Highlights of the April Sky. . .

- - - 1st - - -

DUSK: A waxing crescent Moon is 1½° above the Pleiades.

- - - 2nd - - -

DUSK: The Moon is 4½° to the upper right of Jupiter.

- - - 4th - - -

First Quarter Moon @ 10:15 pm EDT

- - - 5th - - -

DUSK: A waxing gibbous Moon, Mars, and Pollux form a right triangle.

- - - 7th - - -

DUSK: The Moon is about 6° above Regulus, the heart of Leo the Lion.

- - - 12th - - -

Full Moon @ 8:22 pm EDT

DUSK: Only ½° separate the Moon and Spica, in Virgo, when they rise in the east-southeast before 9:00 pm EDT.

- - - 17th - - -

AM: A waning gibbous Moon is about 4½° to the lower left of Antares.

- - - 20th - - -

Last Quarter Moon @ 9:36 pm EDT

- - - 22nd - - -

AM: The Lyrid meteor shower is predicted to peak.

- - - 24th - - -

DAWN: Venus is about 4° to the upper left of Saturn. A waning crescent Moon is 10° to the pairing's right.

- - - 25th - - -

DAWN: The Moon, Venus, and Saturn form a triangle low in the east.

- - - 25th - - -

New Moon @ 3:31 pm EDT

- - - 28th - - -

DUSK: A sliver of a waxing crescent Moon is just over 4° to the lower right of the Pleiades low in the WNW.

- - - 30th - - -

DUSK: The Moon is nearly 6½° above Jupiter.

Prime Focus

A Publication of the Kalamazoo Astronomical Society

★ ★ ★ April 2025 ★ ★ ★

This Month's KAS Events

General Meeting: Friday, April 4 @ 7:00 pm

Kalamazoo Area Math & Science Center • See Page 24 for Details

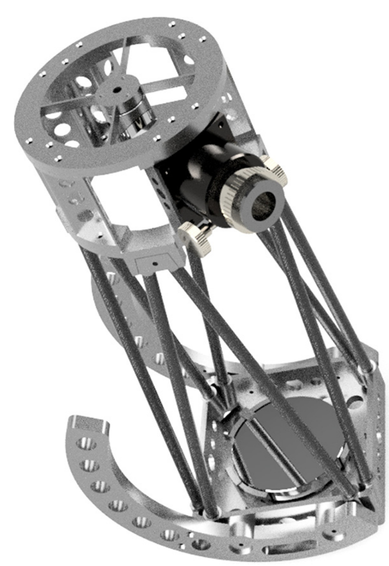
Observing Session: Saturday, April 5 @ 8:00 pm

Kalamazoo Nature Center • Visit Observing Page for Details

Observing Session: Saturday, April 19 @ 8:00 pm

Kalamazoo Nature Center • Visit Observing Page for Details

Inside the Newsletter. . .

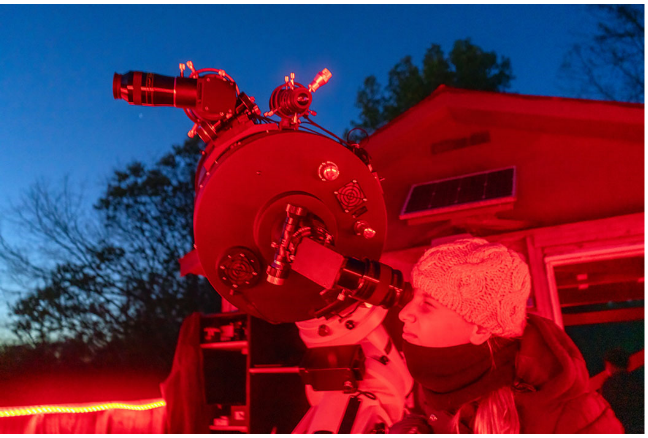


Observations by Richard S. Bell

What an absolute gift to have (mostly) clear skies on the morning of March 14th (Pi Day!) for the total lunar eclipse. It was a pleasant surprise to actually be able to hold a Total Lunar Eclipse Watch at the Nature Center. Our last two attempts were unsuccessful. We got clouded out in May 2022, and the bitterly cold night in January 2019 forced us to cancel despite clear skies. On March 14th, the temperature was undoubtedly tolerable, and the eclipse was always visible despite the minimal amount of occasional cloud cover.

Only a handful of members brought telescopes or binoculars to share. Matt Borton shared views through his refractor and took images with his Celestron 11-inch Schmidt Cassegrain. Tim Kurtz set up his 20×80 binoculars and took images with a Sigma 150-600mm lens (set at 600mm) on a Sky-Watcher Star Adventurer GTi mount. I brought my Stellarvue 130mm refractor and shared the latest eclipse images as they came in on my laptop. Members and the public could also enjoy views of the eclipse through the 16-inch Leonard James Ashby telescope and 4-inch Tele Vue refractor (Nona) in Owl Observatory. Thanks to Don Stilwell for operating the observatory telescopes. It's difficult to say exactly how many people attended, but the area around the observatory was so filled with viewers that a couple of groups set up on either side of me across the dirt road.

At first, I didn't think very many people were going to attend by the time the event officially started at 11pm. People started showing up closer to midnight, and we even saw some cars drive in at 1:15 am! Normally, when people arrive that late to a regular session, I tell them they may as well turn around and go home as we're about to leave! By 4am, everyone had left except for me. I started packing up shortly after 5am and was in bed about an hour later.



We very likely won't hold an event for the lunar eclipse on Tuesday, March 3, 2026, since totality doesn't begin until 6:04 am and ends at 7:03 am! Thereafter, our next chance to see the Moon plunge into Earth's inner shadow isn't until June 2029. Special thanks to all the members who submitted lunar eclipse images. I managed to squeeze in one image (or one composite) from each person who sent me something. Please enjoy them starting on page 11.

Now that our renewal period is over, I've published another membership list in this issue starting on page 16. Notice the membership level is 317; it was at an all-time high of 378 at the end of 2024. In all, we lost 75 memberships. That's very likely the largest one-year loss in KAS history. However, the club has never been as big as it was in 2024. This drop isn't surprising and shows that most people are getting back to normal as we get further away from the pandemic.

Some people said they did not renew because they're too busy with family, work, etc. How is that any different from when they first joined? *Everyone* is busy with life stuff, but somehow people find enough time to attend a meeting or join us under a starry sky. It just takes effort and enough enthusiasm. You just have to WANT to do it!

So, make an effort and attend the next general meeting on April 4th and the first Public Observing Session of the season on April 5th (if skies are clear). Our special guest speaker at the meeting is Dr. Nicolle Zellner from Albion College. She's a lively and engaging speaker, so please plan to join us at KAMSC (or on Zoom, if you must) on April 4th.

March Meeting Minutes

KAS President Richard Bell brought the general meeting to order on Friday, March 14, 2025, at 7:05 pm EDT. At least 37 members and guests were in attendance at the Kalamazoo Area Math & Science Center (KAMSC), while about 61 people joined us virtually on Zoom.

Before introducing our featured speaker, Richard gave his President's Report. We still need volunteers for outreach opportunities. These include STEAM Night at St. Michael Lutheran School on Friday, April 11th, from 6 to 8pm and the Rock and Mineral Show at the Expo Center on May 3rd and 4th. We plan to pass around a sign-in sheet for the latter at the April meeting.

We will be starting another fundraiser for the Remote Telescope in the near future. Before the support for Windows 10 ends this October, we need to replace the current computer, which is about 10 years old. We also plan to replace the CCD cameras with CMOS cameras due to their increased sensitivity and reduced noise. Finally, we hope to replace the focuser on the CDK20 with one that has a built-in rotator. All this would cost about $18,000. While this is a substantial amount, it pales in comparison to the $122,000 we initially raised for the Remote Telescope Project.

Finally, Owl Observatory needs a good cleaning before Public Observing Sessions begin again starting April 5th. The planned date is March 22nd, at 1pm. (UPDATE: Thanks to Richard Bell, Pete Mumbower, and Philip Wareham for their assistance getting Owl Observatory all spiffed up.)

The featured speaker of the evening was KAS member and WMU professor of astronomy Dr. Kirk Korista. The title of Kirk's latest presentation for the KAS was *Stars Without Nuclear Fusion: Much of the Physics Without All of the Confusion*.

Instead of the standard summary in the *minutes*, we refer to Kirk's article *Why Do Stars Shine?*, first published in the May 2020 issue of *Prime Focus*. We have republished it in this issue, beginning on page 4, for your convenience. It encompasses a significant portion of Kirk's presentation and surpasses any possible summary here.

Another article by Kirk worth reviewing is in the April 2023 issue. Titled *The Virus of Misconception* (on page 9), it clarifies a misleading answer to a question about stars submitted to *Astronomy* magazine.

Kirk spent part of his presentation discussing the work of Sir Arthur Eddington on stars in the early 1920s. Kirk covered some of that in his presentation, *Sir Arthur Stanley Eddington: With Stars in His Eyes*, at the March 2023 general meeting. The summary of that talk can also be found in the April 2023 issue, and the talk itself can be viewed on YouTube.

Finally, you can watch Kirk's entire talk on *Stars Without Nuclear Fusion* on our YouTube channel.

Special thanks to Mike Dupuis for providing snacks during the break. Pete Mumbower volunteered to bring snacks to the April meeting.

We then unboxed the latest addition to our Equipment for Loan program. The main content of the box was a ZWO Seestar S50 All-in-One Smart Telescope.

As its name suggests, this 50mm triplet apochromatic refractor integrates a telescope, camera, tracking mount, focuser, astronomy filters, and a tabletop tripod into one unit weighing just 5.5 lbs. It can connect to a smartphone or tablet, allowing you to take images of nebulae, galaxies, star clusters, plus the Sun and Moon with only a few taps.

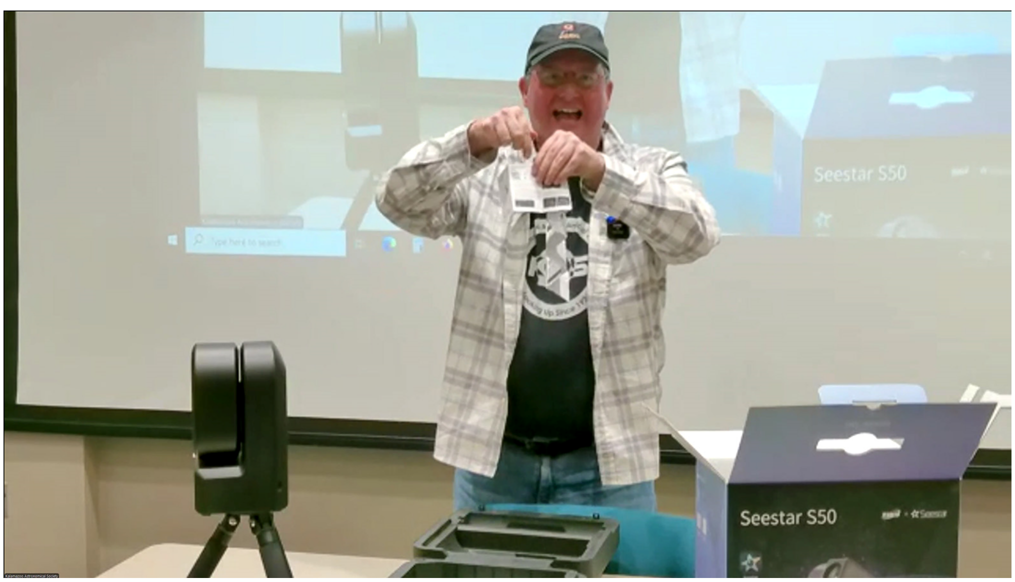
Also included are a Type-C USB cord, solar filter, and case. Additional accessories we purchased are a dust plug, dew shield, and tripod leveling base to use with a Celestron photo/video tripod already owned by the KAS.

We hope to make the Seestar S50 available for loan starting at the April General Meeting. All those that responded to our poll about purchasing the Seestar will get first dibs.

The majority of observing reports focused on the total lunar eclipse that occurred on the day of the meeting. Considering the eclipse took place in the early morning hours, we had decent attendance at the Nature Center.

In astronomical news: Barnard's Star hosts four tiny planets, Firefly Aerospace's Blue Ghost mission captured a total solar eclipse...from the Moon, Saturn now has 274 moons, and NASA's SPHEREx and PUNCH missions launched together on March 11th.

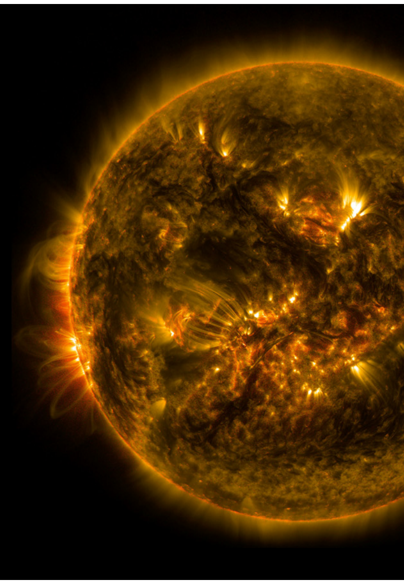
Karen Woodworth reminded everyone about the KAS library. With that, the meeting concluded at 9:11 pm.



Why Do Stars Shine?

Or what is a star and how does it work?

by **Dr. Kirk Korista**



A Beautiful Story—Nearly Lost

Try googling "Why do stars shine?". A common answer in reply usually has the word "fusion" appearing in the first two sentences in addressing that most basic question. Often, it is said that photons emitted in nuclear fusion reactions are the ultimate source of the light the star emits at its surface. Or perhaps you will be informed that the energy generated by fusion is what makes the gases of the star hot—and therefore luminous.

The story of how a star works will then frequently go on to say that fusion provides or exerts the pressure that supports the star against the force of gravity to prevent gravitational collapse. The narrative might then go on to explain where this pressure comes from: that photons emitted in the nuclear fusion reactions exert *radiation pressure*. Or it might hedge a bit and inform the reader that the energy from fusion is what provides the thermal energy content in the gas ("keeps the star hot"), so that the gas can exert the appropriate pressure to oppose the force of gravity. Or it might just say that it is the photons inside a star, origin left unspecified, that exert the pressure to oppose the force of gravity. But that in any case, in the absence of fusion, the star (or perhaps just its central core) loses its ability to exert the pressure needed to oppose gravity and must therefore undergo rapid gravitational collapse.

In the course of painting the story of the lives of stars, a substantial majority of narratives will then inform the reader that once a massive star forms an *iron core*, it is doomed to "collapse under the crush of gravity." It will then go on to explain that iron, having the highest nuclear binding energy per nucleon (i.e., per proton plus neutron number), does not participate in exothermic nuclear reactions: those that release energy into the surrounding gas. Without energy generated by fusion, the poor core can no longer generate the pressure it needs to support itself or the rest of the star above, and so gravity wins and crushes the core in a violent collapse. This is the lead-in narrative to the creation of a neutron star or black hole and of the spectacular stellar explosion called a 'supernova.'

If you're reading this article, it's because you're curious about the universe you live in, and so almost certainly you've read one, many, or all of the above. They should sound familiar. You might have encountered them on internet science/astronomy education sites, *including those sponsored by NASA* or on-line notes from 100- or 300-level university astronomy courses. Or perhaps you've read them in a book or introductory astronomy textbook, or seen and heard them described on an astronomy special on TV. These explanations of what stars are, how they work, and why they shine are ubiquitous.

And they are also *all wrong*.

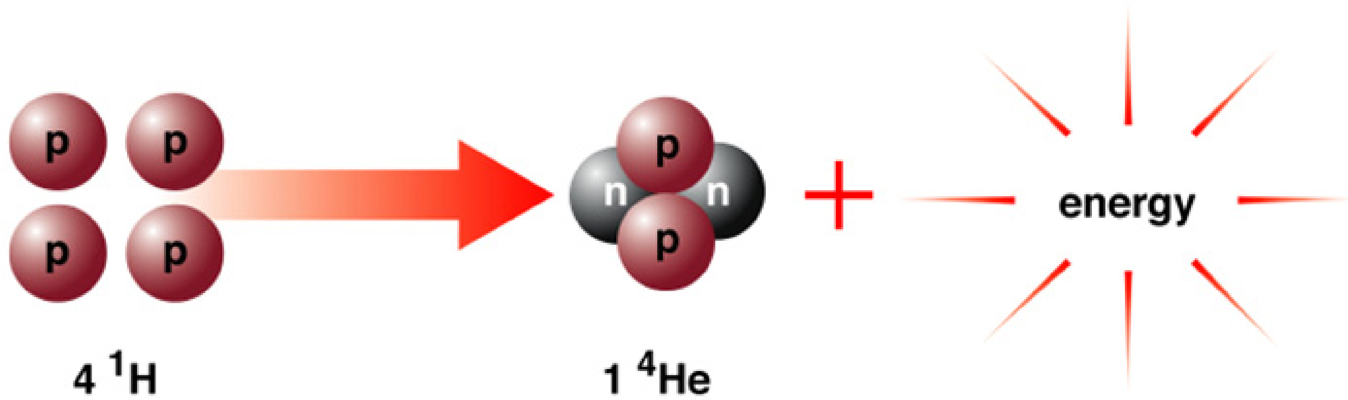
They're not just a little bit wrong, or "technically" wrong. Nor are they merely reasonable simplifications of complex physics to help the non-specialist understand something really cosmic about the universe they inhabit. They are wrong in the sense that these explanations *explain nothing* and even *raise their own conundrums* regarding stars and how they work. These two attributes are polar opposites of the scientific endeavor to understand the world around us and the universe.

I do not know where they all came from, nor do I understand why they continue to be perpetuated. Not all of these fallacies and falsehoods are aerosolized by all educational outlets, but the vast majority spray out at least one of them. Some sources are better than others, some worse, and others are horrible. And I am not even discussing websites that offer crackpot conspiracy theories about stars. Whatever the origins, the internet has been a fantastic vector for the virus of misconception. But sorting out where they came from and when they arose isn't my purpose here.

Mine, here, is to shine some light (*cough*).

Ok, so where to start? Well, let's start with an observation. Look briefly back at that list of misconceptions. Nearly all of them have one thing in common—fusion. *Nuclear fusion has somehow become the answer to all questions about what a star is, how it works, and even how it shines*. But if the above *are not* the roles of nuclear fusion in stars, then what are these roles?

A bit of background on nuclear fusion: Nuclear fusion is the process by which two atomic nuclei *fuse* together under the strong nuclear interaction. If the product atomic nucleus is bound more tightly under the strong nuclear interaction than the reactant nuclei, energy is deposited into the environment via an increase of the particle kinetic energies. Because atomic nuclei contain 1 or more positively charged protons (and often a roughly equal number of neutrons),



they feel a repulsive force upon approach to one another during a collision (“like charges repel”). Only in the centralmost regions of the star (its “core”), where the temperatures and densities are greatest, are the conditions appropriate for collisions of sufficient kinetic energy that a few of the nuclei approach close enough during a collision to “tunnel through” the repulsive barrier to allow the strong nuclear interaction to fuse the colliding nuclei into a heavier element, releasing energy into the environment.

The primary roles of fusion in stars are:

1. Fusion *dumps energy into the star* so that the star doesn't simply slide deeper (*slowly contract)* into the potential energy well of gravity. *If* the rate of energy production by fusion, L_{fusion}, equals the star’s luminous power (its luminosity L_*), the rate at which it dumps energy into space, we say that the star is in *energy balance*. Stars spend most, but not all, of their existence in this state. We’ll discuss this further later in our story.
2. Consequently, the energy released by fusion *slows* the rate of a star's time evolution by roughly a factor of 400. This number is the ratio of the mass-to-energy conversion efficiencies of hydrogen fusion and the conversion of gravitational potential energy into kinetic energy.
3. Fusion transmutes lighter elements into heavier ones. In particular, stars convert hydrogen and helium, the two most abundant elements in the universe (which originated in the high energy-density early universe), into the periodic table. Thermonuclear fusion in stars is the origin of elements up through those near iron ($^{56}_{26}Fe$) on the periodic table, while other nuclear processes in stars account for the remaining elements heavier than iron. All atoms that compose you, planet Earth, and all upon it, with the exception of hydrogen (locked mainly within H_2O and hydrocarbons), were forged in 2-3 generations of stars that lived out their lives prior to the formation of our Sun and solar system, 4.57 billion years ago.

In summary, this transmutation of lighter elements into heavier but fewer-in-number elements and the resulting energy deposited into the star thus slow and change its evolutionary trajectory: stars generally evolve much more slowly to become larger, rather than smaller in size, in the absence of fusion.

Notice that I’ve said nothing about fusion being the origin of the star’s luminosity, nor anything pertaining to fusion supporting the star against the force of gravity. Those are not accidents of omission. Before exploring any further, however, let’s first come up with some defining properties of a star.

A Basic Definition of a Star

A star is a large, massive, dense sphere of *hot*, highly ionized, opaque *gas* (usually composed of mostly hydrogen and helium), held together under the force of gravity between each of its particles and all of the others.

- Unless rapidly rotating or sharing a tight orbit with a sibling star, stars are spherical (1) because they are very massive and so gravity is a dominant force acting between the particles, and (2) due to the simple radial nature of the force of gravity acting between their constituent matter particles. Left alone, gravity would pull all of the matter into a very small volume otherwise known as a black hole.
- Gas is a state of matter in which the average kinetic energy of the particles is far greater than the average interaction energy between the particles (e.g., electrical interactions between charged particles). In “normal” gases, the particle average kinetic energy (energy of motion) is directly proportional to the temperature.
- An ionized gas is one that is sufficiently energetic that most of the electrons are free to move independently of, and so are unattached to, the atomic nuclei.
- *The ionized matter within the star emits particles of light*, known as photons, and this matter emits light in a manner determined by its temperature, also known as thermal or blackbody radiation. Higher temperature matter emits more photons of higher energies and more photons in total per cubic meter of emitting gas.
- Because stars are very dense, they are also highly opaque. The only photons emitted by the ionized gas within the star that can leave the star for the cold

vacuum of space are those emitted in gases within a very thin layer defining the star's luminous surface known as its photosphere ("light sphere"). The total luminous energy emitted into space per second at the star's surface is known as the *star's luminosity*, L_*.

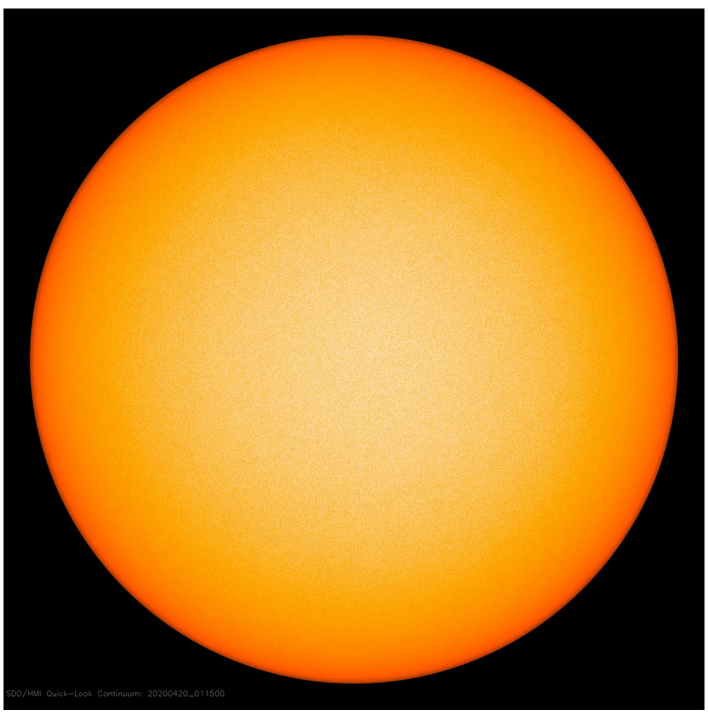
Note that the origin of the light emitted by a star ("Why do stars shine?") lies with the emission of light by its hot gases through electromagnetic interactions; *it has nothing to do with fusion*. Next, we'll learn how stars support themselves against the force of gravity and why it is that they are so hot.

Supporting Stars—It's Gas Pressure!

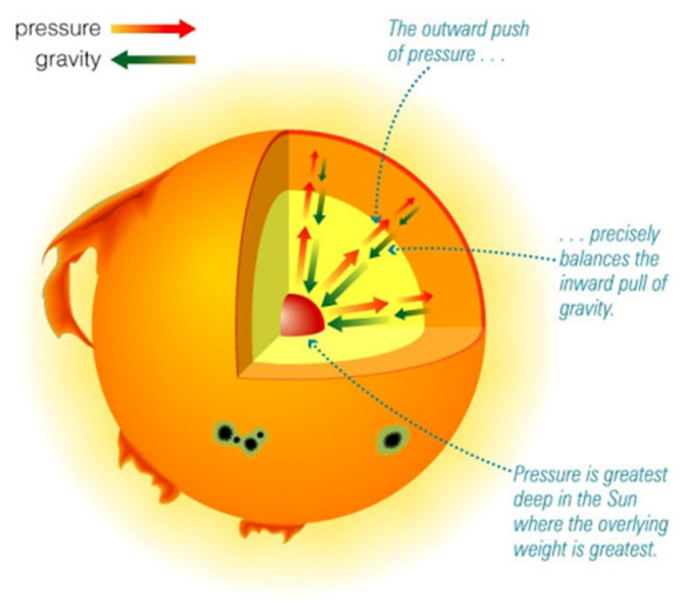
Other than during very temporary special circumstances, a star is in a state known as "hydrostatic equilibrium." This is a technical-sounding name for a phenomenon otherwise known as force balance—that between gravity and forces generated internally within some structure, e.g., within a building, a bridge, *or a star*. Small disturbances to this force balance result in *very rapid* and most often *tiny adjustments in structure*, mediated by the speed of sound within the structure. However, a sufficiently large disturbance can lead to an instability that can grow to a catastrophic failure of force balance, leading either to a *rapid collapse* of the system under its own weight or to an explosion.

In stars, the two opposing agents are *gravity*, which would like to accelerate all of the mass into a tiny point at the center of the distribution, and the *pressure* exerted by the gas within the star. And so this condition is sometimes more colloquially referred to as *pressure-gravity balance*.

Details, details: Within every star, the pressure ex-



The vast majority of the light emitted by a star (above, our Sun) emerges from a thin surface layer known as the photosphere. (The Sun's upper atmosphere, also emits a tiny amount of light, < 0.1% of the total.)



Stars are generally in a state of force balance, often referred to as hydrostatic equilibrium: the inward force of gravity is opposed by a *net outward* push by gas pressure.

erted by the force of gravity (the weight of the overlying layers) diminishes from its center towards its surface, where it is some 12 powers of ten smaller! Within every mass layer at distance r from the center of the star, the pressure exerted by the gas over the surface area of that layer, $4\pi r^2$, must be able to support the weight of the layers above. Or a bit more precisely, the difference in pressure above and below each mass layer multiplied by the surface area of that layer is equal to the weight of that layer. These are the conditions of hydrostatic equilibrium, or "pressure-gravity" balance, usually found throughout a star.

The pressure exerted by gases can usually be described as follows: $P_{gas} = n \times \frac{2}{3}\langle KE \rangle$, where n is the number of gas particles per cubic meter (the particle number density), and $\langle KE \rangle$ is the average kinetic energy per particle, which is usually directly proportional to the temperature T of the gas. Thus, denser, higher-temperature gases exert greater pressures. For this reason, the gas within stars is densest and (generally) hottest at their centers—where the pressure imposed by the force of gravity bearing down is greatest. The gas is therefore coolest and least dense at the luminous surfaces of stars.

If somewhere within a star the gas pressure is set well above its pressure-gravity equilibrium value, a *rapid expansion* will ensue until that mass layer is again in pressure-gravity balance. Likewise, if the gas pressure is set to a value well below its equilibrium point, a *rapid collapse* will ensue until pressure-gravity balance is re-established. If Dr. Evil turned on his ray gun and dramatically reduced the gas pressure within our Sun, the Sun would collapse under the force of gravity into a very small object in about 25 minutes!

The *more massive* a star, the *higher* their average temperatures must be and the *lower* their average densities

must be in order to meet the conditions of *pressure-gravity balance* involving a "normal" gas. Stars are composed of *very hot gases* because their high masses, through the force of gravity, demand this to be so in order to be in pressure-gravity balance. Being much less massive than stars, planets (or the bulk of their masses) are not composed of matter in a gaseous state and are never as hot as stars. Due to their finite temperatures, planets emit light (contrary to some claims) primarily in the infrared, in addition to reflecting light from their parent star. Stars, by contrast, are both hotter and larger in size than planets and are therefore far more luminous than planets.

To sum up: Stars shine so brightly because they are large, hot balls of matter in pressure-gravity balance emitting thermal radiation!

But what about radiation pressure?

As mentioned previously, the hot gases within a star emit particles of light called photons, and each photon has an energy and momentum associated with it. As such, photons can exert a pressure on the matter with which they interact via absorption, scattering, and re-emission. This form of pressure is known as "radiation pressure" and depends simply upon the temperature of the gas, $P_{rad} \propto T^4$. In most stars, radiation pressure contributes very little to the total pressure exerted within a star, despite unsubstantiated claims to the contrary. In our Sun, it's about 1 part in 1500 (teachers of science: just do the math!). And the photons involved in this pressure are those emitted by the local gases—again, nothing to do with photons emitted in some fusion reactions.

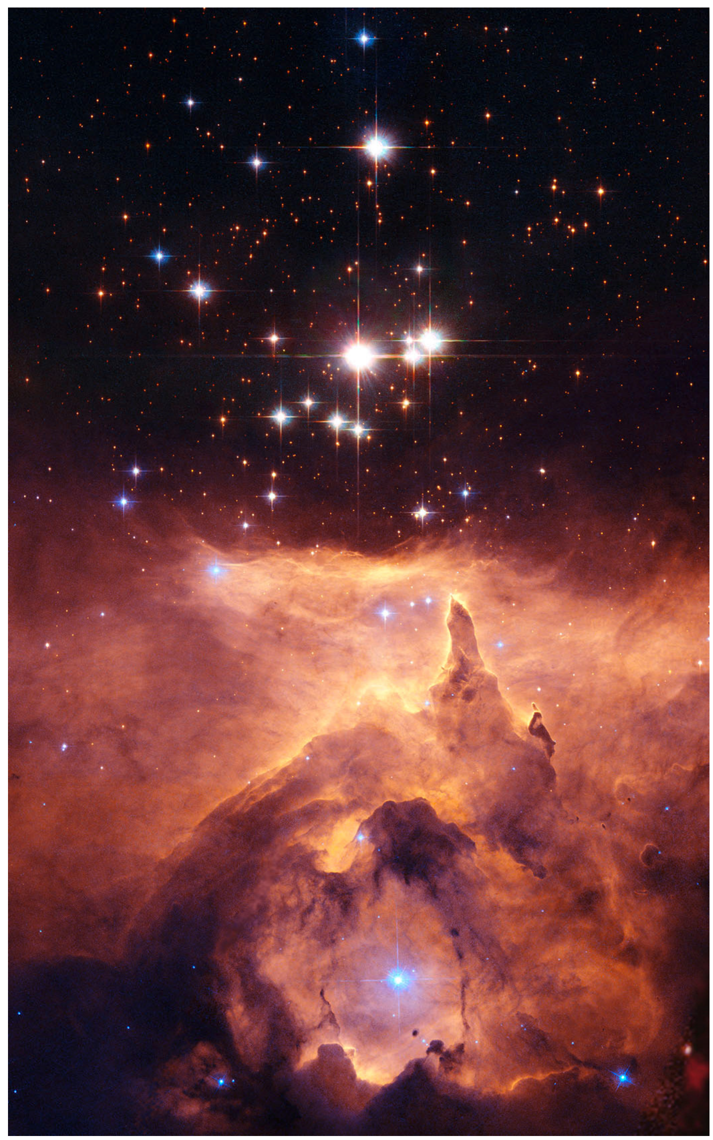
The contribution of radiation pressure to the total pressure does become significant in massive stars—they are hotter and less dense, favoring photons over matter particles in exerting pressure. But only in the most massive stars does P_{rad} begin to compete with P_{gas}, and it is this very fact that helps set an upper limit to the masses of stars (~150 solar masses). As P_{rad} becomes an appreciable fraction of P_{gas} within a particular star, the star becomes ever less tightly bound by the force of gravity. Thus the role of radiation pressure is irrelevant in most stars, and to the extent it is relevant in massive stars, its role is to act toward destabilizing the star—to push it apart!

To sum up: In massive stars, radiation pressure is better described as a disruptor, not a supporter of stars against the force of gravity, and in all other stars, it is largely irrelevant.

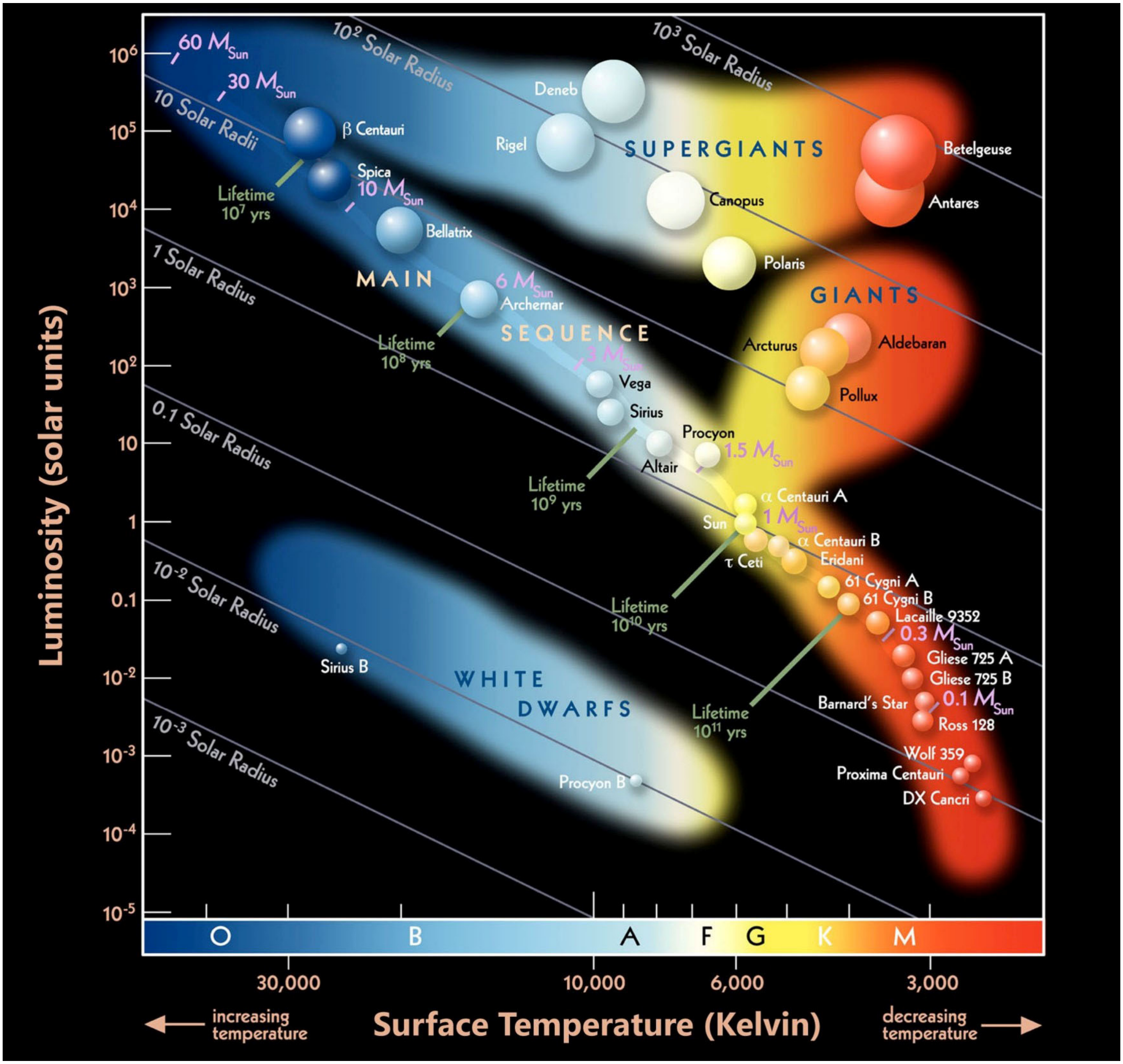
How *do* stars become so hot?

The story of star formation begins with an external pressure disturbance of a giant molecular cloud orbiting within a galaxy, consisting of, as the name implies, mainly molecular gases (e.g., H_2, H_2O, CO, CO_2, etc.) plus helium, as well as condensed solids, often called dust grains. These are the densest (~10^{11} molecules per m^3, which is yet a profound laboratory vacuum) and coldest (T = 10 - 30 Kelvin) gas clouds in any galaxy and, as such, exert the strongest gravitational field and weakest gas pressure (given its density). A spatially large external pressure disturbance destabilizes a portion of the cloud, and it undergoes rapid gravitational *collapse*. That collapse fragments into a fine spray of 100s or 1000s of collapsing globules, each of which is eventually to become a star or two. As in any fragmentation process (smashing a cookie on a table), a lot more low-mass globules arise than high-mass ones. As the collapse within a globule proceeds, the density of the gas increases, and potential energy of gravity is converted into various forms of kinetic energy. (This presented story of star formation is a greatly simplified, yet hopefully useful, overview of a complex process, which isn't yet entirely understood.)

As the density becomes high enough for the globule to become opaque to photons emitted by the gas, the gas temperatures rise dramatically—and eventually, a *proto-star stabilizes in pressure-gravity balance*. Initially the proto-star's central temperature is about 150,000 K, its mean tem-



Stars form within giant molecular clouds of dust and gas when dense cores become unstable and collapse under the influence of their own gravity. Pictures above is the emission nebula NGC 6357 in Scorpius with the open cluster Pismis 24, as imaged by the Hubble Space Telescope in 2006.



The Hertzsprung-Russell Diagram of stars plots the star's luminosity vs. its surface temperature. Stars spend 80-90% of their lives on the main sequence (the diagonal band) fusing hydrogen into helium. Giants and Supergiants are stars in old age.

perature about 80,000 K, the surface temperature is approximately 4000 K, and the proto-star of mass M has a radius $R \approx 50\ (M/M_{sun})$ in units of our Sun's present radius. (For comparison, our Sun's central and mean temperatures are 100× higher, its surface temperature is 50% higher, and its size is 50× smaller.) Fusion involving hydrogen isn't possible until the core temperatures rise above ~2 million Kelvin and generally isn't energetically important until the central temperature rises above several million Kelvin.

So here we have a star, usually referred to as a proto-star, shining with great luminosity—all without fusion taking place within the star. It is for this reason that these objects are also referred to as *pre*-main sequence stars, the Main Sequence being the major portion of a star's life spent fusing hydrogen into helium in the central core. It is the fact that this protostar is losing energy in the form of light into the cold vacuum of space at a rate set by its luminosity L_* that it *slowly contracts* in a shifting force balance of pressure-gravity. That is, pressure-gravity balance is maintained—the star *does not* collapse—despite the lack of a fusion energy source! Instead, sufficient gas pressure is maintained as approximately half of the potential energy drop goes into continuously raising the kinetic energy (temperature) of the gas particles. Note the curious situation that a star with a net energy leak *becomes hotter*! (This remains true as long as the kinetic energies of the gas particles are related to the temperature.)

Here is another common misconception related to a star's pre-main sequence contraction phase: the protostar of a particular mass and radius contracts at a rate dictated by its finite L_*, and *not the other way around*. The protostar's luminosity does *not* physically originate in its rate of contraction. Rather, the proto-star has a luminosity—and thus a net energy leak—the consequence of which is quasi-static gravitational contraction of the star at a rate determined by the rate of the net energy leak from the star (L_*).

The reader may have noticed the use of two distinct words and their adjectives in describing an object becoming smaller/denser under the force of gravity: rapid *collapse* and slow *contraction*. The former is what happens in the absence of *pressure-gravity balance,* with gravity having the upper hand. The latter is what happens in the absence of *energy balance*—there is a net loss of energy to space in the form of the star's luminosity, and little or no energy is generated by fusion in the star's core. Collapse, contraction... You say potato, I say potahtoh…right? I mean, what's the difference?

In the case of a star like our Sun, the *contraction* (energy imbalance) time scale is about *25 million years*. Recall that our Sun's time scale to *collapse* (force imbalance) is about *25 minutes*. So despite the nearly universal laziness of astronomy textbook authors, these two phenomena really are different in process and in the time scale over which they act. Doesn't a factor of *500 billion* differ sufficiently to merit being careful and consistent in terminology? I think so.

In fact, if Dr. Evil used his ray gun to shut off nuclear fusion in our Sun, *very little* would measurably happen to our Sun for ~100,000 years. (Well, the astrophysicists measuring particles known as neutrinos emitted in some of the nuclear fusion reactions in our Sun would become alarmed.) Eventually, our Sun would begin undergoing very gradual, *slow* gravitational contraction.

Fusion is neither responsible for the star's luminosity nor the ability of the star to be in pressure-gravity balance. **And in the absence of the energy produced by fusion, stars not only *gradually* become smaller, they *become hotter,* and their *pressures increase*!** These are in direct contradiction to the mantra of the virus.

Attaining stardom & what determines a star's luminosity?

(It's not fusion.)

Continuing our story, the protostar continues to slowly contract in a shifting force balance, becoming both denser and hotter along the way, converting the potential energy of gravity into the thermal kinetic energy of the particles. As the temperatures in the center of the protostar reach several million degrees, energy from nuclear reactions associated with the fusion of hydrogen into helium begins entering the star from its central regions. As this energy source ramps up, the *net* rate of energy leakage from the star (energy out minus energy in) diminishes. The protostar then makes final, *slow* adjustments in its structure to accommodate this new, centrally located source of energy—and as it does so, the star's luminosity *decreases*. Yes, you read that correctly. As the energy production rate from the fusion of hydrogen into helium ramps up within the star's core toward matching the star's luminosity, the star's luminosity goes down!

Finally, the rate of energy production via fusion, L_{fusion}, comes into balance with the star's luminous power, L_*, and the star attains the state of *energy balance*. Gravitational contraction stops, and the star is then said to have arrived onto the *Main Sequence* of stars, fusing hydrogen into helium in its central core. Such a star now evolves on the *much slower nuclear time scale*, that which is dictated by the rate at which 4 hydrogen nuclei are fused into 1 helium nucleus. This is about 10^{10} years for stars of our Sun's mass and is shorter/longer for stars more/less massive than our Sun, roughly in proportion to the star's mass to its luminosity, M_*/L_*.

Clearly, the rate of energy released from fusion, L_{fusion}, does not determine a star's luminous power L_*. So what does? The brilliant astrophysicist, Sir Arthur Stanley Eddington (the same who led the 1919 total solar eclipse expedition that ushered in Einstein's new theory of gravity/space-time), had worked out the first physical structure of stars by **1920** (*On the Internal Constitution of Stars*)—100 years ago(!). His model predicted many of the important physical characteristics of stars—including their luminosities, L_*. While he suspected that interacting atomic nuclei are somehow involved in converting matter into energy at a rate matching a star's luminosity, the first quantitative determinations of thermonuclear fusion of hydrogen into helium had to wait another 18 years (Hans Bethe and others). In any case, his model prediction of a star's luminosity had nothing to do with fusion. Eddington's model, however, initially lacked knowledge of one key ingredient—the star's elemental composition. When Cecelia Payne demonstrated in her 1925 Ph.D. dissertation that stars are composed almost entirely of hydrogen and helium, Eddington's model then correctly predicted the luminosities of the stars as a function of their mass.

Here is Eddington's 100-year-old model in a nutshell.

1. Stars are self-gravitating objects in pressure-gravity balance composed of a gas whose particle average kinetic energies are set by the temperature T, which declines from center to surface, emitting thermal radiation.
2. The energy content in the radiation field is transported via interactions with matter (radiative transport), moving downhill in temperature—from hot to cold (just as we're all familiar with).
3. The opacity, matter's tendency to interact with photons through scattering or absorption, opposes and *slows* this flow of energy through the star.
4. The star's luminosity is then proportional to the total energy of photons within the star in ratio to the time over which this energy slowly leaks out:

$$L_* \propto \frac{< avg.\ mass.per.particle >^4 \ \ M_*^3}{< opacity >}$$

The star's mass M_* contains the thermal energy that emits the thermal radiation. The average mass per particle sets the temperature scale. A greater value means fewer particles for a given mass density, requiring higher T to provide the required gas pressure. All else being equal, a star composed mainly of helium, with a consequently larger average mass per particle, is more luminous than one composed of mostly hydrogen or a standard hydrogen/helium mix. The gas opacity opposes and slows the flow of radiation through the star (just as a thermal insulator slows the rate of energy transfer by conduction) and generally diminishes with increasing temperature. Thus, more massive stars, possessing higher average temperatures, *more quickly leak out their larger stores of radiative/luminous energy*.

→ The more massive the star, the greater its luminosity!

Details, details: Eddington's model includes a correction factor, not shown in the above luminosity relation, for the contribution of radiation to the pressure exerted within a star. As radiation's contribution to the total pressure becomes significant, the gas temperature required by pressure-gravity balance is lowered. In brief, lower temperature gas emits fewer photons per cubic meter, and thus another role of radiation pressure is to reduce a very massive star's luminosity. This becomes an important and growing correction in stars with masses exceeding roughly 30 solar masses.

Finally, stars within which either convection or conduction, rather than radiation, dominates the flow of energy downhill in temperature, or whose particle kinetic energies are set by density rather than temperature, will have a different set of rules governing the determination of their luminosities. Eddington was generally unaware of such stars in 1920. And of course, I paint here a simplified, yet scientifically useful, picture of stars.

British astrophysicist Sir Arthur Eddington published *On the Internal Constitution of Stars* 100 years ago.

Summing up: L_* vs. L_{fusion}

To the extent that there is a direct causal relationship between L_* and L_{fusion}, it is that L_{fusion} is what it is because the star has a luminosity L_*—and *not the other way around*, as is so often wrongly presumed or misleadingly implied in textbook/webpage discussions. In other words, **it is the star's luminosity L_* that sets the power generated by fusion L_{fusion}**. More massive stars' higher average temperatures demanded by *pressure-gravity balance* allow them to attain *energy balance* at their greater luminosities L_*, because the fusion reactions run more quickly at higher temperatures, and thus L_{fusion} is correspondingly greater.

Most introductory educational resources have misinterpreted the condition of energy balance, which they nearly always describe as $L_* = L_{fusion}$, as a statement that a star owes its luminosity to and/or is set by the energy generated per second by fusion. I prefer, instead, to write the condition of energy balance as $L_{fusion} = L_*$, which more naturally and correctly directs one's thinking that L_{fusion} is set by L_*, *if and only if* the equality holds. More generally, **L_* and L_{fusion} are two distinct physical processes** in stars, whose energy rates can be the same (they are in main sequence stars), but can also be wildly (many powers of 10) different from one another during various stages in a star's life.

Unfortunately, nearly all of the more advanced discourses of stars discuss in some detail what's going on with nuclear fusion and the energy per second it generates, and then—without informing the reader—use that as a proxy for telling the reader what L_* is doing(!). This presumes, of course, that energy balance ($L_{fusion} = L_*$) holds, which is *not* always the case over a star's life. Obviously, this approach can leave readers with confused ideas of what's going on. Very few advanced sources discuss **what's going on in the star's structure, state of the gas, or energy transport mechanism(s) to inform the reader of what's going on with the star's luminosity**. And even the sources that do will fall back into the trap of discussing what's happening to nuclear fusion (sigh) to inform the reader that the star's luminosity is changing.

Why all the fuss?

For hundreds of thousands of years, human beings have looked to the skies with their sharp eyes and large brains and wondered about those points of light (and our Sun!). What are they, and how do I fit in with all of this? In the 20th century, the human scientific endeavor allowed us to tell a beautiful story that finally answers these profound questions. Science seeks to illuminate, clarify, and unify the workings of the universe. This is one of science's great gifts to humanity—our human cosmic perspective. We owe it to our students *and to humanity* to tell the right story. Science and astronomy educators unite!

Dr. Kirk Korista has been a KAS member since 1997 and is a WMU professor of astronomy.

Pi Day ECLIPSE of the WORM MOON

March 14, 2025

↑ **Richard Bell** | Kalamazoo Nature Center · Stellarvue 130mm f/7 · Astro-Physics Mach1GTO · Canon 6d · 1/1000 to 6 seconds · ISO 200

← **Chris Dobie**
Jackson, MI
8-inch f/5 Newtonian · Galaxy S23+ · 1/4 second · ISO 4000

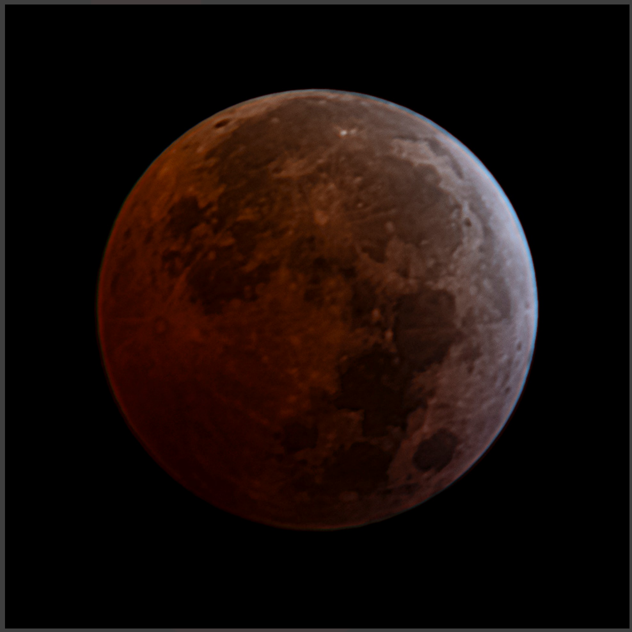
Eric Klien →
Kalamazoo, MI
S-W Adventurer 2i Pro · Canon 40D · 200mm f/14 · 38 seconds · ISO 320

Pi Day ECLIPSE of the WORM MOON

March 14, 2025

↑ **Brody Wesner** | Richland, MI · Sky-Watcher Evostar 72ED f/5.8 · Celestron AVX Mount · Nikon D5300 · 1/2000 to 6 seconds · ISO 200

Donald Clark →
Richland, MI
Canon R7 · Canon EF 400mm w/ 1.4x teleconverter · 10 seconds · ISO 100



← **Stephen McDonald**
Buckeye, AZ
ZWO Seestar S30 · Video (Raw) capture at 1 frame/second

Pi Day

ECLIPSE of the WORM MOON

March 14, 2025

← **Richard Pipkin**

Phoenix, AZ

Celestron Origin · 0.8 second · ISO 100

Mike Van Goor →

Chelsea , MI

Celestron 8″ Dob w/ 21mm EP · Canon EOS 6D Mark ii · 1/3 second · ISO 1600

↑ **Dan Foley** | Kalamazoo, MI · Canon EOS RP · Rokinon 14mm f/2.8 · 1/4 second each · ISO 400

Pi Day

ECLIPSE of the WORM MOON

March 14, 2025

↑ **Matt Borton** | Kalamazoo Nature Center · Celestron 11" f/6.3 · Losmandy G-11 · Canon 5D Mark III · 1/400 to 15 seconds · ISO 100 to 200

← **Mike Melwiki**

Plainwell, MI

250mm f/3.5 homemade refractor w/ 27mm Panoptic · Phone 14 Pro Max · 1/15 sec. · ISO 12500

Pi Day ECLIPSE of the WORM MOON

March 14, 2025

Tim Kurtz
Kalamazoo Nature Center
S-W Star Adventurer GTi · Canon 90D · Sigma 600mm f/6.3 · 56 x 1.3 sec. · ISO 800

Dave Woolf
Parchment, MI
Tele Vue NP-101is · Canon 5D Mk III · 0.8 seconds · ISO 800

Gregory Shanos
Longboat Key, Sarasota, Florida
ZWO Seestar S50 · 90 second video stacked

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Joseph Tourtois
Kalamazoo, MI
Family | 2025

Jonathan Towne
Bangor, MI
Senior Family | 2025

Matt Tuley
Kalamazoo, MI
Family | 2025

Henry & Martha Upjohn
Decatur, MI
Family | 2026

Michael Vandeveer
Lawton, MI
Senior | 2025

Mike Van Goor
Chelsea, MI
Family | 2025

John Vantland
Grand Rapids, MI
Senior | 2025

Rick Viel
Kalamazoo, MI
Senior Family | 2025

Alvaro Villamizar
Carlsbad, CA
Supporting | 2025

Gary & Christina Vincent
Portage, MI
Senior Family | 2026

Richard Voorman
Kalamazoo, MI
Senior Family | 2025

Jim Vukelich
Bloomingdale, MI
Senior | 2025

Allan Wachter
Tempe, AZ
Regular | 2025

Robert Wade
Salem, NH
Supporting | 2026

Brian Walesh
Oostburg, WI
Family | 2025

William Walkowiak
Portage, MI
Senior Family | 2025

Kelly Walters
Portage, MI
Regular | 2025

David Ward
Vancouver, BC
Supporting | 2025

Lynn Ward
Green Bay, WI
Supporting | 2025

Philip Wareham
Portage, MI
Regular | 2026

Todd Watson
Mattawan, MI
Regular | 2026

Mark Watts
Portage, MI
Senior | 2026

Caroline & John Webber
Kalamazoo, MI
Senior Family | 2025

Katie & Duane Weller
Grand Rapids, MI
Family | 2025

Brody Wesner
Richland, MI
Family | 2025

Fred Western
Kalamazoo, MI
Regular | 2025

John Wheatley
Louisville, KY
Supporting | 2025

Bob White
Plainwell, MI
Senior | 2025

Jacob White
Kalamazoo, MI
Regular | 2026

Molly Williams
Kalamazoo, MI
Regular | 2025

Ron Williams
Richmond, IN
Supporting | 2025

John Wing
Portage, MI
Senior Family | 2026

Peter Wolczko
Amherst, NH
Senior | 2025

Karen & Klay Woodworth
Kalamazoo, MI
Family | 2025

David Woolf
Kalamazoo, MI
Family | 2026

Doug Wussler
Tallahassee, FL
Supporting | 2026

Mohammed Zafar
Kalamazoo, MI
Regular | 2025

Peter Zillmann
Kalamazoo, MI
Student | 2026

KAS Membership Summary

Regular Members:	75
Students Members:	6
Seniors Members:	85
Family Members:	50
Senior Family Members:	55
Lifetime Members:	3
Supporting Members:	42
Honorary Members:	1
TOTAL NUMBER of MEMBERSHIPS:	317
TOTAL NUMBER of INDIVIDUAL MEMBERS:	~422

Catch the Waves!

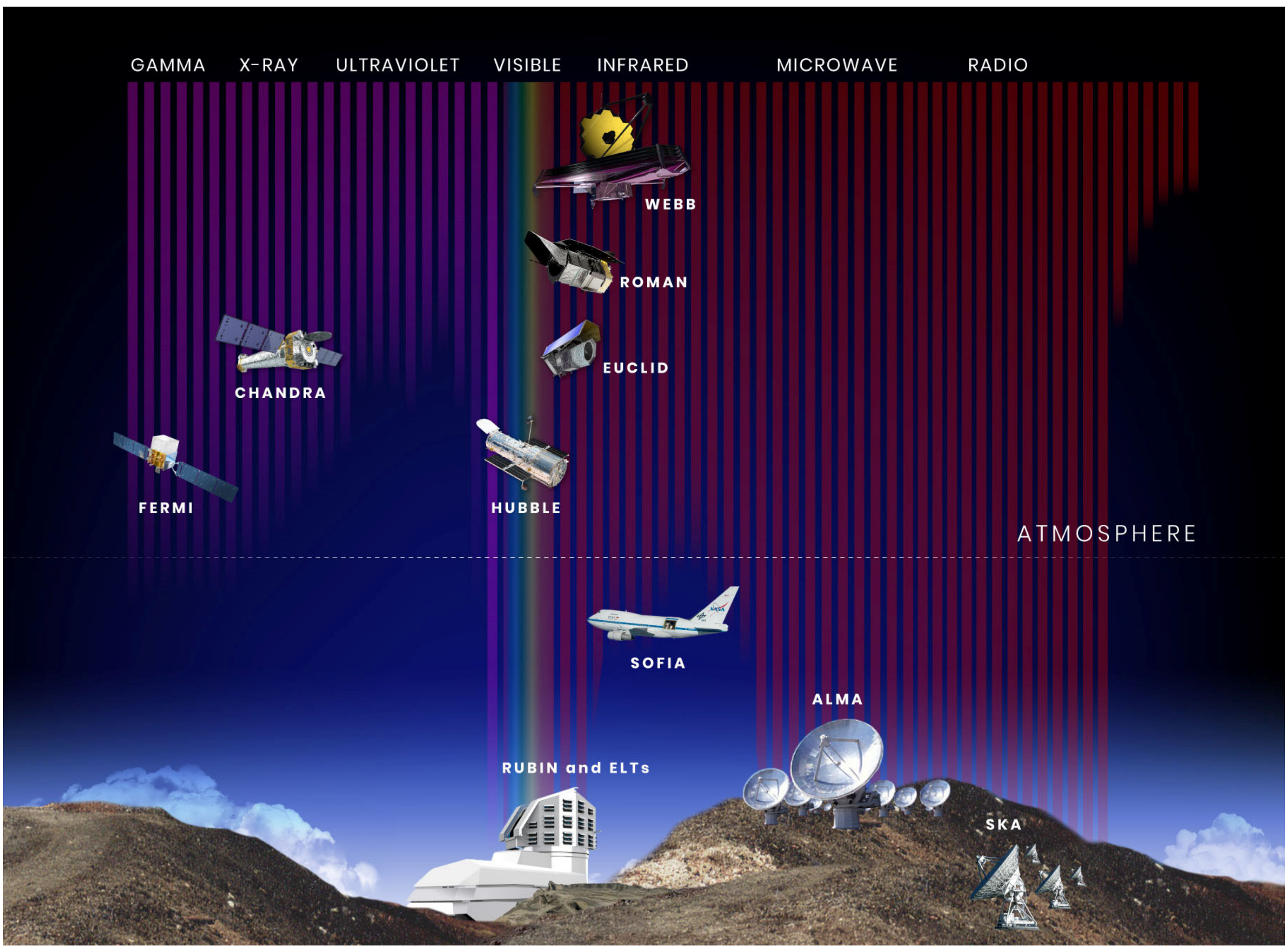
by **Kat Troche**

The Electromagnetic Spectrum

If you've ever heard the term "radio waves," used a microwave or a television remote, or had an X-ray, you have experienced a broad range of the electromagnetic spectrum! But what is the electromagnetic spectrum? According to Merriam-Webster, this spectrum is *"the entire range of wavelengths or frequencies of electromagnetic radiation extending from gamma rays to the longest radio waves and including visible light."* But what does that mean? Scientists think of the entire electromagnetic spectrum as many types of light, only some of which we can see with our eyes. We can detect others with our bodies, like infrared light, which we feel as heat, and ultraviolet light, which can give us sunburns. Astronomers have created many detectors that can "see" in the full spectrum of wavelengths.

Telescope Types

While multiple types of telescopes operate across the electromagnetic spectrum, here are some of the largest, based on the wavelength they primarily work in:



This illustration shows the wavelength sensitivity of a number of current and future space- and ground-based observatories, along with their position relative to the ground and to Earth's atmosphere. The wavelength bands are arranged from shortest (gamma rays) to longest (radio waves). The vertical color bars show the relative penetration of each band of light through Earth's atmosphere. Credit: NASA, STScI

NASA's Hubble Telescope captured the Pillars of Creation in 1995 and revisited them in 2014 with a sharper view. Webb's infrared image reveals more stars by penetrating dust. Hubble highlights thick dust layers, while Webb shows hydrogen atoms and emerging stars. You can find this and other parts of the Eagle Nebula in the Serpens constellation. Credit: NASA, ESA, CSA, STScI, Hubble Heritage Project (STScI, AURA)

Radio: The Very Large Array (VLA) in Socorro County, New Mexico is arguably the most well-known radio telescope observatory. This set of 25-meter radio telescopes was featured in the 1997 movie Contact. Astronomers use these telescopes to observe protoplanetary disks and black holes. Another famous set of radio telescopes would be the Atacama Large Millimeter Array (ALMA) located in the Atacama Desert in Chile. ALMA was one of eight radio observatories that helped produce the first image of supermassive black holes at the center of M87 and Sagittarius A* at the center of our galaxy. Radio telescopes have also been used to study the microwave portion of the electromagnetic spectrum.

The Crab Nebula, located in the Taurus constellation, is the result of a bright supernova explosion in the year 1054, 6,500 light-years from Earth. Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Infrared: NASA/JPL/Caltech; Radio: NSF/NRAO/VLA; Ultraviolet: ESA/XMM-Newton

Infrared: The James Webb Space Telescope (JWST) operates in the infrared, allowing astronomers to see some of the earliest galaxies formed nearly 300 million years after the Big Bang. Infrared light allows astronomers to study galaxies and nebulae, which dense dust clouds would otherwise obscure. An excellent example is the Pillars of Creation, located in the Eagle Nebula. With the side-by-side image comparison below, you can see the differences between what JWST and the Hubble Space Telescope (HST) were able to capture with their respective instruments.

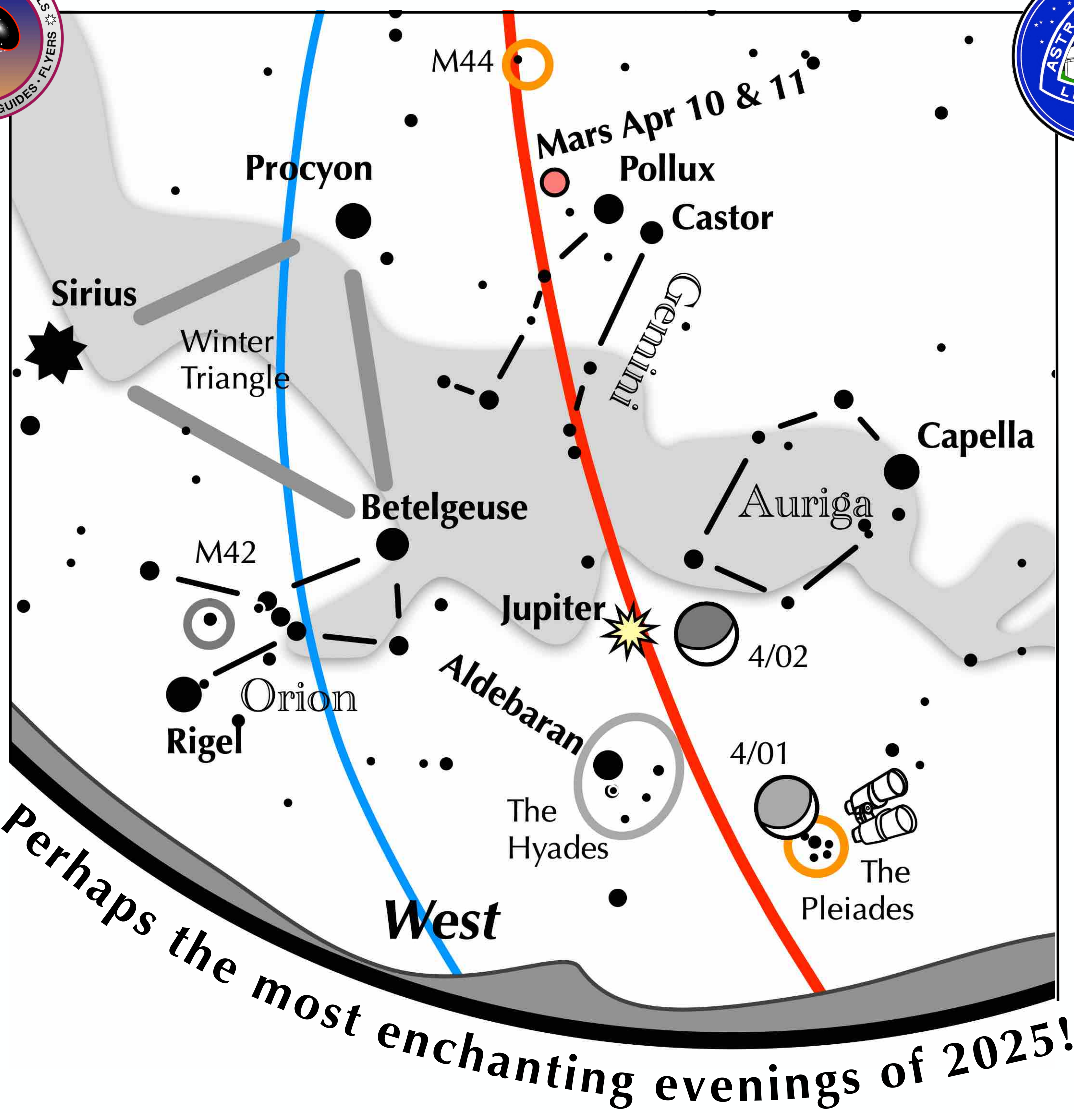
Visible: While it does have some near-infrared and ultraviolet capabilities, the Hubble Space Telescope (HST) has primarily operated in the visible light spectrum for the last 35 years. With over 1.6 million observations made, HST has played an integral role in how we view the universe. Review Hubble's Highlights here.

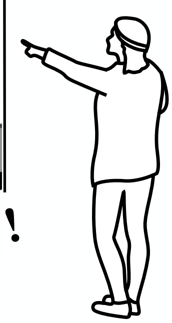
X-ray: Scientists designed the Chandra X-ray Observatory to detect emissions from the hottest parts of our universe, such as exploding stars. X-rays help us better understand the composition of deep space objects, highlighting areas unseen by visible light and infrared telescopes. This image of the Crab Nebula combines data from five different telescopes: the VLA (radio) in red, the Spitzer Space Telescope (infrared) in yellow, the Hubble Space Telescope (visible) in green, XMM-Newton (ultraviolet) in blue, and the Chandra X-ray Observatory (X-ray) in purple. You can view the breakdown of this multiwavelength image here.

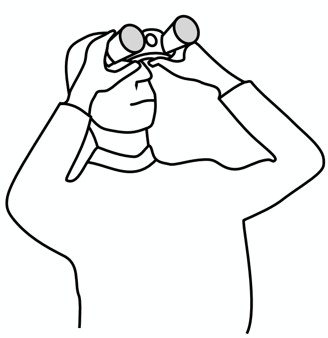
Try This at Home

Even though we can't see these other wavelengths with our eyes, learn how to create multiwavelength images with the Cosmic Coloring Compositor activity and explore how astronomers use representational color to show light that our eyes cannot see with our Clues to the Cosmos activity.

If you can see only one celestial event this April, see this one.







Enhance the scene – use binoculars!

On April 1 & 2, look low in the west-northwest 60 minutes after sunset.

• On the first evening, the crescent moon, glowing full with earthshine, floats immediately above the delicate Pleiades star cluster. To its upper left, shine Aldebaran and the intriguing Hyades star cluster. And bright Jupiter lies above that.

• On the second evening, the slightly thicker, but more pronounced crescent moon moves above the Pleiades and next to Jupiter.

• Above it all, red Mars plows through Gemini, reaching alignment with Castor and Pollux on April 10 & 11.

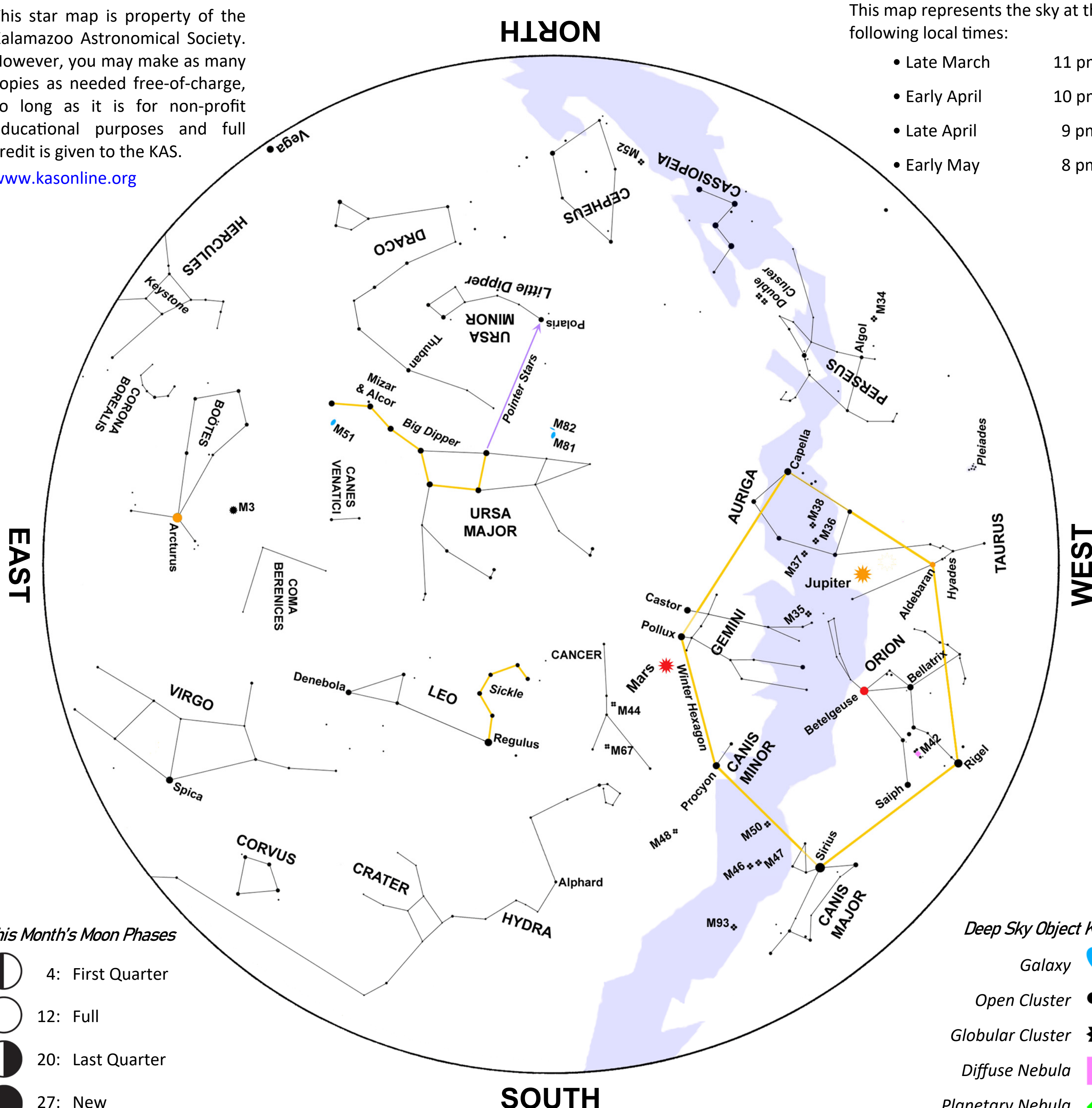
April Night Sky

This star map is property of the Kalamazoo Astronomical Society. However, you may make as many copies as needed free-of-charge, so long as it is for non-profit educational purposes and full credit is given to the KAS.

www.kasonline.org

This map represents the sky at the following local times:

- Late March 11 pm
- Early April 10 pm
- Late April 9 pm
- Early May 8 pm



This Month's Moon Phases

- 4: First Quarter
- 12: Full
- 20: Last Quarter
- 27: New

Deep Sky Object Key

- *Galaxy*
- *Open Cluster*
- *Globular Cluster*
- *Diffuse Nebula*
- *Planetary Nebula*

A waxing crescent Moon passes through Taurus during the first two days of April. On April 1st at dusk, it will only be 1½° above the Pleiades cluster. On April 2nd, look for the Moon 4½° to the upper right of Jupiter. Use binoculars for both encounters.

Only ½° of sky will fill the gap between a full Moon and Spica, Virgo's brightest star, when they rise shortly after dusk on April 12th. Spica will be to the Moon's upper left. Watch them grow apart throughout the course of the night.

The Lyrid meteor shower peaks during the early morning hours of April 22nd. A last quarter Moon will cause some interference, unfortunately. Expect a zenithal hourly rate of 18 meteors per hour.

Venus, freshly returned to the morning sky, blazes about 4° to the upper left of Saturn before dawn on April 24th. On April 25th, a thin waning crescent Moon forms a triangle with Venus and Saturn.

A razor-thin waxing crescent Moon returns to the proximity of the Pleiades on April 28th. This time, they're separated by 4½°. Still close enough to view in binoculars!

Advertisements & Announcements

General Meeting Preview

To the Moon!

What We Know and Why We're Going Back

presented by

Dr. Nicolle Zellner

The Moon continues to provide scientific answers—and pose new questions—over 50 years after the last Apollo mission. As our closest planetary neighbor, the Moon's geologic history and impact record, if properly interpreted, can be used to gain insights into how planetary bodies, including Earth and exoplanets, form and evolve. In this talk, Dr. Zellner will present an overview of the Moon's history and episodes of bombardment (that may have affected life on Earth) and provide an update on plans to return humans to the lunar surface.

— About the Speaker —

Dr. Nicolle Zellner is a professor of physics at Albion College in Albion, MI, where she teaches introductory and advanced astronomy and physics courses and has mentored dozens of student research partners. Supported by the NSF and NASA, Dr. Zellner's research interests focus on understanding the impact history of the Earth-Moon system and how those impacts affected the conditions for life on Earth.

Friday, April 4th @ 7:00 pm EDT

Kalamazoo Area Math & Science Center

Use Dutton St. Entrance • Locked by 7:10 pm

Also held on Zoom • Click to Register