ORIGINS Space Telescope

From the first stars to life

National Aeronautics and Space Administration

JPL Jet Propulsion Laboratory California Institute of Technology

NASA

Mid-Resolution Survey Spectrometer for OST

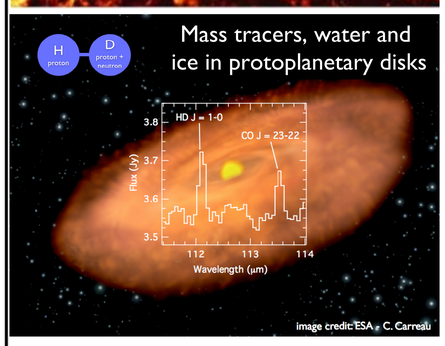
A workhorse far-IR spectrograph powering new discoveries with OST.

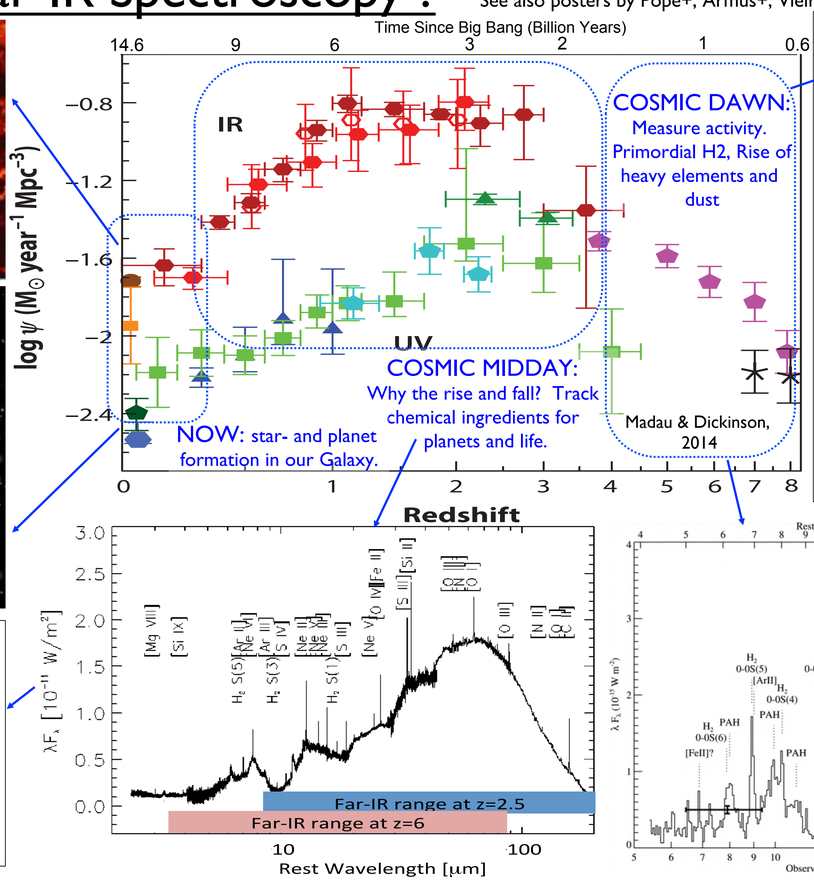
Matt Bradford + MRSS team for the OST

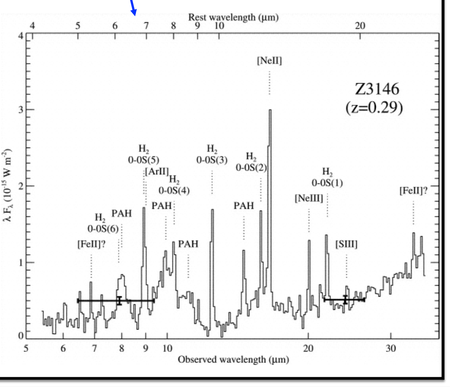
Why Sensitive Far-IR Spectroscopy ?

See also posters by Pope+, Armus+, Vieira+, Wright+, Pontoppidan+

Wide-field, full-band surveys of interstellar coolants in the Milky Way and nearby galaxies







- Strong H2 emitters found in the local-Universe may be analogs of early-Universe shocks produced in galaxy formation and AGN feedback.
- As they arise, PAH features become important ISM coolants. With their large equivalent widths and unambiguous template for redshift identification, they may offer the best probe of heavy metal abundance at early times. While not accessible to JWST or ALMA, OST can detect the PAH emission from galaxies systems at z~6, as they come to be.

- Provides redshifts -- **3-D view of the far-IR Universe**
- **Expect spectra of ~billions of galaxies in blind surveys**
- Measures cooling of the ionized, neutral atomic, and molecular gas, the primary ISM cooling channels.
- N/O ratio a measure of metallicity and stellar processing history.
- Reveals UV field intensity and hardness – constrains ionizing source: accretion or massive stars. (e.g. [OIV] / [OIII], Ne sequence)

MRSS Detector Approach

- Sensitive far-IR detectors are unique to astrophysics, and must be developed by the scientists.
- Need both excellent single-pixel sensitivity,
- And a readout which permits hundreds of thousands of pixels.

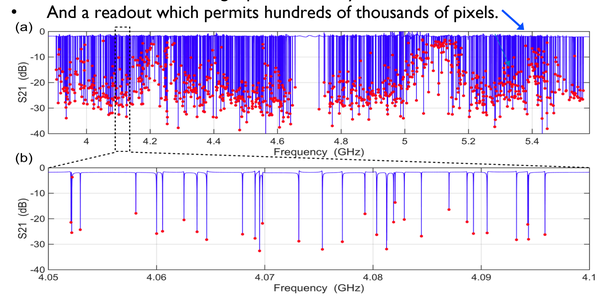
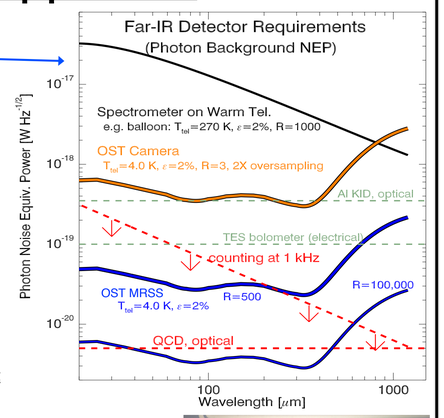


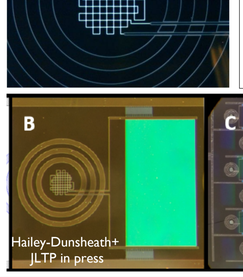
Fig. 3. (a) Frequency sweep of the array, with each dip corresponding to a different MKID pixel. (b) Zoom of a section of panel (a), showing the relative bandwidth of the resonators and the scatter in frequency of the resonators, mainly due to thickness variations in the NbTiN.

Baselmans et al. 2016, frequency MUXing of kinetic inductance detectors.



- Readout using high-Q superconducting resonators enables the large formats.
- MRSS uses 100 MHz to 1 GHz readout band to carry 1500 pixels per circuit: 132 circuits for 200,000 total pixels.

Superconducting Detectors: Photons Break Cooper Pairs

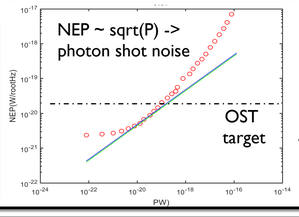


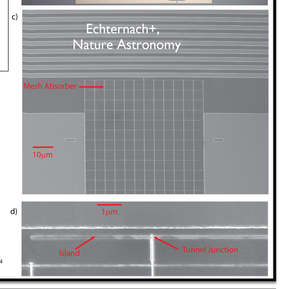
Example 1: Small volume kinetic-inductance detectors (KIDs)

- Inductor/meander is 0.4 μm wide aluminum. 3um total volume.
- 0.5 μm gap at each intersection provides a capacitive short.
- Shows high-yield, 3e-18 W/sqrt(Hz)
- Improvements coming with higher-quality aluminum film.

Example 2: Quantum Capacitance Detectors (QCDs)

- Also patterned aluminum film on silicon.
- Sensitive to single electrons tunneling.
- **Has demonstrated OST sensitivity requirements and 200 micron photon counting.**
- Yield low, work required to mature for OST.

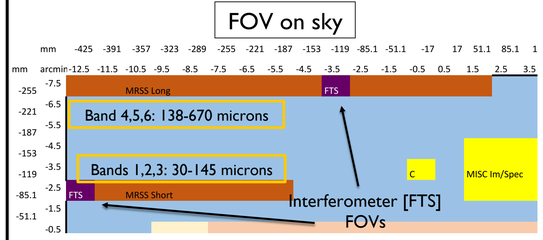




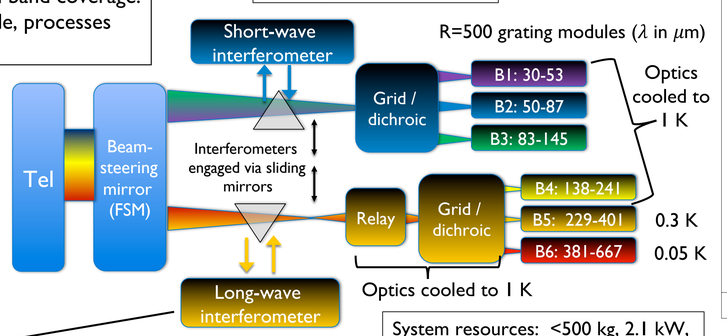
MRSS Approach

- Two long-slit fields on the sky: short wave and long wave.
- Each with 3 wideband grating modules, combine for full band coverage.
- Interferometer engaged when desired for high-res mode, processes light with FTS, feeds to same grating backend.

FOV on sky



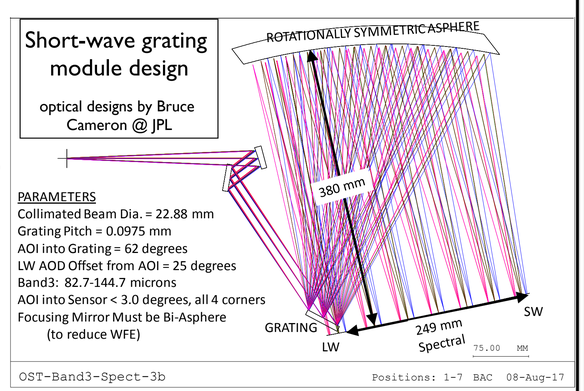
Optical schematic



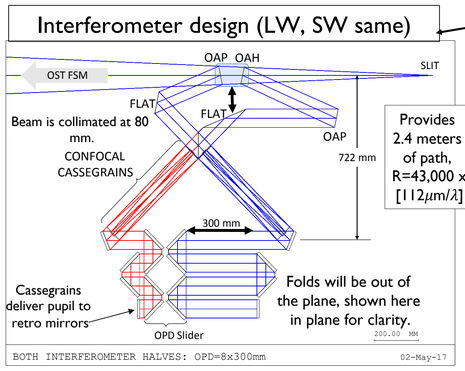
System resources: <500 kg, 2.1 kW, de-scopes available.

Short-wave grating module design

optical designs by Bruce Cameron @ JPL

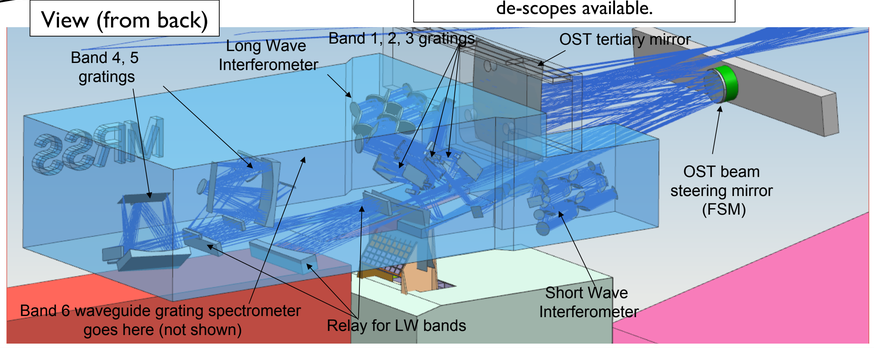


Interferometer design (LW, SW same)

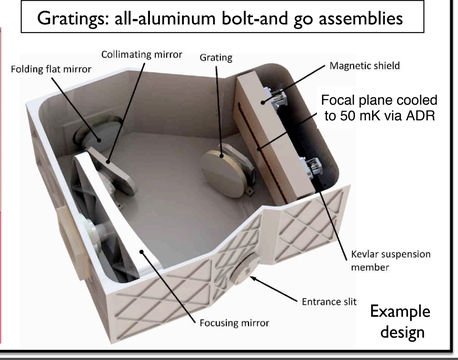


Provides 2.4 meters of path, R=43,000 x [112μm/λ]

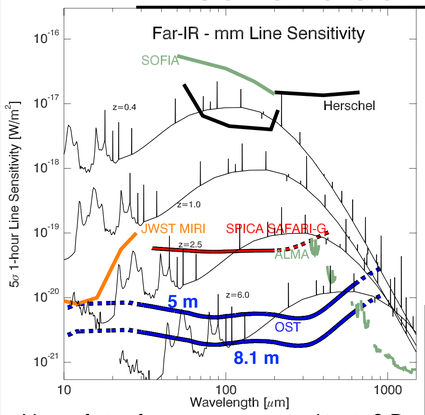
View (from back)

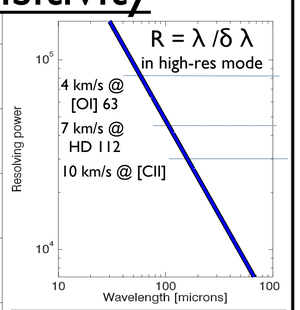


Gratings: all-aluminum bolt-and go assemblies



Excellent Sensitivity





Protoplanetary disk mass sensitivity via HD, OI:

(5σ, 1h, at d= 700 pc, using high-res mode, assume 8m OST)

0.2 $M_{Jupiter}$ in HD J=1-0

0.001 $M_{Jupiter}$ in [OI] 63

No confusion for spectroscopy, working in 3-D.

Parameter	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Scaling w/ D_{tel}
λ [μm]	30–53	50–87	83–145	138–241	229–401	380–667	
Beam size	1.15	1.9	3.2	5.2	8.7	14.4	$\propto D^{-1}$
# beams in slit (approx)	270	166	100	100	100	64	
Instantaneous FOV [sq deg]	3.7e-05	6.2e-05	1.03e-4	2.4e-4	0.0006.6e-4	1.16e-3	$\propto D^{-2}$
Per-beam sensitivities — includes penalty for chopping (w/ OST FSM)							
Point source line sens [W m^{-2}], 5σ, 1h	2.6e-21	2.1e-21	2.0e-21	2.1e-21	1.8e-21	3.9e-21	$\propto D^{-2}$
Line surf bright sens [W m^{-2} sr^{-1}], 5σ, 1h	8.4e-11	2.4e-11	8.6e-12	3.3e-12	1.0e-12	8.1e-13	$\propto D^{0}$
Point source R=4 cont. sens [μJy, 5σ, 1h]	1.5	2.0	3.3	5.7	8.3	29.	$\propto D^{-2}$
Point source mapping speeds — here perfect background subtraction is assumed							
Map. spd [deg^2/(10^{-19}W m^{-2})^2/sec]	6.2e-05	1.7e-4	2.9e-4	6.0e-4	2.2e-3	8.4e-4	$\propto D^{2}$
Map. spd [deg^2/[μJy]^2/sec]	4.5e-08	2.7e-08	1.0e-08	3.3e-09	1.6e-09	1.3e-10	$\propto D^{2}$
Pt. sce map depth in a given field, given time	see example tables below						$\propto D^{-1}$
Intensity mapping sensitivity (noise. equiv. intensity / sqrt(N_{beams})							
NEI /$\sqrt{N_{modes}}$ [MJy/sr/$\sqrt{sec}$], 1σ	0.19	0.11	0.087	0.060	0.031	0.05	$\propto D^{0}$

Numbers are for a 8.14-meter telescope, they can be scaled per the last column, under the assumption that the number of pixels (the optical AΩ or étendu) is fixed. Notes: Sensitivities assume single-polarization instruments with a product of cold transmission and detector efficiency of 0.25, and an aperture efficiency of 0.75. (Each beam has θ_{FWHM} of 1.13λ/D, appropriate for an assumed 10dB edge taper, and a solid angle of $\frac{\pi}{4\ln 2}\theta^2_{FWHM}$.)

The **Origins Space Telescope** is the mission concept for the **Far Infrared Surveyor**, a study in development by NASA in preparation for the *2020 Astronomy and Astrophysics Decadal Survey*.

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http://origins.ipac.caltech.edu/

Secret OST Word: Sensitivity