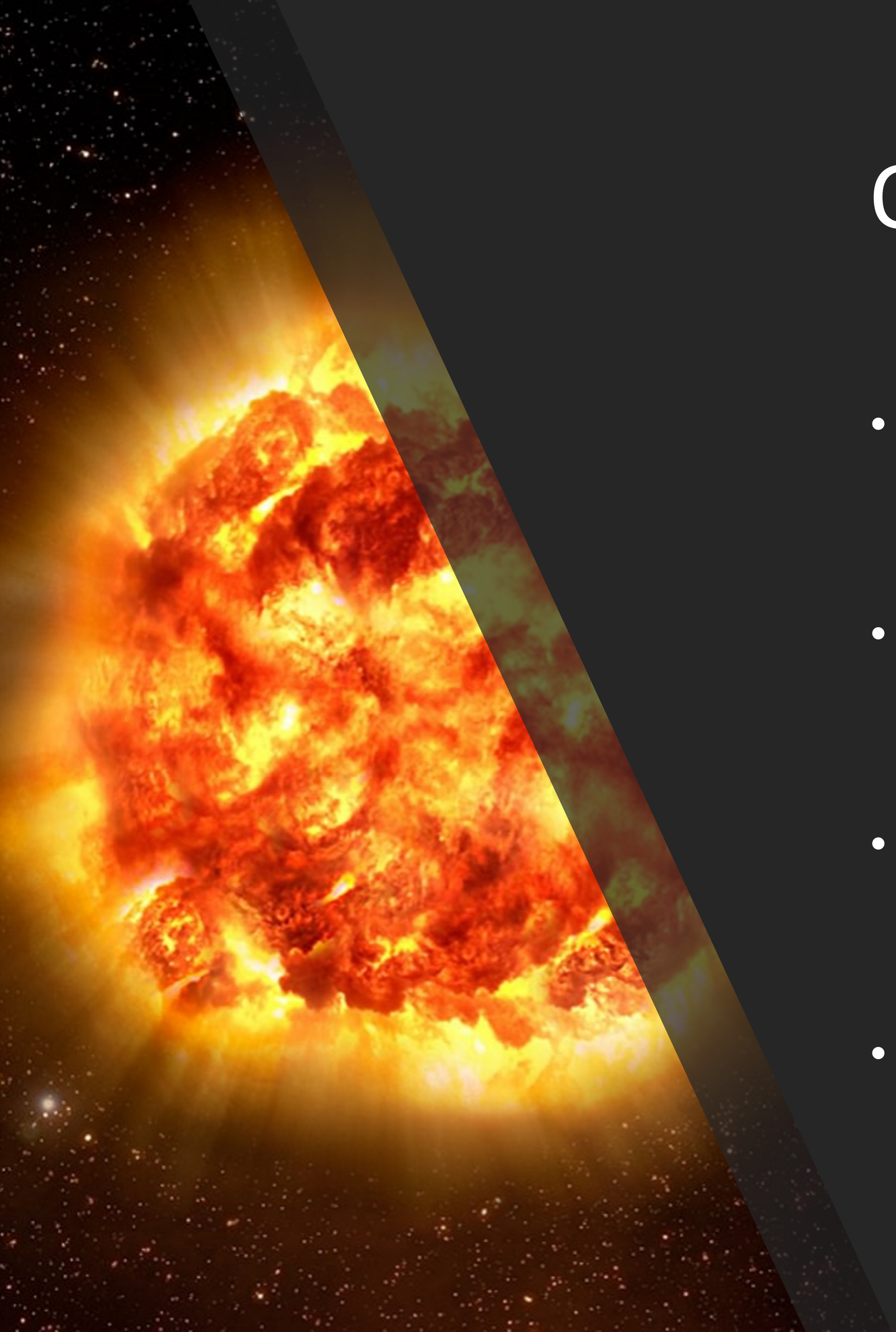
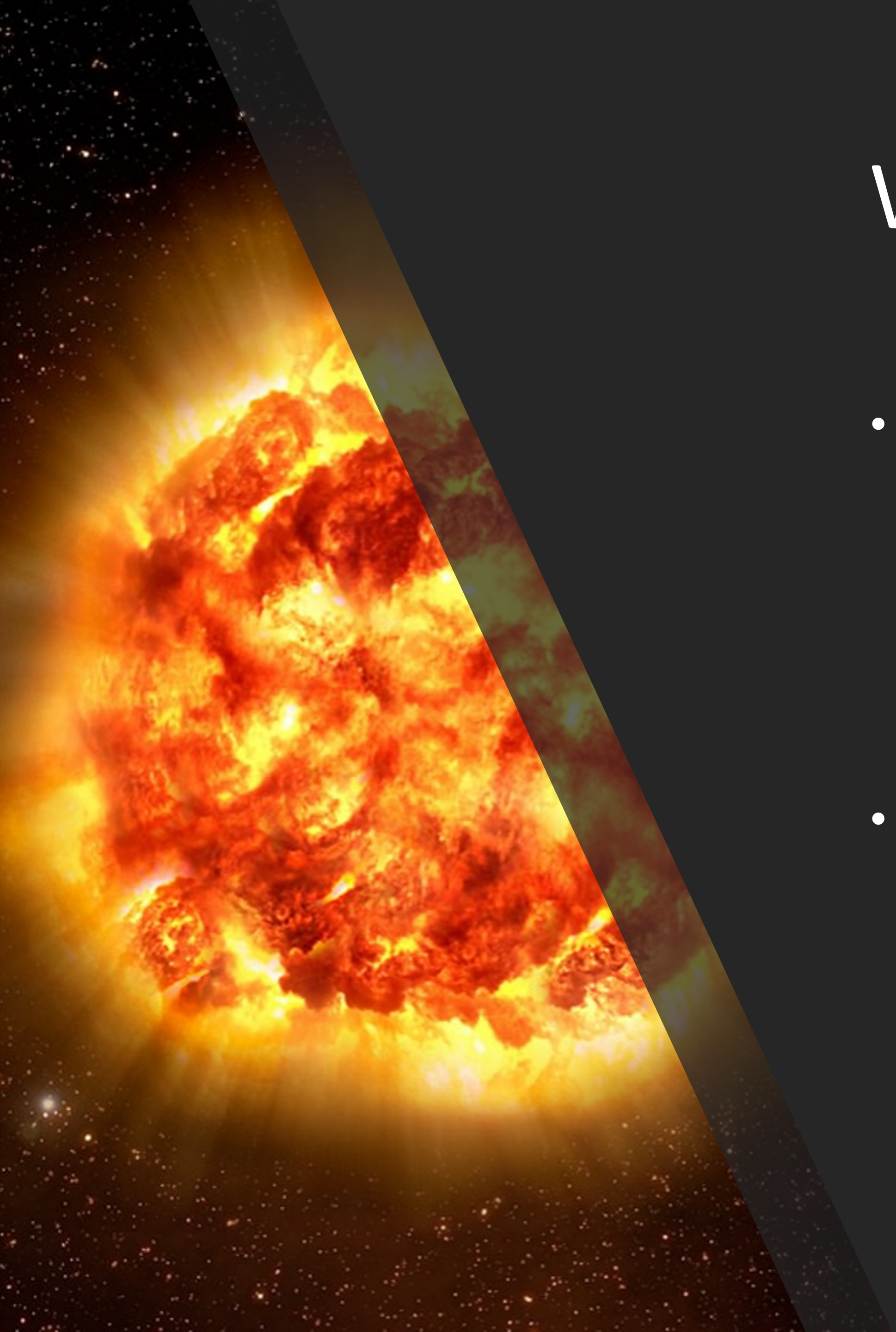
The Physics of Stars

Robert Clemenson



Overview

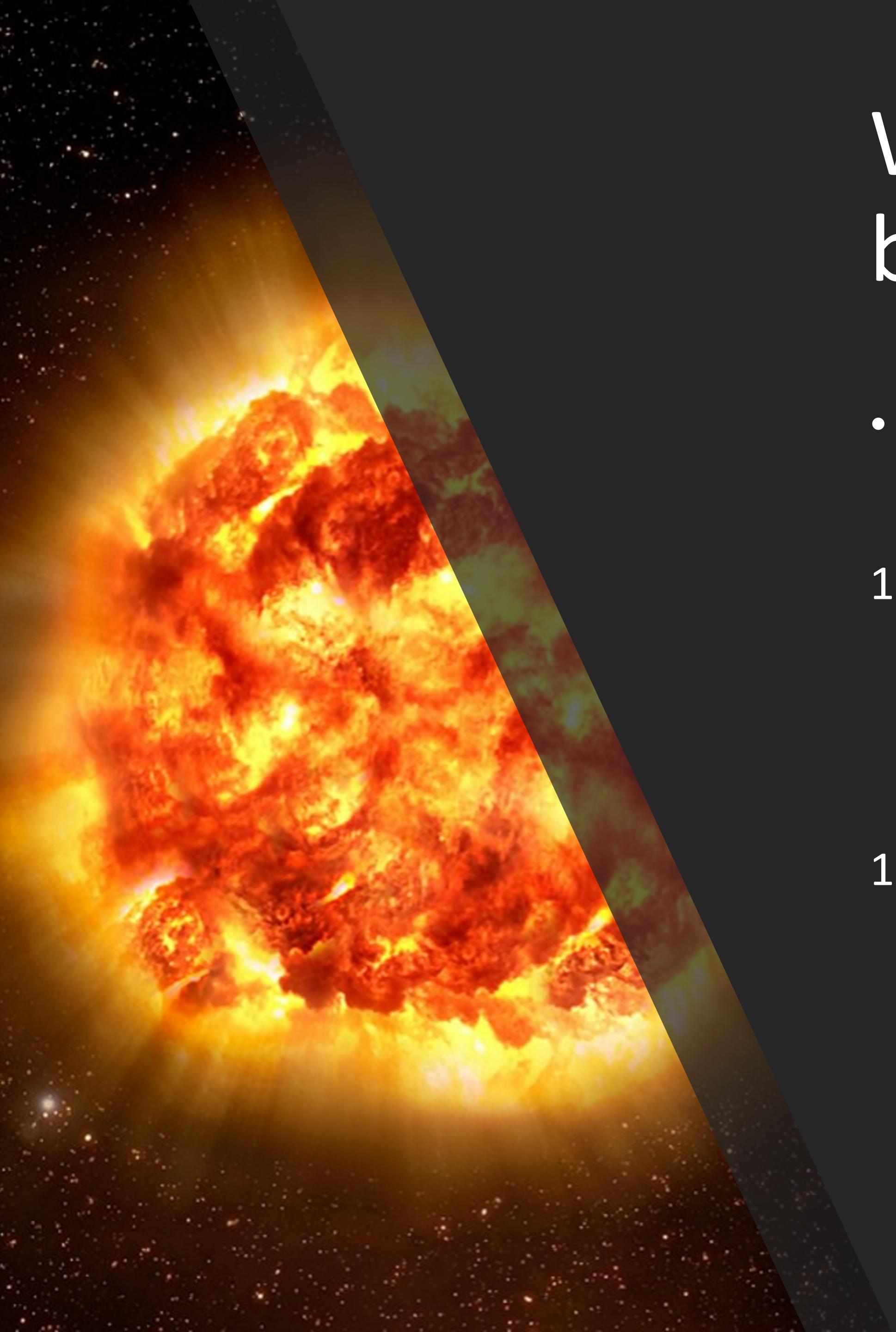
- <u>1) What is a star?</u> – Describing their composition, and interior workings
- <u>2) Where do stars come from?</u> – Describing the process by which stars are born, and looking at different kinds of nebulae.
- <u>3) How do stars change?</u> – Describing the evolutions of stars, and how these lifecycles vary between stars of different masses.
- <u>4) How do stars die?</u> – Describing the end states of different mass stars. Supernovae, white dwarfs, neutron stars, black holes.



What is a star? – Composition

- A star is an hot ball of ionised gas, otherwise known as a plasma (sometimes called the 4th state of matter). The electrons have all been stripped from their nuclei, and coexist in a kind of gaseous state.

- Most stars like our sun are about 75% Hydrogen, 24% Helium, and around 1% other heavier elements.



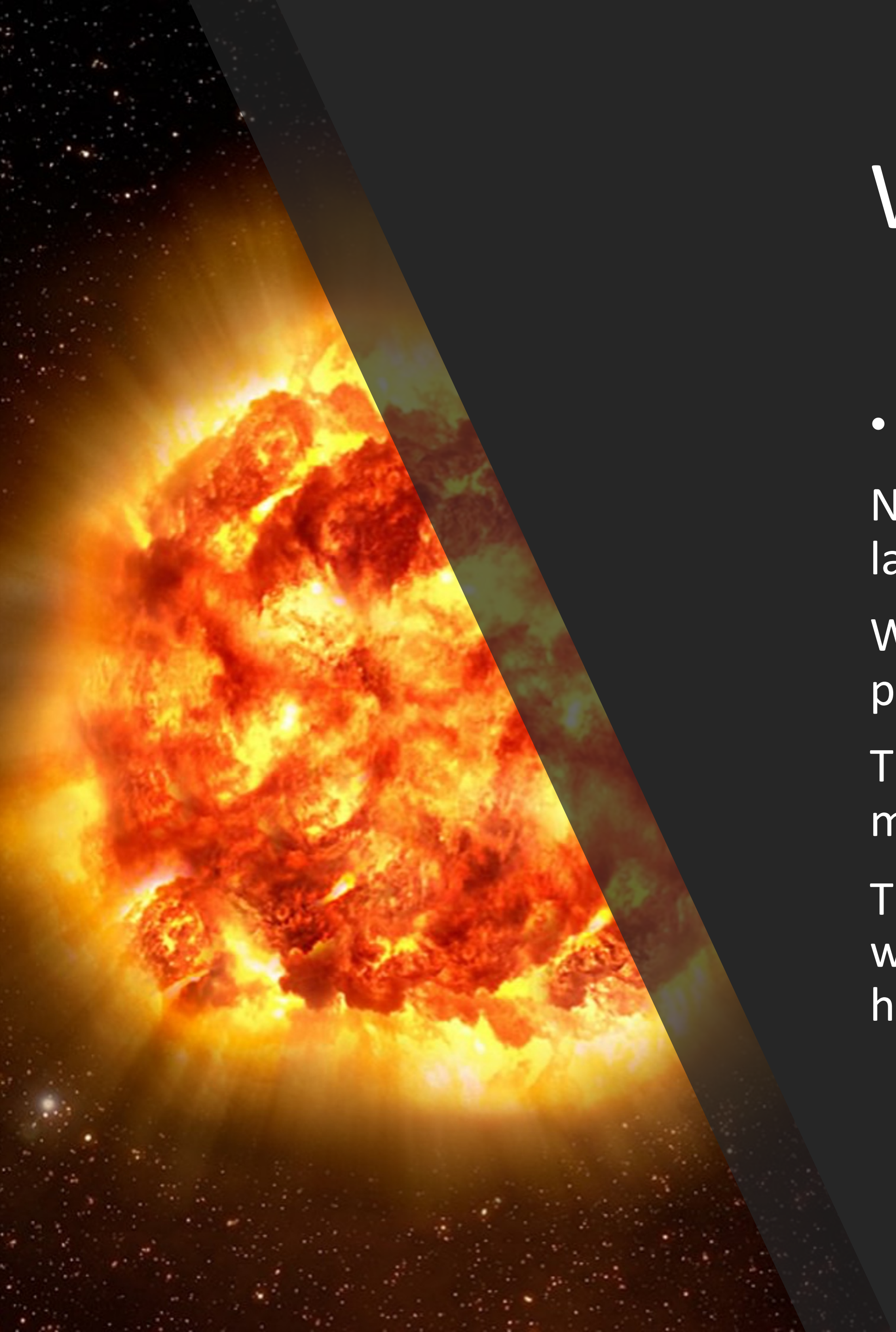
What is a star? – Forces in balance

- Most of a stars life is dominated by two competing forces:

1. Gravity – Pulling the outer layers of the star inwards to the centre.

1. Thermal pressure – Trying to blow the outer layers of the star off into space.

But what creates this thermal pressure?



What is a star? – Forces in balance

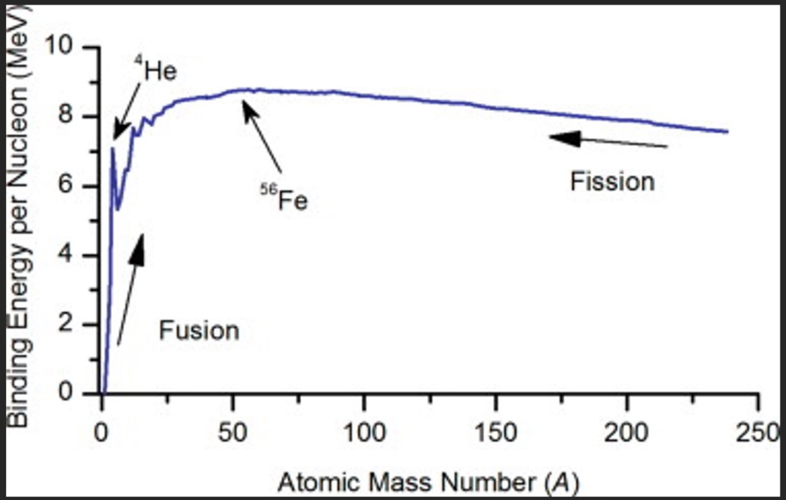
- Nuclear Fusion:

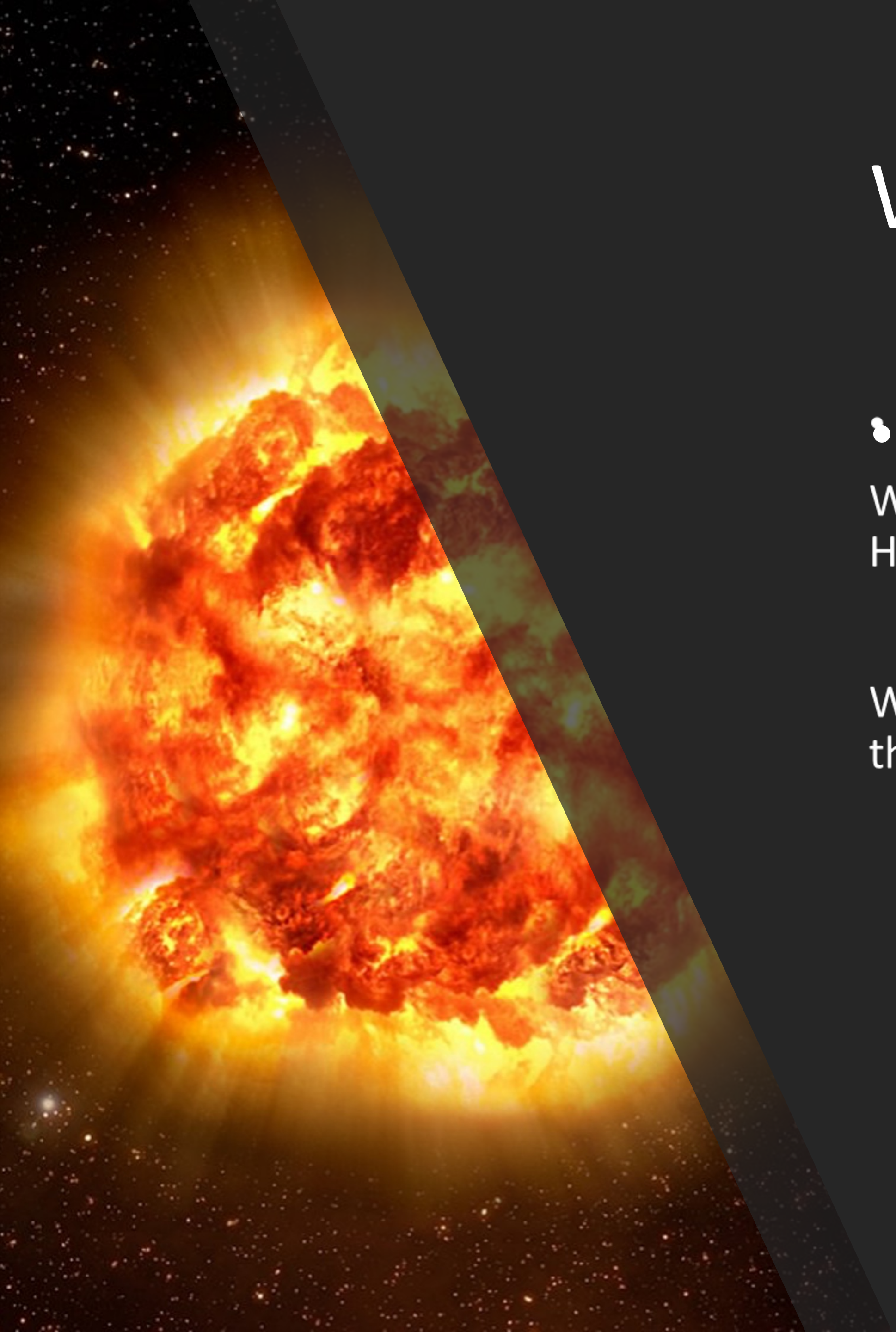
Nuclear fusion is the process of combining smaller nuclei, to form larger nuclei.

When the larger nuclei being formed is smaller than Iron, this process releases energy, and hence generates heat.

This heat then drives further fusion reactions, as well as trying to make the star expand.

The curve to the right explains why stars cannot create elements heavier than Iron in their cores.

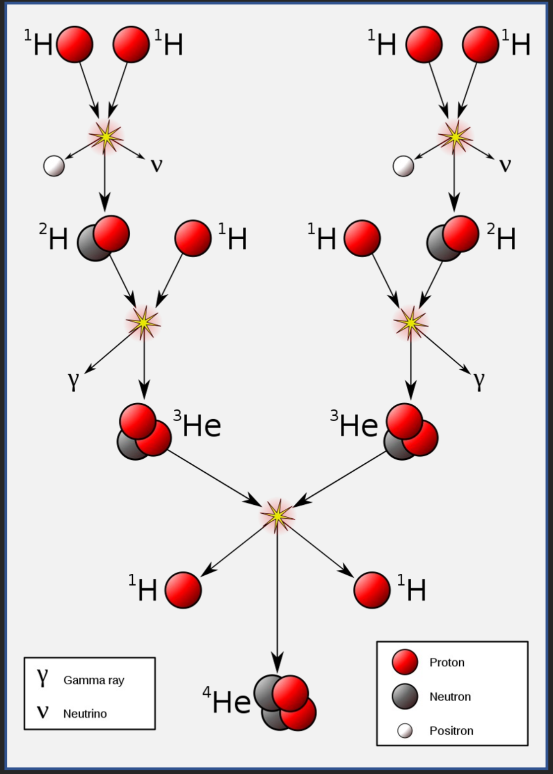




What is a star? – Forces in balance

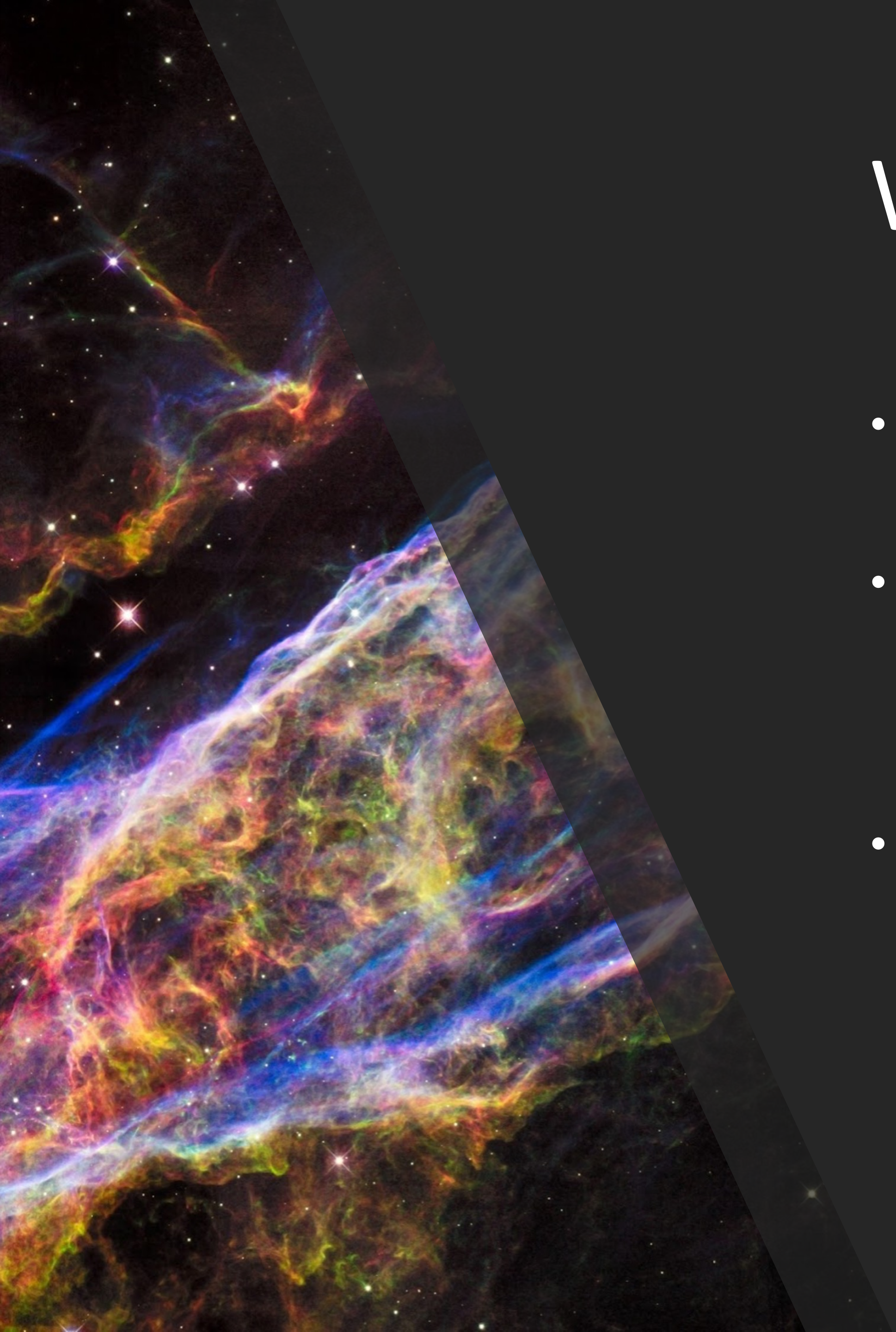
- Nuclear Fusion:

Within stars like our sun, this fusion process mostly involves turning Hydrogen nuclei into Helium nuclei.



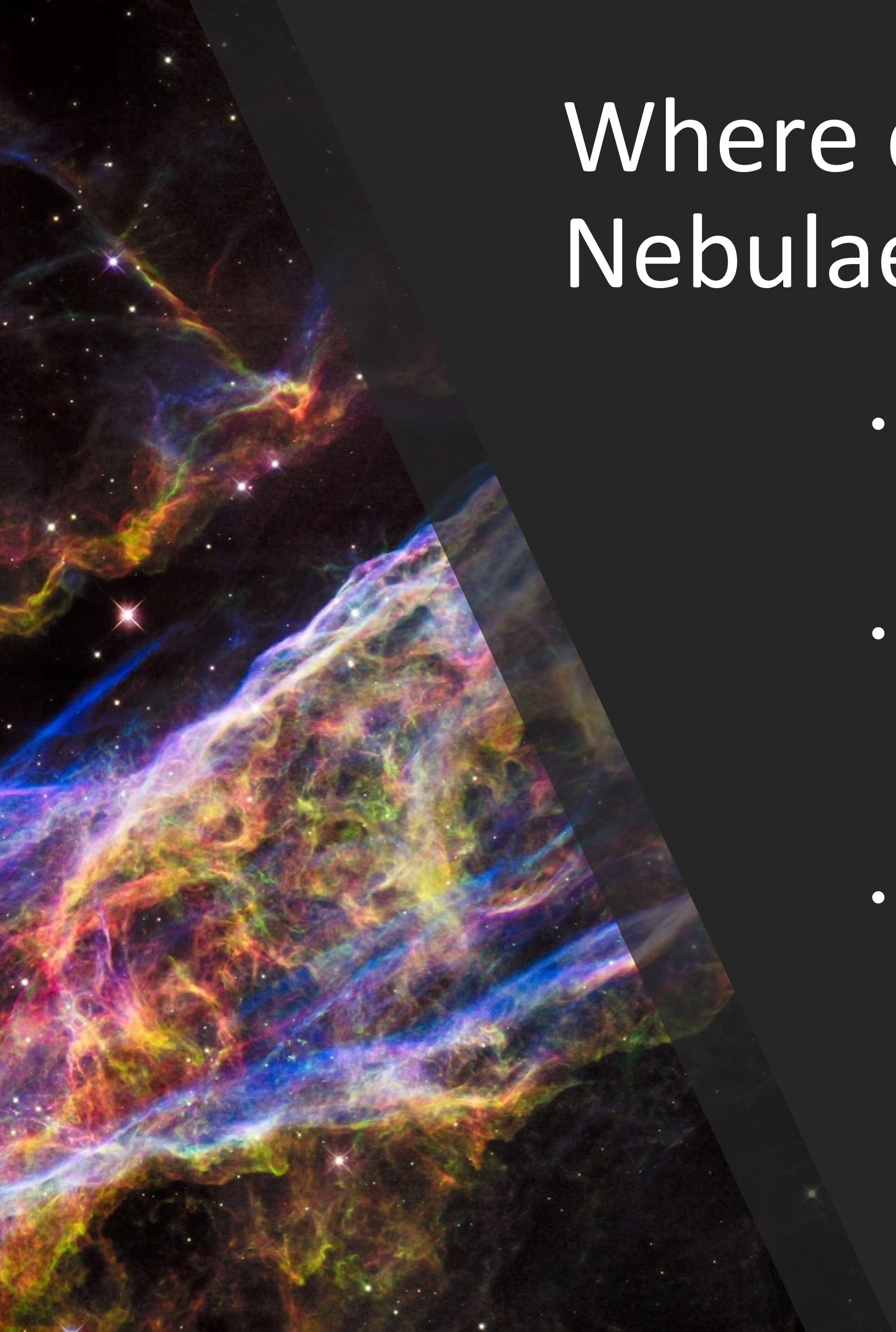
We can calculate the energy released from this fusion process using Einstein's famous:

$$E = mc^2$$



Where do stars come from?

- Stars are born from clouds of (mostly Hydrogen) gas in space.
- The mutual gravitational attraction of atoms in these gas clouds cause dust and gas to clump together around regions of higher initial density.
- When these clumps pass a certain threshold density, Hydrogen fusion begins in their core, and they quickly stabilise into a ‘Main sequence star’.



Where do stars come from? - Nebulae

- Some nebulae contain star forming regions (also called ‘stellar nurseries’).

- Nebulae are (comparatively) dense regions of dust and gas. Some are formed from supernovae, and some are formed from gas that has always been in space.

- These are some of the most beautiful structures in the Universe, so let’s take a look at a few!

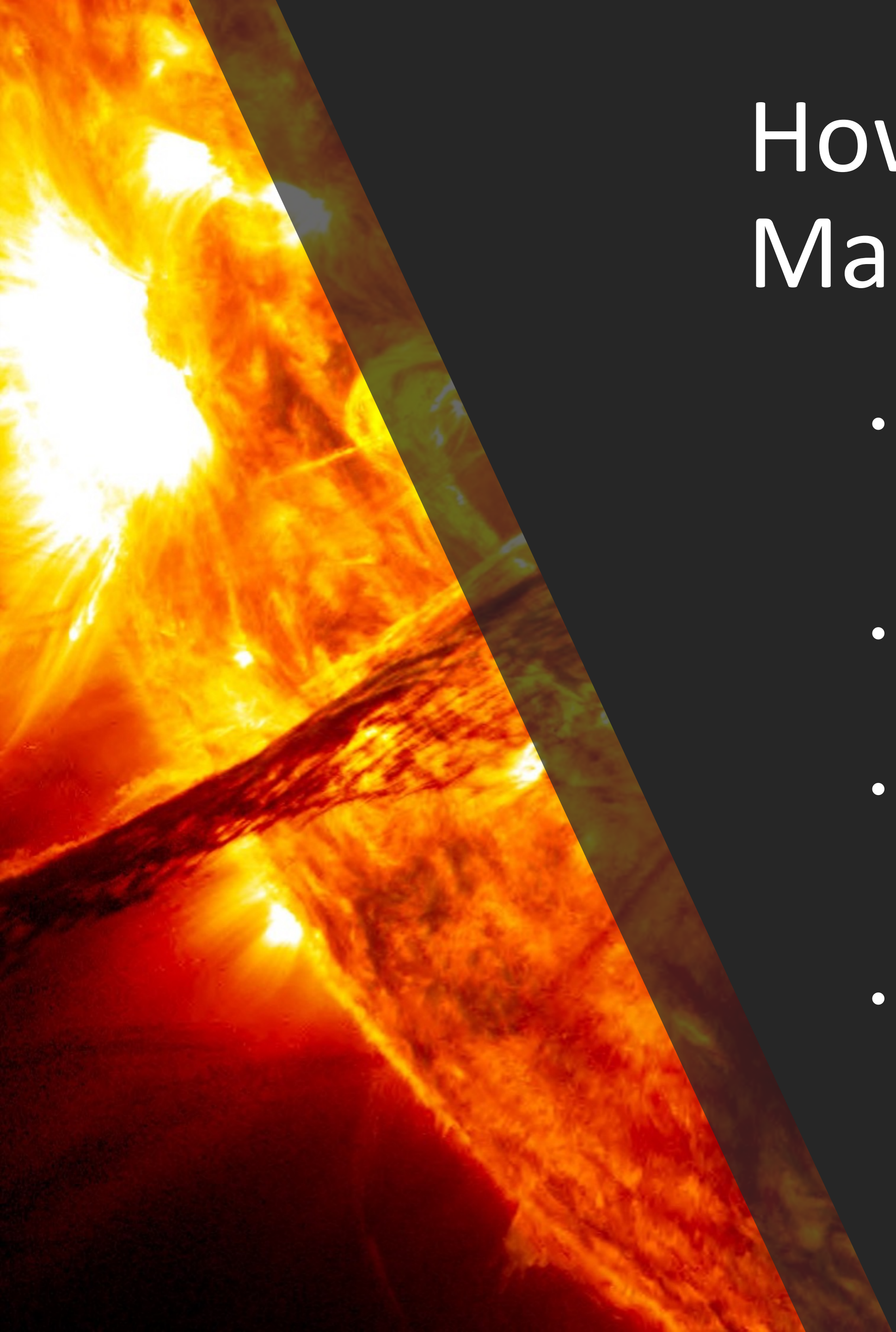
‘The Pillars of Creation’ within the Eagle Nebula

(These pillars are about 4 Ly long!)

(1 Ly = 17 Trillion Miles)

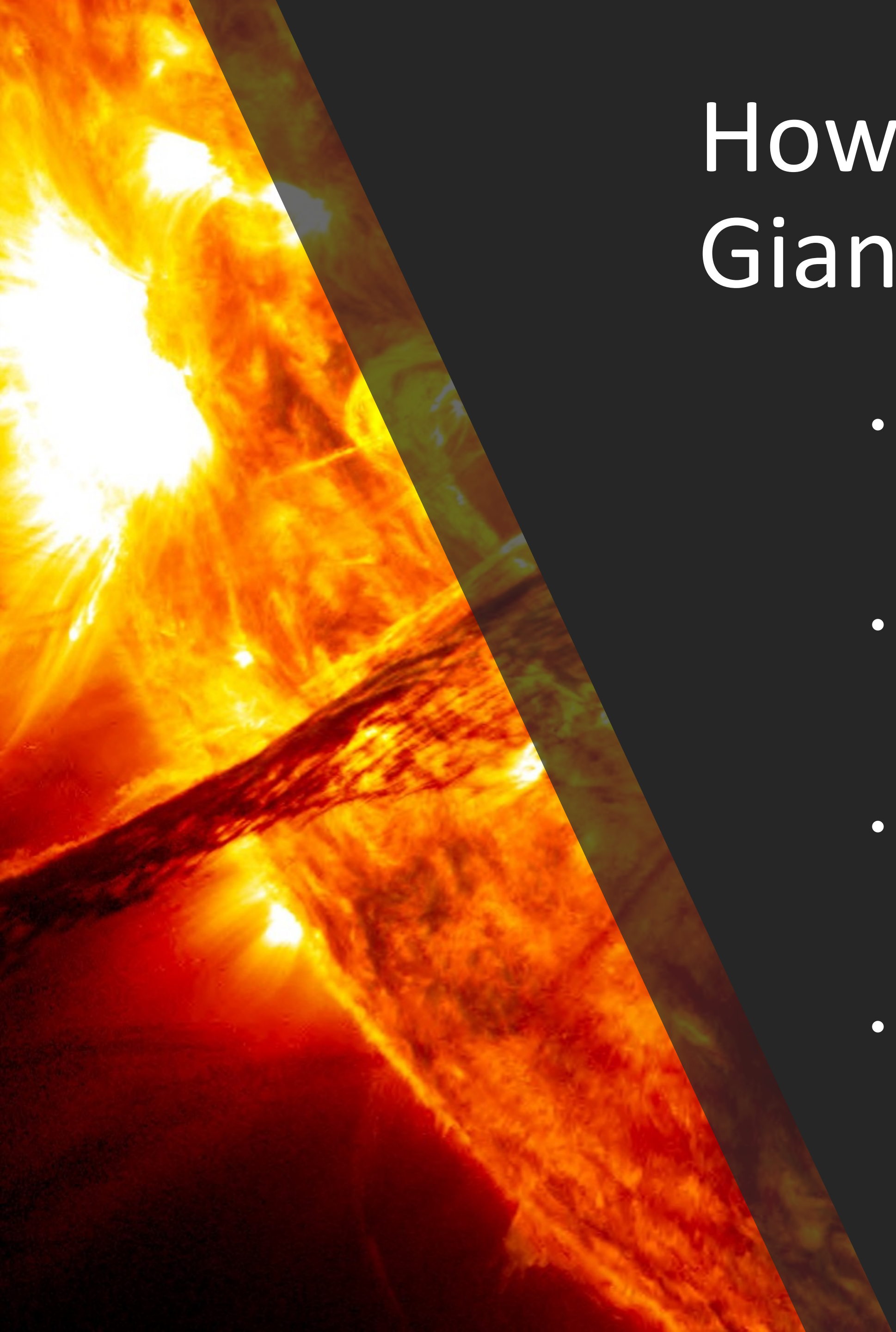
The Carina Nebula

The Butterfly
Nebula



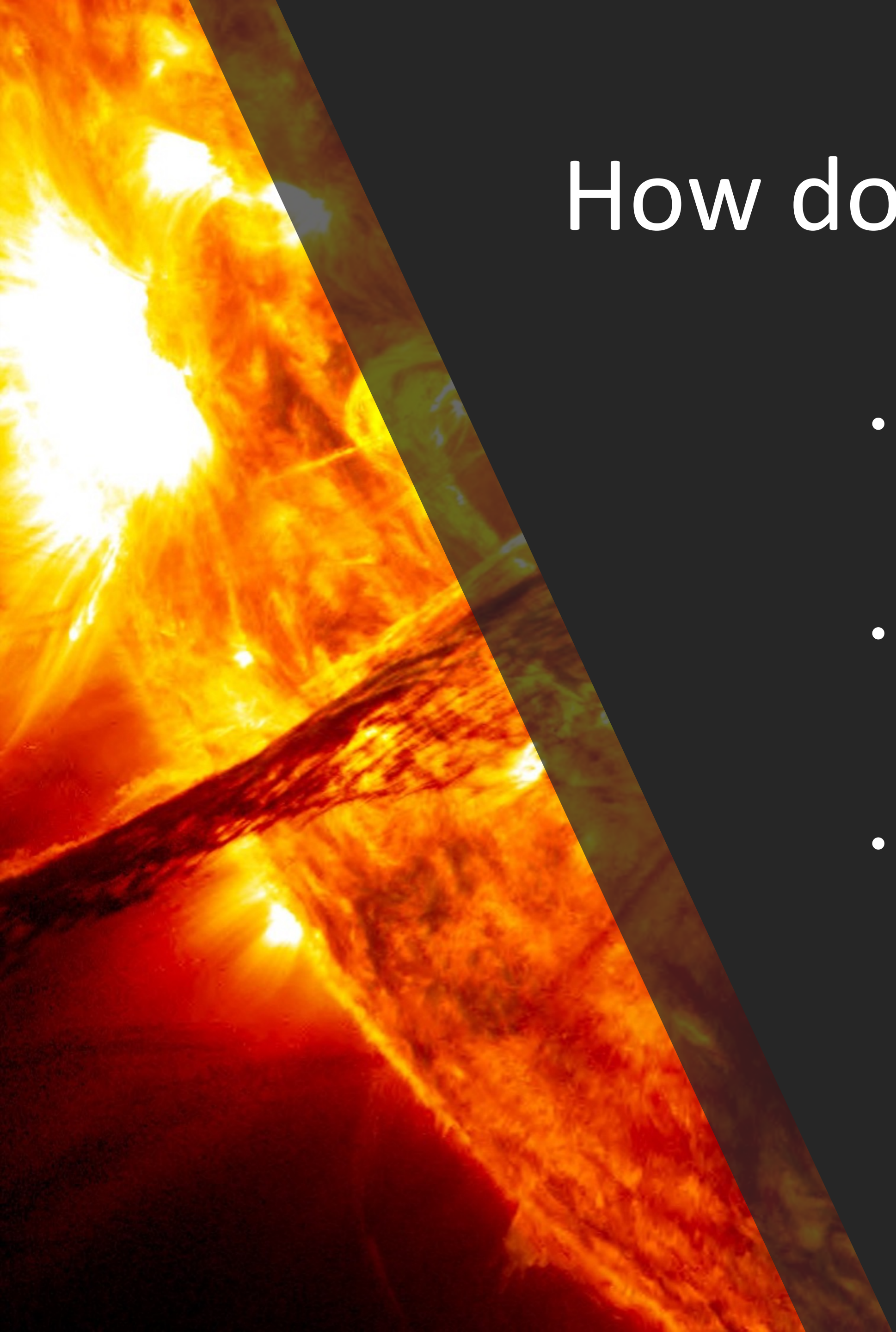
How do stars change? – The Main Sequence

- The majority of a stars life is spent in the ‘Main Sequence’ phase. (Around 10 Billion years)
- This is the phase our sun is currently in.
- This phase in a stars life can be categorised by the star fusing Hydrogen in its core, and very little else.
- Generally, the more massive a star is, the shorter its lifespan.



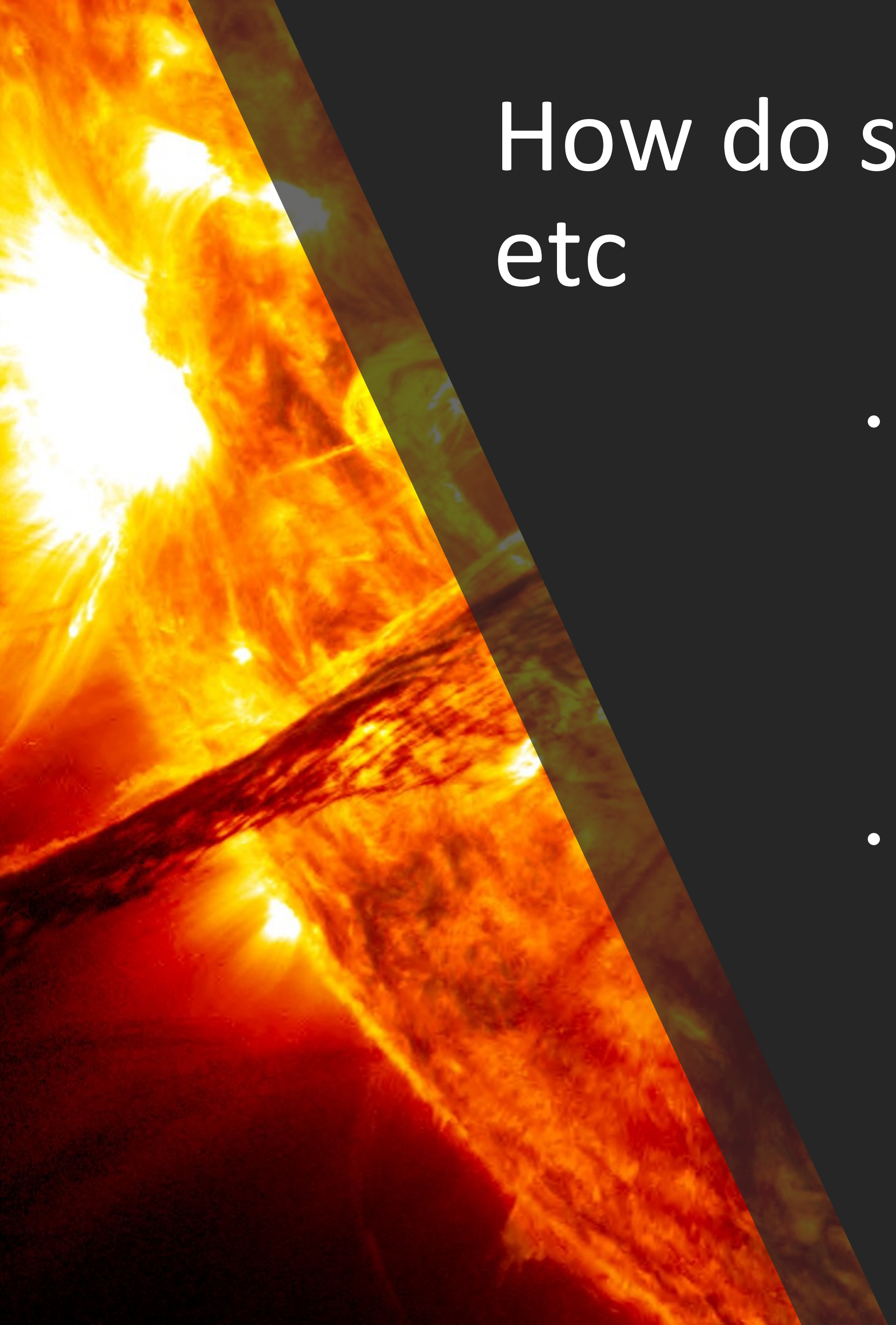
How do stars change? – Red Giants

- Stars with masses between 0.3 and 8.0 times the mass of our sun will evolve into red giants.
- When all the Hydrogen in the core has been burnt up, the thermal pressure provided by the heat of Nuclear fusion begins to decrease.
- Gravity now has the upper hand, and begins to collapse the now mostly Helium core inwards.
- This contraction increases the density of Hydrogen surrounding the core, and allows fusion to take place in this layer just outside of the Helium core.



How do stars change? – Red Giants

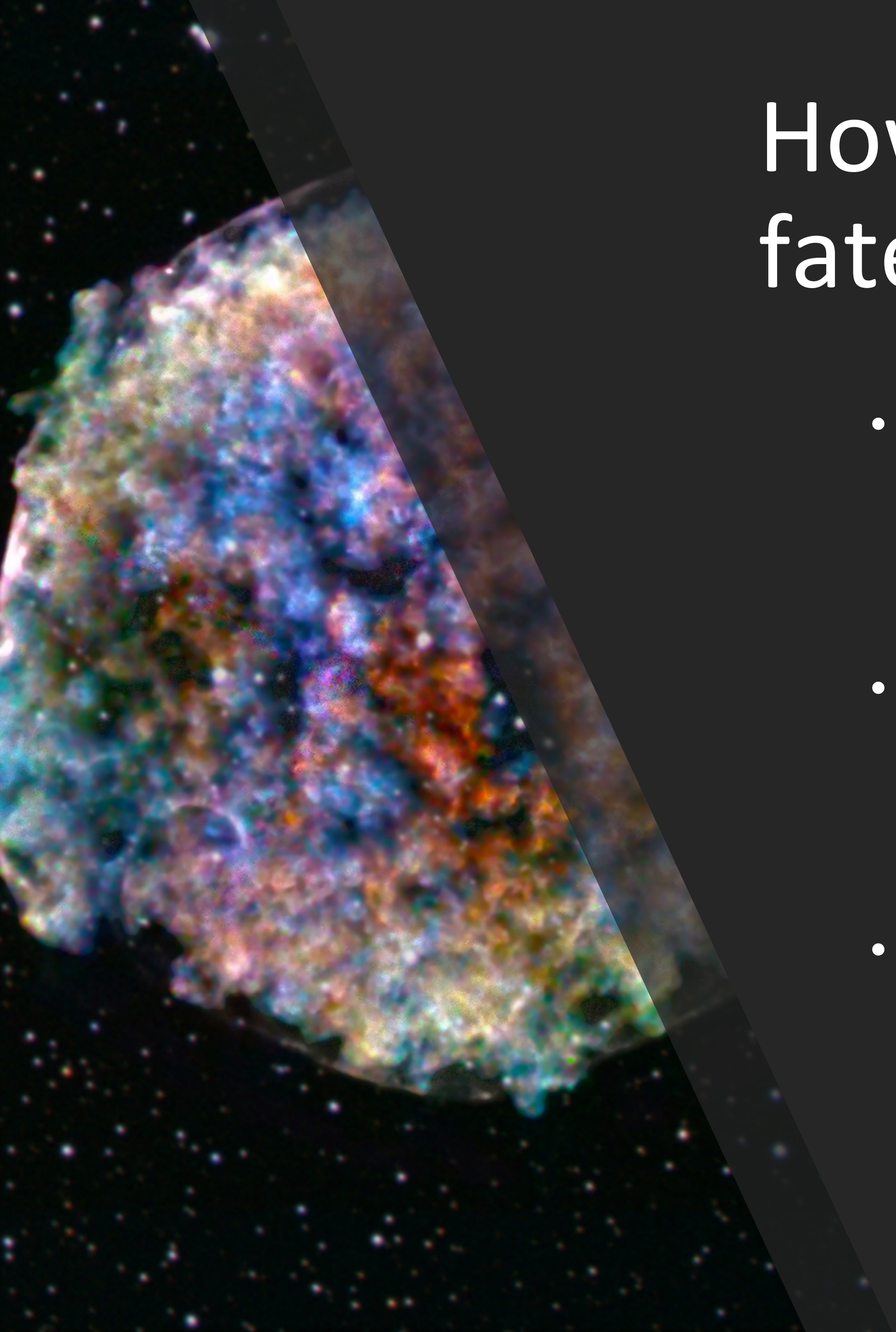
- As the core contracts, the outer layers of the star expand massively.
- The star grows in size, and cools. Resulting in a much more red, and brighter star seen in the night sky.
- Stars that become red giants typically spend about 1 Billion years in this phase of their evolution.



How do stars change? – Supergiants etc

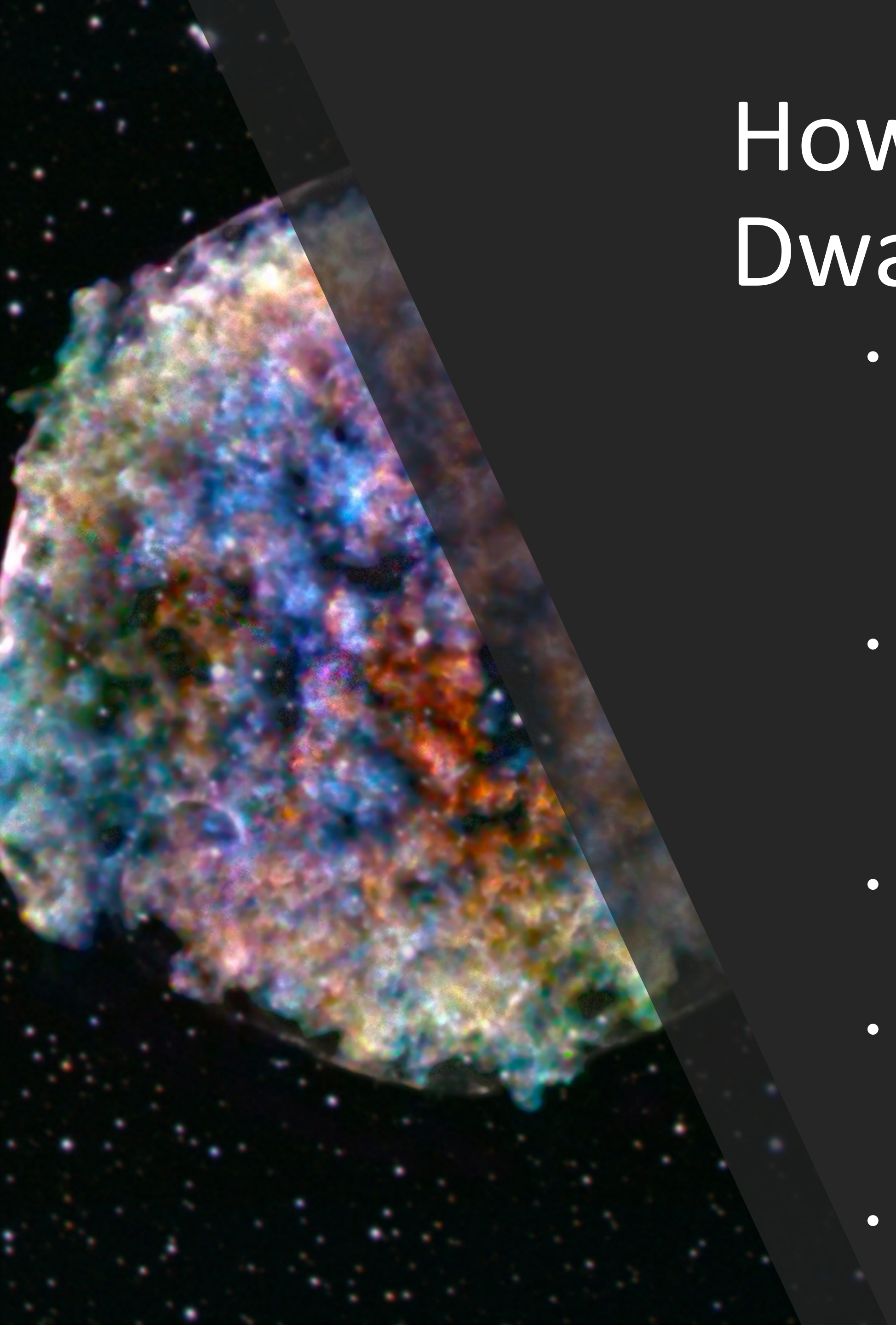
- There are many more late stage evolutionary states of stars, depending on their masses. Including supergiants and hypergiants, with colours ranging from blue to red.

- For example: Shown here is Rigel, a blue supergiant.



How do stars die? – Our Sun’s fate

- Towards the end of our sun’s red giant phase, Helium fusion ignites within the core converting much of the Helium into Carbon in just a few of minutes.
- After this Helium fuel is burnt up, a similar process to the end of the main sequence occurs. Whereby the core will contract, and the outer layers of the star expands greatly.
- With the sun’s mass being too low to fuse anything heavier than Helium outside of the core, the sun will slowly continue to expand eventually leaving behind a remnant of the core (known as a white dwarf) surrounded by a planetary nebula.

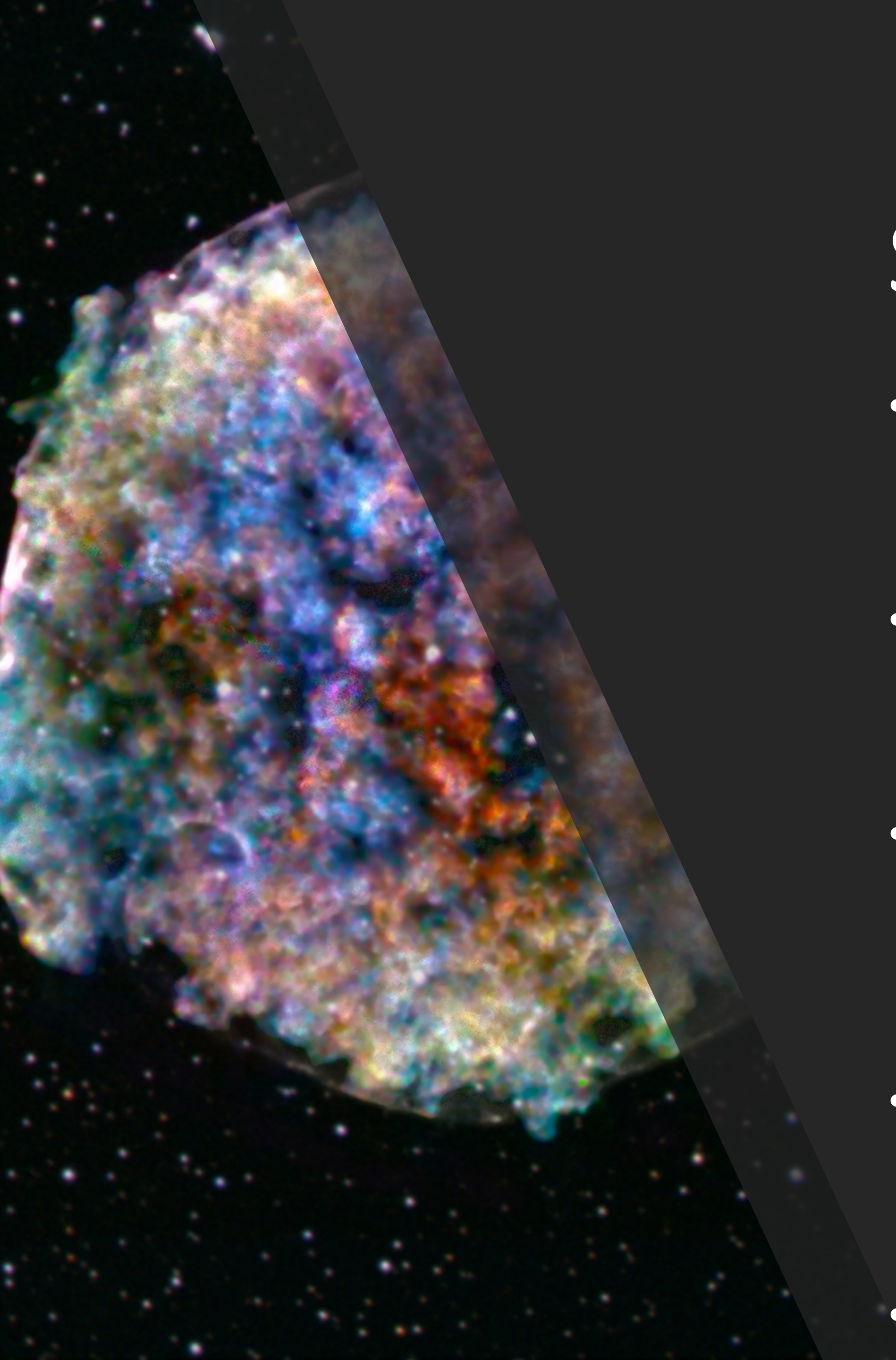


How do stars die? – White Dwarfs

- White dwarfs are the dead remnant of core left behind when stars less than 10 times the mass of our sun die. They're mostly made of Carbon and Oxygen, with insufficient mass to continue fusion to form heavier elements.
- The stellar remnant left after the outer layers strip away (forming a planetary nebula) can be no more massive than 1.33 times the mass of the sun (this mass is called the Chandrasekhar limit).
- White dwarfs are incredibly dense:

  38 Robs per sugar cube

- The gravitational force you'd feel if you stood on the white dwarf Sirius B would be 140,000 times the force you feel on Earth!
- But if white dwarfs aren't generating heat via fusion, why don't they collapse?



How do stars die? – Neutron Stars

- Neutron stars are an even denser remnants of the stellar core, supported by ‘neutron degeneracy pressure’:

(8.4 X All Humans on Earth) per sugar cube

- Neutron stars are made almost entirely out of neutrons, formed when electrons and protons are squashed into each other.
- Neutron stars are usually formed in supernovae, or when a large white dwarf gains enough mass to push it over 1.33 solar masses.
- Neutron stars also have a maximum mass limit, which is about 2.17 solar masses (the Tolman-Oppenheimer-Volkoff limit).
- Even weirder things happen when this limit is passed…..

Black Holes

- Above 2.17 Solar masses, there is nothing that can stop the collapse.
- If you were to stand on V616 Monocerotis, you'd feel a gravitational force about 100 Billion times the force you feel on Earth.
- Matter in the star collapses inwards to a point of **infinite** density.
- Nothing can escape a black hole…