Reading: Chapter 4, Section 4.7 (today),4.4; Chapter 2, Sect. 2.2, 2.4
Homework #2: Due in recitation Friday/Monday!
Homework #3: Available Thursday, due 9-20/23

Brief review of last time: **The Seasons & the motions of the Moon**

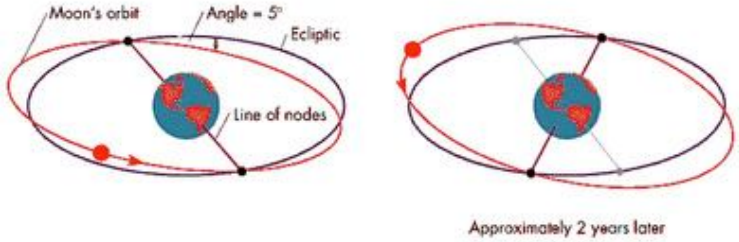
- The Seasons: declination of the Sun drives them
- The Motion of the Moon: sidereal and synodic month
- Phases of the Moon
  - new->waxing->1st Q->Full->waning->3rd Q-> new
- The Moon's Orbit
  - intersects ecliptic at two nodes (ascending, descending)
  - titled 5^{o} to ecliptic; node line goes around the sky in 18.7 years

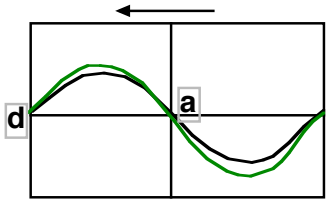
Brief review of last time: **The Moon's Orbit & Eclipses**

- Moon's Orbit and Eclipses
  - eclipses possible only when New/Full moon is at a node
- Anatomy of a Shadow
- Circumstances of eclipses
- Lunar eclipse: Sun at one node, Moon at the other (at full moon)
- Solar eclipse: Sun at one node, Moon at the same (at new moon)

Regression of the line of nodes:

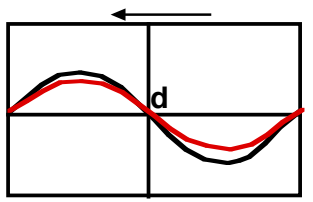
Line of nodes circles WESTWARD in 18.7 years
(caused by "torquing" effect of the Sun):





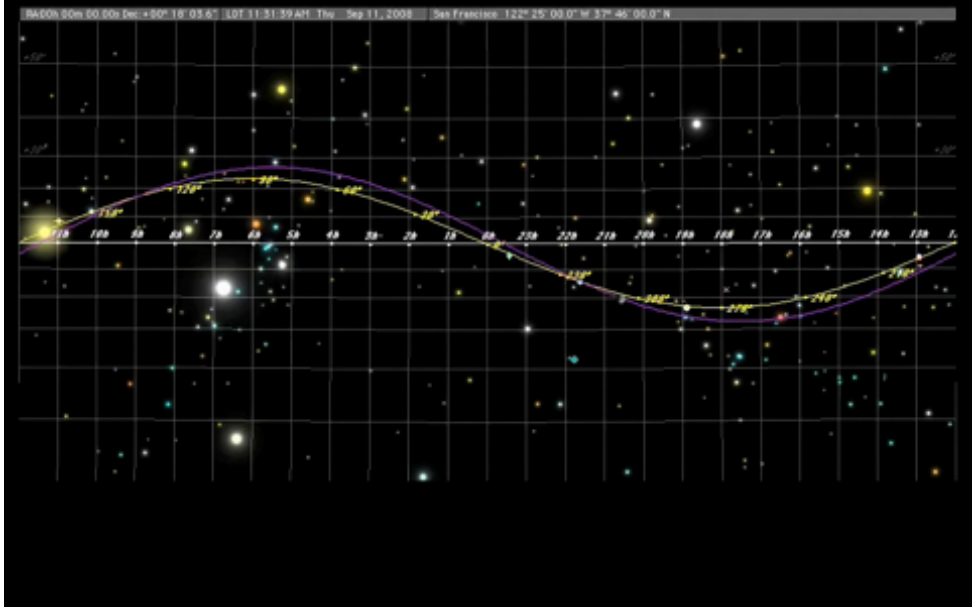
Highest/Lowest Moon

9.35 years later:



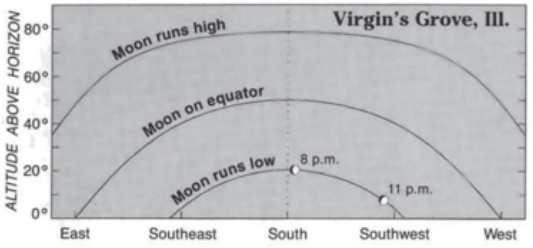
smallest lunar altitude variation

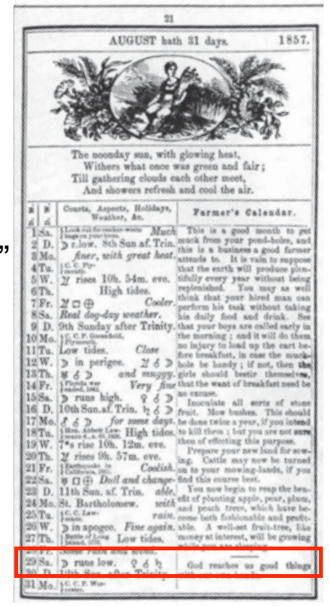
One Saros cycle



Lincoln and the "almanac trial"

- Fatal fight in Virgin's Grove at 11pm on August 29, 1857
- "eyewitness" claimed to see two murderers by light of the bright moon
- Lincoln examined the witness, showing an almanac page with "[moon] runs low"
- witness impugned, defendant cleared!



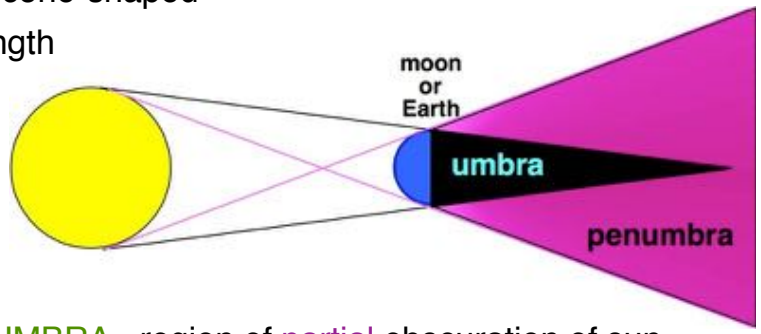


aspects of the lunar orbit
(there is no 'dark side')

- **Tidal locking**
  - moon rotates once per orbit
  - we always see the same face of the moon
  - the lunar "far side" is invisible from Earth
- **libration**
  (inclination of rotation axis to its orbit)
  - allows a "peek" over north pole and under south pole
- **elliptical orbit** causes "nodding" East-West
  - peek around east and west limbs
- **Net effect:**
  we can see ~ 59% of the moons surface from the Earth

Earth and Moon Shadows

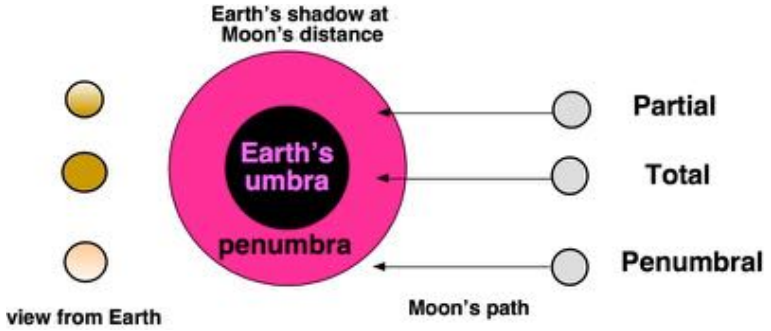
- The UMBRA - region of total obscuration of Sun
  - narrow, cone-shaped
  - finite length



- The PENUMBRA - region of partial obscuration of sun
  - broadening cone-shaped
  - "infinite" length

Circumstances of a Lunar Eclipse

- Moon passes through Earth's shadow
  - total
  - partial
  - penumbral
- visible whenever the moon is above horizon
- duration up to 1.5 hours (total) and 3 hours (partial)



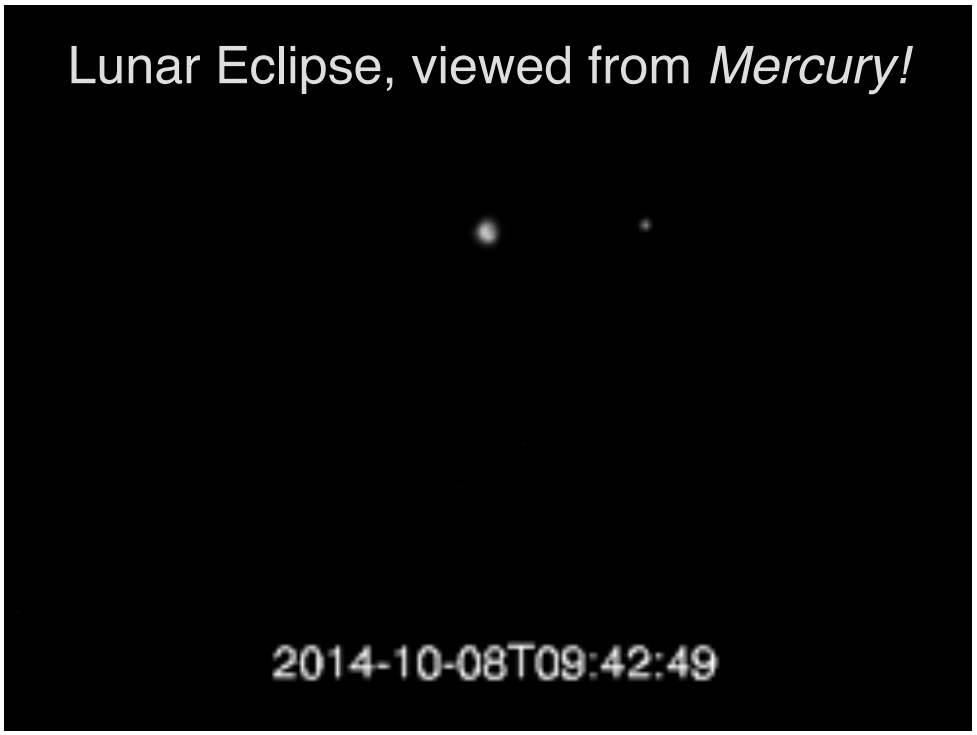
Earth's shadow revealed by a lunar eclipse:

Lunar Eclipses: 2011 - 2020

Calendar Date (Link to Figure)	TD of Greatest Eclipse	Eclipse Type	Saros Series	Umbral Magnitude	Partial/Total Duration	Geographic Region of Eclipse Visibility (Link to RASC Observers Handbook)
2011 Jun 15	20:13:43	Total	130	1.700	03h39m **01h40m**	S.America, Europe, Africa, Asia, Aus.
2011 Dec 10	14:32:56	Total	135	1.106	03h32m **00h51m**	Europe, e Africa, Asia, Aus., Pacific, N.A.
2012 Jun 04	11:04:20	Partial	140	0.370	02h07m	Asia, Aus., Pacific, Americas
2012 Nov 28	14:34:07	Penumbral	145	-0.187	-	Europe, e Africa, Asia, Aus., Pacific, N.A.
2013 Apr 25	20:08:38	Partial	112	0.015	00h27m	Europe, Africa, Asia, Aus.
2013 May 25	04:11:06	Penumbral	150	-0.934	-	Americas, Africa
2013 Oct 18	23:51:25	Penumbral	117	-0.272	-	Americas, Europe, Africa, Asia
2014 Apr 15	07:46:48	Total	122	1.291	03h35m **01h18m**	Aus., Pacific, Americas
2014 Oct 08	10:55:44	Total	127	1.166	03h20m **00h59m**	Asia, Aus., Pacific, Americas
2015 Apr 04	12:01:24	Total	132	1.001	03h29m **00h05m**	Asia, Aus., Pacific, Americas
2015 Sep 28	02:48:17	Total	137	1.276	03h20m **01h12m**	e Pacific, Americas, Europe, Africa, w Asia
2016 Mar 23	11:48:21	Penumbral	142	-0.312	-	Asia, Aus., Pacific, w Americas
2016 Sep 16	18:55:27	Penumbral	147	-0.064	-	Europe, Africa, Asia, Aus., w Pacific
2017 Feb 11	00:45:03	Penumbral	114	-0.035	-	Americas, Europe, Africa, Asia
2017 Aug 07	18:21:38	Partial	119	0.246	01h55m	Europe, Africa, Asia, Aus.
2018 Jan 31	13:31:00	Total	124	1.315	03h23m **01h16m**	Asia, Aus., Pacific, w N.America
2018 Jul 27	20:22:54	Total	129	1.609	03h55m **01h43m**	S.America, Europe, Africa, Asia, Aus.
2019 Jan 21	05:13:27	Total	134	1.195	03h17m **01h02m**	c Pacific, Americas, Europe, Africa
2019 Jul 16	21:31:55	Partial	139	0.653	02h58m	S.America, Europe, Africa, Asia, Aus.
2020 Jan 10	19:11:11	Penumbral	144	-0.116	-	Europe, Africa, Asia, Aus.
2020 Jun 05	19:26:14	Penumbral	111	-0.405	-	Europe, Africa, Asia, Aus.
2020 Jul 05	04:31:12	Penumbral	149	-0.644	-	Americas, sw Europe, Africa
2020 Nov 30	09:44:01	Penumbral	116	-0.262	-	Asia, Aus., Pacific, Americas

http://eclipse.gsfc.nasa.gov/lunar.html

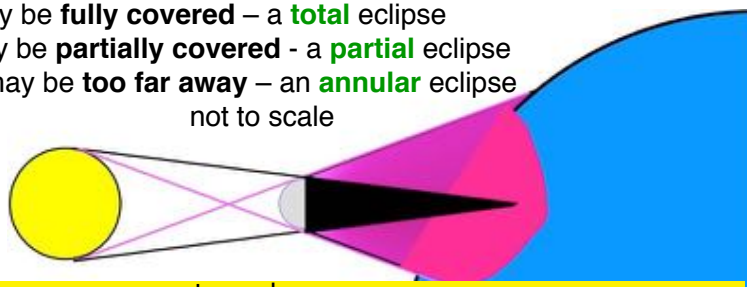
2011 Jun 15	20:13:43	Total	130	1.700	03h39m **01h40m**	S.America, Europe, Africa, Asia, A
2011 Dec 10	14:32:56	Total	135	1.106	03h32m **00h51m**	Europe, e Africa, Asia, Aus., Pacif
2012 Jun 04	11:04:20	Partial	140	0.370	02h07m	Asia, Aus., Pacific, Americas
2012 Nov 28	14:34:07	Penumbral	145	-0.187	-	Europe, e Africa, Asia, Aus., N.A.
2013 Apr 25	20:08:38	Partial	112	0.015	00h27m	Europe, Africa, Asia, Aus.
2013 May 25	04:11:06	Penumbral	150	-0.934	-	Americas, Africa
2013 Oct 18	23:51:25	Penumbral	117	-0.272	-	Americas, Europe, Africa, Asi
2014 Apr 15	07:46:48	Total	122	1.291	03h35m **01h18m**	Aus., Pacific, Americas
2014 Oct 08	10:55:44	Total	127	1.166	03h20m **00h59m**	Asia, Aus., Pacific, Americas
2015 Apr 04	12:01:24	Total	132	1.001	03h29m **00h05m**	Asia, Aus., Pacific, Americas
2015 Sep 28	02:48:17	Total	137	1.276	03h20m **01h12m**	e Pacific, Americas, Europe, Asia
2016 Mar 23	11:48:21	Penumbral	142	-0.312	-	Asia, Aus., Pacific, w Americ
2016 Sep 16	18:55:27	Penumbral	147	-0.064	-	Europe, Africa, Asia, Aus., w
2017 Feb 11	00:45:03	Penumbral	114	-0.035	-	Americas, Europe, Africa, Asi
2017 Aug 07	18:21:38	Partial	119	0.246	01h55m	Europe, Africa, Asia, Aus.
2018 Jan 31	13:31:00	Total	124	1.315	03h23m **01h16m**	Asia, Aus., Pacific, w N.Amer
2018 Jul 27	20:22:54	Total	129	1.609	03h55m **01h43m**	S.America, Europe, Africa, A
2019 Jan 21	05:13:27	Total	134	1.195	03h17m	c Pacific, Americas, Europe,



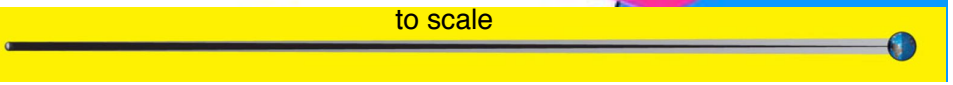
Circumstances of a Solar Eclipse

- Moon's shadow crosses Earth's surface
  - total, partial, annular
- Moon's umbra's length ***almost***
  = average Earth-Moon distance
- Moon and Sun have ~ same angular size
  - so Sun may be **fully covered** – a **total** eclipse
  - or Sun may be **partially covered** - a **partial** eclipse
  - or **moon** may be **too far away** – an **annular** eclipse

not to scale



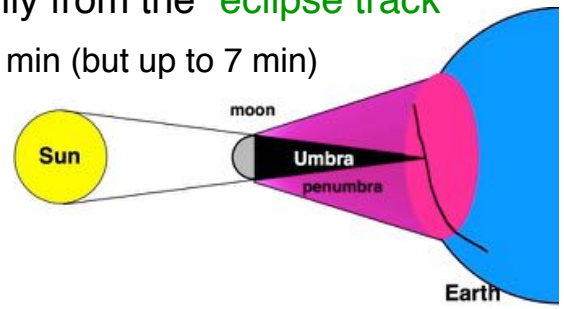
to scale



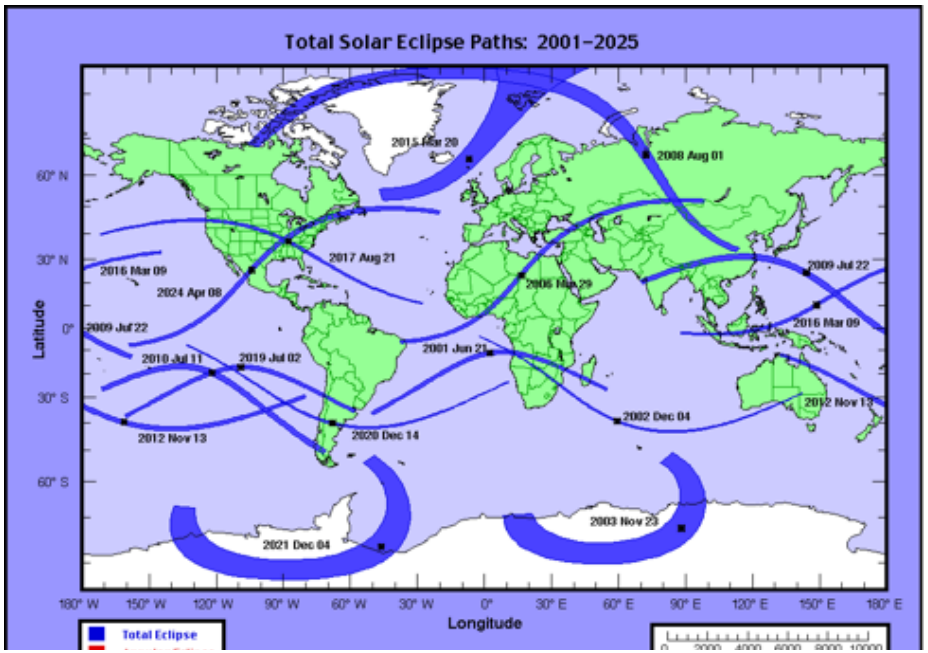
A Total Solar Eclipse

- partial phases (Moon's penumbra) widely viewable
- Moon's umbra sweeps a narrow path across Earth
  - 0 to 200 km across
  - up to 10,000 km long
  - sweeps across Earth at 3400 km/h !

- TOTALITY visible only from the "eclipse track"
  - duration - usually 2-3 min (but up to 7 min)

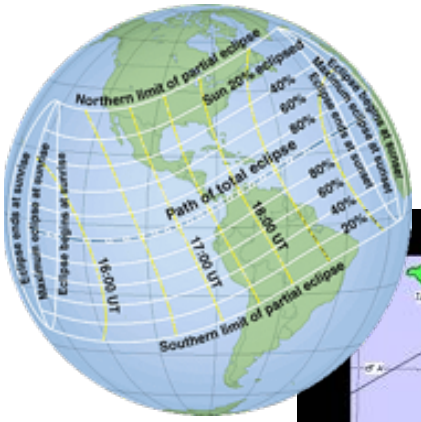


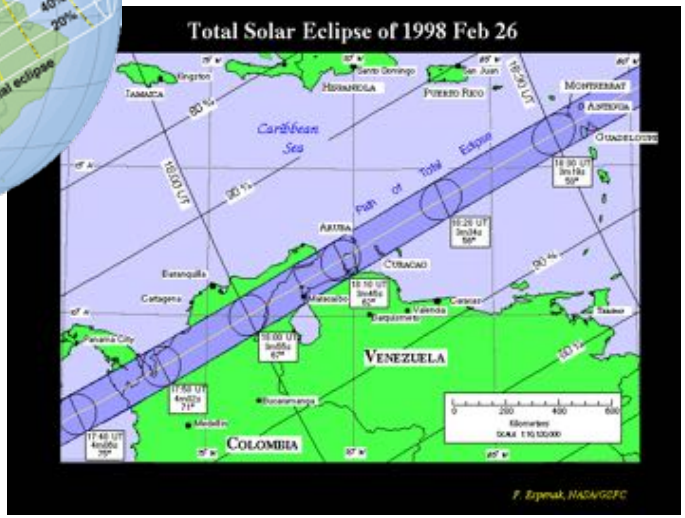
Recent & upcoming total solar eclipses



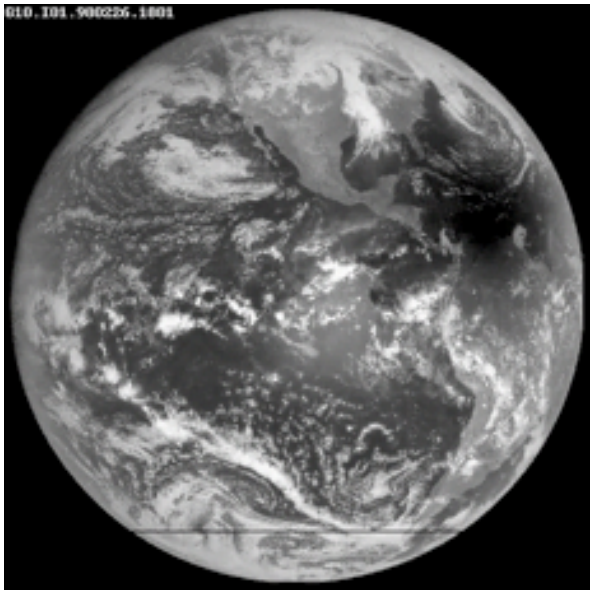
August 21, 2017 Total Eclipse

NASA's Earth Polychromatic Imaging Camera

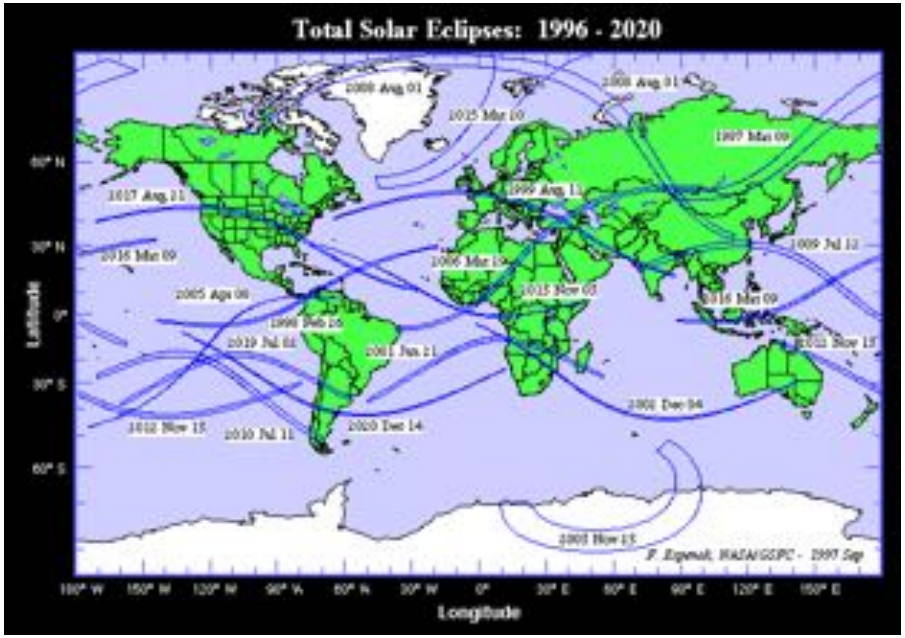




Feb 26, 1998 Eclipse viewed from space

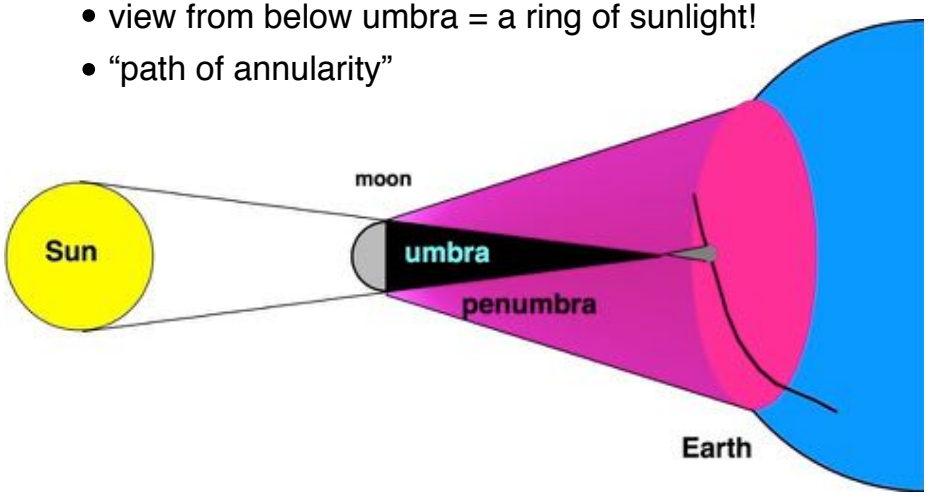


http://goes.gsfc.nasa.gov/text/goes10results.html#eclipse.images

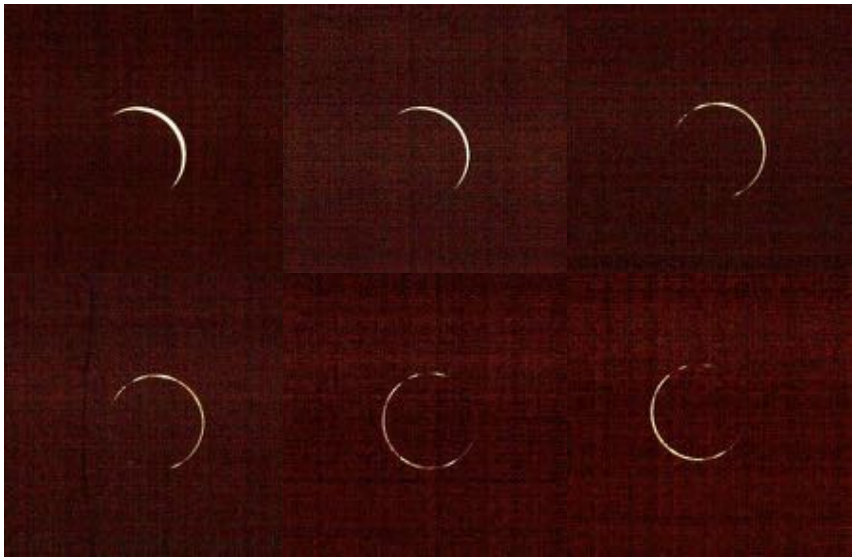


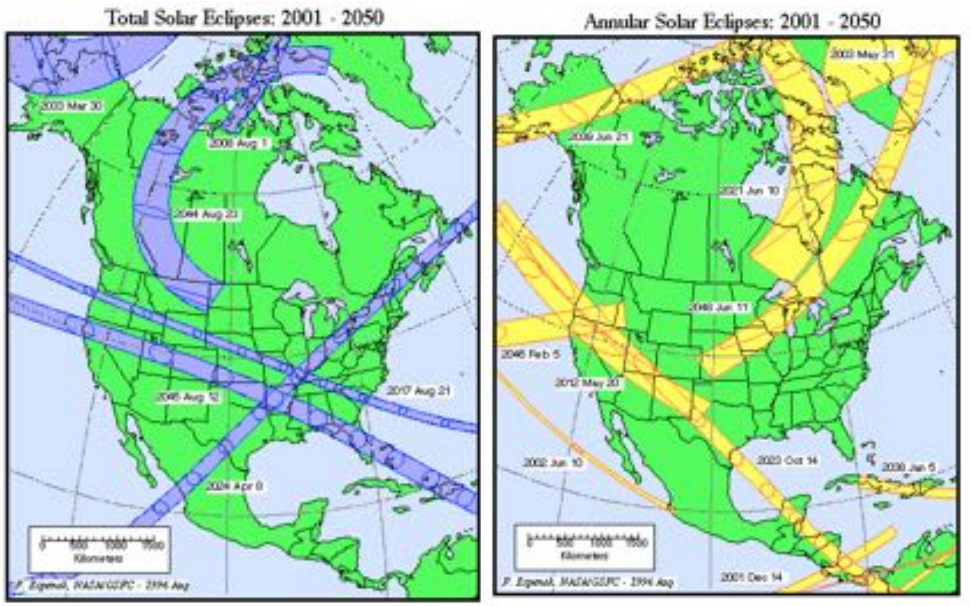
Annular Solar Eclipse

- annular eclipse – umbra tip lies above Earth
- view from below umbra = a ring of sunlight!
- “path of annularity”



May 30, 1984




Total Solar Eclipses: 2001 - 2050
2008 Aug 1
2044 Aug 23
2017 Aug 21
2045 Aug 12
2024 Apr 8
Kilometers
F. Espenak, NASA/GSFC - 1994 Aug
Annular Solar Eclipses: 2001 - 2050
2039 Jun 21
2021 Jun 10
2046 Feb 5
2012 May 20
2002 Jun 10
2023 Oct 14
2030 Jun 5
2001 Dec 14
Kilometers
F. Espenak, NASA/GSFC - 1994 Aug