Astrophysical techniques

Lecture 1B: time and space-based observing

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Time

- Observations often require precisely recorded times
- Complexity increases with required precision

Commonly used calendars

- Gregorian calendar (our civil calendar)
  - e.g. 2011 November 11 11:00:00.0

- Julian date (not same as Julian calendar)
  - e.g. JD 2455876.958333

  - Simple count of days since Greenwich Noon on 1 Jan 4713BC
    - provides useful continuous scale for time measurements
    - consider how many days between e.g. 1998 Jan 17 and 2009 Oct 3 ?!

  - Note: Julian days begin at noon
    - can be useful for astronomy (in Europe at least)
    - but plenty of potential for confusion in converting JD to Gregorian date
  - Also: be aware of commonly used abbreviations
    - Modified Julian Date, MJD = JD - 2400000.5
    - Truncated Julian Date, TJD = JD - 2440000.5 (less used since 1995)
    - Half day difference has extreme potential for confusion / error !

Time systems I

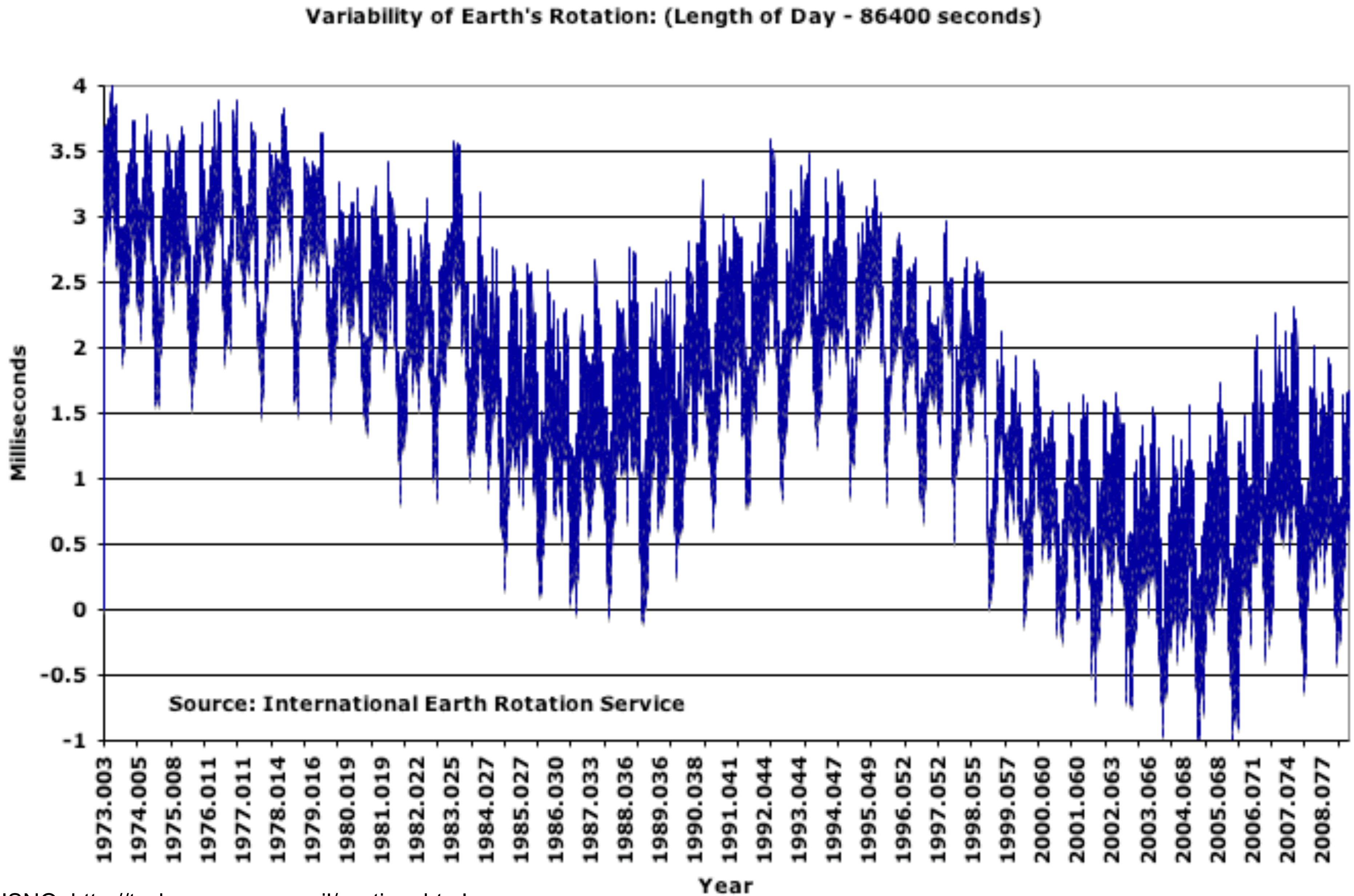
- There are many time systems, the most relevant include:

- Universal time (UT1), previously Greenwich Mean Time
  - This is Solar time based on the (variable) spin of the Earth
  - Always 86400s/day, but day (and hence sec) has variable length

- International Atomic Time (TAI)
  - SI second defined by frequency of hyperfine transition of cesium133
  - Measured and counted with international network of atomic clocks

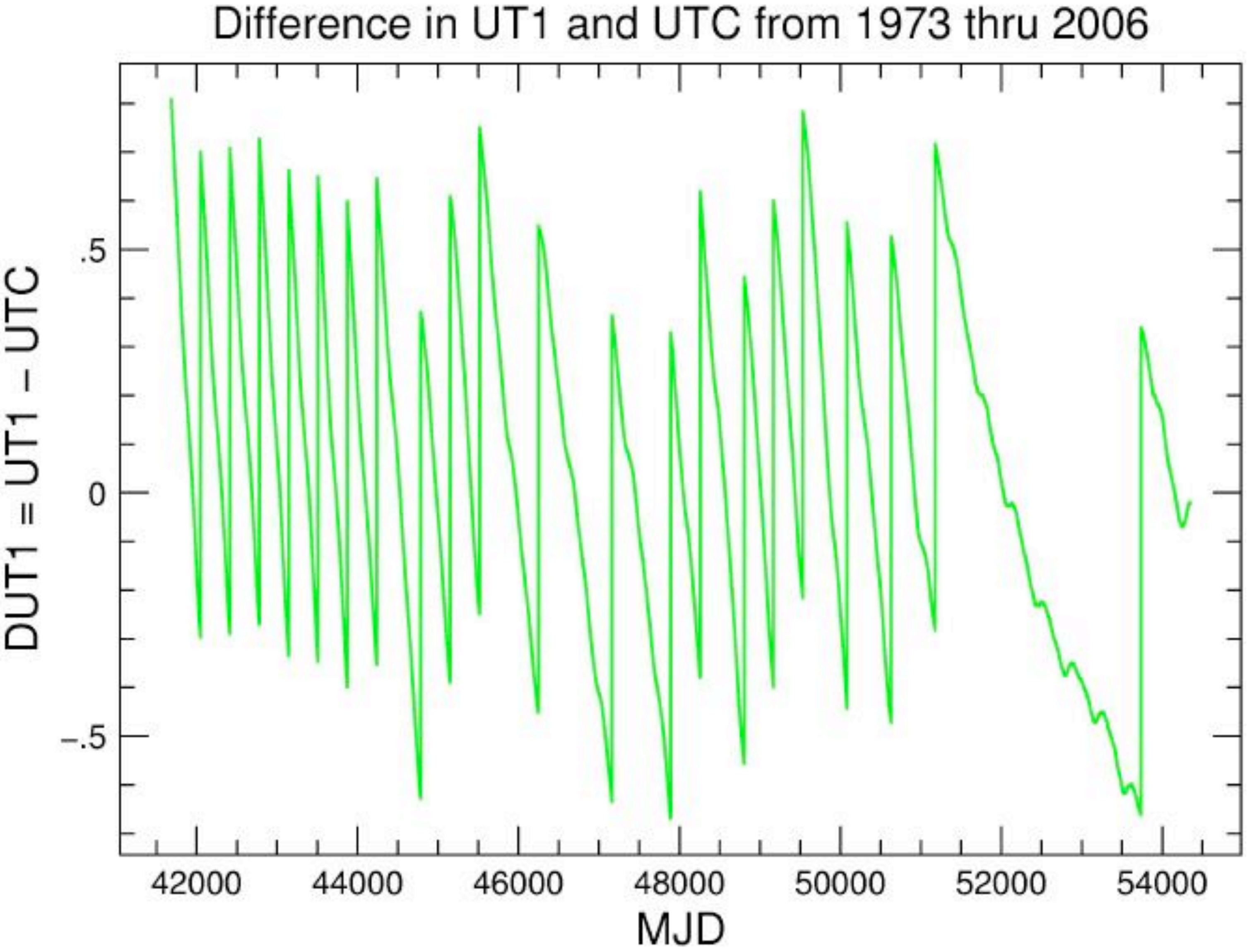
- Co-ordinated Universal Time (UTC)
  - Our civil time (in winter)
  - Based on SI second, with 86400s/day
  - Kept synchronised with UT1 since 1972 by addition of leap seconds
  - Leap seconds not added to TAI, so TAI-UTC is not constant
  - Currently (Nov 2012) TAI - UTC = 35s
  - Use of leap secs currently under discussion (inconvenient for astro)

Length of Earth day

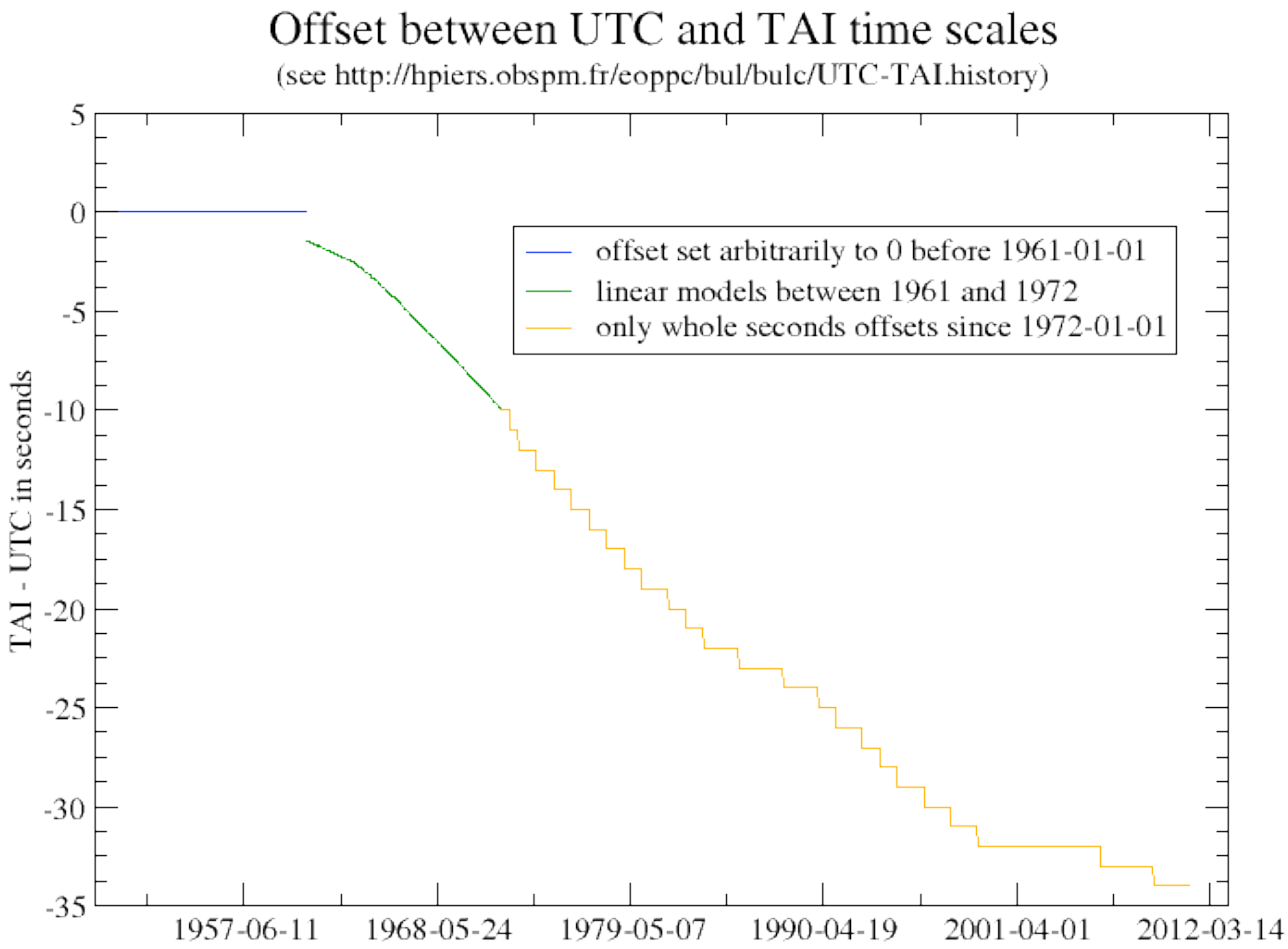


USNO: http://tycho.usno.navy.mil/systime.html

UT1-UTC



Difference in UT1 and UTC from 1973 thru 2006
DUT1 = UT1 – UTC
.5
0
–.5
42000
44000
46000
48000
50000
52000
54000
MJD


Offset between UTC and TAI time scales
(see http://hpiers.obspm.fr/eoppc/bul/bulc/UTC-TAI.history)
offset set arbitrarily to 0 before 1961-01-01
linear models between 1961 and 1972
only whole seconds offsets since 1972-01-01
TAI - UTC in seconds
5
0
-5
-10
-15
-20
-25
-30
-35
1957-06-11
1968-05-24
1979-05-07
1990-04-19
2001-04-01
2012-03-14

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Time systems II

- Co-ordinated Universal Time (UTC)
  - Currently (Nov 2012) TAI - UTC = 35s
- Terrestrial Time (TT)
  - Previously called Terrestrial Dynamical Time (TDT)
  - Relativistic time based on the SI sec on the geoid (Earth surface)
  - TT = TAI + 32.184s (no leap seconds)
  - Offset required for consistency with previous *Ephemeris Time* (ET)
  - Currently (Nov 2012) TT = UTC + 35s + 32.184s = UTC + 67.184s
  - Beware of the one minute offset !
- Barycentric Dynamical Time (TDB)
  - The equivalent of TT for the Solar System Barycenter
  - Differs from TT only by small periodic variations (msec)
- Beyond this time systems get very complicated!
  - But only needed for very precise applications such as pulsar timing

Quoting times

- Calendar is independent of time system, so state both, e.g.
  - 2011 November 11 11:00:00.0 UTC
  - 2011 November 11 11:00:34.0 TAI
  - 2011 November 11 11:01:06.184 TT
  - JD 2455876.958333 UTC
  - JD 2455876.958727 TAI
  - JD 2455876.959100 TT
  - JD(TT) 2455876.959100

- In practice most astronomers use UTC or TT/TDB

- Note: standard is yyyy-mm-ddThh:mm:ss.s
  - 2011-12-31T17:00:00.00 UTC
  - 2011 December 31 17:00:00.00 UTC

Corrections for light travel time

- Heliocentric correction
  - Correction of times to Sun centre
  - +/- 8mins over 6 months for objects in ecliptic plane
  - zero for objects at ecliptic poles
  - Quote corrected times as e.g. HJD 2455876.958333 UTC

- Barycentric correction
  - corrects times to Solar system barycenter
  - more precise (accounts for orbital motion of Sun)
  - Quote as e.g. BJD 2455876.958333 UTC
  - Sometimes see BJDD indicating BJD in TT/TDB time system

- Barycentric correction often also needed to measured radial velocities for Earth / Spacecraft motion

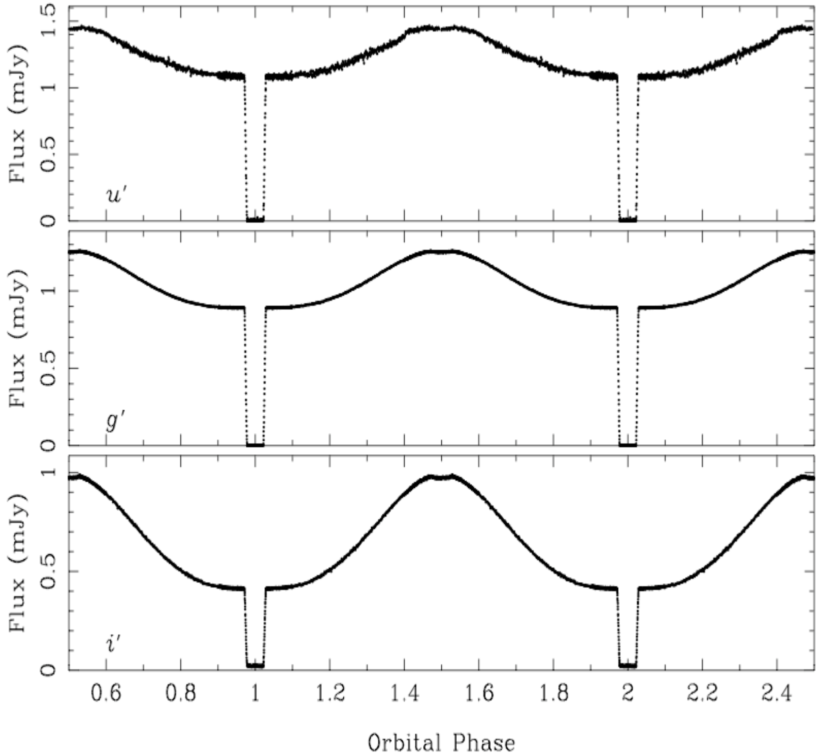
Ephemerides

- Describe periodic signals with an ephemeris, e.g.
  - Linear ephemeris: BJD(TT) = $T_0 + P_0\,E$
    where T_0 is the epoch of phase zero (an example time),
    P_0 is the period, E is the cycle count, and
    BJD(TT) indicates the calendar and time system

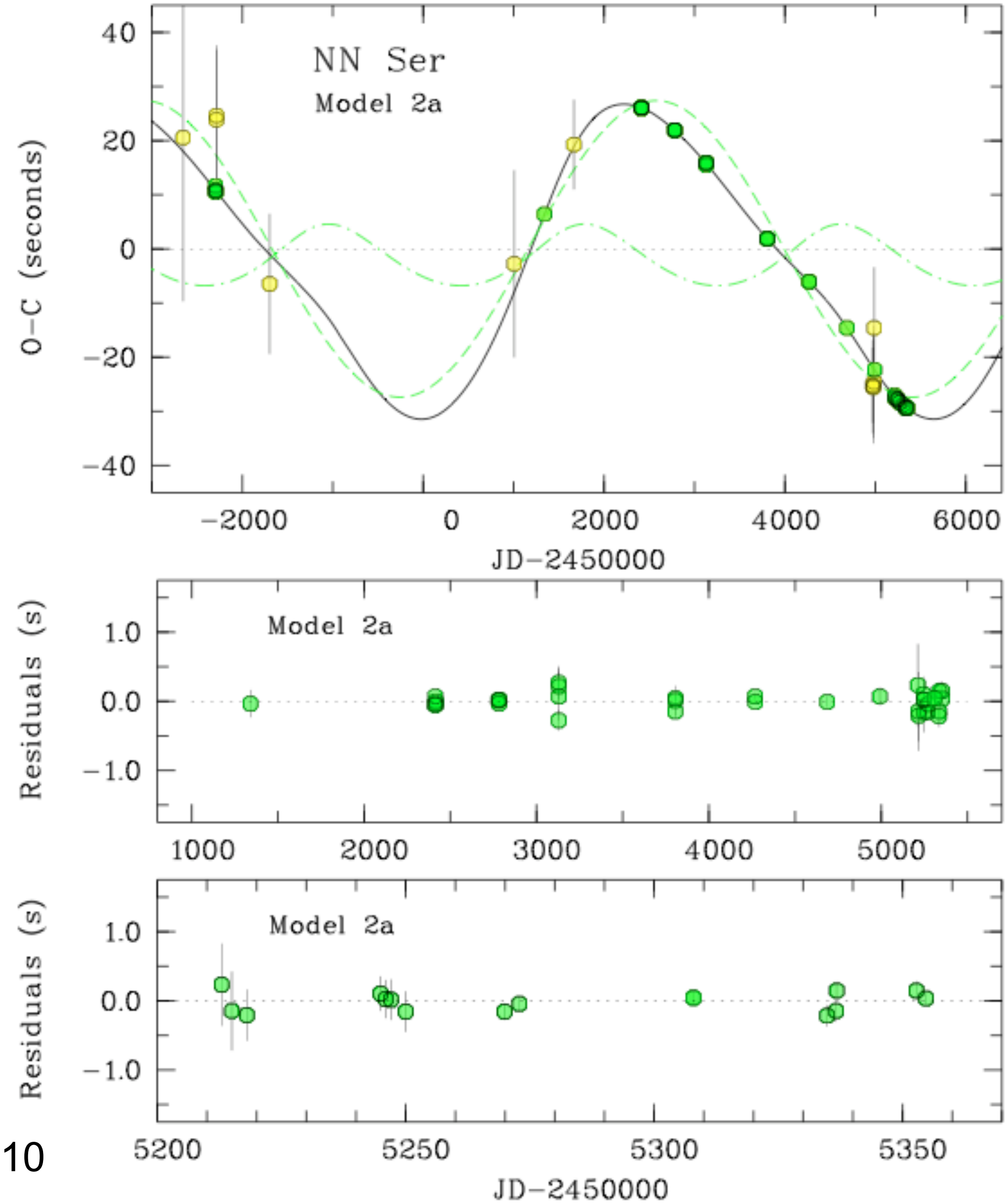
- Can also use more complex functions to describe changing periods, e.g.
  - Quadratic ephemeris: BJD(TT) = $T_0 + P_0\,E + C\,E^2$
  - Sinusoidal ephemeris: BJD(TT) = $T_0 + P_0\,E + A\cos[2\pi(E-B)/C]$
    where A, B and C are constants

- Analyse event timings with respect to an ephemeris using an O-C diagram (observed minus calculated)

O-C diagram



Parsons et al 2010



Discovery of 2 planets orbiting an eclipsing binary

Beuermann et al 2010

Space-based observing

- Avoid seeing and extinction, improved sky background
- But other observing constraints…

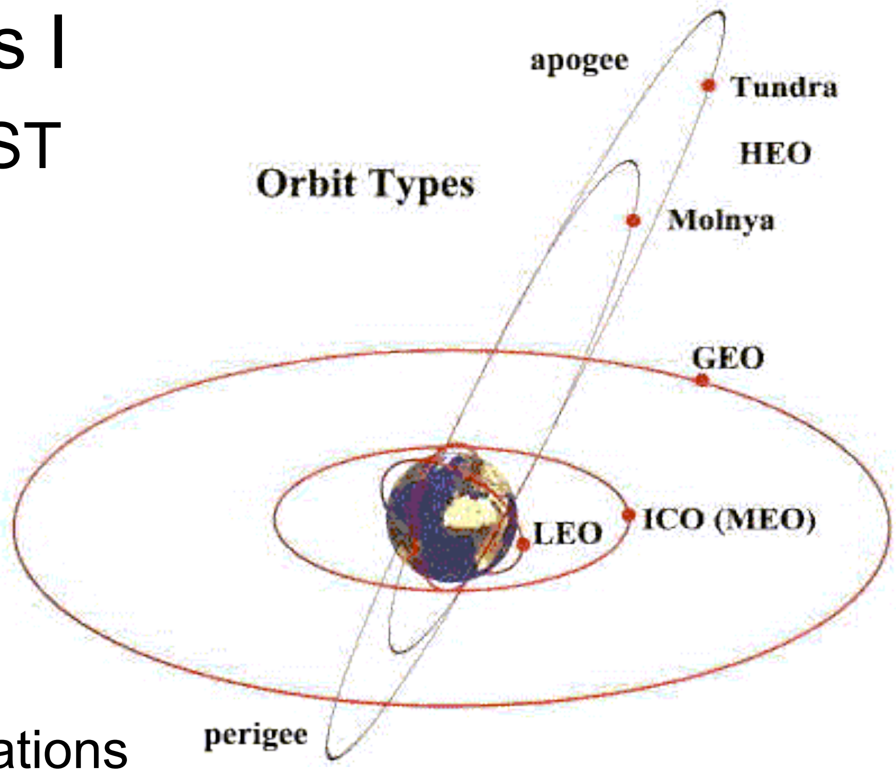
Sky background still important

- UV/Optical/IR: zodiacal light

- Soft X-ray: Solar wind charge exchange
- Hard X-rays: distant quasars

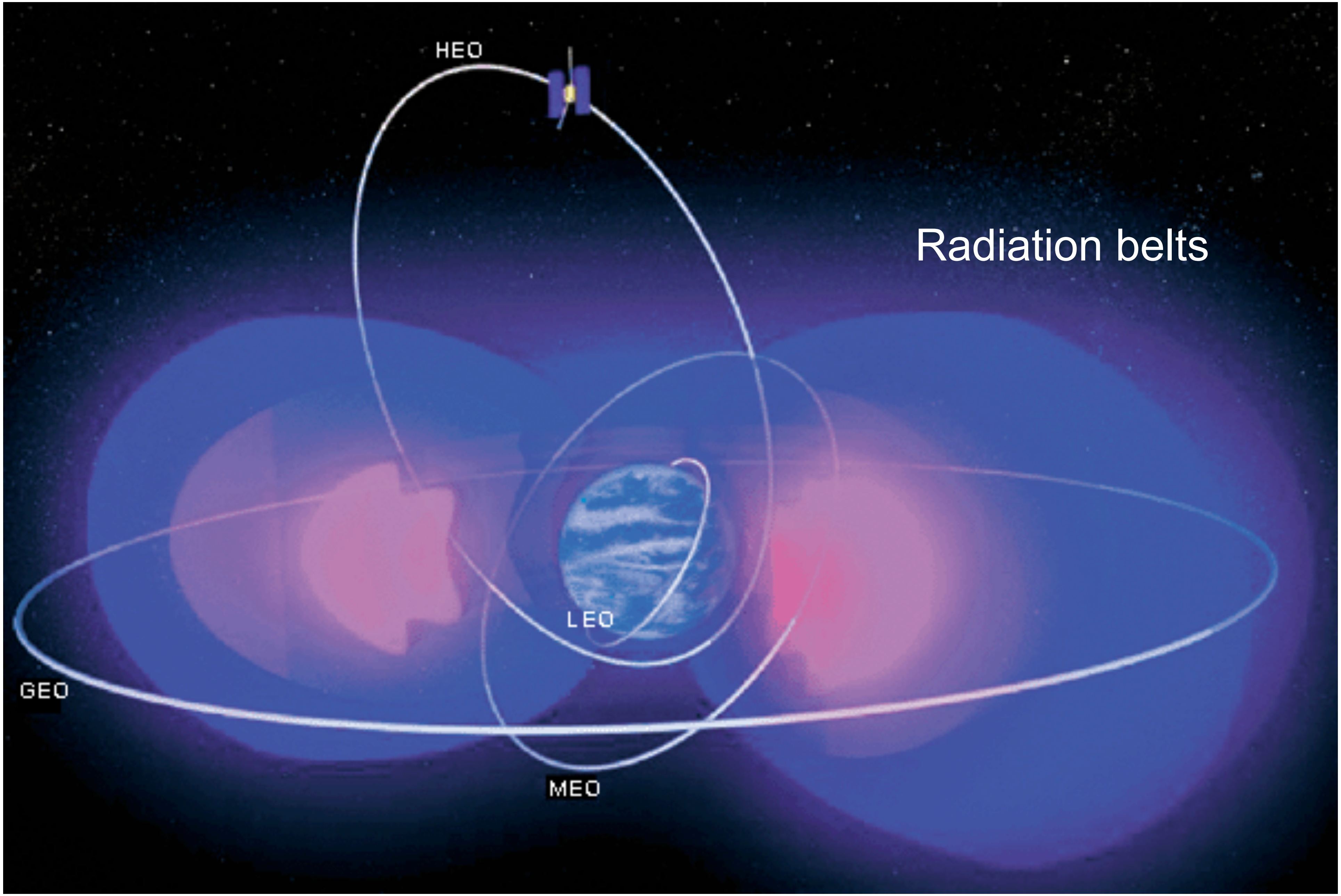
Orbits I

- Low Earth Orbit (LEO) e.g. HST
  - Pros: cheap, repair missions
    low radiation
  - Cons: occultation by Earth,
    unstable thermal environment



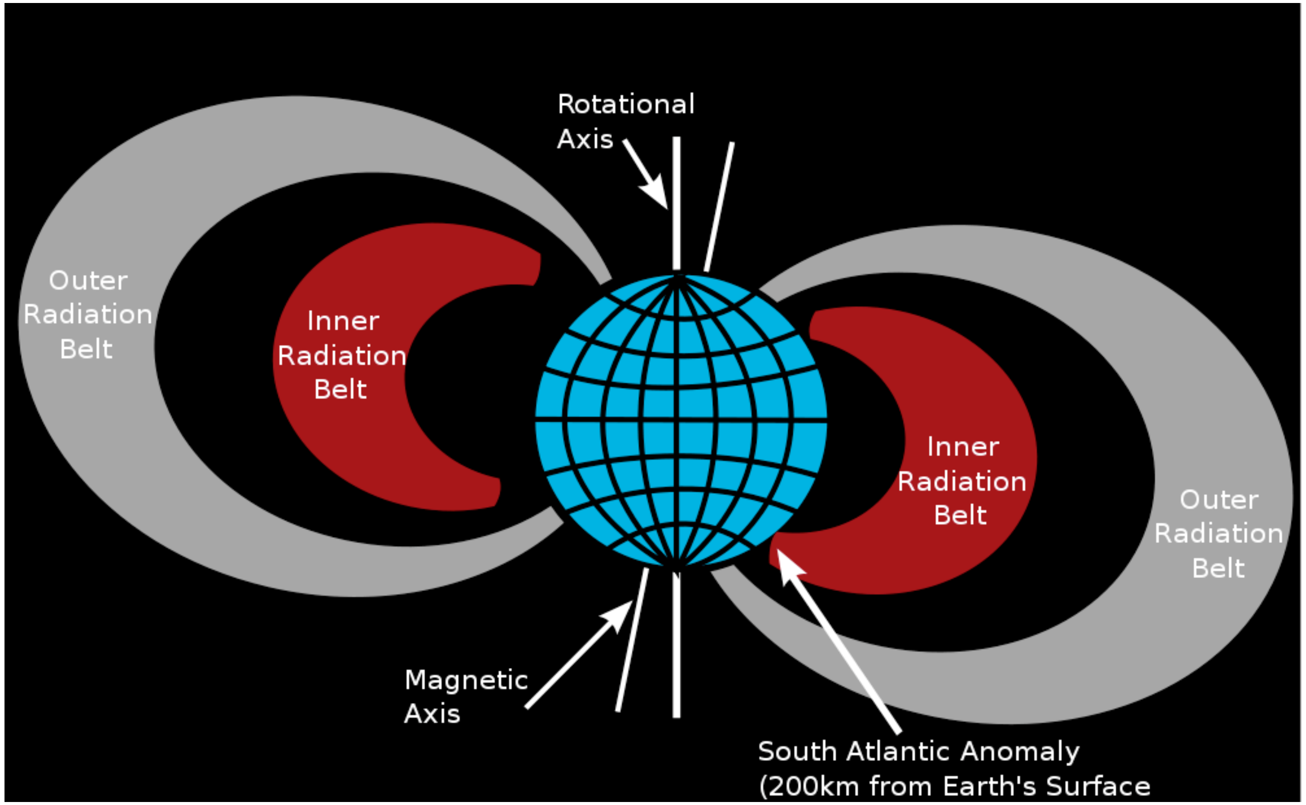
- High Earth Orbit (HEO)
  e.g. XMM-Newton
  - Pros: long uninterrupted observations
  - Cons: expensive, unstable environment (thermal & radiation)

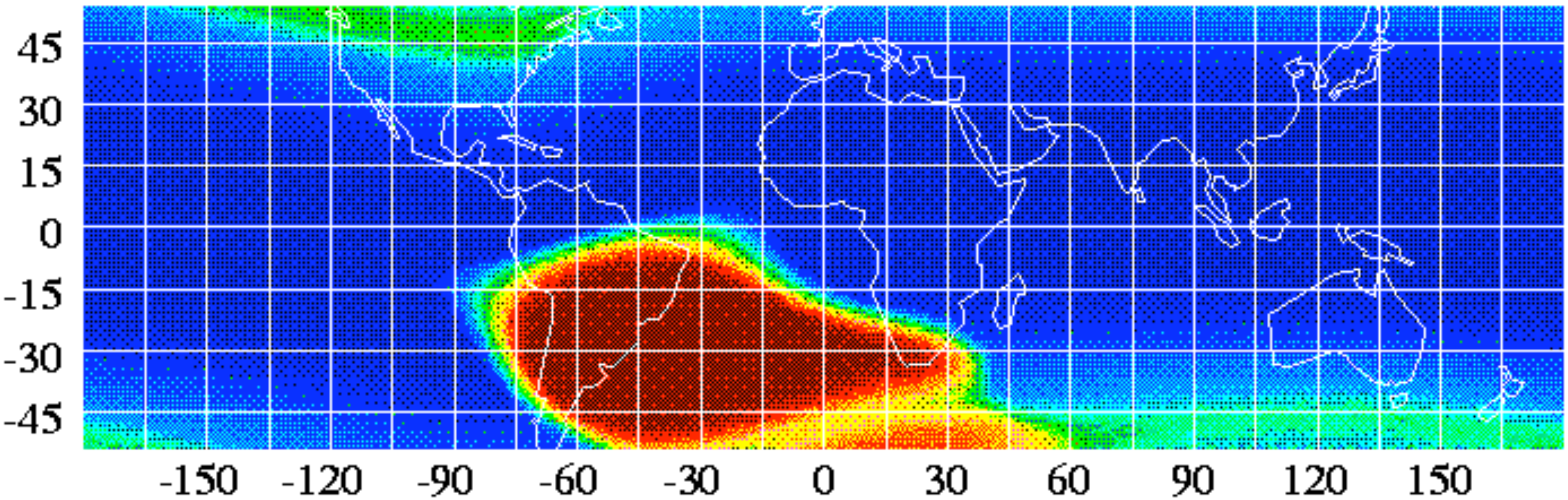
Radiation environment



South Atlantic Anomaly (SAA)

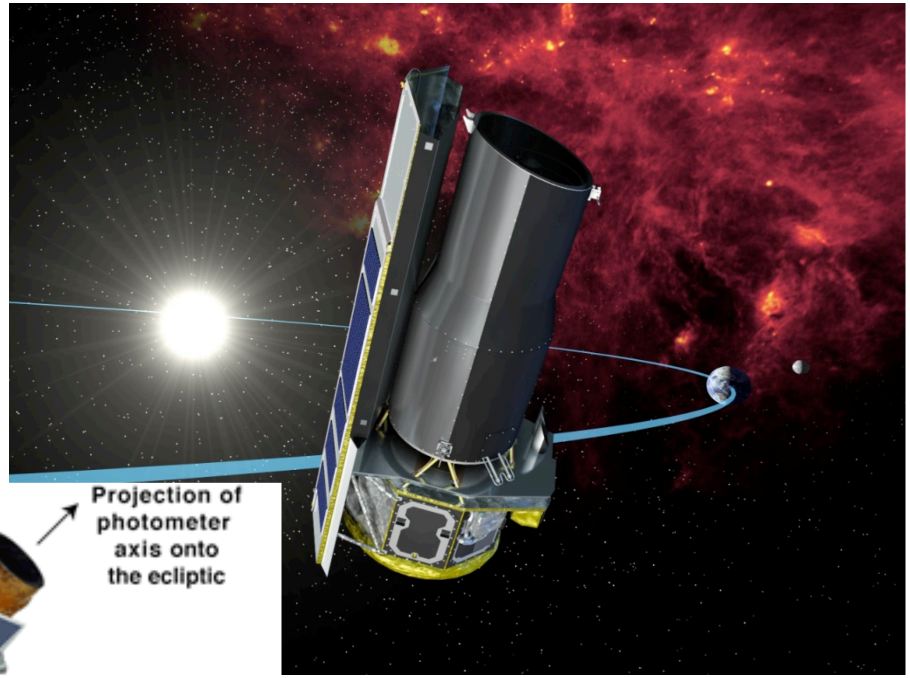
- High radiation region for low Earth orbit

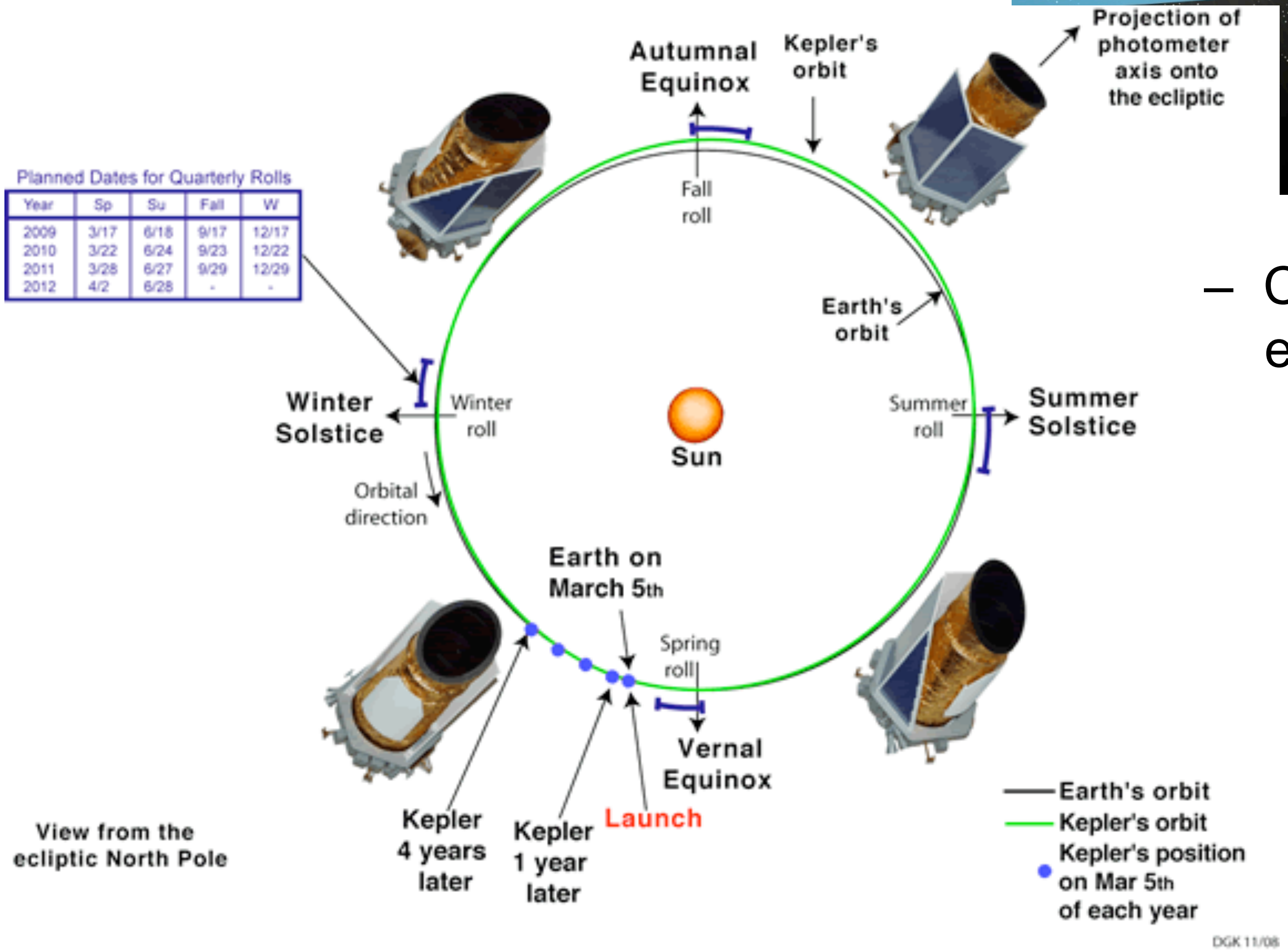




Orbits II

- Earth-trailing heliocentric
  - Pros: Stable (thermal and torques), excellent Earth/Moon avoidance, fairly cheap, e.g. Spitzer, Kepler



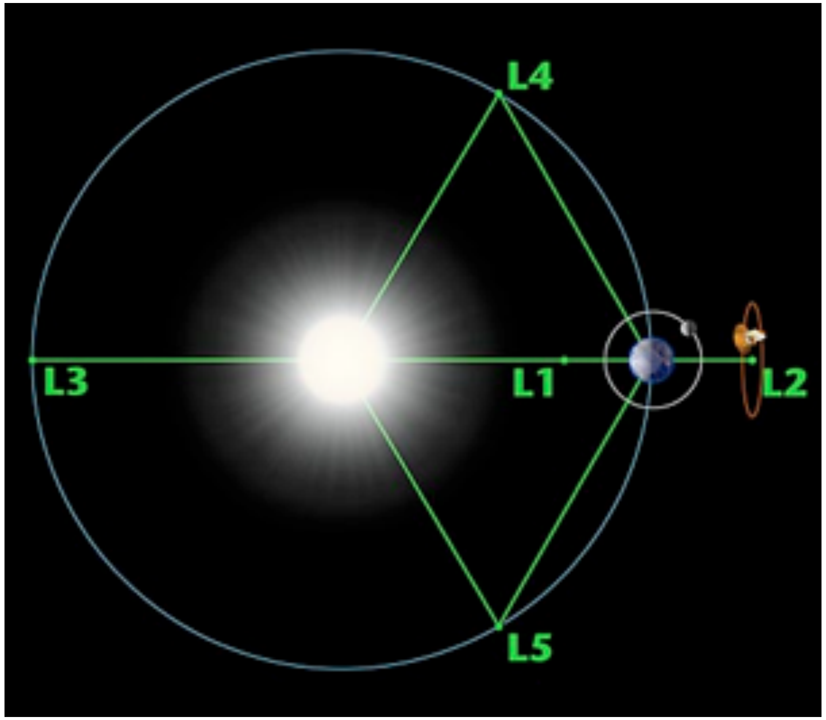


Year	Sp	Su	Fall	W
2009	3/17	6/18	9/17	12/17
2010	3/22	6/24	9/23	12/22
2011	3/28	6/27	9/29	12/29
2012	4/2	6/28	-	-

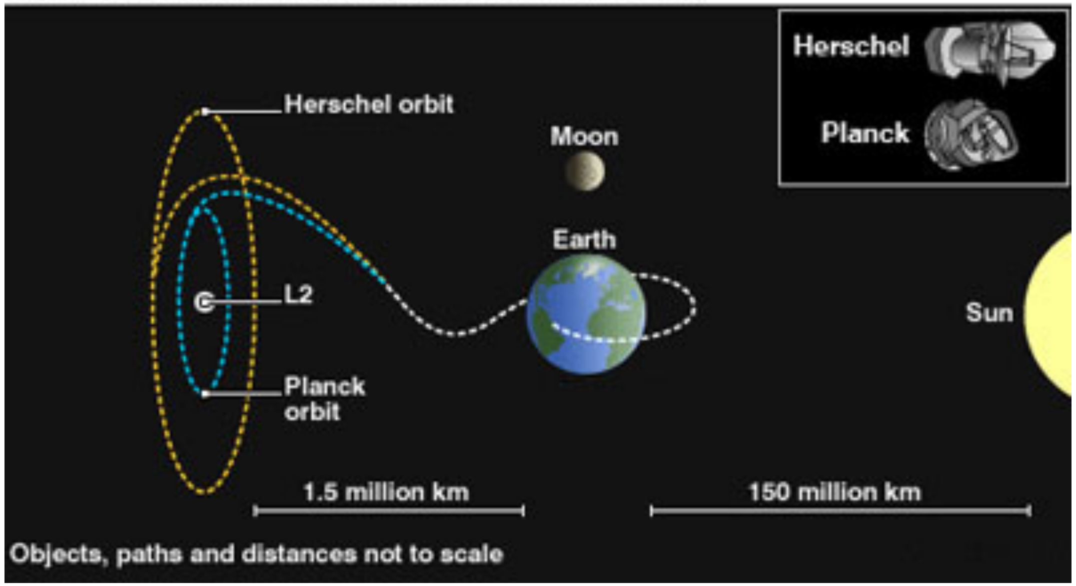
  - Cons: limited lifetime, expensive telemetry

Orbits III

- L1
  - Ideal for continuous viewing of the Sun, e.g. Soho
- L2
  - Stable cool environment, indefinite lifetime, but expensive e.g. Planck, Herschel, JWST



DISTANT OUTPOST: HERSCHEL AND PLANCK IN ORBIT



Visibility factors

- Sun avoidance
  - Wide range depending on design, e.g.
    - XMM-Newton 70-110 degrees
    - HST >50degrees
- Earth and Moon avoidance
  - particular issue for low earth orbit (LEO), e.g. HST
  - mitigated for high Earth orbit (HEO), Earth trailing (e.g. Spitzer) or L2 (JWST)
  - E.g. XMM-Newton 42degree limit on Earth limb, 22deg on Moon
- South Atlantic anomaly
  - Increased radiation environment, sensitive instruments shut down (CoRoT damaged on 2 Nov 2012)
- Pitch and Roll angle constraints
  - Instrument specific due to e.g. thermal or power constraints

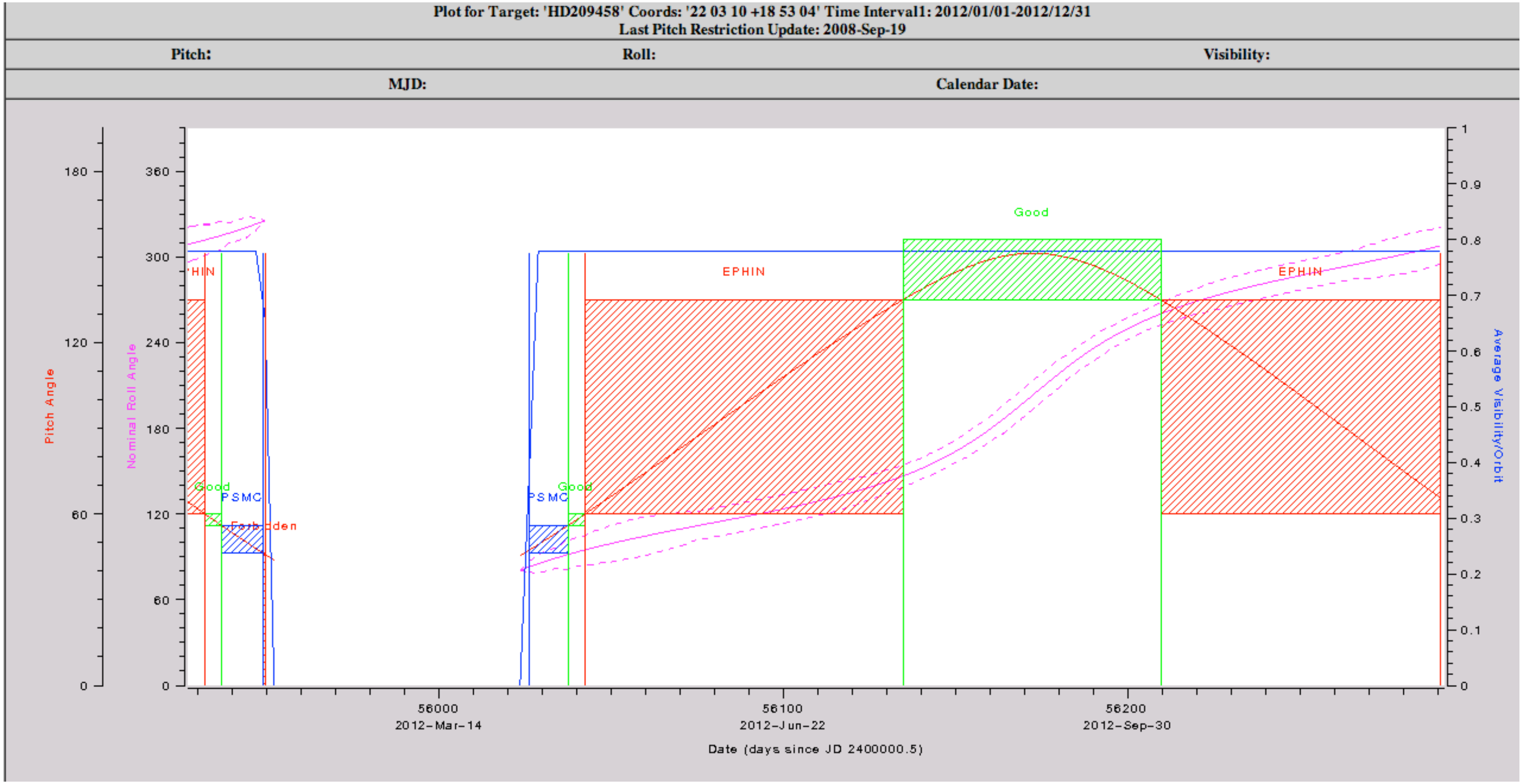
Visibility checkers: e.g.XMM-Newton

Search Results per Target

Target Name	RA	Dec
hd189733	300.1821	22.7109

Rev.	Vis. Start (yyyy-mm-dd hh:mm)	Vis. Window Duration (secs)	Vis. End (yyyy-mm-dd hh:mm)	Rounded Vis.	Visibility Start Phase	Visibility End Phase	Solar Aspect Angle(°)	Mean Astronomical Position Angle(°)
2183	2011-11-09 18:15	127504	2011-11-11 05:40	120000	0.10	0.84	82.8	247.4
2184	2011-11-11 18:07	127541	2011-11-13 05:33	120000	0.10	0.84	81.3	246.0
2185	2011-11-13 18:09	127006	2011-11-15 05:26	120000	0.11	0.85	79.8	244.6
2186	2011-11-15 18:01	127093	2011-11-17 05:19	120000	0.11	0.85	78.3	243.2
2187	2011-11-17 17:53	127184	2011-11-19 05:13	120000	0.11	0.85	76.8	241.8
2188	2011-11-19 17:56	126650	2011-11-21 05:07	120000	0.11	0.85	75.4	240.4
2189	2011-11-21 17:48	126668	2011-11-23 04:59	120000	0.11	0.85	73.9	238.9
2190	2011-11-23 17:40	126664	2011-11-25 04:51	120000	0.11	0.85	72.5	237.4
2191	2011-11-25 17:42	18583	2011-11-25 22:51	15000	0.11	0.22	71.5	237.3
2255	2012-04-01 13:43	105054	2012-04-02 18:54	100000	0.23	0.84	71.5	91.6
2256	2012-04-03 07:28	127661	2012-04-04 18:56	120000	0.10	0.84	72.8	90.0
2257	2012-04-05 07:20	127650	2012-04-06 18:48	120000	0.10	0.84	74.2	88.6
2258	2012-04-07 07:12	127925	2012-04-08 18:44	120000	0.10	0.84	75.6	87.2
2259	2012-04-09 07:03	128212	2012-04-10 18:39	120000	0.10	0.85	77.0	85.8
2260	2012-04-11 06:53	128223	2012-04-12 18:31	120000	0.10	0.85	78.5	84.4
2261	2012-04-13 06:45	58756	2012-04-13 23:04	55000	0.10	0.44	79.6	83.9
2261	2012-04-14 08:06	37537	2012-04-14 18:32	35000	0.63	0.85	80.3	83.5
2262	2012-04-15 06:36	128845	2012-04-16 18:23	120000	0.10	0.85	81.4	81.7
2263	2012-04-17 06:27	129141	2012-04-18 18:20	120000	0.10	0.85	82.8	80.4
2264	2012-04-19 05:43	131595	2012-04-20 18:16	130000	0.09	0.85	84.3	79.1
2265	2012-04-21 05:34	131596	2012-04-22 18:07	130000	0.09	0.85	85.7	77.8
2266	2012-04-23 05:25	132203	2012-04-24 18:09	130000	0.09	0.86	87.2	76.4
2267	2012-04-25 05:17	132215	2012-04-26 18:00	130000	0.09	0.86	88.6	75.1
2268	2012-04-27 05:08	132229	2012-04-28 17:52	130000	0.09	0.86	90.1	73.8
2269	2012-04-29 05:00	132839	2012-04-30 17:54	130000	0.09	0.86	91.5	72.5
2270	2012-05-01 04:52	132841	2012-05-02 17:46	130000	0.09	0.86	93.0	71.2
2271	2012-05-03 04:44	132826	2012-05-04 17:38	130000	0.09	0.86	94.4	69.9
2272	2012-05-05 04:36	132799	2012-05-06 17:29	130000	0.09	0.86	95.8	68.6

Visibility checker: e.g. Chandra



Time systems

```
OBSRVRID=                34329 / Observer ID of Principal Investigator
PROCYCL =                    6 / Proposal Cycle
PROGID  =                  282 / Program ID
PROTITLE= 'Exploring the thermal emission of two new transiting planets from th'
PROGCAT =                   31 / Program Category

          / TIME AND EXPOSURE INFORMATION

DATE_OBS= '2006-12-30T16:43:25.624' / Date & time at DCE start
MJD_OBS =        54099.6968244 / [days] MJD at DCE start (,JD-2400000.5)
HMJD_OBS=        54099.6997337 / [days] Corresponding Heliocen. Mod. Julian Date
UTCS_OBS=        220769005.624 / [sec] J2000 ephem. time at DCE start
SCLK_OBS=        851964352.095 / [sec] SCLK time (since 1/1/1980) at DCE start
SPTZR_X =      39189960.581635 / [km] Heliocentric J2000 x position
SPTZR_Y =      133017033.84629 / [km] Heliocentric J2000 y position
SPTZR_Z =      60537586.272519 / [km] Heliocentric J2000 z position
SPTZR_VX=            -28.72267 / [km/s] Heliocentric J2000 x velocity
SPTZR_VY=             6.879209 / [km/s] Heliocentric J2000 y velocity
SPTZR_VZ=             2.669106 / [km/s] Heliocentric J2000 z velocity
SPTZR_LT=           504.709964 / [sec] One-way light time to Sun's center
ET_OBS  =        220769070.808 / [sec] Ephemeris time (seconds past J2000 epoch)
AORTIME =                  12. / [sec] Duration of AOR
SAMPTIME=                  0.2 / [sec] Sample integration time
FRAMTIME=                  12. / [sec] Time spent integrating (whole array)
COMMENT   Photons in Well = Flux[photons/sec/pixel] * FRAMTIME
EXPTIME =                 10.4 / [sec] Effective integration time per pixel
COMMENT   DN per pixel = Flux[photons/sec/pixel] / GAIN * EXPTIME
FRAMEDLY=                 0.79 / [sec] Frame Delay Time
FRDLYDET= 'T       '           / Frame Delay Time Determinable (T or F)
INTRFDLY=                 0.79 / [sec] Inter Frame Delay Time
IMDLYDET= 'T       '           / Immediate Delay Time Determinable (T or F)
AINTBEG =            493922.98 / [Secs since IRAC turn-on] Time of integ. start
ATIMEEND=            493934.94 / [Secs since IRAC turn-on] Time of integ. end
AFOWLNUM=                    8 / Fowler number
AWAITPER=                   44 / [0.2 sec] Wait period
ANUMREPS=                    1 / Number of repeat integrations
AREADMOD=                    0 / Full (0) or subarray (1)
HDRMODE =                    F / DCE taken in High Dynamic Range mode
ABARREL =                    3 / Barrel shift
APEDSIG =                    0 / 0=Normal, 1=Pedestal, 2=Signal

          / TARGET AND POINTING INFORMATION

OBJECT  = 'WASP1b-ch24'        / Target Name
OBJTYPE = 'TargetFixedSingle'  / Object Type
CRPIX1  =                 128. / Reference pixel along axis 1
CRPIX2  =                 128. / Reference pixel along axis 2
```

Exercise

- Star: HD209458 with transiting planet
- Ephemeris (mid-transit):
  HJD(TT) 2453344.768245 + 3.52474859 E
- Telescope: William Herschel Telescope (WHT)

- Which night in 2012 is transit best observed?
- What is precise UTC of mid-transit?