Euclid and WFIRST-AFTA:

NASA's
Dark Energy Program

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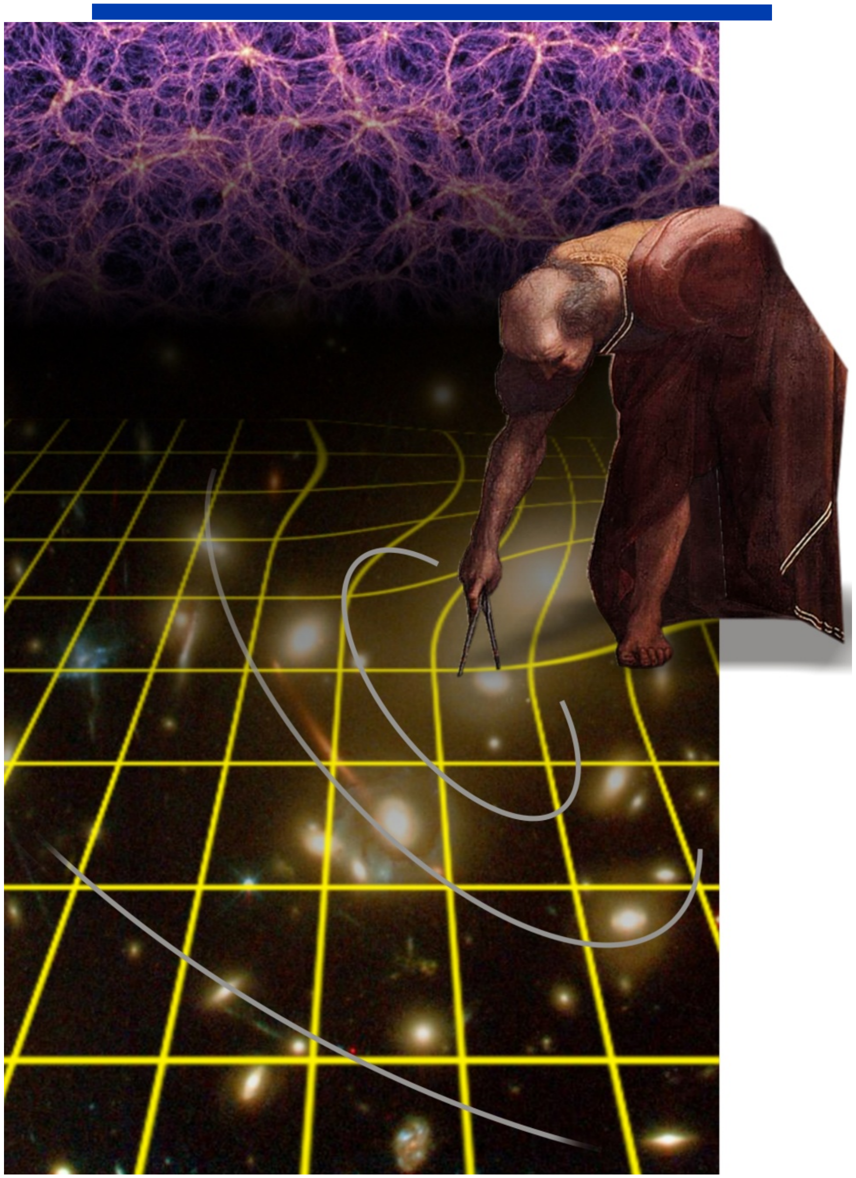
Euclid: Mapping the Geometry of the Dark Universe



2004: Dark Universe Mission Theme proposed to ESA's Cosmic Vision programme

Oct 2007: DUNE and SPACE jointly selected for ESA Assessment Phase

April 2010: Single Euclid Consortium formed

2010-2011: Definition phase

July 2011: Red Book – Final Euclid Proposal

Oct 2011: Cosmic Vision Approval of Euclid

Jan 2013: NASA joins, nominates 40 US scientists for 1200+ member Euclid Consortium

2012-2020: Implementation phase

2020: launch

2020-2026: science operations

Goals of Euclid

Euclid will explore the nature of Dark Energy and Dark Matter by:

•Measuring the DE equation of state to FoM > 500: e.g. measuring w_0 *and* w_a to a precision of 2% and 10% respectively, using both expansion history and structure growth

•Measuring the growth factor exponent γ with a precision of 2%, to distinguish General Relativity from modified-gravity theories

•Testing the Cold Dark Matter paradigm for structure formation, and measuring the sum of the neutrino masses to a precision better than 0.02 eV (when combined with Planck data)

•Improving by a factor of 20 the determination of the initial condition parameters, compared to Planck alone

Responsive to *scientific* goals outlined in NWNH Panel Reports:

- How did the universe begin?
- Why is the universe accelerating?
- What is dark matter?
- What are the properties of neutrinos?

Euclid Concept

Euclid is optimized for two complementary cosmological probes:

- Weak Gravitational Lensing
- Galaxy Clustering (Baryonic Acoustic Oscillations & Redshift Space Distortions)

Additional probes: galaxy clusters, integrated Sachs-Wolfe effect on microwave background

Euclid will survey 15,000 square degrees of the sky

- Imaging and photometry:
  - High precision visible imaging (galaxy shapes)
  - Near-Infrared Photometry (for photo-z)
- Near Infrared Spectroscopy (galaxy redshifts)
- Euclid is not optimized for supernova searches

The Euclid Mission

- 6-year science mission, in orbit at L2
- Telescope: three mirror astigmat, 1.2m primary mirror
- 0.5 deg^2 field of view for Visible and Near-IR imaging

Euclid's two instruments will measure ~2 billion galaxy shapes and ~50 million spectra (depending on luminosity function)

– VIS: Visible imaging channel:
  – 36 CCD detectors, 0.1'' pixels, 0.16'' PSF FWHM; very broad band r+i+z (0.5-0.9μm), to measure galaxy shapes

– NISP: Near Infrared channel:
  – 16 HgCdTe detectors, supplied by NASA, 1-2μm:
  - Photometry: 0.3'' pixels, 3 bands Y,J,H: for photo-z's, when combined with visible colors from the ground
  - Slitless spectroscopy, R=250: for galaxy redshifts

Survey Data Releases

- Q2 2020 launch, ~6 months on-orbit verification, followed by 6 years of science survey operations
- "Quick release" of small survey areas at 14, 38, 62, 74 months after start of survey
  - Small areas only, not suitable for cosmology
- Survey will be released in stages:
  - 26 months after start (2500 deg^2, ~2023)
  - after 50 months (7500 deg^2, cumulative, ~2025)
  - after 86 months (15000 deg^2, cumulative)
- Released survey data will be accessible to the entire science community

Euclid Science Reach

	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν/eV	f_{NL}	w_p	w_a	FoM
Euclid Primary	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current at 9/2011	0.2	0.58	100	0.1	1.5	~10
Euclid, later est.	0.04	0.02		<0.02	<0.1	>500
Improvement Factor	>5	30	50			>50

Euclid Red Book :
sci.esa.int/science-e/www/object/index.cfm?fobjectid=48983

Dark Energy beyond Euclid

WFIRST-AFTA:
Wide Field Infrared Survey Telescope – Astrophysics Focused Telescope Asset

- WFIRST, a near-infrared 'dark-energy+' mission, was the top large space priority for the Astro2010 Decadal Survey
- WFIRST-AFTA uses a 2.4 m telescope from another government agency
- WFIRST-ATFA is "a wide-field Hubble", with a 0.28 deg^2 field of view (larger than the full Moon, 100xJWST), infrared images almost as sharp as Hubble's visible images, and both IFU and grism spectroscopy.

See the WFIRST-AFTA Science Definition Team's final report at http://wfirst.gsfc.nasa.gov/

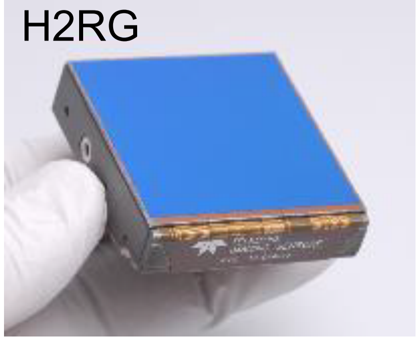
WFIRST-AFTA: beyond a successful Euclid mission

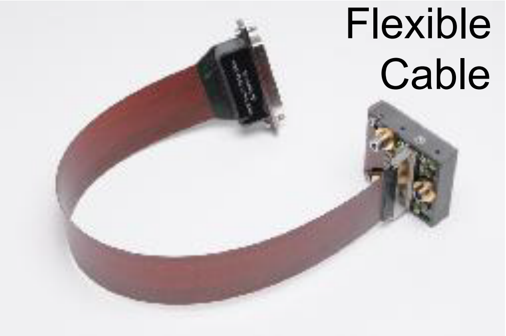
- WFIRST-AFTA is a larger telescope with finer resolution: 0.1” near-IR pixels (vs 0.3” for Euclid). Galaxy shapes measured in IR trace older stars; using 3 bands reduces systematic errors for weak lensing
- AFTA Reference Mission surveys 2000 deg^2 at high Galactic latitude, looking ten times fainter (27 AB-mag) to image 3x as many galaxies per $arcmin^2$ – reduces statistical noise, the main uncertainty in BAO estimates
- WFIRST-ATFA will sweep selected sky areas every 5 days to catch supernova explosions at high redshift, to z~1.7
- Spectroscopy with IR grism (R~600) for ~20M galaxy redshifts; IFU (3”x3.15”, 0.6μm-2μm, R~100) for supernova followup

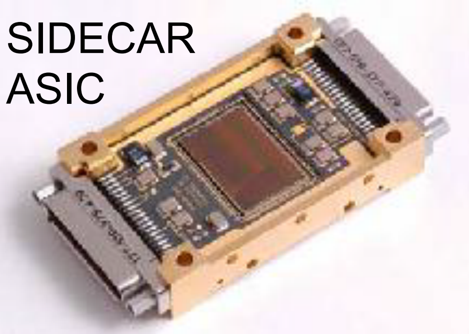
Euclid backup slides

ESA-NASA Partnership

- ESA responsibilities
  - Mission, Spacecraft, Launch vehicle, Ground Data System
- Euclid Consortium (EC) responsibilities
  - Mission, 2 instruments, Science Data Centers, Science
- ESA/NASA MOU signed January 10, 2013
  - NASA responsible for Sensor Chip Systems (SCS) for Near Infrared Spectrometer and Photometer (NISP) Instrument. ($45M)
    - Teledyne H2RG HgCdTe detector, SIDECAR ASIC, and flexible cryogenic cable. (16 flight models, 4 flight spares)
  - JPL Project Office (PM Ulf Israelsson, PS Michael Seiffert)
  - Detector characterization at GSFC Detector Characterization Lab (PCOS Program Office Mission Manager Tom Griffin)
  - NASA nominated 40 new EC members, competitively selected ($50M lifetime science team cost); US Science Lead Jason Rhodes







NASA: Euclid Science Teams Competition

- **ESA-NASA MoU provided for NASA to nominate**
  - **40 members to Euclid Consortium (EC)**
  - **1 member of the Euclid Science Team (EST)**
  - **1 member of the Euclid Consortium Board (ECB)**

ROSES competition for funded teams:
proposals due 31 August 2012; selections 7 December 2012

Jason Rhodes (JPL) selected for EST and ECB

Total of 3 science proposals selected: PIs Rhodes, Kashlinsky, Chary

Join 14 members of US community already part of Euclid Consortium

54 US scientists are now full members of the Euclid Consortium

IPAC is studying NASA contributing a US Euclid Science Data Center, this center is NOT included in ESA-NASA MoU, expect decision in 2014

Science Reach: Red Book

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Parameter	γ	m_ν/eV	f_{NL}	w_p	w_a	FoM
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From **Euclid Red Book** :
sci.esa.int/science-e/www/object/index.cfm?fobjectid=48983

Euclid Mission: Red Book

SURVEYS					
	Area (deg2)	Description			
Wide Survey	**15,000 deg^2**	Step and stare with 4 dither pointings per step.			
Deep Survey	**40 deg^2**	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey			
PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250

Ref: Euclid RB arXiv:1110.3193

~2 billion galaxy shapes and ~50 million spectra

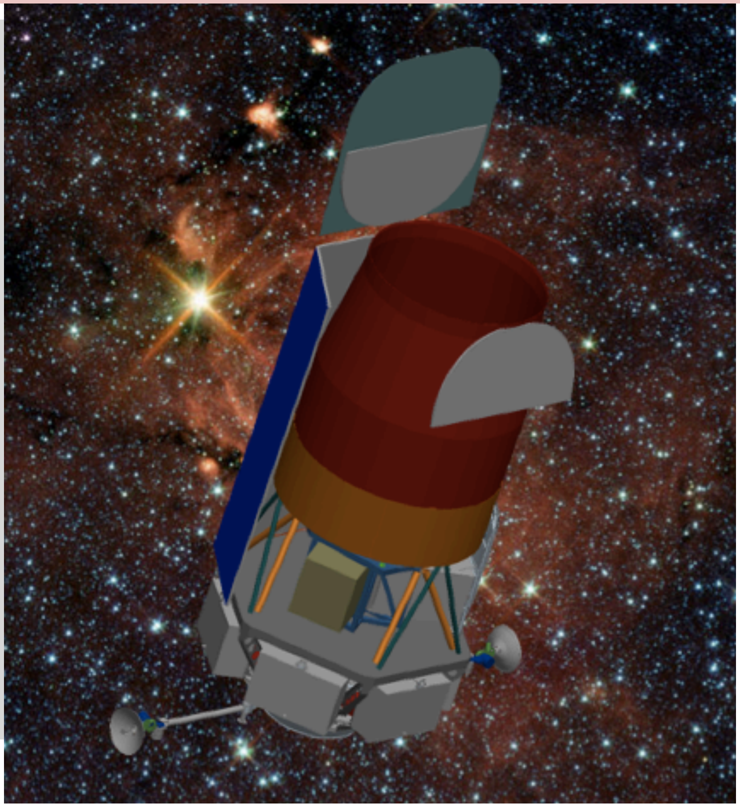
AFTA Backup slides

AFTA will deliver extraordinary science

A 2.4m telescope offers sensitive sharp images at optical and near IR wavelengths across a wide field. With higher resolution and sensitivity in the near IR than planned for the early WFIRST designs, AFTA will be an even more powerful and compelling mission.

AFTA offers both a rich program of community observations and directed programs that address fundamental astronomy questions:

- What is dark energy?
- Is our solar system special?
- Are the planets around nearby stars like those of our own solar system?
- How do galaxies form and evolve?

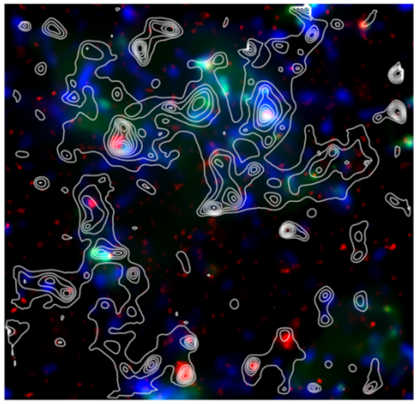


WL: A completely different regime

- WL with AFTA survey would reach >80 galaxies per square arcminute
  - vs ~30 w/Euclid, and even fewer from the ground
- With a deeper survey AFTA could reach HUDF depths of >300 galaxies per square arcminute

This is a fundamentally different WL regime that is not possible from the ground or with a 1.3 meter class telescope due to PSF size.

- Does not necessarily help with DE FoM (wide>deeper for FoM)
- Much better calibration data
- *Much* better for understanding dark matter



Channel field layout for AFTA-WFIRST wide field instrument

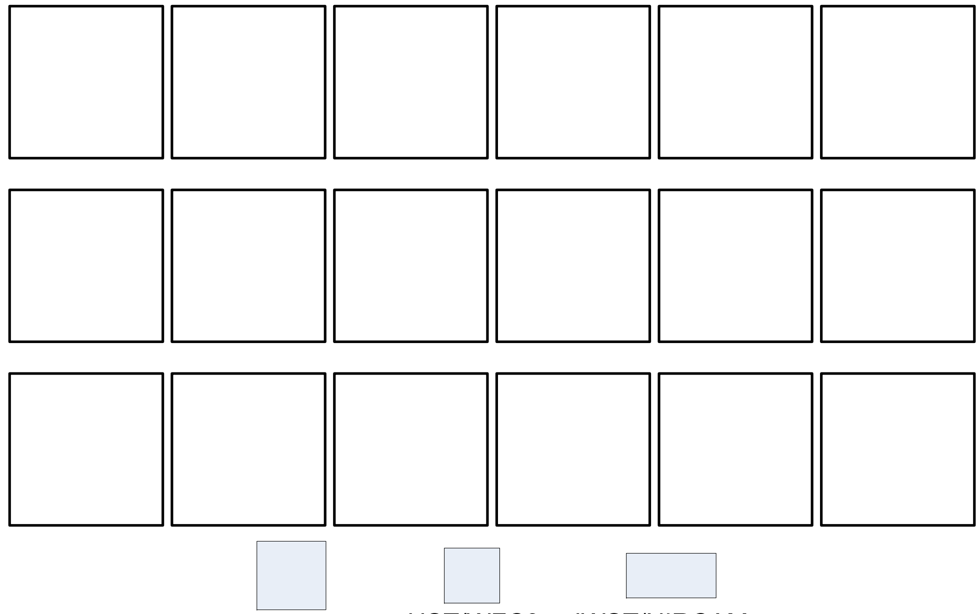
0.788° wide
0.427° high

X gaps 2.5mm
Y gaps 8.564mm

18 NIR detectors

0.11 arcsec/pixel   0.28 deg^2

Moon (average size seen from Earth)



Detector Layout on Sky

Each square is a H4RG-10
4k x 4k, 10 micron pitch
288 Mpixels total

Slitless spectroscopy with grism in filter wheel
R_q ~ 100 arcsec/micron

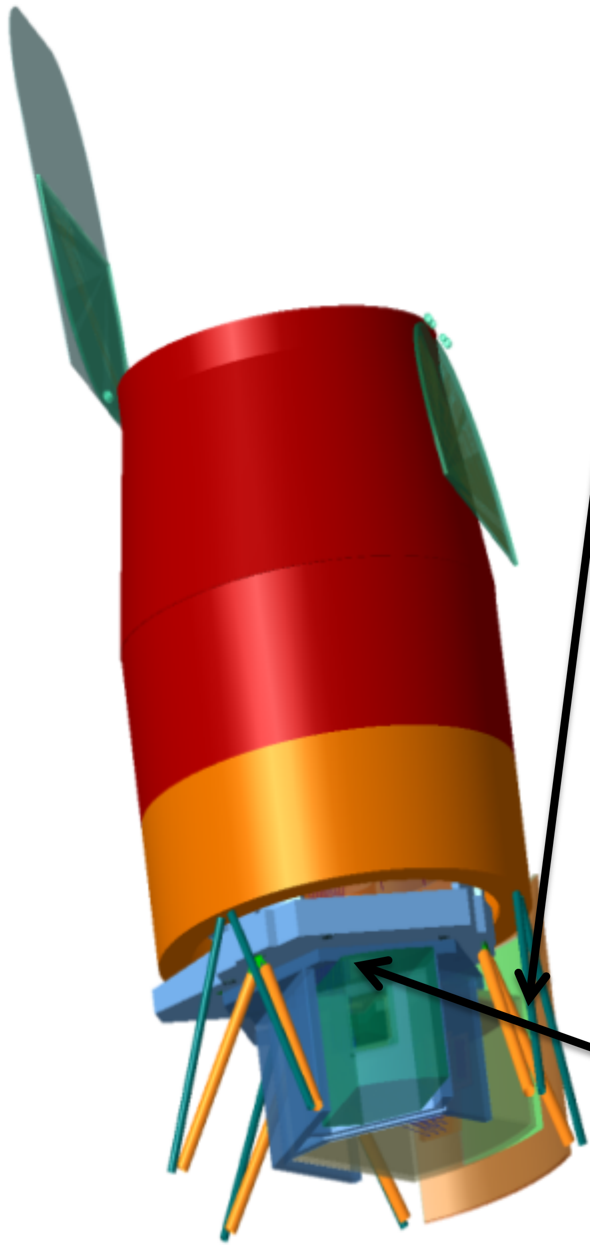
WFIRST-AFTA Extragalactic Surveys

From Chris Hirata

	WFIRST DRM1	WFIRST DRM2	AFTA
Implementation	1.3 m unobs 36 H2RG 0.18”/p	1.1 m unobs 14 H4RG 0.18”/p	2.4 m obs 20 H4RG 0.0975”/p
Imaging Survey* [4 filters for all; depths are 5σ isolated pt src]	0.92—2.40 μm 26.0—26.2 mag AB 2800 deg^2/yr EE50 = 0.15—0.21”	0.92—2.40 μm 25.8—26.0 mag AB 2900 deg^2/yr EE50 = 0.18—0.25”	0.92—2.17 μm 26.9—27.3 mag AB 1080 deg^2/yr EE50 = 0.11—0.14”
Weak Lensing [reddest 3 filters]	30, 33, 32 gal/am^2	24, 26, 25 gal/am^2	79, 82, 72 gal/am^2
Redshift Survey [≥7σ Hα detections]	z = 1.28—2.66 4900 gal/deg^2 2900 deg^2/yr	z = 1.59—2.66 2900 gal/deg2 4400 deg^2/yr	z = 1.13 – 2.20 4900 gal/deg^2 4000 deg^2/yr

* AFTA could in principle support an accelerated imaging mode matching the WFIRST DRM1 survey rate of 2800 deg^2/yr. This reaches depth of 25.8—26.0 mag AB and 26/31/32 galaxies per $arcmin^2$. This survey is heavily read noise limited (90 s exposures) so may not be the best use of a big telescope.

AFTA Instruments



Wide-Field Instrument

- *Imaging & spectroscopy over 1000s sq deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 micron bandpass
- 0.28 sq deg FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 4 filter imaging, grism + IFU spectroscopy

Coronagraph (study option)

- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- 10^{-9} contrast
- 100 milliarcsec inner working angle at 400 nm

Frontiers of Knowledge

As envisioned in NWNH, AFTA uses multiple approaches to measure the growth rate of structure and the geometry of the universe to exquisite precision. These measurements will address the central questions of cosmology