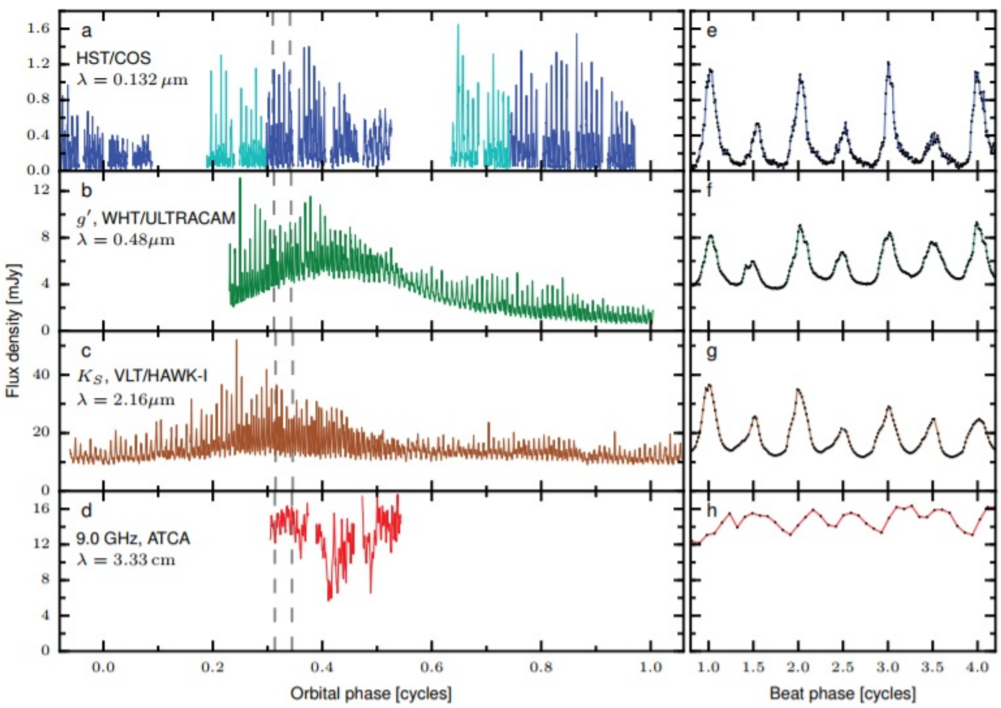
AR Scorpii: A new type of pulsar

Graham Doskoch Follow
Dec 31, 2017 · 5 min read

I'm interested in pulsars, spinning neutron stars that emit radio waves that are detected on Earth as a periodic, varying signal, a set of "pulses". Pulsars are interesting objects in themselves, and they've been studied for 50 years — the anniversary of the first detection was this past November. They're interesting objects in and of themselves, with a peculiar internal structure marked by exotic states of matter under extreme conditions. They're also useful for things like pulsar timing arrays, which let us study gravitational waves.

In mid-2016, new observations of a peculiar object showed something extraordinary: a binary system behaving like a pulsar — without a neutron star! This object is AR Scorpii, and it consists of a red dwarf and a white dwarf. Red dwarfs are stars somewhat similar to our Sun but much less massive. They're cooler and dimmer, and can live for much longer, and they may be the most common type of star in the universe. The nearest star to the Solar System, Proxima Centauri, is actually a red dwarf.



Emission from AR Scorpii across ultraviolet, optical, infrared and radio wavelengths (Figure 2 of Marsh et al. (2016)).

A white dwarf is a stellar remnant — a dead star, if you will. It no longer supports itself through nuclear fusion; instead, the degeneracy pressure of electrons packed tightly together balances with the force of gravity. White dwarfs in binary systems can do interesting things, and can even be the progenitors of supernovae, but AR Scorpii was the first known case of a white dwarf acting in part like a pulsar.

The observations

The paper announcing the discovery was Marsh et al. (2016) (you can read a free version on arXiv). The system had been known for 40 years, but can been classified as a simple lone variable star, with a period of about three and a half hours. The authors first looked at light curves taken in the visible part of the spectrum, which showed only the red dwarf. Using photometry — a way of analyzing how the star is moving relative to Earth — they determined that it was in a binary system, and therefore must have a companion. X-ray emission and models of the masses in the system point to a white dwarf as the companion; a neutron star simply wouldn't fit.

Seven years of optical data shown in a light curve of AR Scorpii (Figure 1, Marsh et al. (2016)).

The astronomers also observed AR Scorpii at ultraviolet, infrared and radio wavelengths — really, checking all across the electromagnetic spectrum — using a selection of instruments, including the Very Large Telescope and the Hubble Space Telescope. They found pulsed emission with a period of 1.97 minutes, including radio pulses, akin to emission from pulsars. This period is much longer than the periods of most classical pulsars, by a couple orders of magnitudes. However, on cosmic timescales, even a period of minutes is like the blink of an eye.

How it works

Pulsar emission is complicated; AR Scorpii's emission is possible even more so. It's an intermediate polar, a binary system consisting of a red dwarf and a white dwarf, where the red dwarf is transferring matter to the white dwarf. This is only an temporary evolutionary stage, and it's unknown how long this could last for AR Scorpii. What's interesting about intermediate polars is that the white dwarf component has a strong magnetic field — and stellar magnetic fields can do weird things.

The exact workings of the emission in this system were unclear at the time of Marsh et al.'s publication. A second paper published in the spring of 2017, Buckley et al. (2017) (arXiv) added more observations and went into more detail about this mysterious emission, partly from the white dwarf and partly from the red dwarf.

As expected, the system is likely powered by the loss of rotational kinetic energy by the white dwarf — *spin-down*. Spin-down is what powers many pulsars; it happens over extremely long timescales and thus provides a constant source of energy. Buckley et al. proposed that the white dwarf accreted a lot of matter sometime in the past, and began rotating quite rapidly. There is little accretion at the moment. The system is therefore behaving quite like a rotating-powered pulsar, emitting synchrotron radiation— radiation from accelerated charged particles, such as electrons.

There are two places in the system where emission occurs:

1. At the white dwarf itself, the strong electric and magnetic fields accelerate electrons to high speeds, leading the synchrotron radiation. There will also be magnetic dipole radiation, also thanks to the magnetic field.
2. At the red dwarf, where the rotating magnetic field of the white dwarf interacts with the red dwarf in a sort of magnetohydrodynamic "wind", producing more synchrotron radiation.

These two mechanisms combine to produce pulsed emission across the entire spectrum.

Why it's exciting

There are a few reasons why I think AR Scorpii is interesting. The obvious one is that it's unique, a new type of object we've never seen before. A new type of star or stellar system also provokes curiosity. Second, the system behaves quite like a pulsar — in fact, Buckley et al. compare AR Scorpii's emission to that of the well-known Crab pulsar. The system's stable — at least on human timescales. The change in period is roughly one in ten million million seconds per second, comparable to that of a pulsar. That won't last forever — remember, an intermediate polar will evolve, as accretion changes — but it's a pretty stunning thought for the moment.

AR Scorpii and AE Scorpii, another intermediate polar, compared to pulsars in an X-ray luminosity vs. spin-down power graph (Figure 8 of Buckley et al. (2017)).

What excites me the most, though, is the red dwarf. Part of the difficulty with detecting pulsars — especially lone pulsars — is that it can be hard to find them, because emission in, say, the visible part of the spectrum is small or nonexistent. However, the red dwarf means that we can find these types of systems at by looking at optical photometry, and we can check previously observed red dwarf-white dwarf systems for this same type of behavior.

What other new systems like AR Scorpii will we find in the future? Will we find more stable emitters? White dwarf pulsars with shorter periods, that could maybe prove useful for pulsar timing arrays? Nobody knows. But if there are more out there, they’re waiting to be discovered.

Astronomy Pulsar