Kinetic Inductance Detectors for space applications

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Outline

1 – Sensitivity

- Where we are now
- What are the needs for space-based applications
- Possible solutions

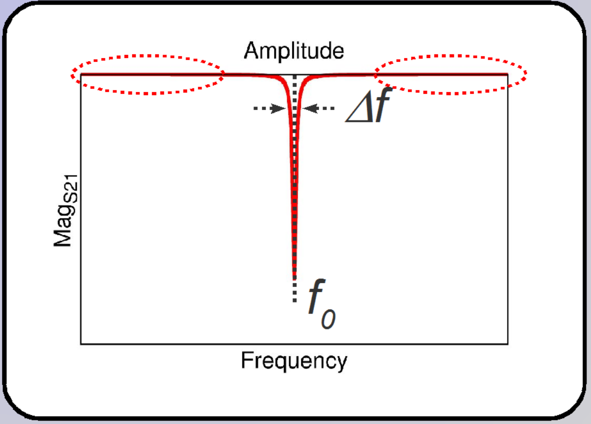
2 – The Cosmic Rays issue

- Effect on the detectors
- Latest measurements
- Possible solutions

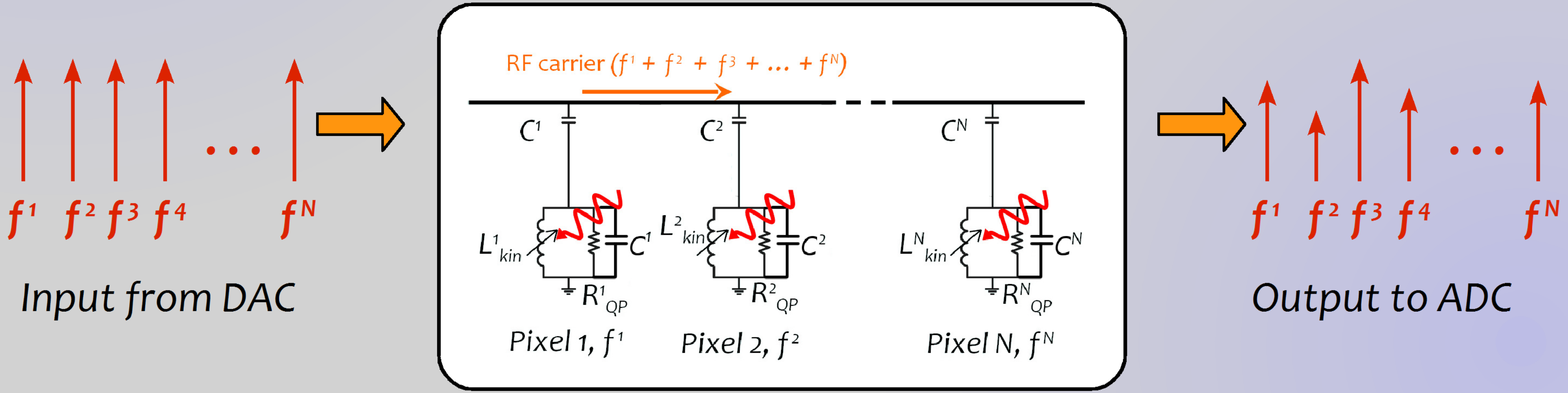
3 – Bonus: cryogenics for space applications!

Kinetic Inductance Detectors

- Superconducting resonators with extremely high quality factors
- The resonant frequency shifts upon the absorption of radiation



- *Intrinsically multiplexable in FD!*



- High MUX factor → low thermal load, simple cold electronics, ...

Sensitivity

Ground based applications : ***ok !***

- High background load
- Consequently, high photon noise level

NIKA pixels : $P_{opt} \sim 10pW \rightarrow NEP_{ph} \sim 5 \cdot 10^{-17} W / Hz^{0.5}$

- Low noise and at the same time **a large dynamic range**

Ideally : $Q_c \sim Q_i$

NIKA :

Al pixels
Strongly coupled to readout line

	150GHz	225GHz
# of det	132	224
NEP (@ 10Hz)	$\sim 8 \cdot 10^{-17} W / Hz^{0.5}$	$\sim 2 \cdot 10^{-16} W / Hz^{0.5}$
NEFD	$15mJy \cdot s^{1/2}/beam$	$30mJy \cdot s^{1/2}/beam$

Sensitivity

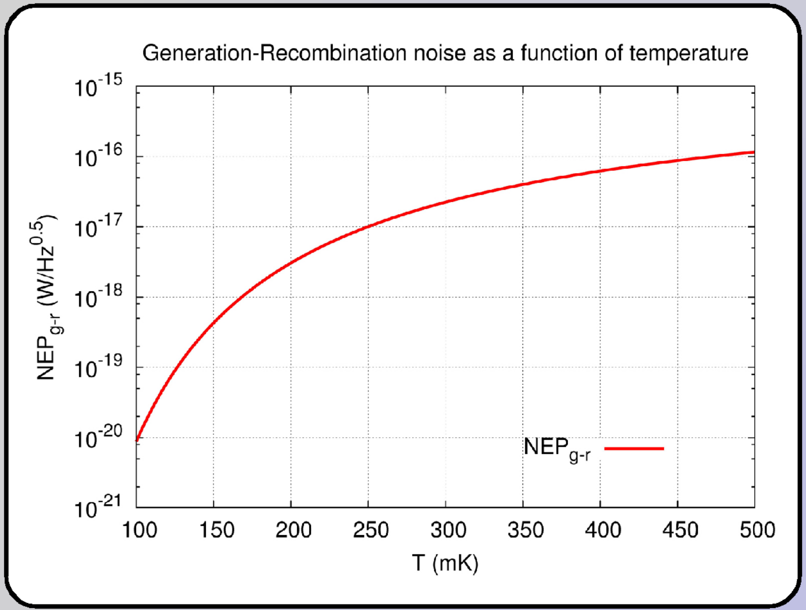
Space based applications : ***to be demonstrated...***

- Background is very low (black body @ 3K)
- $NEP_{ph} \sim 3 \cdot 10^{-18}\ W / Hz^{0.5}$
- A factor ~ **30** must be gained

The good news :

- The fundamental noise limit is given by the *generation-recombination noise* (in theory..)

$$NEP_{g\text{-}r} \propto n_{qp} \propto \exp(-T)$$

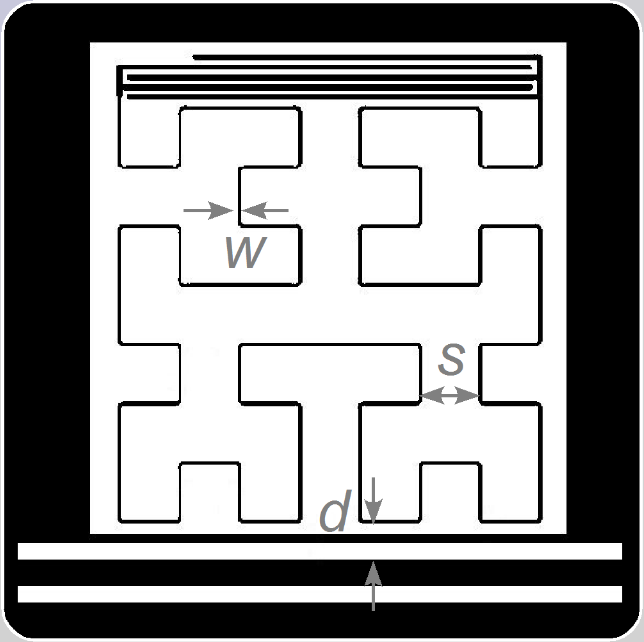


Optimizing sensitivity : *geometry*

The responsivity of a KID is given by:

$$\frac{\delta\theta}{\delta n_{qp}} \propto \frac{\alpha Q}{V}$$

- The geometry can be easily optimized for the expected signal!



For example, in the case of LEKIDs:

w – change the effective impedance Z_{eff}, the volume *V* of the absorber, $L_k(\rightarrow\alpha)$

s – change Z_{eff}, the length of the line *l*, the surface filling factor

d – change the coupling → Q_c → the *power handling*

t – change $L_k(\rightarrow\alpha)$, Z_{eff}, *V*

Optimizing sensitivity : *materials*

The responsivity of a KID is given by:

$$\frac{\delta\theta}{\delta n_{qp}} \propto \frac{\alpha Q}{V}$$

- A wide variety of possible solutions is available

- Al

  $T_c \approx 1.4K$

  $\nu_{gap} \approx 100GHz$

Uniform films
Long qp lifetime (~100μs)
Ideally suited for ground

- TiN

  $T_c \approx 0\text{-}4K$

  $\nu_{gap} \approx 0\text{-}300GHz$

Very high L_k
First tests already carried out →

$NEP \approx \mathbf{5 \cdot 10^{-18}\ W/Hz^{0.5}}$ for $P_{opt} \approx 0.1\ pW$

- NbSi

  $T_c \approx 0\text{-}8K$

  $\nu_{gap} \approx 0\text{-}600GHz$

Very high L_k
A lot of know-how in France

Optimizing sensitivity : *materials*

- TiN

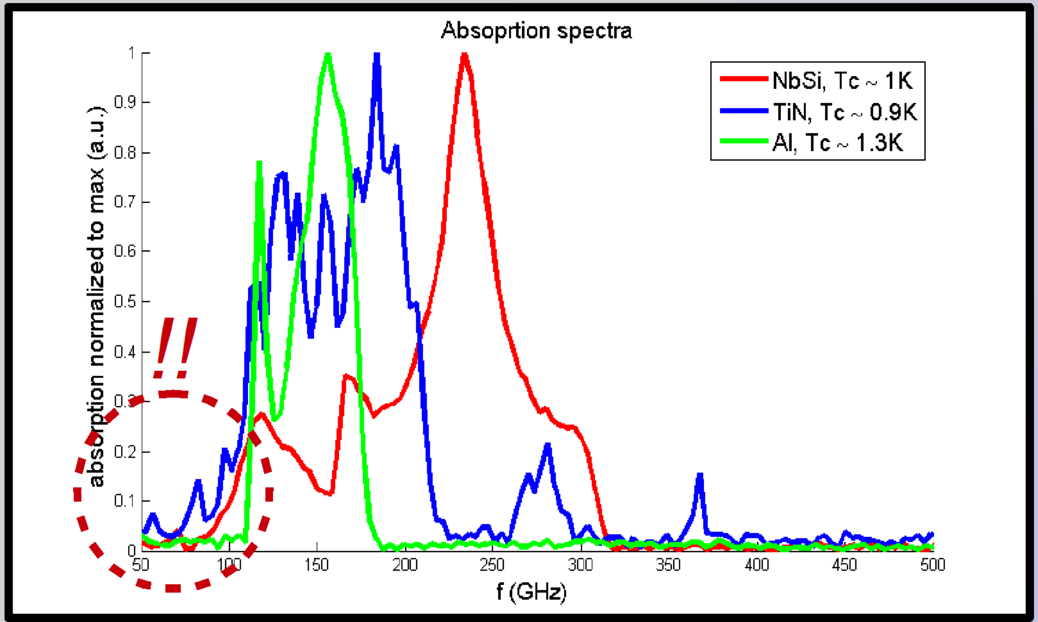
$T_c \approx$ 0-4K

$\nu_{gap} \approx$ 0-300GHz

- NbSi

$T_c \approx$ 0-8K

$\nu_{gap} \approx$ 0-600GHz



But *careful*...

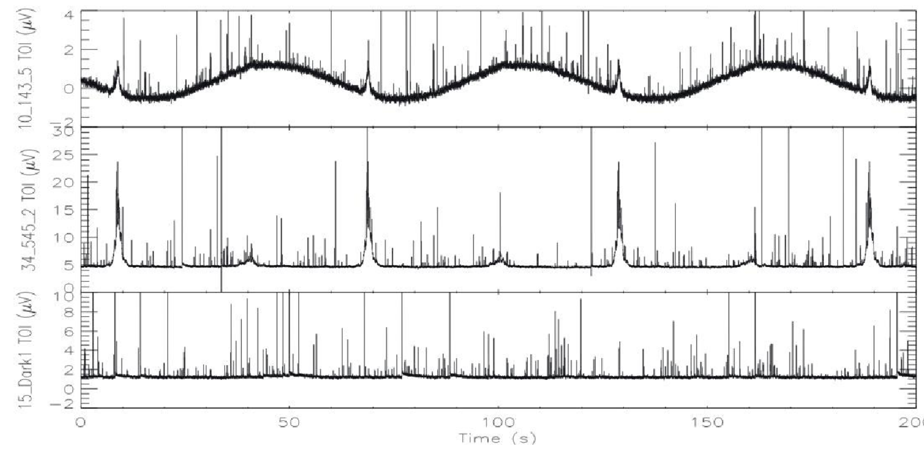
No sharp cutoff is observed below ν_{gap}

- Films are not uniform?
- 'Below-gap' energy levels?

To be investigated...

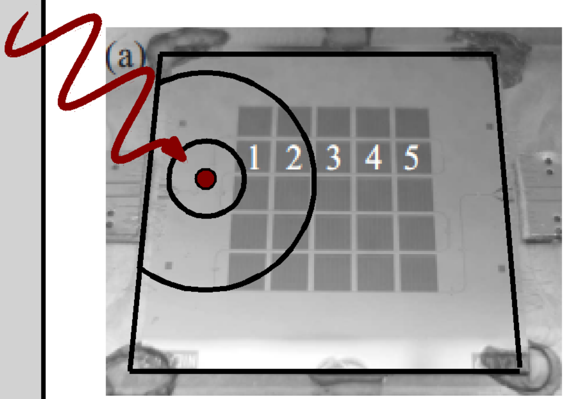
The Cosmic Rays

- In space, the detectors are always exposed to a flux of high-energy particles
- The induced glitches can lead to the loss of a substantial fraction of the data
- For example, *Planck* : ~ 1 glitch/s



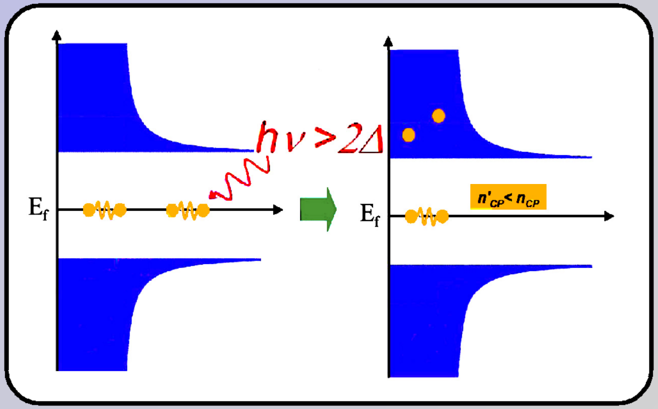
Planck HFI Core team
A&A 536, A6 (2011)

- Until now, full substrates have always been used for the KID!



Advantages of KID

1 – Presence of a band gap in the distribution of energy levels :



- Only photons and phonons of sufficiently high energy can break the Cooper Pairs
- For $T \ll T_c$ the detectors are well thermally isolated from the substrate
- They are not sensitive to thermal effects!

2 – Fast response :

- The response speed is determined by the quasiparticles lifetime, τ_{qp}
- Typically, τ_{qp} is of the order of few hundreds μs
- For the same rate of CR, less data are lost !

How to improve?

KID on membrane: hinder the phonons propagation, decrease the deposited energy

KID on multilayer: maximize the thermal isolation of the detectors

KID on lower resistivity substrates: speed up the downconversion of high energy phonons

KID on etched substrates: lower the effective area of the substrate

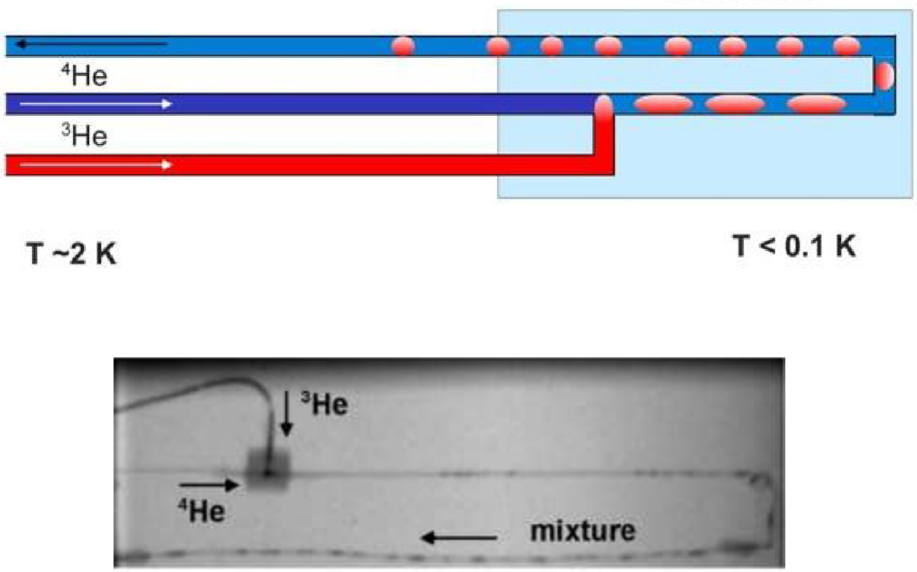
KID suspended via phonon deflectors: block phonon propagation

Or the 'backup solution':

Mosaic-like arrays: each CR hit affects only a sub-sample of the whole focal plane.

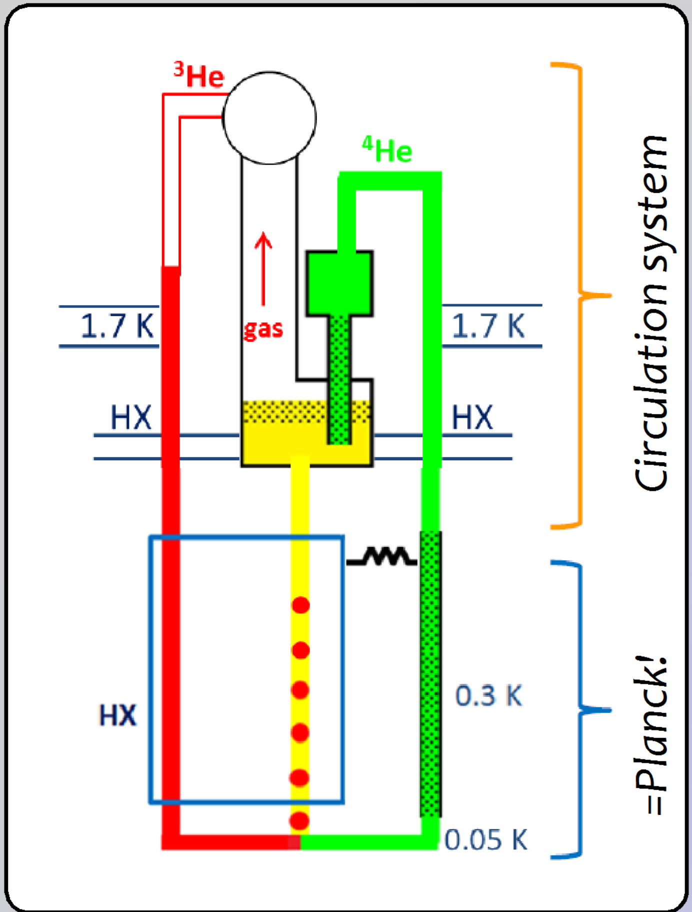
Bonus: cryogenics for space

- A lot of work is ongoing at the Institut Néel for the development of space-compatible refrigerator
- One option: **closed cycle DR for zero gravity**



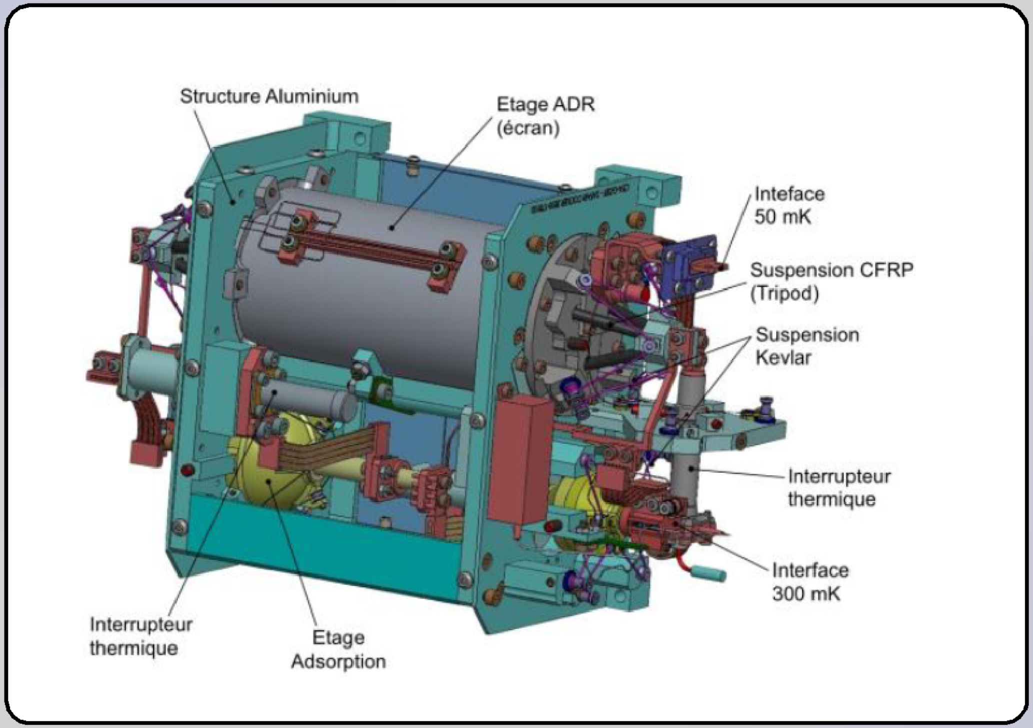
Process vizualisation under a collimated neutron flux :
^{3}He-rich droplets absorb the neutrons and appear in dark
(A.Benoit & S.Pujol, ILL Grenoble 2005)

- **Pros:** no B field, continuous…
- **Cons:** ^{3}He pump to be tested



Bonus: cryogenics for space

- A lot of work is ongoing at the Institut Néel for the development of space-compatible refrigerator
- Second option: **ADR**



- **Pros:** higher maturity level
- **Cons:** magnetic field, recycling

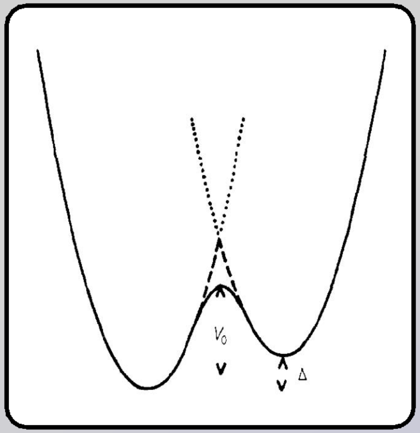
Conclusions

- KID should be able to reach the sensitivity needed to be photon noise limited even from space
- We have already demonstrated NEP values below $10^{-17}\ W/Hz^{0.5}$
- A deep study on the effect of Cosmic Rays is ongoing
- Multiple solutions are available that could contribute lowering the impact of CR on the data
- ***KID detectors are very good candidates for space based missions !***
- The Institut Néel can also provide the know-how for space qualified cryogenics systems (dilution/ADR)

Additional noise sources

The bad news : *reality ≠ theory!*

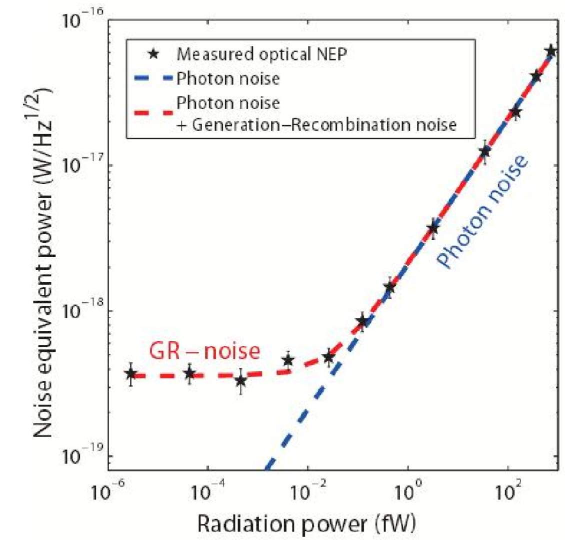
- Two-level systems (TLS)



Variations in the dielectric constant → excess in *phase noise*

- Quasiparticles created by the readout signal power

Quasiparticles background → excees in the *g-r noise*



de Visser et al
arXiv 1306.4238