Photon counting astronomy with TES

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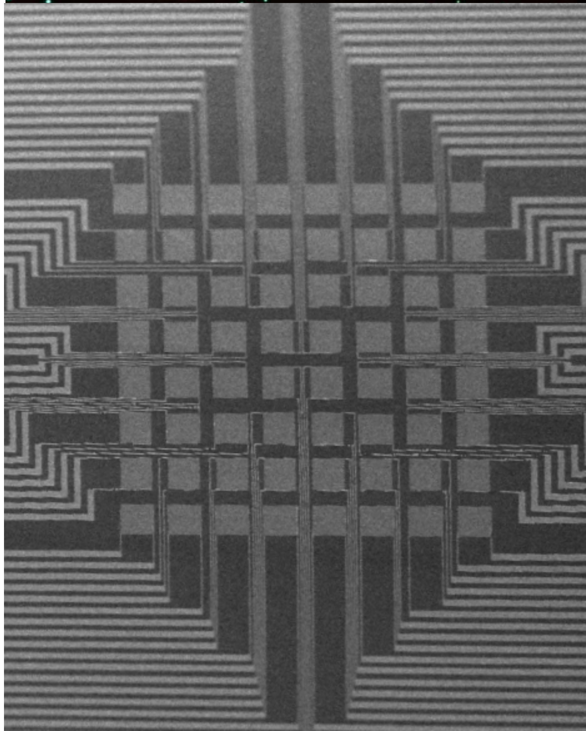
Motivation for Energy-Resolved NIR-UV Imaging



- **The Dream**: ***Everything*** **for each photon**
  - **Broad IR→ UV band**
  - **Direction – large pixel count for big FoV**
  - **Arrival Time**
  - **Energy**
  - **Polarization**
- **The (Near Future) Reality: Limited Arrays**
  - **H-U bands from ground**
  - **<100pix direct read-out → few k-pix multiplex**
  - **~0.1eV, μs, Π~% resolution**
- **The 'Killer App'**
  - **Faint compact objects – pulsars, BH, CV**

Pulsars: Phase-resolved spectro- photopolarimetry

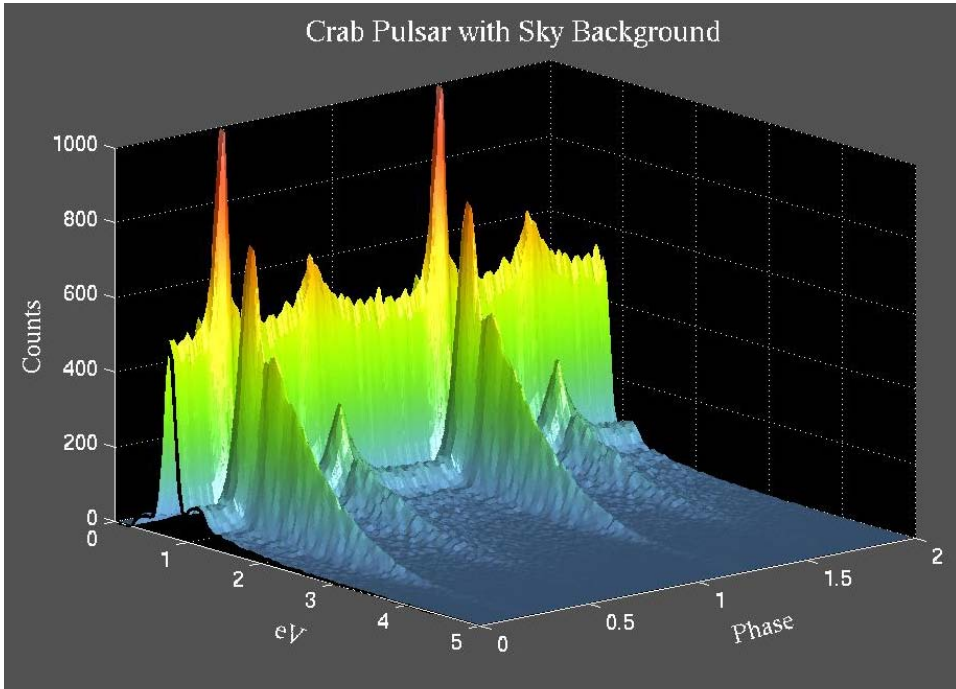
- **Targets are mostly at r >25, i.e. 1%-10% of sky at good sites**

- **Some IR sensitivity helps for distant Galactic sources (extinction)**

- **Spectra are PL (synch, CR) with breaks and, possibly, self-abs.**

- **Polarization is high with very rapid variation through pulse.**

- **Periodicity of signals allows good S/N -- but this means other technologies can compete!**



Stochastic Variability

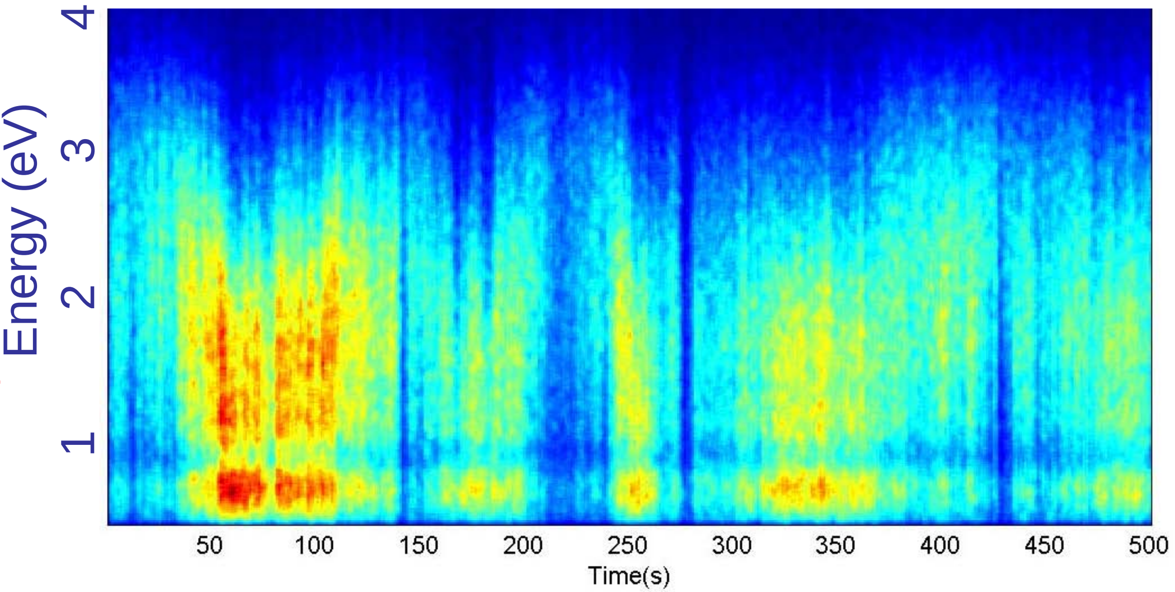
Energy-resolved photon counting has unique impact for *aperiodic* systems

- **BH and NS accretors – relativistic lines in inner disk**
- **WD – polars/IP: cyclotron line oscillation in accretion column**

Example TES observations on small telescopes:

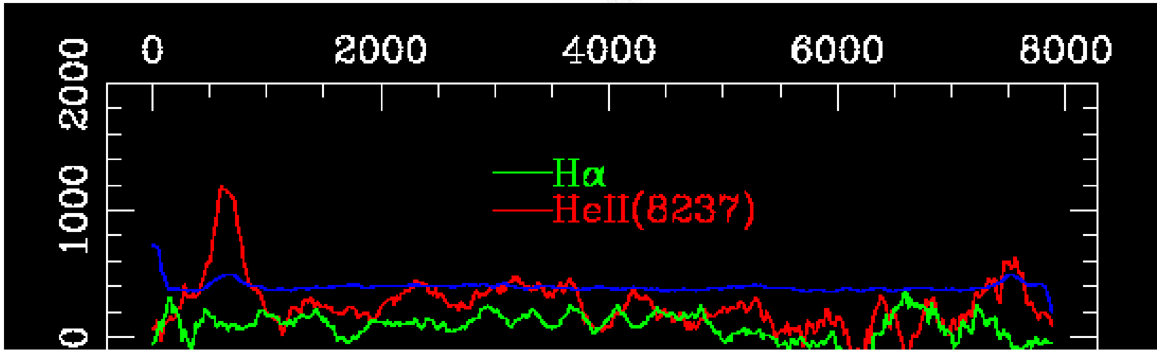
LXRB -- Her X-1

dynamic spectra



Polar ST Leo Mi

Emission line EW variations through orbit



Playing to our Strengths

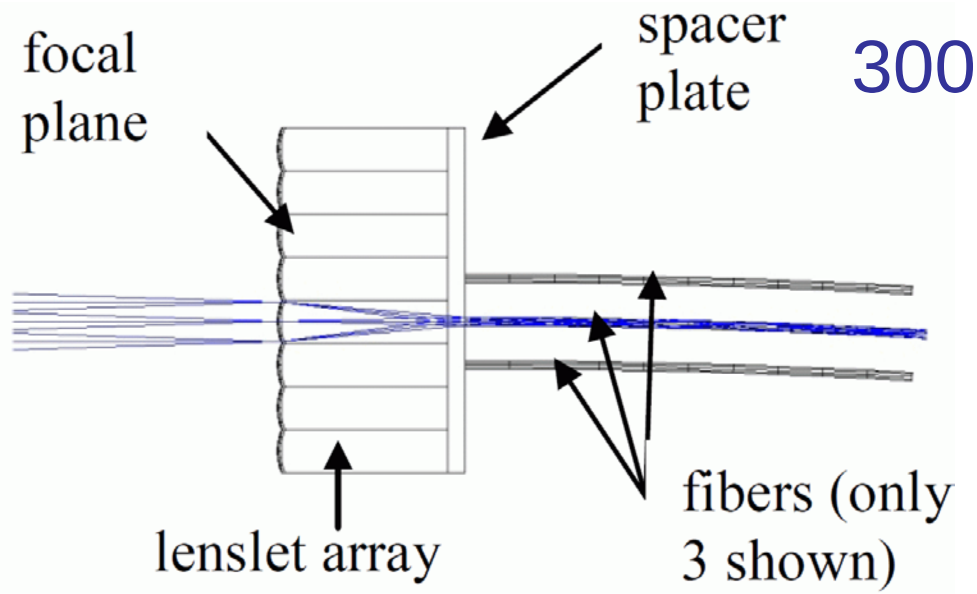
- **To achieve sky-limited studies of stellar-mass compact objects**
  - **Need to sample the PSF (incl Atmospheric dispersion for broad-band)**
  - **get adequate sky**
  - **Need ~5x5 to 10x10 arrays for ground-based work**
  - **Need ~10+x to get comparison objects, mapping, spectroscopy.**
- **Spectral Resolution ~0.1eV, λ_{max}~5λ_{min} .**
  - **continuum, breaks**
  - **high EW (>100A) line fluxes**
- **Other high time resolution work**
  - **following the atmosphere**
  - **eclipse studies, occultations,…**

SISP: The Stanford Imaging SpectroPolarimeter

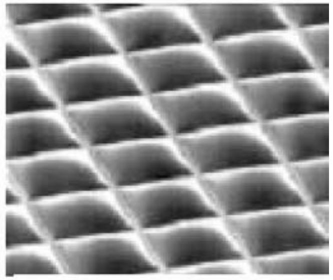
- Fiber-coupled optics
  - At the focus: Microlens array (lenslets) to the fibers
  - At the detector: GRIN and ball coupler to fibers
- NIST or Stanford W TES
- Auxiliary $\lambda/2$ plate polarimeter with optional $\lambda/4$ plate for V
- Direct SQA readout, 64 channels
- Prototyping in a 60cm telescope, aiming for access to 3-8 m class facilities
- Submitted to NSF-AST-ATI in Nov 2009

(PI: Kuo, Co-PI: Cabrera, Romani, Thompson)

SISP: Fiber-coupled optics



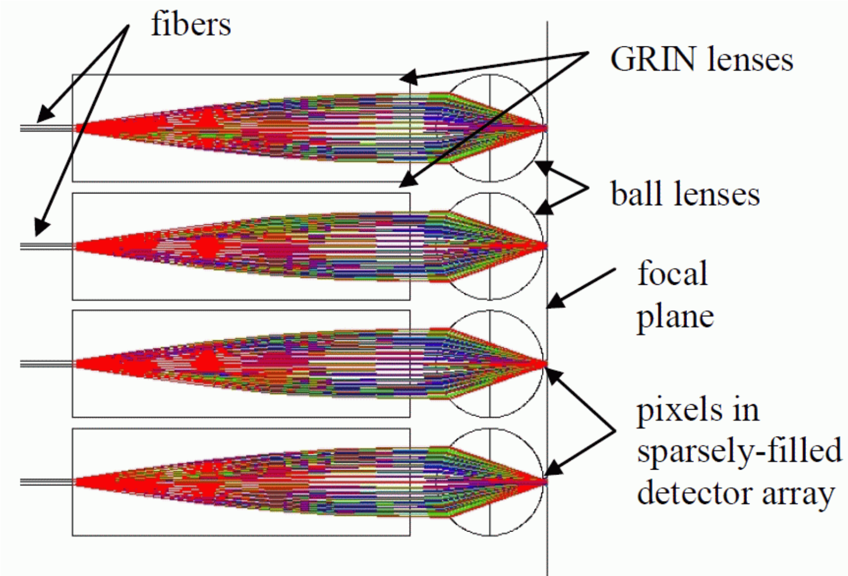
300K



Micromachined Lenslet array

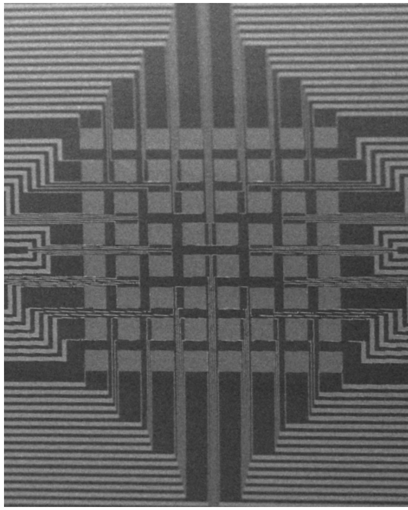
- Possible with moderate size arrays (64 pix)
- Avoid highpass IR blocking filters
- Commercial components identified
- Broadband performance verified (Zemax)

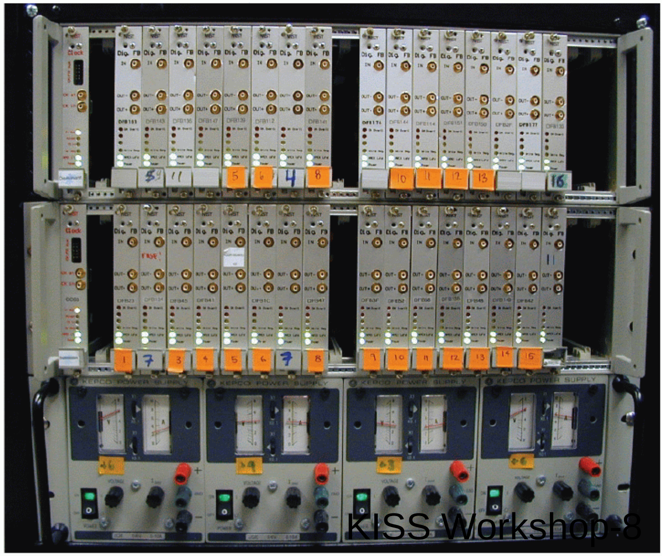
50 mK



SISP: TES and SQUID readout

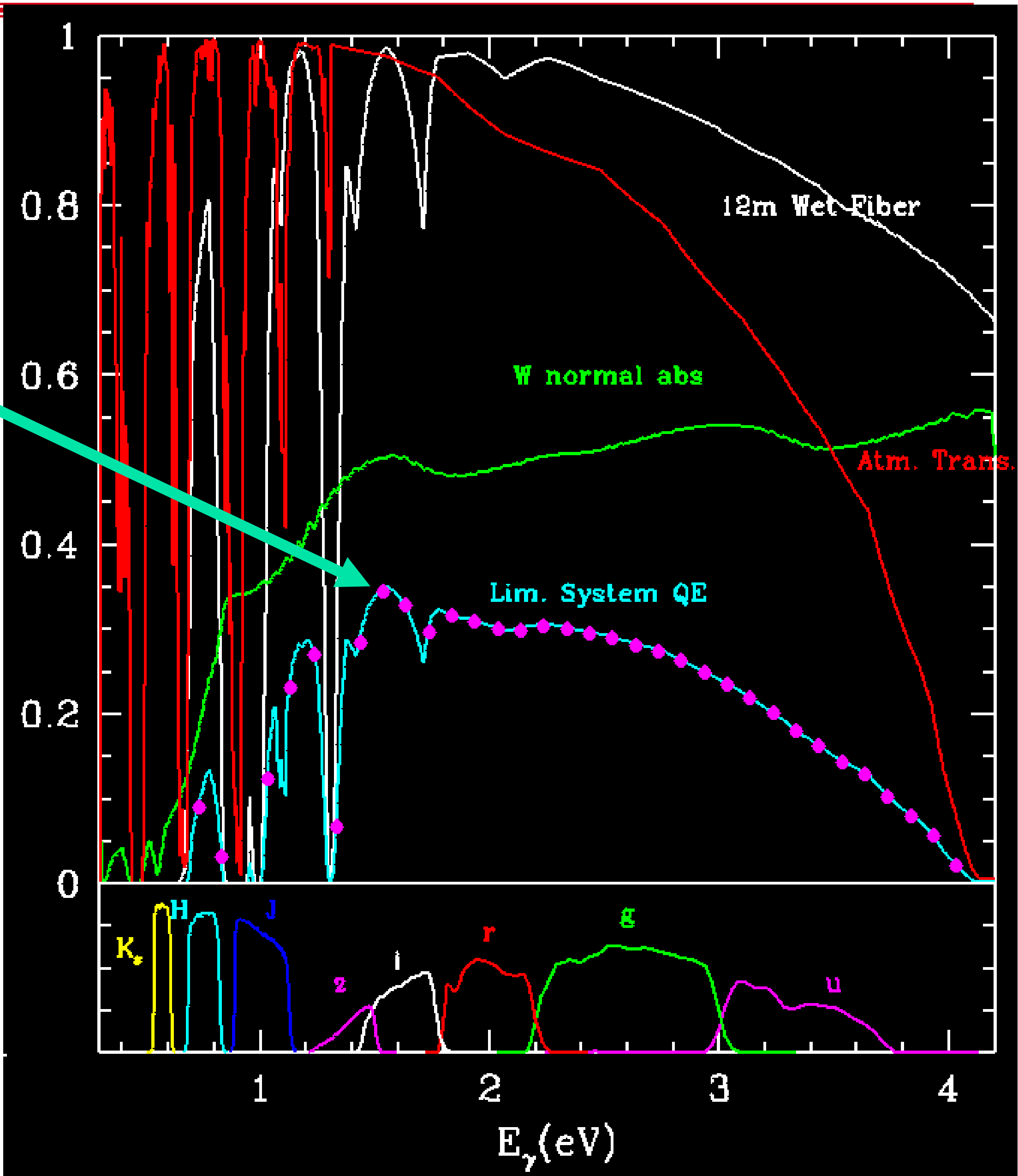
- Tungsten (W) hot electron Transition Edge Sensor, 20 μm, Tc ~ 80mK
  - Long history at Stanford (Cabrera group), used for CDMS-II
  - New developments at NIST (Sae Woo Nam)
    - membrane-supported W film
    - cleaner energy spectra, trace events eliminated
    - room temperature self alignment scheme
- Cooled by existing adiabatic demagnetization refrigerator
- Energy resolution 0.1-0.2 eV demonstrated
- Rise time ~ 1 μs, fall time 10s of μs
- NIST SQUID SQA direct readout for 64 channels





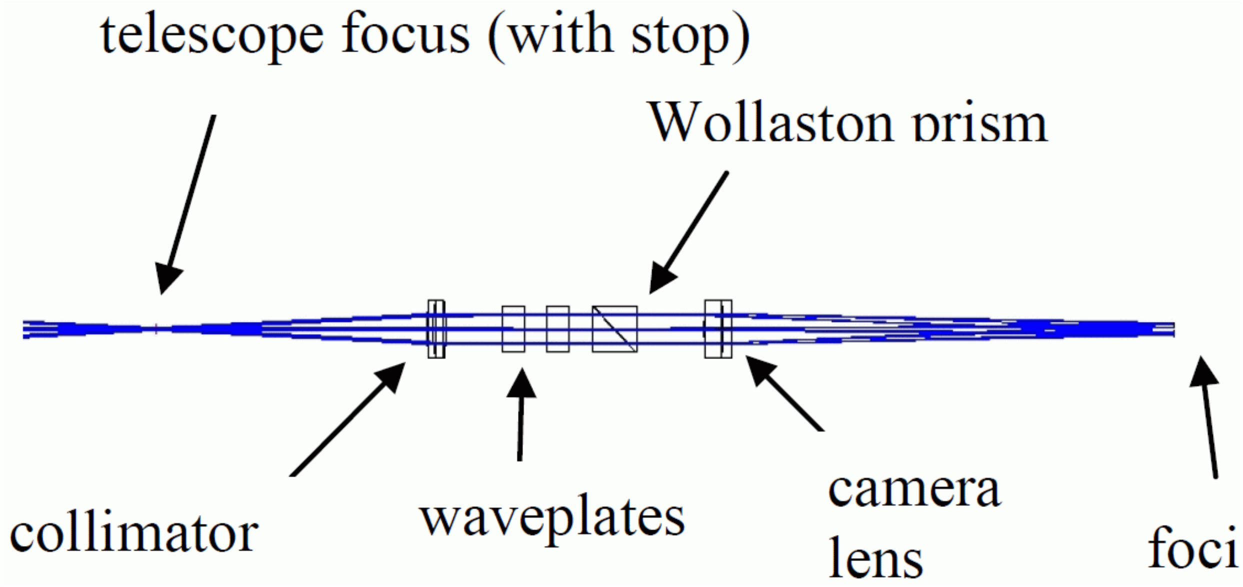
W-TES+fiber performance

- Fiber-coupled W TES
- Throughput from top of atmosphere
- Moderate spectral resolution
  - Breaks and broad lines
  - Multiplexing adv. Cmp. w/ SPADs
  - Helps with ultra wide band polarimetry



Comparison: CCD/InSb+broad-band filt.

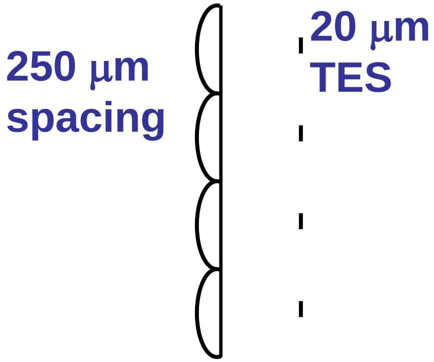
Auxiliary Broadband Polarimeter

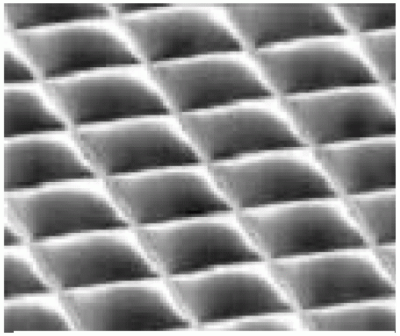


- Energy resolution improves ultra-wideband polarimetry, as each spectral bin can be calibrated independently
- The collimator can be easily changed to match the f/number and plate scale at the observatory

Longer term future (~>5 years)

- Multiplexed readout with GHz SQUIDs (NIST and JPL), n~ 100-500 (1 MHz B.W. per detector)
- Lower Tc (DF), smaller pixels, <<0.1 eV energy resolution
- Development of infrared blocking filter to allow 2-D mapping
- Improvement on pulse processing electronics (count rate, pile up problems, better yet energy resolution)
- High res. Echelle spectrometer “order sorter”
- Lenslet array–coupled TES allows 100x more space for wiring, or even integrated MSQUID





part of a commercial lenslet array (250 μm pitch, 40x40 format) ~$1,000 off the shelf