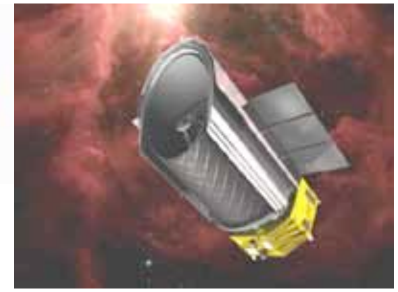


BLISS:

The Background-Limited Infrared Submillimeter Spectrograph for

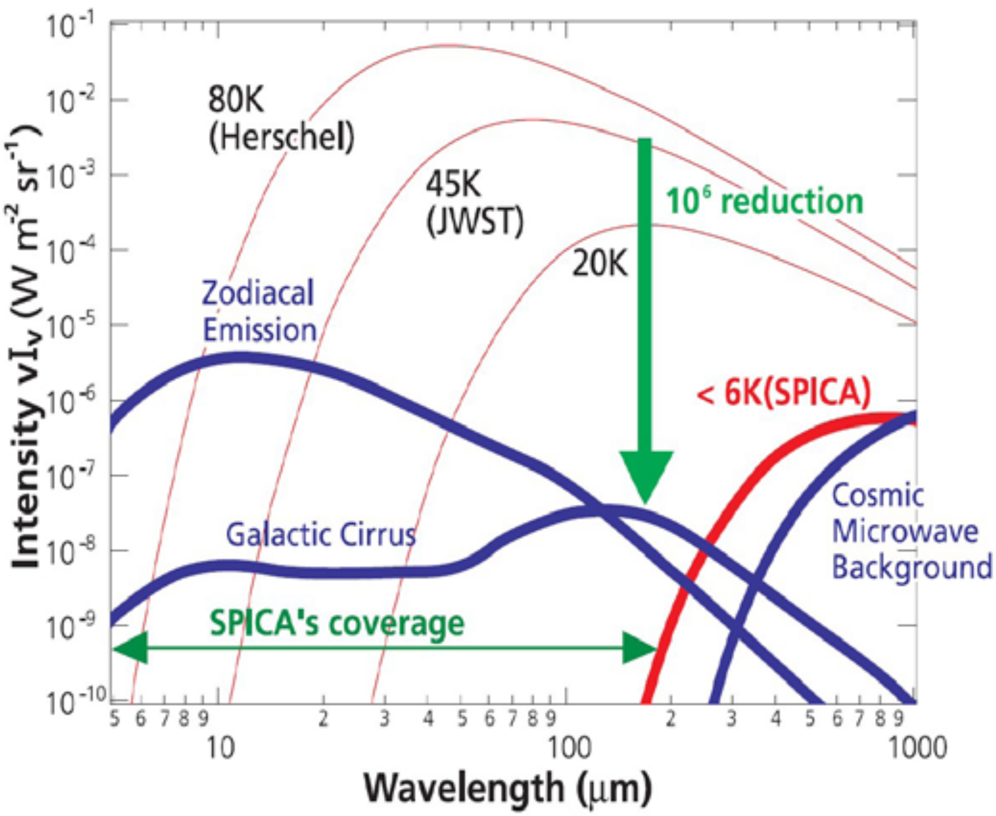
SPICA

Matt Bradford +

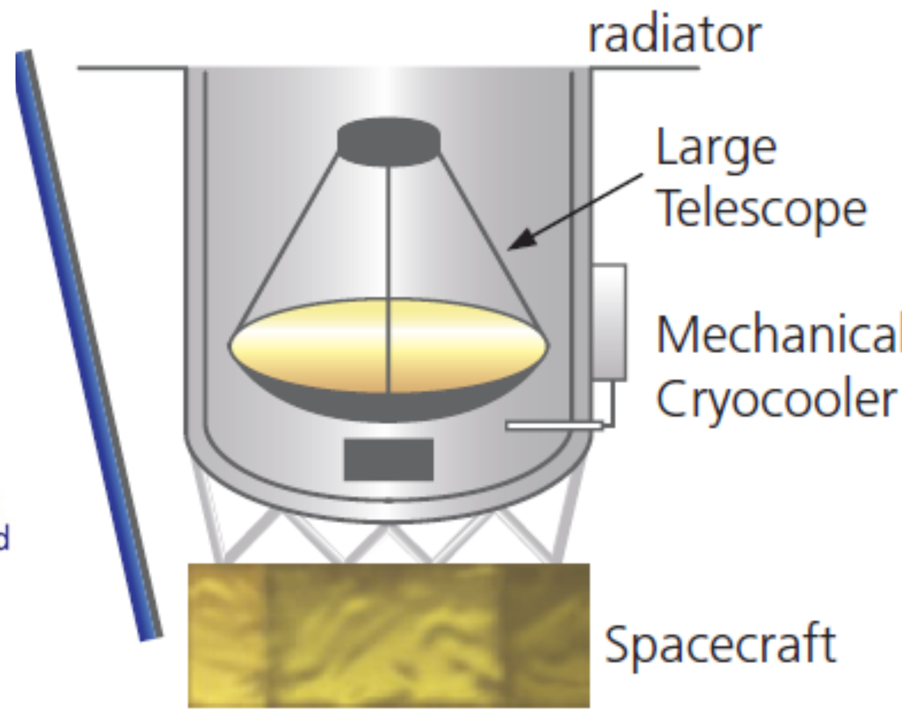
Andrew Beyer, Matt Kenyon, Pierre Echternach, Bruce Bumble, Marc Runyan, Thomas Prouve, Warren Holmes, Jamie Bock, Kent Irwin (NIST)

SPICA CONCEPT: 4 K, 3-M CLASS OBSERVATORY

Astronomical backgrounds

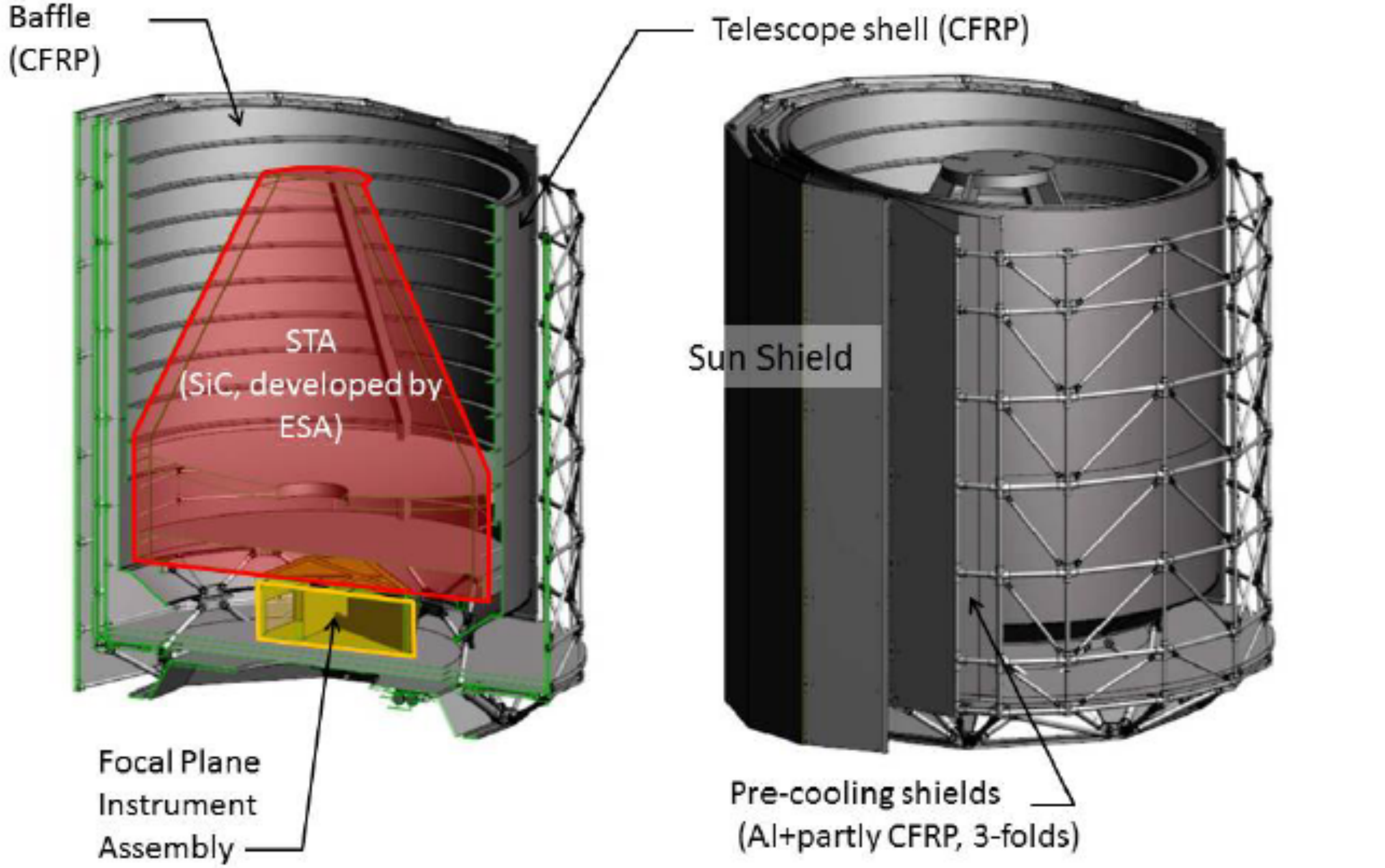


SPICA concept: warm launch to L2 orbit, closed cycle 4.5 K coolers



Low temperature more important than large aperture

SPICA PAYLOAD MODULE

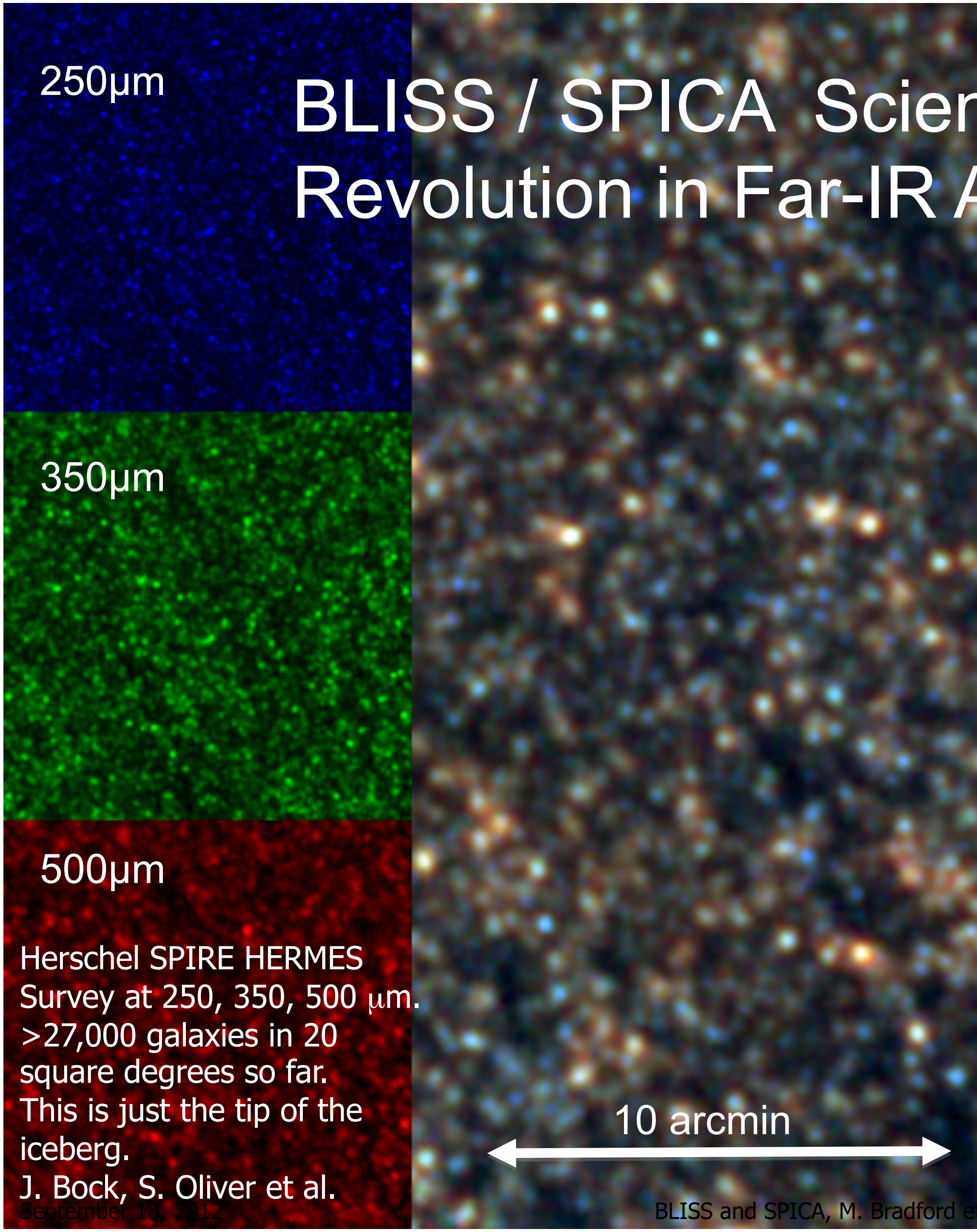


- Closed-cycle coolers with 20 K Stirling stages and JT stages at 4.5 K (40 mW EoL) and 1.7 K (^{3}He J-T, 10 mW EoL).
- Heat switches provide some redundancy against failure of a single cooler stage.

SPICA Focal Plane Instruments

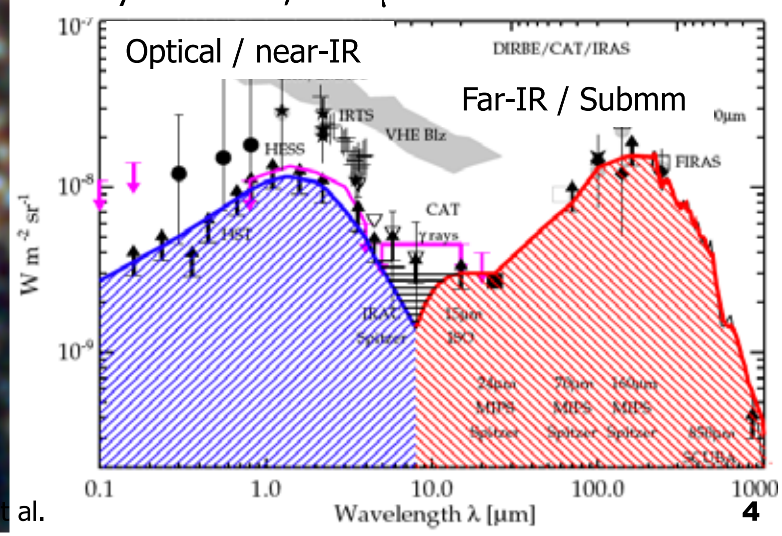
- MCS (P.I. JAXA, Universities, and ASIAA (Taiwan))
  - Mid-infrared camera & spectrometer, including Si:As (2k x 2k) and Si:Sb arrays (1k x 1k)
- 5x5 arcmin FOV imaging
- LRS: R=100 long slit, 5-26 + 20-38 microns
- MRS: R=1000 image slicing IFU, 12-23 + 23-38 microns
- HRS: R=30,000 cross dispersed small slit, 4-8 microns, 12-18 microns
- FPC (focal plane camera)
  - Near-infrared camera and spectrometer
  - P.I. KASI (Korea)
  - SCI (SPICA coronagraphic instrument)
  - P.I. JAXA with Nagoya Univ.
- SAFARI
  - Far-infrared imaging spectrometer
  - P.I. SRON (Netherlands) with SAFARI Consortium
- US Instrument (e.g. BLISS)
  - Ultra-sensitive far-infrared, sub-mm spectrograph

BLISS / SPICA Scientific Motivation: A Revolution in Far-IR Astronomy

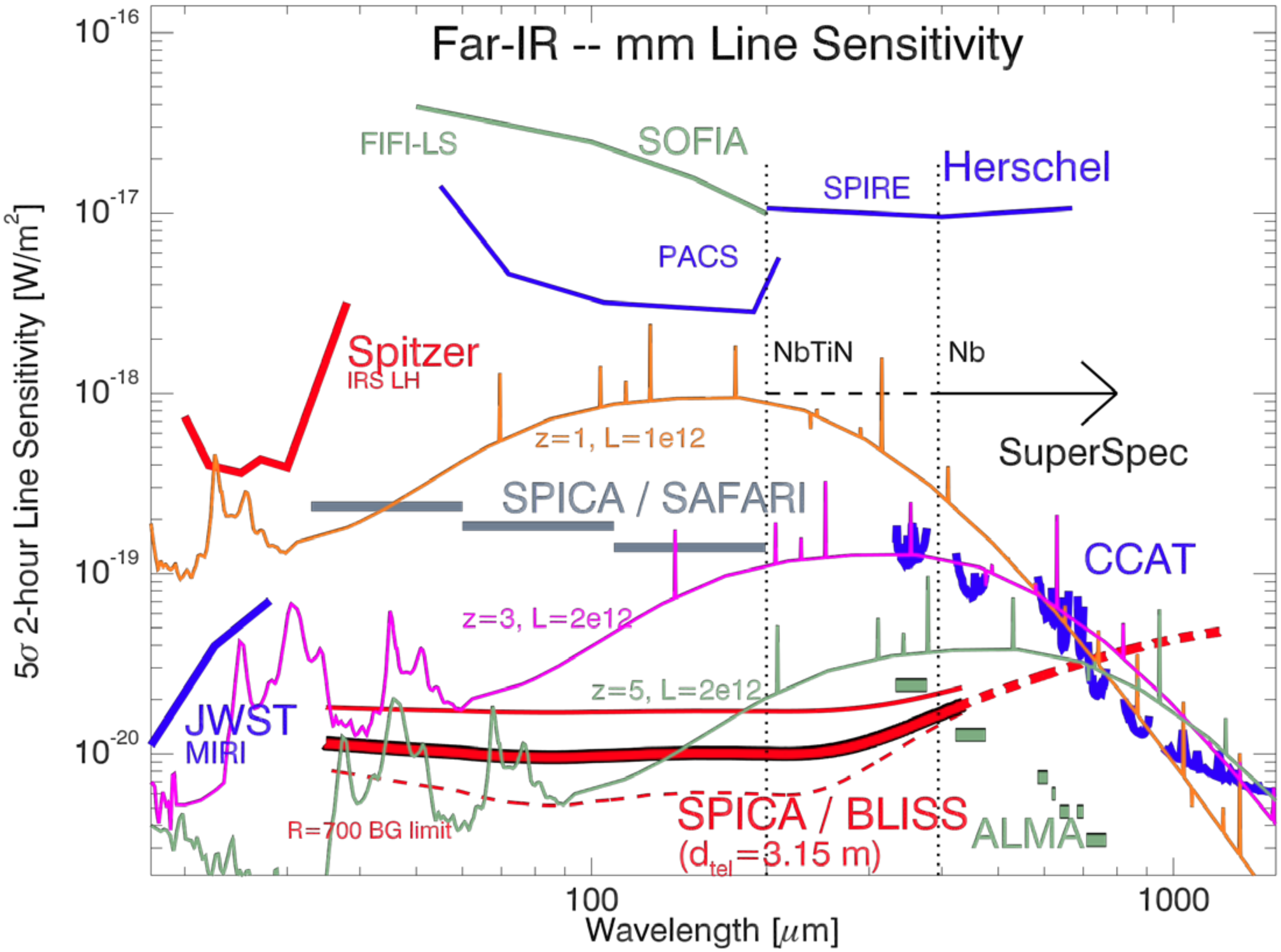


Herschel SPIRE HERMES Survey at 250, 350, 500 μm. >27,000 galaxies in 20 square degrees so far. This is just the tip of the iceberg.
J. Bock, S. Oliver et al.

Backgrounds including Spitzer stacking analyses at 70, 160 μm. *Dole et al. 2006.*



BLISS-SPICA Ultimate Capabilities



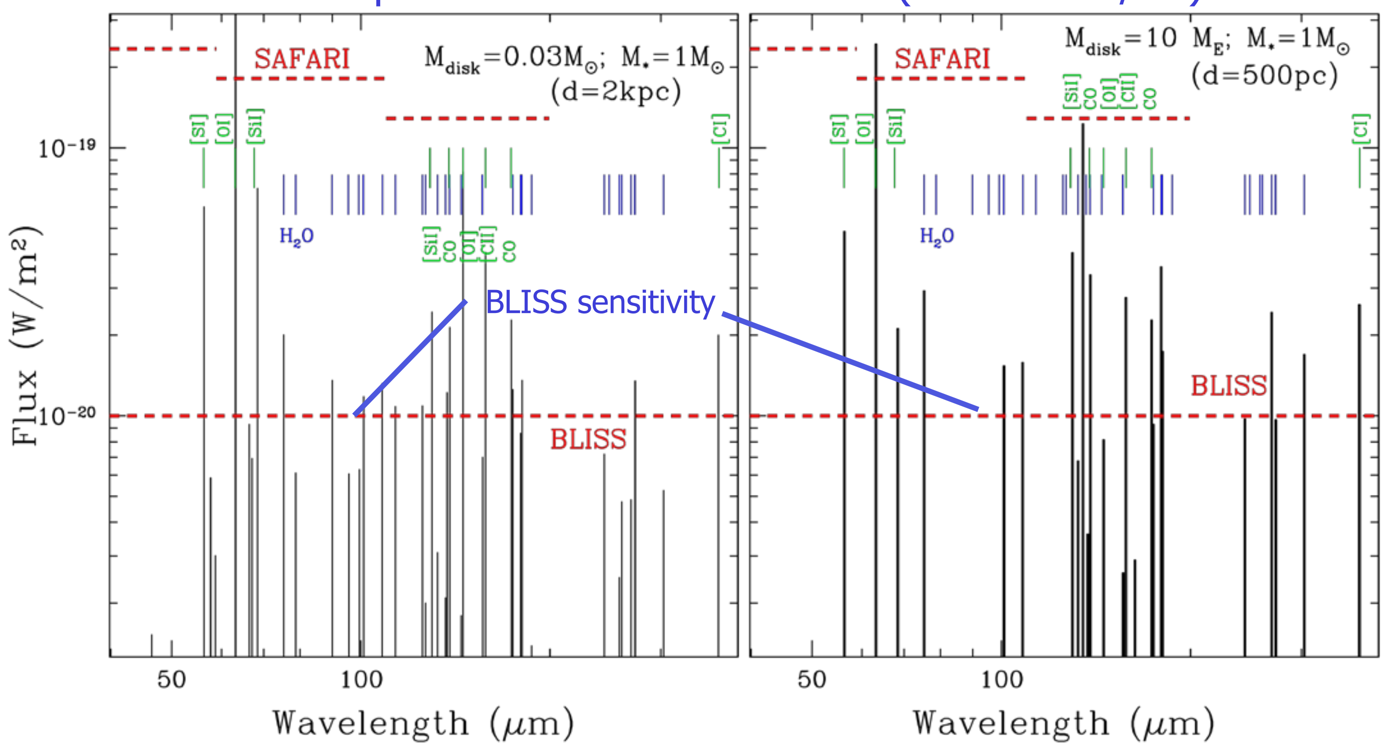
- BLISS-SPICA can obtain spectra of galaxies in the Universe's first billion years as they are borne, comparable to JWST and ALMA in sensitivity.
- Observing speed scales as the inverse square of the sensitivity, factor of 1e6 beyond existing facilities (for point sources).
- Source confusion is not a problem for R~700 spectroscopy.

SPICA: 3.15 m, 5.5 K with 4% emissivity and 75% aperture efficiency

BLISS / SPICA Probes the Birth of Planets and Planetary Systems

- Gas protoplanetary disks is essential for formation of gas giant planets
- Bulk of the mass in the disk is likely at r≥20 AU, cools through [OI], [CII] + rotational lines of CO and H_2O -> dominant coolants are in the far-IR regime.

Model spectra convolved to R=400 (fluxes in W/m^2)



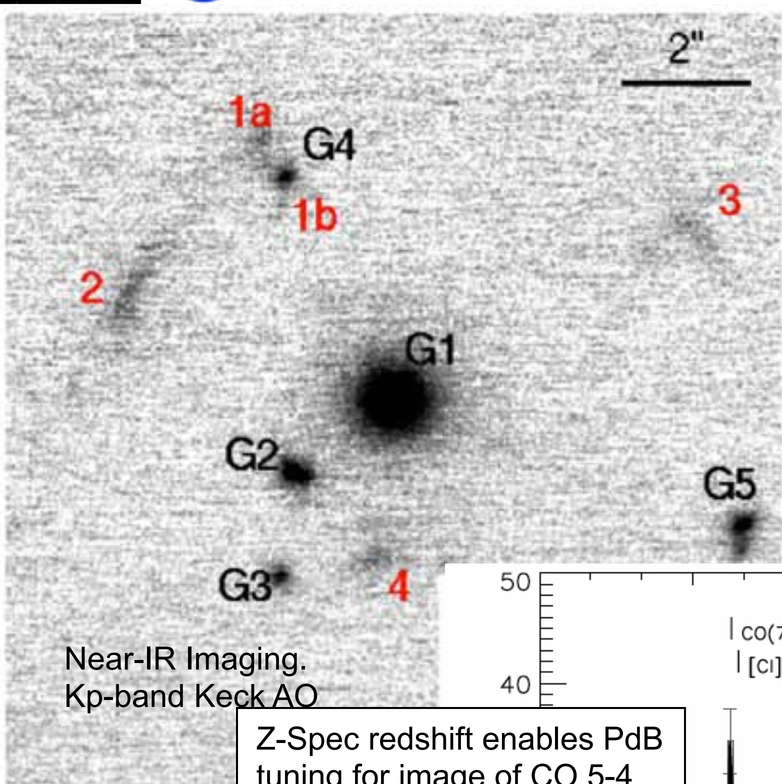
BLISS co-I Uma Gorti

- SPICA/BLISS covers the full evolutionary range, from primordial disks with 0.01 M_{sun} to evolved systems with only a few M_{Earth} of gas remaining.
- SPICA/BLISS allows observations at kpc-distances, accessing clusters with a wide range of ages, can measure the gas disk lifetimes directly for the first time.

Example clusters for SPICA/ BLISS disk spectroscopy:

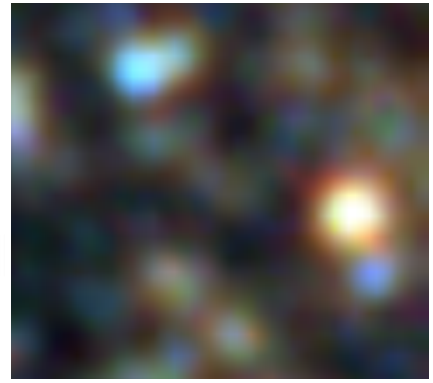
NGC 2362 (5Myr, d=1.5 kpc), NGC 6871 (10Myr,d=1.7 kpc), h-& χ - Per (13Myr, d=2.3kpc), and many more.

Wideband Spectroscopy Probes the Cosmic History of Star Formation



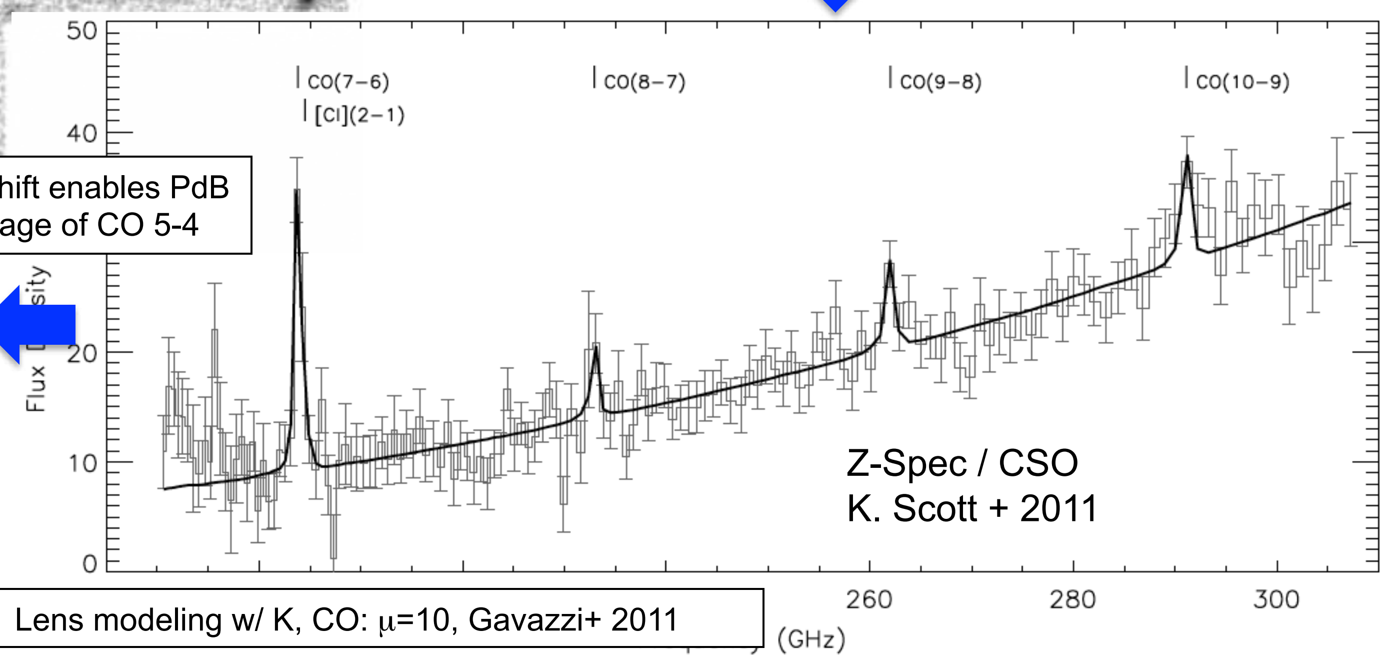
Near-IR Imaging.
Kp-band Keck AO

Near-IR Imaging.
Which / Where is counterpart ??

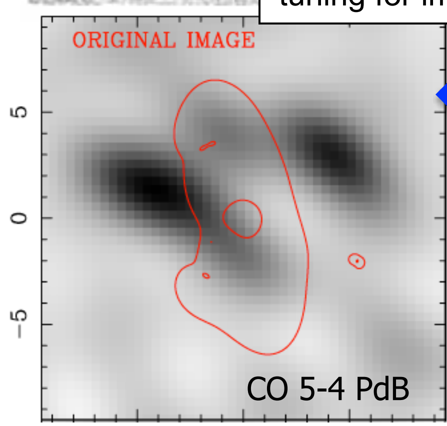


HeRMES Survey Bright (lensed) sources identified at 250, 350, 500 μm.
HSLS 1

Direct Z-Spec redshift with CO lines in the mm: z=2.95

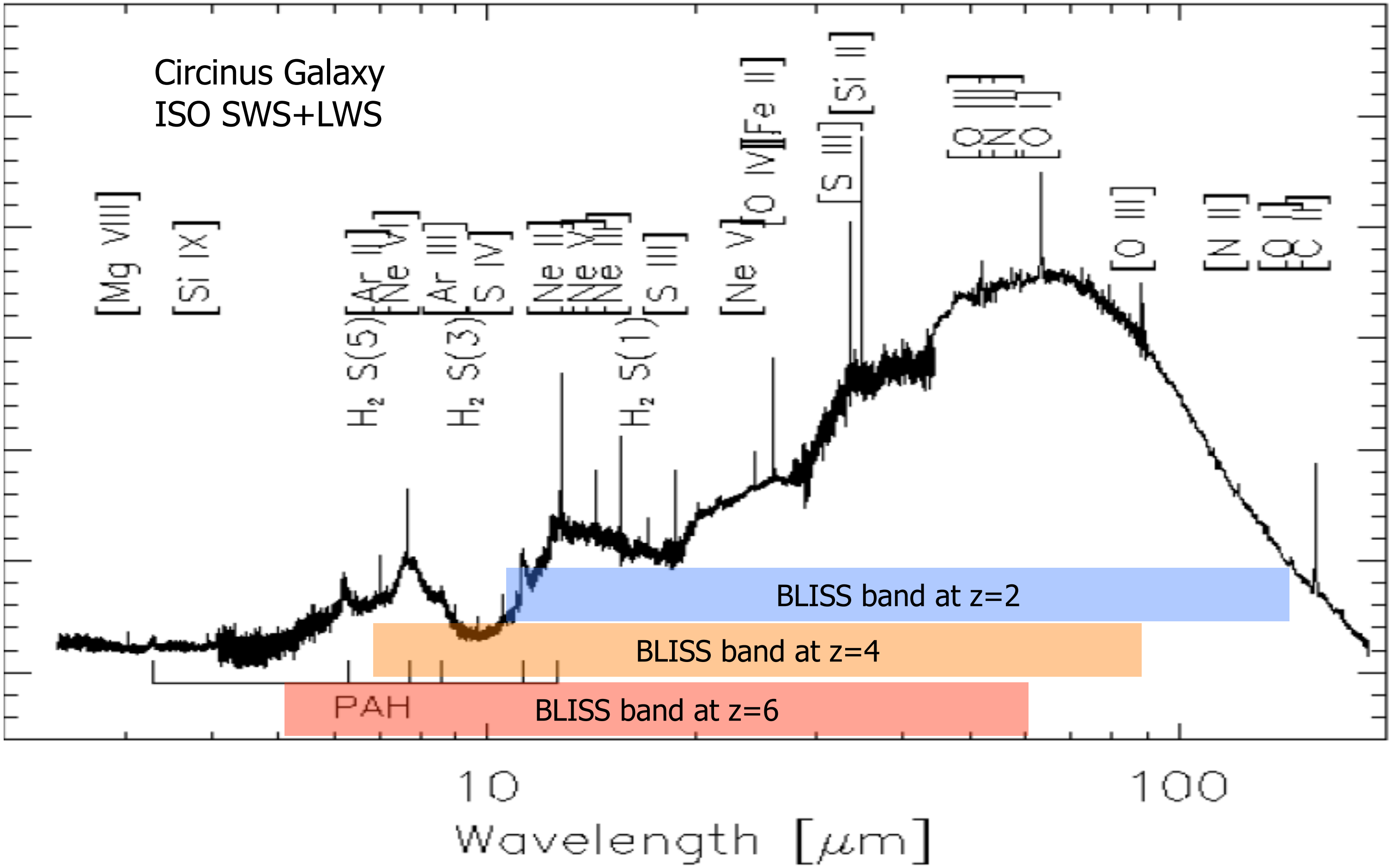


Z-Spec redshift enables PdB tuning for image of CO 5-4



Lens modeling w/ K, CO: μ=10, Gavazzi+ 2011

FAR-IR SPECTROSCOPY PROBES THE COSMIC HISTORY OF STAR FORMATION

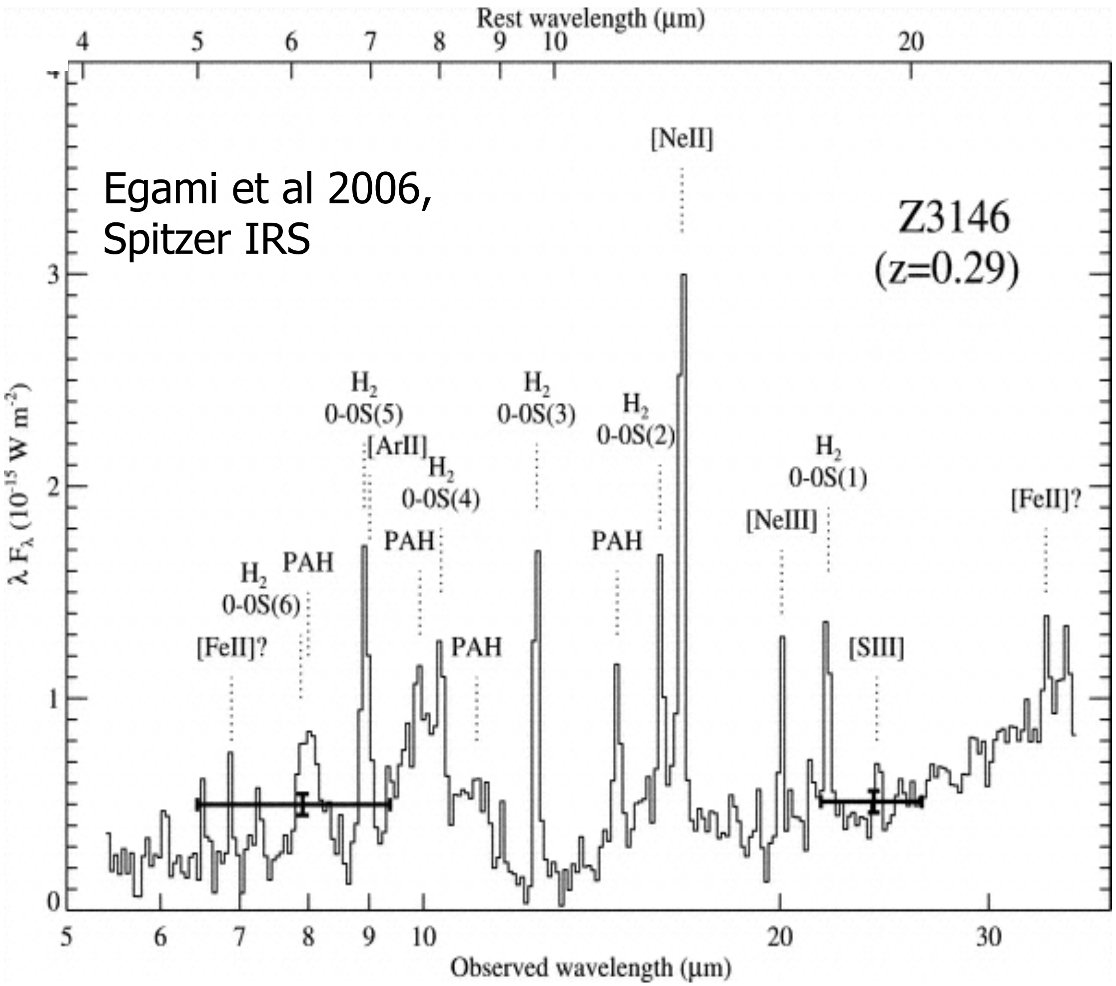


• Star formation rate, gas density and filling factor, and stellar effective temperature are measured with fine-structure lines of Ne^+ (13μm), Si^+ (34μm), C^+ (158μm), and O^0 (63μm, 145μm) together with the far-IR continuum.

• SPICA/BLISS + ALMA will measure the complete mid- far-IR suite in galaxies from z=6 (1 BY after the Big Bang) to the present.

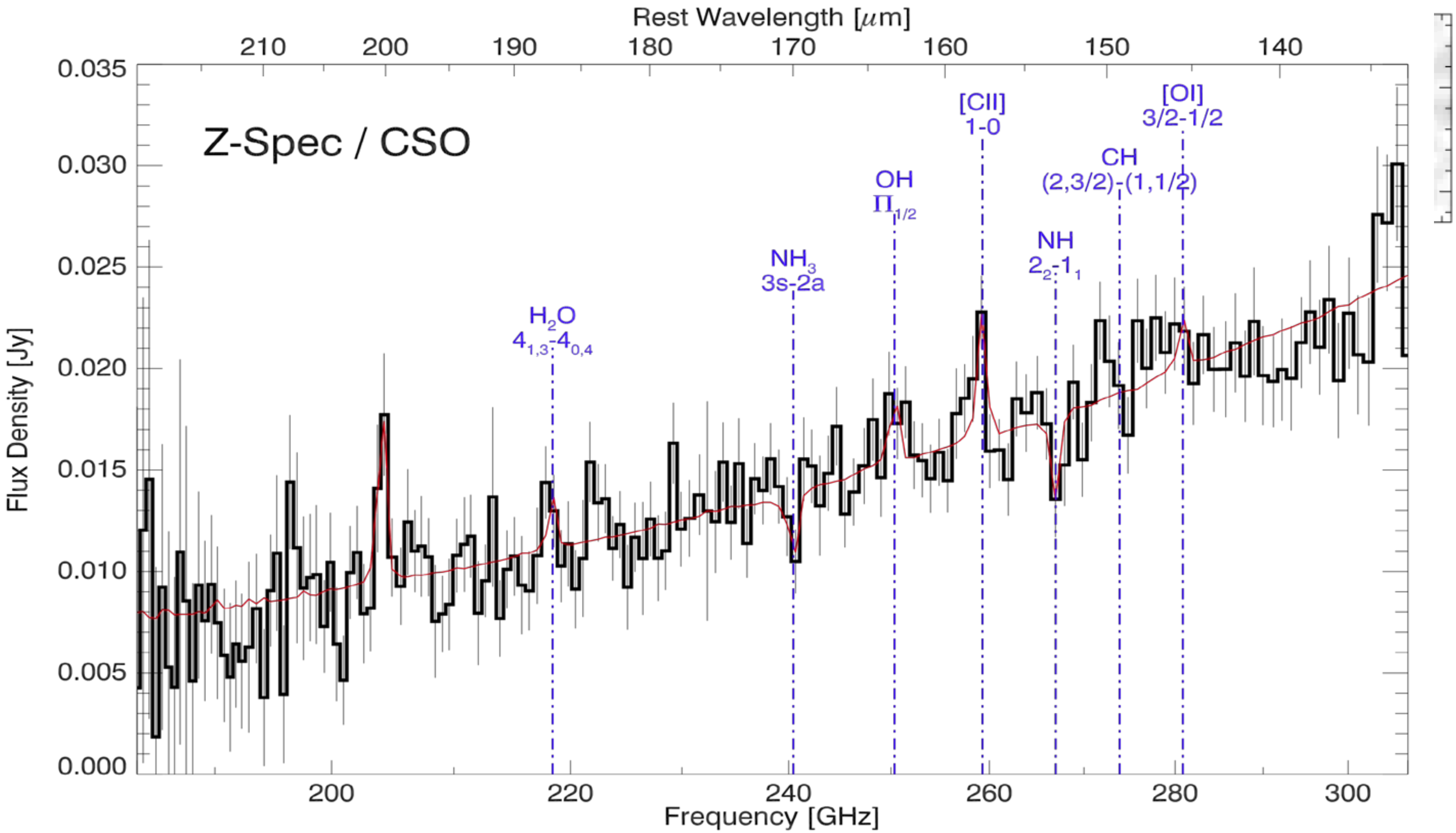
The Cosmic Rise of Heavy Elements and Molecules

As primordial gas is enriched with metals from the first stars, the dominant cooling pathways shift from pure H_2 to fine-structure lines and dust features.



- Strong H_2 emitters found in the local-Universe may be analogs of early-Universe shocks produced in galaxy formation and AGN feedback.
- The Zw3146 spectrum at left would be detectable at z=8-10 with BLISS / SPICA!
- PAH features may offer the best probe of heavy metal abundance at early times.
- SPICA-BLISS can readily detect the PAH emission from galaxies systems at z~6, as they come to be (not accessible to JWST or ALMA.

z>6 survey spectroscopy

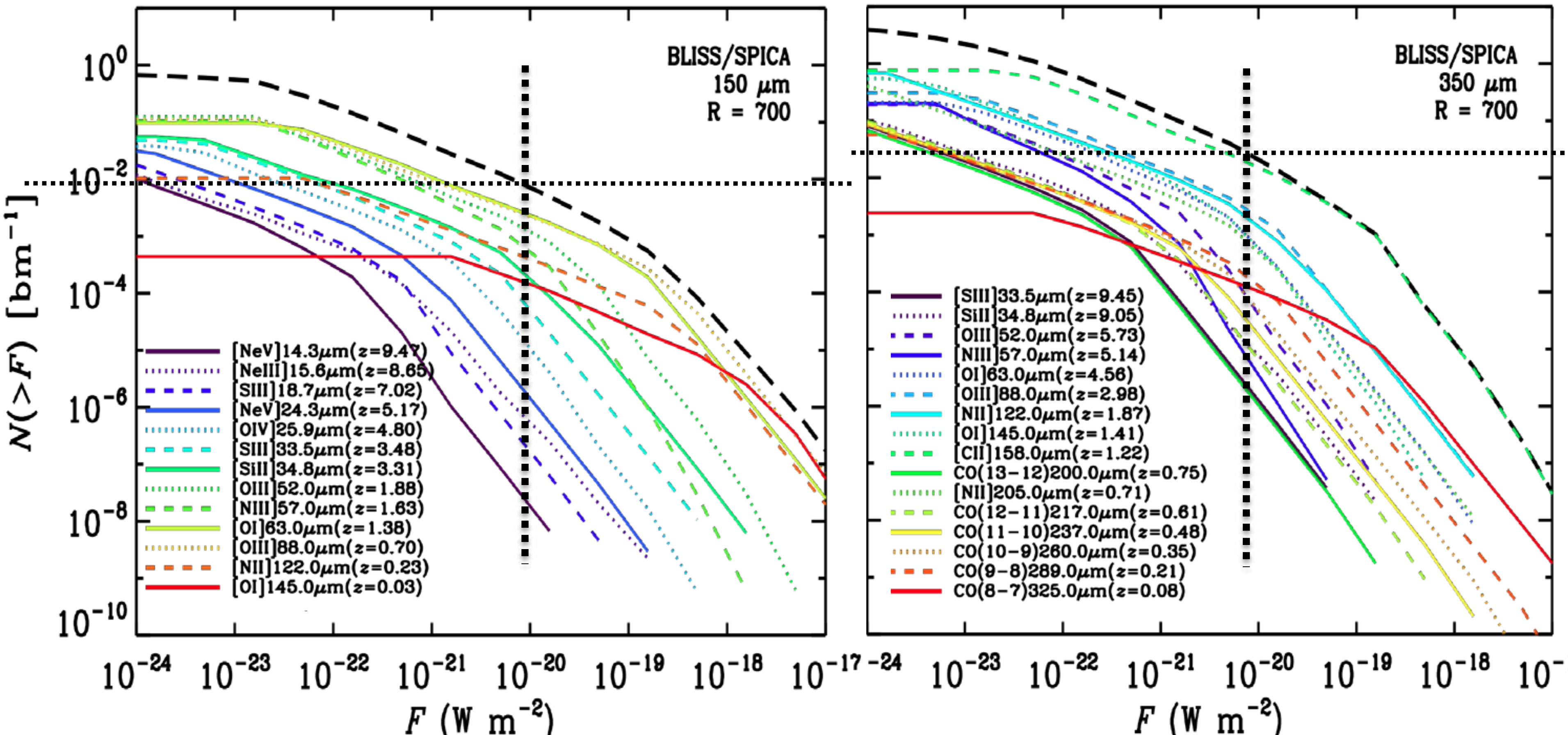


An Arp 220-like evolved starburst (weak C+) before t=1 By.

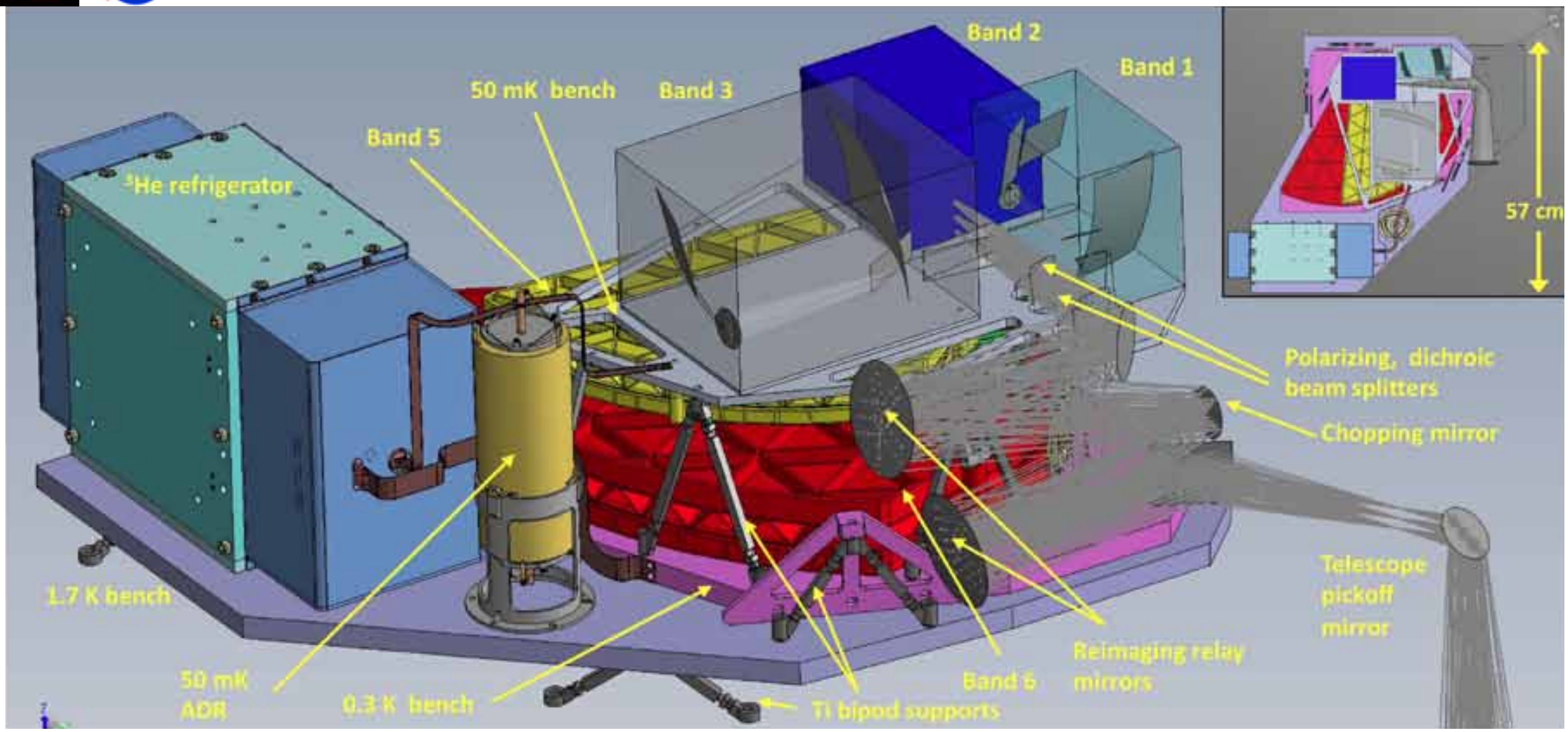
Line Confusion with BLISS / SPICA?

Fine-structure 'line counts' E.J. Murphy et al.

Based galaxy models from Chary & Pope 2010,
(backward evolving from Chary & Elbaz 2001, L* evolution with z)
Lines from galaxy luminosity from Spinoglio 2011 compilation of Spitzer, ISO LWS.
Cumulative counts per SPICA beam per R=700 bin



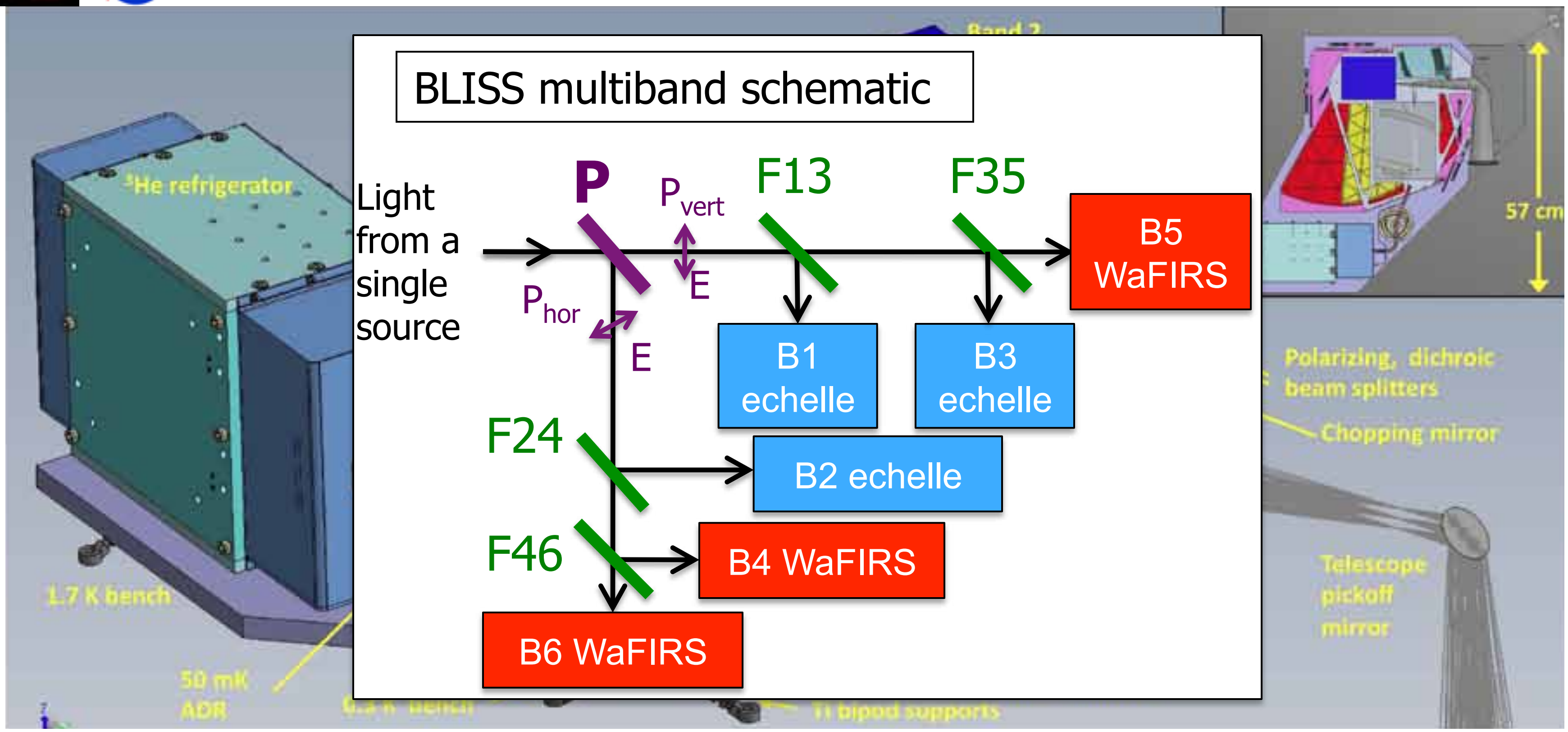
BLISS OVERVIEW



Approach: measure a galaxy's full spectrum from 35-433 μm simultaneously.

- 6 bands (shown B1-B6 in schematic) each coupling 2 sky positions at R~700.
- Use polarizer (P) then couple a single polarization in each spectrometer. Dichroic filters (FXX) separate the bands:
- Short-wavelength bands are echelle spectrometers (blue in schematic), long-wavelength bands are waveguide spectrometers (red in schematic).
- ~4000 superconducting bolometers with SQUID MUX, 700-800 detectors per band.
- Assembly cooled to 50 mK with a 2-stage refrigerator, supported with titanium suspension.
- Bolt and go, no moving parts except for chopping mirror in feed optics (not shown).
- **Specs**: 45x40x40 cm^3, 30 kg cold mass (w/ margin), Power ~100 W.

BLISS OVERVIEW



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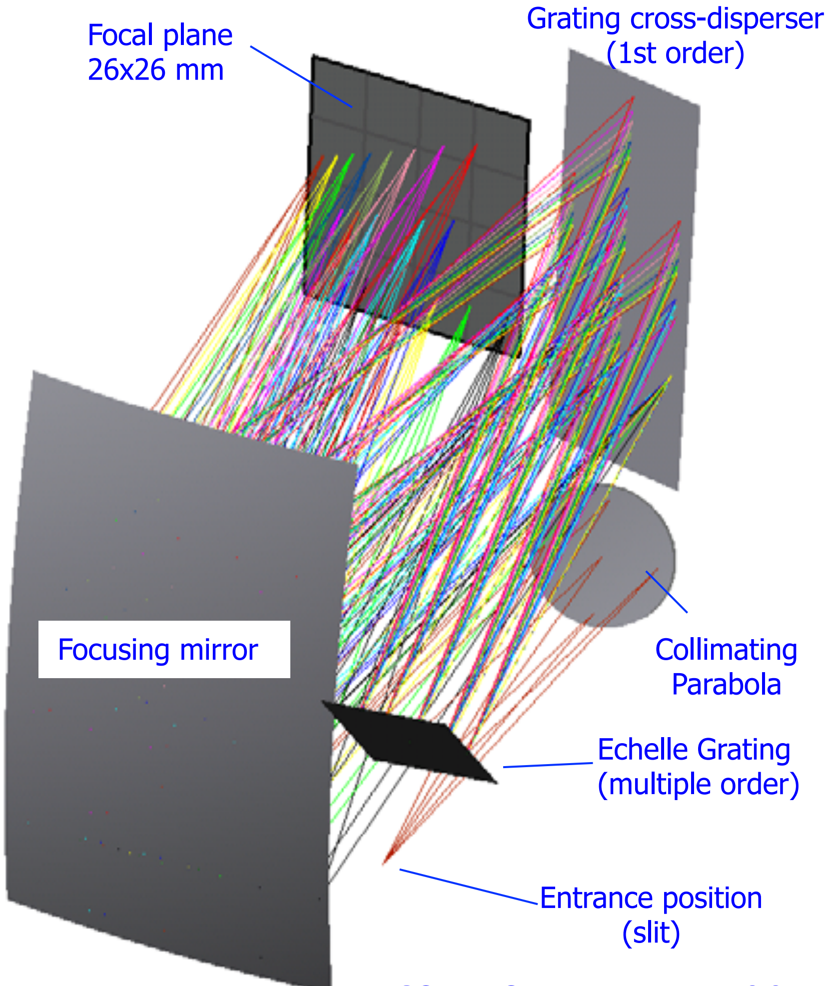
BLISS short-λ echelle spectrometers

BLISS example echelle design



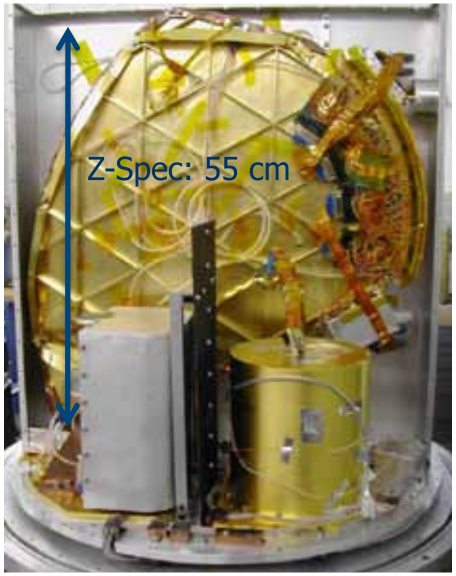
68-118 μm at R=700,
75 x 150 x 115 mm

BLISS requires a wide bandwidth and compact package; imaging not essential -> **Use cross-dispersed echelle grating spectrometers** (for short-wavelength bands).

- Uses Spitzer IRS concept, but we have developed an ultra-compact design for the BLISS wavelengths because package size scales with wavelength.
- Shown is λ=68-118 μm at R=700: 75x150x115 mm (shorter λ even smaller).
- Bolted aluminum construction, no moving parts.

Heritage: Spitzer infrared spectrograph (IRS)

Prototyping of BLISS WaFIRS Modules

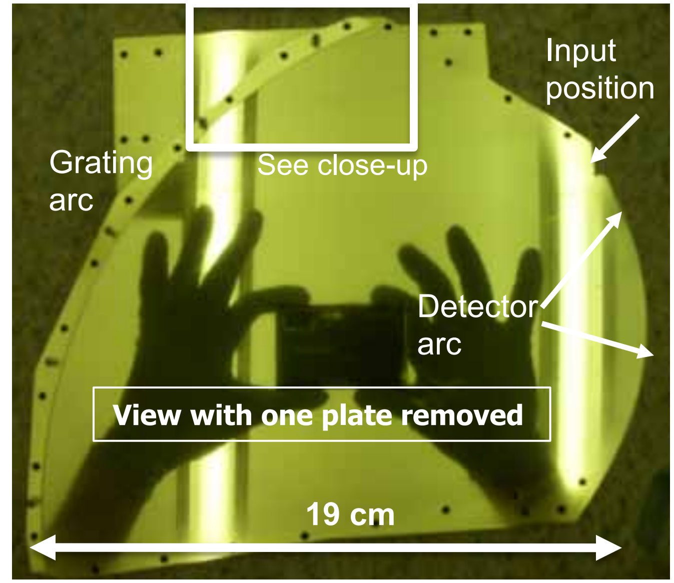


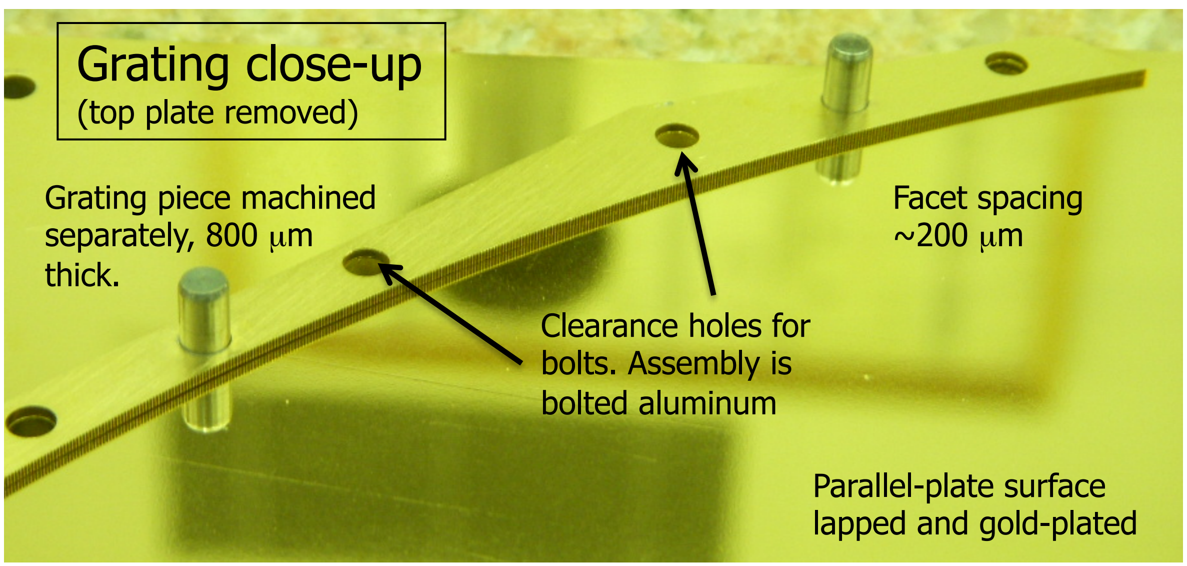
We have built a WaFIRS module for 180-300 μm designed to provide R=700.

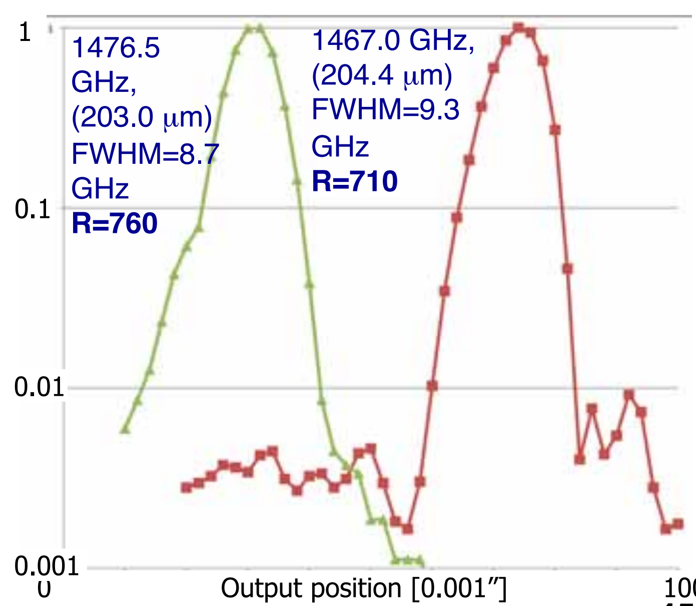
- 980 grating facets.
- Plate spacing 800 μm.
- 19 cm in size.

Initial testing with local-oscillator source & swept output feed demonstrates design resolving power! (below right).

Further testing underway to measure system optical efficiency.

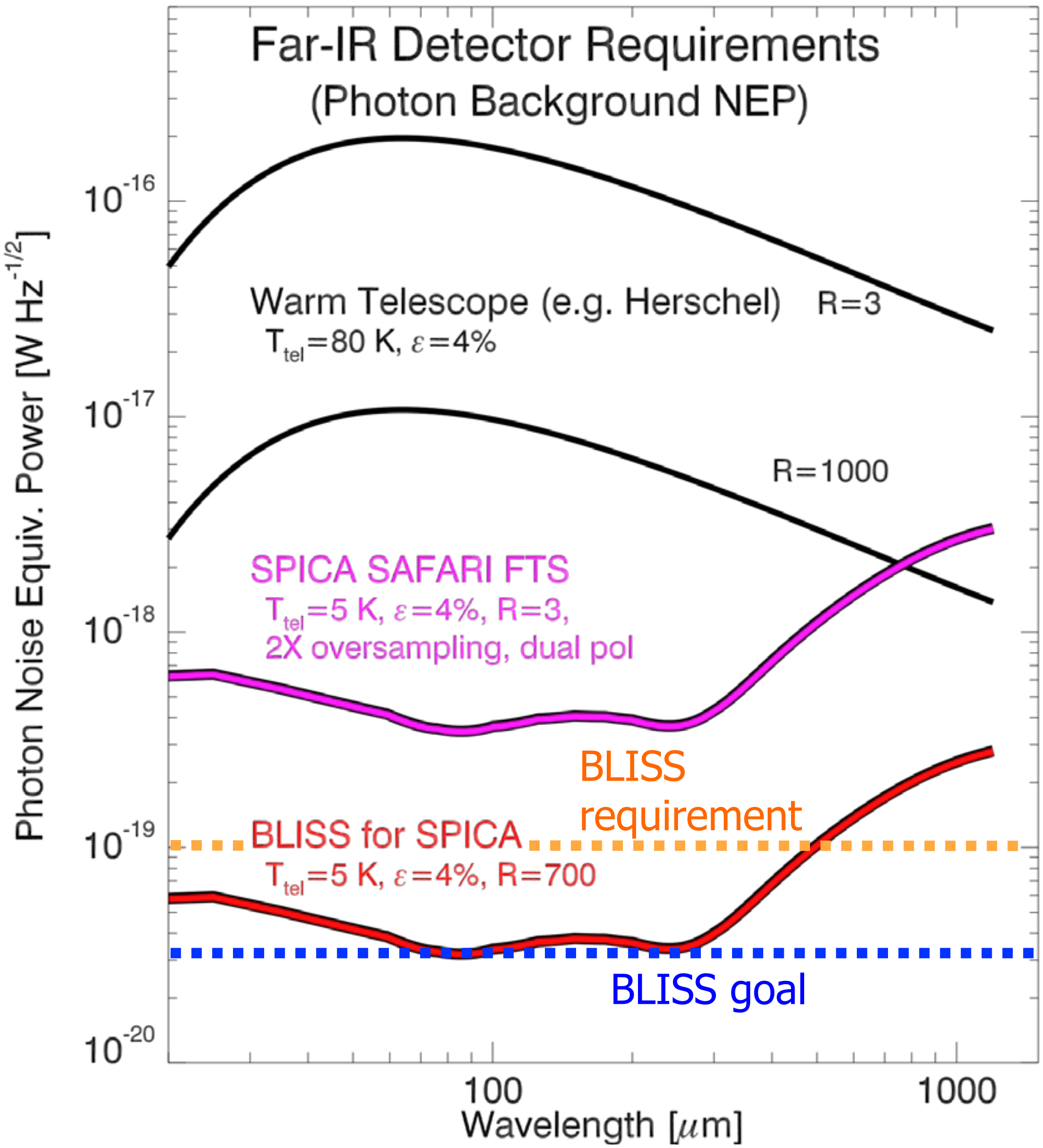






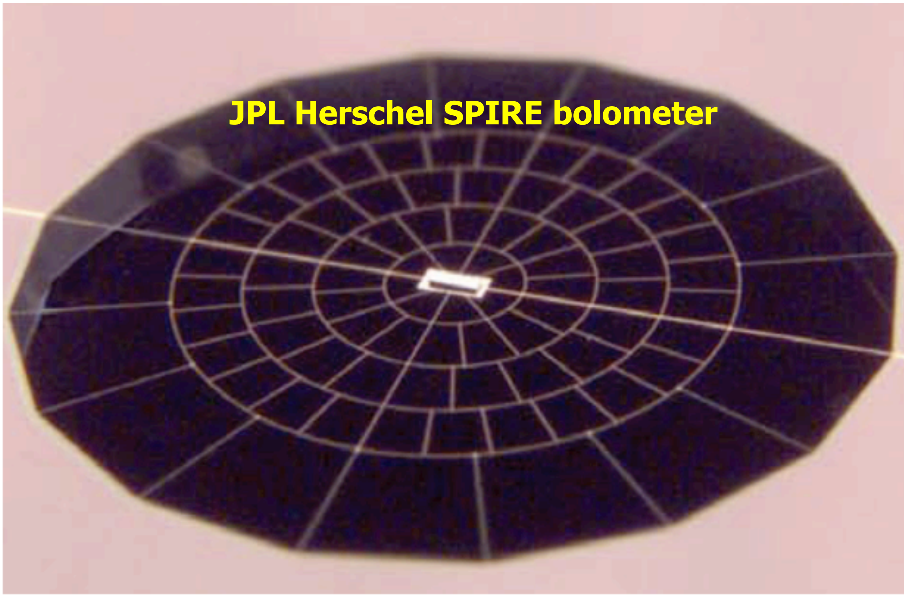
BLISS SENSITIVITY REQUIREMENTS

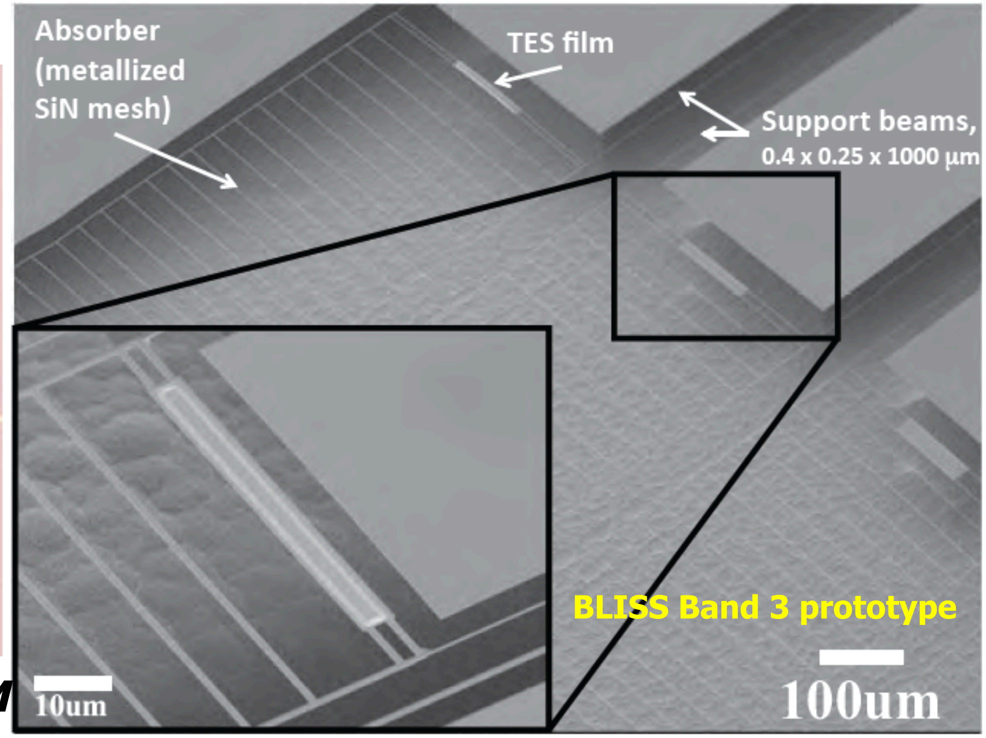
BLISS REQUIRES SENSITIVE DEVICES, PAVES THE WAY FOR FUTURE MISSIONS



- BLISS detectors must match the zodiacal+Galactic dust emission, and the telescope & CMB at 300 μm and longer. The BLISS requirement is set at 1x10^{-19} W $Hz^{-1/2}$.
- No suitable ground-or ballon-borne testbed. Even Herschel with its 80 K telescope has backgrounds 10,000 times too high.
- BLISS for SPICA NEP to astronomical sensitivity conversion:
- MDLF (3 sigma, 1 hour) [W m^{-2}] = 0.21 x NEP [W $Hz^{-1/2}$]
Including 3.15-m telescope @75%
chopping
single polarization @25%
extra factor of 3
1e-19 W $Hz^{-1/2}$ -> 2e-20 W m^{-2} astronomical sensitivity
- BLISS detectors do not have demanding speed requirement. Need to modulate fast enough to beat telescope / observatory optical 1/f. Target 100 ms to comfortably allow 1 Hz modulation (additional chopped bias likely).

BLISS BOLOMETER APPROACH





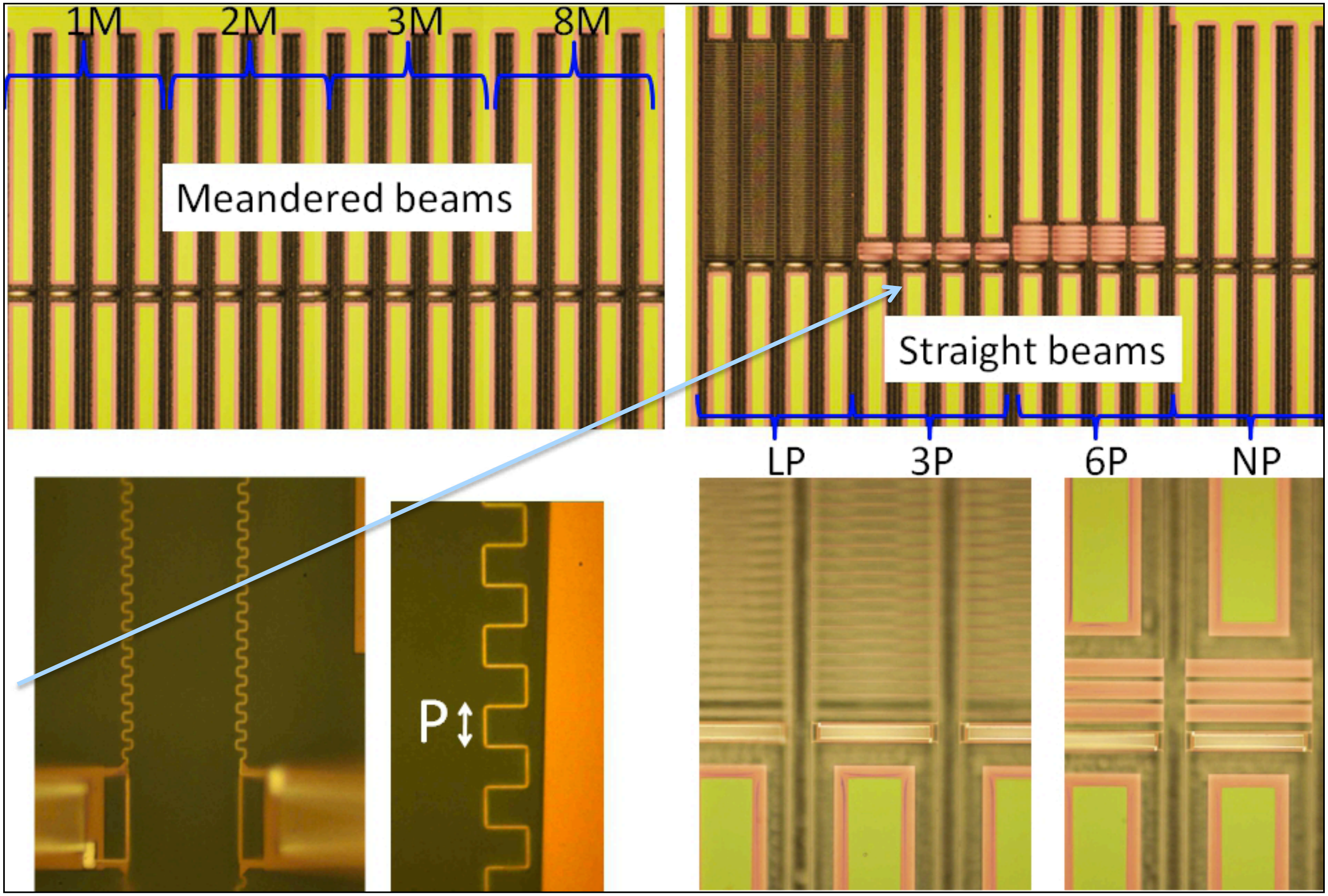
See A. Beyer talk, 8452-15, Wed 11:30 AM

- Silicon nitride micro-mesh approach with quarter-wave backshort.
- Absorber: 2 mm by 300 μm (for example). Gold bars thermalize along length.
- Isolation legs: e.g. 1 mm x 0.4 μm by 0.25 μm.
  - NEP = $(\gamma 4kT^2G)^{1/2}$, G meets BLISS requirement
- XF_2 etch undercuts front side on double SOI (silicon-on-insulator) wafer
  - Also investigating a wet-release process which reduces heat capacity.
- MoAu bi-layer TES (fraction of a square), TiN or niobium leads.
  - Operating impedance 3 milli-Ohms (R_N~7 mOhms).

BLISS PROTOTYPE ARRAYS

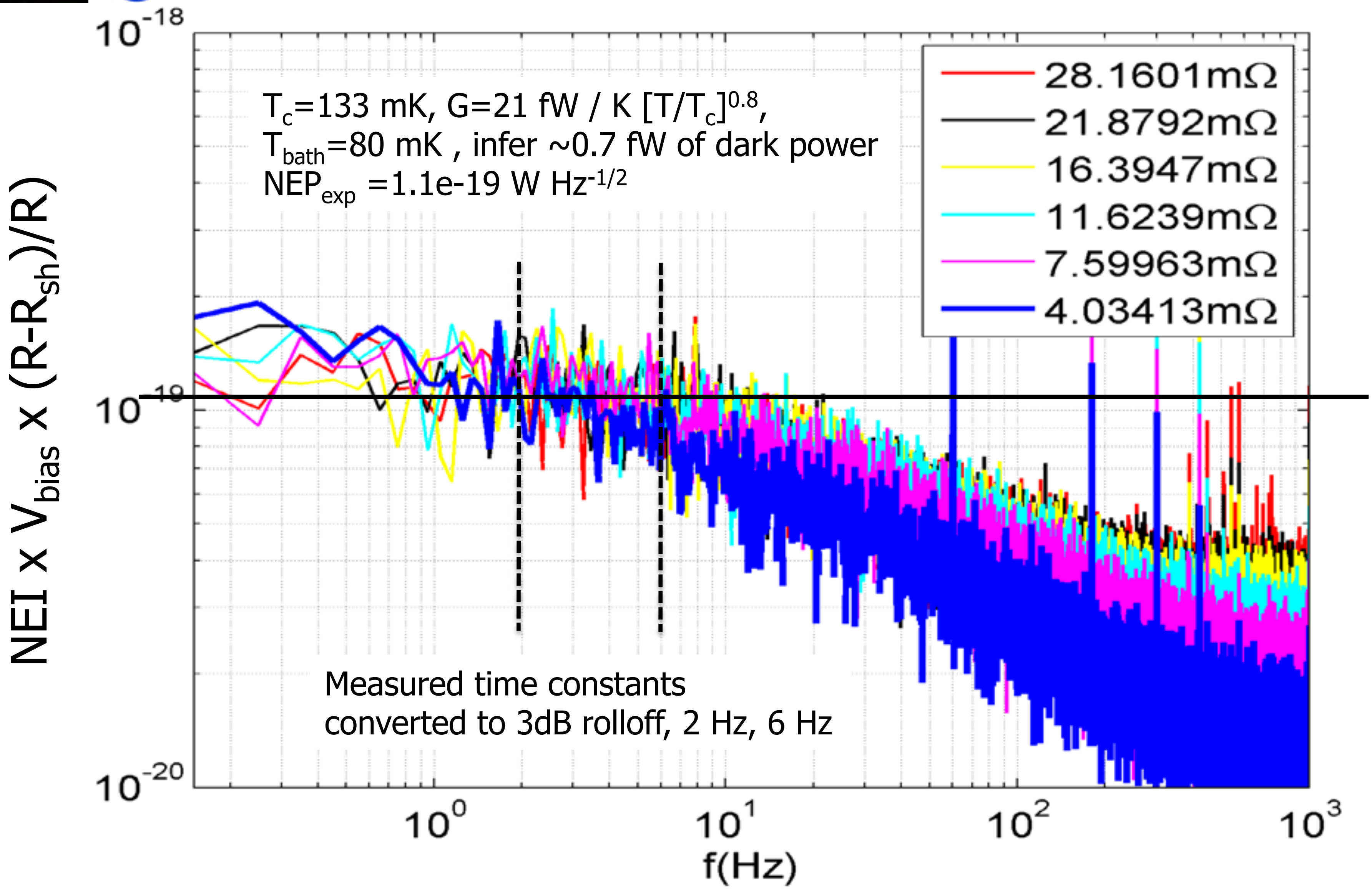
Meanders: total length of 2 mm, cross section 0.4 by 0.25 micron

A variety of absorbers to enable high-speed and probe heat capacity



See A. Beyer talk, 8452-15, Wednesday 11:30 AM

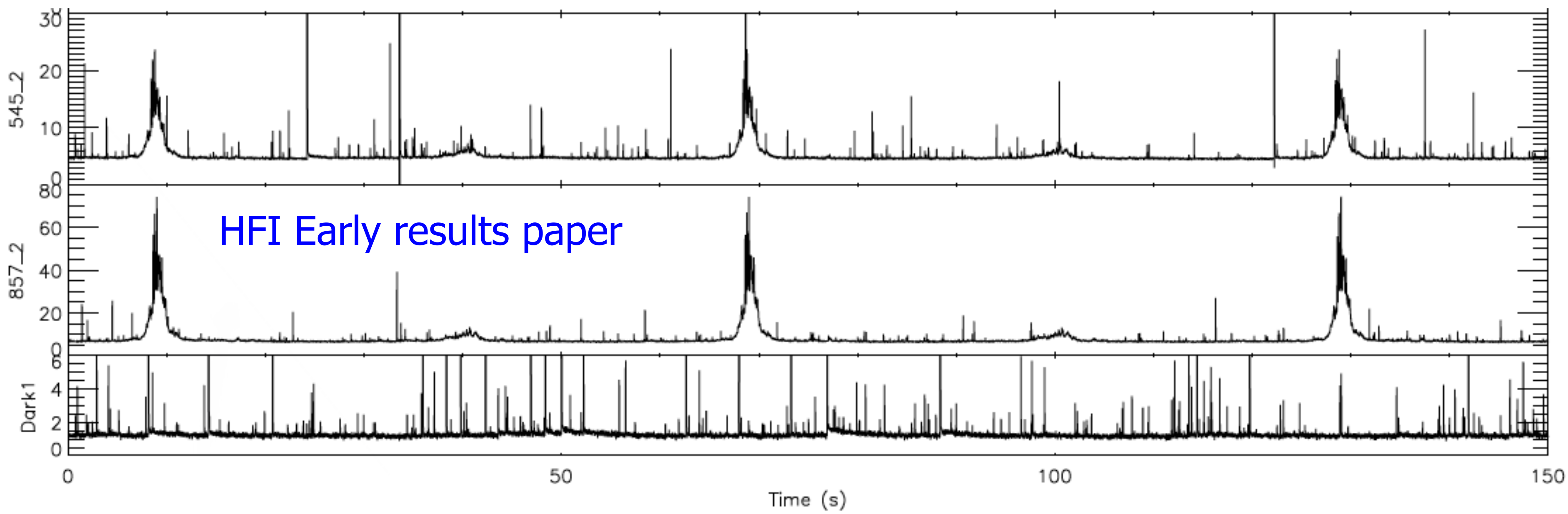
IR TEST DEVICE W/ COMMERCIAL SQUID



See A. Beyer talk, 8452-15, Wednesday 11:30 AM

COSMIC RAY SUSCEPTIBILITY

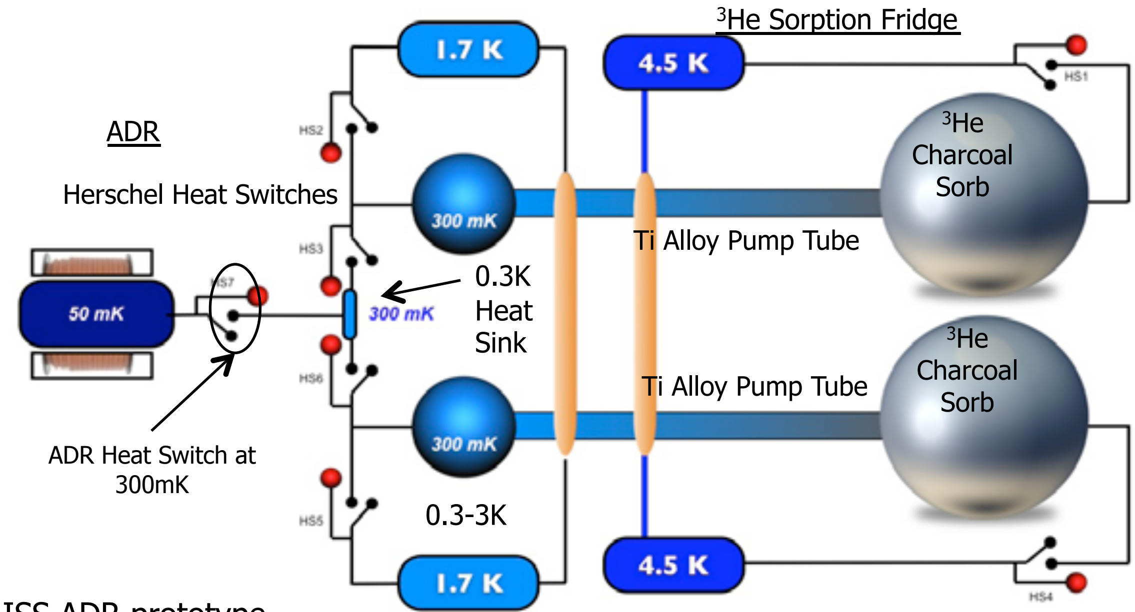
Planck HFI cosmic ray study anticipated.



- Planck HFI detectors have ~80 events per minute, spectrum extends down to detection threshold.
- BLISS detectors ~100x lower NEP than Planck HFI, **but have ~500 times lower cross section than the HFI bolometers.**
  - Scales as mass x Z (atomic number), HFI dominated by chunk of Ge.
- Low energy events not fundamental and are under study.
  - Electron showers from metal surfaces? Add electron absorber
  - Frame hits? Add heat capacity and phonon traps (embedded metal) to the frame. BLISS has 10s to 100s of detectors per frame

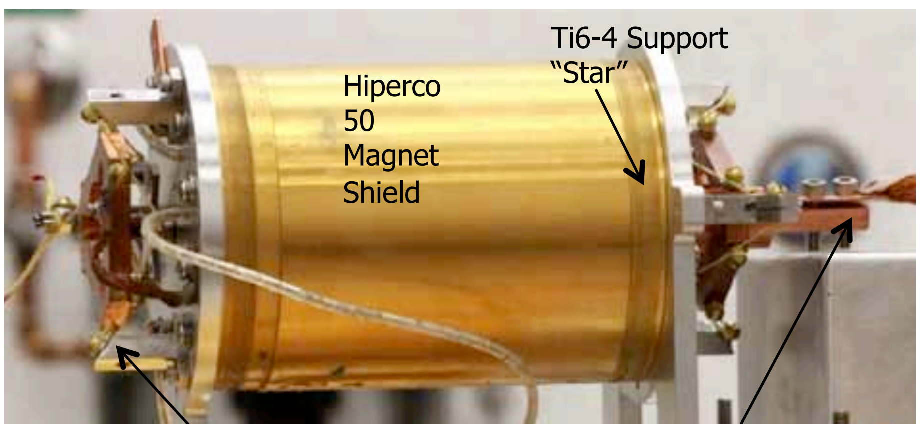
BLISS Cooling Approach:

A high-heritage dual-stage sub-K cooler

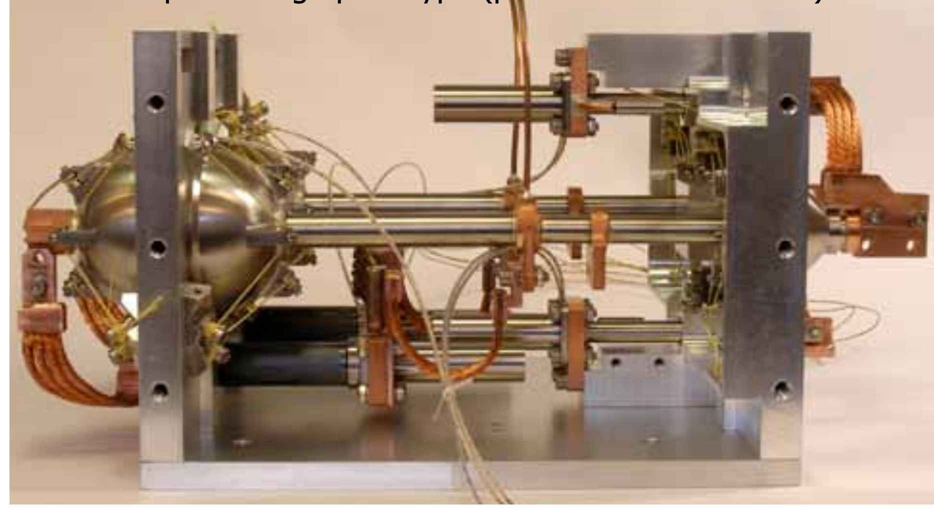


- Use two 'Herschel' coolers at 300 mK to provide a continuously-cooled intercept stage.
- Use a single-shot ADR to cool the spectrometers and detectors to 50 mK.
- 24-hour hold time and >90% duty cycle.
- Heat rejection requirements to 4.5 K, 1.7 K consistent with SPICA allocations

BLISS ADR prototype

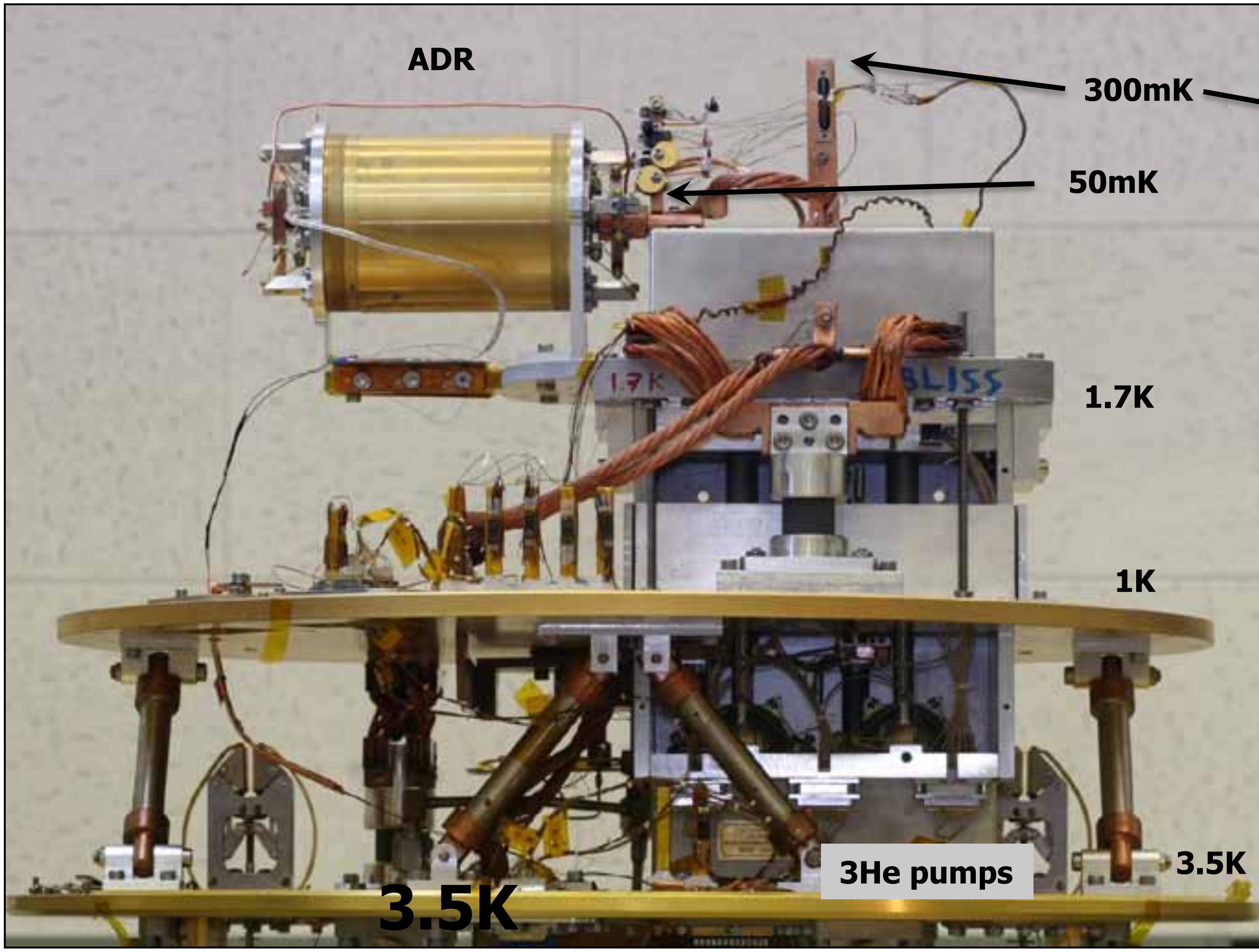


BLISS sorption fridge prototype (procured from Duband)

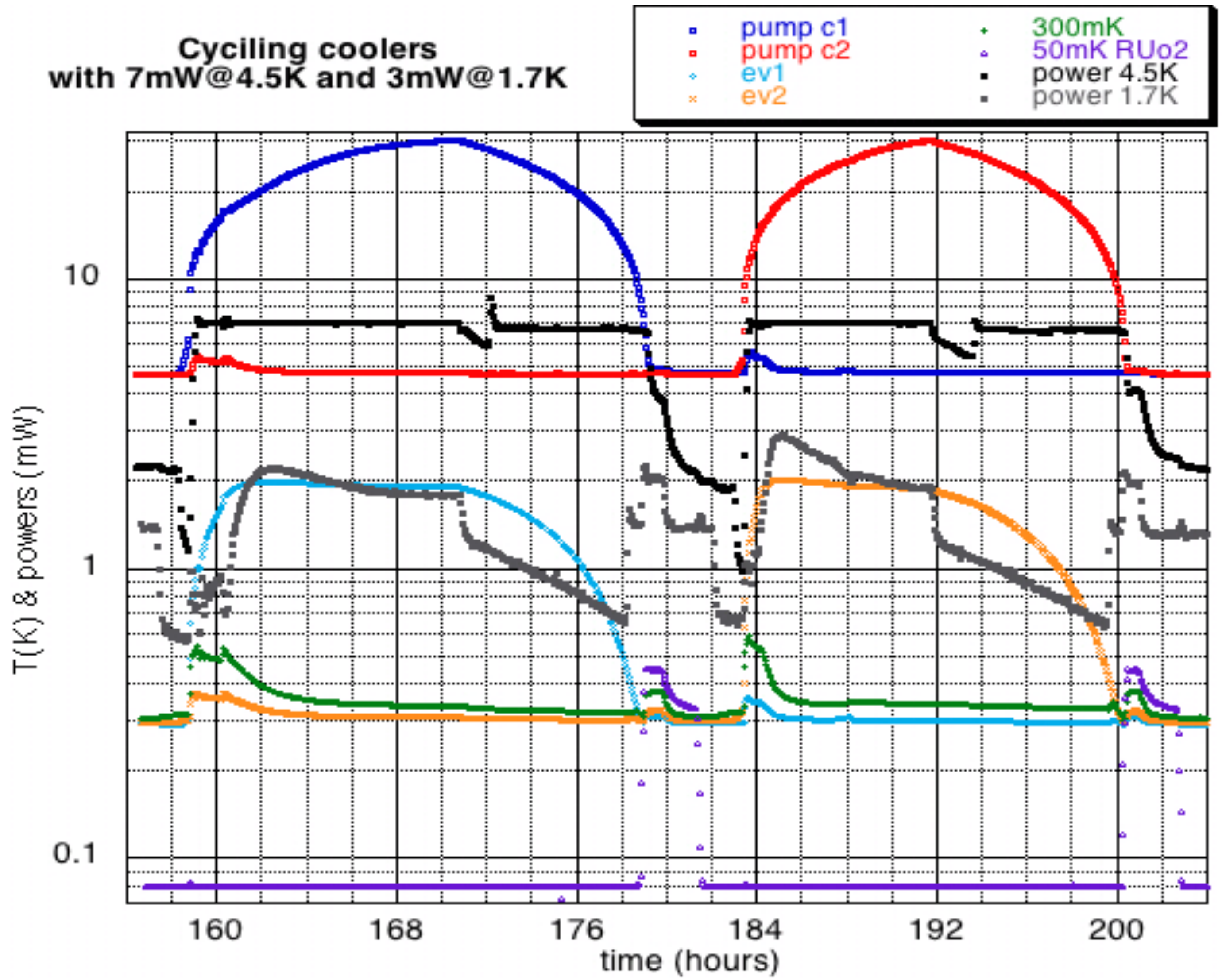


BLISS THERMAL TESTBED

5Kg of Al
Cooled by ADR inside



CONTINUOUS SYSTEM IN OPERATION



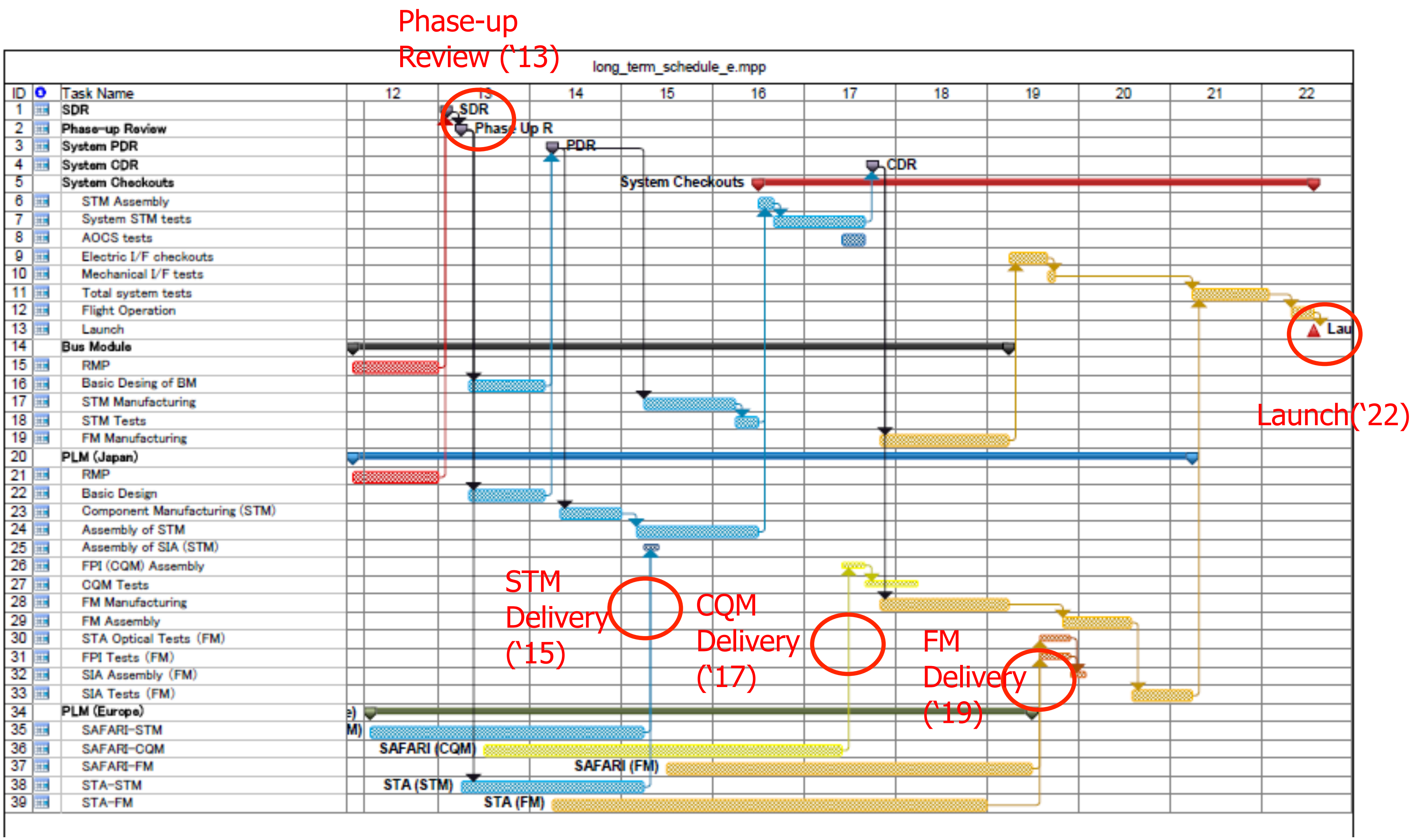
- Regulated stages at 1.7, 4.5 K allow measurement of rejected power
- Can tune to fit SPICA allocations (e.g. 7mW, 3 mW + parasitics)
- 50 mK prototype pill under construction. Likely CCA.

Thomas Prouve (JPL)

SPICA PROJECT STATUS

- JAPAN (JAXA)
  - Pre-project phase started in 2008, SRR in 2010.
  - 2012: JAXA/HQ has approved that SPICA goes to the next phase (risk mitigation phase, RMP)
  - RMP approximately similar to Phase B1
  - Planning SDR and Phase-up Review in 2013
- ESA
  - Assessment Study under ESA Cosmic Vision, RMP participation approved
- SAFARI Consortium (PI: SRON)
  - SRON has funding ! (90% of that required)
  - Dedicated team has been working actively on detector development and detailed instrument design.
- Korea Status (PI KASI)
  - Official Study Team formed with KASI as PI
- Taiwan (PI: ASIAA)
  - Concrete collaboration started.
- US
  - Strong recommendation in the Astro2010 Decadal Survey in 2010.
  - NASA has funded instrument concept studies.
  - Explorer MoO opportunity under study now, but doesn’t fund BLISS

SPICA MASTER SCHEDULE



INTERNATIONAL SPICA TEAM

17 countries and one international org.


SPICA
Space Infrared Telescope for Cosmology and Astrophysics
Space Odyssey

Thank you!

More information: `http://www.submm.caltech.edu/BLISS/`