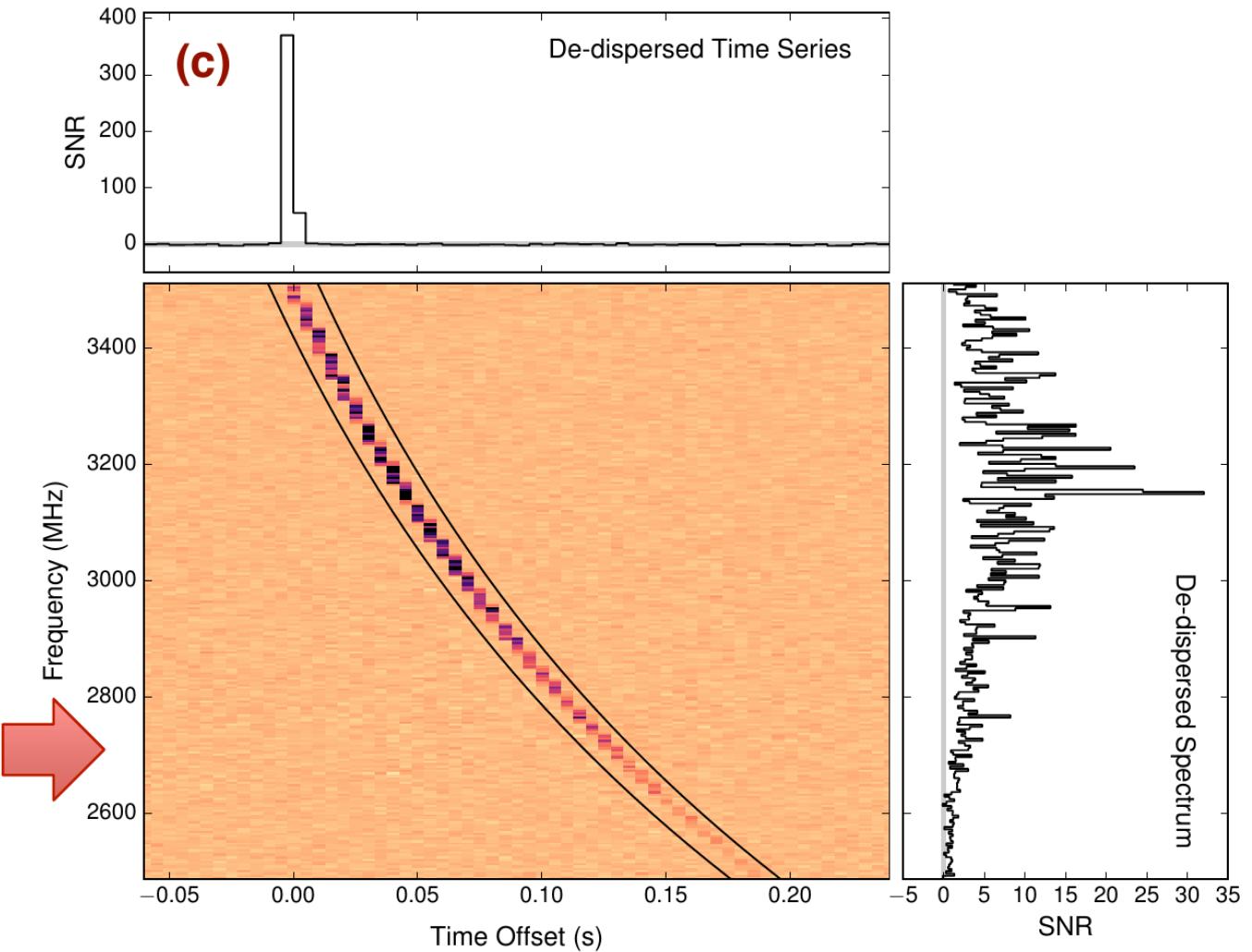
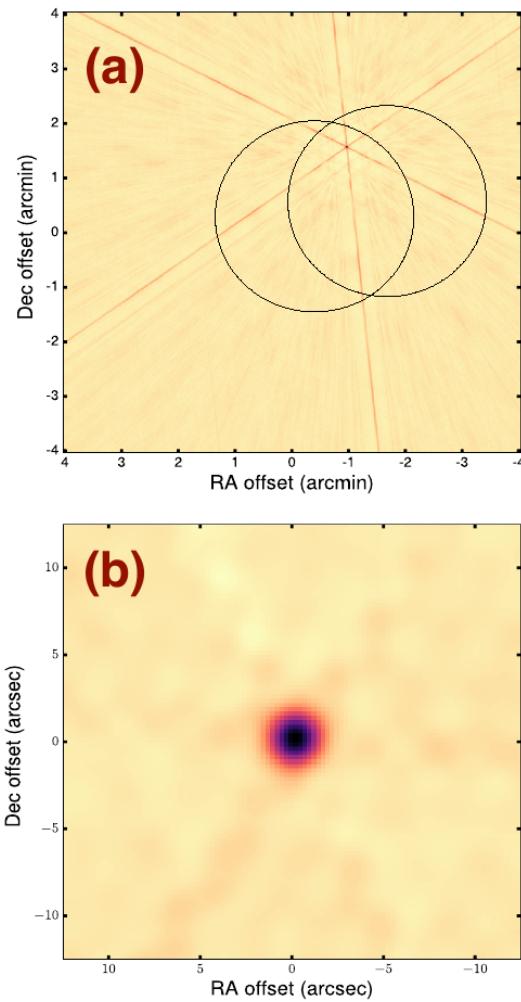


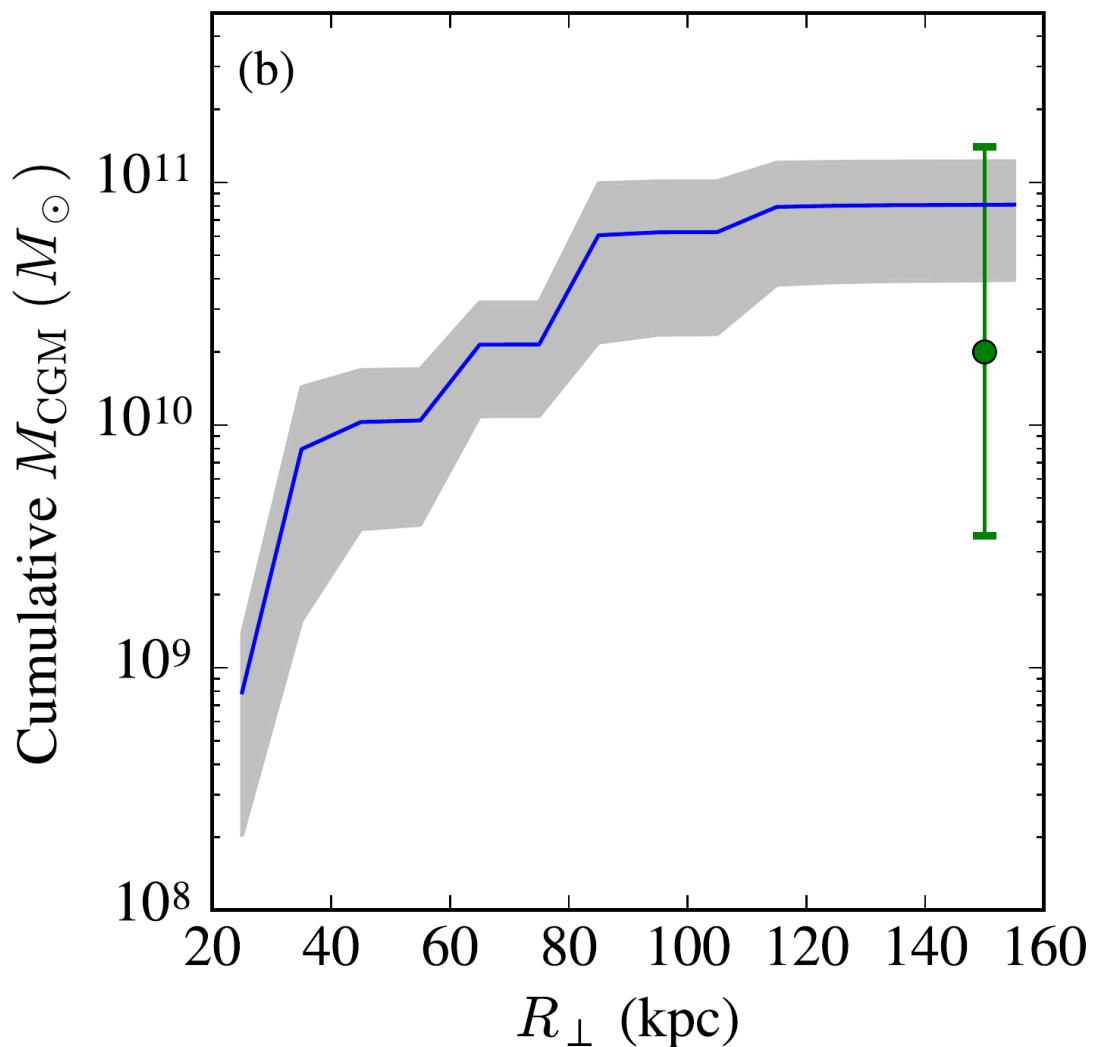
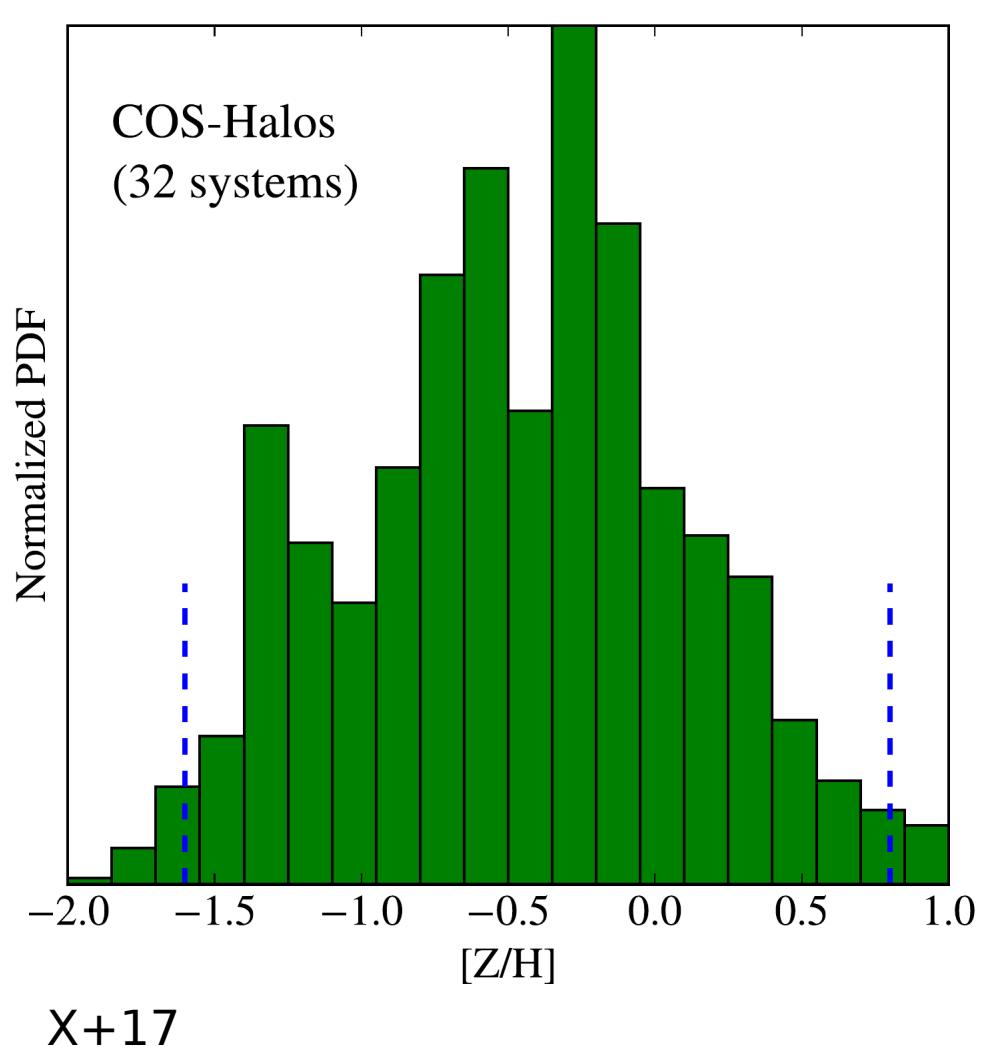
A Few Unpublished Thoughts on the CGM

J. Xavier Prochaska

@IMPS @UCO @ UCSC @IPMU

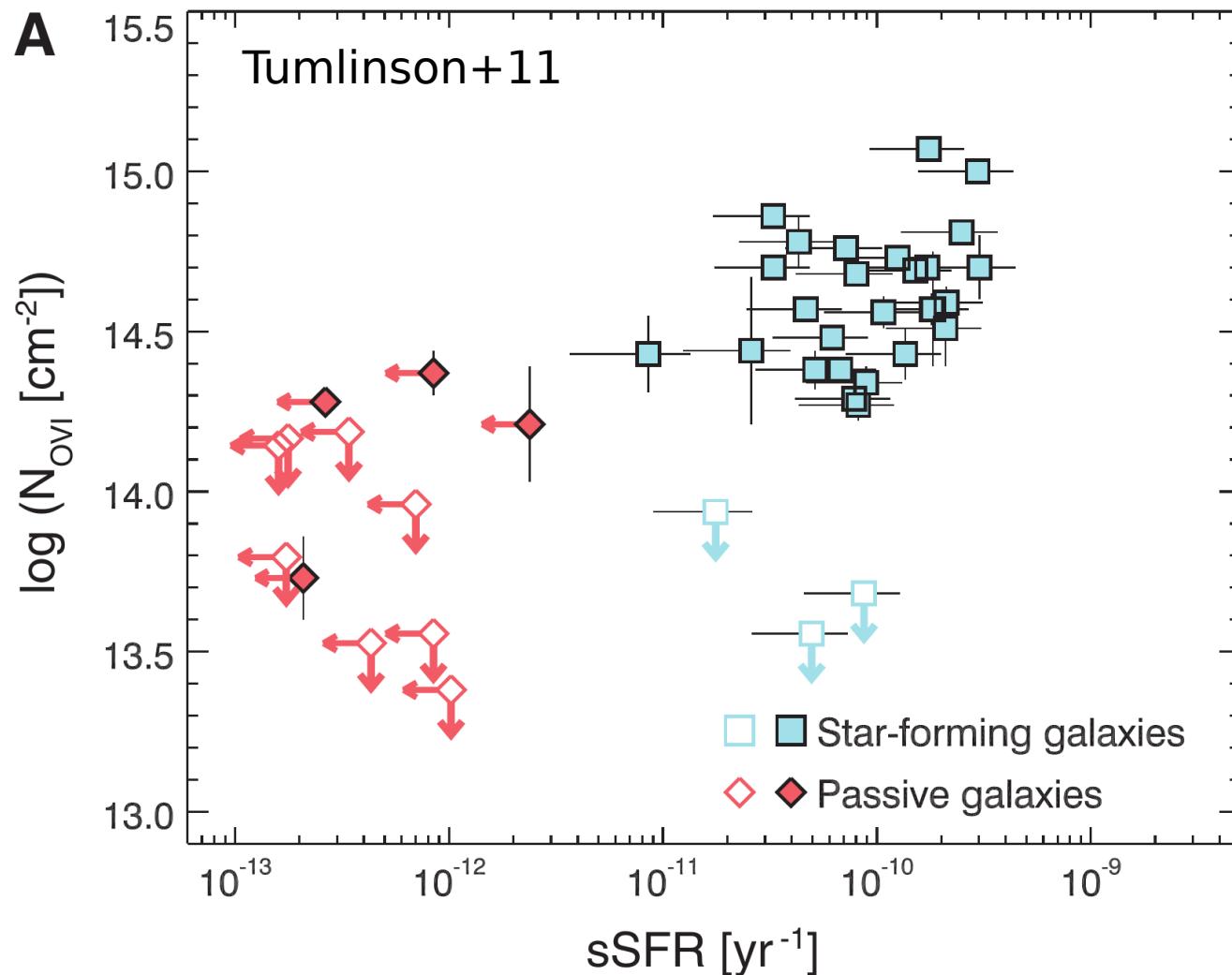


Cool CGM Mass+Enrichment at $z \sim 0$



Our latest results on the cool CGM of L* galaxies

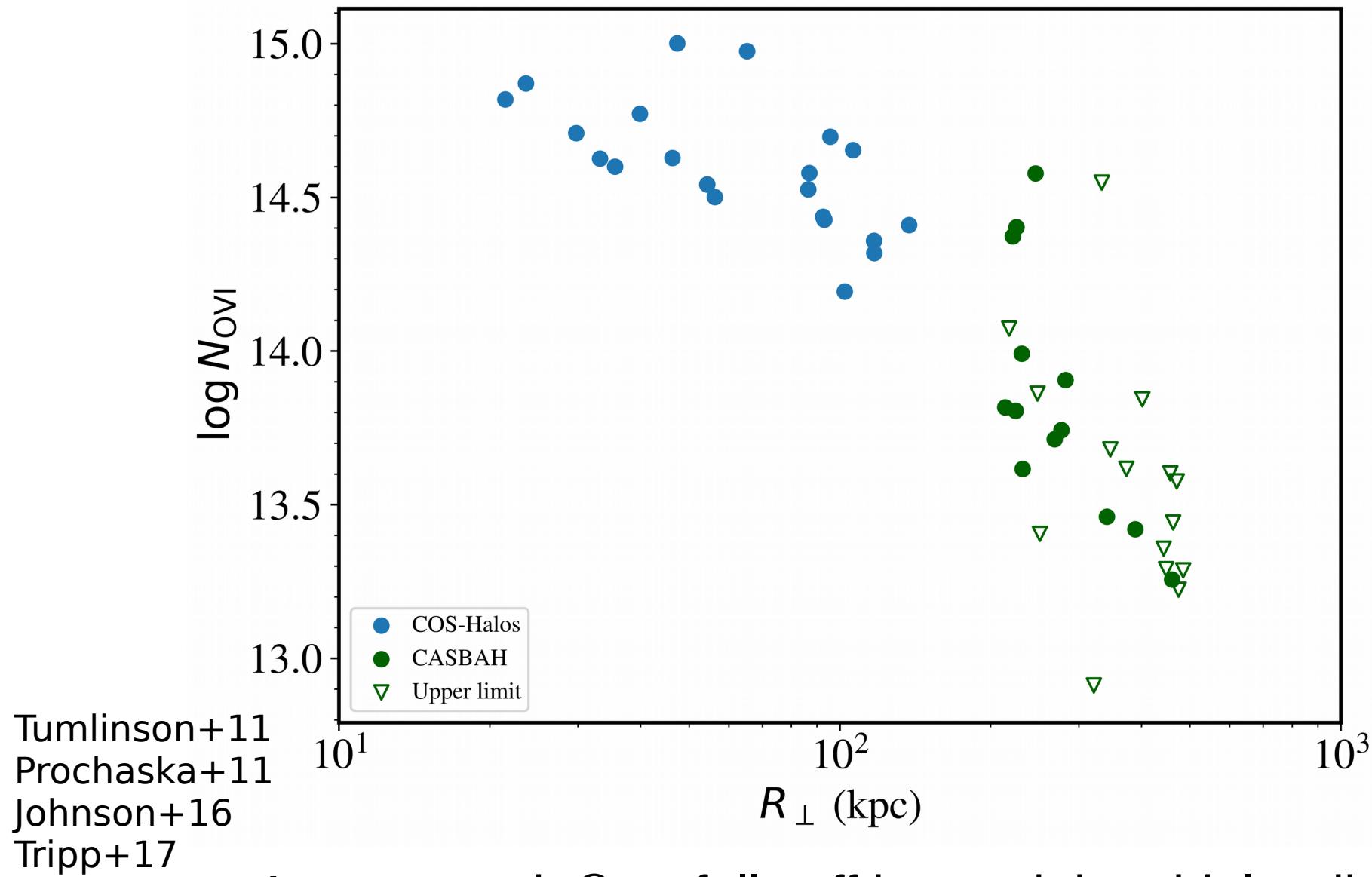
OVI and Warm/Hot Galactic Halos



Mathews&X 17'

A new approach to a challenging problem...

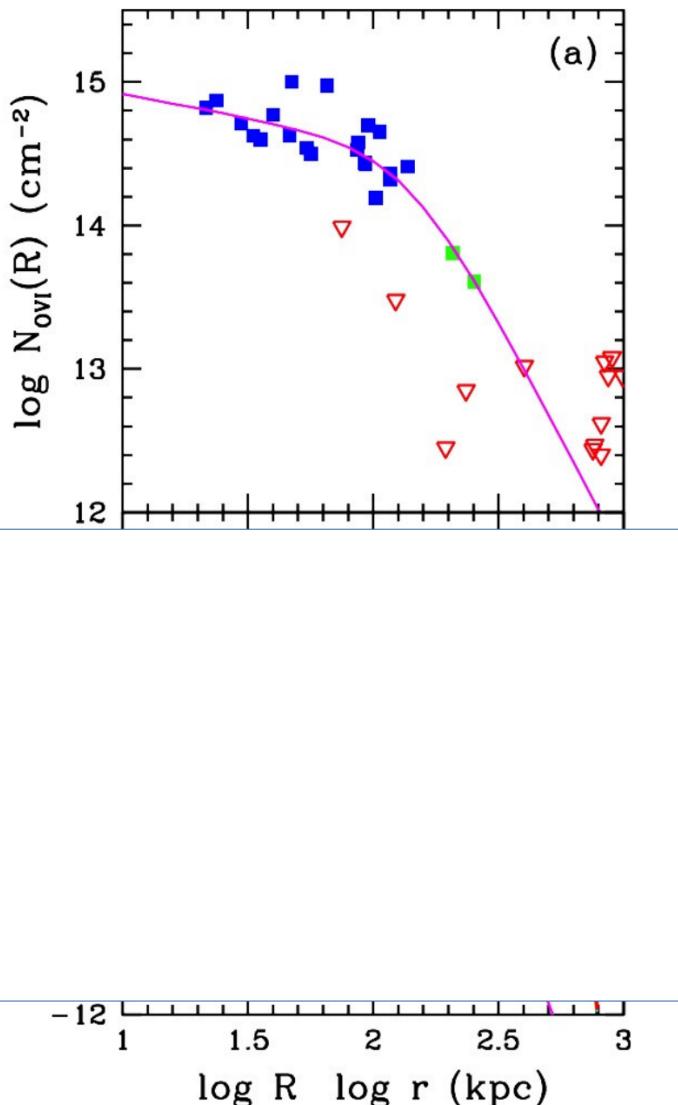
OVI Data beyond 150kpc (L*, SF galaxies)



Tumlinson+11
Prochaska+11
Johnson+16
Tripp+17

As expected, O VI falls off beyond the virial radius

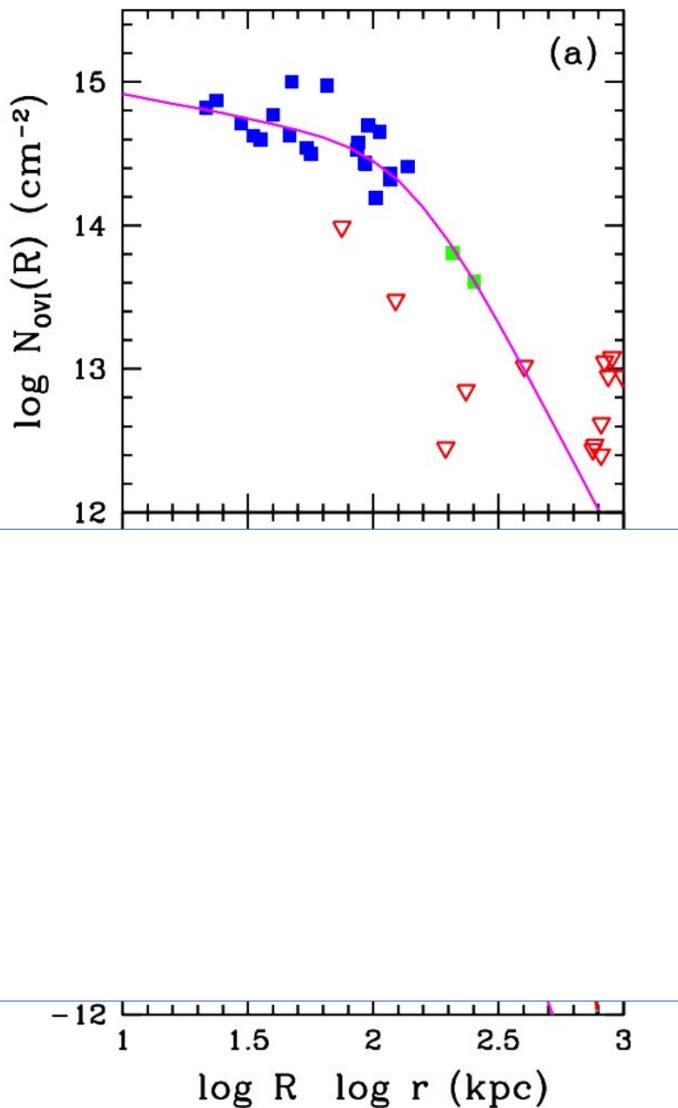
A Classic X-ray Technique: Abel Inversion



Ansatz:

1. Gas is smoothly distributed (at least crudely).
2. Spherical symmetry.

A Classic X-ray Technique: Abel Inversion

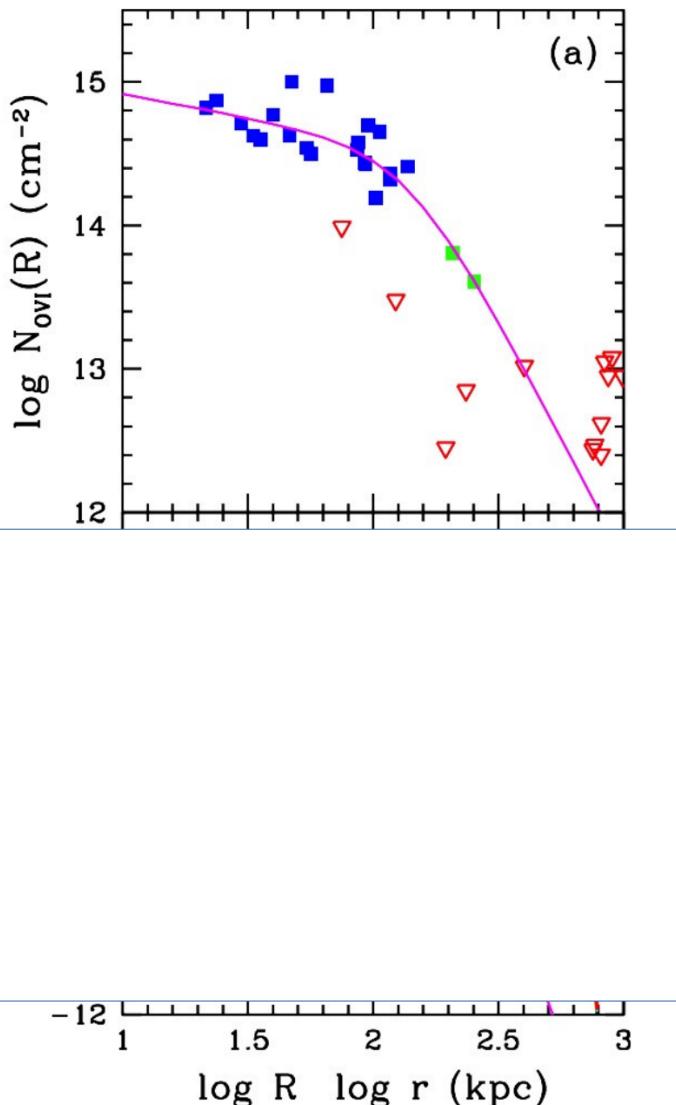


Ansatz:

1. Gas is smoothly distributed (at least crudely).
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$$\tilde{n}_{O+5}(r) = -\frac{1}{\pi} \int_r^{\infty} \frac{dN}{dR} \frac{dR}{(R^2 - r^2)^{1/2}}$$

A Classic X-ray Technique: Abel Inversion



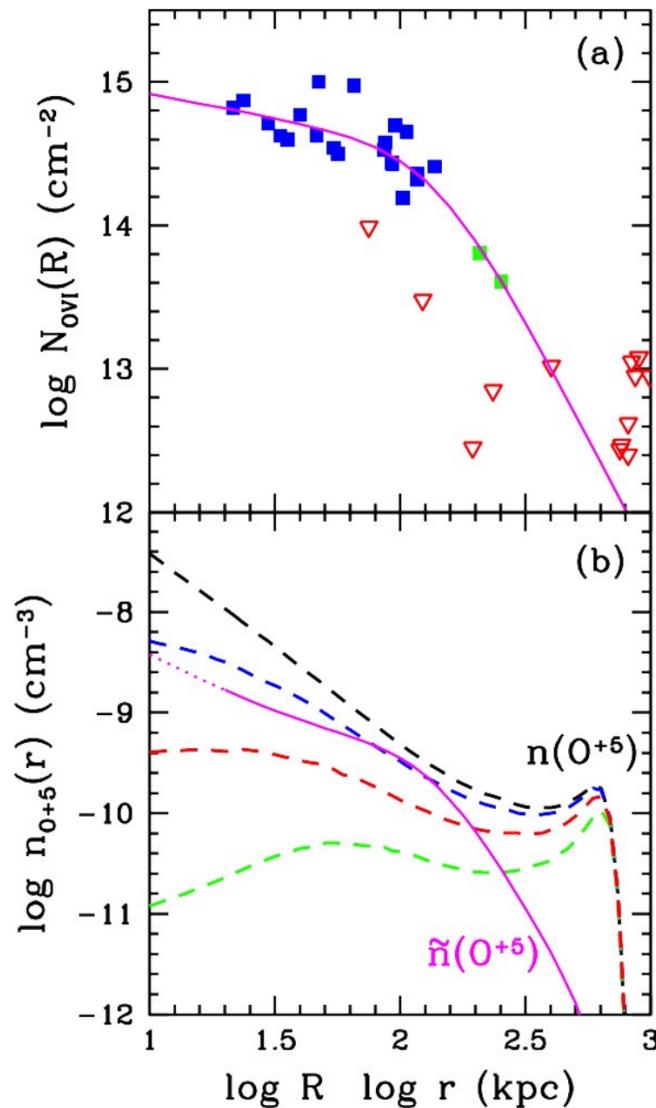
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$$N_{\text{OVI}} = N_0 [1 + (R/R_0)^p]^{-1} (R/R_1)^q$$

A Classic X-ray Technique: Abel Inversion



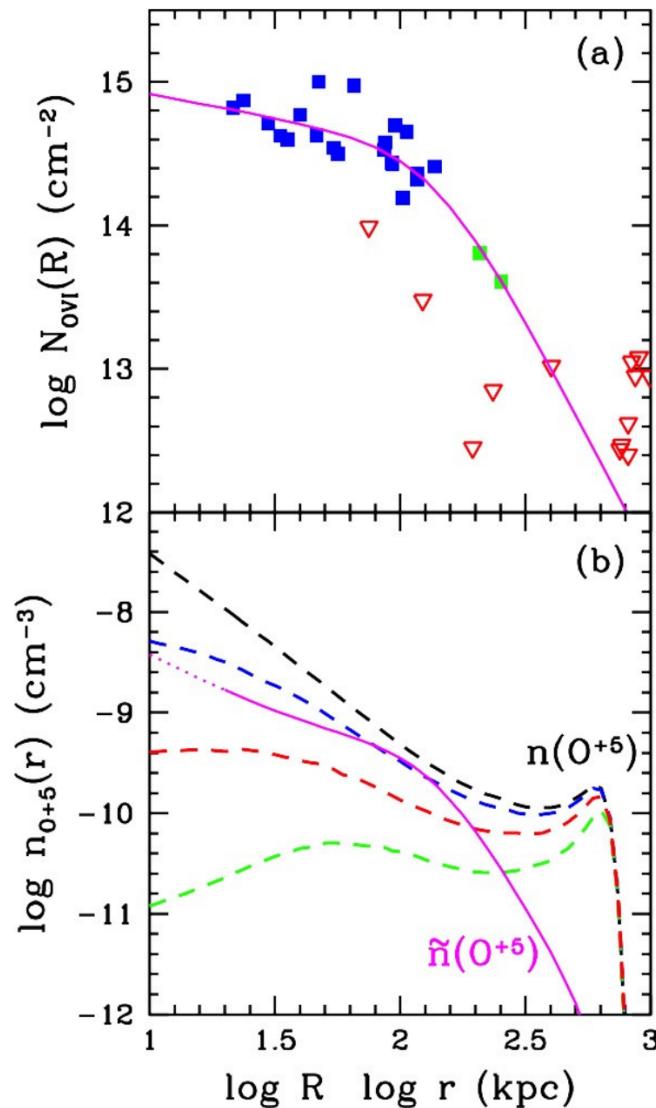
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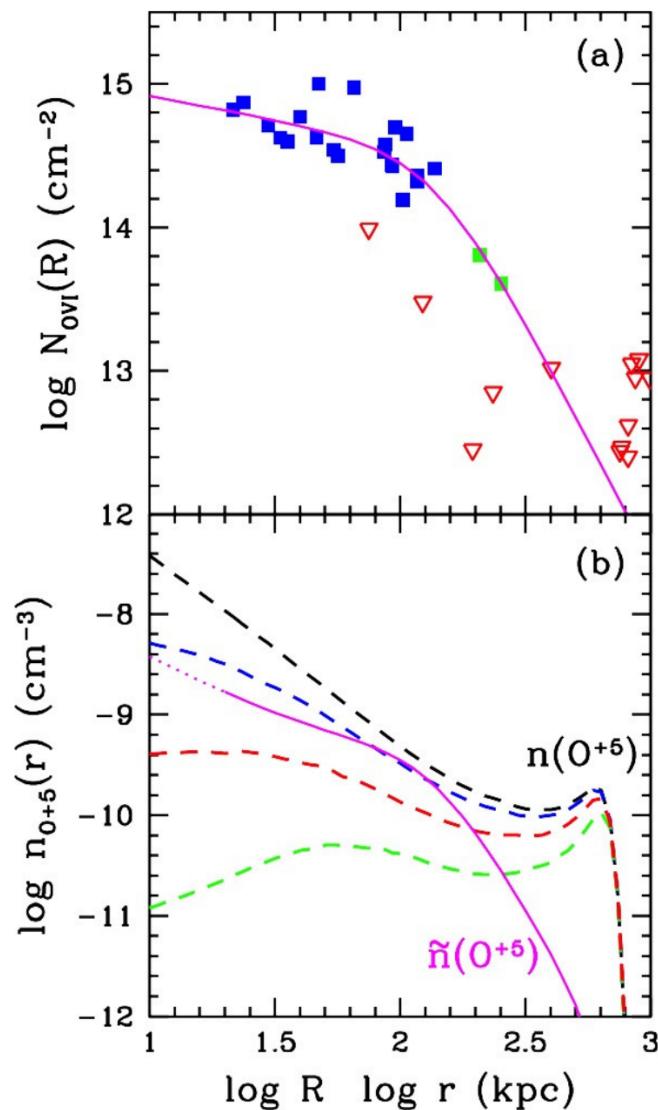
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This can and probably should be applied to **all** CGM ions.

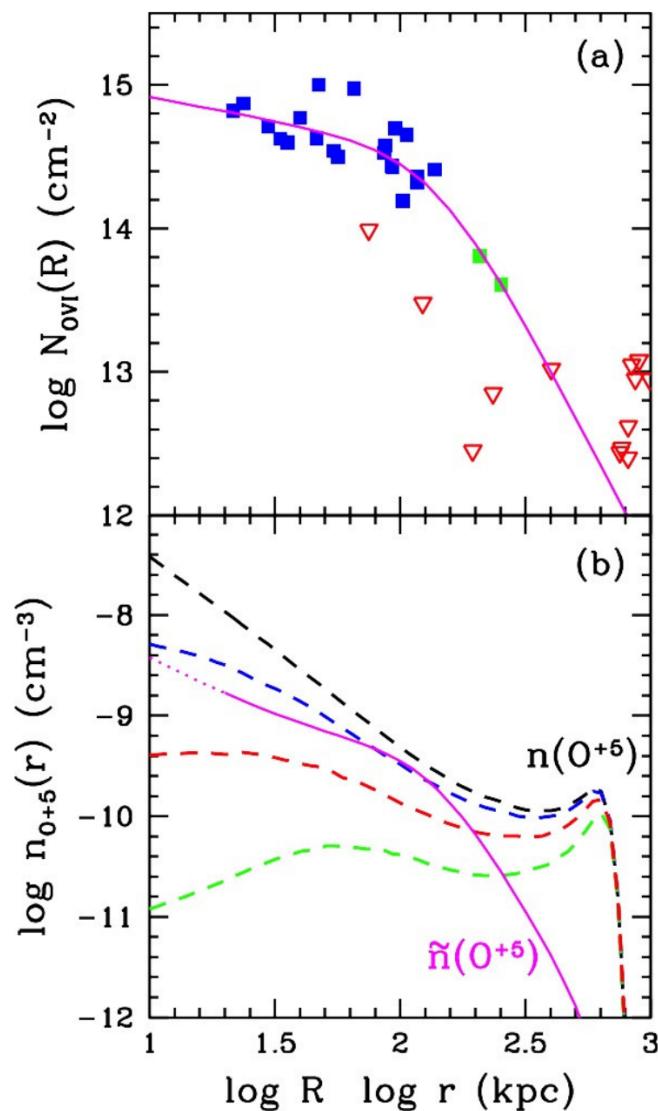
Hydrostatic models in an NFW Potential



Methodology:

1. NFW with $M_{\text{halo}} = 10^{12.2} M_{\text{sun}}$
2. Atmosphere in hydrostatic equilibrium
3. Density profile modified by 'feedback'
4. OVI arises in CIE gas

Hydrostatic models in an NFW Potential



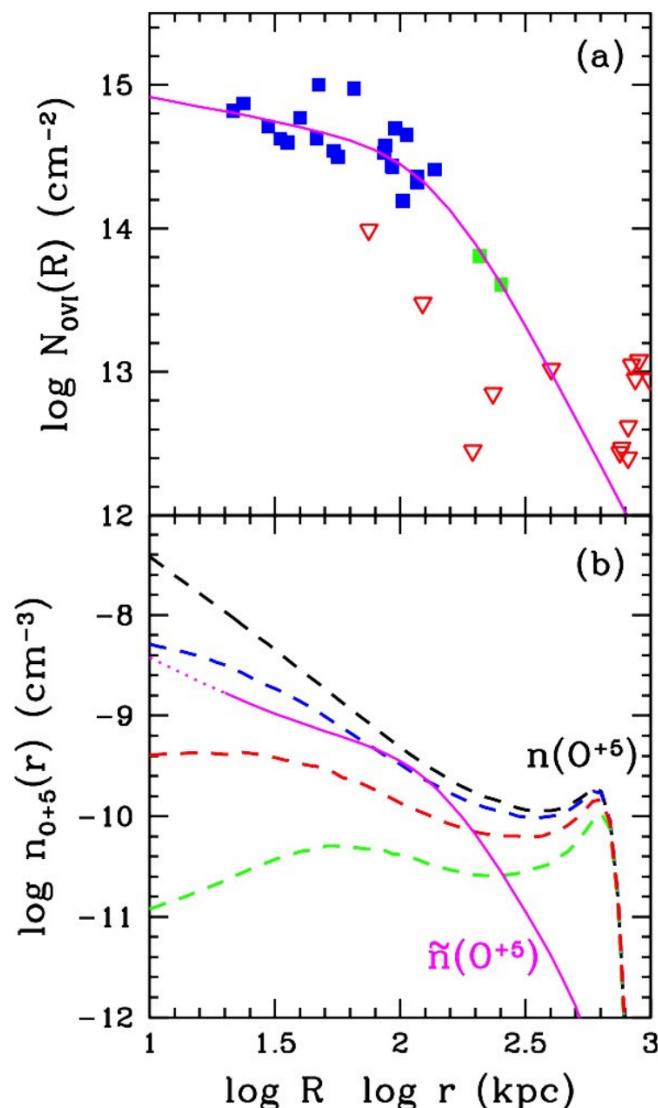
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$$dT/dr = -(T/r)(d \log \rho / d \log r) - g_{\text{nfw}}(\mu m_p / k)$$

Hydrostatic models in an NFW Potential



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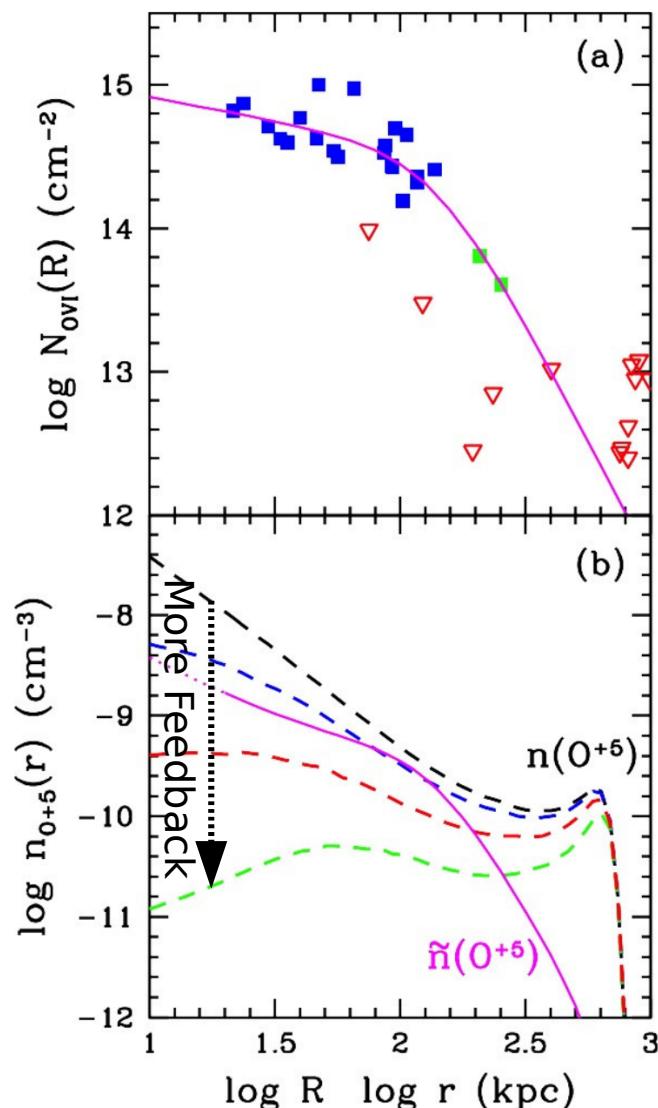
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Hydrostatic models in an NFW Potential



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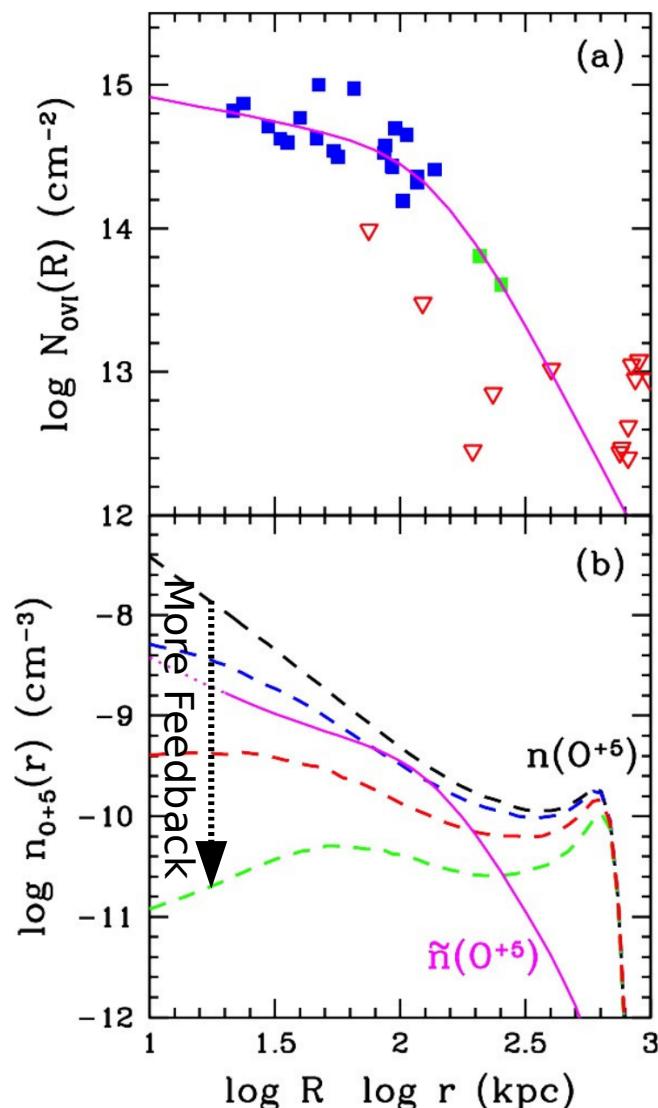
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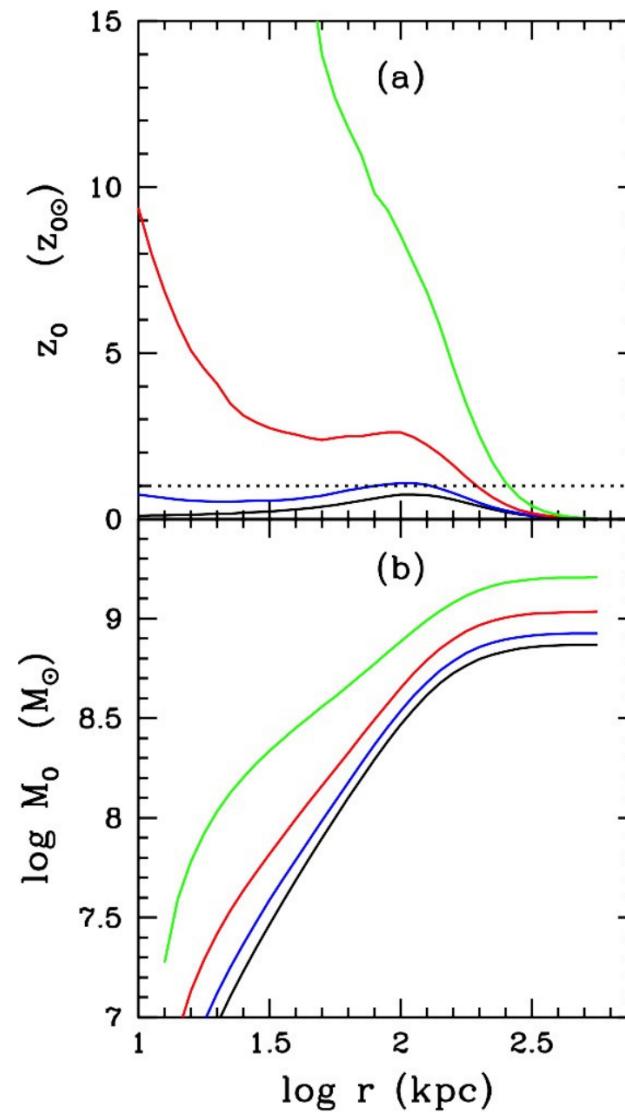
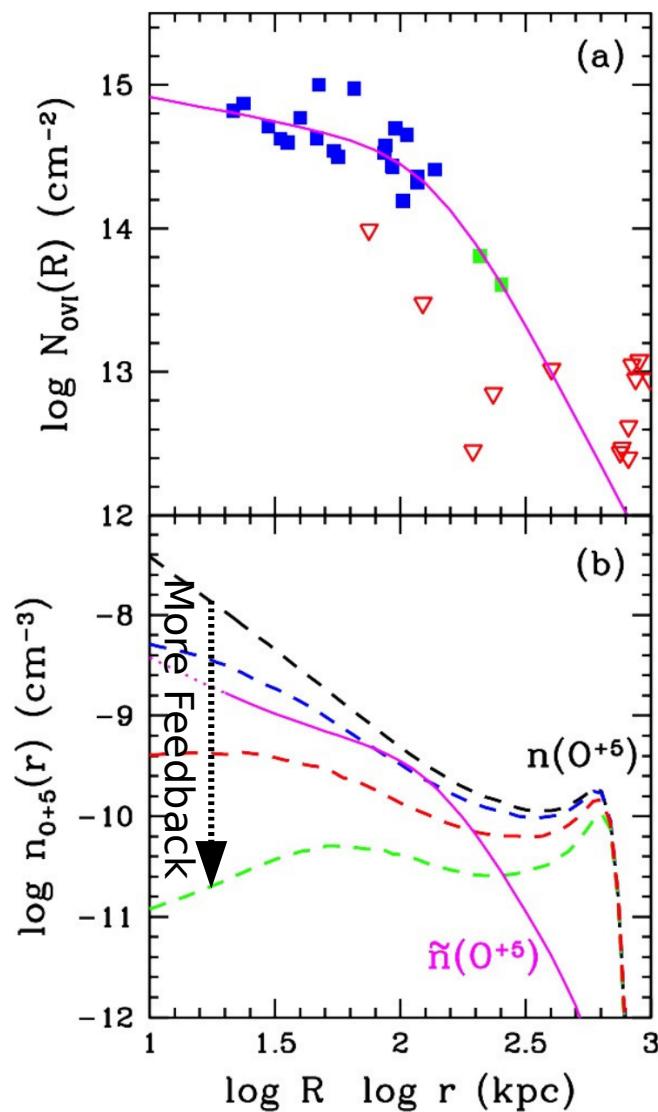
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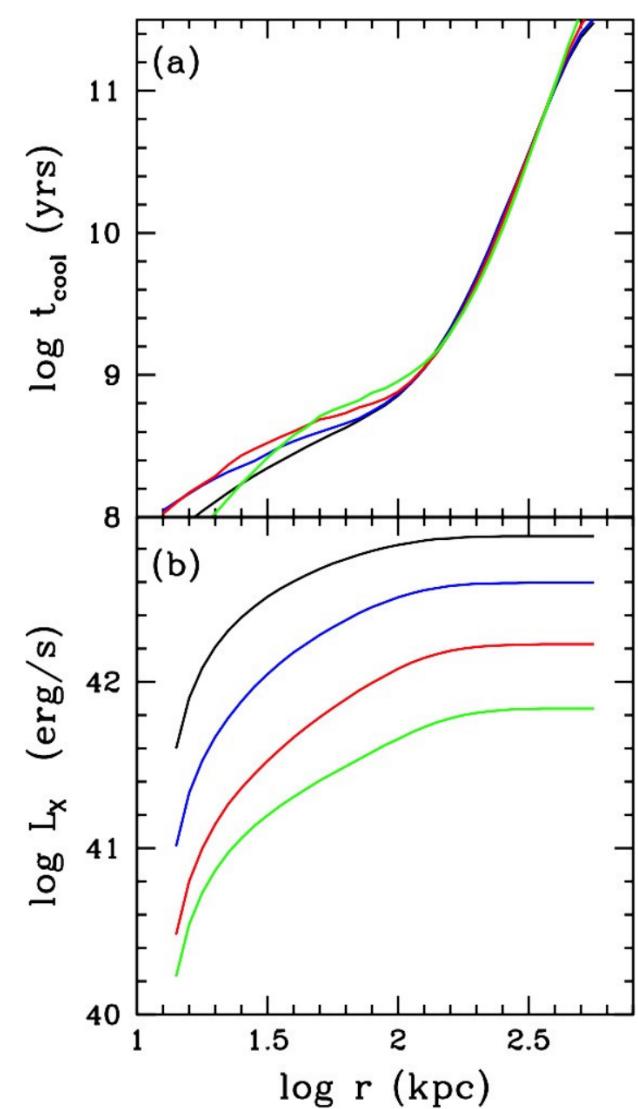
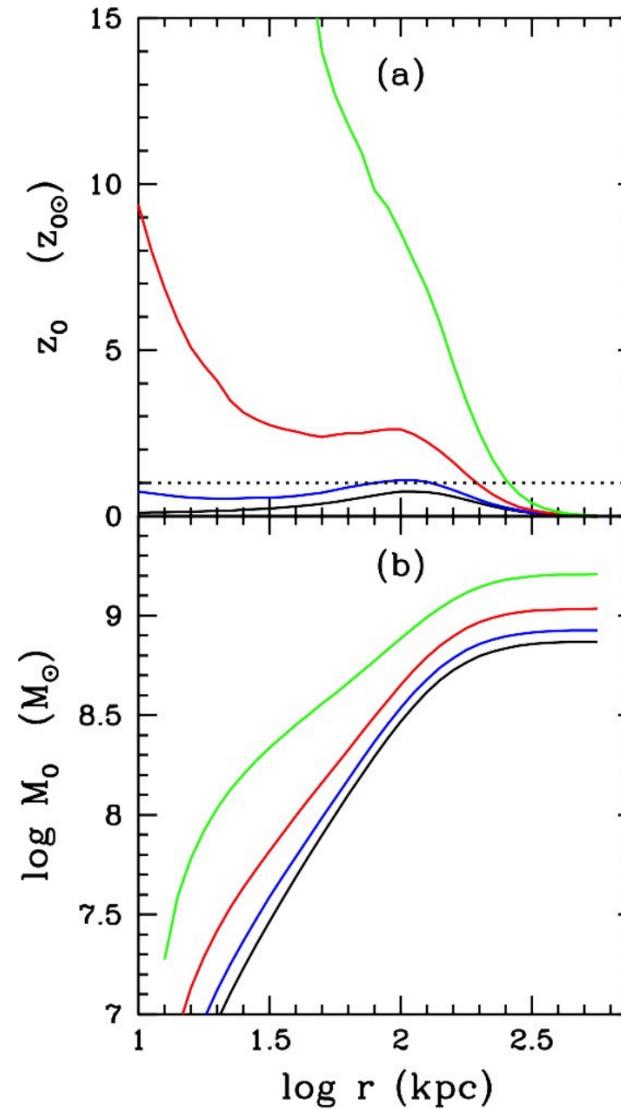
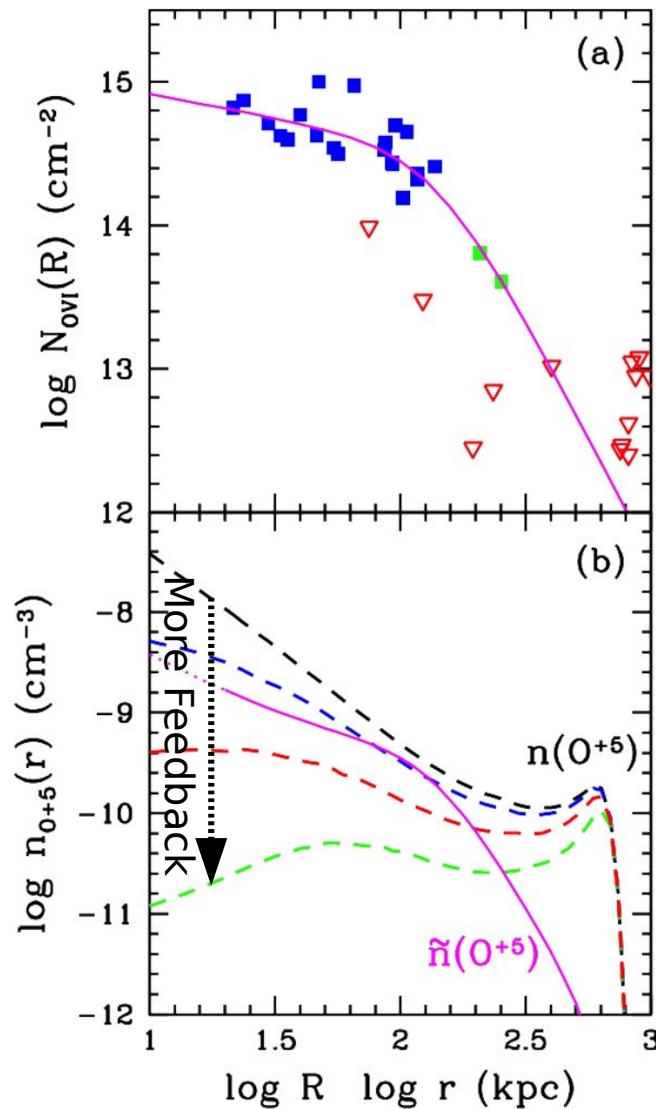
The plots here assume solar metallicity and give a poor 'fit'.

Metallicity Profiles



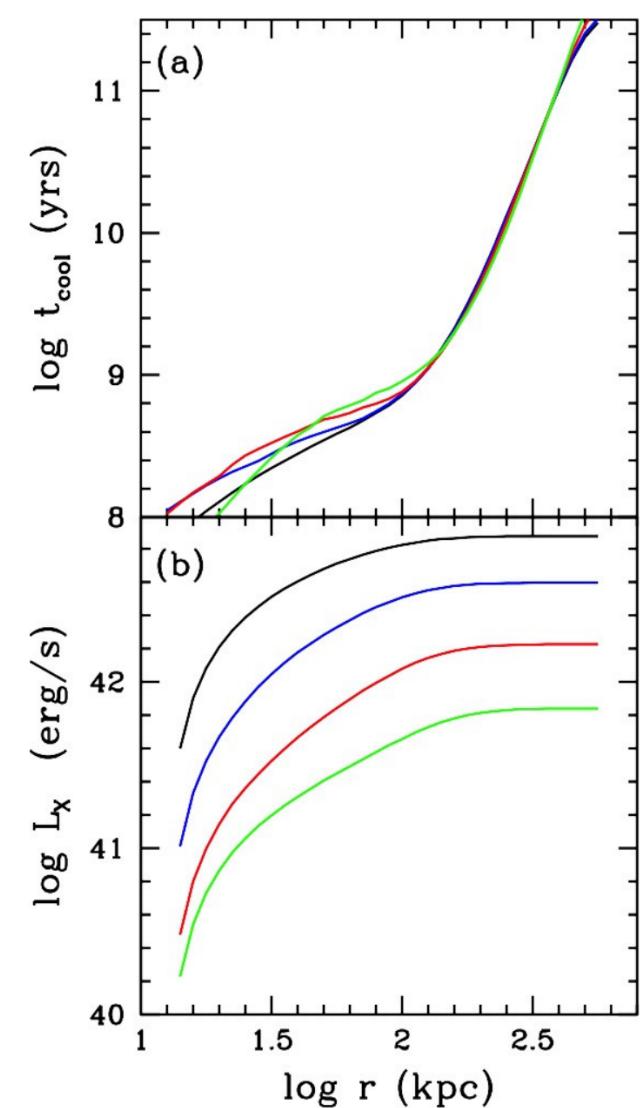
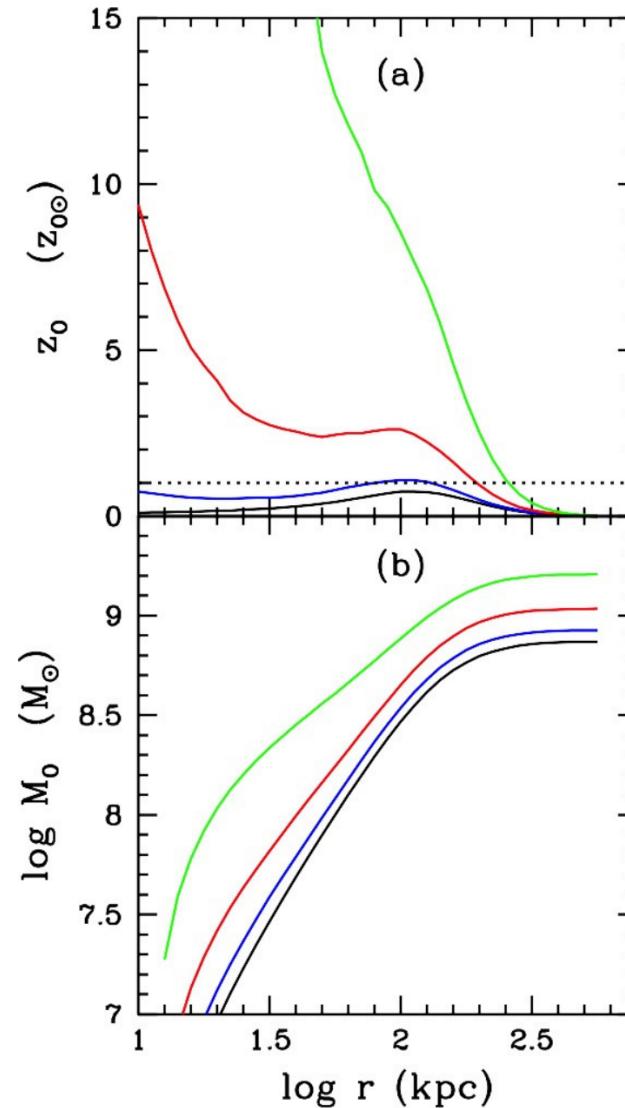
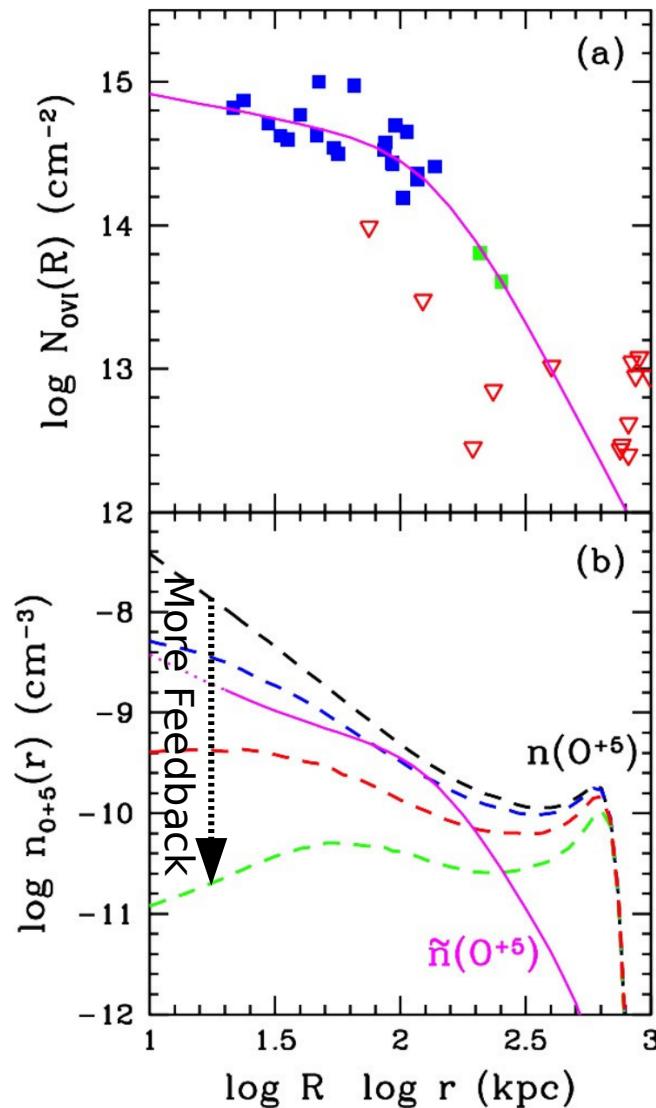
Aggressive feedback would require $Z \gg Z_{\text{Sun}}$ at $R < 100 \text{kpc}$

Tension with X-ray Emission



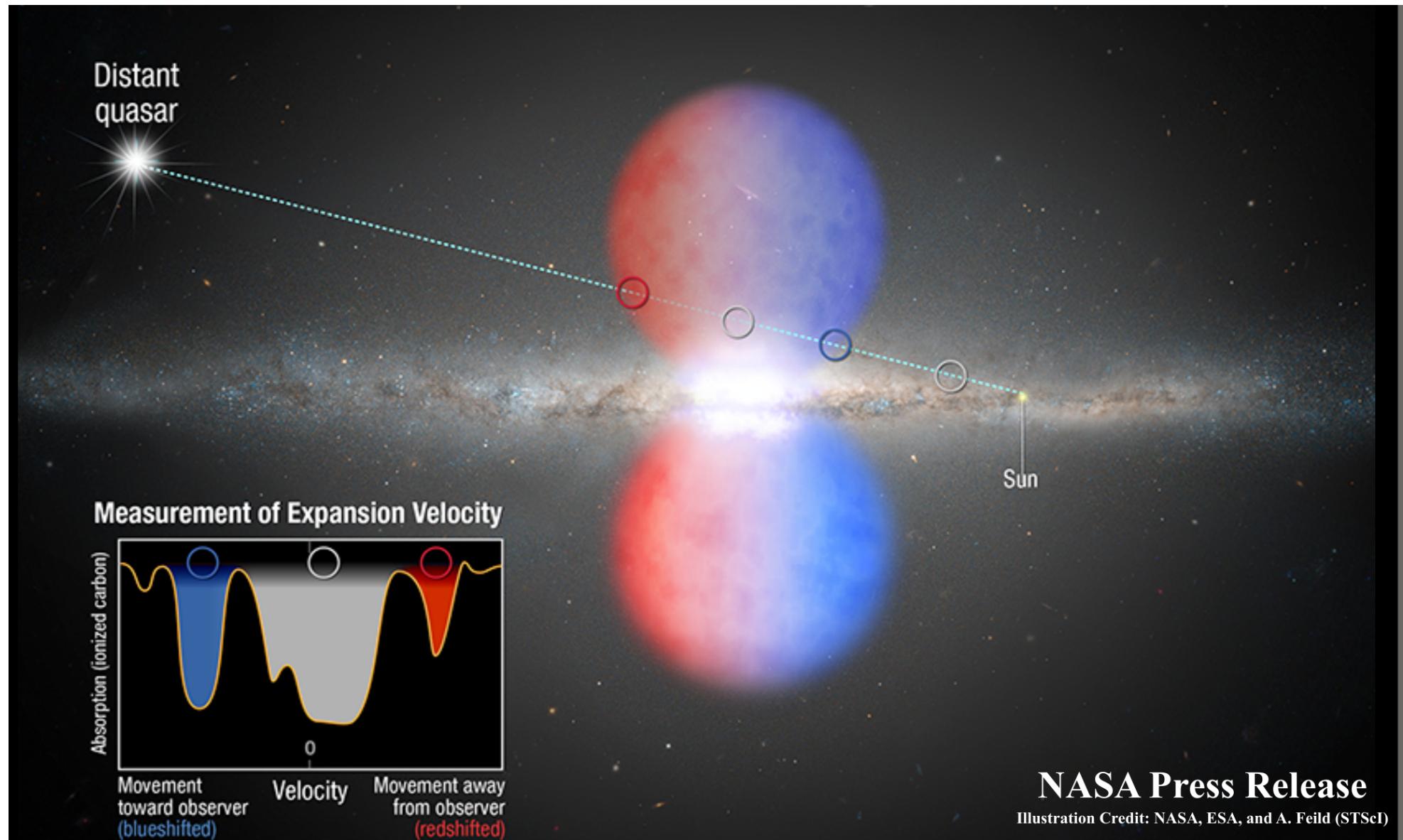
NFW profile over-predicts constraints on X-ray emission

'Universally' Short Cooling Time

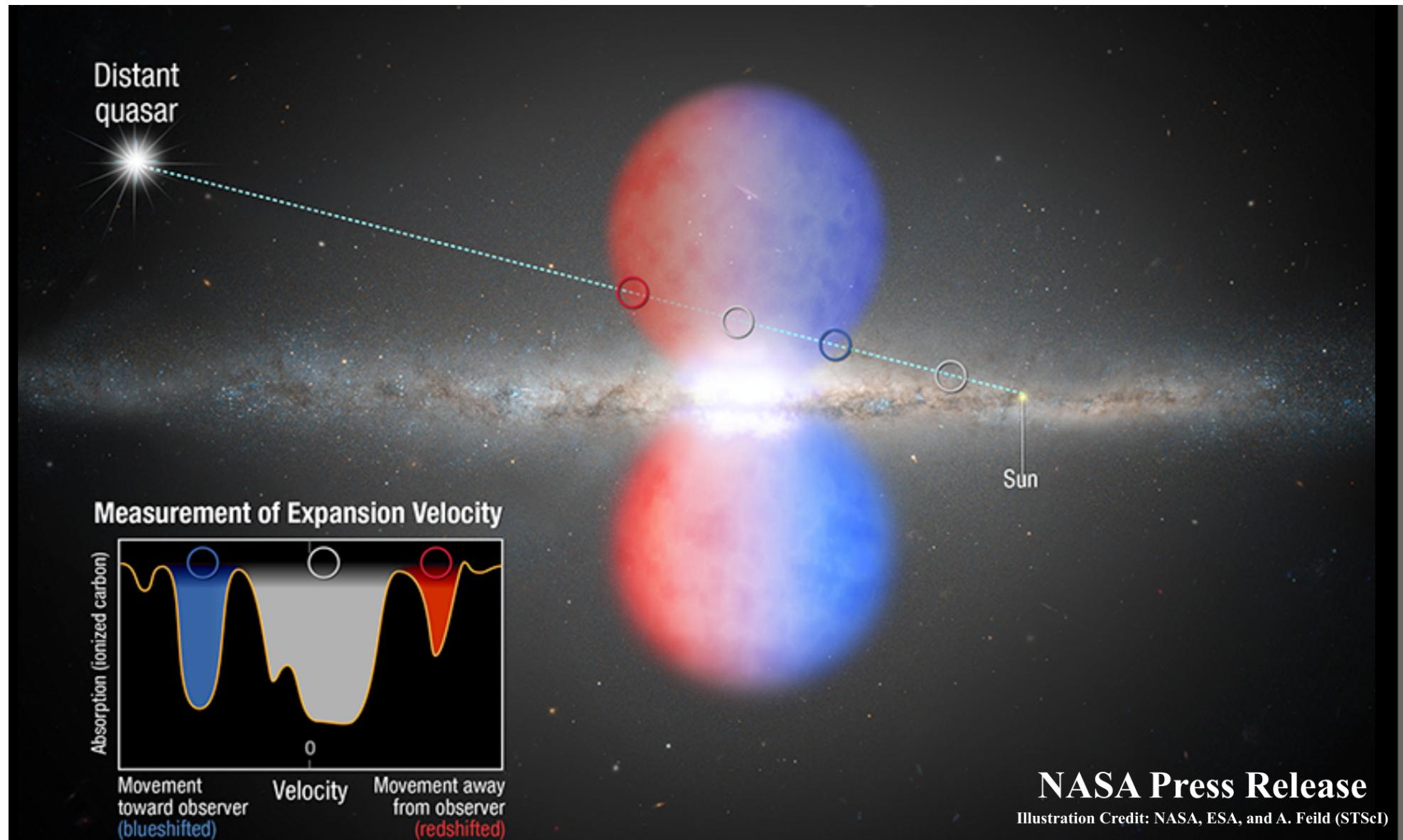


$t_{\text{cool}} < 10^9$ yr; This likely requires a heat source (feedback).

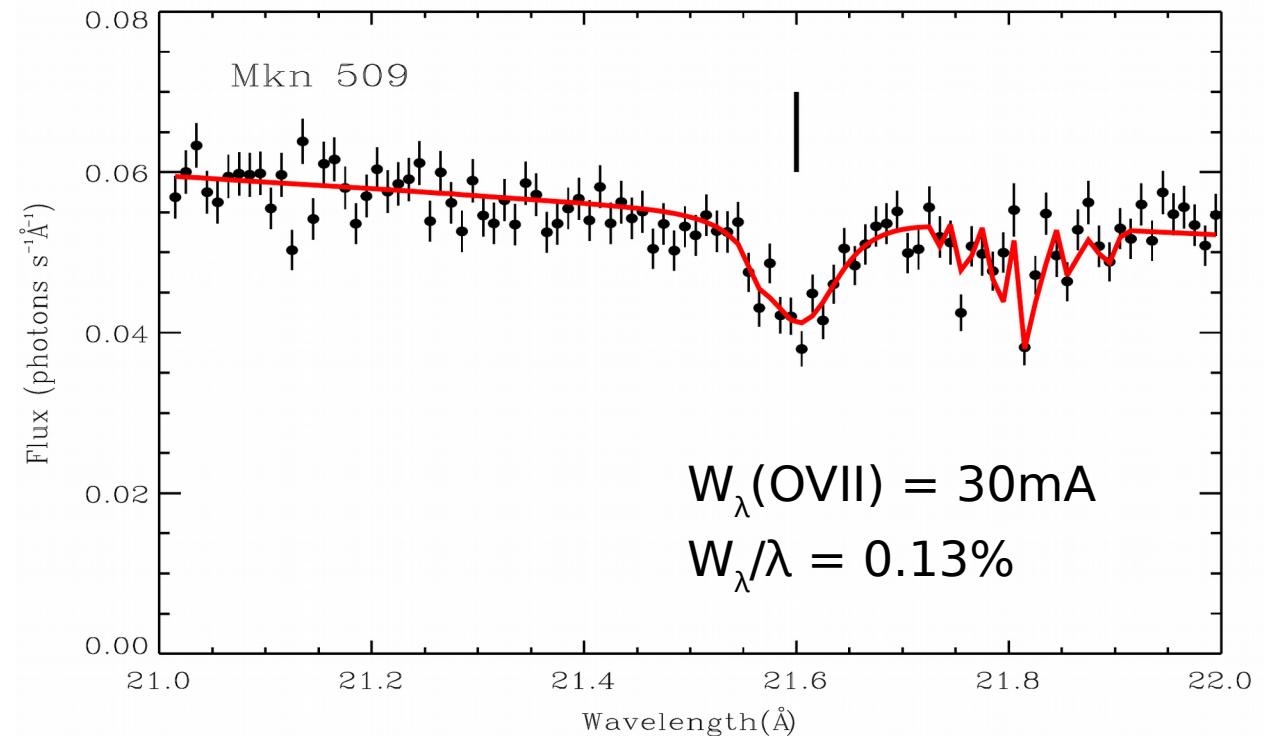
Fermi Bubbles?



Fermi Bubbles?

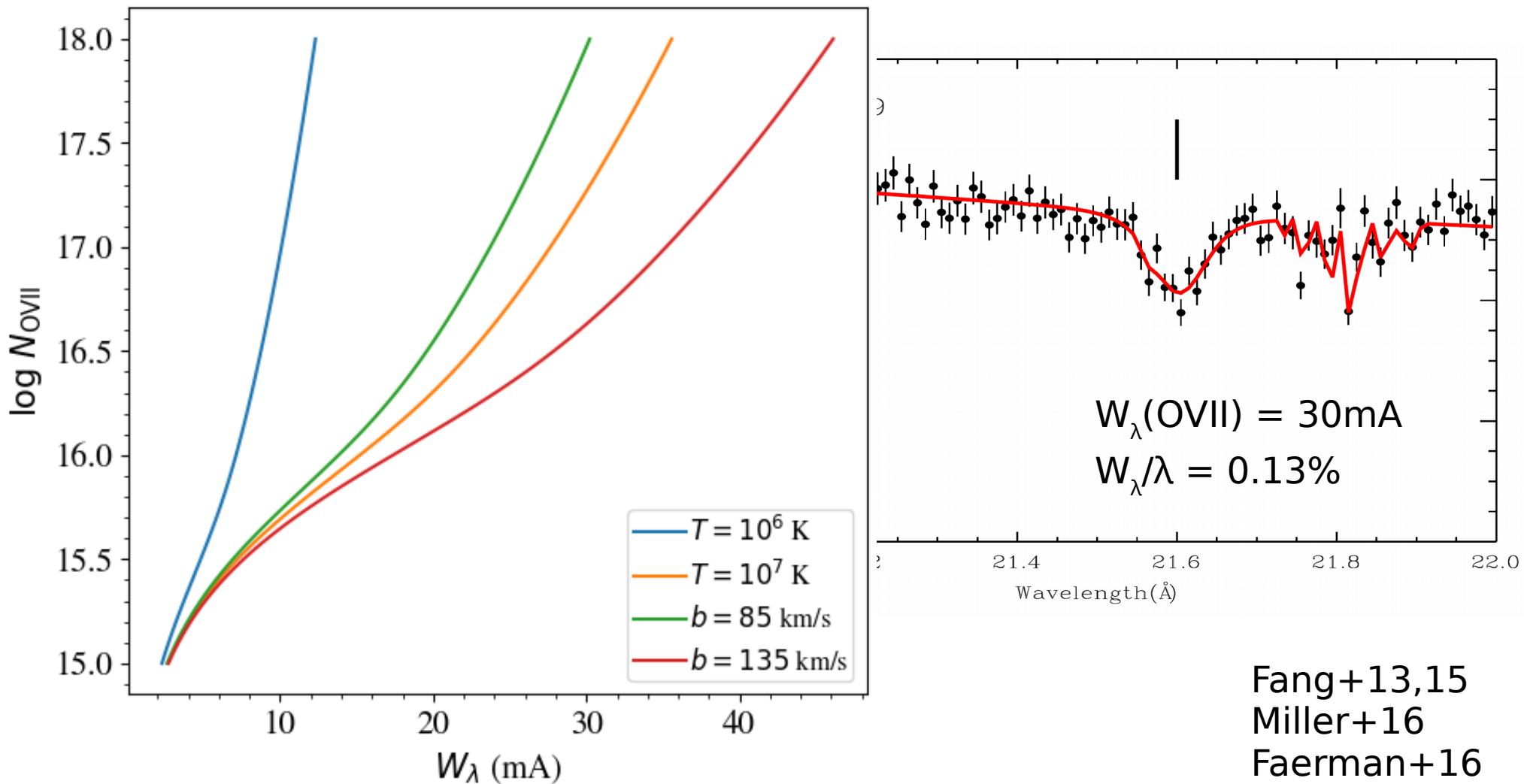


OVII Absorption (X-ray)

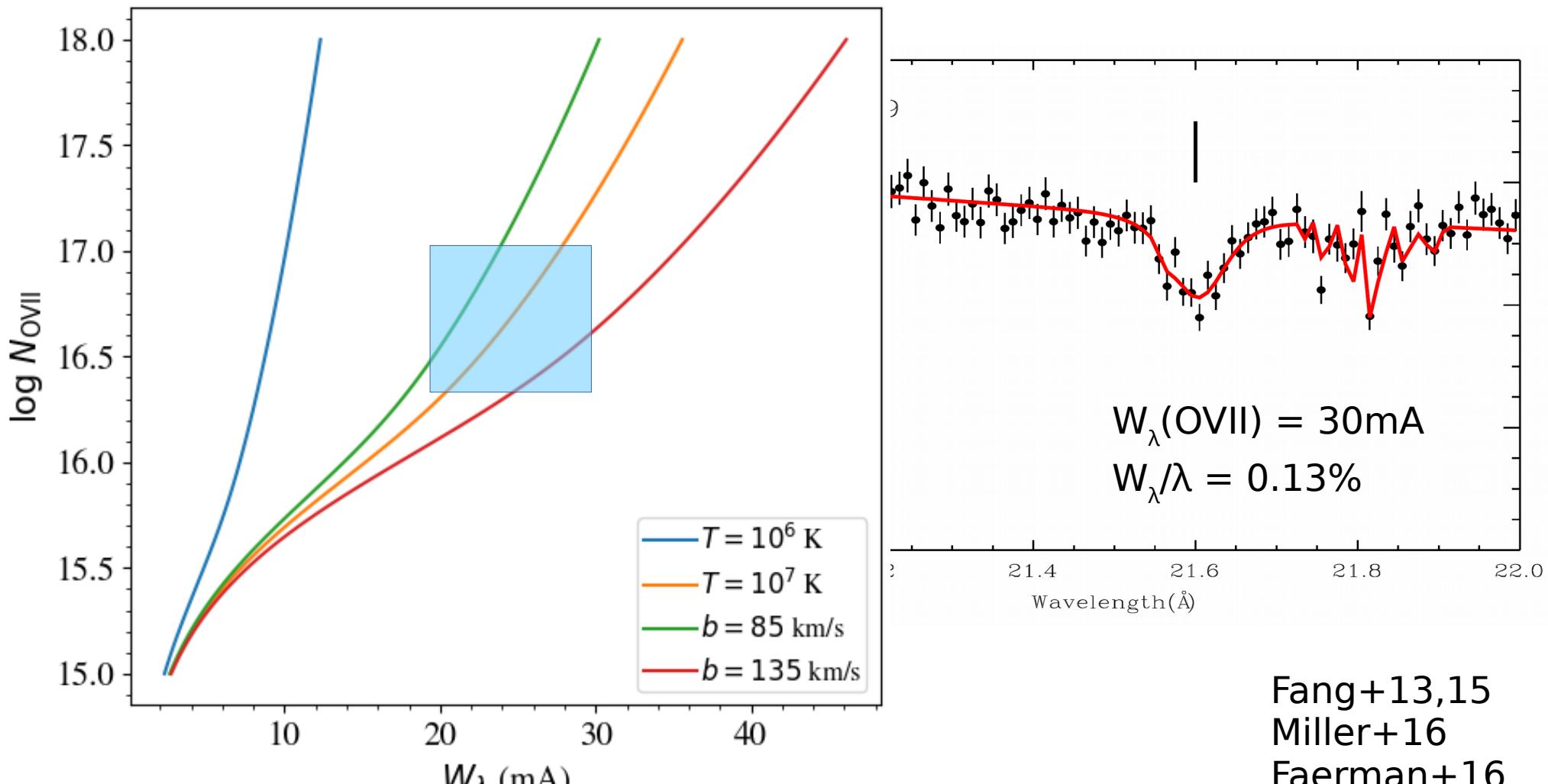


Fang+13,15
Miller+16
Faerman+16

OVII Absorption (X-ray)

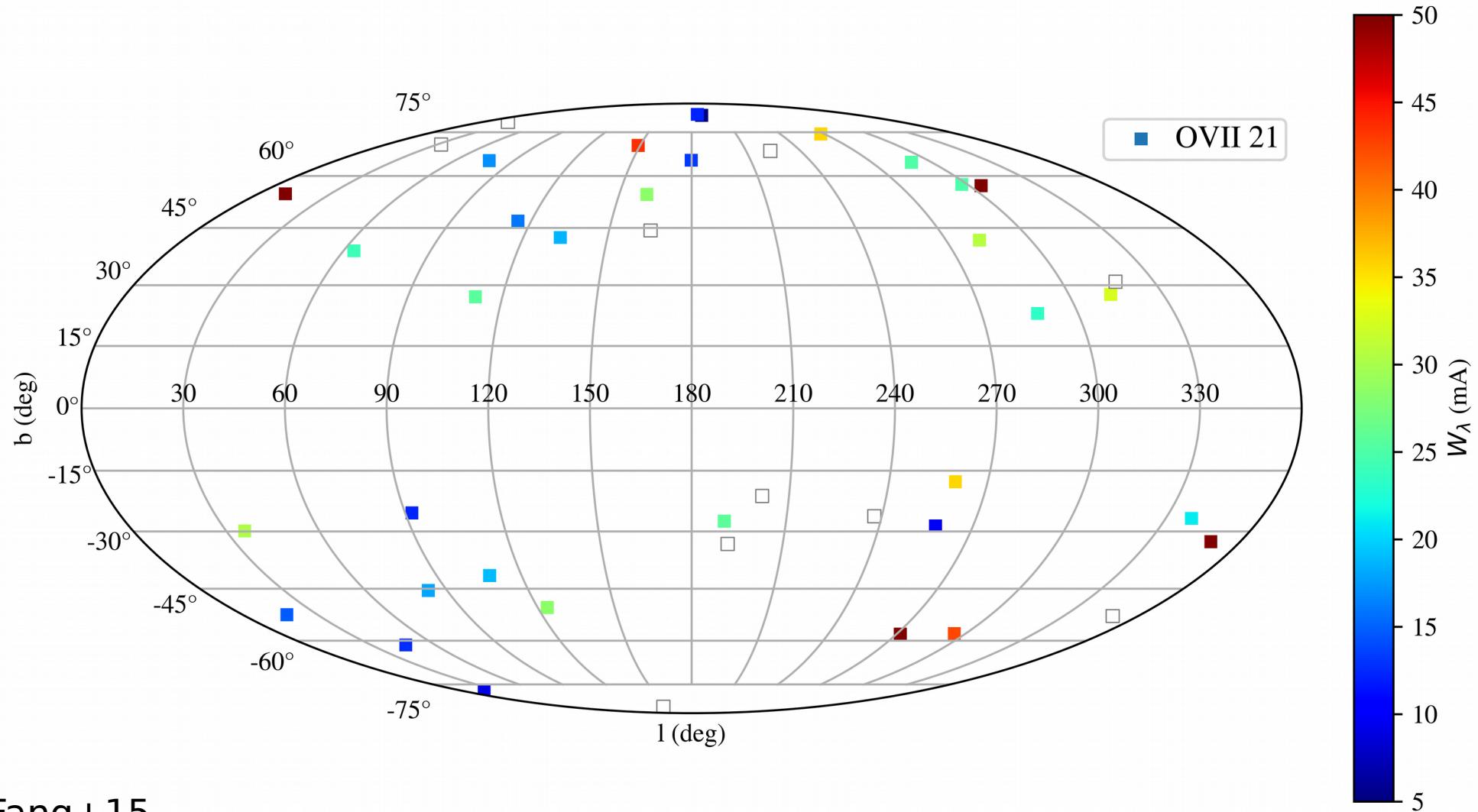


OVII Absorption (X-ray)



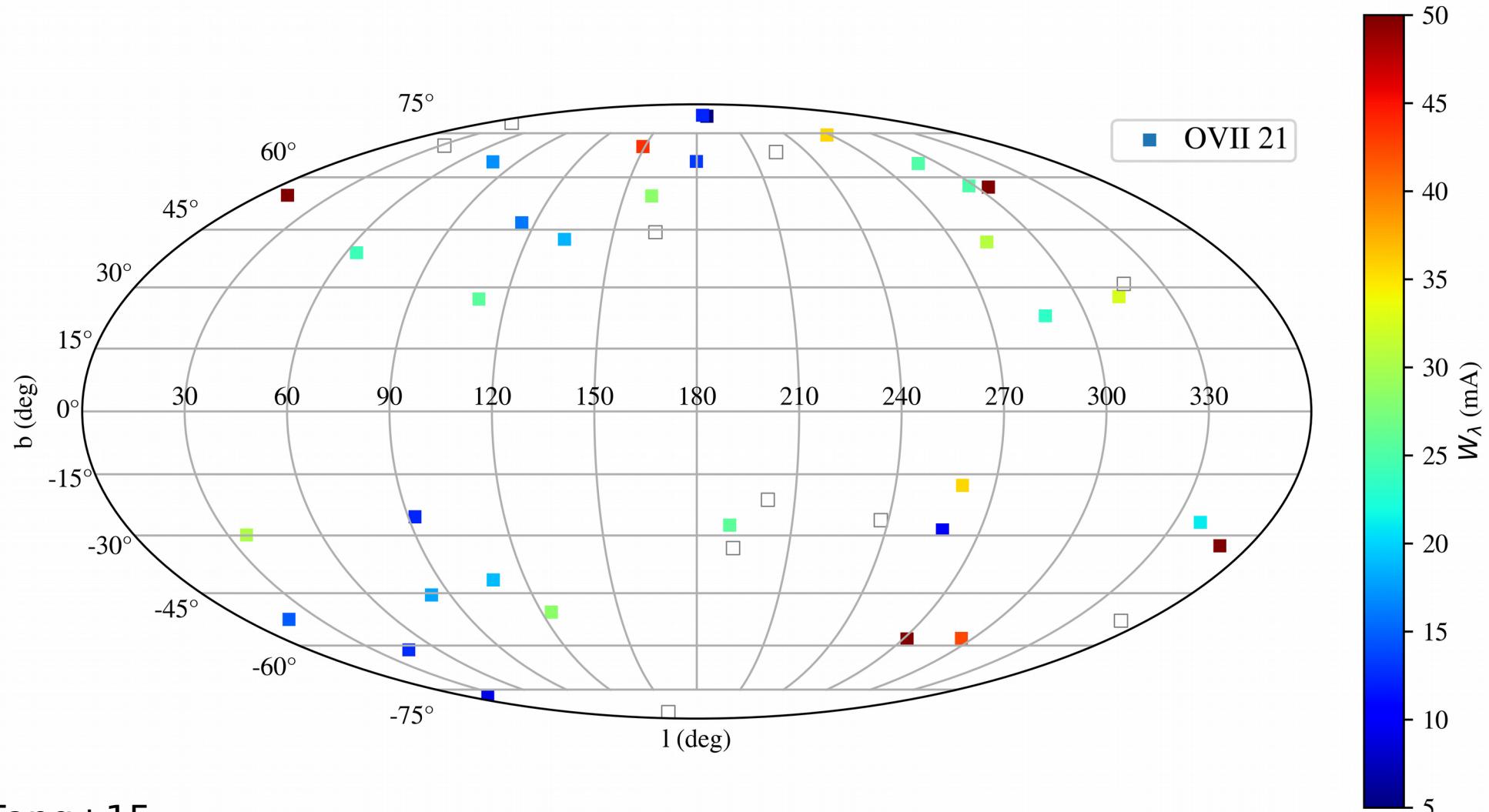
For $W_\lambda(\text{OVII}) \sim 20\text{-}30 \text{ mA}$, estimate $\log N(\text{OVII}) \sim 16.5$

OVII Equivalent Widths



Fang+15

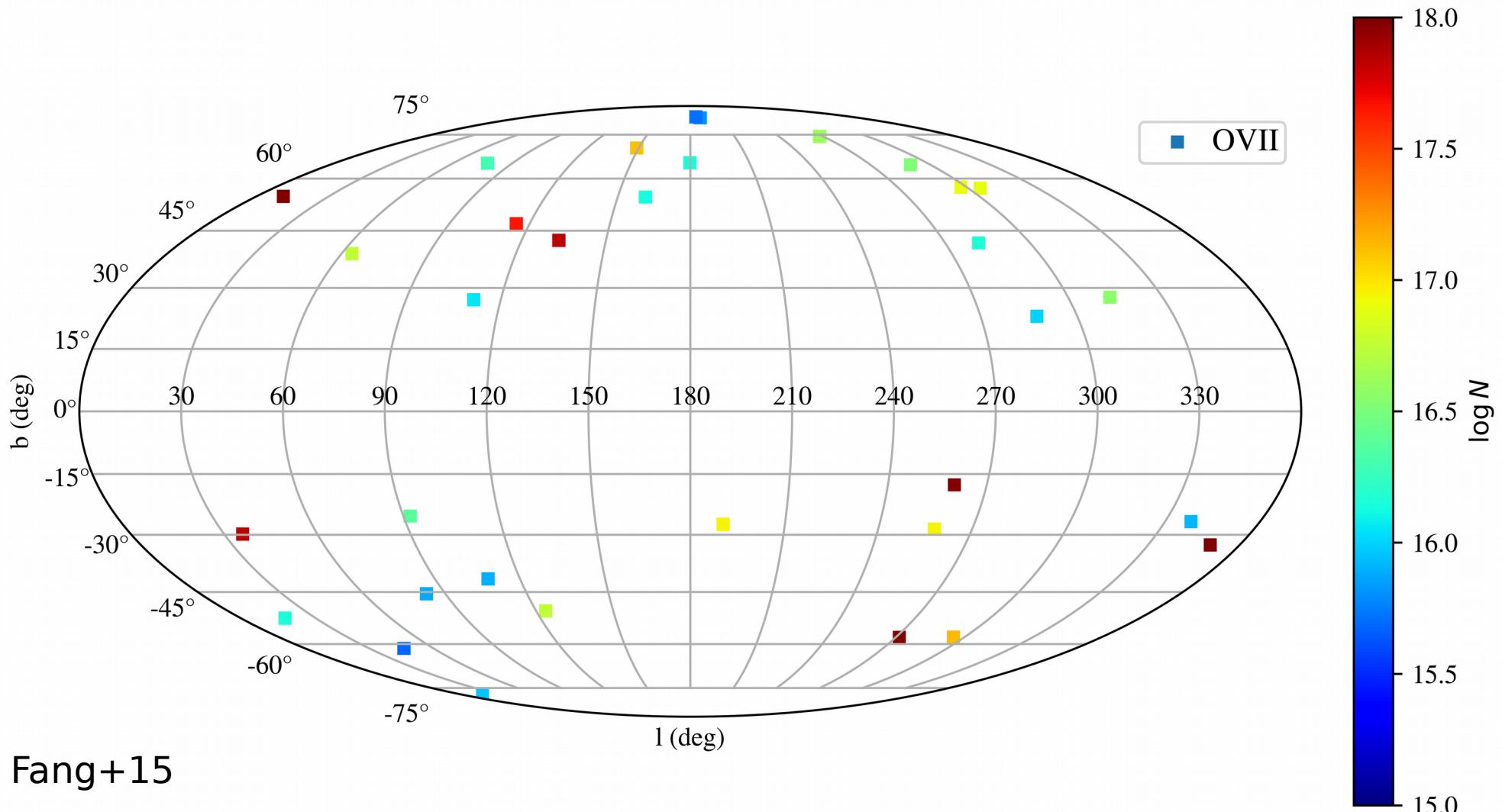
OVII Equivalent Widths



Fang+15

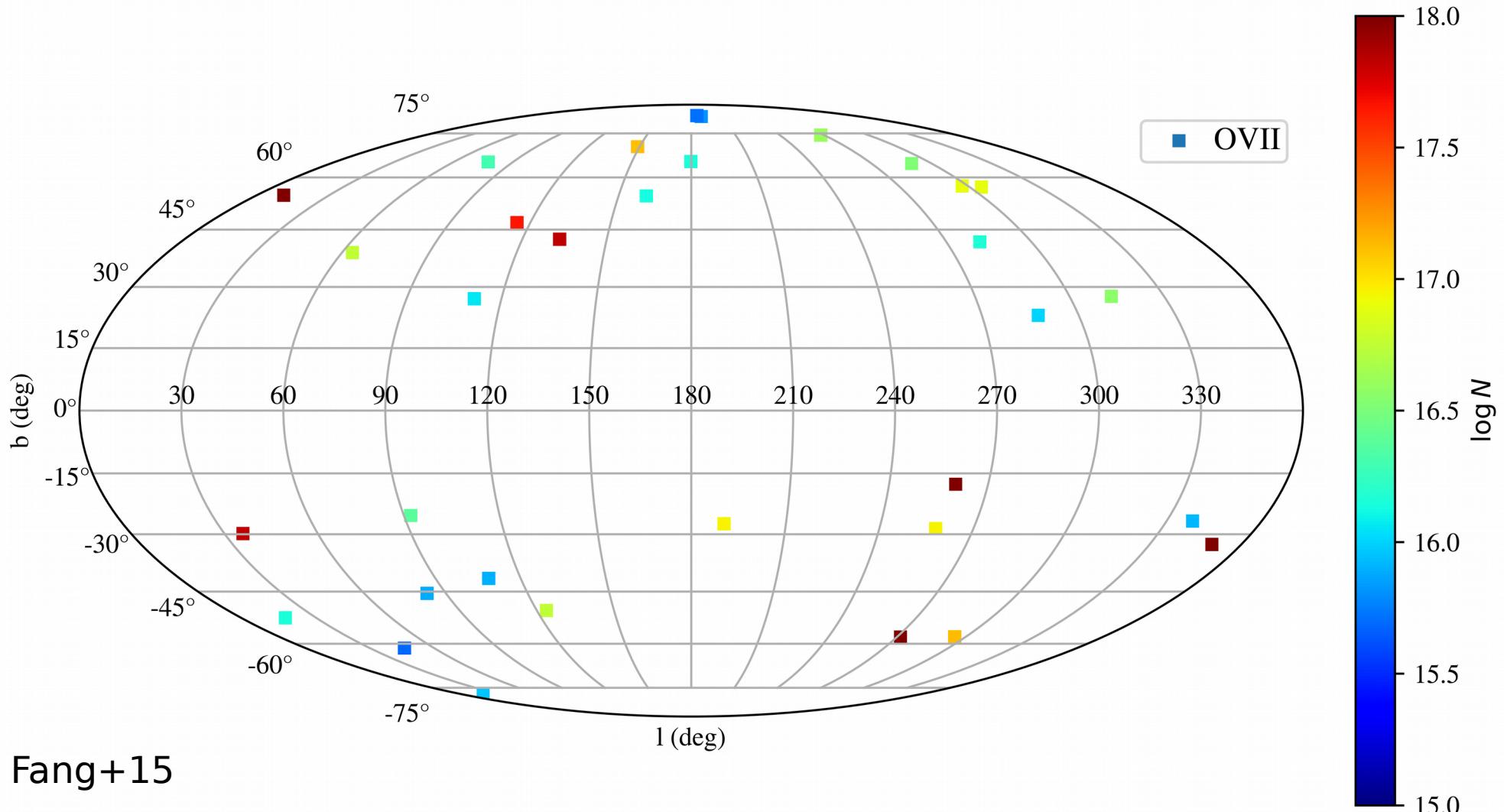
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Galactic N(OVII)



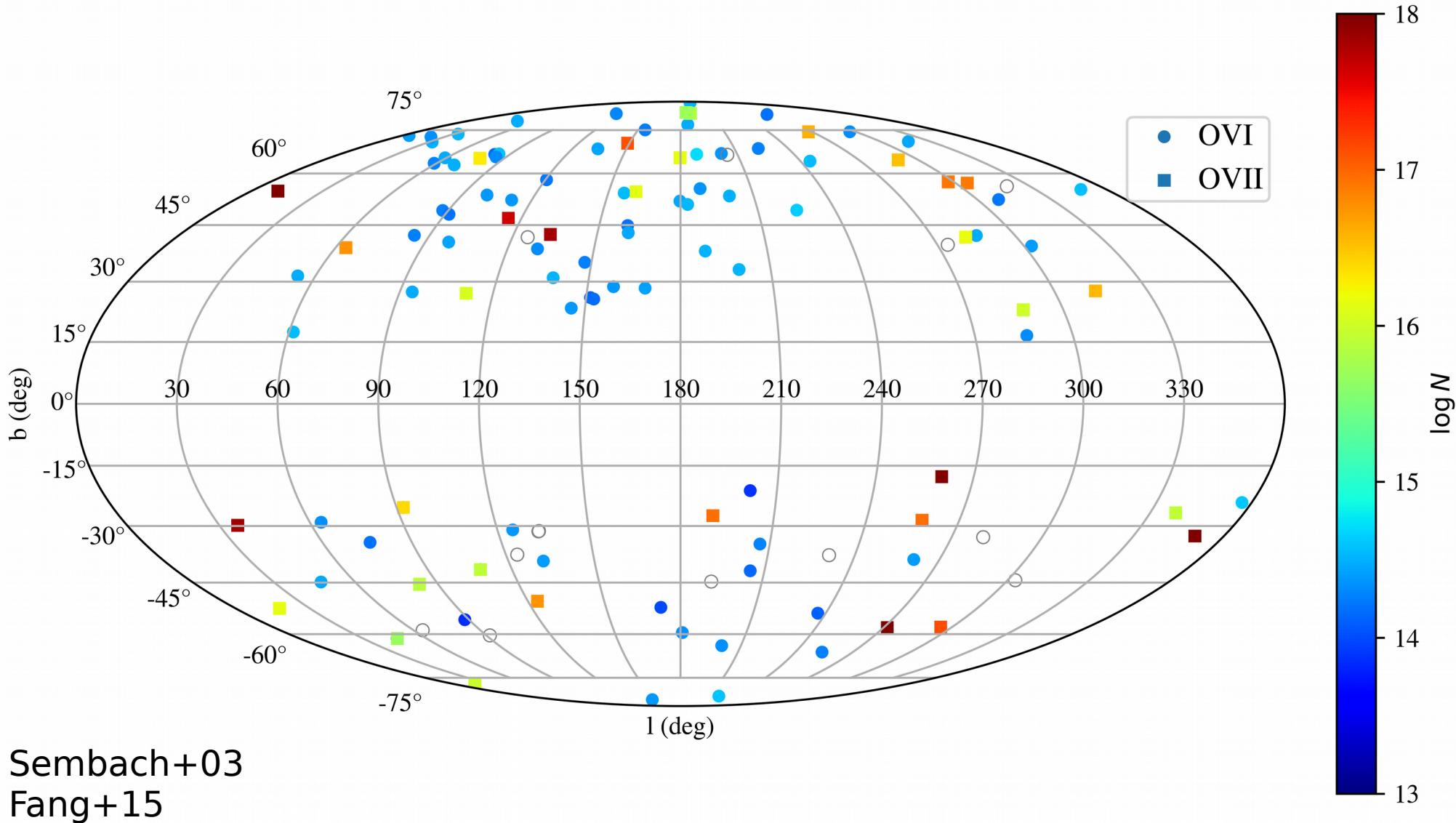
Fang+15

Galactic N(OVII)



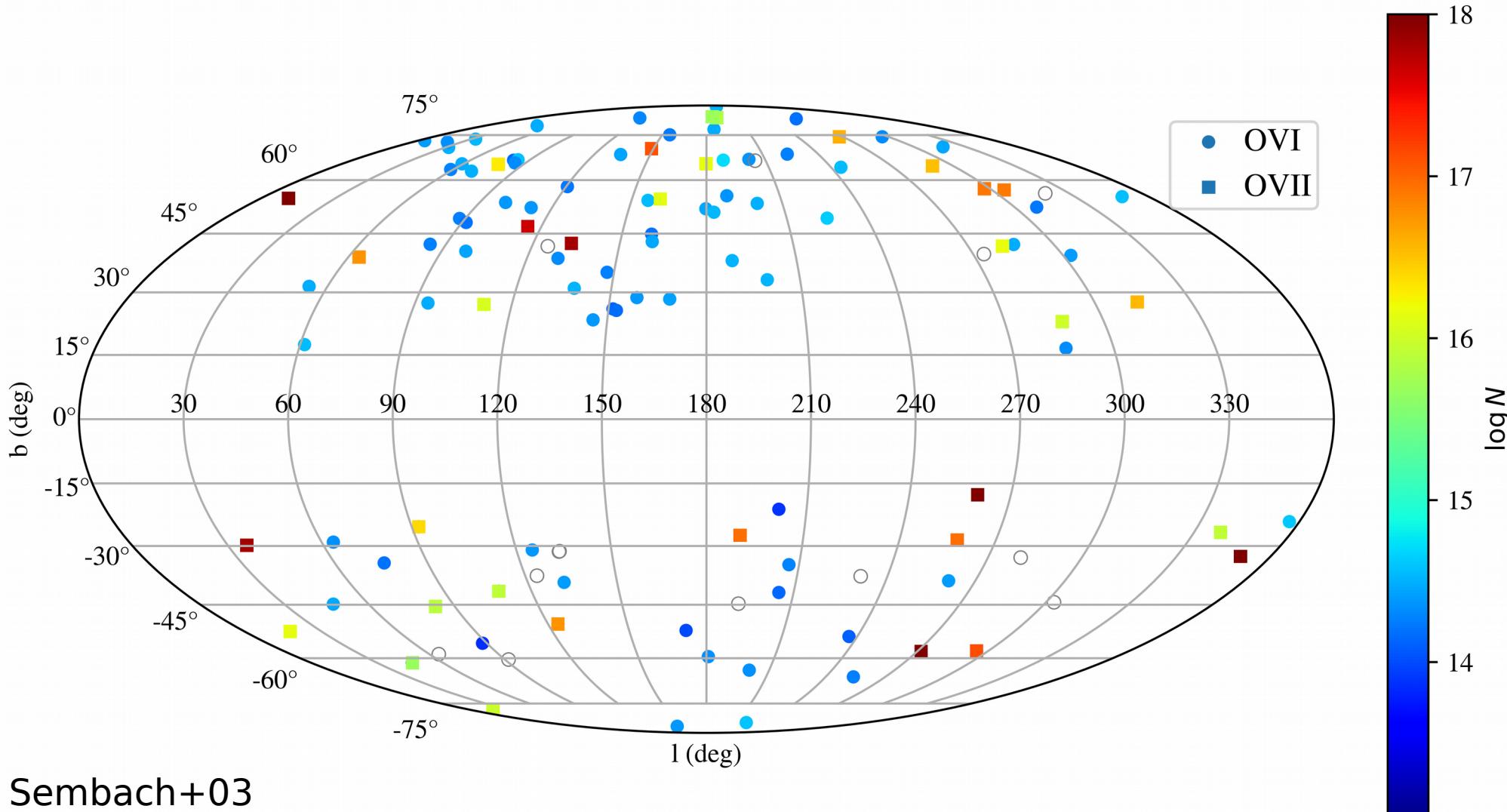
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Galactic N(OVI) and N(OVII)



Sembach+03
Fang+15

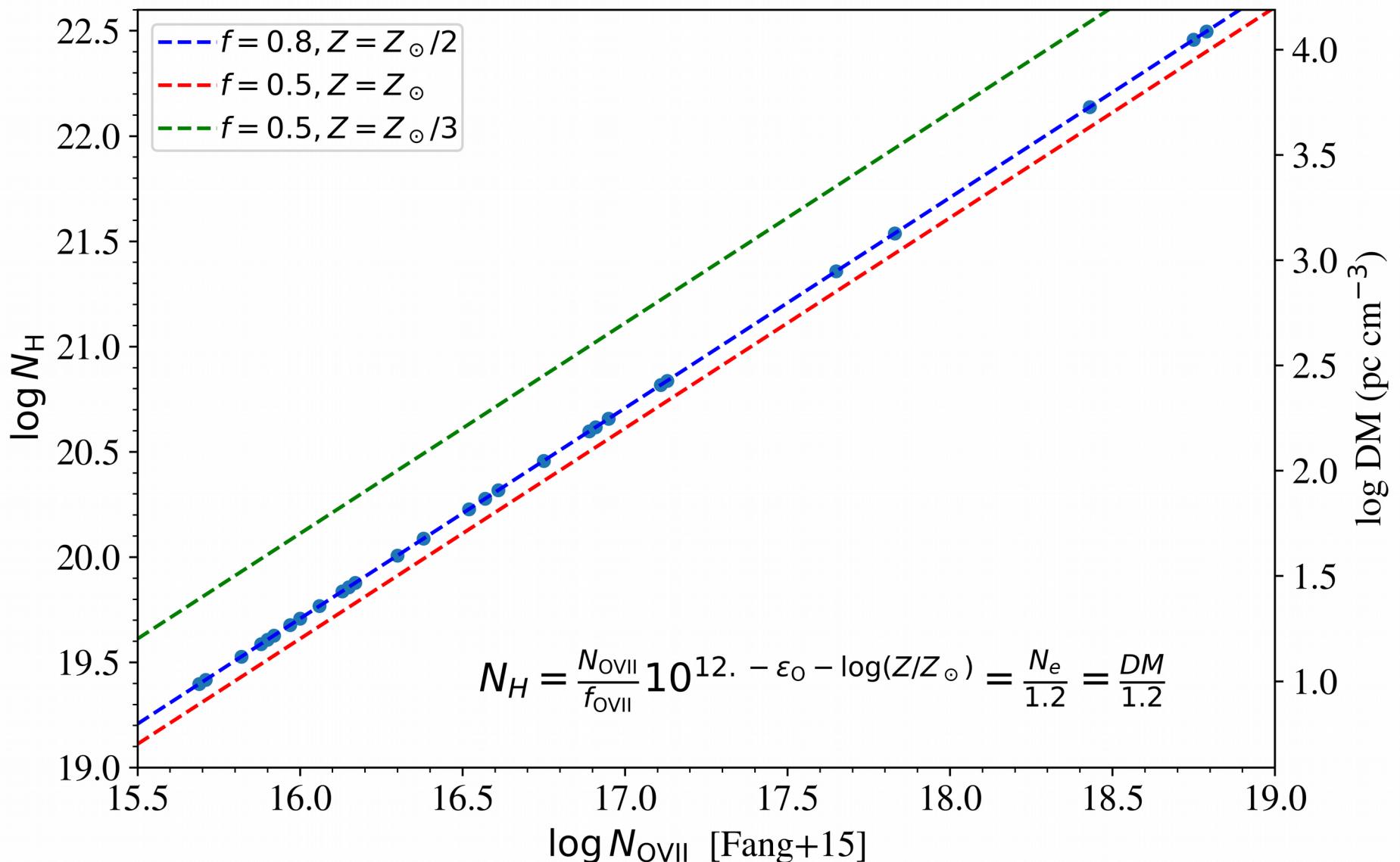
Galactic N(OVI) and N(OVII)



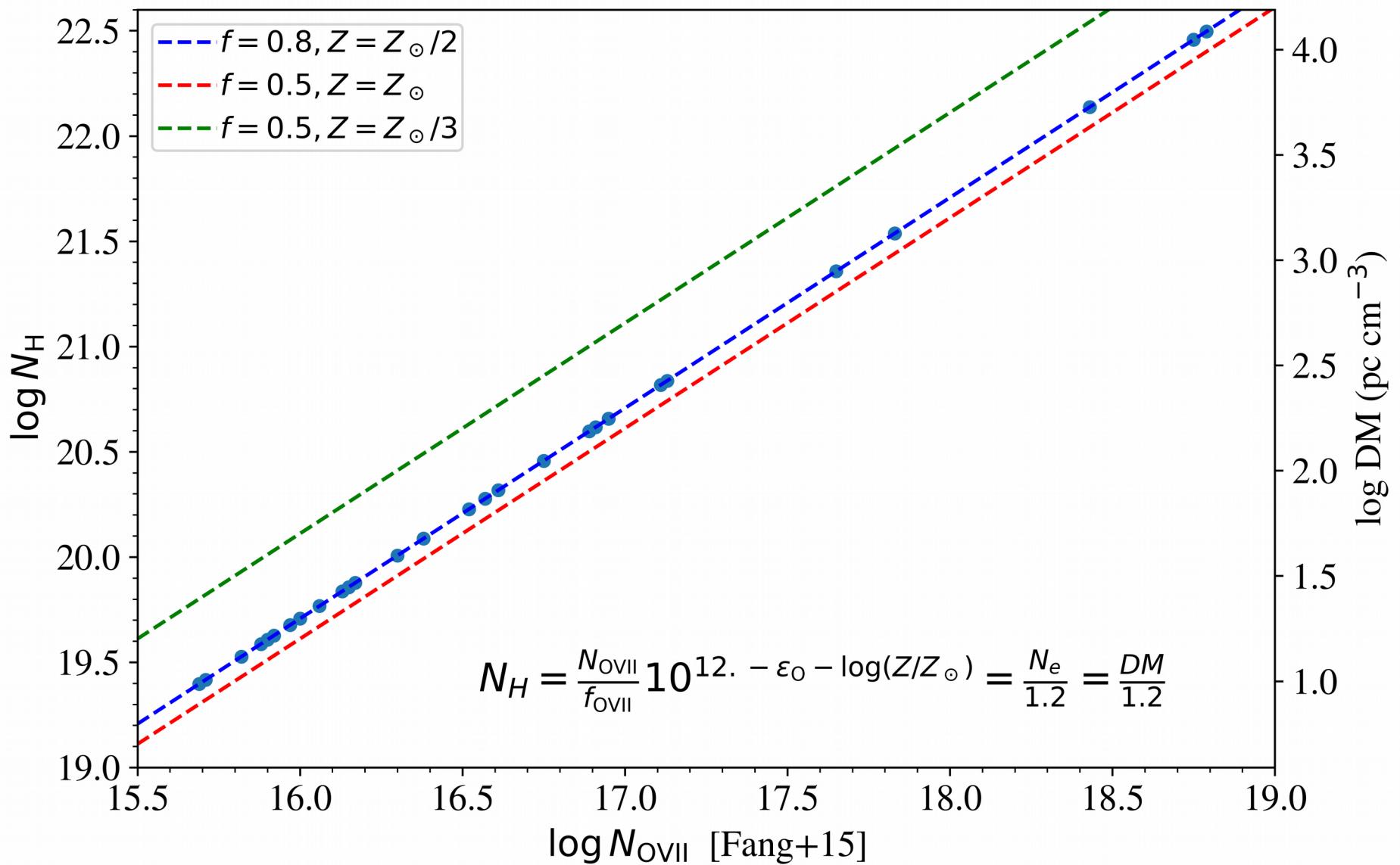
Sembach+03
Fang+15

$N(\text{OVII}) \gg N(\text{OVI})$, as expected for a $T \sim 10^6$ K halo

N_H , N_e , and the Dispersion Measure

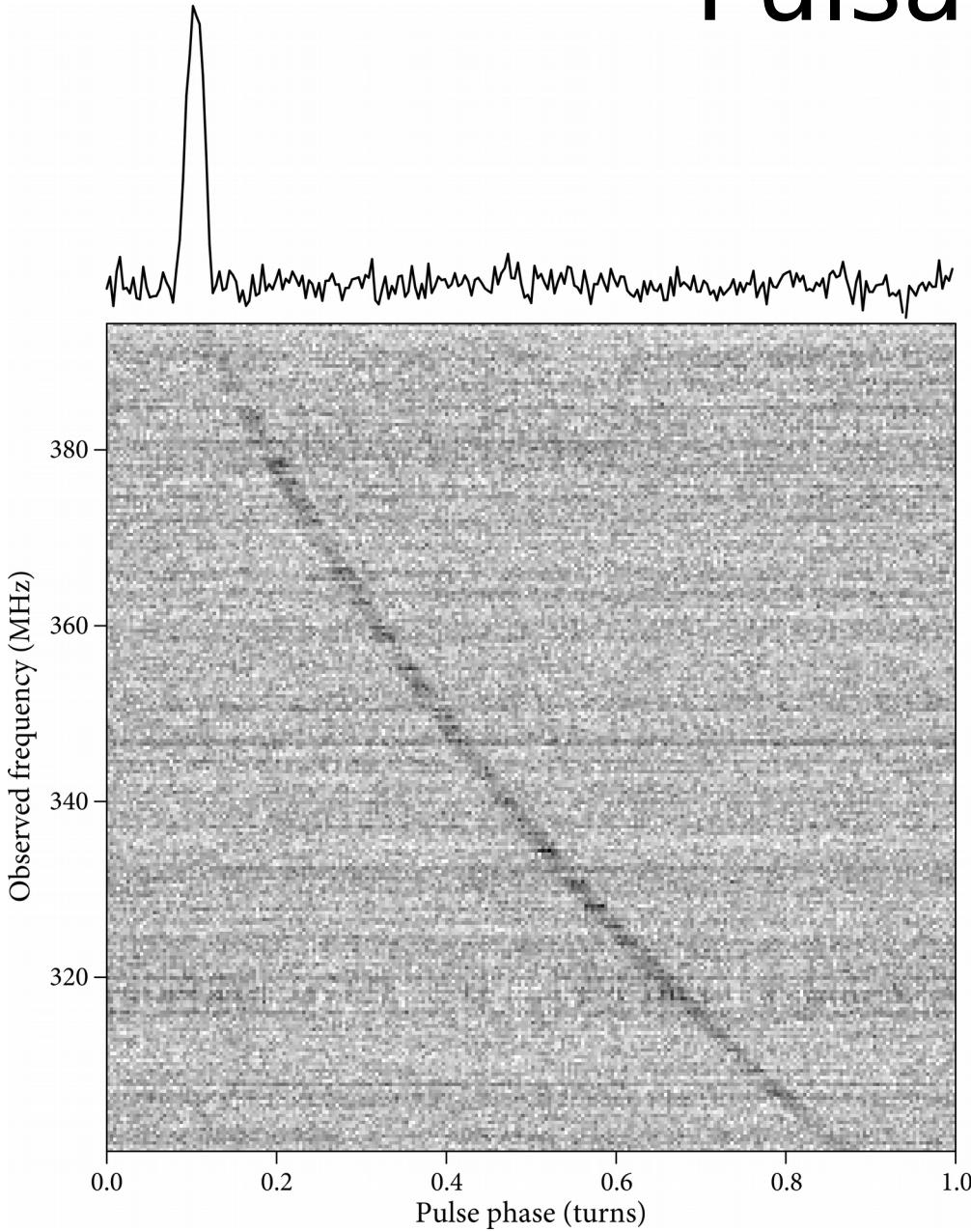


N_H , N_e , and the Dispersion Measure



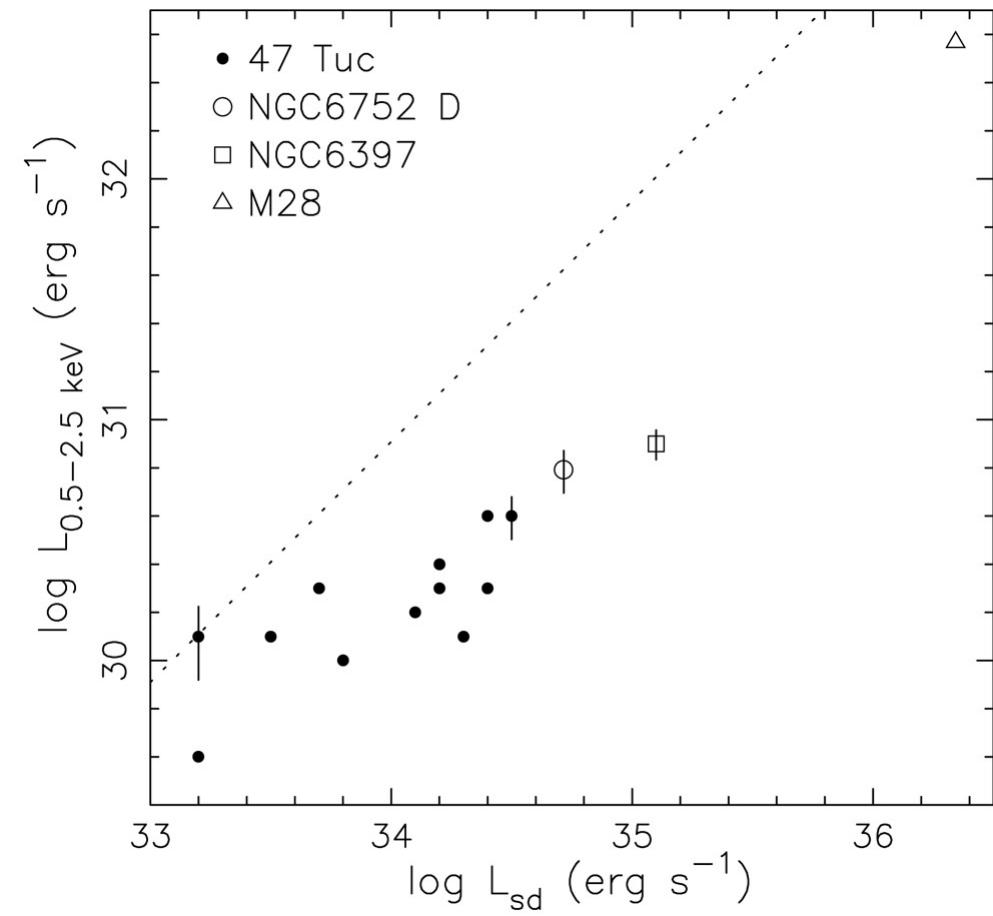
$N(\text{OVII}) \sim 16.5$ implies $N_H \sim 20.3$ and $\text{DM} \sim 50 \text{ pc cm}^{-3}$

Pulsar DM



S. Ransom

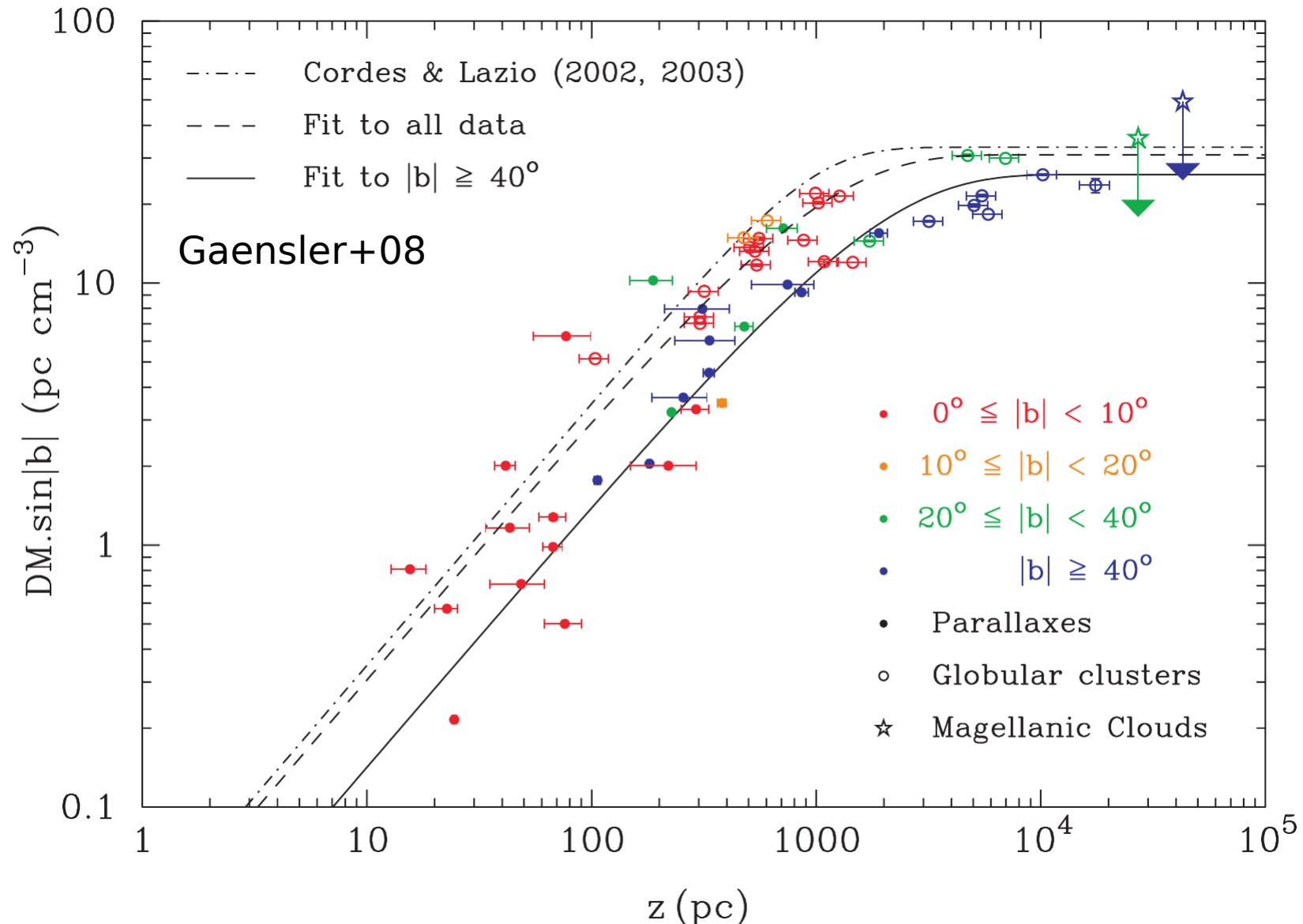
Durham 17'



Verbunt

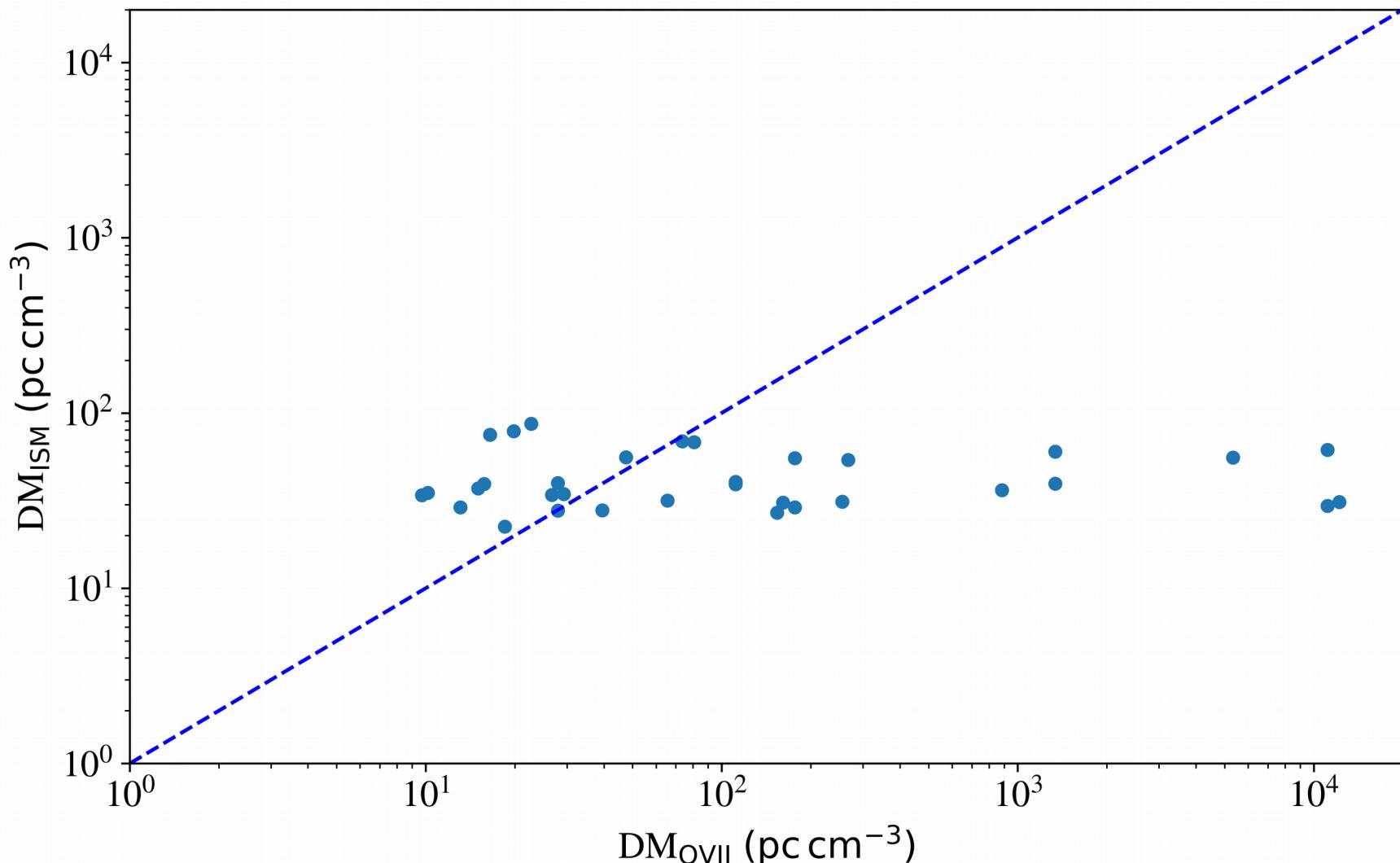
31

Electrons in the Warm Ionized Medium



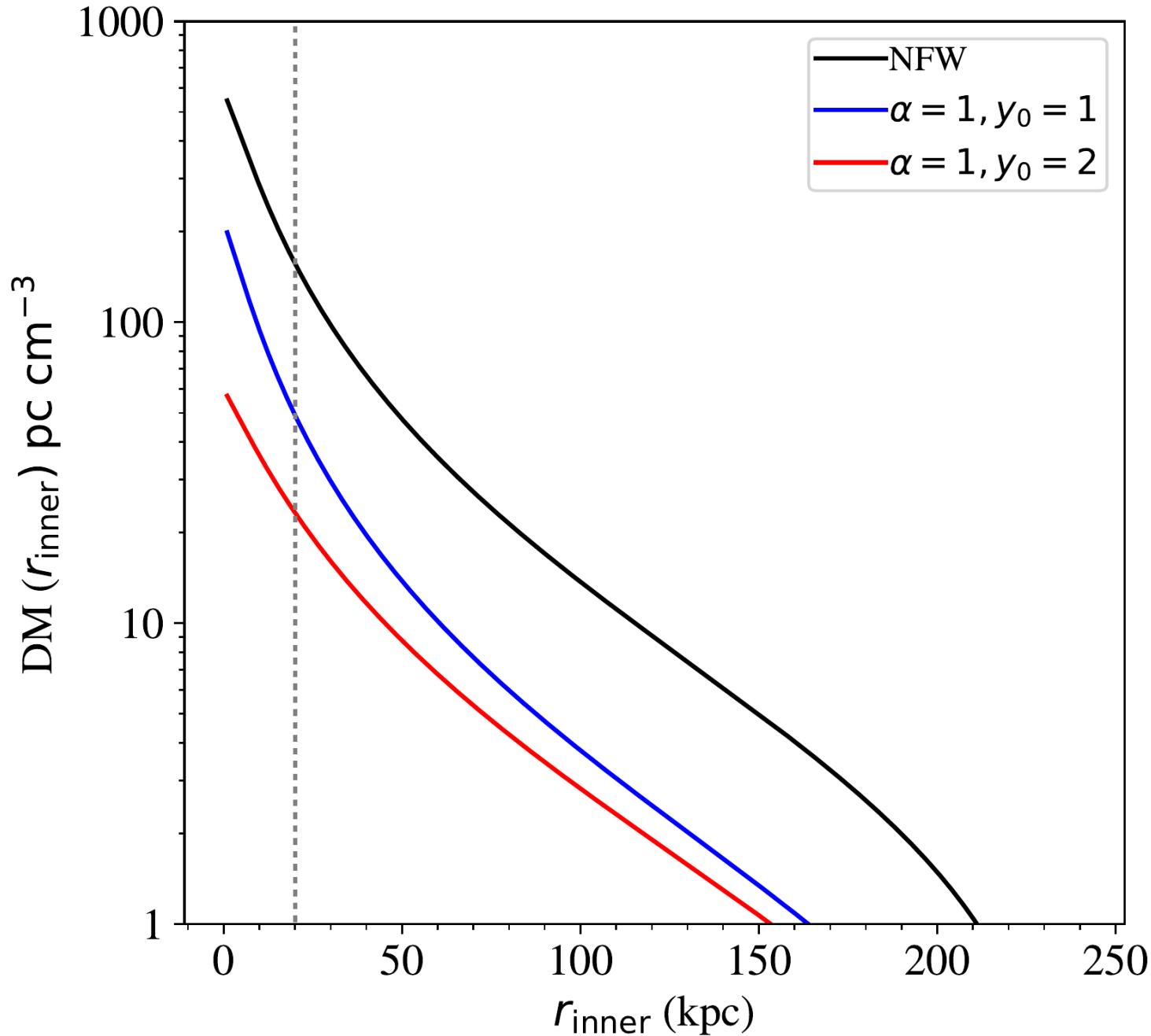
Combined with DM from pulsars in the disk, we have a model of electrons throughout the ISM (NE2001)

DM_{ISM} vs. DM_{OVII}

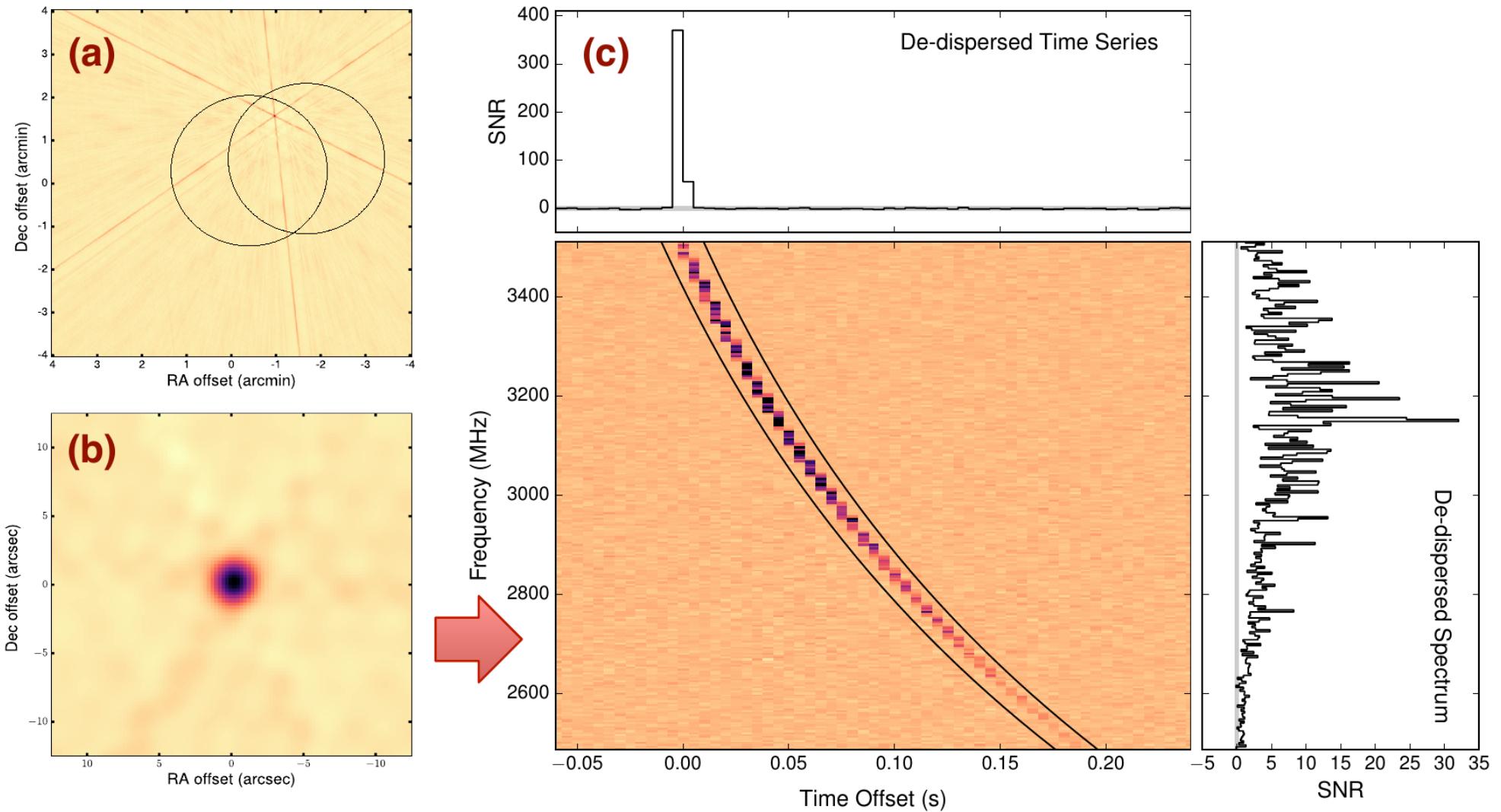


(At least most) OVII must lie (far) beyond the WIM.

Tracing the Galaxy's DM

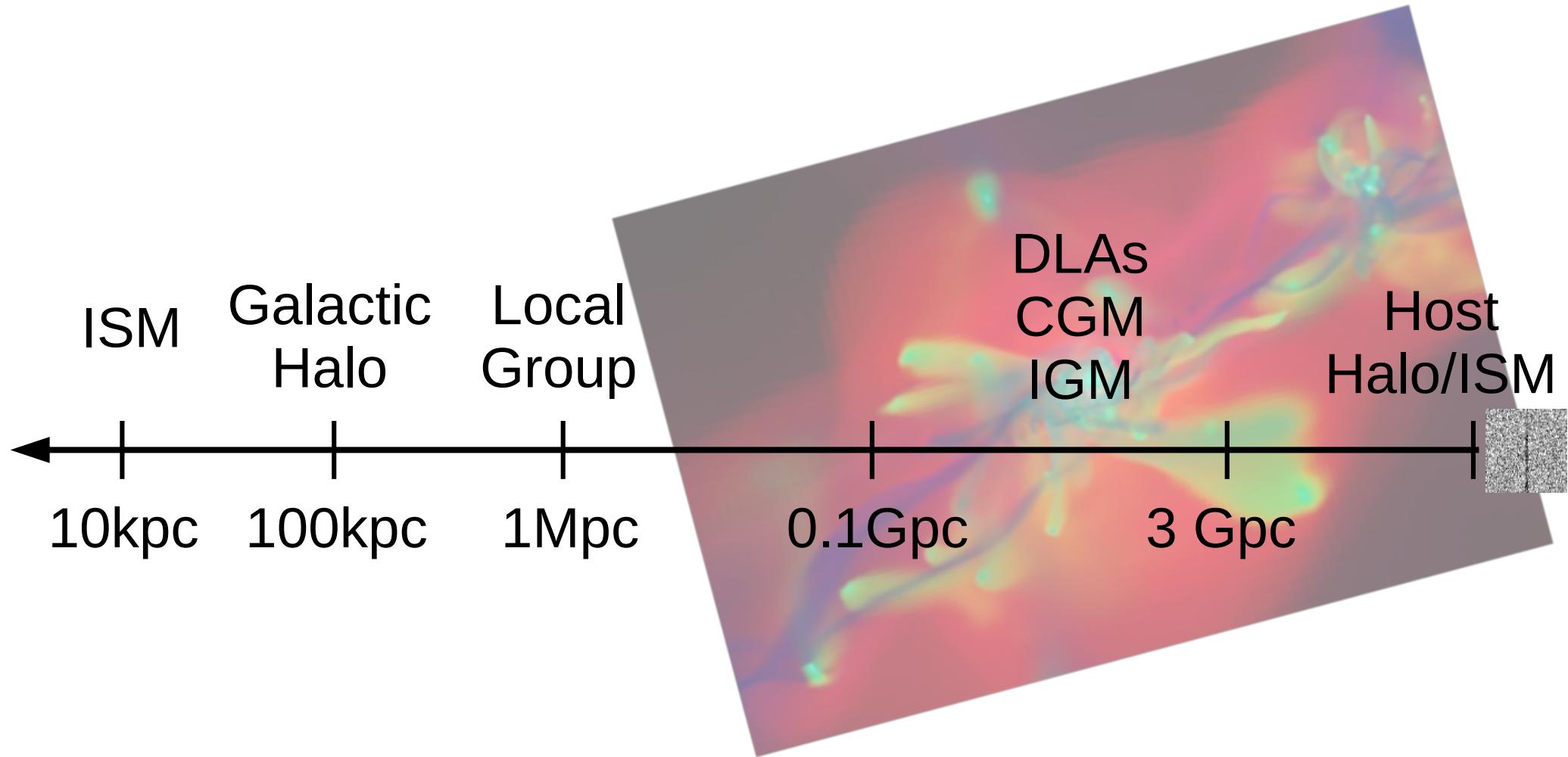


Enter the Scene: FRBs!



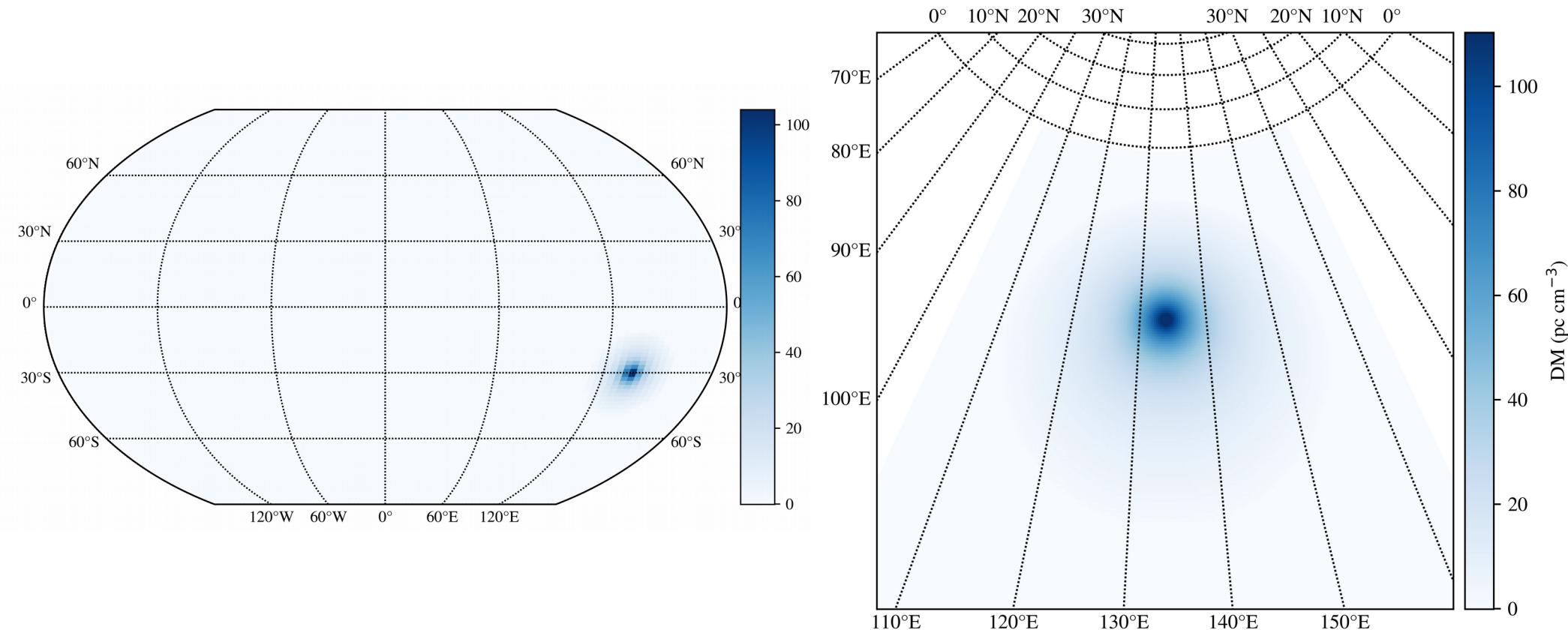
No longer just someone's re-heated lunch...

A Complete Census of N_e



Sensitive to **all** the electrons: A blessing (and a curse?)

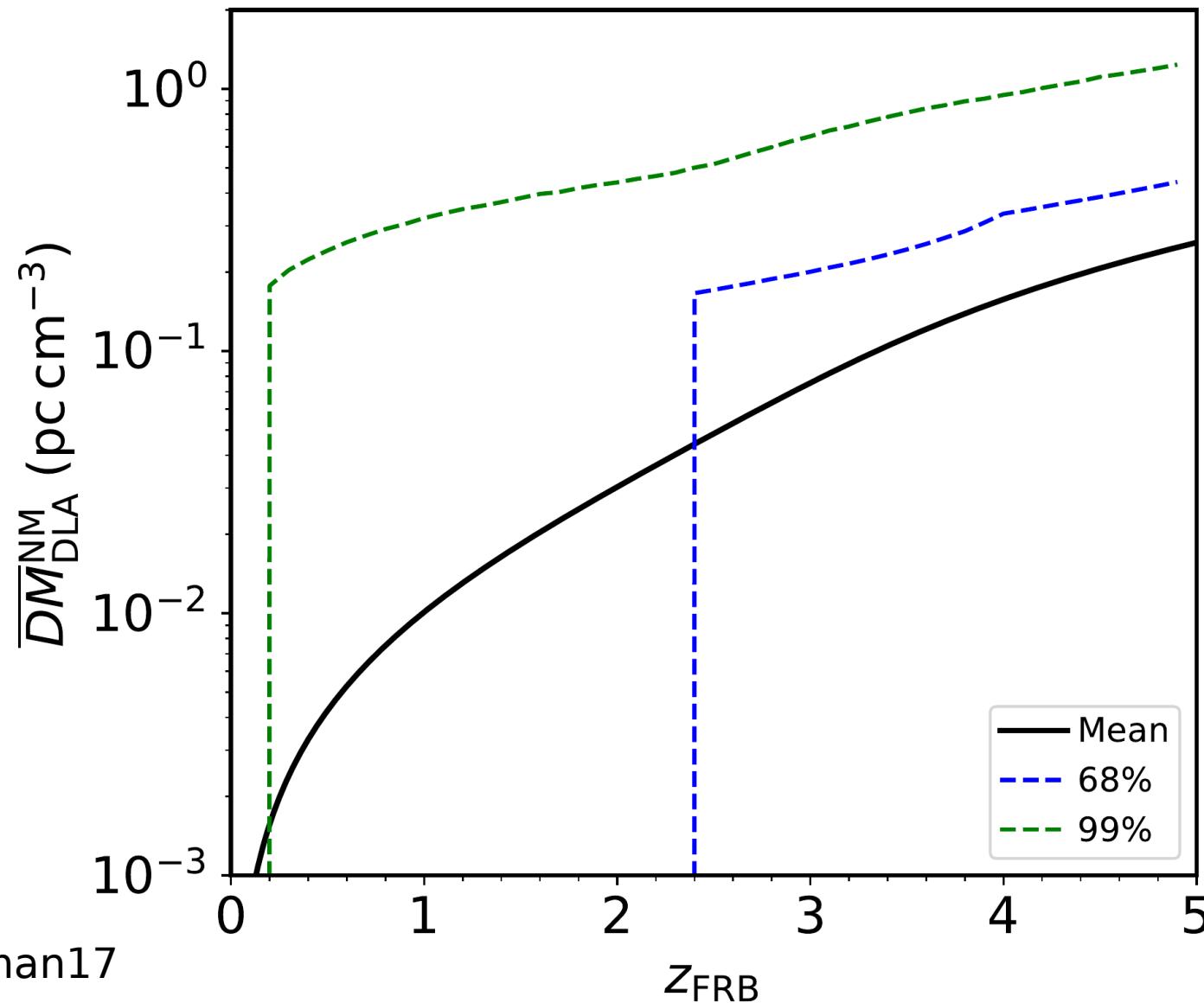
DM from the Local Group



X&Zheng17

e.g. M31

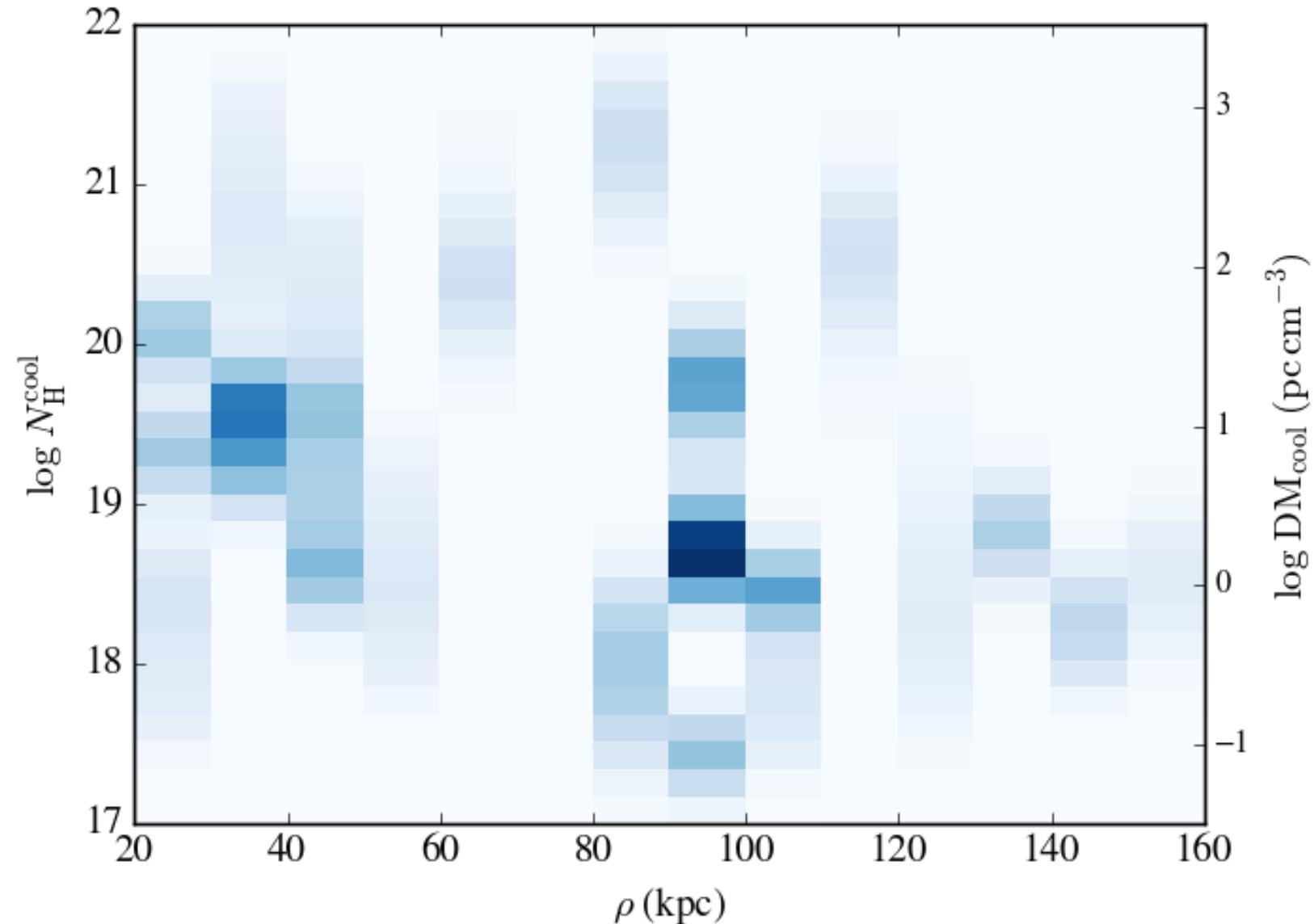
DM from Intervening Galaxies (DLAs)



X&Neeleman17

Of minor consequence, even if they have a WIM.

DM from Cool CGM

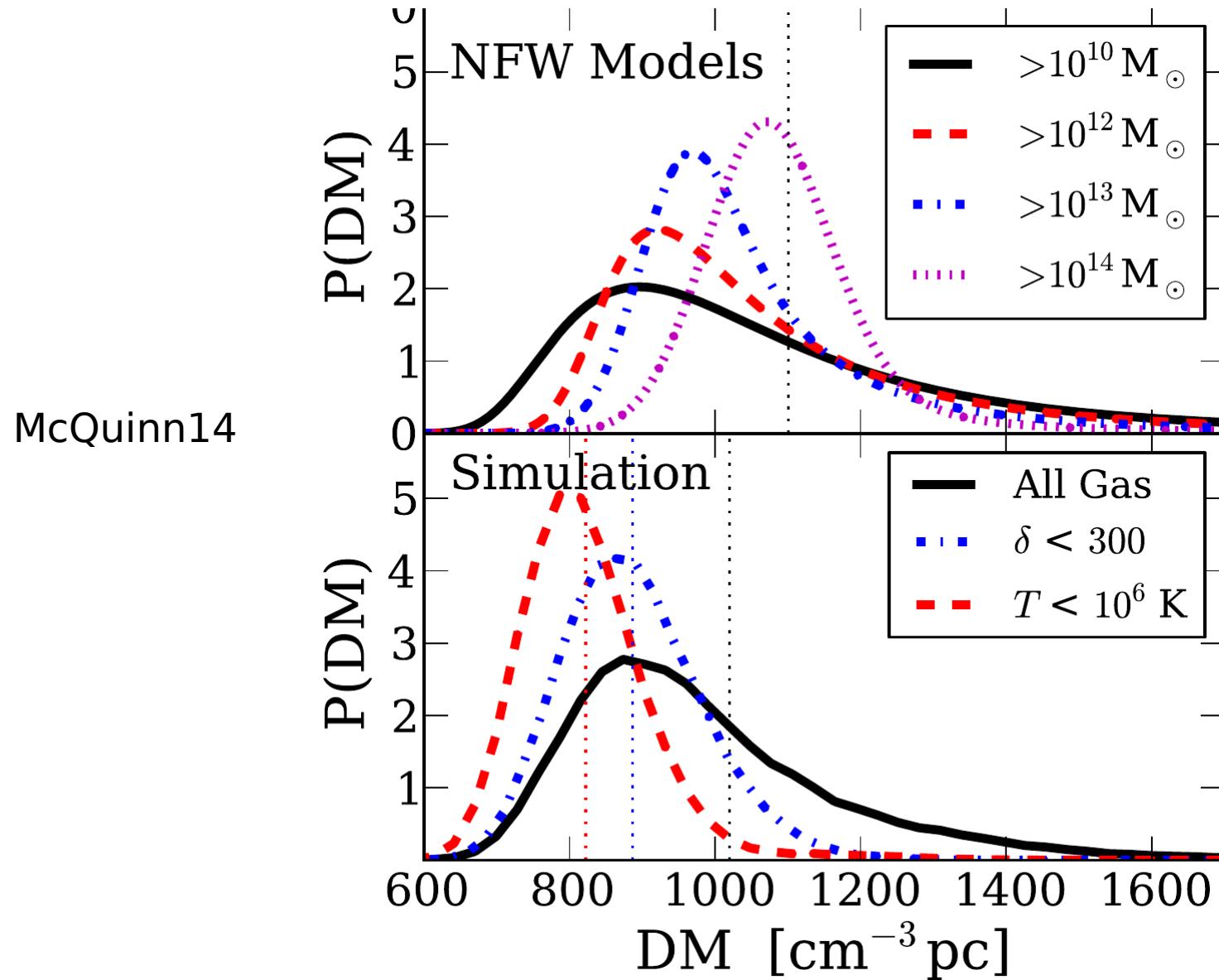


X+17

ρ (kpc)

Approximately 10 pc cm^{-3} , with great scatter.

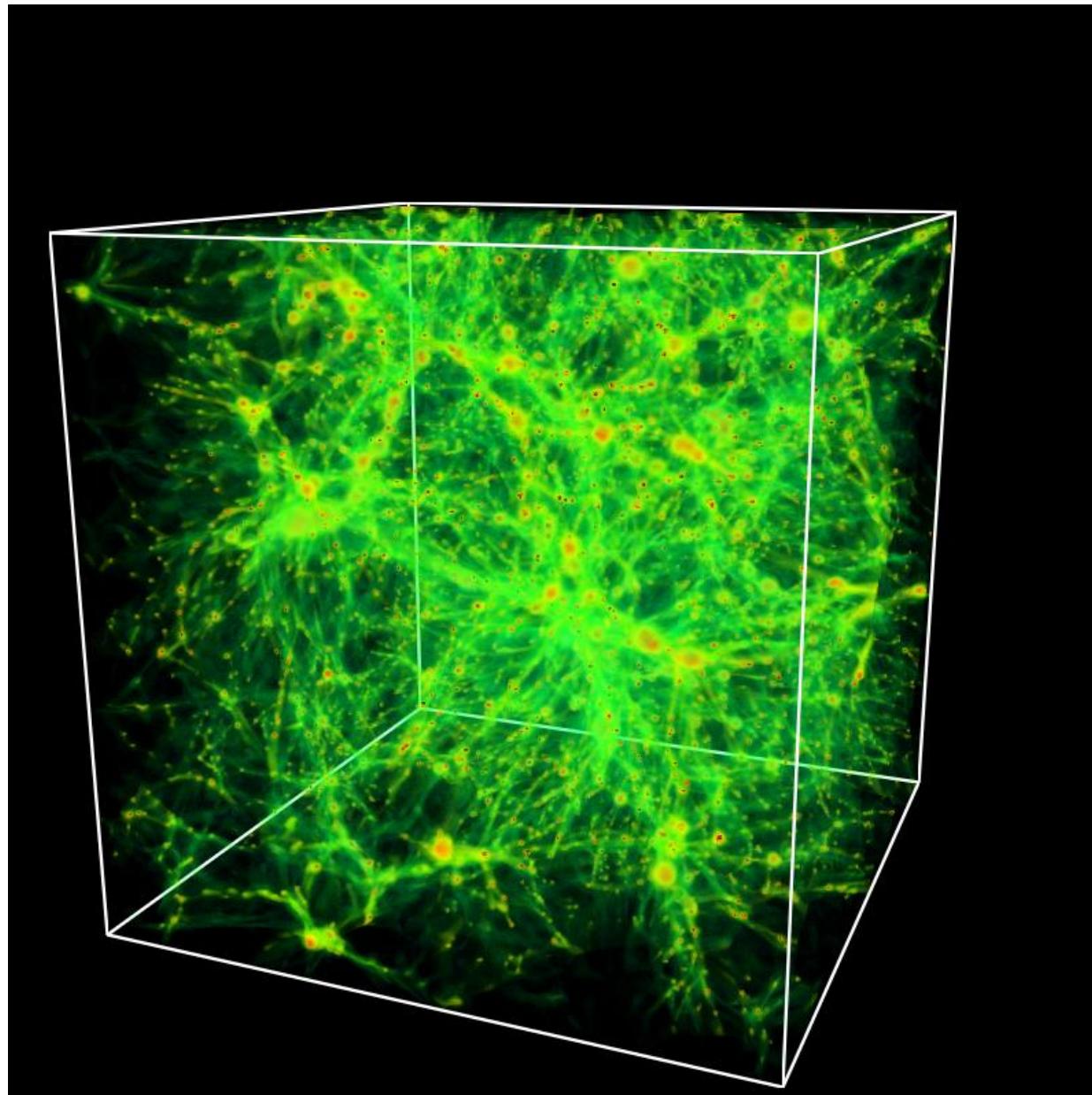
DM from Halos (Cool,Warm,Hot)



Median and scatter are sensitive to halo gas distribution.

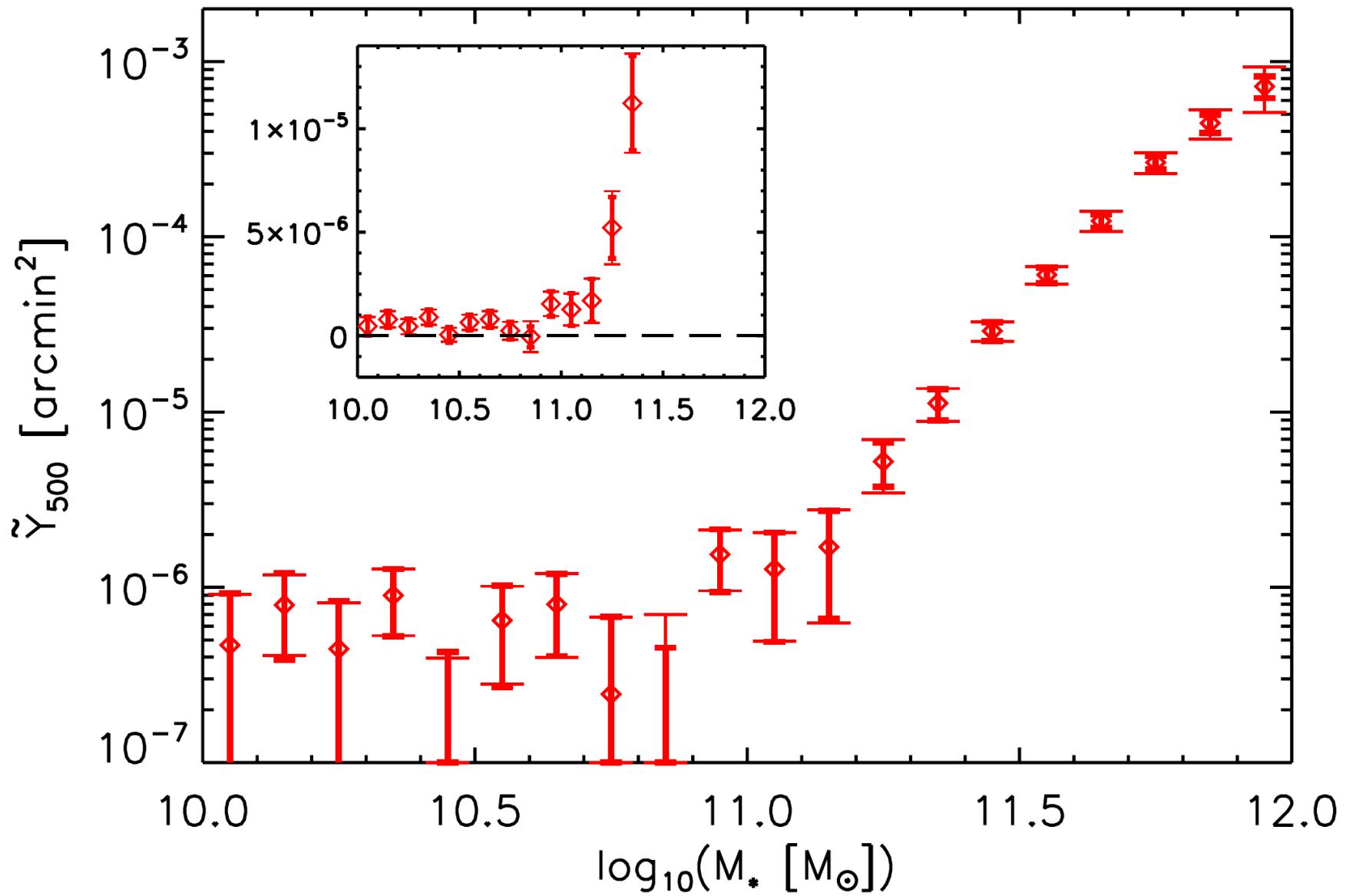
Is there really a Cosmological WHIM?

How is warm/hot gas distributed in/ around galaxies?



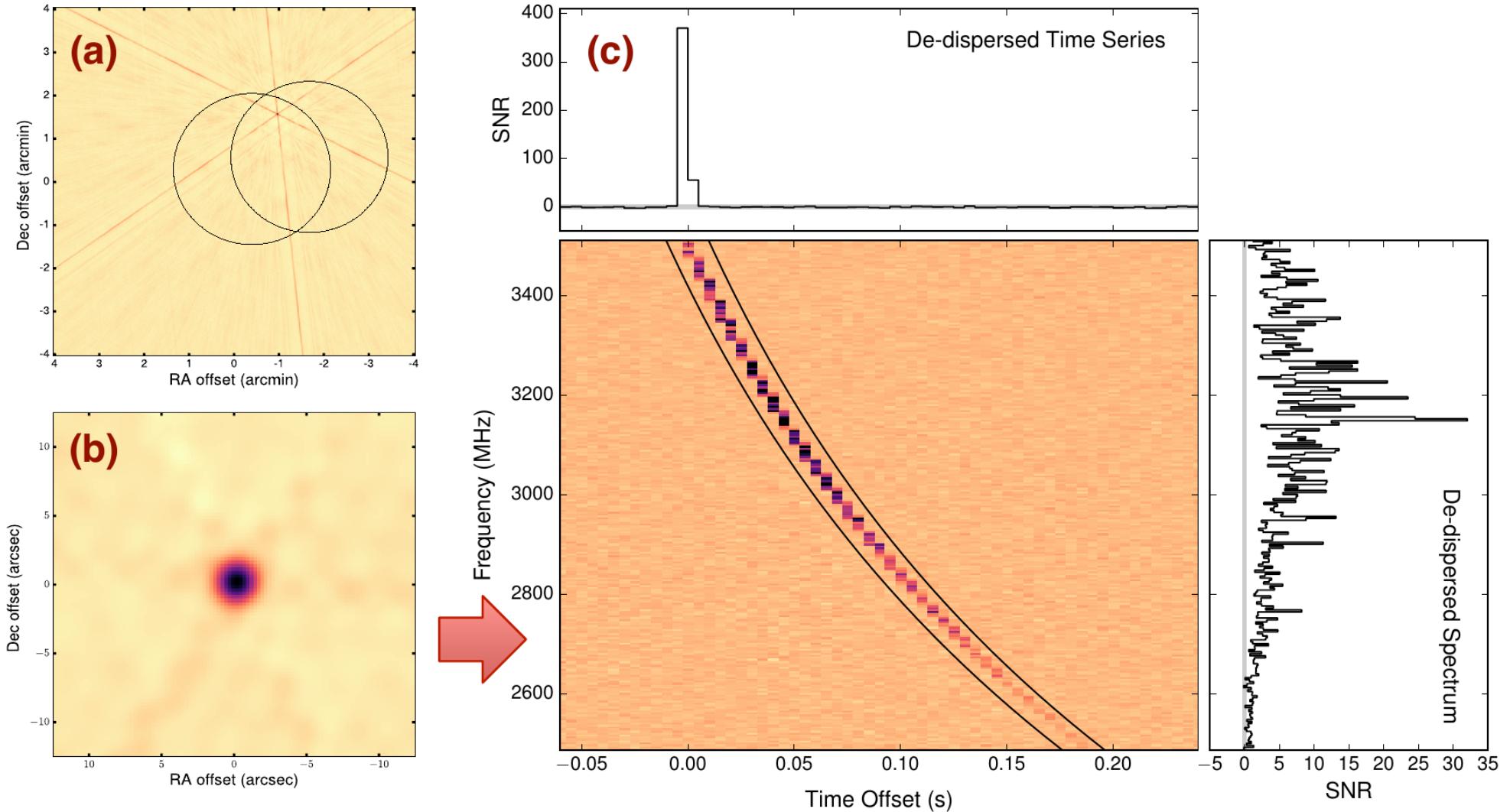
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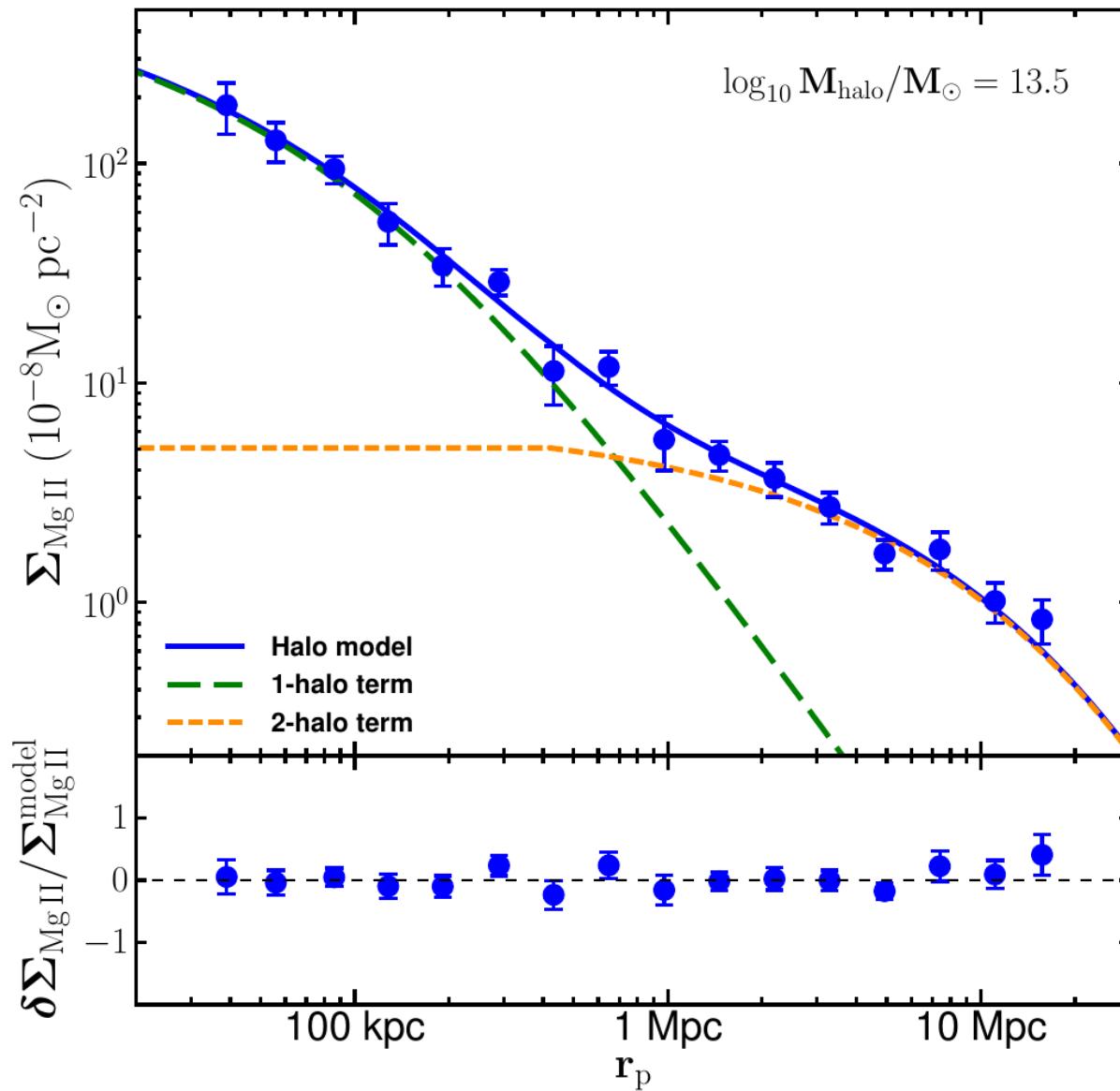
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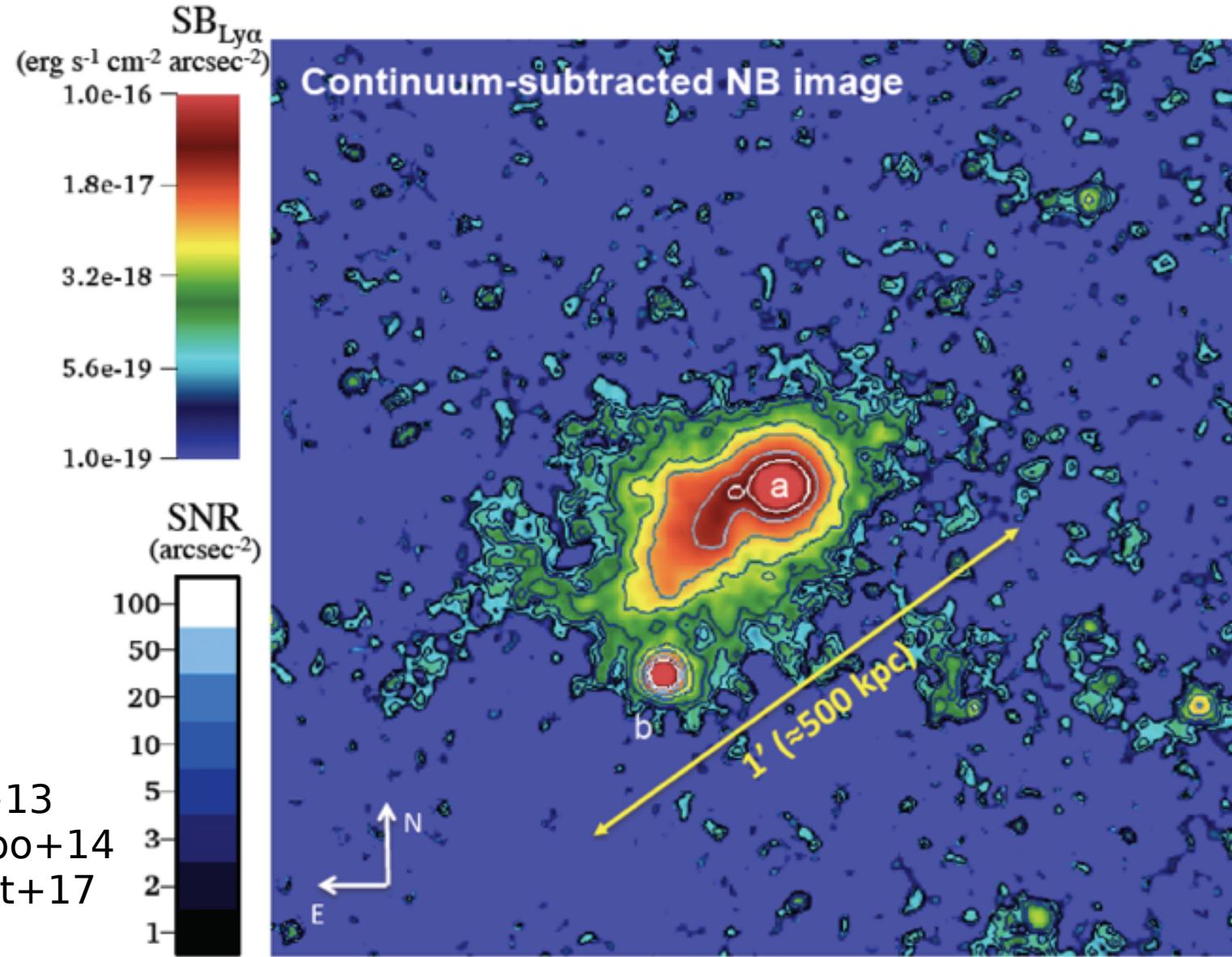
Is the cool CGM transient?

What processes drive its formation/evolution?



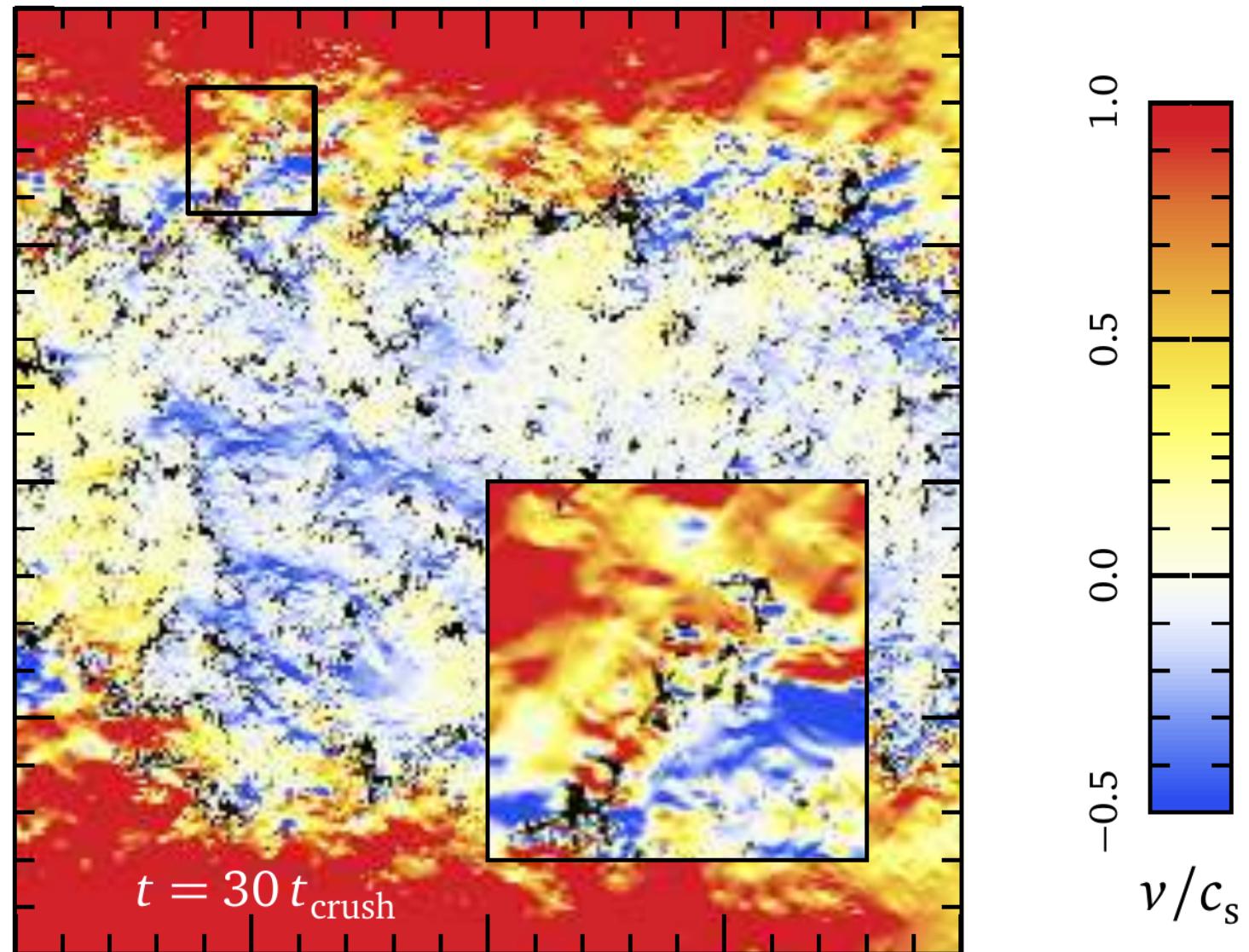
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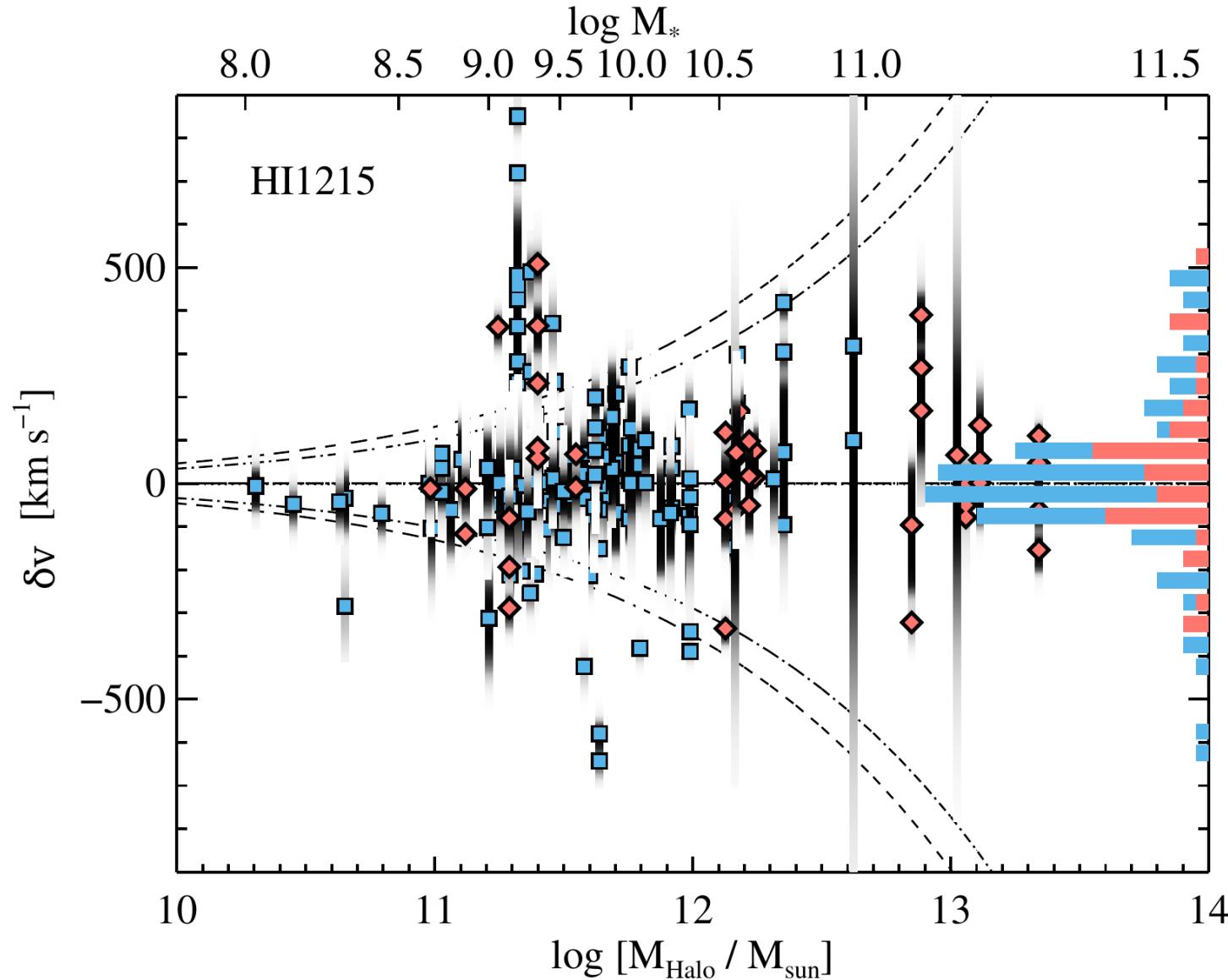
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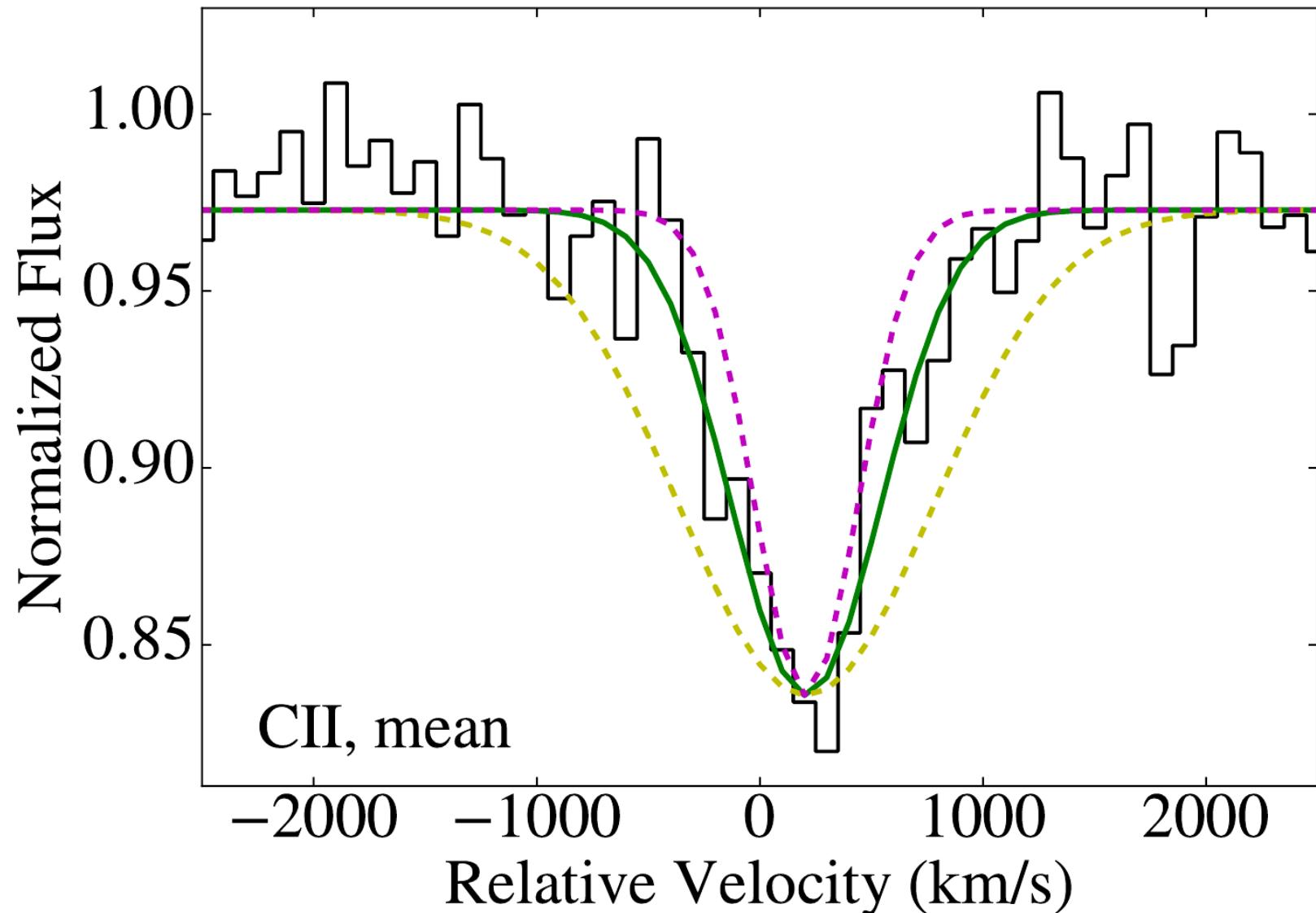
Do winds directly affect the CGM?

How/when is the CGM enriched?



Do winds directly affect the CGM?

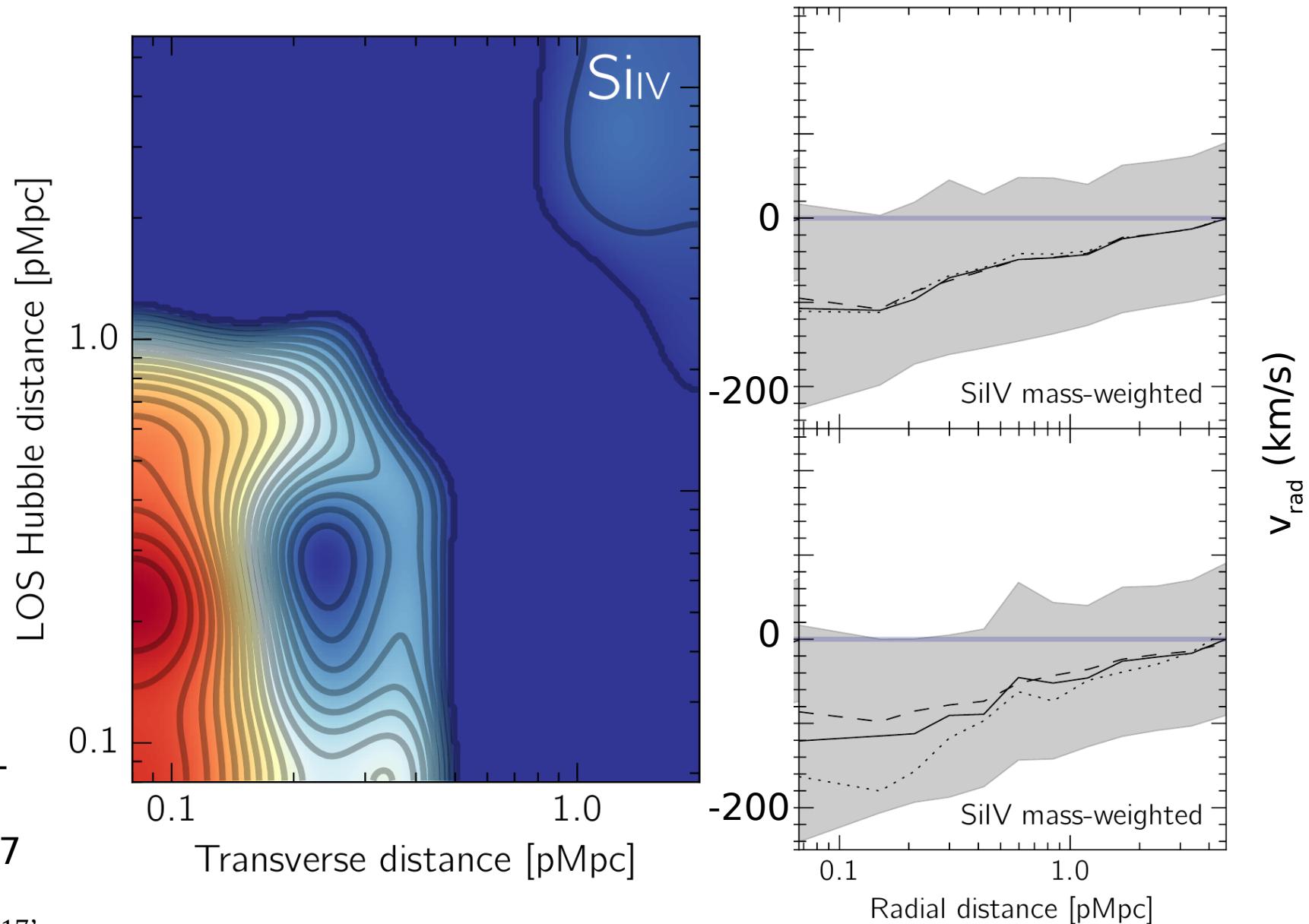
How/when is the CGM enriched?



Bordoloi+
Lau+17
Turner+17

Do winds directly affect the CGM?

How/when is the CGM enriched?



Summary

- Warm/Hot Corona traced by OVI
 - Abel inversion yields $n(O^{+5})$ profile
 - Significant tension between metallicity and X-ray emission
 - Short cooling time ($<10^9$ yr) implies continuous energy input (e.g. Fermi bubbles)
- Warm/Hot Corona from OVII and FRBs
 - Large N(OVII) must arise well beyond the Galactic ISM/WIM ($DM \sim 50$ pc cm $^{-3}$)
 - FRBs offer a new and powerful opportunity to trace **all** of the electrons in and around galactic halos.
 - Expect 100s and likely 1000s of FRBs in the next few years.

