“Immature” Avalanche of Nebular Particles Possible in Star Formation, Finds FAST

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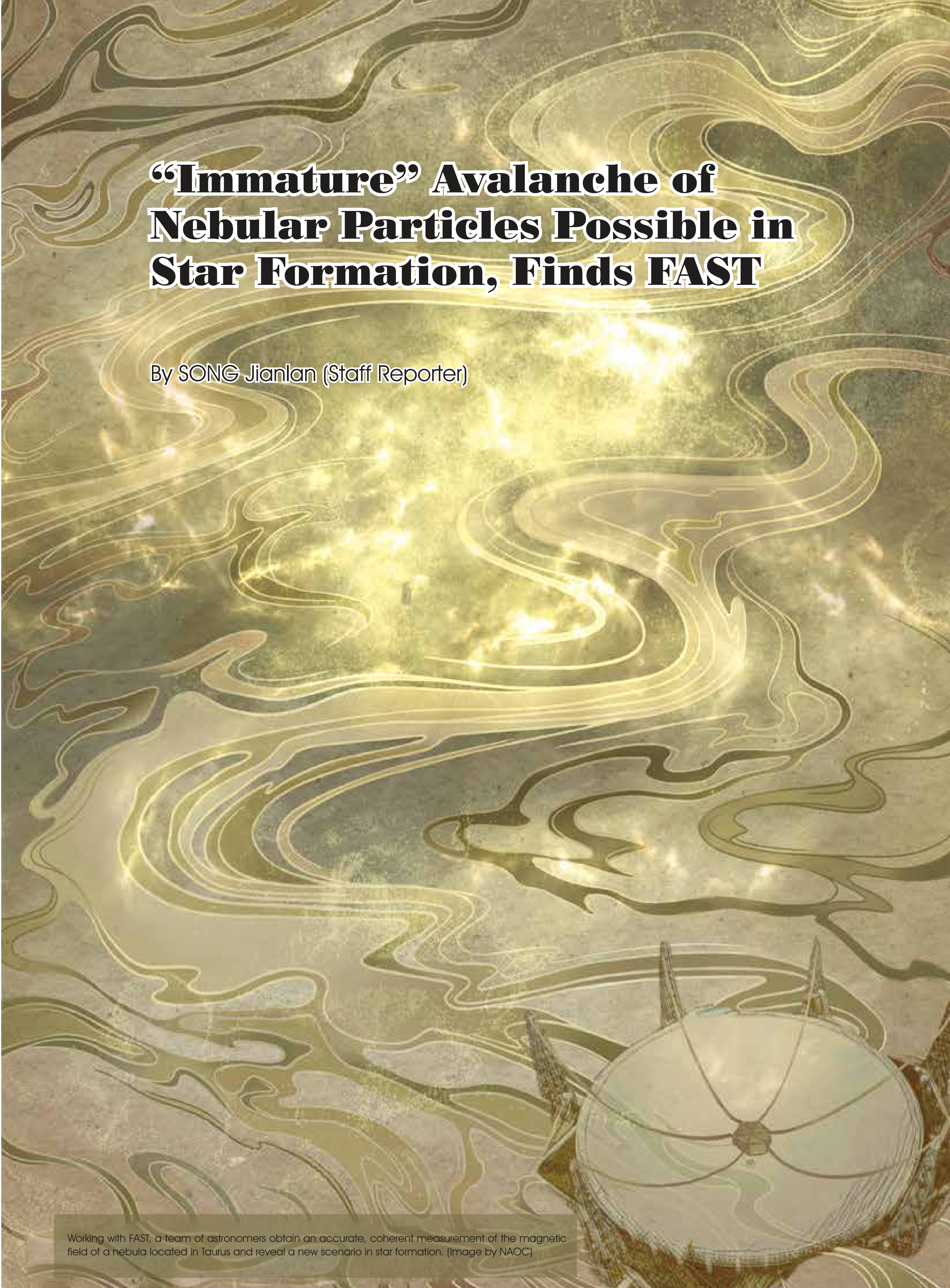

Working with FAST, a team of astronomers obtain an accurate, coherent measurement of the magnetic field of a nebula located in Taurus and reveal a new scenario in star formation. (Image by NAOC)

Scientists have sought to measure the magnetic fields of nebulae, which are believed to be the matrix of stars, in the hope of better understanding star formation, as the flux of magnetic fields across different parts of these "clouds" might give some clues about how stars are born. Decades of efforts have converged to build up a method called Zeeman measuring to reconstruct the magnetic strength from the observed spectrum. Unfortunately, accurate measuring is sparse due to the great difficulty in observation.

Filling this gap, a team of scientists from the National Astronomical Observatories, Chinese Academy of Sciences (NAOC) reported early January in *Nature* their successful measurement of a magnetic field of 4 μGauss from L1544, which is the relatively condensed core of a nebula located in Taurus. This marks a magnetic field strength only about one hundred thousandth that of Earth. The team made an accurate HI narrow self-absorption (HINSA) Zeeman effect observation with aid from FAST, the Five-hundred-meter Aperture Spherical Telescope of China. Combining data from Zeeman measurements of quasar HI absorption, HI emission, OH emission and HINSA, they reconstructed a coherent magnetic field structure throughout the cloud, transecting the cold neutral medium, the molecular envelope and the dense core L1544, with similar orientation and magnitude. Their analysis revealed a possibly "immature" fall of particles in this prototypical pre-stellar core, which happens to be in its early transition from a starless state to a proto-stellar phase, with progenitors of stars beginning to take shape.

The First Kick

Peaceful and quiet as the diffuse nebulae are, under some suitable conditions they can condense and "implode" to give birth to stars.

The "floating" particles in these "clouds"can fall on their own gravity, according to a star-formation model, when the magnetic strength cannot sustain them. In this case these particles will heat up and become plasma as a result from their mutual friction on the way falling to the mass center of the cloud. In prime conditions, the high temperature and pressure can trigger a nuclear fusion reaction to produce a star.

Therefore, loss of the balance between the magnetic strength and the gravity of the particular matter in these "clouds" acts as "the first kick" to trigger the avalanche. When the particles in the nebula aggregate together, the density grows bigger, eventually the magnetic field can no longer support the gravity of the particles, and hence arrives at a supercritical sate that leads to a collapse. The model describes this scenario as a "dissipation" of magnetic field, the culprit of the collapse. What could contribute to the dissipation of magnetic field, however, has remained elusive.

This supercritical state in L1544 might have occurred earlier than previously thought, say the authors, based on their observation using FAST.

The team measured the magnetic field strength of the nebula and reconstructed the coherent magnetic field transecting its peripheral part through its dense core, namely L1544. The core has drawn the attention from many astronomers as it seems to be on the brim of producing a star – it happens to be in an early transformation from a starless phase to the "pregnancy" to bear a fetal star. They discovered that in the "envelope" – a region wrapping up the core L1544 of the nebula – the magnetic field has already diminished to somewhere too weak to sustain the particles from falling. This region has a magnetic field comparable to that of the surrounding atomic, diffuse cold neutral medium, despite its significantly larger density. This means a large drop in magnetic flux relative to the mass, a necessity for star formation, could have happened when the atomic cold neutral medium turned into molecular envelopes. In contrast, in a scenario previously conceived, the magnetic field would not dissipate until the condensed cores form out of envelopes. The dissipation seems to occur earlier than traditionally believed.

"Our results show that the magnetic field strength remains about the same extending from the peripheral regions to the core, despite the big variation in density. This means, before the nebular matter gets as dense as in the envelope region, the transition has occurred – which is earlier than previously believed," says Prof. LI Di, the corresponding author of the paper and principal scientist of FAST.

This naturally raises new questions on the mechanism of magnetic dissipation. Previously, a hypothesis called "ambipolar diffusion" attributes the dissipation to the decoupling of neutral particles from plasma in cloud cores. If the dissipation occurs earlier, in the transition from cold neutral medium to molecular envelope rather than in the cores, this model will not hold water anymore, as such decoupling is impossible in the cold, neutral medium.

"We might need theories alternative to ambipolar diffusion to explain this," says Prof. LI.

"The Only Direct Probe of Interstellar Field Strength"

According to a well-agreed model for star formation, in the evolution from diffuse, cold molecular gas to a newborn star, the subtle balance between the magnetic field and the nebula matter's own gravity plays a key role: the magnetic field gives pressure to the mostly charged particles, drives them to move in high speeds, and hence provides necessary momenta to prevent them from falling on each other. Once this magnetic field declines to a critical value, the latter would fall on their own gravity.

To understand this scenario, accurate measurement of the magnetic field of a nebula in transition from a pre-stellar to a proto-stellar state is crucial. For this sake, the Zeeman effect offers the only direct probe. A spectral line will split into several components in the presence of a magnetic field, hence observation of the spectral line can reconstruct the information about the magnetic field. However, the particles of a star-forming nebula are mainly molecules – they mostly produce a weak Zeeman effect difficult for instruments to pick up; and their complex chemistries also add to the difficulty in tracking the signals.

A discovery by LI and Paul Goldsmith in 2003 shed new light on this technology. When working with the Arecibo telescope, they found a feature called atomic-hydrogen narrow self-absorption (HINSA) in the spectra of molecular clouds they observed. HINSA produces a much more prominent spectral feature and responds strongly to variations in magnetic field strength. These make HINSA Zeeman effect a promising probe of the magnetic field in remote molecular clouds – if only at a sufficient resolution. It requires a large, well-calibrated telescope that can detect radiowaves of decimeter wavelengths.

Now FAST makes their dream true.

"The recent FAST result adds to the number of Zeeman studies, but more importantly is unique in that it helps fill in a gap between observations in the diffuse interstellar medium (HI emission Zeeman), where magnetic pressure clearly dominates gravity, and in molecular clouds and cores (OH and CN Zeeman), where gravity is comparable to or dominates magnetic pressure," remarks Richard Crutcher, Professor at the University of Illinois, Urbana, USA. "The HI self-absorption result toward L1544 probes an intermediate state, where gravity clearly was not able via ambipolar diffusion to reduce the relative importance of the magnetic field. Hence, a different physical process than ambipolar diffusion is required. That is why this new result is unique and important," he adds.

"It does suffer however for being only a single result toward a single cloud, with again only the line of sight component of the magnetic field being measured. Hopefully, FAST will continue this program to add many more clouds to the single result and conclusively test the ambipolar diffusion model," he comments.

In a briefing published in the same issue of *Nature*, Prof. LI reveals a plan to continue his exploration by taking a systematic survey of the HINSA Zeeman effect in star-formation clouds, aiming to increase the cases of measurements of such clouds.

References

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