Optical and near-IR MKIDs for future cosmic surveys

Juan Estrada CPAD 2017

Fermilab

There is information in the large scale structure that we are missing with LSST and DESI (**high resolution photo-z**)

LSST

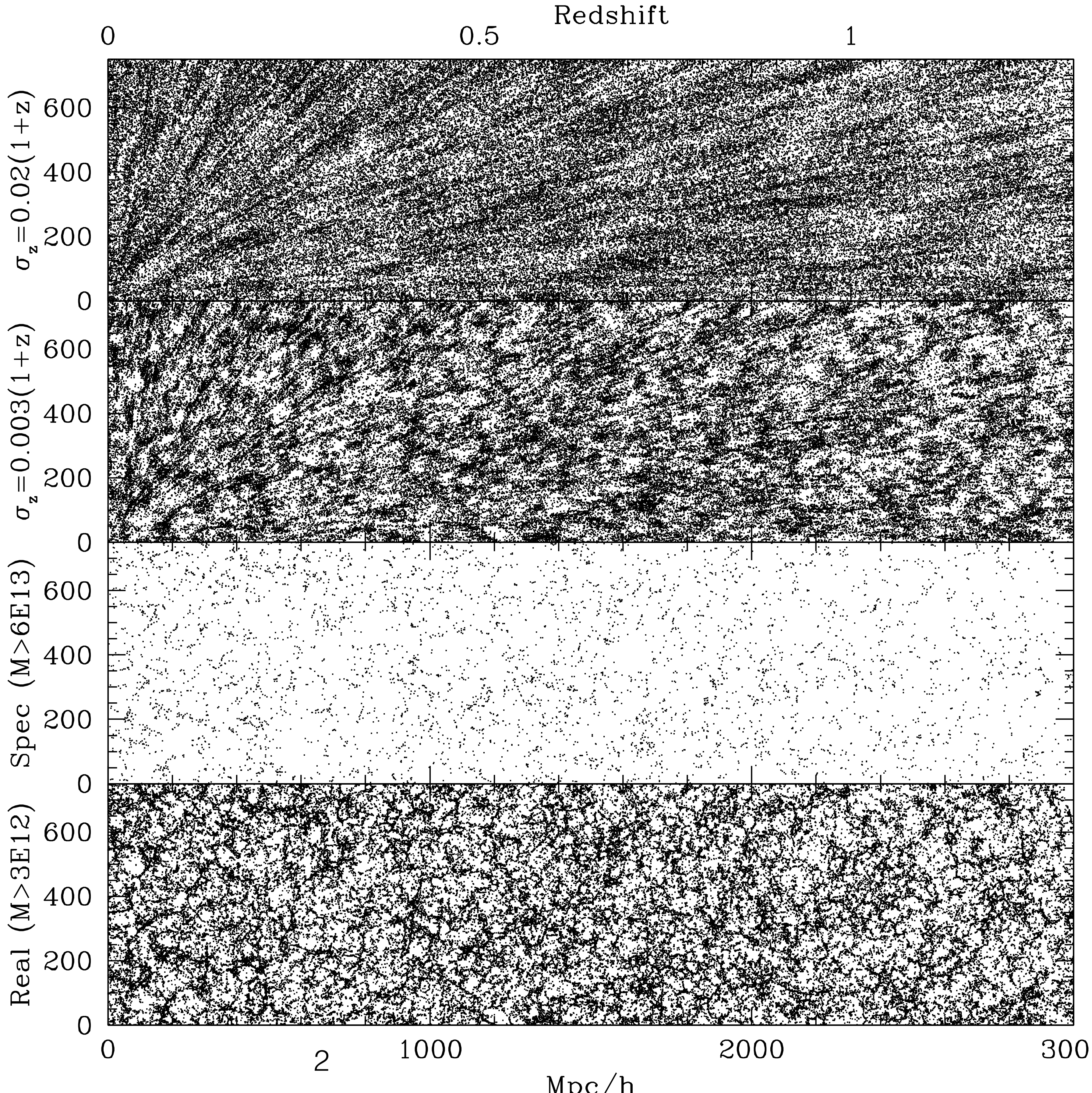
low z resolution
high spatial density

high resolution photo-z

DESI

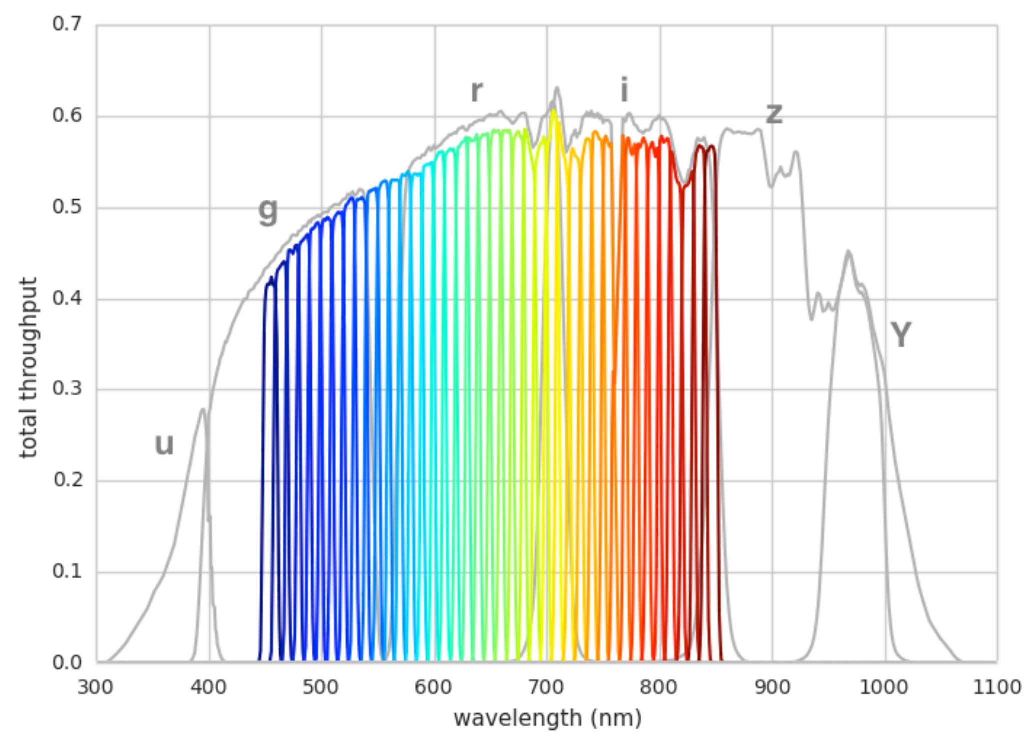
high z resolution
low spatial density

full information



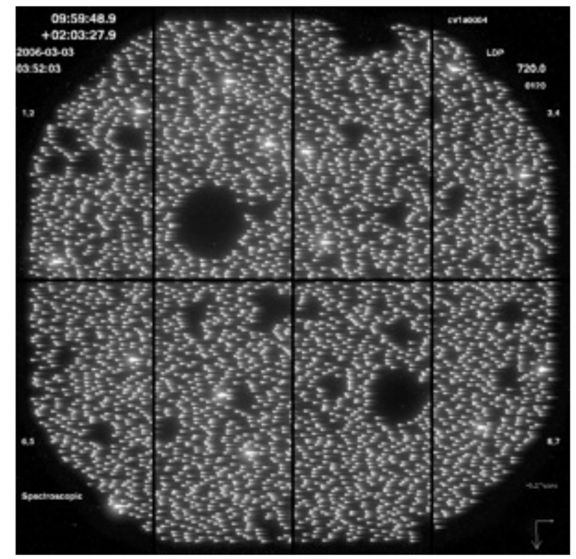
There are a few technologies that could get us this missing information

Narrow band filters

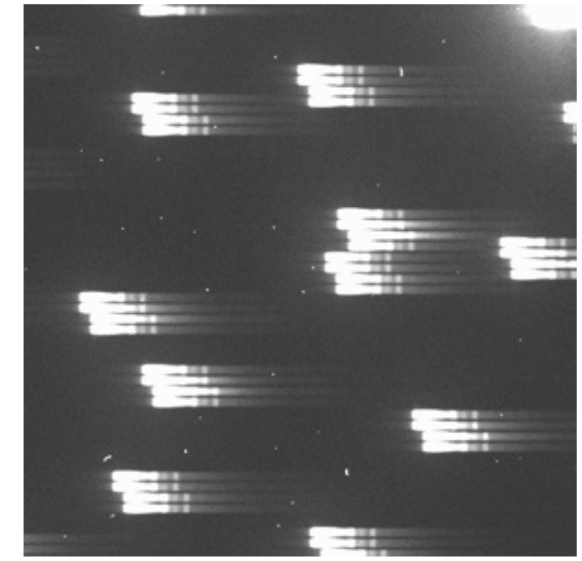


working towards understanding the technological issues and the scientific reach for high resolution photo-z surveys

Prisms

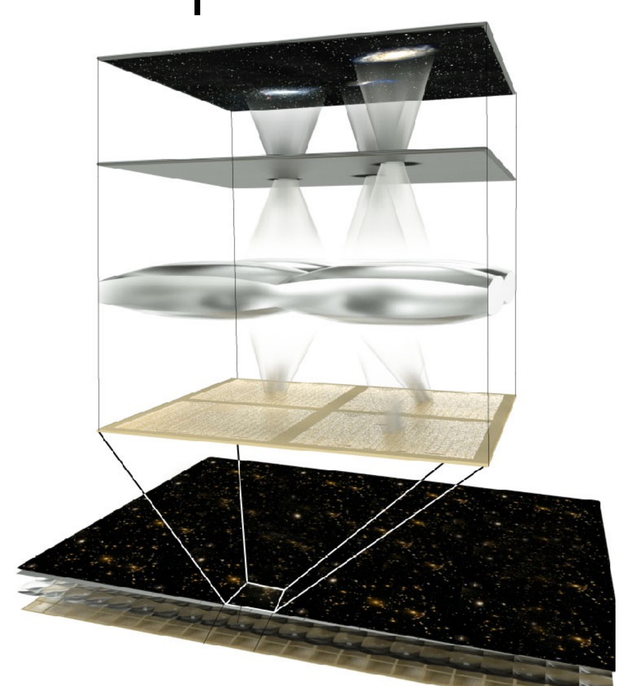


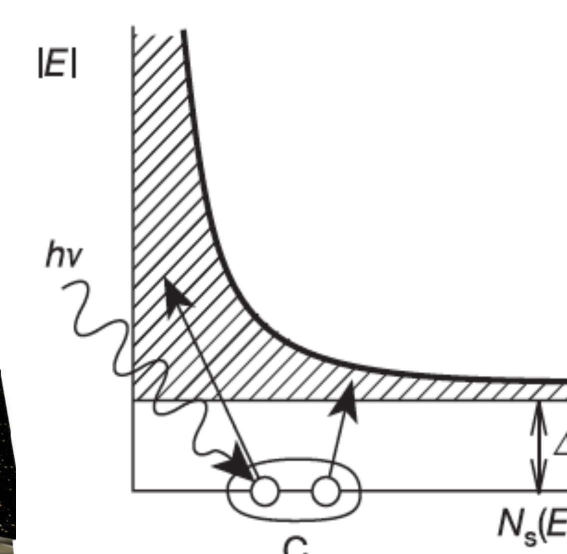
A 24-minute IMACS prism exposure of a slitmask with ~3000 objects in the COSMOS field. Areas around bright stars are masked to avoid scattered light and photometric catalog errors.



A close up of a small portion of a single exposure. Each object has 4 traces; we drill 2 slits for each object and nod the telescope between them. The other 2 traces are sky. The footprint for one object on the detector is 6.4” x 28”.

superconducting detectors MKIDs





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Filters

Survey	D (m)	FoV (deg^2)	$N_{\rm gals}$ /sq deg	Sq Deg	Mag limit (i)	R	$\sigma_z/(1+z)$	Comp.	λ Coverage
Low-Res Wide1	8.0	1.5	3.7e4	5,000	24.0	100	0.003	50%	4000-9500
Low-Res Wide2	8.0	1.5	3.7e4	15,000	24.0	100	0.003	50%	4000-9500
Low-Res Deep1	8.0	1.5	7.5e4	800	25.0	100	0.003	50%	4000-9500
Low-Res Deep2	8.0	1.5	7.5e4	8,000	25.0	100	0.003	50%	4000-9500
LSST	6.5	10	1.4e5	20,000	25.3	6	0.025		
DESI	4.0	7.0	1.4e3	14,000	23	4000	0.0001		

during the workshop we concentrated on the potential science achievable with a low resolution survey.

seems like we can not afford the inefficiency of filters

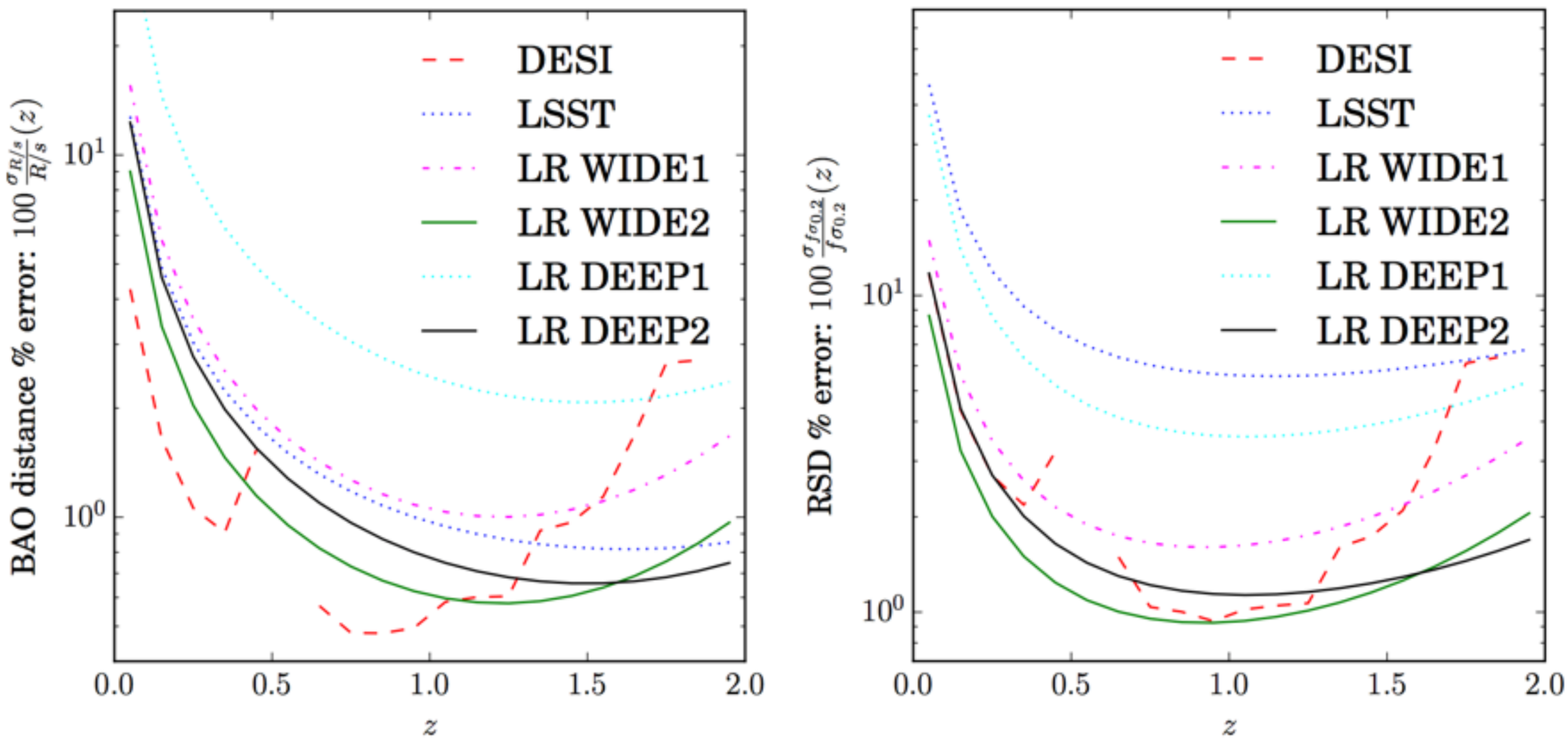
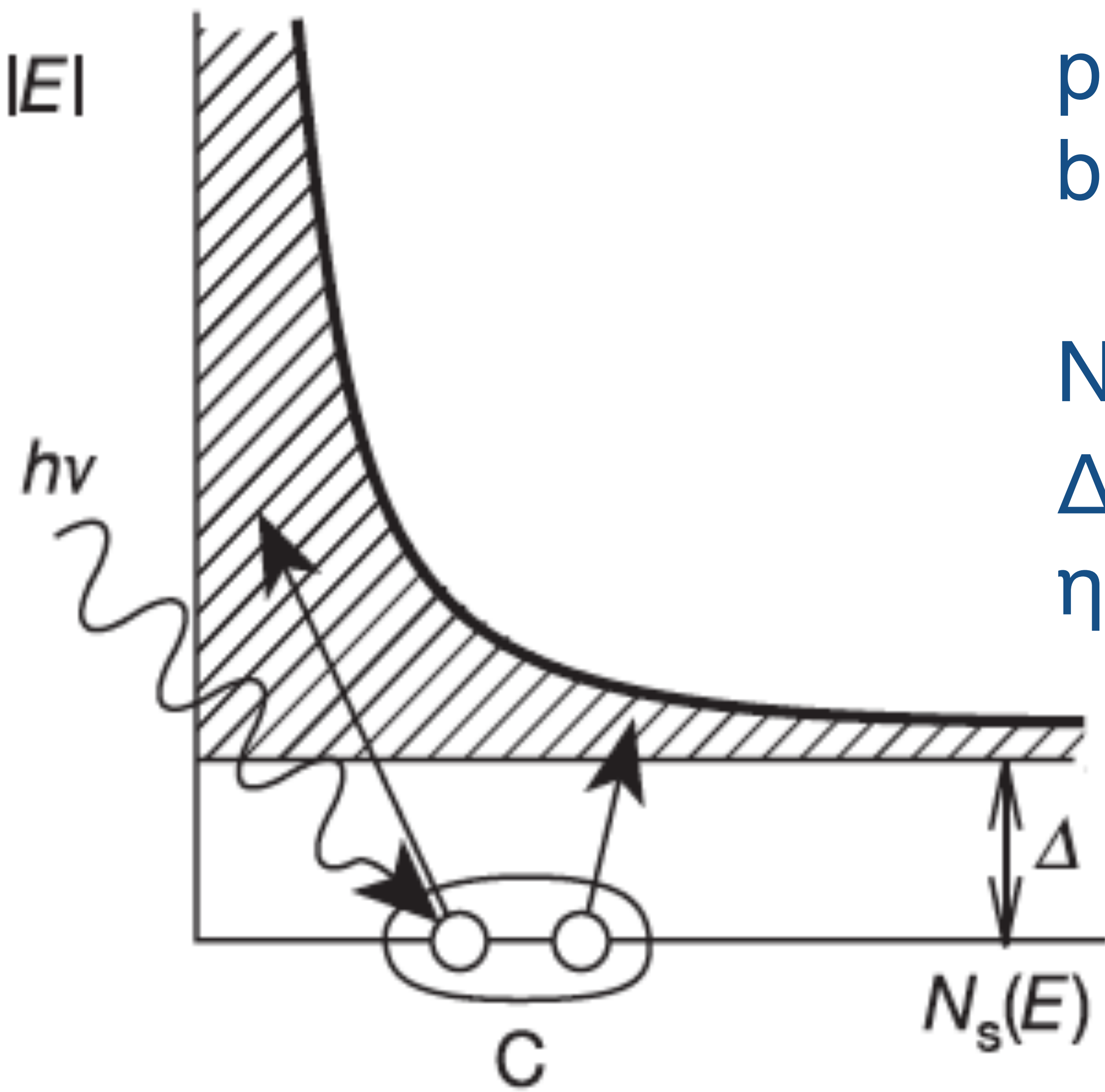


FIG. 1: Fractional errors on the BAO distance scale dilation factor R (left) and on the parameter combination best constrained by redshift-space distortions, $f\sigma$ (right), where we include scales at $k < 0.2h/\mathrm{Mpc}$. We can see that DESI will set the benchmark for the accuracy of both measurements; LR surveys will approach DESI accuracy, but they will not easily exceed it. The high number density that is achievable with photometric and LR surveys could provide relatively high accuracy in the high-redshift regime ($z > 1.2$), where DESI is far from the cosmic variance limit; however, in this range the success rate of photometric redshifts is expected to degrade rapidly, thus making our LR forecasts at $z > 1.2$ certainly optimistic.



Quasiparticles are created when a photon hits a SC (Cooper pairs broken)

$N_{qp} = \eta h\nu/\Delta$

Δ : Energy gap ~ 0.001 eV

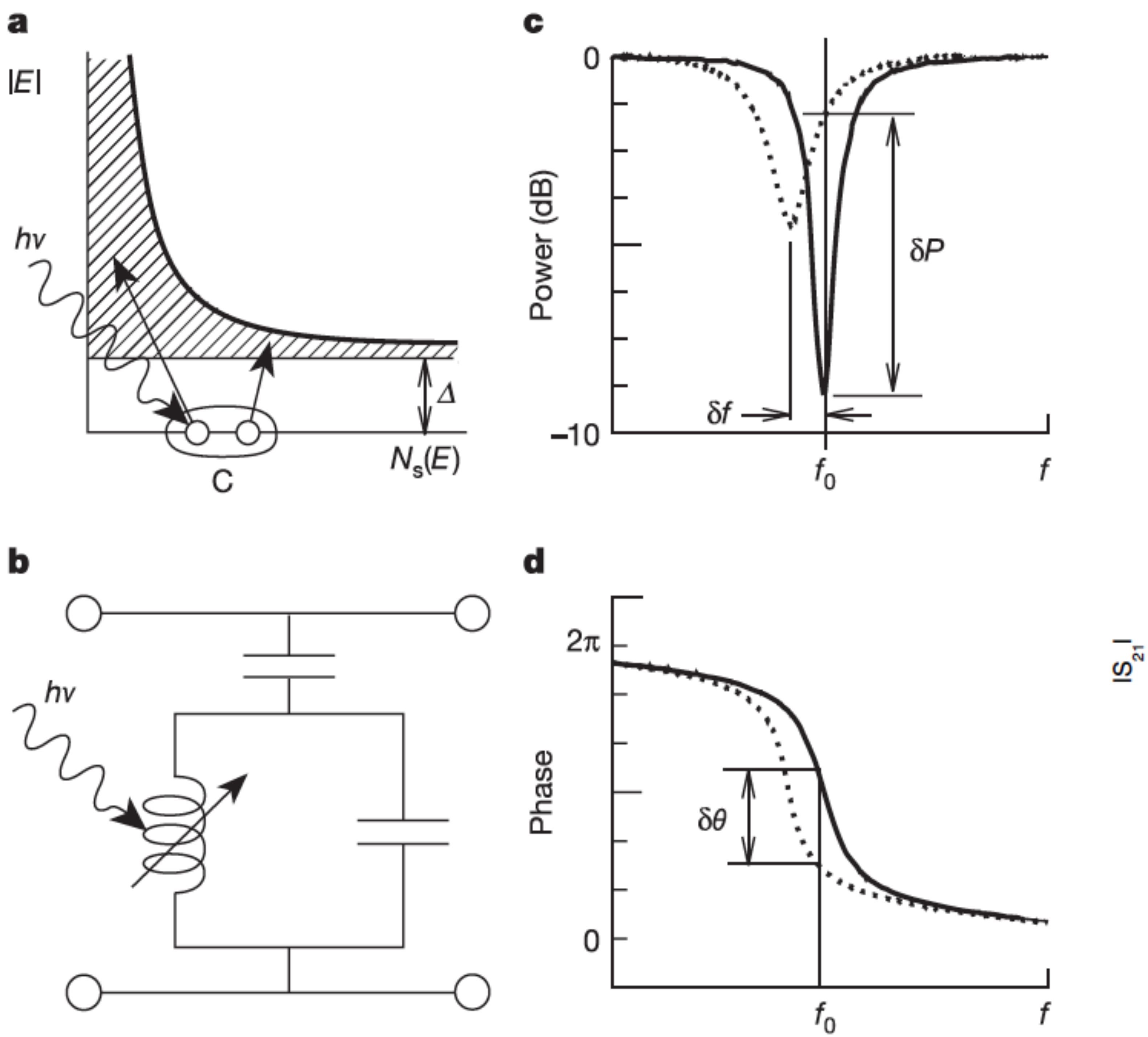
η: is an efficiency ~ 0.6

	Niobium $T_c = 9.25$ K $\Delta = 1.4$ meV	Tantalum $T_c = 4.47$ K $\Delta = .68$ meV	Aluminum $T_c = 1.175$ K $\Delta = .18$ meV	Titanium $T_c = 0.4$ K $\Delta = .06$ meV	Hafnium $T_c = 0.128$ K $\Delta = .02$ meV
IR (0.62 eV)	15	22	42	73	126
Optical (3.1 eV)	34	48	94	163	282
UV (10.3 eV)	61	88	171	297	514
X-ray (6 keV)	1500	2140	4000	7200	12500

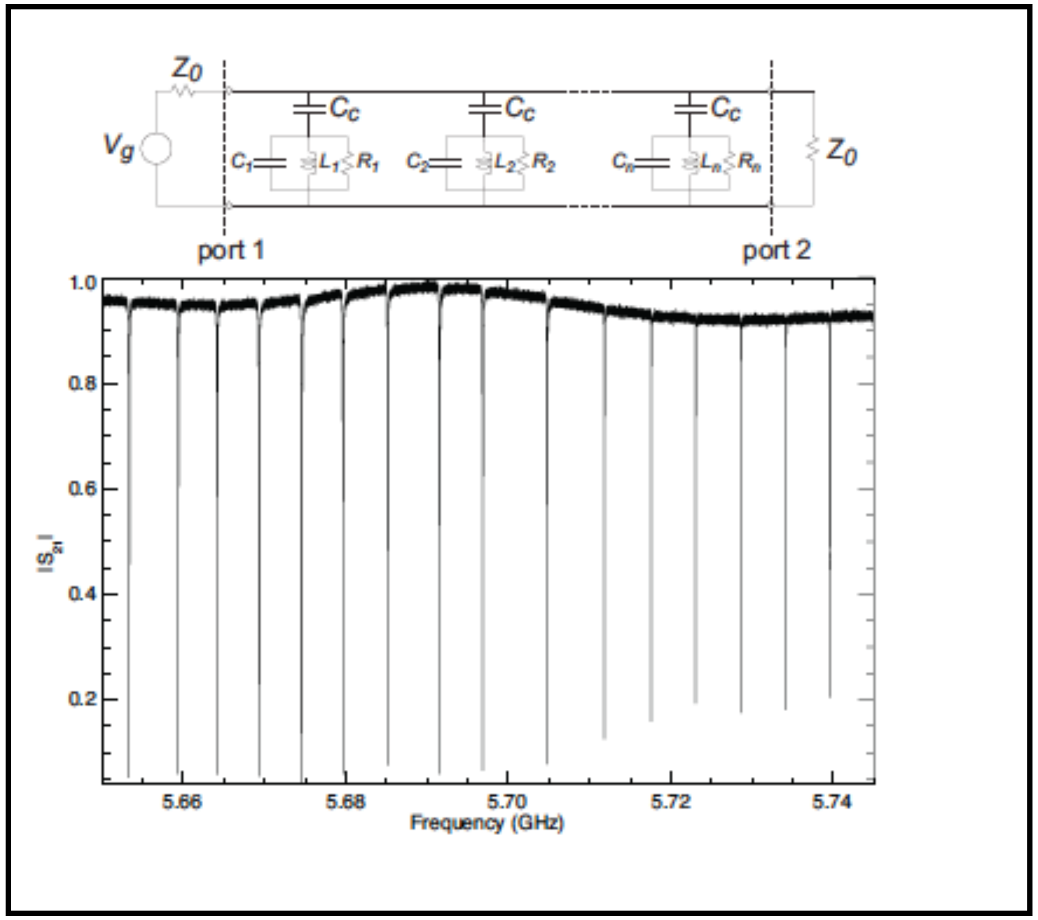
Table 3.2: Energy resolution $R = E/\Delta E$ limits for different superconducting absorbers for photon counting detectors. These calculations were done with an IR wavelength of 2 μm, optical wavelength of .4 μm, UV wavelength of .12 μm, and X-ray energy of 6 keV.

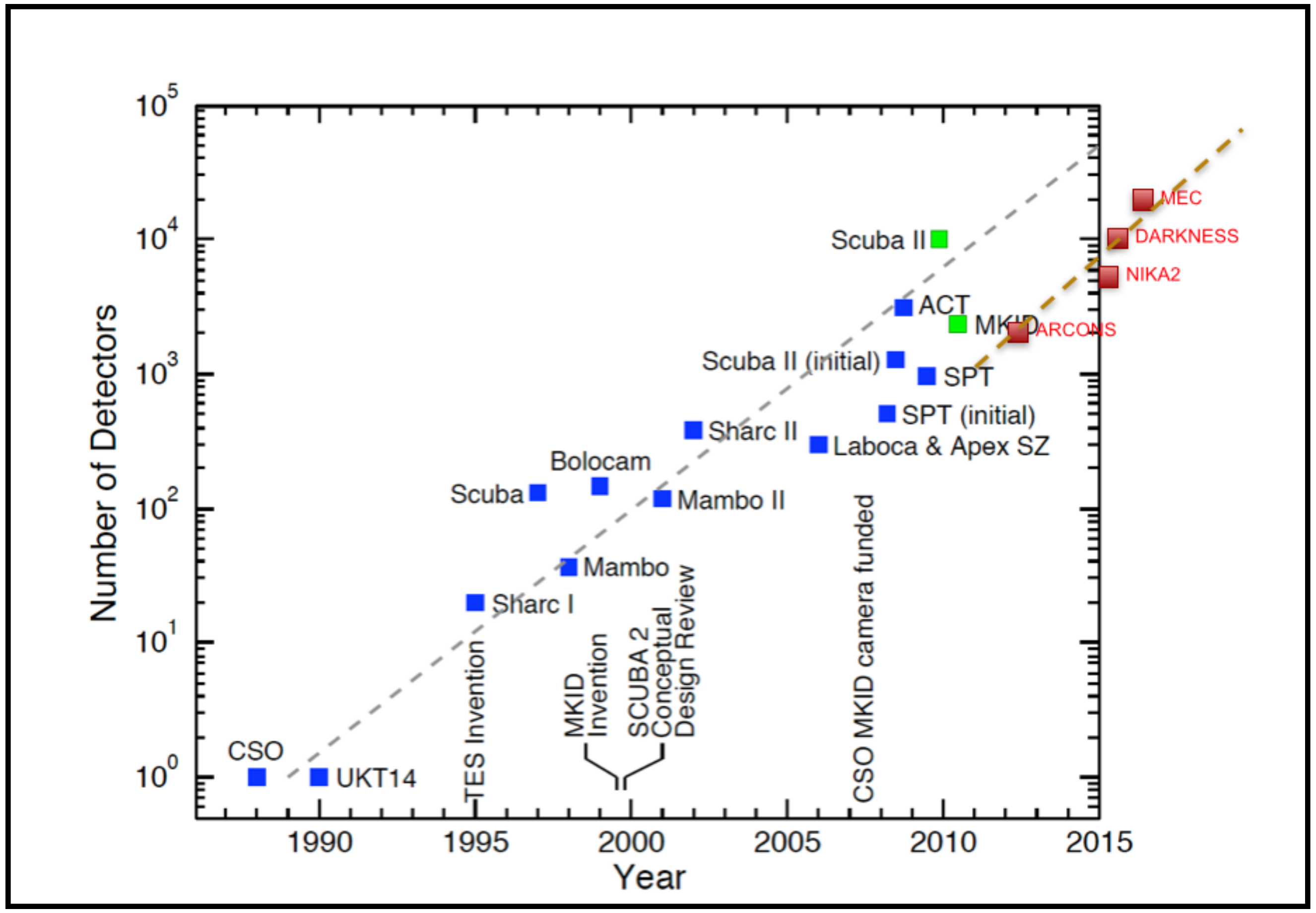
Number of quasiparticles is proportional to photon energy!
~5000 quasiparticles for a visible photon

Microwave Kinetic Inductance Detectors



Superconductor sensors with "easy" frequency multiplexing

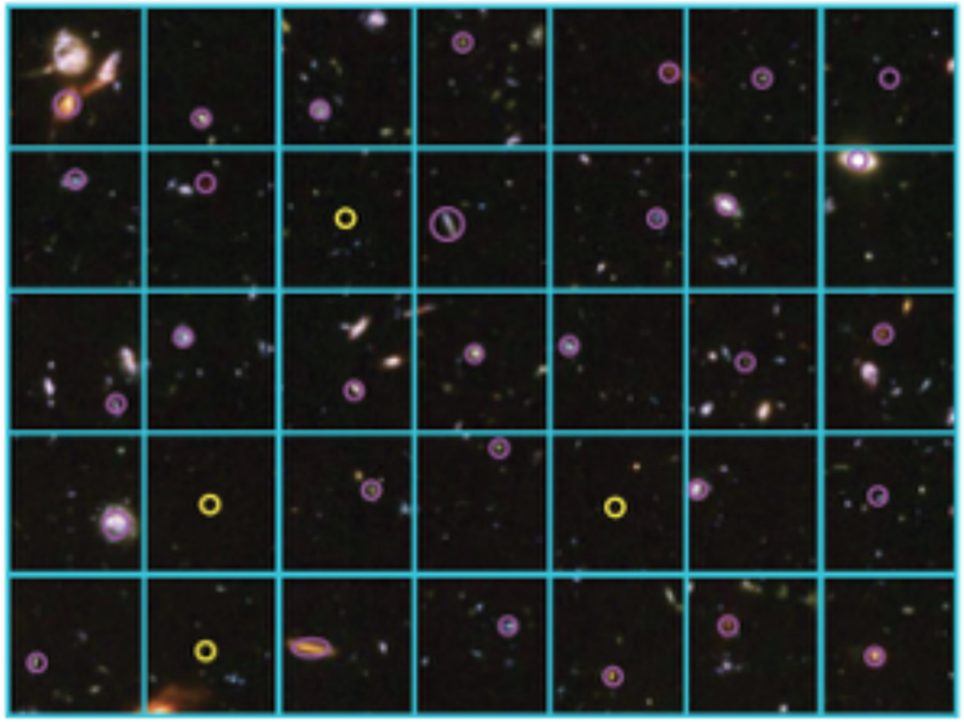




Each pixel is tuned to a different frequency. Photons each a pixel and move the resonance for that pixel. Digital FM radio. Large array of superconducting detectors are NOW possible.

GigaZ/MegaZ

- Marsden et al 2013
- LOI ESO 2014 (Oxford,Fermilab,UCSB)



100k channel low resolution spectroscopic instrument.

Marsden et al 2013.

This paper discusses what is possible with an MKID base survey. Some aspects of the science with MKIDs after LSST are presented.

There is still a lot of work to do in this area.

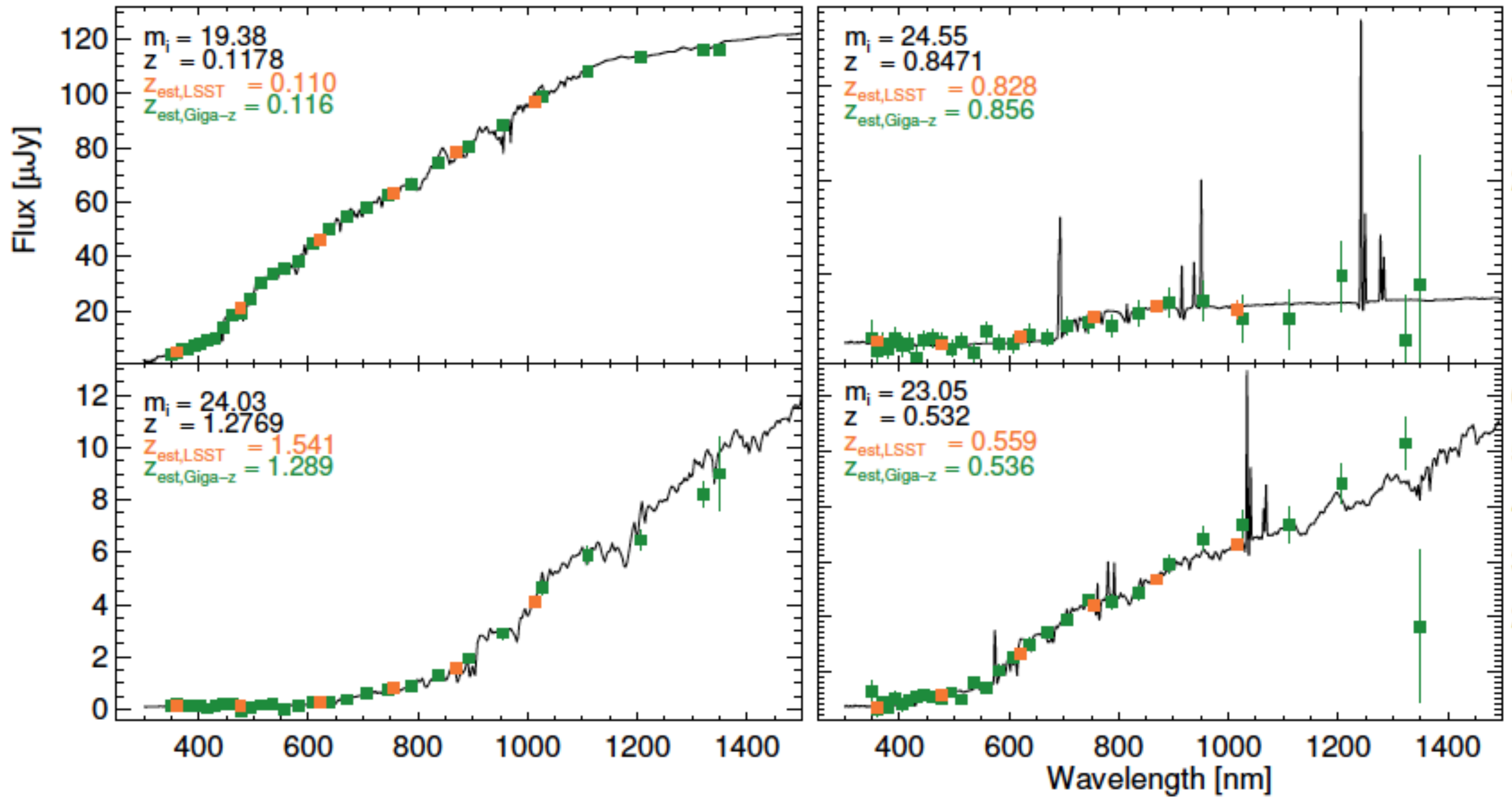
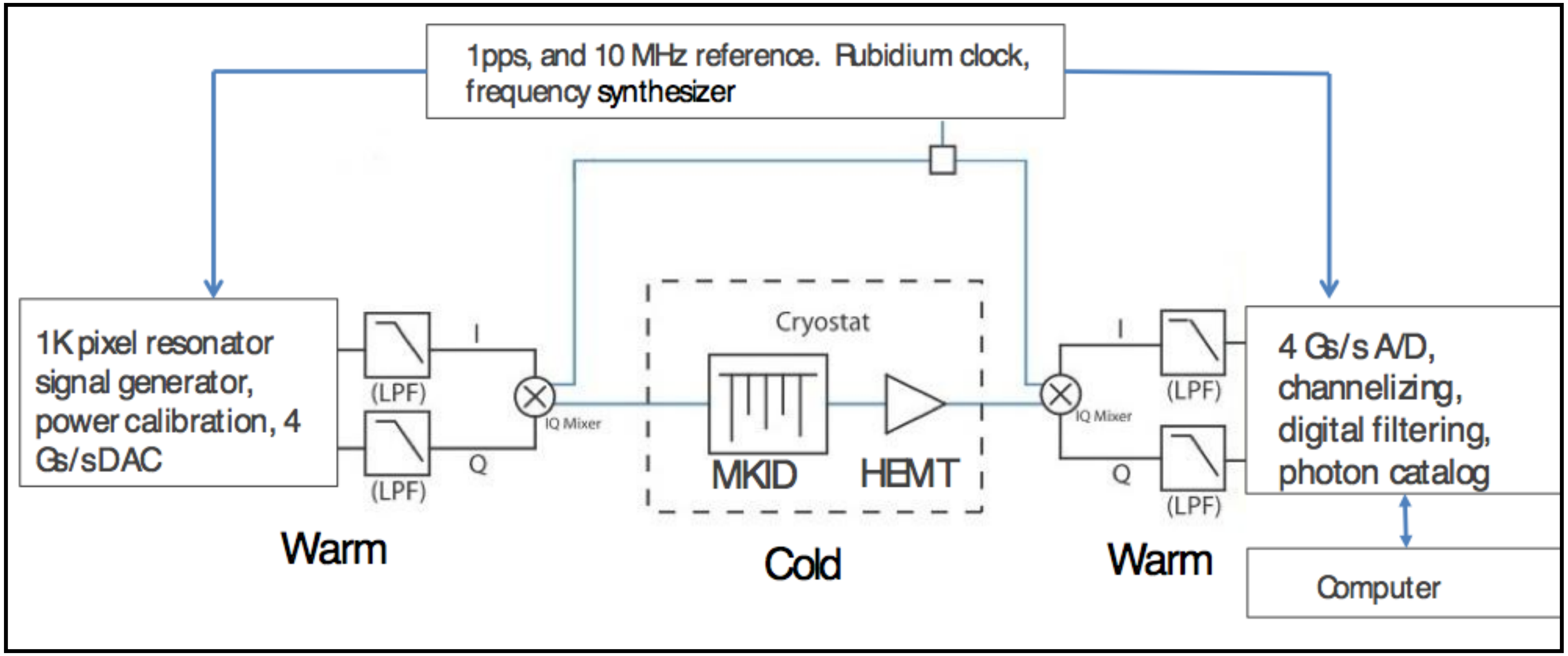


TABLE 4

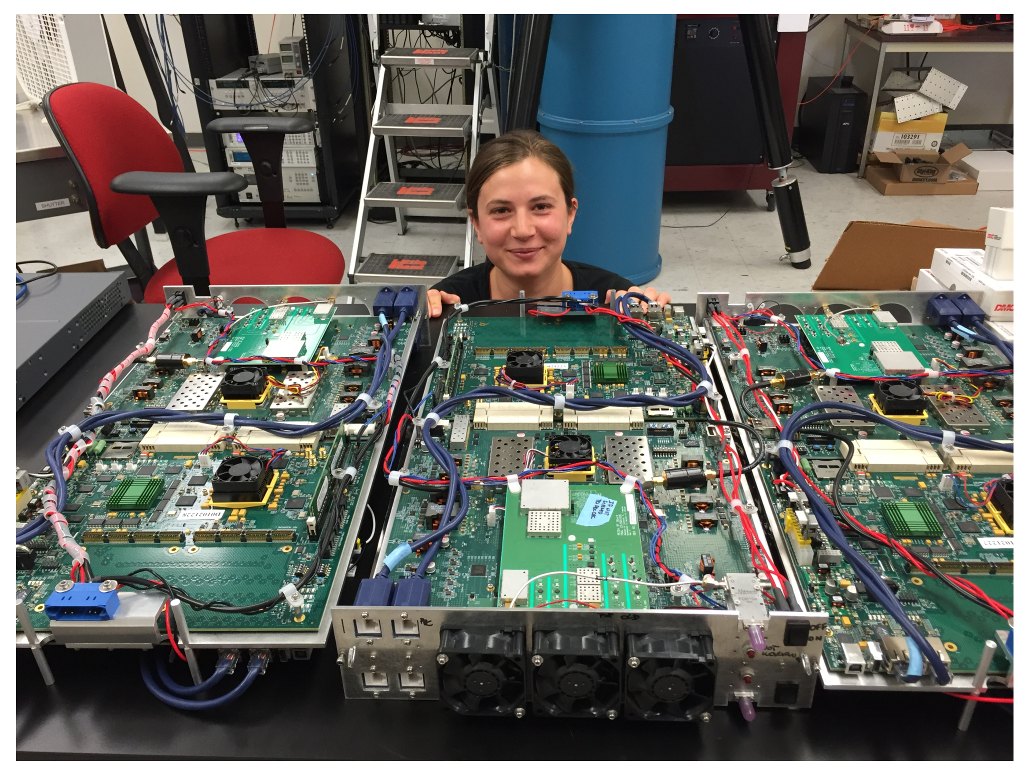
A COMPARISON OF REDSHIFT RECOVERY STATISTICS BETWEEN MULTI-BAND PHOTOMETRY OR MULTI-OBJECT SPECTROSCOPY EXPERIMENTS, BOTH PAST AND PLANNED.

Experiment	N_{gals}	Area [deg^2]	Magnitude Limit	N_{filts}/Resolution	Scatter	Cat. Failure Rate
COMBO 17 [a]	~10,000	~0.25	$R < 24$	17	0.06	$\lesssim 5\%$
COSMOS [b]	~100,000	2	$i^+_{AB} \sim 24$	30	0.06	$\sim 20\%$
	~30,000	2	$i^+ < 22.5$	30	0.007	$< 1\%$
CFHTLS - Deep [c]	244,701	4	$i'_{AB} < 24$	5	0.028	3.5%
CFHTLS - Wide [c]	592,891	35	$i'_{AB} < 22.5$	5	0.036	2.8%
PRIMUS [d]	120,000	9.1	$i_{AB} \sim 23.5$	$R_{423} \sim 90$	~ 0.005	~2%
WiggleZ [e]	238,000	1,000	$20 < r < 22.5$	$R_{423} = 845$	$\lesssim 0.001$	$\lesssim 30\%$
Alhambra [f]	500,000	4	$I \leq 25$	23	0.03	...
BOSS [g]	1,500,000	10,000	$i_{AB} \leq 19.9$	$R_{423} \sim 1600$	$\lesssim 0.005$	~2%
DES [h]	300,000,000	5,000	$r_{AB} \lesssim 24$	5	0.1	...
EUCLID [i]	2,000,000,000	15,000	Y,J,K $\lesssim 24$	3+	$\lesssim 0.05$	$\lesssim 10\%$
	50,000,000	15,000	$H_\alpha \geq$ 3e-16 erg/s/cm^2	$R_{1\mu m} \sim 250$	$\lesssim 0.001$	$< 20\%$
LSST [j]	3,000,000,000	20,000	$i_{AB} \lesssim 26.5$	6	$\lesssim 0.05$	$\lesssim 10\%$
Giga-z	2,000,000,000	20,000	$i_{AB} \lesssim 25.0$	$R_{423} = 30$	0.03	$\sim 19\%$
	224,000,000	20,000	$i_{AB} \lesssim 22.5$	$R_{423} = 30$	0.01	0.3%

one of the critical needs was electronics



Critical: Scalable electronics being developed at FNAL and UCSB together.



DAQ crate concept. Each crate with 10 systems reads 10K pix. Successfully tested in telescope.

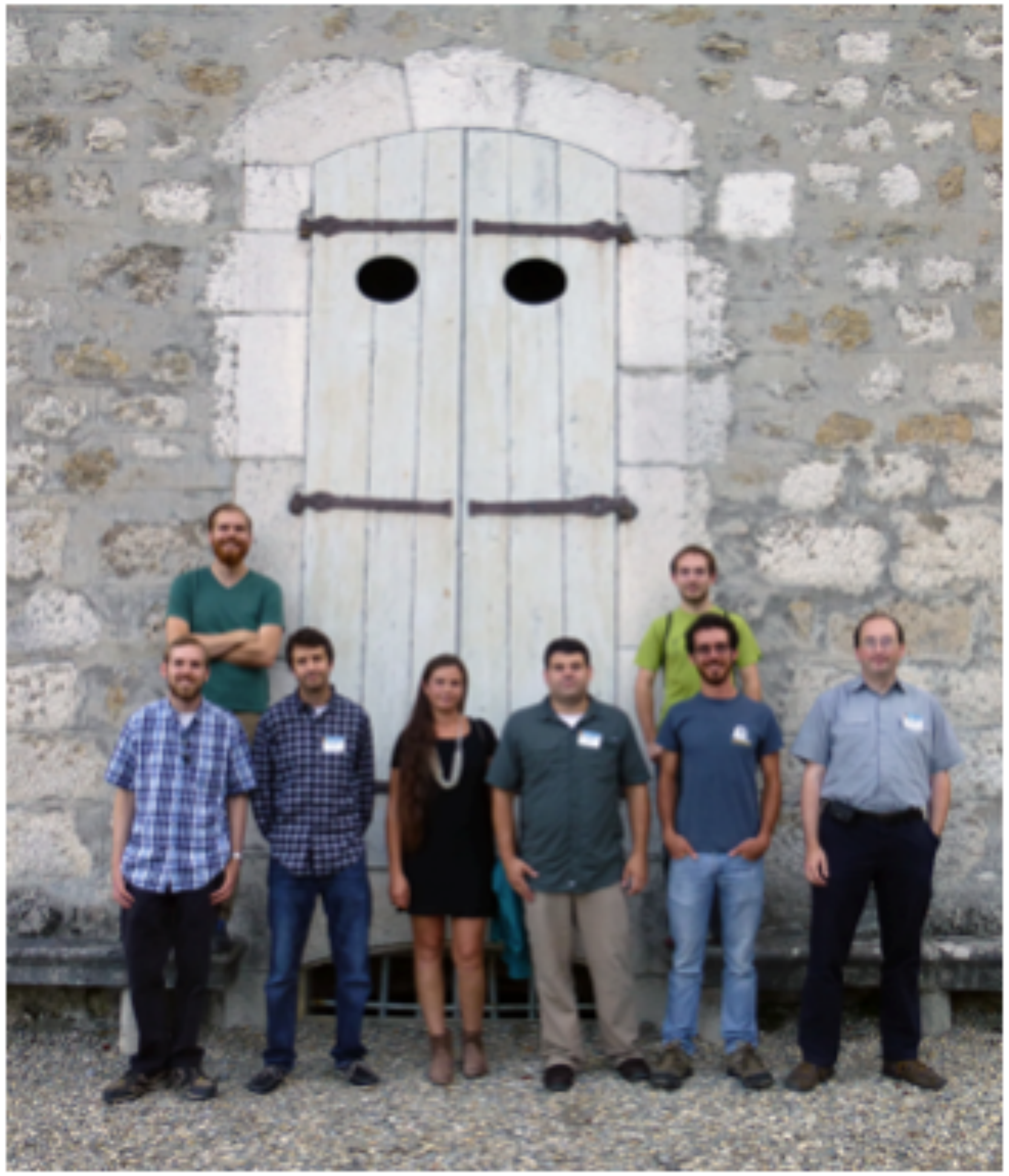
Mazin Lab at UCSB
http://mazinlab.org

Microwave Kinetic Inductance Detectors fo UVOIR Astrophysics

Ben Mazin, October 2016

The UVOIR MKID Team:

UCSB: Ben Mazin, Seth Meeker, Paul Szypryt, Gerhard Ulbricht, Alex Walter, Clint Bocksteigel, Giulia Collura, Neelay Fruitwala, Isabel Liparito, Nicholas Zobrist, Gregiore Coffard, Miguel Daal
JPL/IPAC: Bruce Bumble, Julian van Eyken
Oxford: Kieran O'Brien, Rupert Dodkins
Fermilab: Juan Estrada, Gustavo Cancelo, Chris Stoughton



MazinLab.org @ UCSB JPL

Update from Ben Mazin to the CPAD 2016

Mazin Lab at UCSB
http://mazinlab.org

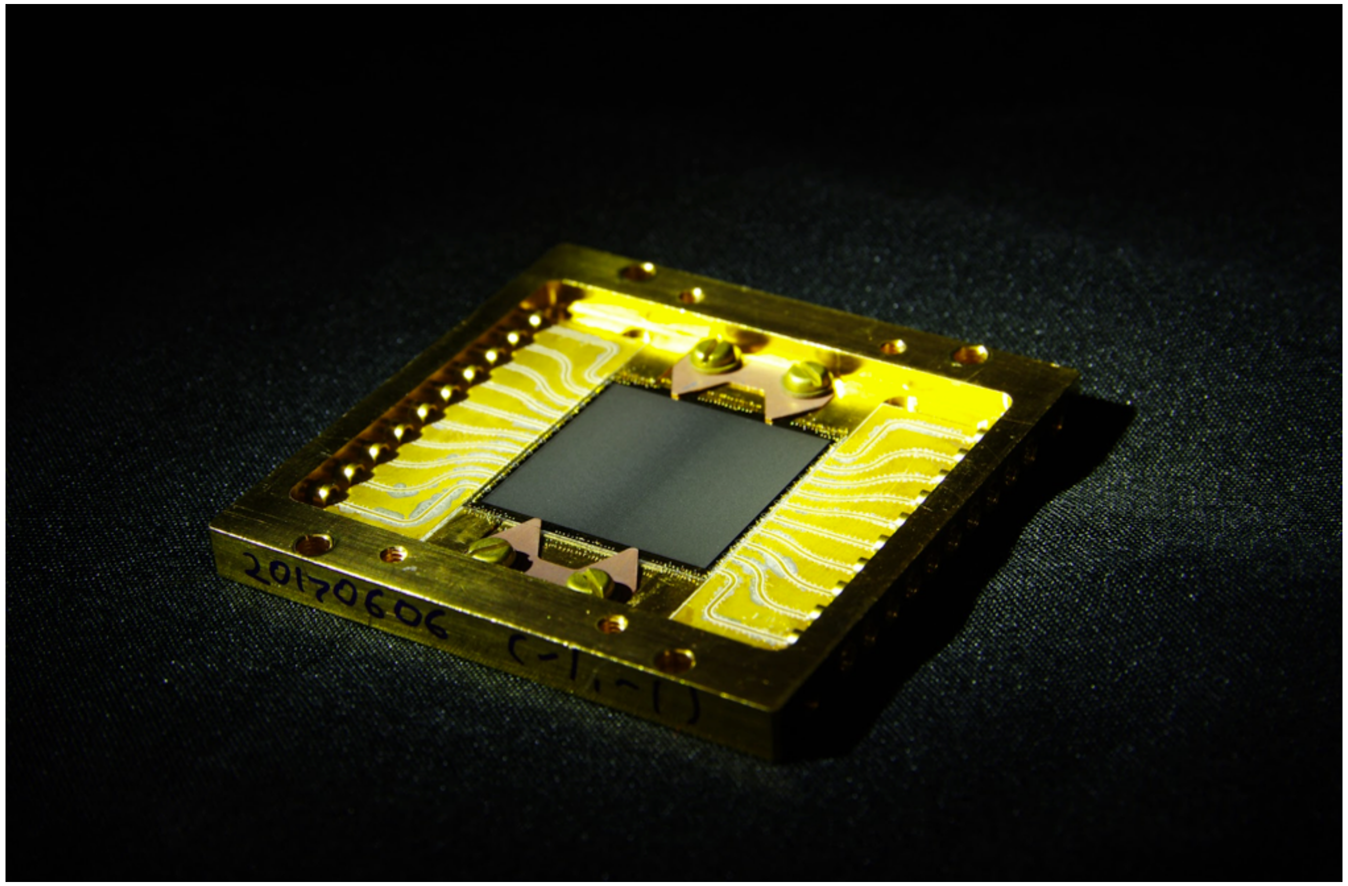
Outstanding Issues

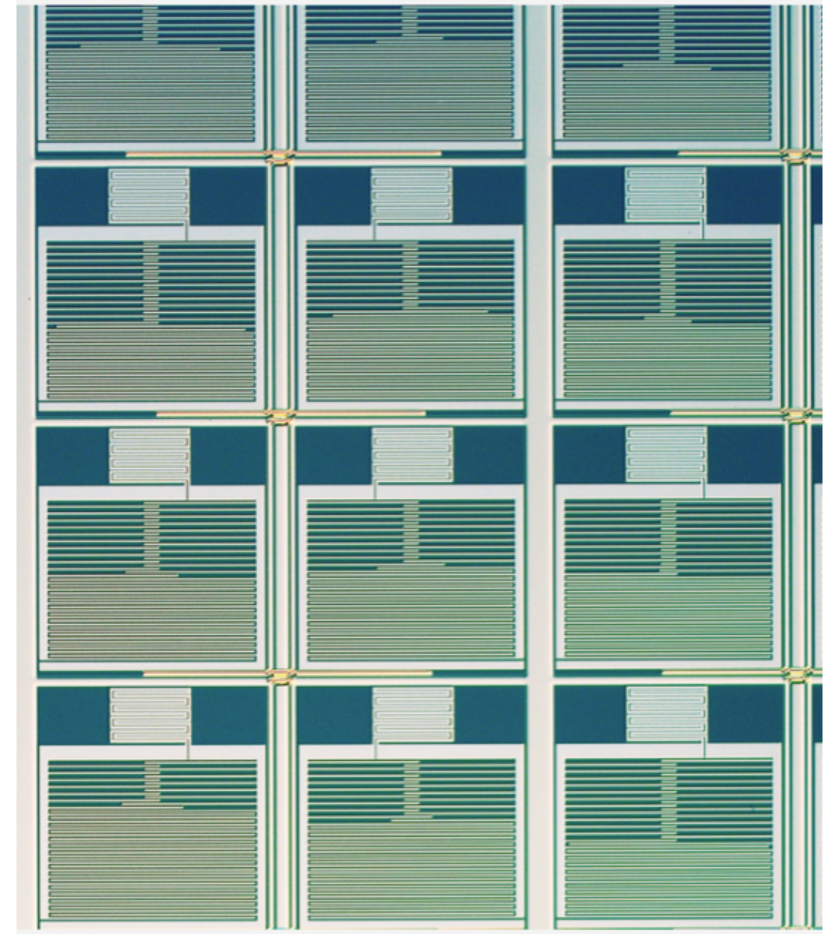
- Three main issues need improvement!
  - Pixel Yield
    - 75% in ARCONS
    - DARKNESS/MEC: Req. 85%; 95% goal
  - Spectral Resolution
    - R=8 at 400 nm in ARCONS
    - R=8 at 1000 nm (R~15-20 at 400 nm) in PtSi
    - DARKNESS/MEC: Req. R=8 at 1000 nm; R=15 goal
  - Quantum Efficiency
    - ARCONS TiN: 40% at 400 nm, 15% at 1000 nm
    - DARKNESS/MEC PtSi: Req. 15% at 1000 nm; >25% goal

  - Attempting to improve yield and R first as they are the biggest impacts on the science we want to do
    - Exoplanet High Contrast Imaging from the ground is far from photon shot noise limited at the moment!

Update from Ben Mazin to the CPAD 2016

20K pixel array (10 feed lines!!)





arXiv:1610.00725

High Quality Factor Platinum Silicide Microwave Kinetic Inductance Detectors

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[1)] *Department of Physics, University of California, Santa Barbara, California 93106, USA*
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(Dated: 6 October 2016)

We report on the development of Microwave Kinetic Inductance Detectors (MKIDs) using platinum silicide as the sensor material. MKIDs are an emerging superconducting detector technology, capable of measuring the arrival times of single photons to better than two microseconds and their energies to around ten percent. Previously, MKIDs have been fabricated using either sub-stoichiometric titanium nitride or aluminum, but TiN suffers from spatial inhomogeneities in the superconducting critical temperature and Al has a low kinetic inductance fraction, causing low detector sensitivity. To address these issues, we have instead fabricated PtSi microresonators with superconducting critical temperatures of 944±12 mK and high internal quality factors ($Q_i \gtrsim 10^6$). These devices show typical quasiparticle lifetimes of $\tau_{qp} \approx$ 30–40 μs and spectral resolution, $R = \lambda/\Delta\lambda$, of 8 at 406.6 nm. We compare PtSi MKIDs to those fabricated with TiN and detail the substantial advantages that PtSi MKIDs have to offer.

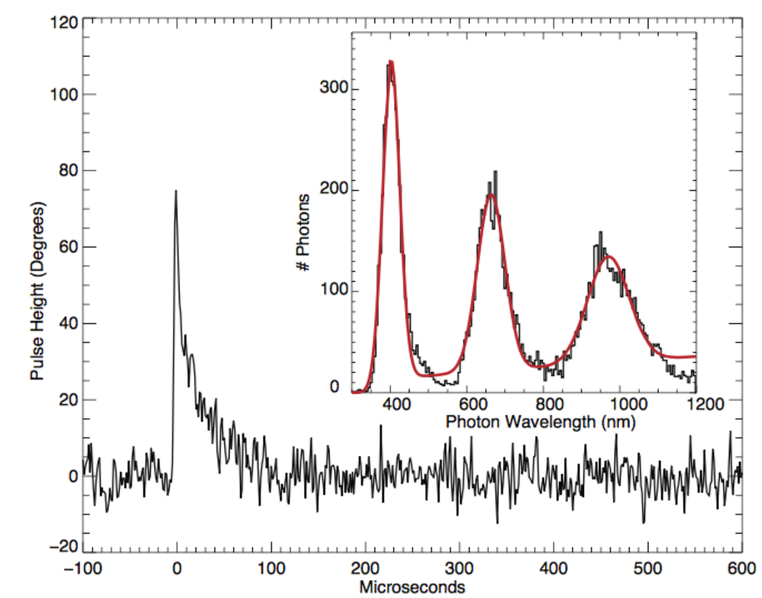
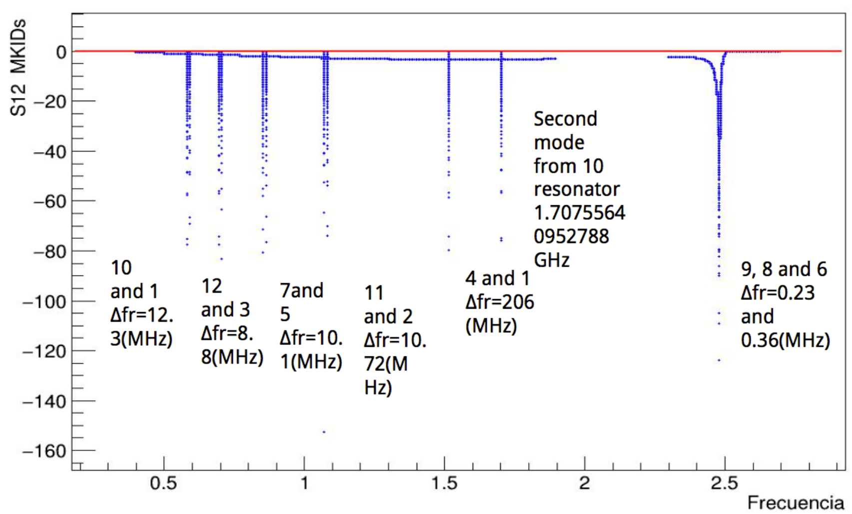


FIG. 4. A typical single 671.0 nm photon being absorbed by a PtSi MKID with f_0=4.876 GHz, Q_c=15,700, and Q_i=147,300. This particular resonator was probed with a power level of −108 dBm. The fitted quasiparticle recombination time is 36 ± 2 μs. Inset: The spectrum of the same MKID that has been illuminated with 406.6, 671.0, and 982.1 nm lasers. The data is transformed from phase height into wavelength using these known laser wavelengths[16]. The red line is a fit with three Gaussians and a linear background term, yielding a nearly uniform spectral resolution $R=\lambda/\Delta\lambda=8$ across the entire 400–1000 nm range.

Started R&D effort for simple MKIDs (small number of resonators) to understand some of the fab issues.

[JE (FNAL), A. Miceli (ANL), E.Shirikoff (UChicago)]



using ALD to control the fabrication of the film.

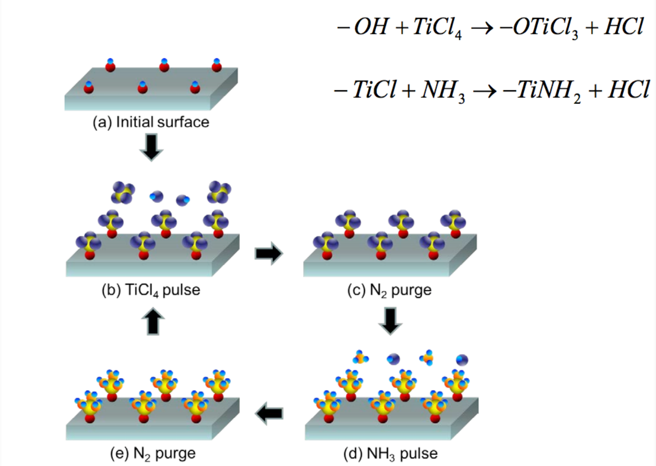
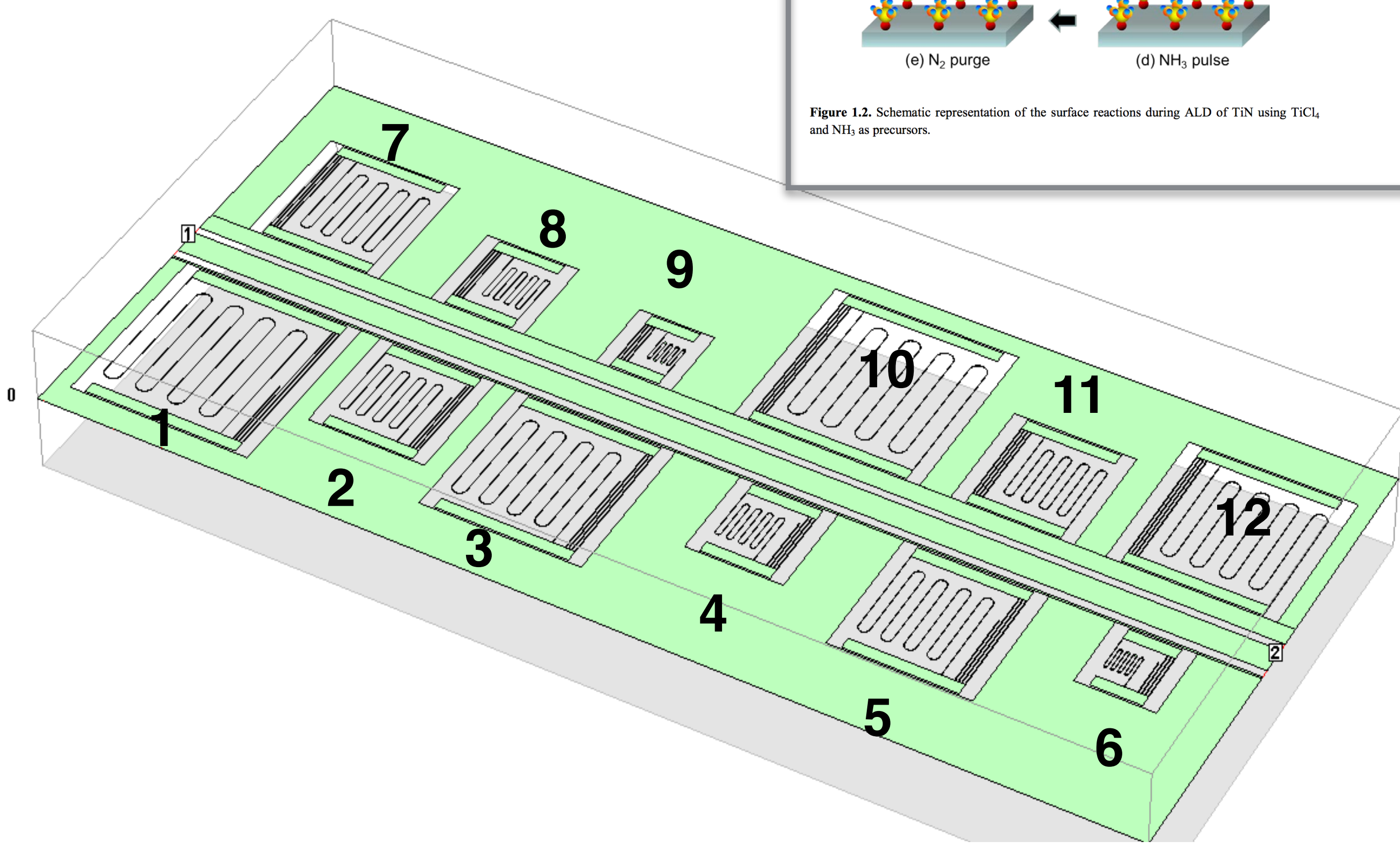
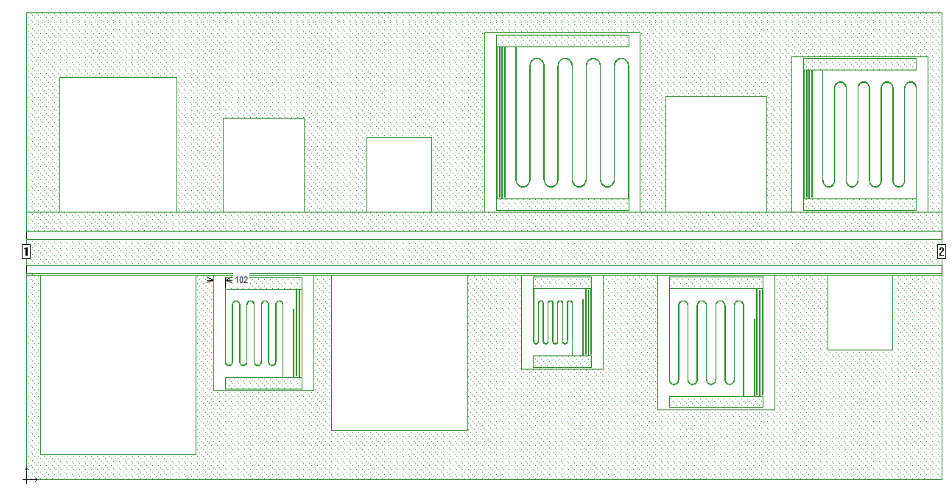
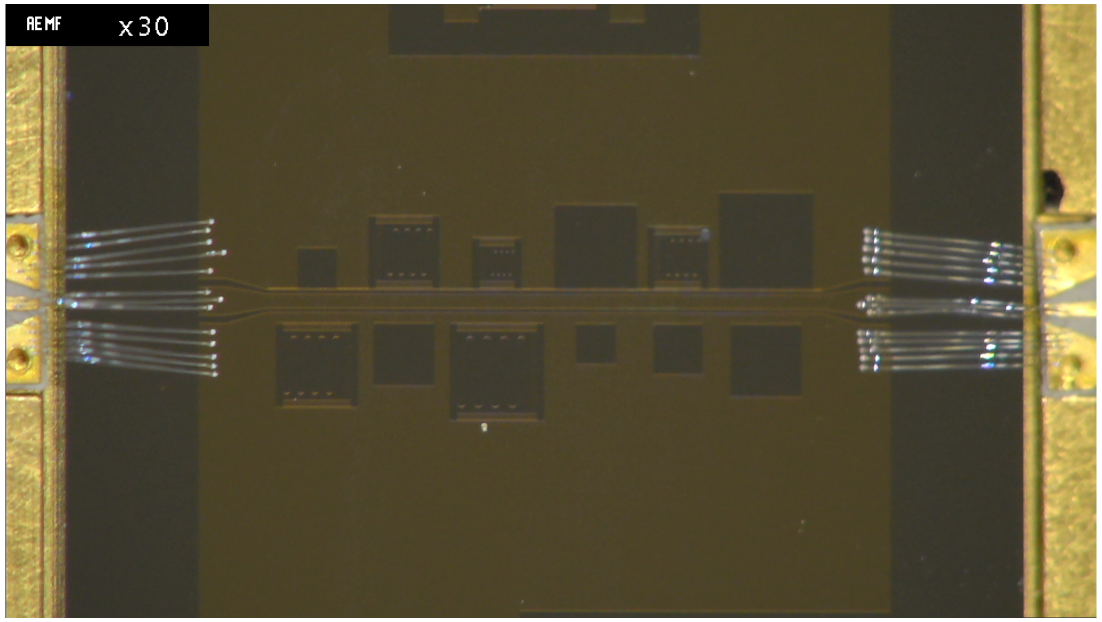


Figure 1.2. Schematic representation of the surface reactions during ALD of TiN using $TiCl_4$ and NH_3 as precursors.

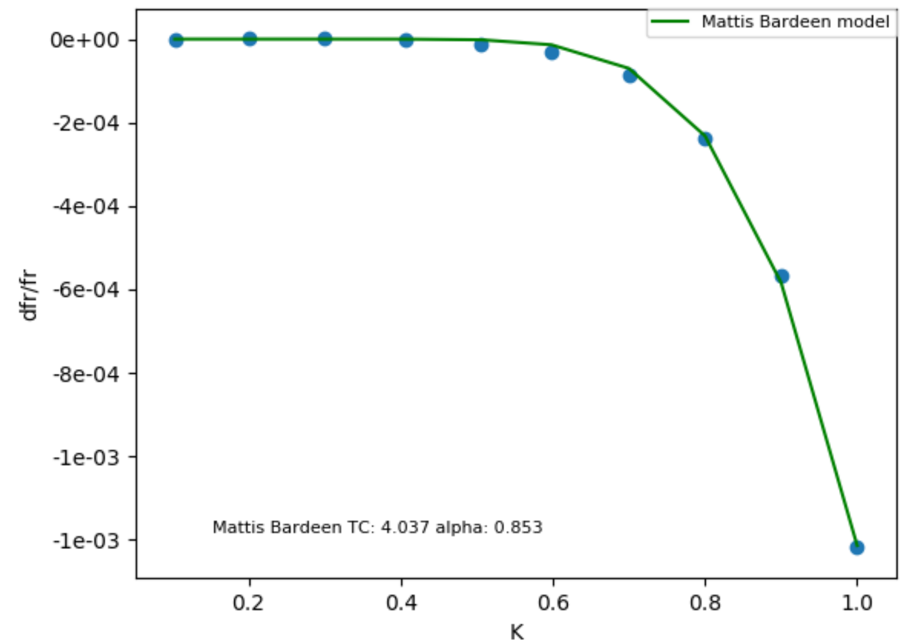


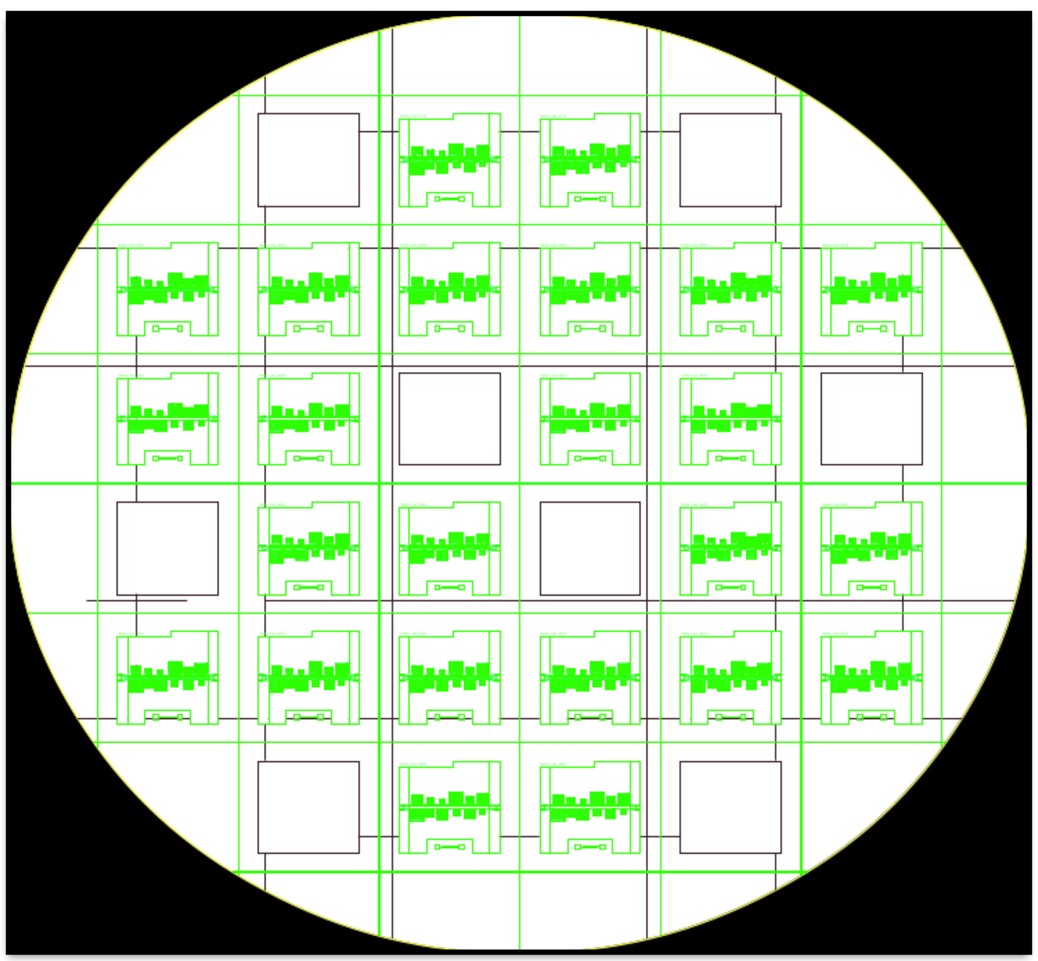


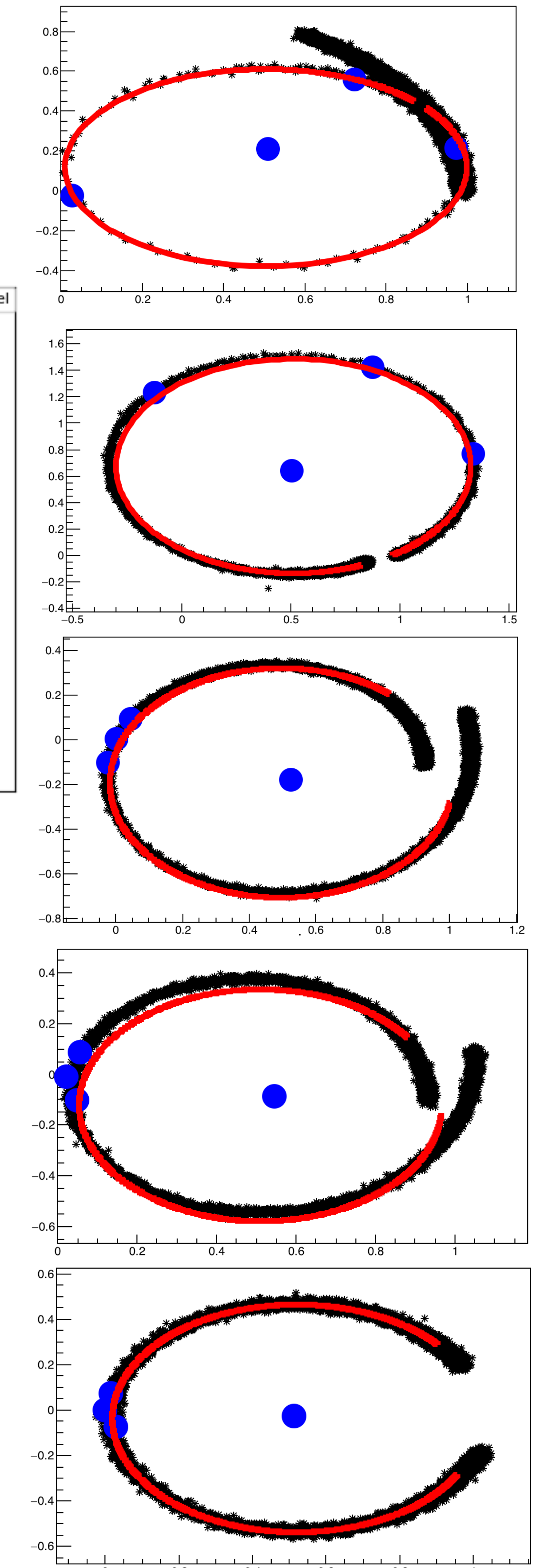
also made some MKIDs with 5 resonators to check any effect of coupling.



$Q_i \sim 10^5$





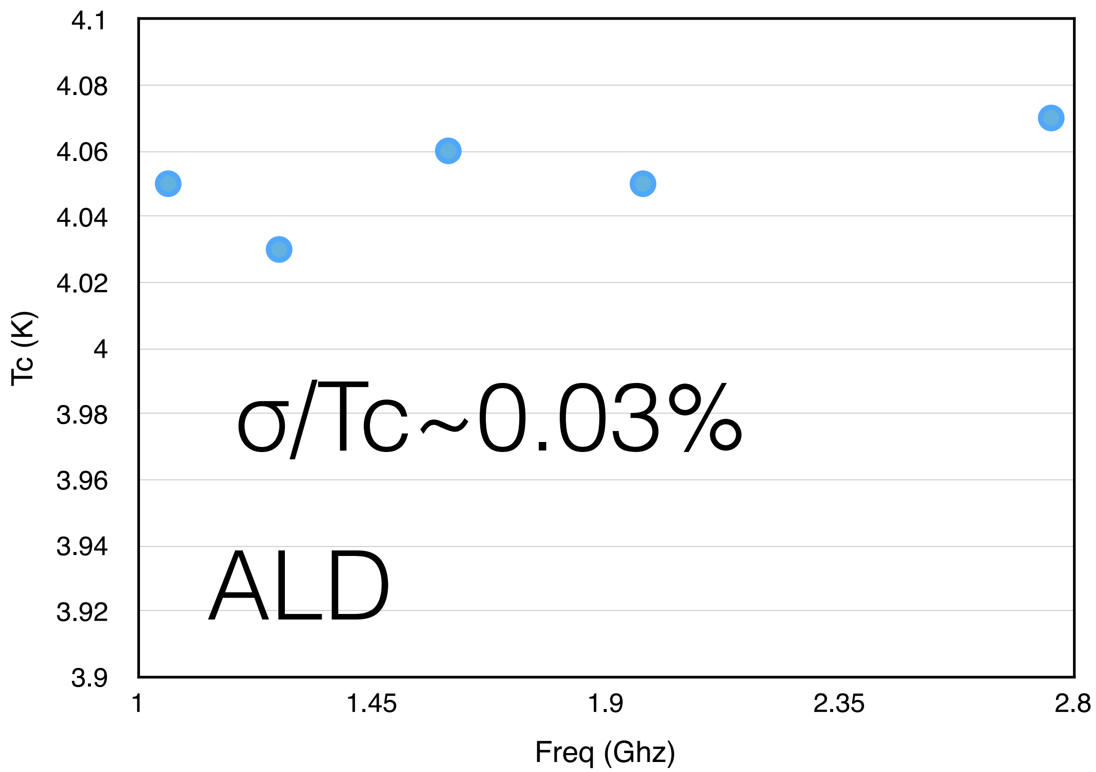


We are just starting the characterization of these devices and the comparison with the simulations.

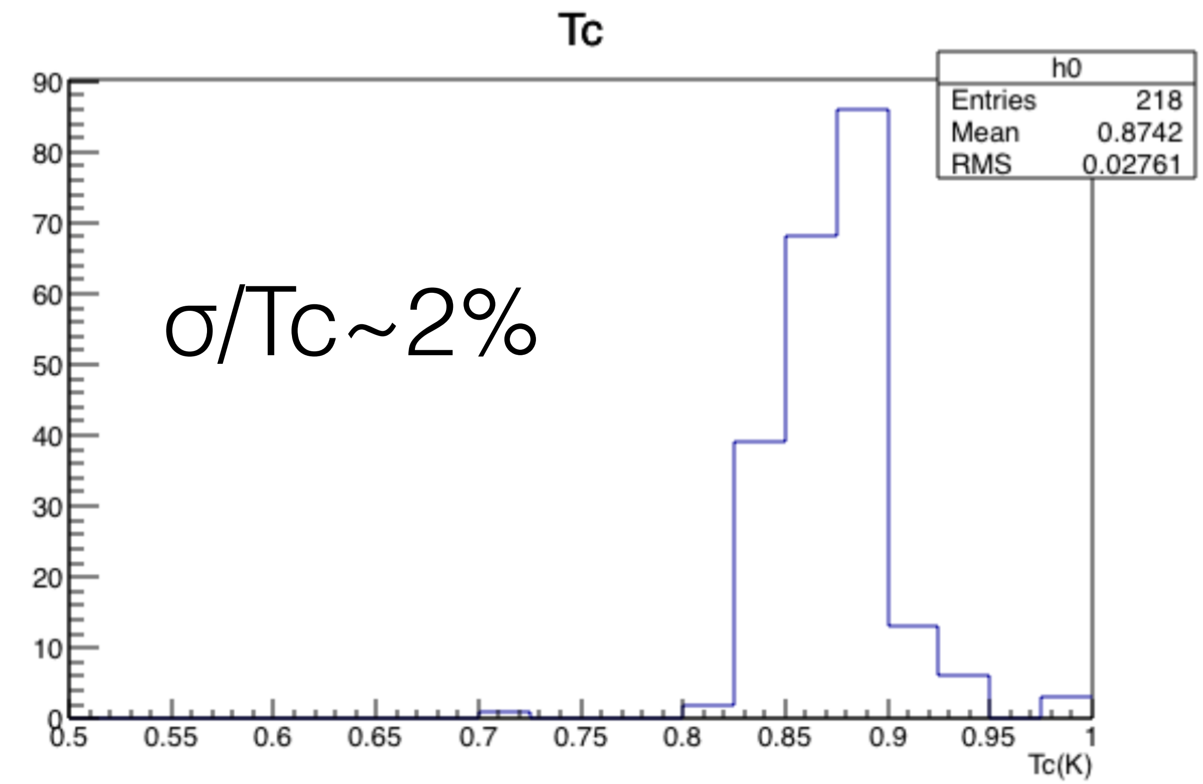
All devices in the wafer should look the same (ALD).

They should also look like the simulation.

ALD - 20nm film



sub-stoichiometric TiN



Coiffard et al, arXiv:1510.01876

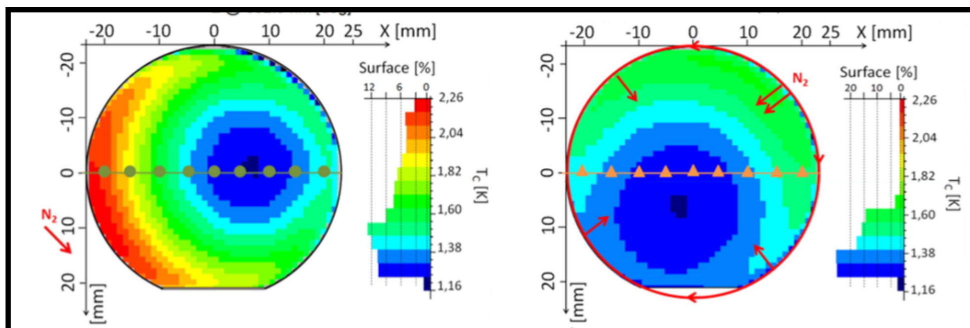


Fig. 2 *Top left* The critical temperature T_C scales with the optical parameter Δ determined with the ellipsometer *Top right* Value of T_C vs. the radial position on the wafer for three different configuration of the deposition chamber *Bottom left* Mapping of the T_C of TiN substrate with 6'' Ti target and the single point injection *Bottom right* Ring injection. The N_2 inlets for both configuration are shown (color figure online)

This is just starting…

Other things we want to try:

1) modify resonator-transmission line coupling in order to reduce parameter scatter due to pixel-to-pixel interactions.

2) Variation in capacitor and inductor size, which will verify the expected scaling of noise and optical response and allow for optimization of the sensitivity of future pixels.

3) Test devices featuring long linear inductors and very low detector coupling Qs, designed to explore spatial variation in response and intrinsic time-constant when measured with a scanning and chopped laser source.

4) Test devices fabricated on intermediate dielectric layers designed to quantify resolution limitations associated with the generation of above-gap substrate photons.

5) Variation in packaging and readout wiring to explore the role of box lid coupling and amplifier interactions on device performance.

Conclusion

- MKIDs with high resolution R~100, could be very interesting for next cosmic surveys.

- 20k MKID exists (Mazin et al)

- R&D going on to push this technology to the maximum potential (increasing R).