M-AERIs and ISARs

Peter J Minnett
Rosenstiel School of Marine & Atmospheric Science
University of Miami

fiducial reference
temperature
measurements

ISFRN Workshop, NOCS, February 27 – 28, 2019

NASA

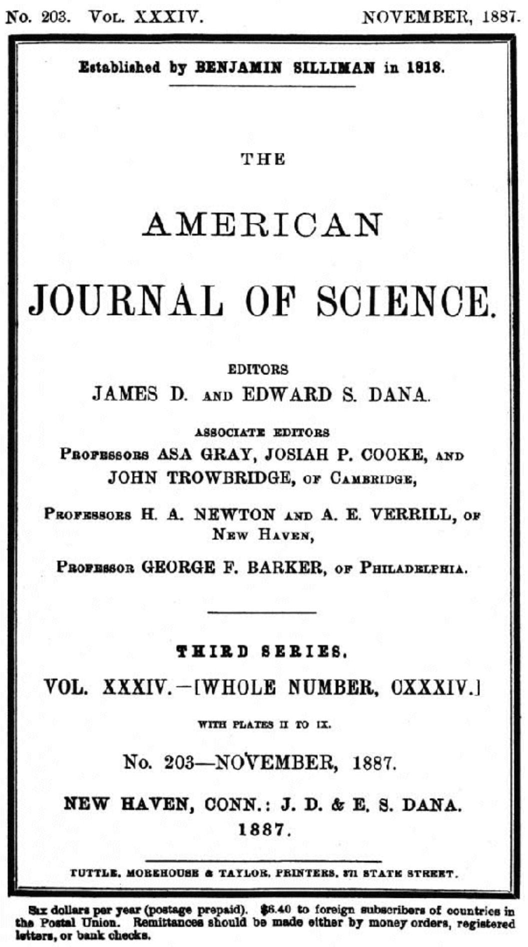
UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE

Outline

- M-AERI – Well calibrated FTIR, now using 3 Mk2s and 1 Mk3.
    - Principle of operation
    - Accuracy
- ISAR – Well calibrated filter radiometer.

Michelson-Morley Fourier-transform interferometer

Michelson-Morley Fourier-transform infrared (FTIR) interferometric spectroradiometer, were first developed in the 1880's to make accurate measurements of the speed of light.



No. 203. Vol. XXXIV. NOVEMBER, 1887.

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITORS
JAMES D. and EDWARD S. DANA.

ASSOCIATE EDITORS
Professors ASA GRAY, JOSIAH P. COOKE, and
JOHN TROWBRIDGE, of Cambridge,

Professors H. A. NEWTON and A. E. VERRILL, of
New Haven,

Professor GEORGE F. BARKER, of Philadelphia.

THIRD SERIES.
VOL. XXXIV.—[WHOLE NUMBER, CXXXIV.]

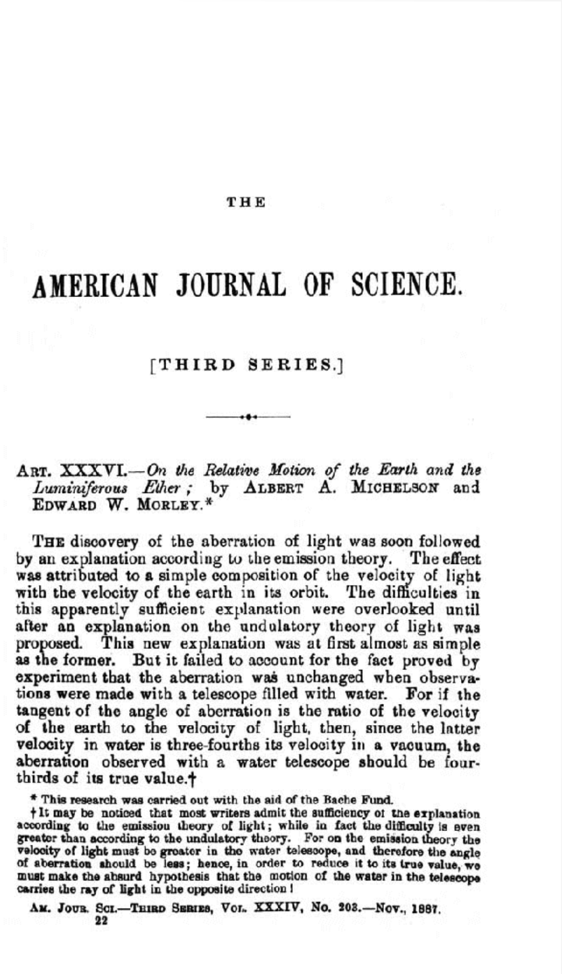
WITH PLATES II TO IX.

No. 203—NOVEMBER, 1887.

NEW HAVEN, CONN.: J. D. & E. S. DANA.
1887.

TUTTLE, MOREHOUSE & TAYLOR, PRINTERS, 371 STATE STREET.

Six dollars per year (postage prepaid). $6.40 to foreign subscribers of countries in the Postal Union. Remittances should be made either by money orders, registered letters, or bank checks.



THE
AMERICAN JOURNAL OF SCIENCE.
[THIRD SERIES.]

Art. XXXVI.—*On the Relative Motion of the Earth and the Luminiferous Ether*; by Albert A. Michelson and Edward W. Morley.*

The discovery of the aberration of light was soon followed by an explanation according to the emission theory. The effect was attributed to a simple composition of the velocity of light with the velocity of the earth in its orbit. The difficulties in this apparently sufficient explanation were overlooked until after an explanation on the undulatory theory of light was proposed. This new explanation was at first almost as simple as the former. But it failed to account for the fact proved by experiment that the aberration was unchanged when observations were made with a telescope filled with water. For if the tangent of the angle of aberration is the ratio of the velocity of the earth to the velocity of light, then, since the latter velocity in water is three-fourths its velocity in a vacuum, the aberration observed with a water telescope should be four-thirds of its true value.†

* This research was carried out with the aid of the Bache Fund.

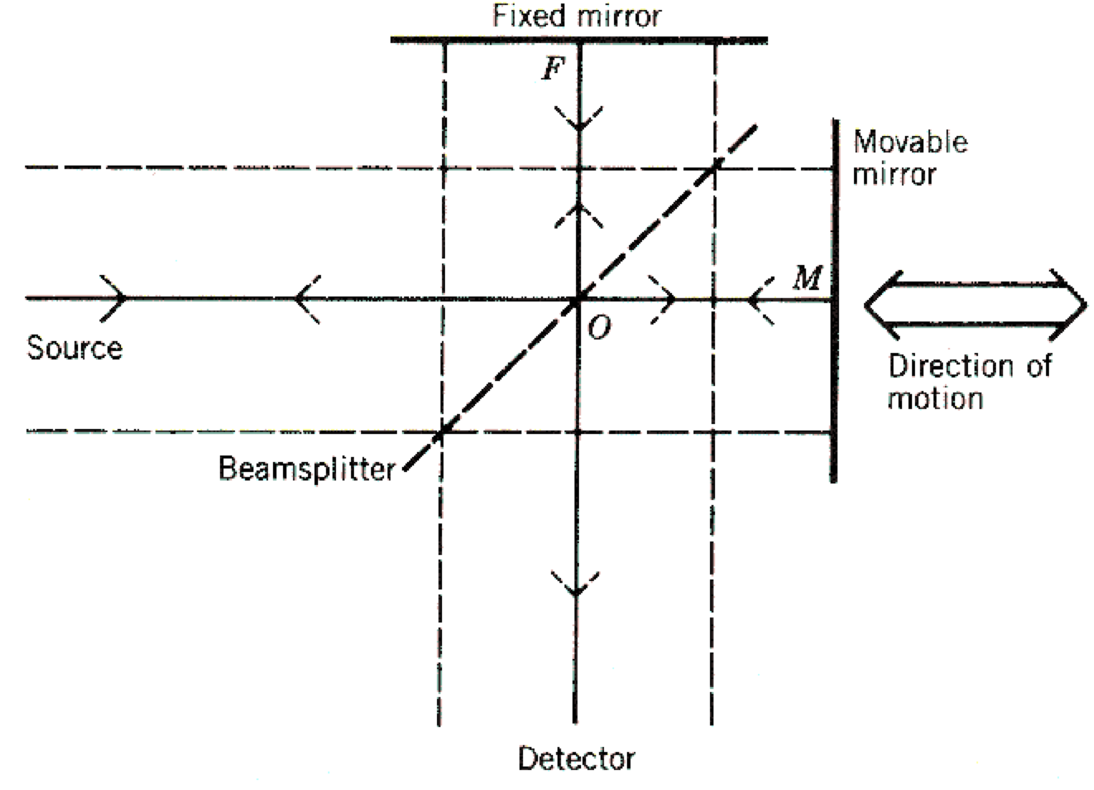
† It may be noticed that most writers admit the sufficiency of the explanation according to the emission theory of light; while in fact the difficulty is even greater than according to the undulatory theory. For on the emission theory the velocity of light must be greater in the water telescope, and therefore the angle of aberration should be less; hence, in order to reduce it to its true value, we must make the absurd hypothesis that the motion of the water in the telescope carries the ray of light in the opposite direction!

Am. Jour. Sci.—Third Series, Vol. XXXIV, No. 203.—Nov., 1887.
22

fiducial reference temperature measurements

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Michelson-Morley interferometer



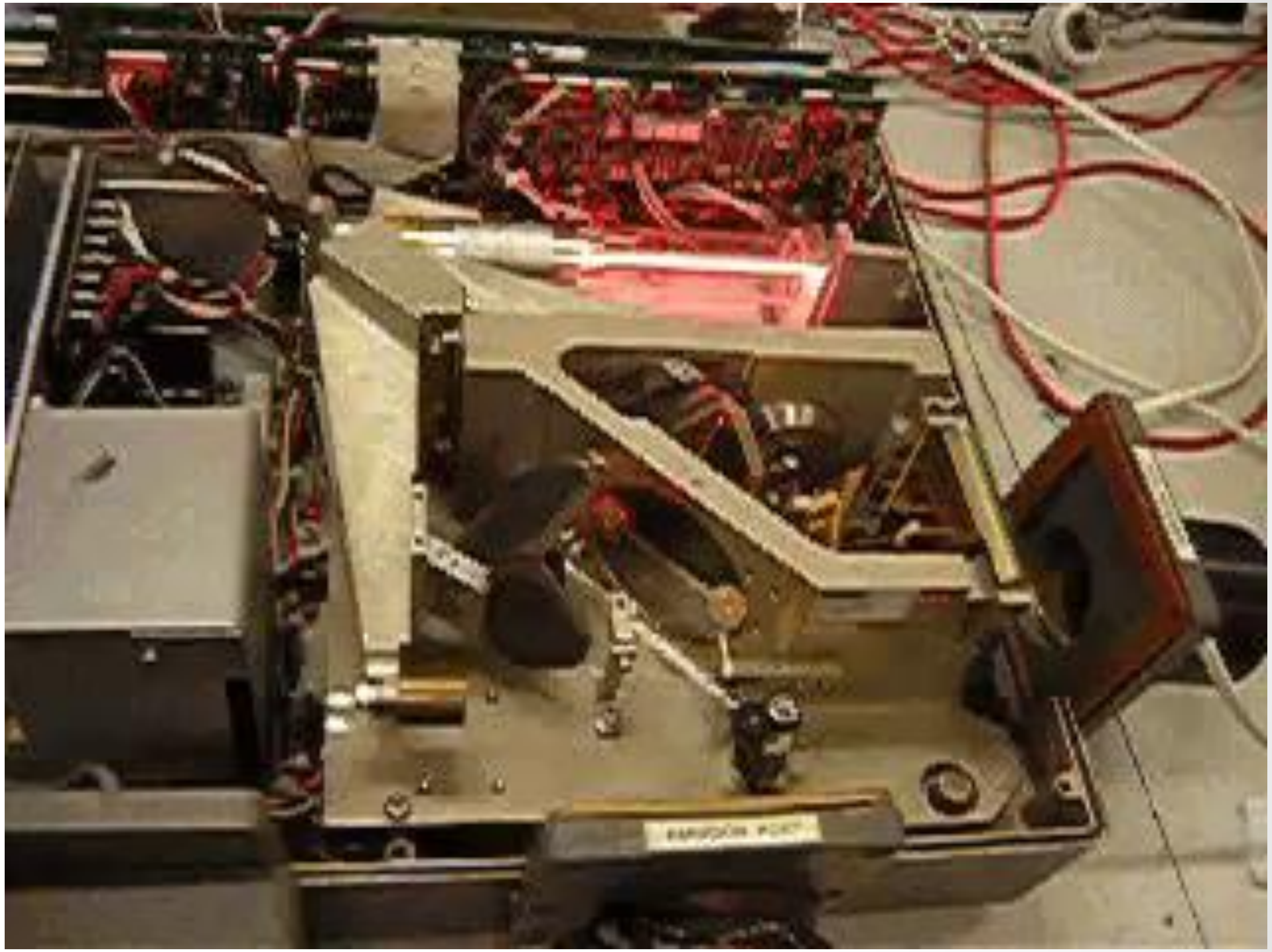
Interference between the beam to the fixed mirror (F) and to the moving mirror (M) depends on the ratio path length difference to the wavelength of the radiation

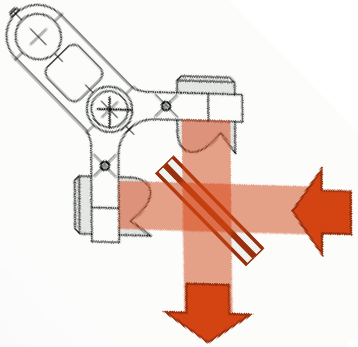
The spectral information in the source radiation is converted to time variation of the interference signal at the detector.

Schematic representation of a Michelson-Morley interferometer. Median ray is shown by the solid line and the extremes of the collimated beam by the broken lines.

Marine –Atmospheric Emitted Radiance Interferometer

- Oscillating yoke provides a robust infrared radiometer for shipboard deployments.
- Visible He-Ne laser used for wavelength calibration.
- Two blackbodies used for radiometric calibration.

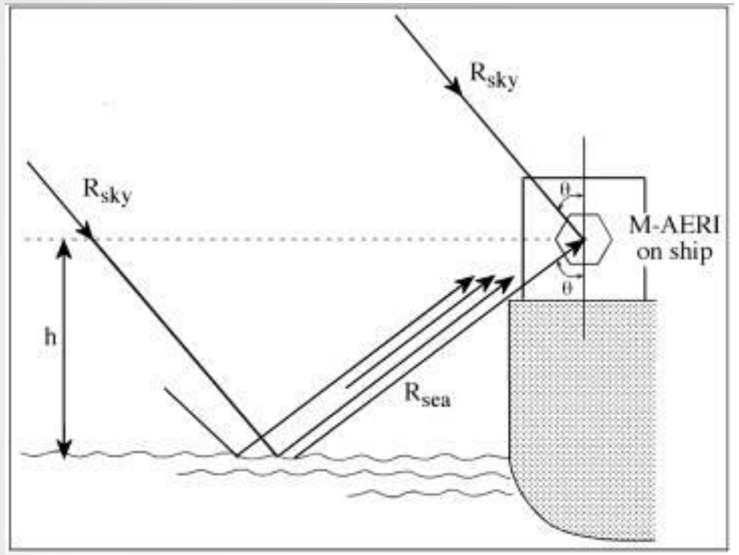




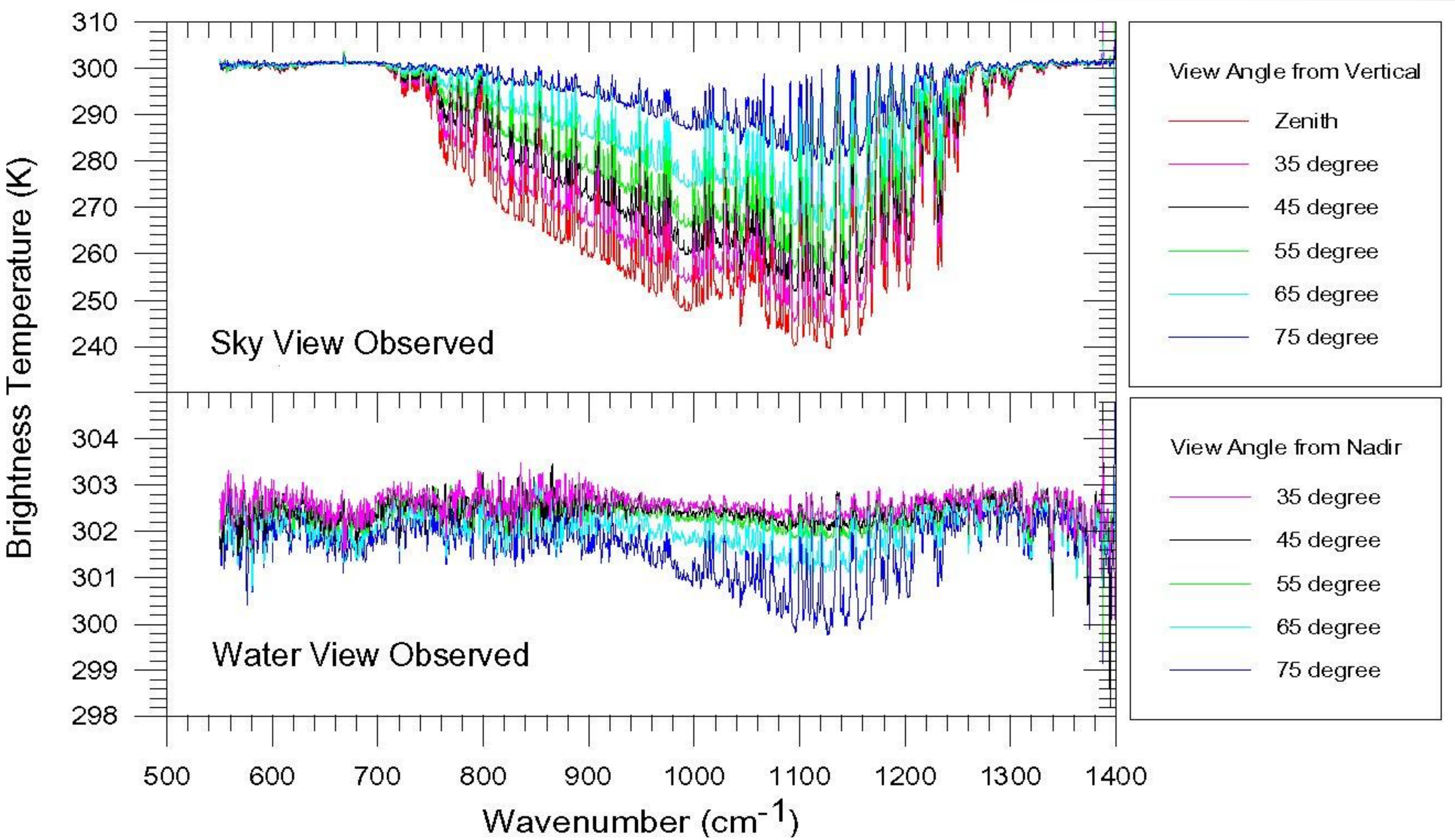
http://www.arcoptix.com/

At-sea measurements

Correct for surface emissivity not being unity.

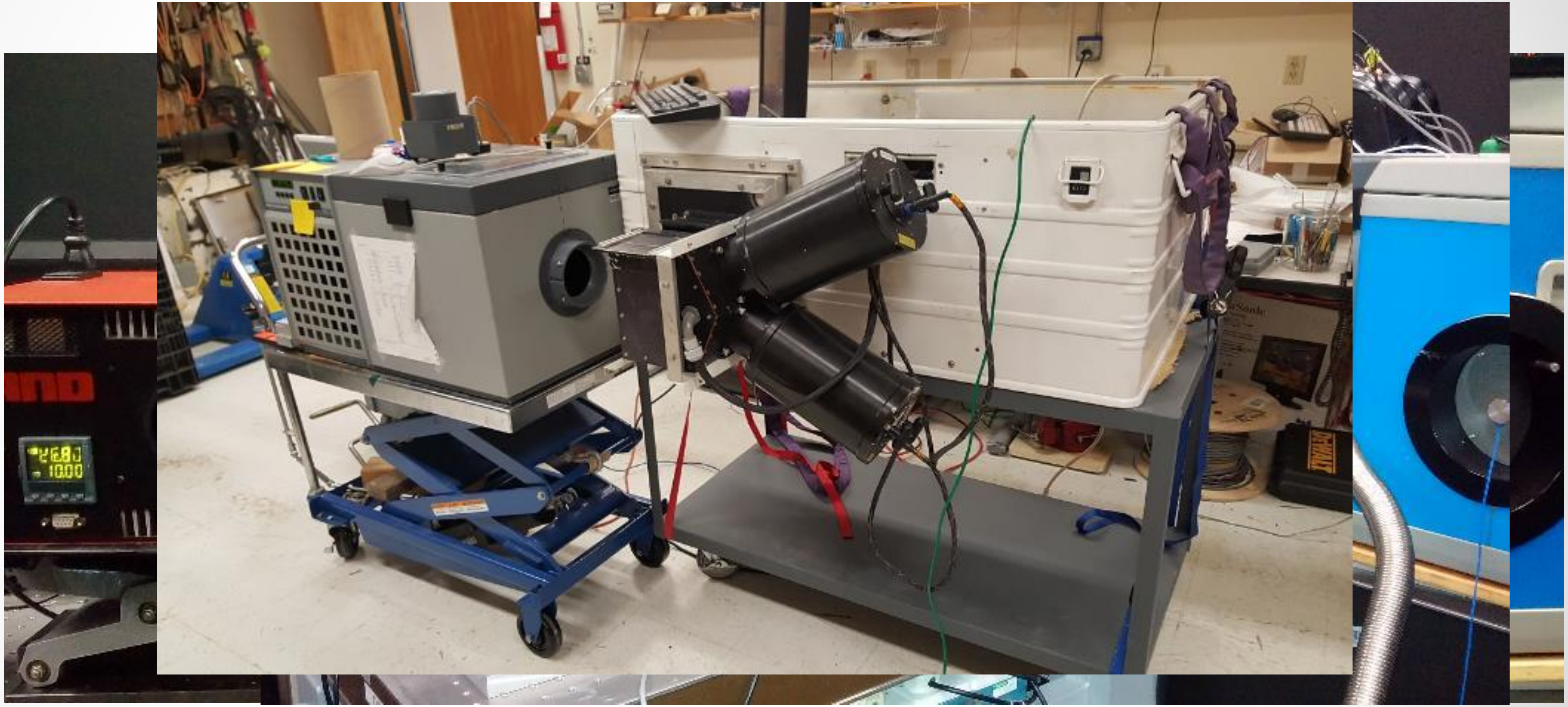


$$
\begin{aligned}
R_{\text{water}}(\lambda,\ \theta) = {} & \varepsilon(\lambda,\ \theta)B(\lambda,\ T_{\text{skin}}) \\
& + (1 - \varepsilon(\lambda,\ \theta))R_{\text{sky}}(\lambda,\ \theta) \\
& + R_h(\lambda,\ \theta)
\end{aligned}
$$



Minnett, P.J., Maillet, K.A., Hanafin, J.A., & Osborne, B.J. (2005). Infrared interferometric measurements of the near surface air temperature over the oceans. *Journal of Atmospheric and Oceanic Technology*, *22*, 1016-1029

Fiducial Measurements for Surface Temperatures Workshop – NPL, June 2016.

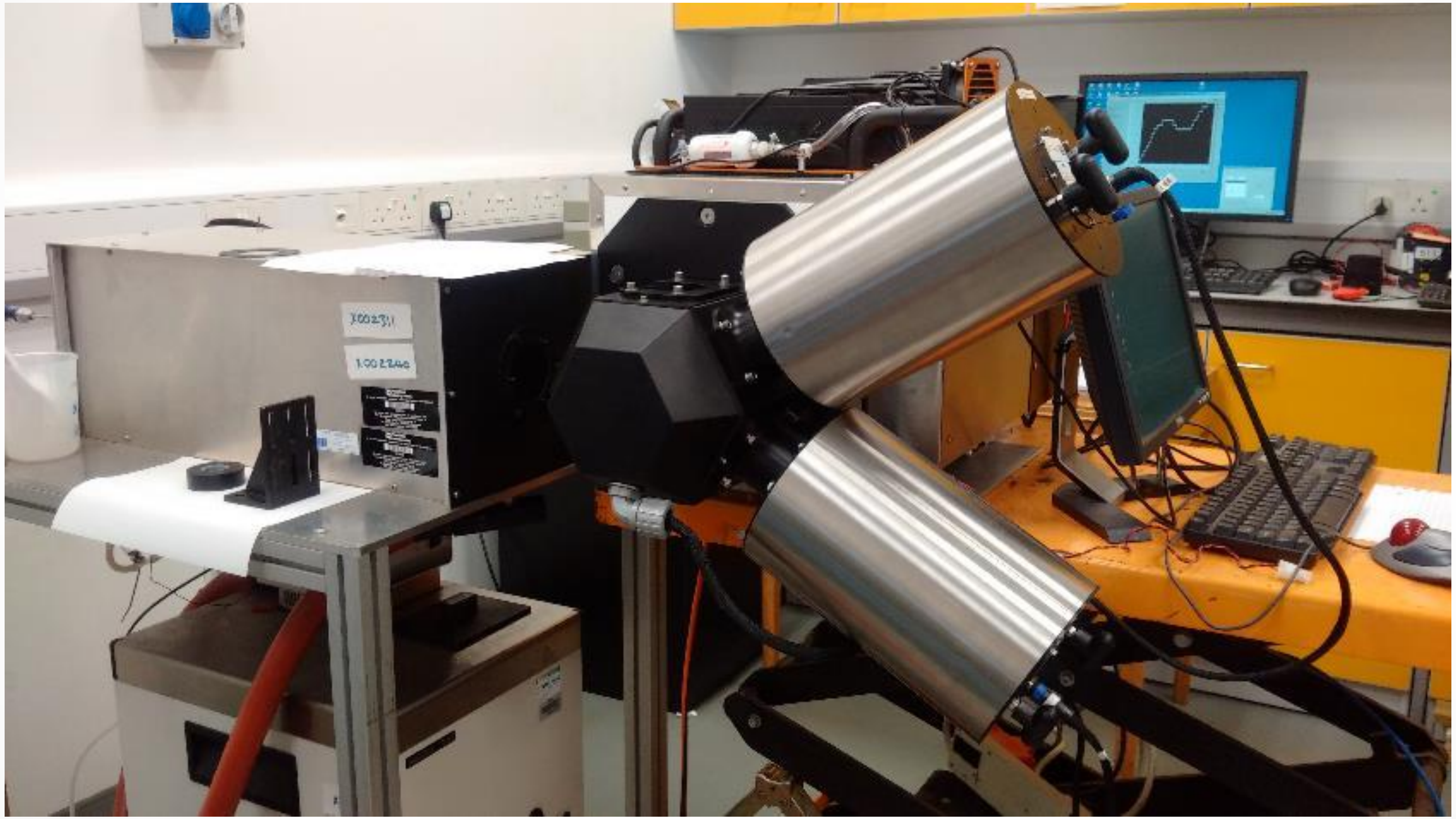


fiducial reference temperature measurements

NASA

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Fiducial Measurements for Surface Temperatures Workshop – NPL, June 2016.



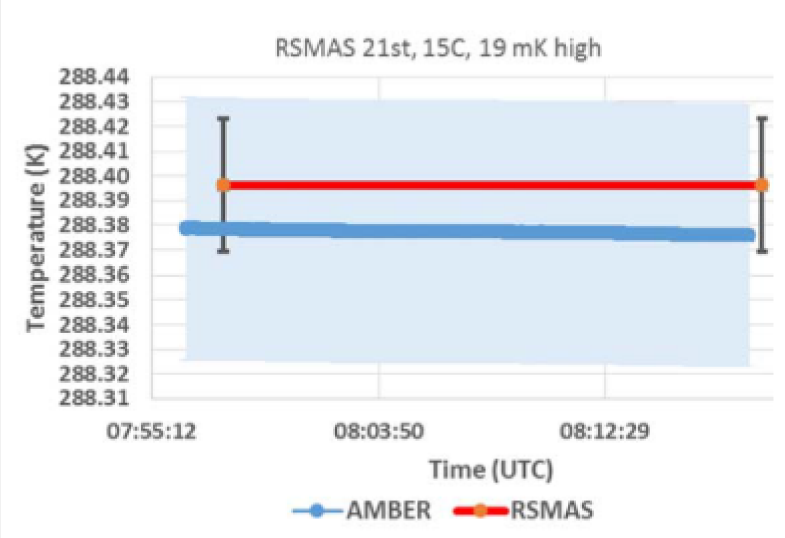
fiducial reference temperature measurements

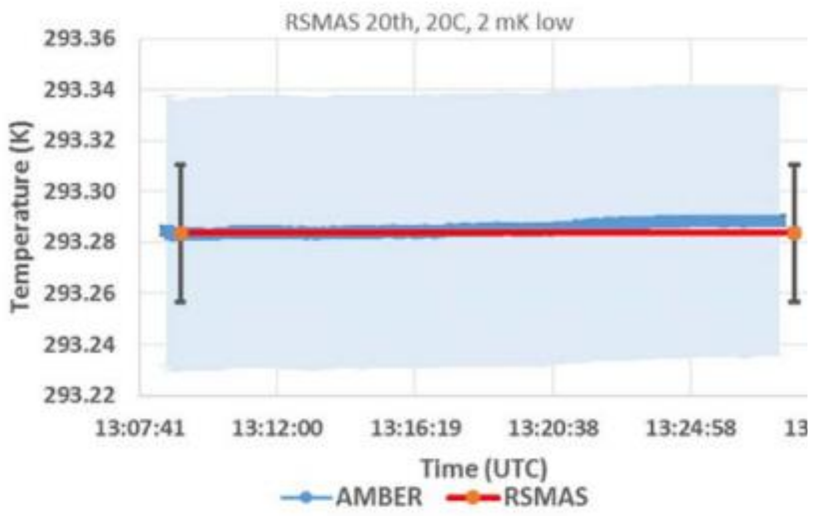
UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

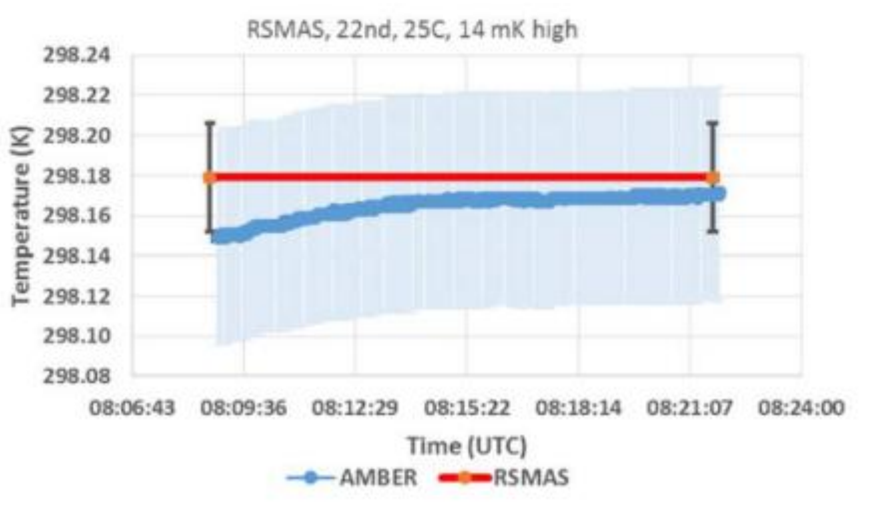
Error Budget of Miami Water-bath Blackbody Target

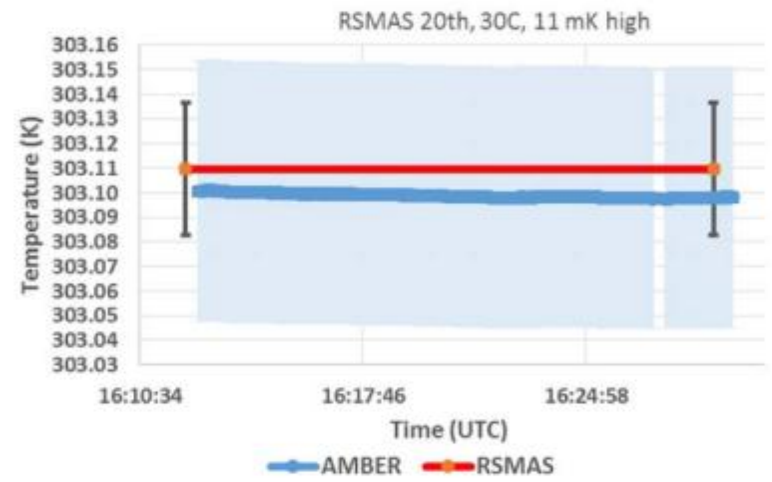
Uncertainty Contribution	Set point temperature							Comments
All values in mK	288	293	298	303	308	313	318	
Thermometer calibration	4.24	4.24	4.24	4.24	4.24	4.24	4.24	Average of two thermometers, each with uncertainty (k=2) of 6.0 mK (Fluke calibration reports, 5 April, 2016)
Blackstack thermometer resistance measurement	0.54	0.12	0.35	0.42	0.13	0.35	0.19	k=2. Fluke calibration report.
Conversion of resistance to temperature	0.35	0.23	0.08	0.07	0.19	0.27	0.30	k=2. Fluke calibration report.
Stability of the water bath	0.16	0.16	0.17	0.17	0.18	0.19	0.17	k=2. 2x standard error of temperature measurements at set points
Emissivity uncertainty	50.0	50.0	50.0	50.0	50.0	50.0	50.0	Fowler, 1995; Rice et al, 2004. Upper bound. (k=2)
Temperature drop across copper cone	0.5	0.0	0.5	1.0	2.6	2.2	2.8	Fowler, 1995, Table 4. (k=2)
Spatial temperature gradients in cavity	5.0	5.0	5.0	5.0	5.0	5.0	5.0	Thermal imager – no gradients detectable with FLIR SC3000 with sensitivity of 20mK
Radiative heat exchange with environment	15.0	15.0	15.0	15.0	15.0	15.0	15.0	Assumes uncertainty in knowledge of ambient temperature of 0.5K and uncertainty in cone reflectivity of 0.0003; Fowler, 1995.
Convective heat exchange with environment	1.0	1.0	1.0	1.0	1.0	1.0	1.0	From uncertainty budget of NPL Gallium reference BB

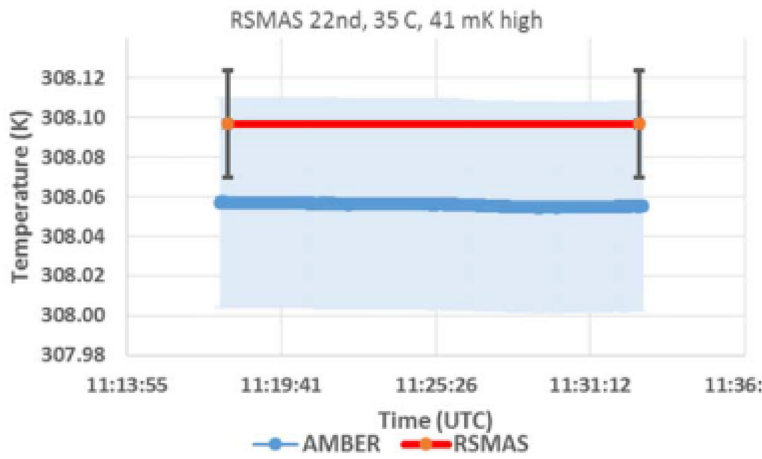
RSMAS Water-bath Blackbody *vs* AMBER



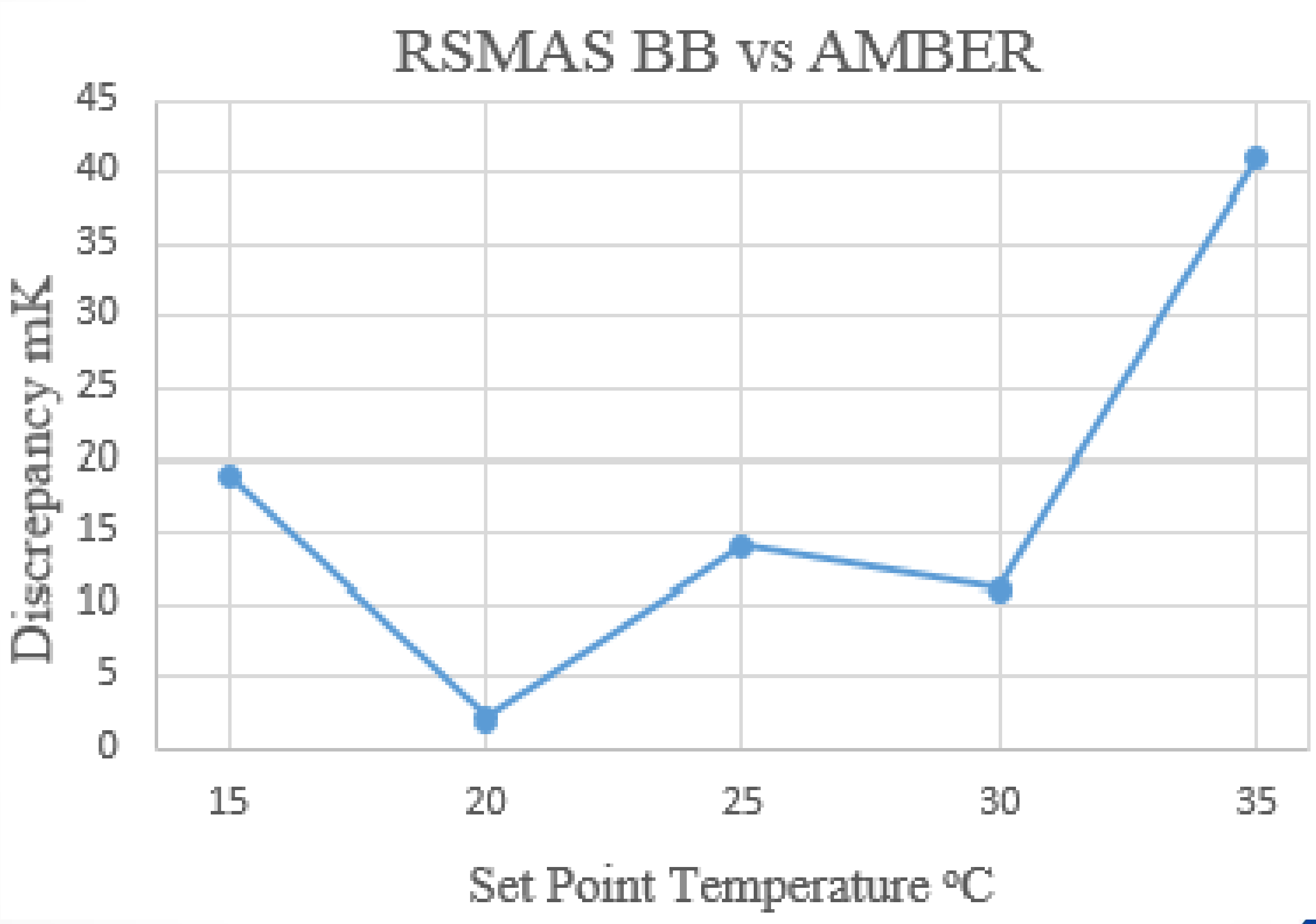








RSMAS Water-bath Blackbody *vs* AMBER

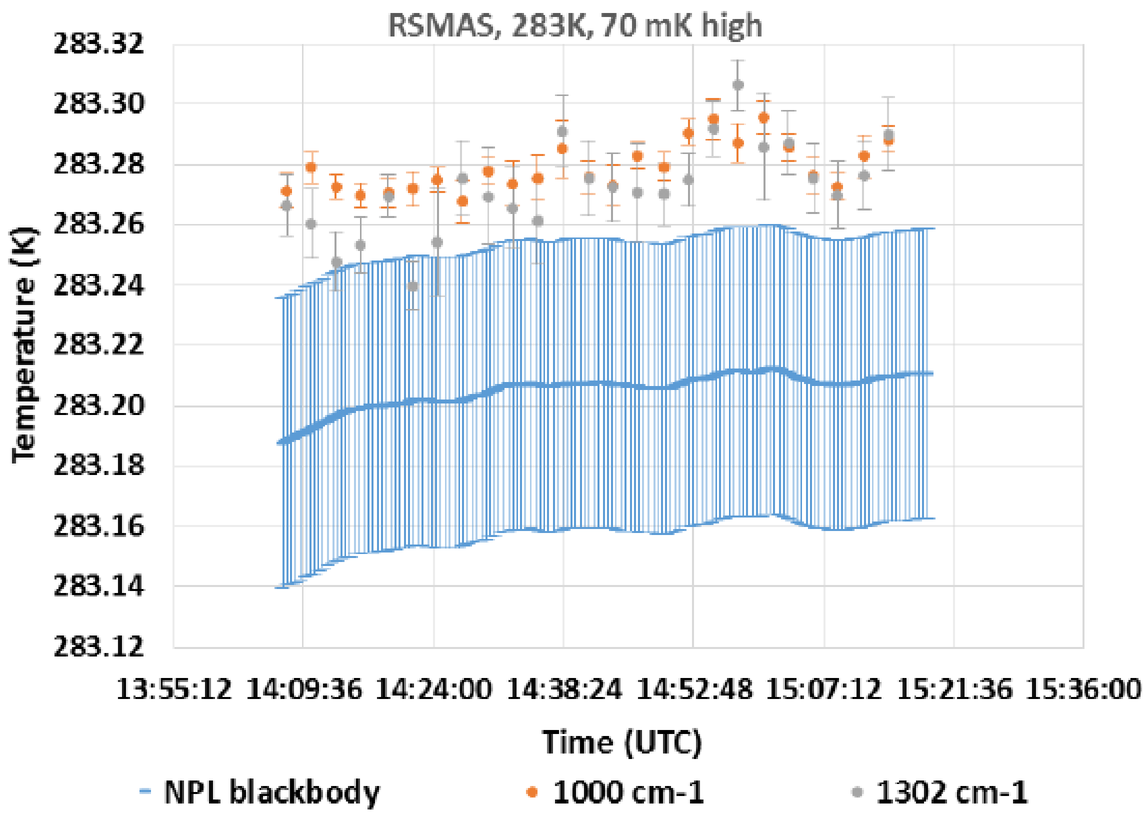


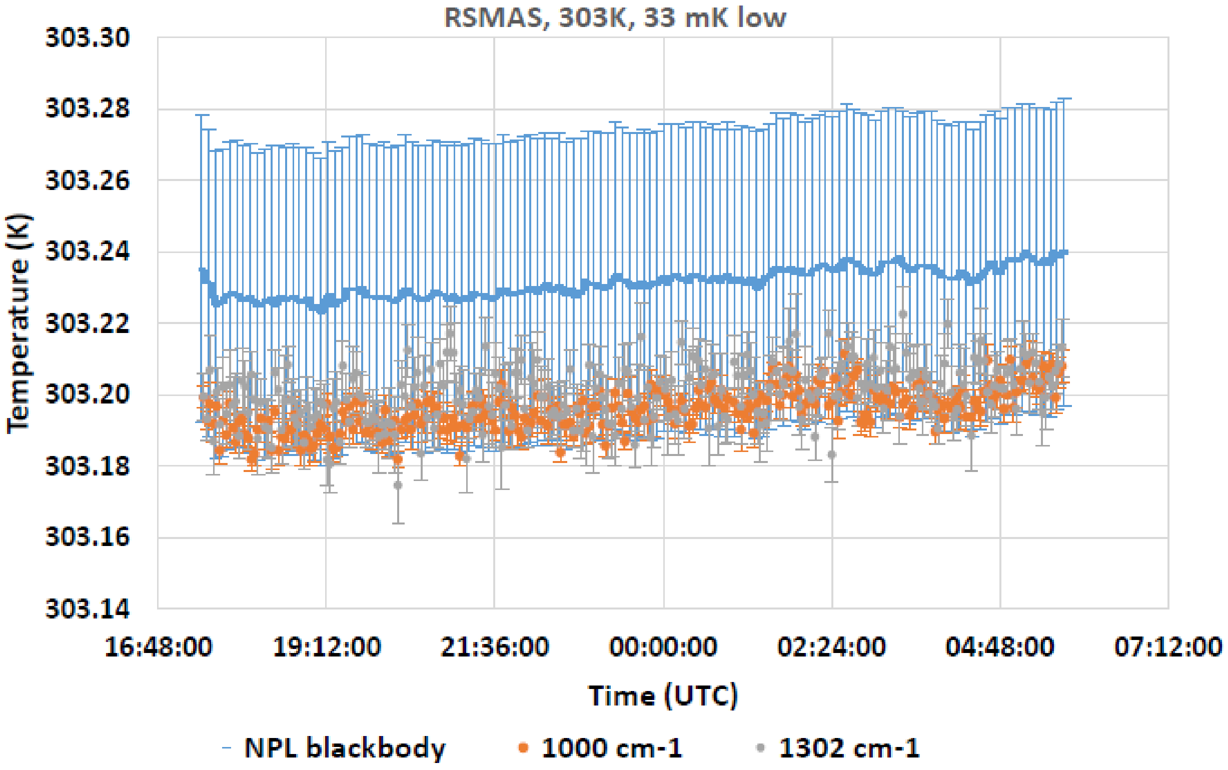
Note: discrepancies are within uncertainties of AMBER reference radiometer.

fiducial reference temperature measurements

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

M-AERI *vs* NPL Reference Blackbody



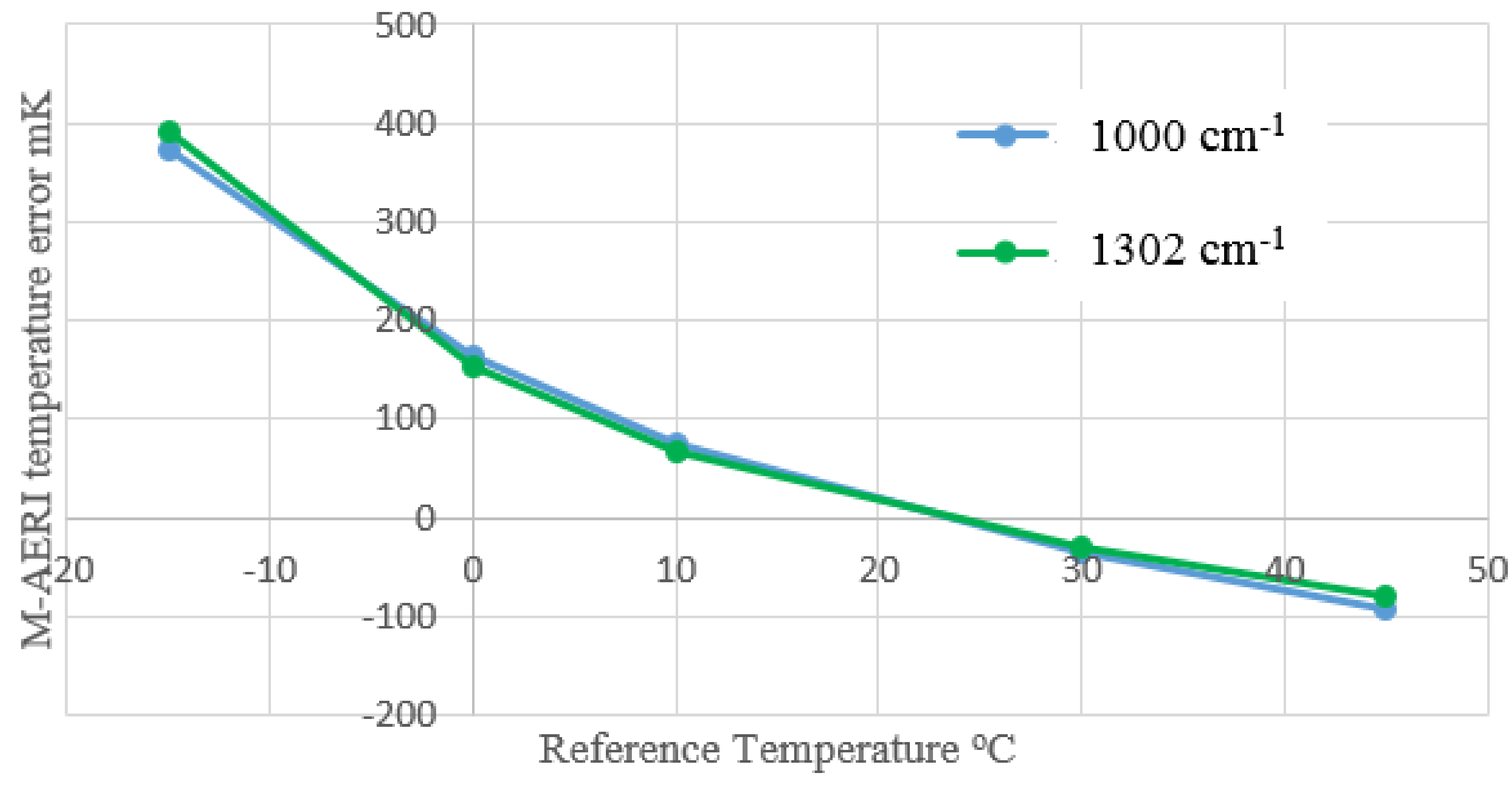


From: Theocharous, E., Barker-Snook, I., & Fox, N.P. (2016). 2016 comparison of IR brightness temperature measurements in support of satellite validation. Part 1: Blackbody Laboratory comparison. NPL REPORT ENV 12. pp. 104. Teddington, Middlesex, UK: National Physical Laboratory

fiducial reference temperature measurements

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

M-AERI *vs* NPL Reference Blackbody



fiducial reference temperature measurements

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

M-AERI *vs* RSMAS Blackbody

R_m is measured radiance from the RSMAS WB BB cone, which is:

$R_C = [R(T_{BB})*\varepsilon_{BB} + (1-\varepsilon_{BB})*R(T_{amb})]$.

Error is $R_m - R_{C.}$

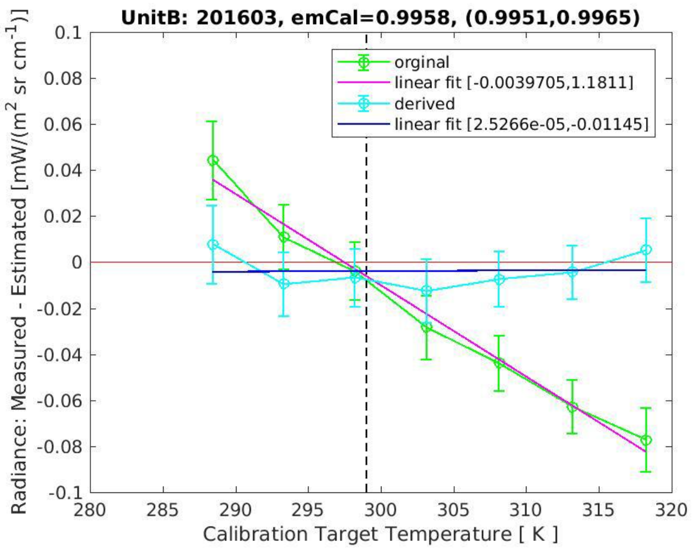
Wavelength dependence treated explicitly.

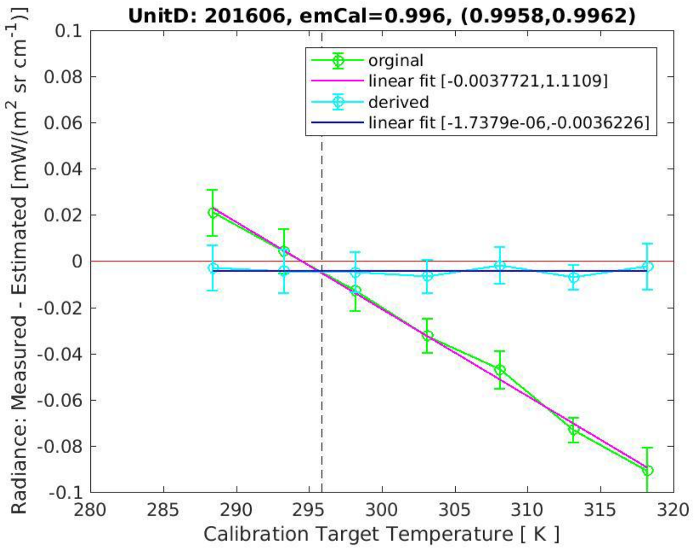
Measurements taken at a range of set point temperatures.

Measurements sometimes include a third M-AERI BB mounted on the zenith view port of the M-AERI, and sometimes a LN_2 open Dewar at nadir.

ε_{BB} is adjusted to minimize dependence of the error on the target temperature.

Estimates of Cone Emissivity


UnitB: 201603, emCal=0.9958, (0.9951,0.9965)


UnitD: 201606, emCal=0.996, (0.9958,0.9962)

Date	Unit	1300 cm^{-1}	1000 cm^{-1}
2015/03	A	1.0000	1.0000
2015/05	A	1.0000	1.0000
2016/02	A	1.0000	1.0000
2016/02	A	0.9982	0.9989
2017/04	A	0.9982	0.9981
2017/04	A	0.9997	0.9993
2016/03	B	0.9985	0.9984
2016/03	B	0.9958	0.9959
2014/02	C	0.9967	0.9969
2014/02	C	0.9957	0.9955
2015/10	D	0.9963	0.9964
2016/02	D	0.9962	0.9961
2016/02	D	0.9966	0.9964
2016/06	D	0.9961	0.9961
2016/06	D	0.9960	0.9960
2017/06	D	0.9939	0.9937
2017/09	D	0.9946	0.9947
Average		0.9972	0.9971

Four M-AERIs show very similar results for the cone emissivity.

These results are for new or recently cleaned mirrors.

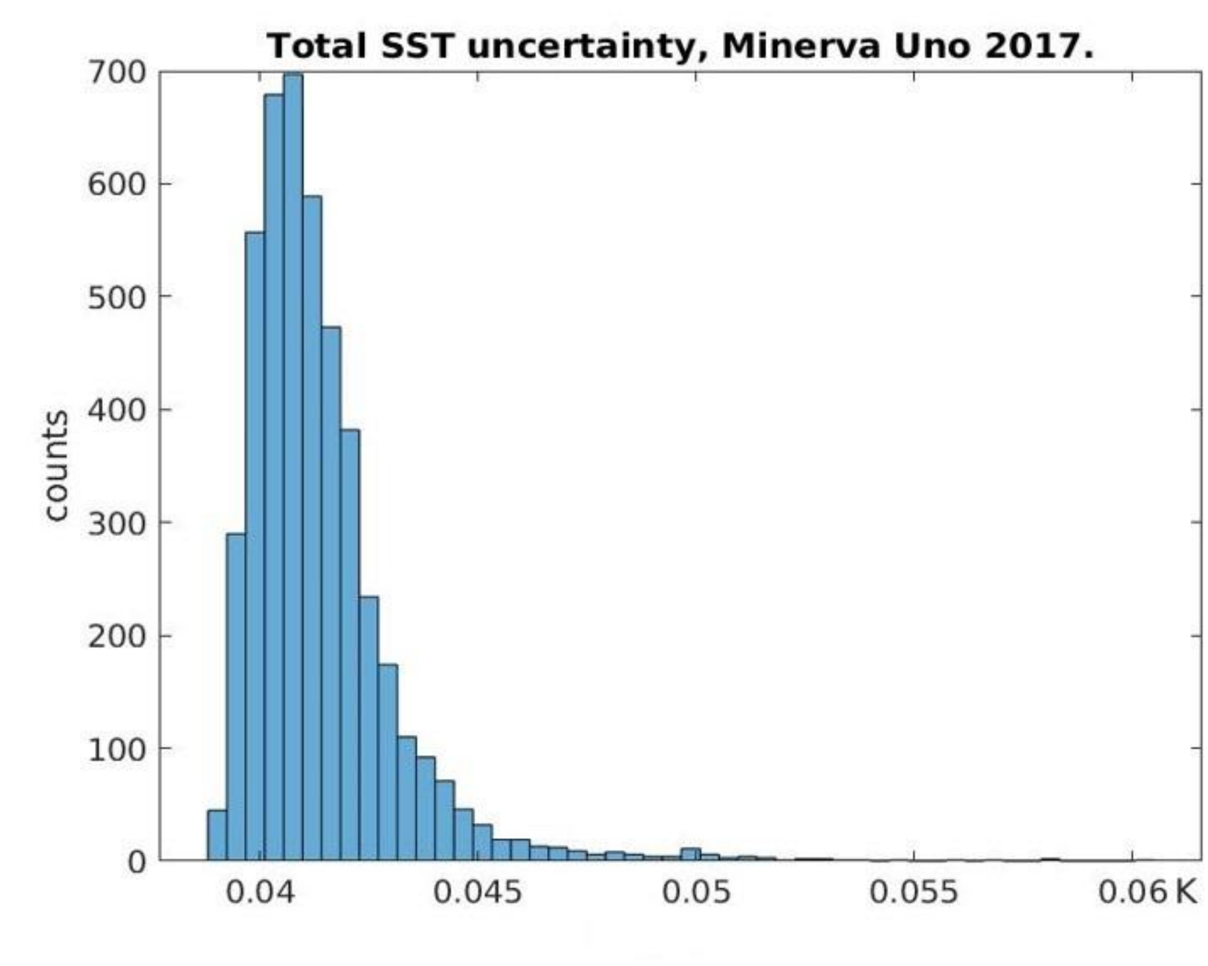
Is this a reasonable approach?

Error Budget of M-AERI measurements

At λ= 10.0 μm (1000 cm^{-1})			
Parameter	Type A Uncertainty [K]	Type B Uncertainty [K]	Uncertainty in Brightness temp [K]
Repeatability of Measurement	0.014		0.014
Reproducibility of Measurement	0.0058 (0.0035)		0.0058 (0.0035)
Linearity of Radiometer		0.0003	0.0003
Primary calibration		0.0097	0.0097
Drift since calibration			0
RMS total	0.0152 (0.0144)	0.0102	0.0182 (0.0176)

At λ= 7.7 μm (1302 cm^{-1})			
Parameter	Type A Uncertainty [K]	Type B Uncertainty [K]	Uncertainty in Brightness temp [K]
Repeatability of Measurement	0.0349		0.0349
Reproducibility of Measurement	0.0178 (0.0089)		0.0178 (0.0089)
Linearity of radiometer		0.0003	0.0003
Primary calibration		0.0086	0.0086
Drift since calibration			0
RMS total	0.0392 (0.0360)	0.0091	0.0402 (0.0372)

M-AERI SST_{skin} uncertainties



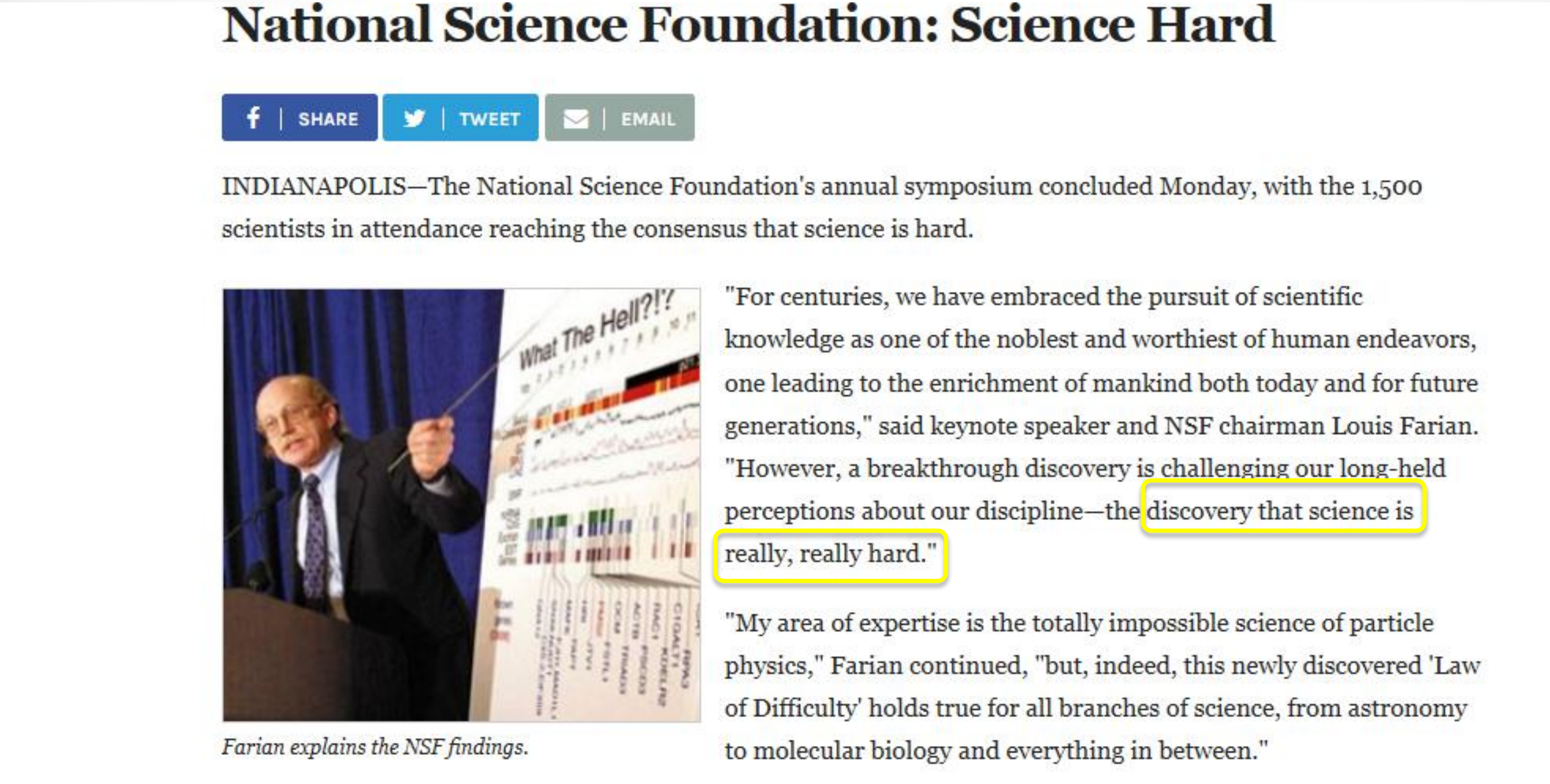
fiducial reference temperature measurements

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

ISARs

- Same instruments as used by other groups.
- Same calibration procedure as M-AERI, with some calibrations being done in Andy Jessup's lab at the APL, University of Washington, Seattle, USA.
- Data transfer in real-time by Iridium Short Burst Data (*SBD*).
- Deployments generally <6 mo, before being swapped over and refurbished and recalibrated.

Conclusion



National Science Foundation: Science Hard

INDIANAPOLIS—The National Science Foundation's annual symposium concluded Monday, with the 1,500 scientists in attendance reaching the consensus that science is hard.

Farian explains the NSF findings.

"For centuries, we have embraced the pursuit of scientific knowledge as one of the noblest and worthiest of human endeavors, one leading to the enrichment of mankind both today and for future generations," said keynote speaker and NSF chairman Louis Farian. "However, a breakthrough discovery is challenging our long-held perceptions about our discipline—the discovery that science is really, really hard."

"My area of expertise is the totally impossible science of particle physics," Farian continued, "but, indeed, this newly discovered 'Law of Difficulty' holds true for all branches of science, from astronomy to molecular biology and everything in between."

Acknowledgements

- RSMAS group:
  - Goshka Szczodrak, Miguel Izaguirre, Kay Kilpatrick, Liz Williams, Sue Walsh
  - Mike Reynolds, RMRCo, Seattle
- Royal Caribbean International – hosting M-AERIs.
- NYK Lines – hosting ISARs.
- Captains, officers and crews of many research vessels.
- NASA MODIS Mission and NASA Physical Oceanography & International Participating Investigator programs for funding.

fiducial reference
temperature
measurements

NASA

UNIVERSITY OF MIAMI
ROSENSTIEL
SCHOOL of MARINE &
ATMOSPHERIC SCIENCE