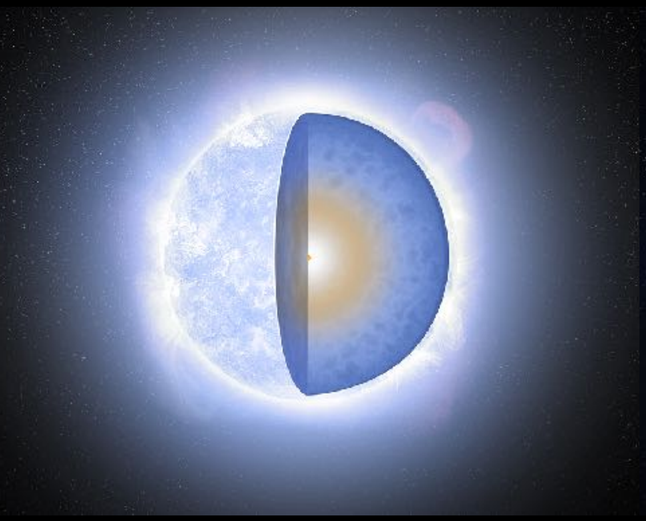
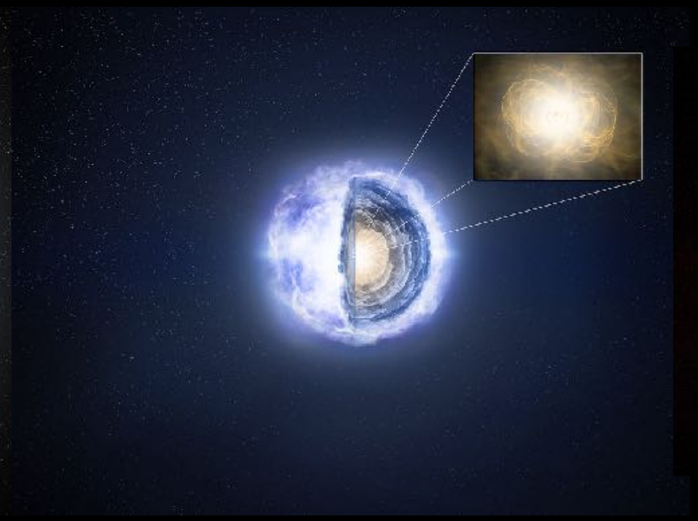
Discovery of an extremely luminous, decades-old pulsar wind nebula in the Very Large Array Sky Survey





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Art credit:
Melissa Weiss

Part I: The story of an emerging pulsar (magnetar) wind nebula

Part II: How we pieced together the story

Part III: The bigger picture

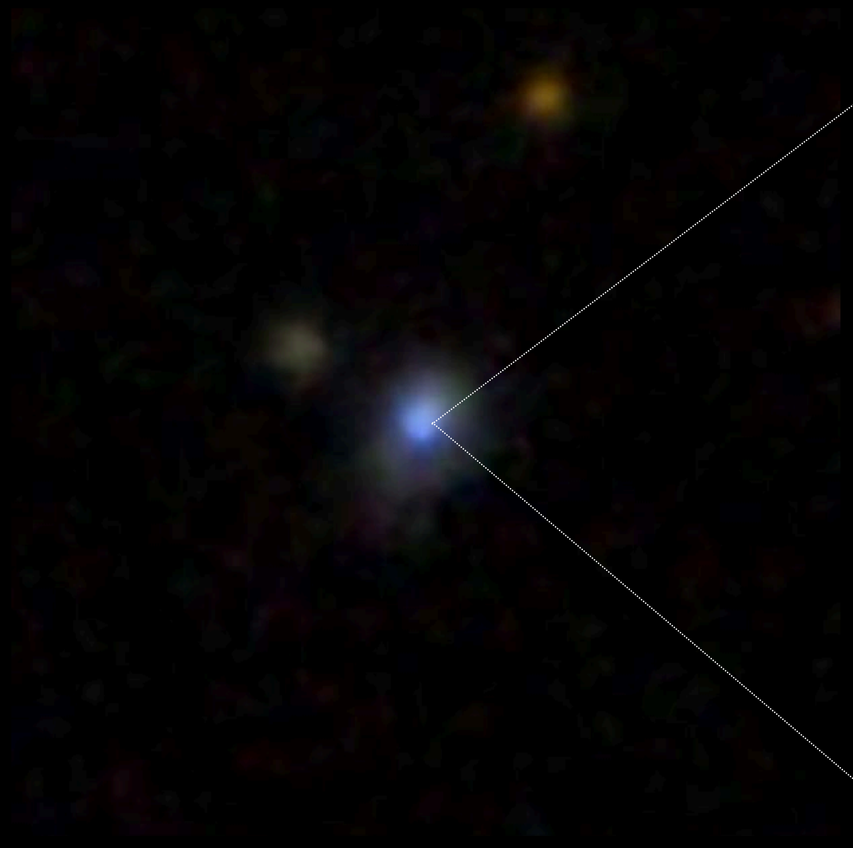
Part I:
The story

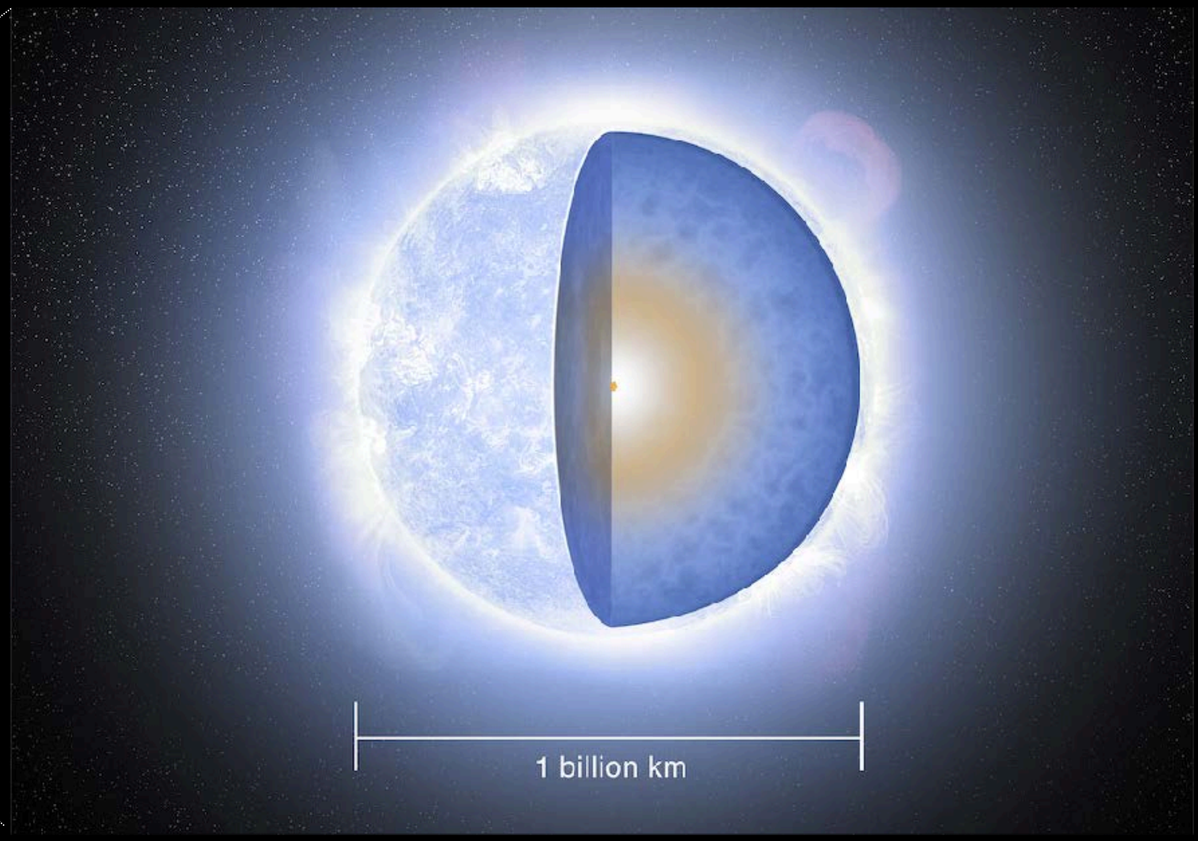
(Not so) long ago in a galaxy (kind of) far away…

Dwarf galaxy 400 million light years away

Approximate year on Earth: *~1990*

…there was a massive star with a core of iron on the verge of collapse



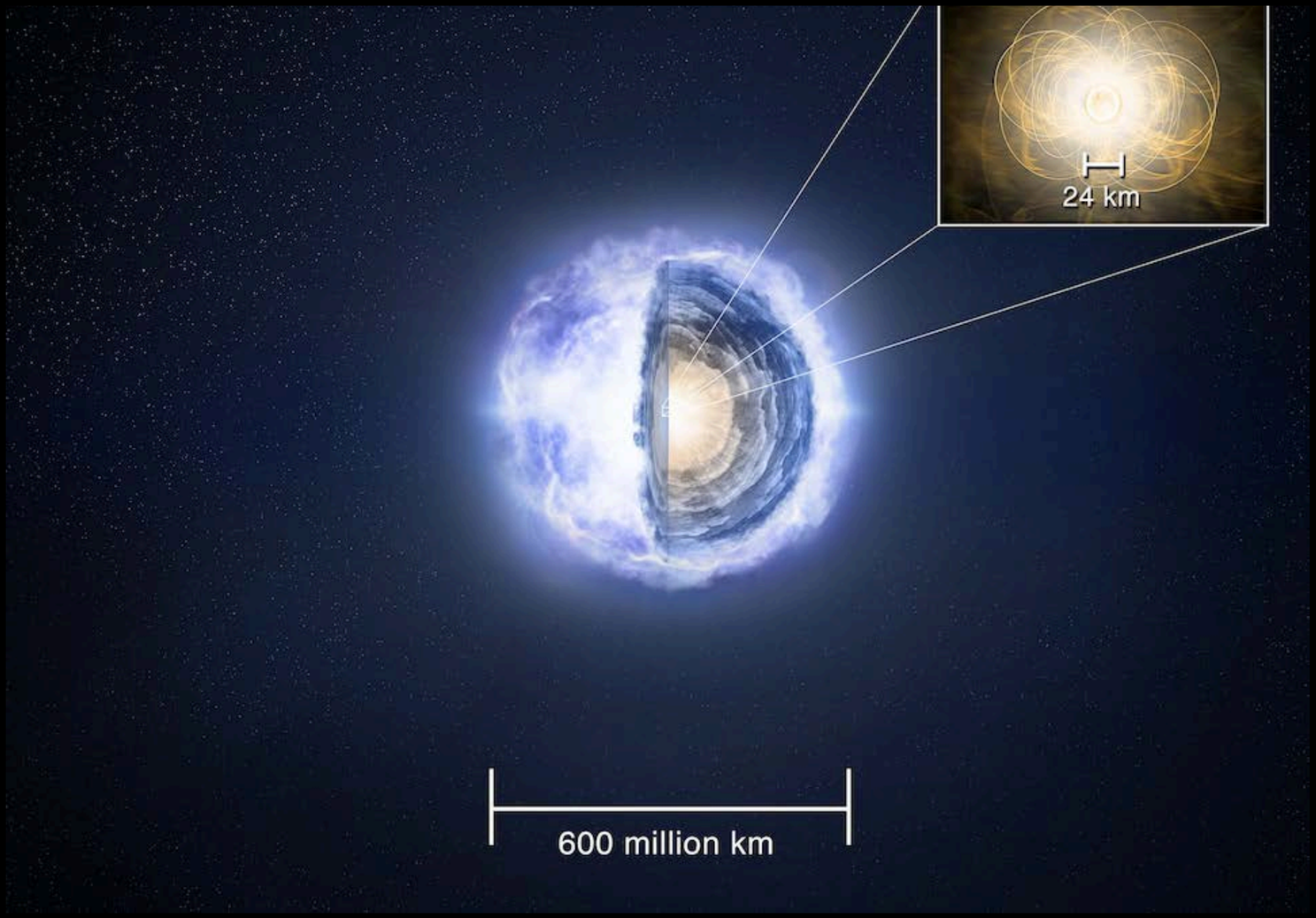


Dwarf galaxy 400 million light years away

Massive star a few decades ago (Earth time)

~1990

When its iron core collapsed, it was crushed into a neutron star with an extremely powerful magnetic field



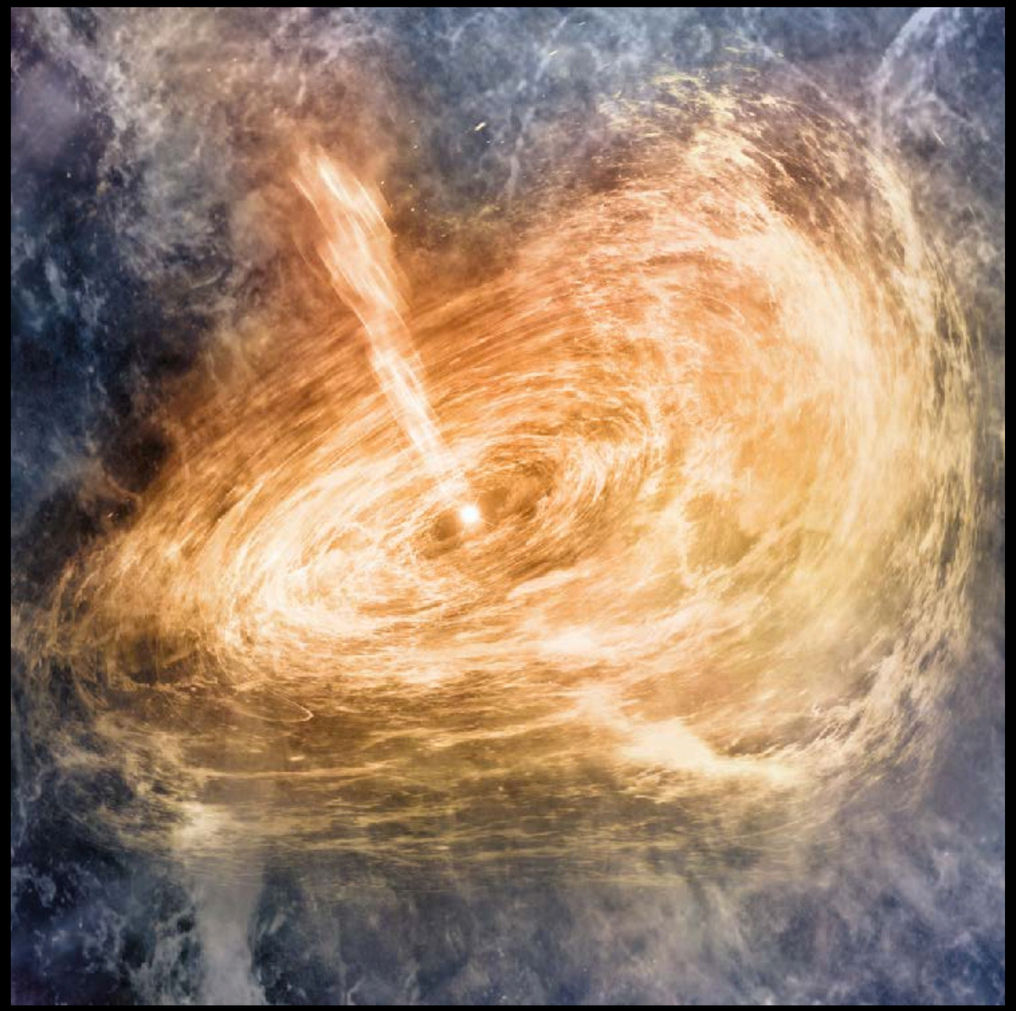
Neutron star
born with an unusually
strong magnetic field

Star in the process of imploding

~1990

Shortly after birth, the neutron star started to dump a huge amount of magnetic energy into its surroundings carving out a monstrously energetic wind nebula

Highly magnetized neutron star
at the center of the former star



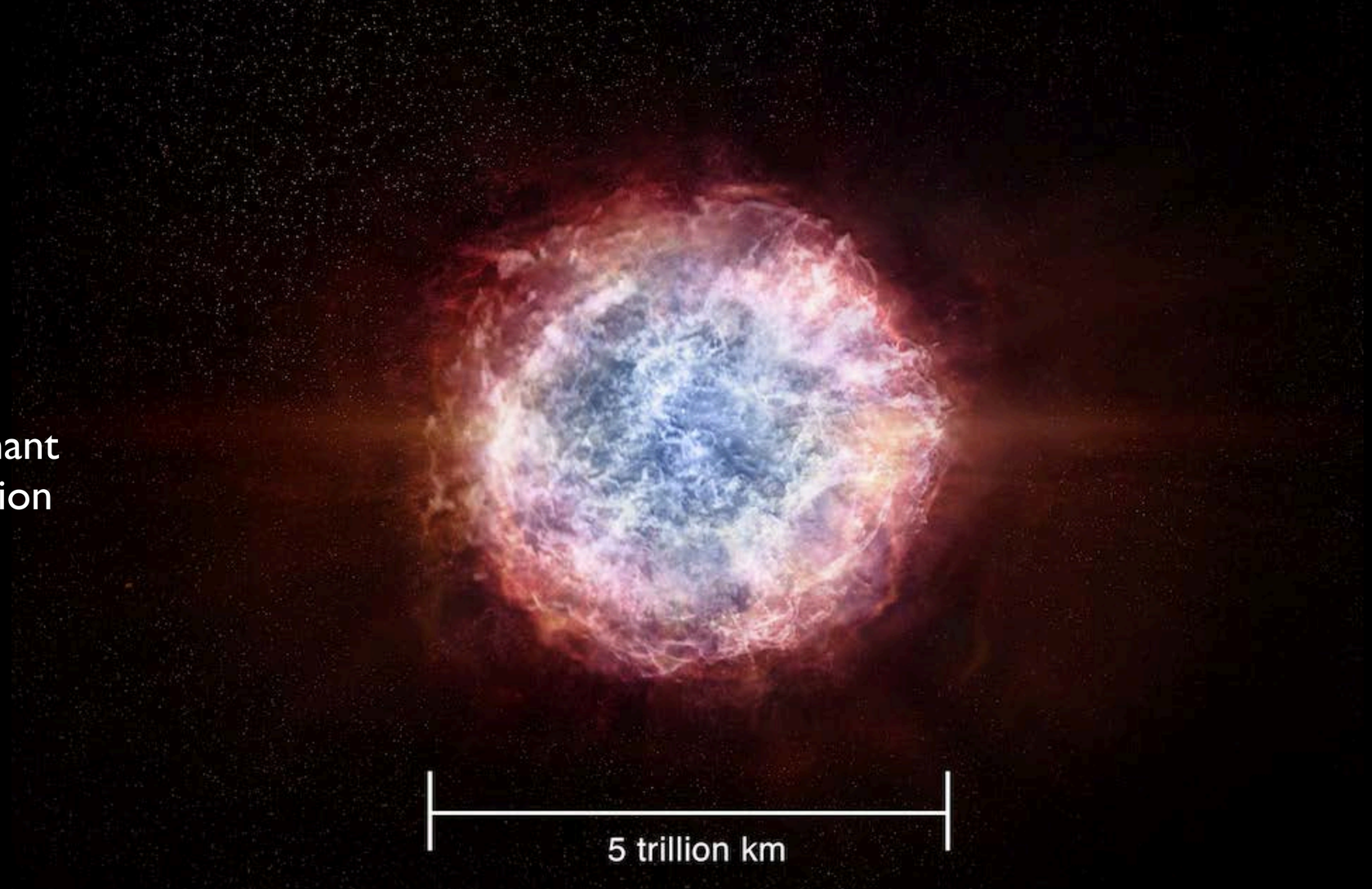
Wind nebula launched by the neutron star

~1990

~1990 - Today

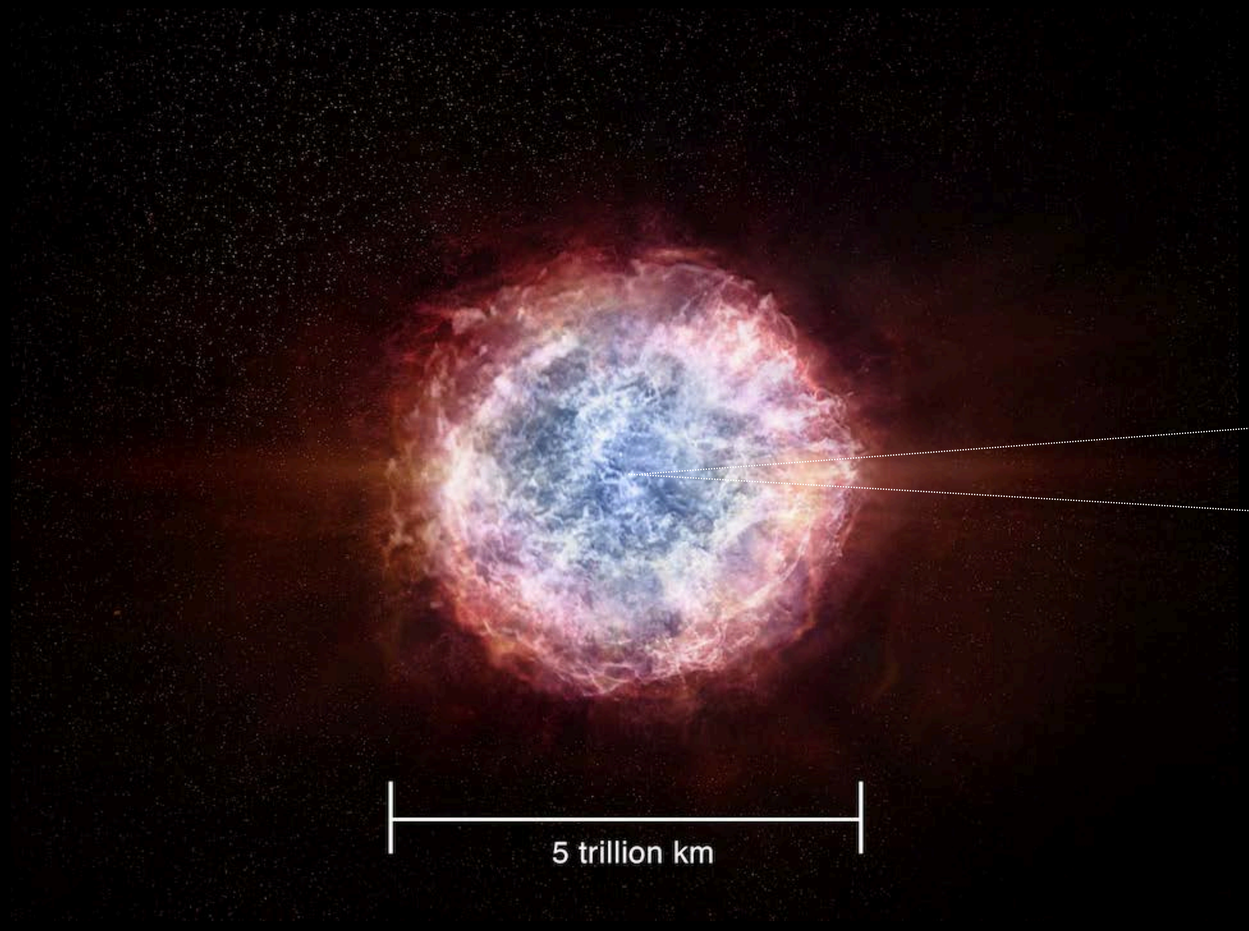
Meanwhile, the star blew up in a supernova around the neutron star launching its guts outwards and creating a supernova remnant

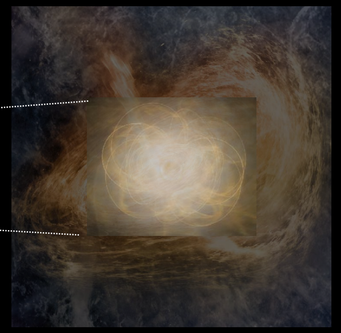
Young supernova remnant
~10 years after explosion



~2000

For the first few decades, the wind nebula was hidden within the supernova remnant



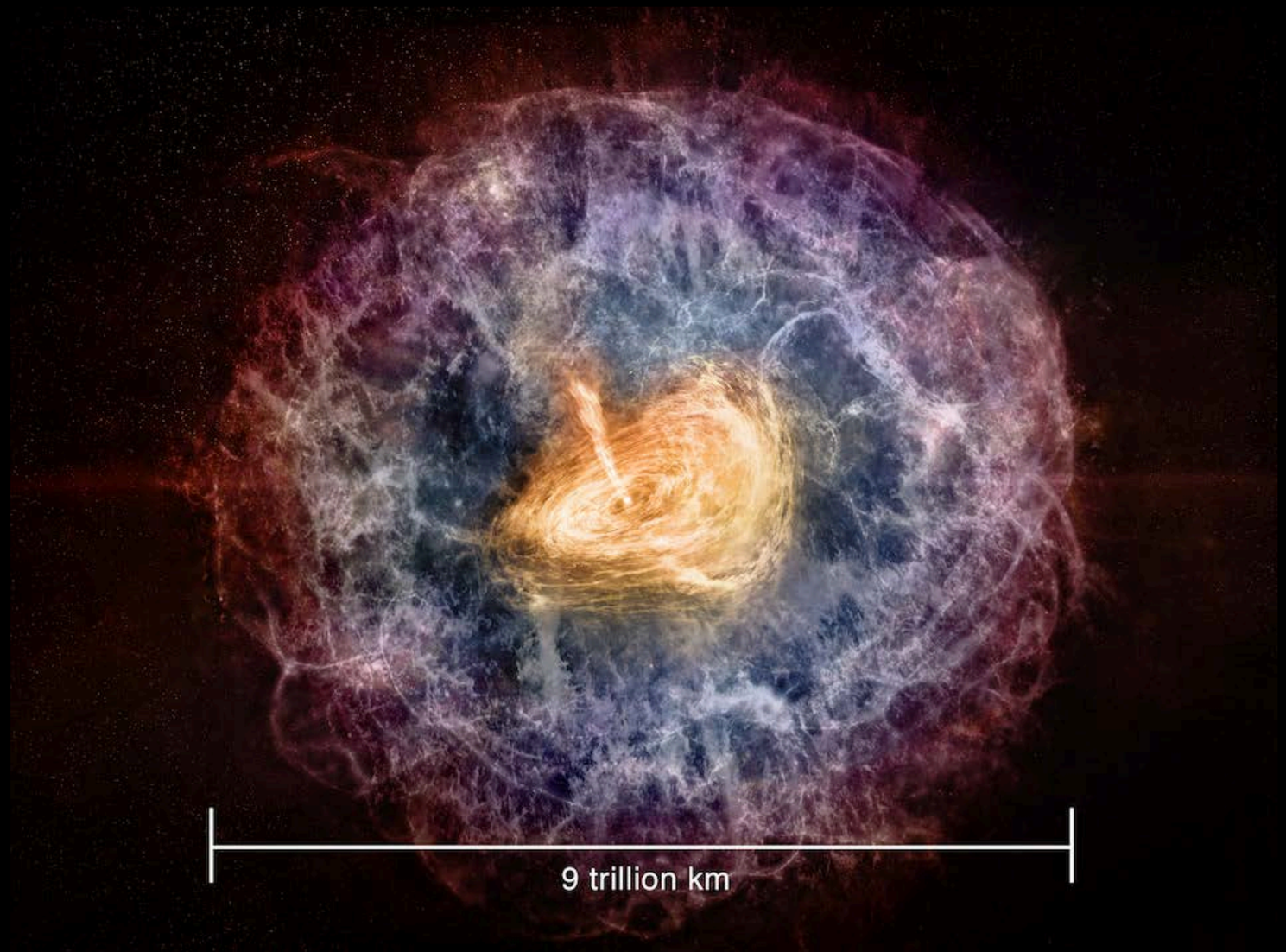


Wind nebula hidden
inside the supernova remnant
~10 years after explosion

The remnant is so dense and ionized
that it traps all radio emission inside

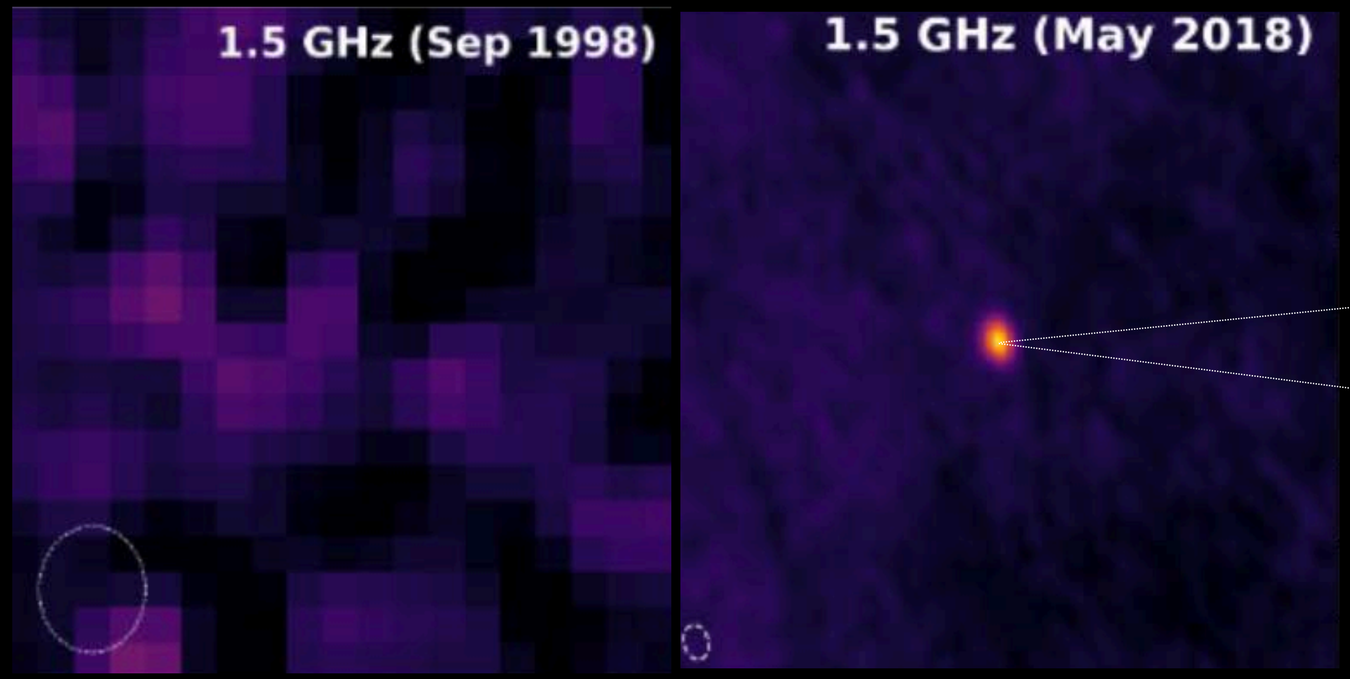
~2000

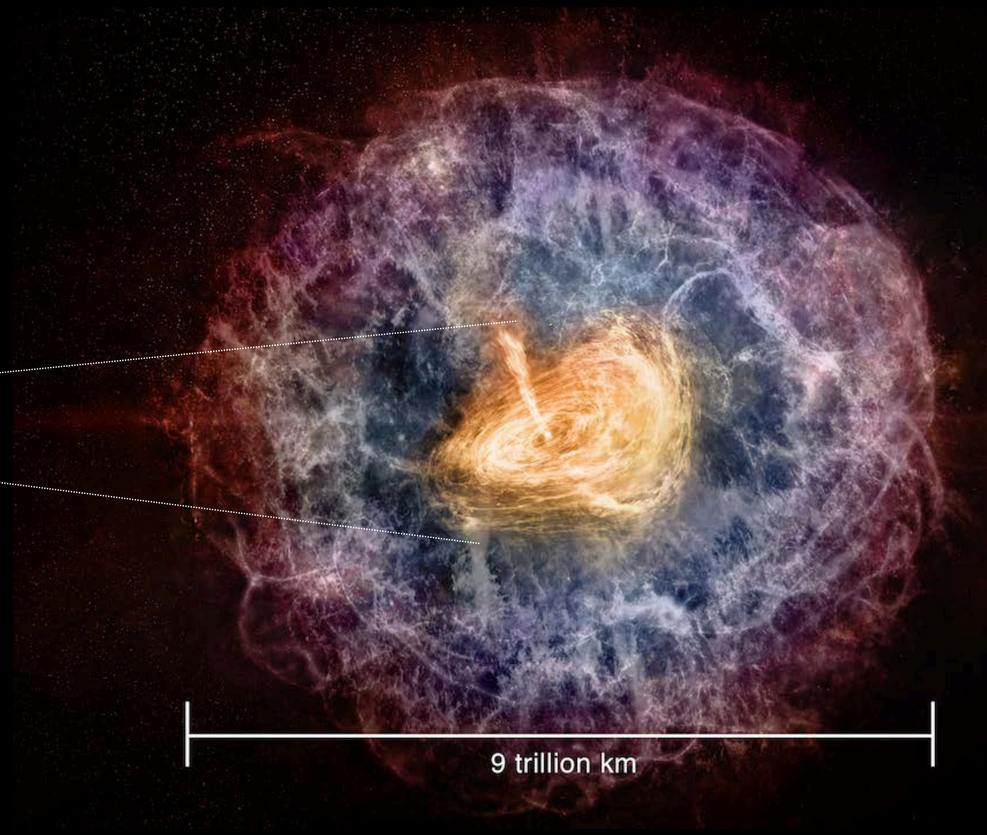
But recently, the supernova remnant has expanded to the point where it has become *transparent,* revealing the nebula within



~2010s

Using the Very Large Array Sky Survey, we discovered this emerging wind nebula as a radio transient

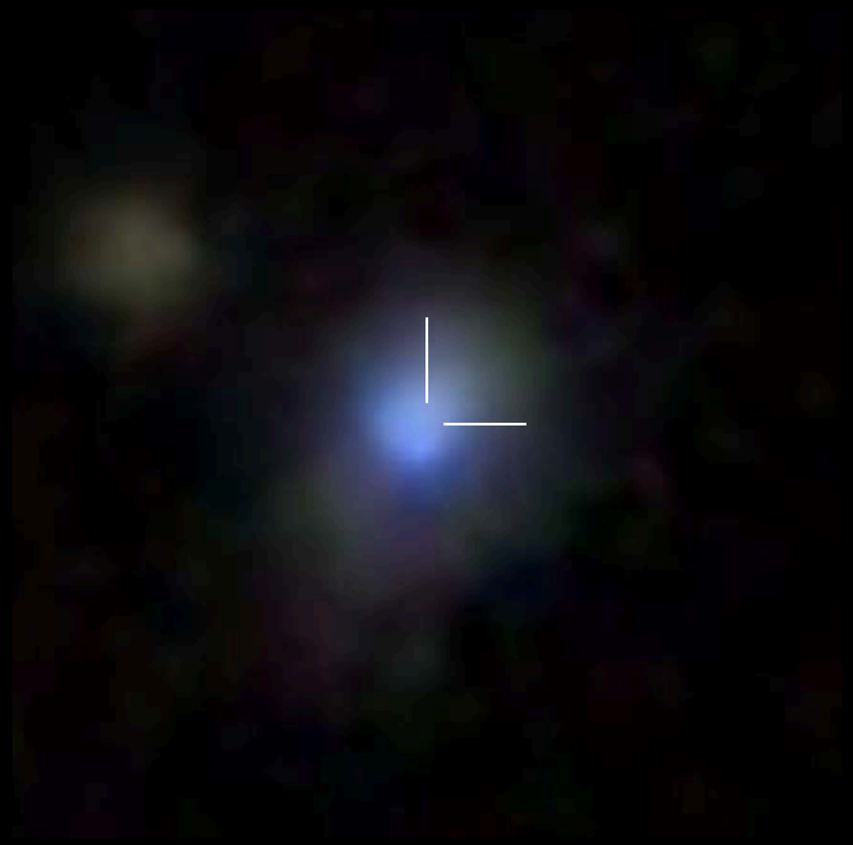




2018 - Today

Part II:
How we pieced together the story

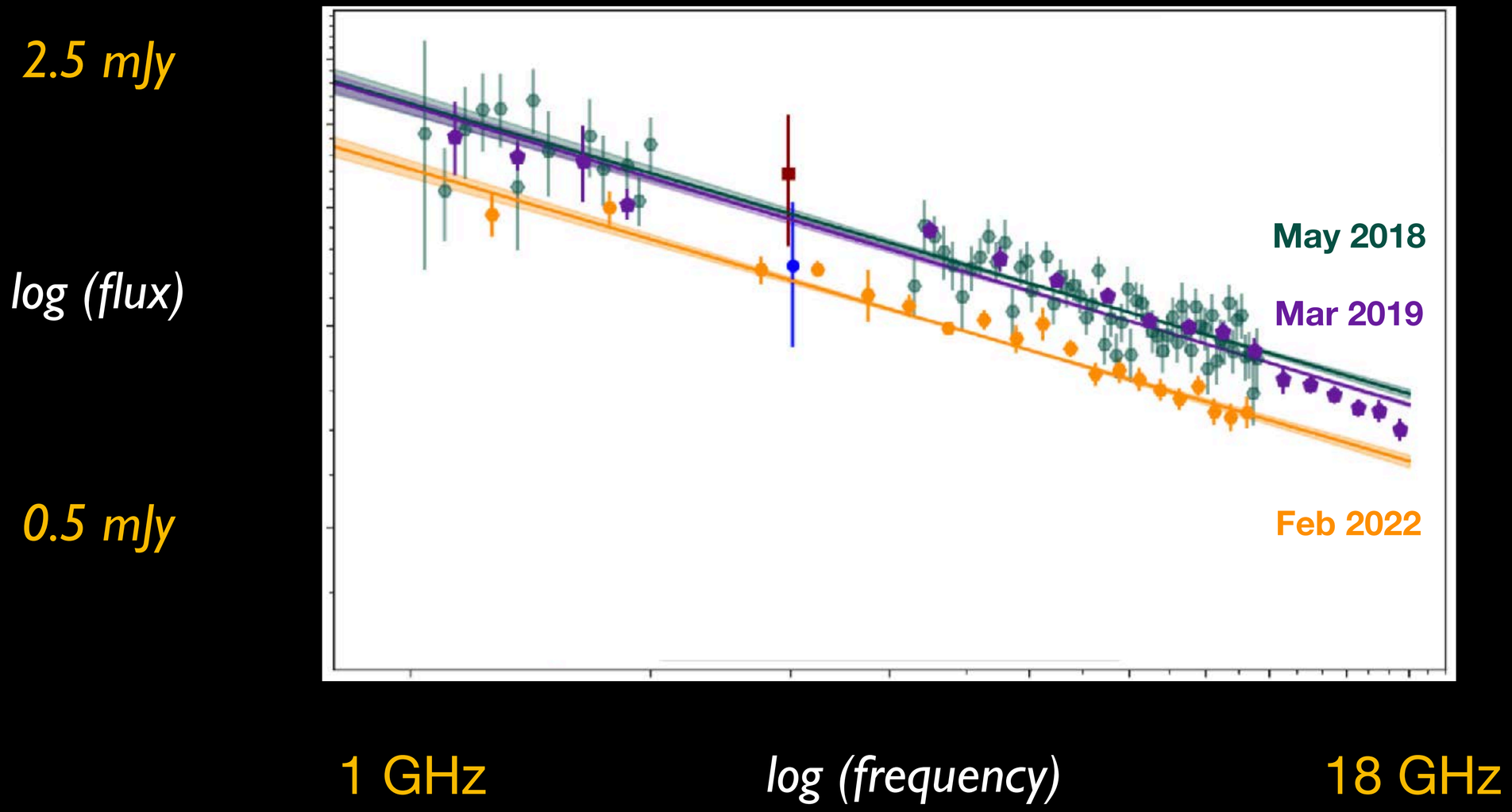
Clue #1: The transient is located in the central star cluster of a dwarf starburst galaxy



- Galaxy has similar mass to the Small Magellenic Cloud, but is forming stars 100x faster

- Suggests association with massive stars or their remnants

Clue #2: The radio transient has a very unusual flat radio spectrum and is fading slowly at 5% per year from 2018 - 2022



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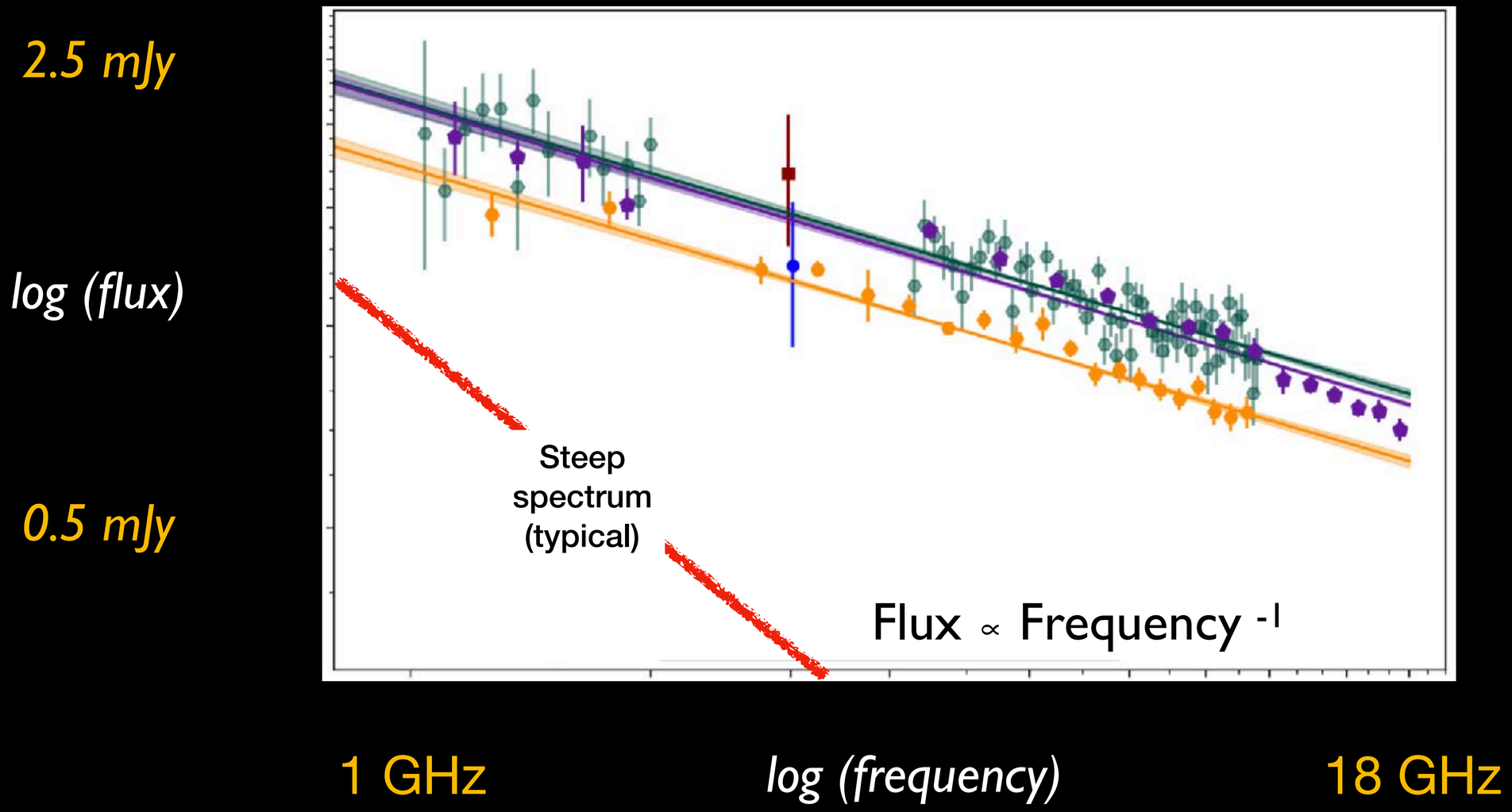
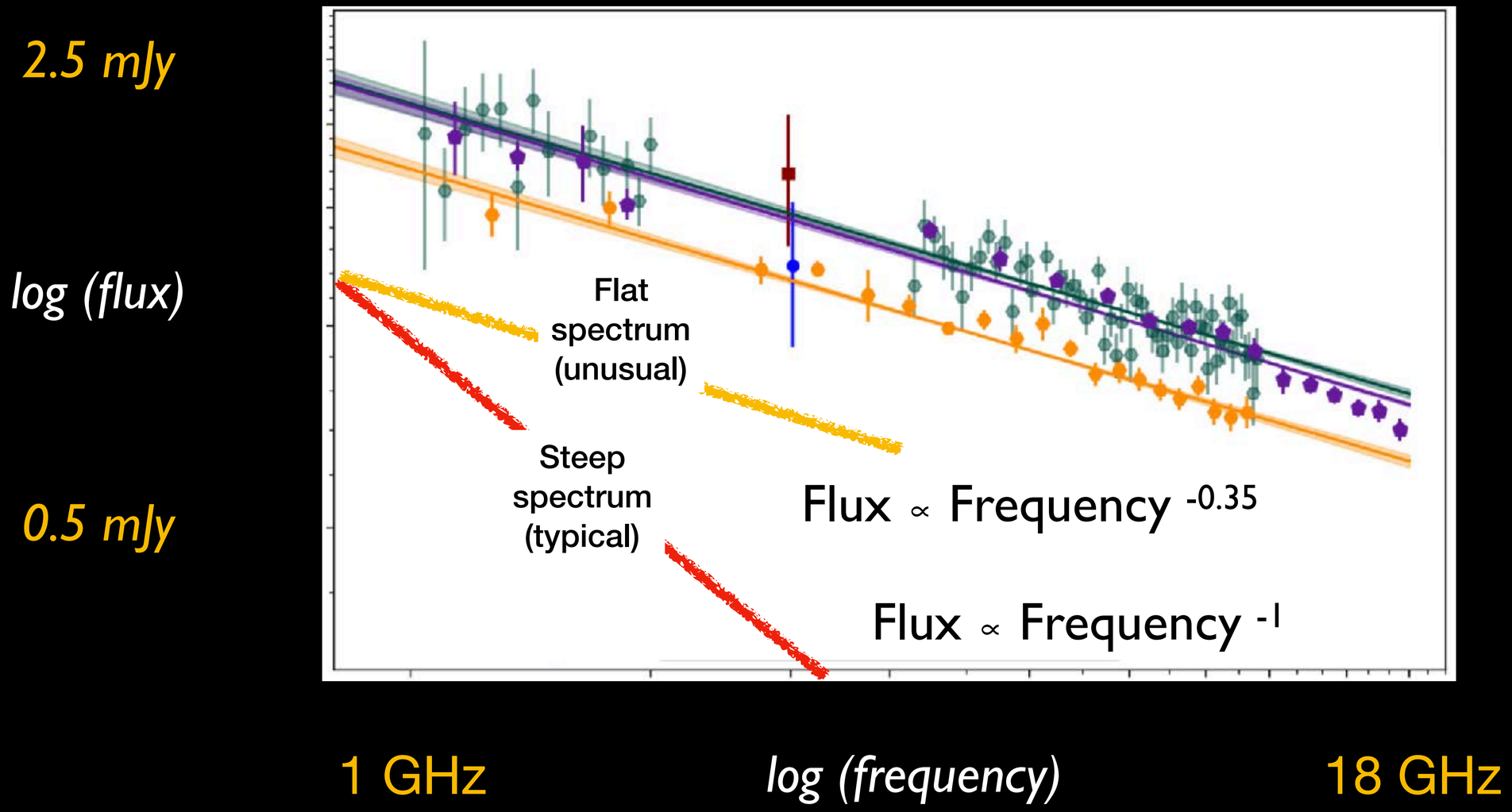


Clue #2: The radio transient has a very unusual flat radio spectrum and is fading slowly at 5% per year from 2018 - 2022

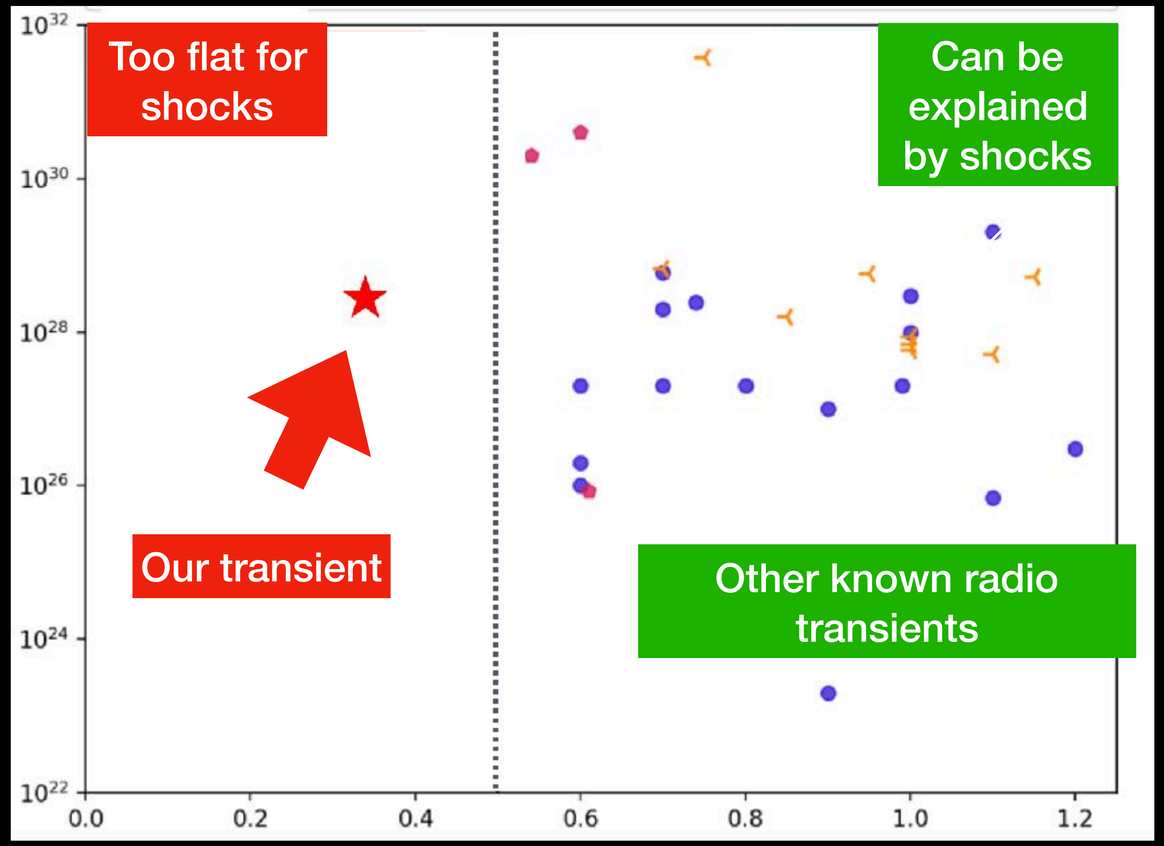


Explosive radio transients have never before been observed with such a flat spectrum

More luminous

Luminosity

Less luminous



Spectral index

Flat spectrum → *Steep spectrum*

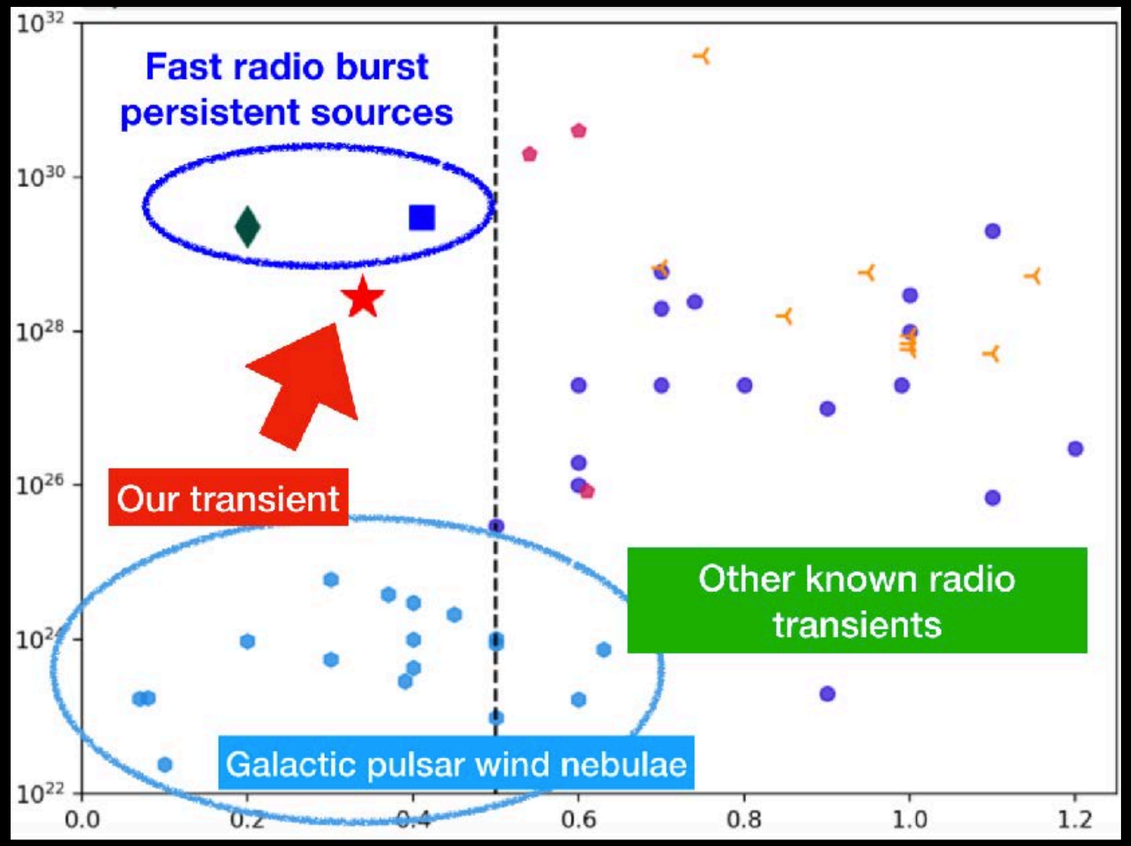
- Flat spectrum is incompatible with diffusive shock acceleration (the primary method for accelerating radio-emitting particles)

The two flat spectrum source types expected in dwarf starburst galaxies are pulsar wind nebulae and fast radio burst persistent sources

More luminous

Luminosity

Less luminous



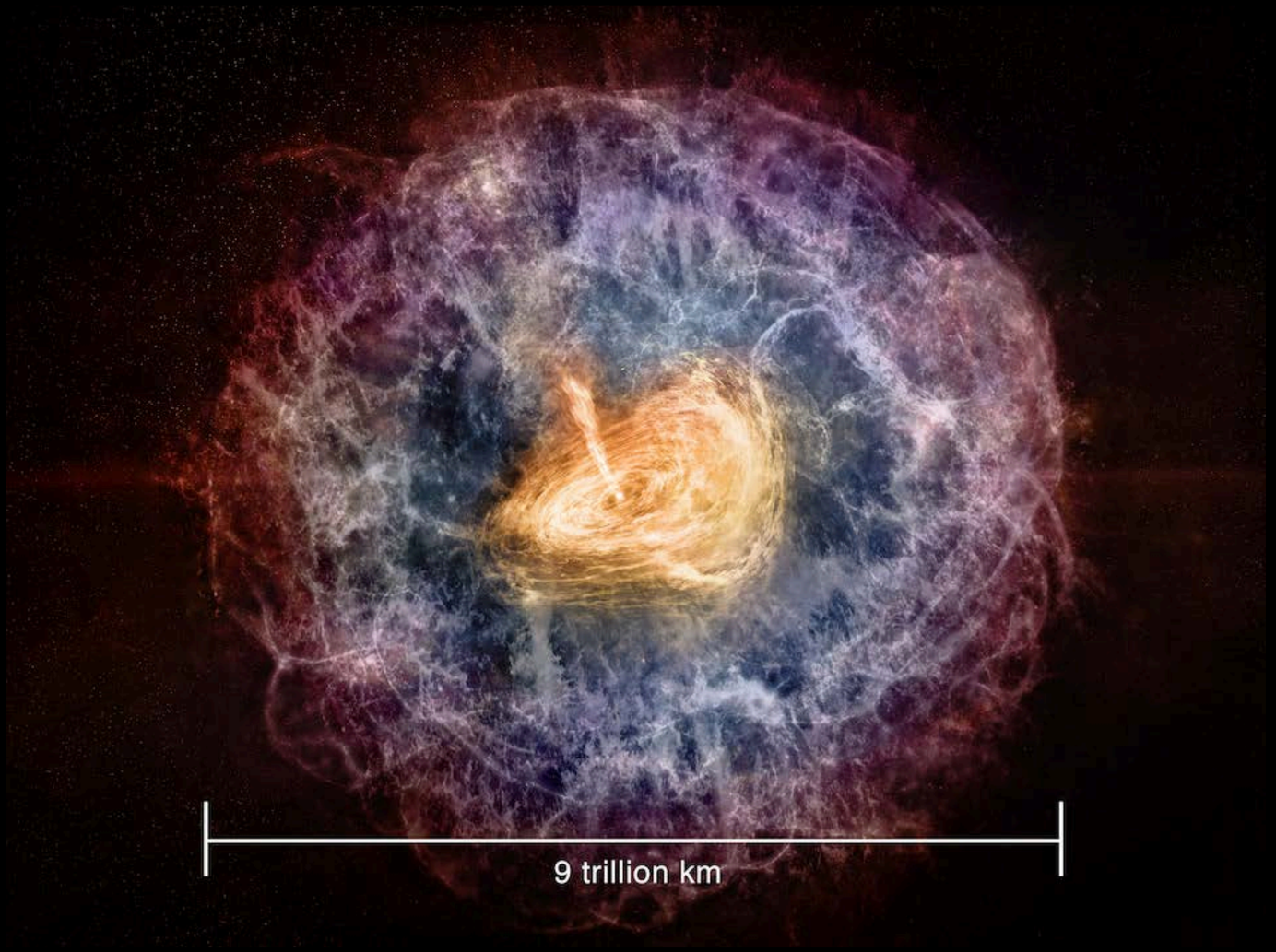
Spectral index

Flat spectrum → *Steep spectrum*

- Both thought to be associated with highly magnetized neutron stars
- Neither previously observed as transients, but both theoretically predicted to be transient
- We have not (yet) observed any associated fast radio bursts, but we are now searching for them

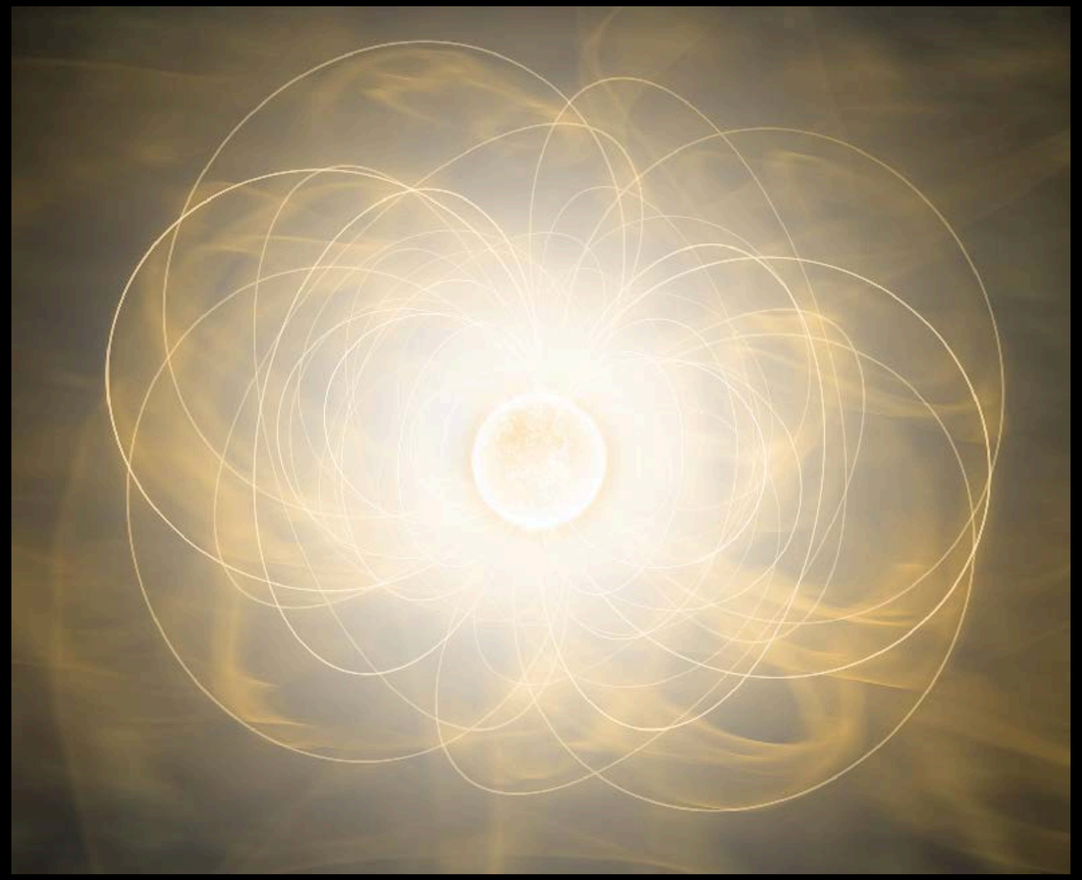
Part III:
The broader context

Potentially the youngest known pulsar (or magnetar) wind nebula



- Age is in a 20 year sliding window starting from the time the remnant becomes transparent (a few decades ago)
- This age (14 to 80 years old) also explains the 5% per year fading
- It also explains why the nebula is so luminous (10,000x the luminosity of the Crab Nebula)

First radio glimpse of a previously hidden nebula powered by a young, highly magnetized neutron star

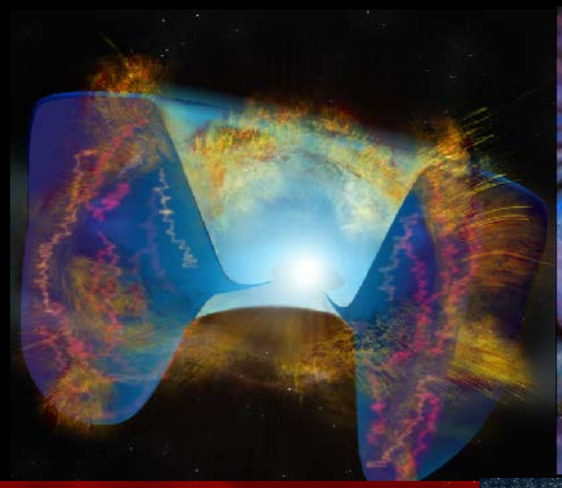
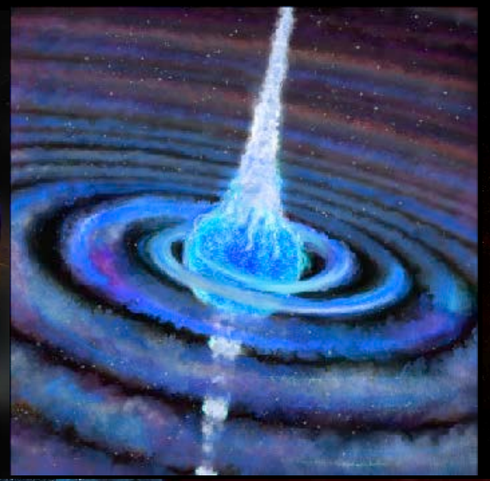
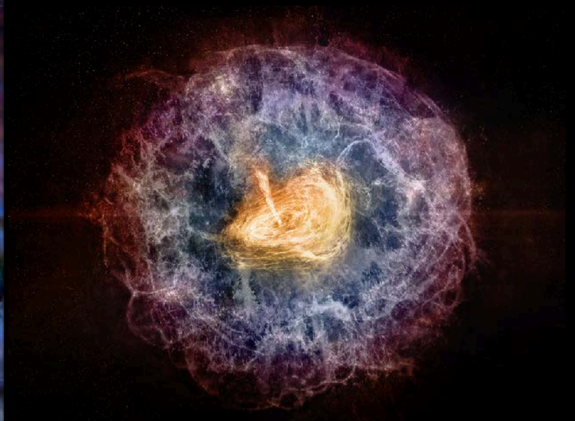
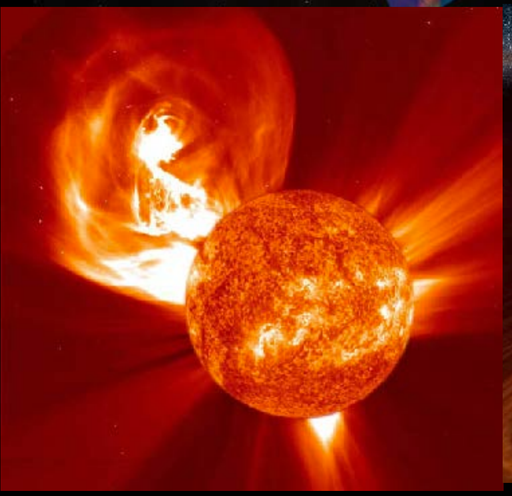


Two potential power sources both involving strong magnetic fields

- Magnetic braking of neutron star rotation
- Decay of internal strong fields (possibly through flares)

After ~1000 years, it might look similar to some highly magnetized pulsars / magnetars that we observe in the Milky Way

Part of a rapid increase in the detection rate of radio transients made possible by the Very Large Array Sky Survey

If you would like to learn more,
please come to my talk (409.09)
at 11:20 AM Thursday

or send me an email
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