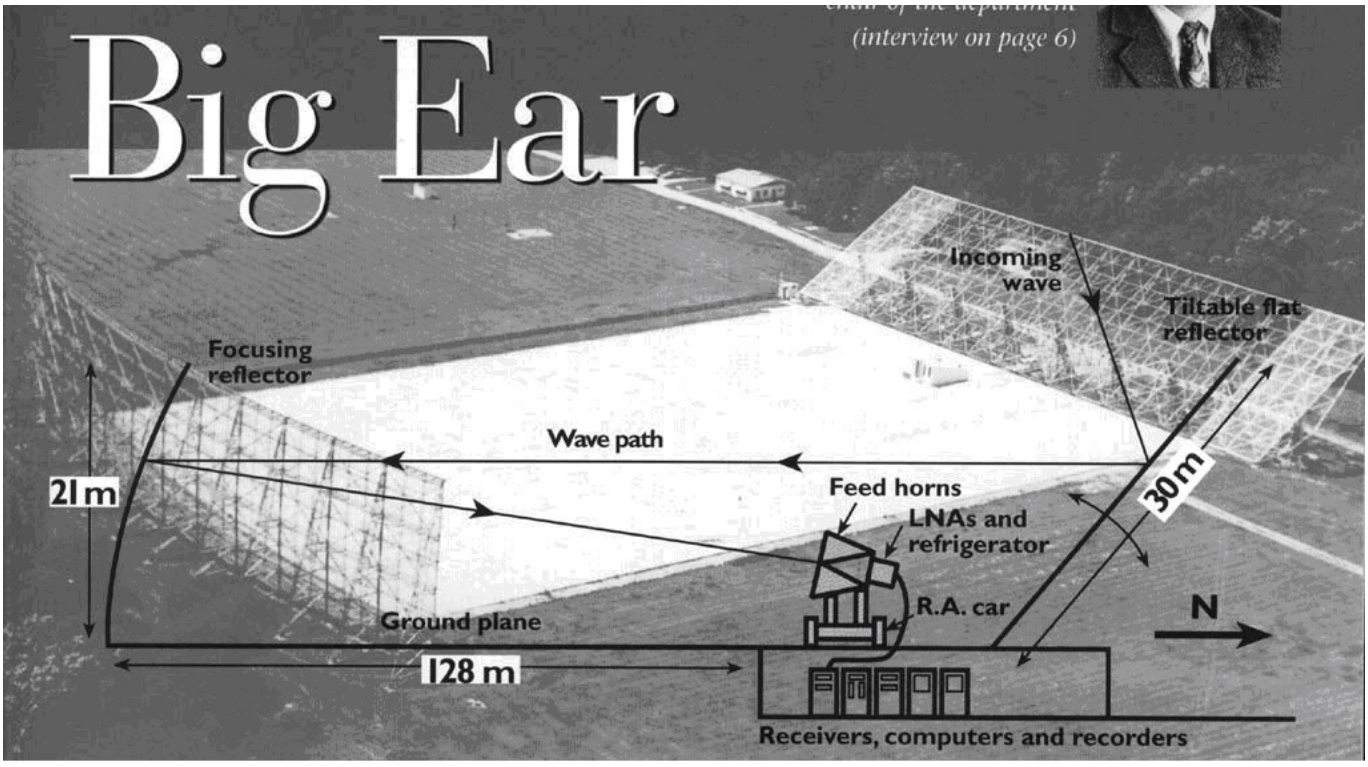
The Wow! Signal – explained?

A review of
Arecibo Wow! I: An Astrophysical Explanation for the Wow! Signal

David F Gahan

The Wow! signal was detected by the Big Ear radio telescope of Ohio State University in 1977 - and never observed subsequently. A recent paper by Mendez et al has put forward a new explanation for the signal origin. David Gahan examines the paper in the context of other explanations in the search for extraterrestrial intelligence.

Modern scientific SETI is the search for technosignatures - and also the search for alternative, natural explanations until the great day when there is no alternative explanation. Great science and ingenuity are involved in both aspects, as when Jocelyn Bell Burnell discovered the first Pulsar and a new branch of astrophysics was born. A similar hunt for natural explanations was launched when, in 1977, a researcher noted an intense narrowband signal on the real-time data print-out from Ohio State University's 'Big Ear' radio astronomy receiver and marked it with the famous, circled 'Wow!' (see Wow! signal - Wikipedia en.wikipedia.org/wiki/Wow!_signal). The radio signature had enough of the features you might hope for from an artificial signal that it excited the interest of SETI pioneers such as Carl Sagan, but also presented the corresponding challenge: what else might have caused it?



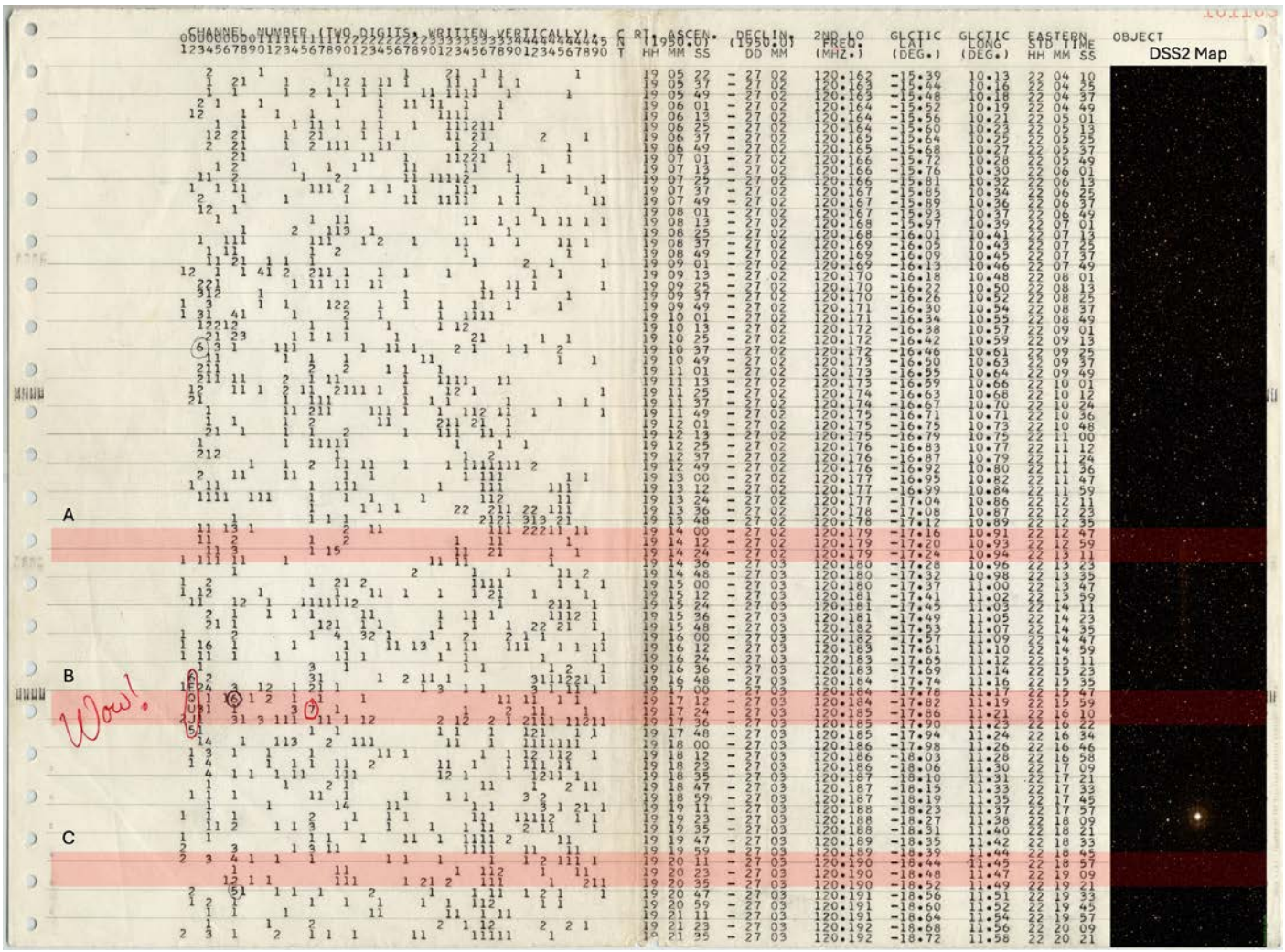
Big Ear Radio Telescope - Aerial View & Diagram of Ray Path

In the summer of 1956 Ohio Wesleyan University (Delaware, Ohio) allowed OSU use of "20 acres more or less" of land near the Perkins Observatory, about 2 miles south of the city of Delaware, on which to build a new radio telescope. Dr John D Kraus's design was for a tiltable flat reflector, a fixed paraboloidal reflector and an aluminum covered ground plane in between. Originally, John had planned for the fixed paraboloidal reflector to be 610 meters (2,000 feet) wide by 61 meters (200 feet) high and the flat reflector to be 610 meters (2,000 feet) wide by 85 meters (280 feet) in slant height. Due to insufficient funding available, the paraboloidal reflector ended up with dimensions of 360 feet by 70 feet, and the flat reflector with dimensions of 340 feet by a slant height of 100 feet. Observations began in 1961. This design became known as a "Kraus-type" radio telescope, and the nickname of "Big Ear" was also linked to this telescope. A telescope of very similar design was built in Nancay, France. Another telescope of a somewhat similar design, called the RATAN 600, was built at Zelenchuckskaya, Russia.

Credit (image and caption): NAAPO (North American AstroPhysical Observatory) www.naapo.org/W8JK/W8JK.htm

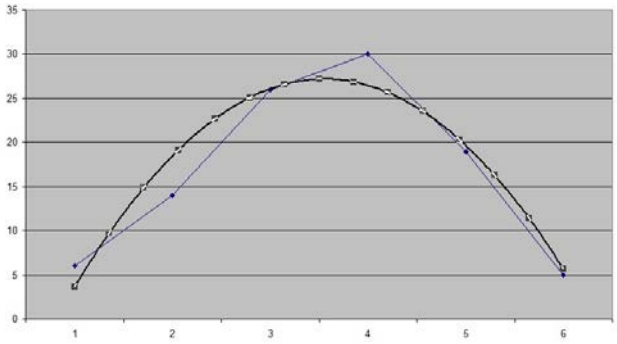
An August 2024 paper *Arecibo Wow! I: An Astrophysical Explanation for the Wow! Signal* (Méndez et al arxiv.org/pdf/2408.08513) seems to provide the most convincing explanation yet. NB despite the title, the Wow! signal was observed in Ohio; the great observatory at Arecibo still does important astronomy despite the destruction of its great dish in 2020 (en.wikipedia.org/wiki/Arecibo_Telescope). Méndez is based there and has 50 years of data available for re-analysis with modern techniques.

There was mystery from the outset. Big Ear, a kind of flat-pack Arecibo with two 'wall-like' reflector panels focusing a portion of sky onto horn antennae, relied on the Earth to do the turning. Two antennae were used in subtraction mode. You were never quite sure exactly which one did the receiving (and hence location, although clearly 'somewhere in Sagittarius') but it was good for signal-to-noise ratio.



Full page of the computer printout with the Wow! Signal labeled in handwritten red ink. The coordinates column corresponds to the location of the positive horn. The signals are calculated from the signal-to-noise ratio (SNR) of the absolute value of the difference between the positive (ON) and negative (OFF) horn, which is 45 arcminutes ahead (3 minutes). Three locations of interest were added to the figure, labeled A, B, and C, and highlighted in red. They have the approximate azimuth size of the Big Ear telescope (8 arcminutes). The actual location of the Wow! Signal is either in B or C. If the signal was present and persistent in B, then the signal would appear in both A and B, but there is nothing in A. If present and persistent in C, then it would appear in both B and C, but there is nothing in C. A Digitized Sky Survey 2 (DSS2) frame was included for reference with the objects in the observed field (right).
Printout credit: The Ohio History Connection Collections. Figure 1 (www.ohiohistory.org/wow/).

That was what really stood out – the sequence of 6EQUJ5 (see the printout and also the sidebar), showing the intensity sequence during the whole 72 seconds the source was in the observational window, reaching an impressive thirty standard deviations above background noise and centred on the 21 cm neutral hydrogen line right where SETI pioneers might have expected.



6EQUJ5 with polynomial trend line).

It was never seen again despite Big Ear's daily passes over the same region of sky so it had to be a transient phenomenon. Later calculations (in Méndez's paper) would reveal that the intensity of the transient (if isotropic and lasting of the order of the minutes/hours) could have been the order of 10^{-8} - 10^{-6} luminosity of the Sun at that wavelength. Big Ear averaged over 10-second 'buckets' so wouldn't be sensitive to signal modulation faster than this; the 'signal' was therefore assumed to be unmodulated.

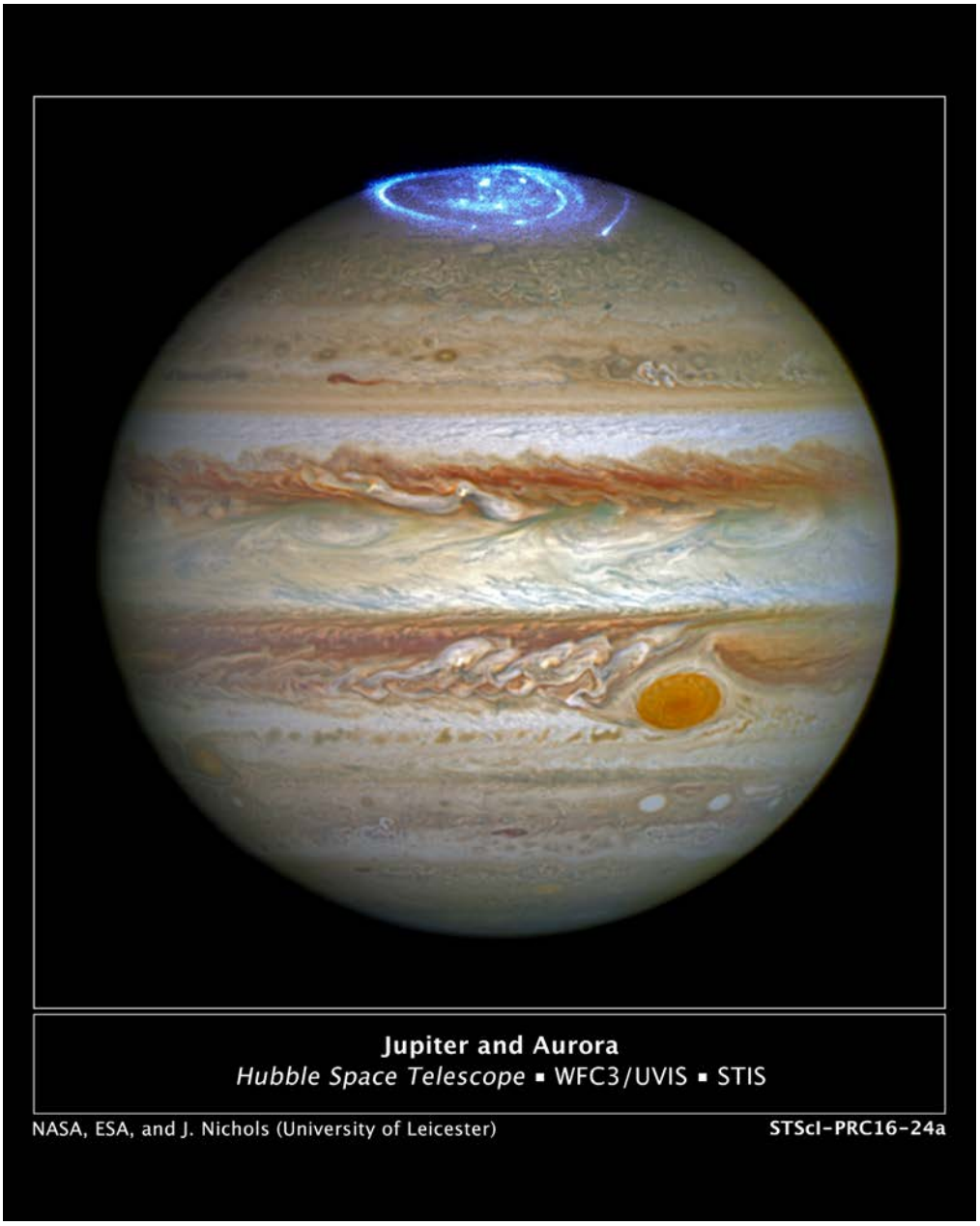
Méndez et al do a good job of examining the best current explanations. Their work on the Arecibo archive led them to see that observational techniques and data formats allowed them to do plenty of read-across. Their data showed similar narrow-linewidth sources (particularly around the pleasantly named 'Teegarden's Star') which they could attribute to clouds of cool, neutral hydrogen. So there was nothing really special about the 10 kHz linewidth (SETI researchers would be more excited about much narrower linewidth sources of a few Hertz) and in fact this points to relatively cold hydrogen without much thermal broadening. The absolute frequency of Wow! - which would be red or blue shifted depending on its rotation rate within the Milk Way - was also consistent with gas clouds between us and the galactic centre and with little Doppler shift either way. But their archival data hasn't show them (yet, although they have 50 years of data to trawl through) anything of the same power as Wow! to within two order of magnitude. So what could cause the faint 21 cm glow of a cloud of cool hydrogen to massively brighten, then quickly fade?

Interpretation of the Wow! data

Part of the cultural history of the Wow! Signal is the misinterpretation of the format of the data as a message from the stars. One SETI enthusiast asked: "What does the progression 6EQUJ5 actually stand for? A sequence in need of completion? A matrix in need of expanding? A computer malfunction? The ASCII equivalent to a binary code?" (www.setileague.org/articles/calibwow.htm). In fact, you have to take yourself back to the 'steam-punk days of computer print-outs. There was no sophisticated real-time processing of data by complex decision trees with user changeable parameters (eg by Visual Basic), and no spitting out of beautifully graphed intensity charts emailed to your phone. No, you actually had to READ THE PRINT OUT from a chattering printer, maybe with a golf-ball head or daisy wheel. You needed a string of characters that would draw the eye to something unusual, but cover a big dynamic range so as not to lose any information. The researchers came up with an alphanumeric code to represent the integrated signal strength over 10 second buckets (12 seconds including processing time). Specifically, the symbols represent the number of standard deviations by which the received signal exceeded average background noise, on a scale of 0 to 35. So a 0 means no stronger than background noise, 1 is one sigma above noise, 9 means nine sigma above noise, an A would be ten units, and U (the strongest peak of the actual signal) is 30 standard deviations above the mean background noise in the receiver ie 6EQUJ5==6,14,26,30,19,5. If you graph the sequence as amplitude values over time you get roughly a Gaussian distribution, consistent with the antenna 'field of view' pattern of Big Ear in drift-scan mode (ie, as the Earth rotates). The data set depicts signal amplitude over six sample buckets of 12 seconds at the receiver frequency.

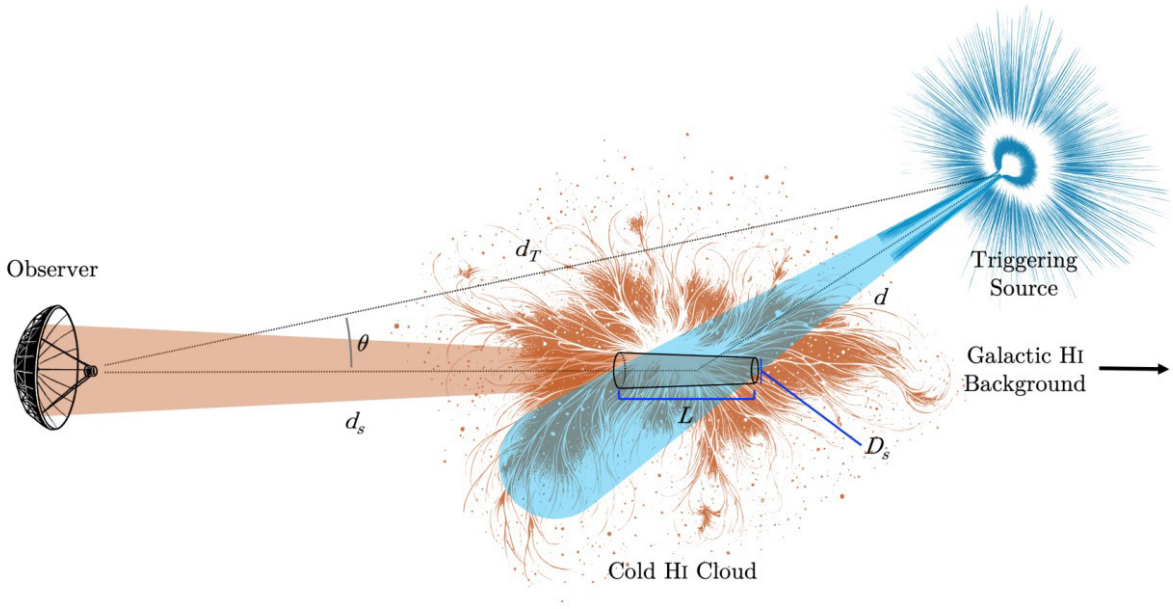
I spent three enjoyable years working with erbium doped fibre amplifiers (EDFAs); every data-packet you receive from California will go though about 200 of these to boost the signal. So I accepted gladly when John asked me to do this review, especially after seeing the word 'MASER' in the paper. Lasers/Masers both depend on having more atoms in the excited state than the ground state, which only happens if they are 'pumped' by an energy transfer mechanism to achieve 'population inversion'. Both lasers and the sort of maser used for frequency reference have feedback cavities (mirrors!) which select a very specific frequency even if the lasing (or 'gain') medium can support a broader range. A simple LED with a short cavity with no feedback (for example) gives a broader spectrum with low coherence versus a solid-state laser.

No feedback cavity but a longer path length (with plenty of population inversion), gives you 'super-radiance' where the signal is boosted as it travels along, with more coherence and a narrower linewidth (the two are mathematically related). This is very like what happens in an EDFA over several meters of erbium doped fibre. (Although Méndez et al try to make a distinction between super-radiance and maser amplification, it's a matter of taste which term you use,)
Astrophysical masers certainly exist (Astrophysical maser en.wikipedia.org/wiki/Astrophysical_maser). Here's a lovely Hubble image of Jupiter with a false-colour image of the permanent, circular aurorae 16 degrees from the magnetic pole. There's plenty of pumping from electron currents flowing in the magnetosphere which give rise to maser amplification. Jupiter is a powerful radio source as a consequence. But the conditions to allow masing in cold, isolated clouds of hydrogen – to achieve population inversion over a large object possibly millions of kilometres long - are much less probable. The Wow! signal looked like a maser emission pumped by a transient energy source (hence the short, unrepeated, duration of the event) but what could be the energy source?



Aurorae on the north pole of Jupiter generate cyclotron masers (Hubble)
Astrophysical maser -en.wikipedia.org/wiki/Astrophysical_maser
Credit: NASA, ESA, and J Nichols (University of Leicester)

Enter the Magnetar. Magnetars (en.wikipedia.org/wiki/Magnetar) are the 'bad boys' of the local neighbourhood. Recently formed neutron stars, they spend a round 10k years in a violent phase. Their magnetic fields are around 1,000x that of a 'normal' neutron star and could wipe your credit card at earth-moon distance. Any hydrogen atom in the vicinity would be massively distorted into a thin cigar shape as its s-orbital would be compressed 200-fold by the field. They are prone to starquakes giving rise to huge flares, of great interest to astrophysicists. Only 30 have been discovered so far but there could be 30 million in the Milky Way. Any flare would have plenty of UV radiation to pump atomic hydrogen to population inversion state and allow masing to begin at the characteristic 21 cm wavelength. Méndez et al do a good job of running through all the relevant numbers and making the case. You still need a long, thinnish cloud of hydrogen pointing more-or-less at us, and a local magnetar to give off one of its flares - but the whole story appears to be plausible, and currently may be the simplest explanation. While searches for sun-like stars (possible homes for ET) has been made, no specific search for candidate hydrogen clouds has yet been made, nor has a magnetar yet been spotted. The imprecision in directional data from Big Ear makes this more work but the effort should be worth it. And Méndez et al still have 50 years-worth of Arecibo data to trawl through for possible similar signals. An ETI origin cannot be ruled out, as the authors say, but the existence of a natural mechanism (if confirmed) for strong signals on the 21 cm line would make this a less favourable choice for ET to choose as their hailing frequency.



The proposed Wow! Signal emission source is a region of a cold H_I ['neutral hydrogen' ie clouds of atomic (not molecular) H.] cloud at a distance d_s that emits a superradiance radio beam along a line of sight L and with a diameter D_s. This event is triggered by a strong radiation source, at a distance d from the cloud and d_T from the observer. The trigger beam is not necessarily observed depending on its distance, size, and separation angle Θ. Since the superradiance event also takes a time to build up, the trigger beam if observed always precedes the superradiance event by seconds to hours.
Credit(image and caption): Menendez et al. Figure 6.

About the Author
David F Gahan is a regular contributor to Principium and has a special interest in Schelling Points – logical locations and modes of communication that intelligent species might be able to mutually guess. His first article on the subject 'AMiTe Treffpunkt' was published in Principium 32. He is an Imperial College physicist and (relevant to this paper) worked on Optical Amplifiers at Corning Incorporated from 1996-99.