The "Missing Photons" & Reionization

z=30.0

нн 10 крс z = 30.0



Gas: Magenta: cold $(< 10^4 K)$ Green: warm (ionized) Red: hot $(> 10^6 K)$

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and the FIRE team

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Stars (Hubble image): Blue: Young star clusters Red: Dust extinction

Big Bang to Us: STARS "LIGHT UP" THE UNIVERSE



electrons & protons combine: Cosmic Microwave Background released

Re-ionization: starlight fills the Universe, can reach us

Simulating First Light (Re-ionization):



(Animation: T. Abel)

Re-ionization: IONIZING PHOTONS FROM STARS MUST "ESCAPE" GALAXIES

of photons emitted (how many stars)
(galaxy counts, re-emitted/absorbed H-alpha light)



of photons *needed* (how much stuff is ionized) (CMB, Gunn-Peterson effect, Lyman-alpha forest)

(e.g. Robertson et al. 2015, 2016)

~20% must *escape* their galaxies

Problem: STARS FORM IN DENSE, COLD CLOUDS

• Naively: form the stars, calculate where the light goes



Xiangcheng Ma (arXiv:1503.07880)



• Nothing escapes! $f_{\rm escape} \ll 0.1\%$

Problem: STARS FORM IN DENSE, COLD CLOUDS

- Actually:
 - Stars destroy the cloud
 - Stars get "flung around" ("runaway stars")



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Star-forming cloud:

If stars were passive ("no feedback") Realistic (stellar winds & radiation included)

It's Not Enough! TAKES TOO LONG TO DESTROY THE CLOUDS

Xiangcheng Ma (arXiv:1503.07880)



Ionizing photon production rate: (from a stellar population)



- Invariant to:
 - Resolution
 - Strength of feedback
 - Numerical methods
 - Star formation rates
 - IMF shape / sampling
 - Runaway stars

Simulation: only ~1% escape!

(also Wise et al., Kimm & Cen 2015)

Other Mysteries? SOME PHYSICS IS MISSING HERE



unexpectedly massive black hole mergers



"mass-gainers": (stars more massive & longer-lived than they should be)





Binary Stars: THE ORIGIN OF THE "MISSING PHOTONS"

Xiangcheng Ma (arXiv:1601.07559)





Simulation: ~20% escape!

Binaries Work EXPLAIN THE MYSTERIES OF HIGH-REDSHIFT GALAXIES

Ma, Hopkins et al. (arXiv:1601.07559)



Binaries Work EXPLAIN THE MYSTERIES OF HIGH-REDSHIFT GALAXIES



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(Animation: J. Wise)