Escape of Ionizing Radiation From Galaxies

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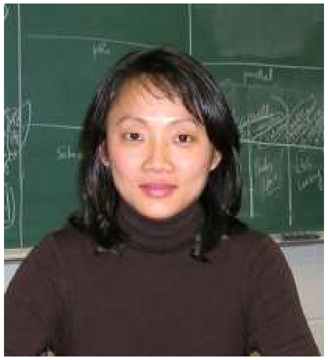
Fermilab

THE UNIVERSITY OF CHICAGO

Co-starring

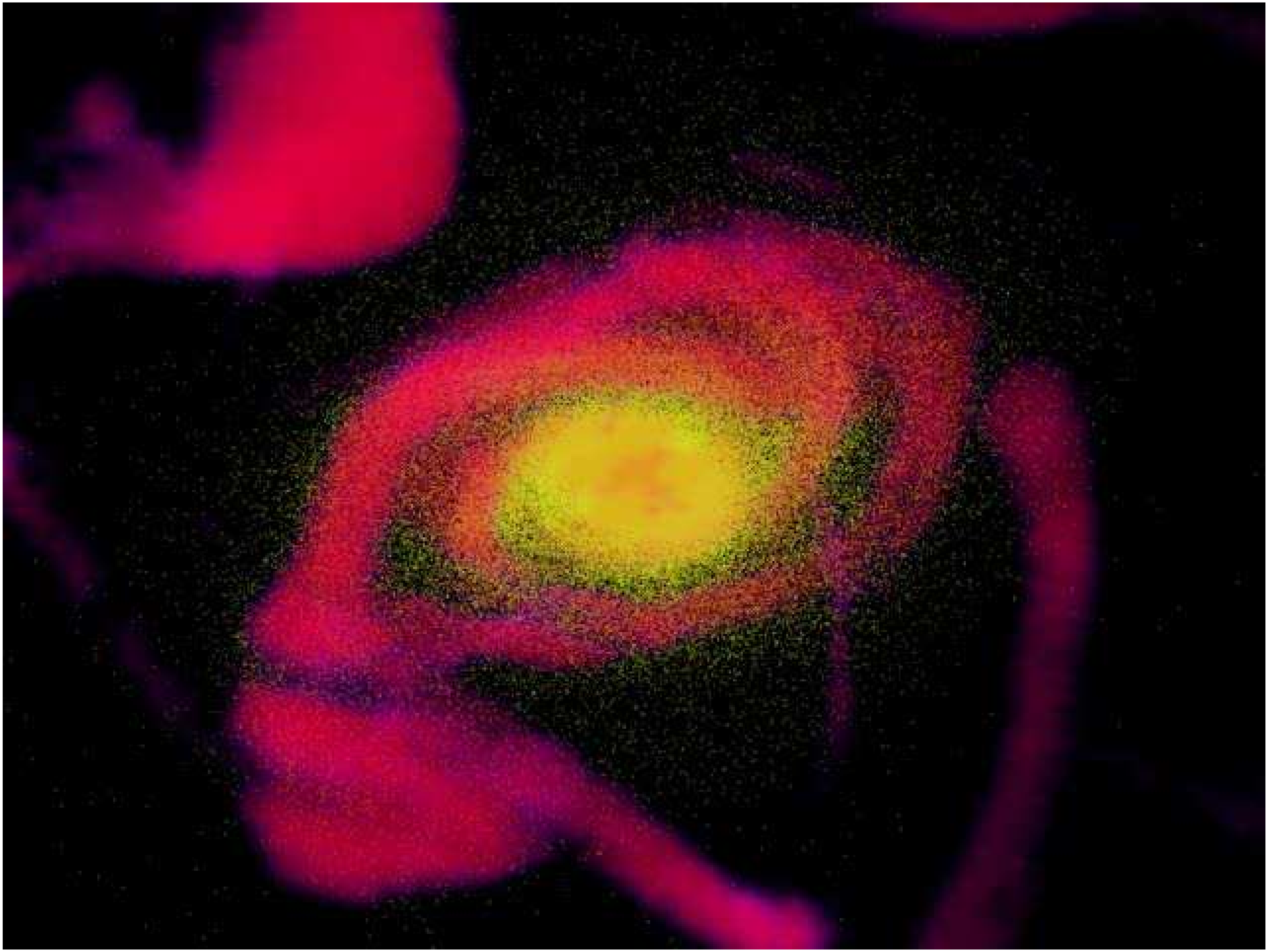
 

Outline

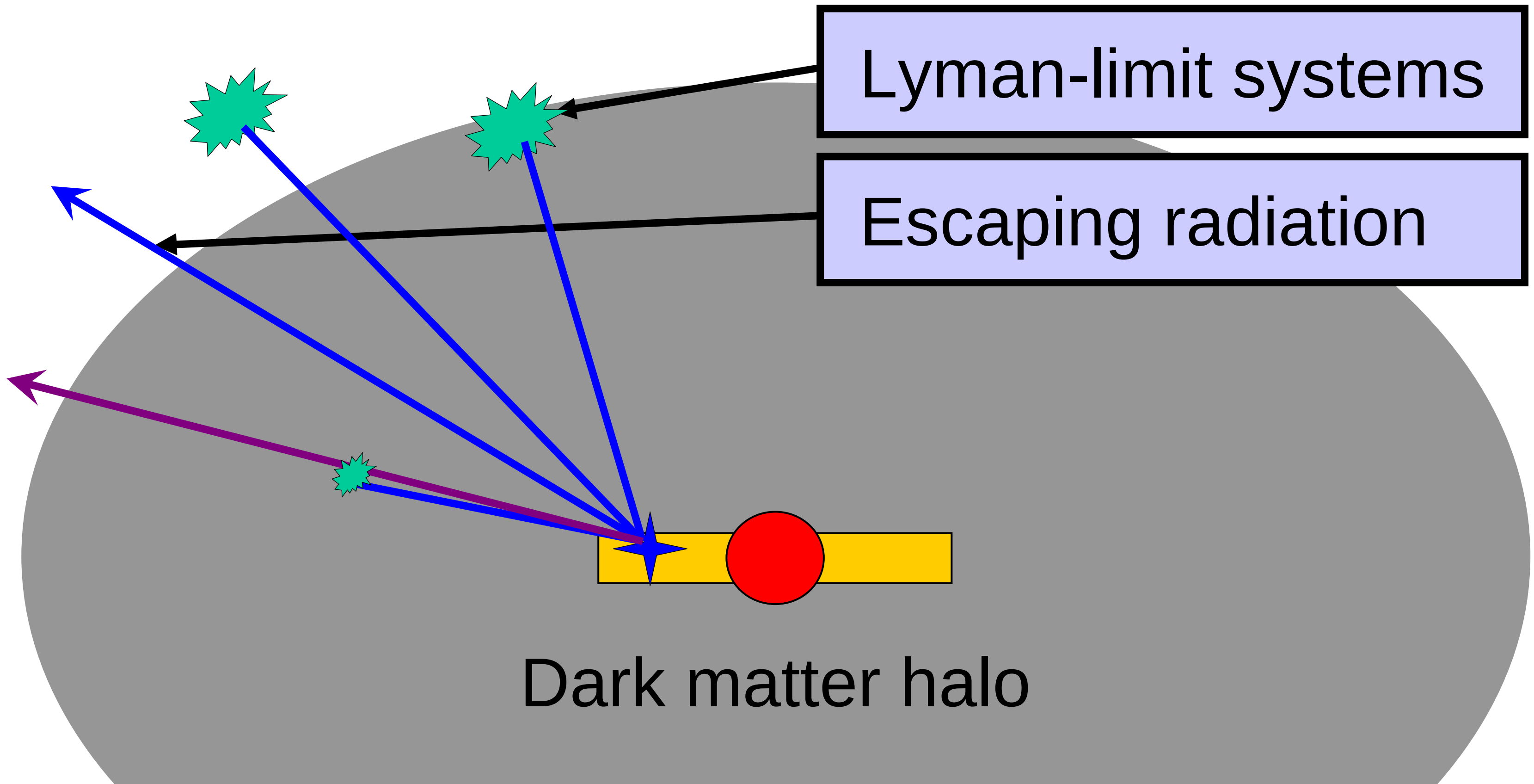
- Simulating escape, and what it actually means.
- Cosmologist's bane, and how it affects escape fractions.
- Escaping from simulations.
- Does it all make sense – or, who is fatter in the world of galaxies?
- Conclusions.

Simulating Escape

- Adaptive Refinement Tree (ART) code.
- A Milky Way type progenitor in a 6 CHIMP box.
- Spatial resolution ~50 pc @ z~3.
- Stars form only in gas with n_H>50 cm^{-3} with rate consistent with Krumholts & McKee 2005, Krumholts & Tan 2007.
- Optically Thin Variable Eddington Tensor (OTVET) approximation is used for modeling Radiative Transfer.
- Non-equilibrium ionization balance and cooling function are computed “on the fly”.



Measuring Escape Fraction



$$f_{\rm esc} \equiv f_{\rm esc}(\nu, \vec{\theta})$$

Many Faces of f_{esc}

$$f_{\rm esc} \equiv f_{\rm esc}(\nu, \vec{\theta})$$

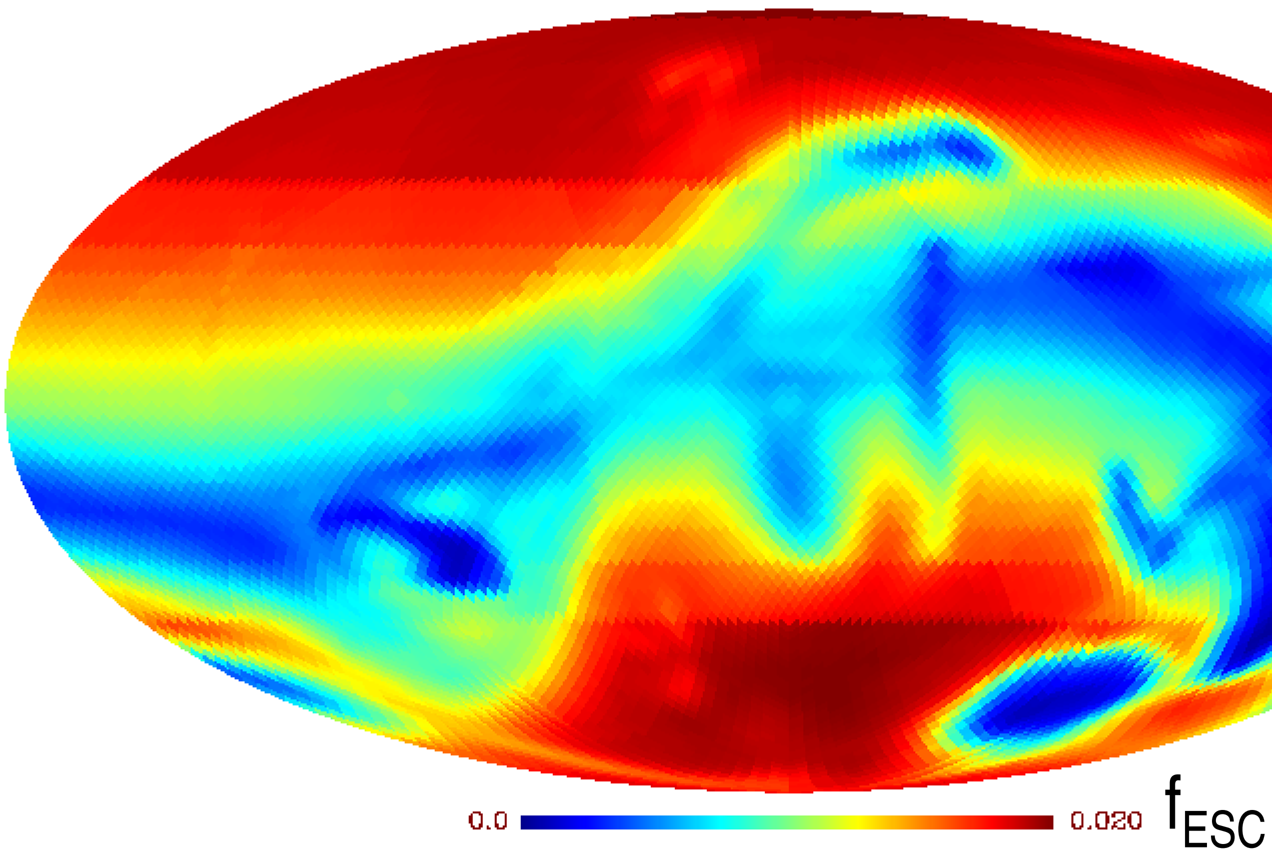
- Integrate over angles: ***angular-averaged*** $f_{esc}(\nu)$.
- Integrate over frequencies:

$$f_{\rm esc}^{j}(\vec{\theta}) \equiv \frac{\int d\nu\, f_{\rm esc}(\nu,\vec{\theta})\sigma_\nu^j S_\nu}{\int d\nu\, \sigma_\nu^j S_\nu} \qquad (j = {\rm H\,I, He\,I, He\,II})$$

escape fraction of ionizing radiation.

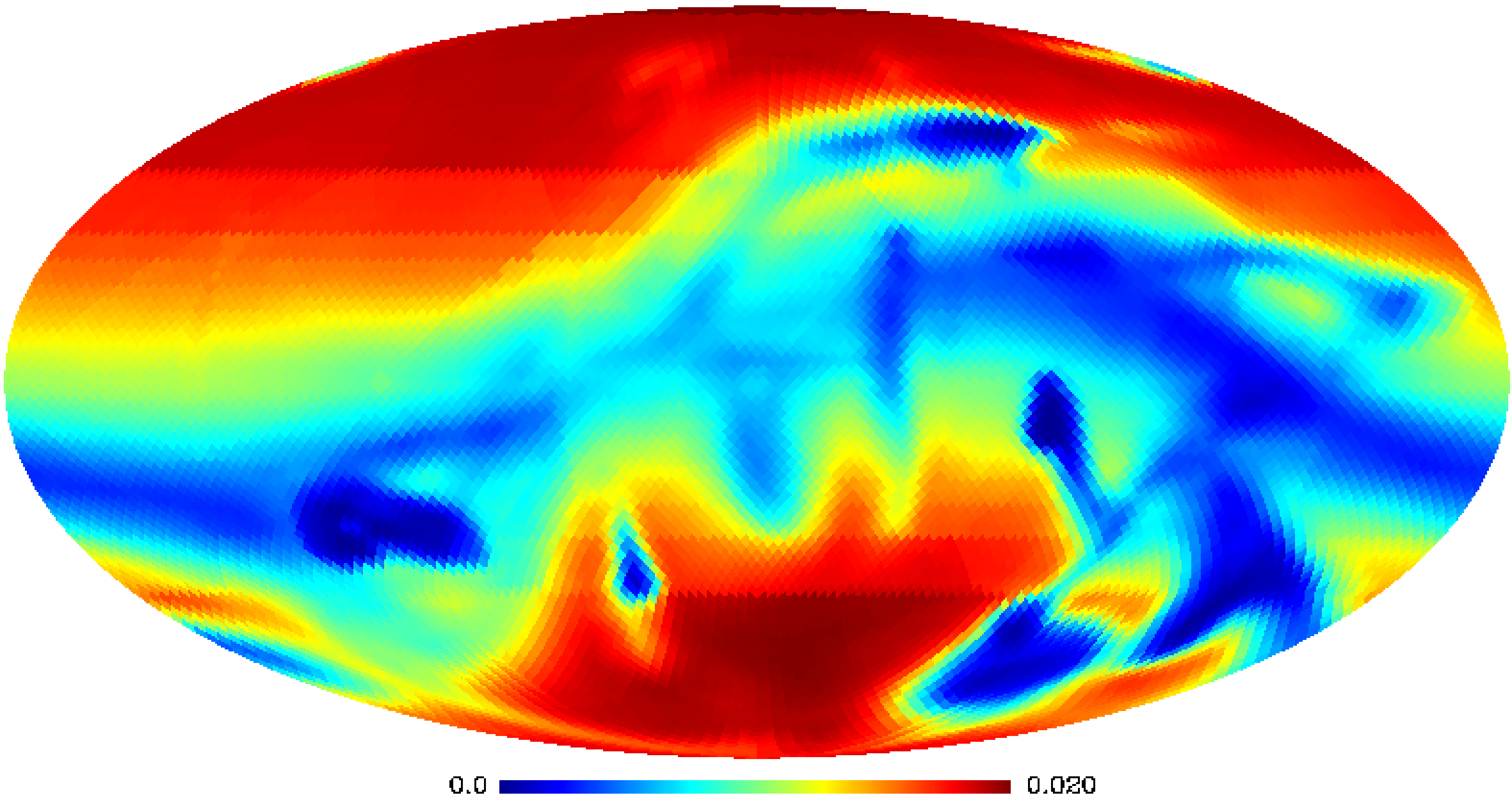
- A number = ***angular-averaged escape fraction of ionizing radiation.***
- ***Know your escape fraction!***

A View from the Source



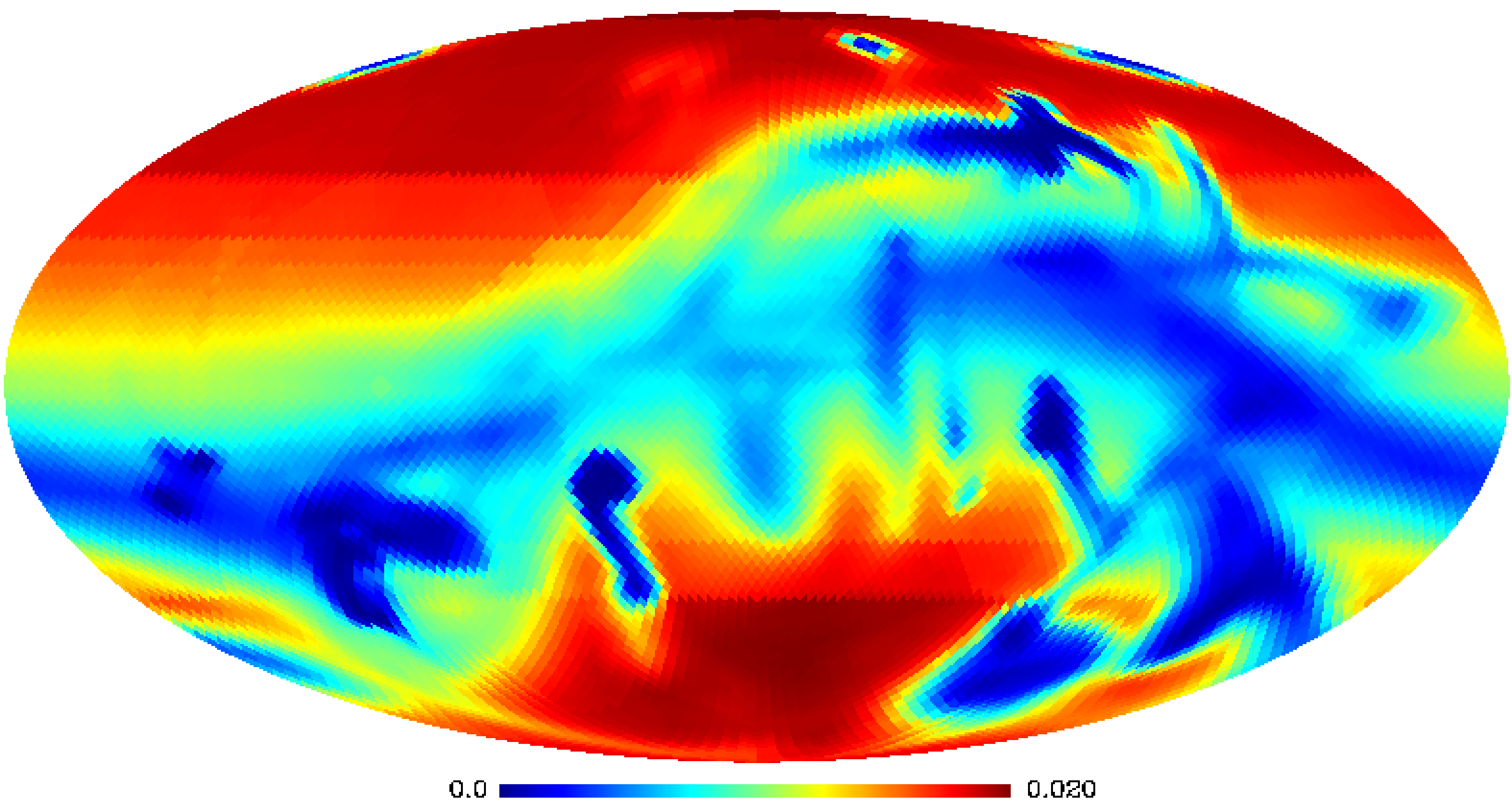
@ $D = 0.5\ R_{VIR}$ (50 h^{-1} kpc, 0.0006 λ_{LL})

A View from the Source



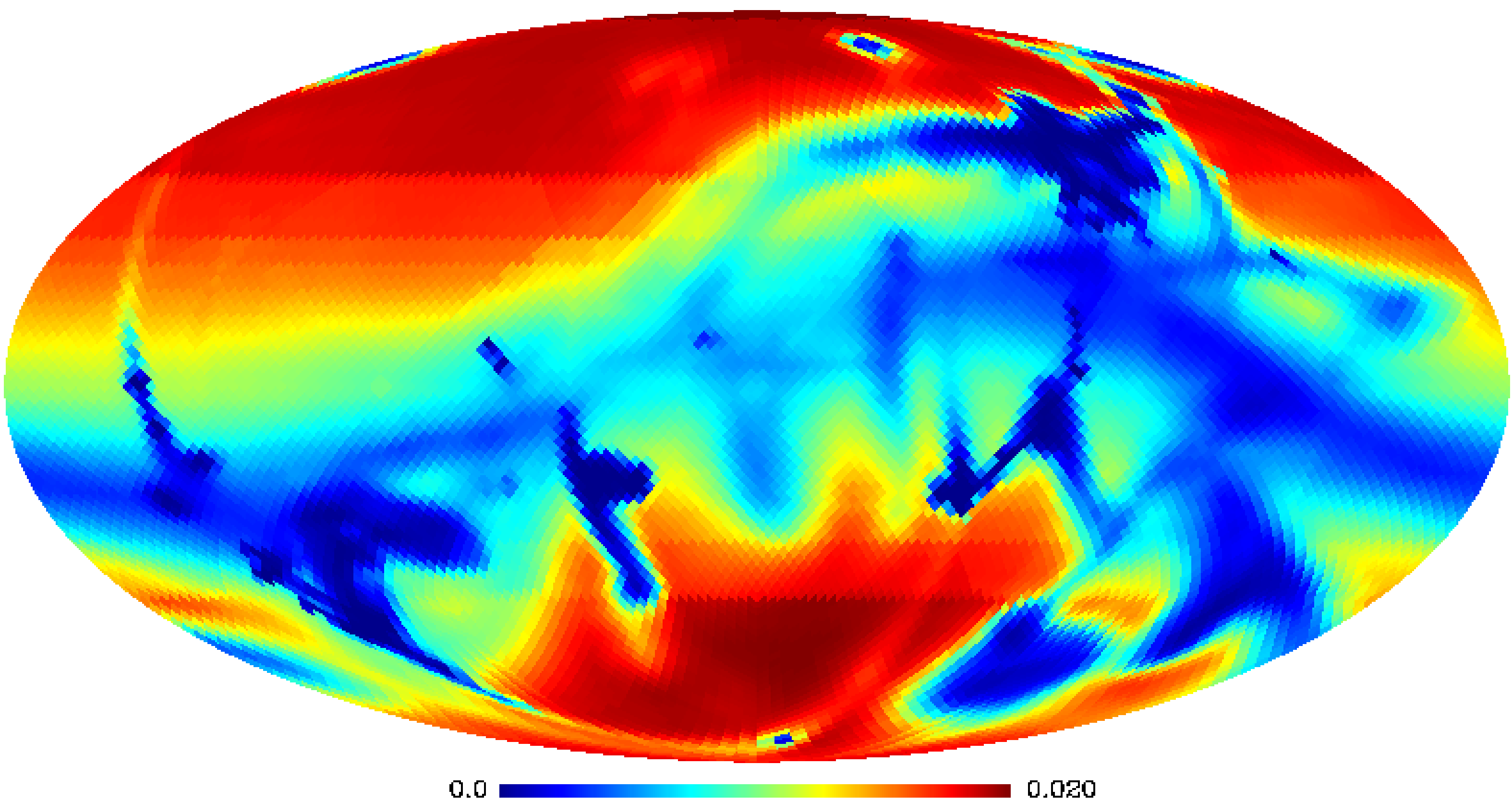
@ D = 1.0 R_{VIR} (100 h^{-1} kpc, 0.0012 λ_{LL})

A View from the Source



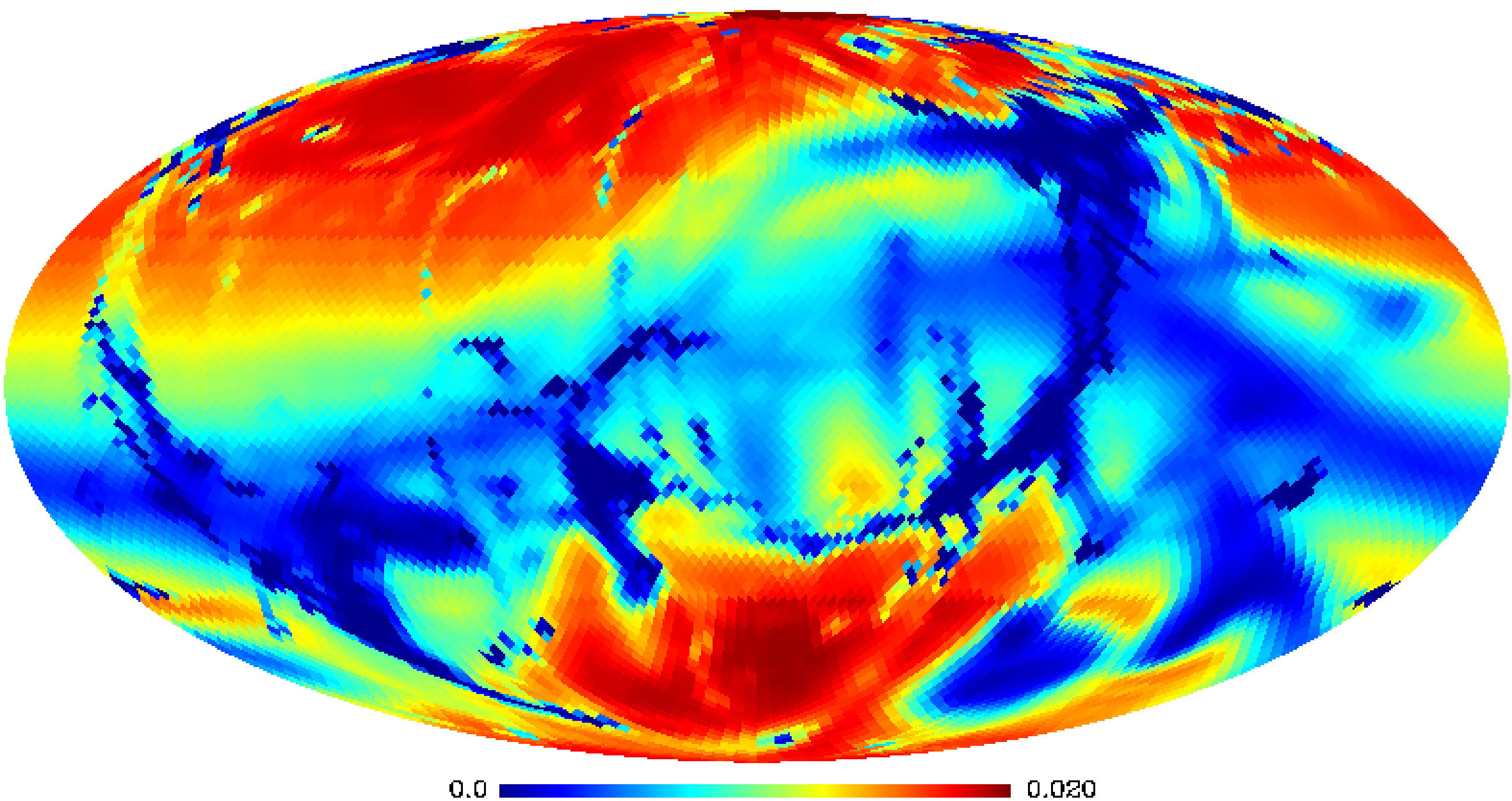
@ D = 2.0 R_{VIR} (200 h^{-1} kpc, 0.0025 λ_{LL})

A View from the Source



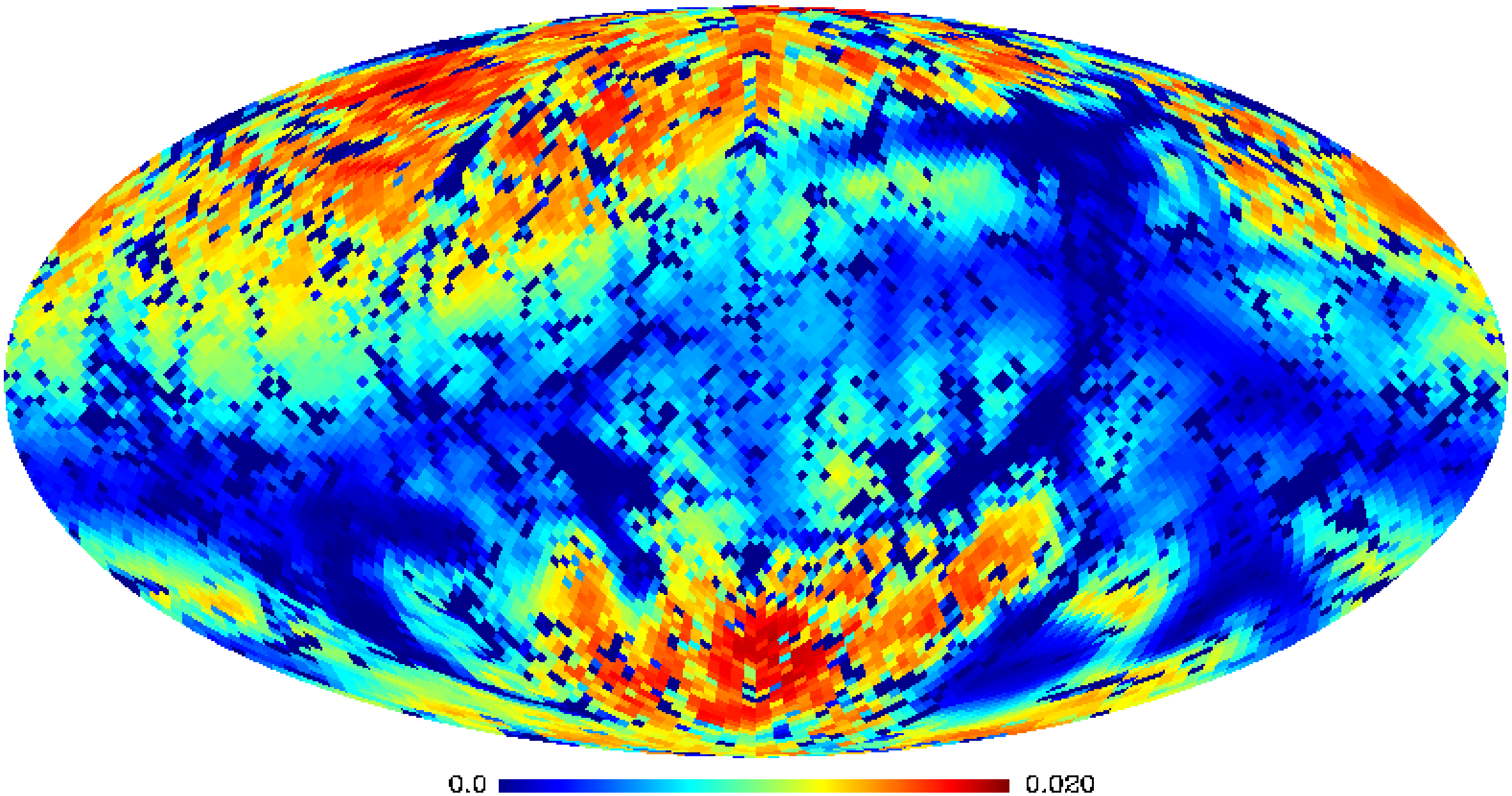
@ D = 5.0 R_{VIR} (500 h^{-1} kpc, 0.005 λ_{LL})

A View from the Source



@ D = 30 R_{VIR} (3 h^{-1} Mpc, 0.03 λ_{LL})

A View from the Source



@ D = 100 R_{VIR} (10 h^{-1} Mpc, 0.1 λ_{LL})

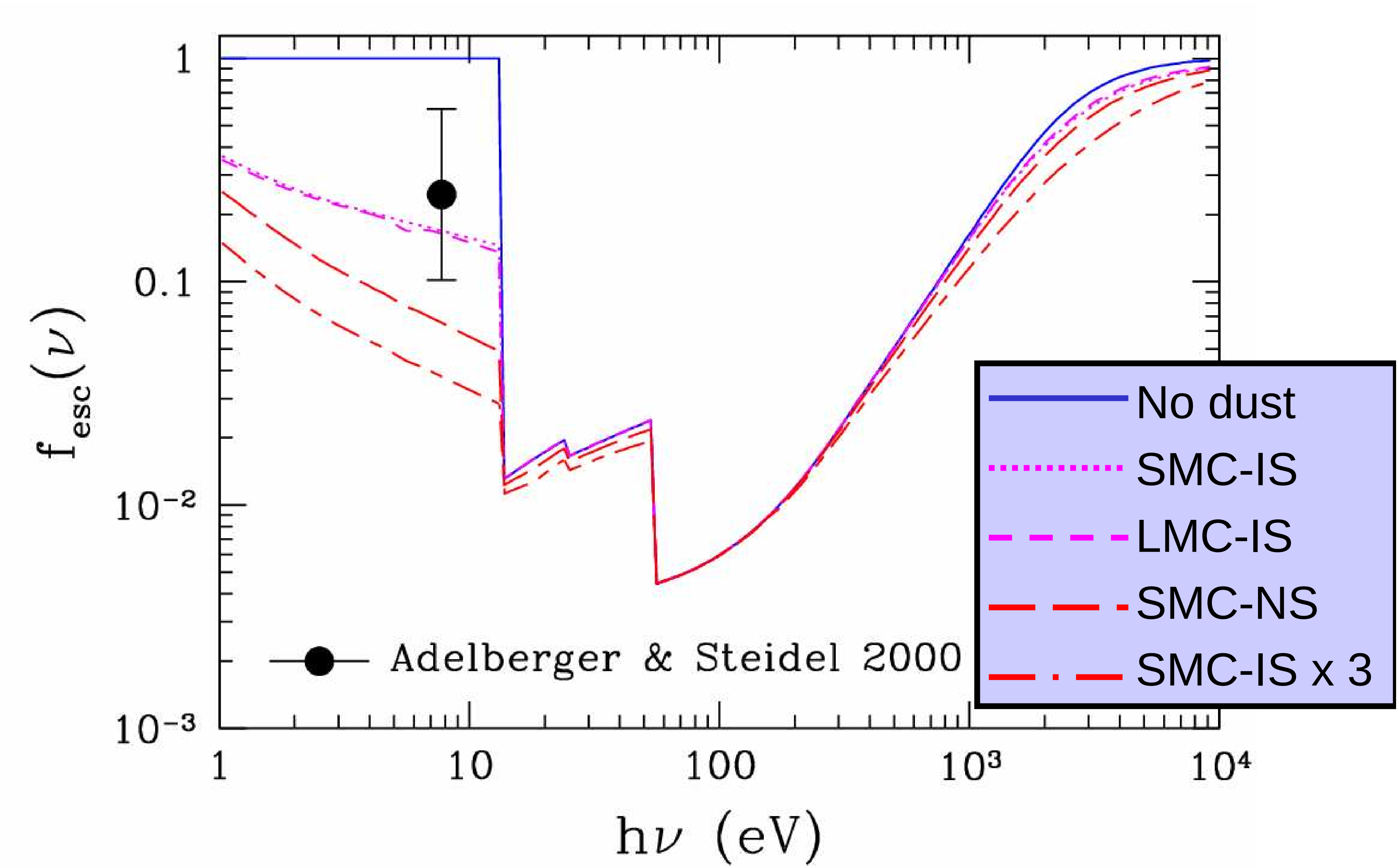
Cosmologist's Bane: Dust

- Assume: dust-to-gas ratio scales with metallicity. Two models:

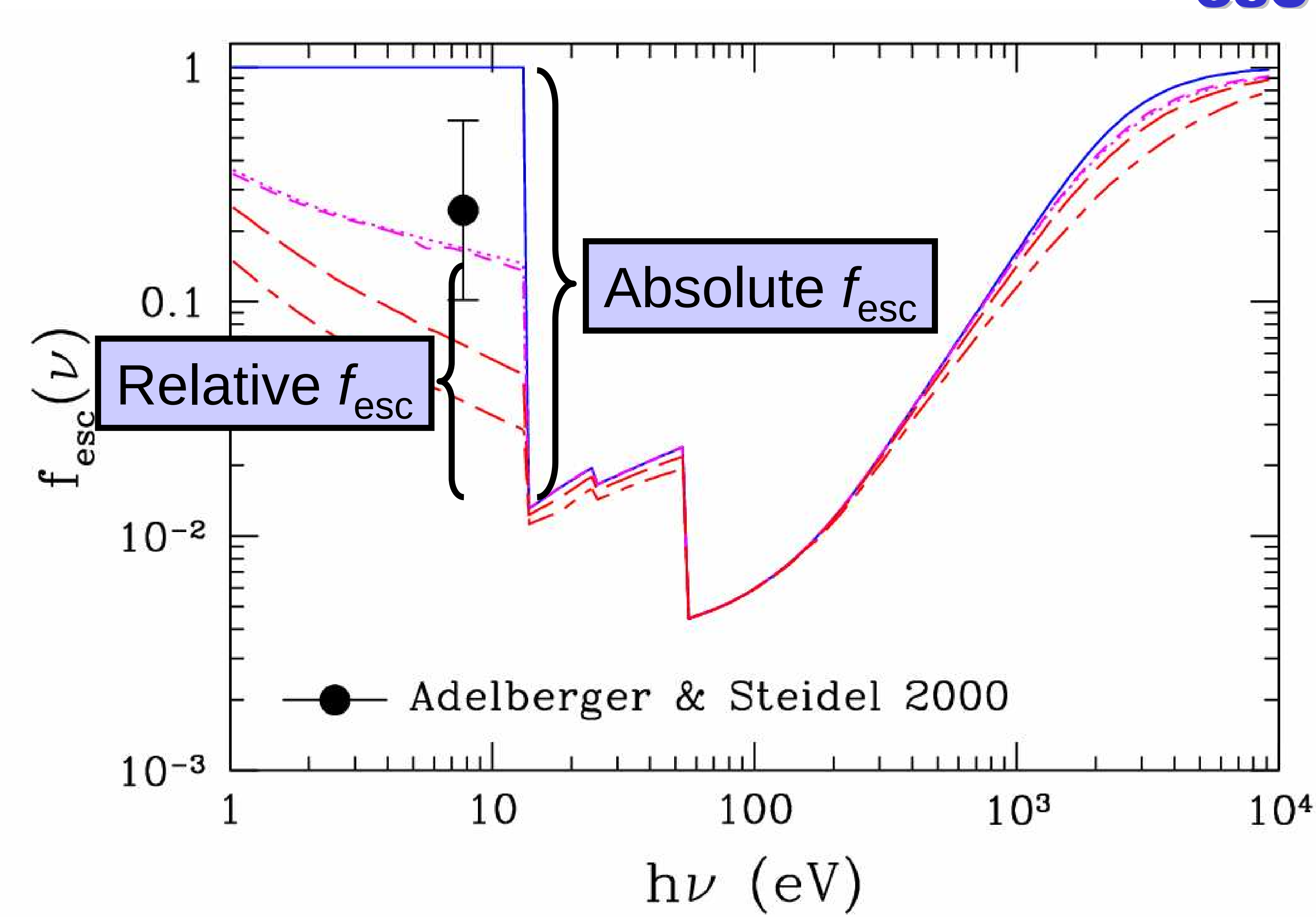
• ***Instant sublimation***	$N_{\rm dust} = \frac{Z}{Z_0} \times (N_{\rm H\,I} + 2N_{\rm H_2})$
• ***No sublimation***	$N_{\rm dust} = \frac{Z}{Z_0} \times N_{\rm H}$

- Use Pei (1992) parameterization.
- Adjust Pei's parameters to reproduce Weingartner & Draine (2001).

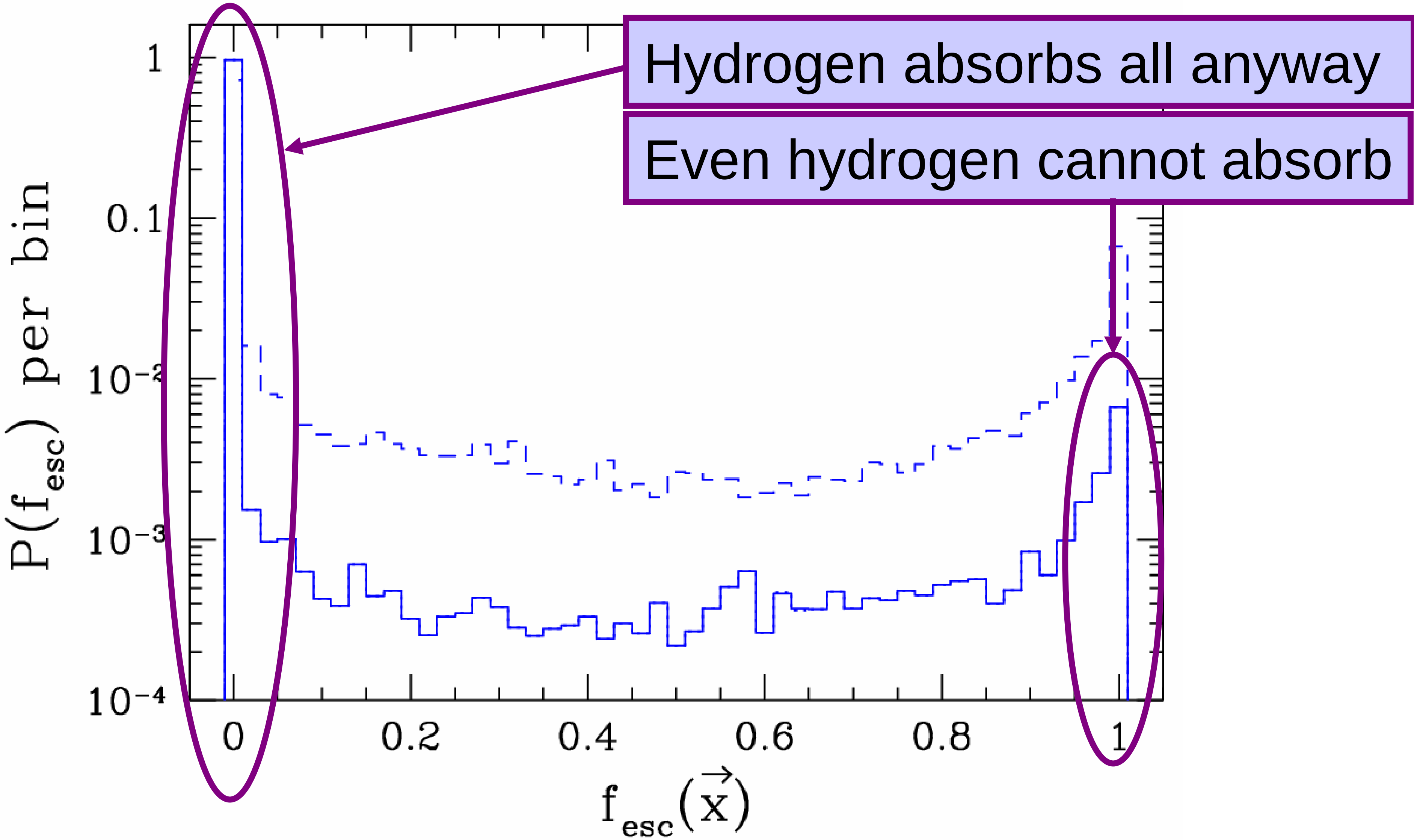
Various Dust Models



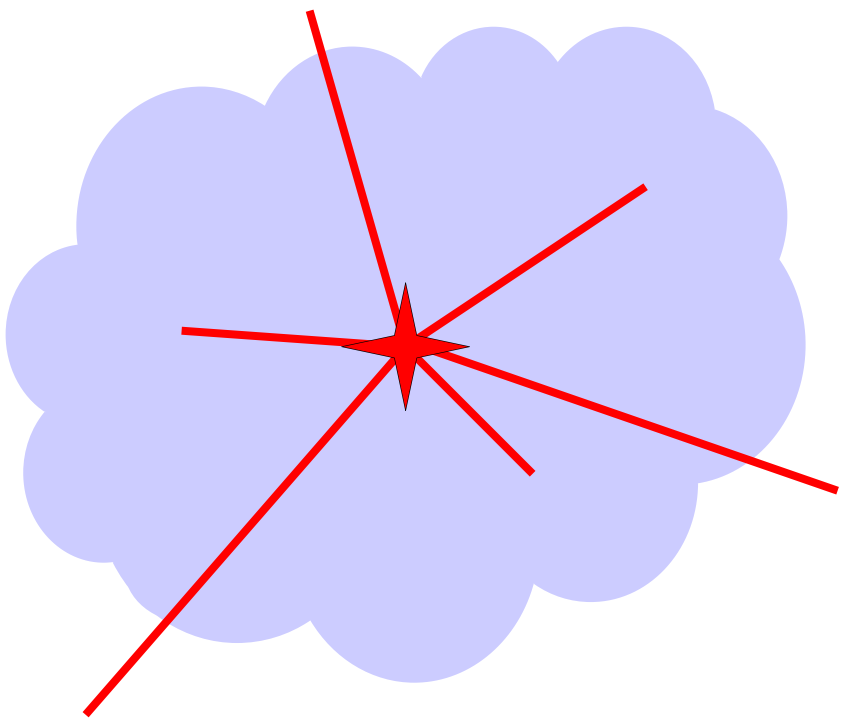
Absolute & Relative f_{esc}



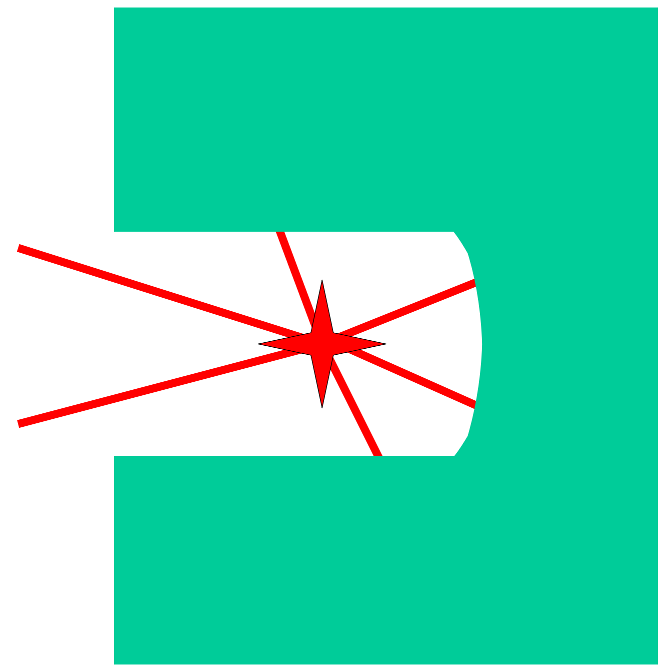
Why Dust Does Not Matter?



Why Dust Does Not Matter?
Cartoon Version

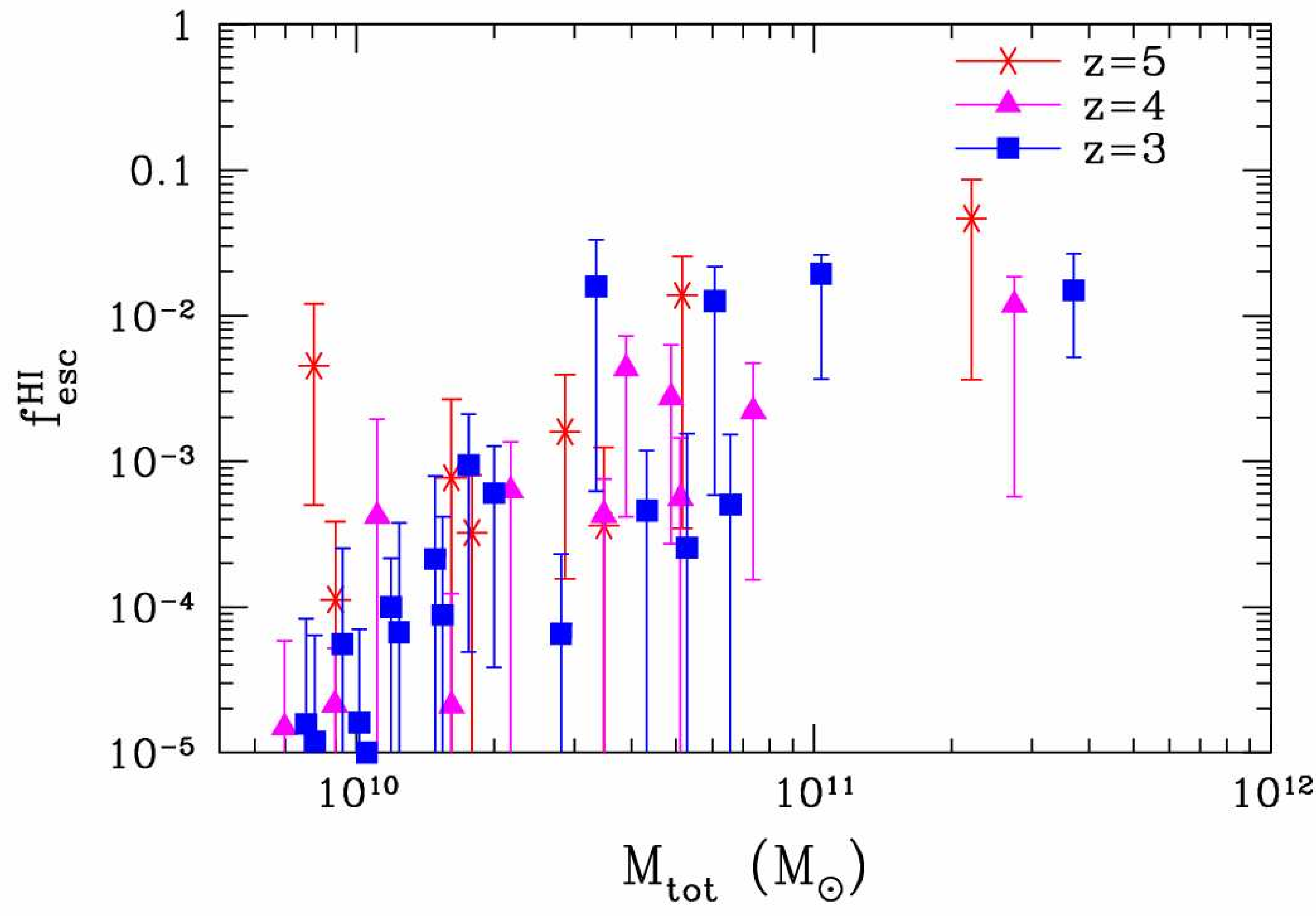


"Fog" model

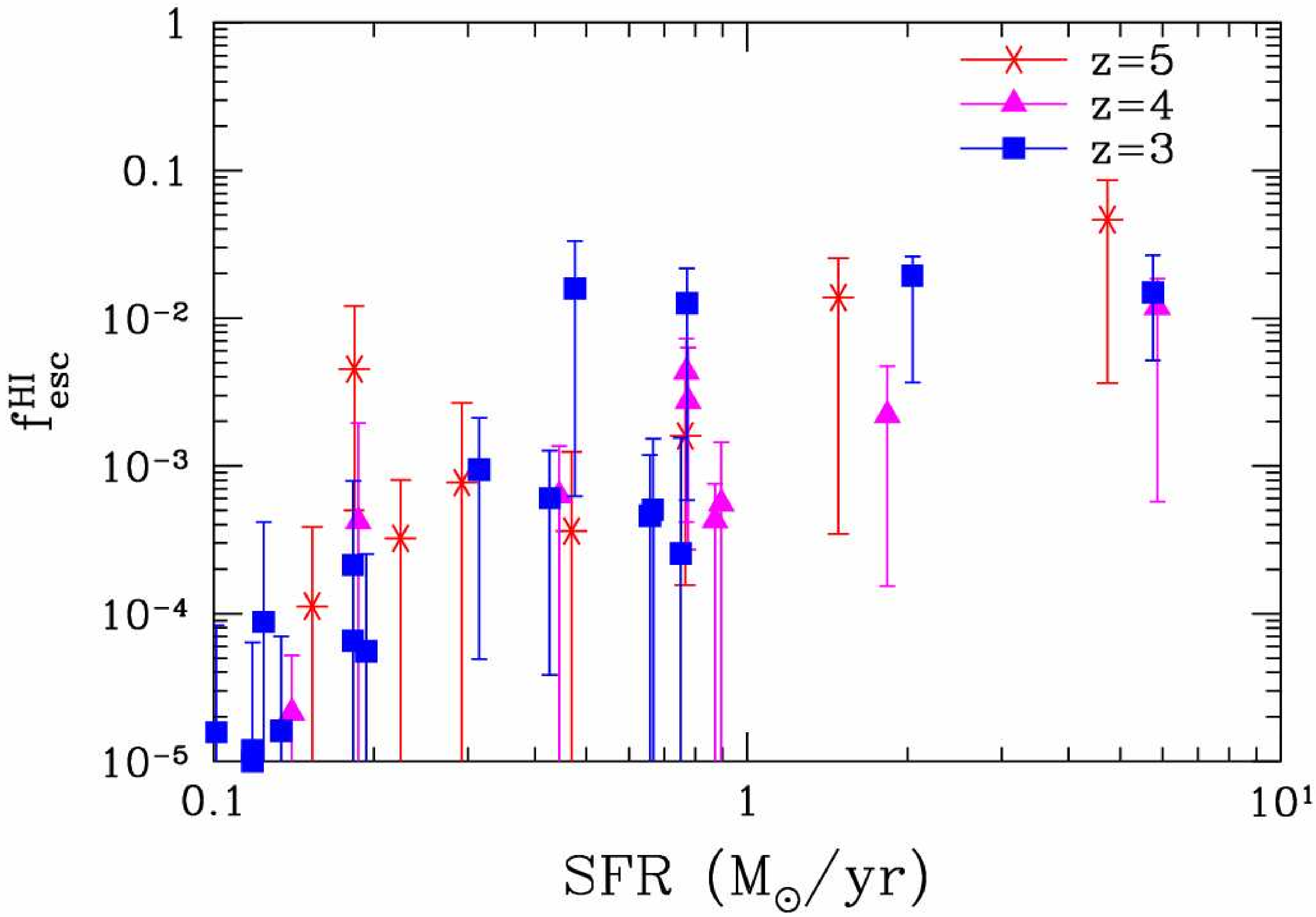


"Cave" model

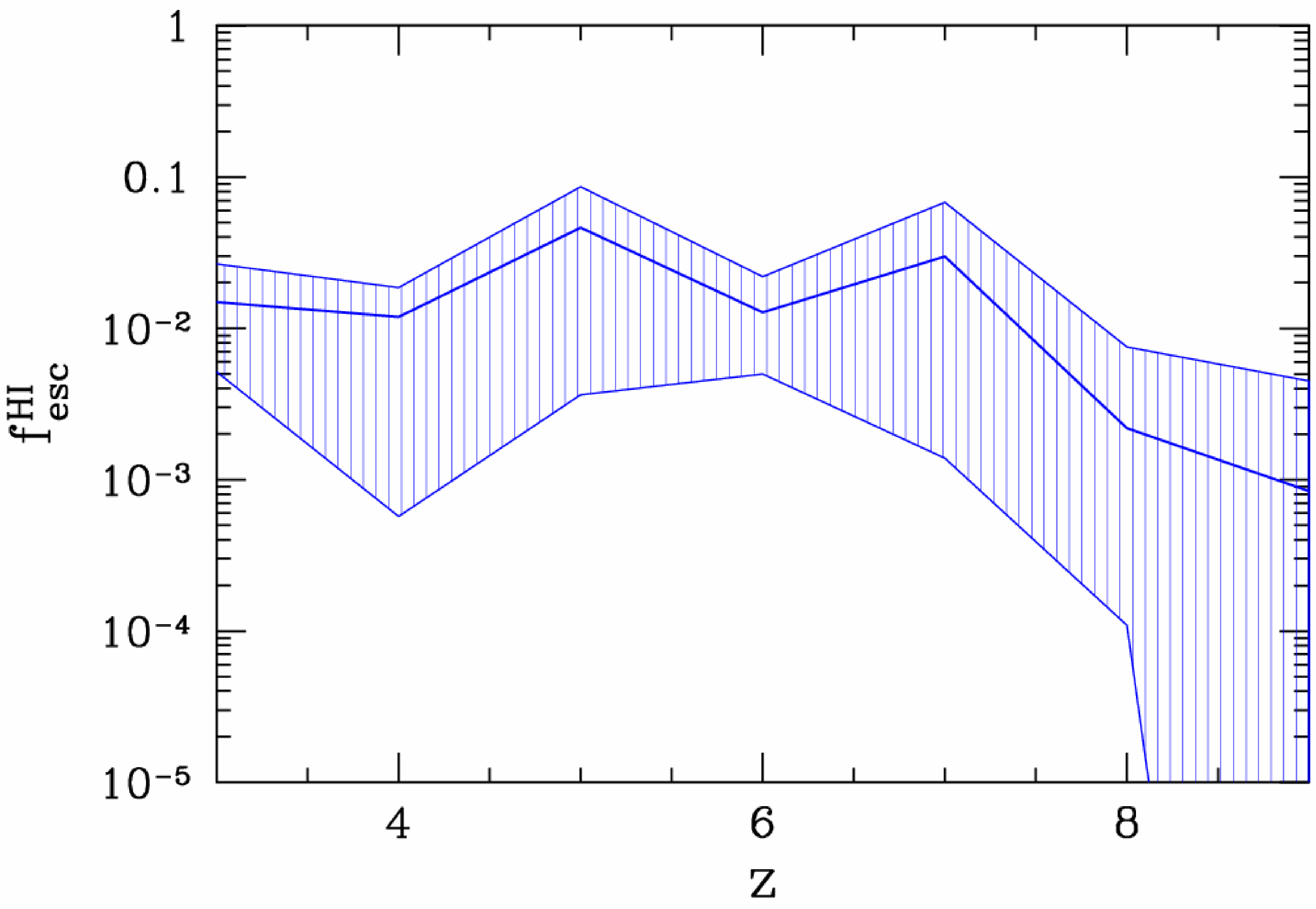
Escape Fractions in Galaxies



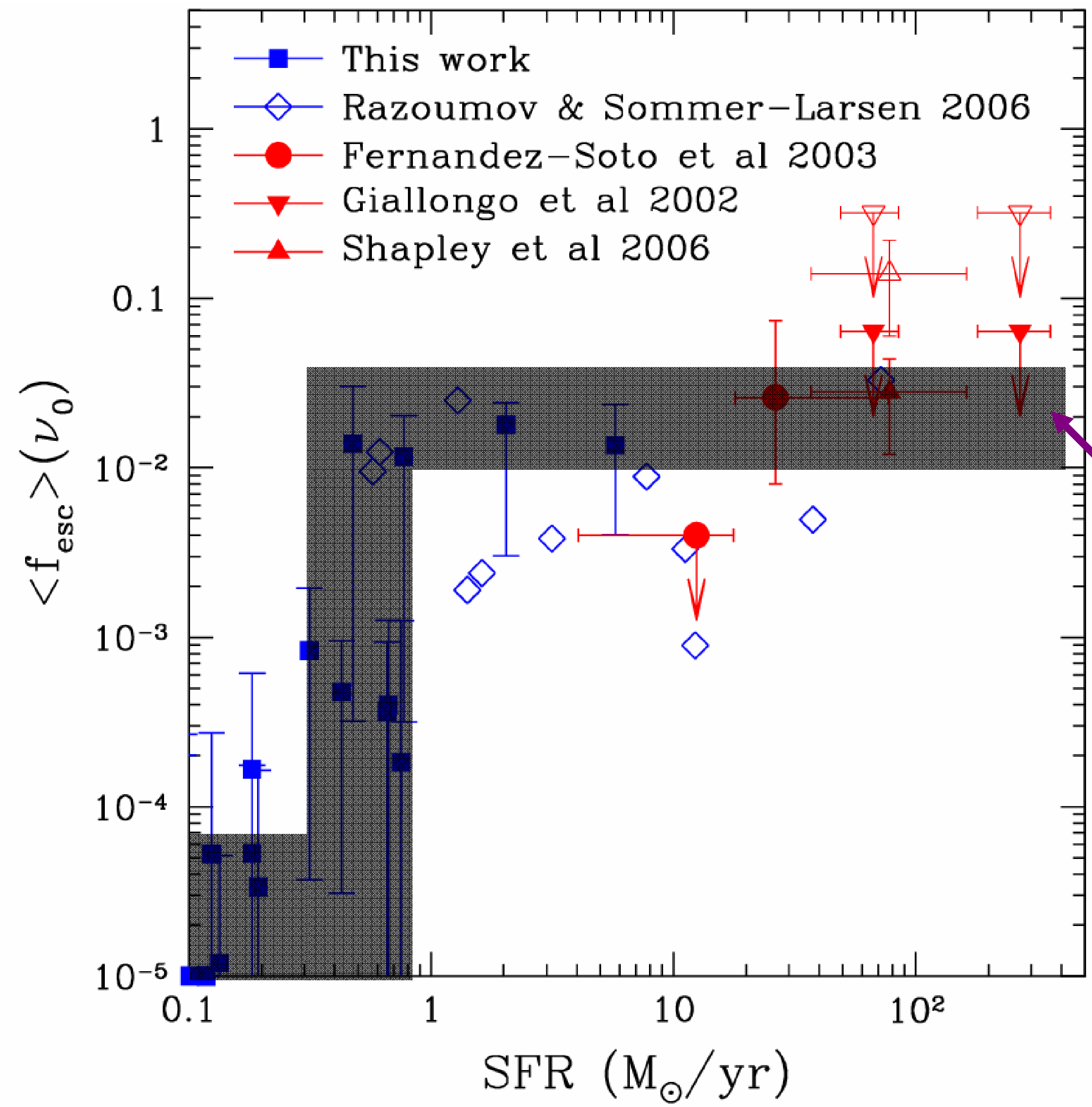
Escape Fractions in Galaxies



Redshift Evolution



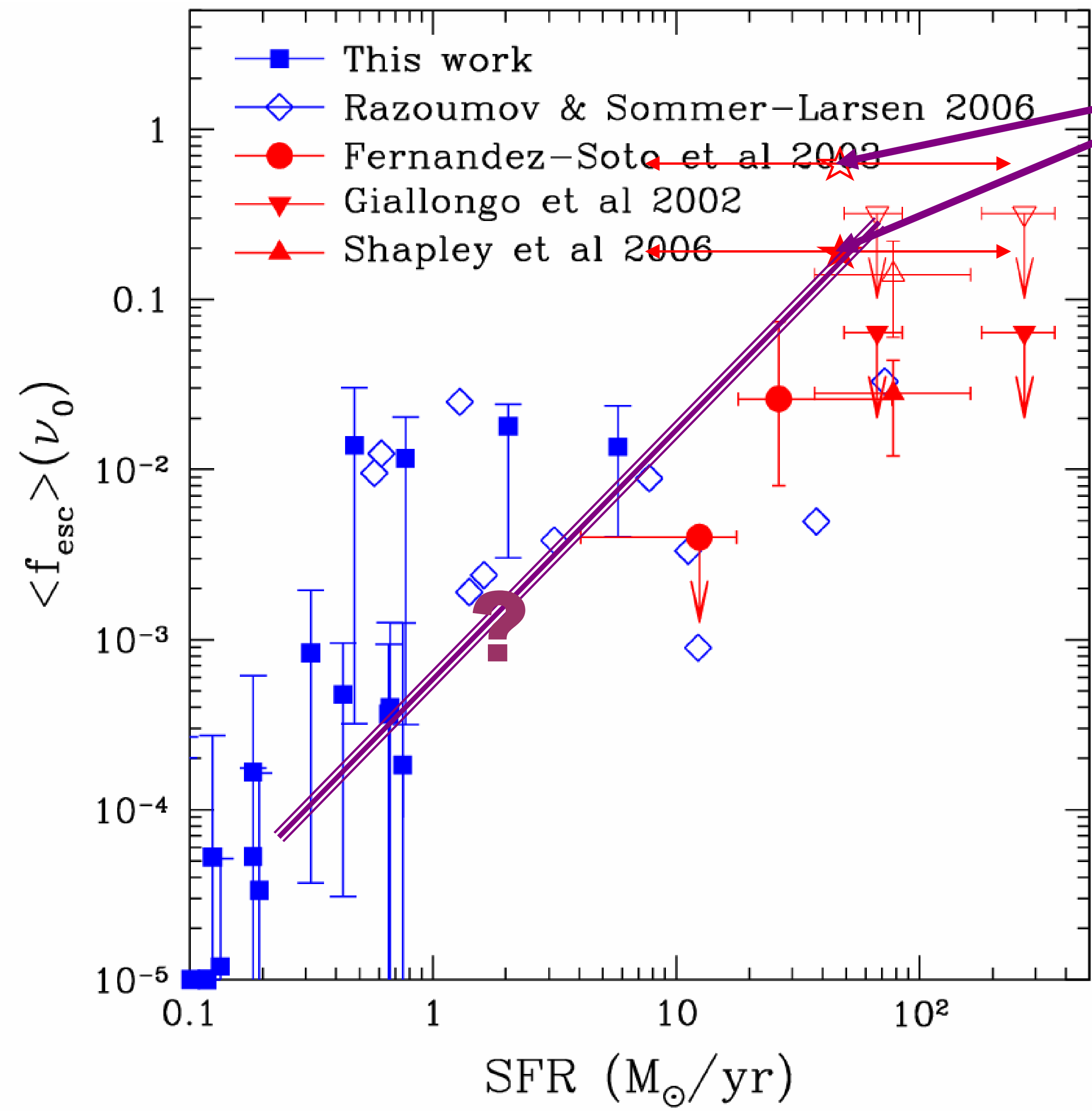
Model vs Data



} Correction from relative to absolute f_{esc}.

Consistent with f_{esc} in GRB hosts.

Model vs Data

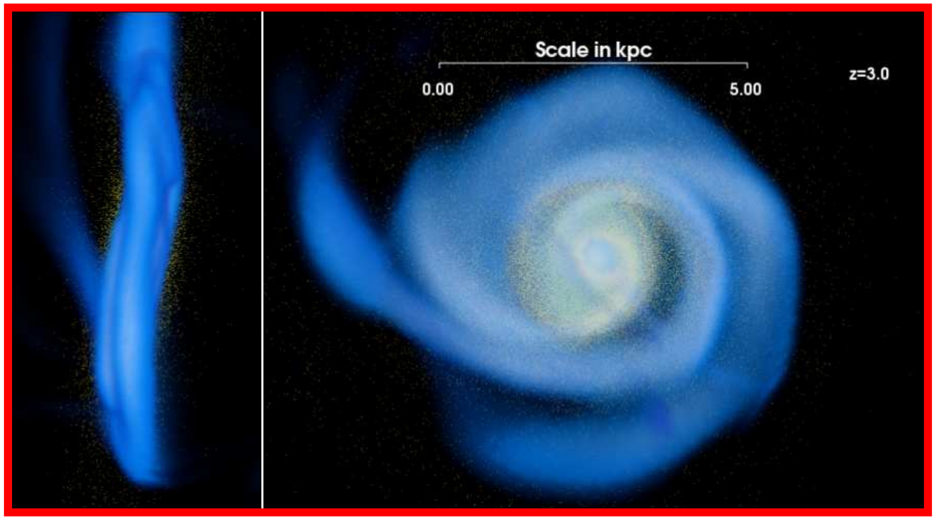


Iwata et al poster

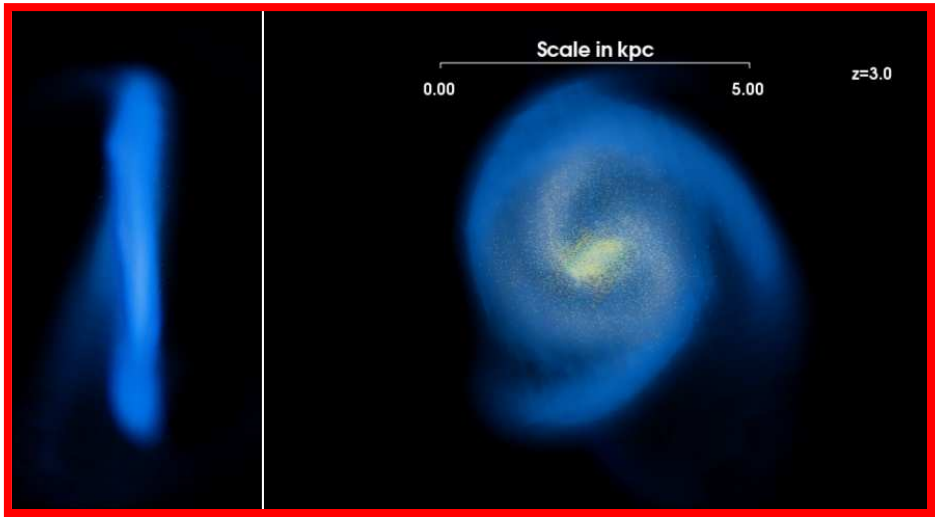
Correction from relative to absolute f_{esc}.

How Radiation Escapes

- Large galaxy

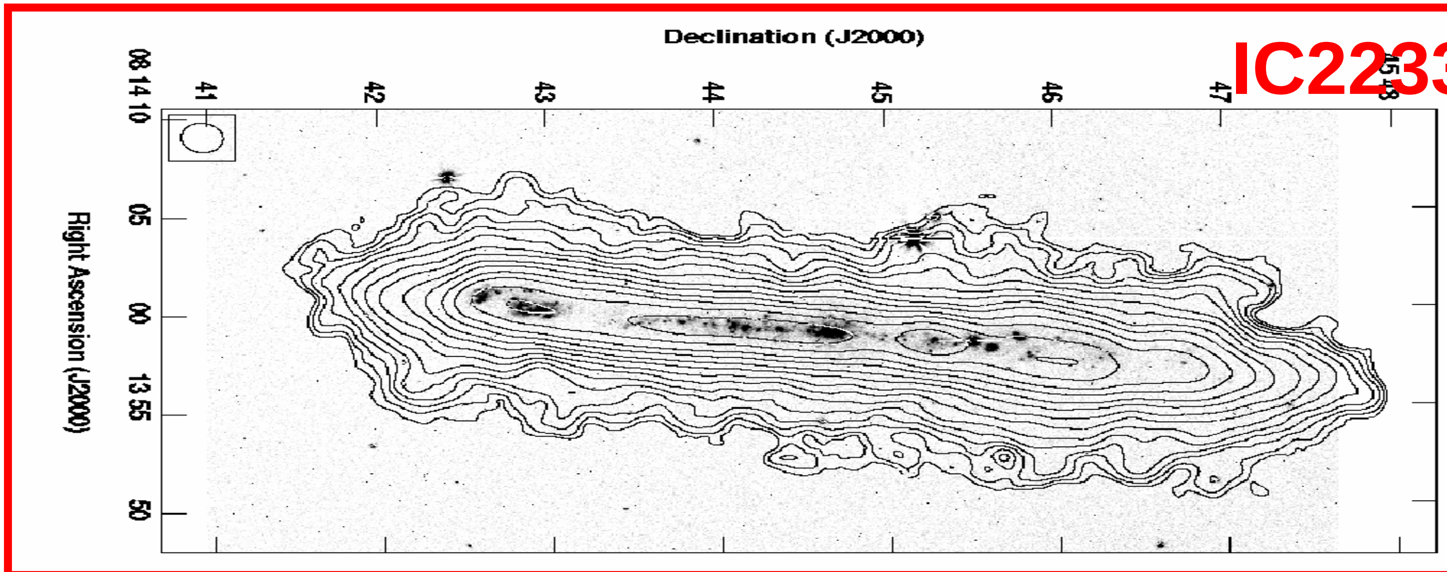


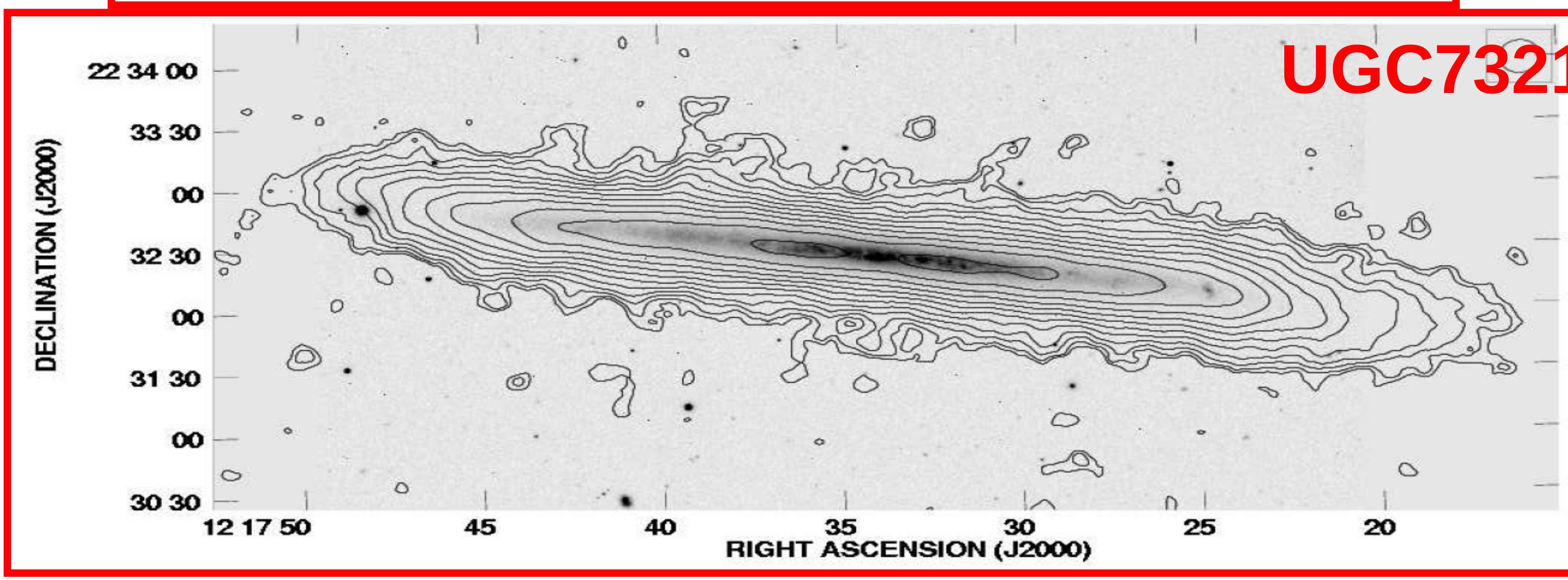
- Dwarf galaxy



- In large galaxies only radiation from young stars that find themselves near or outside the edge of HI disk can escape.
- In dwarf galaxies HI disks are much thicker than stellar disks, so no radiation escapes.

Are Real Dwarfs HI-fat?





Are Real Dwarfs HI-fat?

Galaxy	***IC2233***	***UGC7321***
Dynamical mass	$9.5\times10^{9}\ M_\odot$	$3.2\times10^{9}\ M_\odot$
Stellar disk height	**240** pc	**150** pc
HI disk height	**800** pc	**580** pc

(Matthews & Wood 2003; Matthew & Uson 2008)

Conclusions

❑ Ionizing radiation escapes from galaxies in a “cave”-like mode: some of the young stars get exposed to the exterior of the HI disk due to

- waves on the surface of the HI disk;
- their own peculiar motions.

❑ That results if a few % (?) ***angular averaged*** escape fractions, and a factor of >10 variation in any given direction.

❑ In dwarf galaxies ($M < 10^{11}\ M_\odot$, SFR < 1 $M_\odot$/yr) HI disks are way too fat for that to happen, their escape fractions are predicted to be negligible. ***Observers, please check!***

❑ Because of “cave”-like mode of radiation escape, dust has little impact on the values of escape fractions.

The End