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TPF Terrestrial Planet Finder Interferometer

Exoplanet Detection and Characterization with Mid-Infrared Interferometry

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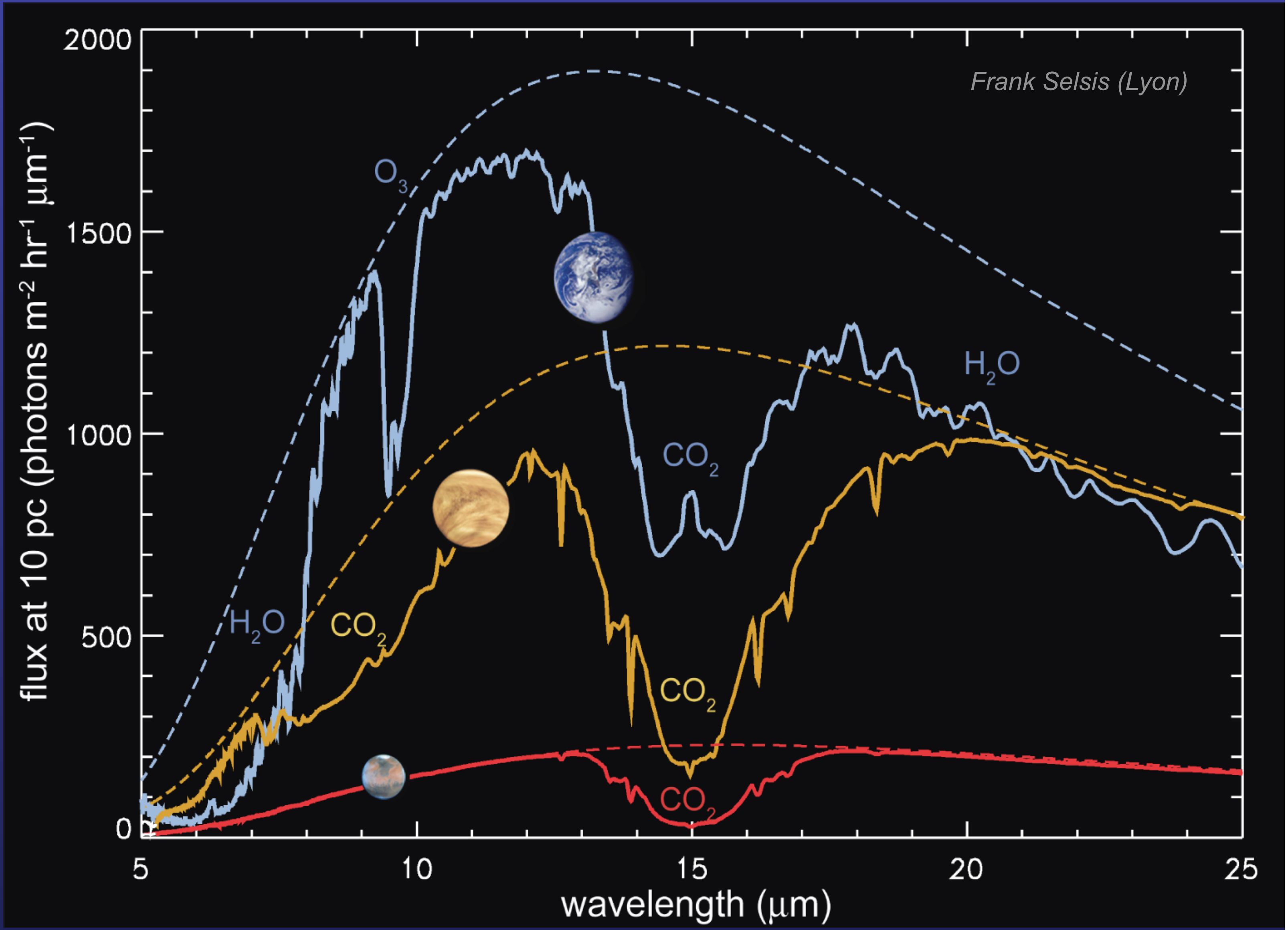
Outline

- Why mid-infrared?
- Why interferometry?
- Mission characteristics and necessary technologies
- Design choices

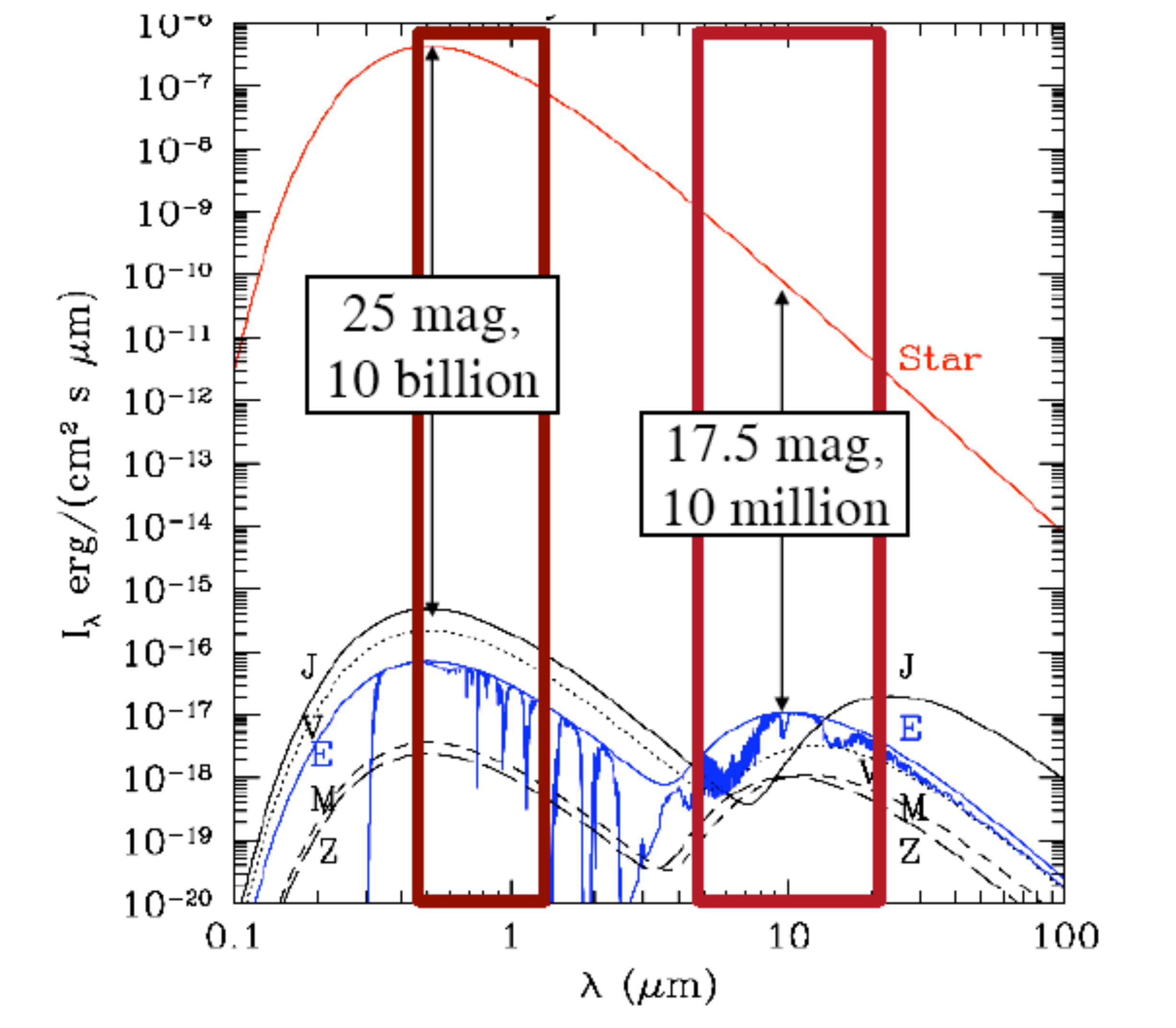
Why mid-infrared?

1. Key atmospheric features



Why mid-infrared?

2. Contrast ratios



The solar system at 10 pcs (Traub and Jucks 2002)

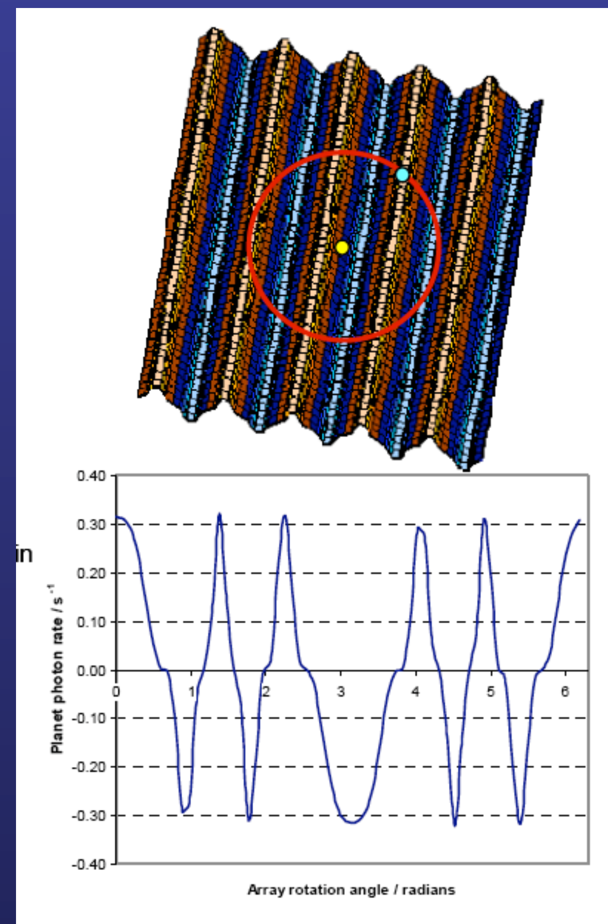
Why interferometry?

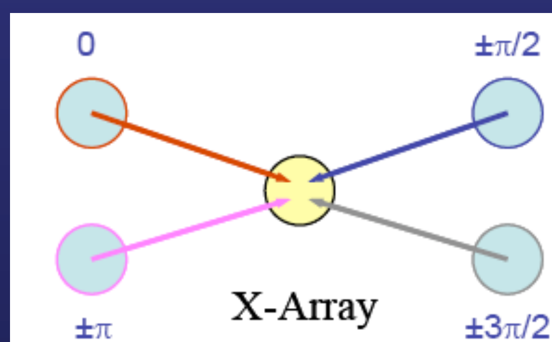
1. Resolution
   - 1 AU subtends 100 milliarcsec at 10 pc
     - To resolve this scale at 10 microns with a single telescope ($\lambda/2D$) you need diameter < 10 meters
       - This is possible, but requires deployed apertures
     - For an interferometer, the resolution is $\lambda/2B$, where B is the baseline between the two telescopes

Why interferometry?

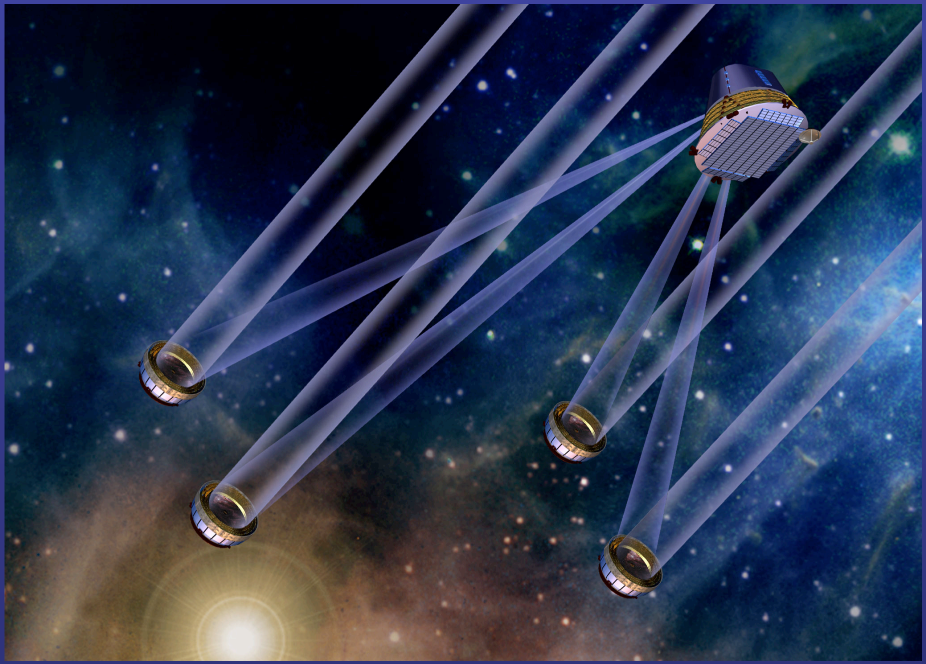
2. Starlight suppression

- Even in mid-IR, the star is a million times brighter
- Deconstructive interference fringe can be formed (i.e. nulling)
- Different baseline lengths can be scaled for the different spatial scales
    - Detecting planet
    - Suppressing starlight
    - Phase light to produce asymmetric beam





Terrestrial Planet Finder Interferometer



Overview

- Formation Flying Mid-IR nulling Interferometer
- Starlight suppression to 10^{-5}
- Heavy launch vehicle
- L2 baseline orbit
- 5 year mission life (10 year goal)

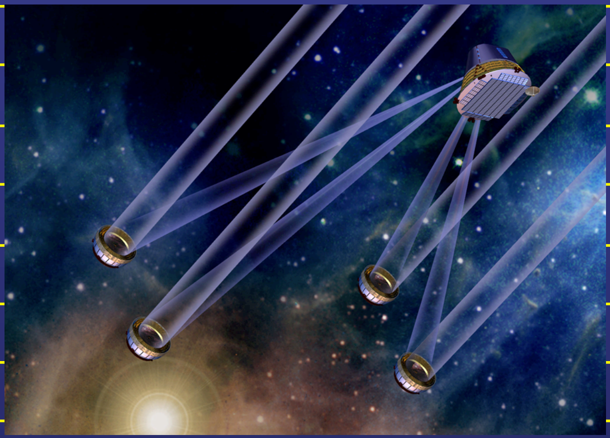
Science Goals

- Detect as many as possible Earth-like planets in the “habitable zone” of nearby stars via their thermal emission
- Characterize physical properties of detected Earth-like planets (size, orbital parameters, presence of atmosphere) and make low resolution spectral observations looking for evidence of a *habitable* planet and bio-markers such as O_2, CO_2, CH_4 and H_2O
- Detect and characterize the components of nearby planetary systems including disks, terrestrial planets, giant planets and multiple planet systems
- Perform general astrophysics investigations as capability and time permit

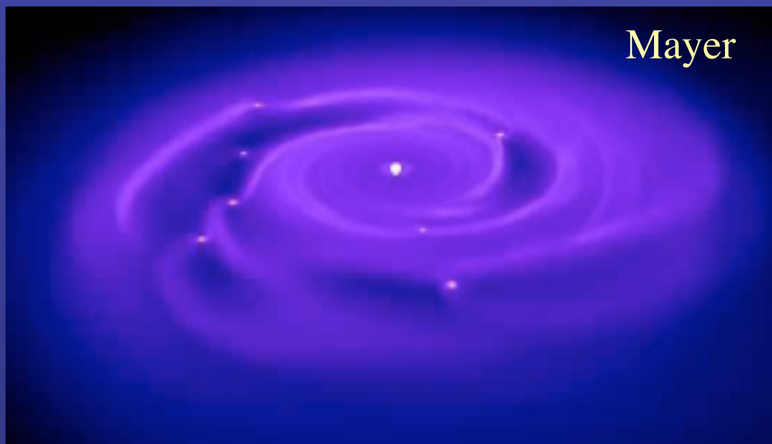
Properties of a TPF-I Observatory

Illustrative Properties of a TPF-I Observatory Concept

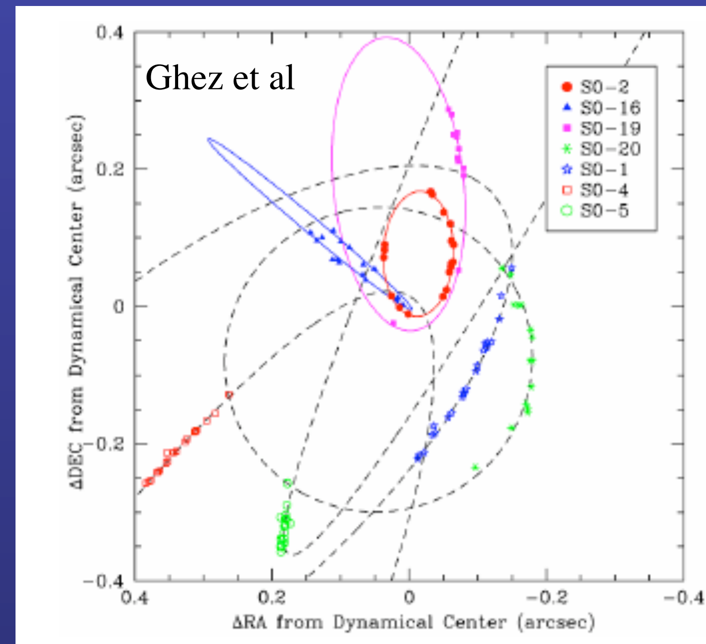
Parameter	4-Telescope Chopped X-Array Emma Design
Collectors	Four 2-m diameter spherical mirrors, diffraction limited at 2 µm operating at 50 K
Array shape	6:1 rectangular array
Array size	400 × 67 m to 120 × 20 m
Wavelength range	6–20 µm
Inner working angle	13–43 mas (at 10 µm, scaling with array size)
Angular resolution	2.4 mas to 8.2 mas (at 10 µm, scaling with array size)
Field-of-view	1 arcsec at 10 µm
Null depth	10^{-5} at 10 µm (not including stellar size leakage)
Spectral resolution Δλ/λ	25 (for planets); 100 for general astrophysics
Sensitivity	0.3 µJy at 12 µm in 14 hours (5σ)
Target Stars	153 (F, G, K, and M main-sequence stars)
Detectable Earths	130 (2 year mission time, 1 Earth per star)
Exozodiacal emission	Less than 10 times our solar system
Biomarkers	CO_2, O_3, H_2O, CH_4
Field of regard	Instantaneous 45˚ to 85˚ from anti-Sun direction, 99.6% of full sky over one year.
Orbit	L2 Halo orbit
Mission duration	5 years baseline with a goal of 10 years
Launch vehicle	Ariane 5 ECA or equivalent



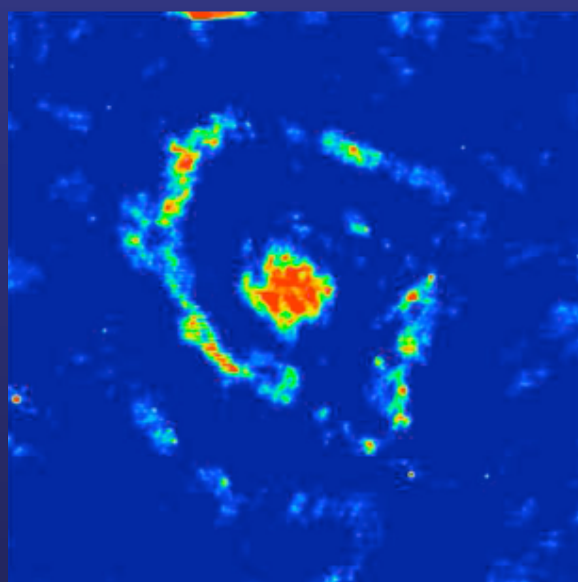
General Astrophysics



Planet forming disks

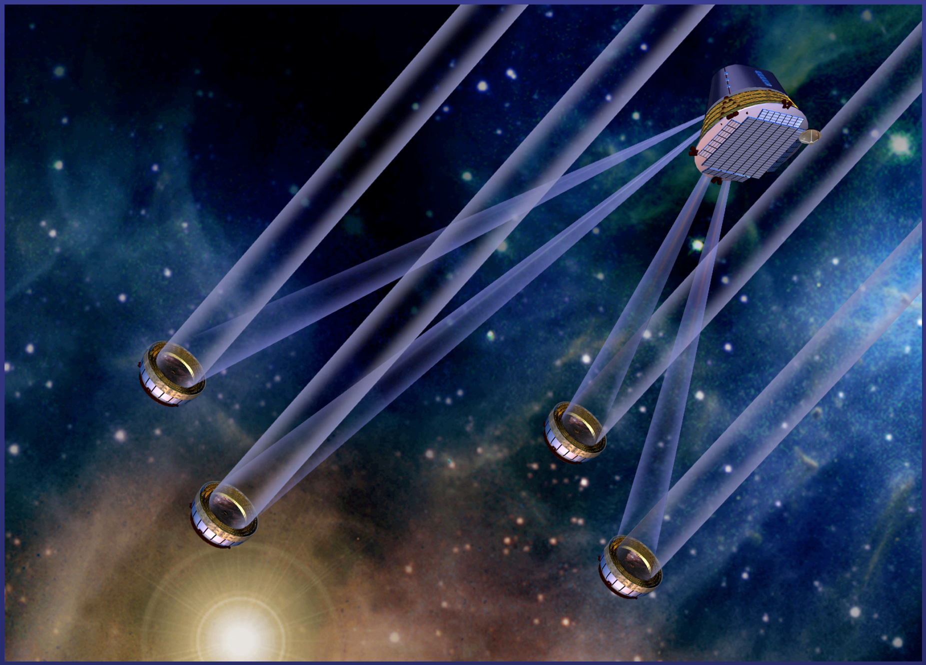


Galactic Center dynamics



Imaging distant galaxies

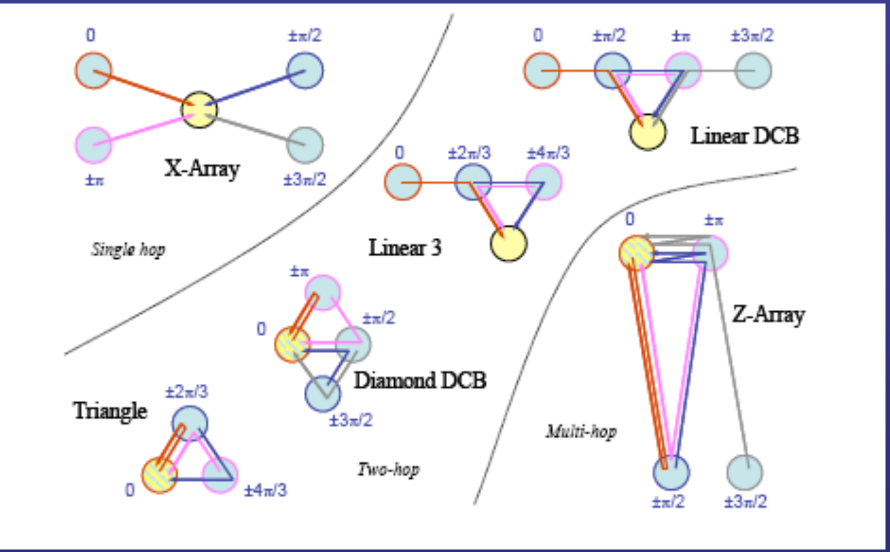
Technology for a Mid-IR Interferometer



- Starlight suppression
  - Null depth & bandwidth
  - Null stability
- Formation flying
  - Formation control
  - Formation sensing
  - Propulsion systems
- Cryogenic systems
  - Active components
  - Cryogenic structures
  - Passive cooling
  - Cryocoolers

Design trade-offs

- Telescope aperture size vs. mission lifetime
  - Larger telescopes cost more, but can detect planets more quickly
  - Longer mission costs more
- Telescope formations
  - Equal pathlengths
  - Beam combination spacecraft



- Spectral resolution vs spectral coverage
  - For a given array size, N, the resolution is $R=\lambda N/(\lambda_{long}-\lambda_{short})$
    - Better spectral resolution gives more channels across each line, but fewer lines covered

Opportunities with smaller mission

- Example: Connected interferometer
- Fourier-Kelvin Stellar Interferometer (Danchi et al)