Development of new-generation transfer-standard pyroelectric radiometers for monochromator use

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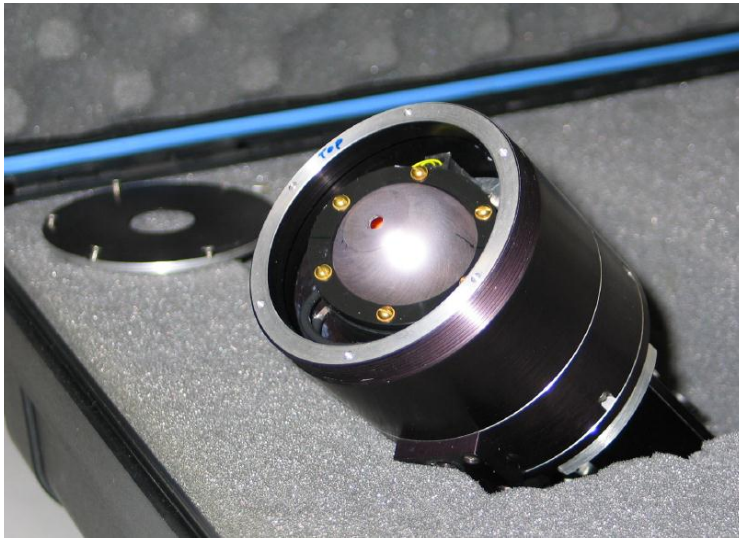
Introduction

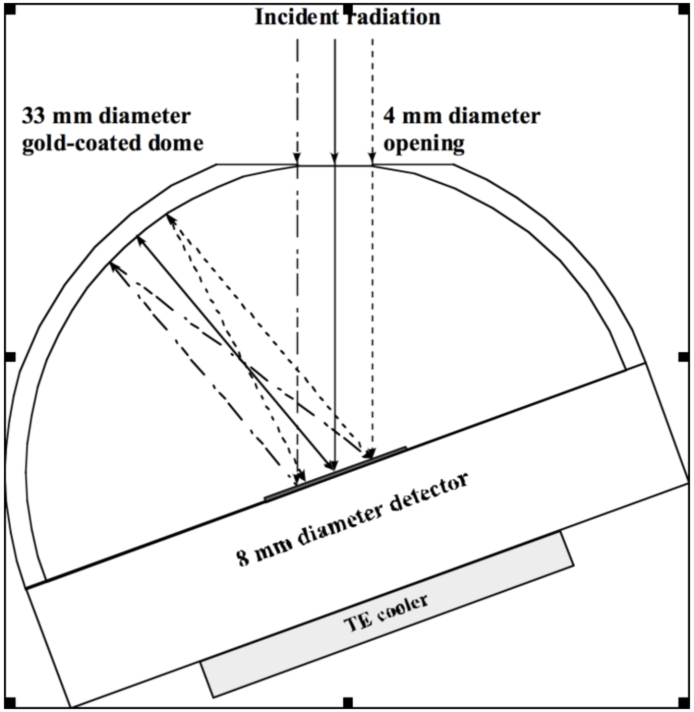
- There are no room-temperature detectors available with low enough NEP to measure less than 1 μW power levels in the IR.
- Radiometers with NEP close to 1 nW/Hz$^{1/2}$ are needed for spectral responsivity scale extension with monochromators.
- Monochromators can perform routine (fast) spectral responsivity measurements in the IR only with low-NEP detectors.
- The NIST cryogenic radiometer and IR-SIRCUS calibrations are too slow and very expensive to cover the IR range.

Previously developed pyroelectric detectors

- The earlier developed pyroelectric transfer standard detectors have too high NEPs for monochromator use.
- The previously developed trap-pyro using $LiNbO_3$ crystal has NEP=80 nW (τ=2 s). Advantage to keep: It can accept f/4 beam to match the input geometry to the monochromator. Because of multiple reflections between detector and dome, most of the incident radiation is absorbed by the detector-coating. The high absorption makes it possible to smooth out the structures from the spectral responsivity curve.
- The previous pyros need laser sources to obtain high signal-to-noise ratios.

Previous generation $LiNbO_3$ trap-pyro





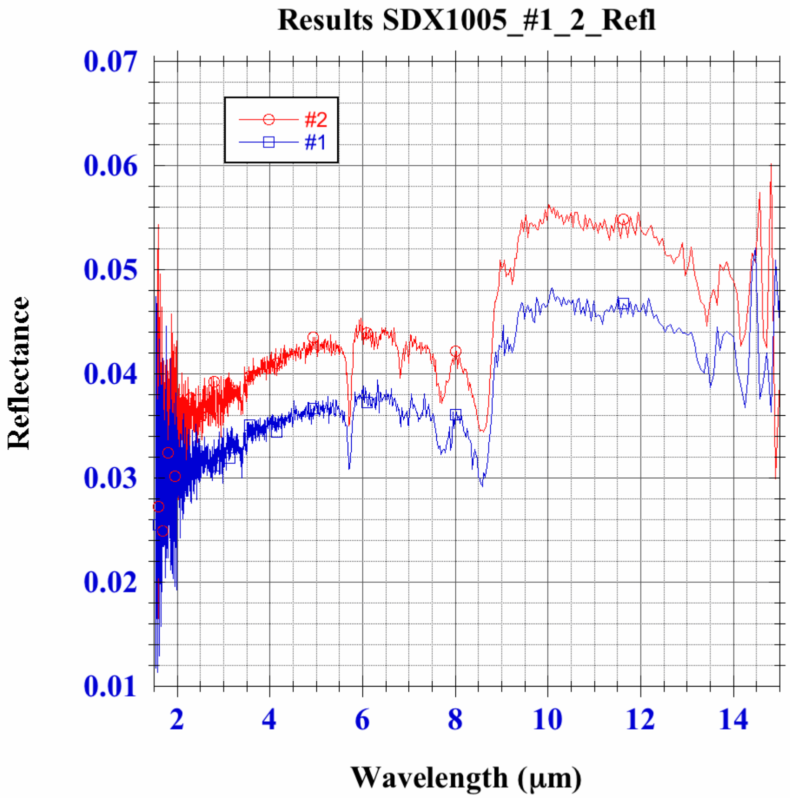
Low-NEP pyroelectric radiometer developments (Goal of the project)

- Develop temperature stabilized pyroelectric radiometers (with improved geometry and characteristics) that can extend the NIST spectral responsivity scale to the IR (to 25 µm)
- They are more user friendly than the earlier developed cryogenic bolometers
  - The relative spectral responsivity can be determined for the IR using the NIST FT spectrometer
- They can be used as transfer and working standards with monochromators:
  - with large and spatially uniform area,
  - decreased NEP (increased responsivity and decreased noise-amplification)
  - high and constant signal-gain versus frequency
  - with multiple input reflections (using dome-traps)
- Target uncertainty: 1 % (*k*=1) to 18 µm and 2.5 % (*k*=1) to 25 µm

Reducing NEP of pyroelectric radiometers

- Develop custom-made pyroelectric radiometers
- Chose 3 to 5 mm diameter detectors
- Apply frequency-compensation with the black-coating
- Decrease the feedback stray capacitance to 0.2 pF
- Increase the feedback resistor to 10 GΩ
- Decrease the crystal thickness to increase responsivity
- Select the best (lowest NEP) detectors
- Decrease noise amplification using small detectors with low detector-capacitance
- Decrease electrical bandwidth

5 mm single-element low-NEP hybrid pyroelectric radiometer with temperature-control



<u>Hybrid:</u> the detector crystal and the pre-amplifier are in the same can. (fabrication by Gentec E.O. USA)

The structures of the FT measured spectral reflectance curve is caused by the organic-black coating!

Responsivity increase of single-element pyros with decreased thickness of crystal ($LiTaO_3$)

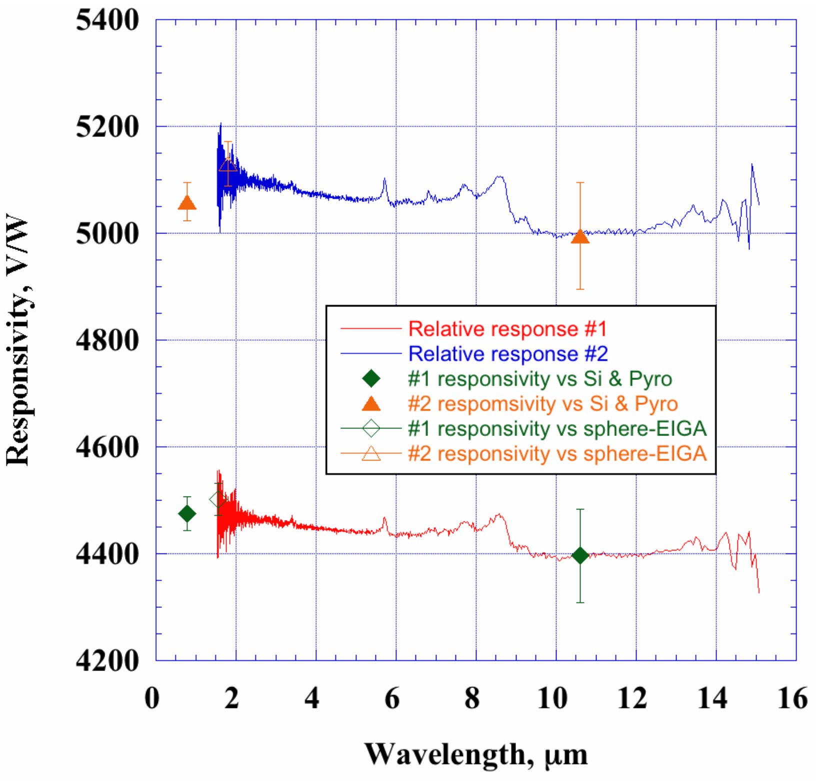
Hybrid detector #	Coating	Size mm dia.	Thickness (µm)	3 dB rolloff (Hz)	Responsivity (V/W)
2	OB	5	100	100	5059 (785 nm)
3	OB	5	50	109	16985 (1.32 µm)
5	OB	3	50	60	16352 (1.32 µm)
6	OB	3	25	128	35879 (1.32 µm)

OB: Organic Black

The NEP has decreased to ~1 $nW/Hz^{1/2}$

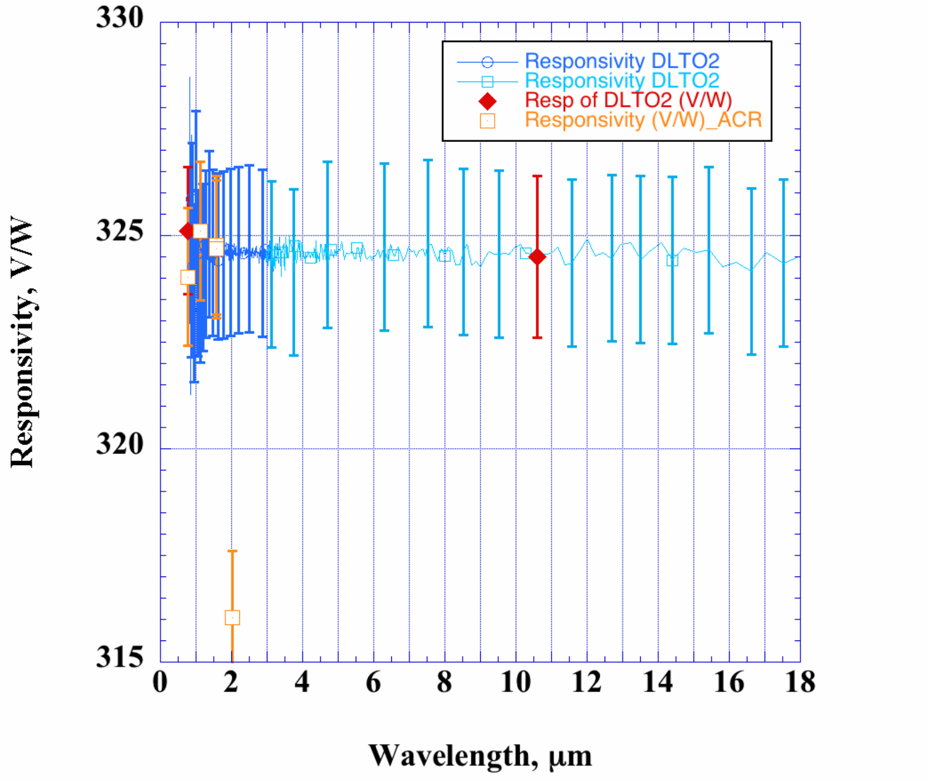
Spectral responsivity of previously developed dome-input and newly developed single-element pyroelectric radiometers

Single-element low-NEP pyros:



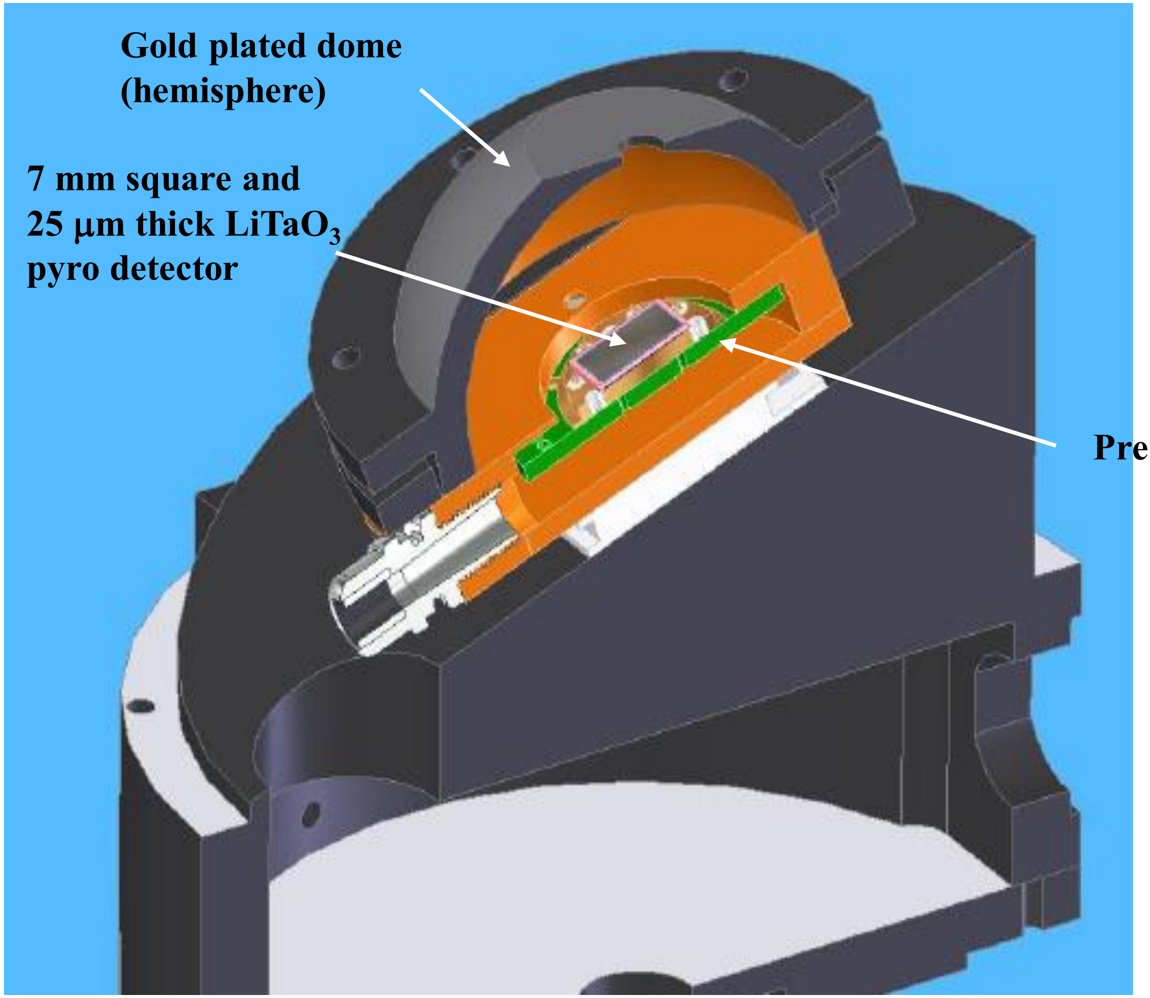
2 % structure (jump) at ~9 µm

Previously developed (high-NEP) dome-pyro:



The dome minimizes the structures!

Design of the low-NEP dome-input pyroelectric trap-detector



Gold plated dome (hemisphere)

7 mm square and 25 µm thick $LiTaO_3$ pyro detector

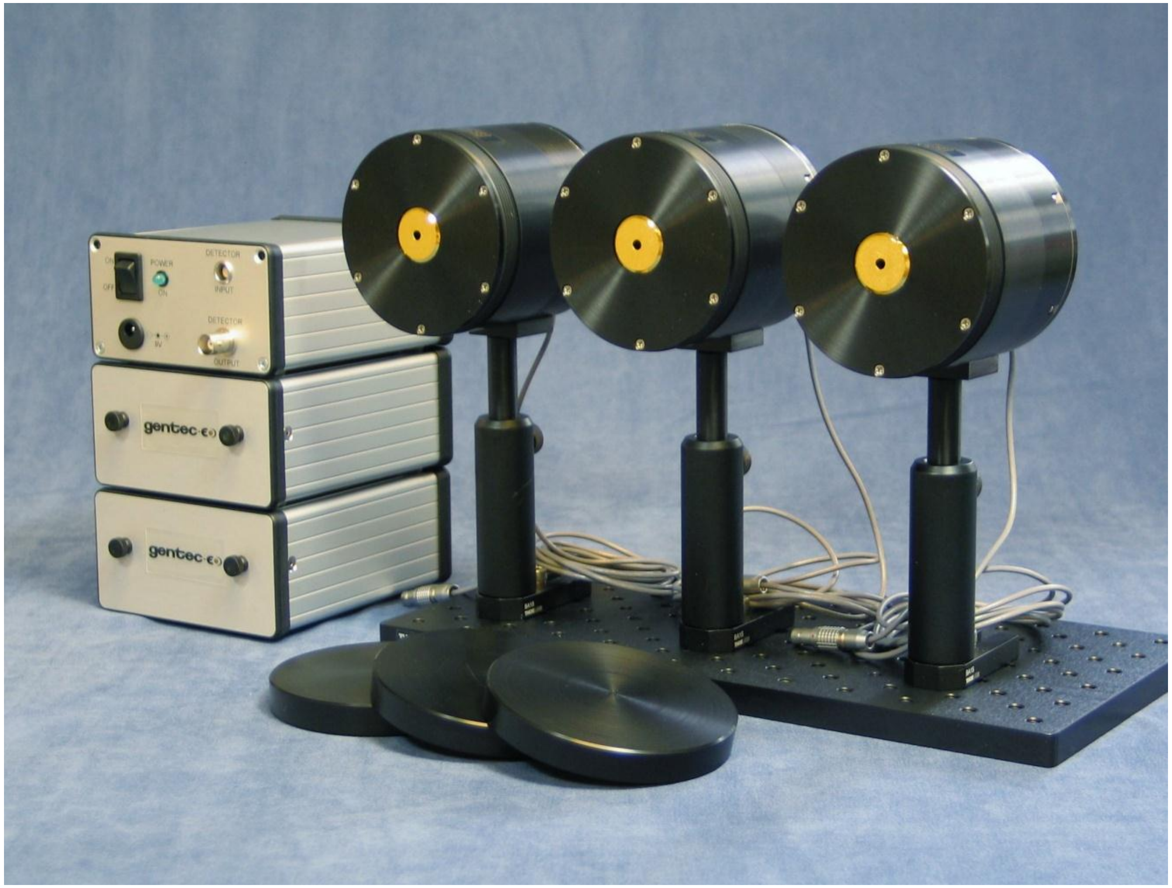
Preamplifier PCB

Reflecting domes

Gold-plated PYREX hemi-sphere (previously used)

Gold-plated metal hemi-sphere (used recently)

A group of low-NEP dome-input pyroelectric radiometers

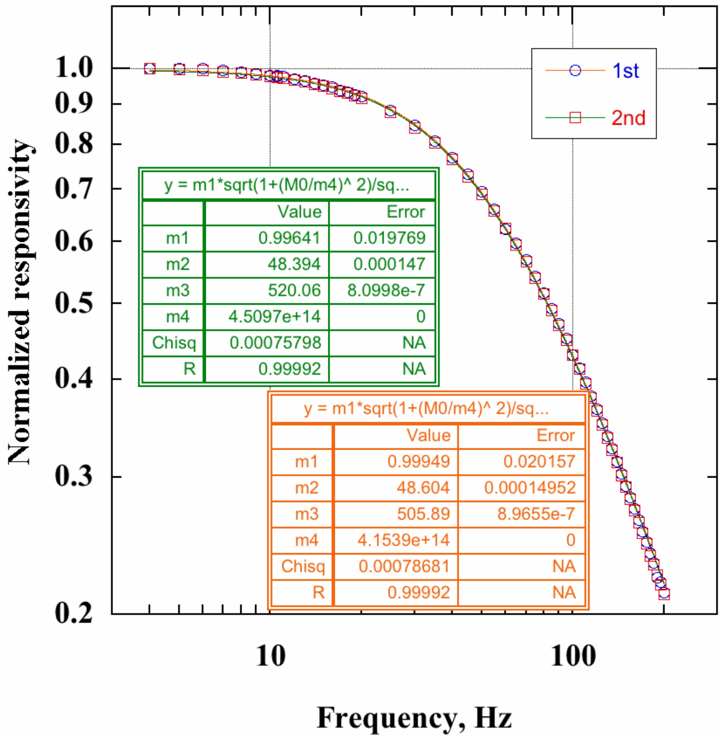


The NEP of the prototype is ~8 nW (τ=1s)

Reason of NEP increase: The large capacitance of the thinner and larger crystal increased the noise amplification.

Frequency dependent responses of low-NEP prototype-dome and single-element pyros

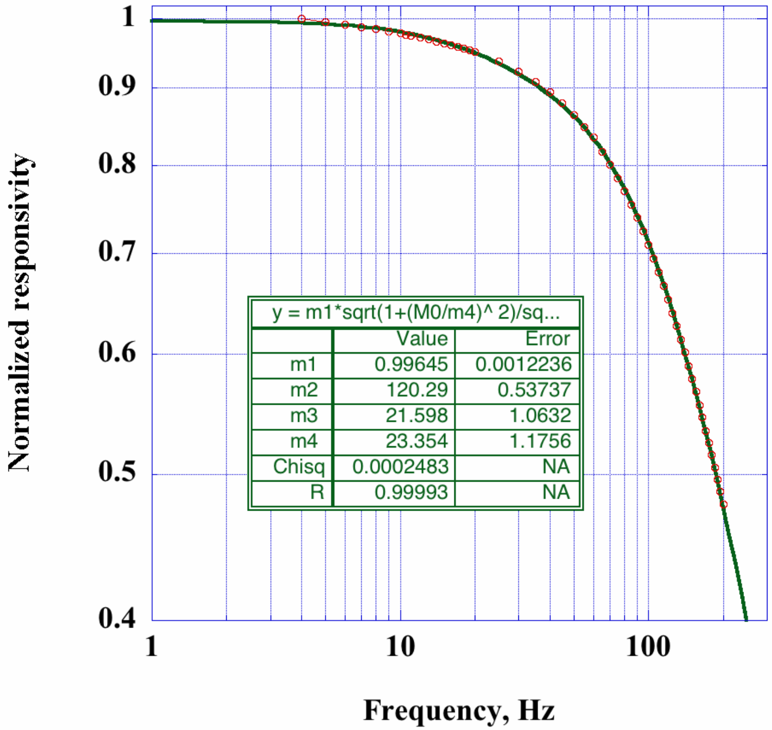
Improved dome-trap pyro prototype



y = m1*sqrt(1+(M0/m4)^ 2)/sq...		
	Value	Error
m1	0.99641	0.019769
m2	48.394	0.000147
m3	520.06	8.0998e-7
m4	4.5097e+14	0
Chisq	0.00075798	NA
R	0.99992	NA

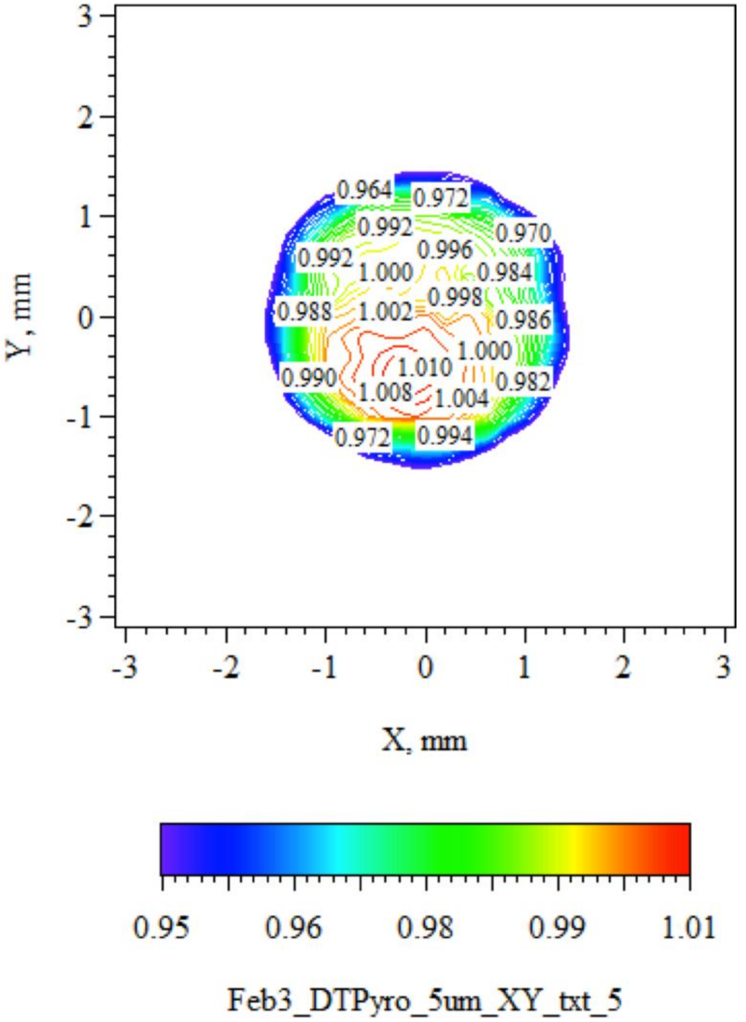
y = m1*sqrt(1+(M0/m4)^ 2)/sq...		
	Value	Error
m1	0.99949	0.020157
m2	48.604	0.00014952
m3	505.89	8.9655e-7
m4	4.1539e+14	0
Chisq	0.00078681	NA
R	0.99992	NA

Single-element hybrid pyro



y = m1*sqrt(1+(M0/m4)^ 2)/sq...		
	Value	Error
m1	0.99645	0.0012236
m2	120.29	0.53737
m3	21.598	1.0632
m4	23.354	1.1756
Chisq	0.0002483	NA
R	0.99993	NA

Spatial non-uniformity of prototype dome-trap pyroelectric radiometer at 5 µm

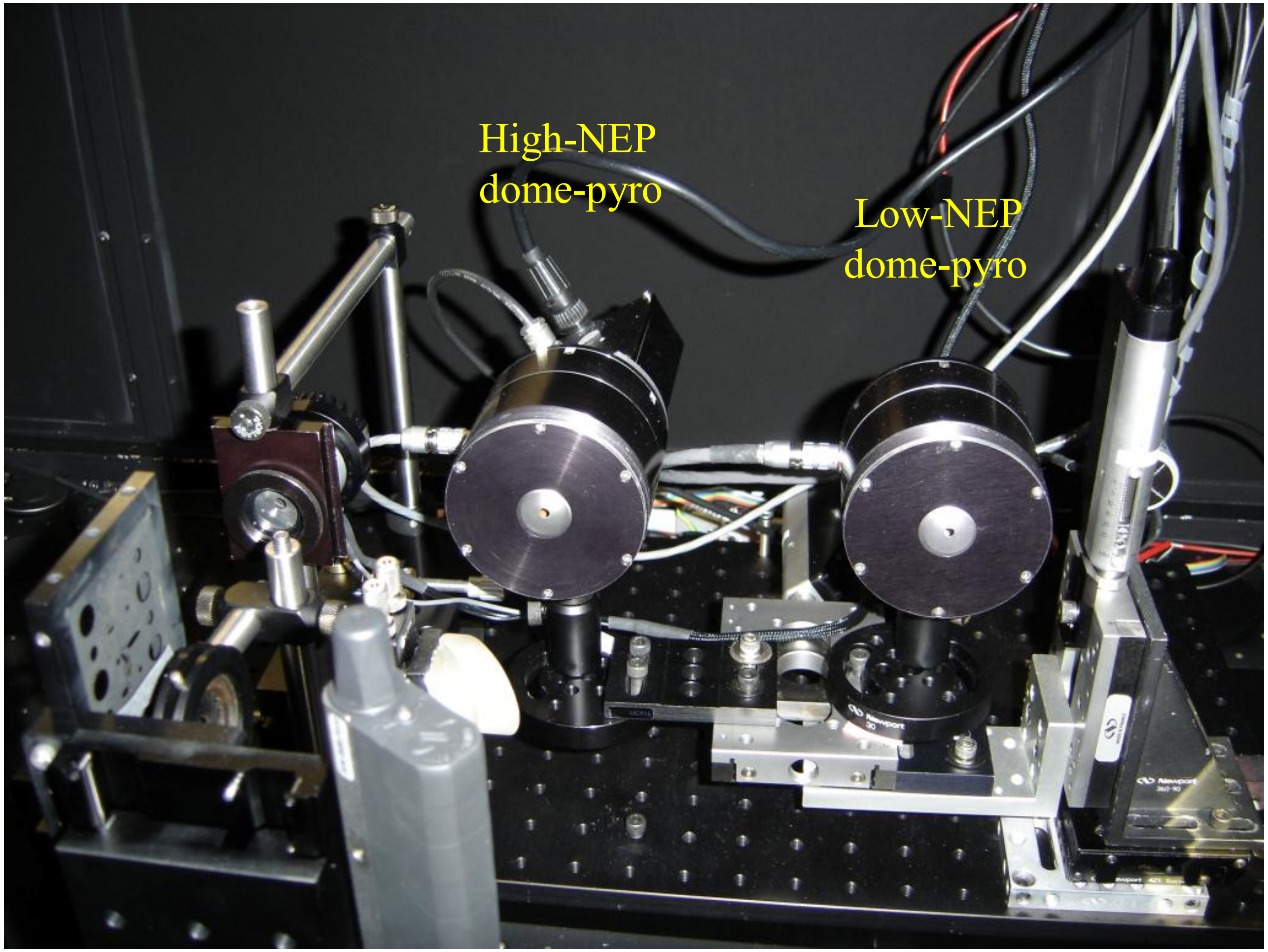


Test results of 3 pyroelectric transfer standards

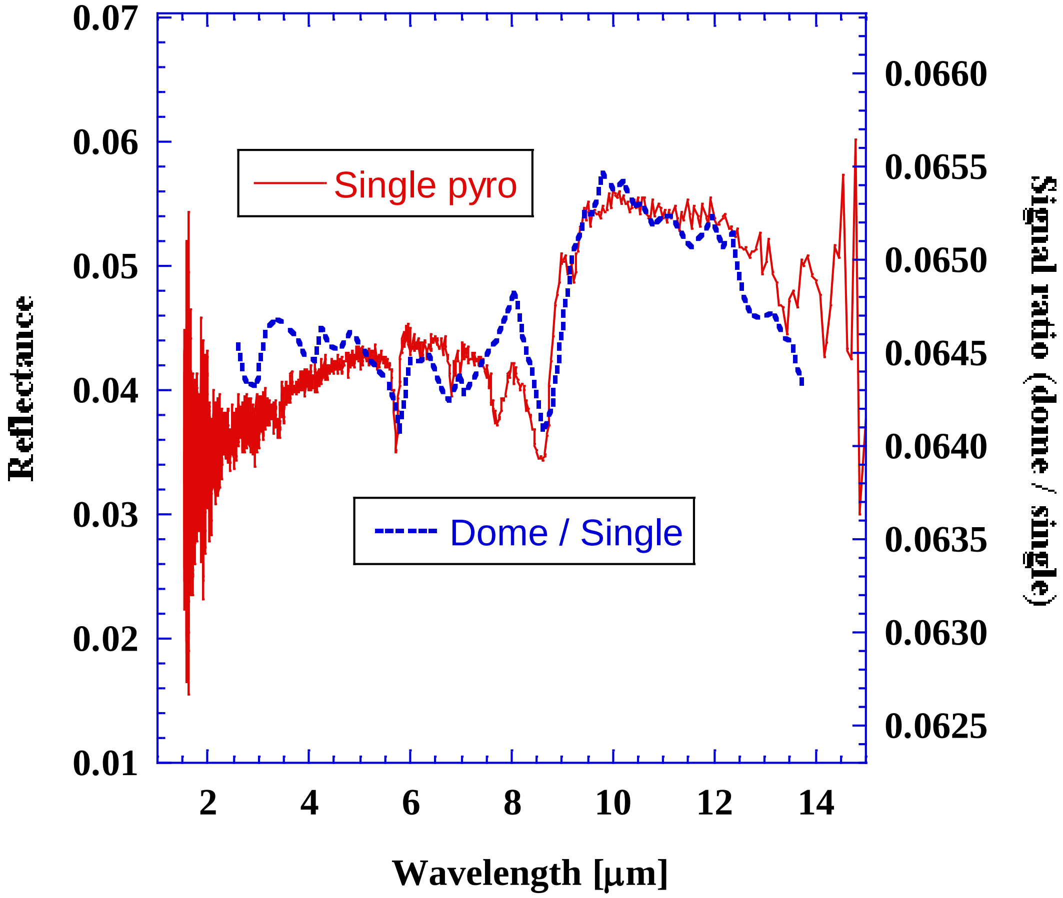
Comparison of the main characteristics

	Low-NEP dome-trap prototype	**High-NEP (previously made) dome-trap**	**Single-element (hybrid) detector**
Freq 3 dB roll-off [Hz]	49	75	120
NEP [nW/shown bandwidth]	8 ($\tau = 1$ s)	76 ($\tau = 2$ s)	2 ($\tau = 1$ s)
Resp @ 785 nm [V/W]	1.43×10^4	325.1	5.06×10^3
Resp @ 4.97 µm [V/W]	1.45×10^4	324.6	5.07×10^3
Resp @ 10.6 µm [V/W]	1.47×10^4	324.5	5.00×10^3
Fixed feedback resistor of amplifier	10 GΩ	1 GΩ	10 GΩ

Example for spectral comparison of dome pyros at the Circular-Variable-Filter Spectrometer

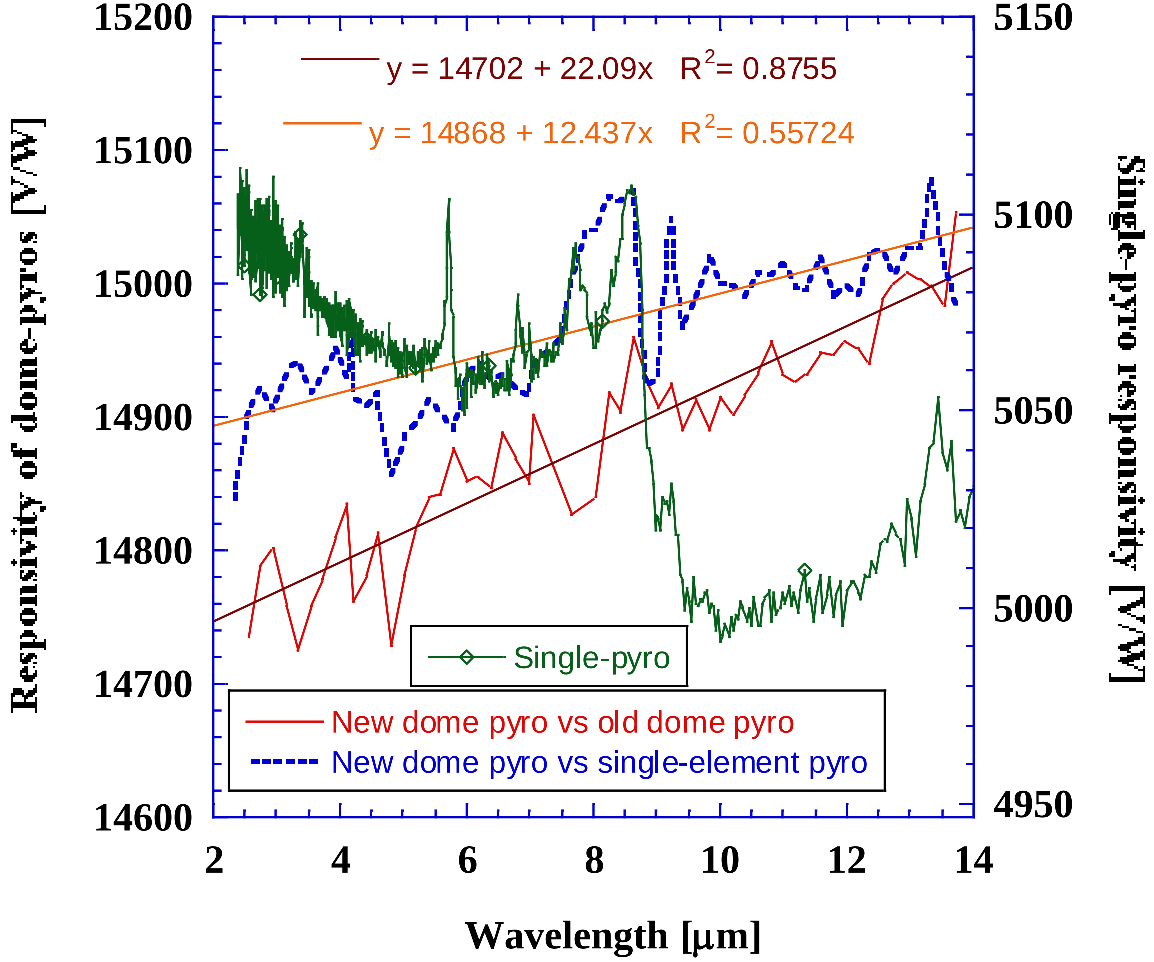


Single-element pyro reflectance (from FT Spectrometer) and signal-ratio of dome-pyro-prototype to single-element pyro (using FT)



The good agreement of the two curve shapes demonstrates the good spectral uniformity of the dome-pyro prototype.

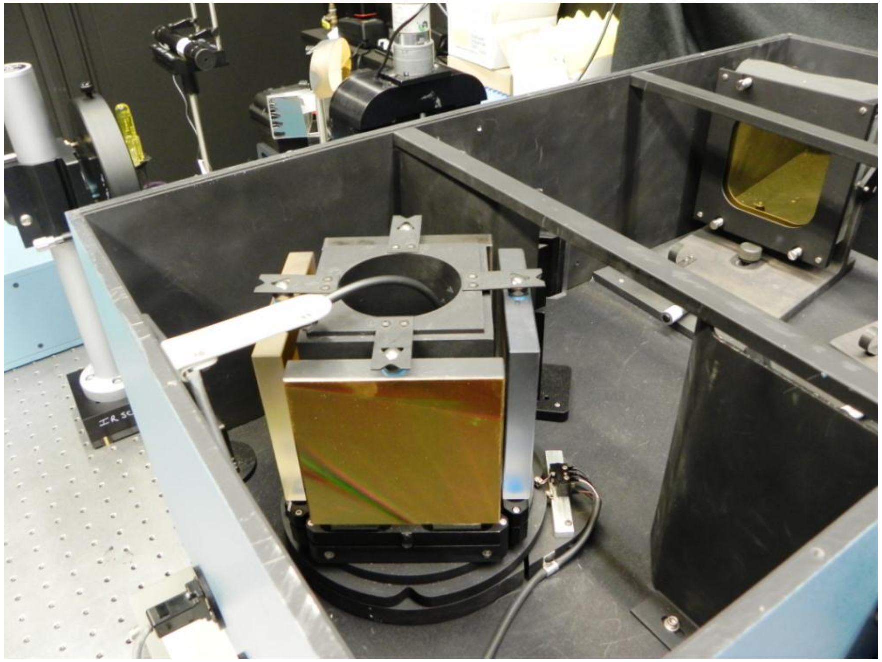
Spectral responsivity of the low-NEP dome-pyro (prototype) when calibrated against the high-NEP (previously made) dome-pyro and the single-element pyro

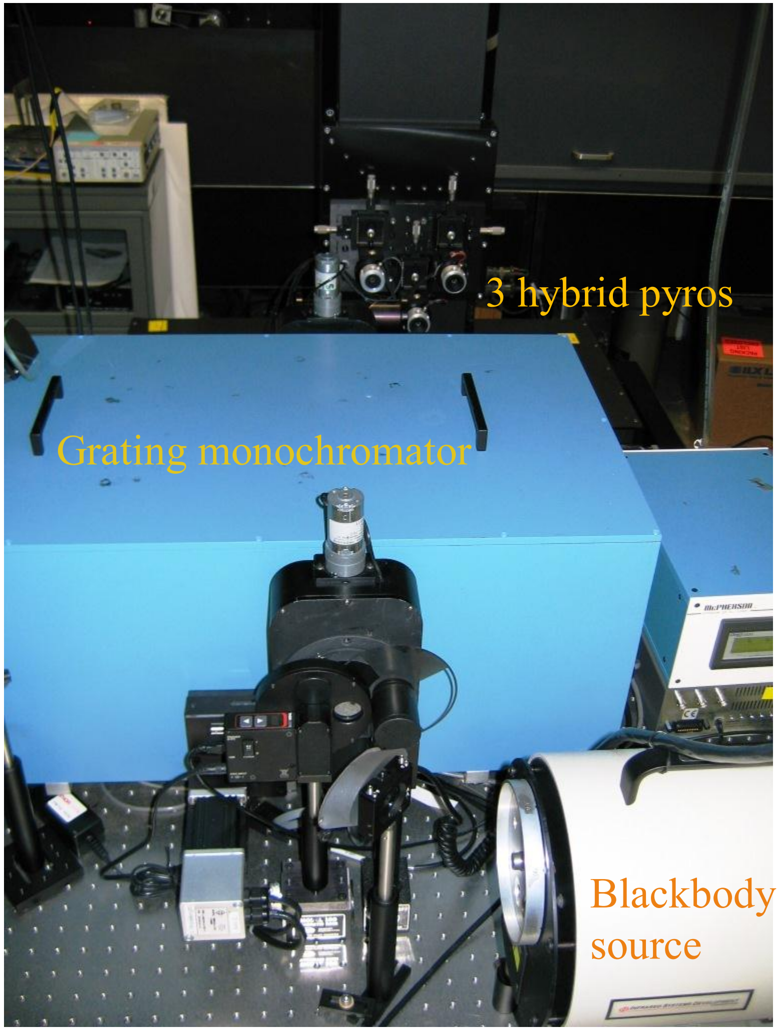


The 2 % spectral structure in the responsivity of the single-element detector cannot be seen in the dome-pyro responsivity curves. The difference between the responsivity from the two different calibrations is about 0.5 % at the short wavelength-end (caused by the difference in the input geometries between the domed and single-element inputs at calibrations).

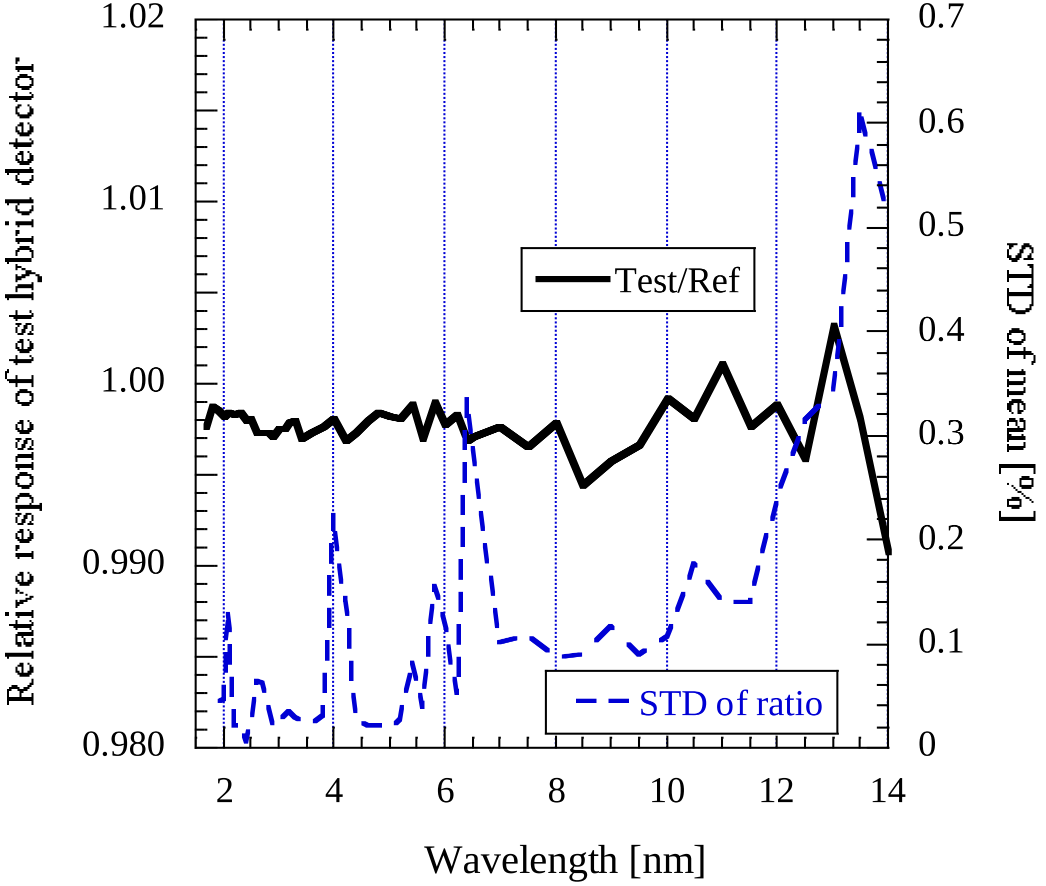
Increase of monochromator throughput for the IR

Switching monochromators from f/8 to f/4
resulted in a 10 x increase in the throughput





f/4 monochromator-based relative spectral response calibration of a low-NEP single-element pyro against a low-NEP single-element reference-pyro



The low STDs of the ratios show that the signal-to-noise ratios are large enough in the overall spectral range (between 1.5 µm and 14 µm) and spectral responsivities can be continuously determined.

- The standard deviation of the mean was calculated from 16 data points versus wavelength
- The ratio of a 5-mm pyro-hybrid (test detector) to the 5-mm pyro-hybrid reference detector gives the relative response which is to be multiplied by the absolute responsivity of the reference detector to obtain the spectral power responsivity of the test detector.

Conclusions

1. Development of low-NEP pyroelectric single-element radiometers with temperature control has been done.
2. A prototype low-NEP dome-trap pyroelectric-radiometer with temperature-control has been developed. The NEP=8 nW(τ=1s), factor of 14 lower than before.
3. Based on the prototype, a group of low-NEP dome-trap pyroelectric-radiometers have been fabricated.
4. The f/8 monochromator has been replaced with an f/4. Now, the throughput is 10 x higher.
5. The spectral responsivity measurements now can be performed to 14 μm using the 2 nW ($\tau = 1$ s) low-NEP pyros.
6. It has been demonstrated that infrared spectral response measurements can be performed at the output of a regular monochromator with low measurement uncertainty.
7. Future work: finalize the IR responsivity scale to 25 μm.