STELLAFANE Observing Olympics 2023

The Hidden Gems of Stellafane - Planetary Nebulae

Observe any 15 Objects in any Telescope – Receive a Pin

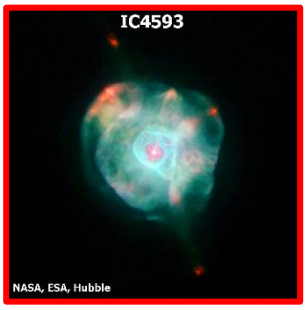
Name	Alt. Name	J2000	Const.	Size.	Mag. Neb.	Mag. CStar	Est. Dist. LYrs
☐ **IC4593**	PK25+40.1	16 11 44.5 +12 04 17	Her	30.0”	10.8 (V)	11.2	3,400
☐ **NGC6153**	ESO331-6	16 31 30.6 -40 15 12	Sco	24.0”	11.5 (P)	16.1	4,000
☐ **NGC6210**	“Turtle”	16 44 29.7 +23 47 58	Her	30.0”	9.3 (P)	12.6	5,444
☐ **NGC6302**	ESO392-5	17 13 44.3 -37 06 13	Sco	85”x 44”	10.1 (V)	21.1	2,625
☐ **NGC6337**	The “Cheerio”	17 22 15.6 -38 29 02	Sco	51.0”	12.0 (V)	14.9	3,000
☐ **NGC6369**	“Little Ghost Neb”	17 29 20.5 -23 45 34	Oph	37.0”	12.0 (V)	15.9	2,000
☐ **Hubble 4**	Koh 4-55	17 41 52.8 -24 42 08	Oph	6.0”	13.1 (P)	17.0	8,300
☐ **NGC6445**	**“**Little Gem Neb”	17 49 14.9 -20 00 36	Sgr	44”x30”	13.2 (P)	19.0	3,260
☐ **NGC6543**	“Cat’s Eye Neb”	17 58 33.5 +66 37 59	Dra	20.0”	11.3 (V)	11.1	3,300
☐ **NGC6572**	PK34+11.1	18 12 06.4 +06 51 11	Oph	11.0”	10.8 (V)	13.1	3,912
☐ **Minkowski 1-64**	“Other Ring”	18 50 02.3 +35 14 33	Lyr	24.0”	12.8 (P)	--	19,560
☐ **NGC6751**	**“**Glowing Eye Neb”	19 05 55.5 -05 59 33	Aql	26.0”	12.5 (P)	15.4	6,500
☐ **NGC6781**	PK41-2.1	19 18 28.2 +06 32 15	Aql	1.8’	11.8 (V)	16.7	1,500
☐ **NGC6818**	“Little Gem Neb”	19 43 57.8 -14 09 10	Sgr	48.2”	9.3 (V)	16.9	4,250
☐ **NGC6826**	**“**Blinking PN”	19 44 48.2 +50 31 31	Cyg	38.0”	9.6 (V)	10.4	3,590
☐ **NGC6905**	**“**Blue Flash Neb”	20 22 23.0 +20 06 16	Del	72”x37”	14.5 (V)	15.7	5,540
☐ **NGC7008**	“Fetus Nebula”	21 00 33.1 +54 32 32	Cyg	86.0”	13.3 (P)	12.2	2,800
☐ **NGC7009**	“Saturn Nebula”	21 04 10.9 -11 21 49	Aqr	70.0”	12.1 (V)	12.7	3,750
☐ **NGC7026**	**“**Cheeseburger Neb”	21 06 18.5 +47 51 08	Cyg	40.0”	12.7 (P)	14.2	6,800
☐ **NGC7027**	**“**Jewel Bug Neb”	21 07 01.8 +42 14 07	Cyg	60.0”	8.8 (V)	16.2	2,900
☐ **NGC7293**	The “Helix”	22 29 38.4 -20 50 12	Aqr	16.0’	13.5 (V)	13.5	655
☐ **NGC7662**	“Blue Snowball”	23 25 53.9 +42 32 06	And	37.0”	12.0 (V)	13.2	6,450
☐ **NGC40**	“Bow Tie Neb”	00 13 00.9 +72 31 19	Cep	70”x60”	11.5 (V)	11.5	3,500
☐ **Messier 76**	NGC650-1	01 42 19.9 +51 34 35	Per	167.0”	12.2 (P)	15.9	3,030
☐ **IC1747**	PK130+1.1	01 57 36.0 +63 19 17	Cas	13.0”	13.60 (P)	15.4	7,825

Larry Mitchell – Eileen Myers

STELLAFANE Observing Olympics 2023 - *Planetary Nebulae*

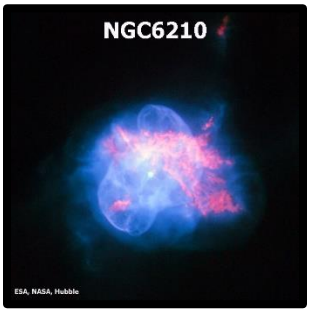
Observe any 15 Objects to receive a Pin

Planetary Nebulae (PNe) are the product of low and intermediate mass stars that underwent extensive mass loss during the Asymptotic Giant Branch (AGB) phase. The textbook version is that planetary nebulae are the swan song of stars between 1 and 8 solar masses that are nearing the ends of their lives. These stars shed their outer layers, growing brighter and hotter while ionizing the newly formed nebula, before they ultimately cool and fade into white dwarfs. A significant fraction of planetary nebulae are produced by systems that have undergone binary interactions.



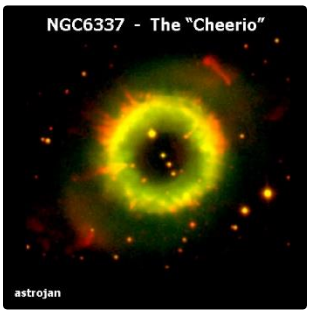
IC4593 is a bright planetary nebula located in southern Hercules at distances estimated from 3,000 to 14,000 light years, with 3,400 light years a recent estimate. A giant surrounding halo extends over three times the size of the inner halo, which gives the entire structure a diameter of 0.7 light years, considered small when compared to other similar objects. The central star is relatively bright at 11.3 Vmagnitude and still is heating up with a current relative low temperature for planetary nebulae of 35,000 Kelvin, although here also is an estimate, with the range extending from 28,000K to 42,000 K. The expansion rate of the nebula is a low 12 kilometers per second. The small diameter, the low temperature, and low expansion rate, are all strong indicators that this is a young planetary nebula. The complex system of shells and condensations consists of a bright core 10 arcseconds in diameter. Protruding from the core, into the 'inner halo', are opposing lowly ionized bright knots, which are collimated outflows which culminate ≈ 12 arcseconds from the central star. The outer halo is irregular and elliptical in shape and 120 x 130 arcseconds in size. The bright bulging feature to the northeast of the central region is a high excitation FLIER (Fast Low Ionization Emission Region), which are often referred to as Ansae. The reddish color is due to low-excitation [N II] λ6584 Å ionized nitrogen. On the opposite south-west segment of the faint, clumpy outer halo are irregular strings of lowly ionized emission line knots.

NGC6153 is a bright, southern planetary nebula located about 4,000 light-years away in Scorpius, and is elliptical in shape, with an extremely rich network of loops and filaments. It is a fairly young elliptical shaped nebula at only 4,000 years of age and is thought to be the product of a high-mass (4.5 MΘ) progenitor. Unlike many elliptical shaped planetary nebulae, NGC6153 lacks ANSAE, which are thought to reference the initial ejection of material from the dying star. The central region is extremely active and a diffuse X-ray emission is confined to the inner shell. NGC6153 has played an important part in the chemical abundance discrepancy problem. An abundance discrepancy was first noted by Wyse (1942), who observed a much higher oxygen abundance than the forbidden [O III] lines that originate from the same O^{2+} ions. NGC6153 contains unusually large amounts of neon, argon, oxygen, carbon, and chlorine — up to three times more than is found in the Solar System. It also contains a whopping five times more nitrogen than the Sun! These systematically larger abundances are greater than the forbidden lines present and this has been called the "*Abundance Discrepancy Problem*". The star may have developed higher levels of these elements as it grew and evolved, but it is more likely the star originally formed from a cloud of material that already contained huge amounts of these elements. The Gaia Observatory has found the central star of NGC5613 is a close binary system, with the energizing member at 109,000 K. A weak O VI λ3811 Å emission line from the central star suggests the nucleus of NGC6153 has a hydrogen-deficient surface and a high degree of excitation. The central stars of planetary nebulae that are H-deficient and display spectroscopic evidence for fast stellar winds and high mass-loss rates (up to 10^{-6} MΘ yr^{-1}) are classified as Wolf-Rayet [WR]-types because of their similarity, as a class, to luminous Wolf-Rayet (WR) stars. The primary difference between the two classes is that the [WR]-type stars descend from intermediate mass (1–8 MΘ) stars, whereas "classical" WR stars are the descendants of massive (>25–30 MΘ) stars. A diffuse X-ray emission is enclosed within the central optical bubble, although the morphology of the X-ray emission varies considerably from object to object.



NGC6210 or the Turtle is a bright planetary nebula located in Hercules, approximately 5,444 light years from the Sun. It is located 38° above the galactic plane at a vertical distance of about 3,300 light years, and thus has little extinction from intervening interstellar dust. NGC6210 forms a rough ellipsoid but is "very amorphous and irregular" in shape with the initial ionization occurring 3,500 years ago. Its chaotic appearance may be due to it being shaped by a mass transfer in a triple star system. NGC6210 has five distinct ejection areas which include the inner and intermediate shells, two bipolar flows forming the outer lobes, and a collimated jet outflow to the NW of low ionization knots. The majority of these redshifted knots have ages greater than 2,000 years while the majority of blueshifted knots have ages younger than 2,000 years. This sudden and permanent 180-degree flip in the ejection axis at a relatively late stage is difficult to explain. The bright inner region is filled with arches and filaments spanning 13 × 16 arcseconds, with an expansion velocity ranging over 12–15 miles s^{-1}. A larger and fainter outer volume has a pair of "tubular" structures which span 40 x 30 arcseconds and contribute only 1% of the total emission. At the given distance the size of the entire nebula is 1.07 x 0.8 light years. The central star has a temperature of 65,000 K with an apparent visual magnitude of 12.66, and the spectrum matches a hydrogen-rich star. The abundances of the nebula suggest a low initial mass for the central star, probably ~0.9 $M\odot$. Outflow from this star has been measured with velocities of 2,180 km/s, and the estimated mass loss rate is 2.2×10^{-9} $M\odot$ yr^{-1}.

NGC6302 is commonly called the "**Bug Nebula",** as it resembles a bug splat on a car windshield. It is a classic butterfly shaped bipolar nebula although this is not noticed in amateur sized telescopes. It is located 2,624 to 3,815 light years away and is a post asymptotic giant branch (AGB) outflow which has lasted 2,200 years. The varied structures within the object are among the most complex ever observed in planetary nebulae. The apparent 21.1 magnitude central star is a controversial object, which was erroneously discovered by the HST in 2009. It had escaped prior detection because it radiates mainly in the ultraviolet due to its extreme temperature, has a very dusty torus, and has a very bright background. However, newer images taken in 2020 reveal this "central star" has a huge proper motion of nearly 125 miles per second, which is more than any other nearby field star. Therefore, the star previously identified as the central star of NGC6302 is unrelated to the nebula and is an unfortunately placed foreground star at a distance of ~1,630 – 2,445 light years. Thus, the old question still remains of exactly where is the central star of NGC6302? All lines of evidence indicate the unseen NGC6302 central star is one of the hottest stars in the galaxy, with a range of 221,000 K to an incredible 430,000 K. The initial mass was 5 to 8 solar masses, which is very near the upper end of the mass range that can generate a planetary nebula. NGC6302 has undergone three distinct episodes of internal ejections. First came the inner ionized torus, then a slowly expanding molecular torus, followed by the giant expanding lobes. It took 4,600 years in which to build the torus, which began 7,500 years ago, and finished about 2,900 years ago, while the inner torus formed about 1,200 years ago. The lobes formed after the torus was formed in a short-lived energetic event and have an estimated age of about 2,240 years. There was a delay of approximately 650 years between the time the torus was formed and the ejection of the lobes.



Visually **NGC6337** resembles a piece of the breakfast cereal Cheerios, hence the name. NGC6337 is a bipolar PN seen almost pole-on and is a bright 11.9 V magnitude. We view only the thin waist of the nebula, which is tilted only 15 degrees to our line of site and we are looking down and through an expanding blueshifted lobe of the nebula. Its distance is 2,800 to 5,550 light years. A binary nucleus exists at the center of the nebula, with a cool main sequence star with a mass of 0.6 and a white dwarf of 0.35 MΘ, with a temperature of ~43,000 K. These are closely separated with an orbital period of only slightly over 4 hours. The Cheerio is expanding at a slow 0.6 – 1.2 miles per second which is only slightly higher than the earlier asymptotic giant branch (AGB) expansion rate. The main component of NGC6337 is the circular ring. In [O III] light the inner and outer radii of the ring are 14 and 24 arcseconds respectively, with the surface brightness peaking at 20 arcseconds from the central star. The shell which surrounds the inner ring contains a number of low-ionization knots and outward tails due to dynamical instabilities, which will lead to the fragmentation of the ring. A faint extended halo is elongated NW-SE and is about 1.8 arcminutes in length with bright ANSAE seen at the ends. In [O III] light this halo has a pretty uniform surface brightness while in the less energetic [N II] light the halo is more irregular and broken up.

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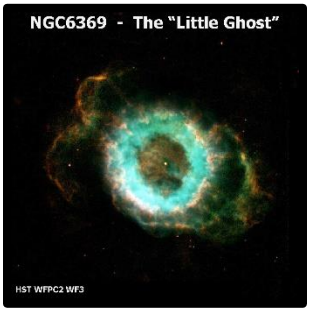
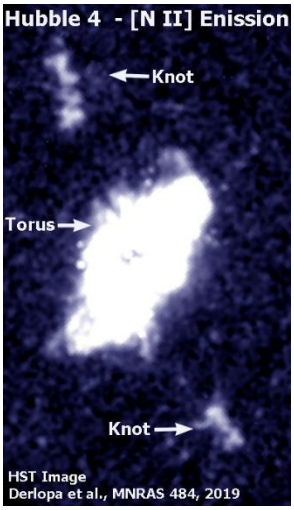
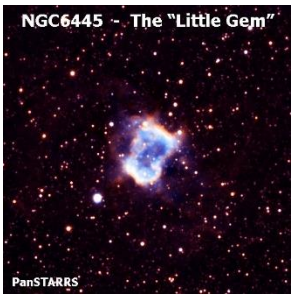


NGC6369 is an object with a complex morphology, consisting of a main bright annulus with a diameter of 40 arcseconds, and fainter curved outer structures on two sides in the east-west direction. We are viewing the bi-polar planetary nebula from a pole-on orientation at a distance of various estimates from 1,075 to 6,520 light years. It possesses a double-shell morphology consisting of a round bright inner shell, and a fainter filamentary outer shell or envelope. Two remarkable morphological features are extensions of the inner shell situated along the east and west directions and faintly visible in the photograph. The western extension is a large, filamentary blister or ansae, while the east member is a bifurcated structure, divided into two branches or forks. The bright inner shell contains a system of 'cometary' knots and faint bipolar extensions, and a filamentary envelope. The lack of kinematical evidence for shell expansion and the knotty appearance of the envelope are strong indicators the envelope is a flattened structure at its equatorial regions. This ring-like structure is about a light year in diameter and glows from oxygen, hydrogen and nitrogen atoms which are colored in the photo blue, green and red respectively. The central star is thought to be a binary system with the excitation member at 67,000 K with a spectral type [WO3], which is similar to oxygen rich Wolf-Rayet stars. True Wolf-Rayet stars typically have masses in excess of 25 solar masses, and end their lives as supernovae explosions and not planetary nebulae. Highly energetic central stars in planetary nebulae are referred to as Wolf-Rayet type stars as they exhibit similar energies.

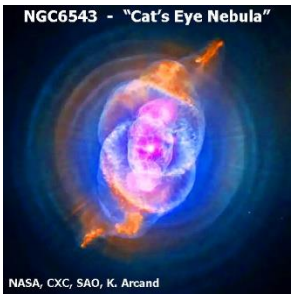


Hubble 4 is a high-excitation planetary nebula located in the Galactic disk, in the direction of the Galactic bulge, with an estimated distance of 8,300 light years (2.55 kpc). It is a multipolar nebula with an irregular structure and a deformed ring-like inner region. In the outer regions, Hb 4 also shows a pair of collimated, detached jets or elongated knots moving with a velocity of ~95 miles s^{-1}. These elongated, low-ionization knots protrude from either side of the main body of the nebula. The north and south knots are well collimated structures, with length-to-width ratios of D3. The northern knot is off by approx. 5 degrees with respect to the axis defined by the southern counterpart as if a torque or warping from the collimating structure has taken place. A very faint secondary bipolar structure close to the central region is aligned with the minor axis, which implies a poly-polarity for this nebula. The nucleus is both classified as a hydrogen-deficient star of [W03] class and of a [WC4] class. A possible link between jets and knots with binary systems or Wolf–Rayet (WR) central stars in planetary nebulae has also been proposed. The knots are possibly FLIERs (Fast Low Ionization Emission Regions) which typically have expansion velocities of 15–125 miles s^{-1} with respect to the main bodies. These FLIERS are the most protruding part of planetary nebulae halos and typically appear as 'handles' on either side of the nebula. They are thought to be the initial ejection of material from the dying star, which imparts a high velocity on the material, resulting in strong ionization features as it interacts with the interstellar medium (ISM).

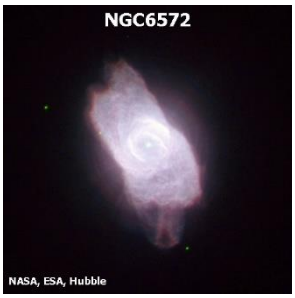


NGC6445 is located 2.1 degrees southwest of the open cluster Messier 23 in Sagittarius. Its distance is slightly more than 3,260 light years (1,000 parsecs), which is based on parallax measured by Gaia. NGC6445 is a bipolar planetary nebula with He/H and N/O abundance ratios consistent with a Type I PN definition. Optical images show a bright central ring-shaped morphology, which is the torus, with open bipolar lobes. This torus was ejected in the AGB phase, when the progenitor star was a red giant, and is now being disrupted by interactions with the fast stellar wind that was developed later. This irregularly shaped central region is ~40 × 50 arcseconds in size and [O III] emission dominates. The south region of the torus is much more disrupted than its north counterpart. The bipolar lobes are situated along the east–west (EW) direction stretching to about 1.8 arcminutes from the center. If the distance is accurate, this implies the nebula is 4 light years in diameter which is among the largest known for planetary nebulae. Within the EW bipolar lobes there are two arcs in H_2 emission, a northeast (NE) arc and a southwest (SW) arc, and both are ~1.0 arcminute from the nebular center. These two H_2 arcs might define a second set of bipolar lobes. There are also many filamentary structures located across the nebula, which hint at a more complex morphology. The outer halo which defines the bipolar morphology is much more extended and dominated by the lesser energetic [N II] emission. Within the halo there

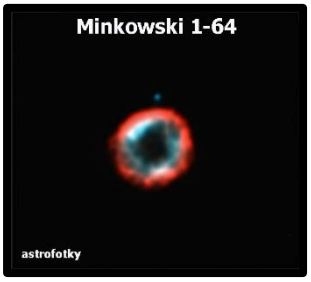
are filamentary features located well outside the central region, located 1.3 – 1.6 arcminutes from the center, along the N-S direction.



NGC6543 or the **Cat's Eye Nebula** is 3,300 to 5,300 light-years from Earth and is a very complex object, consisting of knots, jets, bubbles, and arcs, with a combined magnitude of 8.1 and a high surface brightness. NGC6543 is only 4.4 arcminutes from the north ecliptic pole and the current location of the Earth's northern axis of rotation. A small inner nebula has a diameter of 16.1 arcseconds while an outer condensation subtends 25 arcseconds. Its age is based upon its angular expansion, so if it has been expanding at a constant rate of 10 milliarcseconds per year, then it would take 1,000 ± 260 years to reach its present 25" diameter. Deep images reveal an extended halo of about 6 arcminutes across, which is the product of a slow wind ejected by the central progenitor star during its red giant phase. The bright nebulosity has temperatures between 7,000 and 9,000 K, with densities averaging about 5,000 particles per cubic centimeter. Its outer halo has a higher temperature of around 15,000 K, but it is of much lower density. A fast stellar wind is expanding at 1,180 miles/second, and has hollowed out the inner bubble which has burst at both ends. The current rate of mass loss averages twenty trillion tons of material per second. The binary central star has a spectral type of O7 + Wolf-Rayet type star, and a temperature of about 80,000 K, with a radius of about 0.65 that of the Sun. It is about 10,000 times as luminous as the Sun, and currently is slightly over one solar mass, with a theoretical initial 5 solar masses. The concentric rings were ejected in a series of pulses at 1,500-year intervals while the star was on the asymptotic giant branch, and are evenly spaced indicating regular expulsions. Each 'ring' is actually the edge of a spherical bubble seen projected onto the sky, which is why it appears bright along its outer edge. The pulsations that formed the rings probably started 15,000 years ago, and ceased about 1,000 years ago when the formation of the bright central part began. Low temperature stellar dust is indicated at far-infrared wavelengths, while the Chandra X-ray Observatory revealed extremely hot gas with temperatures 1.7 million K due to the interactions of the fast stellar wind.

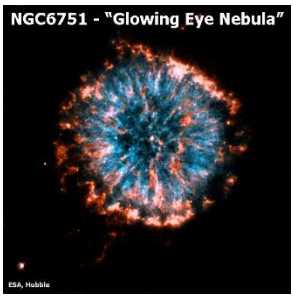


NGC6572 in Ophiuchus is very bright at an 8.1 Vmagnitude, a good indication that this is a very young planetary nebula which began to shed its gasses only a few thousand years ago. Its brightness also shows the material is concentrated and its gaseous envelope is currently expanding into space at 9.3 miles per second. The central star has a spectral type of Of-WR(H) and is responsible for highly collimated bipolar outflows. A strong interaction between the collimated outflows and the elliptical nebular shell creates a double point-symmetric structure. As a consequence of this interaction, the elliptical shell has been broken up, and parts of the shell have been accelerated, while the collimated outflows have been slowed down and/or deflected. At the given expansion velocity, a distance of 1.2 kpc or 3,912 light years has been determined. Distances to galactic planetary nebulae have been difficult to accurately constrain and this expansion distance has uncertainties ranging from 15% to 30%. Images of NGC 6572 show a limb brightened inner region surrounded by a more diffuse, egg-shaped nebula. Three different interacting winds have been involved in the formation of NGC6572. A slow wind from the red giant progenitor first produced a dense equatorial zone, which was followed by a second fast wind from the central star. This interacted with the slow wind, and the interaction between the fast wind and the anisotropic slow wind resulted in the formation of an elongated highly ionized shell. Finally, a third, collimated bipolar outflow wind determined the observed point symmetry and the peculiar kinematics of the shell.

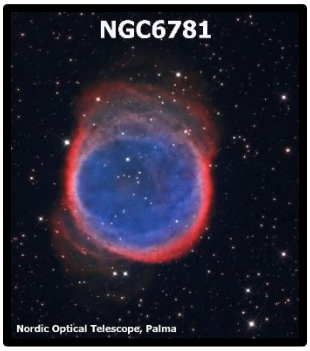


Minkowski 1-64 is a beautiful 13th-magnitude planetary nebula, and is a classic ring-like or annular planetary which looks like a perfect "donut" with a hole in the central region. It is an elliptical planetary nebula, and is located inside the "rectangle" of Lyra and near its much more famous member Messier 57, the "Ring Nebula". Thus, M 1-64 is often overshadowed and overlooked by its more famous 'ring'. The distance to M 1-64 has been widely estimated depending upon the analysts and the analysis method used. Estimates have ranged from 12,975 light years (3.98 kpc) to 35,000 light years, with the most recent at 19,560 light years (6.00 kpc, Phillips, 2004). All of these distances are much farther than the distance to Messier 57 which is a mere 2,300 light years. The magnitude of its central star is unknown, but a 15th magnitude star is located on the north edge of the large and faint 36 arcminutes diameter halo. The halo is extended which is due to an earlier emission of relatively slow-moving material ejected when the star was in the red giant or asymptotic giant branch phase in its evolution. Mi 1-64 is easily visible in an 8-inch telescope as a round disk

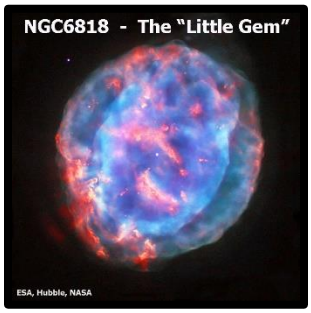
with a uniform brightness and well-defined edges, with the star situated on the northern edge of the nebula. Slightly larger instruments hint at the ring structure and the bright knot located on the northeastern side of the ring.



NGC6751, also known as the **Glowing Eye Nebula**, is a complex highly structured multiple-shell planetary nebula with a bipolar 19.0-mile s^{-1} outflow, estimated to be about 6,500 light years away. The eastern side of the nebula is nearer than the western side. The thick equatorial structure is fragmented into multiple knots that enclose a fast-expanding bubble with a filamentary surface structure. The knotty ring is surrounded by faint emission from a disk-like envelope. Lobes with embedded filaments form a bipolar outflow. The equatorial ring is tilted with respect to the line of sight and with respect to the bipolar outflow. A spherical faint broken halo surrounds the nebula and there is material further out at a radius of 50 arcseconds, identified as a fragmented outer halo. The inner bubble is bright and surrounded by the two fainter halos. An extended filamentary nebulosity is seen approximately 2 arcminutes to the northeast of NGC6751 and is tentatively identified as part of a halo. The central star has Wolf-Rayet characteristics (spectral type [WC4]) with a temperature of 140,000 K, and a radius of 0.13 $R_{\odot}$. It is losing mass at a rate of 1×10^{-6} $M_{\odot}$ yr^{-1}, and its surface composition is mostly helium and carbon, indicating its progenitor was slightly more massive than the Sun, and possibly had a late thermal pulse event. NGC6751 is approaching the Solar System with a heliocentric radial velocity of −23 miles per second.

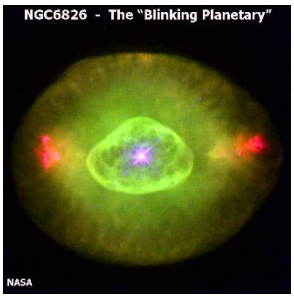


NGC6781 is a prominent visual planetary nebula located 1,500 light years from the Sun. It has a visual magnitude of 11.4 and spans an angular size of 1.9 × 1.8 arcminutes. We are viewing the nebula from a near pole-on orientation, inclined at ~23° to the line of sight with its south side pointed toward Earth. The inner diameter of the barrel shaped spherical cylinder is 108 arcseconds while the outer diameter of the nebula, including the lobes, is 122 arcseconds, equivalent to a physical radius of 0.44 light years (0.135 pc). The shell is expanding at 9.3 miles per second (15 km s^{-1}) and the total mass of the shell is estimated at 0.86 MʘThe bipolar dust shell of this nebula is also barrel-shaped and is rich in amorphous carbon, with temperatures ranging from 26 to 40 K. The total mass of gas ejected as the central star passed through its last asymptotic giant branch (AGB) thermal pulse event is 0.41Mʘ, with an estimated dust mass of 1.53 Mʘ. The optical surface brightness of NGC6781 is very low and rather uniform, indicative of its relatively evolved state. The low surface brightness is also because the ring emission is embedded within faint extended lobes that are elongated along the NNW-SSE direction, and we are viewing the ring through the blue-shifted lobe. The central star is a binary, and the energizing member is a white dwarf of magnitude 16.88, with a temperature of 121,000 K but a luminosity of only 385 Lʘ. Originally the white dwarf star had an estimated mass of ~2.25 – 3.0 Mʘ, but has been depleted to a mass of 0.60 solar masses. It is currently terminating its planetary nebula evolution stage and passing into the white dwarf cooling track. The star left the AGB and entered the cooling stage around 9,400 years ago, while the red giant branch stellar ejecta has been expanding for 20,000 to 40,000 years. The dwarf's companion is an M-type co-moving star at a projected separation of less than 5,000 AU.



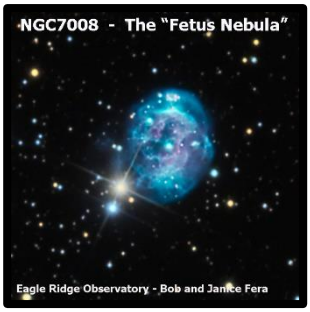
NGC6818, or **the "Little Gem Nebula"**, is an elliptical shaped planetary nebula roughly 5,550 light years away from Earth, but has published distances from 4,250 to 6,500 light years. It was discovered by Sir William Herschel during his "sweeps" of the heavens in 1787. It is located only 40 arcminutes to the northwest of Barnard's Galaxy, NGC6822. The structure is bright at a visual magnitude of 9.3, with a slightly oval diameter of 15 by 22 arcseconds. Its brightest parts are located toward the central regions, and the glow of the nebula is just over half a light-year across. NGC6818 has knotty filament-like structures and distinct layers of material, with a bright and enclosed elongated central bubble surrounded by a larger, more diffuse cloud. NGC6818 is a very young planetary nebula only 3,500 ± 400 years of age, and is optically thin with a double shell of material of about 0.13 Mʘ which surrounds a very hot central star at 145,000 K. The star has a very low luminosity of only ~3.1 Lʘ, which is an indicator the initial mass of the star was low. NGC6818 is located 18° from the galactic plane which is relatively distant, and another indication the progenitor was a low mass star. The stellar mass of the primary central star is relatively large at about 0.625 Mʘ, when compared to other planetary nebulae. The central star is a visual binary with the primary having an estimated Vmagnitude from 15.0 to 17.06 ± 0.05. A faint red companion of Vmag. 17.73 ± 0.05 is located 0.093 arc-seconds to the south (PA = 190°) of the primary. This

corresponds to a separation of ≥ 150 AU resulting in an orbital period of ≥ 1,500 years. NGC6818 is at the start of the recombination phase following the luminosity decline of the central star, which has recently exhausted the hydrogen shell nuclear burning and is rapidly moving toward the white dwarf domain on the classic HR Diagram. The nebula is destined to become thicker and thicker, with an increasing fraction of neutral, dusty gas in the outermost layers as the evolutionary decline continues.



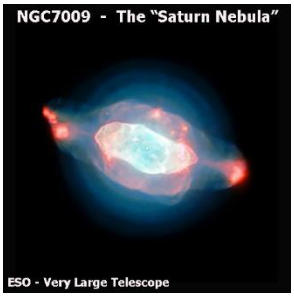
NGC6826 is commonly referred to as the '**Blinking Planetary**" although many other nebulae exhibit such "blinking" capabilities. When viewed through a small telescope, the brightness of the central star overwhelms the eye when viewed directly, obscuring the surrounding nebula. However, the nebula can be easily viewed using averted vision, which causes it to "blink" in and out of view as the observer's eye wanders from the star to the nebula and back. NGC6826 is 3,590 light years distant and has a bright inner ring with dimensions 12.7 × 8.7 arcseconds and an outer ring of 36 × 36 arcseconds. A fainter halo surrounds both structures with a diameter of 142 arcseconds. The inner ring is formed by a fast wind slamming into the earlier expelled slow-wind material, producing a hot interior bubble which pushes the older gas ahead of it to form a bright rim. The central star of NGC6826 is an O-type star with a spectral type of O6fp. It has an effective temperature of 50,000 K and a Vmagnitude of 10.41, with variability timescales of 3.8 ± 1.7 hours. This variability could be due to the rotation of the star, a companion star, or shifting dust clouds in the atmosphere. A distinctive feature of NGC6826 are the two bright fast low-ionization emission regions (FLIERs), or ANSAE on either side of the nebula. The two bright FLIERs appear to be relatively young and are moving outward at supersonic speeds. Their shapes suggest that material ejected from the star flows past them as fast winds. Terminal velocities of the winds have been estimated to be in the range of a thousand km s^{-1} or 621 miles s^{-1}.

NGC 6905, also known as the **Blue Flash Nebula**, is a planetary nebula in Delphinus. It was discovered by William Herschel in 1784. The central star has a Vmagnitude of 14.0 and its distance is not well determined with estimates ranging between 5,540 and 8,475 light years. NGC6905 has an internal shell with angular dimensions of 47 × 34 arcseconds and roughly conical extensions, with a total gas mass between 0.31 $M\odot$ and 0.47 $M\odot$. FLIERS or ANSAE-type formations are located along the major axis, and are particularly intense. NGC6905 belongs to a small group of very high excitation planetary nebulae that exhibit very strong emission lines of OVI near λλ3811Å, 3834Å, the so-called OVI sequence. The nucleus of NGC6905 possesses one of the broadest ultraviolet OVI emission lines found among all planetary nebulae, and OVIII emission has also been detected in NGC6905. This indicates a very high degree of excitation. The central star, HD193949, has a spectral type of [WO2], meaning it has a spectrum similar to Wolf–Rayet stars and is rich in oxygen. It is estimated to have a very hot surface temperature of 150,000 K, which produces the excitation. The spectrum also shows signs of neon emission lines (Ne VII and Ne VIII). Currently the central star has 0.31 to 0.47 times the mass of the Sun, but before becoming a planetary nebula it had a mass of about 1.07 M⊙. An analysis of *Gaia* data suggests that the central star may be a binary system.

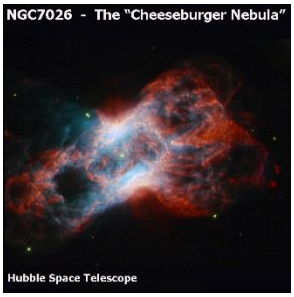


NGC7008 (PK 93+5.2), or the **Fetus Nebula,** is an elliptical planetary nebula with an apparent size of 1.4 x 1.1 arcminutes, which approximates an actual size of 1 light-year. It is a complex gas-filled structure located 2,800 to 4,250 light years away, and is found in northern Cygnus. Its stated magnitude varies from around 9 to 12, which is typical of many planetary nebulae. The nebula visually has a distinct hook-shape with the hook oriented north and south. There are two elongated shells of expanding gas, one inside the other, with the inner shell expanding at a faster rate (2X) than the outer shell. This causes a snow plow effect where the internal fast wind plows into the slower moving RGB or AGB expulsion material. The 13.23 V mag type O7.O(H) central star is offset and lies slightly to the west of center of the nebula. NGC7008 is a very dusty nebula with dust temperatures measured from 95 K to 146K, and a total mass of 6.6 x 10^{-2} MΘ. Its Mgas / Mdust ratio of around 59 indicates the gas-to-dust ratio in NGC7008 is significantly lower than the average value of 160 for the interstellar medium, which hints at a significant dust enrichment for NGC7008. Visually NGC7008 shows a lot of detail, especially when a nebular filter is employed, and besides the central star three areas

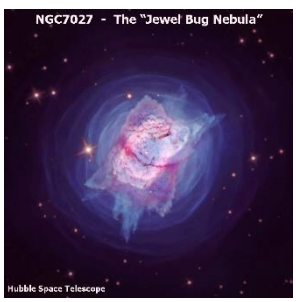
stand out. ***Condensation A*** is the bright roundish knot K 4-44 located 22 arcseconds NW of the central star. It has been classified in the past as a distinct planetary nebula (K4-44, 93+ 5°1), but is only an internal knot. ***Condensation B*** is an oval of 11 x 8 arcseconds located 40 arcseconds north of the central star. ***Condensation C*** is a roundish knot 3 arcseconds in diameter although it appears larger and much fainter than A and B, and it lies 35 arcseconds SW of the central star. These are parts of the nebula visible in [N II] λ6584 Å light. Condensations A and B are expanding with the velocity of the shells, so there is no doubt they are part of the nebula.



NGC7009 or The **Saturn Nebula** is a planetary nebula located 1 degree west of the star Nu Aquarii. It was discovered by William Herschel on September 7, 1782. The Saturn Nebula was named by Lord Rosse in the 1840s and gets its name from its resemblance to the planet Saturn with its rings nearly edge-on to the observer. The distance to NGC7009 is not known precisely but estimates range from 3,750 to 6,520 light years, with a diameter of 0.5 light years for the entire object. Its radial velocity of -28 miles per second means it is moving toward the Earth. The Saturn Nebula is a complex object and contains many sub-systems in three dimensions, including a halo, jet-like streams, multiple shells, ansae ("handles"), and small-scale filaments and knots. The central region measures 25 × 17 arcseconds, while the outer shell extends to 41 × 35 arcseconds. The ansae are expanding from the central star and represent one of the earliest episodic expulsions of material from the star. The central star is a very hot bluish dwarf with a temperature of 82,000 K, a visual magnitude of 11.5 but a luminosity of only 20. Visually the nebula appears as a greenish-yellowish hue in amateur telescopes. The strong ultraviolet radiation from the central star creates doubly ionized oxygen [O III], which emits this characteristic fluorescent green tint.



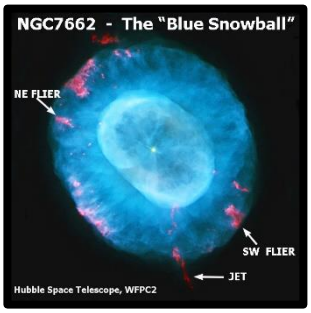
NGC7026 or The **Cheeseburger Nebula** is a well-studied and highly ionized complex bipolar object, which is also one of the most peculiar planetary nebulae. It is located at an estimated distance of 6,800 light years, with an age of approximately 15,000 years. The central star has a Vmagnitude of 14.2 and an estimated temperature of 80,000K to 130,000K, with a luminosity 2,100 times that of the Sun. The central star is a hydrogen deficient Wolf-Rayet type star with strong carbon emission lines (WC3). The illuminating central star is probably a dwarf in a binary star system, which once was a massive object, but this is yet to be proven. The terminal wind velocity has been measured at 2,175 miles per second so this is a highly energetic object. As with many planetaries, shock heated gas is produced when the fast wind collides or plows into the dense slow-moving wind produced when the star was in the asymptotic giant branch (AGB) stage. The present core mass of the star is 0.56 solar and it is estimated the parent star would have originally had a mass just over 1.1 times that of the Sun. The strongly ionized nebula indicates a moderately evolved planetary nebula. There are four separate outflows of material and a central spherical shell. The bipolar structure is still in the early stages of formation. Diffuse X-ray emissions are all confined to the bipolar lobes, which reveal a plasma temperature of 1.1 million degrees K. The main symmetry of NGC7026 is nearly north-south with the northern lobe slightly more compact, reaching a distance of 27 arcseconds away from the central star. The northern lobe points away from the Earth, while the southern lobe is blueshifted. However, the lobes appear to be split into four major sections, northwest, southwest, northeast, and southeast. There is a gap in the visually faint southeast lobe which is open ended and blown out while the other lobes appear to be closed.



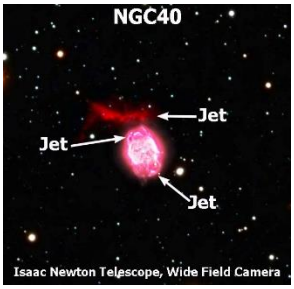
NGC7027 or The **Jewel Bug Nebula** is a planetary nebula with one of the hottest central stars known, and a bright surrounding nebula which is very dusty and young. Until recently, astronomers were unsure how to classify NGC7027 as they could not locate the central star. This was because of the massive amounts of dust present which completely hid the central star, plus the central star is extremely hot and radiating mostly in ultraviolet light. NGC7027 has a post asymptotic giant branch (AGB) age of only 600 – 1,200 years, and the distance has been approximated from 2,900 to 3,260 light years (1 kpc). Visually NGC7027 is an elongated ellipsoidal shell which is tilted 30° to the line of sight. NGC7027 is not only very young, but it is small in apparent size at only 0.22 light years. The nebula is multi-lobed and rich in carbon, so the large amount of dust present is carbon dust. Dust at 130 K is present within the central cavity and in the northwest (∼100 K) and southeast (∼90 K) regions. The binary central star has a separation of approximately 1 au. The

progenitor was a massive star of 3 - 4 solar masses, and has lost a considerable amount of material as it has a present-day mass of ~0.6 – 0.7 MΘ, which is a relatively high mass for a planetary nebula, but NGC7027 is young. The irradiating star is an extremely hot white dwarf star of over 200,000 K, with an estimated luminosity of 6,200 LΘ, with estimates ranging from 5.5 x 10^3 – 2 x 10^4 LΘ. At this temperature, the vast majority of the energy is in the ultraviolet. A very thick accretion disk around the white dwarf has been proposed as one reason for such a high stellar temperature. The stellar mass loss rate has been computed at less than 5 X 10^{-7} MΘ yr^{-1}, which is consistent with mass loss rates in other planetary nebulae central stars. However no stellar wind from the central star in NGC7027 has yet been detected, which is very unusual for a central star with the hot temperature measured. The compact central region is approximately 10 arcseconds in diameter and is very bright in visual, infrared and radio wavelengths.

NGC7293 or the **Helix Nebula** is one of the closest of all the bright planetary nebulae to Earth. The distance, measured by the *Gaia* mission, is only 655±13 light-years so the nebula visually is huge, with an age estimated to be 10,600 years. The age is based on the ratio of its size to its measured expansion rate of 19.3 miles s^{-1} (31 km·s^{-1}). The Helix Nebula is shaped like a prolate spheroid (Football Shaped) with strong density concentrations toward the filled disk along the central star's equatorial plane. The major axis is inclined about 21° to 37° from our vantage point. The size of the inner disk is 8 × 19 arcminutes or 1.7 light years, while the outer torus is 12 × 22 arcminutes in size, which equates to a diameter of 2.5 light years. The outer-most ring or halo is about 25 arcmin in size or 5.7 light years in diameter, and appears flattened on one side due to it colliding with the ambient interstellar medium. The expansion of the outer halo began about 12,100 years ago at a rate of 20 miles s^{-1} while the inner disk has been expanding for 6,560 years at a rate of 29 miles s^{-1}. The Helix Nebula was the first planetary nebula discovered to contain cometary knots of nebulosity which are found in the main ring. These features have now been detected in several nearby planetary nebulae. These knots are radially symmetric from the central star and are "cometary" in appearance. Each is centered on a core of neutral molecular gas and contains bright local photoionization fronts or cusps towards the central star with tails pointed away from it. Excluding the tails, each knot is approximately the size of the solar system and there are about 40,000 cometary knots in the Helix Nebula. NGC7293 truly is a huge object.



NGC7662 or the **Blue Snowball** is a visually bright, early planetary nebula with a Vmagnitude of 8.3 which spans an angular size of 32 x 28 arcseconds. Velocity factors yield a distance of 3,880 light years while parallax measurements result in 6,450 light years. The nebula has an overall elliptical shape composed of a triple-shell structure. The inner main thick shell is the brightest with a 12 x 18 arcsecond size, and this is surrounded by a fainter elliptical shaped shell. Both shells are enclosed by a faint, circular halo, about 134 arcseconds in diameter. The two shells are prolate (football shaped) spheroids, with the inner shell having the greater elongation. The major axis is tilted 50° to the line of sight, with a hull thickness of ~2.5 arcseconds. About 10% of all planetary nebulae contain low ionization structures (LIS), and NGC7662 contains several of these features, which are distributed along the outer edge of the outer shell. These low ionization structures are broken into two classifications. FLIERS or Fast Low-Ionization Emission Regions have radial velocities of 15 – 125 miles s^{-1} (24-200 km s^{-1}) with respect to the PN main components. SLOWERS or Slow-Moving Low-Ionization Emission Regions do not show peculiar velocities and share typical 19 miles s^{-1} (30 km s^{-1}) slow moving low-ionization emission regions. Several SLOWER knots and a pair of FLIERS are found in the outer regions of NGC7662, along with a jet-like structure extending toward the south. These are all are low ionization emission line structures. The FLIERS of NGC7662 are less dense than the inner regions of the nebula, but they are at the same time much denser than the outer shell in which they are located. Based on the expansion rate, the estimated age of NGC7662 is 3,080 years. The central star of NGC7662 is a subdwarf O-type star with a spectral type of sdO. It has an effective temperature variously measured at 95,000 K to 113,190 K, with 5,250 times the luminosity of the Sun and 57% - 61.5% of the Sun's mass. X-ray emission from the nebula is being generated by the stellar wind from this star striking previously ejected matter.



NGC40 or **the "Bow-Tie Nebula**" is 3,500 light years away and has ejected its outer layer resulting in a diameter of about one light-year. The nebula will fade away in about 30,000 years, leaving only a white dwarf star approximately the size of Earth. NGC40 has a barrel shaped main cavity with the long axis pointing towards the north-northeast. A set of optical and infrared concentric filamentary rings surround the main cavity disclosing the last gasps in the asymptotic giant branch (AGB) of the central star of NGC 40, HD 826. The filamentary structure suggests the nebula is interacting with the interstellar medium (ISM) due to its relatively high velocity. The northern and southern caps open into a set of lobes or blisters which are sometimes associated with jets. However, there is no kinematical evidence of fast outflows. There are two additional pairs of lobes around the poles, which correspond to additional ejections from the star. The central star HD 826, is hydrogen deficient and has a surface temperature of about 71,000 K, and a spectral type of [WC8], indicating a spectrum similar to that of a carbon-rich Wolf–Rayet star. The nebula exhibits a large C/O ratio, as derived from abundance determinations based on collisionally excited lines. This is in line with the carbon-rich [WC8]-type of its star.

Messier 76, NGC650-1, The Little Dumbbell Nebula is the archetypical example of a bipolar planetary nebula (PN) with butterfly morphology, and is located only 3,030 – 3,912 light years away. It was discovered in 1780 by P. Mechain and recorded the same year by C. Messier, but it was William Herschel in 1787 who noticed that the nebula had two lobes, barely separated. This led to the assignment of the two NGC numbers by J. Dreyer. The morphology of NGC 650-1 is similar to a butterfly-shaped pattern, with a thick equatorial waist or torus observed almost edge-on ('the butterfly body') and two broad bipolar lobes ('the butterfly wings'). The overall nebula diameter is a large 300 arcseconds. Narrow-band imaging shows knots and filaments of material in the core region which is 100 X 40 arcseconds and rectangular shaped. The torus has a clumpy inner structure which is probably produced by dust, and is expanding at a velocity of 27 miles per second. It is inclined at an angle of 75° with respect to the line of sight, while the bipolar lobes which are clearly seen are inclined 85°. Visually the nebula has a central elliptical ring which is seen nearly edge-on, with two half shells consisting of inner and outer lobes, which extend ~90 and ~150 arcseconds from the central star. The NW lobe extends toward the observer and the SE lobe extends away. The bright semicircular lobes are expanding at 37 miles s^{-1} while the fainter outer shell maintains a low expansion velocity of only ~3.1 miles s^{-1} (5 km s^{-1}) and carries the spectral photometric characteristics of the central star. The central star has a Vmagnitude of 17.48 and is very hot at 140,000 K although one estimate rates it as high as 208,000 K, with a luminosity LʘO = 261. Large field of view deep images show an arc-like diffuse envelope in low- and high-excitation emission lines located up to 180 arcseconds towards the east–south-east of the central star, which is well outside of the main nebula. CO molecular emission is not detected although NGC650-1 is a carbon-rich (C/O > 2) nebula. The carbon dust grains in the ionized nebula are large and would have diameters of 0.30 µm. Most likely these large grains were inherited from the asymptotic giant branch (AGB) phase.

IC1747 in Cassiopeia is a very bright member of a small group of high excitation objects known as the "O VI Sequence". These planetary nebulae are identified by the O VI emission lines at λλ3811Å, 3834Å in the spectra of their central stars and belong to the highest excitation class of planetary nebulae. Optical and ultraviolet emission lines of O VII and O VIII have also been observed, but these lines are thought to be excited by shocks since the central stars are not hot enough to ionize O VIII, whose ionization potential is 871 eV. IC1747 has an angular diameter of 13 arcseconds with a magnitude of 13.6 (P). The Wolf-Rayet type central star has a Vmagnitude of 15.4 and IC1747 is 7,825 light years from the Sun.

Good Luck - Clear and Steady Skies,

LARRY MITCHELL - EILEEN MYERS

Stellafane Observing Olympics - 2023