



Observational Signatures of the Gas In and Around Galaxies

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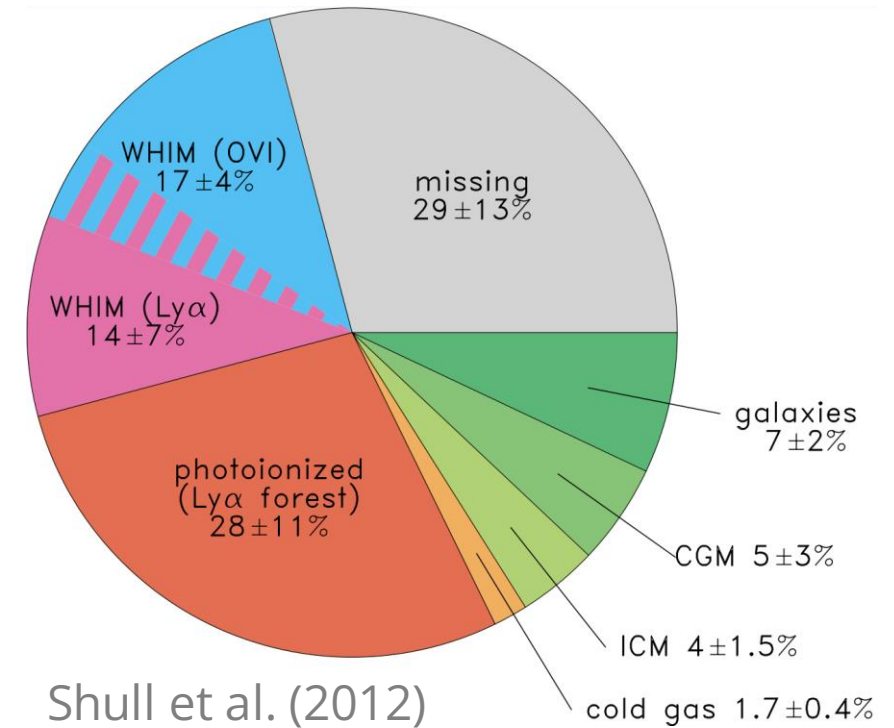
Overview

- Background
 - The Missing Baryon Problem
 - Cosmological Simulations
- Ionization Table
- Application to simulations
- Conclusion

Background

Missing Baryons

- Current surveys cannot account for all baryons—*Cosmic* missing baryons
- Galaxies have less baryonic matter than expected—*Galactic* missing baryon problem
- Circumgalactic Medium (CGM) is a potential 'reservoir'



Background

Cosmological Simulations

- Ideally, tracking all the ions of interest
- Instead, evolve H, He, Z, and post-process
 - Analysis that adds information that's too costly to calculate in the simulation
- e.g. number density of specific ion

Background

Post-Processing

- Start with H number density, metallicity
- Assume solar abundance \rightarrow number density of any element
- Element number density & ionization fraction \rightarrow ion number density

Background

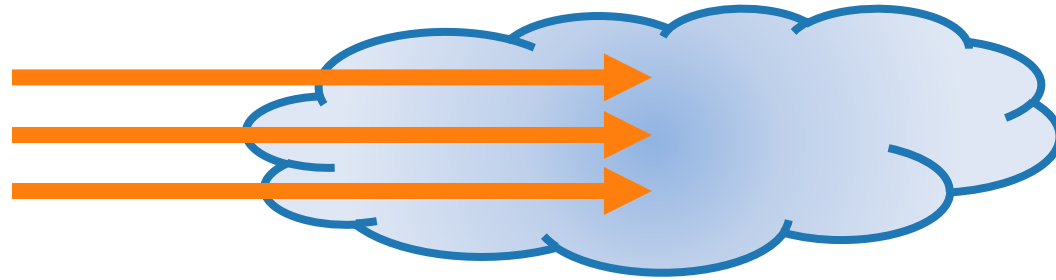
Ionization Table

- Pre-computed table of ionization fractions
- Function of:
 - Density
 - Temperature
 - Redshift, as a proxy for radiation
- Existing tables assume optically thin or self-shielding but solar metallicity

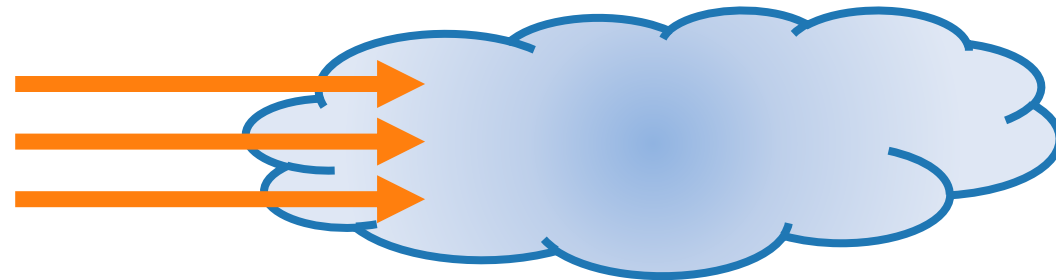
Background

Self Shielding

- Optically thin: ionizing radiation reaches everywhere in a cloud



- Self-shielding: the outside of a cloud is ionized, no radiation reaches the centre



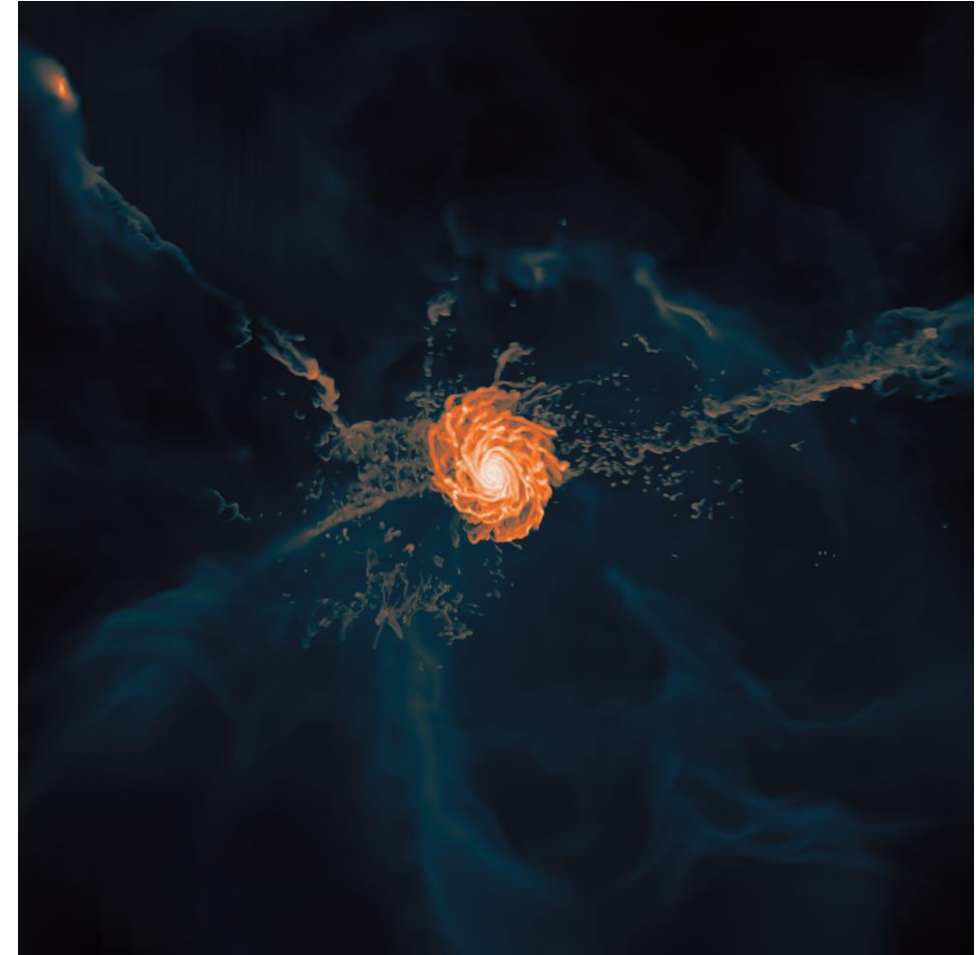
The Ionization Table

New Table

- What's new:
 - I'm considering self-shielding, with varying metallicity
 - The CGM is dense, and enriched
- Created table from CLOUDY models
- Added code to YT and TRIDENT libraries to work with higher dimensional ionization table
- Will be made available for other research

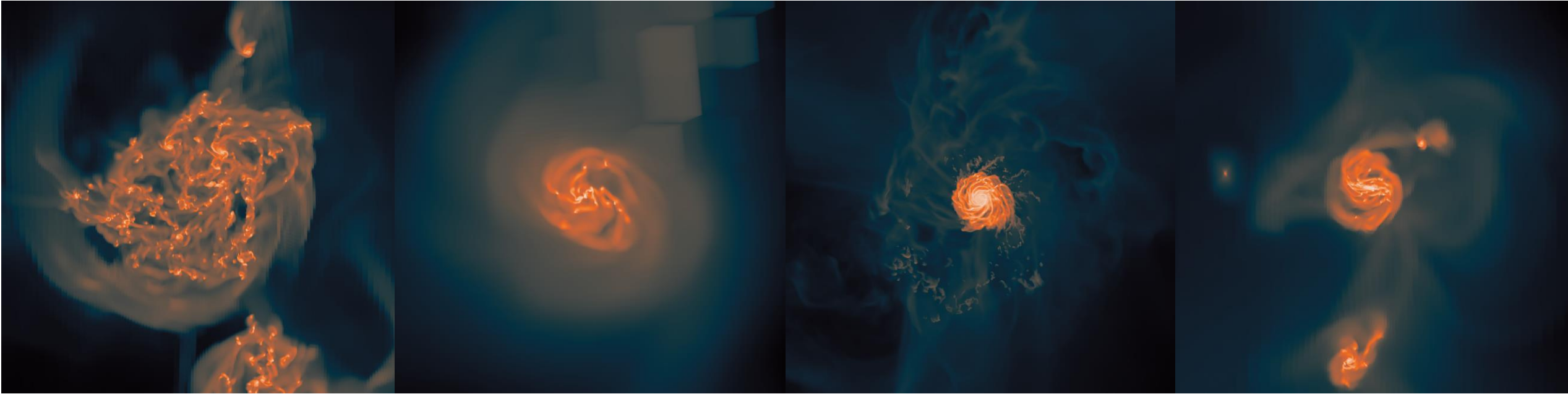
Simulation Data

- 6 Simulated Galaxies (5 evolved to $z=0$)
- Figuring Out Gas and Galaxies In Enzo (FOGGIE) project (Simons et al. 2020)
- High-resolution zoom simulations
- Focused on resolving the CGM



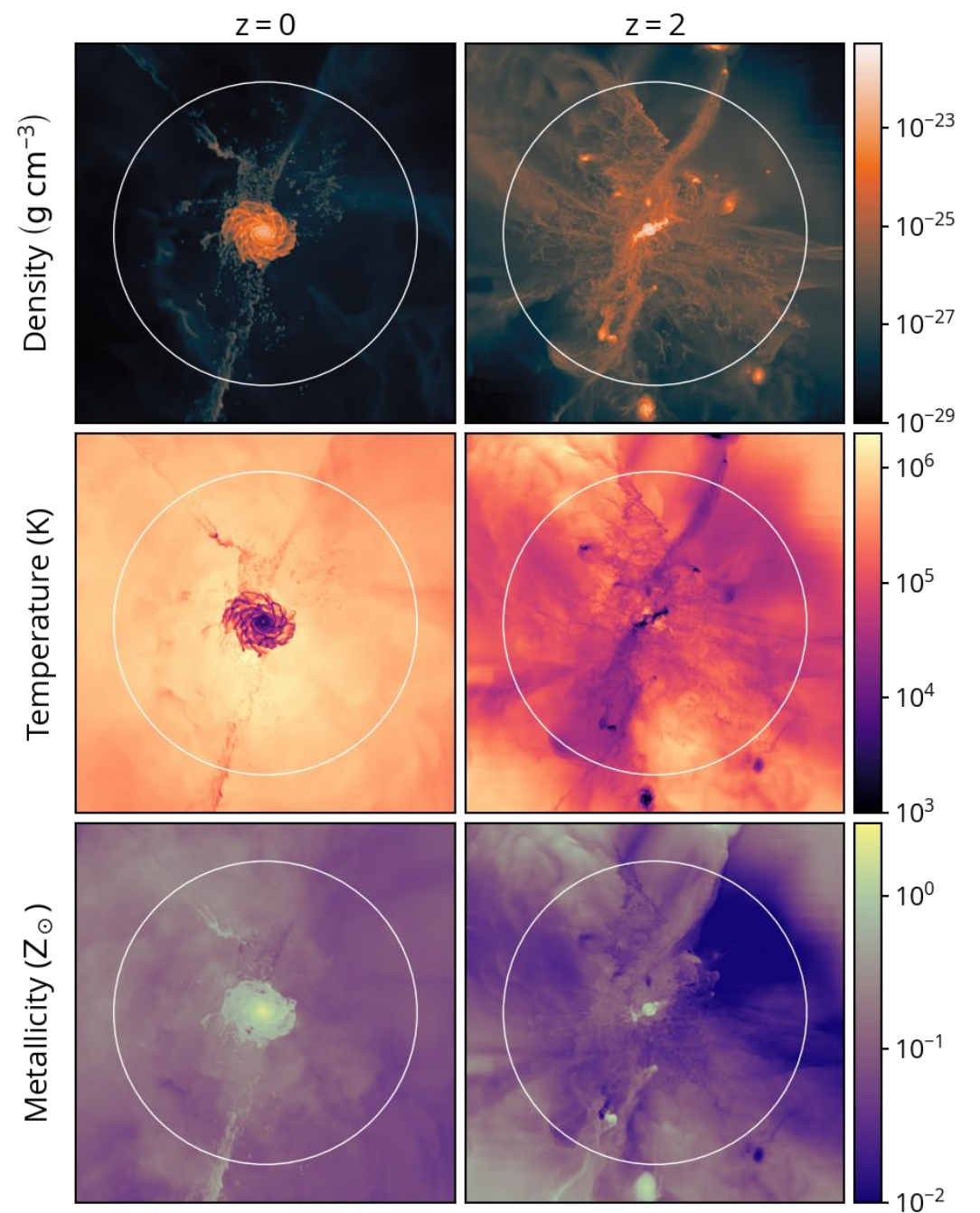
Simulation Data

- Other examples:



Simulation Data

- Cool, dense, clouds exist in the CGM
- Non-solar metallicities
- Analyse 100kpc sphere:
 - Total mass
 - Average number density

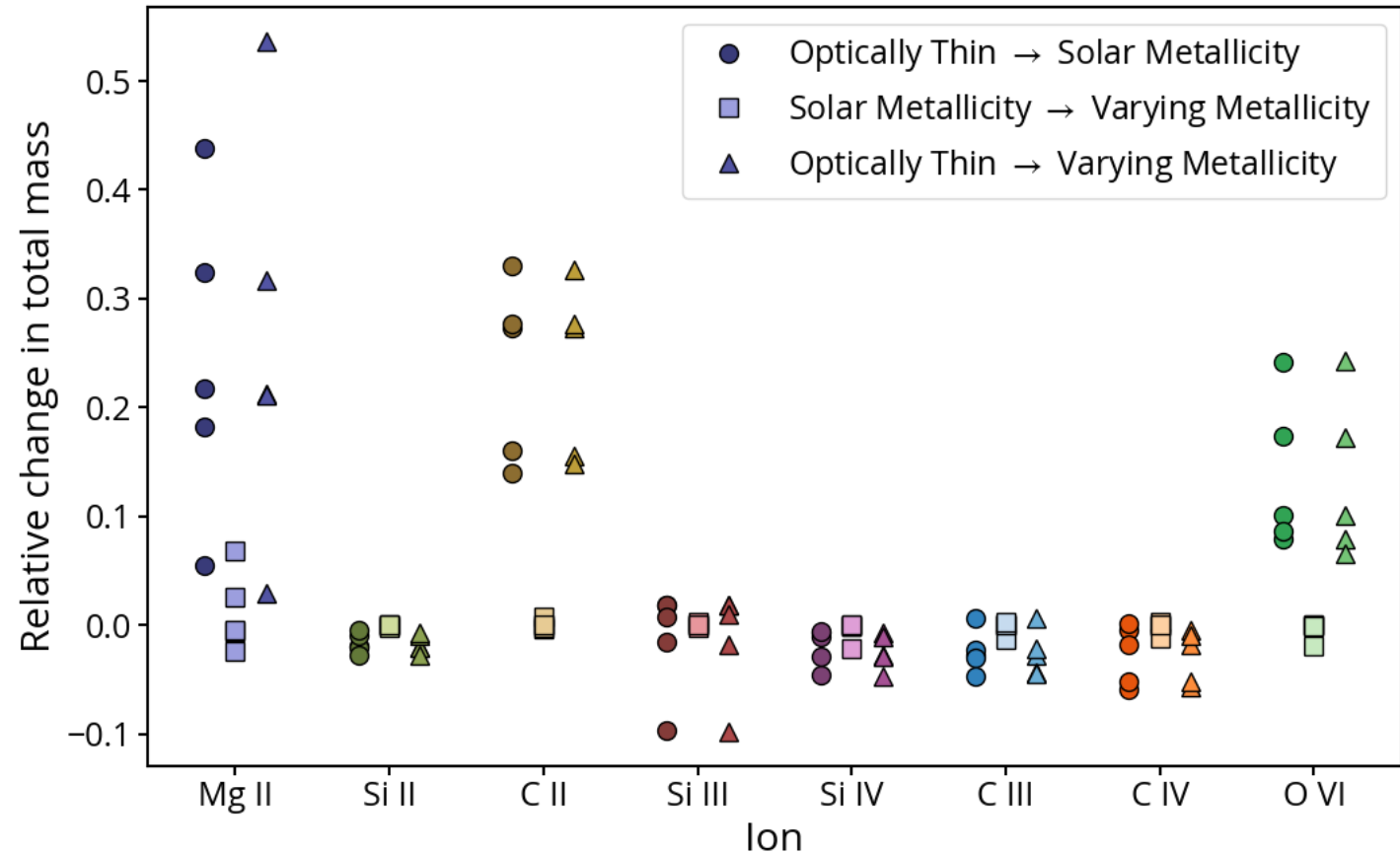


What are we comparing?

- 3 Ionization Tables:
 1. Optically thin
 2. Self-shielding, solar metallicity
 3. Self-shielding, non-solar metallicities
- 3 Comparisons:
 1. Optically thin vs. self-shielded (solar metallicity)
 2. Solar metallicity vs. varying metallicity
 3. Optically thin vs. self-shielded (varying metallicity)

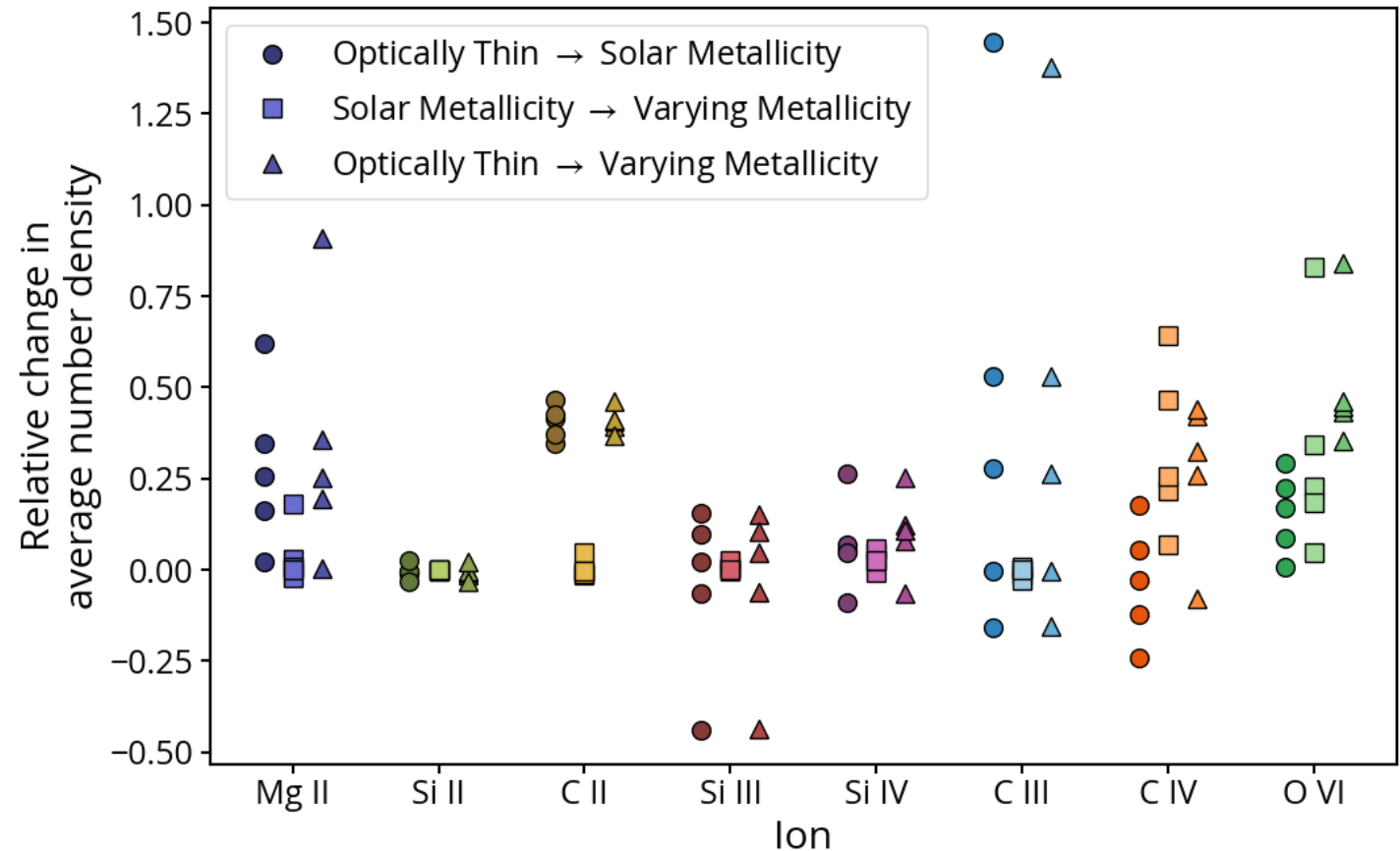
Total mass

- Metallicity has little effect
- Self-shielding important



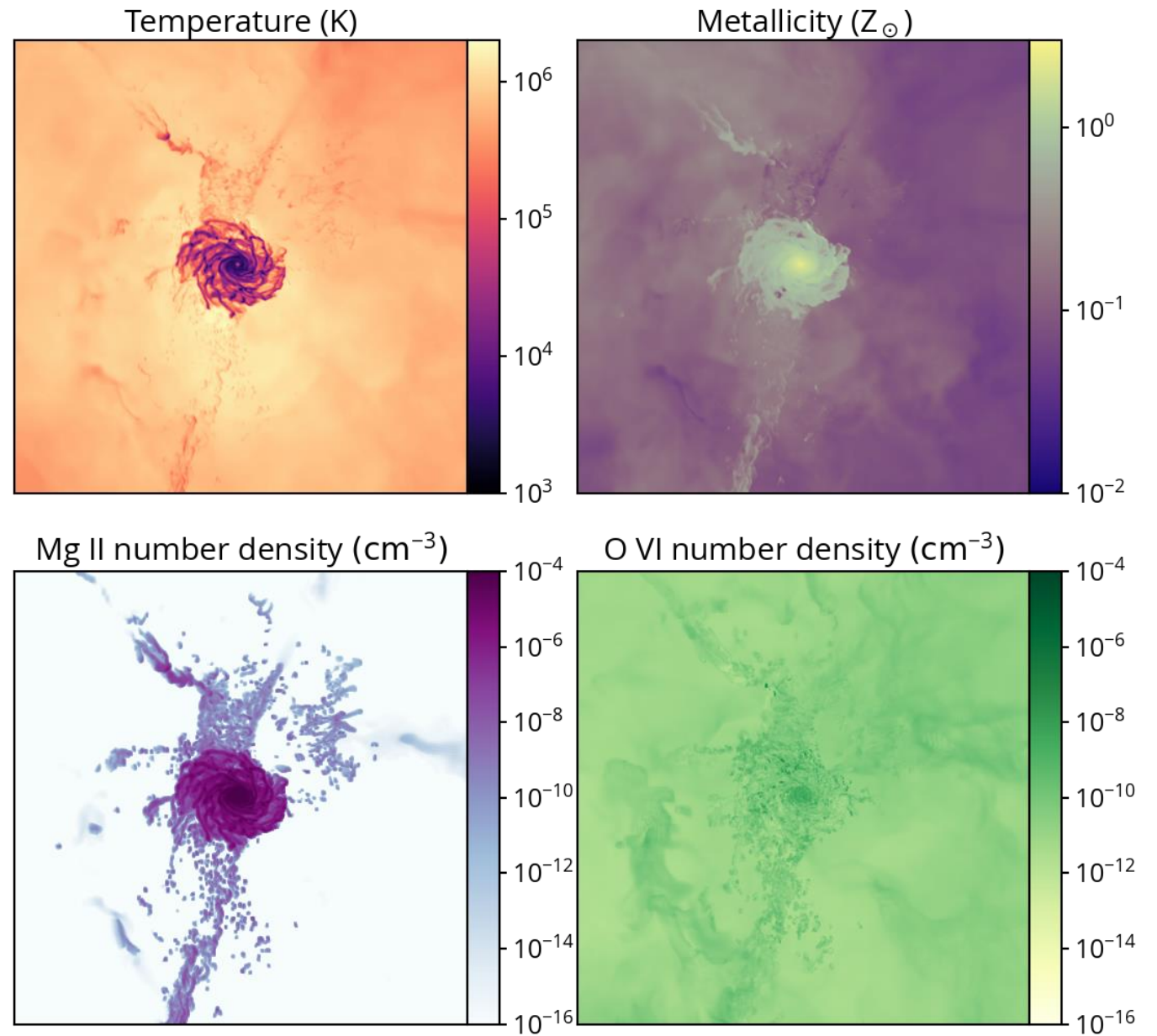
Average Number Density

- Similar trend, but metallicity more important for some ions
- Why?



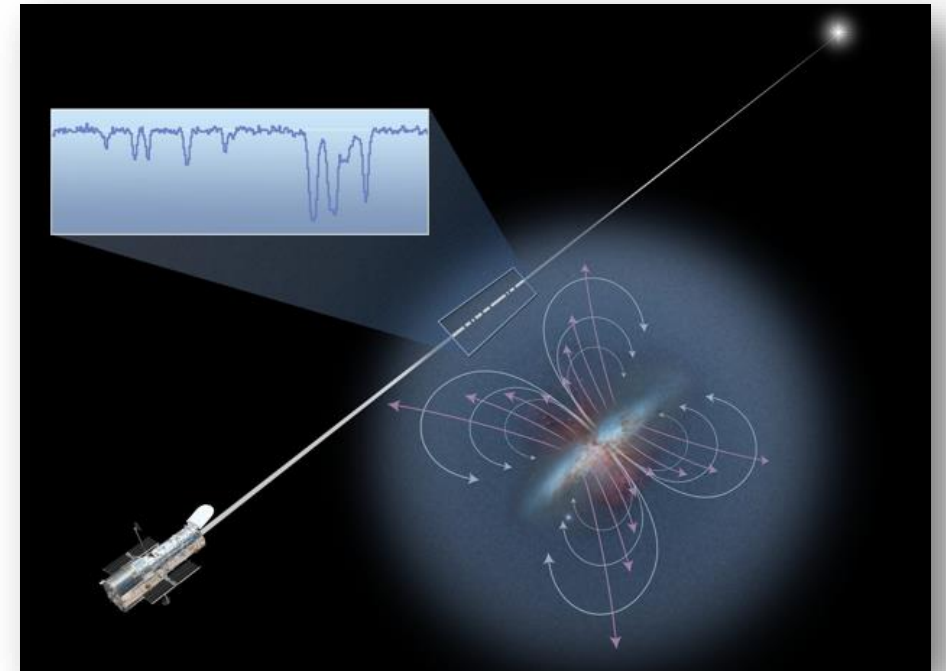
Why?

- These ions trace hotter, lower metallicity gas
- Solar metallicity is sometimes valid, other times not



Observationally

- Can these be discerned observationally?
- Look at column density for three different tables
- Compare to observational data (Peeples et al 2019)



NASA/STScI/Ann Feild

Observationally

- Consider the fraction (%) of column densities that are detectably different:

| Ion | Optically Thin → Solar Metallicity | Solar Metallicity → Varying Metallicity | Optically Thin → Varying Metallicity |
|-------|---------------------------------------|--|---|
| Si II | 0.552 | 0.000 | 0.574 |
| Si IV | 0.014 | 0.002 | 0.015 |
| C IV | 0.007 | 0.020 | 0.013 |
| O VI | 17.507 | 0.022 | 17.509 |

- Observationally challenging to tell apart

To Conclude

- Observational Baryon Censuses incomplete: look to Circumgalactic Medium
- Created a new ionization table that includes self-shielding and varying metallicity
- Makes a difference, especially for *high* ions, but challenging to detect observationally.

Bibliography

J. Michael Shull *et al* 2012 *ApJ* 759 23

Molly S. Peeples *et al* 2019 *ApJ* 873 129

Raymond C. Simons *et al* 2020 *ApJ* 905 167