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Scientists are using artificial intelligence to see inside stars using sound waves

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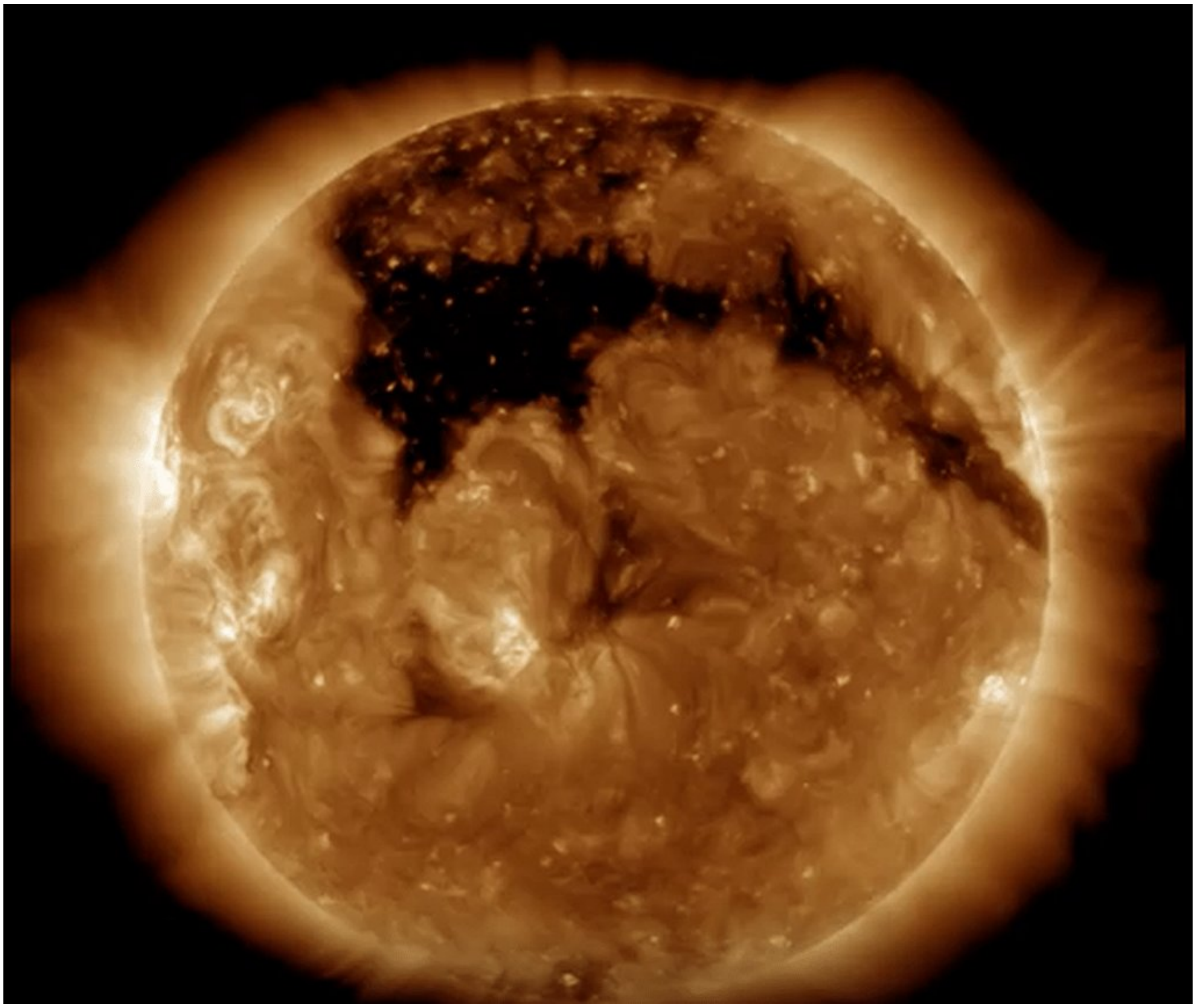


Credit: NASA

How in the world could you possibly look inside a star? You could break out the scalpels and other tools of the surgical trade, but good luck getting within a few million kilometers of the surface before your skin melts off. The stars of our universe hide their secrets very well, but astronomers can outmatch their cleverness and have found ways to peer into their hearts using, of all things, sound waves.

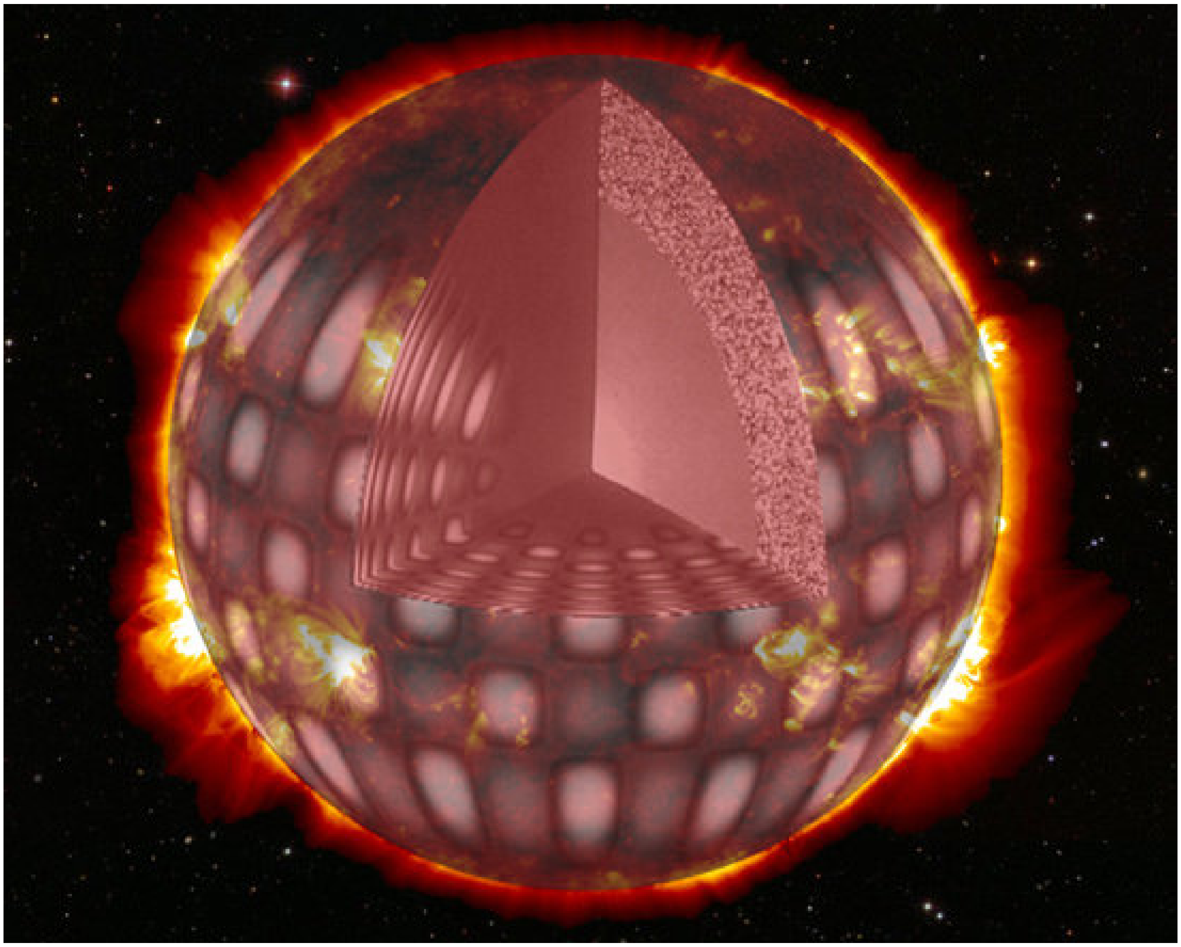
Starquakes

"Sound waves in space" is a pretty confusing phrase, but don't worry, these sounds waves stay strictly within their stellar spheres. Every star is a dynamic, vibrating maelstrom of intense frenetic activity. On the inside you have the insanity of the nuclear core, forging new elements by the second at temperatures of millions of degrees. On the outside you have the vacuum of space itself, colder than cold at a temperature barely above absolutely zero.

The job of the body of a star is to get all that heat from the inside to the outside, where it desperately wants to go. While throughout their lives stars exist in a state of equilibrium (they're not exploding in a supernova or collapsing into a black hole right now), any slight disturbance can persist as slight bumps and wiggles throughout the bulk of the star – and on its surface.

"Bumps and wiggles throughout the bulk" are also known as sound waves.

There are a few different ways that stars can start screaming. If a patch or entire layer of star-stuff just happens to be a little bit more dense than average, it can trap radiation underneath it, preventing it from escaping. This heats the layer abnormally, causing it to rise and expand, freeing the trapped heat and allowing the layer to cool back off and settle back to the way it started, resetting the entire process. As this cycle continues, sound waves emanate from the pulsation, temporarily encompassing the entire star.



As stars pulse, heave, and quiver from the complex physics in their interiors, their surfaces vibrate with standing sound waves, which we can see from a distance as tiny changes in brightness.

The convection inside the star plays a role too, as giant blobs of stellar material make their way up to the surface, touch the coldness of space, release their heat, and slink back down into the fiery depths. This continuous stirring, like the boiling surface of a pot of water on the stove, resonates throughout the entire star.

Even a nearby companion can drive the creation of sound waves, as the gravity of the orbiting partner tugs and tweaks on the star, reaching out with invisible gravitational slaps and squeezes, igniting more quakes.

Simulation meets sound wave reality

Stars host all sorts of vibrations inside them. Some only last for a little while, some stay for a long time. Some stick just to the surface or just below it, while others zip up and down, ricocheting off the dense core in the process. This means that the vibrations are very useful diagnostics into the conditions of the star. How old is it? What percentage of heavier elements swim around inside it? How are the various internal layers connected (or not) to each other?

The particular mix of ingredients that go into any particular star subtly changes the kinds of vibrations that live on the surface. It's like stellar phrenology but actually science: studying the bumps and wiggles on the surface of a star reveals its character.

This is where computers come into the picture in a big way, and why asteroseismology is a relatively new field. We don't have catalog upon catalog of dissected, displayed stars to compare against living specimens. Instead we have computers – lots of them. Model after model, we bake every possible kind of star in our silicon ovens, spanning the range of every kind of input parameter manageable.

And we tune the physics too, tinkering and toying with various theories on how stars work on the inside. How well are the cores connected to the atmospheres? How important are magnetic fields? What's the relationship between rotation and heat transfer? Important questions with not a lot of answers.

Rise of the machines

These extensive simulations of pretend stars give us the necessary "back catalog" to compare against observations. But the observations aren't easy. We can't observe the surface of most stars – we can only watch distantly as the light from the stars dims and brightens.

Some of that variation is due to random flare-ups or other temperamental activity. Some of that variation is due to an orbiting planet crossing the line of sight. And some of that variation is due to sound waves crashing through the star and bubbling up onto the surface, ever-so-slightly changing the brightness in the shine of the star.

It's here where theory meets reality, but the observations are extremely short (we don't get to observe the stars for very long), and incomplete (we can't see all the vibrations on the surface). To better make sense of it all, astronomers recently developed an entire machine learning pipeline to compare data with models.

In this pipeline, the scientists trained a neural network on the simulations, allowing it to discover all the subtle relationships between model input parameters (mass of the star, metallically, etc.) and vibration patterns on the surface. Then, using that sophisticated knowledge, the algorithm can look at real stars with real, messy data and find the best match in the models. This technique is still in its infancy when it comes to asteroseismology, but opens up a promising future for mining through stellar samples, understanding how stars work on the inside.

More information: Luc Hendriks, Conny Aerts. Deep Learning Applied to the Asteroseismic Modeling of Stars with Coherent Oscillation Modes: arXiv:1811.03639 [astro-ph.SR]. arxiv.org/abs/1811.03639

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