Small Satellite Implementation of a Lunar Relay Satellite

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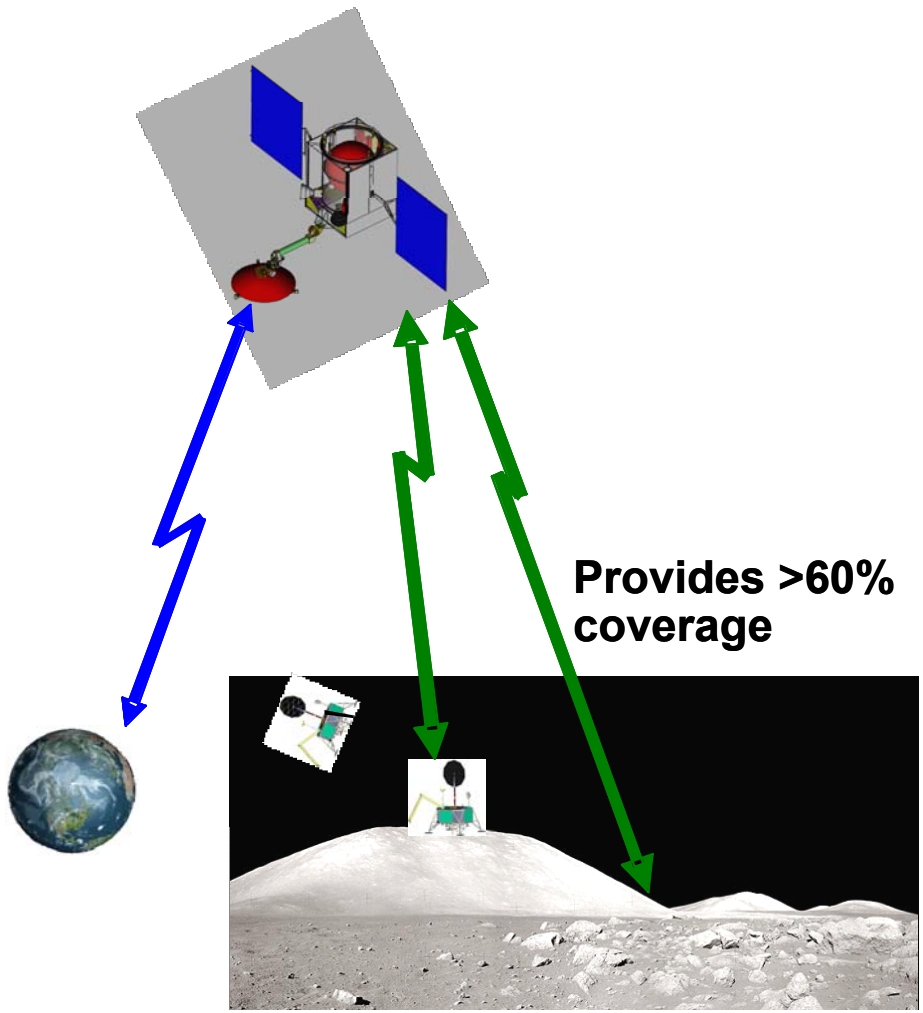
Lunar Relay and NASA's Vison for Space Exploration

- **Permanent human presence on the moon no later than 2020**
- **South Polar region initial destination**
  - **Resource extraction and scientific research**
- **Communication challenge**
  - **Around 14 days/month, no direct Line of Sight (LOS) to Earth**
  - **Terrain will cause additional blockages**
- **Lunar Relay needed to provide communications**
  - **Various studies conducted for Lunar Relay concepts**
  - **Want low cost launch vehicle option**
  - **Targeted Minotaur V launched from Wallops Island**
    - **Lower mass than most options previously proposed**

Concept of Operations

- S band support to users within 250km of south pole
  - Support outside south pole with lesser capability depending on location and equipment of surface user
- Forward command at 4kbps
- Return data
  - 192kbps for up to 3 simultaneous users

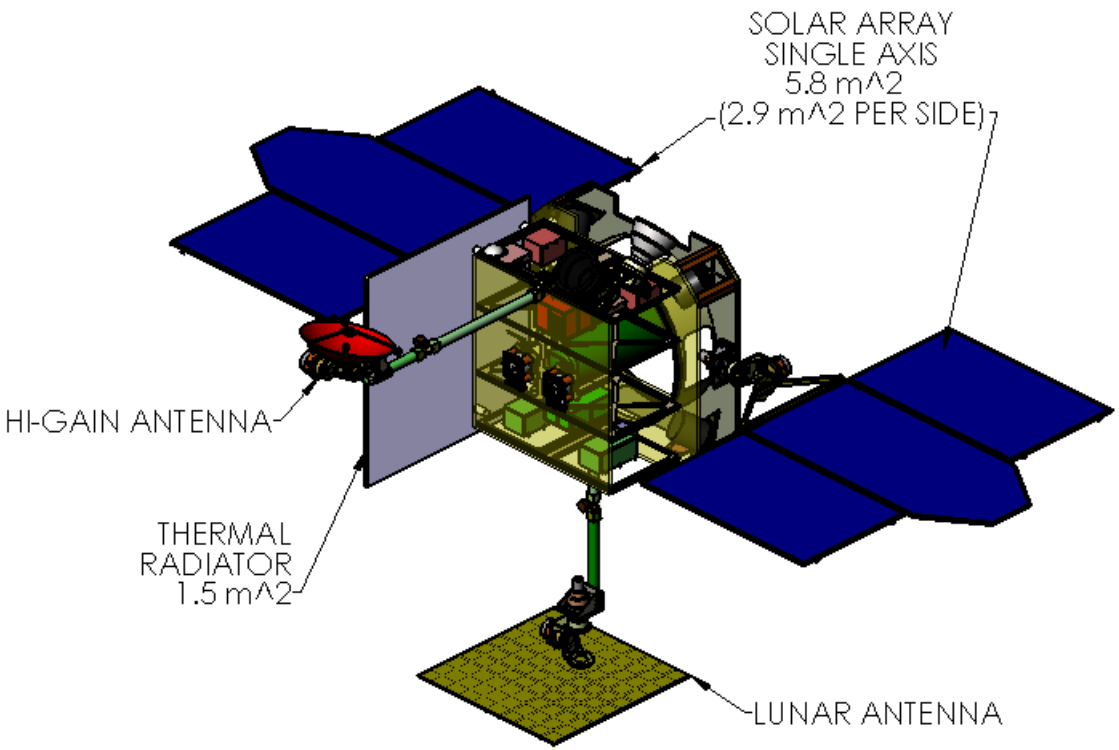
  or
  - 3Mbps for 1 user
- 1 and 2 way ranging
- Doppler tracking and time dissemination
  - For lunar approach, low orbit, descent/ascent, surface ops
- Trunk line to Earth on Ka 37/40GHz
- 60% coverage from 12 hour frozen orbit with one satellite



Launch Vehicle

- **Driving requirement is to reduce cost by fitting within capabilities of Minotaur V launch vehicle**
  - **Wallops island launch of 400 to 450kg to lunar transfer orbit**
  - **Compare to Delta II that can lift 605kg (7326) and 650kg (7920-10)**
  - **Launch windows limited to several short windows/month**
- **Minotaur V configuration**
  - **Star 48 4th stage**
  - **Star 37M or 37FMV 5th stage**
  - **Stages 1 to 3 of Peacekeeper heritage**
  - **Project availability 24 months after contract award**
    - **NRE 6 months**
    - **Normal flow 18 months**

Spacecraft



3 year life
50Krads

Electrical Prop. S/C 389kg
Chemical Prop. S/C 436kg

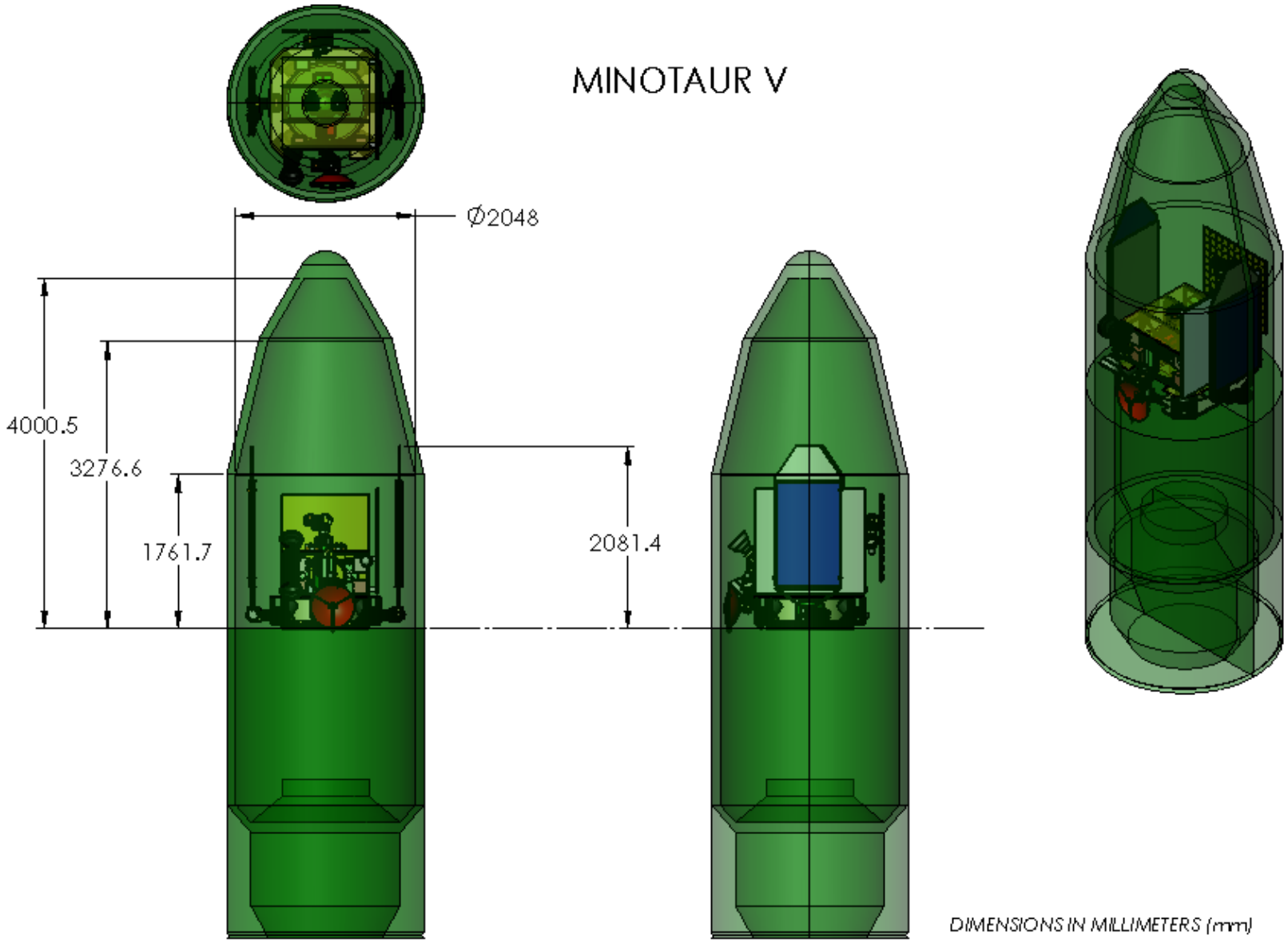
S band proximity link
Ka37/40GHz trunk

2 axis gimbal, hemisphere + 20degrees
Solar arrays one axis gimbal

Power
28Vdc unregulated bus
Triple junction GaAs
Lithium ion battery with DOD of 80%

SPT-70 thruster
Small hydrazine system

S/C in Minotaur V Fairing

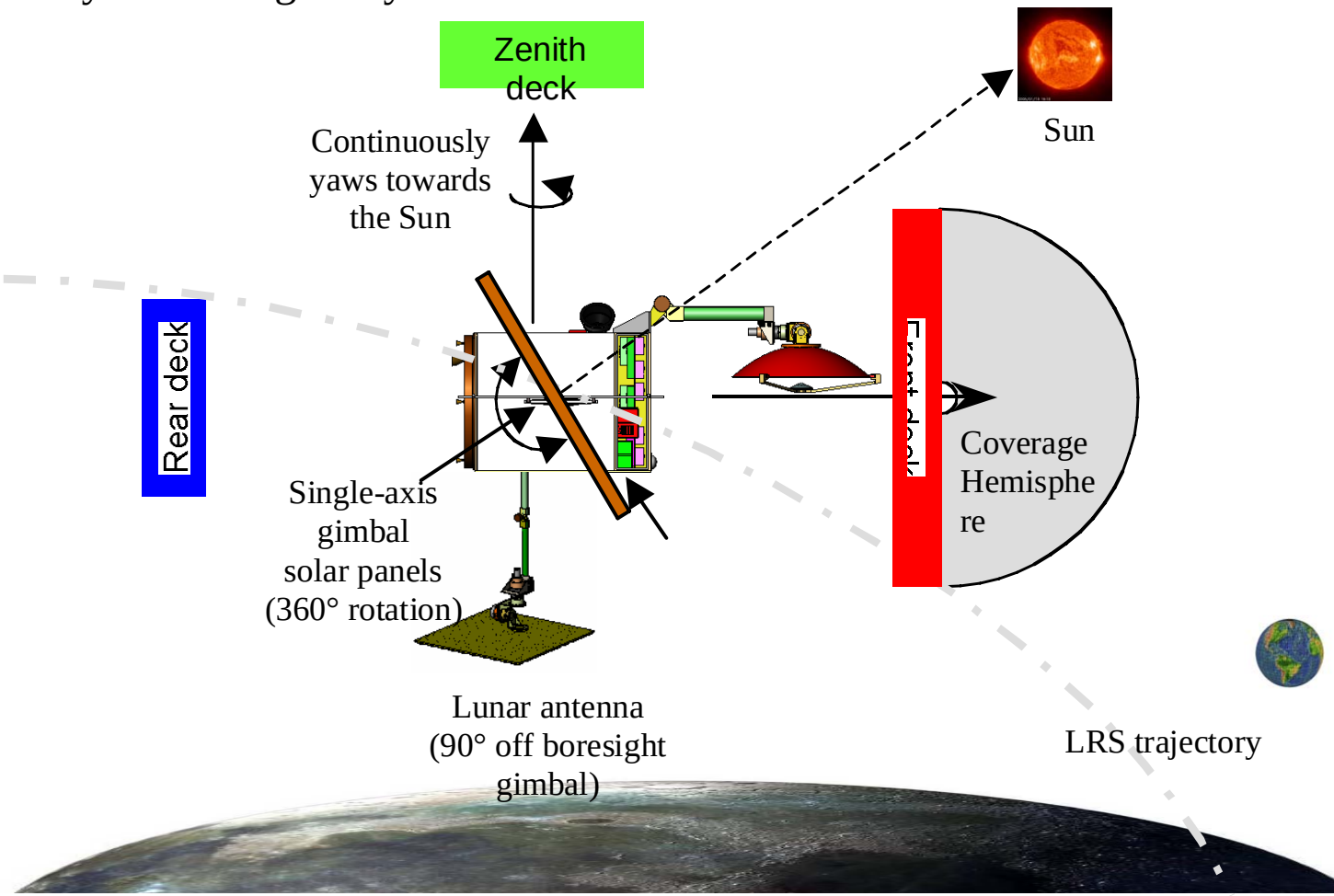


Orbit

- **Orbit**
  - 718 x 8090km altitude (12 hour period) with lunar inclination of 57° and argument of periapsis of 90°
  - Stable, bounded motion of semi-major axis, inclination and, most importantly, argument of periapsis
  - Apoapsis location can be set in southern hemisphere and will stay there without stationkeeping
- **Launch vehicle dispersions**
  - Direct injection would require >230 m/s ΔV correction maneuver 24 hours after separation
  - Phasing loop reduces by half
  - 841 m/s for phasing loop vs. 965 m/s for direct injection
  - Following lunar swingby, electric propulsion system used to target capture and spiral into final mission orbit

Antenna Placement and Pointing

Pitches to keep nadir deck (with lunar antenna) towards moon
Yaws to keep solar arrays toward sun
Earth antenna covers hemisphere plus 20deg
covers when orbital plane edge on to Earth, avoids need to flip
Still need to yaw 180deg every two weeks



Coverage

- **Coverage from South Pole to user**
  - **63% visibility to South Pole user (average 7.6/12 hour orbit)**
  - **100% with two satellites phased 180° apart**
- **Coverage from lunar Relay to Earth**
  - **Full coverage with 3 ground station**
  - **81% with two, 43% with one**

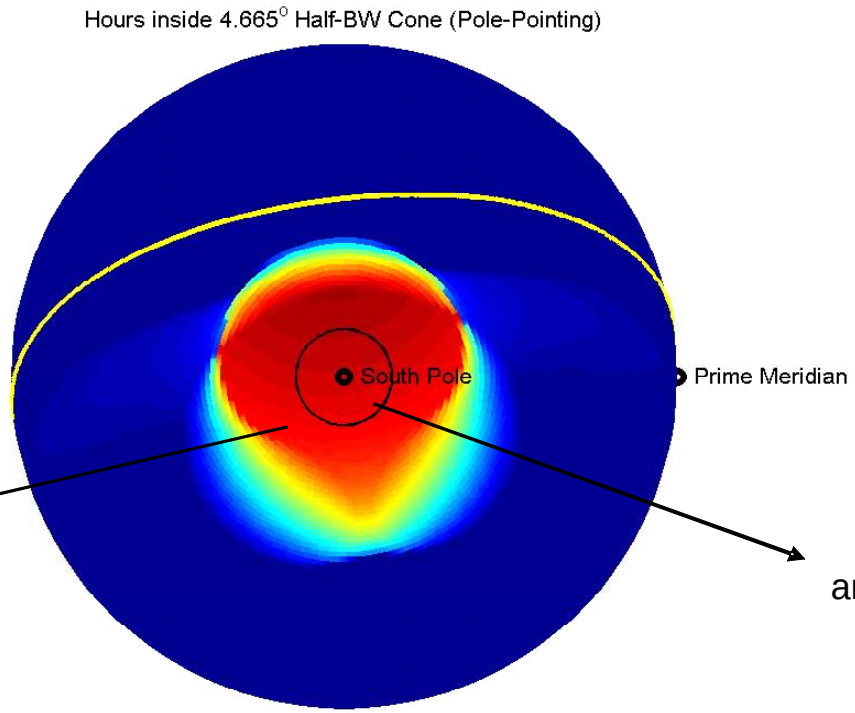
Satellite Coverage Time Per Orbit

15 Lunar Elevation Mask

1 meter antenna chosen
1.5 m covers, but is too large for s/c

Lunar Back Side

Lunar Front Side



orange to red shade area indicates 1m antenna 7-9 hrs of coverage beyond service area

250 km service area perimeter

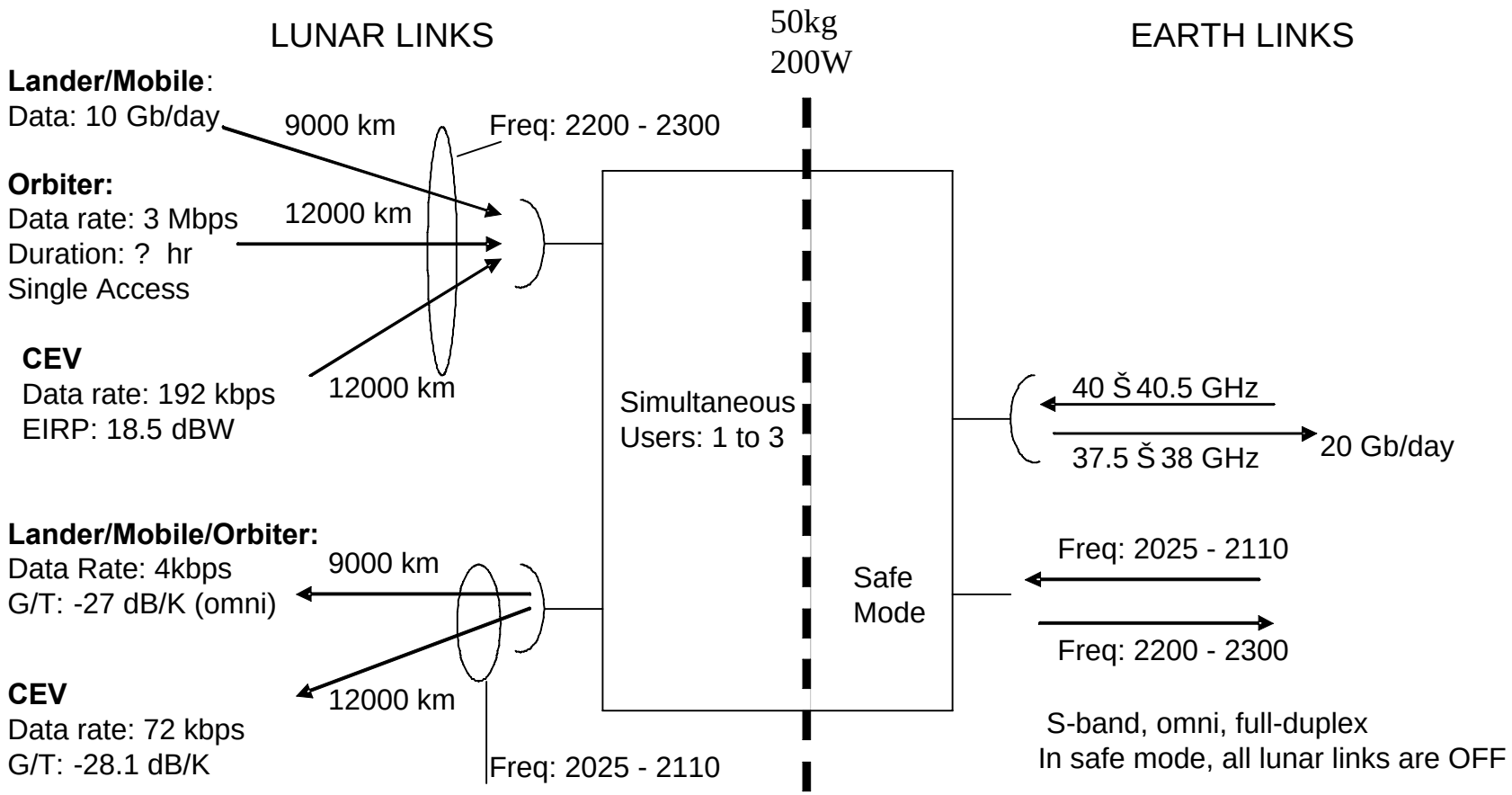
Hours Inside Service Area

Eclipses

- Many short eclipses (about 1 hour)
- Few long eclipses (one or two per mission at most of more than five hours)
- Battery sized to operate through short eclipses, safe mode during long eclipses

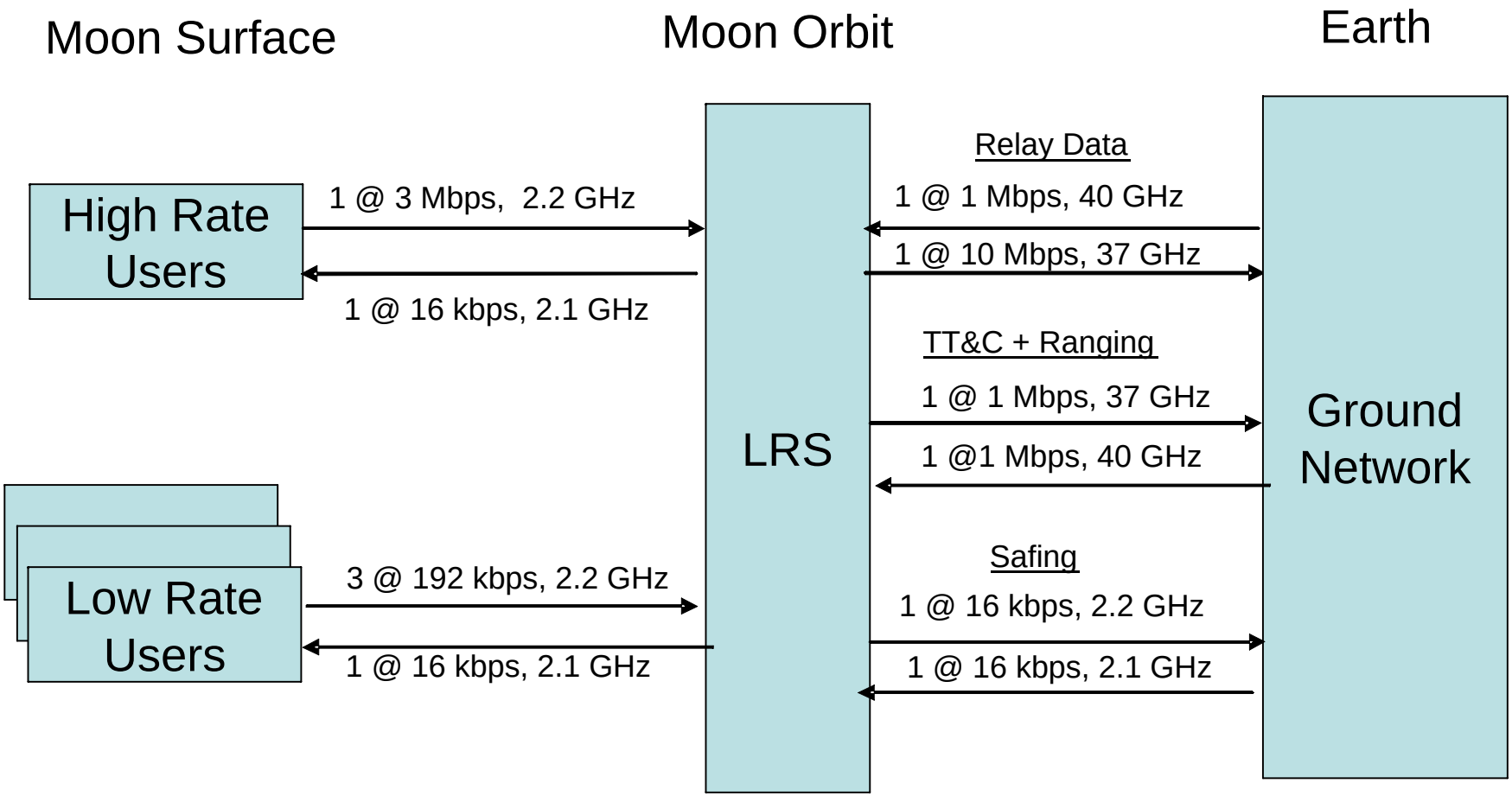
QuickTime™ and a
Graphics decompressor
are needed to see this picture.

Payload Requirements



User	Relay Return Link	Relay Forward Link
Lander/Rover	10 Gb/day	4 kbps
Orbiter	3 Mbps (duration _ hour)	10 kbps
CEV	192 kbps	72 kbps

Payload


Moon Surface
Moon Orbit
Earth
High Rate Users
1 @ 3 Mbps, 2.2 GHz
1 @ 16 kbps, 2.1 GHz
Low Rate Users
3 @ 192 kbps, 2.2 GHz
1 @ 16 kbps, 2.1 GHz
LRS
Relay Data
1 @ 1 Mbps, 40 GHz
1 @ 10 Mbps, 37 GHz
TT&C + Ranging
1 @ 1 Mbps, 37 GHz
1 @1 Mbps, 40 GHz
Safing
1 @ 16 kbps, 2.2 GHz
1 @ 16 kbps, 2.1 GHz
Ground Network

Navigation

- **Provides radiometric tracking services to users in vicinity of moon for approach, orbiting, descent/ascent, surface phases**
  - **1 Way or 2 Way range**
  - **Dopper and time correlation (via 1 Way ranging)**
  - **Atomic clock onboard enable synchronous 1 way service (like GPS) when lunar network has multiple element**
- **Works conceptually like GPS with support for formation of 2 way observables**
- **Preliminary assessments suggest orbit determination of 10-100m (1σ)**
  - **Navigation studies ongoing**

Conclusion

- **Lunar return will require solutions meeting technical and cost constraints**
- **Small lunar relay satellites, such as this one, provides technically capable but less costly alternatives to help meet the technical, cost and schdedule objectives of the overall program**