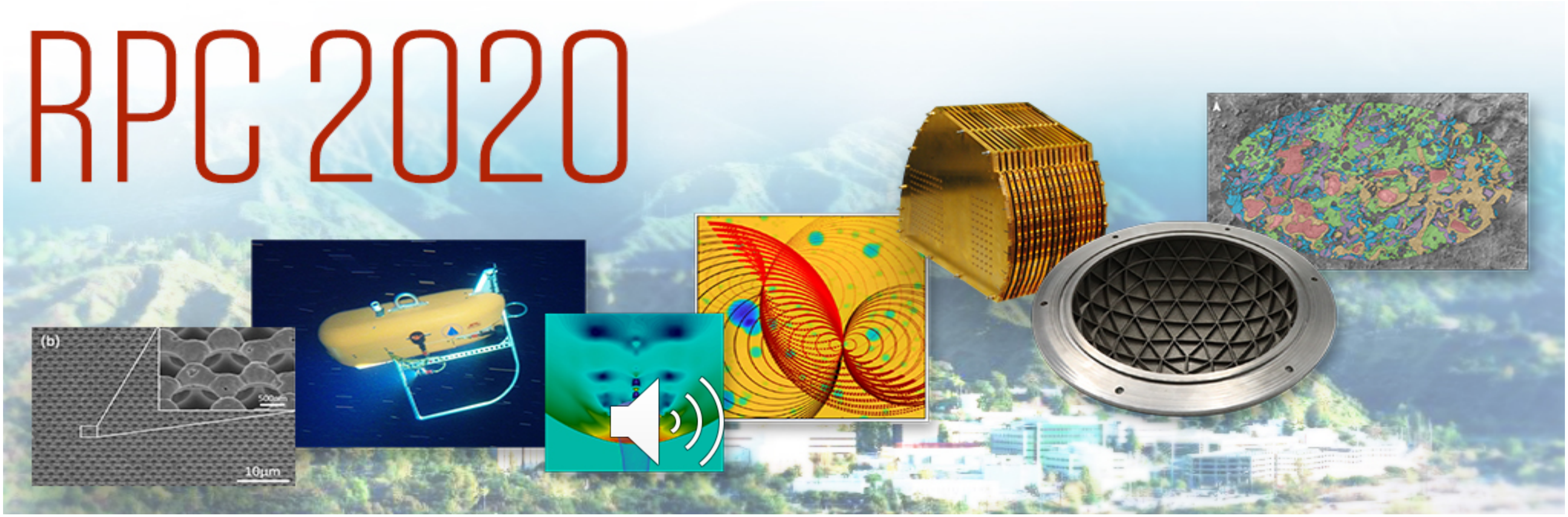

Virtual Research Presentation Conference

Mapping the Baryonic Majority: Comprehensive Multi-Mission Analysis of the Circumgalactic Medium (CGM) and the Intergalactic Medium (IGM)

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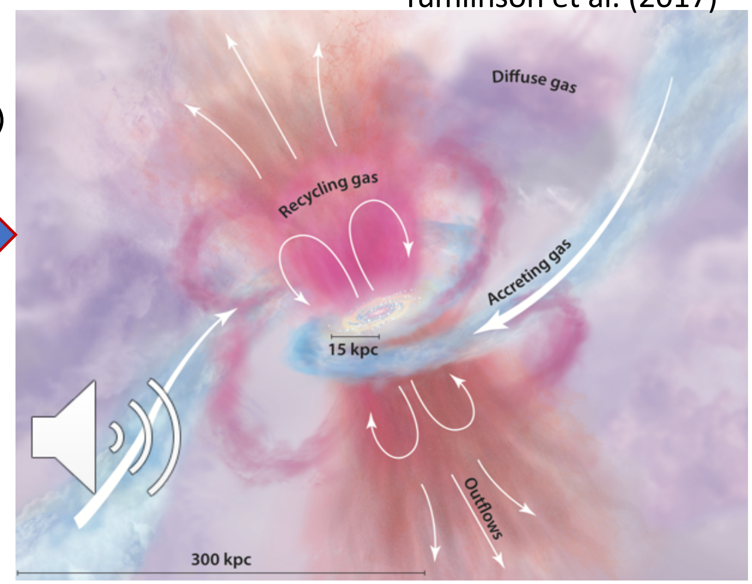
Program: Strategic Initiative
Assigned Presentation RPC-014

Jet Propulsion Laboratory
California Institute of Technology

Where are the baryons[1] and what are they doing?

<u>The Problem</u>: Less than 10% of ordinary matter in the universe makes the visible stars that we see in galaxies. The other 90%, the “Baryonic Majority” should also have cooled to make stars, but did not. Instead, it has been banished as a gaseous relic to galaxy halos (the circumgalactic medium, CGM) and the more broadly distributed intergalactic medium (IGM). **As the figure illustrates, the visible stars of a galaxy are but a small drop condensed out of a much larger reservoir of baryons.**

Tumlinson et al. (2017)



<u>The Questions</u>: What prevents this gas from making stars? How is it distributed in the CGM and IGM? What is its physical state and relation to the stellar component? What is the role of the CGM/IGM in galaxy formation?

<u>The Research Program</u>: These fundamental questions motivate a variety of observational approaches across the electromagnetic spectrum, involving disparate scientific communities and mission concepts. **Our Strategic R&TD seeks to combine these techniques into a more coherent approach, to provide a comprehensive view of the CGM/IGM and its role in galaxy formation.**

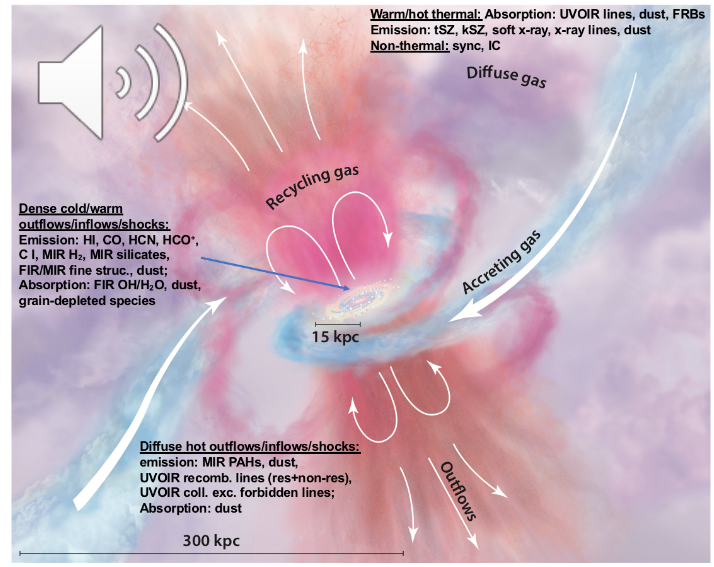
[1] *”Baryons” in cosmology refers to ordinary matter, consisting mainly of Hydrogen and Helium with traces of heavier elements.*

Need for a Unified Approach

- **Why:** State-of-the-art = many different techniques proposed by a variety of missions/experiments (e.g., all four flagship concepts), **but each approach is developed within its own narrow sphere (waveband, imaging, spectroscopy).**

  - We believe that what is needed is a more unified view of the observational signatures, their relation to each other, to the physical state of the CGM/IGM and to host galaxy properties.

- NASA Astrophysics seeks understanding of the origin and evolution of galaxies. Our program will inform mission concept development and enable JPL to identify and exploit new mission opportunities in this central area NASA SMD research.



Tumlinson, Peeples, and Werk ARAA (2017)

Methods

Theory: predictions via **simulations**

- Predict key/distinguishing correlations between CGM/IGM and galaxy observables
- Predict multi-wavelength/multi-technique imaging and spectroscopic signatures

Advancement:

1. Infrastructure in place to calculate and compare predictions from all state-of-the-art simulations (EAGLE, FIRE, IllustrisTNG) and Galacticus SAM.
2. Analysis of CGM properties in Galacticus base model.
3. Ability to search parameter space in Galacticus.

Methods:

- Exploit new wavebands (e.g., trans-millimeter)
- Combine observations from multiple missions to measure key correlations

Advancement:
Measurement of gas density and pressure profiles using tSZ and kSZ observations with ACT (Amodeo et al. 2020).

Innovations:

- Comparison of different models.
- Physics/parameters <=> observational signatures.
- Combination of probes across wavebands & techniques.

Mission Portfolios:

- Quantify what will be possible with planned missions
- Identify new mission opportunities

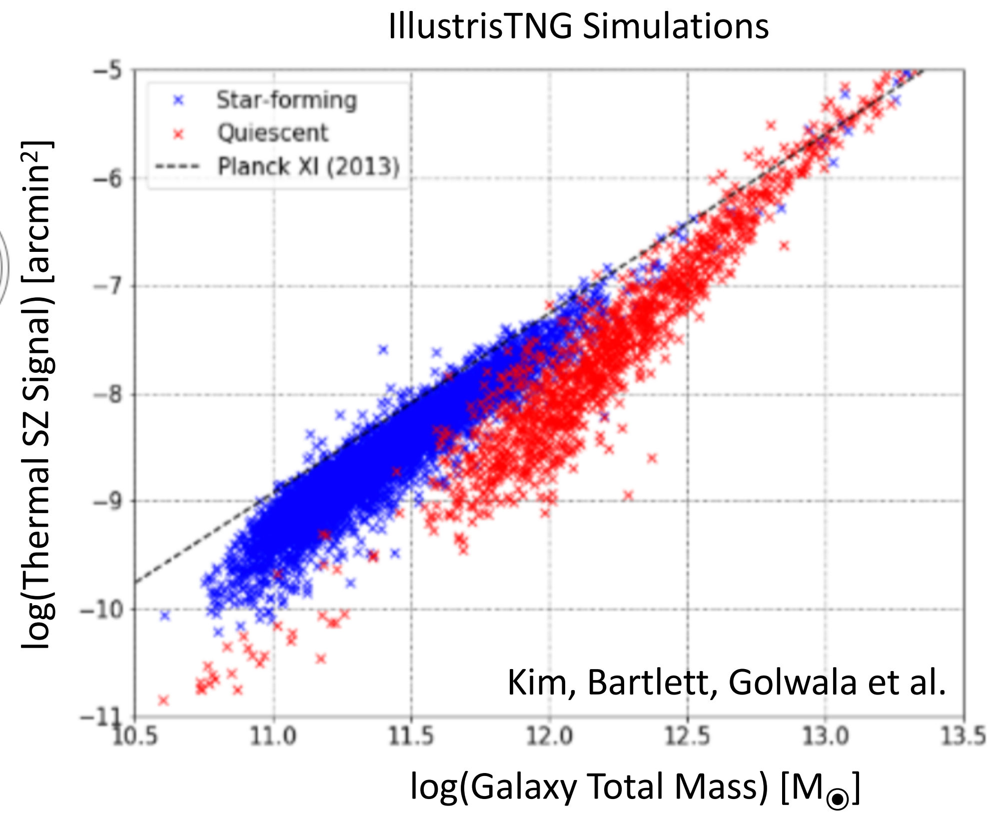
Advancement: predictions of UV emission from CGM in low-z galaxies.

Results – Prediction of Observable Signals

a) Accomplishments versus goals
   a) The ability to make predictions like these is a milestone for our program.

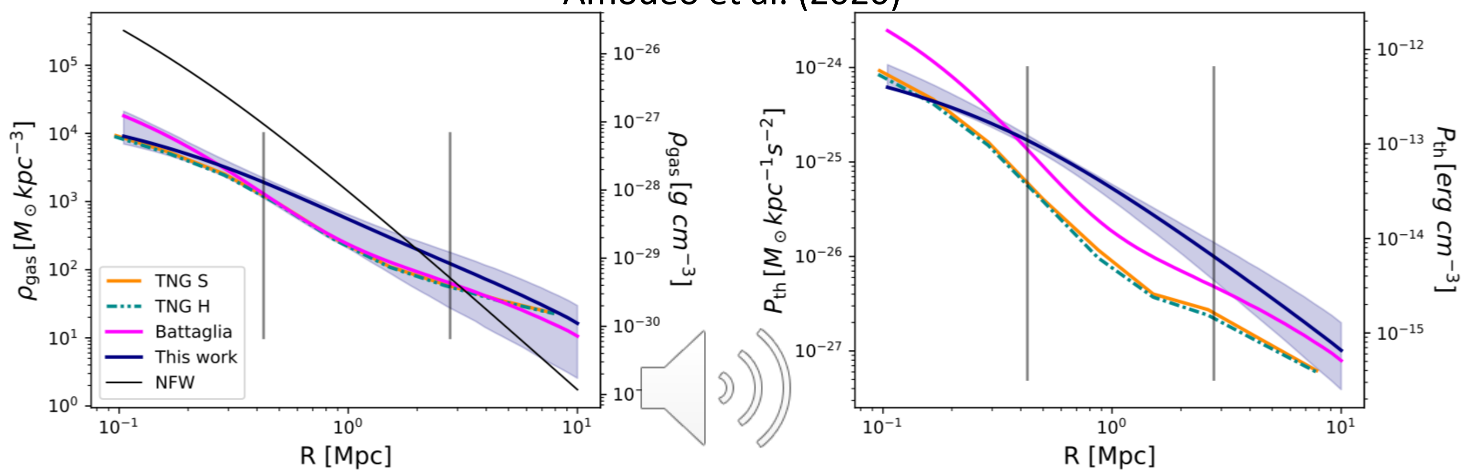
b) Significance
   a) We have linked observable CGM properties to host galaxy properties.
   b) The difference in the SZ signal between star-forming and quiescent galaxies is a testable prediction

c) Next steps
   a) Predict suite of observational signatures across wavebands for the different models



Results – Application of New Measurement Method

Amodeo et al. (2020)



a) Accomplishments versus goals: the tSZ and kSZ effects are novel probes of the CGM and IGM developed by our team members. This result is their first combined application to the new ACT dataset.

b) Significance: This is a first-of-its-kind measurement of both the gas density and pressure profile around massive galaxies.

c) Next steps: Evaluation of the knowledge gain from combining these kinds of observations with other CGM probes, such as stacks of spectra along sightlines through the CGM.

Publications and References

Publications:

- Amodeo, S., Battaglia, N. et al. 2020, arXiv:2009.05558

References:

- Tumlinson et al. 2017, ARA&A 55, 389
- Hopkins et al. 2014, MNRAS 445, 581 – FIRE2 simulation suite
- Benson 2012, New Astron. 17, 175 – Galacticus semi-analytical model (SAM)
- Pillepich et al. 2018, MNRAS, 473, 4077 – IllustrisTNG simulation suite
- Schaye et al., 2015, MNRAS, 446, 521 – EAGLE simulation suite
- Planck Collaboration 2013, A&A, 557, A52 – Thermal SZ measurements around galaxies (Fig. slide 5)