What do X-Ray Observations Teach Us About The Circumgalactic Medium?

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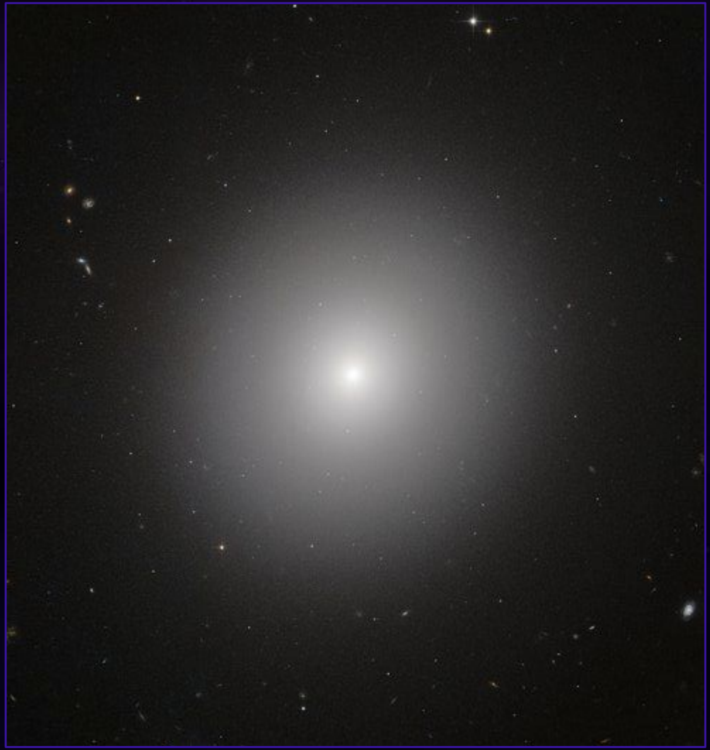
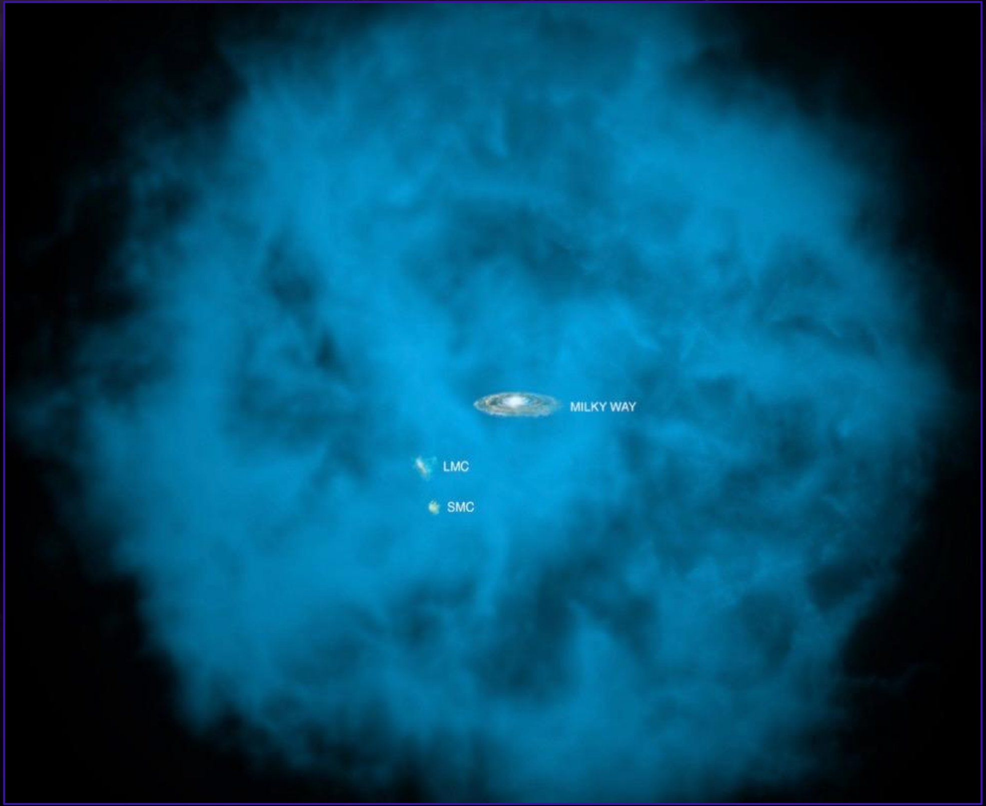
Advisor: Prof. Matthew McQuinn

What is a Galaxy?

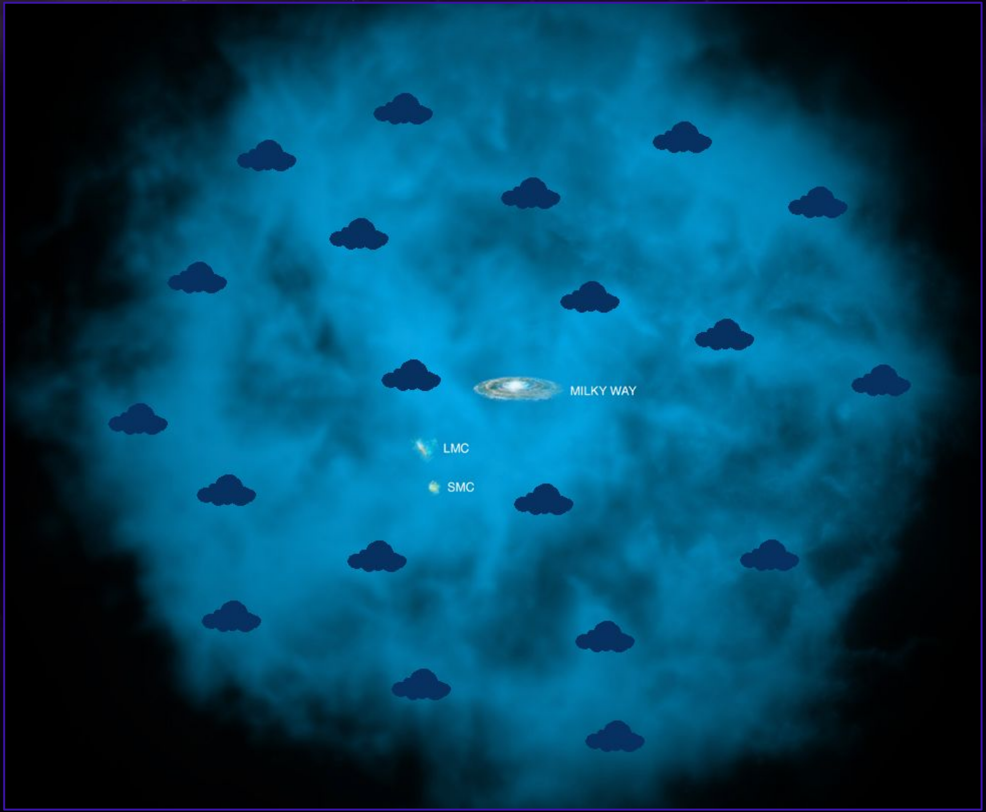


What is a Galaxy?



- The Circumgalactic Medium (CGM) is a non-uniform cloud of gas surrounding a galaxy
- Much larger than the central galaxy:
  - ~10–30 times the diameter

What is a Galaxy?

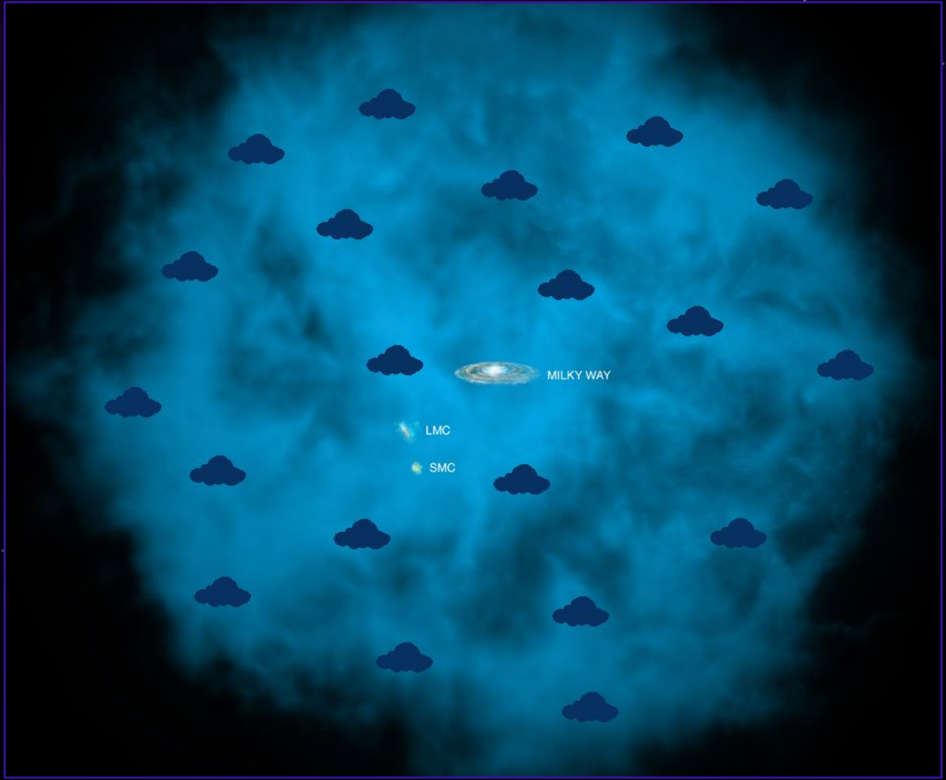


- The Circumgalactic Medium (CGM) is a non-uniform cloud of gas surrounding a galaxy
- Much larger than the central galaxy:
  - ~10–30 times the diameter
- Comprised of:
  - **Hot-phase (~10^6 K)**
  - Cold-phase (~10^4 K)

Why is the CGM Important?

- CGM interfaces between Inter*stellar* Medium and Inter*galactic* Medium
  - Gas condenses and cools into clouds, accreted into the central galaxy to form stars

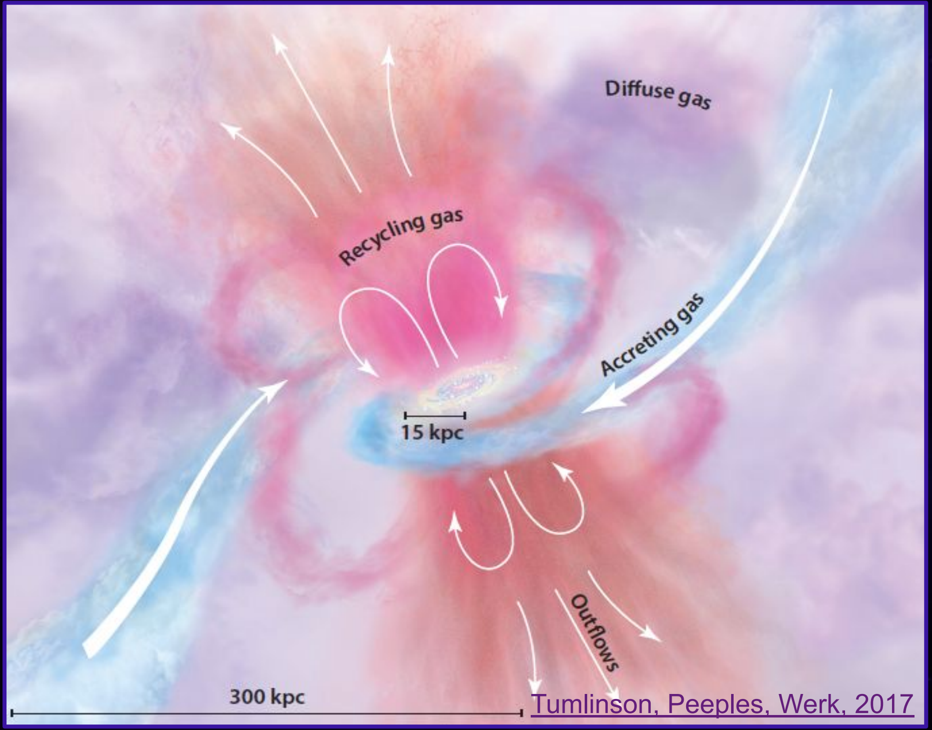
- Could possibly shed light on the transformation from star-forming to quiescence.



Why is the CGM Important?

- CGM interfaces between Inter*stellar* Medium and Inter*galactic* Medium
    - Gas condenses and cools into clouds, accreted into the central galaxy to form stars

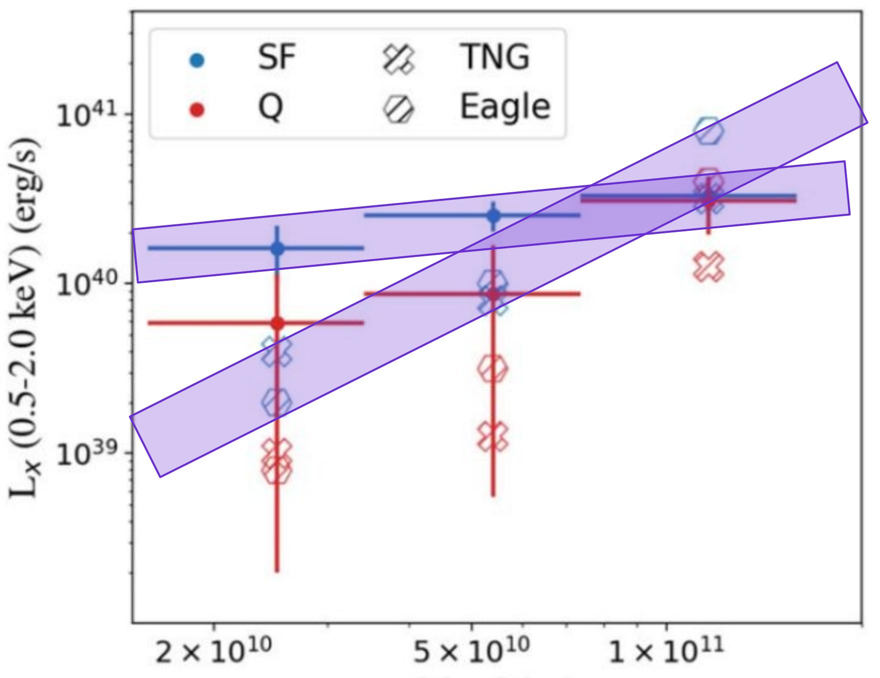
- Studying the CGM is necessary to understand how galaxies evolve over time
    - Sheds light on the transformation from star-forming to quiescence



Tumlinson, Peeples, Werk, 2017

New Observational Data

- New observational data from eROSITA has shown to conflict with cosmological simulations (Chadayammuri et al. 2022)
  - Implies a gap in our understanding of the formation and heating of the CGM



(Chadayammuri et al. 2022)

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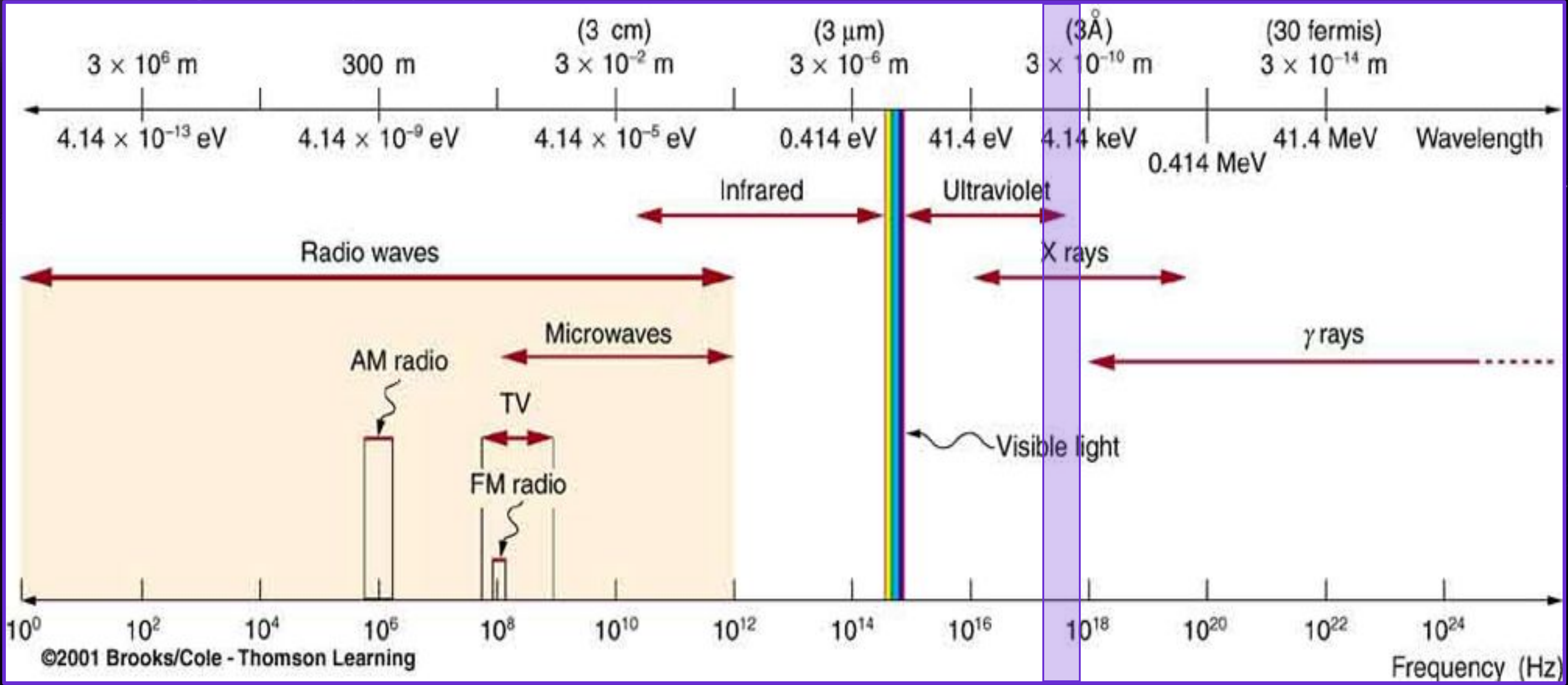
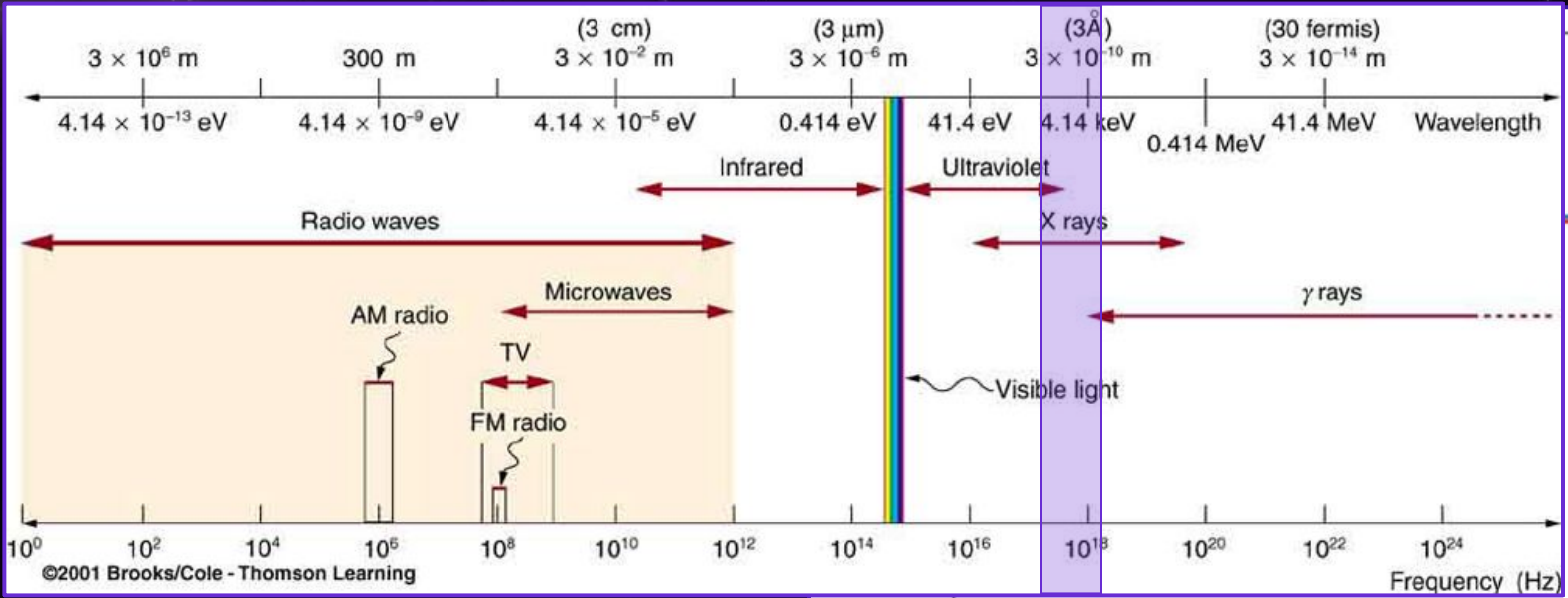
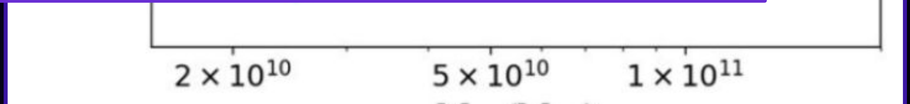


Why Hot CGM?





(Chadayammuri et al. 2022)

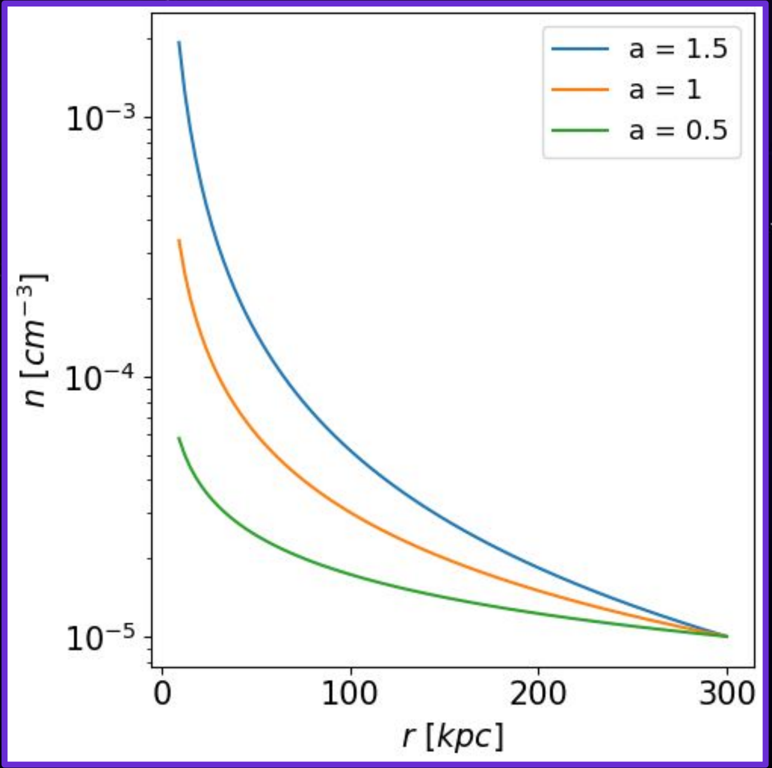
The Model: Density

Power law density distribution

$$n(r) = n_0 \left(\frac{r}{r_{CGM}} \right)^{-a}$$

- r_{CGM}: outer radius of the CGM *(300 kpc)*
- n_0: density at r_{CGM} *(2×10^{-5} cm^{-3})*
- a: slope of power law *(1)*

Constant Temperature *(1.5×10^6 K)*



The Model: Density

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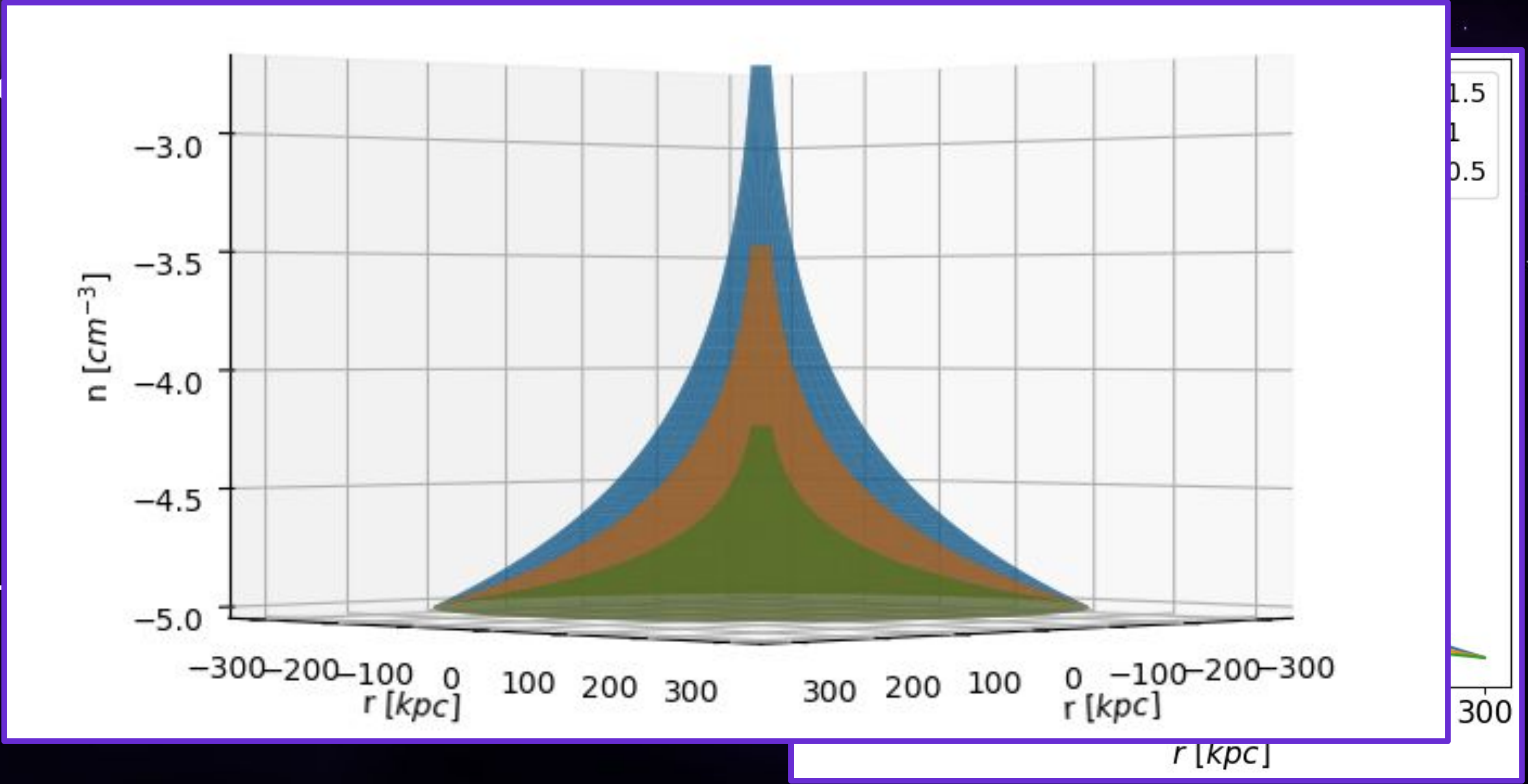


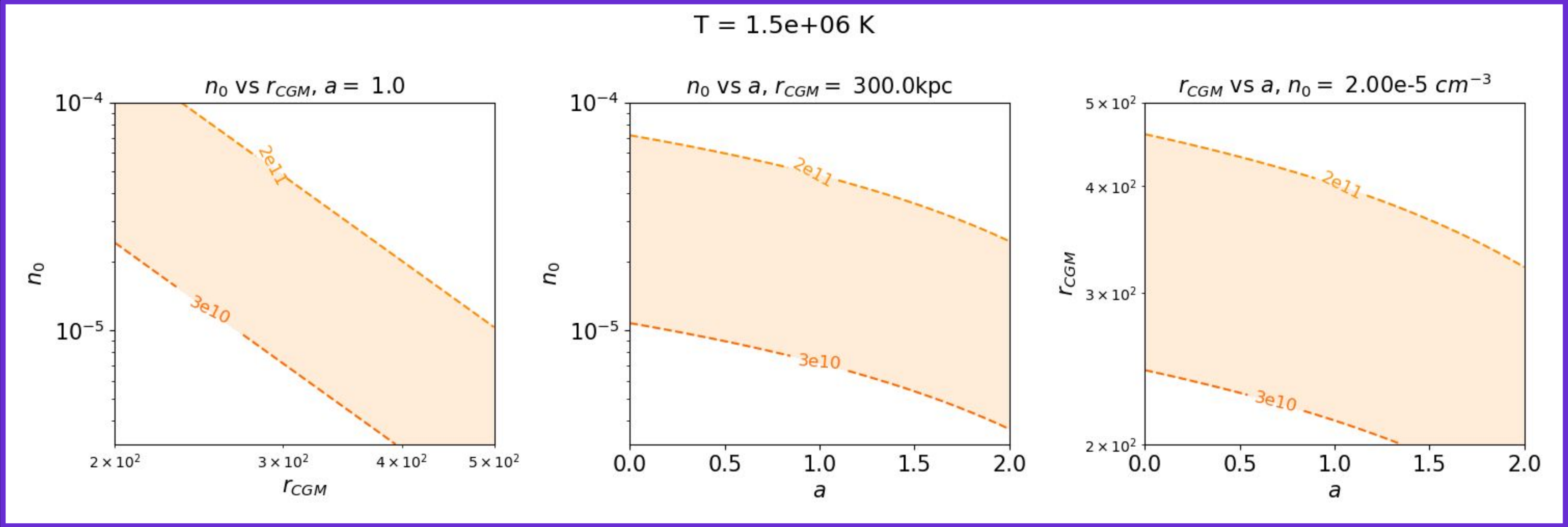
Cons

$$M = 4\pi\overline{m}\int n(r)\, r^2\, dr$$

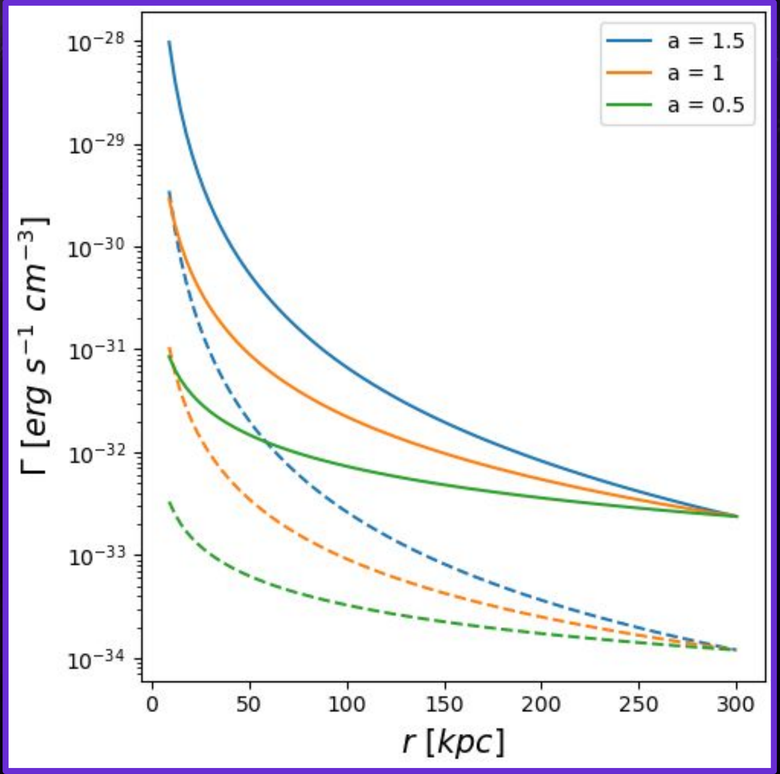
The Model: Mass

$$n(r) = n_0\left(\frac{r}{r_{CGM}}\right)^{-a}$$

- Define a plausible range for the mass of the CGM of **3×10^{10} — 2×10^{11} $M_\odot$**
    - Estimates based on the halo baryon budget of galaxies used in Chadayammuri et al.



The Model: Emission

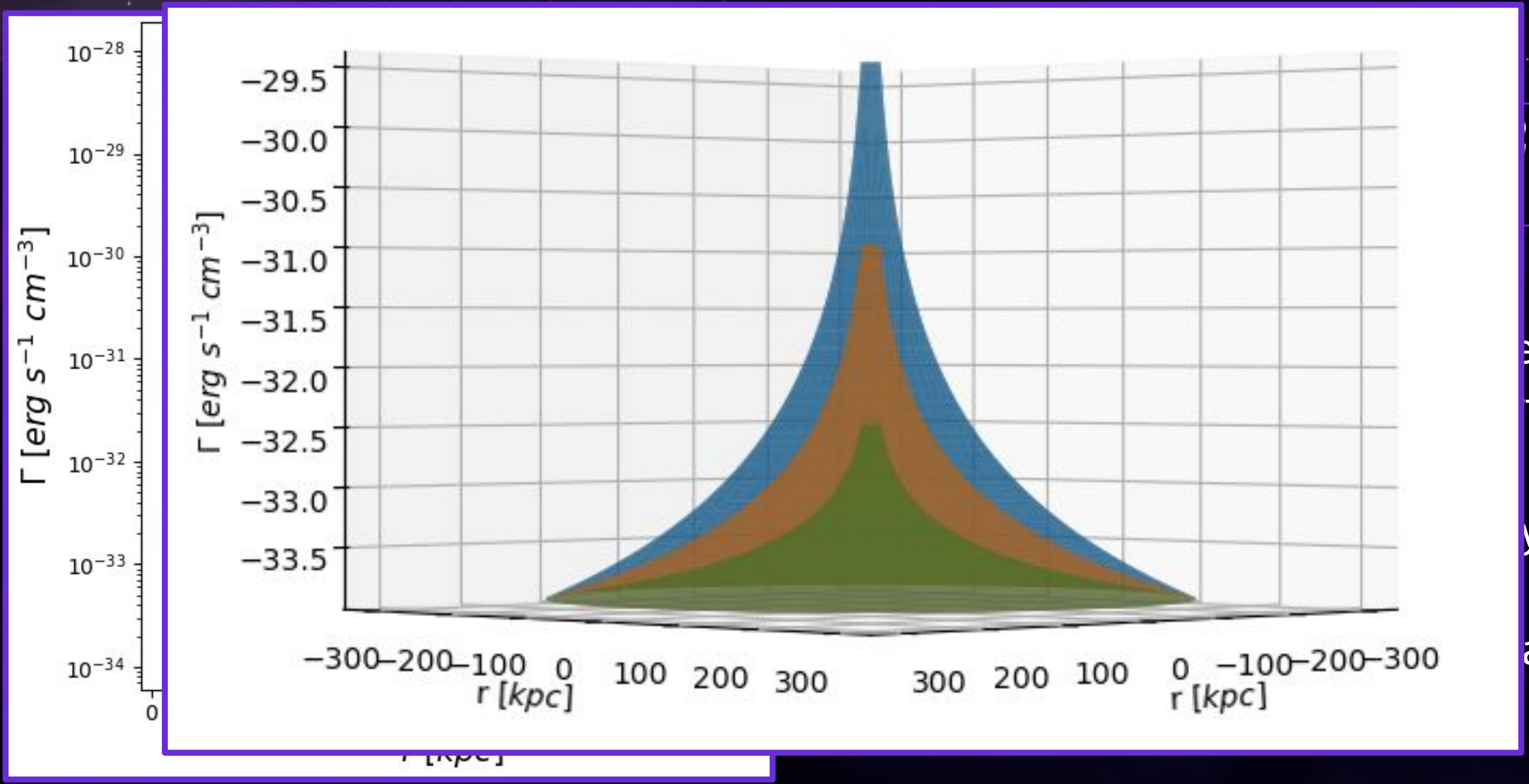


Emission

$$\Gamma = \Lambda(r)\, n(r)^2$$

- Λ : cooling coefficient
  - calculated using Cloudy (atomic physics code)
  - dependent on gas properties
- Γ : local emission rate
  - the amount of energy emitted per unit volume

The Model: Emission



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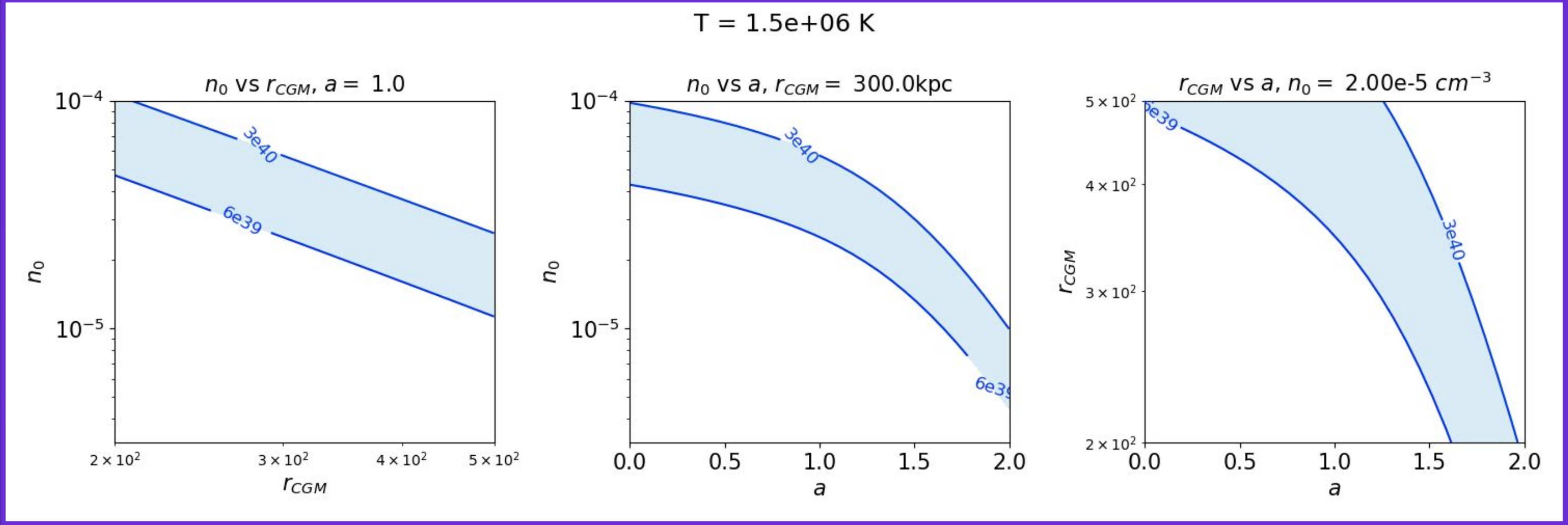
and

$$L = 4\pi \int \Lambda(r)\, n(r)^2\, r^2\, dr$$

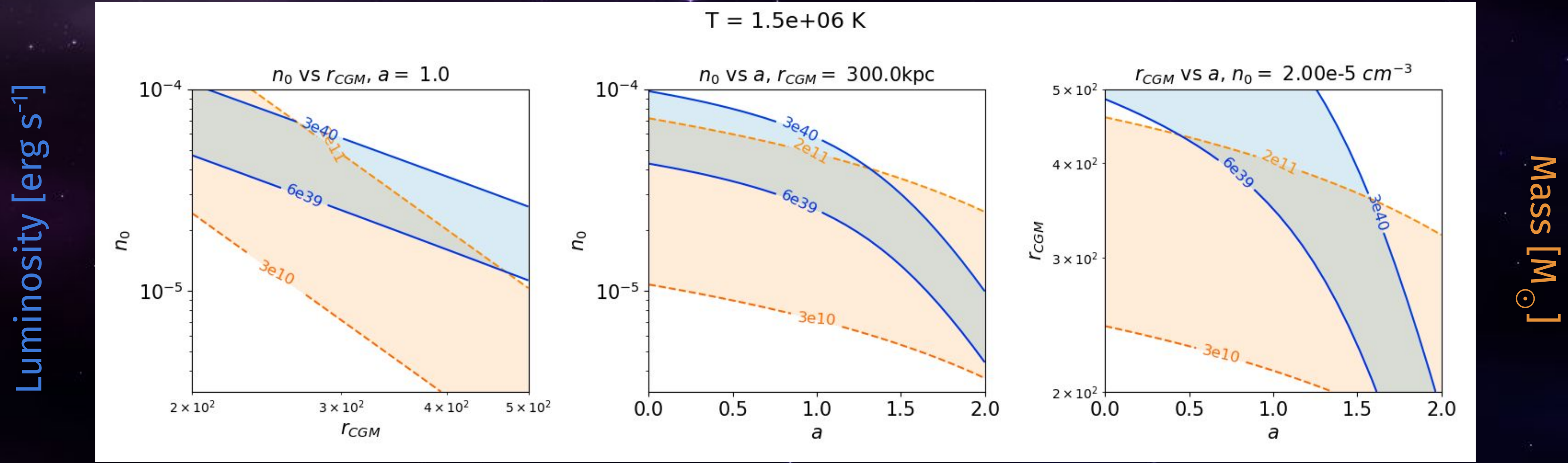
The Model: Luminosity

$$\Gamma = \Lambda(r)\, n(r)^2$$

- Define luminosity constraints of **6×10^{39} – 3×10^{40} erg s^{-1}** from soft X-ray observations by eROSITA
  - Calculated by integrating radial shells of local emission



Conclusion



- Model constrains physical properties of the CGM that can reproduce observations
    - Can guide future simulations
- Modulating the temperature affects overlapping region

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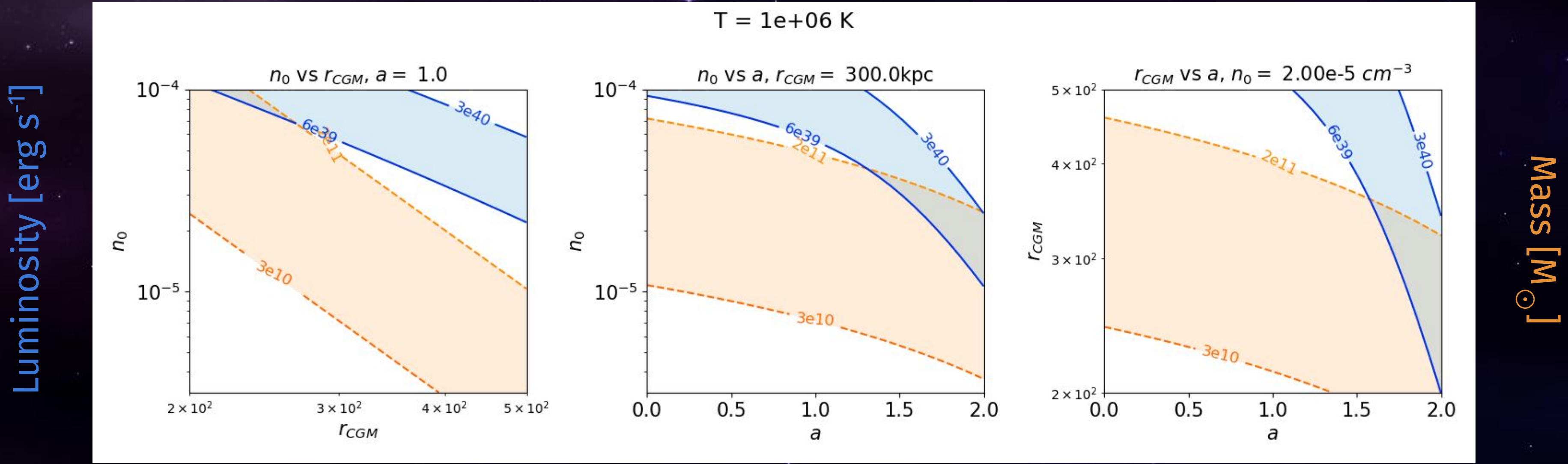

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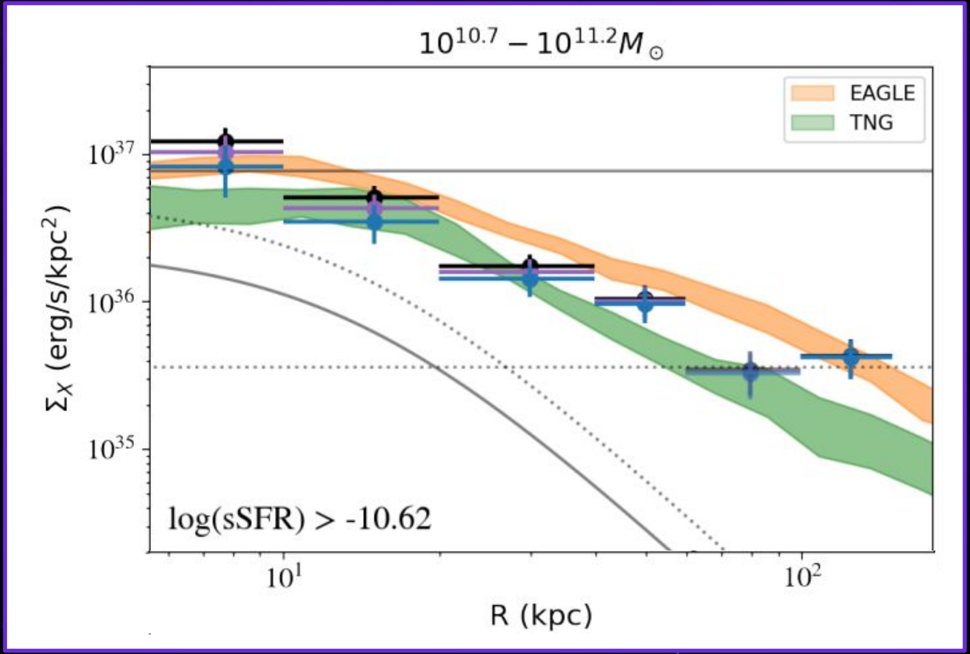
Next Steps

- Radial temperature profiles
- Spatially resolved emission profiles
    - Constrain density slope *(a ~ 1.5)*



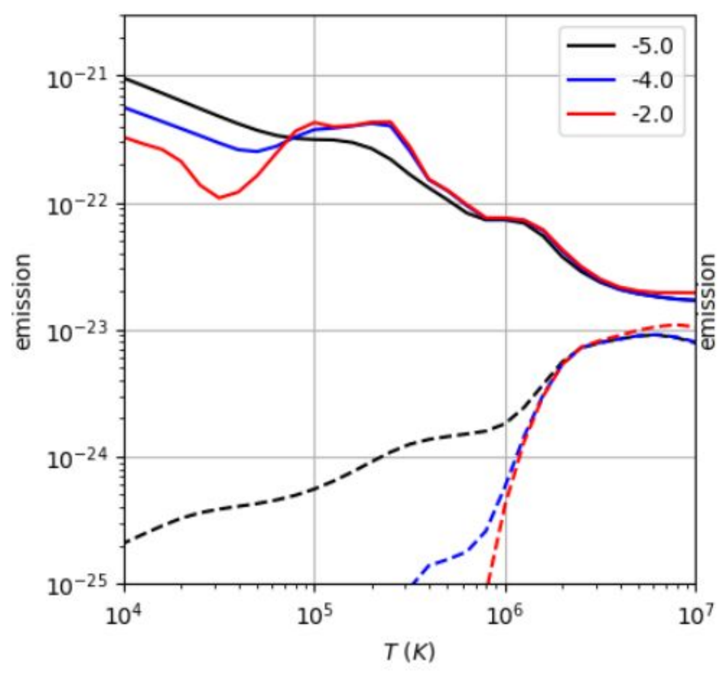
The Model: Emission

$$\Gamma = \Lambda(r)\, n(r)^2$$

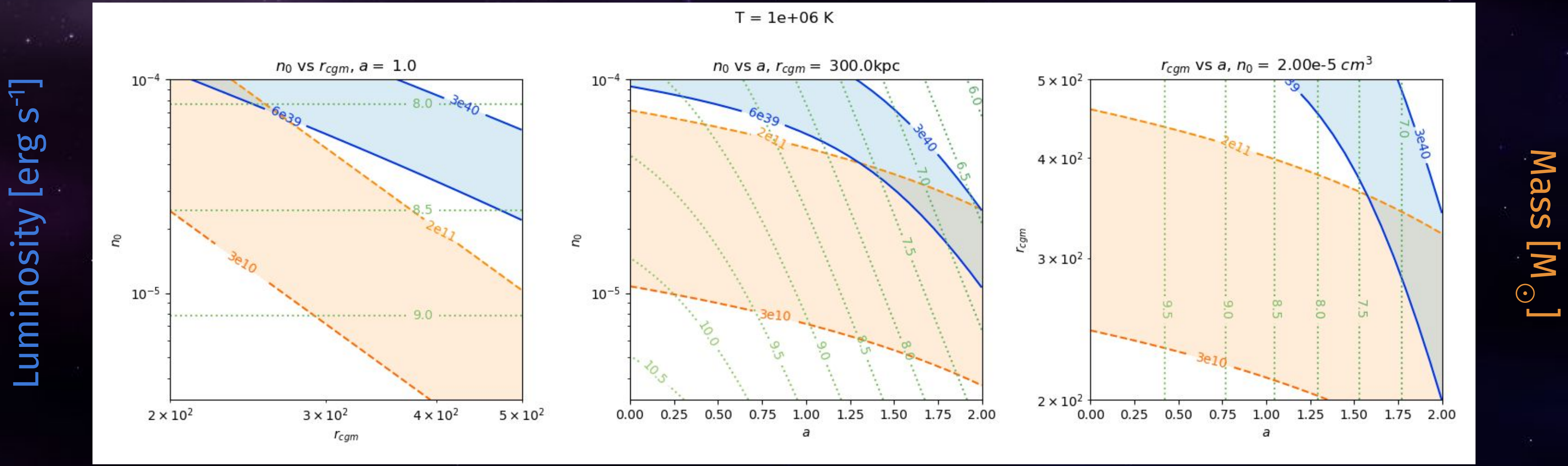
Emission

- gamma: local emission rate
  - the amount of energy emitted at specific local properties
- lambda: cooling coefficient
  - calculated using Cloudy (atomic physics code)
  - dependent on density and temperature

maybe explain the energy band used - total emission is calculated using theory, have to use specific bands to compare to observations (cant just observe everything)



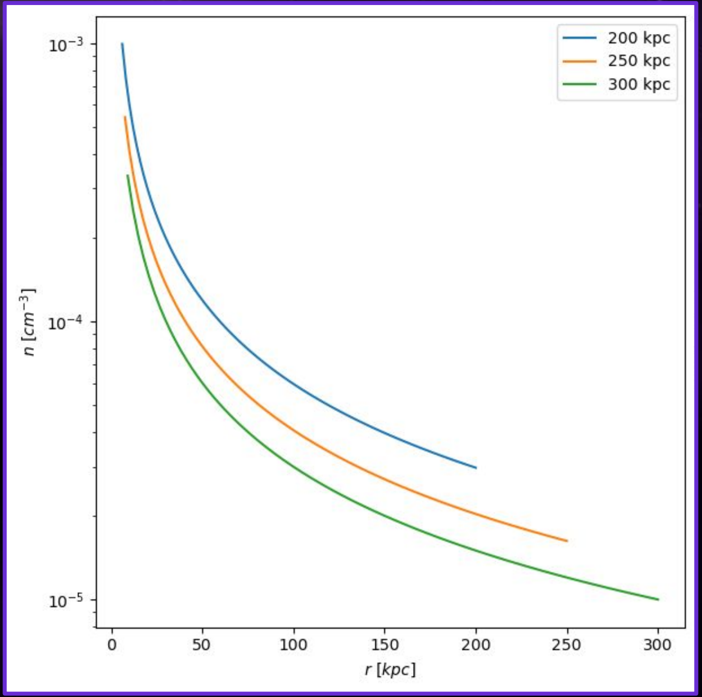
Conclusion

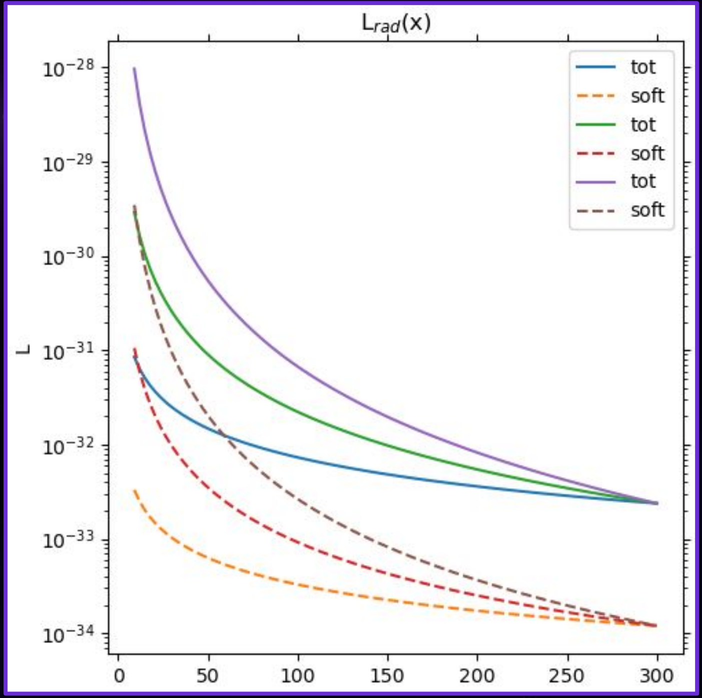


- Modulating the temperature affects which CGM parameters can reproduce observations
- Can be used to guide simulations

The Model

recreate right panel with soft xray





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