Analyzing the Milky Way's Hot Gas Halo with OVII and OVIII Emission Lines

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X-ray View of Galaxy Ecosystems 2014
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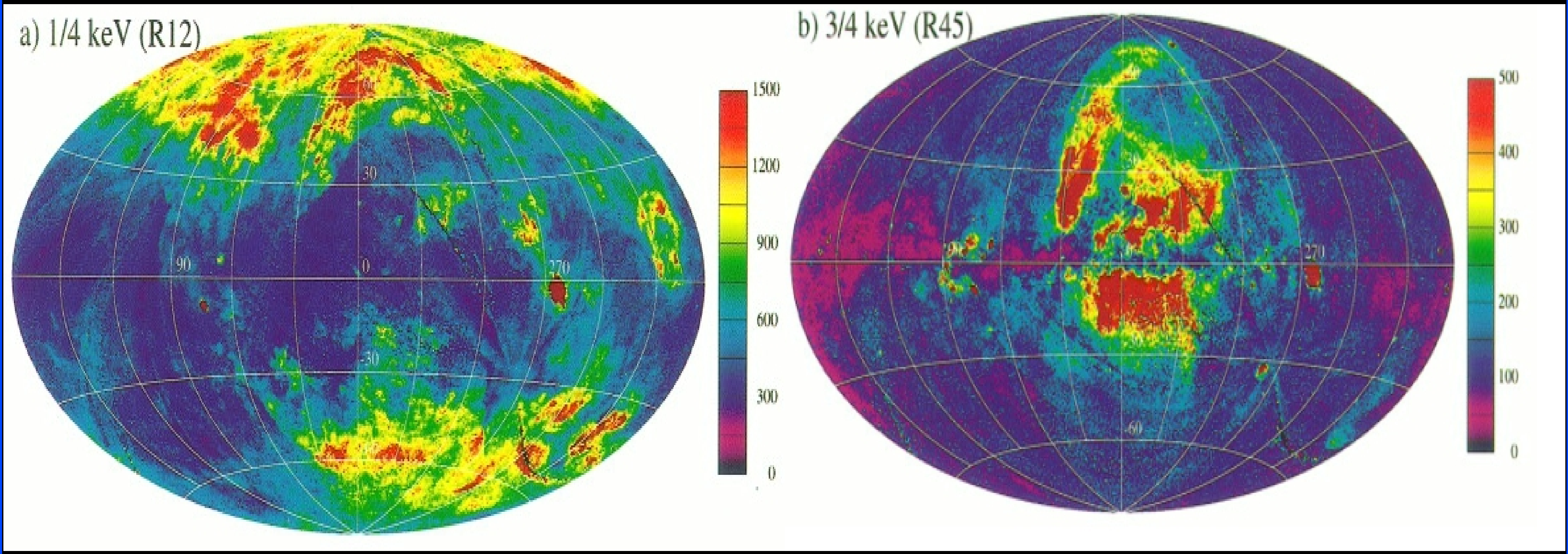
Snowden+97

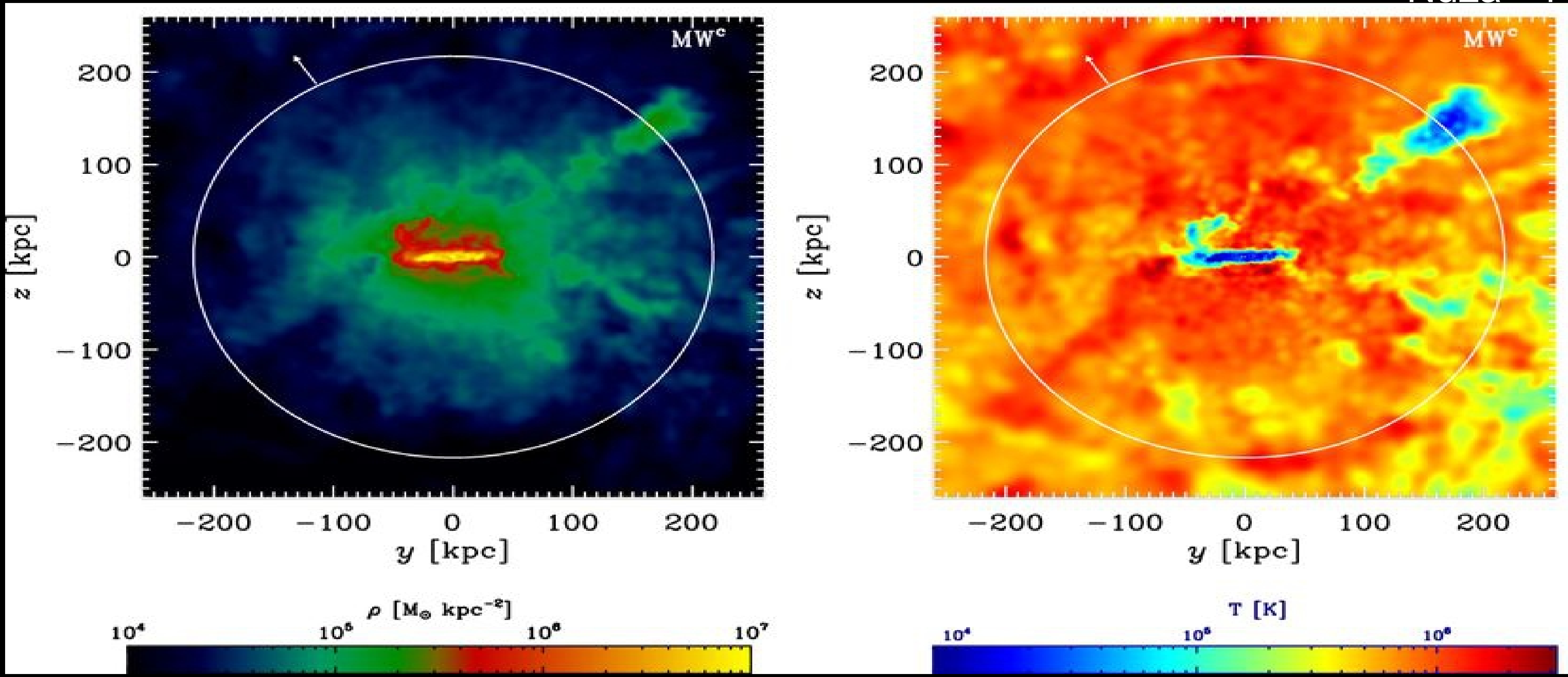


The CGM Ecosystem

- The circumgalactic medium (CGM) around Milky Way-sized galaxies includes...
  - Infalling / outflowing gas
  - Gas shock heated to T_{vir} in quasi-static halo

- Properties tell us about galaxy formation / evolution

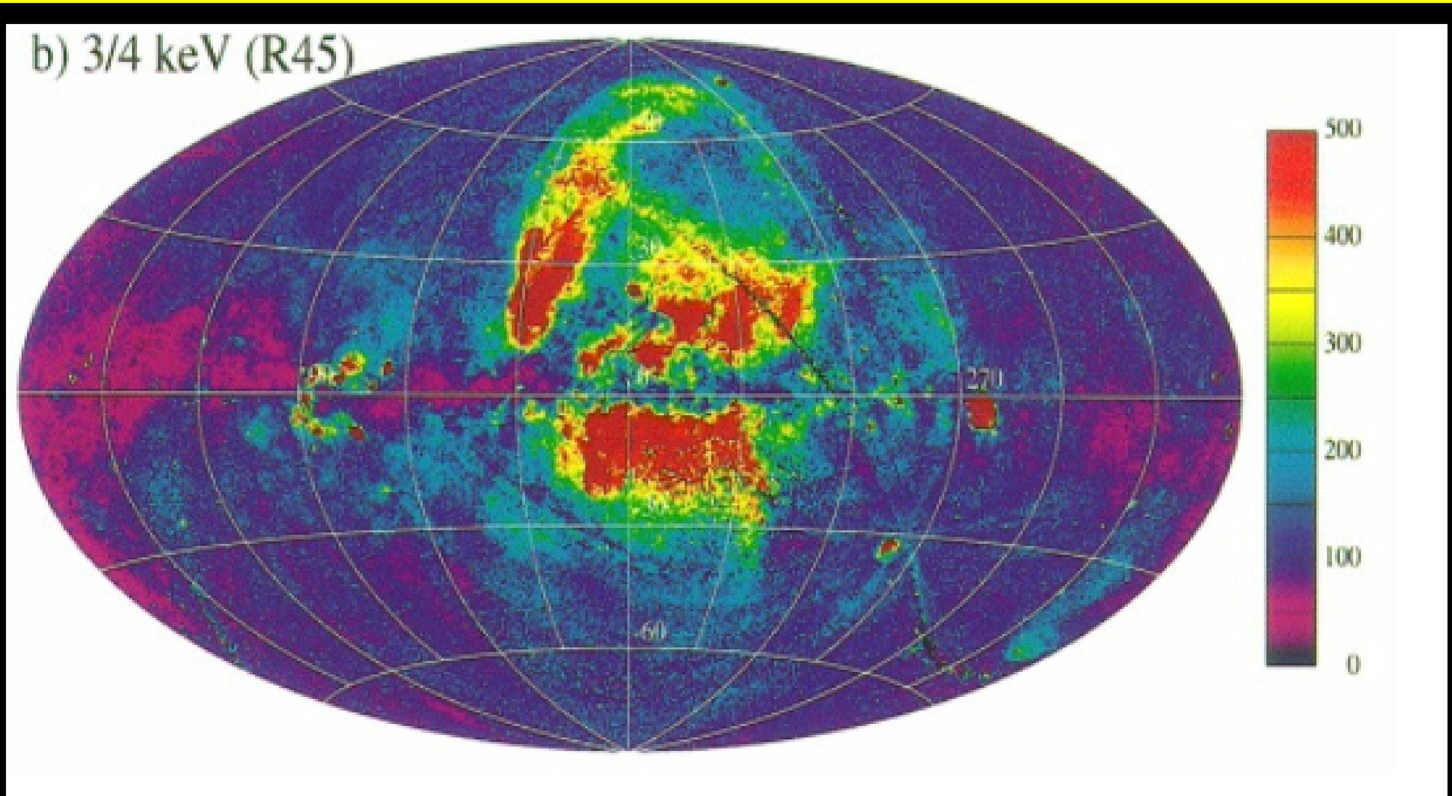
Nuza+ 14



The Milky Way's Ecosystem

- The Milky Way's X-ray halo gas has been observed in both emission and absorption

Emission Source	log(T)	n (cm^{-3})	Scale
Hot Halo	6.3	10^{-5} - 10^{-3}	~r_{vir} ~250 kpc
Local Bubble (LB)	6.1	10^{-3} - 10^{-2}	100-300 pc



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Goals of This Work

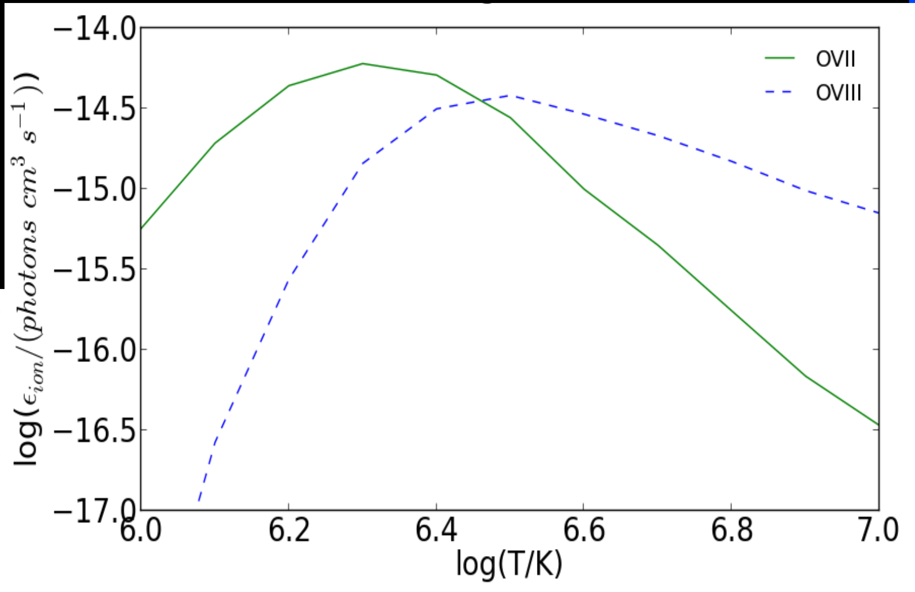
- Improve constraints on the radial distribution of hot halo gas using X-ray emission lines
  - Do emission lines provide an improvement over absorption lines?

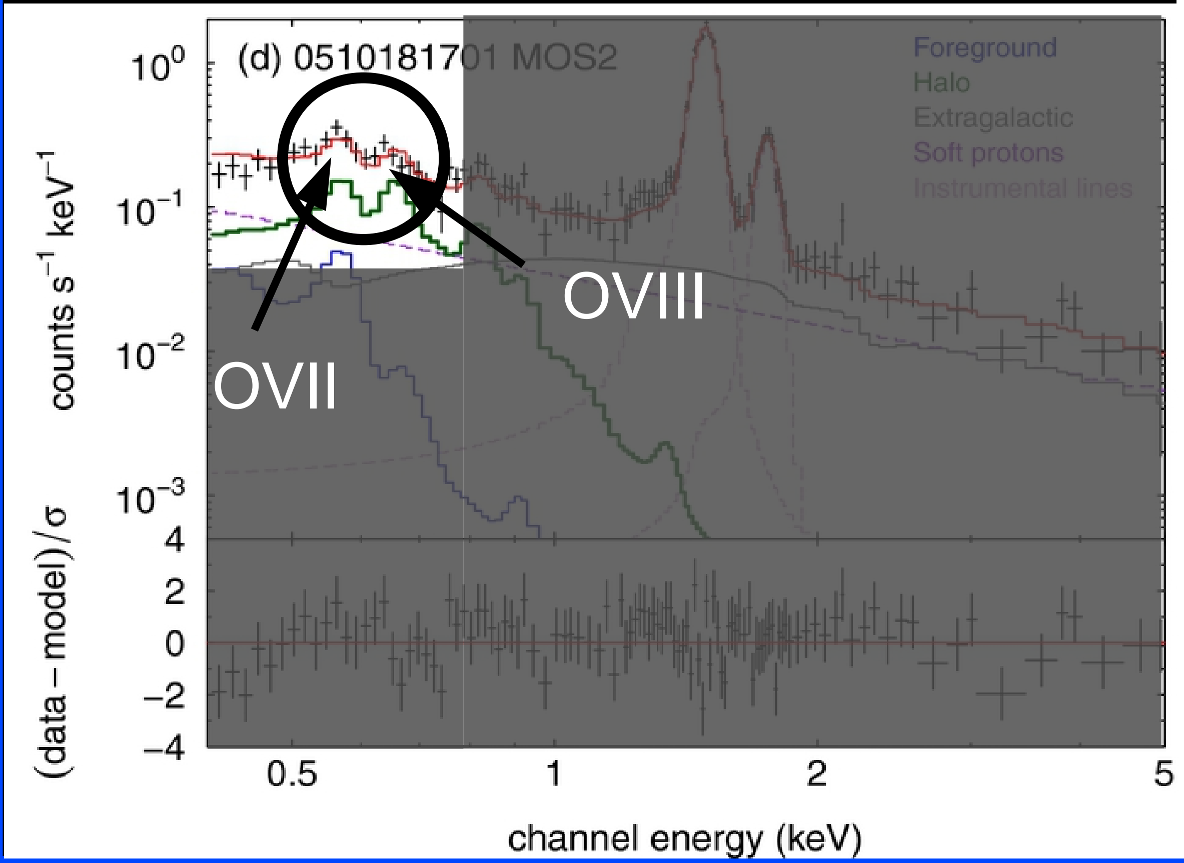
- Estimate the mass of the hot gas halo – is it a significant amount of baryons?

Diagnostics

- OVII - 0.56 keV – He-like triplet emission
- OVIII - 0.65 keV – H-like Lyα emission

- Large ion fractions at ~10^6 K





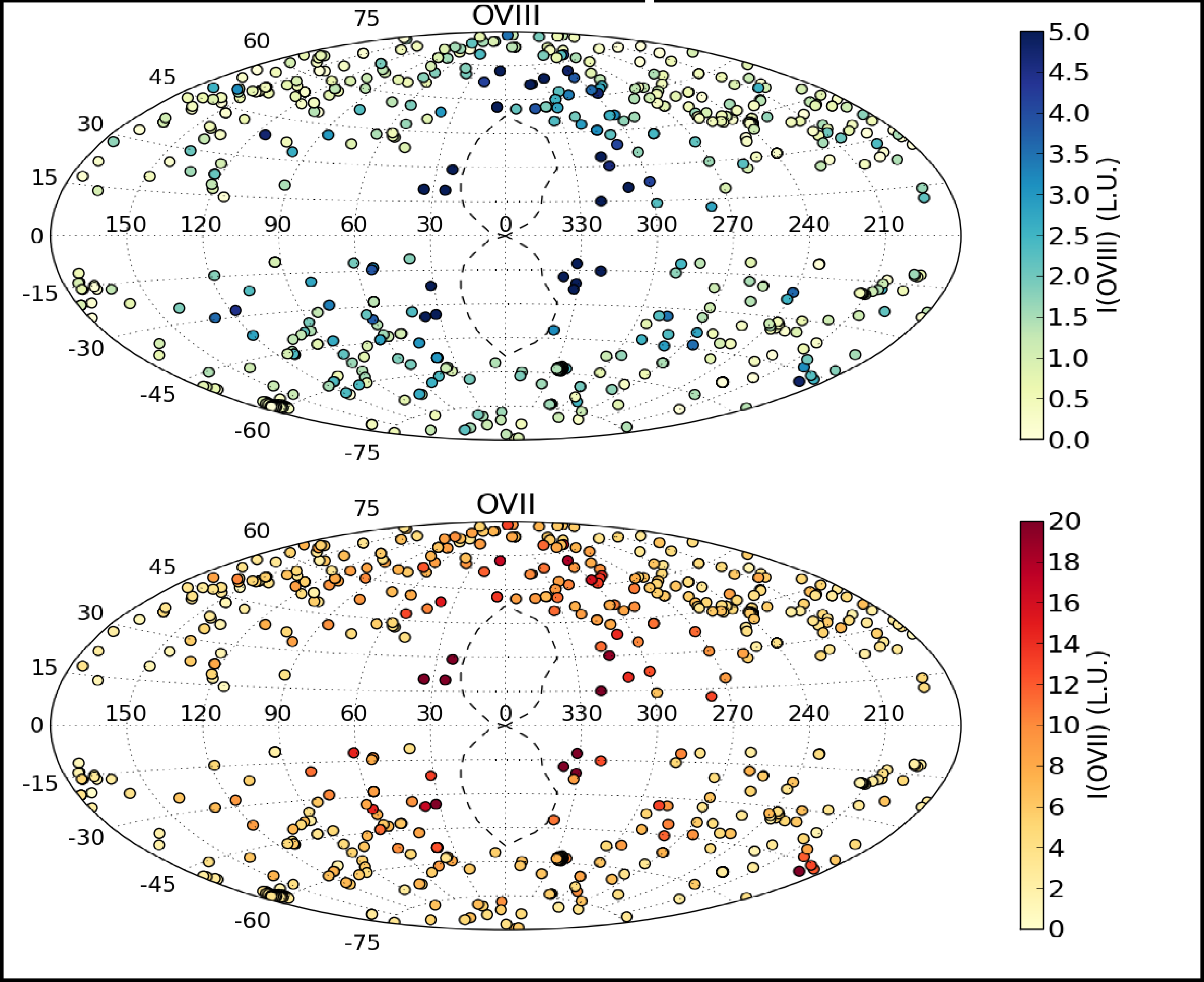
Henley & Shelton 13

Sample

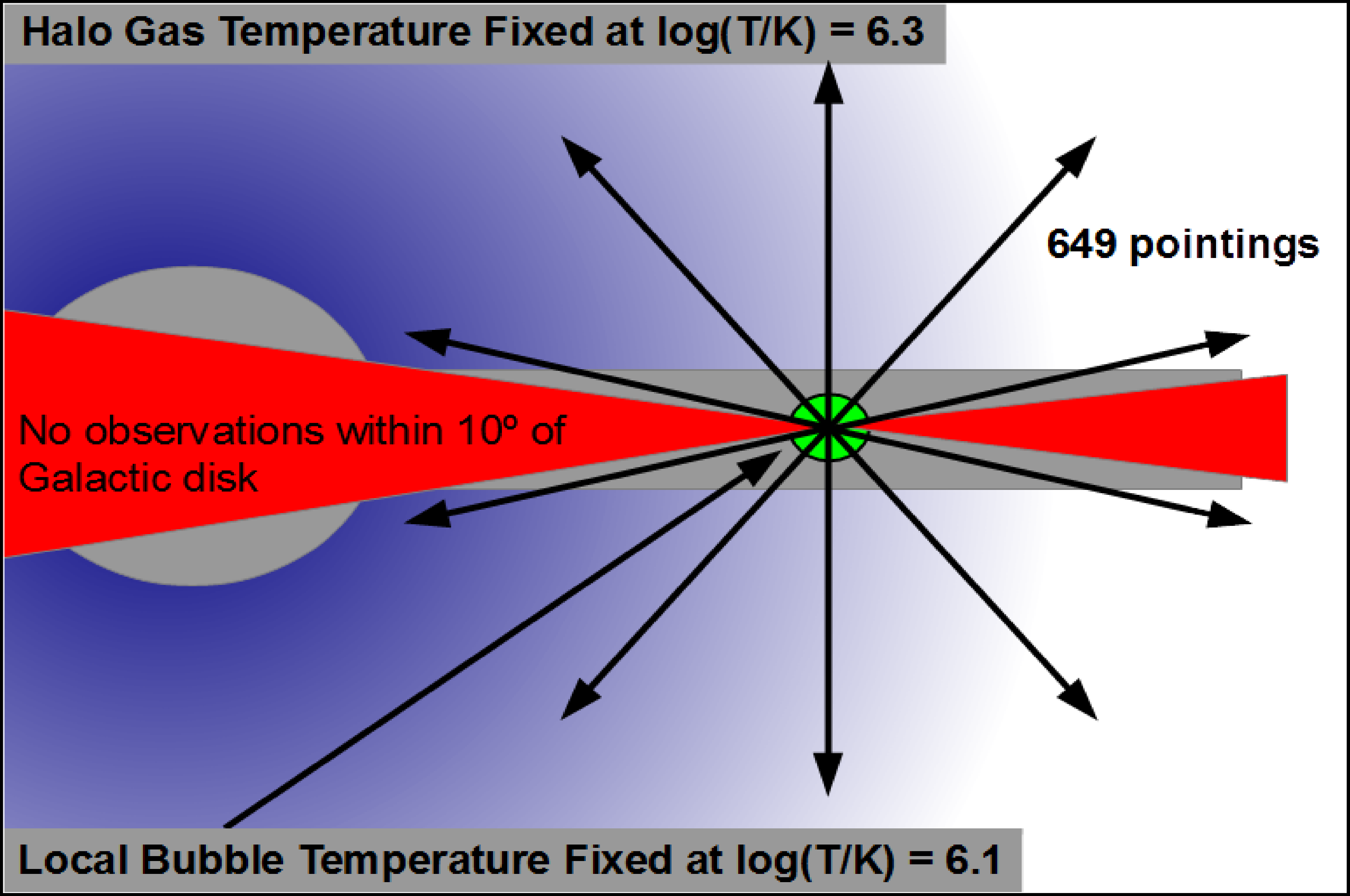
- Archival OVII and OVIII line intensities from Henley & Shelton 2012
  - Full Sample – 1868 pointings
  - Flux Filtered Sample – 1003 pointings

- Our additional screening removes pointings near the Galactic plane, Fermi bubbles, and bright X-ray sources
  - Our Sample – 649 pointings

Sample


OVIII
75
60
45
30
15
0
-15
-30
-45
-60
-75
150 120 90 60 30 0 330 300 270 240 210
I(OVIII) (L.U.)
5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
OVII
I(OVII) (L.U.)
20 18 16 14 12 10 8 6 4 2 0

Schematic



Halo Gas Temperature Fixed at log(T/K) = 6.3
649 pointings
No observations within 10º of
Galactic disk
Local Bubble Temperature Fixed at log(T/K) = 6.1

Model

- Model has 2 components with 3 parameters
  - β model at log(T/K) = 6.3 for halo emission

$$n(r) = n_o \left[1 + \left(\frac{r}{r_c}\right)^2\right]^{-\frac{3}{2}\beta} \approx \frac{n_o r_c^{3\beta}}{r^{3\beta}} \equiv \frac{\text{constant}}{r^{3\beta}}$$

$r_c << r$

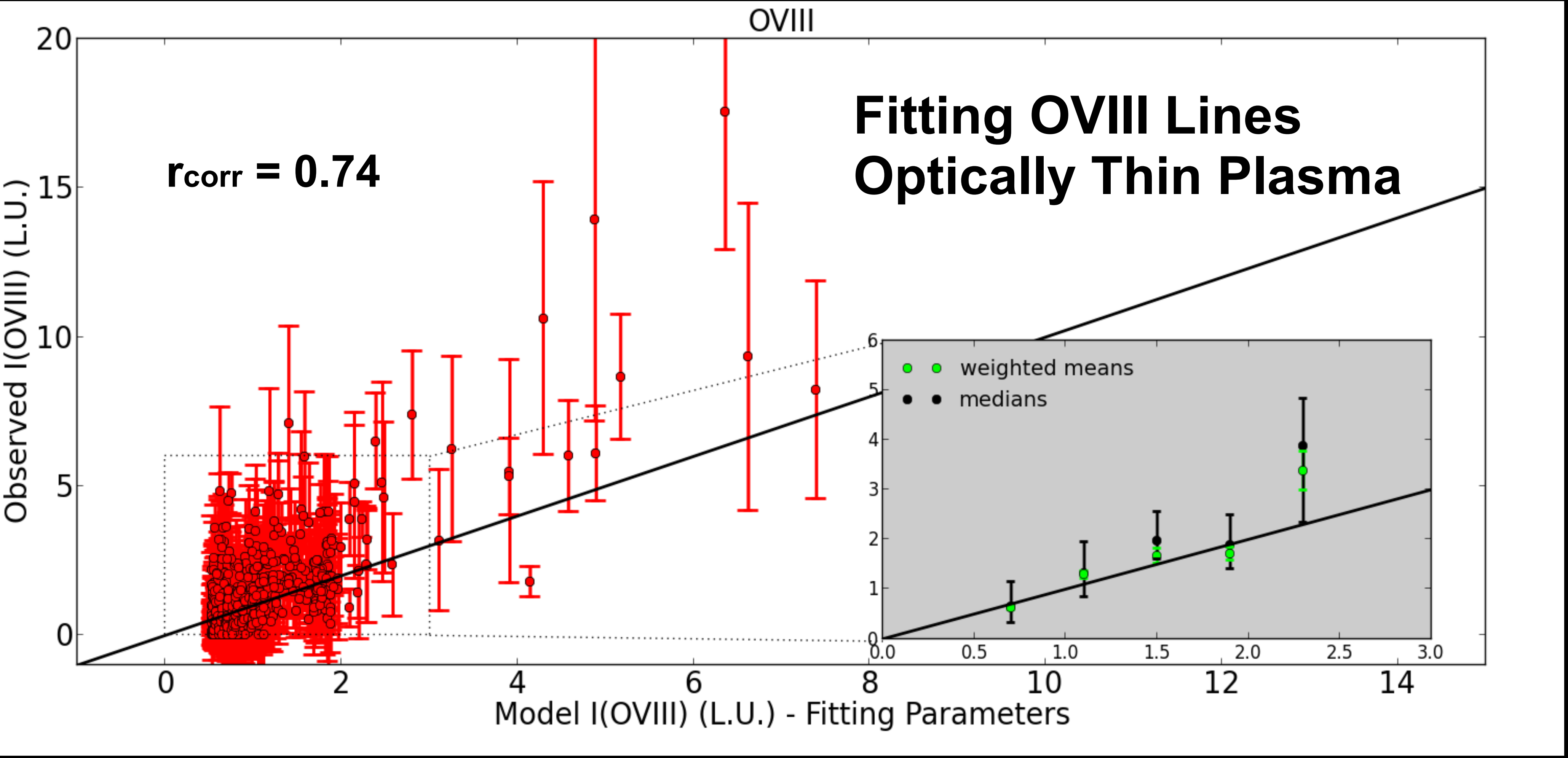
  - Local Bubble at log(T/K) = 6.1

- Collisional ionization equilibrium

- $I = \int n_e^2 \times \epsilon(T)\,dr$

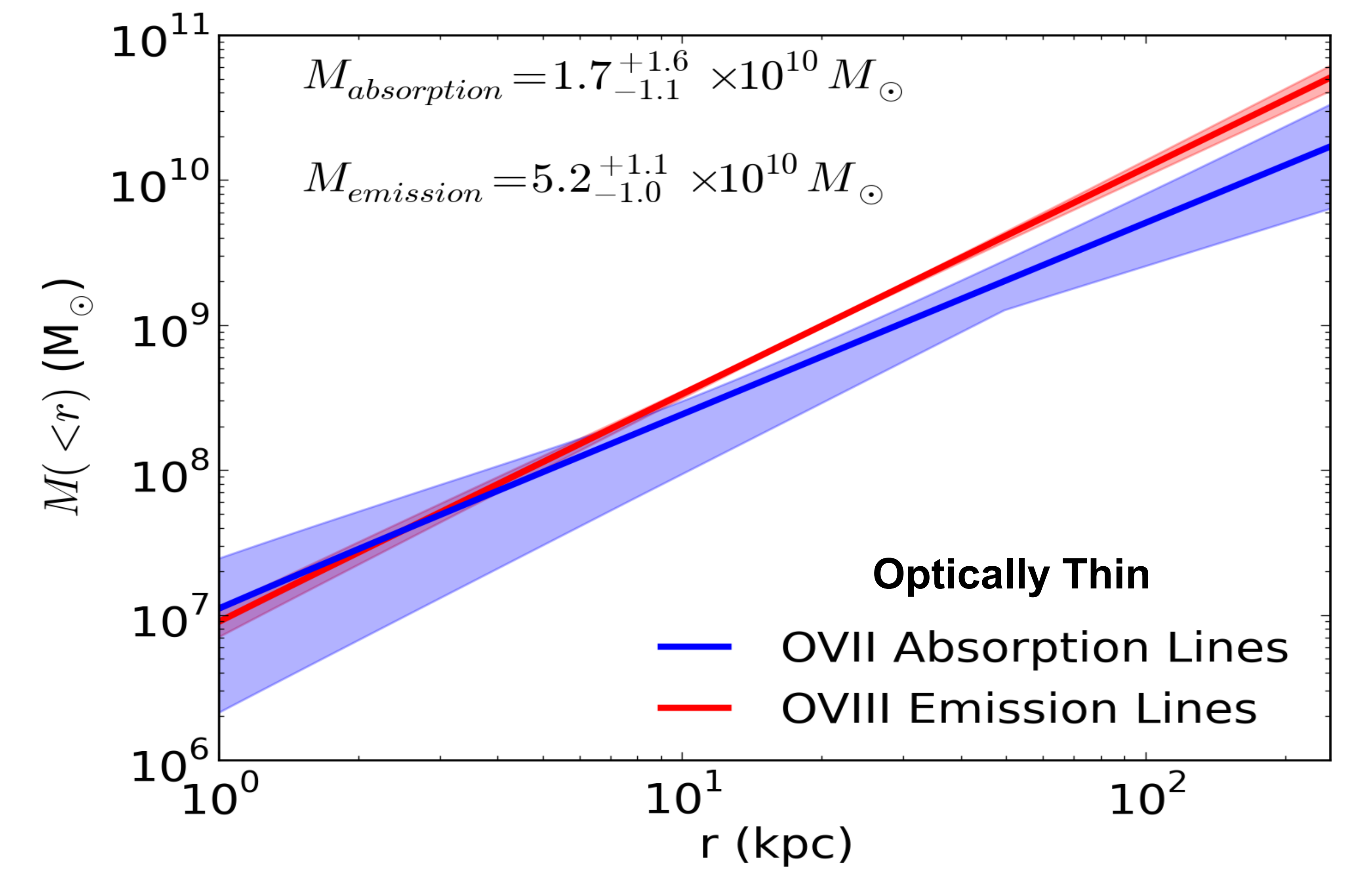
Results

Lines Fitted	$n_o r_c^{3\beta}$ (cm^{-3} $kpc^{3\beta}$)	β	$n_{local\ bubble}$ (cm^{-3})	χ_{red}^2 (dof)
OVII	0.89 ± 0.06 x 10^{-2}	0.43 ± 0.01	3.86 ± 0.26 x 10^{-3}	4.69 (645)
OVIII	1.35 ± 0.24 x 10^{-2}	0.50 ± 0.03	No Contribution	1.08 (644)



Mass Estimates

- Mass inferred from emission line results compared to absorption line results (Miller+ 13)



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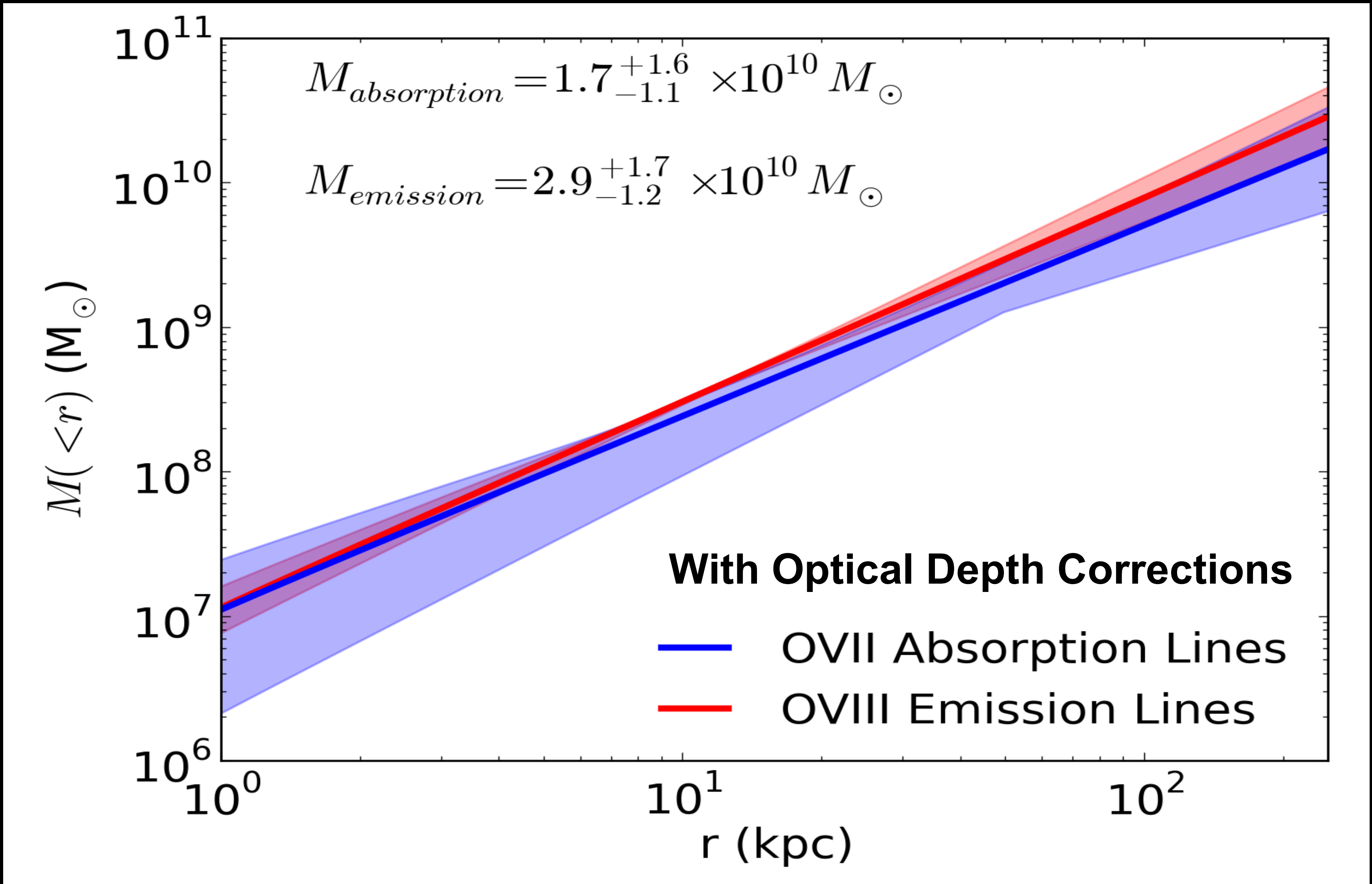

Milky Way Baryon Budget

- For a cosmological f_{bar} of 0.171 ± 0.006 (WMAP)...
  - $M_{(stars + cold gas + dust)} = 6\text{-}7 \times 10^{10} M_\odot$
  - $M_{vir} = 1\text{-}2 \times 10^{12} M_\odot$
  - $M_{miss} = 1\text{-}3 \times 10^{11} M_\odot$
- If the density profile extends to the virial radius...
  - $M_{hot} = 2\text{-}6 \times 10^{10} M_\odot$
- Halo gas contributes $\lesssim$ 20% to the missing baryons
- Profile would need to extend to 2-3 r_{vir} to account for all of the Milky Way's missing baryons

Conclusions

- OVIII emission lines constrain the radial distribution of the Milky Way's hot gas halo significantly better than OVII absorption lines
- Estimated hot gas mass is 2-6 x 10^{10} $M_\odot$
  - Significant, but not all of missing baryons
- Future work will involve understanding optical depth effects in the plasma