WFIRST & Euclid

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Overview

Fundamental Scientific Questions

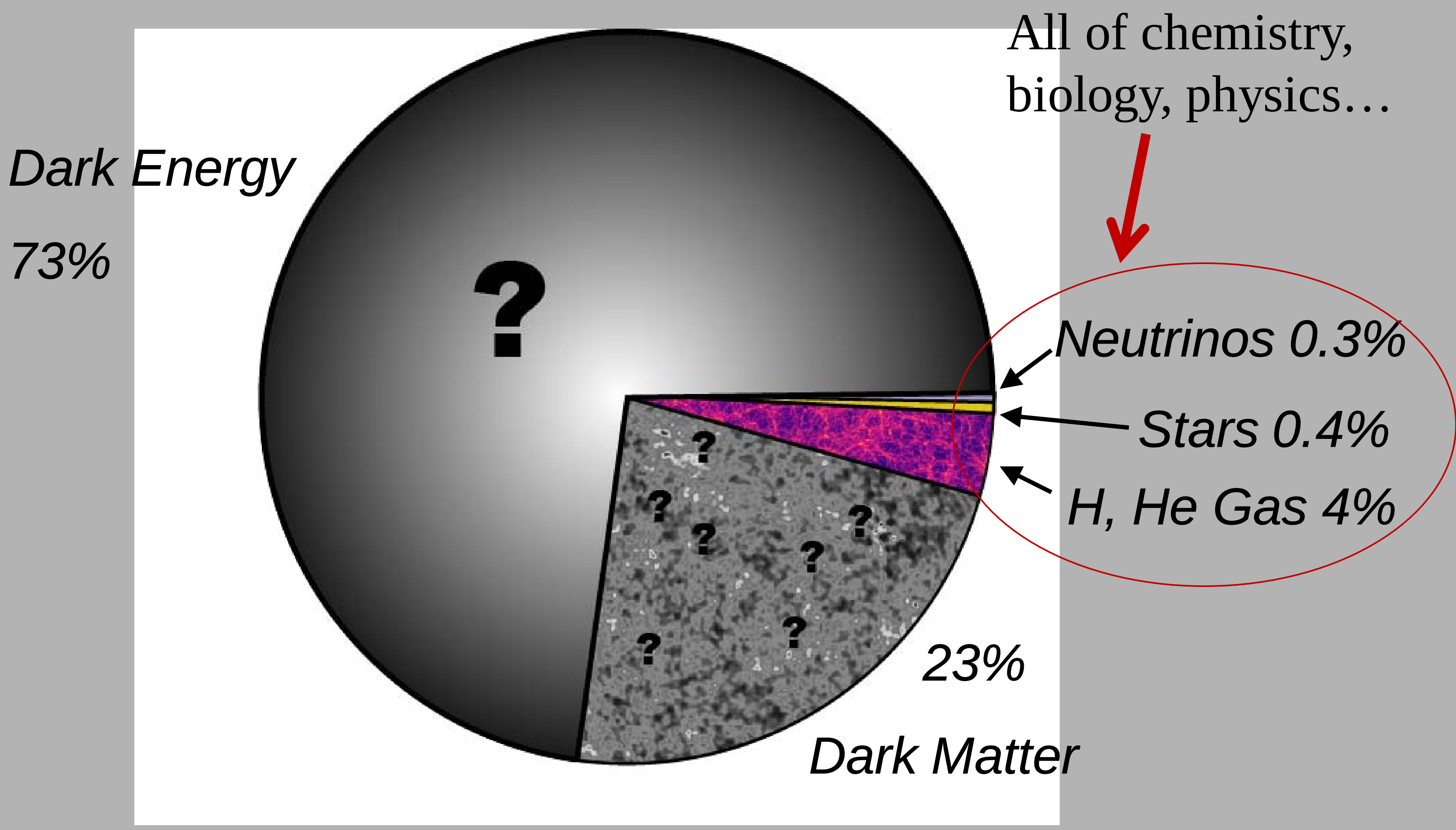
- Dark Matter and Energy
- The abundance of Earth-like planets
- The Evolution of Galaxies & Near Infrared Survey Science

The Missions:

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

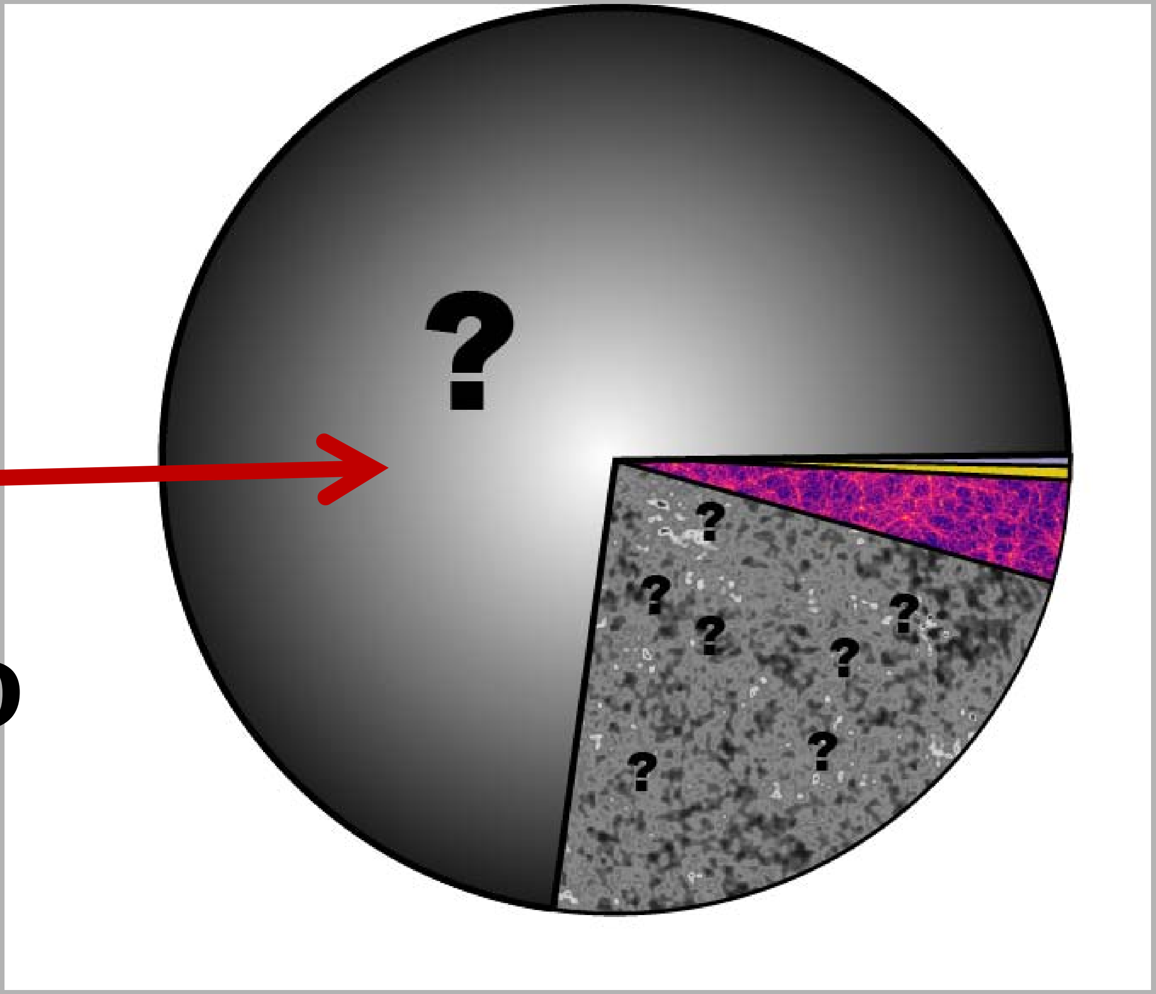
Japan has leading researchers and projects in the above science

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

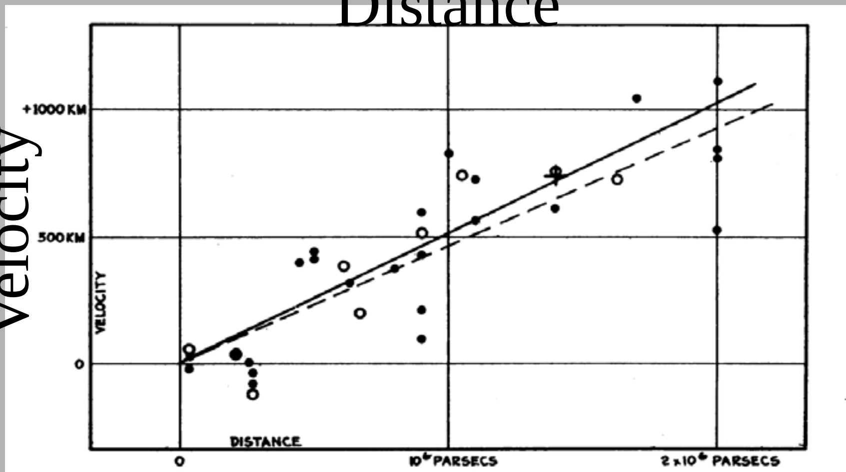
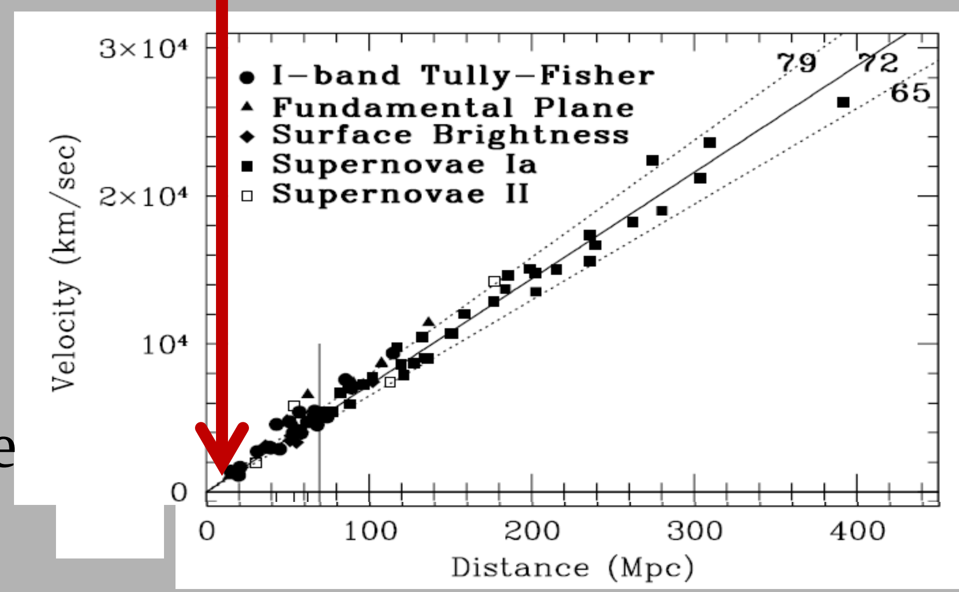


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

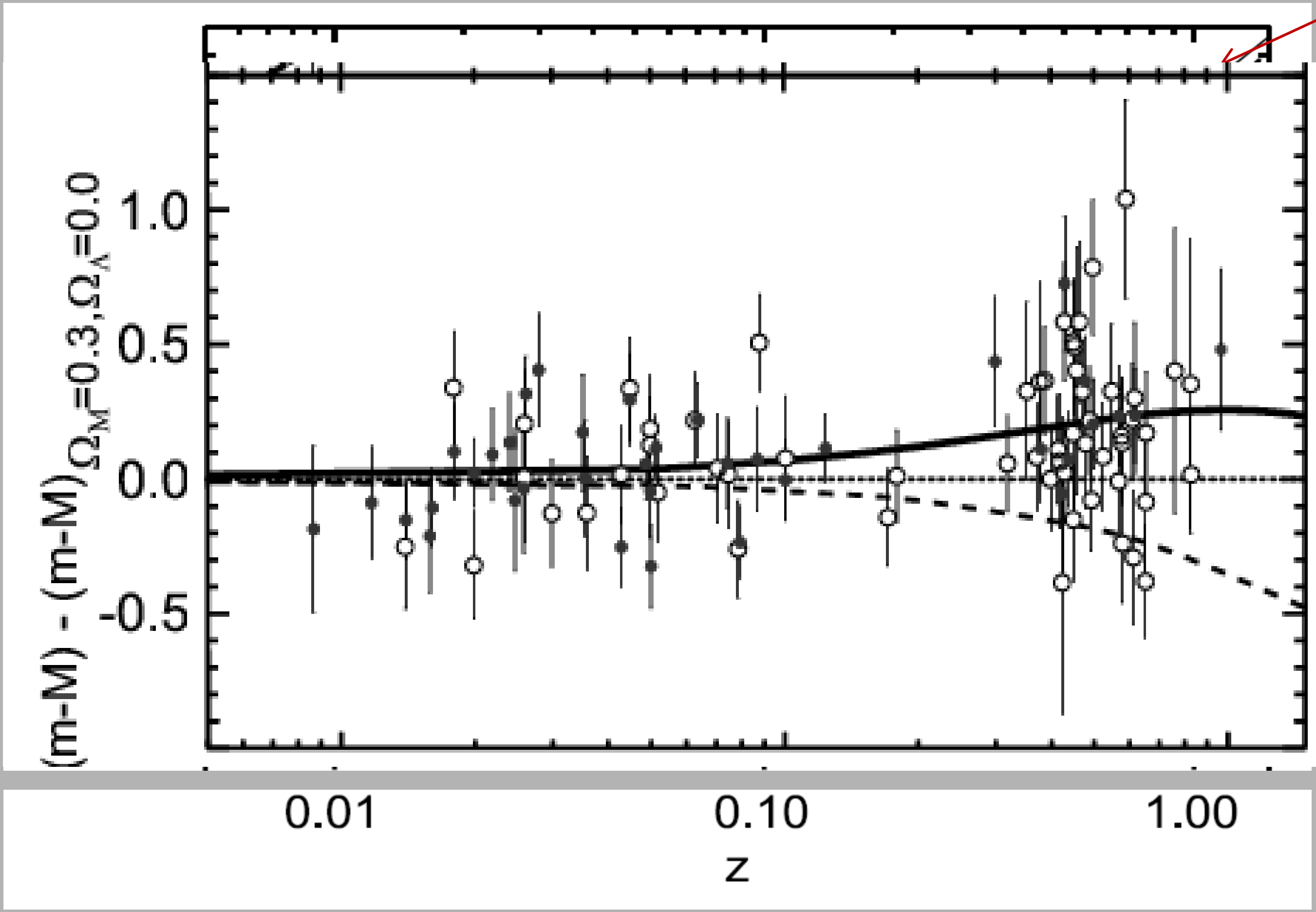
The farther away something is, the faster it is moving away, *in all directions!*

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

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

Gravity or space curvature

Mass and energy

- Λ 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 Equation

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

Gravity or space curvature

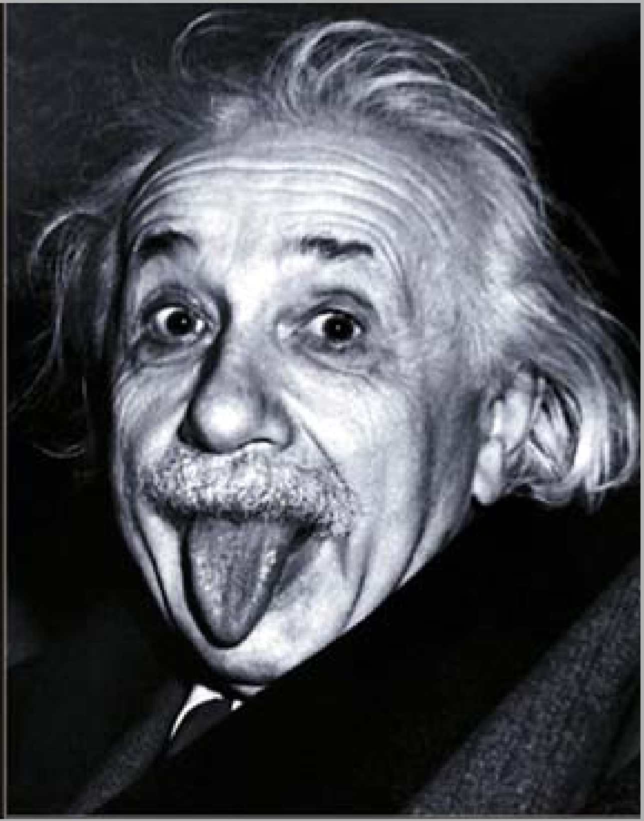
Mass and energy

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

- This only works for a Universe that is 'steady state' or collapsing under gravity
- Doesn't describe our Universe with accelerating expansion

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 Λ 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 Λ

- Einstein called Λ his 'biggest blunder'

In 1998, when the accelerating expansion was discovered, Λ 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 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!*

Three Primary Dark Energy Probes

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

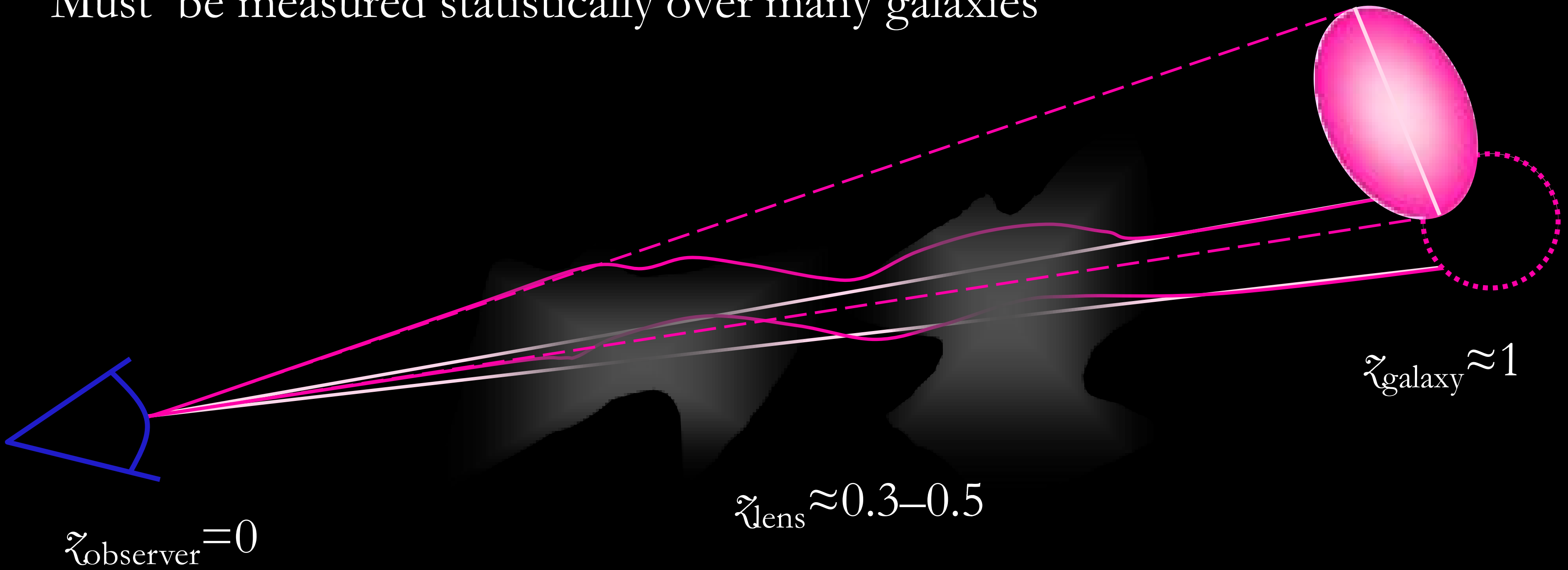
Supernova Ia are *standard candles* that measure the expansion history

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

Weak Gravitational Lensing

Weak lensing effect cannot be measured from any individual galaxy.

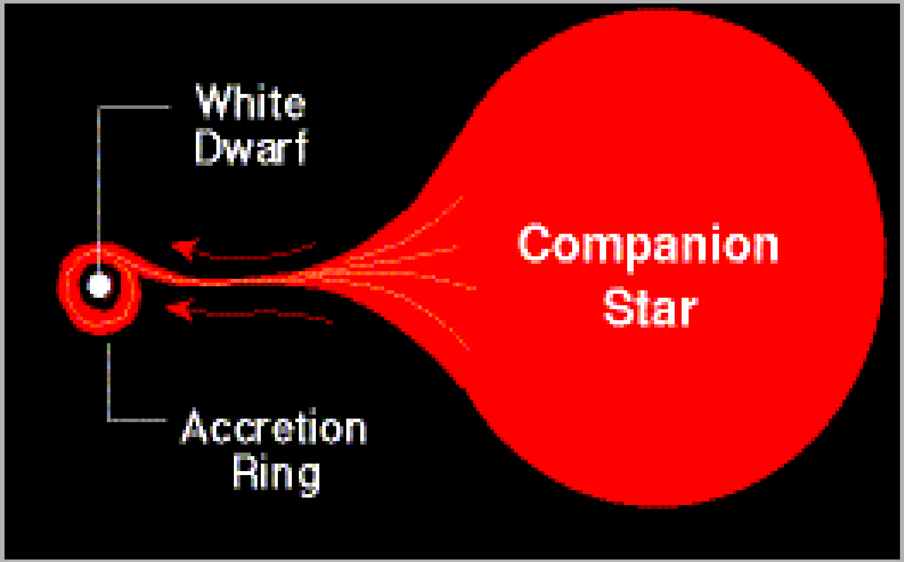
Must be measured statistically over many galaxies



If there is any intervening large-scale structure, light follows the distorted path (exaggerated). Background images are magnified and sheared by ~2%, mapping a circle into an ellipse. Like glass lenses, gravitational lenses are most effective when placed half way between the source and the observer.

Standard Candles

Supernovae Ia are thought to be white dwarf stars that reach critical mass through gobbling up gas from a nearby

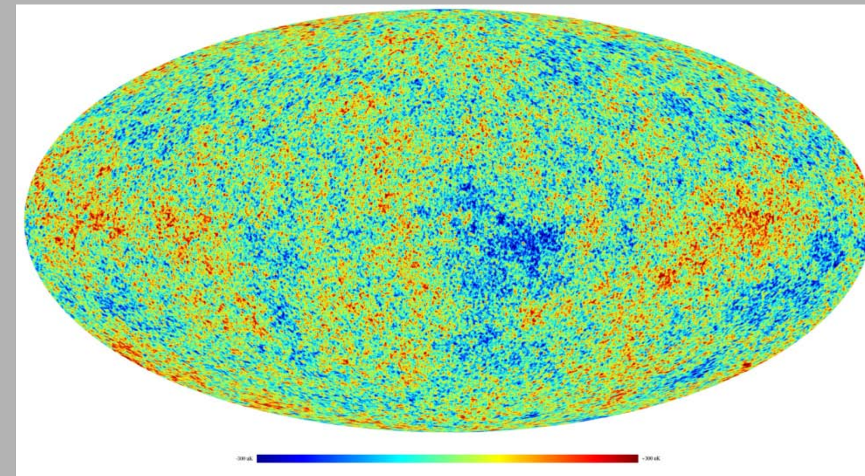


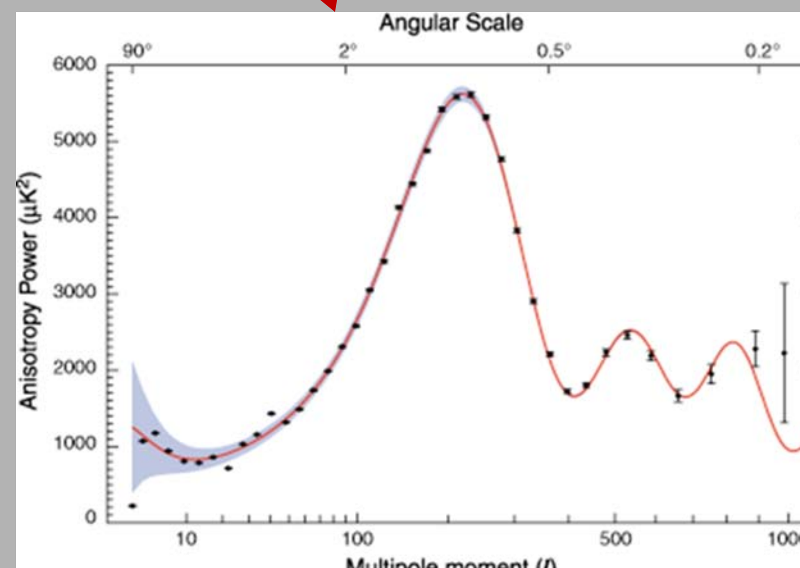
SuperNova 1994D, HST, NGC 4526

- When critical mass is reached, a thermonuclear runaway explosion results, and consumes the entire white dwarf star
- By measuring the timescales of rise and fall in brightness of the supernovae, one can estimate its intrinsic brightness and use it as a standard candle

Standard ruler: baryonic acoustic oscillations (BAO)

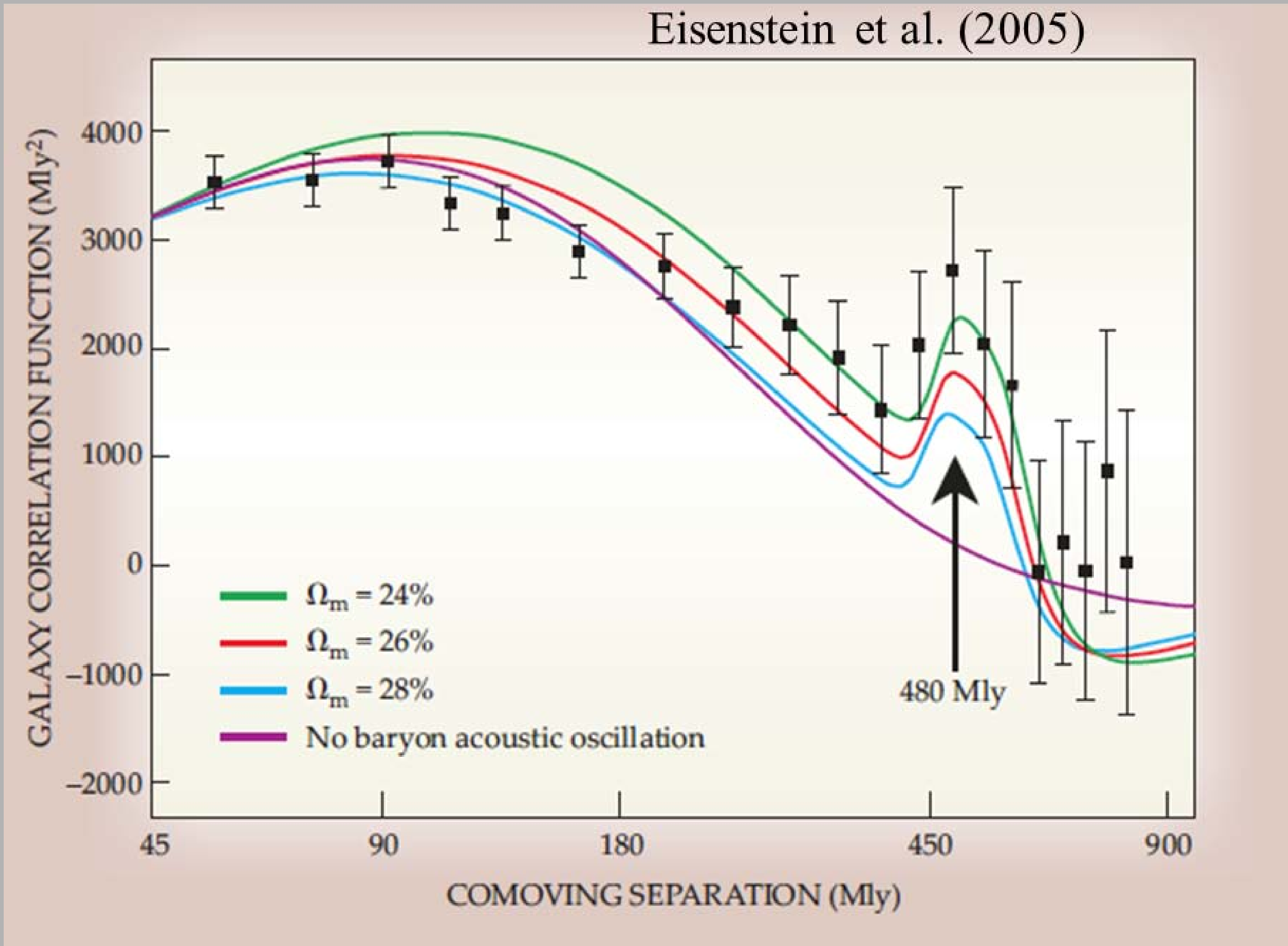
- **In early Universe, sound waves could ripple through plasma like ripples on a pond**
- **Fixed scale imposed when the Universe became transparent (seen in CMB data; 1 part in 10,000)**
- **Fluctuations grew to large structures (DM, galaxies, everything)**





Baryon Acoustic Oscillations

Spectacular confirmation of this prediction from the Sloan Digital Sky Survey –50,000 galaxies with positions and spectra.



The basic picture of structure formation through gravity is confirmed.

Dark energy is required. Without it, the 480 million light-years would be a smaller number.

Why space ?

- WL
  - accurate shapes require small and stable PSF
  - Accurate photometric redshifts (distances) require NIR data
- SN
  - Requires continuous monitoring
  - NIR gives redshift range
- BAO
  - NIR gives redshift range

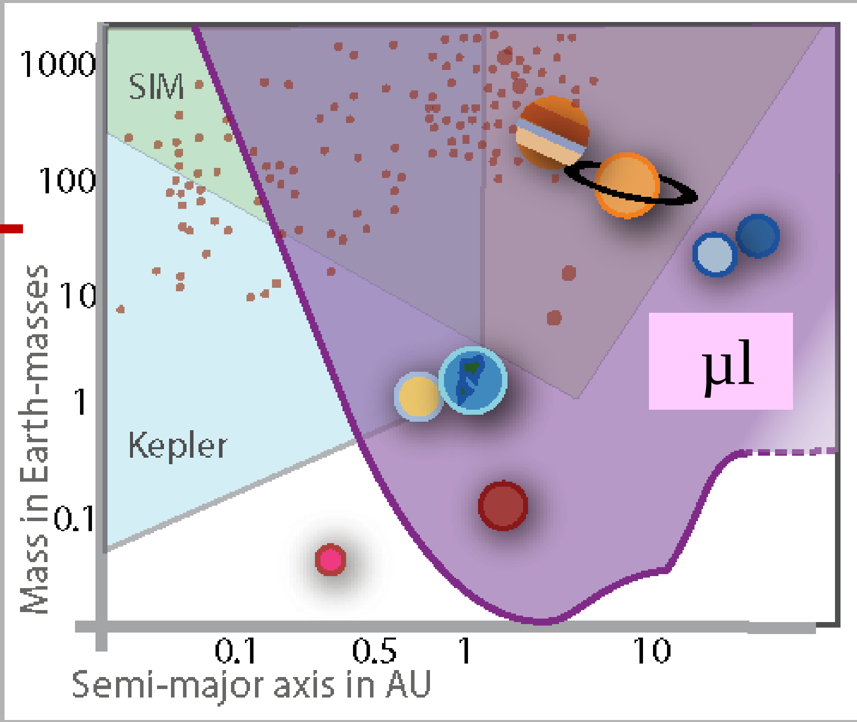
Are We Alone?

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

Multiple techniques exist for finding planets

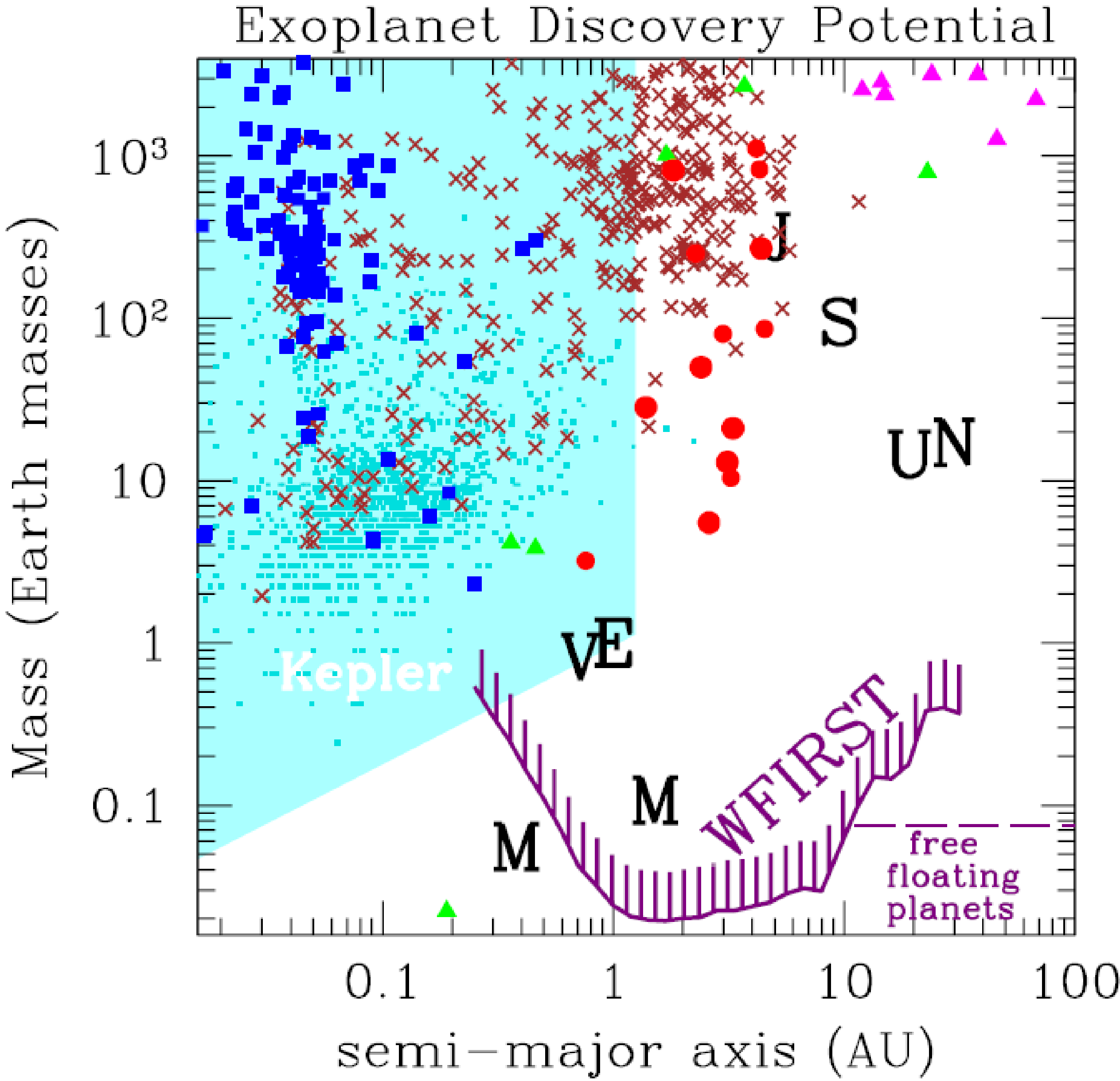
Gravitational microlensing allows a statistical census for planets near the “interesting” region:

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



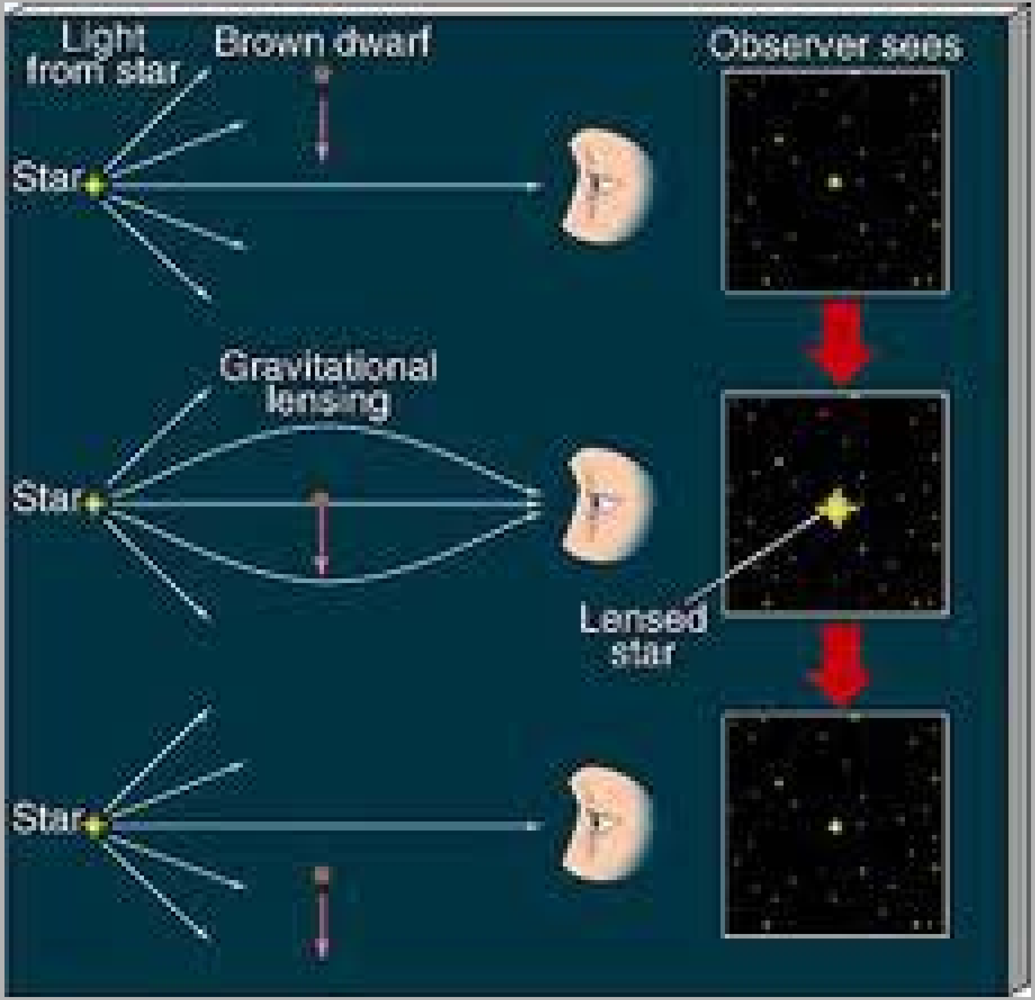
Planet Discoveries by Method

- ~400 Doppler discoveries in black
- Transit discoveries are blue squares
- Gravitational microlensing discoveries in red
  (cool, low-mass planets)
- Direct detection, and timing are magenta and green triangles



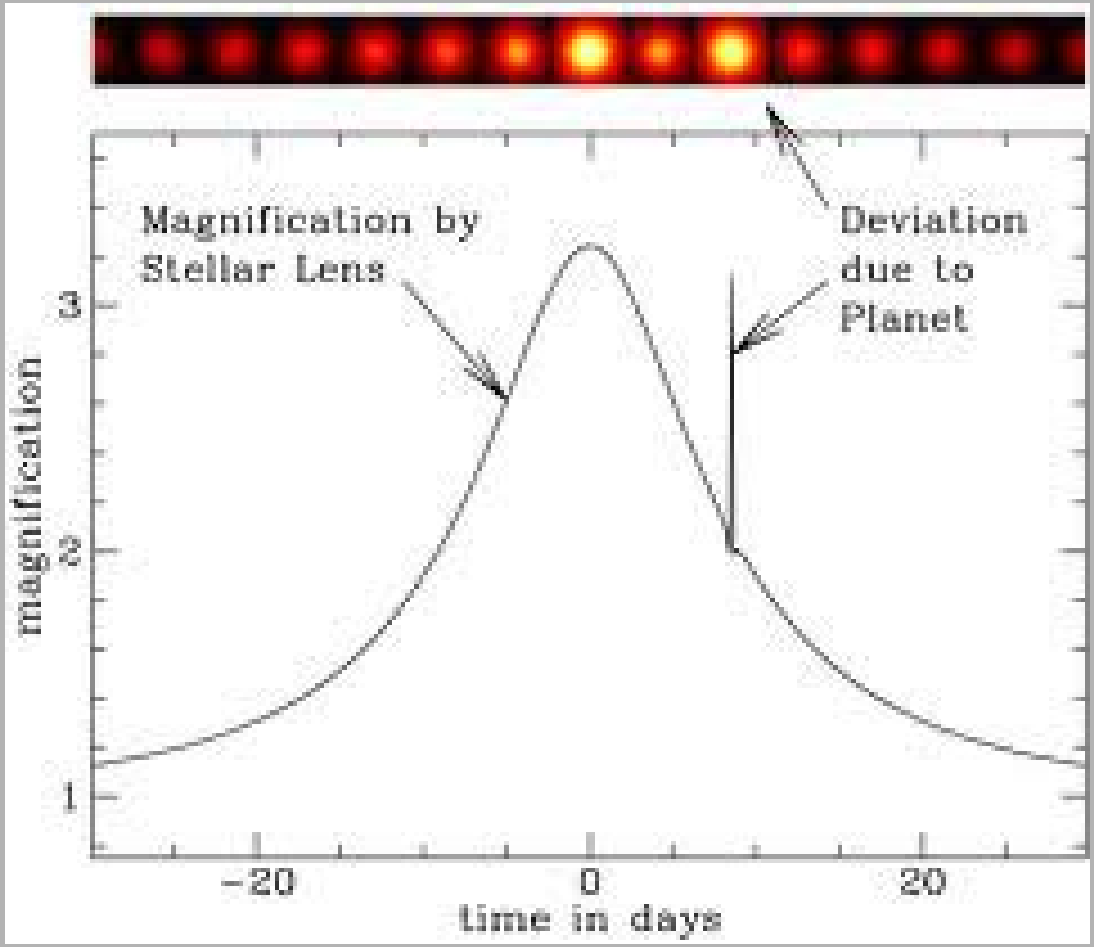
Microlensing of Stars

- When the path of a foreground star crosses near a background star, its gravity bends and focuses the light from the background star.
- The background star is the 'source', and the foreground star is the 'lens'.
- The result is a time-dependent magnification of the light we receive from the 'source' star.



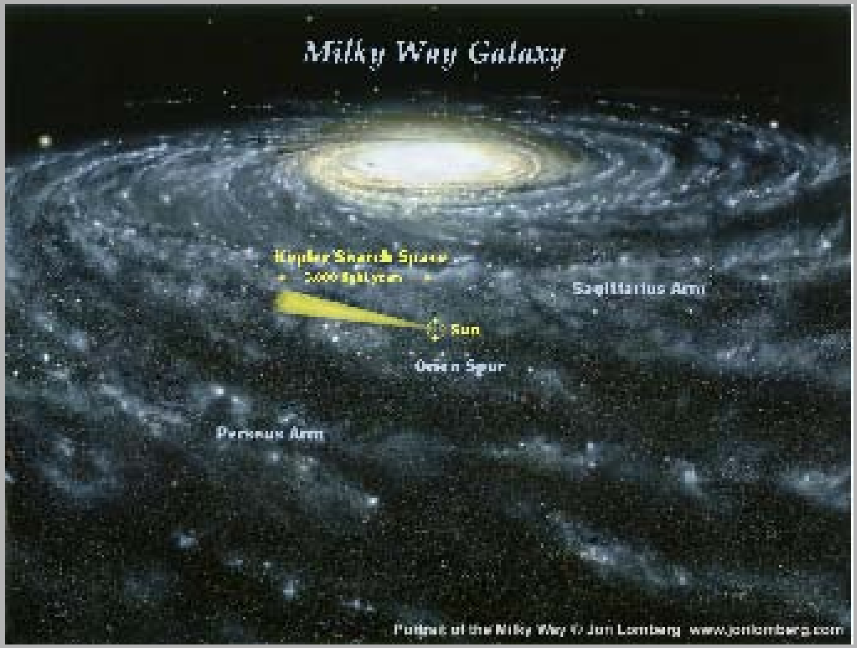
Stellar and exoplanetary microlensing

- Typical time scale for a stellar event is 1 to 2 months.
- If the ’lens’ star has a planet, its gravity may also contribute to lensing the light from the ’source’.
- This produces a secondary peak in the light curve.
- Typical exoplanetary deviation lasts only hours to days.



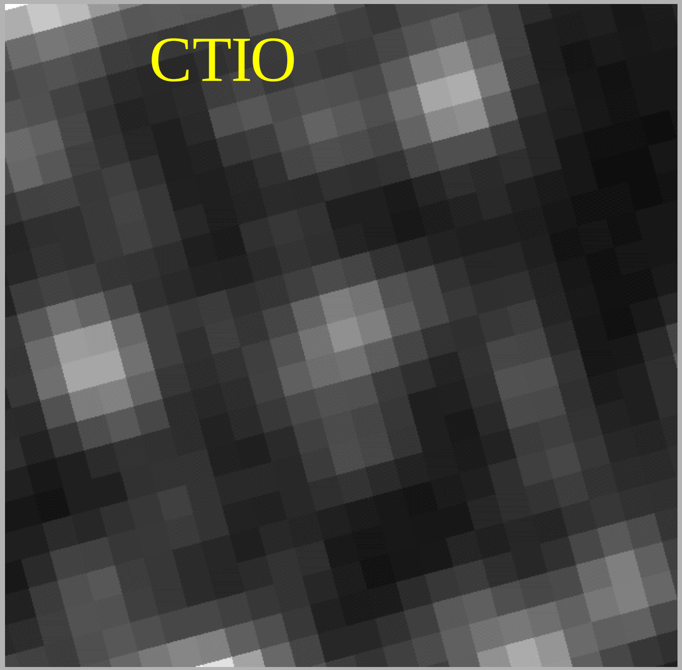
Exoplanet surveys

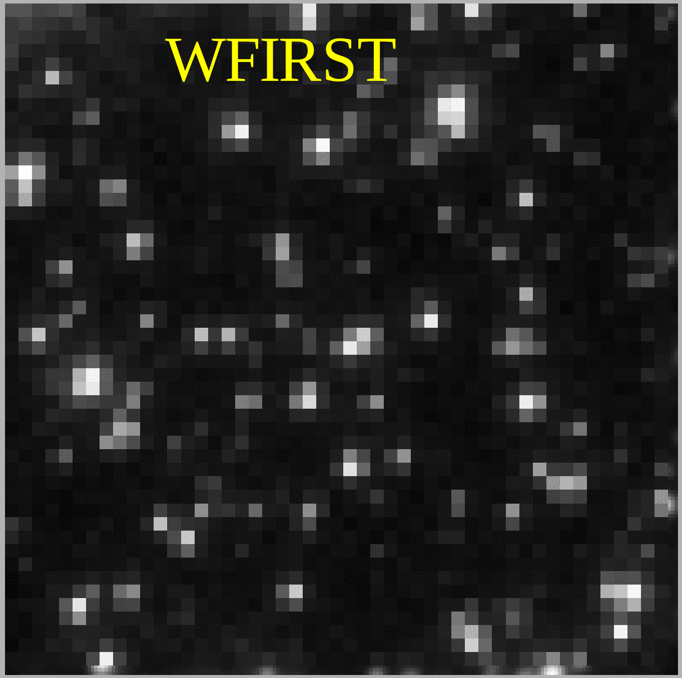
- **Exoplanetary microlensing is a low probability phenomenon.**
- **In order to monitor many potential events, we need**
  - **A Wide-field survey**
  - **Pointed at a region that is dense in stars, e.g. the galactic bulge**
- **High-cadence continuous sampling**
- **IR telescope, because**
  - **Can see farther through dust, and**
  - **Most stars are M stars, which strongly radiate in the IR**



Typical 'Source' star is a giant or dwarf in the bulge.
Typical 'Lens' star is a red main-sequence star in the foreground disk or bulge

Why do we need a space-based survey?

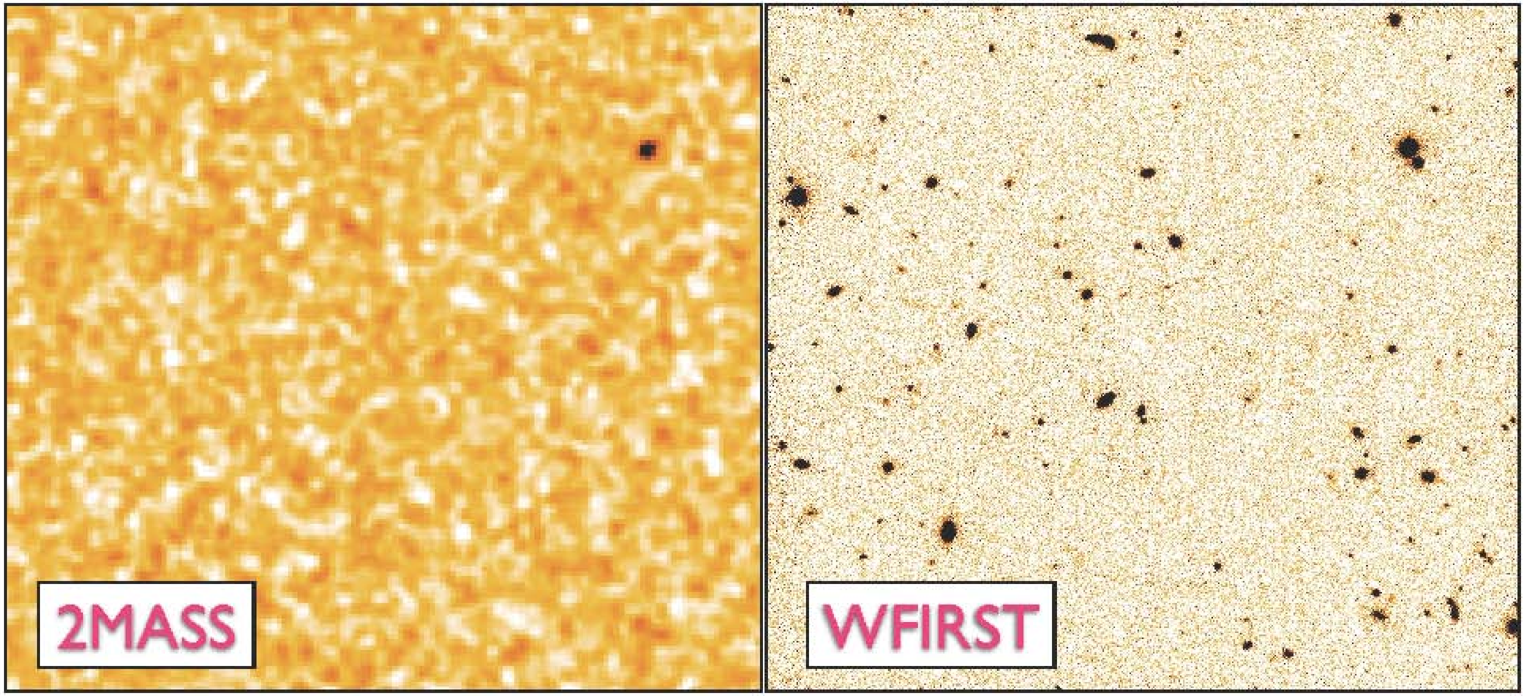




- **Space-based imaging is needed for high precision photometry of main sequence source stars (at low magnification) and lens star detection**

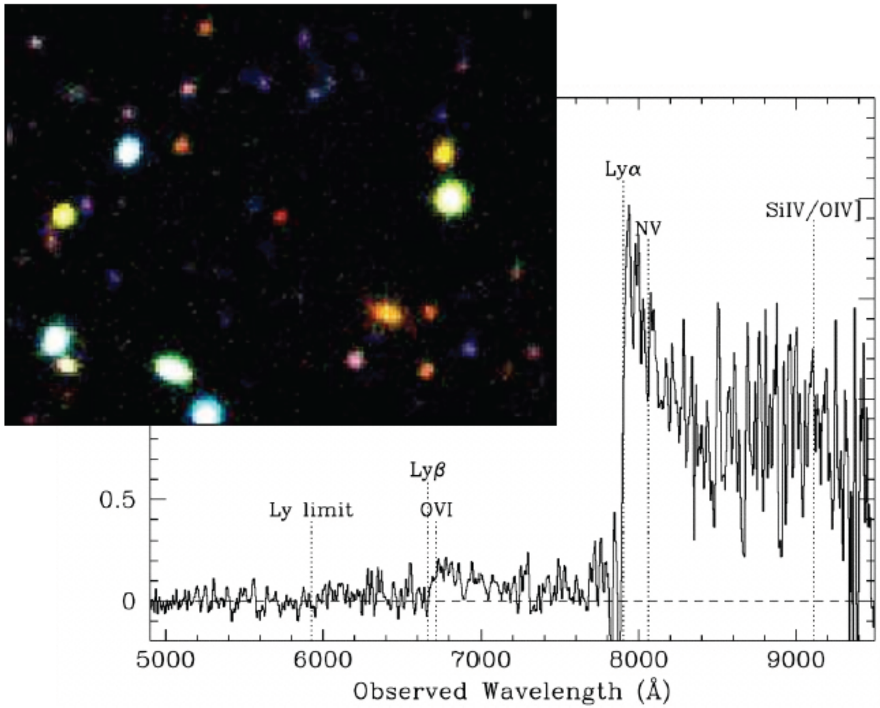
- **High Resolution + large field + 24 hr duty cycle**

NIR Survey Science



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

High Redshift Quasars



WFIRST
Precursor concept

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
  - early history of black hole growth
  - proxy for early galaxy growth / growth of large-scale structure (LSS)
  - large numbers of high-redshift QSO pairs

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

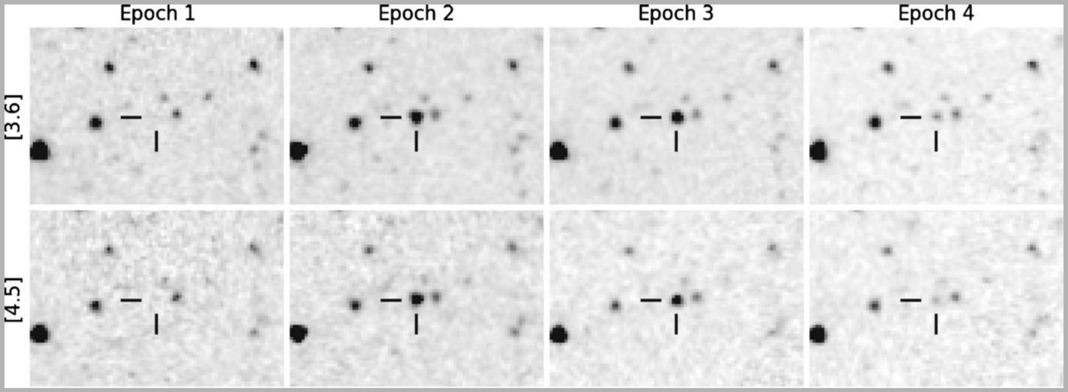
• grism/spectroscopy data data too...

• depth slightly lower than COSMOS, but covering >1000x greater area

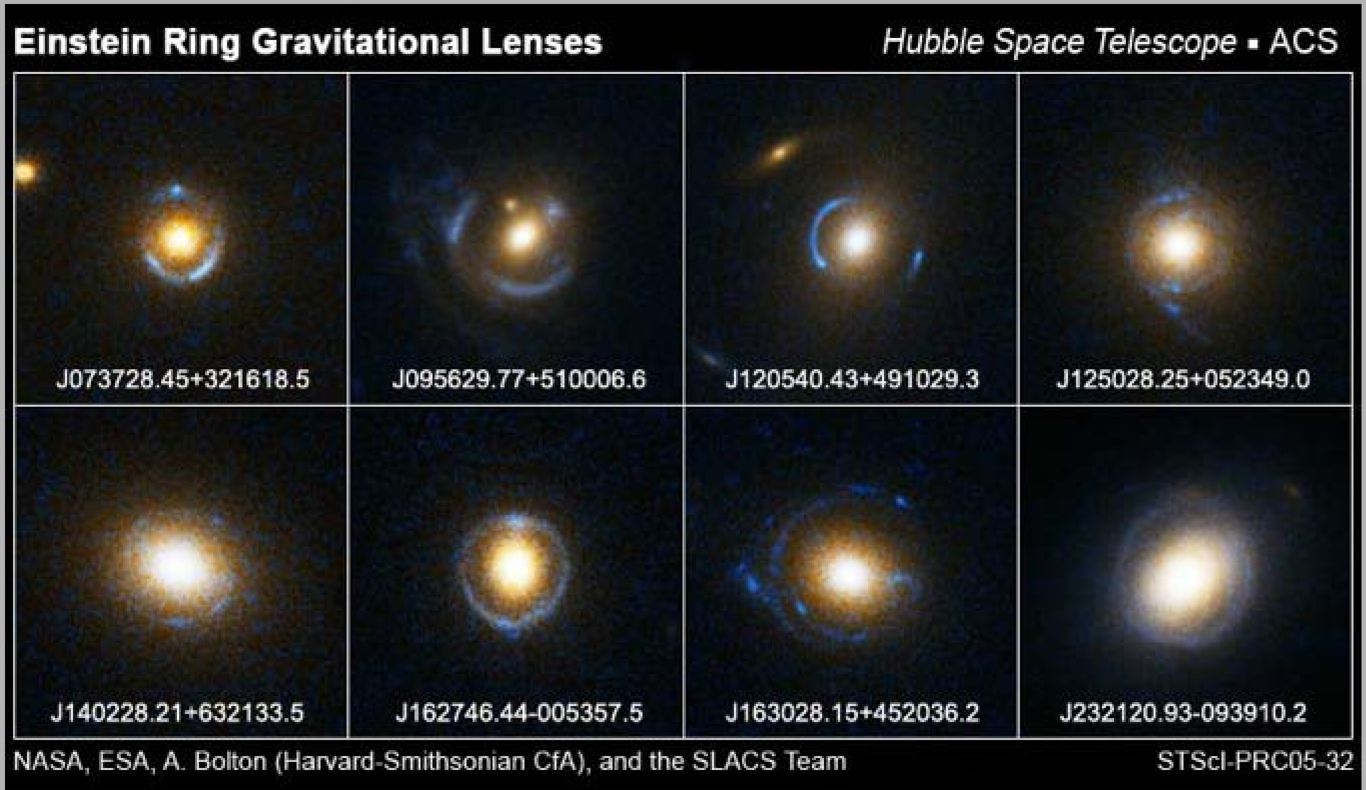
- near-IR very powerful for identifying massive galaxies and clusters at $z>1$

Serendipity

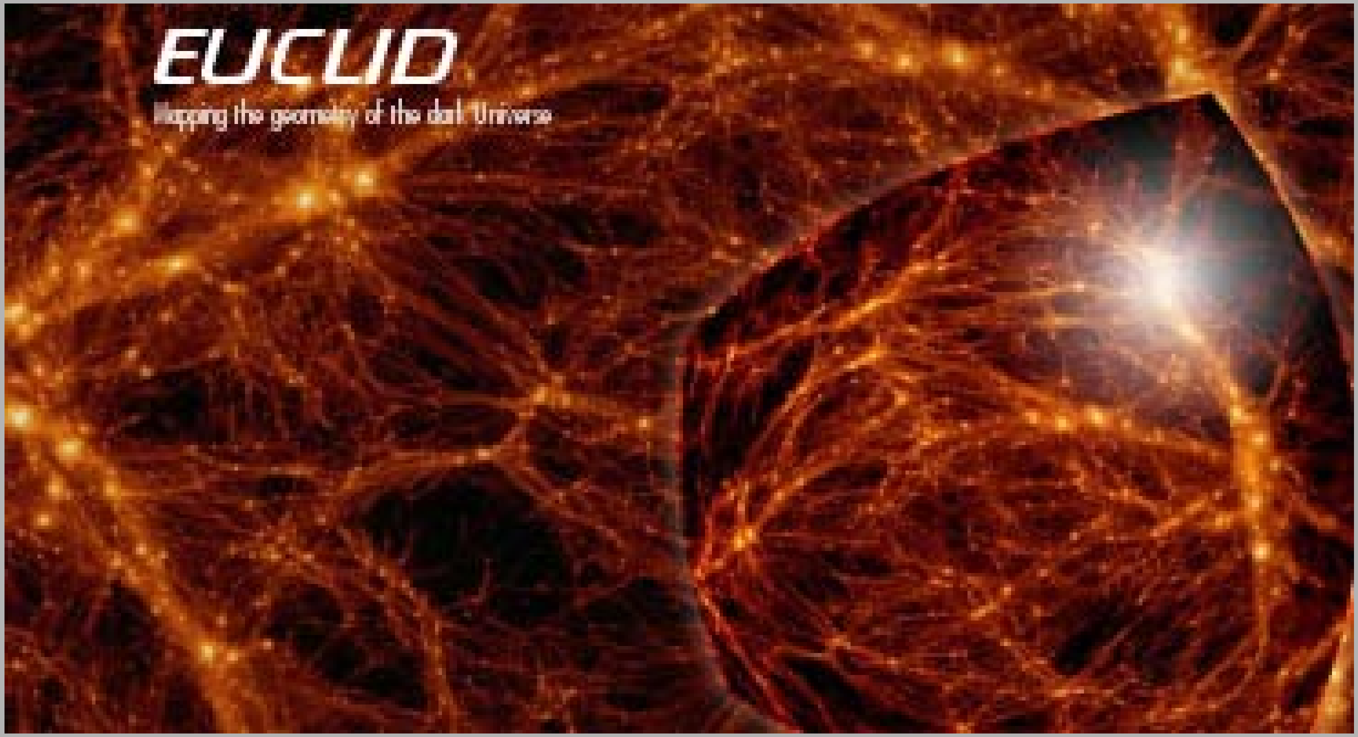
- Variable and rare objects
- Strong gravitational lenses
- ???

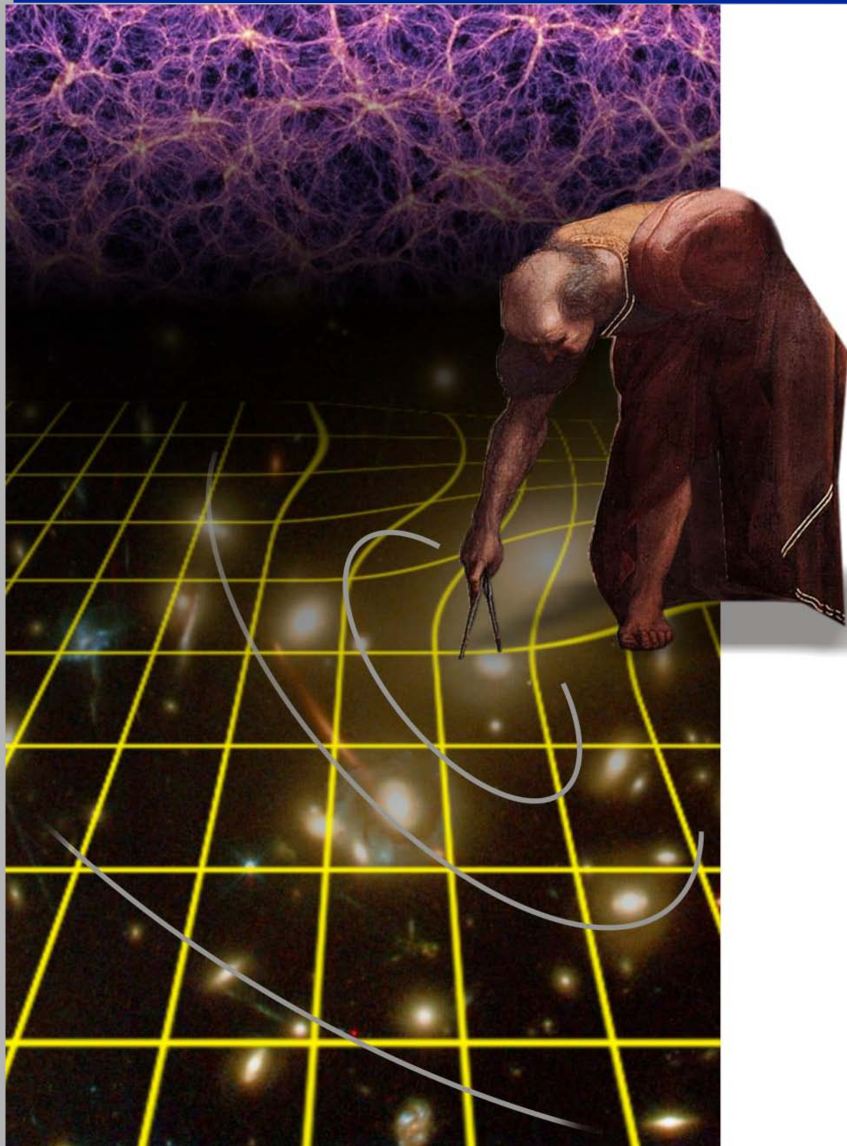


- most variable source in Spitzer Deep, Wide-Field Survey
- • a dust-enshrouded supernova at z~0.2 (SN 2007va)
- • ηCarinae analog



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

April 2010: Formation of single Euclid Consortium

2010-2011: Definition phase

July 2011: Final Euclid Proposal- Red Book

Oct 2011: Cosmic Vision Selection

2012-2018: Implementation phase

2018: launch

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 γ 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 concept

- **Optimized for two complementary cosmological probes:**
  - —**Weak Gravitational Lensing**
  - —**Baryonic Acoustic Oscillations**
  - **Additional probes: clusters, redshift space distortions, ISW**
- **15,000 square degree survey**
  - —**Imaging (WL):**
    - **High precision imaging at visible wavelengths**
    - **Photometry/Imaging in the near-infrared**
  - —**Near Infrared Spectroscopy (BAO)**

- **No SN, exoplanet microlensing for now**

Euclid Mission Baseline

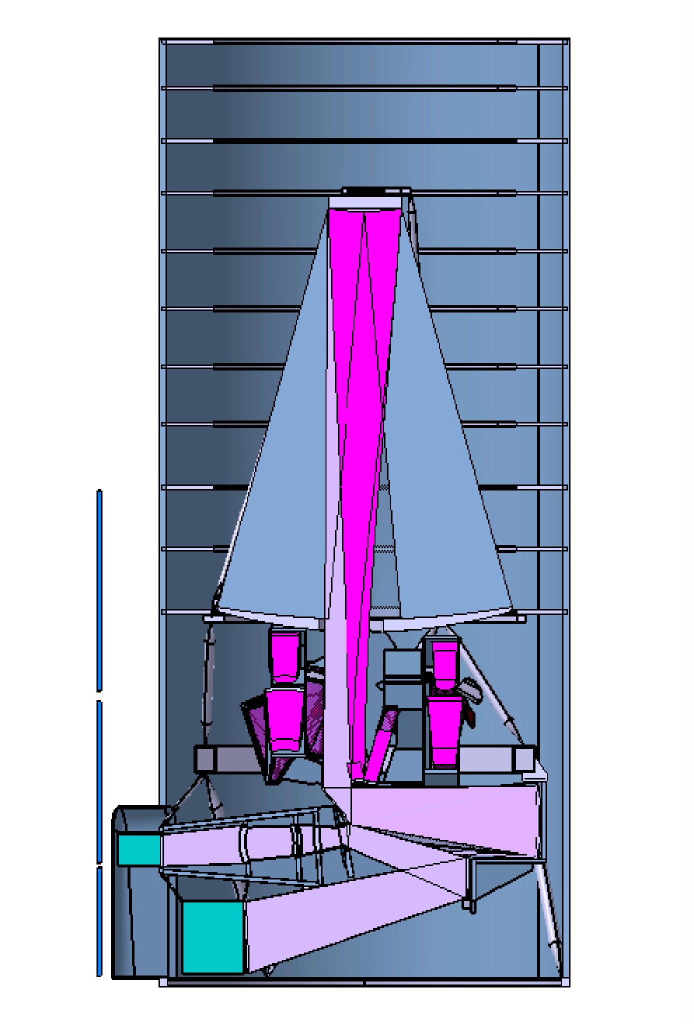
Mission elements:

- L2 Orbit
- 5-6 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	γ	m_ν/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**

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

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

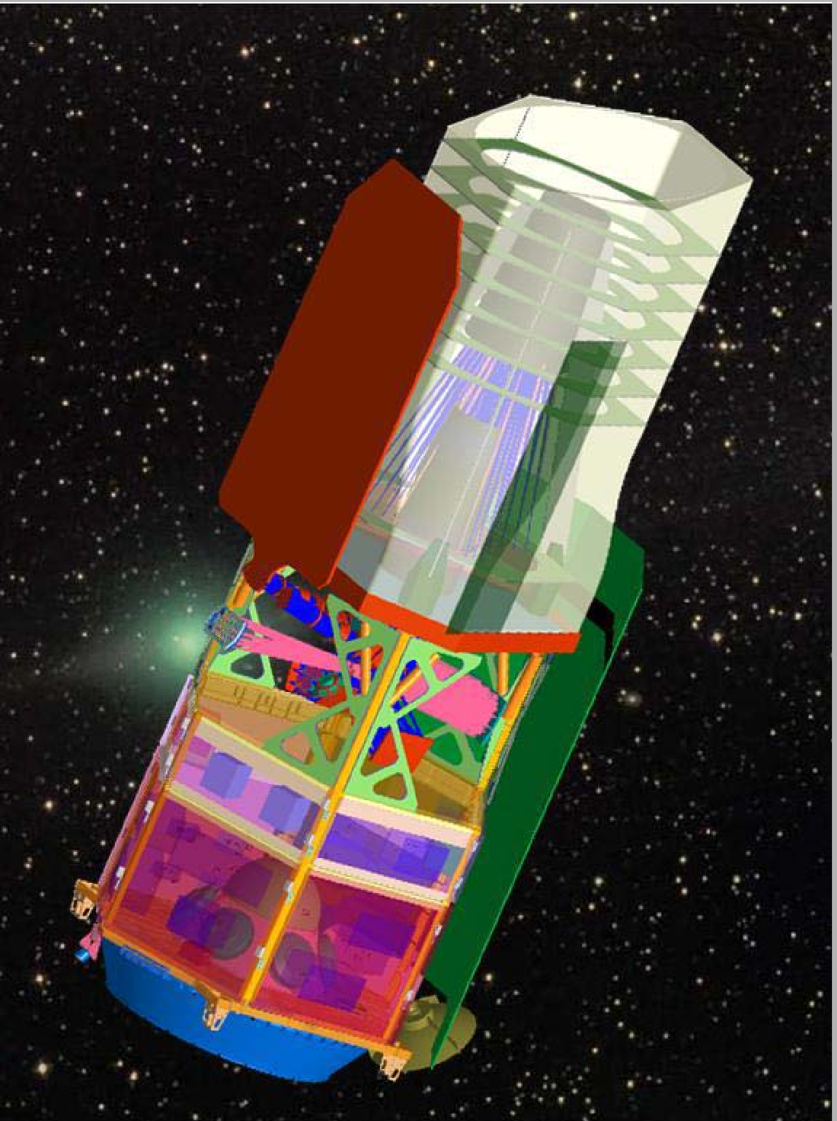
$FoM=1/(dw_p dw_a)$

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

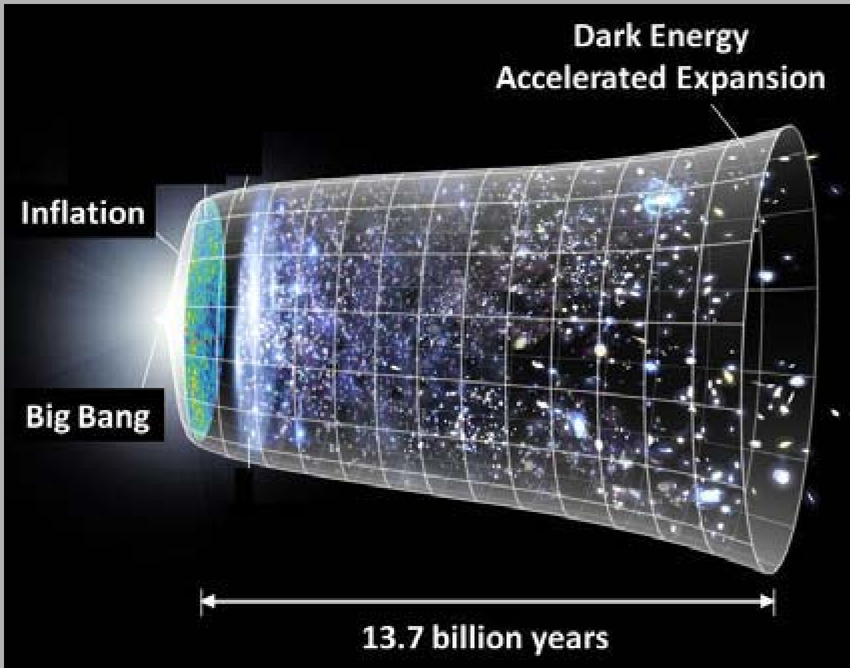
All: Including RSD, ISW and clusters from same survey data

WFIRST

Wide Field Infrared Survey Telescope



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



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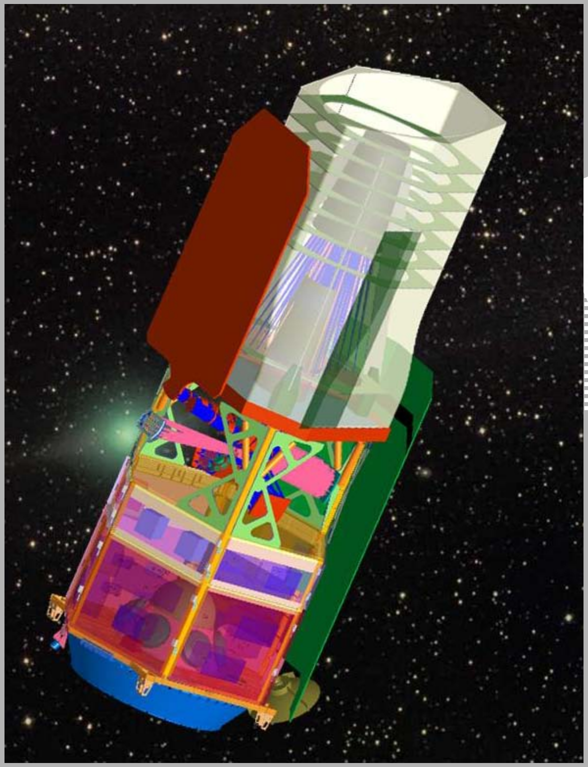

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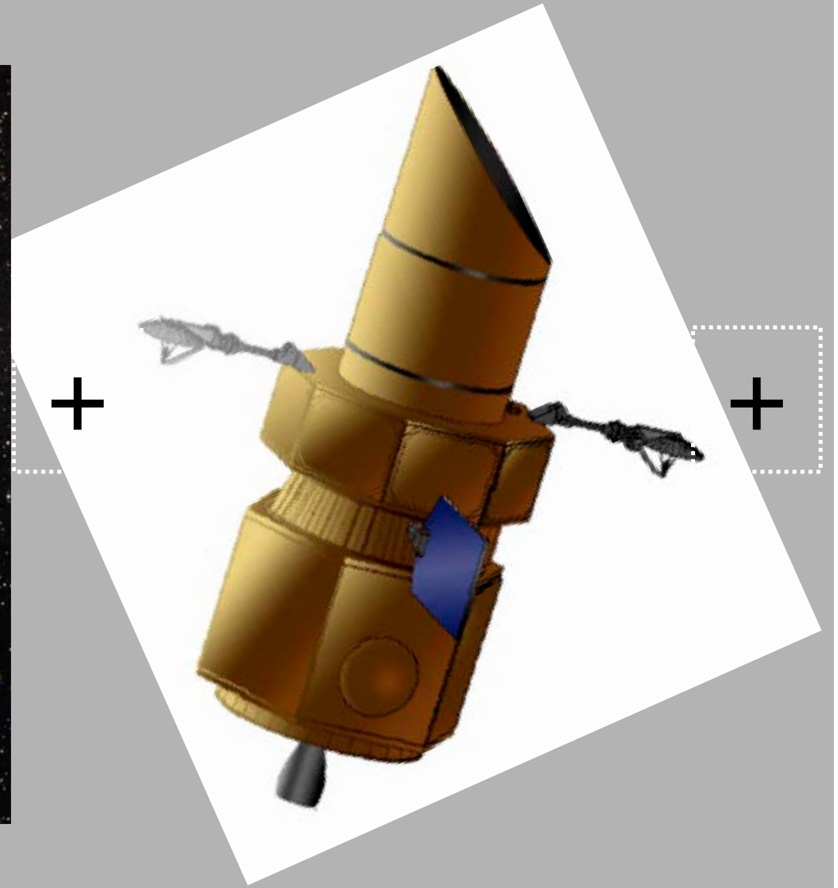

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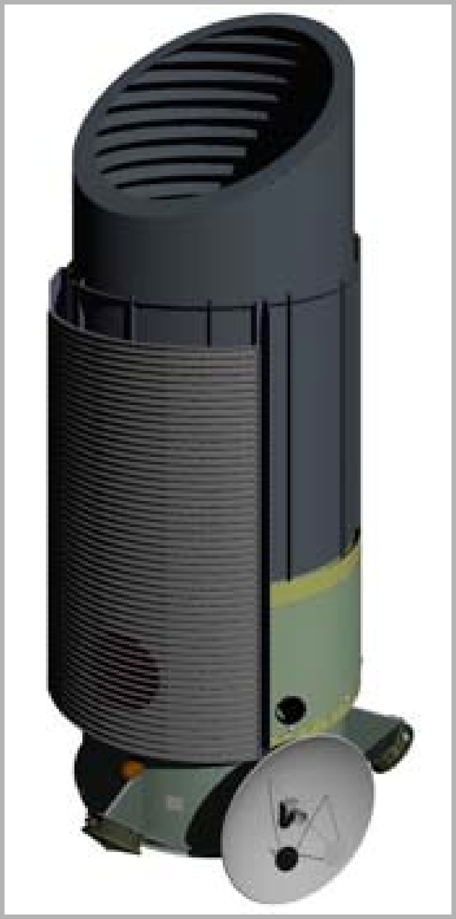


JDEM-Ω

MPF

NIRSS

WFIRST History and Philosophy

- Decadal Survey Astro2010 top large space recommendation: do WFIRST to accomplish as many of the JDEM, NIRSS, and MPF goals as possible

- 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

- Current design has imaging and spectroscopy up to 2 microns on a 1.3m telescope

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 $z>10$.

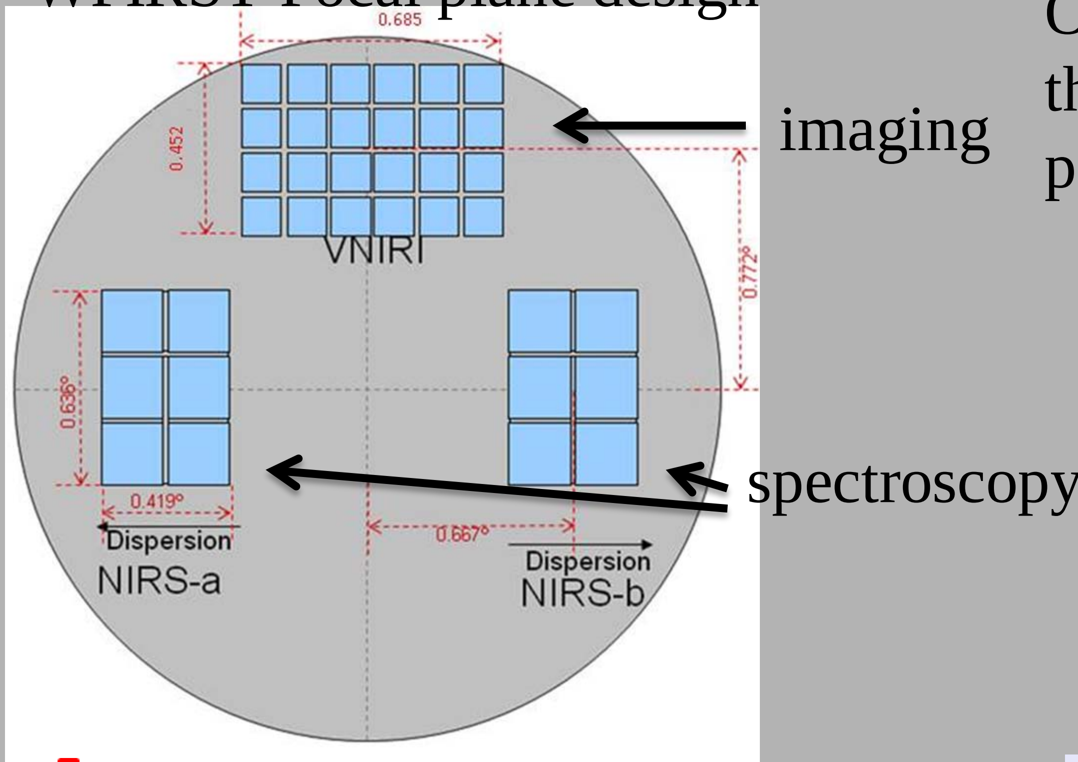
WFIRST Status

- 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)

- Earth-Sun L2 orbit, 5 year lifetime, 10 year goal
- 1.3 m **unobstructed** telescope
- NIR instrument with ~36 HgCdTe detectors

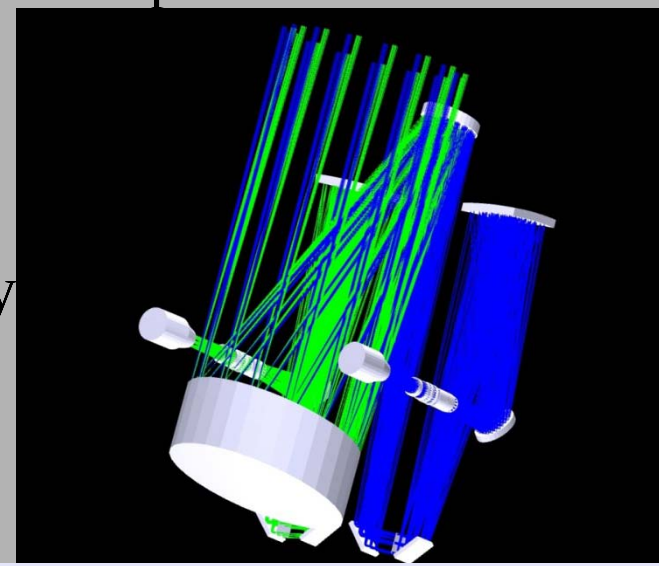
WFIRST – A **Survey** Telescope

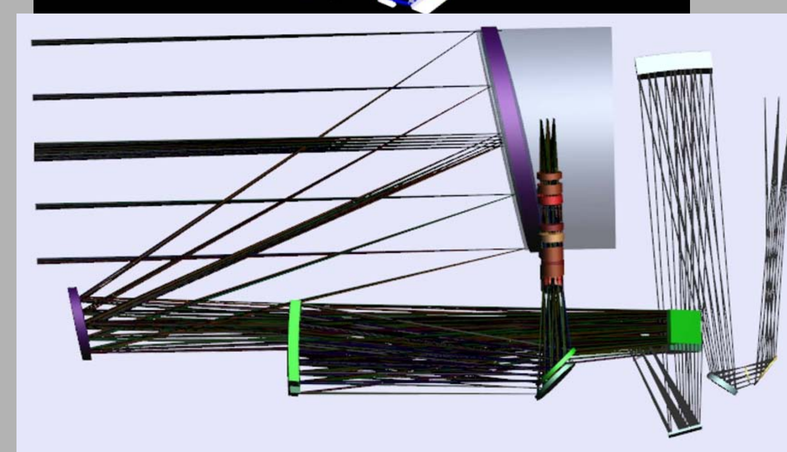
WFIRST Focal plane design



Approximate HST/JWST field of view. These telescopes cannot do WFIRST wide surveys.

Off-axis design gives high throughput and excellent point spread function





Exoplanet Microlensing 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 $\geq$30/$amin^2$, shapes resolved plus photo-zs
- **SNe-Ia Survey:**
  - >100 SN per Δz= 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/Astro2010 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**