# Fluorescent rings in RELHICs

**Calvin Sykes**

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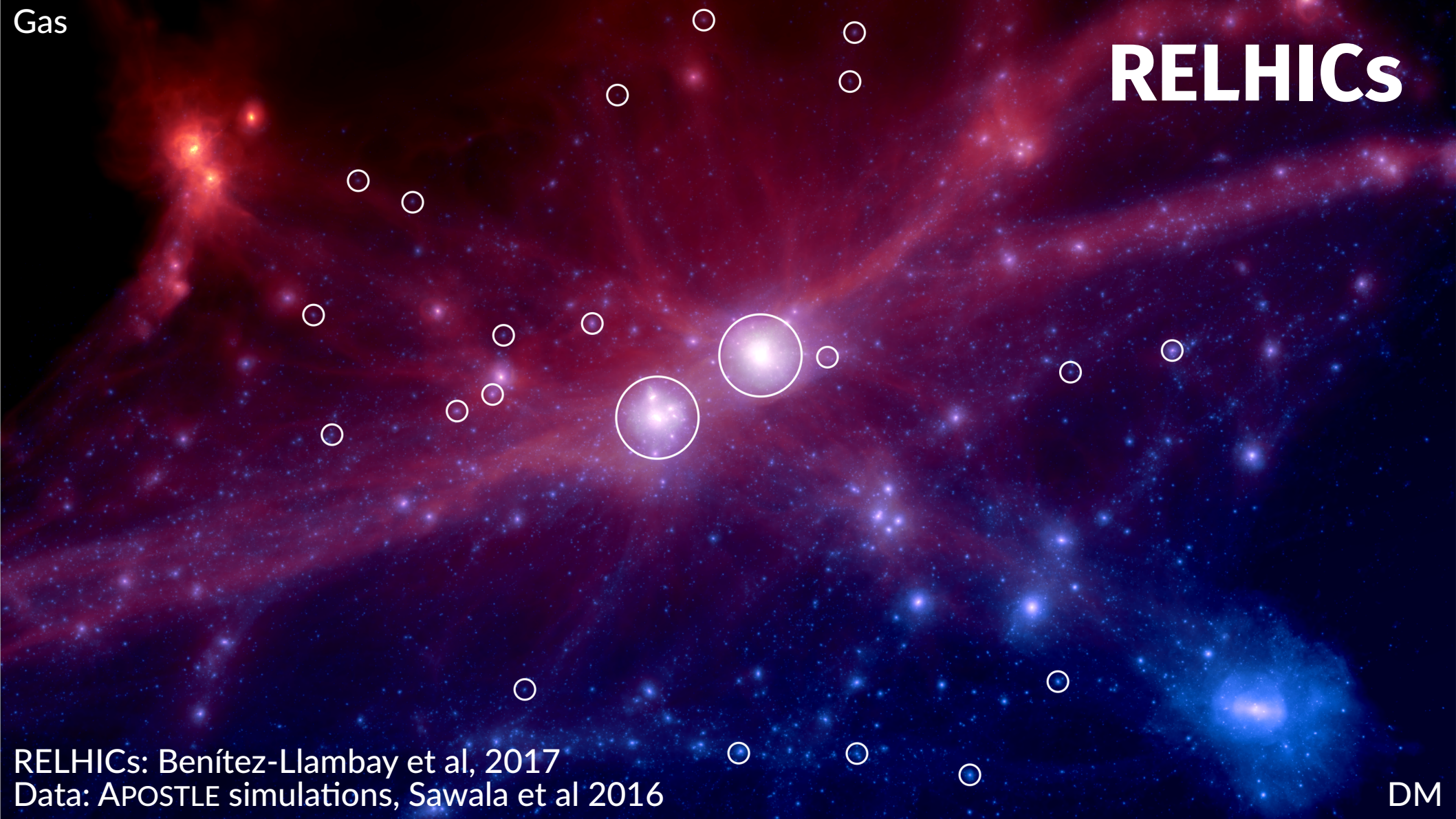
(*with M. Fumagalli, R. Cooke, T. Theuns, A. Benítez-Llambay*)

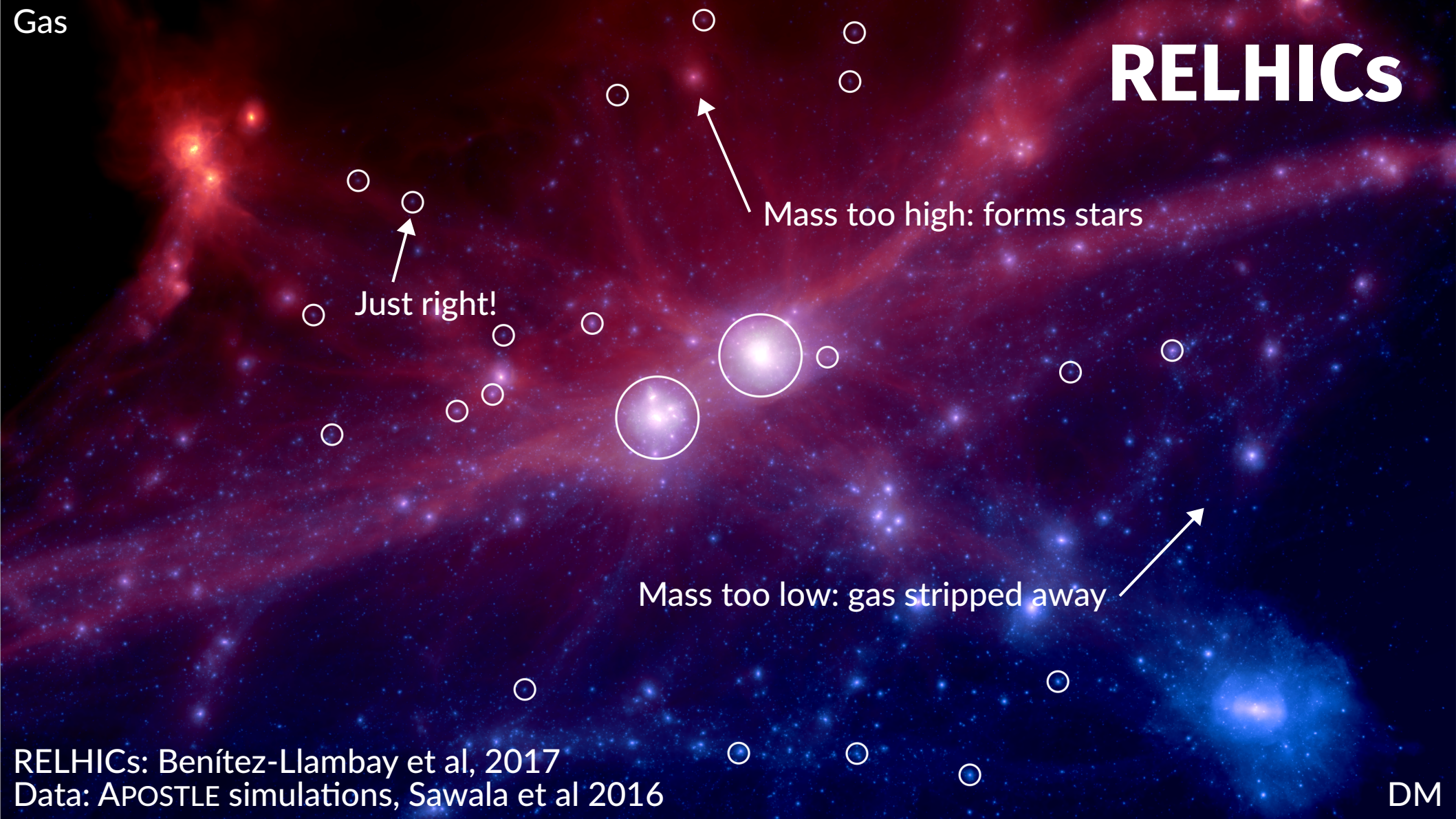
**Small Galaxies, Cosmic Questions**
**Durham, 29 July 2019**

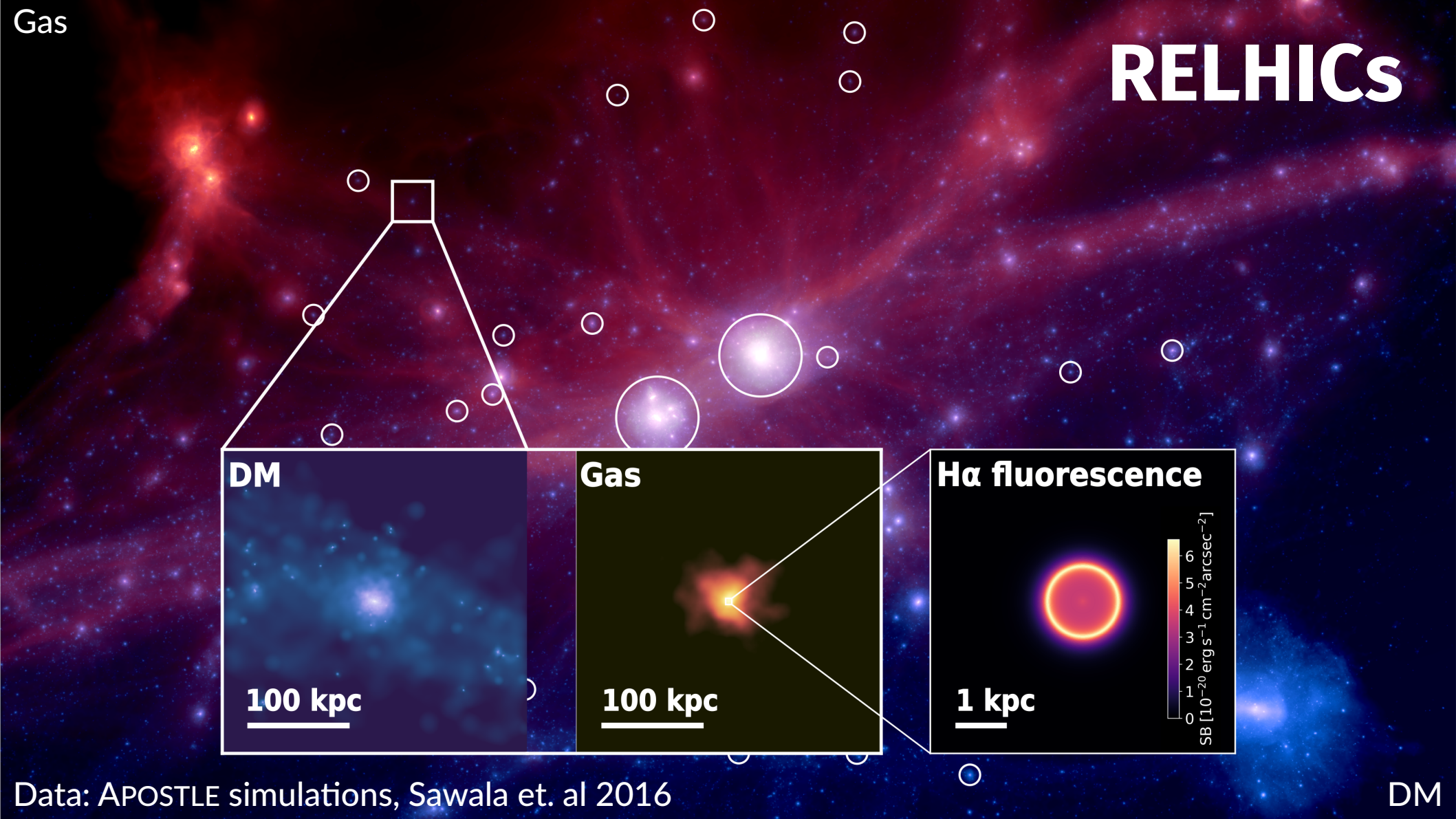
Durham University

ICC

Durham Centre for Extragalactic Astronomy


Gas
RELHICs
RELHICs: Benítez-Llambay et al, 2017
Data: APOSTLE simulations, Sawala et al 2016
DM


Gas
RELHICs
Mass too high: forms stars
Just right!
Mass too low: gas stripped away
RELHICs: Benítez-Llambay et al, 2017
Data: APOSTLE simulations, Sawala et al 2016
DM


Gas
RELHICs
DM
100 kpc
Gas
100 kpc
Hα fluorescence
1 kpc
SB [$10^{-20}$ erg $s^{-1}$ $cm^{-2}$ $arcsec^{-2}$]
0
1
2
3
4
5
6
Data: APOSTLE simulations, Sawala et. al 2016
DM

# Why does this happen?

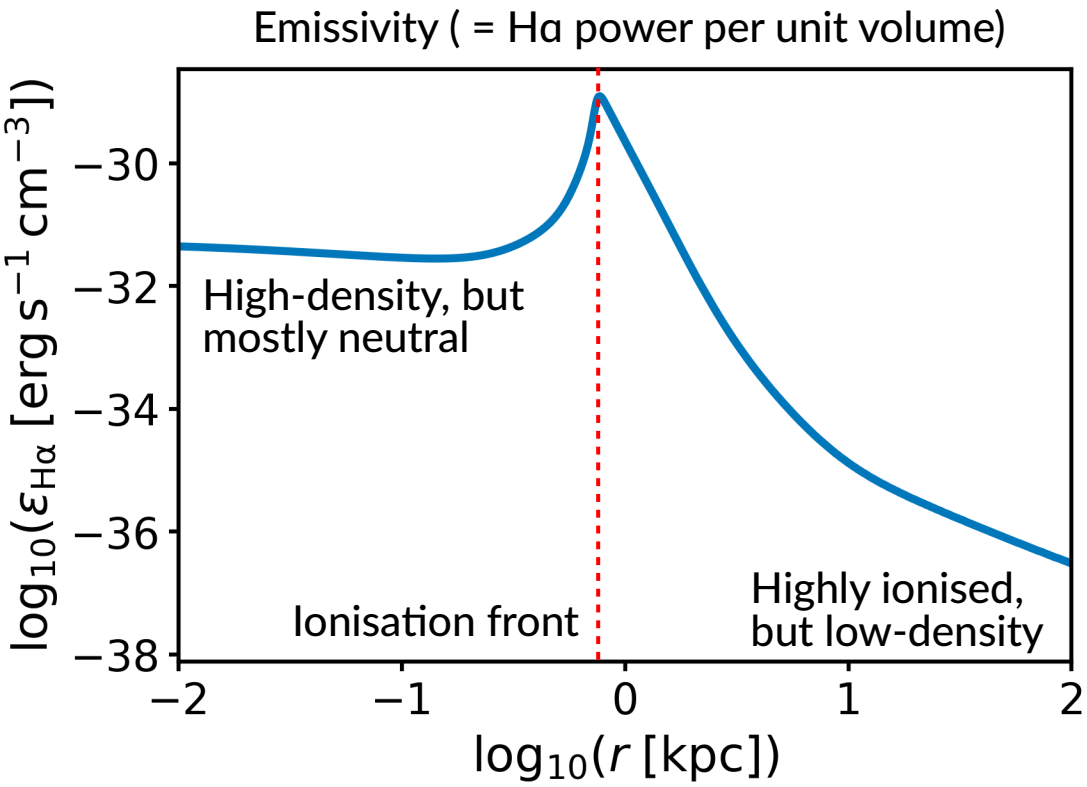
# Predicting Hα emission

Gas in RELHICs is illuminated by the ultraviolet background (UVB)

Model this interaction using our own radiative transfer code*

Solve for hydrostatic, thermal and ionisation equilbrium to determine Hα emissivity

Sharp peak at ionisation front...




*https://github.com/calvin-sykes/spherical_cloudy

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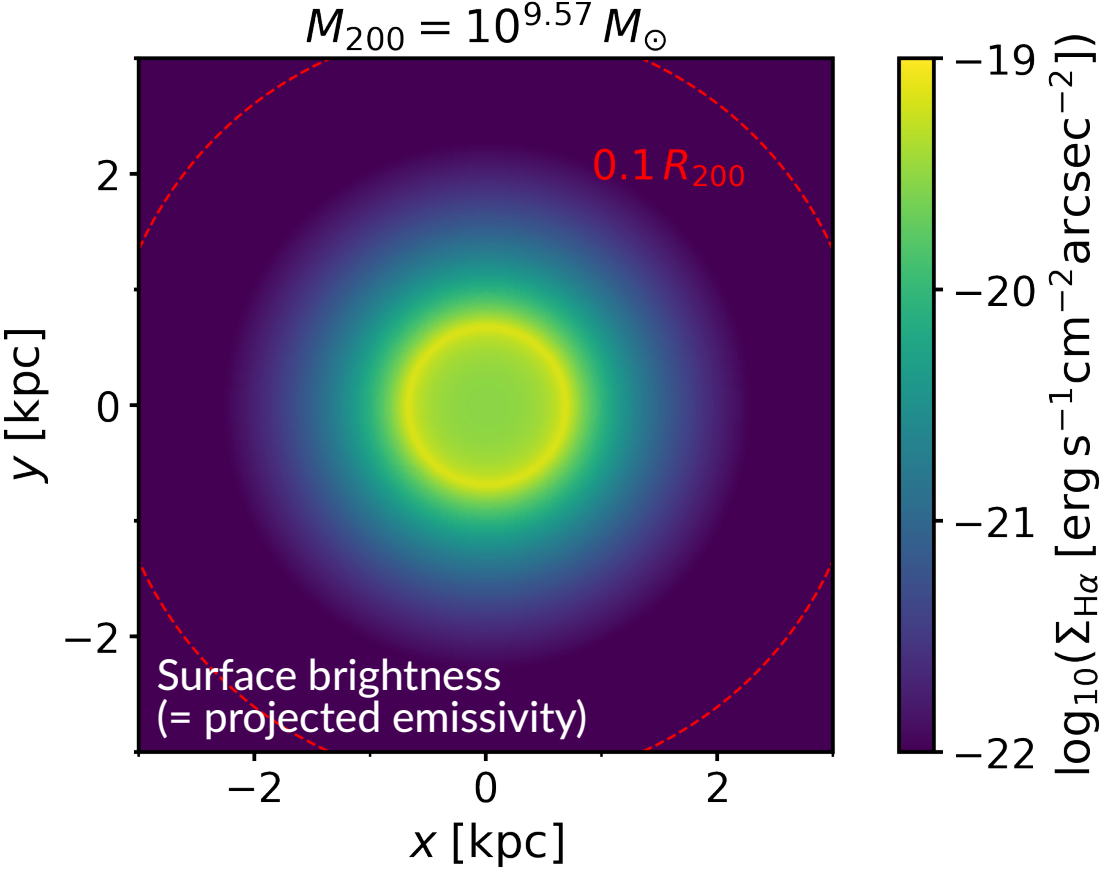


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See Sykes et al 2019, *MNRAS* 487, 609-621

# Predicting Hα emission

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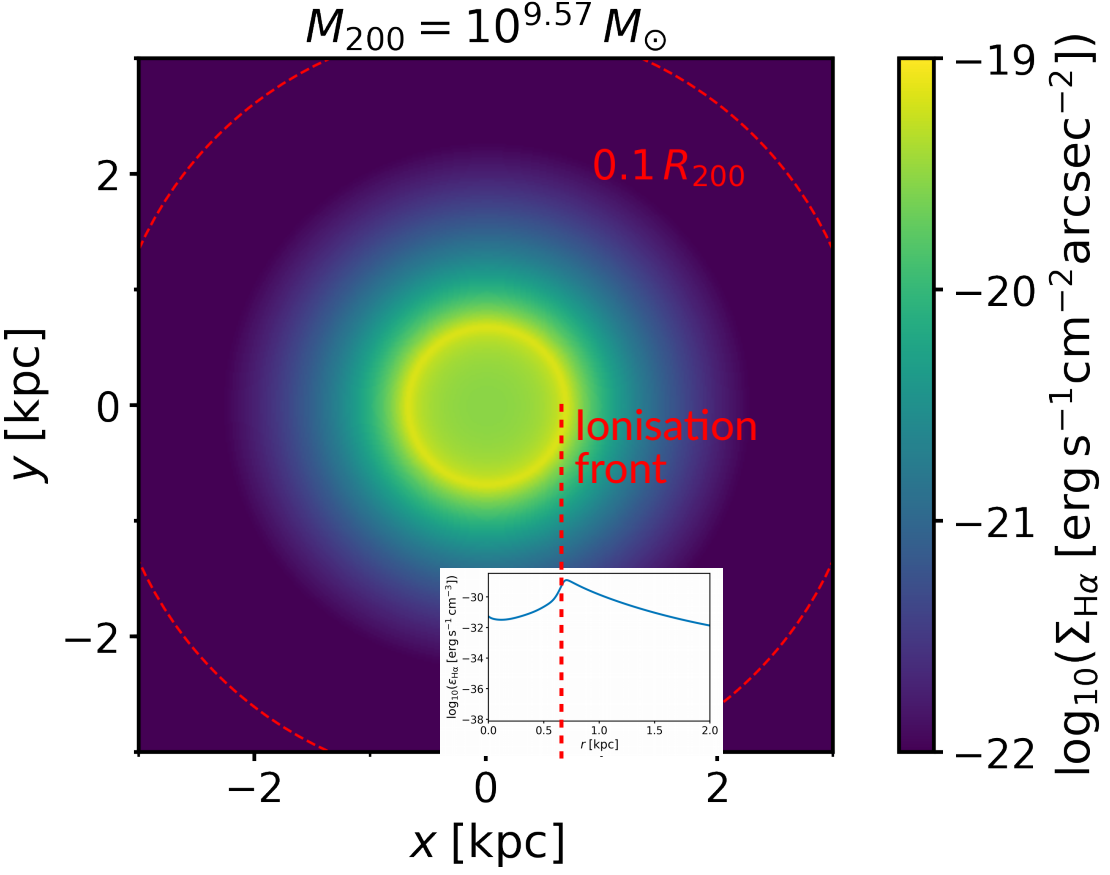


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# What can we learn from rings?

# What can we learn?

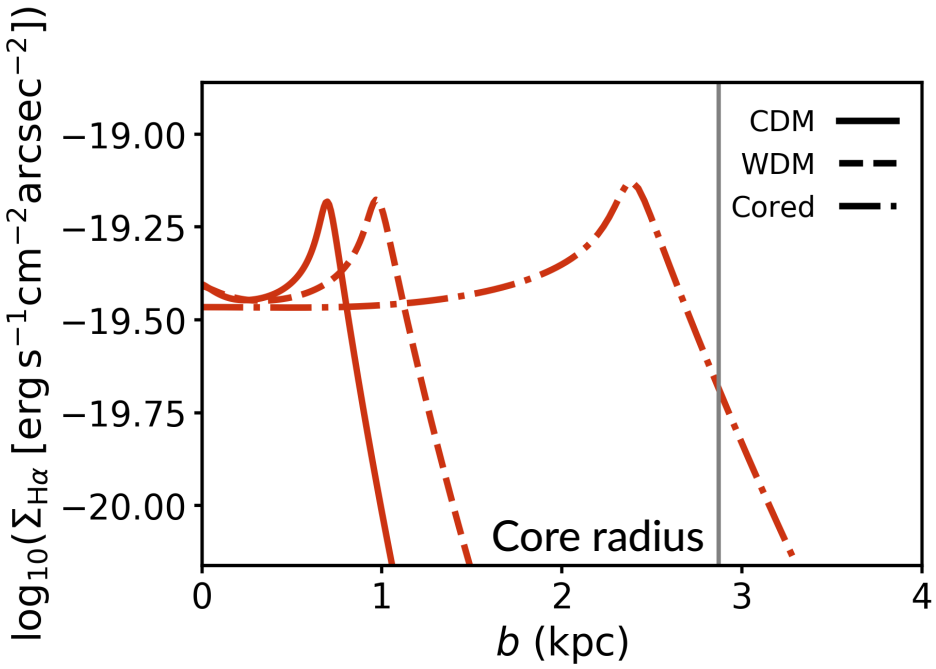
Observable properties of these rings are sensitive to:

- Properties of dark matter (CDM/WDM, cusps/cores)
- Primordial abundance of helium
- Amplitude and shape of the ultraviolet background

# DM properties from size of ring

Projected size of the ring is sensitive to properties of DM halo

Apparent size of ring is degenerate with distance and halo mass



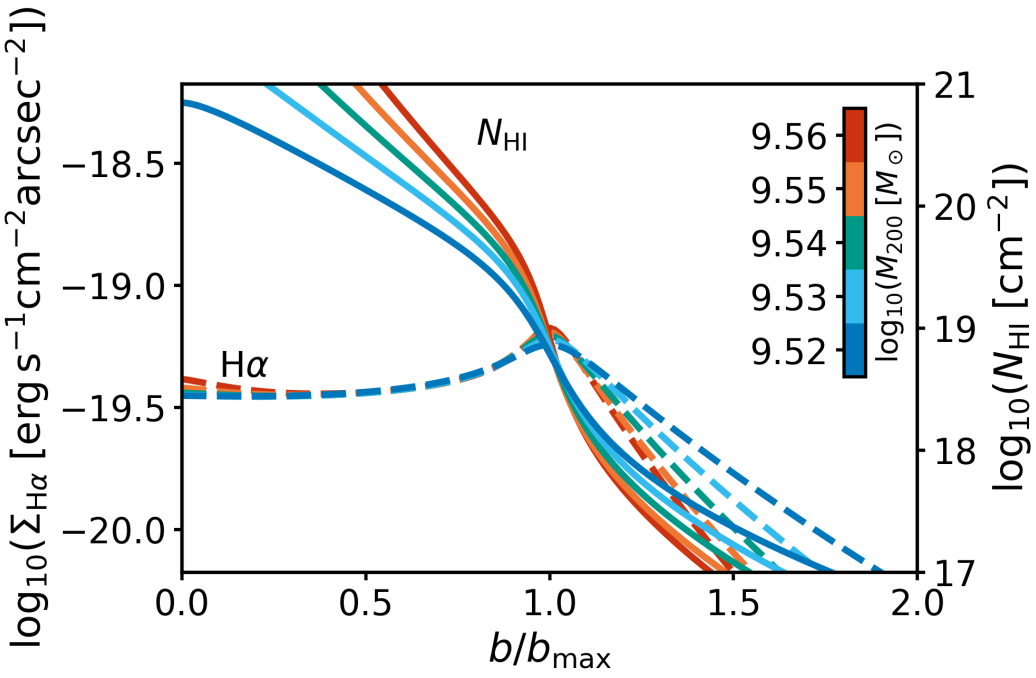

(N.B.: models shown here are illustrative only!)

# Combined constraints from Hα + HI 21cm

Can break this degeneracy if HI profile is also known

Within a family of models, profiles are steeper for higher masses

Combining ring size, brightness, and profile slope can uniquely determine DM profile




Sykes+ 2019a, *MNRAS*

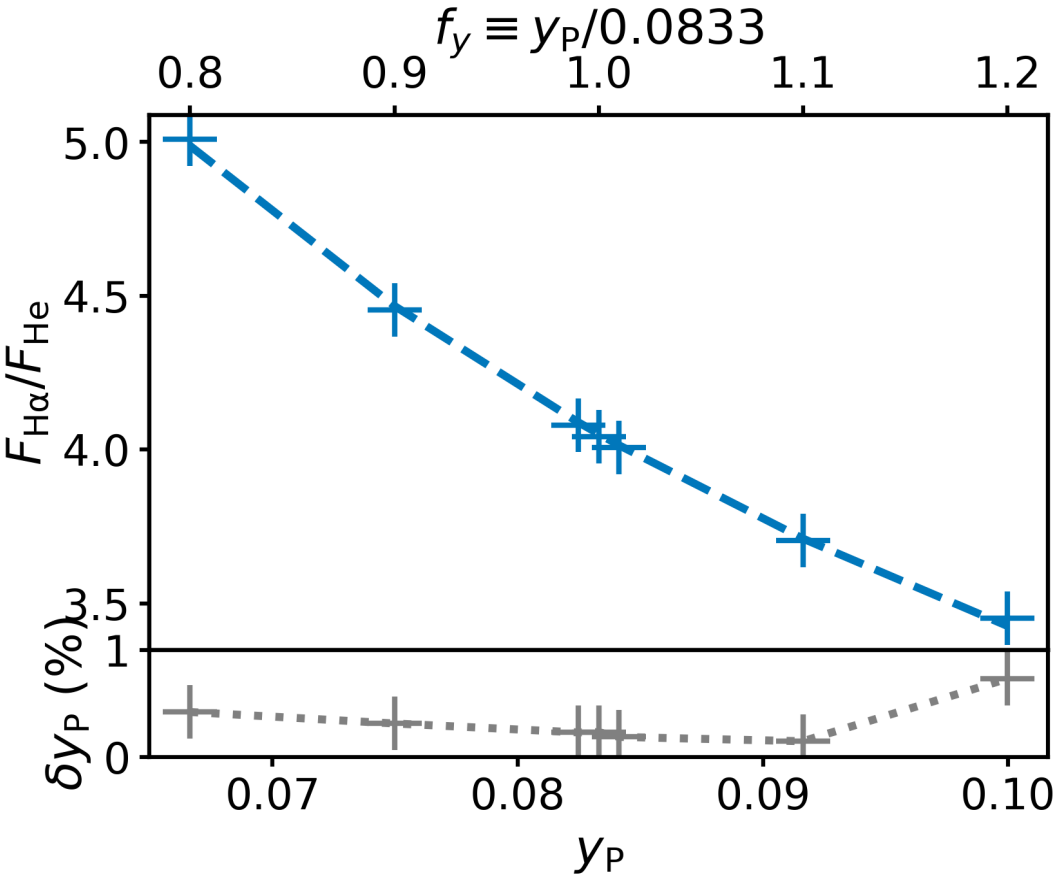
# Primordial helium from flux ratios

Rings are expected for helium recombination lines too!

Comparing Hα and He integrated flux gives $y_p$ to within 1% precision

Compared to using H II regions:

- fully in low density regime
- no stellar contamination




Sykes+ 2019b, in prep

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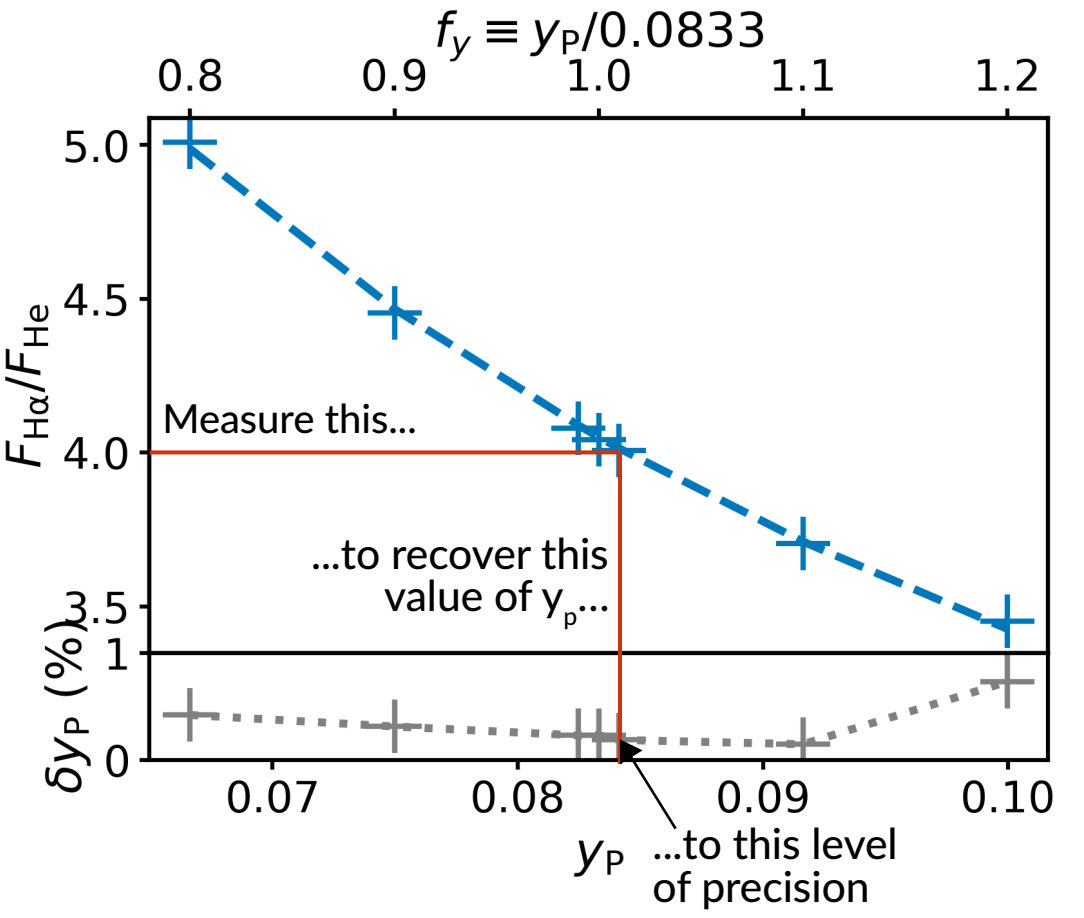
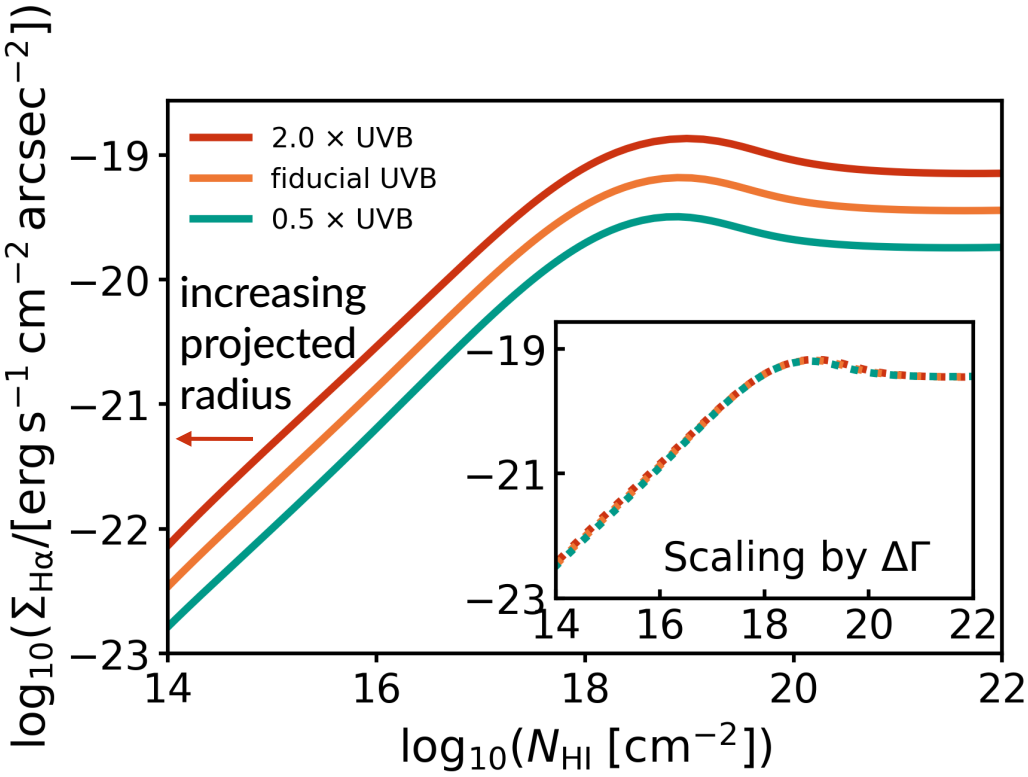



Sykes+ 2019b, in prep

# UVB intensity from brightness of ring

UVB is difficult to constrain at low-$z$ due to stellar contamination

Star-free RELHICs provide a solution: Hα ring brightness is directly proportional to UVB intensity



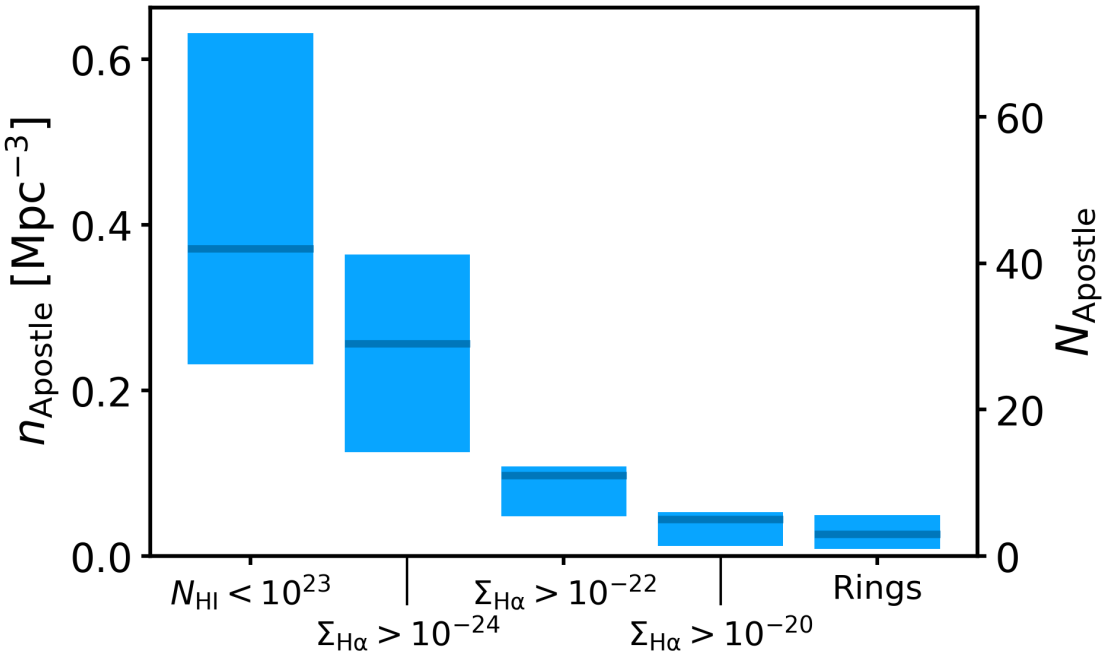

Sykes+ 2019a, *MNRAS*

# Are they actually detectable?

# Number density of rings in LG

Rings are rare: expect ~few per Apostle volume

Impractical to find around MW, but surveying comparable volume much easier around other galaxies

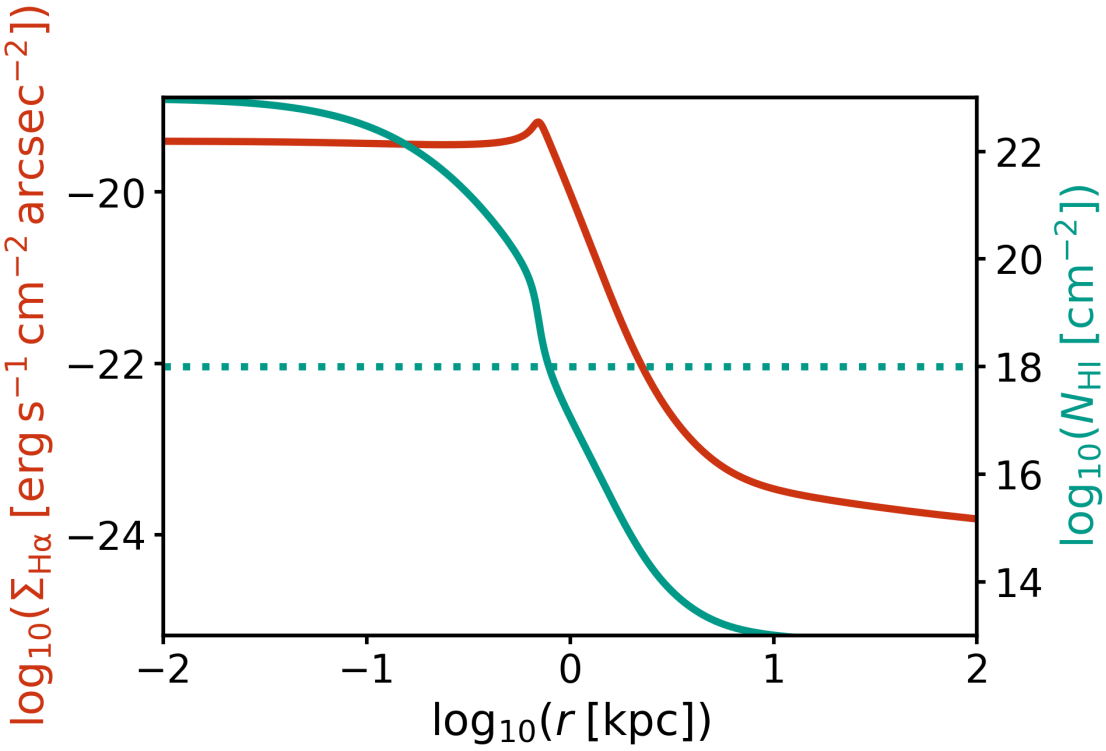



Sykes+ 2019a, *MNRAS*

# Detection strategy

Higher-mass RELHICs are bright HI emitters detectable in deep HI surveys

Followup with deep imaging to rule out stellar component, then search for Hα with MUSE



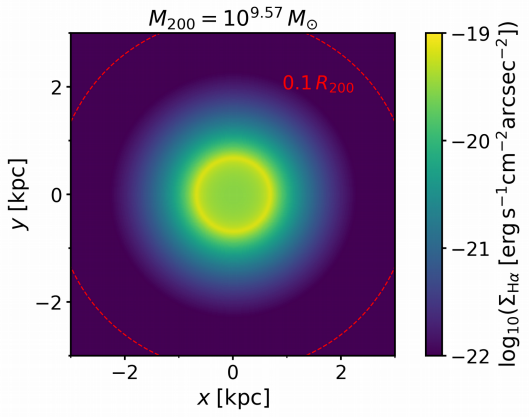
# Summary

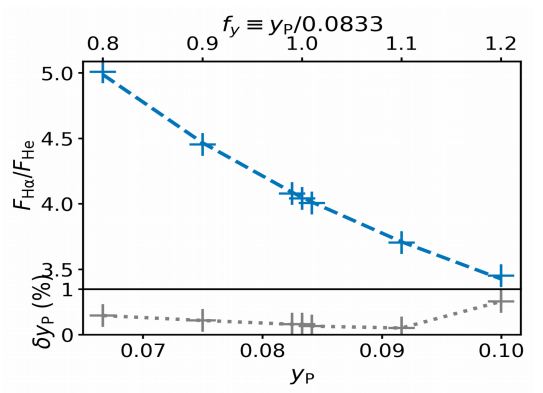
Hα emission from massive RELHICs appears ring-shaped in projection

Properties of rings are sensitive to UVB, halo mass and density profile, and $y_p$

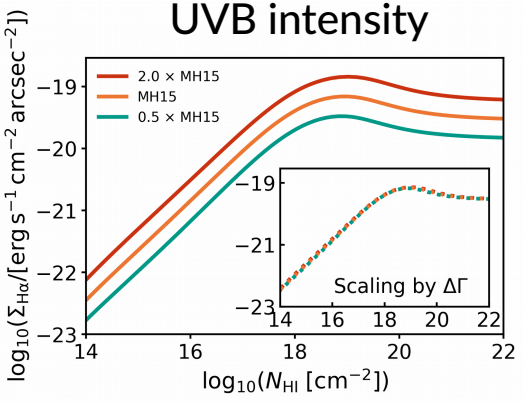
Observing a ring would allow these to be constrained

Primordial helium abundance

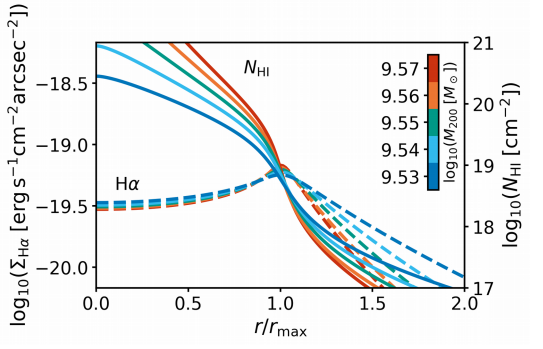



UVB intensity




DM mass and properties

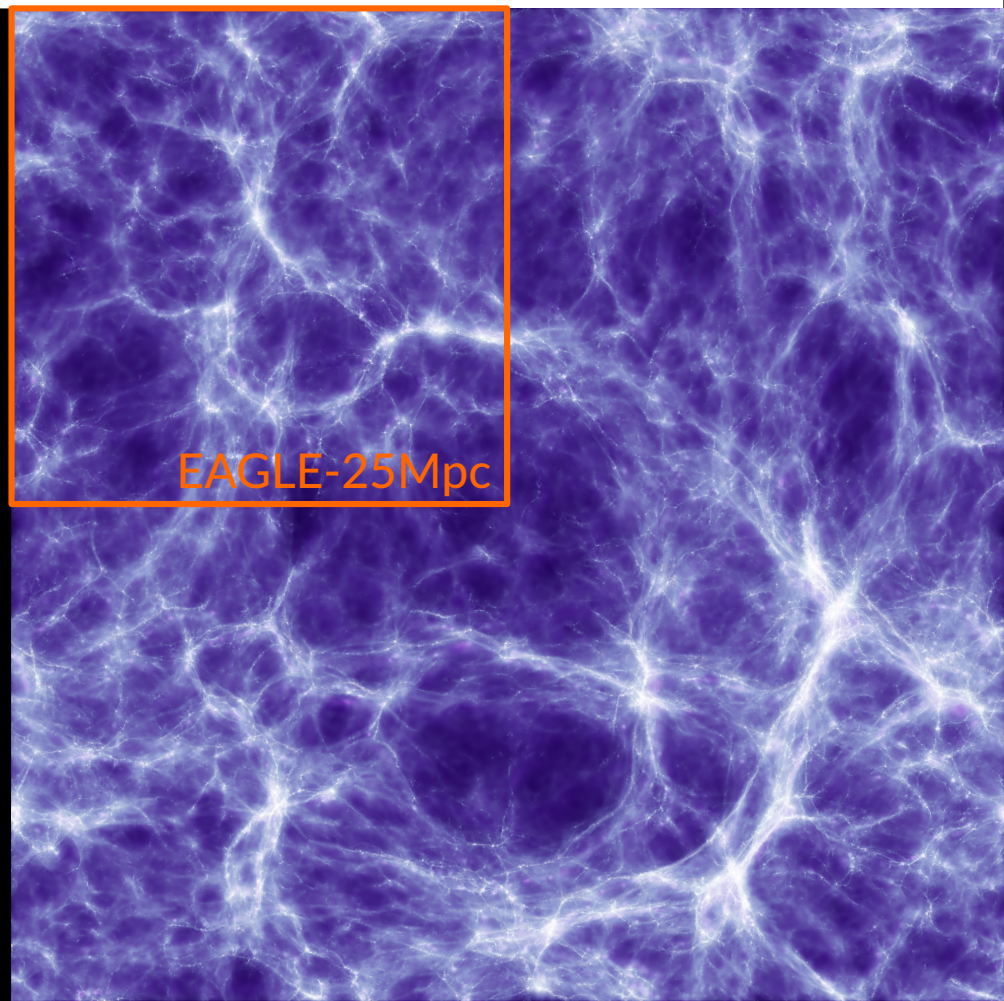



Sykes et al 2019, *MNRAS* 487, 609-621

# ENGinE

Suite of 50 Mpc/h boxes at same resolution as EAGLE high-res ($M_{bar}$=2.3x$10^5$ $M_\odot$)

Aim: do RT in postprocessing and look at distribution, properties of HI absorbers



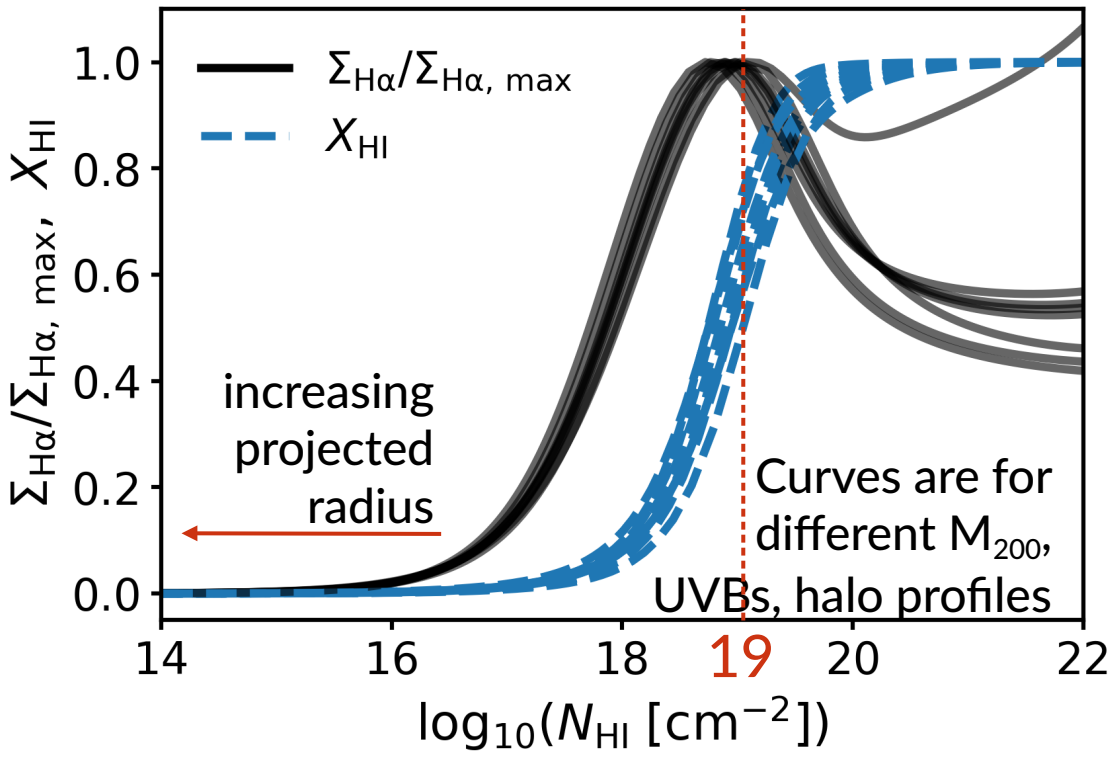
# Extra slides

# Self-similarity in profiles

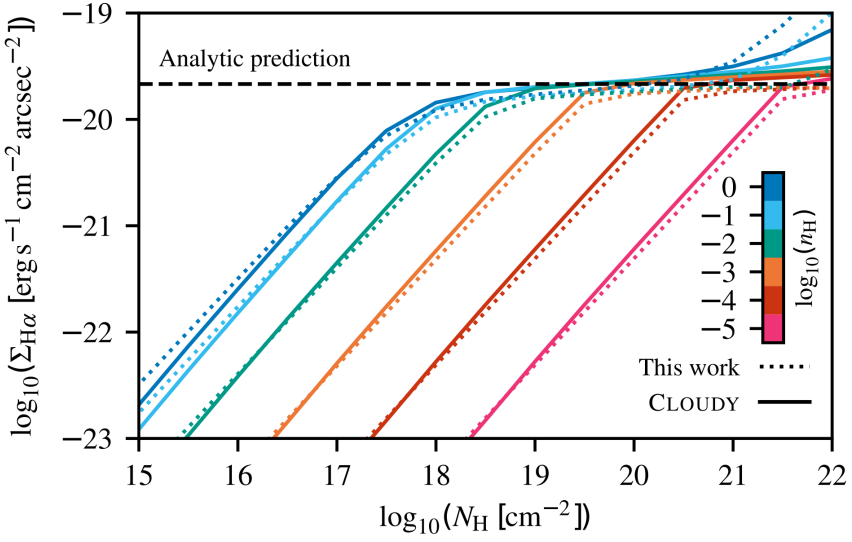
Surface brightness always maximal at $N_{HI} \sim 10^{19} cm^{-2}$

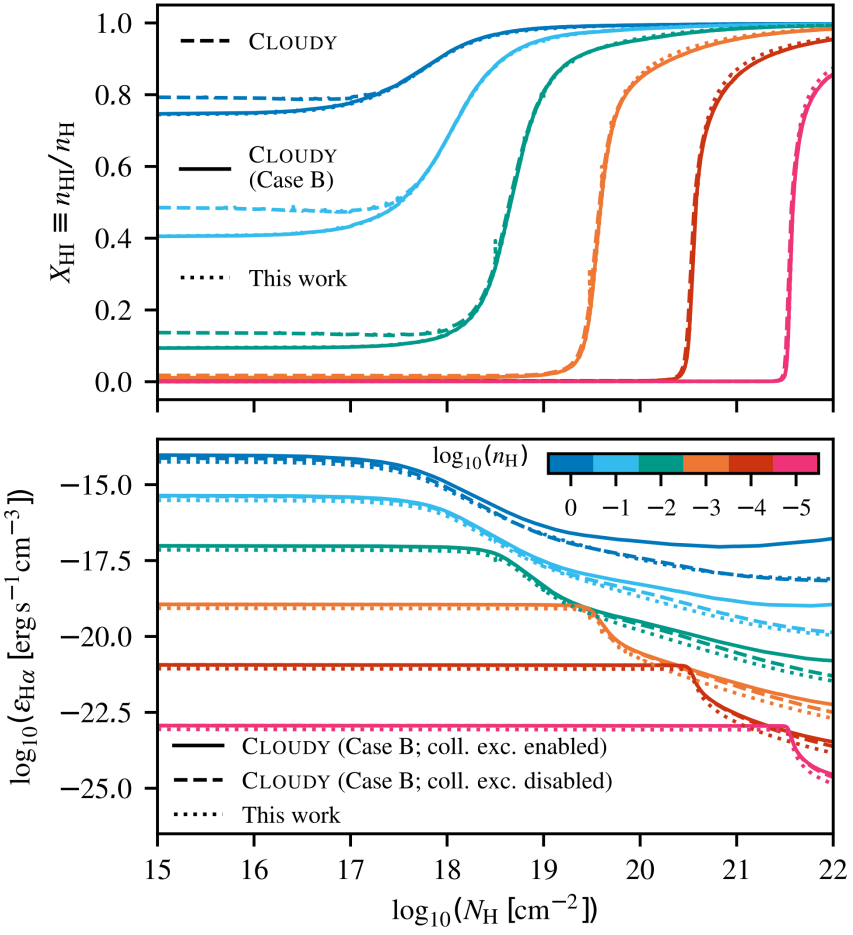
This coincides with the ionisation front

Provides a “fixed point” despite substantial variation in profile size and shape

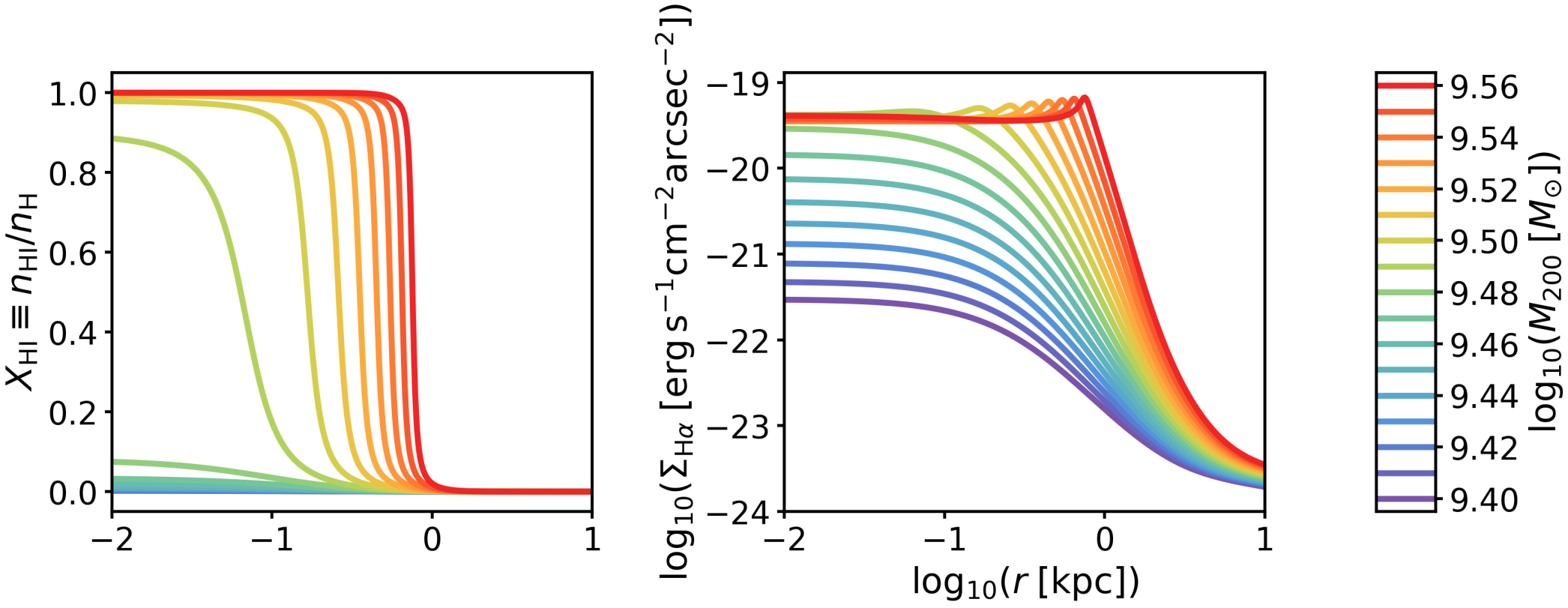


# Tests of our RT code

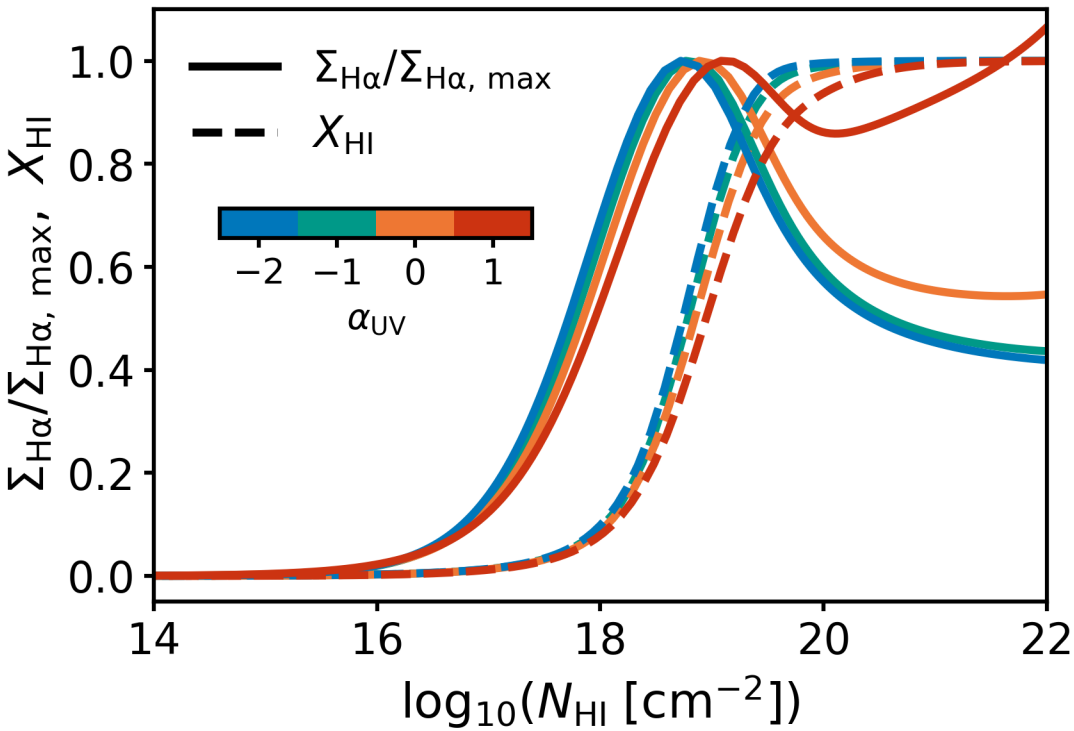


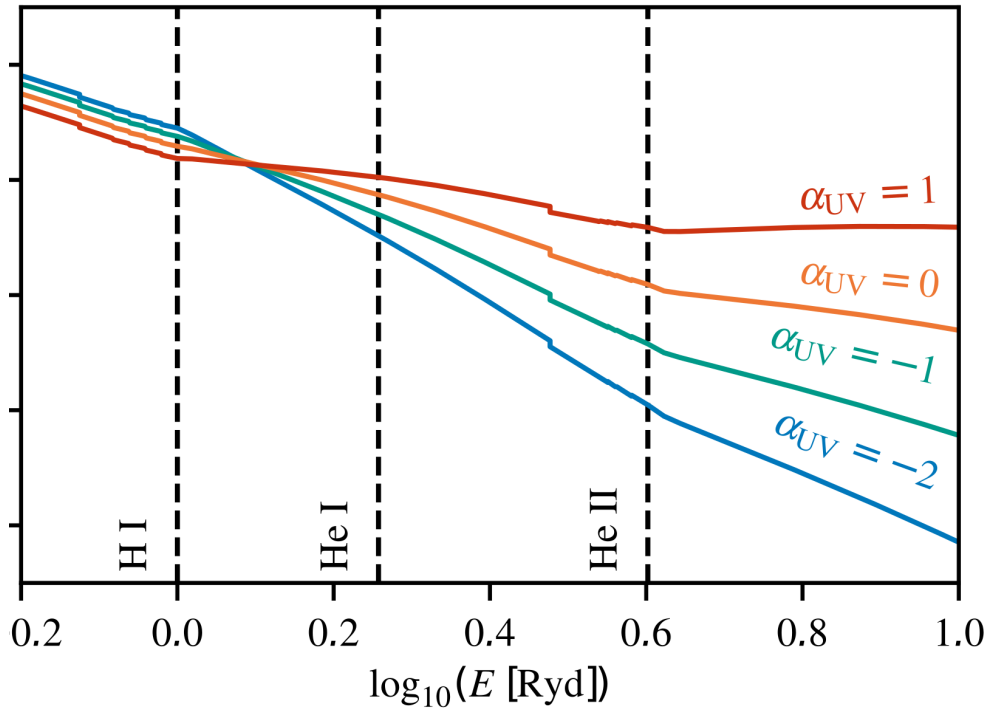



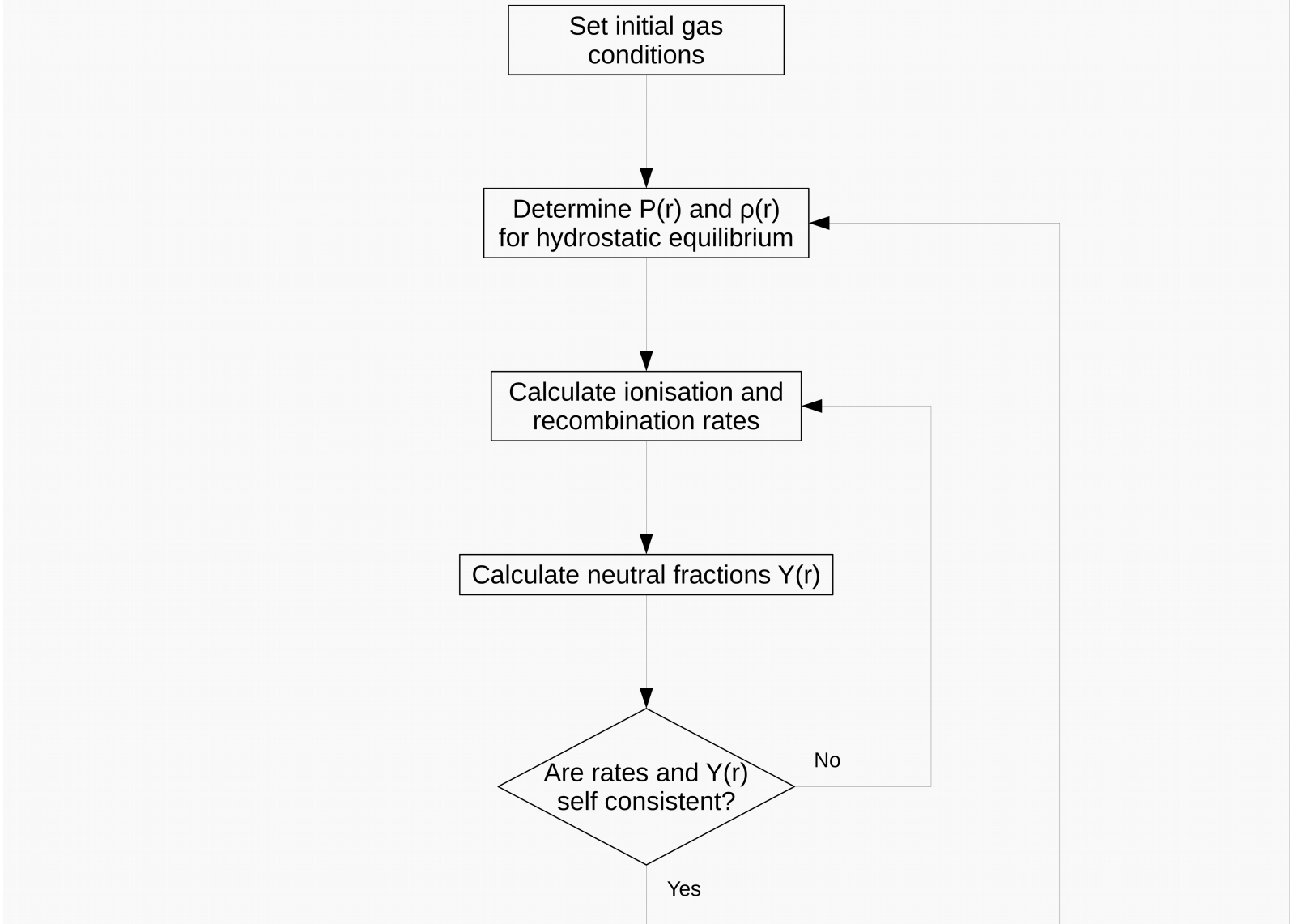
# Mass range for which rings appear

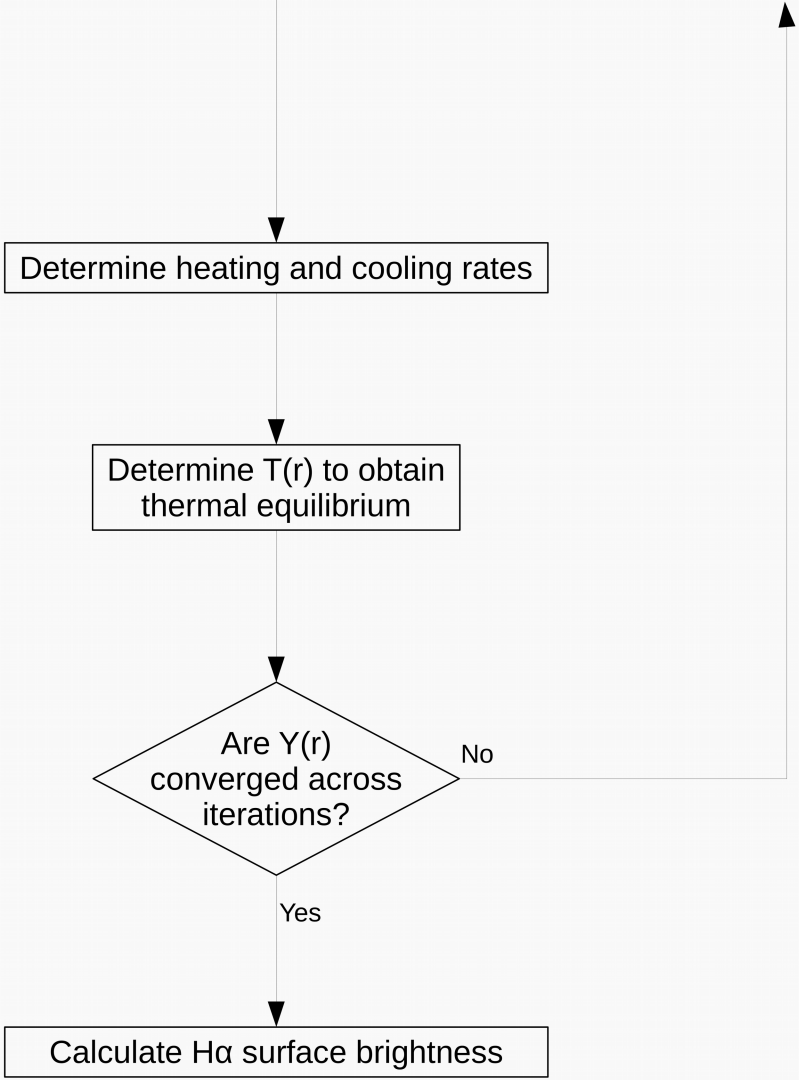


# UVB slope


$\Sigma_{H\alpha}/\Sigma_{H\alpha,\,max}$
$X_{HI}$
$\alpha_{UV}$
−2 −1 0 1
$\Sigma_{H\alpha}/\Sigma_{H\alpha,\,max}$, $X_{HI}$
0.0 0.2 0.4 0.6 0.8 1.0
14 16 18 20 22
$\log_{10}(N_{HI}\,[cm^{-2}])$


$\alpha_{UV} = 1$
$\alpha_{UV} = 0$
$\alpha_{UV} = -1$
$\alpha_{UV} = -2$
H I
He I
He II
0.2 0.0 0.2 0.4 0.6 0.8 1.0
$\log_{10}(E\,[Ryd])$


Set initial gas conditions
Determine P(r) and ρ(r) for hydrostatic equilibrium
Calculate ionisation and recombination rates
Calculate neutral fractions Y(r)
Are rates and Y(r) self consistent?
No
Yes


Determine heating and cooling rates
Determine T(r) to obtain thermal equilibrium
Are Y(r) converged across iterations?
No
Yes
Calculate Hα surface brightness

# ENGinE halo mass function