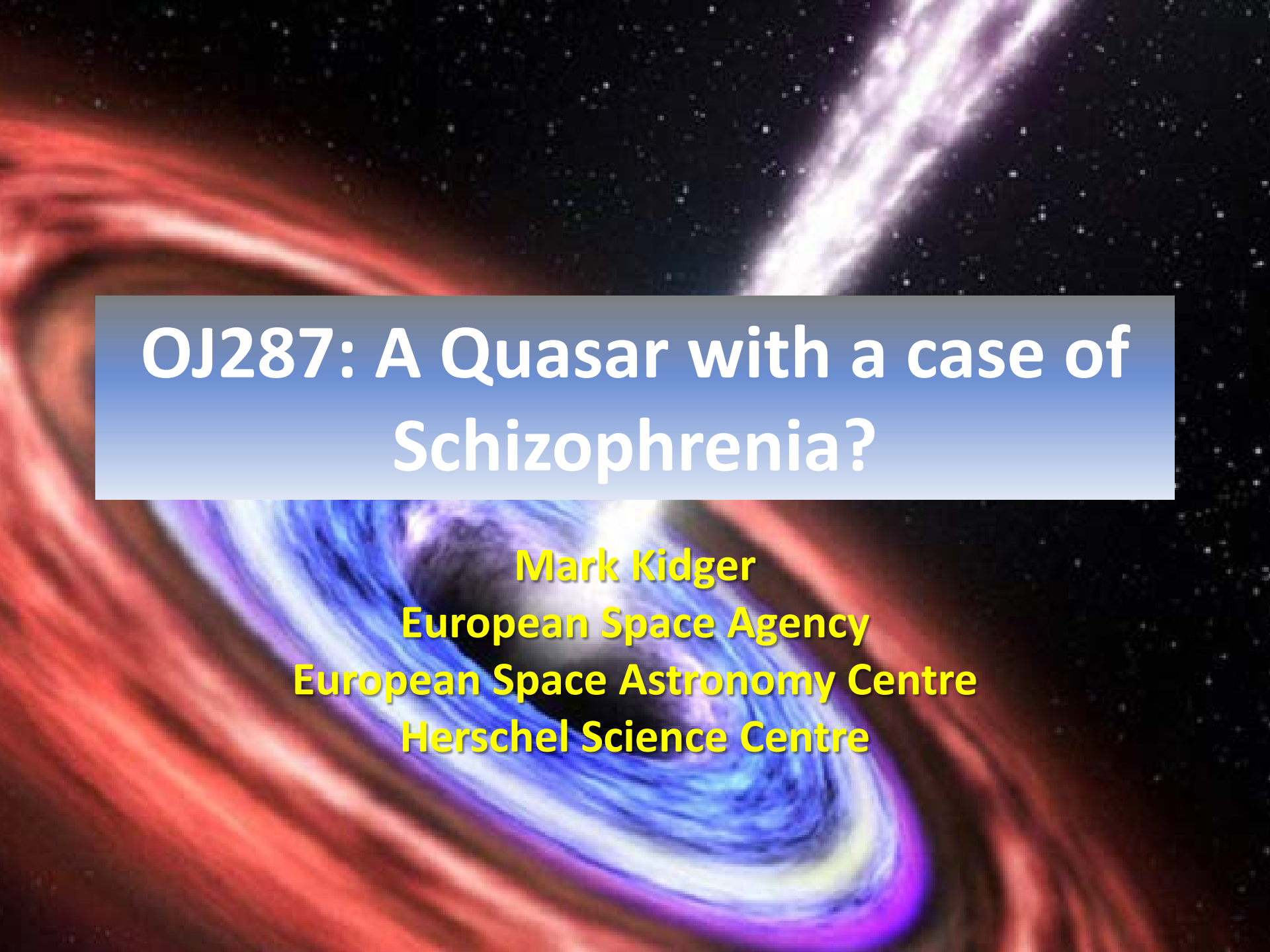


OJ287: A Quasar with a case of Schizophrenia?

Mark Kidger
European Space Agency
European Space Astronomy Centre
Herschel Science Centre

What is a Quasar?

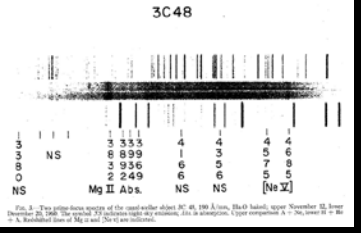
- Quasar is a contraction of Quasi-Stellar Object.
- They are objects that look like faint, blue stars, but are really incredibly distant.
- They are the extremely luminous nuclei of distant galaxies.
- Quasars are powered by supermassive black holes that are practicing cannibalism of their (usually invisible) host galaxy.
- A quasar can be as much as 1000 times more luminous than the Milky Way.

Discovering Quasars

- In the early-1950s, only 8 radio sources in the sky had been identified.
- A race started to identify objects, particularly from the new 3rd Cambridge (3C) catalogue of radio sources.
- Many were found to be faint galaxies, but a few defied identification.
- In 1960 Tom Matthews and John Bolton identified 3C 48 with what appeared to be a 16th magnitude star with a nearby wisp of nebulosity.

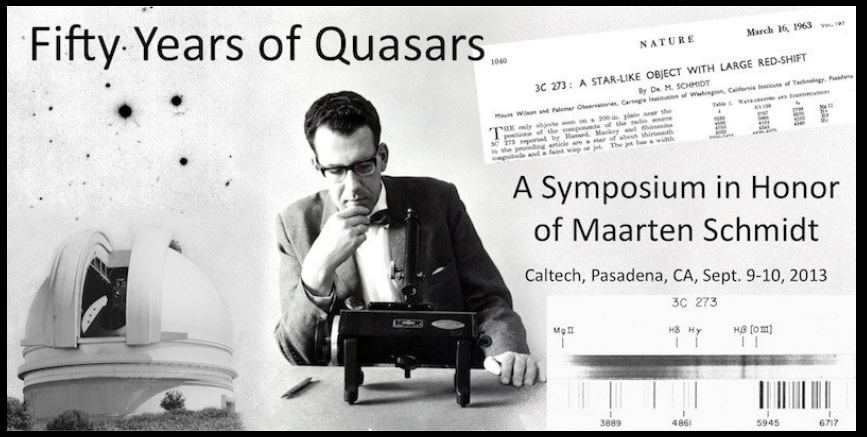
Radio stars?

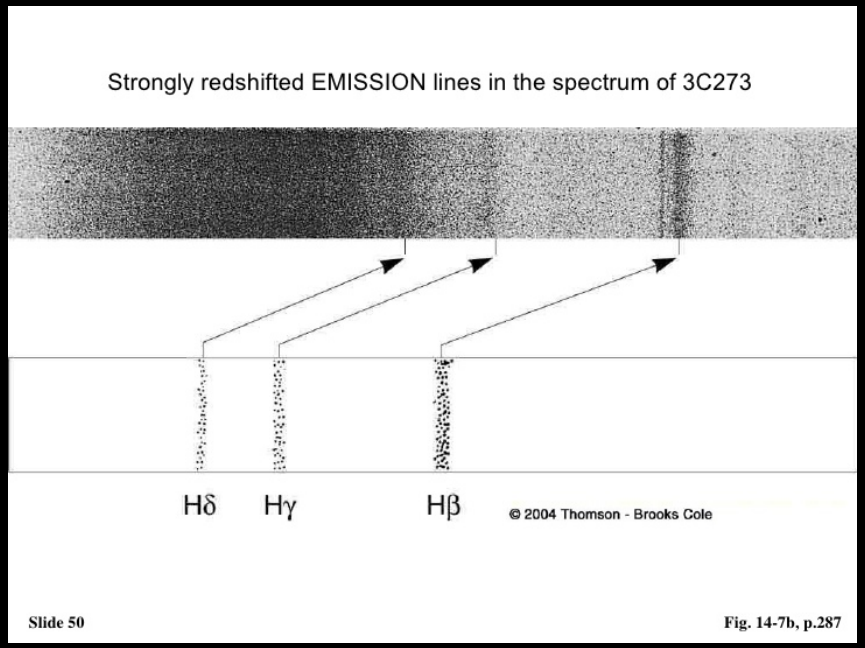
- A second, 13th magnitude “star” – 3C273 – was identified at Mount Palomar in 1962.
- Very long baseline interferometry between Jodrell Bank and other locations in the UK had already established that some 3C radio sources were very small.
- Even interferometry between continents failed to resolve some of these objects.
  - The central source of 3C345 appeared to be less than 0.0004 arcseconds across.
- Could these objects be radio-emiting stars?



Odd Stars. Odd spectra

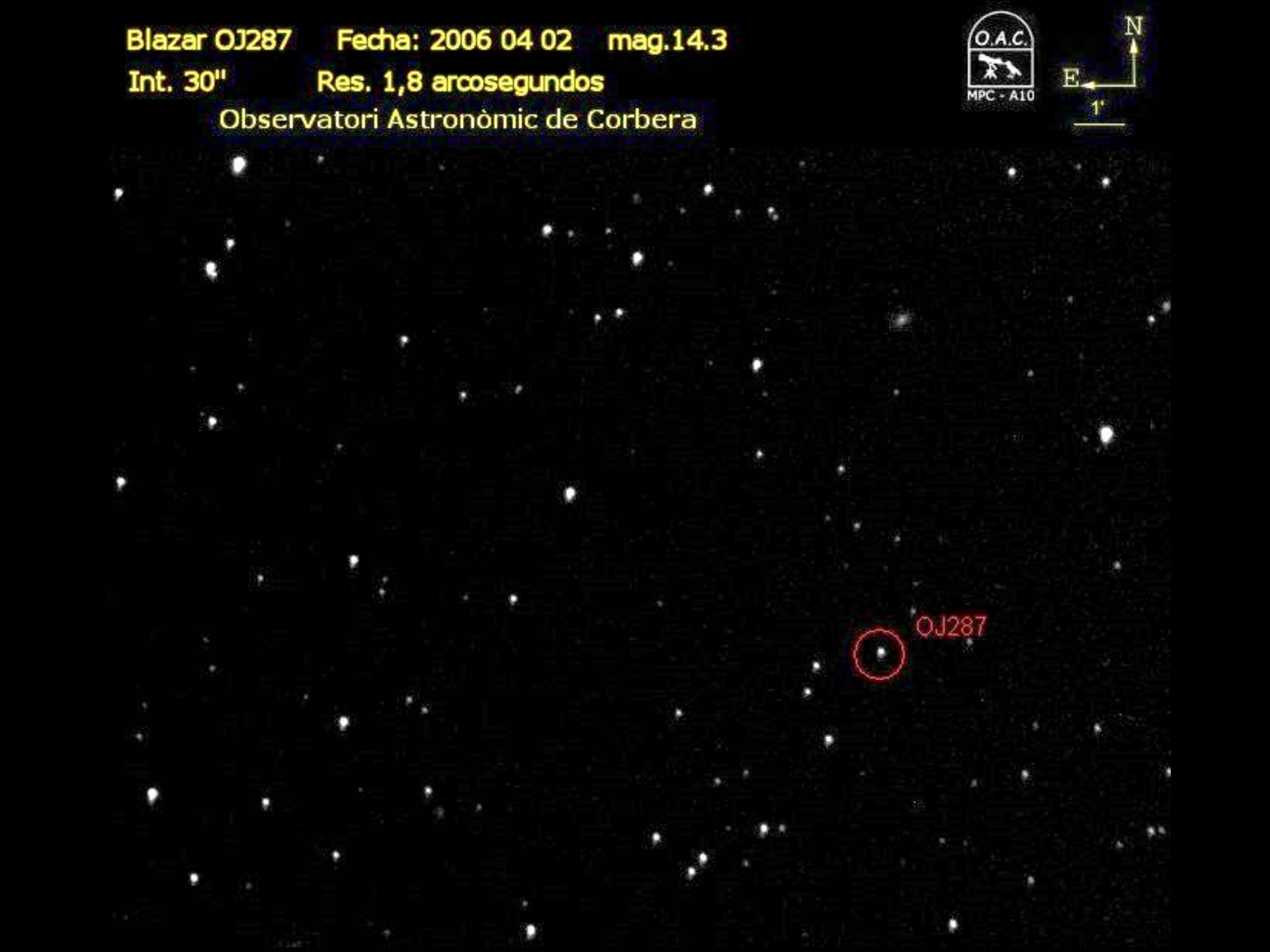
- Normal stars have dark lines in the spectra.
- 3C48 and 3C273 had bright, emission lines.
- The pattern *looked* familiar, but no one could identify the lines with known elements.
- In 1963 Maarten Schmidt realised that the lines were highly redshifted hydrogen.
- **Quasars were born.**





A Test: Can you recognise a quasar when you see one?

Will Gary Poyner please step forward…


Blazar OJ287 Fecha: 2006 04 02 mag.14.3
Int. 30" Res. 1,8 arcosegundos
Observatori Astronòmic de Corbera
O.A.C.
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N
E
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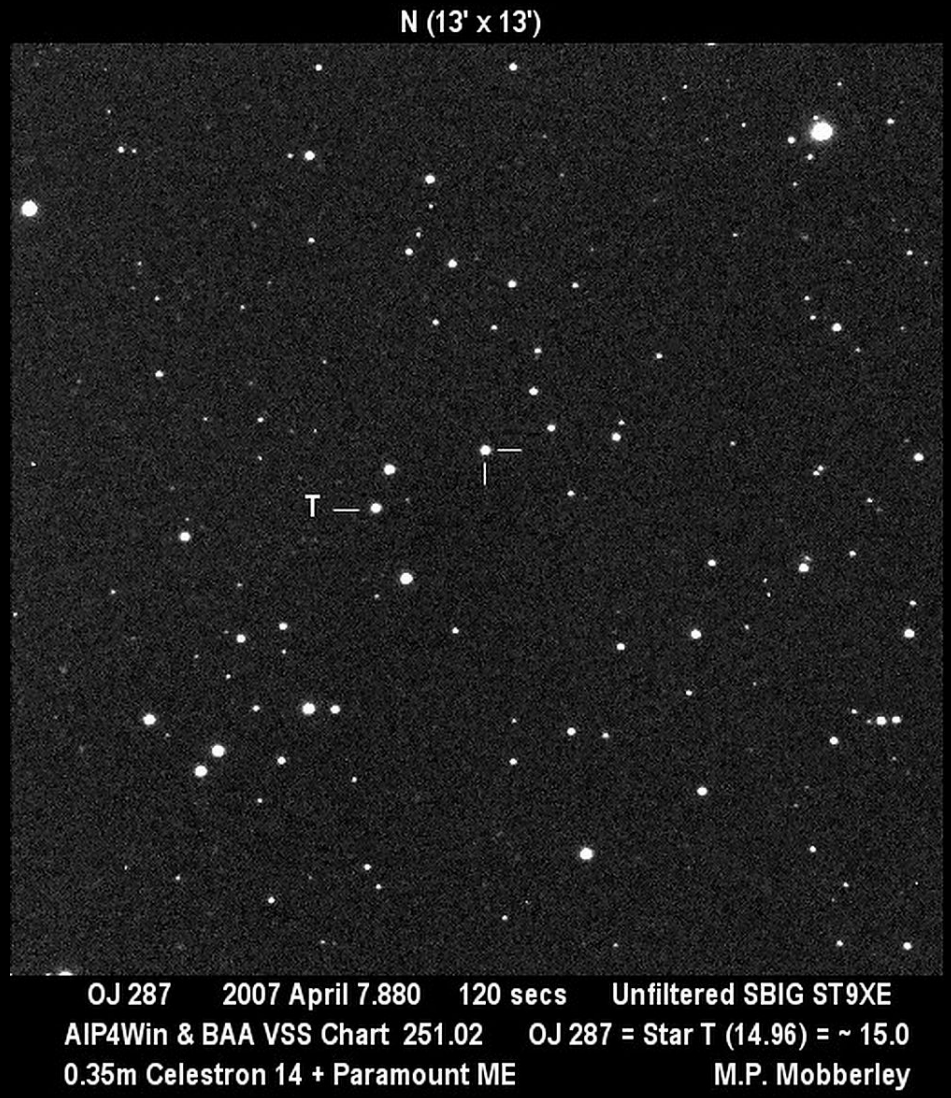
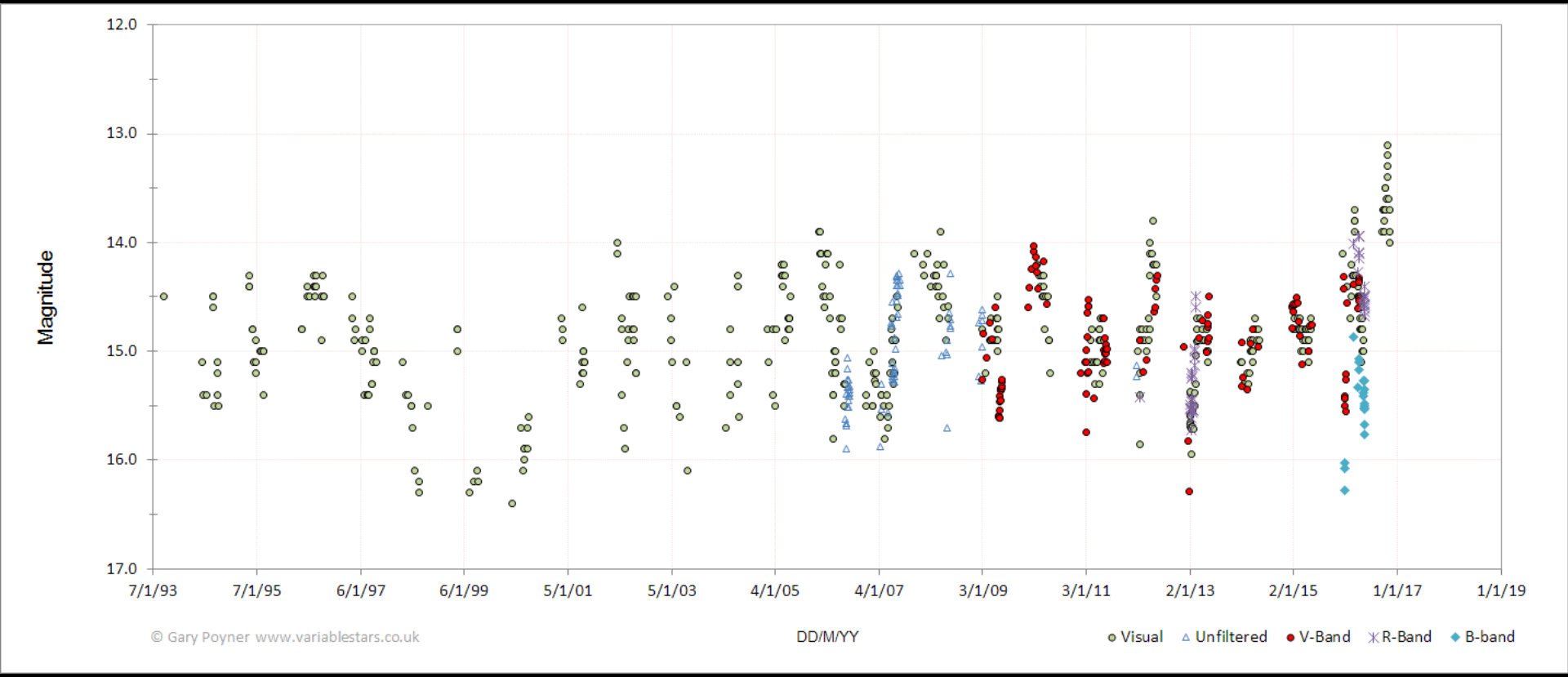
OJ287

OJ287 must be interesting: even Martin Mobberley has observed it!



Where is OJ287?

This is Gary's light curve for OJ287

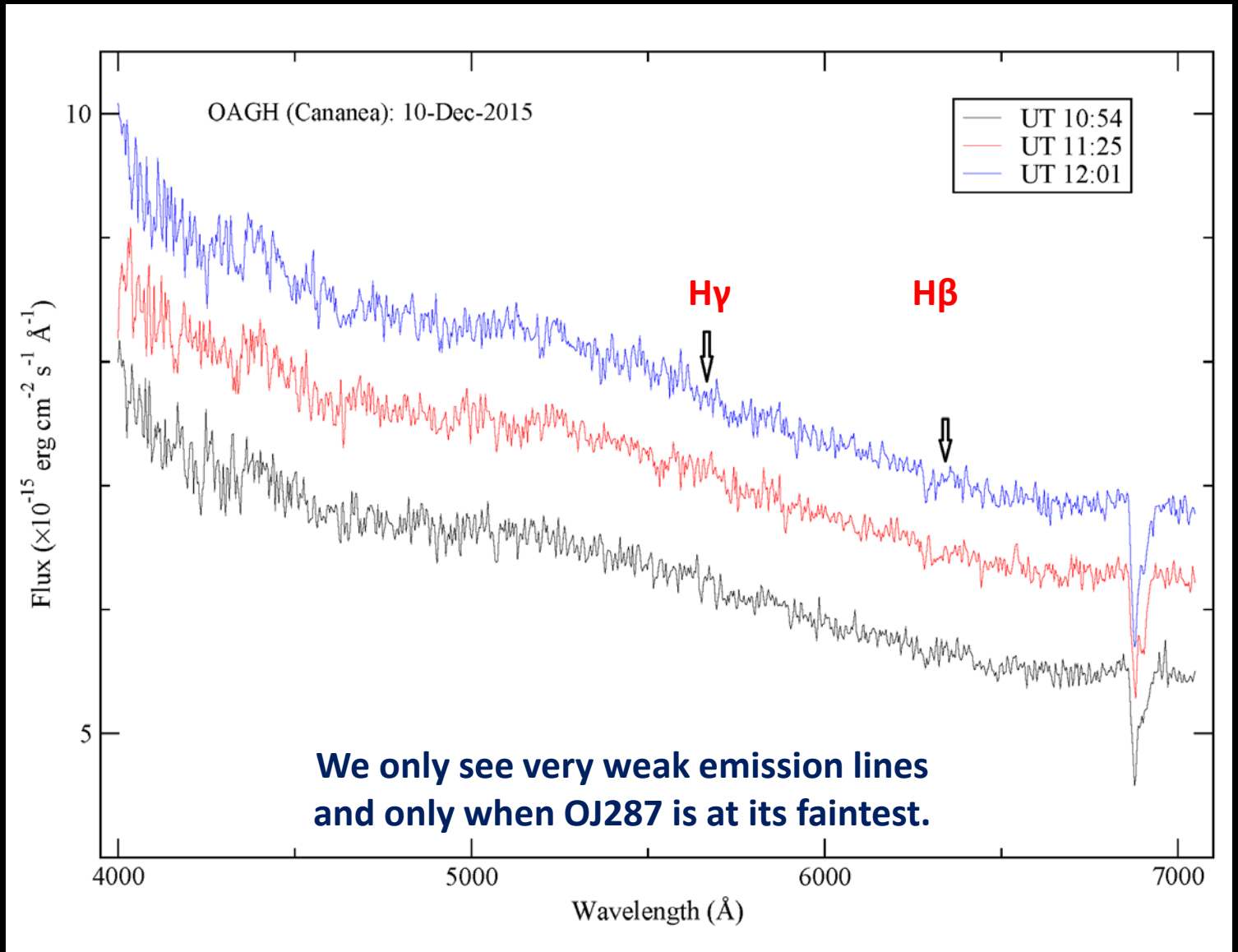


The brightness of OJ287 goes up and down violently, even in just a few tens of minutes.

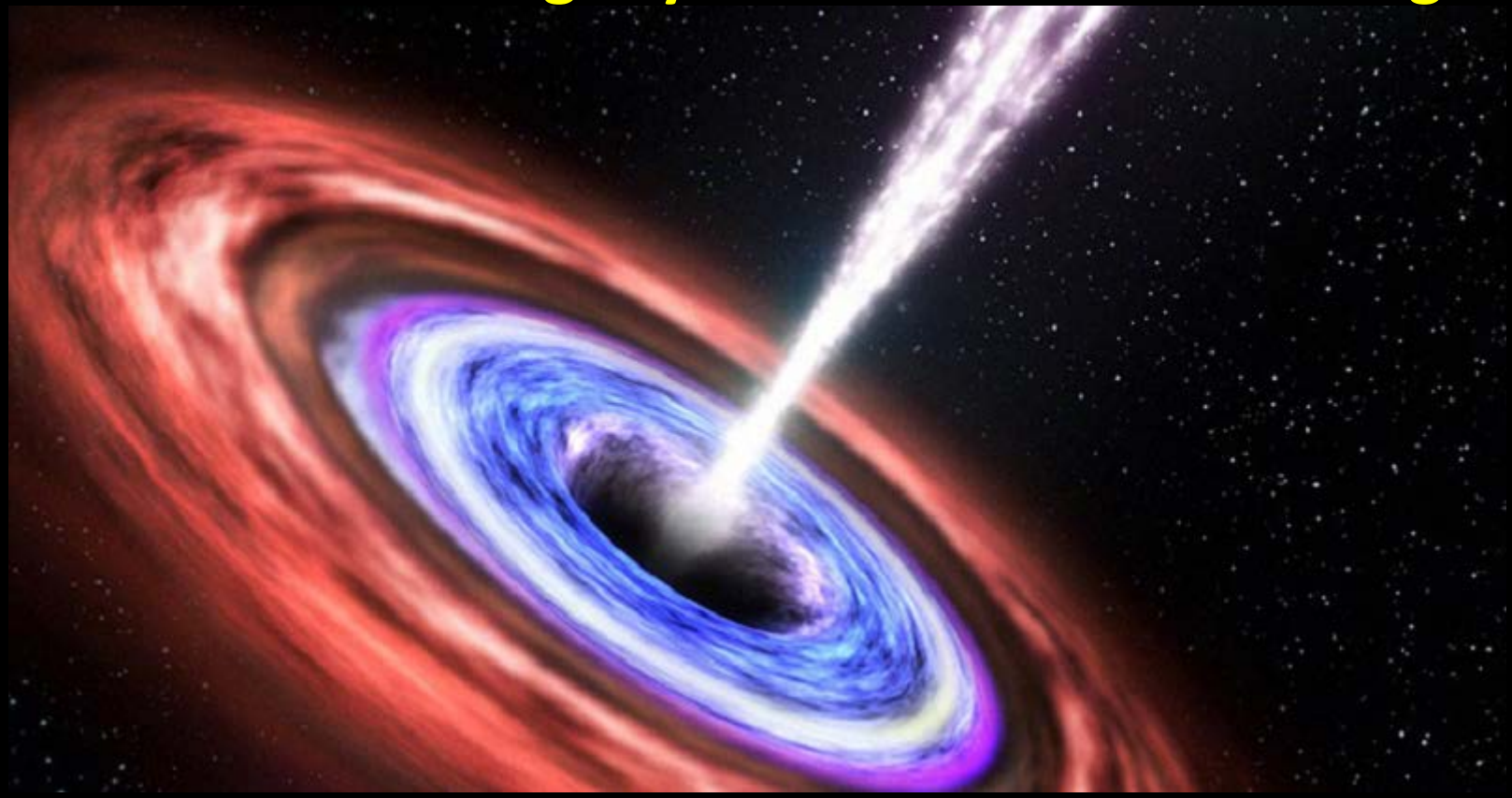
OJ287 is termed a Blazar – literally, a Blazing Quasar.

Its historical range is from magnitude 12 to 18.

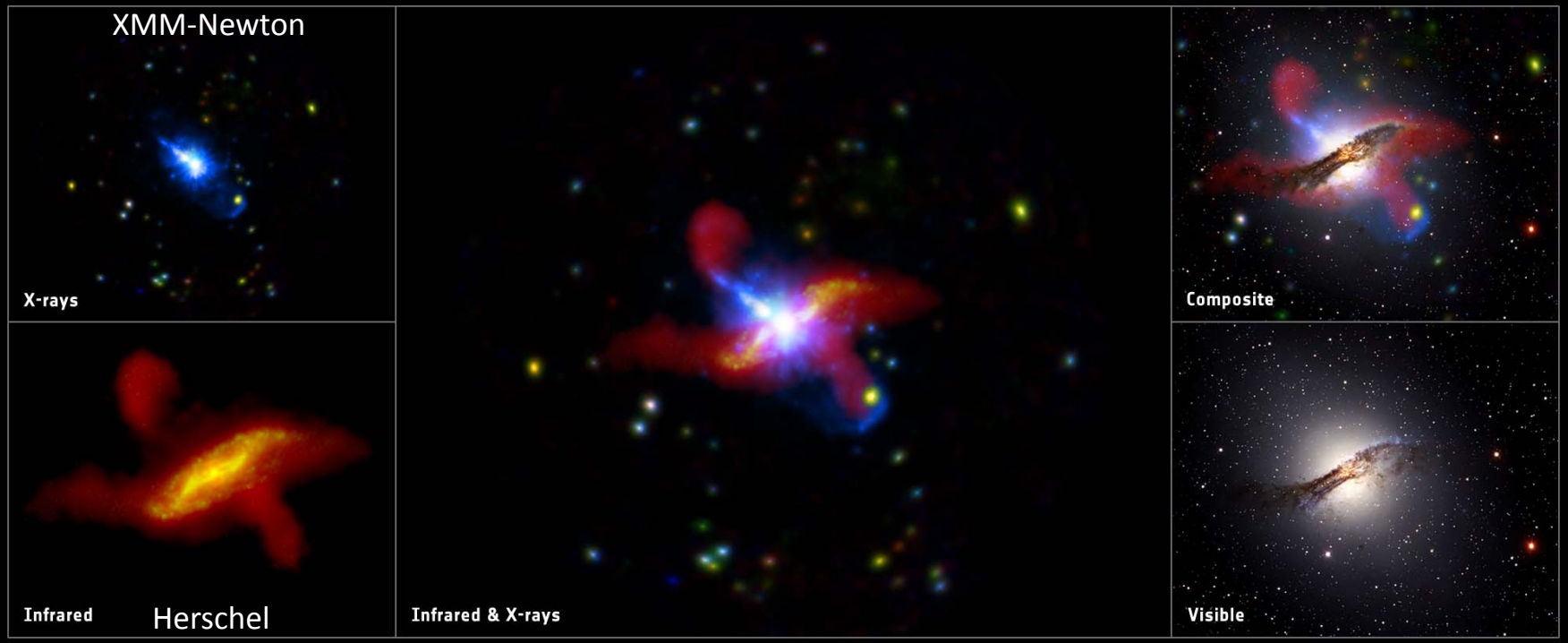
But the spectrum of OJ287 does not look like a normal quasar



In OJ287 we are looking at a quasar with a bright, relativistic jet that is pointing towards us, like a lighthouse beam: the beam drowns out everything else, including the spectral lines that are emitted from clouds a few light years from the central engine.



In a few objects, such as the galaxy Centaurus A, we can actually observe the jet directly. It shows up in x-rays from XMM-Newton and at 500 microns in the image from Herschel.



Why is OJ287 special?

We look down the throat of the dragon!

It is the jet most closely aligned to us that we know…

Unique Behaviour

- OJ287 was first identified in the Ohio catalogue of radio sources in 1968.
- A huge outburst in 1972, which appears to have lasted about 4 years, drew attention to it.
- And OJ287 played to the gallery by showing something unique to this object… rapid periodicity.

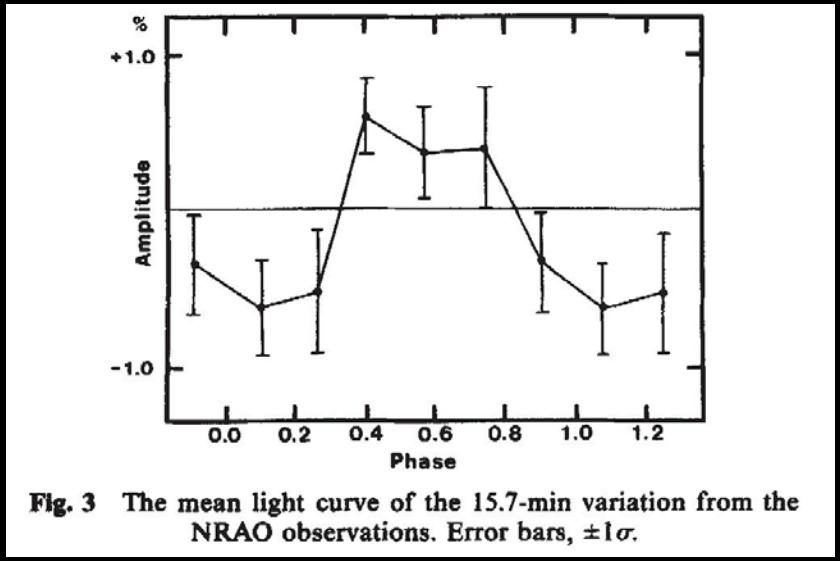


Fig. 3 The mean light curve of the 15.7-min variation from the NRAO observations. Error bars, $\pm 1\sigma$.

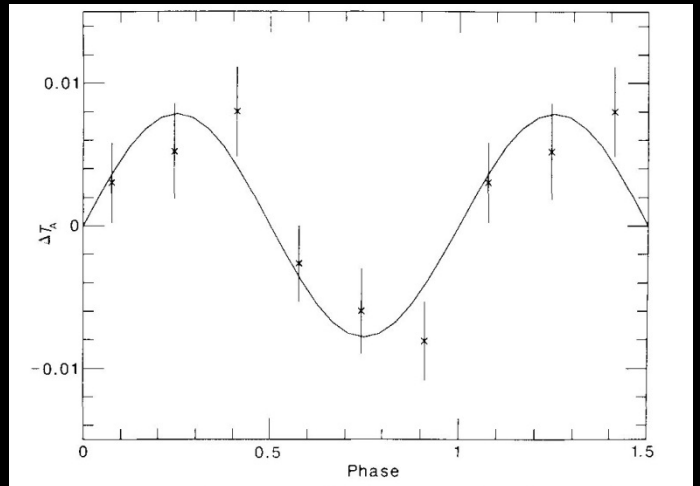


Fig. 3 Data folded into six bins using a period of 35 min. The plot shows the means from each bin, with error bars twice the error in the mean. Also shown is a least-squares fit sine wave with a period of 35 min.

OJ287 Periodicity: now you see it and now you don't!

- A Finnish group found that their 15 minute period appeared & disappeared over 2 years of observations, but was sometimes even seen simultaneously in radio and optical!
- This is the radio light curve in which another group found a 35 minute period of amplitude 2%.
- It is not obvious!

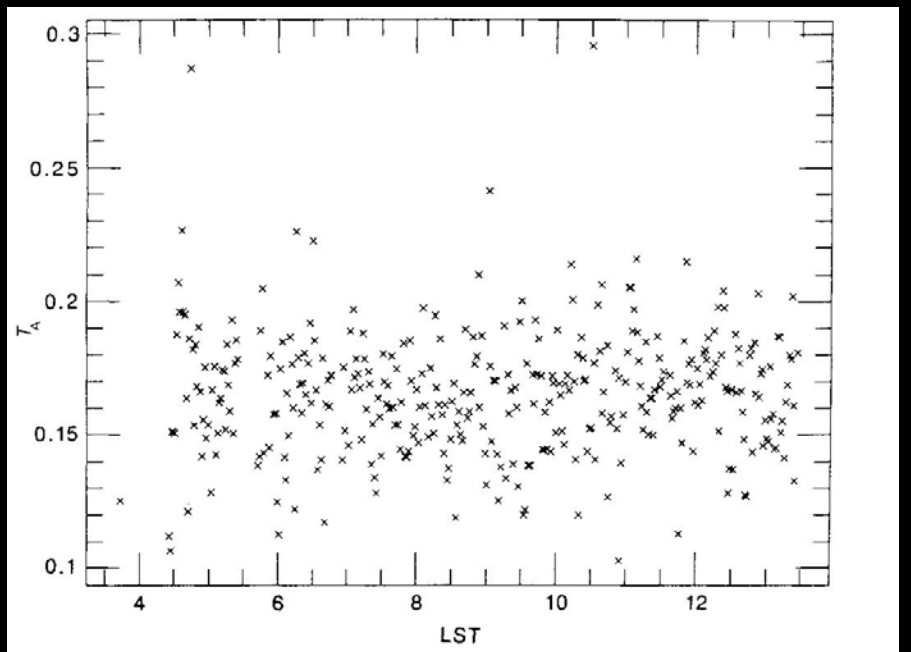


Fig. 1 Antenna temperatures for OJ287 measured on the morning of 1 Feb. 1987. The mean value is 0.165 ± 0.001 K. The typical error in a single measurement is 0.016 K.

Lots of groups saw periods in the light curve of OJ287…

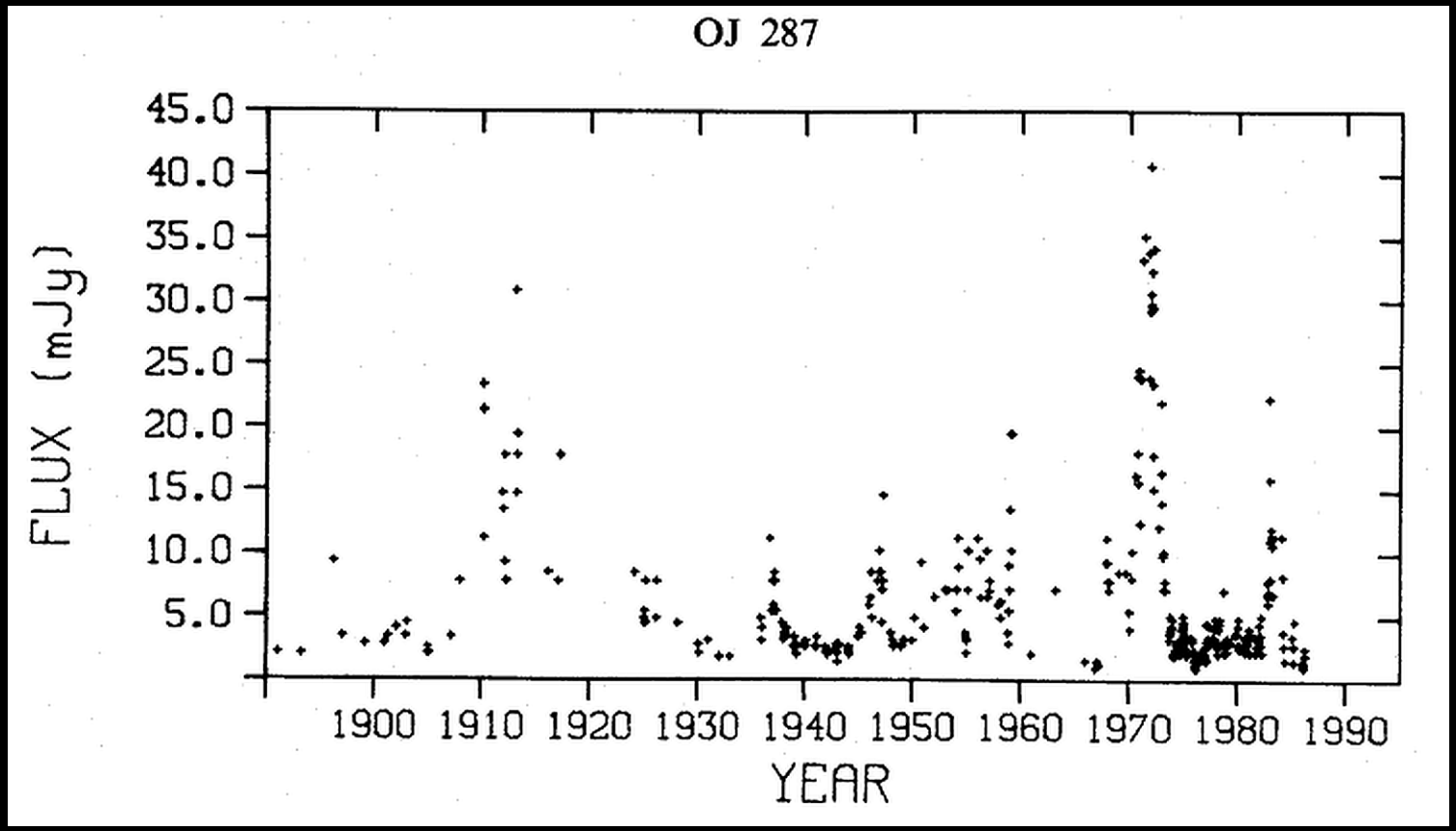
- But they could not agree what the periods were.
- Different groups observing simultaneously, or nearly simultaneously got completely different results.
- But it attracted even more attention to OJ287.

Table 2 Observed periodicities of OJ 287

Date(s)	Frequency	Period (min)	Amplitude (%)	Reference
16–21 Mar. 1972	‡	39.2	1	5
2 Feb. 7 Mar. 1973	‡	—	<0.15	9
9, 10 Mar. 1973	‡	40.0	~1	6
24 Apr. 1981	37 GHz	15.7	*	8
26 Feb. 1982	22 GHz	15.7	*	8
	§	16.3	*	8
	§	15.6	*	8
5–7 Mar. 1982	22 GHz	15.7	*	8
Jan.-Mar. 1983	§	22.8	3	7
		42.2	2	7
23 May 1983	5 GHz	—	<0.1	3
	22 GHz	15.7	0.5	8
	22 GHz	13.0	*	8
	37 GHz	15.7	*	8
	37 GHz	13.0	*	8
1 Feb. 1986	42 GHz	35.1	4	This work
20–24 Feb. 1986	8 GHz	—	<(0.7–3.)†	‖
27 Jan. 1987	42 GHz	—	<2	This work

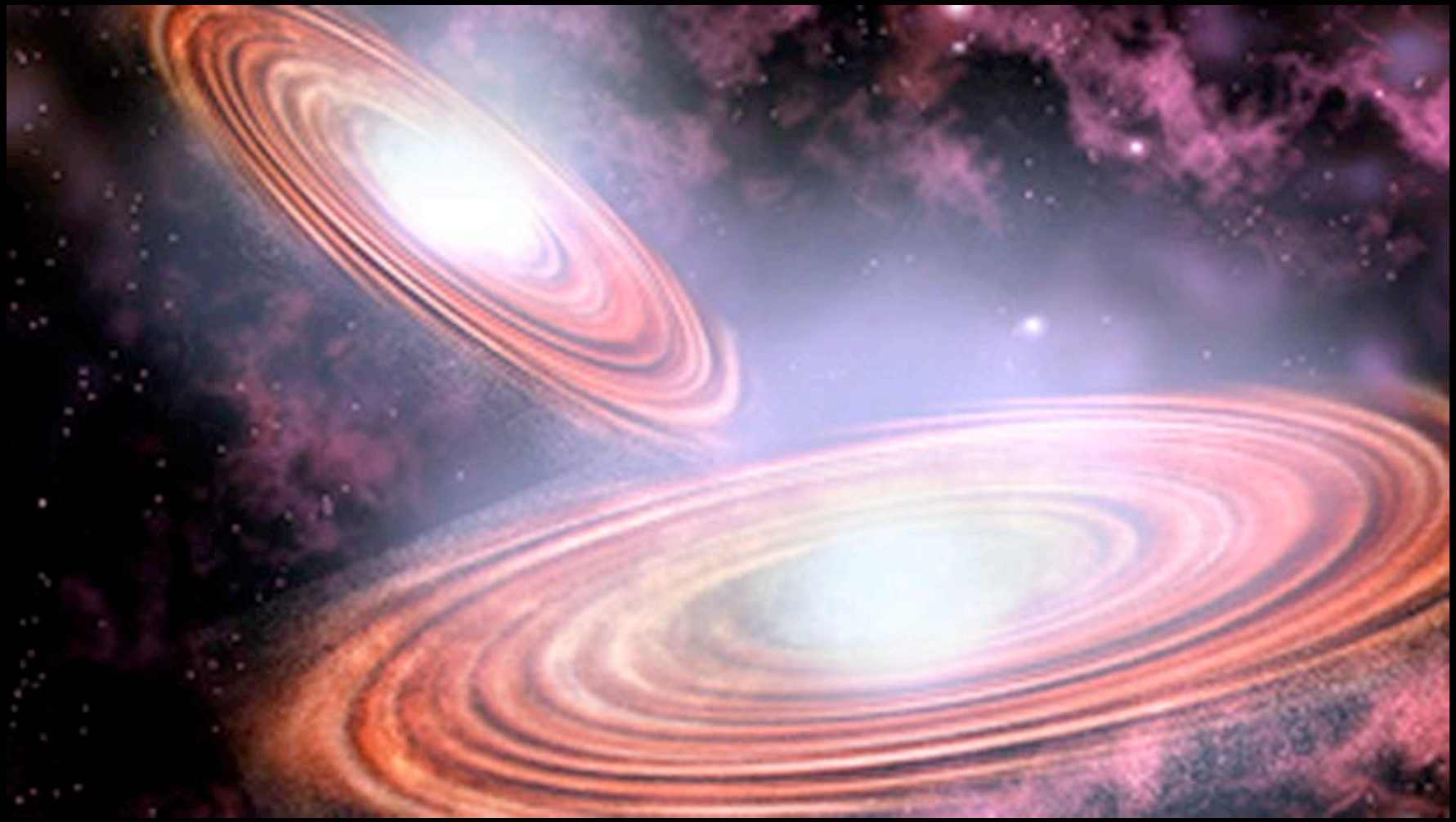
* Amplitude not stated by authors.
† Amplitude limit depends upon day.
‡ Unfiltered optical photometer.
§ Optical photometer with B-band filter.
‖ M. M. Komesaroff, J. A. Roberts & J. D. Murray (personal communication).

Aimo Sillanpää sees eclipses…



Mauri Valtonen, his Ph.D supervisor, suggests that maybe instead, OJ287 is showing regular outbursts every 11-12 years! Each outburst was followed by a second about a year later.

And OJ287 sees double

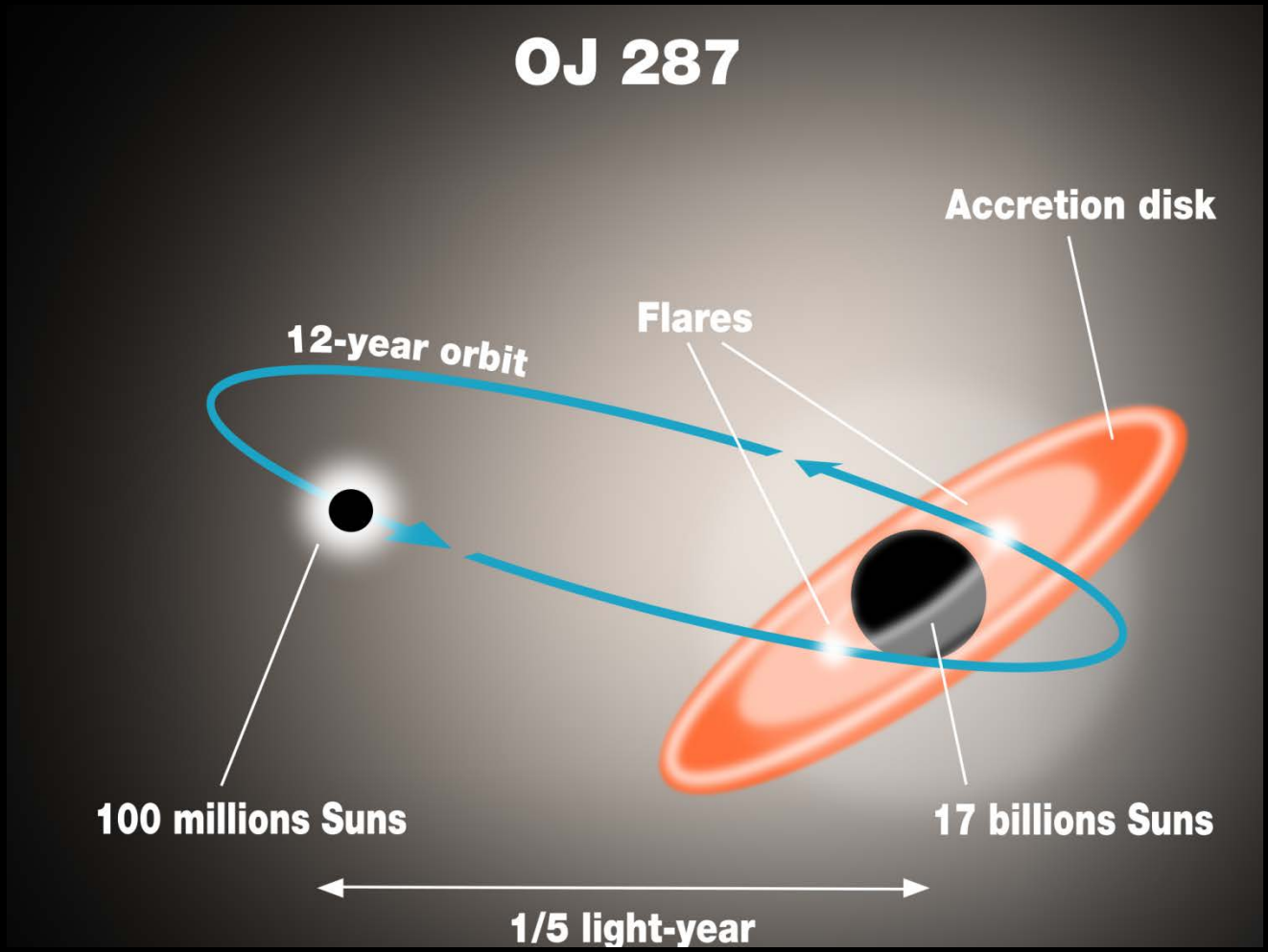


The best fit to the light curve was found to be a binary black hole with a primary of 5 billion Solar Masses & a secondary of 20 million Solar Masses in an elliptical, 9 year orbit.

Making a very big bang…

At closest approach, the small black hole passes through the accretion disk of the large black hole, causing a massive infall of material.

The large black hole literally chokes and we see a huge outburst along the jet.



Two Playmates Who Fight Dirty

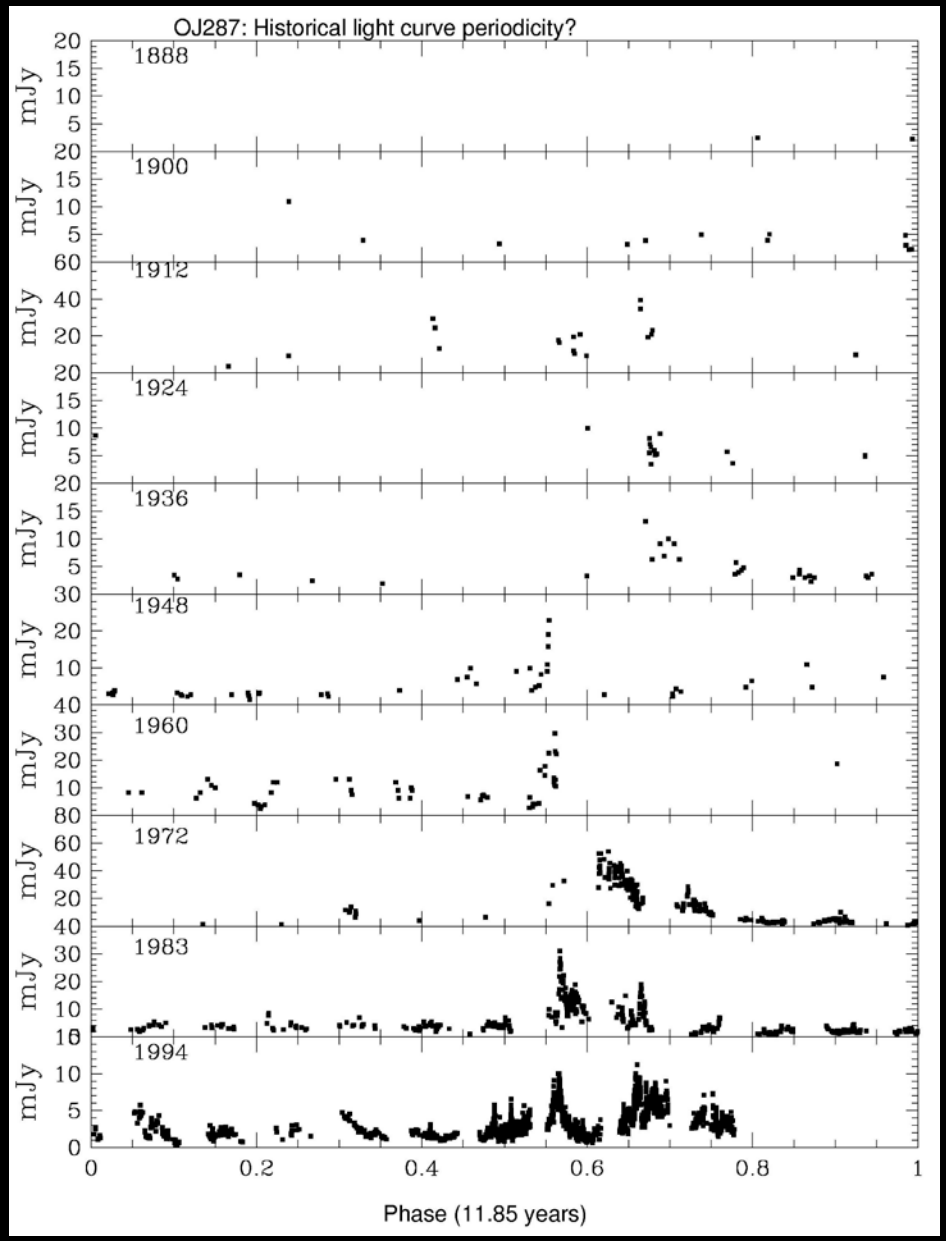
Every 11.6 years approximately, the secondary punches through the accretion disk of the primary, comes round the back and then, about 14 months later, does it again, provoking a violent reaction.

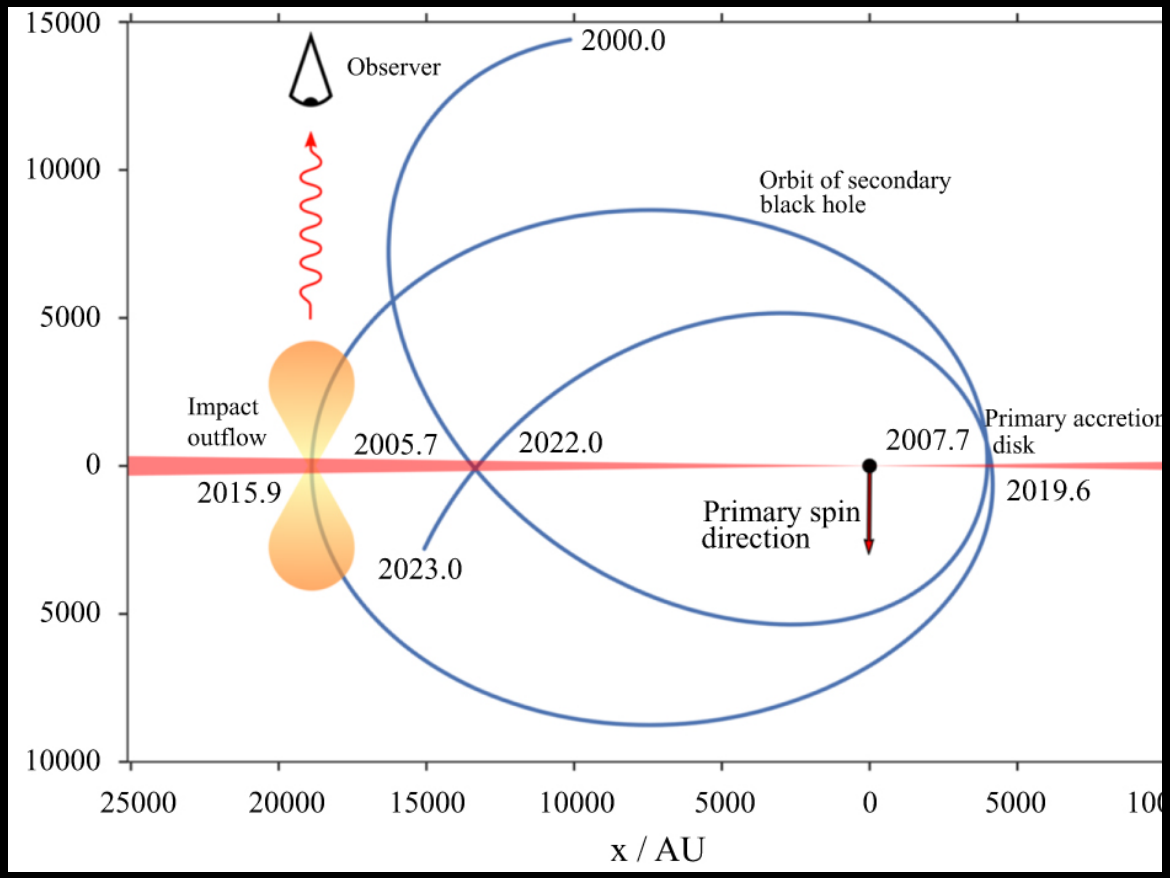
But things are never that simple…

If you line up the light curve of OJ287 over the best period in recent decades (11.85 years), you discover that the old outbursts do not fit the period.

Something more is happening.

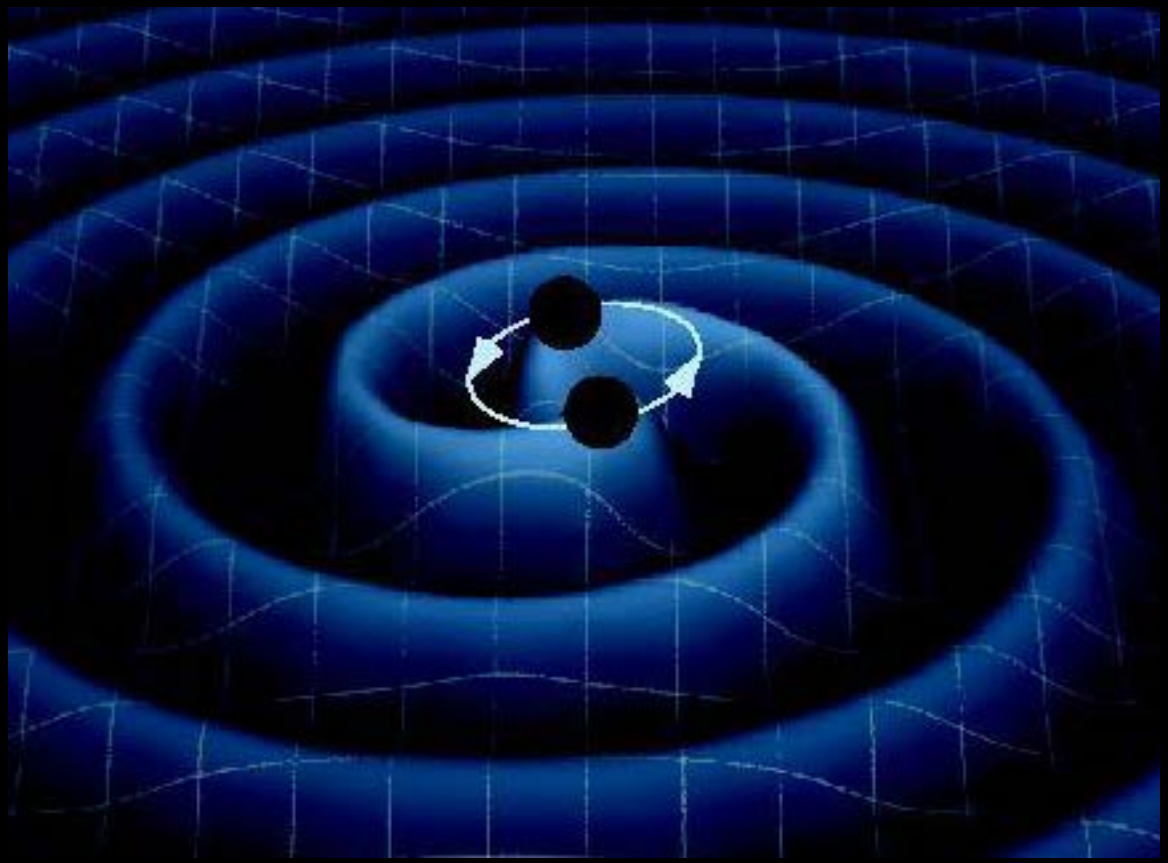
Enter Einstein…





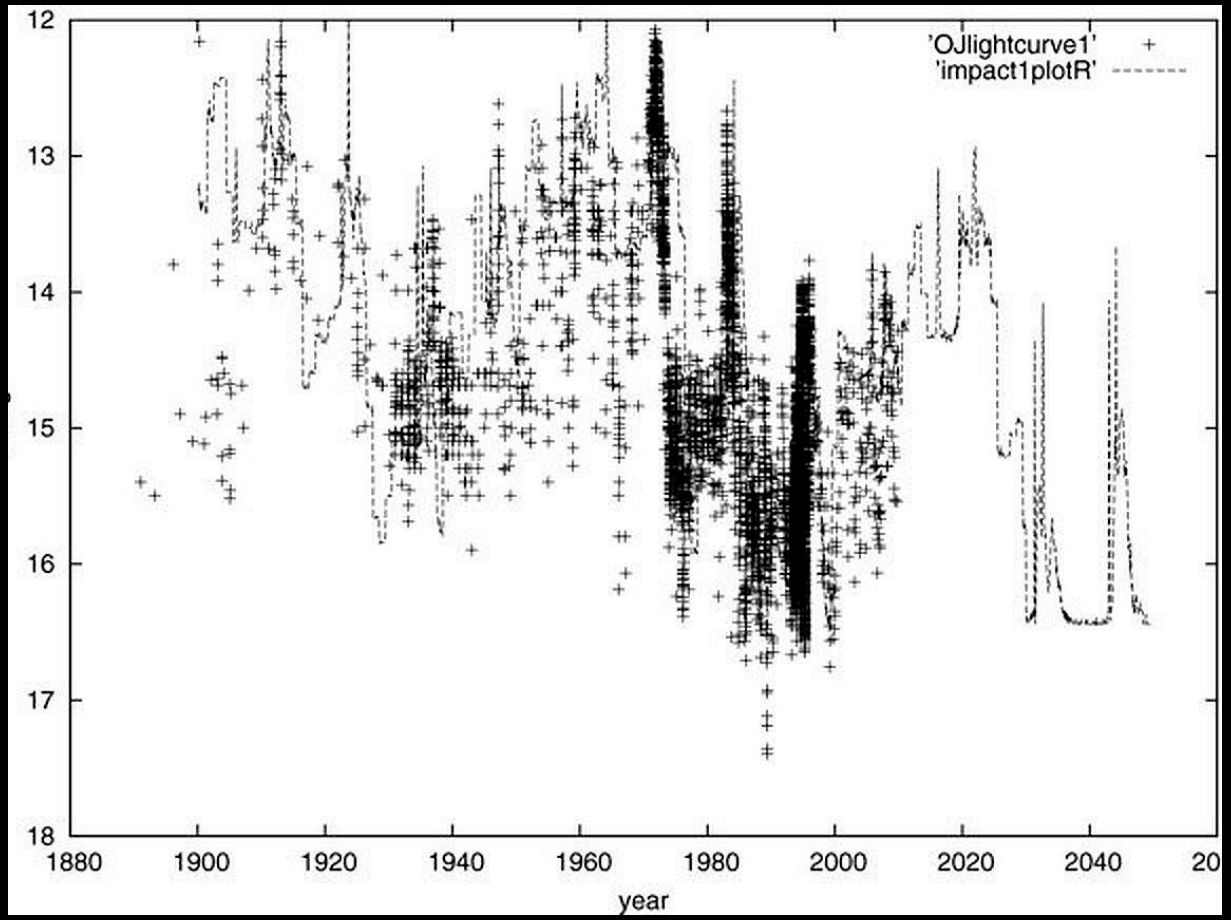
Like Mercury's Perihelion Advance Gone Mad

Mauri estimated that relativity makes the pericentre of the orbit advance by 29^{o} per orbit. Every 6 orbits it would flip by 180^{o}



What Else Happens?

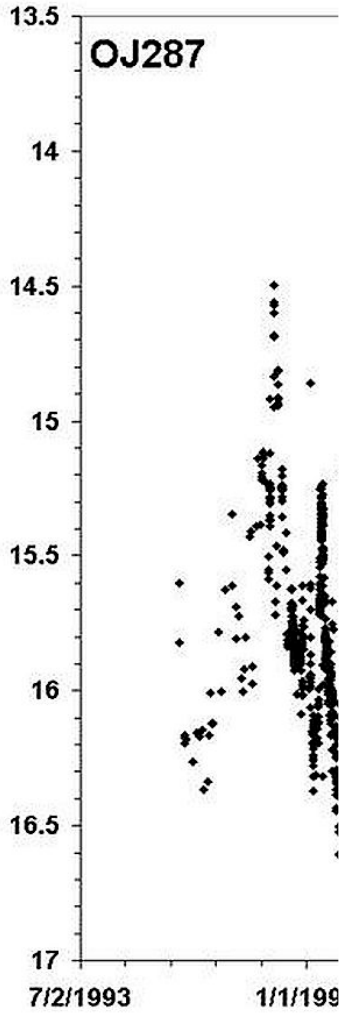
The system is emitting gravitational radiation like crazy. The estimated life of the system was 50 000 years before coalescing.



Even Better: You Can Make Predictions

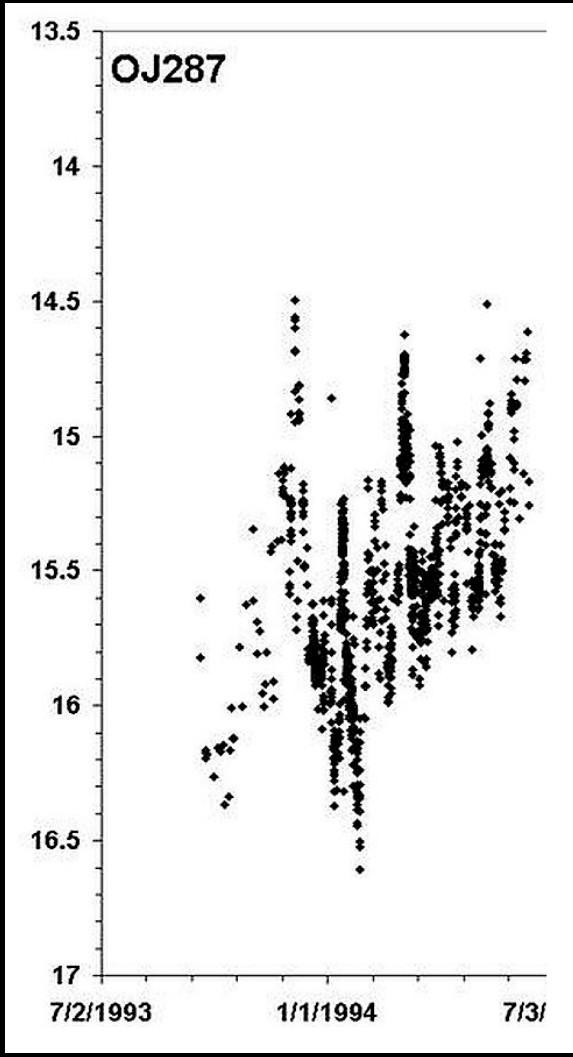
Mauri Valtonen has mapped out what OJ287 should do until 2050, based on his model.

First stop: would there be an outburst, as predicted in 1994?



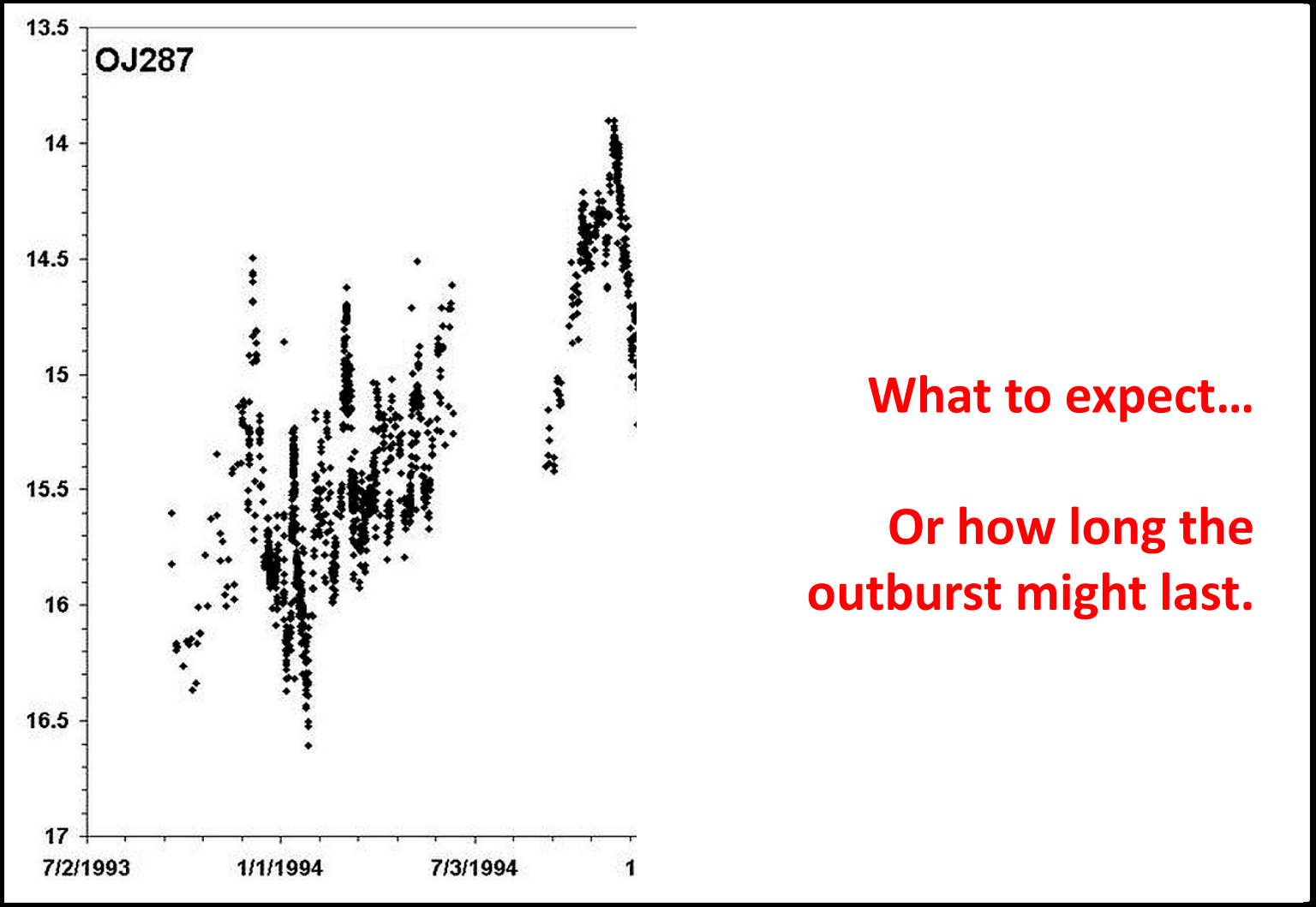
The trouble was that the exact date was quite uncertain…

First stop: would the be an outburst, as predicted in 1994?



And that no one knew…

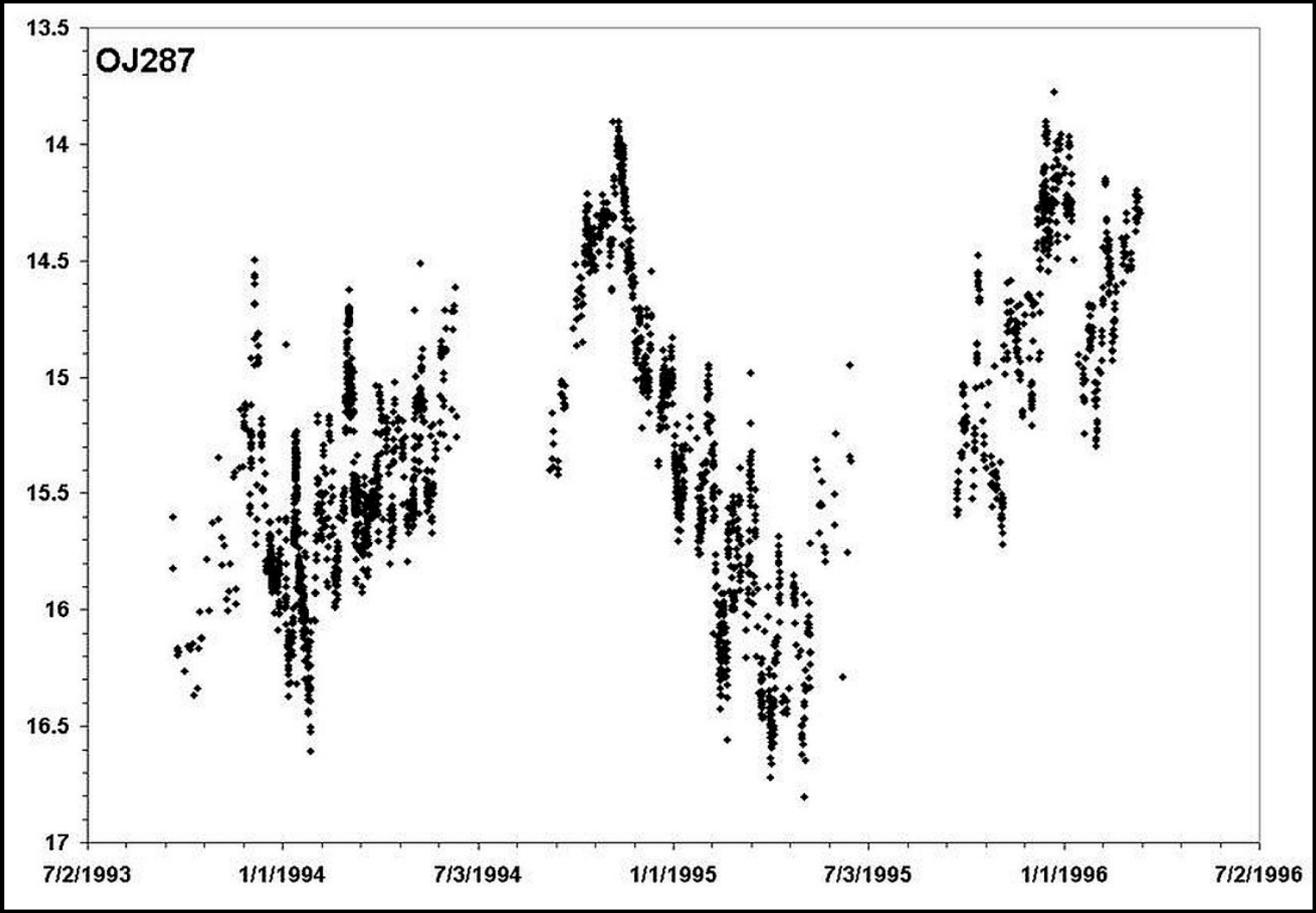
First stop: would the be an outburst, as predicted in 1994?



What to expect…

Or how long the outburst might last.

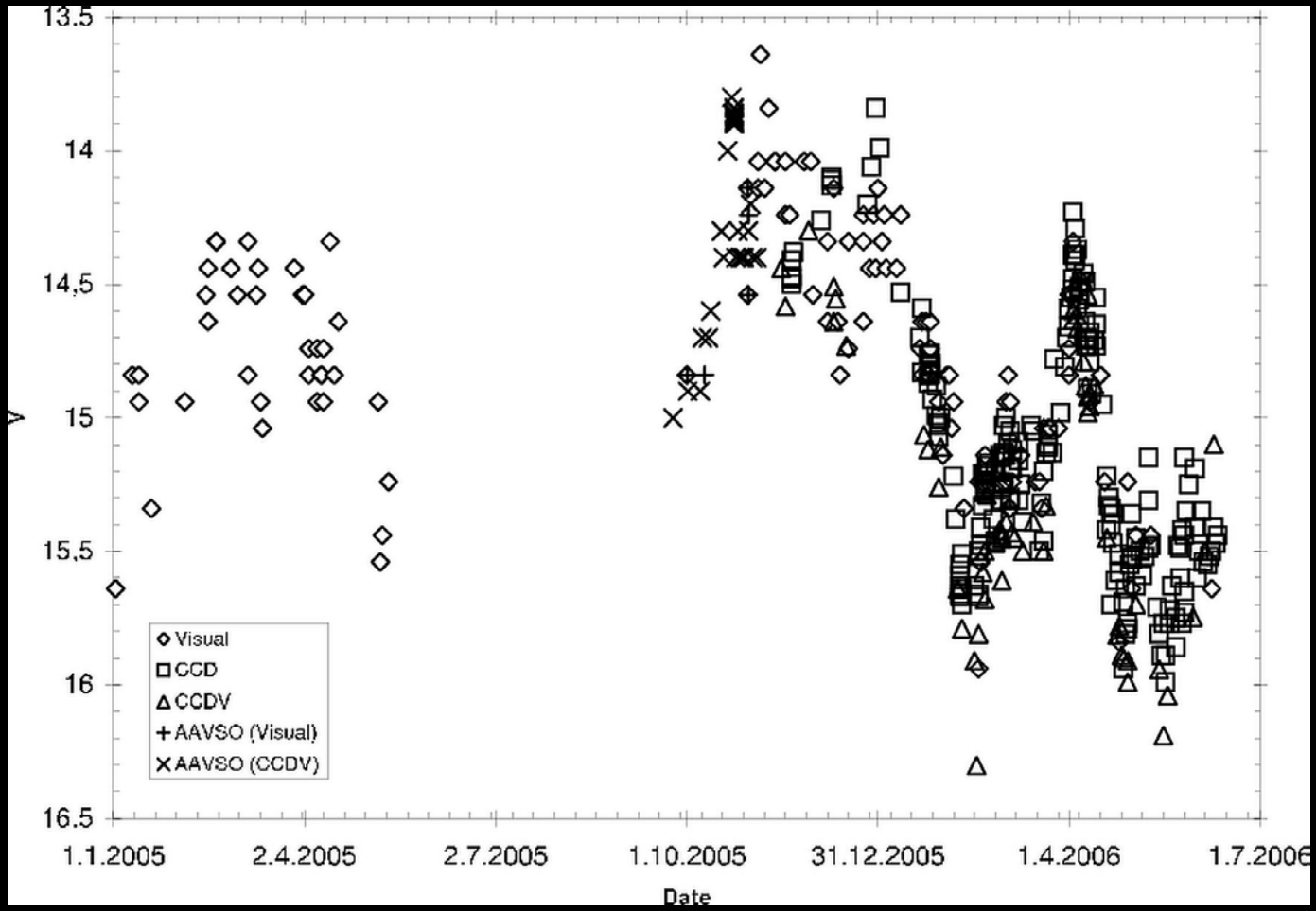
It was not until a year later that what we had seen became obvious!



Mauri Re-calculated

- As very few of the previous outbursts had been well-observed, the models were very uncertain – they had given a range of at least 9 months in the date of outburst.
  - Many parameters (masses, orbit, energy loss to gravitational radiation, spin, etc …) to fit.
  - Not enough precise timings of outbursts to do it.
- The 1994 maximum allowed the models to be refined.
  - It was one of the smallest ever observed.
  - Based on the new data, a slightly larger outburst was predicted for January 2006.

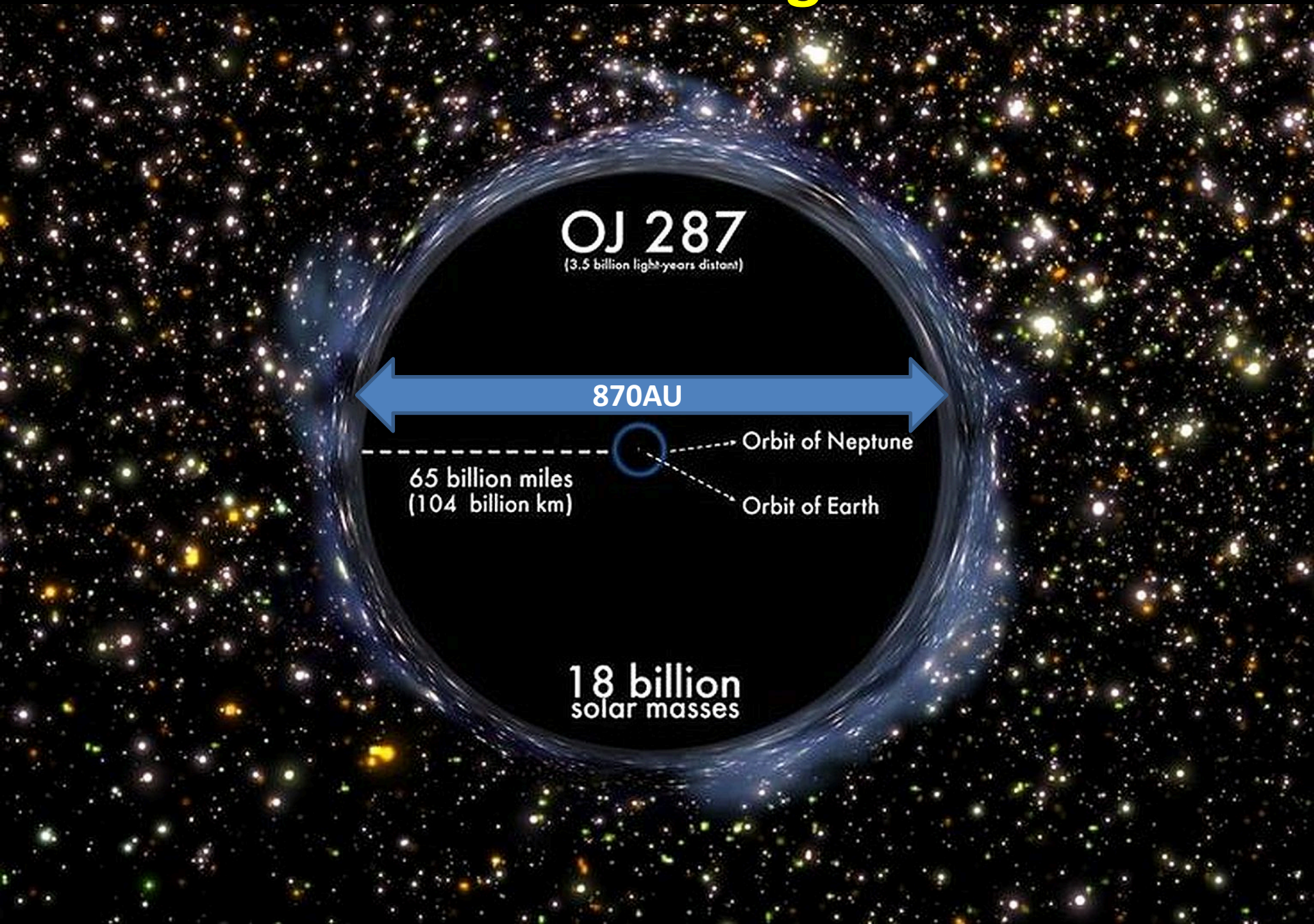
Success!! The first outburst came a couple of months early, in early November 2005, but the second outburst, predicted for September 13th 2007, with OJ287 very low in the dawn sky, came exactly at the predicted time of the further-refined model.



Conclusions

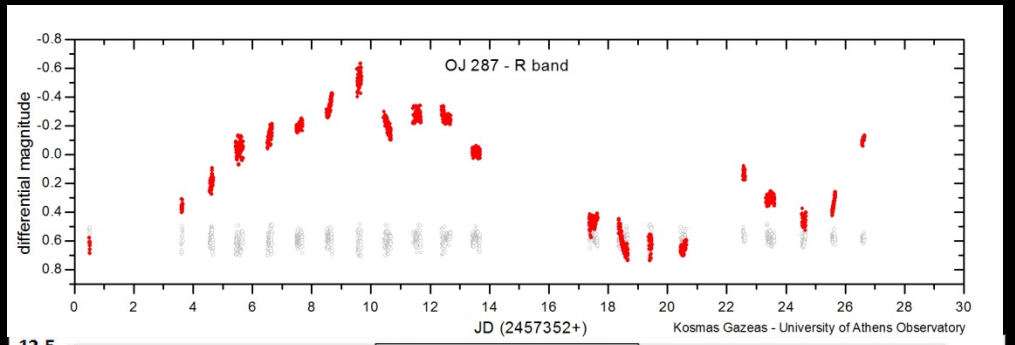
- A Letter published in Nature, including Gary among the authors – a rare honour for a non-professional scientist.
  - **Primary black hole mass**: revised up to 18 billion solar masses.
  - **Precession rate**: refined to 39^{o} per orbit – a confirmation of General Relativity.
  - **Gravitational radiation emission**: equivalent to the total energy emitted by the quasar as electromagnetic radiation.
    - The gravitational radiation would be an ideal target for ESA's proposed LISA gravity wave satellite.
  - **Next outburst**: Initial prediction of January 2016 (later revised to early December 2015).

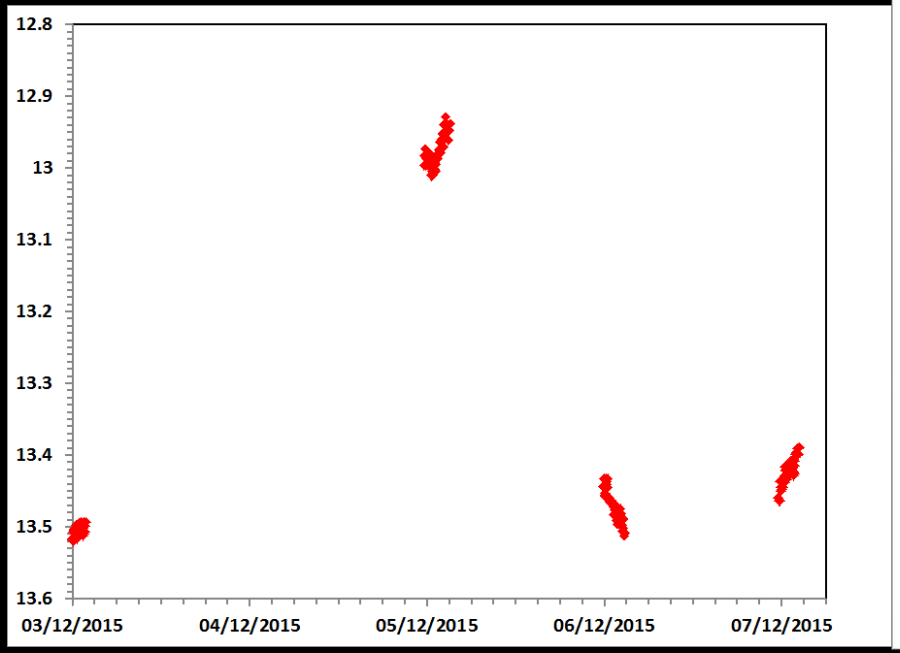
Meet the dragon!

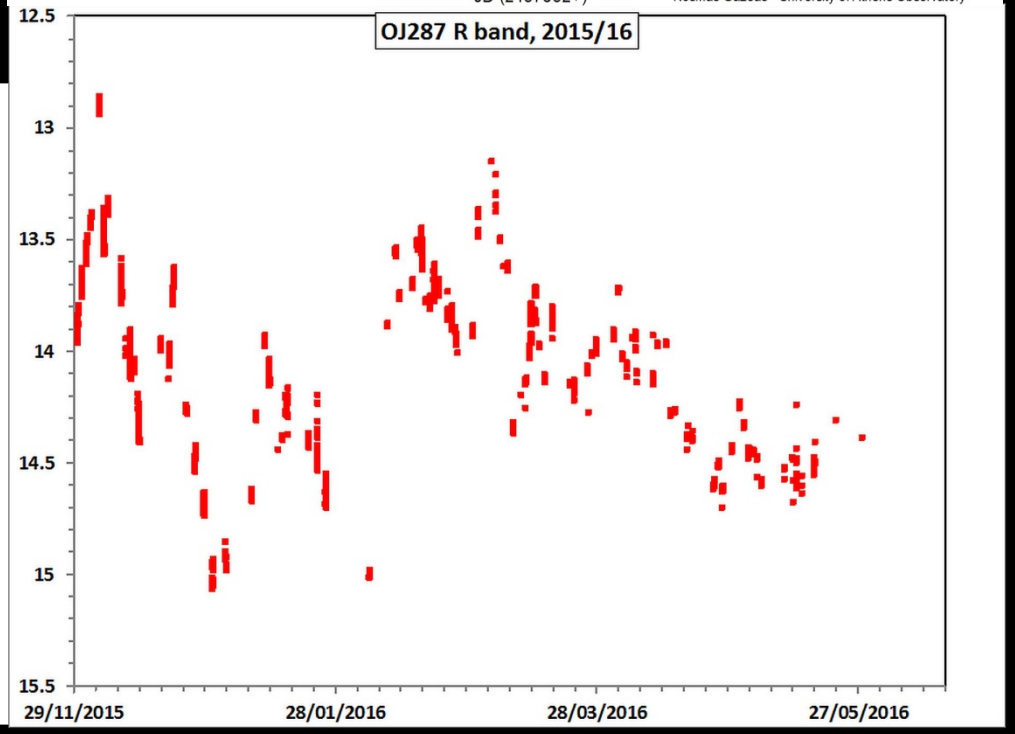


The 2015 Outburst

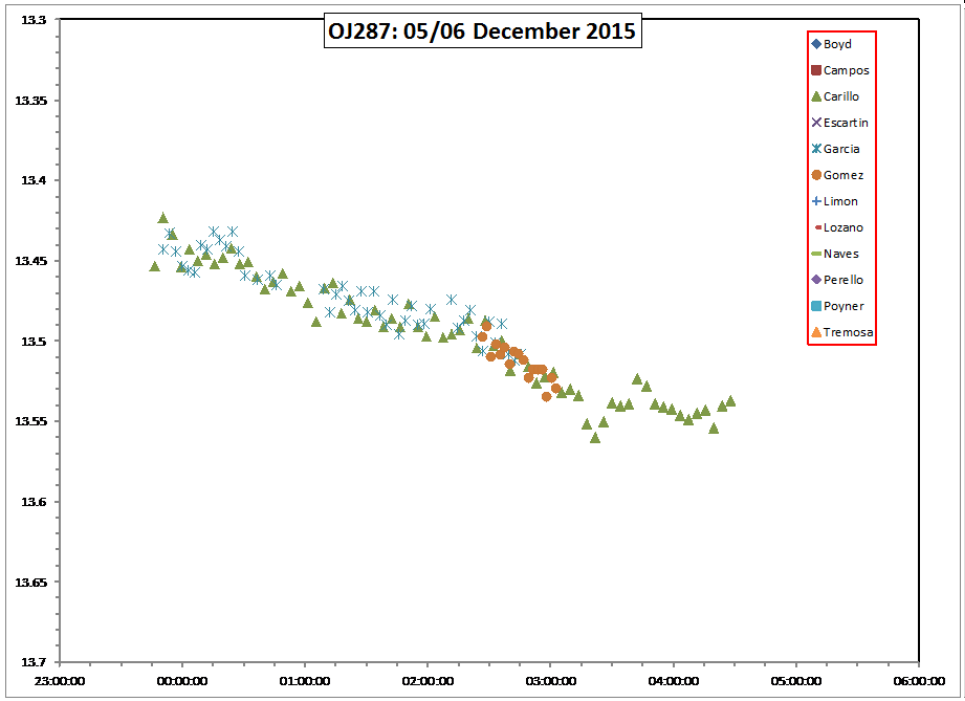
Predicted: Dec 13
Observed: Dec 05/06
Maximum captured by Faustino García in Spain.

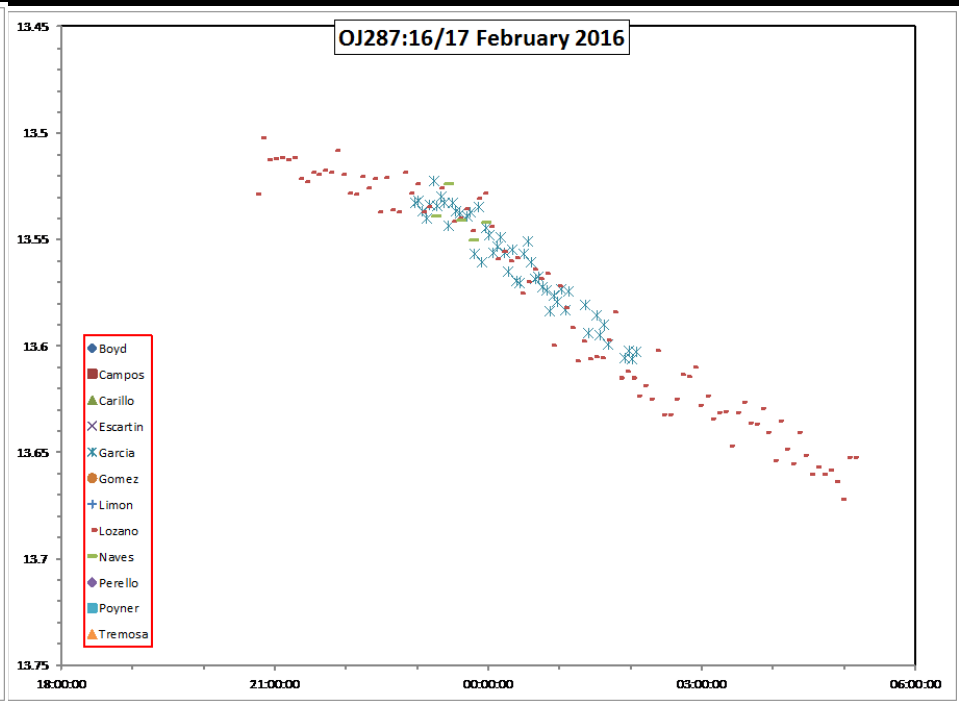






A couple of nice examples of fast variations seen recently with multiple amateur telescopes.



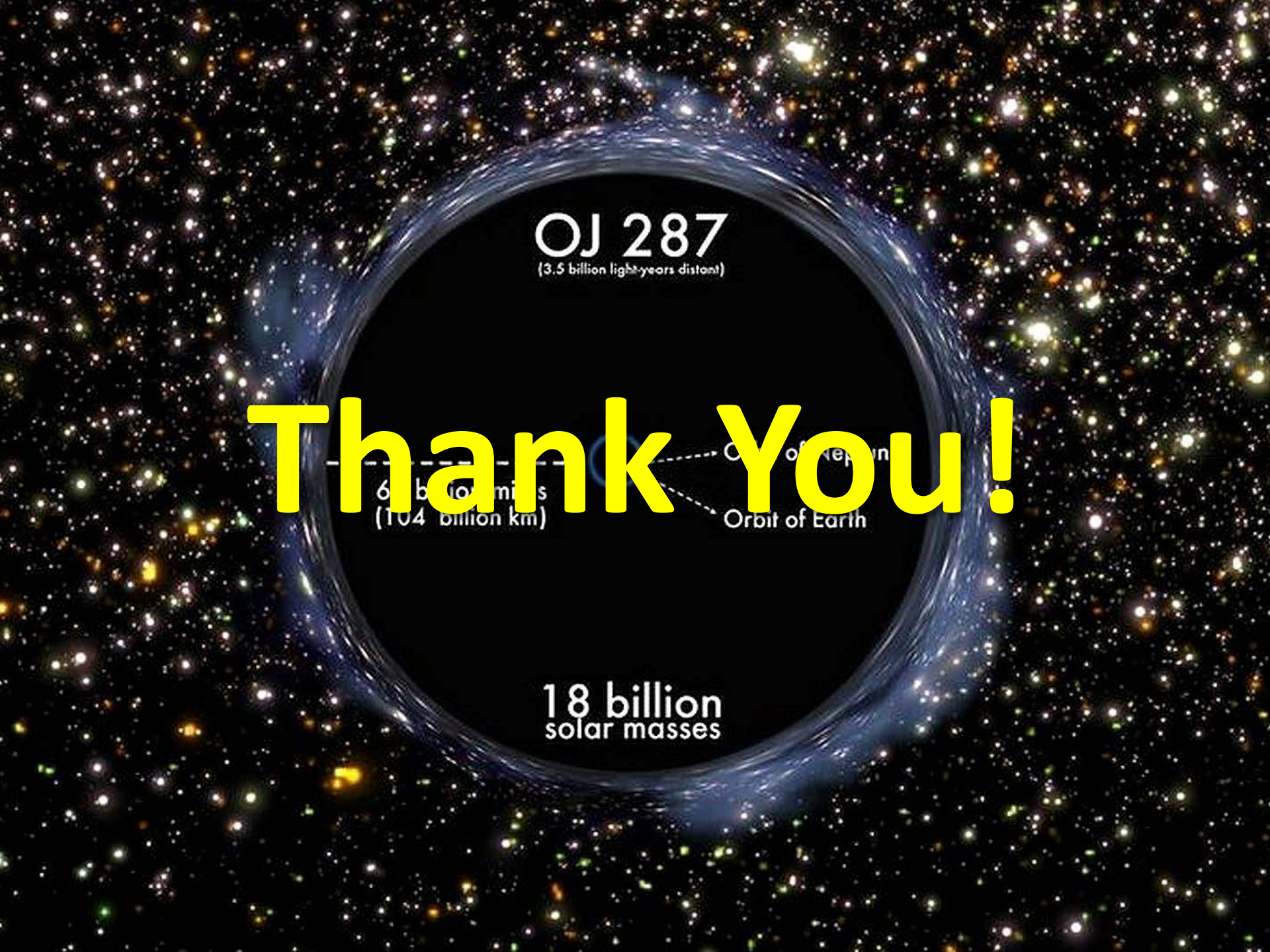


Latest Weights and Measures

- The very precise prediction has allowed the model to be refined still more exactly.
  - Can now calculate the spin of the black hole as 0.31±0.01 (the maximum for a Kerr black hole is 1).
    - The previous estimate was 0.28±0.08.
  - Lifetime ≈10 000 years
  - Primary mass 18.3±0.1 billion Solar masses.
  - Secondary mass 150±10 million Solar masses.
  - Eccentricity of orbit 0.7
- Further observations over the next few years should demonstrate at a 10% level that **black holes have no hair**.

No Hair?

- This is the theorem that says just three observable properties can describe a black hole exactly
  - Its mass, its electrical charge & its angular momentum.
- The model gives a prediction of a second outburst on July 22nd 2017.
  - An accurate prediction would be the final confirmation of the binary black hole model & would suggest strongly that the no hair theorem is correct.
    - At the moment we can only demonstrate it to ±30%.
  - Observational confirmation is crucial.
    - But, OJ287 will be only 23^{o} from the Sun in the evening sky.
    - **Conclusion**: if your next door neighbour's house obstructs your view of sunset, Gary, get planning permission for its immediate demolition **NOW**!


OJ 287
(3.5 billion light-years distant)
(104 billion km)
Orbit of Earth
18 billion
solar masses

Thank You!