Astrophysics
Large Strategic Missions

Committee on Strategic Science Missions
National Academies’ Keck Center
Washington, DC

October 5, 2016
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
Large Strategic NASA-led Mission

Medium Strategic NASA-led Mission

No Small Strategic NASA-led Missions in Astrophysics

Astrophysics Mission Portfolio 2016

Visible light

Radio

Microwaves

Infrared

Ultraviolet

X-rays

Gamma Rays

Cosmic Rays

Gravitational Waves

Hubble

Chandra

XMM-Newton (ESA)

Spitzer

Swift

Fermi

Kepler

NuSTAR

SOFIA

NICER

TESS

JWST

Euclid (ESA)

WFIRST

Athena (ESA)

AMS

LISA Pathfinder (ESA)

CREAM

L3 (ESA)
ASTRO-H was PI-led Recovery Mission will be Strategic
Hubble Space Telescope

Hubble probes the halo of the Andromeda Galaxy

MACS J0416.1-2403
MACS J0416.1-2403
MACS J0152.5-2852
MACS J0152.5-2852
MACS J0717.5+37.45
MACS J0717.5+37.45
Hubble Space Telescope: Refereed Science Publications

- Unassigned
- Part GO, Part Archival
- Archival
- GO (General Observer)

Number of Refereed Papers per Year

Year of Publication

Chandra X-ray Observatory

Publication Year - 2000

Chandra Science Papers

<table>
<thead>
<tr>
<th>Year</th>
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Spitzer Space Telescope
Senior Review Proposal
January 22, 2016

Spitzer Space Telescope

- Cryo-Archival Only
- Cryo-GO+Archival
- Cryo-GO

- Warm-Archival Only
- Warm-GO+Archival
- Warm-GO
NASA Astrophysics

Missions in Development includes Webb, ISS-NICER, ISS-CREAM, TESS, Euclid, WFIRST

Missions in Operation includes Hubble, Chandra, XMM-Newton, Spitzer, Swift, Fermi, Kepler, NuSTAR, SOFIA, LISA Pathfinder

Infrastructure & Other includes data archives, suborbital balloons, ground-based telescopes, management

Research & Technology includes basic technology, strategic technology, suborbital payloads, theory, data analysis, fellowships

FY 2016
Total US$ 1,333 M
**Astrophysics Missions in Development**

<table>
<thead>
<tr>
<th>Mission</th>
<th>Due Date</th>
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<tbody>
<tr>
<td>ISS-NICER NASA Mission</td>
<td>2/2017</td>
</tr>
<tr>
<td>ISS-CREAM NASA Mission</td>
<td>6/2017</td>
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<tr>
<td>TESS NASA Mission</td>
<td>12/2017</td>
</tr>
<tr>
<td>Webb NASA Mission</td>
<td>10/2018</td>
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<tr>
<td>Euclid ESA-led Mission</td>
<td>2020</td>
</tr>
<tr>
<td>WFIRST NASA Mission</td>
<td>Mid 2020s</td>
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</table>

**Missions Overview**

- **ISS-NICER**
  - Neutron Star Interior Composition Explorer
  - Due: 2/2017

- **ISS-CREAM**
  - Cosmic Ray Energetics And Mass
  - Due: 6/2017

- **TESS**
  - Transiting Exoplanet Survey Satellite
  - Due: 12/2017

- **Webb**
  - James Webb Space Telescope
  - Due: 10/2018

- **Euclid**
  - NASA is supplying the NISP Sensor Chip System (SCS)
  - Due: 2020

- **WFIRST**
  - Wide-Field Infrared Survey Telescope
  - Due: Mid 2020s
James Webb Space Telescope

Large Infrared Space Observatory
Top priority of 2000 Decadal Survey

**Science themes:** First Light; Assembly of Galaxies; Birth of Stars and Planetary Systems; Planetary Systems and the Origins of Life

**Mission:** 6.5m deployable, segmented telescope at L2, passively cooled to <50K behind a large, deployable sunshield

**Instruments:** Near IR Camera, Near IR Spectrograph, Mid IR Instrument, Near IR Imager and Slitless Spectrograph

**Operations:** 2018 launch for a 5-year prime mission

**Partners:** ESA, CSA

http://jwst.nasa.gov/

JWST remains on track for an October 2018 launch
WFIRST
Wide-Field Infrared Survey Telescope

WFIRST highest ranked large space mission in 2010 Decadal Survey
– Study Dark Energy, Exoplanet Census, NIR Sky Survey

Use of 2.4m telescope enables
– Hubble quality imaging over 100x more sky
– Imaging of exoplanets with $10^{-9}$ contrast with a coronagraph

http://wfirst.gsfc.nasa.gov/
NASA Astrophysics Budget: FY04-FY16 Appropriated, FY17 Request, FY18-FY21 Notional Planning

- JWST Program
- WFIRST
- Rest of Astrophysics

Includes SMD E/PO and SMD STEM activities
Astrophysics Budget by Function
FY05-FY14 Actual, FY15 Op Plan, FY16-FY20 Request

Strategic Mission Development
(Fermi to FY08, Hubble to FY09, Kepler to FY09, Herschel to FY09, Planck to FY09, SOFIA to FY14, JWST to FY18, WFIRST-AFTA to end)
Fraction of budget on Large Observatories

![Graph showing the fraction of the Astrophysics Budget allocated to Large Observatories from 1985 to 2015. The graph indicates a general increase in the fraction over time, with a notable peak around 2005.](image-url)
Astrophysics Mission Timeline

Does not include missions in formulation or pre-formulation

US-led strategic missions
- Large strategic mission
- Medium strategic mission

Updated October 2015

Note: All US-led large strategic missions launched since 1990 are still operating

* active missions
* active missions with no NASA Astrophysics support
* unaunched missions
# Current Strategic Missions

<table>
<thead>
<tr>
<th>NASA-led (launch year)</th>
<th>Development Cost Phases C-D ($M)</th>
<th>FY16 Operating Cost ($M)</th>
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<tbody>
<tr>
<td>Hubble Space Telescope (1990)</td>
<td>$1,526.2 M</td>
<td>$ 98.3 M</td>
</tr>
<tr>
<td>Chandra X-ray Observatory (1999)</td>
<td>$1,514.0 M</td>
<td>$ 59.8 M</td>
</tr>
<tr>
<td>Spitzer Space Telescope</td>
<td>$707.0 M</td>
<td>$15.2 M</td>
</tr>
<tr>
<td>Fermi Gamma-ray Space Telescope</td>
<td>$418.8 M</td>
<td>$15.9 M</td>
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<tr>
<td>SOFIA (2014)</td>
<td>$1,048.9 M</td>
<td>$83.6 M</td>
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<tr>
<td>James Webb Space Telescope (2018)</td>
<td>$6,188.8 M</td>
<td>N/A</td>
</tr>
<tr>
<td>WFIRST (mid-2020s)</td>
<td>$2,363.9 M</td>
<td>N/A</td>
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</table>

<table>
<thead>
<tr>
<th>Not NASA-led (lead agency) (launch year)</th>
<th>Development Cost Phases C-D ($M)</th>
<th>FY16 Operating Cost ($M)</th>
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<tbody>
<tr>
<td>XMM-Newton (ESA) (1999)</td>
<td>$28.3 M</td>
<td>$ 2.9 M</td>
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<tr>
<td>LISA Pathfinder (ESA) (2016)</td>
<td>$82.8 M</td>
<td>$1.2 M</td>
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<tr>
<td>Euclid (ESA) (2020)</td>
<td>$117.7 M</td>
<td>N/A</td>
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<tr>
<td>X-ray Recovery Mission (JAXA)</td>
<td>Under discussion</td>
<td>N/A</td>
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<tr>
<td>Athena (ESA)</td>
<td>Under discussion</td>
<td>N/A</td>
</tr>
<tr>
<td>L3 Gravitational Wave Observatory (ESA)</td>
<td>Under discussion</td>
<td>N/A</td>
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Current Mission Sizes

• Small missions are PI-led, AO selected through the Astrophysics Explorers Program
  – Small Complete Missions of Opportunity (SCM MO): AO cost cap $75M
  – Small Explorers (SMEX): PI-managed cost cap $125M; LCC $250M
  – Medium Explorers (MIDEX): PI-managed cost cap $250M; LCC $400M

• Medium missions (also called Astrophysics Probes) are strategic missions recommended by the Decadal Survey
  – Total LCC between $400M and $1B

• Large missions are strategic missions recommended by the Decadal Survey
  – Total LCC in excess of $1B

• Contributions to non-NASA missions may either by PI-led, AO selected (Partner Missions of Opportunity) or may be strategic in origin.
  – Partner Missions of Opportunity (PMO): AO cost cap $75M
  – Strategic Contribution: Typically $100-300M
Committee Questions: Strategic Science

- Decadal survey science priorities require large missions. The following examples are from the 2010 Decadal Survey:
  - Dark energy
  - Exo-Earth characterization
  - Gravitational wave detection
  - Large area, high resolution X-ray spectroscopy

- Large missions have pros and cons
  + Large missions accomplish science that cannot otherwise be done
  + Large, general purpose observatories can be used by the general observer community in ways that were not envisioned by the designers nor captured in the science requirements
  + Large missions drive development of new capabilities that can be infused later into smaller missions without further technical development
    - Large mission costs must be carefully managed to preserve programmatic balance
    - Large missions are too big to fail
Committee Questions: Capability and Leadership

- What concerns do you have about how long flagship missions take for development and the difficulty for young researchers or even potential future PIs to gain experience?
  - Flagship mission instruments are for the most experienced PIs
  - A balanced program provides opportunities for PI development through suborbital investigations, instruments, small missions

- What is the value of flagship missions for science base concerns? Talent pools, corporate knowledge, continuity of capabilities etc., and the impact on the future health of this support base?
  - It is conceivable that the science base could be maintained with a large fleet of small observatories, but it would not be paradigm shifting science
  - The US has unique capabilities for large mirror systems, low noise detectors, high contrast imaging, etc.
  - Many of these capabilities are unique to astrophysics; some have dual use
  - Without an ongoing program of missions that use these capabilities, the capabilities will be lost

- What is the role of international partnerships in strategic and flagship missions? How is this different for other classes of missions?
  - It is anticipated that all future large missions will be international in nature
  - That is not true for medium and small missions
Committee Questions: Technology Development

• Do you have a separate technology development line?
  – Astrophysics develops technology primarily through three mechanisms:
    – Astrophysics Research and Analysis (APRA) is a 100% technology R&A program. Approximately 50% of the funding goes toward low TRL work (TRL 1-3) in detectors and other technology areas, and the other 50% goes toward suborbital payloads that use balloons, sounding rockets, cubesats, and the ISS to take technologies to TRL 7/8/9.
    – Strategic Astrophysics Technology (SAT) is a combination of competed and directed technology efforts directed at developing the technologies needed for future strategic missions, usually identified in the Decadal Survey or Astrophysics Roadmap, through TRL 3-5/6.
    – Preformulation of large strategic missions includes focused technology development of any outstanding technology needs. For instance, WFIRST has been developing detector and coronagraph technology.
    – Relevant technology is also developed by NASA STMD and other Federal agencies.
Committee Questions: Technology Development

- Do you primarily use flagship missions for technology development?
  - Not primarily. However midTRL technology development is always a part of preformulation for large strategic missions.
  - Large strategic missions that do not require technology development are generally less compelling.

- Can you afford the risk of including new technologies on flagship missions?
  - Yes but it must be appropriately funded, appropriately managed, and begun during preformulation.

- Can you do technology development with smaller size missions?
  - Yes but Explorers are by definition expected to be low risk and to apply already developed technology.
  - The technology for Explorers, as well as strategic missions, is developed in the APRA and SAT programs and generally tested on suborbital missions.

- Do you treat new technology at all differently on flagship missions vs. small missions (by, for example, incentivizing missions to use new technologies)?
  - Astrophysics has not yet chosen to incentivize PI-led Explorers to use new technologies. All the relevant technologies can be tested in the suborbital program before being infused into an Explorer.
  - Flagships are generally enabled through the application of new technology. Technology development is a necessary part of preformulation and is the objective of the SAT program.
Committee Questions: Cost Control for Large Missions

• How do cost overruns on flagship class missions affect the other mission classes in your portfolio?
  – Lessons learned from JWST:
    • Mature technology early
    • Properly scope the effort (descope early, assess requirements)
    • Budget adequate reserves year-by-year
    • Understand the budget impact of carrying risks and delays into the future
  – Program balance can be maintained (no impact to other mission classes) by extending development period without increasing annual budget. Impact is delay to start of next large strategic mission.
  – Lowest cost impact is to solve overruns when they happen, but this necessarily has a current impact on other mission classes, so not always chosen.

• How do you address cost overruns on flagship missions vs. how you address cost overruns on smaller class missions?
  – Large strategic missions are probably too important scientifically to cancel when they overrun. Overruns must be handled through descopes and replanning.
  – PI-led Explorers are cost capped, and they should be terminated if they overrun significantly before confirmation. The ability to stay within the cost cap is a feature of the mission class and also a factor in the selection.
Fraction of budget on Large Observatories

Note: When Webb was replanned in 2011 to a larger total cost, the fraction of the Astrophysics budget spent on large observatories did not increase.