Center for Quantum Technologies of NNSTU

Institute for Physics of Microstructures of RAS

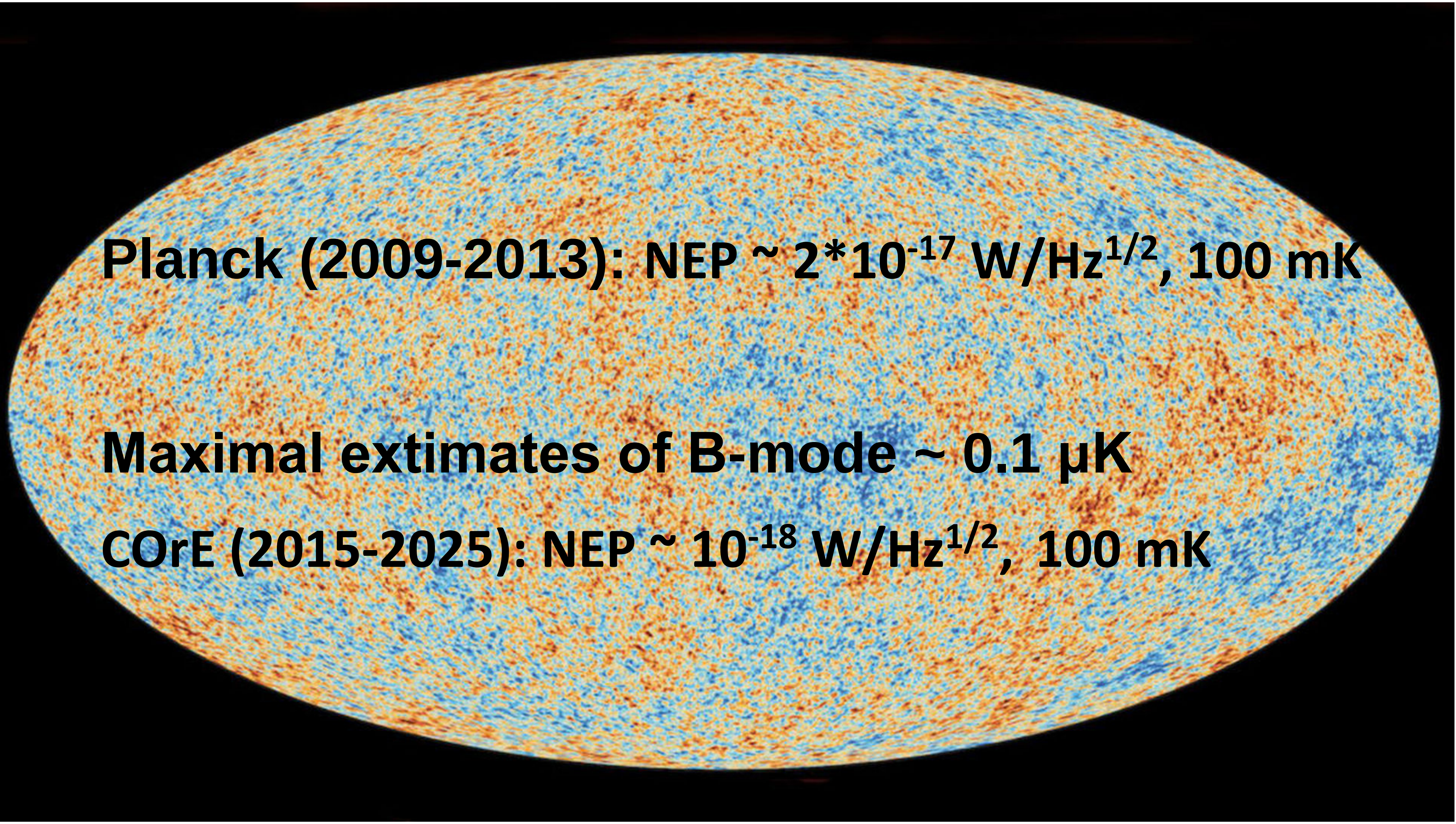
Cold-Electron Bolometers for Radio Astronomy Missions

A.L. Pankratov[1,2], L.S. Kuzmin[1,3], A.V. Gordeeva[1,2,3], L.S. Revin [1,2], A.V. Chiginev [1,2], V.O. Zbrozhek[1], A.V. Blagodatkin[1], D.A. Pimanov[1], S. Masi[4] and P. de Bernardis[4]

1 Center for Quantum Technologies of NNSTU, Nizhny Novgorod
2 Institute for Physics of Microstructures of RAS, Nizhny Novgorod
3 Chalmers University of Technology, Gothenburg
4 La Sapiensa University, Rome

Moscow,
2021

Investigation of cosmic microwave background



Planck (2009-2013): NEP ~ $2*10^{-17}$ W/Hz$^{1/2}$, 100 mK

Maximal extimates of B-mode ~ 0.1 μK

COrE (2015-2025): NEP ~ 10^{-18} W/Hz$^{1/2}$, 100 mK

Illustration of ESA, Planck Collaboration.

Problems of deep cooling in space

Temperatures of order 100 mK and below are a serious challenge for space applications since the conventional closed-cycle dilution refrigerators require gravity for their operation. In particular, the open-cycle dilution refrigerator (OCDR) aboard the Planck satellite operated in zero gravity by ejecting the 3He/4He mixture into space. The lifetime of this OCDR with 0.1 μW of cooling power at 100 mK was about two years. Instruments aboard future space missions such as SPICA and COrE require higher cooling powers of the order 1–3 μW at 100 mK and longer operating times of about five years.

APPLIED PHYSICS LETTERS **110**, 162603 (2017)

Observation of photon noise by cold-electron bolometers

A. V. Gordeeva,[1,2,3,a)] V. O. Zbrozhek,[1] A. L. Pankratov,[1,2,3] L. S. Revin,[1,2,3]
V. A. Shamporov,[1,2,3] A. A. Gunbina,[1] and L. S. Kuzmin[1,4]
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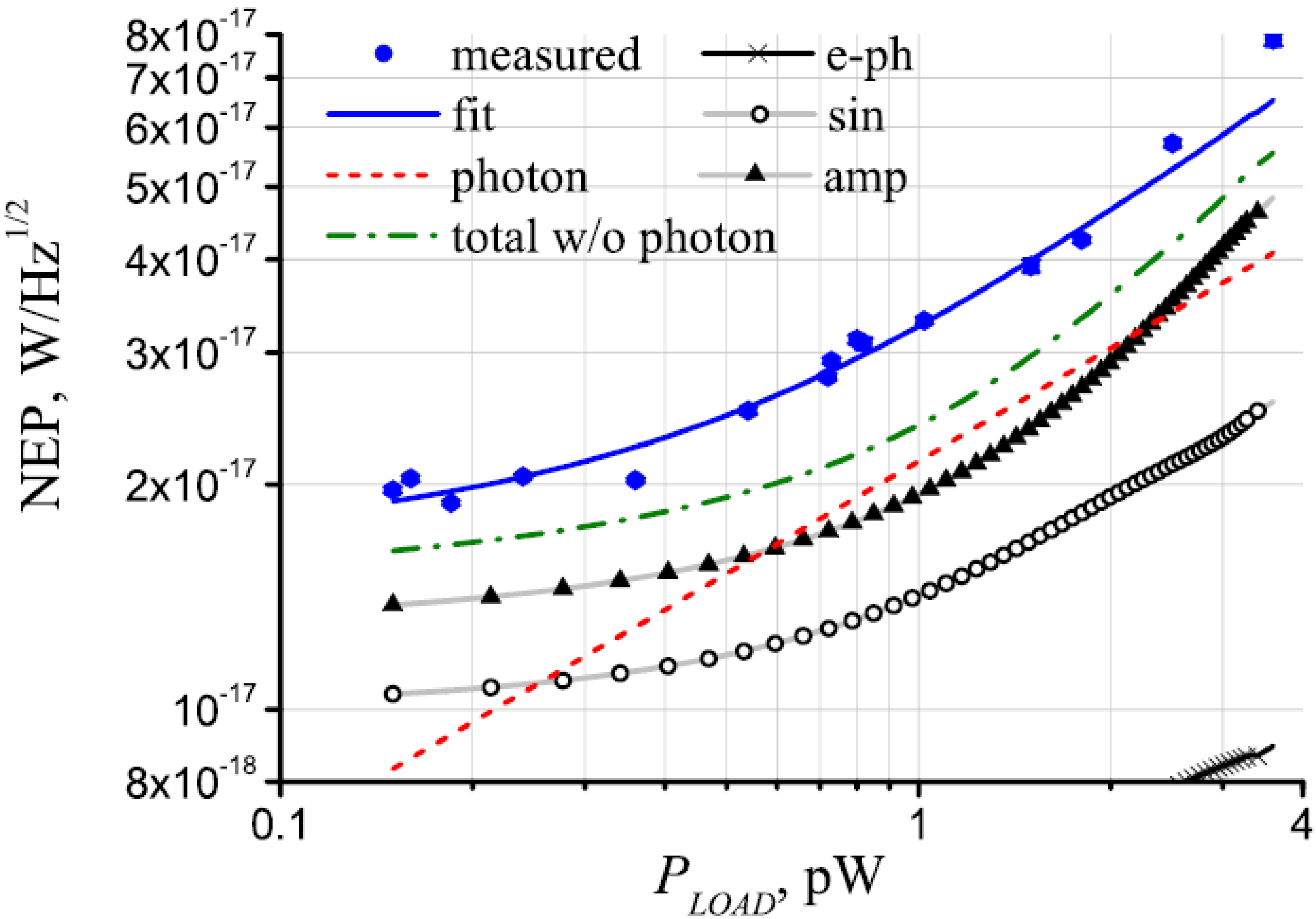
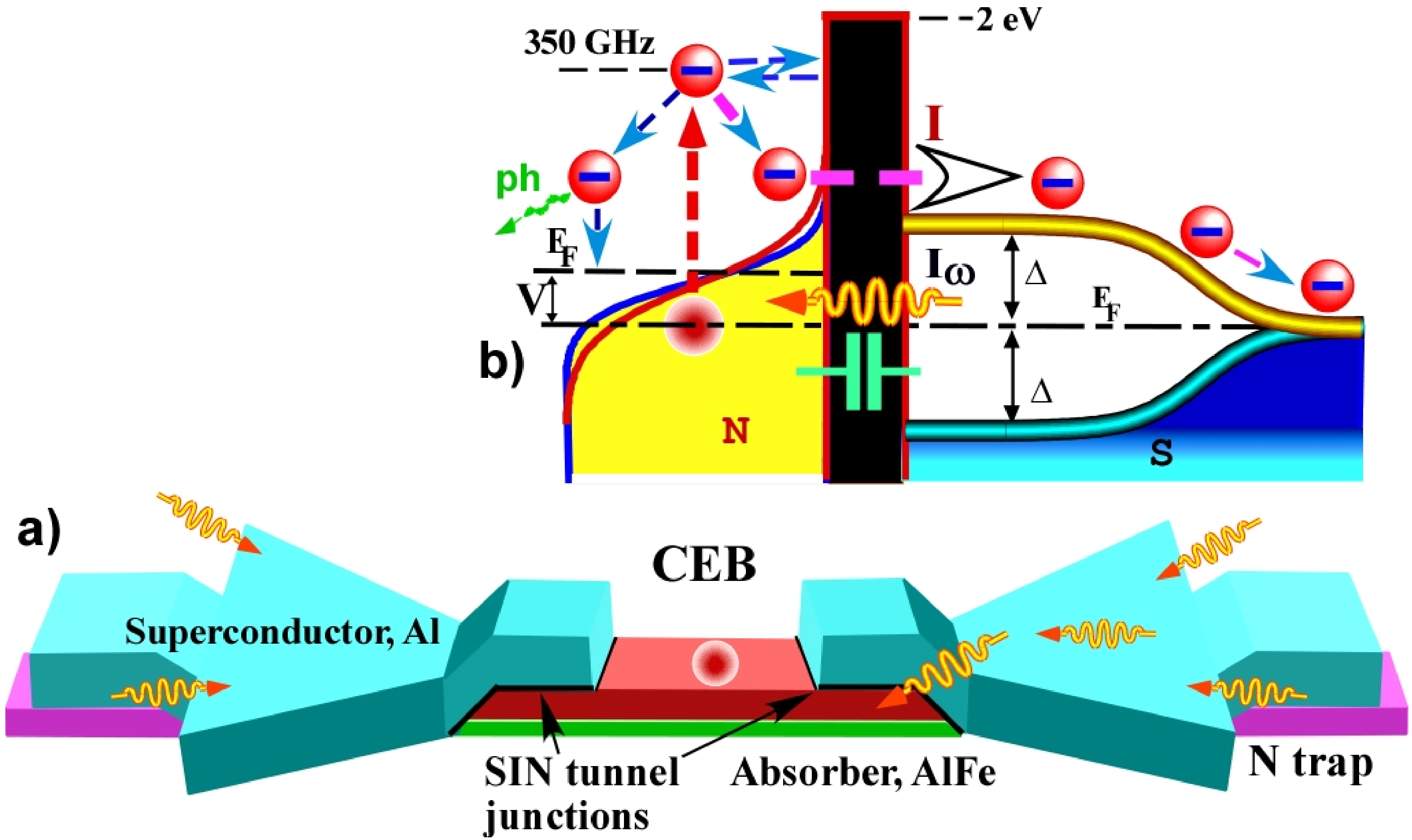
[3]*Lobachevsky State University of Nizhny Novgorod, GSP-20, Nizhny Novgorod 603950, Russia*
[4]*Chalmers University of Technology, 41296 Gothenburg, Sweden*



Cold-Electron Bolometers for Radio Astronomy

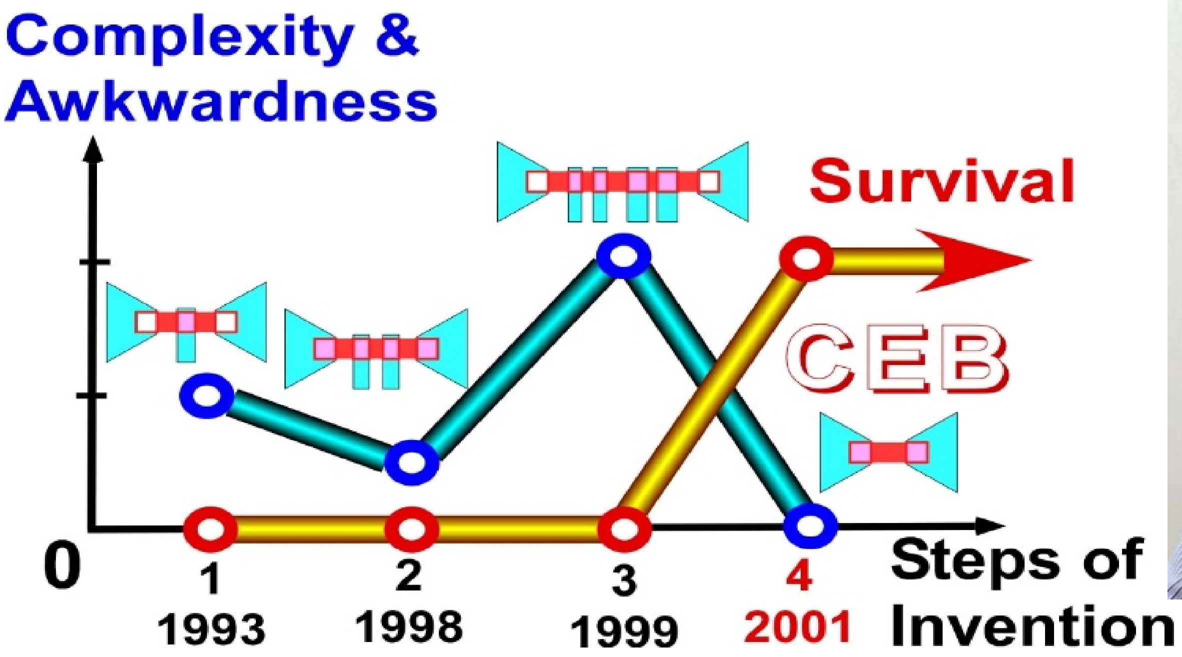


Tunnel SIN junctions perform 4 functions:

1) capacitive AC connection, 2) thermal isolation, 3) thermometry
4) electron cooling.

Comment in **Nature Research Communities blog** **BEHIND THE PAPER**
with CEB progress description
«Story of the Invention of a Cold-Electron Bolometer»

https://astronomycommunity.nature.com/channels/1490-behind-the-paper/posts/53529-story-of-the-invention-of-a-cold-electron-bolometer



4. Cold-Electron Bolometer (CEB) with SIN tunnel junctions as the thermometer, electron cooler, RF capacitive coupling and thermal isolation. L. Kuzmin (2002).

APPLIED PHYSICS LETTERS **105**, 043509 (2014)

A strained silicon cold electron bolometer using Schottky contacts

T. L. R. Brien,[1,a)] P. A. R. Ade,[1] P. S. Barry,[1] C. Dunscombe,[1] D. R. Leadley,[2] D. V. Morozov,[1] M. Myronov,[2] E. H. C. Parker,[2] M. J. Prest,[2] M. Prunnila,[3] R. V. Sudiwala,[1] T. E. Whall,[2] and P. D. Mauskopf[1,4]

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[4]*Department of Physics and School of Earth and Space Exploration, Arizona State University, 650 E. Tyler Mall, Tempe, Arizona 85287, USA*

(Received 20 May 2014; accepted 23 July 2014; published online 31 July 2014)

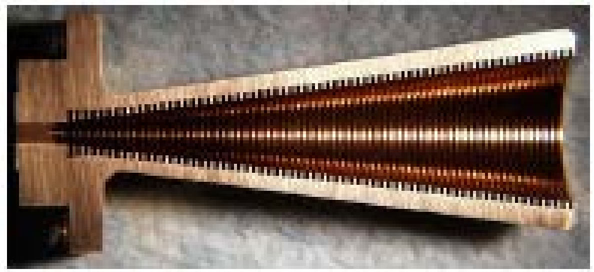
J Low Temp Phys (2016) 184:231–237
DOI 10.1007/s10909-016-1569-x

Optical Response of Strained- and Unstrained-Silicon Cold-Electron Bolometers

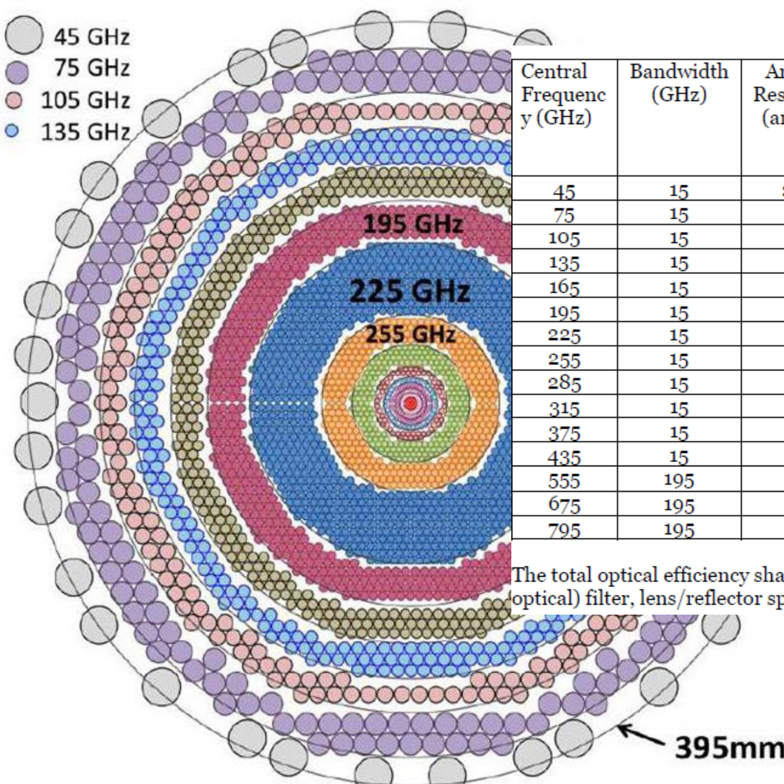
T. L. R. Brien[1] · P. A. R. Ade[1] · P. S. Barry[1] · C. J. Dunscombe[1] · D. R. Leadley[2] · D. V. Morozov[1] · M. Myronov[2] · E. H. C. Parker[2] · M. J. Prest[3] · M. Prunnila[4] · R. V. Sudiwala[1] · T. E. Whall[2] · P. D. Mauskopf[1,5]

Shortcomings of current technologies:

Focal plane of Planck mission

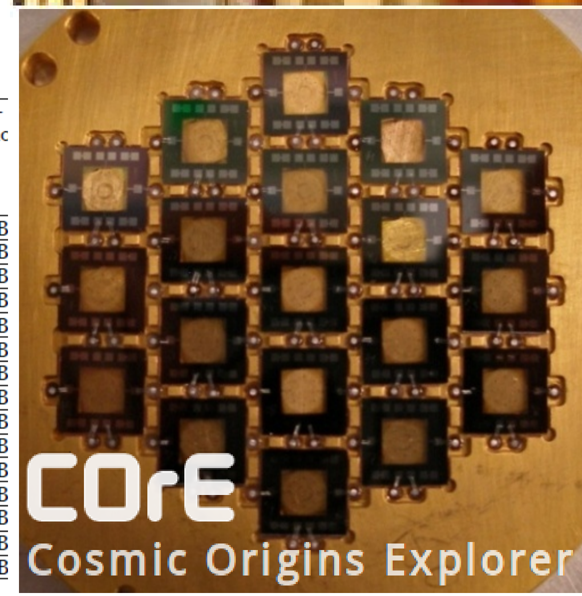


Focal plane of COrE mission



Central Frequency (GHz)	Bandwidth (GHz)	Angular Resolution (arcmin)	Q&U Sensitivity (μK· arcmin)	Out of band Rejection (above 1THz)	Beam Ellipticity (% @-3dB)	Cross – polarisatic (dB)
45	15	23.3	9.0	> 120 dB	< 1%	< -30 dB
75	15	14	4.7	> 120 dB	< 1%	< -30 dB
105	15	10	4.6	> 120 dB	< 1%	< -30 dB
135	15	7.8	4.5	> 120 dB	< 1%	< -30 dB
165	15	6.4	4.6	> 120 dB	< 1%	< -30 dB
195	15	5.4	4.5	> 120 dB	< 1%	< -30 dB
225	15	4.7	4.5	> 120 dB	< 1%	< -30 dB
255	15	4.1	10.4	> 120 dB	< 1%	< -30 dB
285	15	3.7	17	> 120 dB	< 1%	< -30 dB
315	15	3.3	46	> 120 dB	< 1%	< -30 dB
375	15	2.8	117	> 120 dB	< 1%	< -30 dB
435	15	2.4	255	> 120 dB	< 1%	< -30 dB
555	195	1.9	589	> 120 dB	< 1%	< -30 dB
675	195	1.6	3420	> 120 dB	< 1%	< -30 dB
795	195	1.3	20881	> 120 dB	< 1%	< -30 dB

The total optical efficiency shall be larger than 50% (TBC). This includes any (quasi-optical) filter, lens/reflector spillover loss etc, and include the (bolometer) coupling.



Receiving system for OLIMPO 350 GHz

Requirements:

Focal plain power:
Band 3 – 38 pW (photometr), 66 pW (spectrometer)

Frequency band: 330-360 GHz

Ratio of photon noise power to the self-noise of detector: 1.5-2 or more

Bias regime: current bias

Amplifier noise:
Voltage: 5 nV/Hz$^{1/2}$
Current: 15 fA/Hz$^{1/2}$

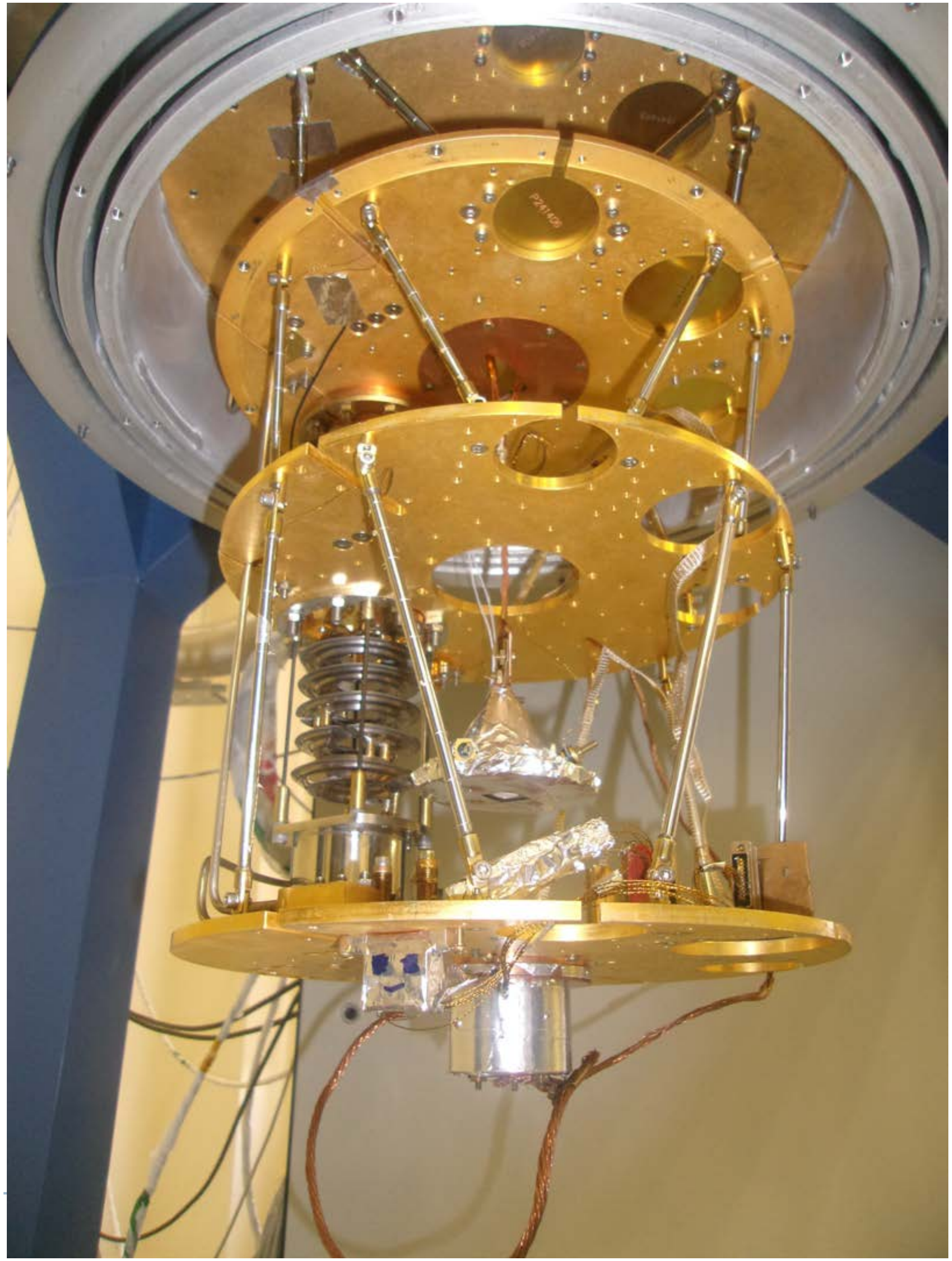
Detector working temperature: 300 mK


vST
vST
OXFORD
INSTRUMENTS

Cryostat Triton 200

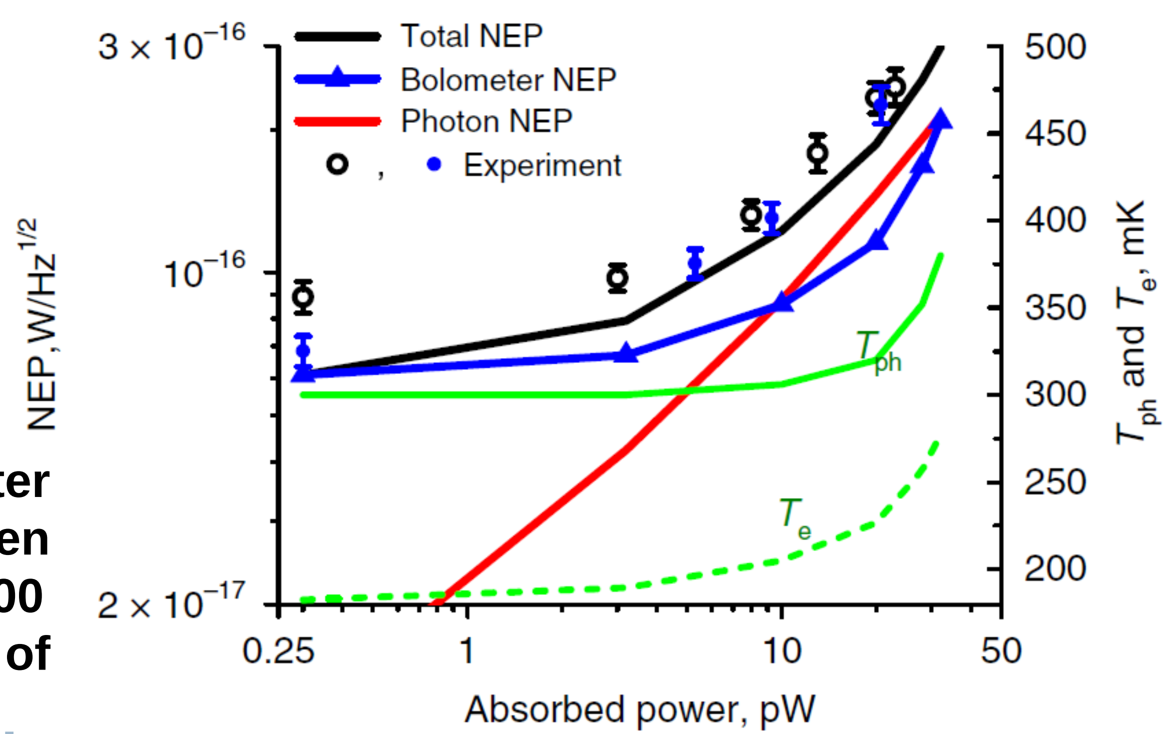
Heating of BB source,
attached to 4 К plate,
up to **58 К** at stabilized
low plate temperature of **0.3 К**
allows to perform tests with
a high power load up to 50pW

Moving of BB source to 1 K plate
allows to greatly improve NEP
and responsivity due to less
background power, but then only
12 K BB temperature can be
reached.

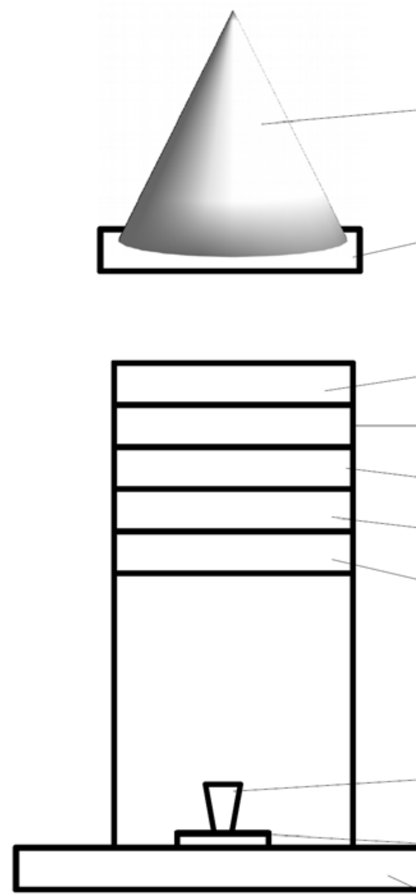


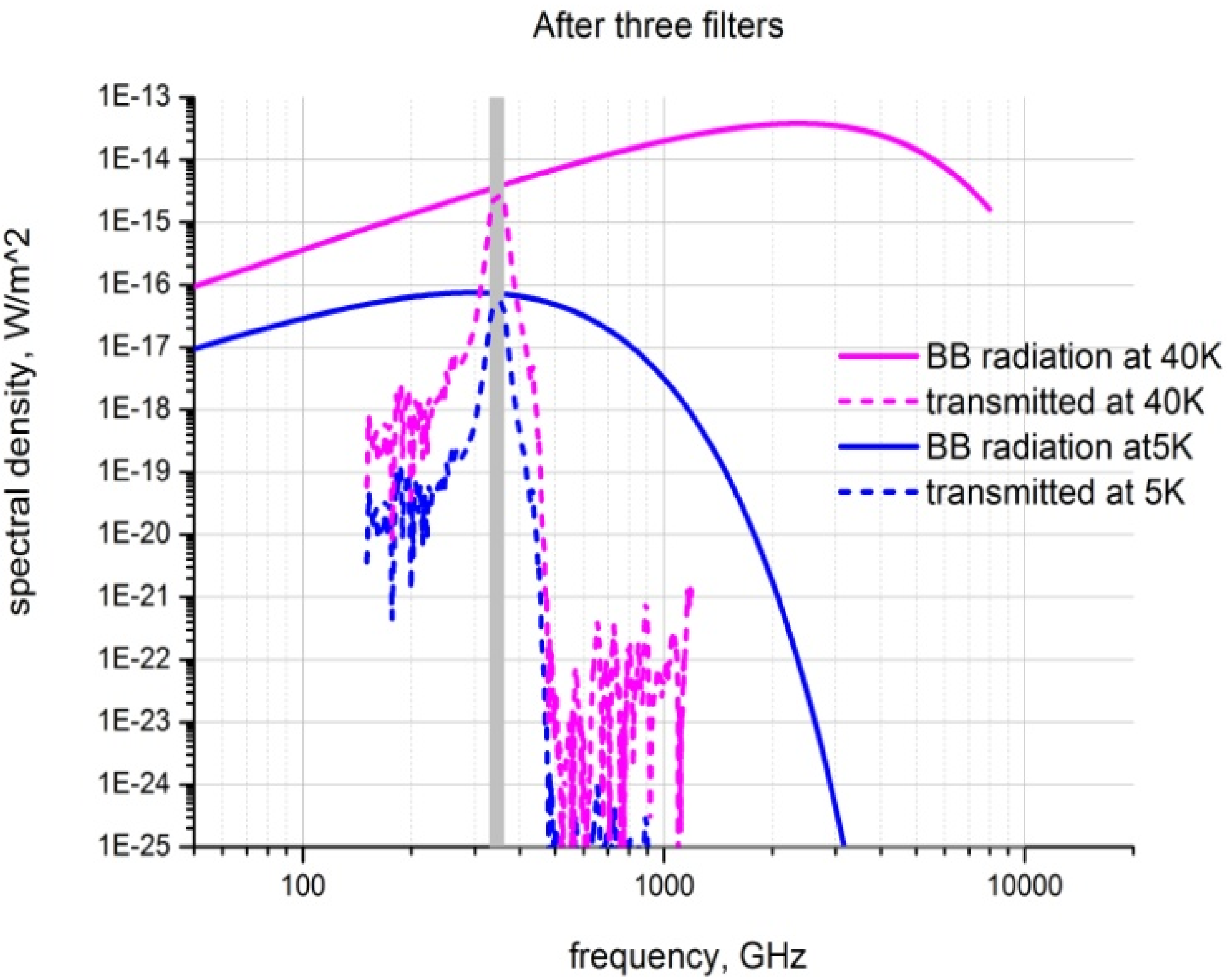
A. Paiella *et al* JCAP01(2019)039

OLIMPO configuration	Photometric				Spectrometric			
Channel [GHz]	150	250	350	460	150	250	350	460
Background Power [pW]	2.7	14	4.9	13	7.6	50	15	33
optical NEP $\left[\mathrm{aW}/\sqrt{\mathrm{Hz}}\right]$	65	140	90	140	110	260	160	240

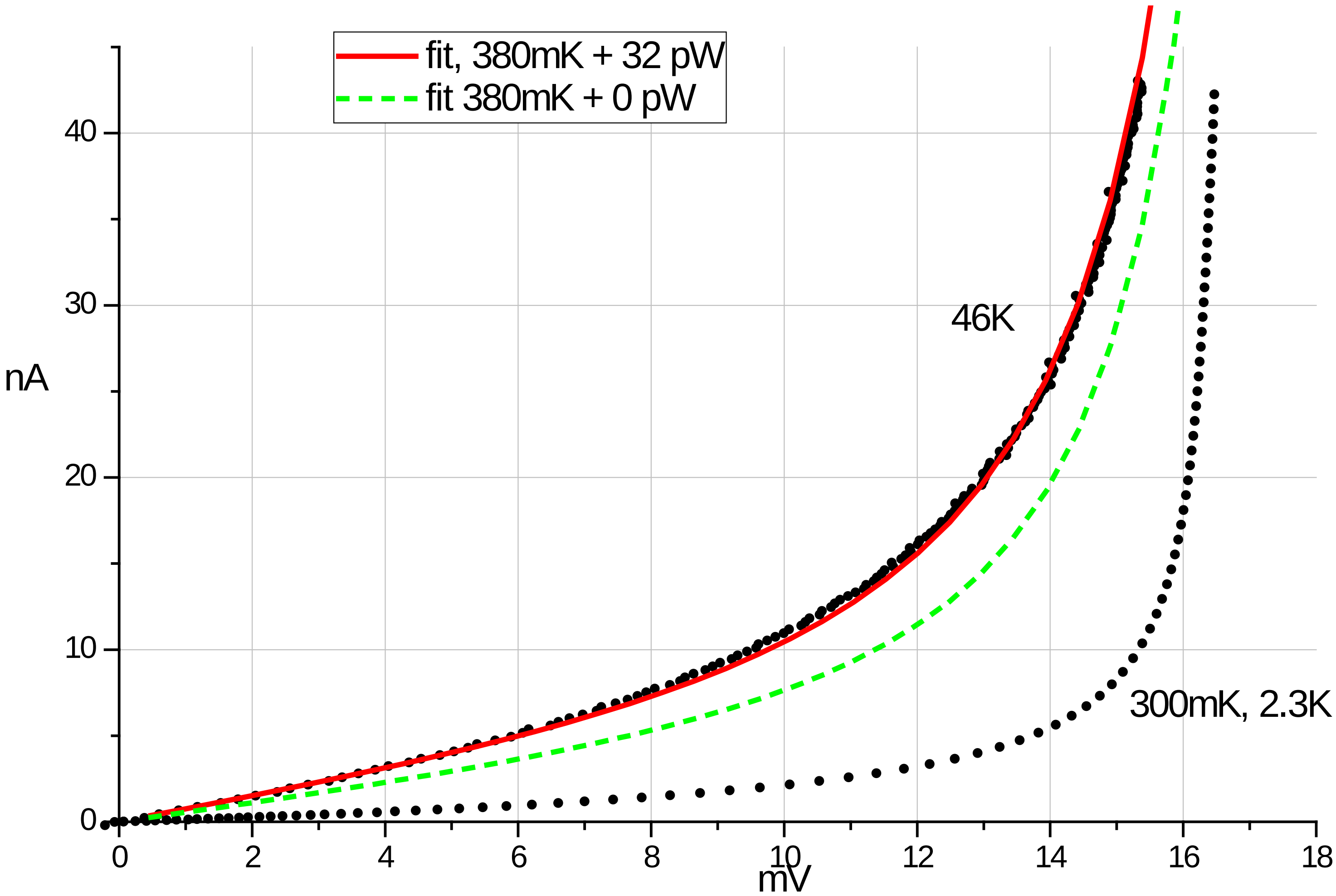


With a cold-electron bolometer the required NEP has been reached at 310 mK in Triton 200 dry cryostat in spite of compressors, pumps, etc.


Black body
source
Zitex
Zitex 108
LP 480
Gortex
LP380
BP350
Horn
Sample
300mK plate



Bandwidth of 3 filters LP 480, LP 380 и BP 350, fabricated in Cardiff.



Current-voltage characteristics of CEB at various black-body temperatures. The temperature of the chip is precisely controlled by the on-chip thermometer.

COMMUNICATIONS PHYSICS

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ARTICLE

https://doi.org/10.1038/s42005-019-0206-9 OPEN

Photon-noise-limited cold-electron bolometer based on strong electron self-cooling for high-performance cosmology missions

L.S. Kuzmin[1,2], A.L. Pankratov[2,3], A.V. Gordeeva[2,3], V.O. Zbrozhek[2], V.A. Shamporov[2,3], L.S. Revin[2,3], A.V. Blagodatkin[2,3], S. Masi[4] & P. de Bernardis[4]

https://www.nature.com/articles/s42005-019-0206-9

COMMUNICATIONS PHYSICS

Article | 03 September 2019 | Open Access

Photon-noise-limited cold-electron bolometer based on strong electron self-cooling for high-performance cosmology missions

A scanning electron microscope image of the Cold-Electron Bolometer with on-chip self-cooling, integrated into a gold antenna. Credit: Leonid Kuzmin

Announcement

Travel Grant for Early Career Researchers

Early Careers and no funds to attend your dream conference? Applications are now open for grants to support travel in 2020.

Announcement

Dario Bercioux joins our Editorial Board

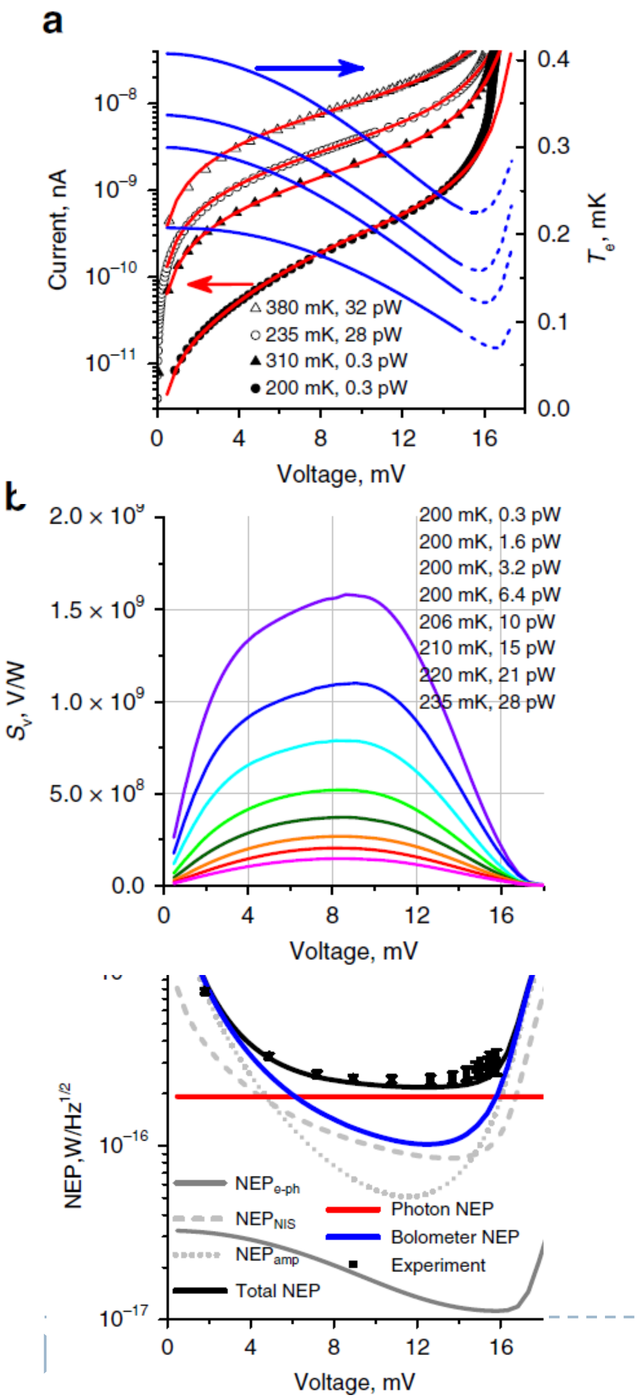
A warm welcome to our new Editorial Board Member Dario Bercioux. Dario will work with the journal editors in... show more

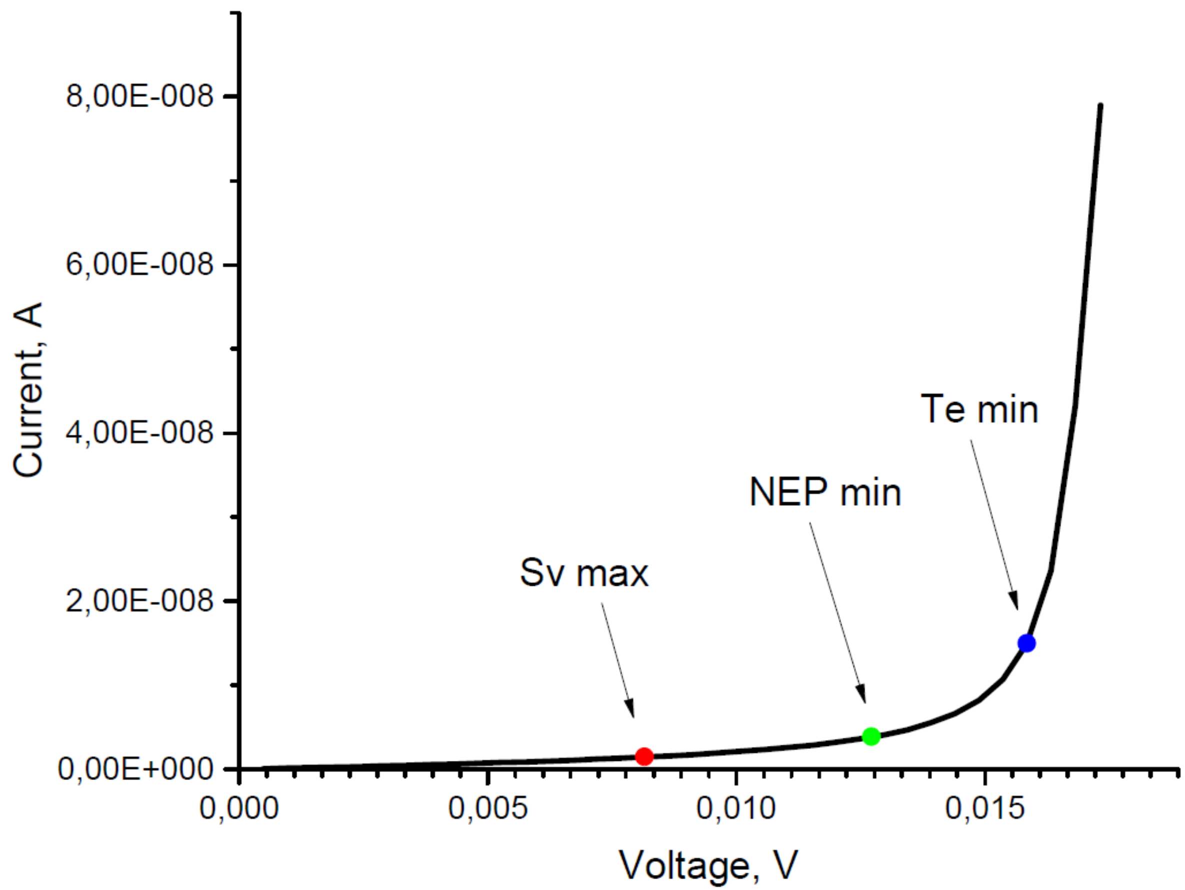
Announcement

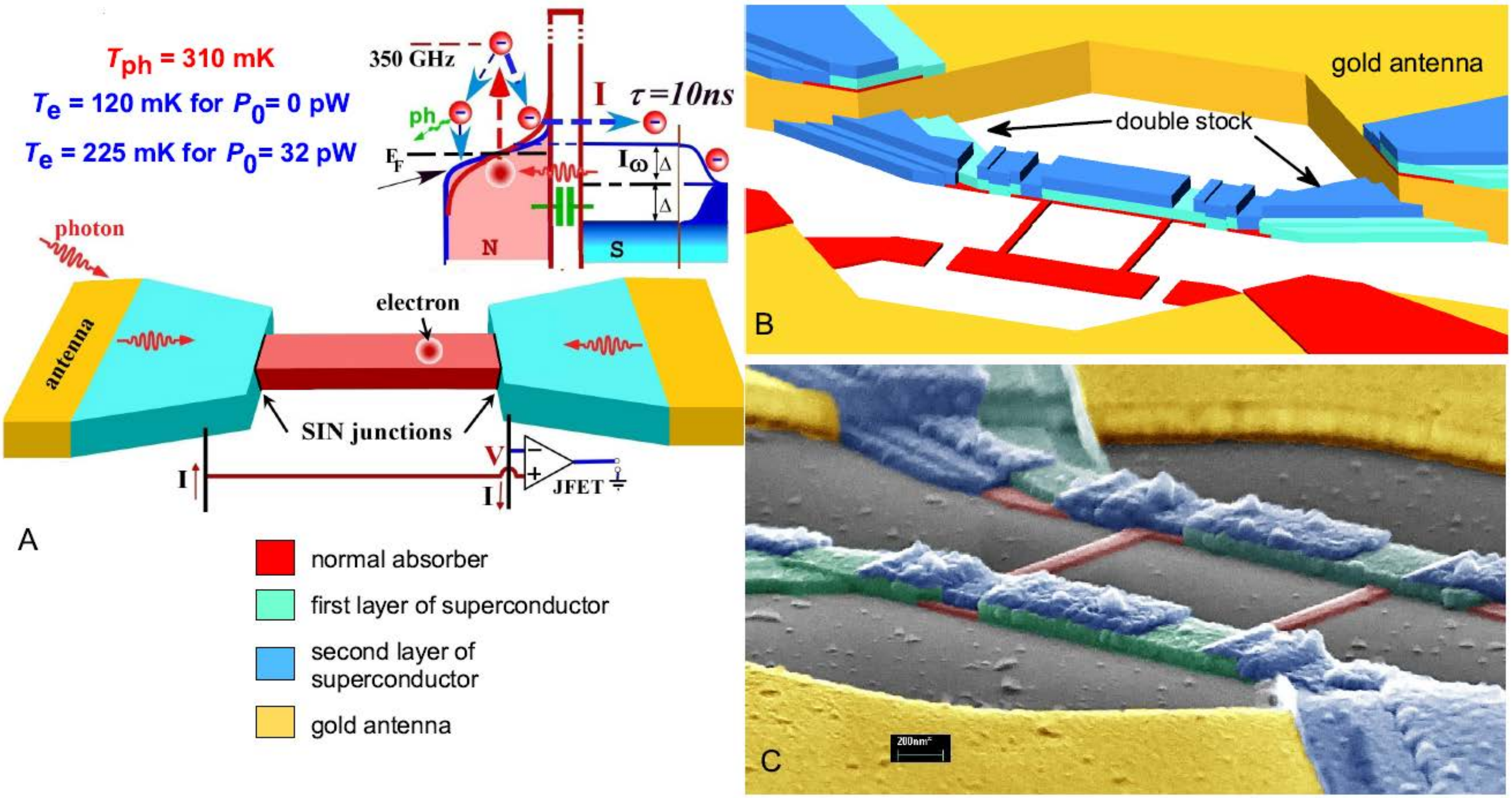
Carl Ganter is our reviewer of the month

Carl Ganter provided an exceptionally thorough review, stretching to verify the calculations presented in the paper.

Effective electron cooling decreases NEP



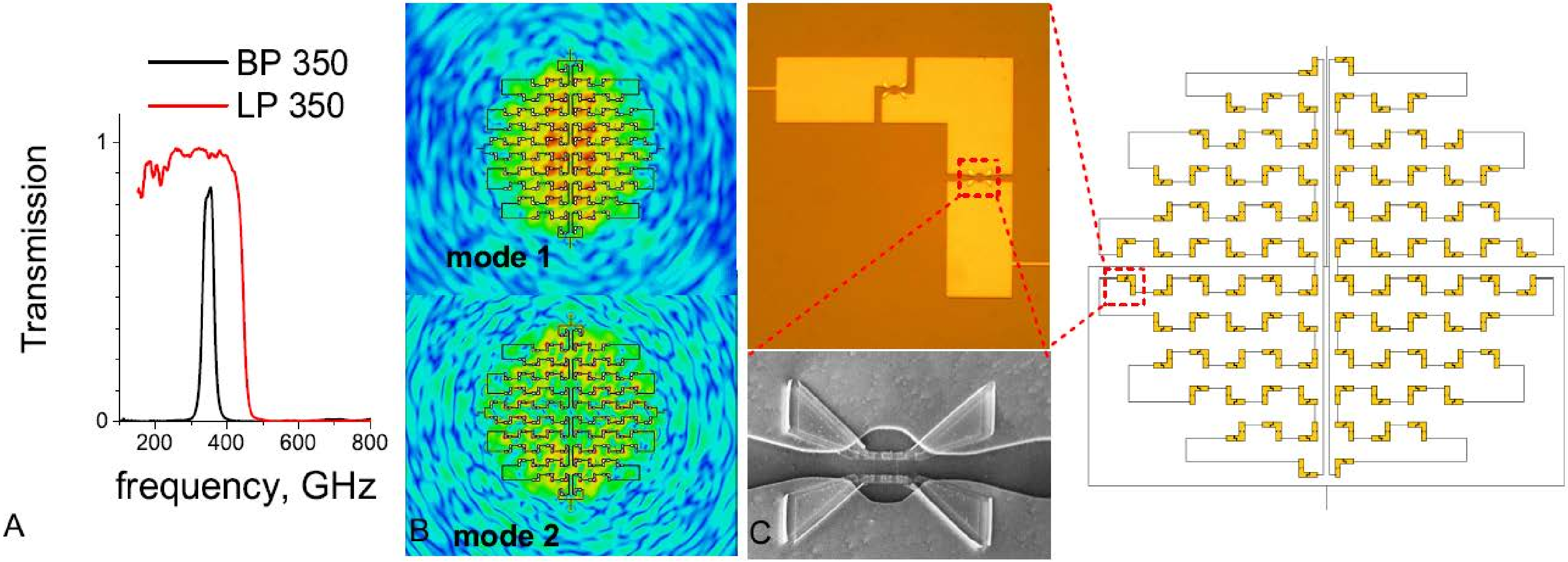




L.S. Kuzmin, A.L. Pankratov, A.V. Gordeeva, V.O. Zbrozhek, V.A. Shamporov, L.S. Revin, A.V. Blagodatkin, S. Masi, P. de Bernardis, Photon-noise-limited cold-electron bolometer based on strong electron self-cooling for high-performance cosmology missions, **Comm. Phys.,** 2, 104 (2019).

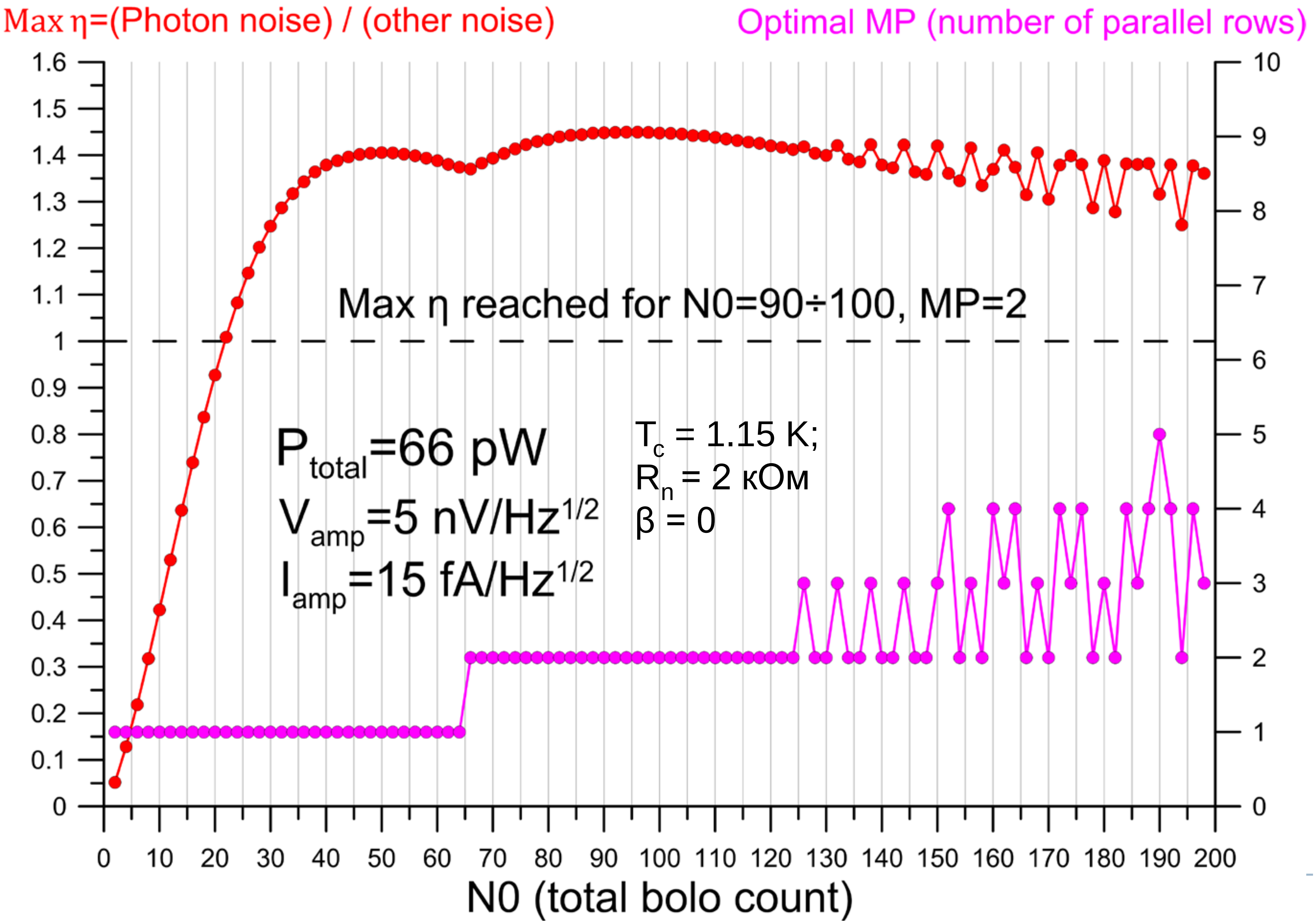
Patent № 178649

Patent № 2016616727

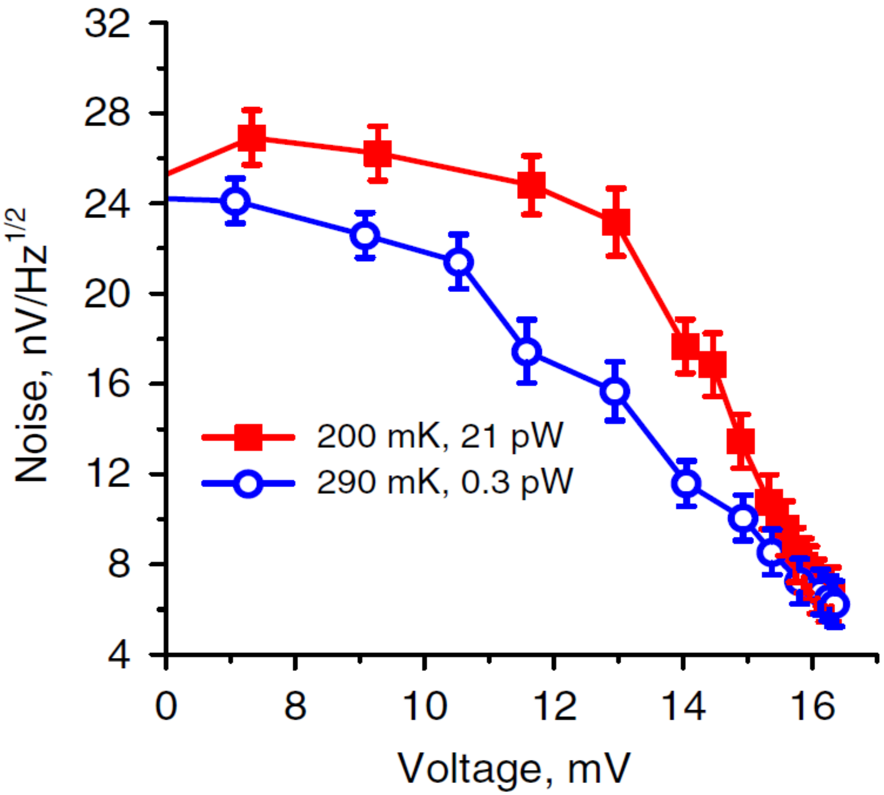


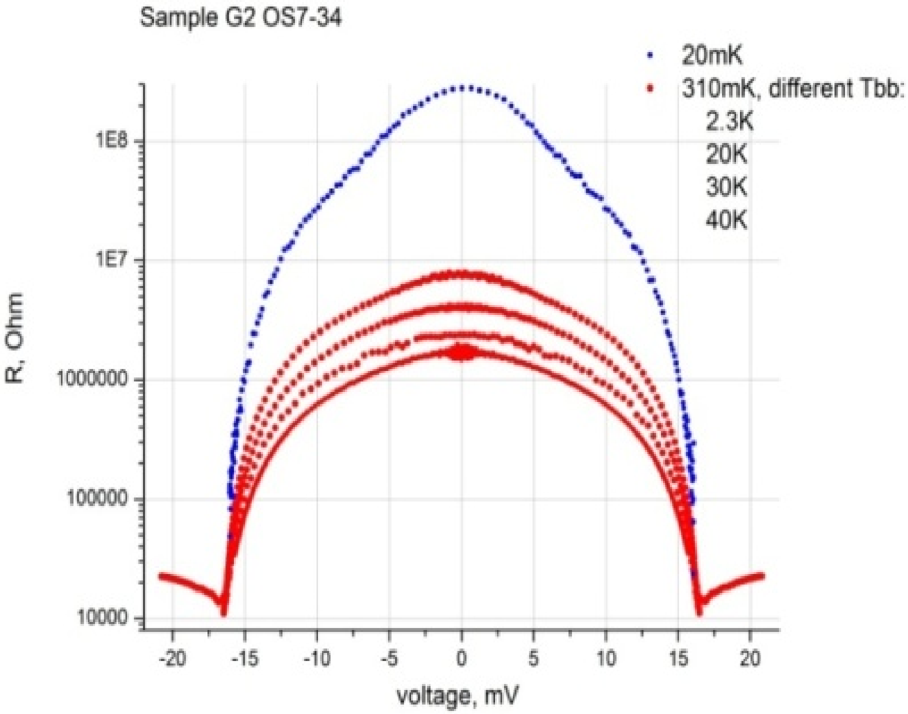
L.S. Kuzmin, A.L. Pankratov, A.V. Gordeeva, V.O. Zbrozhek, V.A. Shamporov, L.S. Revin, A.V. Blagodatkin, S. Masi, P. de Bernardis, Photon-noise-limited cold-electron bolometer based on strong electron self-cooling for high-performance cosmology missions, **Comm. Phys.,** 2, 104 (2019).

Optimization of the full bolometer number in series-parallel arrays



Measurements of a single pixel – photon noise contribution





Measurements of a single pixel

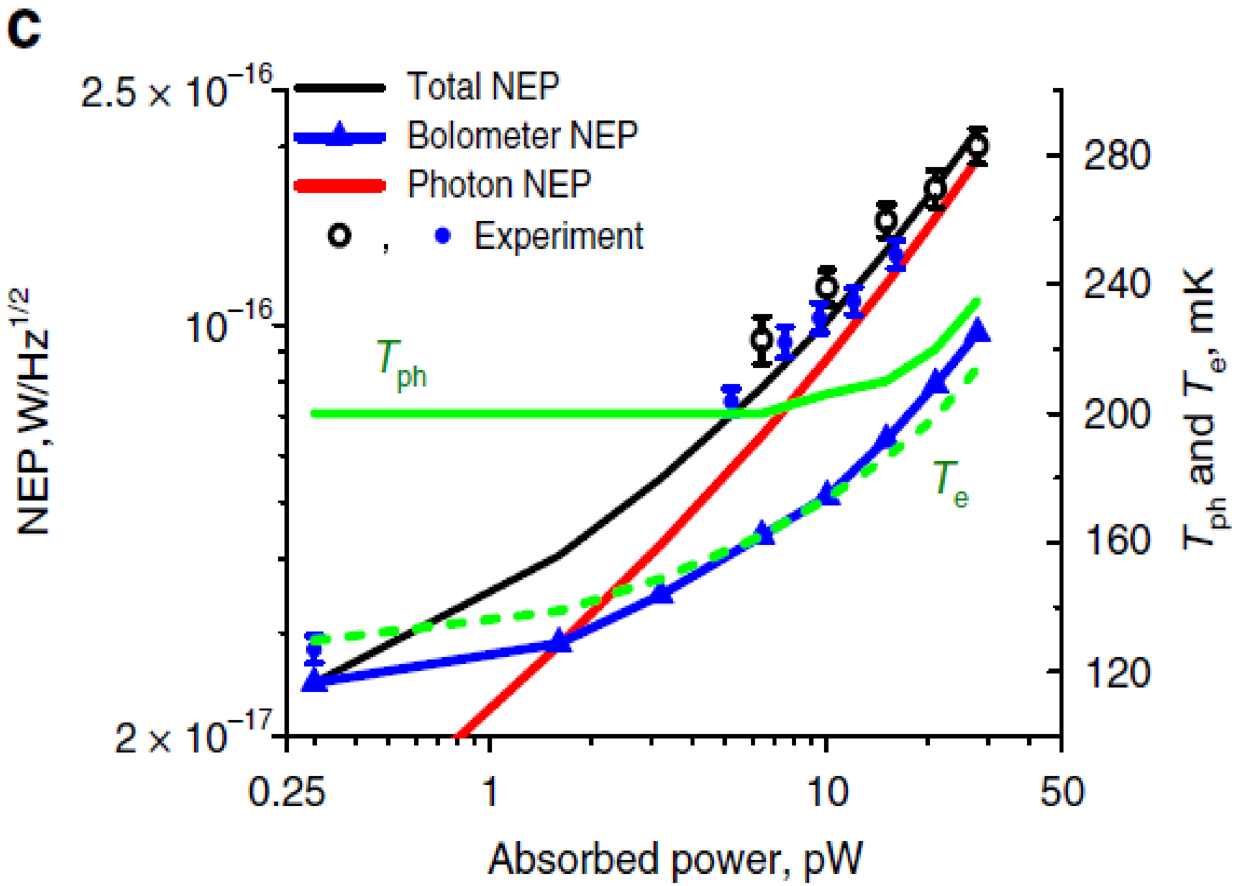
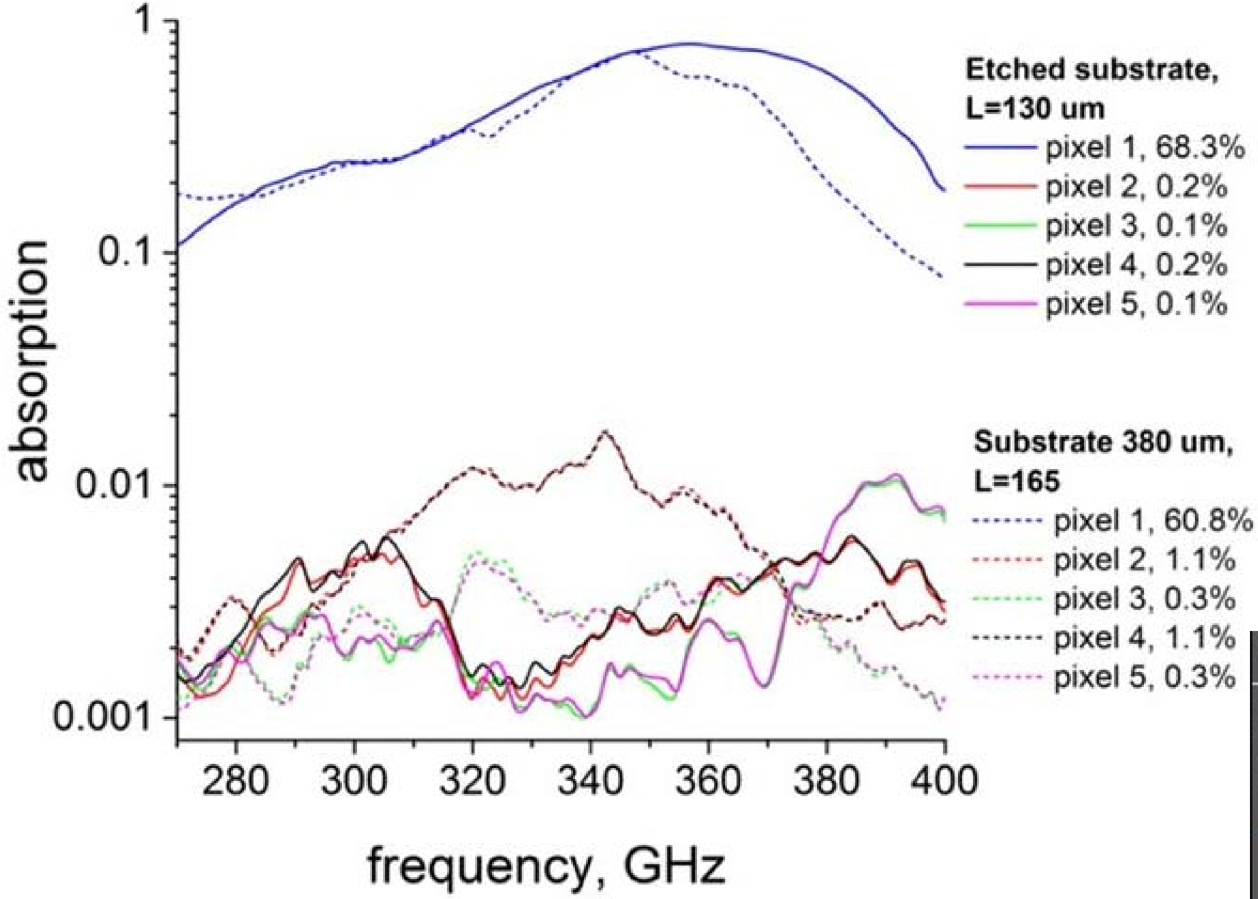
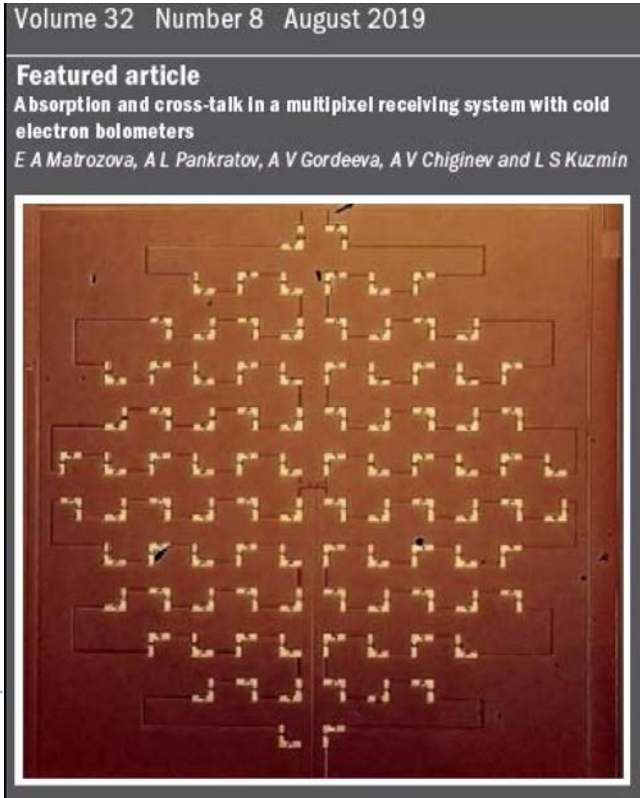


Fig.3c. NEP of the receiver. Red curve - photon NEP described by formula

$$\mathrm{NEP_{ph}} = \sqrt{P_0 hf + P_0^2/\delta f}$$

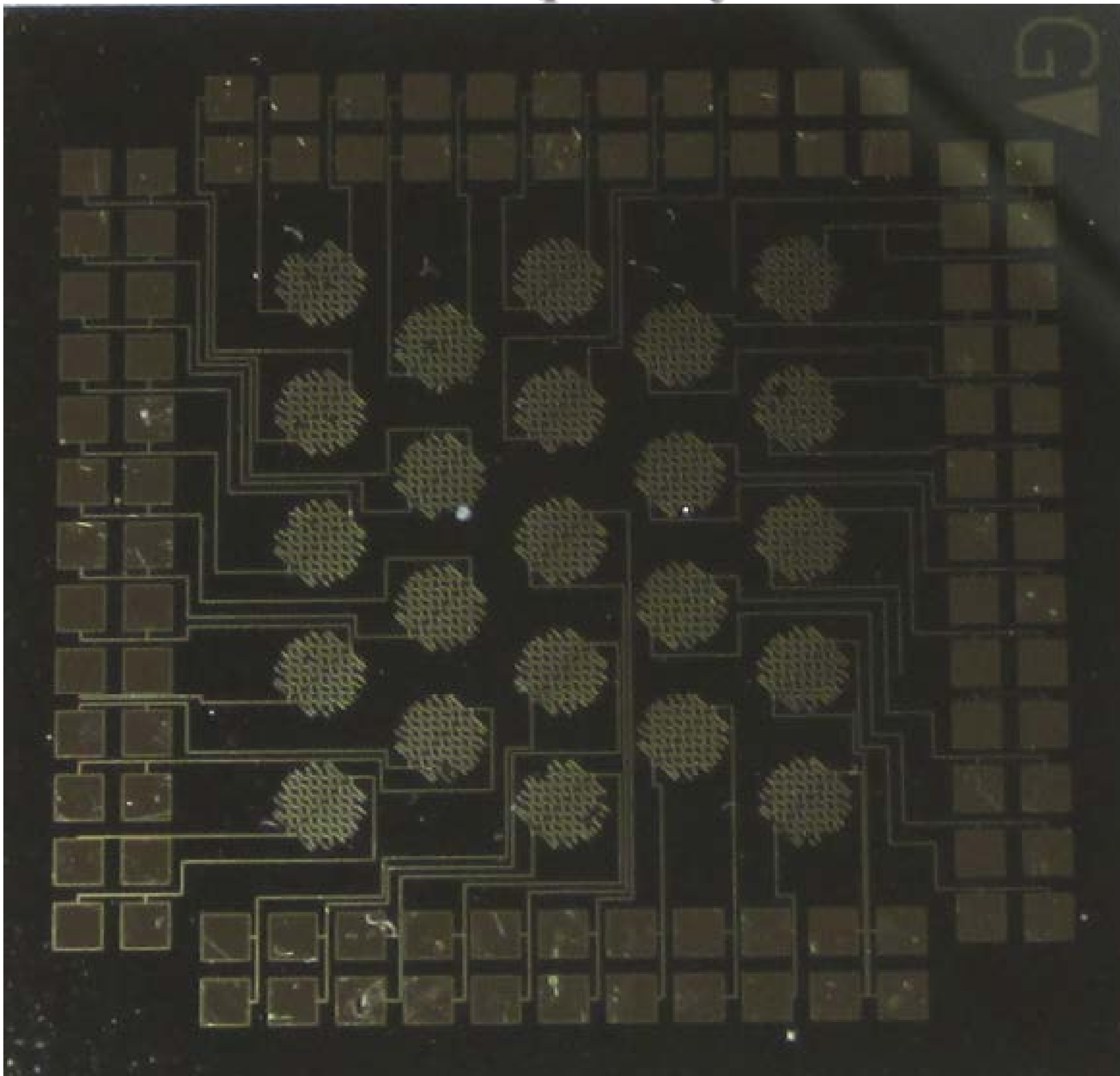




Comparison of λ/2 and 3λ/2 substrates
Cross-talk in multi-pixel systems

https://iopscience.iop.org/article/10.1088/1361-6668/ab151d

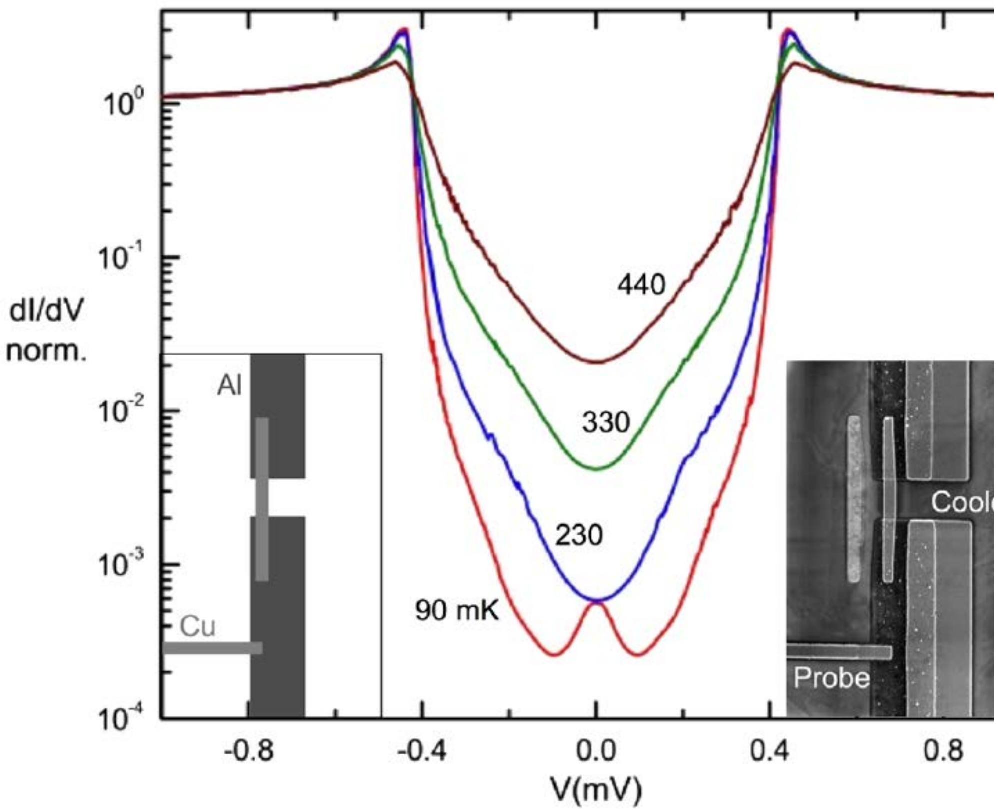
Photo of 23 pixel system

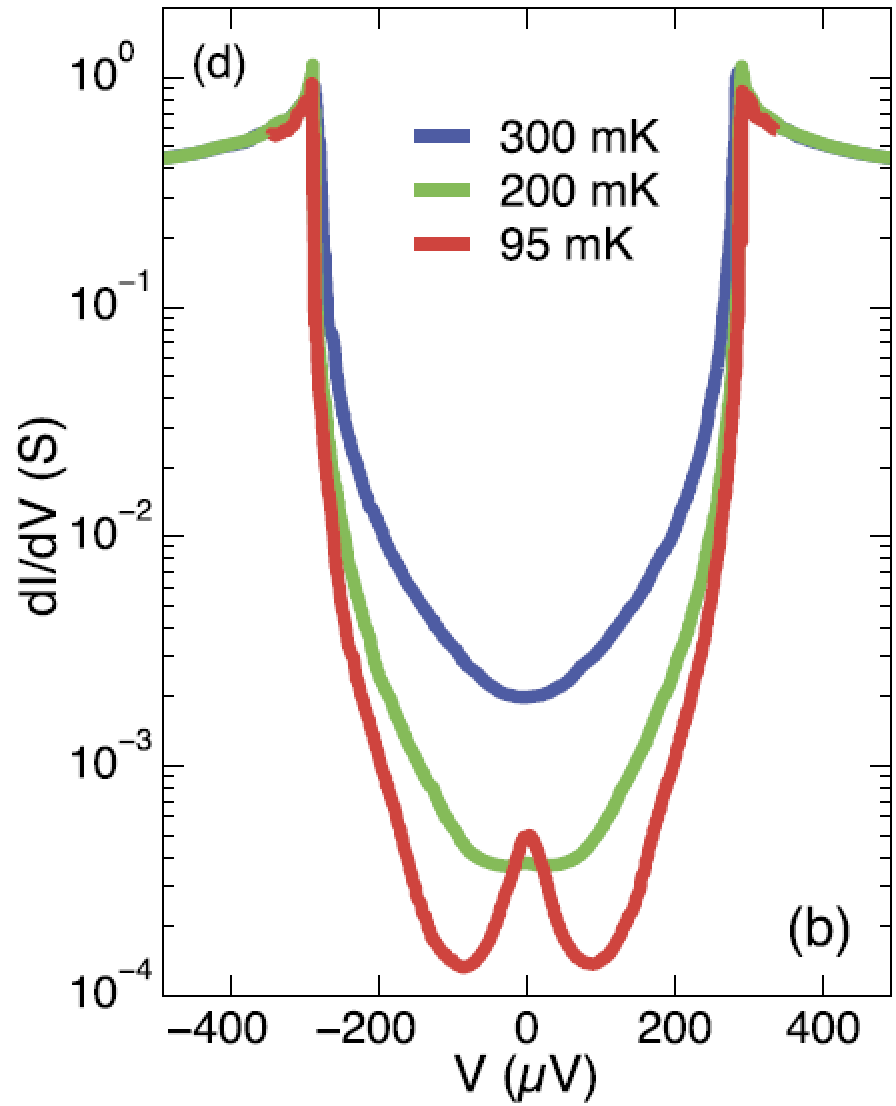


Effect of Andreev current (overheating)

B. J. van Wees, P. de Vries, P. Magnee, T. M. Klapwijk, Phys. Rev. Lett., 69, 510 (1992).

H. Courtois, H. Q. Nguyen, C. B. Winkelmann, J. P. Pekola, Comp. Ren. Phys. 17, 1139 (2016).





Suppression of Andreev current

APPLIED PHYSICS LETTERS **103**, 032602 (2013)

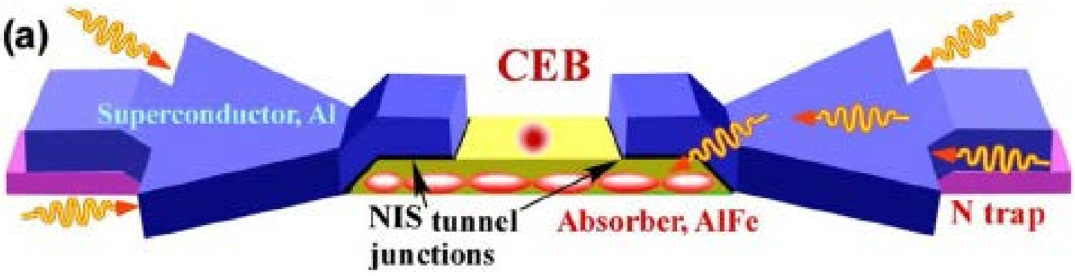
CrossMark
click for updates

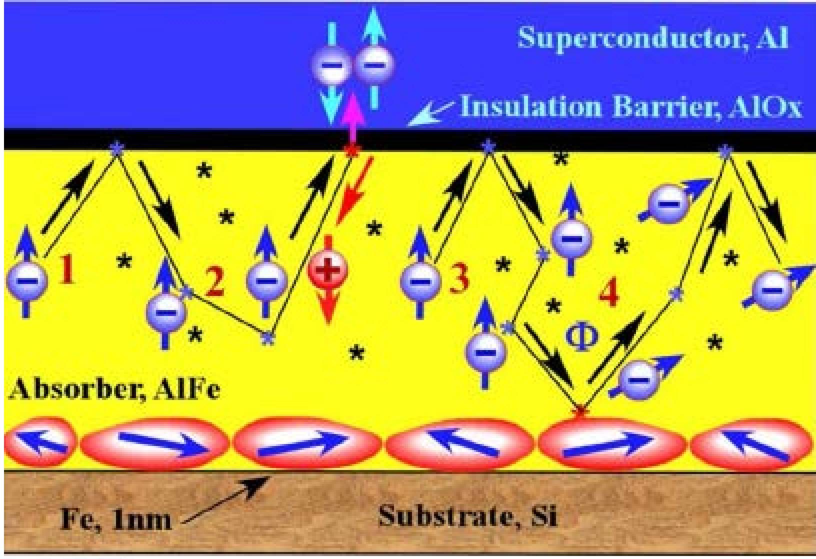
Efficient electron refrigeration using superconductor/spin-filter devices

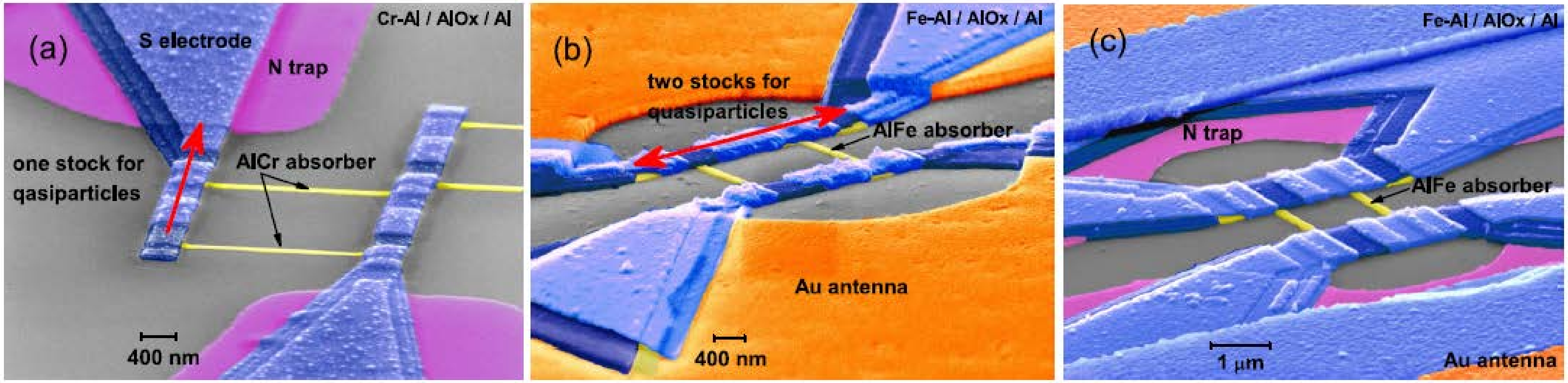
Shiro Kawabata,[1] Asier Ozaeta,[2] Andrey S. Vasenko,[3] Frank W. J. Hekking,[3,4]
and F. Sebastián Bergeret[2,5]

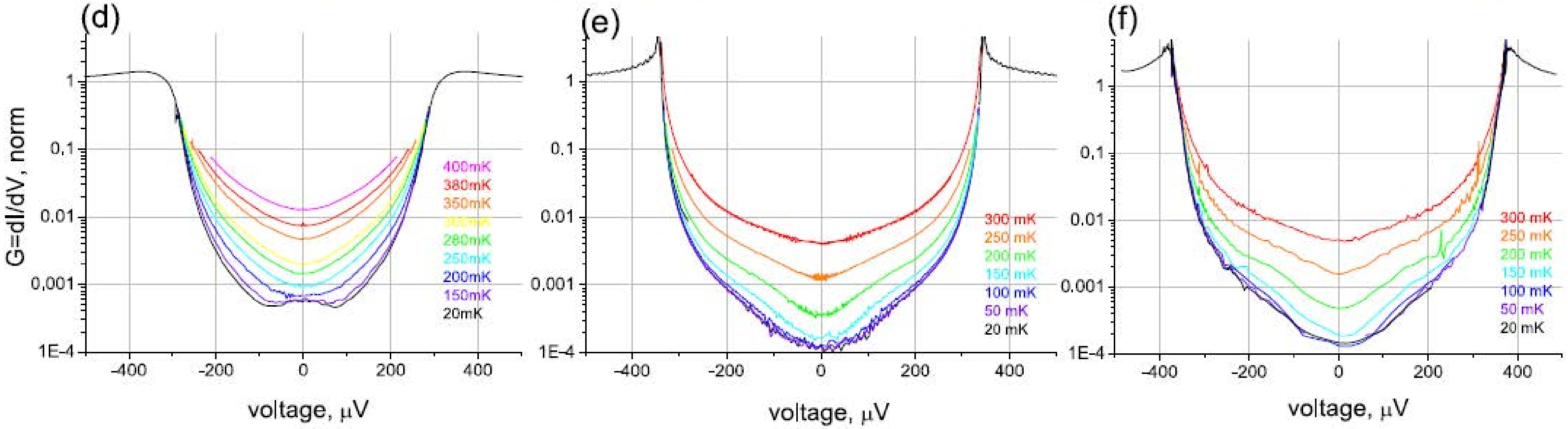
It is proposed to use hybrid superconductor/ferromagnet structures to increase the efficiency of electron cooling. It is argued that in this case, cooling from **300 to 50 mK** is possible**!**

Suppression of Andreev current

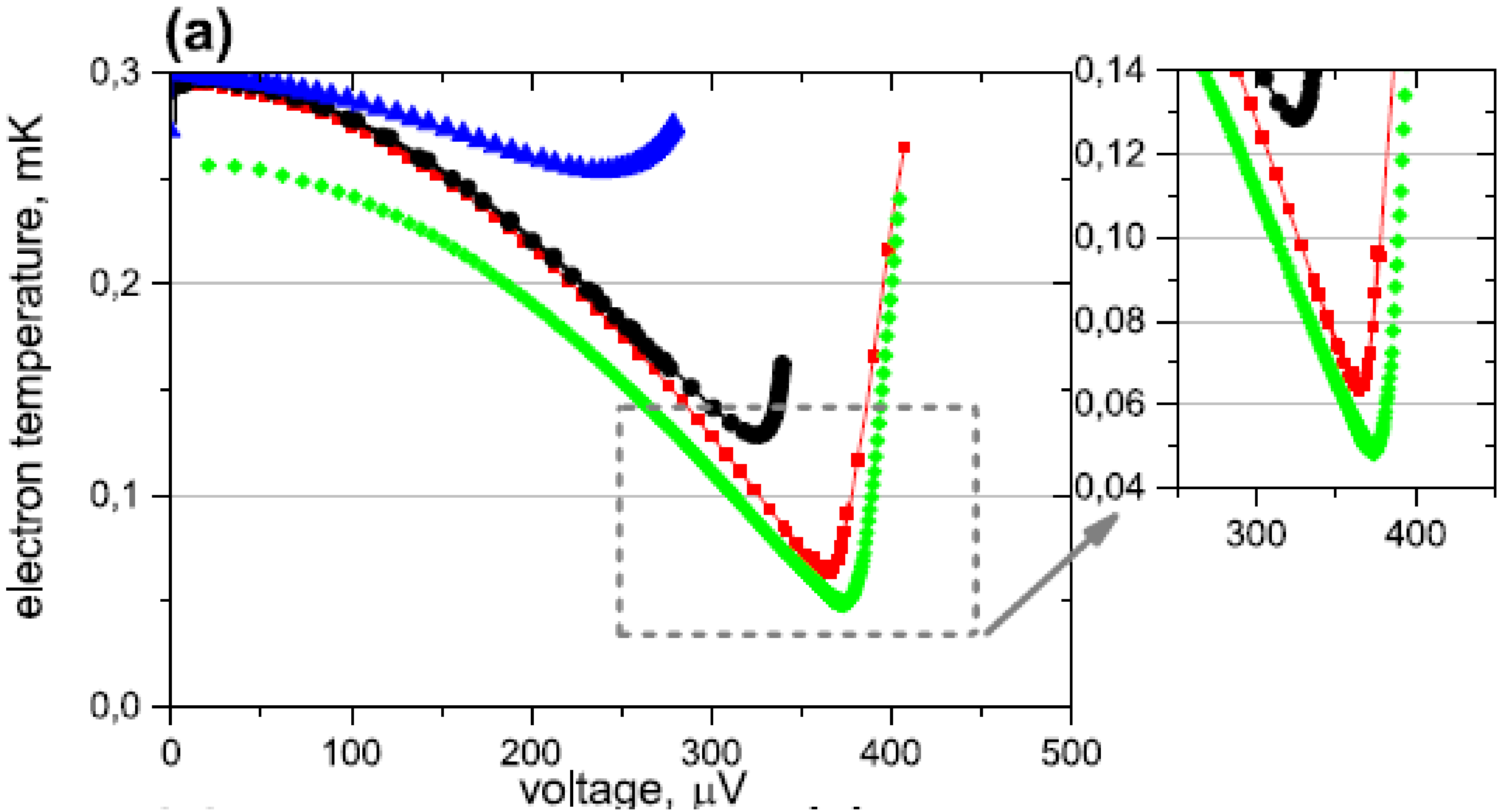








Design 1 - Design 2 - Design 3



Record electron cooling from 300 to 65 mK!
And from 256 to 48 mK, by a factor of 5.3!

A.V. Gordeeva, A.L. Pankratov, et al, Scientific Reports, 10, 21961 (2020)
https://www.nature.com/articles/s41598-020-78869-z

Cosmic rays – dramatic problem!

M. Salatino, P. de Bernardis, L. Kuzmin, S. Mahashabde, S. Masi, J. of Low Temperature Physics (2014).

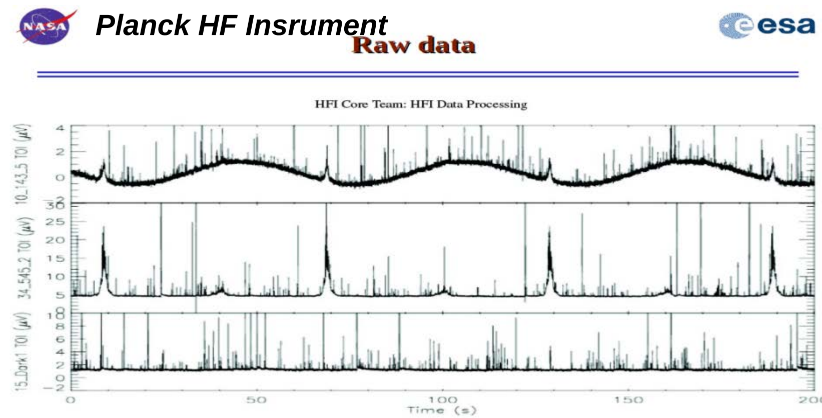
-137Cs source (660 keV photons)

- in front of the window

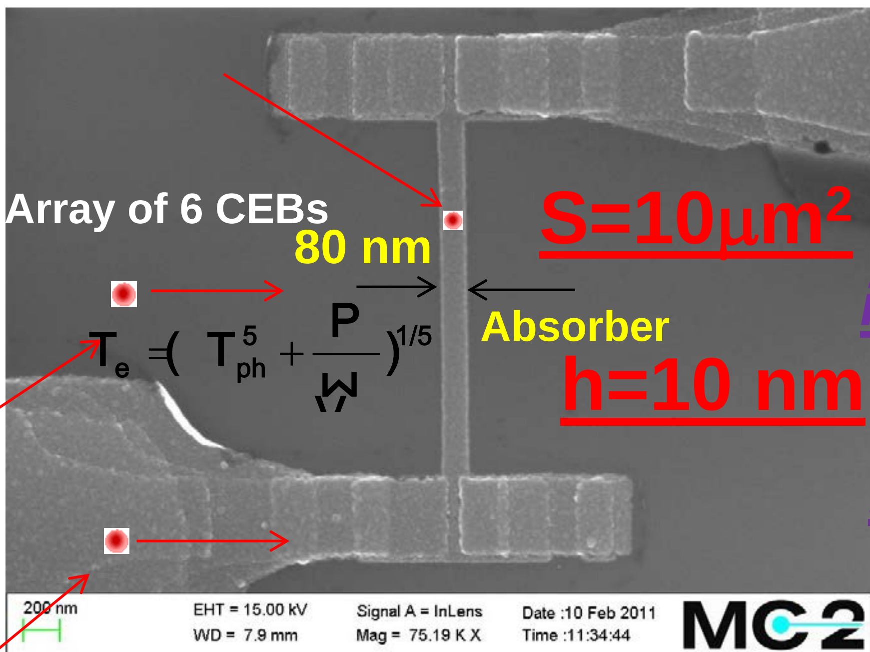
- No single glitch was detected!

Expectation time for a single glitch – 40 days!

Double protection against Cosmic Rays by extremly smalll volume of absorber and decoupling of electron and phonon systems!



CEB for LSPE



Gain

in Area

:1000

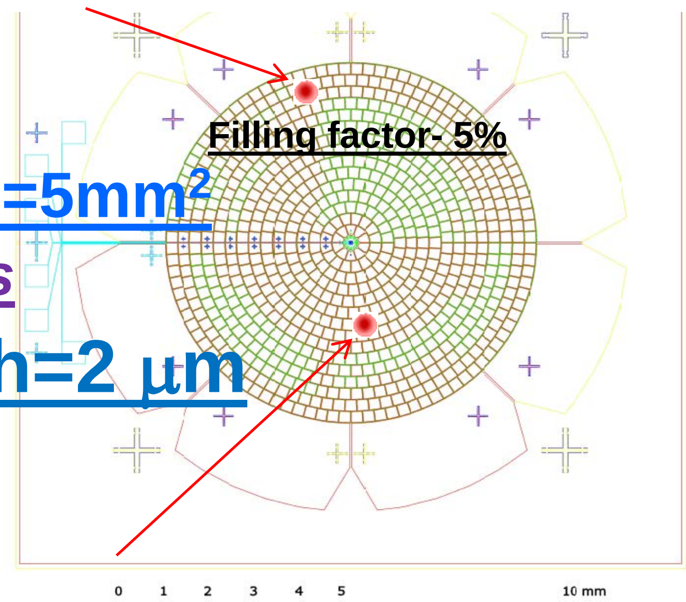
in thickness

:100

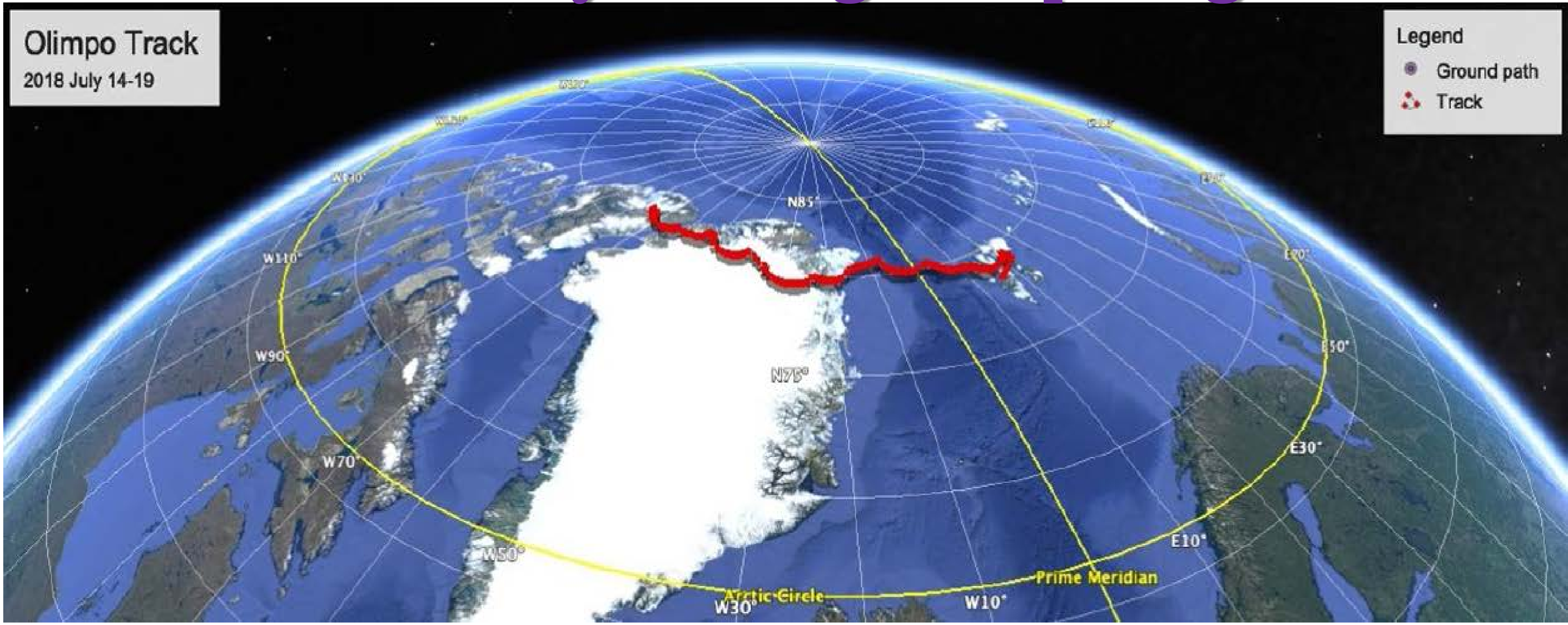
in volume

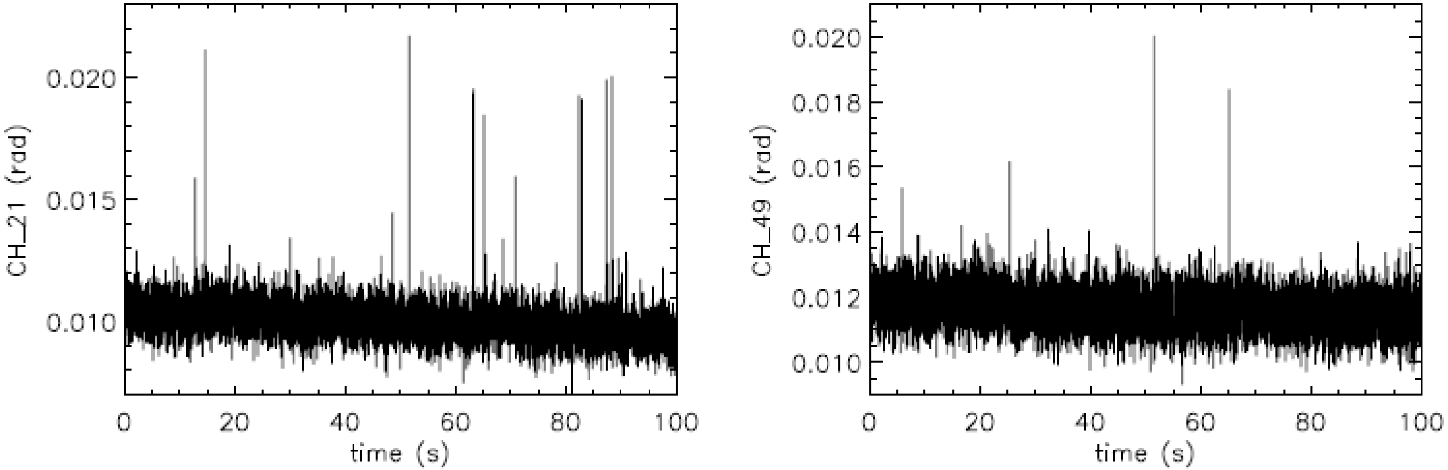
$:10^5$

Spider-web with TES for LSPE



Cosmic rays during Olimpo flight

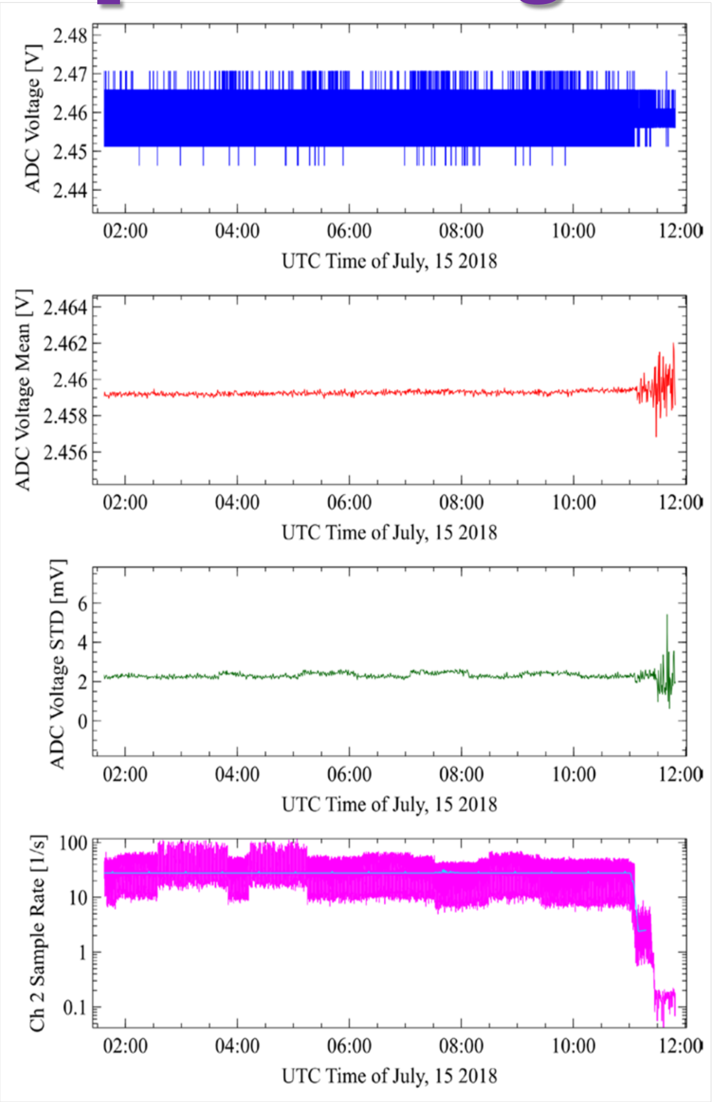




For KIDs – 2-3 glitches per minute!

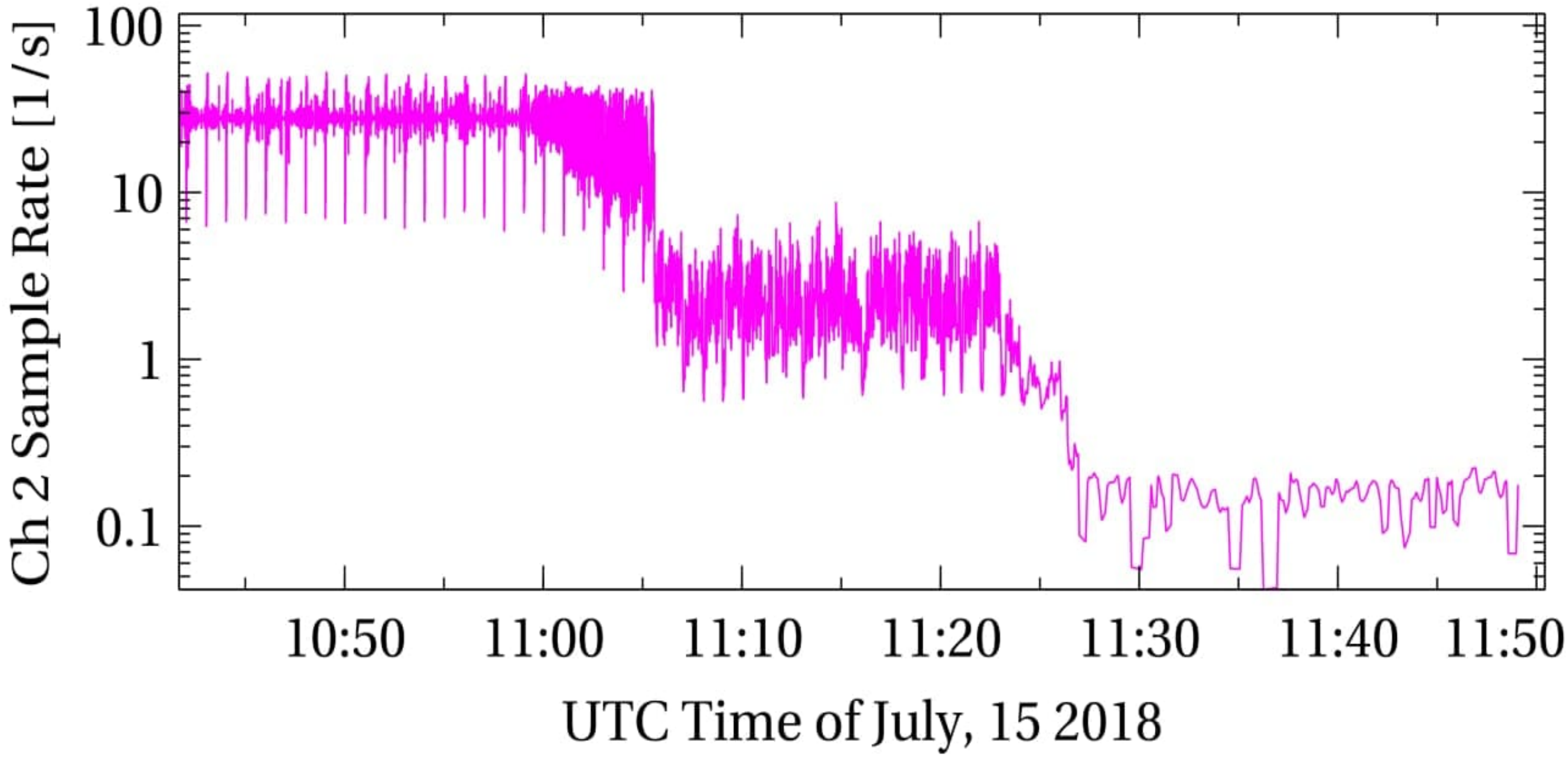
S. Masi, P. de Bernardis, A. Paiella et al, JCAP 07, 003 (2019)

CEB dark pixel during Olimpo flight



No CR events were detected from the dark CEB. This would confirm the high CR immunity of the CEB. However, since we did not detect any other signal from this channel during the entire flight, we cannot be sure that it was working properly.

Risky flights around Northern pole due to many military radars, which can destroy electronics



Conclusions

CEB arrays can be designed to work at photon-noise limited mode at any frequency of mm and submm region for any power load at 300 mK (without dilution refrigerator) due to effective self-cooling mechanism.

CEBs demonstrate high immunity to cosmic rays.

This work was supported by the Russian Science Foundation (projects 16-19-10468 and 21-79-20227).

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Guest Editors :

Prof. Dr. Leonid Kuzmin

kuzmin@chalmers.se

Prof. Dr. Andrey Pankratov

alp@ipmras.ru

Special Issue: Design and Application of Cold-Electron Bolometers

Submission Deadline: 31 May 2021

Bolometers have been extensively developed in recent years. The major pathway lowers the operating temperature to reach higher sensitivities. On-chip electron cooling by SIN (superconductor–insulator–normal metal) tunnel junctions decreases the electron temperature of the absorber, thus improving performance.

In this Special Issue, we invite submissions exploring the development of electron cooling, cold-electron bolometers, thermoelectric bolometers, and electron cooling platforms. Contributions can focus on different concepts and a vatiety of applications. Survey papers and reviews are also welcome.

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Keywords

- cold-electron bolometer (CEB)
- electron cooling
- nanoabsorber