National Aeronautics and Space Administration

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

Principal Investigator: James Bartlett (326); Co-Investigators: J. Colin Hill (Columbia University), Nicholas Battaglia (Cornell University), Andrew Benson (Carnegie Institution for Science), Phil Hopkins (Caltech), Sunil Golwala (Caltech), Lee Armus (Caltech)

Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Tracing Baryons Through Comprehensive Multi-Mission Analysis**

Objectives

The circumgalactic medium (CGM) is a diffuse gas that fills galaxy dark matter halos and trails off into the more uniformly distributed intergalactic medium (IGM, see figure to right). The CGM/IGM can be observed through imaging and spectroscopy in different wavebands from the radio to hard X-rays [Tumlinson et al. 2017, ARA&A 55, 389]. Observations of the CGM/IGM are the prime scientific motivation for a number of mission concepts. Each, however, is focused on its own specific waveband and technique. Our objective was to identify, develop, evaluate and deploy observational techniques that combine these wavebands and techniques in a coherent framework with the goal of unveiling the physical state of the CGM/IGM.

Background

Together, the CGM and IGM host the vast majority (90% or more) of all cosmic baryons, but at their characteristic densities and temperatures they are very difficult to observe. The role of the CGM/IGM in galaxy formation is one of the central outstanding questions in extragalactic astrophysics.

Approach and Results

We predicted signatures of the CGM using state-of-the-art simulations (GALACTICUS [Benson 2021, New. Astron. 17, 175], FIRE [Hopkins et al. 2014, MNRAS 445, 581], IllustrisTNG [Pillepich et al. 2018, MNRAS 473, 4077] and EAGLE [Schaye et al. 2015, MNRAS 446, 521]) to guide development of observational methods and their joint analysis. As an example, the second figure on the right compares the predictions from IllustrisTNG and EAGLE for the thermal Sunyaev-Zeldovich effect from the CGM as a function of galaxy mass, from a paper in preparation [F]. Based on results like these, we examined the combination of data available in a variety of possible mission portfolios in the coming decade, looking for strategic opportunities to define new mission concepts. Our program motivated the development of the MAGIC mission concept to observe the CGM via its Lyman-alpha line emission; the concept will be proposed by JPL as an Explorer Mission of Opportunity in 2021.

Significance/Benefits to JPL and NASA

Our results contribute to JPL's ability to identify new opportunities in detector development and to propose new mission concepts in this strategic astrophysics research field. By taking a global view and integrating effort across different communities, our program established the framework for identifying new opportunities and for proposing new mission concepts, particularly important with numerous flagship and probe-class mission studies underway for the Decadal Survey. Our program unifies diverse efforts into a comprehensive assault on a fundamental scientific question, and it provides JPL with the technical means to lead major discoveries in astrophysics.

Publications

[A] Emmanuel Schaan et al., "Atacama Cosmology Telescope: Combined kinematic and thermal Sunyaev-Zel'dovich measurements from BOSS CMASS and LOWZ halos," Physical Review D **103** (March 2021): id.063513.

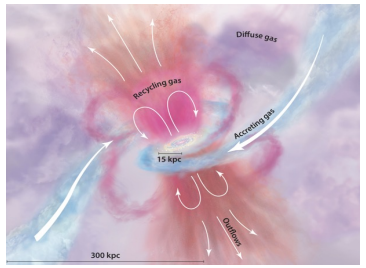
[B] Stefania Amodeo et al., "Atacama Cosmology Telescope: Modeling the gas thermodynamics in BOSS CMASS galaxies from kinematic and thermal Sunyaev-Zel'dovich measurements,", Physical Review D **103** (March 2021): id.063514.

[C] M. Gatti et al., "Cross-correlation of DES Y3 lensing and ACT/*Planck* thermal Sunyaev-Zel'dovich Effect I: Measurements, systematics tests, and feedback model constraints," arXiv:2108.01600 (August 2021).

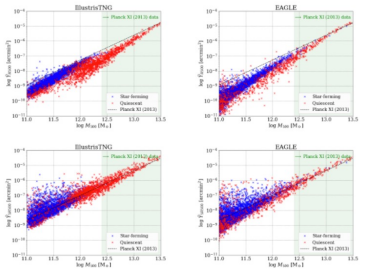
[D] S. Pandey et al., "Cross-correlation of DES Y3 lensing and ACT/Planck thermal Sunyaev-Zel'dovich Effect II: Modeling and constraints on halo pressure profiles," arXiv: 2108:01601 (August 2021).

[E] Aleksandra Kusiak et al., "Constraining the baryon abundance with the kinematic Sunyaev-Zel'dovich effect: Projected-field detection using *Planck*, WMAP and unwise," arXiv:2102:01068 (August 2021).

[F] Junhan Kim et al., in preparation.



Schematic of the CGM and IGM surrounding a galaxy. The galaxy appears as the spiral in the center of the image with radius 15 kpc. The CGM is a diffuse gas in the dark matter halo around the galaxy. The arrows show the gas flows between the CGM and its host galaxy and with the IGM. (Reproduced from Tumlinson et al. 2017, ARA&A 55, 389)



Thermal Sunyaev-Zeldovich flux as a function of halo mass, M500, integrated out to R500 (upper), and to 5xR500 (lower) in TNG (left column) and EAGLE (right column). The shaded green region shows the mass range of the galaxy samples used in the *Planck* analysis (Planck Collaboration 2013, A&A 557, 52), and their best-fit scaling relation is shown as the dotted line (reproduced from [E]).

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: James.Bartlett@jpl.nasa.gov

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