Telescope Reference Design for Observing Exoplanet Nightside City Lights

Gerard T. van Belle[1]
[1]Lowell Observatory

What would it take to make a definitive technosignature detection via direct observation of a planet's city lights? The notional design parameters of an optical telescope array capable of imaging the nightside of a nearby planet are presented.

Targets at 4 parsecs
77 systems
8 FGK stars, only 2 G's (alf Cen A, tau Cet)
60 M dwarfs

Angular Sizes for an Earth at 4pc
Star-planet separation: 1 AU at 4pc = 0.25"
Angular size of Earth at 4pc = 21μas

Apparent Brightness of Earth at 4pc
Solar flux at Earth: F = 1360 W/m^2
Earth cross-section area: A = πR^2 = 1.275×10^{14}m^2
Reflected power (albedo A_B=0.3): P = F×A×A_B = 2.6×10^{16}W
Power at 4pc = P / 4πd^2 = 1.4×10^{-19}W/m^2
In magnitudes ($F_{V,0}$=3.6×10^{-8}W/m^2), m_V≈28.6
Scales with amount of illuminated disk relative to observer

Apparent brightness of City Lights at 4pc
- Single city like Tokyo or New York: 50GW in artificial lighting
- At 4pc, this is 2.6×10-25W/m^2 → m_V=42.8 mag
- In the optical, this is directional and albedo-dependent
- In the thermal IR (~10um), this is isotropic and efficient (eg. all energy use ends up as waste heat eventually) → m_N~36 *but* there are then contrast issues with surrounding countryside

Required Interferometric Baseline
Baseline length (Rayleigh criterion)
λ / B at 500nm for 21μas → 6km
So for 100x100 pixels → 600km

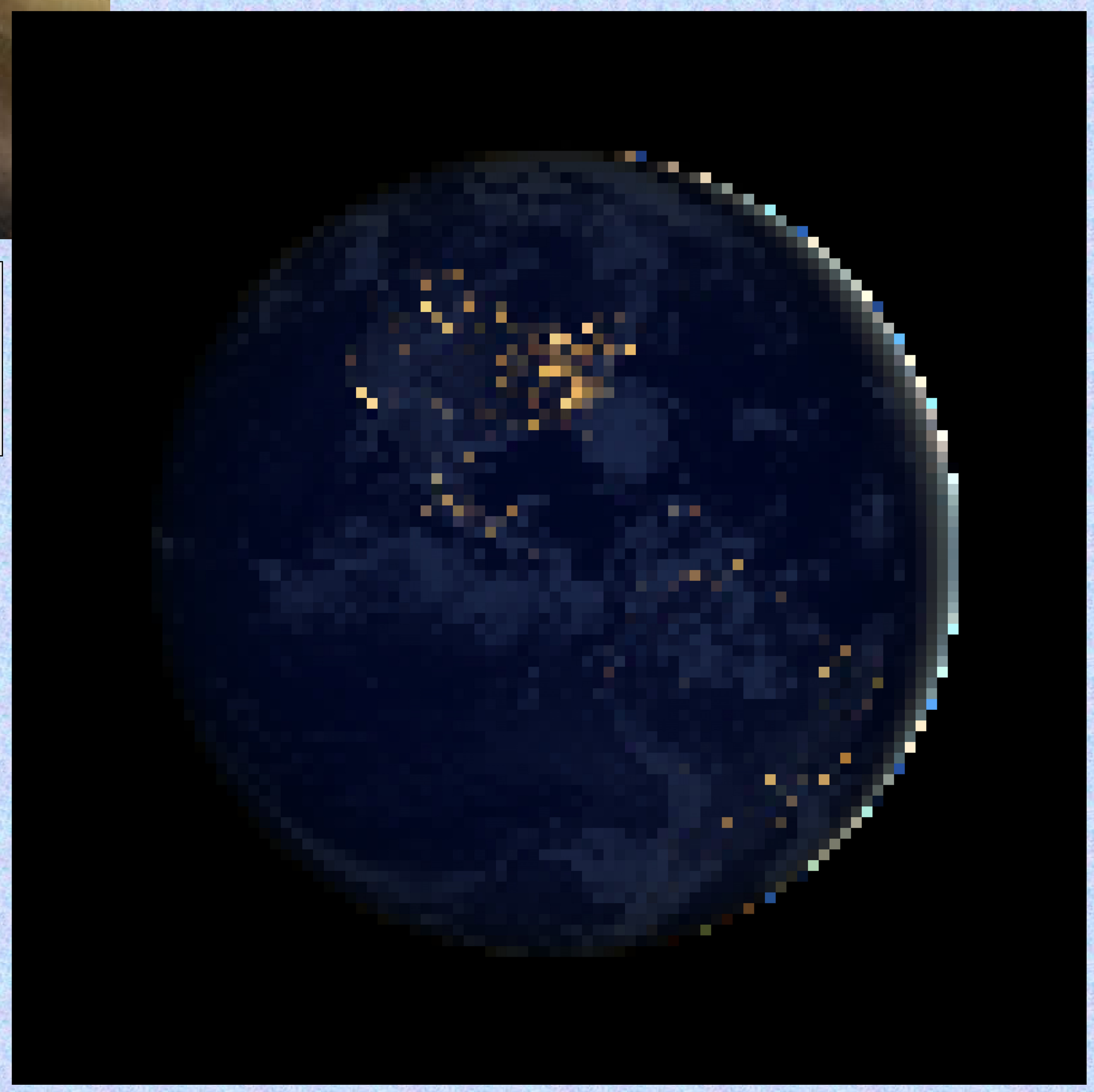
Aperture Quantity
For model-independent image reconstruction, N>16

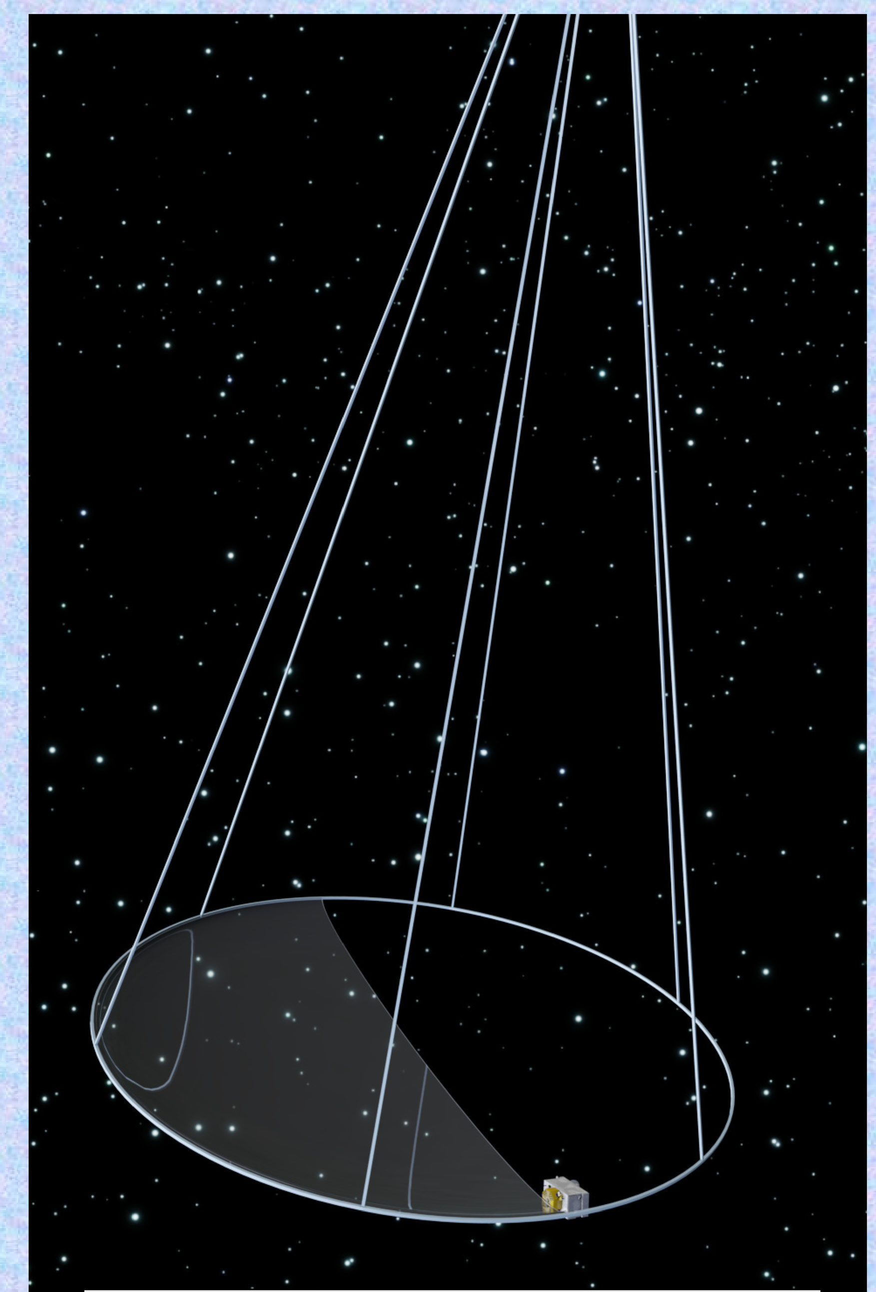
Individual Aperture Size
- HST @ 2.4m can hit mV ≈ 31 with very long exposures (~days)
- Scaling by area to mV ≈ 42.8 in 1 hour → D≈1.3km
  - Scaling goes as ~D^2 for background-limited (eg. sky glow, zodiacal light, and detector noise; the case for HDF)
  - If source-photon-limited (photon shot noise), scaling is more like ~D^1
  - This size is a lower limit

Rayleigh Beam Propagation
- Rayleigh length: Z = πd^2 / 4 / λ
- Beam propagation distance L
- As L / Z → 1, a 1/e (37%) reduction in flux
- For L / Z ≈ 0.001, need d~20m at λ=500nm

Bottom Line

16 × 1,300m apertures, manufactured in space, flying in formation with separations 120 to 600km





How to Build?
In-space manufacturing
In-situ resource utilization (ISRU)

Wildcard Issues
- At m_V=43, you see **everything**
  - All background stars of Milky Way
  - Individual supergiant stars out to z = 20
  - All interstellar comets like 3I/ATLAS along line-of-sight
    - Population density?
  - Background galaxies back to the cosmic horizon at z~1000
- Scattered light
  - Micrometeorite punctures, dust collection
- Shielding of relay beams

Better Options?
- Look for gamma-ray / neutrino emission from nuclear reactors → blocked by atmosphere / flux is too low
- Longer wavelengths → contrast issues
- Glints from solar panels → efficient panels will absorb all light

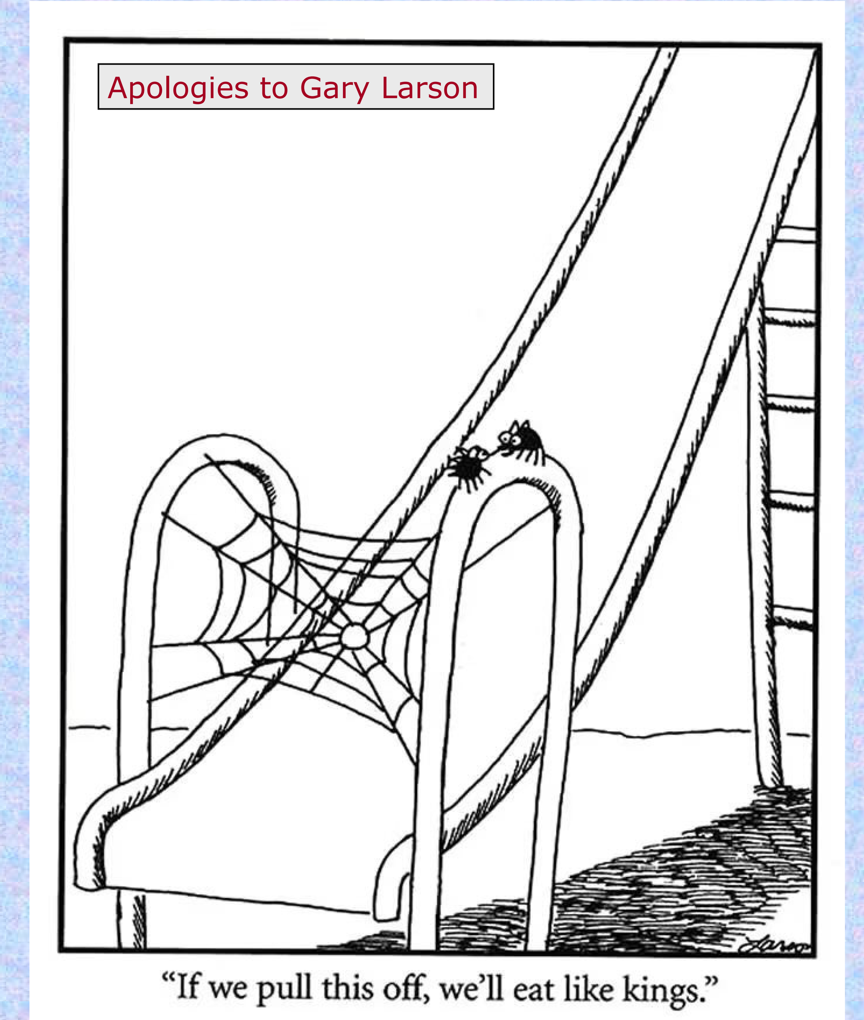
Examples in Sci-Fi literature
Olaf Stapledon – *Star Maker* (1937)
"…every solar system… surrounded by a gauze of light traps, which focused the escaping solar energy for intelligent use"
Arthur C. Clarke – *Childhood's End* (1953)
"The lights of Earth's cities were like a glowing web seen from above."
Frank M. Robinson, *The Dark Beyond the Stars* (1991) – strange lights seen on a rogue planet by a generation ship

Contact: Gerard van Belle, Director of Science, Lowell Observatory
gerard@lowell.edu

Acknowledgements: This work has been supported by the Lowell Observatory.

ONLINE RESOURCES

Like this poster? Get it!



"If we pull this off, we'll eat like kings."