National Aeronautics and Space Administration

Large-format high-sensitivity detector arrays for far-infrared balloon-borne and space telescopes

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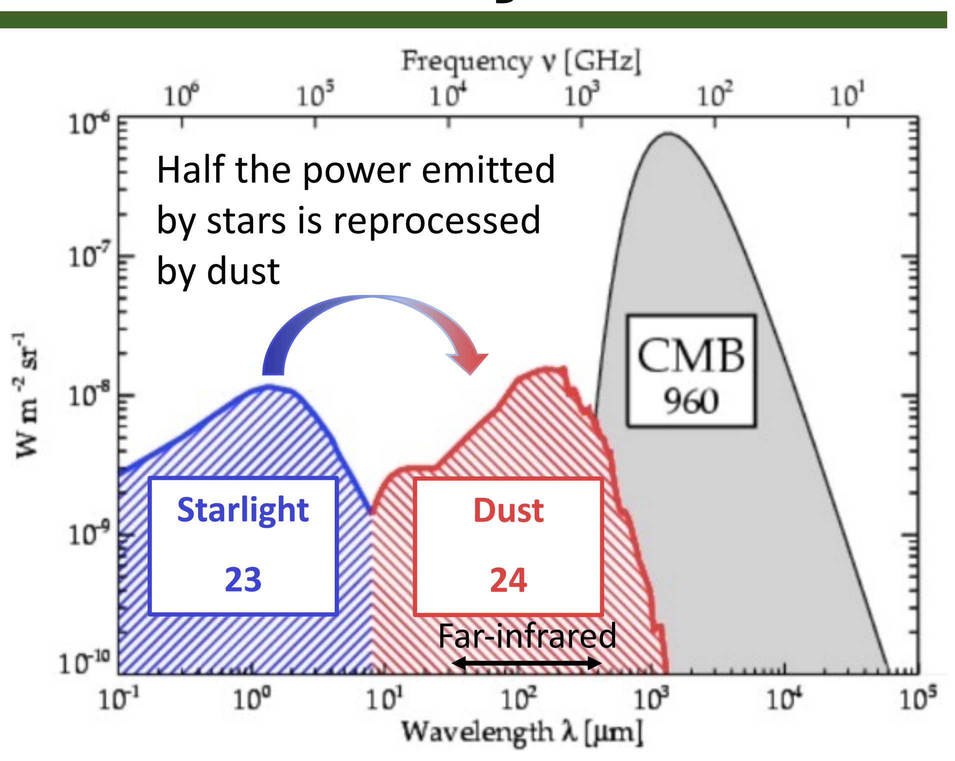
Far-IR astronomy

Interstellar Dust

- Absorbs UV/VIS radiation
- Enshrouds most star formation
- Re-emits the energy in (far-)infrared

Luminous Infrared Galaxies

- Contribute >70% of the star formation (@ z ~ 1)
- Dust obscuration makes them (nearly) invisible in UV/VIS
- Bright in the (far-)infrared (broad-band and line emission)

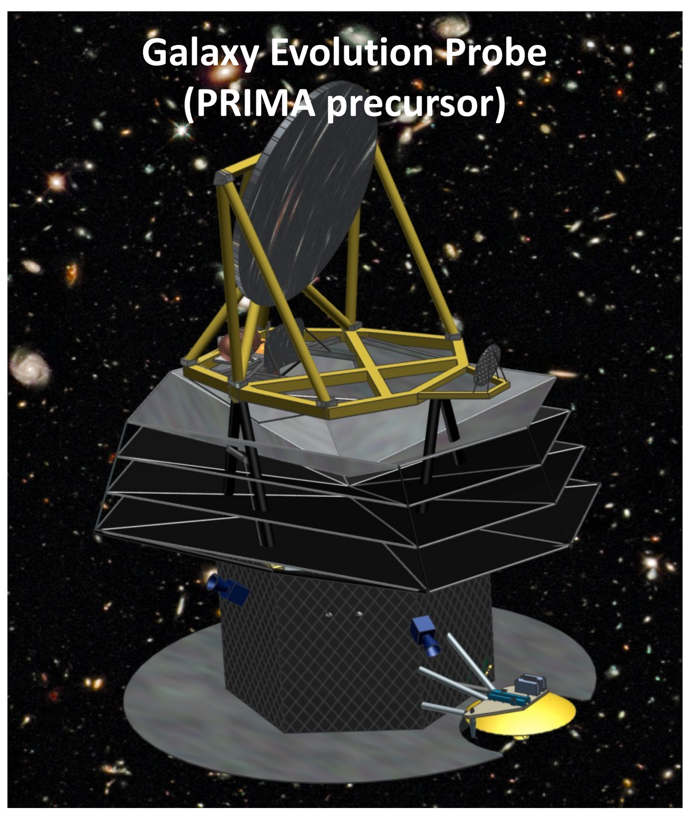


Far-infrared fine-structure lines

- Unattenuated by dust
- Emitted by C+, N+, CO (and others)
- Enables determination of distance (through redshift of the lines)
- Line fluxes and ratios are a key diagnostic tool for star formation, active black holes and other galactic processes.

Spectroscopic observations in the far-infrared are crucial for locating and understanding the bulk of the star formation in our universe.

Future mission requirements



Terahertz Intensity Mapper

- Balloon mission
- 2 x 3600 detectors
- Photon noise limit @ 100 fW
- NEP < 4×10^{-18} W $Hz^{-0.5}$
- Temperature detector ~250 mK

Far-infrared Probe (Astro2020 recommendation)

- e.g. PRIMA
- Orbital platform
- ~ 50000 detectors
- Photon noise limit @ ~3 fW
- NEP < 1×10^{-19} W $Hz^{-0.5}$
- Temperature detector ~100 mK

Future far-infrared spectroscopy missions, such as the JPL-led PRIMA concept, require large numbers of highly sensitive detectors

KIDs for space missions

Kinetic Inductance Detectors are the baseline detectors for future far-infrared Probe-class missions such as the JPL-led PRIMA mission. Starting from the detectors presented here, a key step to achieve the requirements for PRIMA is to improve the sensitivity by at least an order of magnitude. Based on physically motivated models calibrated using the balloon-ready detectors this can be achieved by:

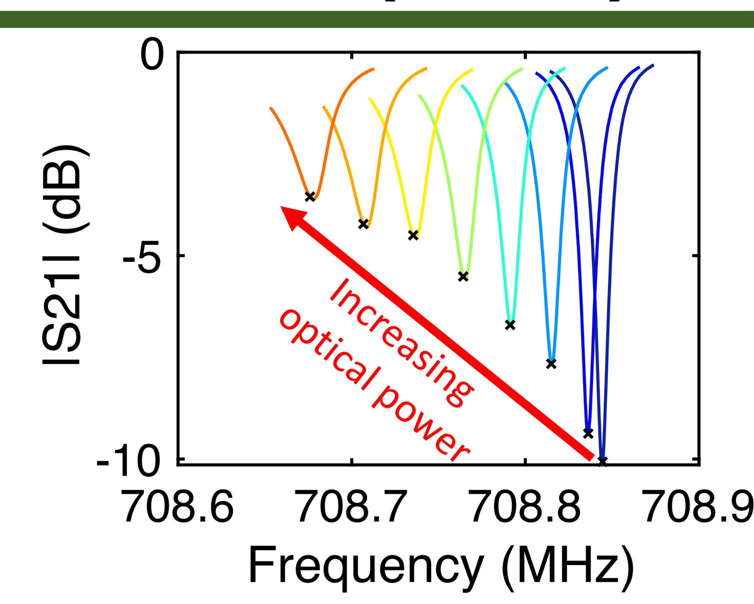
- a lower absorber volume
- a decrease in the operation temperature

With minor changes demonstrated balloon arrays are expected to satisfy requirements for a far-infrared probe class mission.

Kinetic Inductance Detectors (KIDs)

Kinetic Inductance Detector (KID)

- Electrical RLC resonator with high Q
- Made from a thin film (30 nm) of a superconducting material (aluminum)
- Optimized to absorb radiation.



Optical Response

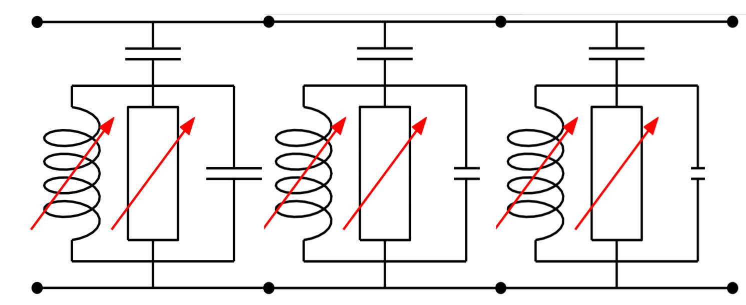
- Absorption of optical power changes inductance

➔ Shift in resonance frequency

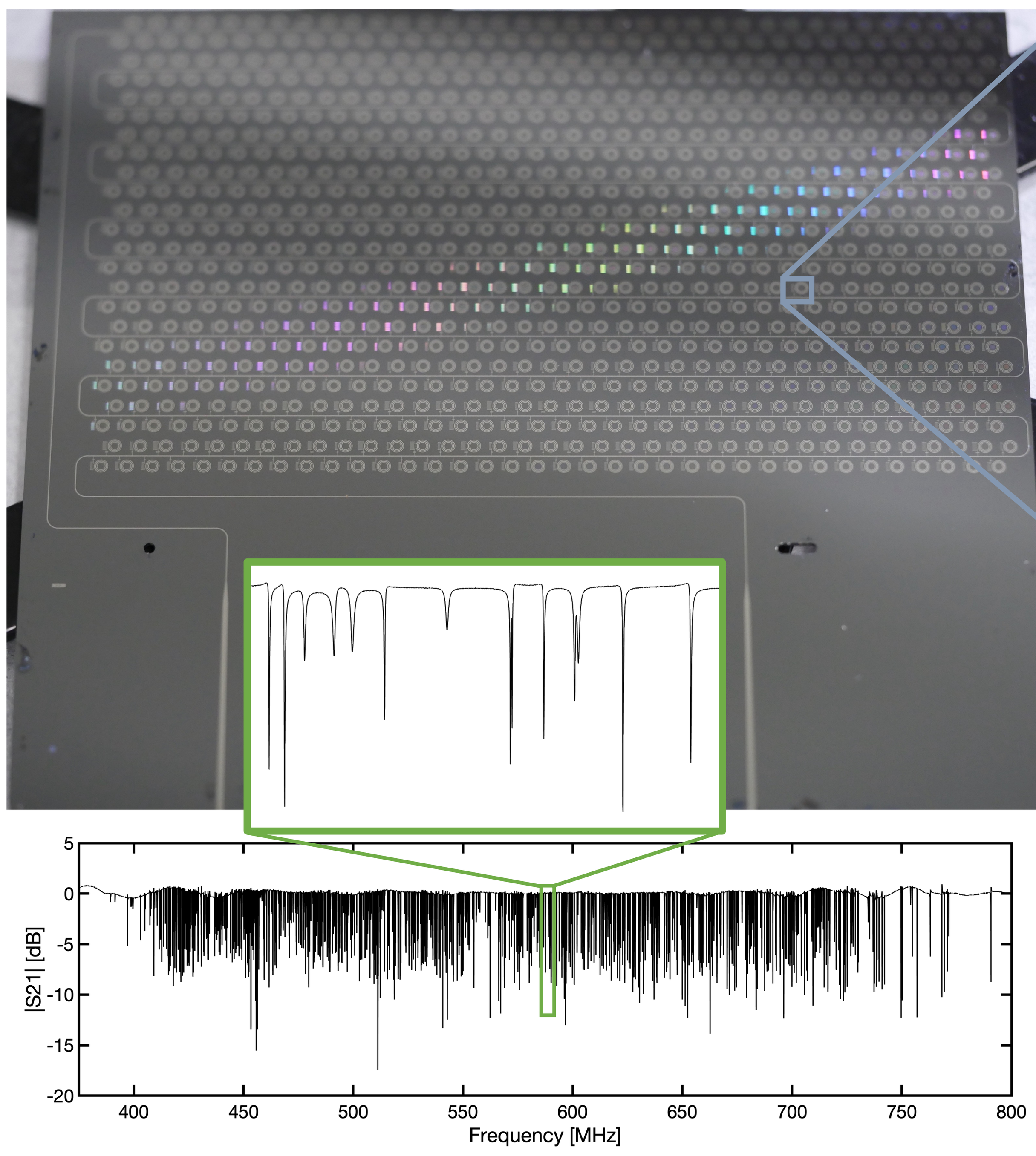
Frequency Domain Multiplexing (FDM)

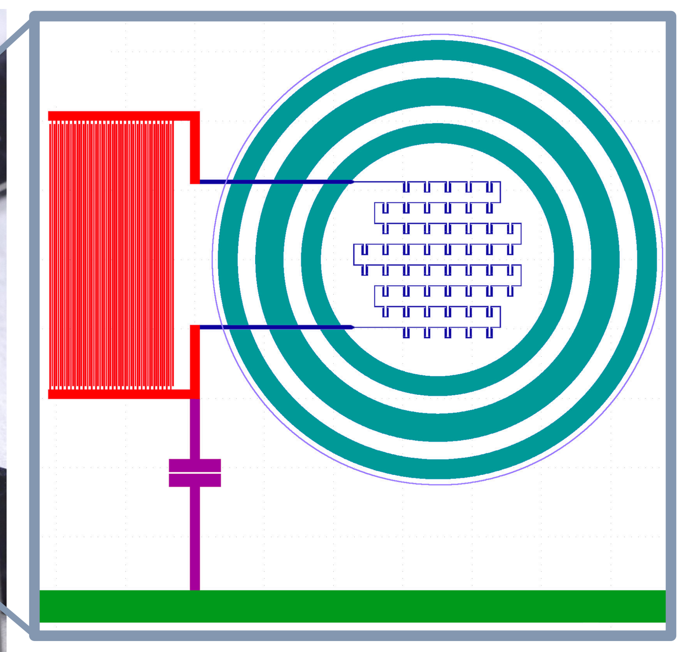
- Inductor of each KID is identical
- Capacitor is varied to set the resonance (read) frequency

➔ Each KID has a unique read frequency



Kilopixel array for balloon-missions





Absorber / Inductor
➔ "Chainlink" design
➔ >90% absorption efficiency

Optical choke structure
➔ Reduced optical cross-talk to <1%

Main interdigitated capacitor
➔ Area determines resonance frequency

Coplanar coupling capacitor
➔ Sets resonator Q~10^5

Readout line
➔ Single line connects all 864 detectors

Yield

➔ 95% yield

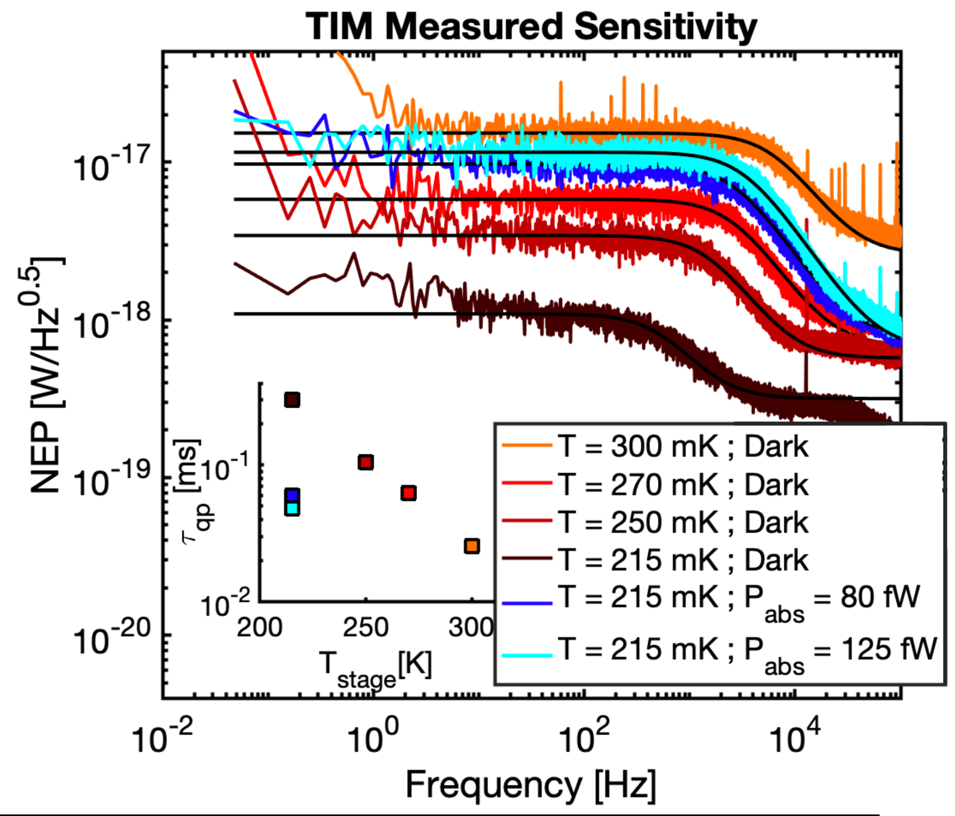
- Single readout line for 823 KIDs (864 designed)
- 500 MHz readout bandwith

Sensitivity

➔ Photon noise limited @ ≥50 fW if cooled <270 mK

- 30x more sensitive than Herschel SPIRE

Based on resonator in the dark we estimate an detector limited NEP = 1.3×10^{-18} W/$Hz^{0.5}$



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