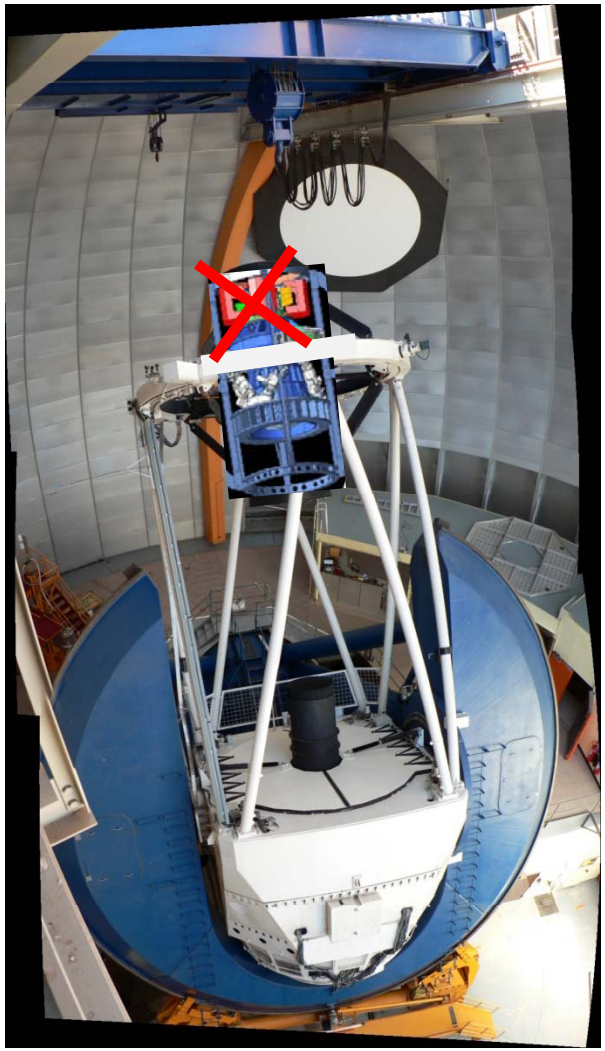
DESpec

Outline

- Introduction to DESpec
  - The “notion”
- Progress in the past year: White Paper =>
  - Science
  - Simulation
  - Hardware
- The Way Forward



Tom Diehl, FCPA Retreat June 2012

DESpec Began as a “Notion”

DARK ENERGY SURVEY

- Build an instrument to perform spectroscopic follow-up of millions of targets identified in DES data, taking advantage of the DECam strengths (red-sensitivity).
- Capitalize on DECam infrastructure to minimize cost and shorten schedule, balancing frugality with science capability
- Identify existing or planned components at other instruments for technical feasibility and to minimize the cost (conservative design)
- It’s necessary that the instrument can be inter-changed with DECam in a reasonably short time.

Rationales for DESpec

We realized that the scientific power that will come from:

- Excellent site: 0.65” seeing (0.9” Mosaic), high number of useable nights (80%) yield fast (hence cheap) survey
- Uniform, deep imaging catalogs from DES+VHS for targeting: enable powerful new science beyond what spec. redshifts or imaging alone provide
  - Maximally enhance science reach of DES: improve all the DE methods+enable new methods (RSD, radial BAO)
- Hemispheric synergy with LSST: part of a broader eventual strategy for LSST follow-up: extend to ~15,000 sq deg

History of the White Paper

- By August 2011 we had a first draft with sections on science, survey, and hardware concepts.
- Then people really got to work
- Current version May 2012 is V7
- There will be one more, due in a couple weeks.

http://astro.uchicago.edu/~frieman/DESpec/DESpec-white-paper-v7.pdf

- The new version is very much improved over the previous ones, reflecting the work that has been done in the interim.
- Highlights from Workshop last week in Chicago

Overview | Registration | Participants | Program | Talks | Logistics

OVERVIEW

The Kavli Institute for Cosmological Physics (KICP) at the University of Chicago will host **The Dark Energy Spectrometer** workshop on May 30-31 to discuss DESpec, a conceptual next generation dark energy project to enable massive spectroscopic surveys in the southern hemisphere. It would naturally synergize with the Dark Energy Survey (DES), which will start taking data later this year, and with LSST in the longer term. The goal of this meeting is to review past and present work on DESpec and to make plans for how to proceed. We will briefly review the current state of the instrument design and then identify the next steps in the project, including describing the R&D necessary to proceed with theory, survey strategy, and instrument definition. The goal of the workshop will be to begin to assemble the DESpec team, define the project's mission statement, and plan how to proceed in the coming year.

- **Status of DESpec**
- **Organizing Committee**
- **Registration**
- **OnLine Materials**
- **Contact Us**

Organized by Jennifer Marshall (TA&M)
plus a local committee

http://kicp-workshops.uchicago.edu/DESpec2012/

Workshop (DESpec's 3rd) @ KICP

DARK ENERGY SURVEY

ATTENDEES

- 65+ & 15+ from overseas
- Good Representation from DES Collaborators
  - UCL, U. Portsmouth, Imperial College, Barcelona, CIEMAT (Madrid), Zurich, UoC, OSU, ONL Brazil, Texas A&M, Harvard CfA, ANL, FNAL
- Also AAO, Durham U., JPL
- SLAC, KIPAC, U. Pittsburg, Carnegie Obs.

TOPICS

- Introduction
- DESpec Science
- Spectroscopic Follow-up for DES Photo-Z Calibration
- "Same-Sky"
- Other Surveys
- DESpec Survey Strategy
- DESpec Hardware Concepts

Science

Decide what science and how well

Science –> Survey –> Hardware

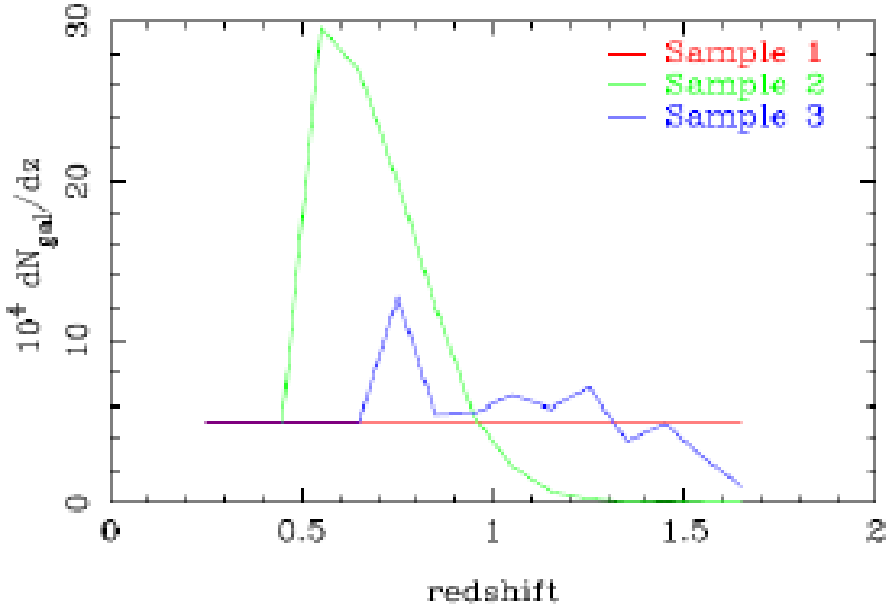
sort of

Original White Paper Target Selection

DARK ENERGY SURVEY

- Early on in the white paper process we asked that physics groups consider 3 “strawman” surveys w/ 10M galaxies
  1. Constant z density 0.2<z<1.7
  2. Constant z density 0.2<z<0.5, plus I<22.5 for 0.5<z<1.7 @65% eff’y. Note redshiftcut-off
  3. Constant z density 0.2<z<0.7, plus emission line galaxies for 0.7<z<1.7.

Figure shows distribution of redshifts in the 3 samples



Abdalla & Jouvel have made big improvements using sophisticated selection techniques

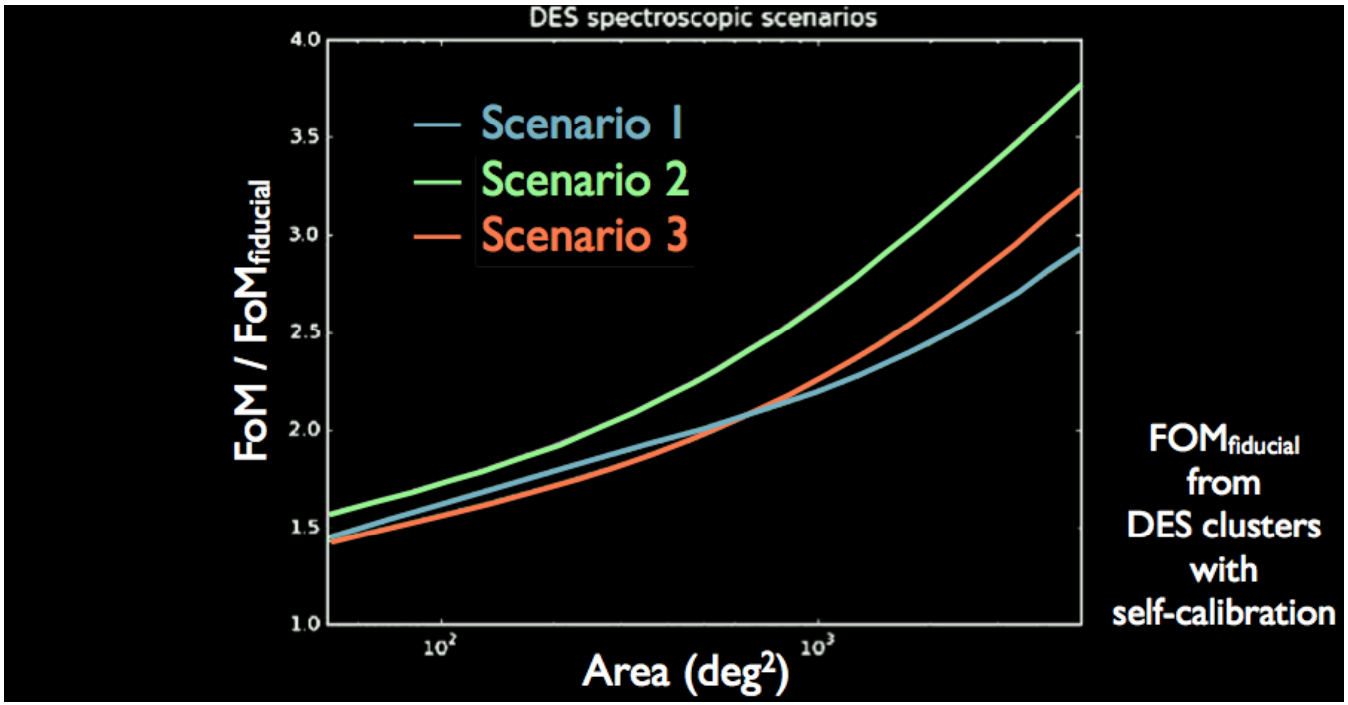
DESpec Spectroscopy of DES Targets Provides

DARK ENERGY SURVEY

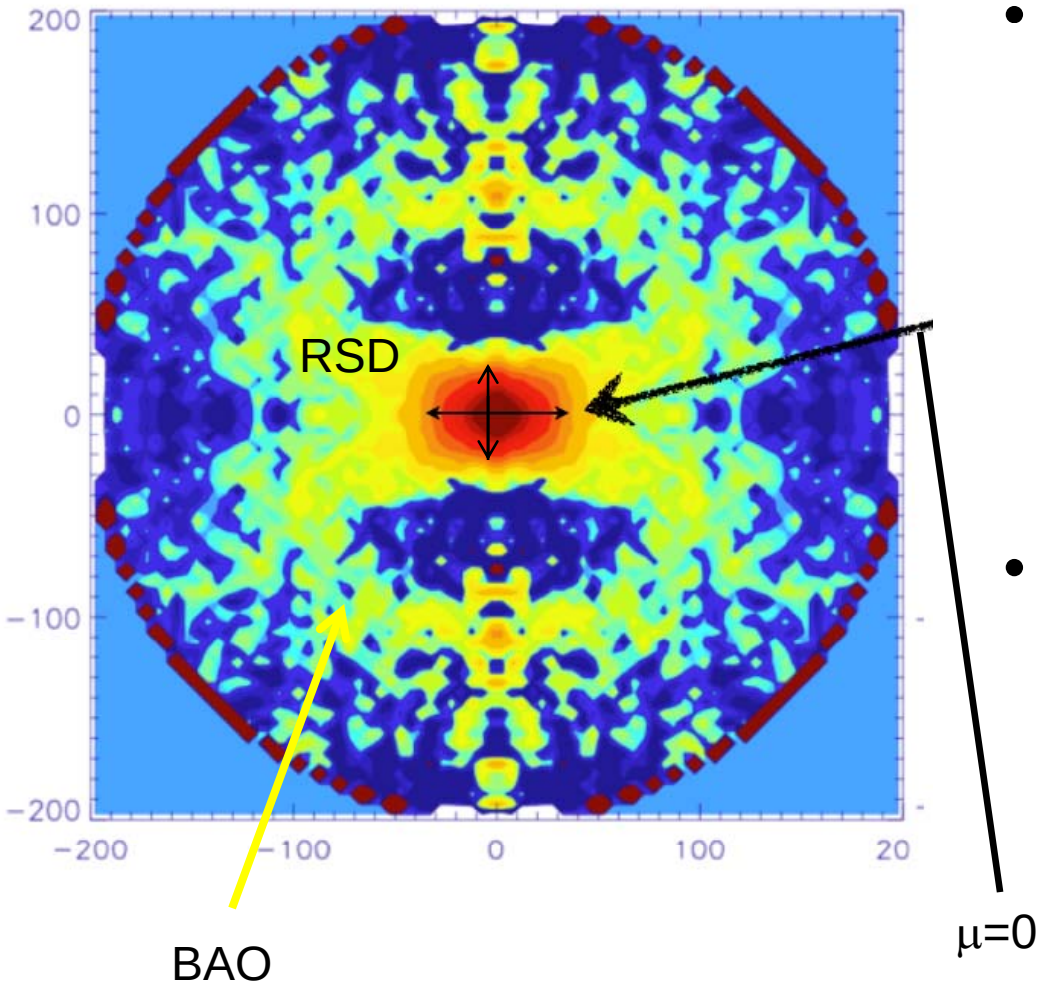
- Clusters: cluster spec. z's and dynamical masses from velocity dispersions: improve mass-observable calibration
- Weak Lensing: Improve systematics from intrinsic alignments
- WL+RSD: DESpec Redshift Space Distortions plus DES WL: powerful probe of DE and test of GR+DE vs Modified Gravity
- LSS: radial BAO: $H(z)$, and improved $D_A(z)$
- SNe, galaxy evolution: host-galaxy z's and spectroscopic typing (metallicities, stellar masses) to control systematics
- Enhanced DES science reach: improved calibration of photo-z $N(z)$ via angular cross-correlation (Helsby+Lin) improves all DE constraints
- Strong Lensing: lens & source redshift confirmation, improved modeling

Example: Clusters Working Group

- Dark Energy measurements (w vs w') come from # of galaxy clusters as a function of cluster mass
- Spectroscopic data provides improved knowledge of the cluster masses



Redshift Space Distortions



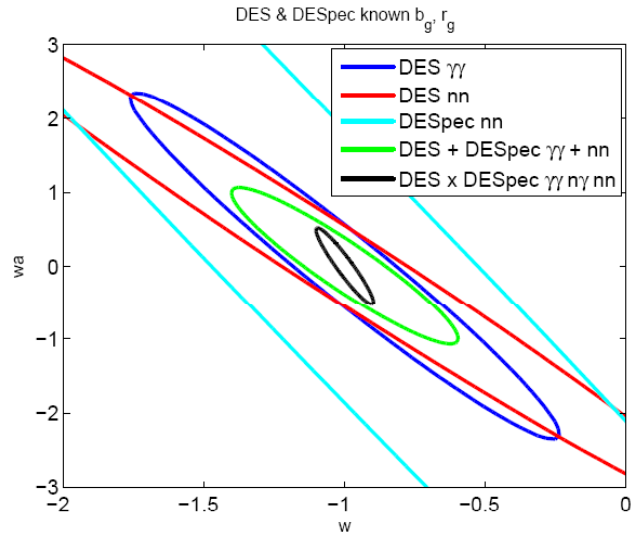
- Plot shows radial vs transverse seperation between galaxies. Mass falls towards the mass overdensities and accelerates away from voids.
- Provides a mass estimate, breaks M-L bias degeneracy from WL

$$\delta_g(k,\mu) = (b + f\mu^2)\delta(k)$$

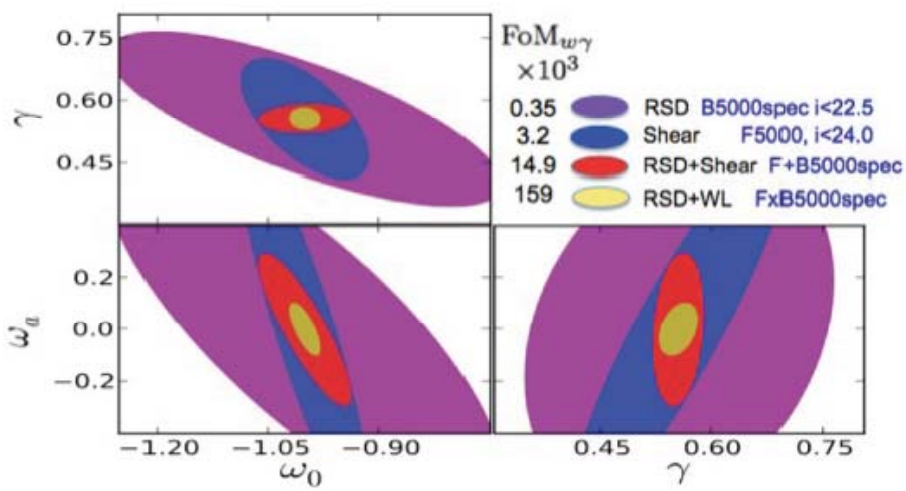
Combining
BAO + P(k) + RSD's...

DARK ENERGY SURVEY

- Leads to much tighter FoMs (everybody agrees)
- "Same sky" is even better (everybody agrees)
- Not that everybody agrees on by how much, depends on what one assumes for priors



DES(WL) + DESpec(LSS)
Kirk, Lahav & Bridle, in prep, strong priors on bias



Gaztanaga et al

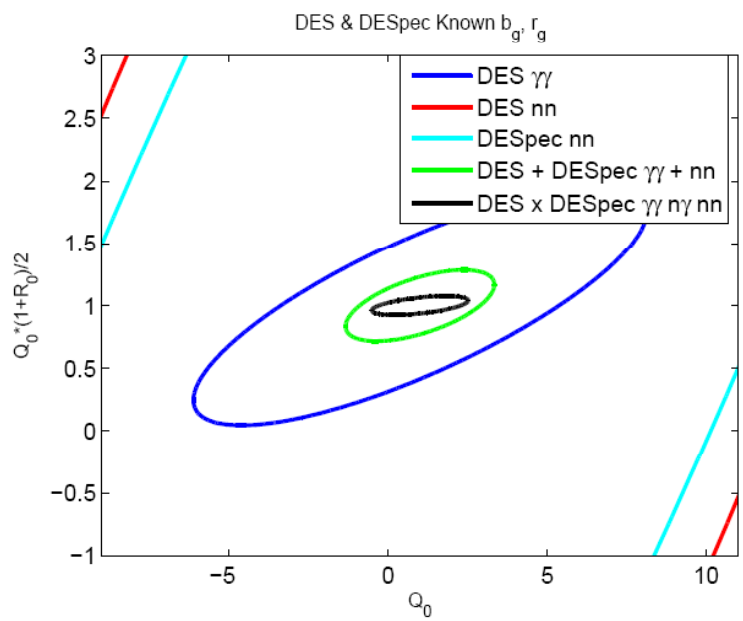
Not same sky vs same sky

Example: Modified Gravity

$$ds^2 = -a(\tau)^2\left[1 + 2\Psi(\mathbf{x}, t)\right] d\tau^2 + a(\tau)^2\left[1 - 2\phi(\mathbf{x}, t)\right] d\mathbf{x}^2$$

- By the time DESpec is ready to go we may have a new definition of the FoM.

In this modified gravity, WL shear is from $\Psi + \phi$ but galaxy position and peculiar velocities fare from Ψ.
Joint constraints show a marked improvement
MG FoM



DES(WL) + DESpec(LSS)
Kirk, Lahav & Bridle, in prep
(strong priors on bias)

survey

strongest science case

Science –> Survey –> Hardware

Optimize the survey depending
On the science priorities

The DESpec Mock Catalogs

Abdalla & Jouvel

DARK ENERGY SURVEY

Important to have

- **Realistic redshift distribution,**
- **Realistic galaxy size distribution,**
- **Emission line fluxes catalogue**

Select LRGs and ELGs

Based on the COSMOS Mock catalogue

COSMOS catalogue (**position, size**, photometry) 1 million galaxies

Jouvel et al. 2009

Photoz, SED, **emission lines**

Photometry in DE mission filter sets + Photometric errors

Jouvel et al 2010

COSMOS photoz from Ilbert et al. 2009

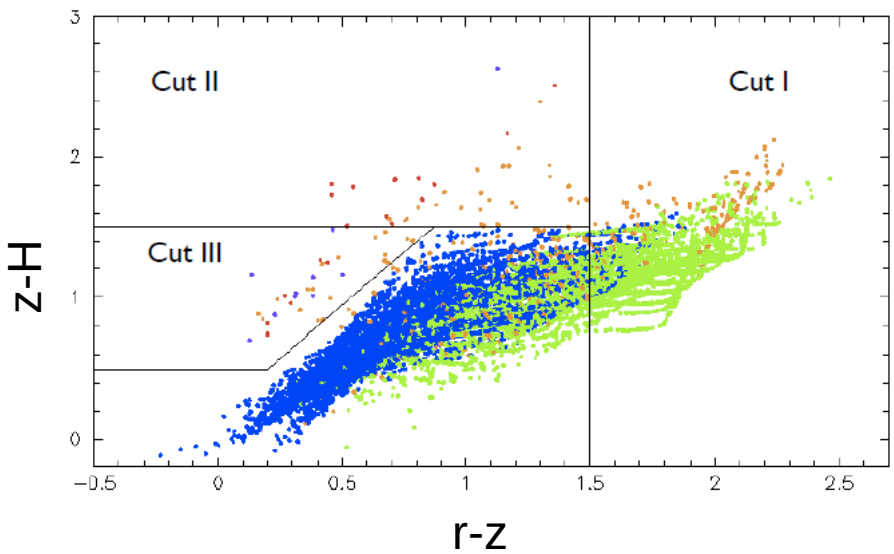
UCL

LRG target selection (ANN)

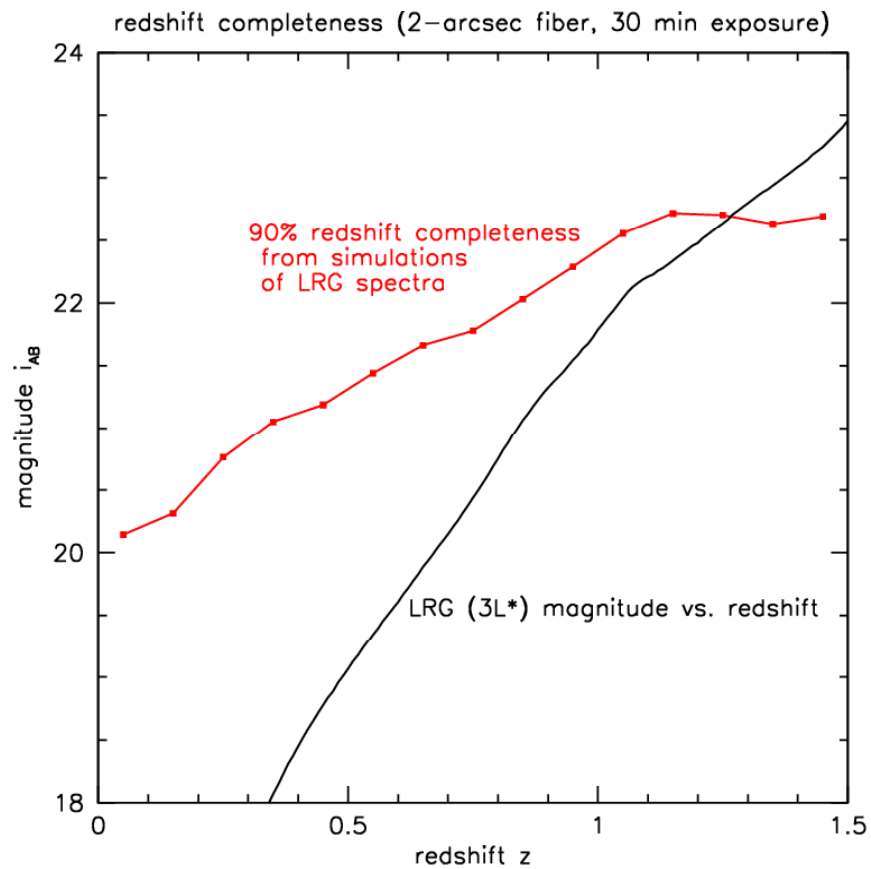
DARK ENERGY SURVEY

Selection: color-color cut
Z(DES)-H(Vista) vs r-z(DES)

z<22 mag



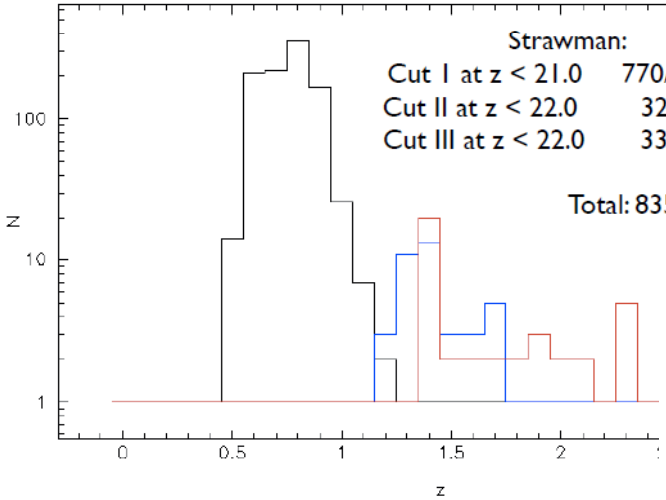
z<0.5 (blue)
0.5<z<1.1 (green)
z>1.1 (gold)



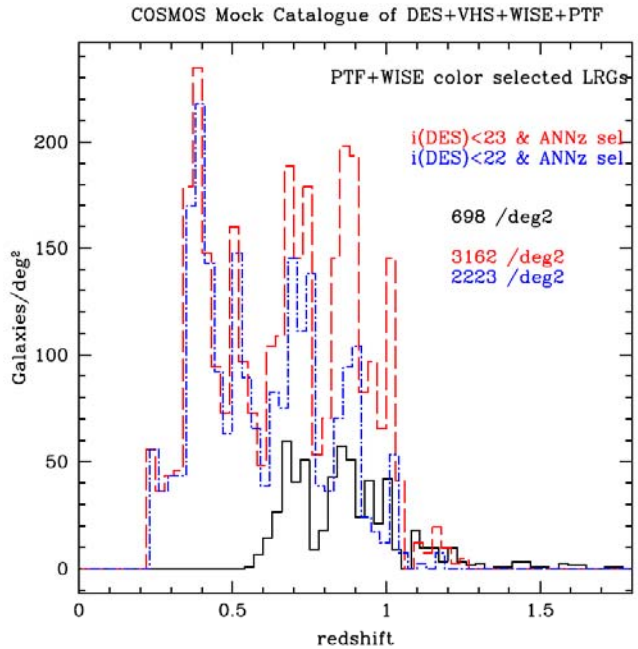
Strawman LRG target selection vs WISE/PTF vs full ANN selection.

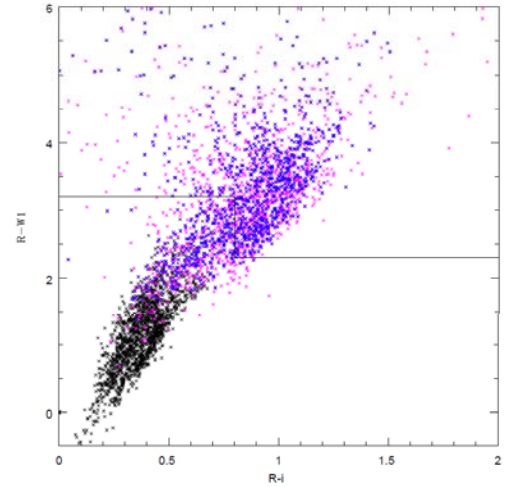
DARK ENERGY SURVEY

Cut I 0.5 < z < 1.2
Cut II 1.2 < z < 1.7
Cut III 1.4 < z < 2.5



Cut I z = 0.81
Cut II z < 1.50
Cut III z < 1.78



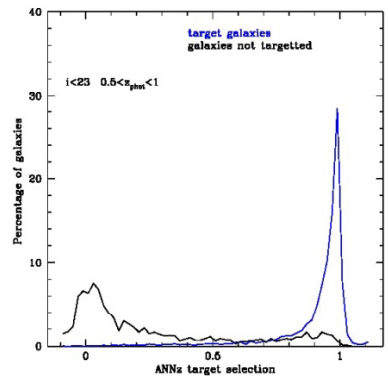


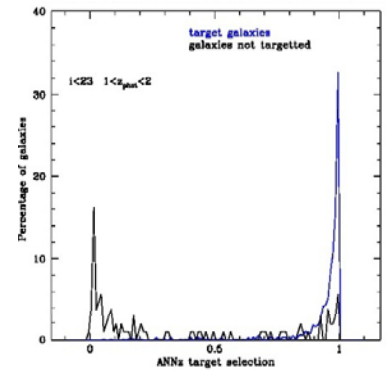
Above: see colors (red, blue, black) in figure just to left

Emission Line Galaxy Target selection using ANNz + DES Photo-z

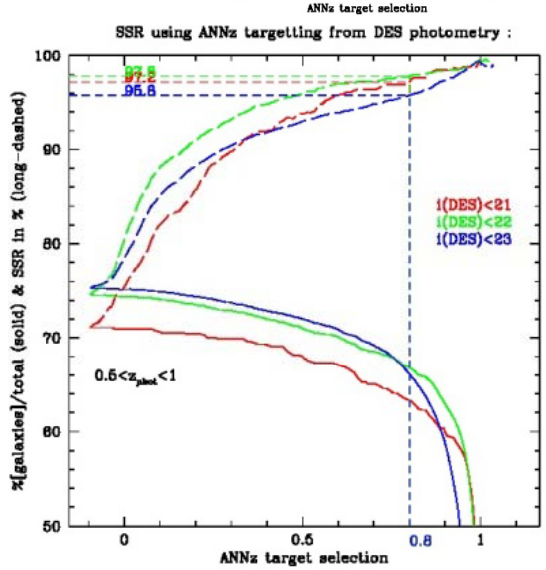
DARK ENERGY SURVEY

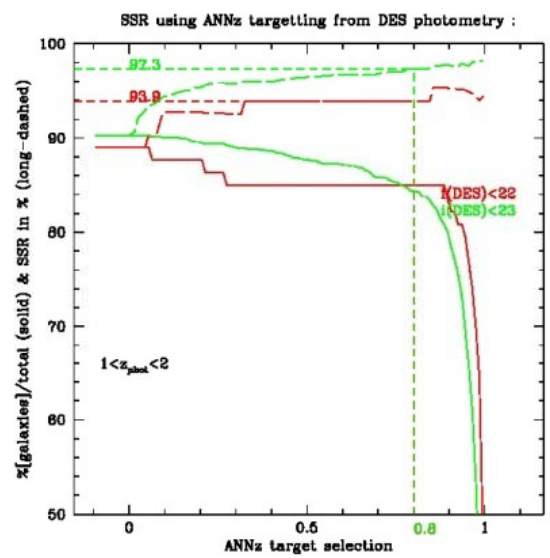
- Neural net output
  (Left 0.5<z<1.0)
  (Right 1.0<z<2.0)





- % of Total [solid] and success rate [dashed]
  (Left 0.5<z<1.0)
  (Right 1.0<z<2.0)

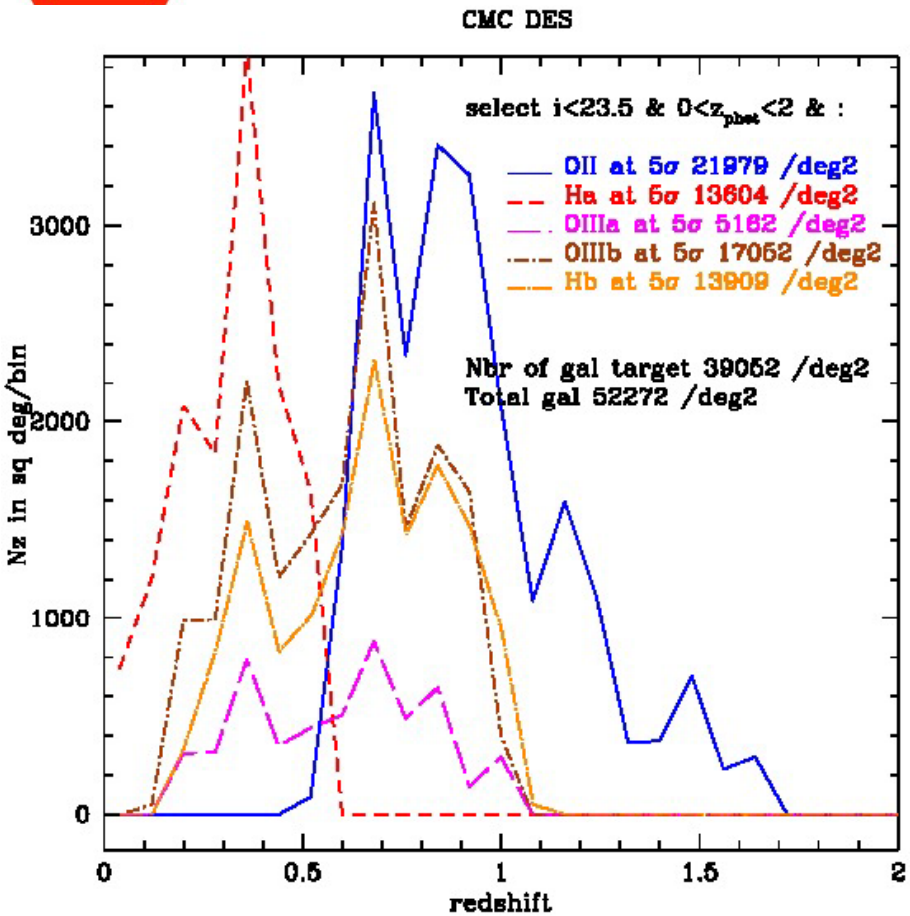




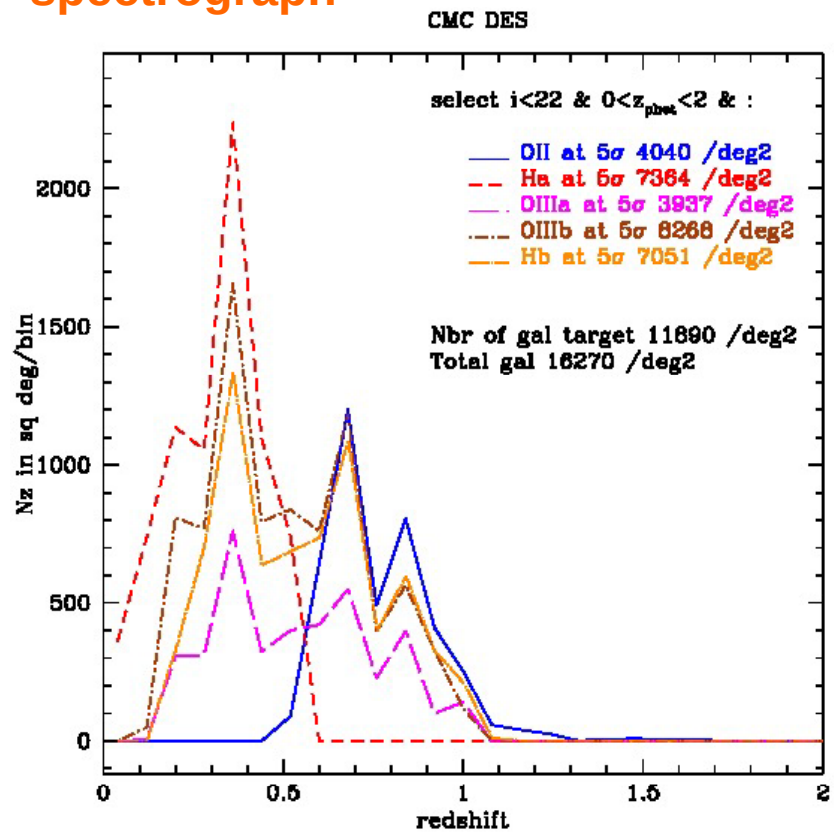
THE ROYAL SOCIETY
CELEBRATING 350 YEARS

UCL

Emission Line Galaxies
Redshift distribution

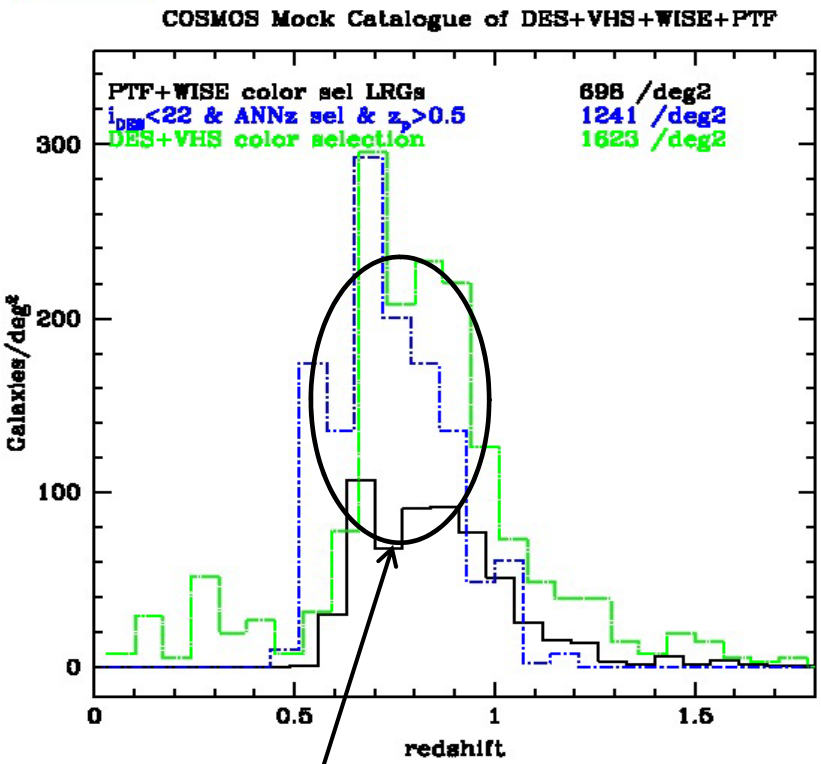


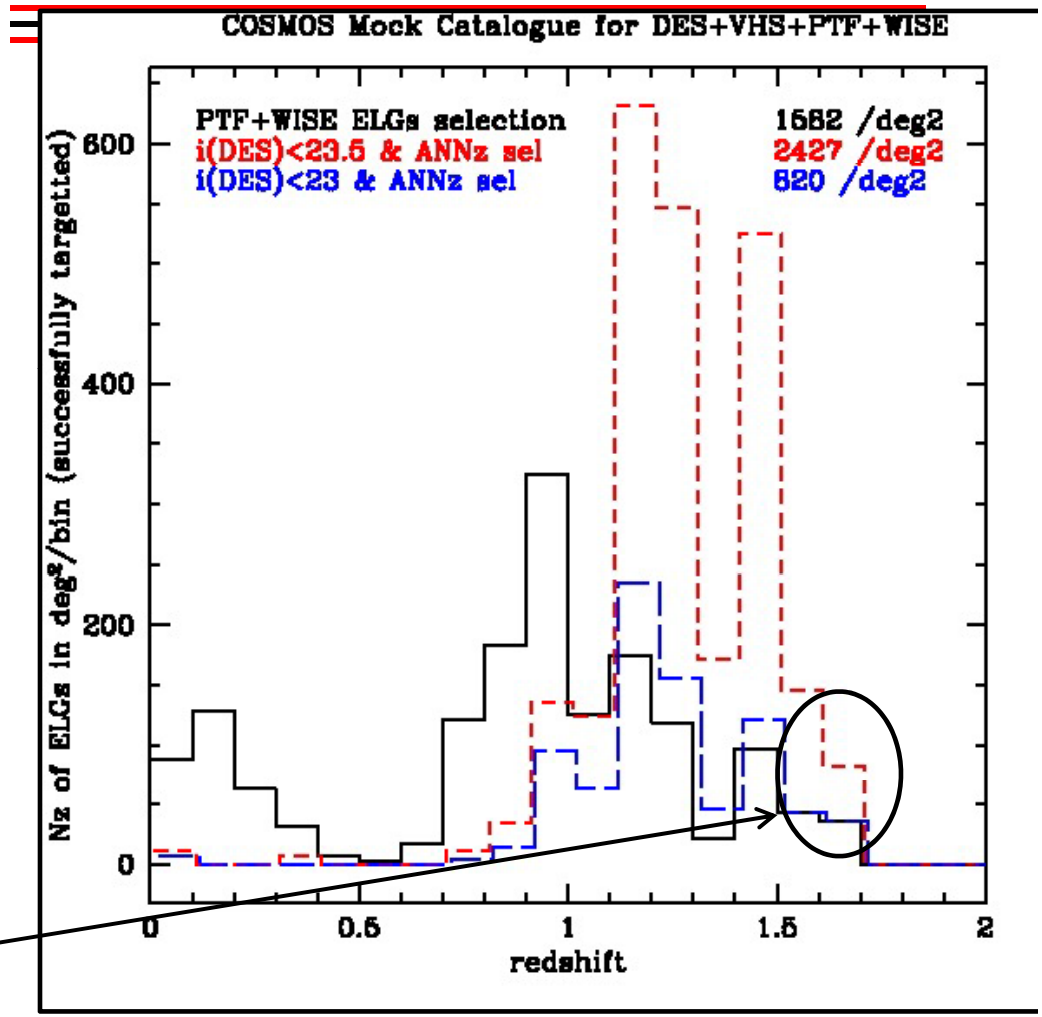
Redshift will be measured with OII mainly for a 0.6 to 1um spectrograph



Exploring 2 different selections

Cut to the Chase: final target selection





High number density for bias cross-corr at z~0.7
Number density to be shot noise limited is around 80 per sq deg in a 0.1 z bin

The point is: it's hard to beat DES (+VHS) imaging as input to the spectroscopic target selection

hardware

Best target selection

Science –> Survey –> Hardware

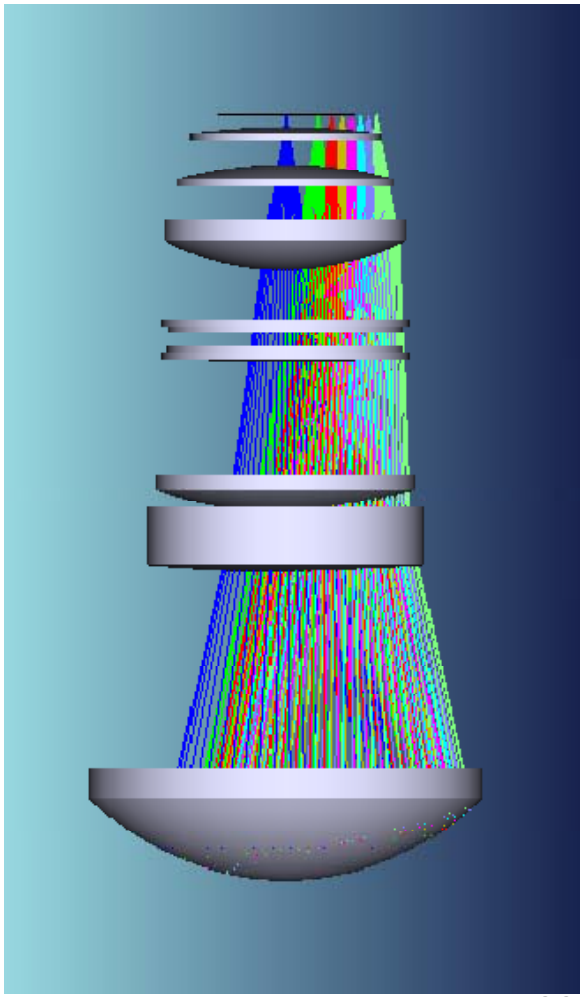
And not the other way around

DESpec Optics

Version SK-V3C
by Steve Kent

DARK ENERGY SURVEY

- Reuse the DECam optics C1-C4 (focal ratio f/2.9)
- The DECam Dewar needs its window (C5) as the cover. SK designed C5' and C6 made from fused silica. C5' has an aspheric on the concave side.
  - Good spot size, focal surface has a slight curvature, worst chief ray (edge) comes in at 0.45 deg angle of incidence.
- Discussions about ADC or not
- Steve & David Brooks (UCL) are developing the design. Possibly one that could accommodate an ADC later on.



FP FoV has Radius = 225.54 mm

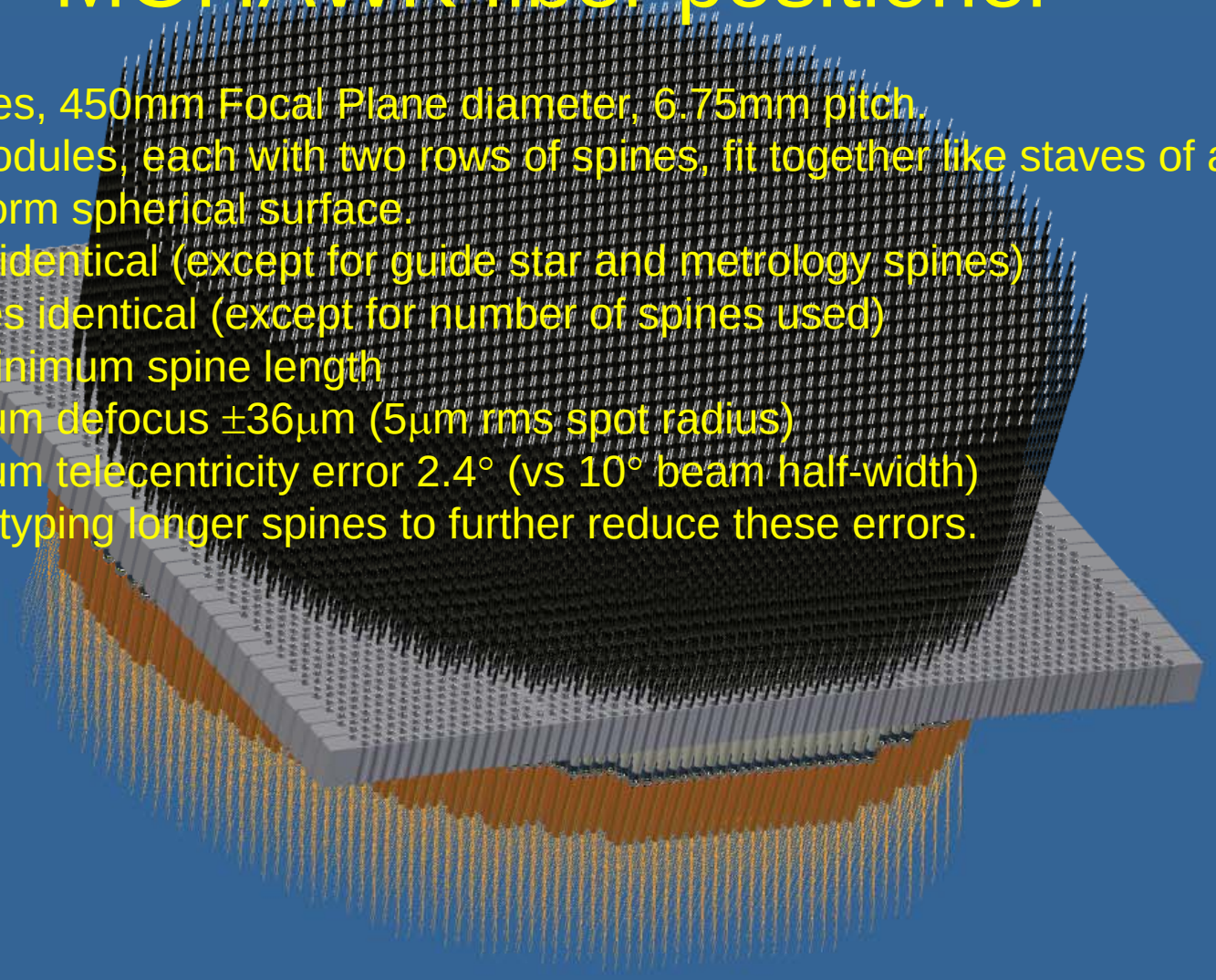
Optical Fiber Positioners

DARK ENERGY SURVEY

- Precisely hold the tip of optical fibers on the desired RA & DEC of the galaxy
  - Premium on small (7 mm) spacing between actuators (pitch)
  - ± 0.14” (± 1/2 pixel on DECam) position accuracy corresponds to ±7.5 um.
  - 60” target separation is ~3.2 mm spacing between fiber tips
  - Fast reconfiguration time: 90 seconds or less
  - Maximum throughput, highly reliable …
- Tilting Spines and Twirling Posts
  - A kind of Twirling Posts (Cobra) design is being planned for Sumire. We are in reasonably close contact with Mike Seiffert.
  - A Tilting Spines design is battle-tested on FMOS. We are working with AAO.

MOHAWK fiber positioner

- 4000 spines, 450mm Focal Plane diameter, 6.75mm pitch.
- Curved modules, each with two rows of spines, fit together like staves of a barrel to form spherical surface.
- All spines identical (except for guide star and metrology spines)
- All modules identical (except for number of spines used)
- 160mm minimum spine length
  $\Rightarrow$ maximum defocus $\pm 36\mu m$ (5μm rms spot radius)
  $\Rightarrow$ maximum telecentricity error 2.4° (vs 10° beam half-width)
- Now prototyping longer spines to further reduce these errors.

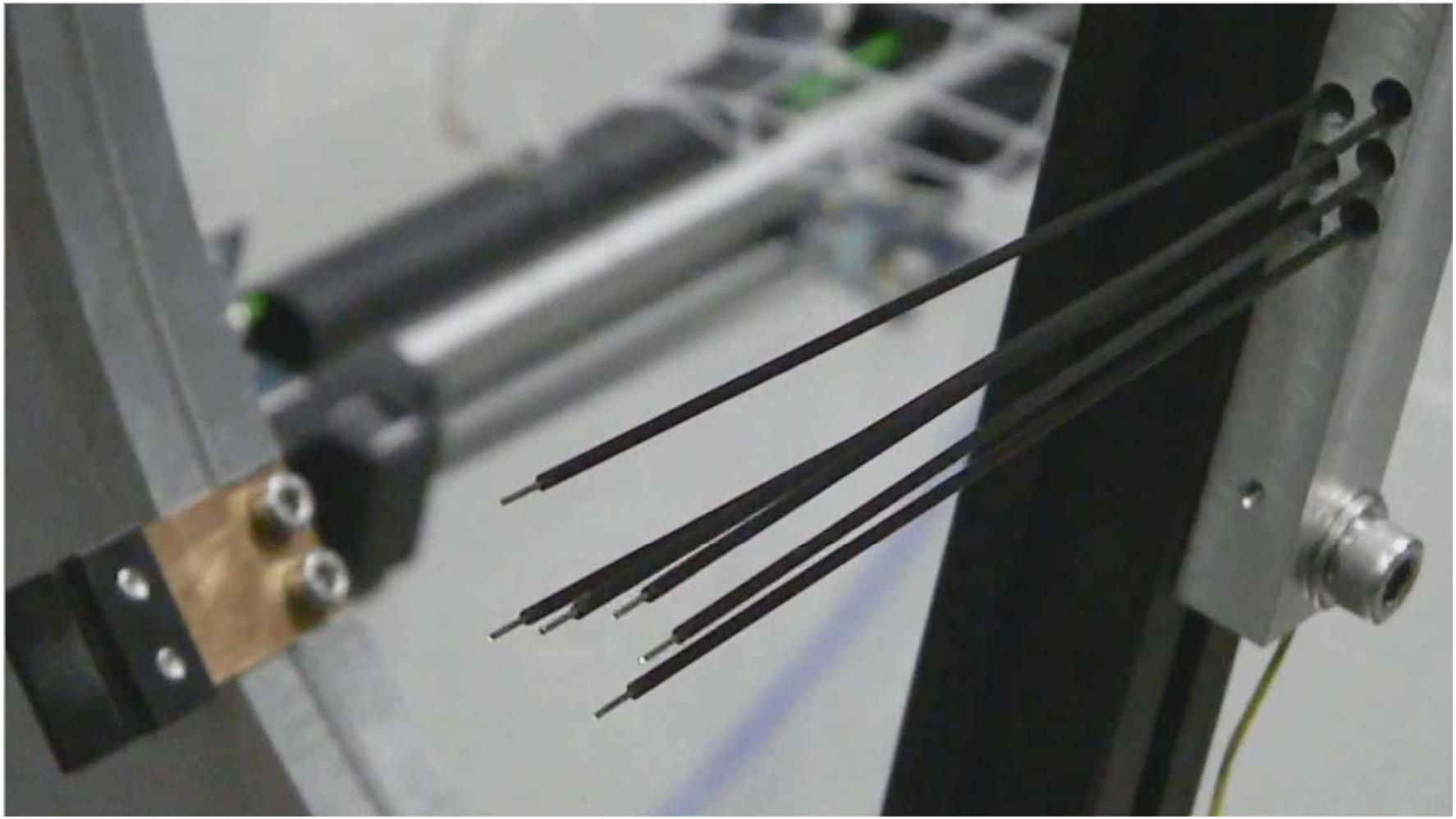


Will Saunders, AAO

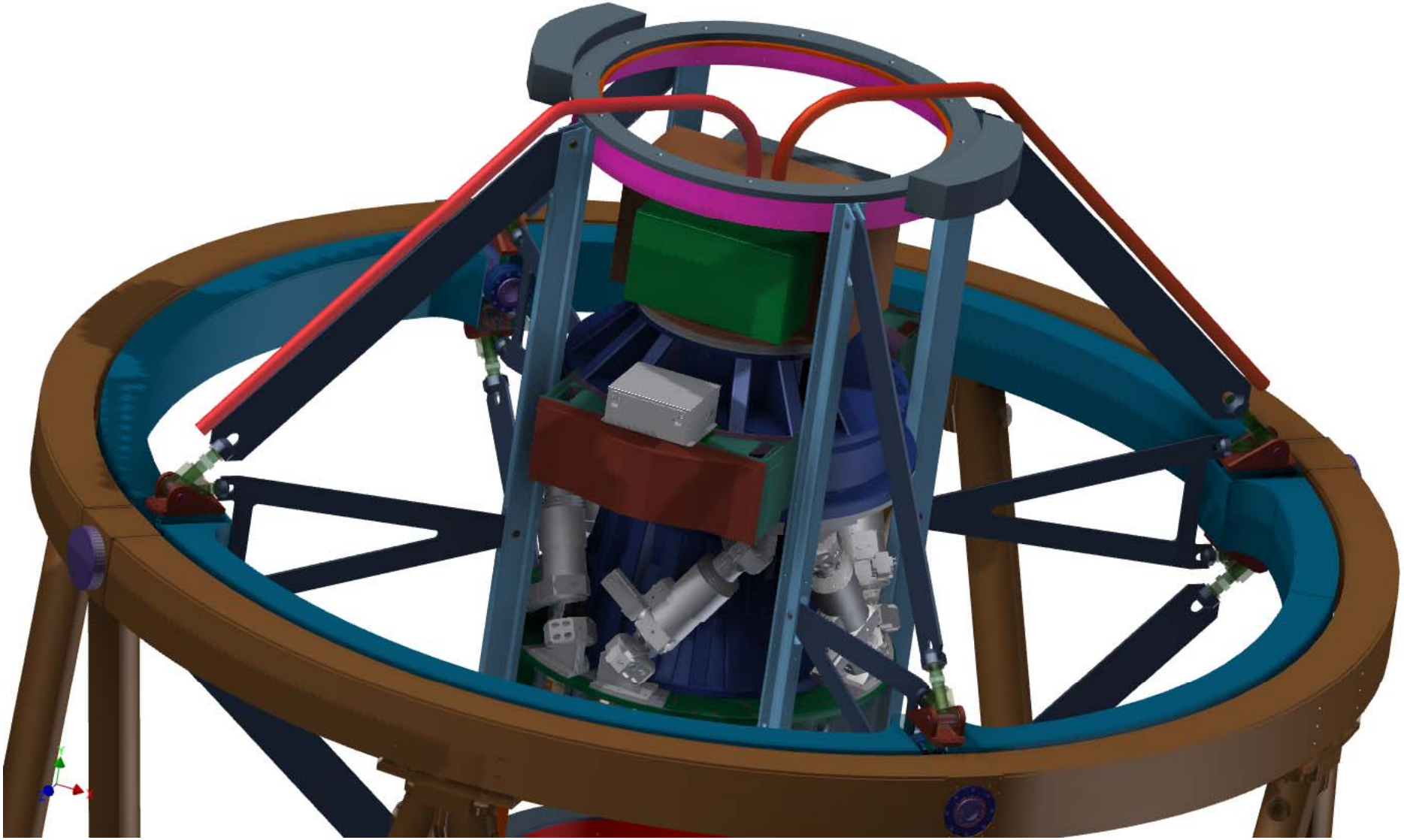
Development of Mohawk Spines

DARK ENERGY SURVEY

From AAO May 31, 2012

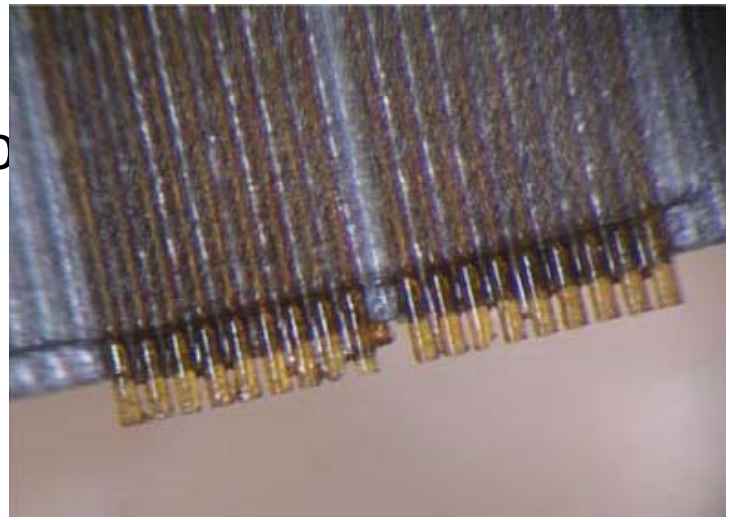


MOHAWK on the Blanco



Fiber R&D Opportunities

DARK ENERGY SURVEY



- F/3 is ideal for injection into fibers
- Check fiber width w/ more simulatio
- Fibers run to where?
  - Coude Room (75m?)
  - Under and behind the telescope (60m)
  - Ring Girder or Horseshoe (20 or 30 m)
  - Truss (<10m) – probably cannot
- Throughput vs length. J-P's data from Polymicro for a 100m fiber (100 microns?):
  - <70% throughput at 500nm
  - ~83% throughput at 600nm
  - ~96% throughput at 850nm (peak)

Some fiber chemistries are better in the blue (red) than others.

- Connections at FP or anywhere else cost 2-5% light?
- Backlight mechanism for fiber positioner tips (UCL)!

Spectrographs (new default for white paper is due)

DARK ENERGY SURVEY

- There's trade offs and limitations between the following design parameters
  - wavelength range – want to take advantage of the red imaging
  - spectral resolution – need R >3000 at λ = 950 nm
  - # pixels on CCD – we can get the as big as 2kx4k
  - Fiber size – S/N vs throughput
  - f/# of the spectrograph optics – hard to make them f/1.3, easier to make them f/1.6
  - Cost

Default Option: 2 arm (above), Descope: 1 arm (below)

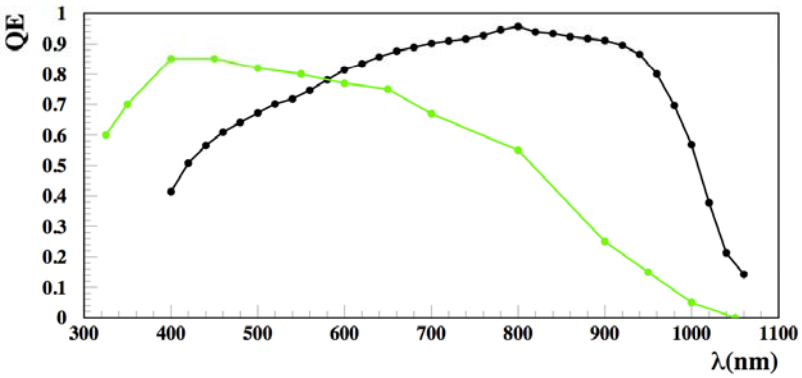
Parameter	Blue Side	Red Side
Fiber Diameter	100 μm	
Wavelength Range	450<λ<760	760<λ<1050
CCD	E2V or DECam 2kx4k	DECam 2kx4k
Resolution(Δλ nm/pixel) (use 4000 pixels)	0.0775	0.0725
# pixels/fiber	4	4
Camera f/#	f/1.7	f/1.7
Spectral Resolution	2016 @ 625 nm	3276 @ 950 nm 3621 @ 1050 nm
Camera Type	Reflective or refractive	

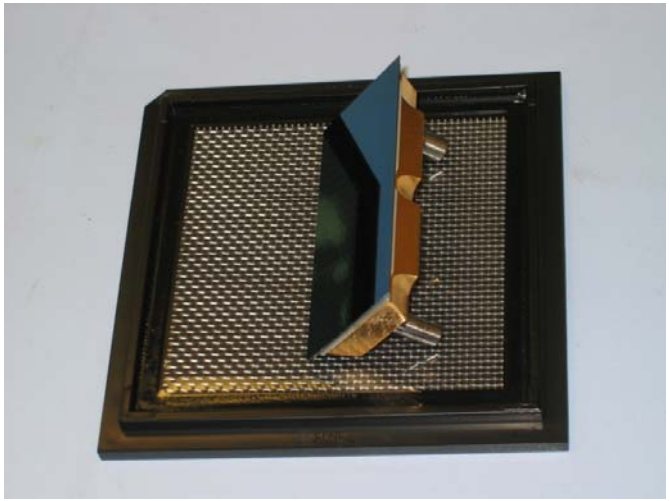
Parameter	Single-Arm Spectrograph (B)
Fiber Diameter	80 μm
Wavelength Range	600<λ<1000
CCD	DECam 2kx4k
Resolution(Δλ nm/pixel) (use 4000 pixels)	0.1
# pixels/fiber	3
Camera f/#	f/1.6
Spectral Resolution	3334 @ 1000 nm
Camera Type	VIRUS

CCDs and Readout

DARK ENERGY SURVEY

- 20+ good leftover DECam CCDs
- DESpec CCD readout can use DECam readout, probably repackaged
- For a 2-arm spectrograph with a blue-sensitive side, we need to adapt the controller
  - Straightforward, but we don't yet know the CCD.
- Probably want < ~3 e^-/pixel RMS RO Noise
  - DECam is getting 7 e^- RMS in 250 khz (17s) readout.
  - Readout speed could be slower than DECam to get to the improvement.
  - Low (<0.5 e^-) noise is nice but not necessary, we'll take it if we can get it.





Interchangeable w/ DECam

DARK ENERGY SURVEY

- To install DESPec 1st stow DECam off-telescope
  - We are providing hardware to install/remove DECam as part of that project (see right)
- Then pick up DESpec, and using similar hardware, install it on the end of the barrel.
- In reverse, either store DESpec on the telescope or produce a convenient way to connect/disconnect the fibers.

- If need an ADC, then can remove filter changer and shutter
- Probably a few work days for swap, and can use f/8 in between

Path Forward

DARK ENERGY SURVEY

- DESpec a natural "upgrade" to the science capability of DES. Project could structurally follow the path blazed by DES: international collaboration with DOE+NSF support in the US, building on the successful DES collaboration with opportunities for new partners. The Collaboration Building is underway!
- Release the White Paper "shortly" (few weeks timescale).
- Next few months: keep moving forward on all fronts. Aim for external review in the Fall.
- R&D funding so far: from STFC, KICP, AAO is doing theirs, and more in the works
- Rocky III: DOE forming a group to write another Dark Energy White Paper to explore intermediate timescale projects.

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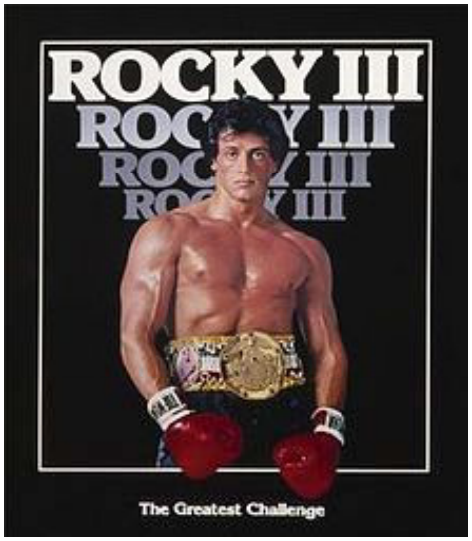
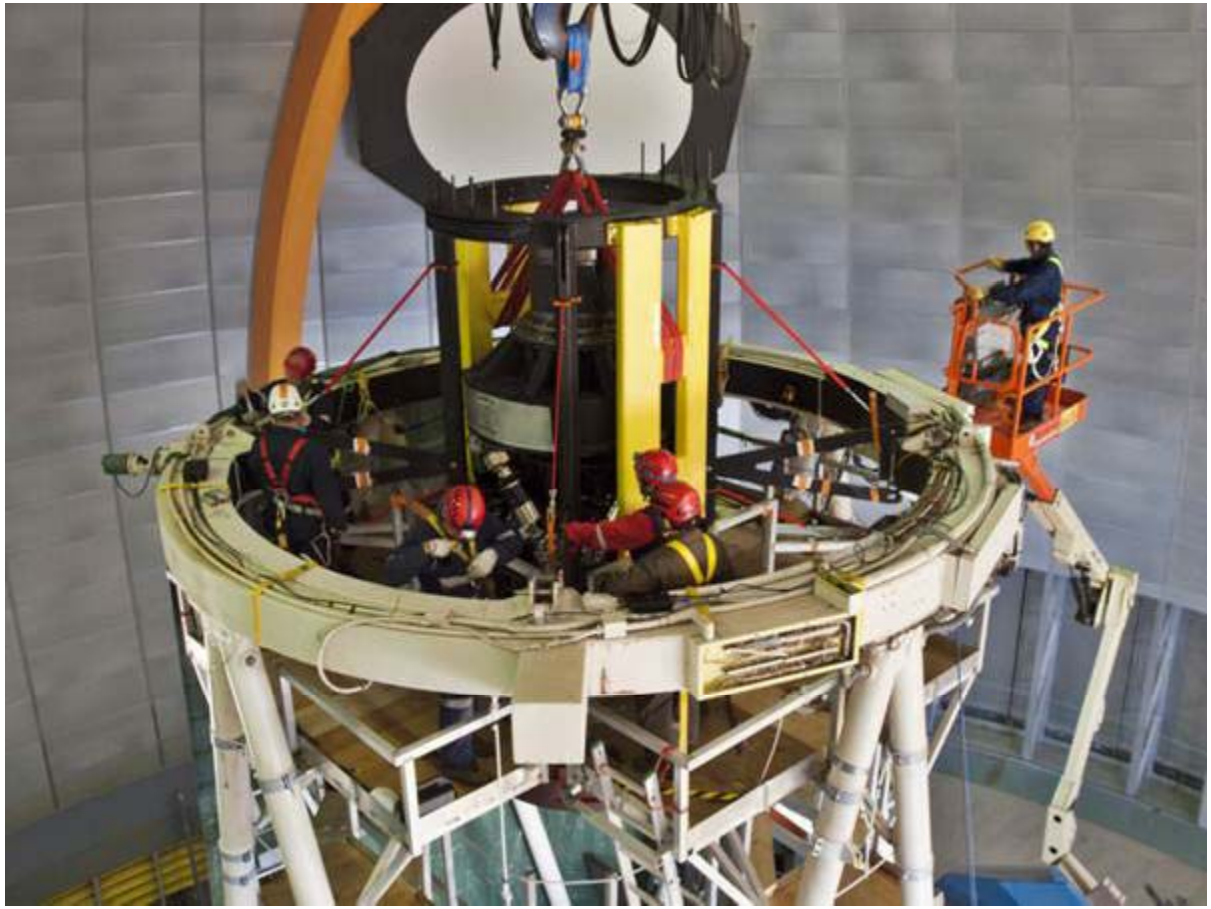


Finally: DESpec Schedule

- DESpec is ~80% complete (by weight)
- Right: New DESpec Cage and optical corrector being installed on the Blanco
- Of WF surveys being considered we're doing very well. Longest leadtimes ~ 2 yrs.



Least cost hardware

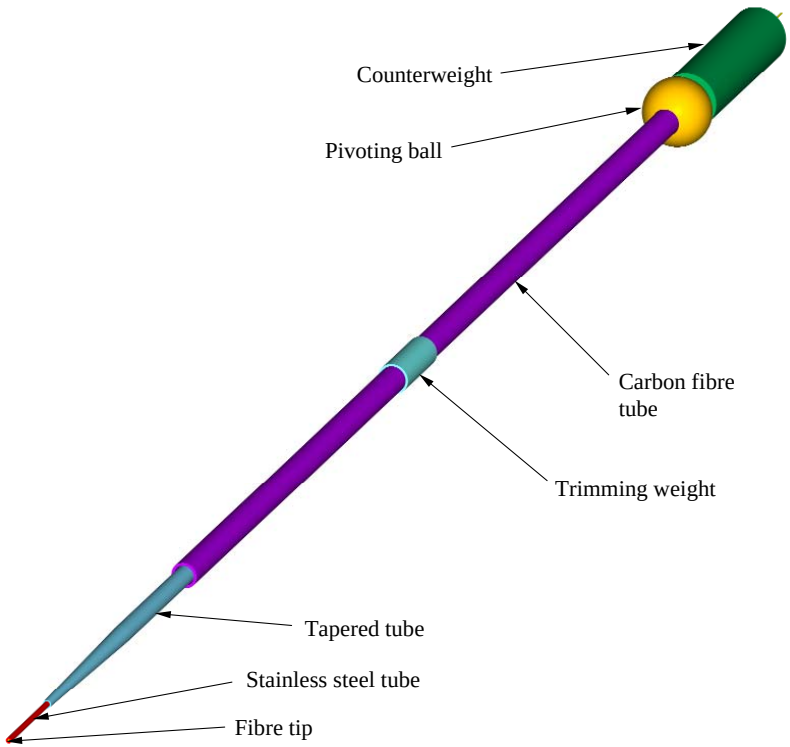
DARK ENERGY SURVEY

Acknowledgements

- Darren DePoy, Jennifer Marshall, J.-P Rheault,
- Steve Kent, Brenna Flaugher, Rich Kron, Anderson West, Josh Frieman, Huan Lin
- Ofer Lahav, Filipe Abdulla, Stephanie Joubert
- Matthew Colless, Guy Monnet, Will Saunders, Jon Lawrence
- Michael Seiffert, Richard Ellis
- David Schlegel
- Gary Poczulp

Tilting Spine

- 7 mm pitch is available
- Adjustable length about 16 cm
- Patrol radius ~ 7 mm
- Positioning accuracy < 10 microns is already achieved
- Improved configuration time is about 60 seconds.
- Issue of “tilt defocus” drives the design to long spines.
- “Mohawk” spine derived from AAO’s WFMOS idea is mechanically simpler than the Echidna spine (<$)

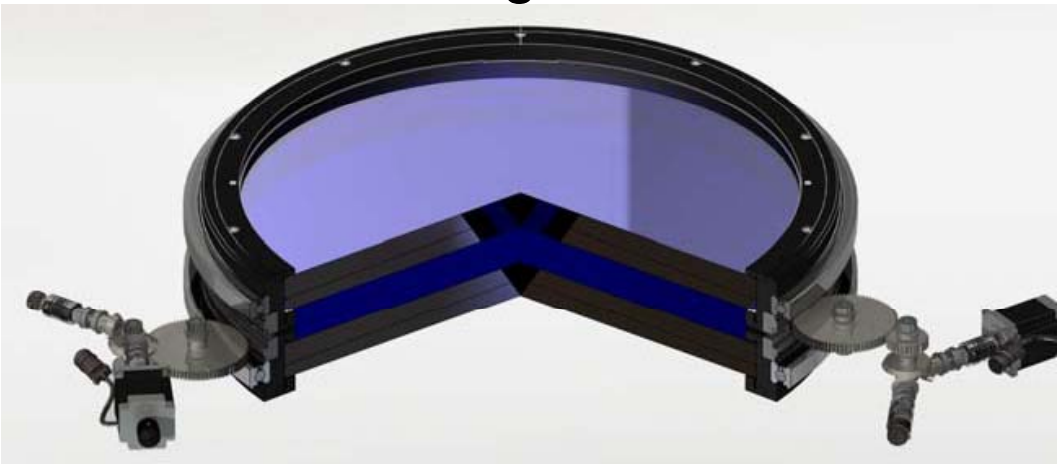


Echidna spine picture from Graham Murray (Durham)

Atmospheric Dispersion Compensator Example from WYIN

DARK ENERGY SURVEY

- When not at zenith the sky acts as a prism.
- The ODI ADC has diameter 635 mm. The prisms are rotated using a pair of encoded stepper motors.
- Two prisms each made from two wedge-shaped pieces of different glass materials.
- Issues include optical alignment and position (movement) tolerance and backlash, introduction of ghosts
- ODI ADC is very close to size required for DESpec



ADC or Not ADC

DARK ENERGY SURVEY

- In the white paper we plan to provide an ADC.
- The technical justification for the D.E. science needs to be worked-out so that the question (ADC or not) isn't a matter of guesswork. Quantify:

Reasons For (Default)

- Better Spot Size especially at 50+ deg from zenith
  - Better signal-to-noise
  - Faster measurements
  - Fainter objects
- Provides a more useful Instrument to astronomical users. That could be required in an AO.

Reasons Against

- Cost $800k to $1000k
- Increases time to change instrument by 2-4 hours?

Instrument Simulation I

- Model the effect on survey completeness and spectral success
- Targeting Efficiency (can we put a fiber on the galaxy?)
  - Fiber pitch
  - Patrol radius
  - Minimum fiber-tip spacing
  - # fibers needed for sky background over the FOV
- Throughput
  - Spot size vs wavelength with and w/o ADC
  - Diameter and type of optical fiber
  - Length of optical fiber and # connections
  - Effect due to the small non-telecentricity vs radius
  - Tilt-defocus (or not) from a fiber-positioner
  - Spectrographs vs wavelength

Instrument Simulation II

- A good instrument simulation will allow us to optimize the targeting strategy
  - Costs 60 seconds to retarget
  - CCD Readout and telescope pointing time is less than that
- Results in MORE galaxy spectra

- A good instrument simulation will allow us to simulate more science

Cost

- In July 2010 we made a top-down cost estimate based on our experience with DECam including separate estimates for
  - Management, CCDs, CCD Readout Electronics, “SISPI”, optics with ADC, Fiber Positioner with Fibers, Spectrographs, Mechanical Integration, Survey Planning & Simulation
  - MIE Cost = $39M, counting the in-kind contributions of equipment, and including 50% contingency
- We’ve refined this since, still including the cost of in-kind contributions. It’s still generally top-down
  - 2-ARM design: $28M with ADC without contingency
  - 1-ARM design: $22M with ADC without contingency
- Next step is to reevaluate bottoms-up and redo using actual vendor quotes.