# WFIRST & Euclid

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# Overview

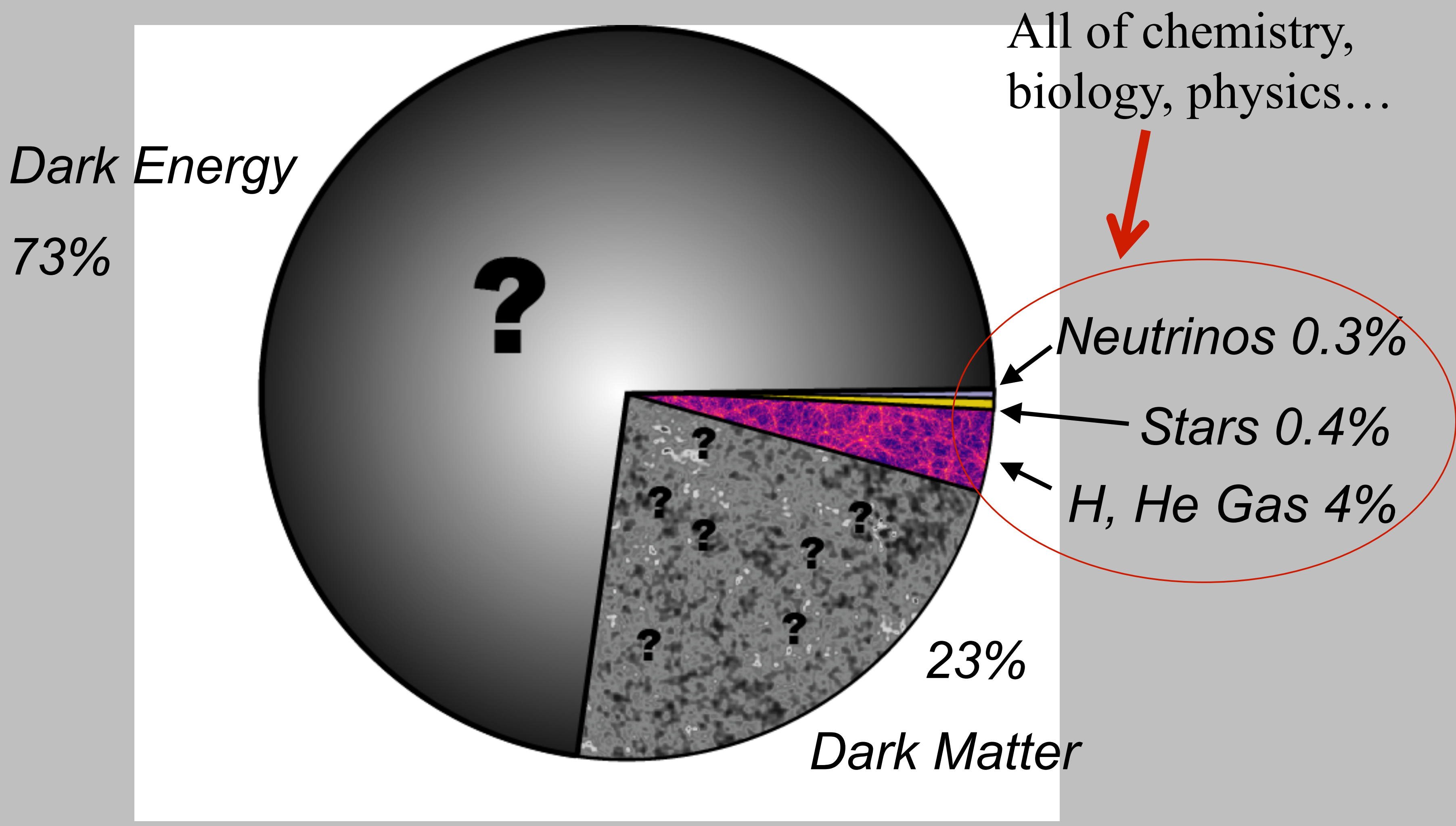
Fundamental Scientific Questions

- Dark Matter and Energy
- The abundance of Earth-like planets
- The Evolution of Galaxies & Near Infrared Survey Science

The Missions:

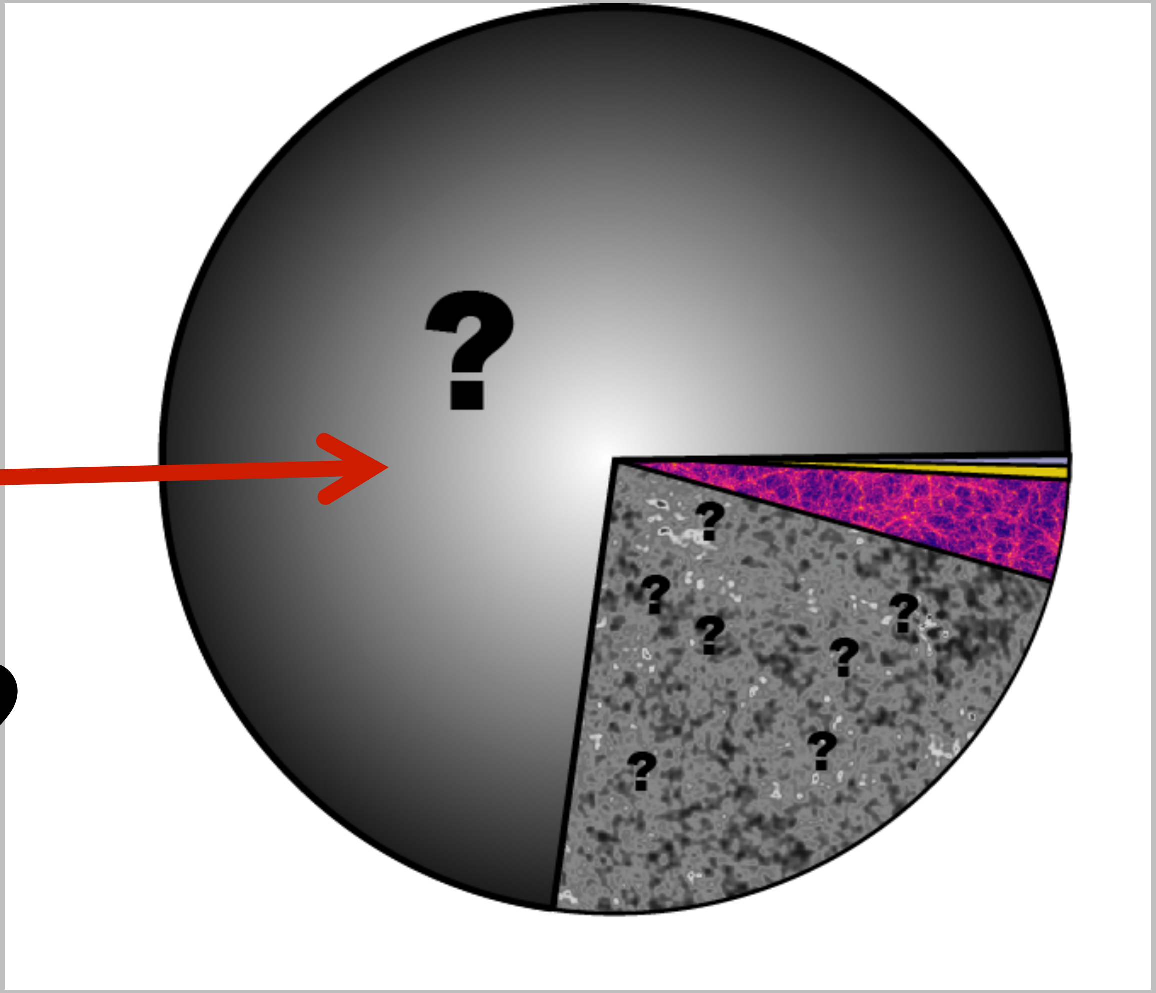
- Euclid- ESA Cosmic Visions
- Wide Field Infrared Survey Telescope - NASA

# The Components of the Universe



# The Next Piece of the Pie

What is
that
stuff????




One of the most compelling and important questions in science!

# The Universe is Expanding

Distance

Velocity

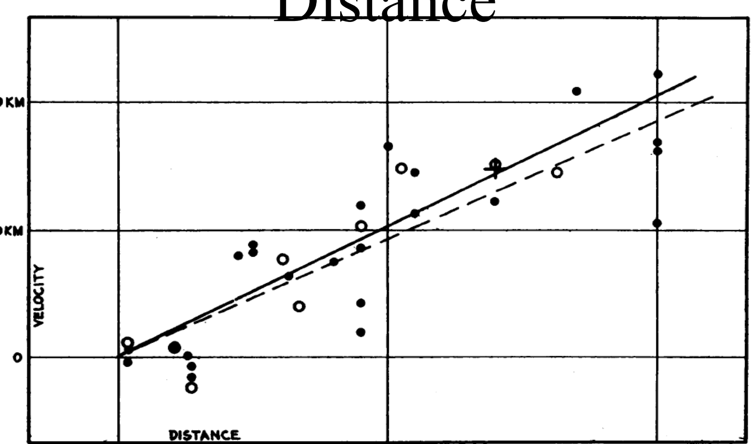
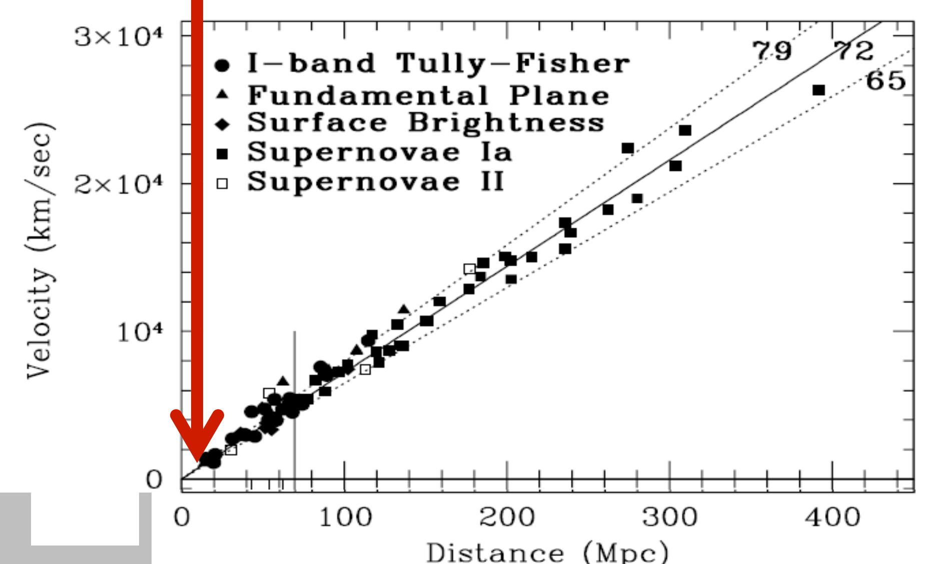



FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

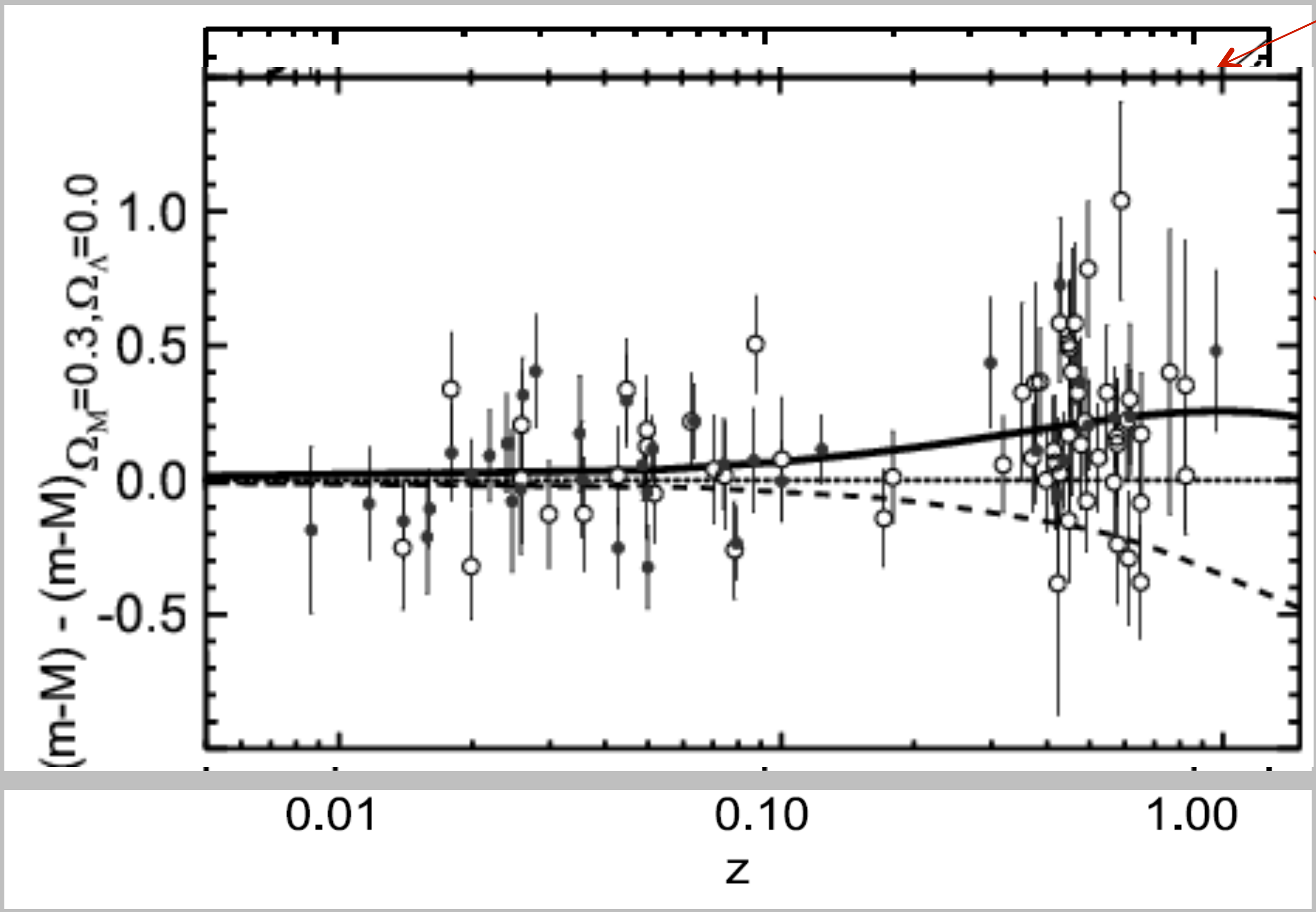
The farther away something is, the faster it is moving away, *in all directions!*

Hubble, 1929




Hubble Space Telescope

# The Expansion is *Accelerating!*




Universe with *something* (dark energy) making the expansion accelerate "recently"

Universe with just mass

Perlmutter & Schmidt, 2003

# Einstein's Equation

$$G_{\mu\nu} = 8\pi T_{\mu\nu} + \Lambda g_{\mu\nu}$$

Gravity or space curvature

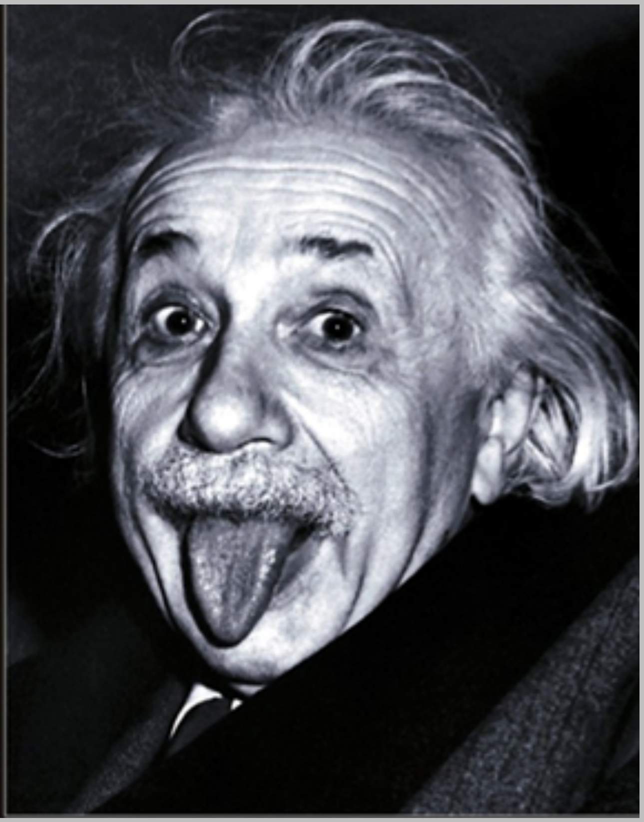
Mass and energy

Cosmological constant or Dark Energy (but maybe not actually a constant)

- $\Lambda$ term on right hand side introduced to allow for a 'steady state' Universe
- Don't need it if the Universe is expanding but decelerating

We could also be "wrong" about the left hand side (gravity). *We will test this* as we attempt to measure dark energy.

# Einstein's Blunder (?)



•Einstein added the cosmological constant $\Lambda$ so his equations would work for a static universe

•Before Hubble, it was assumed that the universe was static- that was aesthetically pleasing

•When the expansion of the Universe was discovered, the equations held without $\Lambda$

•Einstein called $\Lambda$ his 'biggest blunder'

In 1998, when the accelerating expansion was discovered, $\Lambda$ was reintroduced!

## Einstein's 'biggest blunder' is going to win somebody a Nobel Prize!

# Two Effects

Dark Energy affects the:

- Expansion history of the Universe
  - How fast did the Universe expand?
  - Also called the geometry of the Universe

- Growth of structures
  - How do the dark matter structures (like the ones we recently measured with Hubble) evolve and grow over time
  - Attractive gravity competes with repulsive dark energy

If Einstein's General Relativity is wrong, modified gravity theories could explain the accelerating expansion.

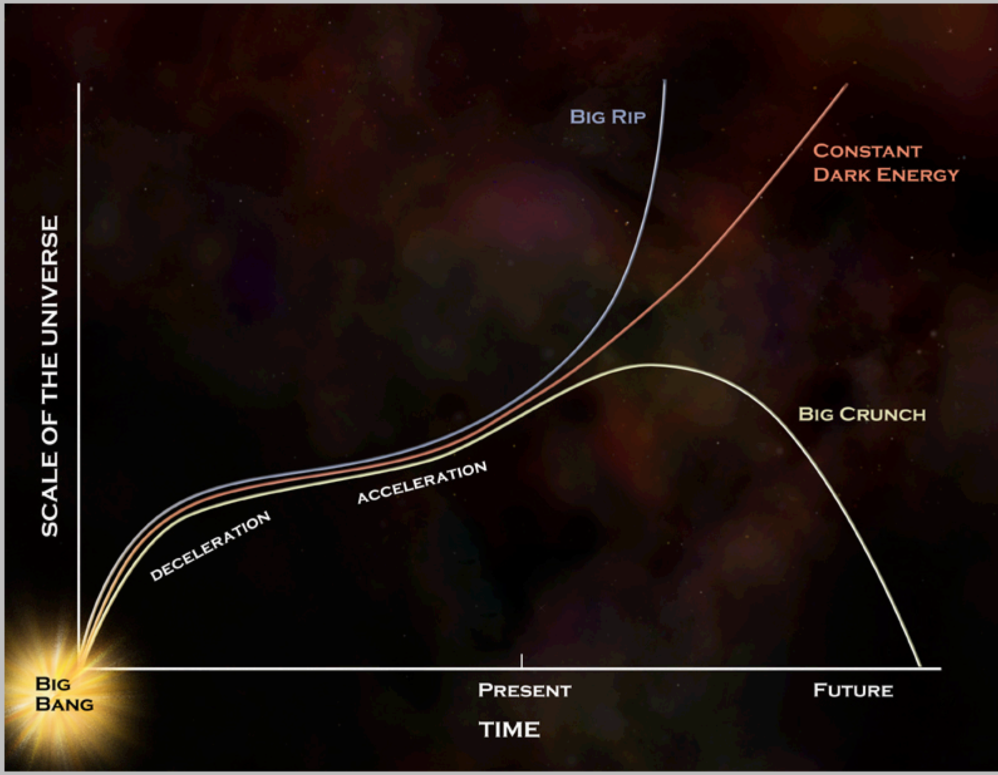
This would change the above effects differently, *so we must measure them both!*

# Future of the Universe

Universes with Dark Energy and

**$-1 < w < -1/3$ :**

- eternal expansion
- other galaxies eventually disappear beyond the horizon
- gravitationally bound objects stay bound




Universes with Dark Energy and $w < -1$ :

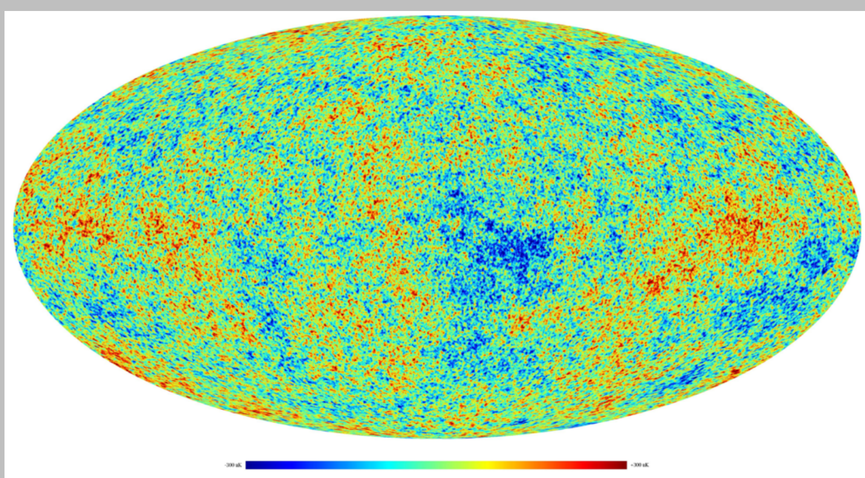
- DE density becomes infinite
- bound objects torn asunder!
- even atoms broken apart!
- **the "Big Rip" !!**
- **if** $w = -1.5$, Big Rip happens in **22 billion years**.

# Three Primary Dark Energy Probes

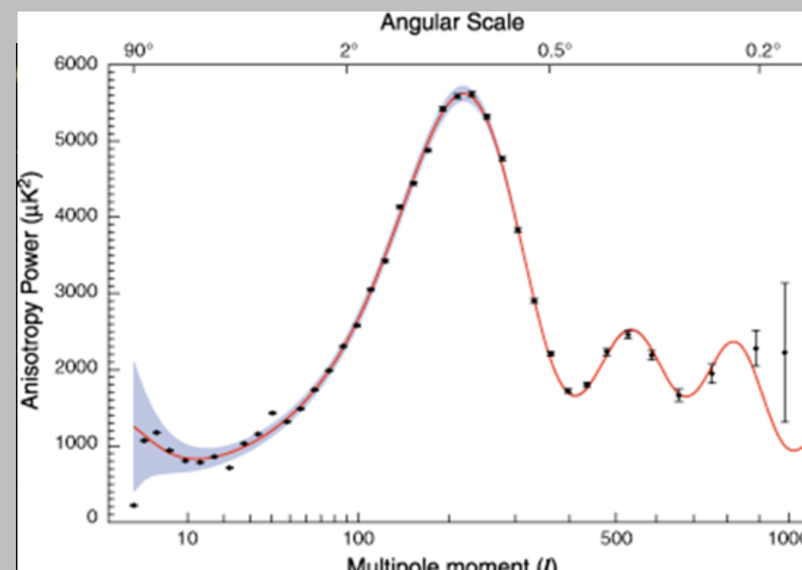
Weak lensing can measure the expansion history *and* the growth of structure *simultaneously*

Supernova Ia are standard candles that measure the expansion history

Baryon Acoustic Oscillations make use of the clustering scale of galaxies as a *standard ruler* to measure the expansion history



CMB




Clustering of Galaxies

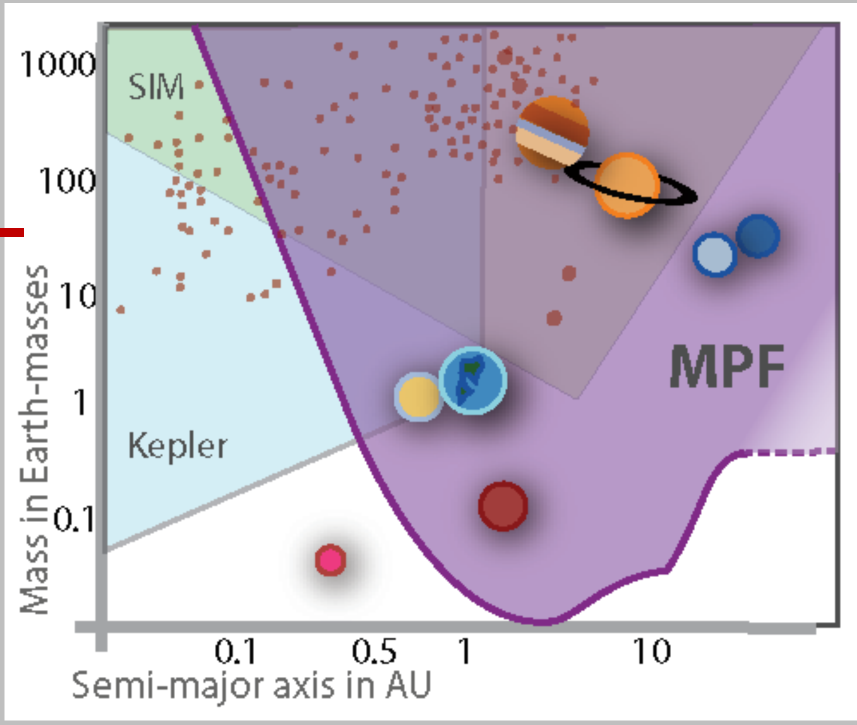
# Are We Alone?

The search for planets is fundamental to the search for alien life

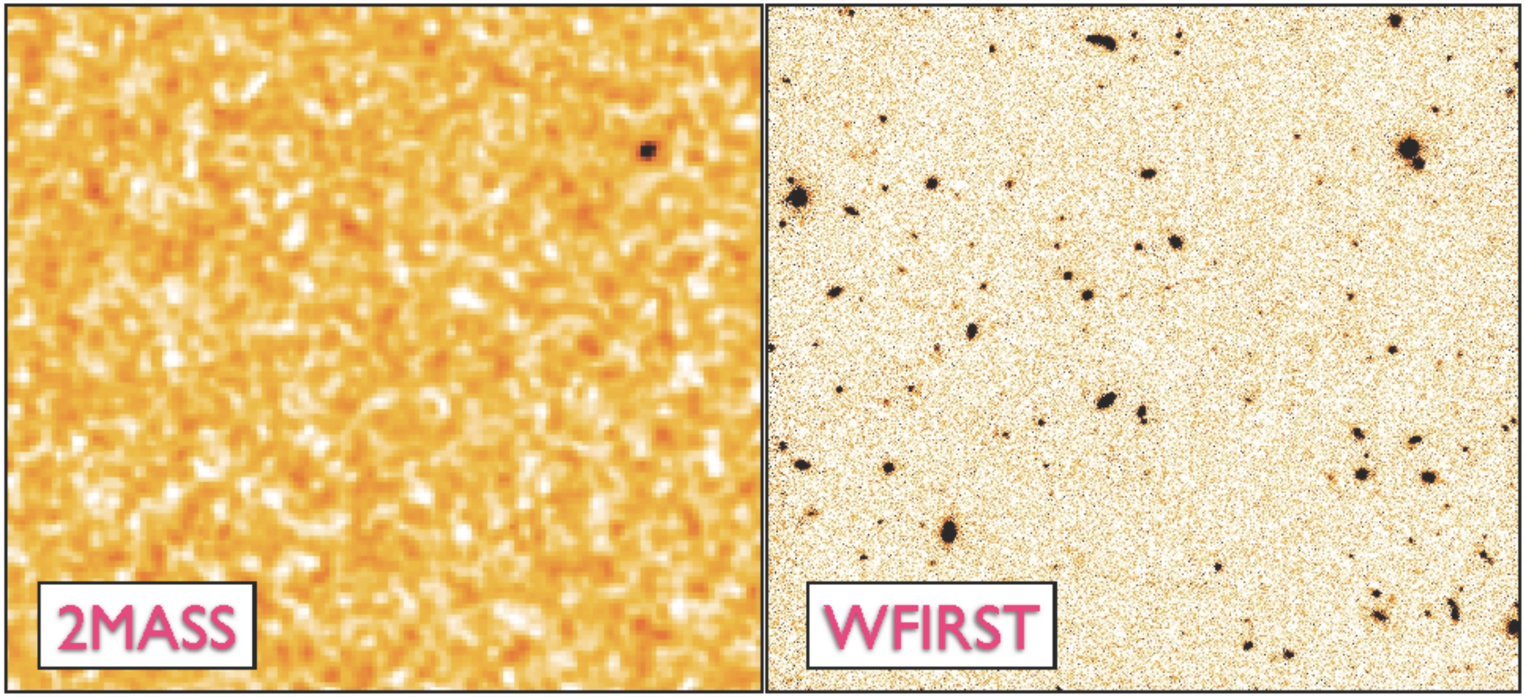
Multiple techniques exist for finding planets

Gravitational microlensing allows a statistical census for planets near the "interesting" region:

We want to find Earth-like planets in the habitable zone

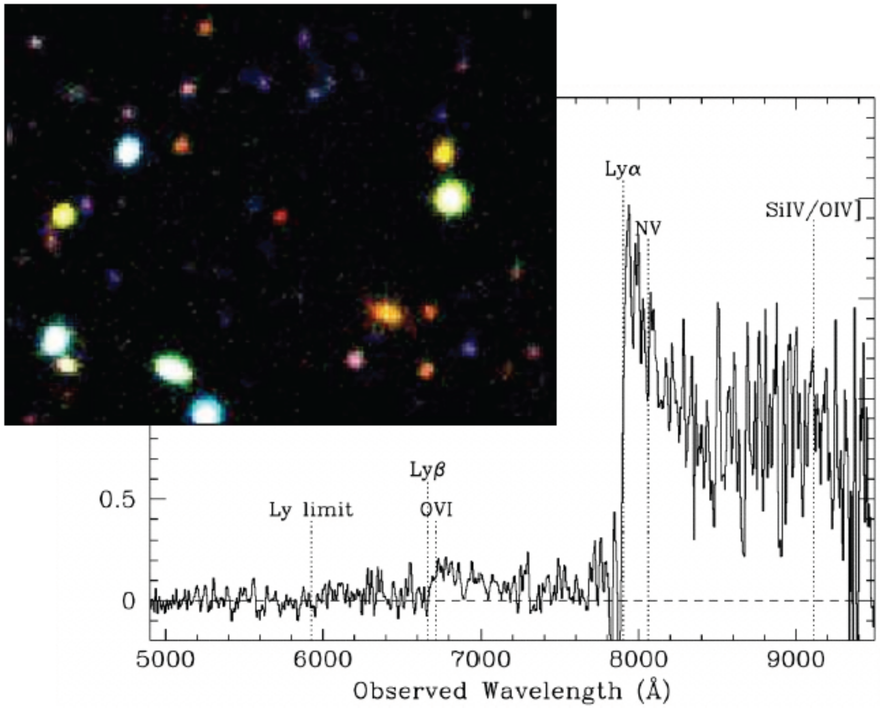


# NIR Survey Science




- Targets for JWST and TMT/ELT's.
- Compliments WISE, Planck, DES/Pan-STARRS/LSST, eROSITA/ART-XC, ...

# High Redshift Quasars




| Redshift | UKIDSS | NIRSS |
|---|---|---|
| 6<z<8 | 70-150 | ~100,000 |
| 8<z<10 | 1.3-2.6 | ~35,000 |
| z>12 | – | ~7,000 |
| z>20 | – | ~100 |

predicted number of high-redshift quasars from SDSS QLF (Fan et al. 2001, 2004)

# High Redshift Quasars

- WFIRST or Euclid will identify quasars at $z>6$ in unprecedented numbers

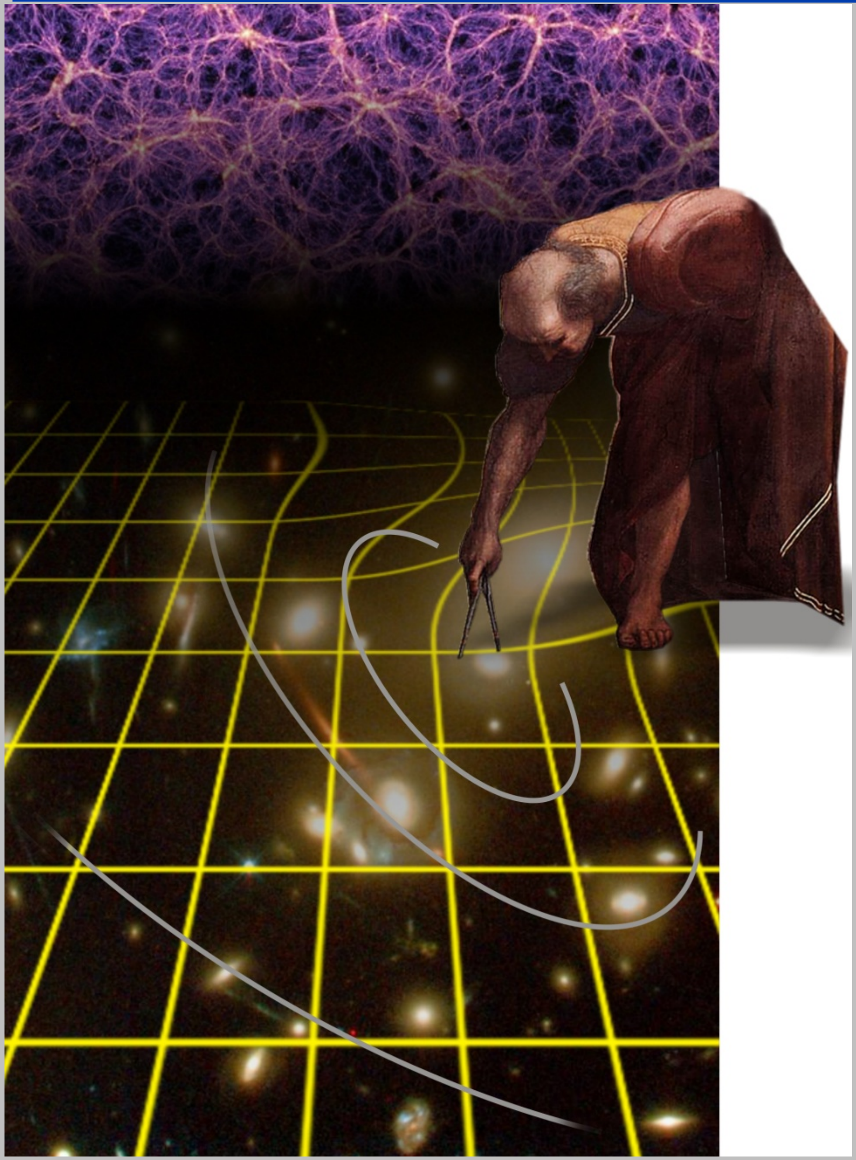
- Science afforded by high-redshift quasars (QSOs):
    - probe the epoch of reionization in several ways:
    - luminous background probes for studying intervening universe
    - Lyα profiles probe state of local gas (e.g., Strömgren sphere radii)
    - QSO luminosity function (QLF) gives contribution to ionizing budget
    - radio-loud QSOs provide additional 21 cm probe of reionization
    - early history of black hole growth
    - proxy for early galaxy growth / growth of large-scale structure (LSS)
    - large numbers of high-redshift QSO pairs

- brightest (e.g., tip of the luminosity function + lensed) galaxies will likely be selected by the same color criteria. Such sources buy significant additional science, such as early IMF, metallicities, ages of first galaxies (c.f., substantial panchromatic literature on cB58, a strongly lensed $z\sim3$ LBG)

# Normal Galaxies

• new near infrared surveys will detect vast numbers of normal galaxies
• near-IR data buys improved photometric redshifts: necessary for weak lensing cosmology program, but also essential for studying galaxy evolution
• though WFIRST resolution < HST resolution, still expect to resolve most (~80%) of sources brighter than H ~ 25
• grism/spectroscopy data data too...
• depth slightly lower than COSMOS, but covering >1000x greater area
• near-IR very powerful for identifying massive galaxies at z>1
• very powerful tool for studying high z galaxy clusters:

# The Missions

# Euclid

Mapping the geometry of the Dark Universe

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

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

2010-2011: Definition phase

April 2010: Formation of single Euclid Consortium

December 2010: NASA Call for 2 US Euclid Science Teams

July 2011: Final Euclid Proposal- Red Book

**Oct 2011: Cosmic Vision Selection**

2012-2017: Implementation phase

2017-2018: launch

# Euclid concept

- **High-precision survey mission to map the geometry of the Dark Universe**
- **Optimized for two complementary cosmological probes:**
  - — **Weak Gravitational Lensing**
  - — **Baryonic Acoustic Oscillations**

  **Additional probes: clusters, redshift space distortions, ISW**
- **Full extragalactic sky survey with 1.2m telescope at L2:**
  - — **Imaging:**
    - **High precision imaging at visible wavelengths**
    - **Photometry/Imaging in the near-infrared**
  - — **Near Infrared Spectroscopy**
- **Synergy with ground based surveys**
- **Legacy science for a wide range of areas in astronomy**
- **Survey Data public after one year**

# Euclid goals

***Understand the nature of Dark Energy and Dark Matter by:***

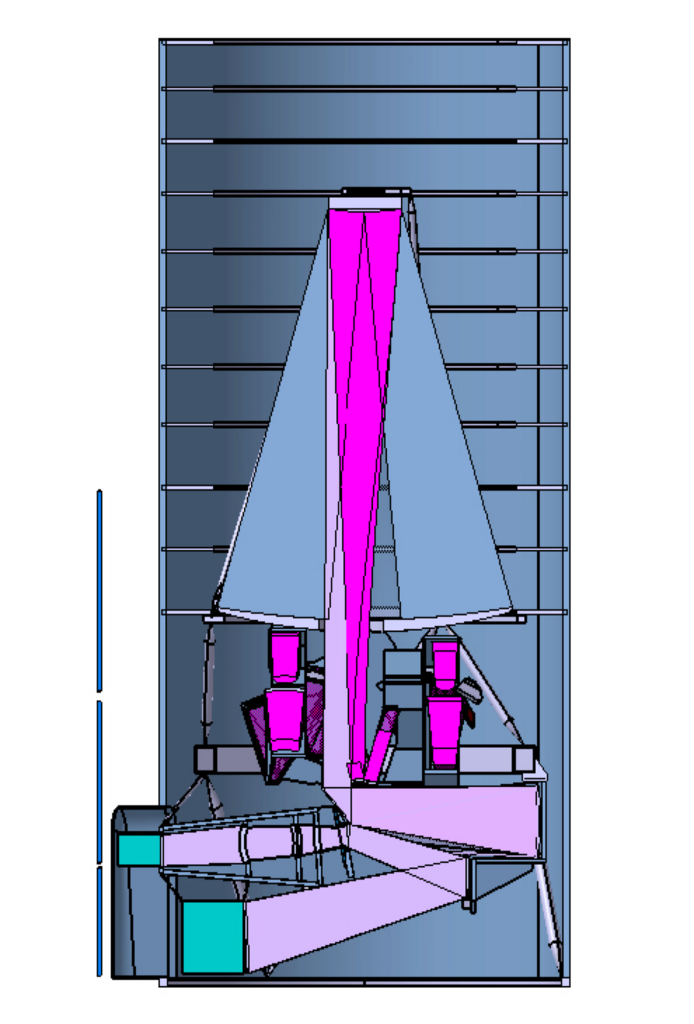
•Measuring the DE equation of state parameters $w_0$ *and* $w_a$ to a precision of 2% and 10%, respectively, using both expansion history and structure growth.

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

•Testing the Cold Dark Matter paradigm for structure formation, and measure the sum of the neutrino masses to a precision better than 0.04eV when combined with Planck.

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

# Euclid Mission Baseline



Mission elements:

- L2 Orbit
- 4-5 year mission
- Telescope: three mirror astigmat (TMA) with 1.2 m primary
- Instruments:

– VIS: Visible imaging channel: 0.5 $deg^2$, 0.10” pixels, 0.16” PSF FWHM, broad band R+I+Z (0.5-0.9mu), 36 CCD detectors, galaxy shapes

– NISP: NIR channel: 0.5 $deg^{2,}$ 16 HgCdTe detectors, 1-2mu:

  - Photometry: 0.3” pixels, 3 bands Y,J,H, photo-z’s
  - Spectroscopy: slitless, R=500, redshifts

# Impact on Cosmology

| | Modified Gravity | Dark Matter | Initial Conditions | Dark Energy | | |
|---|---|---|---|---|---|---|
| Parameter | $\gamma$ | $m_\nu$/eV | $f_{NL}$ | $w_p$ | $w_a$ | FoM |
| Euclid Primary^ | 0.01 | 0.027 | 5.5 | 0.015 | 0.150 | 430 |
| Euclid All | 0.009 | 0.02 | 2 | 0.013 | 0.048 | 1540 |
| Euclid+Planck | 0.007 | 0.019 | 2 | 0.007 | 0.035 | 4020 |
| Current* | 0.2 | 0.58 | 100 | 0.1 | 1.5 | ~10 |
| **Factor Improvement** | **30** | **30** | **50** | **>10** | **>50** | **>300** |

$f = d\ln\delta_m/d\ln a \propto \Omega_m^{\gamma}$

$w(a)=w_p+w_a(a_p-a)$

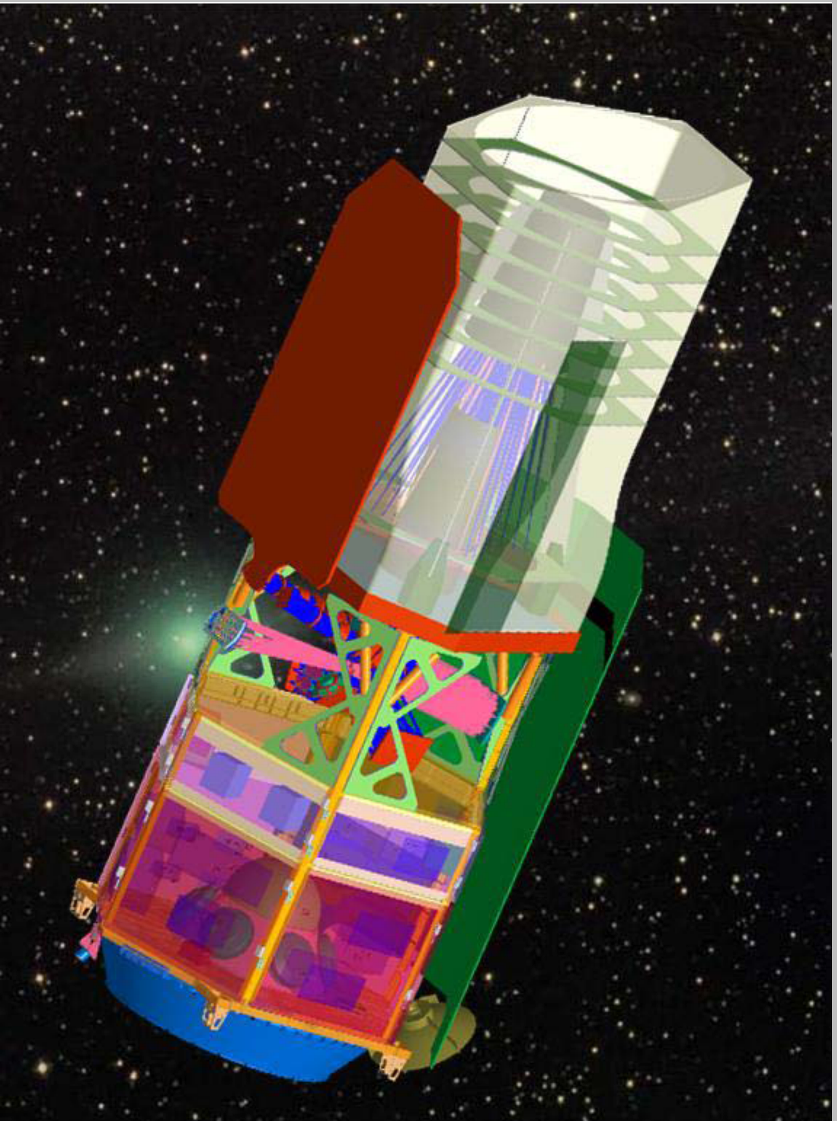
$FoM=1/(dw_p dw_a)$

**Primary:** Five year survey with weak lensing and galaxy clustering from 15,000 deg$^2$ of optical/NIR imaging and slitless spectroscopy (RIZ > 24.5, YJH > 24) and DES/PS2 ground-based data

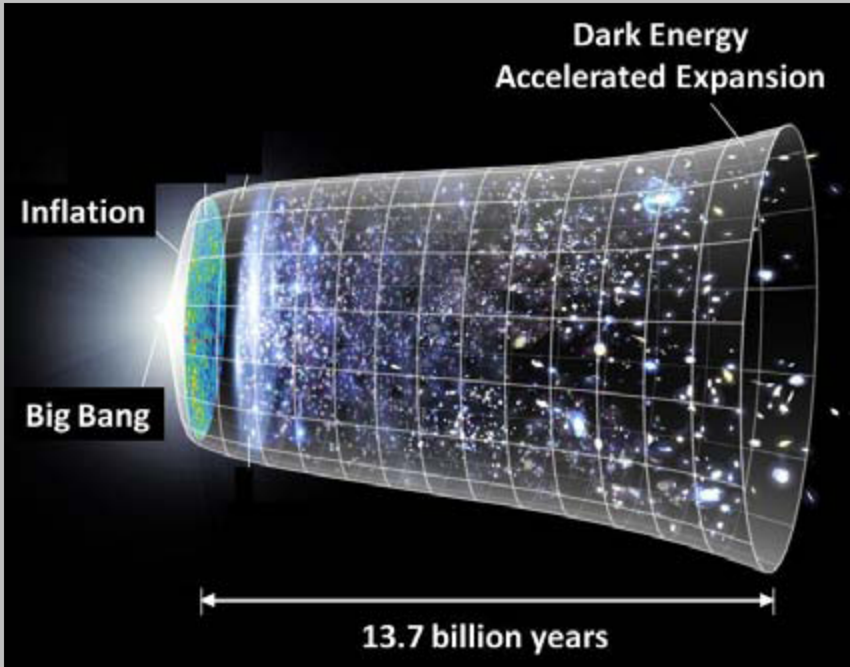
**All:** Including RSD, ISW and clusters from same survey data

# WFIRST

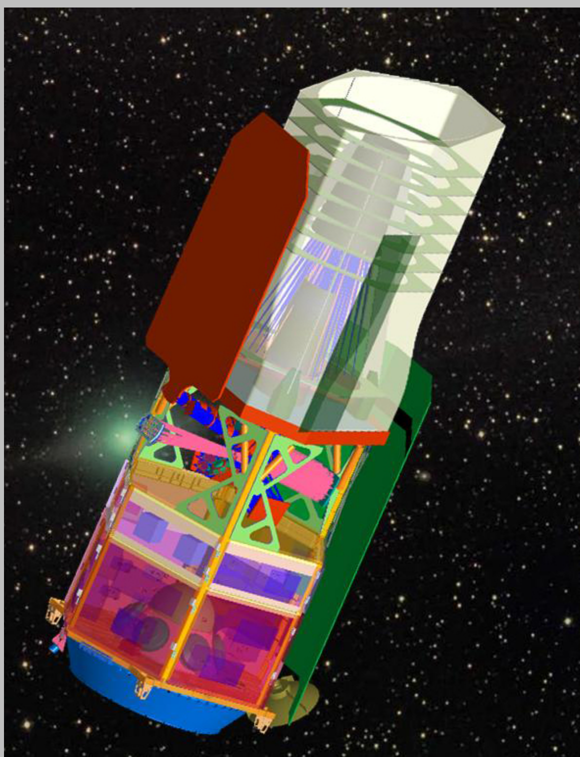
## Wide Field Infrared Survey Telescope



- Dark energy and modified gravity
- Microlensing searches for exoplanets
- Near infrared survey for galaxy formation and evolution



# WFIRST =



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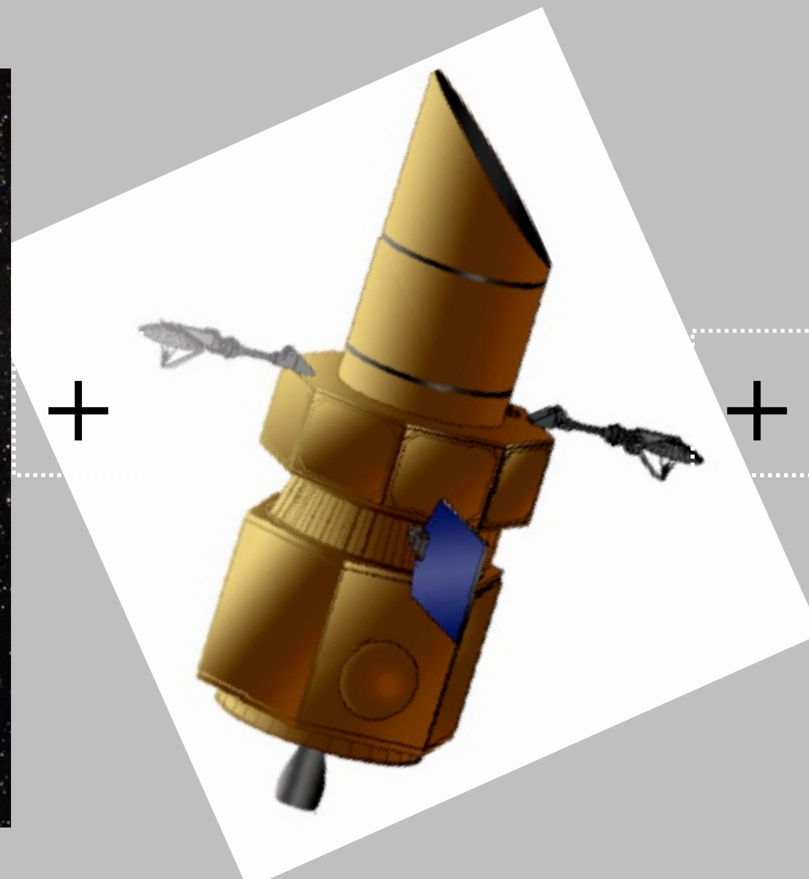

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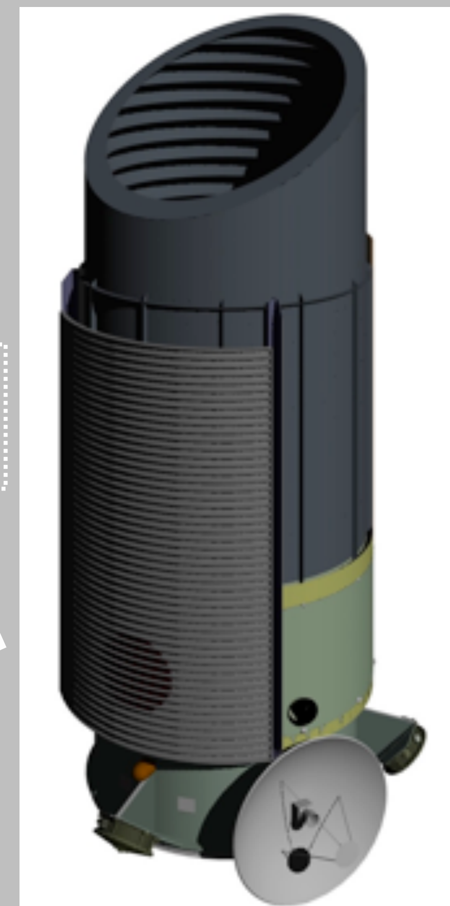


JDEM-Ω

MPF

NIRSS

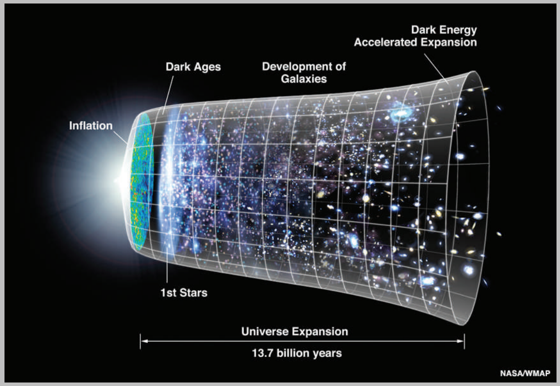
# WFIRST History and Philosophy

- Several high-priority science areas required similar hardware
  - Near infrared (500nm -2+ micron) detectors w ~100Mpix
  - 1-1.5 meter mirror
  - Stable platform in space
- Most robust and capable design was from JDEM, a NASA/ DOE dark energy mission
  - JDEM had several incarnations- JDEM Ω was the one chosen as a baseline
  - Imaging and spectroscopy up to 2 microns on a 1.3m telescope
- Astro2010 top large space recommendation: do WFIRST to accomplish as many of the JDEM, NIRSS, and MPF goals as possible

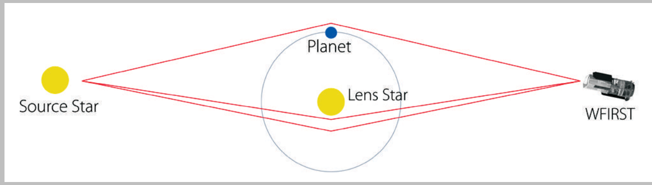
# WFIRST Summary

❖ WFIRST is the highest ranked large space mission in NWNH, and plans to:

- complete the statistical census of Galactic planetary systems using microlensing
- determine the nature of the dark energy that is driving the current accelerating expansion of the universe
- survey the NIR sky for the community




❖ Earth-Sun L2 orbit, 5 year lifetime, 10 year goal

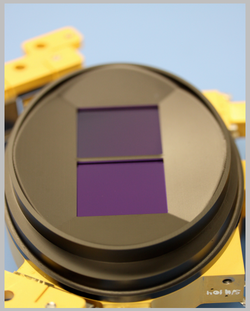


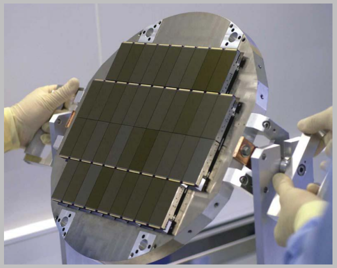

❖ The current Interim Design Reference Mission has

- 1.3 m unobstructed telescope
- NIR instrument with ~36 HgCdTe detectors
- >10,000 deg$^2$ 5-sigma NIR survey at mag AB=25

❖ The time is ripe for WFIRST:

- Space-qualified large format HgCdTe detectors are US developed technology and flight ready





# WFIRST Status

- Science Definition Team has delivered interim report and associated design reference mission
- Must be sold to OMB (Congress) and the OSTP (President)
- Negotiations with ESA will likely take place after Euclid downselect
- Could start an 84 month development and implementation cycle as soon as 2013 (funding permitting)

# WFIRST – Science Objectives

1) Complete the statistical census of planetary systems in the Galaxy, from habitable Earth-mass planets to free floating planets, including analogs to all of the planets in our Solar System except Mercury.

2) Determine the expansion history of the Universe and its growth of structure in order to test explanations of its apparent accelerating expansion including Dark Energy and possible modifications to Einstein's gravity.

3) Produce a deep map of the sky at NIR wavelengths, enabling new and fundamental discoveries ranging from mapping the Galactic plane to probing the reionization epoch by finding bright quasars at $z>10$.

# Exoplanet Survey Capability

- **Planet detection to 0.1 Earth mass ($M_{Earth}$)**
- **Detects ≥ 30 free floating planets of 1 $M_{Earth}$ in a 500 day survey***
- **Detects ≥ 125 planets of $M_{Earth}$ (in 2 year orbits) in a 500 day survey***
- **Detects ≥ 25 habitable zone† planets (0.5 to 10 $M_{Earth}$) in a 500 day survey ***

*** Assuming one such planet per star; "500 day surveys" are concurrent**

**† 0.72-2.0 AU, scaling with the square root of host star luminosity**

## Data Set Rqts include:

✓Observe ≥ 2 square degrees in the Galactic Bulge at ≤ 15 minute sampling cadence;
✓Minimum continuous monitoring time span: ~60 days;
✓Separation of ≥4 years between first and last observing seasons.

# Dark Energy Survey Capabilities

- **BAO/RSD: … “WIDE” survey mode**
  - 11,000 $deg^2$/dedicated year
  - Redshift errors $\sigma_z \leq 0.001(1+z)$, over redshift range $0.7 \leq z \leq 2$
- **Weak Lensing: … “DEEP” survey mode**
  - 2700 $deg^2$/dedicated year
  - Effective galaxy density ≥30/$amin^2$, shapes resolved plus photo-zs
- **SNe-Ia Survey:**
  - >100 SN per $\Delta z$= 0.1 bin for most bins $0.4 < z < 1.2$, per dedicated 6 months
  - Redshift error $\sigma_z \leq 0.005$ per supernova

# NIR Survey Capability

- **Identify ≥100 quasars at redshift *z*>7**
- **Obtain broad-band NIR spectral energy distributions of ≥$10^9$ galaxies at z>1 to extend studies of galaxy formation and evolution**
- **Map the structure of the Galaxy using red giant clump stars as tracers**

**Data Set Rqts include:**

✓High Latitude data from Imager and Spectrometer channels during BAO/RSD and WL Surveys;
- Image 2500 deg$^2$ in 3 NIR filters to mag AB=25 at S/N=5

✓Galactic Plane Survey (~0.5 yr, per EOS Panel);
- Image 1500 deg$^2$ of the Galactic Plane in 3 NIR filters

✓Guest Investigator observations (~1 yr, per EOS Panel) will supplement

# Science Return

## Mission Performance: EOS Panel vs WFIRST IDRM

| Science Investigation | EOS Panel Report | WFIRST IDRM |
|---|---|---|
| WL Survey | 4000 $deg^2$ | 2700 $deg^2$/yr |
| BAO Survey | 8000 $deg^2$ | 11,000 $deg^2$/yr |
| SNe | Not Mentioned | 1200 SNe per 6 months |
| Exoplanet Microlensing | 500 total days | 500 total days |
| Galactic Plane Survey | 0.5 yr GP Survey | 0.5 yr GP Survey |
| Guest Investigators | 1 year GI observations | 1 year GI observations |

## Dark Energy Performance: NWNH Main Report vs WFIRST IDRM

| DE Technique | NWNH Main Report | WFIRST IDRM 5 yr mission | WFIRST IDRM 5 yr Dark Energy* |
|---|---|---|---|
| WL Galaxy Shapes | 2 billion | 300 million (1 yr) | 600 million (2 yr) |
| BAO Galaxy Redshifts | 200 million | 60 million (1 yr) | 120 million (2 yr) |
| Supernova SNe-Ia | 2000 | 1200 (1/2 yr) | 2400 (1 yr) |

***Including 5 year extended mission**