

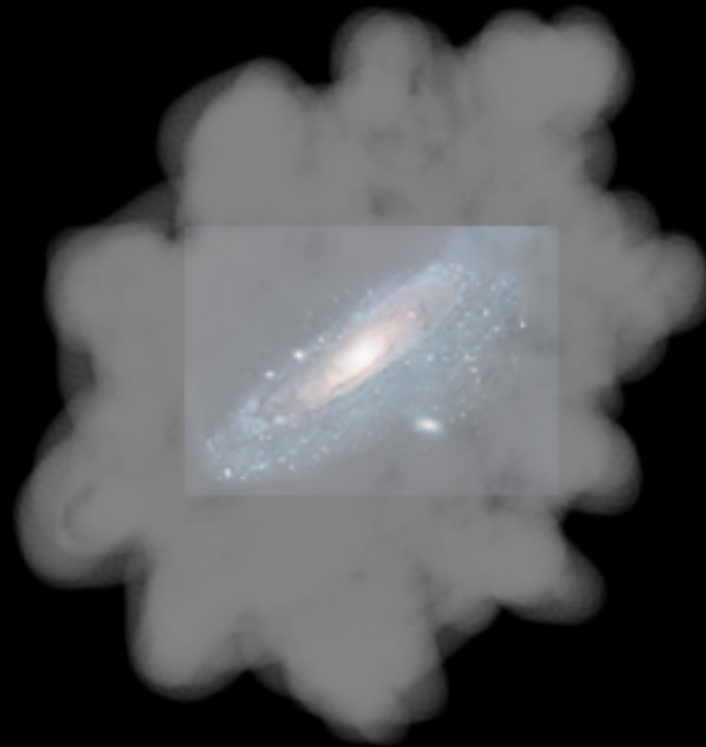
Circumgalactic Medium Constraints on Feedback

Cameron Hummels
University of Arizona

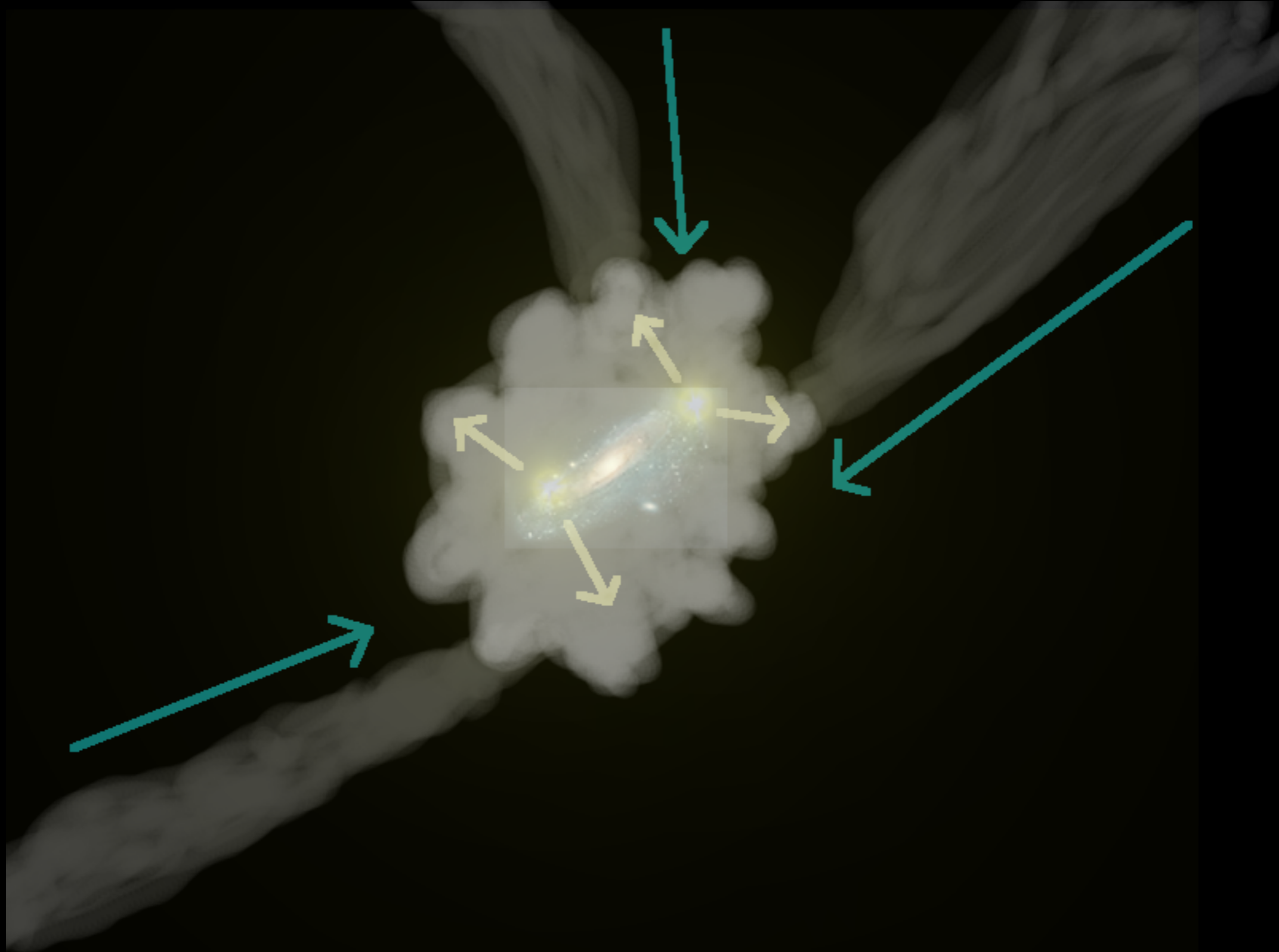
Collaborators

Greg Bryan (Columbia)
Britton Smith (Edinburgh)
Matthew Turk (NCSA)
Brant Robertson (Arizona)

What is the circumgalactic medium and how is it observed?

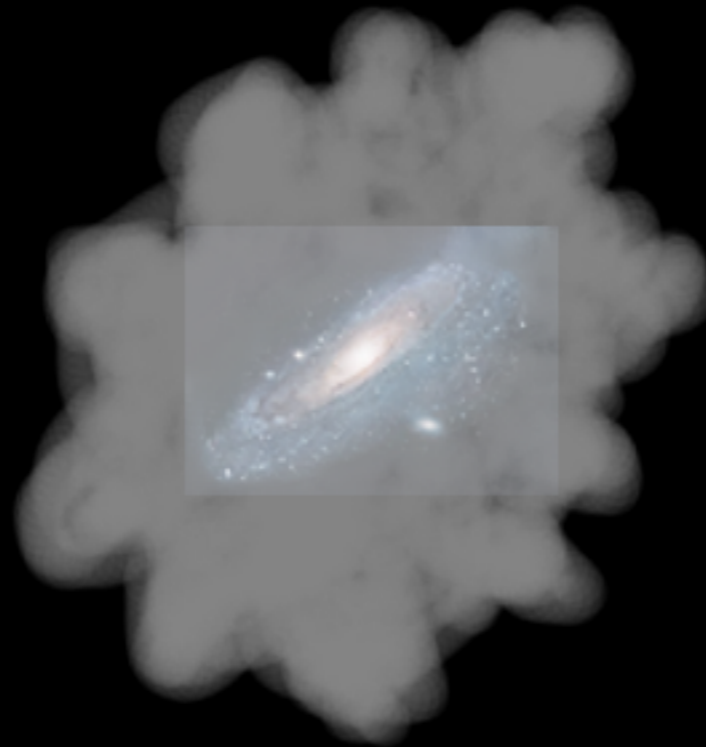


What is the circumgalactic medium and how is it observed?



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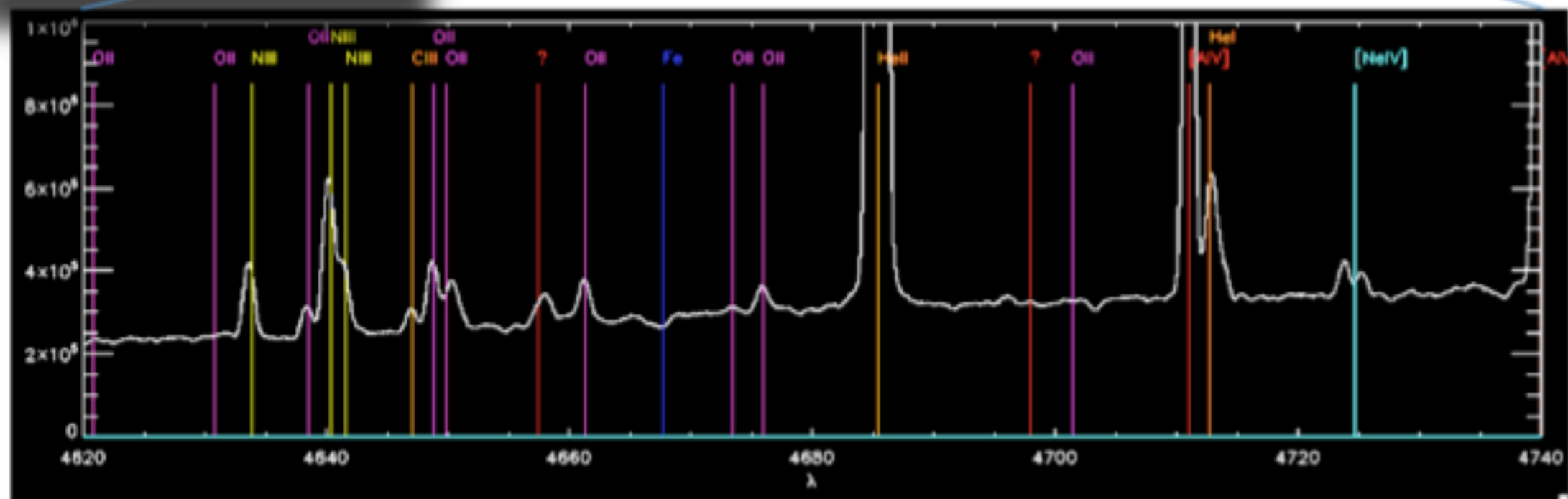
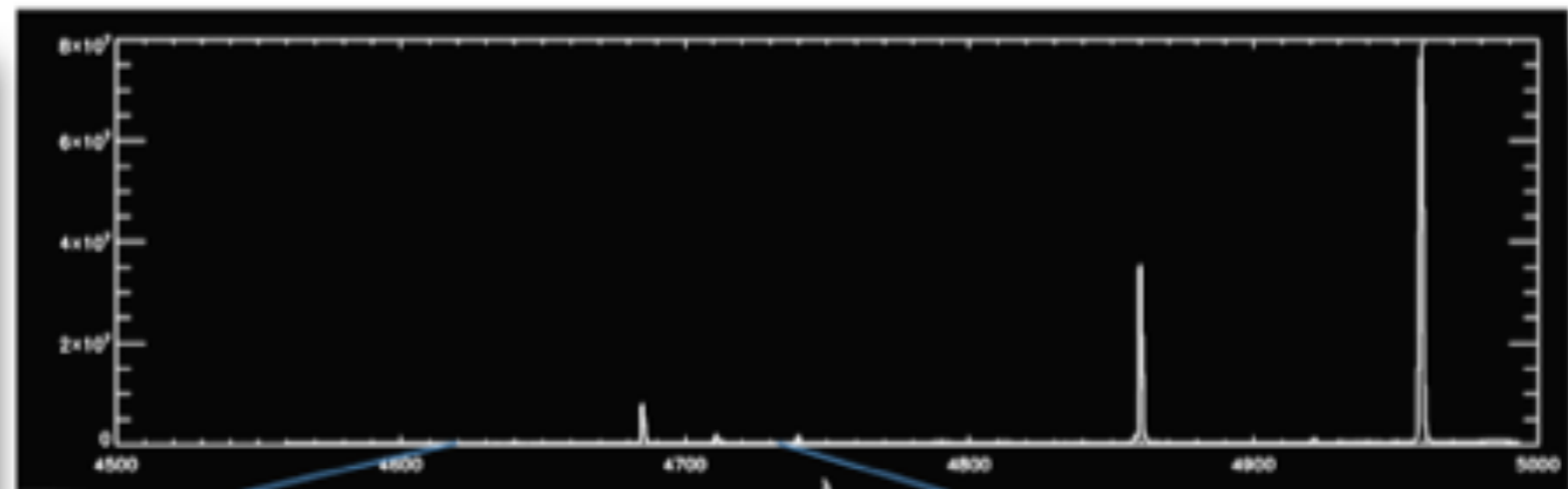
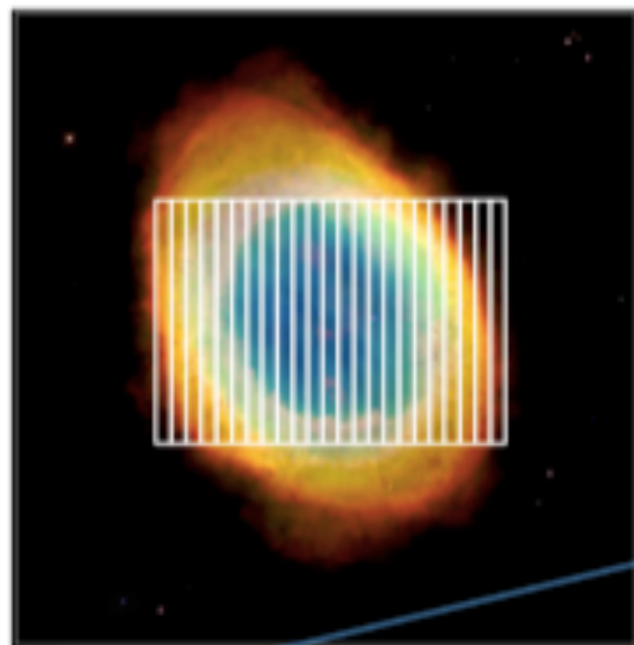
- In emission $\sim N^2$
- In absorption $\sim N$



What is the circumgalactic medium and how is it observed?

Use atomic transitions!

- In emission $\sim N^2$
- In absorption $\sim N$



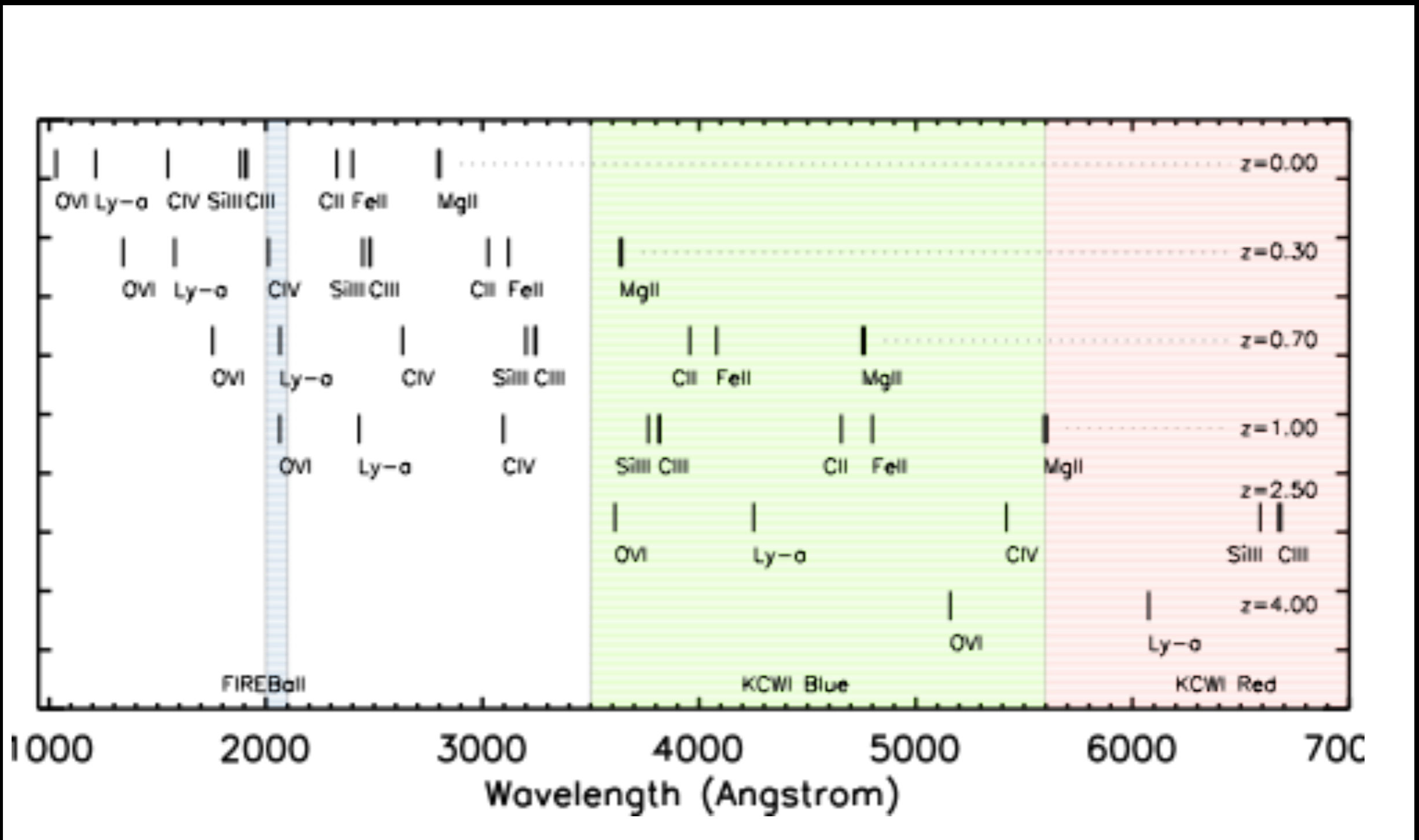
What is the circumgalactic medium and how is it observed?

Commonly Used Transitions

	<u>Ion</u>	<u>E_{ion}</u>
“Low Ions” (Photo)	Ly-alpha	13.6 eV
	Mg II	15.0
	Si II	16.3
	C II	24.4
“Intermediate Ions” (Mix)	Si III	33.5
	Si IV	45.1
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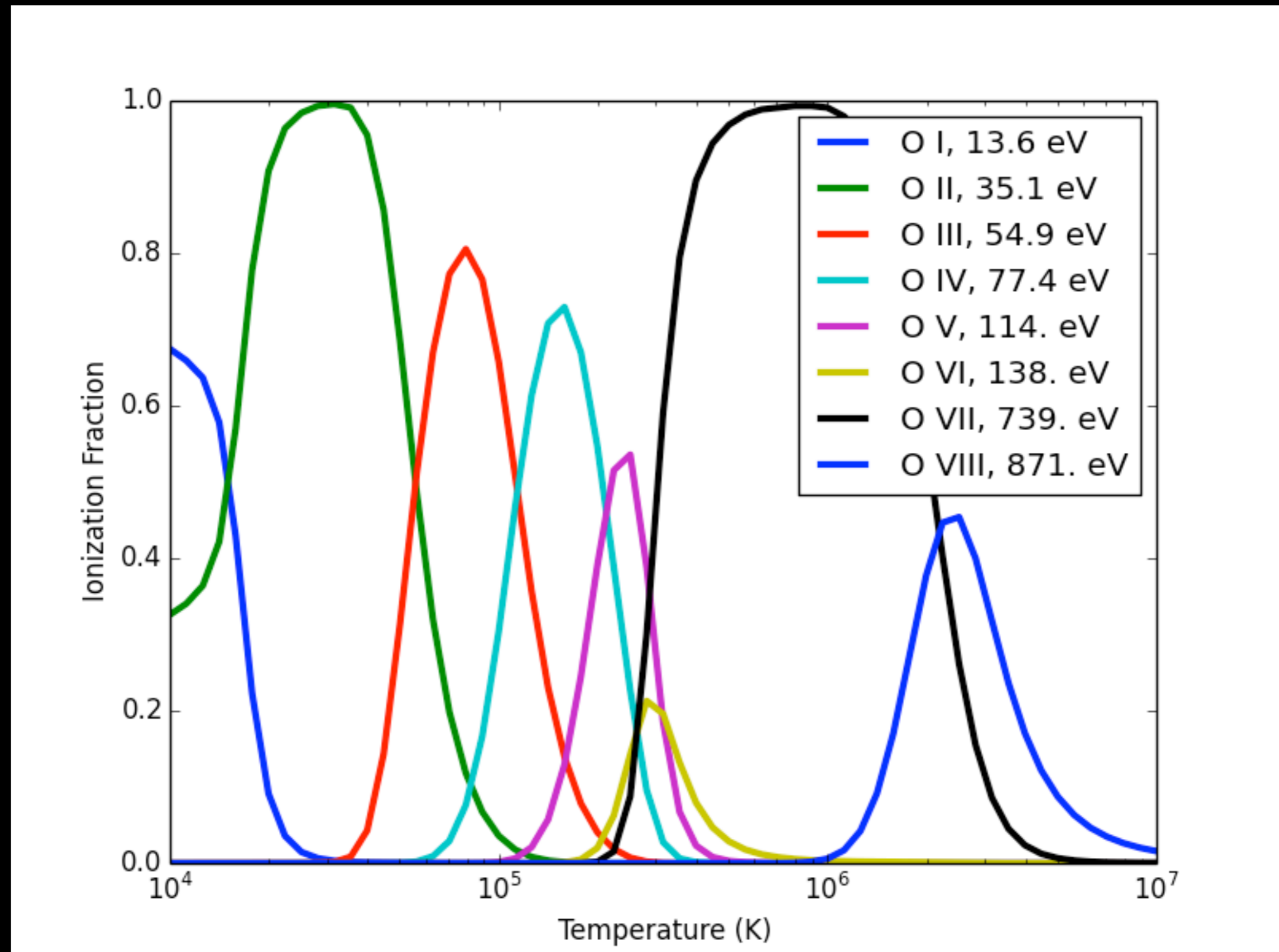
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Commonly Used Transitions



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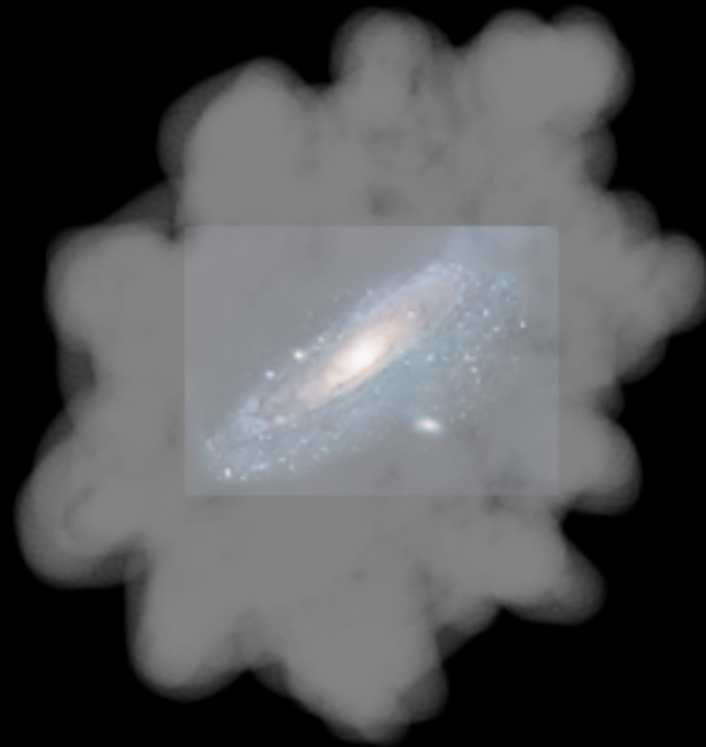
Oxygen Ionization States



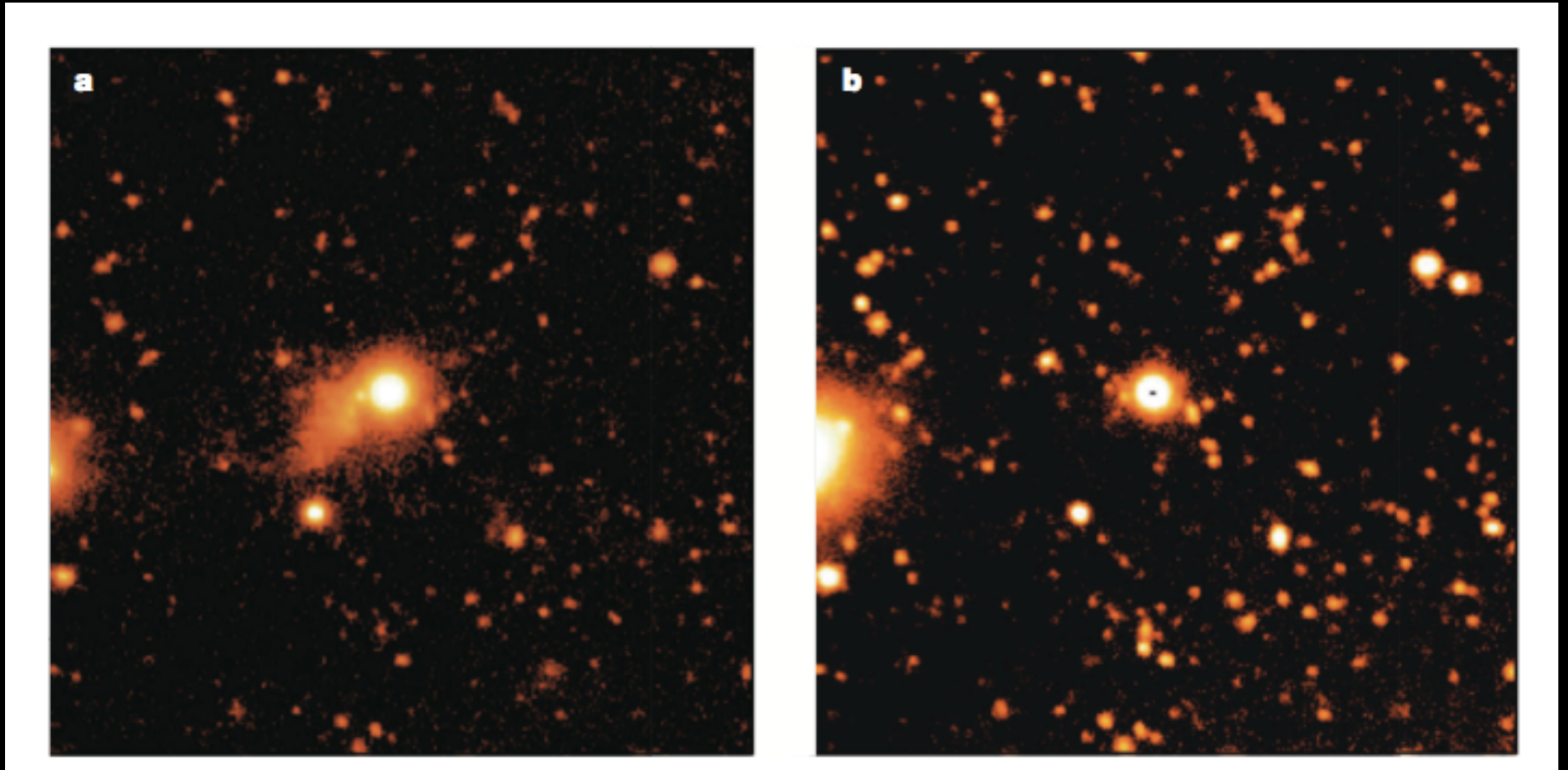
(generated from Cloudy)

What is the circumgalactic medium and how is it observed?

- In emission $\sim N^2$
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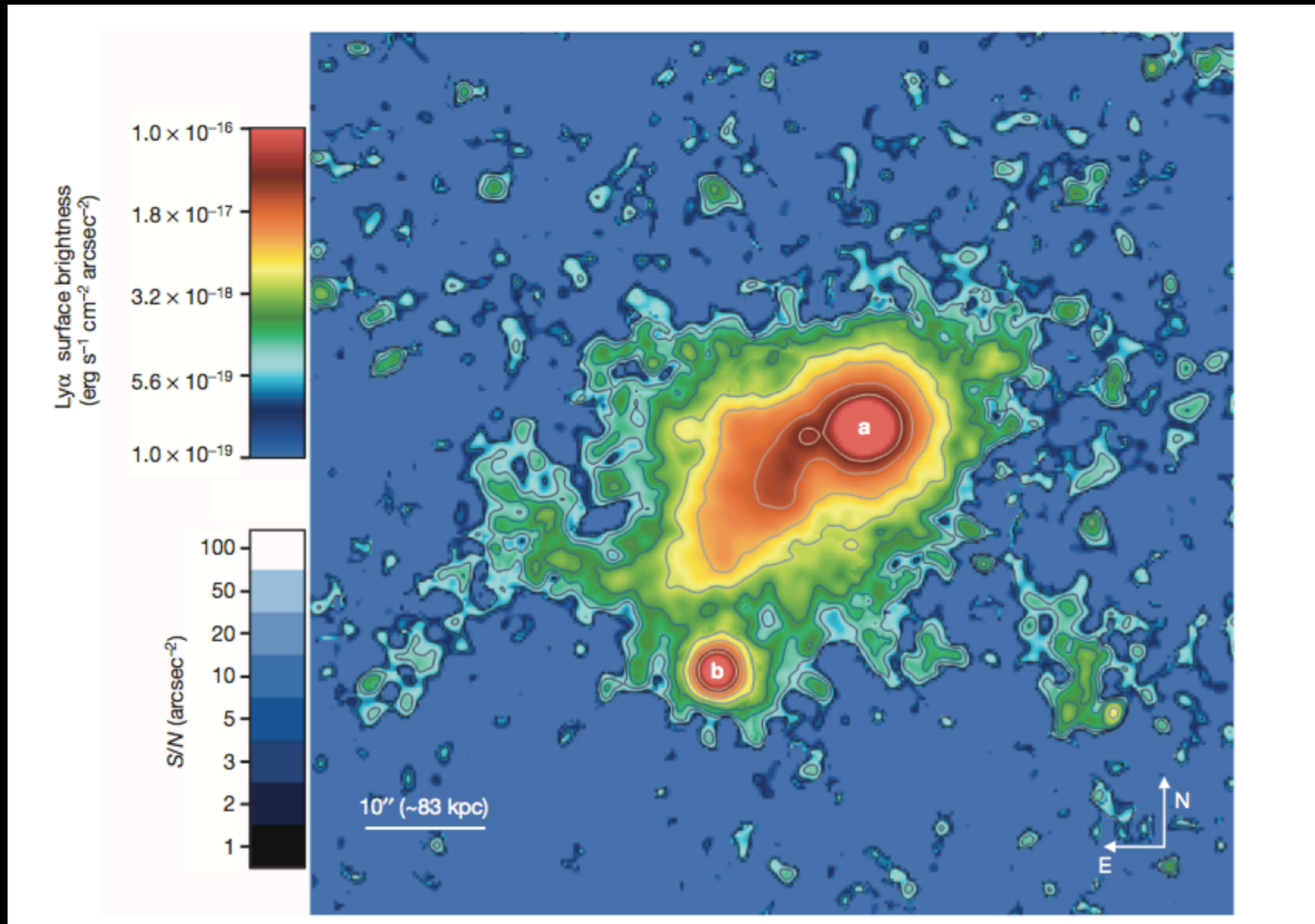


Extended Lyman-alpha emission from quasars



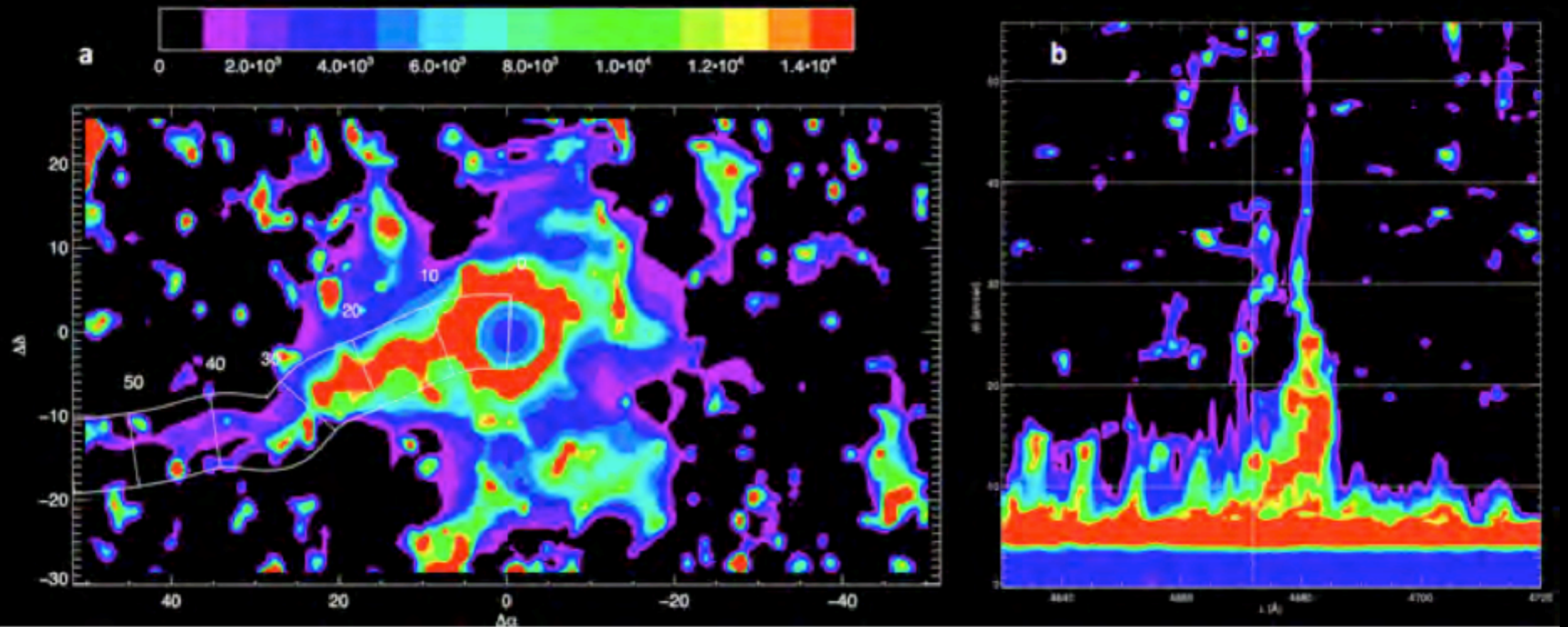
Keck + LRIS
Cantalupo+ 2014

Extended Lyman-alpha emission from quasars



Keck + LRIS
Cantalupo+ 2014

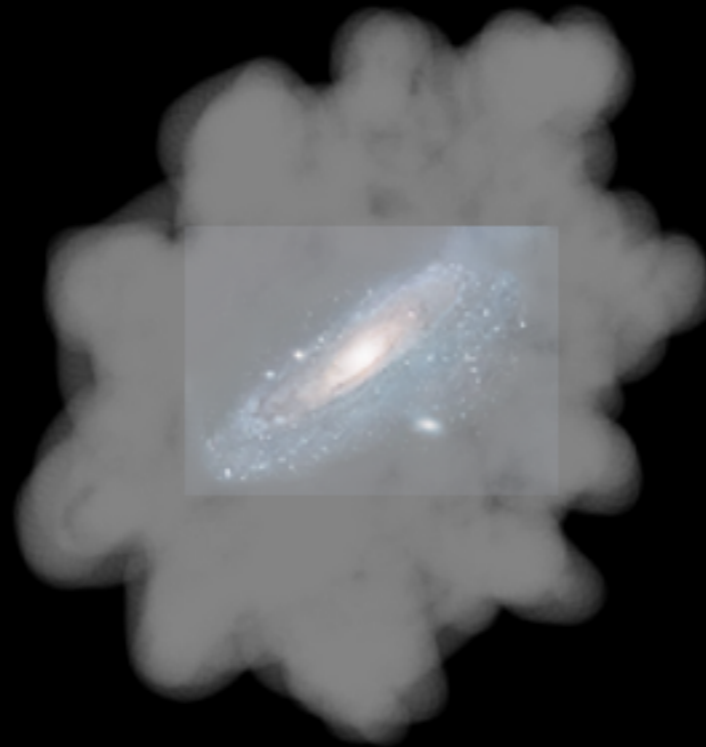
Extended Lyman-alpha emission from quasars



PCWI (IFU)
Martin+ 2014

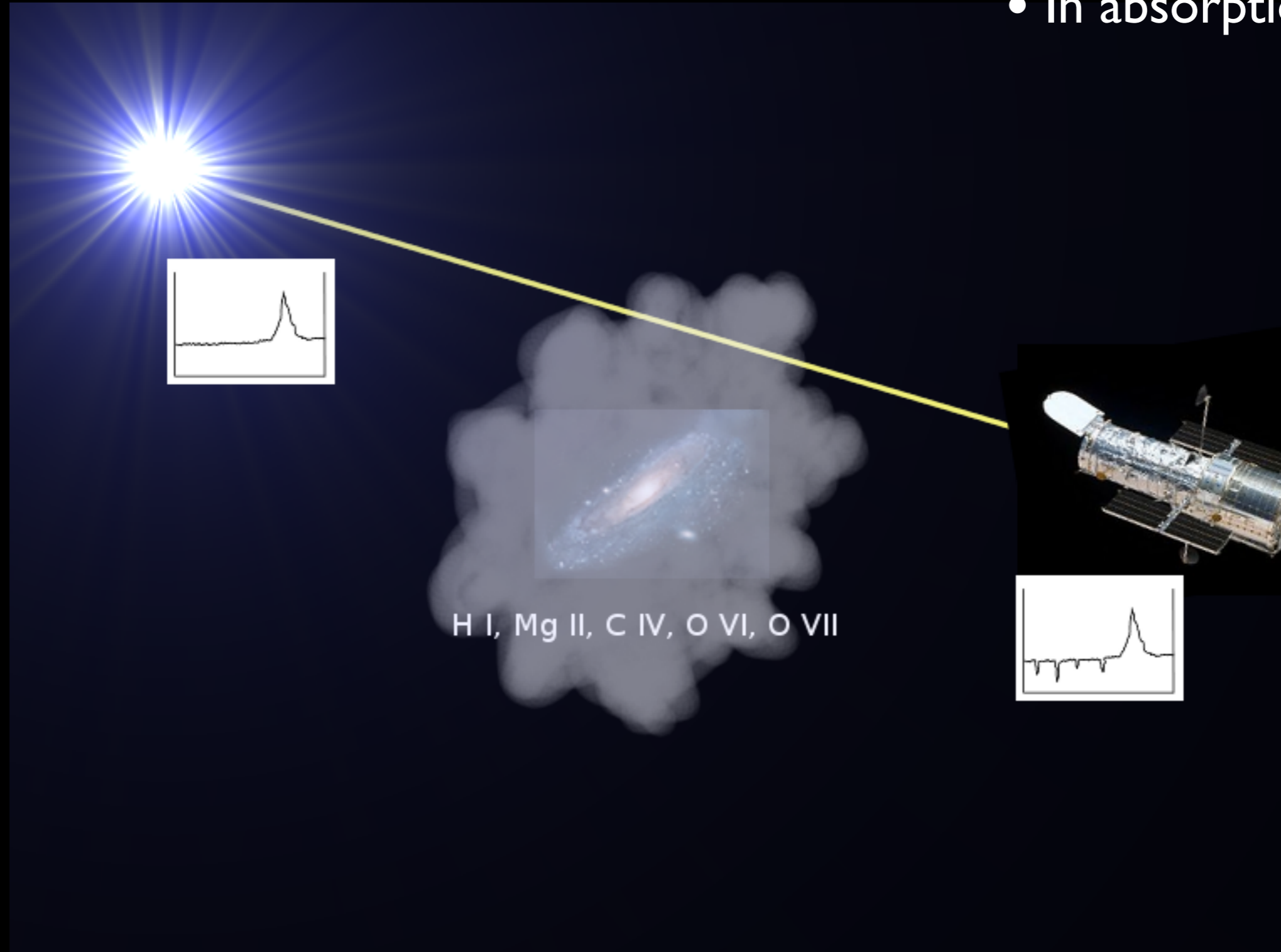
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- In absorption $\sim N$



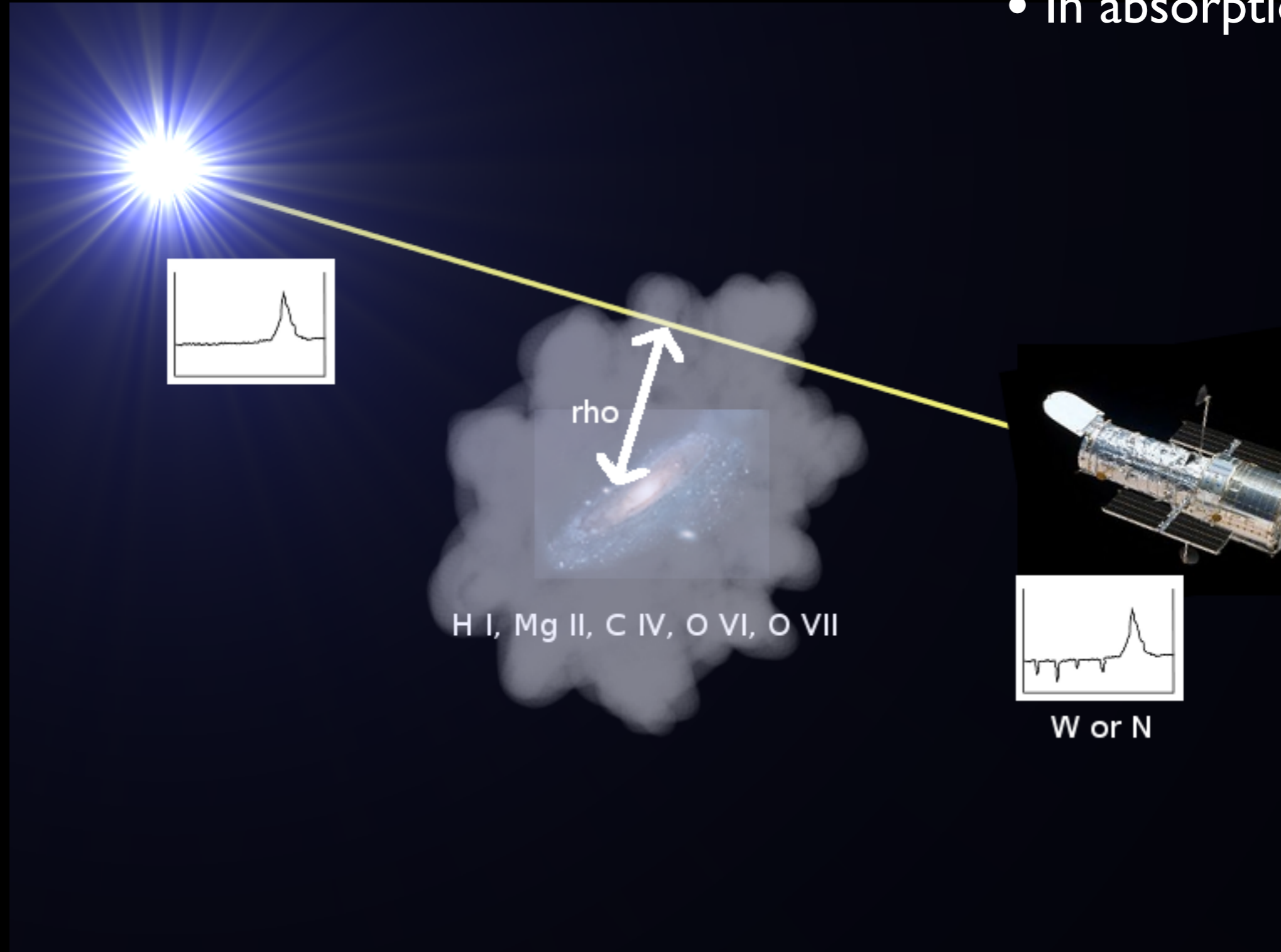
What is the circumgalactic medium and how is it observed?

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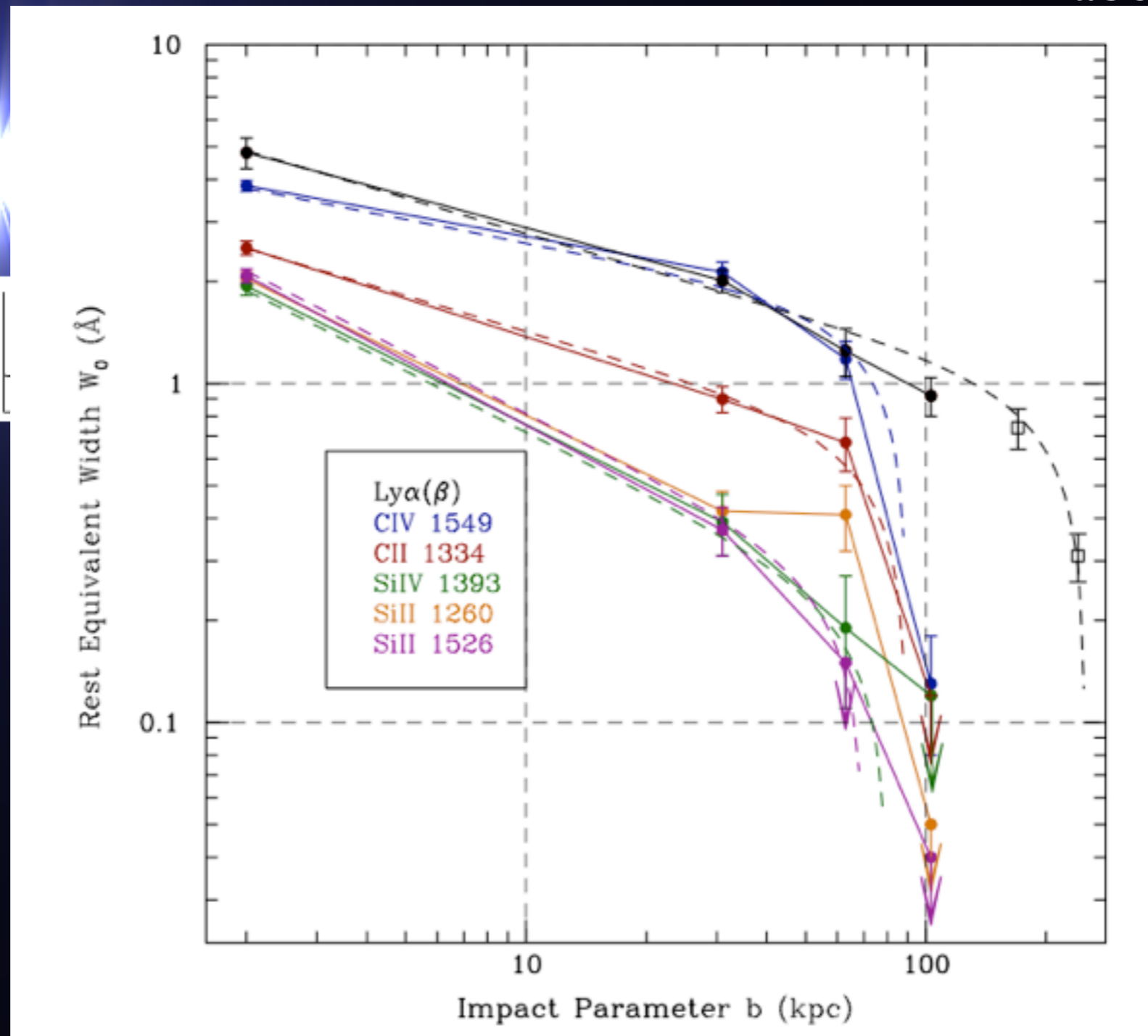
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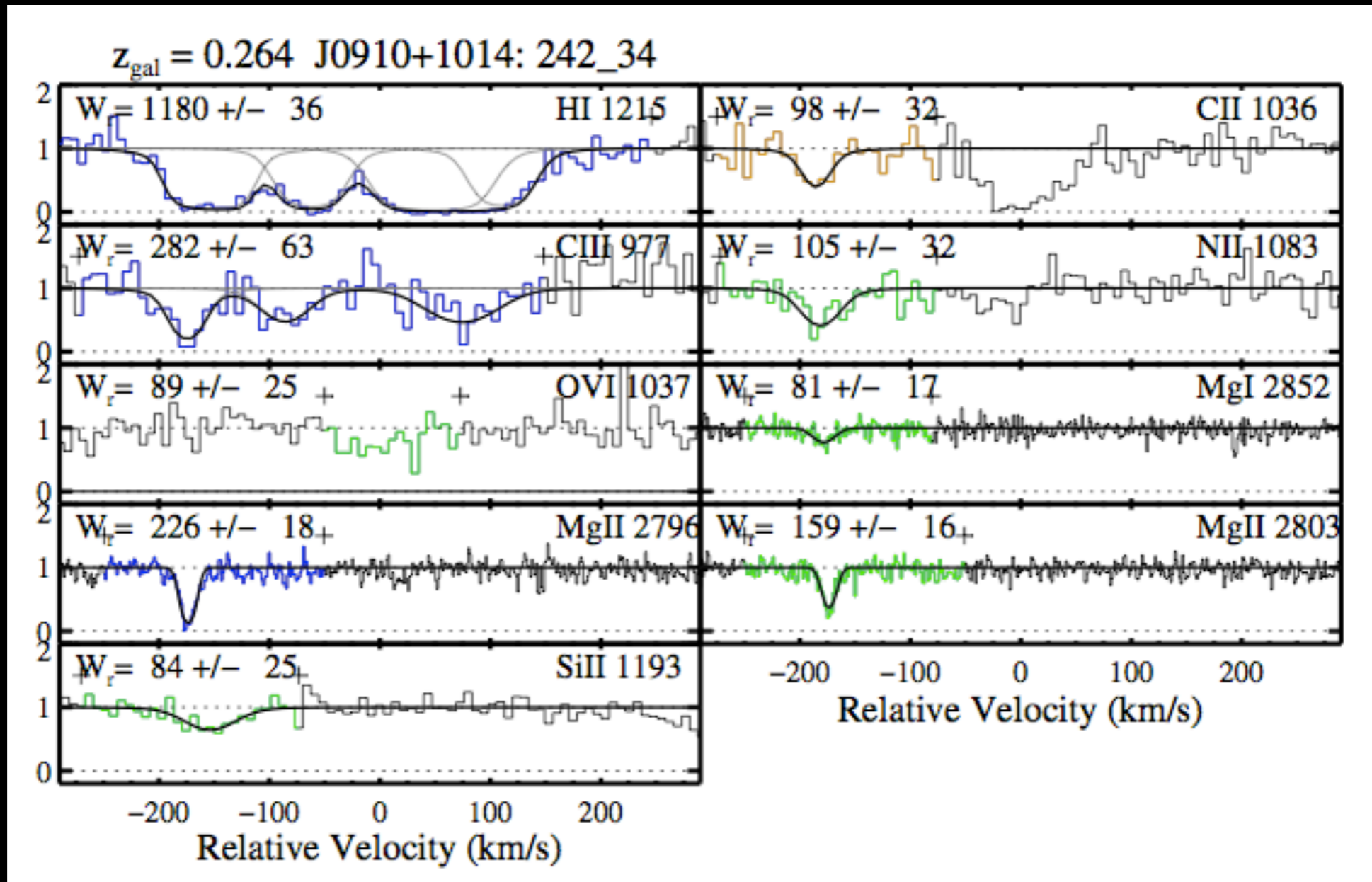
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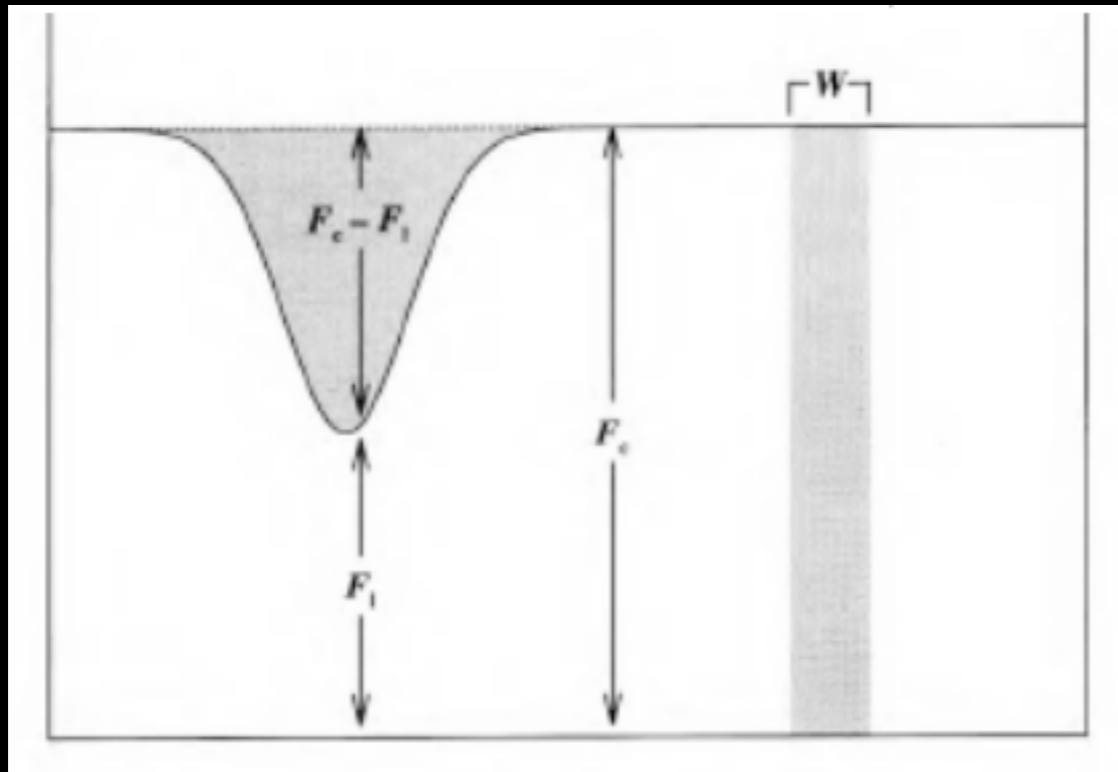


Steidel+ 2010

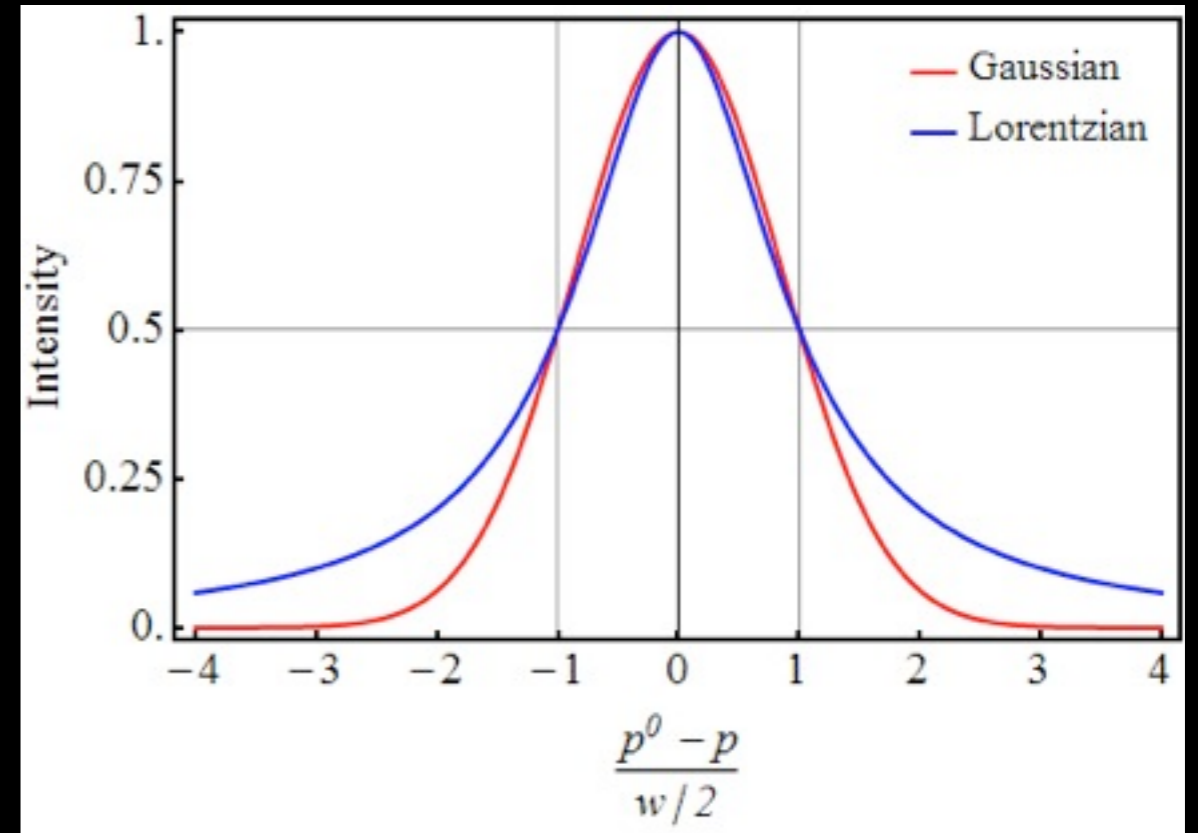
Need good spectral resolution to get column density from equivalent width due to Voigt Profile



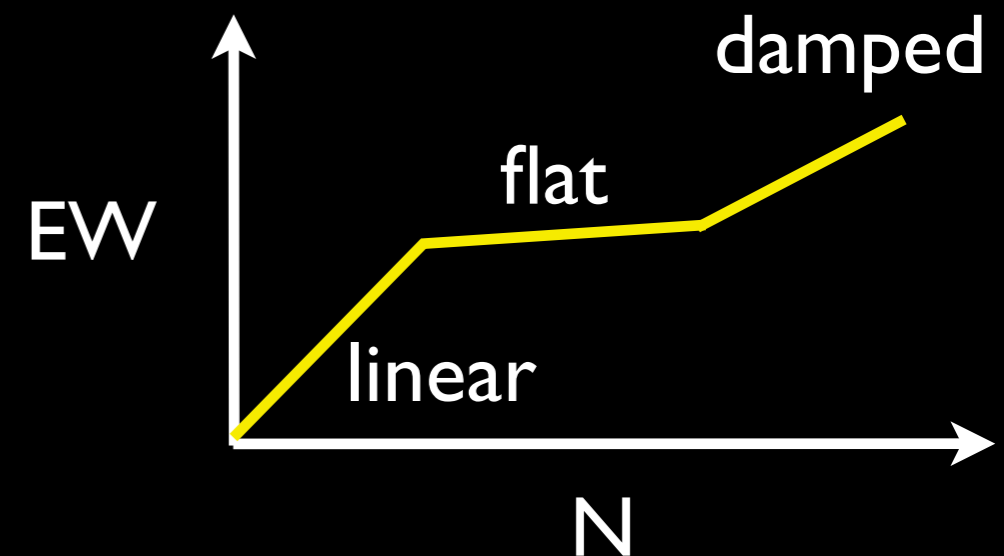
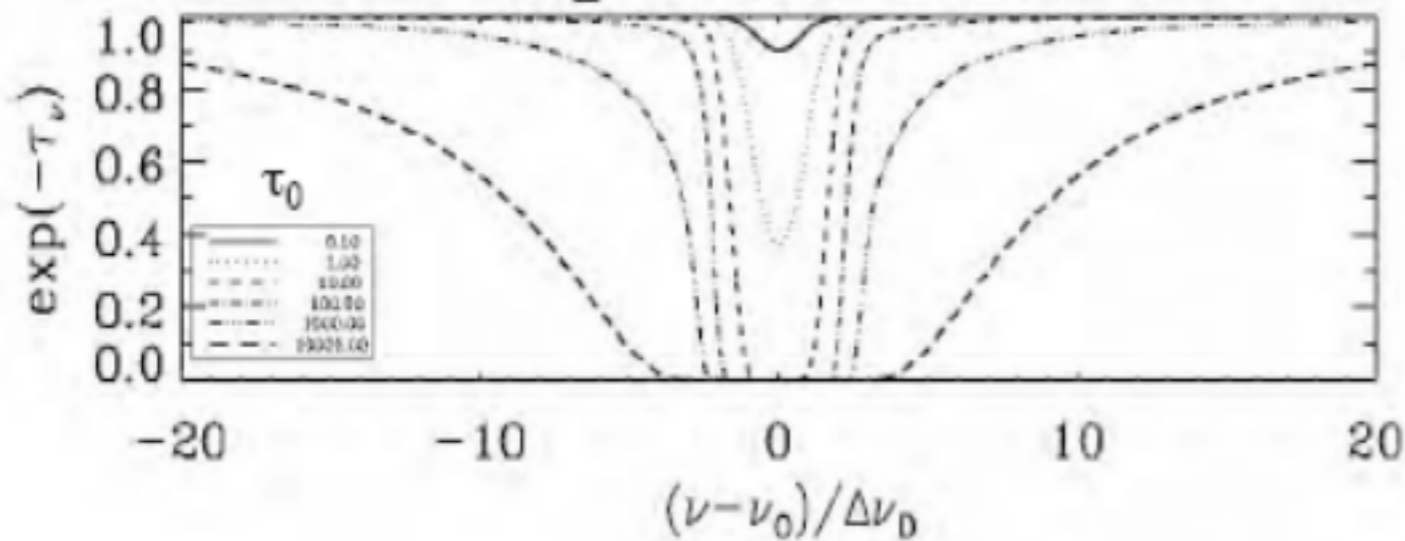
Equivalent Width



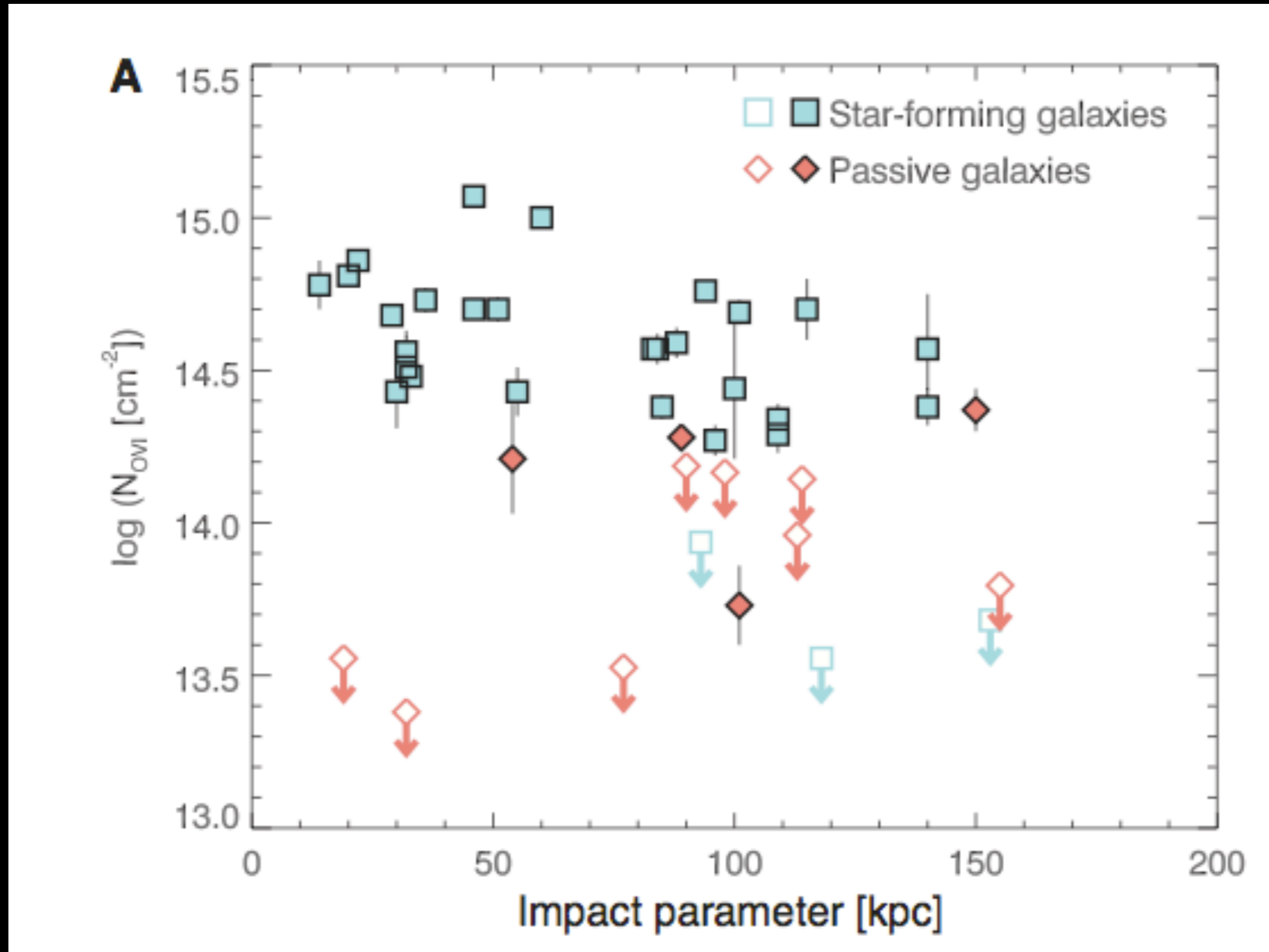
Voigt Profile



Voigt Profile $a=0.01$



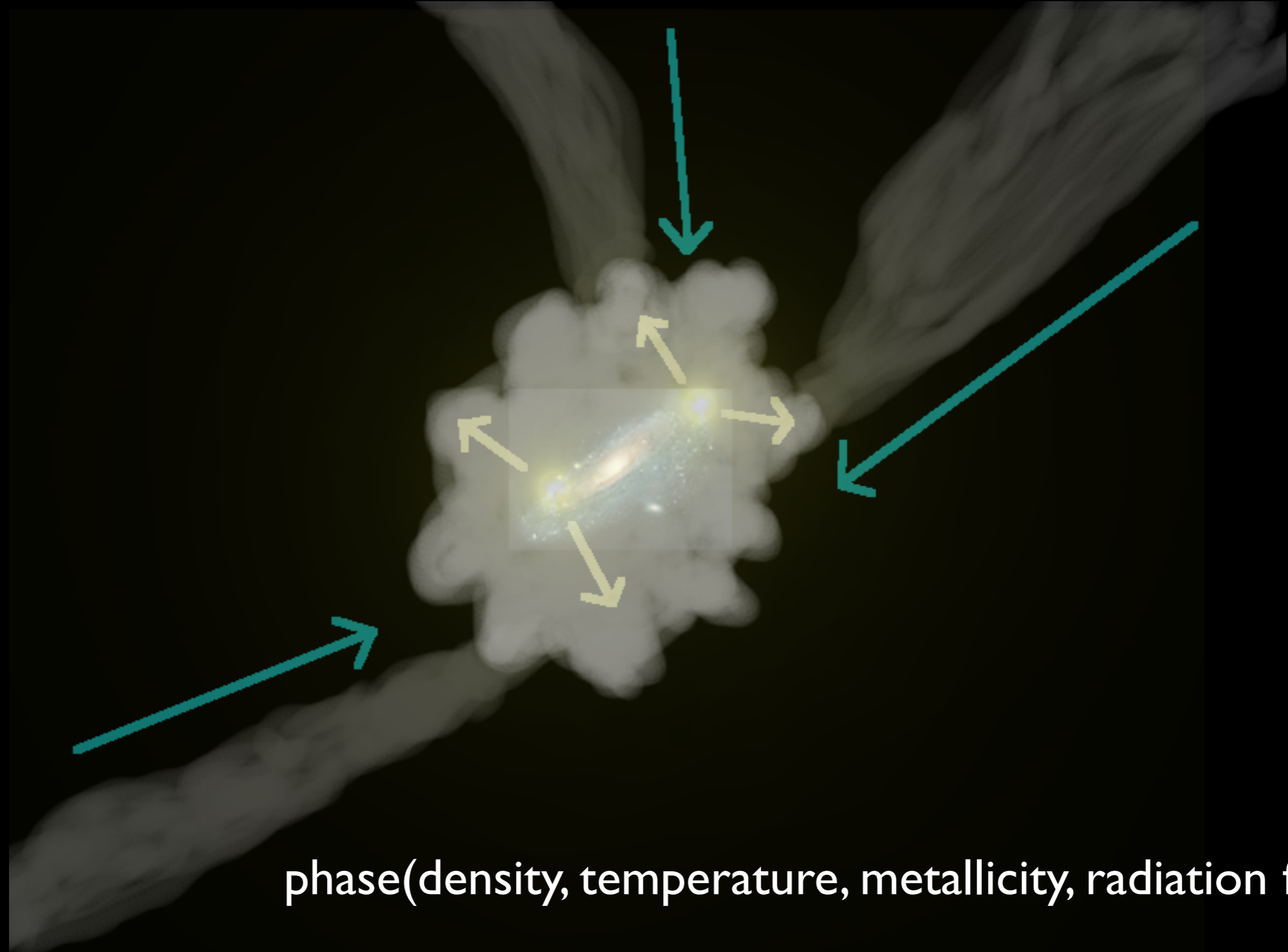
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Why should theorists care about the CGM?

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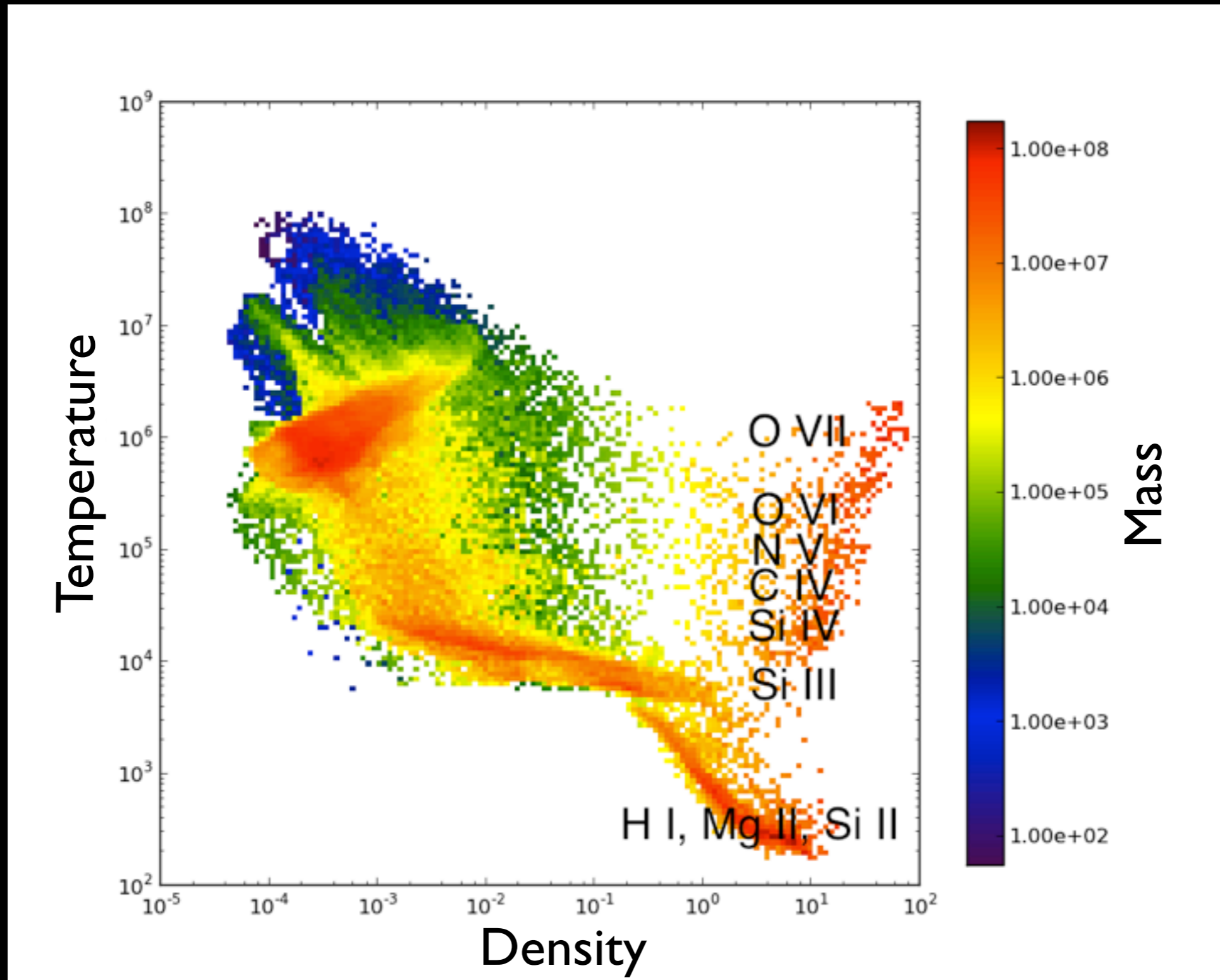
CGM is direct probe of feedback



Commonly Used Transitions

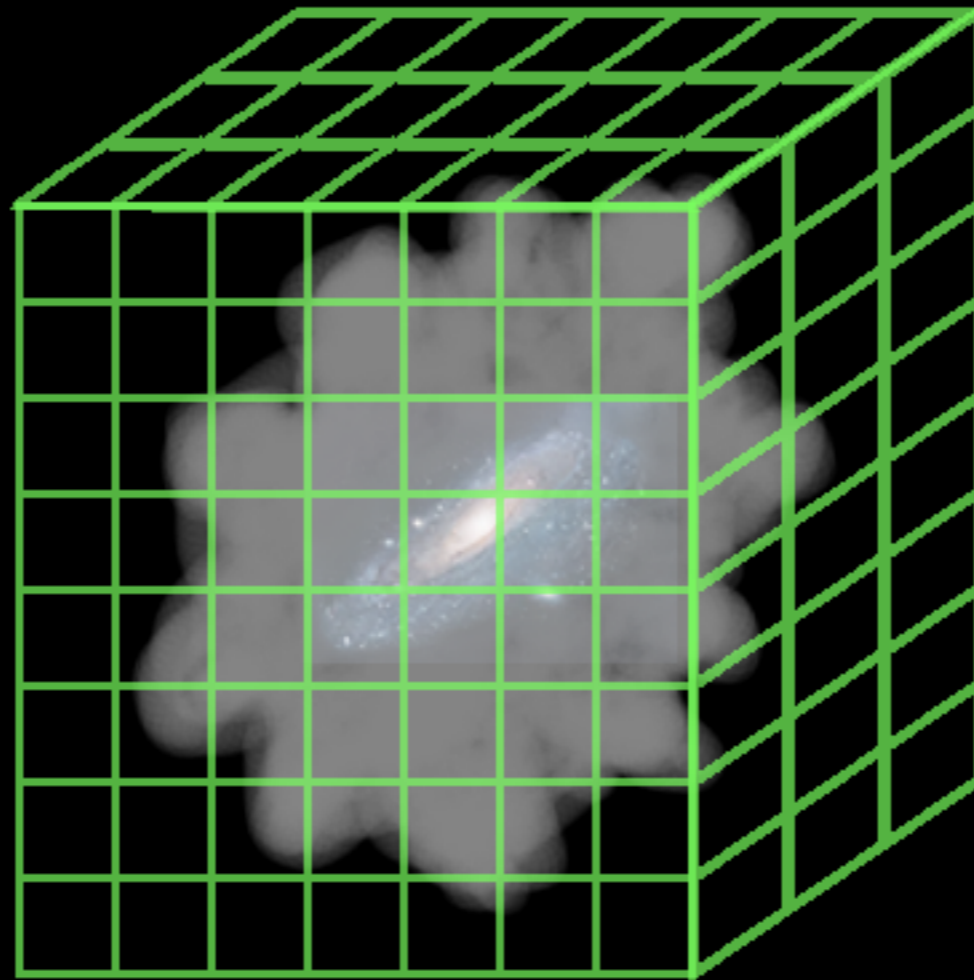
	<u>Ion</u>	<u>E_{ion}</u>
“Low Ions” (Photo)	Ly-alpha	13.6 eV
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How can simulations be compared against these CGM observations?



phase(density, temperature, metallicity, radiation field)

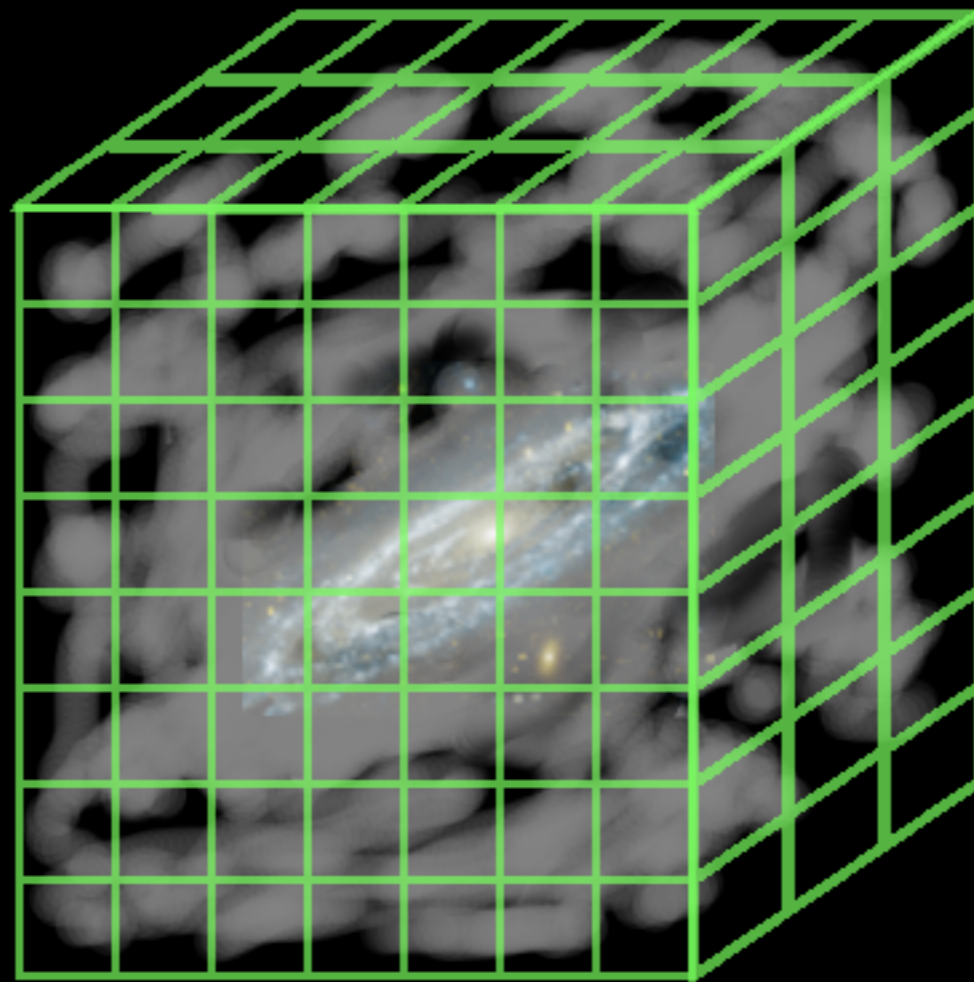
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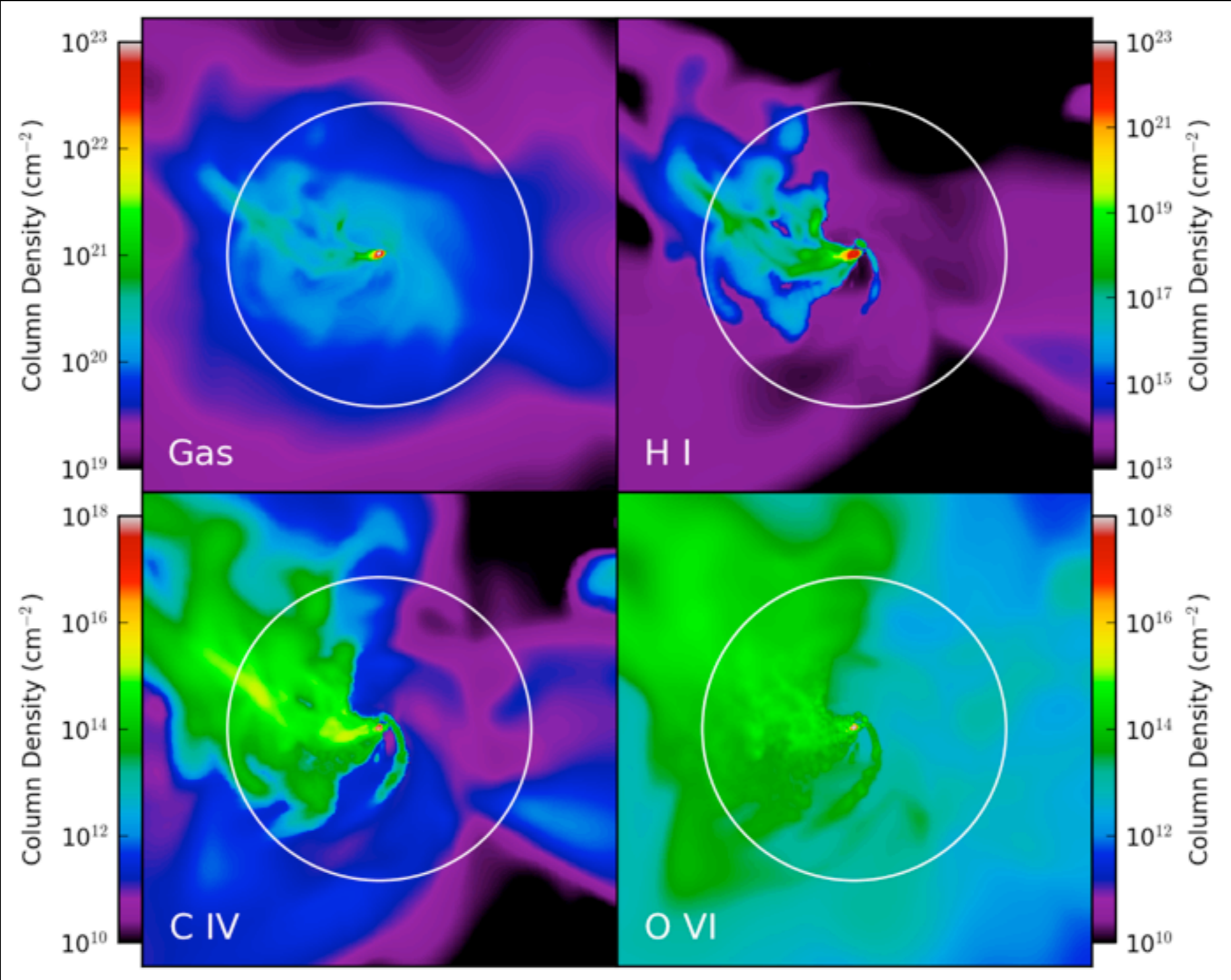
How can simulations be compared against these CGM observations?

OVI



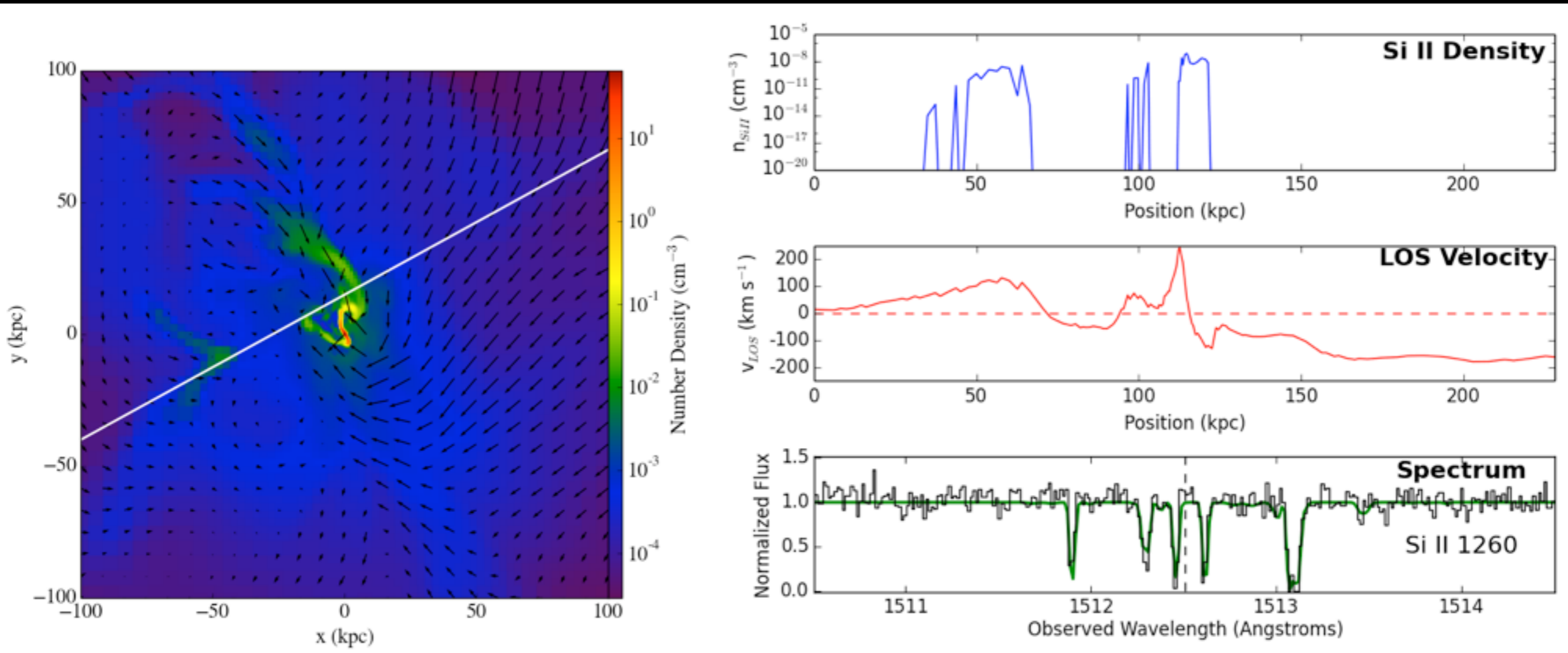
phase(density, temperature, metallicity, radiation field)

How can simulations be compared against these CGM observations?



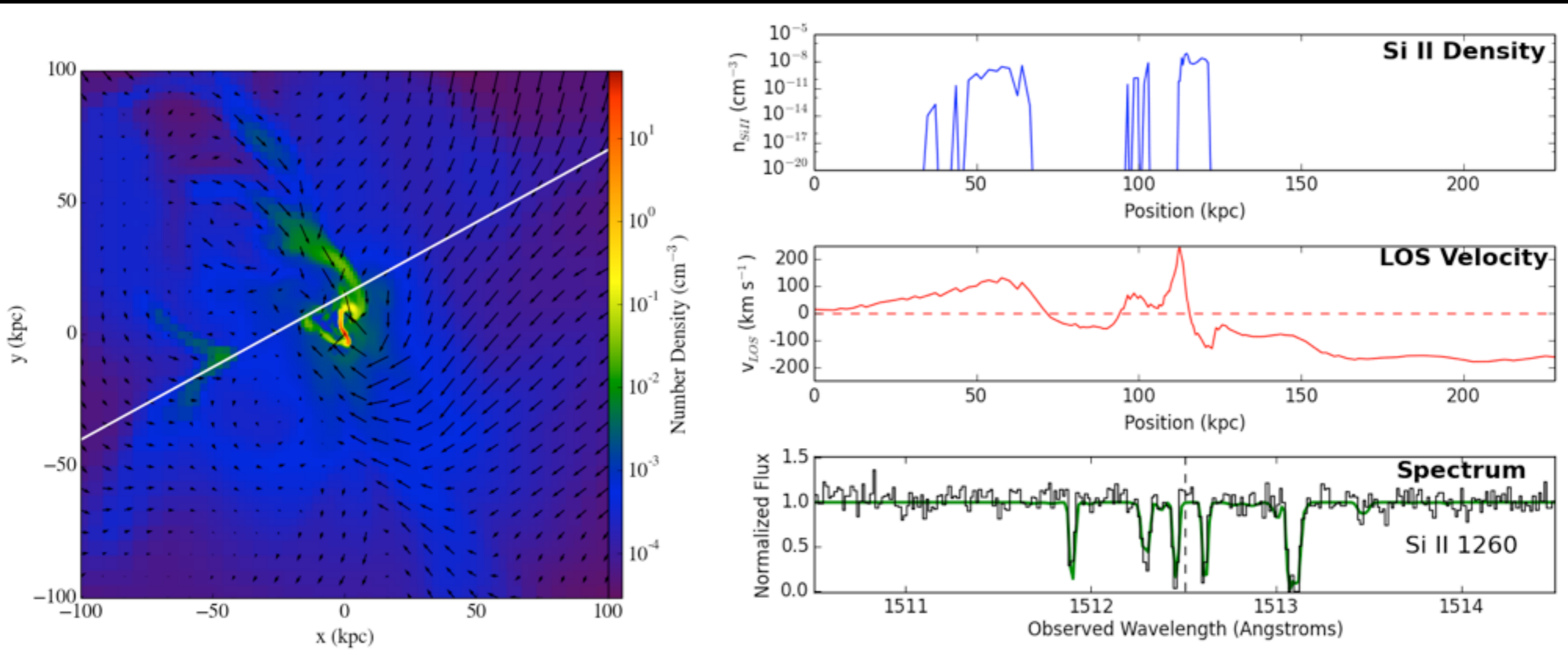
How can simulations be compared against these CGM observations?

Make synthetic observations of simulated data

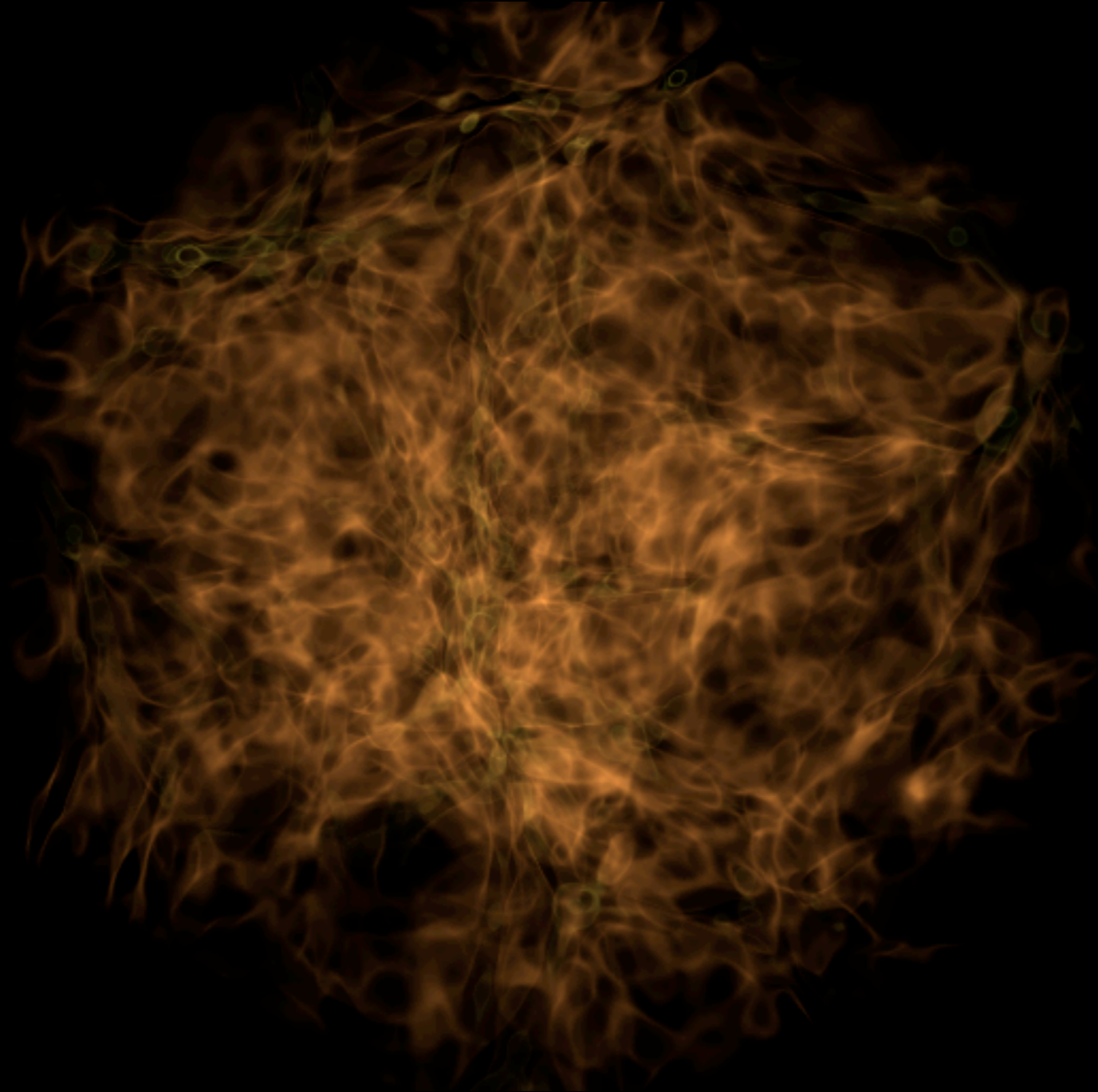


How can simulations be compared against these CGM observations?

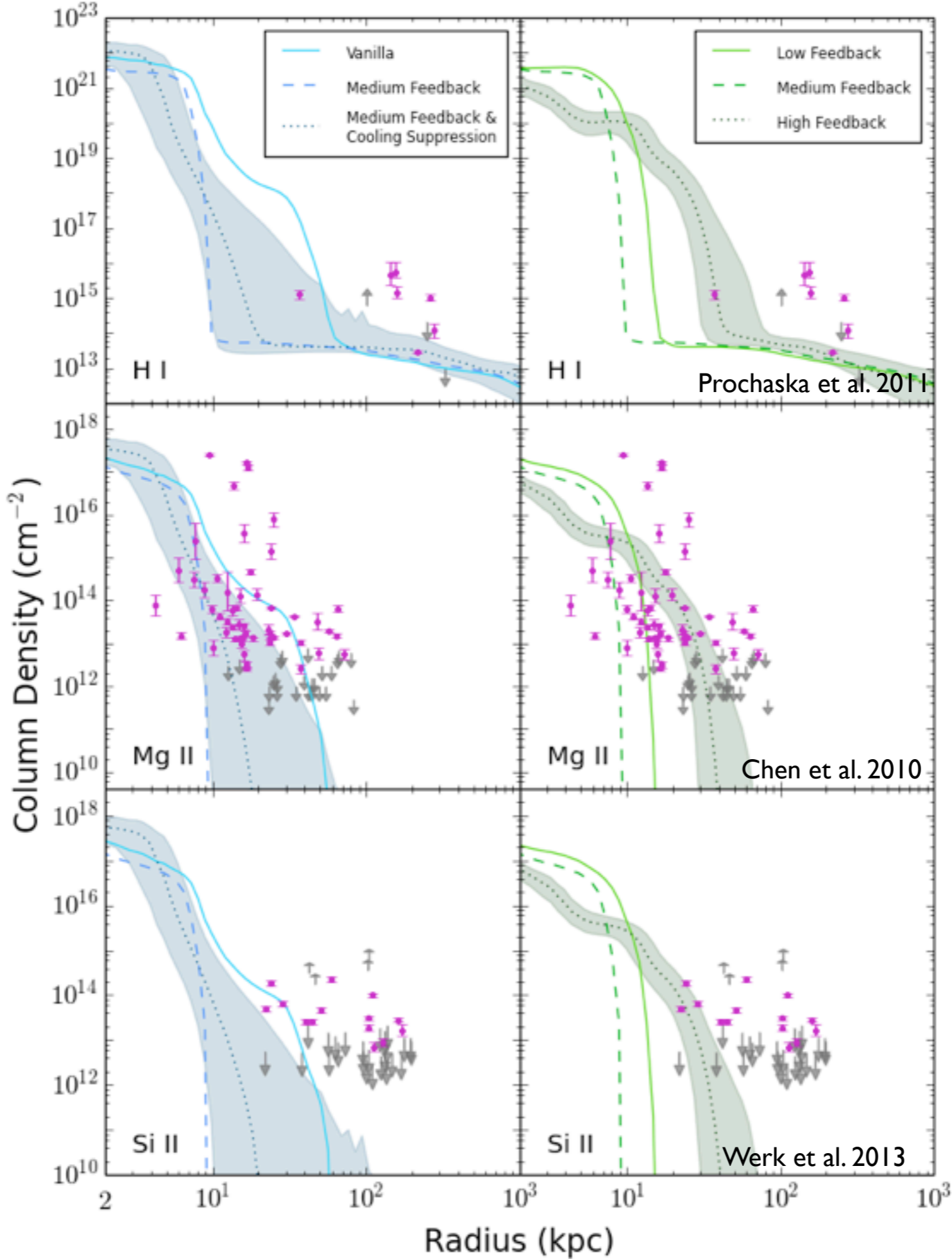
Radial profiles of different ions



Simulation Specifics



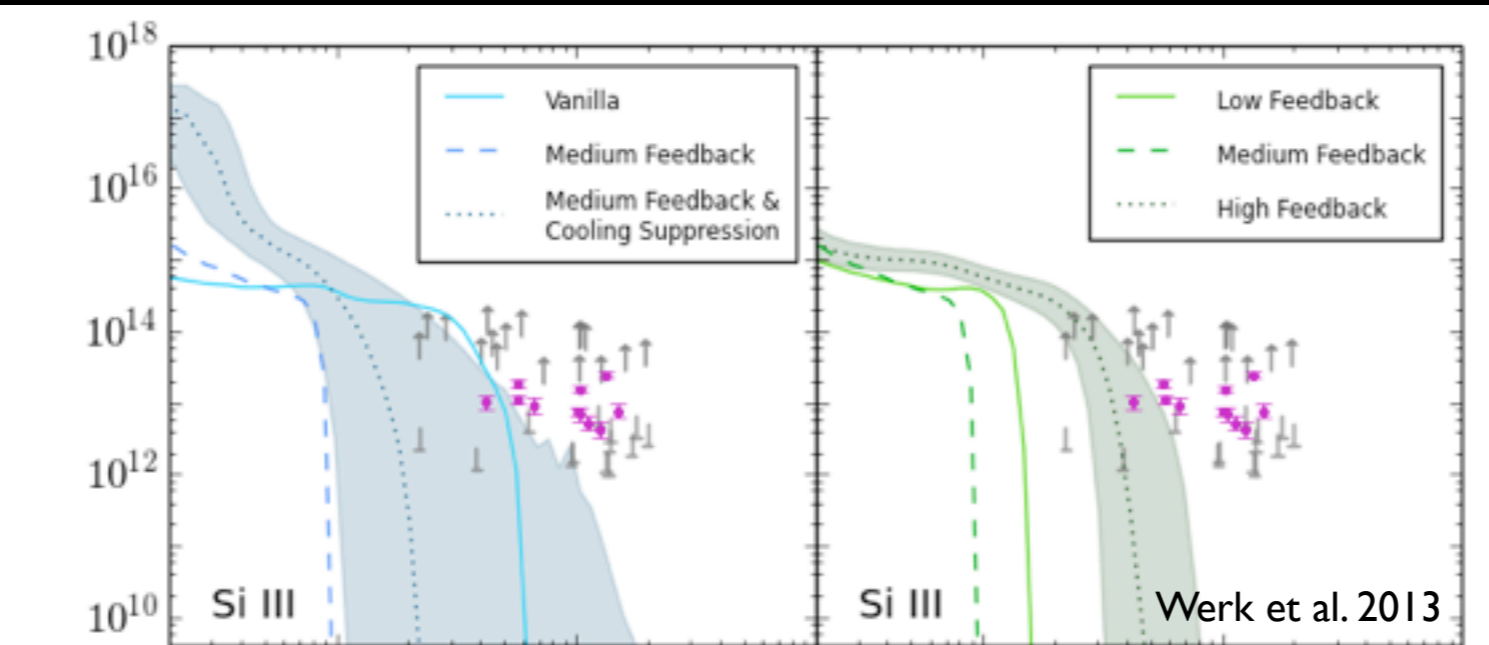
H I



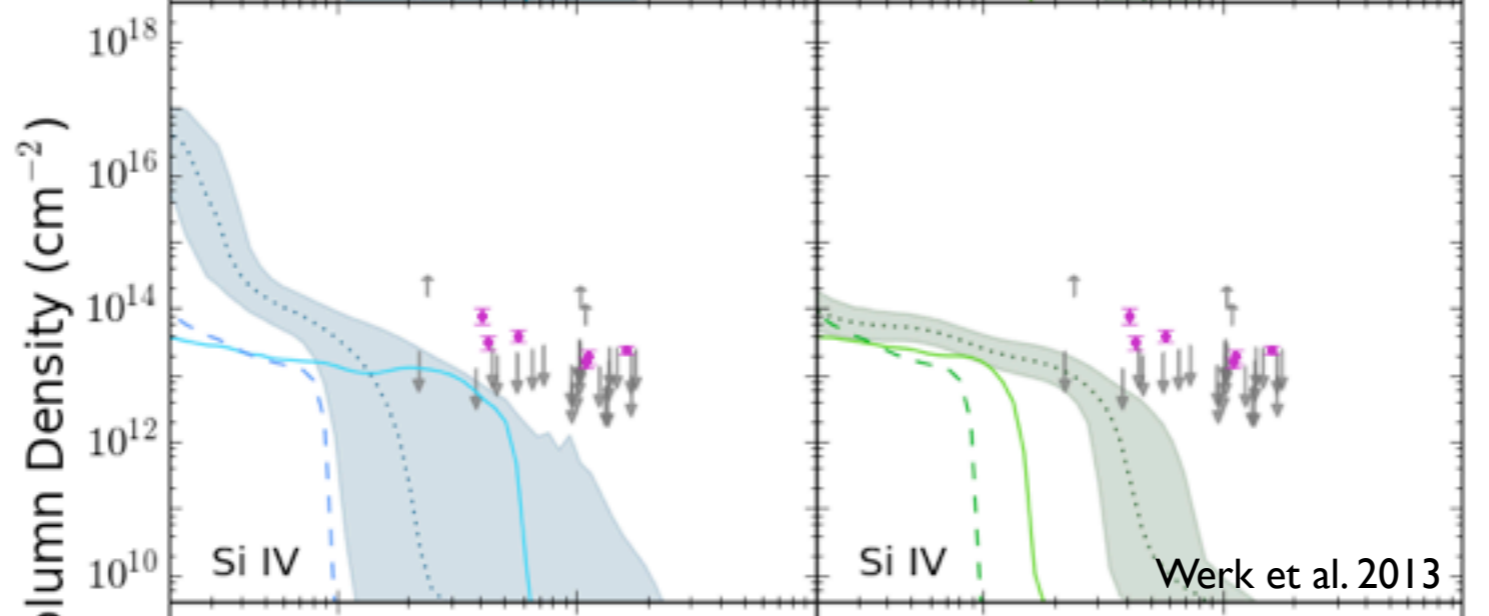
Mg II

Si II

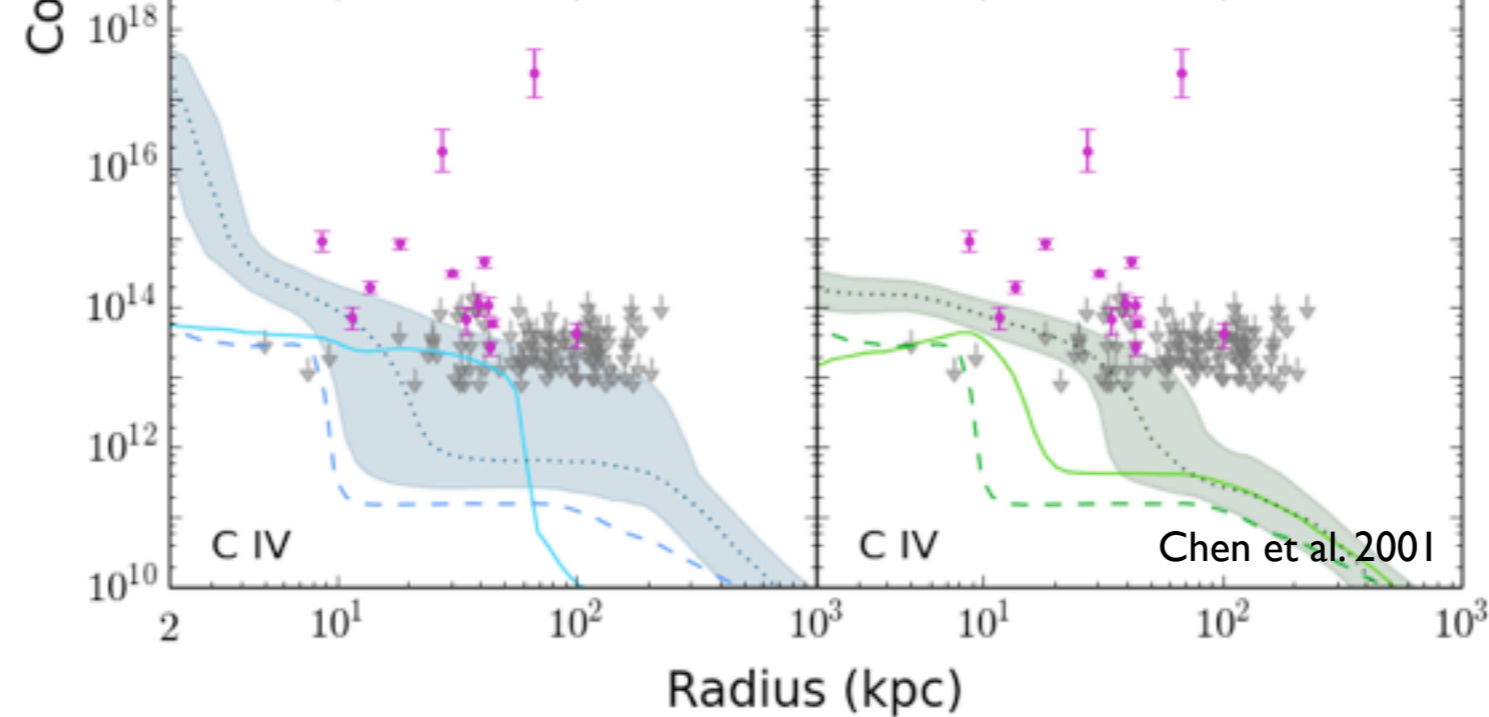
Si III



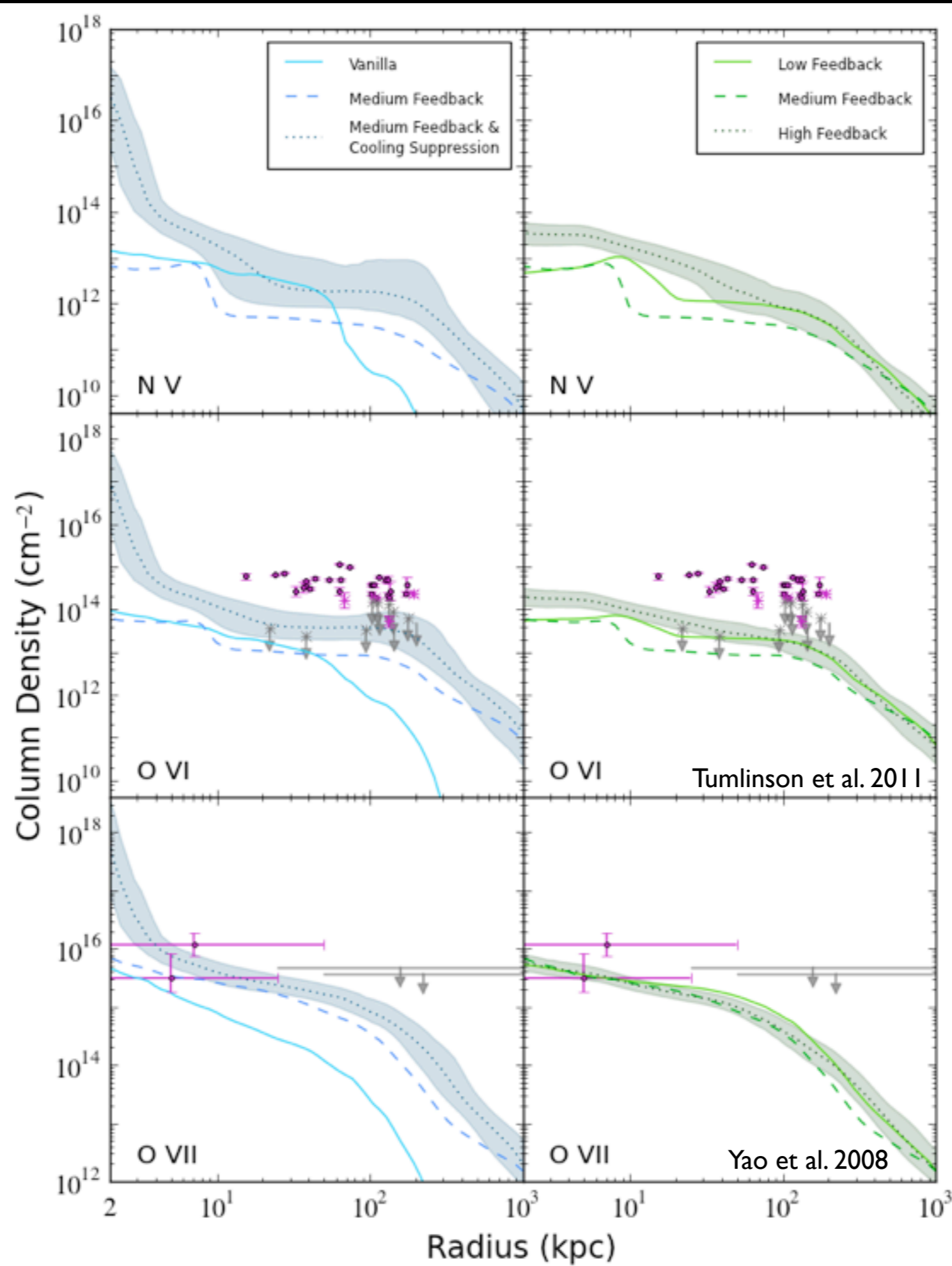
Si IV



C IV



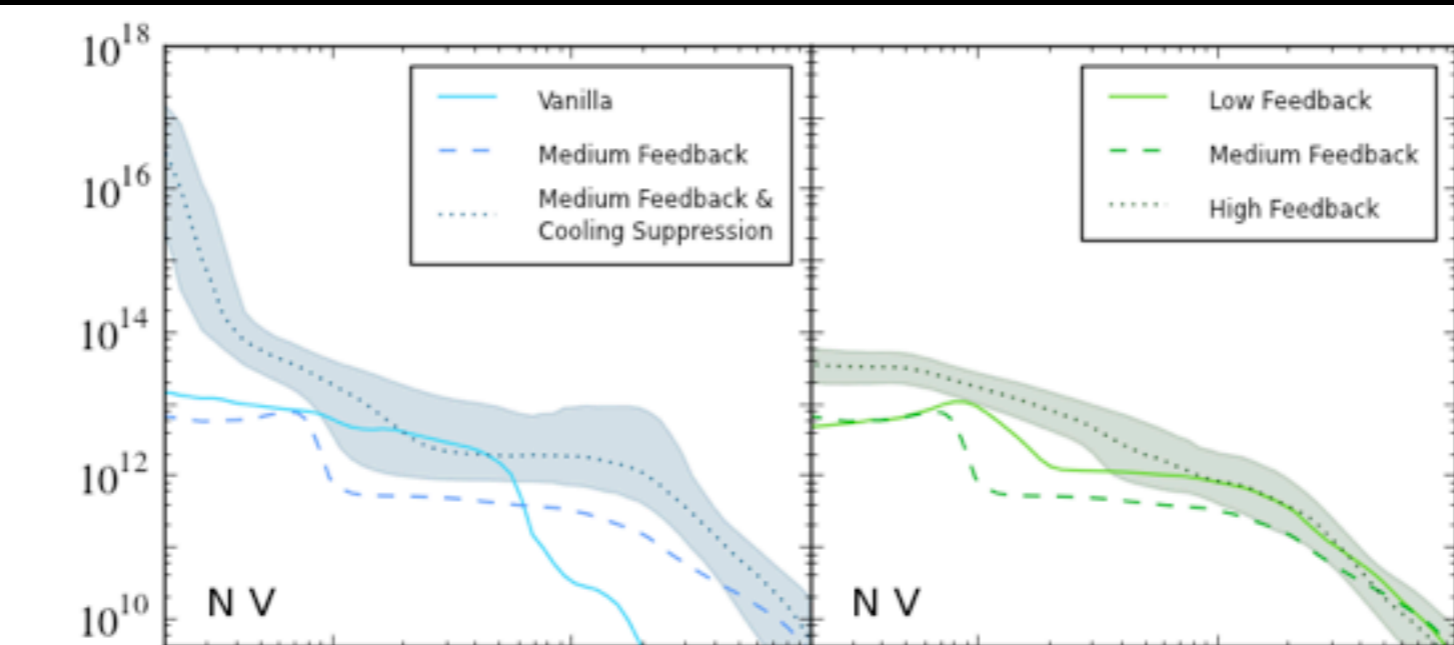
N V



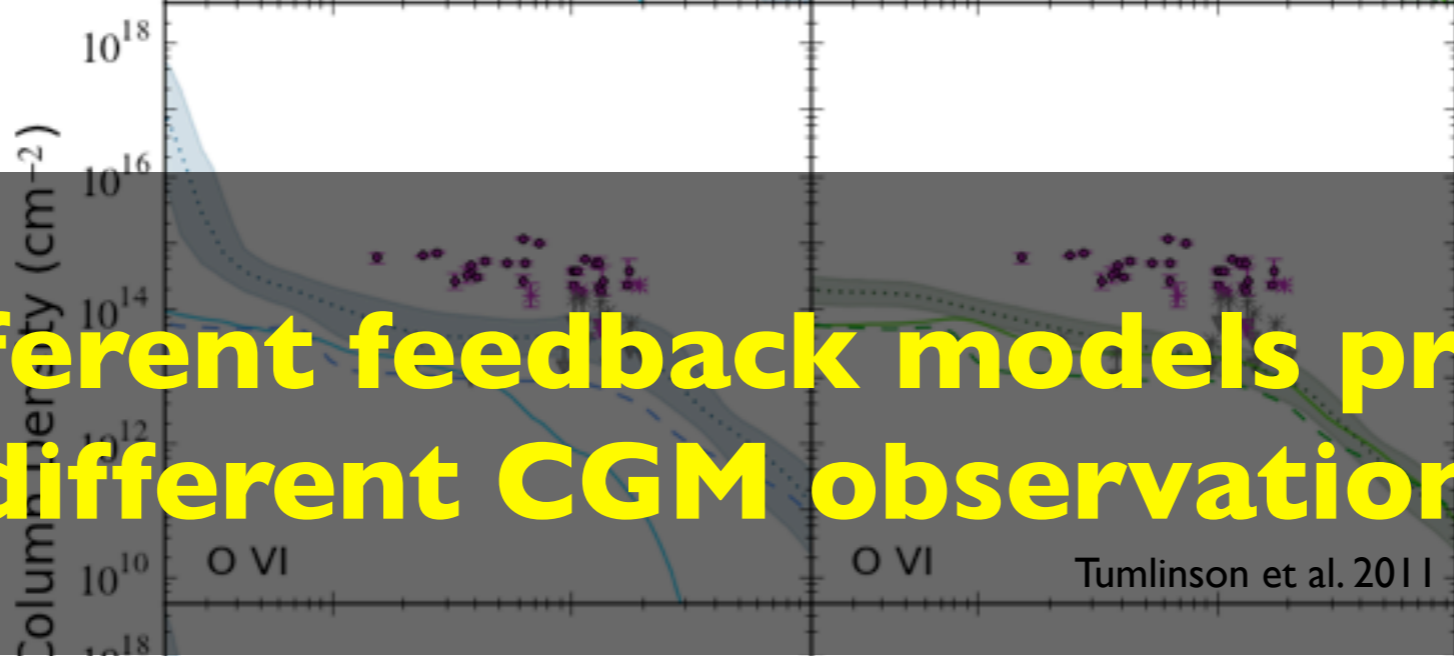
O VI

O VII

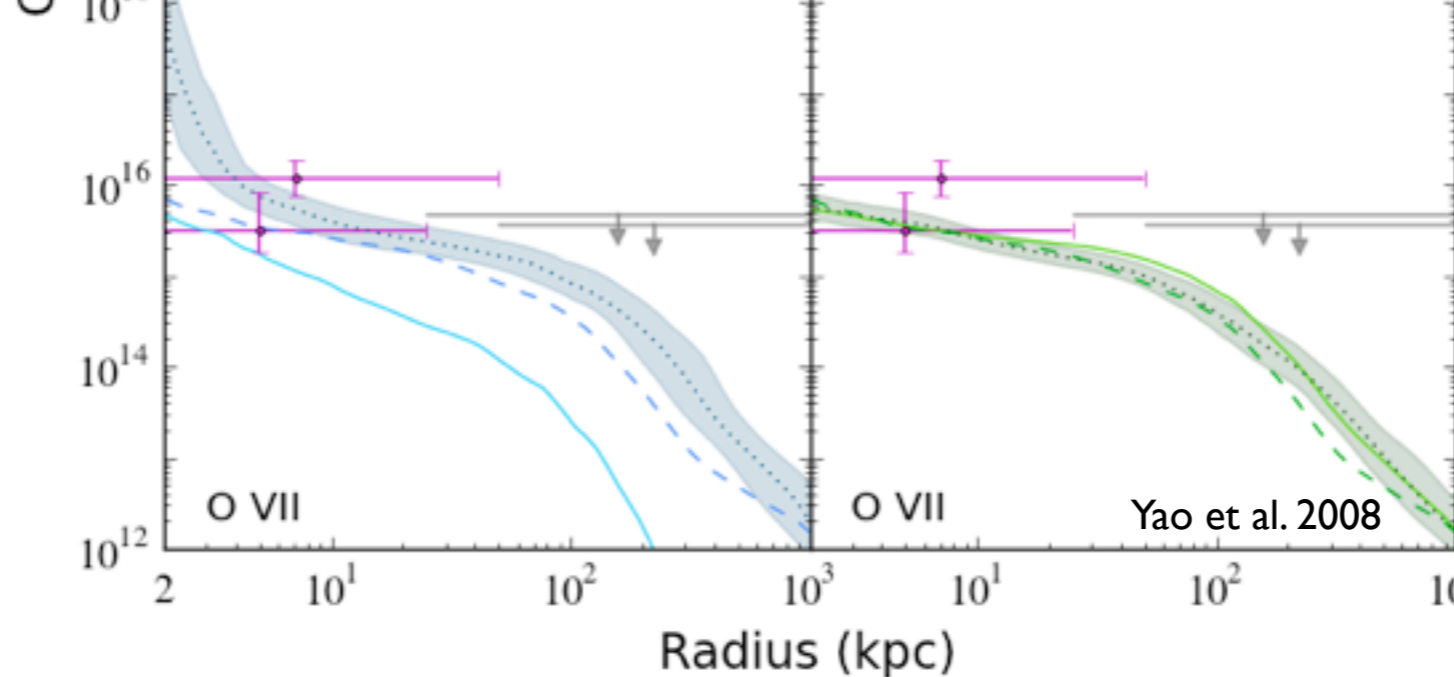
N V



O VI

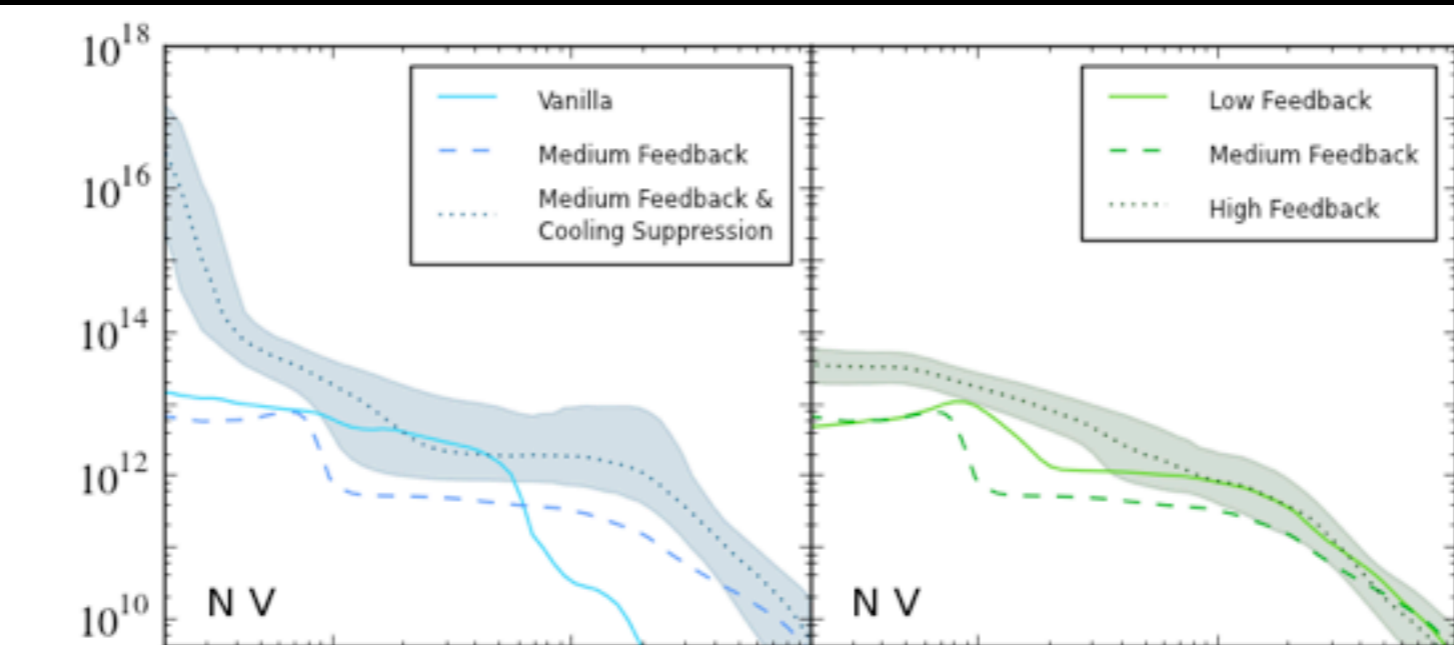


O VII



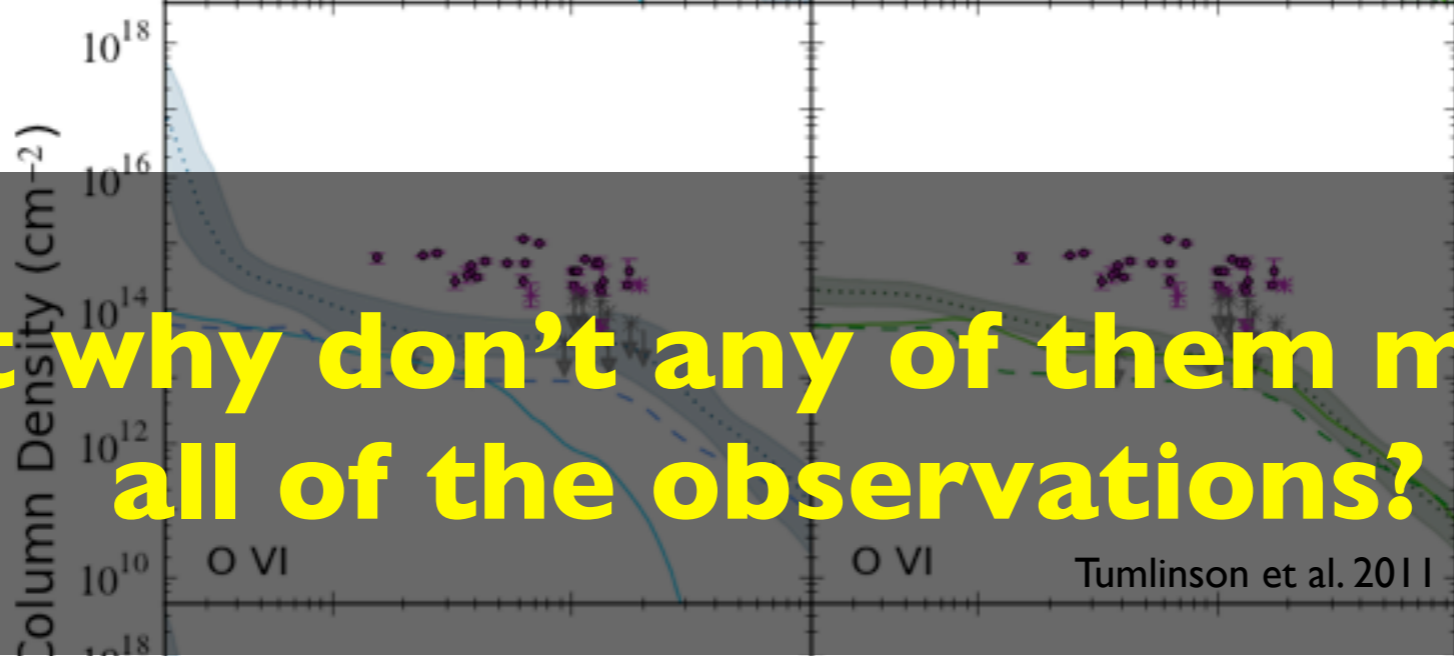
Different feedback models predict different CGM observations!

NV

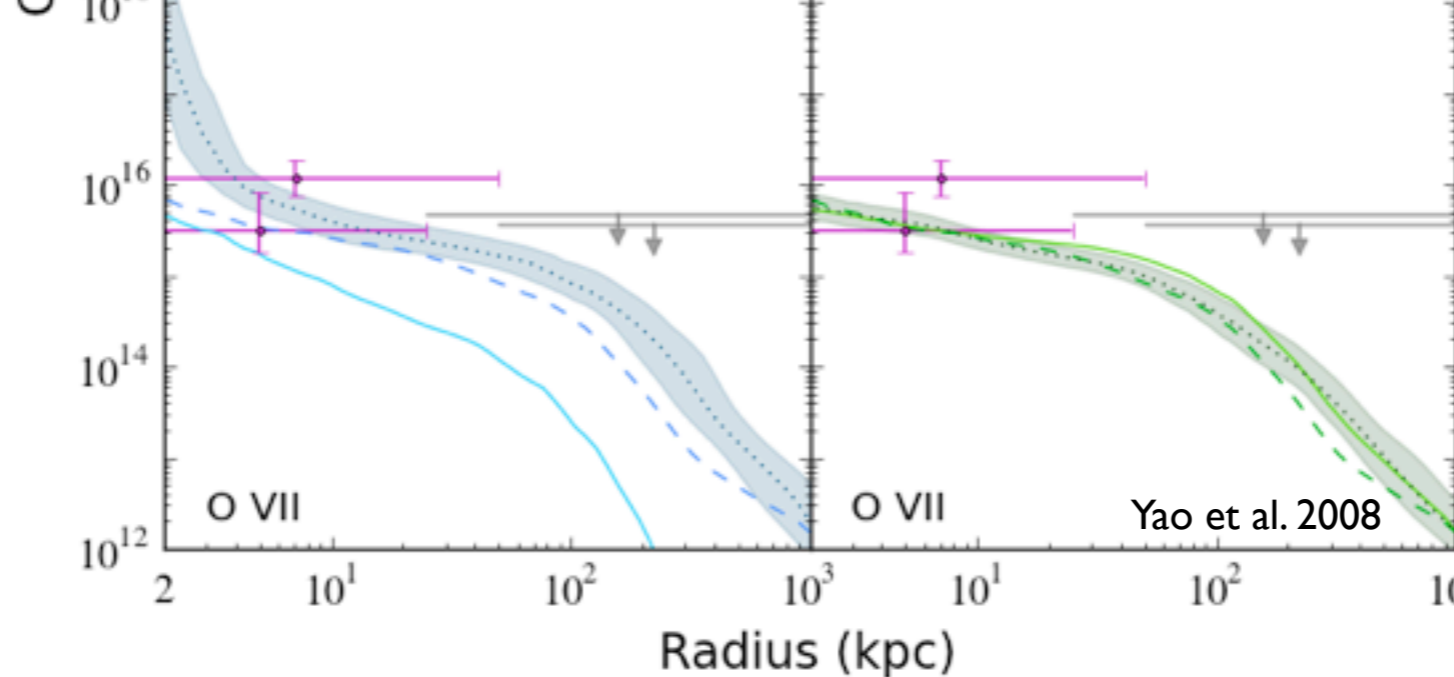


O VI

But why don't any of them match all of the observations?



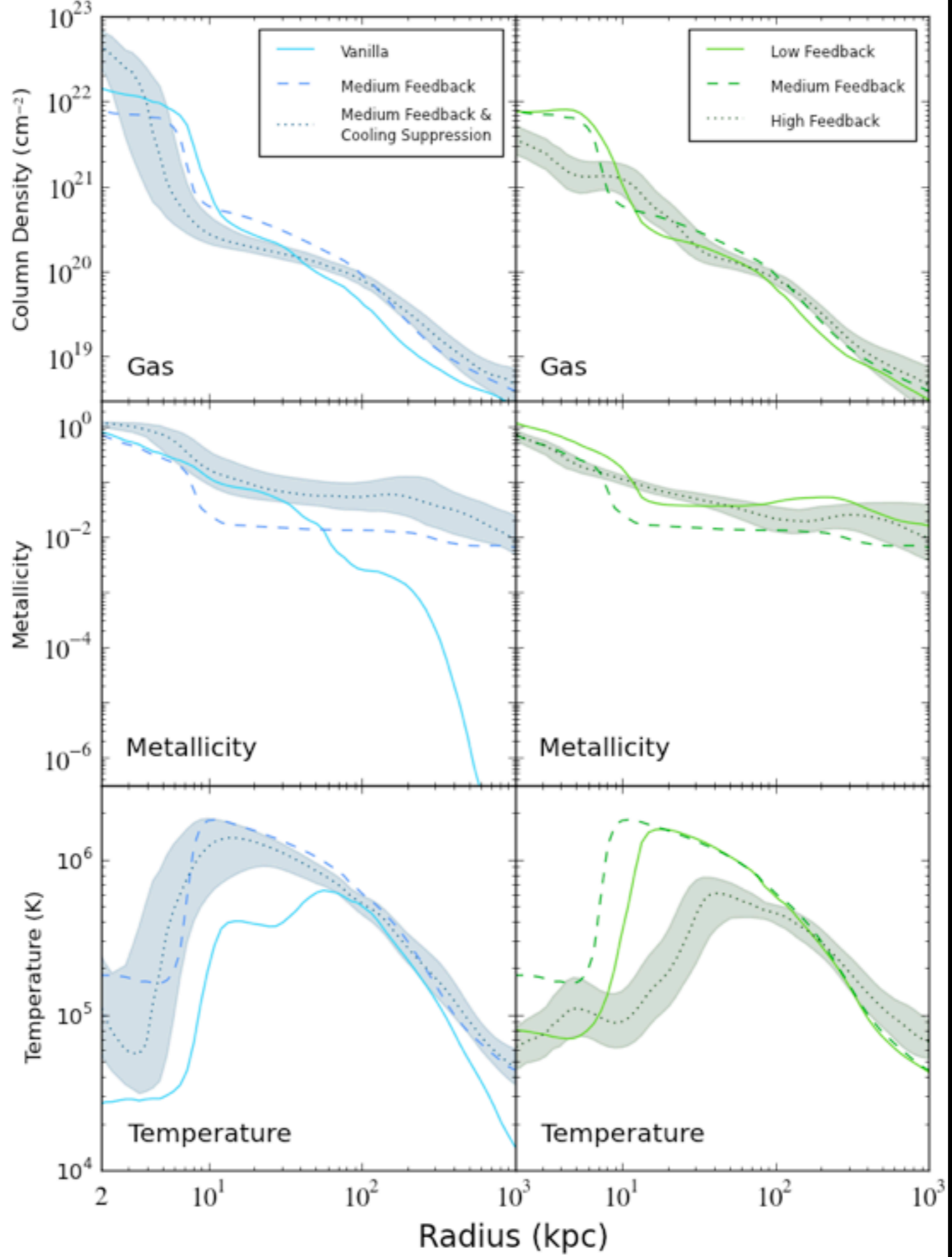
O VII



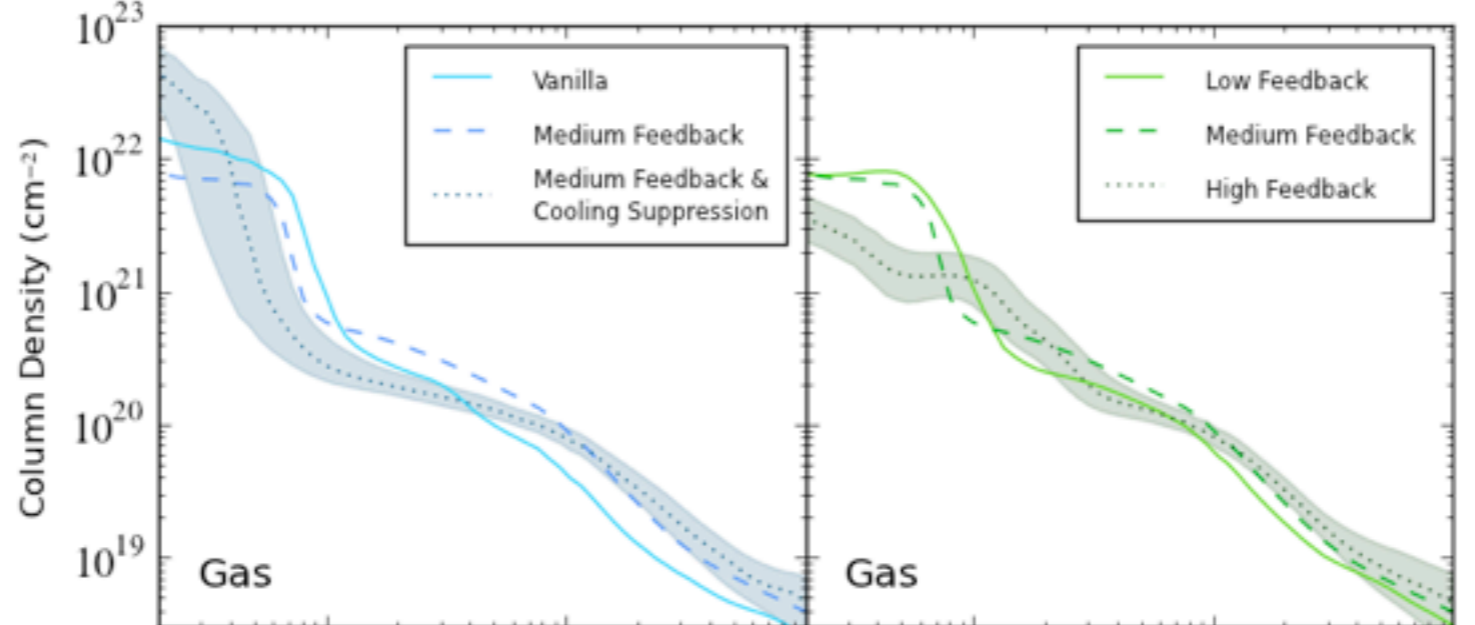
All Gas
Column Density

Metallicity

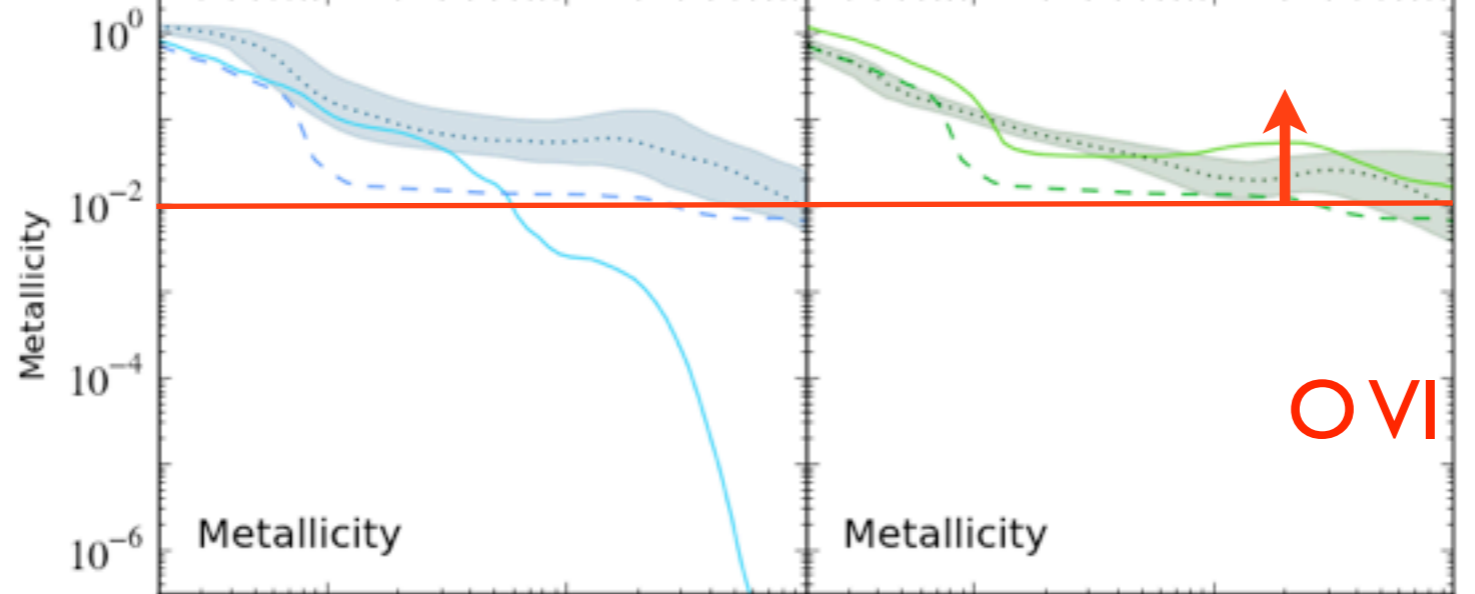
Temperature



All Gas
Column Density

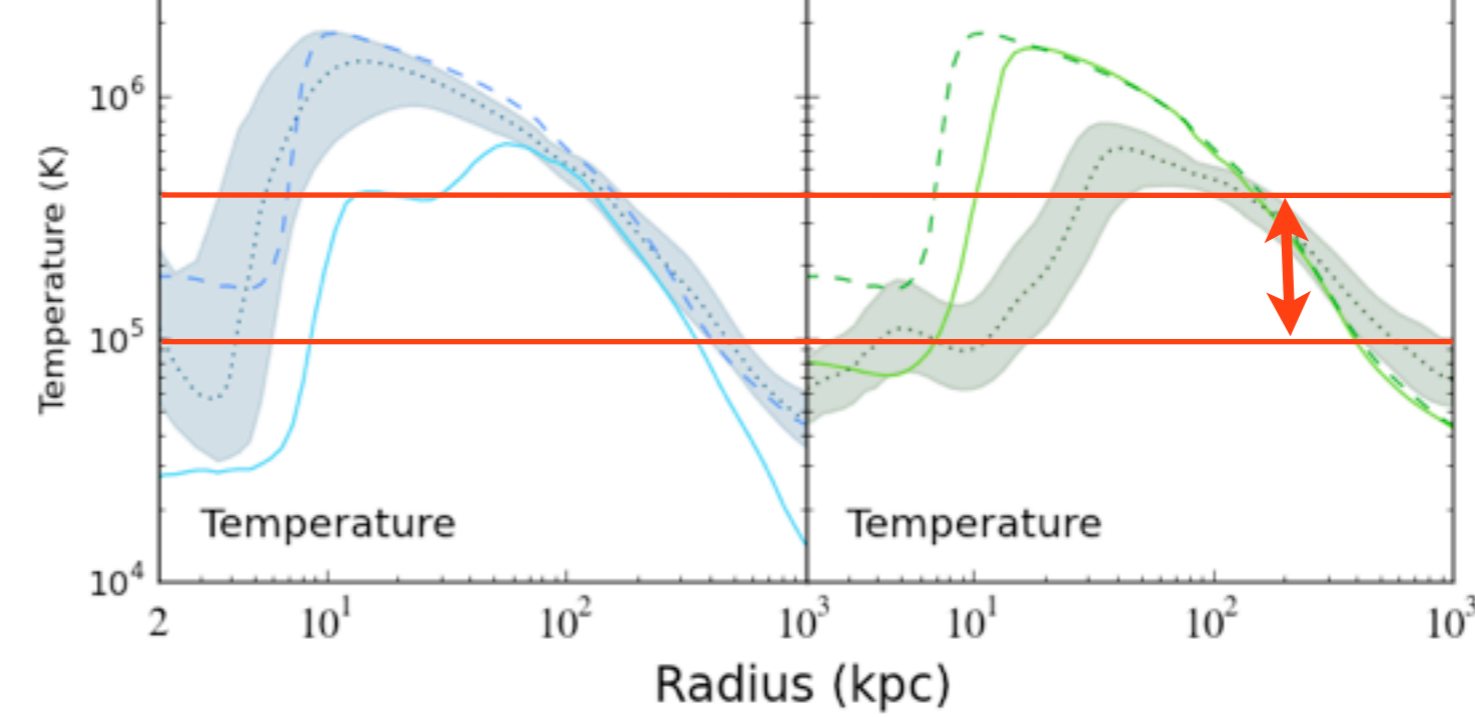


Metallicity

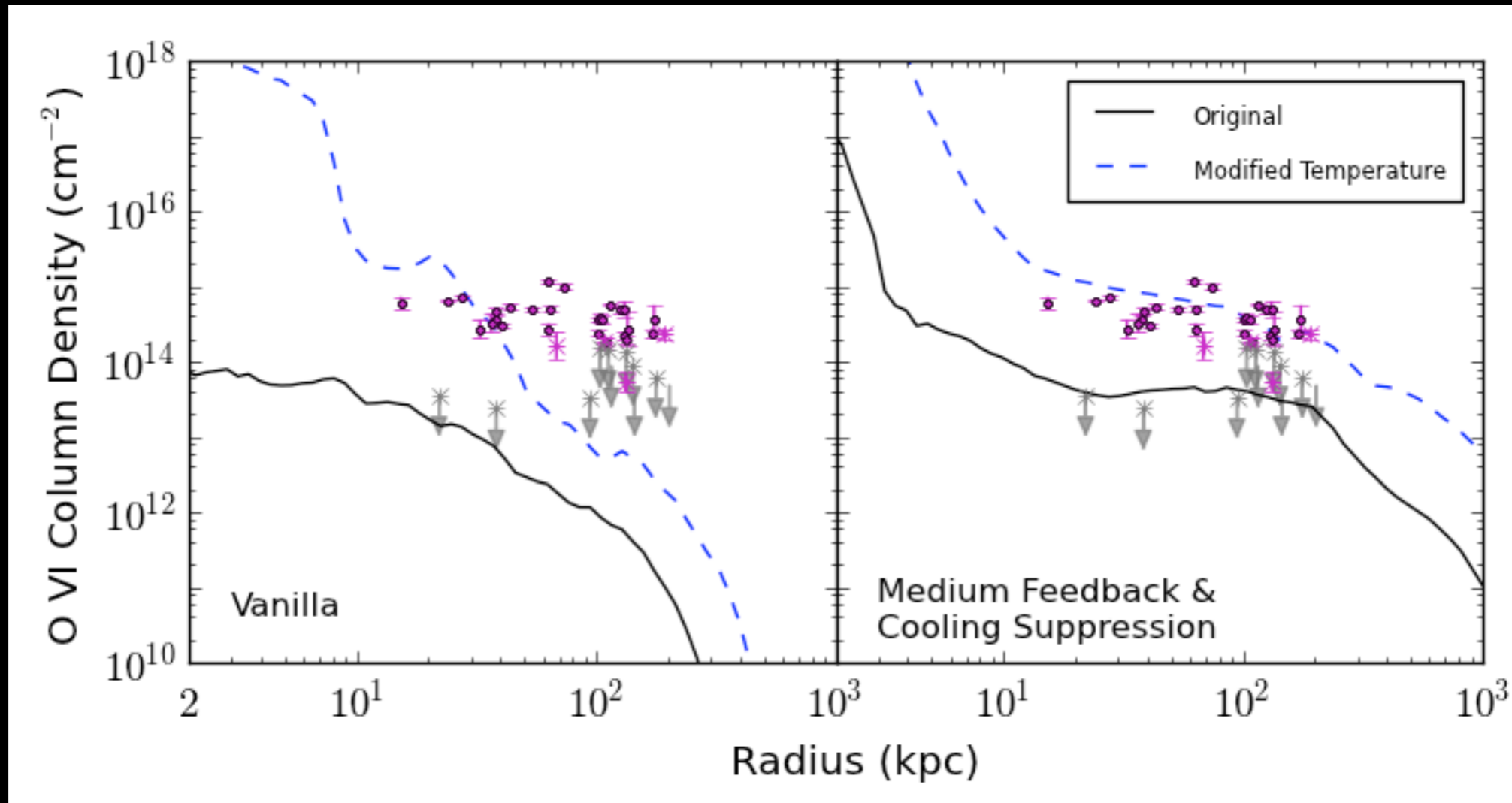


O VI Requirements

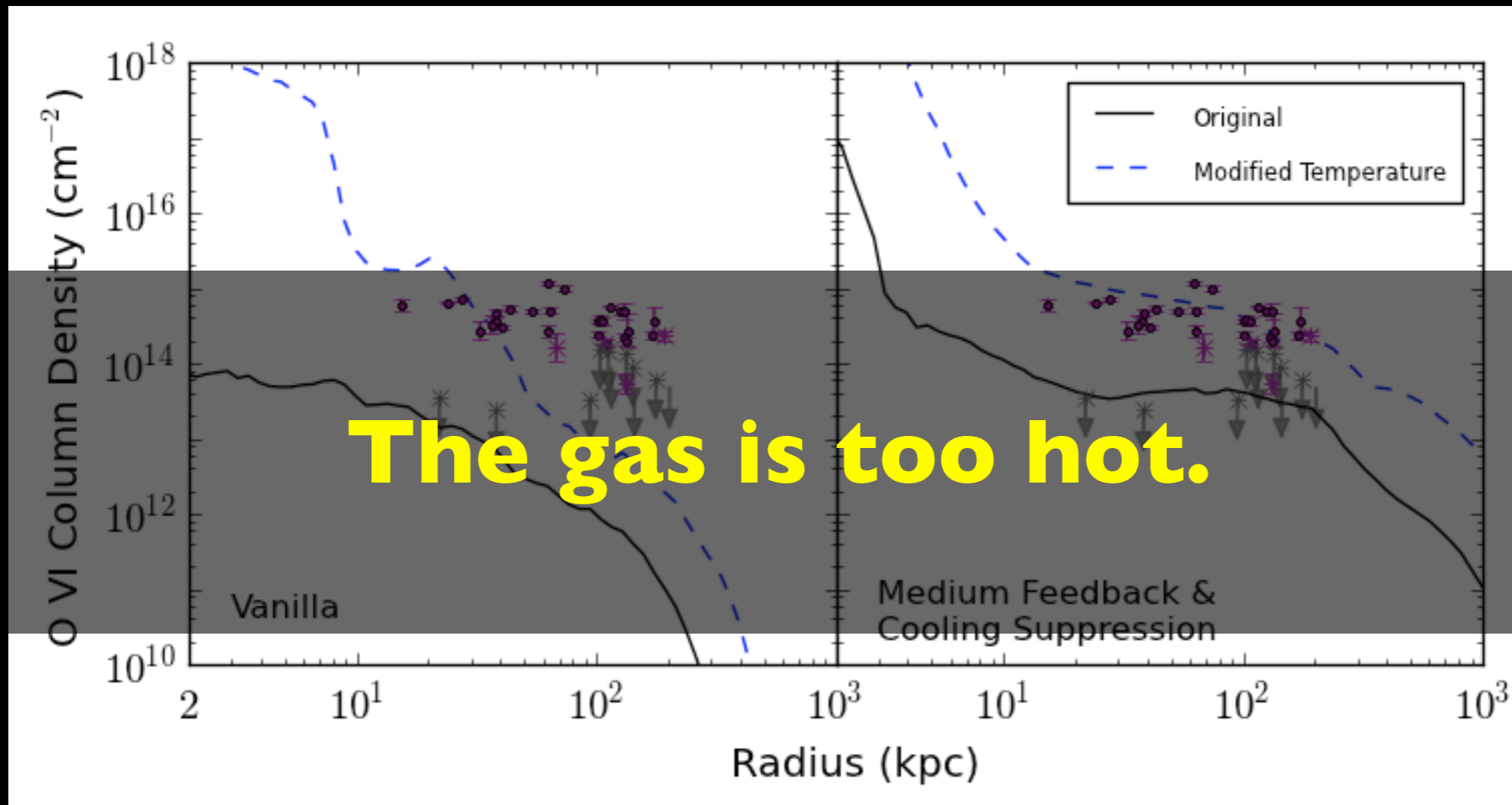
Temperature



How can simulations be compared against these CGM observations?

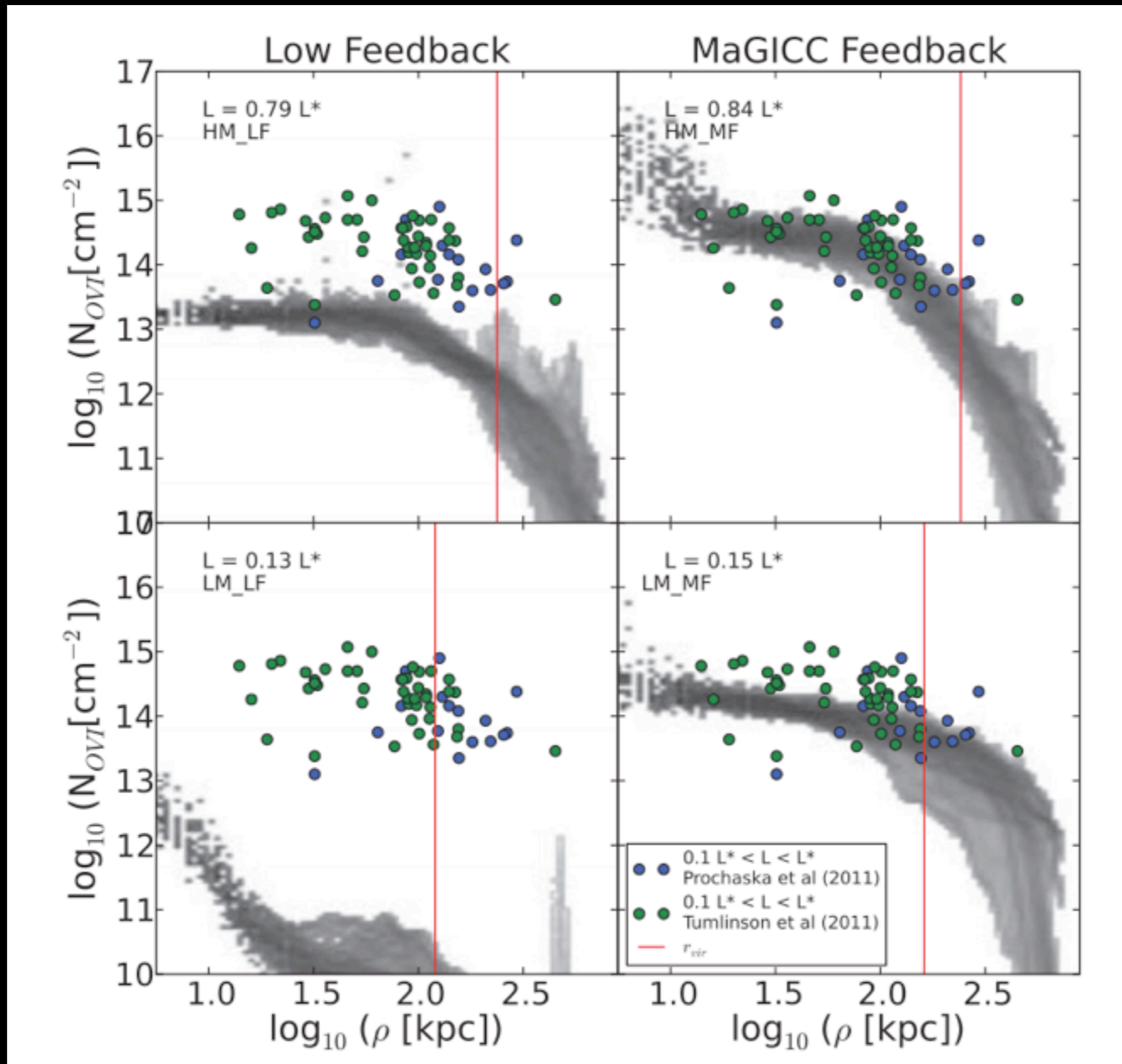


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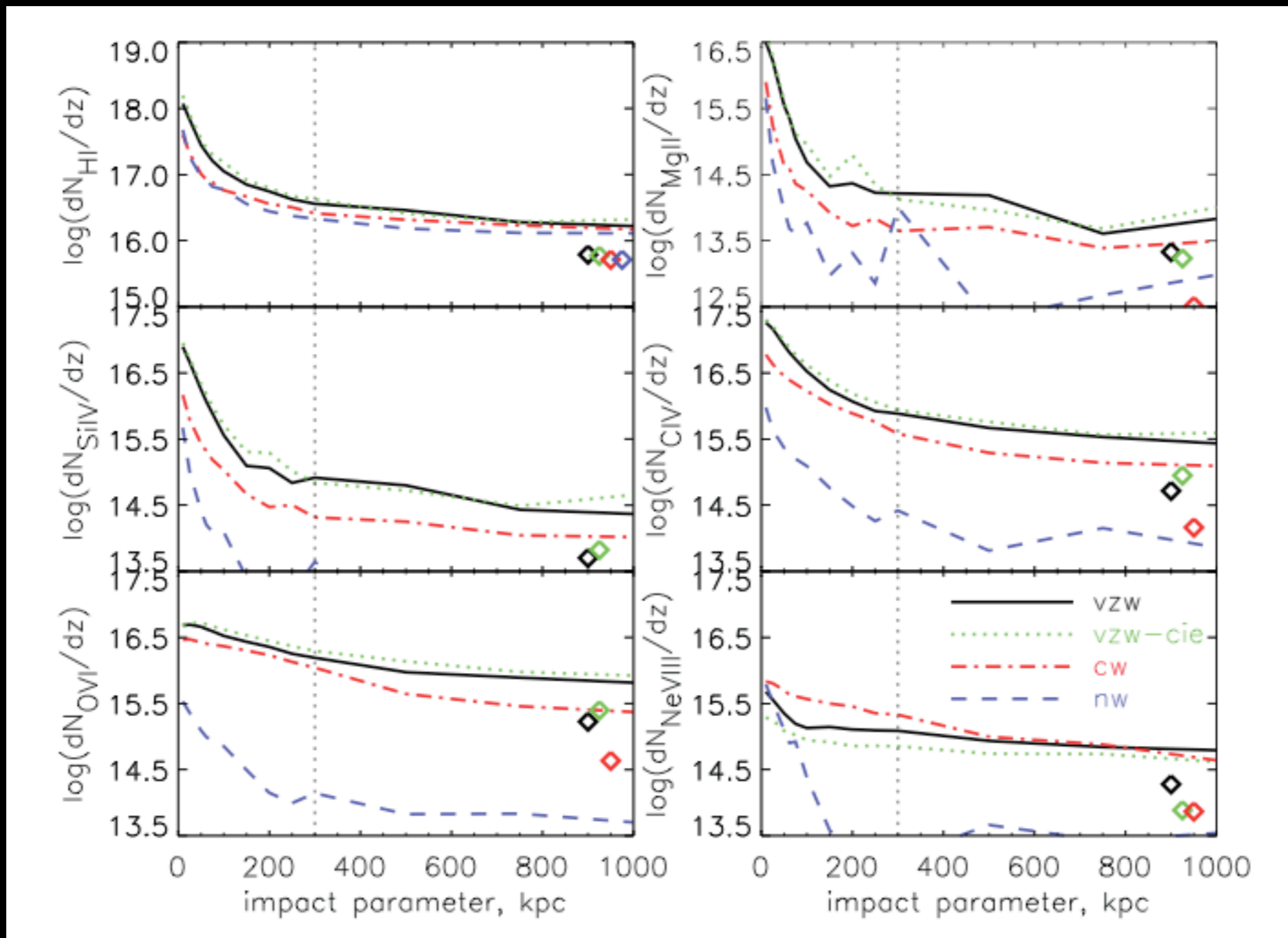
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Radial profiles of different ions



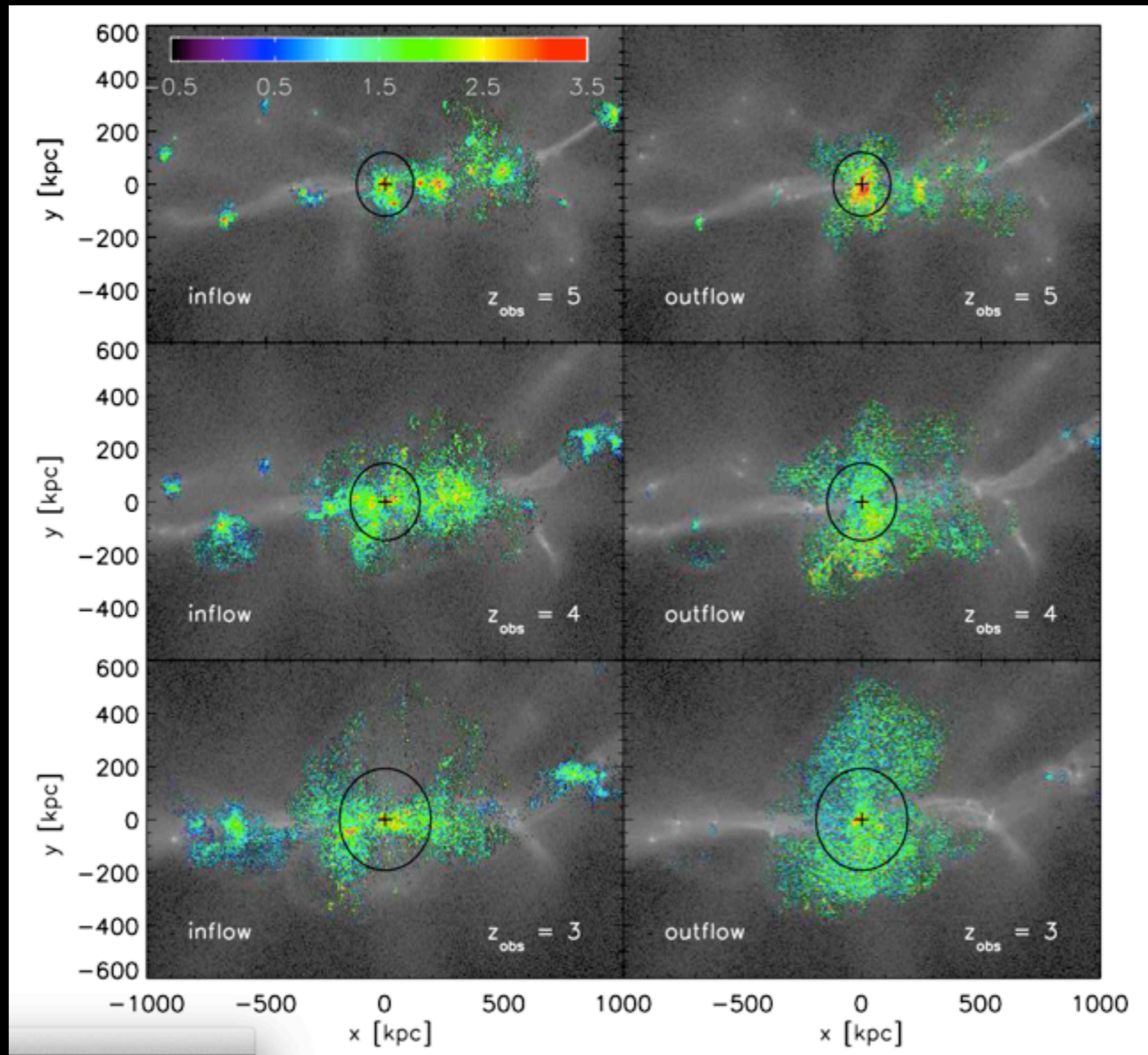
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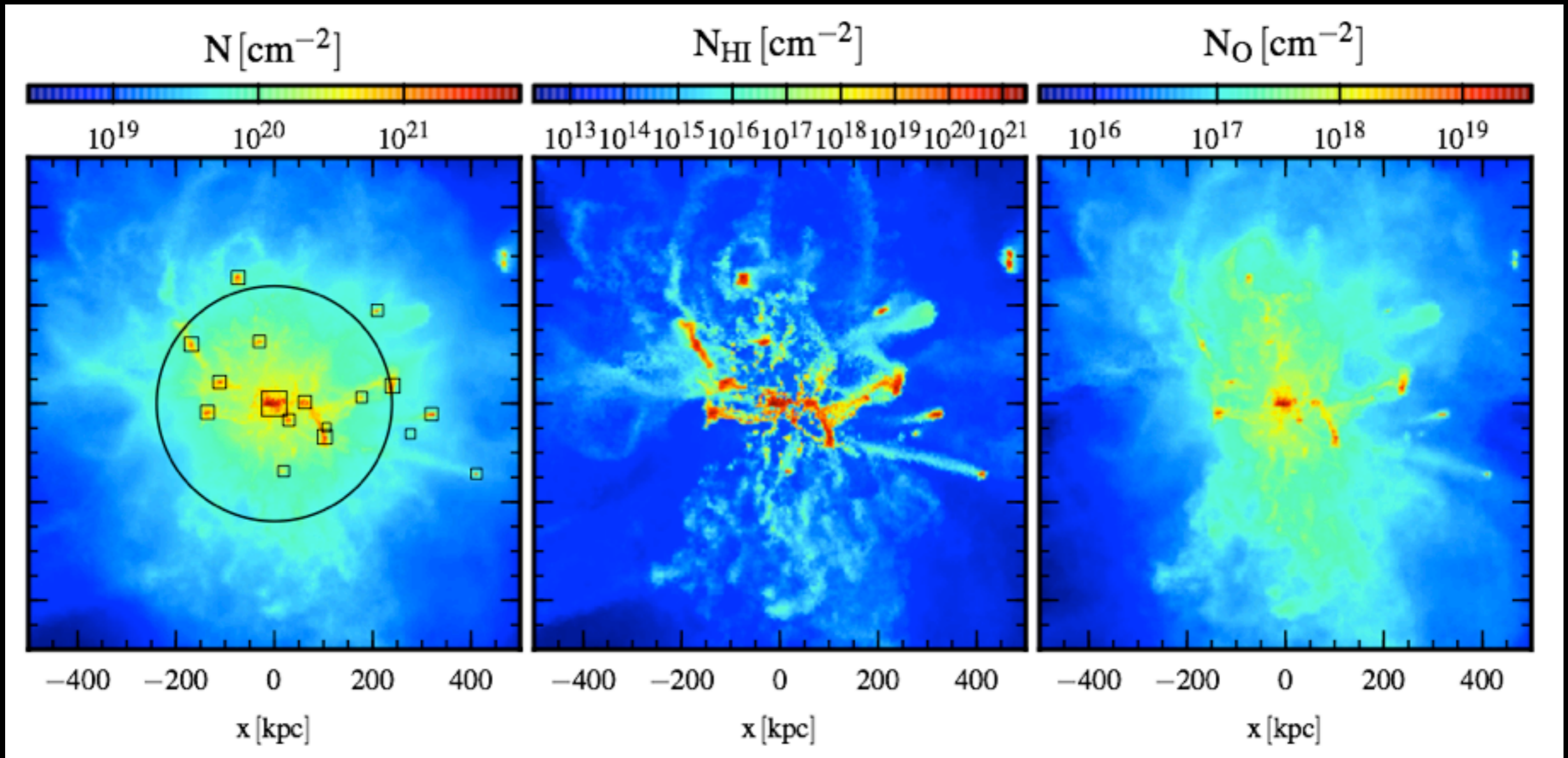
How can simulations be compared against these CGM observations?

Investigating inflow/outflow orientation



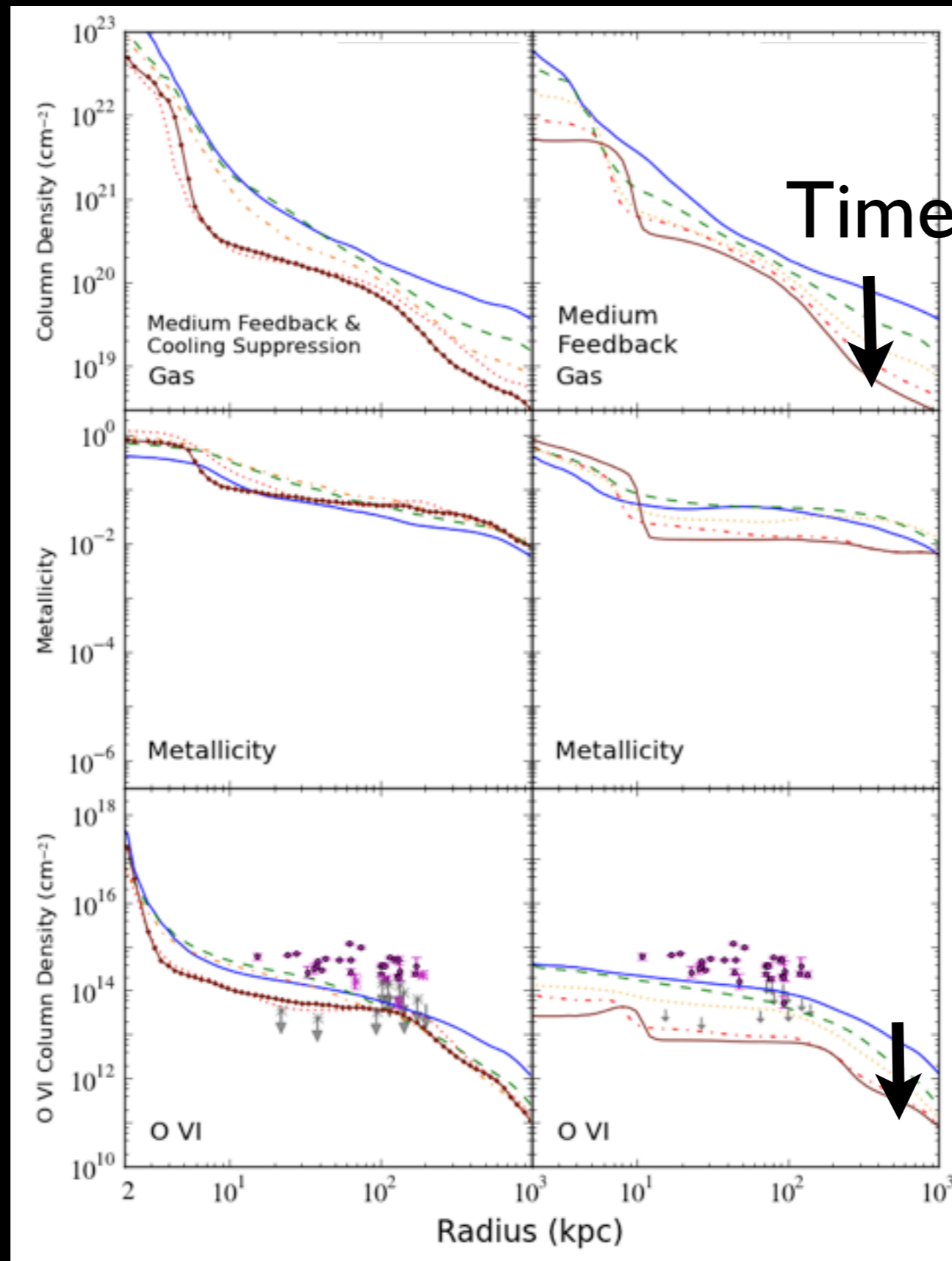
How can simulations be compared against these CGM observations?

Investigating inflow/outflow orientation



How can simulations be compared against these CGM observations?

Redshift evolution of radial profiles



Time

z = 2.0 - 4.0

z = 1.0 - 2.0

z = 0.5 - 1.0

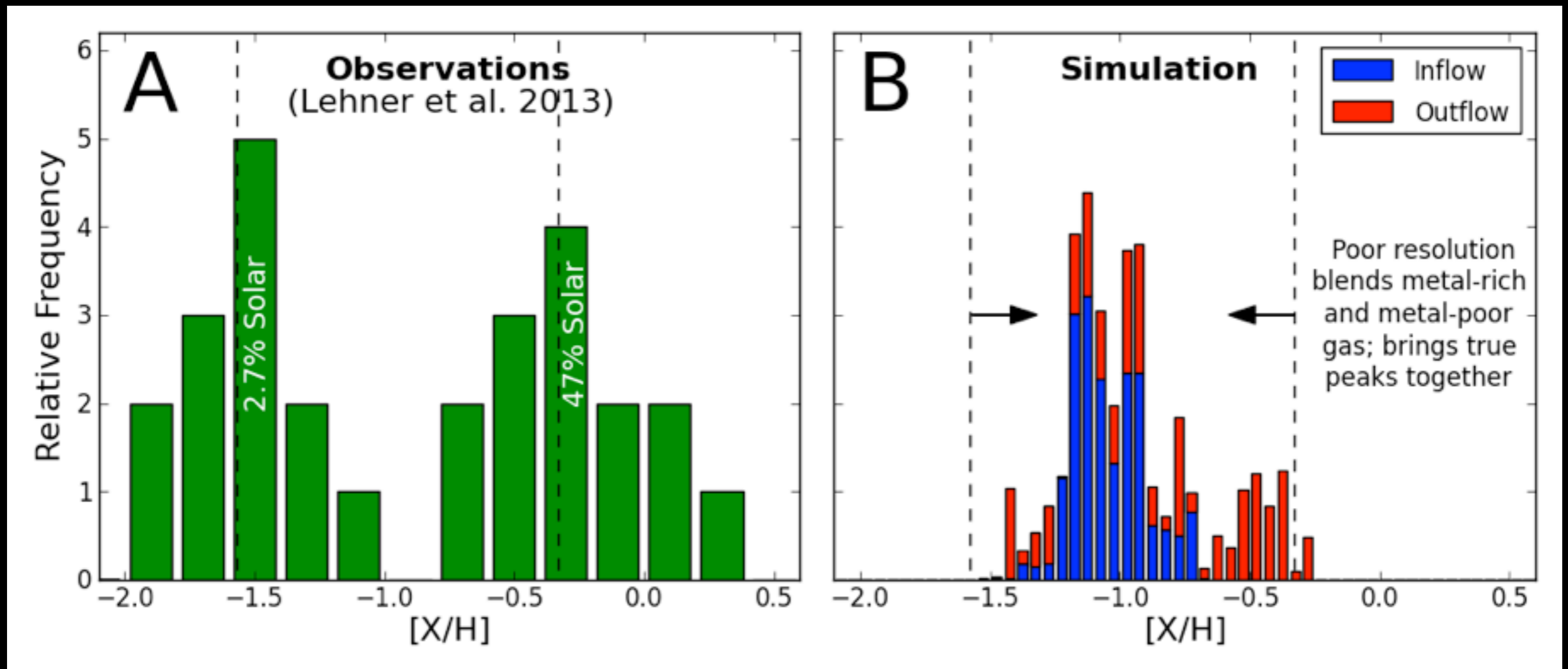
z = 0.2 - 0.5

z = 0.0 - 0.2

Hummels+ 2013

How can simulations be compared against these CGM observations?

Investigating inflow/outflow metallicities



Lehner+ 2013

Hummels+ in prep