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Saving Kepler

The Kepler space telescope has been wobbling around the sun for almost a year now, its photometer no longer scanning the stars for Earth-like planets. The industry-government team in charge of the $650-million planet hunter has come up with a proposal for restarting science work with the wounded spacecraft. Soon that team will learn whether NASA HQ will authorize the new K2 mission at a cost of perhaps $11 million a year. Erik Schecter explains.

If reviewers at NASA headquarters give their blessing, the malfunctioning Kepler space telescope could be back in action, this time balancing itself largely with the pressure of charged particles from the sun as it hunts for exoplanets, supernovae and other phenomena.

Ironically, this very same solar pressure posed a problem for Kepler last May, when a second reaction wheel failed inside its navigation system. Kepler and other spacecraft spin reaction wheels at different speeds to stay properly oriented. With only two reaction wheels, Kepler could have used up all its fuel trying to keep the solar wind from turning its telescope aperture toward the sun and its damaging rays. Engineers at Ball Aerospace in Boulder, Colo., and scientists at NASA's Ames Research Center in California rushed to get the spacecraft wobbling safely around the sun in an orbit that would minimize its fuel use and give them time to figure out how they might resume science work with just two reaction wheels. The team expects to find out in May if the proposed mission they call K2 will proceed. This is the story of what went wrong with Kepler, and the workaround the Kepler team devised.

Reaction wheels begin to fail

For four years, scientists at NASA Ames Research Center employed Kepler to find Earth-like planets orbiting sun-like stars at distances that could support liquid water and possibly life. Some 150,000 stars in the constellations of Cygnus and Lyra were scanned for intermittent drops in light output that scientists expect to see when a planet

Kepler space telescope on its upper stage on the Delta rocket.

NASA

Kepler's mirror could be shifted to a new field of view every 80 days.

crosses, or transits, in front of a star. By the time of the second reaction wheel failure, Kepler had discovered 3,538 potential planets, 246 of which have so far been confirmed by other telescopes.

When Kepler was launched in 2009, it had four reaction wheels in separate housings. Each wheel weighs 2.3 kilograms and resembles a squashed aluminum top hat 33 centimeters in diameter. The reaction wheels must spin at just the right speed to generate momentum to counter any unwanted turning of the spacecraft. Friction is the enemy inside these reaction wheel assemblies, so the wheels are attached to Kepler by lubricated ball-bearing assemblies and axles. The temperatures are controlled by plastic patch heaters commanded from the ground.

Only three reaction wheels are required for this sort of balancing act, but "it's very common practice for spacecraft to fly with four, having the wheels in skewed axes, so you can afford to lose any one of the four wheels and still control the spacecraft," says Charlie Sobeck, an electrical engineer and NASA's Kepler deputy project manager.

The Kepler team was aware that losing a reaction wheel was a possibility, because it's happened on other NASA spacecraft. The reliability of reaction wheels has always been a challenge because moving parts tend to wear out, says Ball's John Troeltzsch, an aerospace engineer and the company's Kepler mission program manager.

NASA'S Sobeck puts it like this: "As best I can determine, reaction wheels are born either good or bad…If they are bad, they're going to fail, and if they are good, they are going to last forever. And there's no ready way to tell one from another."

Kepler's reaction wheels were built by Ithaco Space Systems, which has since been bought by UTC Aerospace. A spokesman for UTC Aerospace referred any questions about reaction wheels to NASA.

In July 2012, during a routine semi-weekly check-in with Kepler, Ball ground control staff realized that a reaction wheel had failed. NASA and Ball experts were unsure what caused this failure, but they were not panicking. The spacecraft's "hot spare" meant the science mission could continue unaffected. In the meantime, NASA scientists reviewed data from the defective reaction wheel to see if it had shown any overlooked signs of trouble. They discovered that, yes, six months prior to failure, the motor turning the wheel was drawing more current than normal, suggesting it was taking more energy to keep the wheel turning at the right speed.

The Kepler team was already exploring ways to prolong the lifespan of the remaining reaction wheels when, in January 2013, a second reaction wheel began drawing more current. This was a far more serious development, but it was hard to know what to do, because no one was sure why the wheels were failing. "So we did a number of things," Troeltzsch says.

More current was sent into the plastic patch heaters to raise the temperature inside the housings by a few degrees. The idea was to re-lubricate the bearings.

In addition, the Kepler team didn't let the wheels spin more slowly than 300 rpm. "There was some theory that if you ran them very, very slowly, then any damage in the [ball] bearing could compound," Troeltzsch says. Ball engineers also didn't let the wheels change rotational direction, which is sometimes done to counteract solar pressure.

Kepler's focal plane array detects the dip in intensity when a planet crosses in front of a star.

NASA/Ball Aerospace

Flying on two reaction wheels

Despite it all, the second wheel failed last May, and the spacecraft turned its solar panels flat toward the sun, exposing them to the force of the solar wind. This potentially could have caused Kepler to twist so far that the sun would shine inside the telescope and deform the black-coated interior of its barrel. A bigger danger was that too much fuel would be expended trying to keep the spacecraft stable. The team used the vehicle's eight thrusters, each about half the size of a white-board marker, to right the spacecraft. They accepted that Kepler would need to orbit in a wobbly rest state to use as little as possible of its remaining five-and-a-half kilograms of hydrazine fuel.

As the situation stood, the two remaining wheels could control pitch and yaw, but not the roll of the vehicle. This meant it could point anywhere in the sky, but then it would drift, making the stars appear to rotate. Any images would be blurry, so the 4.7-meter-long telescope ceased operation and was left pointing in the general direction of the North Star while the team tried to figure out how Kepler might get back to work.

The breakthrough came from Doug Wiemer, a staff consultant for Ball. He suggested using the sun itself to control the roll, which he had seen done with the U.S. Navy's GeoSat Follow-On satellite, a radar altimetry spacecraft whose reaction wheel electronics wore out after 10 years. The idea was to tip Kepler over on its side so the sun's pressure would fall evenly on the solar panels, keeping the vehicle from rolling.

The tradeoff was that the telescope would have to point in the plane of its own orbit around the sun. The new reliance on this delicate combination of reaction wheels, solar pressure and thrusters ruled out maintaining Kepler's original, constant field of view. Every 80 days controllers plan to shift to a new field of view. The team will use the time between each pair of fields as an opportunity to download the light curves — graphs of light intensity — collected from the stars observed, explains Sobeck.

There's also a new communications challenge. The Kepler team will need to pause collections once every 80 days to communicate with the spacecraft, which means a heavy dose of automation will be required in between. "What we do is we give it a playbook. We write the entire playbook up, and we load it up to the spacecraft and say, 'Here's what we want you to go do for 80 days,'" says Troeltzsch. Should something go wrong during that period, Kepler will reorient itself vis-à-vis the sun and go into "rotisserie" spin, sweeping its antenna into space and eventually in the direction of Earth.

The honeycombed blank for Kepler's primary mirror in a clean room.

K2: Proposed science mission

NASA officials canvassed the astronomy community in August for ideas about how they might utilize a K2 mission. A few dozen replies came back. As expected, many suggested their pet projects, but says NASA Kepler project scientist and astrophysicist Steve Howell, there were common themes, including the continued investigation of extrasolar planets (albeit smaller ones going around smaller stars), studying black holes at the center of active galaxies, and scanning for supernovae.

Those hunting for supernovae hope that K2, by scanning distant galaxies, will chance upon a supernova with an early light curve, one in its infancy, a phenomenon that could not be captured from Earth. This might offer scientists insight into what actually exploded. Right now, no one is sure what creates a supernova, whether it is a single or binary star, says Howell. Other researchers wanted to find black holes still bombarding their galaxies with high-energy X-rays and gamma rays.

The Ball and Ames team submitted a Senior Review Proposal for the K2 mission to the NASA astronomy committee in January. The team was scheduled to follow up with an oral presentation detailing the results of a 30-day test of its K2 concept. If the committee accepts the scientific case made on behalf of the mission, it will then decide how much funding K2 should get, sending along its recommendation to NASA Headquarters for a final decision in late May.

Howell says the competition for K2 funds will be tough because of its home in the NASA Astrophysics Division, which includes Hubble, the Chandra X-ray observatory "and all these sorts of famous missions NASA has launched."

Still, Ball officials think the K2 mission has a very good shot at being accepted. "We are very confident that NASA is going to approve this idea… based on what I've heard from the astronomers, based on what I've heard from NASA, based on the validity of our idea, and the huge investment that's been made in Kepler," says Troeltzsch.

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