Hubble Science Briefing

The Transit of Venus: A Cosmologist Prepares

3 May 2012
Dr. Susana Deustua
Transits of Venus

- What are they?
- How often do they occur?
- Why are they interesting?
- Where can I see one?
- How can I observe a transit this year?

Credit: NASA/LMSAL
When Does a Transit Occur?

When Venus is between Earth and Sun (Inferior Conjunction)

AND

When Venus crosses the Earth’s orbital plane

Figures are from http://astrobob.areavoices.com/2010/10/28/allow-me-to-introduce-you-to-venus-dark-side/
The image above shows the model of the orbit of Venus, relative to the Earth, made by Benjamin Cole in London to explain the transit of Venus to the Fellows of the Royal Society before 1761 (courtesy Science Museum, London).
Venus Transits from Earth

<table>
<thead>
<tr>
<th>Date</th>
<th>Interval years</th>
<th>Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1631 December 7</td>
<td>-</td>
<td>Ascending</td>
</tr>
<tr>
<td>1639 December 4</td>
<td>8</td>
<td>Ascending</td>
</tr>
<tr>
<td>1761 June 6</td>
<td>121.5</td>
<td>Descending</td>
</tr>
<tr>
<td>1769 June 3</td>
<td>8</td>
<td>Descending</td>
</tr>
<tr>
<td>1874 December 9</td>
<td>105.5</td>
<td>Ascending</td>
</tr>
<tr>
<td>1882 December 6</td>
<td>8</td>
<td>Ascending</td>
</tr>
<tr>
<td>2004 June 8</td>
<td>121.5</td>
<td>Descending</td>
</tr>
<tr>
<td>2012 June 6</td>
<td>8</td>
<td>Descending</td>
</tr>
</tbody>
</table>

Node: direction of Venus motion in its orbit when it crosses the plane of the Earth’s orbit.
Transit of Venus

• Why all the excitement?
  – Because we want to know
  – How Big is/are
    • The Universe
    • The Galaxy
    • The Solar System
    • Stars
    • Planets
  – Which means we want to know distances between objects
Principal Ways We Estimate Cosmological Distances

- Parallax
- Proper Motion
- Main Sequence Fitting
- RR-Lyrae and Cepheids
- Supernovae
- Redshifts

Distance in parsec

- Stars in the Milky Way Galaxy
- Star Clusters in the Milky Way Galaxy
- Nearby Galaxies
- Distant Galaxies
- Galaxies, Quasars, Galaxy Clusters
How do you measure the size of things?
How do you measure the size of things?

With a ruler, of course!
Imagine

What do you do when you can’t use a ruler at all?
Imagine

WHAT DO YOU DO WHEN YOU CAN’T USE A RULER AT ALL?

Can you get relative sizes?
   – *That* is $x$ times bigger than *this*?
Imagine

WHAT DO YOU DO WHEN YOU CAN’T USE A RULER AT ALL?

• Can you get relative sizes?
  – That is $x$ times bigger than this?

• **Can you use geometry? Trigonometry?**
soh, cah, toa (sine, cosine, tangent)
Parallax

Parallax is conceptually very simple - all one needs to do is measure angles and know the exact value of the Earth-Sun distance

$1 \text{ AU} = X \text{ miles}$

But how to measure it?
$A^2 + B^2 = C^2$

$\sin a = \frac{B}{C}$  \hspace{1cm}  $\sin b = \frac{A}{C}$

$\cos a = \frac{A}{C}$  \hspace{1cm}  $\cos b = \frac{B}{C}$

$\tan a = \frac{B}{A}$  \hspace{1cm}  $\tan b = \frac{A}{B}$
Jeremiah Horrox (1619-1641)

- Predicted and observed the 1639 transit of Venus
The Transit of Venus over the Sun:

OR

AN ASTRONOMICAL TREATISE

ON

THE CELEBRATED CONJUNCTION

OF

VENUS AND THE SUN

ON THE 24TH OF NOVEMBER, 1639.

BY JEREMIAH HORROX.

“In the second place, the distance between the centres of Venus and the Sun I found, by three observations, to be as follows:

<table>
<thead>
<tr>
<th>The Hour</th>
<th>Distance of the Centres</th>
</tr>
</thead>
<tbody>
<tr>
<td>At 3.15 by the clock.</td>
<td>14’ 24”</td>
</tr>
<tr>
<td>“ 3.35 “</td>
<td>13’ 30”</td>
</tr>
<tr>
<td>“ 3.45 “</td>
<td>13’ 00”</td>
</tr>
<tr>
<td>” 3.50 the apparent sunset.</td>
<td></td>
</tr>
</tbody>
</table>

The true setting being 3.45, and the apparent about 5 minutes later, the difference being caused by refraction. The clock therefore was sufficiently correct.”
Predicted and observed the 1639 transit of Venus
He based his predictions on Kepler’s laws
Published his results in *Venus in Sole Visa*
and
determined the diameter of Venus to be $\sim 1/30^{th}$ of the Sun’s
and
the relative distance of Venus:Sun and Earth:Sun
to be 72333:100000
Edmund Halley

- In 1676 a young Edmund Halley sets sail for the island of St. Helena, with a 5-foot sextant, a 24-foot long telescope, and a clock
- In November 1677 he observed and accurately recorded a transit of Mercury
- Consequently he realized that if a transit were observed at different latitudes, the solar parallax could be calculated from the apparent paths of the planet across the Sun.
The Solar Parallax

\[ \tan(SP) = \frac{\text{Radius of Earth}}{\text{Earth-Sun Distance}} \]

1 AU = \frac{\text{Radius of Earth}}{\tan(\text{SP})}
Two observers on Earth see two paths projected on the Sun. The difference in the paths is a parallax angle.

\[ \text{Earth-Venus Distance, } EV \]

\[ \text{EV} + \text{VS} = \text{ES, Earth-Sun Distance} \]

and know the ratio \( \text{VS} = 0.72 \text{ ES} \)
120 observers at 60 stations, among which were French and English astronomers who voyaged thousands of miles to set up observation posts.

**Results**

- **solar parallax**
  8.28 – 10.60 arcseconds

- **earth-sun distance**
  77 x10^6 – 97 x10^6 miles
1761 Cape Town, South Africa

**Venus Transit Diagram**

- 09h
- 08h
- 07h
- 06h
- 05h
- 04h
- 03h
- 02h
- Zenith
- Nadir

**Solar Location Diagram**

- North
- East
- West
- South

- $\lambda = 18^\circ 28' 00'' 0 \ E$
- $\varphi = 33^\circ 57' 00'' 0 \ S$

**Local Circumstances for Cape Town**

- Exterior ingress on: 1761/06/06 at 02h05m08.7s UT
- Interior ingress on: 1761/06/06 at 02h23m23.6s UT
- Minimum separation on: 1761/06/06 at 05h25m26.8s UT of 582.9 arcseconds
- Interior egress on: 1761/06/06 at 08h24m39.0s UT
- Exterior egress on: 1761/06/06 at 08h42m20.7s UT
1769 Transit Map of M. de la Lande
Some veterans of the 1761 expeditions and new actors:

1. Guillaume Le Gentil – left Manila and headed to Pondichery, India (where he was clouded out!)
2. Alexandre Pingre – Santo Domingo
3. Jean Baptise Chappe d’Autreroche – San Jose del Cabo in Baja California (died, typhus epidemic)
4. Father Maximilian Hell - Vardö, Lapland
5. Stepan Rumovsky – Kola Peninsula
6. Joseph Dymond & William Wales-Hudson Bay, Canada
7. James Cook & Charles Green to the South Seas (Tahiti)

If anything, more enthusiasm for the next transit.

Results
600+ papers written
⇒ solar parallax: 8.43 – 8.80 arcseconds
⇒ earth-sun distance 90 x 10^6 – 94 x 10^6 miles

Better – but still not accurate enough at 5%.
1769: Papeete, Tahiti

**Venus Transit Diagram**

1769/06/03–04

**Solar Location Diagram**

North

South

West

East

\[ \lambda = 149^\circ 31' 00" - 0 W \]

\[ \varphi = 17^\circ 30' 00" - 0 S \]

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**Local Circumstances for Papeete**

- Exterior ingress on 1769/06/03 at 19h21m01s4 UT
- Interior ingress on 1769/06/03 at 19h39m57s7 UT
- Minimum separation on 1769/06/03 at 22h24m51s1 UT of 623.5 arcseconds
- Interior egress on 1769/06/04 at 01h09m55s1 UT
- Exterior egress on 1769/06/04 at 01h28m53s8 UT
A view from the South Seas

Captain James Cook’s & Charles Green’s observations of the transit of Venus in 1769

Note the ‘Black Drop’.
Nevertheless, in 1891 Simon Newcomb, American Astronomer, re-analyzed ALL the Venus transit data using meta-analysis. His Results:

- **solar parallax:** 8.79 arcseconds
- **earth-sun distance:** 92.99 x10^6 miles

NB: 1771 analysis by Thomas Hornby, English scientists, based on observations from 5 locations.

- **solar parallax:** 8.65 arcseconds
- **earth-sun distance:** 93.72 x10^6 miles

for an earth radius of 3985 miles.
Astronomers use RADAR echoes (just like state troopers with their radar guns) to measure distance to Venus from Earth over a period of time.
20th Century

- radio signal travels at light speed
- measure time for signal roundtrip
- calculate

\[ \text{distance} = \text{velocity} \times \text{time} \]

Today’s accepted values

⇒ **solar parallax**
   8.794148 arcsecond

⇒ **Earth-Sun distance**
   92,958,329 miles
Pete Lawrence’s montage of the 2004 transit, including an annular eclipse of the planet.
21st Century Observations of Venus: Hubble Space Telescope
21st Century Observations of Venus: Hubble Space Telescope

In January, 2012 HST practiced for the June 5/6 2012 Transit of Venus

• by acquiring data of two craters on the moon: Hipparchus-C and Dolland-E

• to test the orbit at a similar moon phase as during the 2012 transit of Venus, select an appropriate location to target on the Moon and fine-tune the exposure times for the different instruments and filters used.

Ref: Visit Status Report
Venus reflected off the moon
In a relatively near future, numerous transiting extrasolar planets will be discovered \{gaseous giant planets, Earth-size planets and temperate Uranus in the form of "Ocean-planets"\}. Space telescopes operating in the UV-optical-IR will allow the study of their atmospheres. We have to show if and how these observations will give access to the detection of atmospheric species, particularly when telluric (Earth-like) planets will be observed, to demonstrate that life may be possible on one of them. For that purpose, we propose to use the unique event of the century, the Venus transit in 2012 \{next Venus transits are in 2117 and 2125!\}, to demonstrate the feasibility of these observations and show precisely what a Venus-like planet will look-like. To observe the Venus transit with similar conditions as extrasolar planets \{no spatial resolution\}, we propose to observe the solar light reflected on the Moon during the Venus transit on June 5-6 2012, lasting about 7h 40mn, i.e. about 4 HST orbits. A total of 5 HST orbits will allow us to obtain high S/N transit spectra and reference spectra to reveal the detectable atmospheric species with current space instrumentations. Similarly, in a companion proposal, we propose to observe the Earth transit on the Moon through the reflected light during a total Moon eclipse to directly compare the observed atmospheric signatures of Earth-like and Venus-like extrasolar planets.”

5/6 June 2012 Transit of Venus
World visibility of the transit of Venus on June 6 & June 5, 2012

General circumstances of the transit:

1. 22:09:42 UT: Venus touches Sun's disk at start of transit, exterior contact
2. 22:27:30 UT: Venus within Sun's disk at start of transit ingress, interior contact
3. 04:19:37 UT: Transit maximum, minimum separation
4. 04:31:44 UT: Venus within Sun's disk at end of transit ingress, interior contact
5. 04:49:32 UT: Venus touches Sun's disk at end of transit egress, exterior contact

Times given in Universal Time (UT) for locations where Venus is overhead. Contact times around the world vary as much as nearly seven minutes because of parallax. For local transit times, see http://transitofvenus.nl/wp/where-when/local-transit-times/
6 June 2012 Transit of Venus in Australia

<table>
<thead>
<tr>
<th>Location</th>
<th>Ingress</th>
<th>Max</th>
<th>Egress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
</tr>
<tr>
<td>Adelaide</td>
<td>7:46 am</td>
<td>8:04 am</td>
<td>11:01 am</td>
</tr>
<tr>
<td>Brisbane</td>
<td>8:16 am</td>
<td>8:34 am</td>
<td>11:30 am</td>
</tr>
<tr>
<td>Canberra</td>
<td>8:16 am</td>
<td>8:34 am</td>
<td>11:31 am</td>
</tr>
<tr>
<td>Darwin</td>
<td>7:45 am</td>
<td>8:03 am</td>
<td>11:01 am</td>
</tr>
<tr>
<td>Hobart</td>
<td>8:16 am</td>
<td>8:34 am</td>
<td>11:31 am</td>
</tr>
<tr>
<td>Melbourne</td>
<td>8:16 am</td>
<td>8:34 am</td>
<td>11:31 am</td>
</tr>
<tr>
<td>Perth</td>
<td>Before sunrise</td>
<td>9:32 am</td>
<td>12:29 pm</td>
</tr>
<tr>
<td>Sydney</td>
<td>8:16 am</td>
<td>8:34 am</td>
<td>11:30 am</td>
</tr>
<tr>
<td>Townsville</td>
<td>8:16 am</td>
<td>8:34 am</td>
<td>11:31 am</td>
</tr>
</tbody>
</table>
Sun Funnel

- [http://cdn.transitofvenus.org/docs/Build_a_Sun_Funnel.pdf](http://cdn.transitofvenus.org/docs/Build_a_Sun_Funnel.pdf)
A pinhole camera
A pinhole camera

You will need

1. **a white screen:**
   1. blank sheet of white paper, a sheet on a wall, a white wall

2. **a pinhole:**
   1. index card, sheet of cardboard
      1. cut out a 2cm-sized hole (round or square or triangle or any shape really)
   2. tape aluminum foil over hole in cardboard
   3. Poke hole in foil with pin

OR

2. cover window except for a very small area with black material/paper

3. **Project image of sun through pinhole onto screen.**
   - The larger the distance between pinhole and screen the larger the image

http://www.exploratorium.edu/eclipse/how.html
General Advice

Check with your local astronomy clubs, community colleges, science centers, museums and similar organizations for transit events in your community.

And, of course, **NEVER** stare directly at the SUN.
Be Safe
Eye Safety

See Viewing the Transit & Eye Safety at june2012/eye-safety/280-viewing-the-transit-eye-safety for definitive advice on viewing the sun safely; by B. Ralph Chou, MSc, OD. (linked from http://www.transitofvenus.org/june2012/eye-safety)

"It is never safe to look at the sun without proper eye protection. No filter should be used with an optical device (e.g. binoculars, telescope, camera) unless that filter has been specifically designed for that purpose and is mounted at the front end (i.e., end towards the Sun). Unsafe filters include all color film, black-and-white film that contains no silver, photographic negatives with images on them (x-rays and snapshots), smoked glass, sunglasses (single or multiple pairs), photographic neutral density filters and polarizing filters, computer disk media. Most of these transmit high levels of invisible infrared radiation which can cause a thermal retinal burn. The fact that the Sun appears dim, or that you feel no discomfort when looking at the Sun through the filter, is no guarantee that your eyes are safe. A person with eye damage from improper viewing may not notice the damage until hours later."
some websites

- http://transitofvenus.com/
- http://transitofvenus.org/
- http://www.exploratorium.edu/venus/
Questions?