Observational Signatures of the Gas In and Around Galaxies

Evan Jones

Supervisor: Dr Britton Smith

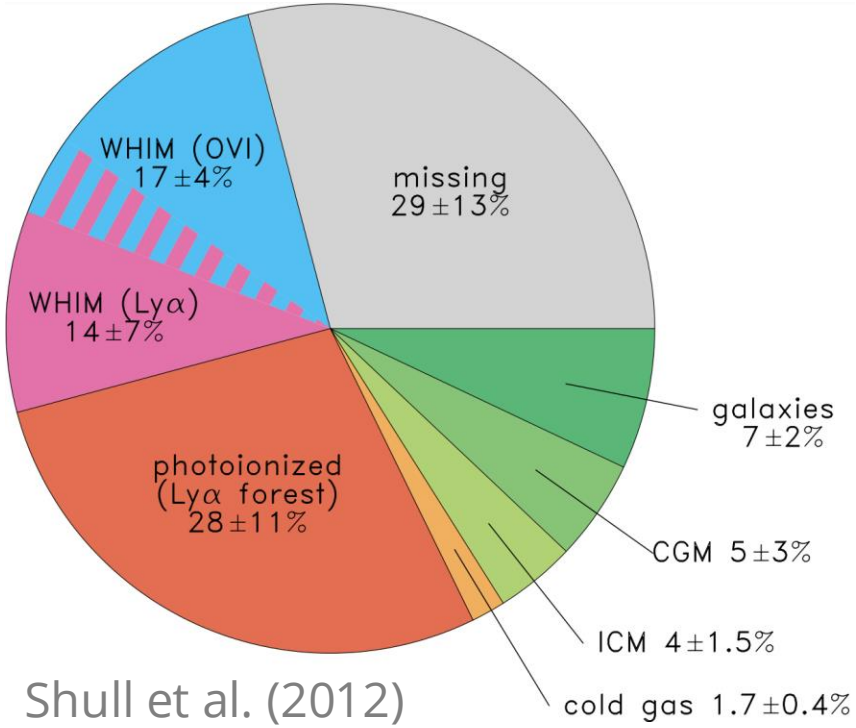
Overview

- 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’



Shull et al. (2012)

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 → number density of any element
- Element number density & **ionization fraction** → ion number density

Background

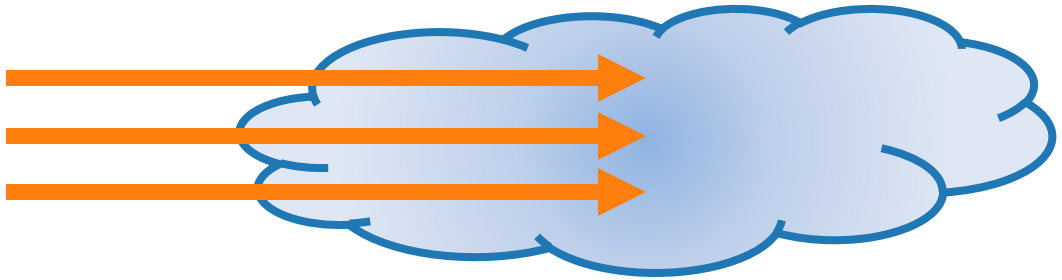
Ionization Table

- 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

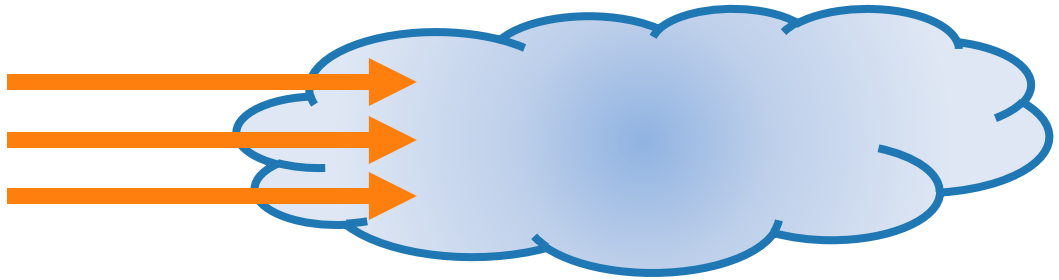
Background

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



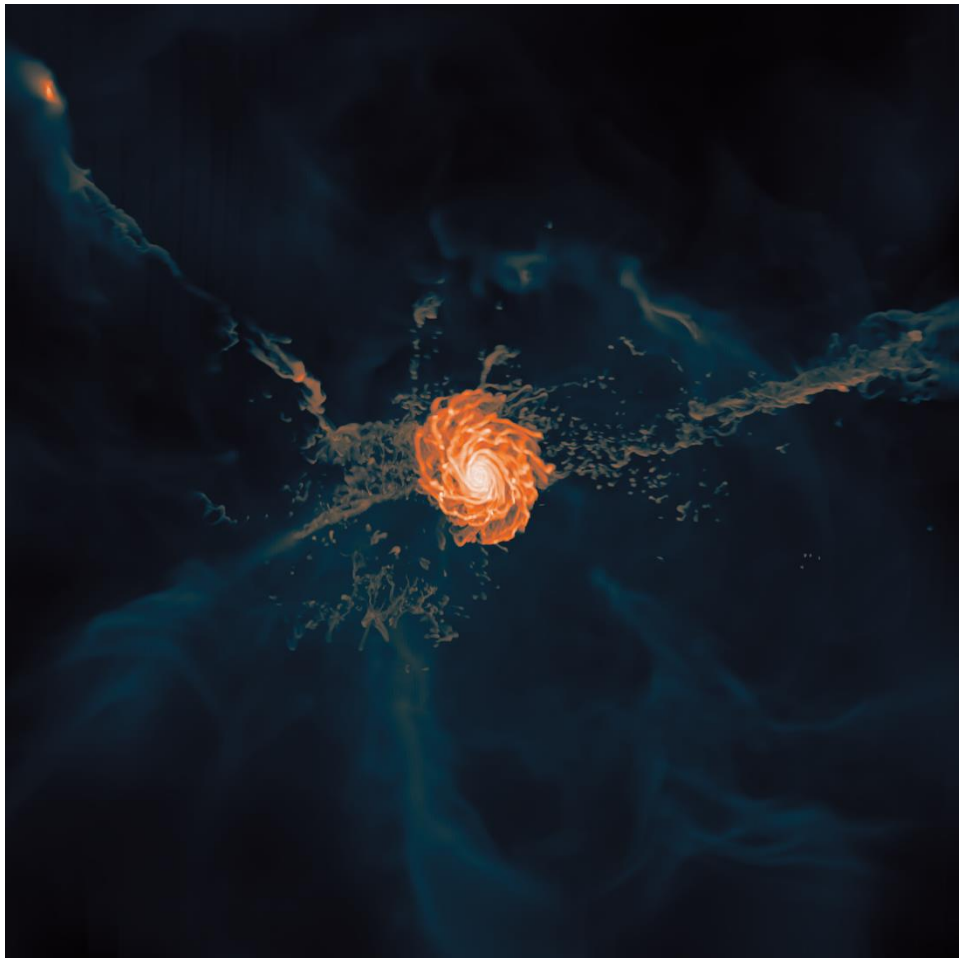
The Ionization Table

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

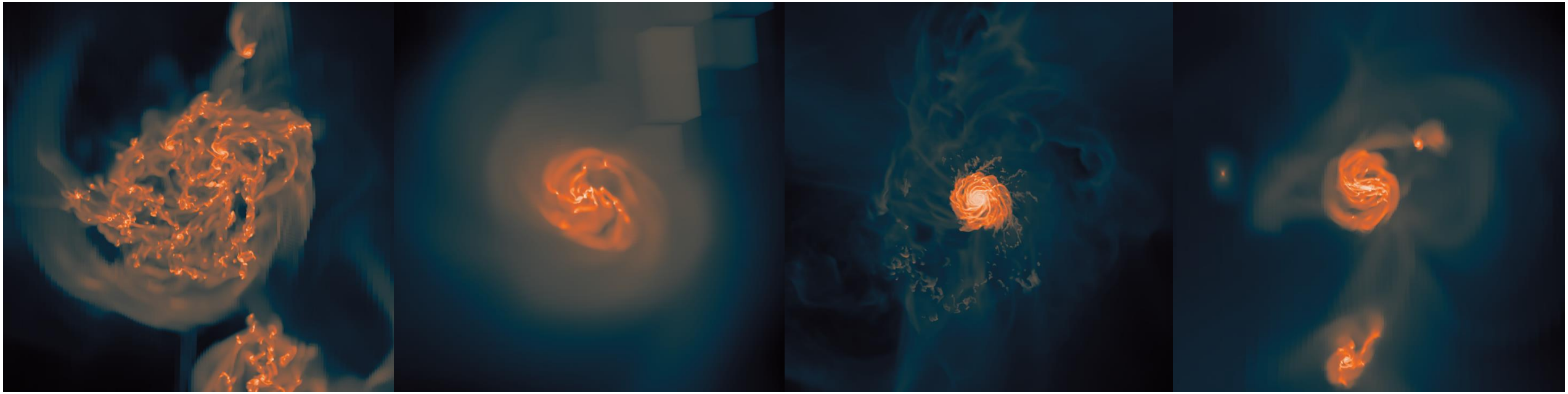
Simulation Data

- 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



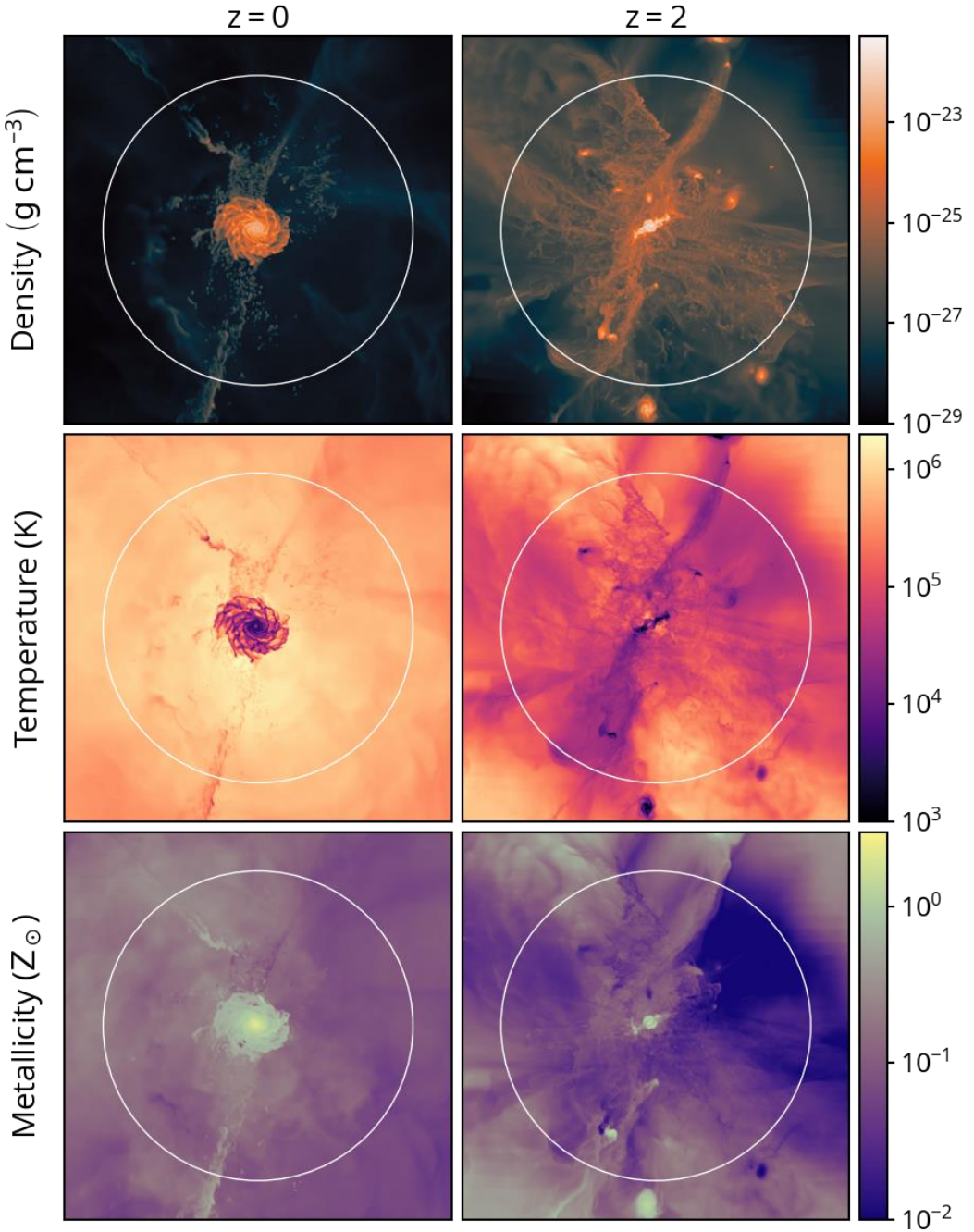
Simulation Data

- Other examples:



Simulation Data

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

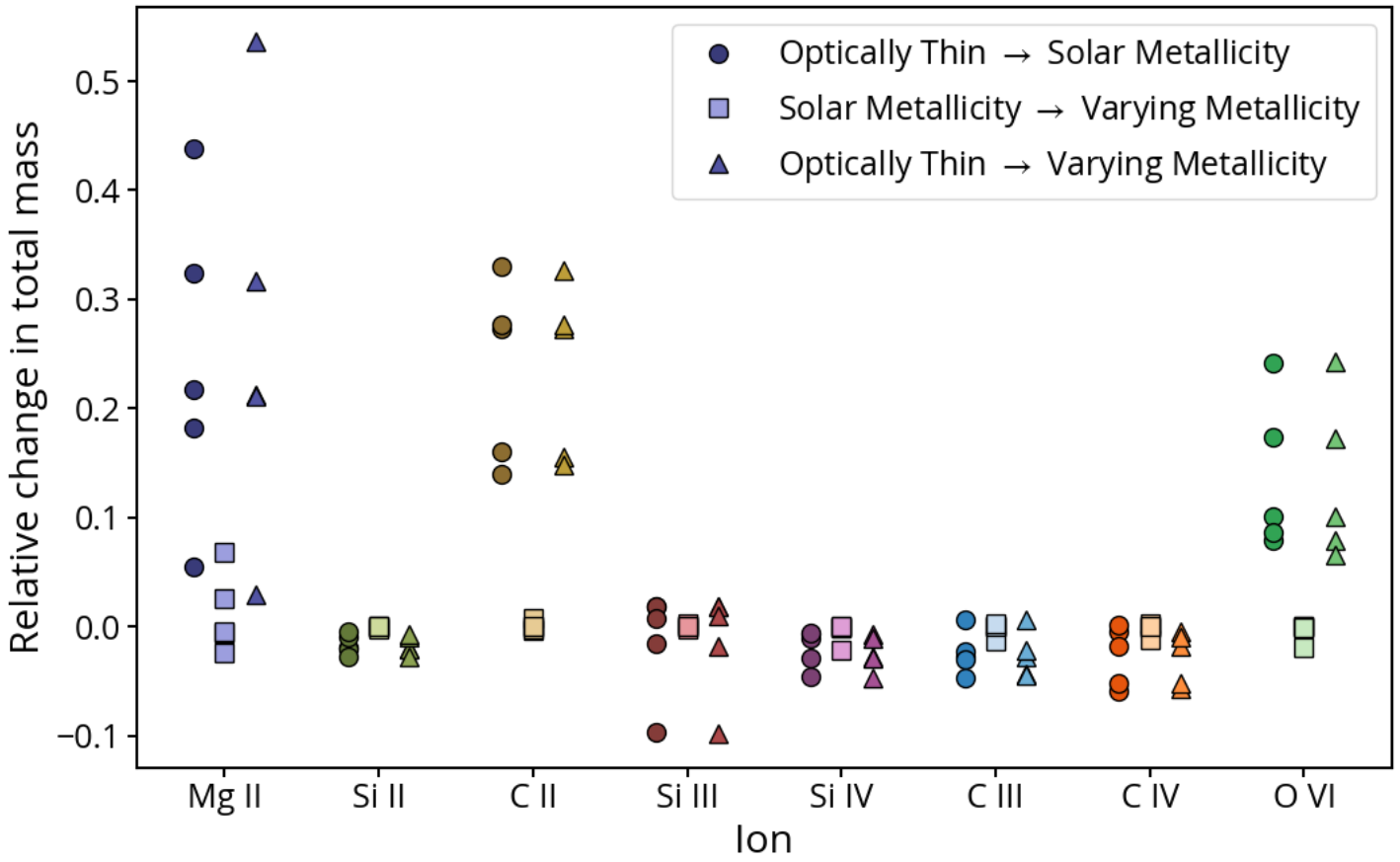


What are we comparing?

- 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)

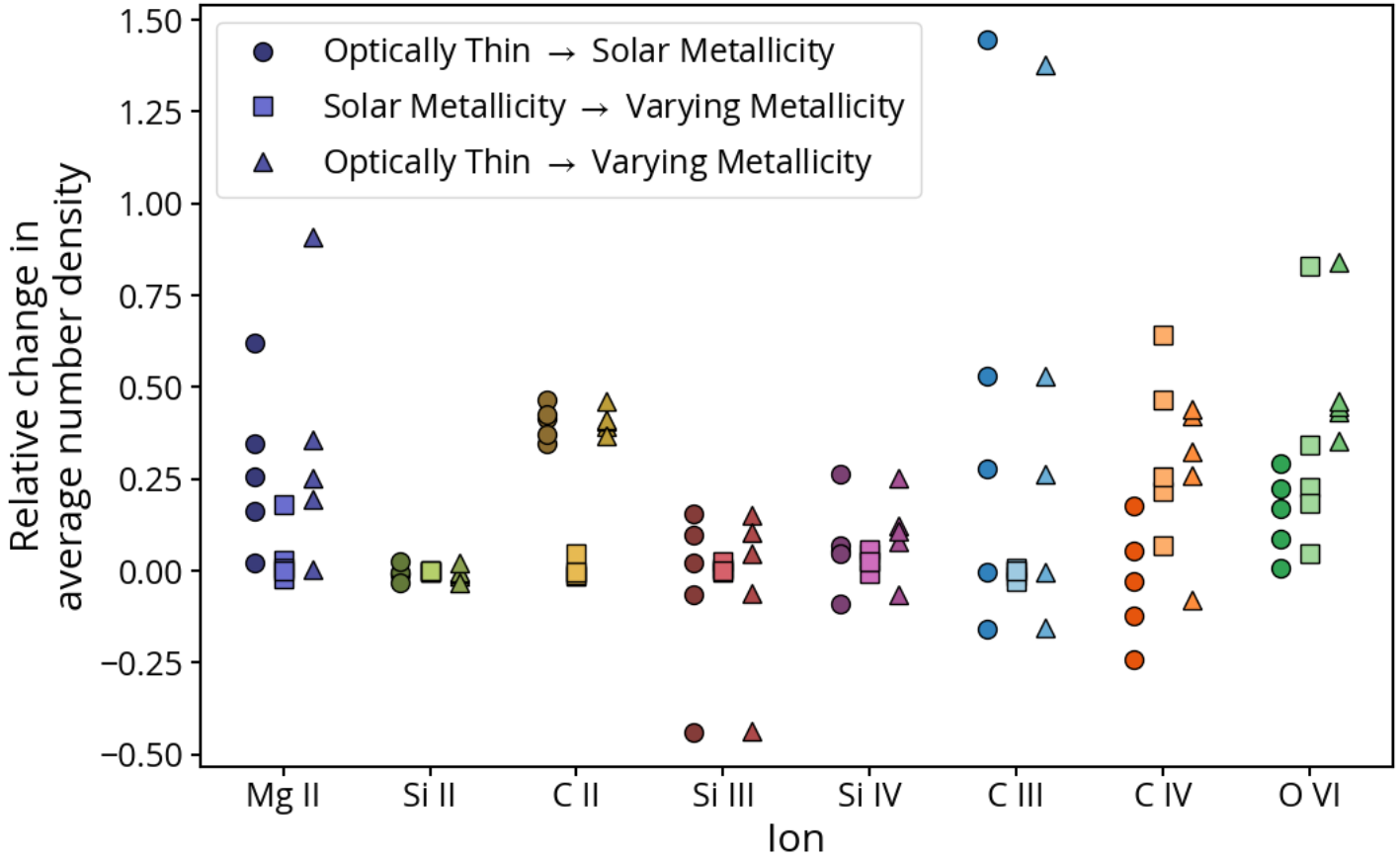
Total mass

- Metallicity has little effect
- Self-shielding important



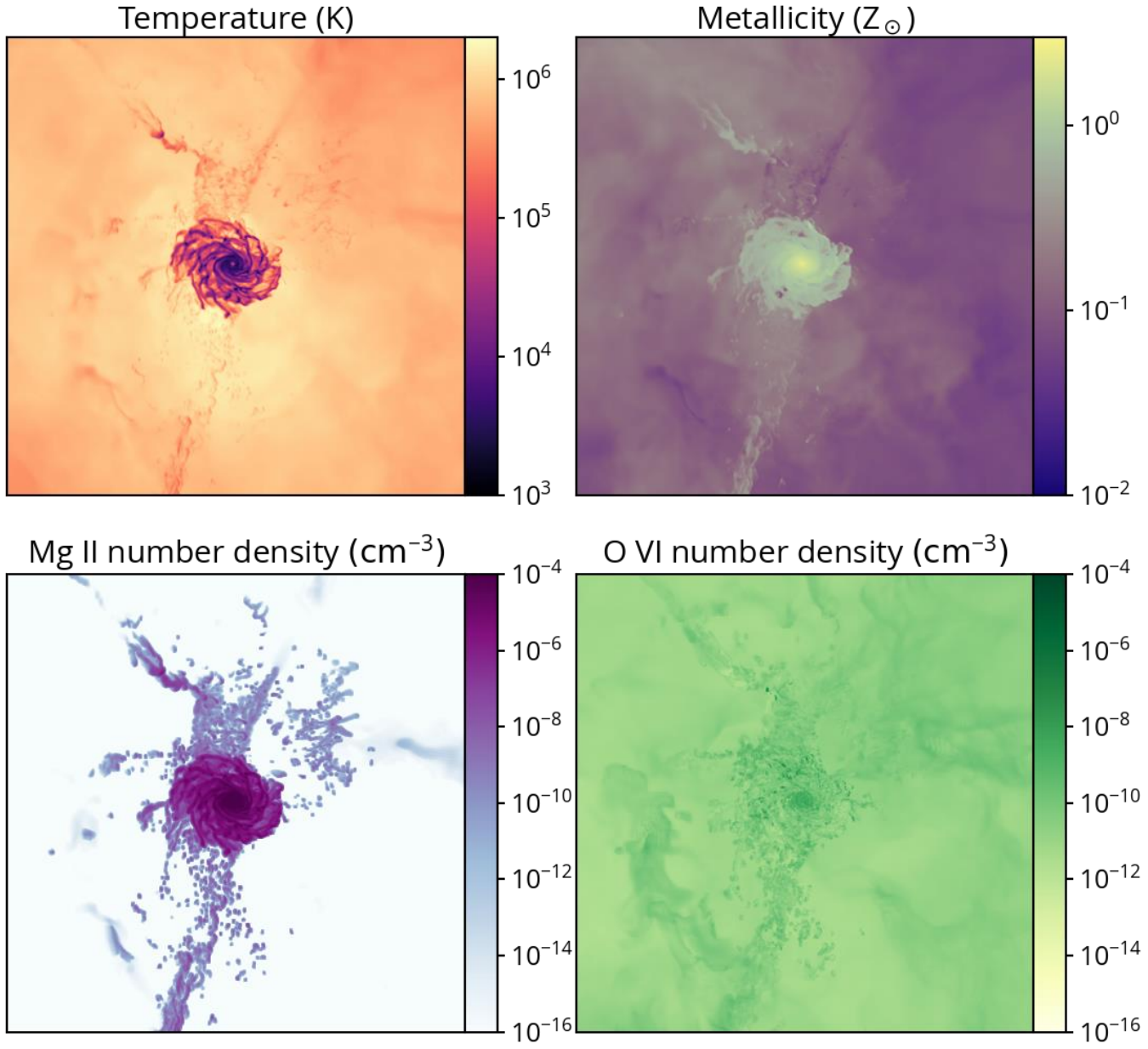
Average Number Density

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



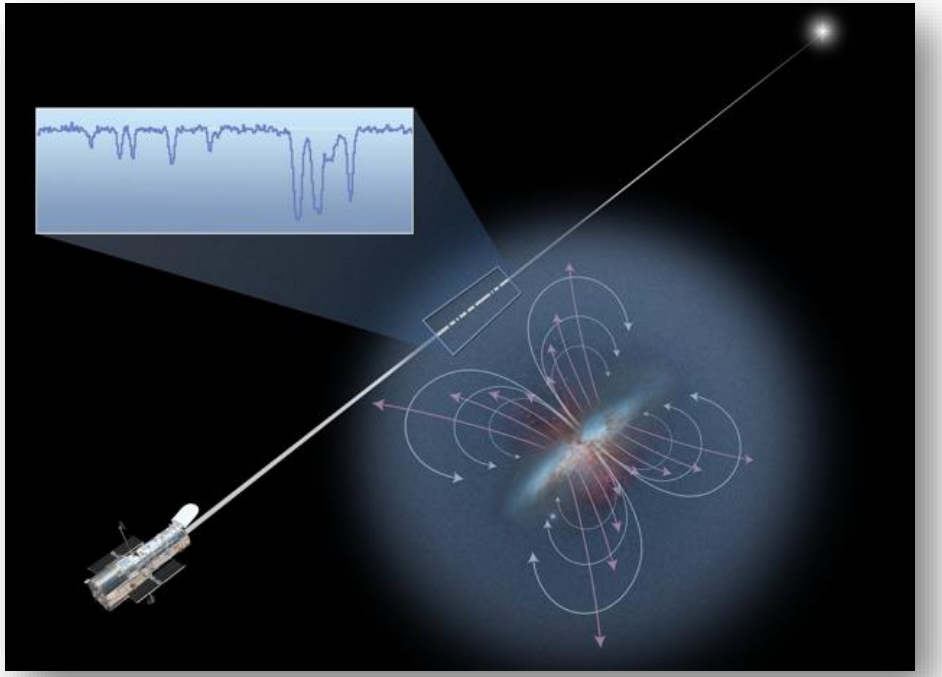
Why?

- 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