Cosmology
Lecture 16

Baryons and Photons I

Lectures

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Learning Objectives

- Know that baryonic matter is able to cool more readily than Dark Matter as it is able to release energy via photons.

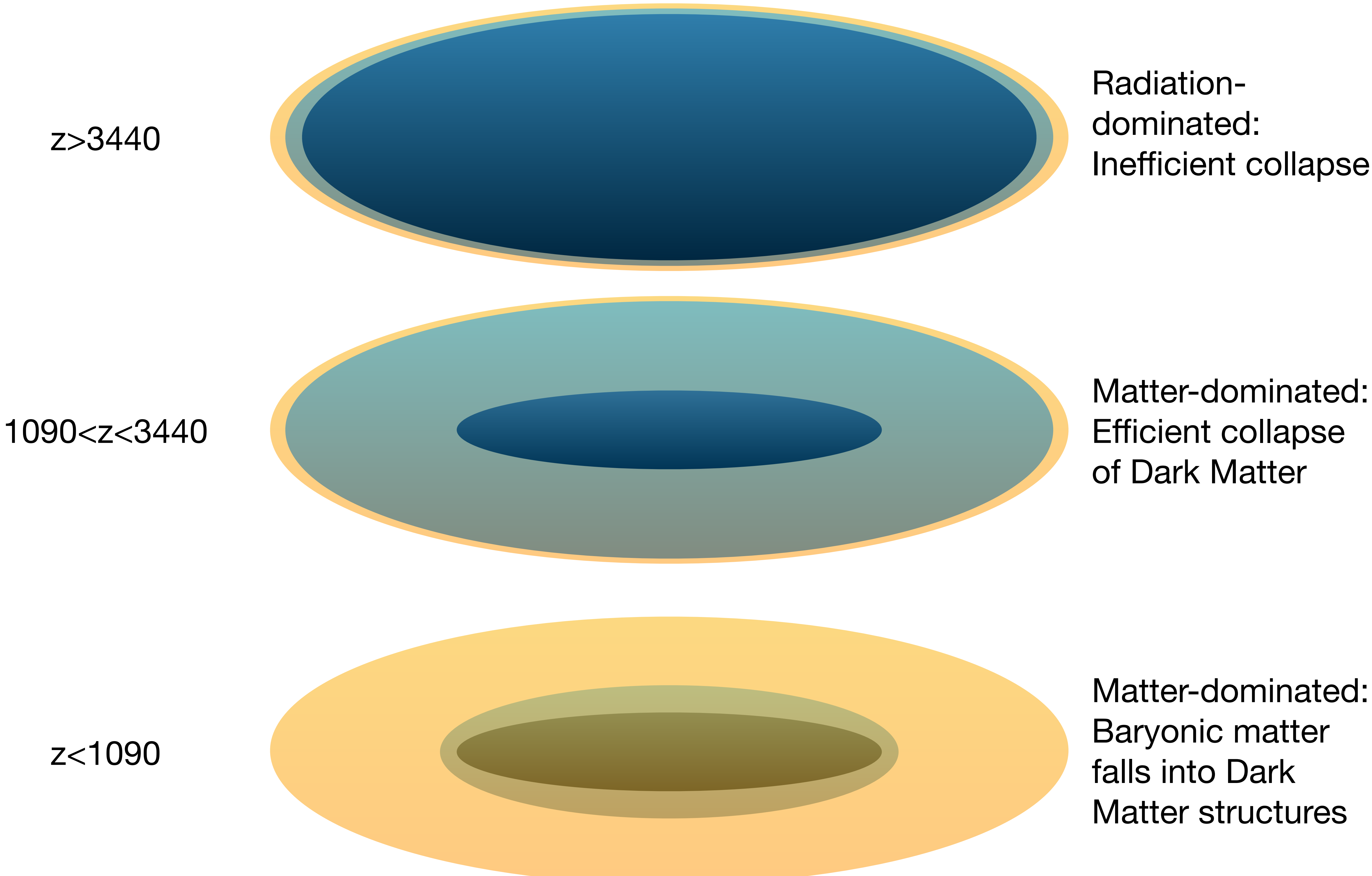
- Know that most baryonic material in the Universe is extremely tenuous and ionised.

- Understand what is meant by the “epoch of reionisation”.

- Understand how cosmologists can use the CMB to gain insights into when the epoch of reionisation occurred.

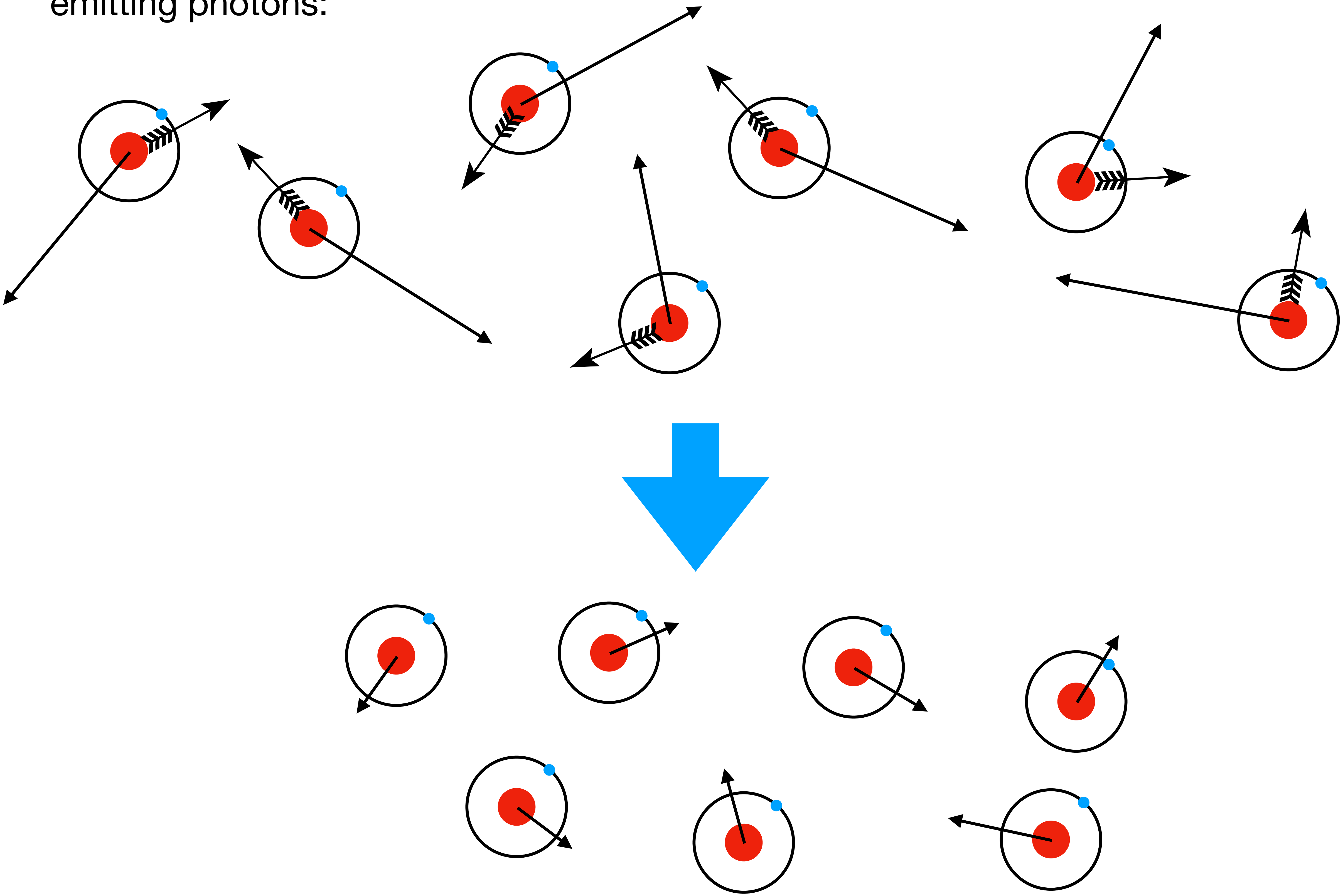
- Know the likely causes of reionisation.

The behaviour of Baryonic Matter



The collapse of Baryonic matter

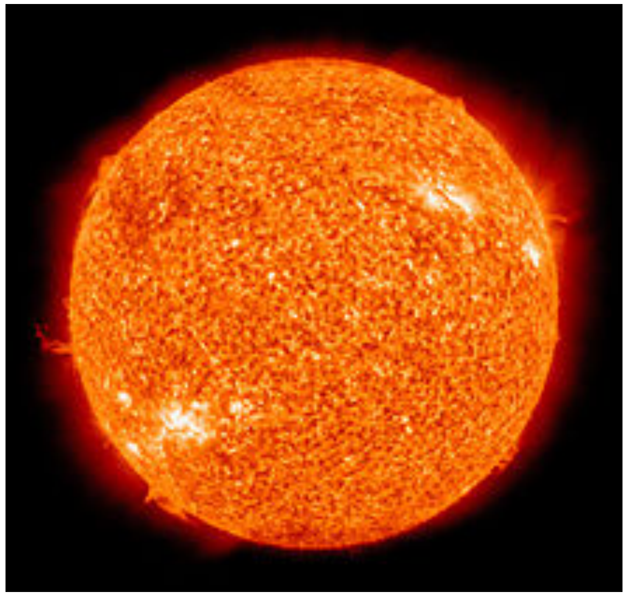
The collapse of baryonic matter is aided by the fact that it can lose energy by emitting photons:



High density vs. low density

This loss of energy helps baryonic matter collapse to form dense objects.

For example, while the average baryonic density of the Universe is 4.2×10^{-28} kg m^{-3}, the average density of a Sun-like star is…



…1400 kg m^{-3}, representing an overdensity of

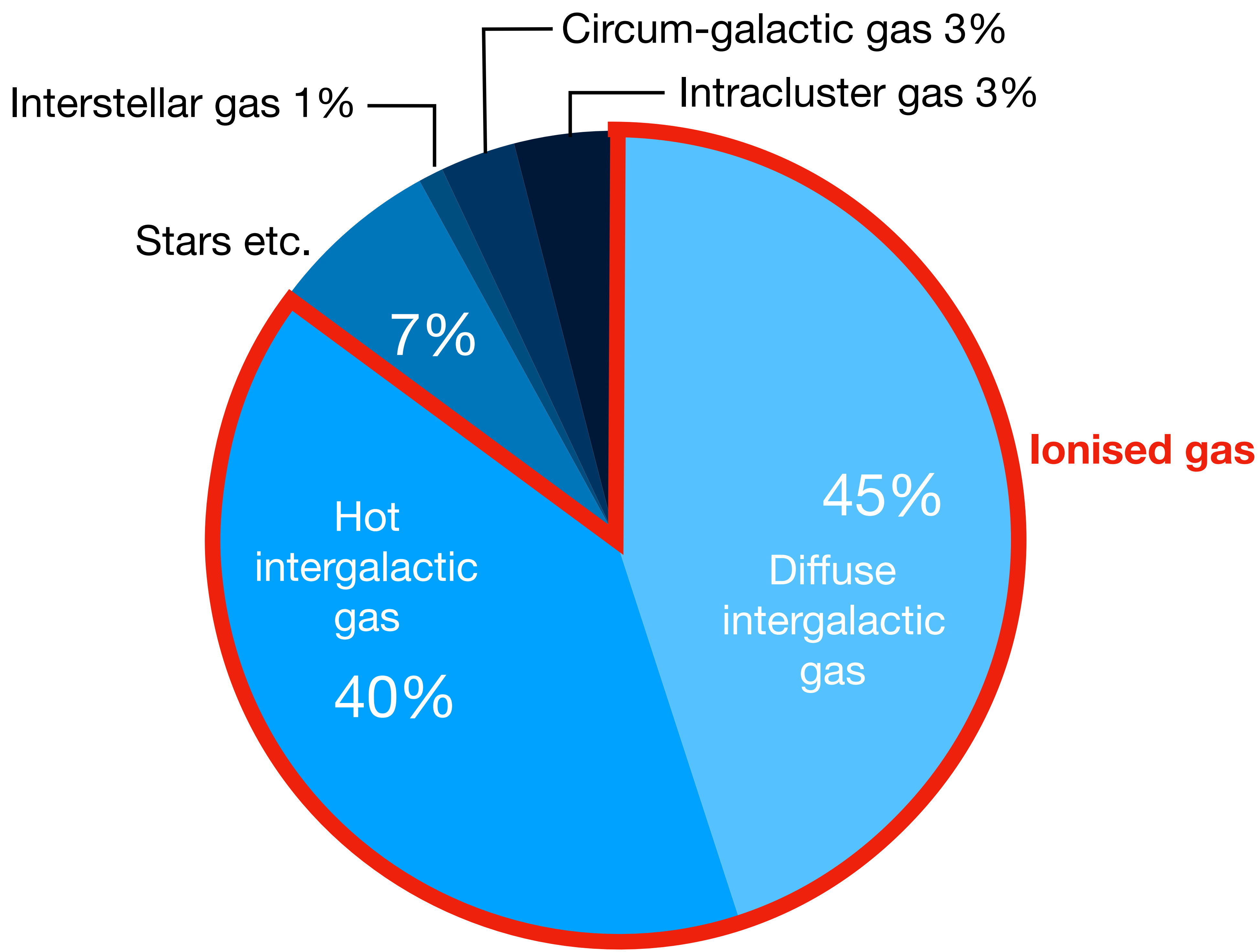
3×10^{30}

relative to the average baryonic density!

What causes some matter to collapse, and some to stay diffuse?

A census of baryons

We saw in lecture 8 that about 85% of all baryonic matter in the Universe is in the form of tenuous gas *between* galaxies.

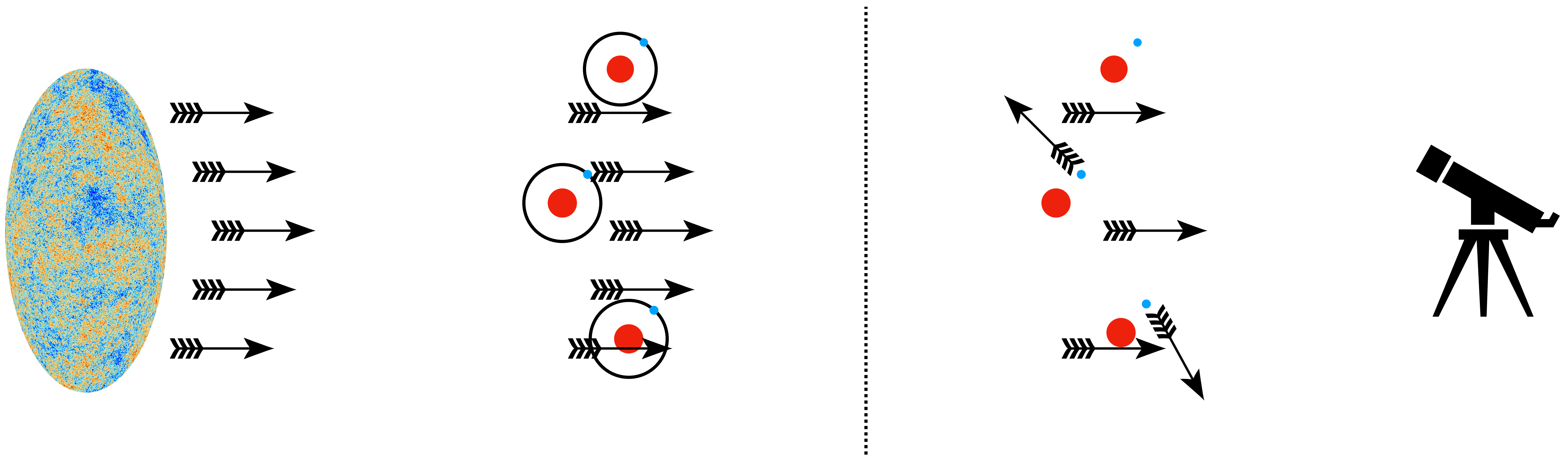


The re-ionisation of the Universe

After recombination, how did *85% of the baryons* in the Universe become reionised again?

To help answer this, let's start by asking:
When did reionisation happen?

We can use the CMB to help us answer that…



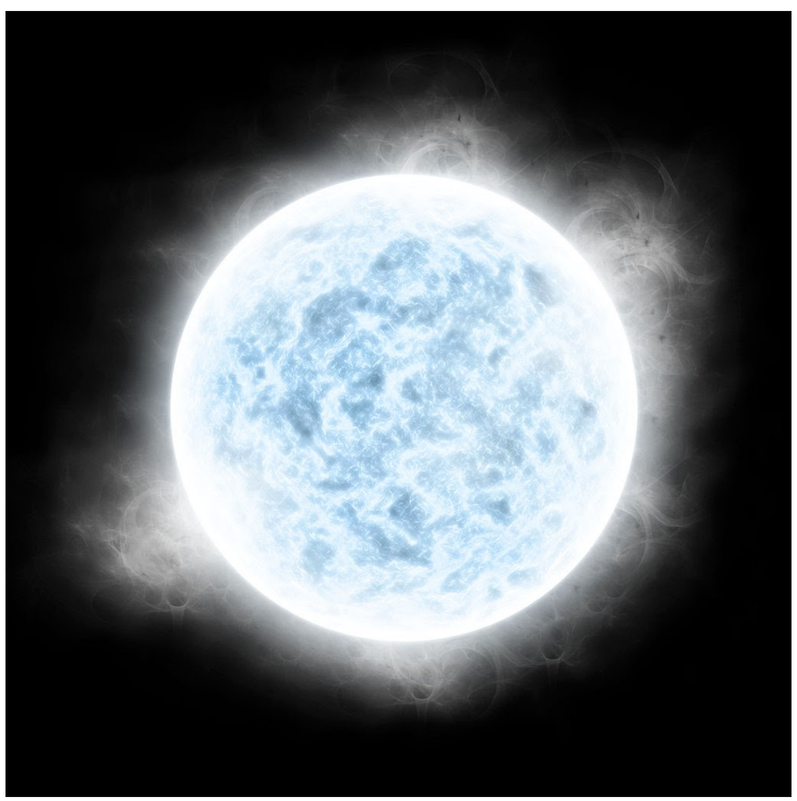
Epoch of reionisation

What reionised the Universe?

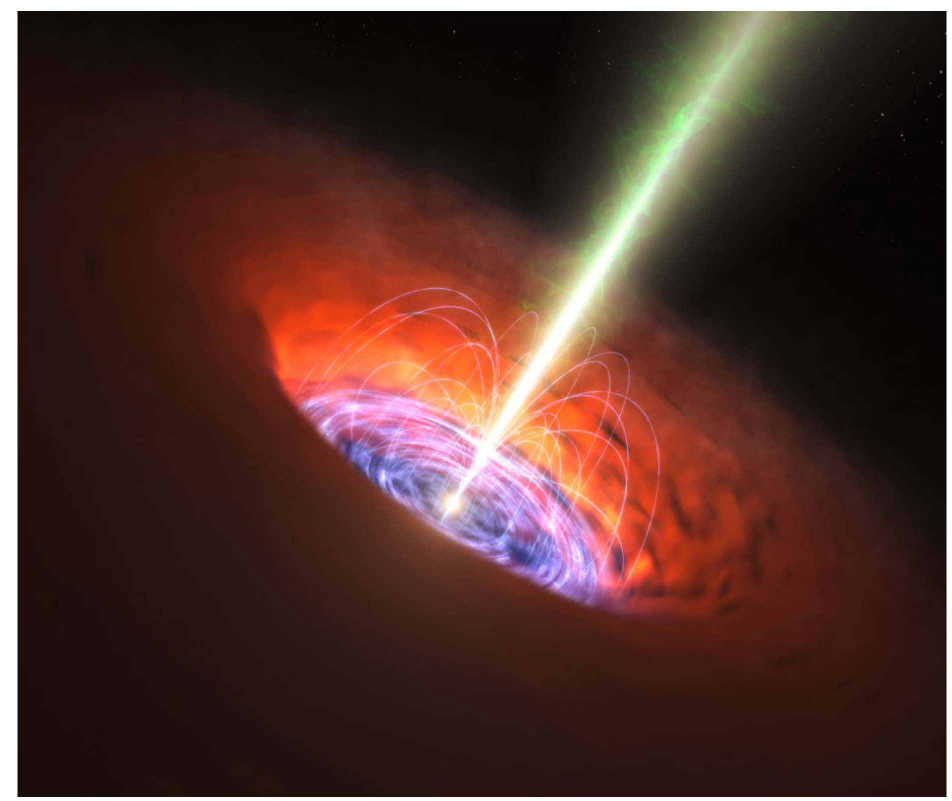
Analysis of the CMB tells us that deionisation took place at z~7.8.

But what could have reionised the Universe?

We need high energy photons…

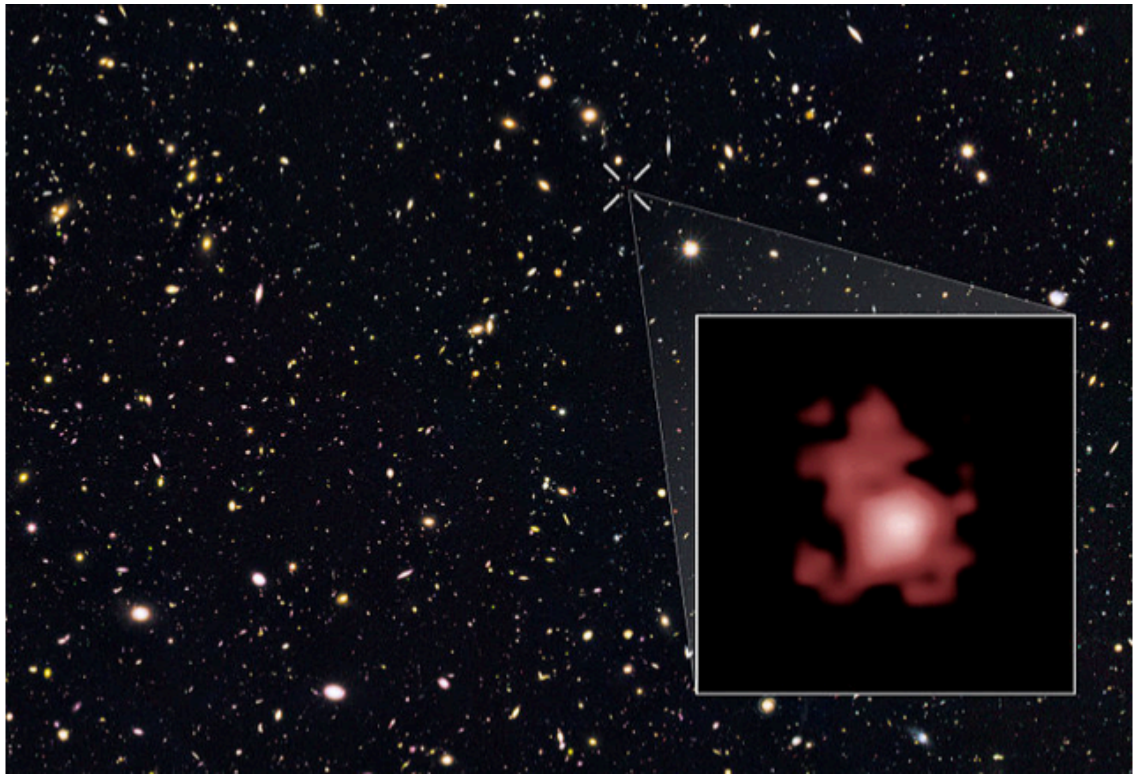


O/B-Type stars



Active Galactic Nuclei

The first stars and AGN



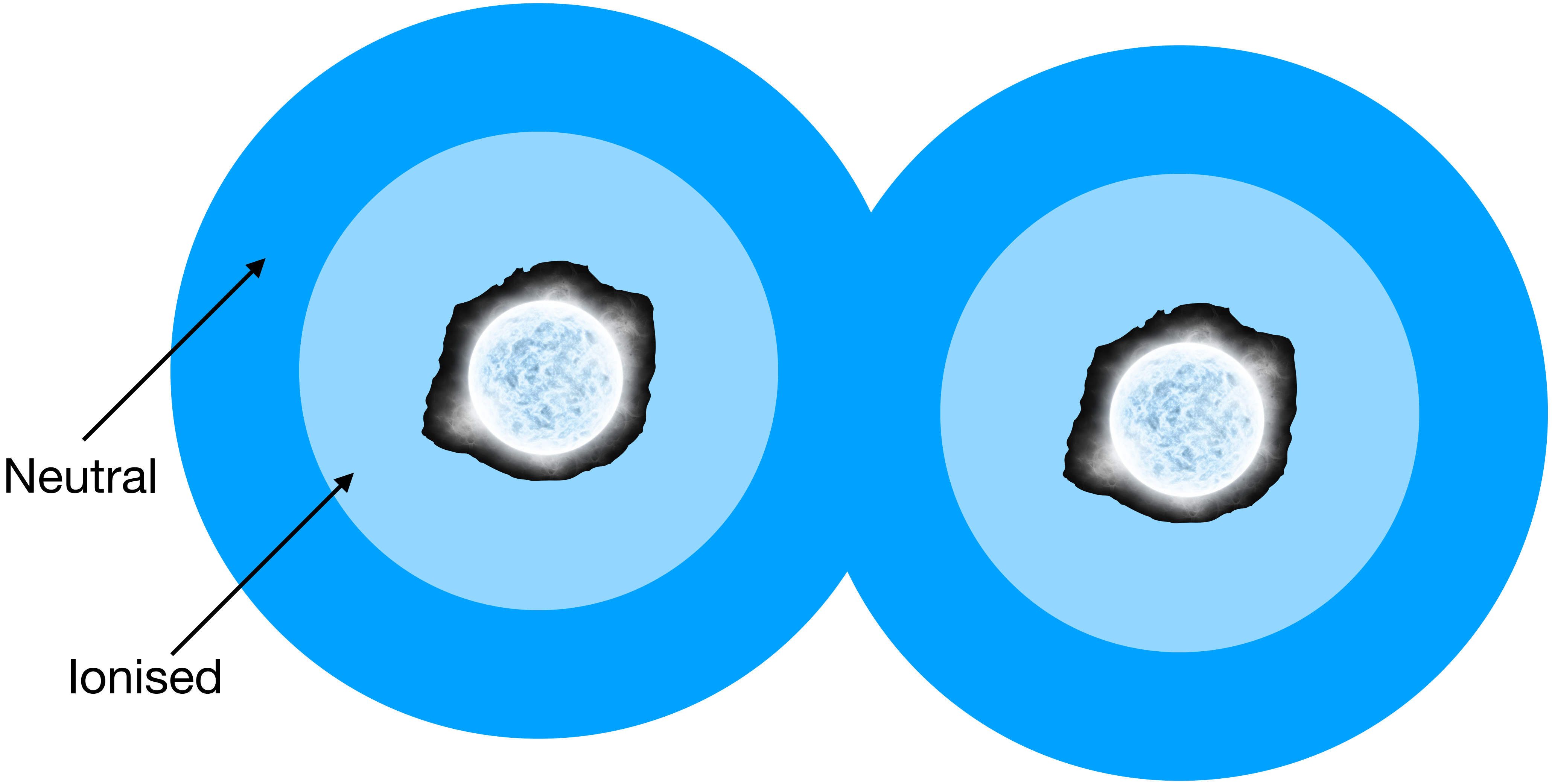
Highest redshift galaxy at z=11

Highest redshift AGN at z=7.54

Astronomers have found galaxies and AGN at redshifts broadly consistent with reionisation, so we know that stars and AGN existed at this time.

But, do they provide enough ionising photons?

Do stars and/or AGN reionise the Universe?



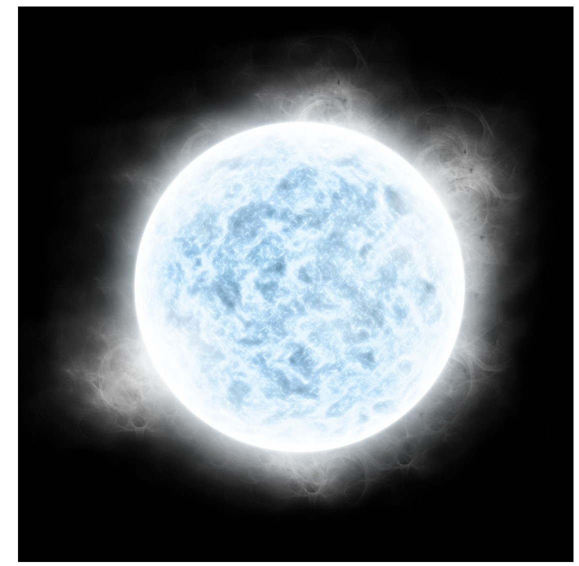
If a source of ionising photons ionises a large enough volume, and such sources are close enough together, then eventually their ionised volumes will overlap, and the Universe will become wholly ionised.

How may ionising photons do we need?

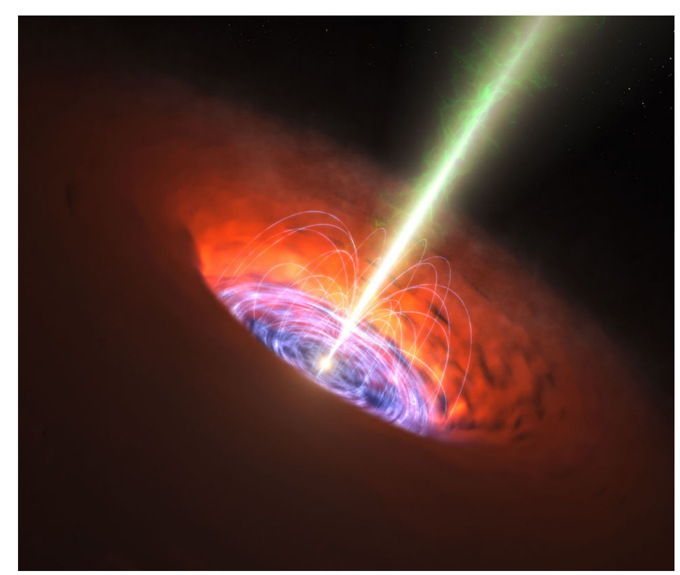
How many galaxies and/or AGN do we need?

We need 7.3×10^{67} ionising photons per comoving Mpc to reionise the Universe.

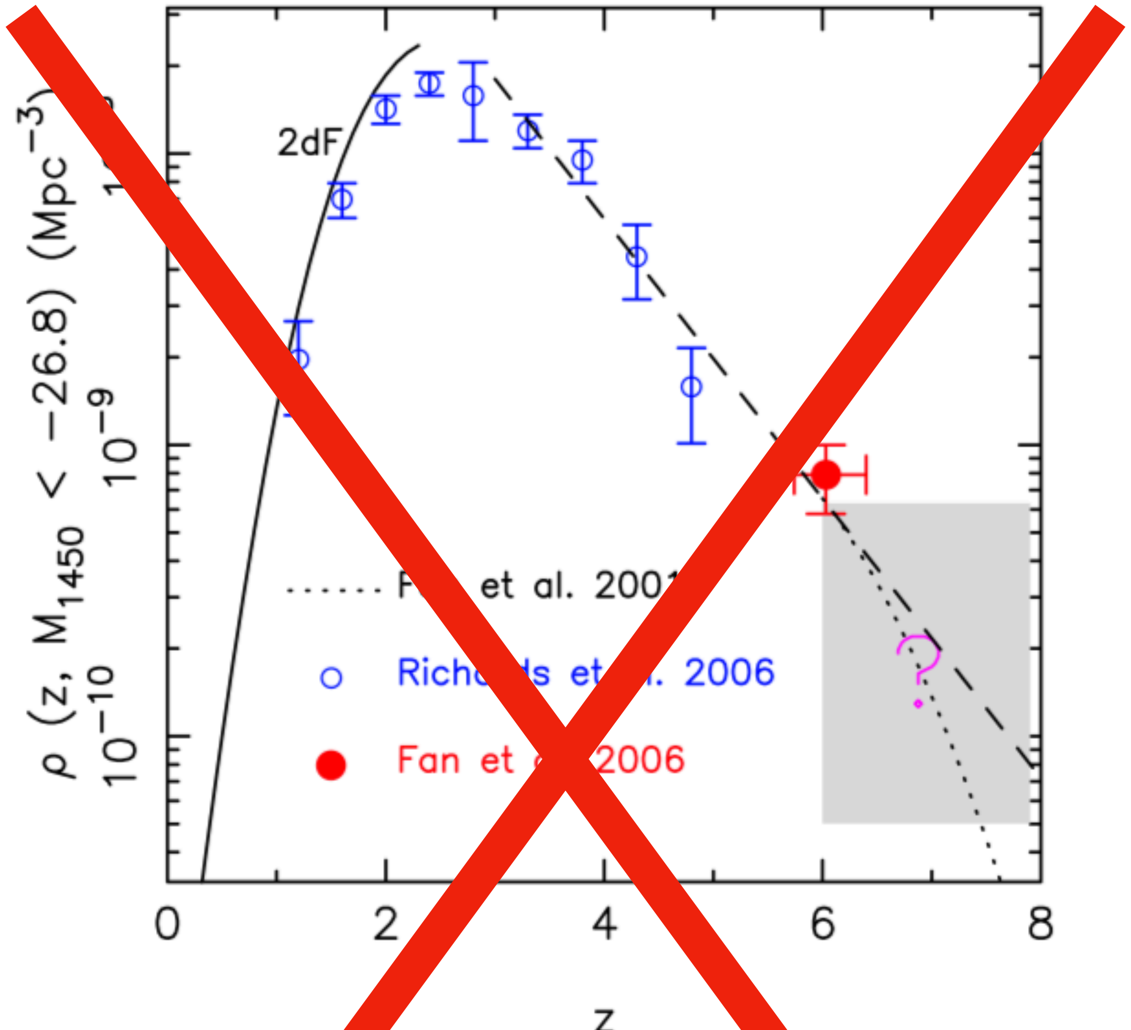
This corresponds to the lifetime of 40,000 O-stars…



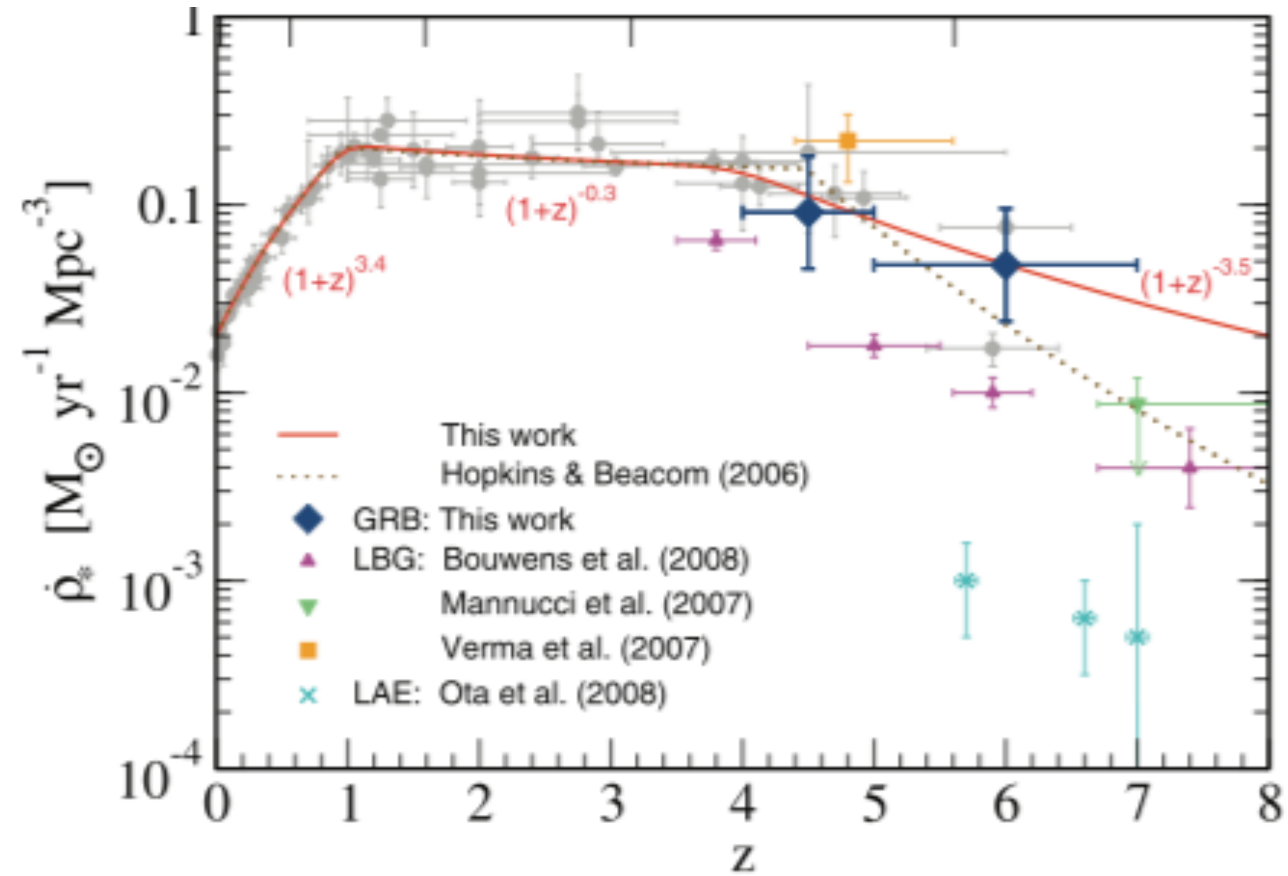
…or 1 luminous AGN shining for 4000 years.



The number density of stars and AGN



At z~8, the number density of luminous AGN is around 1 per 10^{10} comoving Mpc.



At z~8, the comoving star formation rate density is about 20,000 solar masses per Mpc per megayear.

Yes - within about 600 Myr

Getting the feel for it…

- Most of the baryonic material in the Universe is tenuous and ionised.

- But, we know that, after recombination, the Universe was neutral.

- The Universe has undergone a period of reionisation between recombination and today.

- From CMB measurements, we know this took place at around z~8.

- AGNs and O-stars are possible candidates for causing reionisation, with observations suggesting that the latter is most likely.