I. SUPPLEMENTARY MATERIALS

Supplementary Note 1 | Time constants and cooling power

In Supplementary Figure 1 the heat conductance, the time constants and the powers from the heat balance equation (Equation (4) in the main article) are shown as a function of voltage across the bolometer array. As we have mentioned, the data above 15 mV (also note T_e, shown by dashed curve in Figure 3A in the main article) should be taken with awareness due to overheating of superconducting electrodes. All curves from this plot are obtained from fitting of IV-curve at 235 mK of the phonon temperature and 28 pW of the absorbed power.

The heat from the absorber can be removed through either electron-phonon interactions ($G_\text{e-ph} = 5\Sigma V_\mathrm{N} T_\mathrm{e}^4$ is the electron-phonon thermal conductance of the absorber) or the tunnel barrier ($G_\mathrm{COOL} = \partial P_\mathrm{COOL}/\partial T_\mathrm{e}$ is the cooling thermal conductance of the NIS (normal metal - insulator - superconductor) junction). As one can see, the heat conductance of the tunnel junction is ~ 20 times larger than the electron-phonon conductance at the bias point 13 mV. The ratio of two conductances is given by L (right axis).

The time constants of cold-electron bolometer (CEB) are obtained directly from the heat conductances [1]:

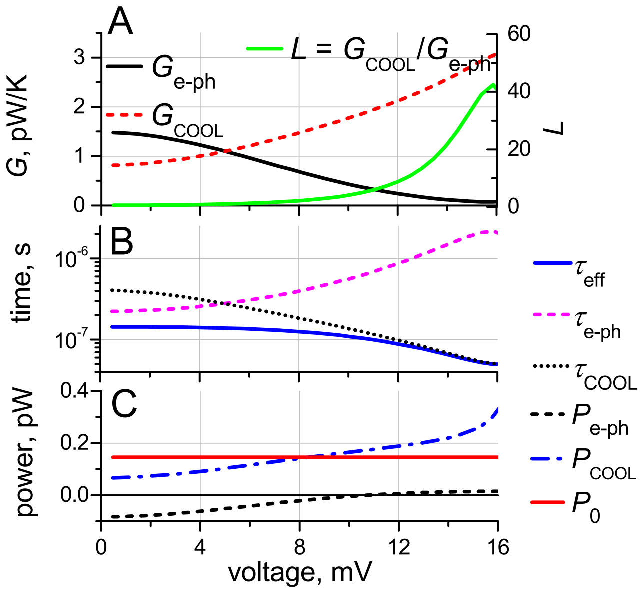
$$\begin{aligned}\tau_\mathrm{eff} &= \frac{V_\mathrm{N}\gamma T_\mathrm{e}}{G_\mathrm{COOL}+G_\text{e-ph}},\\ \tau_\mathrm{COOL} &= \frac{V_\mathrm{N}\gamma T_\mathrm{e}}{G_\mathrm{COOL}},\\ \tau_\text{e-ph} &= \tau_\mathrm{eff}(L+1),\end{aligned} \tag{1}$$

where $\gamma = 9.77 \cdot 10^{-17}$ J/(μm^{3}K^2) is the electron specific heat. The calculated time constants are shown in Supplementary Figure 1B. It can be seen, that at the bias point the time constant of CEB is determined by the tunneling time.

Three main powers, which balance the heat flow in CEB, are shown in Supplementary Figure 1C for one bolometer of an array. $P_\text{e-ph}$ removes the heat from the absorber if the bolometer array is biased below 10 mV. Above 10 mV it changes the sign and heats the absorber together with incoming radiation (P_0).

Supplementary Note 2 | Experimental setup

A scheme of the experimental setup is shown in Supplementary Figure 2. The black body is a copper cone covered from inside with a specially made black paint, and is attached to the 4 K cryostat plate. The sample holder is attached to the 10 mK plate. Due to thermal decoupling of the black body and the sample we can change the black body temperature in a broad range. The sample is placed inside a cylinder sample holder, made of copper. There are two filters on top of the sample holder and one filter on the black body. The distance between the black body edge and the filters on the sample holder is less than 1 cm. After filters the radiation from the black body goes through the back-to-back horn and silicon substrate. The antennas and the bolometers are situated from the bottom side of the substrate. The horn is a multi-mode horn, which transmits three modes of radiation at 350 GHz (two of them with two orthogonal polarizations). The total power, radiated from the black body is much higher than



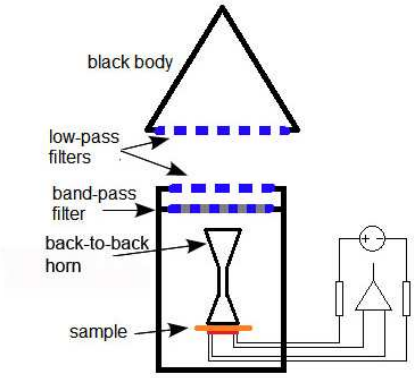
Supplementary Figure 1: Characteristics of cold-electron bolometer array versus voltage. A) Left axis: Electron-phonon thermal conductance and cooling conductance through the NIS junctions. Right axis: ratio of two conductances. B) Time scales of cooling processes. C) Cooling/heating powers (for one bolometer from the array) due to electron-phonon interaction ($P_{\text{e-ph}}$), due to NIS tunneling (P_{COOL}) and due to absorbtion of radiation (P_0). For all figures the cryostat temperature 200mK, black body temperature 35K, chip phonon temperature 235 mK, absorbed power 28 pW.

the power, reaching the sample. The rest of the radiated power is dissipated in the sample holder walls and in the cryostat shields. That is why we detect the heating of the sample substrate with increase of the black body temperature. This heating is measured with on-chip thermometers, made with the same technology as the bolometers.

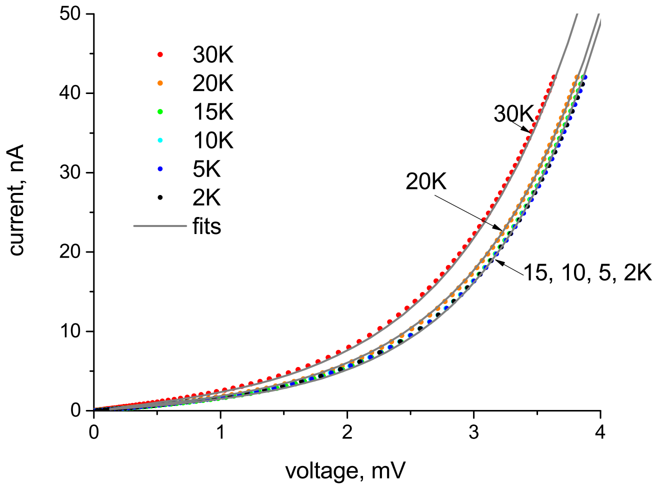
The thermometer is an array of SIN junctions with 32 series and 4 parallel connections. Its IV-curves have been fitted with the same heat balance model (equation (4) in the mail article), as we use for bolometers, but with simplifications. The term P_0 is absent, while terms βP_{S} and P_{COOL} are with the coefficient 1.The equation (5) from the mail article is not used for thermometer.

The parameters of the thermometer are: the normal resistance of the whole structure is 7.5 kOhm, the volume of normal electrode is $0.12\mu\text{m}^3$. For black body at temperatures $2.3 - 15$ K the phonon temperature of the thermometer coincides with the temperature of the cryostat plate. The phonon temperature is a fitting parameter. We have found, that for described setup the thermometer is heated up by 6 mK for black body temperature $T_{\text{bb}} = 20$ K, and by 20 mK for $T_{\text{bb}} = 30$, see Supplementary Figure 3.

The normal state resistance R_{n} of bolometer and thermometer arrays is measured above the critical temperature of aluminum. Also it can be measured below the critical temperature, but it requires voltages 3-4 times higher than the gap, because the IV-curve approaches the asymptotic line $V = I * R_{\text{n}}$ very slowly. This is illustrated in Supplementary Figure 4, where the differential resistance of the array is plotted versus voltage at the cryostat temperature 200 mK and the normal state resistance is shown by the blue line. It is seen that one needs much higher voltages than 20 mV, shown in the figure, to reach



Supplementary Figure 2: Scheme of the experimental setup.

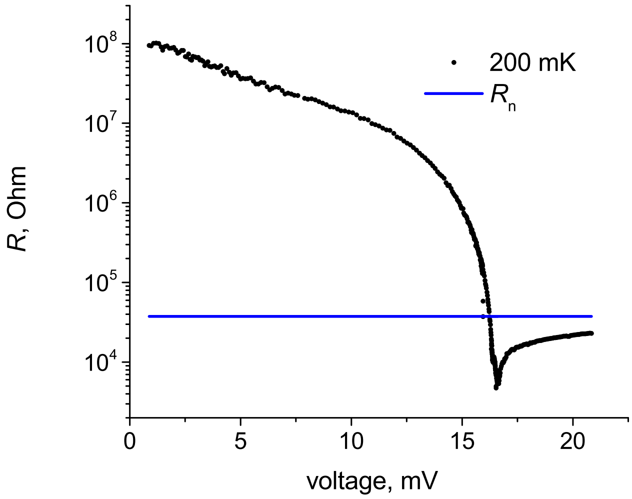


Supplementary Figure 3: Thermometer IV-curves for several temperatures of the black body. Cryostat plate temperature 310 mK. Dots - experiment, gray lines - fit.

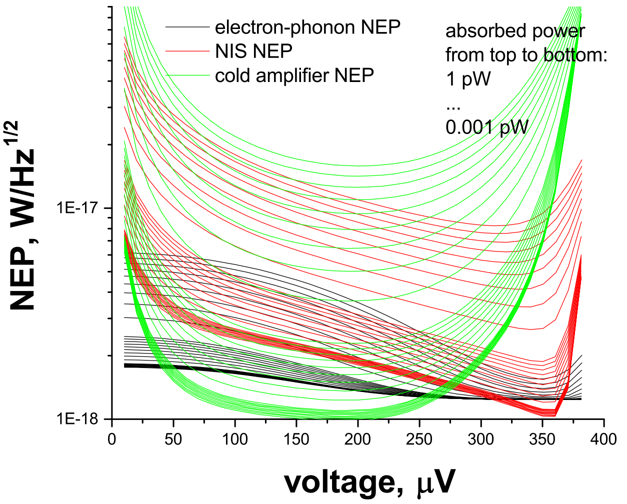
the resistance R_{n}. Therefore, it is more convenient to measure R_{n} just above the critical temperature.

Supplementary Note 3 | Components of NEP in cold electron bolometer

In Supplementary Figure 5 three componenets of NEP versus single CEB voltage are presented for various power loads from 0.001 pW to 1 pW. One can see that the electron-phonon NEP approaches the level of $1.2 \cdot 10^{-18}$ W/Hz$^{1/2}$. Other NEP components reach even smaller values, but their minima are located at different voltage values. Therefore the sum of three components (the bolometer NEP) will have the minimum at voltage 300 μV reaching the value of $2.4 \cdot 10^{-18}$ W/Hz$^{1/2}$ for powers below 0.01 pW.



Supplementary Figure 4: The differential resistance of the bolometer array at 200 mK. The blue line is the resistance of the array in normal state, measured at 1.5 K.



Supplementary Figure 5: Three NEP components of single CEB versus voltage for different power loads and plate temperature 260 mK. The power changes over three decades: from 0.001 pW to 0.01 pW with step 0.001 pW, from 0.01 pW to 0.1 pW with step 0.01 pW and from 0.1 pW to 1 pW with step 0.1 pW.

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[1] Golubev, D. & Kuzmin, L. Nonequilibrium theory of a hot-electron bolometer with normal metal-insulator-superconductor tunnel junction. *Journ. Appl. Phys*, **89**, 6464 (2001).