Satellite Constellation Fundamentals

ITU Space Connect

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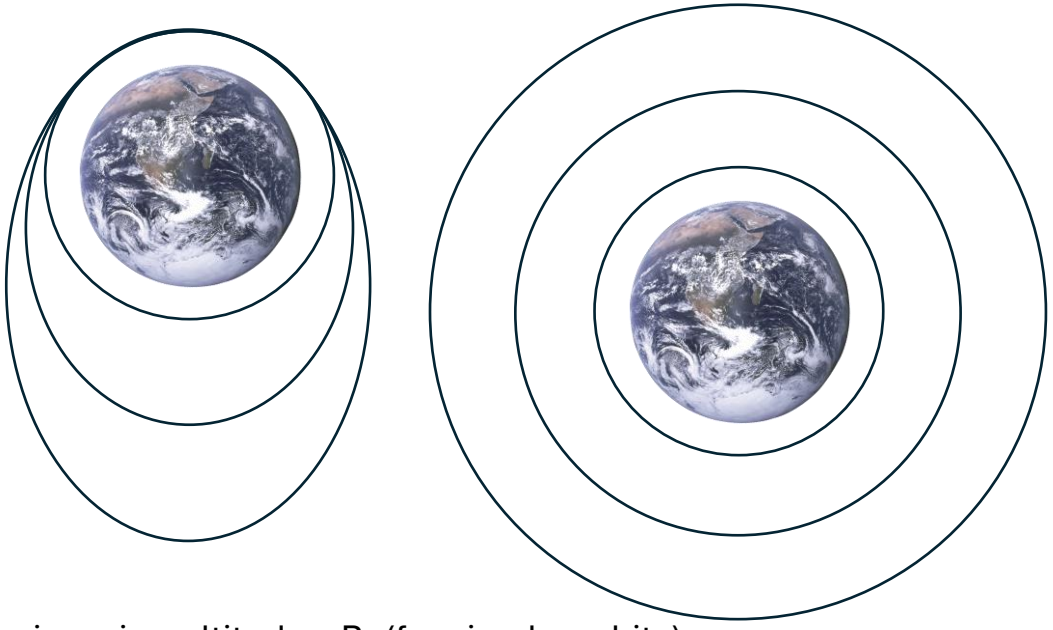
Orbit Fundamentals

Kepler's laws of planetary motion … a simple world, where all orbits are perfect ellipses

Six parameters define an orbit's shape, size, orientation, and a satellite's position within it

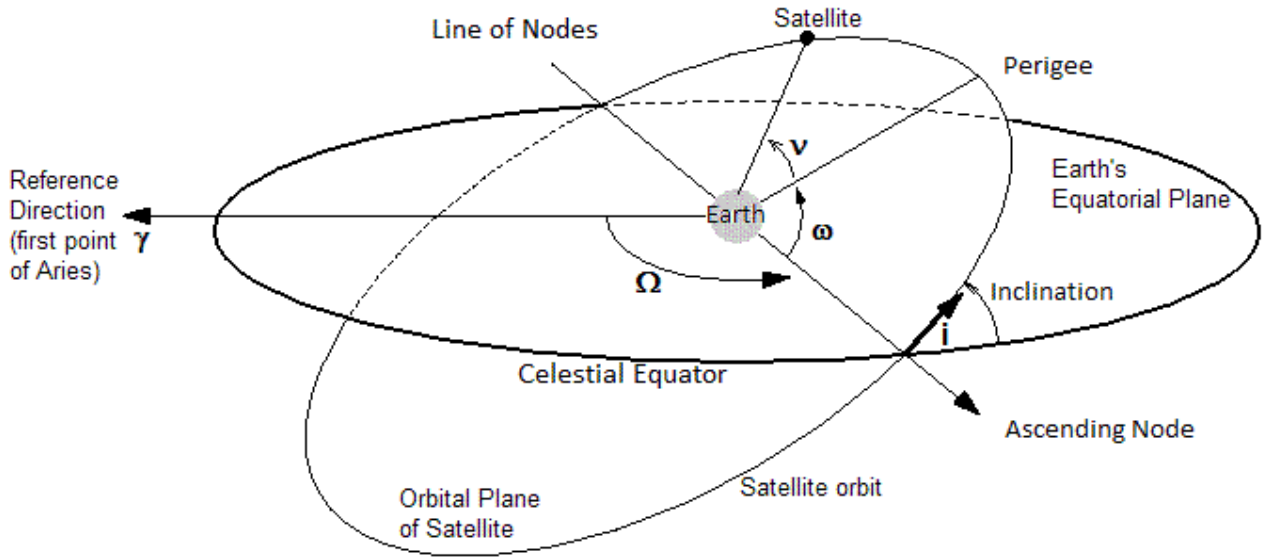
Shape
(eccentricity)

Size
(semimajor axis)



Orientation
(inclination, Ω, ω)

Position
(ν)



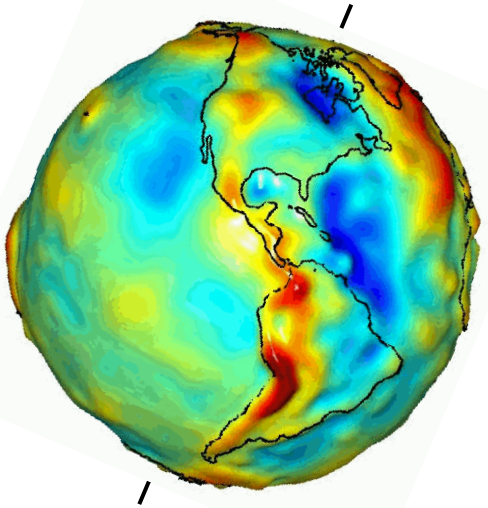
semimajor axis = altitude + R_e (for circular orbits)
Ω = right ascension of the ascending node (RAAN)
ω = argument of perigee
ν = true anomaly

Credit: Australian Space Academy

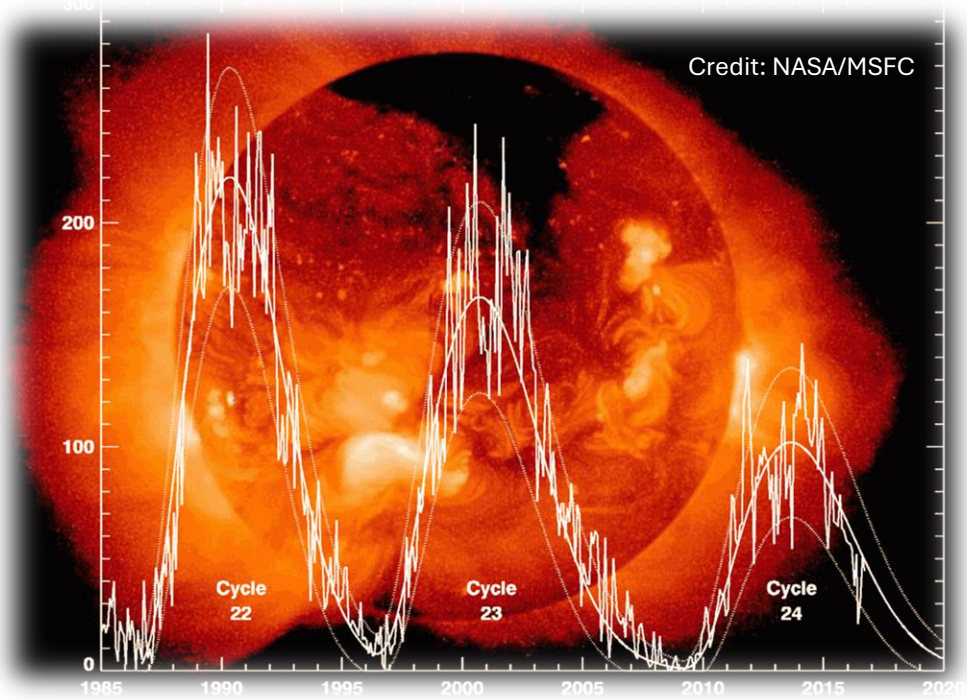
A Closer Look

Newton's second law … a complicated world, where forces dictate motion

- Satellites orbit a wobbly-spinning planet that orbits the Sun on a tilted axis
- The Earth's gravitational field is non-uniform
- Satellites in LEO are subject to atmospheric drag, which is driven by solar activity
- The Sun and Moon tug on satellites too
- The Sun's radiation exerts pressure as well



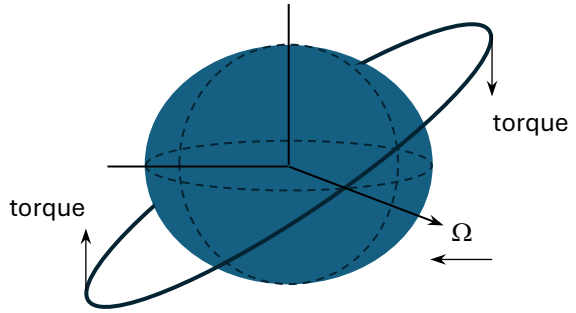
Credit: NASA/JPL

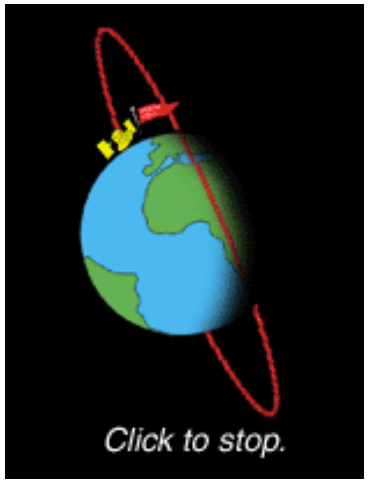


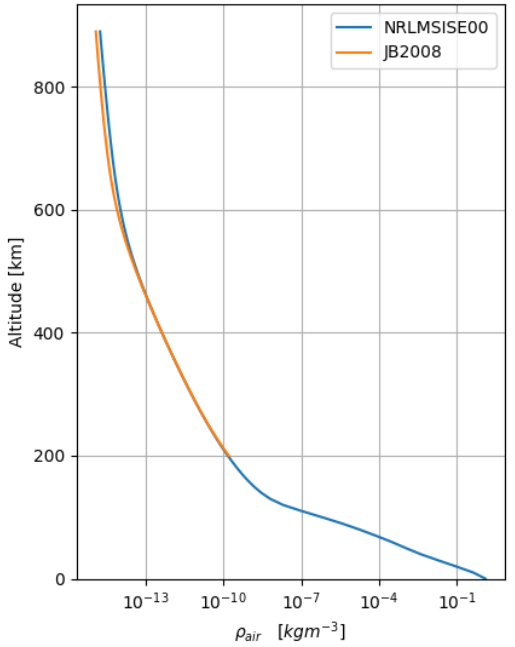
Not All Orbits are Created Equal

Using perturbing forces as orbital design tools

- Careful selection of parameters leads to interesting orbits
  - Equatorial bulge causes RAAN (Ω) and perigee (ω) to drift
  - Rates are primarily dependent on altitude and inclination
  - **Sun Synchronous**
    Ω drift is calibrated to Earth-Sun line, such that for a given location, every pass occurs at the same local time
  - **Exact Repeat**
    Ω drift is calibrated to Earth rotation rate, such that ground tracks pass over the same points at regular intervals
  - **Frozen**
    Perigee stays at 90°, reducing relative motion in a constellation
- Atmospheric drag provides a natural cleansing mechanism for low-Earth orbits
  - Drag force lowers orbit over time
  - Rate of orbital decay is proportional to atmospheric density
  - Atmospheric density decreases exponentially with altitude
  - Drag offers a natural means of disposal at lower altitudes



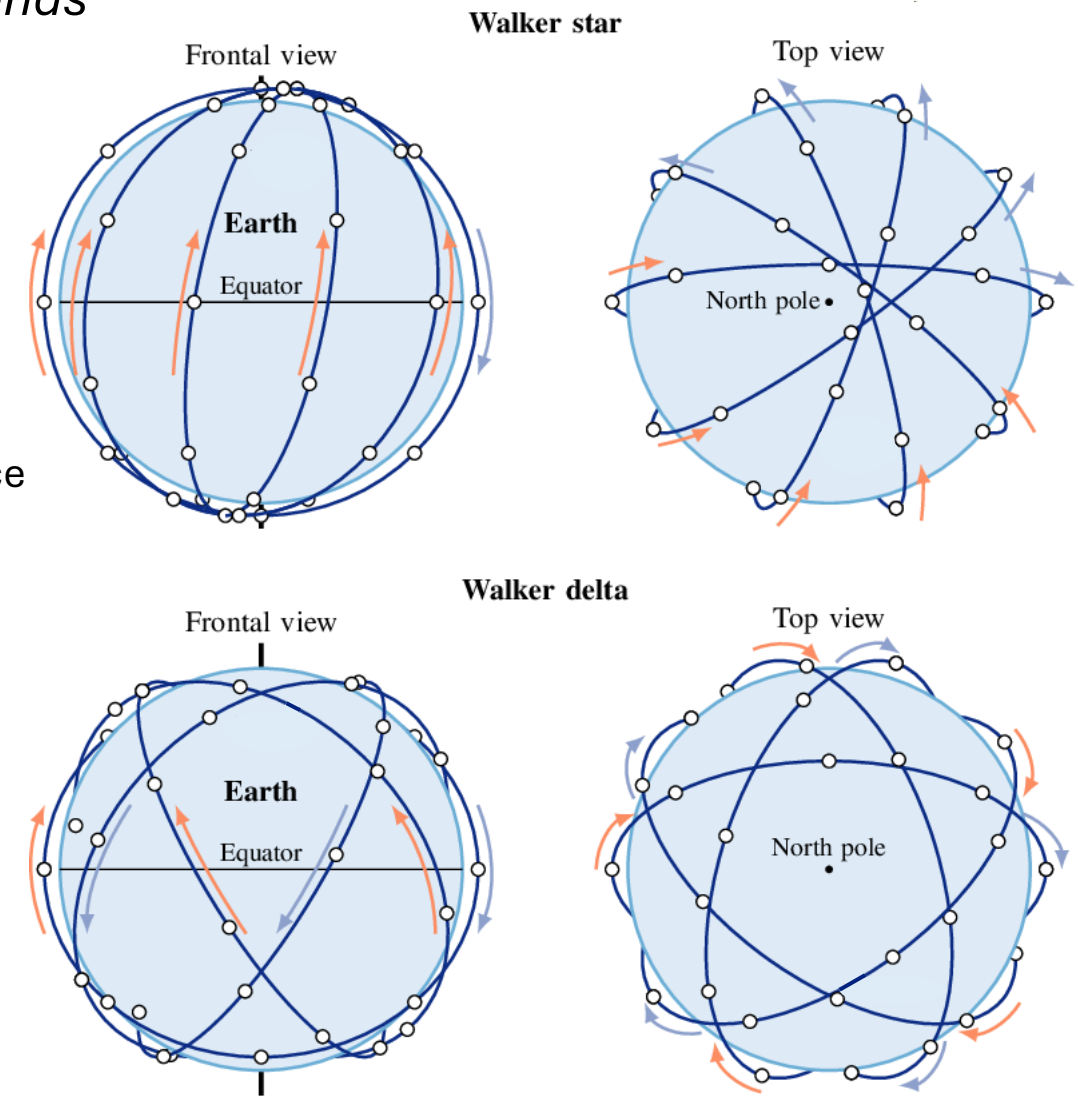




Satellite Constellations

There is no single, ideal constellation … it all depends

- Definition
  - “A group of satellites working together as a system” – Wikipedia
  - Similar design? Coordinated orbits? Unified control?
- Benefits
  - Typically a matter of coverage
  - Persistence, ubiquity, capacity, resilience, performance
- Applications
  - Historically, communications, observation, navigation
  - Novel concepts
- Architectures
  - Walker delta
  - Walker star
  - Tiered
  - Multi-orbit
  - Ad hoc



Credit: Matthiesen, Bho et al. “Federated Learning in Satellite Constellations.” *IEEE Network* 38 (2022): 232-239.

Constellation Design Drivers and Trades

Mission objectives, orbit selection, and satellite design are inextricably intertwined

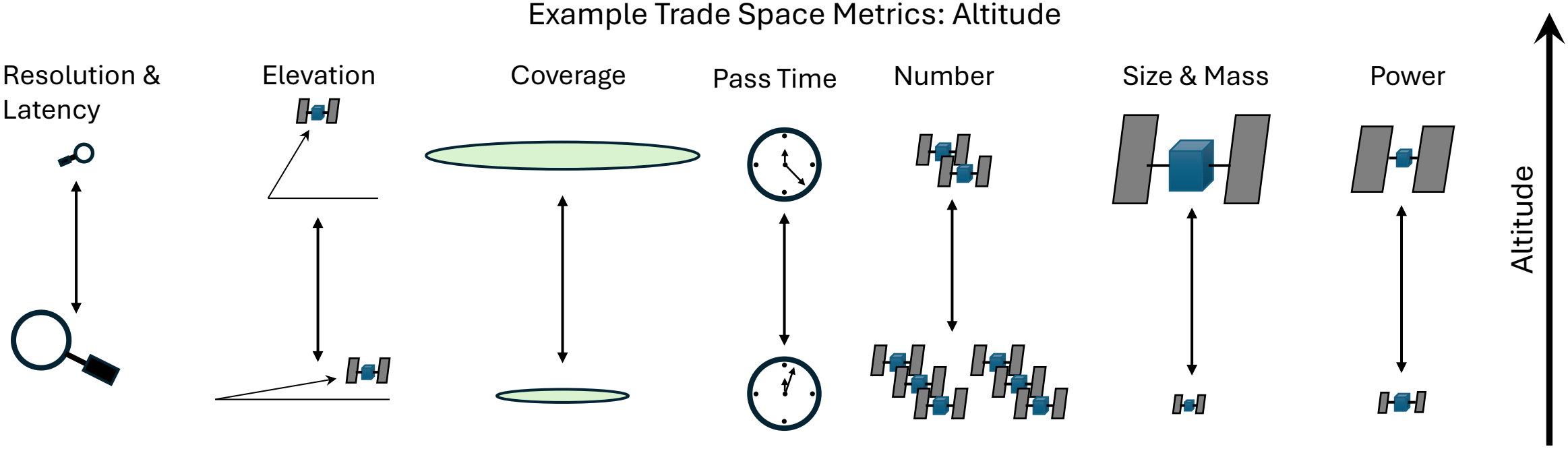
Principal design drivers

- Mission objectives
  coverage, capacity, latency, range, visibility, lighting, etc.
- Licensing requirements
  spectrum, power-flux density, disposal, etc.
- Program constraints
  cost, schedule, risk, technology, etc.

Additional design considerations

- Satellite maneuverability
- Operational coordination and safety
- Satellite reliability
- Overall system performance

Example Trade Space Metrics: Altitude



Constellation Trends and Challenges

- Constellations are not new
  - GEO: communications and weather
  - MEO: navigation
  - LEO: communications and Earth observation
- Popularity is growing rapidly
  - Reduction of launch costs
  - Proliferation of technology
  - Demand for services
  - Scarcity of natural resources (spectrum, orbits)
- Constellations are getting larger and lower
- Challenges accompany progress
  - Global fair access to space
  - Space environment sustainabillity
  - Dark and quiet skies
  - International norms of behavior
  - Licensing and liability
  - Operational coordination

Thank you!

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