National Aeronautics and Space Administration

Mapping the Baryonic Majority

Principal Investigator: James G. Bartlett (326)
S. Allen (Stanford), L. Armus (IPAC/Caltech), N. Battaglia (Cornell), A. Benson (Carnegie Obs.) J.C. Hill (IAS/Princeton), S. Golwala (Caltech), P. Hopkins (Caltech)

Program: Strategic Initiative

Project Objective:

Context

Most of the normal matter (baryons) in the universe does not make stars. The vast majority (~90%) are found in the gaseous phases known as the circumgalactic medium (CGM) around galaxies and more diffuse intergalactic medium (IGM). At their characteristically low densities, the CGM and IGM are not easily seen. A visible galaxy is therefore only the "tip of an iceberg" (see Fig. 1).

Determining the physical state of the CGM/IGM is critical to understanding feedback and galaxy evolution. This is a difficult observational and modeling problem.

Study of the CGM/IGM is the focus of a number of missions and modeling efforts spanning the X-ray to the radio bands. It involves numerous techniques employed by different communities.

Objectives

Our overall objective is to combine these techniques in a comprehensive framework to determine CGM/IGM properties and their relation to the global properties of host galaxies. Specific objectives are to:

1. bring different communities together
2. combine techniques and methodology
3. develop realistic simulations
4. evaluate the science reach of possible mission portfolios in the coming decade.

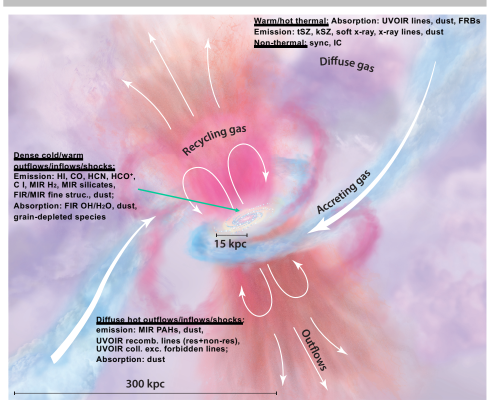

Figure 1. The picture, from Tumlinson et al. 2017, ARA&A 55, 389, depicts, in schematic fashion, the movement of gas, energy, and momentum between galaxies, their CGM, and the IGM, via outflows, accretion, and gas recycling. We indicate on the figure a list of multi-wavelength observational tracers relevant for the key regions in galaxies and their surroundings.

FY19 Results:

Our project is organized around the following three tasks, with our FY19 results:

Simulations. 1) Set-up simulation framework and post-processing steps to enable predictions of new CGM/IGM observables and relations between CGM/IGM and host galaxy properties. 2) Preliminary extraction of CGM properties from Galacticus semi-analytical model (Benson et al. 2012, New Astron. 17, 175) and comparison to observational data (see Fig. 2). 3) Roadmap for Galacticus runs to identify the impact of different galaxy formation parameter choices on the observable multi-wavelength/multi-mission properties of the CGM.

Methods. 1) Exhaustive listing of imaging and spectral techniques for observing the CGM/IGM. 2) Construction of an *Observation Matrix* identifying possible connections between these techniques. 3) Grouping of techniques according to the information they provide on the physical conditions in the CGM/IGM **(**see Fig. 1).

Mission Portfolio Scenarios. 1) A list of possible mission portfolios for the coming decade; 2) Contribution to white papers and experimental concepts (see Fig. 3)

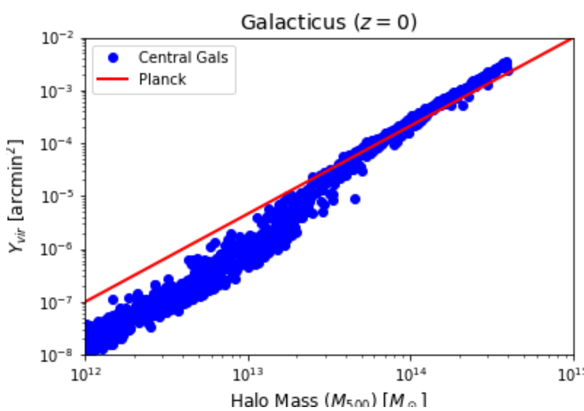

Figure 2. Preliminary extraction of CGM properties from Galacticus model. The blue points show the predicted SZ signal from the CGM around central galaxies in the local universe as a function of their host halo mass. The red line indicates measurements made by the Planck satellite (Planck Collaboration 2013, A&A 557, A52).

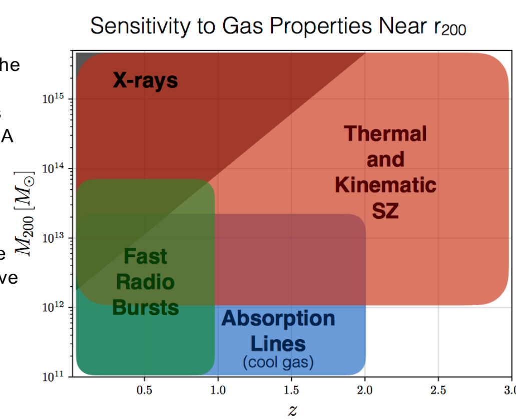

Figure 3. Schematic showing the halo mass and redshift ranges over which different techniques can observe CGM signatures. A key mass range is $10^{12} – 10^{13}$ Msun, where feedback mechanisms likely change (Battaglia et al. 2019). Our program aims to combine these techniques into a comprehensive view of the CGM/IGM and its relation to host galaxies.

Benefits to NASA and JPL (or significance of results):

Our results will contribute to NASA's and JPL's ability to identify new opportunities in detector development and to propose new mission concepts. Our comprehensive approach will optimize interpretation and exploitation of a diverse array of JPL mission data sets, both current (e.g., *Herschel*, *Planck*, *Spitzer*, WISE) and anticipated (e.g, *Euclid*, WFIRST). Our program will improve understanding of the CGM/IGM, a key component of galaxy formation and evolution that is now only very poorly understood. Our program will unify diverse efforts into a comprehensive assault on a fundamental scientific question, and it will provide JPL with the technical means to lead major discoveries in astrophysics.

Publications:

- Abazajian et al. 2019, "CMB-S4 Decadal Survey APC White Paper", arXiv: 1908.01062
- Battaglia et al. 2019, "Probing Feedback in Galaxy Formation with Millimeter-Wave Observations", arXiv:1903.04647
- Basu et al. 2019, "A Space Mission to Map the Entire Observable Universe with the CMB as a Backlight", arXiv:1909.01592
- Hanany et al. 2019, "PICO: Probe of Inflation and Cosmic Origins", arXiv:1908.07495

PI/Task Mgr. Contact Information:

(818)354-4946
james.bartlett@jpl.nasa.gov

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Poster No. RPC-016