National Aeronautics and Space Administration

Presentation to the Committee for an Assessment of the Astrophysics Focused Telescope Assets (AFTA) Mission Concept

January 13, 2014

Astrophysics

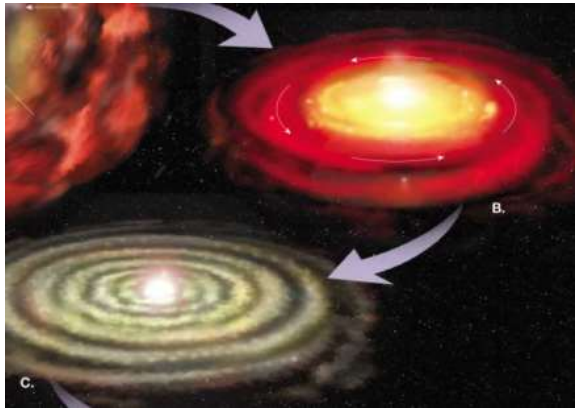
Paul Hertz

Director, Astrophysics Division
Science Mission Directorate

Why Astrophysics?

Astrophysics is humankind's scientific endeavor to understand the universe and our place in it.

1. How did our universe begin and evolve?

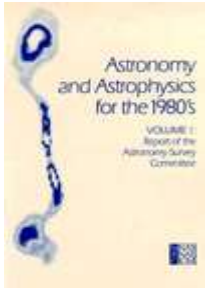


2. How did galaxies, stars, and planets come to be?

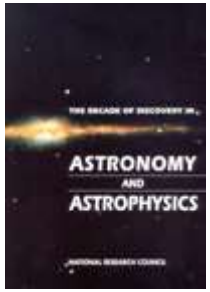
3. Are We Alone?

These national strategic drivers are enduring

1972



1982



1991

2001

2010

ASTROPHYSICS

Decadal Survey Missions

LRD: 2018

LRD: 2020s

2003

1999

1990

1972 Decadal Survey *Hubble*

1982 Decadal Survey *Chandra*

1991 Decadal Survey *Spitzer*

2001 Decadal Survey *JWST*

2010 Decadal Survey *WFIRST*

Exoplanet Missions

JWST

AFTA

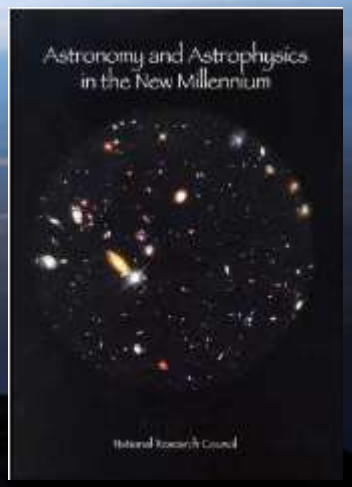
TESS

Kepler

New Worlds Telescope

Spitzer

Hubble

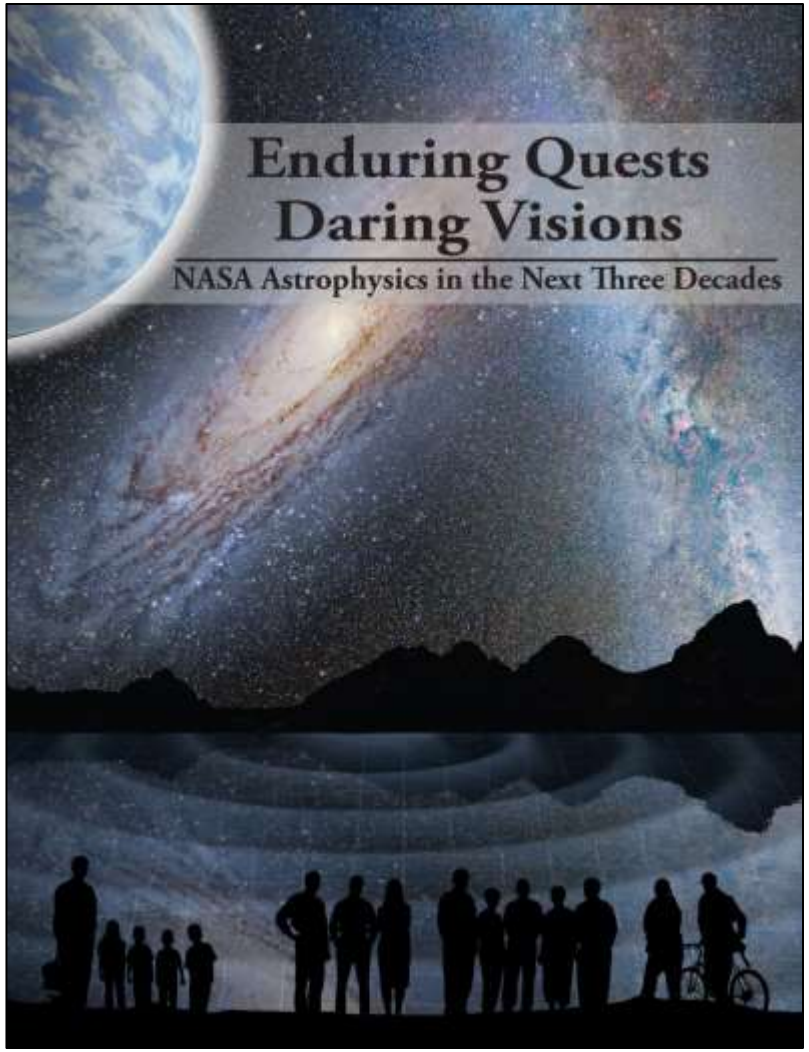


2001 Decadal Survey

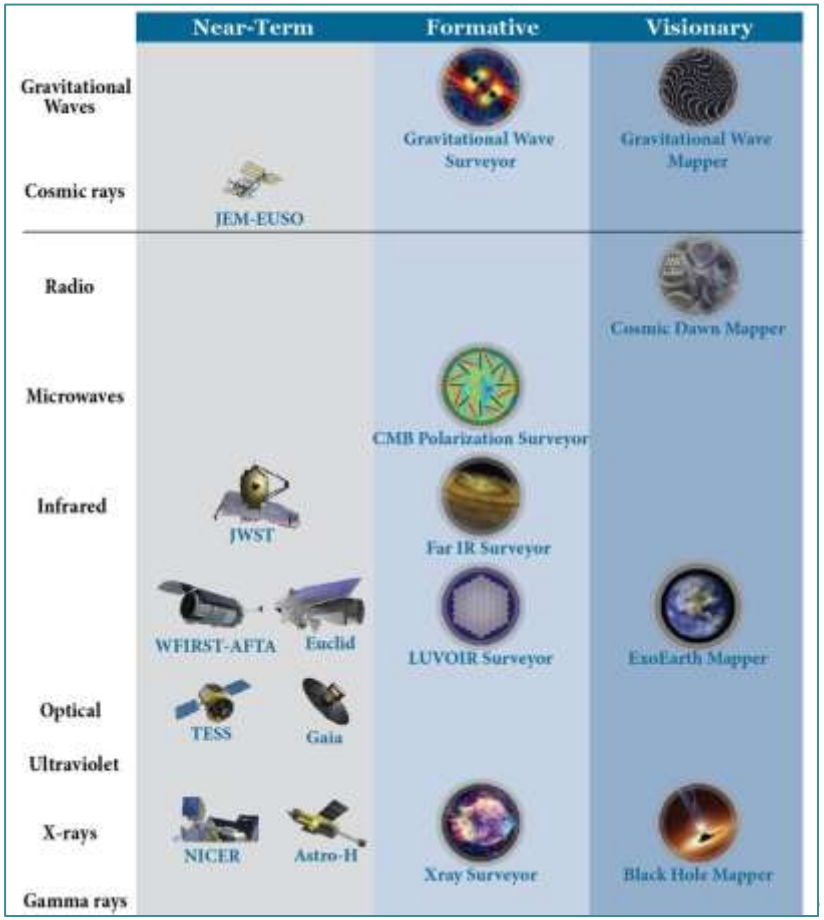
2010 Decadal Survey

Ground-based Observatories

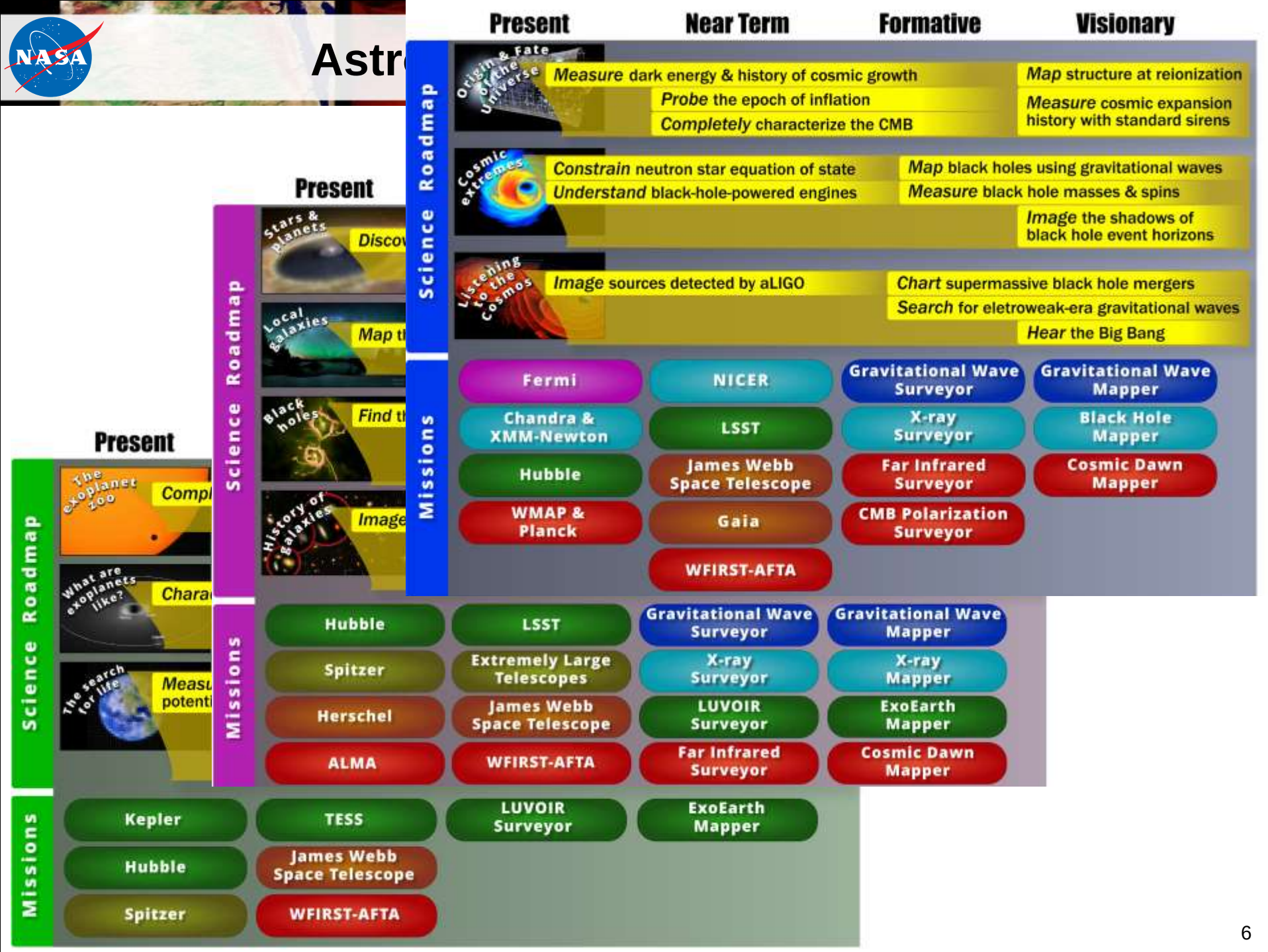
Enduring Quests, Daring Visions

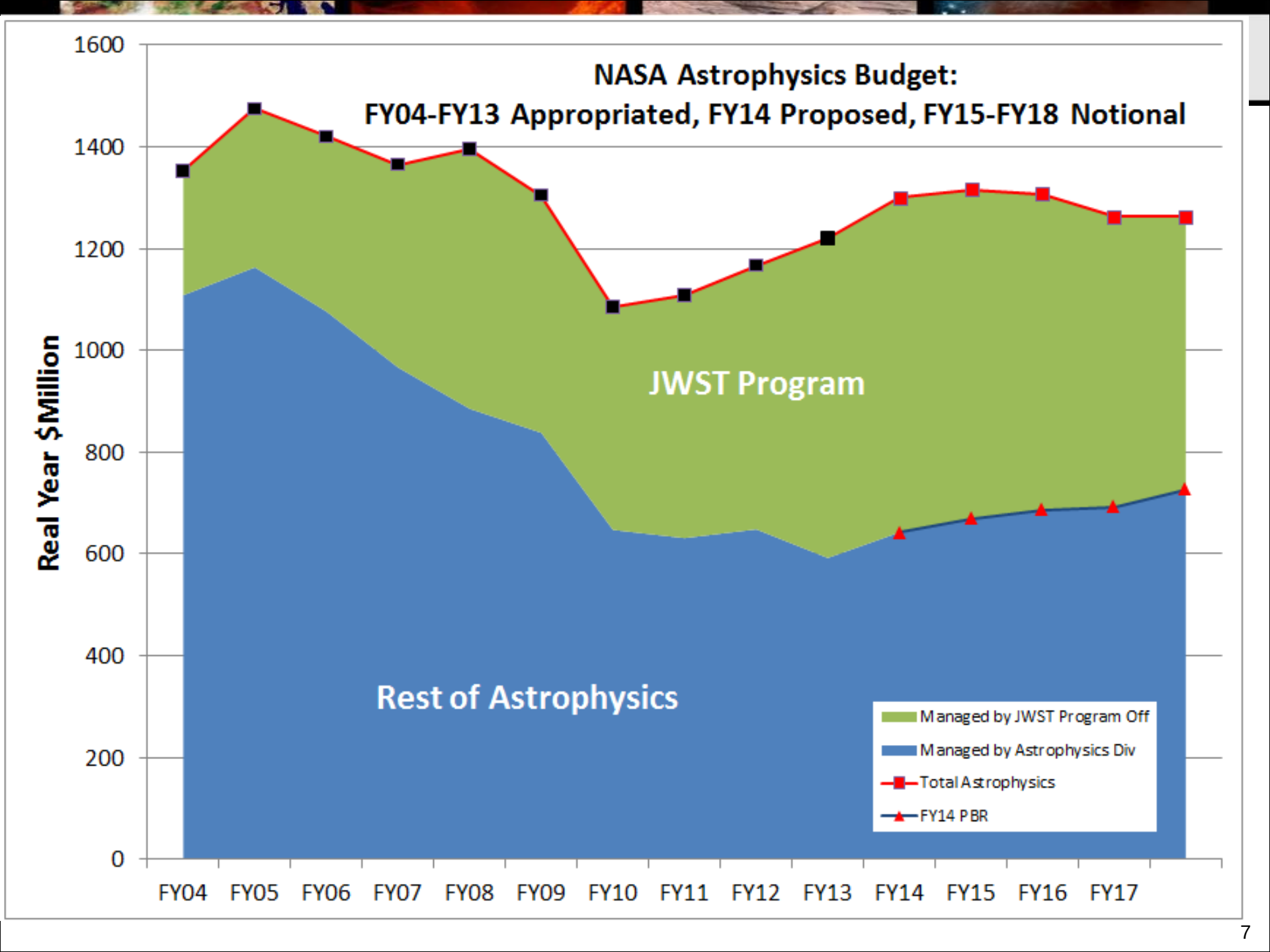


- A 30 year vision to address the enduring questions:
  - Are we alone?
  - How did we get here?
  - How does the universe work?



http://science.nasa.gov/astrophysics/documents


Present
Near Term
Formative
Visionary
Science Roadmap
Origin & Fate of the Universe
Measure dark energy & history of cosmic growth
Probe the epoch of inflation
Completely characterize the CMB
Map structure at reionization
Measure cosmic expansion history with standard sirens
Cosmic extremes
Constrain neutron star equation of state
Understand black-hole-powered engines
Map black holes using gravitational waves
Measure black hole masses & spins
Image the shadows of black hole event horizons
Listening to the Cosmos
Image sources detected by aLIGO
Chart supermassive black hole mergers
Search for eletroweak-era gravitational waves
Hear the Big Bang
Missions
Fermi
NICER
Gravitational Wave Surveyor
Gravitational Wave Mapper
Chandra & XMM-Newton
LSST
X-ray Surveyor
Black Hole Mapper
Hubble
James Webb Space Telescope
Far Infrared Surveyor
Cosmic Dawn Mapper
WMAP & Planck
Gaia
CMB Polarization Surveyor
WFIRST-AFTA
Present
Science Roadmap
Stars & planets
Local galaxies
Black holes
History of galaxies
Missions
Hubble
LSST
Gravitational Wave Surveyor
Gravitational Wave Mapper
Spitzer
Extremely Large Telescopes
X-ray Surveyor
X-ray Mapper
Herschel
James Webb Space Telescope
LUVOIR Surveyor
ExoEarth Mapper
ALMA
WFIRST-AFTA
Far Infrared Surveyor
Cosmic Dawn Mapper
Present
Science Roadmap
The exoplanet zoo
What are exoplanets like?
The search for life
Missions
Kepler
TESS
LUVOIR Surveyor
ExoEarth Mapper
Hubble
James Webb Space Telescope
Spitzer
WFIRST-AFTA


NASA Astrophysics Budget:
FY04-FY13 Appropriated, FY14 Proposed, FY15-FY18 Notional
Real Year $Million
1600
1400
1200
1000
800
600
400
200
0
JWST Program
Rest of Astrophysics
Managed by JWST Program Off
Managed by Astrophysics Div
Total Astrophysics
FY14 PBR
FY04
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17

Key Developments since the Release of the Decadal Survey

- A new launch date of no earlier than 2018 was established for JWST, with a new lifecycle cost commitment of $8.8B, an increase of $3.1B over the previous commitment.
- The budget environment assumed by the Decadal Survey has not been realized.
- Consistent with the recommendations of the NRC report on Assessment of a Plan for U.S. Participation in Euclid, a strategic partnership was established with ESA in 2012 to participate in ESA's Euclid mission.
- Neither LISA nor IXO was selected as the first large mission to go forward by the Decadal Survey nor in May 2012 as the first large mission in the ESA Cosmic Vision Programme.
- NASA announced In June 2012 that the National Reconnaissance Office (NRO) had made available two 2.4m telescope systems for NASA's use.
- In November 2012, an x-ray observatory was selected as the second large mission, and a gravitational wave observatory was selected as the third large mission, in the ESA Cosmic Vision Programme.

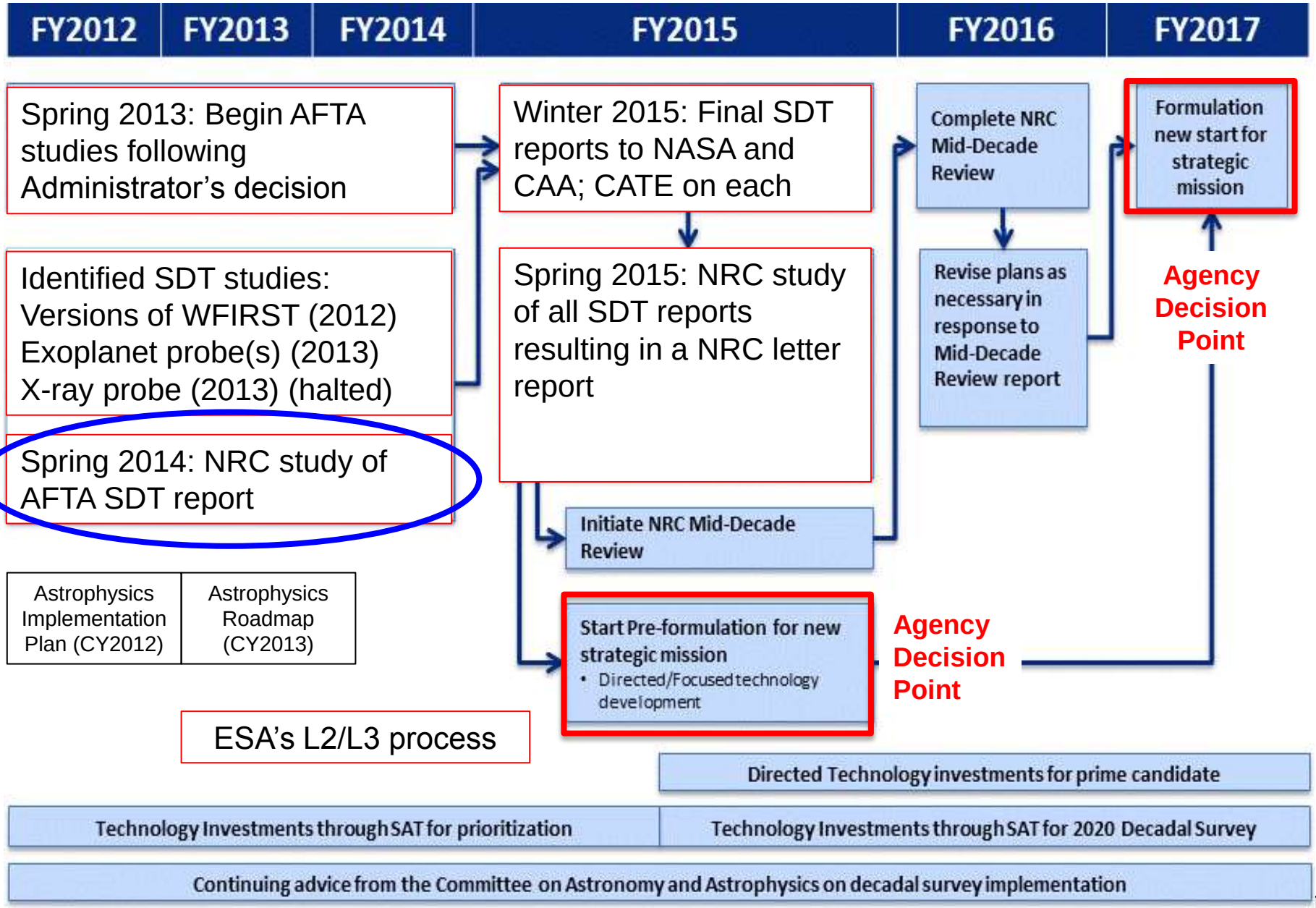
Strategy for Responding to the Decadal Survey

- We are in a period of constrained resources as considered in the Decadal Survey. Decadal Survey recommended priorities:
  - First priority: WFIRST, Explorer Program, Core Program
  - Second Priority: New Worlds Technology, Start LISA, IXO Technology
  - Third Priority: CMB Technology
  - Not Recommended: Participation in SPICA
- NASA is responding to these priorities within the President's FY14 Budget Request and its 5-year runout:
  - Completing JWST is an Agency priority.
  - Core research program has been augmented.
  - Preparing for a WFIRST new start as soon as funding becomes available as JWST approaches launch, which is NET FY 2017.
  - See next chart.

Progress Toward Decadal Survey Priorities

The President's Budget Request for FY14 and its 5-year runout supports	
L1. WFIRST	Preformulation and focused technology development for AFTA (a 2.4m version of WFIRST) are underway to enable a new start NET FY17
L2. Augmentation to Explorer Program	Increased from ~$90M in FY07 and ~$115M/yr in FY10 to ~$140M/yr in FY16 and beyond; supports four AOs per decade including 2014
L3. LISA	Strategic technology investments including LISA Pathfinder technology demo plus discussing partnership in ESA's L3 gravitational wave observatory
L4. IXO	Strategic technology investments plus discussing partnership in ESA's L2 X-ray observatory
M1. New Worlds Technology Development Program	Focused technology development for a coronagraph on WFIRST; exoplanet probe concept studies and strategic technology investments; precursor science through Kepler, LBTI, TESS, JWST
M2. Inflation Probe Technology Development Program	Three balloon-borne investigations with new technology plus strategic technology investments

Implementing the Decadal Survey



Following guidance from NRC Reports regarding WFIRST and Euclid

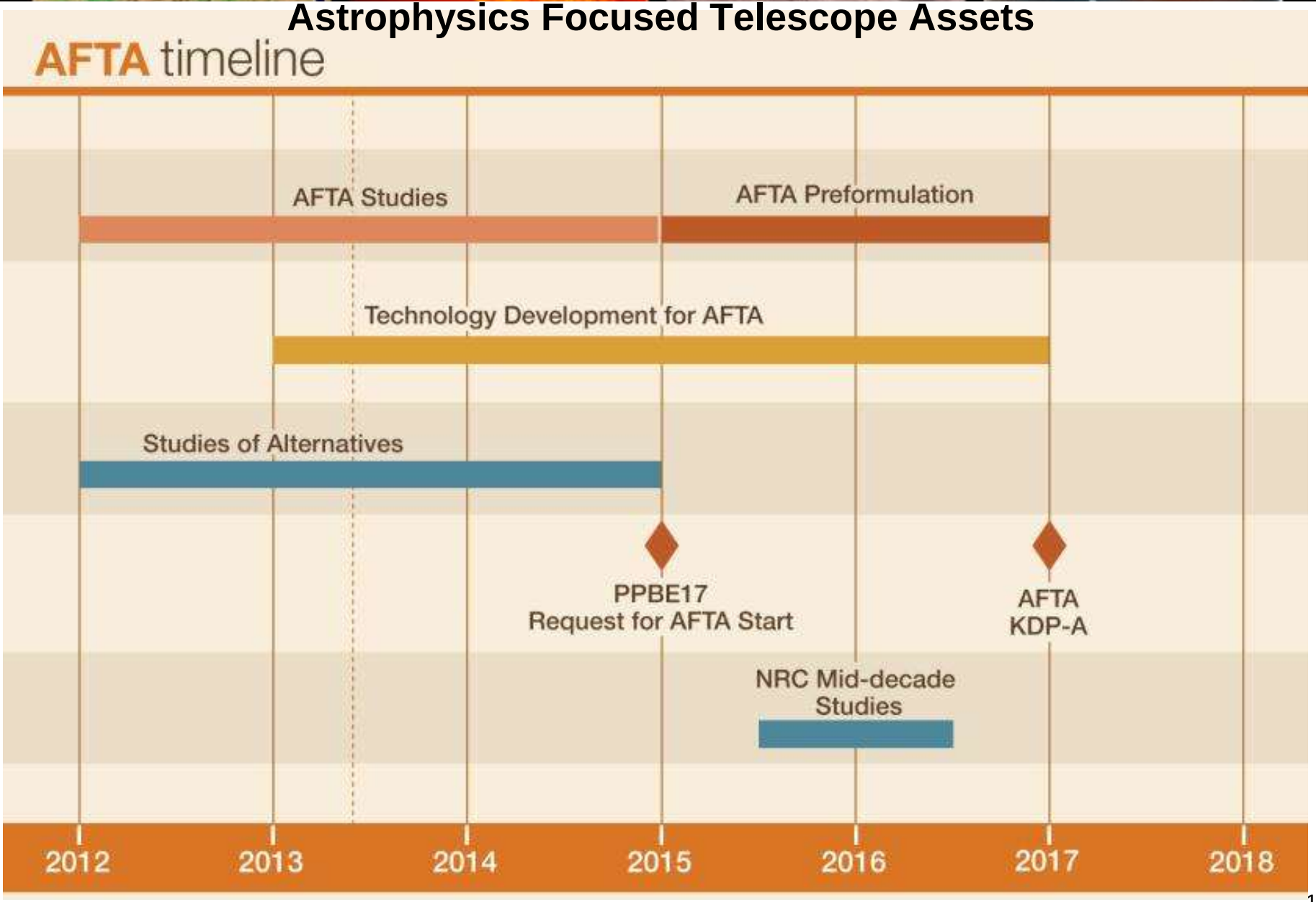
- Not participating in a ESA-led combined mission
- Funding allocated toward Euclid participation does not impact dates for WFIRST new start or WFIRST launch
  - WFIRST cannot start until funding becomes available as JWST approaches launch
  - Euclid funding after FY17 not planned to exceed several million dollars per year (science team, possible data center)
- Obtained membership on Euclid Science Team, Euclid Consortium, and data access
- Consulted with CAA on cost of Euclid hardware components
  - Also consulted with CAA on non-hardware activities required to meet expectations of Euclid partnership, i.e. science team and possible U.S. data center
- Taking steps necessary to keep options for WFIRST viable, pending future decisions
  - U.S. leadership
  - International participation in SDT (ESA, JAXA, CSA)

AFTA Study

- Initiated September 2012 in response to prior Administrator's direction
- Ground rules included
  - Use telescope assets "as is"; realize savings
  - Address decadal survey science objectives for WFIRST
  - Study options for servicing, coronagraph, optical comm
- Participants included
  - Science Definition Team (SDT) – Co-chaired by David Spergel (Princeton) and Neil Gehrels (GSFC)
  - Mission Study Office – Managed by Kevin Grady (GSFC)
  - Telescope Study Team – Managed by Jennifer Dooley (JPL)
  - Cost Assessment and Technology Evaluation – Aerospace Corp
- SDT report available at http://wfirst.gsfc.nasa.gov/

Plan for WFIRST-AFTA Preformulation

Widefield Infrared Survey Telescope using Astrophysics Focused Telescope Assets



WFIRST – AFTA

Widefield Infrared Survey Telescope with Astrophysics Focused Telescope Assets

- **Top priority in 2010 Decadal Survey**
- **Study Baseline Payload:**
  - 2.4m existing telescope assets
  - Widefield imager
  - Coronagraph
- **Science objectives:**
  - Hubble-quality imaging over 200x the field
  - Comprehensive study of dark energy
  - Systematic census of outer planets
  - Coronagraphic imaging of exoplanets
  - 25% time for community competitive selected GO program
  - Enhancing JWST science

CURRENT STATUS:

- May 2013, NASA Administrator Bolden directed Astrophysics Division to study WFIRST-AFTA and preserve option for FY17 new start if budget is available
  - No decision expected before early 2016
- Currently in pre-formulation phase
  - NRC study in early 2014
  - SDT final report due Jan 2015
- Maturing key technologies to TRL 5 by FY17 and TRL 6 by FY19
  - Infrared detectors
  - Internal coronagraph for exoplanet characterization

Mission description:

- #1 Large-Scale Priority: Widefield infrared survey telescope for Dark Energy, Exoplanets, IR Surveys
- #1 Medium-Scale Priority: Development and demonstration of technology for direct imaging and characterization of exoplanets

AFTA Would Deliver Extraordinary Science

1. Frontiers of Knowledge

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

2. Exoplanets

- How diverse are planetary systems?
- Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet?
- How do circumstellar disks evolve and form planetary systems?

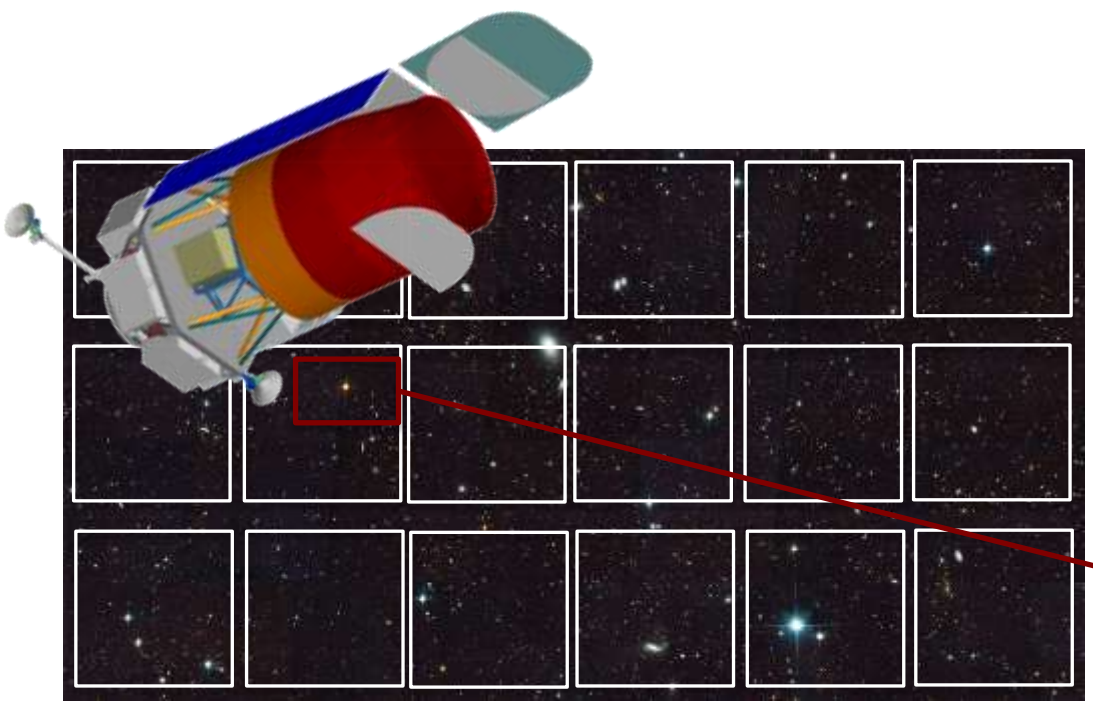
3. Understanding our Origins

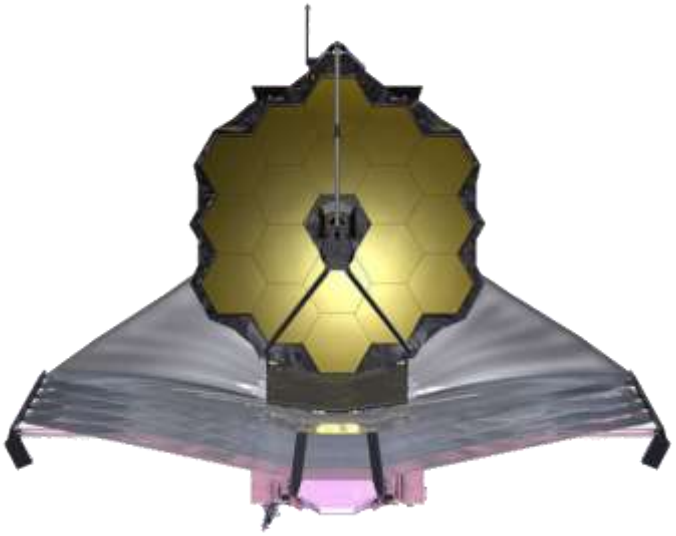
- How did the universe begin?
- What were the first objects to light up the universe, and when did they do it?
- How do cosmic structures form and evolve?
- What are the connections between dark and luminous matter?
- What is the fossil record of galaxy assembly from the first stars to the present?

4. Exoplanets: Stars + Galaxies

- What controls the mass-energy-chemical cycles within galaxies?
- How do the lives of massive stars end?
- What are the progenitors of Type Ia supernovae and how do they explode?

AFTA Would Enhance JWST Science



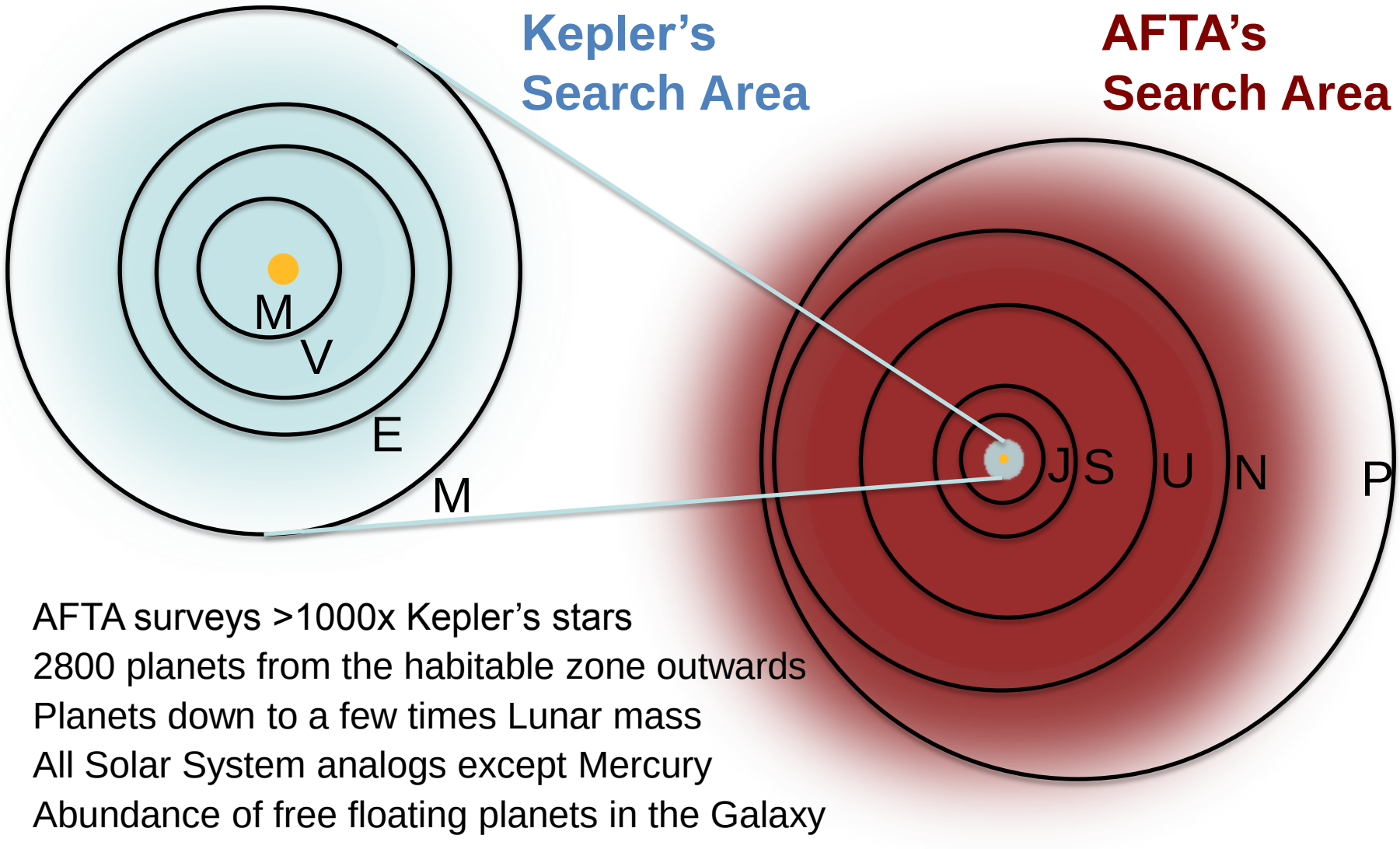


AFTA discovery of high-z galaxies
AFTA finds first stellar explosions
AFTA wide field survey of galaxies
AFTA maps of halo tidal streams
AFTA monitoring of exoplanets

ENHANCES

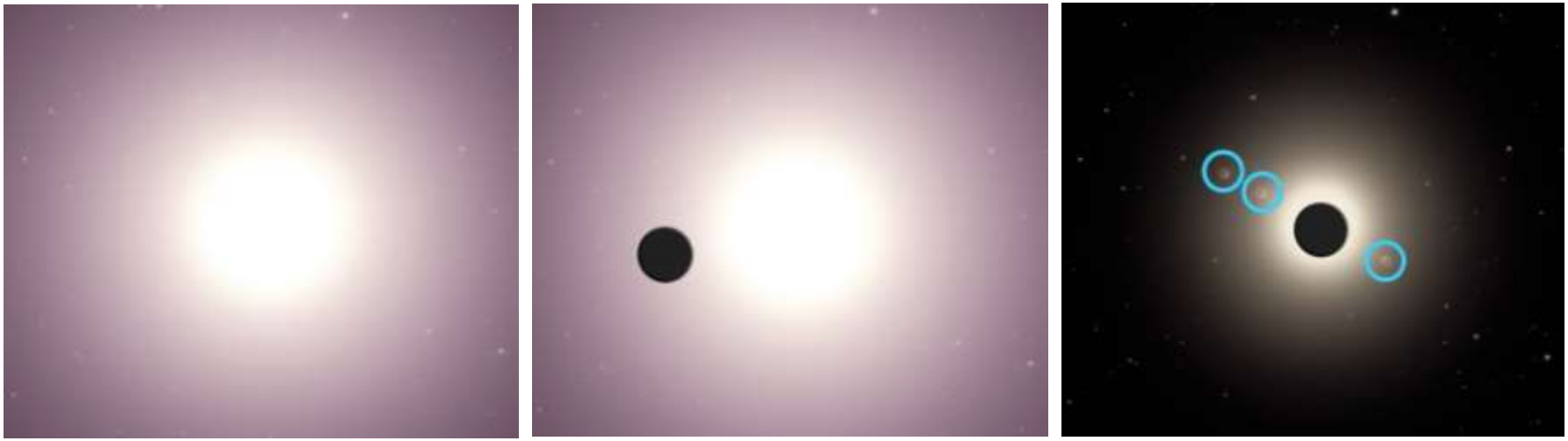
JWST NIR and MIR detailed spectroscopy
JWST light curves and host galaxy properties
JWST Sne spectra with pre-detonation images
JWST ages and abundances of substructure
JWST transit spectroscopy of atmospheres

AFTA Compliments Kepler to complete Census



- AFTA surveys >1000x Kepler's stars
- 2800 planets from the habitable zone outwards
- Planets down to a few times Lunar mass
- All Solar System analogs except Mercury
- Abundance of free floating planets in the Galaxy

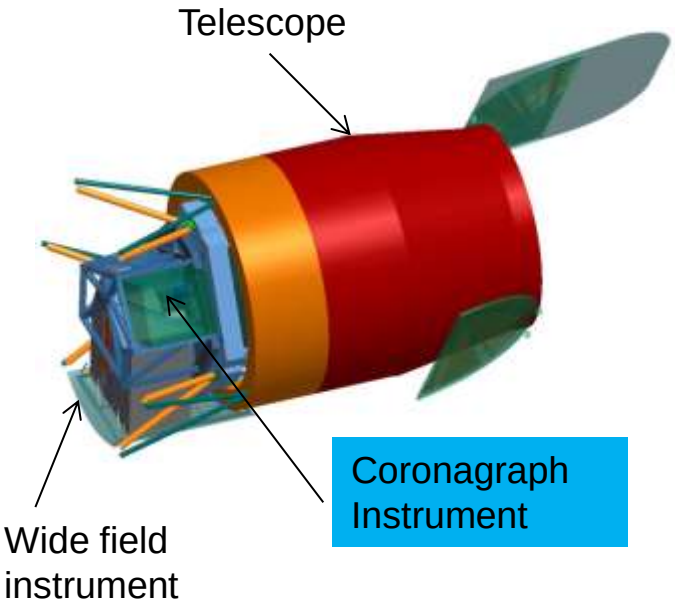
Toward the Pale Blue Dot



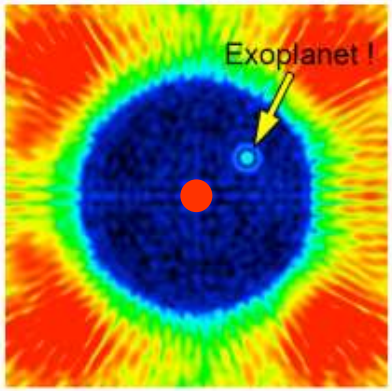
AFTA's optional coronagraph lays the technological foundation for future flagships

- First direct images of giant planets around nearest stars
- Physics of planetary atmospheres through comparative planetology
- Study populations of debris disks that serve as confusion for flagship missions
- Develop technologies and provide a practical flight demonstration

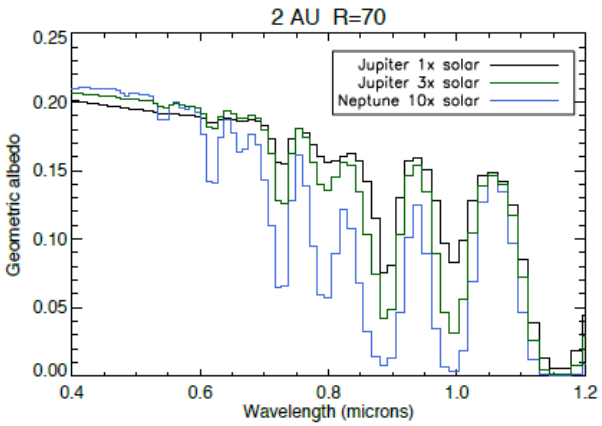
AFTA Coronagraph Instrument



Coronagraph Instrument



Exoplanet Direct imaging



Exoplanet Spectroscopy

Bandpass	400-1000 nm	Measured sequentially in five 18% bands
Inner Working Angle	100 mas	at 400 nm, 3 λ/D driven by challenging pupil
	250 mas	at 1 um
Outer Working Angle	1 arcsec	at 400 nm, limited by 64x64 DM
	2.5 arcsec	at 1 um
Detection Limit	Contrast $=10^{-9}$	Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extrememe stability requirements.
Spectral Resolution	70	With IFS, ~70 across the spectrum.
IFS Spatial Sampling	17 mas	This is Nyquist for λ400 nm.

WFIRST final report May 23, 2013
http://wfirst.gsfc.nasa.gov/

AFTA Coronagraph Instrument will:

- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.

Downselect from 6 to 2 primary Coronagraph architectures in December 2013

- Coronagraph architectures considered: shaped pupil, phase induced amplitude apodization (PIAA), hybrid lyot, vector vortex, visible nuller (2 different concepts)
- Process for conducting the downselect
  - **AFTA SDT:** Set the science requirements
  - **ACWG:** Delivered technical FOMs and technology plans
    > *Aim for the positive: a consensus product*
    > SDT delivers science FOMs
  - **TAC:** Analysis of technical FOM, TRL readiness plans, and risks
- **ExEPO and ASO** recommendation to **APD Director** based on:
  - Technical and Programmatic criteria
  - Musts (Requirements), Wants (Goals), and Risks
  - Opportunities
- **APD Director** made the decision on
  December 23, 2013

ACWG = AFTA Coronagraph Working Group:
representatives of ExEPO, ASO, SDT, Community

Acronyms:
ExEPO: Exoplanet Expl. Prog. Office
ASO: AFTA Study Office
SDT: Science Definition Team
FOM: Figure of Merit
TRL: Technology Readiness Level

TAC: Technical Analysis Committee
Alan Boss (Carnegie Inst.)
Joe Pitman (EXSCI)
Steve Ridgway (NOAO)
Lisa Poyneer (LLNL)
Ben Oppenheimer (AMNH)

Rationale for the Downselected Coronagraph Architectures

- Downselect decision:
  - Primary Architecture - **Occulting Mask Coronagraph (OMC)**
  - Back-up Architecture – **Phase-Induced Amplitude Apodization Complex Mask Coronagraph (PIAACMC)**
- Assumptions:
  - Plan is to mature both Primary and Backup architecture technologies. The OMC primary includes both Hybrid Lyot (HL) and Shaped Pupil (SP) masks in a single optical design, and the current thinking is that we would fly both masks.
  - If programmatic, technical or scientific factors suggest off-ramping of one approach is appropriate (either part of the primary or the backup), that will be done in a timely manner.
- Benefits:
  - OMC in its “SP mode” provides the simplest design, lowest risk, easiest technology maturation, most benign set of requirements on the spacecraft and “use-as-is” telescope. This translates to low cost/schedule risk.
  - In its “HL mode”, the OMC affords the potential for greater science, however the increased risk is mitigated by the SP safety net.
  - PIAACMC offers the possibility of even greater science and at greater complexity. Hardware demonstrations and more detailed analyses are necessary to substantiate projected performance.
  - Taken together, the primary & backup architectures afford numerous “built-in descopes” and/or opportunities to accept greater risk due to the diversity of the approach.

Space Technology Mission Directorate Contributes to Astrophysics

Space Technology Mission Directorate

*FY13 budget; STMD supports other Science Divisions & HEOMD.

NIAC
Center Innovation Fund
Space Tech Res Grants

$45M*

Small Business Innovative Research (SBIR)/
Small Business Technology Transfer (STTR)

$165M*

Game Changing Development

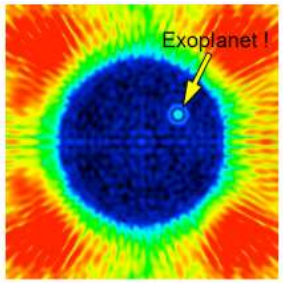
$151M*

Small Spacecraft

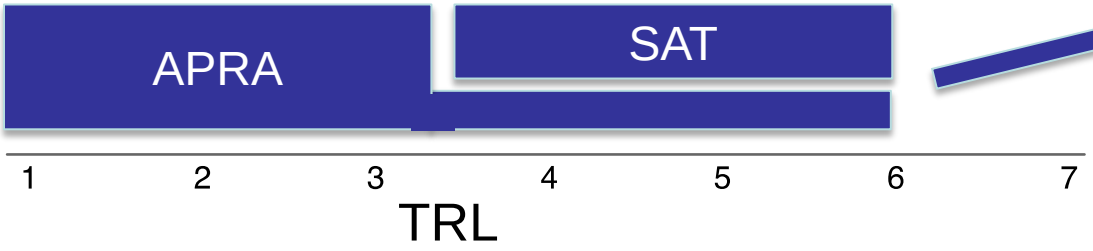
$15M*

Tech Demo
Missions

$184M*



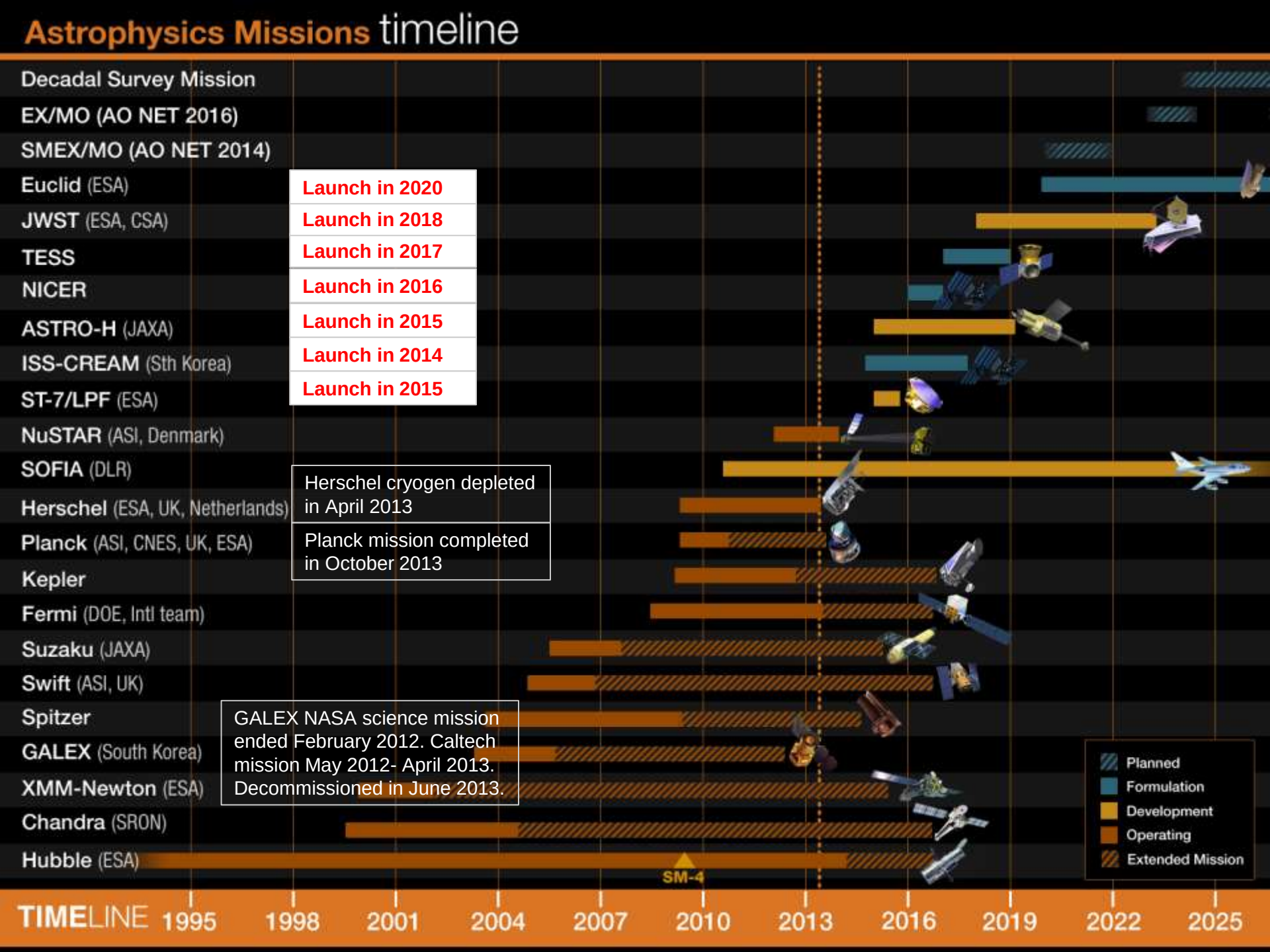
SMD Astrophysics Division



AFTA as WFIRST

- The AFTA 2.4m version of WFIRST offers advantages over the earlier design reference missions
  - Larger aperture and superb mirror quality leads to increased science return
  - Existing hardware leads to decreased design and cost risk
  - Potential to add a second instrument, e.g. coronagraph, leads to broader science return
  - The cost of AFTA (without coronagraph) is comparable to earlier DRM for WFIRST
- All of these advantages must be validated through further study

Astrophysics Missions timeline



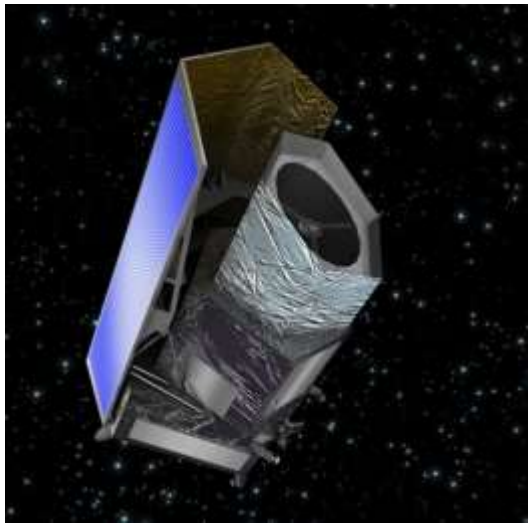
Backup

Guidance from NRC Reports regarding WFIRST and Euclid

- New Worlds, New Horizons in Astronomy and Astrophysics (2011)
  - The European Space Agency (ESA) is considering an M-class proposal, called Euclid, with related goals. Collaboration on a combined mission with the United States playing a leading role should be considered so long as the committee's recommended science program is preserved and overall cost savings result.
  - The overlap in goals and scope between the proposed U.S. and European missions is significant, and there is potentially a grand partnering arrangement involving NASA, DOE, and ESA if the expanded scientific priorities set by Astro2010 for such a mission can be aligned among the partners, and assuming that the arrangement is consistent with the United States playing a clear leadership role.
  - There have been discussions between the U.S. agencies and ESA about mounting a joint mission, which could be a positive development if it leads to timely execution of a program that fully supports all of the key science goals of WFIRST (planet microlensing, dark energy science, and guest observer investigations) and leads to savings overall. It is expected that the United States will play a leading role in this top-priority mission.
- Report of the Panel on Implementing Recommendations from the New Worlds, New Horizons Decadal Survey (2011)
  - The panel reaffirms the centrality to the overall integrated plan articulated in NWNH of embarking in this decade on the scientifically compelling WFIRST mission. If WFIRST development and launch are significantly delayed beyond what was assumed by NWNH, one of the key considerations that led to this relative ranking is no longer valid.
  - A 20 percent investment in Euclid as currently envisioned and as presented by NASA is not consistent with the program, strategy, and intent of the decadal survey.
- Assessment of a Plan for U.S. Participation in Euclid (2012)
  - NASA should make a hardware contribution of approximately $20 million to the Euclid mission to enable U.S. participation. This investment should be made in the context of a strong U.S. commitment to move forward with the full implementation of WFIRST in order to fully realize the decadal science priorities of the NWNH report.
  - In exchange for this small, but crucial contribution, NASA should secure through negotiation with the European Space Agency both a U.S. position on the Euclid Science Team with full data access and the inclusion of a team of U.S. scientists in the Euclid Consortium that would be selected by a peer-reviewed process with full data access as well as authorship rights consistent with Euclid policies still to be formulated.
  - NASA should seek independent community review of any financial commitment for hardware expenditures beyond $30 million for Euclid.

Euclid

A visible and near-infrared telescope to explore cosmic evolution



- **ESA Cosmic Vision 2015-2025 Mission**, M-Class with NASA participation.
- 1.2-m mirror, visible & near-IR images, spectra
- **Launch Date**: Mar 2020, 5 year prime mission
- **Science Objectives**:
  - Euclid will look back 10 billion years into cosmic history.
  - Probe the history of cosmic expansion (influenced by dark energy and dark matter) and how gravity pulls galaxies together to form the largest structures.
  - The shapes of distant galaxies appear distorted because the gravity of dark matter bends their light (gravitational lensing). Measuring this distortion tells us how the largest structures were built up over cosmic time.
  - Measuring how strongly galaxies are clumped together tells us how gravity influences their motions, and how dark energy has affected the cosmic expansion.

CURRENT STATUS:

- Currently in implementation phase.
- ~50 U.S. scientists are members of the Euclid Science Team that will analyze the data, and make maps of the sky.
- First experimental manufacturing run for the Euclid near-infrared detectors to complete in FY 2014 (ESA).
- NASA will initiate the buy for the flight infrared detectors in FY 2014.
- NASA will test and characterize the near-IR flight detectors.