Slide 2: Welcome to the final webinar of our three-part series on visual satellite observing. I'm T.S. Kelso from the Center for Space Standards & Innovation. Today's webinar will cover another special topic of visual observing: satellite transits of the Sun and Moon. Whether you're a regular user of STK or someone new to this topic, I think you'll find today's webinar both interesting and informative. The goal of today's webinar is to show you how easy it is to use STK to prepare to observe these unique events.

Unlike our previous two topics, observing satellite transits can be considerably more challenging. While it's much easier to know where to look, the angular size of the satellites and the speed of the events will likely require a telescope—with a solar filter, if observing solar transits—and some type of imaging equipment such as a video camera or CCD. Plus, you'll need to make sure you have an accurate time source. Of course, as with our previous topics, we'll provide you all the tools to do this and visualize what's going on in STK.

We'll be following the same format as we did in Parts 1 and 2 of our series, so those of you that joined us for either of those should be pretty familiar with how we'll proceed. So, I'd encourage you to go to full-screen mode now, to best see what we'll be presenting.

Slide 3: [Pause] So, let's get started. Today's webinar will begin by discussing the basics of when satellites transit the Sun or Moon and look at some recent examples of what's possible with the right preparation. Then, we'll focus the majority of the webinar on some examples that I think you'll find particularly interesting. As before, we'll tie these examples to actual observations so that we can see what kind of performance we can expect.

Slide 4: [Pause] It should be pretty obvious, but satellite transits occur whenever a satellite passes directly in front of the Sun or Moon as seen from a particular observing location. However, the particular circumstances of such events are far from obvious. I hope that by the end of this webinar, you will have a much better idea of what to expect while observing a satellite transit.

I originally became involved with this topic when writing my column for the January/February 1997 issue of *Satellite Times.* **That column focused primarily on tracking the Sun and the Moon and how doing so differed from tracking satellites. In that column—for which I provide the link here for your reference—I mentioned a report from Gary Eldridge in August 1996, where he said he "got a GREAT silhouette view of Mir last Saturday night…the detail was incredible while using an 8-inch reflector scope and 17mm eyepiece."**

At the time, I could only imagine what Gary had seen and the challenges of predicting such events seemed pretty formidable. Some ten years later, though, we're about to see that they are pretty easy to predict with the right tools.

The primary advantage of observing a satellite transit is that we know just where to look and the bright background makes for good contrast, allowing for super-resolution—or the ability to see features smaller than the theoretical resolution of our optical system.

As we're about to see, due to its large size and low orbit, the International Space Station—or ISS—is once again an excellent target for observing under these circumstances. The biggest challenge, however, is that its low orbit can result in transits which last less than half a second. You'd better not blink at the wrong time!

Another challenge in looking for transits by a particular satellite, such as the ISS, is that they are pretty rare—at least at a fixed location. Of course, there are lots of other satellites up there and—as we'll see later—dozens of these transit the Sun or Moon every day. Plus, as a satellite's orbital altitude increases, so does the transit time and objects at geostationary altitude can take over 120 seconds to transit the Sun or Moon. But, now you'll be trading off the angular size of the satellite for a longer pass.

Slide 5: [Pause] Well, let's look at some recent examples of what's possible, before you become too discouraged. All of these pictures were featured on the Astronomy Picture of the Day web site in the past two years. I encourage you to check these out when you get a chance, by following the embedded URLs in this PowerPoint briefing. The picture on the left was taken this past September, just after the US space shuttle undocked from the ISS. The picture in the upper right, shows the ISS as it crosses the Sun during the transit of Venus in June 2004. We're going to spend some time analyzing this event in detail. And, the picture in the lower right is another shot of the US space shuttle docked to the ISS, taken in July 2005. While it is difficult to see here, when you look at these photographs in their full resolution, I think you'll agree they are all pretty impressive!

Slide 6: [Pause] Now, before you get too excited about observing a satellite transiting the Sun, I want to take a moment to remind you that this can be a very dangerous activity without taking the proper precautions. It can be done safely, but please don't cut corners here. Doing so can not only ruin some pretty expensive equipment but can also result in permanent blindness. I've provided a link to some excellent information on safely viewing the Sun, provided on the NASA Eclipse web site and would be more than happy to answer any questions you might have, if you are in any way unsure of what might be safe. Having observed the Sun many times, photographing eclipses and—more recently—the transit of Mercury, I can attest that it is easy to observe the Sun safely, when done properly.

Slide 7: [Pause] Of course, if you're even the slightest bit uncomfortable about observing satellite transits across the Sun, the alternative is to look for them across the Moon instead. Even here, you may need a filter on your telescope, but even if you don't use one, you won't cause any equipment damage or personal injury. Here's an excellent shot by Ed Morana of a transit of the ISS across the Moon taken just two months ago. The amount of detail is pretty phenomenal!

Slide 8: [Pause] So, just how do we set up a scenario to predict the circumstances for a satellite transit in STK? As it turns out, there are several ways to proceed here, depending on what you're trying to do. Let's start by seeing what's required if we want to predict when a specific satellite is visible from a particular location. Here, we'll start by creating an STK scenario with the satellite or satellites of interest and our observing location. Next, we'll add the Sun and Moon objects to

our scenario. Now, to determine when a satellite passes in front of the Sun or Moon, we need to set up two sensors—located at the observing site—one pointing at the Sun and the other pointing at the Moon. The sensors will each be simple conic sensors, with an angular radius equal to the semi-diameter of the Sun or the Moon. For both the Sun and the Moon, this value is approximately 16 arcminutes or about a quarter of a degree. More specifically, it is calculated as the arcsine of the ratio of the radius of the object to the distance of the object from the observer. We'll look at the geometry for determining this angle in more detail in the next slide.

Once the scenario is set up, all you need to do is run Access for each sensor to see when any of the satellites might be visible. Pretty easy!

Slide 9: [Pause] To be precise in our calculations requires that we size each of our sensors properly for each observing opportunity, since the distance to both the Sun and the Moon will vary throughout the year. The good news is that it's pretty easy to find the distance of either the Sun or Moon from your observing location using an AER—or azimuth-elevation-range—report when calculating an Access from your observing location to the Sun or Moon. For maximum accuracy, you'll want to use the distance closest to the time of the transit event, but taking an average value for the day should provide more than enough accuracy.

Slide 10: [Pause] Just to give you some idea of how much these values will vary, I did the following quick analysis with STK for the Sun and Moon for the entire year of 2006. While the distance—here all measured from the center of the Earth—to the Sun varied by almost 5 million kilometers during the course of the year, this only resulted in a difference of about half an arcminute in the solar semi-diamter, or an error of about 3 percent.

Performing the same analysis for the Moon, shows a difference in distance of less than 50,000 kilometers, but since the Moon is much closer than the Sun, the result is a variance of over two arcminutes in the lunar semi-diameter. That means the Moon can be 14 percent larger at its closest point than it is at its furthest.

Slide 11: [Pause] Now, let's look at how to apply this approach to one of the pictures we looked at back on Slide 5. This is the image taken by Tomas Maruska of the ISS crossing the Sun during the transit of Venus on June 8th of 2004.

Slide 12: [Pause] Let's look at the specifics of this observation so that we can replicate it in STK. The observations were taken from the village of Stupava, Slovakia. Tomas used a simple Philips ToUcam Pro webcam attached to his telescope and took video at 30 frames per second with 1/10,000th of a second exposure. A pretty simple setup for some amazing results. Of course, the real work was in the planning.

If we enter the coordinates Tomas provided, we're able to verify the time that he reports the event occurring—at 11:09:18 Central European Time—and…

Slide 13: [Pause] …even replicate the time-lapsed image, just as we see in the original picture. That was pretty easy, especially with the detailed information

provided by Tomas. I've also saved this scenario as an AGI Viewer file that you can download when this webinar is over. When run in its default mode, it should give you a pretty good idea of how quickly this event occurred and it matches quite nicely with the video which Tomas captured.

If you weren't able to join us for either of our last two webinars, you may not know what AGI Viewer is, so I'll take a moment to explain it. AGI Viewer is relatively new to the STK family. AGI Viewer is a free product which allows anyone with a Windows computer to view an STK scenario. Just like with Adobe Acrobat, where the authoring software requires a license but the Adobe Reader is free, STK can produce AGI Viewer files—also known as VDFs—which can then be viewed by anyone with the AGI Viewer software. You can find the free AGI Viewer on the AGI web site.

Once you've downloaded and installed AGI Viewer, you can get the VDF showing this ISS transit of the Sun and watch it unfold in detail. Not only can you watch the event as it would appear in real time, you can animate forward or backward, pause the animation, and zoom or pan the view for a more complete understanding of the event. I think you'll find this gives you a much better appreciation of this event than the screen shots found in this briefing. But don't just take my word for it—check it out yourself. You can find this VDF with the rest of the webinar materials after we're done.

Slide 14: [Pause] Many people think that this event was exceptionally rare. While it is true that it will be some time before such an event might happen again—the next Venus transit isn't until June 6th, 2012—many people throughout Europe and Asia had an opportunity to view this event but were blissfully unaware that it was occurring.

To see this, let's look at how we would predict where this event was visible. To find a viewing location for the transit of a specific satellite using STK, we again want to create a basic scenario with the satellite of interest—in this case the ISS. Then, we want to use Vector Geometry Tool to add coordinate axes to the ISS which will be aligned and constrained such that the Reference Vector points in the Sunlight direction and the Constrained Vector points toward the North Pole.

Next, we'll create a sensor on the satellite which has a simple conic shape of approximately 16 arcminutes—as we discussed before—and points along the Transit coordinate axes we just created.

Slide 15: [Pause] To set the correct size for the sensor, we'll again want to calculate the size of the cone, although this time we will do it slightly differently. As can be seen from this figure, the Sun subtends an angle, alpha, as seen from our target satellite. As it turns out, the projection of this cone toward the Earth also delineates the area on the Earth's surface that can see the target satellite in front of the Sun. In this case, Observer A will see the target satellite on the lower limb of the Sun and Observer B will see the target satellite on the upper limb of the Sun. So, the angle beta—the size of our 'sensor'—is the same as the angle alpha and can again be calculated as twice the arcsine of the radius of the Sun over the distance to the Sun—this time from the ISS.

Slide 16: [Pause] Using the distance to the Sun at the time of closest approach at Stupava, we get a cone angle of just under 16 arcminutes. We could just as easily have used an average value over the time period of interest—only about twenty minutes, in this case—with no significant difference in the results.

Before we look at the track, let's see how we would calculate the size of the footprint where we can see the ISS crossing the Sun. If we take our cone angle at the time of closest approach and combine it with the range, we can determine the along-track diameter to be 3.773 km. Then, if we take the elevation of the Sun into account—just over 63 degrees—we can determine the cross-track diameter to be 4.229 km. While this is not a large footprint, there is plenty of room for many people to see the event as it sweeps over the ground.

To get specific locations of where the ISS would cross the center of the Sun, we can create a sensor report using the Boresight Intersection report to get a listing of specific latitudes and longitudes where, and times when, this event would be visible.

Slide 17: [Pause] But let's take a minute to simply look at the resulting visualization of this event in STK. I've only shown a twenty-minute period of time here, starting at 10:00 UTC—just before the ISS transits the Sun over the Canary Islands. It then moves across central Europe before heading into Russia and Kazakhstan.

Slide 18: [Pause] A closer look shows the transit path crossing just north of the Straits of Gibraltar, over southern Spain and France, northern Italy, Austria, Slovakia, southern Poland and Belarus, and the Ukraine, before heading into Russia. Surely many hundreds of thousands of people must have been along the ISS transit path that day, but just didn't know it was happening.

Slide 19: [Pause] Now, as we move closer, we can see where the transit path moves from Austria into Slovakia as it passes over Stupava.

Slide 20: [Pause] Our final zoom shows the location of Tomas Maruska and his family as they watched the transits. They could have been closer to the center line of the transit path, but had some room to spare. All in all, things worked out quite well and we all got to share in this special event. Thanks, Tomas!

Before we move on, I'd like to point out that I've also saved this scenario, showing the ISS transit path across Europe and Asia from several viewpoints, in an AGI Viewer file that you can examine in more detail once this webinar is over.

Slide 21: [Pause] So, this got me to thinking about how difficult it would be to get a picture or video of this type of event. With the launch of STS 116 this past Saturday, I decided to take a look at what type of ISS transit events might be visible from Colorado Springs.

I began by setting up a scenario much like what we did in the last example. In this case, I looked throughout the period of the STS 116 mission, to see if there might

be any opportunities to see twin transits of the ISS and STS 116 or one with the two docked together. Not too surprisingly, there weren't any transits of either the Sun or the Moon visible from our location at CSSI visible any time during the mission.

This wasn't too surprising for the Sun, since the plane of the ISS orbit is currently aligned such that the orbit is in the Earth's shadow when the ISS passes over the northern hemisphere. But maybe there might be a possibility to see a lunar transit, if I were willing to drive a little to see it.

I decided to use an area target in STK to define the region of Colorado that I might be willing to drive to in order to see such an event. As it turns out, Colorado Springs is located about midway between Denver and Pueblo and all lie along the eastern edge of the Front Range of the Rocky Mountains. Travel through this region is facilitated by a north-south interstate highway—Interstate 25—with speed limits up to 75 mph. It would be fairly easy to drive to any point within this area in a little over an hour.

When I defined my elliptical area target for this region, I found there were actually two ISS transits across the Moon, early in the STS 116 mission. One occurred Sunday morning and the other was this morning.

Slide 22: [Pause] Here's how I set up the scenario in STK. I put in an area target—centered on CSSI—that was 150 km long by 50 km wide and aligned it with 175 degrees azimuth, so that it roughly paralleled the Front Range. I've shown both Denver and Pueblo in this view to give an idea of the scale and have loaded some imagery from Google Earth to help see where the transit paths pass and where the mountains are.

Using the persistence property for the Moon sensor, I was able to show each of the two paths across the region, with the upper path being the one for Sunday morning and the lower path occurring this morning.

To pick a specific point along one of these paths, one could simply double-click in STK's 3D window to get the coordinates, or use the Boresight Intersection report we discussed previously to get specific positions and times along the path.

Slide 23: [Pause] I chose the closest point along the two paths for this example, and have shown it in this shot.

Slide 24: [Pause] By changing our viewpoint to look from this observing point toward the Moon at 04:03:16 MST, we can see that the ISS moves from the upper right to the lower left across this image, with most of the path across the illuminated portion of the Moon. Of course, unless you have very good eyes, you probably can't see the ISS in this still shot. [Build] There, that's a little better. It's still pretty tough to see, though.

Slide 25: [Pause] Even zooming in—which would require a pretty good telescope—doesn't help a lot, but [Build] here's another hint. Plus, when you realize that the

entire transit across the Moon's disc lasts only a hair over half a second from this location, you can see that this type of visual observing will require a good deal of preparation. But, as we saw on Slide 7, the results can be pretty spectacular if you do your homework.

Slide 26: [Pause] So, what if you don't want to drive all over just to see a satellite transit? Does that mean you won't ever see one? Let's look at one more example in order to answer that question. In this case, we're going to build a scenario which will allow us to find all possible satellite transits across the Sun or the Moon, from a given fixed location. If this is possible, this should make it much more likely that you'll be able to see or record one, since it won't take as much time to set up to observe them.

In this example, we'll start by putting in our observing location and then adding objects for the Sun and the Moon, as we did in our first example. Then, we'll create the same simple conic sensors—one each pointed at the Sun and Moon—with the same angular size as our targets. Then, we'll use the DeckAccess feature in STK to run an entire list of satellites to look for transits. Experience may indicate that we should carefully tailor such a list to ensure we have only large objects that orbit at relatively low altitudes, but just to see what's possible, let's look at the entire catalog.

Slide 27: [Pause] Just looking at the 24-hour period starting at local midnight on December 7, I discovered that 75 lunar transits were visible from my location, with the longest lasting 48 seconds, and 59 solar transits, with the longest of those lasting 94 seconds. It sure seems that there are a lot of opportunities!

And, there are some special events when the number of transits can go up significantly. For example, from 40 degrees North latitude, the Sun will pass through the geostationary belt about 15 days before the vernal equinox and 15 days after the autumnal equinox, resulting in transits by virtually every geostationary satellite visible at a particular location. One of these occurrences was on March 4th of this year, when 65 satellites in the geostationary belt alone transited the Sun.

The only downside, particularly for the longest transits, is that their distances are such that the ISS—the largest satellite in orbit today, at about 80 m across—would have an angular size of less than an arcsecond at these distances. Even the largest geostationary satellites, such as Intelsat 10-02—which is 43 m across—are only half the width of the ISS.

Slide 28: [Pause] But, a quick histogram of the transit times show that these very long transits are actually somewhat anomalous and that the overwhelming majority of the transits have durations between 1 and 5 seconds. It seems that there should be ample opportunity to see things which, while not as large as the ISS, don't transit as quickly, either.

As we saw in our last two webinars, the key to success in visual observing is to have tools which will help you with your planning. So let's talk about one that should be quite helpful.

Slide 29: [Pause] Unlike our previous webinars, Heavens Above does not provide transit predictions—at least not yet—so let's jump right into the tool I developed for doing this in STK. Let's start by building a basic scenario with your location. Don't worry about setting anything else right now, unless you want to add terrain to your scenario. Save your basic scenario in a folder and [Build] place the following files in that folder: Transits.html, site.css, and Mean_Geocentric_Distance.rst. These will be provided on the webinar web site when we're done and we'll talk about these as we go.

[Build] Next, let's open an HTML Viewer window by selecting it from the View pull-down menu.

[Build] Now, use the HTML toolbar to browse to the location of the Transits.html file.

That file, together with the site.css file which describes how this HTML page will look…

Slide 30: [Pause] …will pop up an HTML panel on the right side of your STK application. This simple HTML page, which consists of basic HTML and VBScript available on all Windows computers, is only 16 kB, and you can go in and look at the source code and modify it, if desired. It will allow us to do everything we need to do to build a scenario to search for satellite transits from our location. We can do that to visually see what's happening in real time or schedule appointments in Outlook, by simply pressing a couple of buttons. Before we proceed, I would recommend saving your application again, so that it will automatically load with the HTML page already present.

The HTML page automatically sets the scenario time to the beginning of the current hour and looks one day ahead—actually, it uses the number of days at the bottom of the panel. That way you don't have to worry about forgetting to set the appropriate time interval. It also sets the animation time to real time and displays the time in STK as your local time.

The page also adds in the Sun and Moon, and builds sensors pointing at them automatically. This is where Mean_Geocentric_Distance.rst comes in. It is a custom report style which calculates the mean geocentric distance of the Sun or Moon over our scenario period for use in determining the size of the corresponding sensors. Finally, it also pre-builds views of the Sun and Moon from our selected observing location so that we can easily watch any of the transits we predict.

The application is intended to be run in checklist fashion, to make it easy to make the process repeatable. [Build] First, we select the observer location and decide whether we want to look for satellite transits across the Sun or Moon. All facilities loaded into the scenario at startup will be shown in the combo box. If you add new facilities after startup, just be sure to refresh the list before selecting the observer you want to use.

[Build] Next, you'll want to select the file of satellites you want to check for transits. By default, it is set up to look at one of the standard STK TLE files. All you need to do is make sure you have this updated before running this application. I'd recommend that you set it up to auto-update to ensure you have the very latest data and the best chance of making accurate predictions.

[Build] Now, all you have to do is decide which way you want the report data sorted and [Build] then, click the Generate Data button. If you run the entire catalog, this calculation will take 15 seconds or so to complete.

Slide 31: [Pause] When the calculations are done, [Build] the form will report how many transits were found in the designated interval and [Build] then list all of the transits at the bottom of the page. Each line shows the NORAD Catalog Number of the transiting satellite, followed by the start time of the transit.

[Build] If you click on one of the catalog numbers,…

Slide 32: [Pause] …the appropriate object will be automatically loaded from the specified TLE file. Then, [Build] if you click on the time field,…

Slide 33: [Pause] …the animation will automatically go to the time of the beginning of that transit. That was easy!

[Build] But even better, if you click on the appropriate tab for the type of transits you're looking for—in this case, for the Sun…

Slide 34: [Pause] …you'll see the view of the transit as if you were looking at the Sun from your location. You can now view this transit in animation to preview or in real time, as the event unfolds. Wow!

Let's try that again. [Build] Click on 19773 and [Build] then click on the corresponding time to…

Slide 35: [Pause] …jump directly to that transit. Cool! Now, if we decide we want to schedule that transit in Outlook, [Build] we check the checkbox in front of that transit—or any others that we're interested in—[Build] and then, make sure we have our Outlook preferences set. Next, [Build] ensure you have Outlook open and [Build] click Generate Schedule.

Slide 36: [Pause] Once the scheduled appointment is generated, which only takes a moment, you'll get [Build] notification indicating that it's done.

[Build] For each appointment, you'll get something that looks like this, with [Build] subject showing the type of transit and the NORAD Catalog Number of the transiting satellite and [Build] a location field which shows the observing location and time of the beginning of the transit. [Build] The notes section shows the rest of the details, including the start and stop times, duration, and when the appointment item was generated. Once you synchronize your new appointments with your PDA, you'll have no excuse for missing any of these events.

Slide 37: [Pause] For those of you who might be curious about how we interface with Microsoft Outlook, let's take a quick look at the code needed to generate an Outlook appointment. Actually, it's not too hard to use, once you know how. This example uses VBScript and matches pretty closely to what's in the Transits.html file that you can download when we're done.

[Build] You'll start by first creating an Outlook object. You need only do this once. [Build] Then, for each appointment, you'll create an Outlook appointment object, [Build] set all the relevant properties, and [Build] then save the appointment. After saving the appointment, [Build] you'll want to discard the appointment object. That's really all there is to it.

With this tool in hand, you should be all set to go out and observe some satellite transits yourself. I hope to hear reports from some of you—complete with pictures or video—showing how you've mastered this ultimate visual observing challenge.

Slide 29: [Build] That wraps up today's webinar. If you have any questions at this time, and haven't already entered them, please be sure to enter them now. If you'd rather send an e-mail question, you are more than welcome to do so via my CSSI or CelesTrak e-mail addresses.

While you're entering your questions, I'd like to take a moment to review some administrative items. First, I want to remind you that the original PowerPoint briefing used for today's presentation plus all the tools we discussed will be available with the other AGI webinar resources at www.agi.com/webinars. I will also be turning this webinar into a full-blown article, similar to the ones I used to do for *Satellite Times*, which will be available early next year on the CelesTrak web site. It will also include links to all the resources provided and will be updated, as needed.

I also hope to be able to build another STK application which will generate transit paths—as we did in our second example—which can then be automatically loaded into Google Earth or Google Maps, to help you pick the best observing location for unusual transit opportunities. This application will be available with the article on CelesTrak, once it is ready.

Next, I'd like to point out some of our upcoming webinar events. Our next two events are part of the AGI "How-To" series and include how to "Accelerate Application Development by Embedding AGI Technology" on December 14 and how to "Distribute Your Analysis Among Situational Awareness Users" on January 11. Then, our next CSSI webinar, on Probability Computations for Nonlinear Relative Motion," is scheduled for February 6 and will be presented by my colleague, Dr. Sal Alfano. I hope you'll want to join us for some of these events, too.

I want to thank you for joining us today and I hope you'll take time to provide feedback on what you saw today via the feedback form after we're done. Now, on to the questions.