The IllustrisTNG Project

Lars Hernquist
Harvard University

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Our team:
Shy Genel (CCA), Lars Hernquist (Harvard), Federico Marinacci (MIT),
Jill Naiman (Harvard), Dylan Nelson (MPA), Ruediger Pakmor (HITS),
Annalisa Pillepich (MPIA), Volker Springel (HITS/MPA), Paul Torrey (MIT),
Mark Vogelsberger (MIT), Rainer Weinberger (HITS)
**Illustris in one slide**

AREPO Code
106.5 Mpc Cosmological Box
Halo Mass Range: < $2 \times 10^{14}$ Msun
Res: $\sim 1$ kpc, $\sim 10^8$ Msun

Vogelsberger et al. 2014a, b, Genel et al. 2014,
Sijacki et al. 2015
Illustris Limitations, i.e. issues identified in the Illustris galaxies

1. Too high Cosmic SFRD at z<1
2. Too high galaxy stellar mass function at z=0 at the low & high mass ends
3. Too extended stellar sizes for galaxies < 10^{10} M_{\odot}
4. Spurious ring-like features at z=0
5. Too low halo gas fractions with R500 in haloes > 10^{13.5} M_{\odot}
6. Not well enhanced galaxy color bimodality

Problems mostly related to feedback models

Feedback from stars, supernovae

High BH accretion rates
“quasar mode:” local
thermal feedback

Low BH accretion rates
“radio mode:” non-local
to offset cooling
Issue of AGN radio mode feedback

• Too inhomogeneous spatially, too sporadic in time
• New AGN feedback model:
  – high accretion rates (as before): quasar mode -- thermal energy imparted to gas near BH
  – low accretion rates – BH winds: momentum imparted to gas near BH
• Places two modes on same footing
• Motivated by FR0 radio galaxies (Baldi+2016), red geyser galaxies (Cheung+2016)
FR0 galaxies: Baldi+2016

Red geyser galaxies: Cheung+2016
Shocks are a bit like Donald Trump

Courtesy of Lisa Kewley
IllustrisTNG

• Ingredients:
  – new AGN feedback model (Weinberger+ 2017)
  – refinements to stellar feedback (Pillepich+ 2017)
  – MHD (Marinacci+ 2017)
  – r-process elements in NS-NS mergers (Naiman+ 2017)
  – automated shock-finder (Schaal+ 2016)

• New simulations:
  – TNG50: 50 Mpc box, high resolution (in progress)
  – TNG100: repeat of Illustris, Planck cosmology (complete)
  – TNG300: 300 Mpc box (complete)

• First results: problems with Illustris resolved; see 2017 papers by Genel+, Marinacci+, Naiman+, Nelson+, Pillepich+, Springel+, Vogelsberger+
TNG100: $2 \times 1820^3$, $\approx$ same volume, resolution as Illustris; run to $z=0$

TNG50: $2 \times 2160^3$, $\approx$ 20 times better mass resolution, $\approx$ 2.5 times better spatial resolution; running, now at $z \approx 0.9$

TNG300: $2 \times 2500$, $\approx$ 30 times larger volume; run to $z=0$
Halo, galaxy mass functions in TNG100, TNG300

TNG300: several halos about $10^{15} \, M_{\odot}$, $\sim 100,000$ Milky Way halos
TNG100: g-r galaxy color distribution

L75n1820TNG: centrals only

Blue

Red

$M_\star$ [log $M_{\odot}$]

(g-r) color [mag]

$\log N_{\text{gal}}$

Median

P[10,90]
TNG100 g-r colors vs. Illustris, SDSS

Nelson et al., arXiv: 1707.03395
Timescales for blue/red transition

Indicates multiple quenching pathways; also morphologies
Blue galaxies, $M_{\text{halo}} \sim 10^{12} - 10^{12.2} M_{\text{solar}}$

Nelson+2017
Red galaxies, $M_{\text{halo}} \sim 10^{12} - 10^{12.2} M_{\text{solar}}$

Nelson+2017 (recall Mina Pak’s poster)
Blue/Red transition with TNG model

- **Multiple quenching mechanisms suggested**
  - many are rapid \( \sim 1 \) Gyr
  - broad tail to longer times \( \sim 4-6 \) Gyrs
- **Relationship to morphology a key test of model**
  - around transition, not all red galaxies spheroidal
  - subsequent evolution to higher masses?
  - currently being investigated, compared to observations by Sandro Tacchella
- **Can track histories of individual galaxies, compare to data for further tests of model**
Example histories of galaxies

Nelson+2017
Matter clustering in TNG300

Dark matter (top), stellar (bottom) density fields; Springel+2017
• Bias of stars to dark matter:
  – scale-dependent
  – evolves with $z$
  – also for galaxies
  – extends to BAO scales

See Springel+2017
Impact of baryonic processes on matter distribution

Complex evolution with redshift

At $z=0$, dominant effects at $<1$ Mpc, tail to larger scales

Rough agreement with Eagle
Galaxy clustering relative to data

Generally good agreement between TNG100 & TNG300 and with SDSS.
Galaxy clustering in TNG300 relative to data

Generally good agreement, but red galaxies at stellar masses $\sim 10^{9.5} - 10^{10.5}$ near base of blue/red transition: dust, green valley?
Ongoing/future work

- Unusual galaxies: LSBs (Zhu+), jellyfish (recall Samuel Boussier’s talk)
- Some discrepancies with data already identified
  - not enough cool core clusters (Barnes+) \(\rightarrow\) missing physics?
  - many more tests possible
- TNG50 expected completion in \(~3 – 6\) months
  - mass per stellar particle \(~10^5\) \(M_{\text{solar}}\) \(\rightarrow\) Milky Way studies

Pillepich et al. (2017)
Ongoing/future work

- TNG dataset will be made public ~ 1st half 2018
  - collaborators welcome until then
- Larger volume simulations, e.g. Millennium with gas
- Development of more physical sub-resolution models:
  - SMAUG collaboration with CCA (Simulating Multiscale Astrophysics to Understand Galaxies)