Feedback regulated escape of ionising photons from high redshift galaxies

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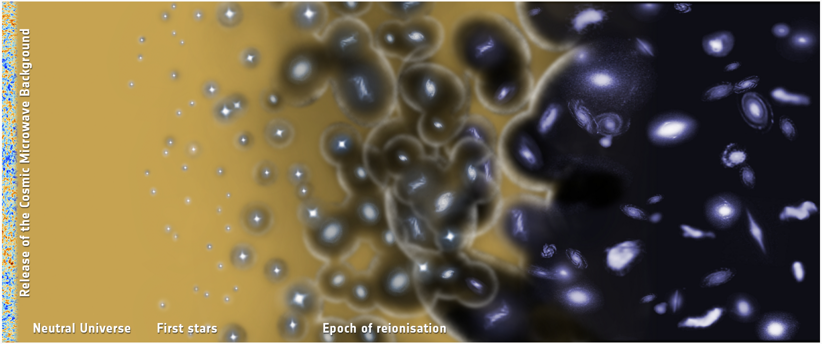
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

The Epoch of Reionisation

After ~ 1 Gyr, the gas in the Universe gets reionised



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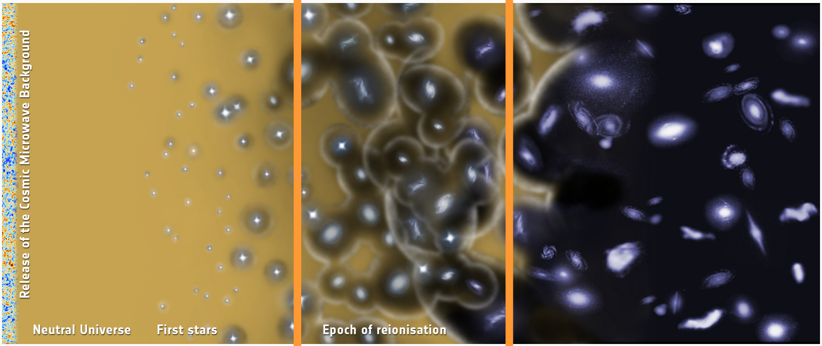
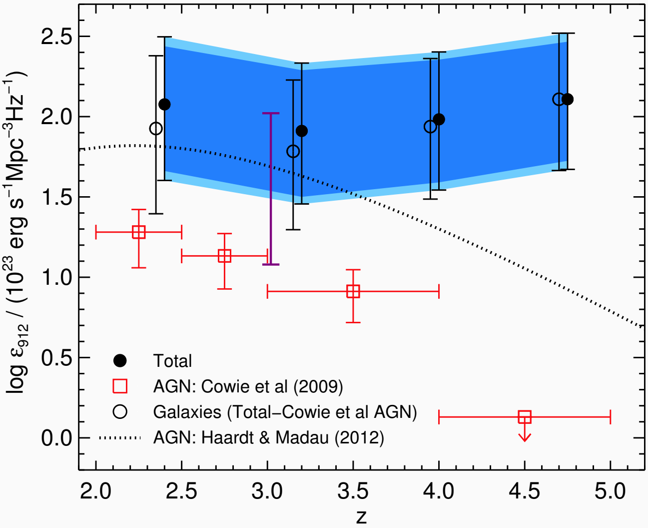


$z \sim 20 \rightarrow 6$

What about the sources?

What about the sources?

Subdominant contribution from QSOs



Becker & Bolton 2013

Reionisation by galaxies

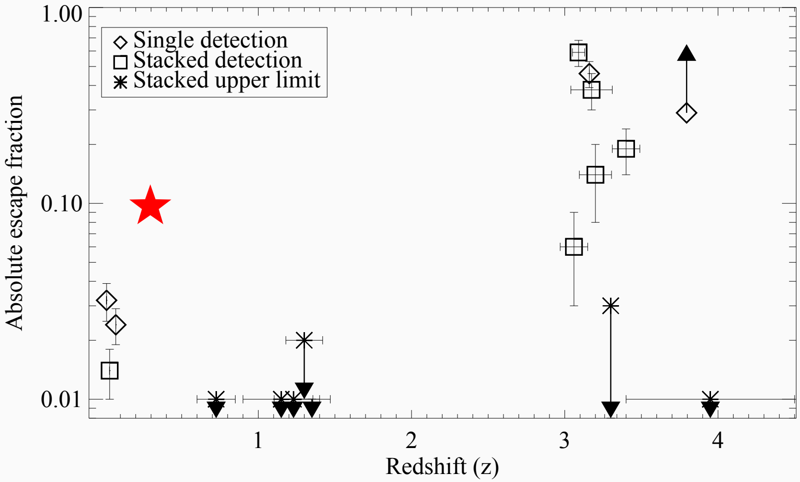
Photon production rate

$$\dot{N}_{ion} = \rho_{\mathrm{SFR}} \times \kappa_{ion} \times f_{\mathrm{esc}}$$
$$= \rho_{\mathrm{UV}} \times \xi_{ion} \times f_{\mathrm{esc}}$$

- $\rho_{\mathrm{UV}} \to$ How many galaxies?
- $\xi_{ion} \to$ How much ionising radiation do they produce?
- $f_{\mathrm{esc}} \to$ How much of this radiation can escape?

Escape fraction

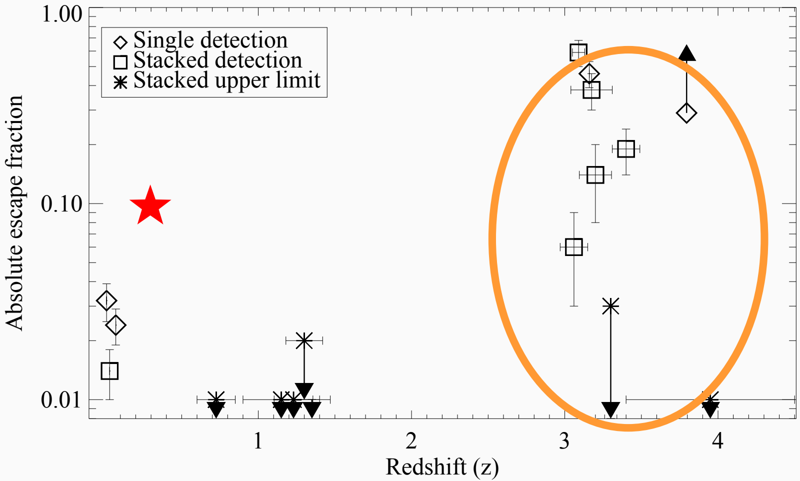
Observational constraints on f_{esc}



Bergvall+2013

Escape fraction

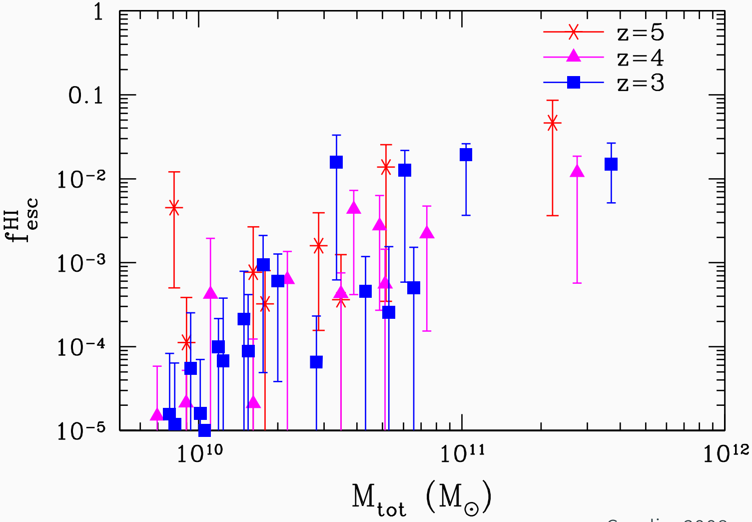
Observational constraints on $f_{\rm esc}$



Bergvall+2013

What can we learn from simulations?

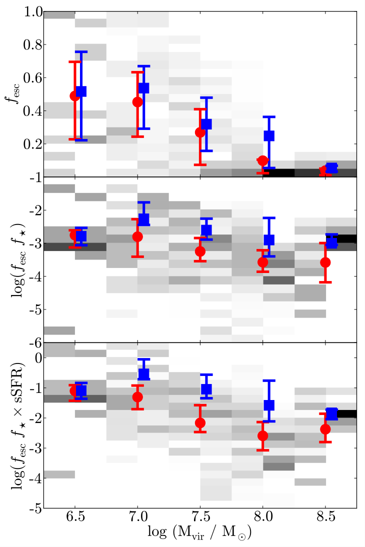
$f_{esc} \nearrow$ with M_{vir}?



Gnedin+2008

Simulating the escape of ionising radiation

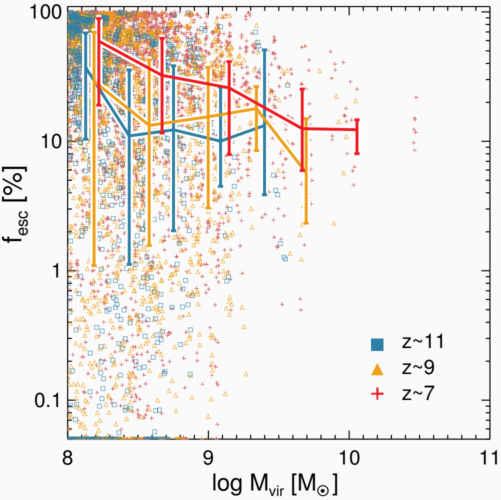
$f_{esc} \searrow$ with M_{vir}?



Wise+2014

Simulating the escape of ionising radiation

$f_{esc} \searrow$ with M_{vir}?



Kimm & Cen 2014

Simulating the escape of ionising radiation

Why no convergence?

- Very different resolutions
- Radiative transfer is different
- “Target selection” is different
- Very different subgrid models (star formation, SN feedback, etc.)
- …

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Can we understand the physical processes regulating f_{esc}?

Simulation setup

- Cosmological zooms in a $10h^{-1}$ cMpc box down to $z \sim 5.6$
- Initial conditions from MUSIC
- RHD runs with RAMSES-RT (Rosdahl+13), 3 photons groups
- Very high resolution
  - $l_{max} = 21 \Leftrightarrow \Delta x \sim 7$ pc
  - $m_{\rm DM} \simeq 2 \times 10^3 M_\odot$
  - $m_\star \simeq 135 M_\odot$
- Three haloes:
  - Small: $\mathrm{M_{vir}} = 8 \times 10^7 \mathrm{M_\odot}$
  - Medium: $\mathrm{M_{vir}} = 6 \times 10^8 \mathrm{M_\odot}$
  - Large: $\mathrm{M_{vir}} = 2 \times 10^9 \mathrm{M_\odot}$

RHD simulations of galaxy formation

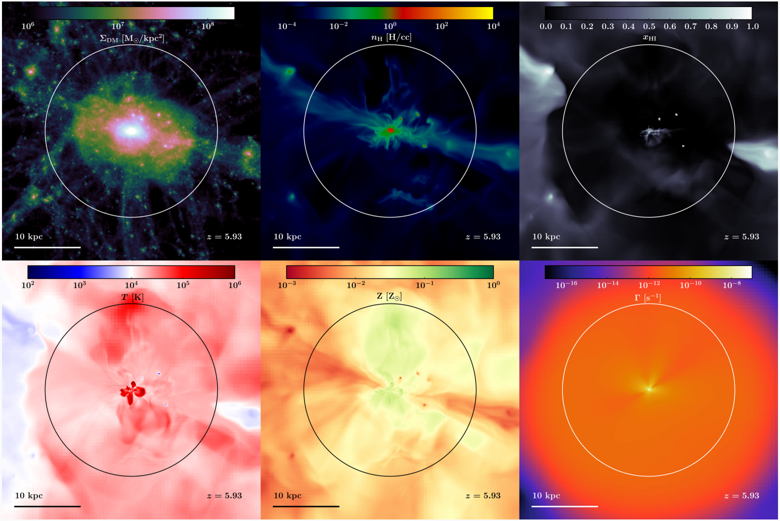
Subgrid physics

- Mechanical SN feedback as in Kimm & Cen (2014)
    - Designed to transfer the “right” amount of momentum at any stage of the SN
    - 10 Myr delay between star formation and SN explosion

  → Powerful galactic winds
- Thermoturbulent star formation (see J. Devriendt’s talk)
    - Account for ISM-scale turbulence
    - Similar to the self-gravitating criterion of Hopkins+2013
    - SF efficiency based on Federrath & Klessen (2012)

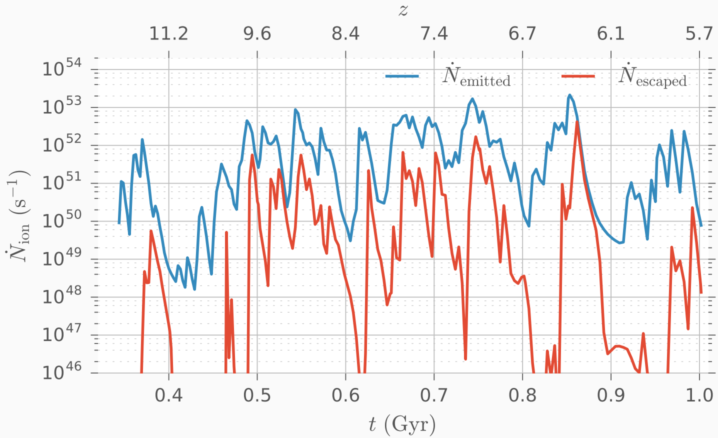
  → SF is clumpy and bursty

Most massive halo ($M_{vir} \simeq 2 \times 10^9 M_\odot$) at $z \sim 6$



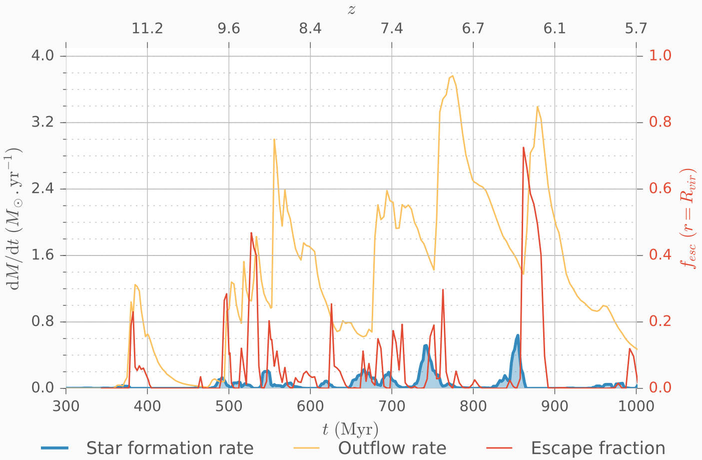
Escape of ionising photons

Photons produced and escape in burst as well



Escape of ionising photons

Feedback regulated escape of photons



Feedback regulated escape of photons

Photons can escape during SN feedback events

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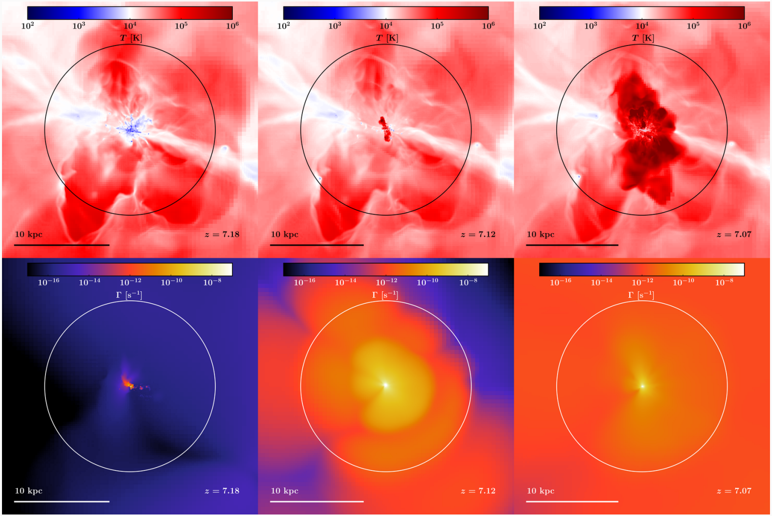
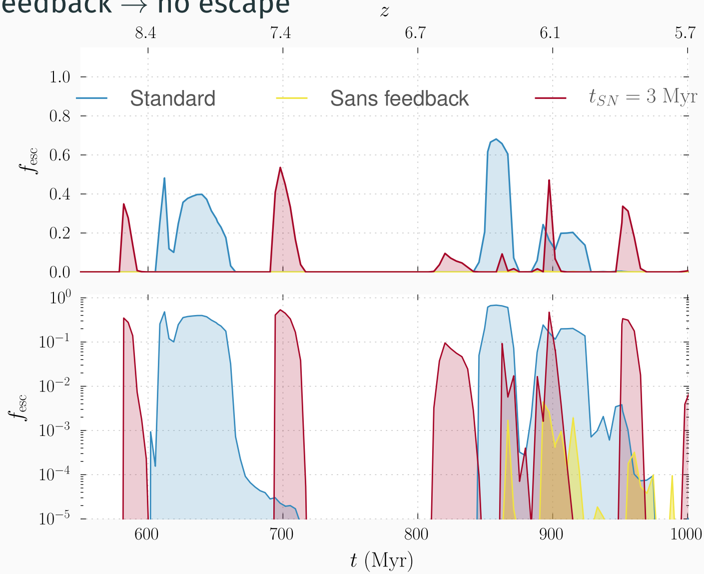


Feedback regulated escape of photons

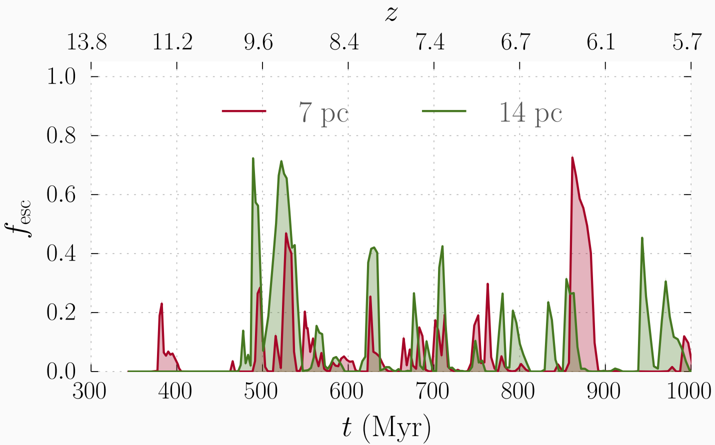
No feedback → no escape



Is all of this robust?

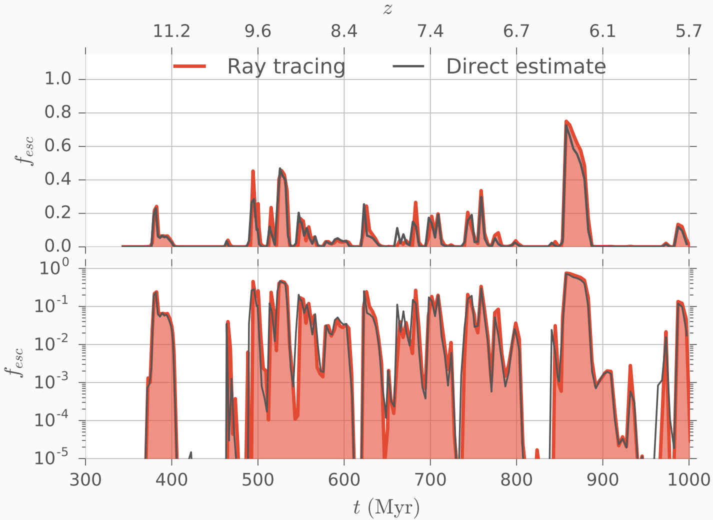
Do we have enough resolution?

Qualitatively, yes. Quantitatively, who knows?



What about the RT method?

Moments methods still preserve (some) directionality



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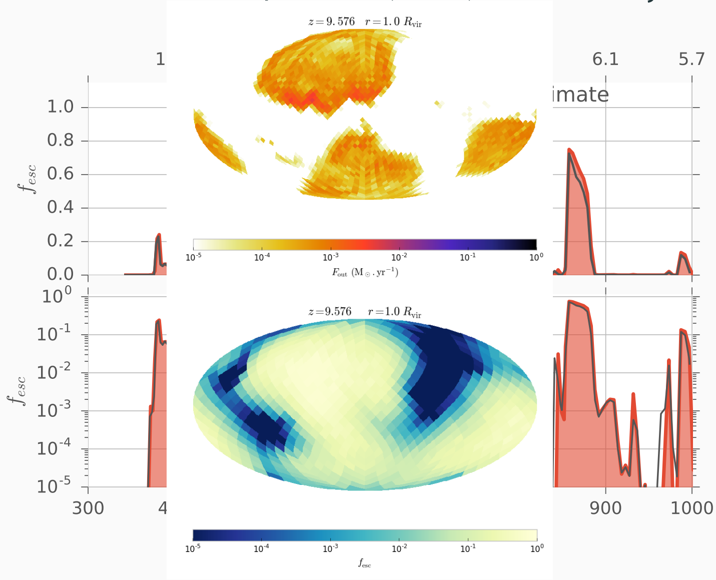


Conclusions

Summary

- Low mass galaxy formation is regulated by the SN feedback.
- SF and the escape of ionising radiation happen in bursts.
- $f_{\rm esc}$ is mostly determined by ISM-scale processes.
- Recent improvements in subgrid modelling should lead to better predictions

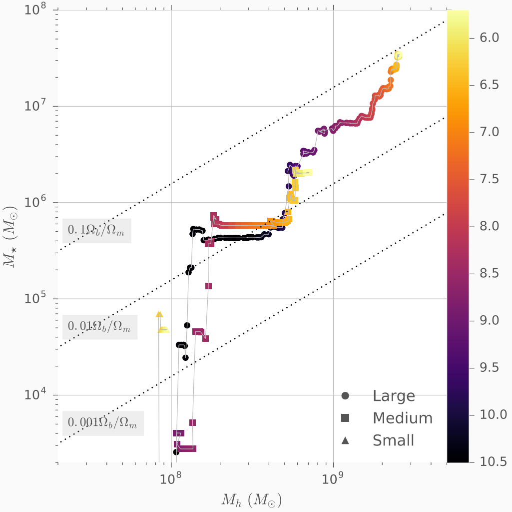
What next?

- Small galaxies are found to harbour central BHs
- At high z, these BHs could be active $\rightarrow$ extra source of feedback!

$\Rightarrow$ Even for "reionisation by galaxies", central BHs could play a role

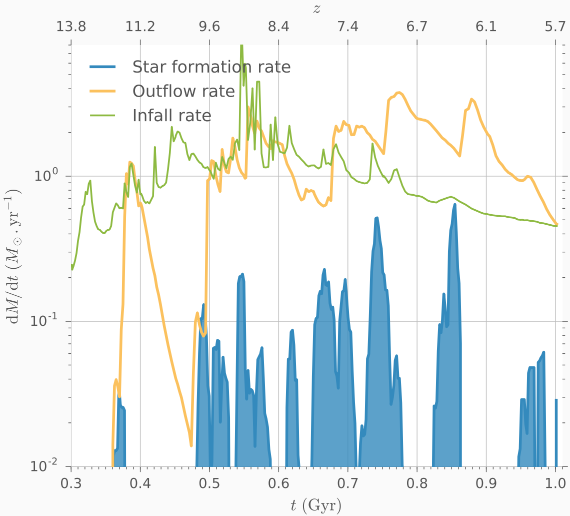
Galaxy properties

Halo mass vs. stellar mass



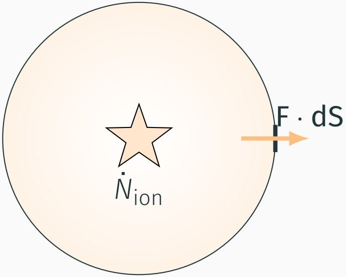
Galaxy properties

Bursty star formation and massive winds

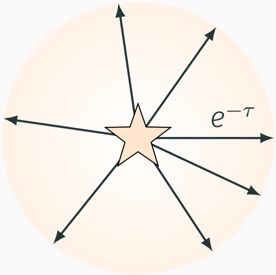


What about the RT method?

Measuring f_{esc}



(a) $f_{esc} \sim \frac{\int \mathbf{F}(t) \cdot d\mathbf{S}}{\dot{N}_{ion}(t - r/c)}$



(b) $f_{esc} \sim \langle e^{-\tau} \rangle$