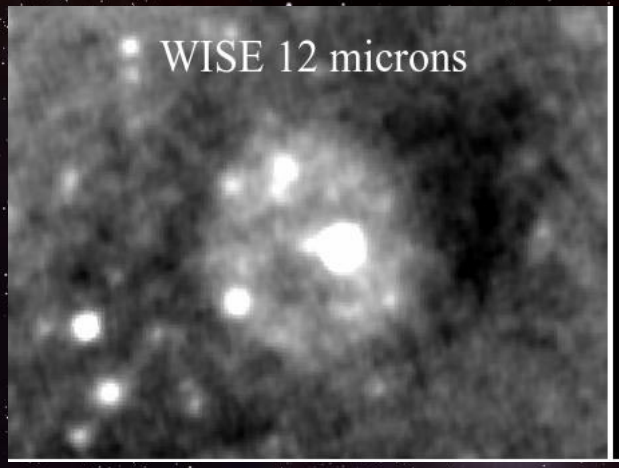
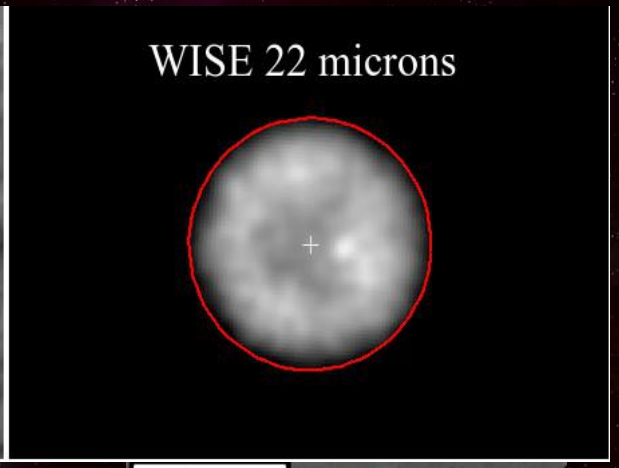
# An Exceptional Supernova Remnant: Pa 30
# --The Remains of a Late 12th Century Historical Supernova --

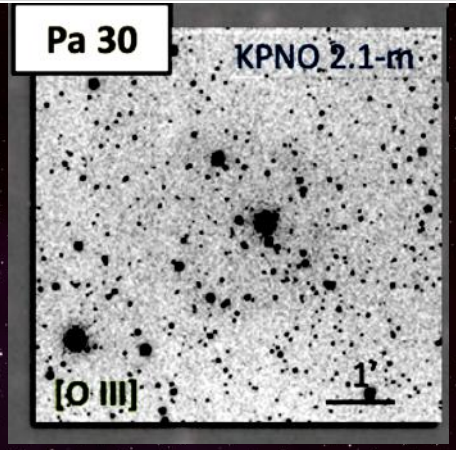
Robert Fesen, Bradley Schaefer, and Dana Patchick
Dartmouth College, Louisiana State University, Deep Sky Hunters Consortium

In 2013, an American amateur astronomer, D. Patchick, searching for new planetary nebulae (PNe), noticed a circular infrared emission nebula in NASA's Wide-Field Infrared Survey Explorer (WISE) data archive. He named it Pa 30, his 30th discovery.




Professional PN astronomers, using a 2.1m telescope at Kitt Peak Observatory south of Tucson AZ, then took a series of images of this suspected planetary nebula but saw only a faint patch of diffuse emission.
No hydrogen emission was seen.



## This was followed by more observations…and misses…

-- 2014: A spectrum of Pa 30 was taken using the KPNO WIYN 3.5 m telescope. Because hydrogen, oxygen, and nitrogen emissions were absent in the raw data, The data were never reduced.

-- 2016: A spectrum of Pa 30 was taken using the 10 m Gran Telescope Canarias (GTC) as part of a study of new PNe carried out by University of Hong Kong astronomers. The data were never reduced.

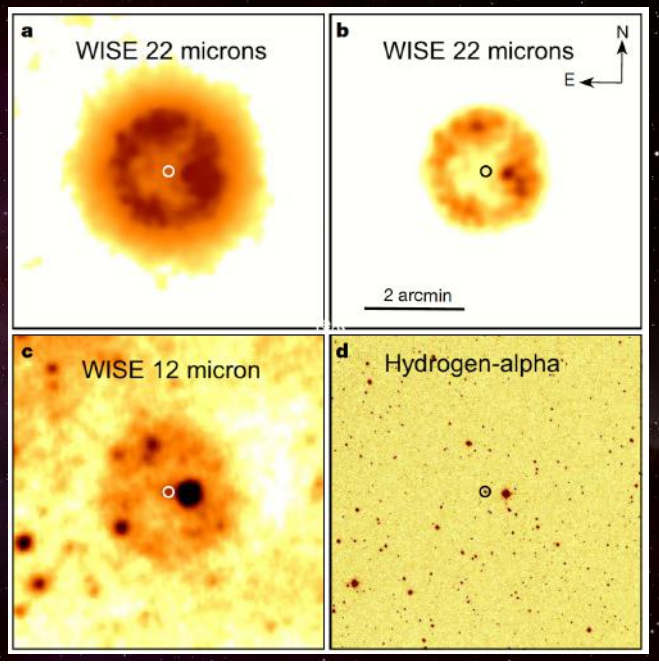
But in 2018 some French amateur astronomers using an 8-inch telescope obtained a spectrum of a very blue star near Pa 30's center. It revealed an odd-looking spectrum with a broad and very bright near ultraviolet emission line.

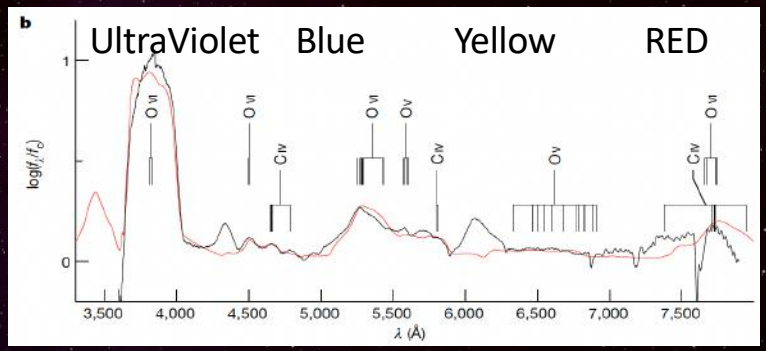
This discovery was transmitted to the University of Hong Kong astronomers who went back and processed their WIYN and GTC data and began preparing a publication.

# But they were beaten to publication by the Russians…

In a 2019 *Nature* paper, Gvaramadze et al. using a 6 m telescope announced the discovery of a massive white dwarf (WD) star inside the WISE infrared shell showing some astounding properties:

- a 16,000 km/s wind velocity!
- a 210,000 K surface temperature
- 36,000 x the Sun's luminosity
- is likely the product of a merger of a C,O and O,Neon white dwarfs
- the merger caused a subluminious SN explosion known as a SN Iax event

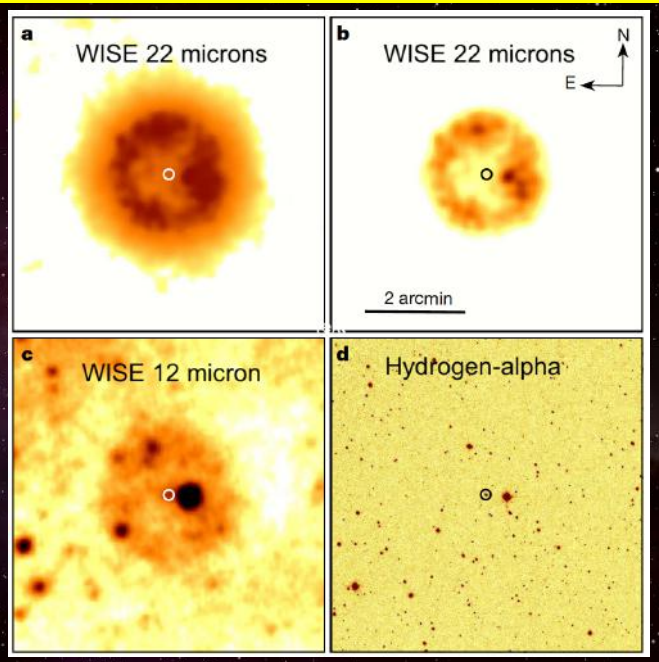


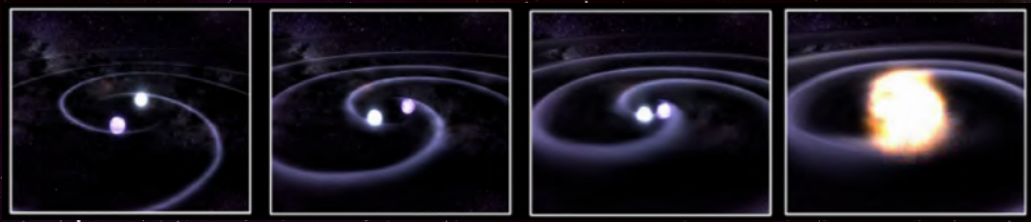



# But they were beaten to publication by the Russians…

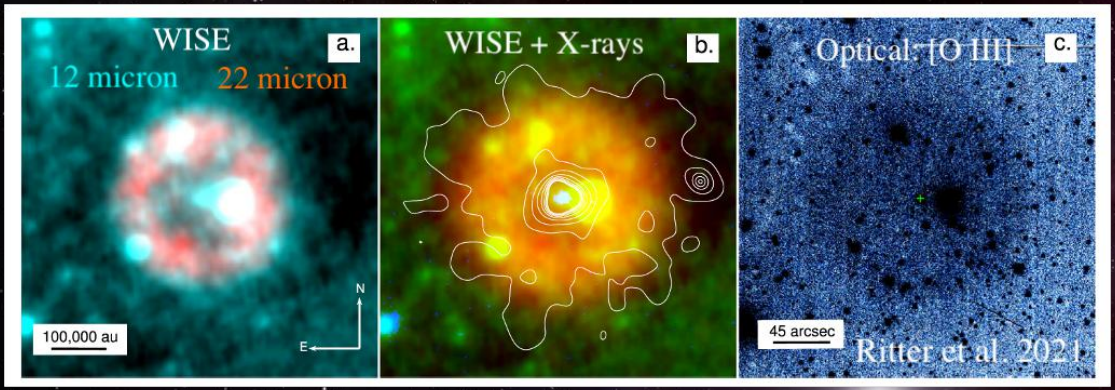
In a 2019 *Nature* paper, Gvaramadze et al. using a 6 m telescope announced the discovery of a massive white dwarf (WD) star inside the WISE infrared shell showing some astounding properties:

- a 16,000 km/s wind velocity!
- a 210,000 K surface temperature
- 36,000 x the Sun's luminosity
- is likely the product of a merger of a C,O and O,Neon white dwarfs
- the merger caused a subluminious SN explosion known as a SN Iax event

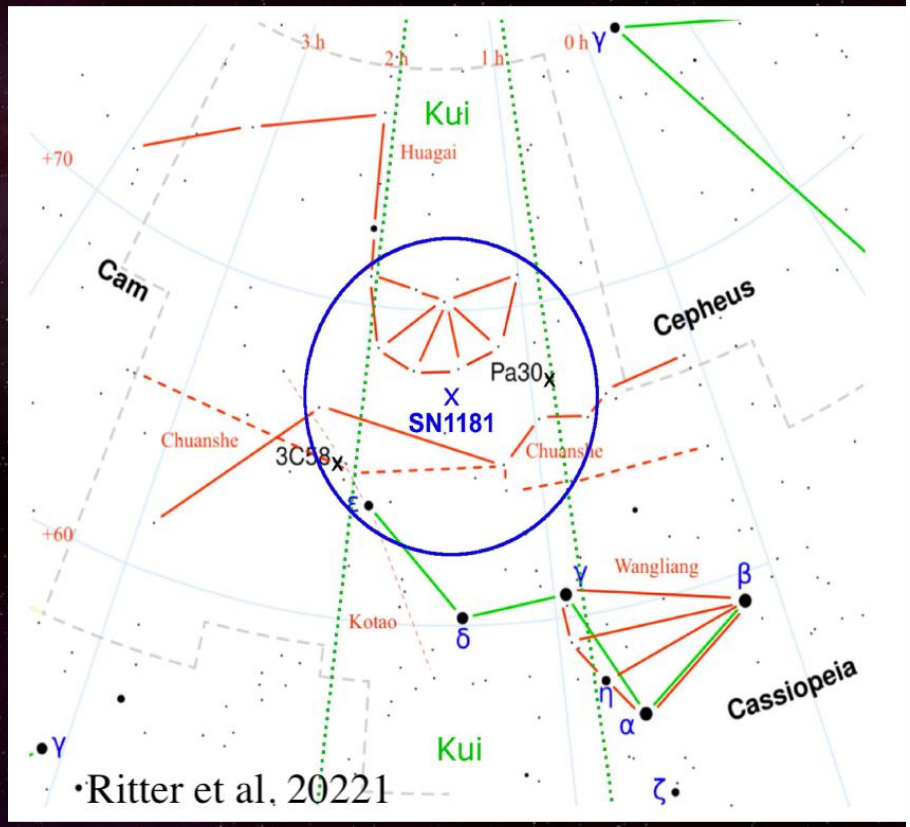


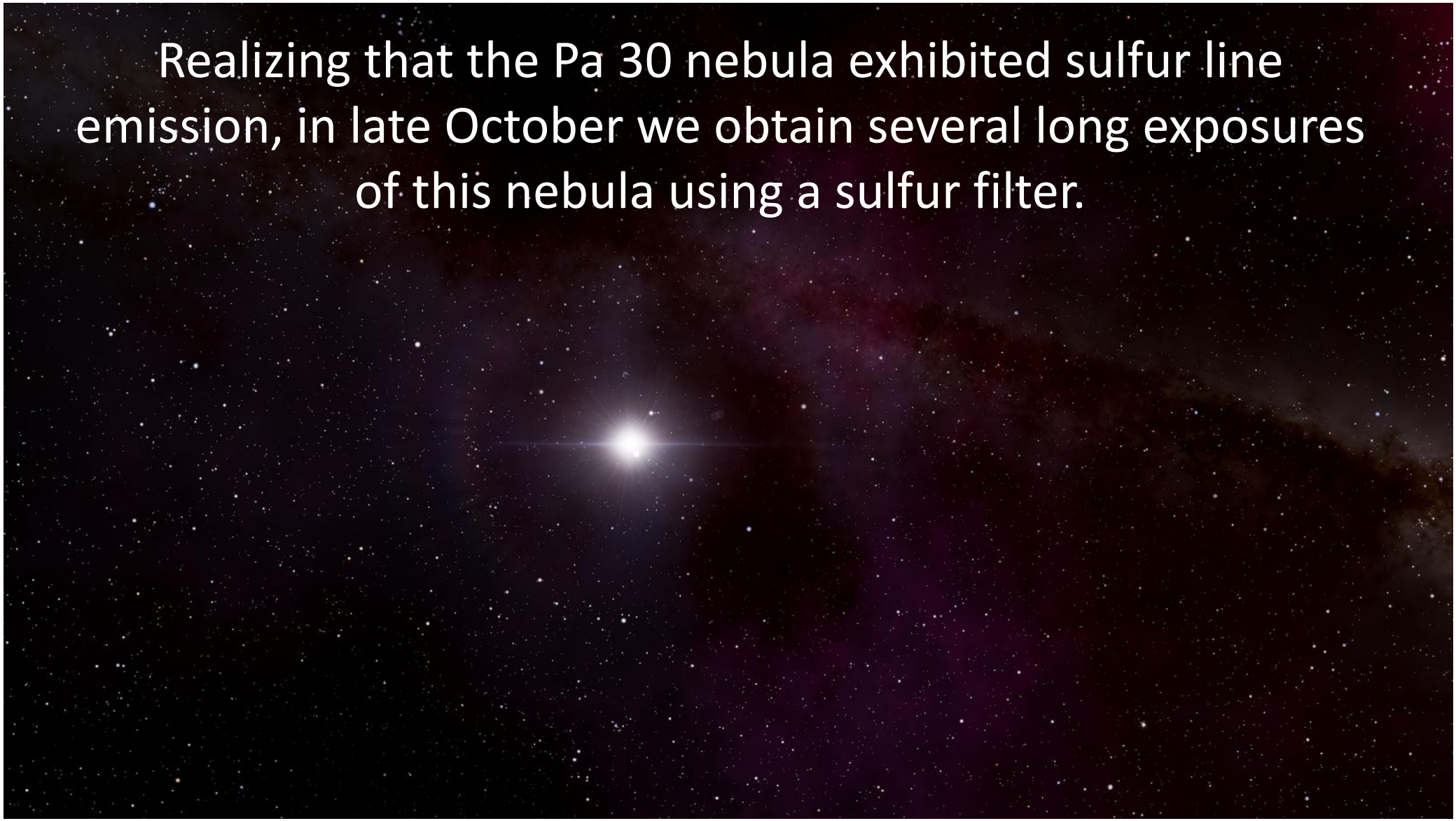



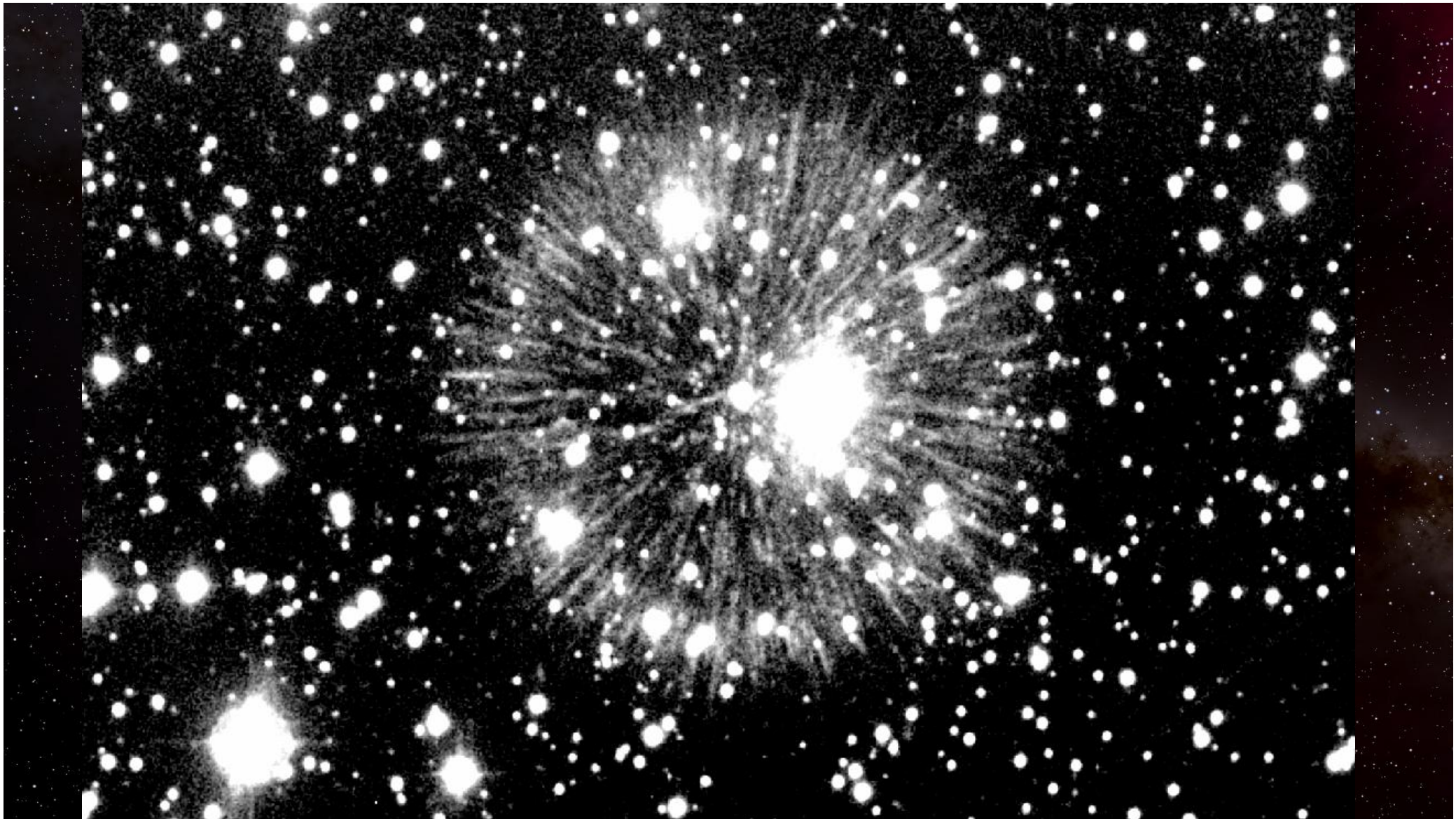
# The University of Hong Kong astronomers published their data in 2021 and added important elements to the story… Pa 30 ➔ SN 1181 AD

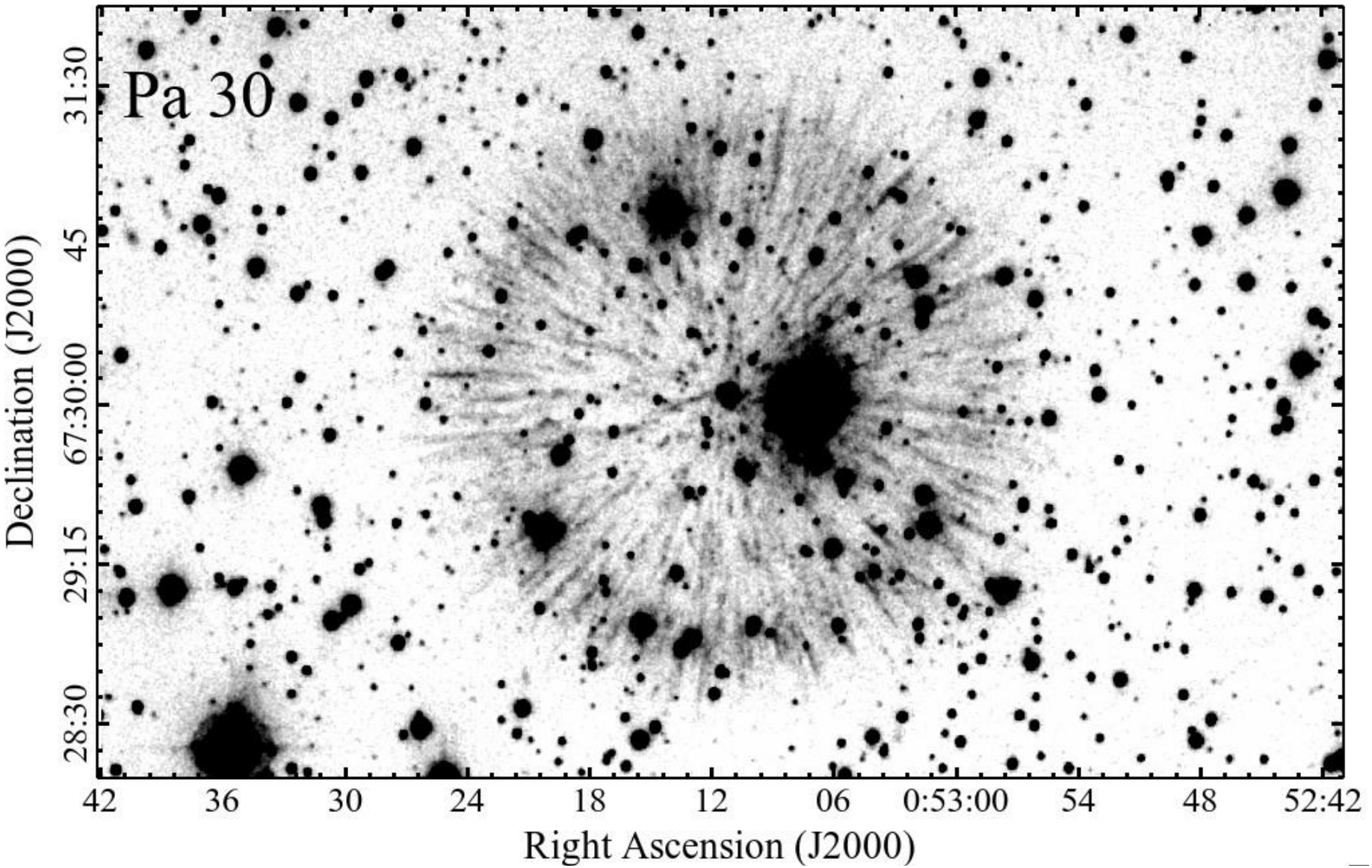


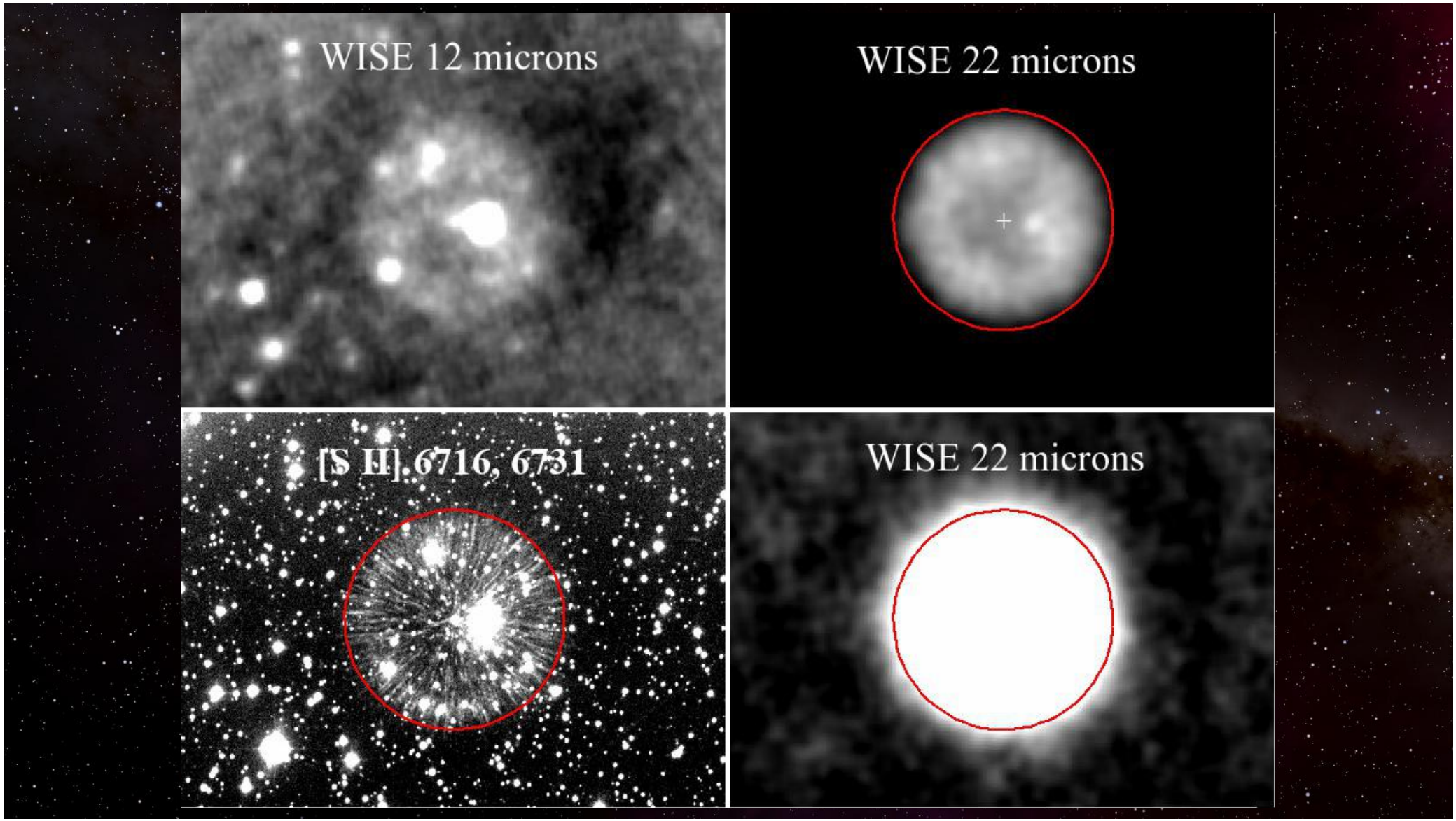

- Pa 30 showed sulfur emission indicating an expansion around 1100 km/s.
- They estimated that Pa 30 was about 1000 years old and located around the spot where Chinese and Japanese astronomers reported a “guest star” in early August 1181 AD.

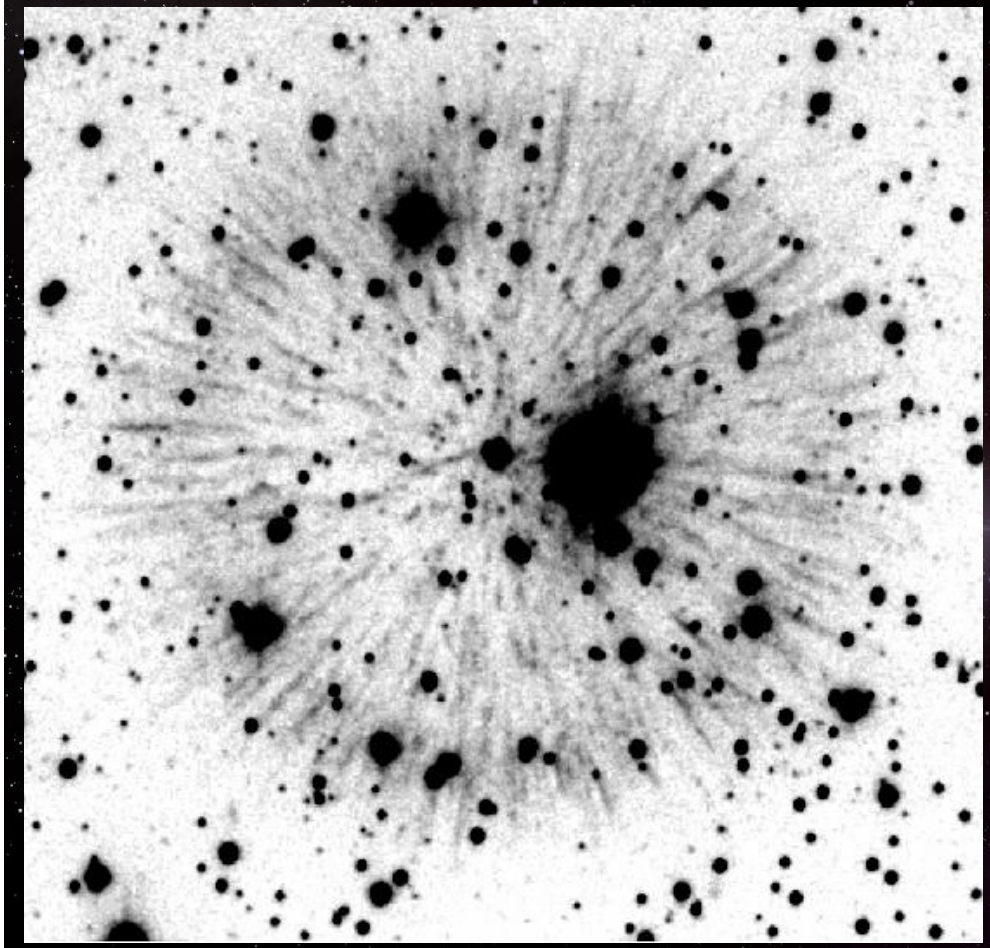



Realizing that the Pa 30 nebula exhibited sulfur line emission, in late October we obtain several long exposures of this nebula using a sulfur filter.




Pa 30
Declination (J2000)
31:30
45
67:30:00
29:15
28:30
42
36
30
24
18
12
06
0:53:00
54
48
52:42
Right Ascension (J2000)


WISE 12 microns
WISE 22 microns
[S II] 6716, 6731
WISE 22 microns



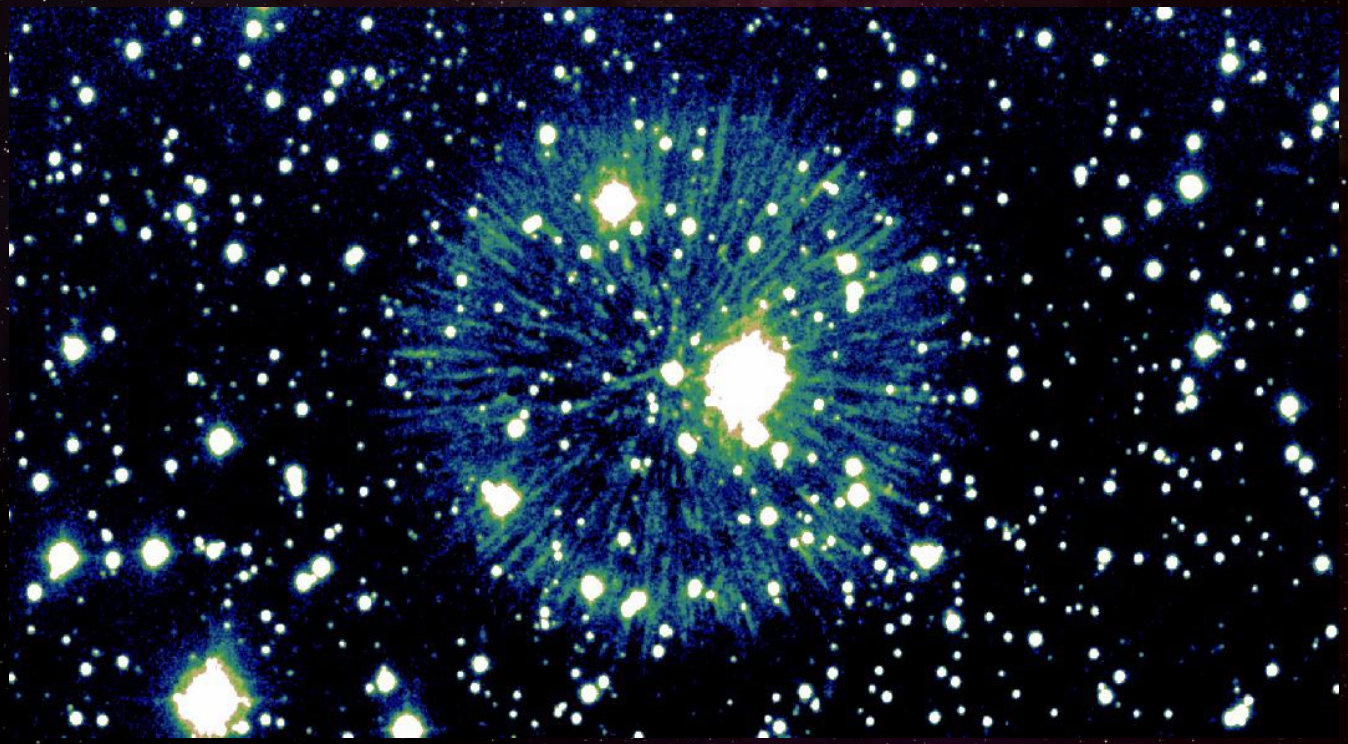
-- Pa 30 exhibits many dozens of long, thin filaments converging near the hot central star the French and Russians identified.

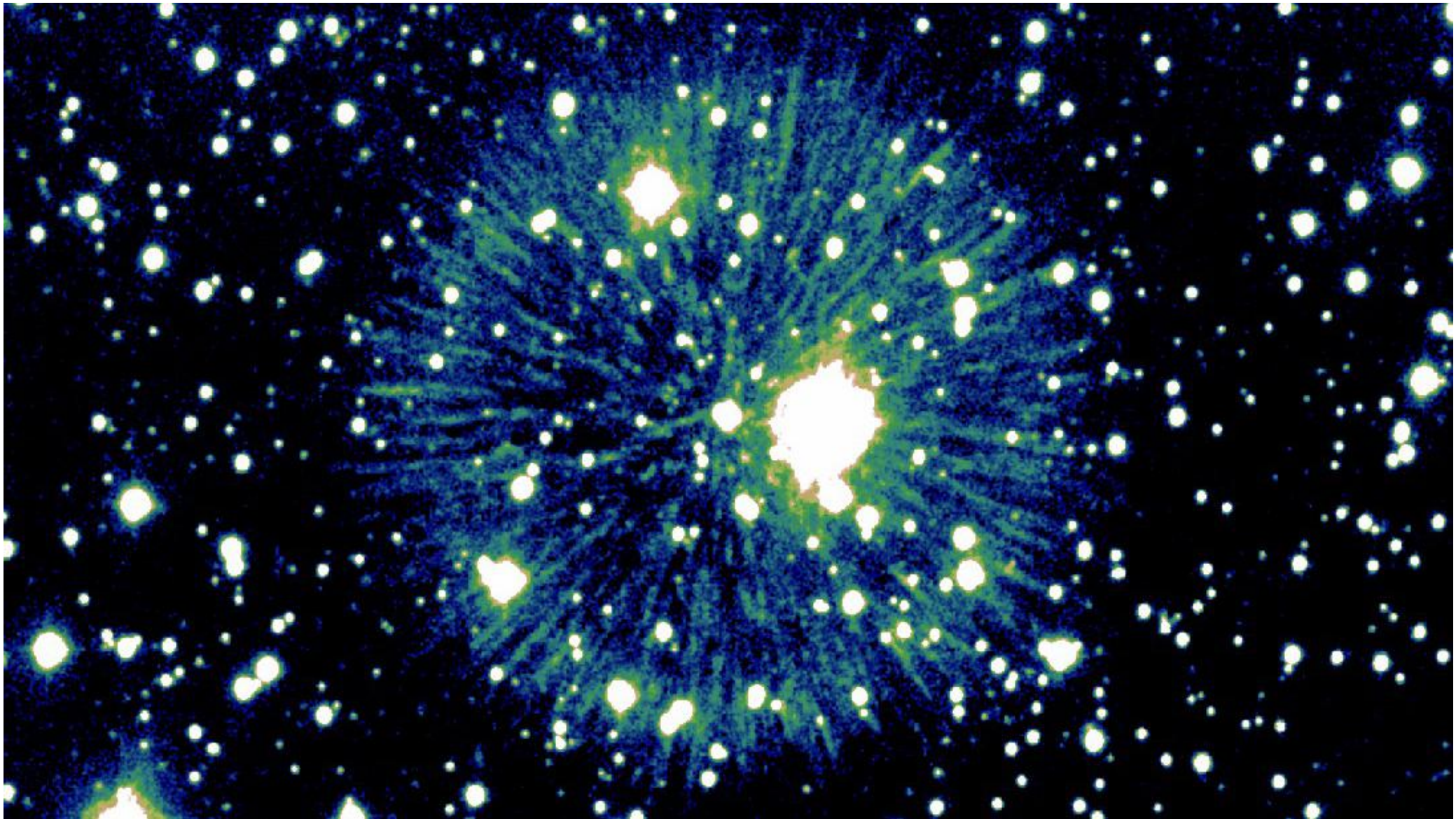
-- Our spectra confirmed an expansion of 1100 km/s. But now knowing its true size, estimate a more precise age of 850 years, linking it to the SN 1181.

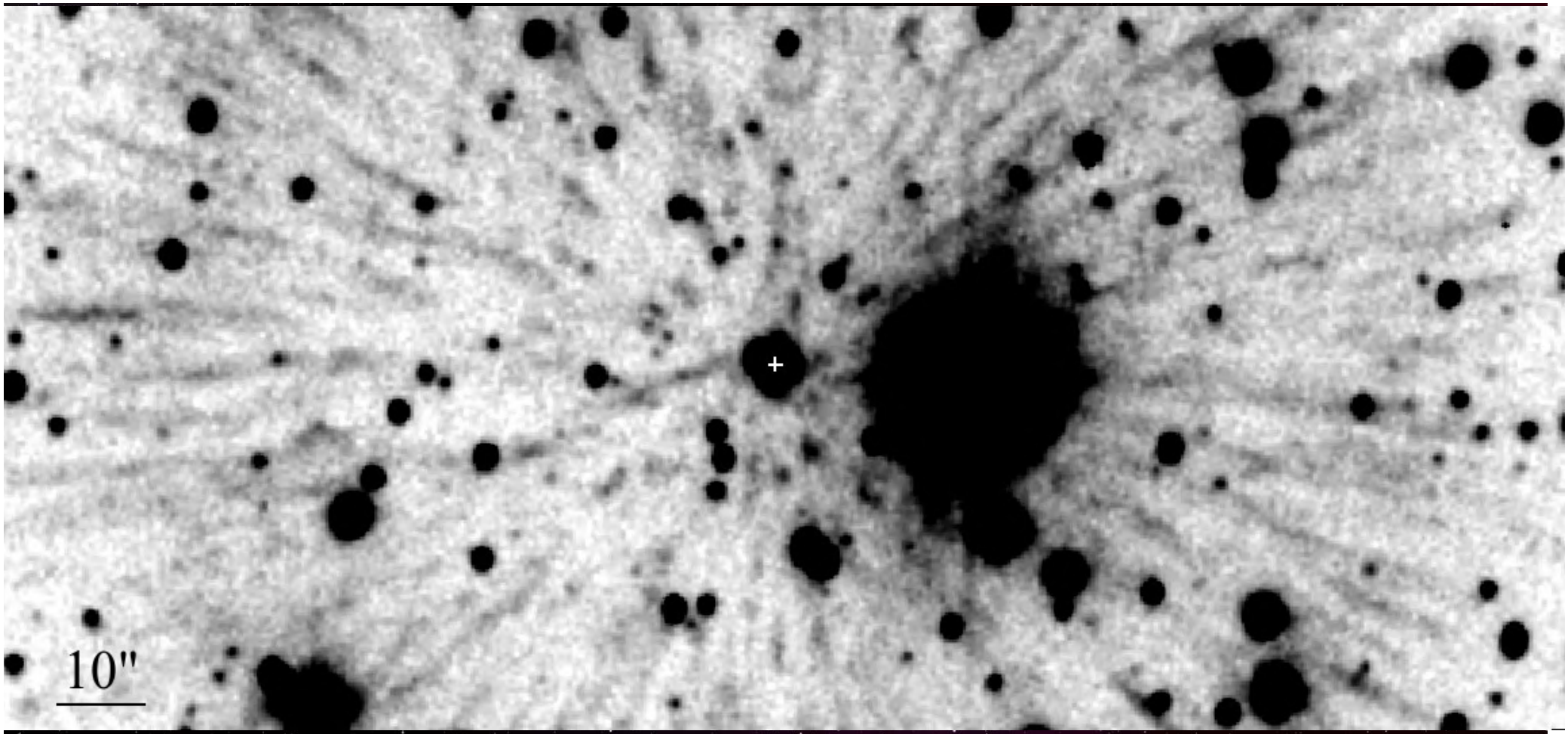
-- We conclude its appearance is due to the central star's extremely high-speed winds blowing over a lumpy shell of supernova ejecta.

## Summary: Pa 30 combines Beauty, Science, and History

- Its beautiful structure is unique among SN remnants.
- It is scientifically important in the study of SN Iax type explosions.
- It is the remains of a Late 12$^{th}$ Century supernova:  SN 1181 AD.








Some filaments do not seem to align exactly back to the hot central star, but instead seem to converge just a bit above it. A post-SN “kick” ?

***Authors:***

Rob Fesen
robert.fesen@Dartmouth.edu
Cell: 1-603-252-9001

Brad Schaefer
bradschaefer@me.com

Dana Patchick
dpatchick@roadrunner.com

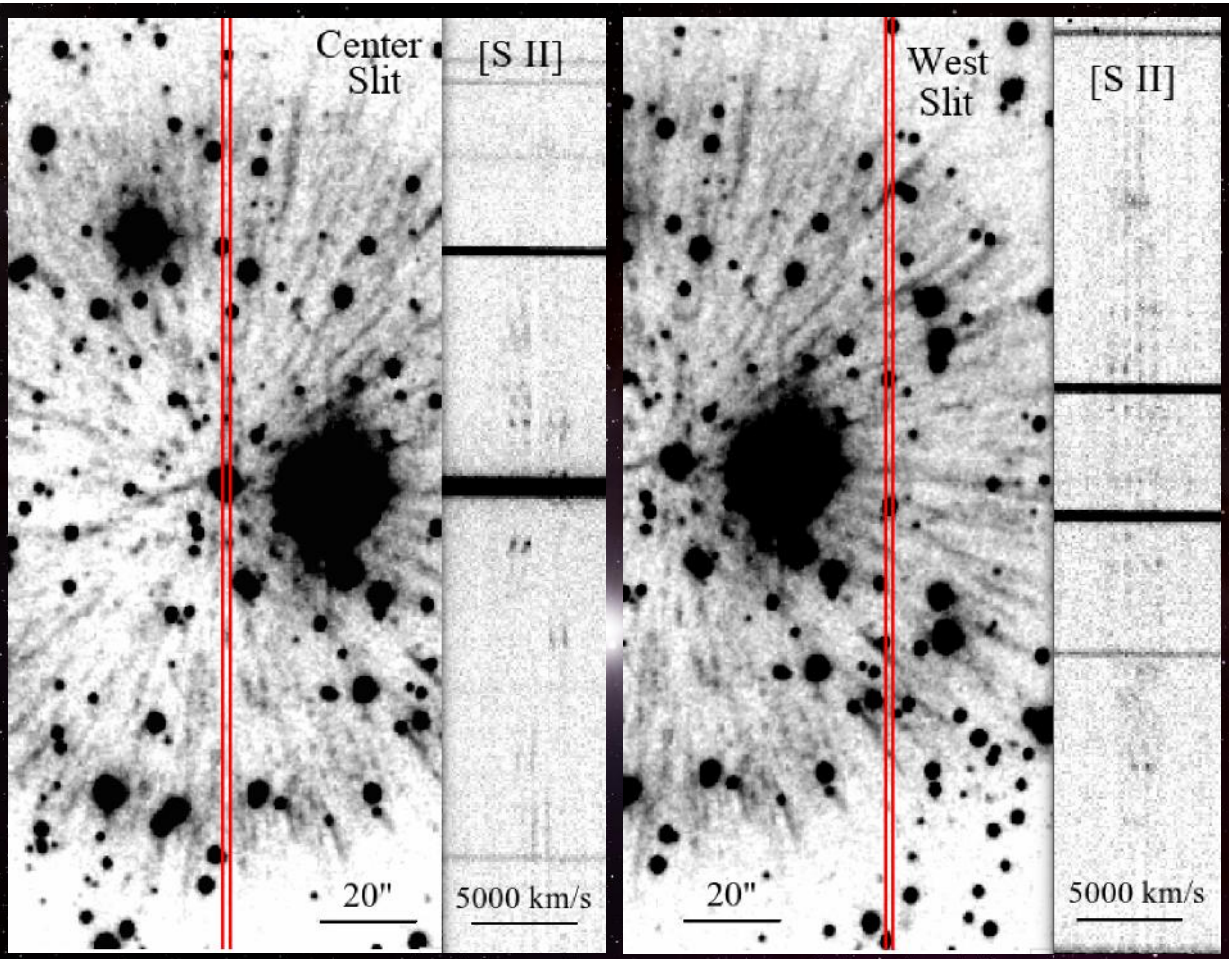
***Background Information:***

**First images of Pa 30 taken at Kitt Peak.**
http://www.astroscu.unam.mx/apn6/PROCEEDINGS/B3-Kronberger.pdf

**History of WYIN, GTC , and French amateur spectra of Pa 30**
https://www.shelyak.com/sn-1181-une-histoire-peu-commune/?lang=en
http://planetarynebulae.net/articles/id0055%20-%20poster.png

**2019 Russian paper on the unusual central star of Pa 30**
https://arxiv.org/pdf/1904.00012.pdf
https://www.nature.com/articles/s41586-019-1216-1

**2021 Ritter et al. paper on:**
"The Remnant and Origin of the Historical Supernova 1181 AD"
https://iopscience.iop.org/article/10.3847/2041-8213/ac2253




Pair of [S II] 6716,6731 images of Pa 30 showing central (left) and west (right) slit positions along with the resulting 2D spectra covering the region around the [S II] emission doublet with wavelength increasing from right to left. Ordinary background stars have their continuum spectra visible as horizontal black lines, with the saturated spectrum of Pa 30's central star appearing as an especially wide horizontal black line in the center slit spectrum.