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The Mass-loss History of the Red Hypergiant VY CMa*

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Outline

-Hypergiants?

-VY Canis Majoris

-Possible implications on the explanation of the recent dimming of Betelgeuse.

Hypergiants

-Hypergiants: how giant are they?

-At the beginning of the article is written that if VY Cma, with radius about 1420 R_sun, would be in place of our Sun, it would reach to Jupiter. Jupiter? I remembered “giants, e.g. Antares, would reach to Mars”, this one ... Jupiter?!

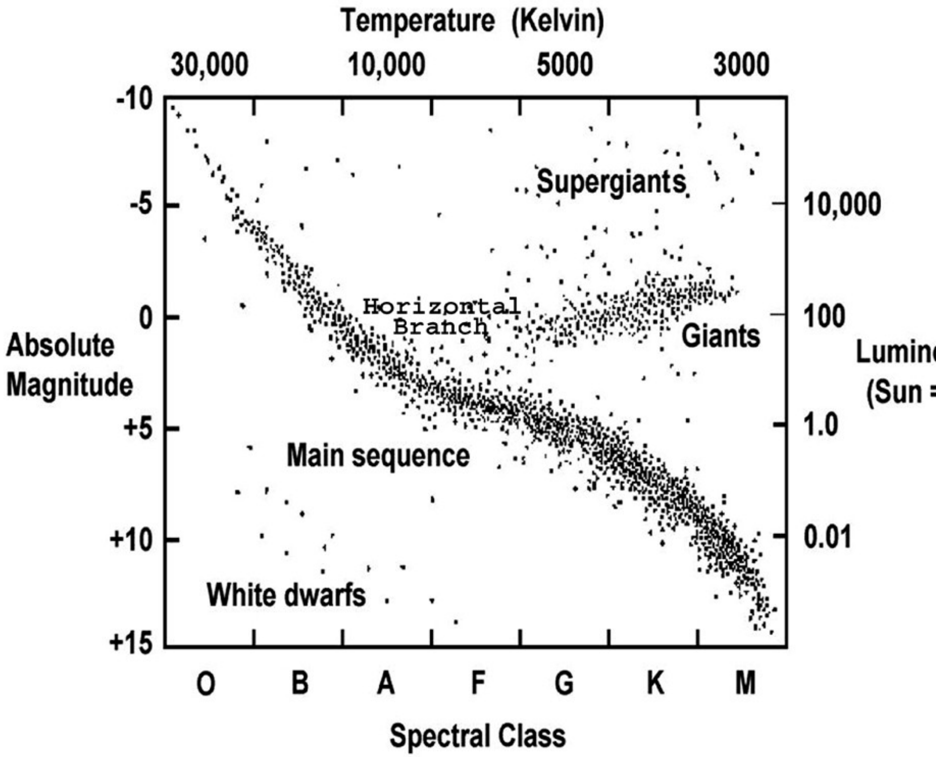
Other supergiants are Westerlund 1-26, WOH G64, with about 1200 and 1500 R_sun, and Stephenson 2-18 with about **2500 R_sun-it would reach to Saturn**!

Light travelling around the equator of VY CMa star would take 6 hours, compared to 14.5 seconds for the Sun.

It is not at all that “obvious” for me that gaseous spheres can be *THAT* big. I did not remember it from the HR diagrams I saw.

“Space is big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist's, but that's just peanuts to space.”
— Douglas Adams, “*The Hitchhiker's Guide to the Galaxy*”

Supergiants in HR diagram



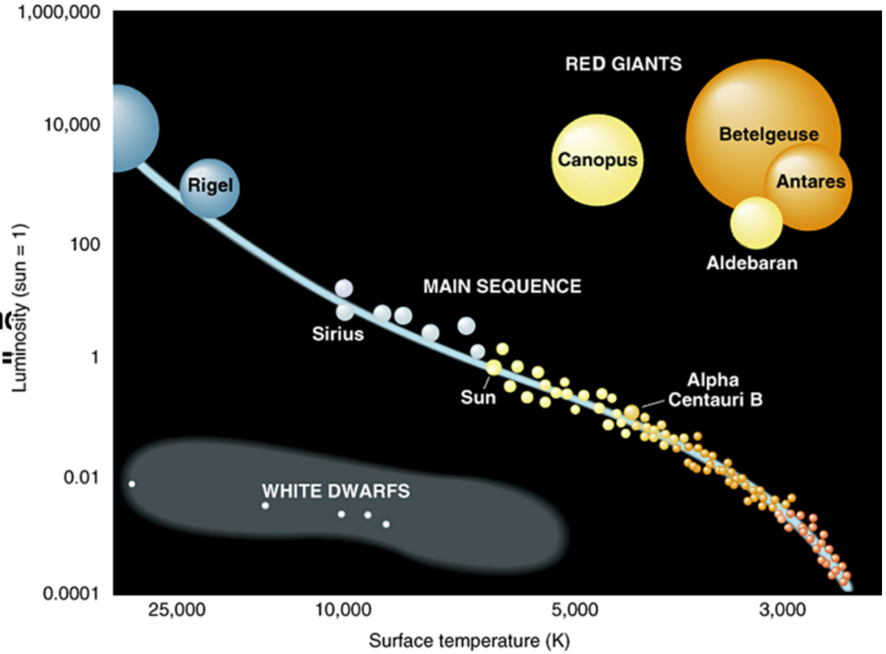
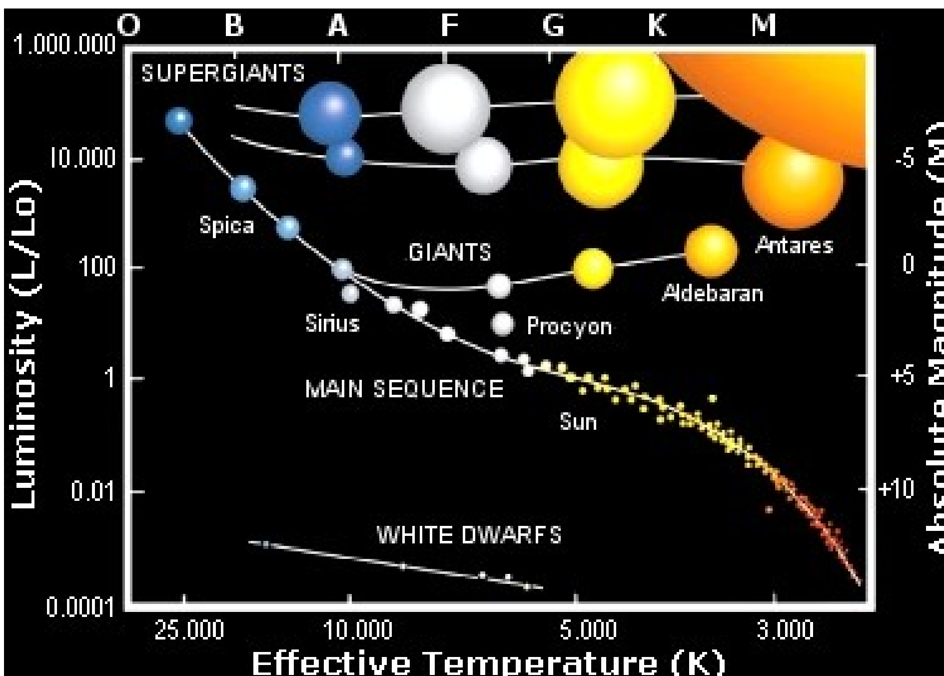


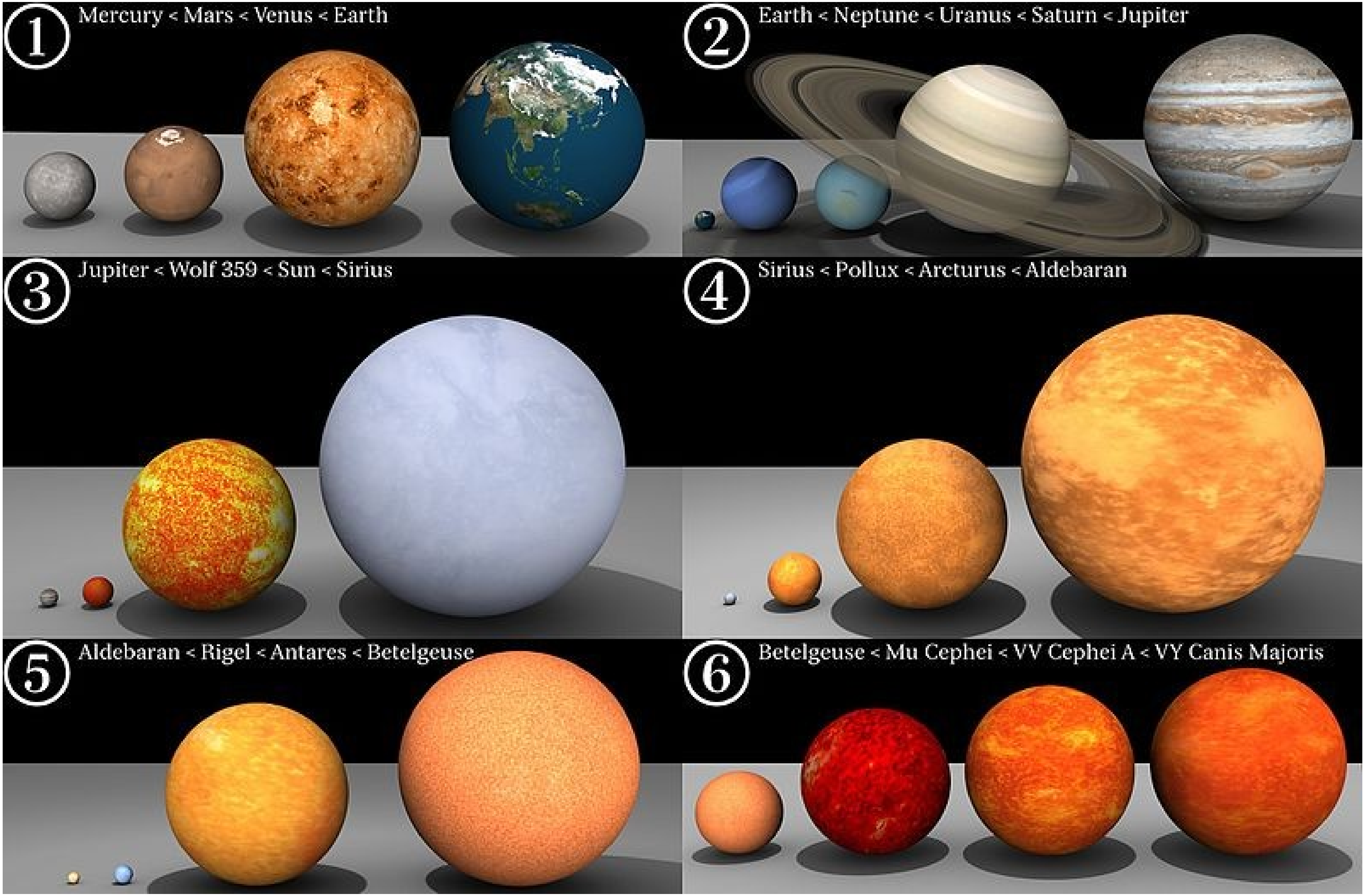
Figure 1 - The Hertzsprung-Russell Diagram. Dim cool stars are at the lower-right, bright hot stars are at the upper-left. The sizes shown for the stars are suggestive, not exact.

Radius of the Sun is about 695,700 km --> **diameter** is of the order of **1 million km**.

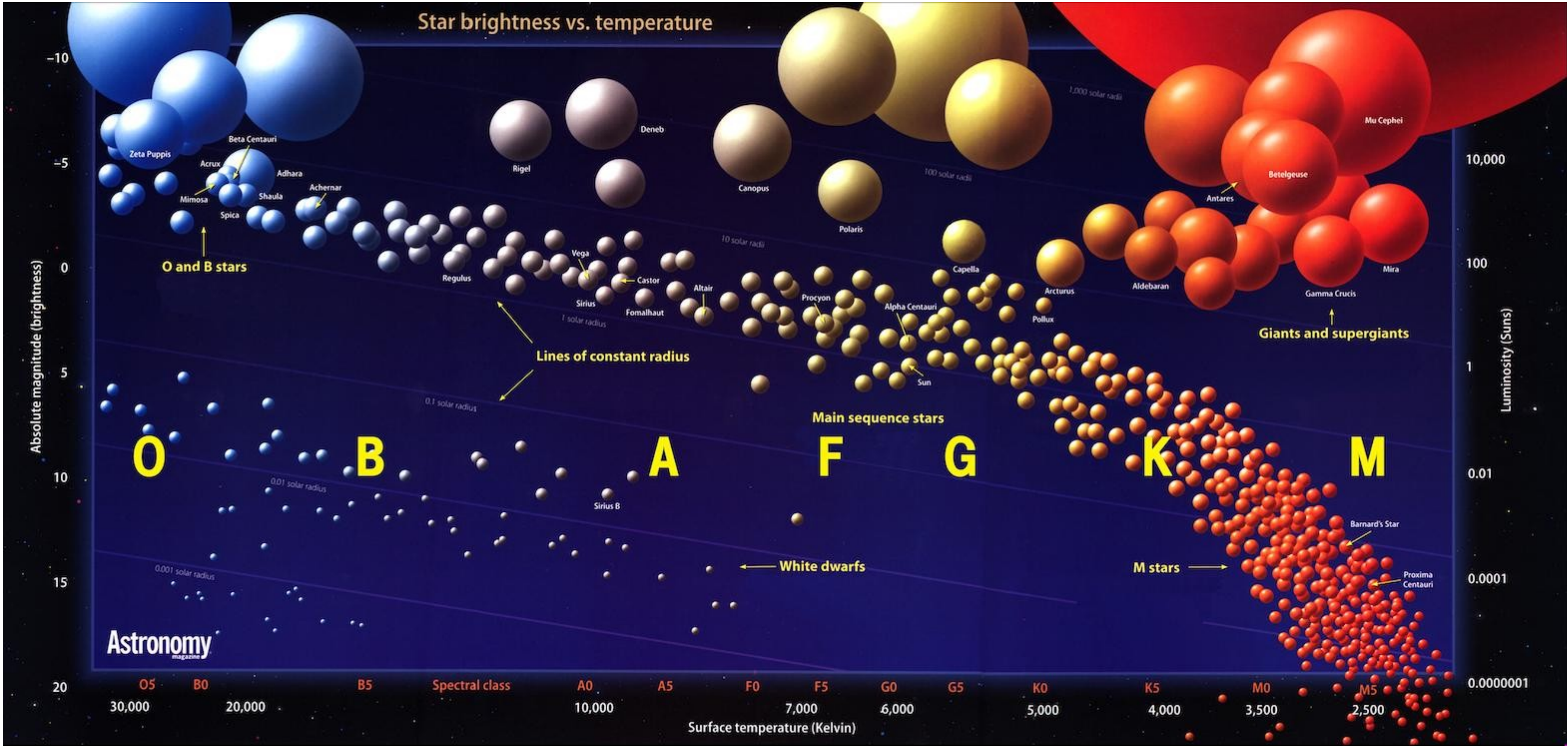
Distance **Earth-Moon** is **384 000 km**.



Hypergiants?

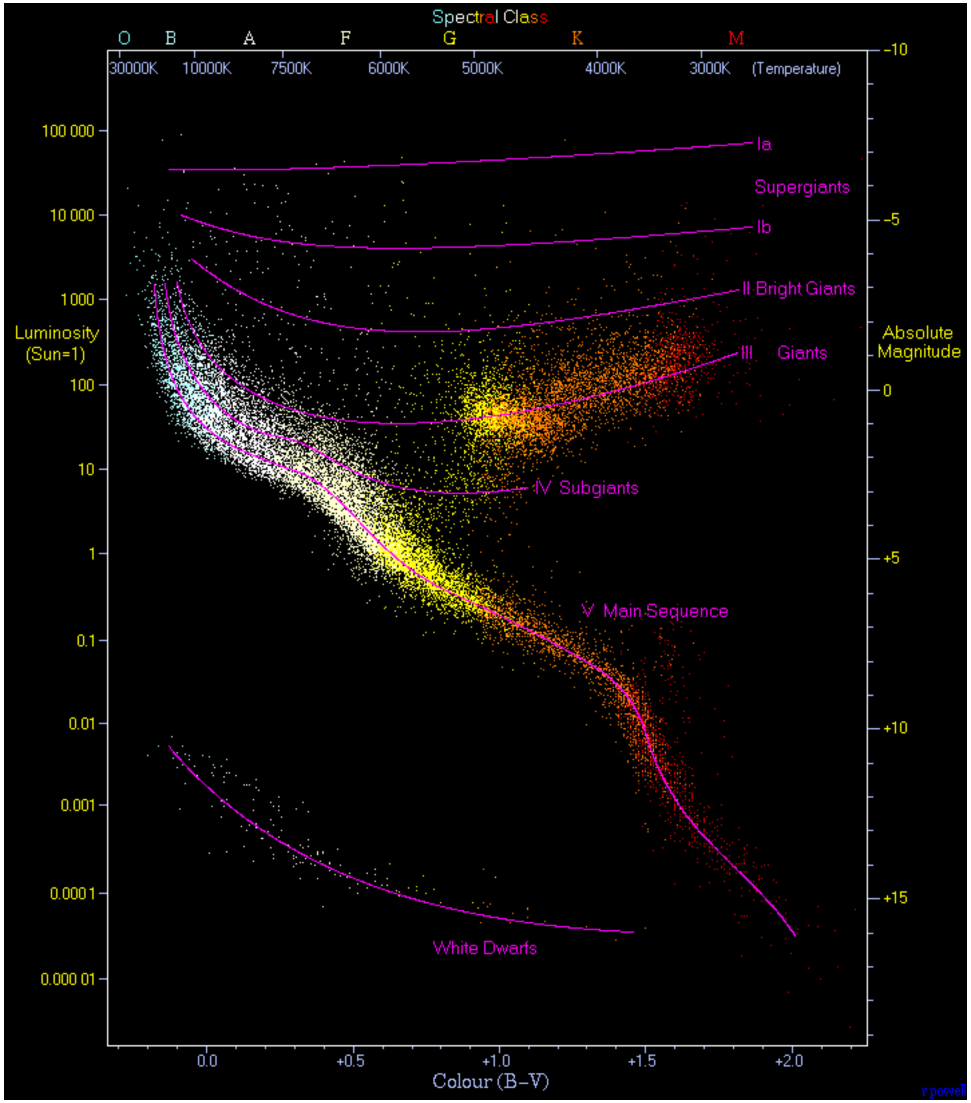


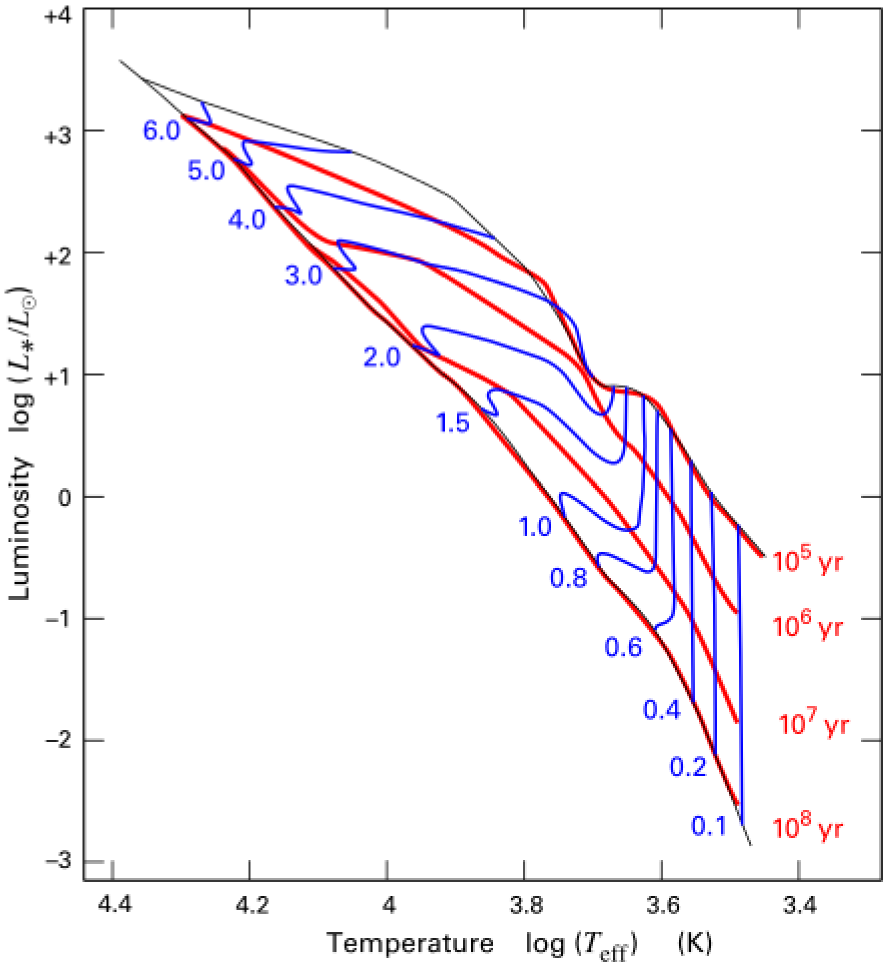
Supergiants in HR diagram



About 90 percent of the stars in the universe exist along Main sequence line at one time in their lives, when they still fuse hydrogen to helium. When they run out of hydrogen and start fusing helium, they become giants or supergiants. Stars like the Sun may take this path, and then shrink down to become white dwarfs, in the lower-left part.

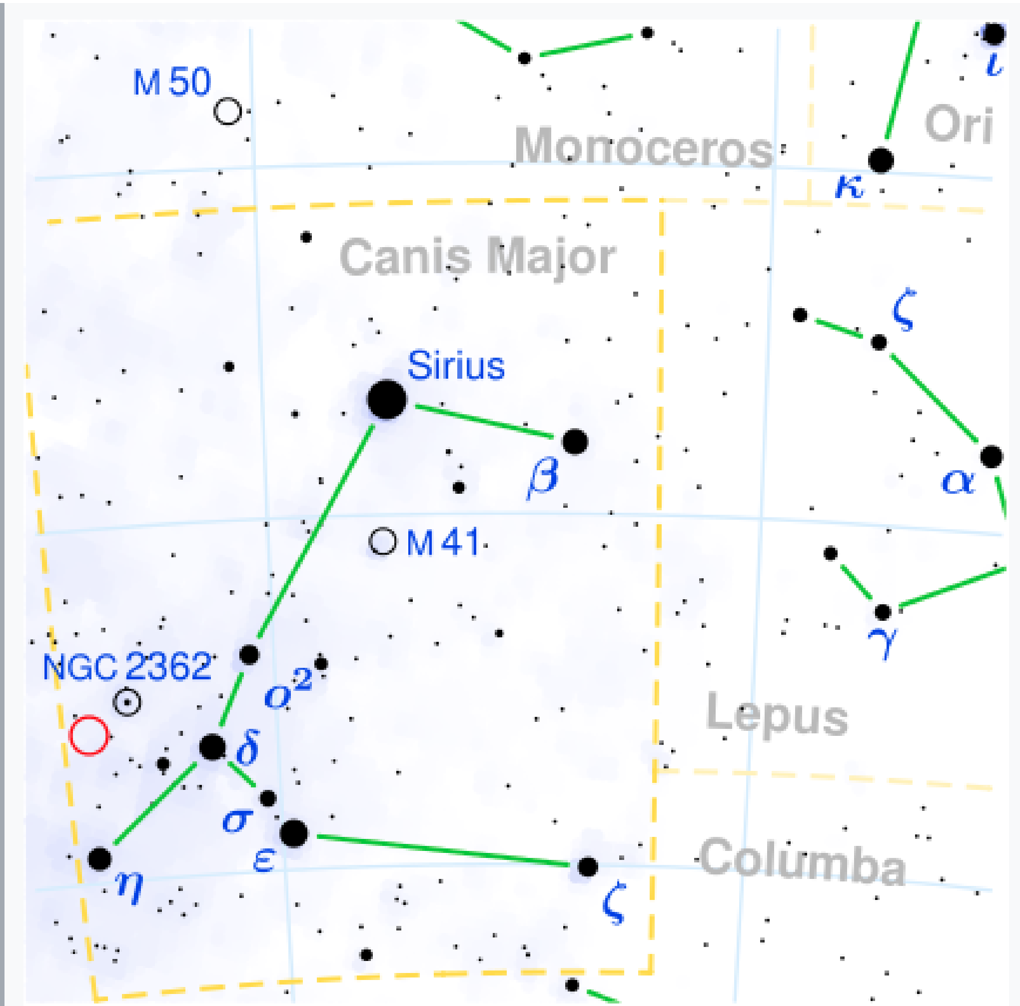
Hayashi track





Stellar evolution tracks (blue lines) for the pre-main-sequence. The nearly vertical curves are Hayashi tracks. Low-mass stars have nearly vertical evolution tracks until they arrive on the main sequence. For more-massive stars, the Hayashi track bends to the left into the Henyey track. Even more-massive stars are born directly onto the Henyey track. The end (leftmost point) of every track is labeled with the star's mass in M_sun, and represents its position on the main sequence. The red curves labeled in years are isochrones at the given ages. Stars 10^5, 10^6 etc. years old lie along the labeled curves.

VY CMa



Location of VY CMa (circled)

-an extreme oxygen-rich (O-rich) red hypergiant (RHG) or red supergiant (RSG) and pulsating variable star 1.2 kiloparsecs (3,900 light-years) from the solar system in Canis Major. It is one of the largest known stars, one of the most luminous and massive red supergiants, as well as one of the most luminous stars in the Milky Way.

-its great infrared (IR) excess makes it one of the brightest objects in local part of the galaxy at wavelengths of 5 to 20 μm and indicates a dust shell or heated disk.

-about 17±8 M_sun, 1420 R_sun. It is surrounded by a complex asymmetric circumstellar envelope (CSE) caused by its mass loss. It produces strong molecular maser emission and was one of the first radio masers discovered. It is close to its Hayashi limit on a Hayashi track, max for its mass and radius.

VY CMa

WFPC2/HST image showing the asymmetric nebula surrounding VY CMa

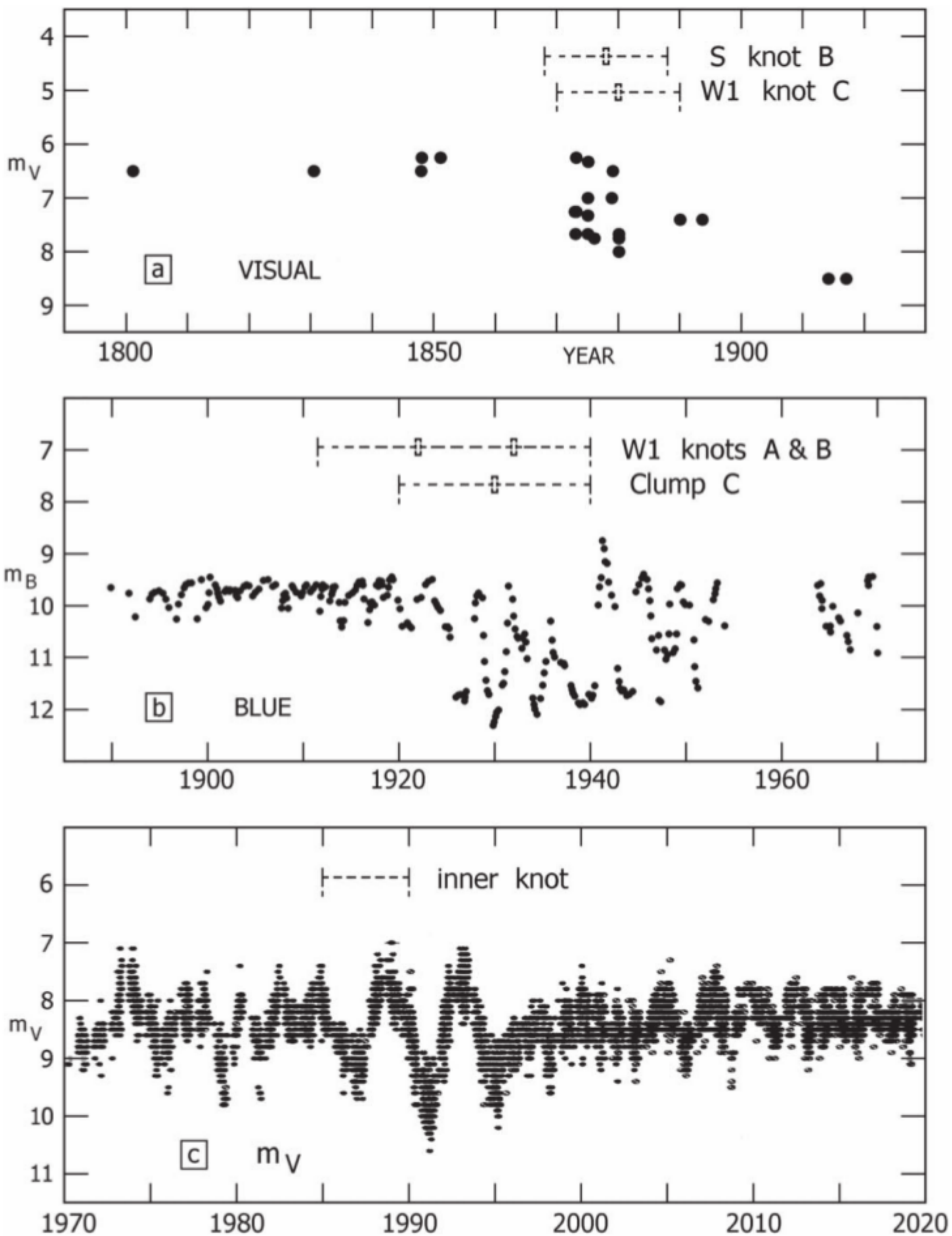
-First record of observation in Lalande star catalogue in 1801, as a 7m star. First a nebula around was interpreted as a multiple star, but later explained as bright spots in the nebula.

- A variable star 9.6m - 6.5 m in 956 days.

-Spectrally very mixed, M2-M5 in different studies.

-3730 K surface temperature.

VY CMa



-nearly visible by the naked eye at about 6–6.5 mag at the start of the 19th century until a major period of variability from ≈1870 to 1880 with multiple dimmings. There is a 20 year gap from ~1850 to 1870, but by 1872 the star is a magnitude fainter, with three recognizable minima. The decline to about 8 mag in 1880 is followed by a gap of 10 years. We do not know if the star recovered or had additional minima, but by 1890–1893, it was a magnitude below its unobscured brightness.
The 20th century light curve, (middle panel) overlaps the 1890–1910 period with no additional deep minima and confirms the decline by 1–1.5 mag to 7.5–8 mag in the visual (9.5–10 blue mag). It has stayed near this fainter magnitude since.

Today it is typically 8 mag in the visual. Since the 19th century the light curves show two periods with significant variability, from ≈1925 to 1945, with dimming by two or more magnitudes in the blue and more recently from about 1985 to 1995 dimming by 1–1.5 mag in the visual.

The ejection ages of several of the knots are marked on the light curves. They agree with the extended periods of variability. The most recent, the inner knot visible in the narrow slit on the star, is consistent with an ejection during VY CMa's most recent active period.

Betelgeuse

From the Abstract: Comparison with VY CMa's historic light curve from 1800 to the present shows several knots with ejection times that correspond with extended periods of variability and deep minima. The similarity of this correspondence in VY CMa with the remarkable recent dimming of Betelgeuse and an outflow of gas is apparent. The evidence for similar outflows from the surface of a more typical red supergiant suggests that discrete ejections are more common and surface or convective activity is a major source of mass loss for red supergiants.

Betelgeuse (α Ori) recently experienced an unexpected visual dimming beginning in 2019 December and continuing well into 2020 (Guinan et al. 2019, 2020) reaching an unprecedented minimum in 2020 February, fading by about 1 mag. Observations show a remarkable corresponding fading of its southern hemisphere.

UV spectra from HST/STIS revealed remarkable changes with an increase in the UV flux and variations in the Mg II line supporting a corresponding outflow of material from the star. The dimming in the light curve is attributed to dust, although other authors have questioned this, and suggest that a change in the photospheric luminosity or a cooling of a large fraction of the photosphere due to dynamical effects may be responsible.

The similarity of the correspondence between the periods of variability and dimming in VY CMa and in Betelgeuse with outflows of gas is clear. High-spatial near- and mid-infrared imaging of Betelgeuse reveals several clumps or knots of dusty material within 1 arcsecond of the star. This current ejection by Betelgeuse may be similar to the recent inner knot ejection observed in VY CMa's spectrum or to its 1920–1940 active period, depending on how long its current variability lasts.

Conclusions

There is definitely a difference in scale between VY Cma and Betelgeuse and very likely in the energies involved.

-the deep minima in VY CMa typically lasted about 3 years, and longer in a couple of cases, while the dimming in Betelgeuse only lasted about 150 days.

-the presence of outflows from the surface of the more typical red supergiant Betelgeuse suggests that these discrete mass-loss episodes are not unique to the extreme hypergiants.

Speaking of Jupiter, Saturn...here is my own observation, 2 days before the big conjunction, Dec. 2020 – home made, with basic equipment, 11 cm reflector telescope and a mobile phone.

Thank you.

Stay safe.
Stay sane.
Do Science!