Measurement of photon noise limited detection with lens-array coupled MKIDs using phase readout

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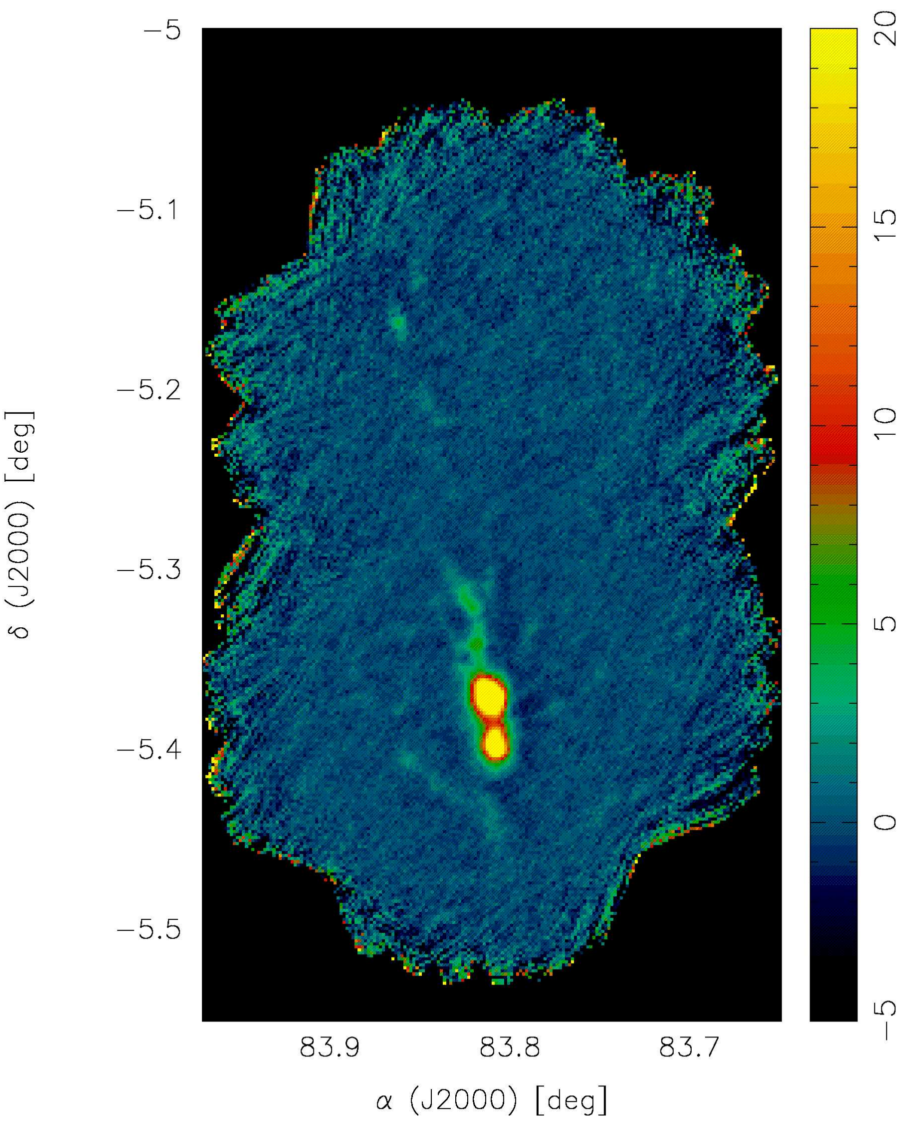

M42 Orion nebula @350GHz

APEX

Photon noise

- Intrinsic noise of incoming radiation

$$NEP_{photon} = \sqrt{2PhF(1 + mB)} \simeq \sqrt{2PhF}$$

- Power dependent!! So NEP required is dependent on situation

Relation to generation-recombination noise

- g-r NEP:

$$NEP_{g-r} = \frac{2\Delta}{\eta_{pb}} \sqrt{N_{qp}/\tau}$$

- Optical signal modifies quasiparticle number
- Generation of quasiparticles correlated with photon noise
- Recombination still gives Poisson noise, taking $N_{qp}=\eta_{pb}P\tau/\Delta$:

$$NEP_{g-r} = \sqrt{2P\Delta/\eta_{pb}}$$

- Giving ratio:

$$NEP_{photon}/NEP_{g-r} \simeq \sqrt{hF\eta_{pb}/(\Delta)}$$

- ~2.1 for F=350GHz, Δ/h=45GHz for aluminium
- Total NEP~1.1 NEP_{photon}

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Remarks

- g-r NEP is 2x less than photon – in aluminium see g-r!
- Like g-r, photon noise is a signal in quasiparticles, so expect a white noise spectrum rolled off by quasiparticle lifetime
- Expect $\sqrt{P}$ dependence for both photon and g-r noise – so ratio photon/g-r should be constant

- Other noise sources…
  - Amplifiers
  - 2LS

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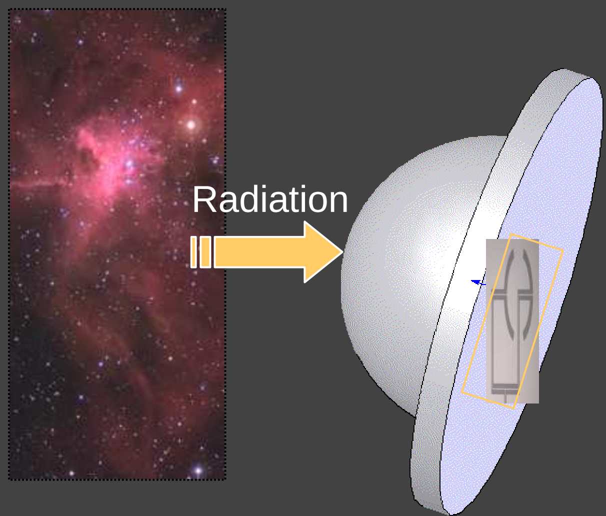
KID antenna lens system

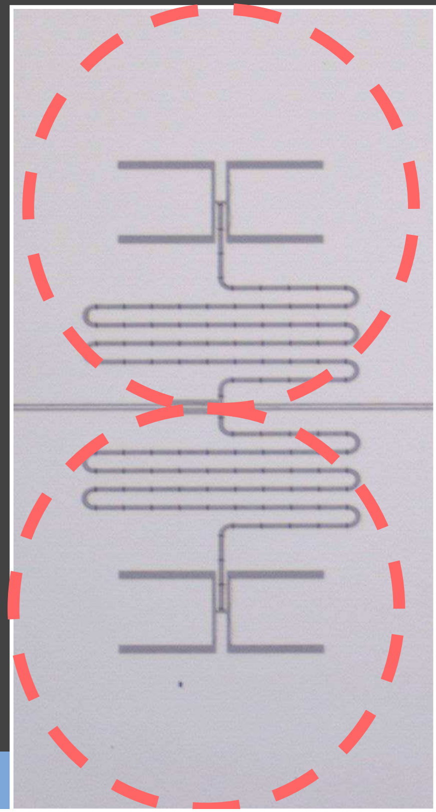
Lens creates room for KID

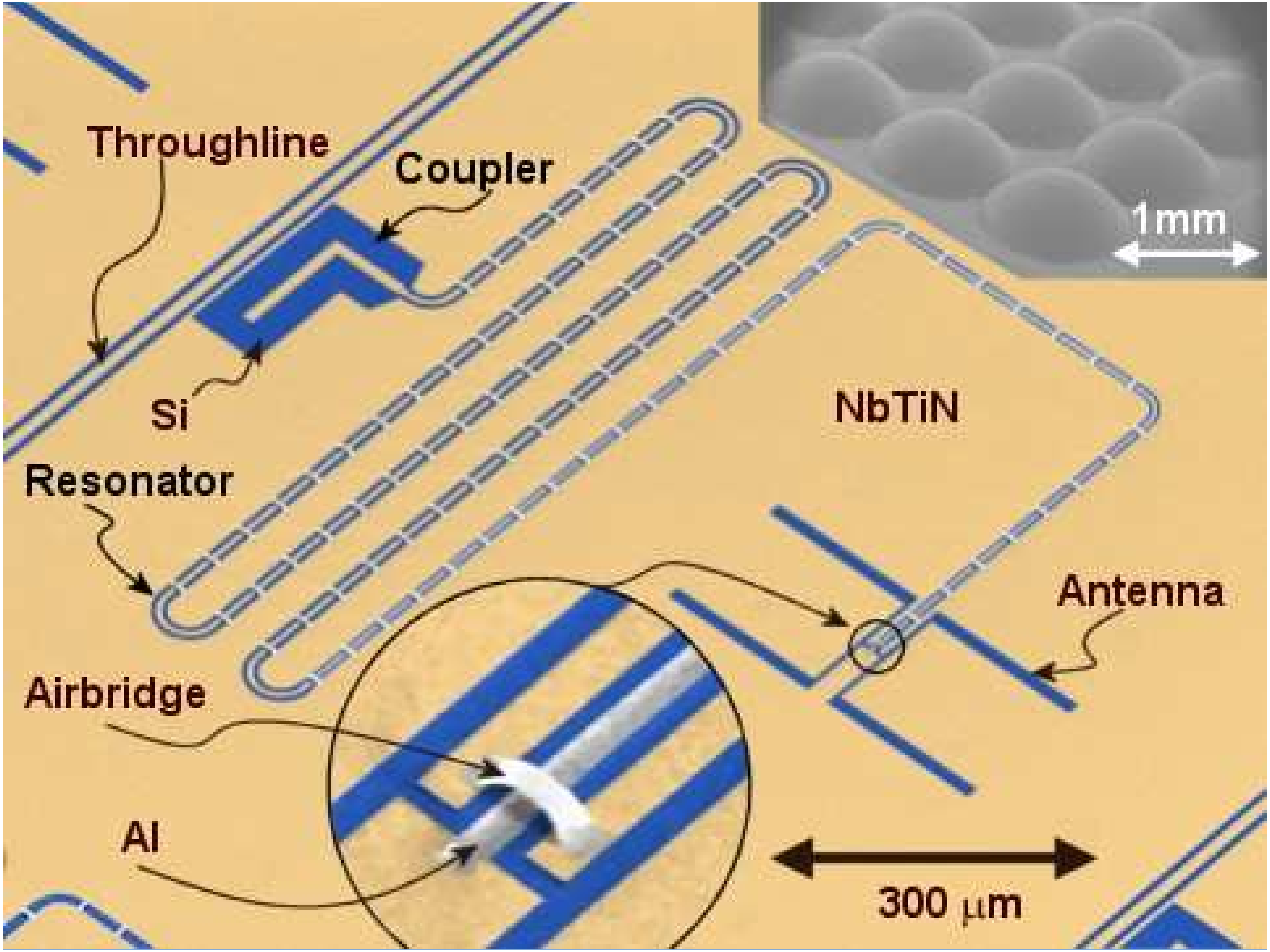
- Flexibility in optics design
- Decouple coupling from sensitivity
- Works for entire FIR & sub-mm
- Octave bandwidth possible
- Simple

Known problems

- 1 polarisation
- Quasiparticle outdiffusion
- Needs antireflection coating
- Needs lens array

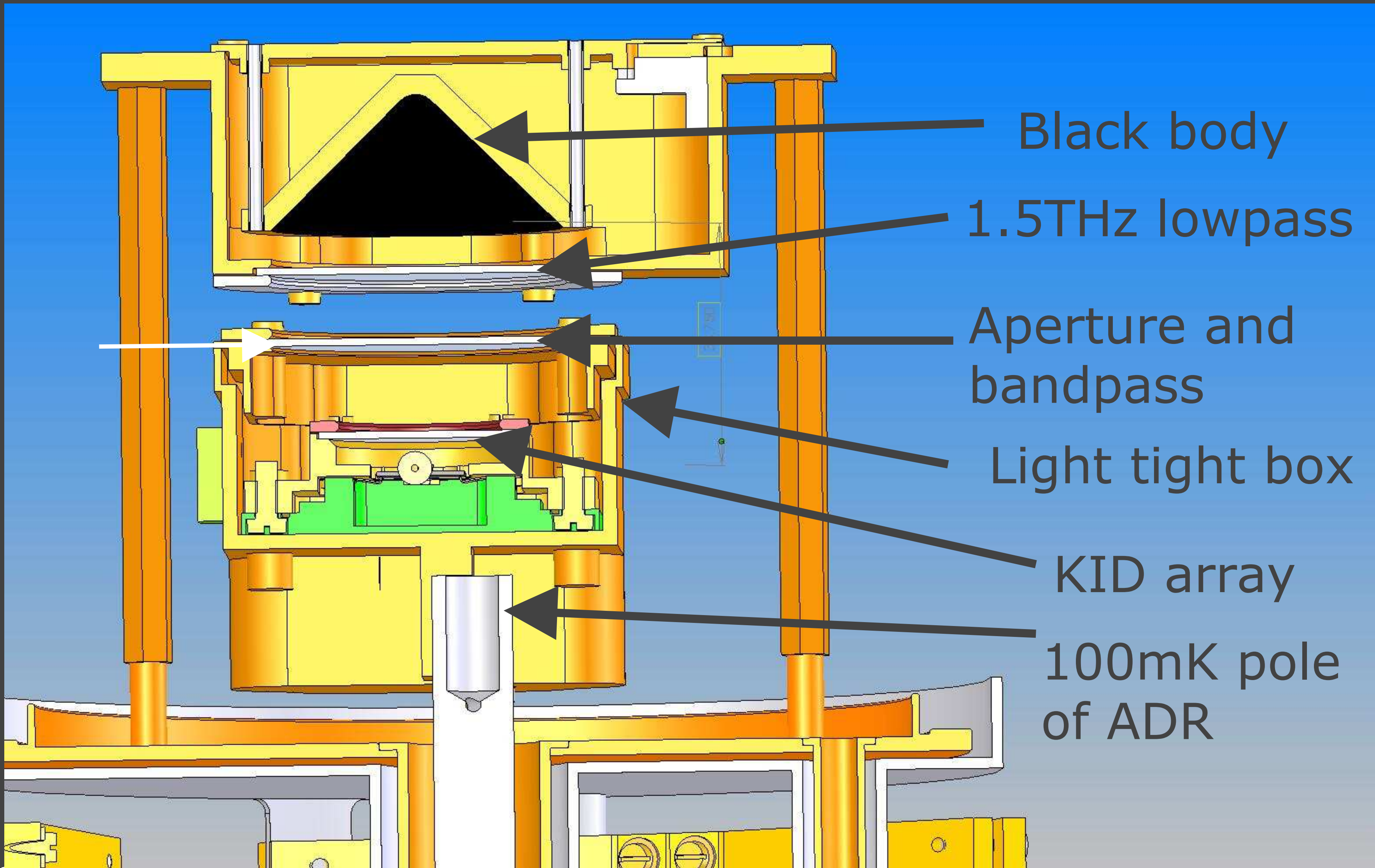




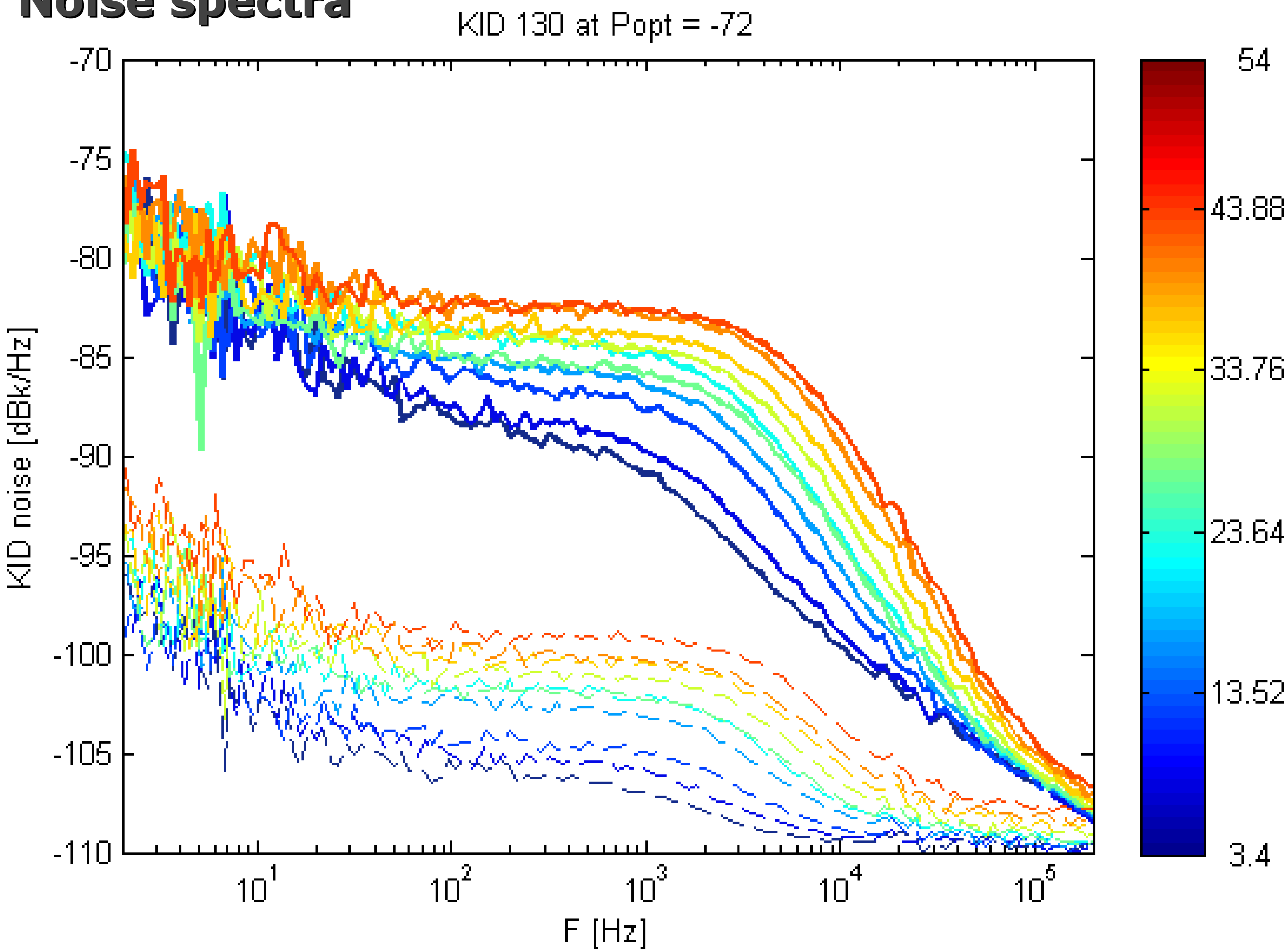


Throughline
Coupler
Si
Resonator
Airbridge
Al
NbTiN
Antenna
1mm
300 μm

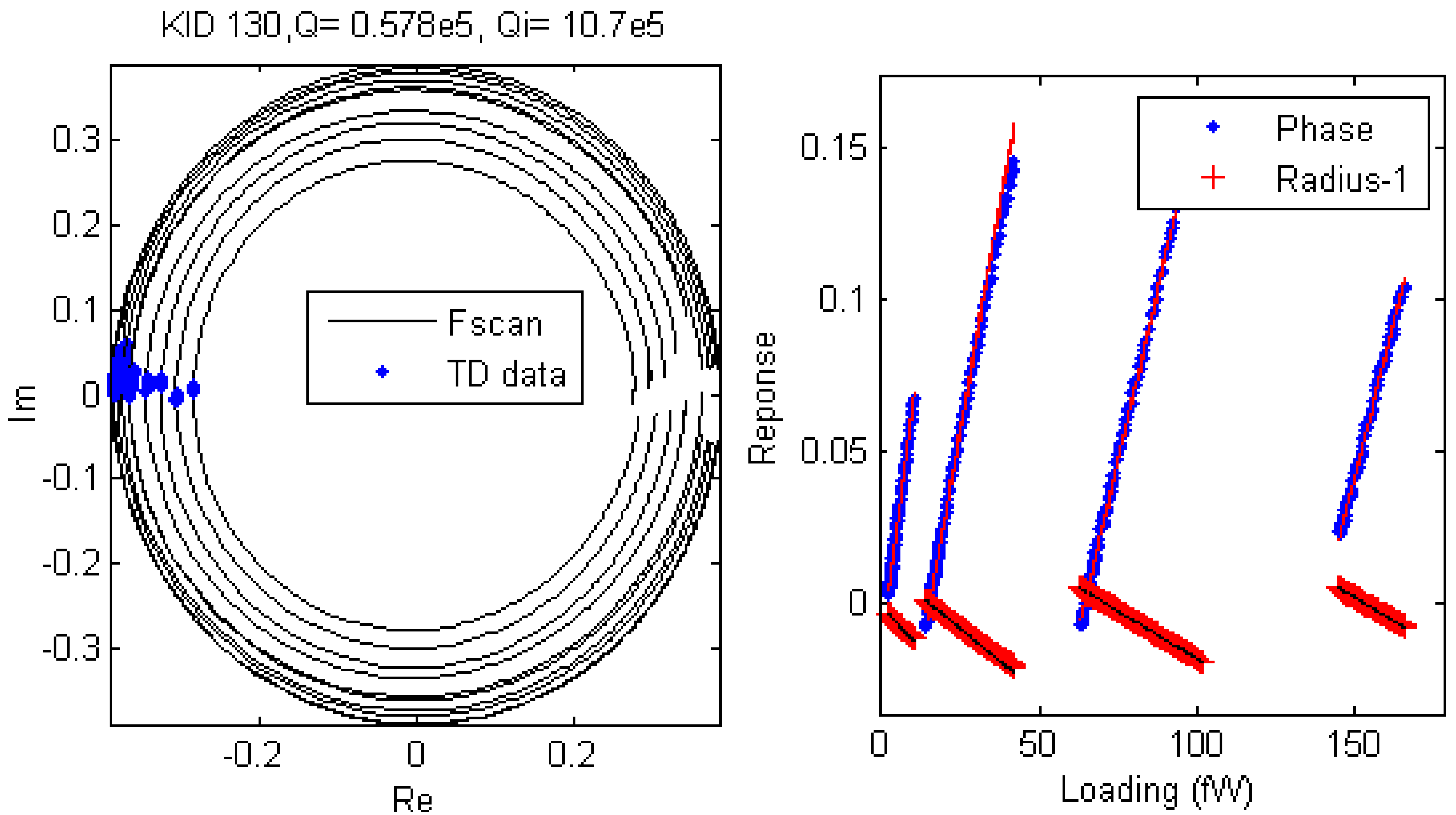
Measurement setup



Noise spectra

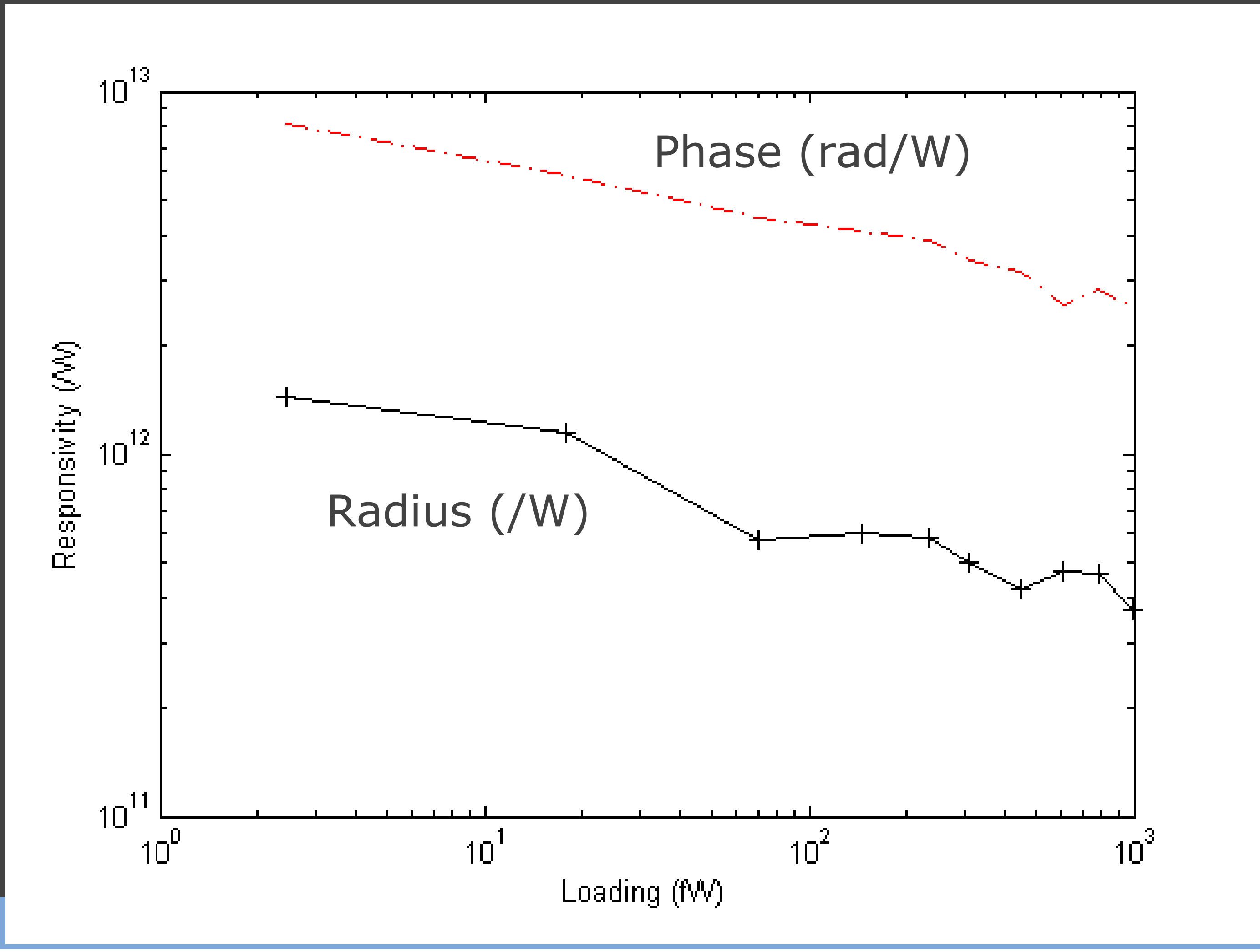


Responsivity calculation

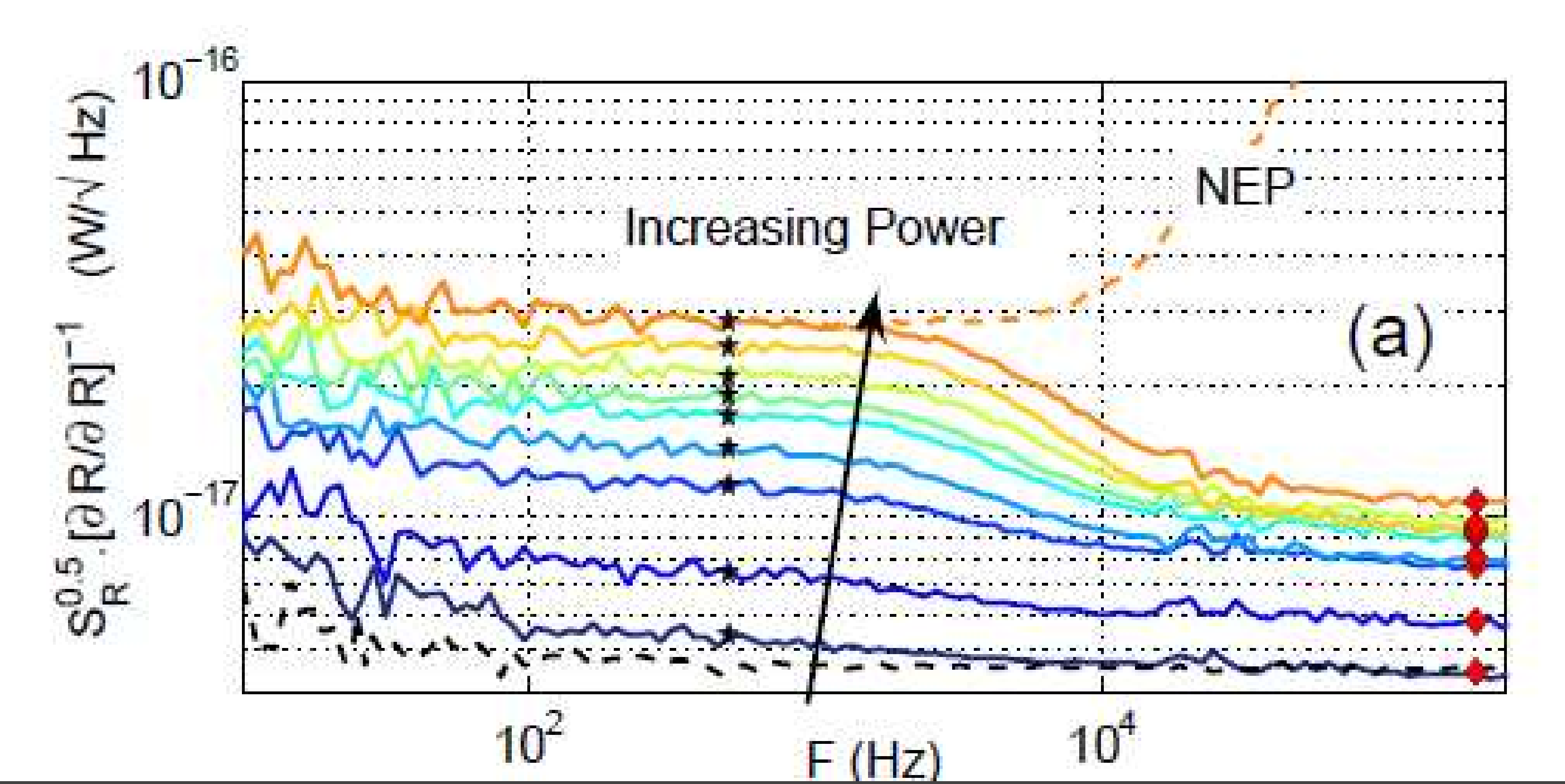


Responsivity versus optical loading

- Naive calculations expect ~√P
- Get slower power ($P^{0.25}$)– so SNR of photon with respect to other noises improves at high loading



Radius NEP



From S. Yates et al., arXiv 1107.4330, accepted for APL

Detector Optical efficiency

- MKIDs aren't bolometers – need calibration
- Calibrate compared to power input to lens
- NEP is the SNR in 1Hz bandwidth
- Loss of photons to detection - decrease signal, increase in NEP

$$NEP^2 = NEP_{det}^2 + (NEP_{g-r}^2 + NEP_{photon}^2)/\eta$$

- Detector NEP – other contributions (amplifier, 2LS etc)

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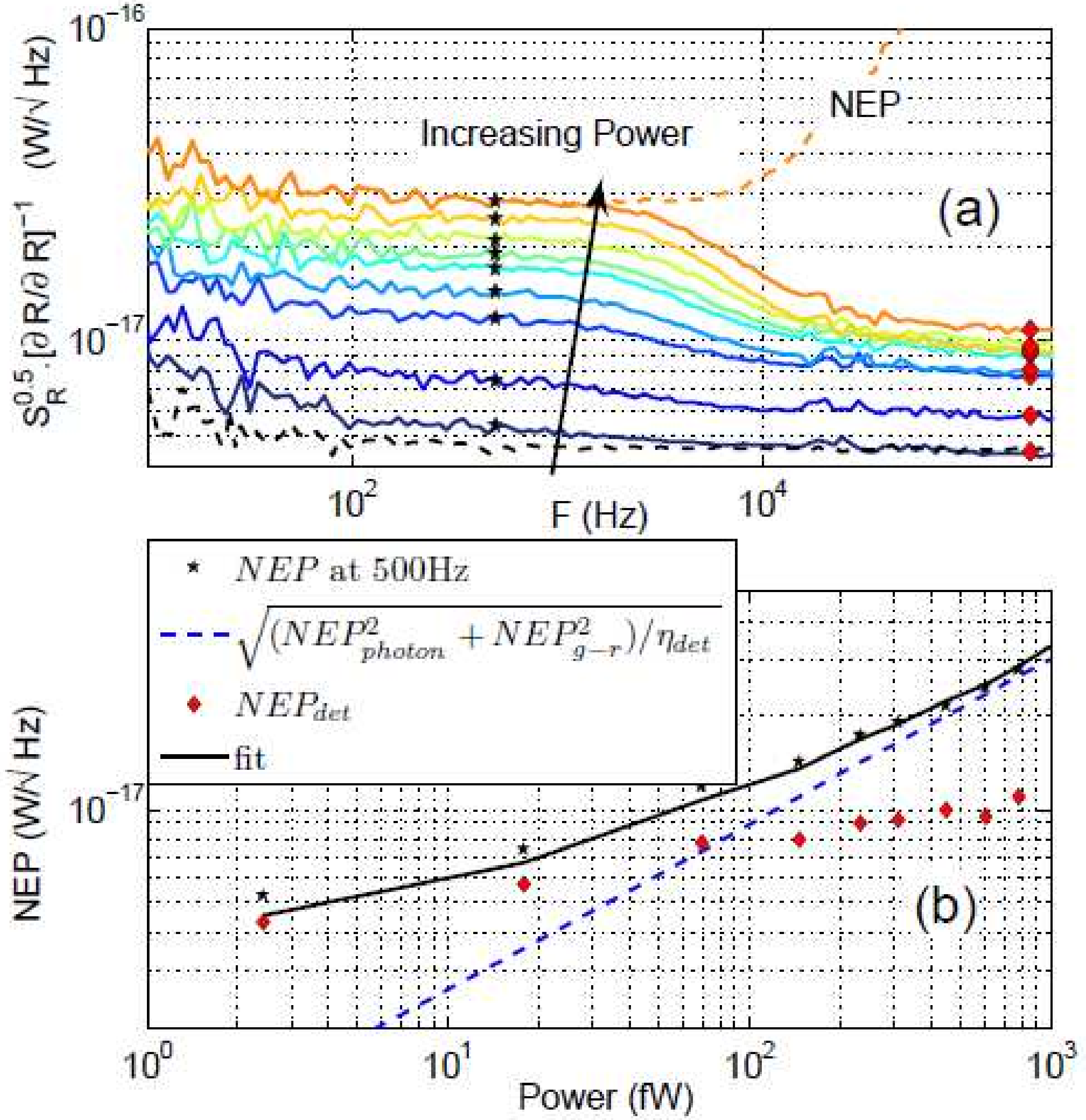
Radius NEP

η_{det}=0.8, 1 polarisation



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Phase NEP

- 2LS $1/f^{0.25}$ to NEP
- Low f also has setup and optical drift
- Phase
  - more signal, so relaxes amplifier requirements
  - larger dynamic range