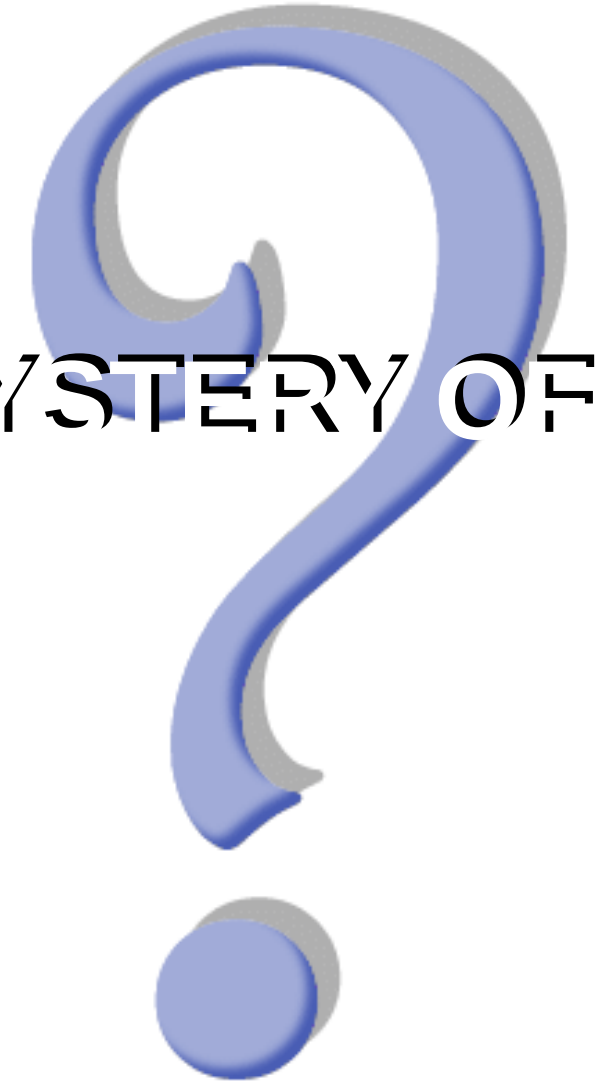
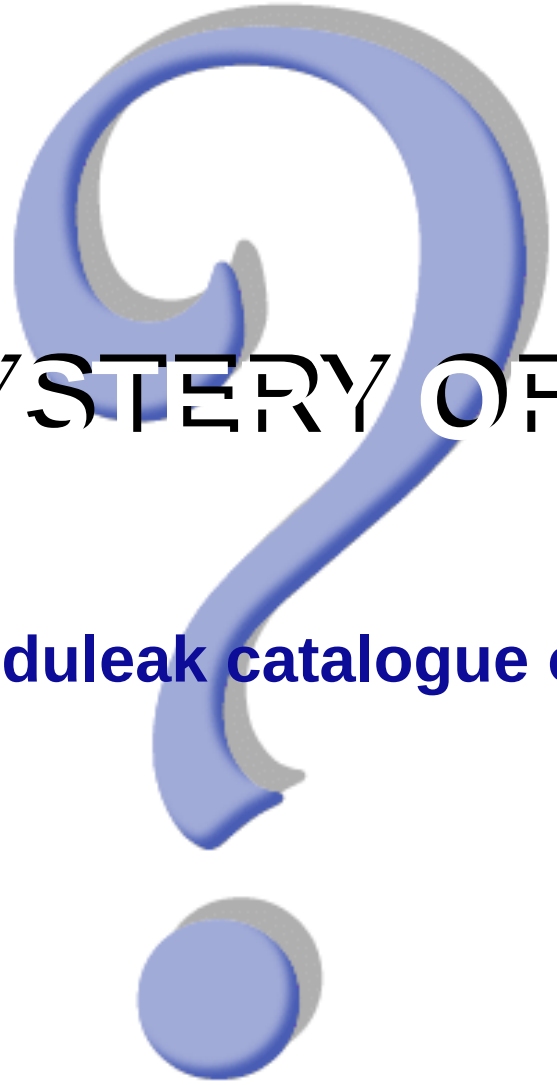
THE MYSTERY OF SS433





THE MYSTERY OF SS433

Stephenson & Sanduleak catalogue object number 433

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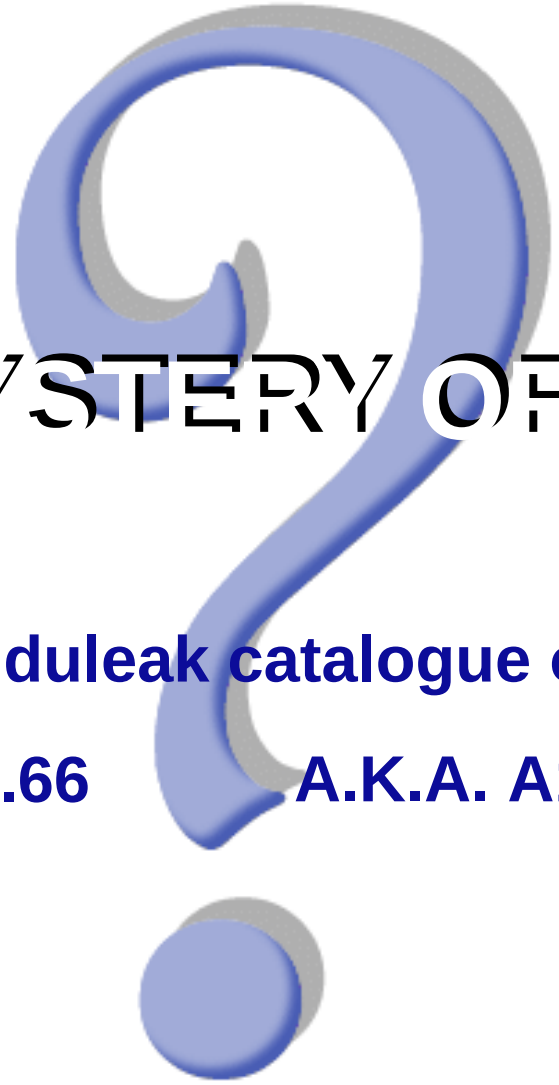
Stephenson & Sanduleak catalogue object number 433

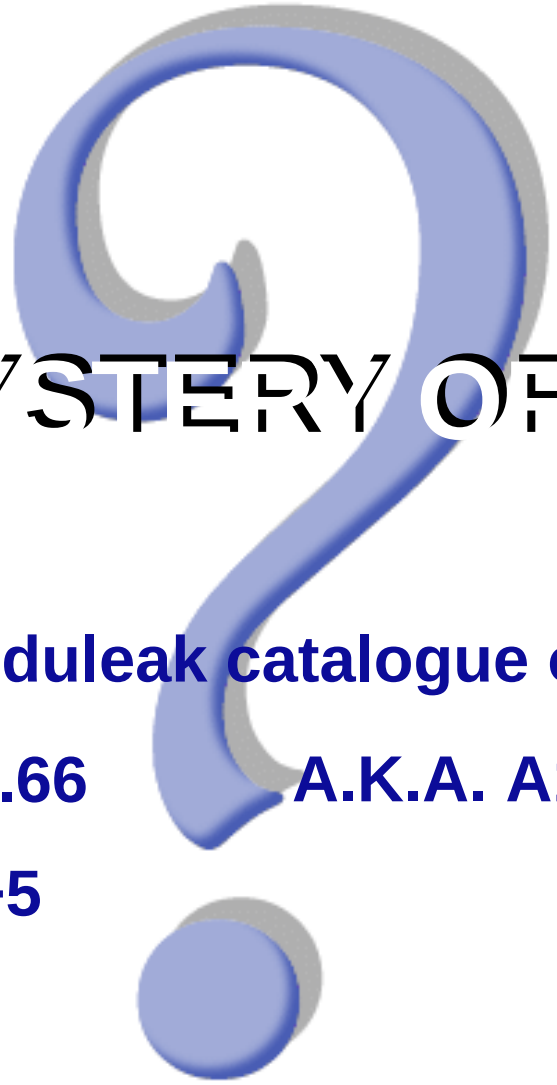
A.K.A. 4C04.66



THE MYSTERY OF SS433

Stephenson & Sanduleak catalogue object number 433

A.K.A. 4C04.66 **A.K.A. A1909+04**



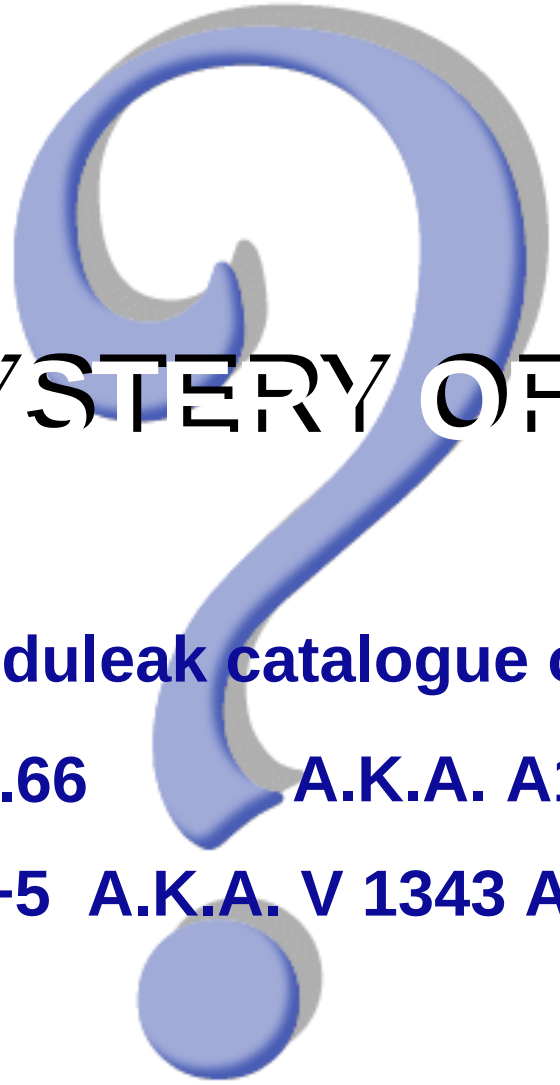
THE MYSTERY OF SS433

Stephenson & Sanduleak catalogue object number 433

A.K.A. 4C04.66

A.K.A. A1909+04

A.K.A. 4U 1908+5

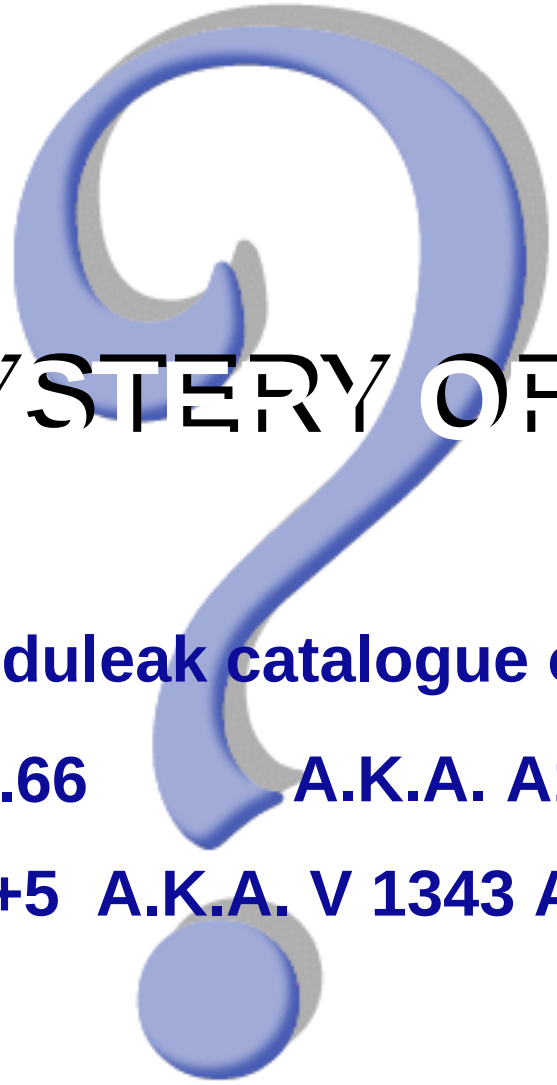


THE MYSTERY OF SS433

Stephenson & Sanduleak catalogue object number 433

A.K.A. 4C04.66 A.K.A. A1909+04

A.K.A. 4U 1908+5 A.K.A. V 1343 Aql



THE MYSTERY OF SS433

Stephenson & Sanduleak catalogue object number 433

A.K.A. 4C04.66 A.K.A. A1909+04

A.K.A. 4U 1908+5 A.K.A. V 1343 Aql A.K.A. W50

What is SS433?

A reddish star (m=14) in Aquila at

$\alpha_{1950} = 19^h09^m21.282^s$, $\delta_{1950} = 04°53'54.04''$

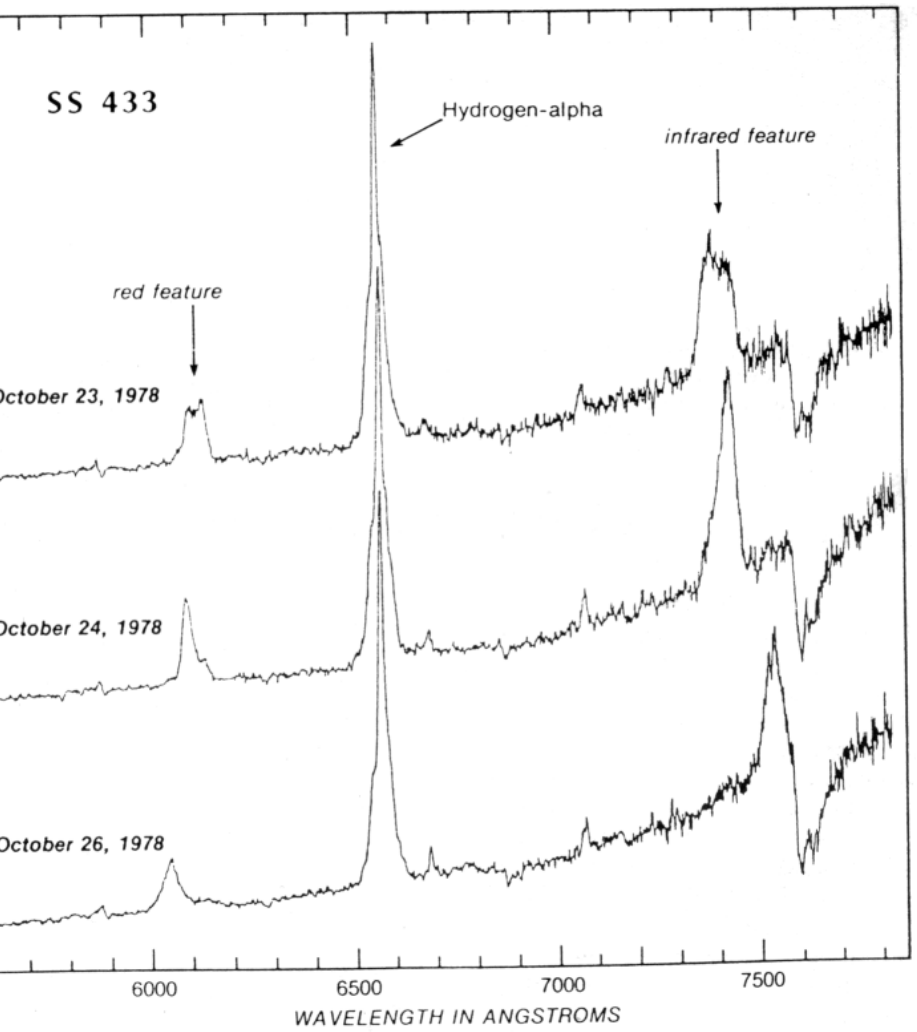
SS: rediscovered it in 1978. Optical counterpart to a highly variable radio point source in SN remnant W50. Ariel-V (GB) discovers X-ray source in the same place.

CONJECTURE 1:

It is a Supernova remnant.

- But all other known remnants are pulsars!

A quasar in our galaxy?



- Spectrum dominated by strong emission lines.
- + HIGLY variable unidentified emission lines, e.g. “infrared” feature changes by 600 angstroms in 28 days!
- If this is Doppler, implies velocities $\sim$ 25000 km/s *in opposite directions at the same time!*

CONJECTURE 2:

It is a quasar

But quasars aren’t blue!

Something else?

Distance (from absorption) $\sim$ 3500 parsecs! (M=-3.5)

At an astrophysics meeting in 1978, theorists began to speculate on ways to produce the shifts.

CONJECTURE 3:

Huge magnetic fields!

Something else?

Distance (from absorption) $\sim$ 3500 parsecs! (M=-3.5)

> At an astrophysics meeting in 1978, theorists began to speculate on ways to produce the shifts.

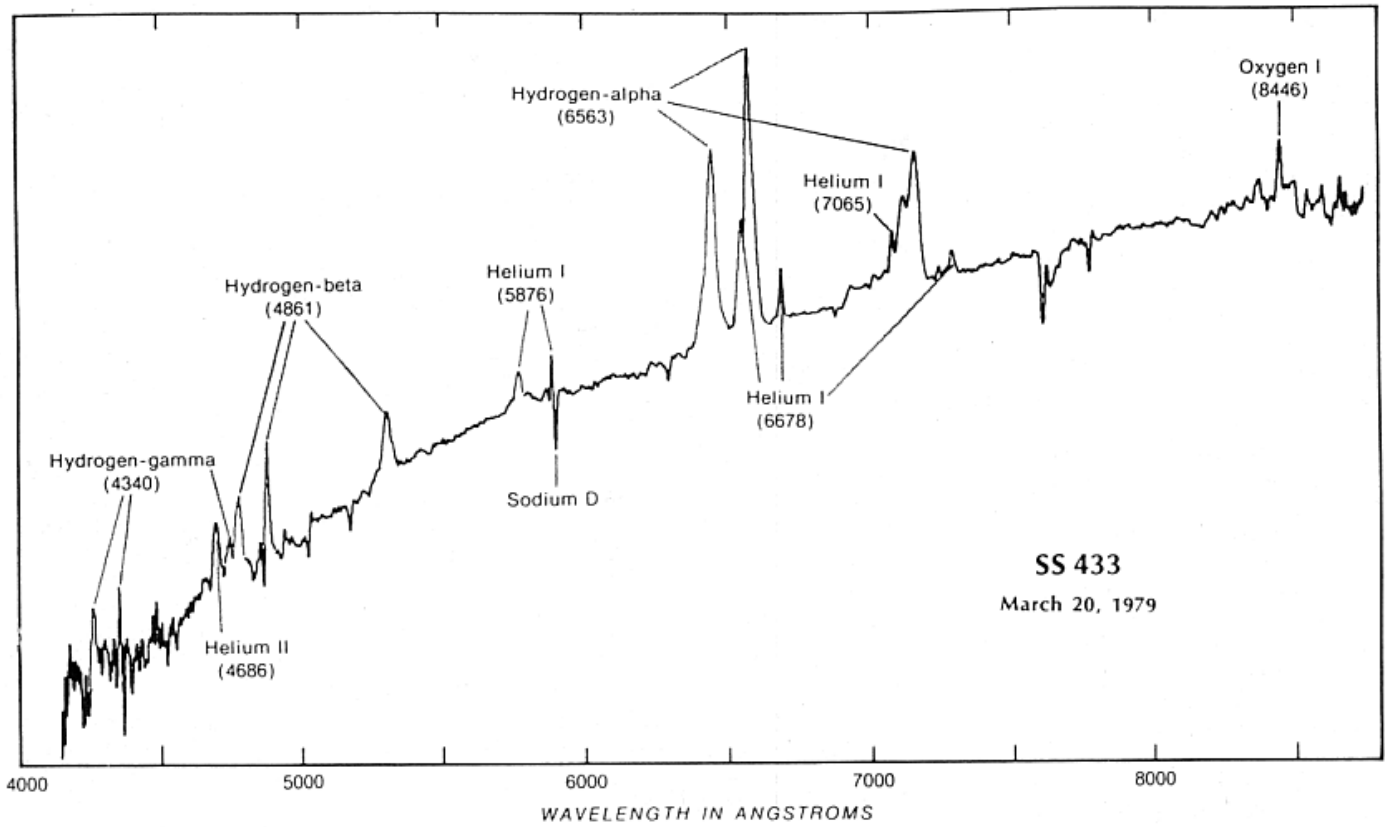
CONJECTURE 3:

Huge magnetic fields!

> "Fortunately, we never published those theories". [Katz]

Triplicate lines.

- At maximum, one part of SS433 seems to be approaching Earth at 35000km/s while another part is receding at 50000km/s!

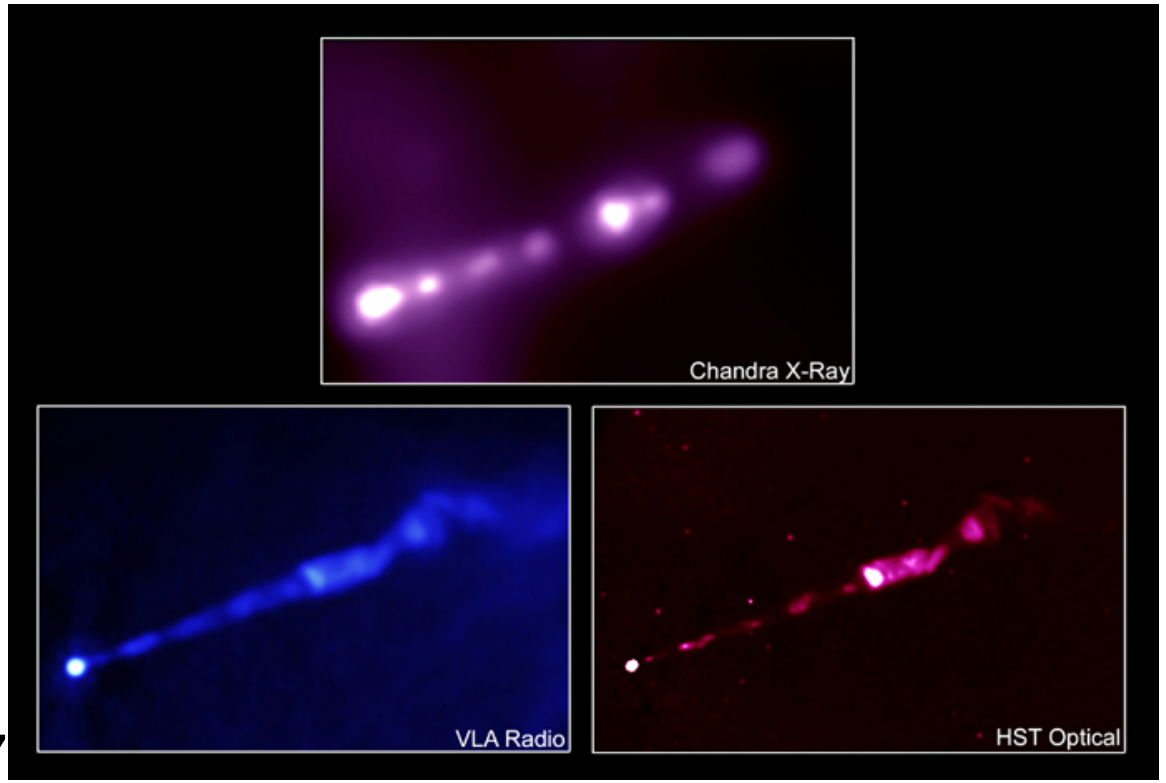


Jets?

Conjecture 4:

High-speed jets of gas ejected from a central, luminous object.

M87



The 164-day period.

1979:

- The shifts vary with a period of 164 days.
- SS433 on Saturday Night Live.

Conjecture 5:

Binary star with period of 164 days.

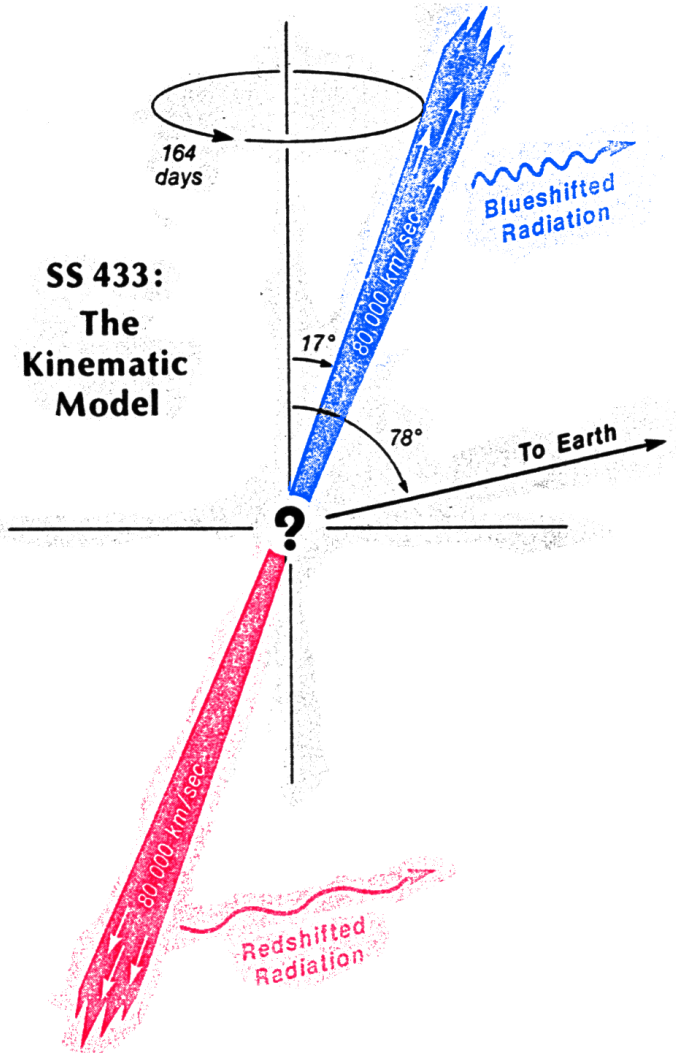
Conjecture 6:

Gas cloud precessing around 1M solar mass BH.

Conjecture 7:

Rotating object with 2 inclined jets.

The kinematic model.



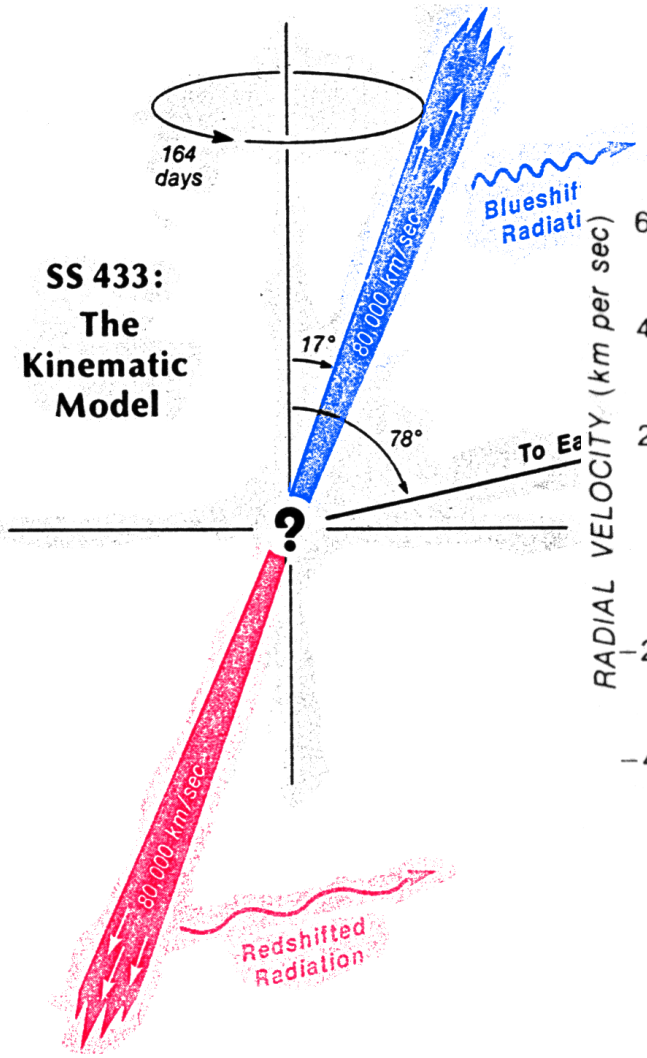
Two jets at 80000km/s (!)

Jet rotation results in the observed 164-day Doppler period.

No hypothesis of central engine, but *prediction of previously unobserved part of the 164d cycle*:

red- and blue-shifted lines should cross (and re-cross) during summer of 1979.

The kinematic model.



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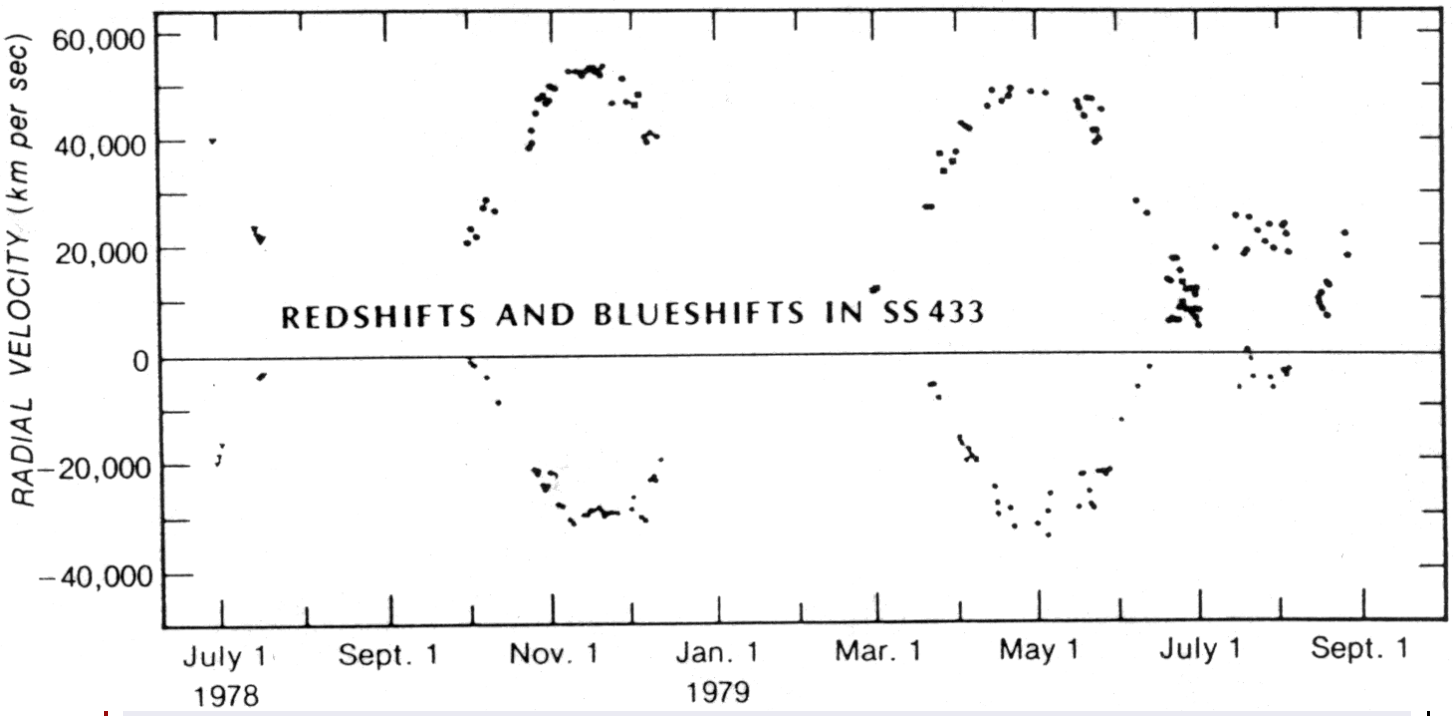


More mysteries

But the fun is far from over... more data was coming in:

- A study of old photographic plates revealed a cyclic variation in the blue light, with a period of 161 days. It seemed to begin in 1929 and may have turned off and on several times since then.

- The total visible output varies by as much as half a magnitude in one day, with similar behaviour in the infrared, but remarkably steady in X-rays.

- The “stationary” lines show a small cyclic variation with a period of 13 days.

The deconstruction continues

Conjecture 8:

The 13-day period indicates orbital motion.

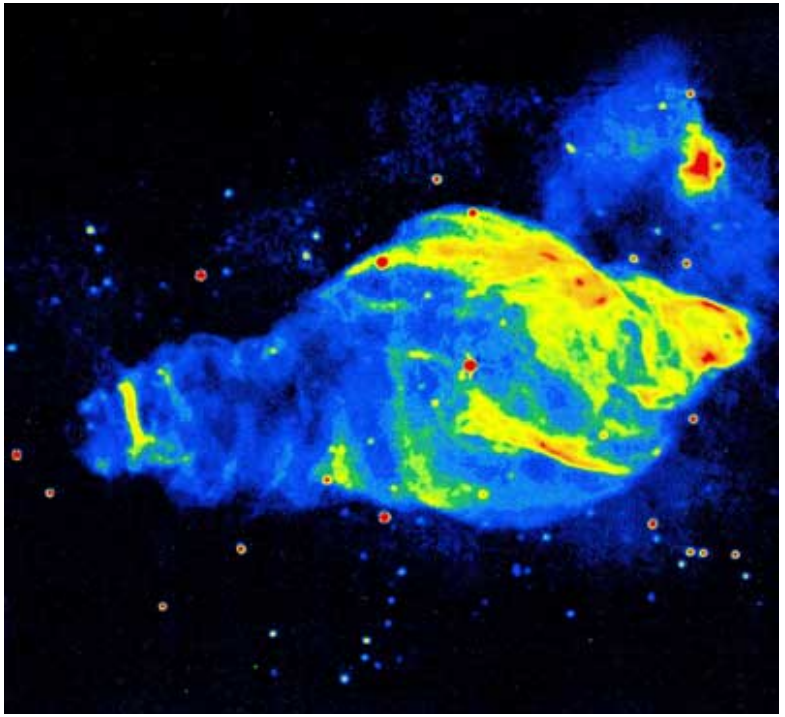
- Fits nicely: Calculated orbital elements consistent with two 1.5 solar mass objects orbiting at high eccentricity. E.g. one is neutron star, other is sun-like F star.
- Big relief: Now 164 days could be a *precession* period of "engine" object, rather than a rotational or orbital period.

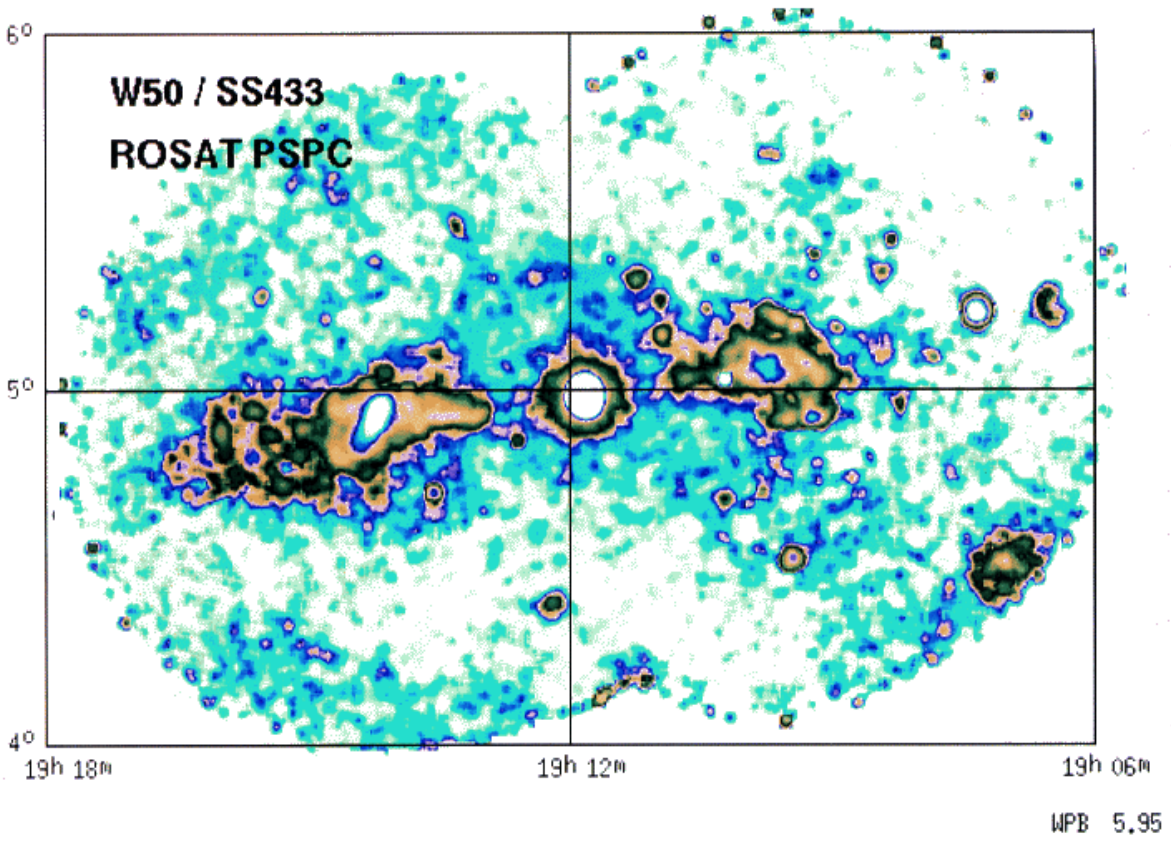
Conjecture 9:

Is this just a normal evolutionary phase for young X-ray binaries?

The Bombay duck: W50

With nice model for SS433, let's look at W50, the Supernova remnant in which SS433 lies smack in the middle.





A supernova remnant?

W50: age 20000 yr, distance about the same as SS433.

- Trouble with SN hypothesis:
  - only 2 known pulsars actually reside *in* SN remnants, and all have large peculiar velocities.
  - SS433 is not a pulsar.
  - How could a binary system survive an SN explosion?

So what is the relation between SS433 and W50?

- Remember: the orbit is highly eccentric!

W50: a beam dump?

- Beam energy output $\sim 10^{24}$ GW ($=10^7\ L_\odot$)

Integrated over 20kyr $\rightarrow 10^{51}$ ergs deposited in nearby interstellar medium, comparable to output of typical SN.

$\Longrightarrow$ Enough to blow a hole the size of W50.

CONJECTURE 10:

W50 is a “celestial beam bag” of SS433.

More mysteries, a microquasar?

- Jets moving at $\frac{1}{4}c$ but lines comparatively narrow!
  $\Longrightarrow$ very efficient acceleration mechanism.
- 100 $\times$ energy output of Crab Nebula in region 0.1 to 30 AU across! What's the energy budget?
- Is there a relation to AGN (Active Galactic Nuclei), Seyfert Galaxies, Quasars, Blazars...?

CONJECTURE 11:

SS433 is a "microquasar".

The 1.000.000 kroner question.

In fact, today “microquasar astrophysics” is a studied field.

But to understand what a microquasar is, let’s follow the story of SS433 a little further, focussing on the question:

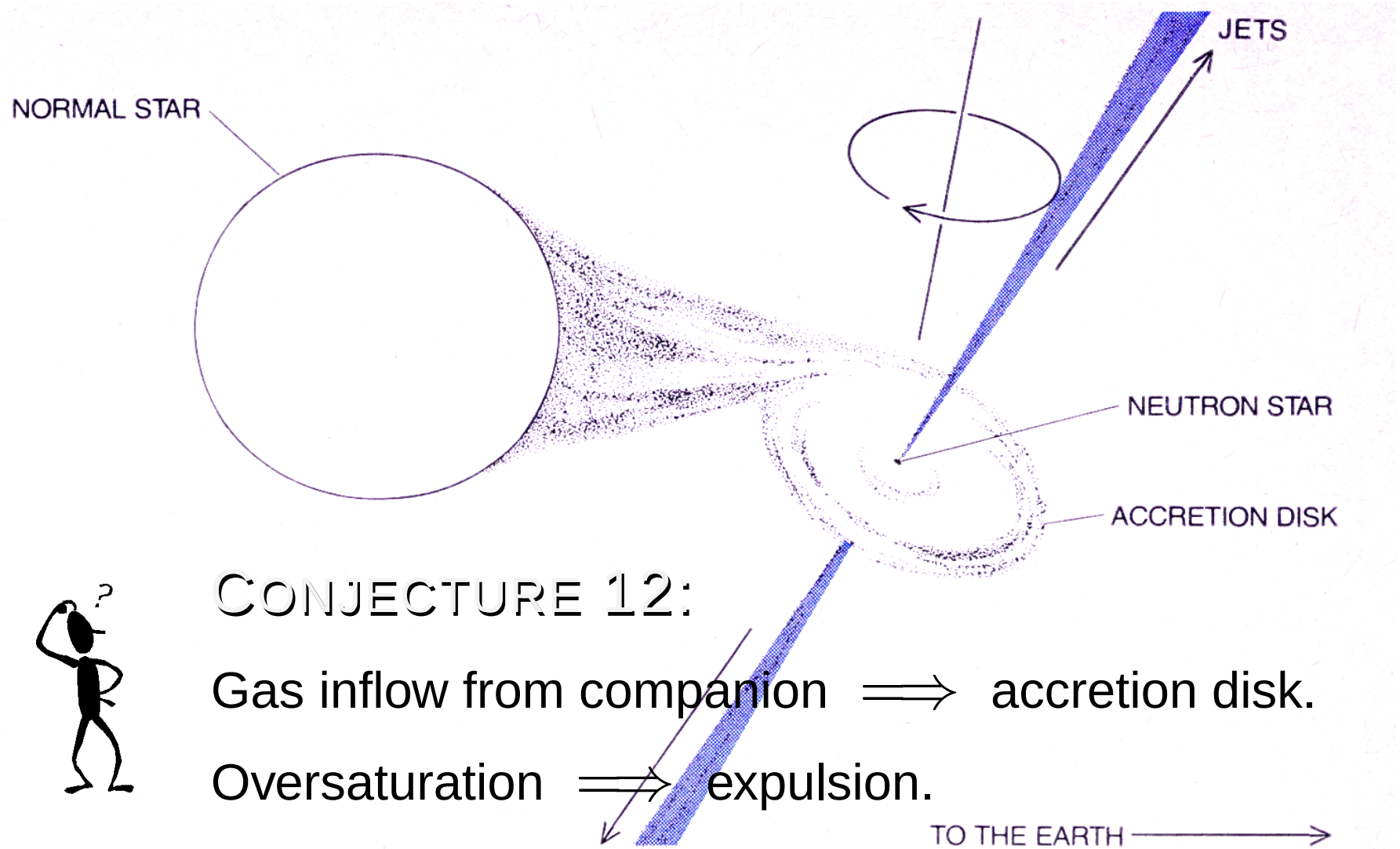
The 1.000.000 kroner question.

In fact, today “microquasar astrophysics” is a studied field.

But to understand what a microquasar is, let’s follow the story of SS433 a little further, focussing on the question:

What is the central engine?

Exploding accretion disk

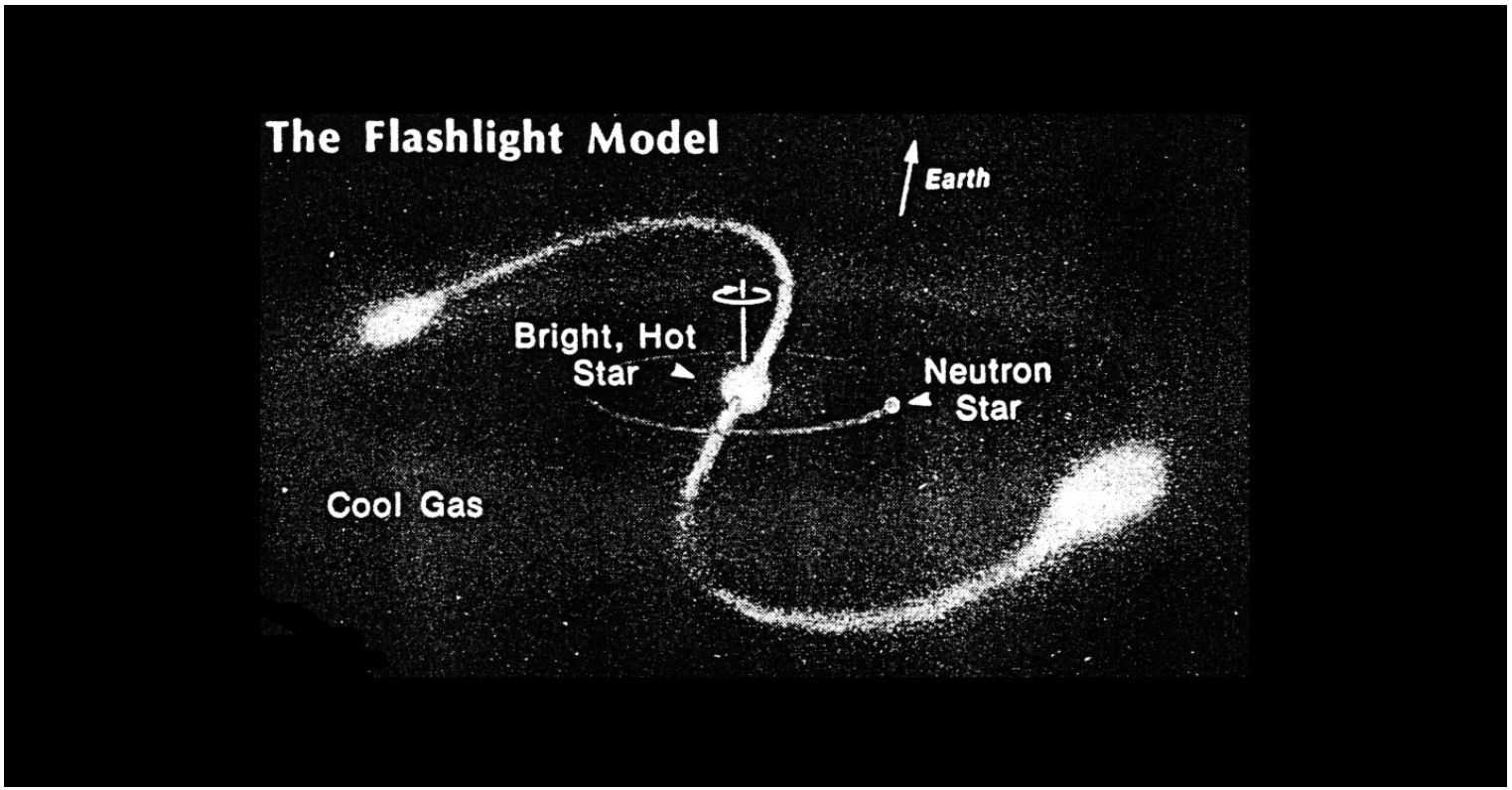


CONJECTURE 12:

Gas inflow from companion $\Longrightarrow$ accretion disk.

Oversaturation $\Longrightarrow$ expulsion.

A cosmic flashlight

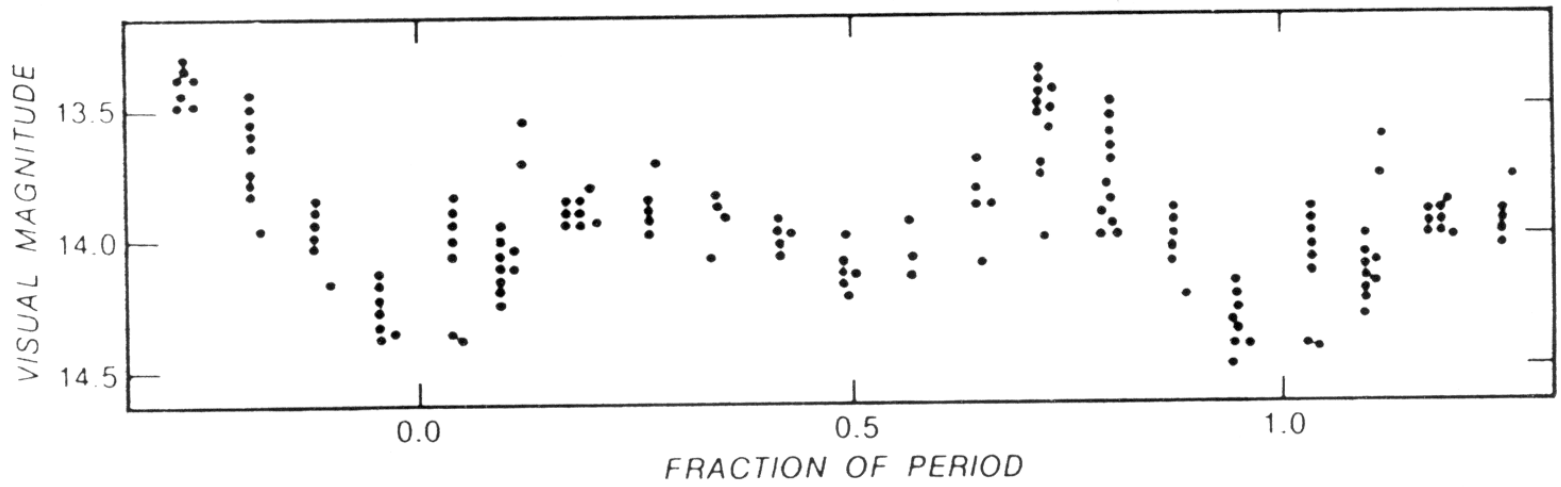


Conjecture 13:

Ionized matter blows off precessing star and strikes a surrounding gas cloud.

Who ordered that?

November 6th, 1979: visible output drops by 50% and returns to previous brightness in less than 1 hour.



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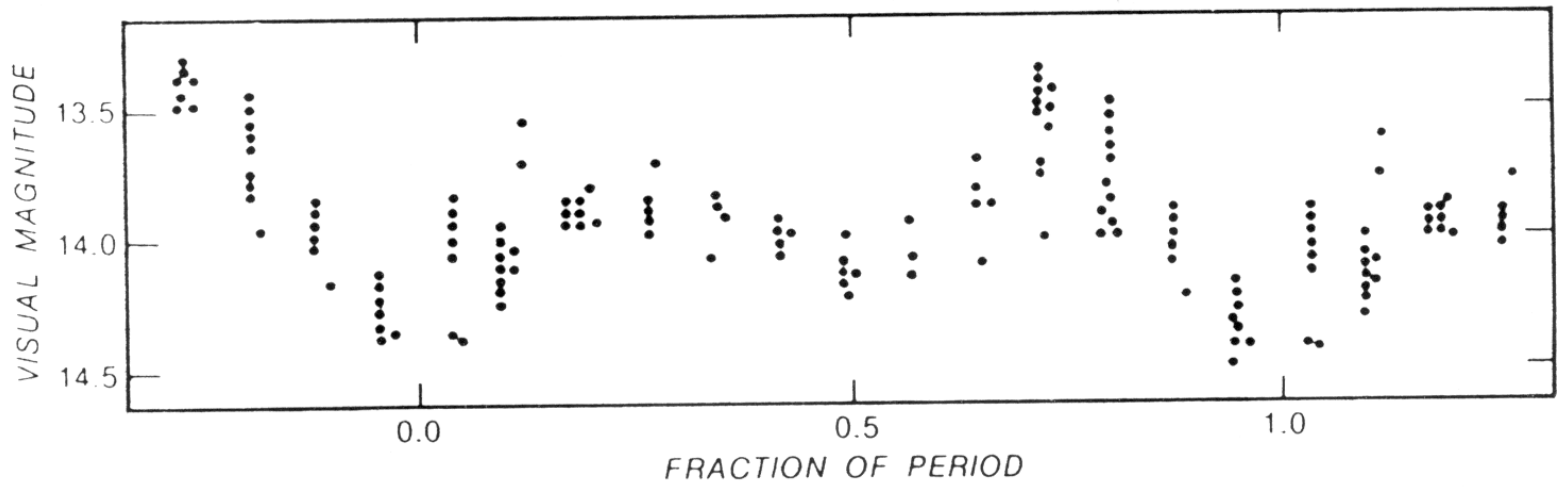


$\Longrightarrow$ on top of everything else:

CONJECTURE 14:

SS433 is an eclipsing binary!

New observations, new periods.

Late 1980: a new period discovered, $T = 6.5$ d

CONJECTURE 15:

Nutation superimposed on precession.

New observations, new periods.

Late 1980: a new period discovered, $T = 6.5$ d

CONJECTURE 15:

Nutation superimposed on precession.

+ Indications that the 164-day period is shortening:

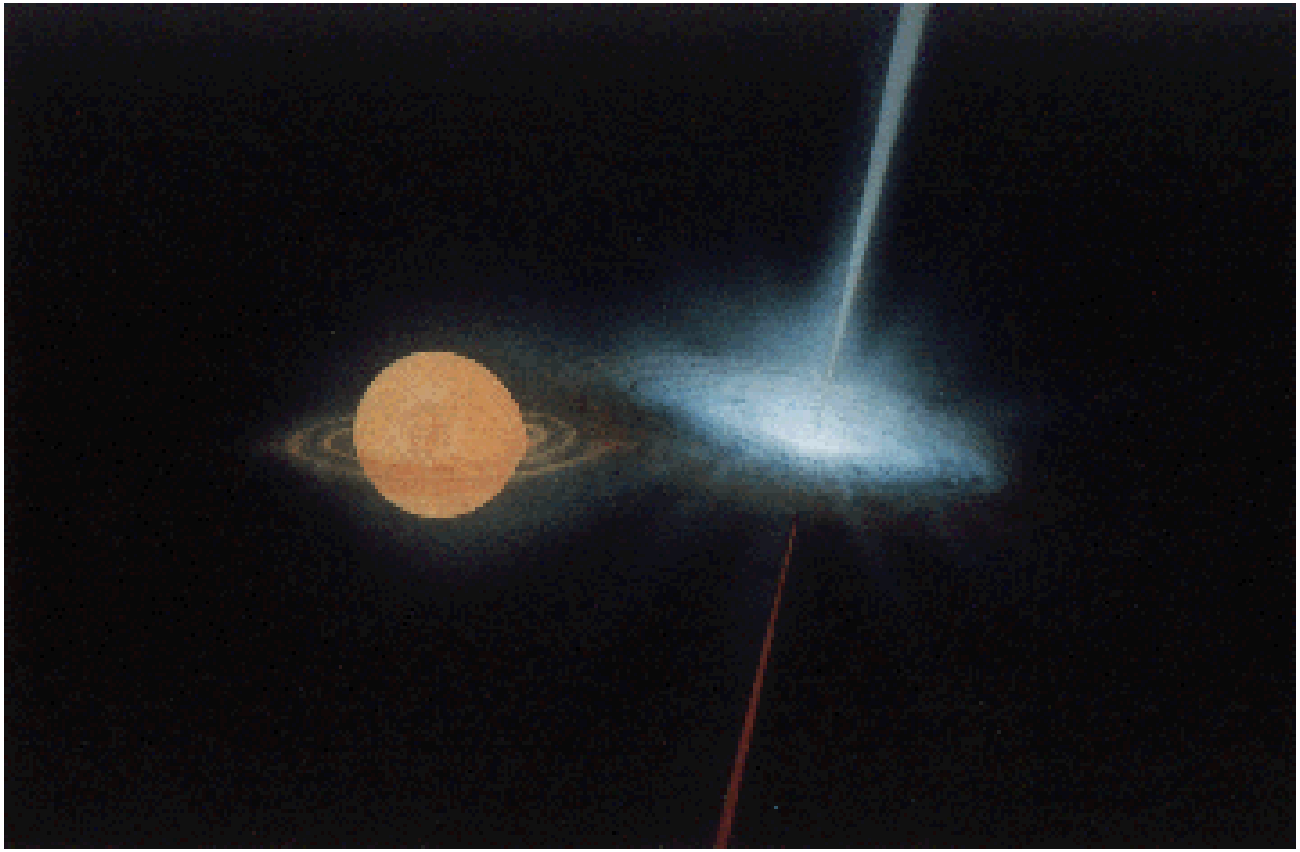
$\dot{T} \simeq -0.01$ days/day

CONJECTURE 16:

The phenomenon has a severely limited lifetime.

The central objects.

Better resolution killed flashlight, so now picture is:



What's inside?

The central objects: sizes.

- 1984: Eclipse durations related to relative sizes of the two objects $\Longrightarrow$ mass ratio: q (assuming star fills Roche lobe).
- He-II line acts as tracer of orbital motion $\Longrightarrow$

$$F = 1.035 \times 10^{-7} K^3 \times P_{\rm orb} (\sin i)^{-3} M_\odot$$
$$= \frac{M_X}{q(1+q)^2} = \frac{M_\star}{(1+q)^2}$$

where K is Doppler modulation in km/s:

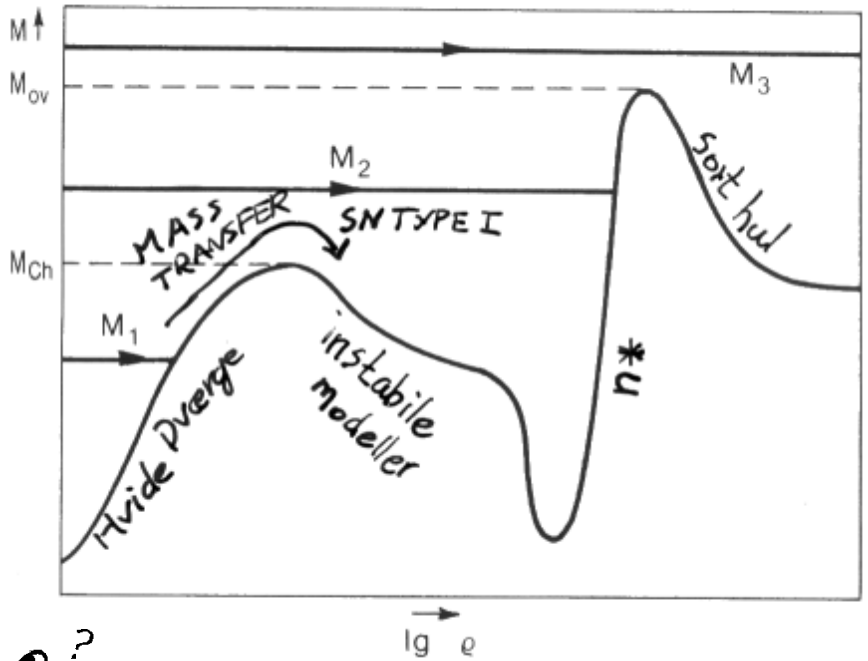
- Combining $q \simeq 0.245$ and $F \simeq 10.6 M_\odot$ gives:

CONJECTURE 17:

$M_X = 4\ M_\odot$ and $M_\star = 16.4\ M_\odot$

Neutron star or black hole?

- White dwarfs and neutron stars are sustained by degeneration pressure.



Evolutionary endpoints:

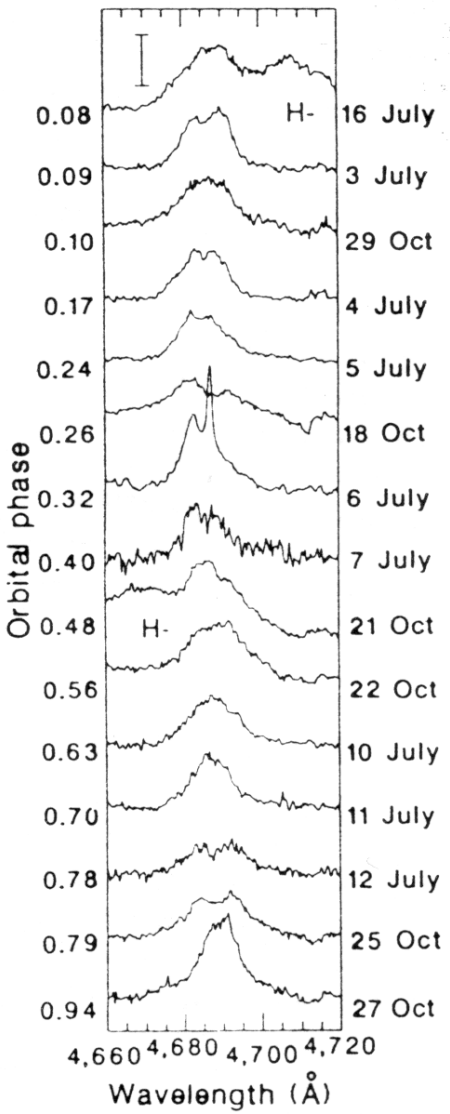
$M_{Ch} \simeq 1.4\ M_\odot$

$M_{OV} \simeq 2 - 3 M_\odot$

CONJECTURE 18:

Compact object is a $4M_\odot$ Black Hole.

Neutron star or black hole II



- Note: complex line profile at low resolution $\Longrightarrow$ separation of true orbital modulation extremely difficult
- Also: mass function, $F \propto K^3$.
- $\leftarrow$ (1991) spectra $\Longrightarrow$ $F = 2.0 \pm 0.3 M_\odot$

CONJECTURE 19:

Compact object is $0.8 M_\odot$ neutron star.

The accretion disk

- What's driving the jets?
- The physical processes involved are not yet well understood. Matter accretes in a spiralling disk around the compact object. Friction/compression $\Longrightarrow$ heating $\Longrightarrow$ radiation (intense X-rays).
- The Eddington luminosity limit: radiation pressure = gravitational pressure. If luminosity larger, accreted material is ejected into space.
- Seen in Wolf-Rayet stars and hypergiants.

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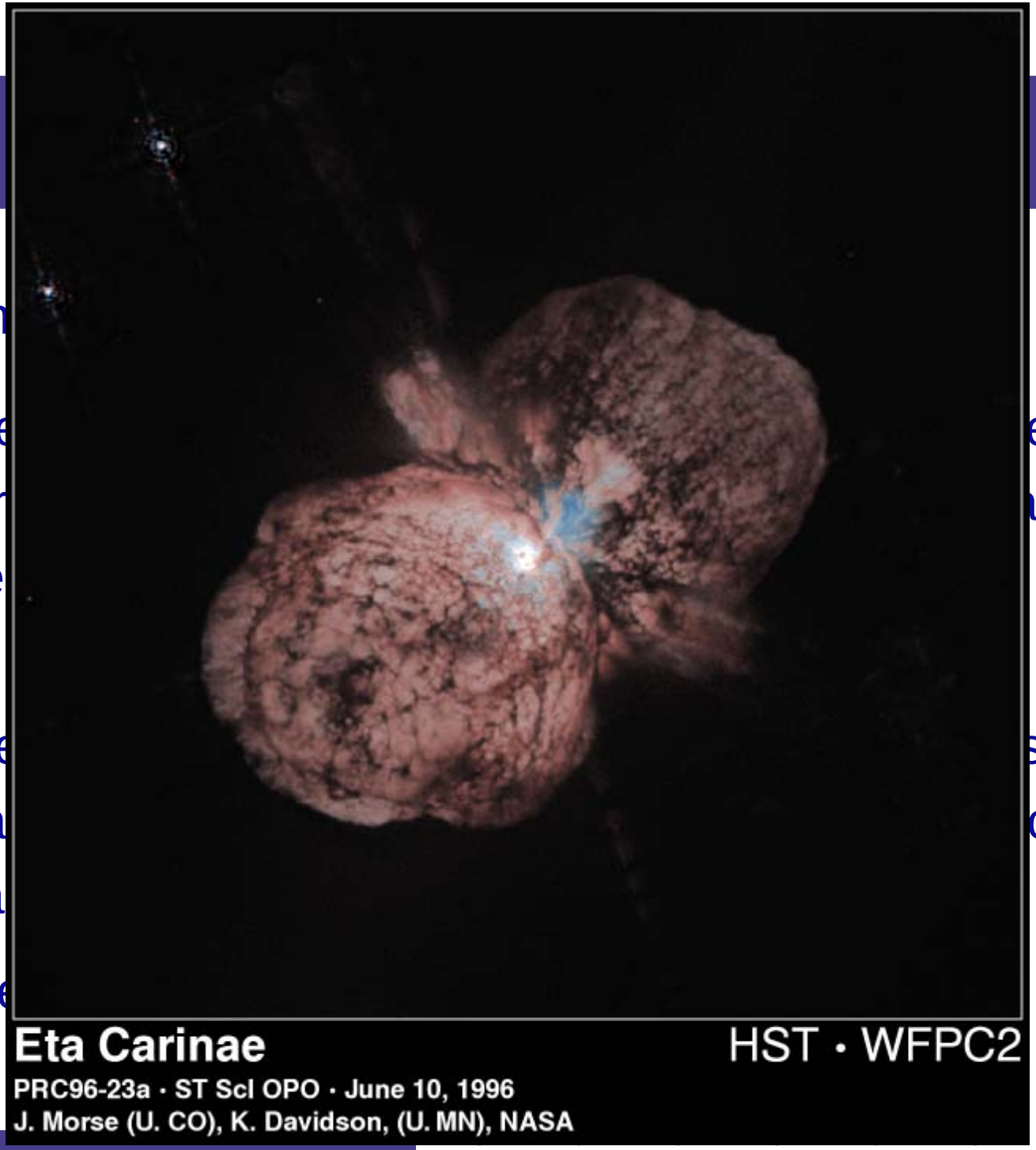


Neutron star or black hole III

- 1999: models of the accretion disk and jet expulsion mechanisms indicated larger transfer rates needed to "drive" the jets.

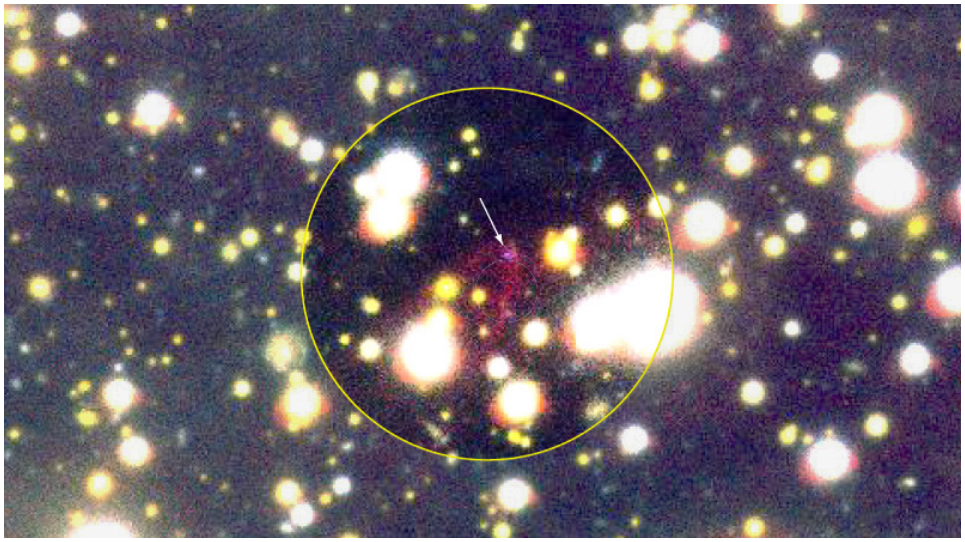
$\Longrightarrow$ companion must be larger (4–12 $M_\odot$)

with q still about $1/4$, there is still room for a black hole accretor.

CONJECTURE 20:

Compact object: $1-4M_\odot$ Black Hole *or* neutron star.

RJX J185635-375: Totally strange?



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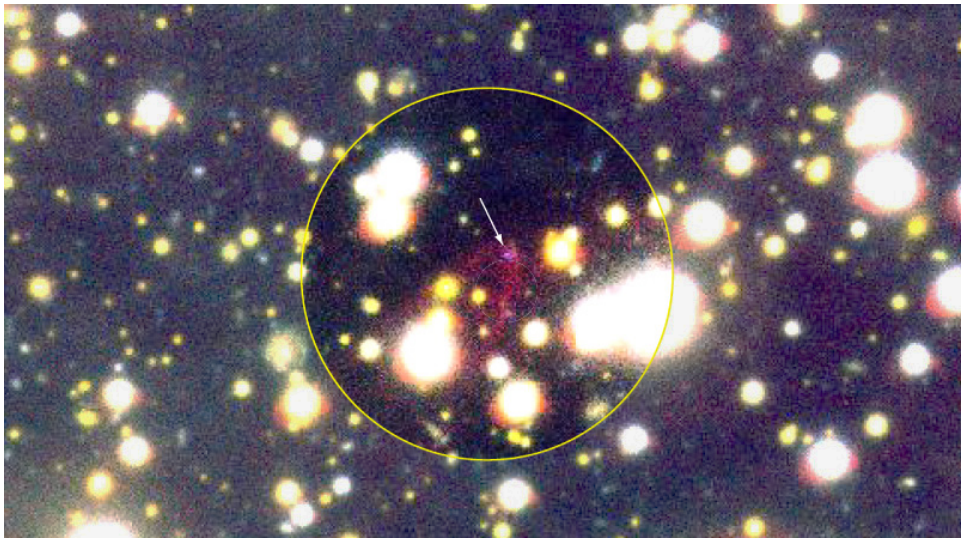

Neutron star, age $\sim$ 1 Myr. Should be much hotter and brighter.

Hypothesis: a quark star, made of strange stuff, between neutron star and BH.

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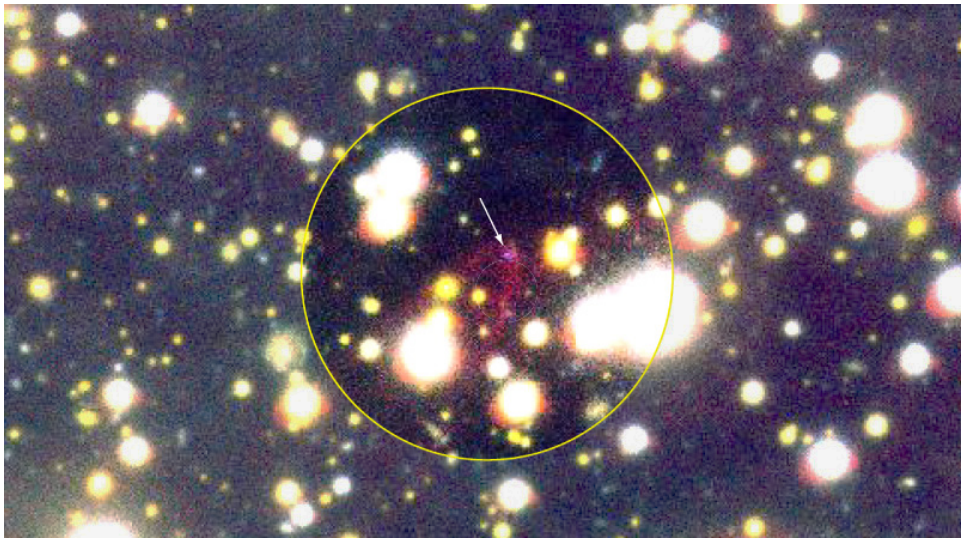

Neutron star, age $\sim$ 1 Myr. Should be much hotter and brighter.

Hypothesis: a quark star, made of strange stuff, between neutron star and BH.

Conjecture 21:

A hadron with strangeness 10^{50}?

To learn more...

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2. The bizarre spectrum of SS433, SciAm, Oct 1980.
3. SS433: Enigma of the Century, S&T, Aug 1981.
4. The SS433 Binary System, AJ 251:604, Dec 1981.
5. Evidence that the compact object in SS433 is a neutron star and not a black hole, Nature, Sep 1991.
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9. SS-433 the link with Active Galactic Nuclei, in Exploring the X-ray Universe, 1995.
10. The evolutionary status of SS433, astro-ph/9912396, 1999.
11. Twenty Years of Timing SS433, astro-ph/0107296, 2001.
12. A 2.4-80μm spectrophotometric study of SS433 with ISO, astro-ph/0112339, 2001.