Star and Planet Evolutionary Conditions Interferometric Exploration Spectrometer (SPECIES)

- Origins Mission Concept by J. Pearson, G. Blake, J. Zmuidzinas, H. Yorke, W. Langer
- Free flying heterodyne interferometer with 6 apertures
  - UV plane filled by low Earth orbit choice
  - Warm deployable apertures (as larger as possible)
- Bands in 1080-1950 GHz ~155-260mm, baseline of 1-20km
  - Dual polarization system

    l/Dl of $1.1x10^6$ to $3.9x10^7$
- Optimized to study early phases of star formation in H_2D^+, H_2O, N^+, C^+, OH, NH_3, H_3O^+, CH, CH^+
  - Goal is to see inside the disk with high spatial and spectral resolution
  - Observe directly the cloud collapse and internal structure
  - Detect observe structure and chemistry in the protostellar disk
  - Follow the water in stellar evolution
- Proposed as an observatory for general observer use

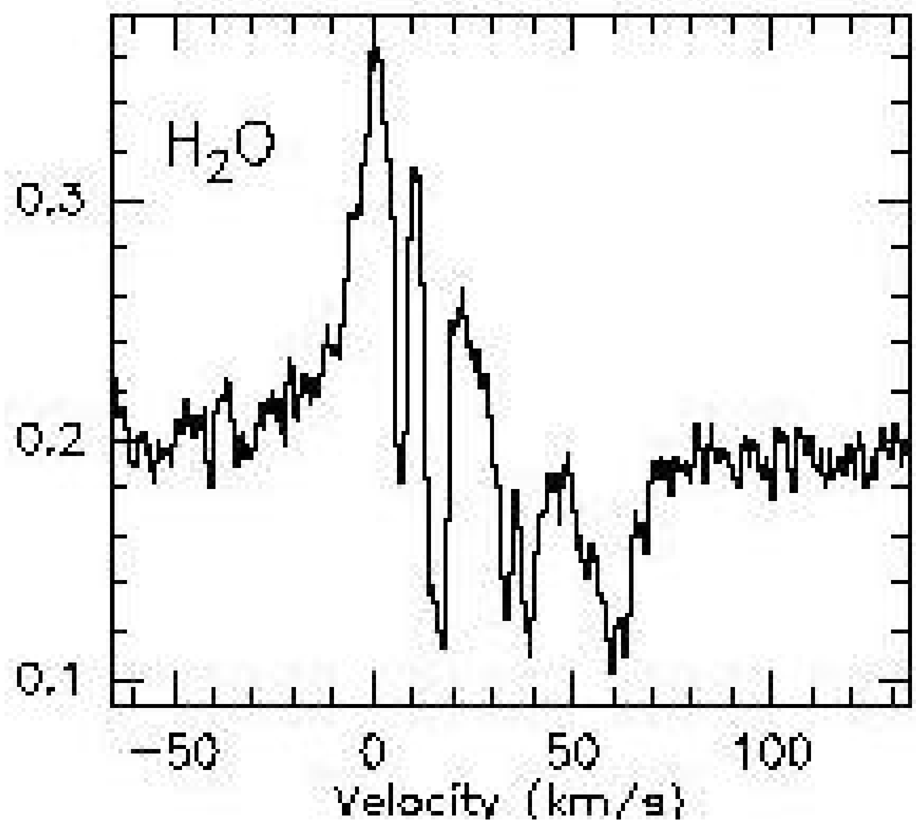
Primary Science Goals 2/2

3. Directly observe and study the distribution and relative abundance of water in star- and planet-forming disks.
   - What is the distribution of vapor phase water relative to water ice (e.g., as determined by Spitzer or JWST) in pre-stellar cores as a function of mass and evolutionary state?
   - How does the abundance and spatial distribution of water change with progressive heating of the star-forming envelope and how does the stellar type affect this process?
   - Are there significant differences in water abundance and distribution as a function of initial stellar mass?
   - Where, spatially, does the water observed by ISO LWS in low-mass Class 0 protostars originate?
   - What is the HDO/H_2O ratio as a function of spatial distribution, initial mass and evolutionary state? Does this have any implications to our understanding of comets and asteroids/chondrites?

4. Determine the velocities and turbulence in the cold core of the debris disk as a function of disk mass, star mass and radial position throughout the formation process.

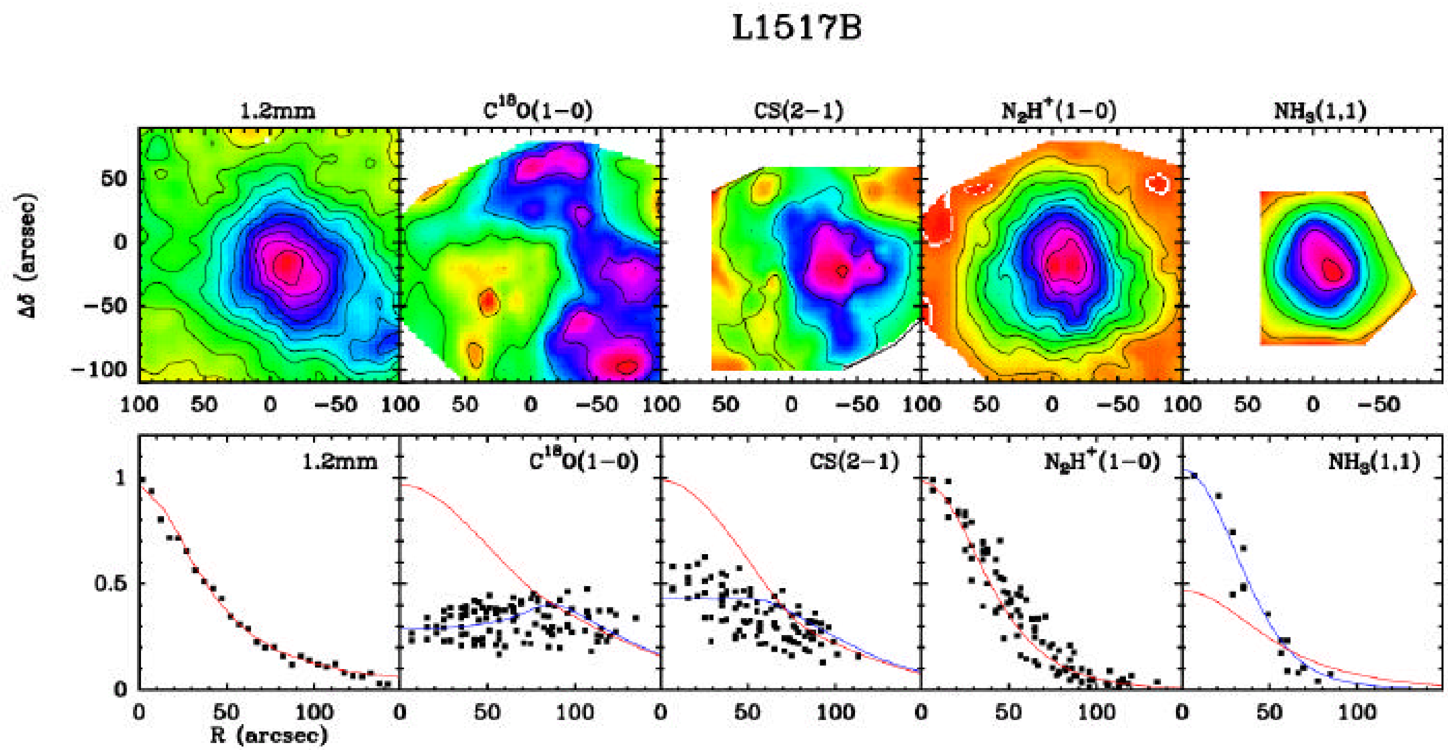
5. Determine the extent and distribution of water in disks surrounding evolved stars, especially first ascent red giants whose increasing luminosity may lead to extensive water sublimation from any attendant Kuiper Belt or Oort cloud.

Complexity in Water Lines



SWAS W49 Spectrum: High spatial resolution is needed to sort out Origins of components

Structure in Cold Cores



From M. Tafella et al. 2003

Cold cores observed to date are ~10K and can be traced in Nitrogen species. If they are colder ~6K and have been around for a while only hydrogen species are not depleted. Lowest H_2D+ and D_2H+ transitions are critical!

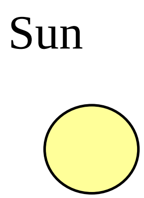
The Mission Concept

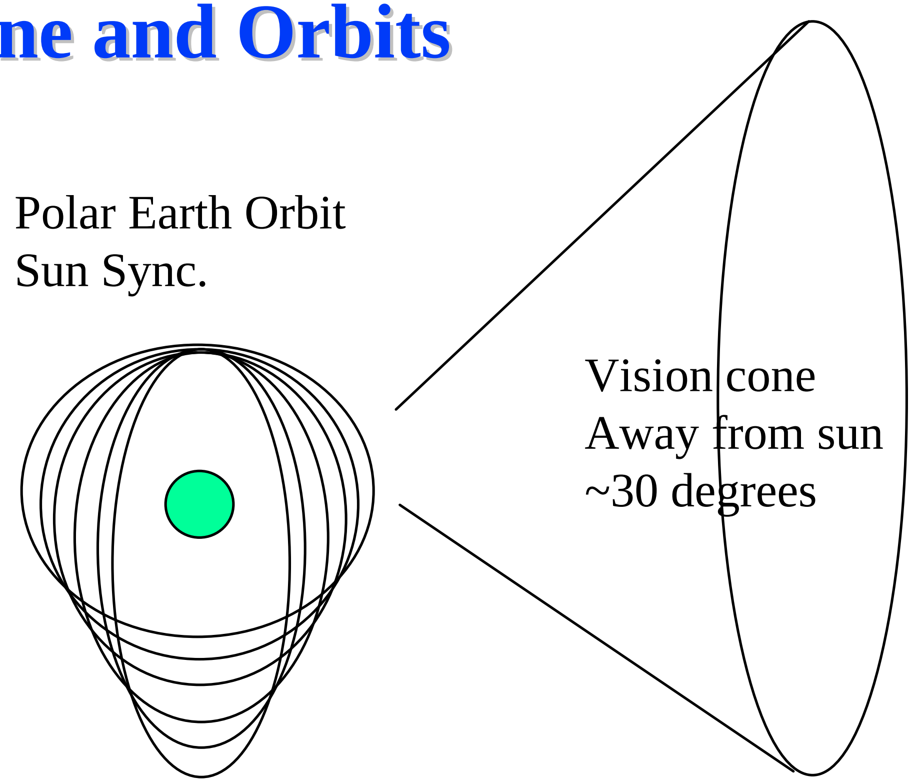
- Free Flying Heterodyne Interferometric Array
  - Concept Study will focus on 6, but 4 would still be effective
  - 4 receiver bands dual polarization one band at a time
  - Spacecraft "identical"
- Operated as an observatory with open observing proposals
- Polar Earth orbit
  - Sun always present, but shielded from receivers
  - Earth shielded from receivers
- Mission duration goal of 3 years (cooling technology dependent)
- Metrology 2 frequency microwave link (~100 GHz) based on GRACE 24/32 GHz system (~1micron accuracy). Combined with LO and IF distribution
  - Position knowledge only (GPS used for course position)
  - Control limited to station keeping

Instrument Concept

- **Heterodyne Interferometer**
  - **Para Water Band covering 1080-1250 GHz. Para Water fundamental R branch $1_{1,1}$-$0_{0,0}$ at 1113 GHz, Also gets the Para lines $2_{2,0}$-$2_{1,1}$ at 1229 GHz, $4_{2,2}$-$4_{1,3}$ at 1208 GHz and the n_2=1 $1_{1,1}$-$0_{0,0}$ at 1205 GHz could also be observed as could the Ortho $3_{2,1}$-$3_{1,2}$ 1163 GHz, $3_{1,2}$-$3_{0,3}$ 1097 GHz, $3_{1,2}$-$2_{2,1}$ 1153 GHz transitions and the J=2_K-1_K NH_3 transitions**
  - **Ion Band covering 1310-1480 GHz. Fine structure transition of N^+ at 1461 GHz, H_2D^+ ground state $1_{0,1}$-$0_{0,0}$ at 1370 GHz, D_2H^+ ground state $1_{1,1}$-$0_{0,0}$ at 1477 GHz and J=1-0 HD^+ at 1316 GHz.**
  - **Ortho Water covering 1620-1750 GHz. Ortho water fundamental R branch $2_{1,2}$-$1_{0,1}$ at 1670 GHz, $2_{2,1}$-$2_{1,2}$ at 1661 GHz, $3_{0,3}$-$2_{1,2}$ at 1717 GHz, the low-lying inversion transitions of H_3O^+ as well as $P_{3/2}$ N=5/2-3/2 CH and J=2-1 CH^+.**
  - **CII band covering Band 1820-1920 GHz. Targets Carbon ion line at 1900.5 GHz and the lowest OH of the upper ^2P ladder at 1835 GHz.**
- **Spectral Resolution ~1x10^6 to ~5x10^8 (1 MHz to 50kHz at backend)**
  - **Two polarizations**
- **Maximum Baseline 1-2km early in mission moving to 10-50km later**
- **Antenna goal of warm deployable membranes backup to use smaller fixed**
  - **Off axis system to minimize standing waves**
  - **Bigger is better for sensitivity**

UV Plane and Orbits





Sun nearly orthogonal to orbit Plane:
Solar panel and shield always in the Sun

Same Period Polar Orbits with slightly different ellipse use to fill UV plane
UV plane filled every 90 minutes
UV coverage like horizon (with movement) on ground based array
Mission starts with maximum baseline ~1km and is increased over time
Sun and Earth shielded from spacecraft

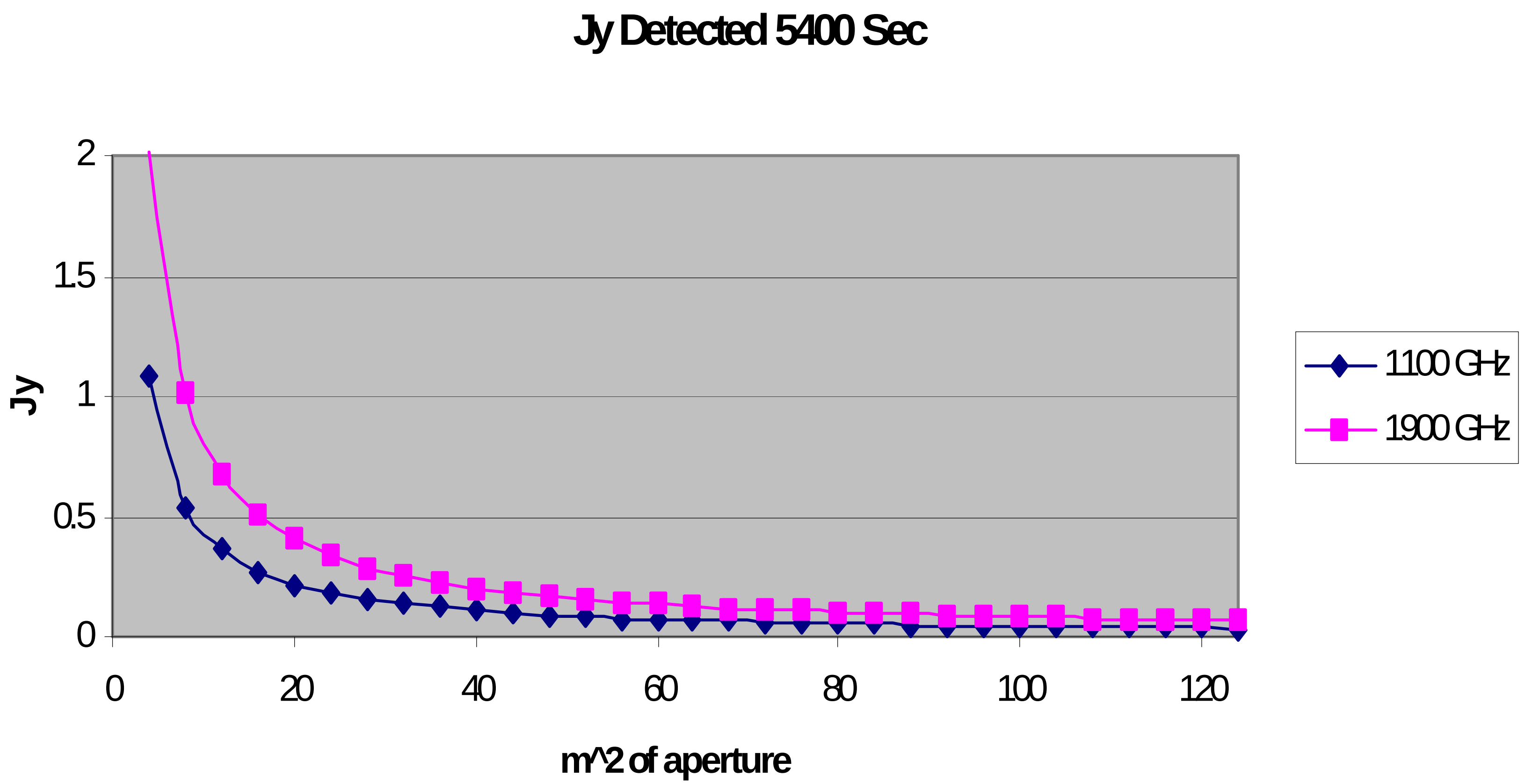
Array Sensitivity

The sensitivity of an heterodyne array is:

$$\Delta S = \frac{\sqrt{2}kT_{sys}}{g e_q A_{eff} \sqrt{n_p [N(N-1)/2] \Delta n \Delta t}} W/m^2/Hz$$

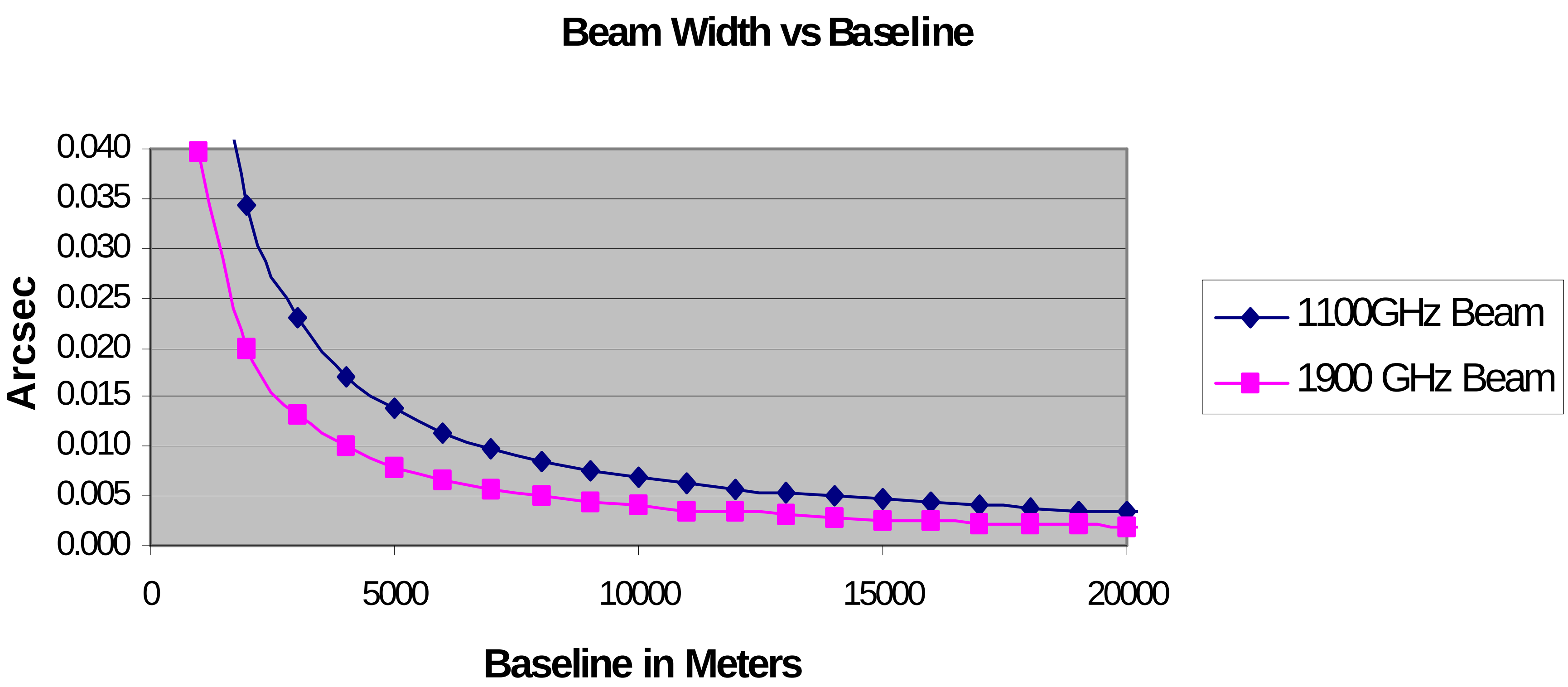
k Boltsmann's constant
T_{sys} the system temperature (800K SSB to 1500K SSB)
γ geometry dependent factor for the array (~1)
ε_q system efficiency (correlator quantization, phase jitter etc..) (~0.9)
A_{eff} effective aperture size (? As big as possible)
N_p number of polarizations (2)
N number of apertures (6)
Δv detection bandwidth (50kHz to 1 MHz)
Δt integration time (~90 minute orbit)

Sensitivity vs Aperture Size 1MHz



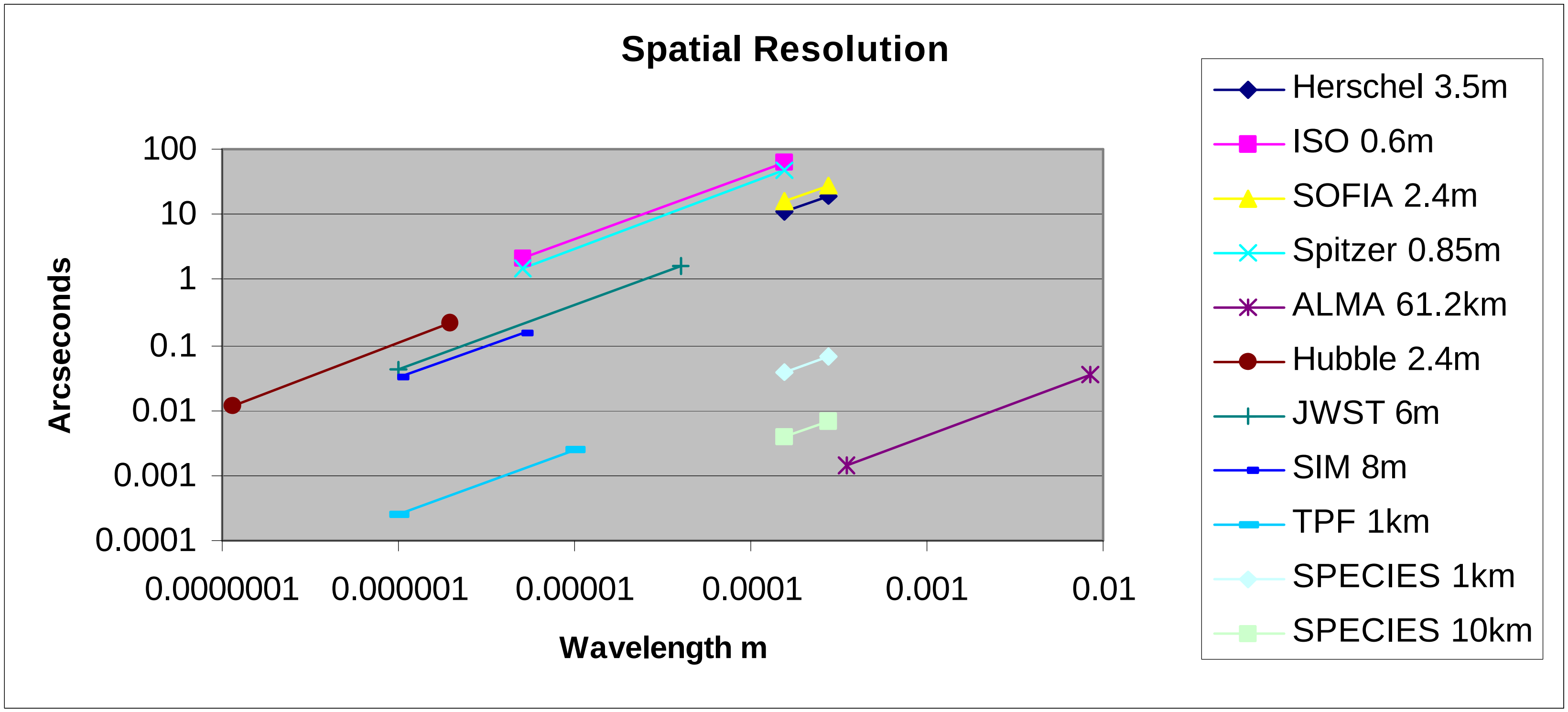
Assumes Tsys of 800K SSB at 1100 GHz, 1500K SSB at 1900 GHz in 1MHz bandwidth.

Spatial Resolution vs Baseline



The nearest star forming region is ~140pc, so 1 AU is 0.007". SPECIES will be resolve be able to resolve these features without going to very long baselines

Relative Spatial Resolution



SPECIES would address the spatial resolution gap in the Far Infrared

Topics for Study

- **Thermal System**
  - **Receivers need 4K with 2K better**
  - **Heat load should be ~10mW at 4K**
- **Simplification of microwave components**
  - **Combination of metrology receiver function**
    - **LO phase reference distribution**
    - **IF return signal for correlation**
  - **Highly integrated receivers**
- **Antennas and optical design**
  - **Ideal application for large deployable antennas**
- **Coolers vs. Cryostats (power vs. mass)**
- **Launch stacking how to launch at one time?**
- **Economy of scale, how to minimize non recurring costs**
- **Optimal sample time, orbit inclination telescope angle**

Uniqueness of SPECIES

- **Unique Features**
  - Submillimeter frequencies allow one observe through dense cold dust
    - Wavelength not available to JWST, SIM, TPF
    - Only long wavelength can observe the early phases of star formation
  - Very high spectral resolution R=>10^6 allows relative motions to be measured
    - Allows detailed study of molecular line shapes
    - Allows chemical details to be studied
  - Wavelength is only chance to observe and identify key chemical species
    - Only instrument that can observe spatial distribution of water
    - Distribution of pre-biotic molecules
    - Chemical composition of dust upon evaporation
  - High spatial resolution allows study of structure ~1AU at 100pc
    - Disk density gradients
    - Details of jets and shocks
    - Interaction of YSO/Late type star with debris cloud
    - Interaction of AGB transition with debris disk remnant