Going Deep Underground to Watch the Stars

Neutrino Astronomy with Hyper-Kamiokande

Jost Migenda*

* they/them

The University Of Sheffield.

35C3
Leipzig, 2018-12-27

@JostMigenda

Hyper-Kamiokande Design Report:
https://arxiv.org/abs/1805.04163

About me

- Grew up near Berlin
- 2009–15: B.Sc. and M.Sc. in Nuclear, Particle & Astrophysics
- since 2015: PhD on Supernova Neutrinos in Hyper-Kamiokande

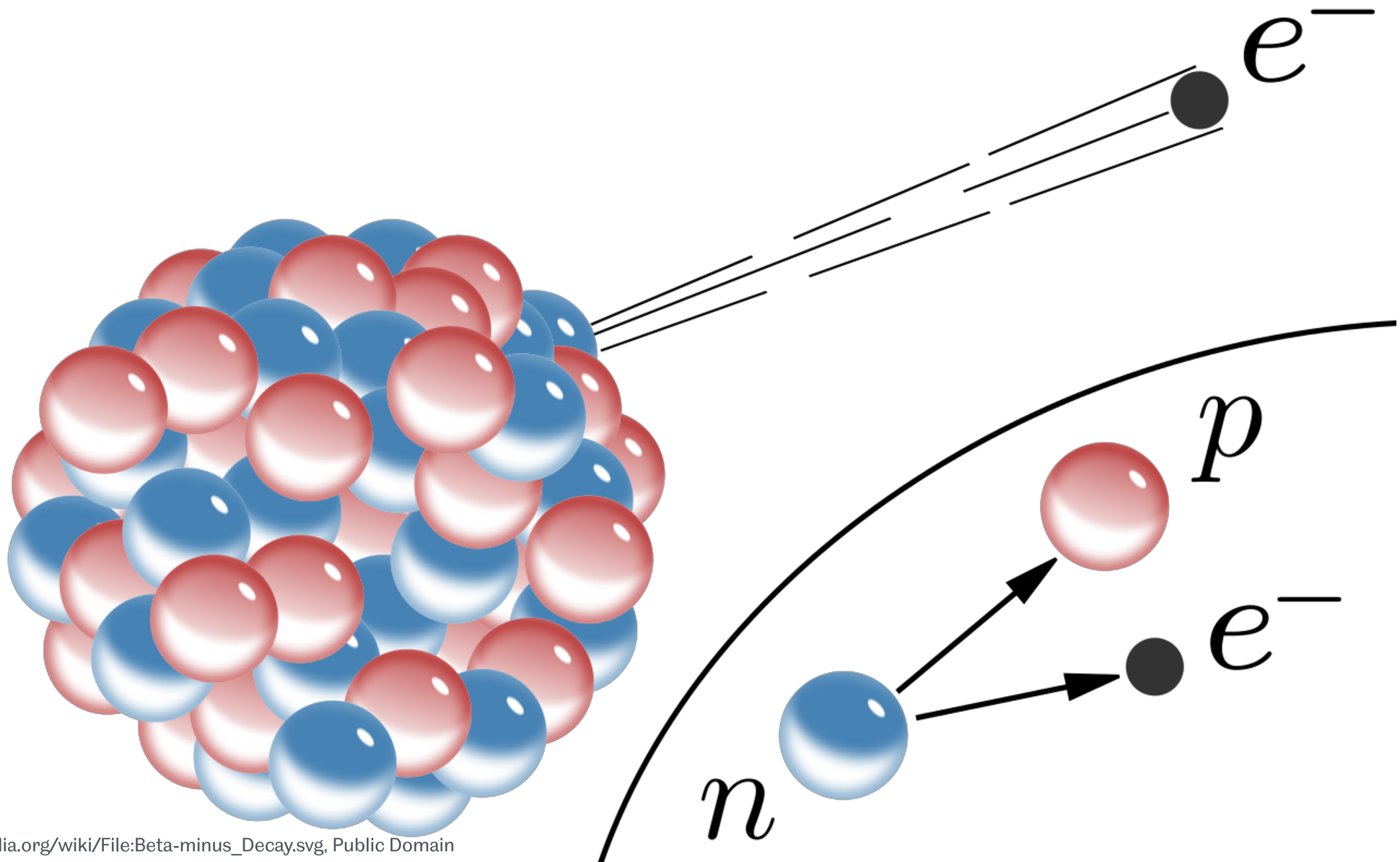
The University Of Sheffield.

@JostMigenda
jmigenda1@sheffield.ac.uk

Agenda

- **What are neutrinos?**
- Building Hyper-Kamiokande
- Let’s get physical!
  - Watching the sun shine
  - Watching stars explode

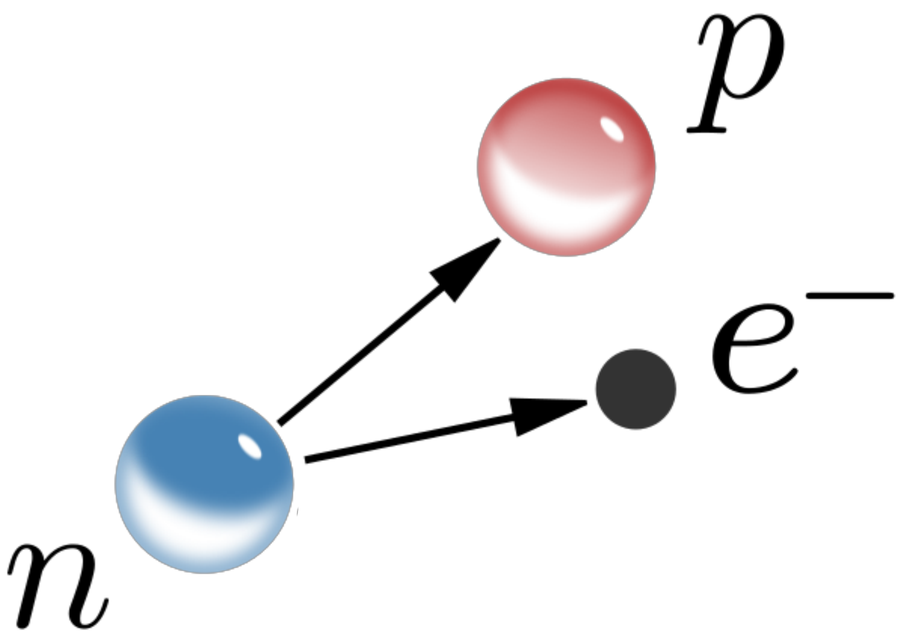
Beta Decay



https://commons.wikimedia.org/wiki/File:Beta-minus_Decay.svg, Public Domain

Conserve Energy!

... it's the law (of nature)



"Dear radioactive ladies and gentlemen,

[...] I have resorted to a desperate way out to save conservation of energy [...]"

— Wolfgang Pauli, letter to Lise Meitner in December 1930

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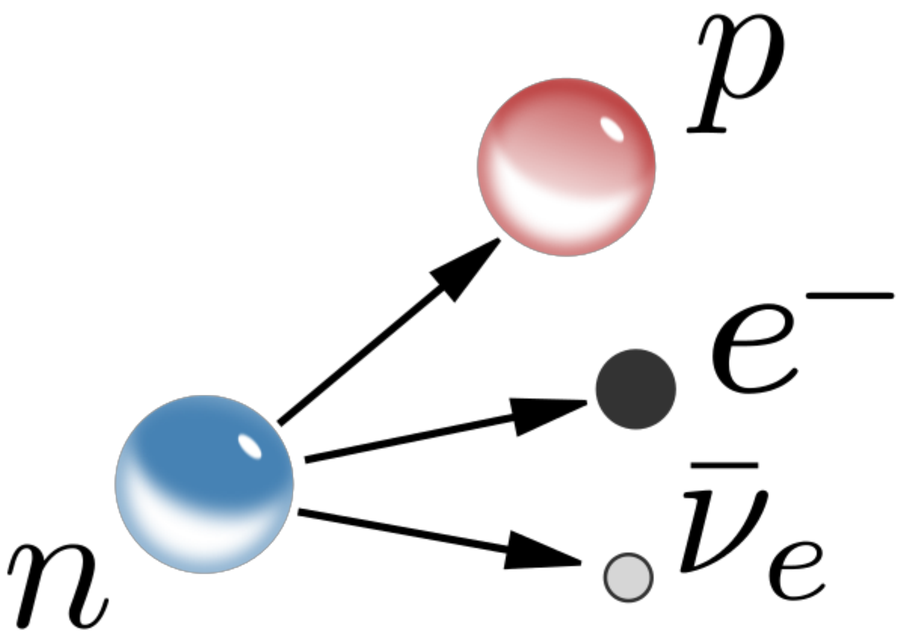

neutron

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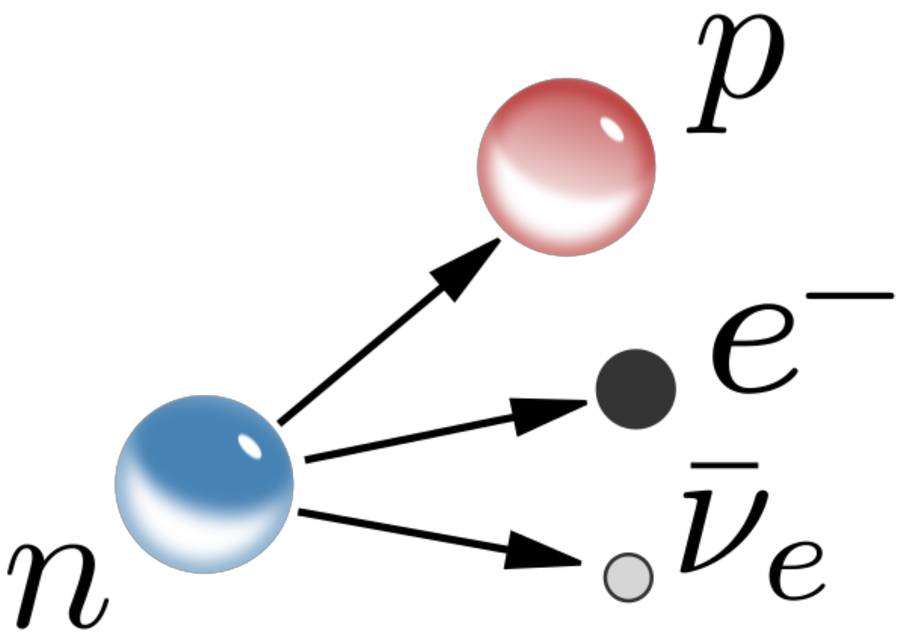

neutron -ino

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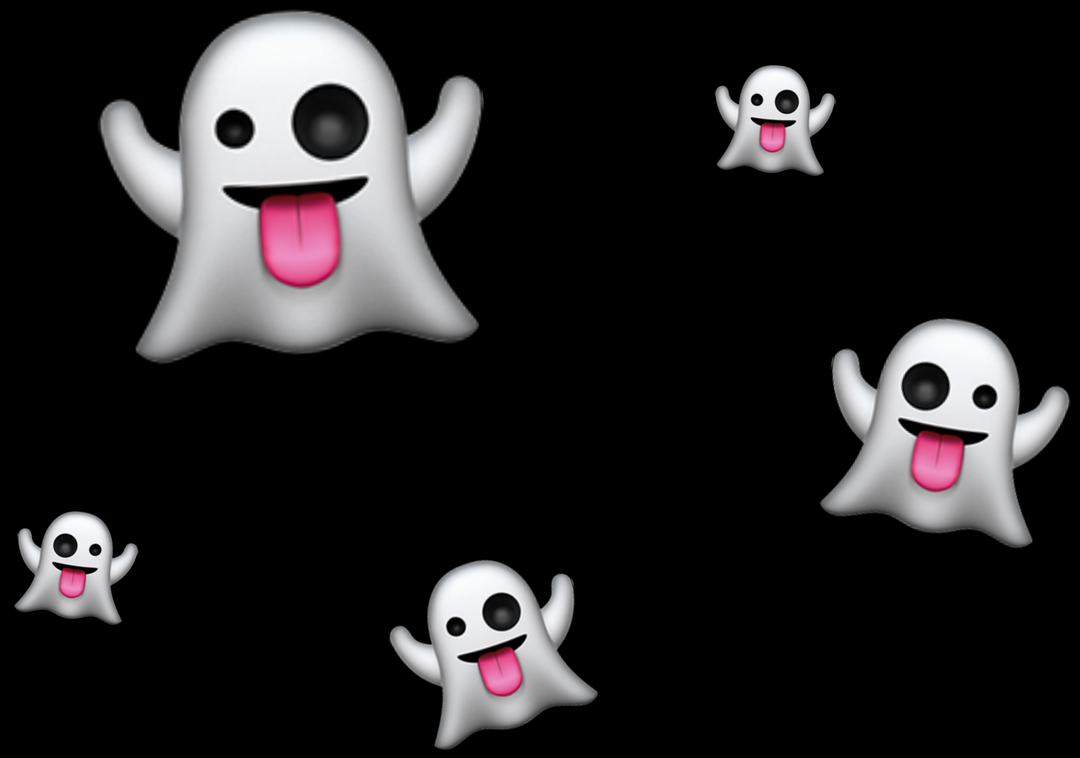
Neutrinos Are Like Ghosts



Let’s Do an Experiment!

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60,000,000,000 neutrinos

every second

Let’s Do an Experiment!

60,000,000,000 neutrinos

every second

“there is no practically possible way
of observing the neutrino”

— Bethe, Peierls: *Nature* **133** (1934), p. 532

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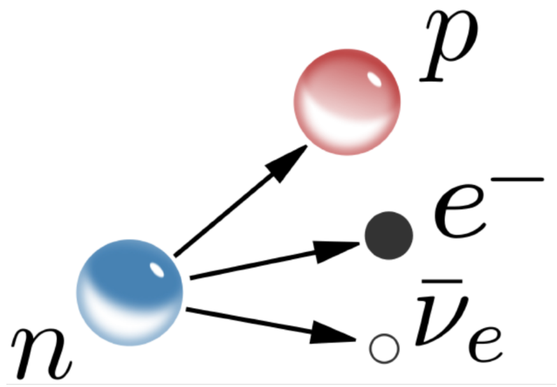
History

1930s: Beta Decay

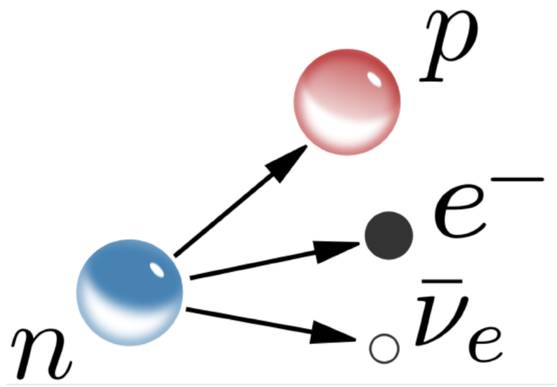


1970s: Grand Unified Theories

➔ Can the proton decay, too?

History

1930s: Beta Decay



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History

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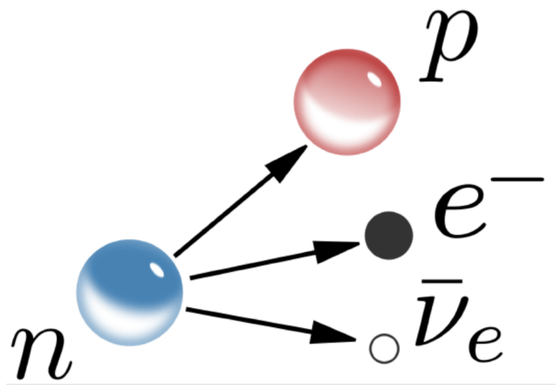


1970s: Grand Unified Theories

➔ Can the proton decay, too?

Neutrino Detection

1983: built the Kamioka **N**ucleon **D**ecay **E**xperiment

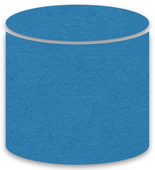
History doesn’t repeat itself

… but it rhymes

Nobel Prize image: ®© The Nobel Foundation

Kamiokande

1983–1996



Koshiba, 2002

History doesn't repeat itself

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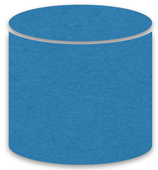
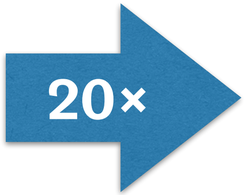
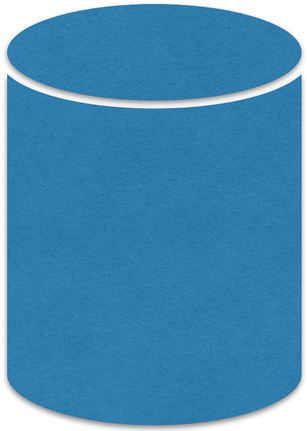
Kamiokande
1983–1996

Super-Kamiokande
1996–today







Koshiba, 2002

Kajita, 2015

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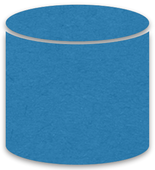
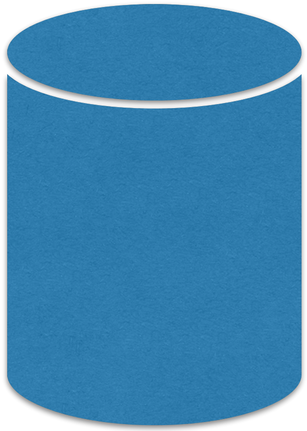
Kamiokande
1983–1996



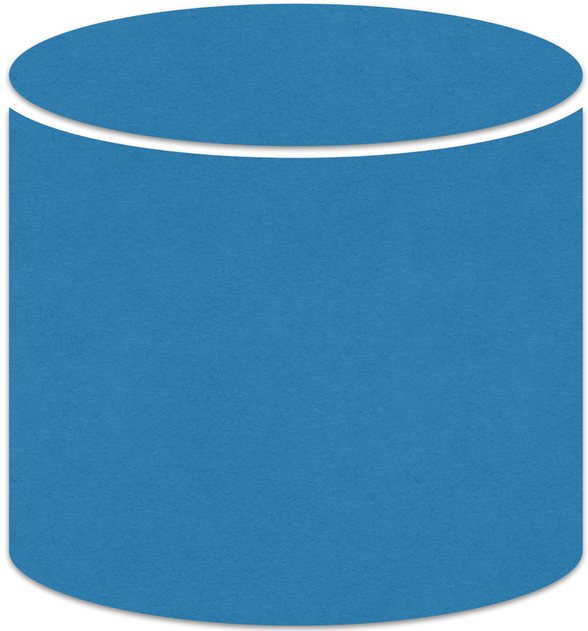
20×

Super-Kamiokande
1996–today



8×

Hyper-Kamiokande
construction starts 2020




Koshiba, 2002


Kajita, 2015


TBD, 20??

In Super-Kamiokande, every day ...

>10,000,000,000,000,000,000,000

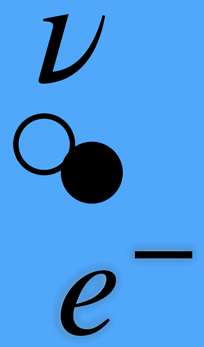
solar neutrinos pass through.
(That's 10^{22}.)

10–15

get detected.

Neutrino-Electron Scattering

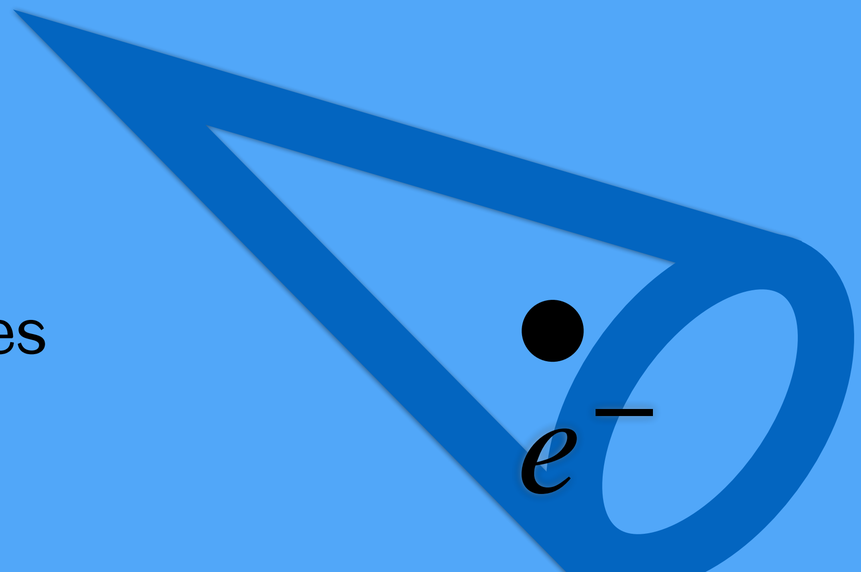
Neutrino-Electron Scattering



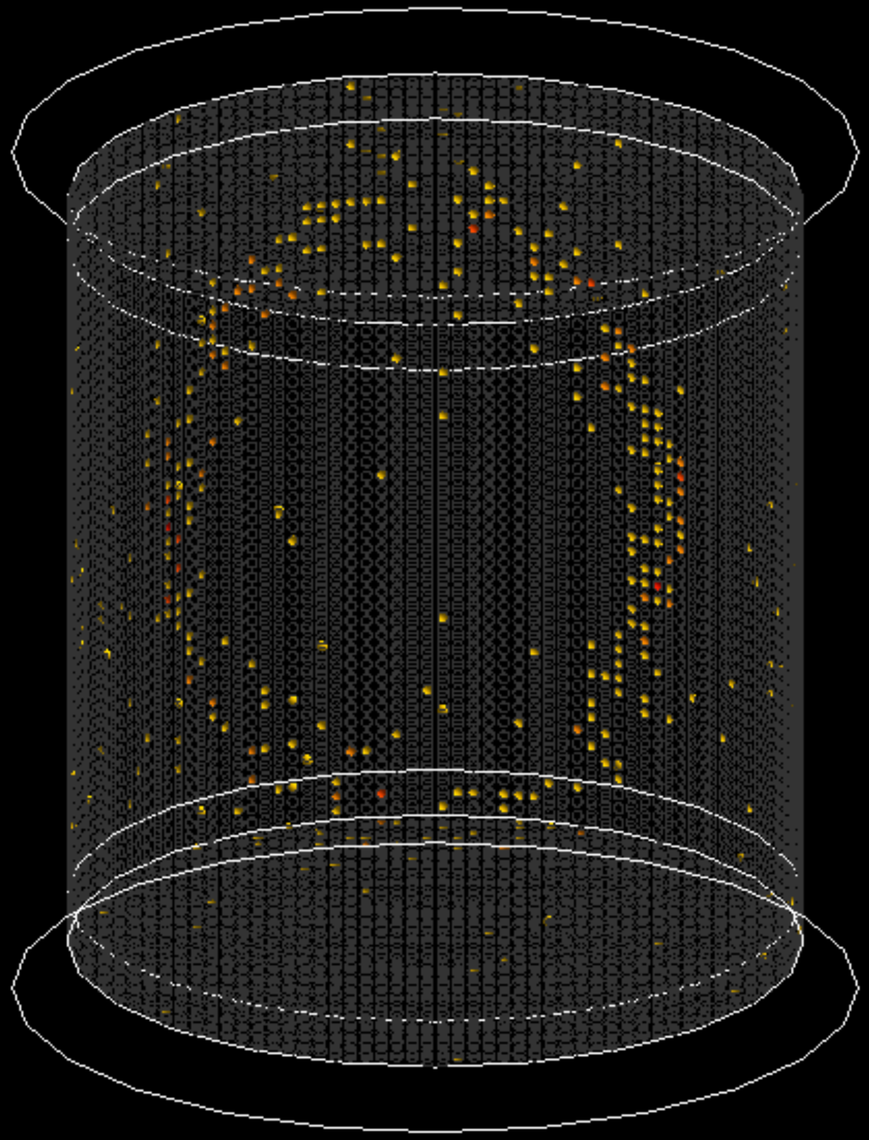
Neutrino-Electron Scattering

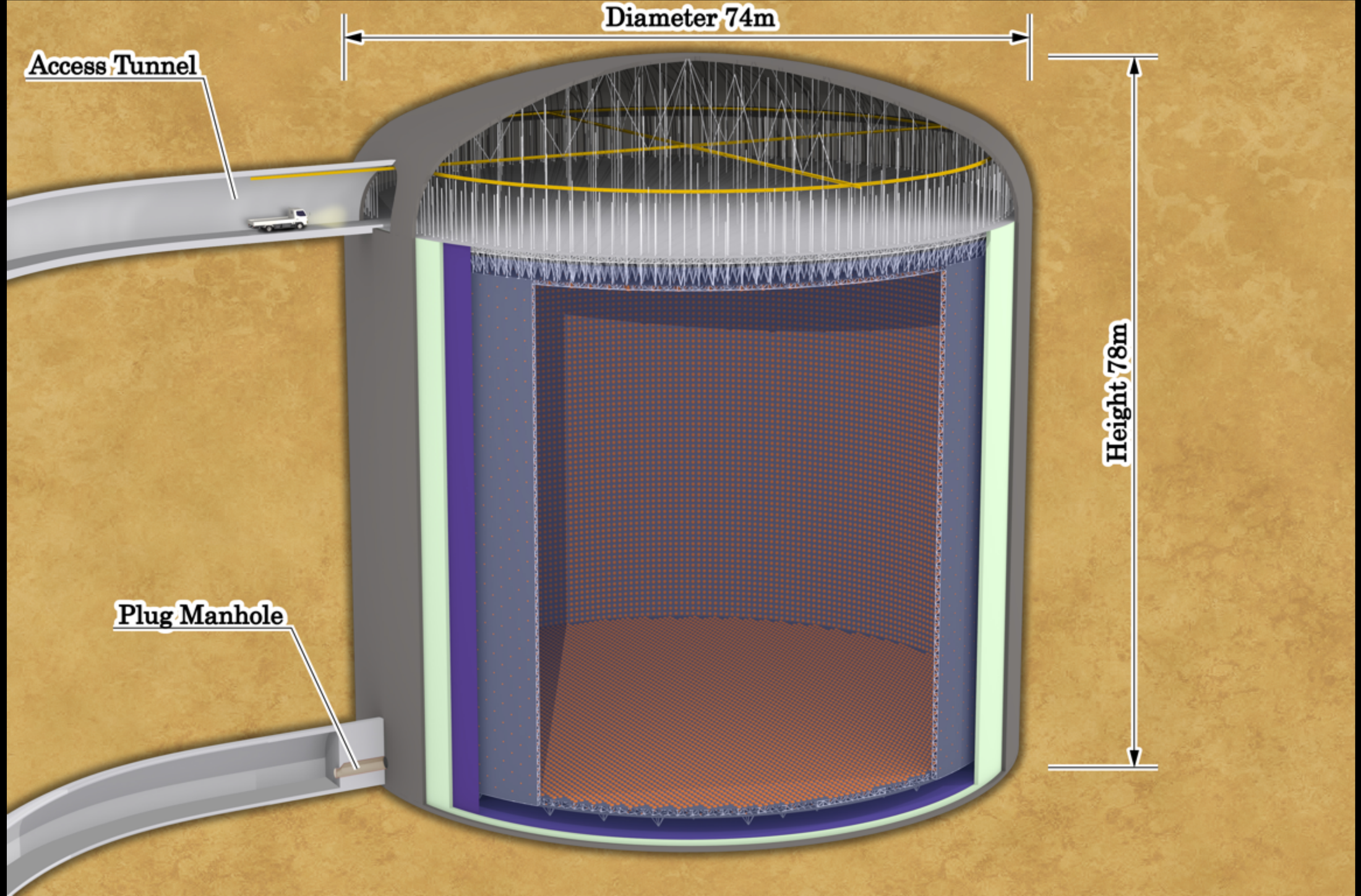
emits Cherenkov light because it moves faster than the speed of light *in water*

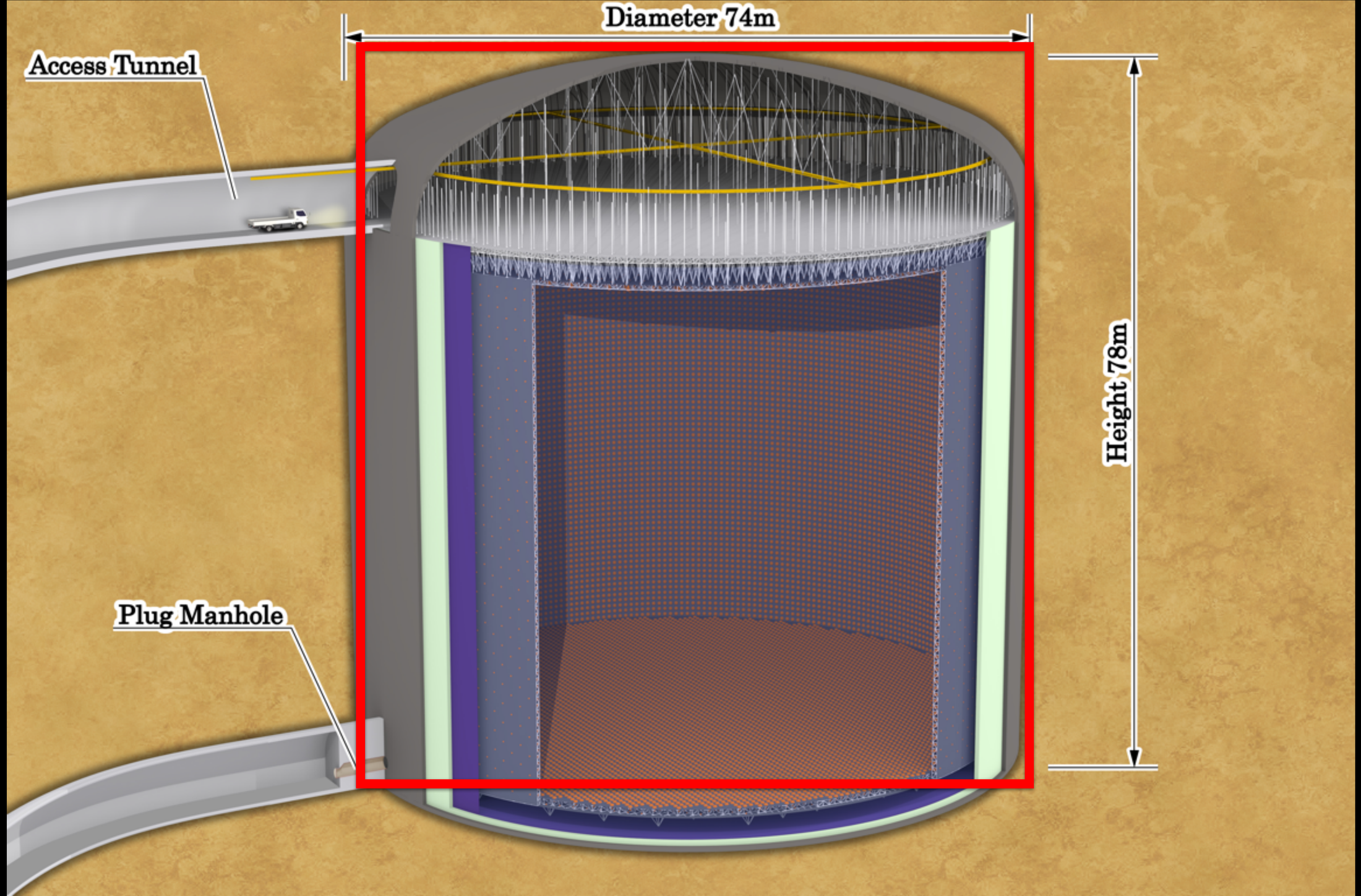
(but still slower than the speed of light *in vacuum)*



Photosensors Detect This Cone of Light




Diameter 74m
Access Tunnel
Height 78m
Plug Manhole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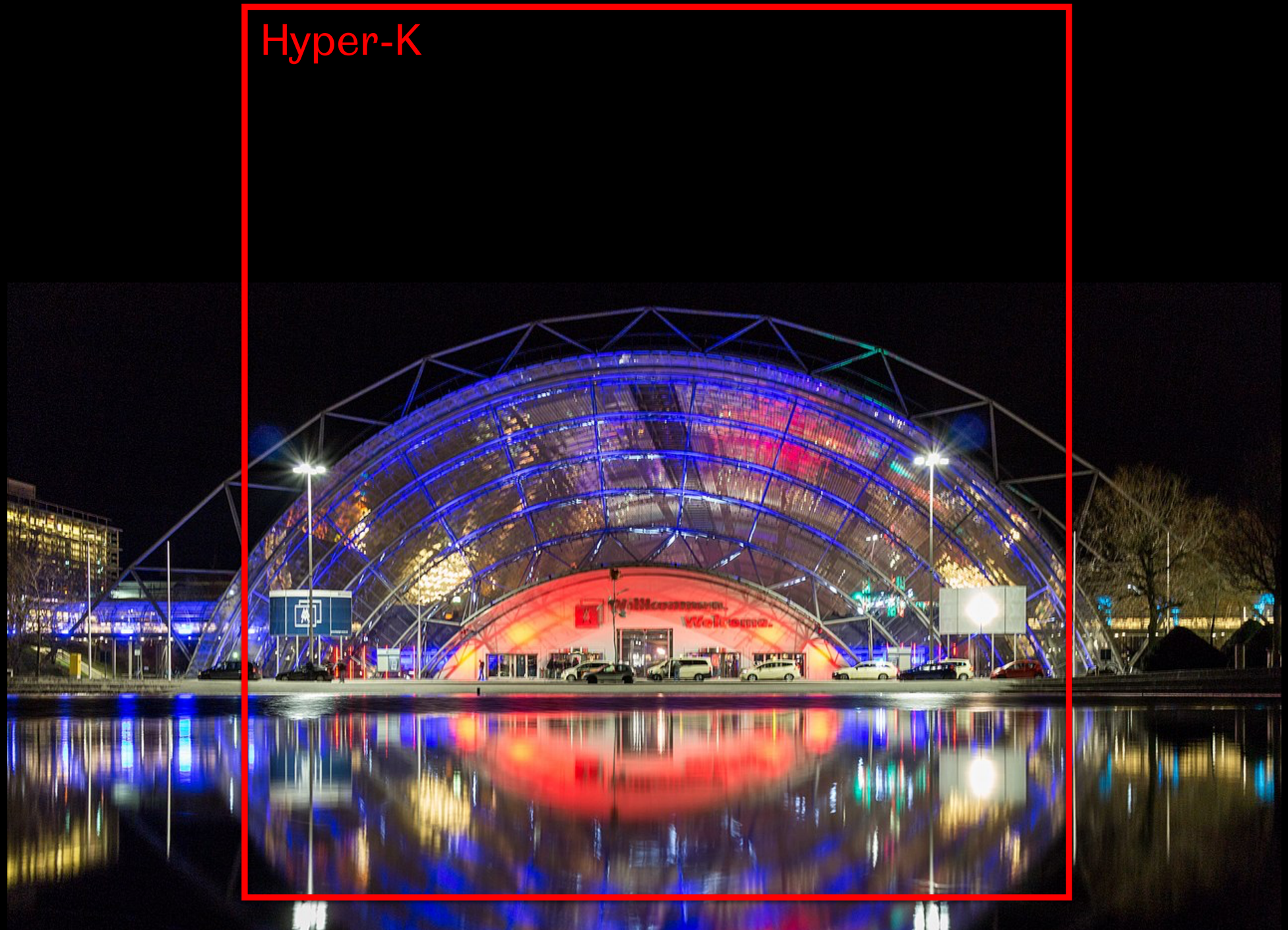
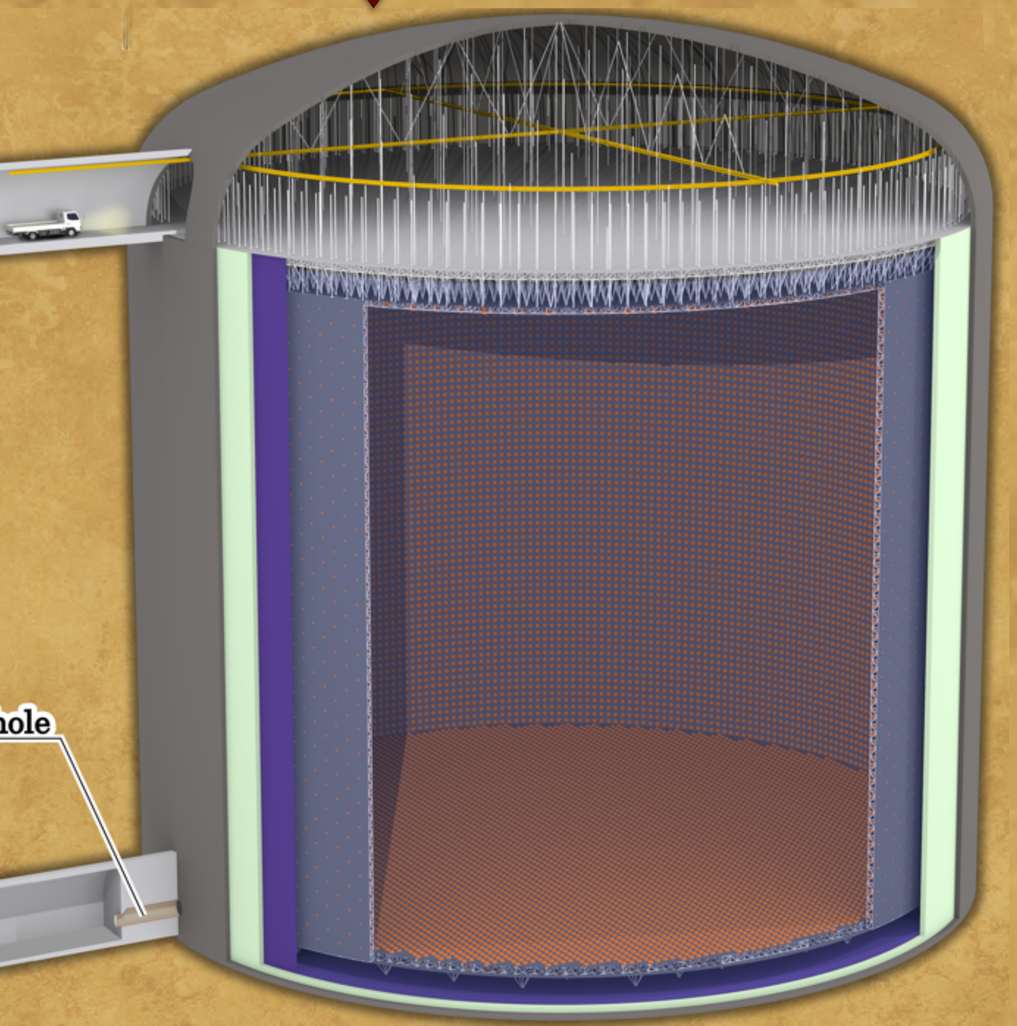


650 m
underground



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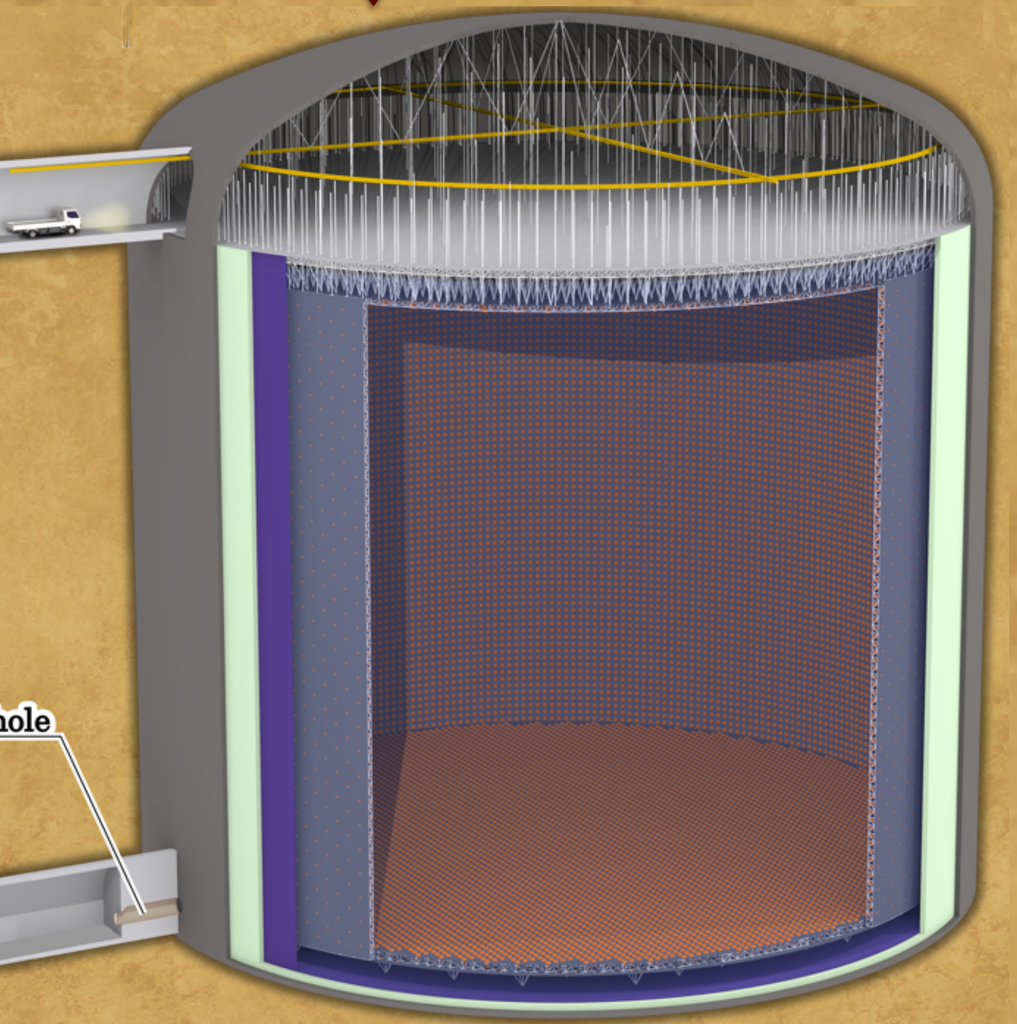


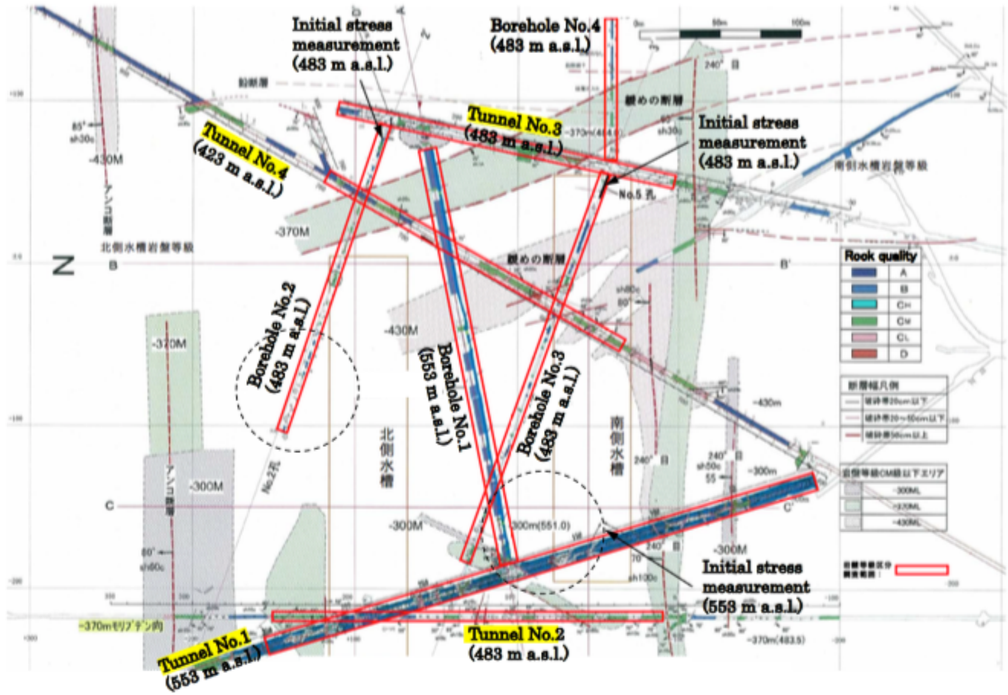
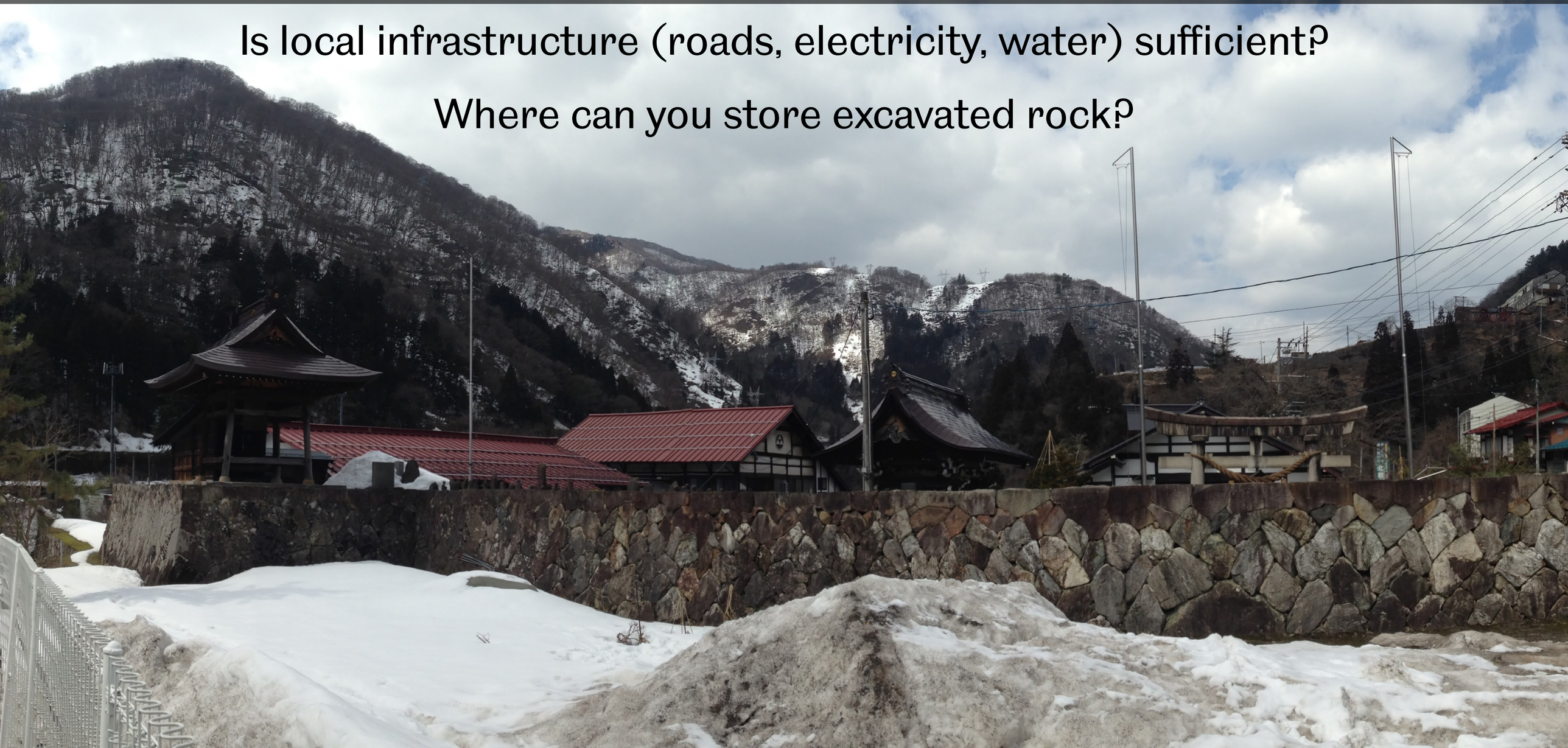


FIG. 22. Location of rock quality measurements in existing tunnels and bore-hole cores at 423 m, 483 m, and 553 m a.s.l. The red rectangulars show the surveyed regions in the measurements. Possible layout of the two caverns is also shown by dashed circles.

“Boring Surveys”

Excavate Cavern

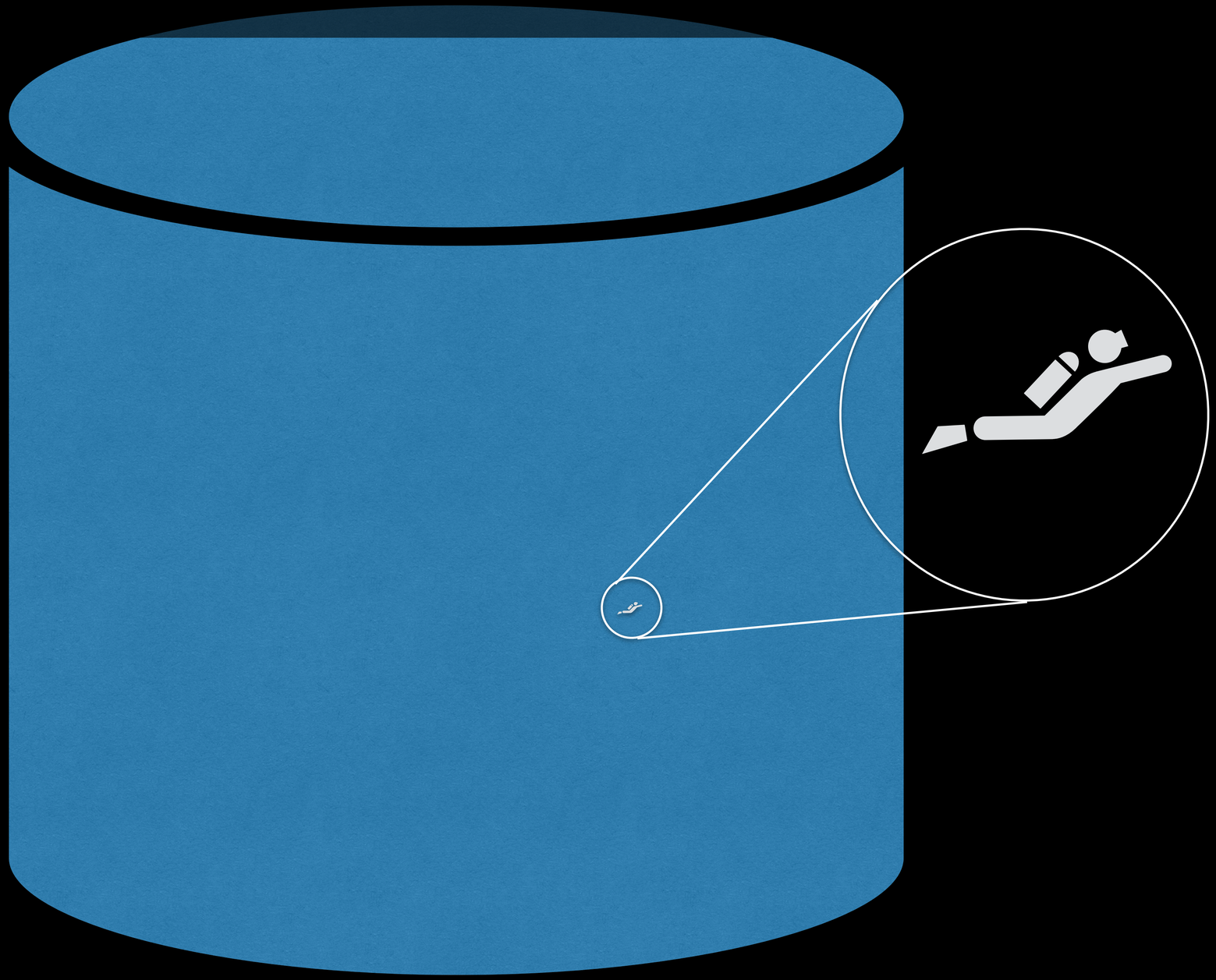


Is local infrastructure (roads, electricity, water) sufficient?

Where can you store excavated rock?

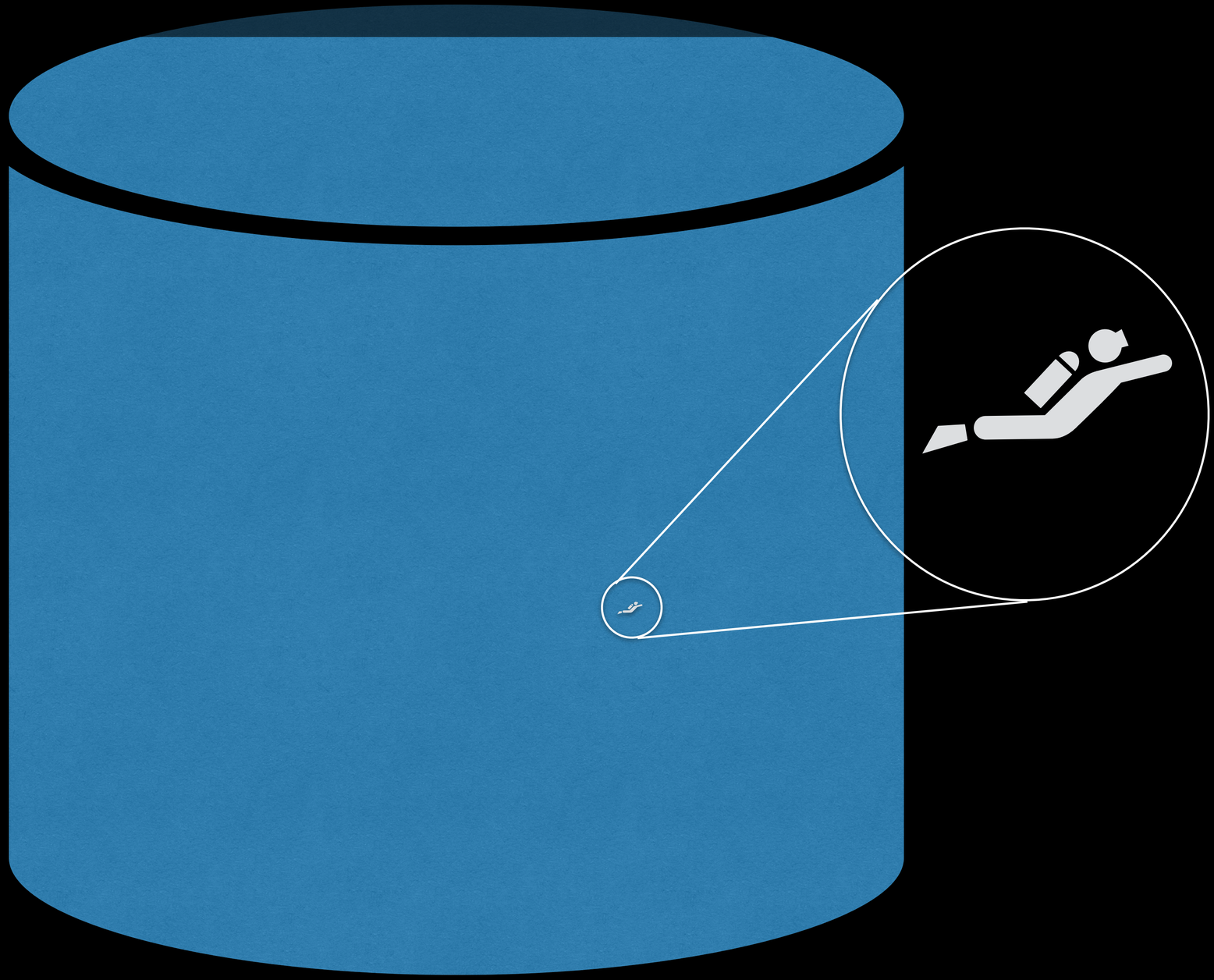
Water for 5000 people

Water for 5000 people



Water for 5000 people

Long hair?
Beware!



40,000 Pixels

- Photomultiplier Tubes (PMTs)
- earlier: one cable per PMT
- now: one cable for multiple PMTs
  - need watertight, low-power electronics to digitize & combine signals
  - need mesh networking for redundancy


光電子増倍管
（こうでんしぞうばいかん）

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Mobiles/PDAs
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Monday, 19 November, 2001, 12:49 GMT

Particle physics telescope explodes

A defective photomultiplier tube exploded, setting off a chain reaction

By BBC News Online science editor Dr David Whitehouse

One of the world's leading particle physics instruments has been severely damaged in an accident.

The underground Super-Kamiokande Observatory in Japan detects elusive neutrino particles from space by using photomultiplier tubes to register the flashes of light they produce when they pass through a huge tank of water.

> **We will rebuild the detector. There is no question**
>
> **Yoji Totsuka, Kamioka Observatory**

On 12 November, one of the photomultiplier tubes exploded causing a chain reaction that resulted in most of the other 11,200 light detectors also blowing up.

See also:

- 18 Dec 98 | Sci/Tech
  Top of the science class
- 05 Jun 98 | Sci/Tech
  Ghostly particles rule the universe

Internet links:

- Super-Kamiokande Official Homepage

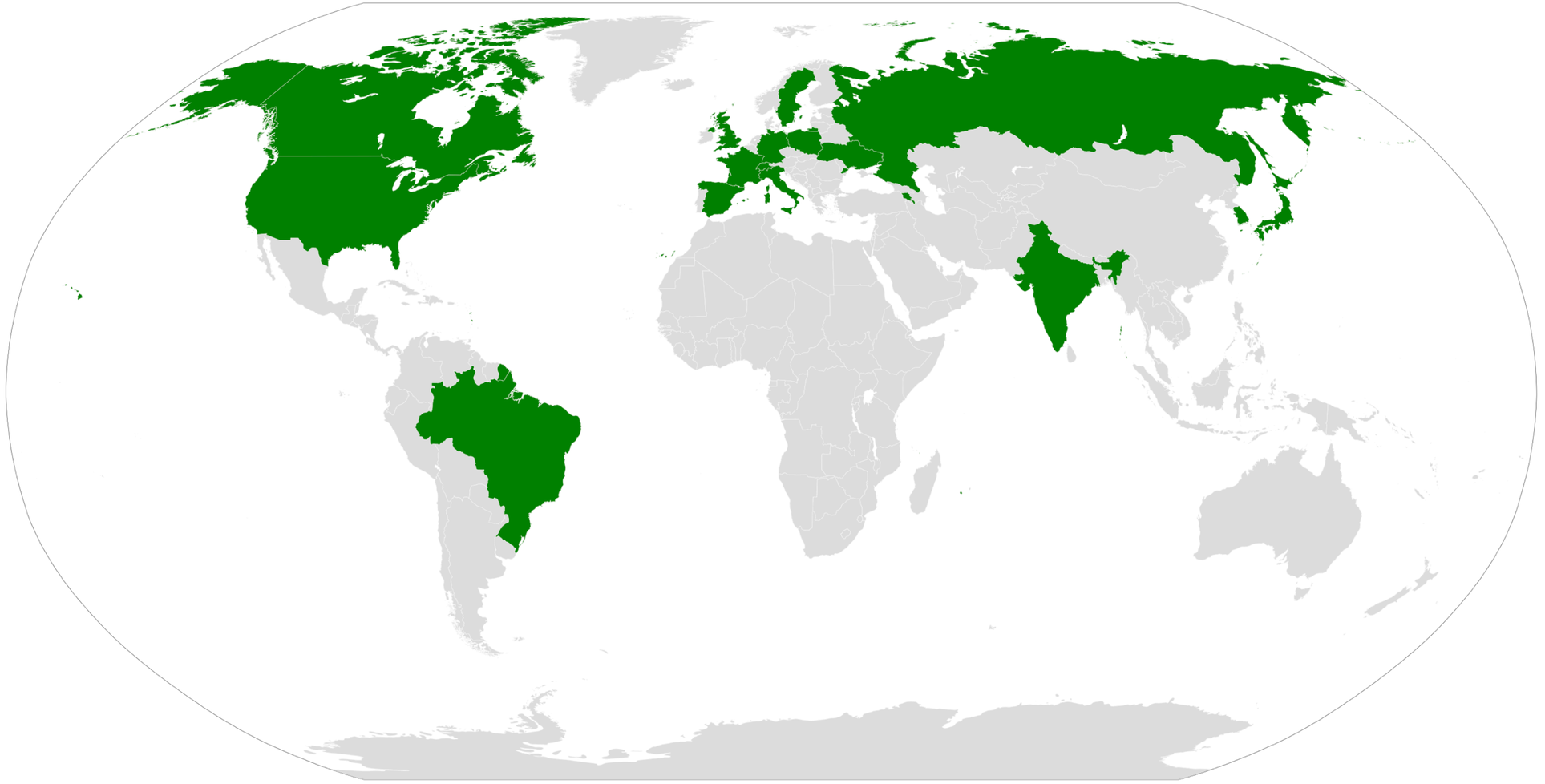
The BBC is not responsible for the content of external internet sites

Top Sci/Tech stories now:

- Astronomy's next big thing
- Ancient rock points to life's origin
- Mobile spam on the rise
- Giant telescope project gets boost
- New hope for Aids vaccine
- Replace your mouse with your eye
- Device could detect overdose drugs
- Wireless internet arrives in China

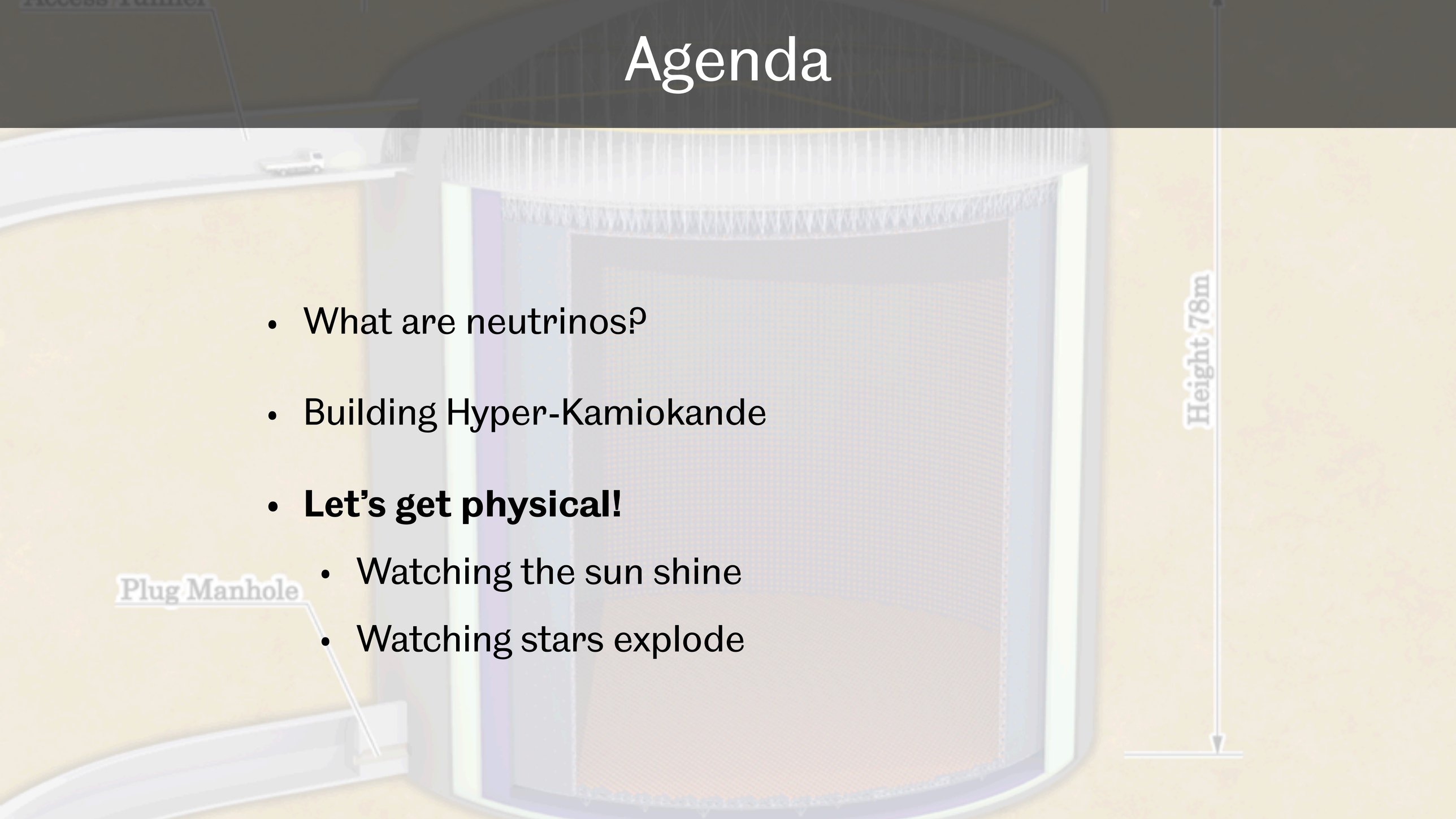
Links to more Sci/Tech stories are at the foot of the page.

Hyper-Kamiokande Members



17 countries, >300 people, many timezones ...

Agenda



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  - Watching the sun shine
  - Watching stars explode

Agenda

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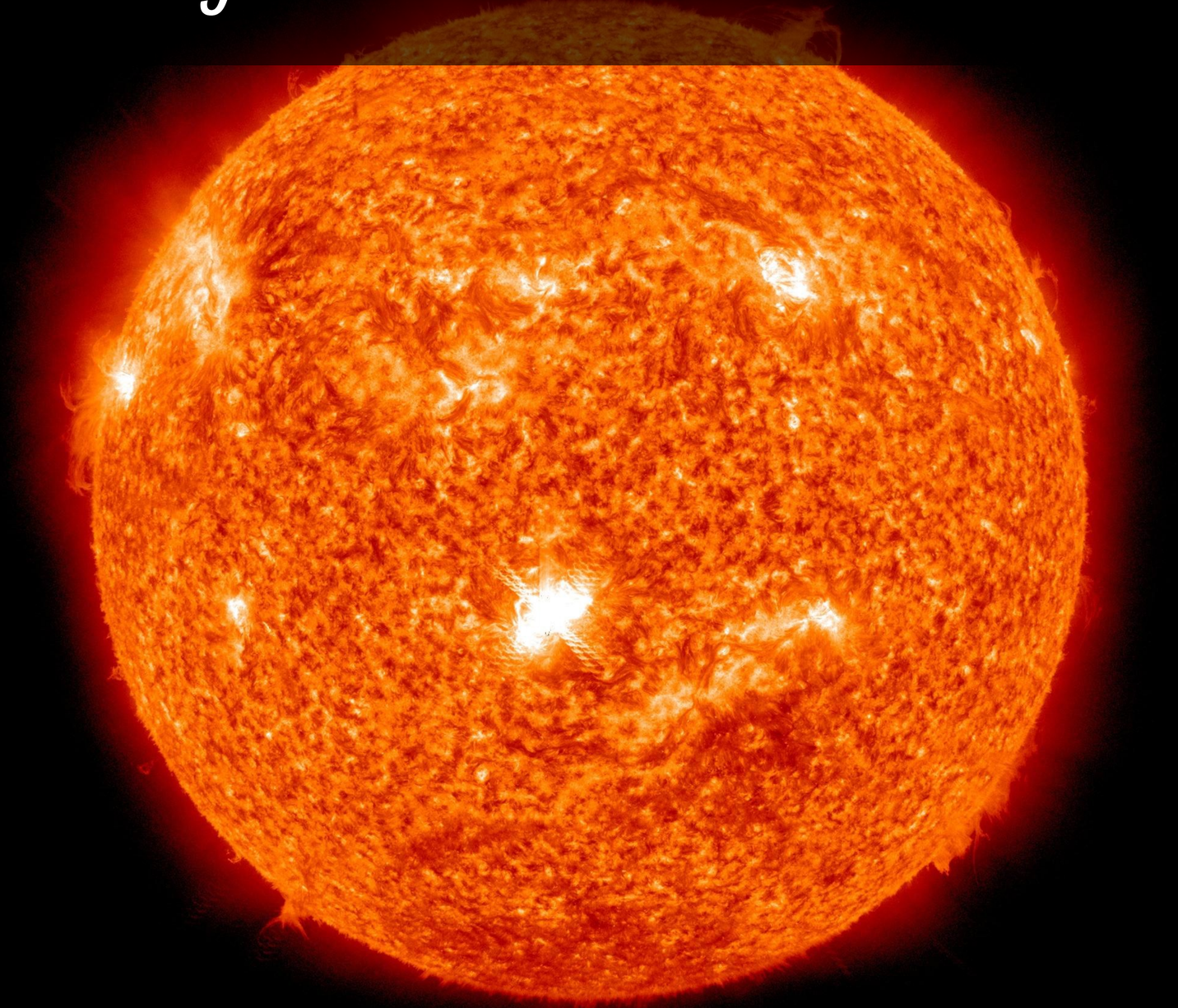
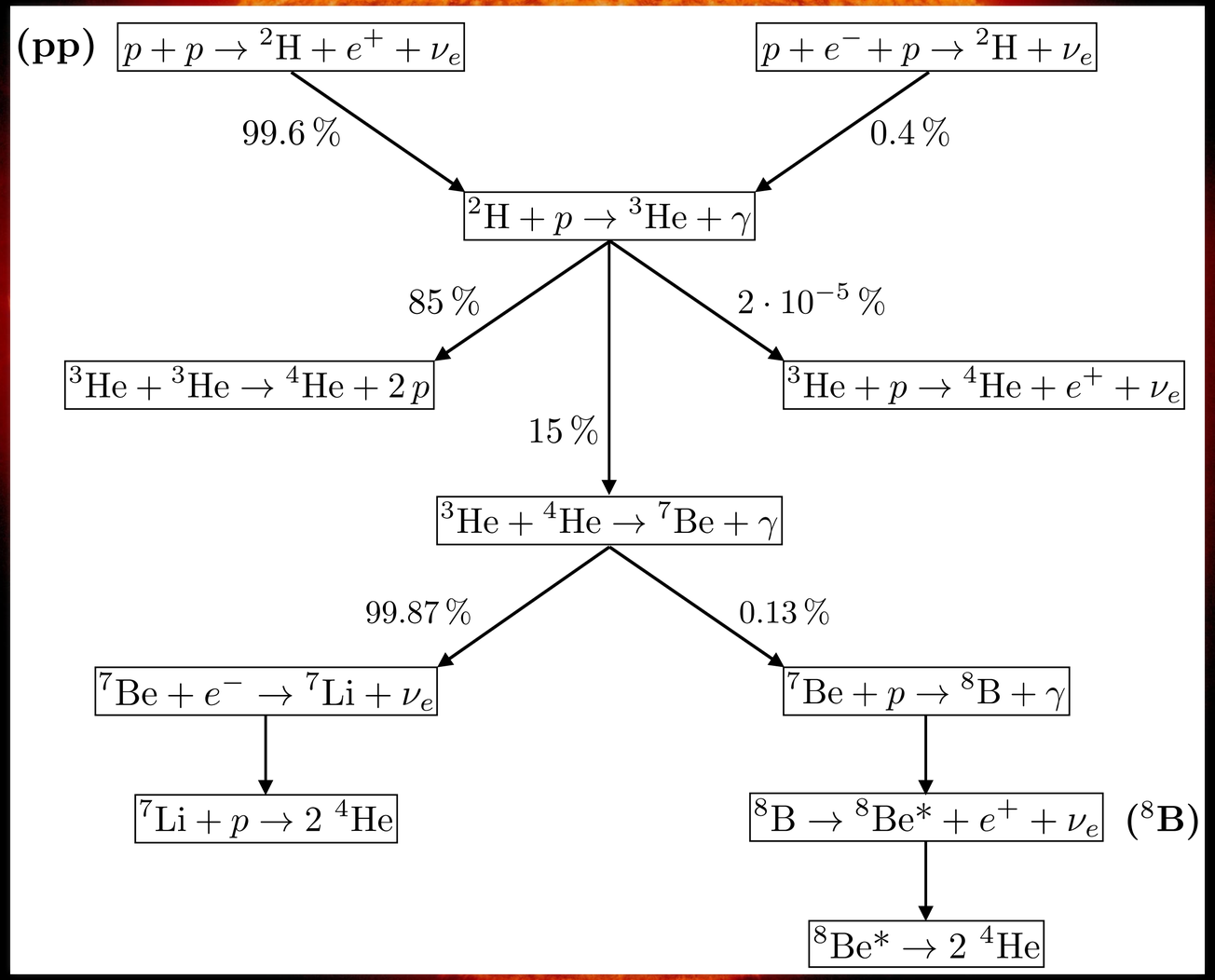
... and much more!

Why Does the Sun Shine?



NASA/SDO: https://www.nasa.gov/mission_pages/sunearth/news/News021311-flare.html

Why Does the Sun Shine?



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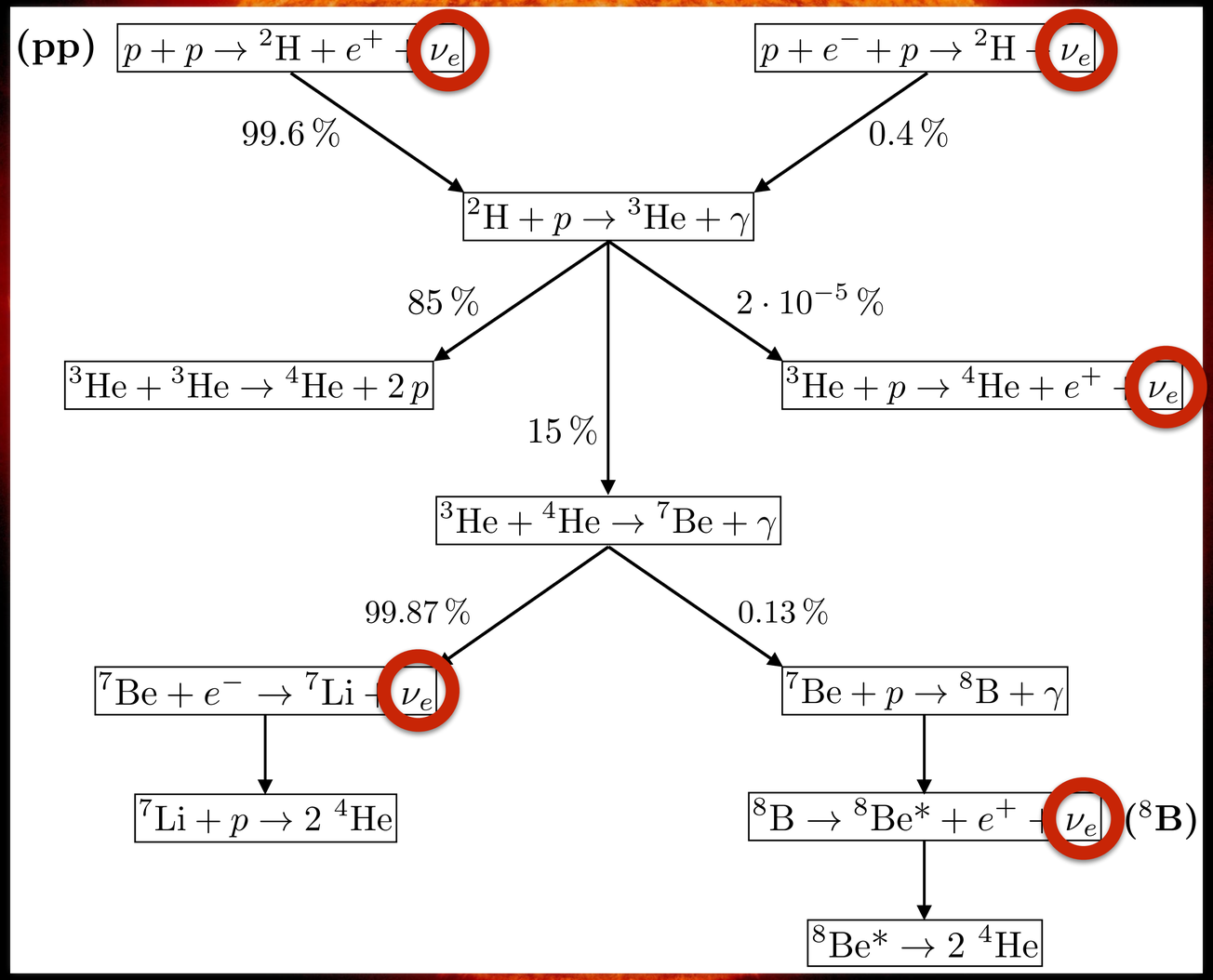
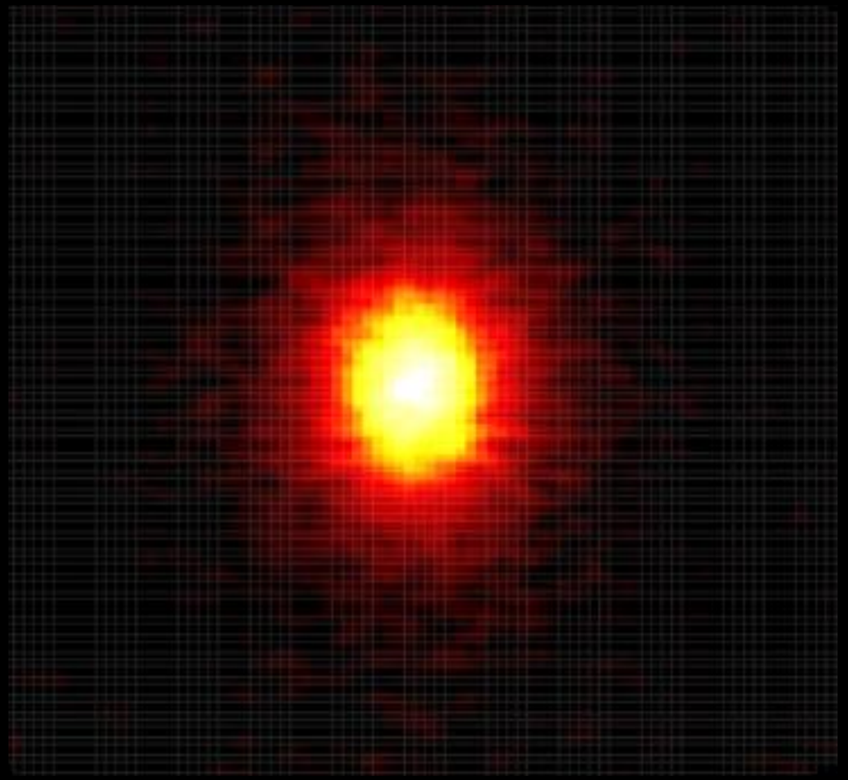


Temperature:
15.5 Mio. K **±1%**

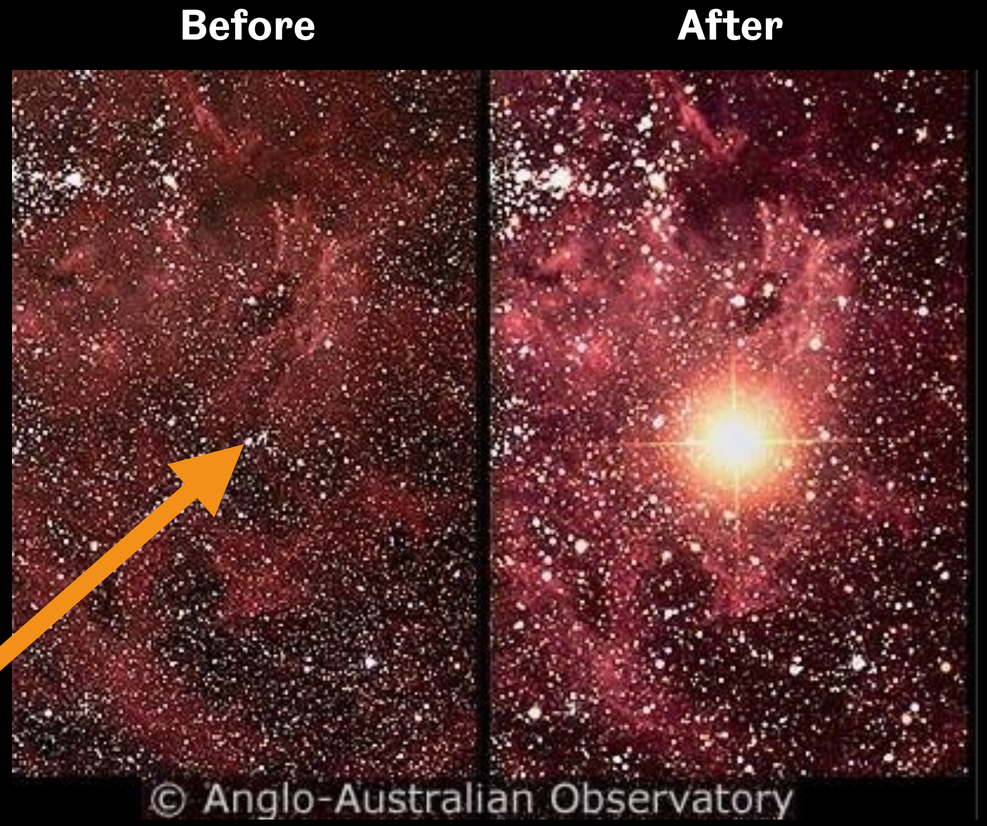
NASA/SDO: https://www.nasa.gov/mission_pages/sunearth/news/News021311-flare.html

The Sun in Neutrinos



Y. Nakano (Super-Kamiokande collaboration): https://indico.cern.ch/event/606690/contributions/2591501/

Exploding Stars – Supernovae



SN1994D in galaxy NGC 4526

NASA/ESA, Hubble Key Project Team, High-Z SN Search Team
http://www.spacetelescope.org/images/opo9919i/

“However big you think supernovae are, they’re bigger than that.”

— Donald Spector

Quoted in: R. Munroe: What if? Serious Scientific Answers to Absurd Hypothetical Questions, p. 175. Houghton Mifflin Harcourt, Boston (2014).

SN1994D in galaxy NGC 4526

NASA/ESA, Hubble Key Project Team, High-Z SN Search Team
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Which of the following would be brighter, in terms of the amount of energy delivered to your retina:

1. A supernova, seen from as far away as the Sun is from the Earth, or

Which of the following would be brighter, in terms of the amount of energy delivered to your retina:

1. A supernova, seen from as far away as the Sun is from the Earth, or

2. The detonation of a hydrogen bomb *pressed against your eyeball?*

Which of the following would be brighter, in terms of the amount of energy delivered to your retina:

1. A supernova, seen from as far away as the Sun is from the Earth, or

2. The detonation of a hydrogen bomb *pressed against your eyeball?*

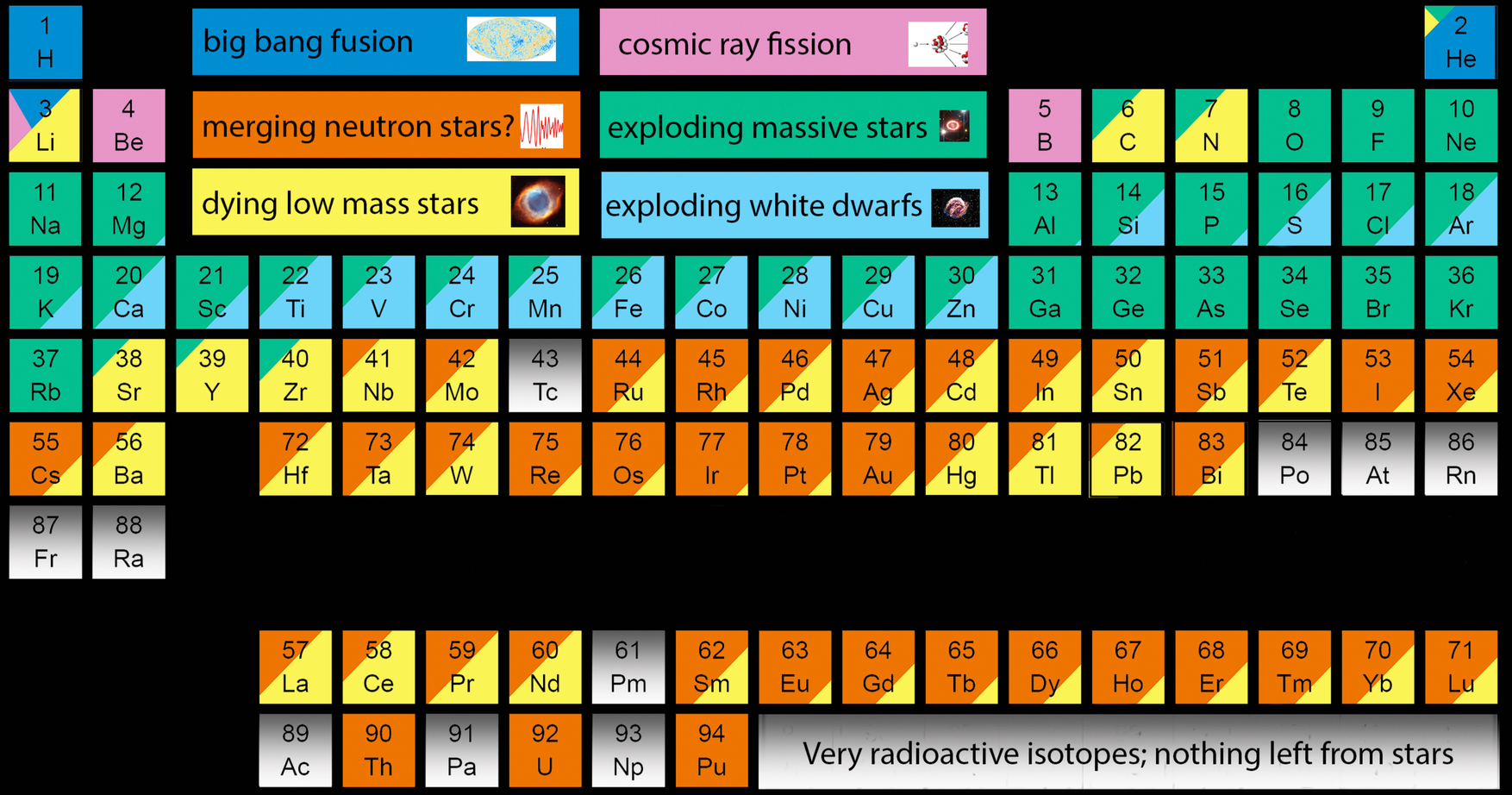
Applying the physicist rule of thumb suggests that the supernova is brighter. And indeed, it is ... by *nine orders of magnitude*.

Supernova

- One of the biggest bangs since the Big Bang!
- Produces a neutron star or black hole
- Birthplace of new stars

NASA/ESA, Hubble Key Project Team, High-Z SN Search Team
http://www.spacetelescope.org/images/opo9919i/

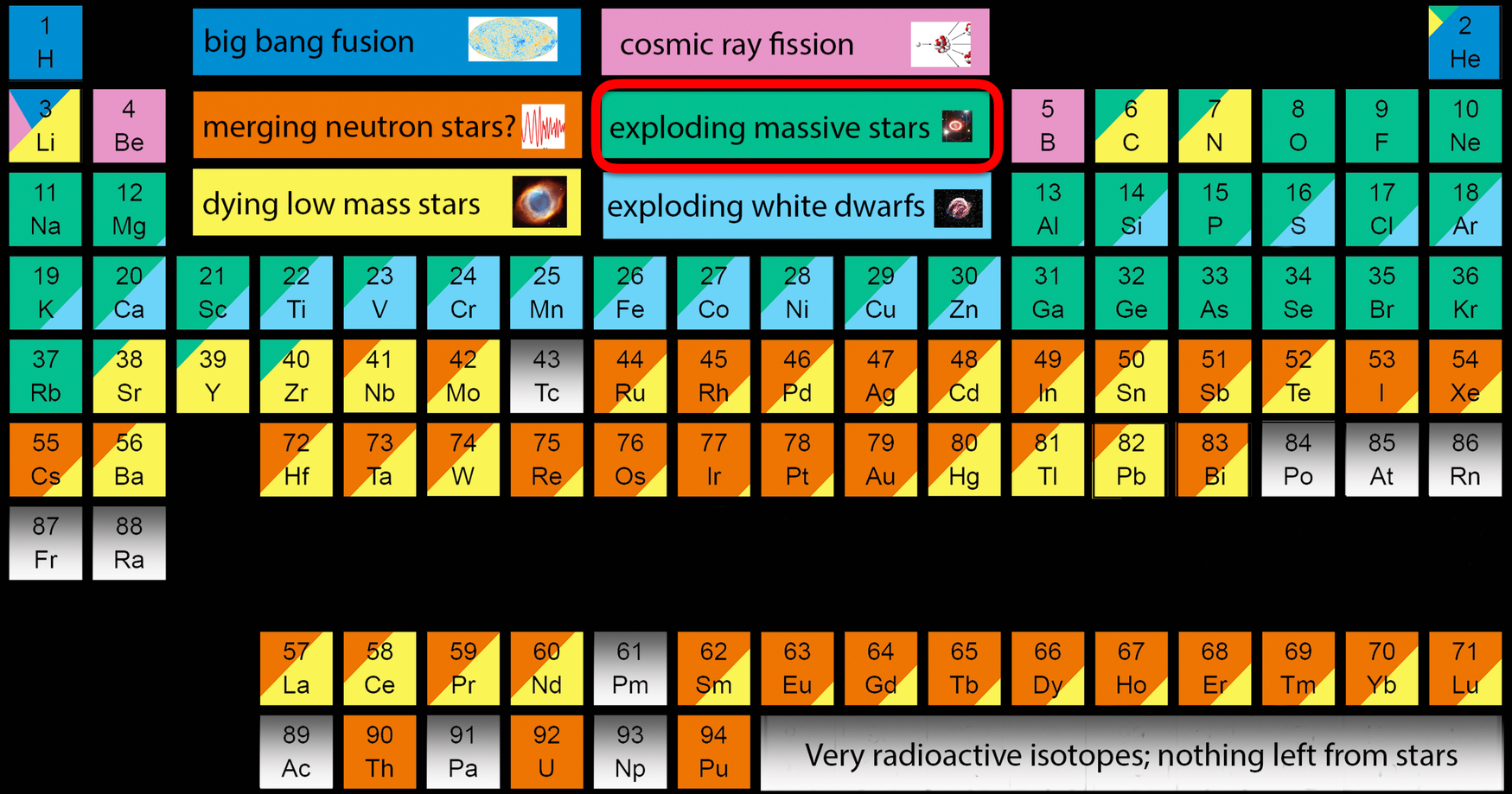
The Origin of the Chemical Elements



Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
ESA/NASA/AASNova

The Origin of the Chemical Elements



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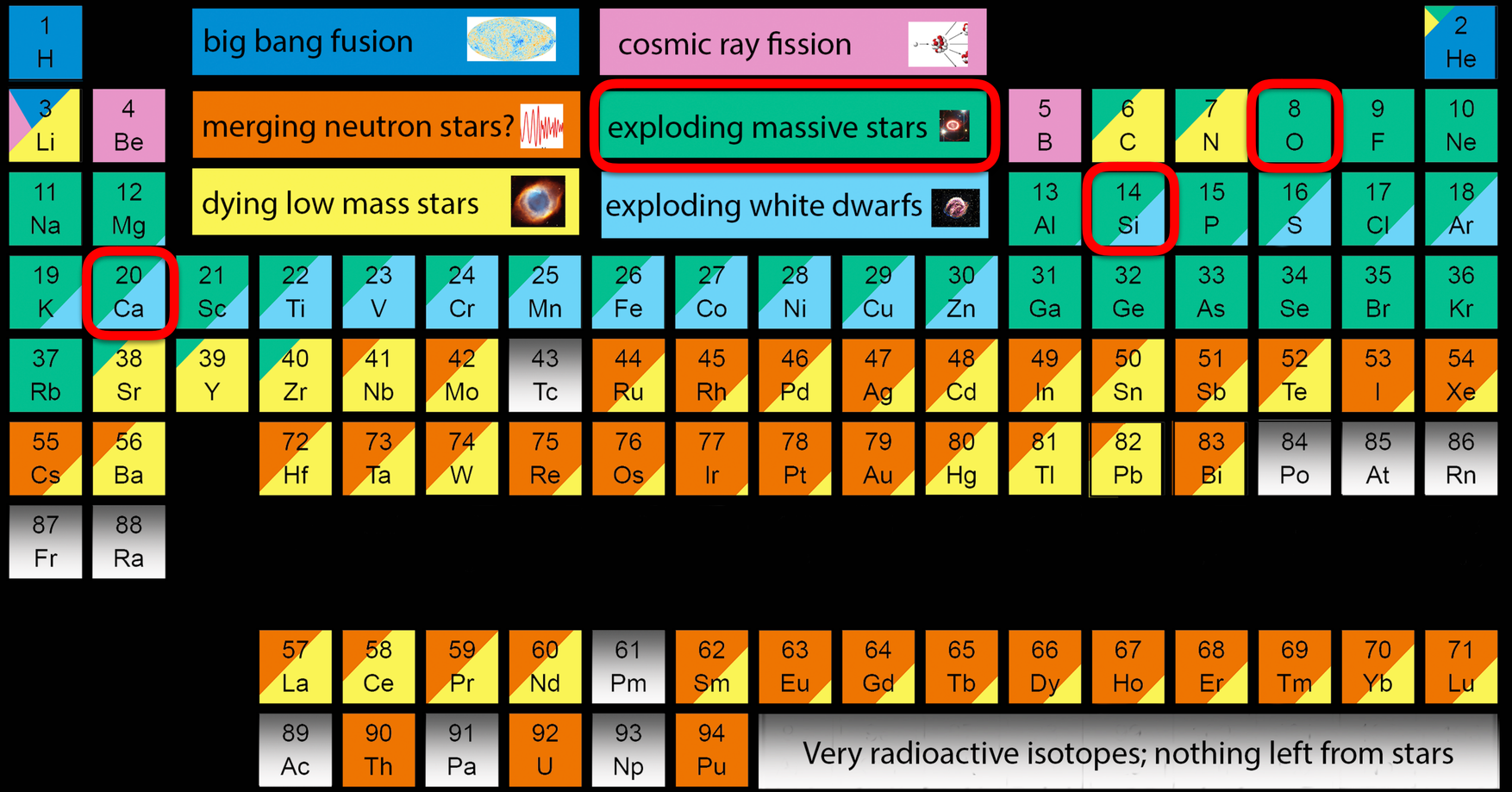
The Origin of the Chemical Elements



Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
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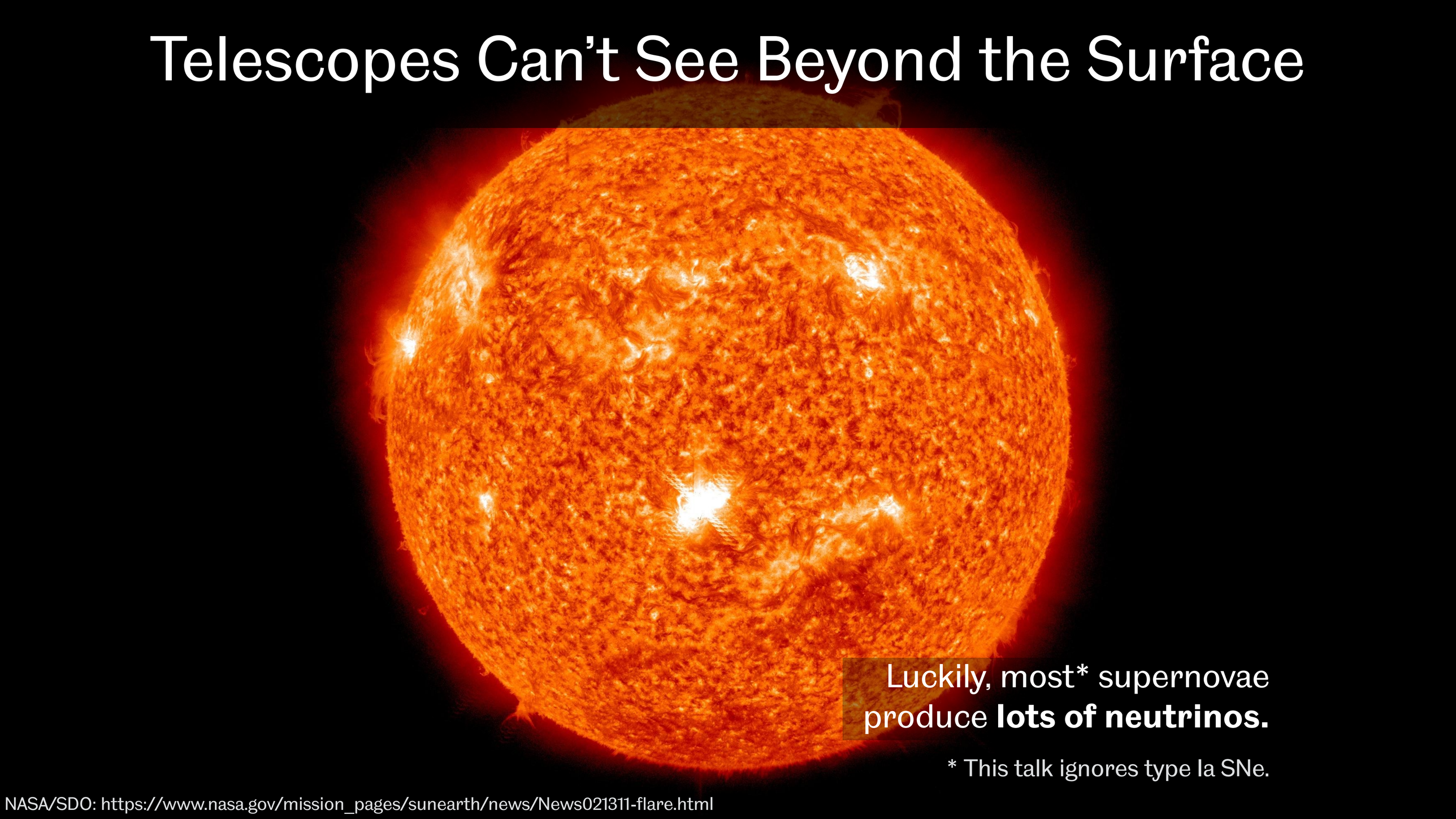
Life can’t exist
without supernovae.

Telescopes Can’t See Beyond the Surface

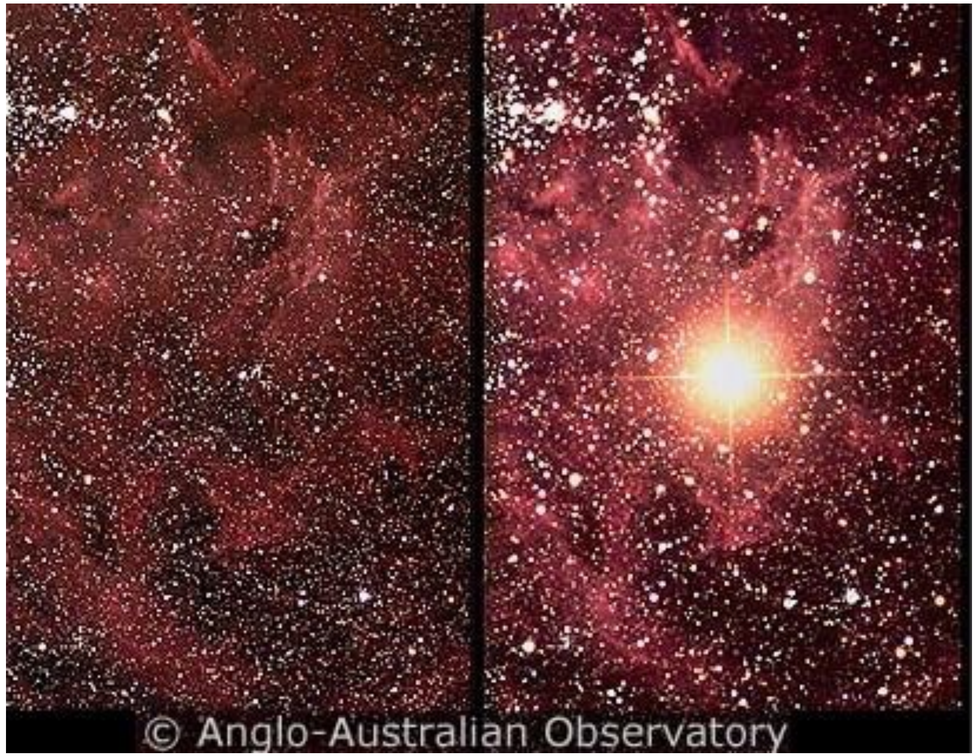


Luckily, most* supernovae produce **lots of neutrinos.**

* This talk ignores type Ia SNe.

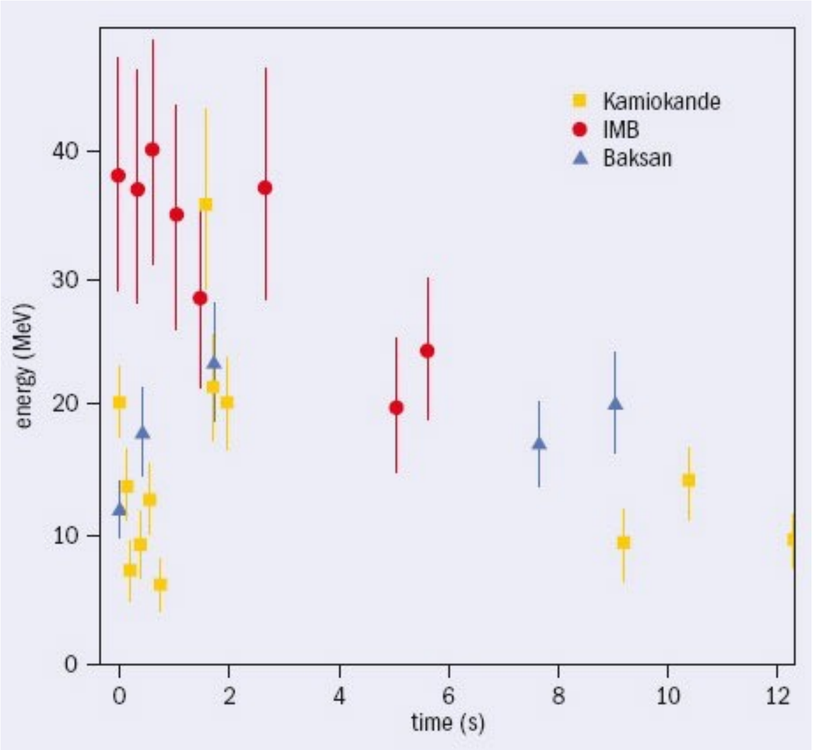
NASA/SDO: https://www.nasa.gov/mission_pages/sunearth/news/News021311-flare.html

What We Know ...

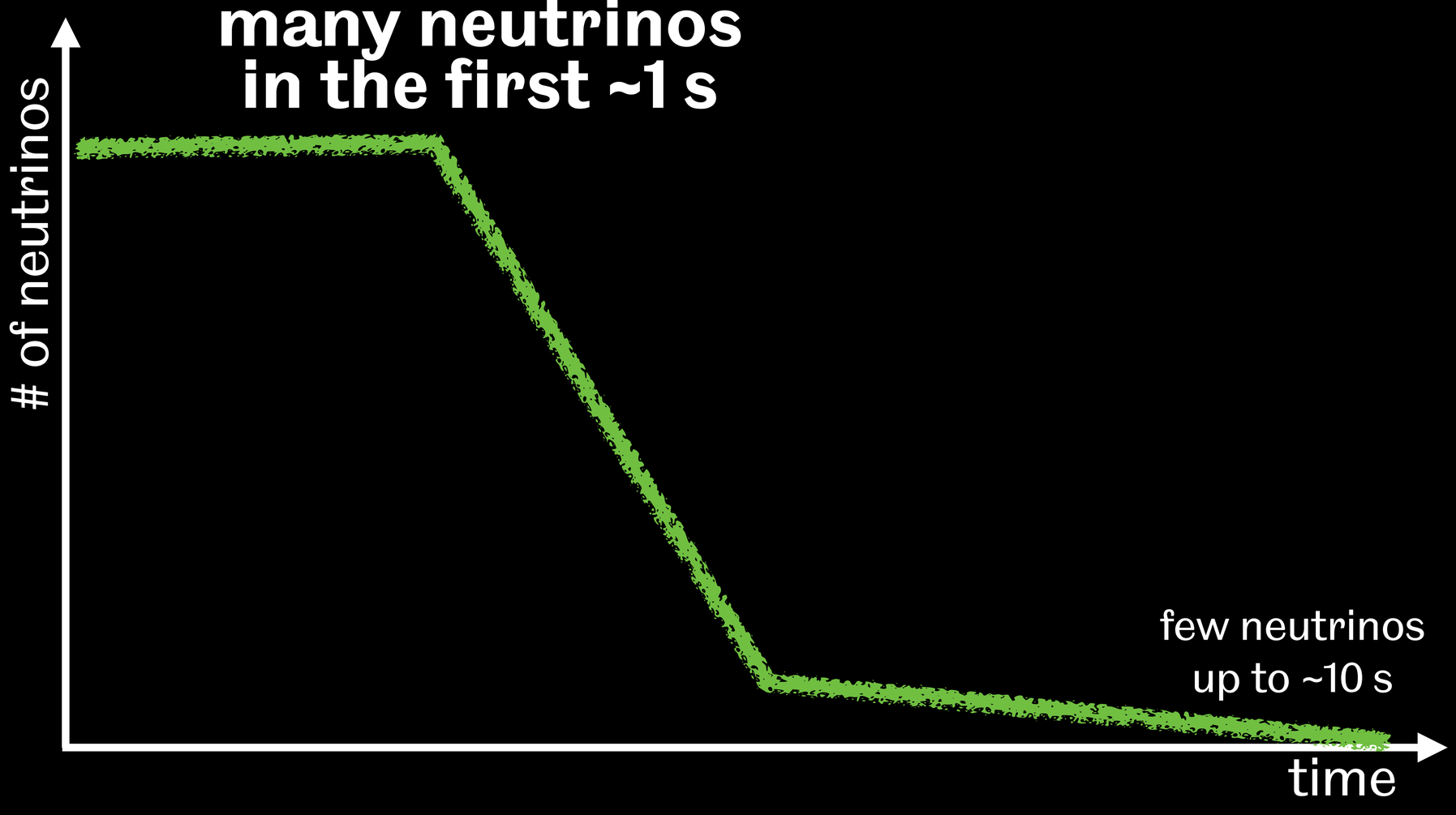


February 23, 1987: SN 1987A

Large Magellanic Cloud, ~160,000 light years

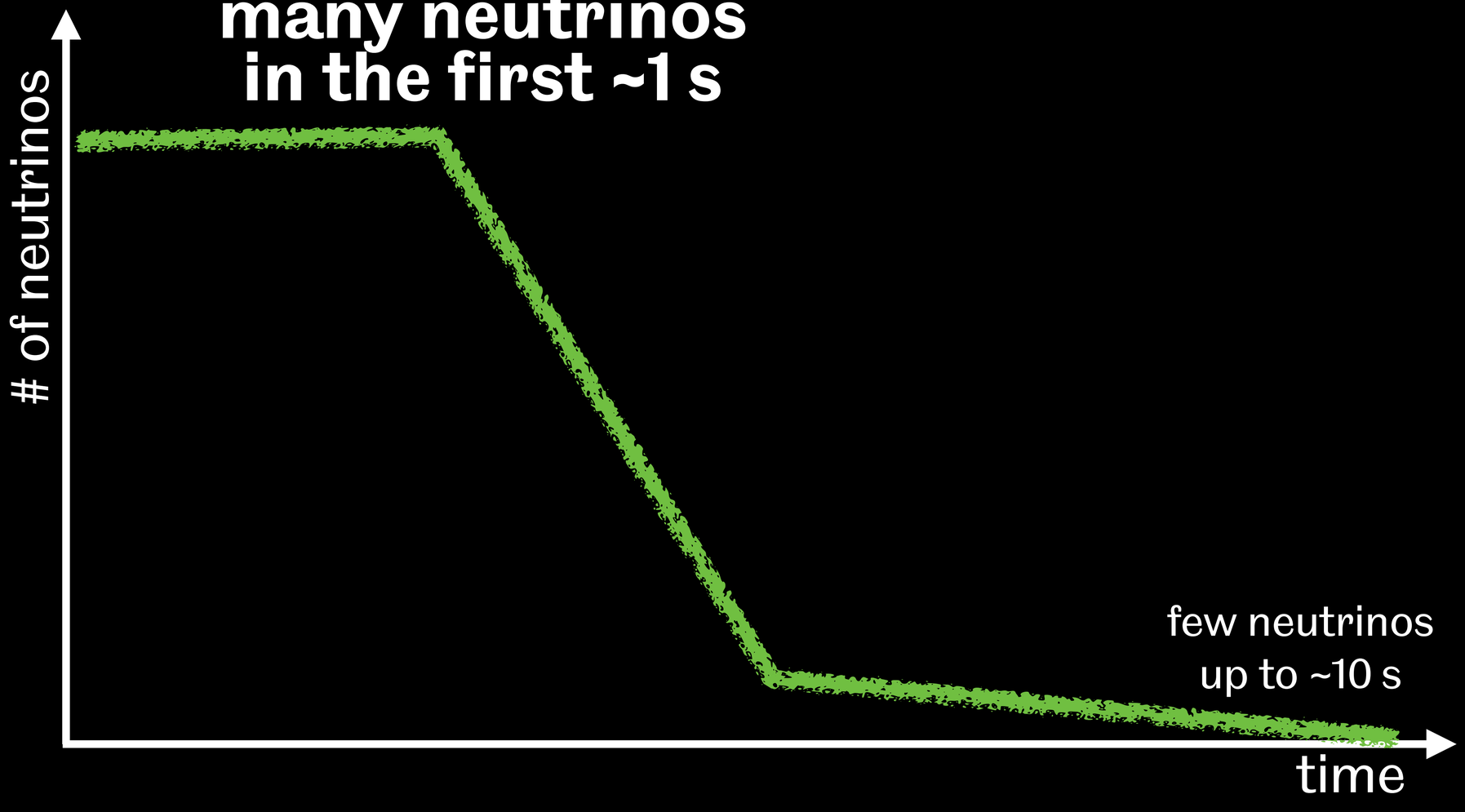


What We Know ...


many neutrinos
in the first ~1 s
# of neutrinos
few neutrinos
up to ~10 s
time

What We Know ...

✅ ~99% of energy ➔ neutrinos



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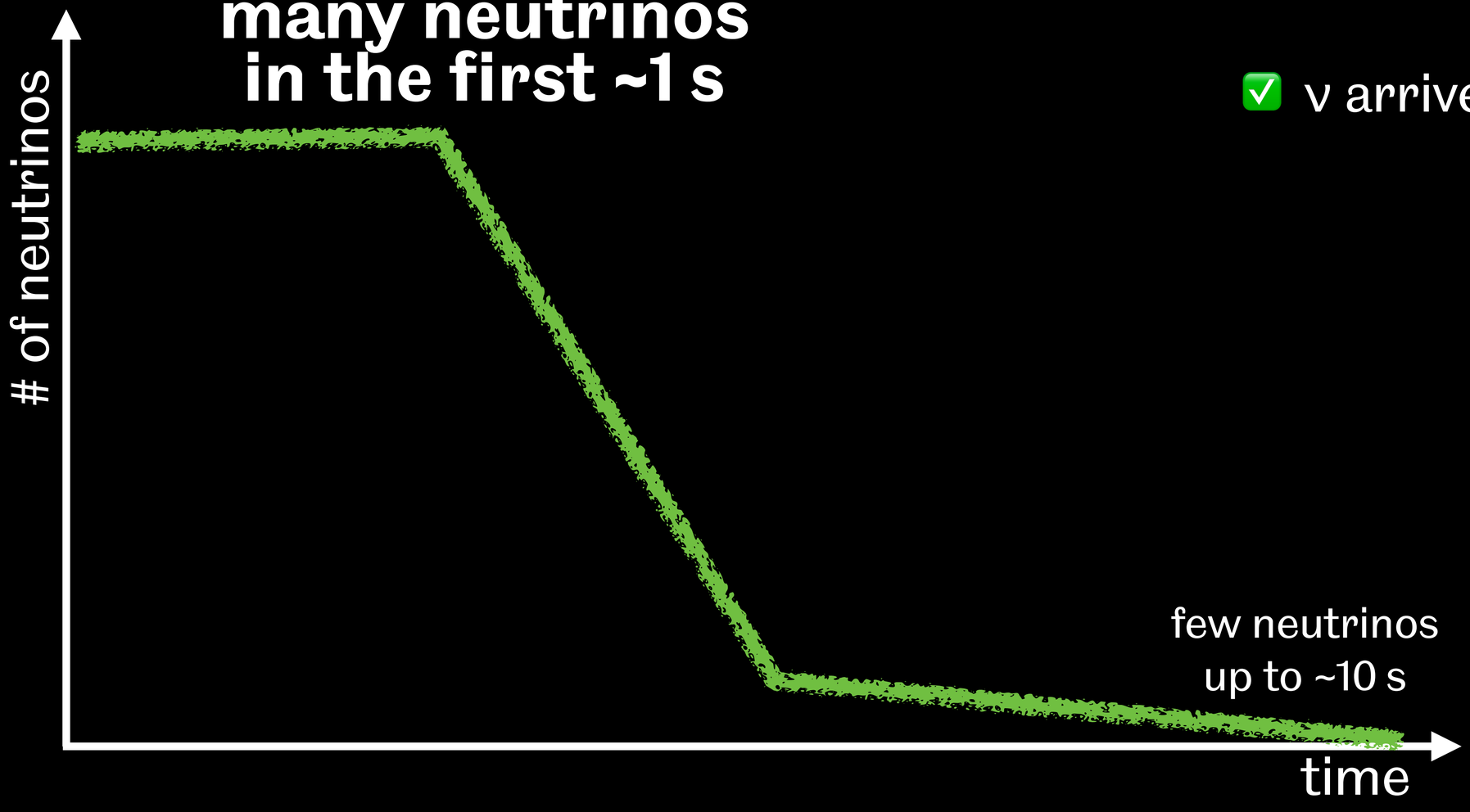
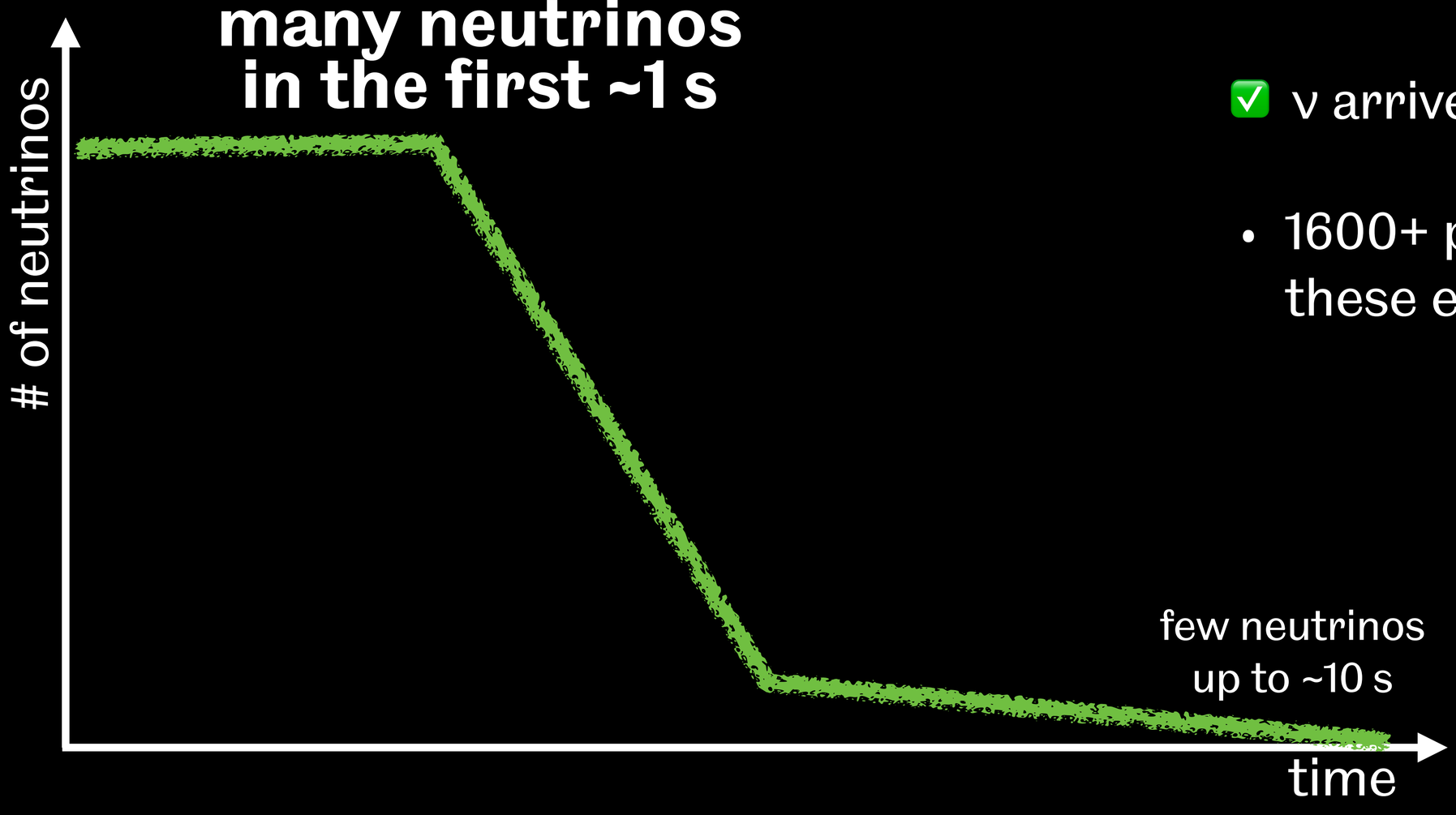


✅ ~99% of energy ➔ neutrinos

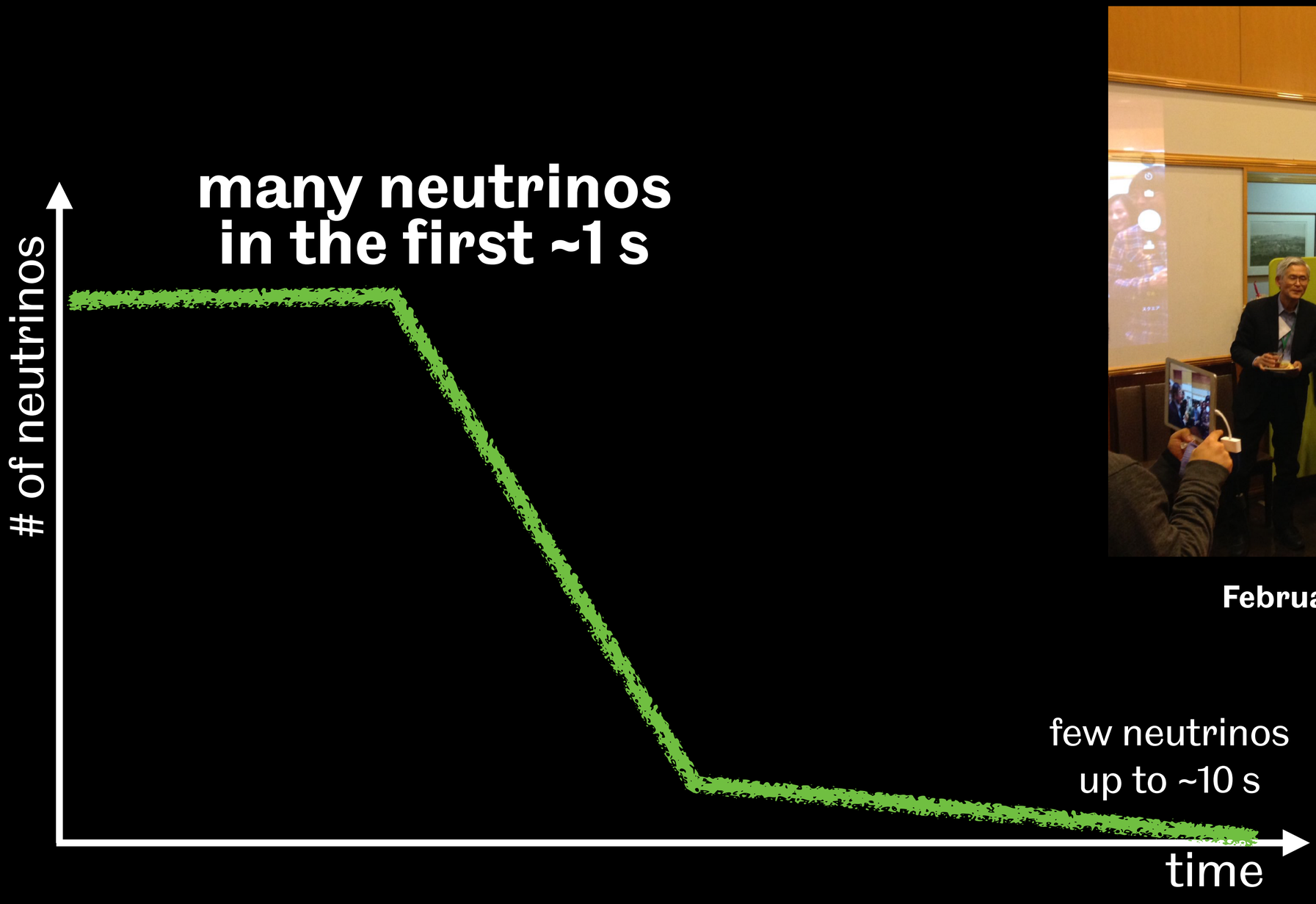
✅ ν arrive ~hours before light

What We Know ...



- ✅ ~99% of energy ➔ neutrinos
- ✅ ν arrive ~hours before light
- 1600+ papers written about these events

What We Know ...



February, 2017: 30th anniversary

Tokyo

What We Think We Know ...

- ... comes from computer simulations – which are *hard*!
  - all fundamental forces play a role
  - nonlinear hydrodynamics
  - relativistic (infall velocity: ~10% of c)
  - extreme conditions

What We Think We Know ...

- ... comes from computer simulations – which are *hard*!

> “There is a rather long list of numerical challenges and code verification issues [...]
> The results of different groups are still too far apart to lend ultimate credibility to any one of them.”
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> — Skinner, Burrows, Dolence (arXiv:1512.00113)

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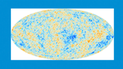
- Stars often don't explode in these simulations?
- Take any simulation results with a grain of salt!

The Life of a Star

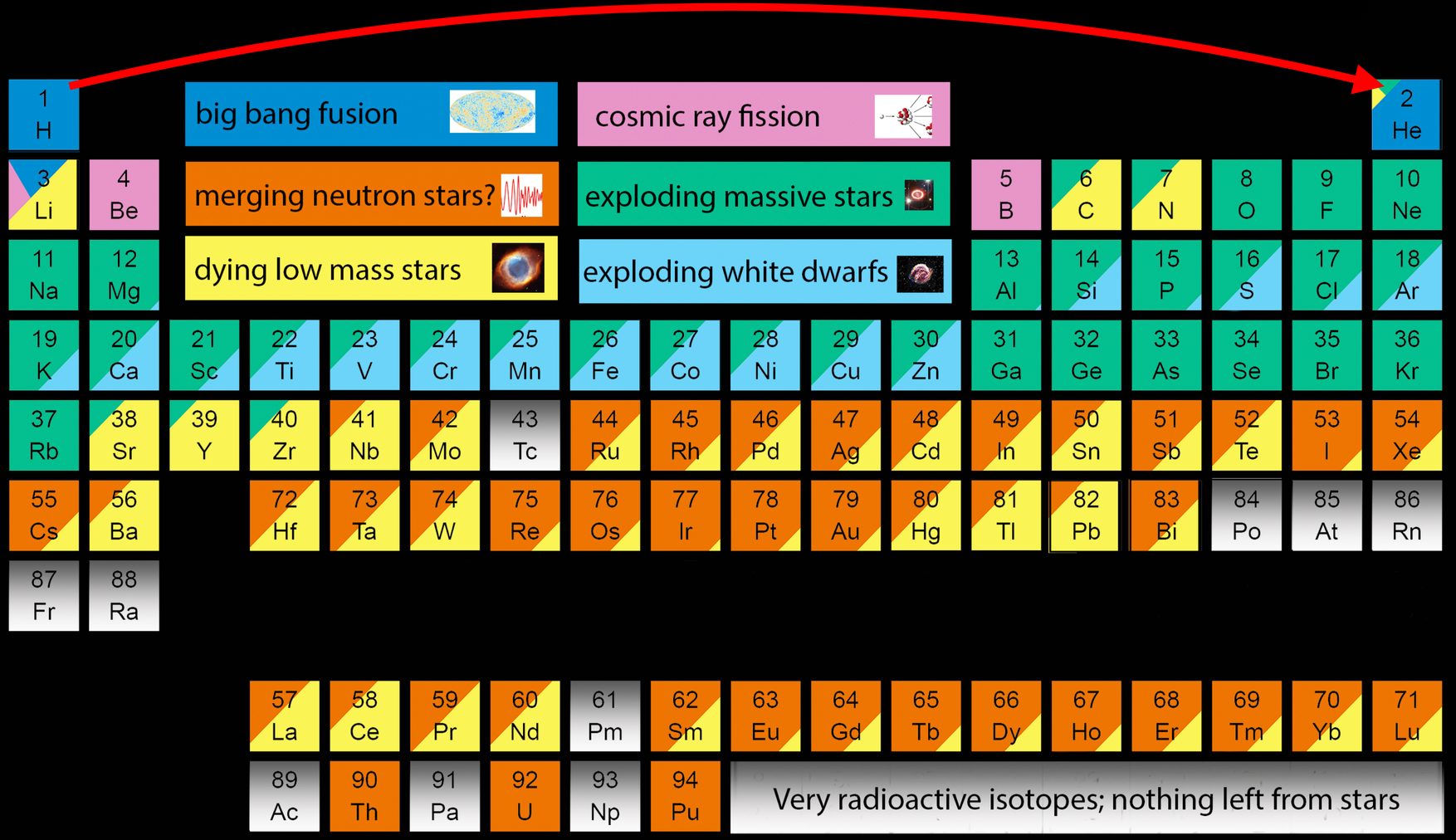
1 H		big bang fusion 					cosmic ray fission 										2 He
3 Li	4 Be	merging neutron stars? 					exploding massive stars 					5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	dying low mass stars 					exploding white dwarfs 					13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra																

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	Very radioactive isotopes; nothing left from stars							

Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
ESA/NASA/AASNova

The Life of a Star



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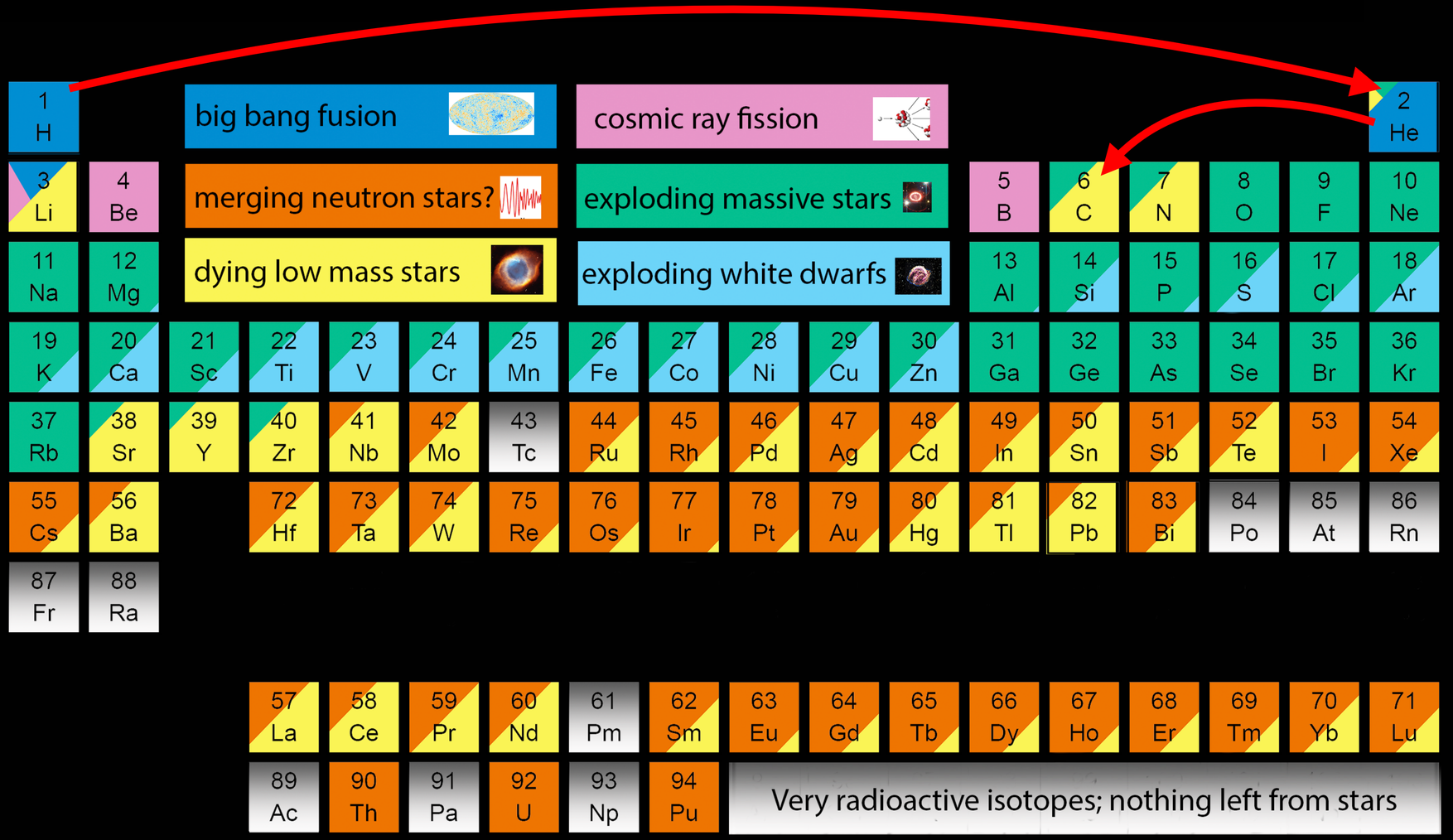
The Life of a Star



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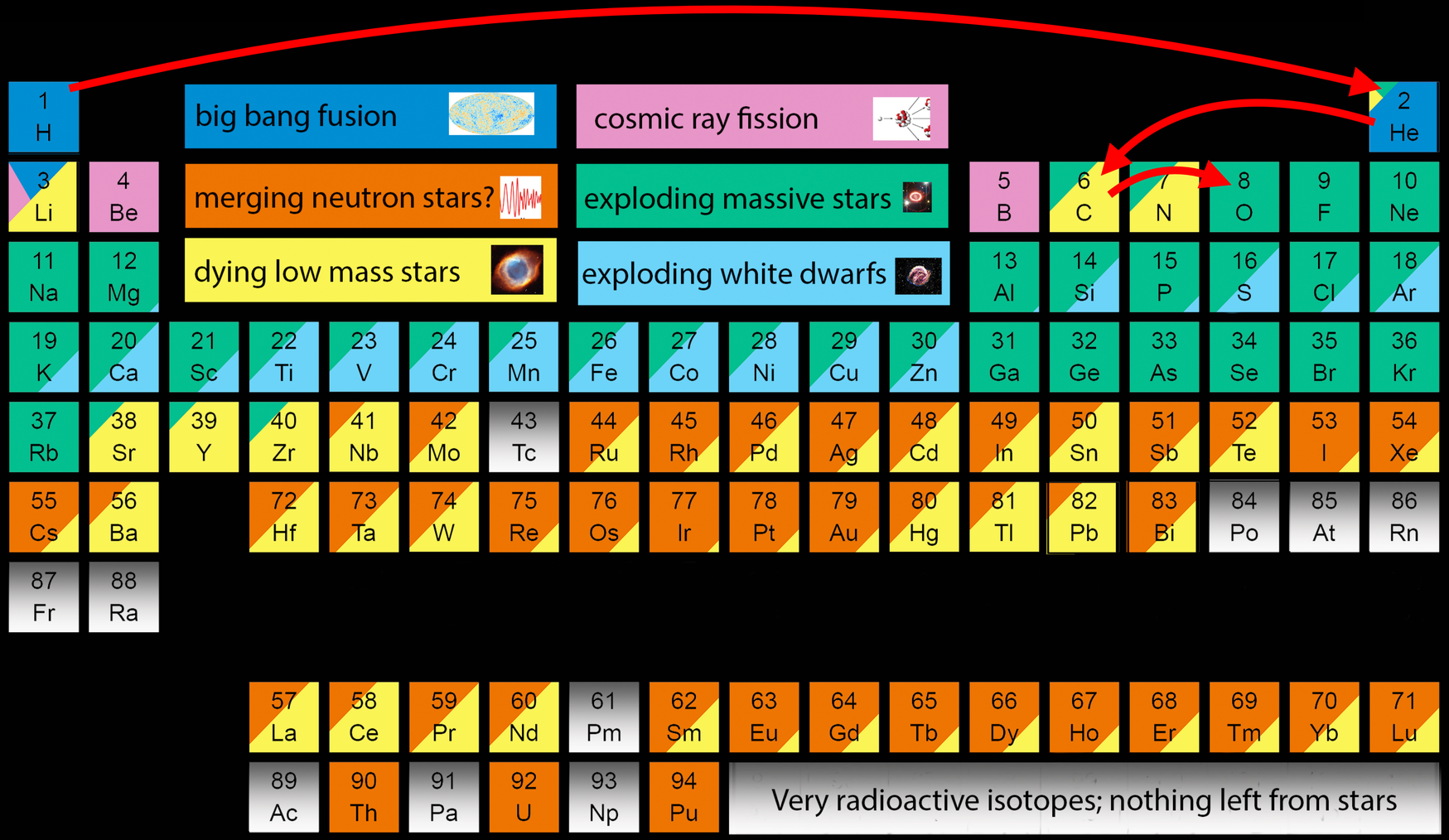

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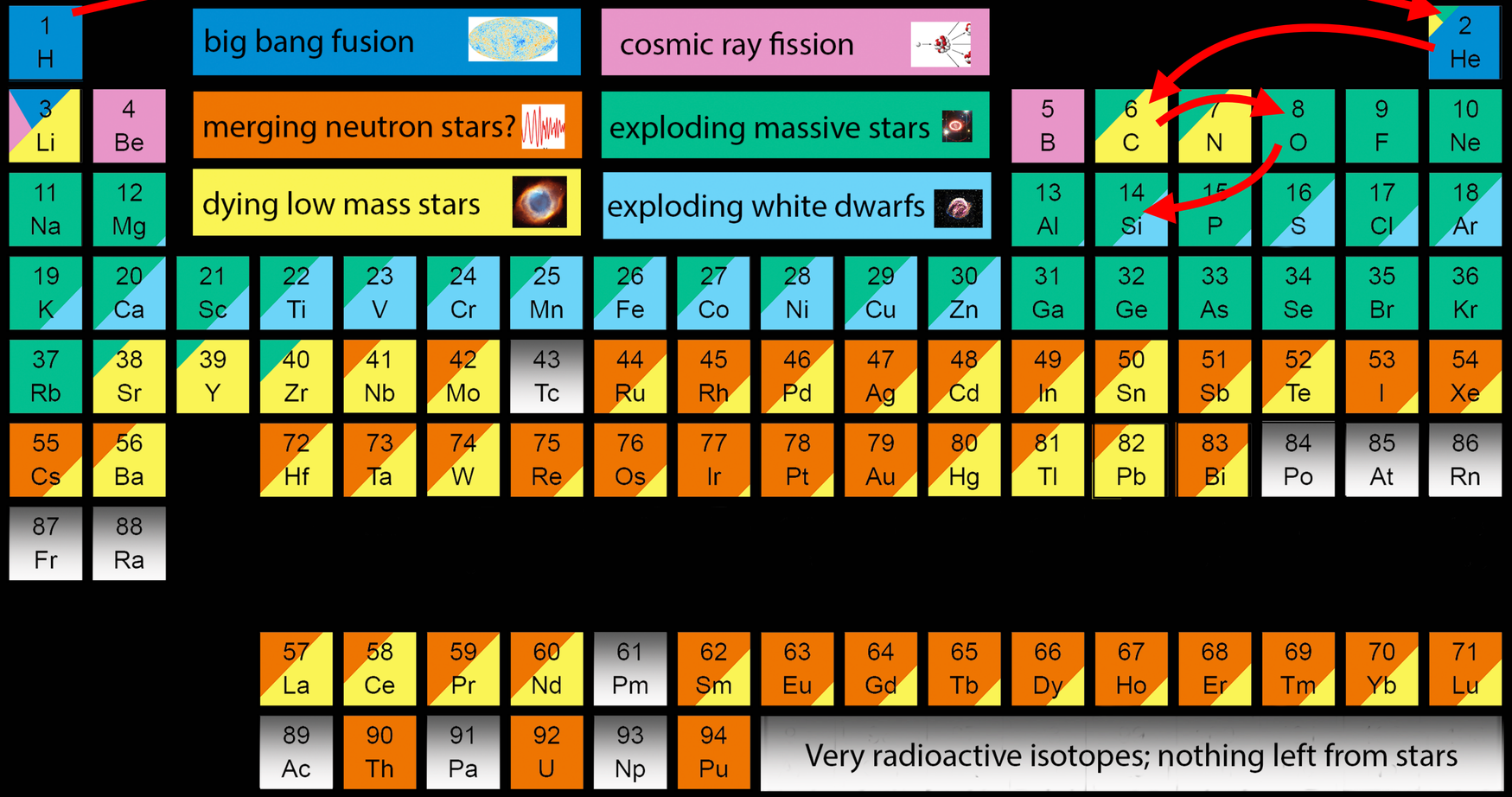

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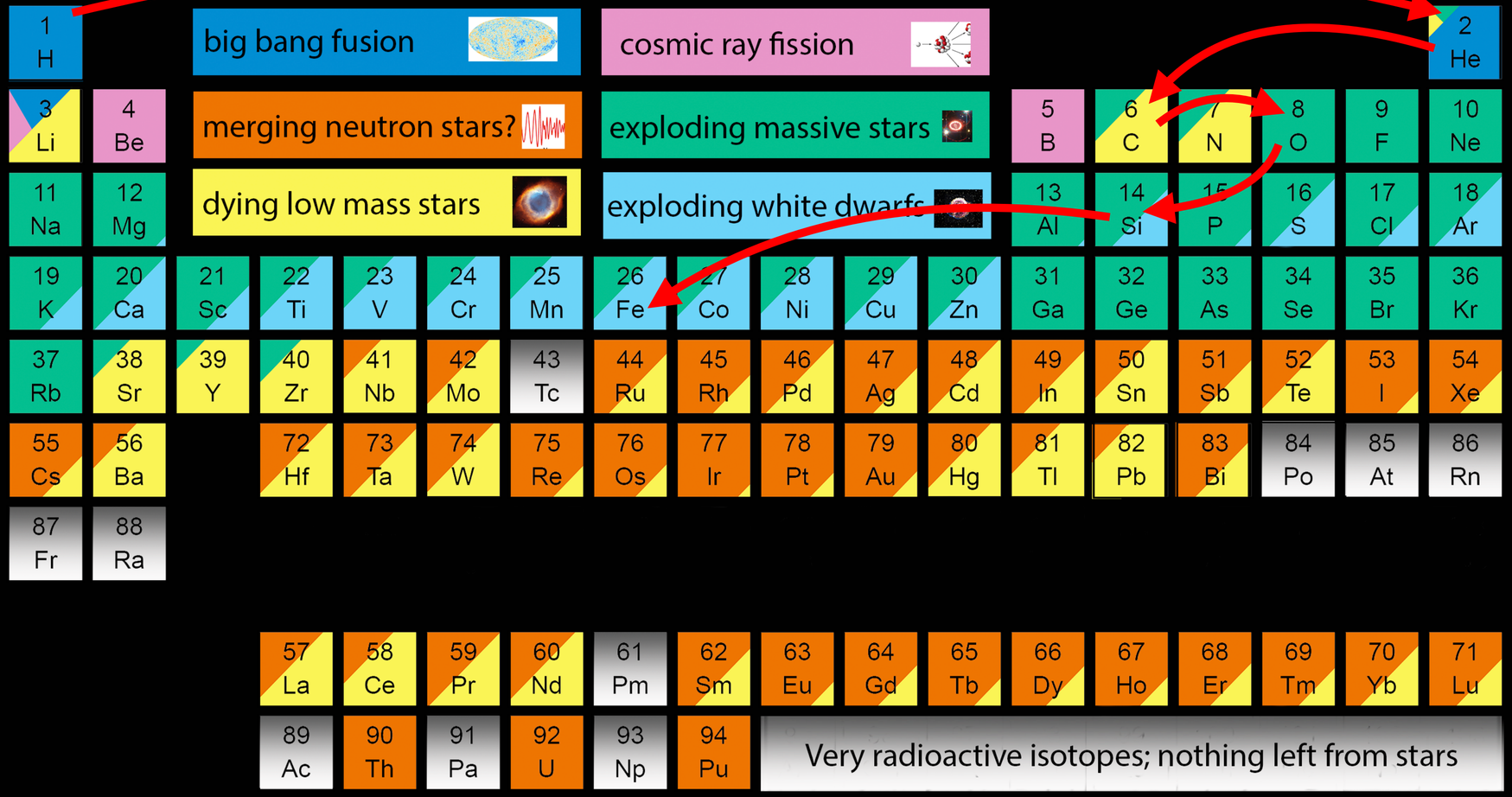

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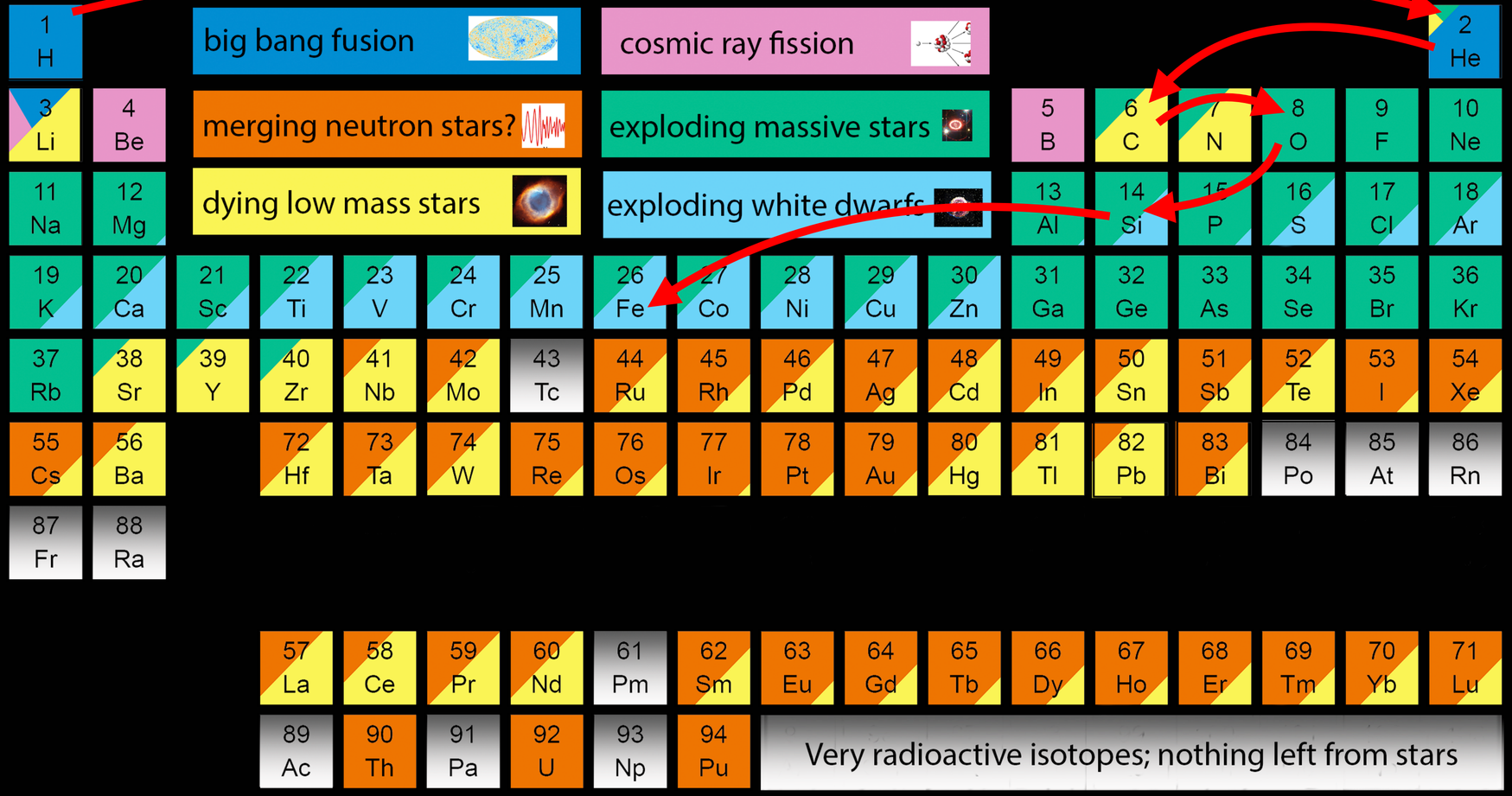
The ~~Life~~ Death of a Star



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Note:

The following slides rely heavily on animations and won't make any sense without them.

If possible, please watch the video.

sorry about that …

😉

1) The Core Collapses

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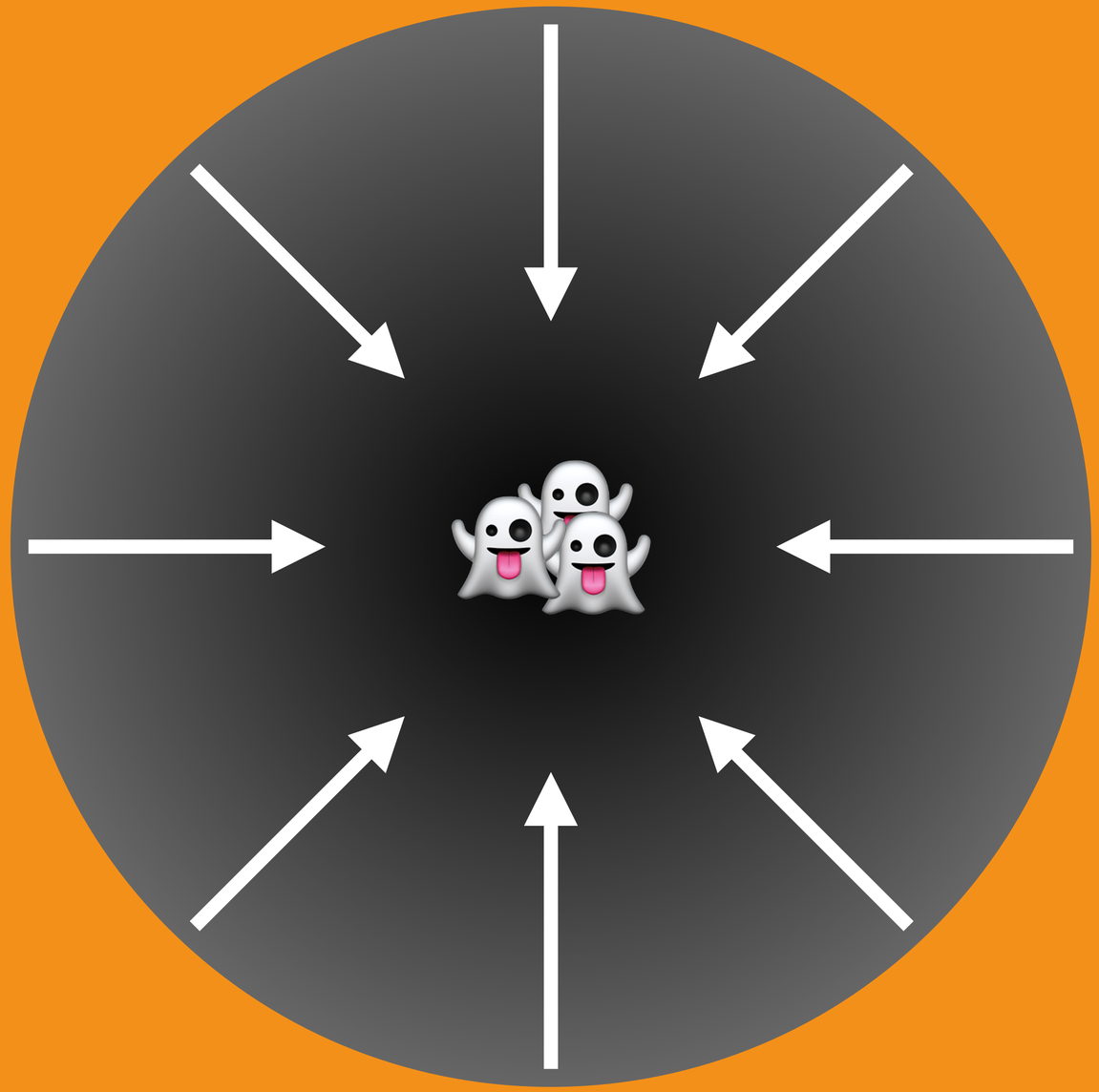

2) A Shock Wave Forms ...

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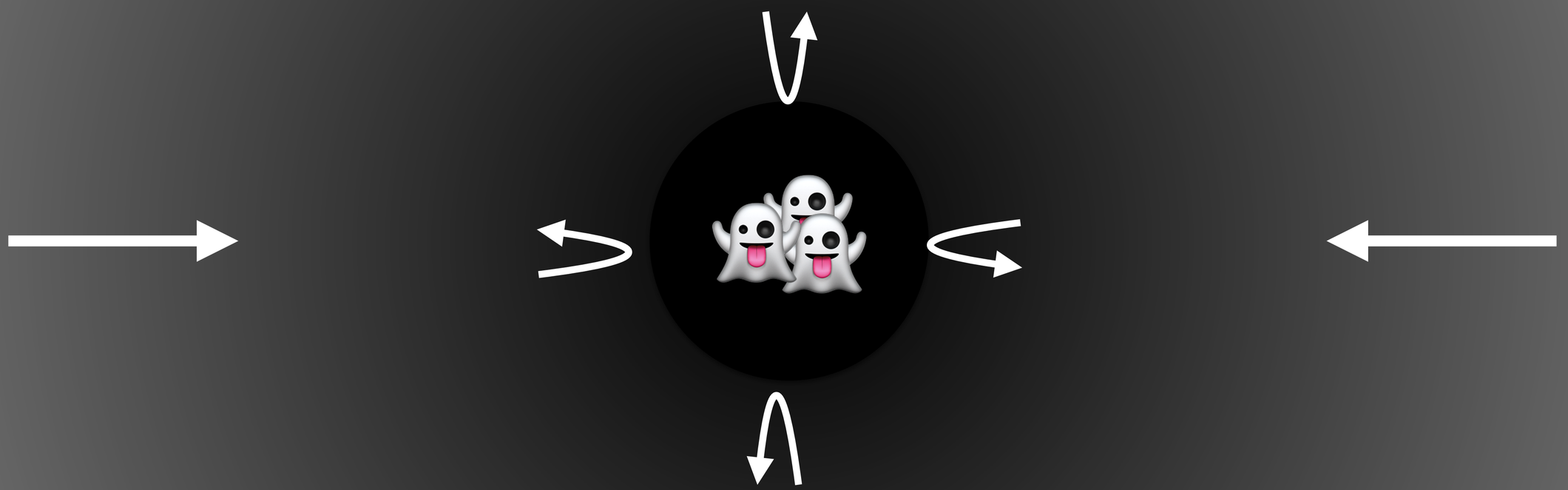

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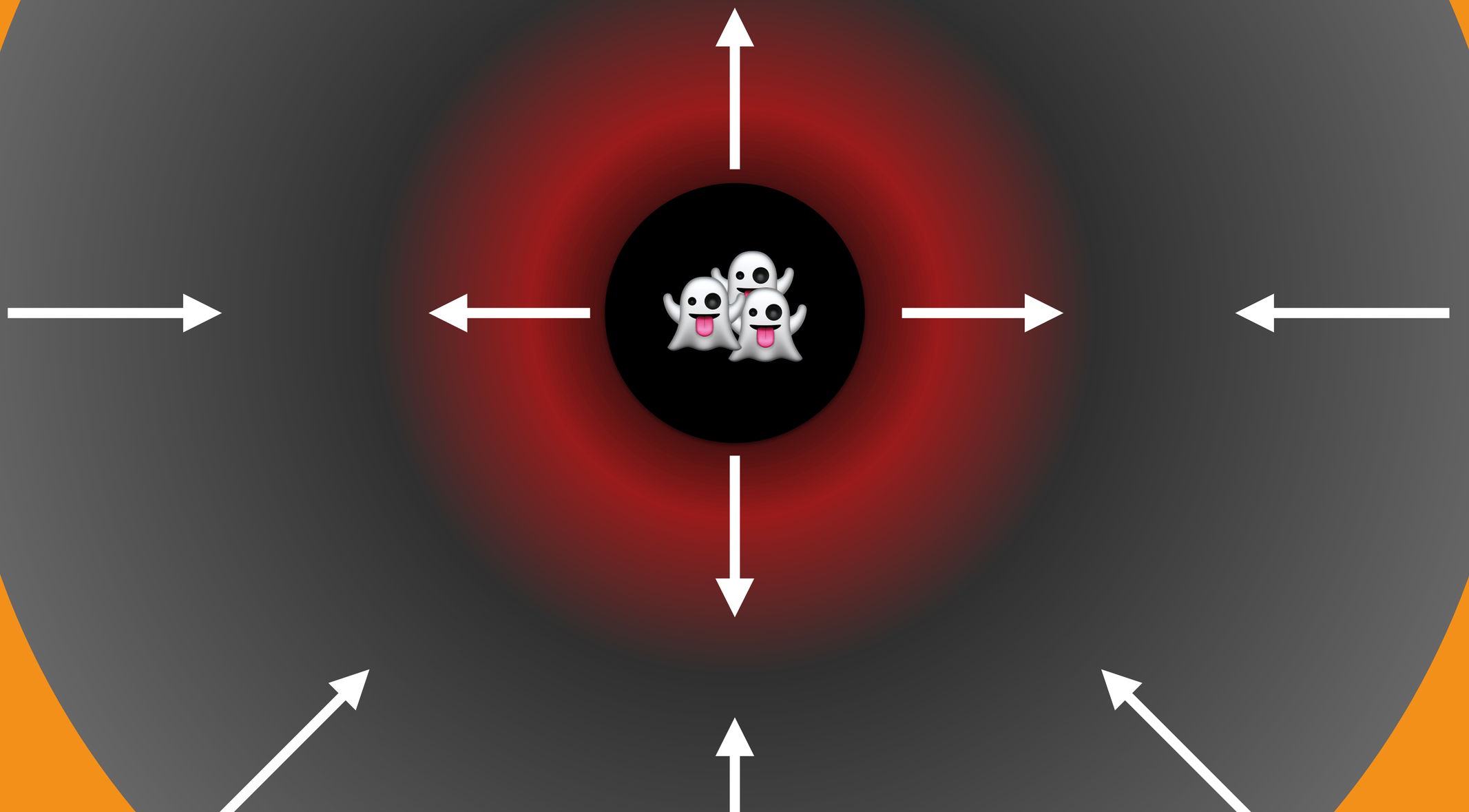

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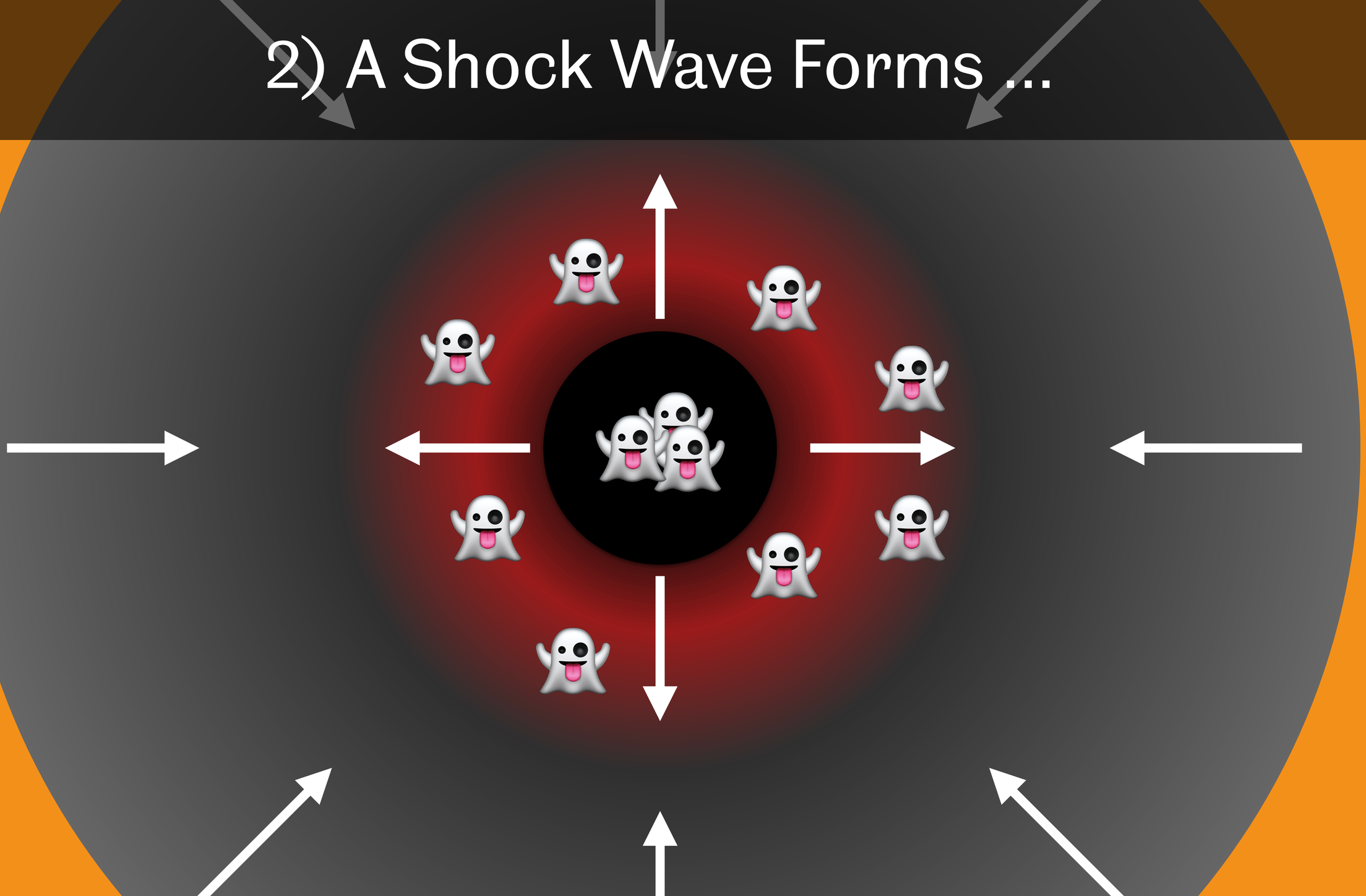

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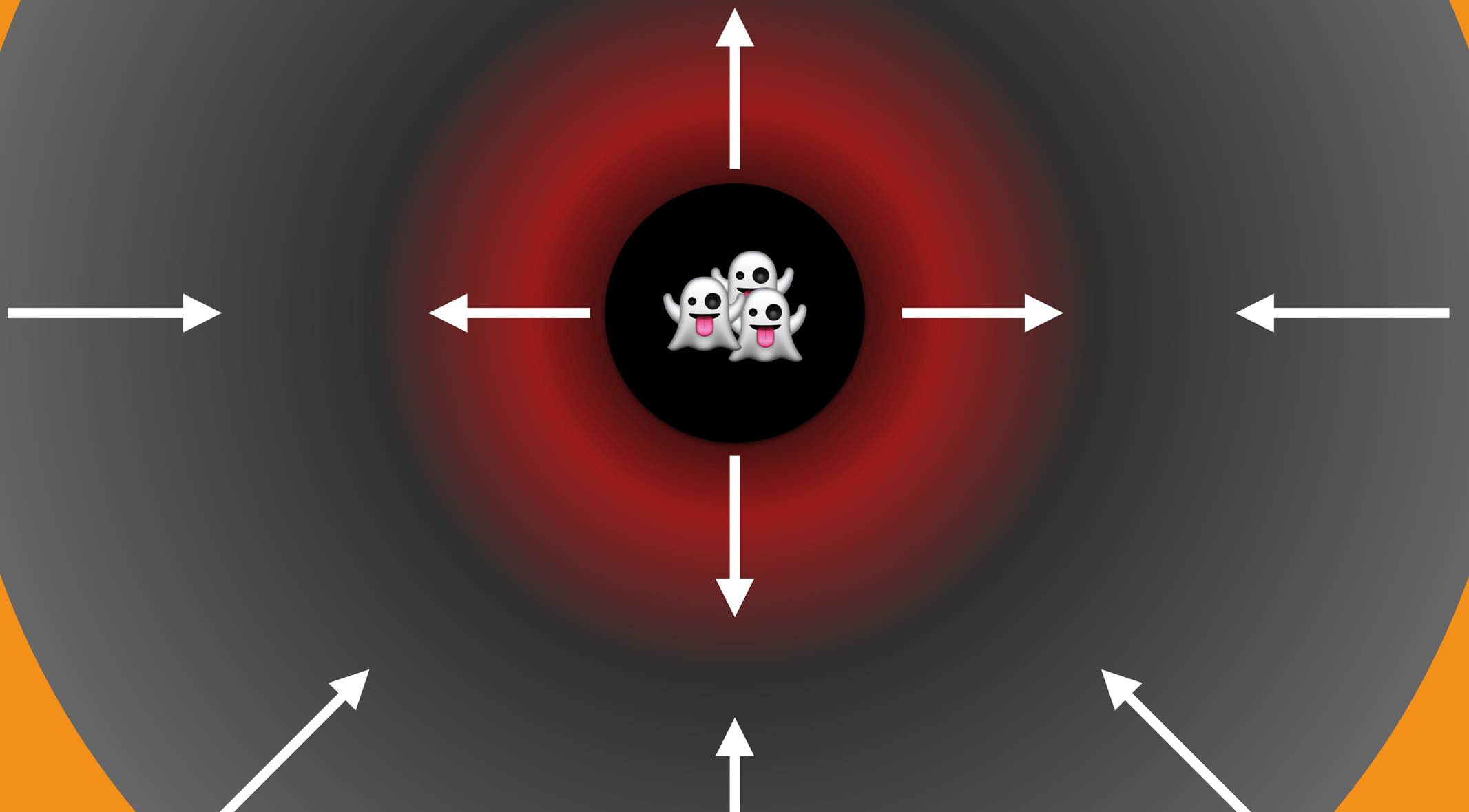
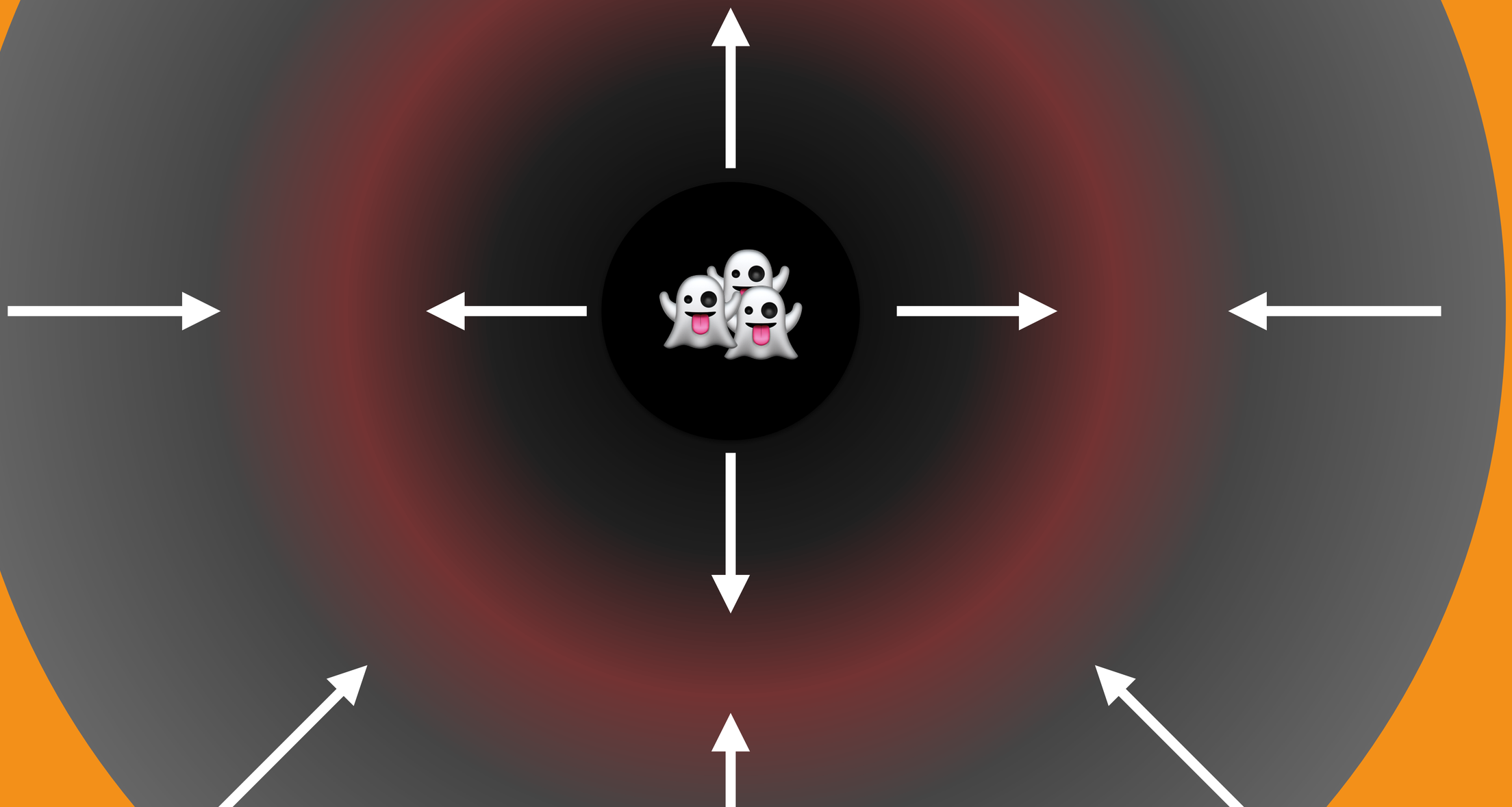
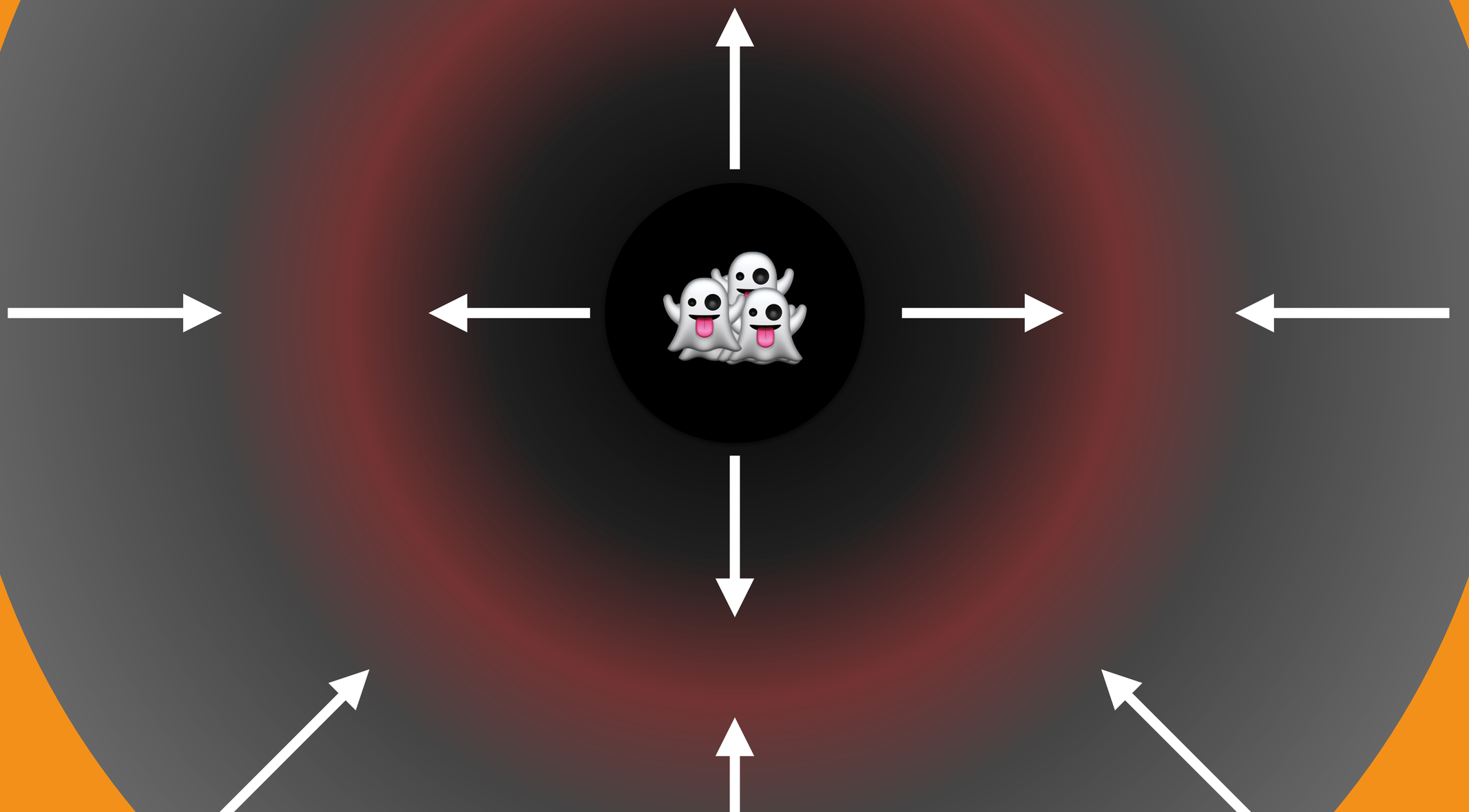


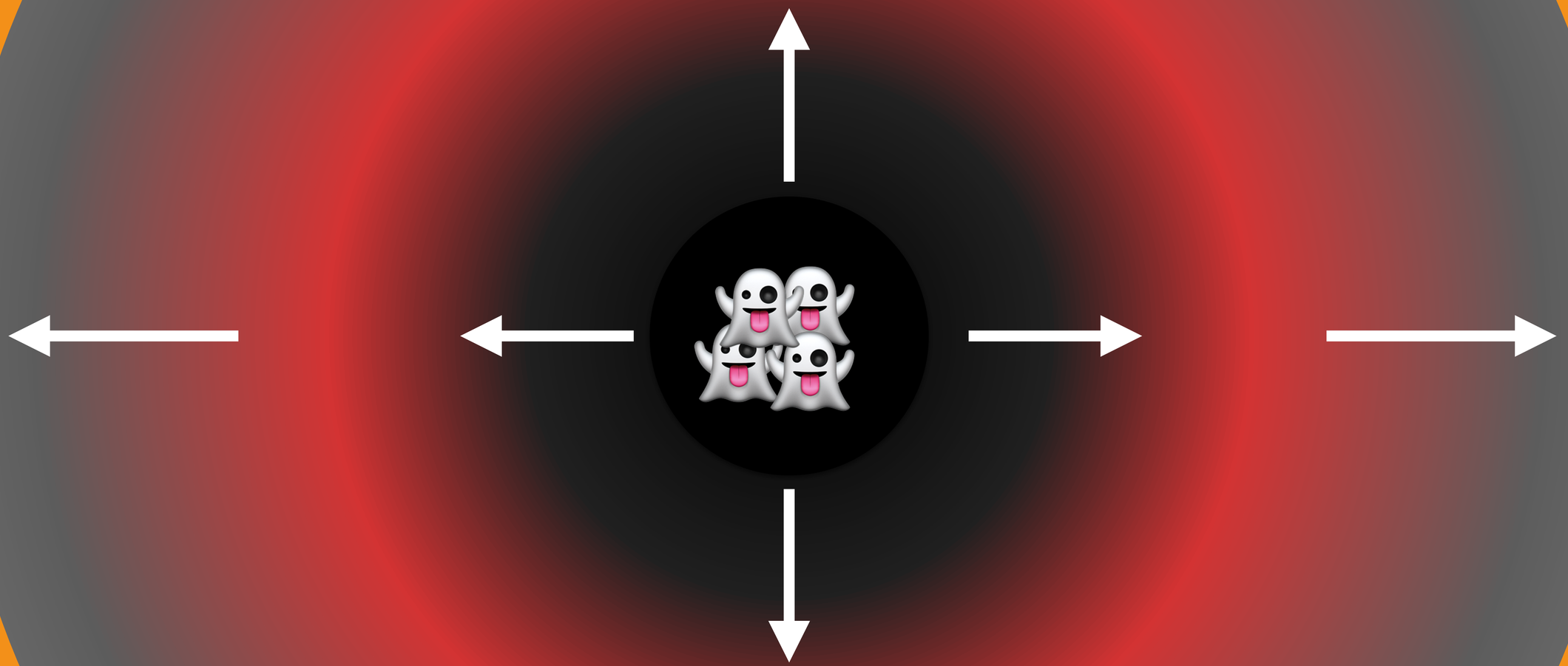
3) ... Slows Down ...



4) ... and Gets Revived



5) The Star Explodes



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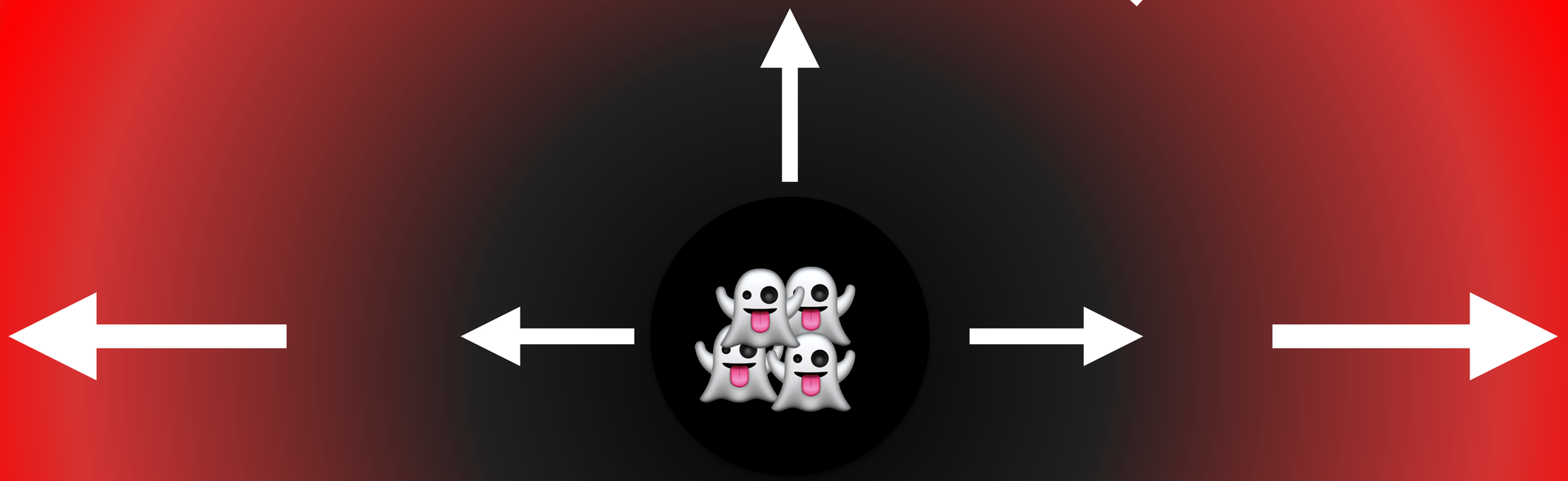

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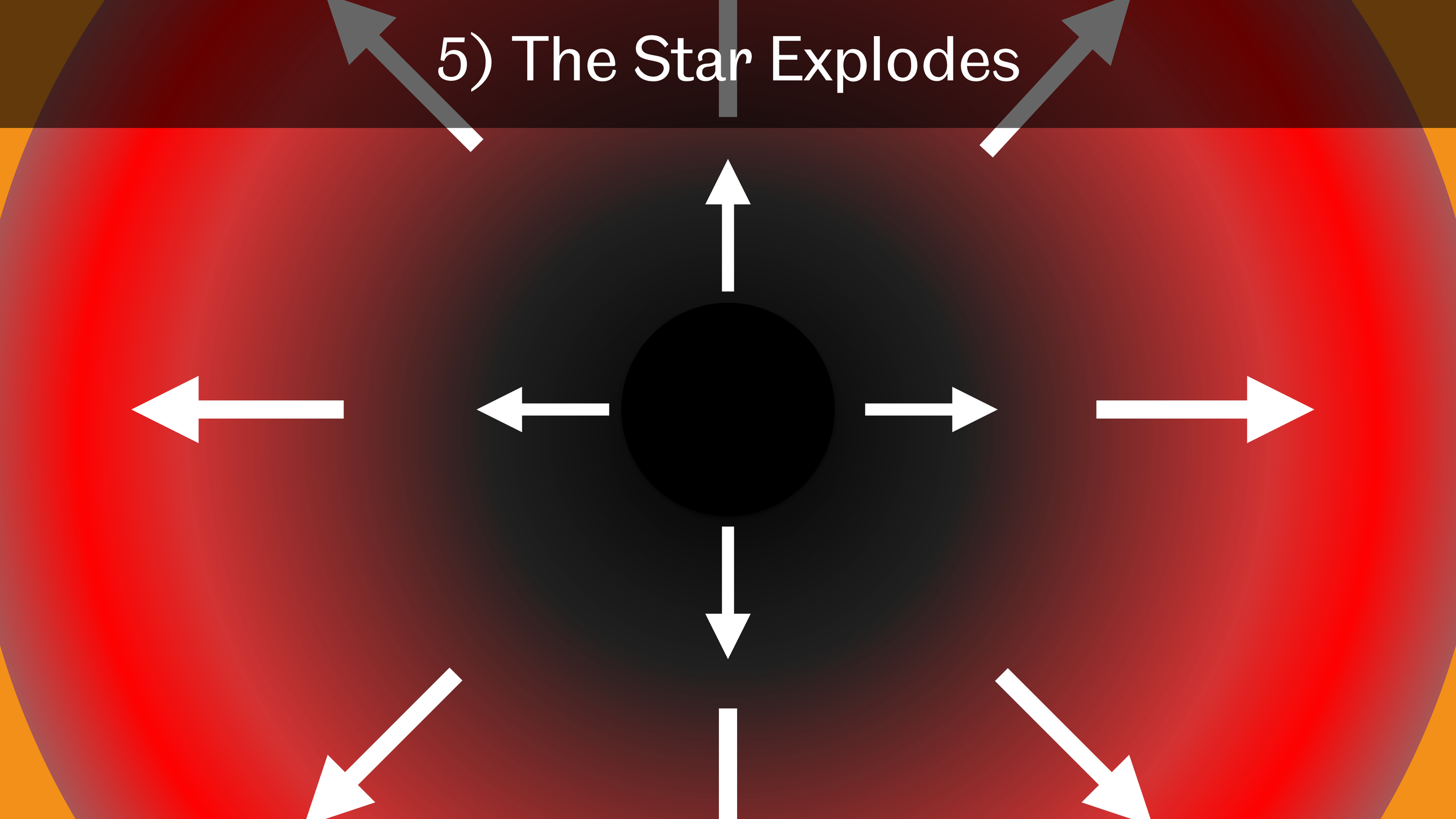
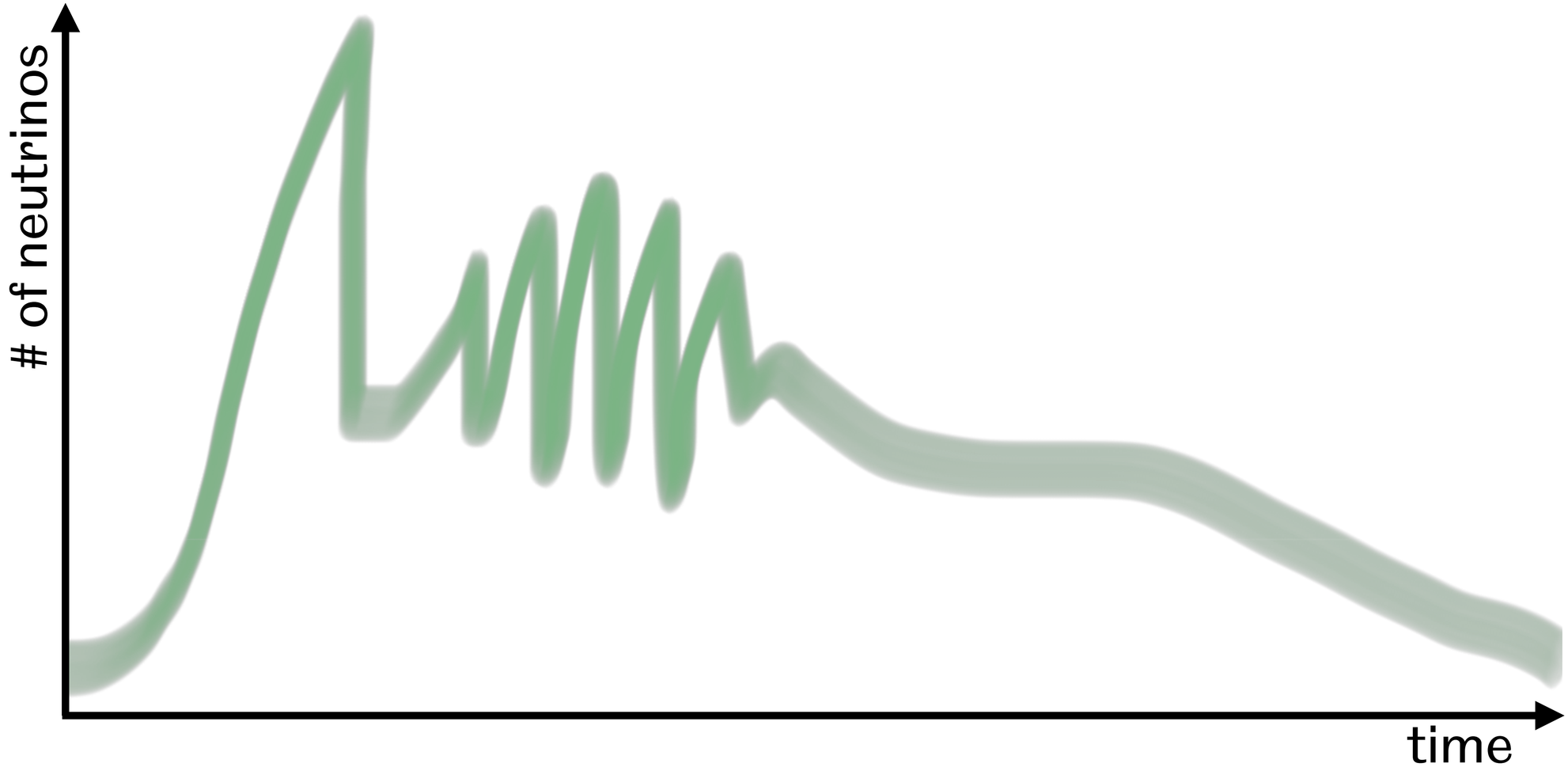


What Might We See?



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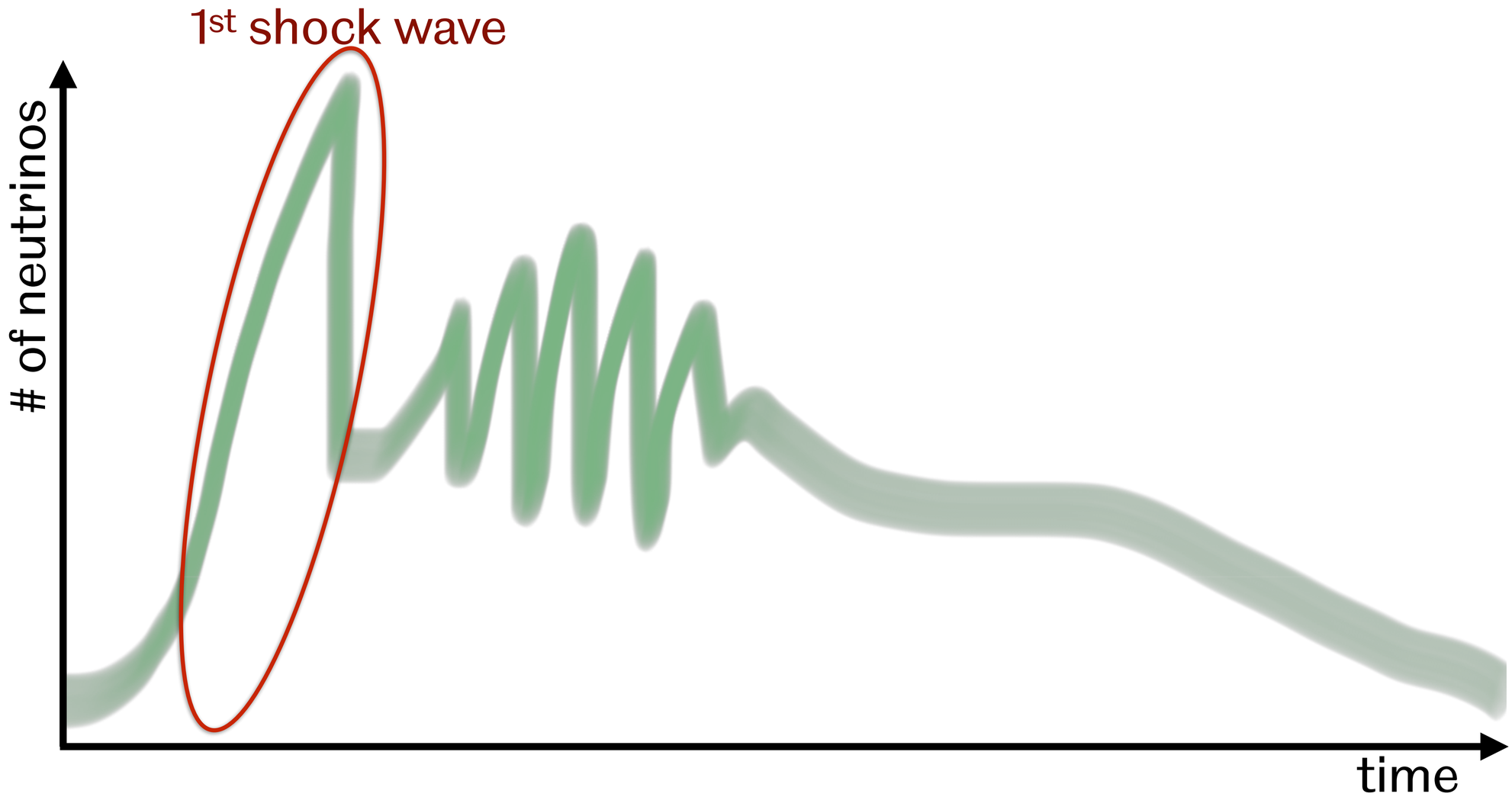

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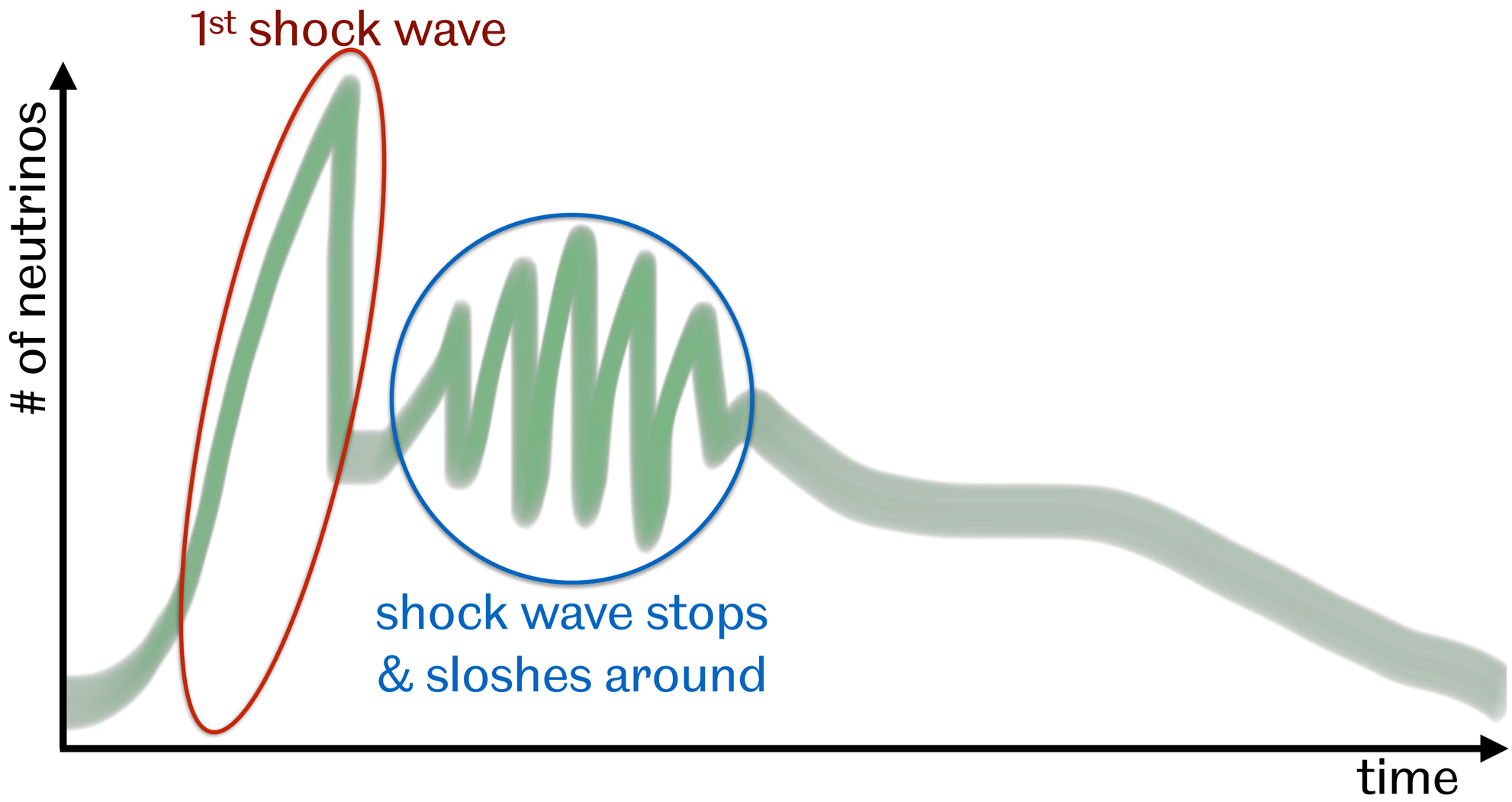

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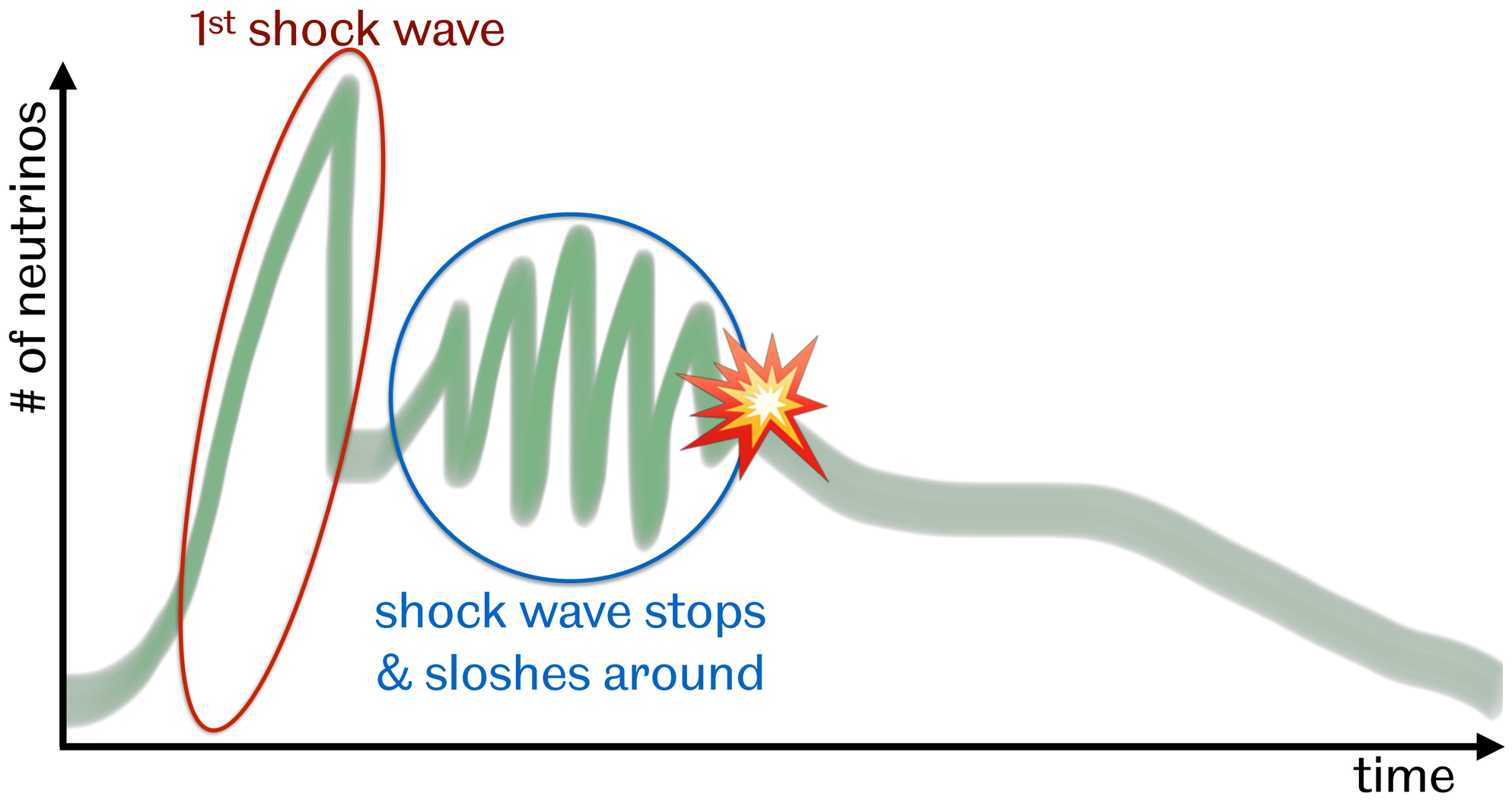

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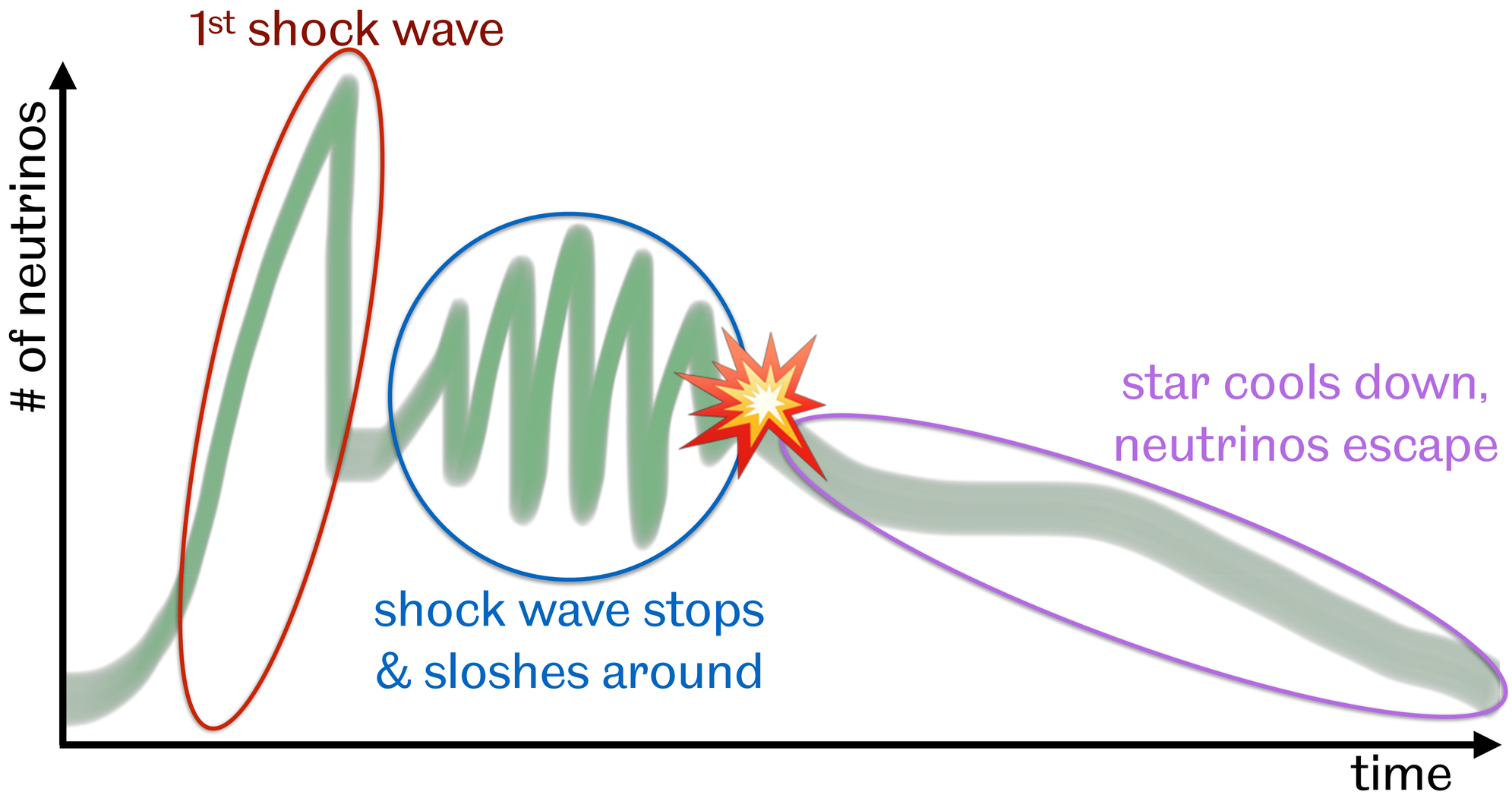
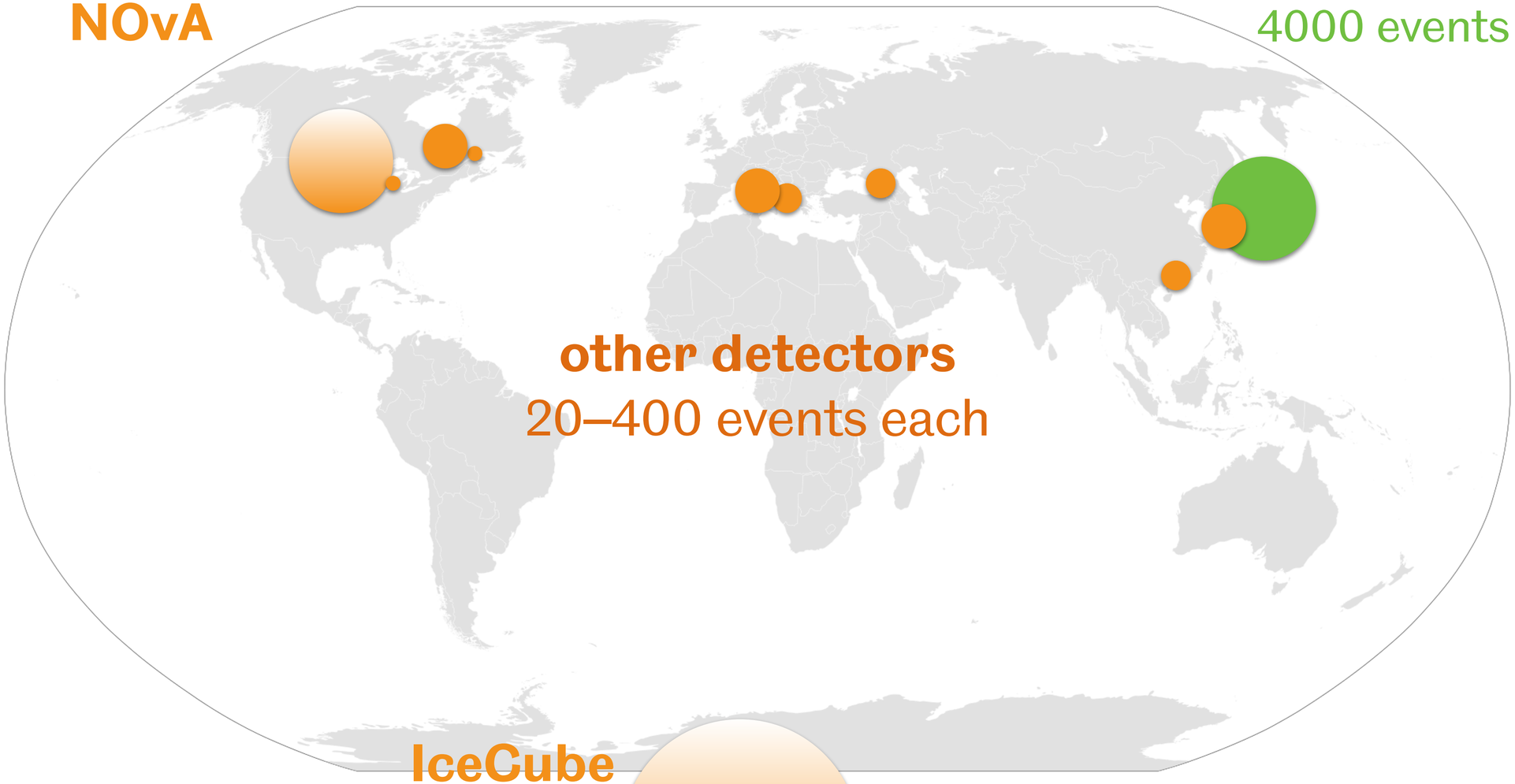


Supernova Neutrino Detectors



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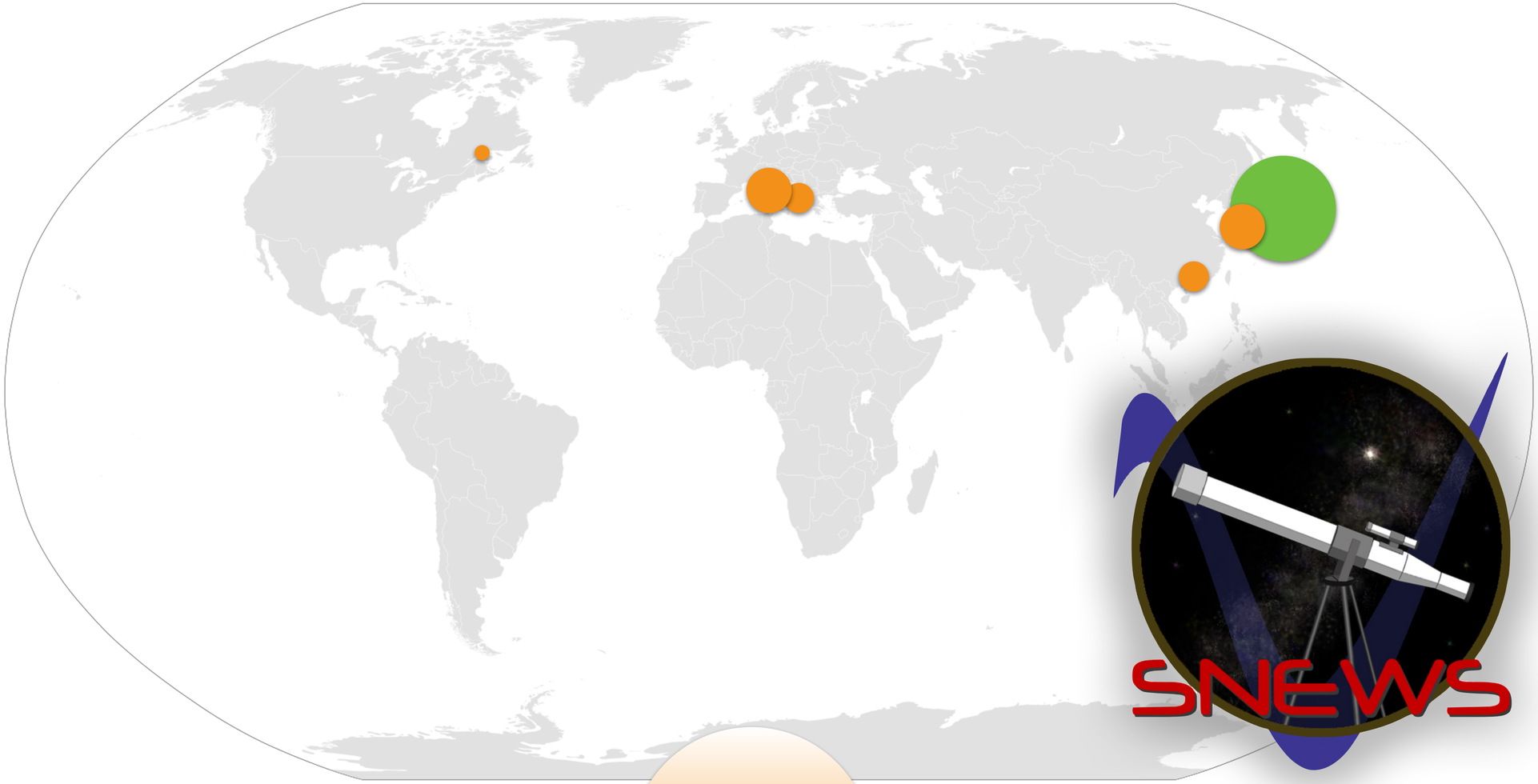
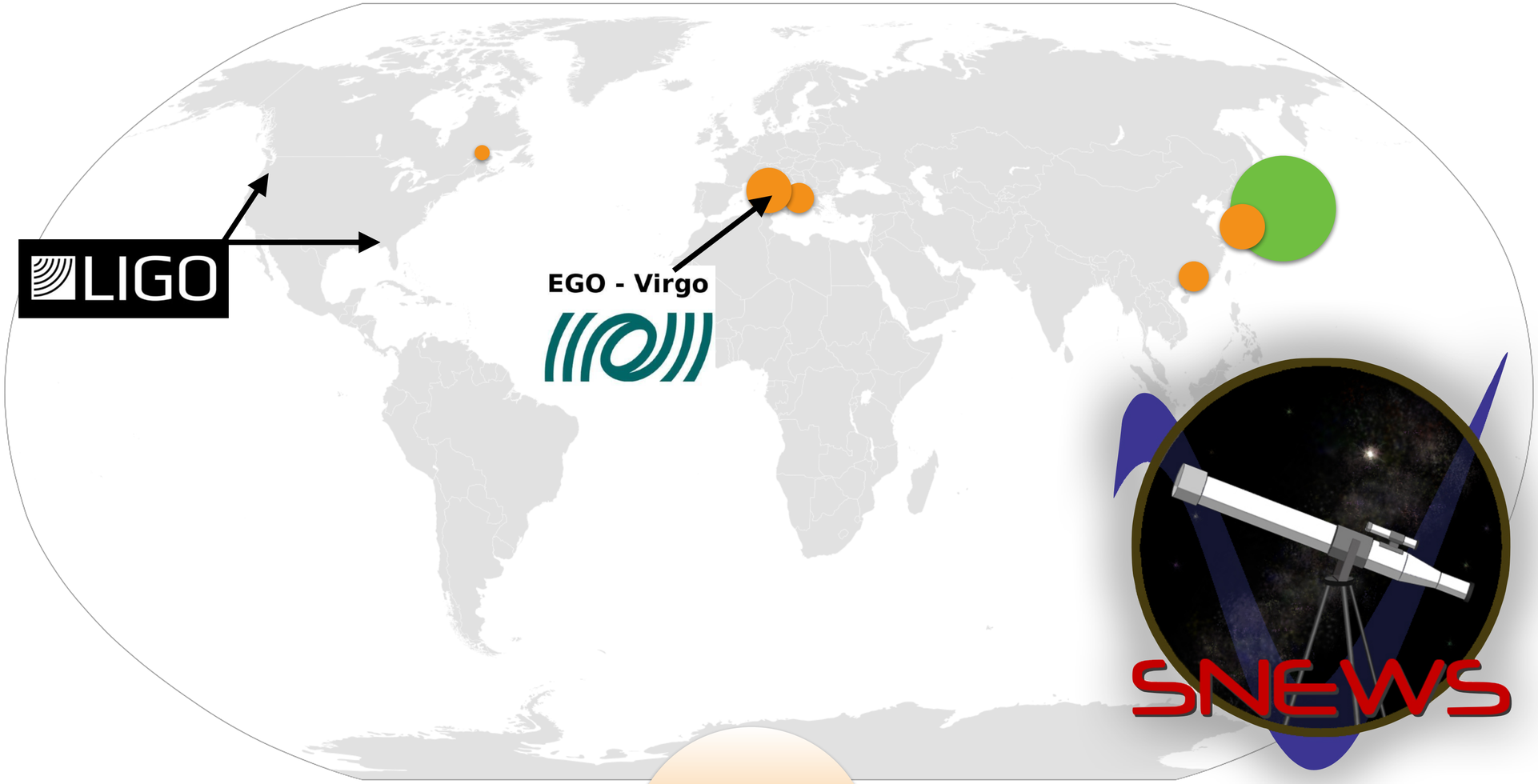


snews.bnl.gov/alert.html

Supernova Neutrino Detectors



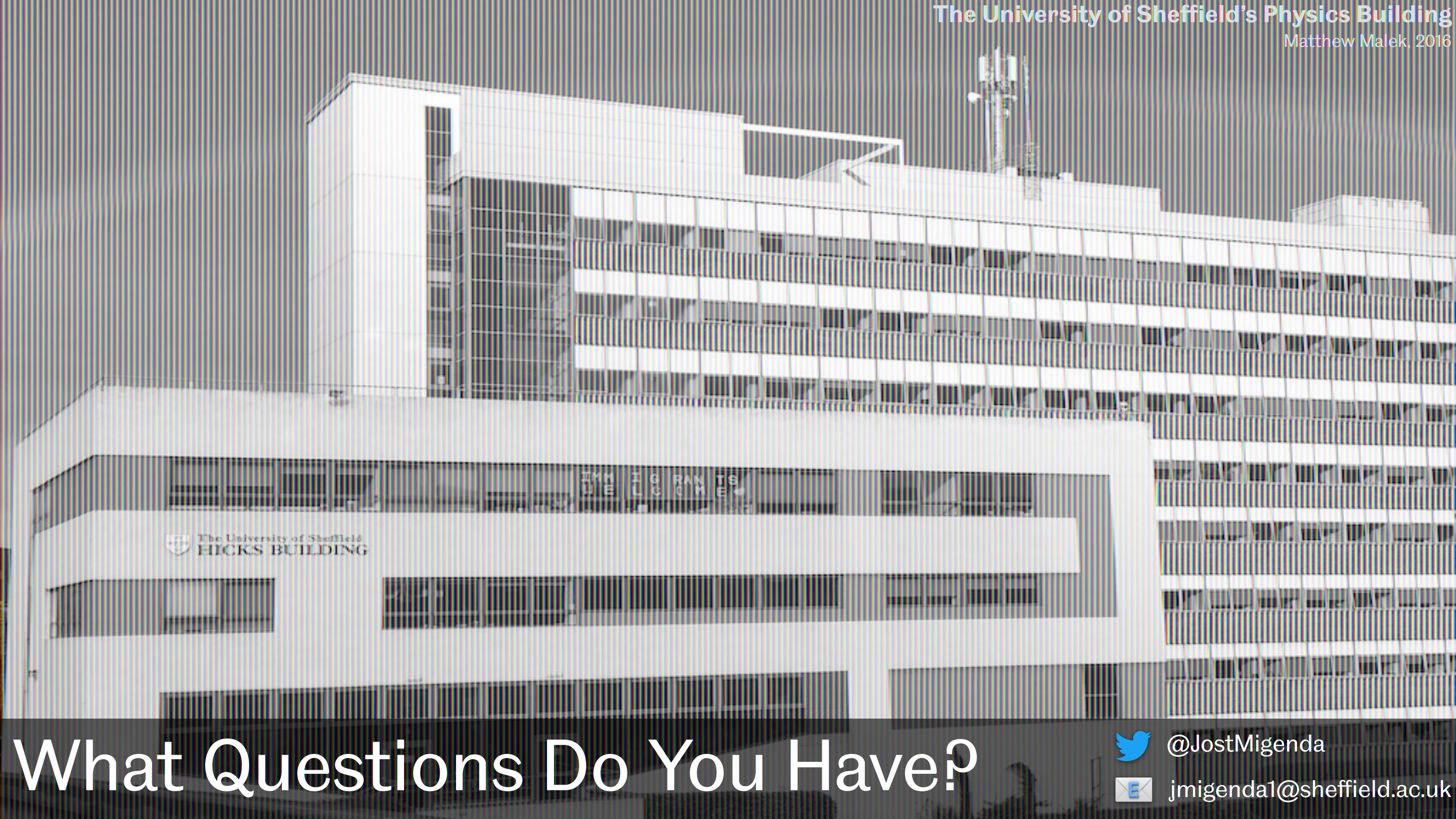
snews.bnl.gov/alert.html

Supernova Neutrino Detectors

snews.bnl.gov/alert.html

Summary

- Neutrinos are “ghost-like” elementary particles
- A glimpse behind the scenes of a next-gen neutrino detector: Hyper-Kamiokande
- Can observe things that can’t be observed directly through any other means
  - energy production inside our Sun
  - how stars explode



The University of Sheffield's Physics Building
Matthew Malek, 2016

What Questions Do You Have?

@JostMigenda
jmigenda1@sheffield.ac.uk