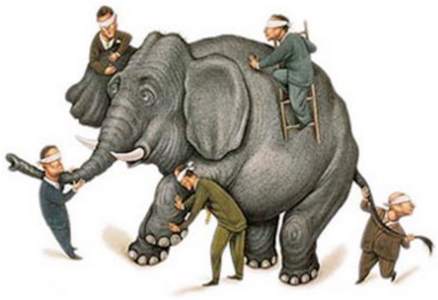


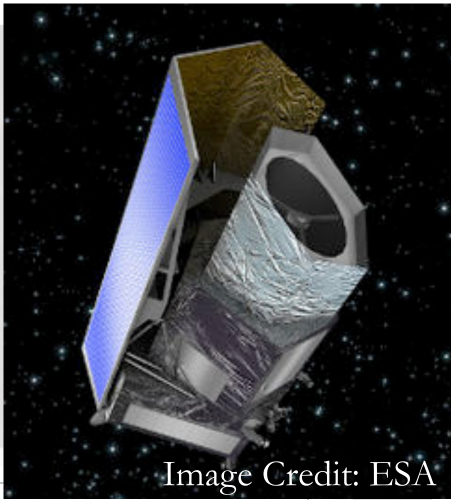


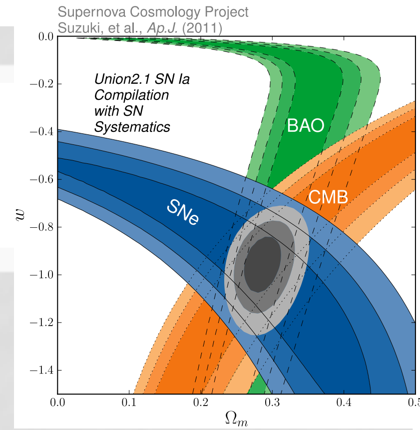
Image Credit: ESA

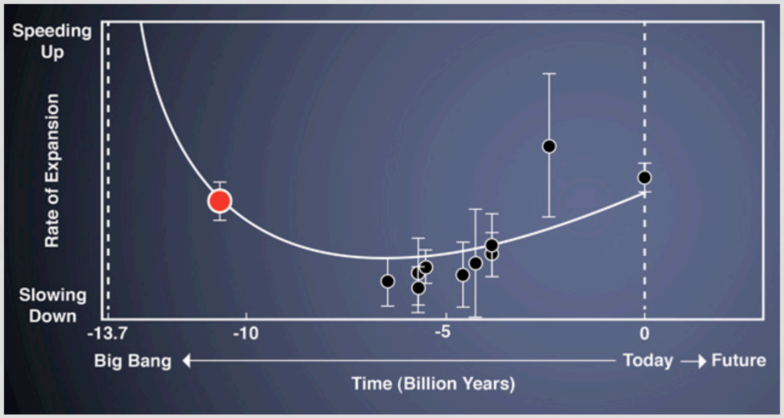
DARK ENERGY IN SPACE: WFIRST AND EUCLID

RACHEL BEAN (CORNELL UNIVERSITY)
ON BEHALF OF THE PHYSPAG DARK ENERGY COMMUNITY

Image Credit: NASA/GSFC

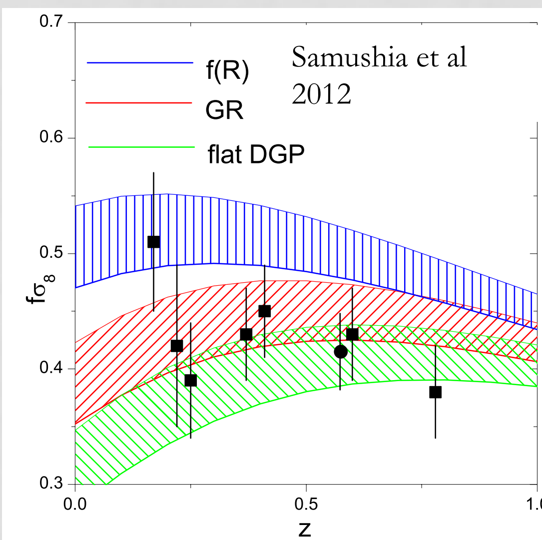
Dark energy science has evolved significantly since its discovery





Rostomian and Ross, BOSS/LBL 2012

Richer, complementary constraints of geometry & expansion on cosmic scales



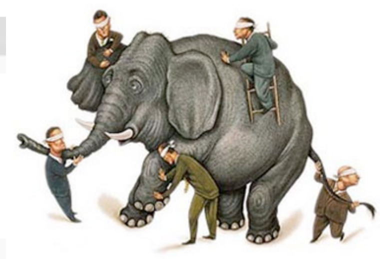
Additional insights from LSS linear growth rate

"Post-parameterized" formalism bridges theory and data

Category	Theory
Horndeski Theories	Scalar-Tensor theory (incl. Brans-Dicke)
	$f(R)$ gravity
	$f(\mathcal{G})$ theories
	Covariant Galileons
	The Fab Four
	K-inflation and K-essence
	Generalized G-inflation
	Kinetic Gravity Braiding
	Quintessence (incl. universally coupled models)
	Effective dark fluid
Lorentz-Violating theories	Einstein-Aether theory
	Hořava-Lifschitz theory
$>$ 2 new degrees of freedom	DGP (4D effective theory)
	EBI gravity
	TeVeS

Baker et al 2012

Vital to test of gravity & matter in environments beyond stellar systems



Phenomenology: effects on relativistic and non-relativistic matter evolution

$$k^2\Psi = -4\pi G_{\rm matter} a^2 \rho\Delta$$

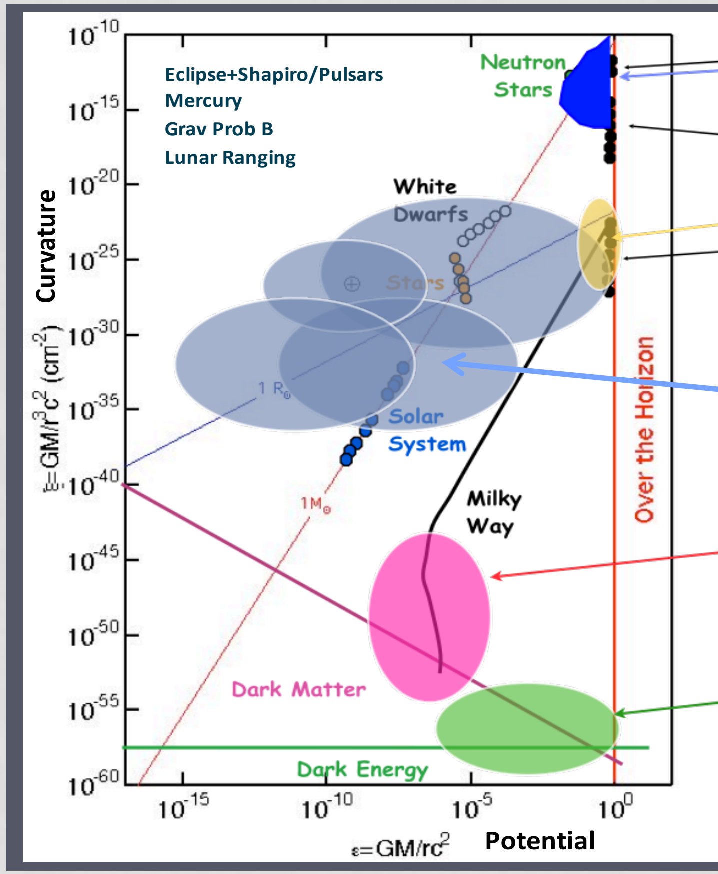
$$k^2(\Psi + \Phi) = -8\pi G_{\rm light} a^2 \rho\Delta\,,$$

new matter: $G_{light} = G_{matter} \neq G$

change to GR: $G_{light} \neq G_{matter}$

smoking gun $G_{light} \neq G_{matter}$

Zhang, Liguori, RB, Dodelson PRL 2007



LIGO

Event Horizon Telescope

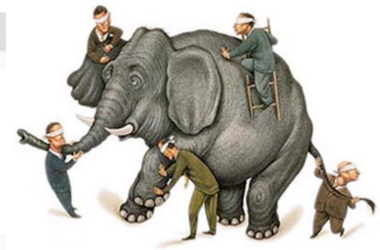
Stellar Systems

Galaxy Rotation and Halo Structure

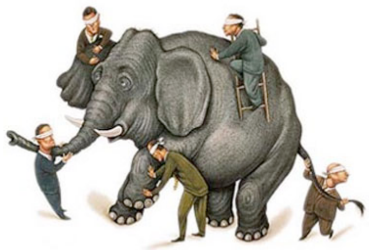
Cosmological Probes

Image Credit: Dimitrios Psaltis

Required breadth, depth & complexity not achievable by a single survey



- Trade offs in
  - Techniques (SN1a, BAO,RSD, WL, Clusters)
  - Photometric speed vs. spectroscopic precision
  - Angular and spectral resolution
  - Astrophysical tracers (LRGs, ELGs, Lya/QSOs, clusters, CMB)
  - Epochs and scales to study
- Much more than a DETF FoM:
  - Astrophysical & instrumental systematic control mitigation is crucial, but not so easily summarized.
  - Readiness vs technological innovation
  - Survey area vs depth and repeat imaging of the same sky (dithering, cadence and survey area overlap/config.)
- WFIRST and Euclid will make distinct and highly complementary contributions both with each other and with ground based surveys (LSST, DESI and others)

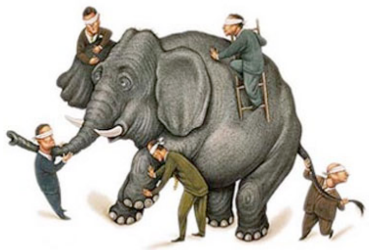


Euclid overview

(based on publicly available data)

	Euclid
Starts, duration	2020 Q2, 7 yr
Area (deg^2)	20,000 (N + S)
FoV (deg^2)	0.54
Diameter	1.3
Spec. res. $\Delta\lambda/\lambda$	250 (slitless)
Spec. range	1.1-2 μm
BAO/RSD	~50m Hα ELGs Z~0.7-2.1
pixel (arcsec)	0.13
Imaging/ weak lensing (0<z<2.)	30-35 gal/arcmin^2 1 broad vis. band 550– 900 nm
SN1a	

- NASA is contributing NIR detectors and associated hardware
- Three US science teams have joined the Euclid Consortium (now including 54 US scientists)
- Euclid public Data Releases at ~26, 50, and 84 months
- NASA has established the Euclid NASA Science Center at IPAC (ENSCI) in order to support the US Euclid science community
- Changes to spectrograph filters, shifting from 2 blue/2 red to all red underway.

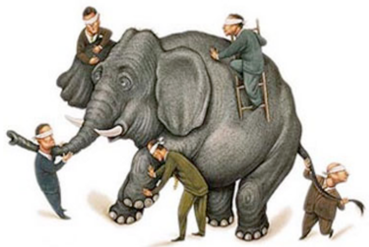


WFIRST overview

(based on publicly available data)

	Euclid	WFIRST-AFTA
Starts, duration	2020 Q2, 7 yr	~2023, 5-6 yr
Area (deg^2)	20,000 (N + S)	2,400 (S)
FoV (deg^2)	0.54	0.281
Diameter	1.3	2.4
Spec. res. $\Delta\lambda/\lambda$	250 (slitless)	550-800 (slitless)
Spec. range	1.1-2 μm	1.35-1.95 μm
BAO/RSD	~50m Hα ELGs Z~0.7-2.1	20m Hα ELGs z = 1–2, 2m [OIII] ELGS z = 2–3
pixel (arcsec)	0.13	0.12
Imaging/ weak lensing (0<z<2.)	30-35 gal/$arcmin^2$ 1 broad vis. band 550– 900 nm	68 gal/$arcmin^2$ 3 bands 927-2000nm
SN1a		2700 SN1a z = 0.1–1.7 IFU spectroscopy

- All 4 probes (SN/BAO/RSD/WL). Unique SN1a IFU characterization.
- Multi-band imaging and DM higher resolution mapping than from ground or with smaller telescope
- Spectroscopically selected galaxies for BAO/RSD 1<z<3
- Systematics' control a priority (e.g. WL shapes, SN1a characterization)
- Congress added $66M WFIRST-AFTA funding added to FY13 &14 NASA budget. Supported in President's FY15 budget.



In the broader context

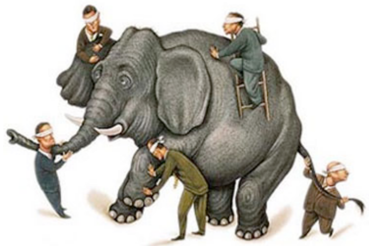
Now & near term: e.g. DES, HSC; BOSS, eBOSS, PFS; J-PAS, JWST; Planck, ACT+, Spider, SPT+

Stage IV	Euclid	WFIRST-AFTA	DESI	LSST
Starts, duration	2020 Q2, 7 yr	~2023, 5-6 yr	~2018, 5 yr	2020, 10 yr
Area (deg^2)	20,000 (N + S)	2,400 (S)	14,000 (N)	20,000 (S)
FoV (deg^2)	0.54	0.281	7.9	10
Diameter	1.3	2.4	4 (less 1.8+)	6.7
Spec. res. $\Delta\lambda/\lambda$	250 (slitless)	550-800 (slitless)	3-4000 (N_{fib}=5000)	
Spec. range	1.1-2 μm	1.35-1.95 μm	360-980 nm	
BAO/RSD	~50m Hα ELGs Z~0.7-2.1	20m Hα ELGs z = 1–2, 2m [OIII] ELGS z = 2–3	20-30m LRGs/[OII] ELGs 0.6 < z < 1.7, 1m QSOs/Lya 1.9<z<4	
pixel (arcsec)	0.13	0.12		0.7
Imaging/ weak lensing (0<z<2.)	30-35 gal/arcmin^2 1 broad vis. band 550– 900 nm	68 gal/arcmin^2 3 bands 927-2000nm		15-30 gal/arcmin^2 5 bands 320-1080 nm
SN1a		2700 SN1a z = 0.1–1.7 IFU spectroscopy		10^4-10^5 SN1a/yr z = 0.–0.7 photometric

Extra slides

WFIRST and Euclid reflect these advances in measurement & theory

- Don't presume a strong theoretical prior a-priori
  - Data will be good enough to test beyond w=-1 or w_0-w_a
  - Constrain growth and expansion in a model- independent way
- Search for a diverse array of signatures:
  - Geometry and inhomogeneity constraints across multiple epochs
  - Multiple tracers sampling distinct gravitational environments (galaxy and cluster positions and motions; CMB lensing and ISW; galaxy and cluster lensing)
  - Probe non-linear regimes (access many more modes & gravitational screening)
- Recognizes importance of systematic control in realizing survey potential
  - Survey complementarity/cross-correlation
  - Ascribe effects to cosmology rather than uncharacterized systematic.



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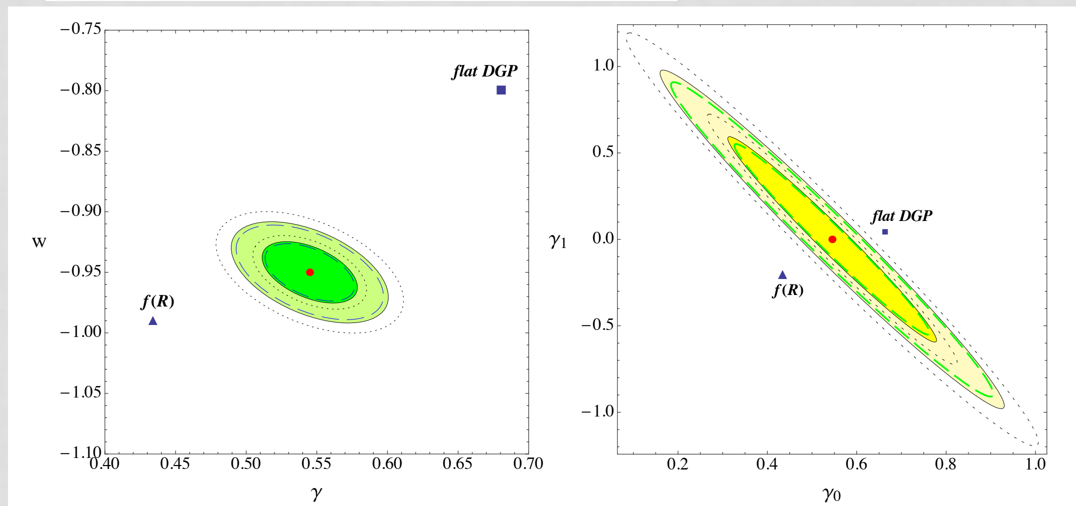
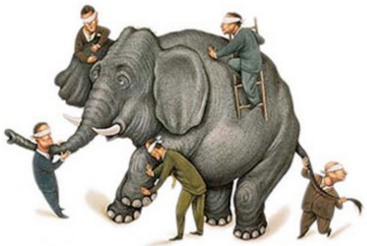
SN1a	

z	f_g^F	σ_{f_g}		
		ref.	opt.	pess.
0.7	0.76	0.011	0.010	0.012
0.8	0.80	0.010	0.009	0.011
0.9	0.82	0.009	0.009	0.011
1.0	0.84	0.009	0.008	0.011
1.1	0.86	0.009	0.008	0.011
1.2	0.87	0.009	0.009	0.011
1.3	0.88	0.010	0.009	0.012
1.4	0.89	0.010	0.009	0.013
1.5	0.91	0.011	0.010	0.014
1.6	0.91	0.012	0.011	0.016
1.7	0.92	0.014	0.012	0.018
1.8	0.93	0.014	0.013	0.019
1.9	0.93	0.017	0.015	0.025
2.0	0.94	0.023	0.019	0.037

Updates to Hα LF, and spectrograph $\sigma(f_g)/f_g$ likely higher



Amendola et al 2012



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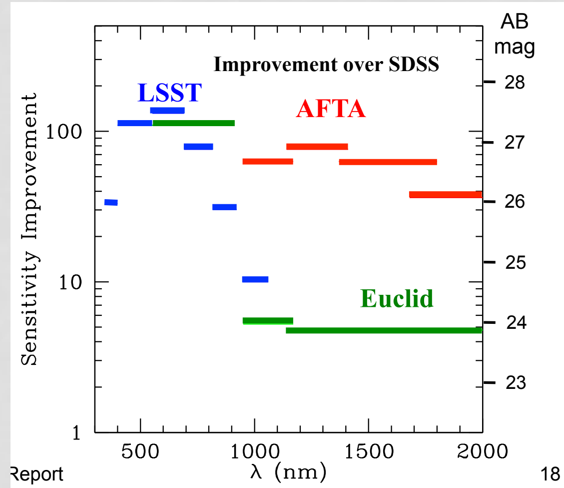
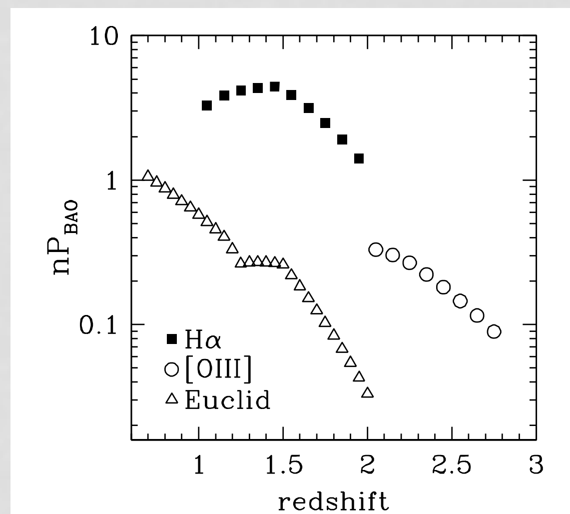
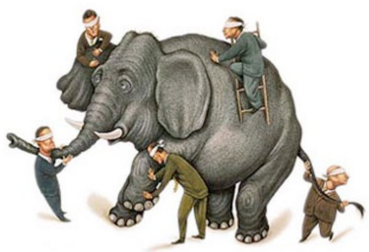




Spergel, Gehrels et al (WFIRST-AFTA SDT) 2013



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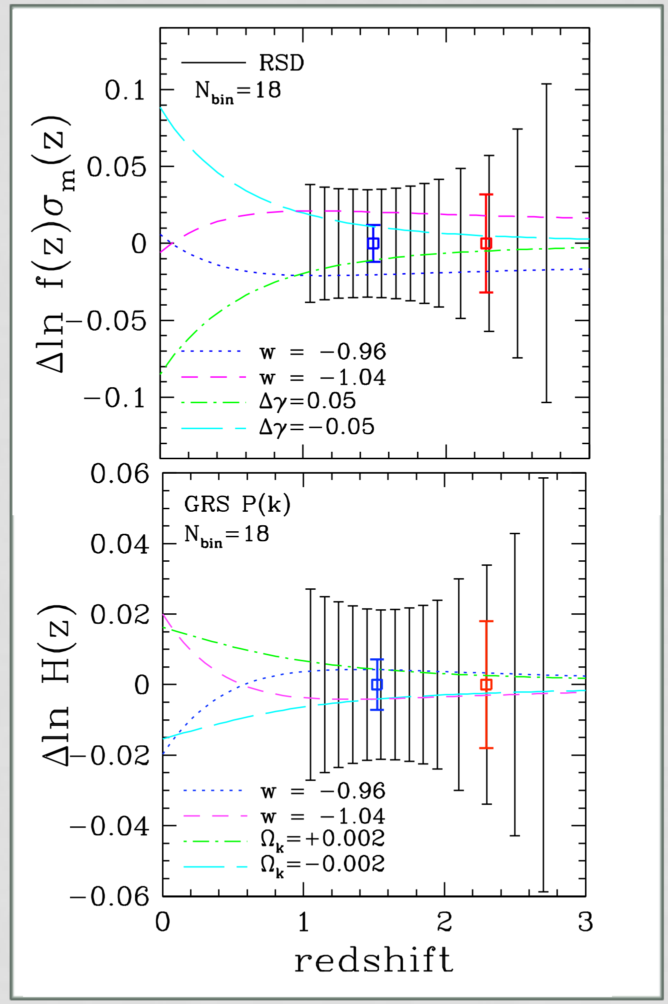

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