MKID plans at DIAS

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G. Ulbricht

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MKID development at DIAS:

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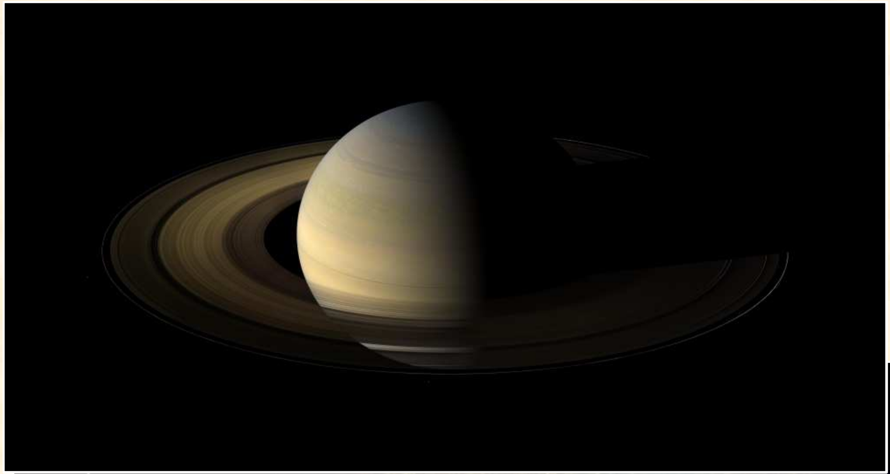
Mario De Lucia

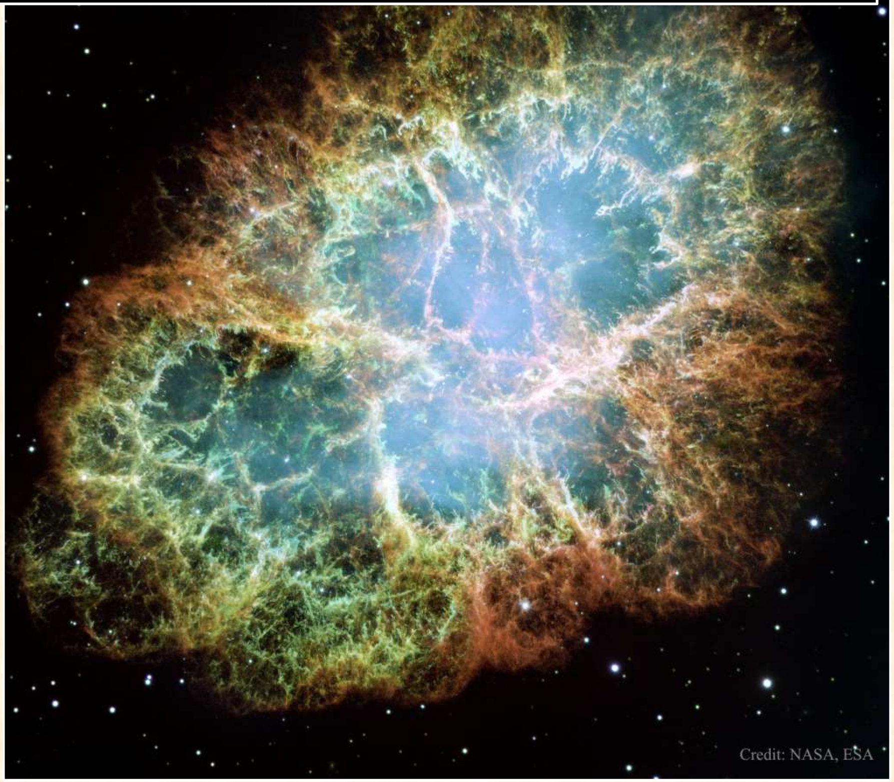
Eoin Baldwin

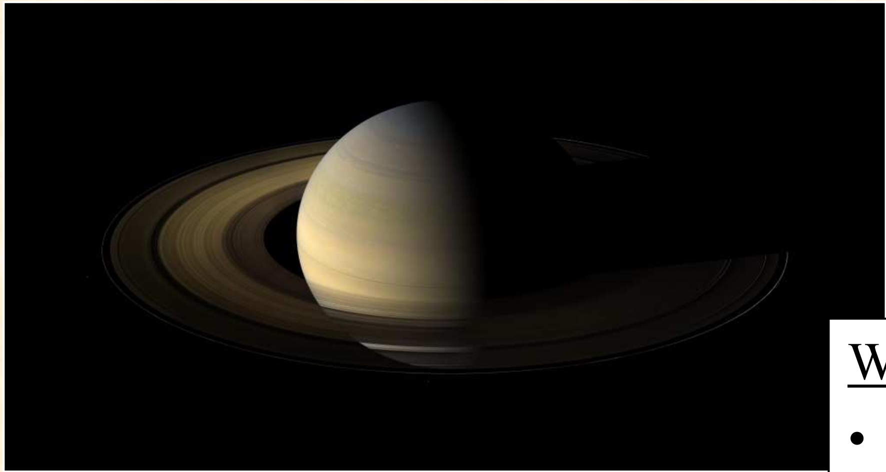
?

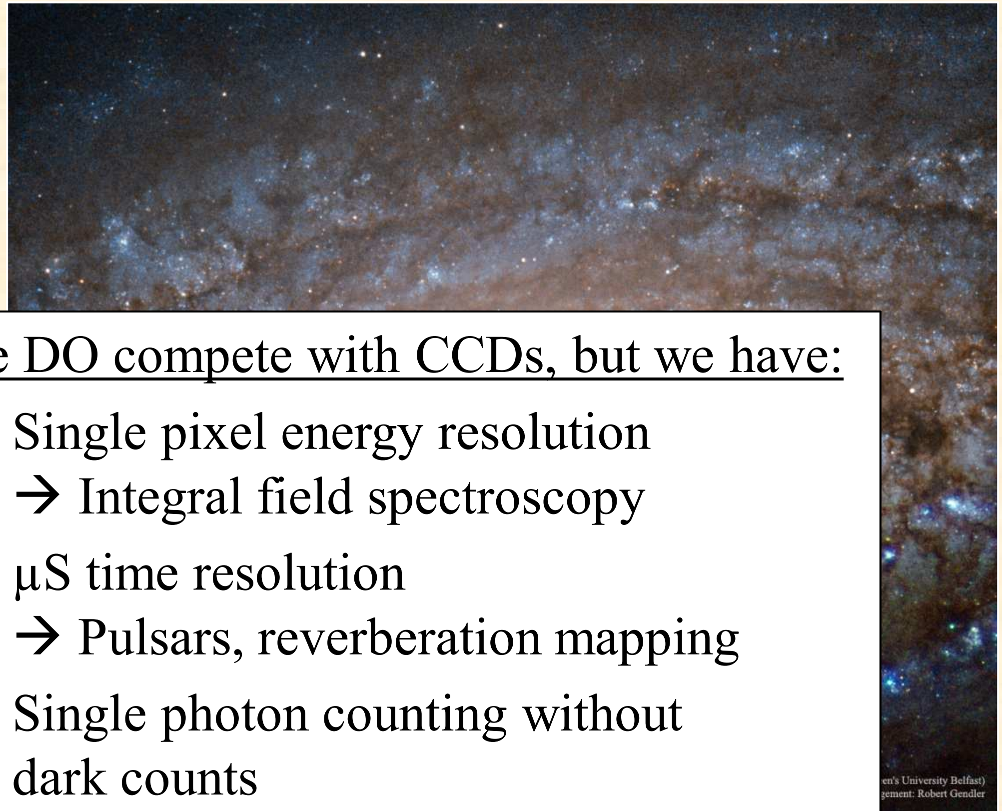
We are still looking for a 3. student

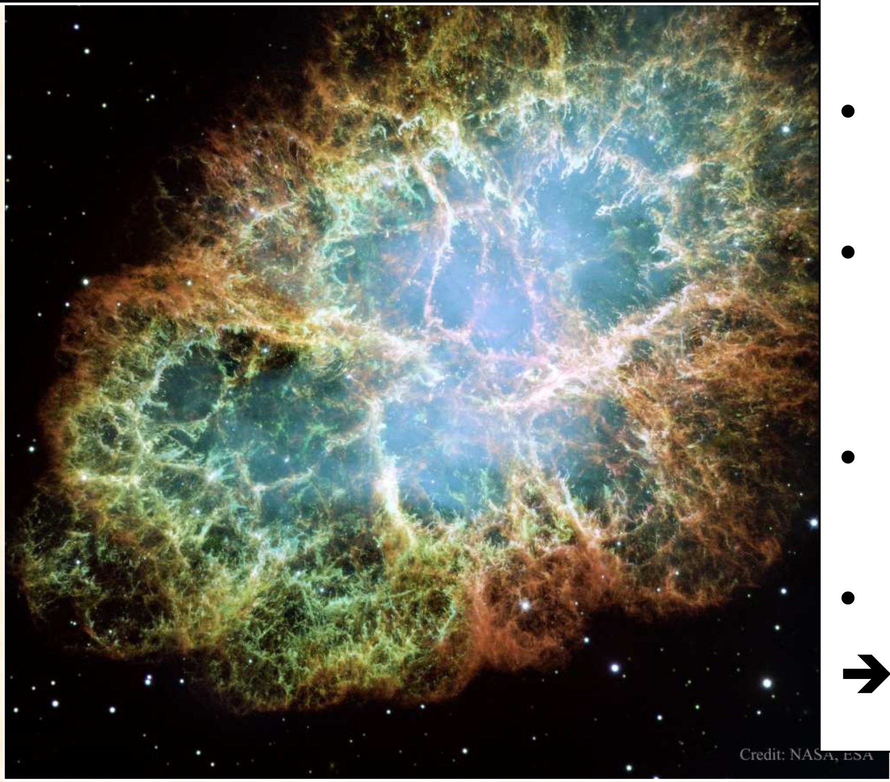
MKIDs for Optical to IR Astronomy

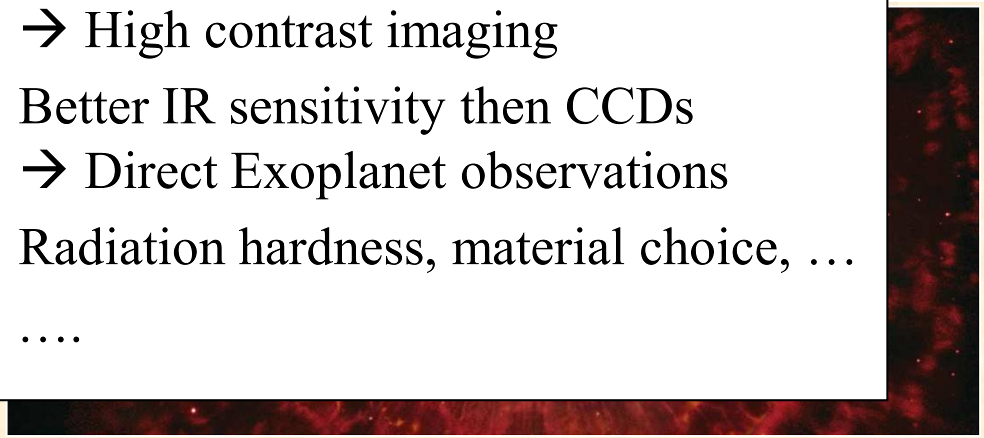










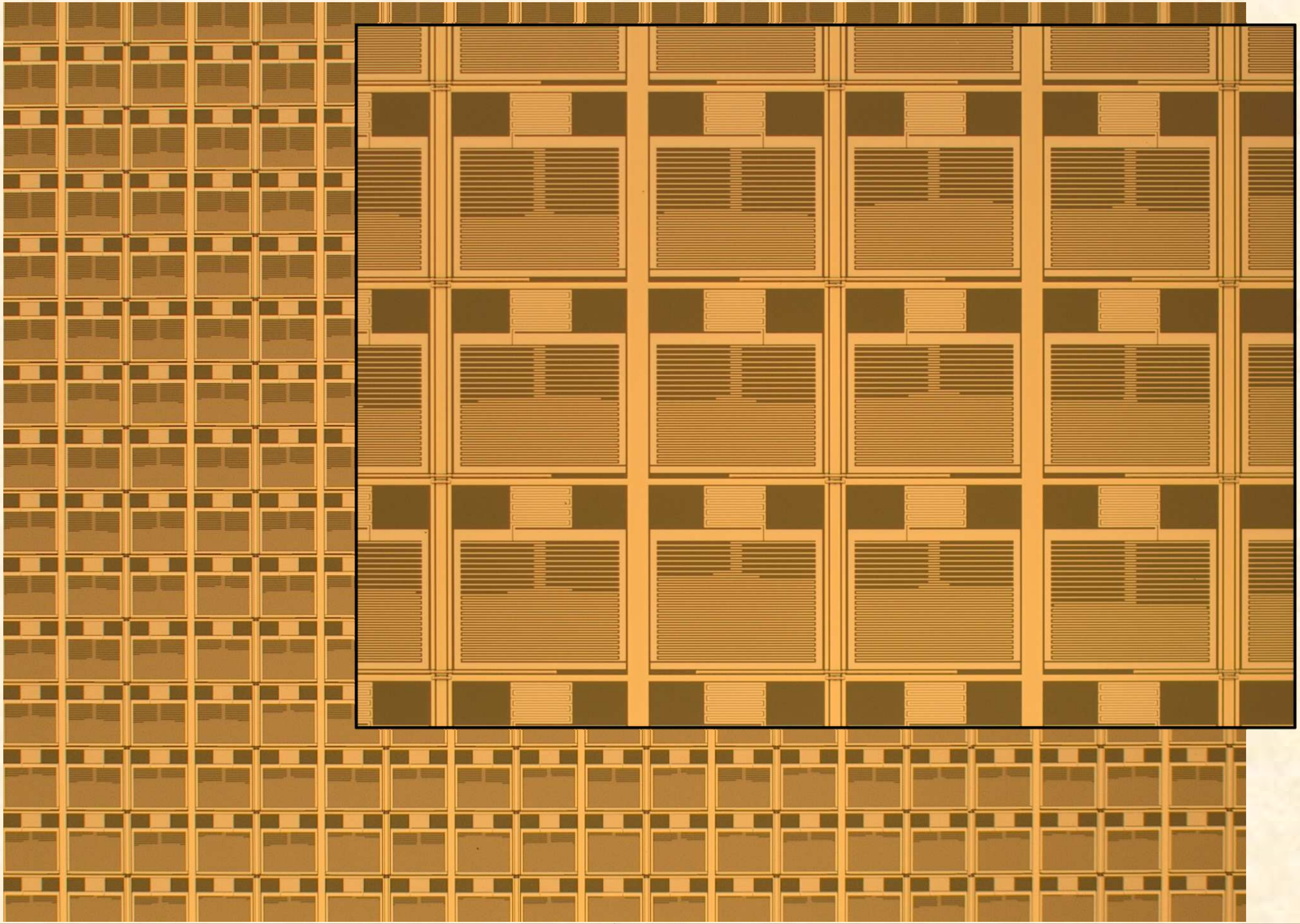


<u>We DO compete with CCDs, but we have:</u>

- Single pixel energy resolution
  → Integral field spectroscopy
- µS time resolution
  → Pulsars, reverberation mapping
- Single photon counting without dark counts
  → High contrast imaging
- Better IR sensitivity then CCDs
  → Direct Exoplanet observations
- Radiation hardness, material choice, …

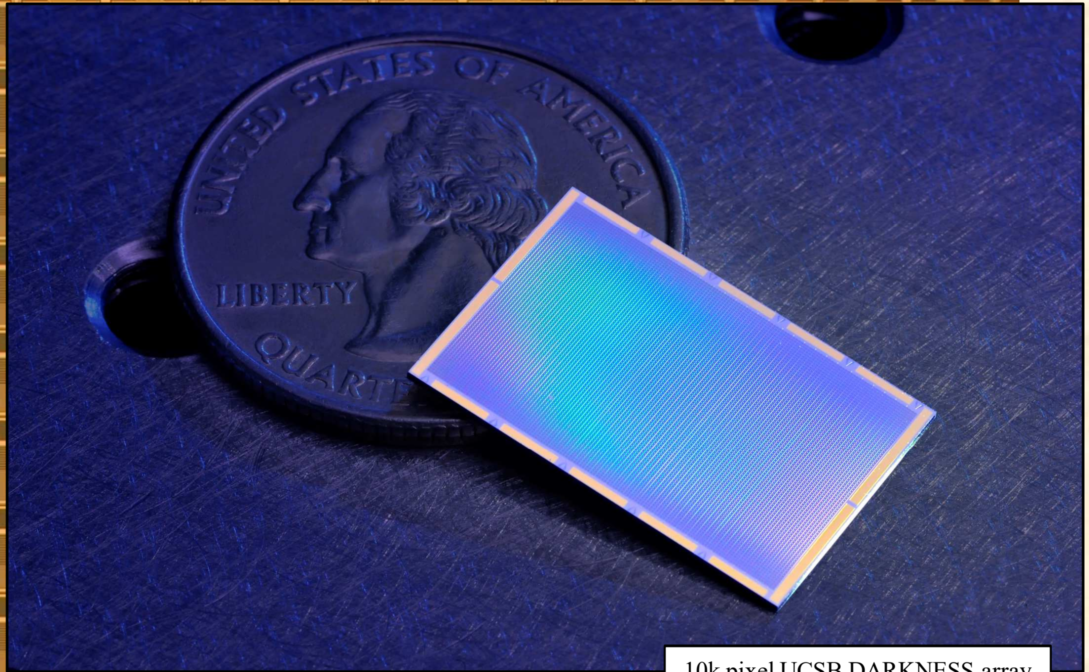
➔ ….

MKID design: lumped element

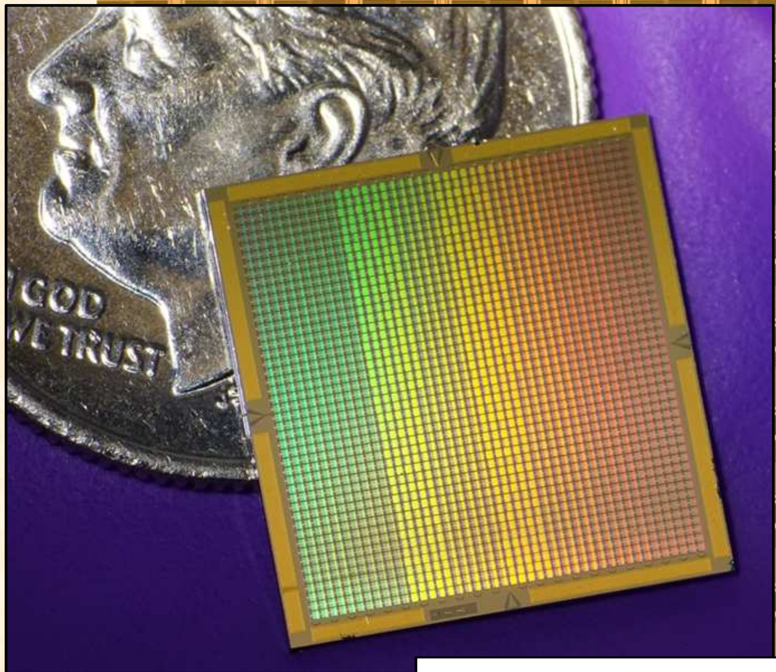


MKID design: lumped element

Array sizes



10k pixel UCSB DARKNESS array


2k pixel UCSB ARKONS array

What does a good superconductor for optical-to-IR MKIDs need:

- High kinetic inductance fraction to be able to keep pixels small enough and to allow thicker films
- The correct T_c = about 8 · base temperature → 800 mK
- High quality = low losses = high Q_i → > 100.000
- Good absorption in the optical band we want to detect = NOT shiny silvery
- QP lifetime clearly above readout sampling speed → > 20 µS

  BUT the QP life time can't be too high as it limits the max. count rate.
- Possibility to deposit homogenously over at least 5x5 cm^2
- As the superconducting film has to be thin to be sensitive: Stable against oxidization even as a thin film.
- Easy to deposit

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<u>Aluminum:</u> T_c= 1.18 K

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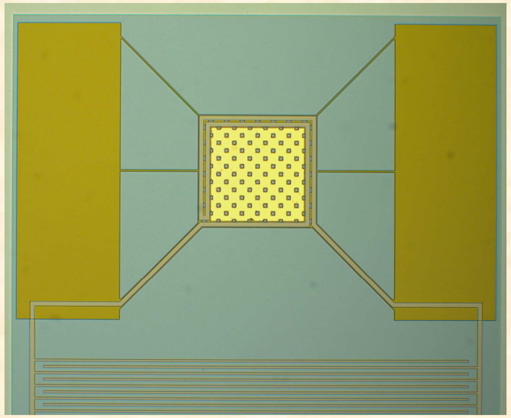

sub-stoichiometric TiN_x: T_c= 0.8 – 1.2 K

What does a good superconductor for optical-to-IR MKIDs need:

- High kinetic inductance fraction to be able to keep pixels small enough and to allow thicker films 😐
- The correct T_c = about 8 · base temperature → 800 mK 😐
- High quality = low losses = high Q_i → > 100.000 🙂
- Good absorption in the optical band we want to detect = NOT shiny silvery 😐
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- Possibility to deposit homogenously over at least 5x5 cm^2 🙂
- As the superconducting film has to be thin to be sensitive: Stable against oxidization even as a thin film. 🙂
- Easy to deposit 🙂

TiN / TiN$_x$ multilayers: T_c= 0.5 – 4.0 K

What does a good superconductor for optical-to-IR MKIDs need:

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$PtSi_x$: T_c= 0.8 – 1.0 K

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WSi_x: T_c= 0.8 – 1.0 K

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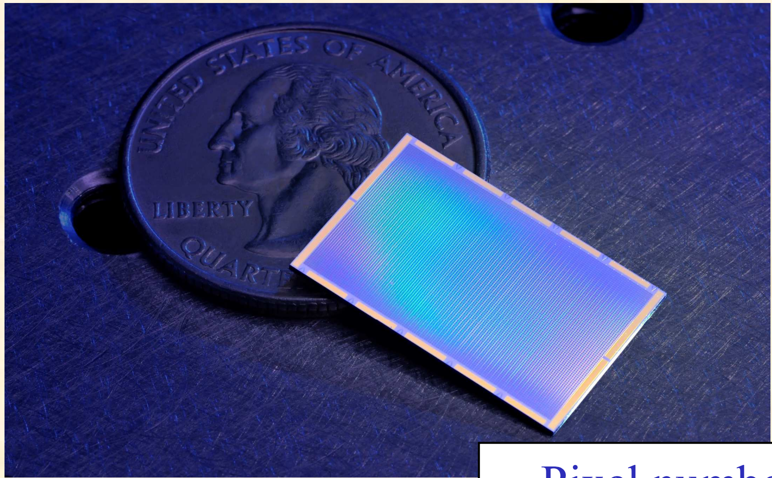
- The correct T_c = about 8 · base temperature → 800 mK
- High quality = low losses = high Q_i → > 100.000
- … very
- …
- …
- … ıst
- …

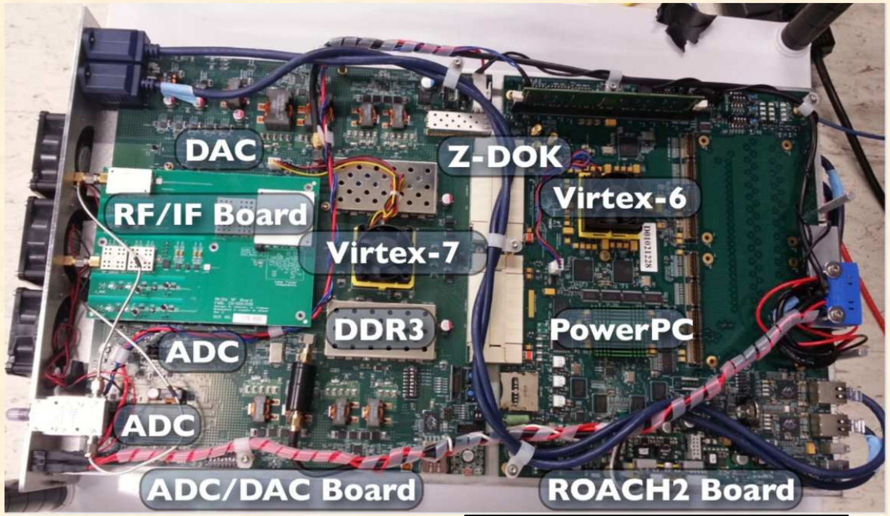
→ **We will start with both sub-stoichiometric and multilayer TiN_x:**

- $PtSi_x$ too expensive
- TiN_x and $PtSi_x$ are already well studied by the Mazin group at UCSB
- Still a good opportunity to compare results on sub-stoichiometric TiN_x
- Not much work yet on Ti / TiN_x multilayers for optical MKIDs.

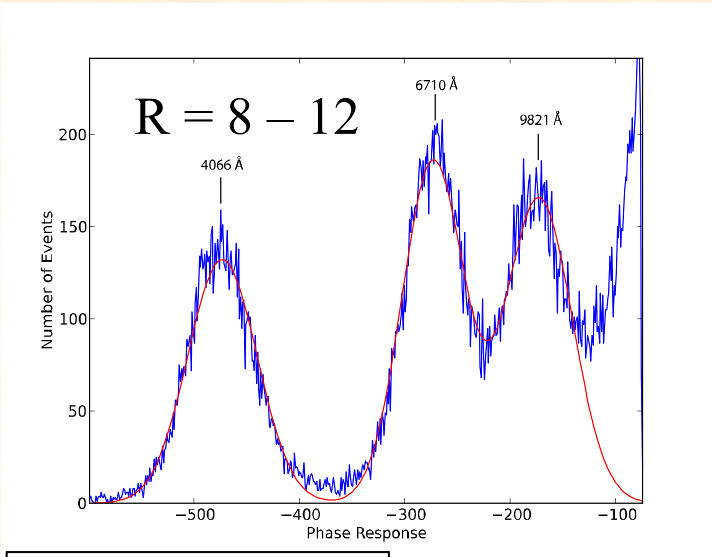
Possible MKID improvements



Pixel number



Readout



Energy resolution

Pixel yield

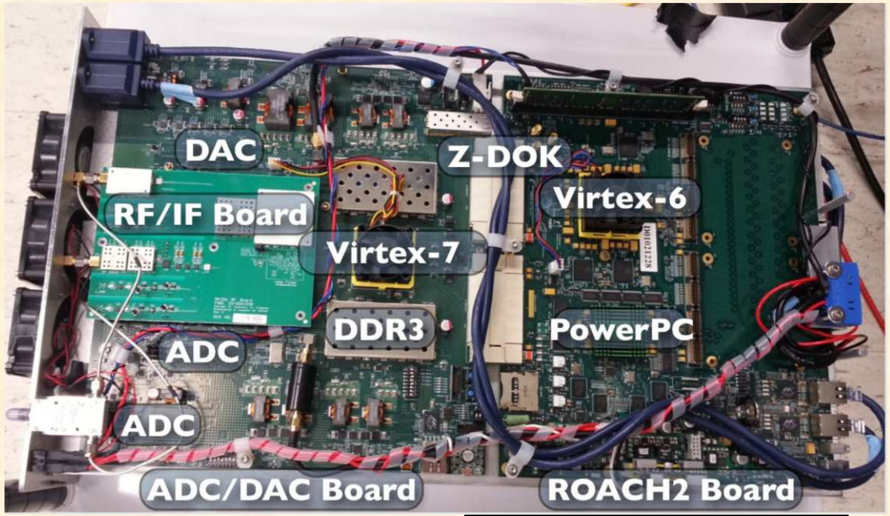
Quantum efficiency

<u>State of the art:</u>

- Roach-2 boards
- 1000 pixels per board

➔ We hope to adapt the **SKA electronics** for MKID readout to profit from:

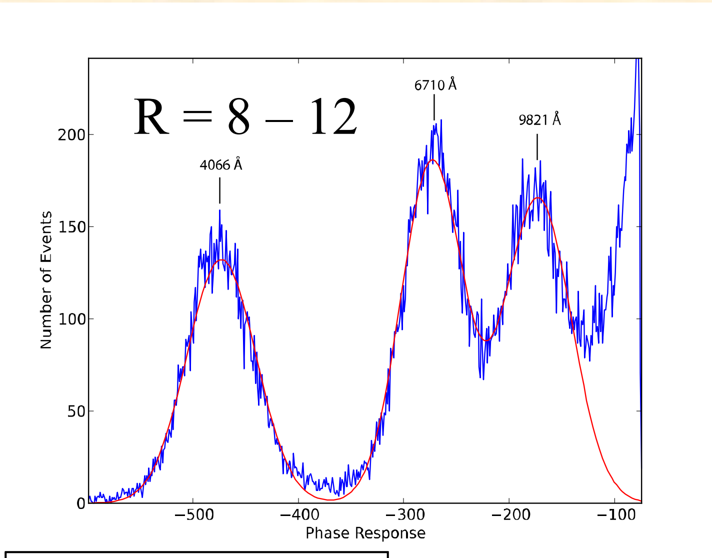
- **Big development team behind the SKA electronics**
- **Possibly cheaper then Roach boards as SKA requires big numbers**
- **Further synergy effects**
- **Good funding argument**



Readout

State of the art:

- Best pixels: R = 12
- Averaged over many pixels: R = 8 – 10



Energy resolution

- **Noise promises R of about 25 → TiN_x inhomogeneity?**
- **Varying T_c could improve R**
- **Optimize data analysis / pulse filtering to reduce effects of non-stationary noise**
- **More drive power and / or better low HEMTs**
- **Membrane suspended TKIDs?**

- The main reason for lost pixels are frequency overlaps, caused by T_c variations (or insufficient simulations.)
- TiN_x especially problematic.

- **Further optimized fabrication.**
- **Better homogeneity with TiN multilayers**
- **Improved frequency simulations**
- **Better suitable superconductors: …**
- **Search for better pixel geometries**

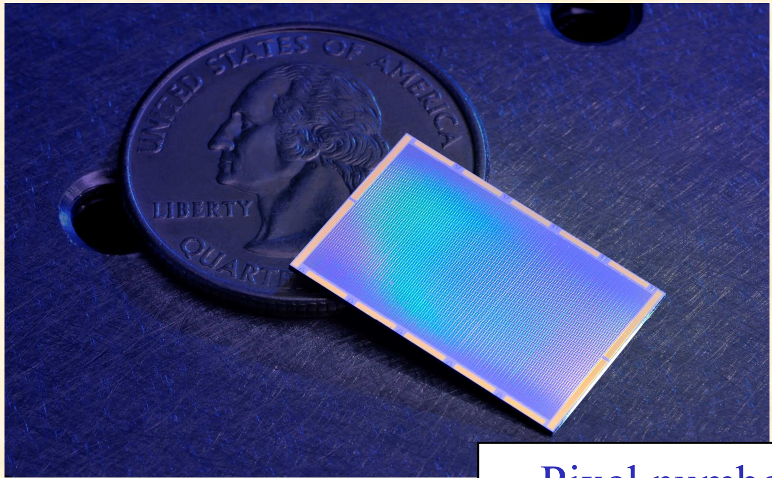
Pixel yield

State of the art:

- For sub-stoichiometric TiN_x QE is wavelength dependent: between 60% and 25%
- The main problem is the superconductor's reflectivity.

- **Deposit anti-reflective layers on the inductor without increasing the phase noise.**
- **Alternatively, apply very black films (e.g. carbon nanotubes, …) on top of the inductor to increase absorption.**
- **Micro-calorimetric, membrane suspended designs would allow much more flexibility with optimized absorbers but would significantly increase fabrication complexity.**

Quantum efficiency



Pixel number

State of the art (UCSB):

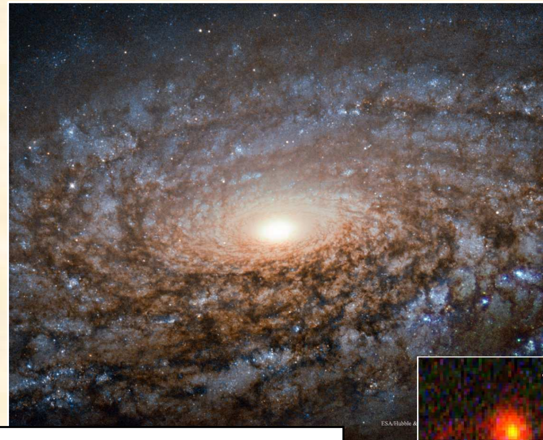
- ARCONs: 2.000 pixels
- DARKNESS: 10.000 pixels
- MEC: 20.000 pixels

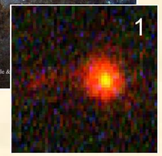
- **At the moment we are only aiming for a camera to demonstrate scientific capabilities → about 10.000 pixels**
- **But the SKA readout could allow a more compact and / or cheaper readout for high pixel numbers.**

Topics in astronomy where MKIDs can beat competing detector technologies:

MKID strengths:

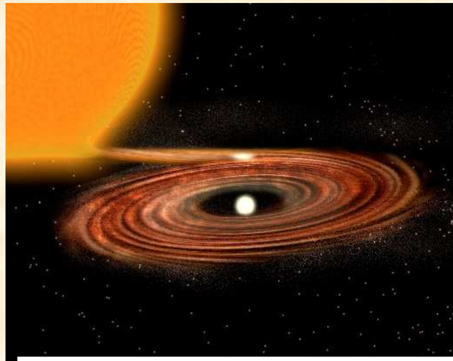
- Single pixel energy resolution
- µS time resolution
- ….
- Good IR sensitivity
  Single photon counting
  No dark counts





high z galaxies

pulsars

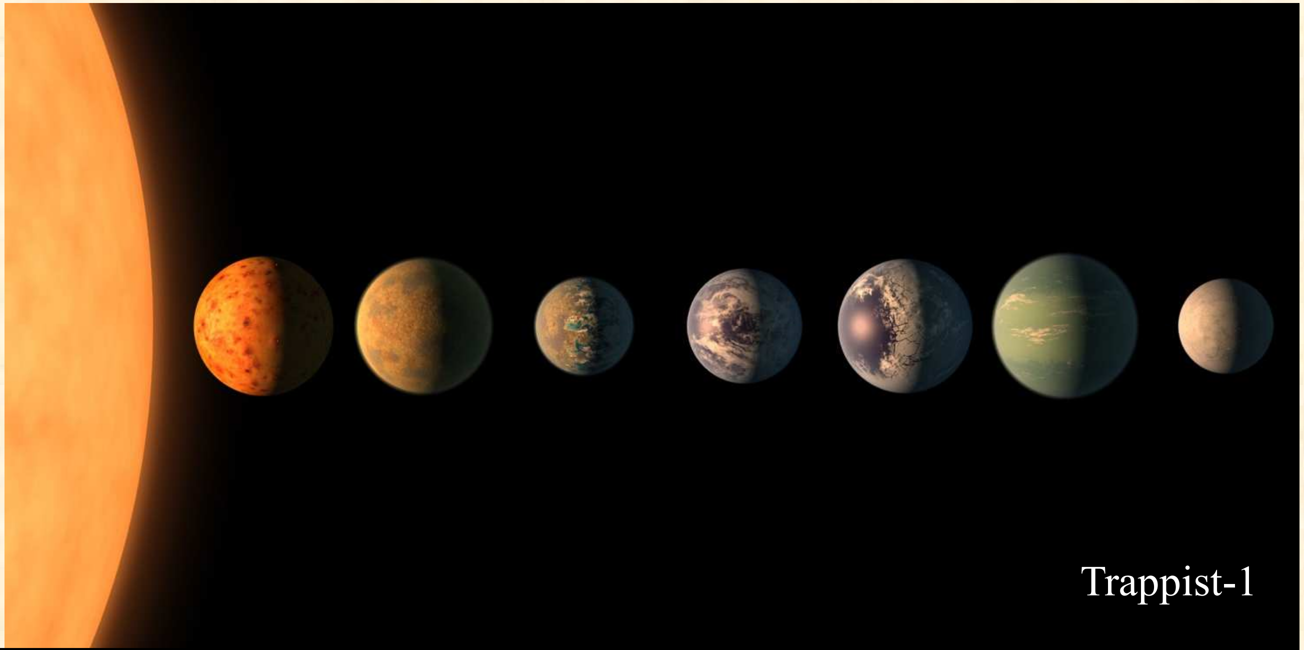


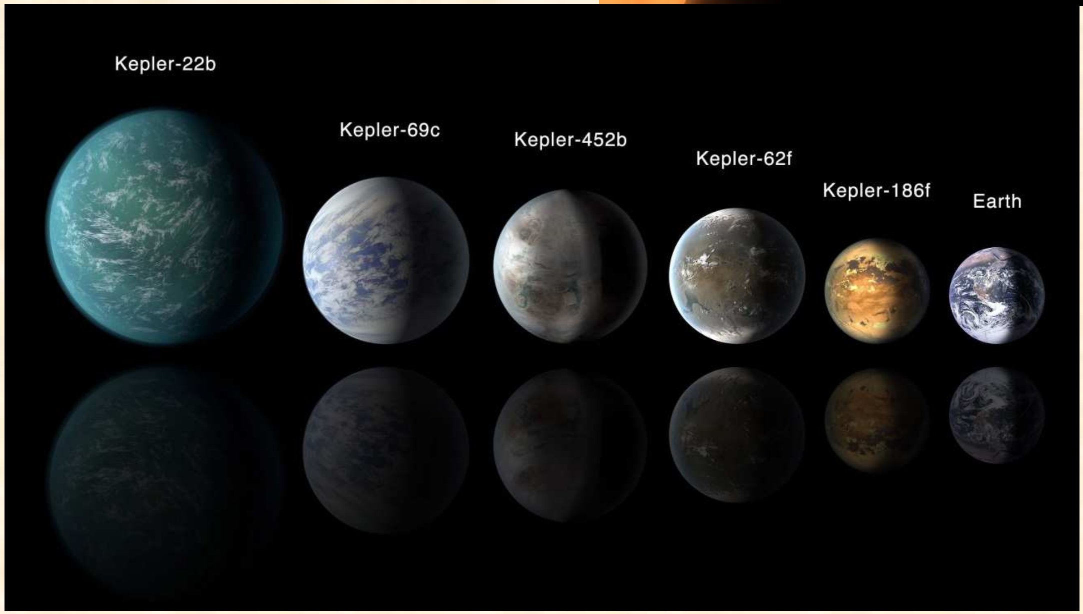
reverberation mapping

direct Exoplanet imaging

Exoplanets:

- Life outside Earth? Habitable planets? …
- Radial velocity, transits, gravitational micro-lensing, … don't allow to study atmospheres



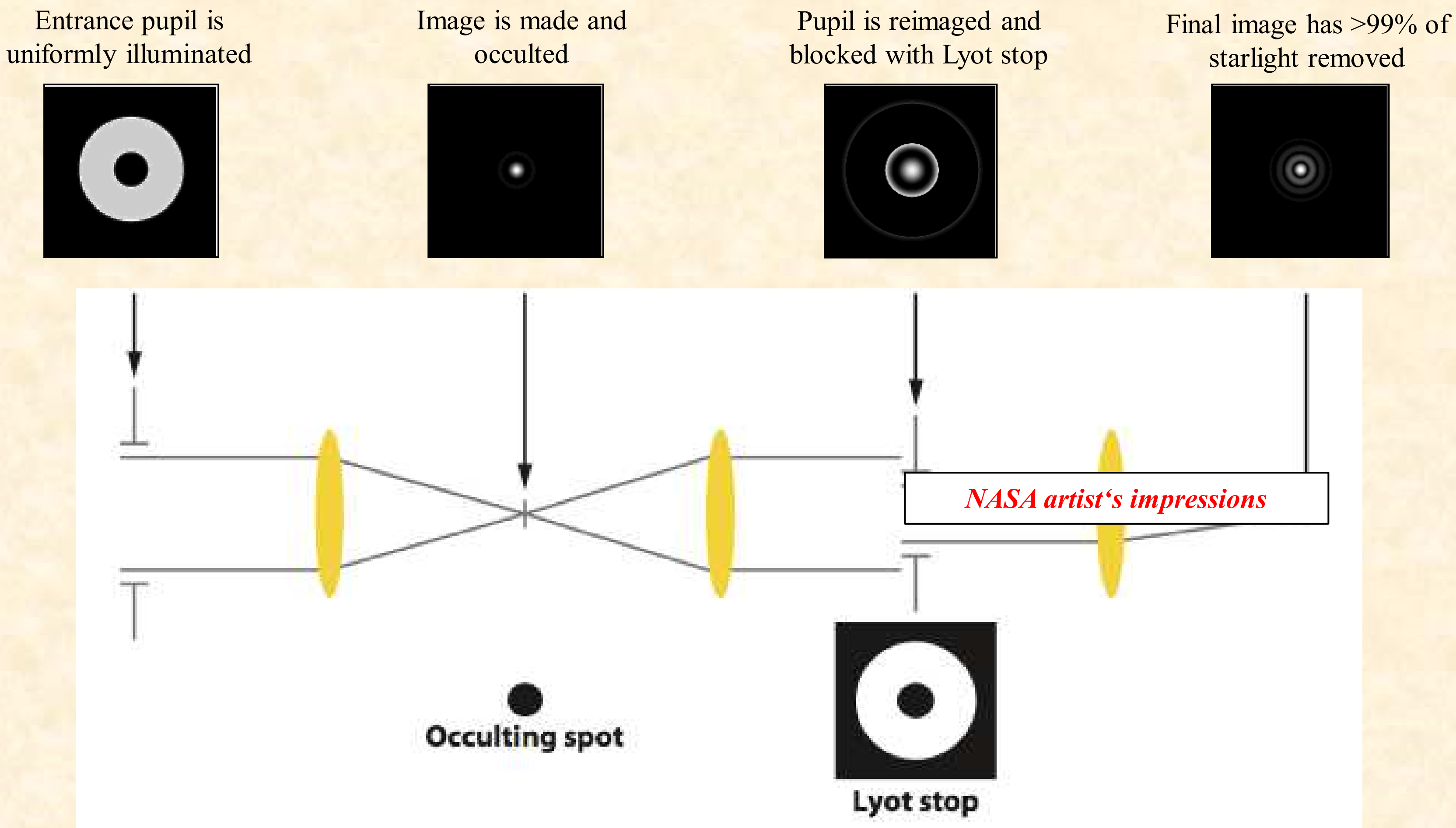


NASA artist's impressions

- Transit spectroscopy is very challenging, especially on rocky planets.
- Direct imaging is best candidate to learn about habitability.

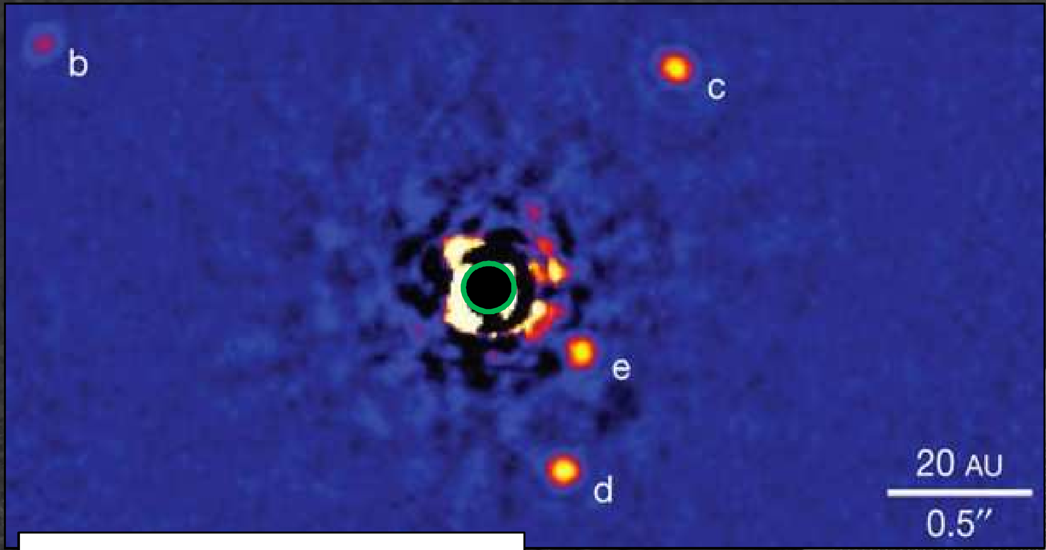
Coronagraph working principle:

adaptive optics with high Stehl ratio (50-90%) necessary



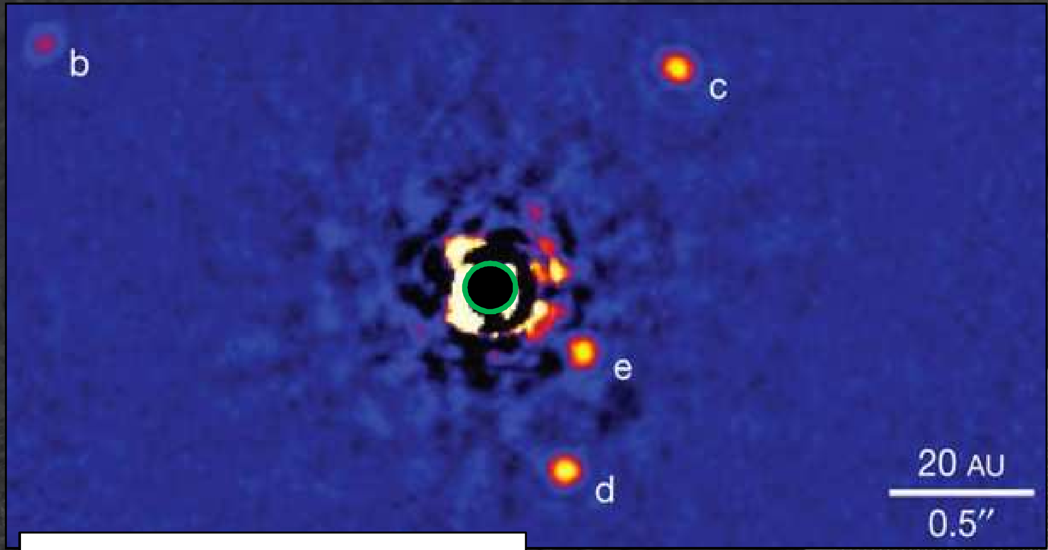
Adapted From Oppenheimer & Hinkley (2009) and Sivaramakrishnan et al. (2001)

Direct exoplanet imaging: Coronagraphy and speckles



HR8799, Marois et al (2010)

Atmospheric speckle elimination with DMs is the main challenge with high contrast imaging and MKIDs are especially well suited for this task:



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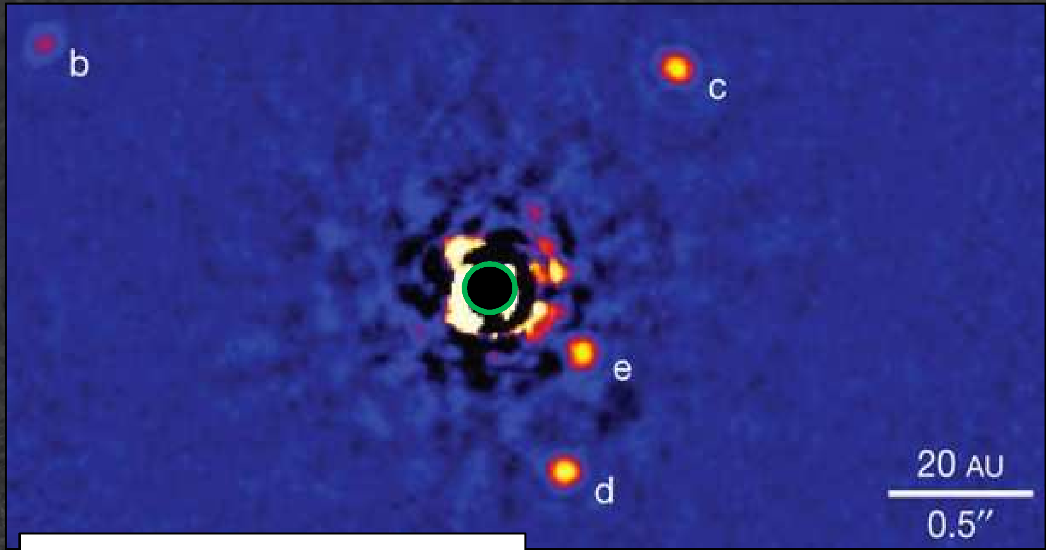

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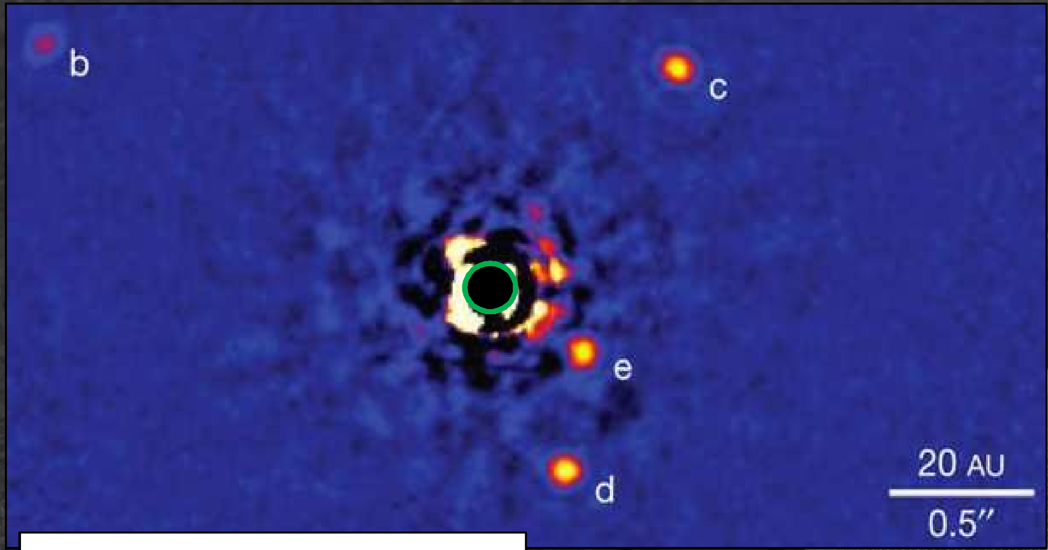
- Speckles are chromatic → MKID energy resolution allows to distinguish between speckles and exoplanets.



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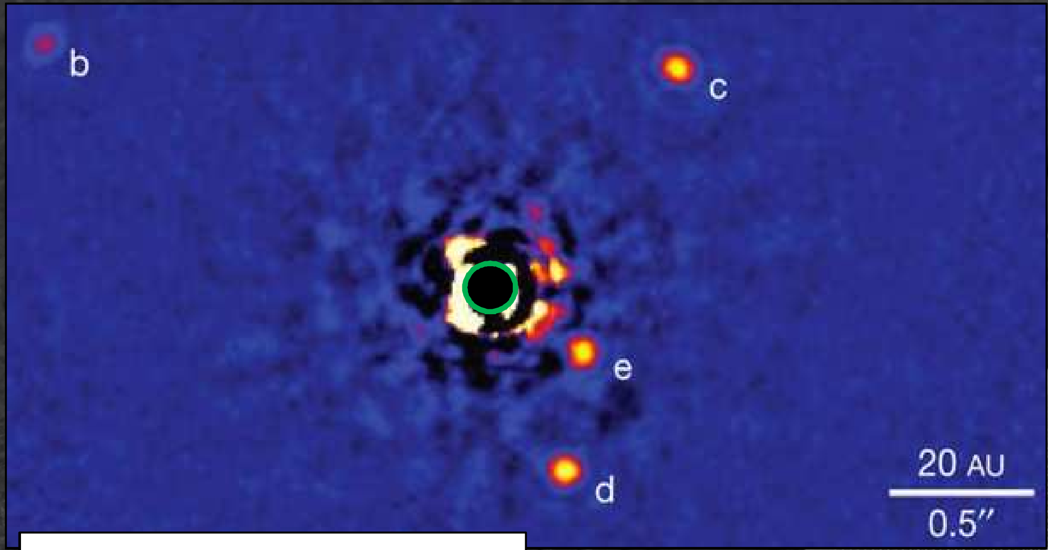
- Photon counting capability and vanishing dark counts allow to analyze the photon arrival statistic to identify exoplanets.

MKID for IR-optical astronomy

Direct exoplanet imaging: Coronagraphy and speckles



HR8799, Marois et al (2010)

MKIDs could increase attainable contrast ratios for exoplanet imaging by up to 2 orders of magnitude compared with competing detector systems:

- Image exoplanet in reflected light
- Much better chance to study habitable zone planets with 30m class telescopes

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