Understanding isolated and satellite galaxies through simulations

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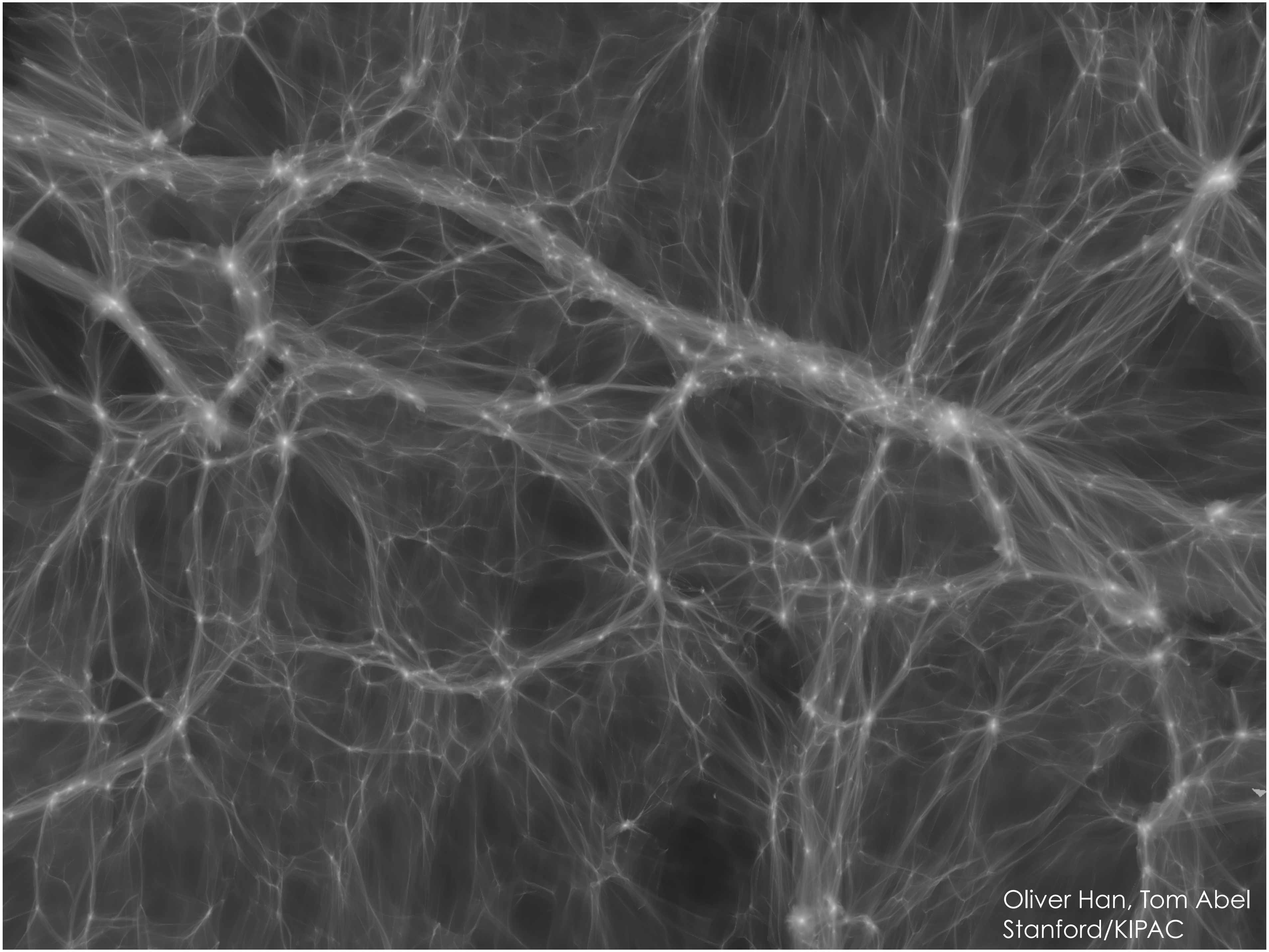
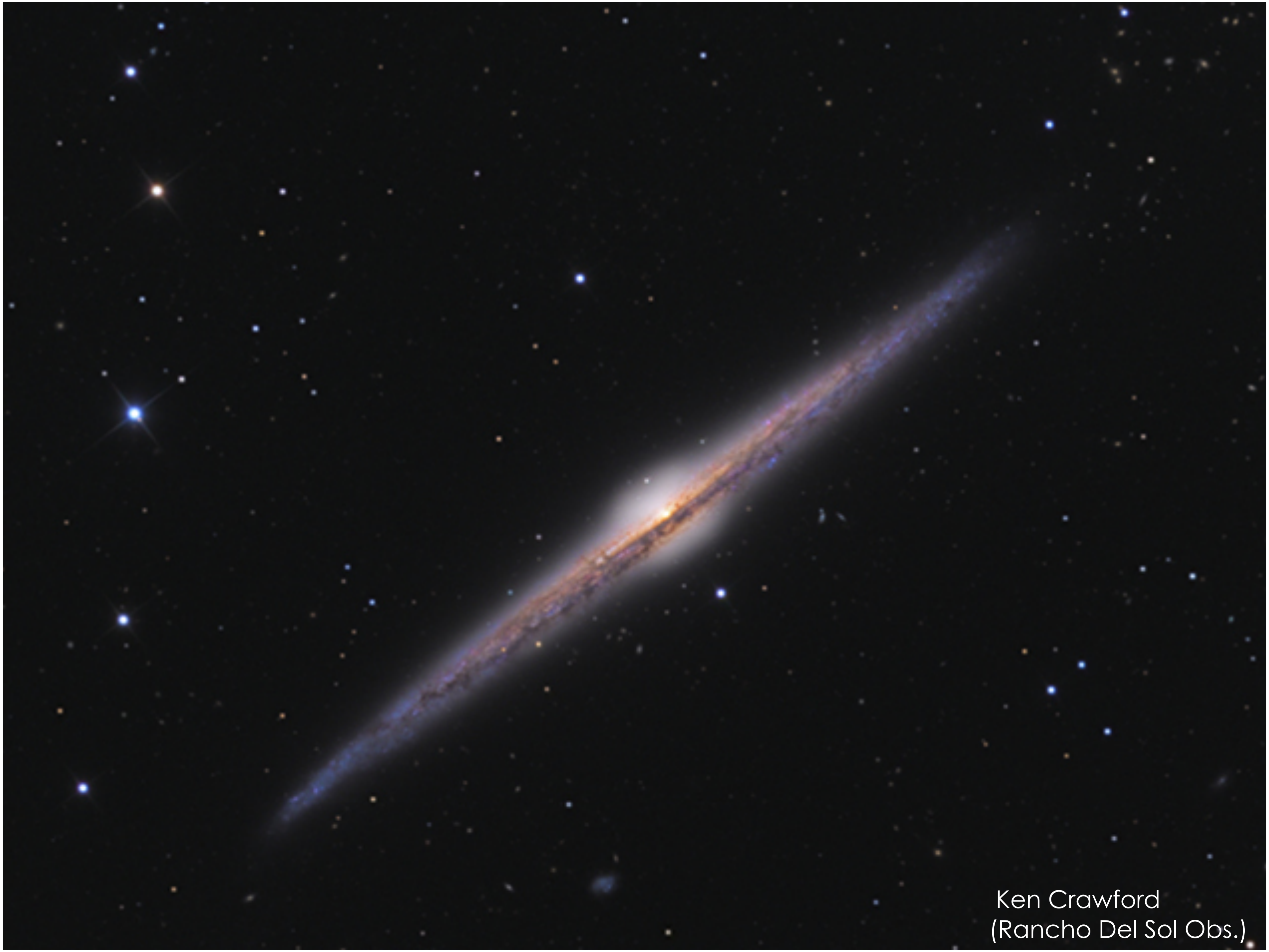
Understanding galaxy evolution

Key Challenges

- Understanding galaxy evolution requires:
  - large volume
  - high spatial resolution
  - long time span
  - good time resolution
  - following of dark matter particles
  - creation of stars and treatment of feedback
  - following gas flows
- Understanding dwarf galaxy evolution requires:
  - even higher spatial resolution
  - large, well resolved volumes

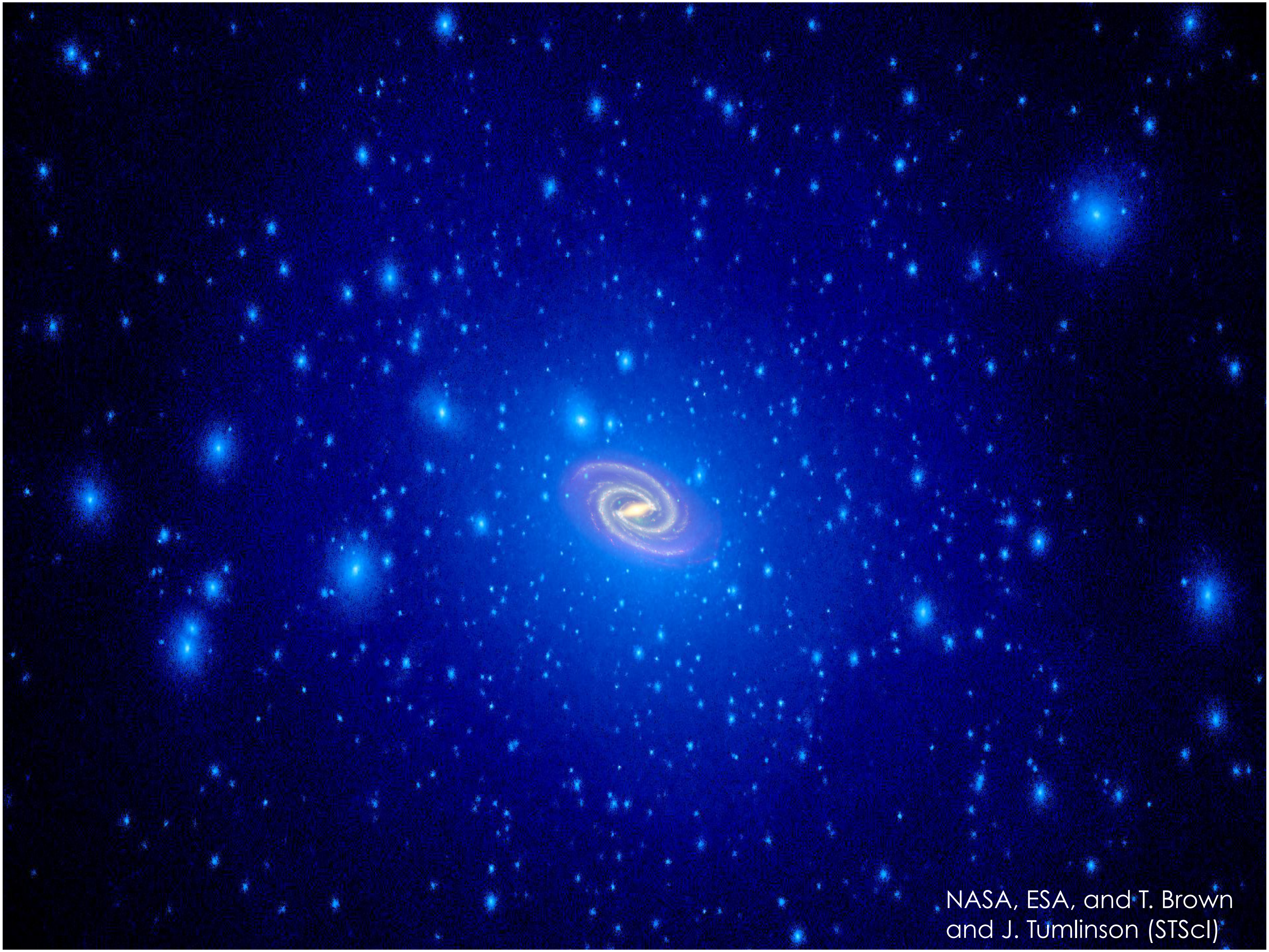

Oliver Han, Tom Abel
Stanford/KIPAC

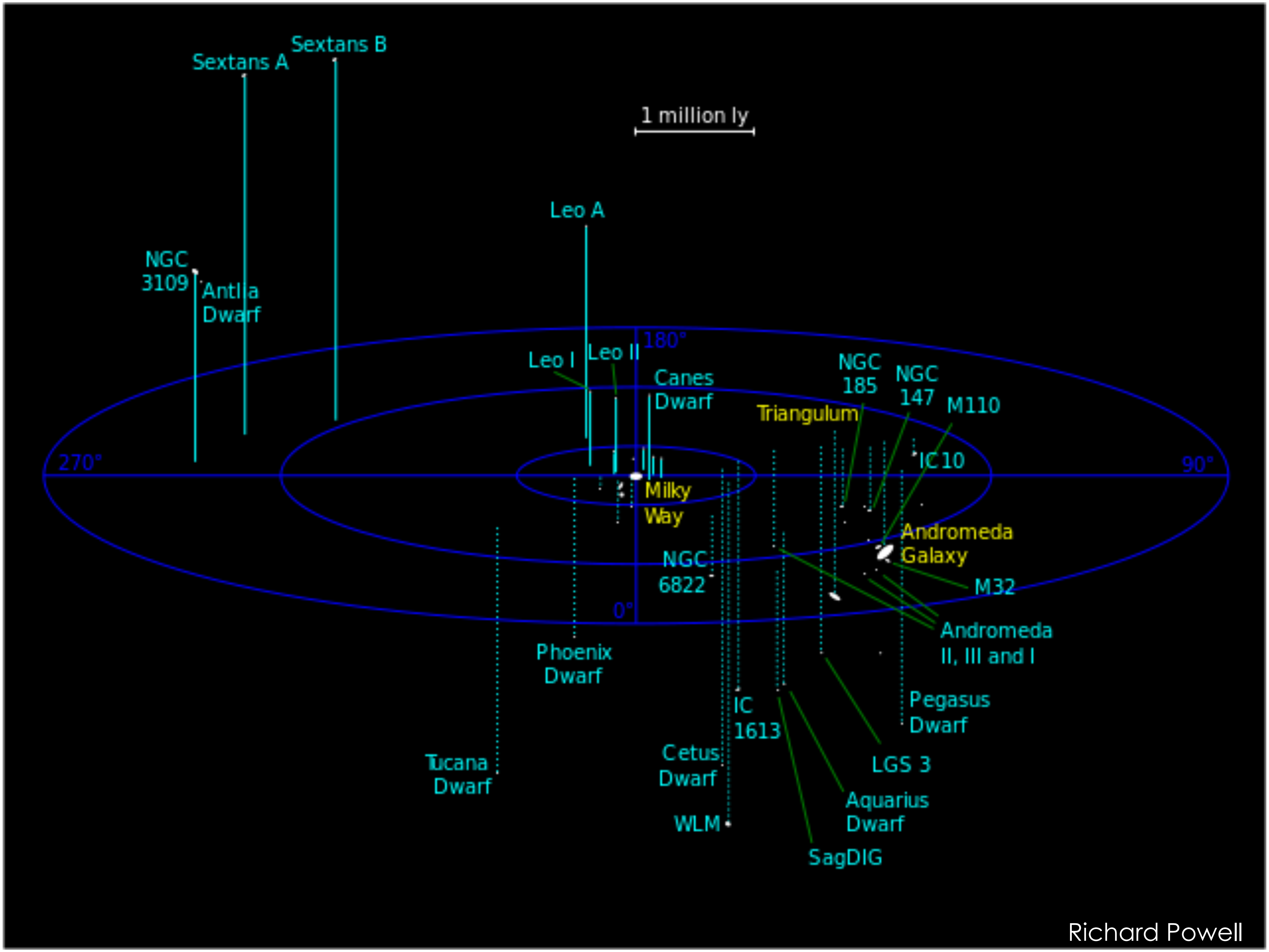

Ken Crawford
(Rancho Del Sol Obs.)


Spiral Galaxy M101
Hubble Space Telescope ▪ ACS/WFC
NASA and ESA
STScI-PRC06-10a

Why it Matters

- Still are discrepancies between theory predictions and observations on small (galaxy) scales
- Gain a better understanding of:
  - how dwarf galaxies build up their mass
  - how many satellite dwarf galaxies there are
  - morphological types of dwarf galaxies as evolution
  - how satellite and isolated dwarf galaxies differ
  - what dwarf galaxies central densities depend on
  - how dwarf galaxies impact their host galaxy
  - where the other 50% of gas mass is around our galaxy
  - what observations are required to find this gas


NASA, ESA, and T. Brown
and J. Tumlinson (STScI)



Sextans B
Sextans A
1 million ly
Leo A
NGC 3109
Antlia Dwarf
180°
Leo I
Leo II
Canes Dwarf
NGC 185
NGC 147
M110
Triangulum
270°
IC 10
90°
Milky Way
Andromeda Galaxy
NGC 6822
M32
0°
Andromeda II, III and I
Phoenix Dwarf
Pegasus Dwarf
IC 1613
Tucana Dwarf
Cetus Dwarf
LGS 3
Aquarius Dwarf
WLM
SagDIG
Richard Powell

Project Goals

- Create galaxies that are:
  - realistic - match observations on a variety of tests
  - high resolution - able to examine these small scales
- Use them to learn about dwarf galaxies
  - isolated and satellite galaxies
  - abundances
  - star formation rates
  - central densities
  - morphological changes
  - tidal disruption and mass loss
  - influence on gas around galaxies

Project Goals

- Tools used to create simulations and use them to learn about dwarf galaxies

  - ART, an Adaptive Mesh Refinement (AMR) code
    - hydrodynamics + dark matter particles + star particles
      - star formation & stellar feedback (stellar winds, supernovae feedback, radiation pressure)

  - "Zoom-in" initial conditions
    - large simulation volume ~ 20^3 Mpc^3 boxes
    - high spatial resolution ~ 20 pc
    - long time span ~ 14 Gyrs
    - good time resolution ~ 1000 yrs

Accomplishments

- Code development has produced significant increase in code speed
- 25 initial conditions generated of massive galaxies with well resolved surrounding regions
- Parameter tests of isolated dwarf galaxy
- Created analysis routines and workflow
- Completed analysis of a set of simulations run with our hydrodynamical code by Daniel Ceverino

Software Products

- Hydrodynamical Simulation Code
  - New feedback implementation for radiation pressure
  - Improvements to code efficiency
    - Full parallelization of density calculations
    - Better IO practices
    - Star particle resampling
    - Different refinement schemes
- Analysis Workflow
  - Workflow for Rockstar halo finding algorithm (Peter Behroozi)
  - Fortran profiling and particle finding code
  - Python plotting and analysis routines
  - yt + ART compatibility

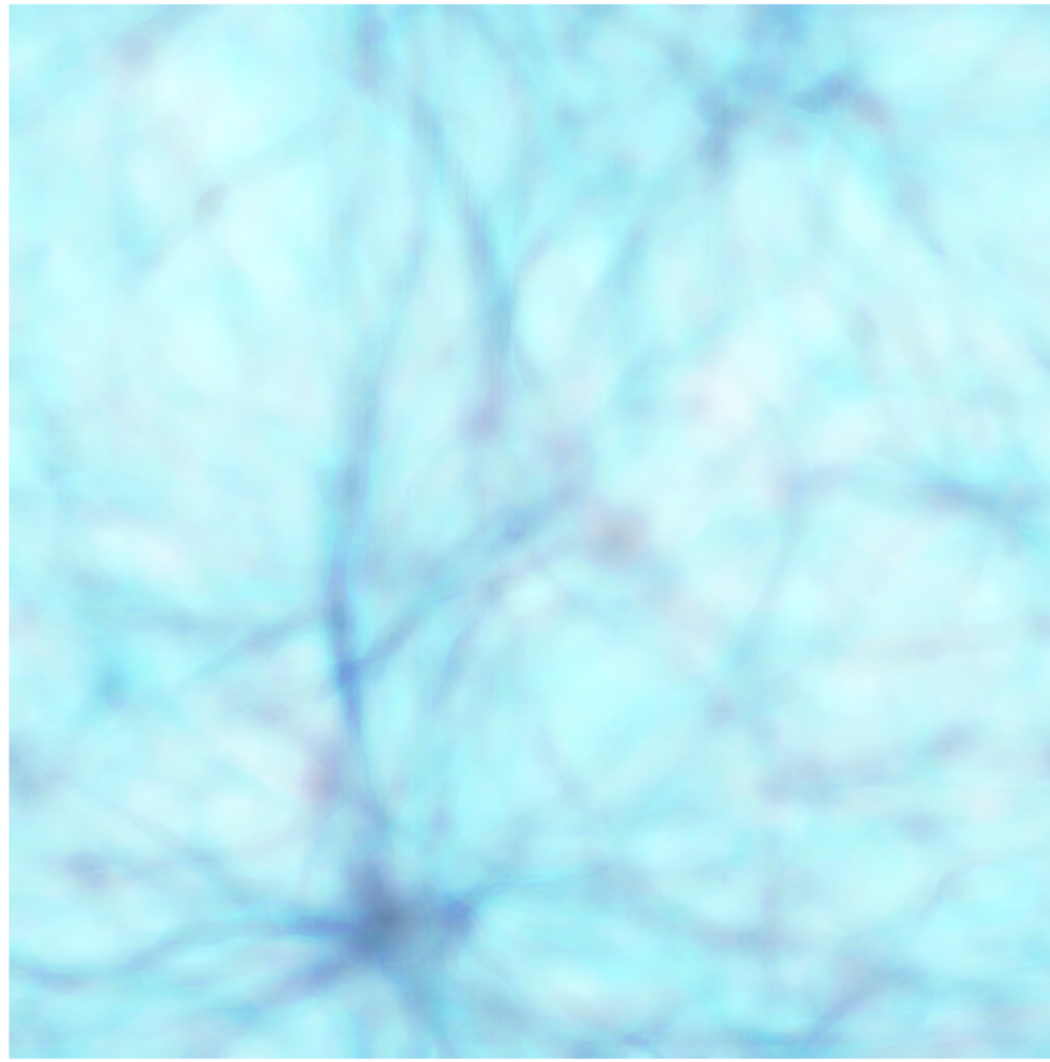
VELA Simulation Suite Analysis

Run by Daniel Ceverino
hydrodynamical ART code

Box length = 20 /h Mpc
DM mass = $8x10^4$ M_{sun}
Resolution = 17 pc

cells = 67 million
particles = 30 million

Stellar winds
Supernovae feedback
Radiation pressure (τ_{IR}=0)



VELA Simulation Suite Analysis

10 VELA host galaxies

Possible MW progenitors

No specific environmental selection

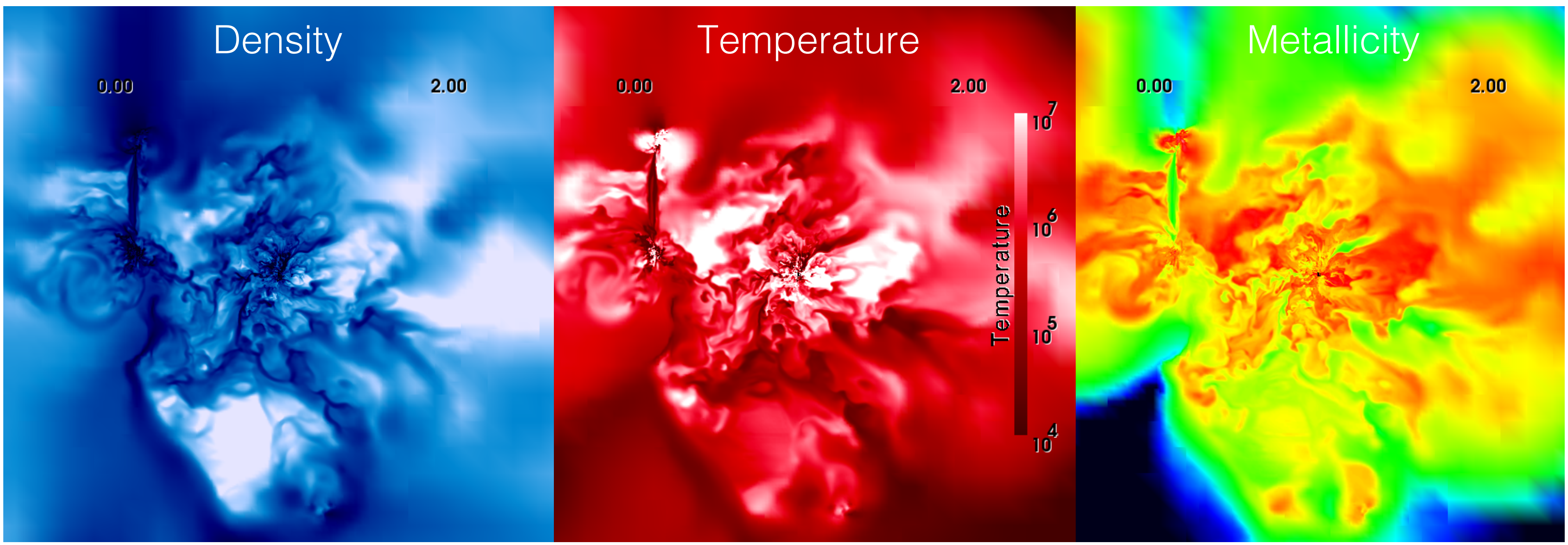
Range of merger histories and M_{vir}

Results from redshift one

$M_{vir} = 2x10^{11} – 1.2x10^{12}\ M_{sun}$

$M_{star} = 6x10^{9} – 8x10^{10}\ M_{sun}$

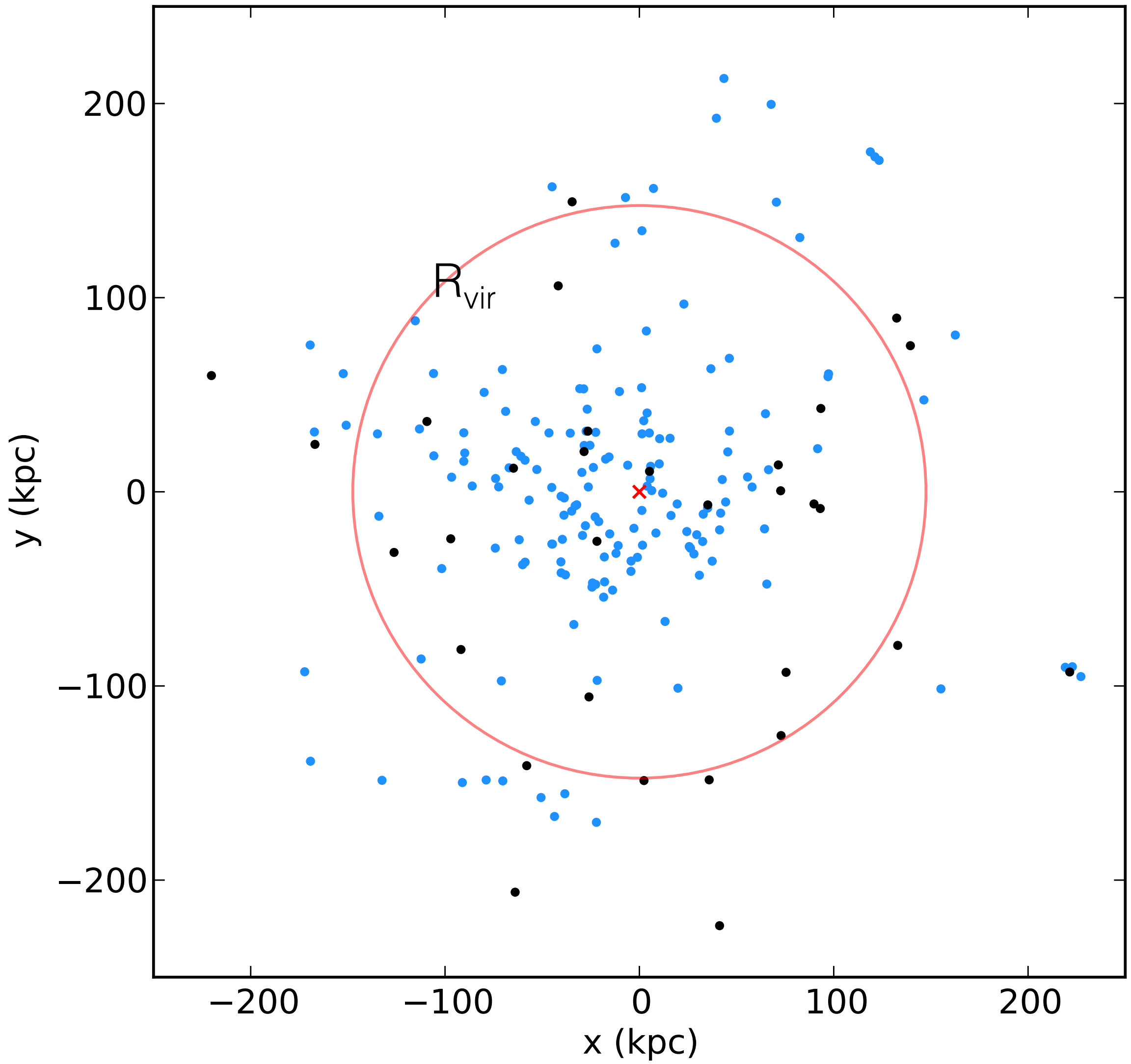
R_{vir} = 92 – 147 kpc



VELA Simulation Suite Analysis

Distribution of galaxies around main halo

- •Red "x" marks the center of main halo
- •Red circle marks the 'edge' of the main galaxy
- •Blue dots are luminous dwarf galaxies
- •Black dots are dwarf galaxies without any stars (dark galaxies)



Future Work

- Run the 25 new initial conditions with our improved code
  - Volume = 100^3 Mpc^3
  - Dark matter particle mass = 1.5×10^5 M_{sun}
  - Physical resolution = 40 pc
  - Produce 500 outputs per simulation (a=0.002)
- Update workflow to include time series analysis
- Run workflow on simulations
  - Select isolated and satellite dwarf galaxies
  - Compare with observations of halo mass – stellar mass, star formation rates, abundance of satellites, merger rates, tidal stripping, luminosity function, circumgalactic medium, metallicity, central density, etc.

Acknowledgements

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- Daniel Ceverino and Sebastian Trujillo-Gomez
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