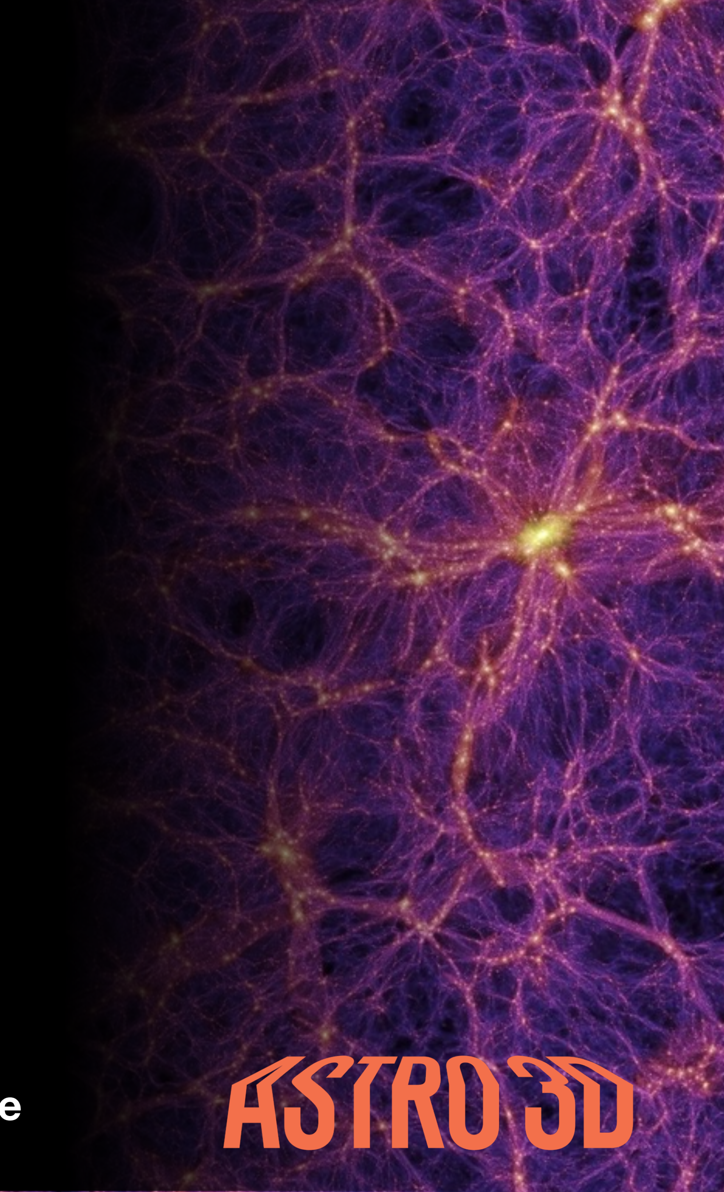
Intergalactic space, fast radio bursts and the hunt for the missing matter

Presented by

Adam Batten



SWIN BUR NE

Centre for Astrophysics and Supercomputing

Swinburne Public Astronomy Lecture
23-04-2021

Image Credit: Ángel R. López-Sánchez (AAO-MQ)

Image Credit: Trevor Dobson

Image Credit: Trevor Dobson

Large Magellanic Cloud

Small Magellanic Cloud

Image Credit: Yuri Beletsky (ESO)

Image Credit: Bogdan Jarzyna

Large Magellanic Cloud

Small Magellanic Cloud

The Andromeda Galaxy

Image Credit: Yuri Beletsky (ESO)

Image Credit: Bogdan Jarzyna

Image Credit: Lorenzo Comolli

Video Credit: NASA, ESA & HUDF Team (STScI)

Edwin Hubble announced that Andromeda is another galaxy in 1929!

The Andromeda Galaxy (aka Messier 31)

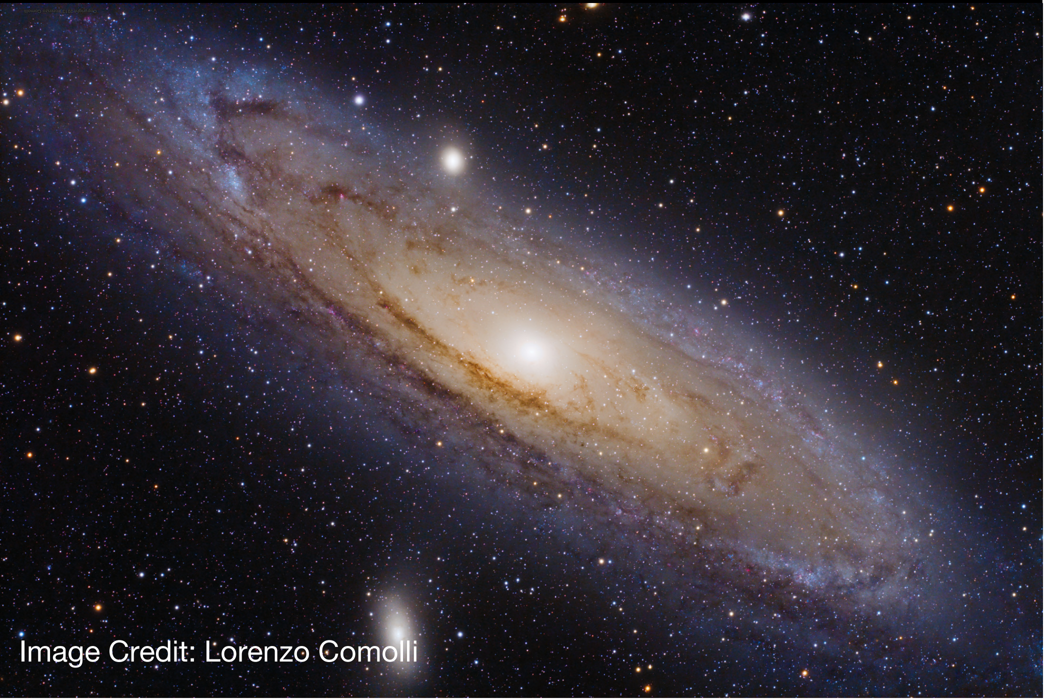


Image Credit: Lorenzo Comolli

A SPIRAL NEBULA AS A STELLAR SYSTEM, MESSIER 31[1]

By EDWIN HUBBLE

ABSTRACT

Material.—The present discussion of M 31 is *based on the study of about 350 photographs* taken with the 60- and 100-inch reflectors, distributed over an interval of about eighteen years. Two-thirds of the total number were obtained by the writer during the five years 1923–1928. Since the image of the nebula is much larger than the usable fields of the telescopes, *attention was concentrated on four regions centered* on (1) the nucleus, (2) 23′ north following, (3) 17′ south, (4) 48′ south preceding the nucleus. The combined *area*, with allowance for overlapping, *represents about 40 per cent of the entire nebula.*

Resolution.—The *outer regions* of the spiral arms are *partially resolved into swarms of faint stars*, while the *nuclear* region *shows no* indications of *resolution under any conditions* with the 100-inch reflector. Intermediate regions show isolated patches where resolution is pronounced or suggested.

Variables.—*Fifty variables* have been found, nearly all in the outer regions where resolution is pronounced. The *survey* is believed to be *fairly exhaustive in the four selected regions down to 19.0 photographic magnitude.*

Cepheids.—*Forty* of the *variables* are *known to be Cepheids* with periods from *48 days to 10 days* and *maxima from 18.1 to 19.3 photographic magnitude;* one exceptional star varies from 17.9 to 19.2 in a period of 175 days. The *period-luminosity relation is conspicuous*, and the slope is *approximately that* found among *Cepheids in other extra-galactic systems.*

Distance of M 31 derived from Cepheid criteria.—Comparisons of period-luminosity diagrams indicate that M 31 is about 0.1 mag. or 5 per cent more distant than M 33, and about 8.5 times more distant than the Small Magellanic Cloud. Using Shapley's value for the Cloud, we find the *distance of M 31* to be *275,000 parsecs.*

Variables other than Cepheids.—Of the 10 remaining variables, 4 are probably very faint Cepheids for which the data are insufficient to establish the characteristics, and 6 are irregular or long-period variables. The latter group includes the brightest variables in the nebula.

Edwin Hubble announ

The Andromeda Galaxy (ak

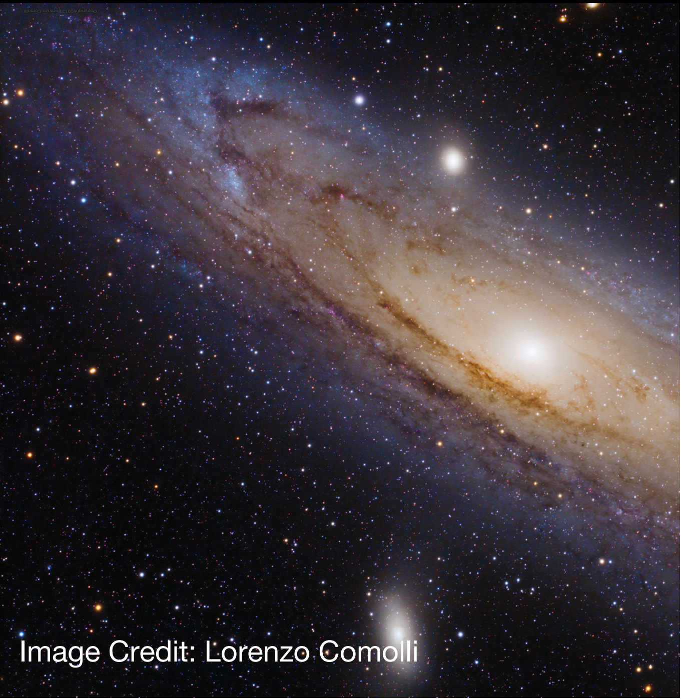


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Image Credit: My Mum

Me

Image Credit: My Mum

Image Credit: My Mum

Image Credit: facemorph.me





Me?

Open questions in galaxy evolution

- What did the first galaxies look like?
- How did galaxies form the first stars?
- What mechanisms stop galaxies from forming stars?
- How do elements throughout galaxies?
- How do galaxies interact with their environment?

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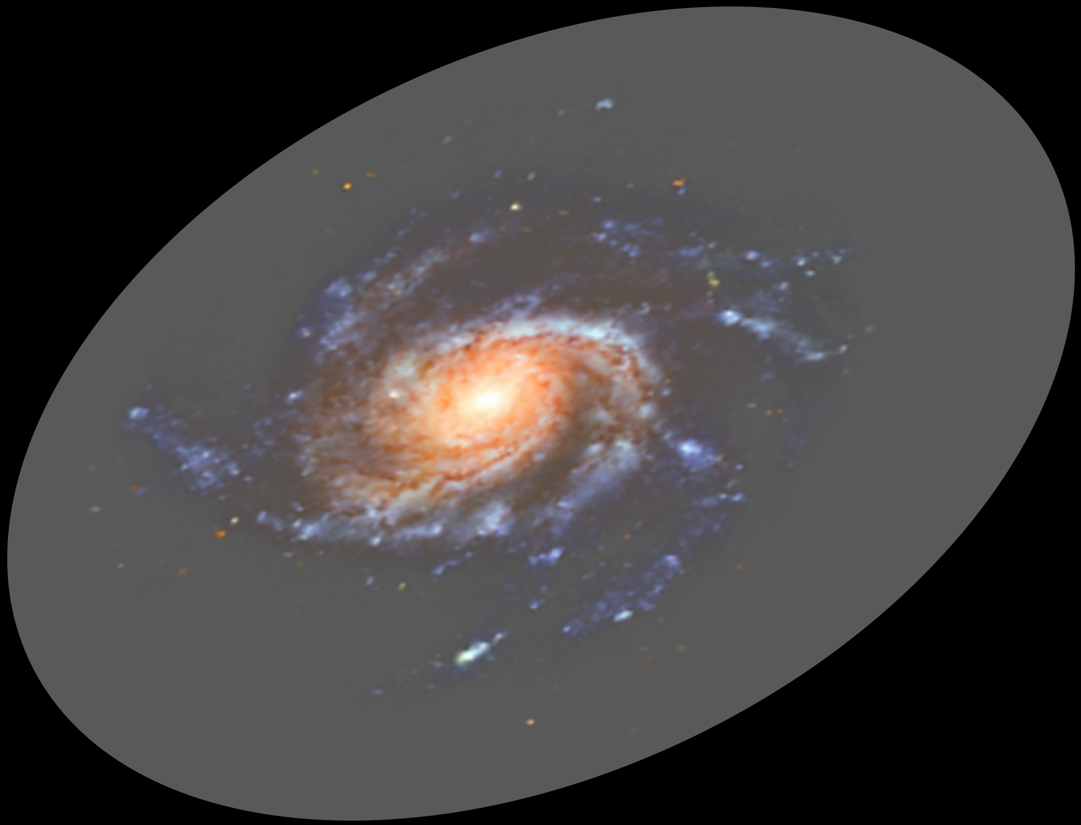
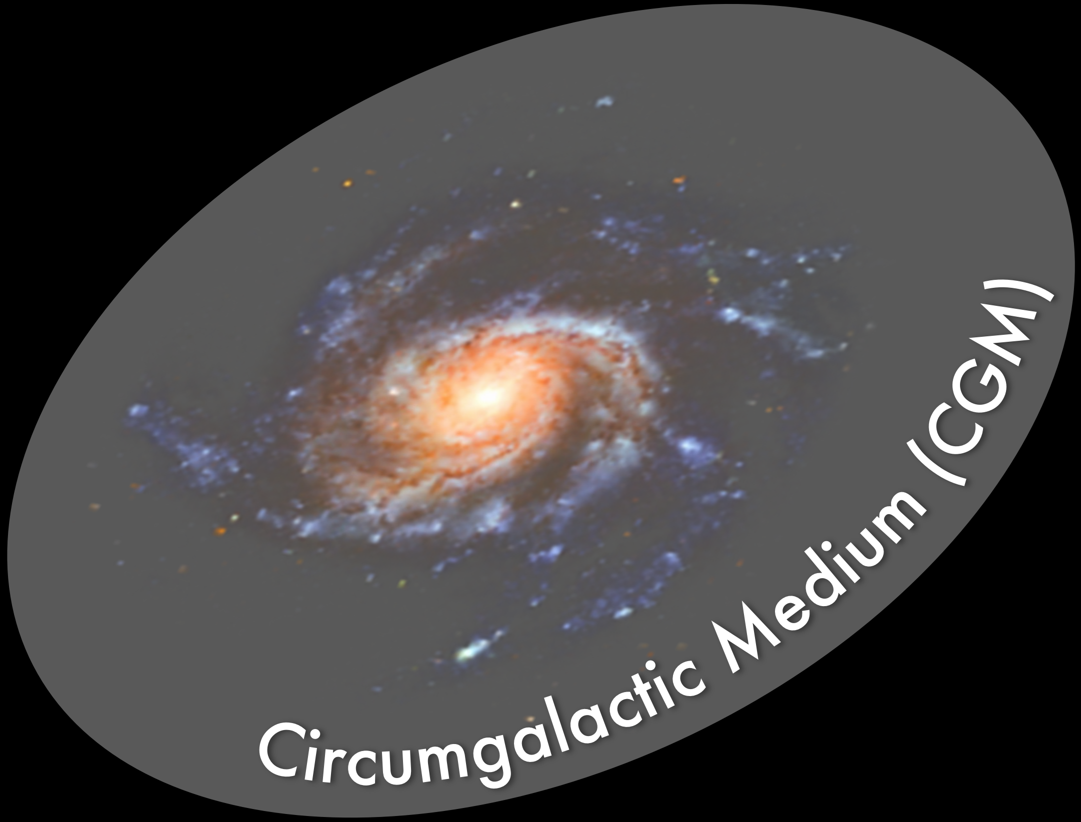
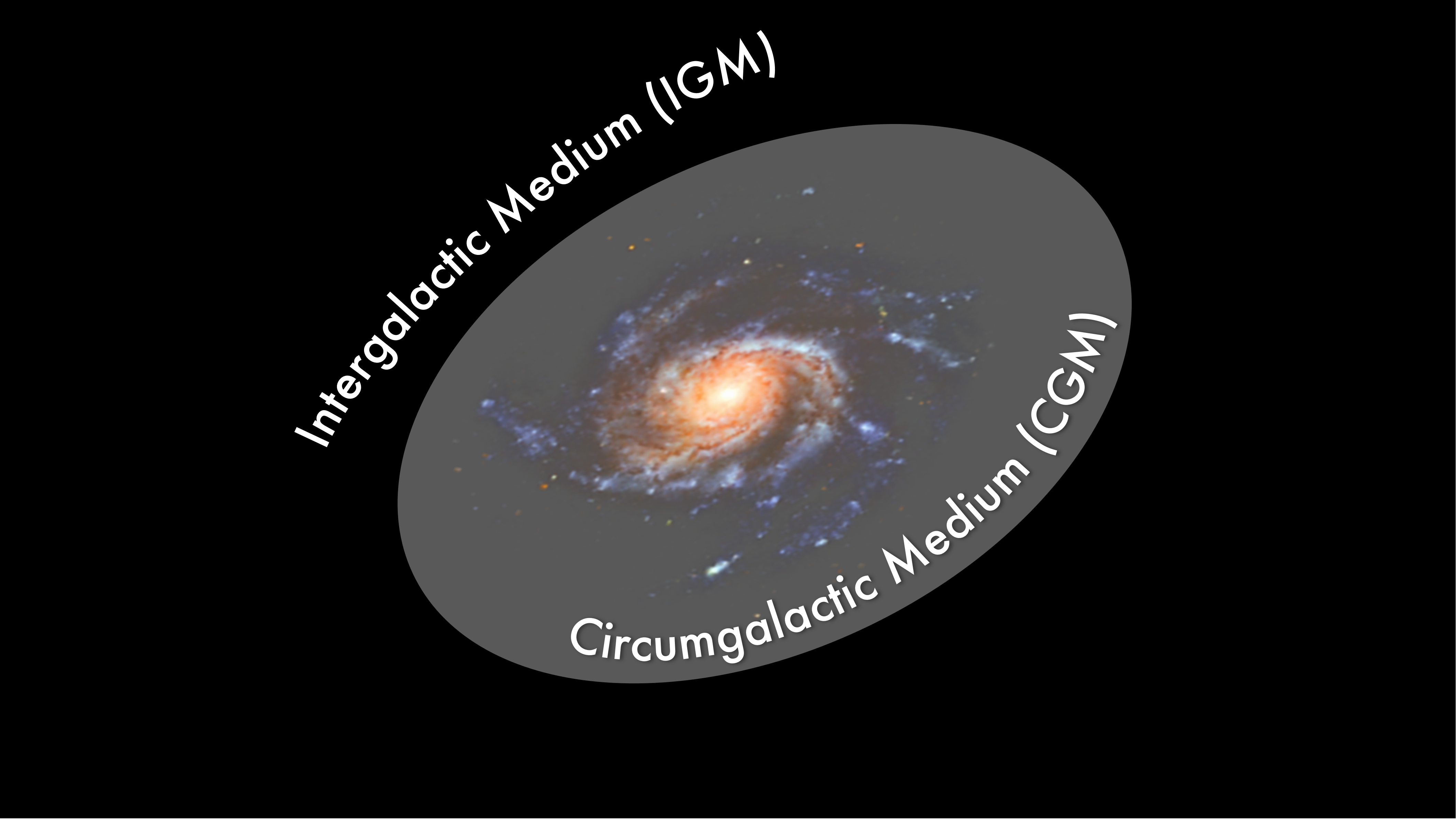


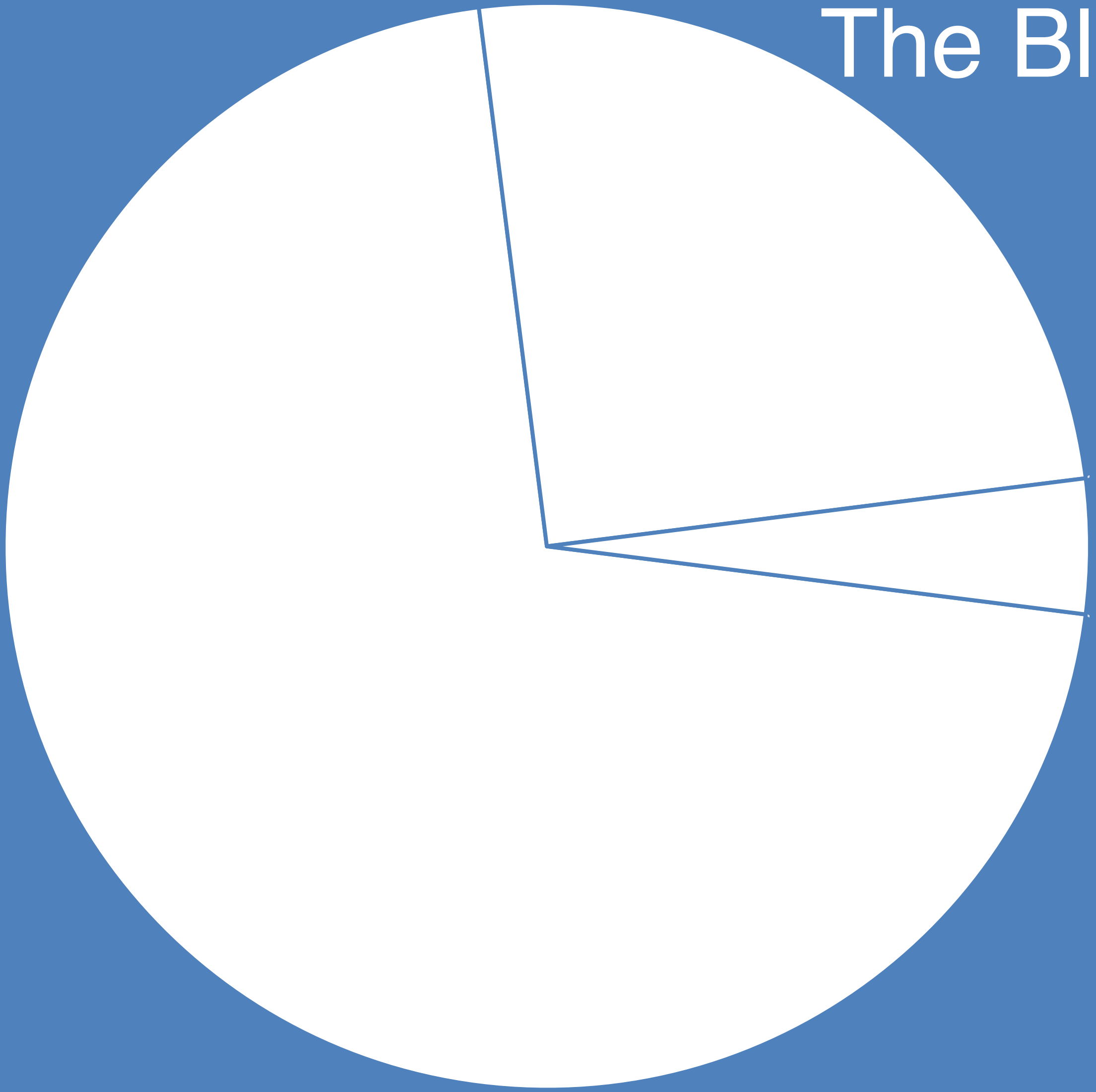

Circumgalactic Medium (CGM)


Intergalactic Medium (IGM)
Circumgalactic Medium (CGM)

Wait…why is intergalactic medium important … isn't that just empty space?

1) Most of the matter in the Universe resides in the Intergalactic Medium.

The Blueprint of the Universe



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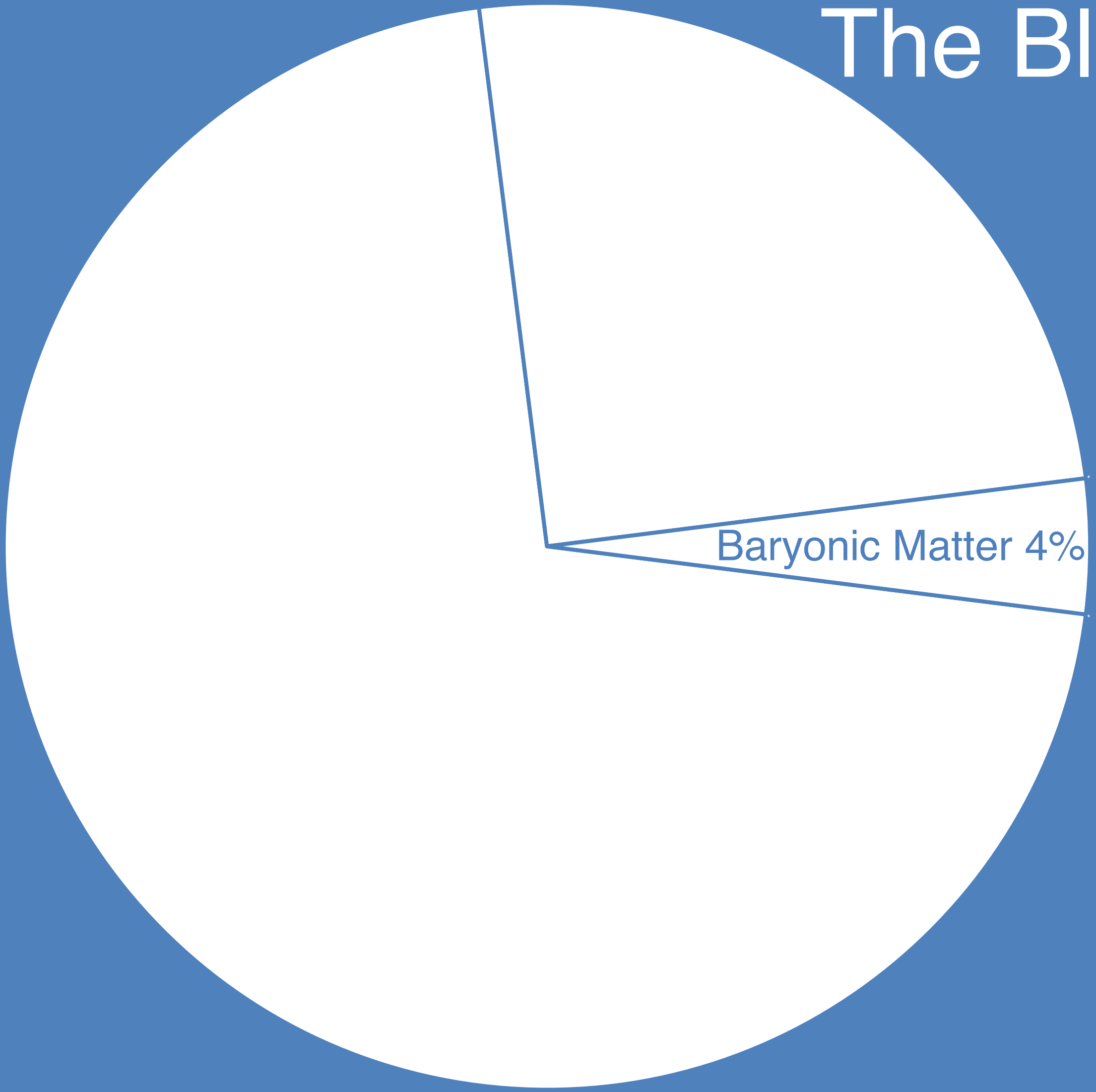
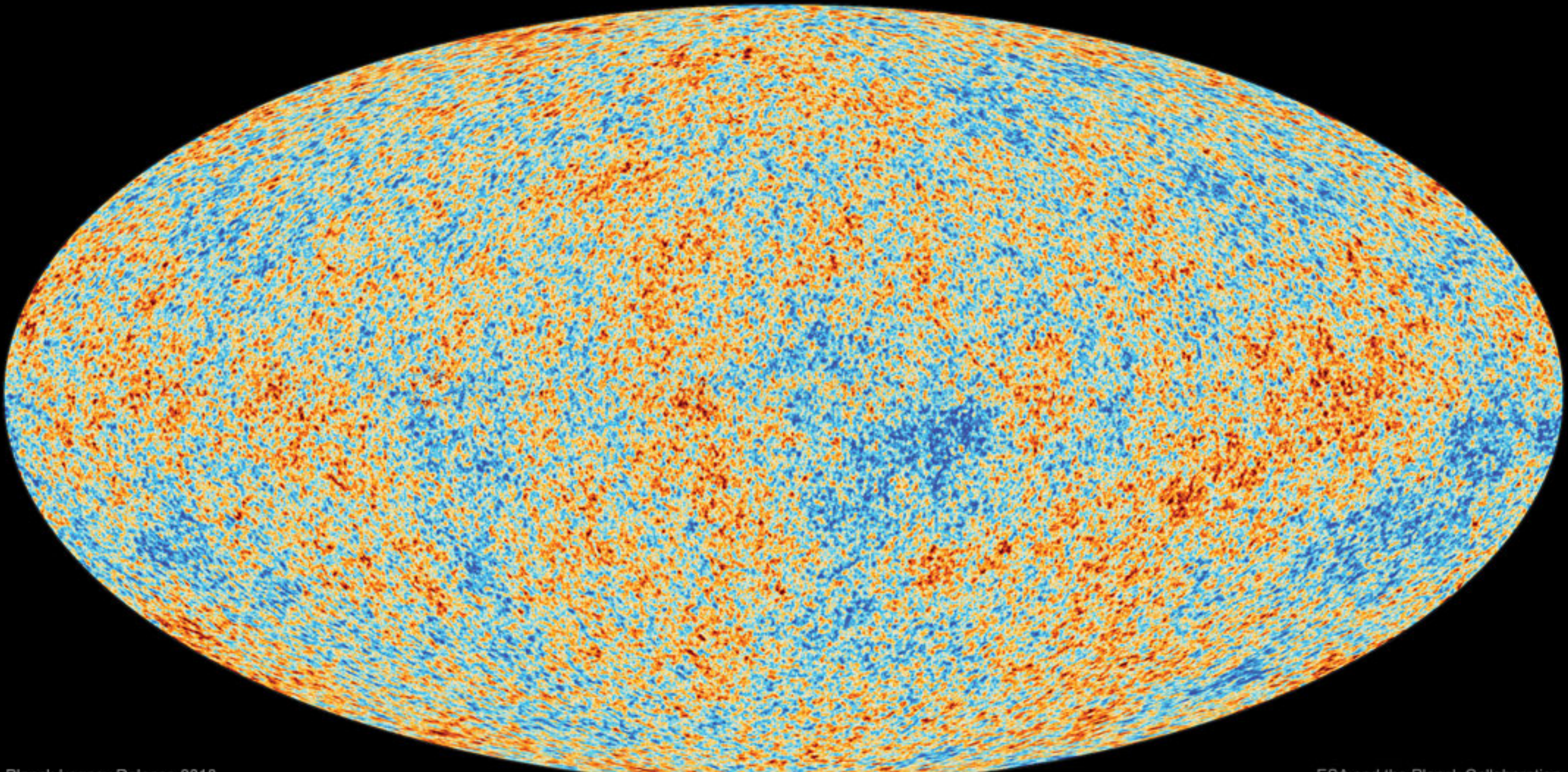


The Cosmic Microwave Background



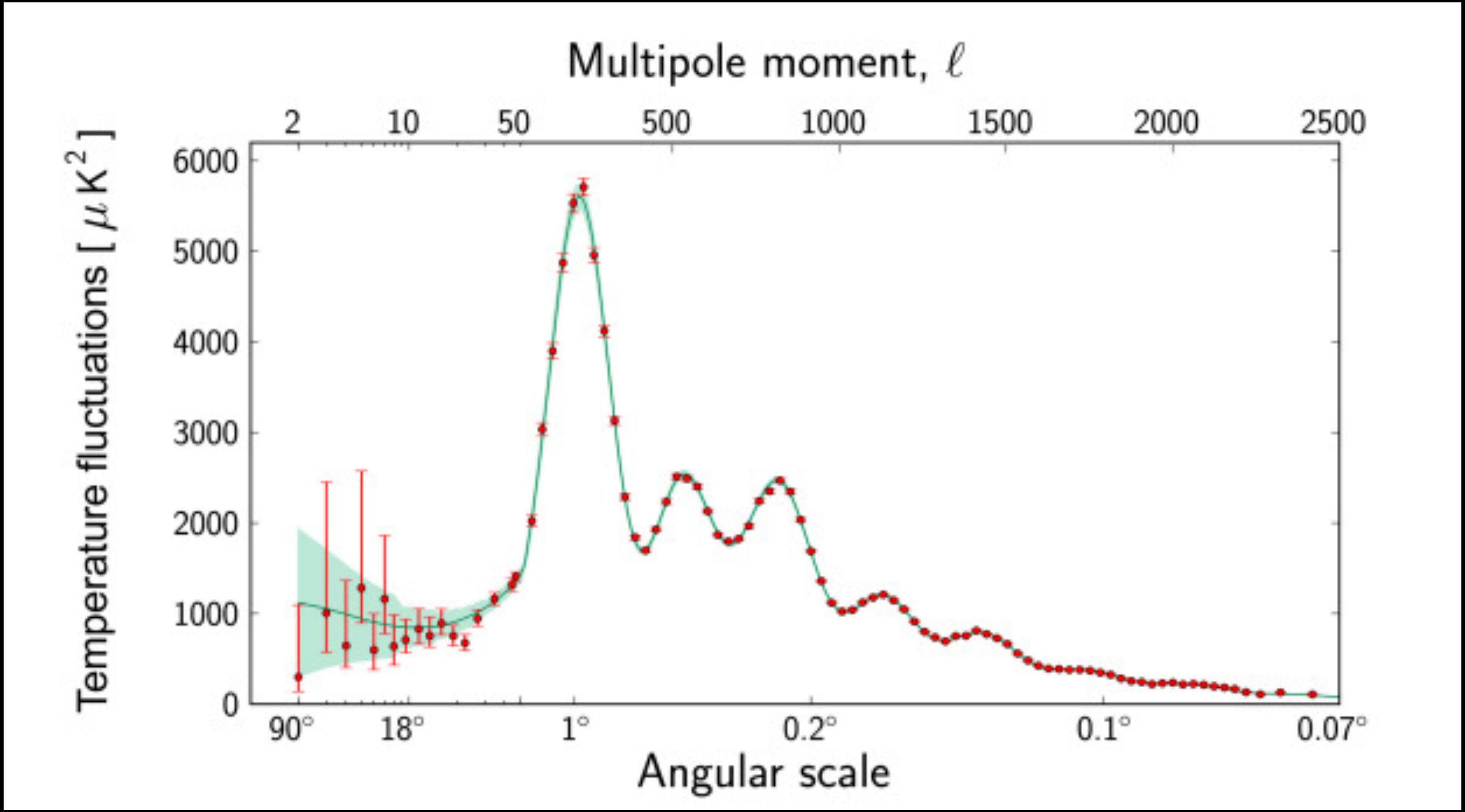
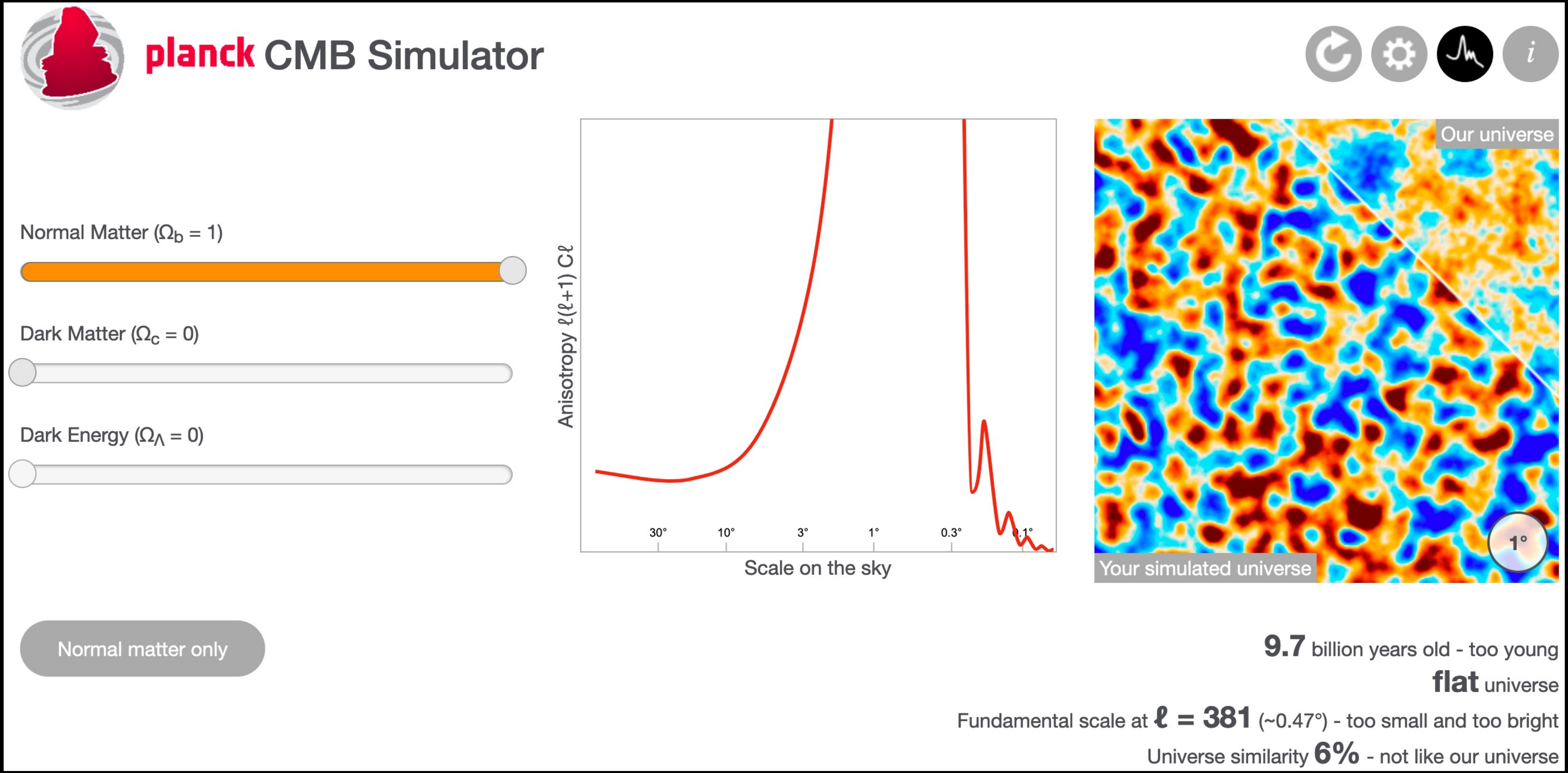
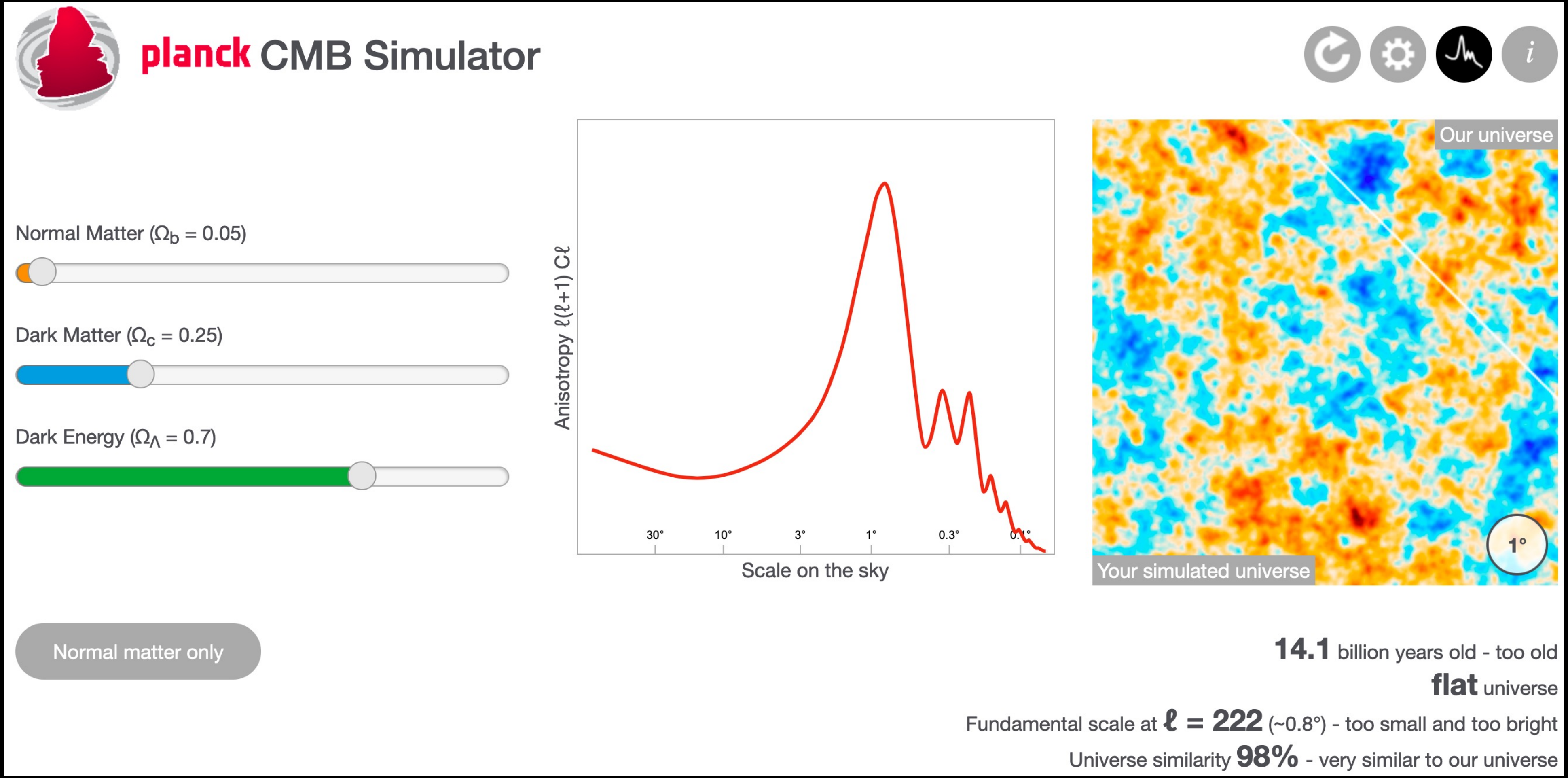


Image Credit: ESA and the Planck Collaboration



https://plancksatellite.org.uk/cmb-sim/



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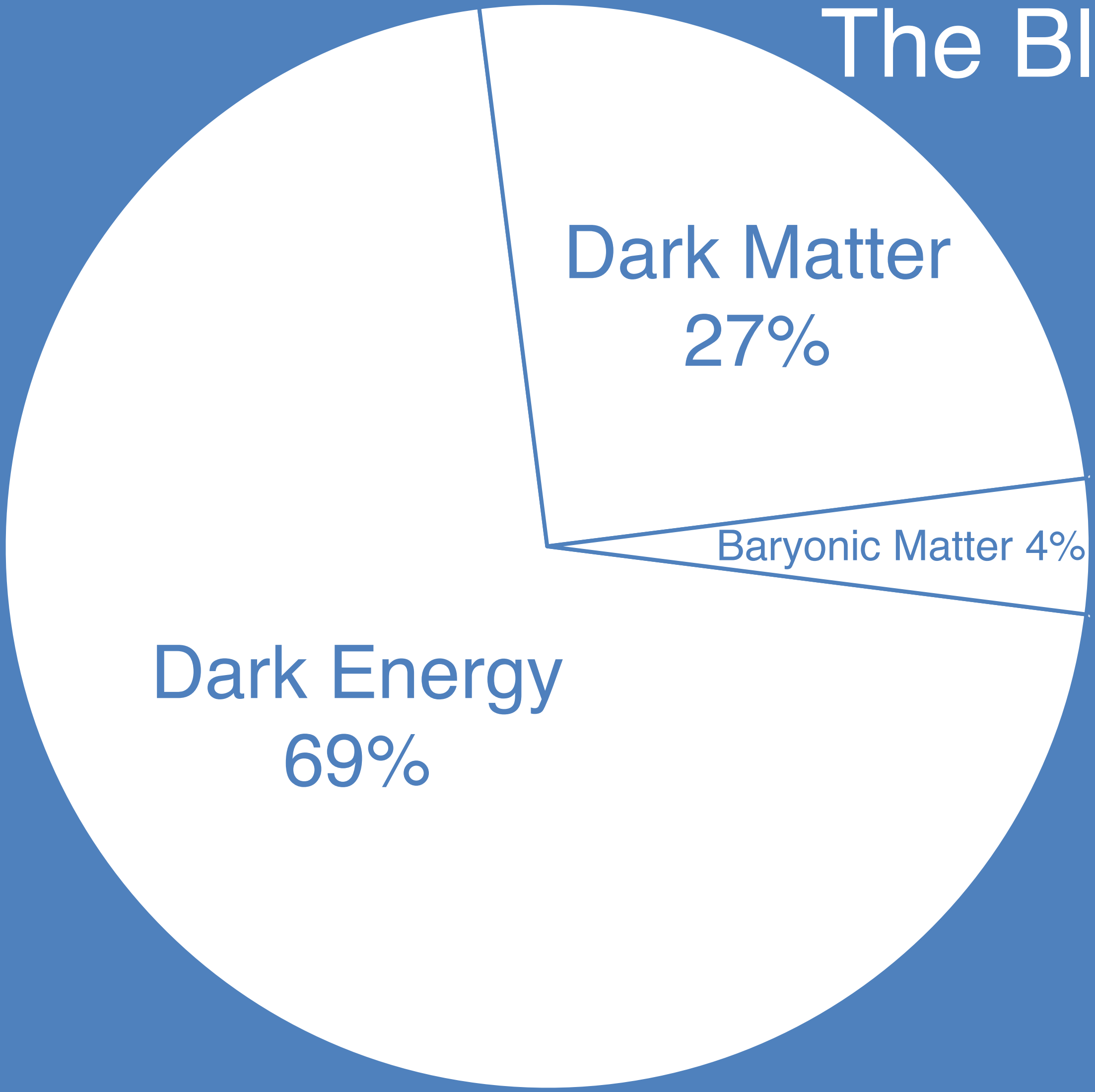
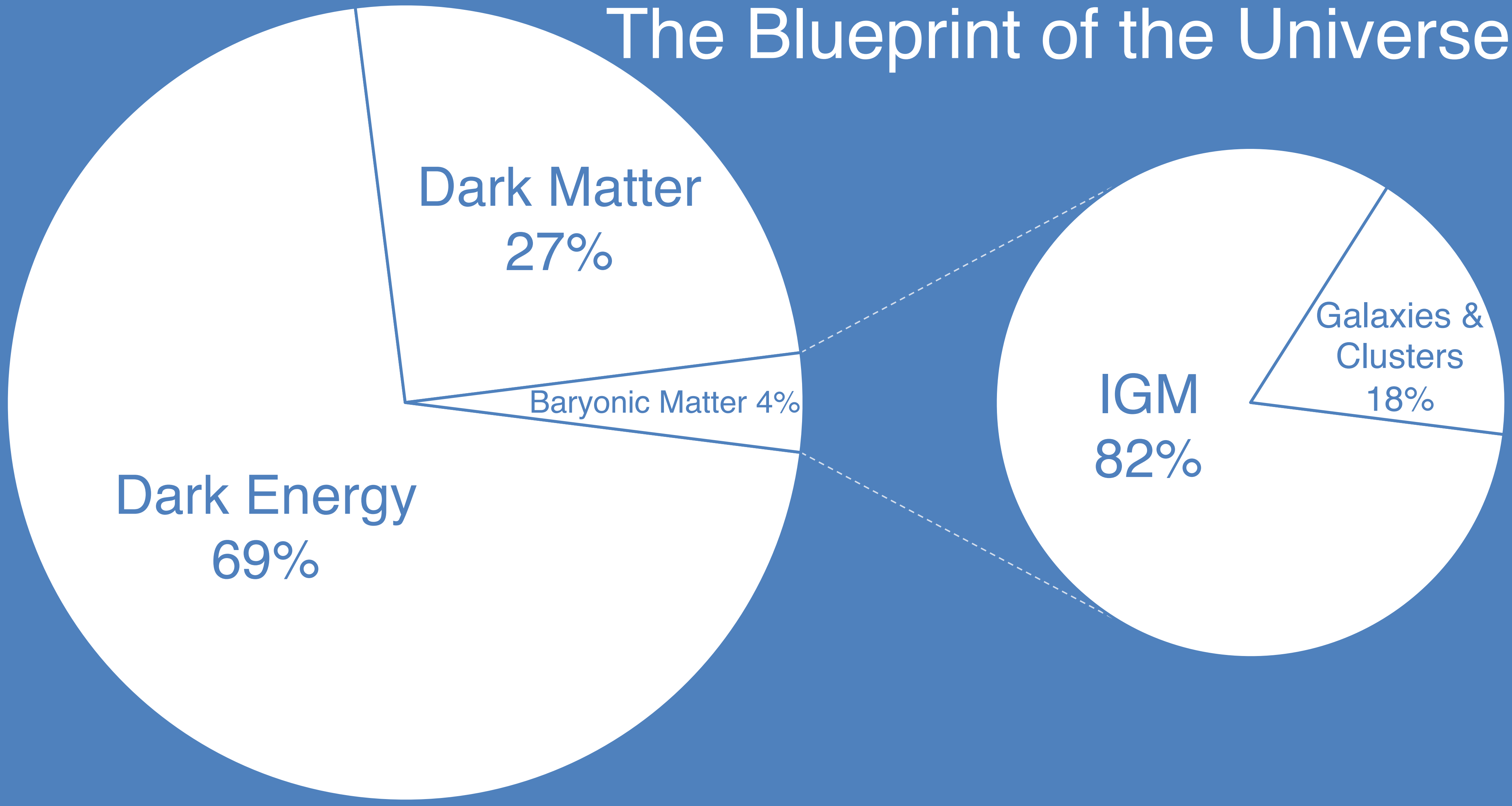
The Blueprint of the Universe

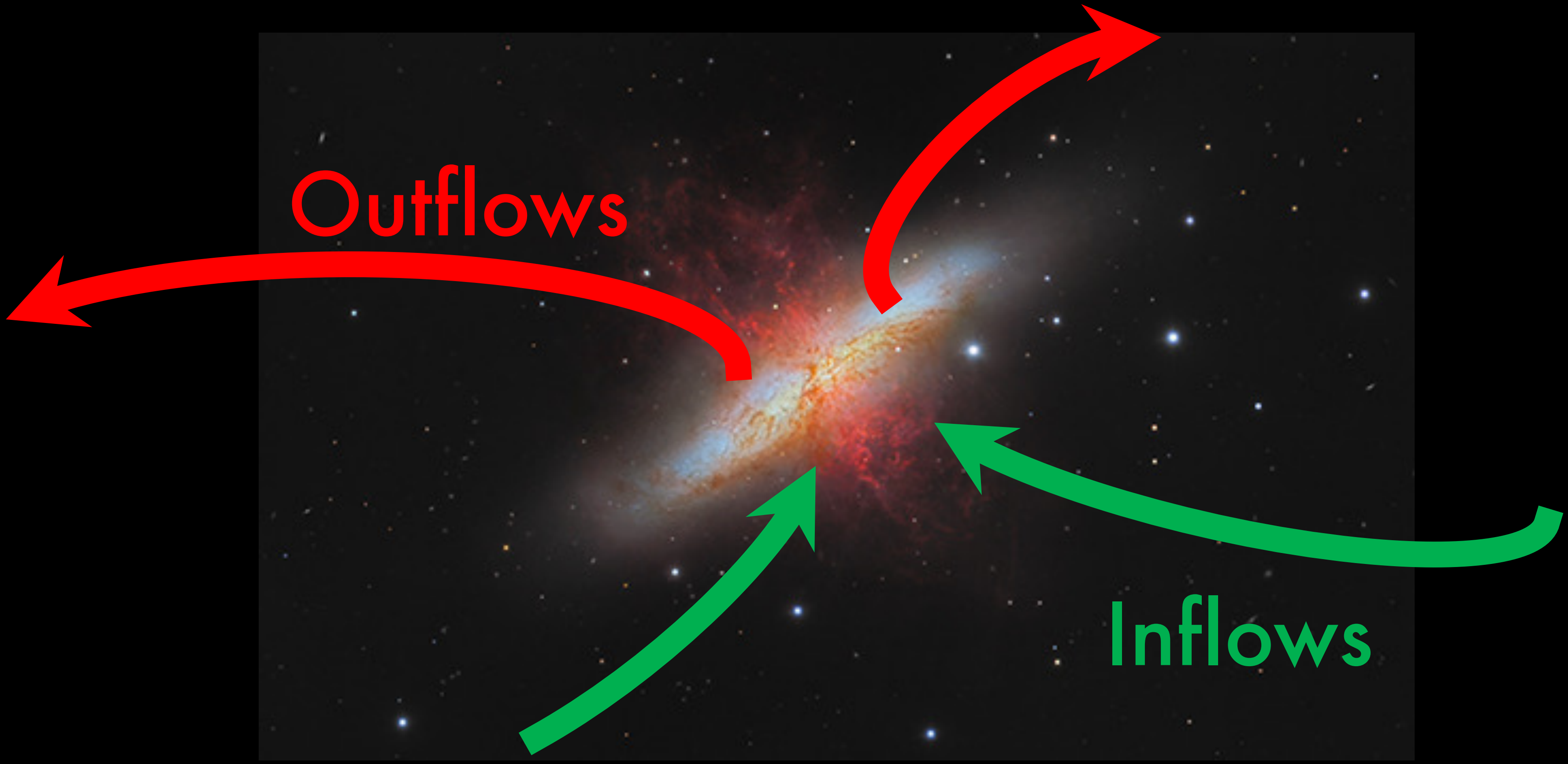


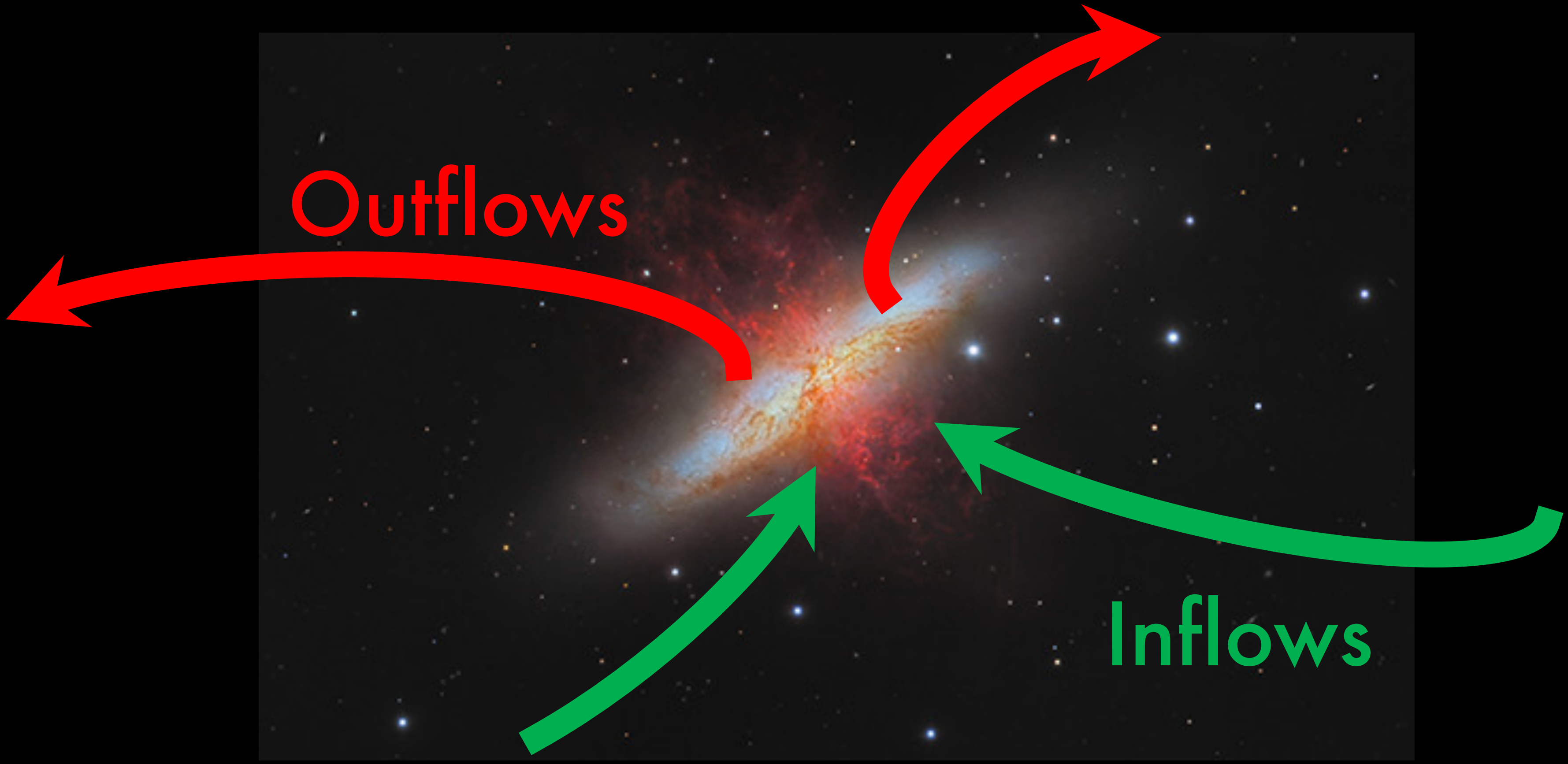
The Blueprint of the Universe



1) Most of the matter in the Universe resides in the Intergalactic Medium.

2) Galaxies and the intergalactic medium evolve together.


Outflows
Inflows



Galaxies and the intergalactic medium, it's impossible to fully understand one without understanding the other.

Astronomy!

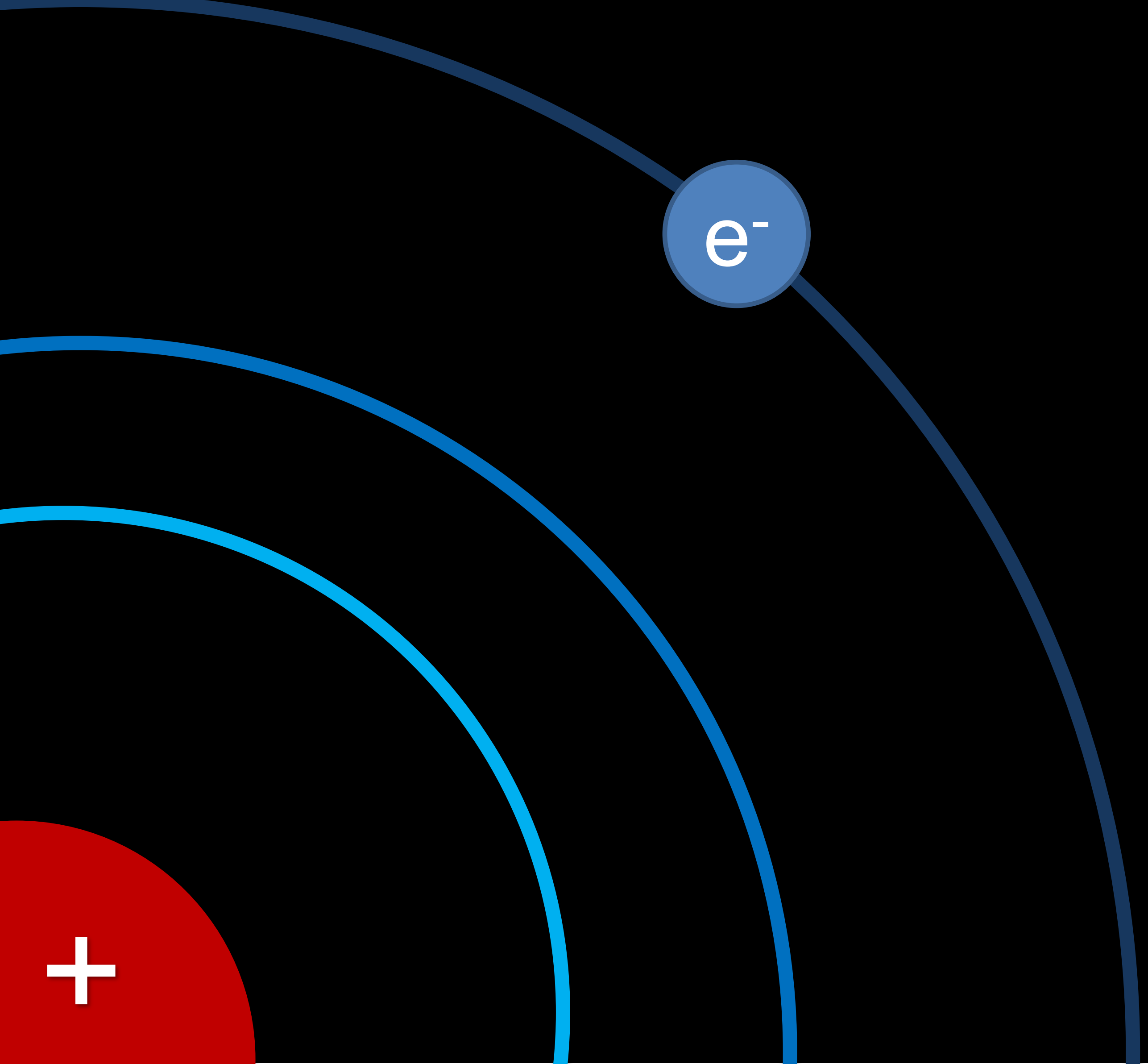
It’s all about light!

Astronomy!

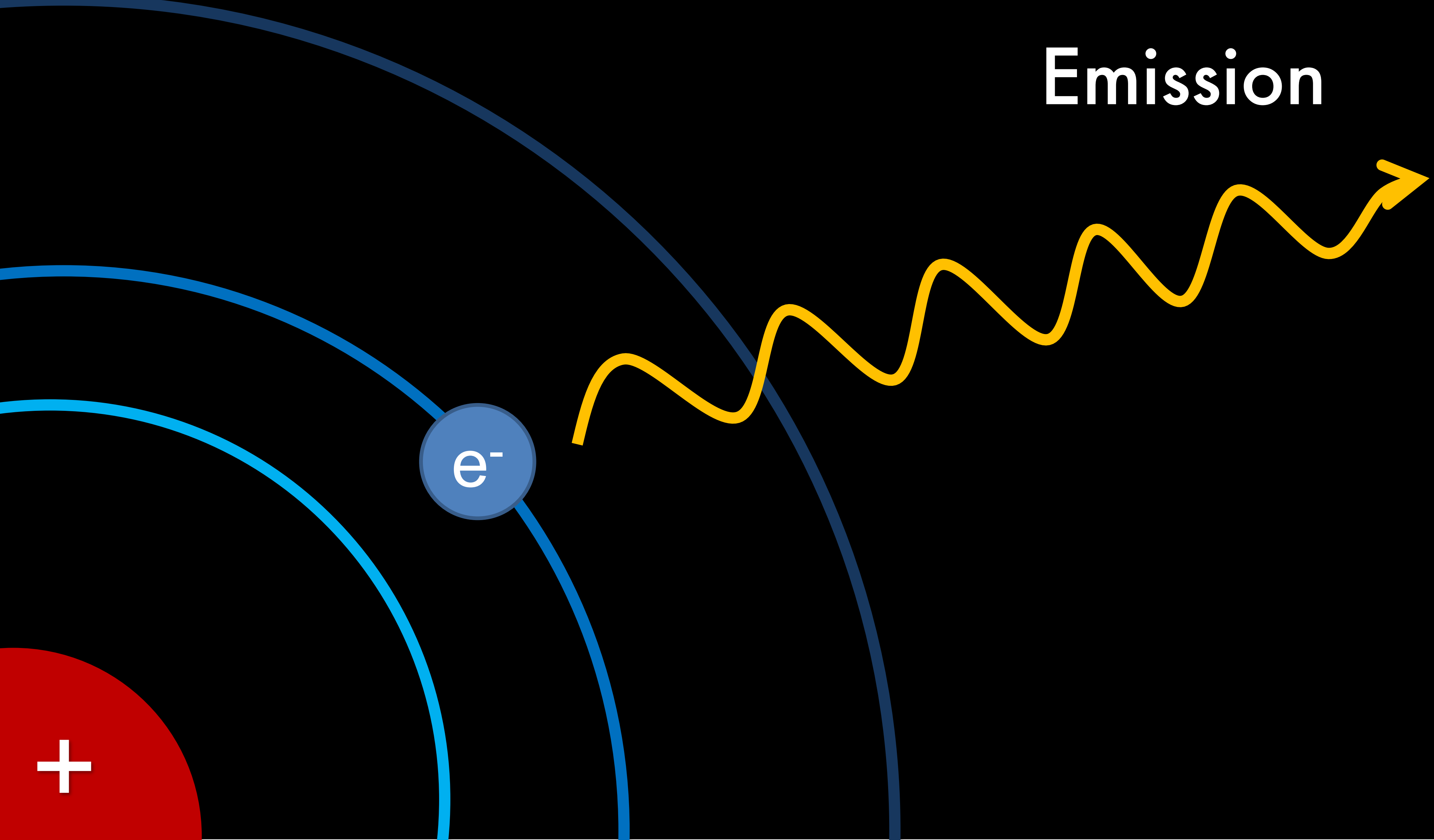
~~It’s all about light!~~

It’s all about how electrons move!

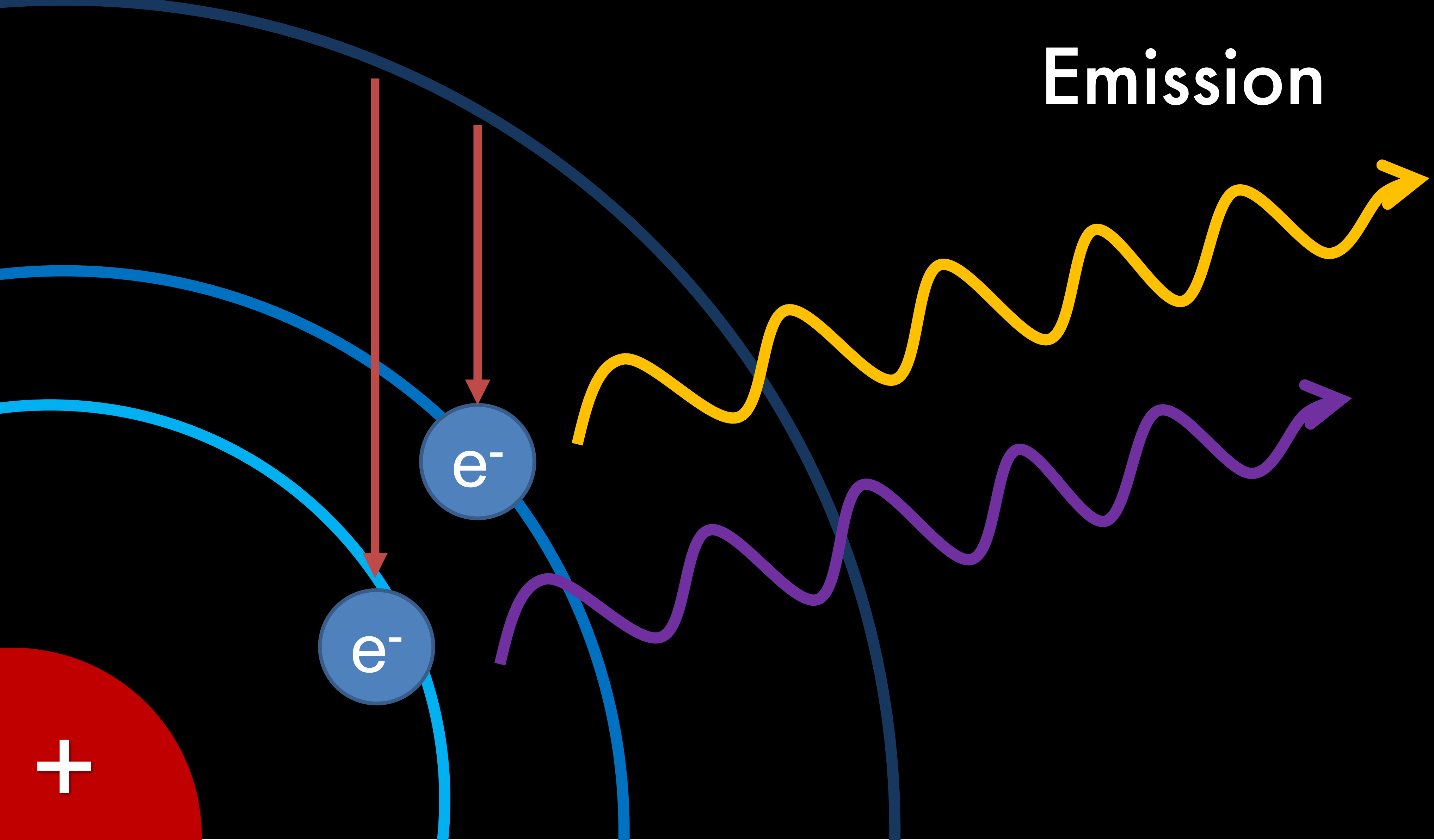
Emission

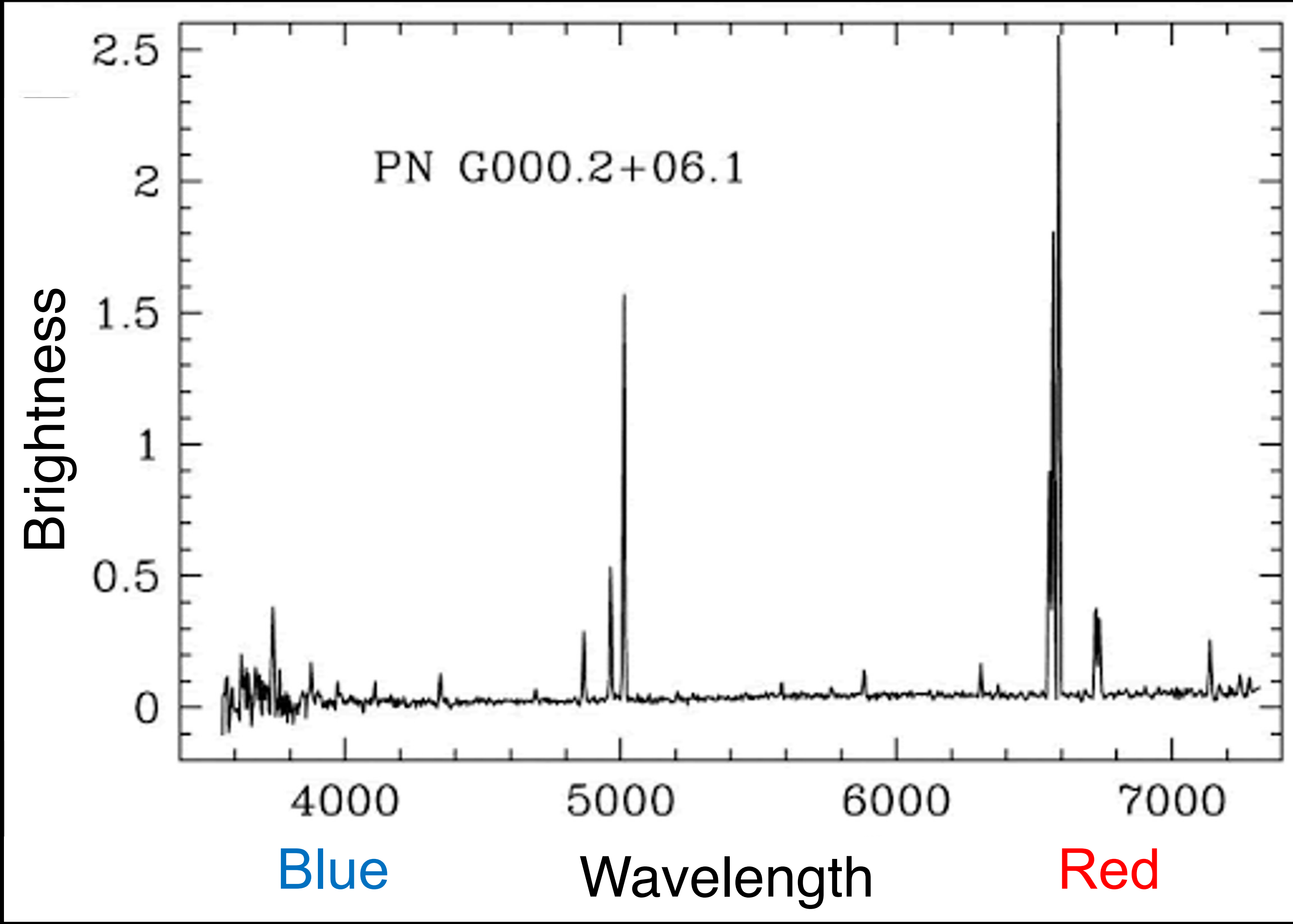


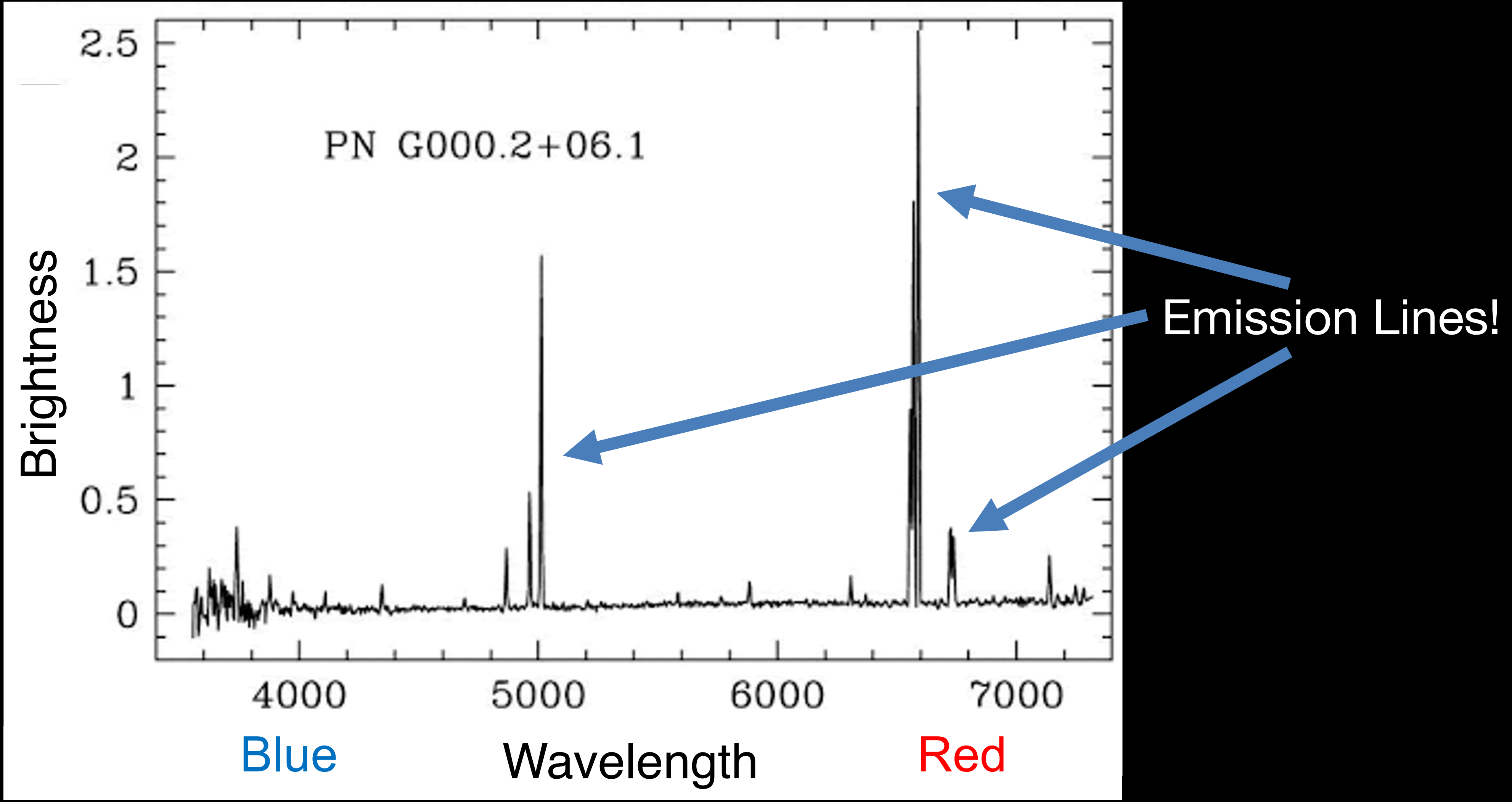
Emission



Emission

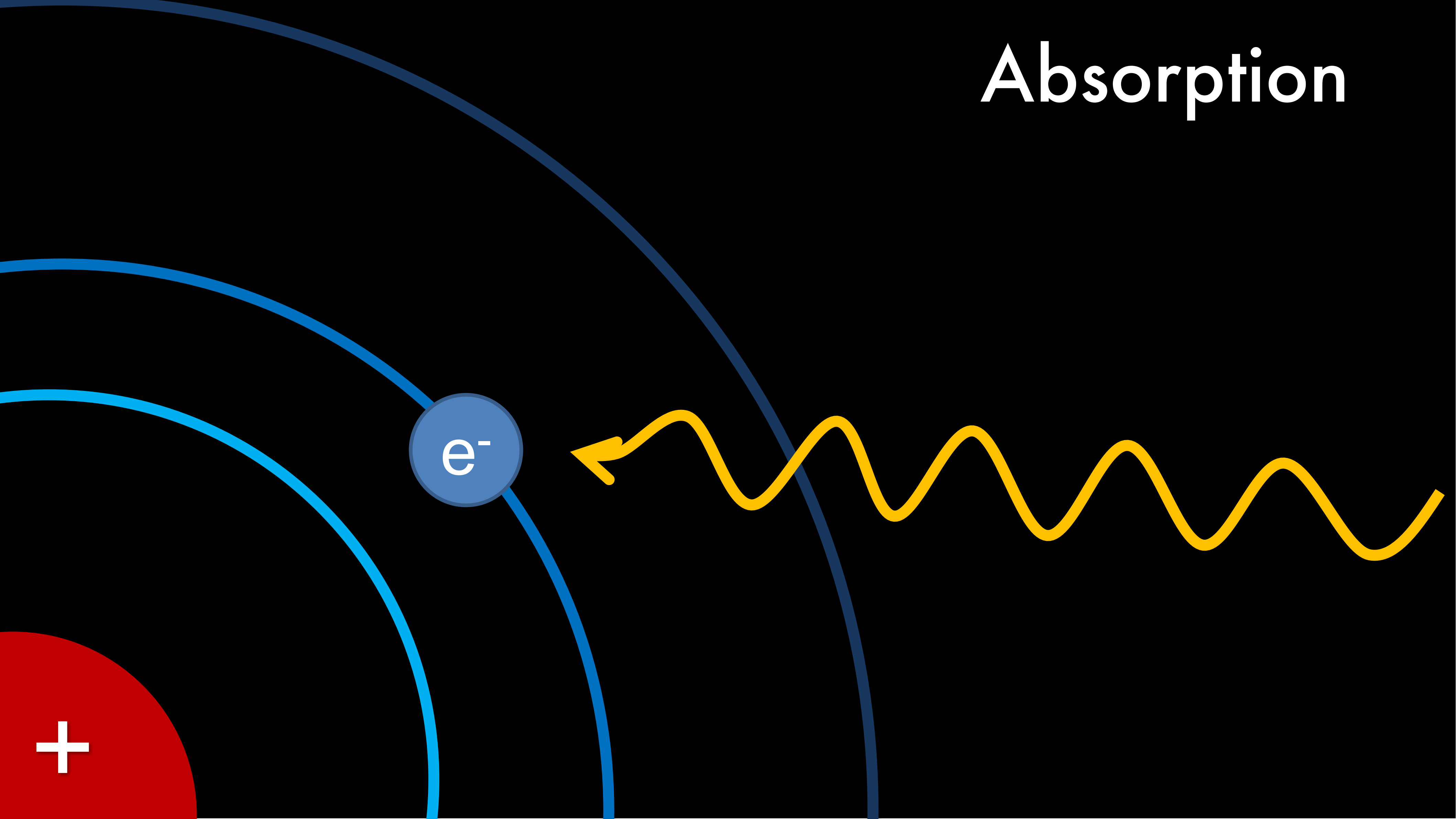


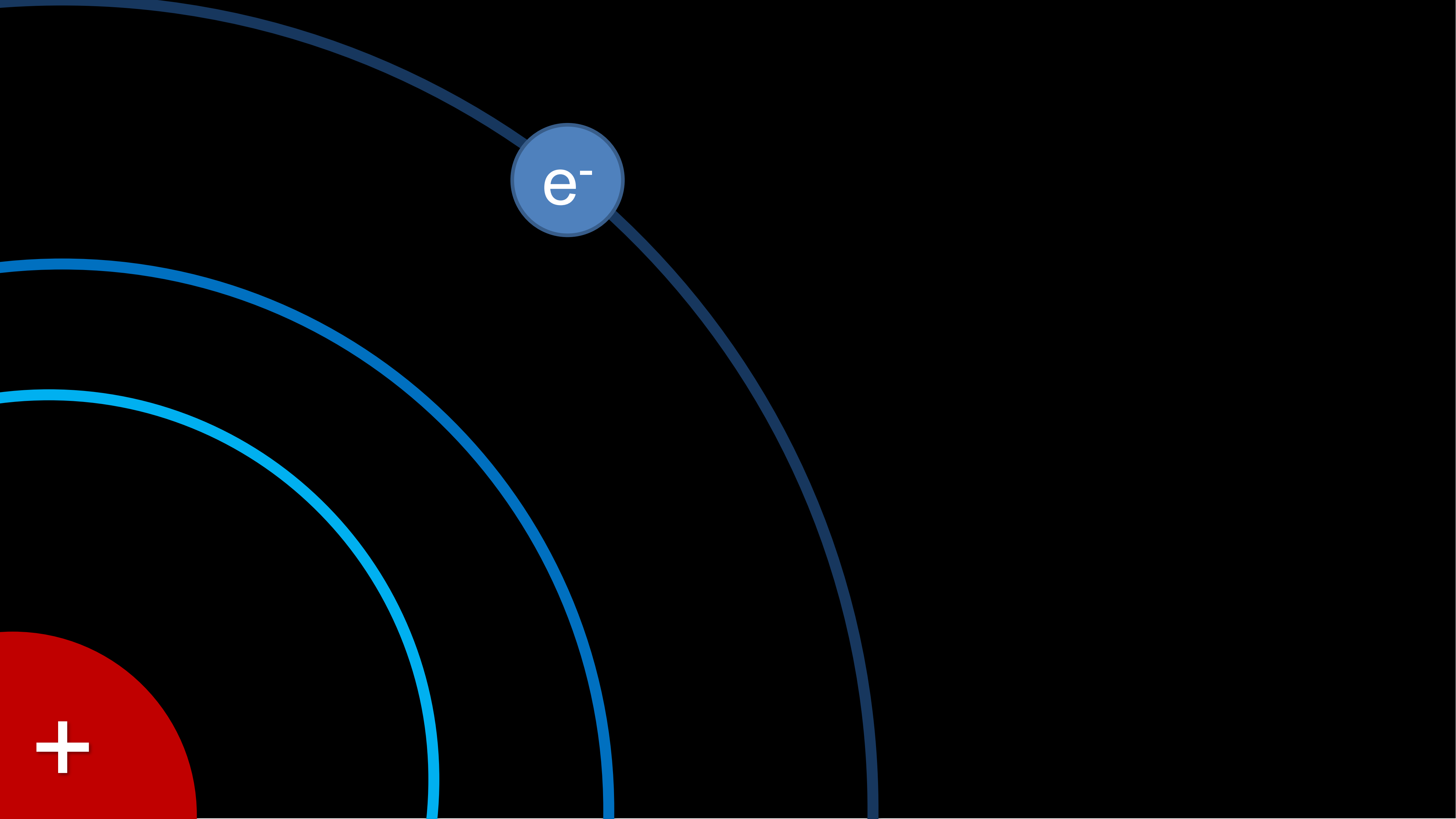

PN G000.2+06.1
Brightness
2.5
2
1.5
1
0.5
0
4000
5000
6000
7000
Blue
Wavelength
Red

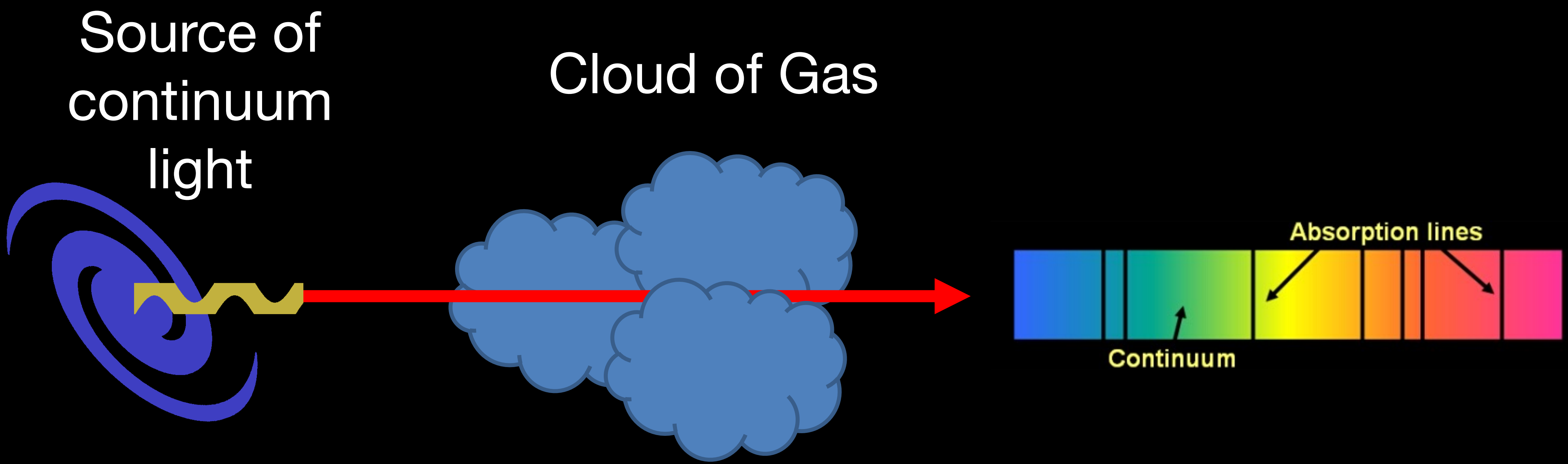


PN G000.2+06.1
Brightness
2.5
2
1.5
1
0.5
0
4000
5000
6000
7000
Blue
Wavelength
Red
Emission Lines!

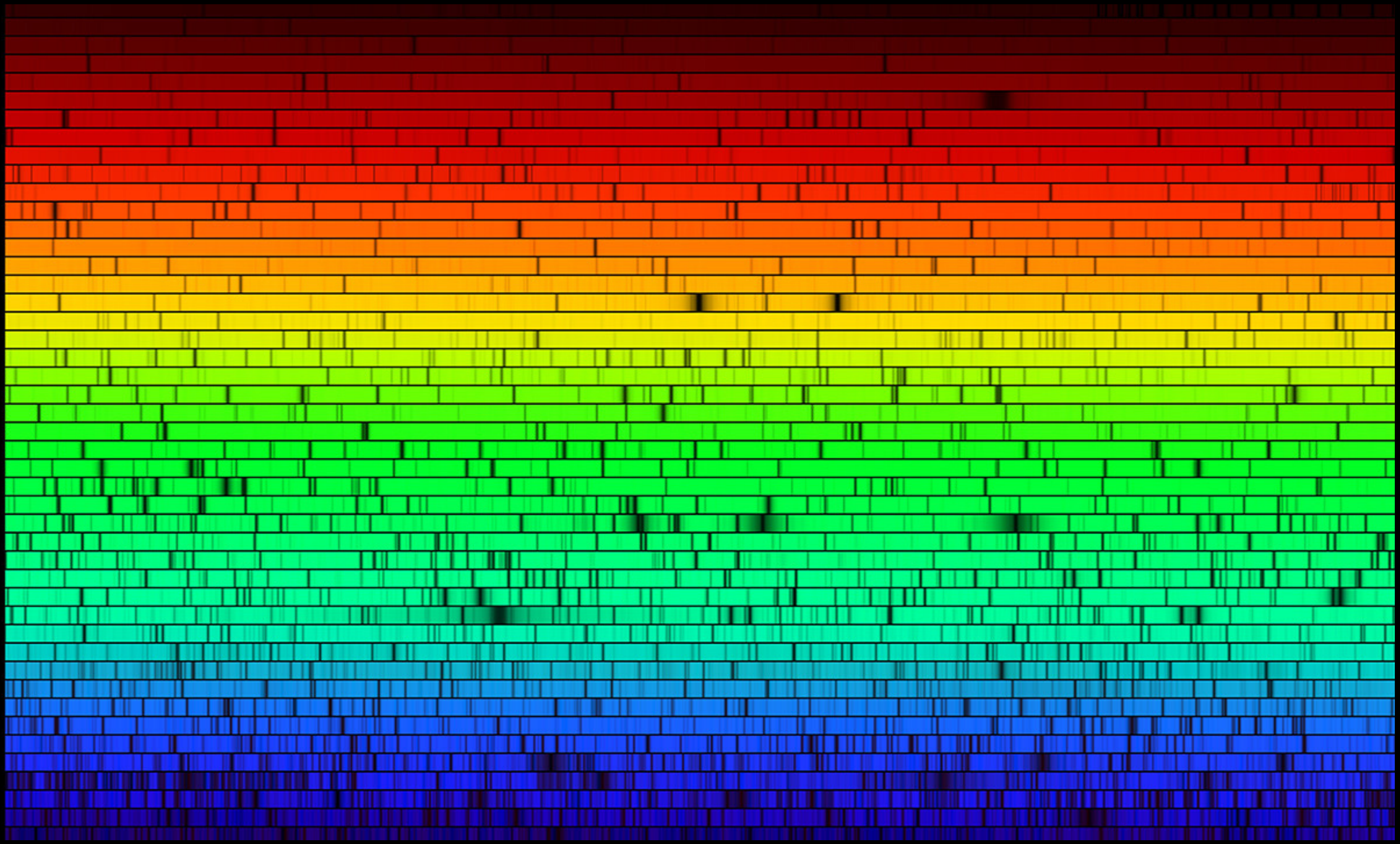
Absorption



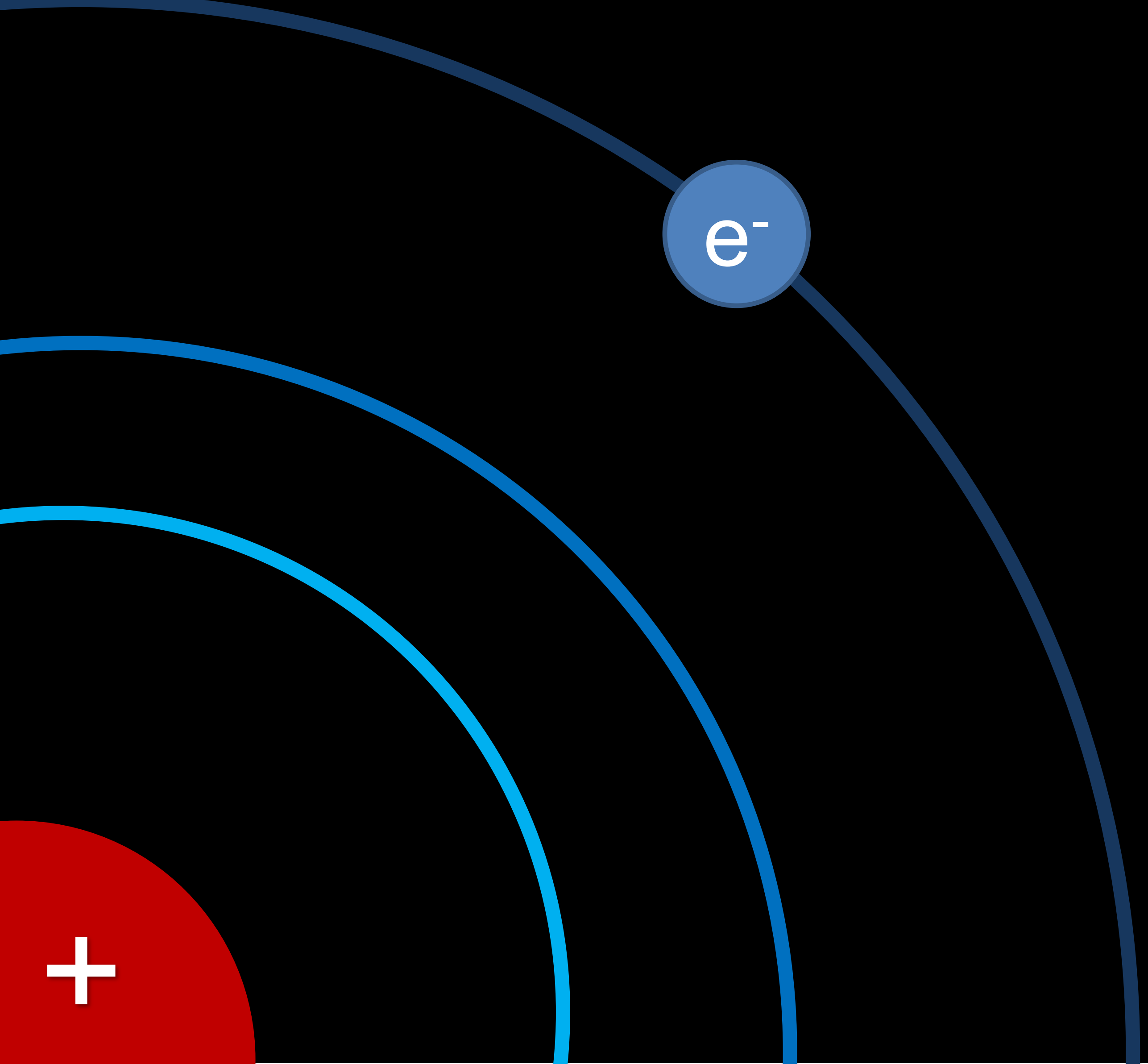

e^-
+


Source of continuum light
Cloud of Gas
Absorption lines
Continuum

The Sun

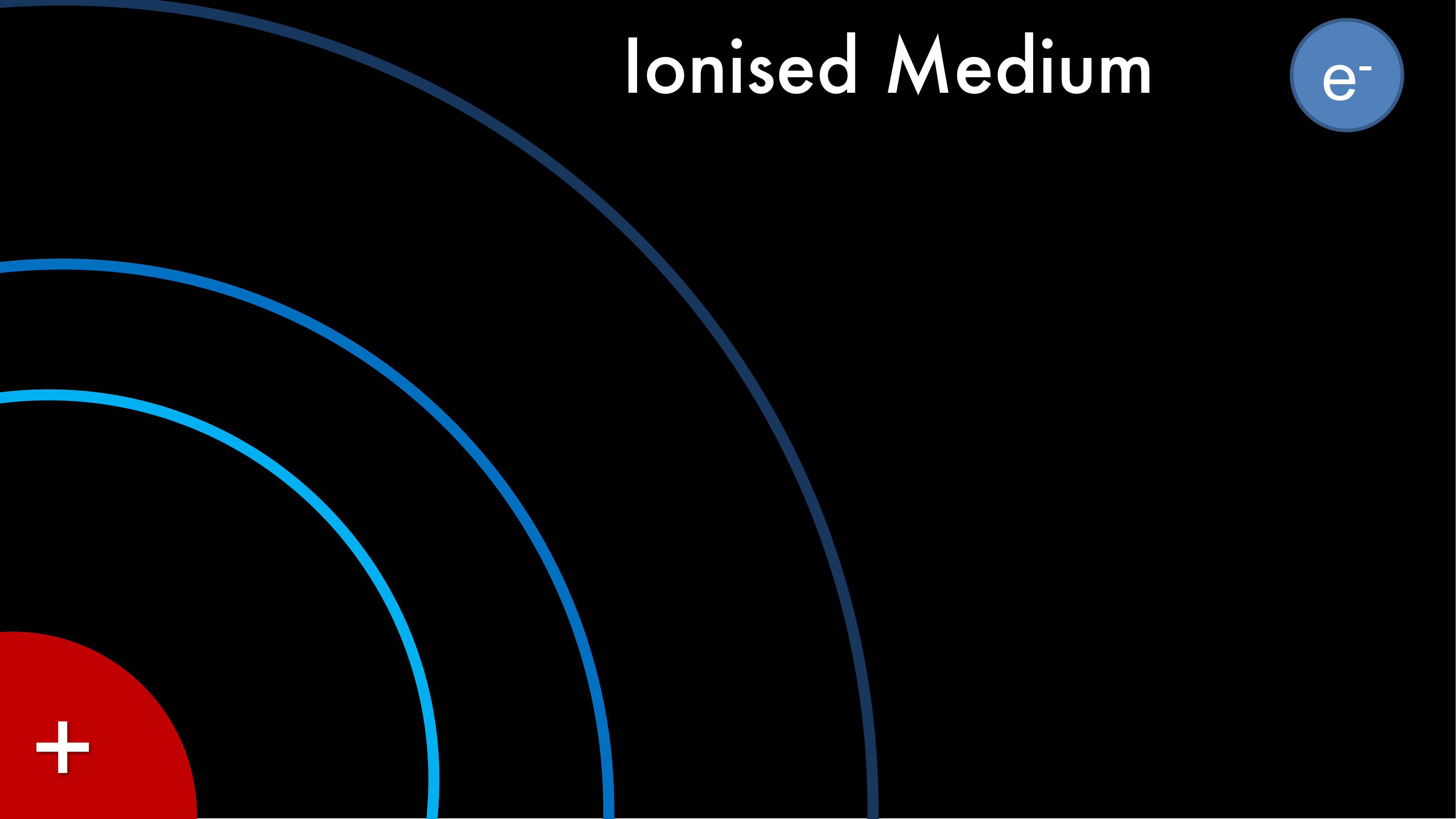


Credit: N.A.Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF



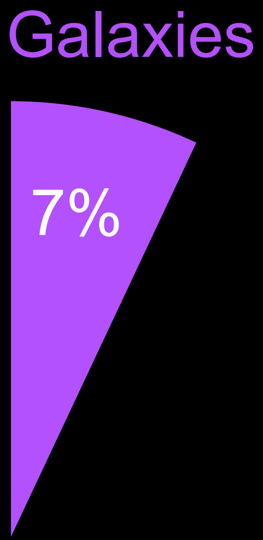
e-
+

Ionised Medium



The Baryon Census

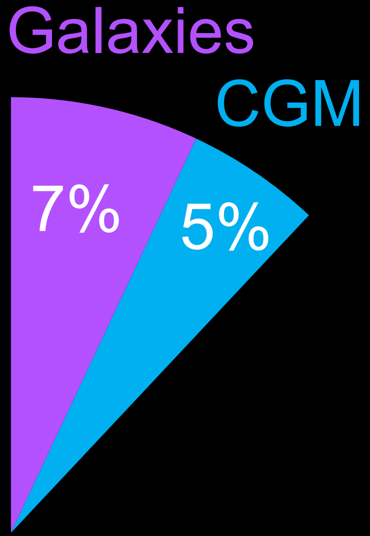
The Baryon Census

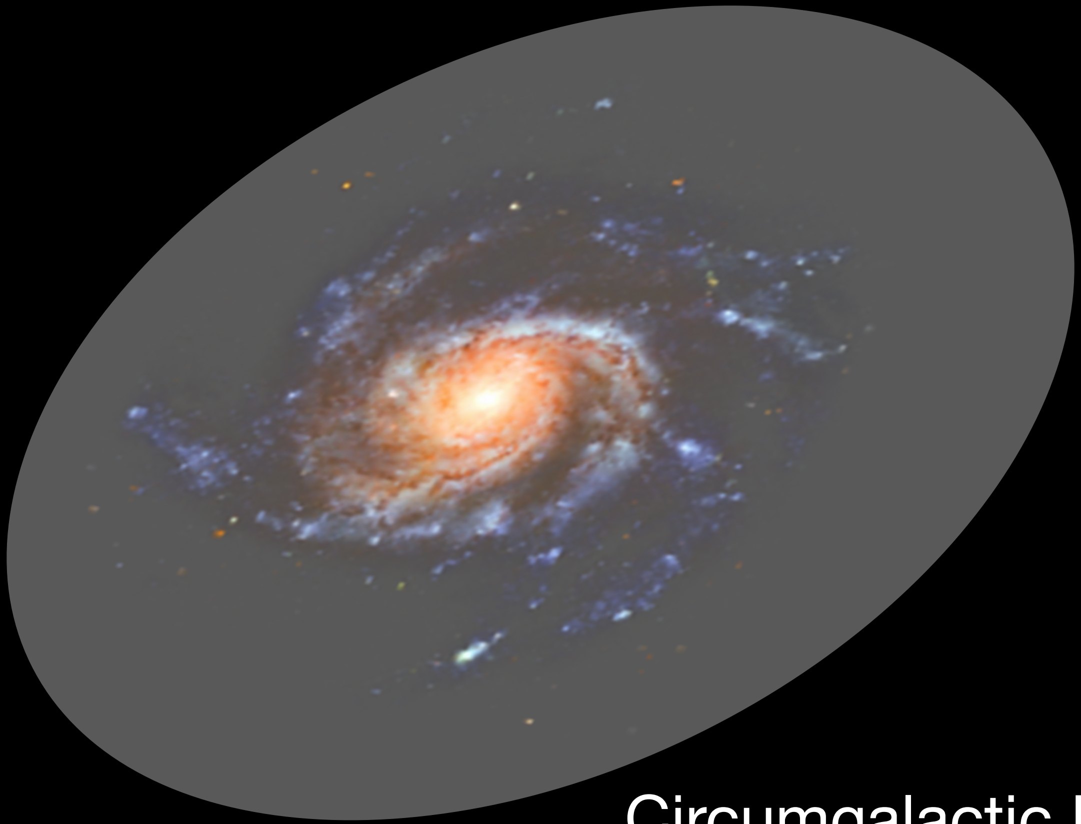


Galaxies

Shull et al. (2012)

The Baryon Census

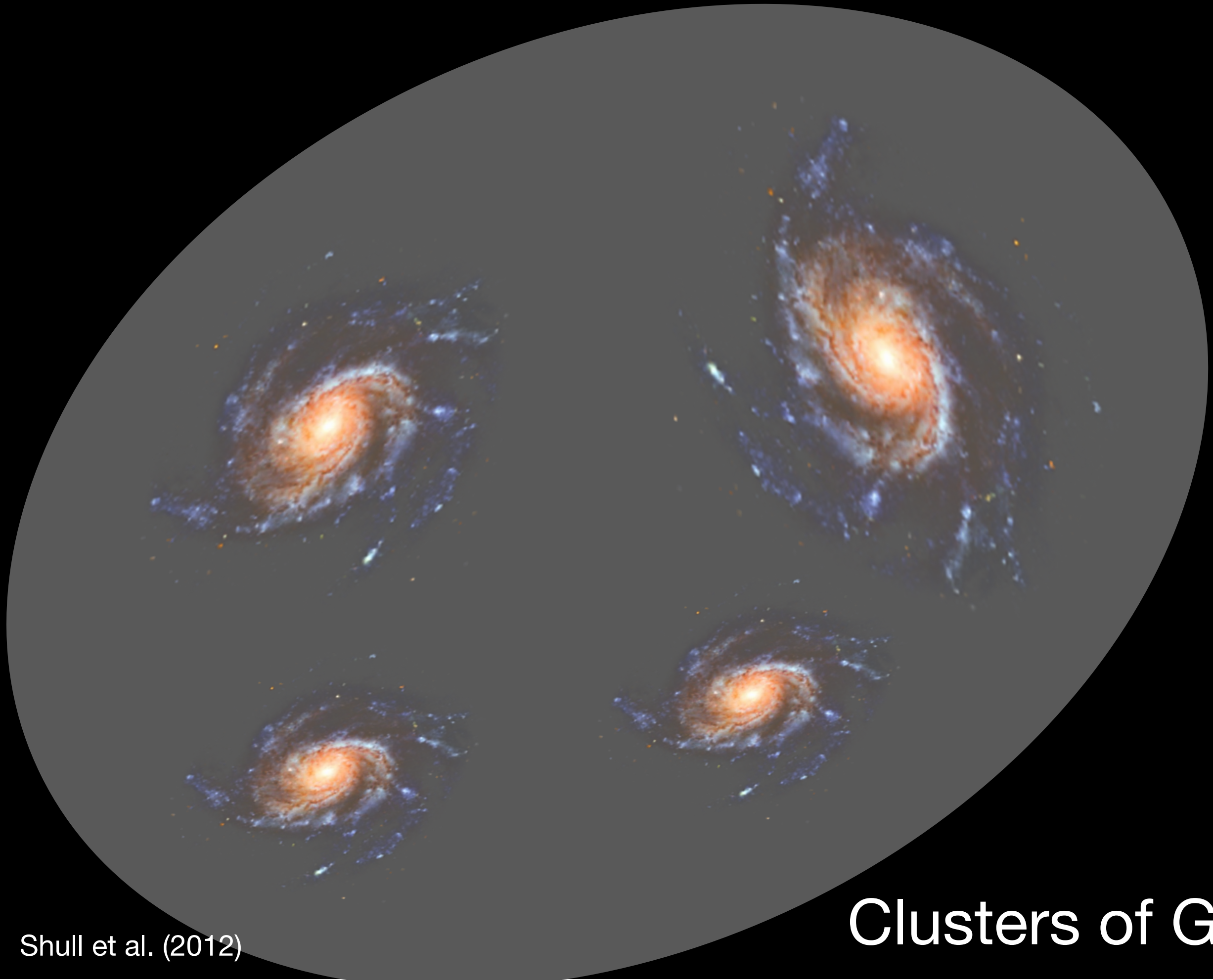


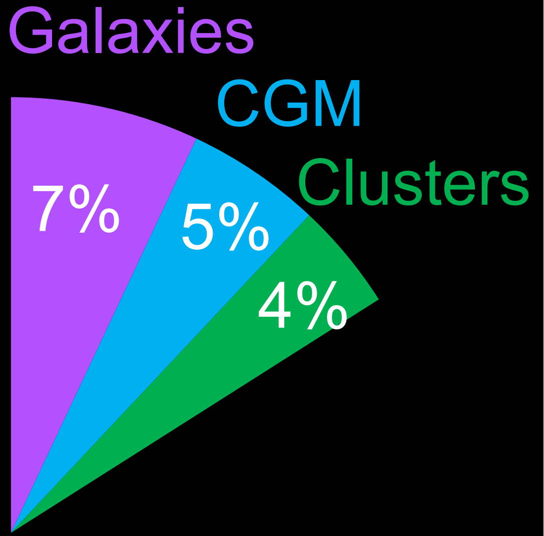


Circumgalactic Medium

Shull et al. (2012)

The Baryon Census

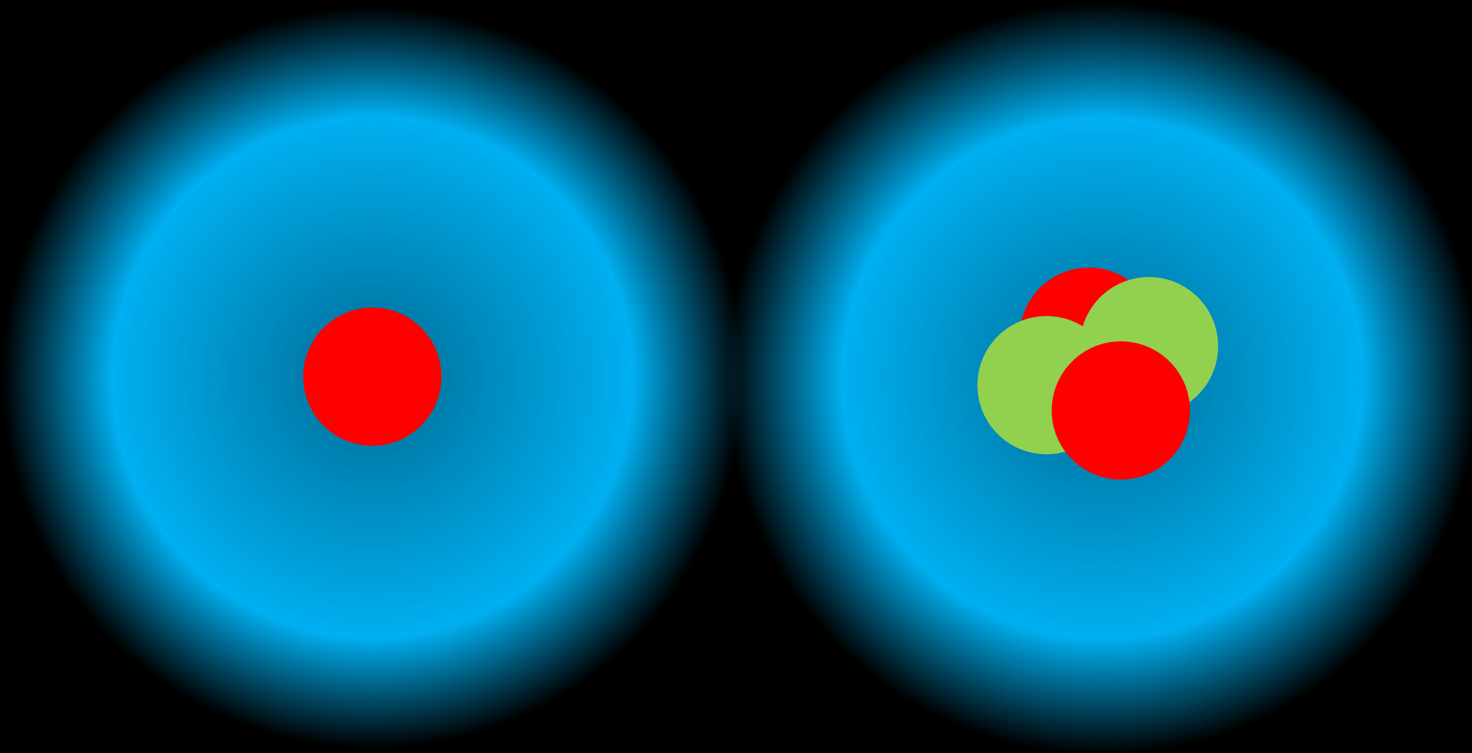




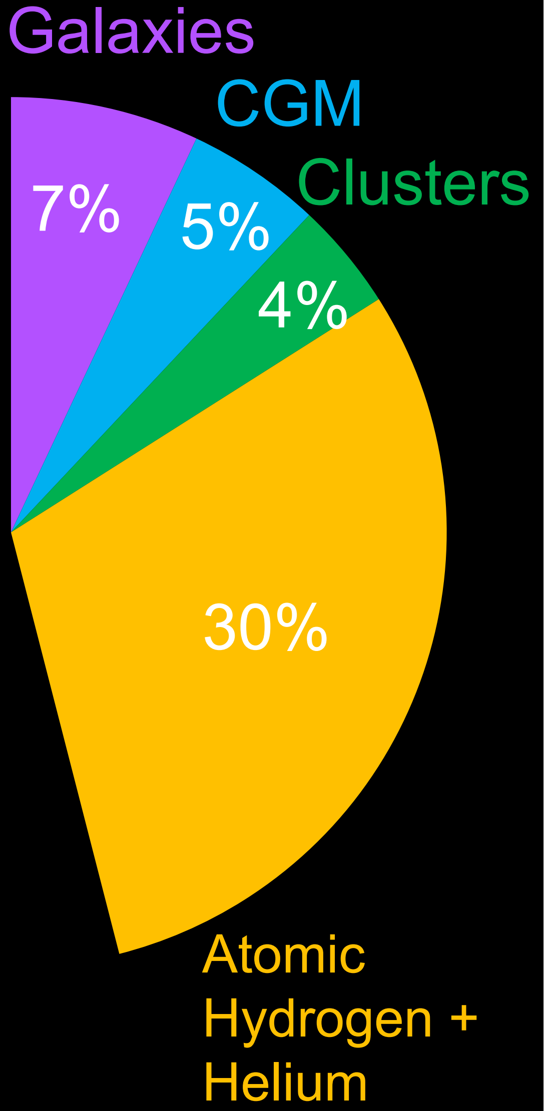
Clusters of Galaxies

Shull et al. (2012)

The Baryon Census



Atomic Hydrogen and Helium



Shull et al. (2012)

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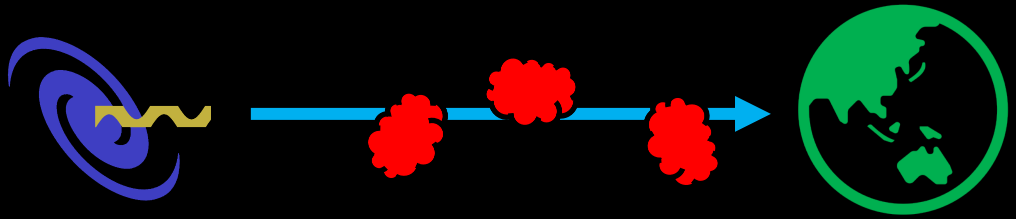
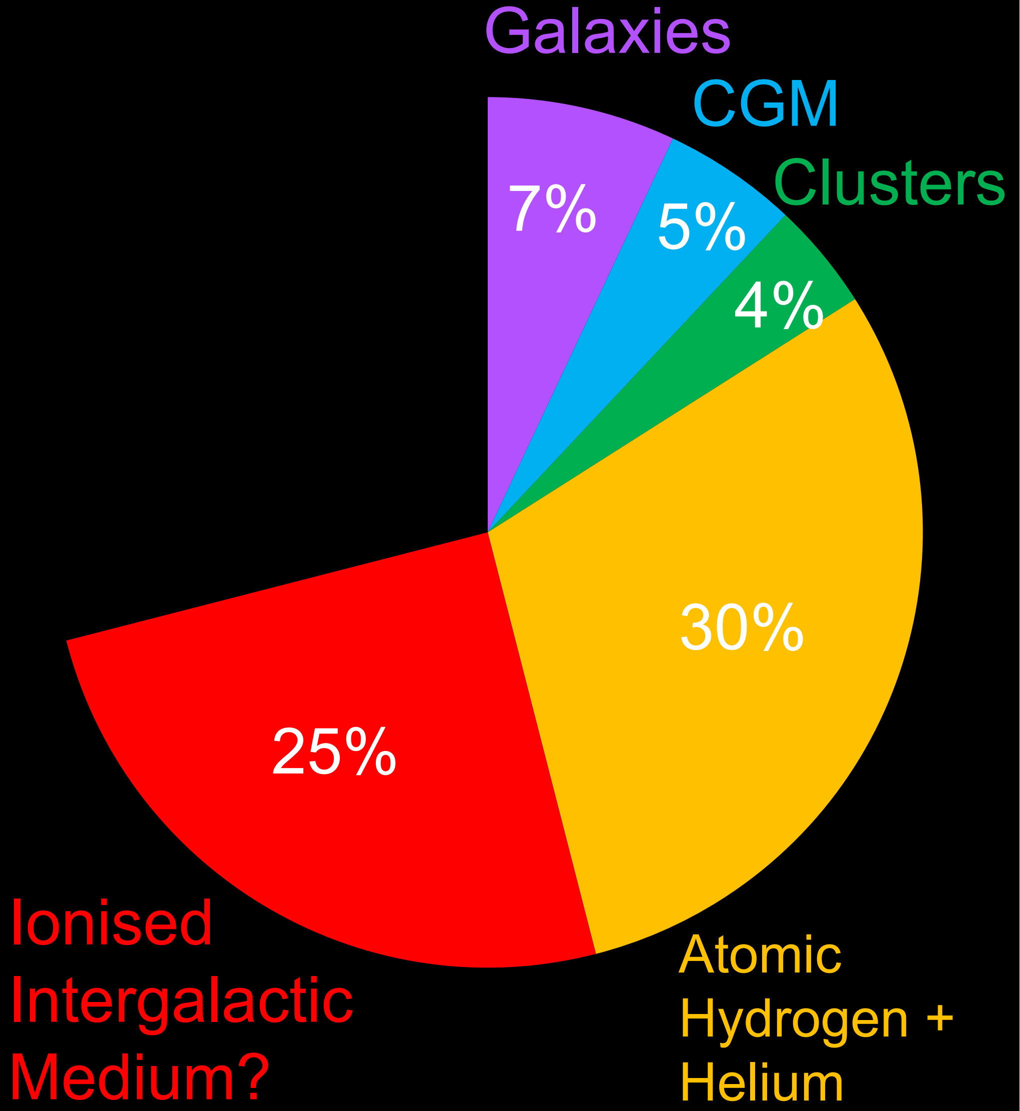


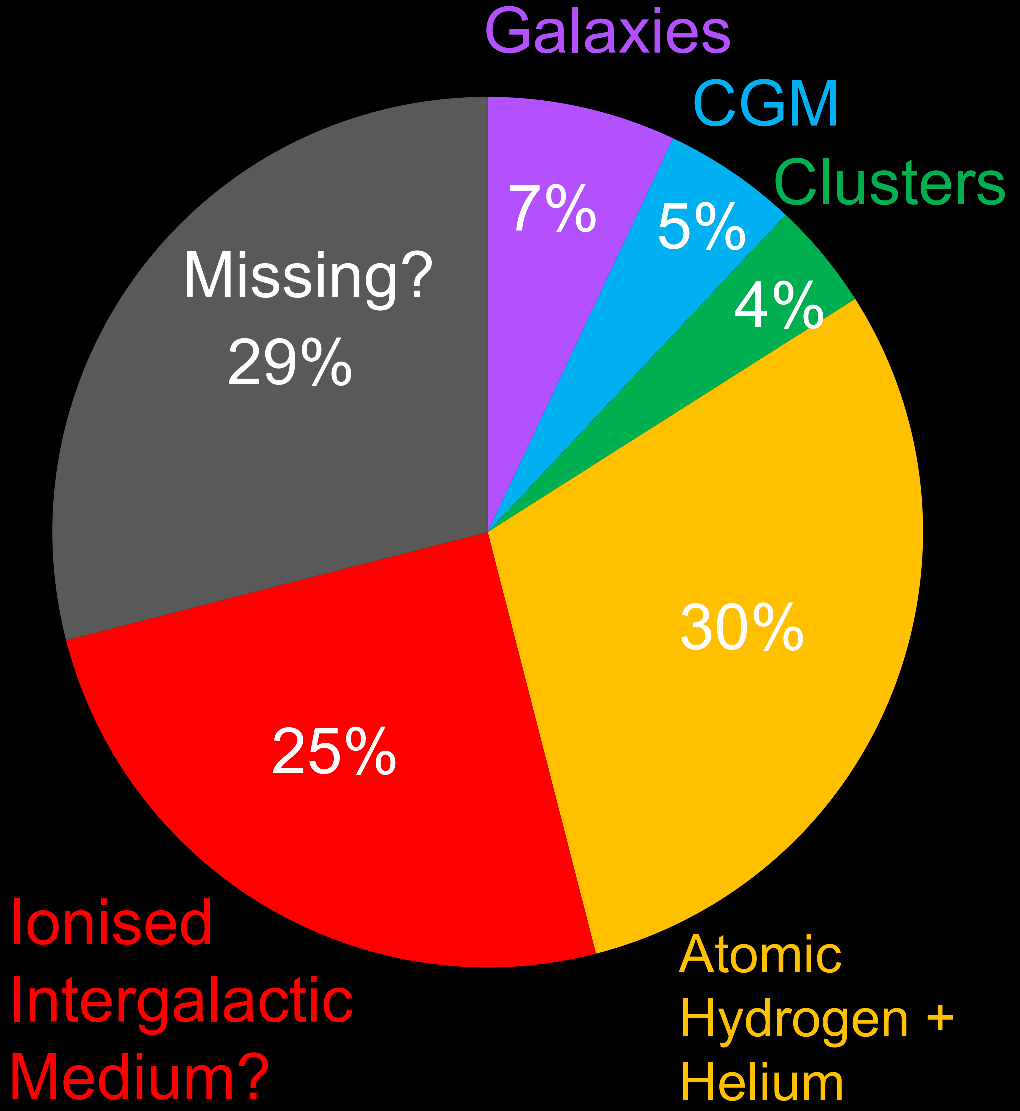
Ionised Intergalactic Medium



Shull et al. (2012)

The Baryon Census

We are missing almost a third of all the matter in the nearby Universe!



Shull et al. (2012)

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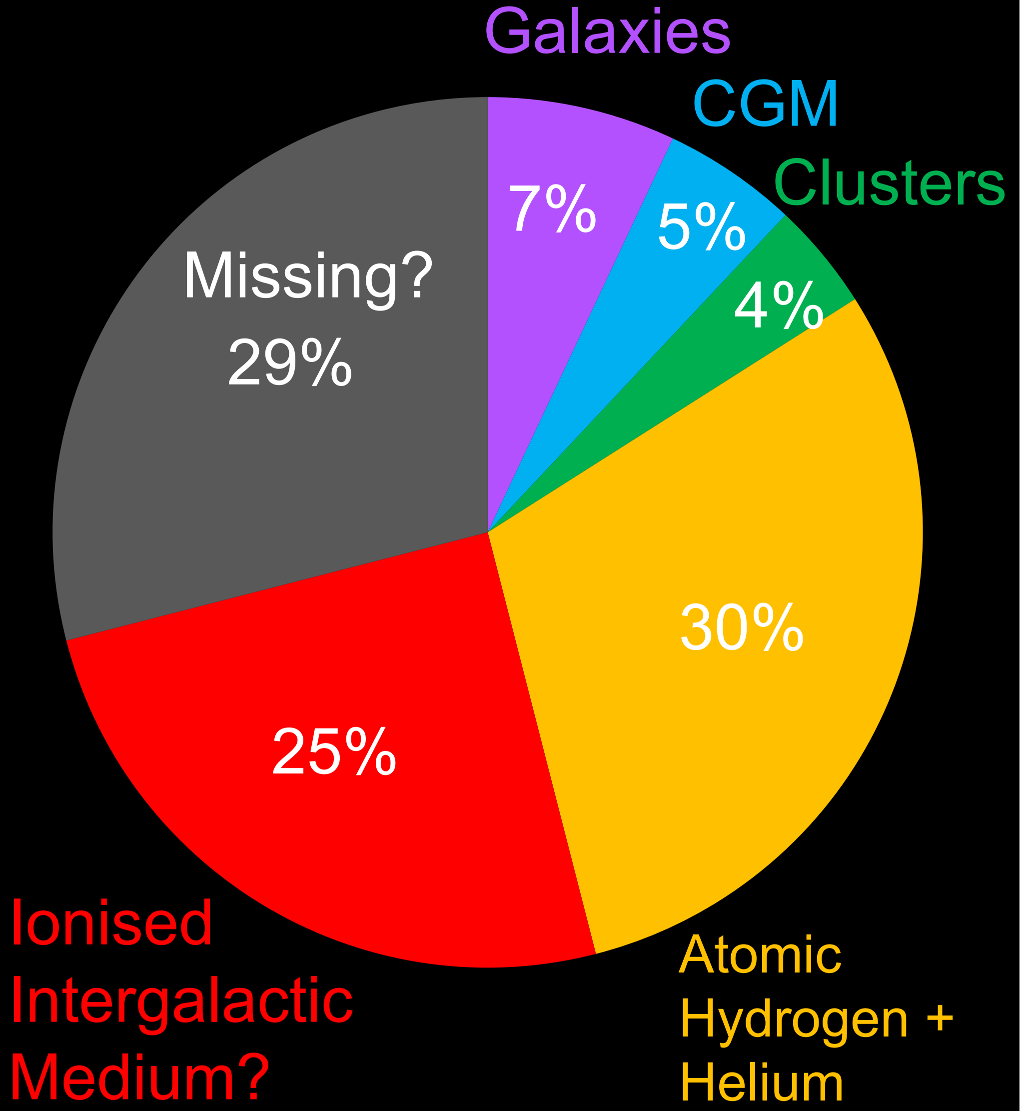
The intergalactic medium is too ionised and low density to detect with optical telescopes!



Shull et al. (2012)

Fast Radio Bursts

An extremely bright *burst* of *radio* signal, which lasts for less than a millisecond

(i.e *fast*).

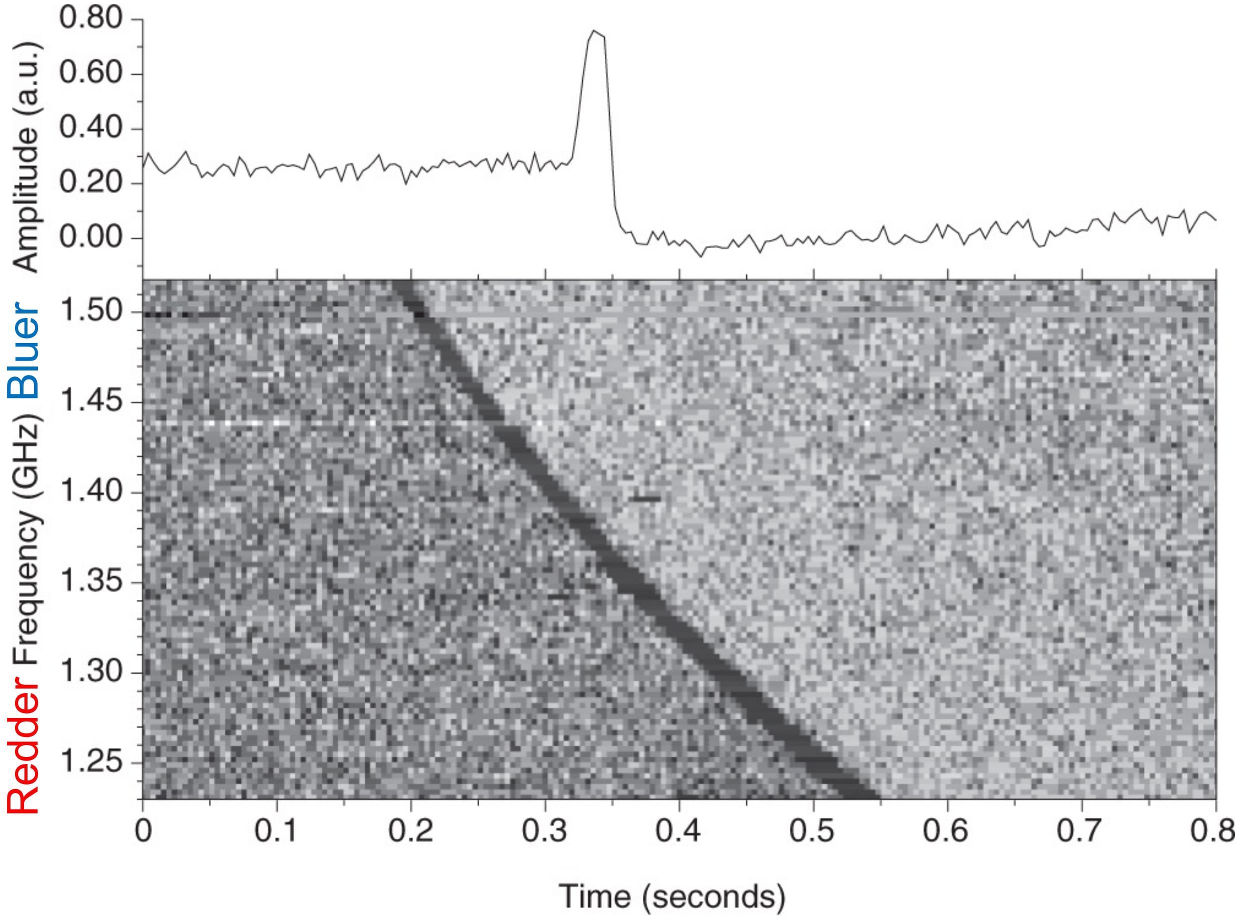


Image Credit: Lorimer (2018)

Video Credit: CSIRO/ICRAR/OzGrav/Swinburne University of Technology

Fast Radio Bursts

This burst went through 10x more matter than expected if it was in the Milky Way.

Fast Radio Bursts must be extragalactic!

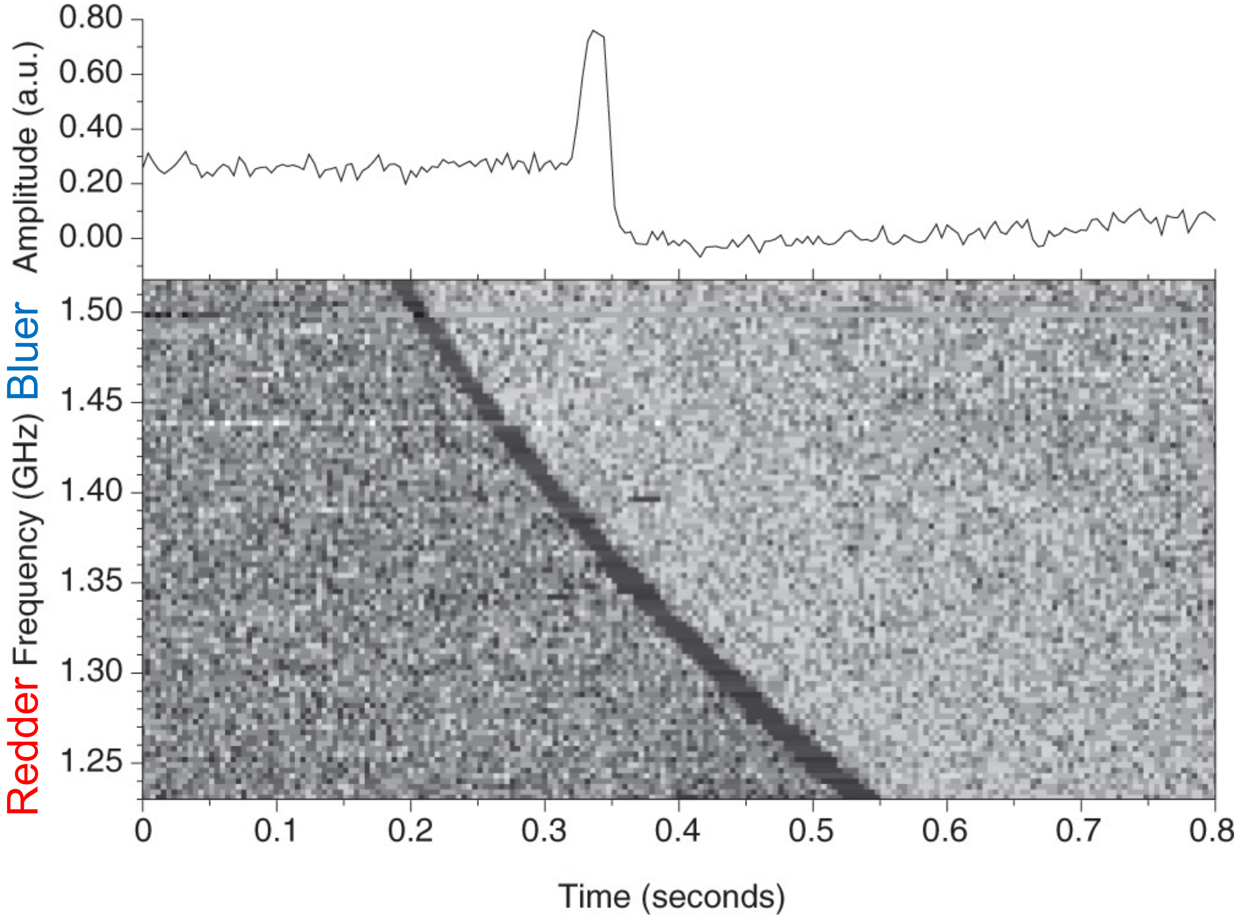


Image Credit: Lorimer (2018)

Fast Radio Bursts

The first fast radio burst detected in the Milky way was found in 2020.

From a Magnetar!

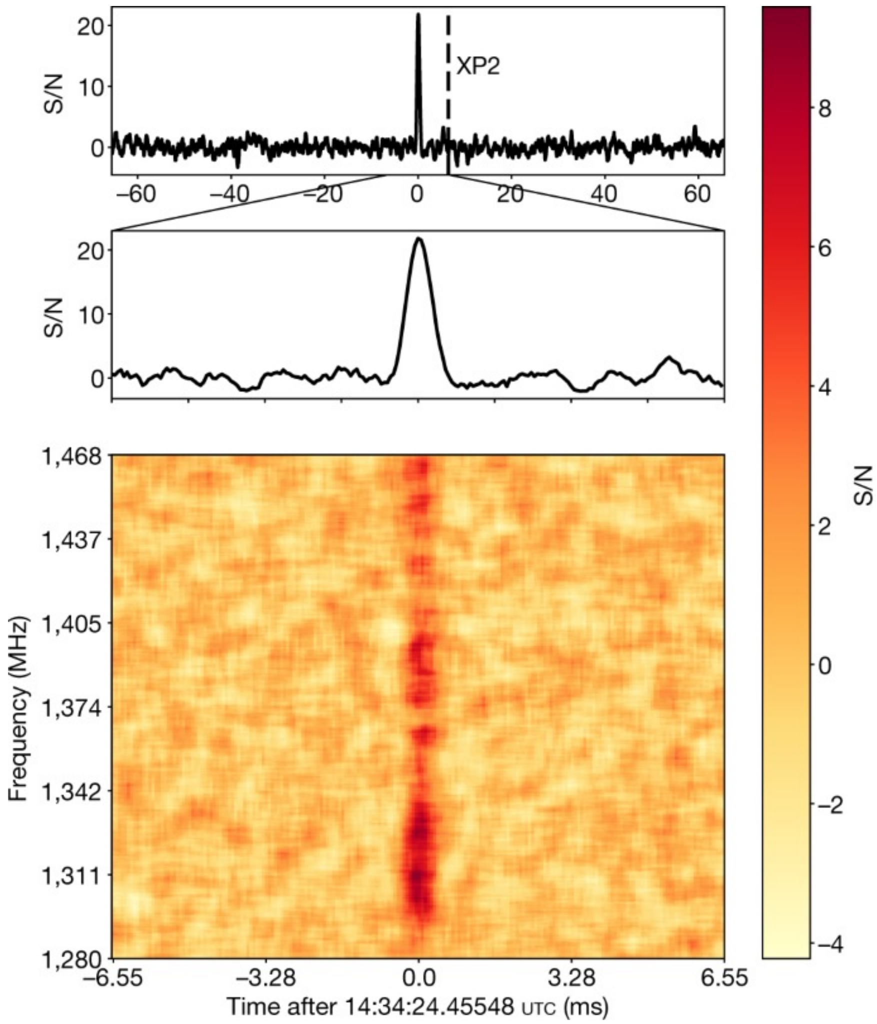


Image Credit: ESO/L. Calçada

Bochenek et al. (2020)

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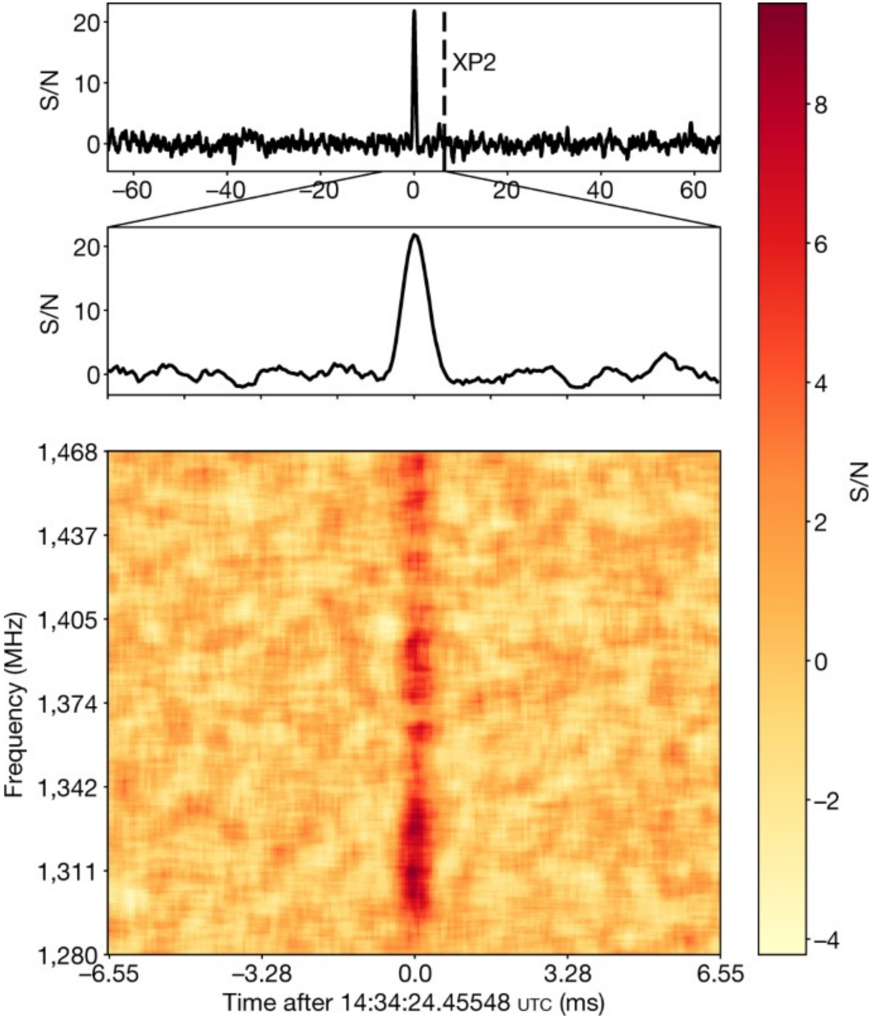
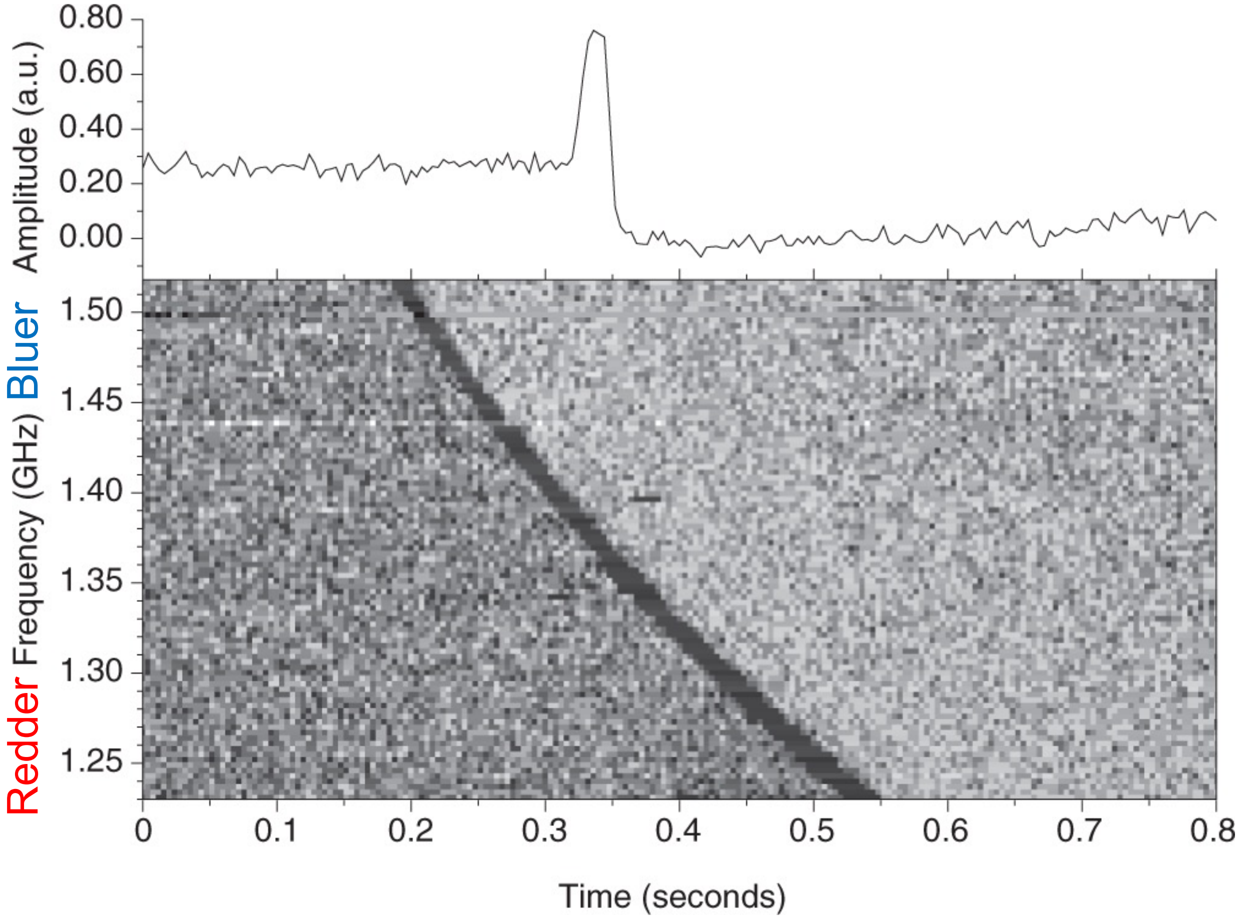


Bochenek et al. (2020)

Fast Radio Bursts

If FRBs are extragalactic, then they can be used to measure the intergalactic medium!



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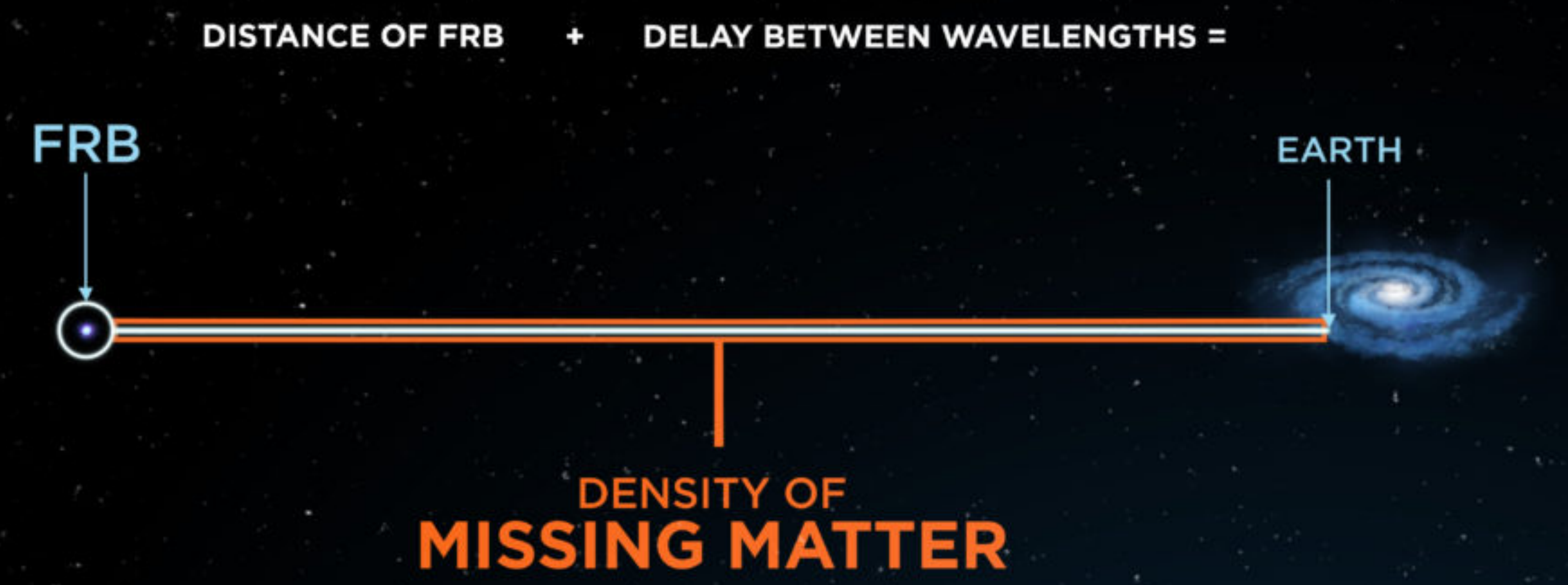


Image Credit: ICRAR

The distance to FRBs is the key!

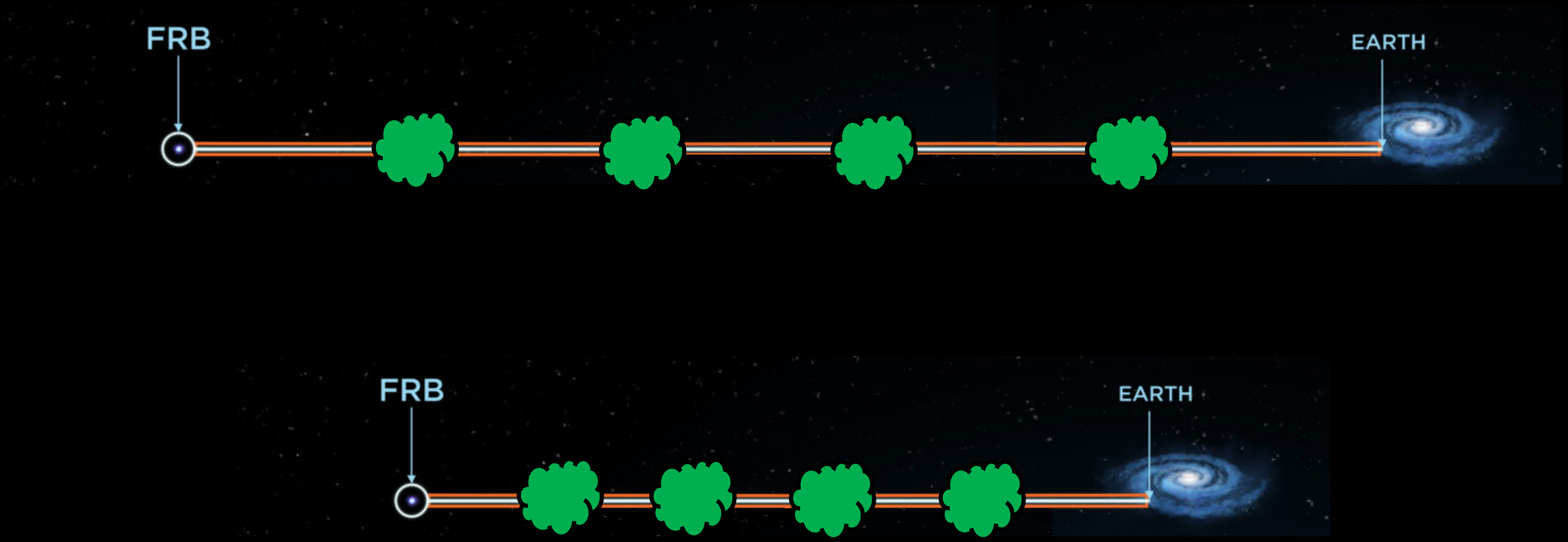
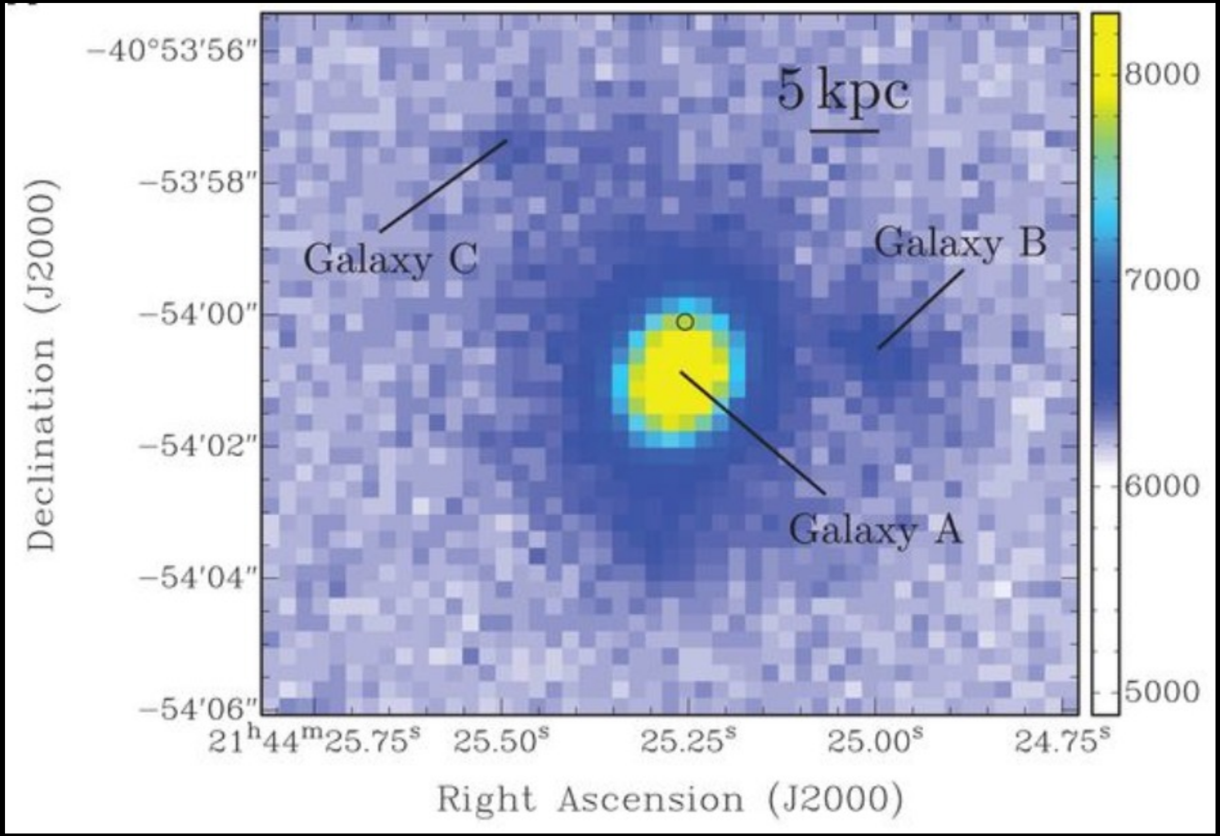


Image Credit: ICRAR

Image Credit: John Sarkissian

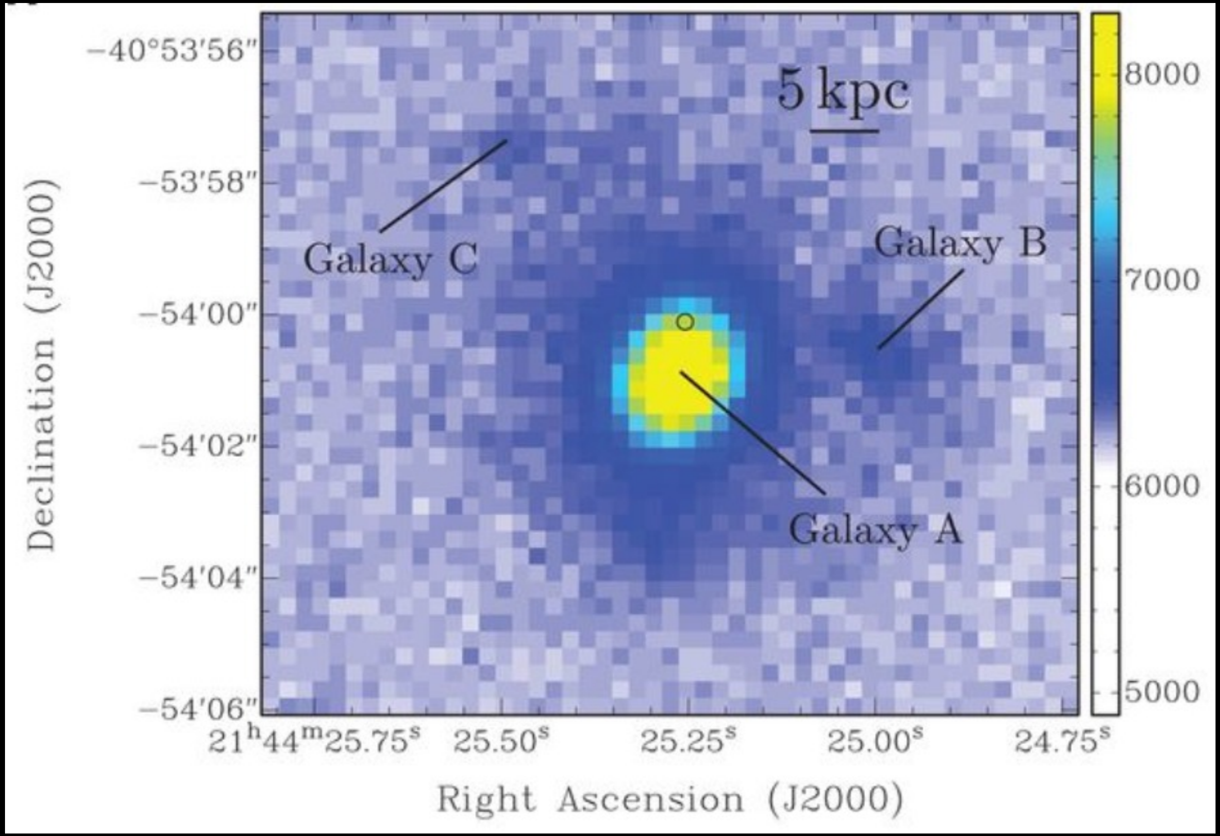
Image Credit: ICRAR

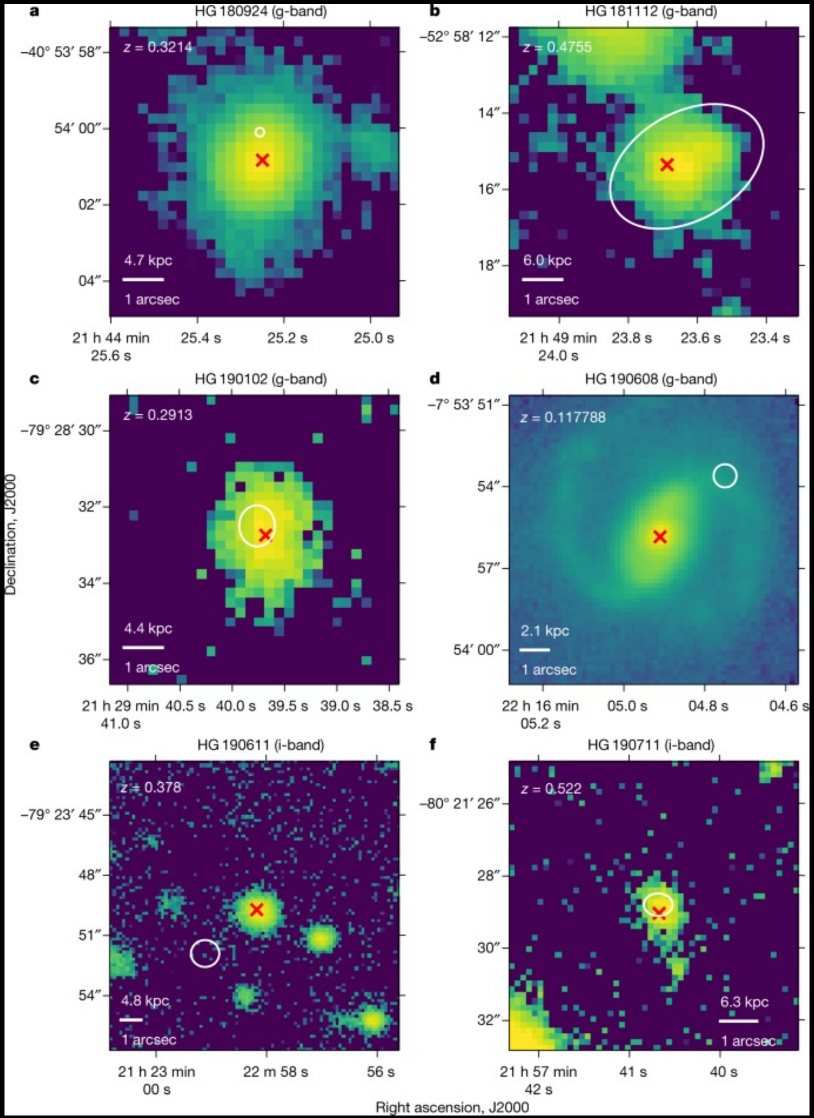
FRB 180924



Bannister et al. (2019)

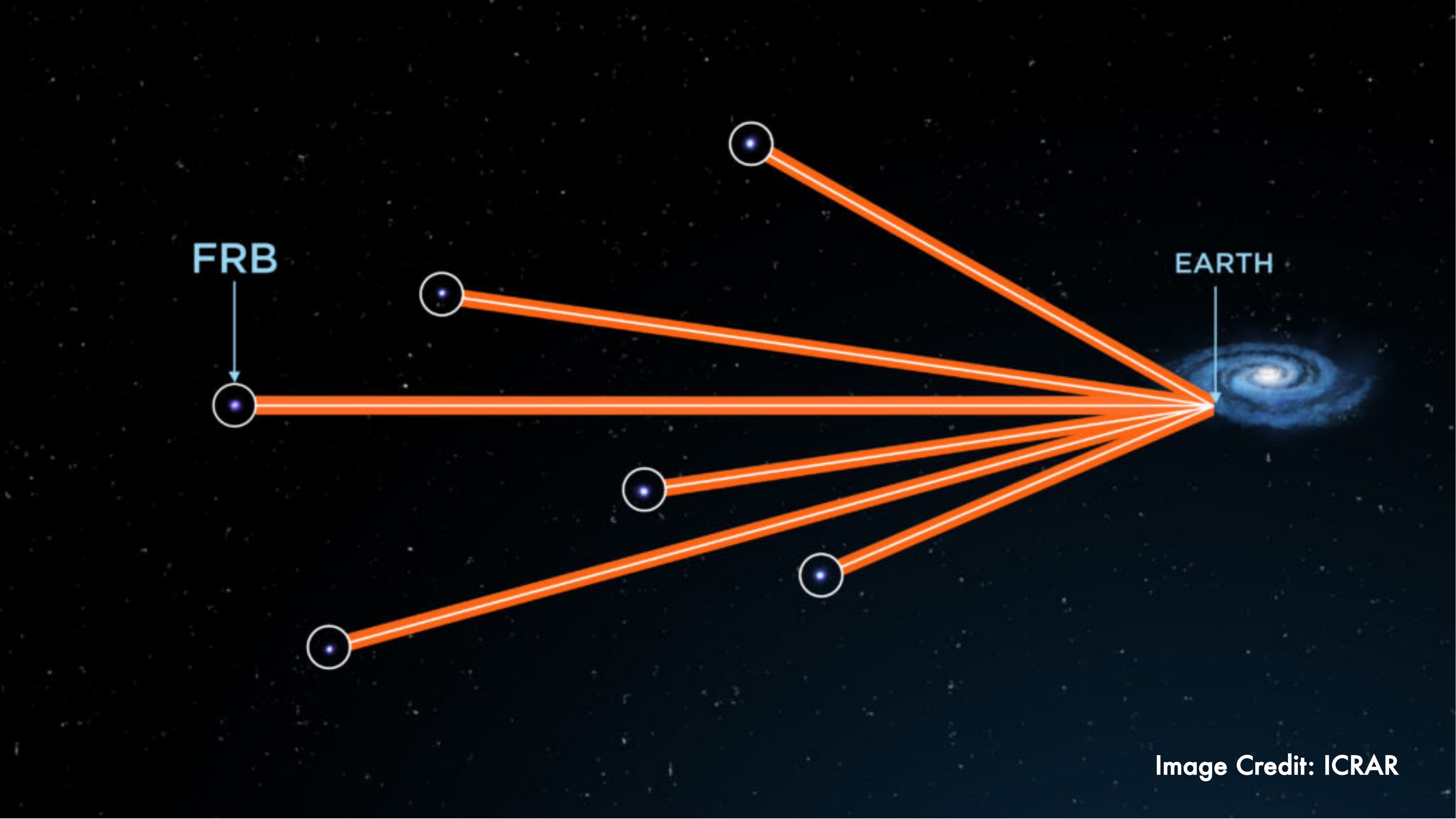
FRB 180924

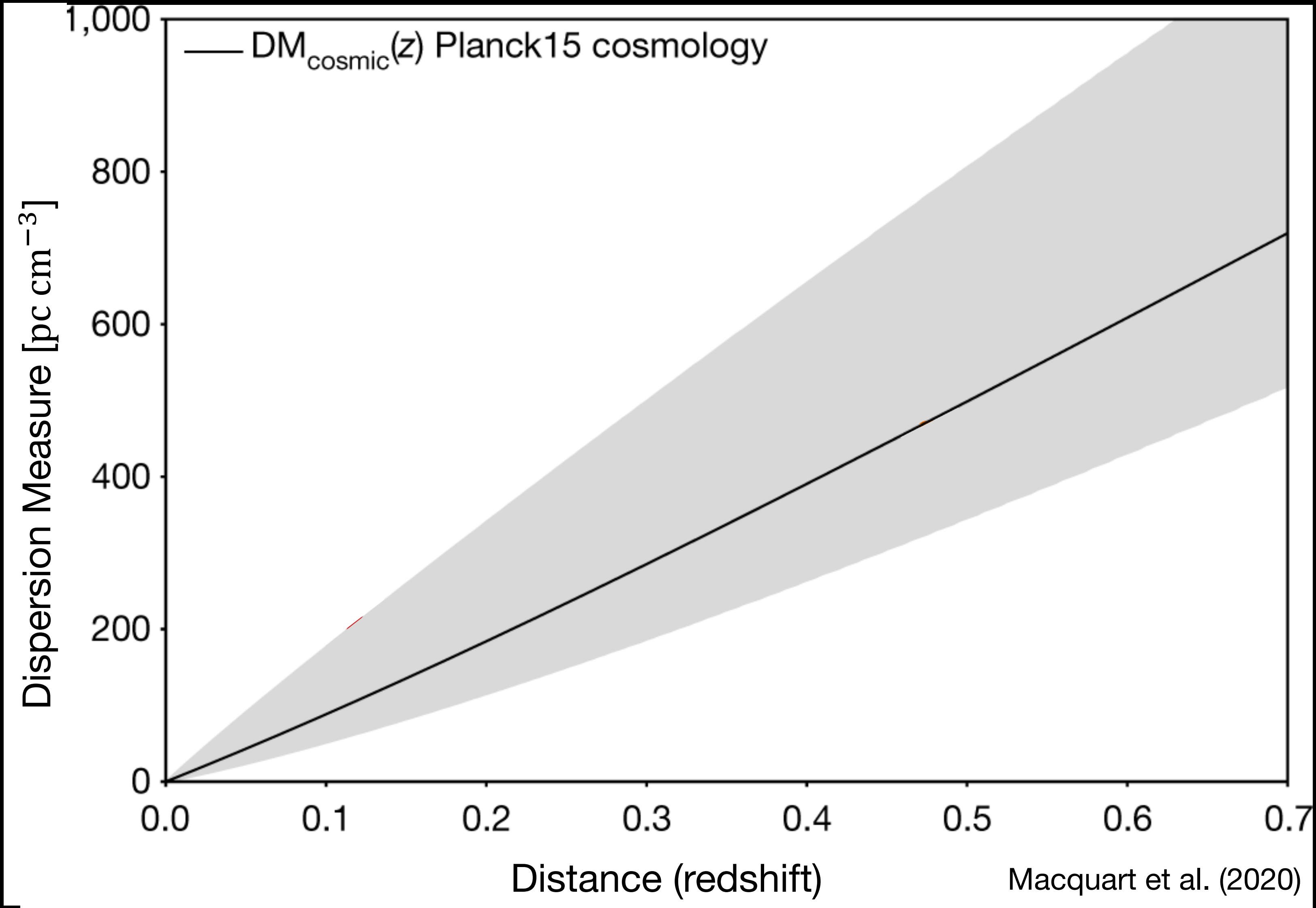




Bannister et al. (2019)

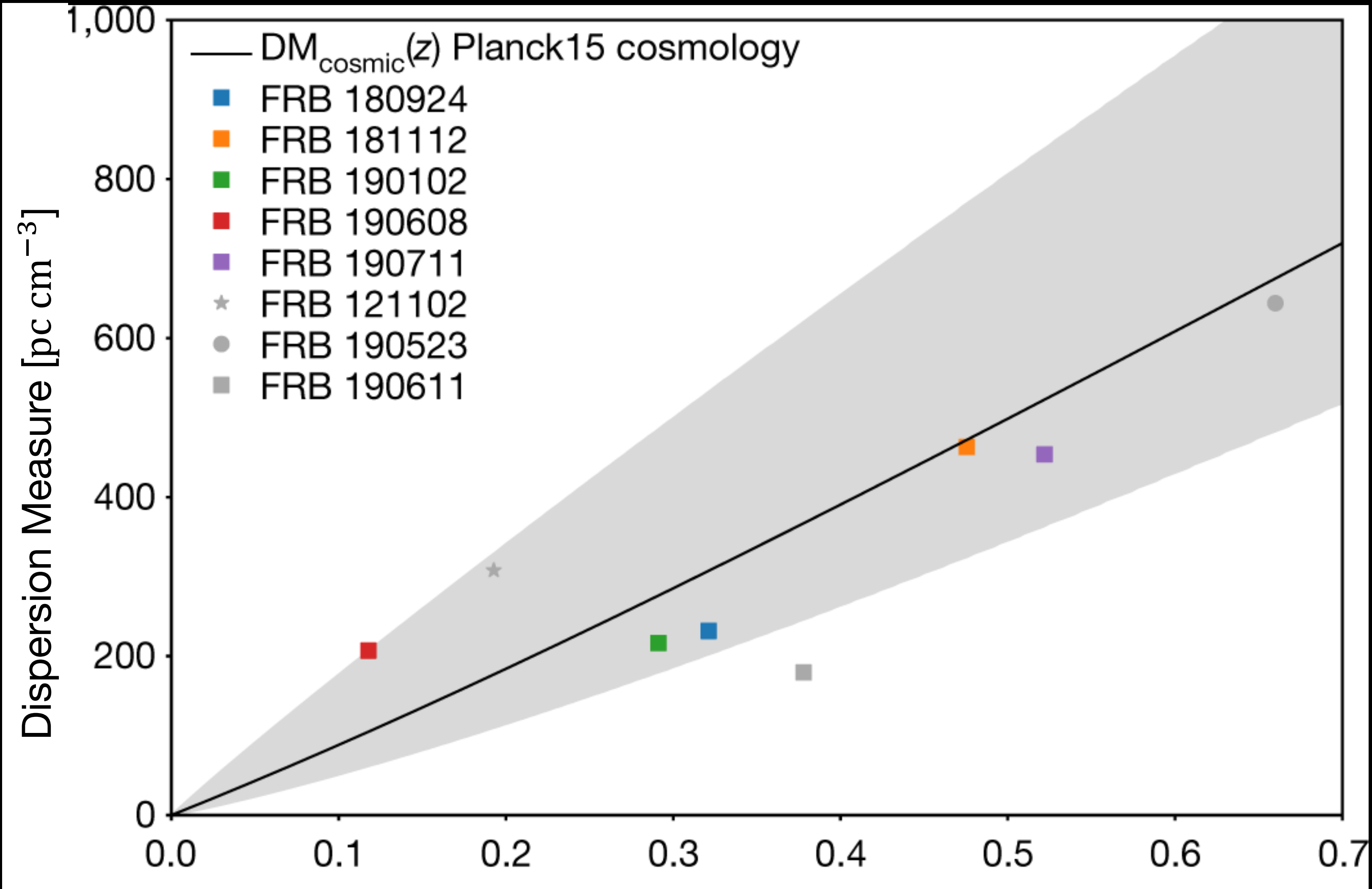
Macquart et al. (2020)


FRB
EARTH
Image Credit: ICRAR



Macquart et al. (2020)

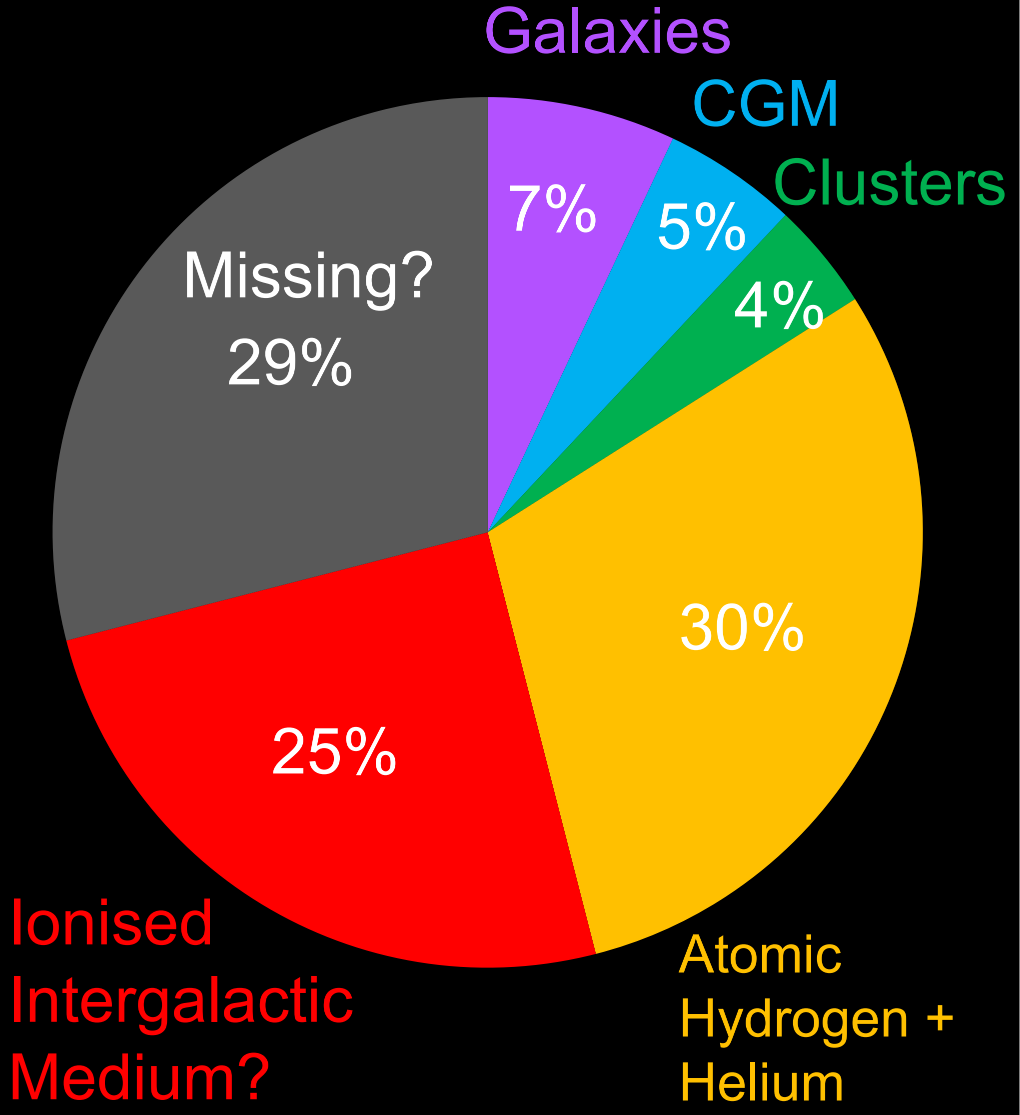
Jean-Pierre Macquart



Macquart et al. (2020)

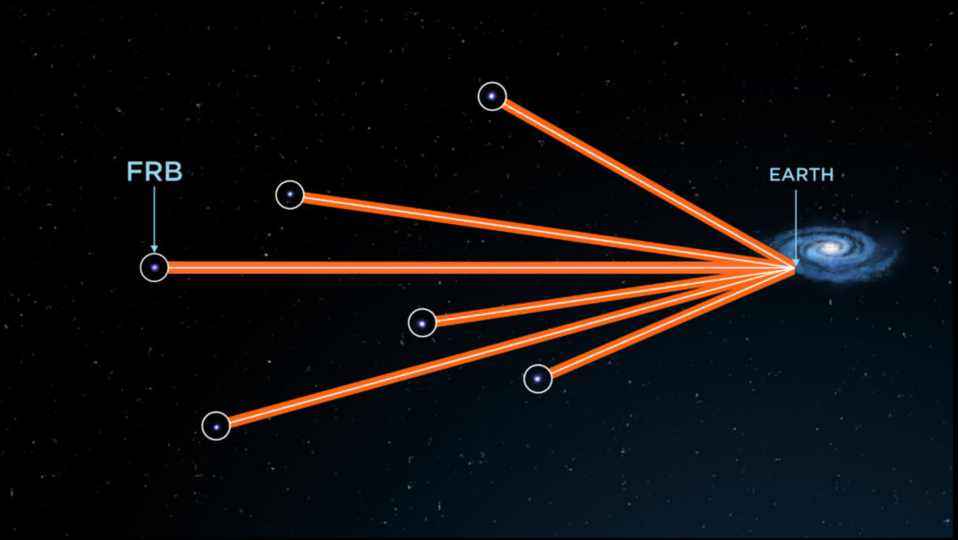
Jean-Pierre Macquart

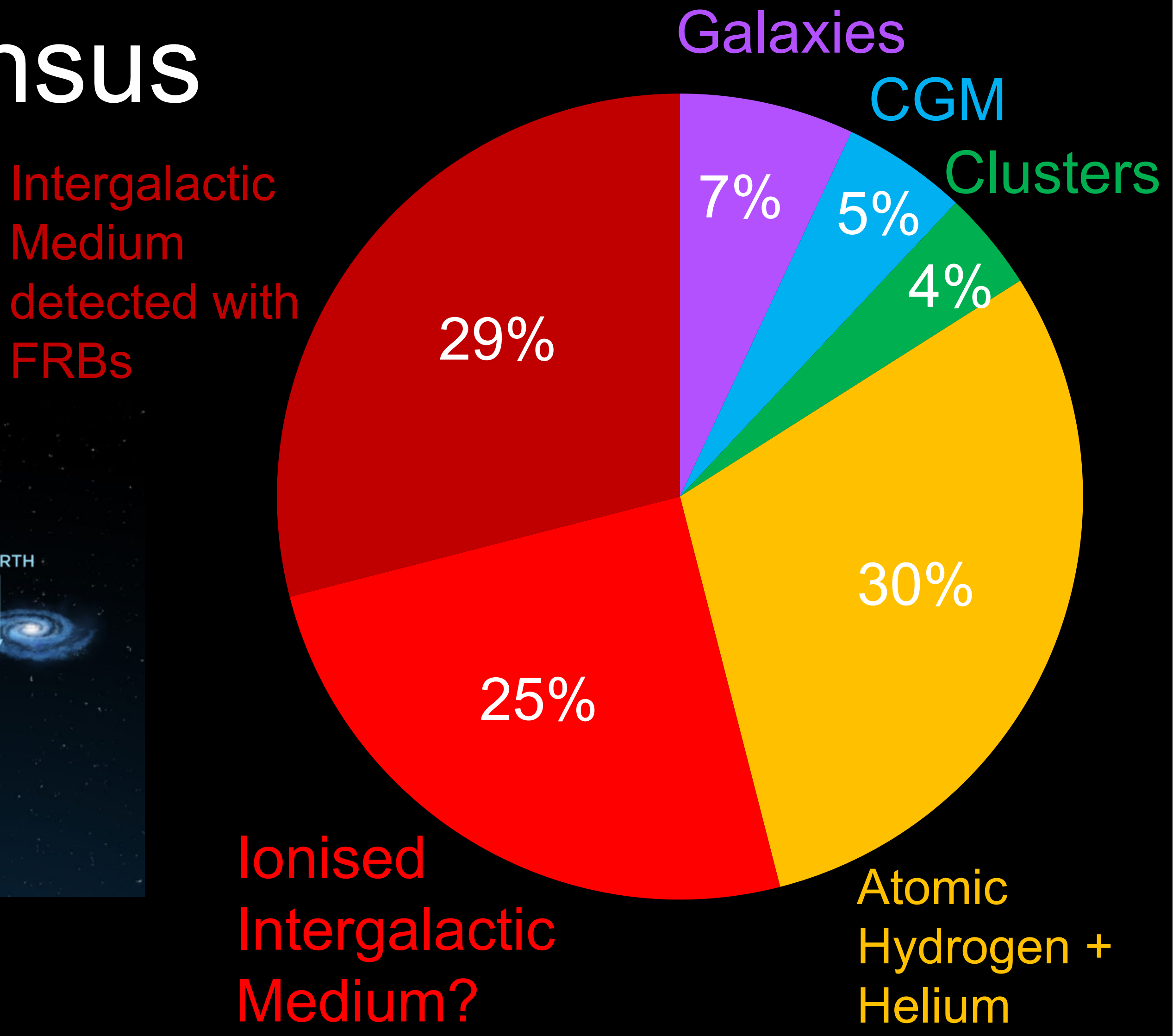
The Baryon Census



Shull et al. (2012)

The Baryon Census



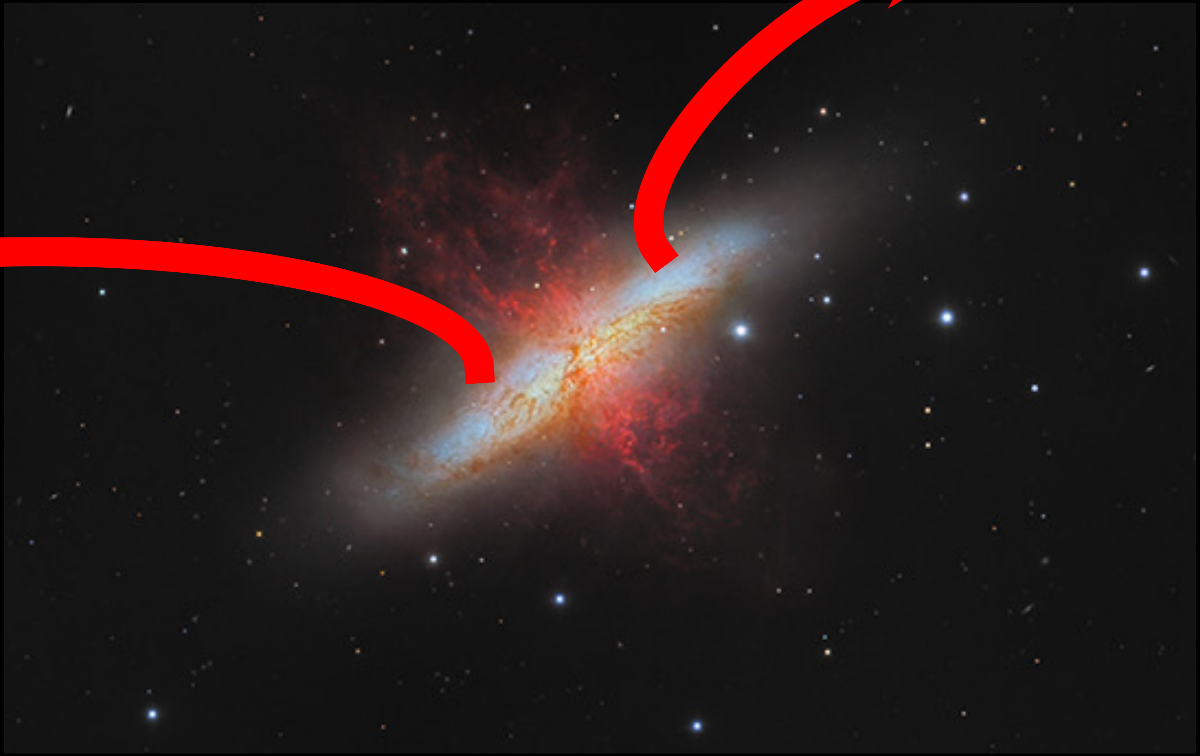


Shull et al. (2012)

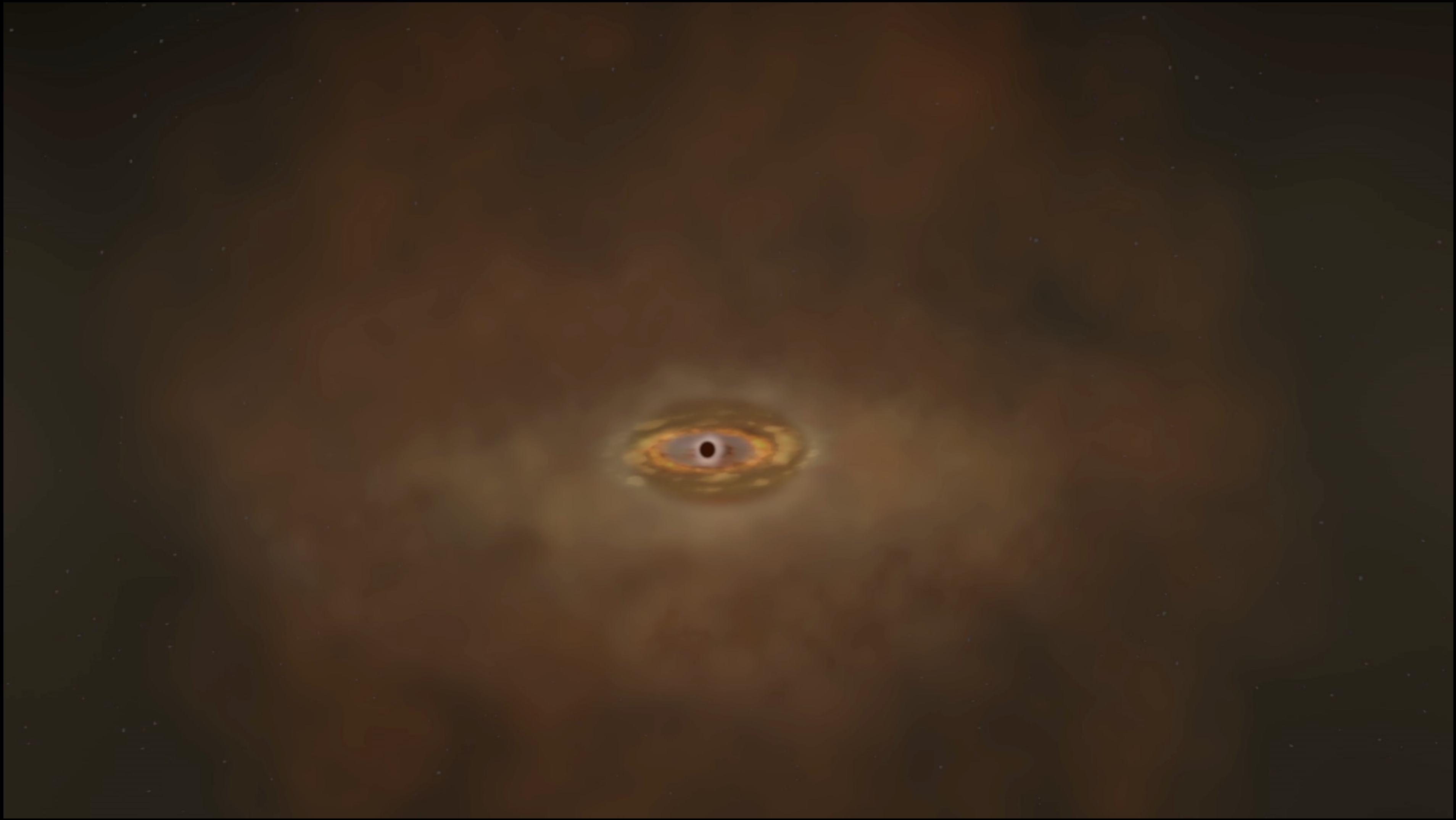
So, what is next?

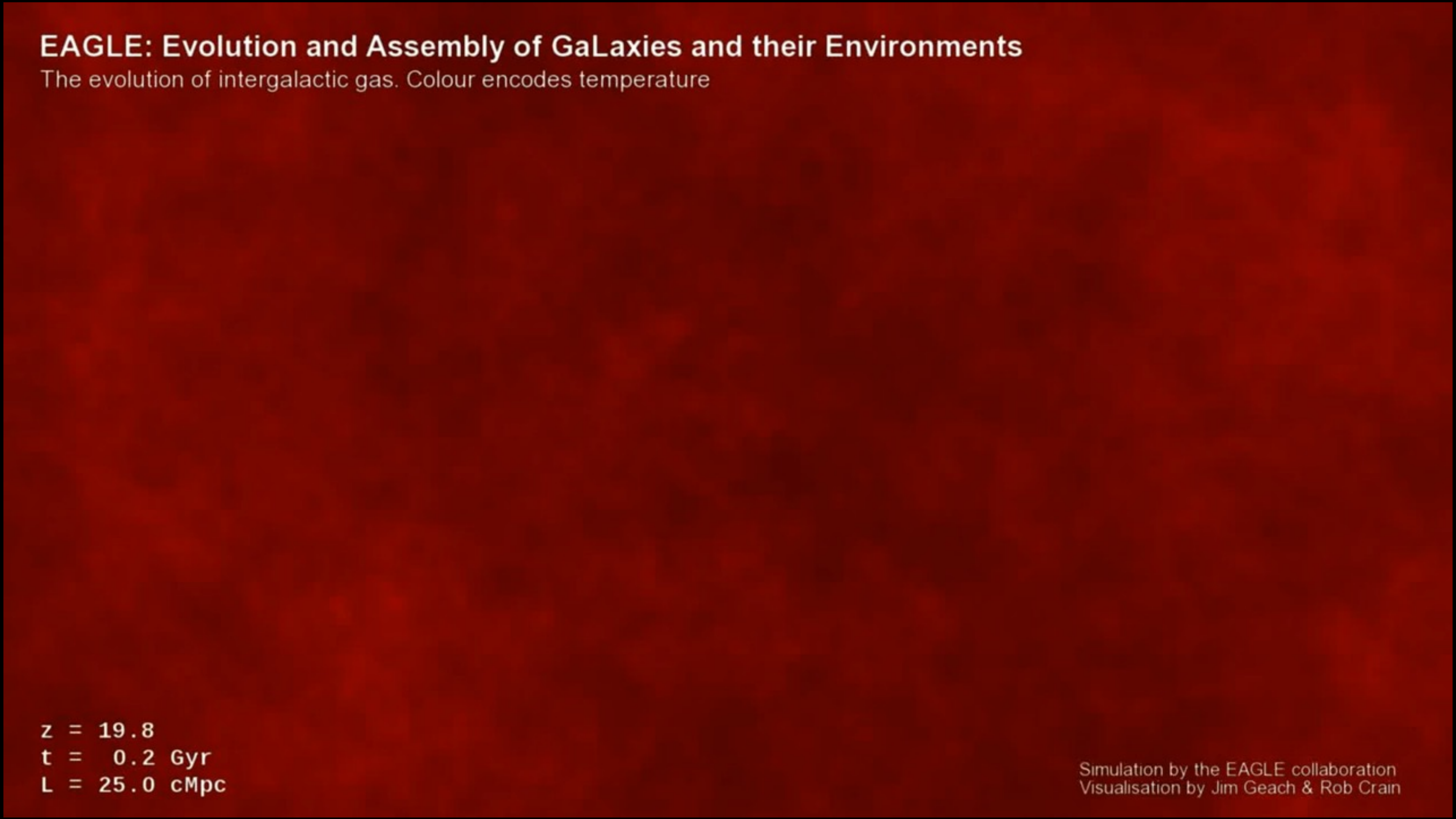
Can we use FRBs to measure properties of galaxies?

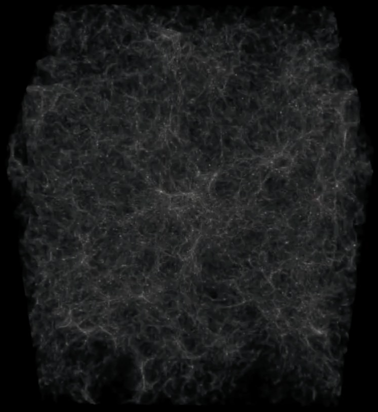
Can we use FRBs to measure properties of galaxies?



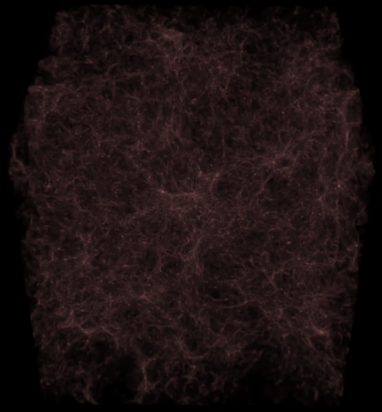
Outflows


Video Credit: NASA's Goddard Space Flight Center

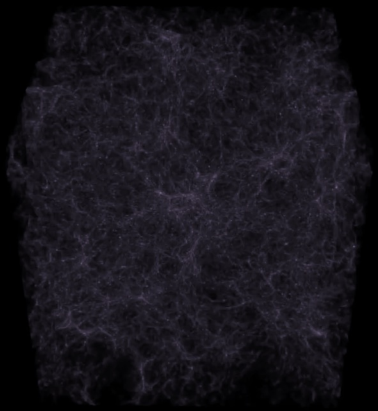

EAGLE: Evolution and Assembly of GaLaxies and their Environments
The evolution of intergalactic gas. Colour encodes temperature
z = 19.8
t = 0.2 Gyr
L = 25.0 cMpc
Simulation by the EAGLE collaboration
Visualisation by Jim Geach & Rob Crain



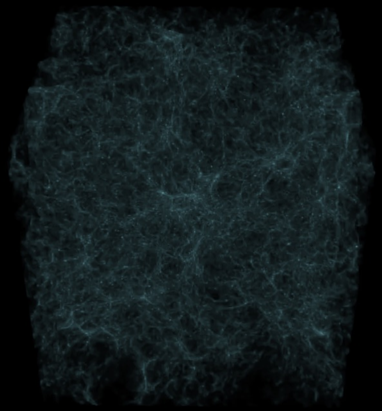
Normal Universe



No Supermassive Black Holes



Strong Supermassive Black Holes



Stronger Supernovae

Can we use FRBs to measure galaxy feedback?

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Maybe?

Can we use FRBs to measure galaxy feedback?

Maybe?

Twitter: @adamjbatten

Summary

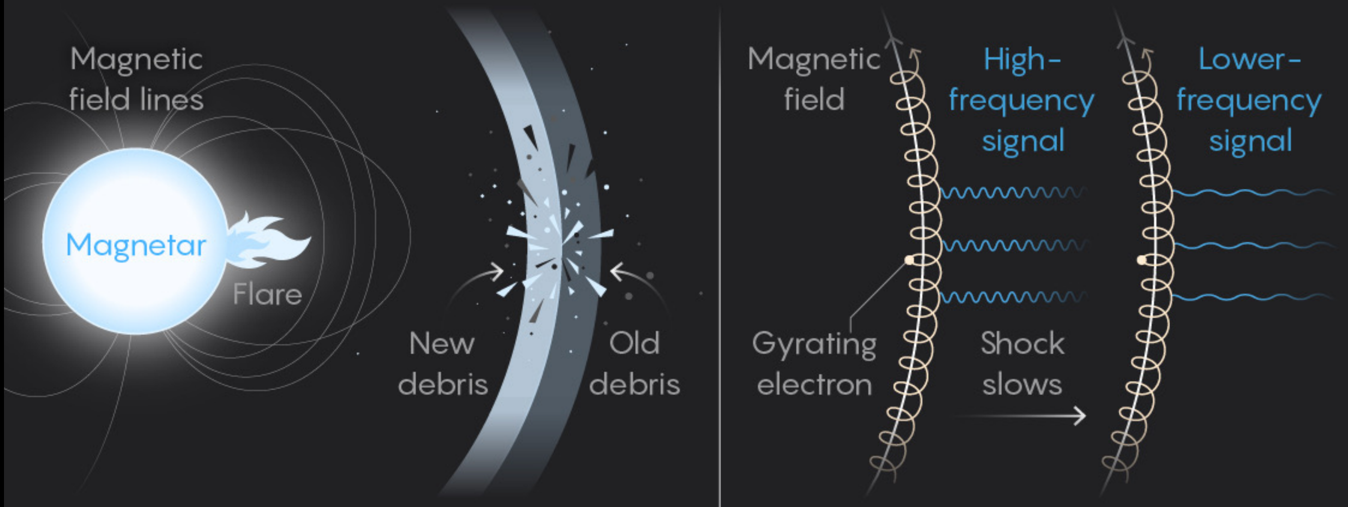
Twitter: @adamjbatten

- The intergalactic medium is the hot, low density material outside of galaxies.
- The intergalactic medium is essential to understanding galaxy evolution but is extremely difficult to observe nearby, leading to the `Missing Baryon Problem’.
- Fast Radio Bursts are bright extragalactic radio sources and are very sensitive to the amount of ionized material along their path.
- Fast Radio Bursts were finally able to find the missing baryons in 2020.
- The future is bright as to what new science we can do with FRBs in the future.

Bonus Slides!!!

How Fast Radio Bursts Work

Fast radio bursts are brief, energetic blips of radio waves. A recent theory suggests that they come from a shock wave created by a magnetar.



1. A magnetar releases a flare of electrons and other charged particles.

2. The flare collides with the remnants from an old flare, creating huge magnetic fields.

3. In the ensuing shock, gyrating electrons generate energetic radio waves. As the shock slows, the radio signal downshifts to lower frequencies.