Low resolution spectroscopy Technological Challenges

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at that point we said, let's not concentrate in the technology, and focus on what would be the goal of 4 very ambitious low resolution spectroscopic surveys.

Survey	D (m)	FoV (deg^2)	N_{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		

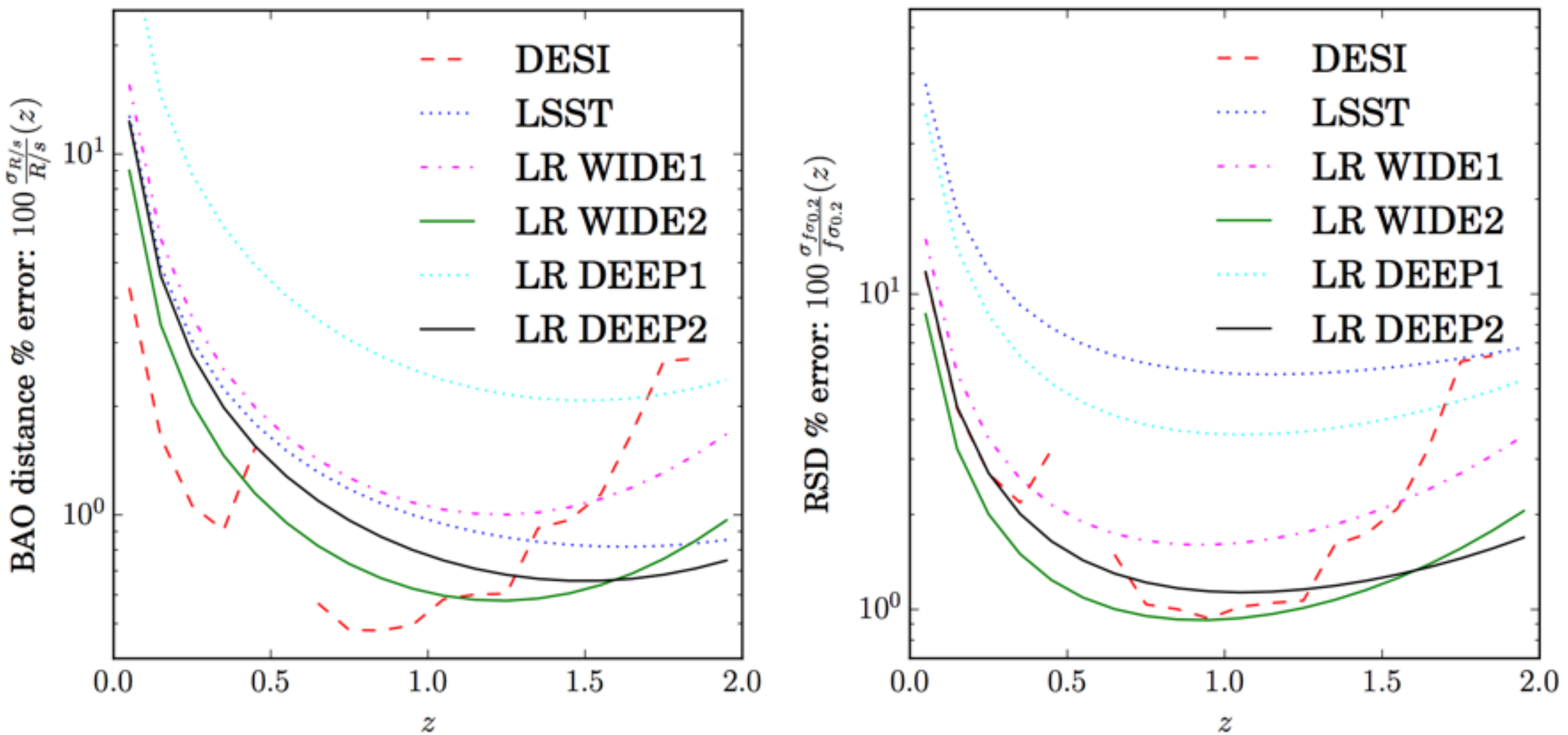
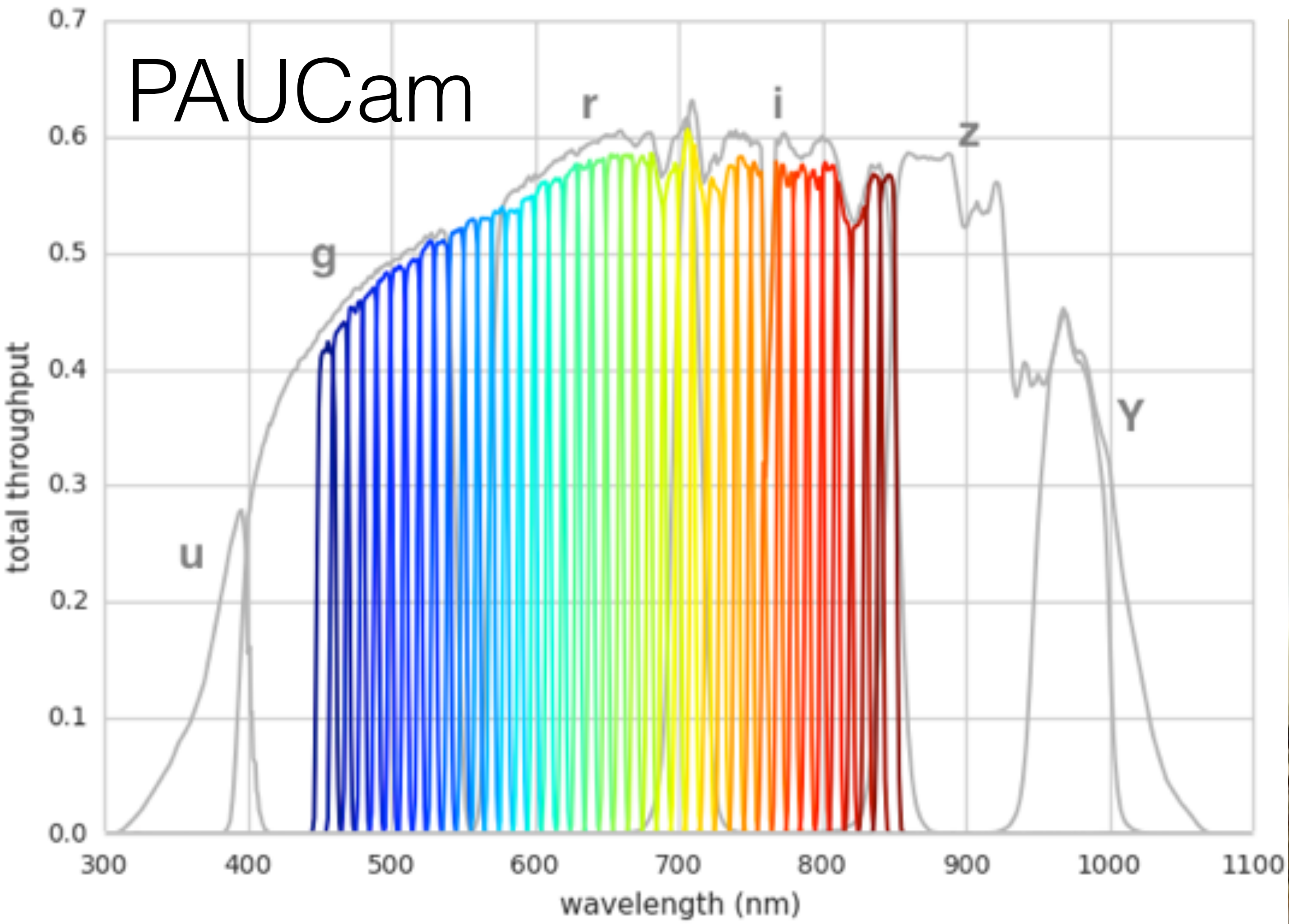


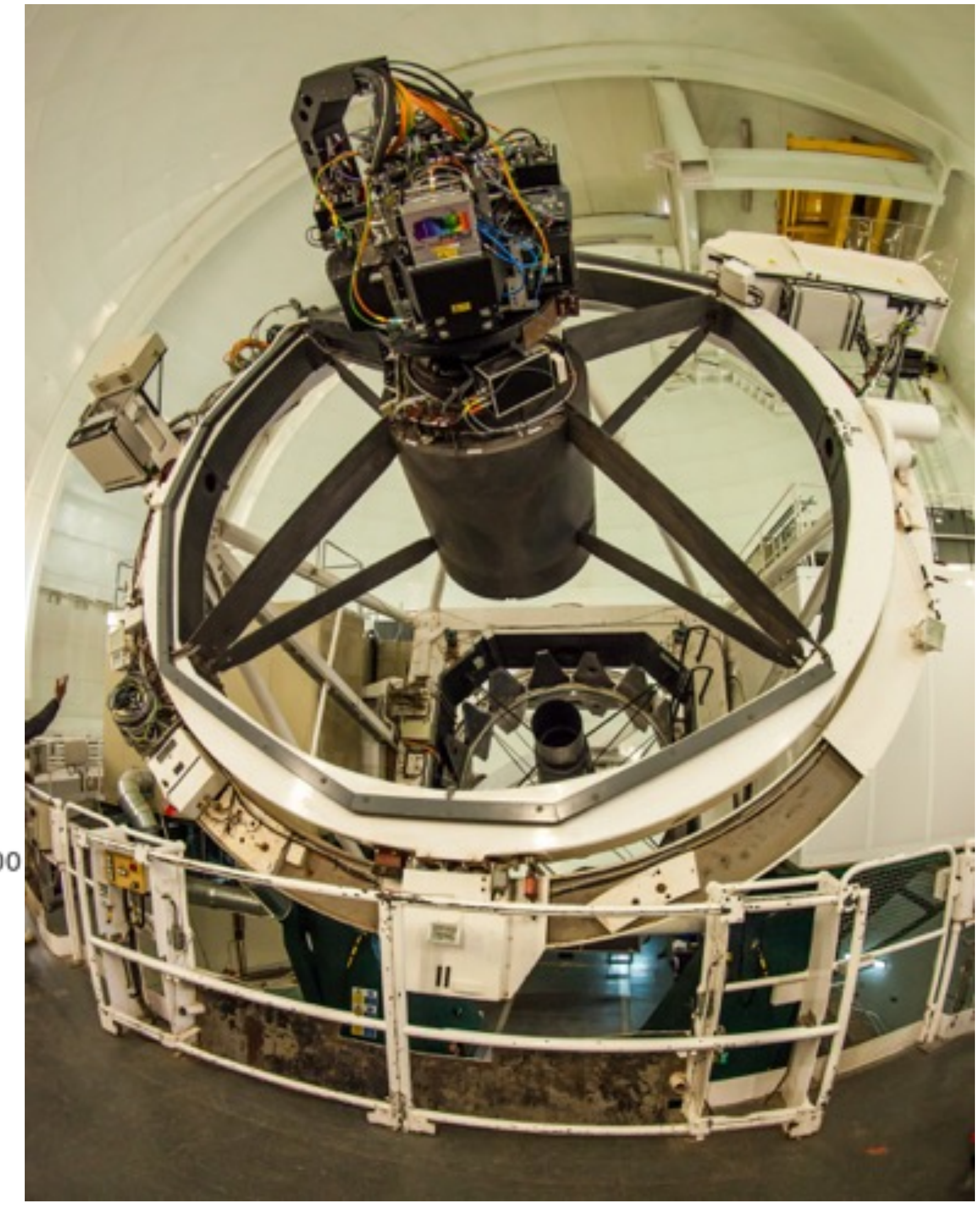
FIG. 1: Fractional errors on the BAO distance scale dilation factor R (left) and on the parameter combination best constrained by redshift-space distortions, $f\sigma$ (right), where we include scales at $k < 0.2h/\text{Mpc}$. We can see that DESI will set the benchmark for the accuracy of both measurements; 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.

seems like the “conclusion” was that we really need to push for the near-IR

Type-1: filters

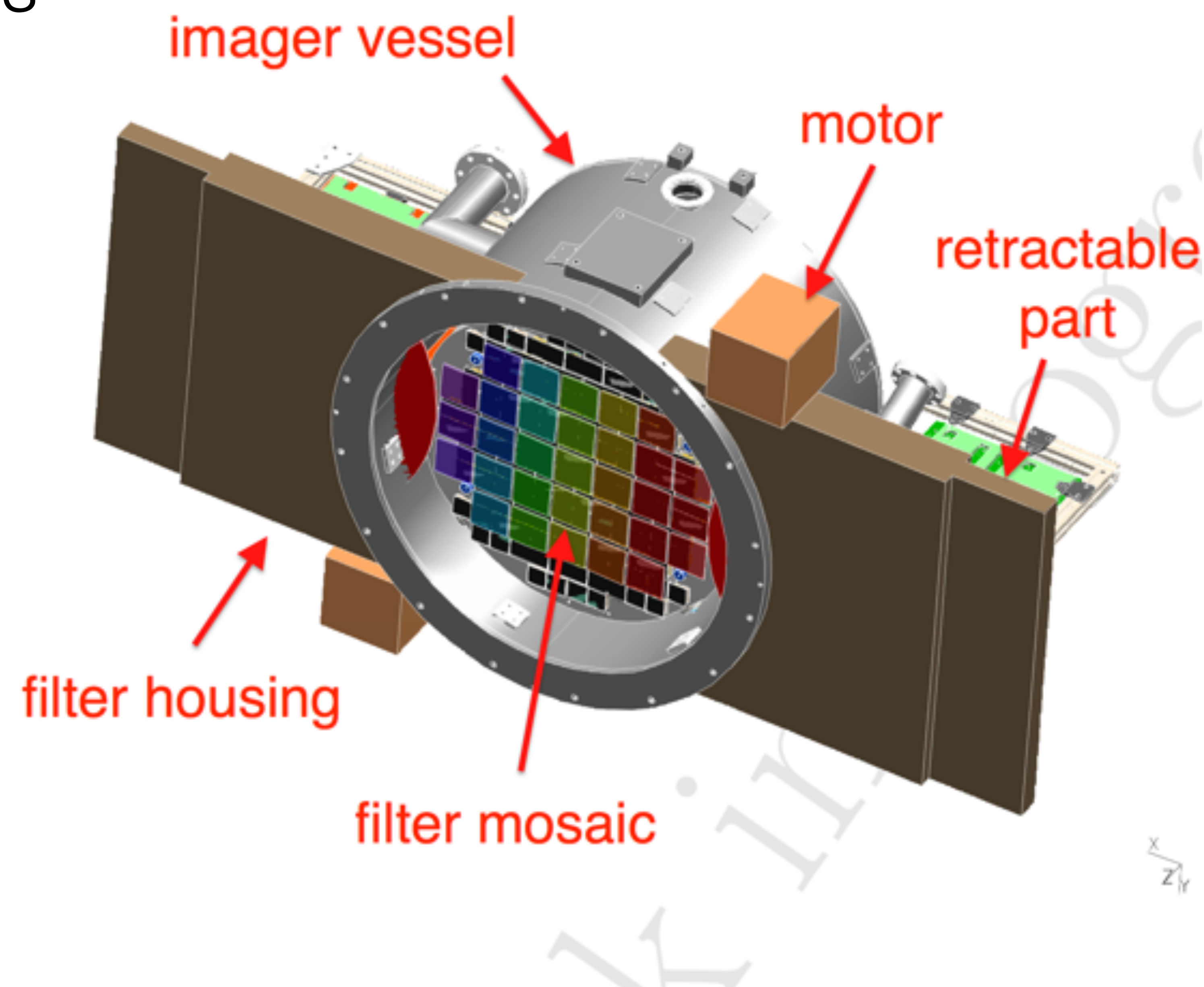


40 narrow band filters



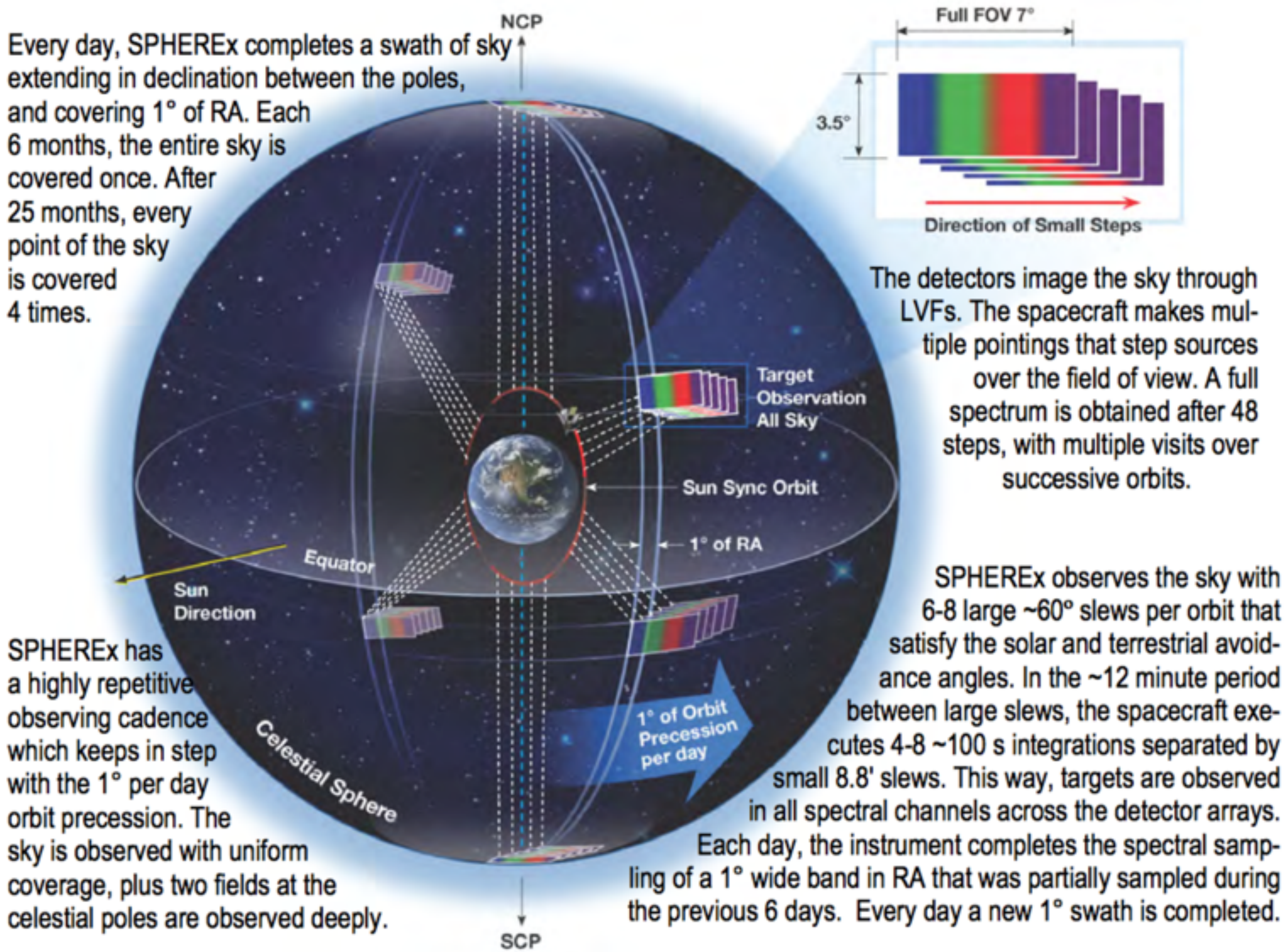
big efficiency loss

Type-1: filters



some us us even considered what would take to make DECam a 40 filter instrument.

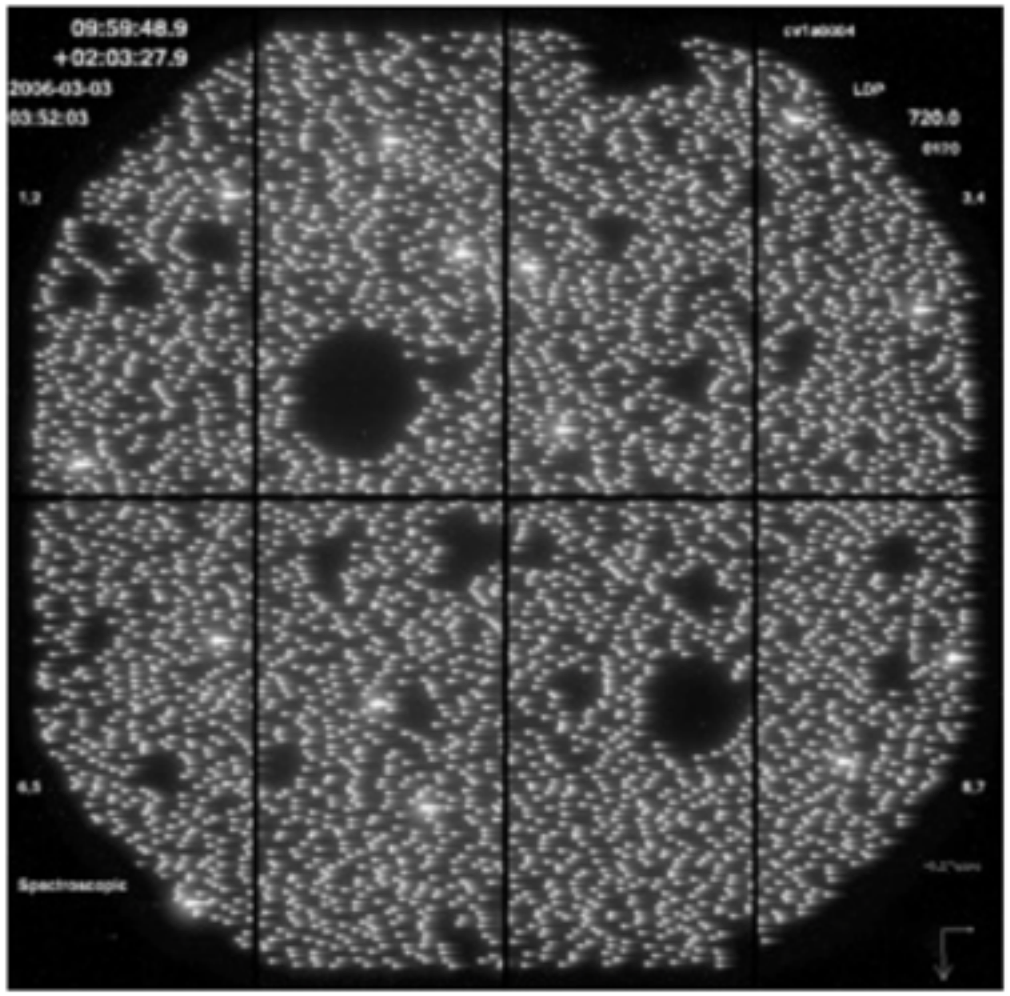
Type-1



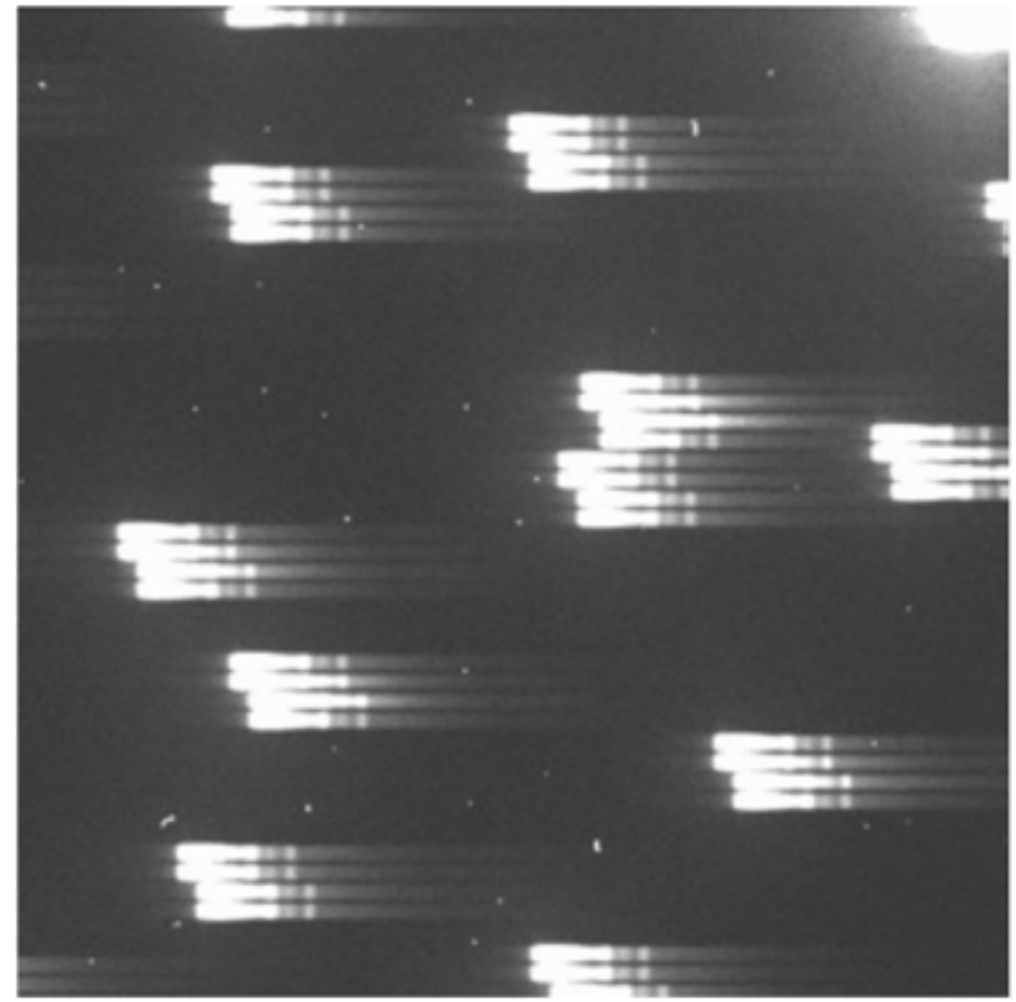
Every day, SPHEREx completes a swath of sky extending in declination between the poles, and covering 1° of RA. Each 6 months, the entire sky is covered once. After 25 months, every point of the sky is covered 4 times.
NCP
Full FOV 7°
3.5°
Direction of Small Steps
The detectors image the sky through LVFs. The spacecraft makes multiple pointings that step sources over the field of view. A full spectrum is obtained after 48 steps, with multiple visits over successive orbits.
Target Observation All Sky
Sun Sync Orbit
1° of RA
Equator
Sun Direction
SPHEREx observes the sky with 6-8 large ~60° slews per orbit that satisfy the solar and terrestrial avoidance angles. In the ~12 minute period between large slews, the spacecraft executes 4-8 ~100 s integrations separated by small 8.8' slews. This way, targets are observed in all spectral channels across the detector arrays. Each day, the instrument completes the spectral sampling of a 1° wide band in RA that was partially sampled during the previous 6 days. Every day a new 1° swath is completed.
1° of Orbit Precession per day
Celestial Sphere
SPHEREx has a highly repetitive observing cadence which keeps in step with the 1° per day orbit precession. The sky is observed with uniform coverage, plus two fields at the celestial poles are observed deeply.
SCP

Type-2 : all the colors at the same time

Primus



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.

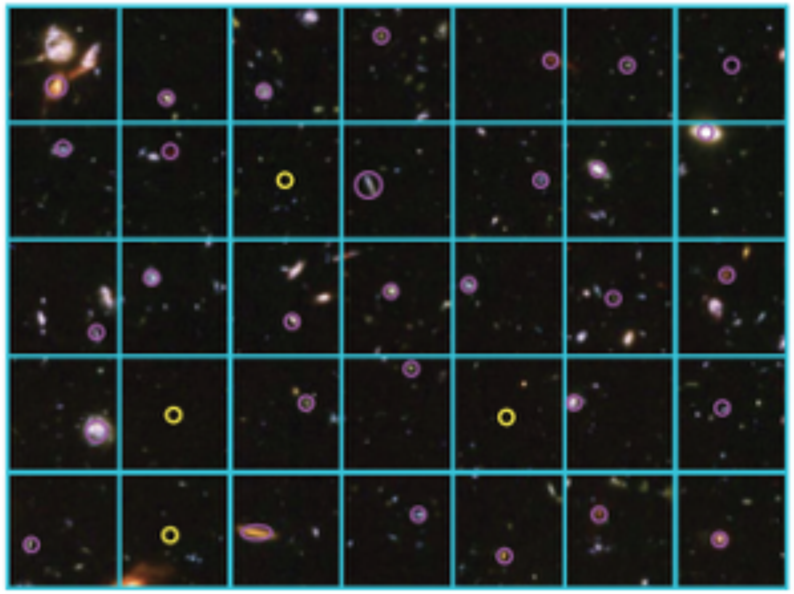


A close up of a small portion of a single exposure. Each object has 4 traces; we drill 2 slits for each object and nod the telescope between them. The other 2 traces are sky. The footprint for one object on the detector is 6.4" x 28".

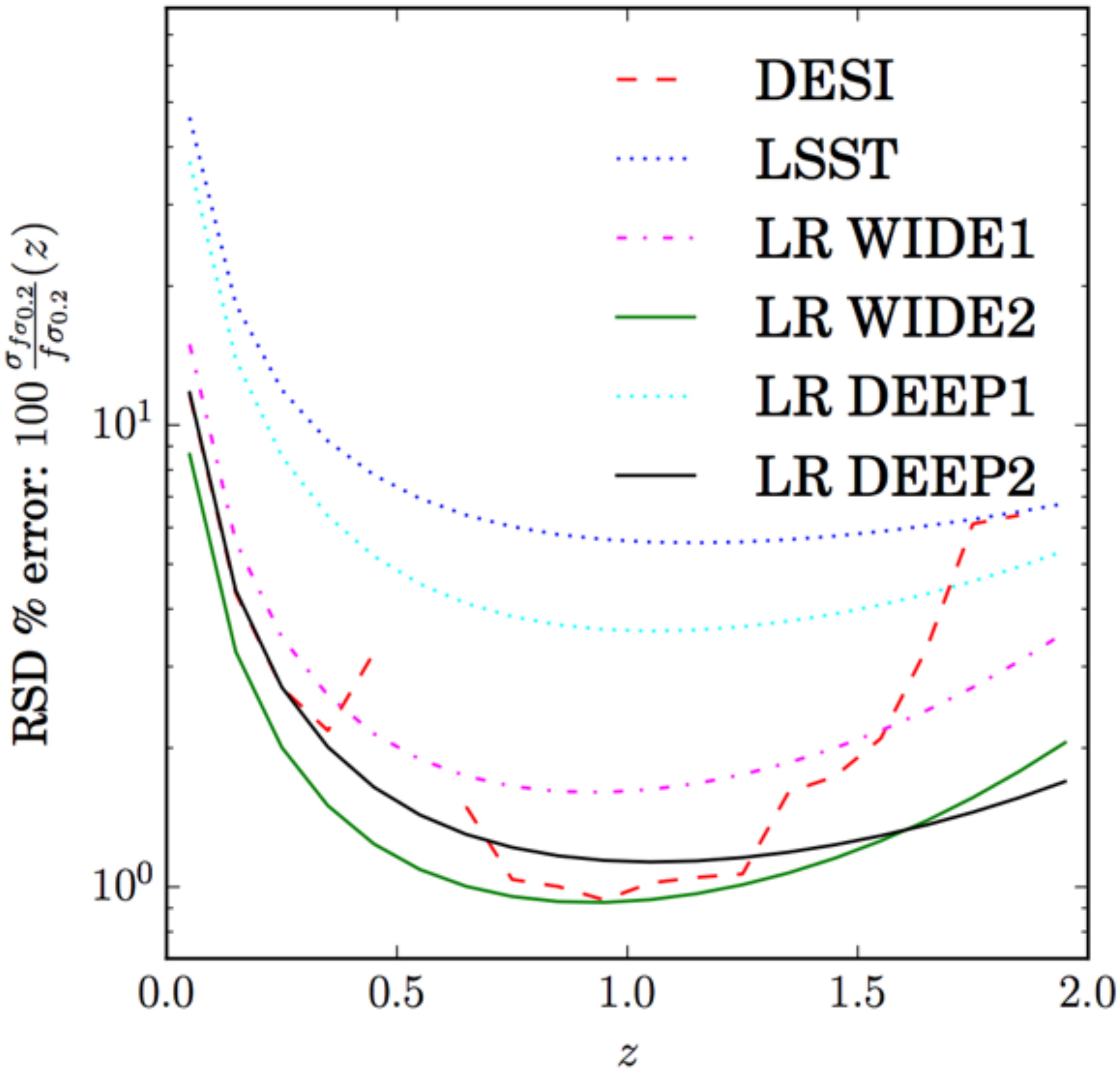
Type-2 : all the colors at the same time

GigaZ/MegaZ

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



superconducting focal plane using the MKIDs developed by UCSB (B.Mazin et al), more later.

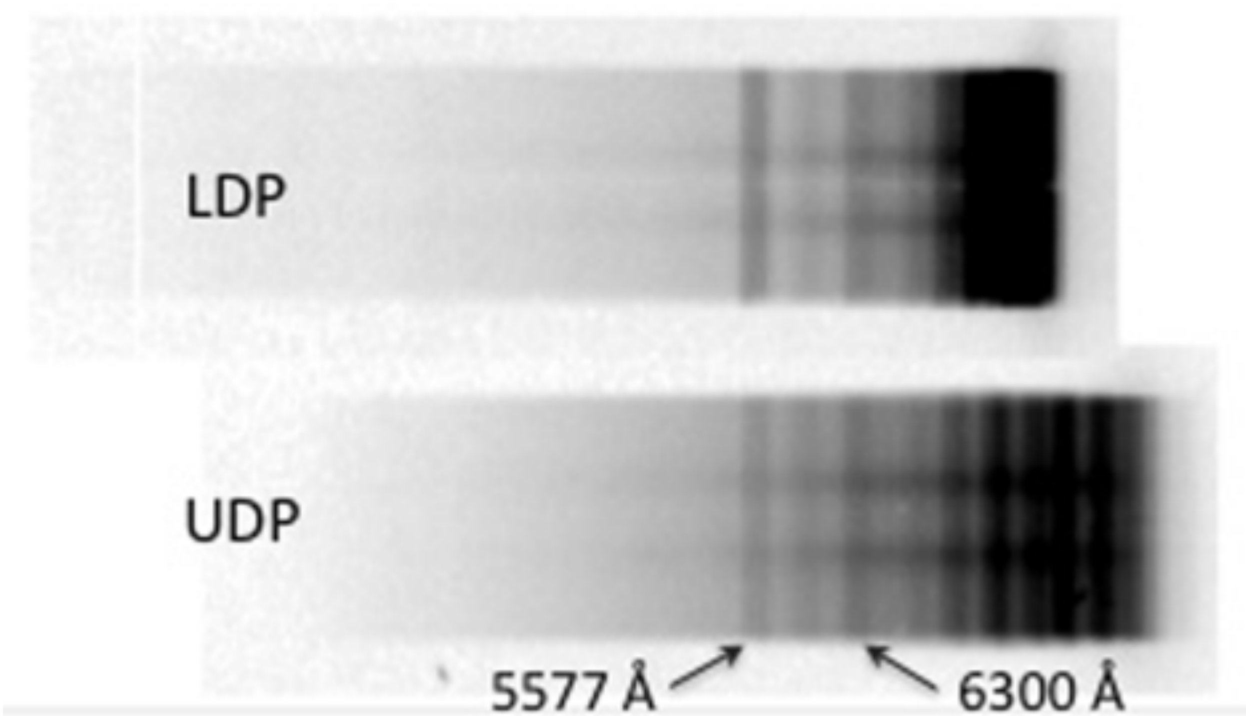


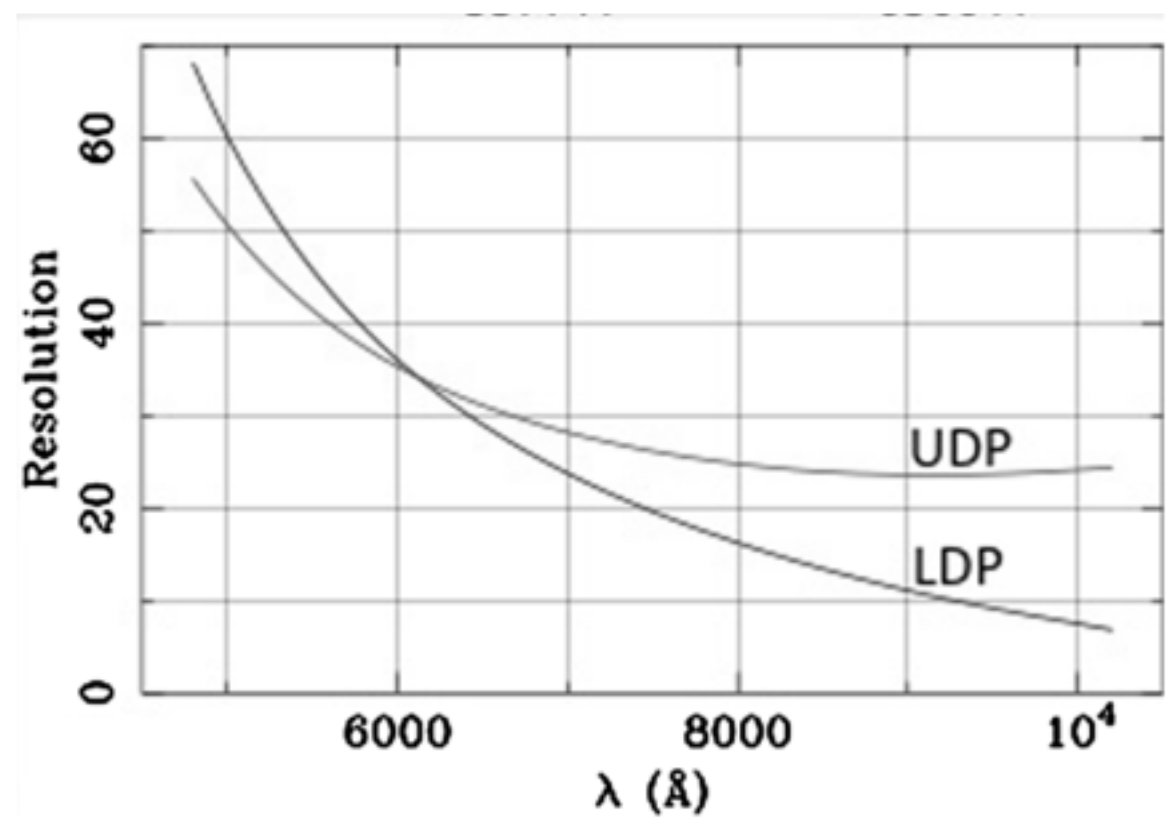
it also looks from this plot, that we can not pay the price of a filter based survey (inefficiency).

Two features to workout on PRIMS technology-1

(text by Guantung Zhu)

One of the challenges in prism spectroscopy is the varying resolution across the wavelength range. The dispersion power of the PRIMUS prism in the blue (about 100 at 4500 Å) is a factor of 5 times higher than in the red (about 20 at 9000 Å). In observation, this puts constraints on the exposure time at both ends – if the exposure time is too long, the red end will saturate, while if it is too short, the blue end cannot achieve the desired S/N per pixel. The exposure time for most of the PRIMUS fields is between 0.5h and 1h. In redshift determination, the low resolution in the red poses challenges for high-redshift sources. However, with the multiple-prism technique (first described in *Opticks* by Isaac Newton) and innovative technology, one can achieve less varying resolution. Stephen Shectman at Carnegie Observatories designed a new prism by alternating 8 pieces of glass (Dressler et al. 2011), achieving a much flatter dispersion curve with a median resolution similar to the PRIMUS prism's without losing much of the high throughput.





we would want to increase this resolution

Two features to workout on PRIMS technology -2

(text by Guantung Zhu)

Another challenge in prism spectroscopy from the ground is the low-dispersing power and strong telluric contamination at the red end. At $\lambda \gtrsim 7500$ Å, the sky background is dominated by the hydroxyl and water emission line forest and a low-resolution spectrograph cannot effectively sift out the spectral features due to the high noises in almost every pixel. With low-resolution spectroscopy, it is therefore difficult to observe galaxies beyond redshift $z \sim 1.2$, where the last prominent spectral feature, the Balmer break, enters the sky line-dominated regime. The redshift distribution of PRIMUS galaxies drops substantially at $z \gtrsim 1.0$ (Figure 7 in Coil et al. 2011), partly due to this reason (and partly because it is a flux-limited survey). However, supplementary deep photometry (or low-resolution spectroscopy) in the NIR and IR, such as from WFIRST or EUCLID, where the spectral features are rich and informative, can significantly improve the efficiency of high-redshift observations.

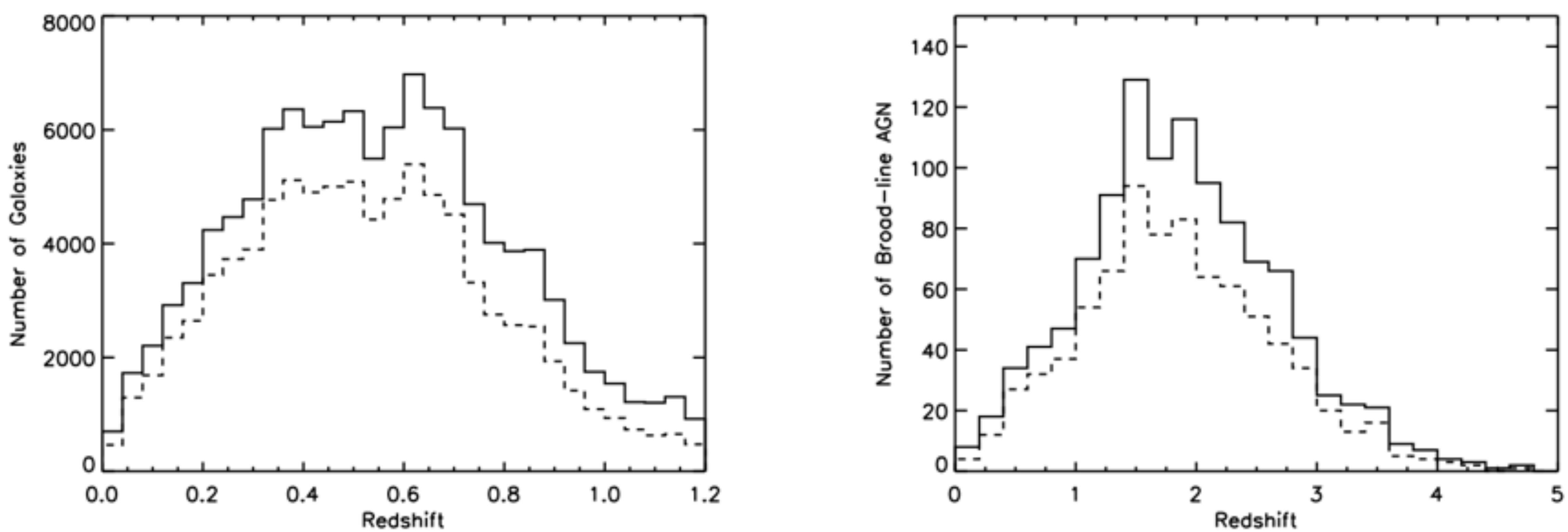
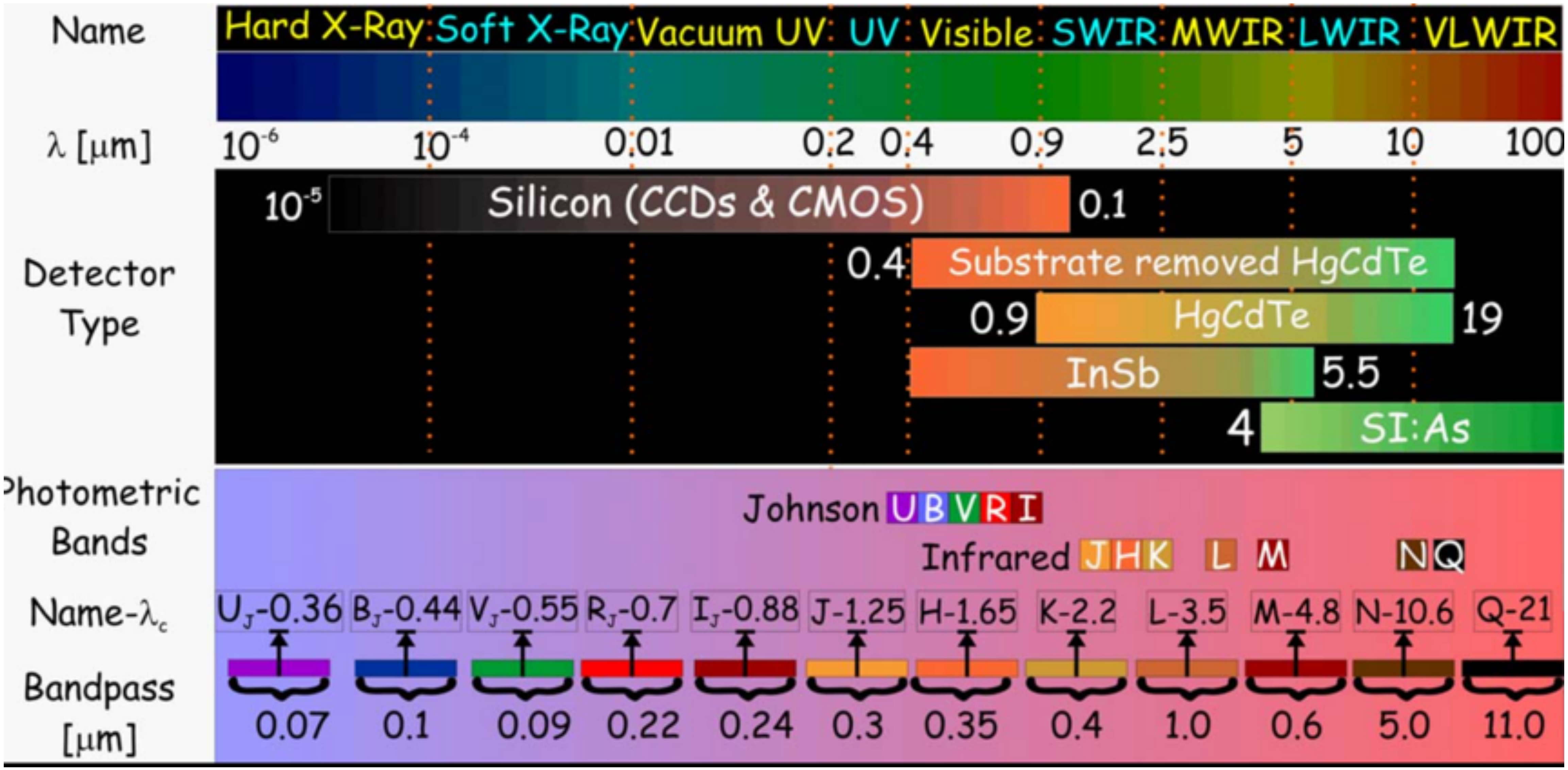


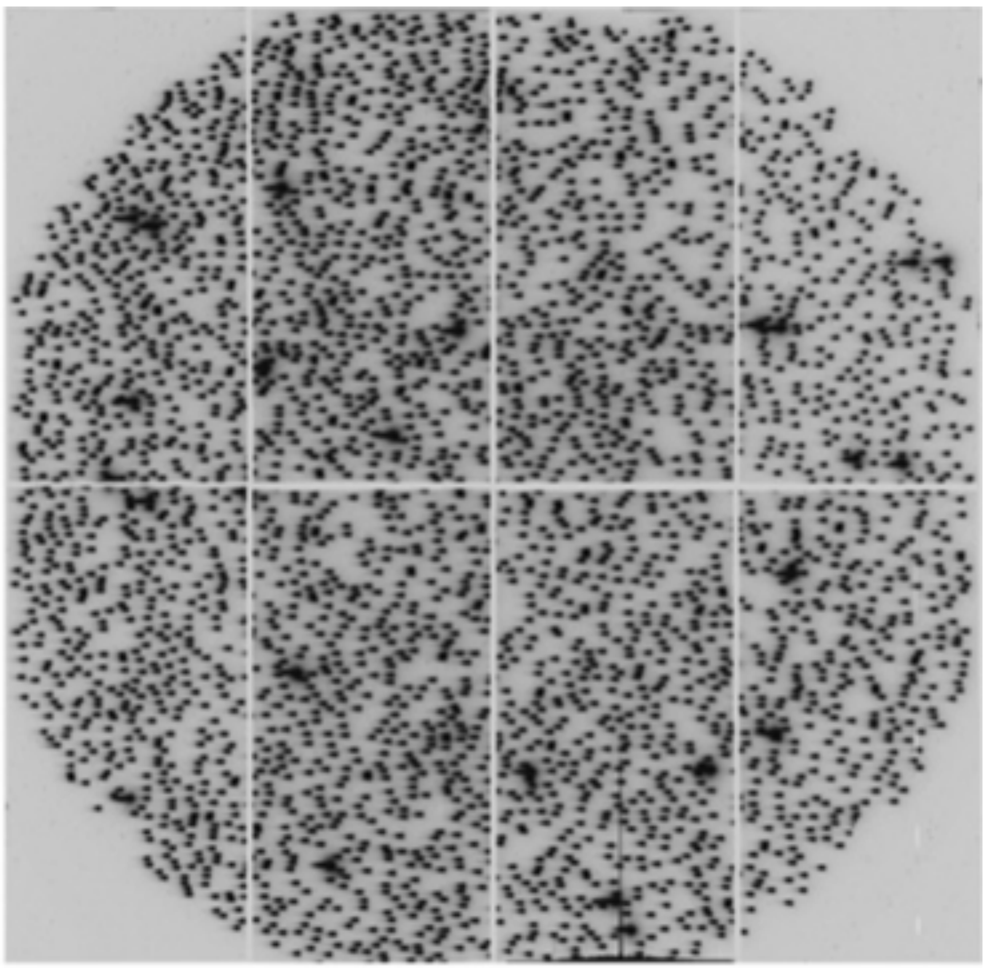
Fig. 7.— Left: Redshift distribution of galaxies in PRIMUS with robust redshifts. The solid line is for the full sample and the dashed line is for the primary sample. Galaxy redshifts are fit from $z = 0$ to $z = 1.2$, the range shown here. Right: Redshift distribution of broad-line AGN in PRIMUS with robust redshifts. Broad-line AGN redshifts are fit from $z = 0$ to $z = 5$, the range shown here.

going deeper with something like primus is not impossible



Si CCD → 1.1 um
RD : Ge CCD → 1.6 um
(*)MKID → 1.4 um

(*)maybe a bit more



3412 objects

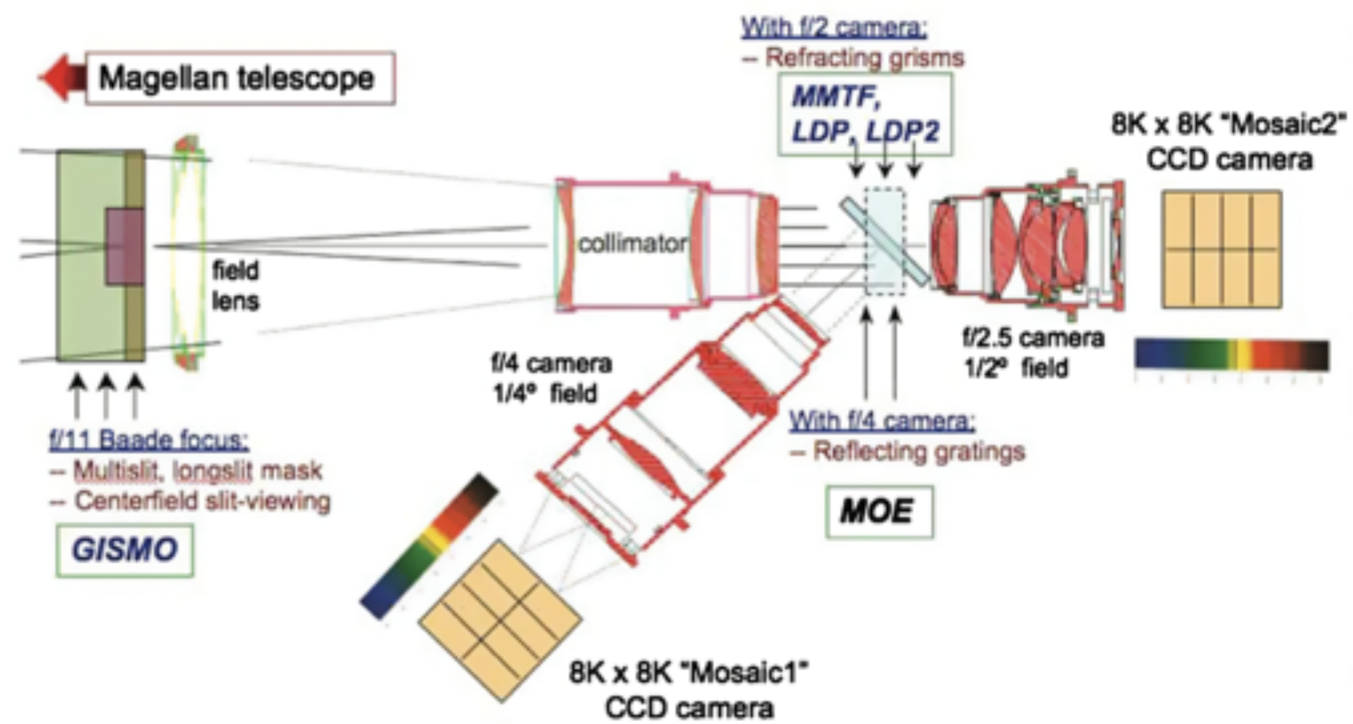
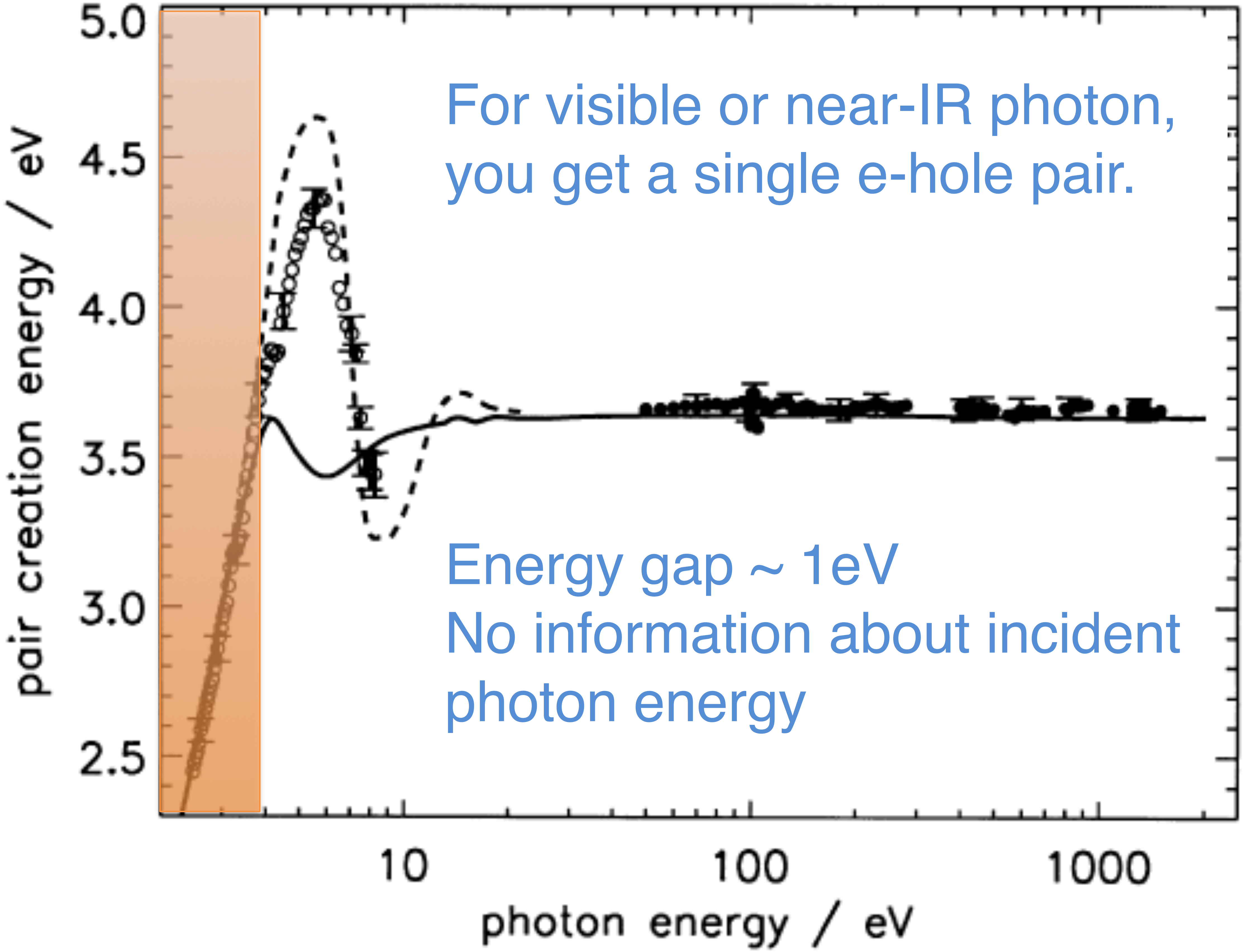


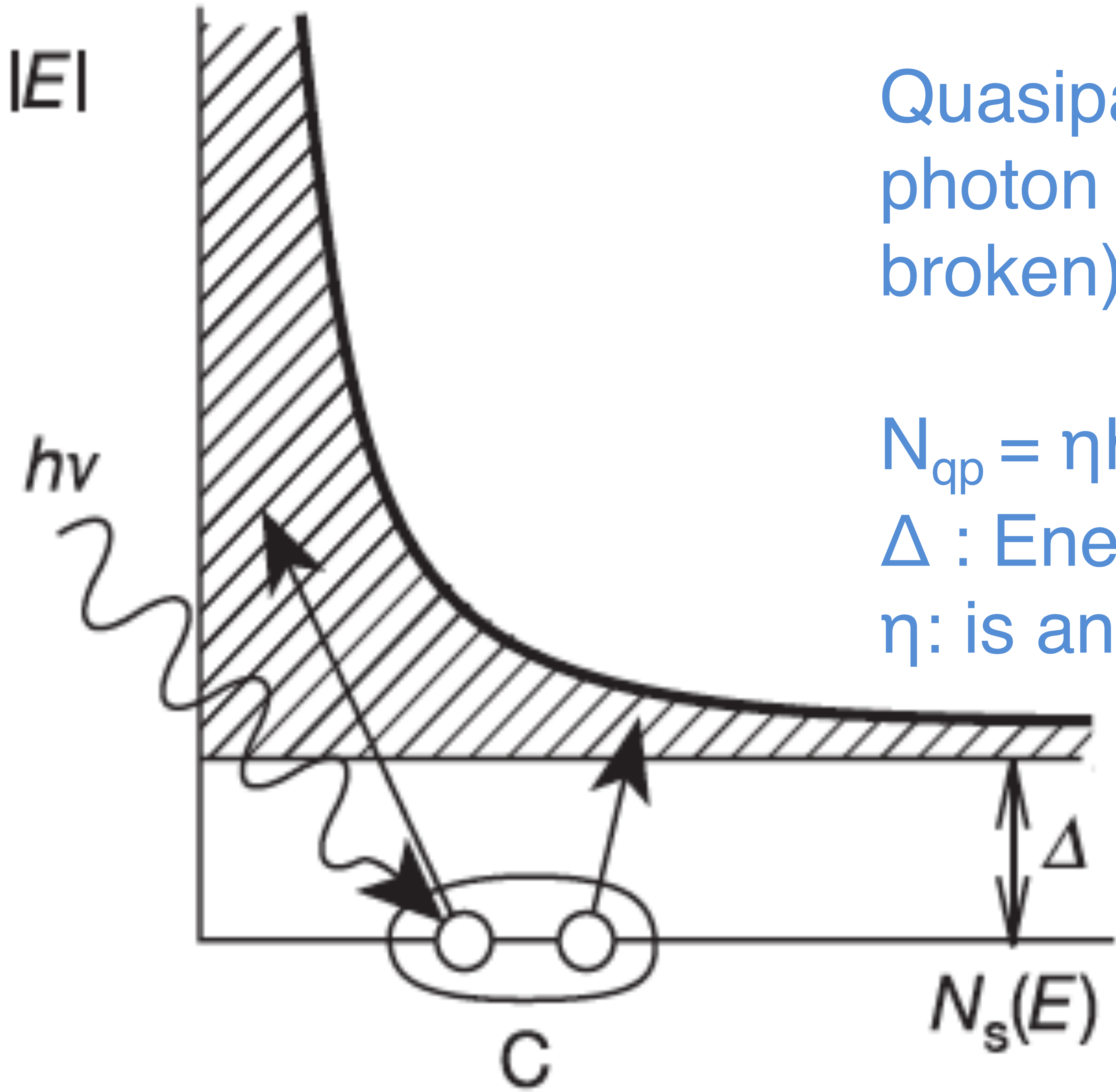
FIG. 3.—Optical and component layout of IMACS.

can this be done a at larger scale?

limitation of Si semiconductor detectors…



superconductors overcome this limitation



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

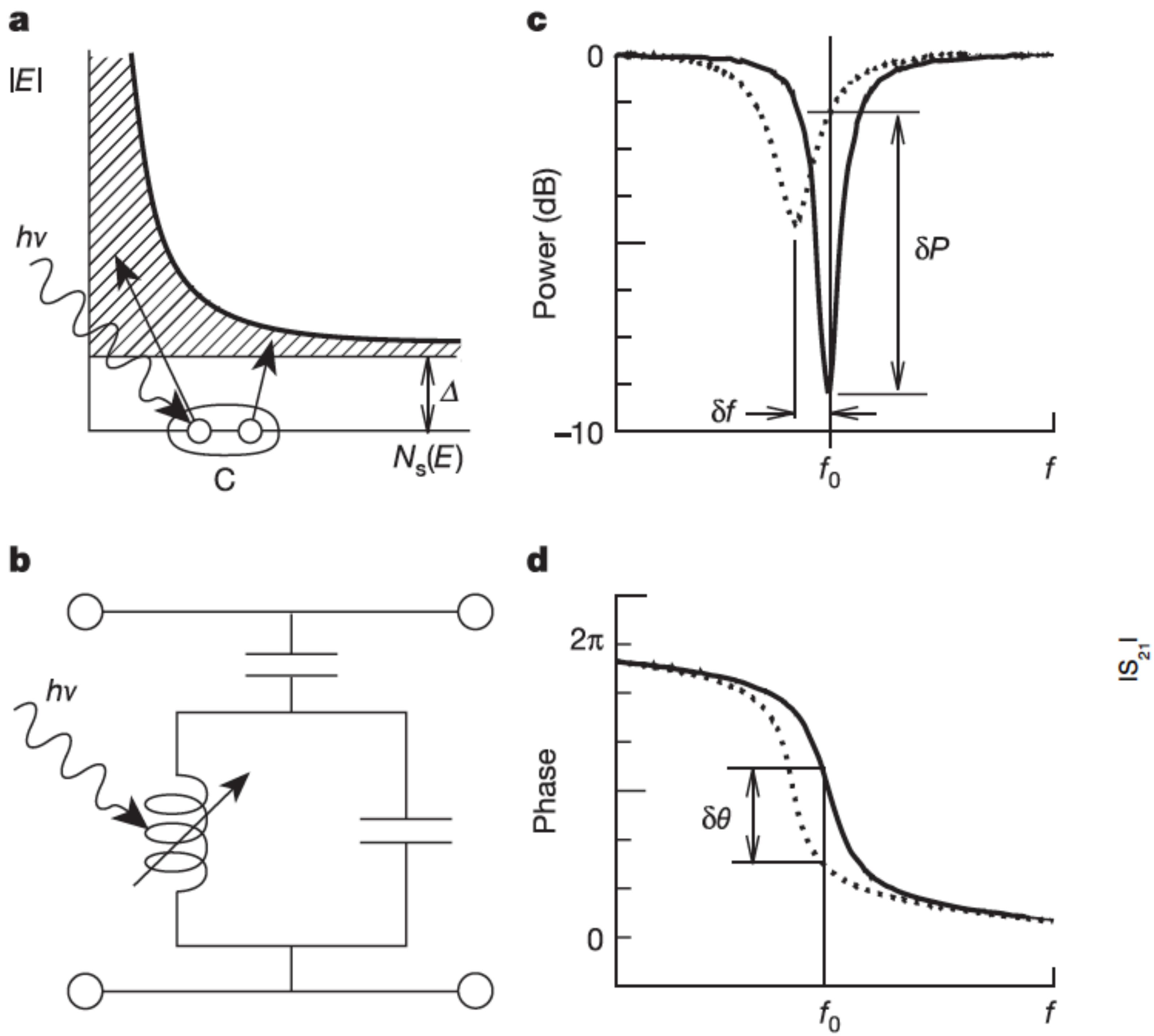
	Niobium $T_c = 9.25$ K $\Delta = 1.4$ meV	Tantalum $T_c = 4.47$ K $\Delta = .68$ meV	Aluminum $T_c = 1.175$ K $\Delta = .18$ meV	Titanium $T_c = 0.4$ K $\Delta = .06$ meV	Hafnium $T_c = 0.128$ K $\Delta = .02$ meV
IR (0.62 eV)	15	22	42	73	126
Optical (3.1 eV)	34	48	94	163	282
UV (10.3 eV)	61	88	171	297	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!

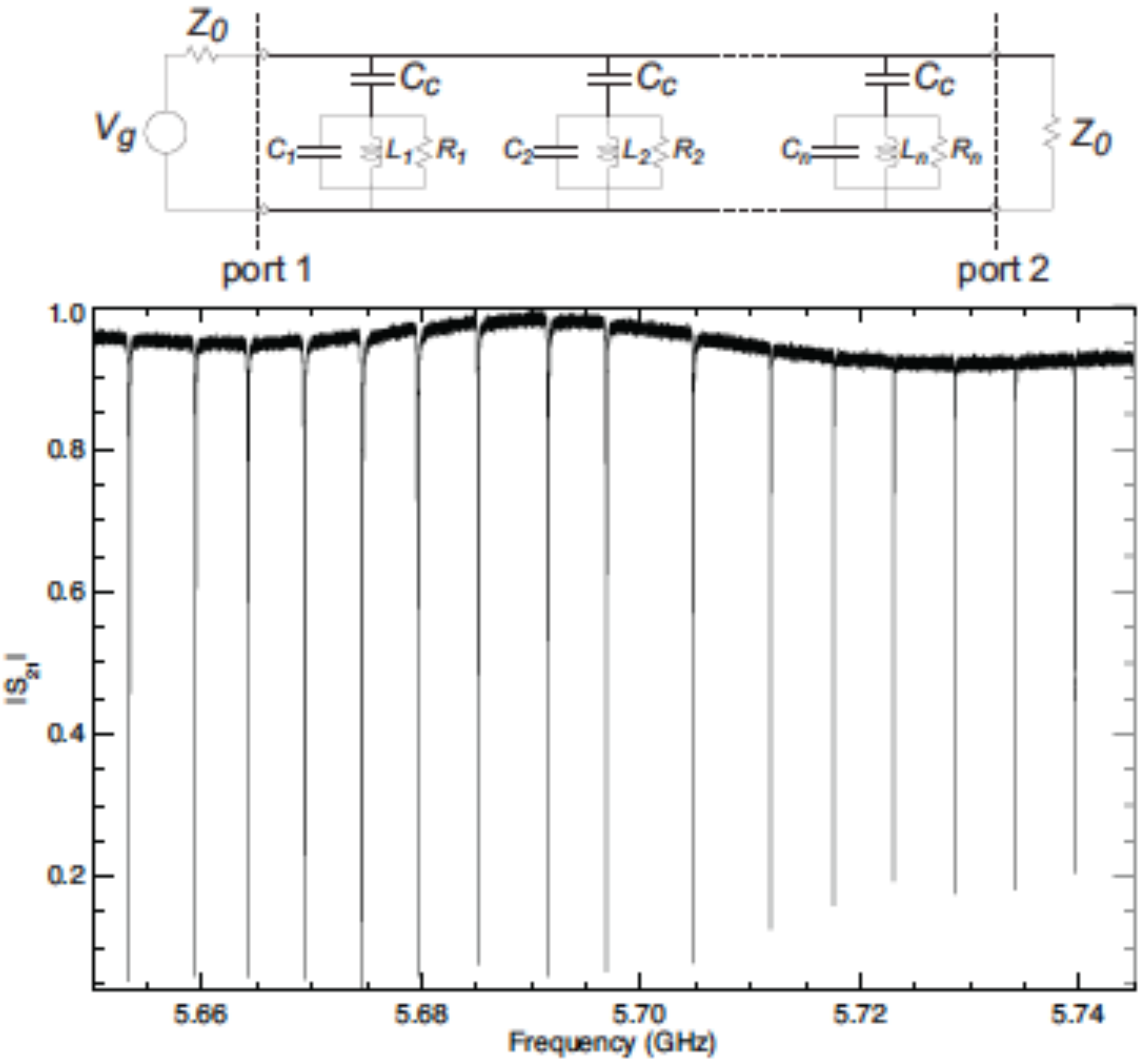
~5000 quasiparticles for a visible photon

Microwave Kinetic Inductance Detectors

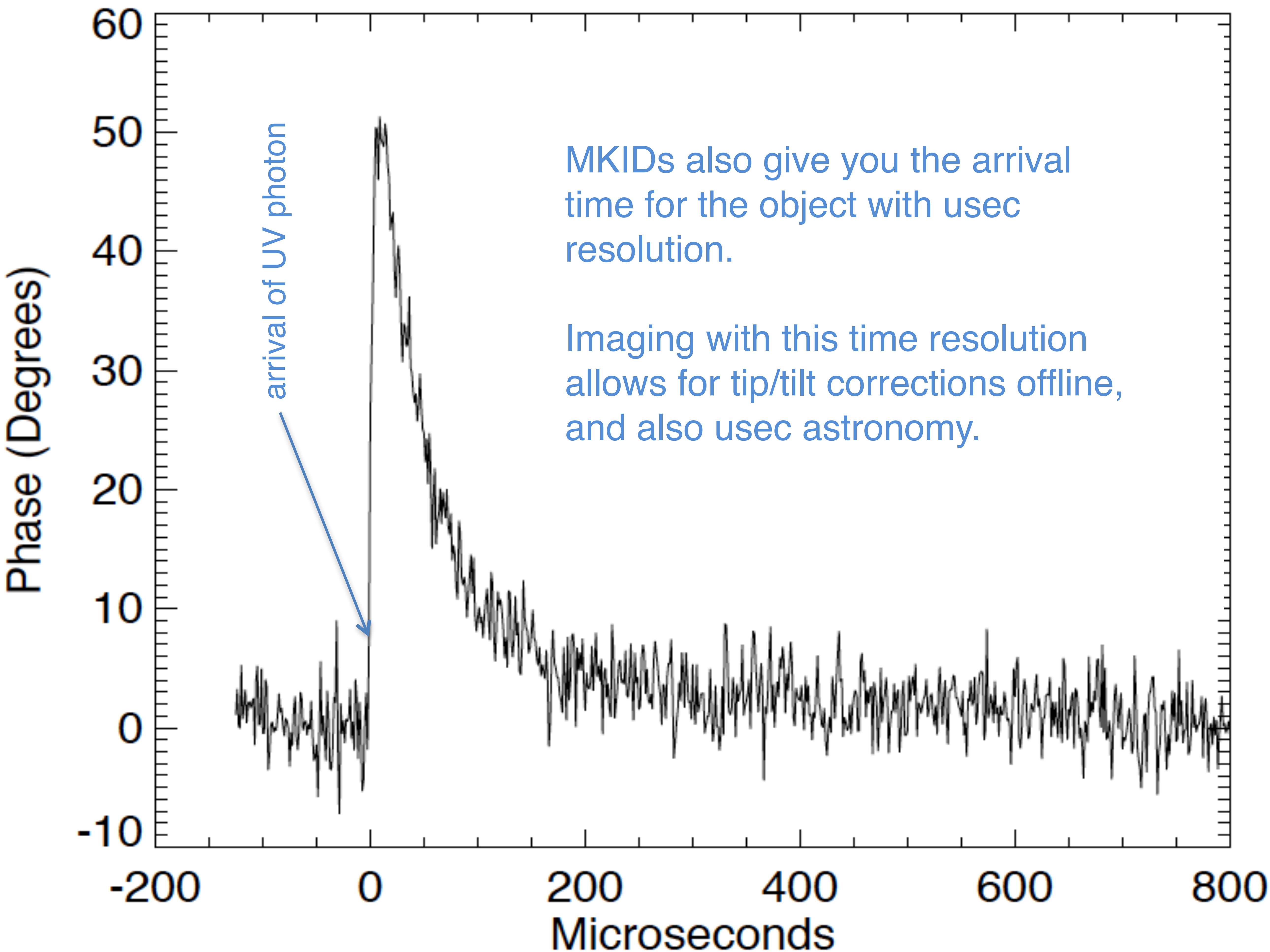


Superconductor sensors with “easy” frequency multiplexing

Each pixel is tuned to a different frequency. Photons each a pixel and move the resonance for that pixel. Digital FM radio.



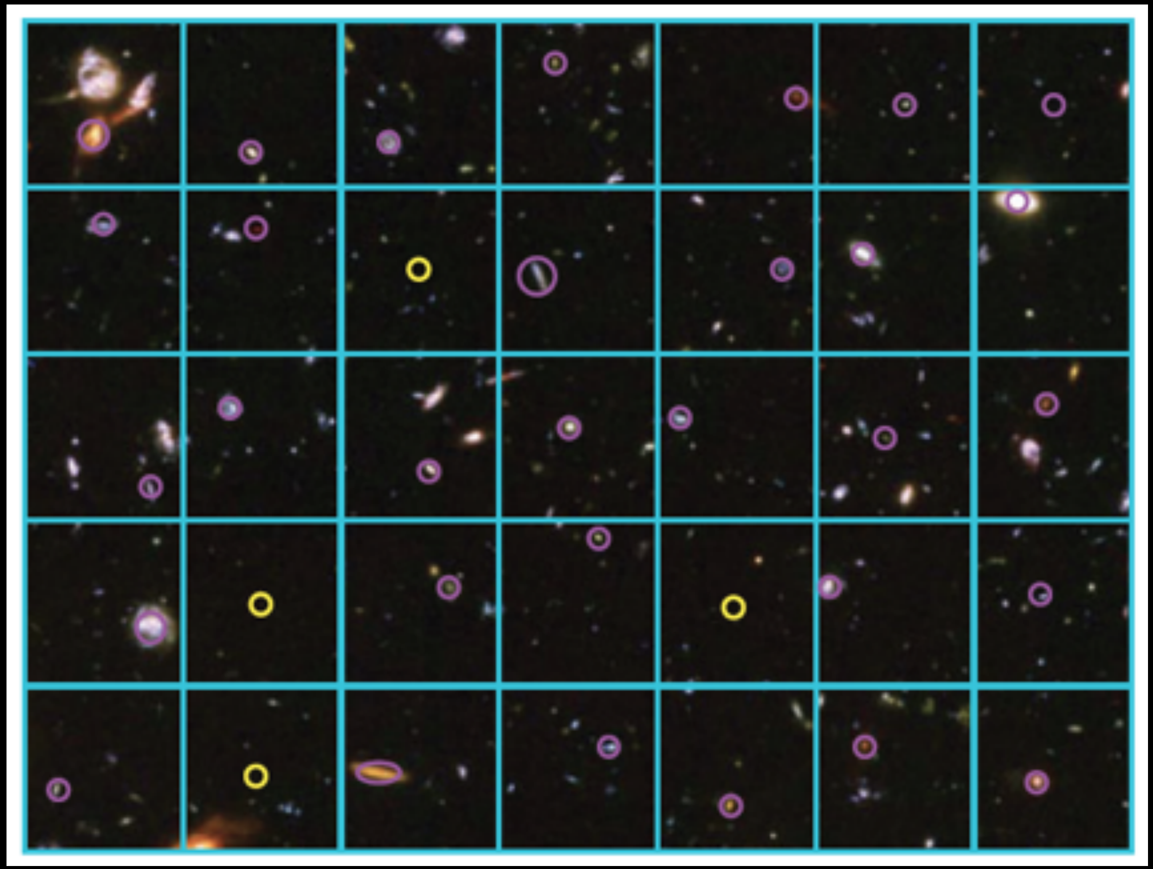
Large array of superconducting detectors are NOW possible.

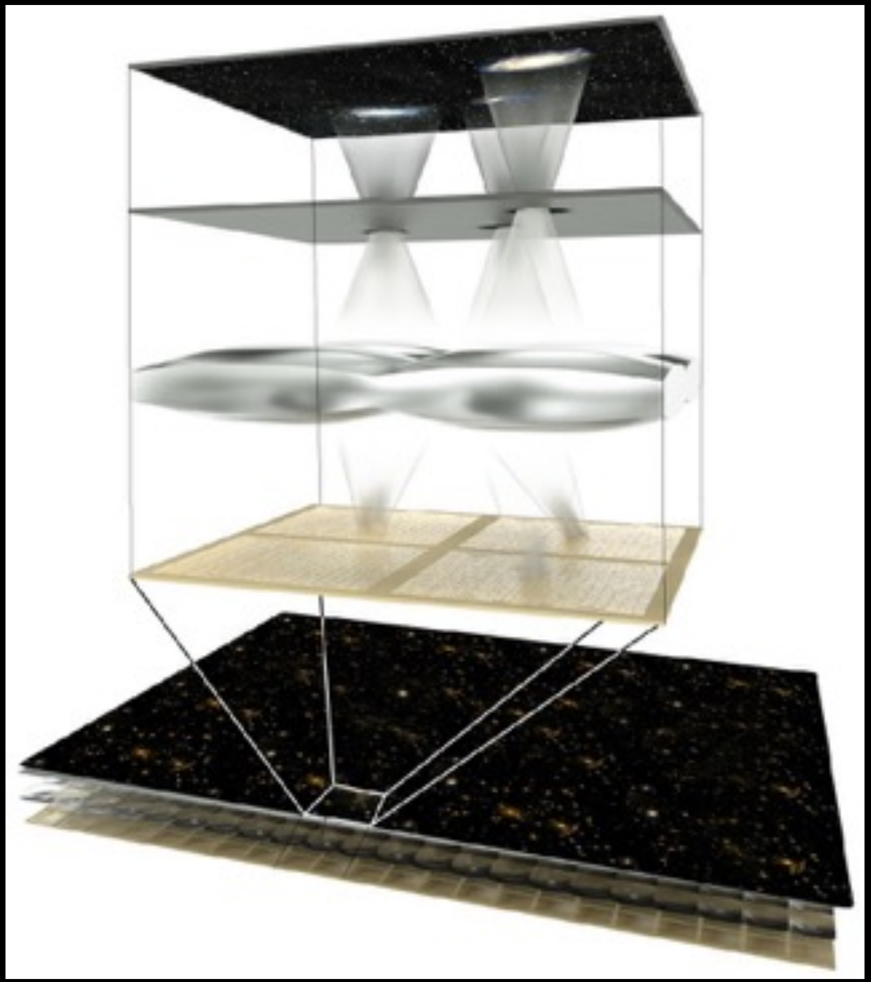


Phase (Degrees)
60
50
40
30
20
10
0
-10
-200
0
200
400
600
800
Microseconds
arrival of UV photon
MKIDs also give you the arrival time for the object with usec resolution.
Imaging with this time resolution allows for tip/tilt corrections offline, and also usec astronomy.

GigaZ/MegaZ : Photo-z machine

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





Make large pixels, and use mask to select a galaxy for each pixel. **100,000 spectroscopic channels in 1 square deg. is possible (20x DESI). Resolution R~100.** White paper to Snowmass 2013. Large project after LSST. (See comment from P5)

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.

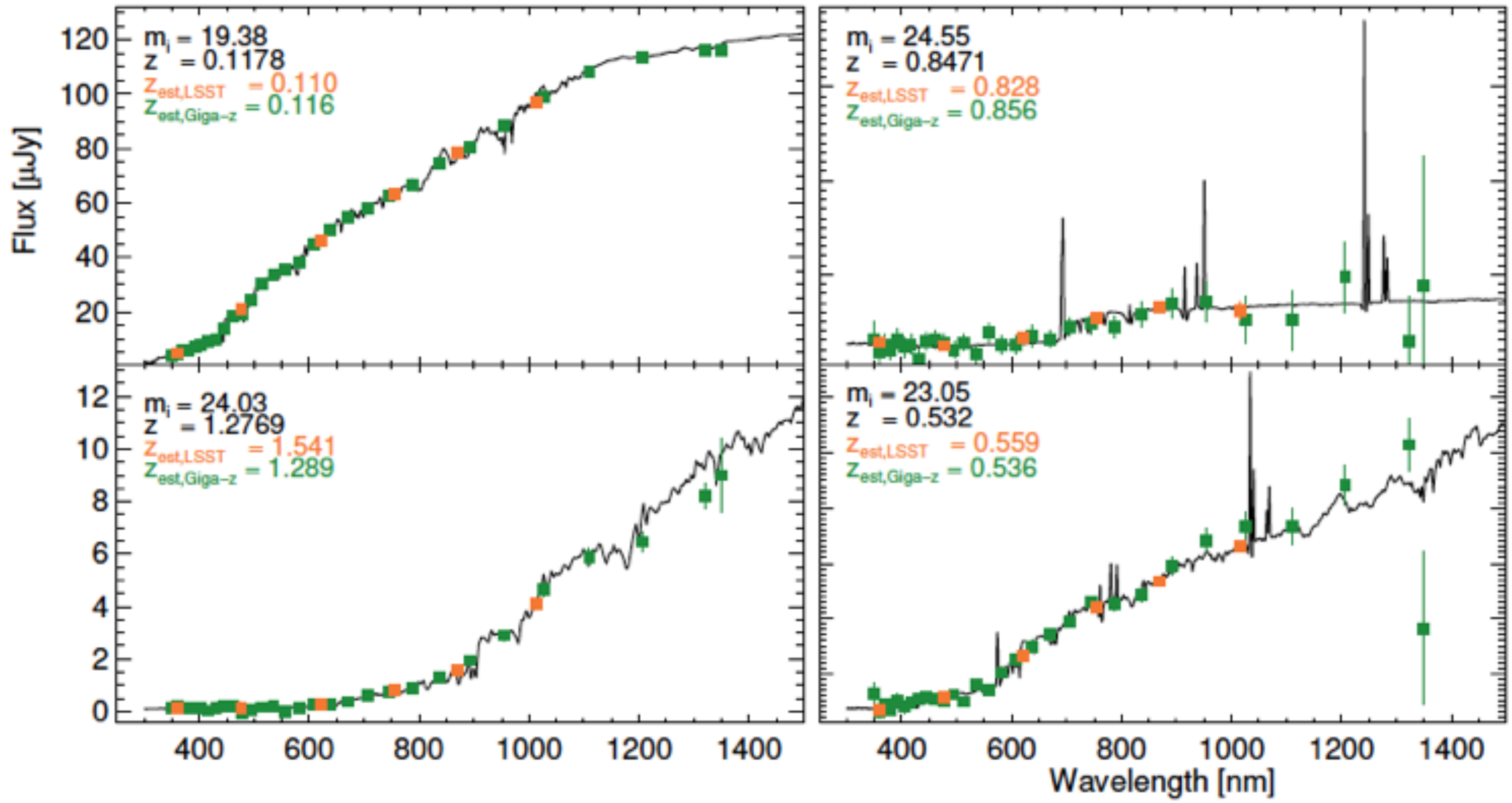


TABLE 4
A COMPARISON OF REDSHIFT RECOVERY STATISTICS BETWEEN MULTI-BAND PHOTOMETRY OR MULTI-OBJECT SPECTROSCOPY EXPERIMENTS, BOTH PAST AND PLANNED.

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	~19%
	224,000,000	20,000	$i_{AB} \lesssim 22.5$	$R_{423} = 30$	0.01	0.3%

Mazin at al 2013.(arXiv:1306.4674)

rate issues

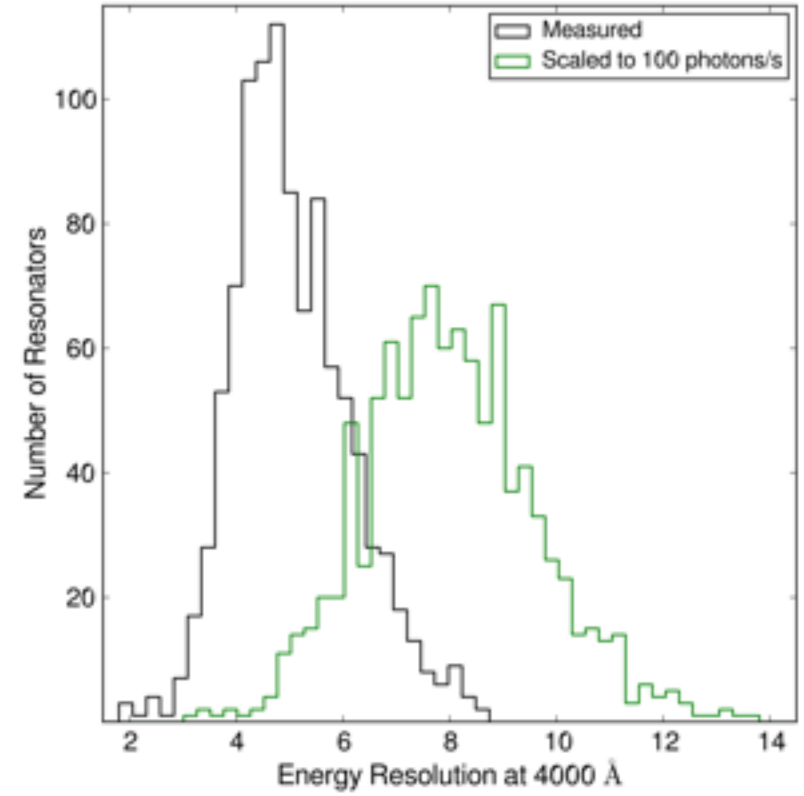
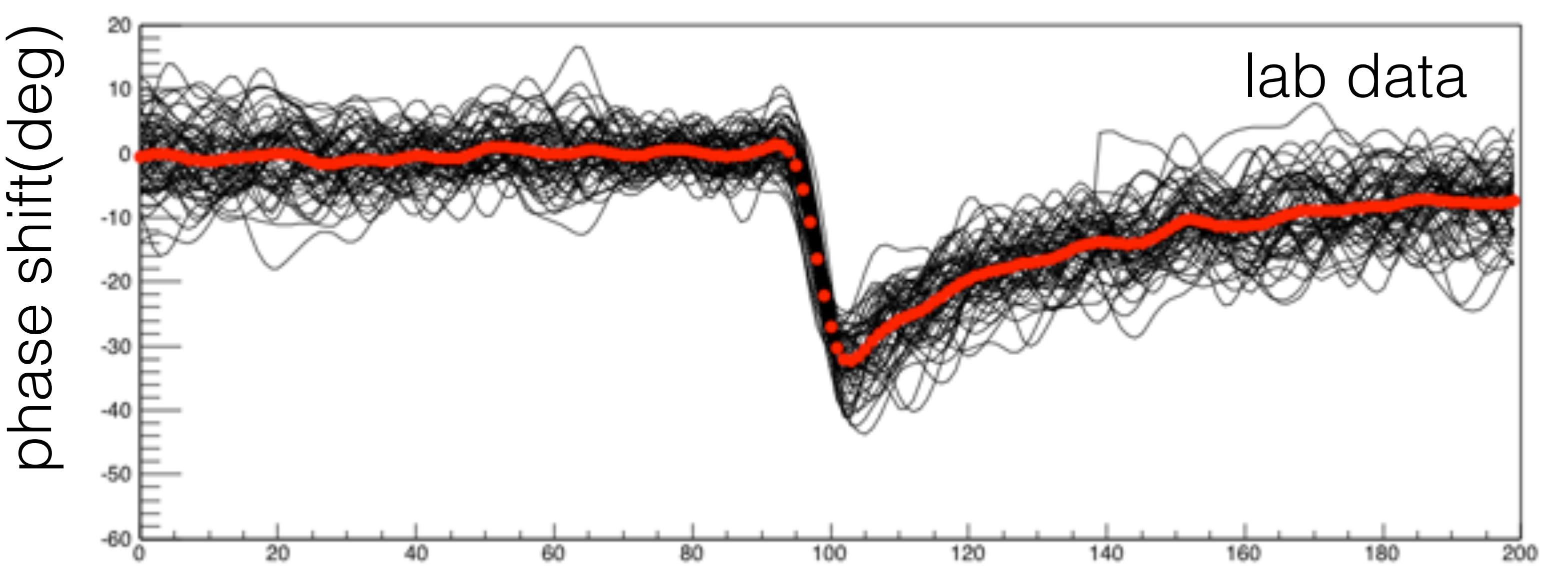


Figure 11. A histogram of spectral resolution of one feedline from the array. The black line shows the energy resolution from calibration files taken at Palomar with a high count rate of ~1000 cts/sec. The green curve shows the projected energy resolution we expect to recover at the nominal sky count rate of 100 cts/sec by scaling the black data by the expected degradation in spectral resolution with count rate, the red curve in Figure 13. The other feedline is very similar.

yield issues

Figure 10. The results of beam mapping the ARCONS array. Pixels with good locations are shown in white. Vignetting is apparent at the bottom right side of the array. The overall pixel yield in this engineering-grade array is ~70%.



noise

time(usec)

the UCSB group has done huge progress. Now we need to invest more resources to make then viable for Dark Energy.

slide from 2015

R&D steps

- HW R&D:
  - Frontend DAQ (Gustavo Cancelo, FNAL):

  Scalable 10k prototype currently in fabrication. need to keep support for this group if we want to have 100k readout system.
  - Backend DAQ : big deal (lots of data) room for contributions
  - sensor performance (Ben Mazin, UCSB):

  lot's of progress needed to get to R~80

  not enough people working on this right now

- Science Case for Low resolution spectroscopy in cosmology:
  - Need to calculate scientific reach of a large MKID based survey:

Proposing two 2-day workshops to do this. Identify the areas where low-res can have an impact, forecast how this could be realized with MKIDs.

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    not enough people working on this right now **need this**

- Science Case for Low resolution spectroscopy in cosmology:
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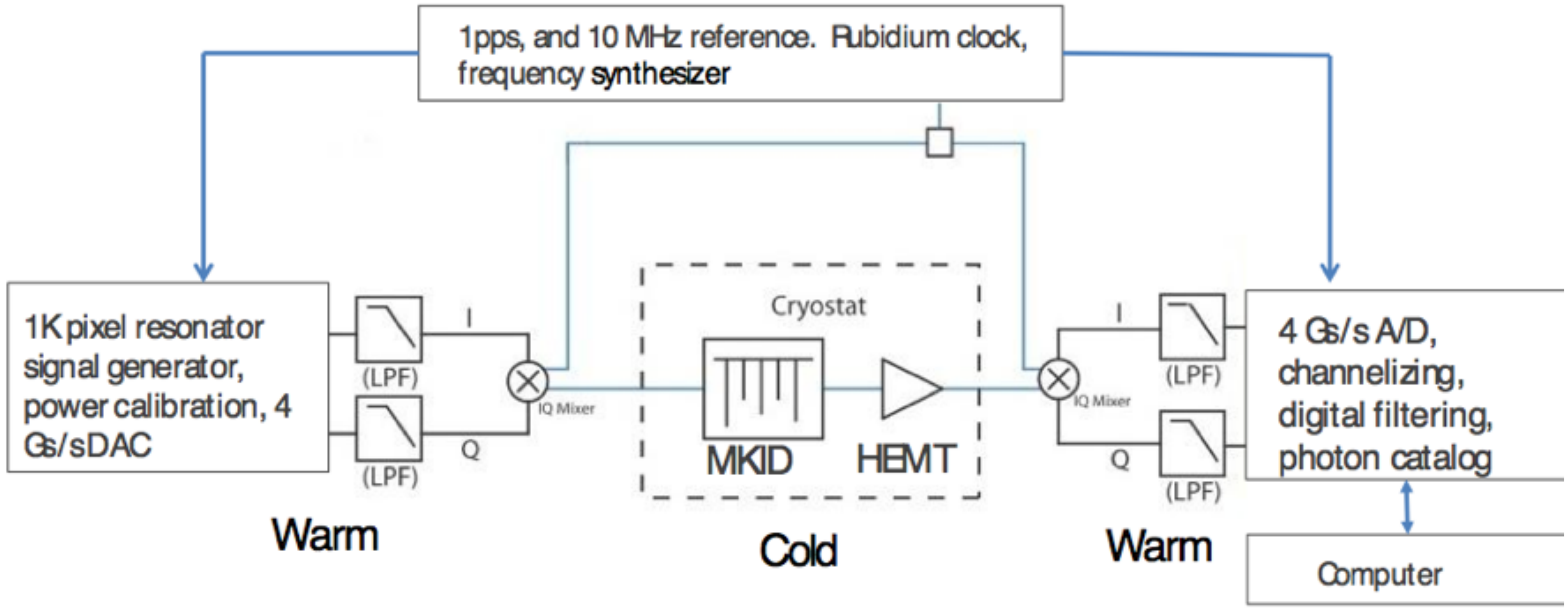
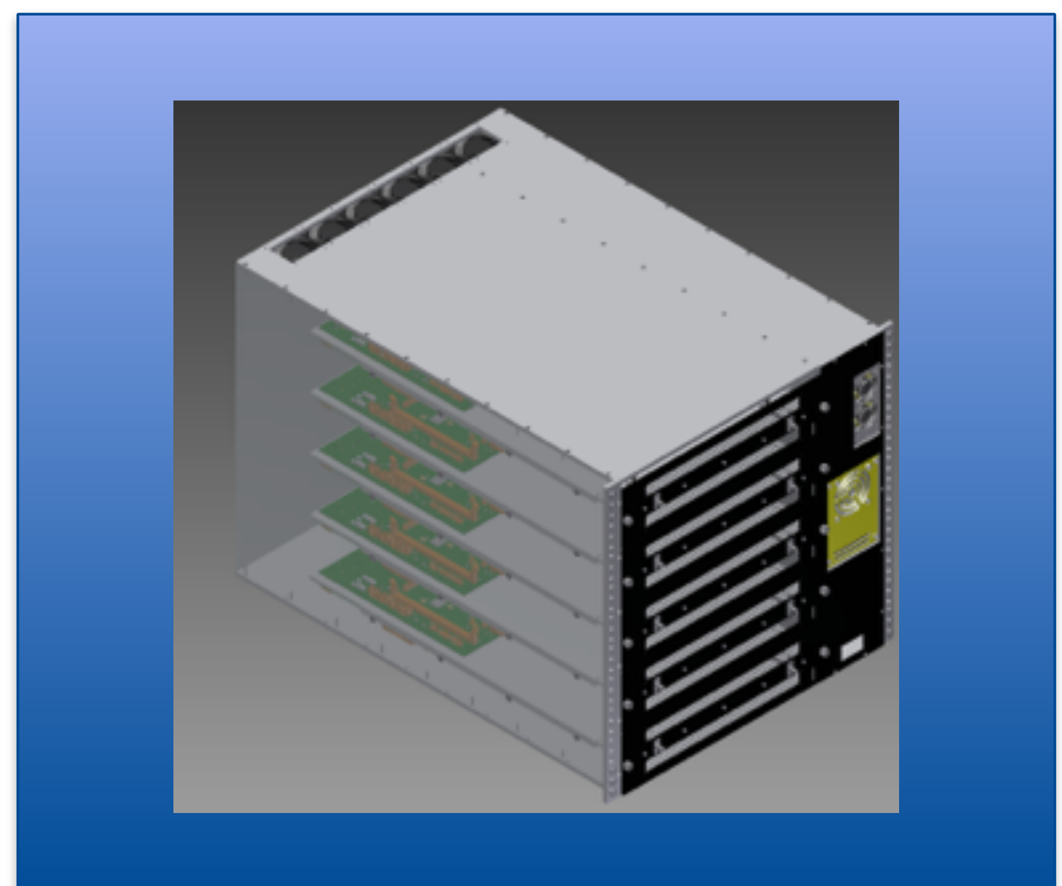
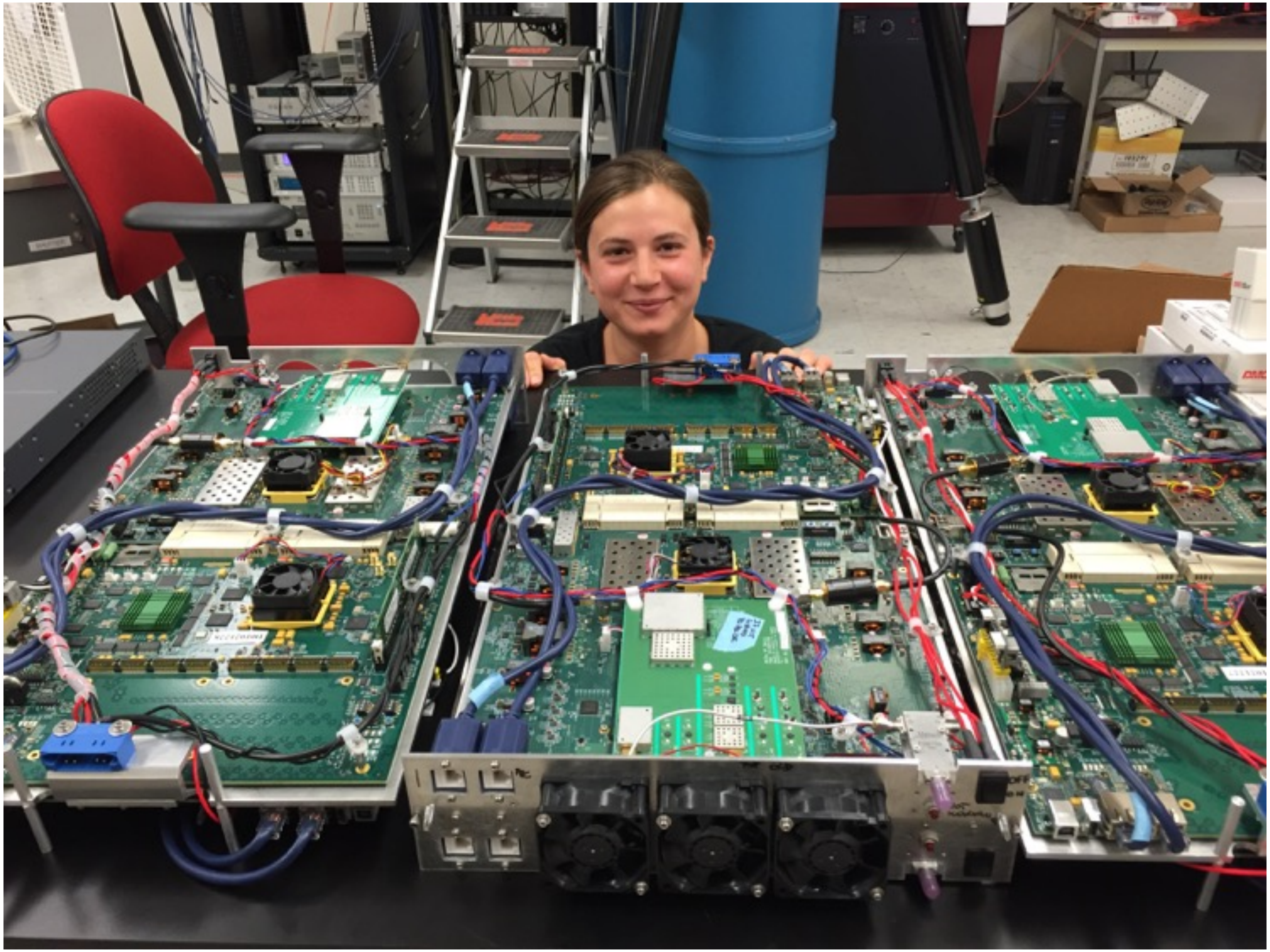
progress on this…



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

DAQ crate concept. Each crate with 10 systems reads 10K pix.





B. Mazin et al.
still making progress

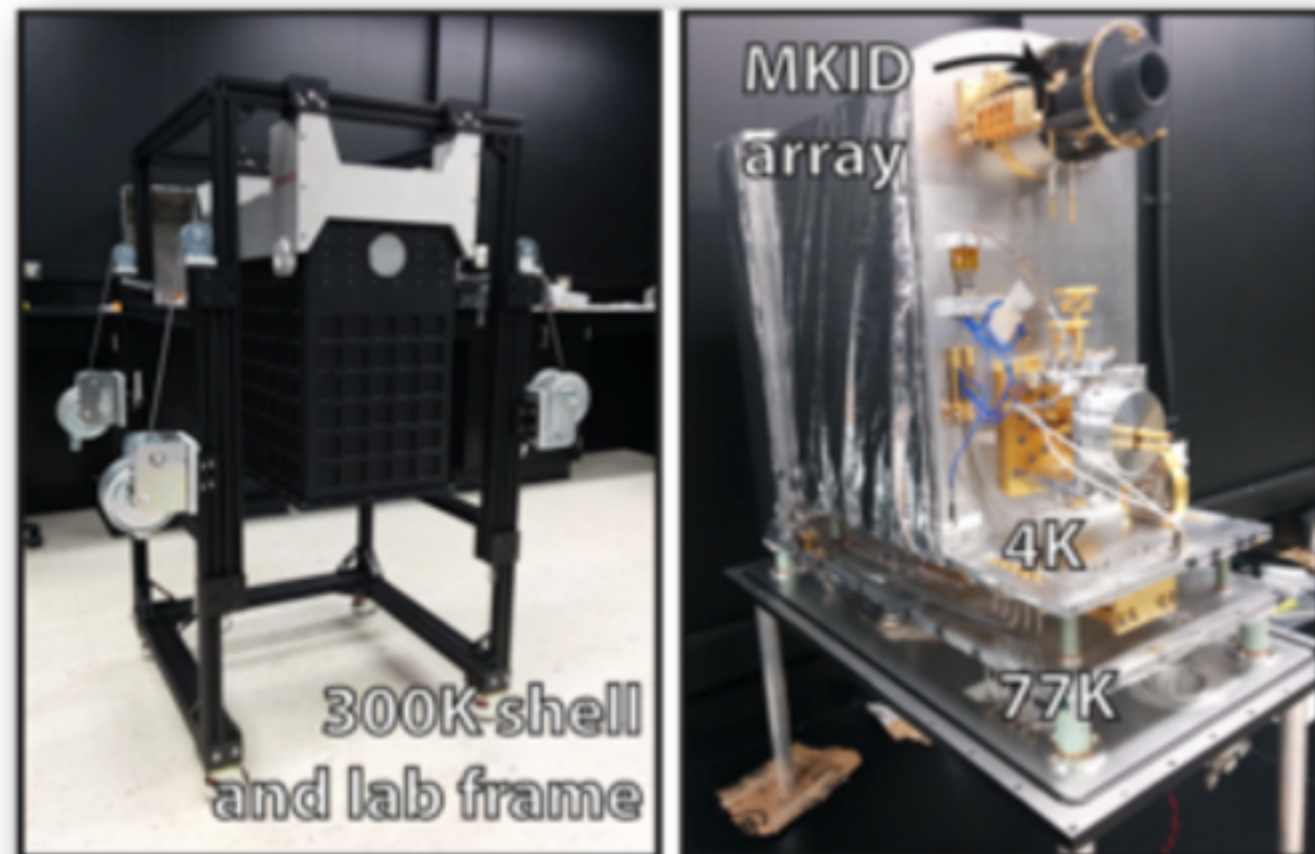
DARKNESS

We will use our revolutionary new detector technology, Optical/Near-IR Microwave Kinetic Inductance Detectors (MKIDs), to build an instrument of unprecedented capabilities for the direct imaging of extrasolar planets. DARKNESS, the Dark-speckle Near-IR Energy-resolved Superconducting Spectrophotometer, will integrate with existing coronagraphs at the Palomar 200" and Subaru telescope. DARKNESS will significantly improve the contrast ratio over what may be achieved with a conventional Integral Field Unit (IFU). Advantages over conventional IFUs include:

1. Vastly simplified optical design with very high throughput

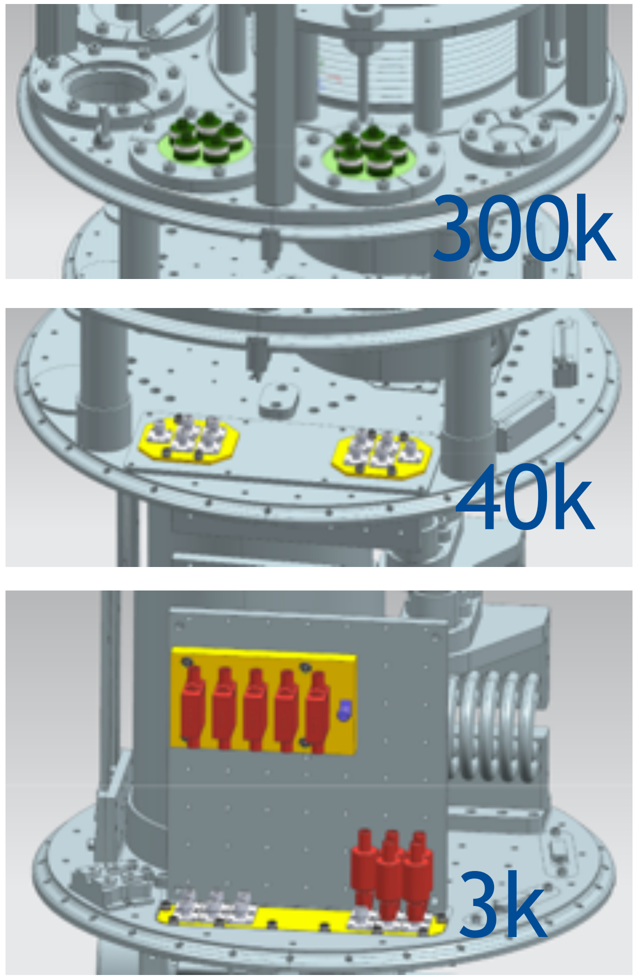
2. Operation from 700--1800 nm with energy resolution R~20 at 1 micron allows spectral suppression of speckles

3. Zero read noise and zero dark current photon counting enabling the Dark Speckle technique for contrast enhancement

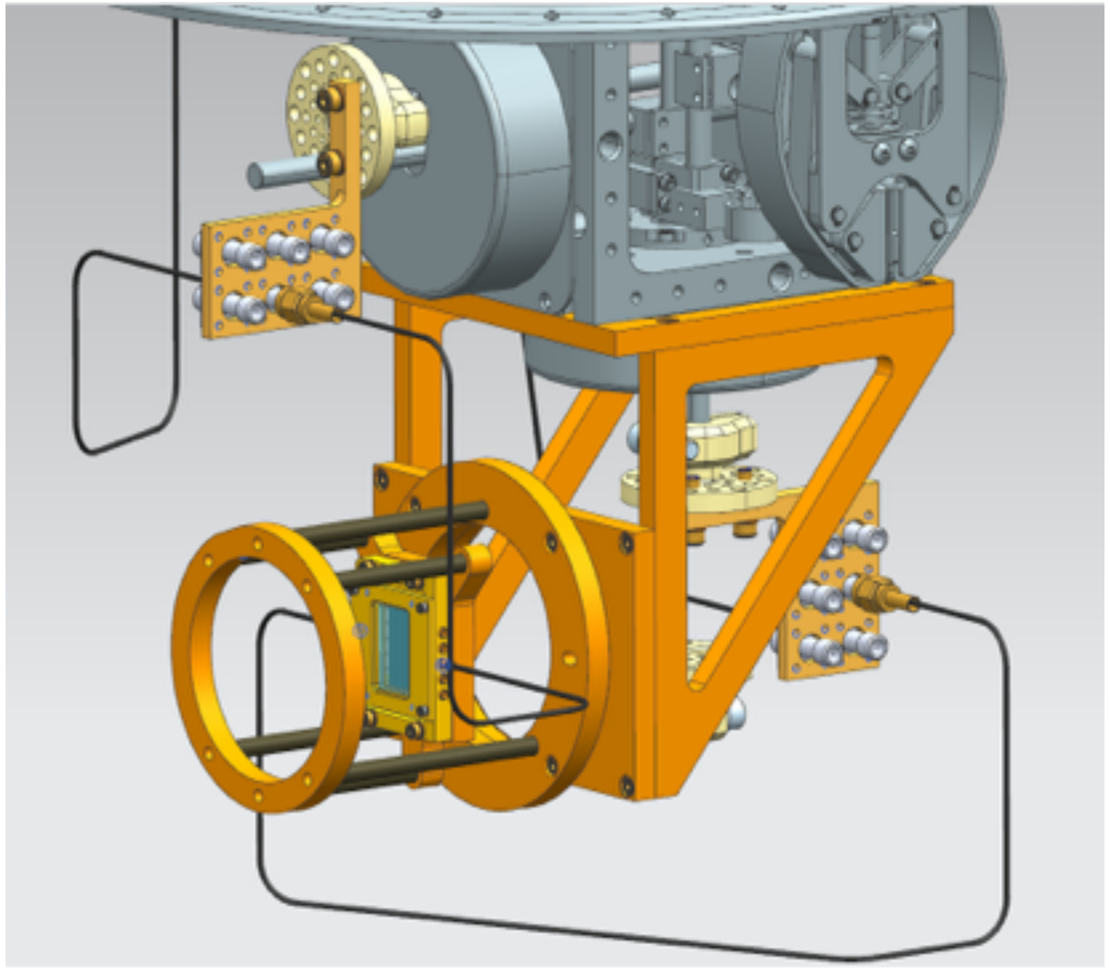


MKIDs prototype instrument

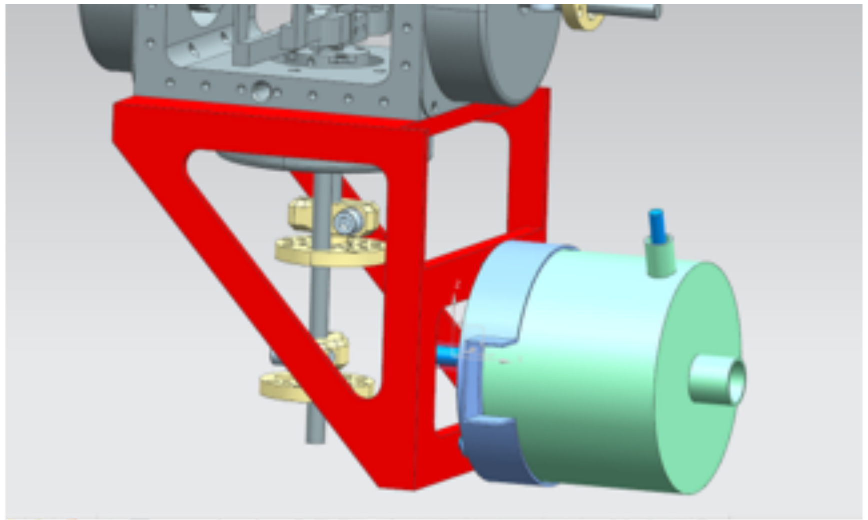
slide from 2015



Cabling + cold electronics



Focal plane



Magnetic shield

prototype instrument at FNAL

LDRD Project Description Outline

ANL-A. Miceli, UChicago - E.Shirikoff, FNAL J.E.

Proposal Title

Microwave Kinetic Inductance Detectors for Dark Energy Surveys

The work proposed here will be divided in three phases, each lasting 12 months. During Phase 1 we will fabricate a series of small arrays of MKID detectors at ANL, starting with designs drawn from existing UCSB arrays. This initial step will not only verify the optical response and noise properties of locally-grown films, but will address resonator parameter scatter which is believed to be due to interactions between resonators in densely packed arrays. Our test devices will include a series of sparse and electrically isolated resonators and several channel pairs designed to preserve the physical interactions seen in existing large arrays. A detailed comparison of test results with simulations of individual channels and interacting pairs carried out using the commercial electromagnetic simulation packages Sonnet and Ansys HFSS will explore parameter scatter and inform the design of improved channels [9]. By the end of Phase 1, we will have detailed statistics on the response, noise properties, fabrication yield, and parameter scatter achievable in individual channels, and we will have demonstrated the ability to fabricate and accurately model the features of state of the art optical MKIDs.

During Phase 2, we will test variations in pixel design informed by detailed simulations and Phase 1 results. Possible variations include: (1) Designs that 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) Devices fabricated on intermediate dielectric layers designed to quantify resolution limitations associated with the generation of above-gap substrate photons. (5) Hybrid designs designed to couple quasiparticles generated in a large absorber to an extremely small volume inductive sensor, decoupling detector properties from absorber properties. (6) Variation in packaging and readout wiring to explore the role of box lid coupling and amplifier interactions on device performance. By the end of Phase 2, we will have designed and carried out the tests needed to design an optimized pixel.

LDRD PROJECT DESCRIPTION OUTLINE

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PROPOSAL TITLE

Microwave Kinetic Inductance Detectors for Dark Energy Surveys

we are not out of ideas (at least Erik is not)

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) Hybrid designs designed to couple quasiparticles generated in a large absorber to an extremely small volume inductive sensor, decoupling detector properties from absorber properties.

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

… not funded (a year ago)

comments

- Hopefully we are making progress on understanding the science potential of a low resolution spectroscopy survey (meeting in Feb-2016 and this meeting).
- We need R&D on the instrument side to make this happen (primus-like or MKIDs).
- A push from this community on the value of the science will make this R&D go faster.

Another low resolution spectroscopy example : PRIMUS

failure rate in redshift measurements with low-res spectra

TABLE 1
PRIMUS REDSHIFT CONFIDENCE CLASSES

Class	$\sigma_{\delta z/(1+z)}$	Outliers[a]	Sample Fraction[b]
4	0.005	7.85	49.2
3	0.022	5.32	21.6
2	0.050	5.06	29.2

[a] Fraction of objects with known redshifts deviating more than 5σ from agreement.
[b] Fraction of PRIMUS primary galaxies which received the specified class designation.

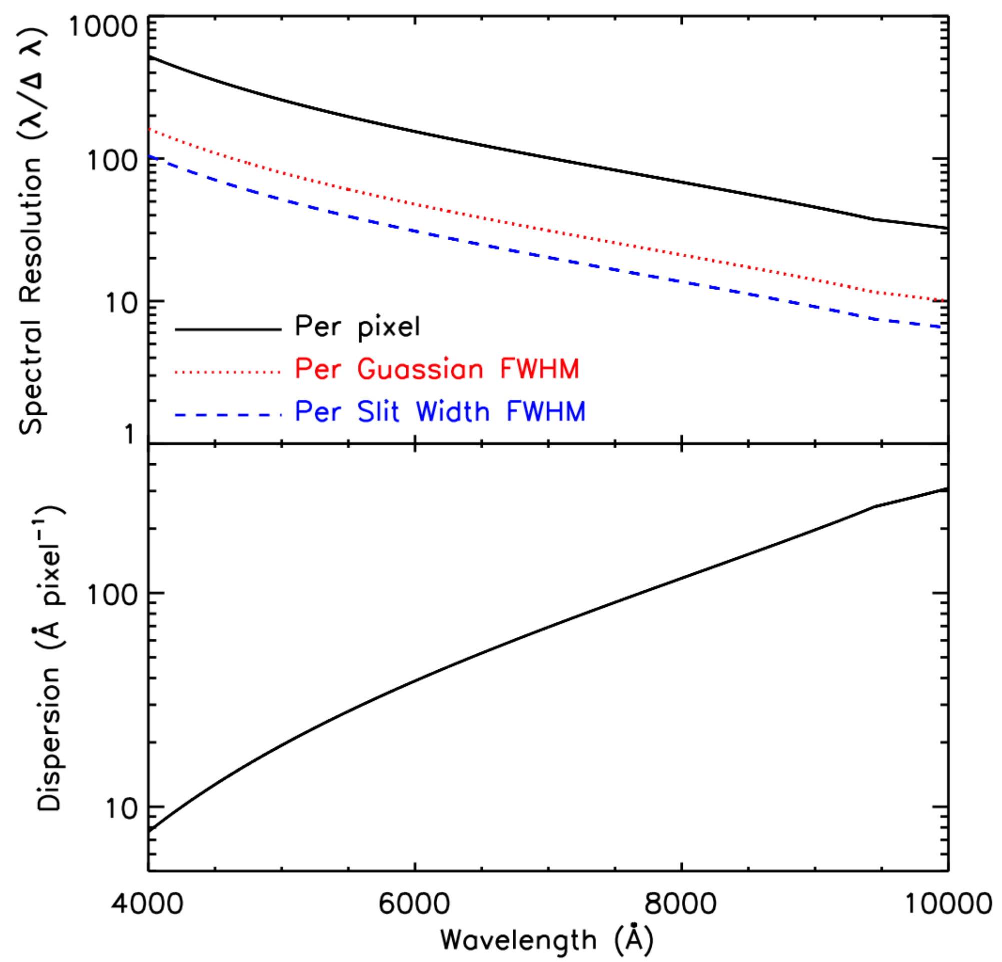

FIG. 2.— Resolution and dispersion of the PRIMUS prism versus wavelength. The resolution and dispersion generated by the low dispersion prism is a strong function of the wavelength with increased resolution in the blue but low resolution at $9000\AA - 1\mu m$. The low resolution allows us to observe the full optical spectrum of a target galaxy on only ~150 pixels on the detector and up to ~3000 galaxies on a single mask.

This is data, not simulation. Primus with R~100 gets in real 5% failure rate in the best 50% sample, and 8% failure in the rest.

the Baade I 6.5m telescope at Las Campanas, PRIMUS spectroscopically measures galaxy redshifts in much less time than would be required with more traditional high-resolution spectroscopic techniques ($\sim 10,000$ galaxies per night) and reaches depths of $i \sim 23$ in one hour. PRIMUS redshifts have typical precision of $\sigma_z/(1+z) = 0.005$. PRIMUS spectroscopy focuses on fields with existing optical imaging for target selection and emphasizes areas with existing high-quality multiwavelength imaging from *GALEX*, *Spitzer*, *Chandra*, and *XMM-Newton*. The

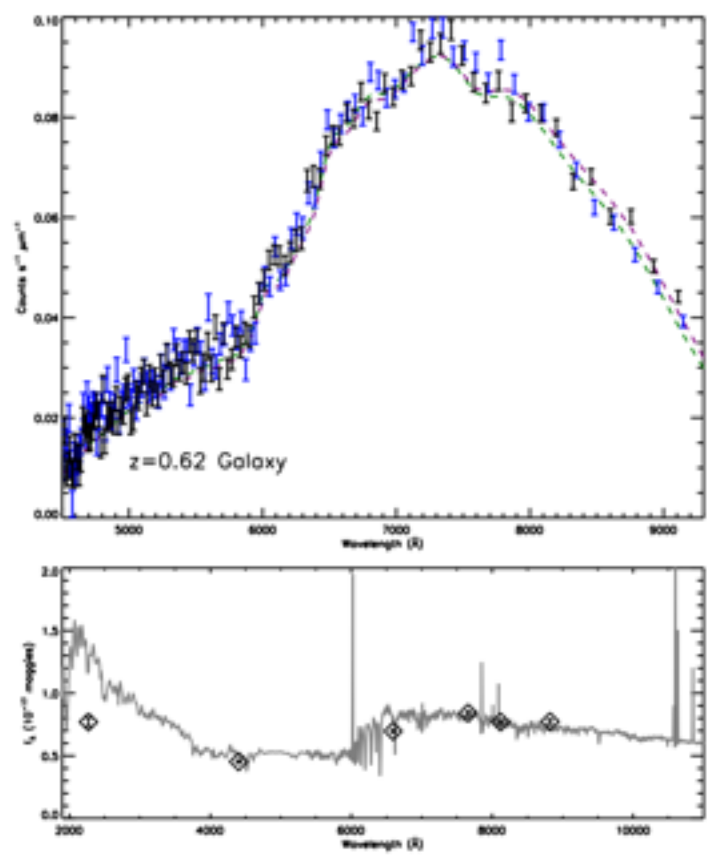

FIG. 17.— Example of a PRIMUS fit to an object identified as a $z = 0.62$ galaxy. The top panel shows the observed PRIMUS spectrum from both slit A (black) and slit B (blue). The dashed line shows the best-fitting model convolved to PRIMUS resolution. In the bottom panel, the grey line shows the full-resolution best-fitting galaxy model. The data points with errorbars mark the broadband UV and optical photometry available for the object.

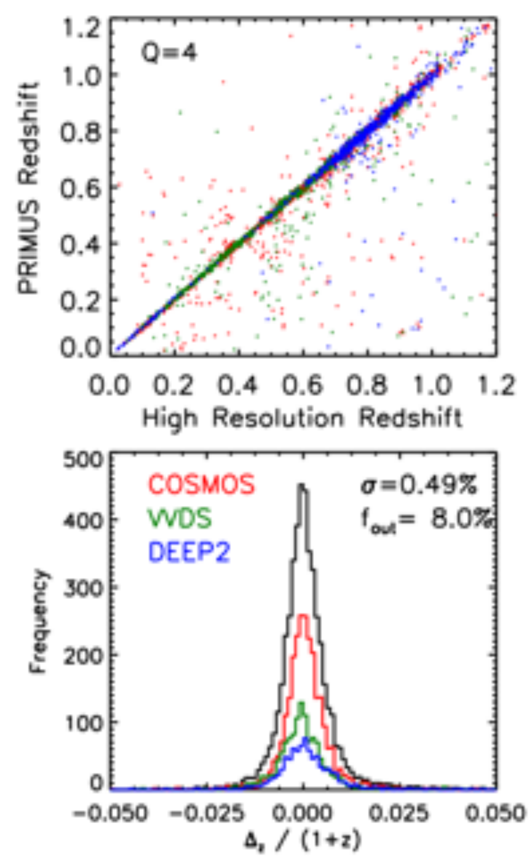

FIG. 20.— Comparison of PRIMUS redshift with redshifts obtained from higher-resolution spectroscopy from COSMOS, DEEP2, and VVDS for $Q = 4$ quality rating. The bottom panel shows the histogram of the difference between the PRIMUS and high-resolution redshift for each survey as well as the full comparison sample. Overall, we find a $\sim 0.5\%$ dispersion between PRIMUS and the high-resolution sample with $\sim 8\%$ of the galaxies falling more than 5σ from agreement.

Marsden et al 2013

3.2. *Sky Subtraction*

When working into the near-IR, sky subtraction becomes a dominant concern. For Giga-z, concurrent with galaxy target selection from the LSST imaging will be the selection of known dark areas of the sky. Approximately 10 - 20% of the macropixels in a typical observation, or each of $\gtrsim 10,000$ MKIDs will collect $\approx 1{,}000$ photons per second from the sky (based on the Gemini South model[1]), with each photon individually time tagged to within a microsecond. This sky background data can then be used to build up a map consisting of spectra as a function of time at every point on the array, facilitating the subtraction of the sky background to the Poisson limit over the entire spectral range of the detectors. In J band, for example, with a sky brightness of ≈ 16.6 magnitudes per square arcsecond, a 24.5^{th} magnitude galaxy with about half its light falling in 1 square arcsecond would have a contrast ratio of $\approx$ 5e-4. Figure 6 shows this measured at a few sigma in a 15 minute exposure.