The Grand Conjunction of 2020

Images from Oregon, Idaho, Utah and Arizona

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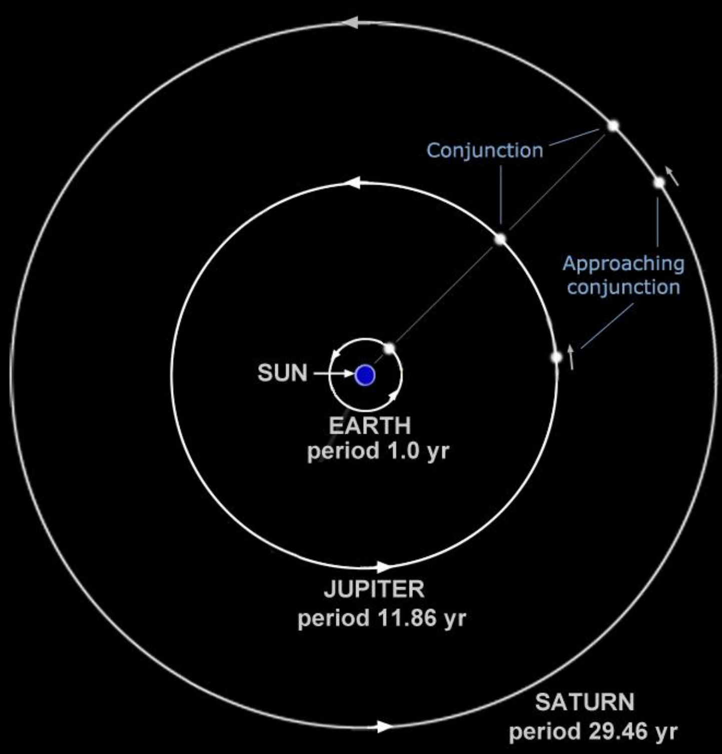
Some Background and History

In the days around December 21, 2020, a “Great Conjunction” was visible in the night sky. What is a conjunction? Why was this one “Great”? Why was it even greater than great (we like to call it “Grand”)? How often do Great and Grand conjunctions happen?

A conjunction occurs when two (or more) objects in the sky that move relative to the stars, such as planets, move closer to each other and then move apart again. This usually causes two slightly different events, which are defined as follows: (1) the instant when the objects are closest to each other, which is called an *appulse*, and (2) the instant when the objects have the same longitude in the sky, which is called a *conjunction*. In informal usage the word “conjunction” is often used for either an appulse or a true conjunction. In this article we adopt the informal convention, and use “conjunction” to mean “two objects being closest to each other in the sky”.

A “Great Conjunction” is simply a conjunction between the planets Jupiter and Saturn. It’s “great” because Jupiter and Saturn are the largest and, especially through a telescope, most visually striking planets. True, conjunctions of Jupiter and Venus are perhaps even more impressive to the naked eye since they are the two *brightest* planets, but for some reason the term Great Conjunction for Jupiter and Saturn has stuck.

Conjunctions of two planets occur when they reach positions in their orbits such that the Earth and the two planets are in (or almost in) a straight line, as illustrated in the diagram below:

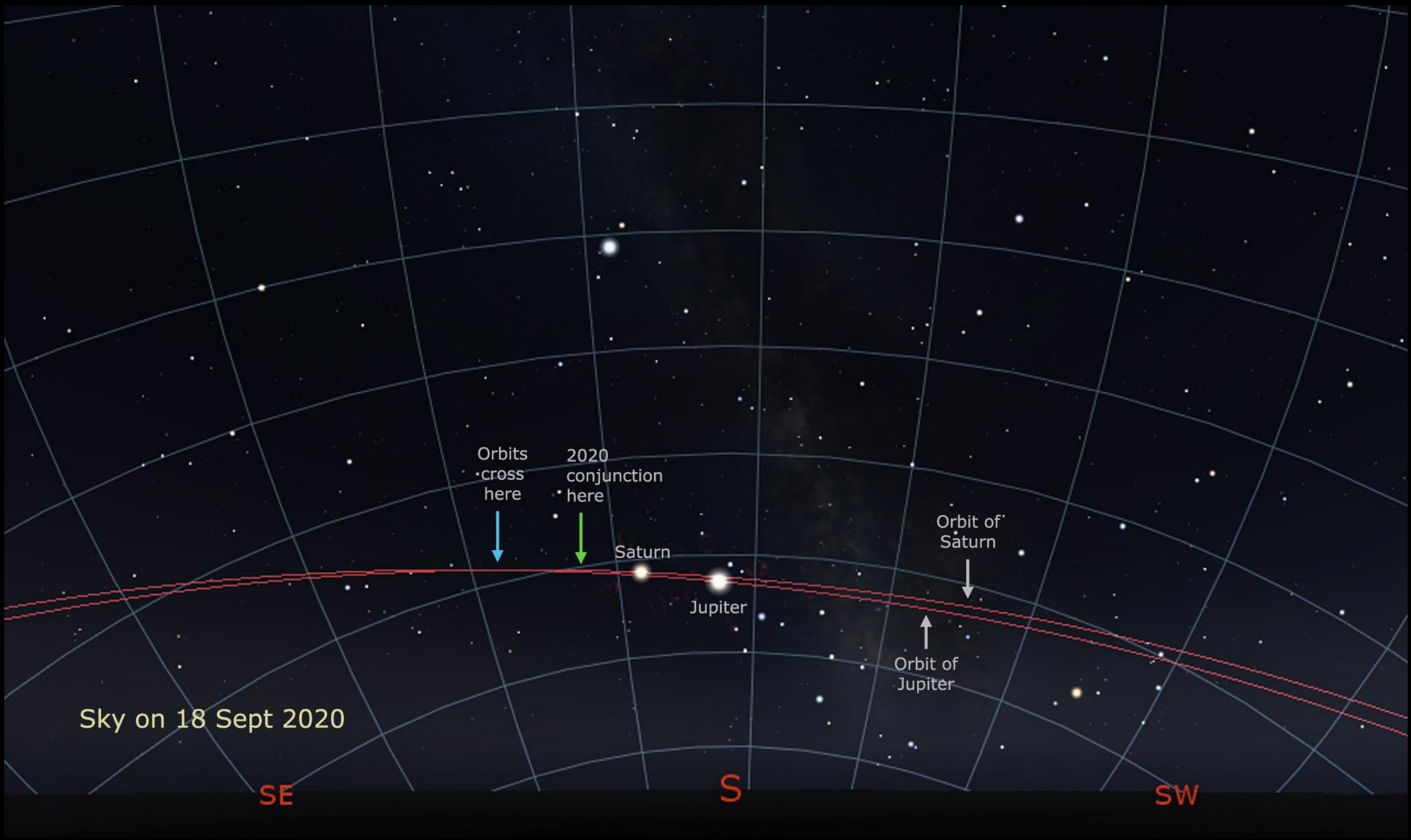


This overhead view of Earth, Jupiter, and Saturn shows their three orbits, and a situation where Jupiter and Saturn are approaching a conjunction and then, some days or weeks later, arrive at the actual conjunction, where the Earth, Jupiter, and Saturn lie approximately in a straight line.

As noted in the diagram, Jupiter makes one orbit every 11.86 years, while Saturn, being further from the Sun, takes longer (29.46 years) to orbit once. From these numbers it can be calculated that faster Jupiter will "catch up" and pass Saturn again once every 19.86 years. This number is nearly 20, so we can say that there's a Great Conjunction roughly once every 20 years. For example, prior to 2020's Great Conjunction there was one in 2000, and there will also be conjunctions in 2040, 2060, 2080, and 2100. At that point the fractional year accumulates enough to break the pattern of round numbers - the next one after that is in 2119.

Since Great Conjunctions happen about every 20 years, why was there so much interest in this one? The answer is simple: Jupiter and Saturn weren't just close for this conjunction, they were *really* close. As it turns out, the minimum separation between Jupiter and Saturn in each Great Conjunction varies, and can be any value up to about 80 arcminutes. (Note: an arcminute is 1/60 of a degree; a degree is about twice the width of a full moon). The 2020 Great Conjunction had a separation of just 6.1 arcminutes (0.1 degrees), about 13 times smaller than the maximum possible value of 80. For this reason we like to call the 2020 conjunction a "Grand Conjunction", defined as a Great Conjunction with a separation of around 6 arcminutes or less. Exactly how rare is this? Let's look into this question a bit more deeply.

First: why does the amount of closeness in a Great Conjunction vary? The simulated night-sky view below, created with Stellarium, is helpful in understanding this.



This is a picture of the night sky from Earth, so we are now looking at the orbits of Jupiter and Saturn from inside them, from the vantage point of Earth, instead of an overhead view. The two red curves show the paths of Jupiter's and Saturn's orbits in the sky, with the two planets' actual positions shown for a single night about 3 months prior to the 2020 Great Conjunction. Note the key feature of the red paths: at one point (the one marked "Orbits cross here") they coincide, and on either side of this point they diverge. This diagram only shows about half of the sky, but if we continue the orbital paths around the other half we find that eventually they reach a point of maximum divergence, and then begin to get closer again. There is a second point in the sky (behind the viewer) where the paths cross again. This is all caused by the fact that the two orbits are (planar) ellipses with the plane of one ellipse tilted relative to the other. Any two concentric tilted ellipses when viewed from their center will show two points where they coincide, with gradual divergence of the orbits as we move away from the crossing points.

The actual position of the 2020 Great Conjunction is shown with the green arrow. Now we see the simple reason why Jupiter and Saturn were so close in this Great Conjunction: the point in the Jupiter/Saturn orbits where the conjunction occurred is quite close to one of the two places where the orbits coincide. The closeness of any given Great Conjunction just depends on how far apart the red curves are at the exact point where the conjunction occurs. This is also where the 80 arcminute value for the maximum possible minimum separation comes from - that's the farthest apart the red orbital curves get in their entire path around the Sun.

To get an idea of the rarity of Grand Conjunctions let's look at some data over a long period. I found a database of all Great Conjunctions between the years 1200 and 2400 compiled by Patrick Hartigan at Rice University and made the plot shown on the next page. All Great Conjunctions are plotted by their year (X axis) and minimum separation in arcminutes (Y axis). In addition, I included information about observability, indicated by the plot symbol (see legend below the graph). The observability rating (green = easy, yellow = observable, but maybe tricky due to twilight, and red = not observable) is, as described at the bottom of the chart, tied to the angular distance of the conjunction from the Sun.

Here are the five data points in the bottom strip - the only Great Conjunctions between the years 1200 and 2400 with a separation of 10 arcminutes or less:

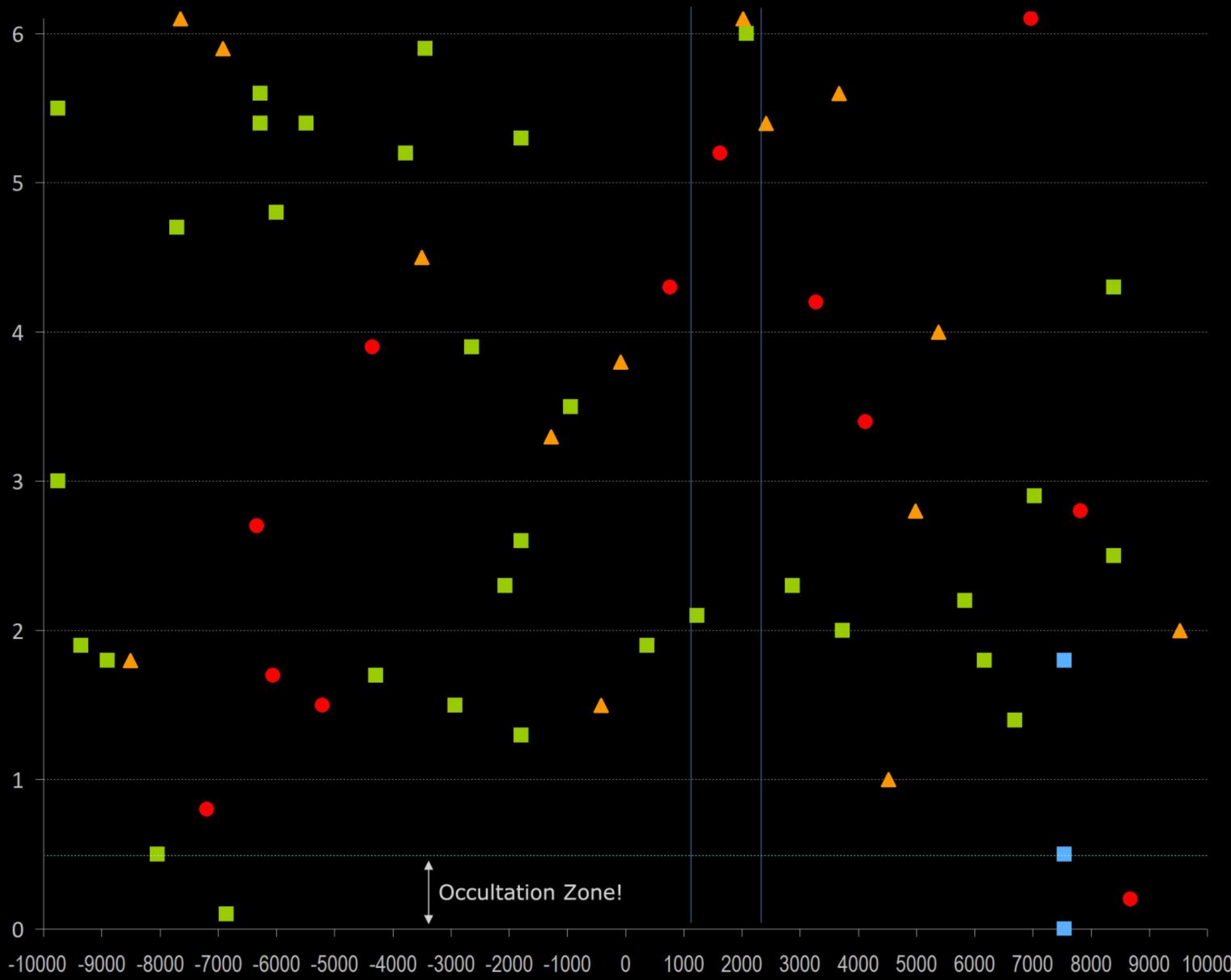
Date	Min. separation
4 Mar 1226	2.1'
25 Aug 1563	6.8'
16 Jul 1623	5.2' (not observable - too close to Sun)
21 Dec 2020	6.1'
15 Mar 2080	6.0'

One of these, in 1623, wasn't observable, and one of these (in 1563) had a separation of more than 6.1' (our limit, based on the 2020 one, for what we consider a "Grand Conjunction"). So from 1200 to 2400 there are just three observable Grand Conjunctions, in 1226, 2020, and 2080. Note also the spectacular closeness (2.1') of the 1226 conjunction.

Since there are just 3 observable Grand Conjunctions in this span of 1200 years, that's one every 400 years on average. So we can see that the 2020 Great Conjunction was not just a once-in-a-lifetime event, but something ever rarer (about 5 times rarer, if we consider a lifetime to be 80 years). And being able to observe Jupiter and Saturn this close at high power in a telescope, or take a close-up photograph, was a first-time-in-human-history-level event, since telescopes and cameras didn't exist in 1226.

Notice the columns of blue blocks. These are Triple Great Conjunctions, which occur when the time of Great Conjunction happens to be close to Jupiter's opposition. Recalling that around opposition is the time when Jupiter undergoes a period of retrograde motion, it follows that there will be one conjunction during Jupiter's prograde motion, then another during Jupiter's retrograde motion as it passes Saturn again, and then a third one after Jupiter resumes prograde motion. We don't need to wonder whether the Sun interferes with seeing these; since they occur around opposition they are by definition opposite the Sun and therefore visible in dark skies almost the whole night.

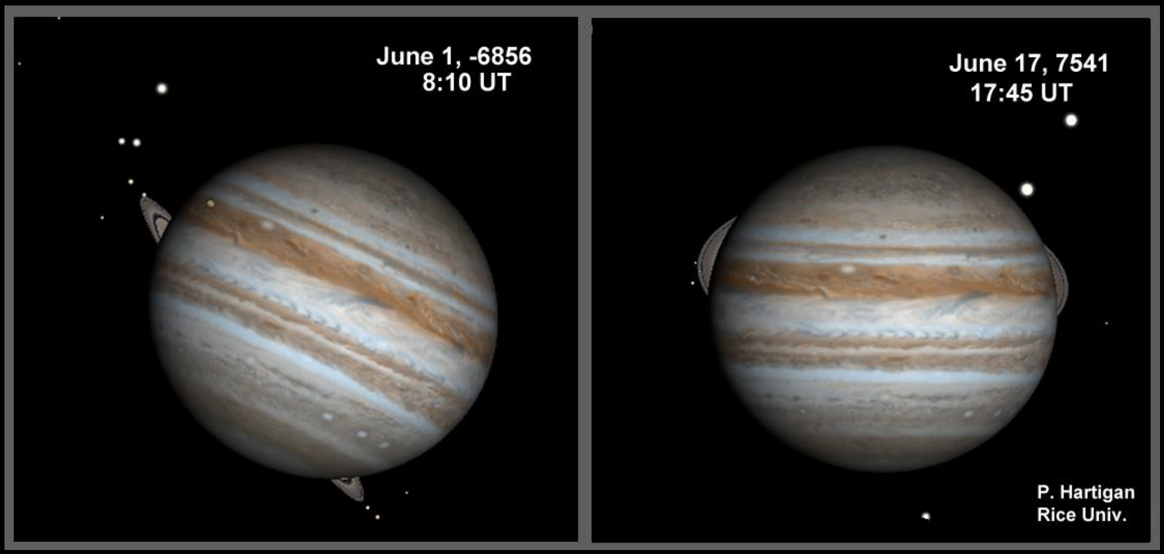
But wait, there's more! P. Hartigan also compiled data for all extra-close conjunctions for the 20,000-year period of the years -10000 (i.e., 10000 BCE) to 10000, from which I extracted just those with a separation of about 6 arcminutes or less (i.e., the Grand Conjunctions). Behold:



The two thin blue vertical lines represent the time period of the previous chart (1200 to 2400). Between them are the same four Grand Conjunctions (one unobservable) already discussed at the bottom of page 4. But as we expand beyond the years 1200-2400 to the full range of -10000 to 10000 we see that Grand Conjunctions continue to appear - though still sparsely - throughout the entire 20,000-year span. There are a total of 50 observable Grand Conjunctions in these 20,000 years, and 20,000/50 = 400, so this data leads to the same estimate we got before: observable Grand Conjunctions occur on average roughly once every 400 years.

Did you notice the horizontal strip at the bottom labeled “Occultation zone”? For data points in this area of the plot, each conjunction has a minimum separation less than 0.5 arcminutes (= 30 arcseconds), which is roughly the apparent size of Jupiter. This means that these Grand Conjunctions will be partial occultations, in which Jupiter partly (up to almost completely) covers Saturn! And as you can see, there are in fact 4 observable occultations (and one unobservable one) in this 20,000-year time period: two nearly-complete occultations (in the years 6856 BCE and 7641), and two so-called “grazing” (very slight) occultations. Even more astoundingly, as indicated by the three blue blocks, two of these four occultations (one full, one grazing) are part of a Triple Grand Conjunction, and therefore occur in the same year (7641). The third member of this triple (the top blue block) isn’t an occultation but an “ordinary” Grand Conjunction with a separation of 1.8’.

Here are simulations of the two nearly-complete occultations (the one on the far left and far right of the graph and near the separation = 0 line on the graph):



Do astronomers have accurate enough orbital elements for the planets to make these kind of very specific predictions this far in the future? We don’t know that the answer is “no”, but we also don’t know if the answer is “yes”. The only way to know for sure is to wait and continue to refine the orbital elements using observations over the upcoming centuries.

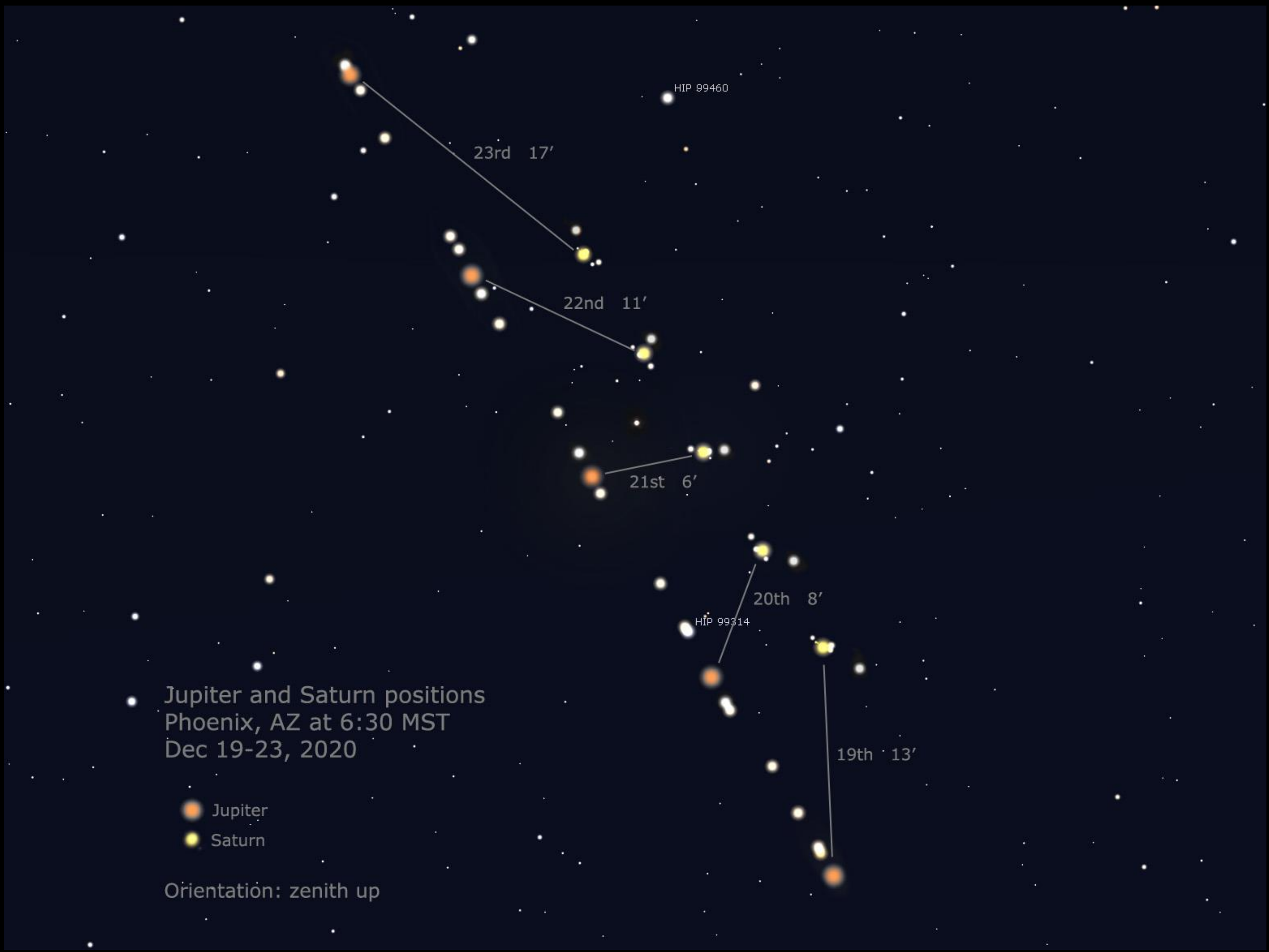
Now that we’ve reached this far-out place, let’s step back and look at some pictures of the 2020 Grand Conjunction.

This picture is the opening act before the main event. It was taken on December 1st at 6:30 PM near the intersection of SW Murray Blvd and SW Scholls Ferry Road in Beaverton, Oregon. Jupiter was about 10 degrees above the horizon with Saturn to its upper left. The distance between the two planets here is about 2.1 degrees (= 126 arcminutes).

To the upper left of the planets, covering the whole upper left quadrant of the image, is the large “triangle” of Capricornus. The two stars well above Saturn make one vertex of this triangle. The upper right of these two stars is Alpha Capricorni, also known as Algedi. As you can see (you may need to zoom in a bit), it is a double star. What’s interesting is that the two stars in this double are separated by 6’ - the same separation that Jupiter and Saturn will have on the day of their Grand Conjunction (Dec 21st).

Due to the weather forecasts as December 21st approached, it was clear that I would have to travel from my home near Portland, Oregon in order to avoid cloudy skies. After much studying of forecasts for a large swath of the western US, I determined that the best option was a 42-hour round-trip drive to Phoenix, Arizona. Using Google Maps satellite and street views, I found a hotel to stay in where I would be able to set up on the edge of the parking lot and be able to see low to the horizon in the required direction (southwest). An added benefit of the Arizona location was that the angle of the ecliptic (as well as the angle of lines of constant declination) was more vertical than in Oregon, due to the lower latitude. This meant that as darkness fell the planets would be higher in the sky and would be observable for a longer period of time.

To plan the widefield and (especially) close-up shots I wanted to get, the sky map below, which I made with Stellarium, was very useful.



This shows the position and orientation of the two planets and their moons for the five nights Dec 19-23. Once again, we can see faster Jupiter “passing” slower Saturn as they both move to the upper left each night. Their separation for each night is shown: 13’, 8’, 6’, 11’, and 17’ for the five nights, with the smallest separation being, as it must be, on conjunction night (the 21st).

Here are widefield images for each of the five nights, taken with a DSLR on a fixed tripod. Compare the orientation of Jupiter and Saturn with the diagram on the previous page and you'll see that they match. Occasional slight discrepancies are due to the time of the photo not being exactly 6:30 (the time the diagram is drawn for). Even over the space of an hour, "field rotation" of the sky compared to the horizon, and the movement of Jupiter relative to Saturn, makes enough of a difference to change the orientation by a visible amount (even to the naked eye).

This photo from Dec 19th was taken on the last day of driving down, soon after crossing the border into Arizona:

This was taken at 7:24 pm on Dec 19th, nearly an hour later than the 6:30 time in the diagram. This is why Jupiter and Saturn make nearly a perfect vertical line, as opposed to the slightly slanted one on the diagram. They were only 4 degrees above the horizon at this time.

The two stars to the upper right of the planets are that same part of the constellation Capricornus described under the photo on page 8 (Algedi is the upper right star of the two). By comparing to the photo on page 8 you can see how much the positions of Jupiter and Saturn have changed relative to Algedi since Dec 1st.

The bright star at center right, flanked by a star on either side, is Altair.

This “behind the scenes” photo of my setup in the Phoenix parking lot, as well as Jupiter and Saturn in the sky, was taken at 6:40 pm on Dec 20th, with the planets at an altitude of 11 degrees. On the laptop screen is a live feed from a separate camera attached to the telescope, showing a magnified view of Jupiter (lower right) and Saturn (upper left) just *barely* fitting in the diagonal corners of the camera’s field of view.

Close-up images from the telescope/camera setup will be shown in a few pages after we finish the widefield images from the five nights.

Here we are - Dec 21st, the night of the actual conjunction. This picture was taken at exactly 6:30 to match our star chart, with the planets at an altitude of 12.3 degrees. You may need to zoom into the picture to see the pair of planets better, since they are so close.

Notice the difference in position of the planets in the closeup view on the laptop, compared to the image on the previous page. The camera in the telescope (the little red cylinder) can be, and usually is, rotated to be at whatever angle one wishes, and so the orientation of the planets in the camera image (shown on the laptop) need not match their orientation in the sky. The telescope camera was rotated in order to position the planets in the corners of the frame for the most comfortable fit.

On this night I was able to observe the conjunction continuously for almost two hours - 1 hour and 58 minutes, to be exact. I first spotted the pair in fairly bright skies at 5:37 with binoculars. By 5:41 I had them in the telescope, and then spent more than an hour taking various photos. I continued to observe them by naked eye, as well as the closeup image from the telescope, until they disappeared at 7:35 behind the distant mountain range you can see in this picture.

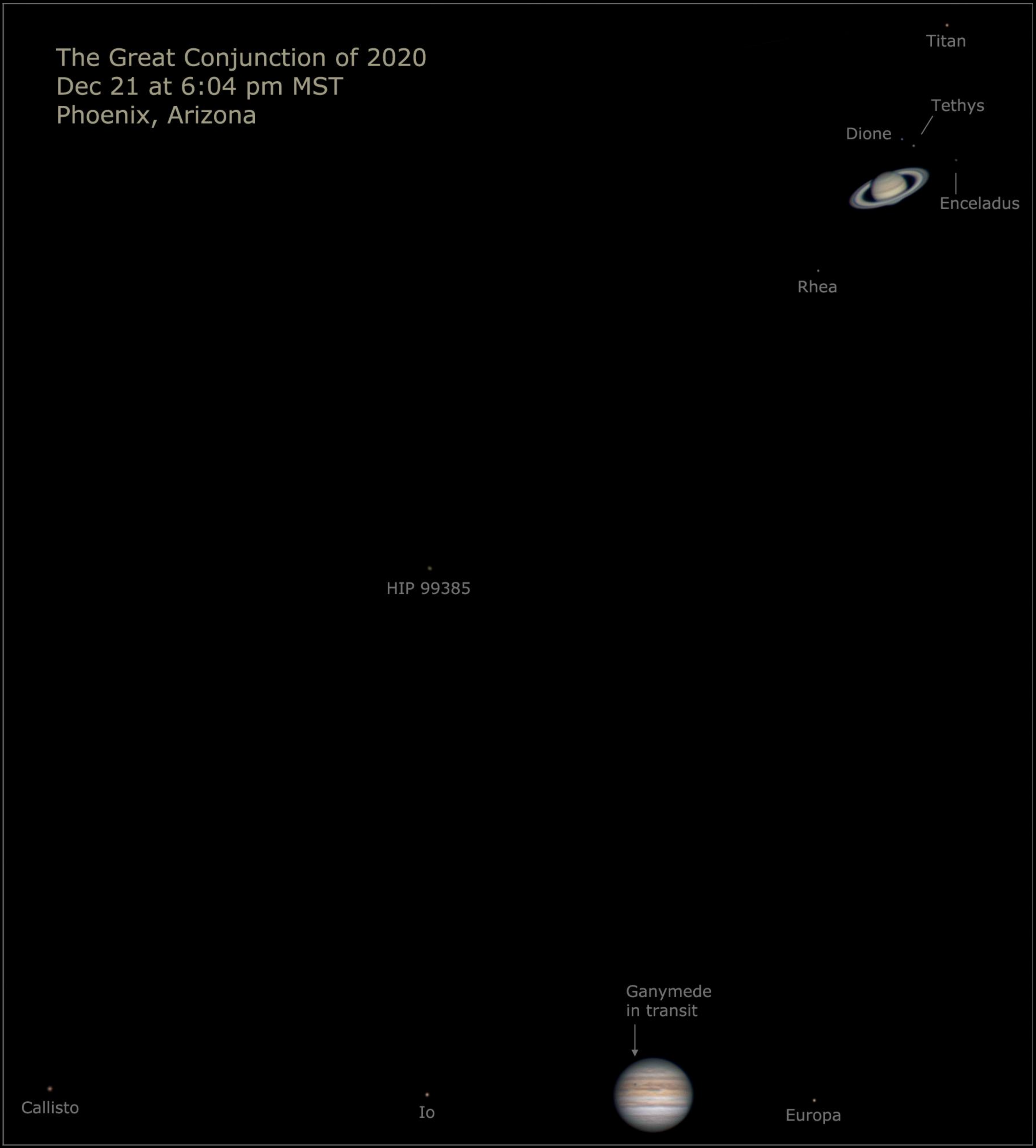
The image on the previous page was taken at 5:39 pm on Dec 22nd in the small town of Kanab, Utah. I was on a small section of local road between two interstates and happened to pass the town Christmas tree. Because the date of the conjunction was close to Dec 25, it was often referred to as "The Christmas Star" in news articles, so this shot seemed appropriate.

This final widefield shot was taken at 6:02 pm on Dec 23rd near the Christmas display in downtown Twin Falls, Idaho. Once again I placed the pair of planets just above the tree. We've arrived at the last configuration in the star chart on page 9, and at a separation of 17' there's somewhat of a sense that this big event is now "over".

Now let's look at some closeup images of The Grand Conjunction of 2020.

This is a close-up view from Dec 20th, the night before the conjunction, when the planets were 8 arcminutes apart. These close-up images were taken with a ZWO ASI224MC camera and a ZWO ADC (atmospheric dispersion corrector) in a Celestron C8 telescope using the “lucky imaging” technique, in which many short-exposure frames are captured over several minutes, and then special software (I used AutoStakkert 3) is employed to automatically find the best (least distorted by the atmosphere) frames and combine them to enhance details. In addition, this is an HDR composite of three stacked images: one with an exposure time optimized for Saturn, one optimized for Jupiter, and one with both planets overexposed to capture the moons.

The Great Red Spot on Jupiter is nicely on display, as are all four Galilean moons of Jupiter and four moons of Saturn. As a nice surprise, Jupiter had a “fifth moon” this night, a random star (HIP 99314) that happened to be located in the same line as the four real moons.



This is it! A close-up view on the actual night of Great Conjunction (Dec 21) at 6:04 pm local time. There's no Great Red Spot this time (it's on the other side of Jupiter) but we get two other nice bonuses. One moon of Jupiter, Ganymede, is passing in front of (transiting) Jupiter. Since Ganymede has a much lower surface brightness than Jupiter, it is visible as a darker spot against

Jupiter's brighter surface. The second bonus is Saturn's moon Enceladus, which was too close to the glare of Saturn on Dec 20th, but is now visible. It is, clearly, the dimmest of the five moons of Saturn that we captured. Here are their magnitudes, in order of decreasing brightness:

Titan	8.9
Rhea	10.3
Tethys	10.8
Dione	11.0
Enceladus	12.3

By contrast, all of Jupiter's Galilean moons are brighter than these, with magnitudes in the 6-7 range. And notice that, like the previous night, there's a random star nearby again, HIP 99385 at magnitude 8.9.

Even though 2020's Grand Conjunction was fairly close to the Sun at about 30 degrees away, and also low to the horizon, the combination of decent "seeing" (steadiness of atmosphere) on this night and the previous night, plus the slightly higher altitude of the planets offered by the Arizona location, allowed a fair amount of detail to be captured. By getting started as early as possible we were able to shoot Saturn for this image at an altitude of 19 degrees and Jupiter at 17.5 degrees. On the next page we'll show an image from an even lower altitude.

This image is from the same night, Dec 21, but almost an hour later, at 6:57 pm. The difference between this image and the previous two close-ups is that it's a *single image* (created from a stream of images using the lucky imaging technique) with no HDR compositing. The whole point of the Grand Conjunction was that Jupiter and Saturn were very close, so it seemed like an absolute necessity to capture a single image with both Jupiter and Saturn in the same frame. I deliberately picked an exposure time such that Jupiter would be right on the edge of being overexposed, in order to make Saturn and Jupiter's moons as bright as possible.

Since separate processing of Jupiter and Saturn was not done here, the brightness difference of the two planets is nicely illustrated. Notice that two of Jupiter's moons are visible - Io to the upper left of Jupiter and Europa to its lower right. And we can still see Ganymede in transit, which in one hour has moved a noticeable distance across Jupiter's face compared to the image on the previous page

And the amazing thing is: this was captured at an altitude of only 7 degrees! Clearly the seeing was pretty good on this night.

Epilogue: A Once-every-32,000-years Image?

As we learned earlier, on average an opportunity to take a picture like the one on page 18, with Jupiter and Saturn separated by about 6 arcminutes or less, comes along only once every roughly 400 years. The image on the next page has an arrangement of visible objects that only occurs (we estimate) about once every 30,000 years.

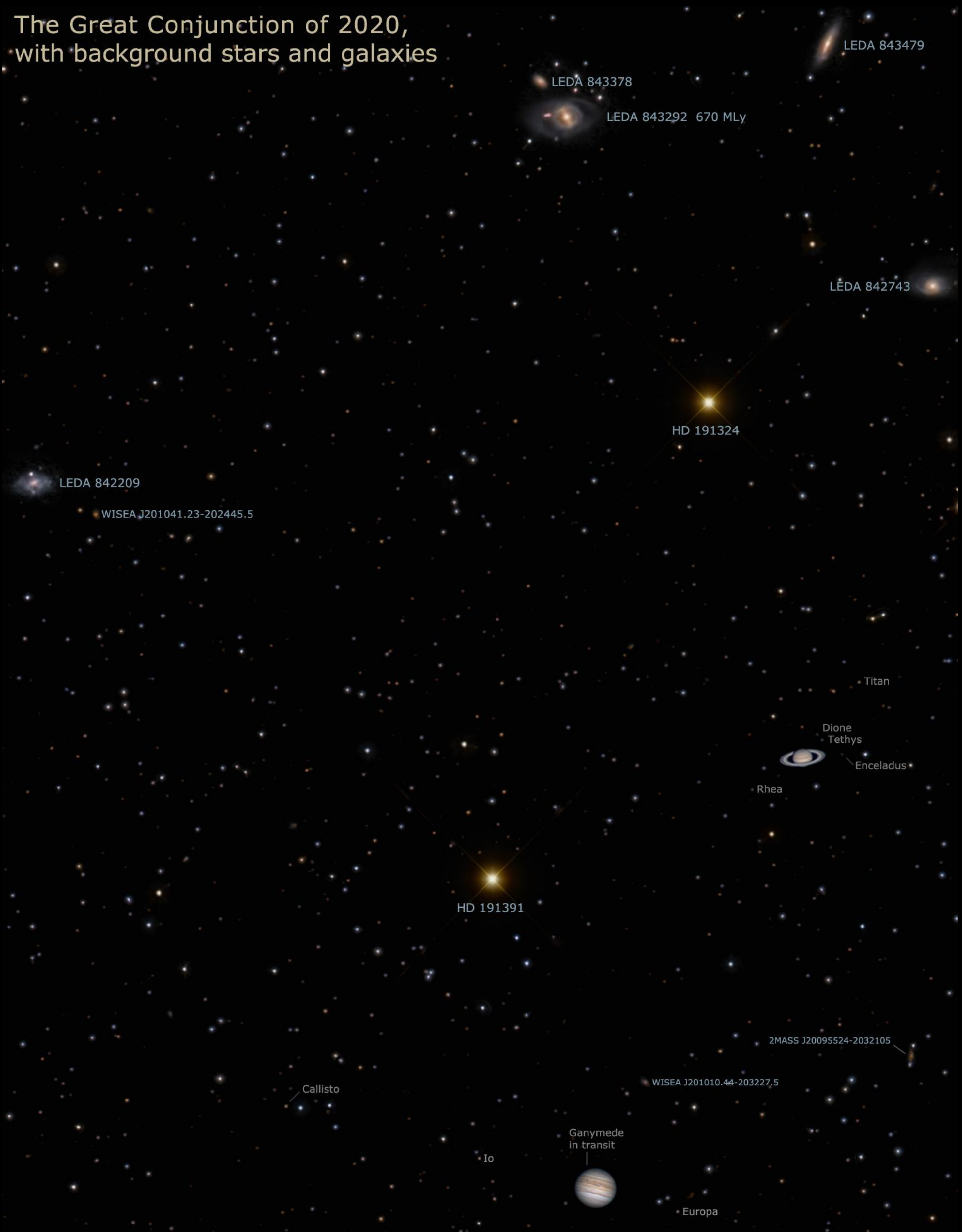
First of all, what is going on in the picture? This is an “extreme HDR” photo of the scene on conjunction night (Dec 21) containing the 3-exposure composite image for the planets from page 16 combined with *another* layer that’s a long exposure (about 2 hours) showing many of the distant stars in the vicinity as well as some of the very distant galaxies.

We noticed during the planning stage for photographing the 2020 Grand Conjunction that the background in this area of the sky contained a few interesting galaxies, including one (LEDA 843292) *that somewhat resembles the planet Saturn!* To me it looks like an overhead view of Saturn, looking down on the pole of the planet with a bright ball in the middle (the spherical part of our imaginary Saturn) surrounded by an oval ring similar to Saturn’s rings. There’s a noticeable gap between the “ball” and the “rings”, just like the real Saturn.

In reality, LEDA 843292 appears to be a barred spiral with somewhat unusual spiral arms, but it could also be a rare “ring galaxy”. I don’t know which, since this galaxy appears to have been barely studied. It has been examined closely enough to determine its redshift (I looked it up using NED, the NASA Extragalactic Database), from which we can calculate that it is about 670 million light years away, but little else is known about it. A Google search for “LEDA 843292” returns zero results, so clearly this galaxy is rather obscure. You’ll notice that none of the other galaxies in the picture have a distance listed - that’s because none of them have yet had their redshift determined (according to NED, which is the authority on these things).

What we have here is a Grand Conjunction with Saturn about 8.7 arcminutes from the “Saturn Ring Galaxy” (LEDA 843292). How often do Grand Conjunctions occur with Saturn being, say, within 10 arcminutes of this galaxy? To estimate this we first note that Grand Conjunctions are limited to span of 20.6 degrees in Right Ascension, since they must lie in one of the two regions (each 10.3 degrees wide) near where Jupiter’s and Saturn’s orbits cross. We measured that there is a range of just 0.25 degrees in RA where Saturn would be within 10’ of the galaxy, which is about 1/80 of 20.6 degrees. So a Grand Conjunction with Saturn near LEDA 843292 is 80 times more rare than an ordinary Grand Conjunction, and therefore should occur roughly once every 400 x 80 = 32,000 years.

Incidentally, the background stars and galaxies were not captured on Dec 21, because the extreme brightness of the planets would overwhelm the stars and galaxies. They were photographed several weeks earlier with a different telescope and camera. The background picture was very carefully aligned and combined with the close-up conjunction image in order to accurately portray what was in the sky in the area surrounding the Grand Conjunction of 2020.


The Great Conjunction of 2020,
with background stars and galaxies
LEDA 843479
LEDA 843378
LEDA 843292 670 MLy
LEDA 842743
HD 191324
LEDA 842209
WISEA J201041.23-202445.5
Titan
Dione
Tethys
Enceladus
Rhea
HD 191391
2MASS J20095524-2032105
WISEA J201010.44-203227.5
Callisto
Ganymede
in transit
Io
Europa