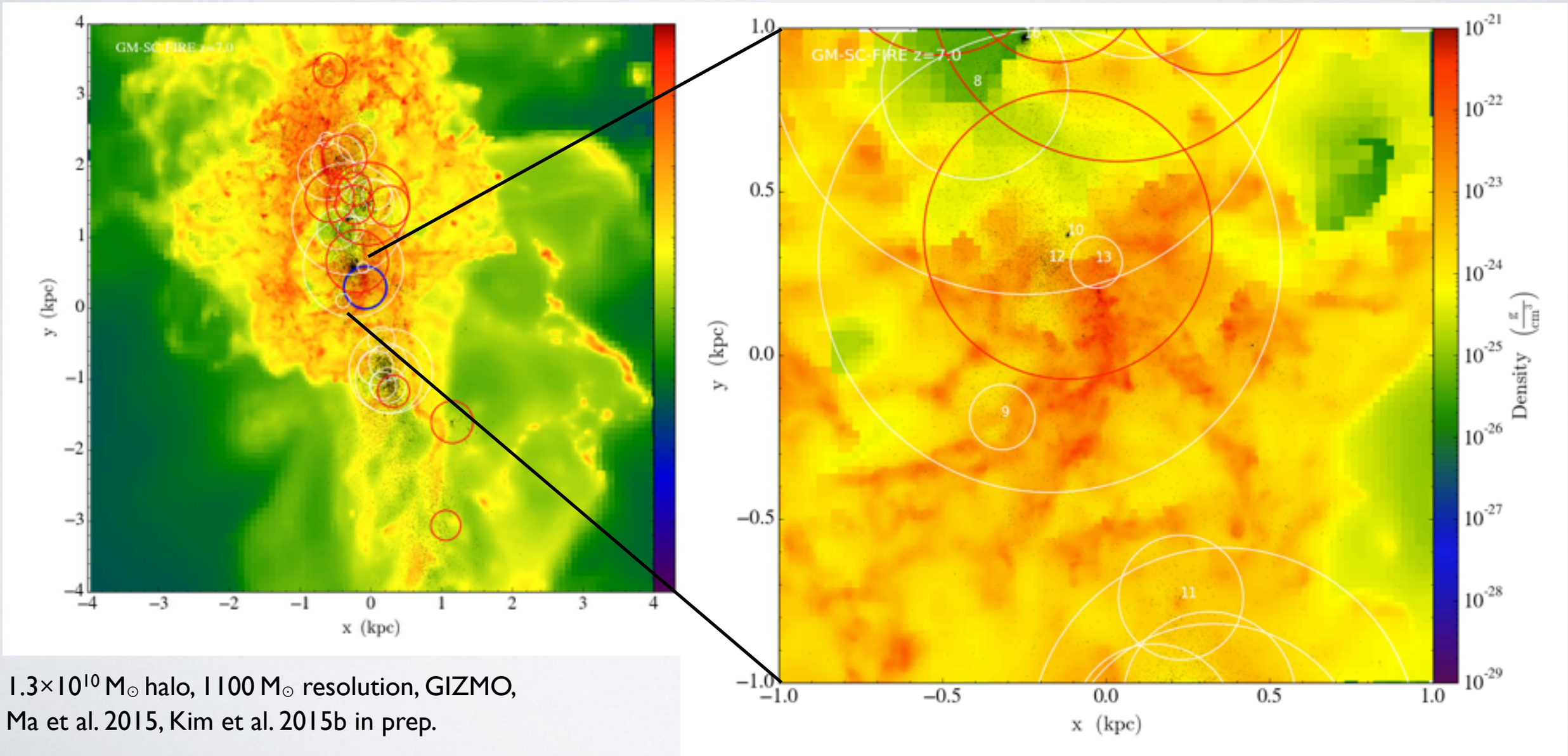
- Only with mass resolution of <~1000 $M_\odot$ can we star to properly resolve the inner dynamics of star clusters

→ challenging to accommodate in a galaxy-scale simulation



Merger-driven Star Cluster Formation

- Realistic descriptions of ISM (e.g. Hopkins et al. 2013) are keys to describe star cluster formation in high-z merging proto-galaxies

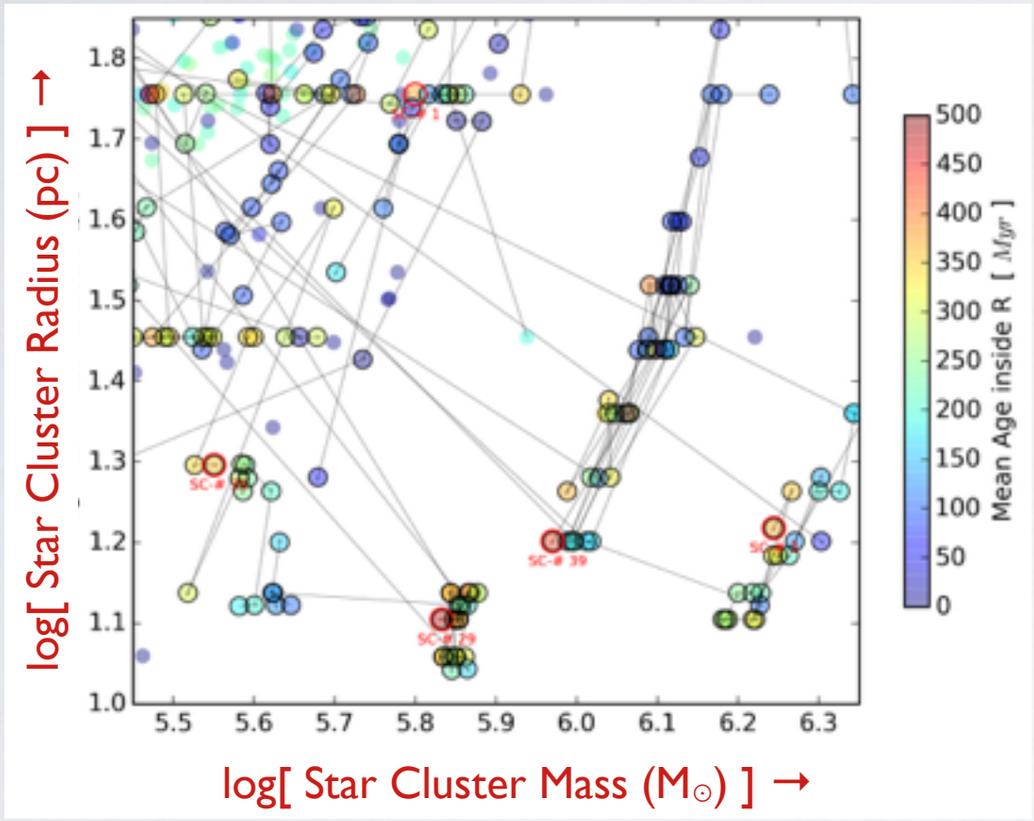


$1.3\times10^{10}\,M_\odot$ halo, 1100 $M_\odot$ resolution, GIZMO, Ma et al. 2015, Kim et al. 2015b in prep.

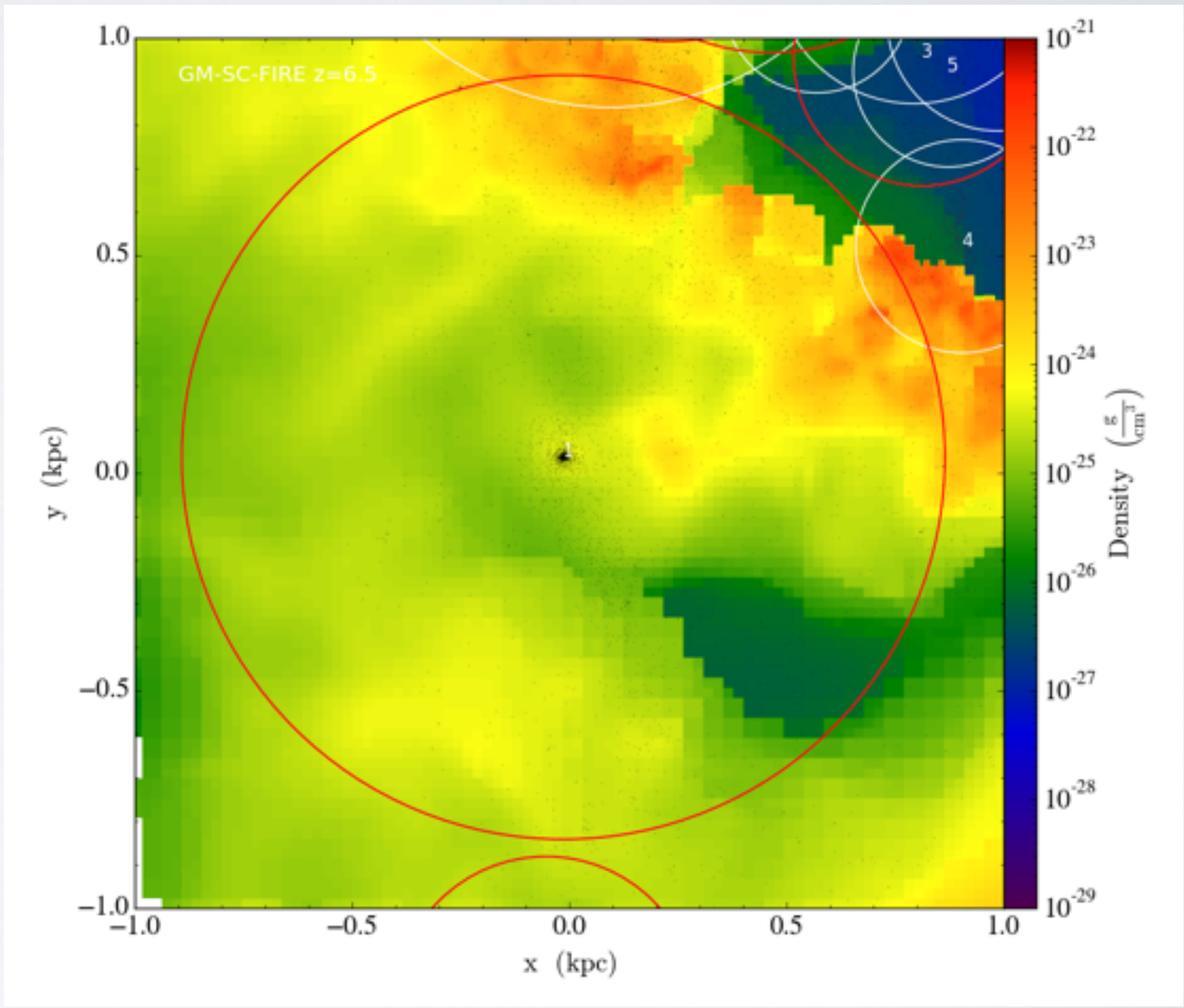
2 kpc width, density projection, centered at cluster's CoM

Present-day Globular Cluster Candidates?

- High dynamic range of the run allows us to trace the relaxation and evolution of these clusters (Kim et al. 2015b in prep.)

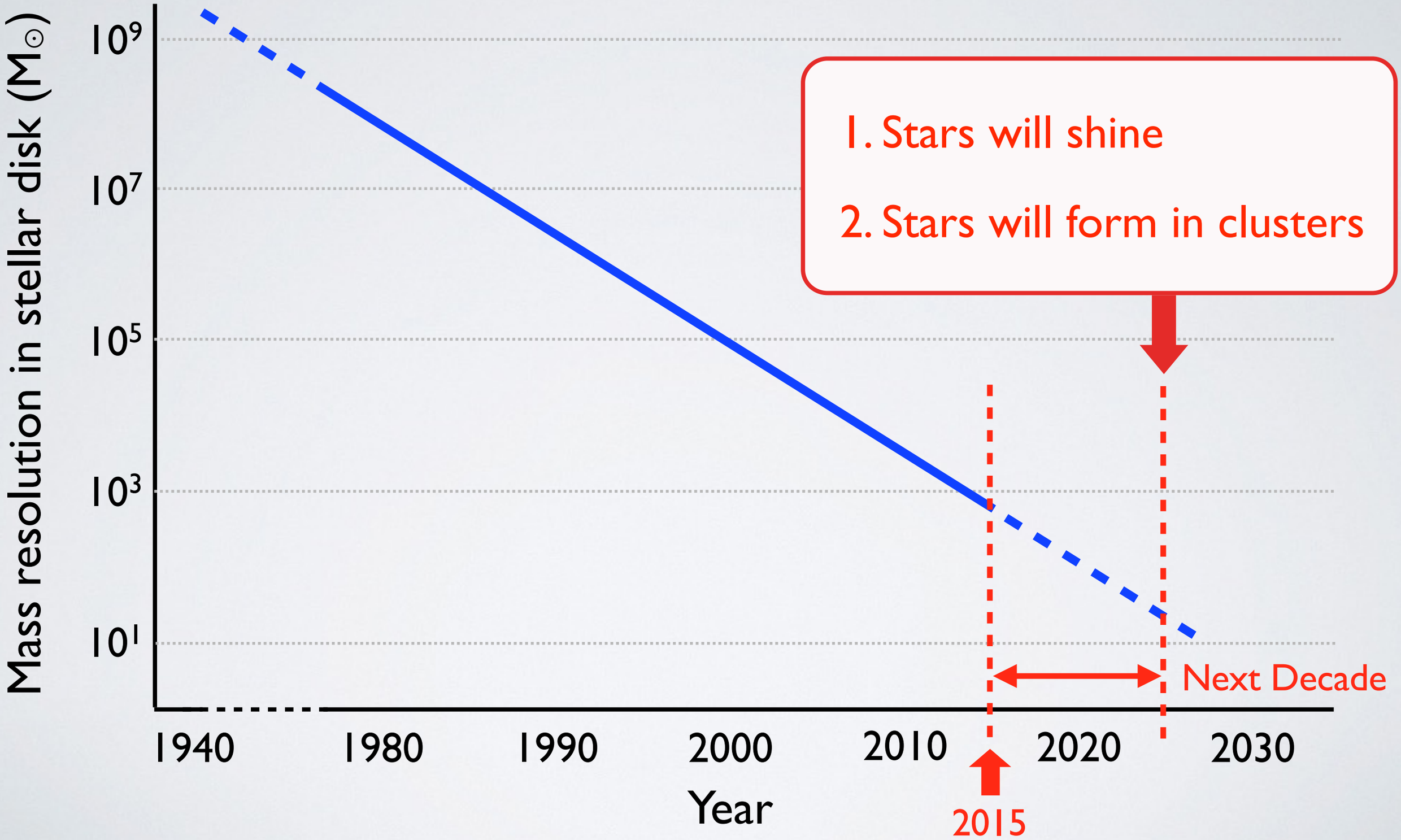


Cluster mass-radius plot, Kim et al. 2015b in prep.



2 kpc width, density projection, centered at cluster's CoM

Numerical Galaxy Formation: Upcoming Era



AGORA

A High-resolution Galaxy Simulations Comparison Initiative: www.AGORAsimulations.org

AGORA Project: Goal and Team

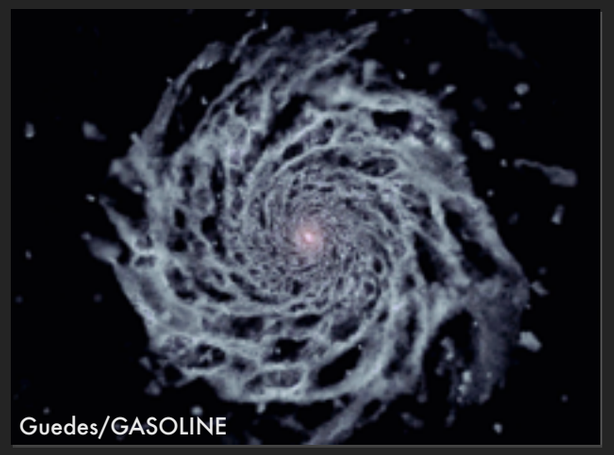
- GOAL: A collaborative, multi-code platform to raise the realism and predictive power of high-res galaxy simulations

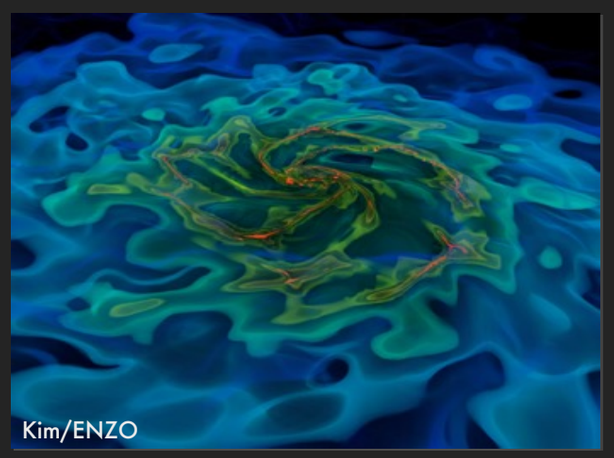
- TEAM - 130+ participants from 60+ institutions, 10/2015
  - 10+ groups each with variations of 9+ codes
  - 7-member Science Steering Committee
  - Project Coordinator: J. Kim

- DATA SHARING: Initial conditions, astrophysics modules, analysis software, and simulation outputs all to be public

- FIRST LIGHT: Flagship paper by J. Kim et al. (2014)

High-res Galaxy Simulation





Variation of the official AGORA intro slide (Credit: Kim & Governato) / Project funded in part by:

New Era in Numerical Galaxy Formation:

New Possibilities and Challenges

- In the next decade, we will come ever so close to understand the process of galaxy formation and evolution with the help of ever-improving tools of numerical experiments.

- Numerical Galaxy Formation - New Possibilities:

The potential is enormous.

- Numerical Galaxy Formation - New Challenges:

We are working on it!