Future (Far-)Infrared (Space) Missions

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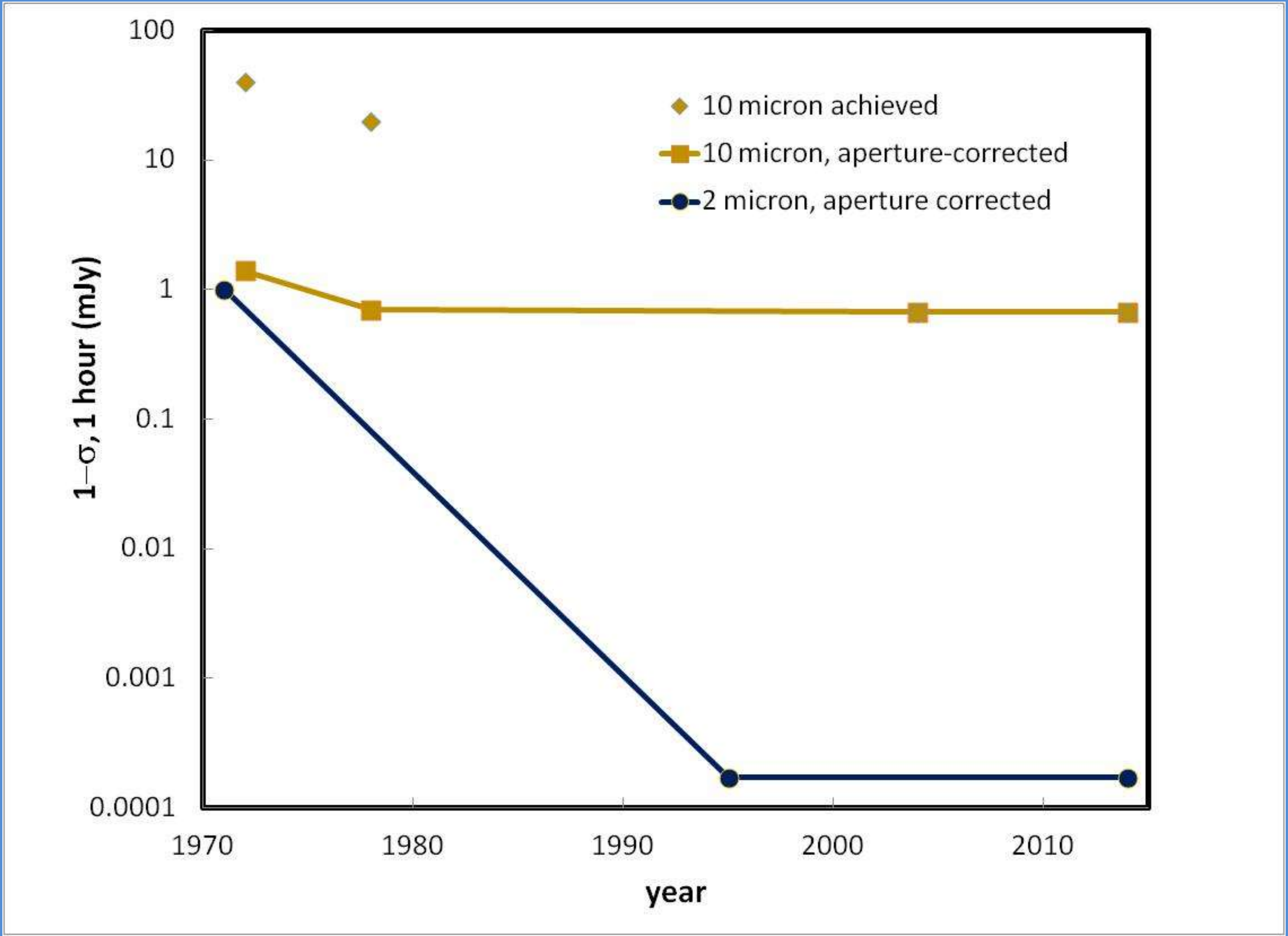
Thanks to Mark Devlin, Craig Kulesa, David Leisawitz, Chris Walker, and Erick Young for slides.

Reminder

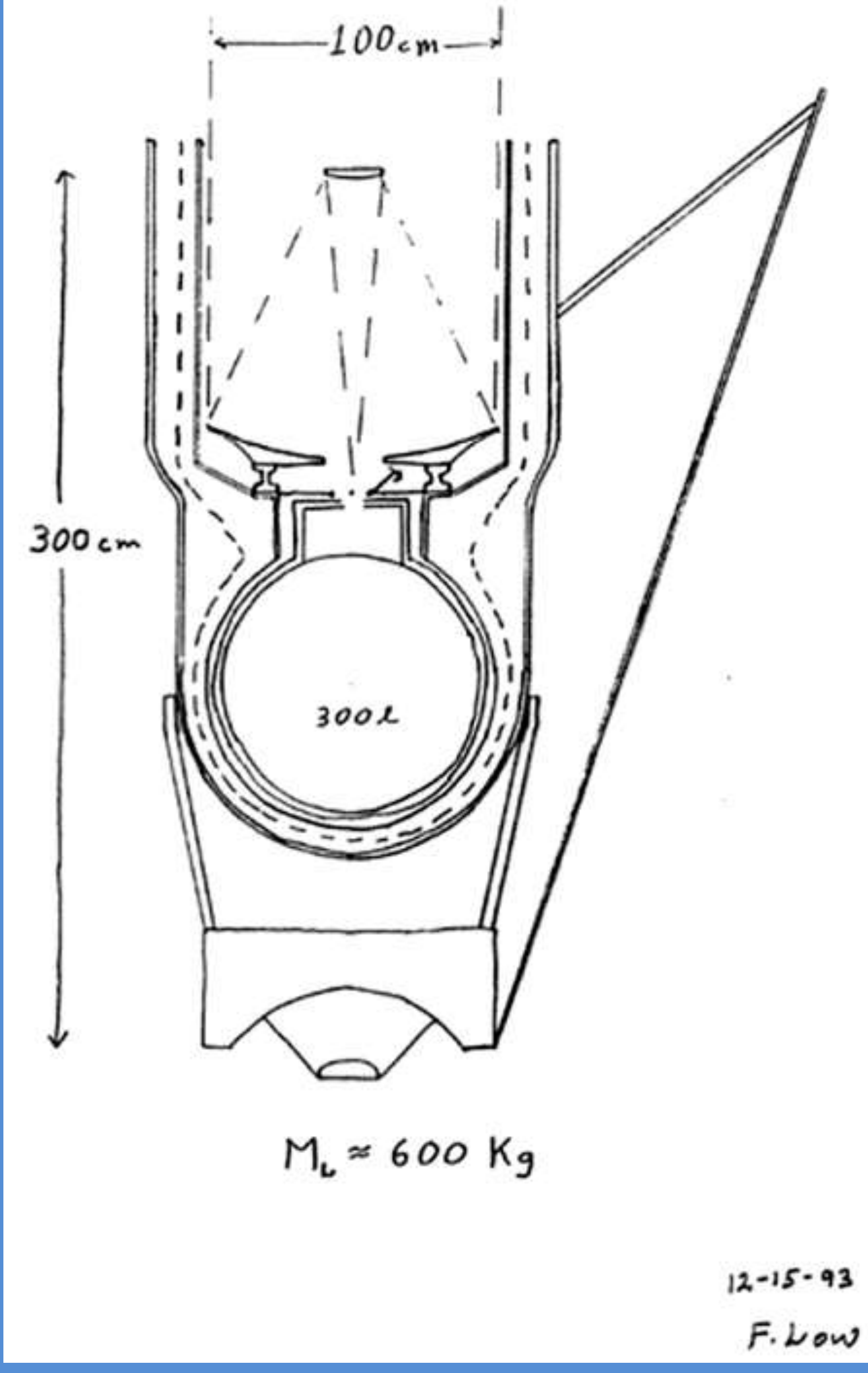
- Mid- and far-infrared led to unambiguous identification of starbursts
- Discovery of extreme objects, ULIRGS
- Account for half of energy density in Universe (excluding CMB)
- Needed to find substantial fraction of hidden star formation
- Essential for accurate SFR determination (especially compared with [OII], for example)

Huge performance increases in the infrared over the past four decades are legendary in astronomy. But all that has happened in the mid-infrared is the telescopes have gotten bigger!

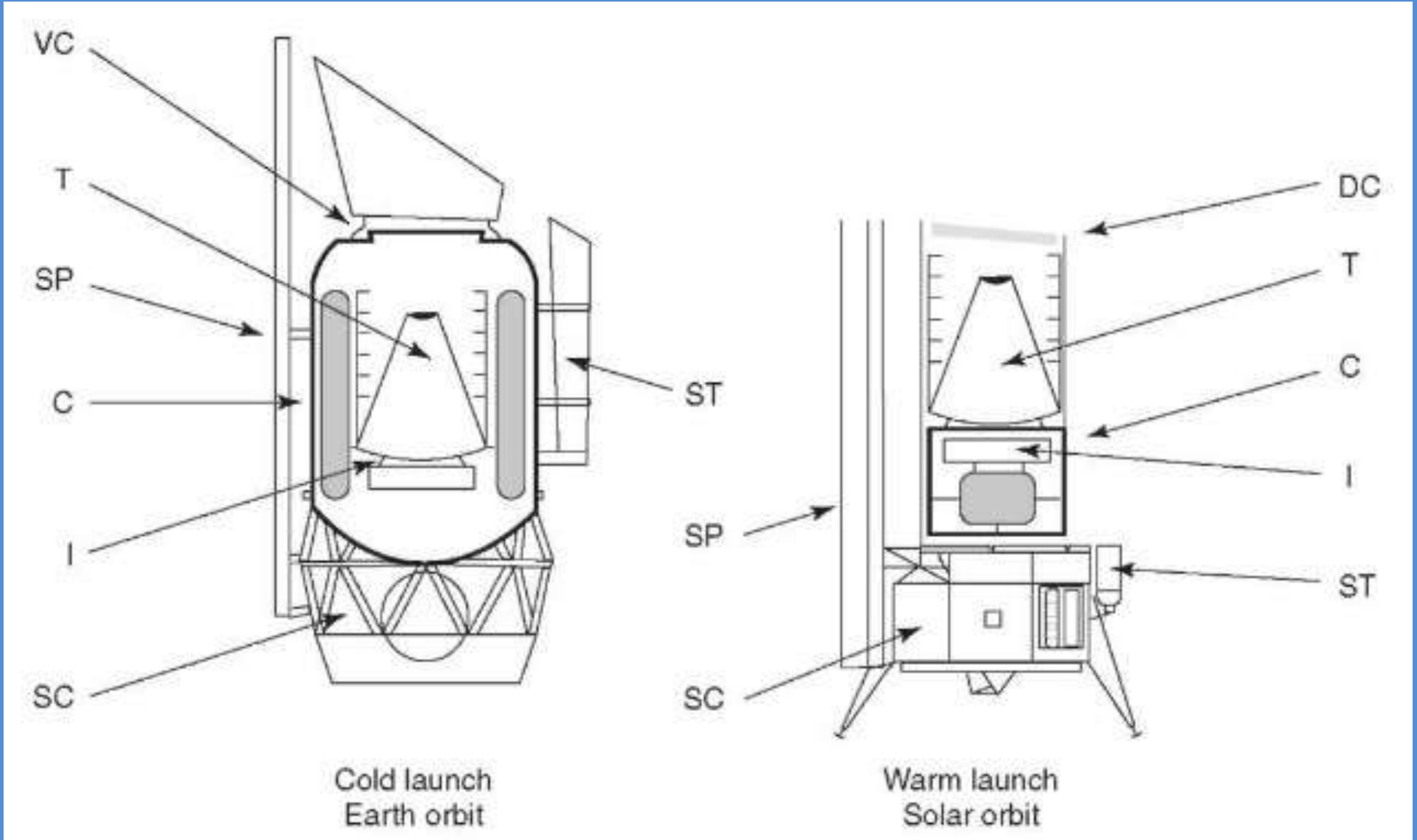


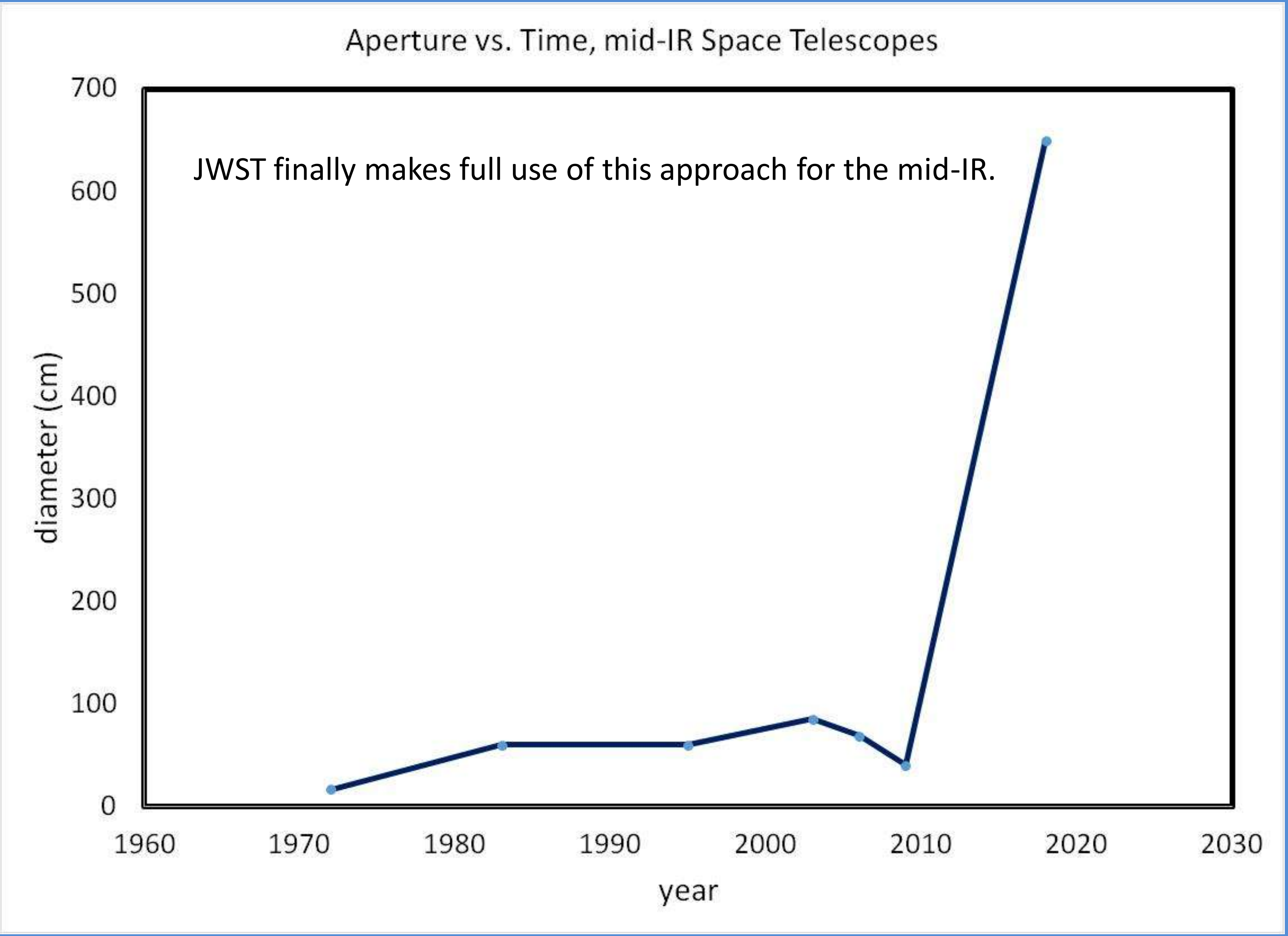
Gaining in the mid-infrared requires a cold telescope in space. The “safe” way to proceed is to put the telescope inside a dewar so it can be completely checked out in its operating condition just before launch, but this limits the size of the telescope severely.

Tim Hawarden, and independently (and later) Frank Low, promoted a warm launch concept, where the telescope radiates its energy and cools after launch and in space.



SIRTF/Spitzer was under great pressure to even exist, and the new concept was used to shrink the observatory and reduce its cost, rather than to make the telescope bigger.




Aperture vs. Time, mid-IR Space Telescopes
JWST finally makes full use of this approach for the mid-IR.
diameter (cm)
year
0
100
200
300
400
500
600
700
1960
1970
1980
1990
2000
2010
2020
2030

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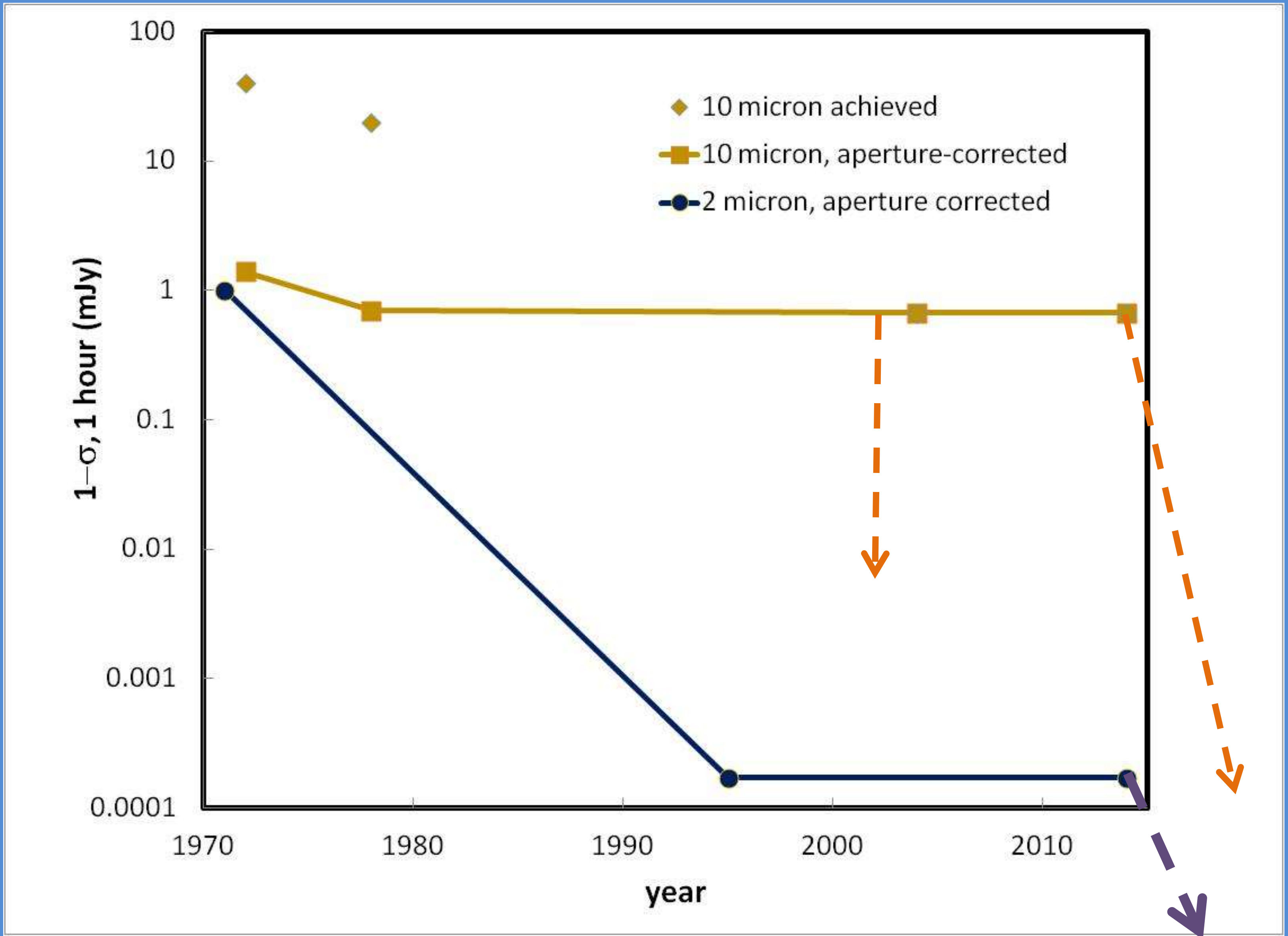

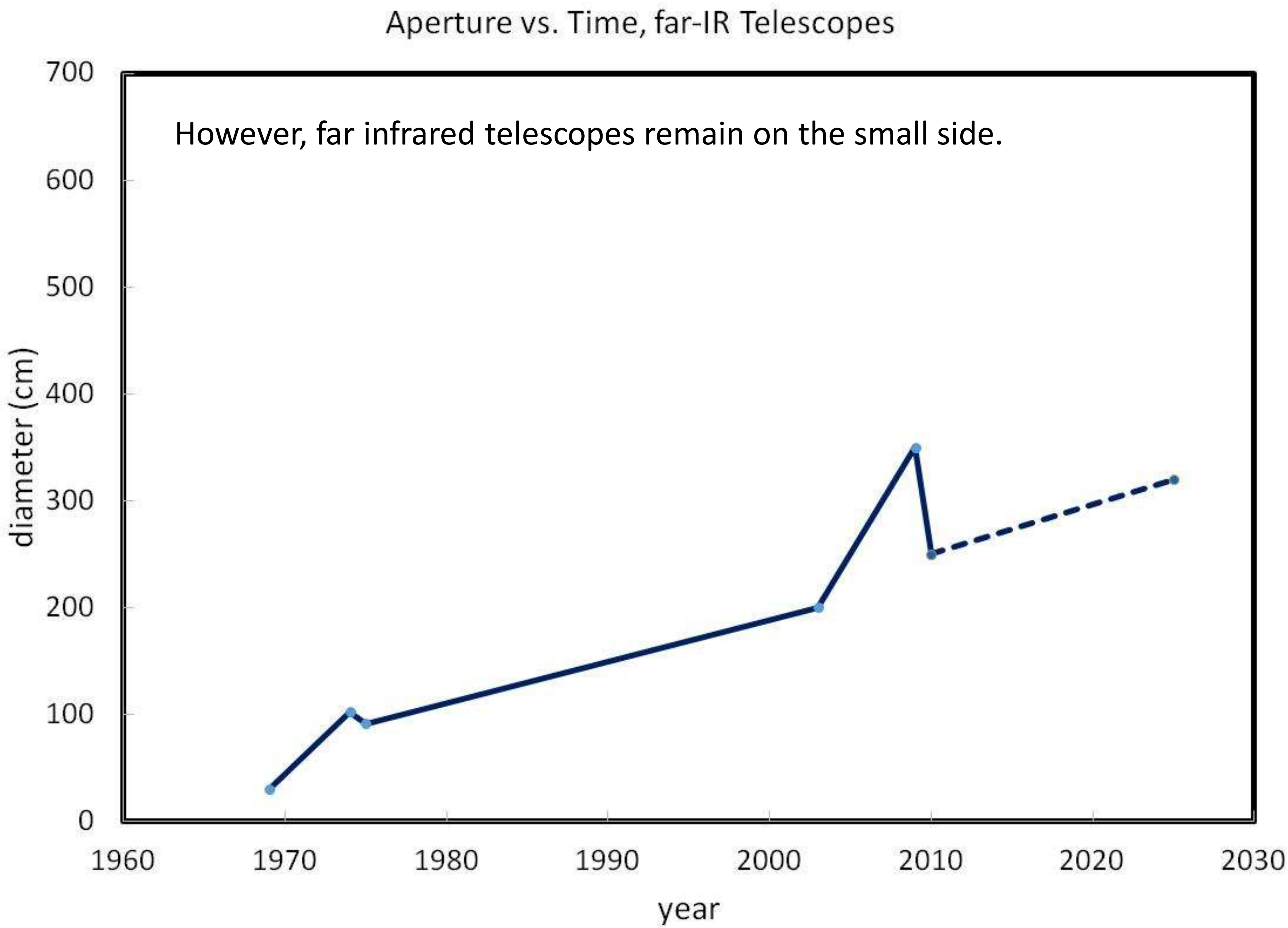
Aperture vs. Time, far-IR Telescopes
However, far infrared telescopes remain on the small side.
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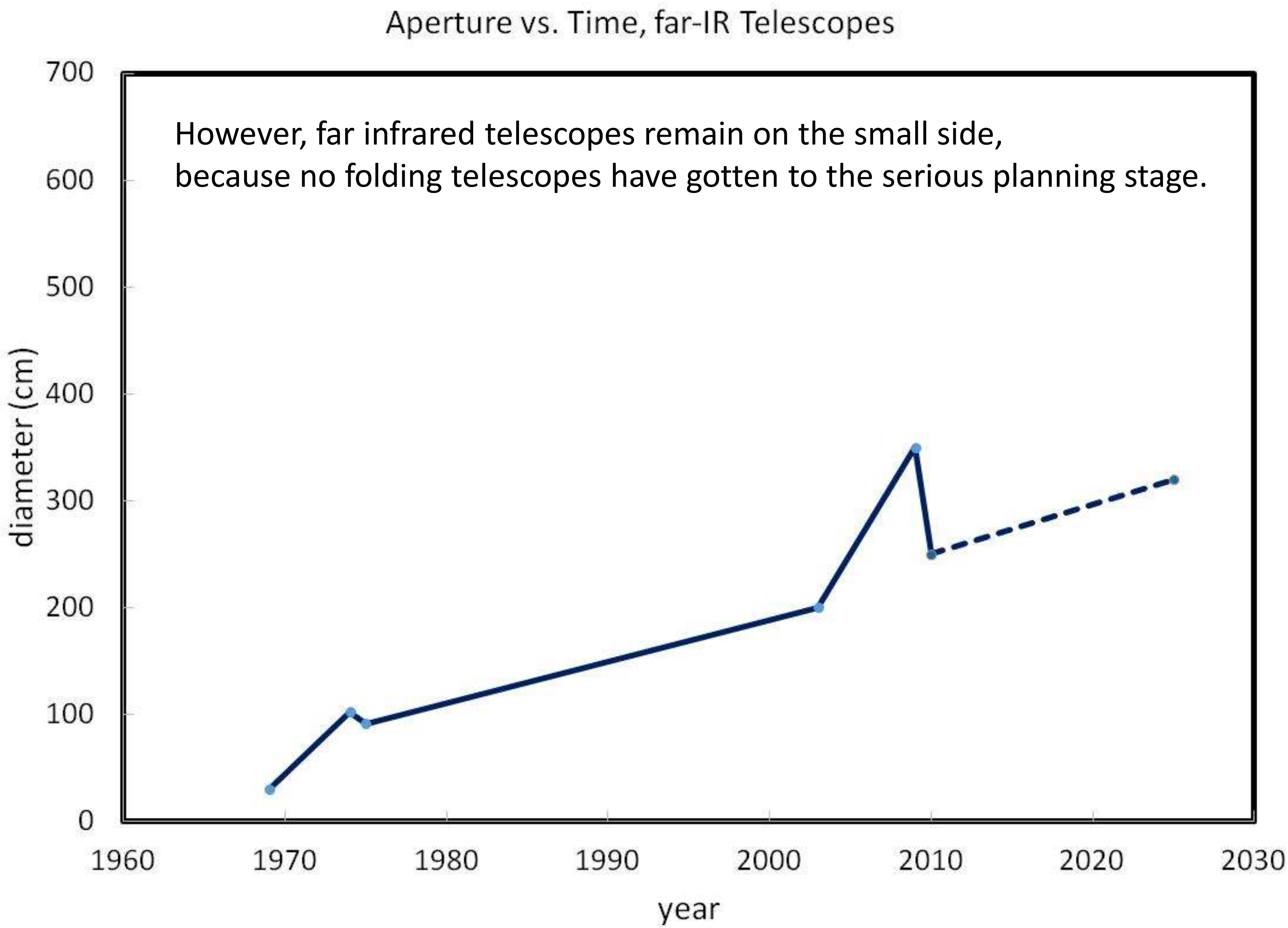
Aperture vs. Time, far-IR Telescopes
However, far infrared telescopes remain on the small side,
because no folding telescopes have gotten to the serious planning stage.
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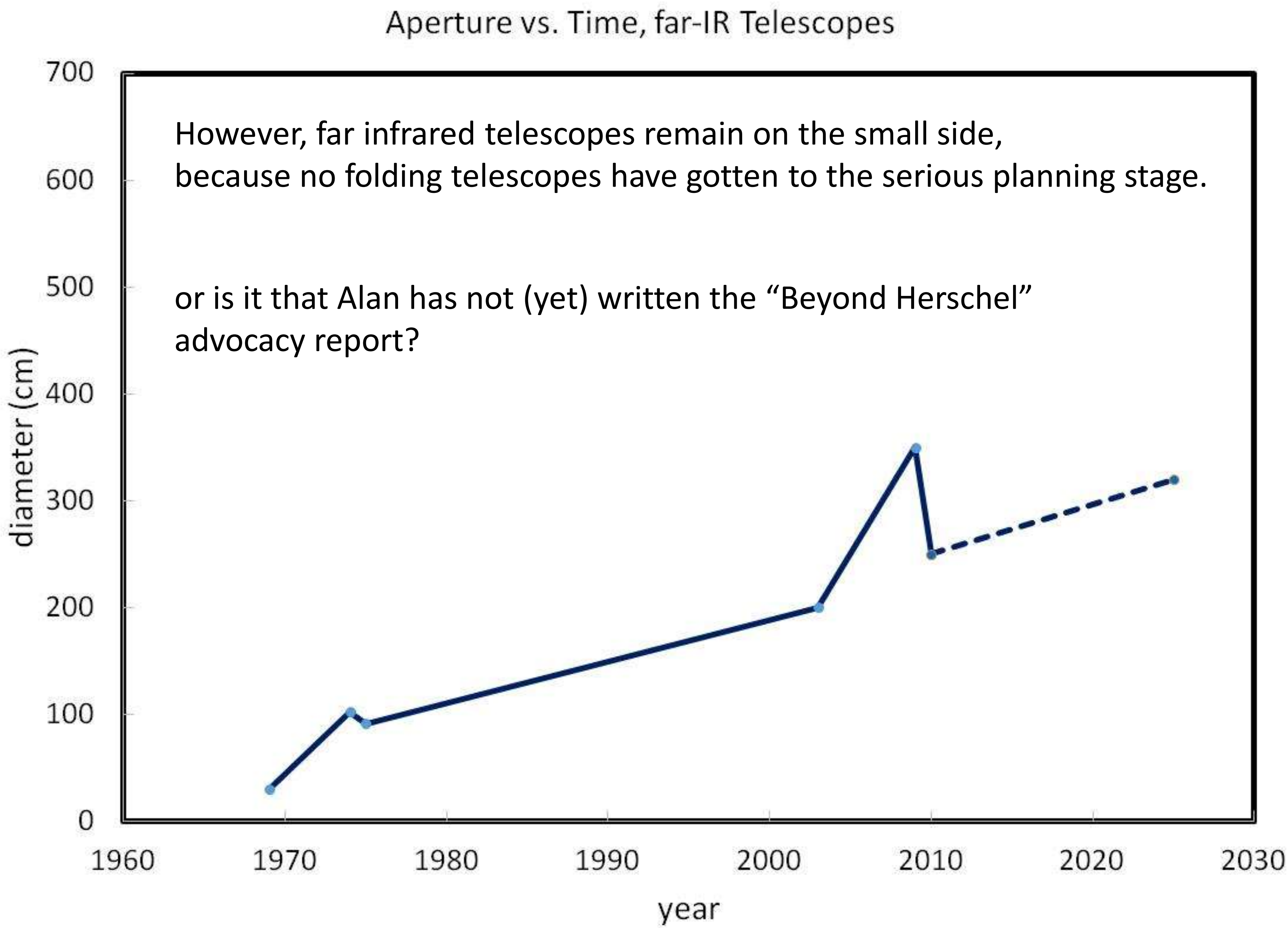
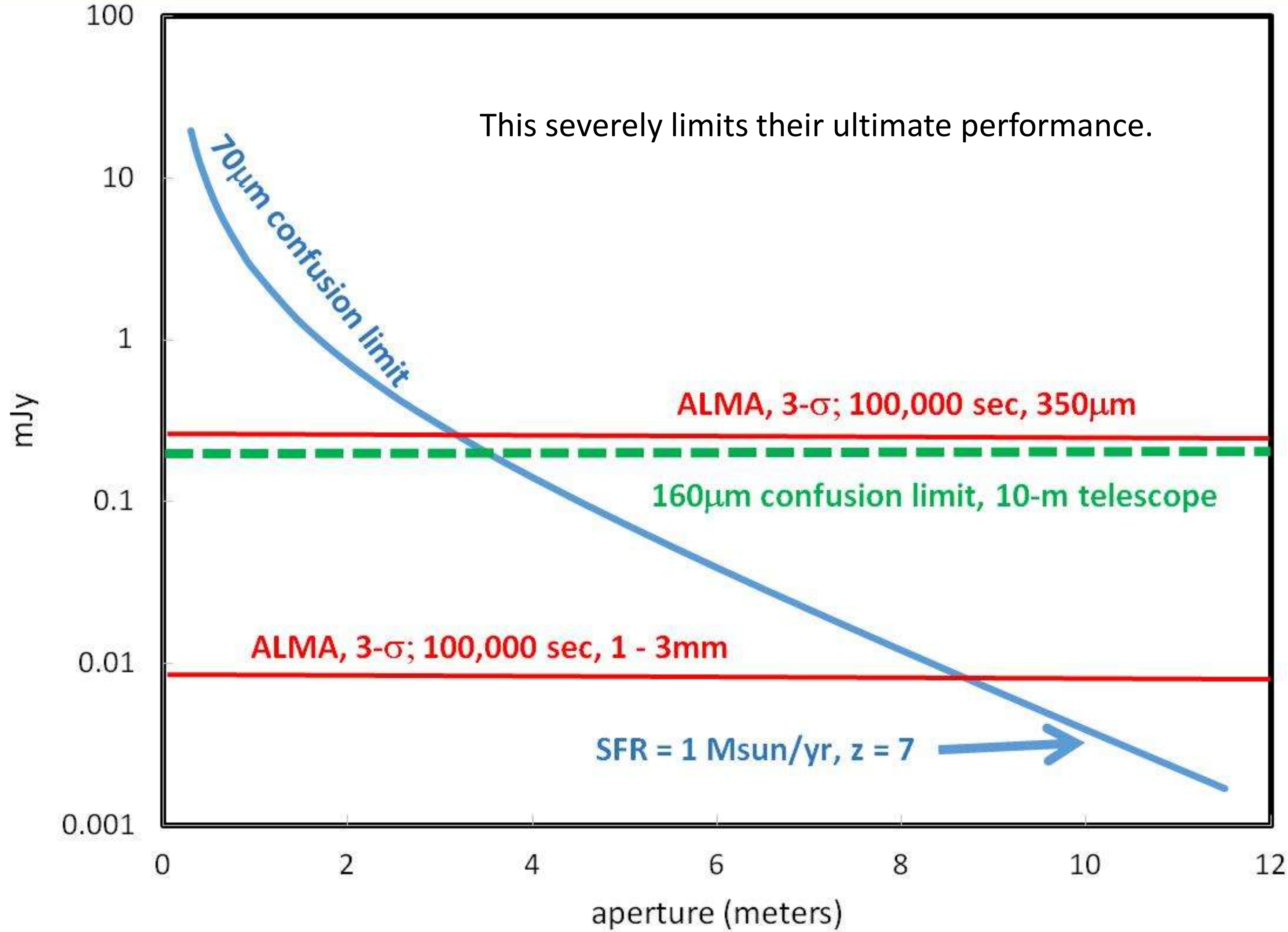

Aperture vs. Time, far-IR Telescopes
However, far infrared telescopes remain on the small side,
because no folding telescopes have gotten to the serious planning stage.
or is it that Alan has not (yet) written the “Beyond Herschel”
advocacy report?
diameter (cm)
700
600
500
400
300
200
100
0
1960
1970
1980
1990
2000
2010
2020
2030
year

This severely limits their ultimate performance.



Now for some far future and present-to-near future facilities.

SPICA

JAXA Mission with major ESA involvement (telescope; SAFARI instrument). Traditional telescope, 3.2-m aperture, crycoolers. New start in 2014 being proposed in Japan with European M-5 proposal (must win open competition in Europe). Decadal survey recommended NASA provide an instrument, but this is not happening. Launch 2027/28?

20 – 210μm. Far infrared to be an imaging FTS (SAFARI). Deal with FIR confusion by spectral mapping and deconvolution.

CALISTO

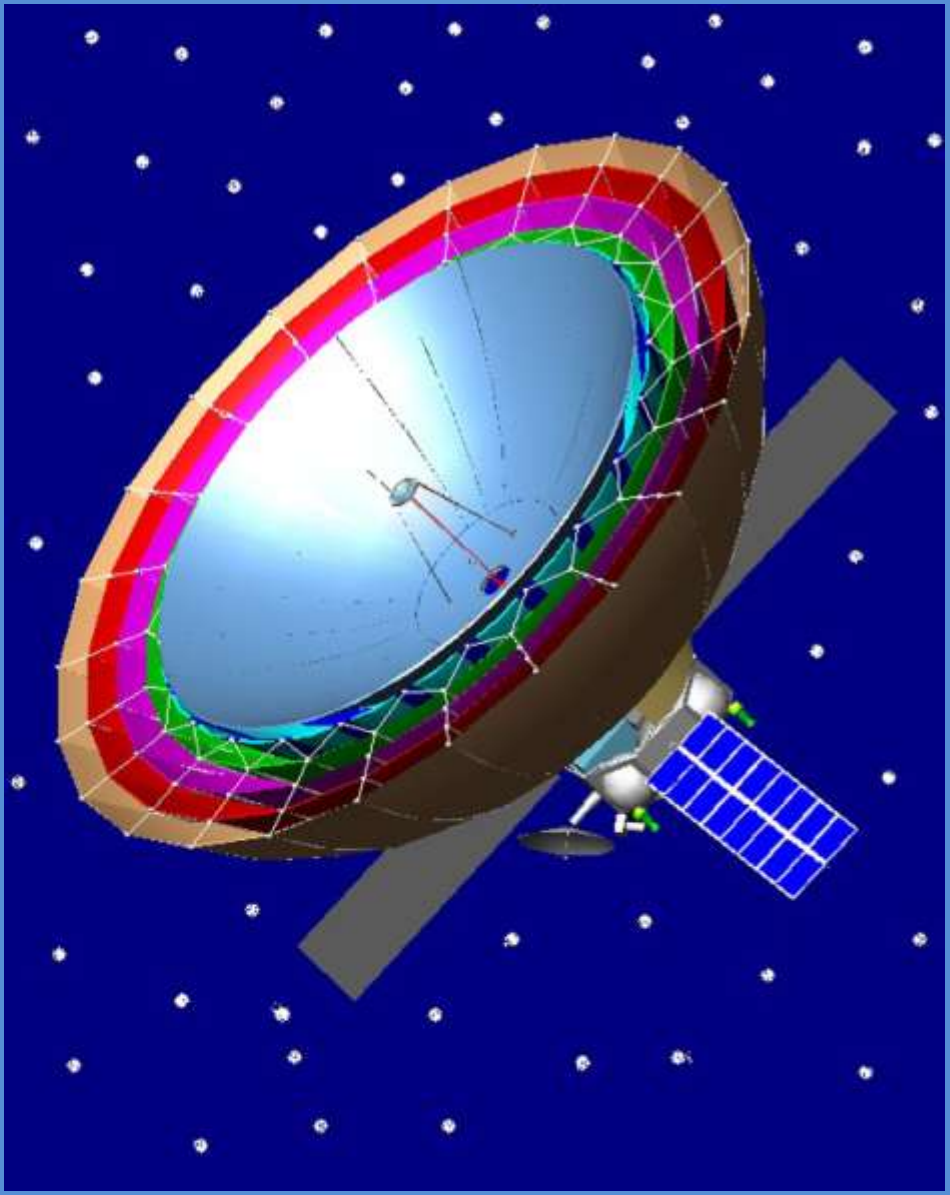
Concept development centered at JPL, offshoot of SAFIR (see previous decadal report). Folding telescope, 4 x 6m, off axis Gregorian for a clean beam, radiation and cryocooler cooling. Launch in the distant future.

30 – 300μm. Primary instrument is a high efficiency multi-pixel far infrared spectrometer. Deal with FIR confusion by spectral mapping and deconvolution.

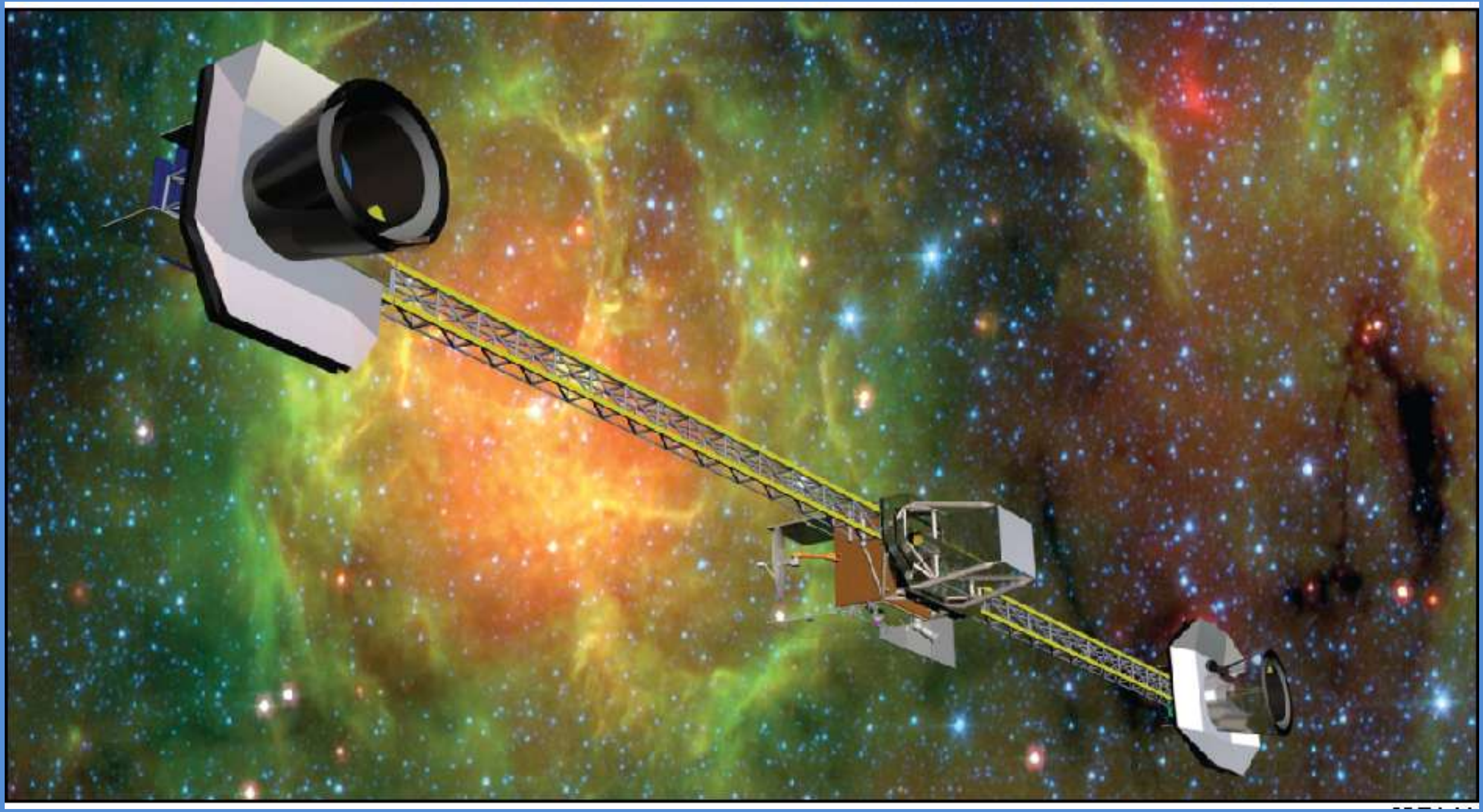
MILLIMETRON

Concept development centered at Lebedev Institute, collaboration with SRON and Italy (but SRON has shifted emphasis to SAFARI/SPICA). Folding telescope, 10m, radiation and cryocooler cooling. Launch in the distant future.

50 – 800μm. Far infrared to include a high efficiency multi-pixel spectrometer plus cameras. Also to be used for space VLBI.

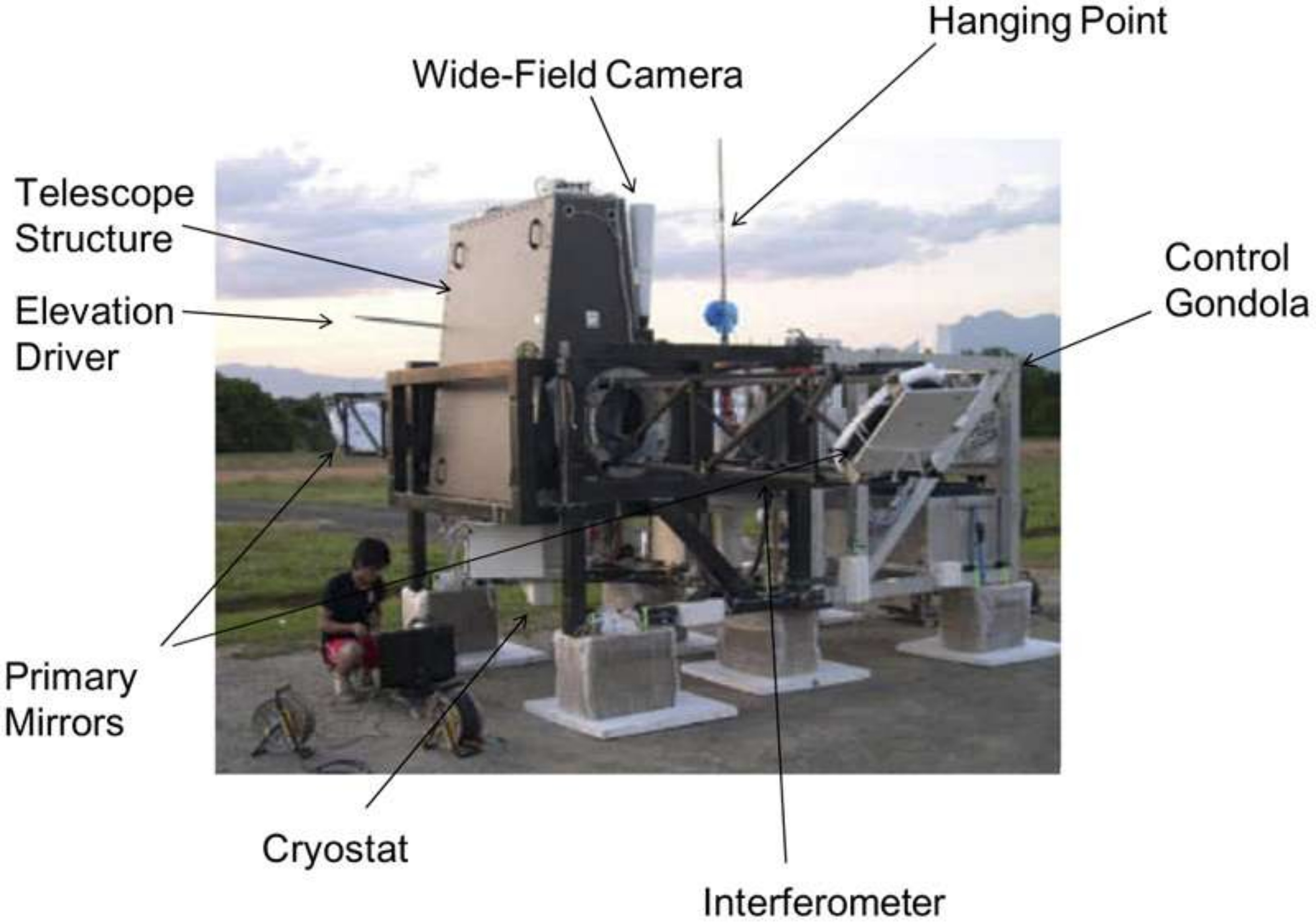


SPIRIT Space Interferometer (centered at Goddard); concept phase



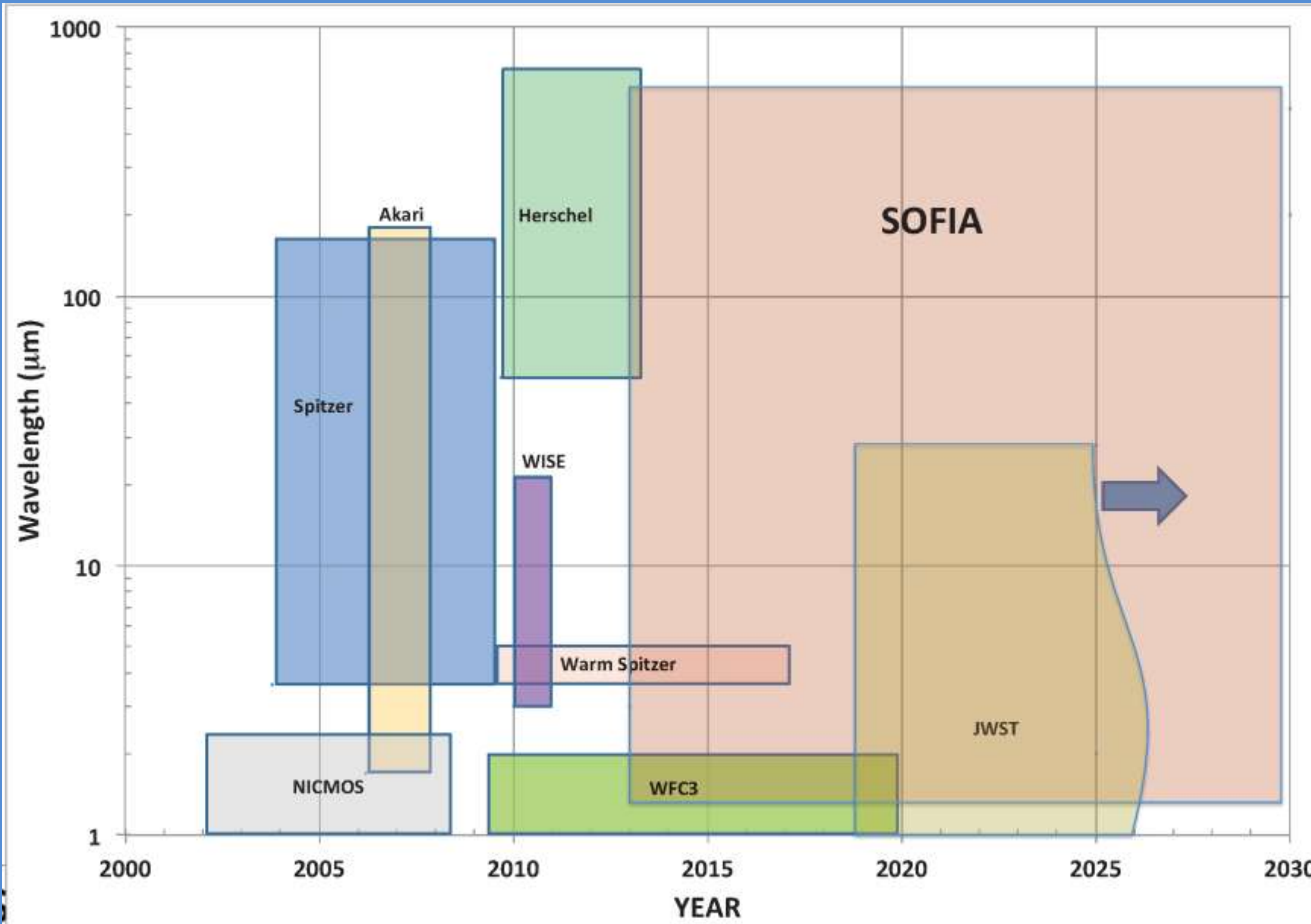
- Wavelength range 25 – 400 μm
- Dense u-v plane coverage
- Spectral resolution $\lambda/\Delta\lambda > 3000$
- Angular resolution 0.3 (λ/100 μm) arcsec
- Integral field spectroscopy over a 1 arcmin FOV
- Sensitivity 10 μJy continuum; 10^{-19} W m^{-2} lines
- Single scientific instrument ("double Fourier" beam combiner)
- Same timescale as the others

FITE, H. Shibai, to fly soon



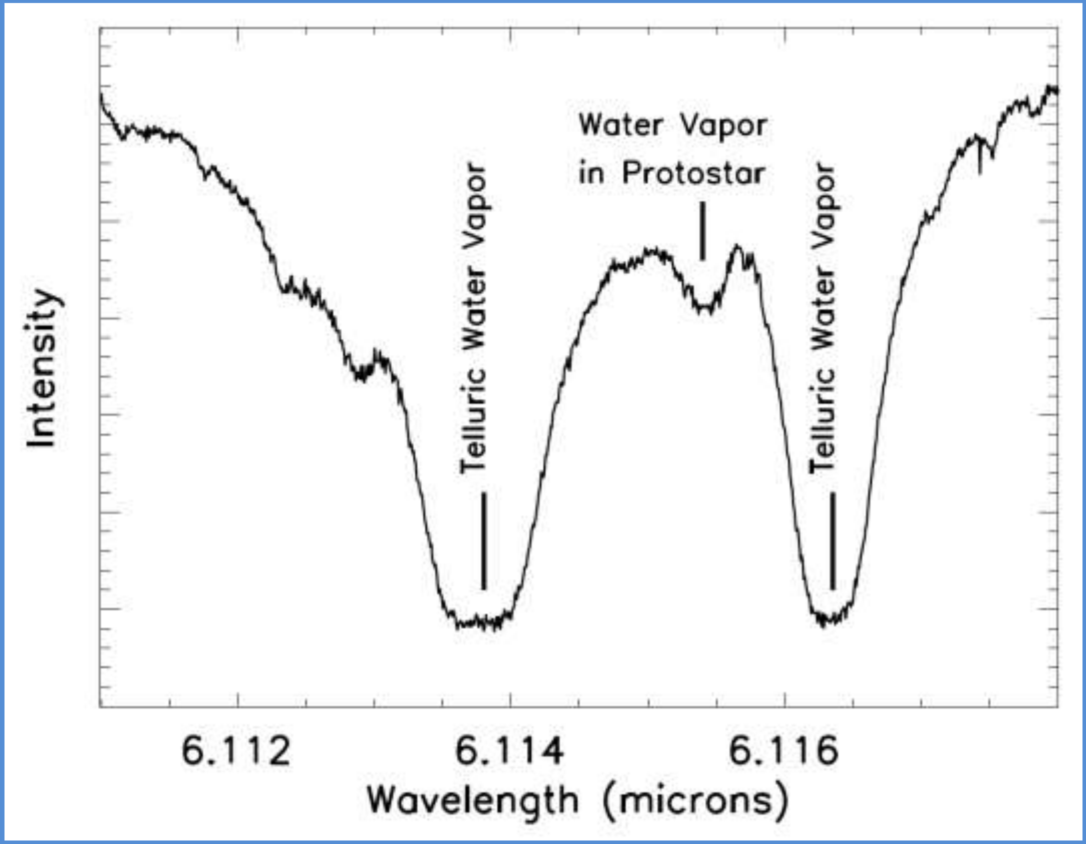
SOFIA

SOFIA will provide multi-purpose access to FIR astronomy.



EXES Observations of Water in AFGL 2591 (10 Msun protostar) [EXES is a very high resolution mid-IR echelle]

- R = 15000, improves on R=2000 ISO studies
- 20 km/s is enough to study motions in protoplanetary system
- T_{ex} ~ 500 K, likely produced by evaporation of grain mantles

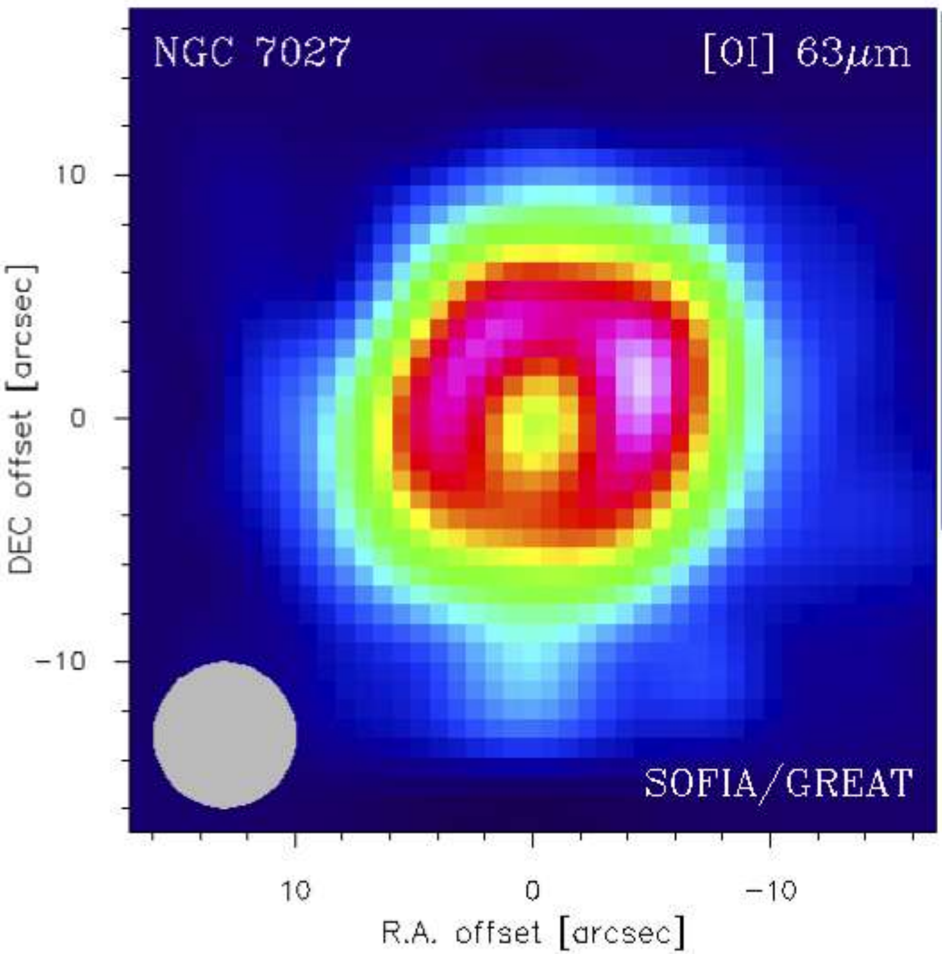


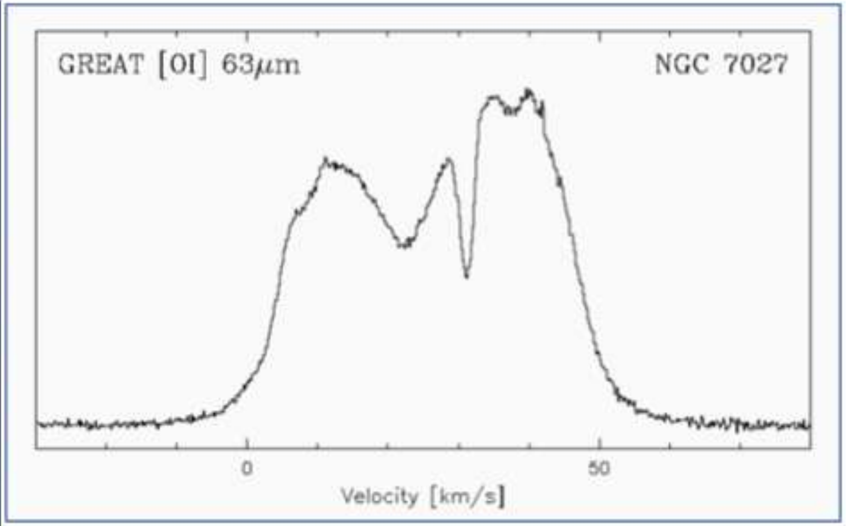
(C. de Witt, M. Richter, EXES Team)

(Colin Aspin et al. , NIRI, Gemini Obs.)

GREAT 4.7 THz First Light
[GREAT is a heterodyne receiver]

- Targets primary molecular cloud cooling lines at [OI] 63μm and [CII] 158μm (plus others)





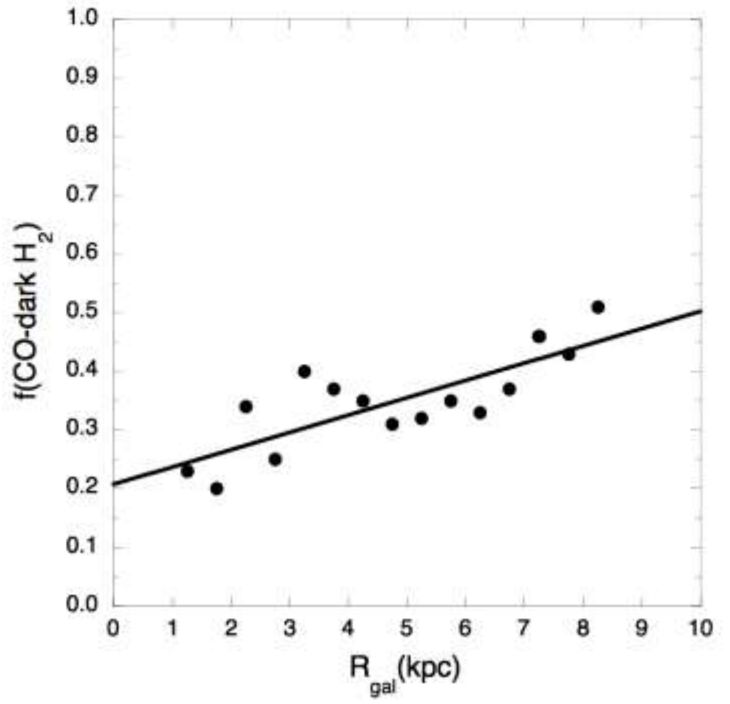
(Rolf Güsten & the GREAT Team)

Phase Balance in the ISM with GREAT

from Karin Sandstrom

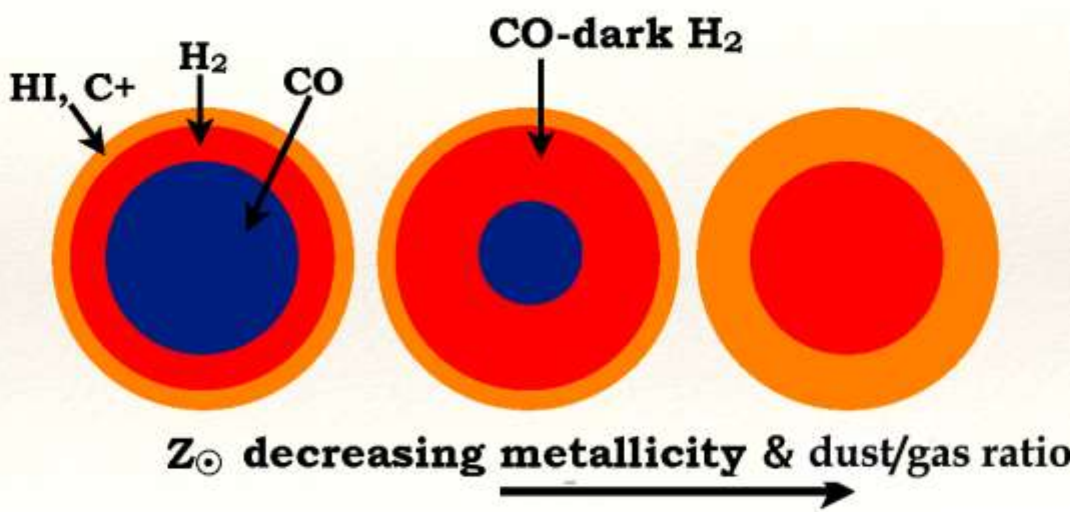
- **Probe specific Local Group sources in velocity-resolved [CII] to determine CO/H_2 vs. metallicity**
- **As primary coolant, 158 μm line will track carbon missing from CO**
- **GUSSTO (coming next) does this science with full maps for the Milky Way**

Langer et al. 2014; GOT C+



GOT C+ measurement of CO-dark H_2 fraction in the MW ISM.

High-velocity resolution [CII] compared to CO/HI is one of the only ways to directly detect "CO-dark" H_2.



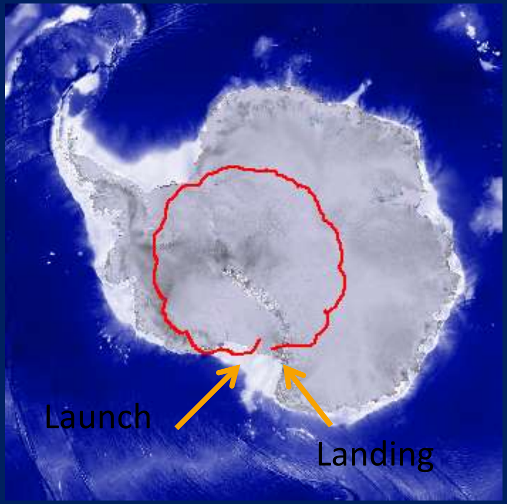
Maloney & Black 1988, Bolatto et al. 1999, Wolfire et al. 2010, Glover & Mac Low 2011

NASA's New ULDB: A "Satellite on a String"

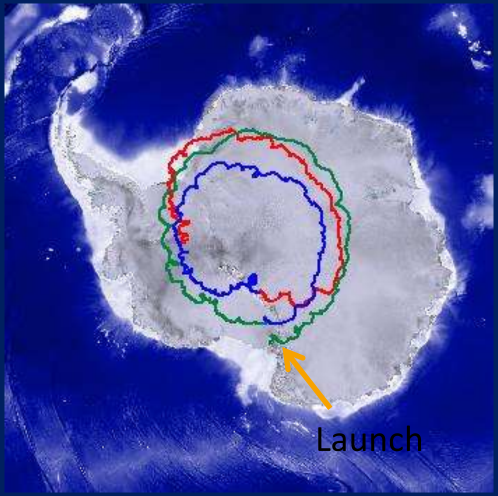
- ULDB enables orbital-quality observations from a 35 km platform at a fraction of the cost.
- High constant altitude, long-duration flights of 100 days or more, large payload capacity, and likely payload recovery establish a **new paradigm** for low-cost, high value scientific observations.

SPB Test Flight, Kiruna, Sweden

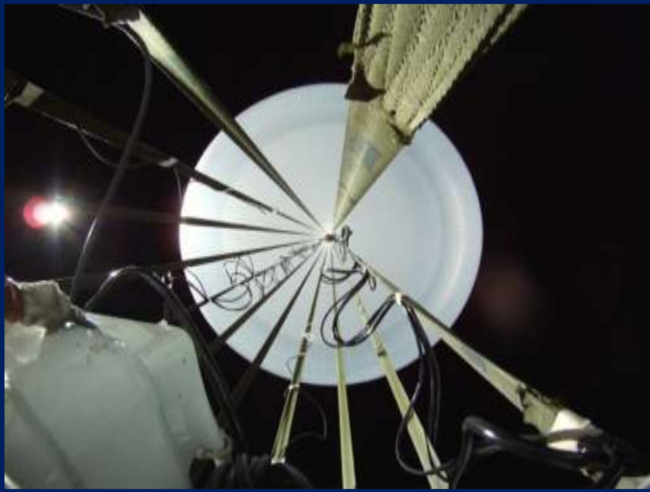
STO 14 day flight



Super-TIGER 55 day flight



Super-pressure balloon deployed



ULDB is a game-changer for FIR spectroscopy

NASA Explorer (SMEX)
SWAS

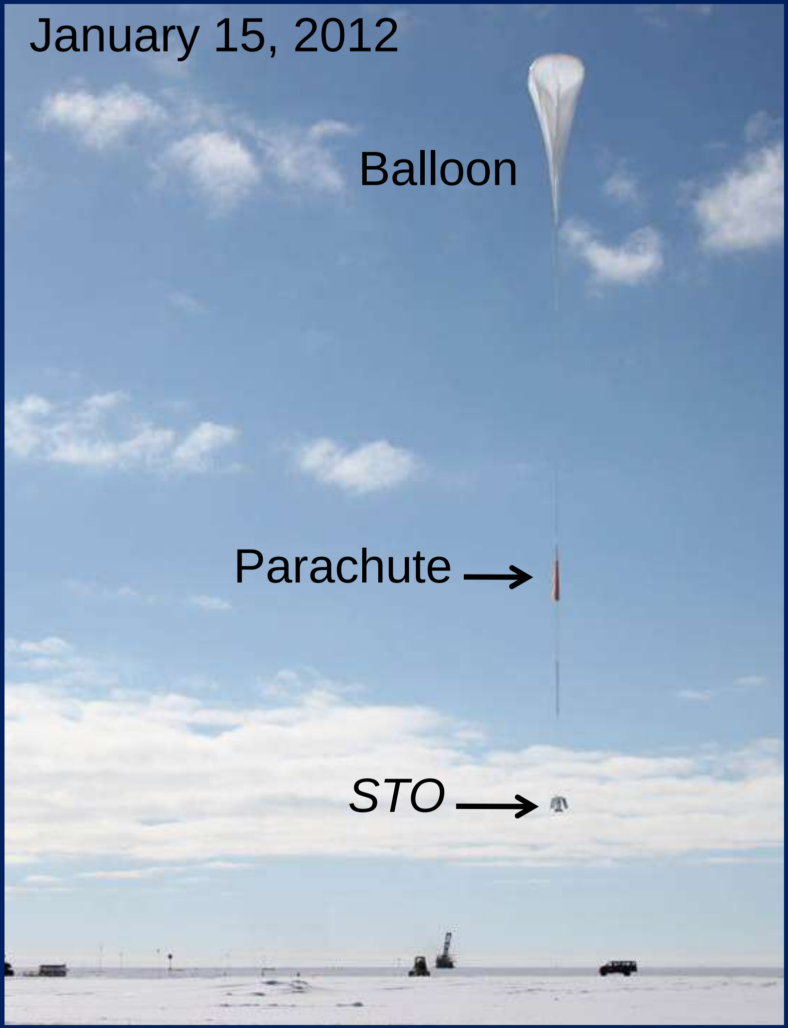
- 250-300 kg including S/C
- 250W power, including S/C
- ~$120M mission cost cap
- 0.5m aperture
- 4 heterodyne receivers

- 1100 kg (instrument+gondola)
- >2000W power
- ~$35M mission cost cap
- 2 meter aperture
- 50 heterodyne receivers
- Re-flyable

ULDB represents a improvement factor of >20 in cost/performance

Stratospheric TeraHertz Observatory (STO): Precursor to GUSSTO

STO **at Launch: Williams Field, Antarctica**

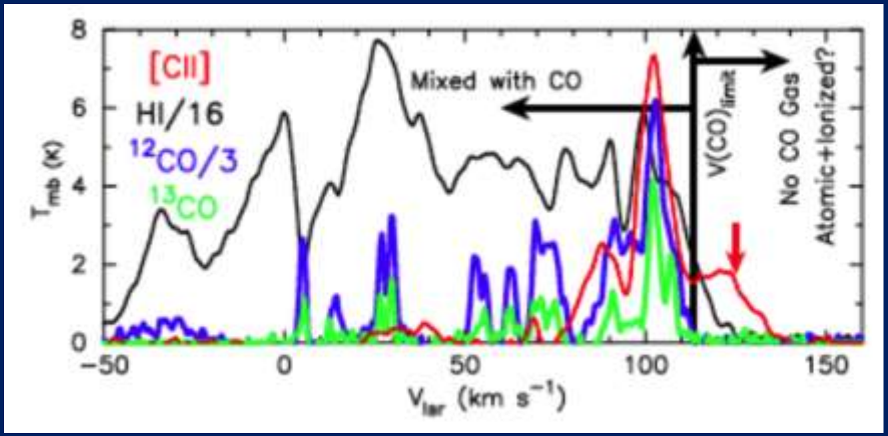


STO provides GUSSTO:

- Team experience
- Gondola and instrument architecture
- Observing profile and mission plan
- Data product management

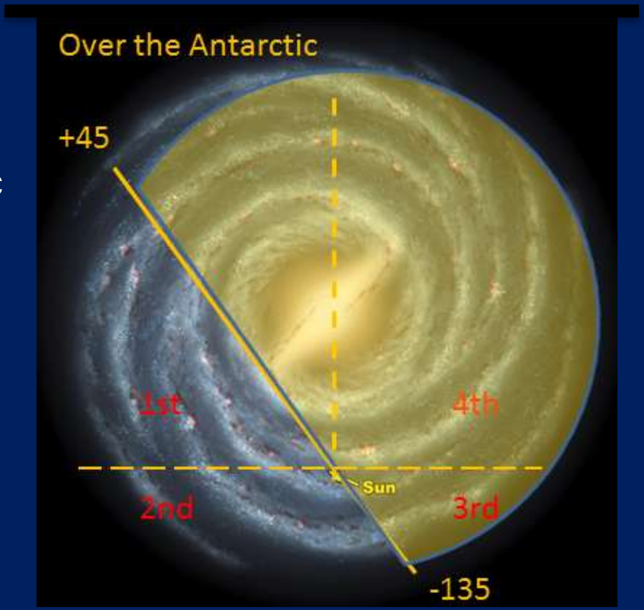
[redacted]

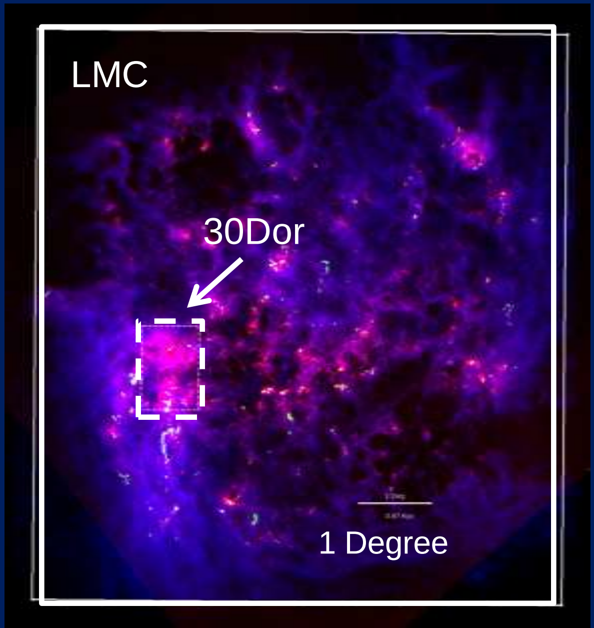
GUSSTO Observational Objectives: [CII], [OI], & [NII] Surveys of MW and LMC



Above: Single line of sight (LOS) spectrum of [CII] (*Herschel HIFI)* towards a Galactic source. *GUSSTO 's* surveys will observe **>100,000 LOS, more than *100x* what was done with *Herschel* HIFI.**

GUSSTO Galactic Plane Visibility:





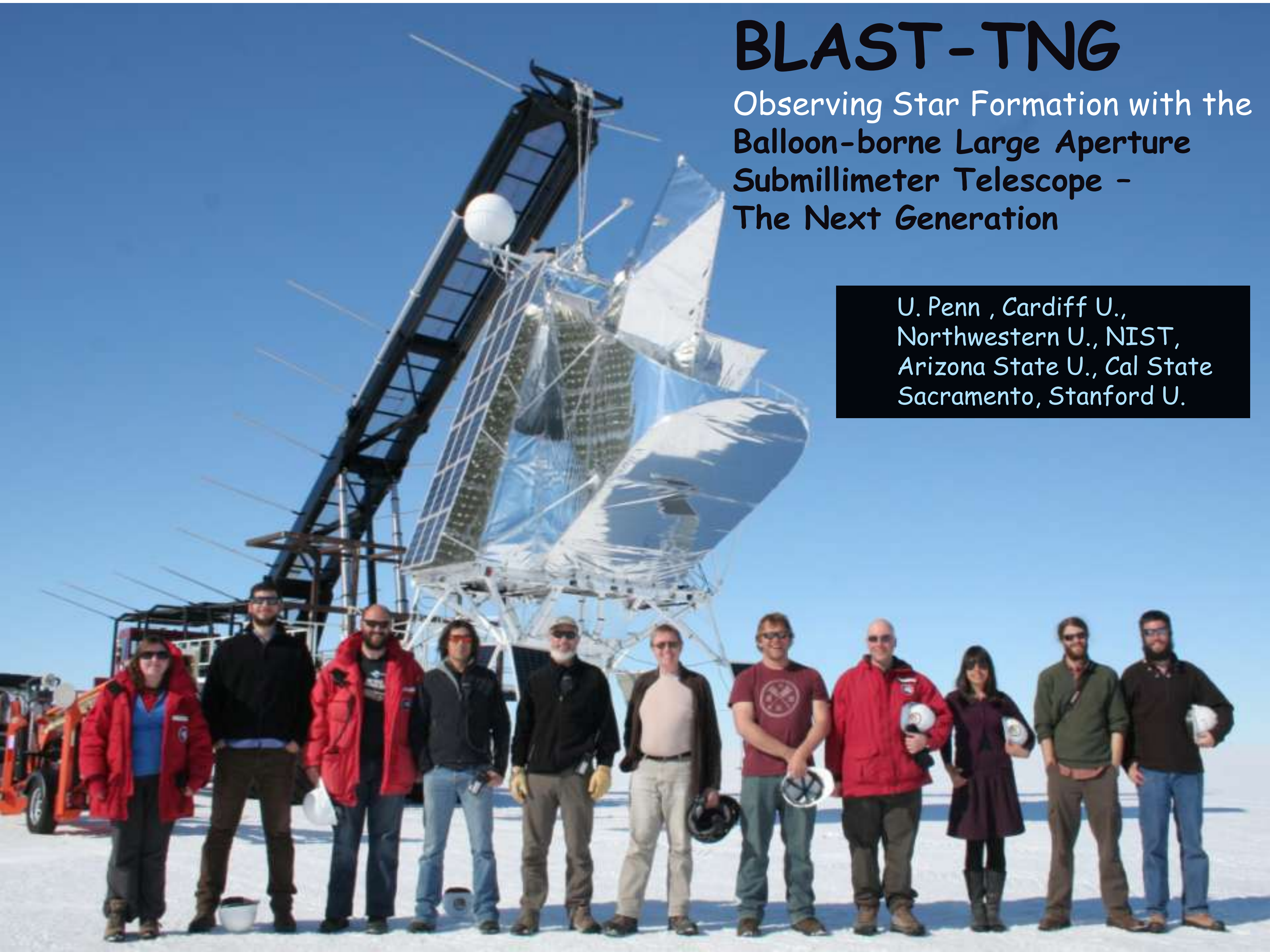
The Large Magellanic Cloud (LMC) in HI (blue), CO (green), *Spitzer* 160µm emission (Red). The solid box represents the area for the large–scale mapping with GUSSTO. The dashed box is the proposed 30 Dor deep integration map.

- Tethers far-IR extragalactic observations to the Milky Way & LMC.
- Calibrates [CII] as tracer of star formation.
- Observes the fraction of "CO-dark H_2 gas" in the Galaxy.
- Determines the life cycle & structure of the ISM as a component of galaxy evolution.

BLAST-TNG

Observing Star Formation with the Balloon-borne Large Aperture Submillimeter Telescope – The Next Generation

U. Penn , Cardiff U., Northwestern U., NIST, Arizona State U., Cal State Sacramento, Stanford U.



Star Formation Takes Place in Large Clouds of Gas and Dust

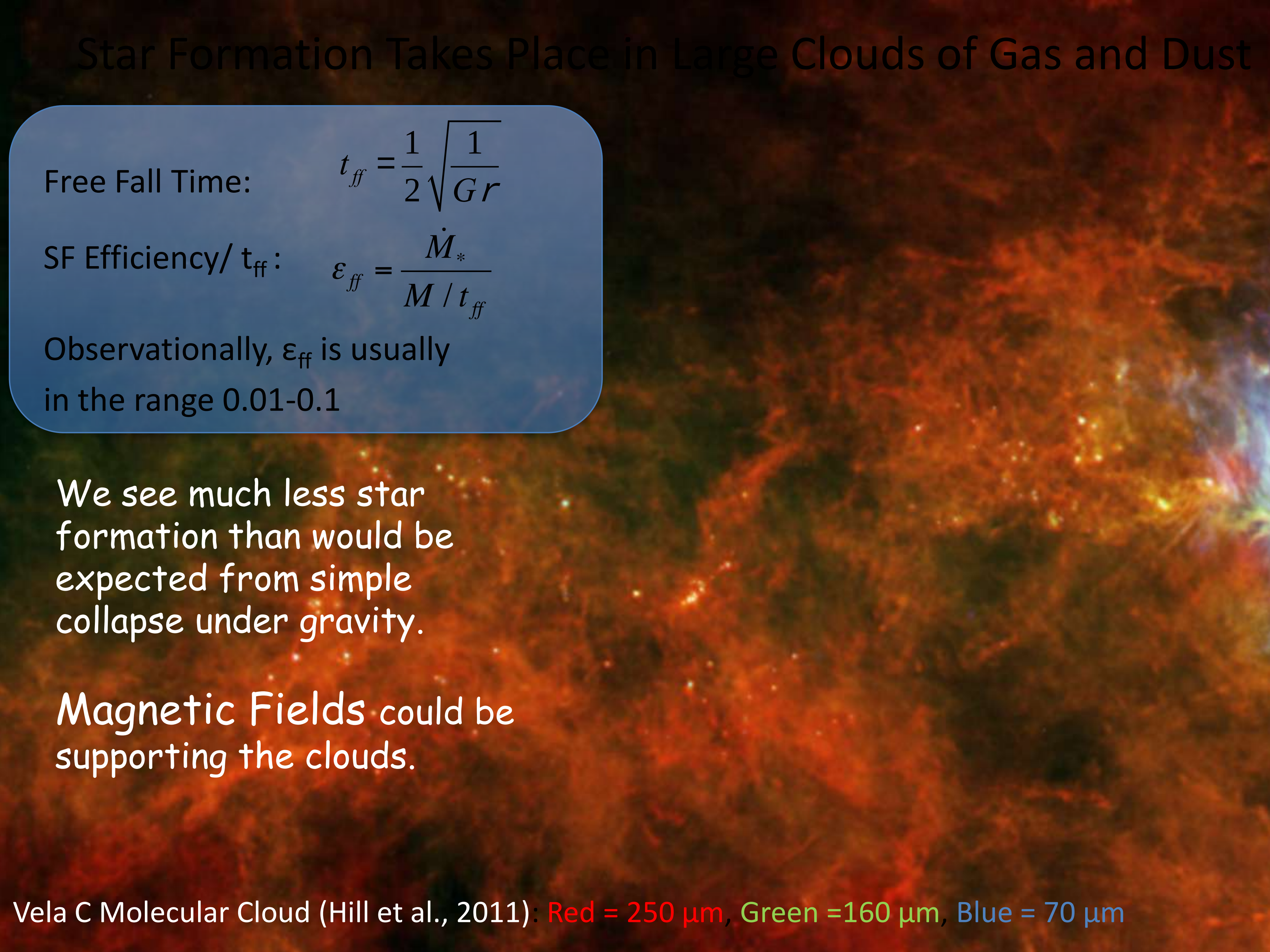
Free Fall Time: $$t_{ff} = \frac{1}{2}\sqrt{\frac{1}{G\rho}}$$

SF Efficiency/ t_{ff} : $$\varepsilon_{ff} = \frac{\dot{M}_*}{M / t_{ff}}$$

Observationally, ε_{ff} is usually in the range 0.01-0.1

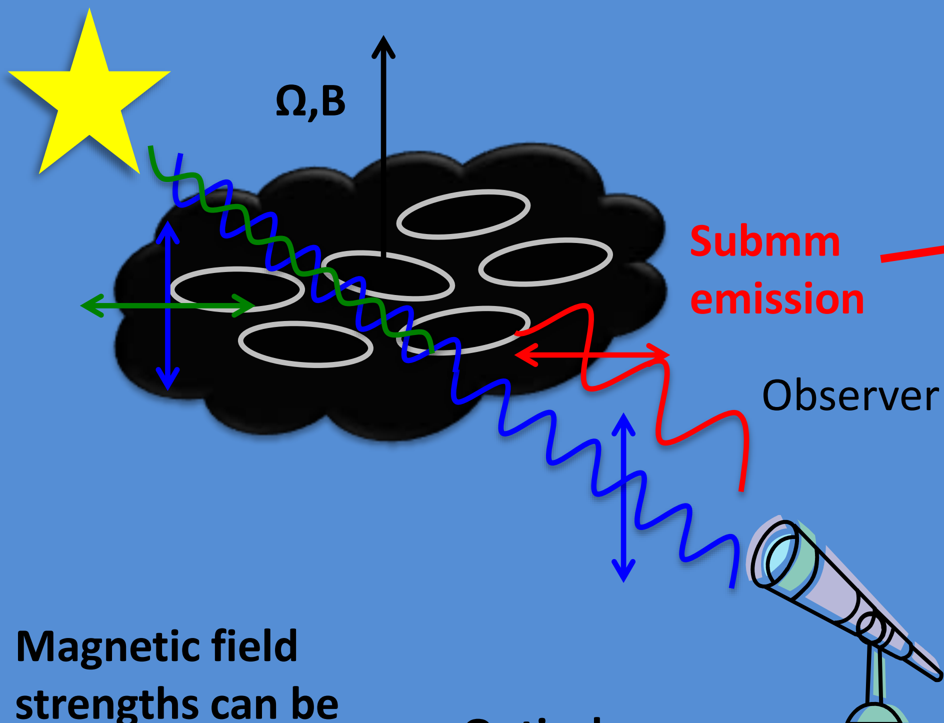
We see much less star formation than would be expected from simple collapse under gravity.

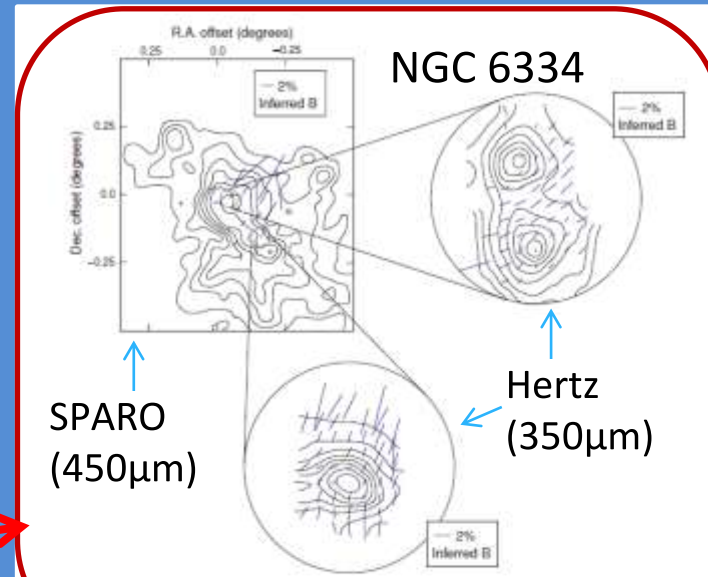
Magnetic Fields could be supporting the clouds.



Vela C Molecular Cloud (Hill et al., 2011): Red = 250 μm, Green =160 μm, Blue = 70 μm

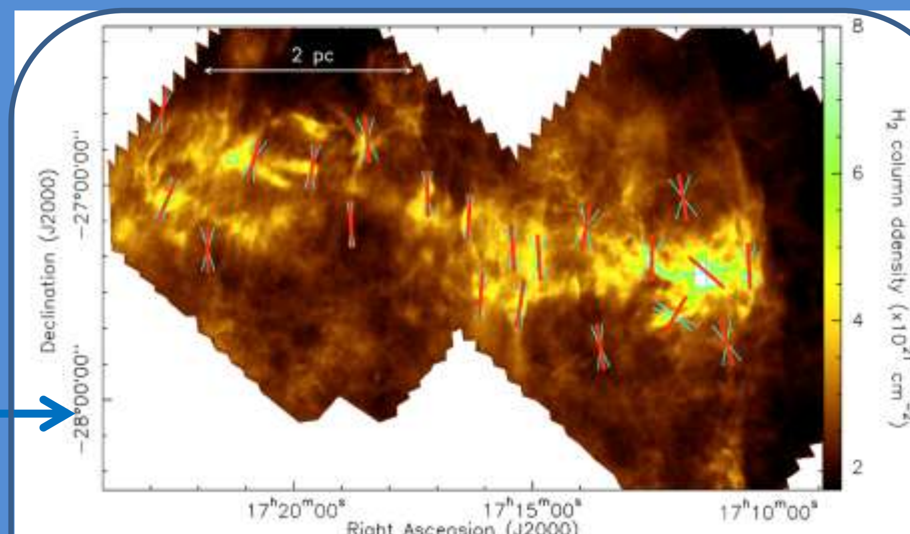
Dust Polarization





Novak, Dotson & Li (2009)

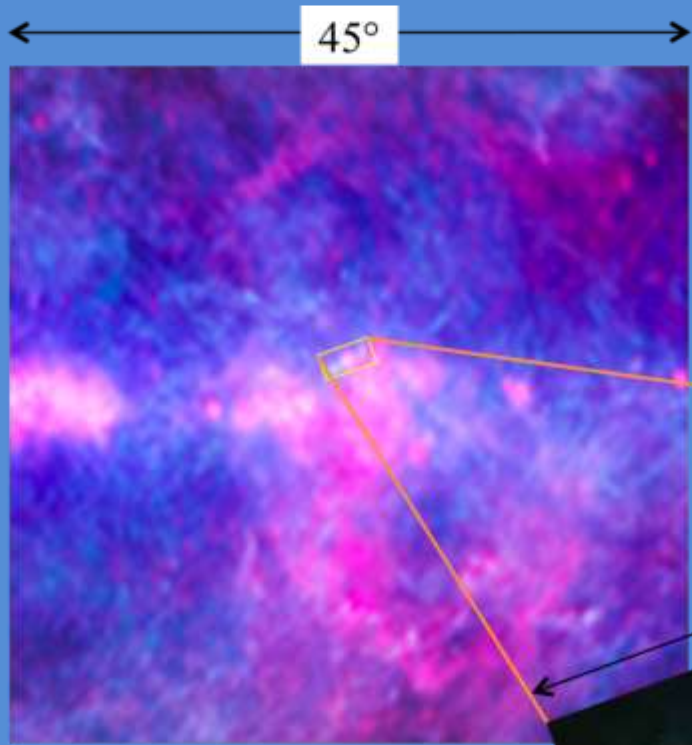
Optical (Transmitted)



Herschel Pipe Nebula: Perotta et al. (2012) with polarimetry from Franco et al. (2010)

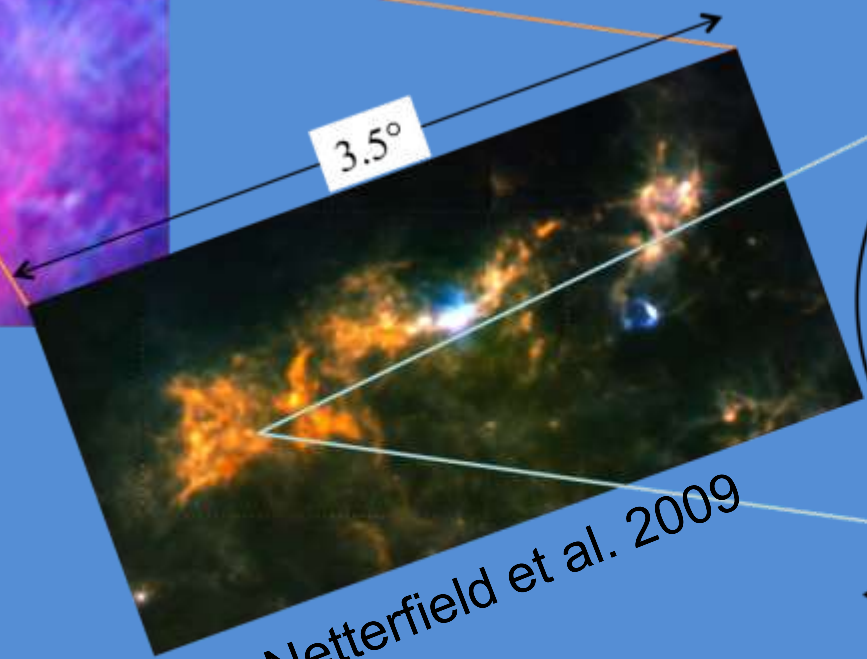
Magnetic field strengths can be modeled from dispersion in polarization angles (Chandrasekhar & Fermi 1953 and following).

BLAST-TNG as a Bridge Between Planck and ALMA



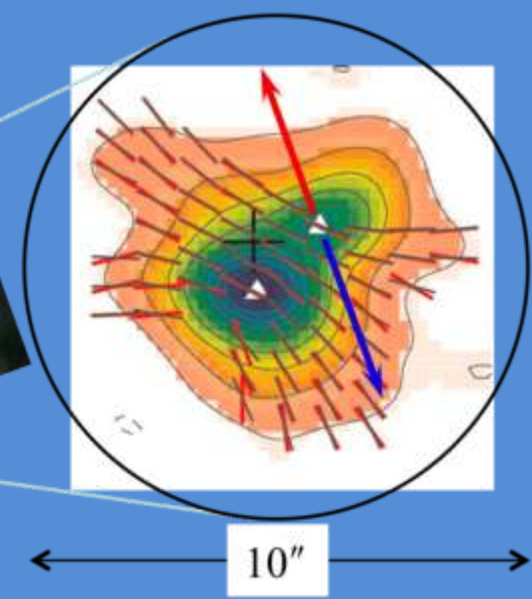
Planck: All sky
5’ resolution

ALMA,~1’’ resolutio
60’’ FOV



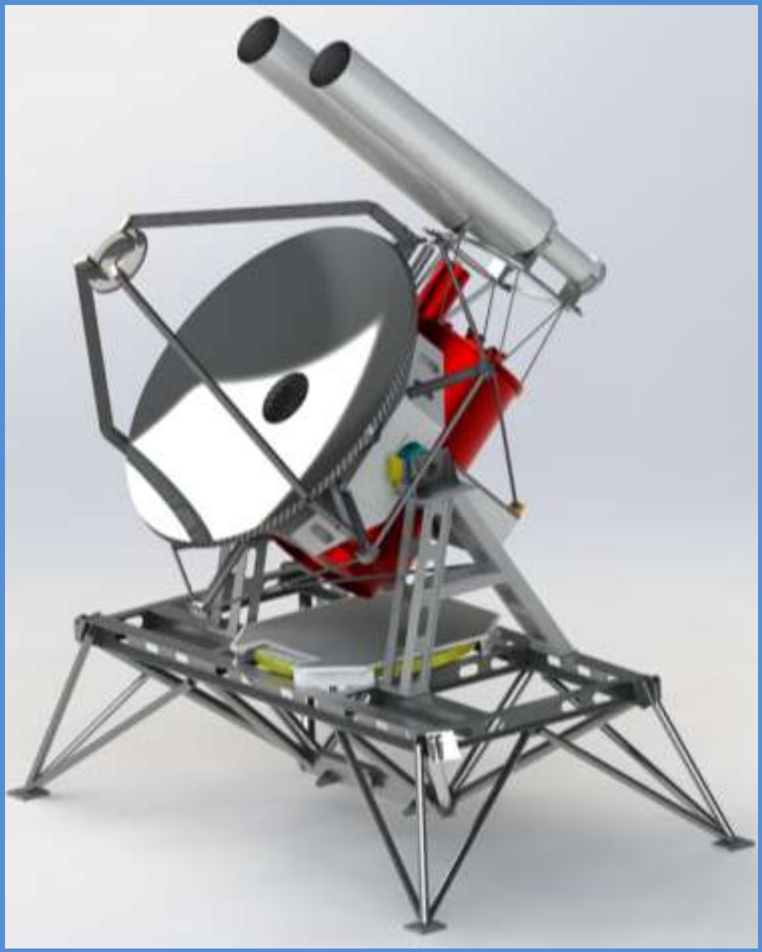
BLASTPol 30’’
resolution

Netterfield et al. 2009

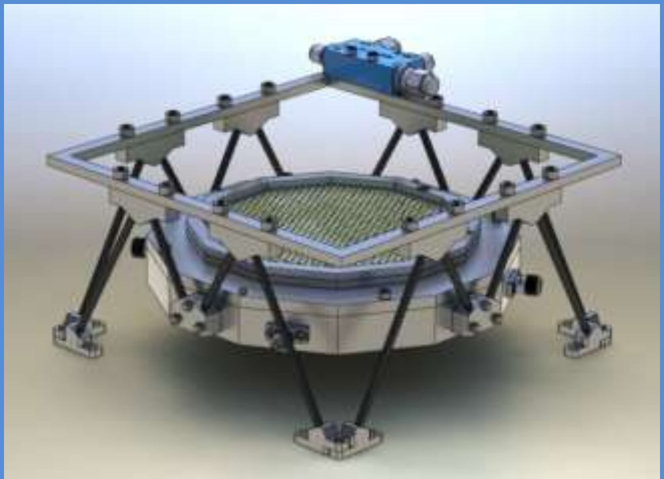


Girart et al. 2006

Key Features of BLAST-TNG



The BLAST gondola including at 2.5 m Carbon Fiber Mirror.
(Sun/Ground shields are suppressed.)



The BLAST 250 μm array with over 550 polarization-sensitive pixels.

BLAST-TNG key specs & recent history:

Wavebands:
- 250, 350, & 500 μm continuum
- 2300 Microwave Kinetic Inductance Detectors
- 1150 Pixels on the sky with 22-30″ resolution

Primary mirror:
- 1.8 m (upgrading to 2.5 m)

Polarimetry flights (Antarctica):
- 2010, 2012, 2016(anticipated)

Conclusion

- There is a future!
- It is not all in space
- SOFIA and Antarctic long duration balloons will play important roles
- Far infrared observatories will continue to make important contributions
- Some examples
  - State of water in protoplanetary disks
  - Molecular hydrogen mass calibration in low metallicity environments (Local Group only)
  - Large-scale maps of magnetic fields, especially in molecular clouds, and possible relation to process of star formation – relation to IMF?
- A major space observatory could contribute much more, for example
  - Hydrogen mass calibration to much lower metallicities
  - Very low levels of obscured star formation at high redshifts

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- A major space observatory could contribute much more, for example
  - Hydrogen mass calibration to much lower metallicities
  - Very low levels of obscured star formation at high redshifts
- This is one area where new technology makes major advances feasible within a realistic fraction of the GDP!