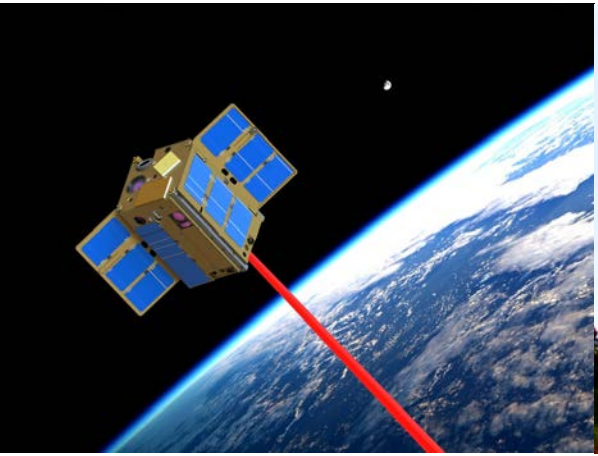
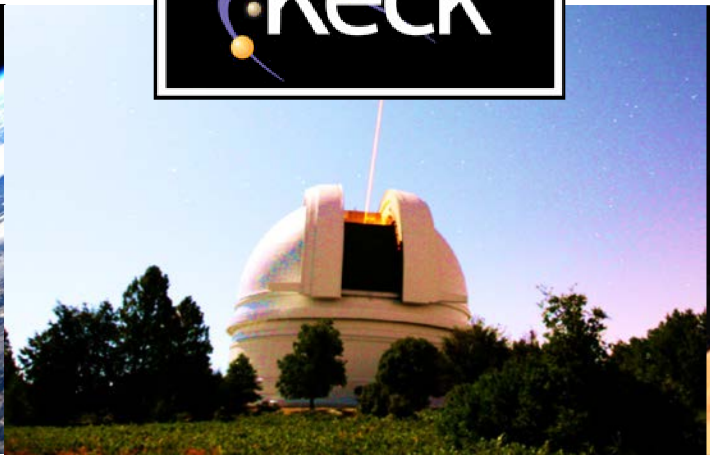
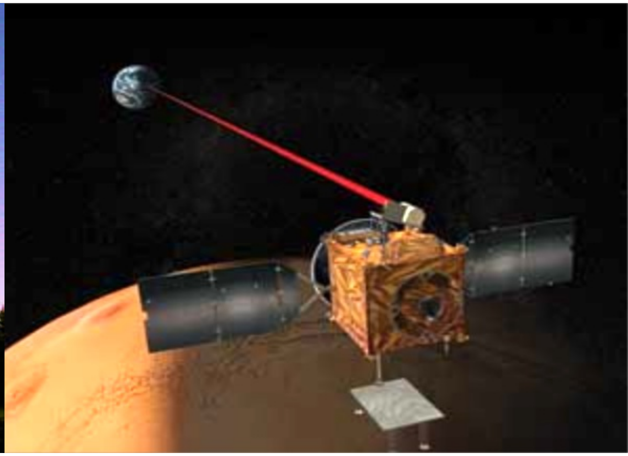




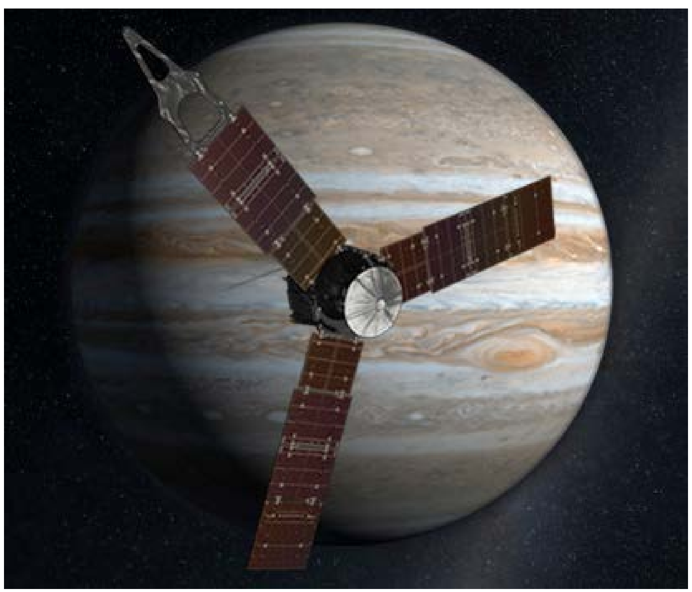


Introduction to Optical Communications for Satellites

Dr. Suzana Sburlan (JPL)

RF vs. Optical

- Fundamental Parameters
  - wavelength / frequency
    - RF = 300 kHz – 300 GHz
    - optical = 300 Terahertz
  - aperture size (antenna size / telescope size)
  - range - distance between transmitter and receiver



http://pics-about-space.com/nasa-juno-satellite?p=1

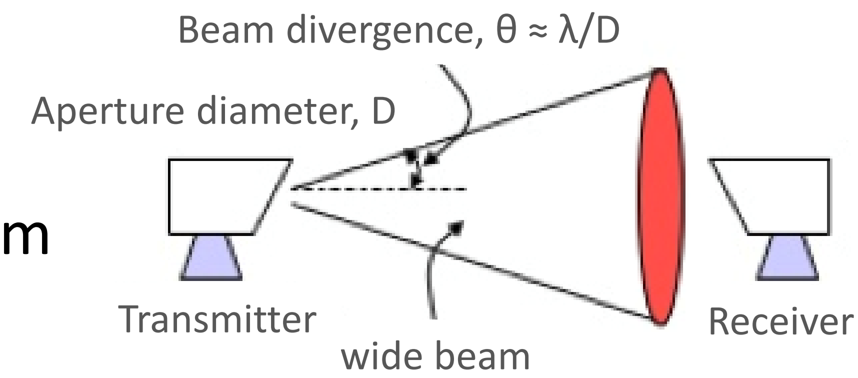
27 January 2015, SPIE Newsroom. DOI: 10.1117/2.1201501.005758

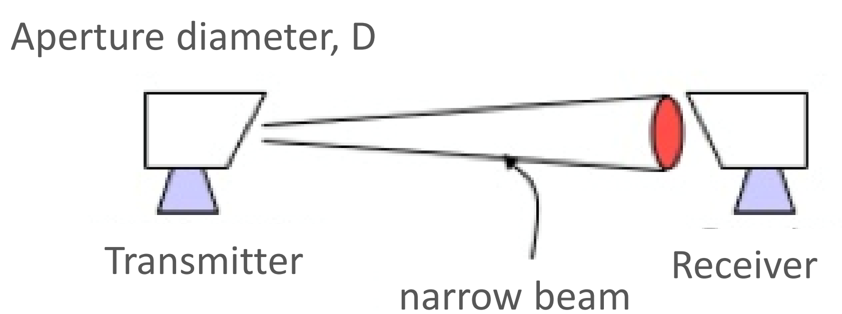
Why Optical?

- Beams emitted from finite-width apertures spread out in space (diverge)
- The angular beam width of the beam depends on wavelength (λ) and aperture diameter (D):

  $\theta \approx \lambda/D = c/(fD)$

  – Shorter wavelength of optical beam means it stays more focused as it propagates (diverges slower)
  – As a result, more power can be collected by the receiver achieving greater signal to noise (SNR)
  – Potentially higher data rates can be achieved

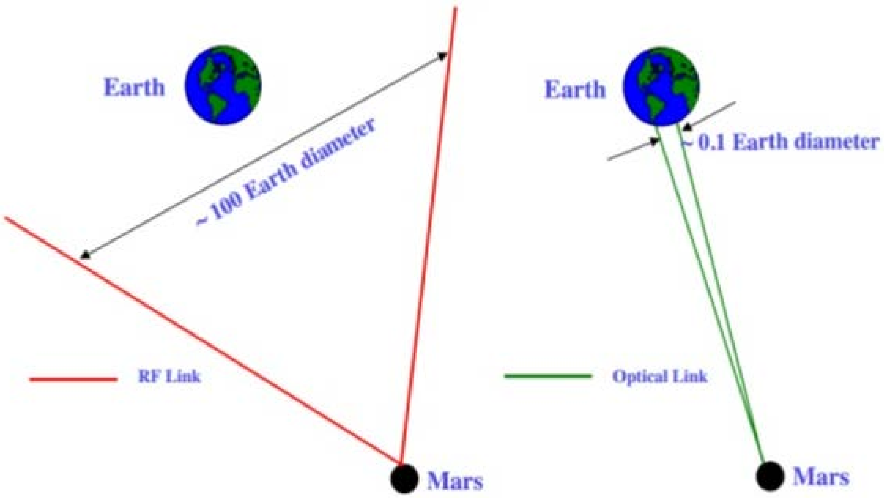




http://www.slideshare.net/wtyru1989/studies-on-next-generation-access-technology-using-radio-over-free-space-optic-links

Beam Widths

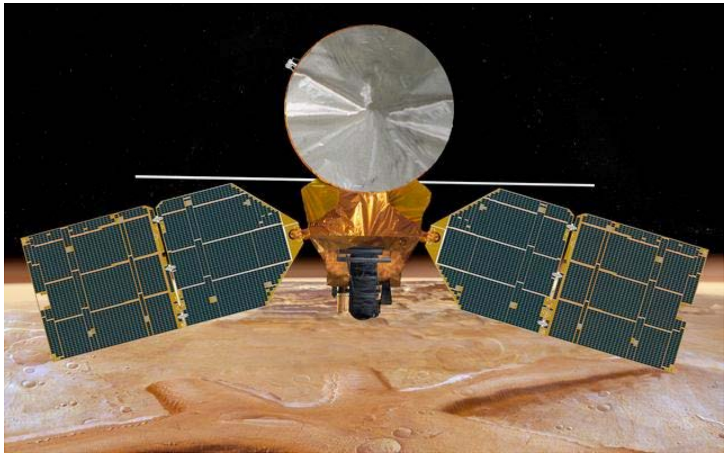
- Beam widths over several distances:
  – RF antennas produce beams that are many times the Earth's size.
  – Optical can produce beams that are a fraction of kms at Earth.



http://www.slideshare.net/BhavikTrivedi1/free-space-optics-fso-27784326

20 cm aperture, 1 AU range

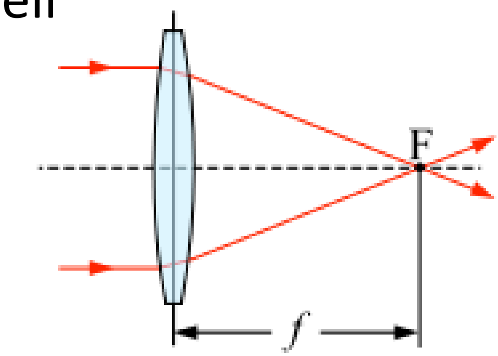
Band	Frequency	Wavelength	Beam Width at Earth
UHF	400 MHz	0.75 m	~2 AU
X-Band	8 GHz	0.0375 m	~1/3 AU
Optical	300 THz	1000 nm	1500 km



http://mars.nasa.gov/mro/mission/spacecraft/

Apertures

- Role of apertures is to shape an EM wave
  - Lenses in optics serve to focus light onto a point
  - Antennas in communication serve to focus EM as well
    - Antenna gain is a measure of how well the antenna can focus EM light (vs. lossless isotropic antenna)
      - Gain = efficiency*Area*4*pi/λ^2 = efficiency*$(D/\lambda)^2$
      - The same dependence of the D/λ ratio



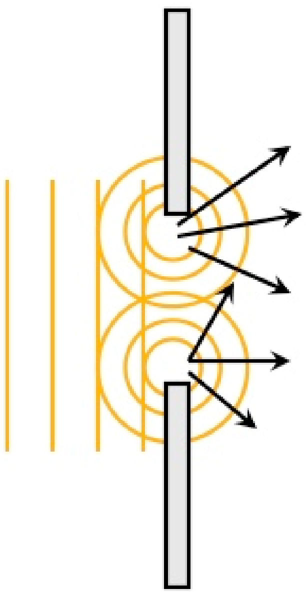
https://en.wikipedia.org/wiki/Focal_length

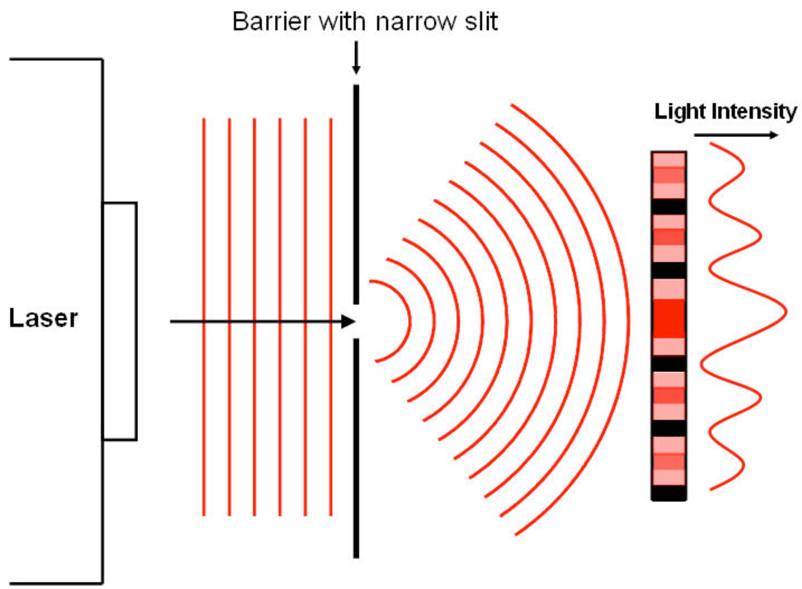
- Directivity of the antenna depends on shape and frequency
- Likewise with optical transmitters, aperture (lens) size also determines the shape of the beam.

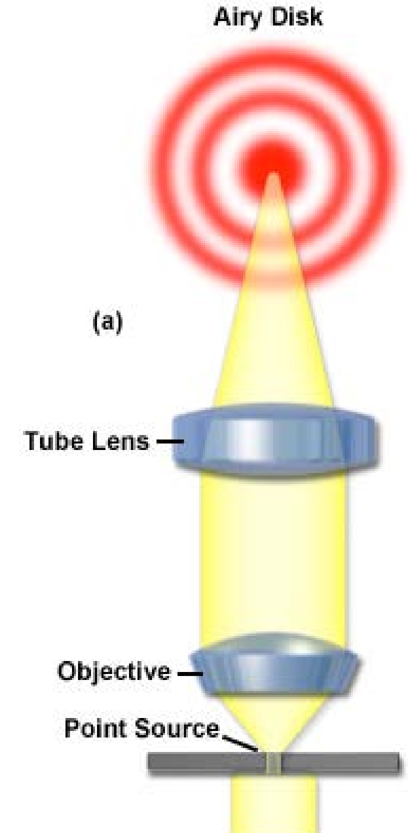
http://enggate.net/telecommunication-engineering/antenna-telecommunication-engineering/t2954.html

Diffraction

- Diffraction phenomenon caused by edge scattering
- Superposition of waves results in spread beam
- Same concept as in optics
  - point source focused down to finite width spot
  - finite resolution caused by overlapping Airy disks







http://umdberg.pbworks.com/w/page/53179895/Diffraction

http://cronodon.com/Atomic/Photon.html

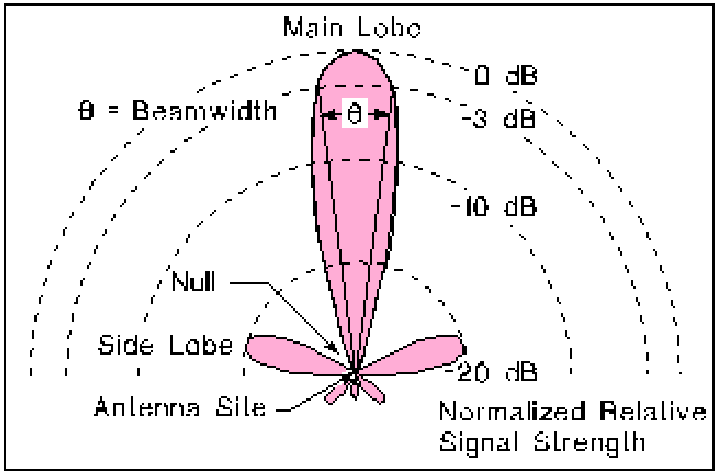
http://zeiss-campus.magnet.fsu.edu/articles/basics/resolution.html

The greater the aperture, the better, but we are limited by the amount of mass we can carry to space (or anywhere).

Directivity

- EM waves will have the shape of a main lobe with side lobes.
- Receiving apertures (ground antennas and telescopes) also have higher receiver gain in preferred direction.
- When we want to detect a signal from space, we want the receiver to find the main lobe, which provides the maximum power.

http://chezasite.com/news/novosti-nauki-8-91971.html



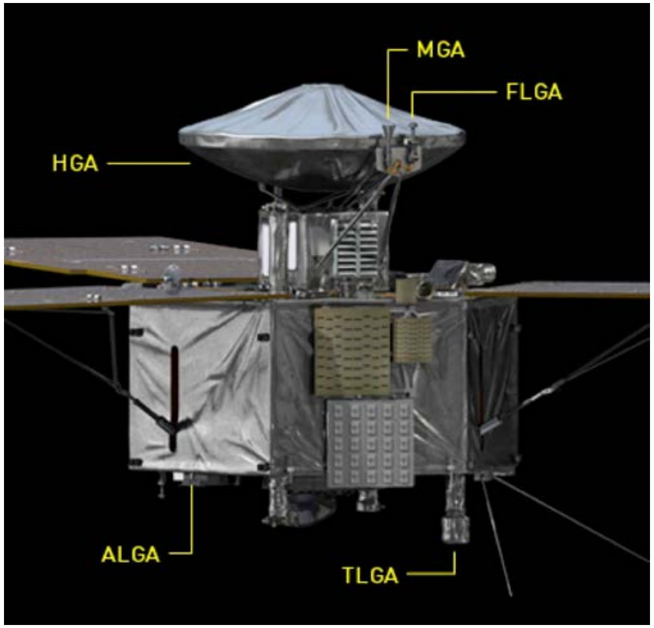
side lobe

http://trizuckr.com/radiation-pattern-of-antenna-ppt/

http://thechronicleofeducation.com/2015/09/21/futa-japanese-institute-to-launch-satellite/

Communications from Space

- Acquisition phase - transmitter and receiver must find each other in space
  - Ephemeris for coarse pointing
  - Feedback from ground for fine pointing (bidirectional link).
- Directivity of antenna makes it challenging
- Deep space (RF) missions often carry multiple antennas with different directivities
  - low gain for acquisition or critical mission phases (orbital insertion)
  - high gain for transmitting science data
  - Juno has five antennas!
    - fore LGA
    - fore MGA
    - aft LGA
    - toroid LGA
    - HGA



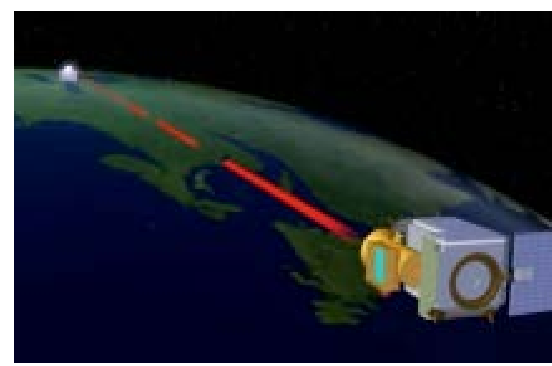
http://sciencenordic.com/spacecraft-could-become-autonomous-new-danish-technology

https://www.missionjuno.swri.edu/media-gallery/spacecraft

Pointing for Optical Comm.

- Spacecraft must hold the beam pointed toward the receiver while rejecting vibrations and other disturbances
- Mechanical gimbals traditionally used for antenna pointing
  - For optical comm., fast-steering mirrors used for fine pointing along with gimbals.
  - Other technologies being considered including piezoelectric and birefringent crystals to steer a beam
  - Body pointing, relying on spacecraft attitude control (ACS)
- Higher directivity of optical comm. beams means more precise pointing is needed

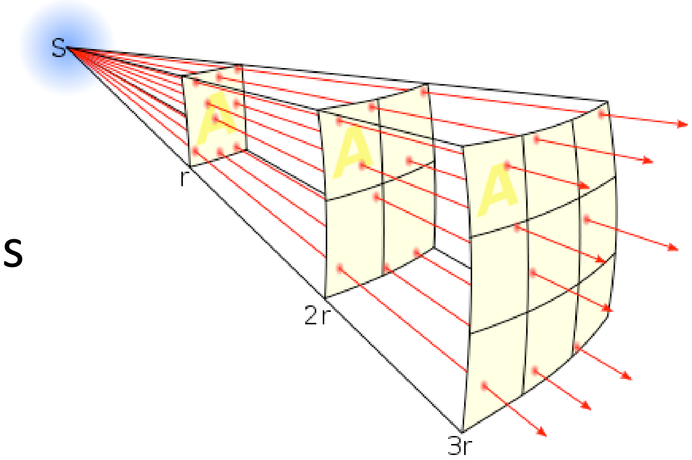
Mass, complexity, and risk can potentially increase!



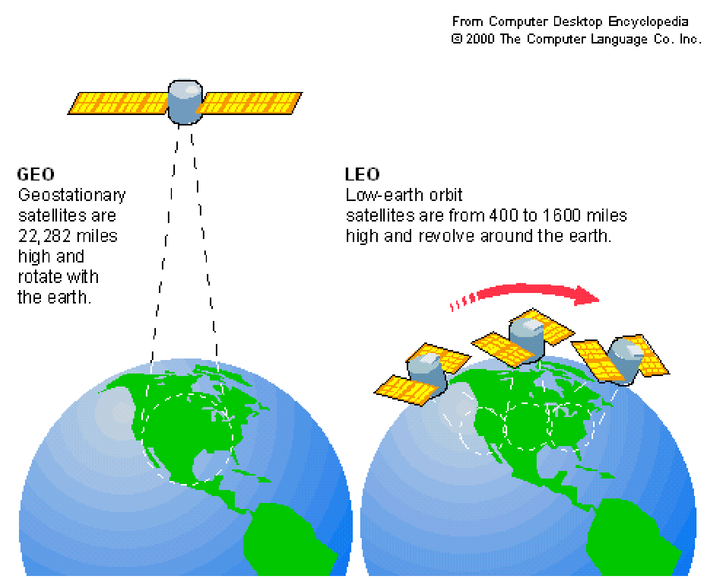
https://uwaterloo.ca/institute-for-quantum-computing/news/iqc-completes-project-points-way-future-quantum-space

Range Considerations

- Link equation
  - $P_r = P_t G_t G_r(\lambda/(4\pi R))^2$
- Telecom. determined by data rate requirements
  - how much data to send and how quickly
  - spacecraft resources (mass, power, volume)
- Low Orbits
  - transmitter passes over receiver quickly
  - dynamic pointing needed
  - low range means low-gain antenna can be considered
  - low directivity, looser pointing requirements
- Deep Space
  - Generally, more data is being demanded
  - High directivity -> optical
  - Precise pointing
  - Keep spacecraft resource similar to RF



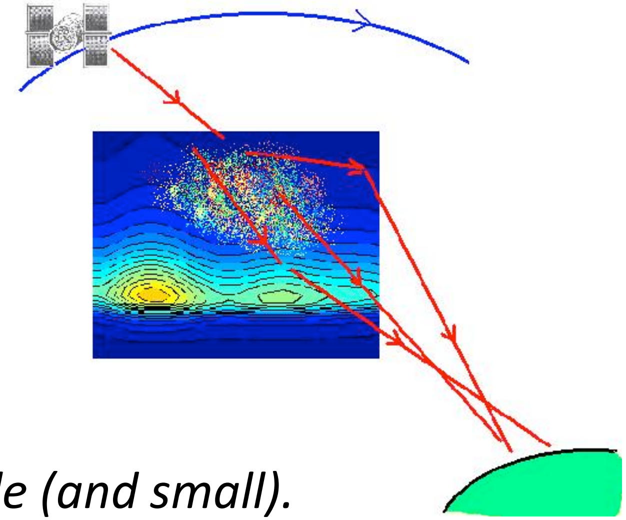
https://en.wikibooks.org/wiki/Basic_Physics_of_Digital_Radiography/The_Basics



http://pics-about-space.com/low-earth-orbit-satellite?p=1#

Other Considerations

- Daytime operation:
  - Sun is a noise source for optical detectors
  - Performance degrades for direct detection modulations
- Atmospheric losses:
  - RF and optical waves are attenuated differently
  - For optical, cloud coverage can be catastrophic
- Achieve greater reliability by:
  - Increasing diversity – more ground stations (?)
  - Hybrid RF/optical transmitters and receivers (?)
  - Space-based receivers above the atmosphere (?)
  - Weather modeling and prediction
- Multi-customer accessibility vs. security
- Scientific observations with optical aperture
- Greater operational costs with increased complexity.

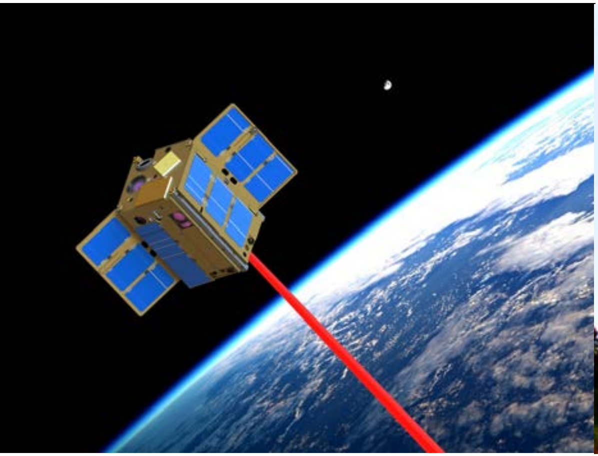
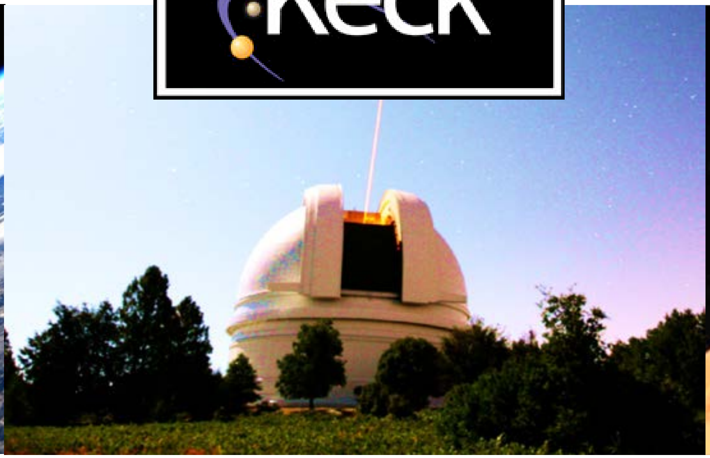
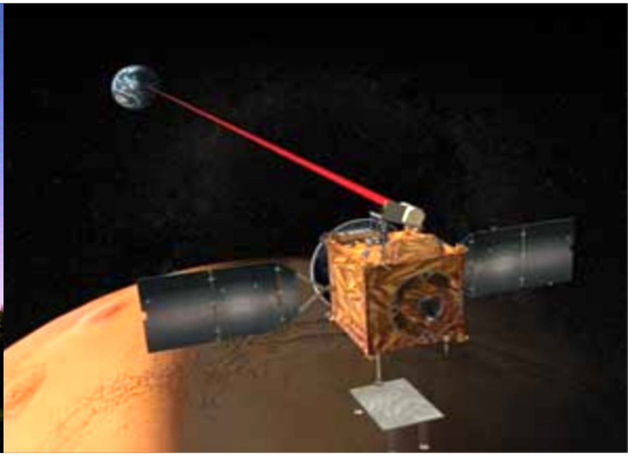


We still want to keep things simple (and small).

http://www.goldenstateimages.com/GSI_big.php?img=SBK-048
http://roma2.rm.ingv.it/en/themes/11/ionospheric_scintillation

Summary

- Fundamental parameters of telecomm. systems:
  - frequency, aperture size, and range
- Optical has higher directivity
  - potentially higher signal to noise (SNR) and data rate
  - better pointing needed
- Optical is currently in demonstration phase
  - retire key risks
  - develop auxiliary capabilities (navigation, science)
  - build ground infrastructure

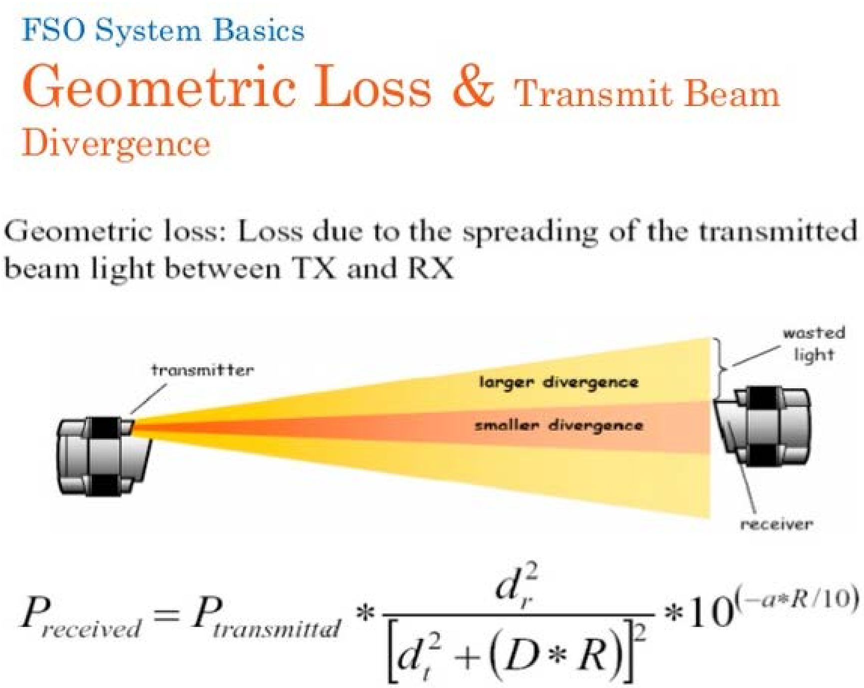




Thank You

Backup

Other Applications

- Ranging for navigation
- Scientific observation with optical aperture
- Security



http://pt.slideshare.net/Gayathrikotapati/fso-final