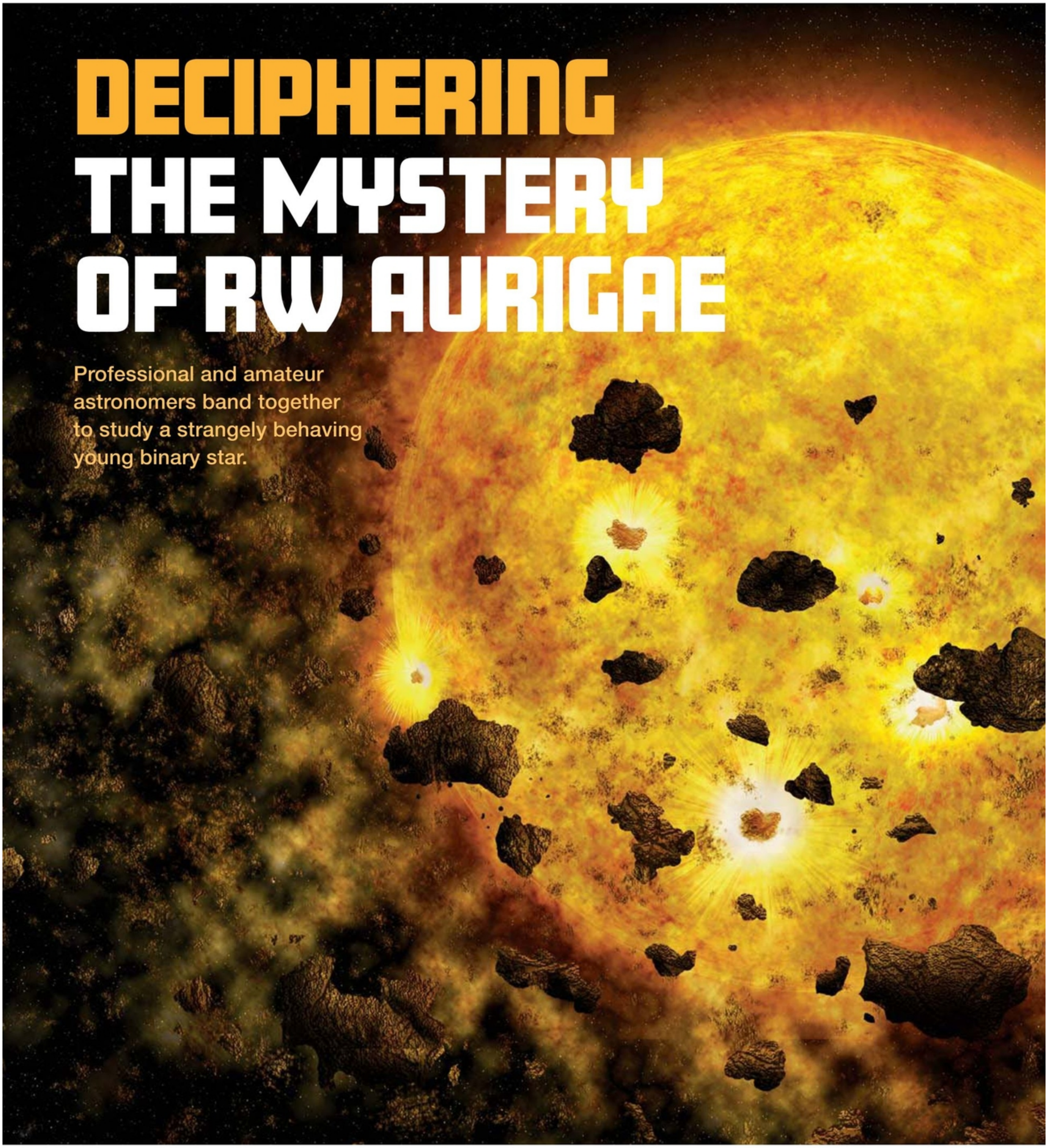
STAR SLEUTHS by Kerry Hensley

DECIPHERING THE MYSTERY OF RW AURIGAE

Professional and amateur astronomers band together to study a strangely behaving young binary star.



ROCKY DEBRIS? This artist's concept shows planetesimal debris falling onto the star RW Aurigae A. Such destruction is one of two main scenarios explaining the star's strange drops in brightness.

The path to becoming an orderly planetary system is a messy one. As young stars collapse onto the main sequence, dust grains in orbit around them begin their long journey toward planethood, racing to cling together and collect gas before furious stellar winds whisk it away. Magnetic fields ensnare ionized gas and siphon it onto the star's surface, causing hotspots that blaze in X-rays. Nearby stars can complicate matters, swinging by and warping the disk.

All this warping, siphoning, collecting, and collapsing has created plenty of work for amateur and professional astronomers alike, who have been observing and modeling the behavior of pre-main-sequence stars for decades. Pre-main-sequence stars can vary in brightness on timescales from minutes to years and at essentially all wavelengths, but the reasons for these variations aren't always known. This is the case for RW Aurigae, a binary of young (about 10 million years old) T Tauri stars in the throes of formation. Typically, RW Aurigae varies over long time scales, punctuated by short brightness dips every few decades. But since 2010, RW Aurigae has been dimming for months at a time every few years, unlike anything recorded for the system before.

To make sense of RW Aurigae's erratic behavior, H. Moritz Günther (Massachusetts Institute of Technology) combined the skills of professional and amateur astronomers to shed new light on this strange binary pair — and potentially catch planet formation in action.

A Combination of Skills

Amateur astronomers from the American Association of Variable Star Observers (AAVSO), an international nonprofit that has coordinated tens of millions of variable star observations to date, have been keeping tabs on RW Aurigae for more than a century. Their records start with measurements from Norwegian observer Sigurd Enebo in 1906. As Günther searched the AAVSO archive for photometry of RW Aurigae, he noticed that many of the measurements he was interested in came from an observer with the initials "DUBF." The initials belonged to Franky Dubois, a 69-year-old retired textile worker and prolific observer in Belgium.

"After about 53 years, astronomy has become one of the principal goals of my life," Dubois says. "Thirty-nine years ago, I started daily observations of the Sun. Today, I still determine five relative sunspot numbers in my observatory at home each day, with an average of 253 observations on a yearly basis."

Günther reached out to Dubois to invite him to collaborate and learned that he was part of a team affiliated with AstroLAB IRIS, a public observatory in Ypres, Belgium. Using the 0.7-meter New Multi-Purpose Telescope — the largest amateur telescope in northern France and the Benelux region (Belgium, the Netherlands, and Luxembourg) — Dubois and others orchestrate an average of 93 observing sessions a year, with a peak of 125 sessions in 2018.

"Each member of the team has his own responsibility, and my responsibility is to collect as many observations as

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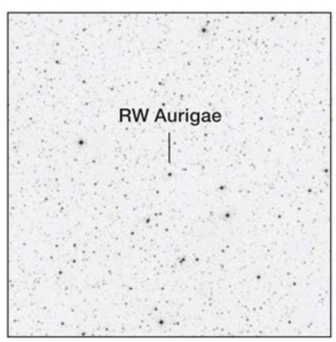
possible," says Dubois. His teammates Ludwig Logie and Steve Rau maintain the telescope while Siegfried Vanaverbeke, a physicist by training, analyzes the data.

In 2014, the team began a program of variable star observations in order to collaborate with professional astronomers. Altogether, the group has provided data and analysis to 27 scientific publications.

Chandra Sheds (X-Ray) Light on the Matter

The decades of ground-based observations of RW Aurigae have given astronomers hints as to the underlying causes of this system's behavior, but the visual-wavelength data don't tell the whole story — especially because the binary pair isn't resolved in the AAVSO observations. To learn more, the team and their collaborators collected X-ray data, which can give insight into the material between us and the star as well as the conditions very close to the star. (Much of the X-ray emission from a young star comes from gas accreting onto the star from its surrounding disk or from the hot, tenuous corona.)



▲ **RW AURIGAE** This binary sits on the southern edge of Auriga, the Charioteer. Its brightness usually varies from about magnitude 9 to 12.5. The star won't be well placed for evening observing for a few months yet; to see it in summer, you'll need to rise well before dawn.

IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; CHART: GREGG DINDERMAN / S&T

"I think the synergy between space telescopes and ground-based telescopes is the part of the work that is new and is a real breakthrough," says Vanaverbeke.

The team analyzed data from the Chandra X-ray Observatory taken in 2013, 2015, and twice in 2017. The secondary star, RW Aurigae B, was fairly consistent over the years: The flux rose and fell, but the overall shape of its spectrum remained the same. Not so for the primary, RW Aurigae A. In 2013, when the system's visual brightness was about average, the star's coronal X-ray emission peaked around 1 keV (rather low-energy, or "soft," for X-rays). But in subsequent observations, when the optical emission was dim, the soft X-ray emission that was so prominent in 2013 practically vanished. This suggests that there was a huge increase in the amount of material between the star and the telescope — jumping by a factor of 70 in 2015 and by a factor of a few hundred in 2017.

In 2017, things got weirder: The star's X-ray emission shifted to higher energies, and a new feature shot up. Previous observations of RW Aurigae A showed an emission line at 6.7 keV, arising from iron atoms stripped of all but two electrons. The 2017 observations were instead dominated by an emission line at a slightly lower energy (6.63 keV), indicating that it came from cooler iron than the 6.7-keV line.

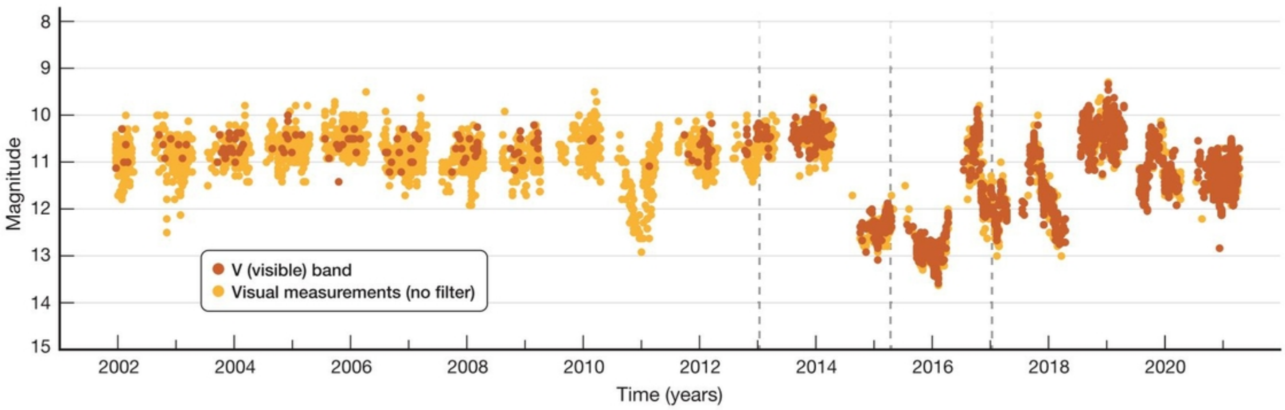
"Cooler iron should emit very few X-rays, so in order to get that much iron emission from this cooler iron you need to have a lot of it," Günther says. The team estimates that the iron abundance in RW Aurigae A's corona is an order of magnitude higher than it is in the Sun. "And then you start questioning where that iron comes from. It essentially must have fallen into the star, because it wasn't there before and stars don't have large reservoirs of iron that suddenly come out without affecting the rest of the spectrum."

So the amount of material around RW Aurigae A has rocketed up by one or two orders of magnitude, and its corona is suddenly rich in iron. What's behind this bizarre behavior?

Planetesimals or Pressure Traps?

One possibility is that in the chaos of formation, collisions between planets growing around RW Aurigae A generated enormous clouds of debris. This dust could be responsible for absorbing the soft X-ray emission that's missing in the later observations and, if it's iron-rich, could cause the enhanced iron in the corona as well.

In this scenario, two planets or planetesimals may have collided in 2011, producing a large brightness dip seen by observers. The fragments from that crash could have collided again around 2015, causing another dimming



▲ **STRANGE BEHAVIOR** RW Aurigae varied sporadically until late 2010, when it began an unusual drop. The system's brightness then plummeted in 2014, as shown by these data collected by various AAVSO observers. Vertical lines mark when the team acquired X-ray observations from the two stars (the two 2017 observations were only two days apart and are combined into a single line).

episode. If by 2017 those planetary fragments had fallen onto the star, that could explain the huge jump in iron emission.

There's another possibility, though. Protoplanetary disks often have striking patterns of bright and dark rings. The most tantalizing explanation for this tree-ring pattern is that baby planets collect gas and dust as they orbit their parent star, carving out dark lanes in the bright disk. But rings can also form thanks to *pressure traps*, high-pressure regions that can collect dust and prevent it from accreting onto the star. Pressure traps can form where gas in the disk freezes or the disk is too dense for the star's radiation to ionize it strongly. (To make matters more complicated, there's also evidence that coalescing planets can cause pressure traps to arise.)

If dust piles up in a pressure trap, it could reach the density implied by the X-ray observations. A gravitational nudge from the close passage of RW Aurigae B could disrupt the pressure trap and send the dust on a collision course with the star. This might explain both the increase in the density and the increase in iron emission, if the dust is iron rich.

Both explanations are exciting. We have indirect evidence of planetesimals accreting onto a star from observations of white dwarfs, but this could be our first opportunity to see it happening in real time. Conversely, if a pressure trap is the cause, then this system could help us better understand the role these traps play in planet formation and accretion. But how do we tell which scenario is actually playing out?

Looking Ahead

Unsurprisingly, it's likely to be challenging. "We don't have enough resolution to see occultations by the planetesimals," says Vanaverbeke. "The amplitude of the occultations would be very small — that would not be observable, I think. So right now, really choosing between accretion of protoplanets and ejection and accretion of dust that is inside the disk and shepherded by tidal accretion will probably have to be because we see chemical differences."

Those chemical differences — things like new elements or ionization levels appearing in the data — might be discernible when the dimming episodes end and RW Aurigae returns to a "normal" state. If the absorbing material around RW Aurigae A disperses, the soft X-ray emission that was all but absent in the 2015 and 2017 observations will shine through once again. That could mean that other chemical species might make an appearance, hopefully clarifying the situation. Seeing those chemical markers "could tell you something about the composition of those grains, and then you can go to a planetary scientist and say, 'I found silicon, iron, and magnesium in a ratio of one to one to one, does it look like a planetary core or not?'" says Günther.

The time scales for the two possibilities might be different as well. In the pressure-trap scenario, the dust grains are separated by size, and grains of different sizes should take different amounts of time to fall onto the star. This could mean that the star is just beginning to accrete the material caught in the pressure trap, and RW Aurigae A's accretion rate might increase over time. On the other hand, in the planetesimal-collision scenario, there might be a wide range of grain sizes that all fall onto the star at the same time.

It's not quite that cut-and-dry, though; as always, protoplanetary disks are complicated. Fragments of planets left over after a collision might themselves undergo collisions, resulting in smaller pieces on orbits of varying eccentricity, which would muddy the calculation. Turbulence and magnetic fields — the two things most likely to keep modelers up at night — have the potential to play a complicating role in either scenario.

Günther, Dubois, and Vanaverbeke plan to keep an eye on the system to see how long it takes to go back to normal — if that ever happens. "RW Aurigae has surprised us so often, it's entirely possible that something unexpected happens," Günther says. "And I don't know what happens after that!"

■ **KERRY HENSLEY** is a planetary scientist and science writer based in Boston.

GREGG DINDERMAN / *S&T*, SOURCES: AAVSO AND GÜNTHER ET AL. / *ASTRONOMICAL JOURNAL* 2018