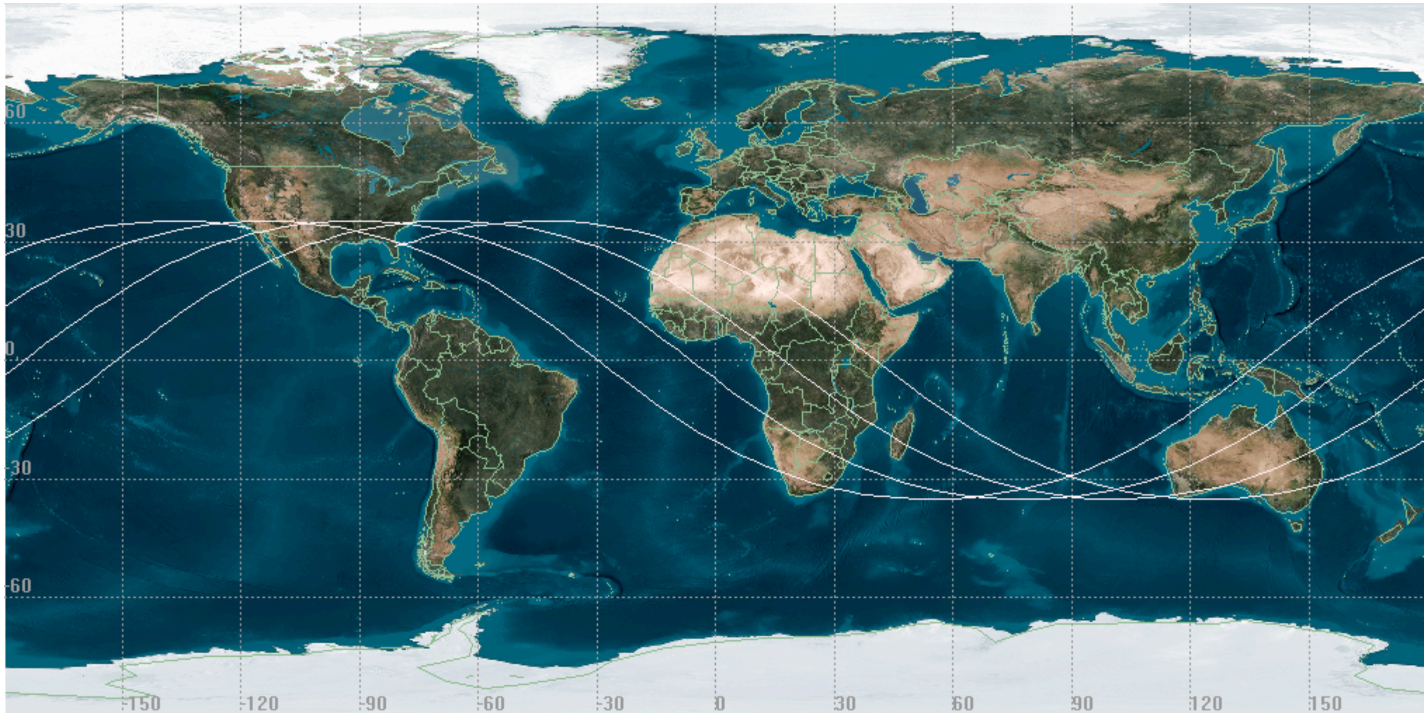
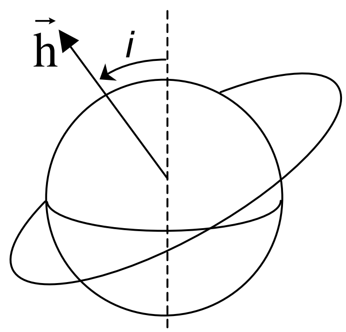
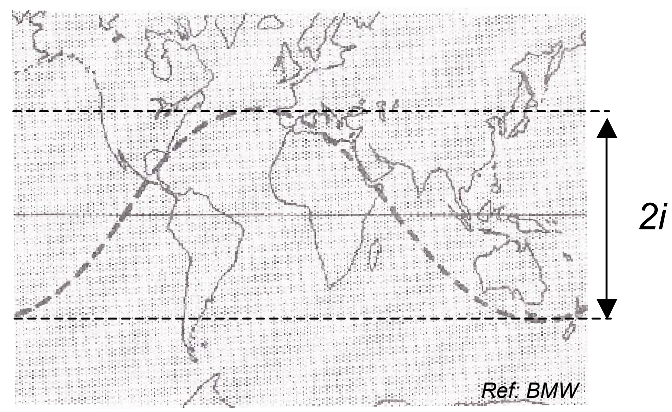
Introduction to Ground Tracks



Ground Track

- Ground track: planetary surface overflight path
- Consider a spherical planet
  - S/C orbit lies in plane passing through center of planet
  - Projection of this plane onto the surface is a great circle
  - For non-rotating planet, the s/c will retrace this same great circle each orbit



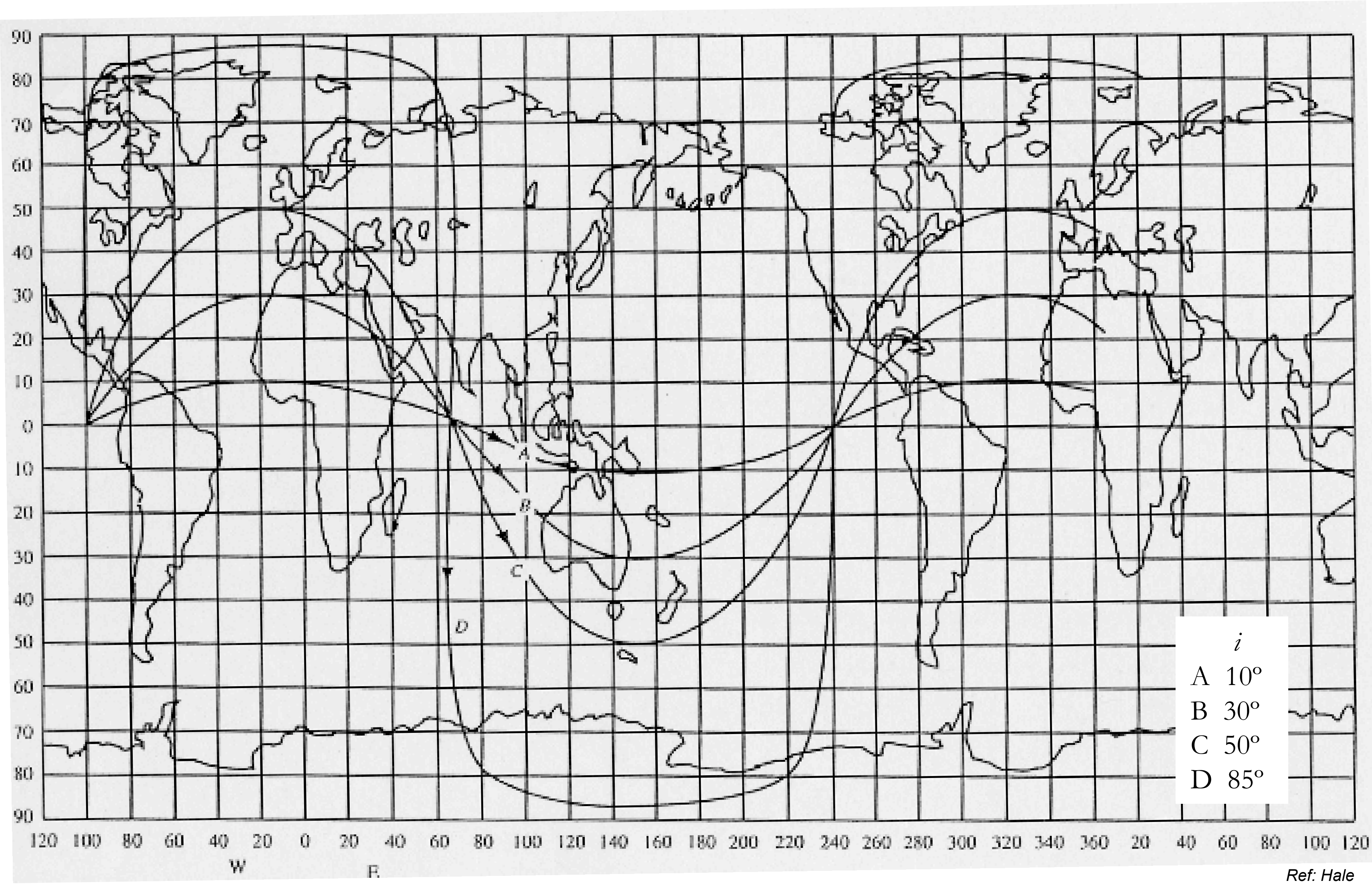


- Inclination
  - Higher inclination orbits result in larger amplitude ground tracks

$$\lambda_{max} = i \qquad (\text{for } 0 \le i \le 90, \text{ posigrade})$$
$$\lambda_{max} = 180 - i \qquad (\text{for } 90 \le i \le 180, \text{ retrograde})$$

- Altitude
  - Altitude ↑, Orbital period ↑, Longer ground track period
  - Orbital period in LEO ≈ 90 minutes, ~ 16 orbits/day

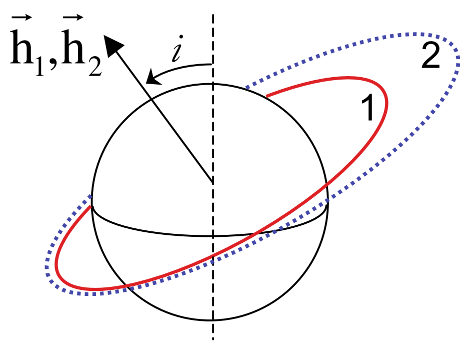
Inclination Example

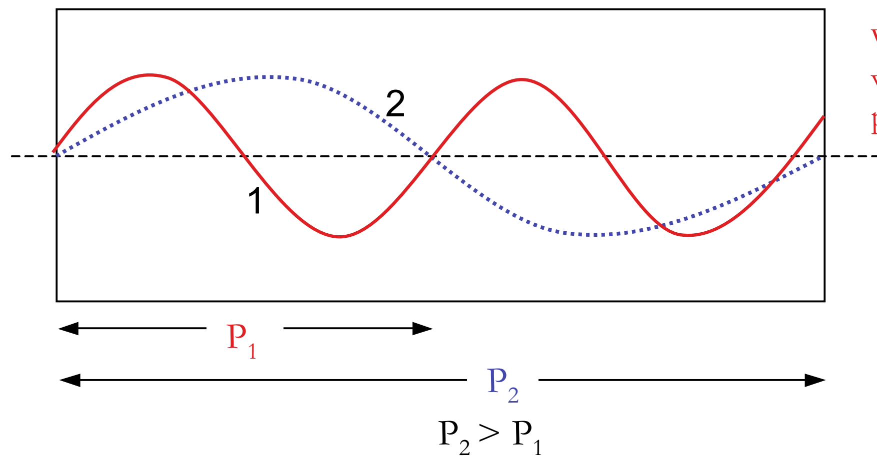


Ref: Hale

Altitude Effects

- Altitude ↑, Orbital period ↑, Longer ground track period





What's wrong with this picture?

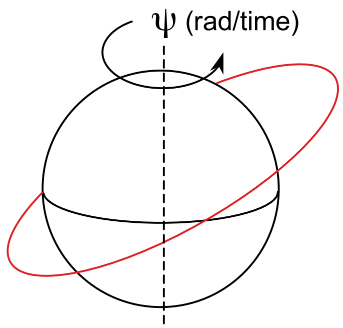
- If ground track period known, can back out semi-major axis (a)

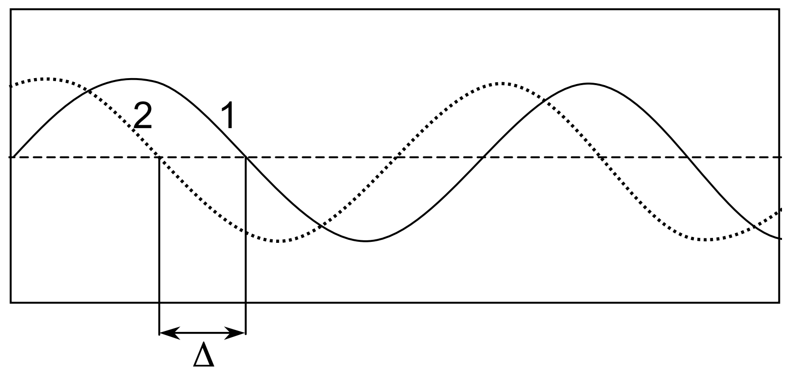
$$P = \frac{2\pi a^{3/2}}{\mu^{1/2}} \rightarrow a = \left(\frac{P\mu^{1/2}}{2\pi}\right)^{2/3}$$

- Orbital period in LEO ≈ 90 minutes, ~ 16 orbits/day

Rotating Planet

- Rotating planet effect
  - Orbital plane of s/c remains fixed in inertial space while planet rotates beneath it
  - Result, the ground track shifts westward (typically) over successive orbits





- From successive ground tracks can determine orbital period

$$\Delta = \frac{P}{R}(360^\circ), \text{ where } R = \text{planet's rotational period}$$

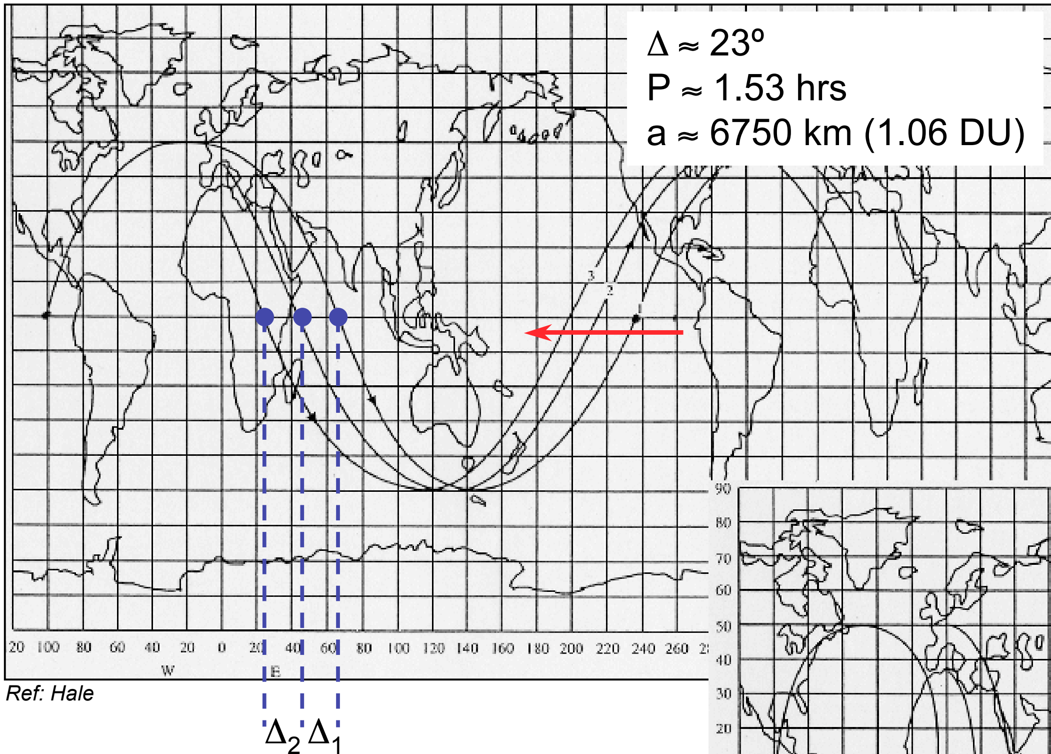
  - LEO example

$$\Delta = \frac{\sim 1.5 \text{ hrs}}{\sim 24 \text{ hrs}}(360^\circ) = 22.5^\circ$$

Is R_{earth} > or < 24 hrs?

  - Conversely, if Δ known, can solve for the orbital period P (and semi-major axis)
- Instead of retracing previous ground track, a s/c eventually covers a swath around the planet between ± *i* latitude
- a↑, Δ?   Δ↑, NB: In some cases, Δ is sufficiently large (2.6DU < a < 4.2DU) that ground track appears to shift Eastward

Shifting Ground Track Example



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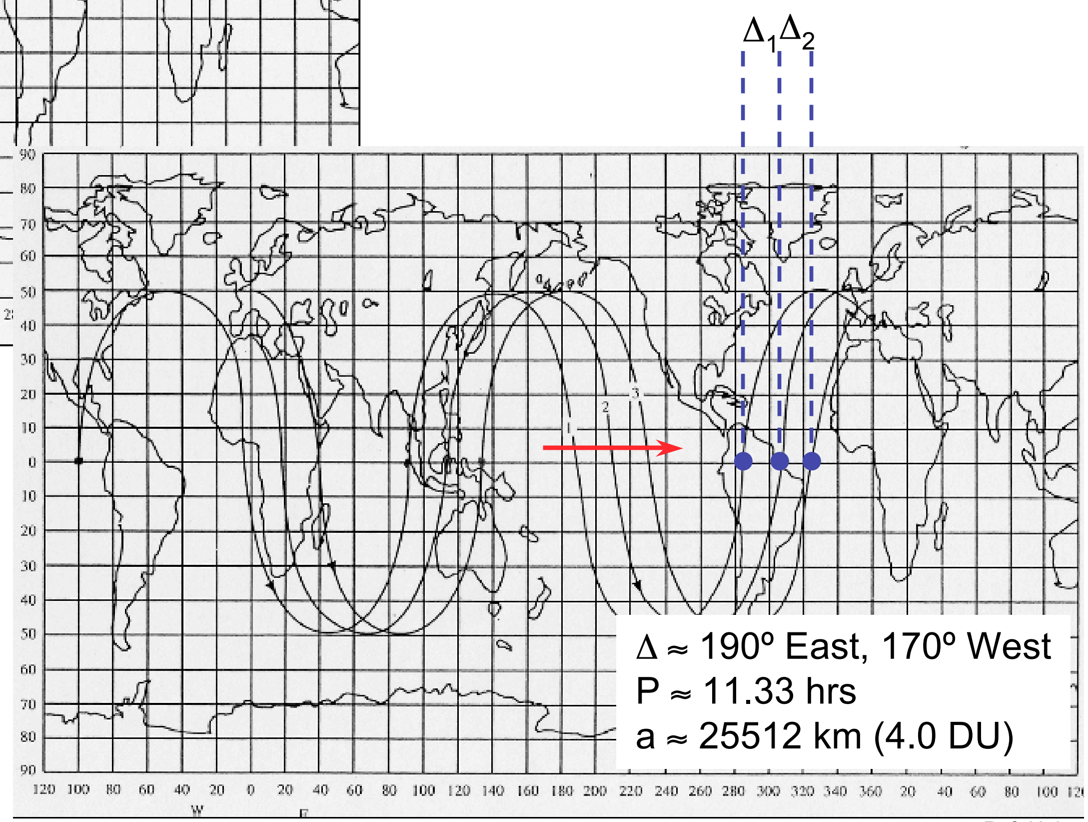

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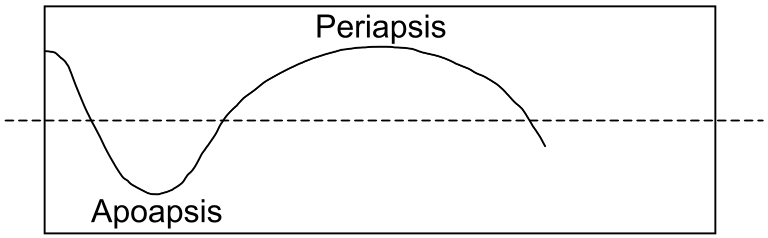
Note: ground tracks become more compact with increasing semimajor axis

What about retrograde orbit ground track shift?

Ground Track Symmetry

- From the ground track we can infer something about the eccentricity of the orbit
- Circular orbit (e=0)
  - Displays longitudinal (vertical) symmetry and equatorial (horizontal) symmetry
- Eccentric orbit (0<e<1)
  - Will not display both characteristic symmetries (may display one or the other or none)
  - Asymmetrical behavior can be used to locate periapsis (and apoapsis)

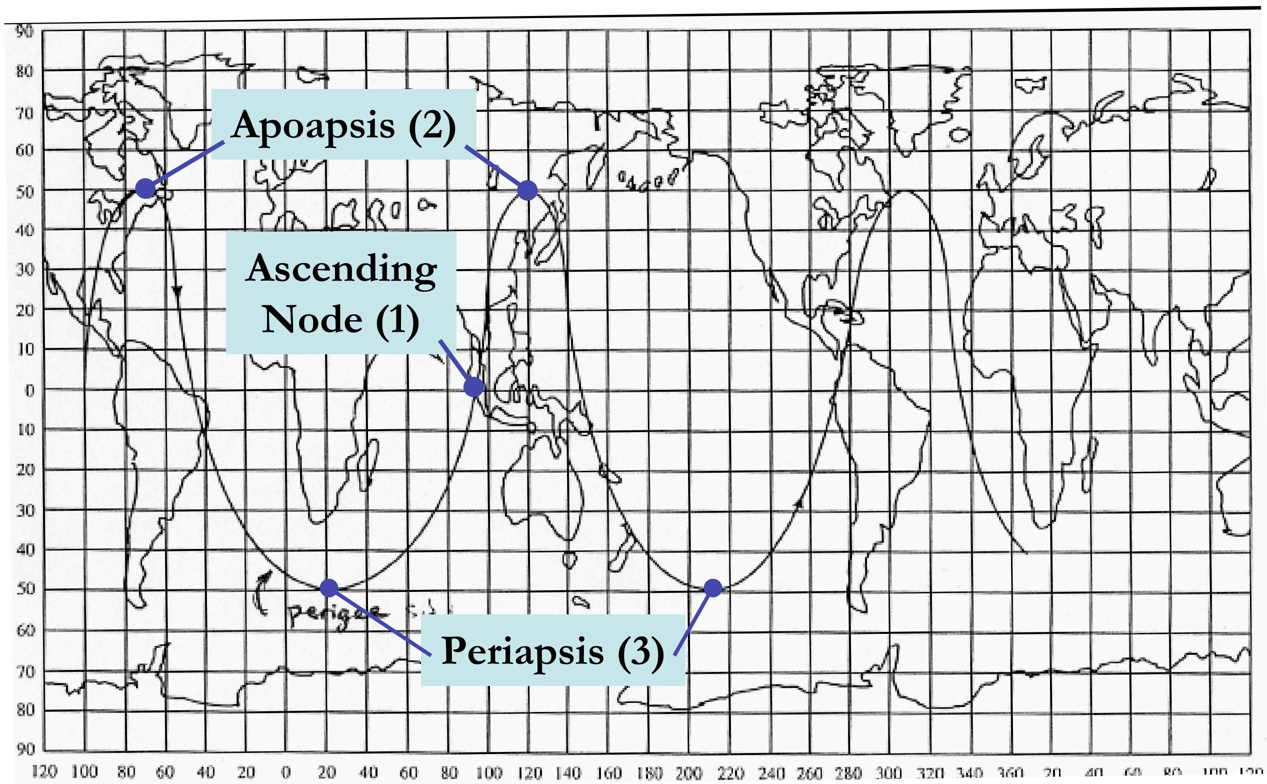


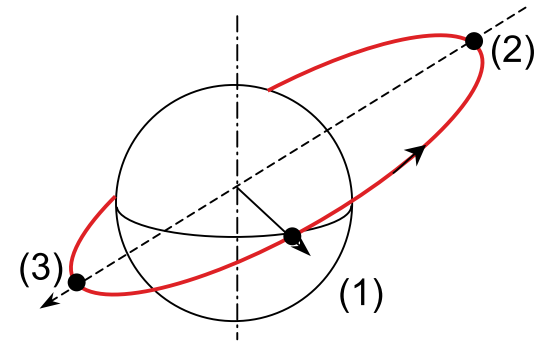
More movement over ground at periapsis (V↑)
Less movement over ground at apoapsis (V↓)

Ascending node?

- Type of symmetry displayed also provides insight into argument of periapsis
  - Longitudinal symmetry only: $\omega = 90^o$ or 270^o (periapsis in Northern or Southern hemisphere)
  - Equatorial symmetry only: $\omega = 0^o$ or 180^o (periapsis along line of nodes)
  - No symmetry: $\omega \neq 0, 90^o, 180^o$, or 270^o

Symmetry Examples (Longitudinal)

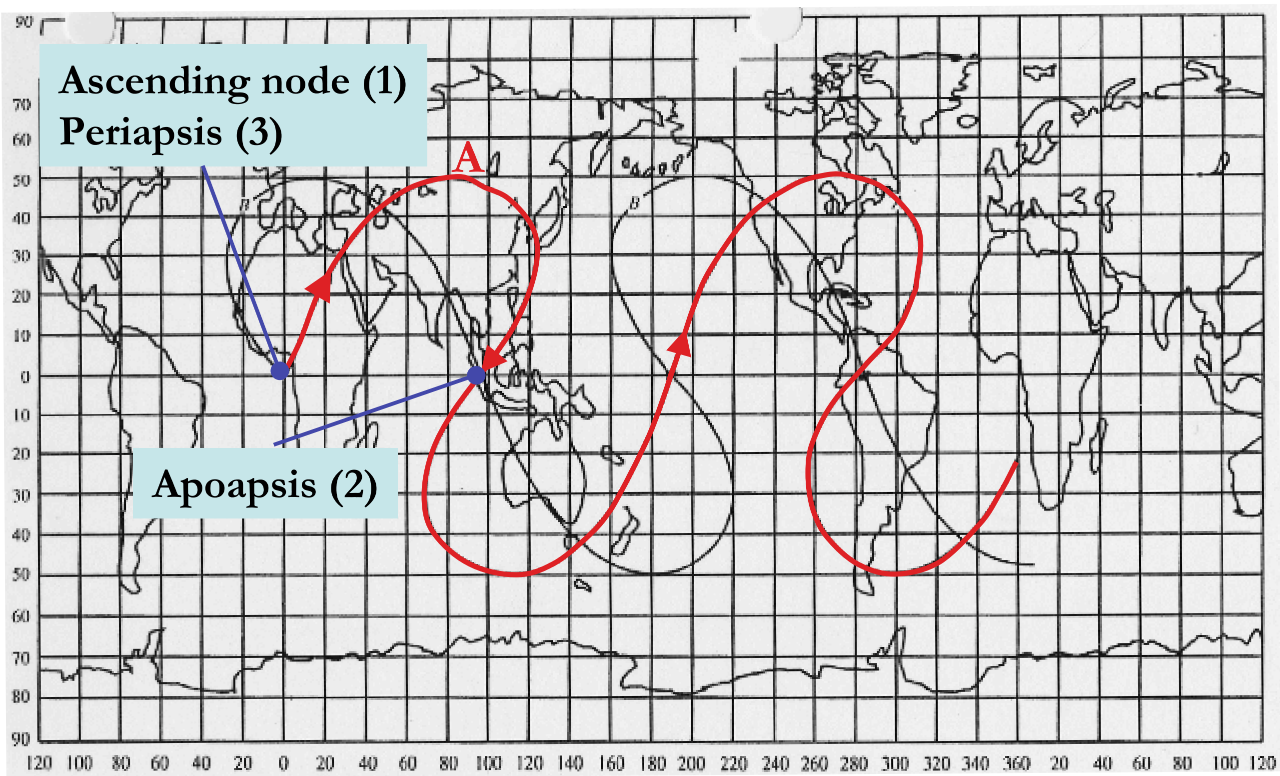


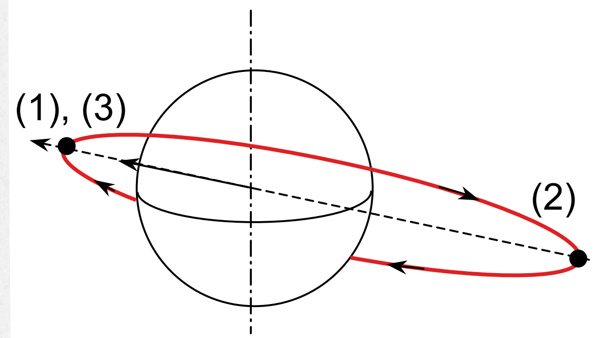


Ref: Hale

- Observations
  - Longitudinal symmetry
  - Periapsis in Southern hemisphere ($\omega = 270°$) What if retrograde?
  - Compressed ground track around apoapsis

Symmetry Examples (Equatorial)



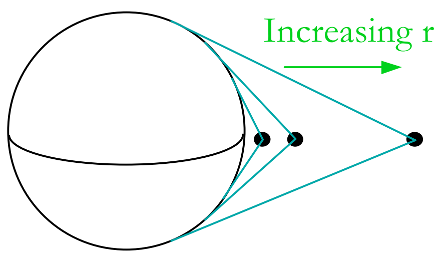


Ref: Hale

- Observations
  - Equatorial symmetry → line of apsides and line of nodes coincide
  - Apparent Westward motion along ground track
  - Descending node occurs during Westward motion → ω = 0º (for curve A)
    - Move quickest East at periapsis

Coverage Contours

- Very high inclination orbits (i ~ 70º-110º) are necessary for significant global coverage
- If time required for one complete planetary rotation is an exact multiple of s/c period (P), then eventually the s/c will retrace its ground path
  - Useful for reconnaissance and landing sites
- Very high altitude orbits increase viewing angle of planets surface
  - Also increase P



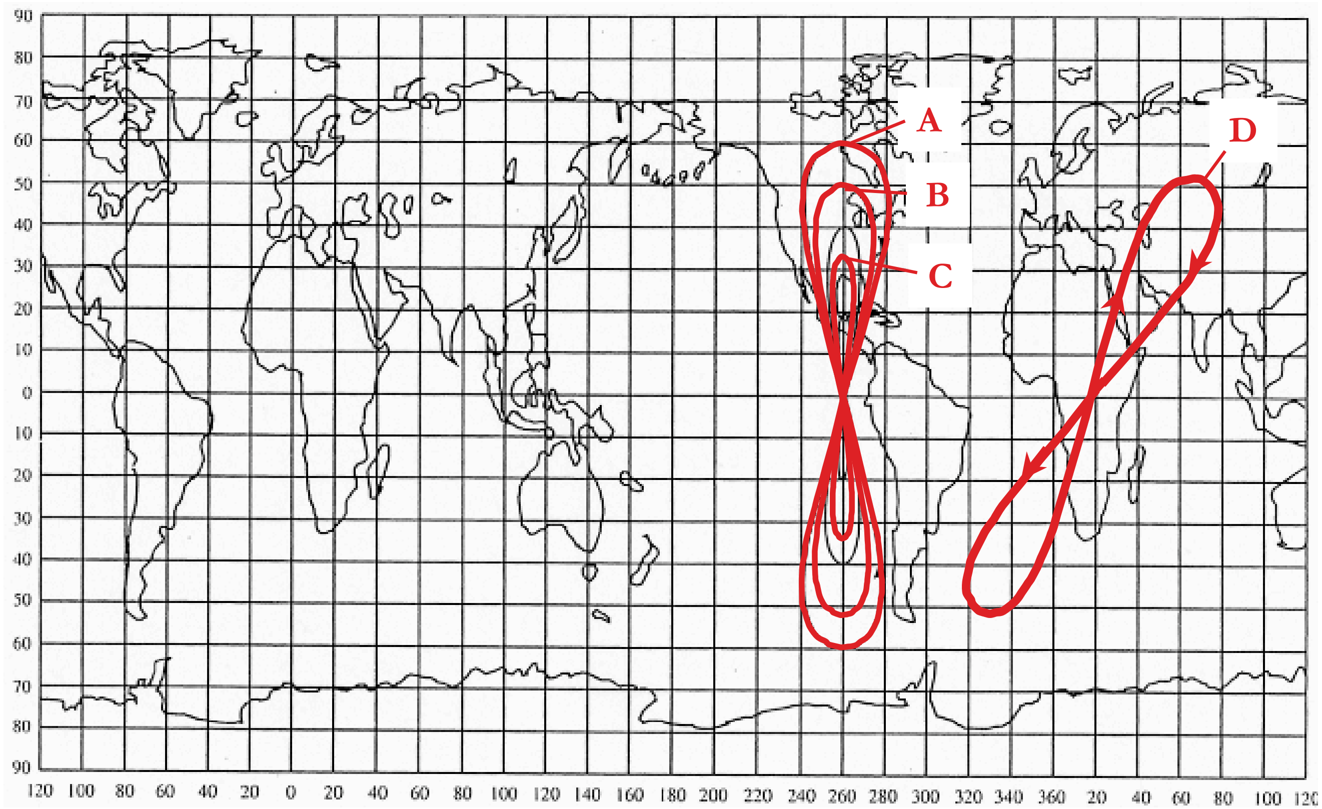
$$FOV\% \cong 50\left(1 - \frac{r_{earth}}{r}\right)\%$$

In LEO, $FOV \sim 2.4\%$

In GEO, $FOV \sim 42\%$

- At synchronous altitude (r = 42,240 km for earth), P = R
  - For all non-zero inclinations, ground track appears as a "figure eight"
  - Stationary orbit implies zero inclination (ground track is a point)

Synchronous Orbit Examples



Ref: Hale

- Observations
  - $i_A > i_B > i_C$
    - With decreasing inclination, figure eights get narrower and shorter
    - The limit is when i = 0° and the figure eight becomes simply a point
  - Orbit D is an elliptical synchronous orbit   ω?

Synchronous Orbits

- For circular synchronous orbits with non-zero inclination
  - Throughout orbit, $V_{s/c} = V_c = V_{synch}$
  - At ascending and descending nodes, $V_{east} = V_c \cos i$
  - At u = 90º & 270º, $V_{east} = V_c$

$$V_{east}\big|_{s/c} = V_c \cos i + V_c(1 - \cos i)\sin u$$

  - Rotational speed of surface point = fn(λ, latitude)

$$V_s = (2\pi r_e \cos\lambda)/day$$

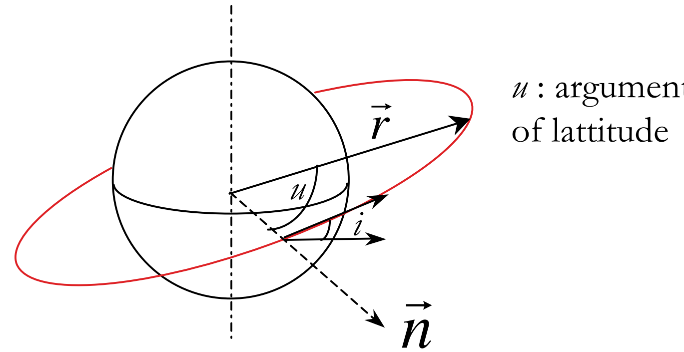
    - At ascending and descending nodes, λ = 0

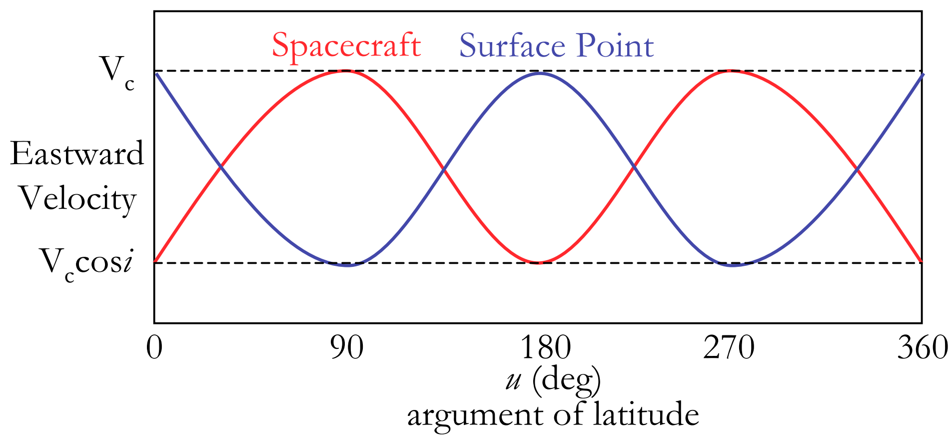
$$V_s = V_c = (2\pi r_e)/day > V_{east}\big|_{s/c}$$

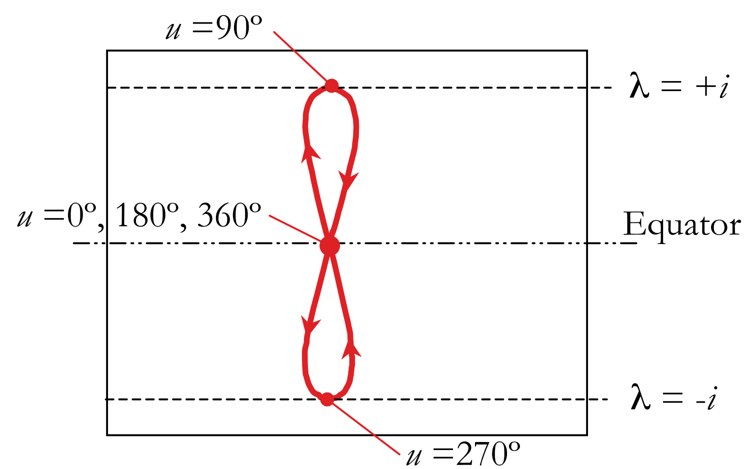
Explains Westward motion on figure eight ground track

    - At u = 90º & 270º

$$V_s = (2\pi r_e)\cos\lambda / day < V_{east}\big|_{s/c}$$







Questions?