DESpec:

the Dark Energy Spectrograph

- Spectroscopic follow-up to DES, mission scope & design.
- Powerful range of science drivers. WGL + LSS.
- Systematics control, synergy with DES science.

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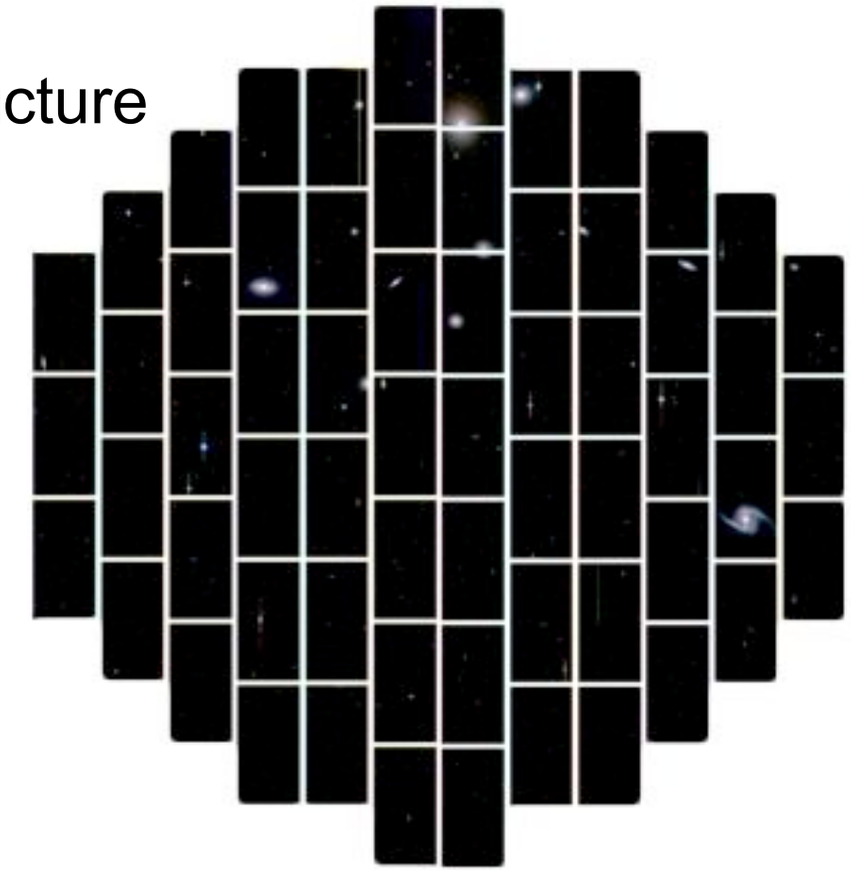
DARK ENERGY SURVEY

DES

Multi-probe approach

- Cluster Counts
- Weak Lensing
- Large Scale Structure
- Supernovae Ia



8-band survey

5000 deg^2 *grizY*

300 million photometric redshifts

+ *JHK* from VHS (1700deg^2 covered at half exposure time)

+SPT SZ (550 clusters observed over 2500 sq deg)

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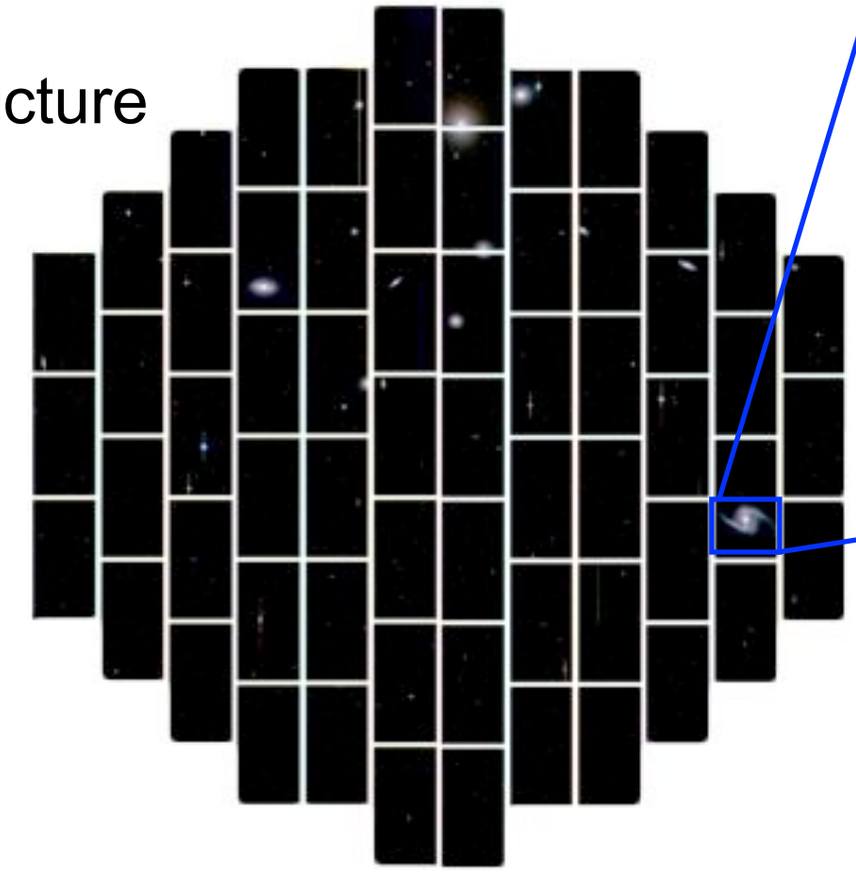
DARK ENERGY SURVEY

DES

Multi-probe approach

- Cluster Counts
- Weak Lensing
- Large Scale Structure
- Supernovae Ia

First light
12th September
2012!



NGC 1365
in Fornax

8-band survey

5000 deg^2 *grizY*
300 million photometric redshifts
+ *JHK* from VHS (1700deg^2 covered at half exposure time)
+SPT SZ (550 clusters observed over 2500 sq deg)

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DARK ENERGY SURVEY

DESpec

• 4000 fibre spectrograph taking 10 million galaxy spectra on the DES footprint over ~350 nights, starting 2017-18.

• Blanco 4m telescope, CTIO, 3.8deg^2 FoV great seeing 0.65", many usable nights, 80% → fast & cheap survey

• DES provides target list, infrastructure & much more. Build on the DES legacy, Stage III -> Stage IV

• Spectral range 600-1000nm, R=3300 (red end)

• Hemisphere synergy with LSST, extend to ~15,000 deg2

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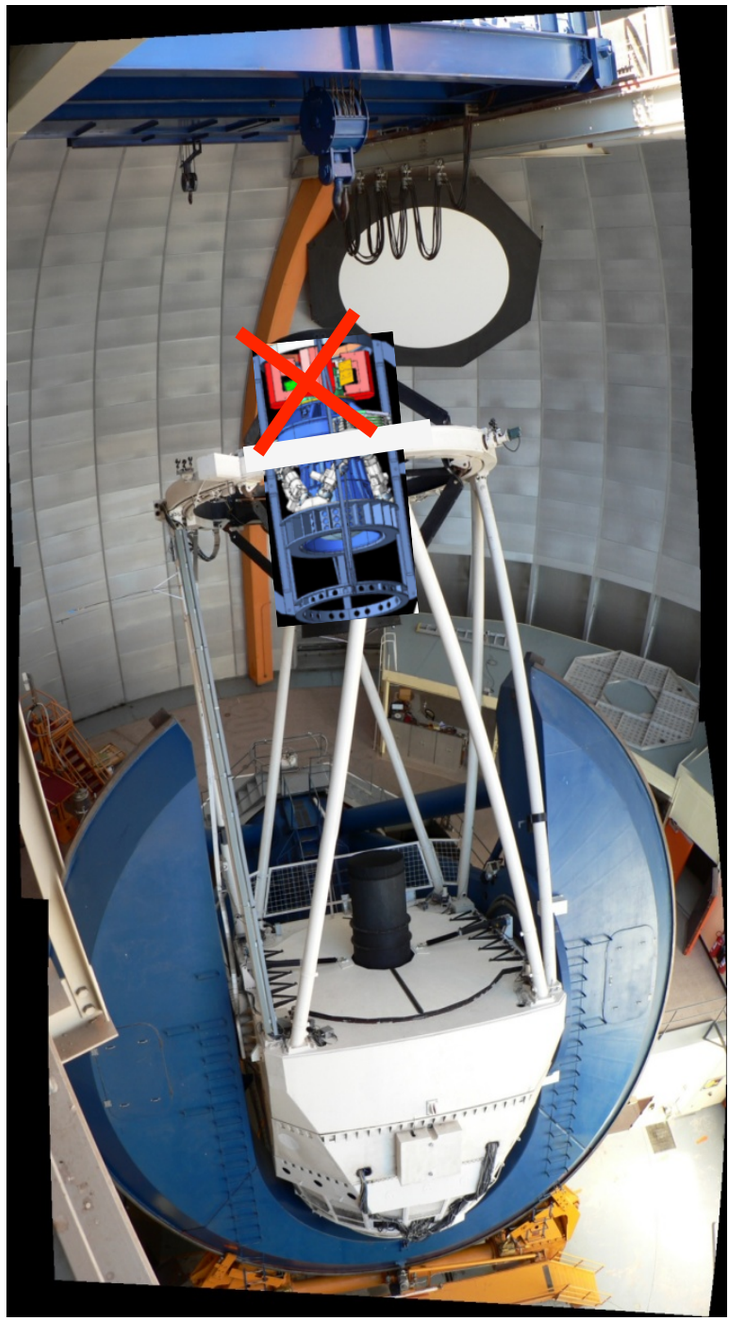
DESpec Practicalities

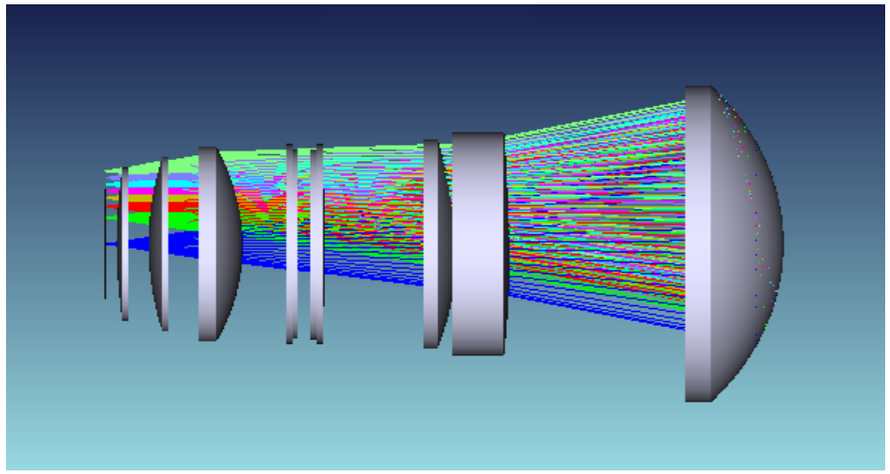


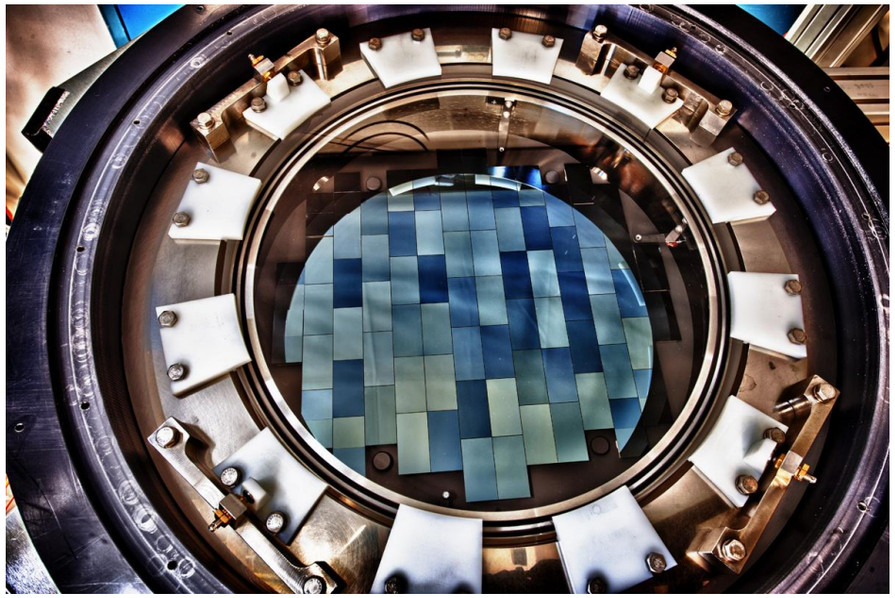
- DESpec intergchangeable with DECam on existing Blanco infrastructure.

- Re-uses most of the DES optics & exploits ready supply of space CCDs.

- R&D continuing on fibre positioner etc. Estimated$40M instrument.

- Low cost/low risk project.





DESpec White Paper

Astrophysics > Cosmology and Extragalactic Astrophysics

The Dark Energy Spectrometer (DESpec): A Multi-Fiber Spectroscopic Upgrade of the Dark Energy Camera and Survey for the Blanco Telescope

F. Abdalla (1), J. Annis (2), D. Bacon (3), S. Bridle (1), F. Castander (4), M. Colless (5), D. DePoy (6), H. T. Diehl (2), M. Eriksen (4), B. Flaugher (2), J. Frieman (2, 7), E. Gaztanaga (4), C. Hogan (2, 7), S. Jouvel (4), S. Kent (2, 7), D. Kirk (1), R. Kron (2, 7), S. Kuhlmann (8), O. Lahav (1), J. Lawrence (5), H. Lin (2), J. Marriner (2), J. Marshall (6), J. Mohr (9), R. C. Nichol (3), M. Sako (10), W. Saunders (5), M. Soares-Santos (2), D. Thomas (3), R. Wechsler (11), A. West (2), H. Wu (11) ((1) University College London, UK, (2) Fermilab, (3) Institute of Cosmology and Gravitation, Portsmouth, UK, (4) Institut de Ciències de l'Espai, Barcelona, Spain, (5) Australian Astronomical Observatory, (6) Texas A&M University, (7) University of Chicago, (8) Argonne National Laboratory, (9) Ludwig-Maximilians University, Germany, (10) University of Pennsylvania, (11) KIPAC, Stanford University)

(Submitted on 11 Sep 2012)

We describe an initiative to build and use the Dark Energy Spectrometer (DESpec), a wide-field spectroscopic survey instrument for the Blanco 4 meter telescope at Cerro Tololo InterAmerican Observatory (CTIO) in Chile. A new system with about 4000 robotically positioned optical fibers will be interchangeable with the CCD imager of the existing Dark Energy Camera (DECam), accessing a field of view of 3.8 square degrees in a single exposure. The proposed instrument will be operated by CTIO and available for use by the astronomy community. Our collaboration proposes to use DESpec to conduct a wide, deep spectroscopic survey to study Dark Energy. In a survey of about 350 nights, the DESpec collaboration proposes to obtain spectroscopic redshifts for about 8 million galaxies over 5000 square degrees selected from the Dark Energy Survey (DES). This Dark Energy Spectroscopic Survey will advance our knowledge of cosmic expansion and structure growth significantly beyond that obtainable with imaging-only surveys. Since it adds a spectroscopic third dimension to the same sky as DES, DESpec will enable increasingly precise techniques to discriminate among alternative explanations of cosmic acceleration, such as Dark Energy and Modified Gravity.

Comments: 57 pages, 28 figures
Subjects: **Cosmology and Extragalactic Astrophysics (astro-ph.CO)**; Instrumentation and Methods for Astrophysics (astro-ph.IM)
Report number: FERMILAB-TM-2547-AE

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DARK ENERGY SURVEY

Wide Range of Science Drivers

- Photo-z/spec: Better calibration (via cross-correlation).
- LSS: Redshift Space Distortions & Radial BAO- FoM x 3-6
- Clusters: better redshifts & velocity dispersions, improve mass-observable calibraion, FoM x several
- WL: Spectroscopy allows calibration of Intrinsic Alignments
- WL+LSS: Powerful combination for DE & particularly MG
- SN Ia: spectra of host galaxies, control systematics & photo-z training, FoMx2
- Galaxy Evolution: Galaxy Properties & star-formation history.
- Strong Lensing: Improved cluster mass models.

Powerful cross-talk with the DES photo-z survey

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DARK ENERGY SURVEY

WGL & LSS

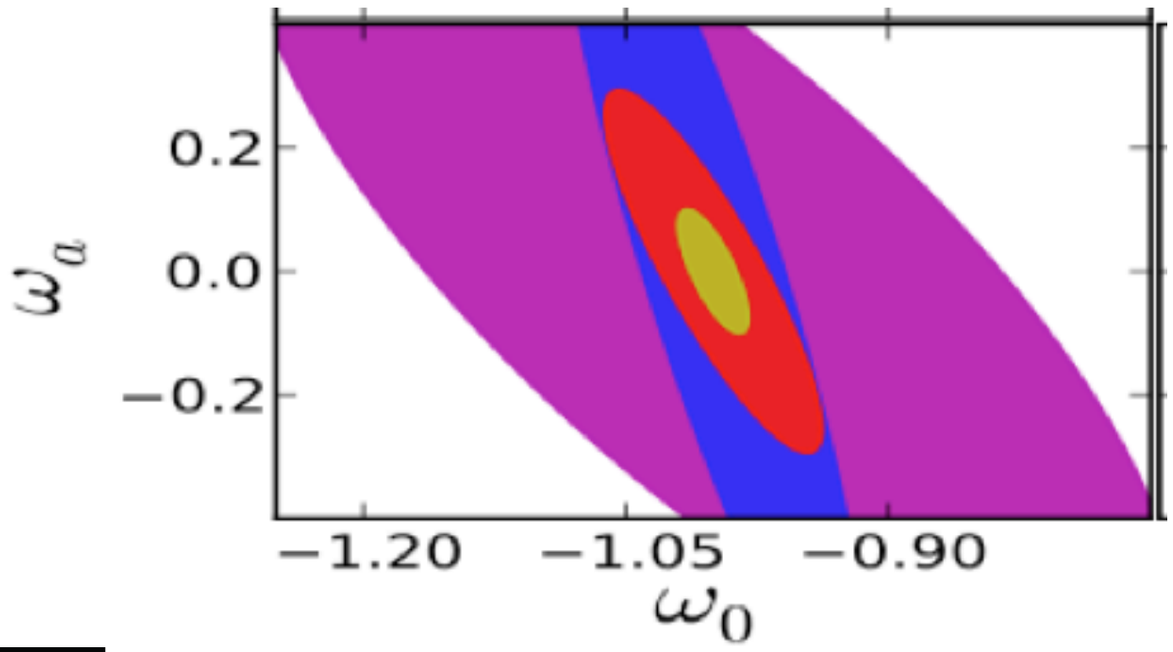
Cosmic Shear	Galaxy Density
Transverse modes only, $N_{modes} \propto l^2$	Line of sight modes accessible, $N_{modes} \propto l^3$ ✓
✓ Directly tied to potential fluctuations	Biased & Stocahstic w.r.t. matter
Redshift of fluctuations not directly observed	Fluctuation redshift known ✓
✓ Distance-ratio factors appear in observables	Distances require *a priori* spectrum model
No access to velocity field	"Contaminated" by velocity field ✓

Combination gives: lowered sample variance, known fluctuation redshift & direct tie to matter

WGL & LSS

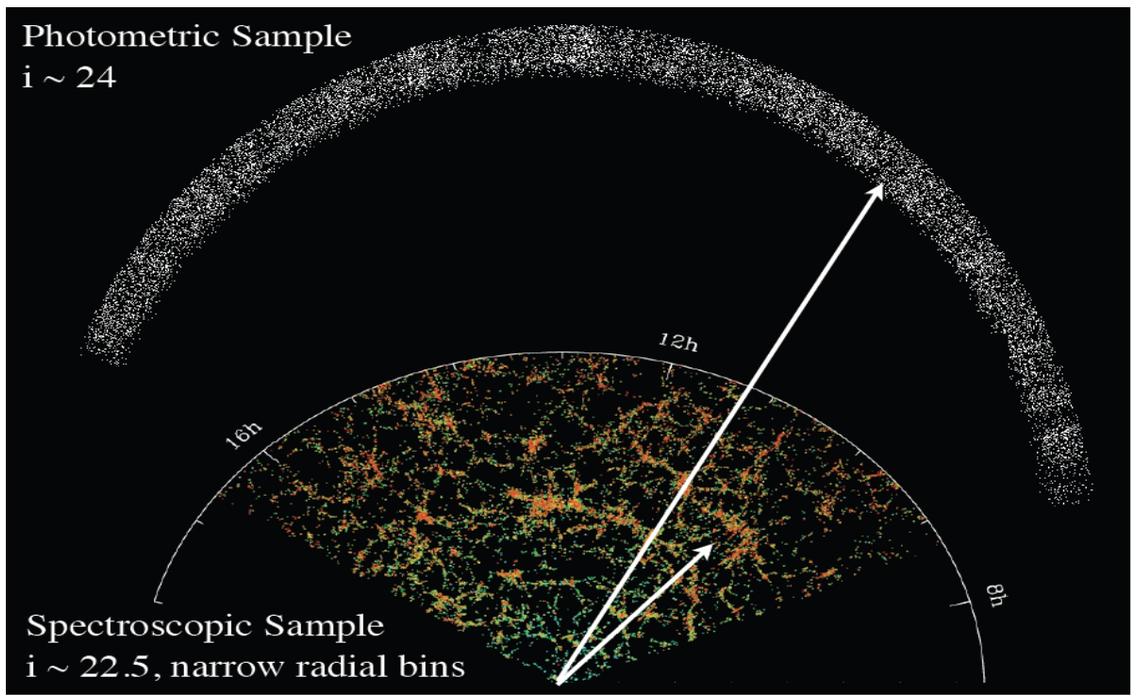
• Combining cosmic shear & RSD from galaxy clustering →DE FoMx5

• 2 Surveys on same sky allows cross-correlation: extra information, calibrate systematics, reduce cosmic variance- can be an order of magnitude improvement.



$\mathrm{FoM}_{w\gamma}$ $\times 10^3$ Gaztanaga et al. 2012

0.35	RSD	B5000spec i<22.5
3.2	Shear	F5000, i<24.0
14.9	RSD+Shear	F+B5000spec
159	RSD+WL	FxB5000spec



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DARK ENERGY SURVEY

Modified Gravity

$$ds^2 = -a(\tau)^2\,[1 + 2\psi(x,t)]\,d\tau^2 + a(\tau)^2\,[1 - 2\phi(x,t)]\,dx^2$$

$$k^2\Phi = -4\pi Q a^2 \rho\delta$$

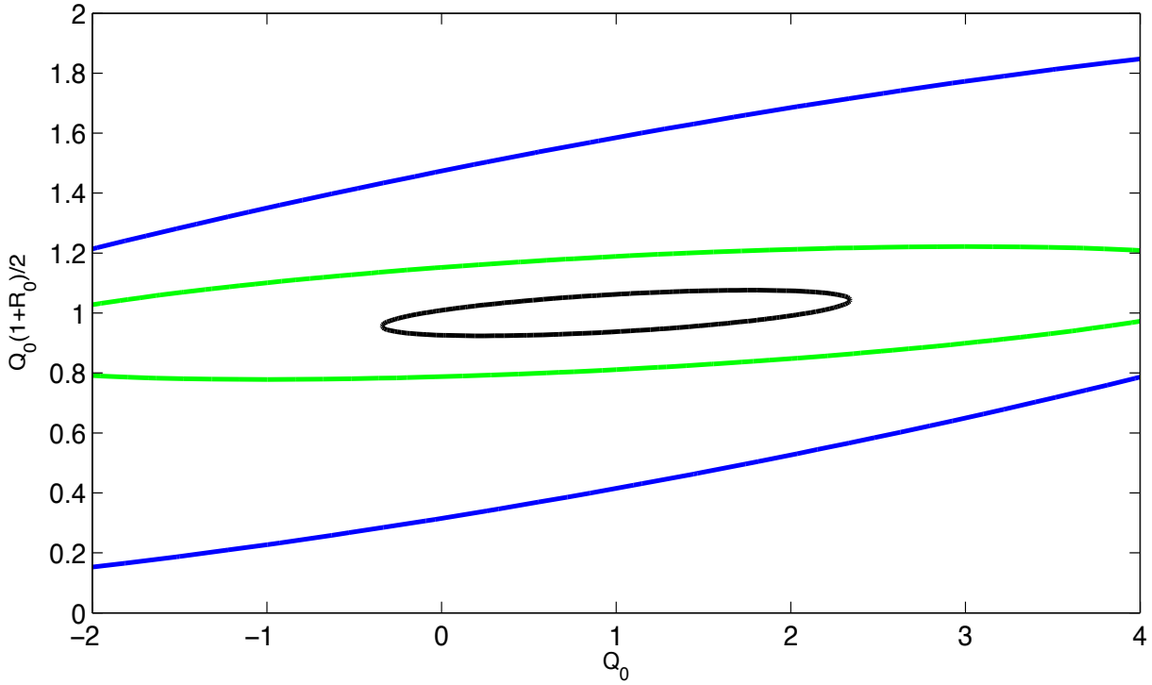
$$k^2\Psi = R\Phi$$

WGL (Φ+Ψ) & Galaxies (Ψ) respond differently to metric potentials.

Parameterise deviations from GR by a) modifying the Poisson equation, Q, and b) altering the potentials ratio, R.

Combination can break strong degeneracies when probing deviations from GR.

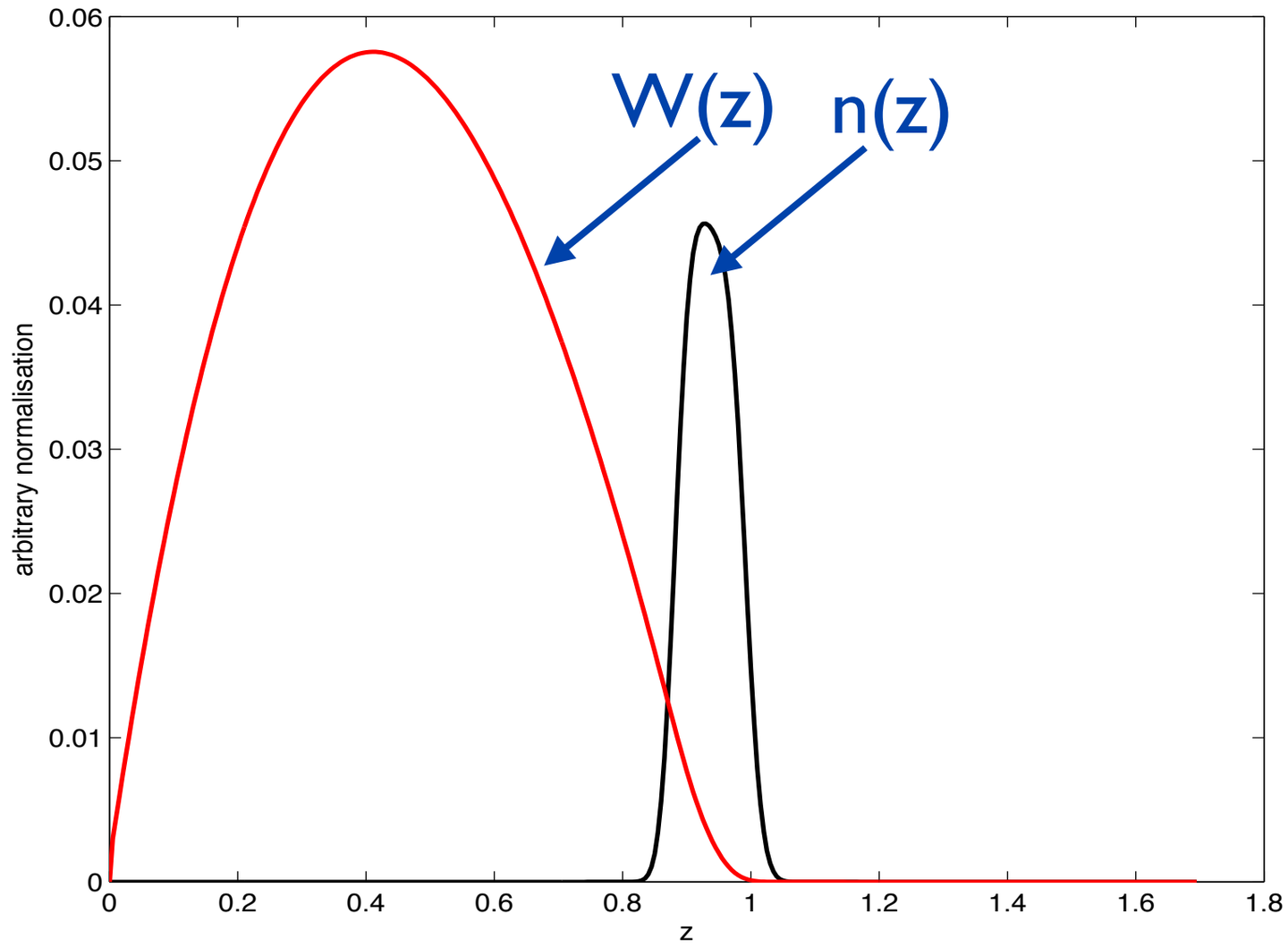
MG FoM x 7-10



Kirk et al. in prep.

Intrinsic Alignments in WGL

- WGL not usually considered to benefit from spectroscopic
- sub-sample due to broad lensing kernel.



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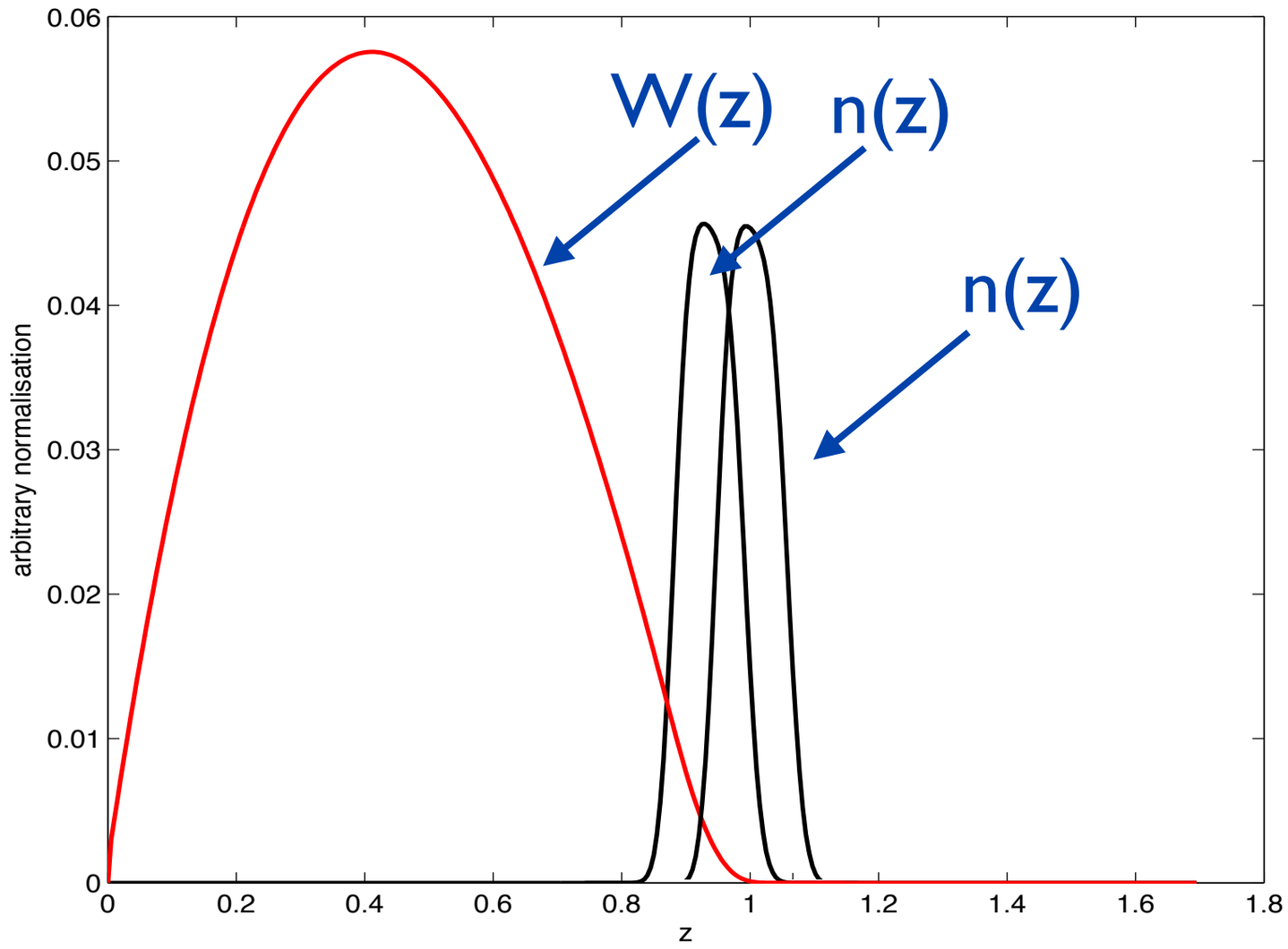
BUT

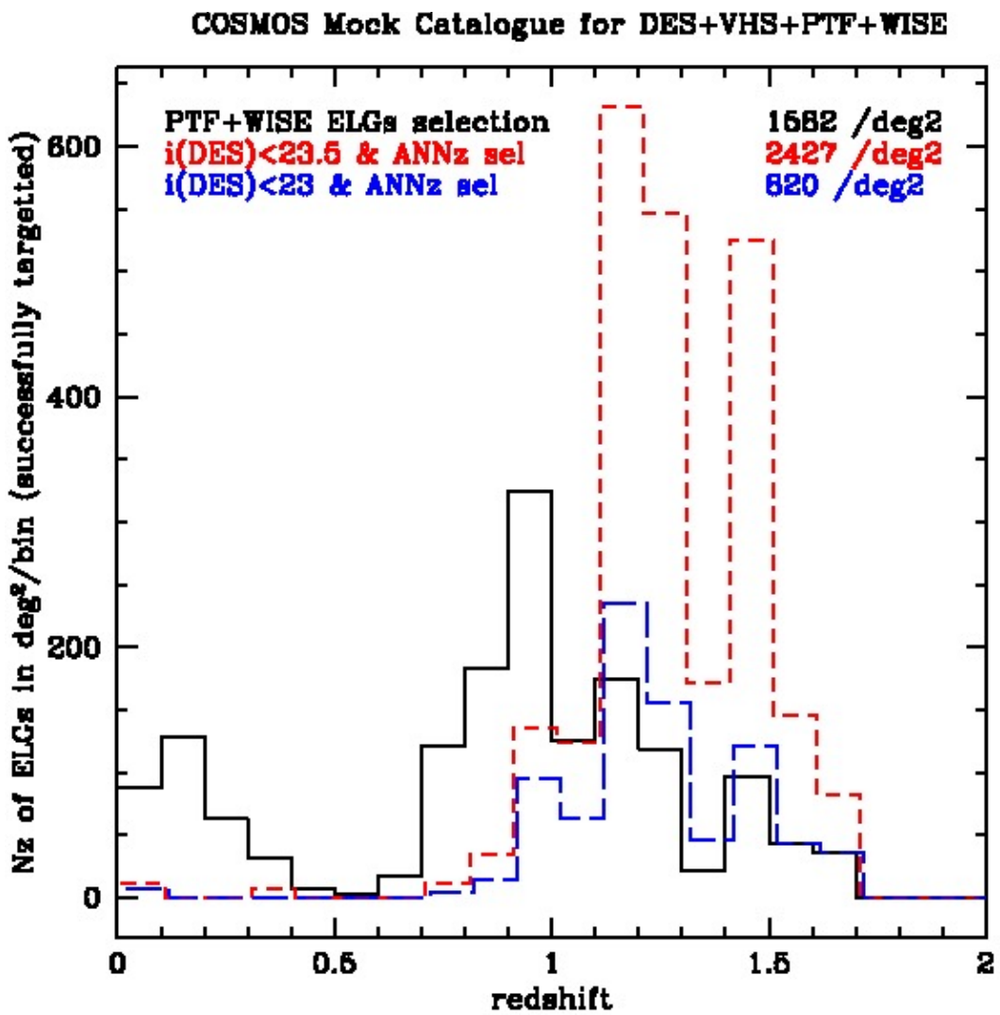


• Galaxy Intrinsic Alignments (IAs)- a key systematic
involve physically close galaxies.

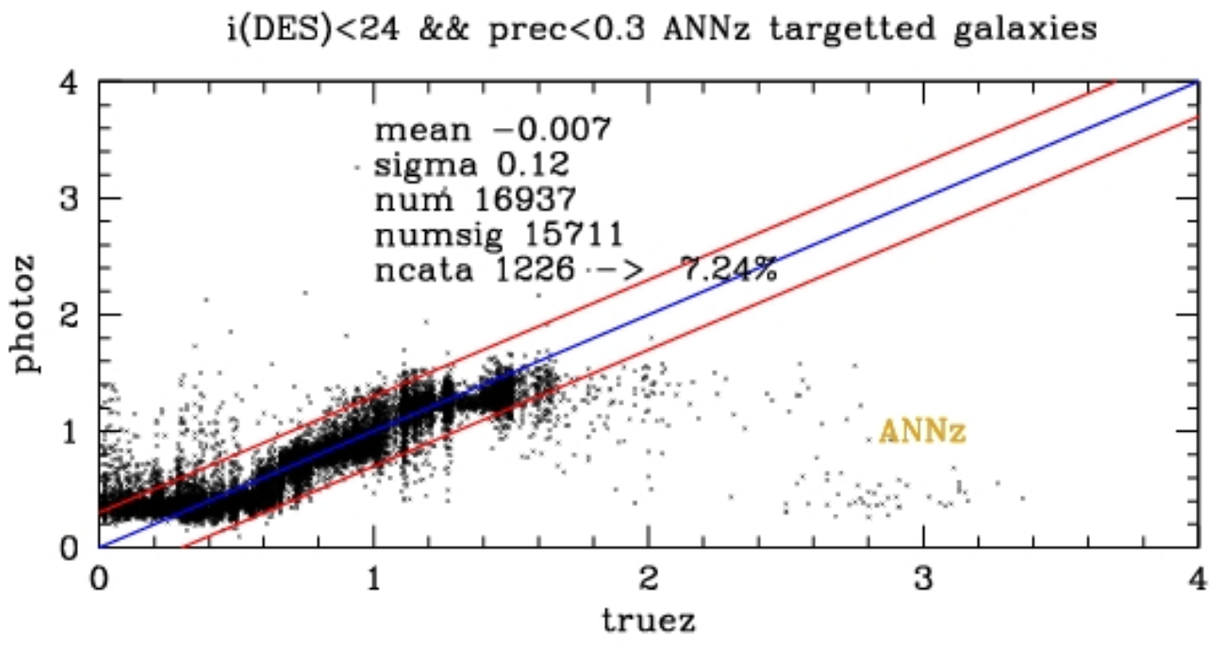
• If a spectroscopic sample can provide a10% prior on IA model ...

→ FoM x5-6 from WGL-alone!

Target Selection



Jouvel & Abdalla, in prep.



The depth & scale of DES tomography provides a perfect target selection list for DESpec.

Research continues on optimizing survey strategy & allocation of "community fibres" throughout a DESpec survey.

Neutrinos

Total Neutrino Mass

DES+Planck vs. KATRIN

$M_\nu < 0.1$ eV $M_\nu < 0.6$ eV

Lahav, Kiakotou, Abdalla and Blake (2010) 0910.4714

Expect DESpec+DES+Planck can reach the lower limit
from Physics experiments (0.05 eV), i.e detection of neutrino mass

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DARK ENERGY SURVEY

Conclusions

- DESpec is a low cost/low risk mission, building on the infrastructure & science legacy of DES.

- 10 million spectra over ~350 nights on the DES footprint. With LSST targetting can extend to 15,000deg^2 with tens of millions of galaxies.

- Huge range of science drivers, from galaxy evolution to SNe.

- WGL & LSS boosts DE/MG FoM x10+

END

Path Forward

•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.

•Revise and then release White Paper that lays out the science case, reference survey strategy & reference technical design motivated by science requirements.

•Next few months: optimize target selection for key DE probes, confirm with more detailed simulations. Continue to elaborate science case, carry out technical R&D, and build collaboration. Aim for external review in the Fall.

•R&D funding so far from STFC, expected from KICP, AAO

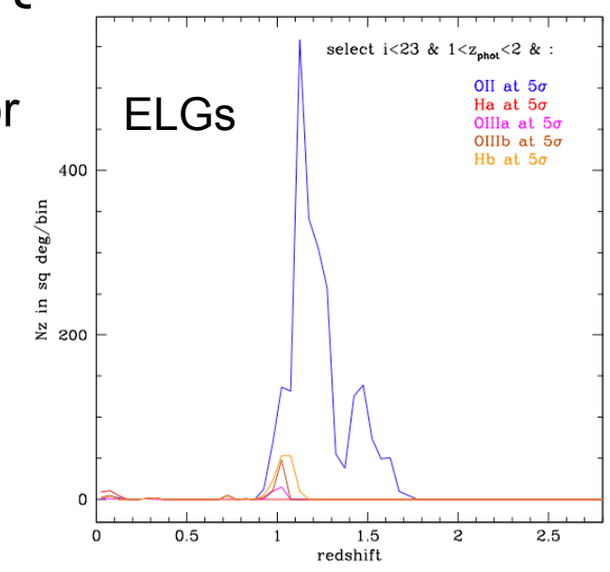
•DOE forming a group to write a Dark Energy White Paper to explore intermediate timescale projects.

Survey Strategy

Filipe, Huan, Jim, Rich, Stephanie and others

DARK ENERGY SURVEY

- There are ~10,000 galaxies w/ mag. < 22.5 per sq. deg
- Assume SS is performed on the 5000 sq-deg DES footprint
- Target a mix of LRGs to z~1 and ELGs to z~1.7. Studies underway use COSMOS Mock Catalog
  - Successful targeting of S/N = 5 for mag 21.5 LRGs in 30 minutes. Similar times for ELGs with i<23.
  - ~1200 ELG/sq-deg
  - ~800 LRGs/sq-deg
- Such a machine could measure the spectra of ~7M galaxies in 270 nights and 20M galaxies in ~800 nights.
- R&D will better define survey requirements and drive the hardware design.



Target selection pipeline:

- Production of a mock catalogue:
  - Colours and spectra
- Production of sensitivity curves
- Production of redshift success rate from the spectrum for each simulated galaxy.
- Production of an algorythm for selection
  - Investigation of impact of this algorythm
- Allocation efficiency from fiber positioner
- Allocation efficiency from a real pointing strategy
- Link with FOM for the given n(z)

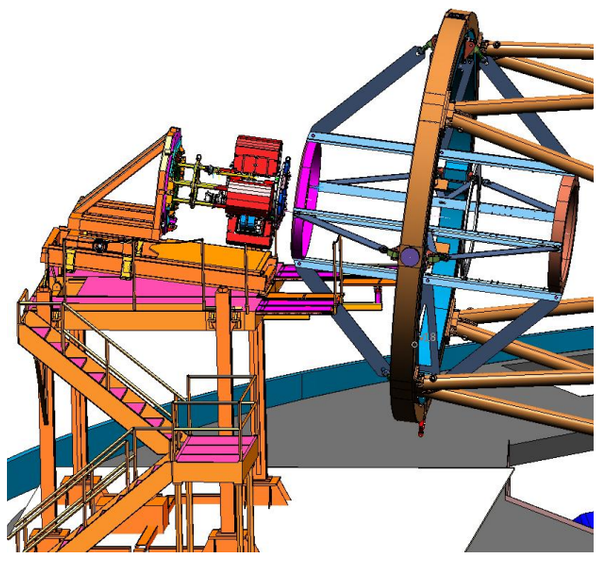
“Strawman Surveys”

- Management Committee outlined a process by which the Collaboration can assess the science value of a “DES Upgrade”. They described 3 “strawman surveys” for the Science Working Groups to evaluate based on Darren’s estimates.

1) 100% spectroscopic completeness of DES galaxies to r=21st magnitude with resolution 50 km/s.
2) Case 1 plus 50% completeness to r=22.5 magnitude evenly distributed over all redshift bins
3) ~300 km/s redshift precision with 100% completeness to r=22nd magnitude

Q Advice on what parameters give the most improvement on FoM and advice as to what new techniques are opened up.

All of the SWG and Task Forces responded.
The DES Science Committee is producing a report summarizing the results.[6]



DESpec: Spectroscopic follow up of DES

- Proposed Dark Energy Spectrometer (DESpec)
- 4000–fibre $40M instrument for the 4m Blanco telescope in Chile, using DES optics and spare CCDs
- 10 million galaxy spectra, target list from DES, powerful synergy of imaging and spectroscopy, starting 2017-18
- Spectral range approx 600 to 1000nm, R=3300 (red end)
- DES+DESpec can improve DE FoM by 3-6, making it DETF Stage IV experiment
- DES+DESpec can distinguish DE from ModGrav
- Participants: current international DES collaboration (incl 6 UK universities) + new teams

Massive Spectroscopy of DES Targets

Would enable:

•Clusters: cluster spec. z's and dynamical masses from velocity dispersions: improve mass-observable calibration

•WL: 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

improved $D_A(z)$

-galaxy z's and spectroscopic
asses) to control systematics

h: improved calibration of photo-z
ation improves all DE constraints

an, DESpec meeting
n, May 2012

DESpec: benefits per probe

- Photo-z/spec: better photo-z calibration (also via cross-correlation)
- LSS: RSD and radial BAO, FoM improved by several (3-6)
- Clusters: better redshifts and velocity dispersions, FoM up by several
- WL: little improvement for FoM (as projected mass), but helps with intrinsic alignments
- WL+LSS: offers a lot for both DE and for ModGrav
- SN Ia: spectra of host galaxies and for photo-z training, improving FoM by 2
- Galaxy Evolution: galaxy properties and star-formation history
- Strong Lensing: improved cluster mass models

DARK ENERGY SURVEY

Fibers vs. # Nights

- There are roughly 50M mag < 22.5 galaxies in 5000 sq-deg and there are ~2.5x that per magnitude.

$$N_{Objects} = N_{Fibers} N_{Nights} N_{Exp/Night} W_{eather}$$

- It is technically possible to get 2000 to 4000 fiber positioners in an area the size of the DECam focal plane.
- For example: 1000 nights, 8 exposures per night, and W=1.0 yields 16M to 32M 1-hr spectra.
- In such a scenario, we observe on a given “tile” 4-5 hrs.
- Intelligent algorithms, which maximize the number of observed objects, result in an even better yield.

Total Neutrino Mass

DES+Planck vs. KATRIN

$M_\nu < 0.1$ eV $M_\nu < 0.6$ eV

Lahav, Kiakotou, Abdalla and Blake (2010) 0910.4714

Expect DESpec+DES+Planck can reach the lower limit
from Physics experiments (0.05 eV), i.e detection of neutrino mass

Lensing + redshift surveys

Lensing Convergence	Galaxy Density
Tranverse modes only, $N_{modes} \propto \ell^2$	Line of sight modes accessible $N_{modes} \propto \ell^3$
✔ Directly tied to potential fluctuations	Biased and stochastic w.r.t. matter
Redshift of fluctuation not directly observed	Fluctuation redshift known ✔
✔ Distance-ratio factors appear in observables	Distances require *a priori* spectrum model
No access to velocity field	"contaminated" by velocity field ✔

Combining these observables gives lowered or vanishing sample variance, known fluctuation redshift, *and* direct tie to matter!

DESpec Concept

- Multi-fiber spectrographs:~4000 fiber system for the Blanco 4-m at CTIO, interchangeable with DECam, feeding ~10 high-throughput spectrographs using spare DECam CCDs
- FOV: 3.8 sq. deg. (delivered by DECam optics)
- Nominal wavelength coverage: 600 to 1000 nm (blue limit set by optics)
- Resolution: R~3300 at 1000 nm
- Optics: Use DECam optics except C5 (dewar window) and add ADC plus small optical element(s)
- Spectrographs: design based on cost-effective HETDEX VIRUS
- Robotic fiber positioner: Echidna and Cobra systems have demonstrated requisite fiber pitch (spacing)
- Tom's talk will cover technical design issues.

The Dark Energy Survey

First Light in September 2012

- 4-probe approach

  Cluster Counts

  Weak Lensing

  Large Scale Structure

  Supernovae Ia

- 8-band imaging

  5000 deg^2 *grizY*

  300 million photometric redshifts

  + *JHK* from VHS (1300 sq deg covered at half exposure time)

  +SPT SZ (550 clusters observed over 2500 sq deg)

Rationales for Blanco Spectroscopy

- Uniform, deep imaging catalogs from DES+VHS for targeting: enable powerful new science beyond what 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
- Excellent site: 0.65” seeing (0.9” Mosaic), high number of useable nights (80%) yield fast (hence cheap) survey
- Low cost & schedule risks by reusing/capitalizing on many DECam components: optics, CCDs, cage, hexapod, shutter

Josh Frieman, DESpec meeting
Munich, May 2012

Parameter	Single-Arm Spectrograph
Fiber diameter	100 mm (1.75 arcsec)
Wavelength range (nm)	550<λ<950
CCD	DECam 2kx4k
Resolution (Δλ)	0.263 nm
# pixels/fiber	2.6
Spectral resolution	R~2850 at 750 nm
Camera *f*/#	*f*/1.3
Camera type	Reflective

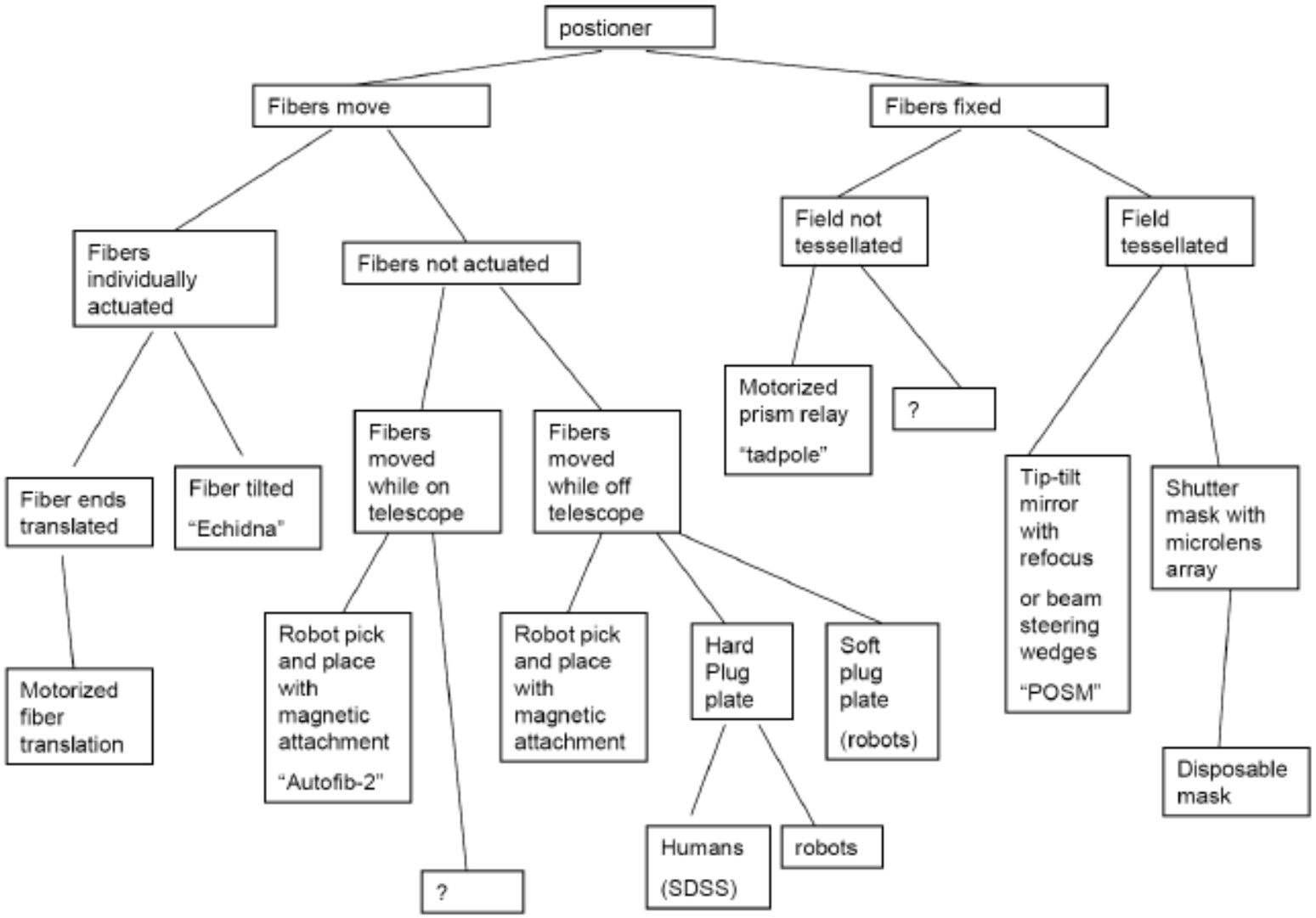
Left: parameters for a potential one-arm spectrograph design

Right: parameters for a potential two-arm spectrograph design

Parameter	Blue Arm	Red Arm
Fiber diameter	100 mm (1.75 arcsec)	
Wavelength range (nm)	480<λ<780	750<λ<1050
CCD	Blue-sensitive 2kx4k	DECam 2kx4k
Resolution (Δλ)	0.228 nm	0.228 nm
# pixels/fiber	3	3
Spectral resolution	R~2760 at 630 nm	R~3950 @ 900 nm
Camera *f*/#	*f*/1.5	*f*/1.5
Camera type	Refractive	

Fiber Alternative Decision Tree

DARK ENERGY SURVEY



M. Seiffert (JPL) presentation at P.U. 11/09