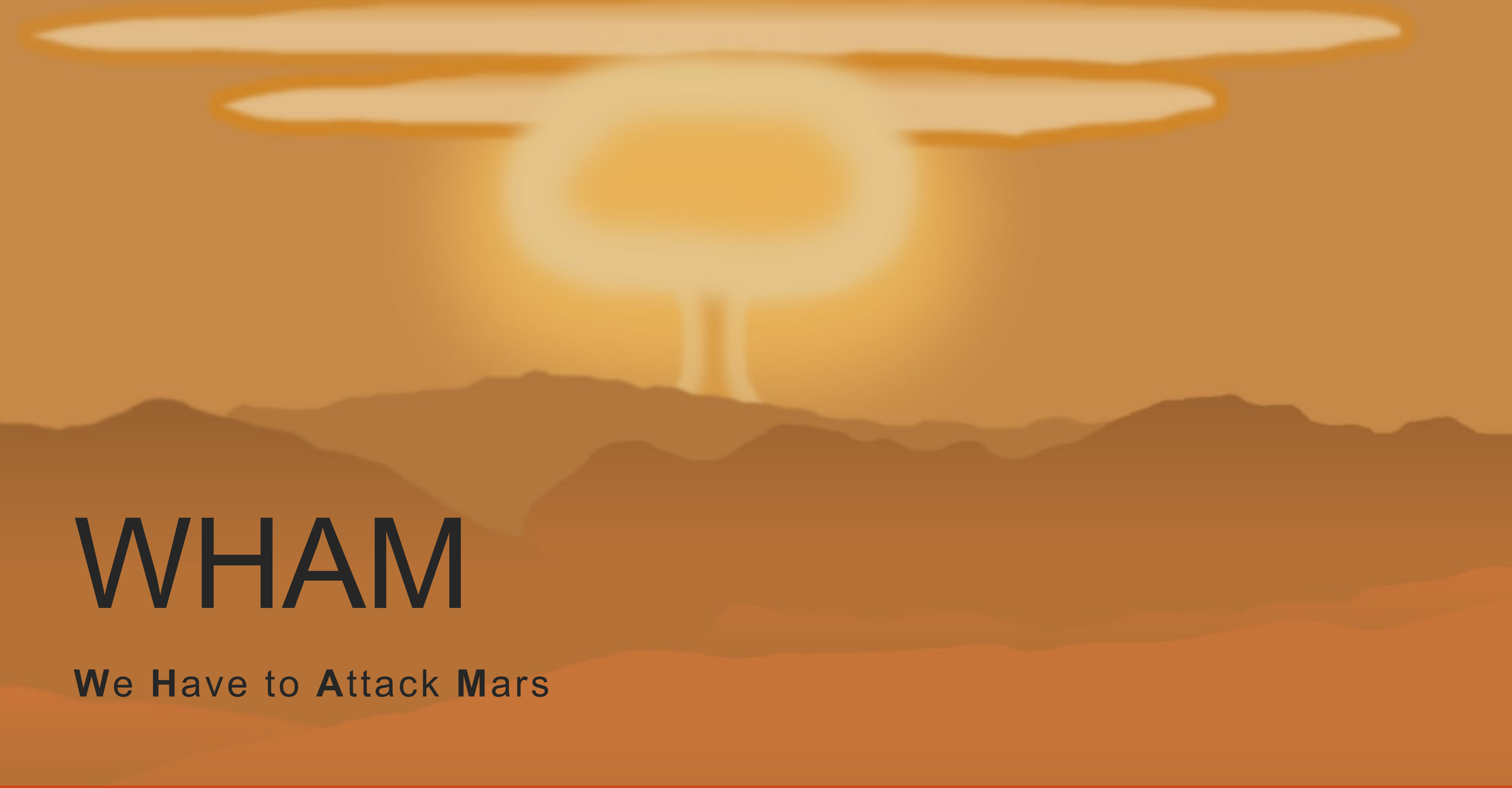

WHAM

We **H**ave to **A**ttack **M**ars

Editor’s note

This presentation dates from shortly after the arrival of the InSight (Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport) lander on Mars in 2018.

InSight is now approaching the end of its nominal lifespan, but the ideas contained herein are no less reasonable today.

Kimberly Hess and Junjie Dong helped make the original version of this presentation.

Synopsis

- I propose to detonate a two-megaton nuclear device on the surface of Mars.
- This mission is readily achievable with existing technology and is within the constraints of NASA’s Discovery Program.
- The detonation would serve as a seismic source for mapping the Martian deep interior.

First…

- This proposal has nothing to do with Elon Musk's idea to terraform Mars by bombing its ice caps.

First…

- This proposal has nothing to do with Elon Musk's idea to terraform Mars by bombing its ice caps.

- Musk's proposal is an unworkable publicity stunt.
  - Even very large numbers of nuclear devices could not vaporize a significant fraction of the ice caps.
  - Any vapor produced would quickly redeposit or be lost to space.
  - Mars would remain completely inhospitable even if all the ice was vaporized.

- My proposal, by contrast, is cogent and plausible.

Elon Musk elaborates on his proposal to nuke Mars

He wants to create two tiny pulsing suns over the Martian poles

By Loren Grush | @lorengrush | Oct 2, 2015, 2:16pm EDT

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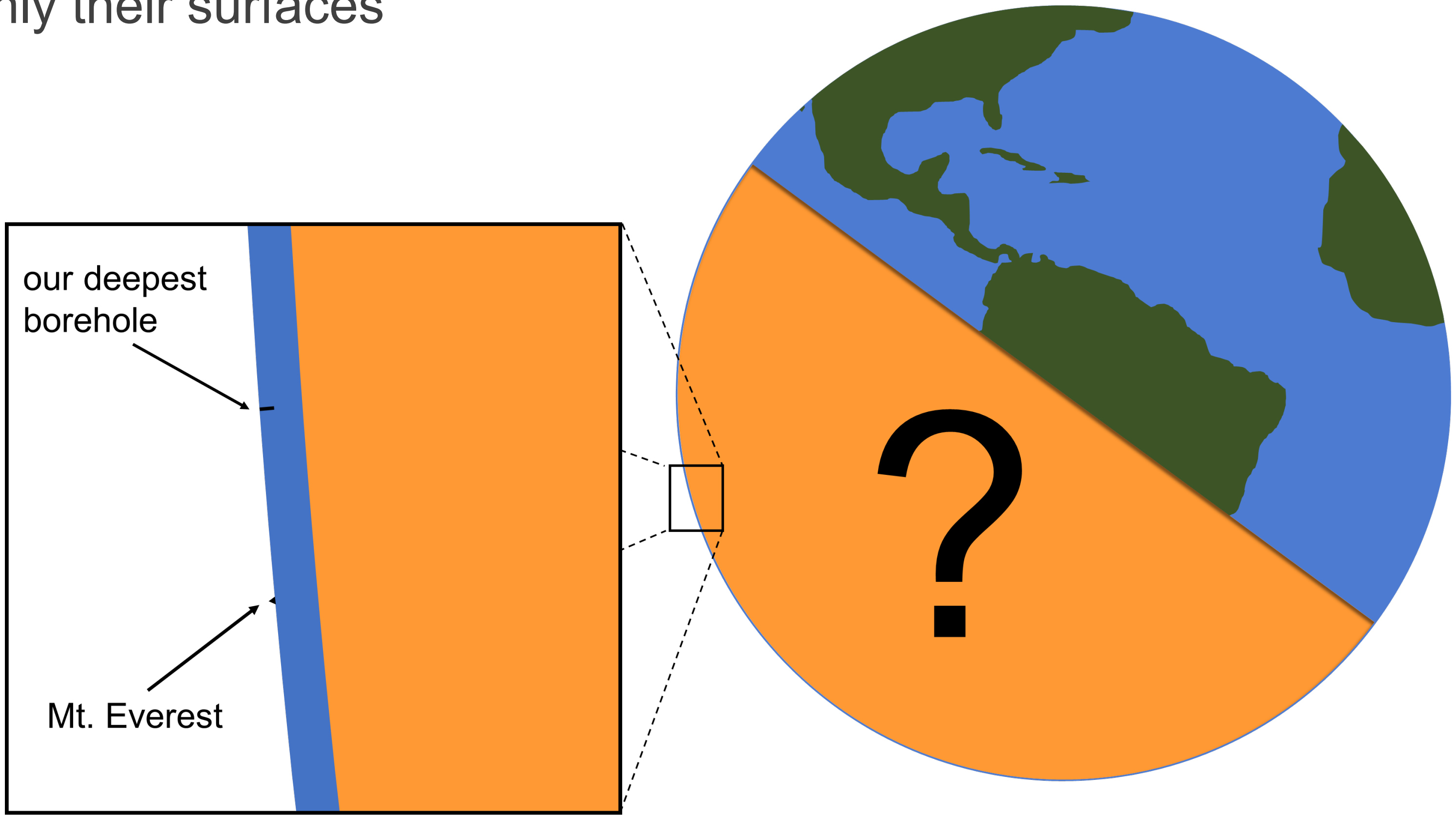
Planetary seismology

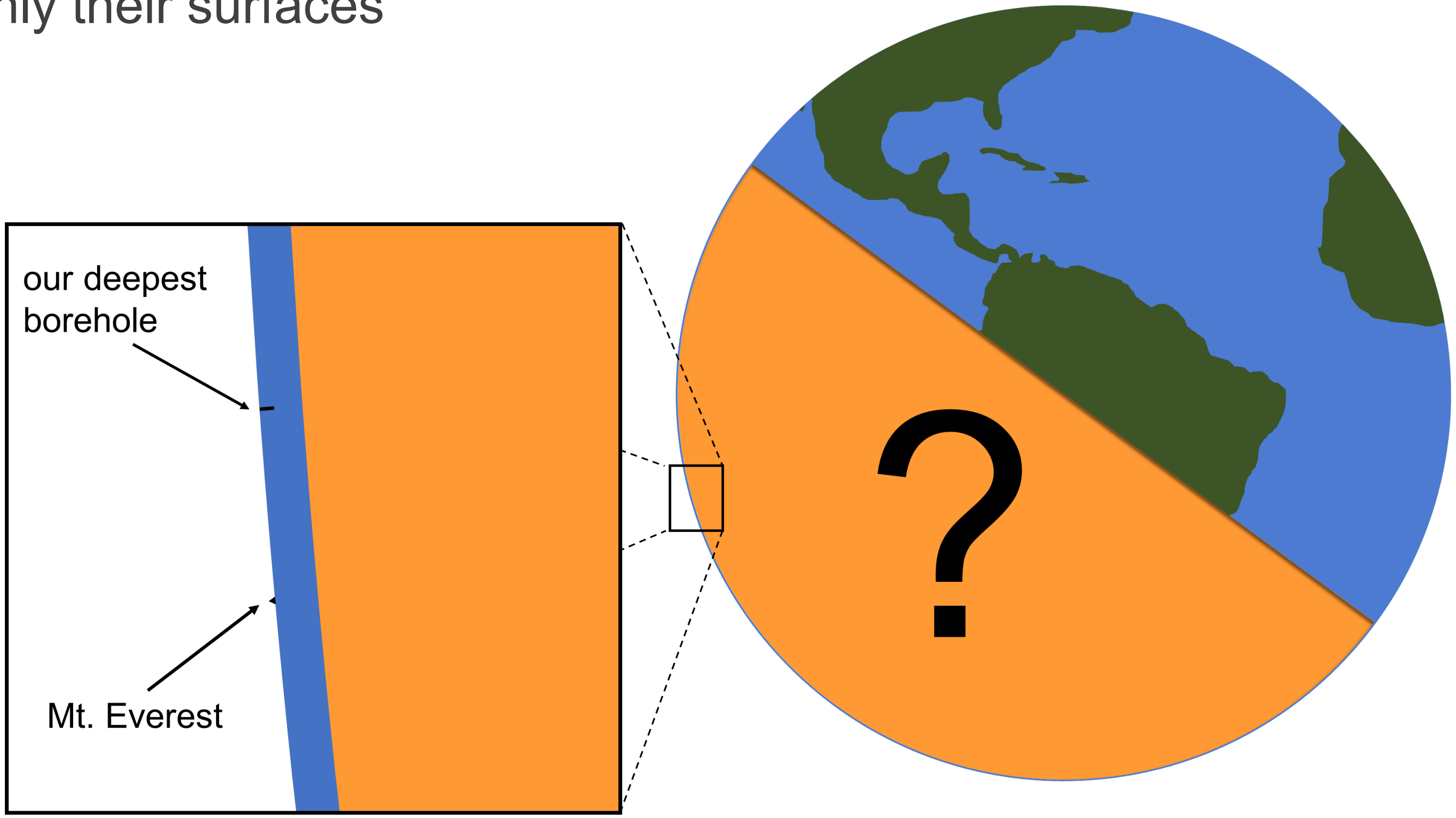
What's down there?

- Planets are extremely large, but only their surfaces are visible to us.



What's down there?

- Planets are extremely large, but only their surfaces are visible to us.
- Volcanoes only excavate rocks from relatively shallow depths.
- Without a more direct method of observation we can only guess at what's inside a planet.



How can we know?

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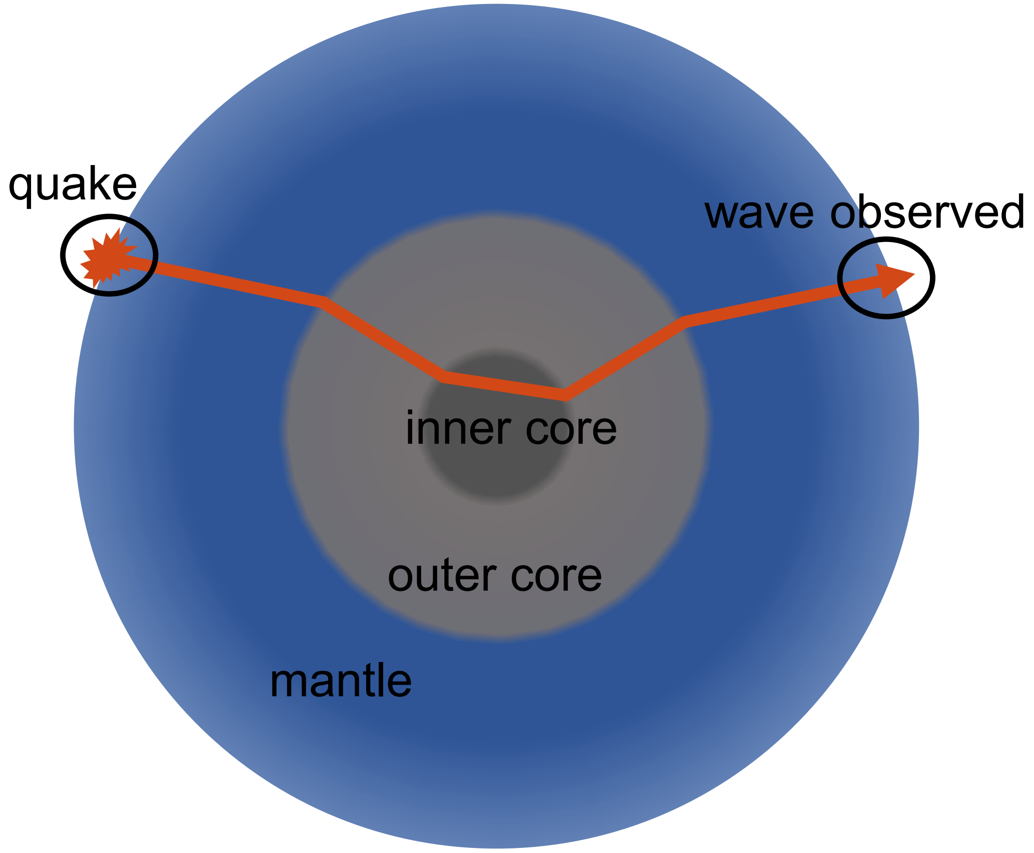

How can we know?

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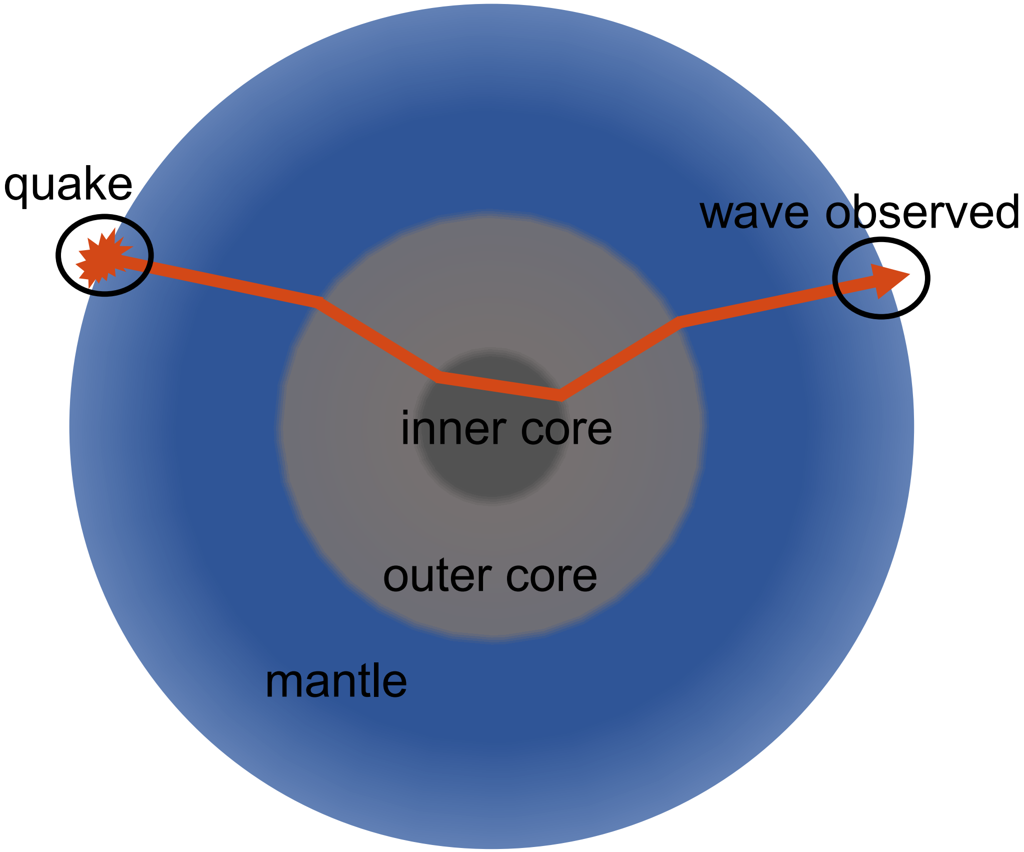
- Seismic waves bend or change speed as they pass through various layers.
  - By measuring where and when the vibrations from a quake are observed, we can infer the sizes and properties of those layers.



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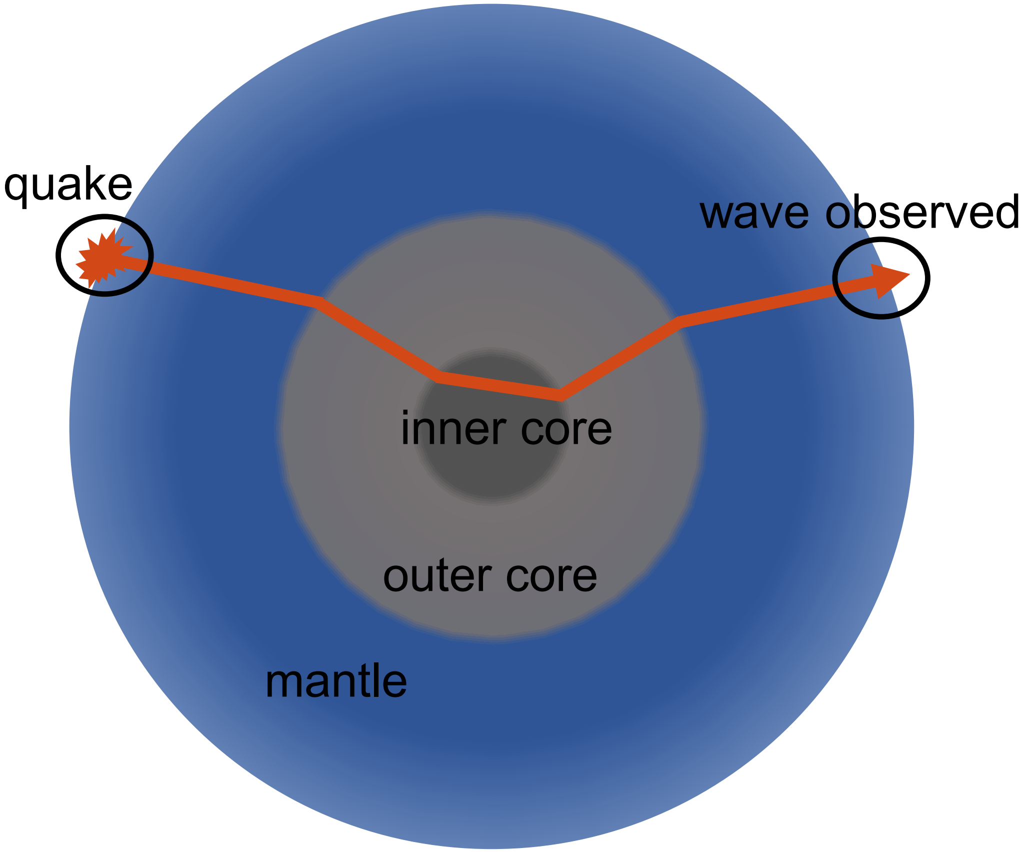

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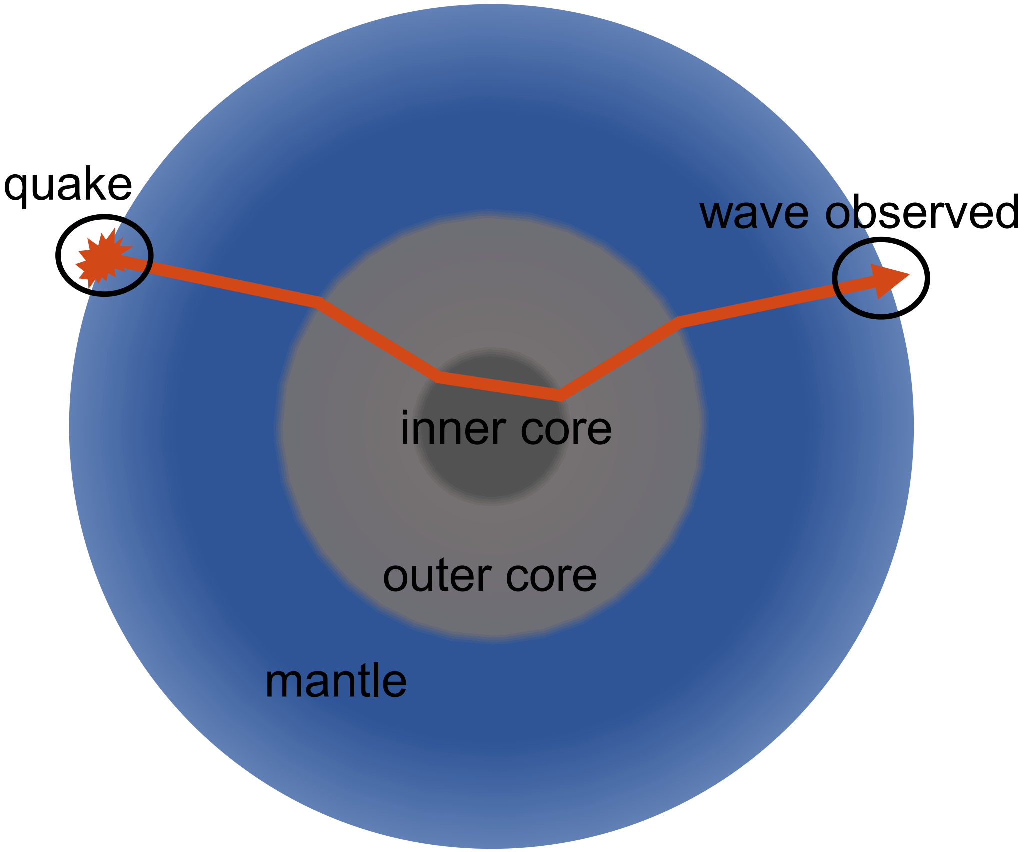
  - (we don't have millions of seismometers anywhere else)



Martian seismology timeline

- We have had a hard time getting even one seismometer to Mars.

Mission	**Year**	**Fate**
Viking 1	1976	Broke (failed to deploy)
Viking 2	1976	Didn’t work*
Mars 96	1996	Broke (exploded)
MESUR	1999	Cancelled
NetLander	2007	Cancelled
ExoMARS	2011	Cancelled
InSight	2018	Working

*The Viking 2 seismometer was mounted on the top of the lander (rather than on the ground as intended)

Martian seismology timeline

- We have had a hard time getting even one seismometer to Mars.
- Without seismic data, the interior of Mars has remained a mystery.
- Now that an instrument has finally worked, we must extract as much information from it as possible.

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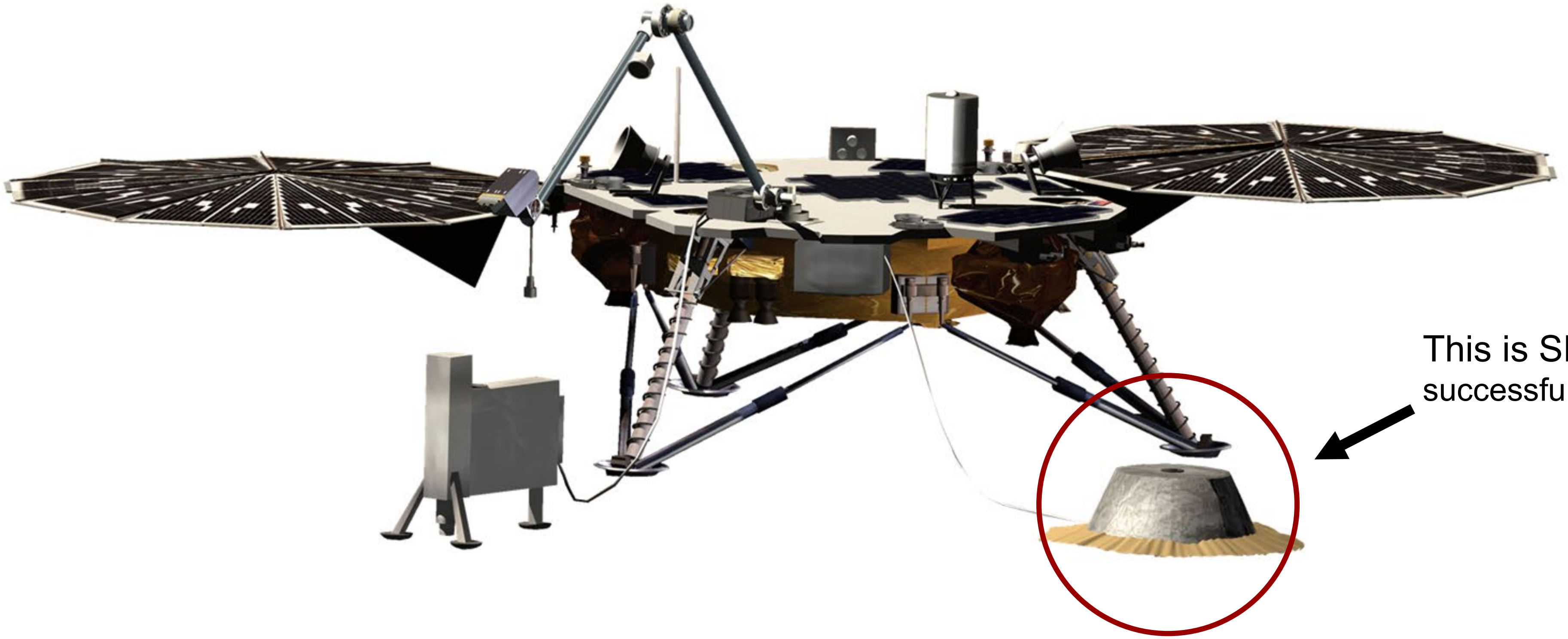
This is InSight



This is SEIS (the only seismometer successfully deployed on another planet)

Aren’t quakes good enough?

- You need a very energetic event to produce waves strong enough to travel though an entire planet.

- On Earth, powerful earthquakes are generated by the movement of tectonic plates.
  - Mars does not have active tectonics, so marsquakes will not be nearly as strong.

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Table 1. Predicted recurrence interval of seismic events on Mars.

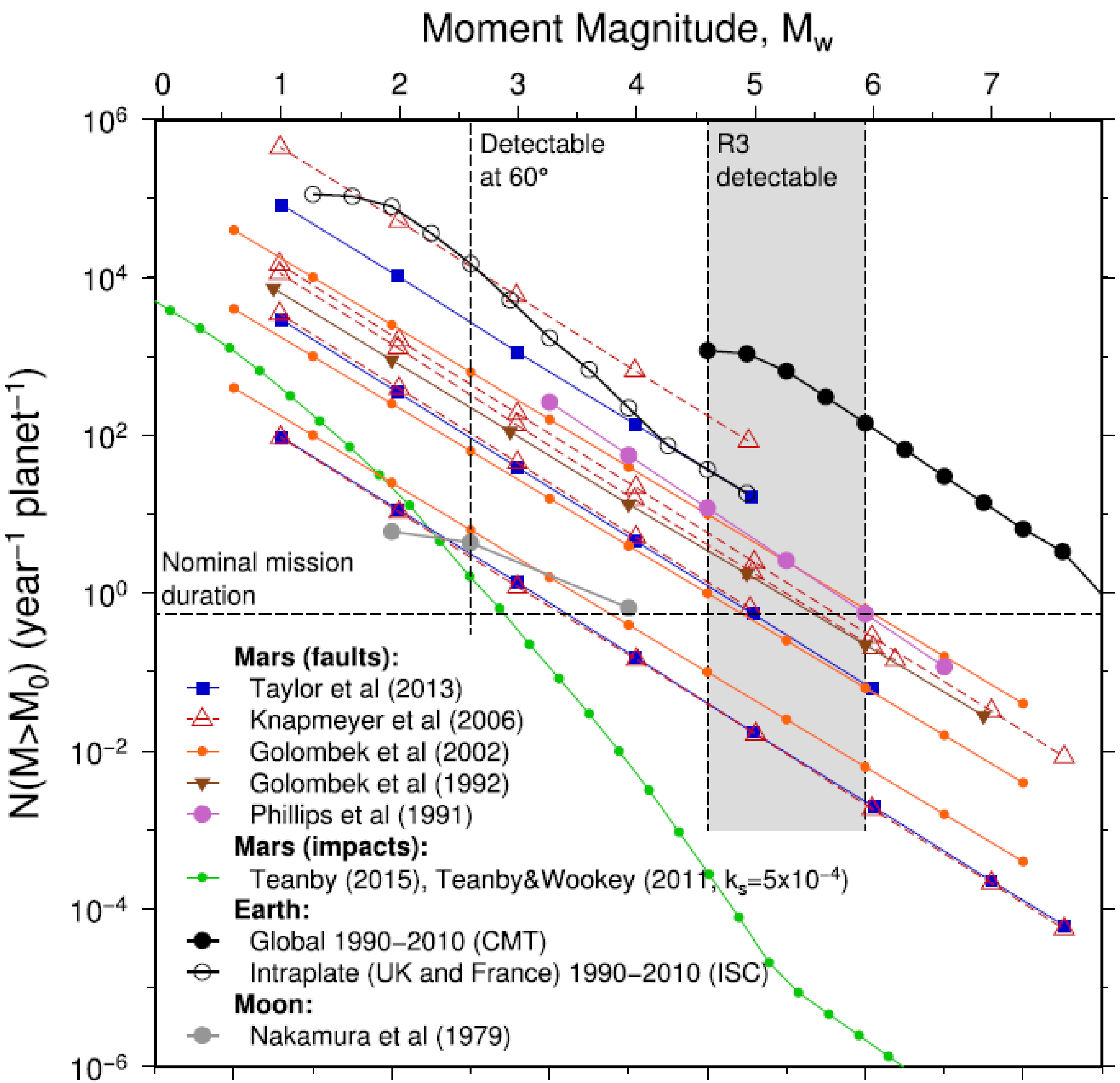
log (Moment) (dyne-cm)	Terrestrial magnitude	Recurrence interval from surface faulting	Recurrence interval for entire lithosphere
26.5	6.7	35,587 years	356 years
25	5.8	4,484 years	4.5 years
23.5	4.9	565 years	6.8 months
22	4	71 years	0.9 month
20.5	3.1	9 years	3.3 days
19	2.2	1 year	9.8 hours
17.5	1.3	52 days	1.2 hours

Golombek et al. (2002)

- This study, for example, predicts that a magnitude 6.7 marsquake will only occur every 356 years.

- On Earth, events that big happen monthly.

- This plot estimates how often InSight will detect marsquakes of various sizes.



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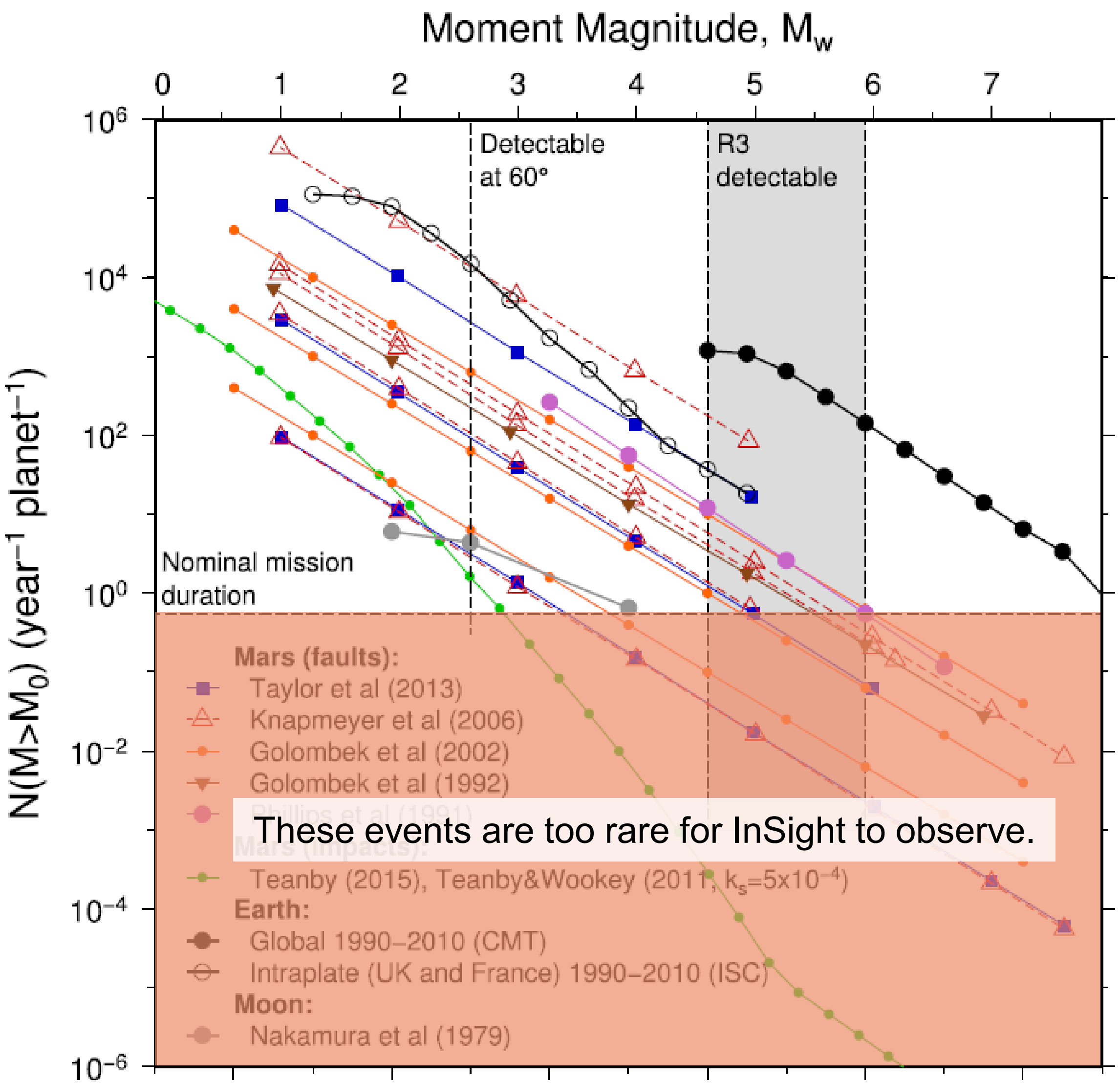

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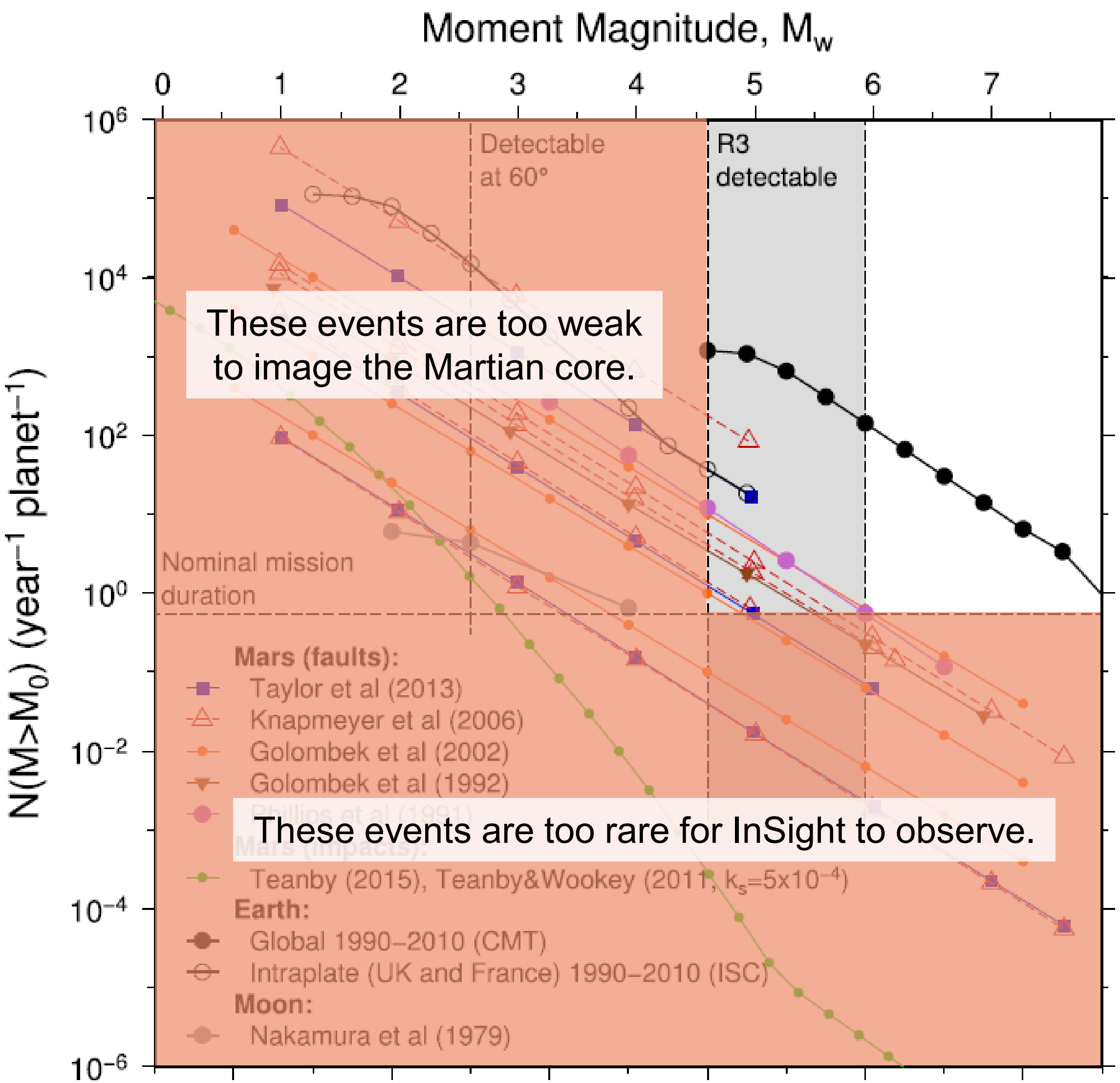

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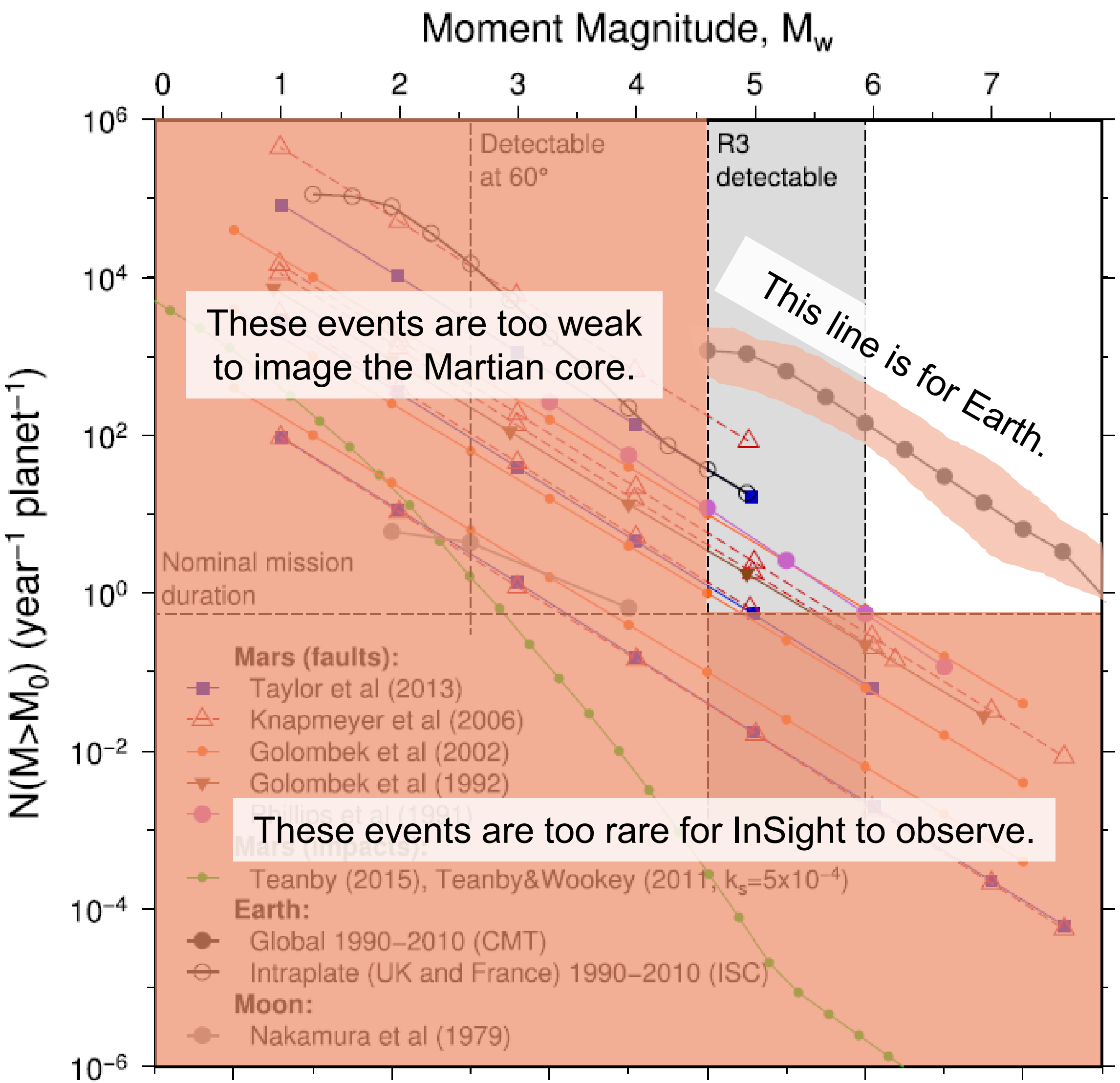

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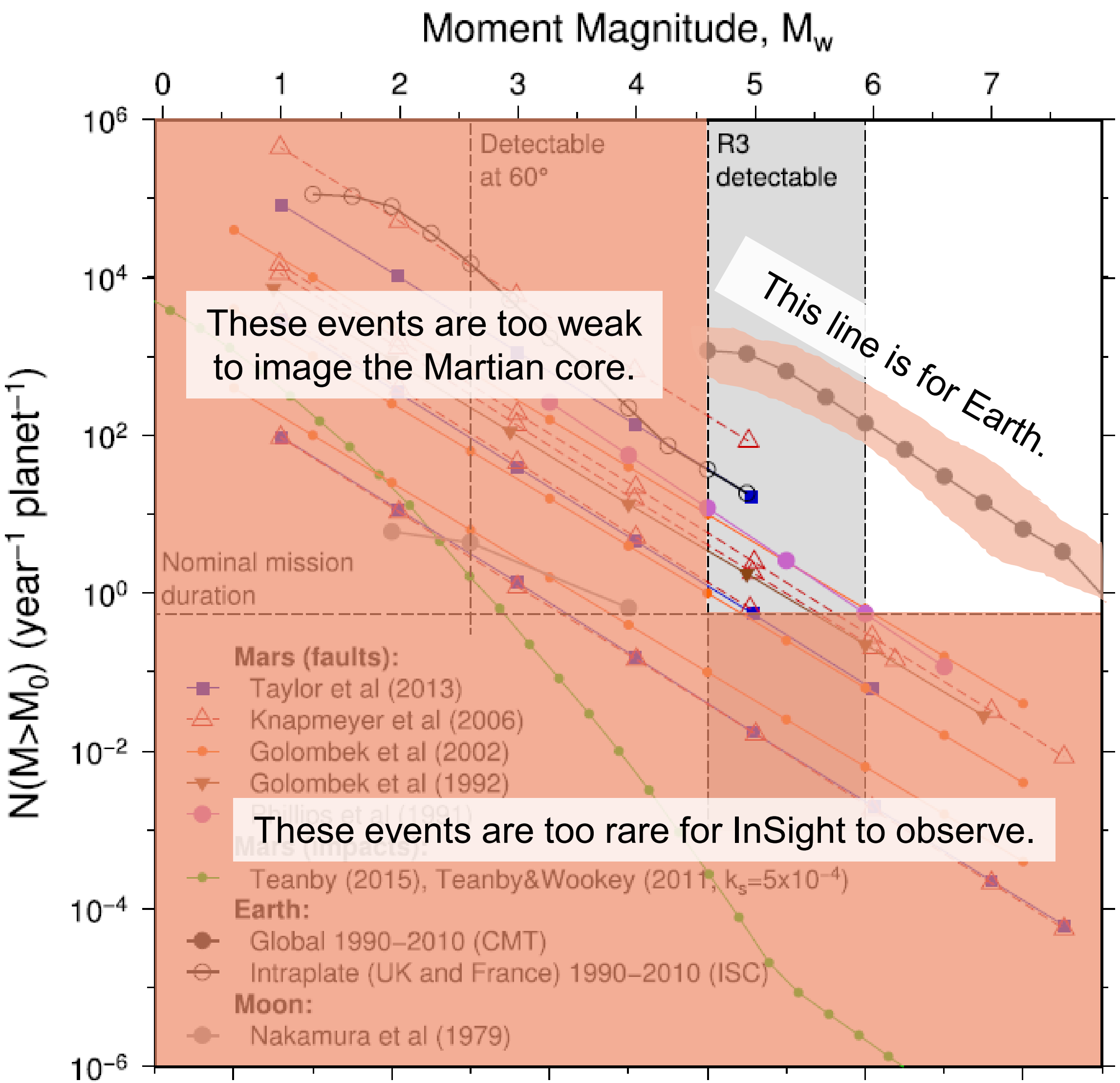

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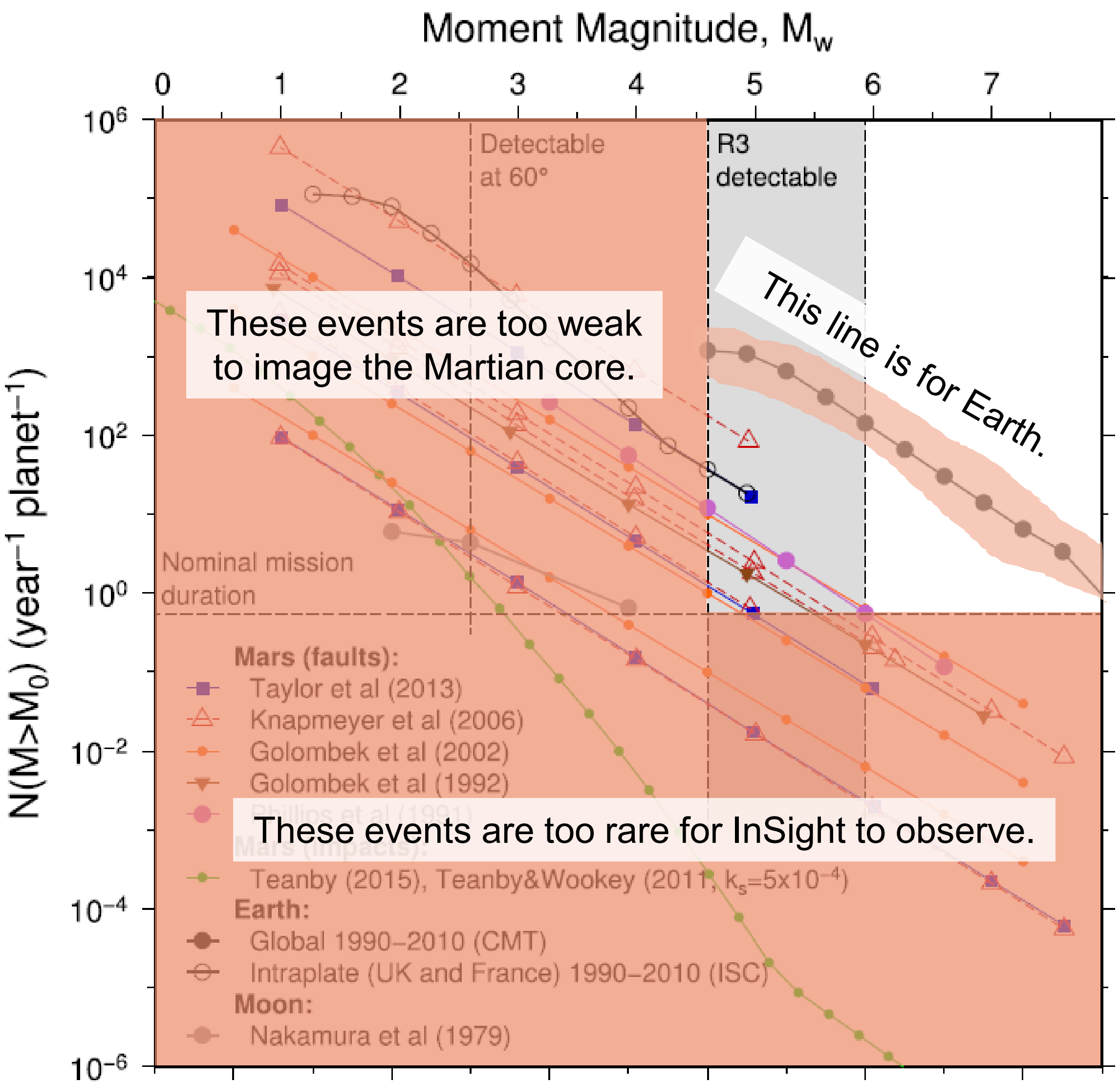

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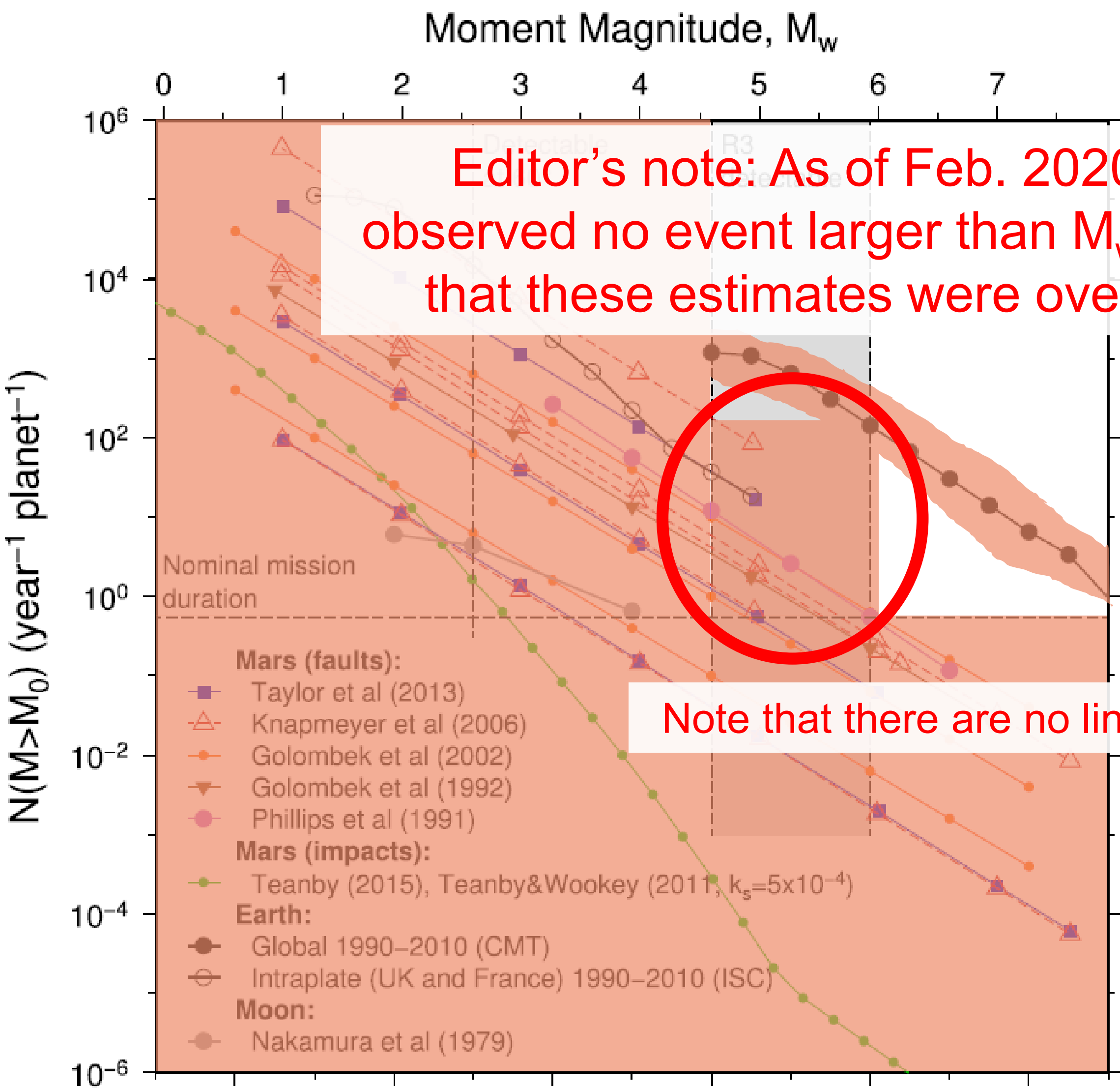


Editor's note: As of Feb. 2020, InSight has observed no event larger than M_w 4, which means that these estimates were overoptimistic too.

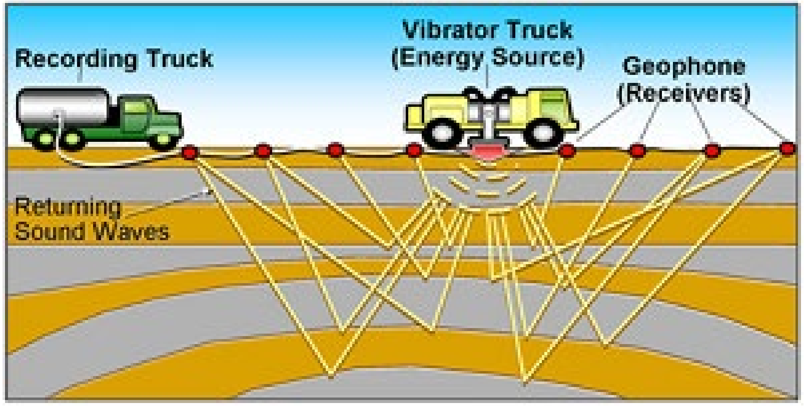
Note that there are no lines left uncovered.

Panning et al. (2017)

Active seismology

Make your own luck

- Quakes need not be the source of seismic energy.
- Various industries image rock layers with artificial seismic sources, rather than waiting for an appropriate earthquake.
  - Artificial sources are either generated by explosives or special trucks.



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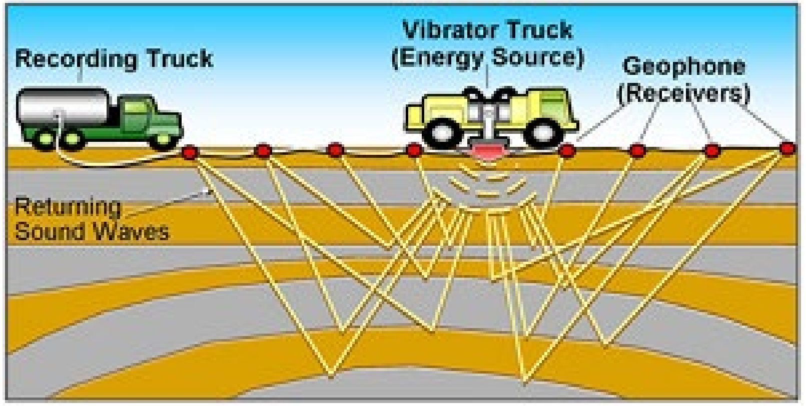
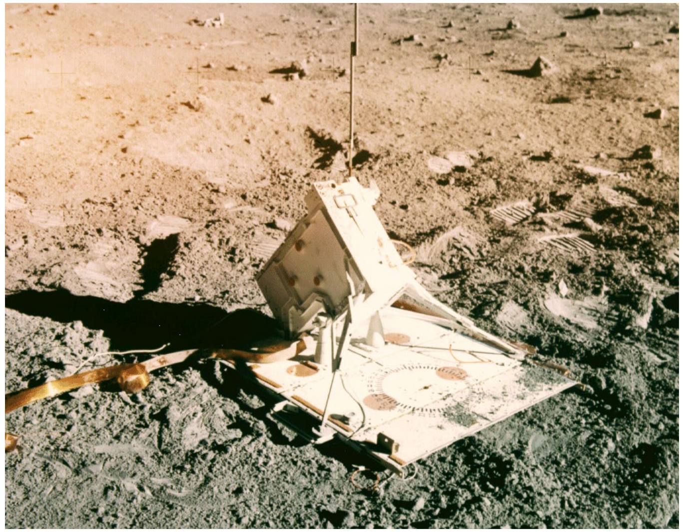
- Several Apollo missions (14,16, and 17) used seismometers and explosive "thumpers" to study the Moon's shallow subsurface.

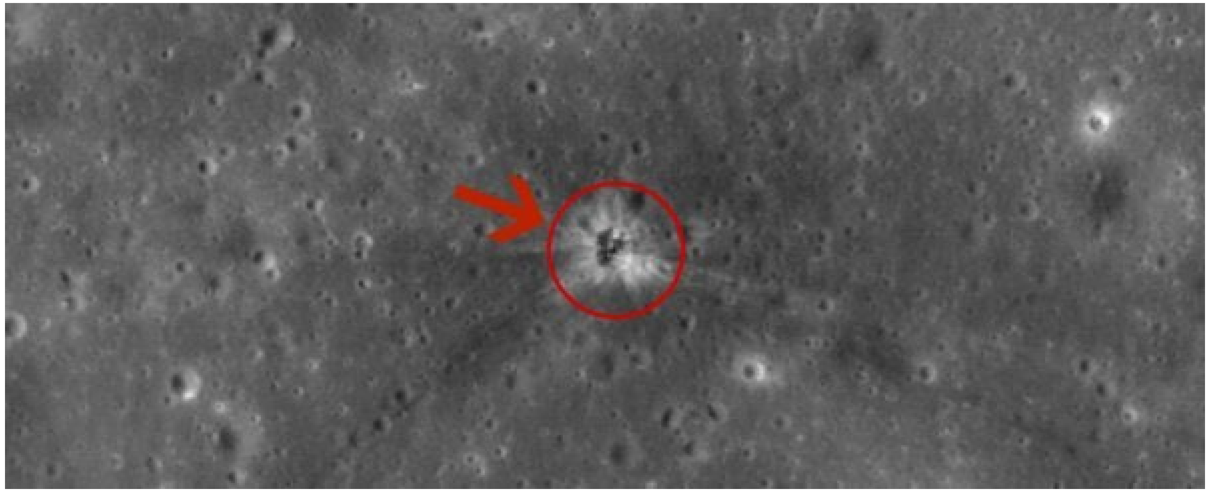




Artificial impacts

- Larger seismic sources were generated by the intentional crash-landing of the Apollo 12 Lunar Module ascent stage and the Apollo 13 third stage booster.

- These impacts were detected by seismometers previously set up on the Moon.
  - They helped measure the thickness of the lunar crust.



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- Unfortunately, the spacecraft used by Apollo were much larger than what we could reasonably hit Mars with.
  - Even so, their impacts were not large enough to detect the lunar core.

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Table 1. Expended LM ascent stage and S-IVB impact parameters. The Apollo 12 seismic station is located at 3°03′S, 23°25′W.

Parameter	LM	S-IVB
Time of impact (G.M.T.)	$22^h17^m16.4^s$	$01^h09^m39.0^s \pm 0.2^s$
Mass (kg)	2,383	13,925
Impact velocity (km/sec)	1.68	2.58
Kinetic energy of impact (ergs)	$3.36(10)^{16}$	$4.63(10)^{17}$
Equivalent energy of impact (lb of TNT)	$1.77(10)^{3}$	$2.44(10)^{4}$
Angle of impact from horizontal	3.7°	76.4°
Distance between point of impact and seismic station (km)	73	135

- The larger (Apollo 13) impact delivered ~10^{10} J of energy to the lunar surface.
- We need ~10^{16} J (a million times more energy) to see core sensitive phases on Mars.
- A more powerful seismic source is required.

Nuclear seismology

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- Nuclear weapons are potent sources of energy; a detonation is detectable by seismometers anywhere on Earth.

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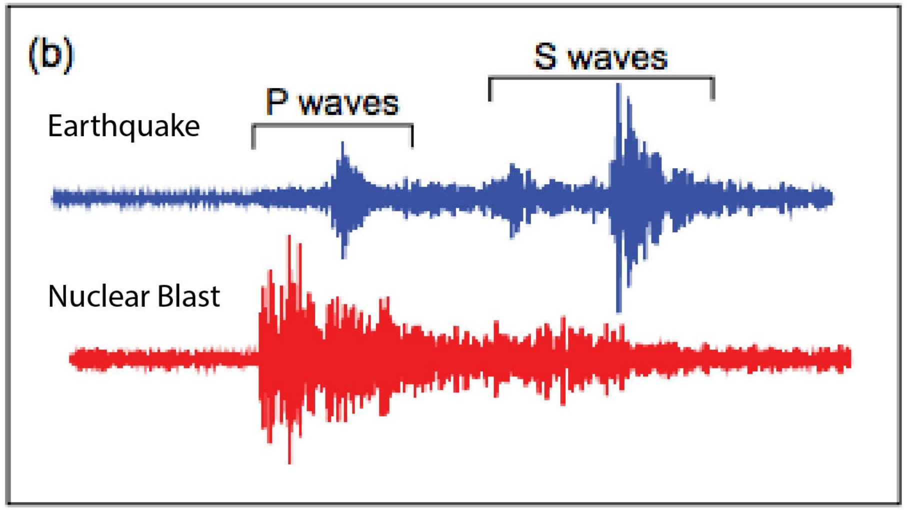

Lawrence Livermore National Lab (2009)

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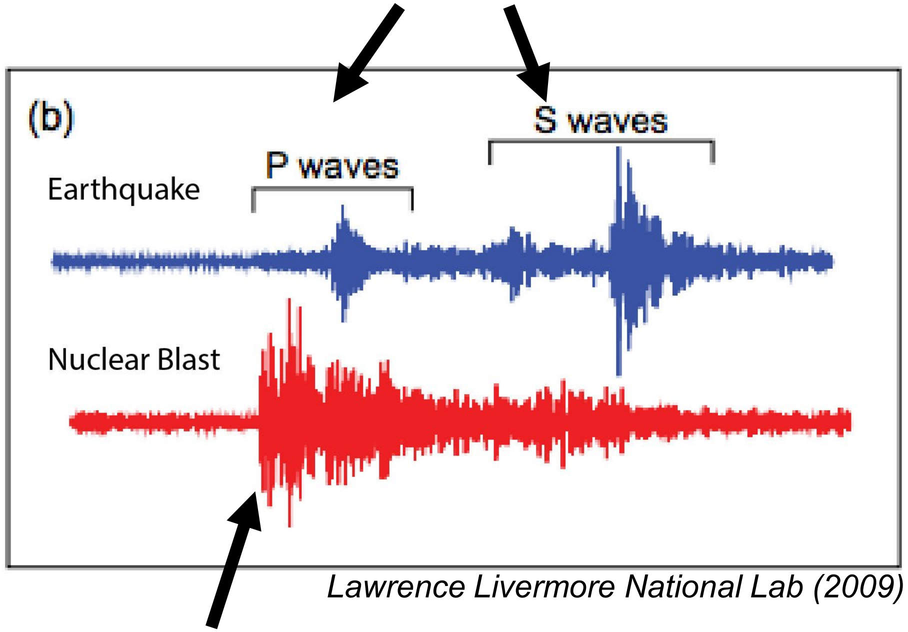

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- The strategic value of locating and measuring an atomic weapon test has ensured that the seismic signature of a detonation is **extremely** well studied.
- Seismic data from an explosion would be easier to interpret than a similarly-sized marsquake.

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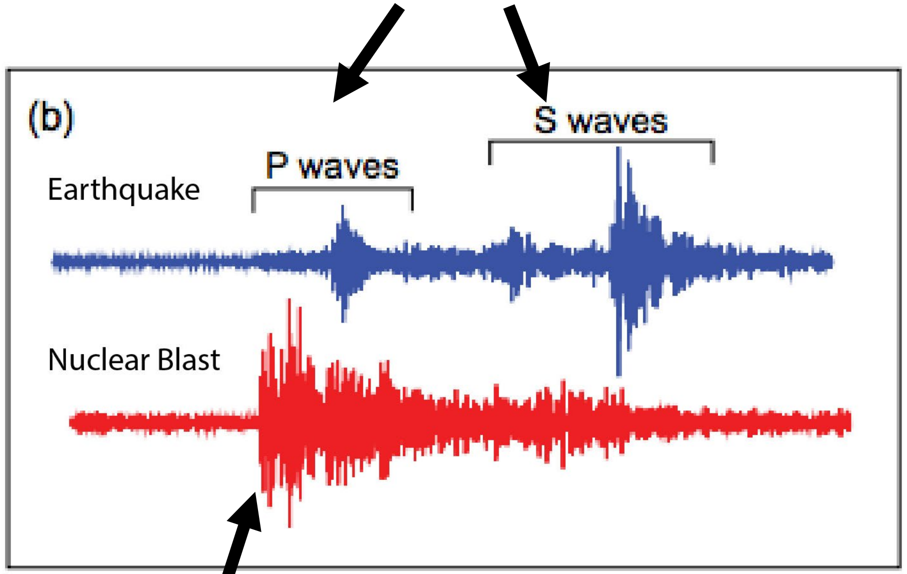

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- Bomb energy arrives as a single large pulse

Energy required

	energy (J)
1 calorie	4×10^{0}
baseball pitched at 94 mph	2×10^{2}
1 ton TNT	5×10^{9}
1 megaton TNT	5×10^{15}
Sumatra earthquake (2004)	1×10^{17}
Tsar Bomba (1961)	3×10^{17}
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- Our threshold for a detecting core seismic phases is 1×10^{16} J.

target

- This means we'll need an explosive yield of at least 2 megatons.

Bomb shopping

- During the Cold War, the US nuclear stockpile had weapons as large as 9 megatons.
  - These were intended to collapse deeply buried bunkers.

Bomb shopping

device	yield (megatons)
W76	0.1
W80	0.15
W84	0.15
W62	0.17
W78	0.35
B61	0.4
W87	0.48
W88	0.48
B83	1.2

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  - These were intended to collapse deeply buried bunkers.
- Nothing in the modern stockpile is nearly that powerful.
- Unless someone is kind enough to declassify a bomb for this mission, we’ll need multiple explosives.
  - Two B83s will get us there.

Will it fit on a spaceship?

- Two unmodified B83 thermonuclear bombs weigh more than 2000 kilograms.
  - This is too heavy for a NASA Discovery Program payload.

Editor's note: "Discovery" is a NASA program in charge of the cheapest, lightest missions.

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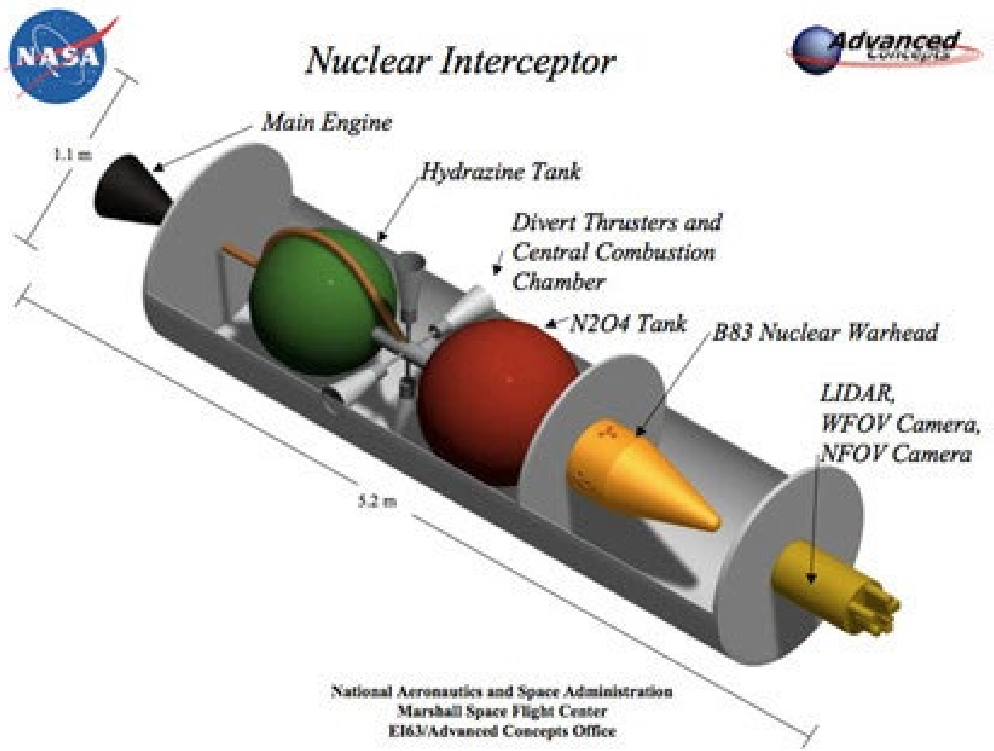
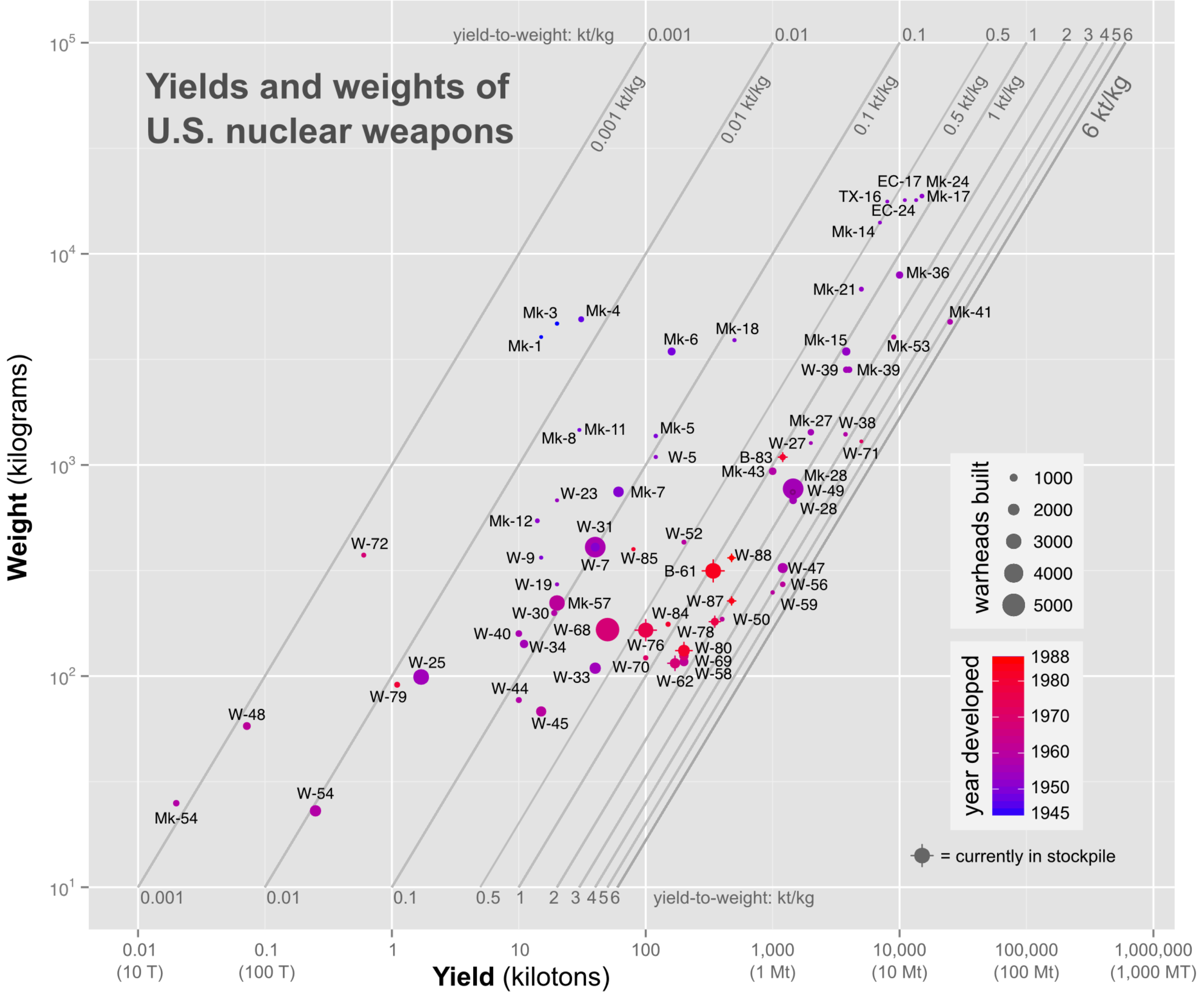
- However, it is possible to pare down the weight to just the “physics package”.
- NASA has already proposed a B83-armed asteroid interceptor that weighs only 1500 kilograms *for the entire spacecraft*.



- The theoretical maximum efficiency of a nuclear weapon is 6 kilotons of energy for each kilogram of weight.
  - This is called the ‘Taylor limit’

Alex Wellerstein (2013)



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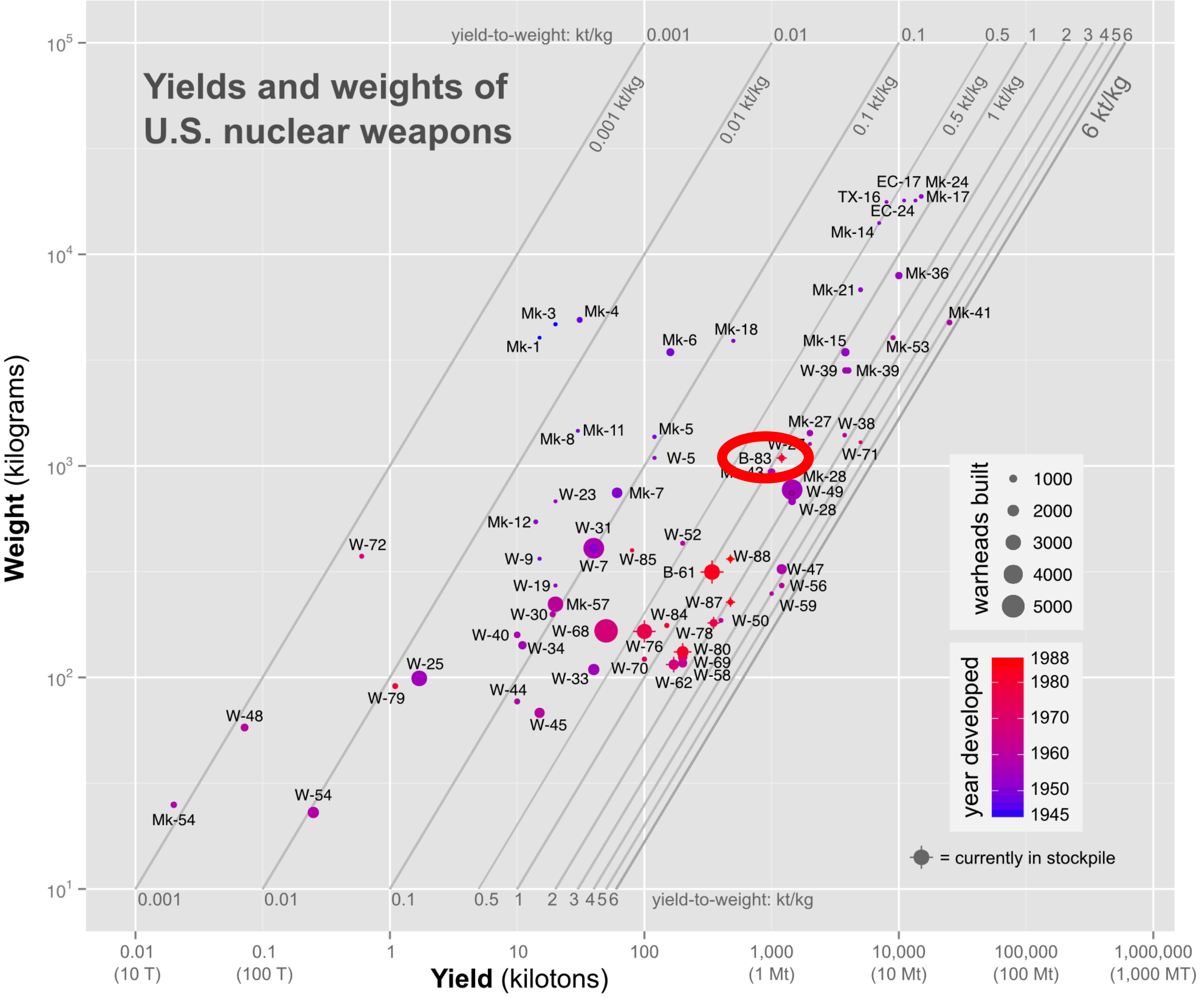

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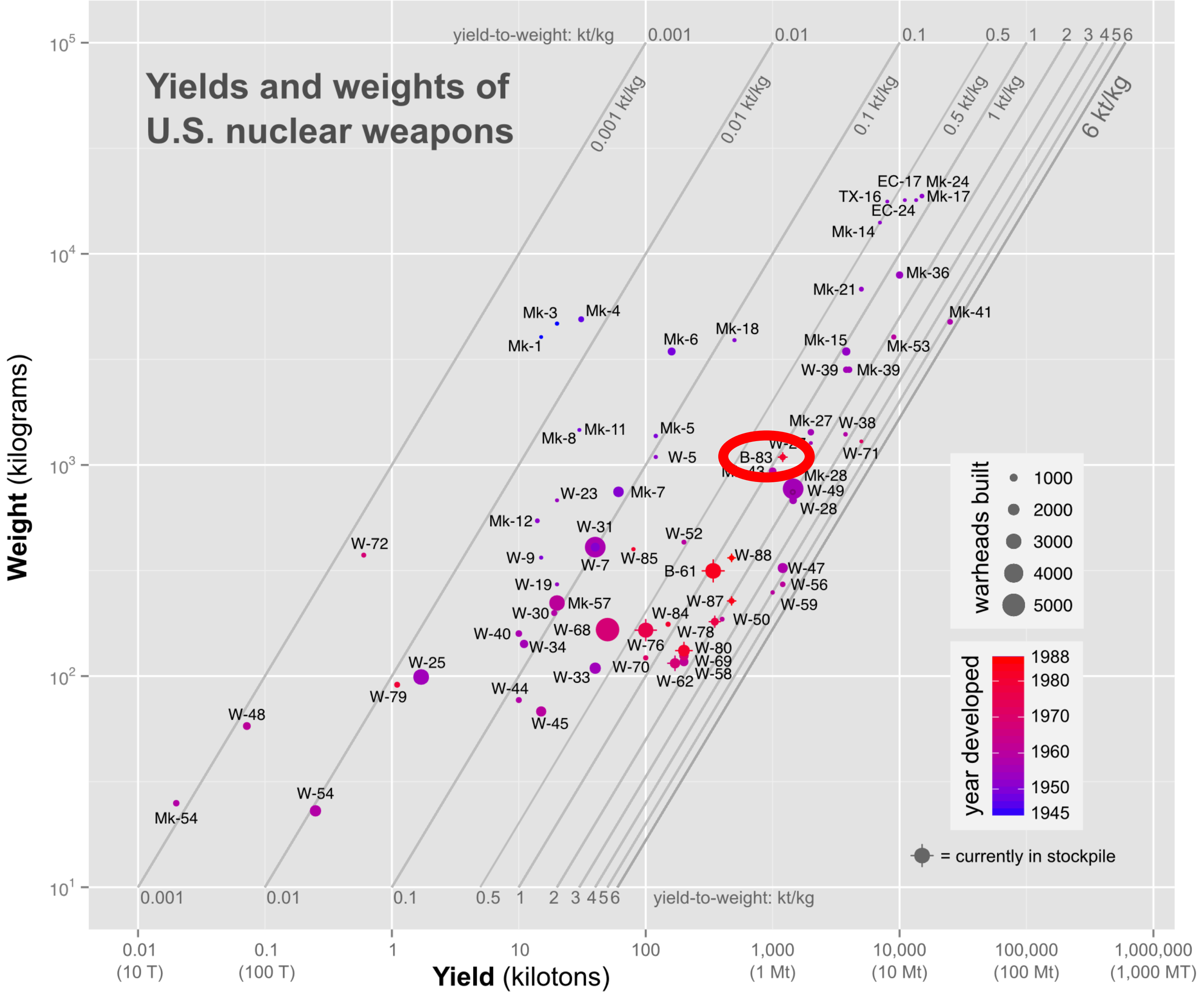

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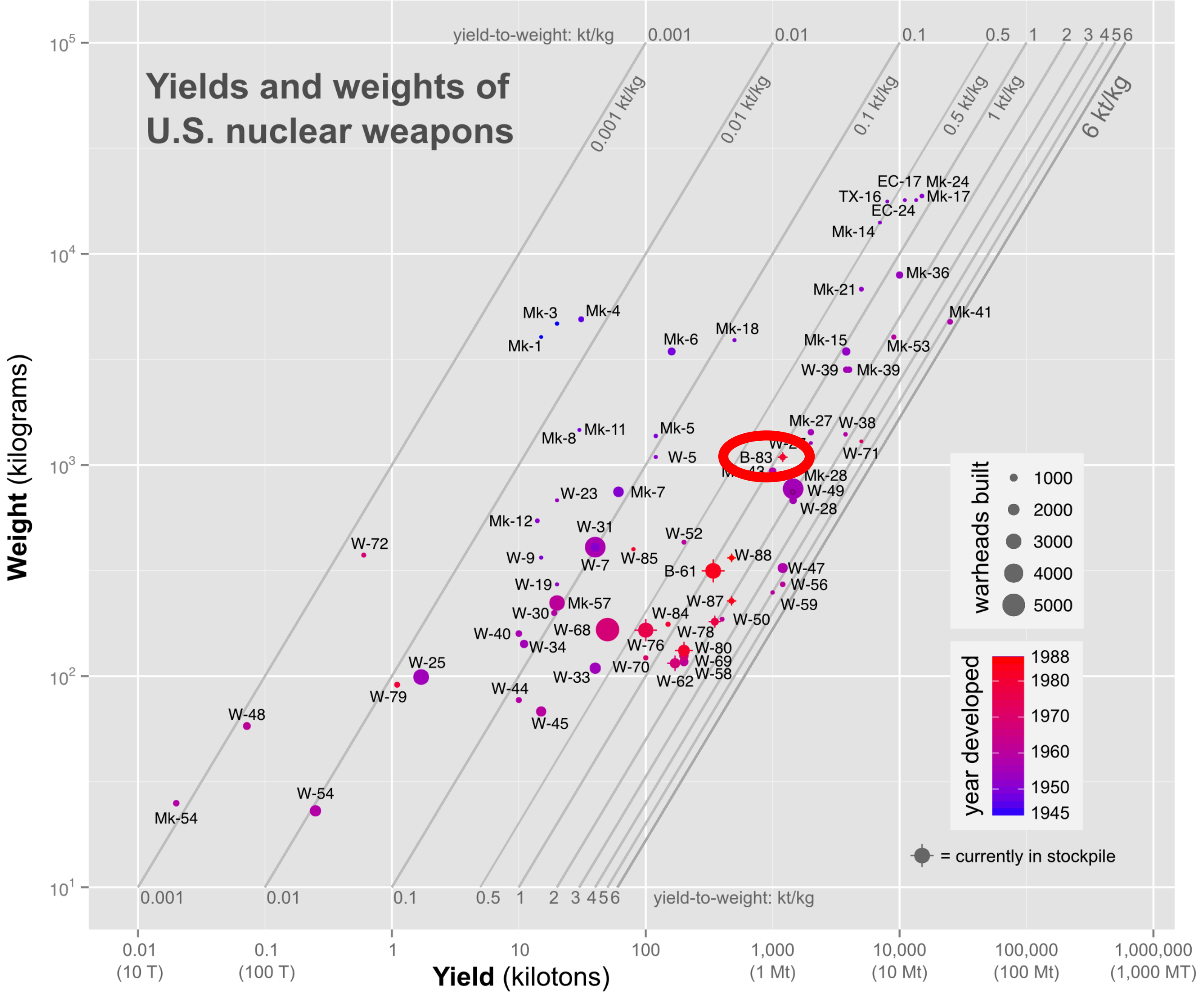
- Our two B83s yield 2400 kilotons, so they can be stripped down to 400 kilograms *at best*.
- Even if we only get to half of max efficiency, 800 kilograms is still light enough for a Discovery payload.
  - (InSight weighed 721 kilograms)

Alex Wellerstein (2013)



Mission details

The trip there

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- Launch will take place in July 2020 in order to maximize the chances of arrival during the InSight lifetime.
  - This launch date takes advantage of an ideal Mars – Earth orbital configuration (also used by the Mars 2020 mission).

The trip there (speculation)

- All previous Mars missions have had the goal of either entering Mars’ orbit or landing on its surface.
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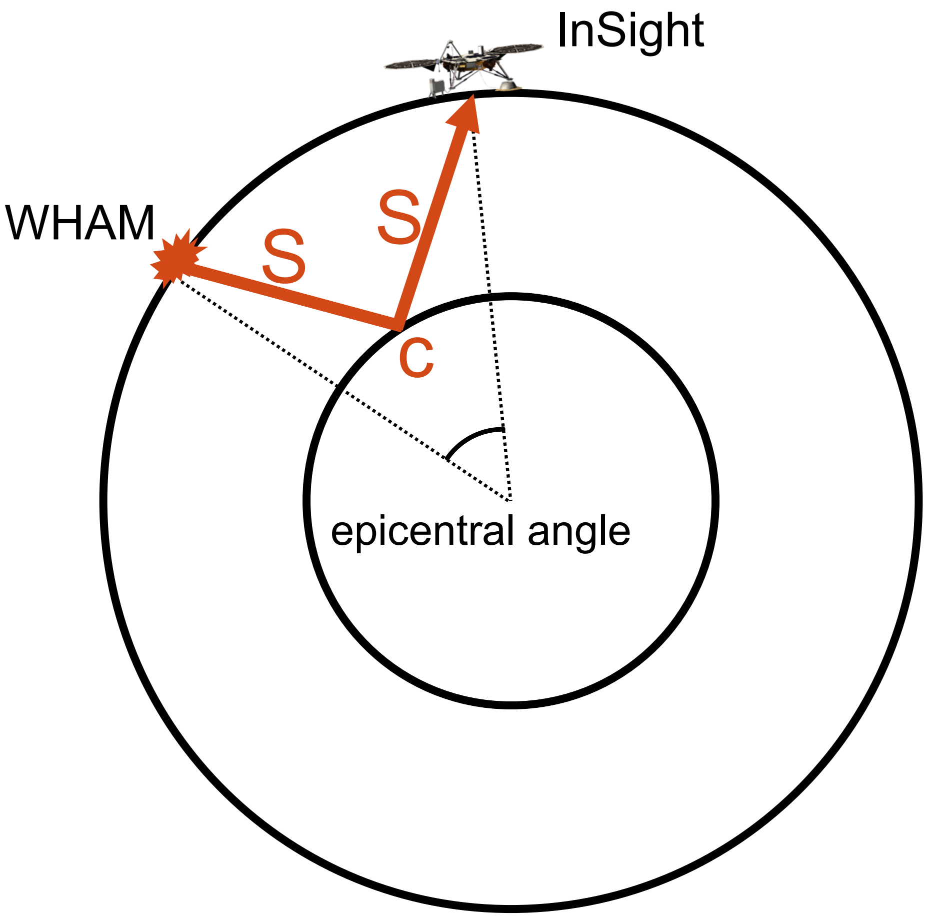
- WHAM *technically* does not have this constraint, so it may be possible to arrive at Mars in less than the standard 6-month travel time.
  - This is especially true if we use some of the weight we saved on the bomb housings to bring extra fuel for a less efficient orbital transfer.

The arrival



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  - This is a shear wave that bounces once off the top of the core.

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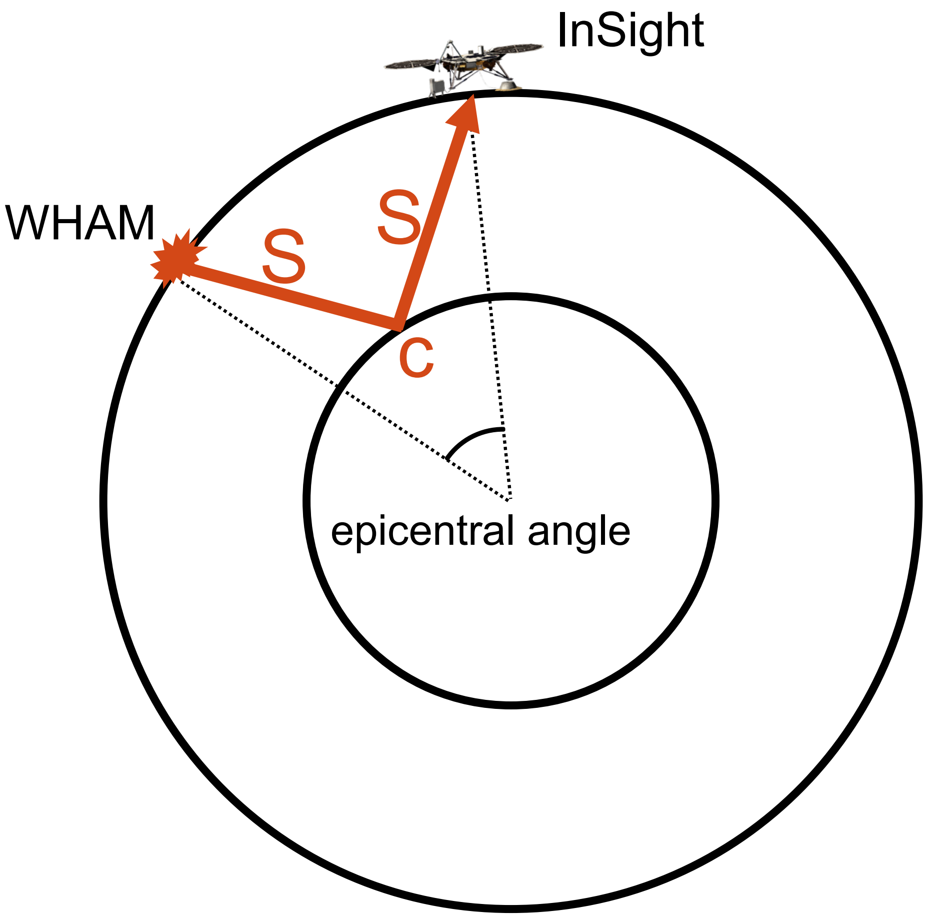

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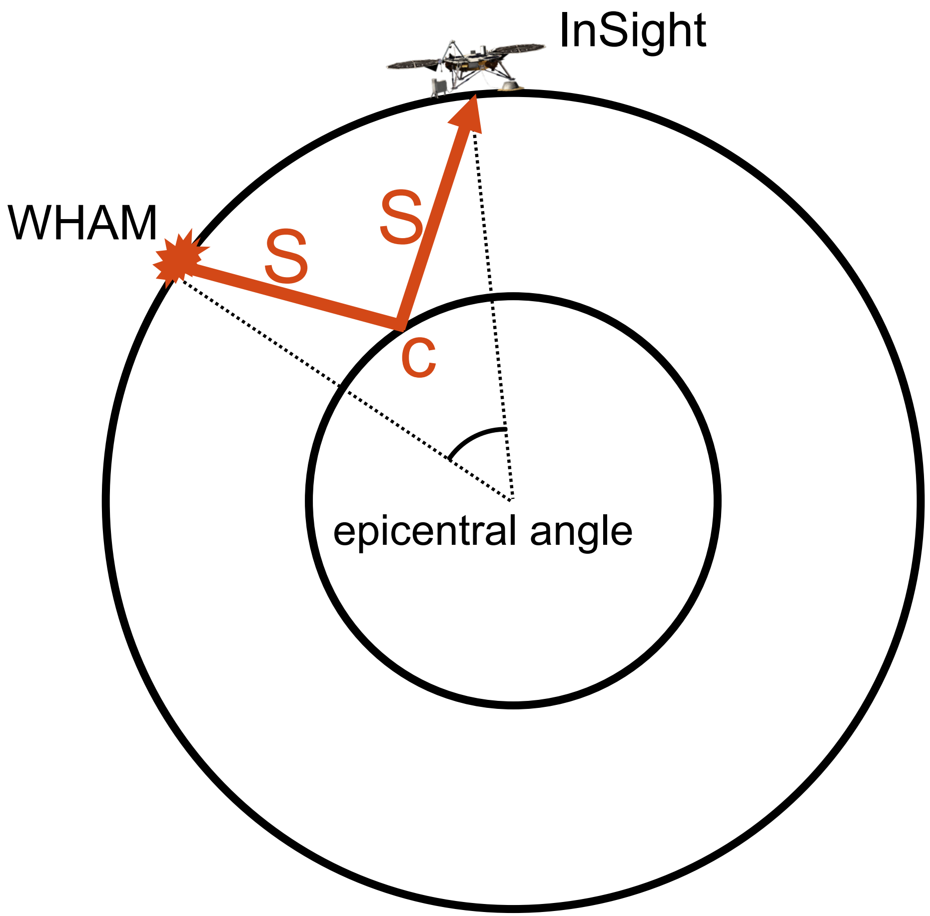
- It is useful to have the explosion occur at a distance that maximizes the possible spread of ScS travel times.
  - Previous research (Brennan et al., 2020) suggests this occurs where the epicentral angle is 30°.
  - This means targeting a site ~1776 km from InSight.

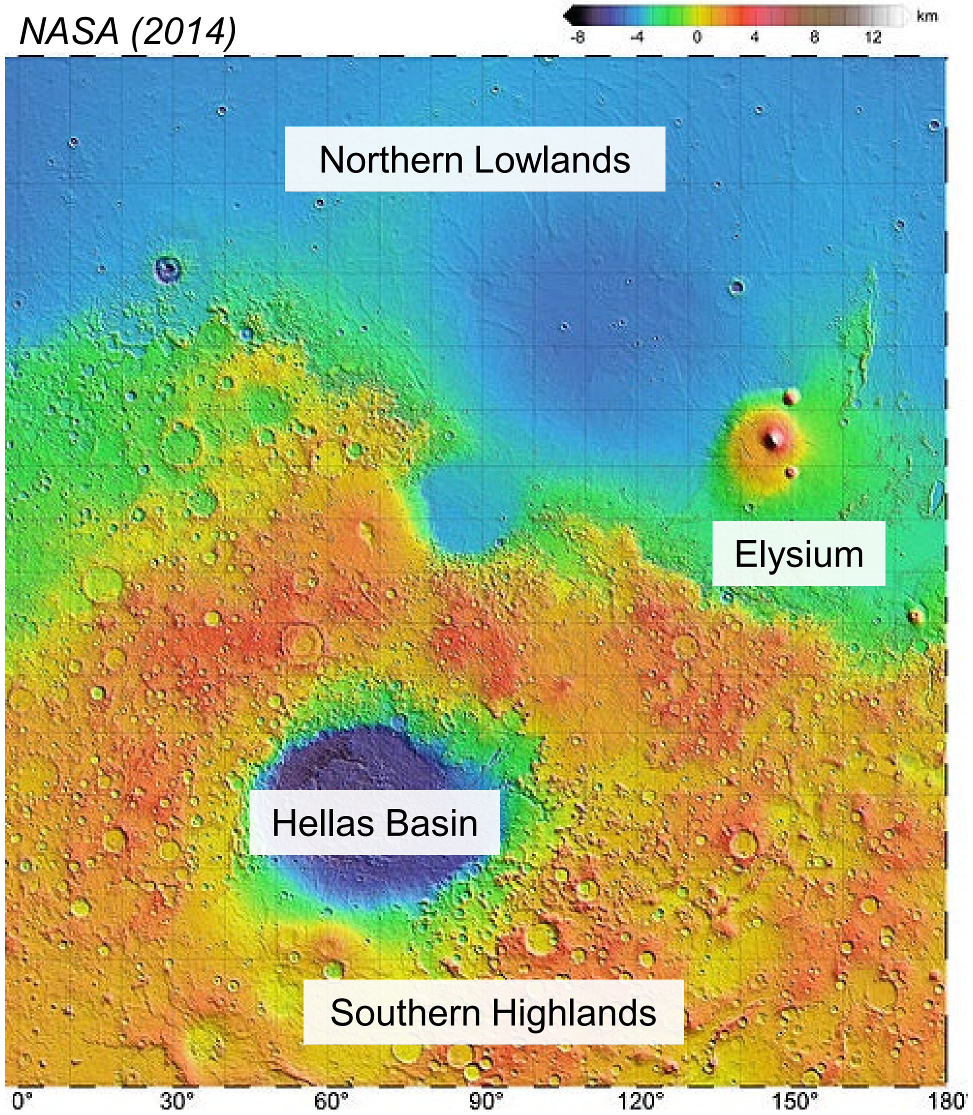
The arrival



- One of the most useful seismic phases for determining the size of the core is ScS.
  - This is a shear wave that bounces once off the top of the core.
- It is useful to have the explosion occur at a distance that maximizes the possible spread of ScS travel times.
  - Previous research (Brennan et al., 2020) suggests this occurs where the epicentral angle is 30°.
  - This means targeting a site ~1776 km from InSight.

Editor's note: Just as the Founding Fathers intended.

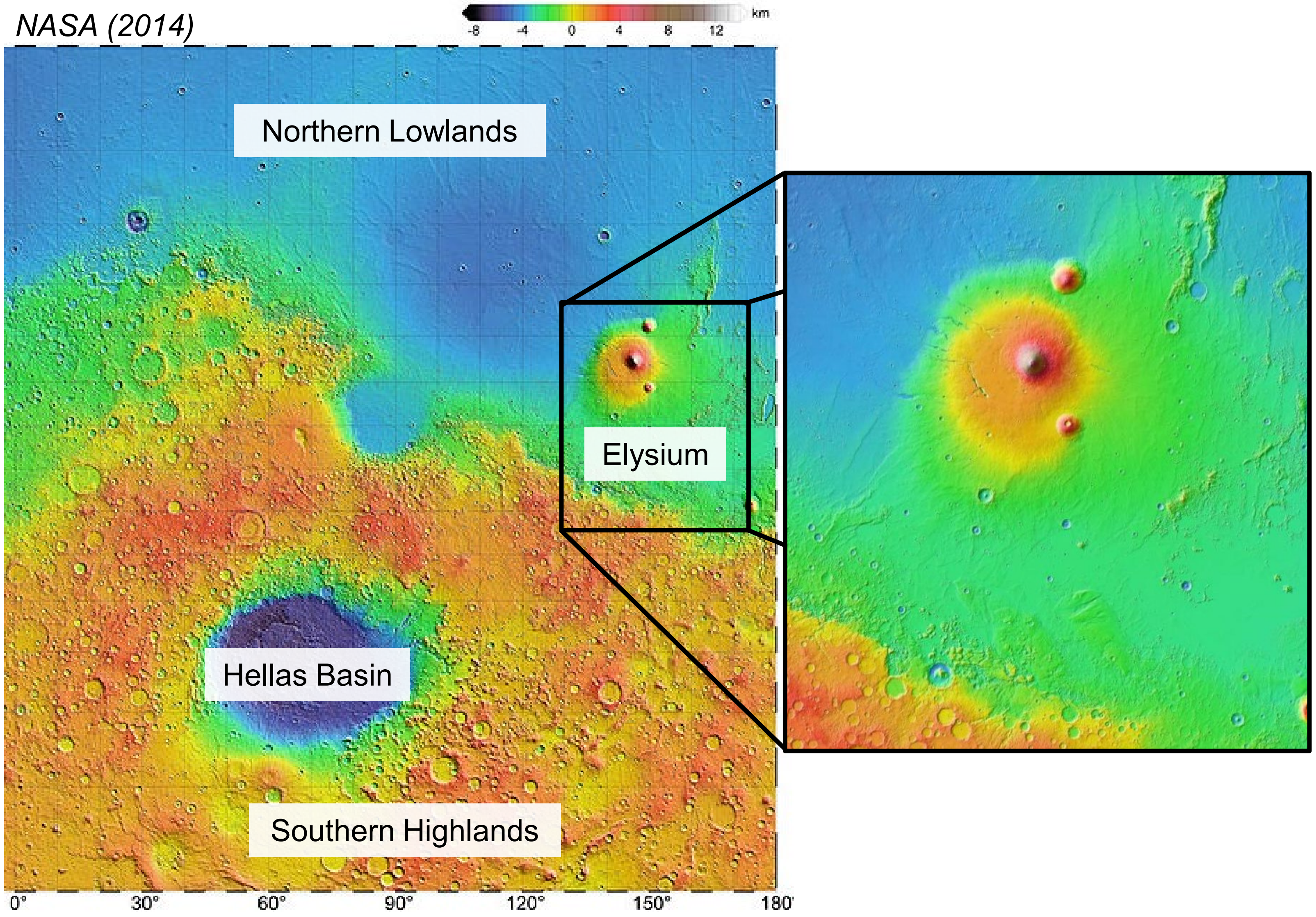
NASA (2014)



The arrival

- This is a topographic map of Mars' eastern hemisphere.

NASA (2014)



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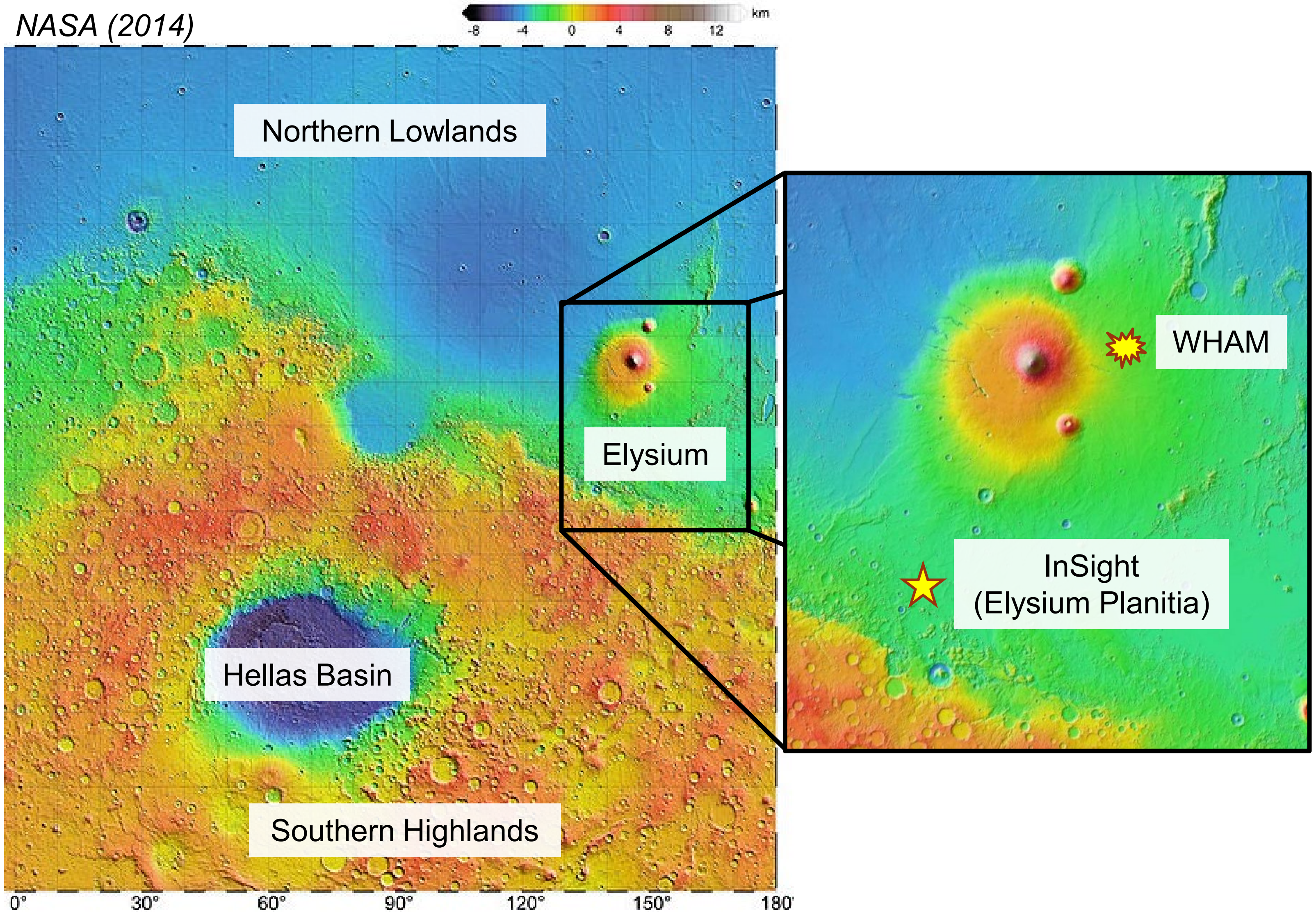
  - This is the Elysium quadrangle.



The arrival

- This is a topographic map of Mars' eastern hemisphere.
  - This is the Elysium quadrangle.
- WHAM will detonate at a site 500 km east of Elysium Mons.
  - This lies on our 30° epicentral angle.
  - The hard, unbroken basalt will transmit the impact energy well.
  - It is far from any interesting geological features.

Response to objections

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- There has never been an accidental nuclear explosion, even when warheads have crash-landed.

This B28 bomb was recovered intact from the seafloor after its aircraft exploded in midair off the coast of Spain.

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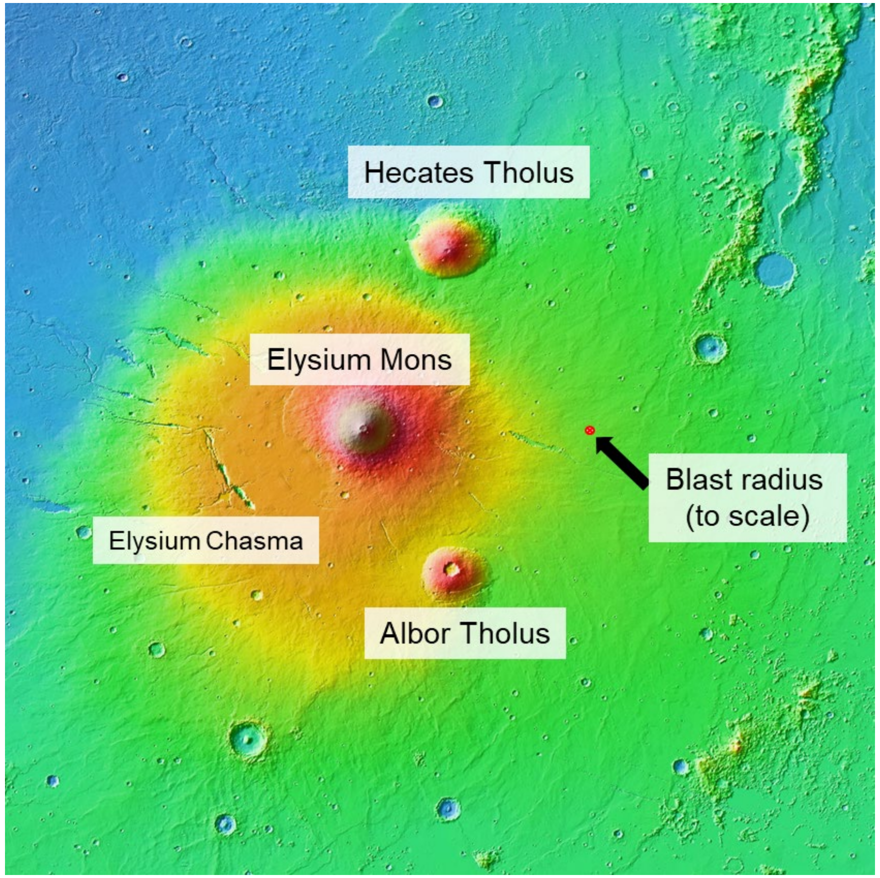
- The fission charge, in turn, is set off by a layer of high explosives.
  - These high-explosives are "insensitive munitions" and cannot detonate due to heat or shock.
- In modern weapons (like the B83), the arming process (which makes the warhead ready to explode) can be performed remotely, once it is away from Earth.

Danger to Mars

- The blast radius of our device is small (15 km) and will not damage or disfigure the Martian surface beyond adding one new crater.



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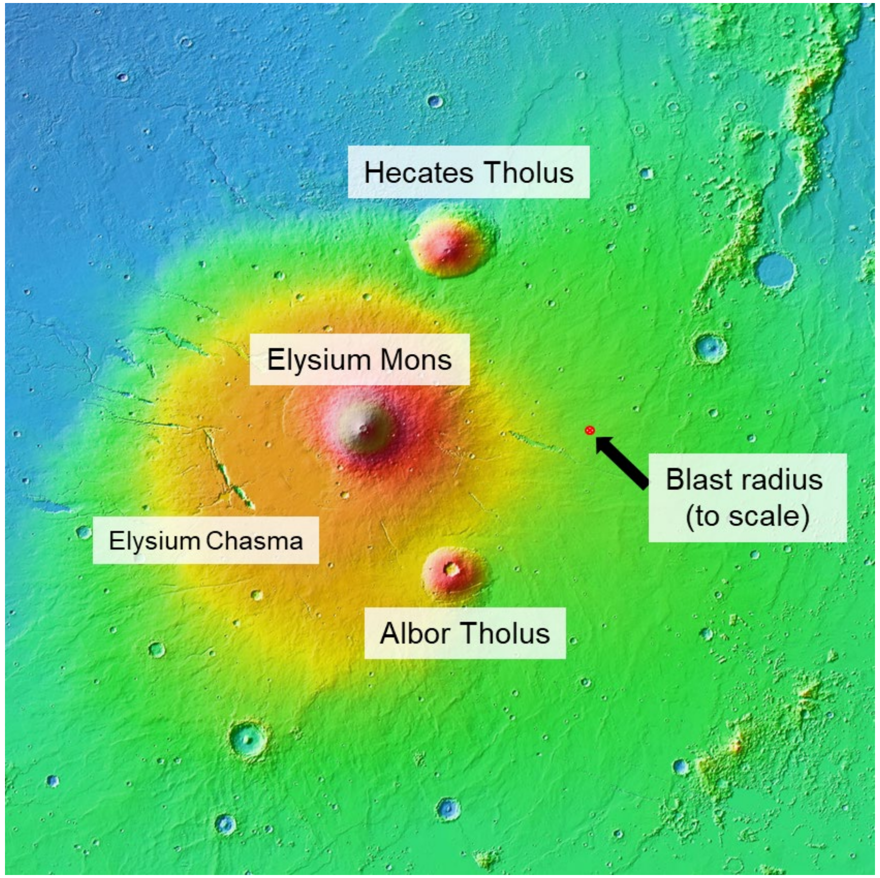

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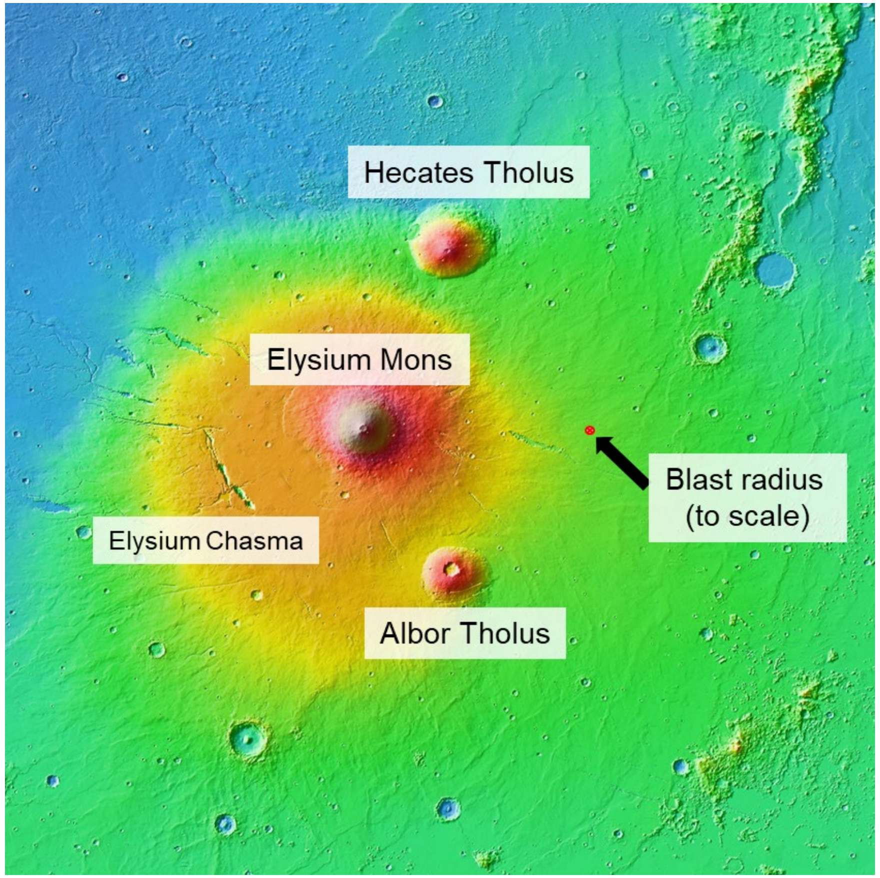
  - Most interplanetary missions require costly Planetary Protection procedures to prevent contamination by Earth germs, but WHAM is entirely self-sterilizing.



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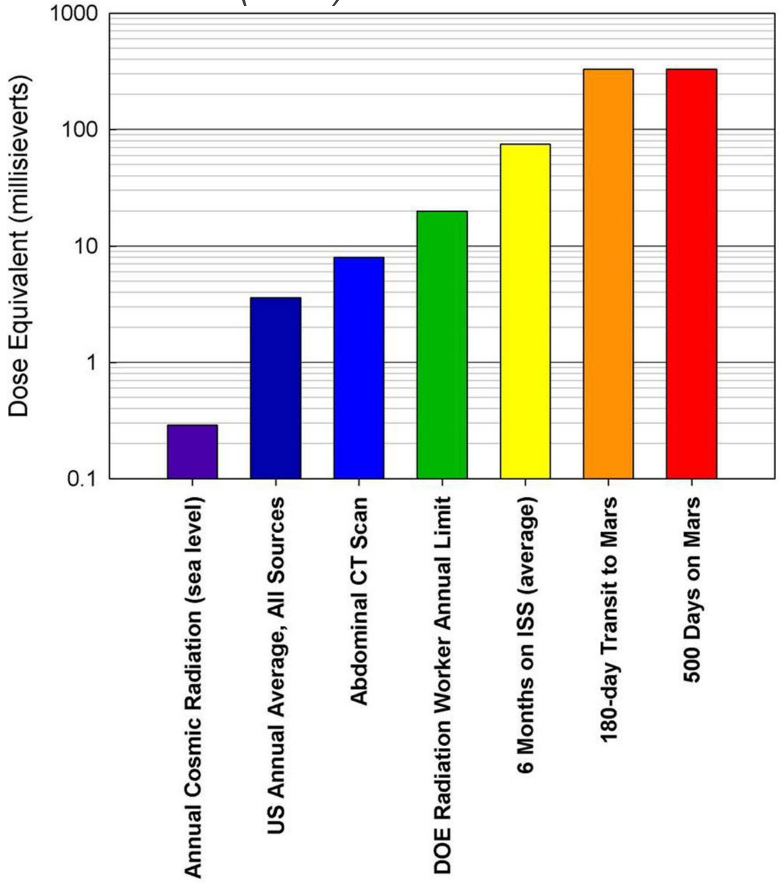
NASA (2013)



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- Without a magnetic field, the Martian surface is constantly bombarded by radiation.
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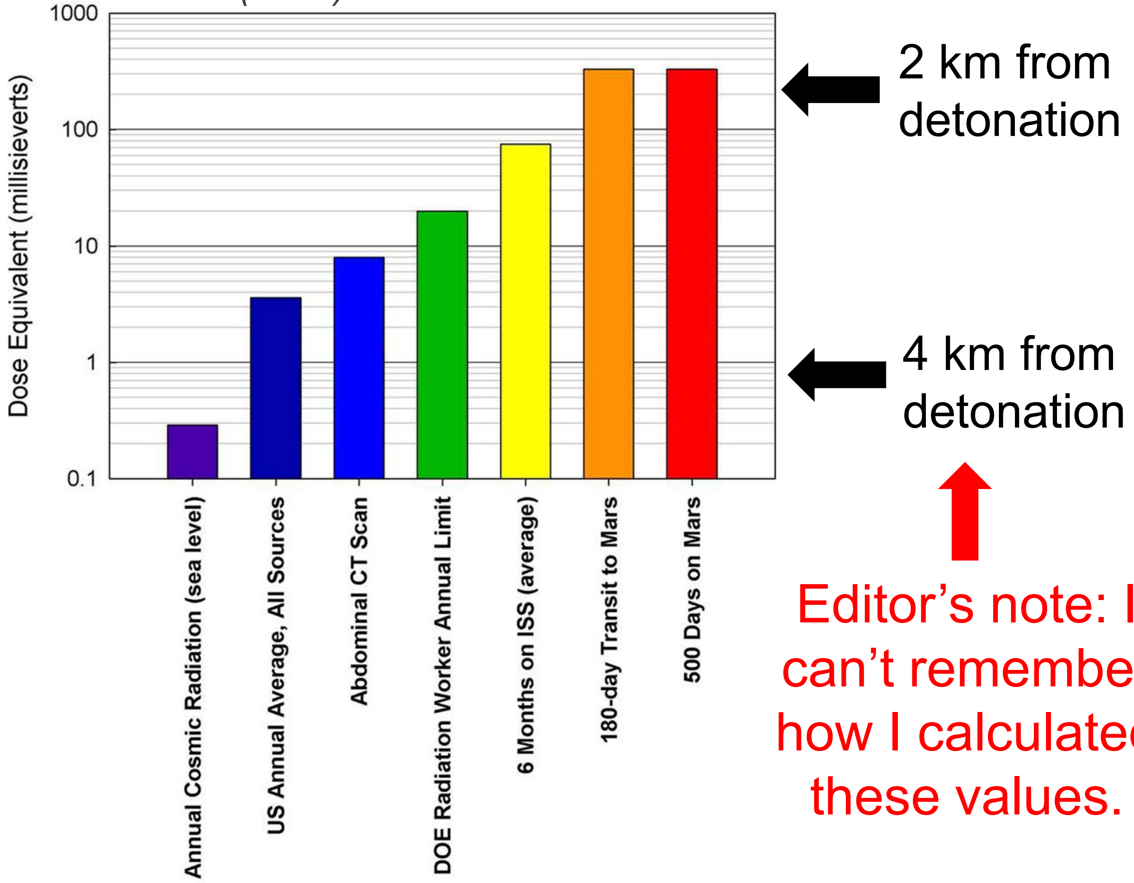

Editor's note: I can't remember how I calculated these values.

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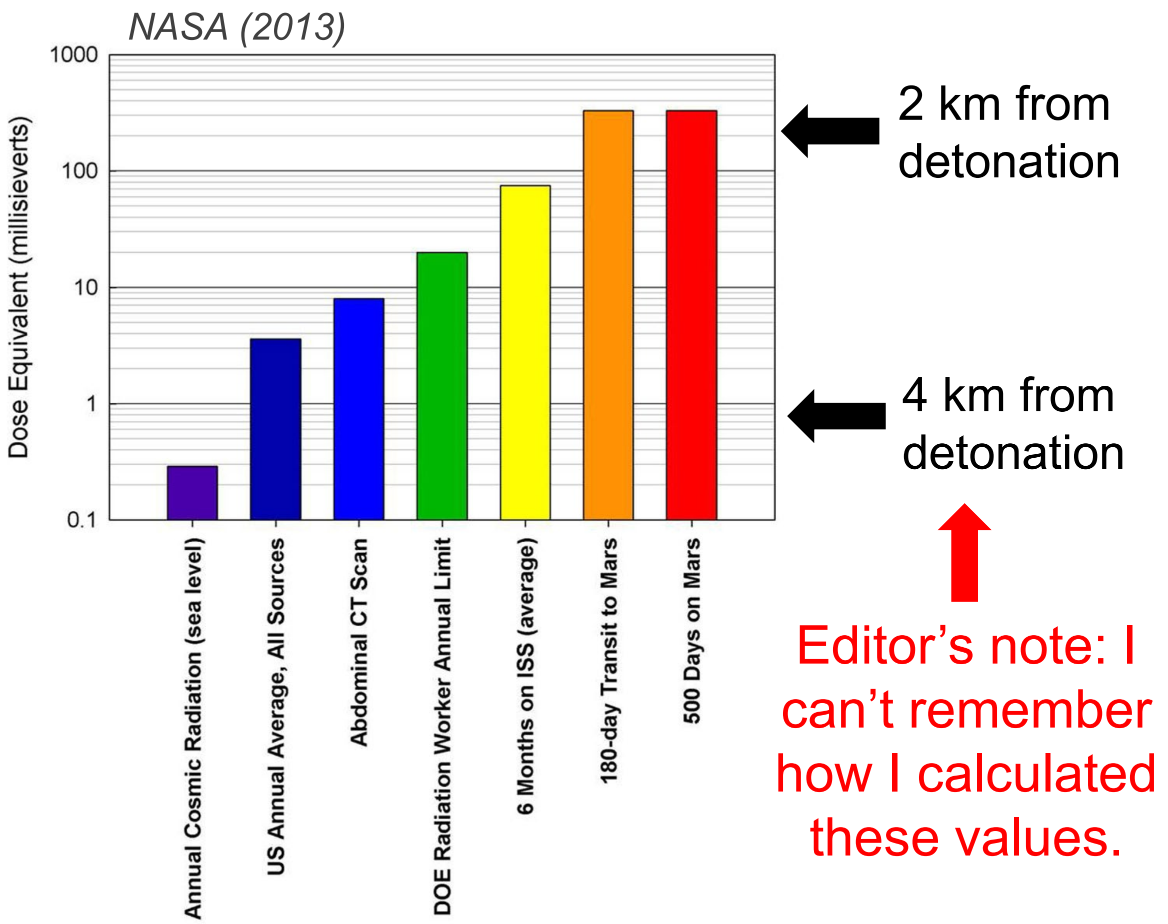
- Any existing microbes are either adapted to high-radiation environments or are sheltered from surface radiation.
  - Radiation cannot penetrate solid rock.



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- Since WHAM does not require orbiting Earth, will not permanently or temporarily install the warhead on Mars, and is not testing the capabilities of the B83, we're ok.

Furthermore: "The use of military personnel for scientific research or for any other peaceful purposes shall not be prohibited. The use of any equipment or facility necessary for peaceful exploration of the moon and other celestial bodies shall also not be prohibited."

- This clause permits the use of military hardware for peaceful scientific missions.

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  - How much R&D is needed to make the instrument?
  - How heavy is it?
- WHAM's R&D piggybacks off both InSight and the strategic defense budget. No new technology is needed.
- The weight will be comparable to other interplanetary missions.

Mission	Launch year	Mass (kg)	Cost (M$)
Mars Pathfinder	1996	264	265
Stardust	1999	391	200
MESSENGER	2004	1108	450
Deep Impact	2005	650	330
Dawn	2007	1218	472
Kepler	2009	1052	640
GRAIL	2011	307	496
InSight	2018	721	830

Selected NASA Discovery program missions. The WHAM mission would weigh at least 400kg, but cost very little.

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  - (https://www.nti.org/analysis/articles/us-nuclear-weapons-budget-overview/)

- This cost includes the storage, security, and maintenance of our remaining 6200 warheads, as well as weapons research and training.
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- By removing two (or more) warheads from the stockpile, WHAM will (eventually) become the only **profitable** interplanetary mission.

In conclusion…

- We’ve got all these nukes just laying around collecting dust and tax dollars.
- We’ve invested more than 40 years and a billion dollars getting a seismometer to Mars.
- We can send some of our nukes to Mars to make sure that we get the data we want.
- This idea is cheap, safe, and easy. It only *sounds* far-fetched.