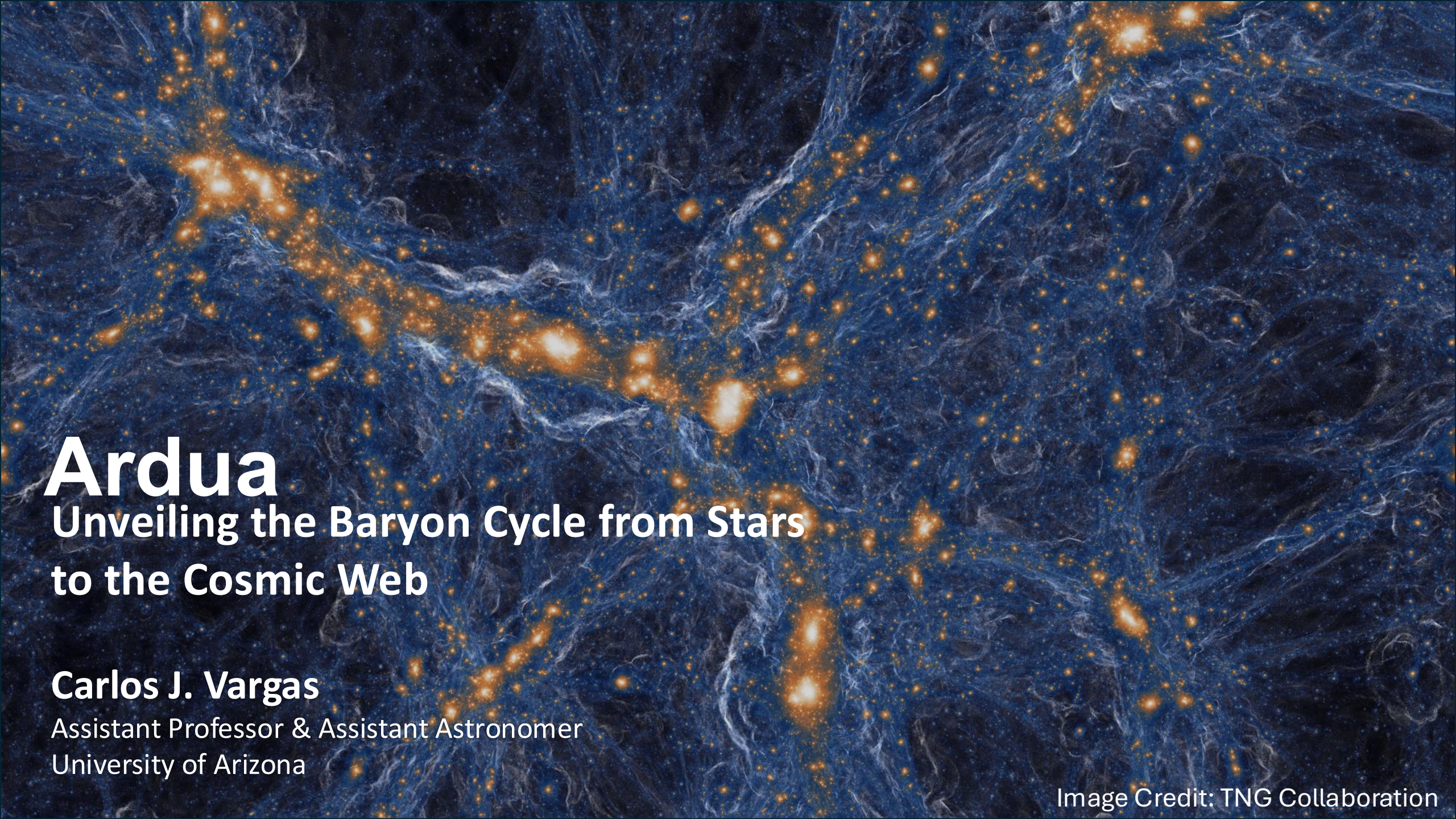


A visualization of the Cosmic Web, showing a complex network of blue filaments and nodes of orange-yellow galaxies against a dark background. The filaments represent the large-scale structure of the universe, while the orange-yellow spots represent individual galaxies and clusters.

# **Ardua**

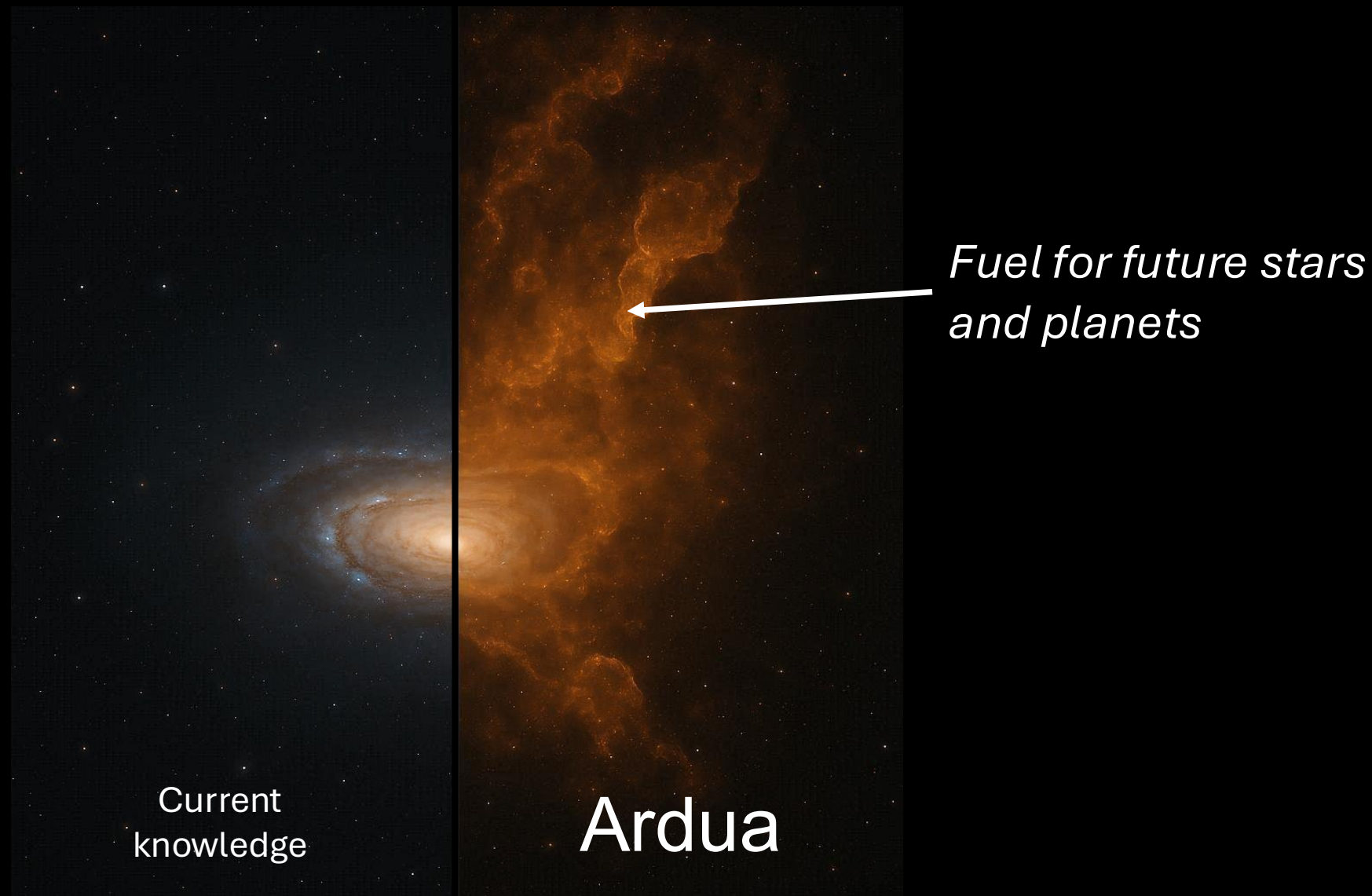
## **Unveiling the Baryon Cycle from Stars to the Cosmic Web**

**Carlos J. Vargas**

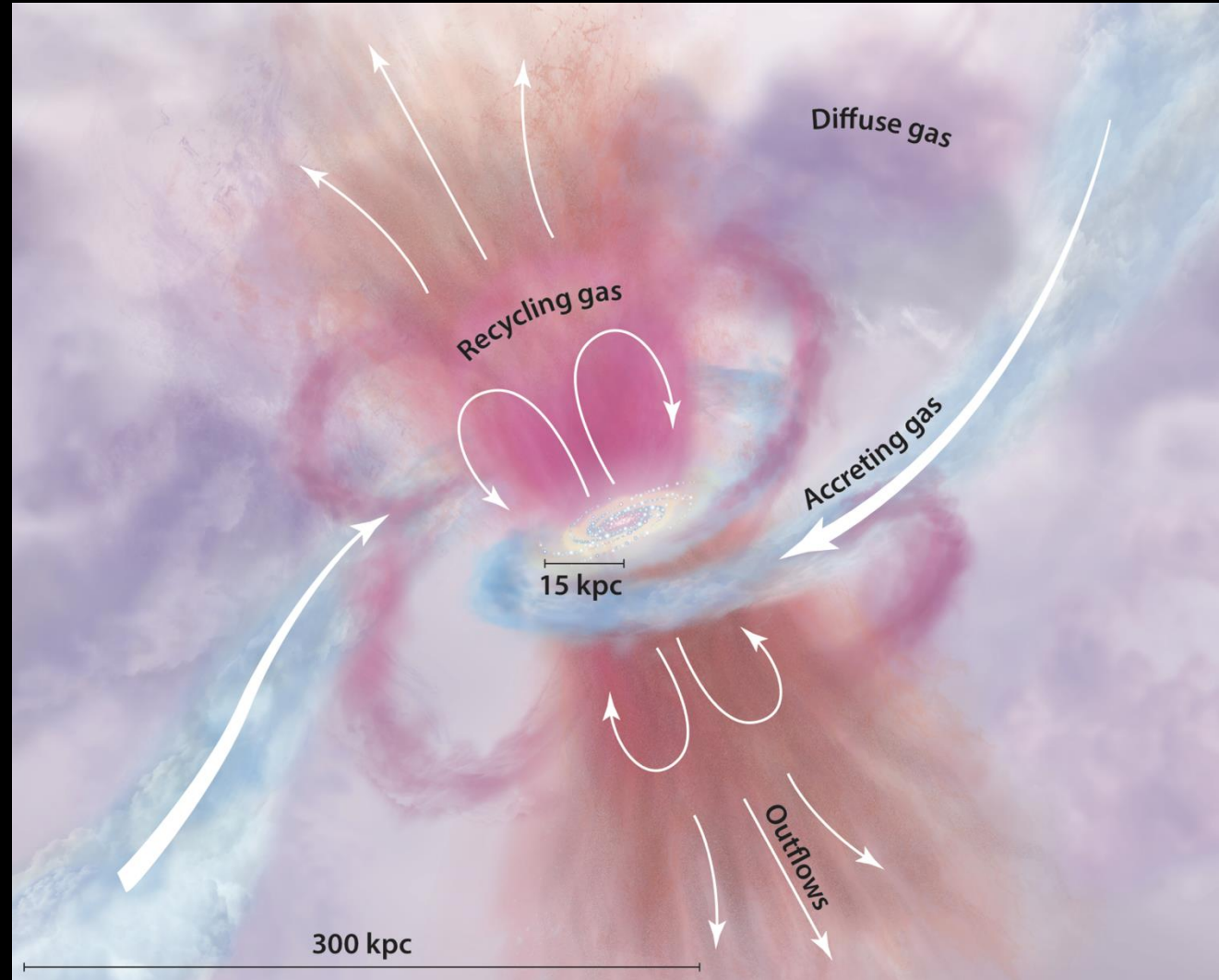
Assistant Professor & Assistant Astronomer  
University of Arizona

Image Credit: TNG Collaboration

# Most of the gas in galaxies is missing



# Why the CGM Matters



Diffuse

Dense

Gas Density

Cold

Hot

Gas Temperature

Early

Late

Star Formation Time

$t = 2.9 \text{ Gyr}$   
 $z = 2.33$

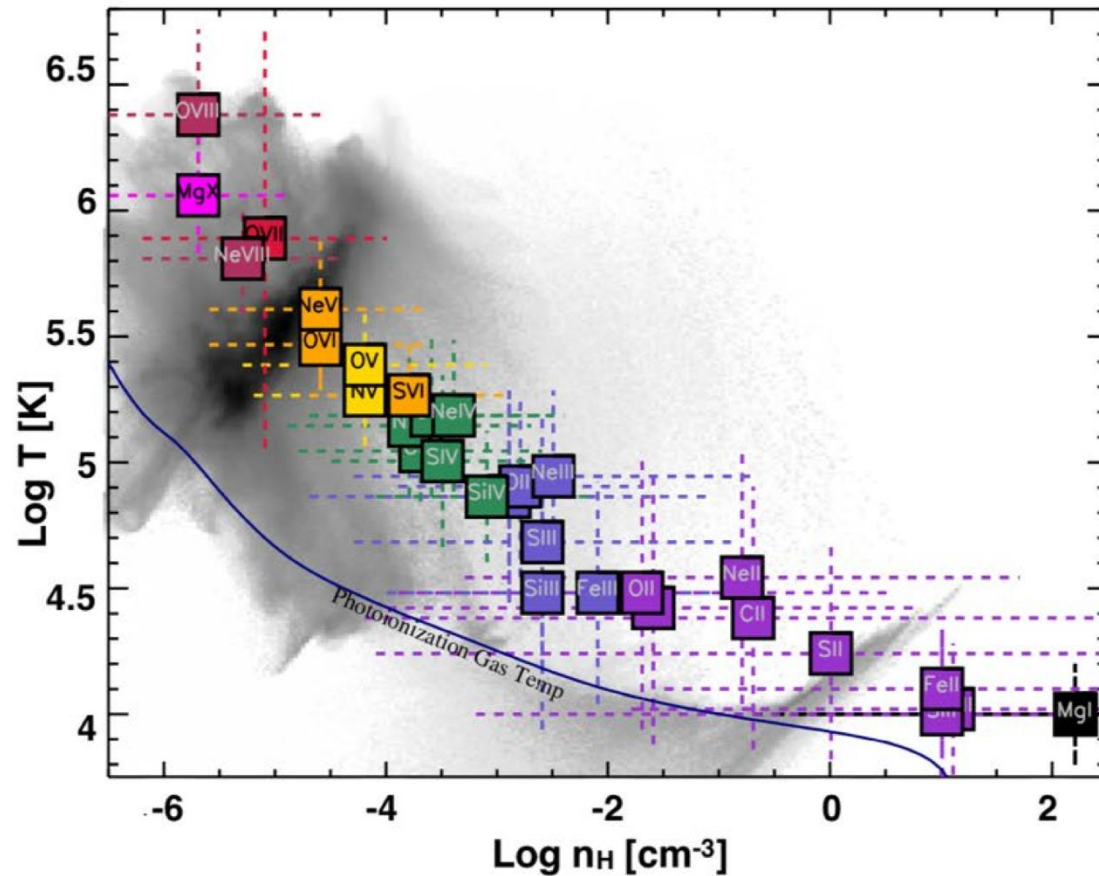
1 second  $\sim$  100 Myr

**GALAXY FORMATION IS COMPLEX AND DYNAMIC**

Peeples et al. (2019)



# The Simulated 'Multiphase' CGM



Tumlinson, Peebles, & Werk (2017)

# X-ray Discovery Space

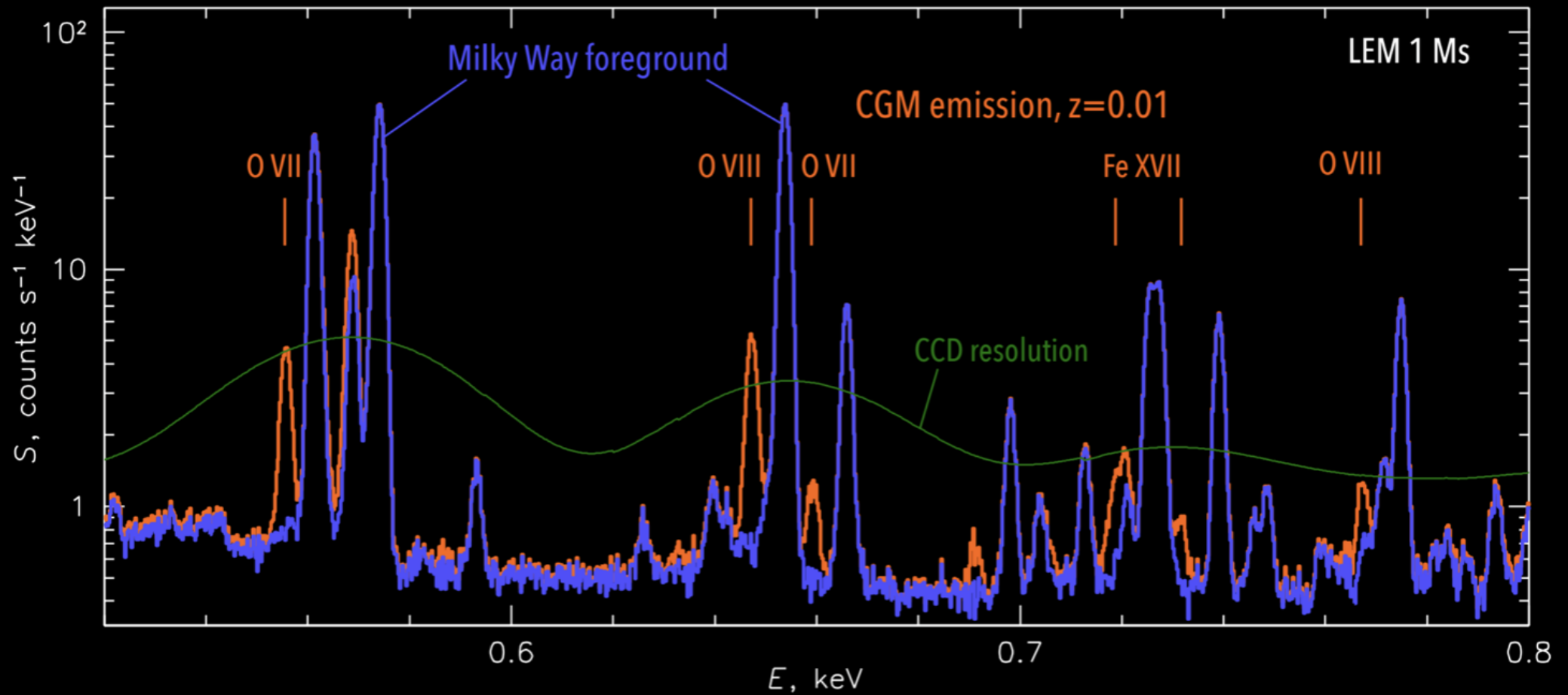
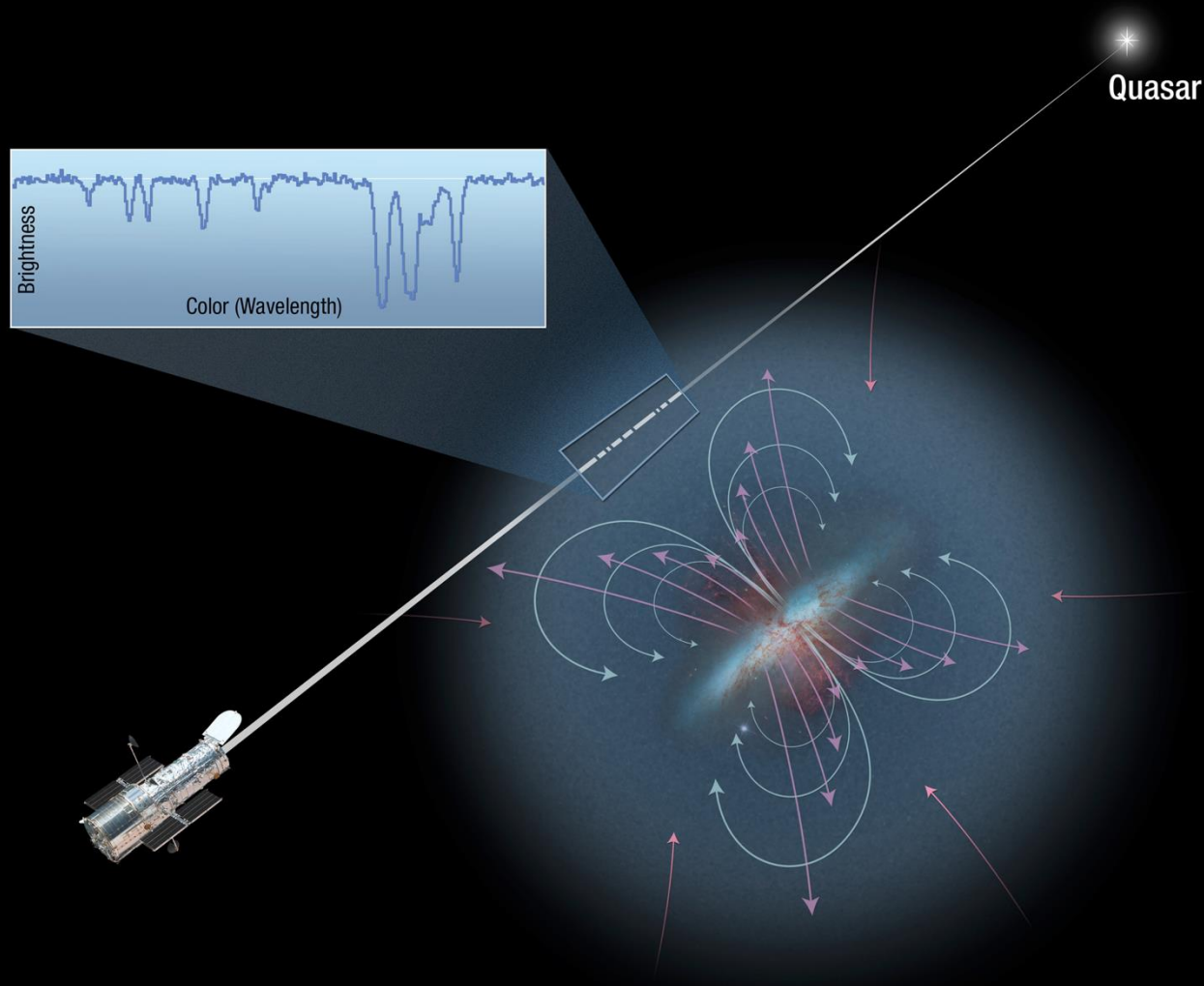


Figure: LEM Team

# What do we see in observations?

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# The Foundation of CGM Observation: Absorption

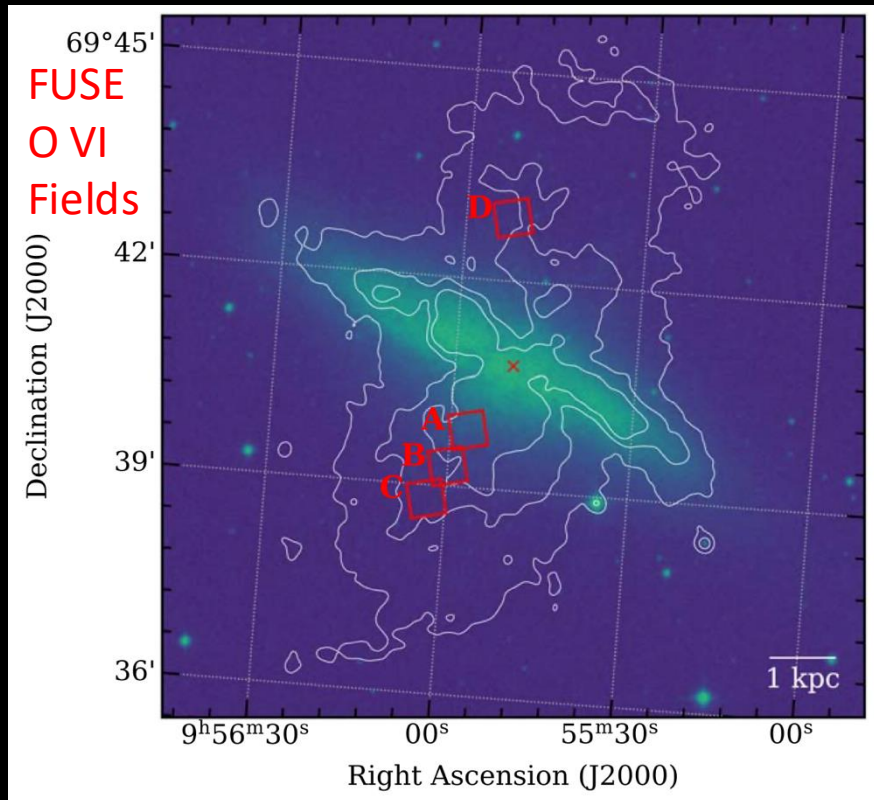


- Large metal line columns to  $\sim 150$  kpc
- High diversity of results
- $>10\%$  of entire galactic feedback energy goes into support
- Contains more mass than stars!
- Morphology?
- **We don't 'have eyes' on the dominant baryonic component of galaxies**

# Current CGM Emission Mapping Limitations

## Nearby Galaxies:

- FUV line emission limited to small individual fields (FUSE)



Kim+24 (M82)

# X-ray CGM Line Emission Results of External Galaxies

## Milky Way Line Emission Examples:

### XMM Newton

- Henley & Shelton 2012
- Miller & Bregman 2015
- Pan+24

### HaloSat

- Kaaret+19
- Kaaret+20



## X-ray Continuum in External Galaxies:

### ROSAT

- Anderson+15

### Chandra

- Dai+12
- Li+2016

### eRosita

- Zhang+24

# Current and Planned Missions

## Ultraviolet

### Aspera

- OVI only
- Low resolution

### UVEX

- Spectral R and FOV limited

### HWO

- UV MOS 'FOV' too small for survey-like mapping
- High sensitivity requires opening of microshutters – reduction in spectral R
- *Ardua is to HWO as Roman is to HST*

# Ardua

Ultra-high sensitivity, large FOV UV + X-ray imaging spectroscopy

| SCIENCE GOAL                                           | OBSERVABLE                                                                                                            | DESIRED CAPABILITY                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| How does the CGM regulate galaxy growth?               | Comprehensive multiphase gas maps around 50+ nearby galaxies; gas kinematics/turbulence; outflow vs. inflow structure | <b>Surface-brightness sensitivity</b><br><100 photons s <sup>-1</sup> cm <sup>-2</sup> sr <sup>-1</sup> (UV)<br><0.01 photons s <sup>-1</sup> cm <sup>-2</sup> sr <sup>-1</sup> (X-ray)<br><br><b>Field of view</b><br>>15' × 15'<br><br><b>Δv</b> ≈ 6 km s <sup>-1</sup> (UV)<br><b>Δv</b> ≲ 50 km s <sup>-1</sup> (X-ray) |
| How do galaxies connect to the cosmic web?             | Metal enrichment of CGM/IGM; hot gas tracing cosmic web filaments on degree scales                                    |                                                                                                                                                                                                                                                                                                                             |
| How do stars and black holes shape their environments? | Energy partition b/w ISM, superbubbles, and CGM; stellar/planetary-host environment characterization for HWO targets  |                                                                                                                                                                                                                                                                                                                             |

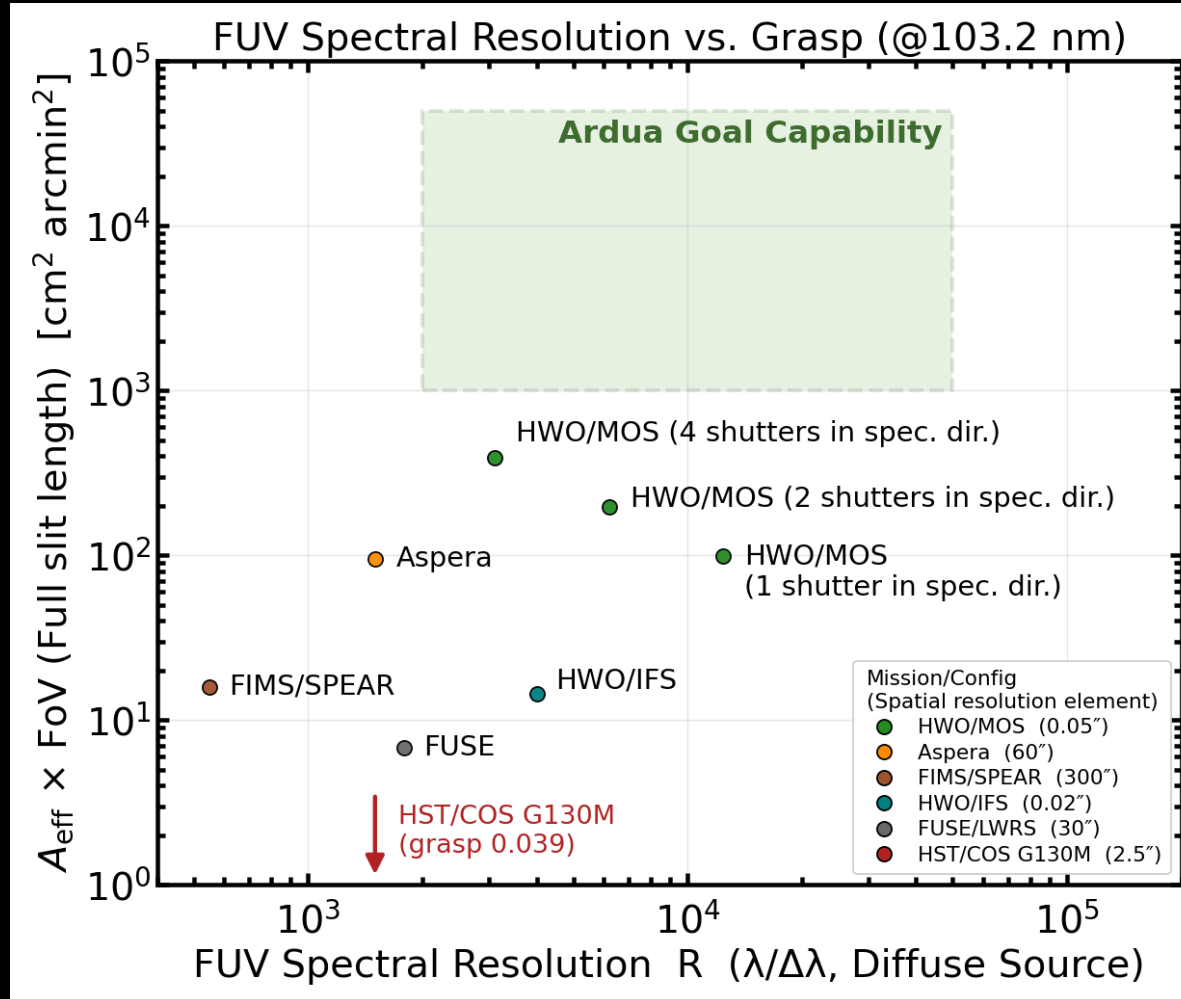
Ardua ASTRA Submission →



# Ardua

## Unveiling the Baryon Cycle from Stars to the Cosmic Web

*Ardua is to HWO  
as  
Roman is to HST*



### X-ray emission sensitivity capability

For extremely faint (0.01 LU) O VIII at  $z \sim 0.01$ :

- 8-sigma O VIII detection in  $\sim 10$  days exposure

# Stay tuned for more!

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## Affiliated talks this week:

- Science with X-ray imaging spectroscopy – **Ralph Kraft** (Monday, Cosmology)
- UV Instrument – **Haeun Chung** (Wednesday, X-ray+UV)
- Galaxy feedback mechanism simulations – **John ZuHone** (Monday, Galaxies)
- X-ray Technology Development – **Steve Smith & Caroline Kilbourne** (Poster)

Ardua ASTRA Submission →



# Takeaway Message



There's a gap in our understanding of the circumgalactic medium (CGM)



We need to make an observational leap to fill this gap



*Ardua* is designed to make that leap

Comprehensive multiphase mapping of the CGM/IGM from X-ray to UV with Ardua!