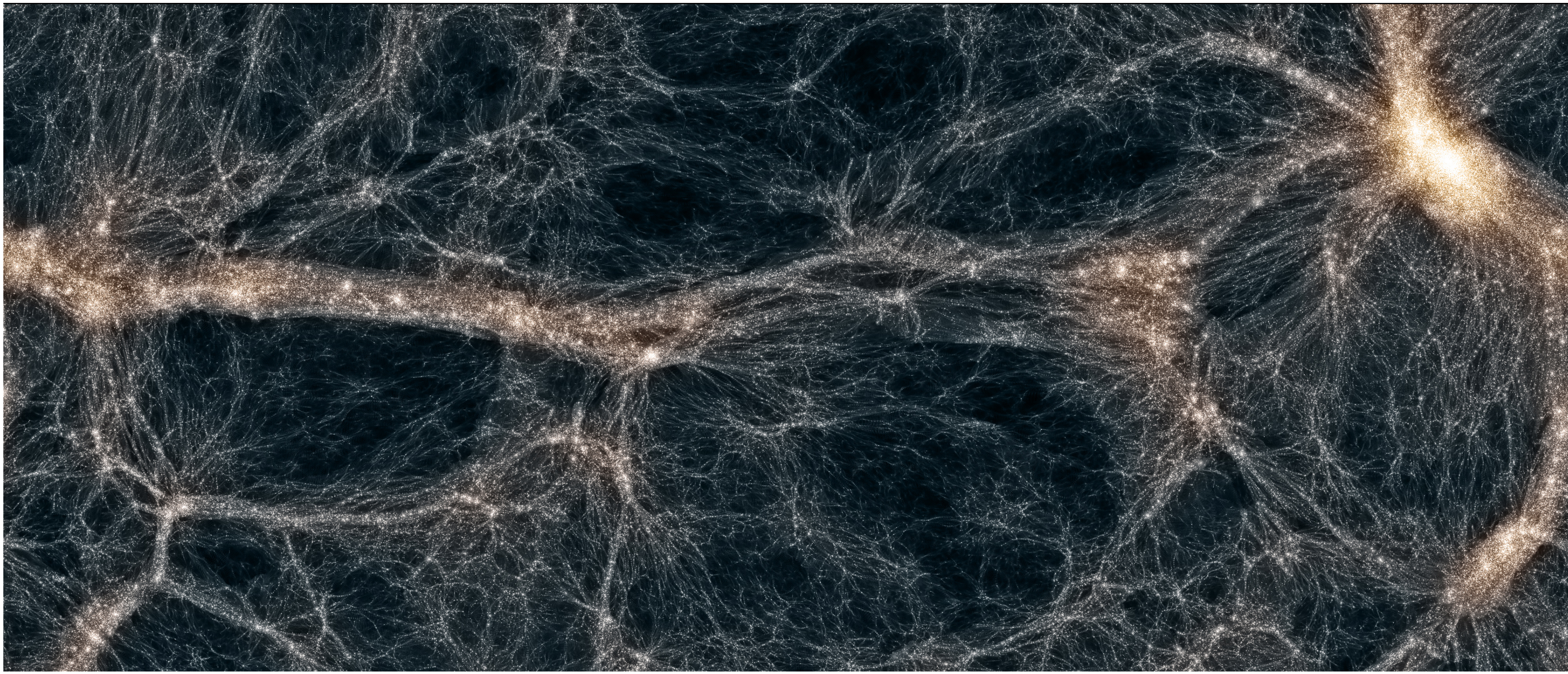
The Contribution of Low Mass Galaxies to Reionization

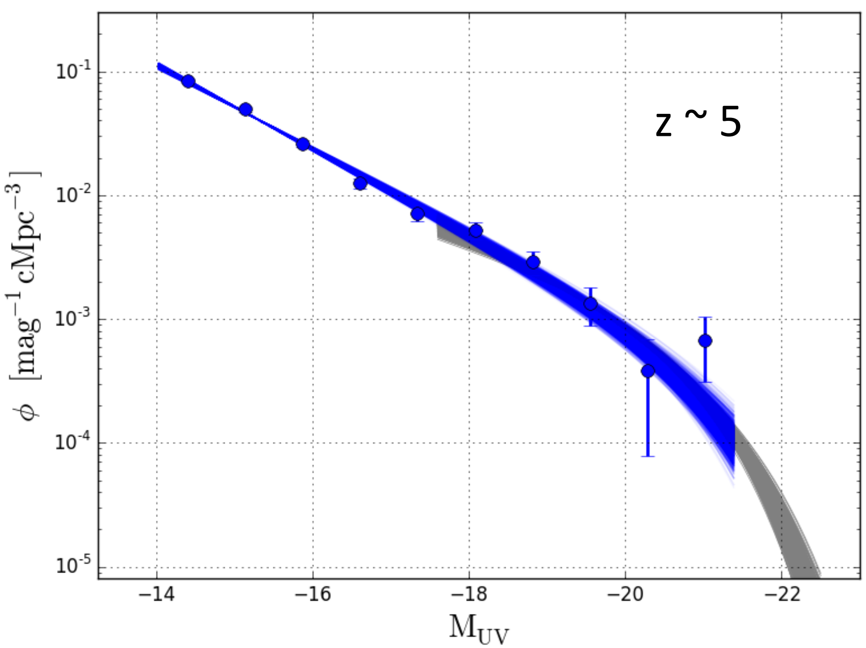


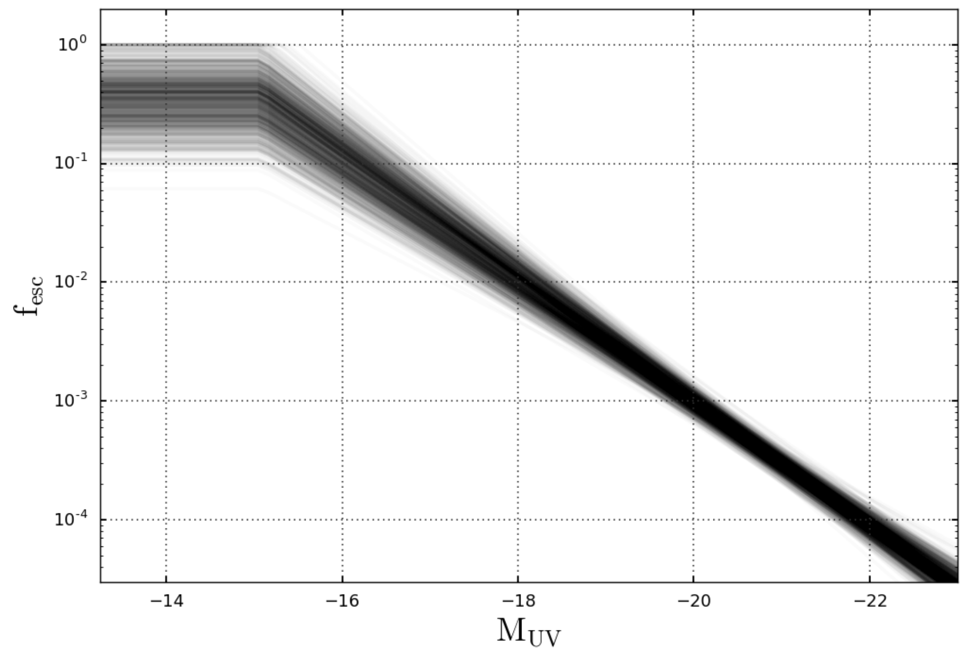
Lauren Anderson

Tom Quinn :: Fabio Governato

Nbody Shop University of Washington

Steep Faint End Slopes + $f_{esc}(M_{UV})$





=

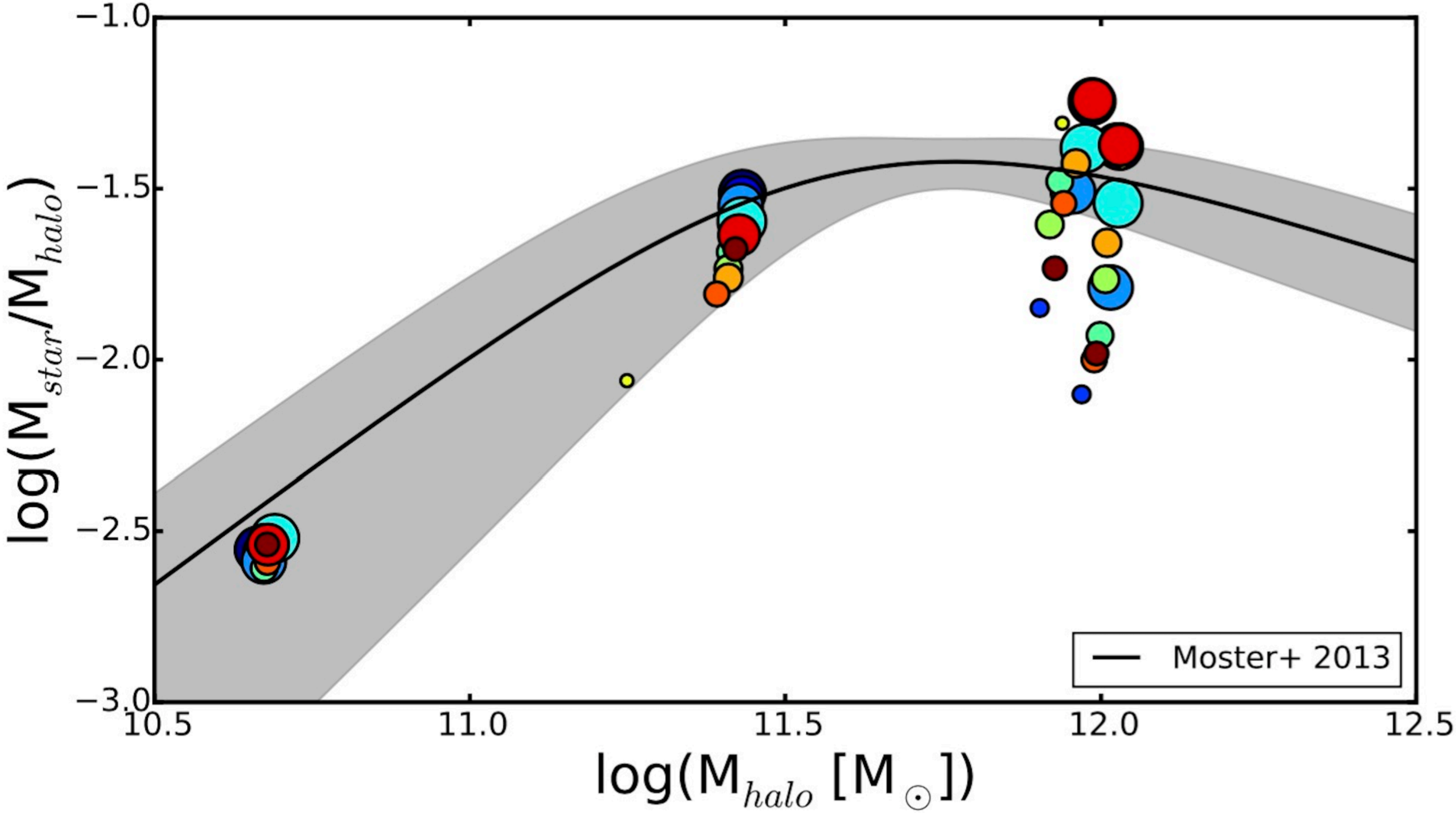
Evolving Ionizing Emissivity Consistent with Observations

Charm Nbody GrAvity solver

- Massively parallel SPH
- SNe feedback creating realistic outflows
- SF linked to shielded gas
- SMBHs
- Optimized SF parameters

Menon+ 2014, Governato+ 2014

Subgrid Parameter Search



The VULCAN

$[25\ \mathrm{Mpc}]^3$

2 billion particles

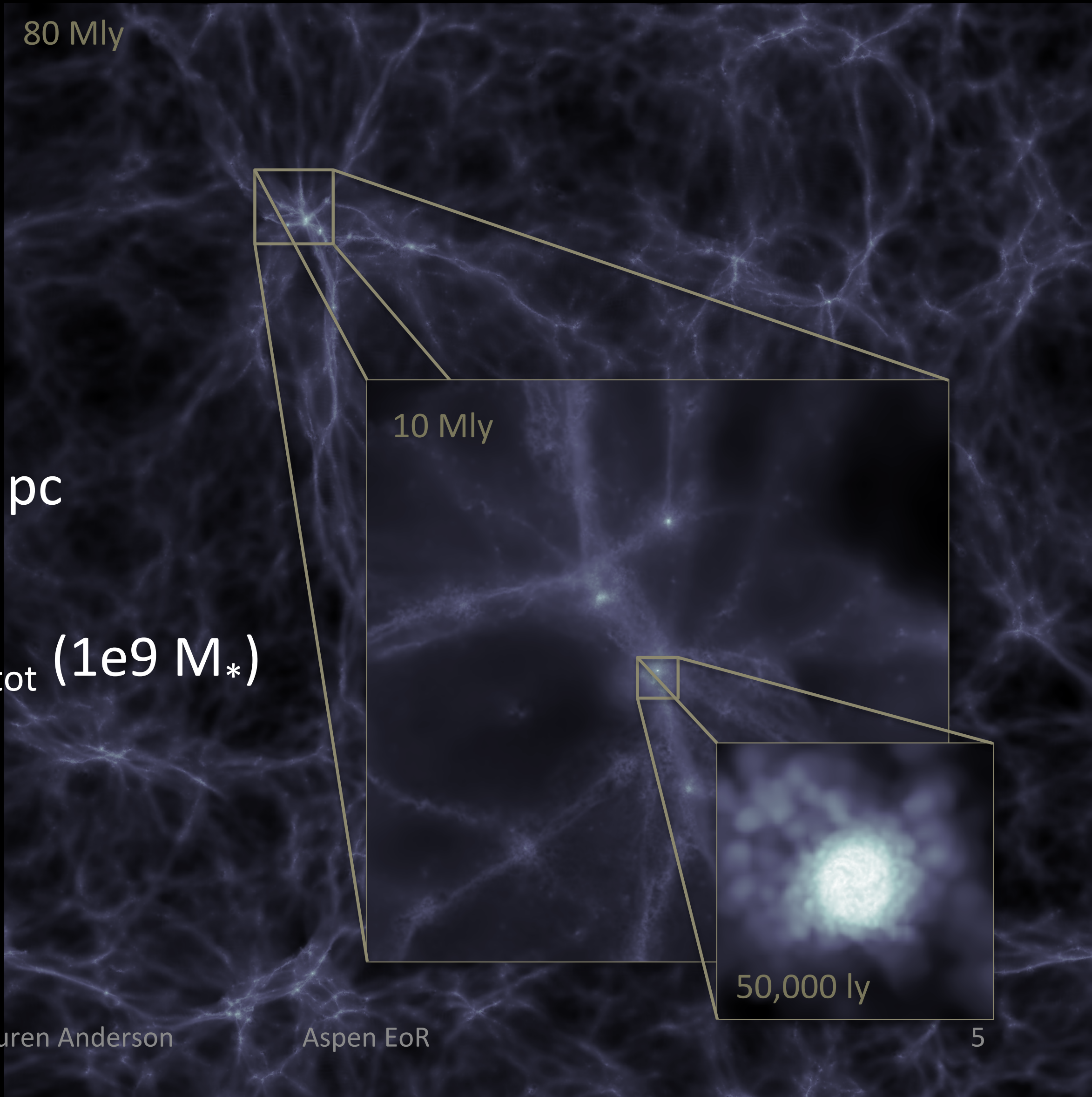
z ~ 100-4

Gravity resolution ~ 350 pc

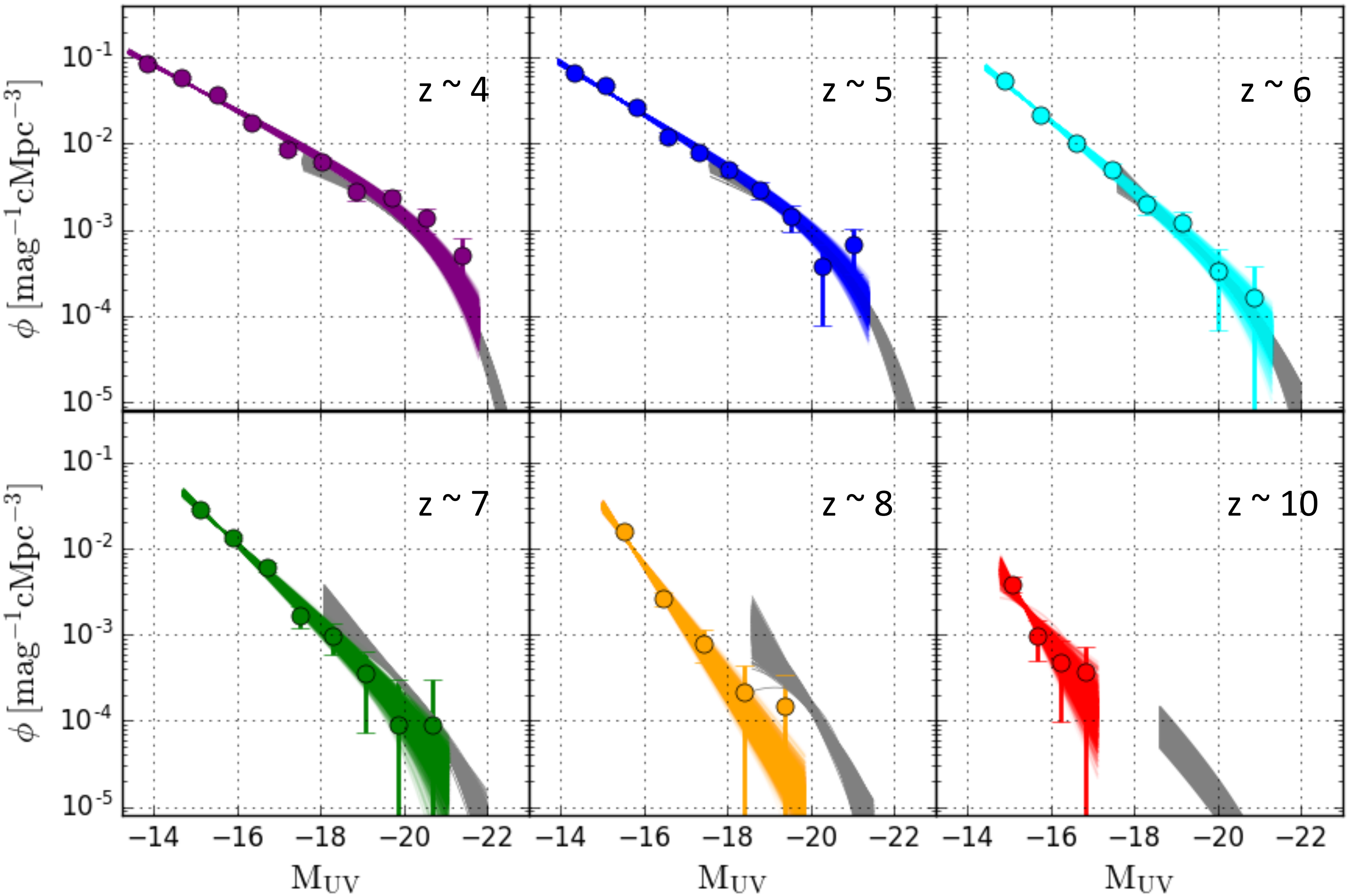
SPH resolution ~ 40 pc

Morphologies ~ 1e11 M_{tot} (1e9 M_*)

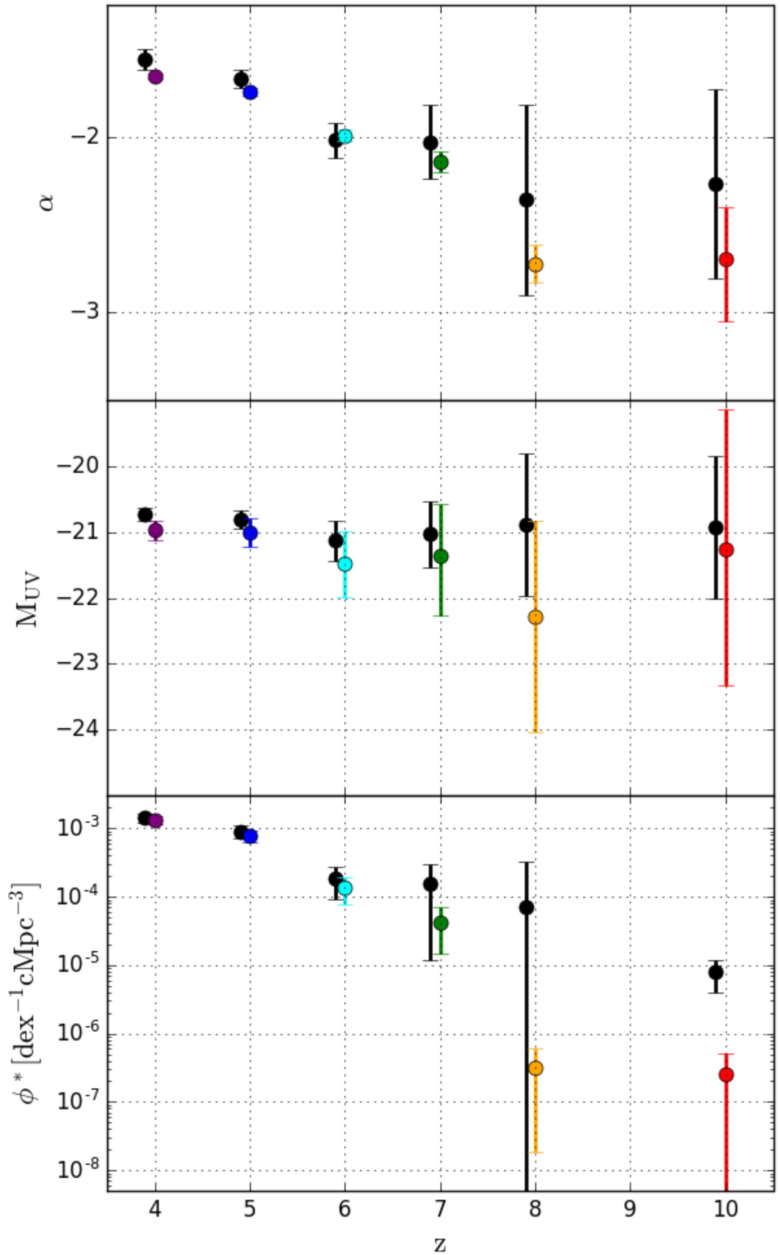
5 TB dataset



Evolution of the UVLF



Anderson+ in prep



Evolution of UVLF Parameters

The faint end slope is getting steeper with redshift

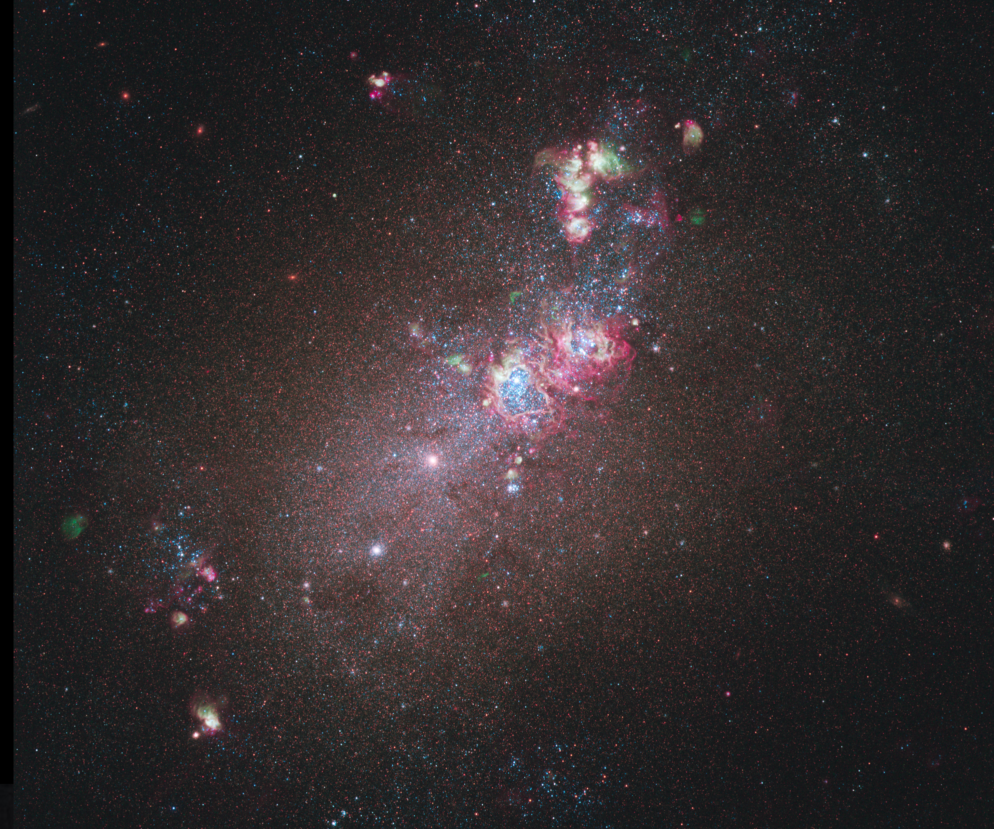
Relatively more faint galaxies at high redshift

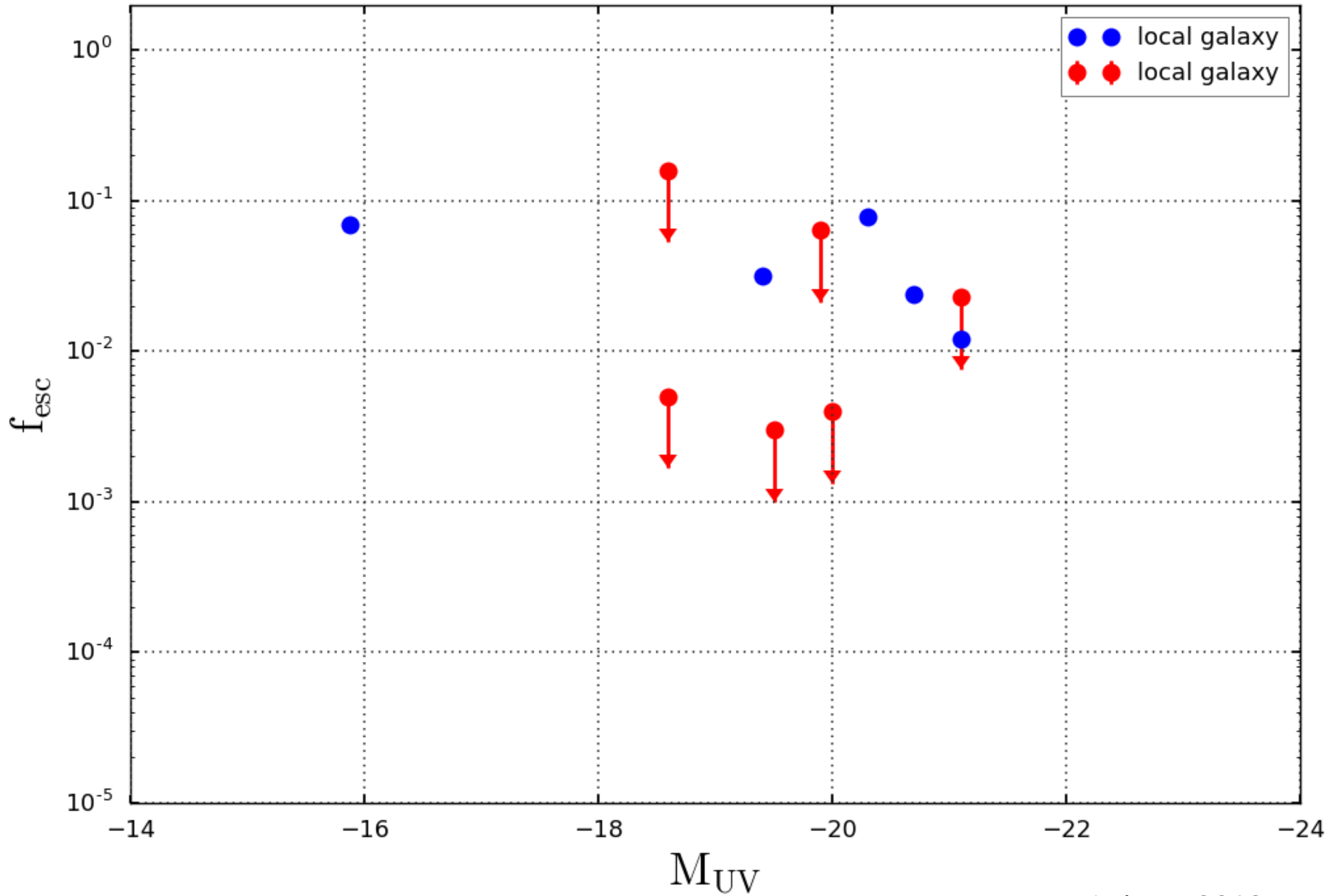
Larger contribution of ionizing photons?

Anderson+ in prep

We may have a
large enough ionizing photon budget…

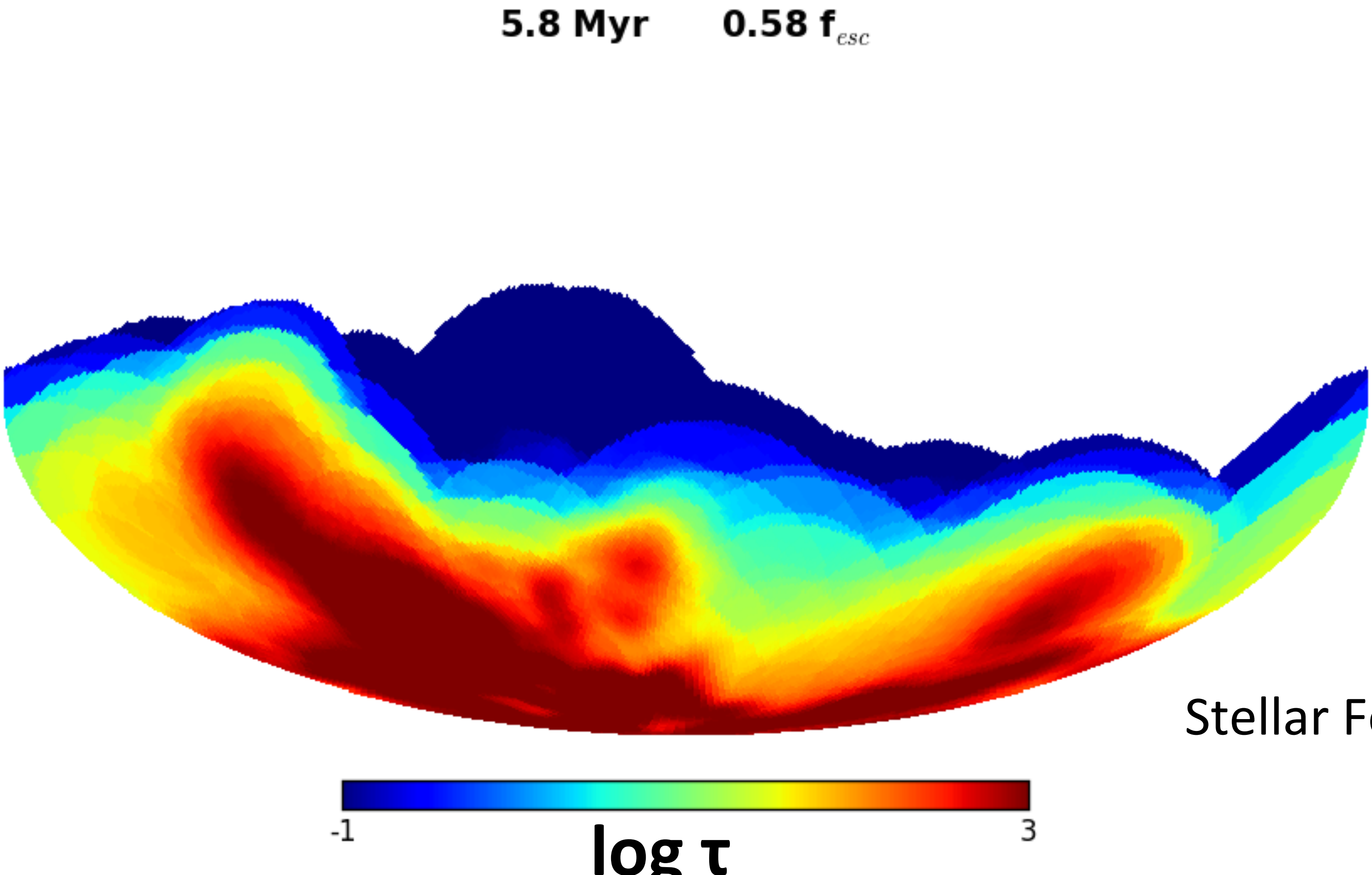
Can these ionizing photons escape
their host halo to reionize the IGM?



local galaxy
local galaxy
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
f_{esc}
−14
−16
−18
−20
−22
−24
M_{UV}

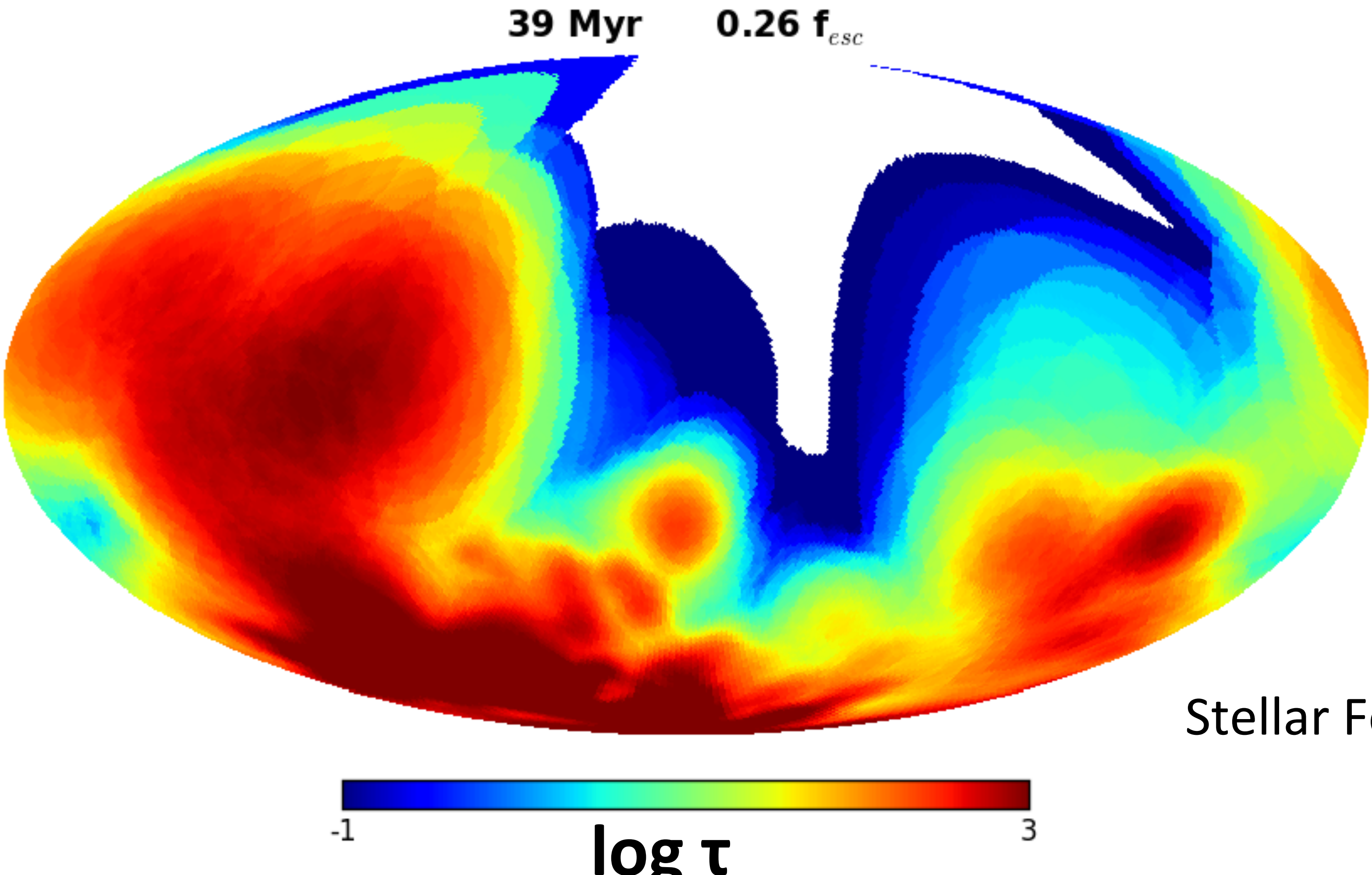
Leitet+ 2013

Optical Depths Seen by One Individual Stellar Particle



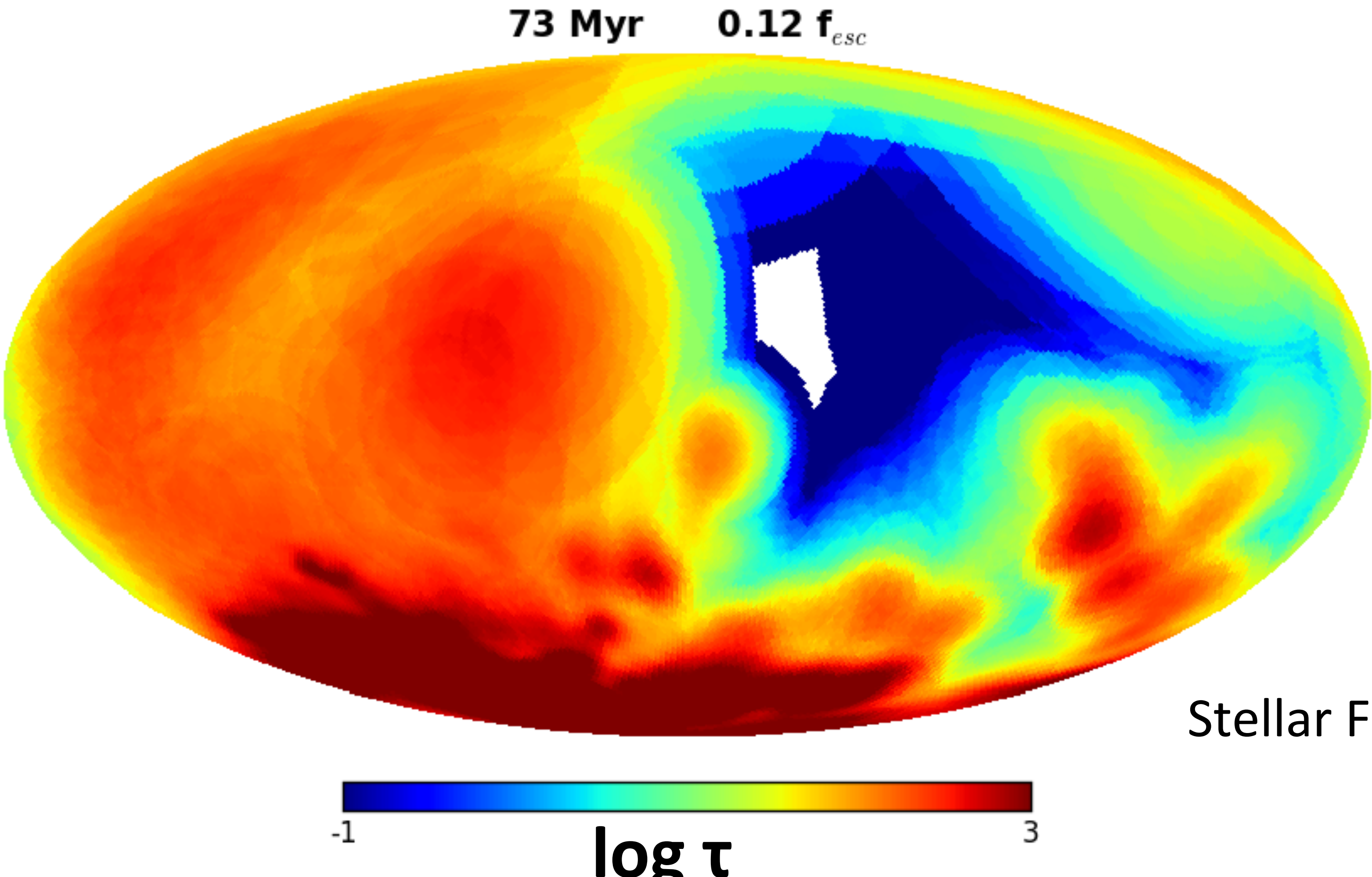
Stellar Feedback

Optical Depths Seen by One Individual Stellar Particle



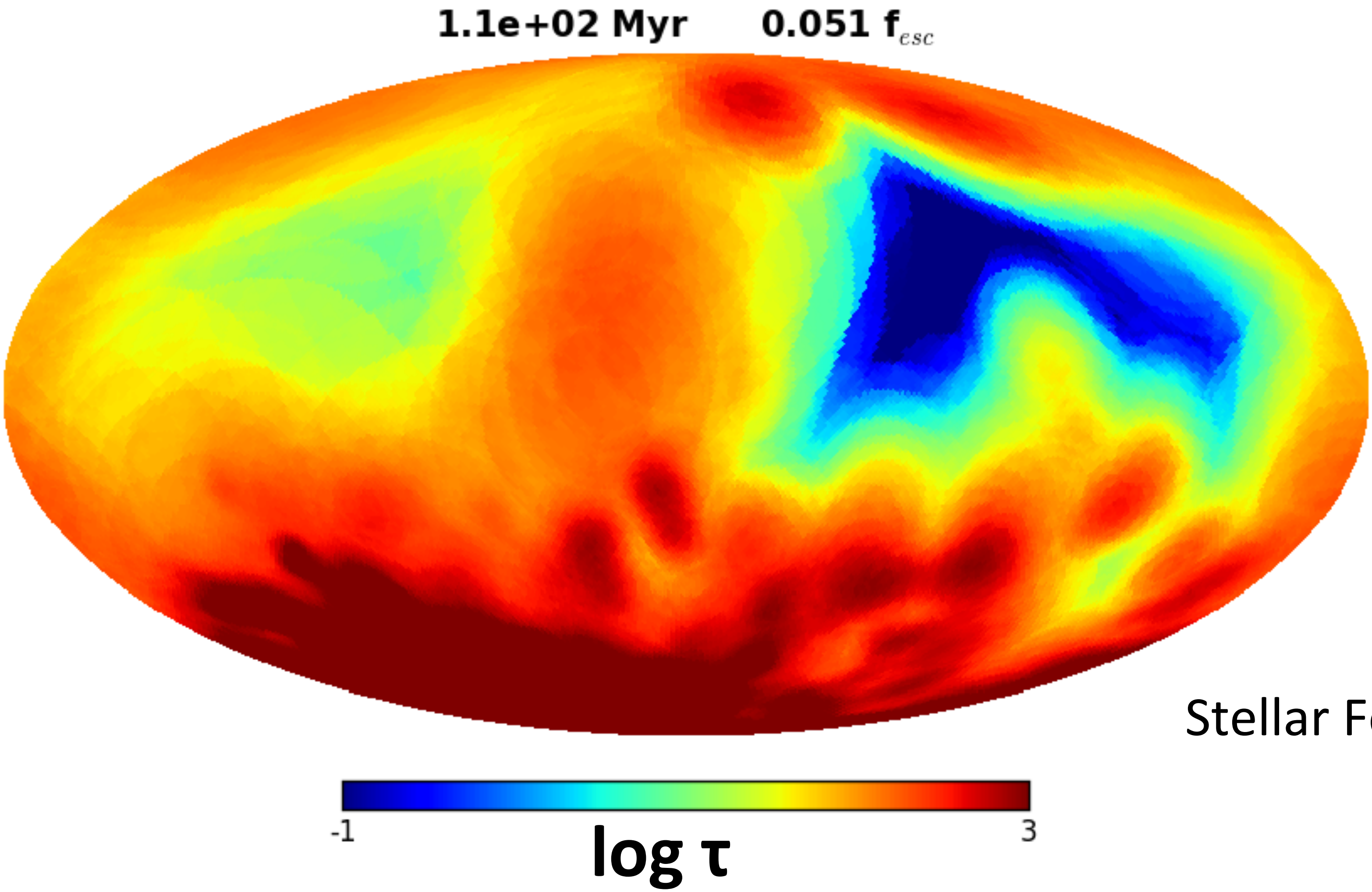
Stellar Feedback

Optical Depths Seen by One Individual Stellar Particle



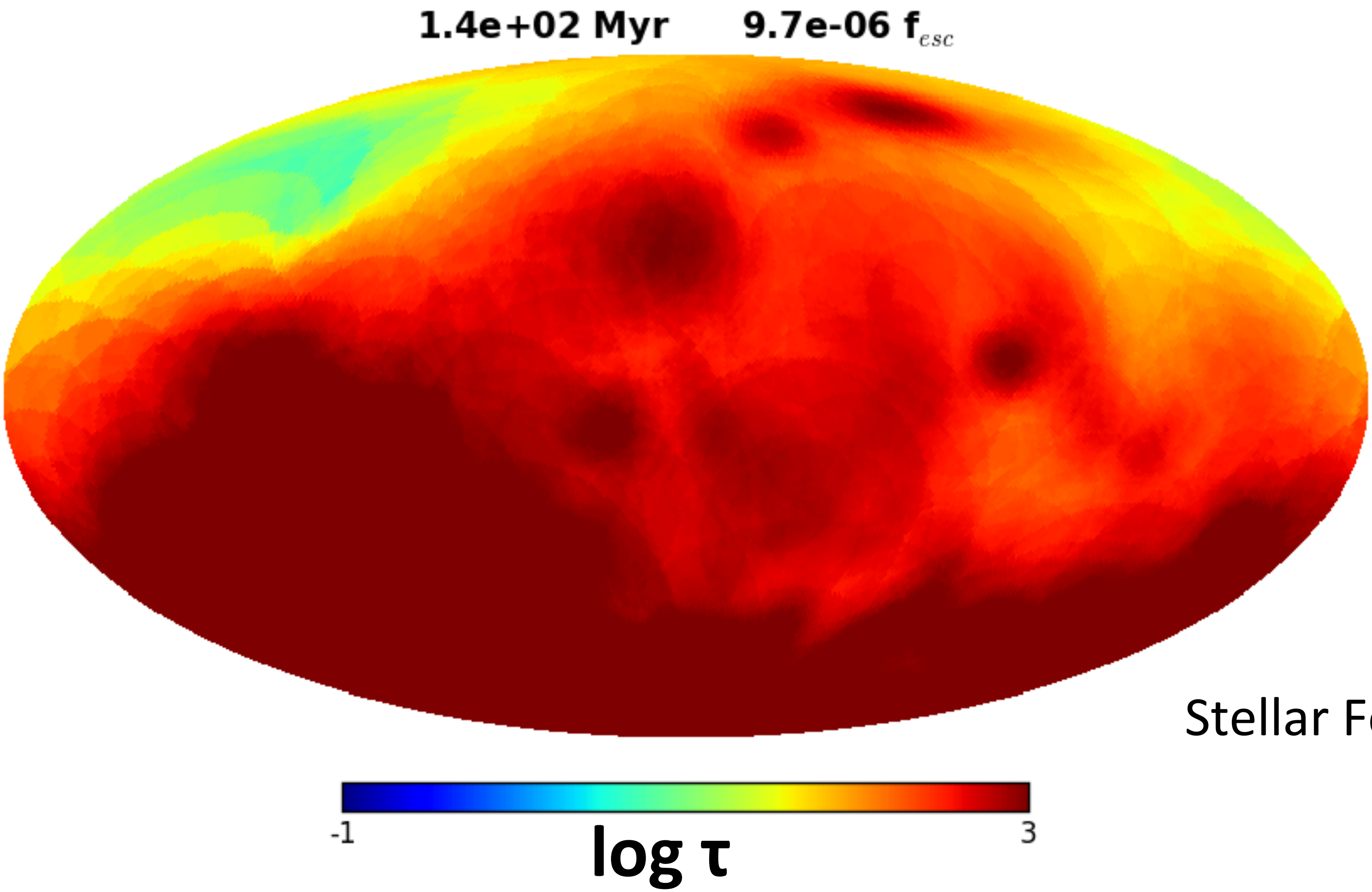
Stellar Feedback

Optical Depths Seen by One Individual Stellar Particle



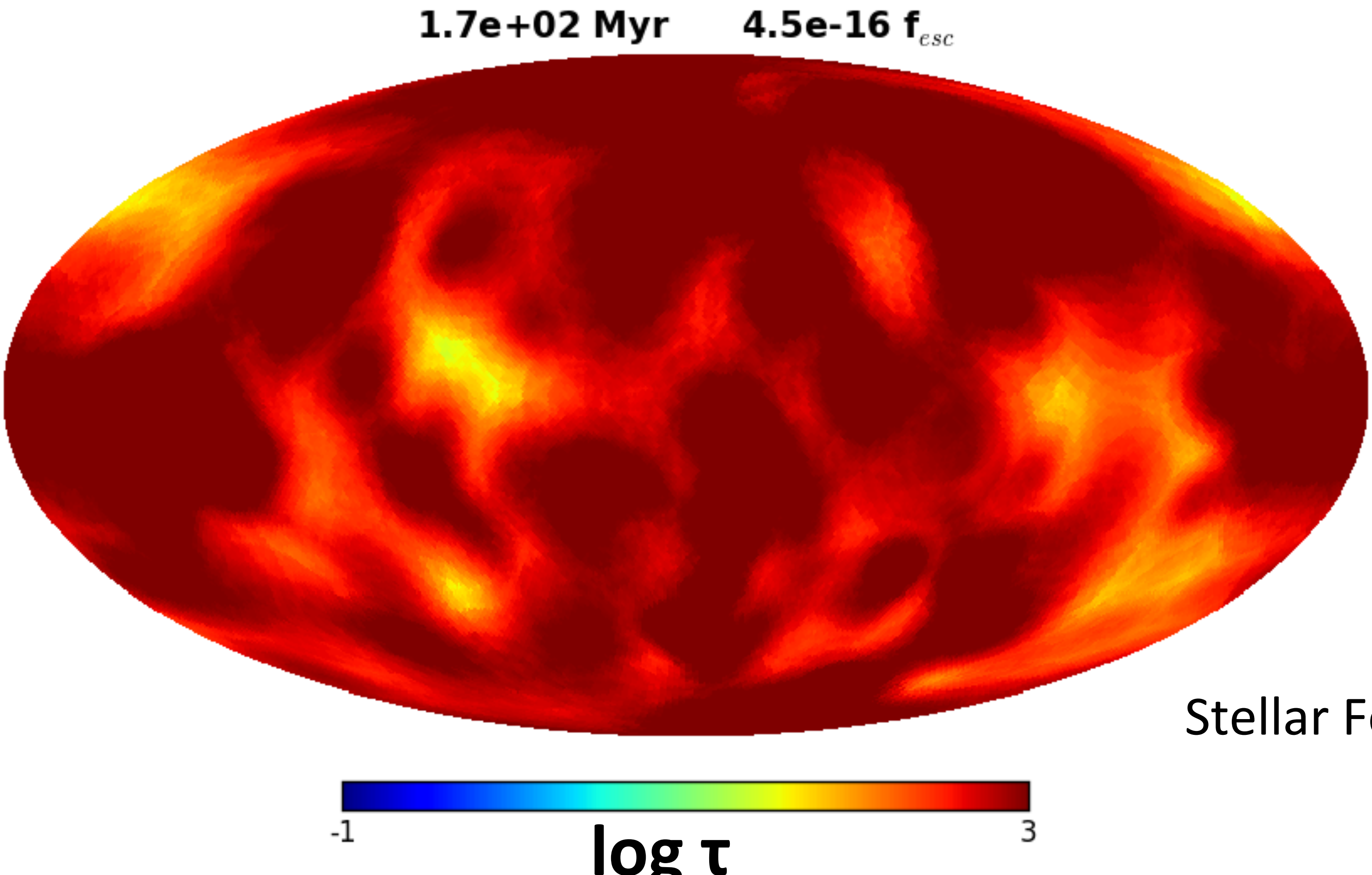
Stellar Feedback

Optical Depths Seen by One Individual Stellar Particle

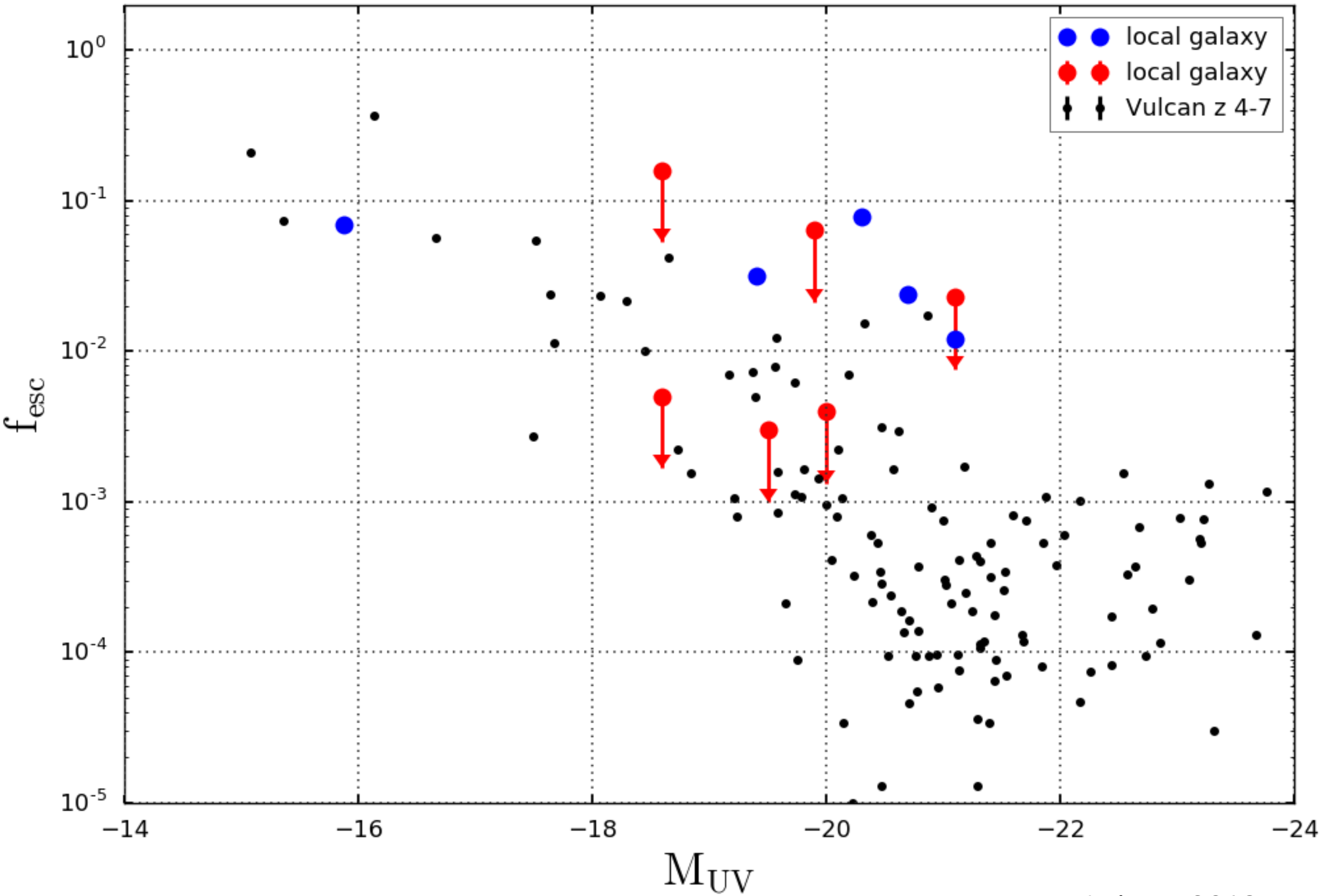


Stellar Feedback

Optical Depths Seen by One Individual Stellar Particle

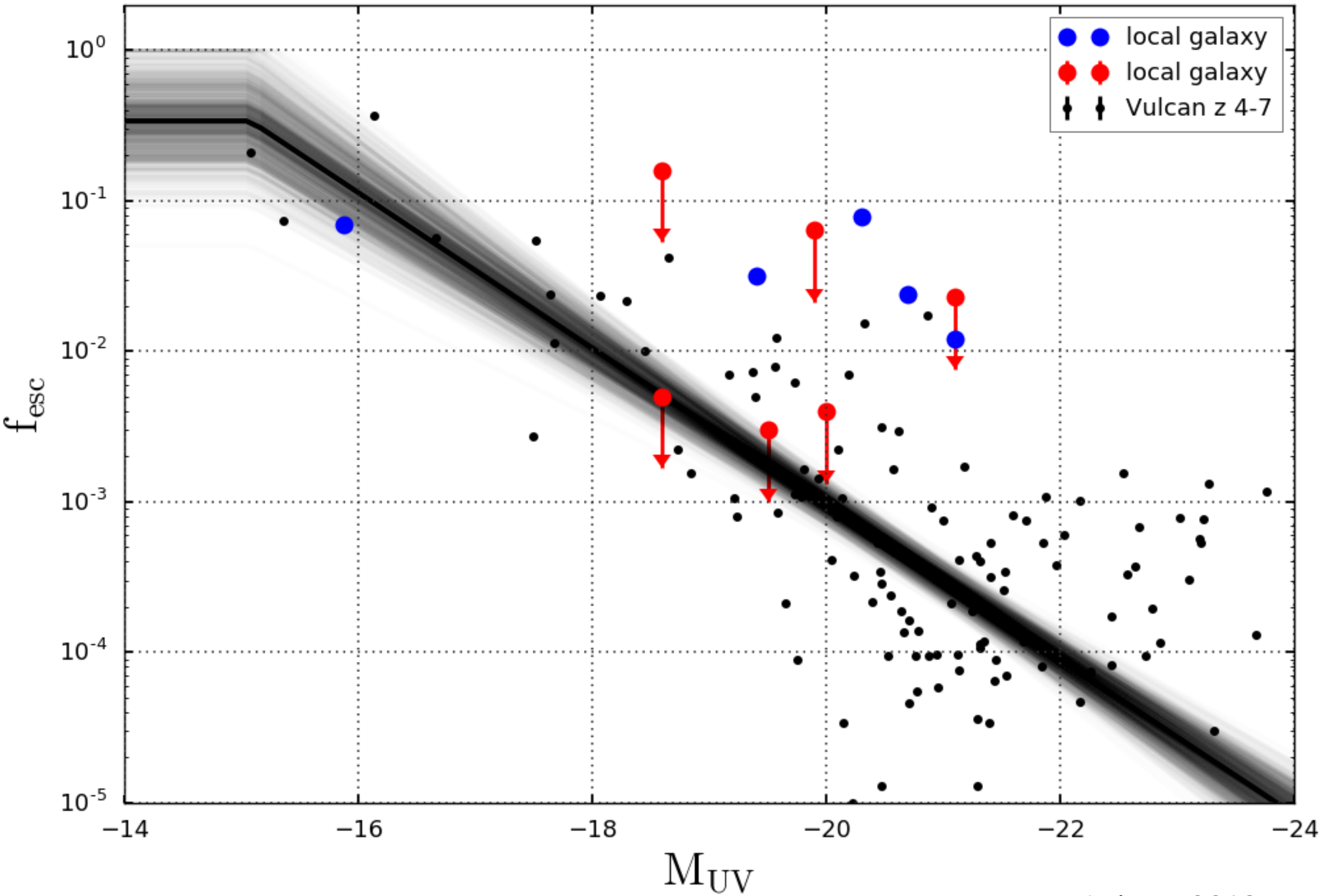


Stellar Feedback



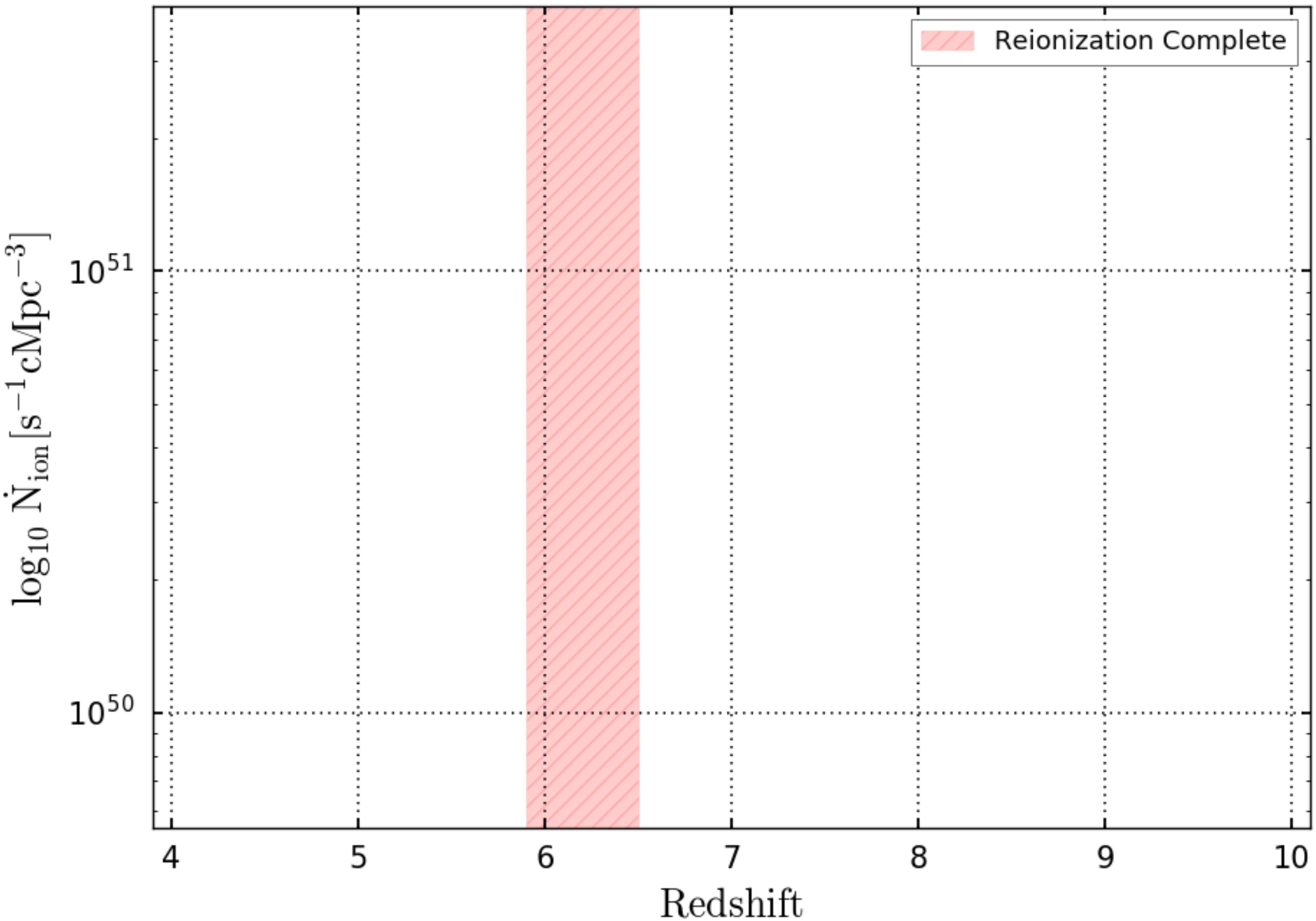
local galaxy
local galaxy
Vulcan z 4-7
f_{esc}
M_{UV}
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
−14
−16
−18
−20
−22
−24

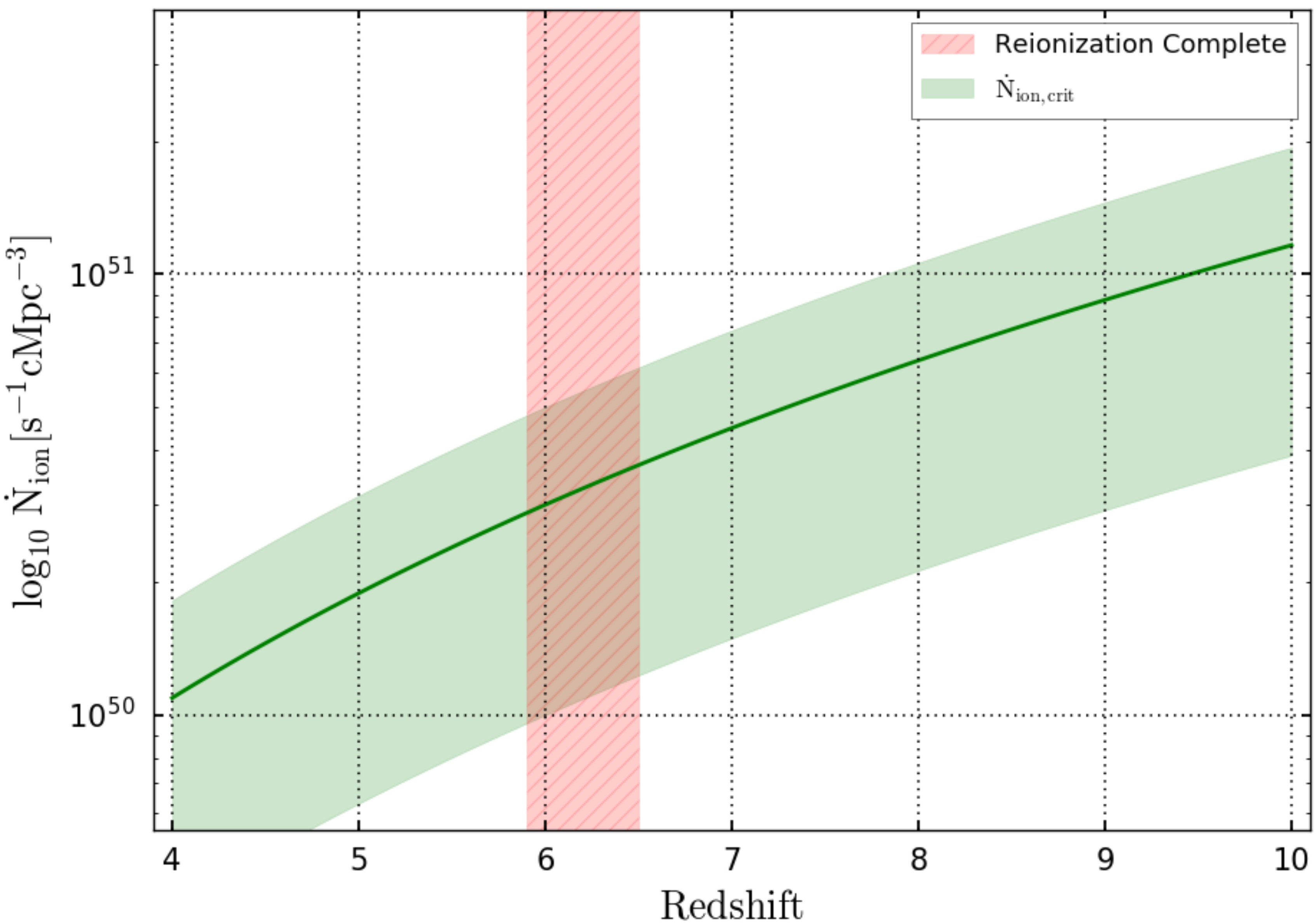
Leitet+ 2013

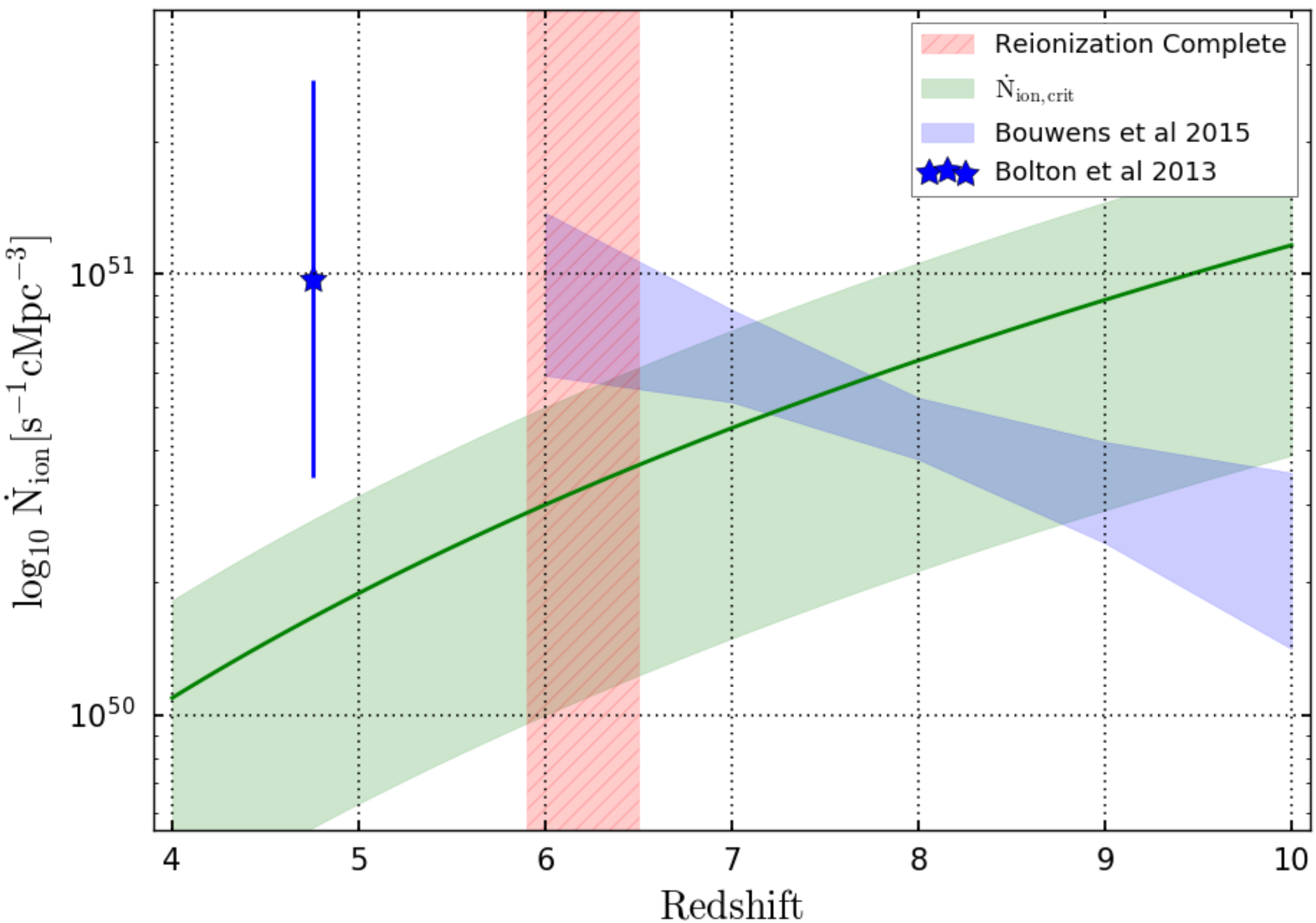


local galaxy
local galaxy
Vulcan z 4-7
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
f_{esc}
−14
−16
−18
−20
−22
−24
M_{UV}

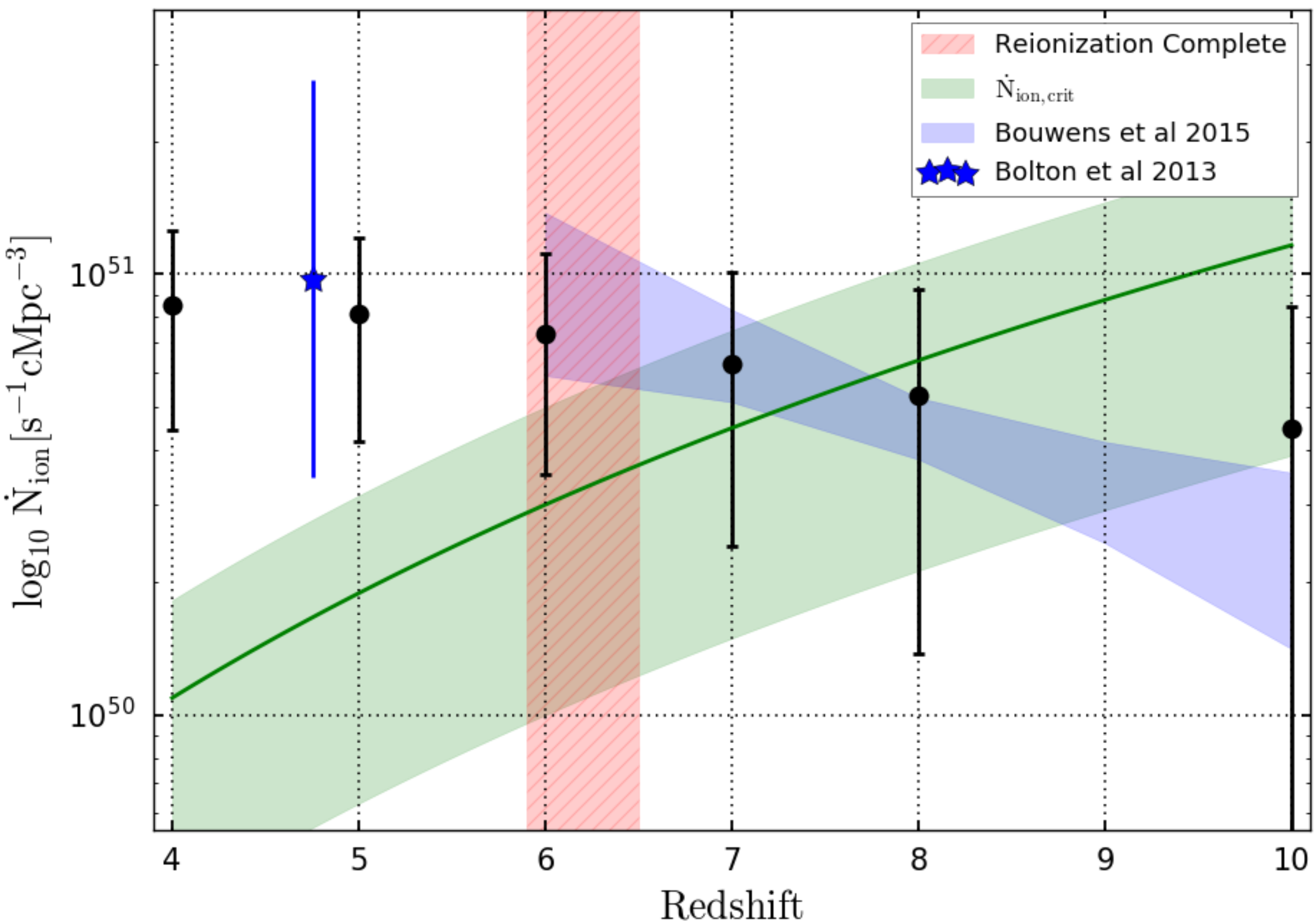
Leitet+ 2013


Reionization Complete
10^{51}
10^{50}
$\log_{10} \dot{\mathrm{N}}_{\mathrm{ion}} [\mathrm{s}^{-1}\mathrm{cMpc}^{-3}]$
4
5
6
7
8
9
10
Redshift

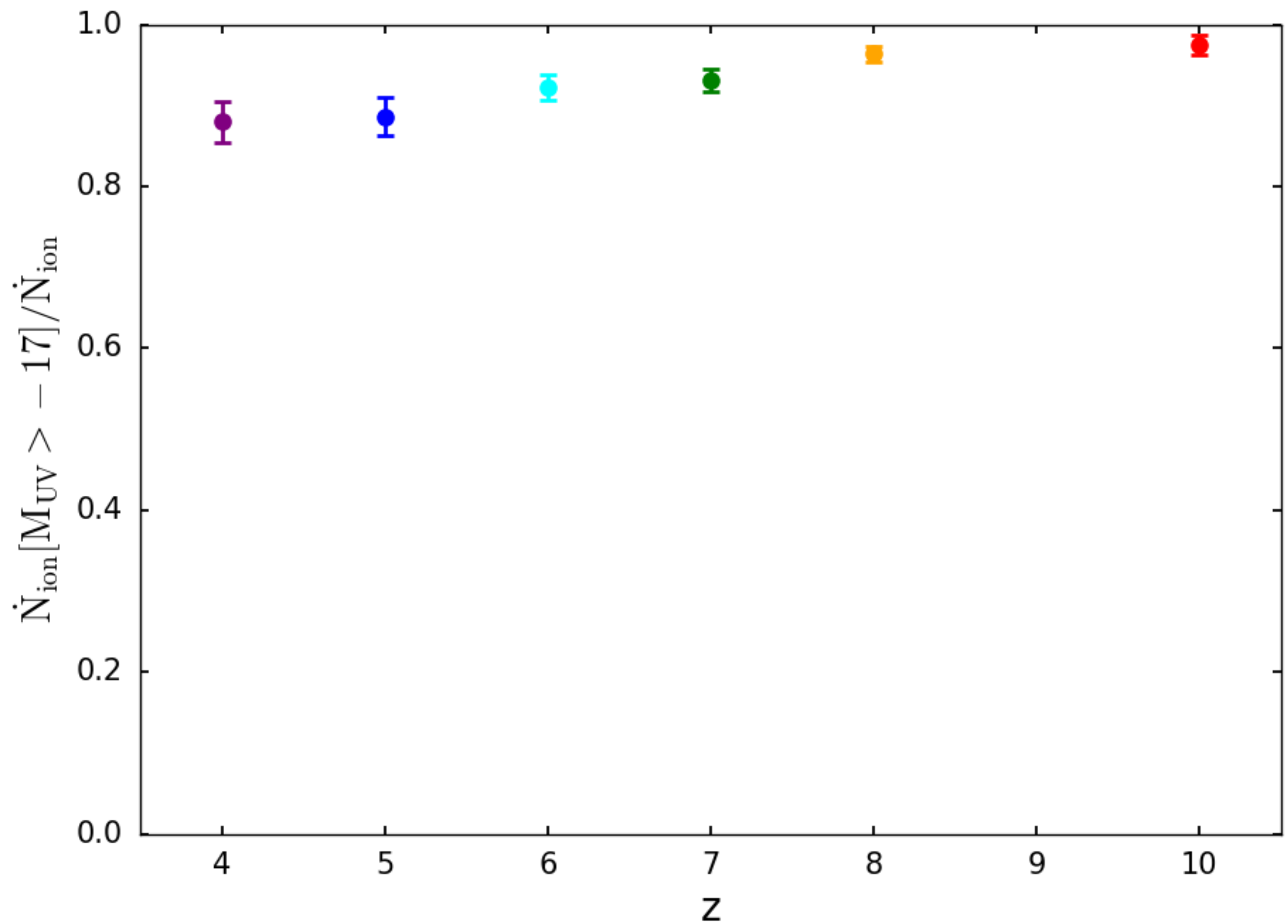

Reionization Complete
$\dot{N}_{ion,crit}$
$\log_{10} \dot{N}_{ion} [s^{-1} cMpc^{-3}]$
10^{51}
10^{50}
4
5
6
7
8
9
10
Redshift



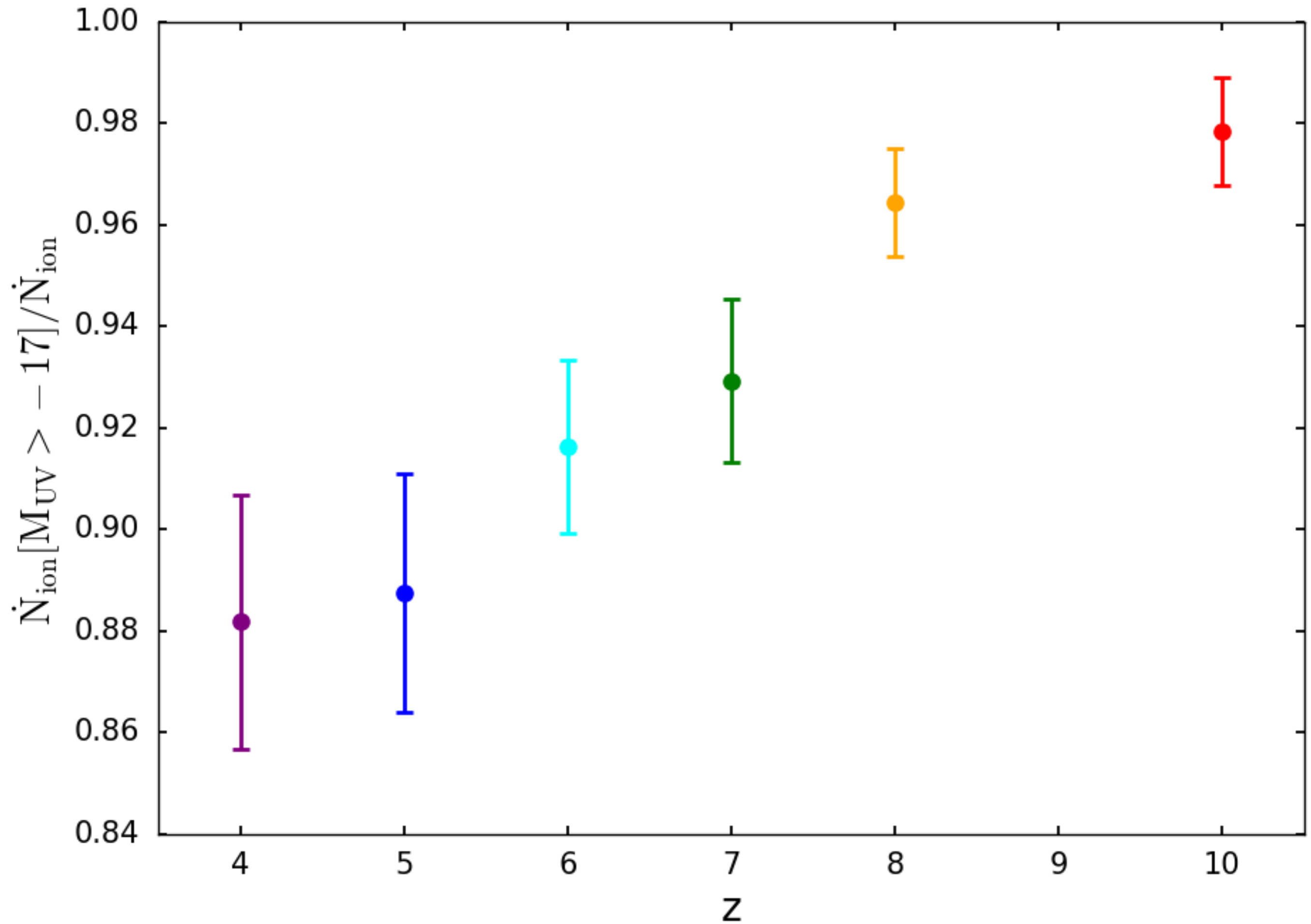
Reionization Complete
$\dot{N}_{ion,crit}$
Bouwens et al 2015
Bolton et al 2013
$\log_{10} \dot{N}_{ion} [s^{-1} cMpc^{-3}]$
10^{51}
10^{50}
4
5
6
7
8
9
10
Redshift


Reionization Complete
$\dot{N}_{\rm ion,crit}$
Bouwens et al 2015
Bolton et al 2013
$\log_{10} \dot{N}_{\rm ion} [s^{-1} cMpc^{-3}]$
10^{51}
10^{50}
4
5
6
7
8
9
10
Redshift

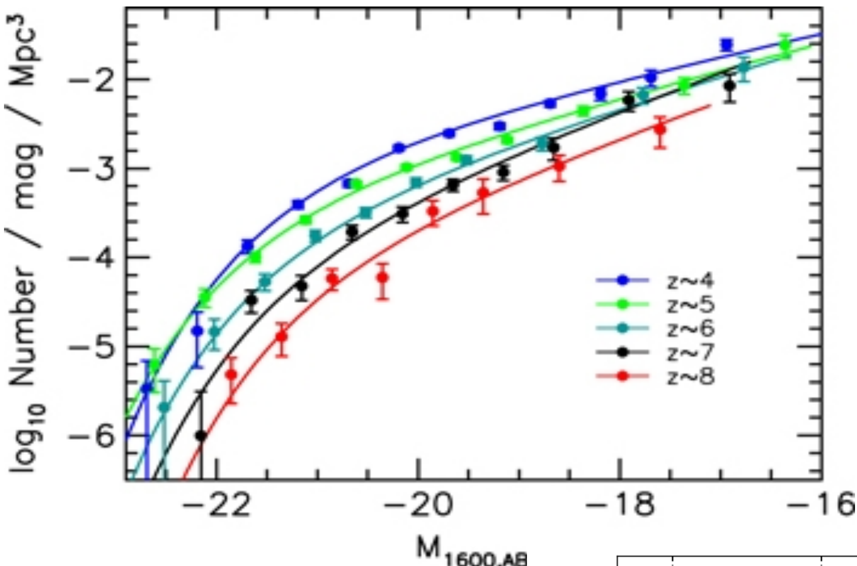
Faint Galaxies dominate contribution to Ionizing Emissivity

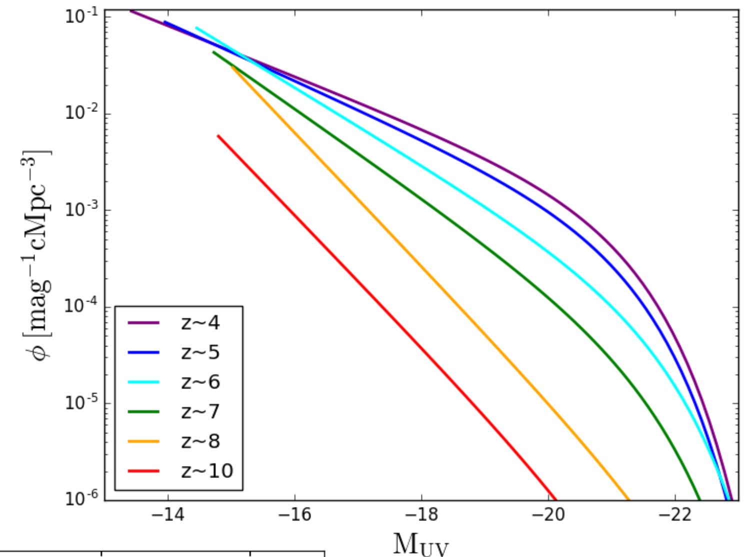


Faint Galaxies dominate contribution to Ionizing Emissivity

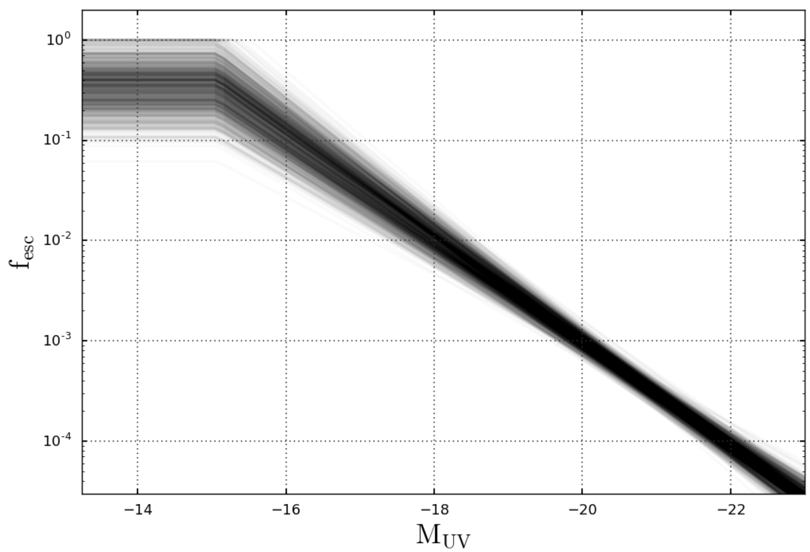


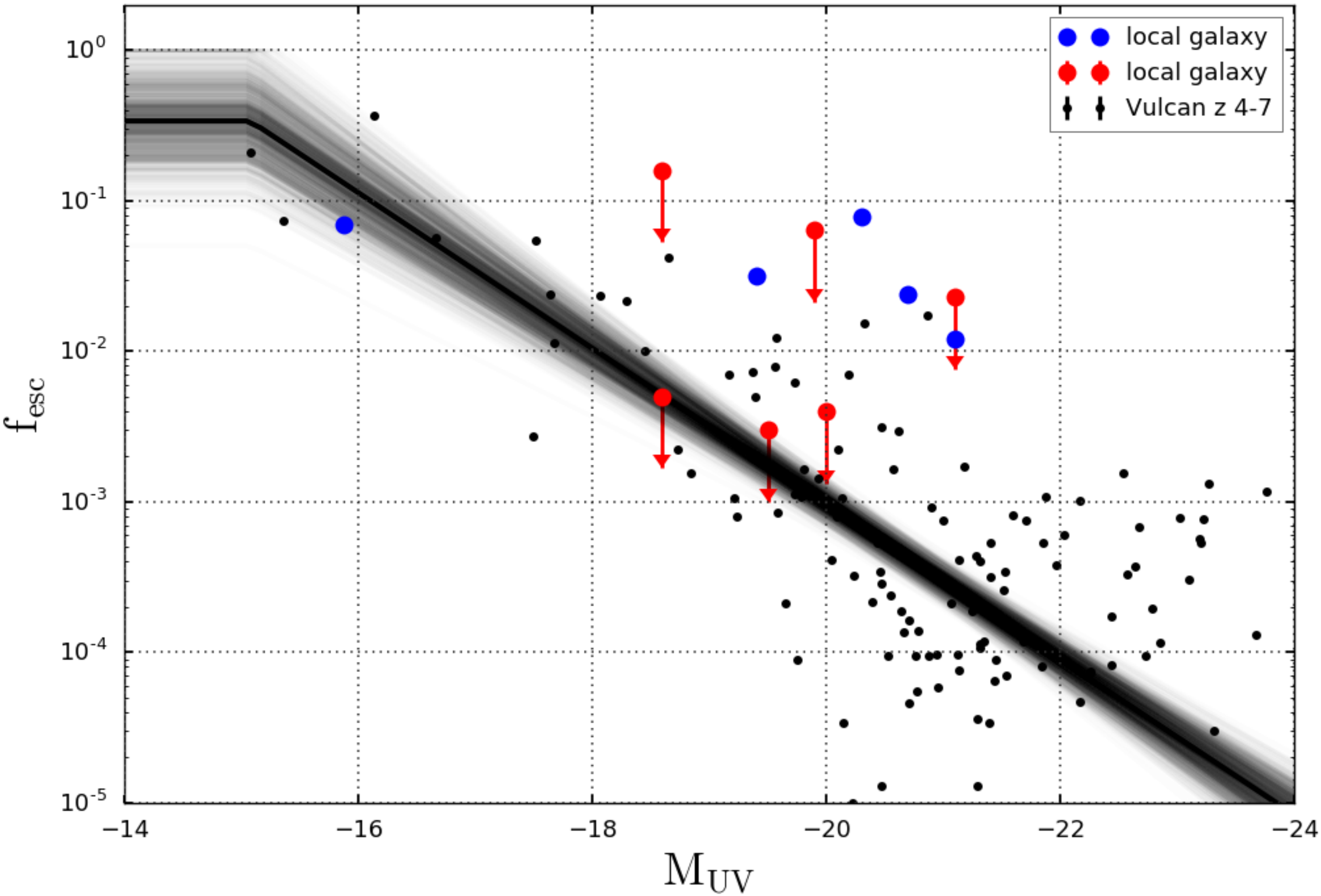
Flat evolution of Ionizing Emissivity due to n(M_{UV} ~ -15) not evolving much

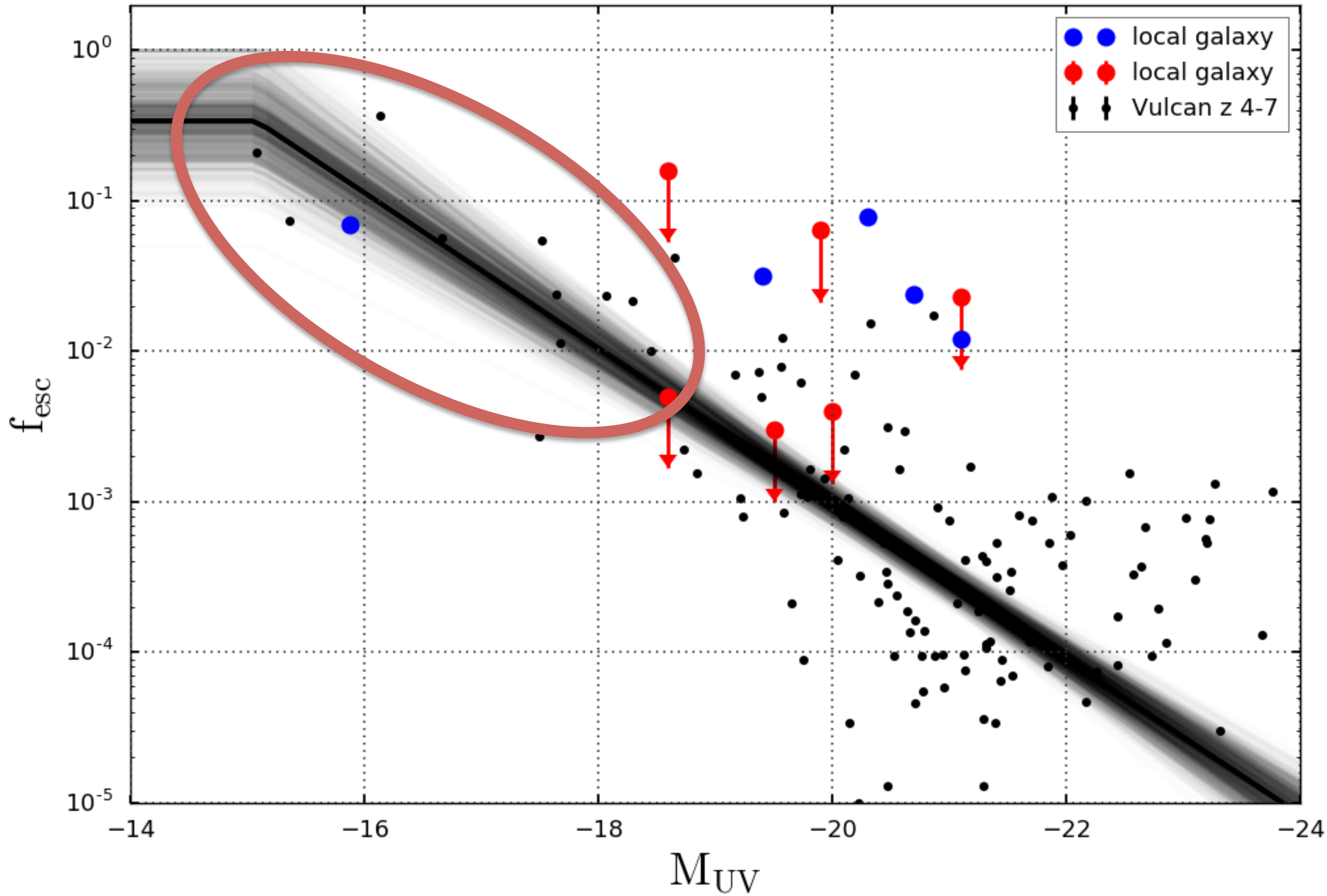




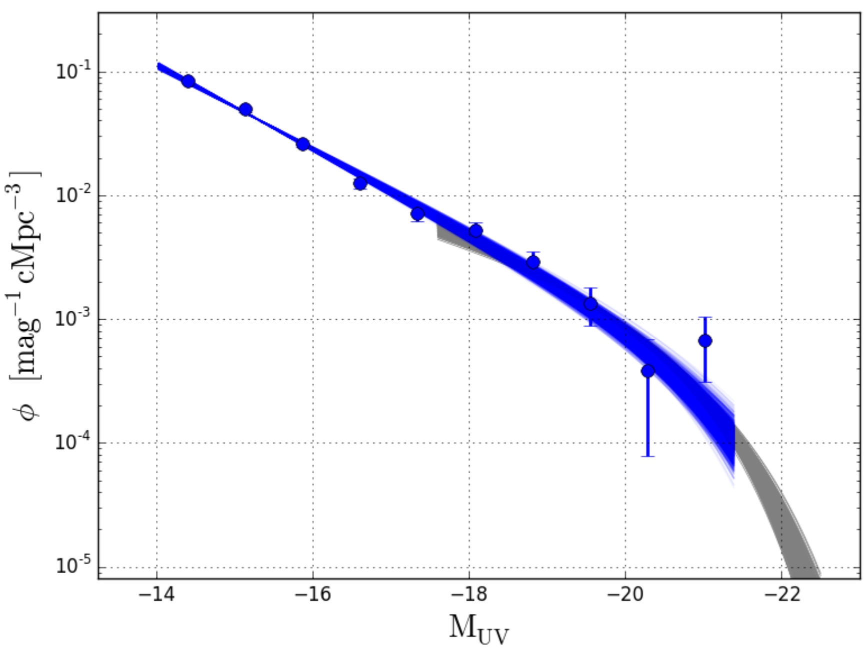
Bouwens+ 2015

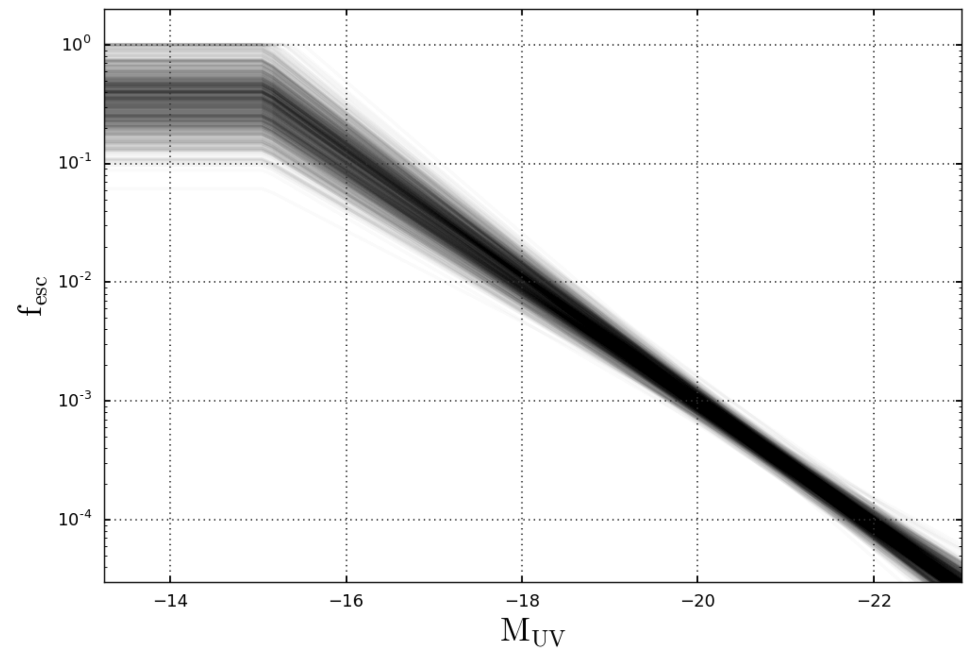



local galaxy
local galaxy
Vulcan z 4-7
f_{esc}
M_{UV}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
−14
−16
−18
−20
−22
−24


local galaxy
local galaxy
Vulcan z 4-7
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
f_{esc}
−14
−16
−18
−20
−22
−24
M_{UV}

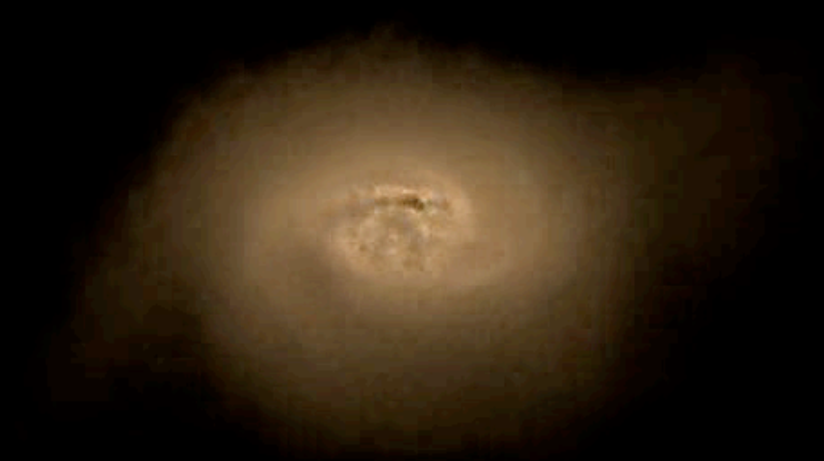
Steep Faint End Slopes + $f_{esc}(M_{UV})$





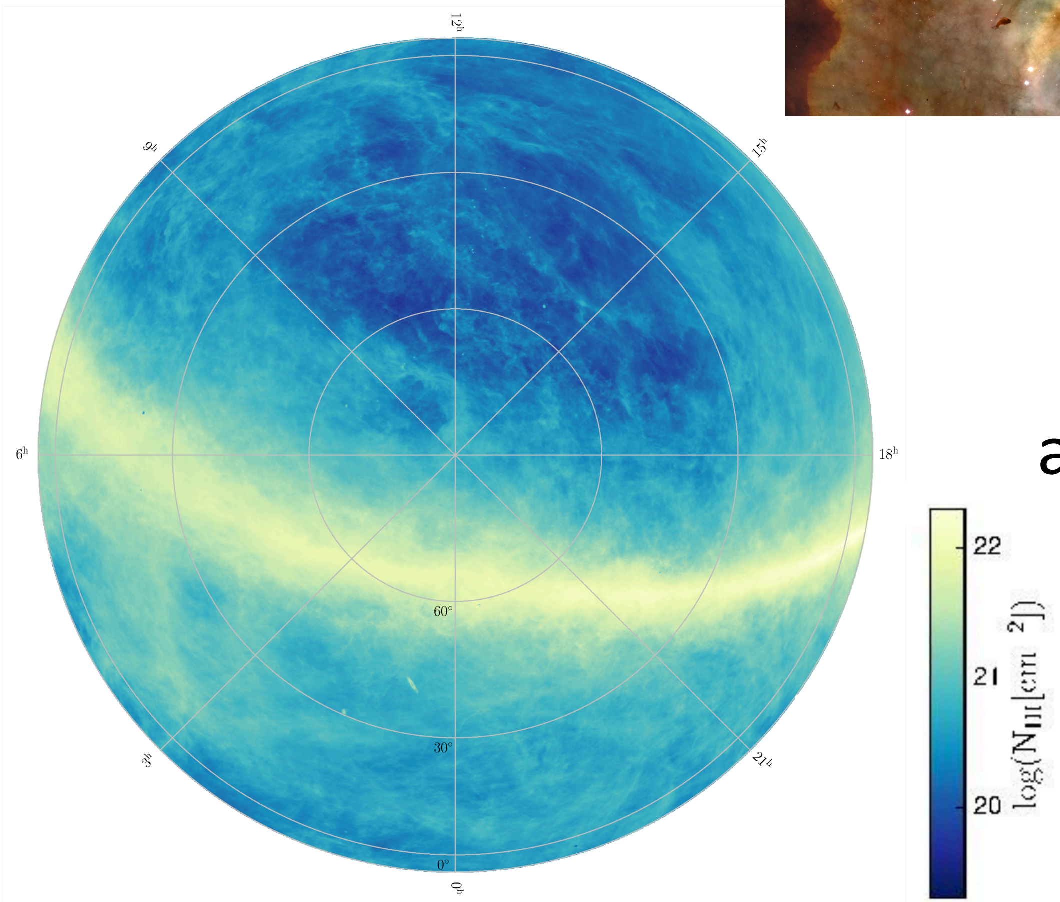
=

Evolving Ionizing Emissivity Consistent with Observations



Ionizing photons must escape the star's birth cloud…

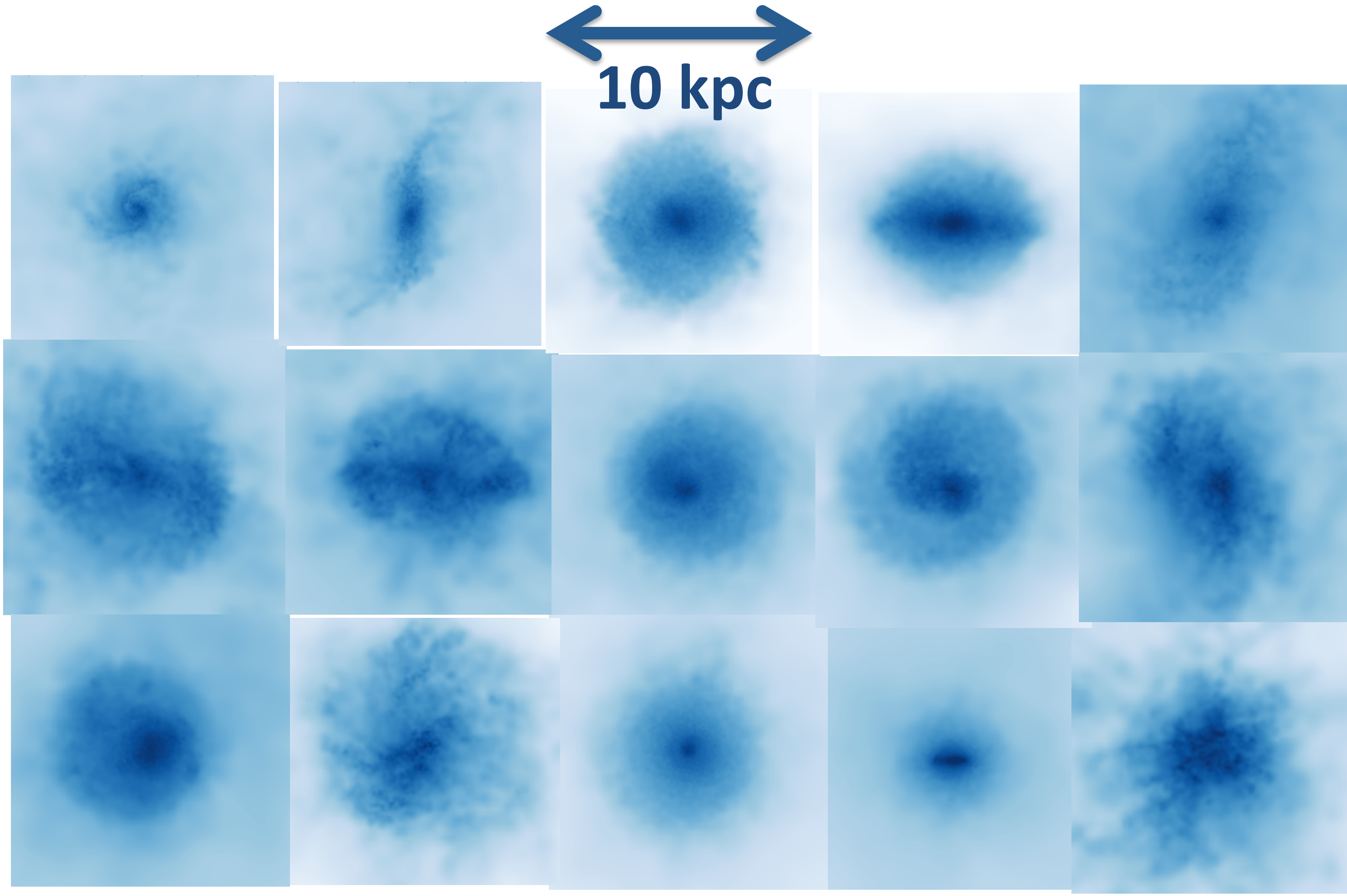
NASA HST



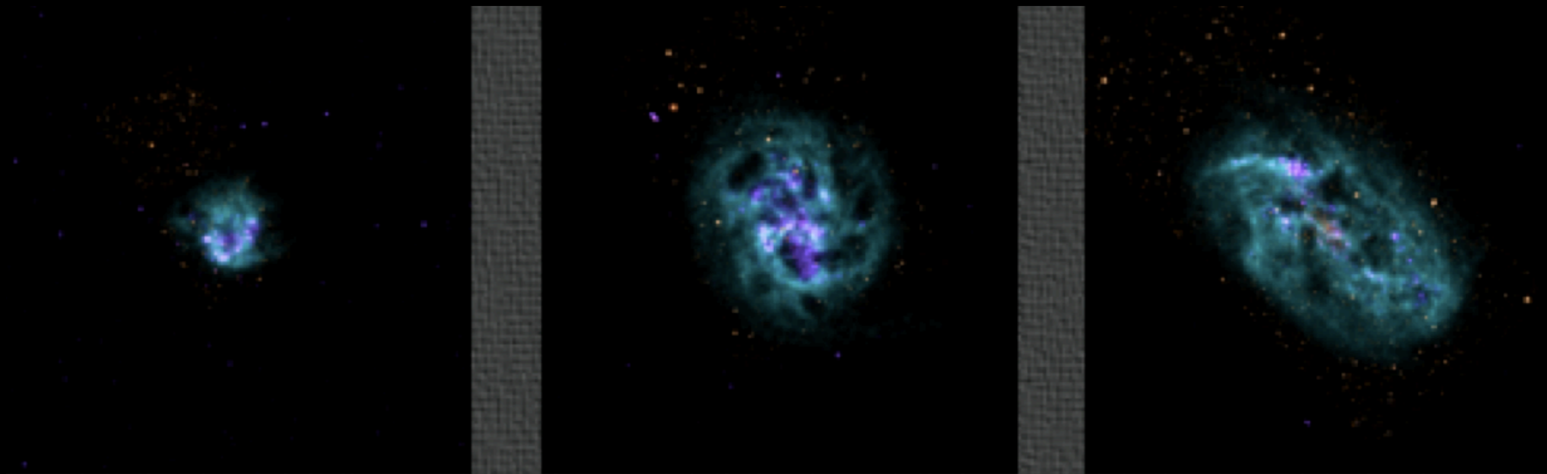
and the host galaxy !

Winkel+ 2016

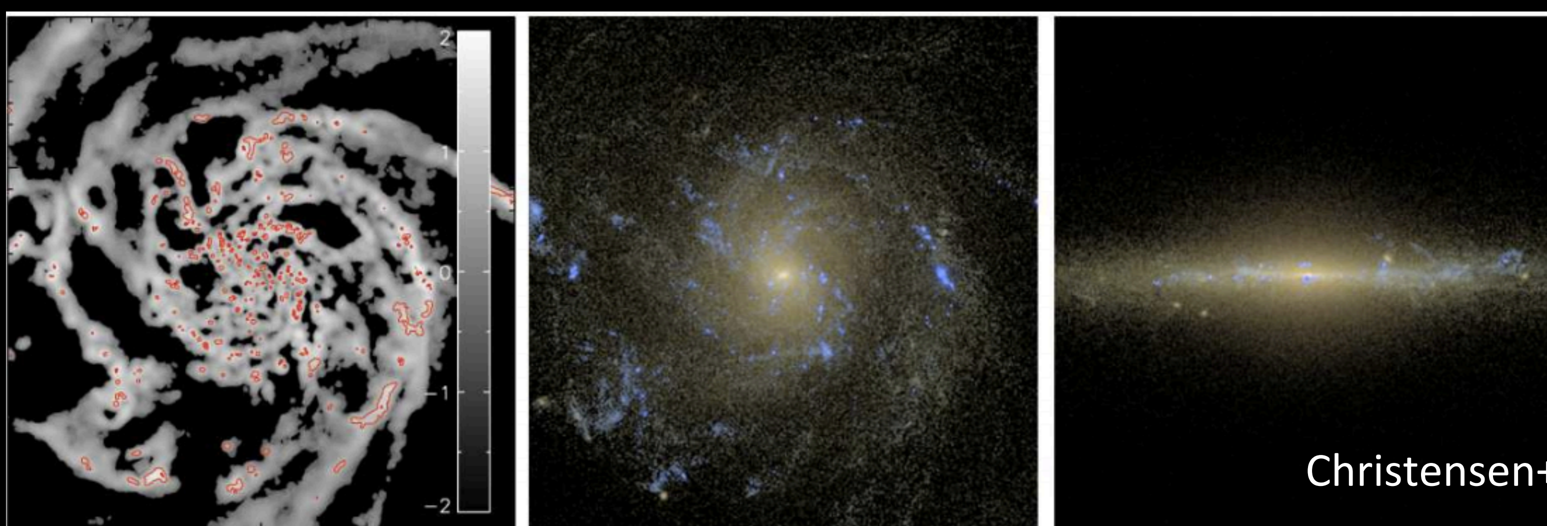
Subsample of Resolved Halos at z ~ 4 (80 total)



Observed Holes in Neutral Hydrogen: THINGS Survey



Simulated Holes in Neutral Hydrogen

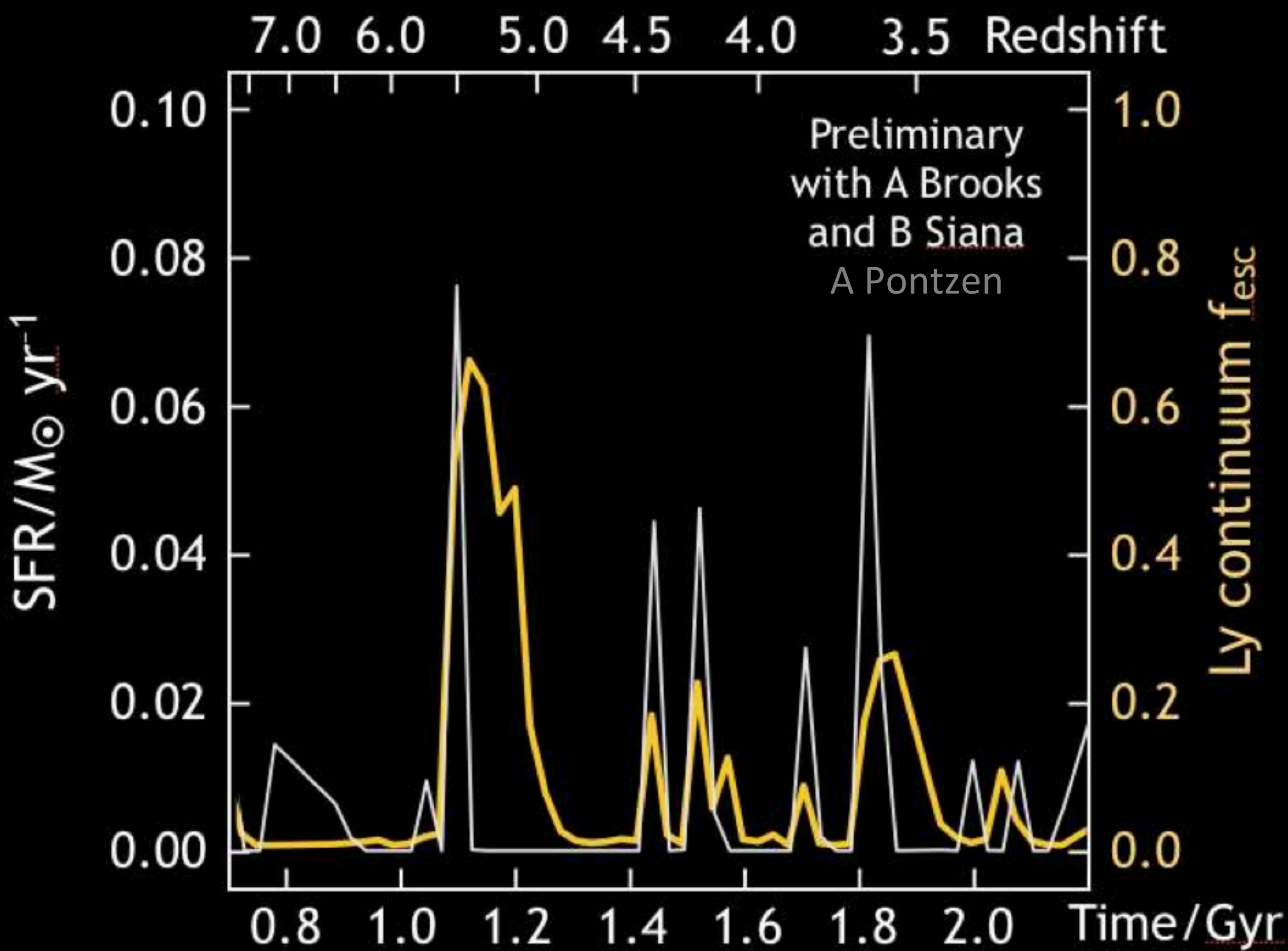


Christensen+ 2012

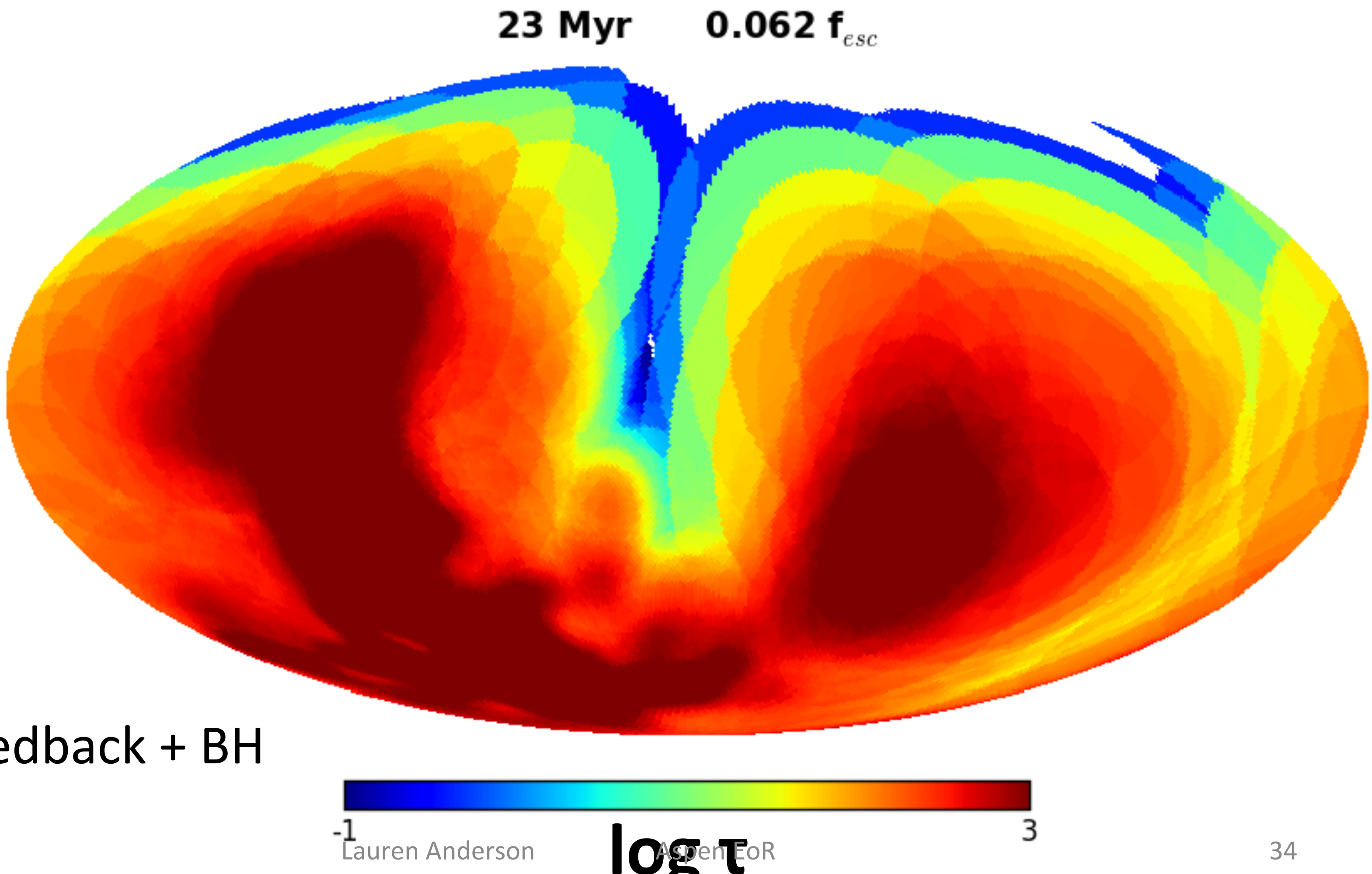
Escape Fractions

SF correlates with the Lyman continuum escape fraction.

High-z low mass galaxies bursty!

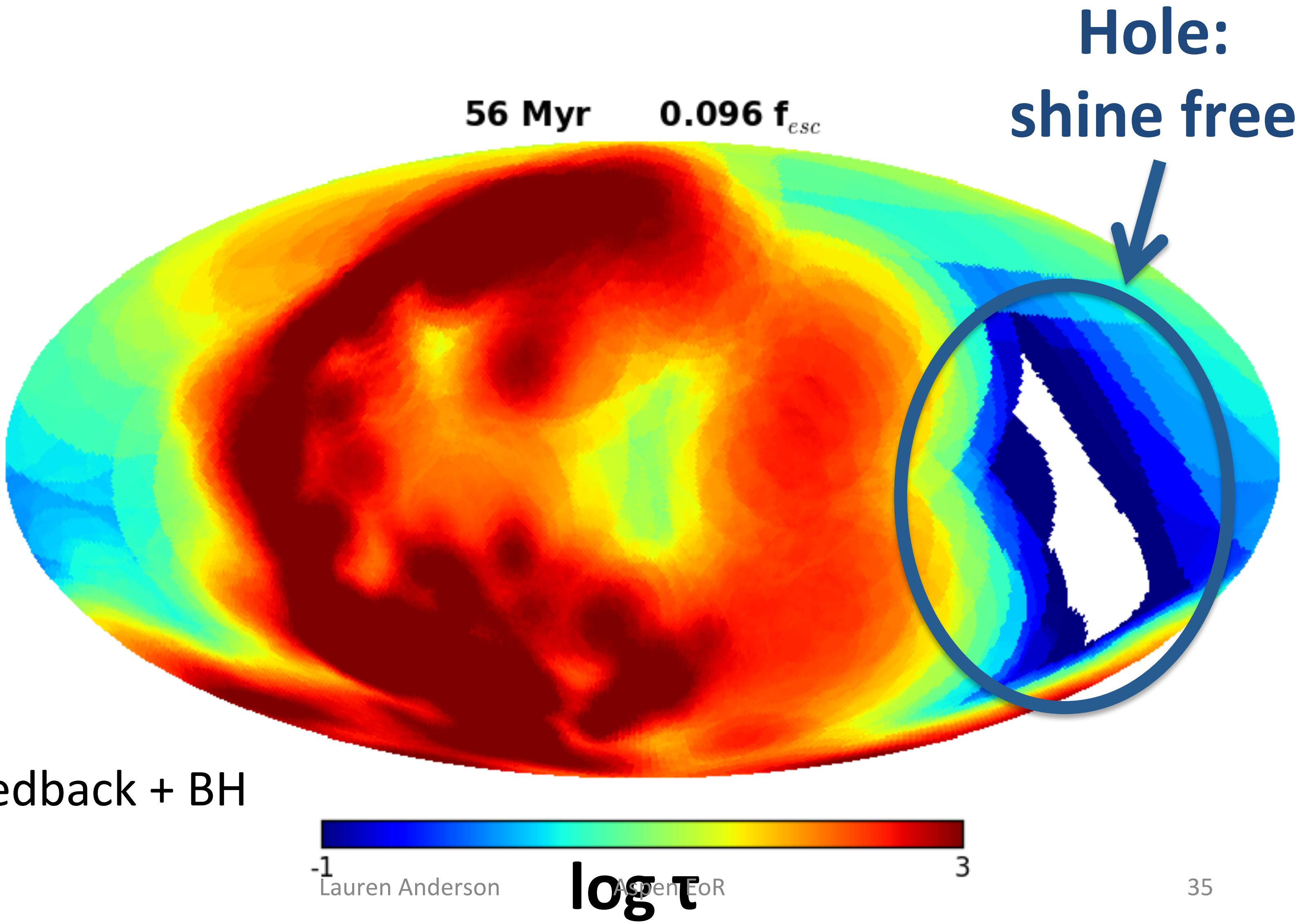


Optical Depths Seen by One Individual Stellar Particle



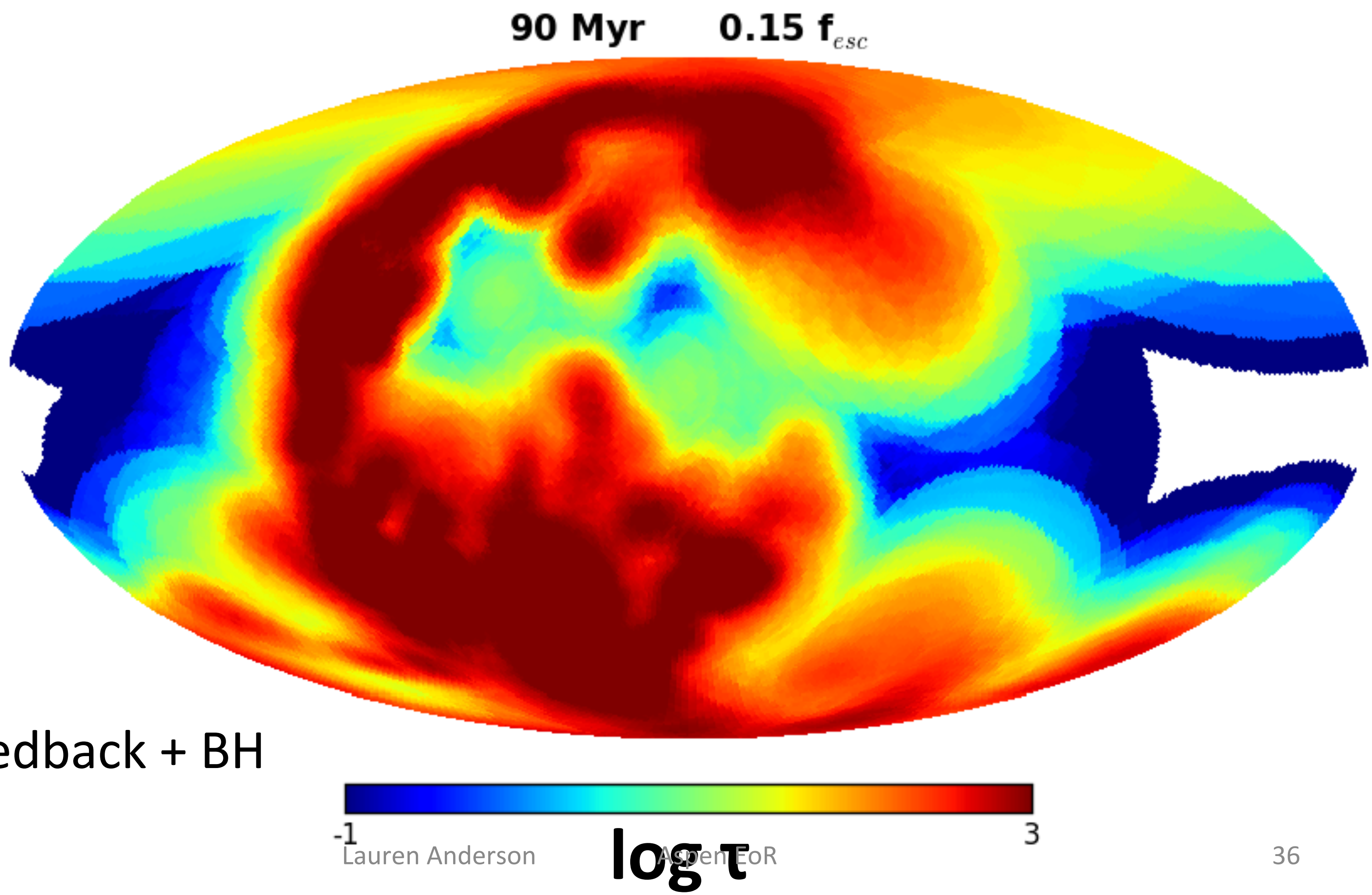
Stellar Feedback + BH

Optical Depths Seen by One Individual Stellar Particle



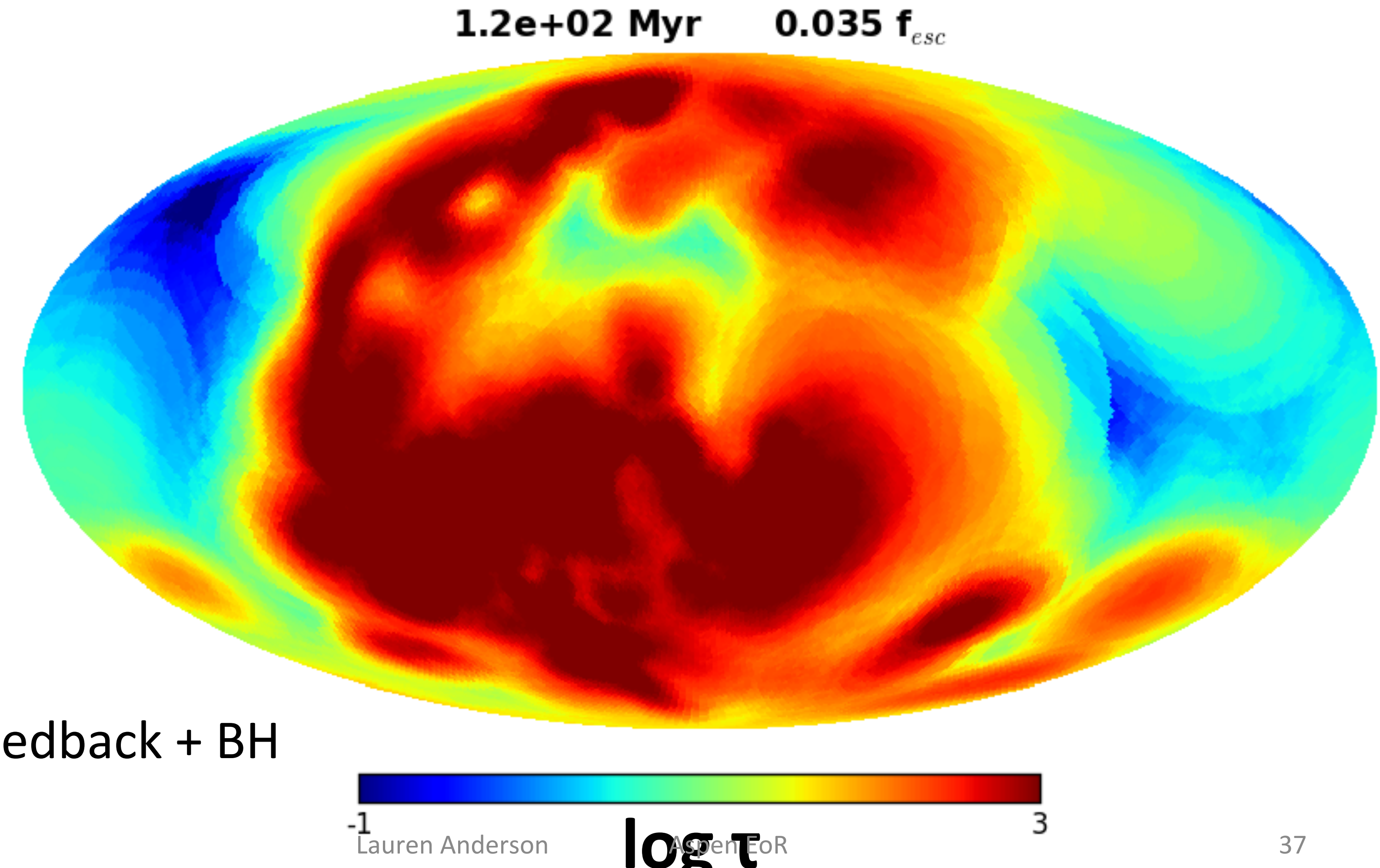
Stellar Feedback + BH

Optical Depths Seen by One Individual Stellar Particle



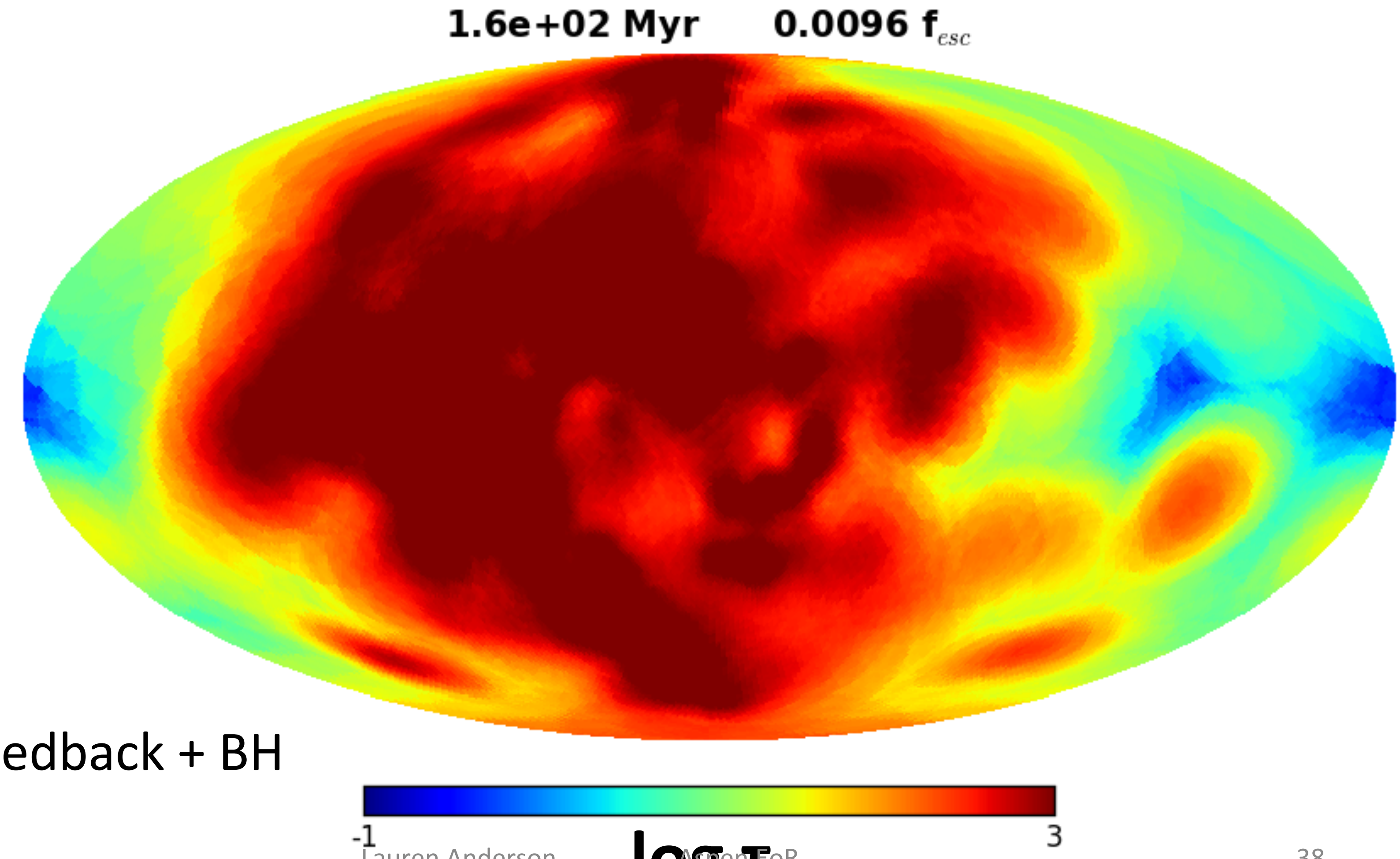
Stellar Feedback + BH

Optical Depths Seen by One Individual Stellar Particle



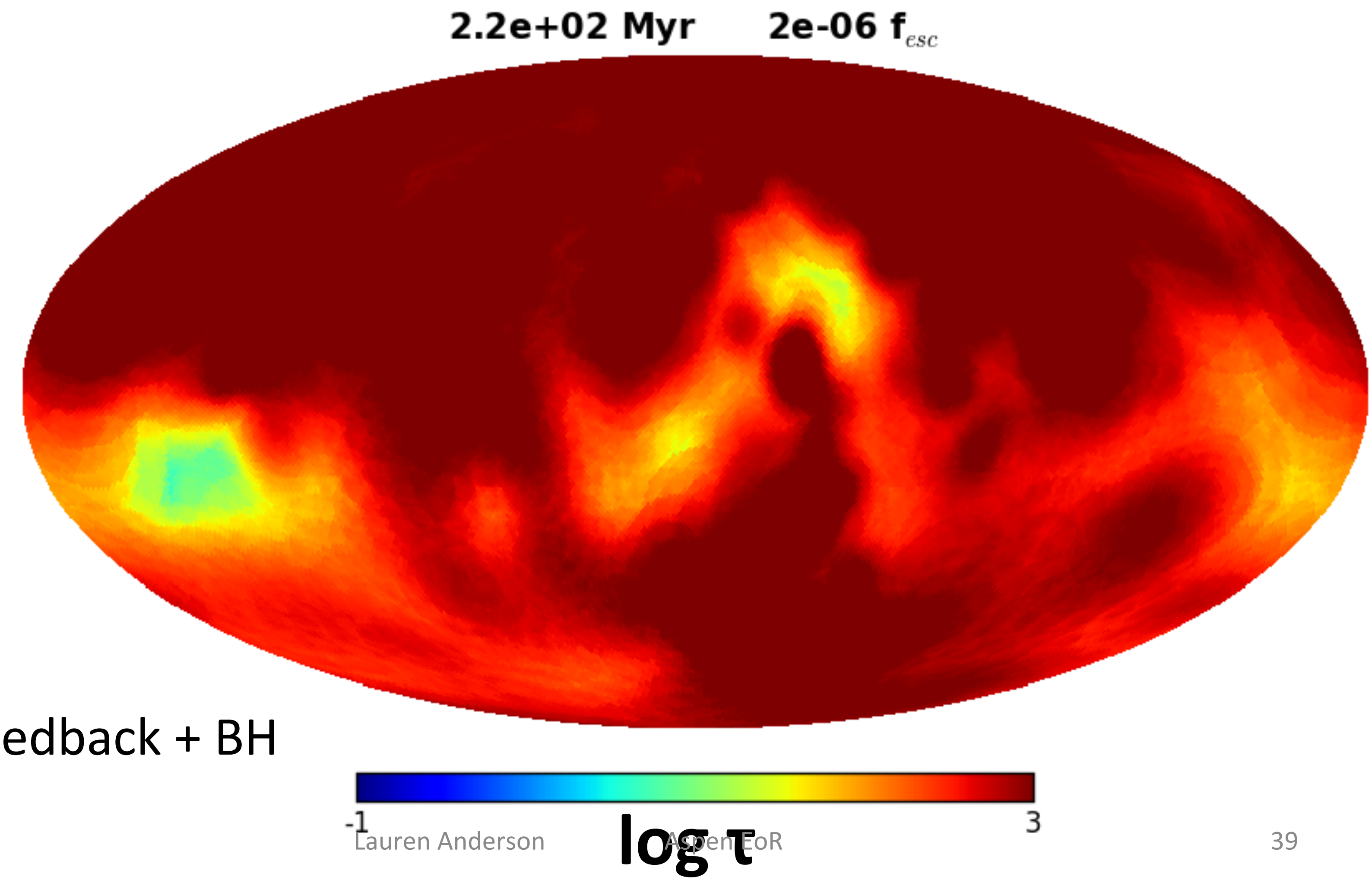
Stellar Feedback + BH

Optical Depths Seen by One Individual Stellar Particle



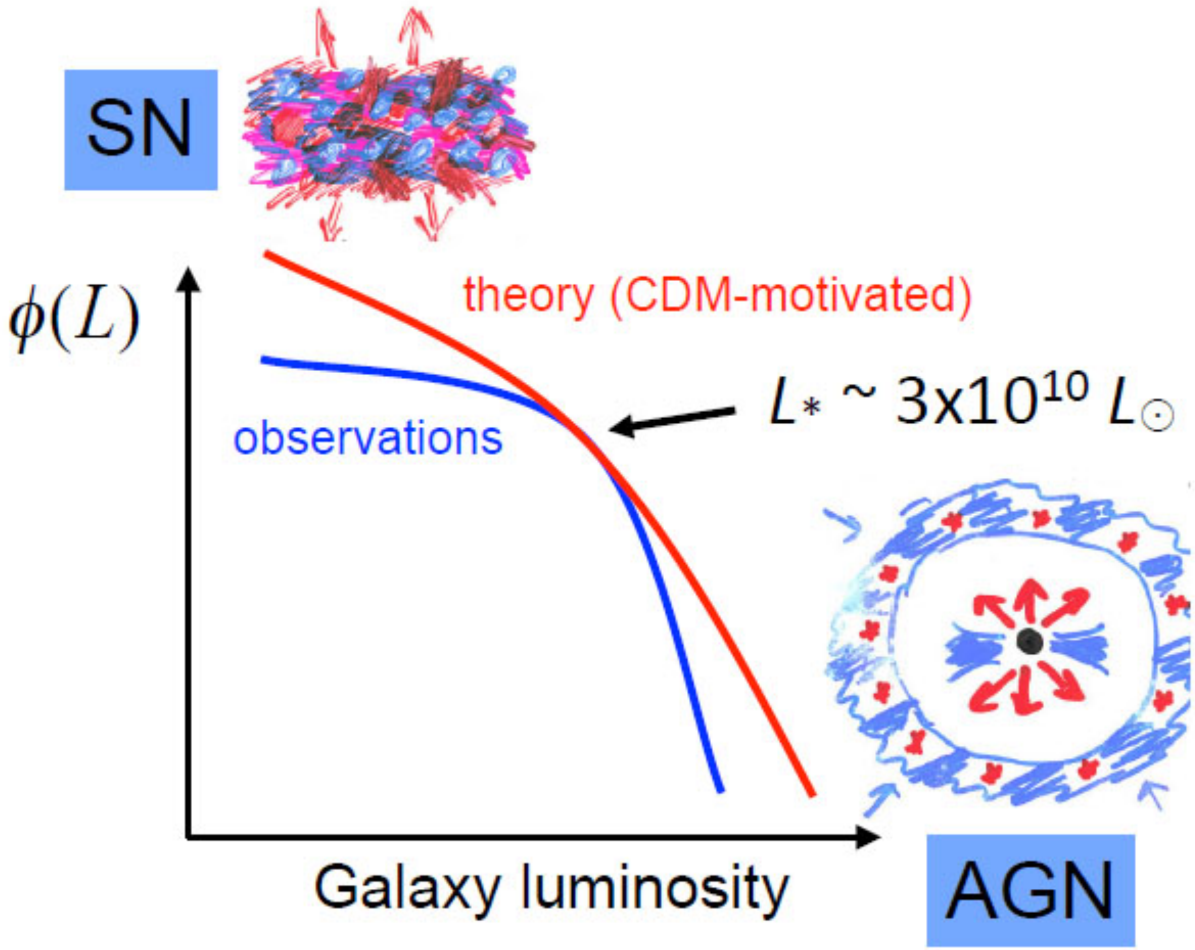
Stellar Feedback + BH

Optical Depths Seen by One Individual Stellar Particle



Stellar Feedback + BH

Black Holes Affect UV LF



Simulations for Future Analysis

	Romulus25	Romulus50	Jericho
Timeline	July 2015	Dec 2016	Dec 2016
Size	$(25\ \mathrm{Mpc})^3$	$(50\ \mathrm{Mpc})^3$	Milky Way
Nparticles	2 billion	15 billion	0.3 billion
Duration in z	100-0	100-0	100-1
Gravity Resolution	350 pc	350 pc	20 pc
Morphologies	5e9 M_*	5e9 M_*	6e8 M_*
Size	10 TB	100 TB	1 TB
Extra Physics	SMBHs		H2 SMBHs