



# NASA Astrophysics Update to the HEPAP

High Energy Physics Advisory Panel Meeting  
Latham Hotel, Georgetown; October 12, 2006

Michael Salamon/NASA HQ/SMD/Astrophysics

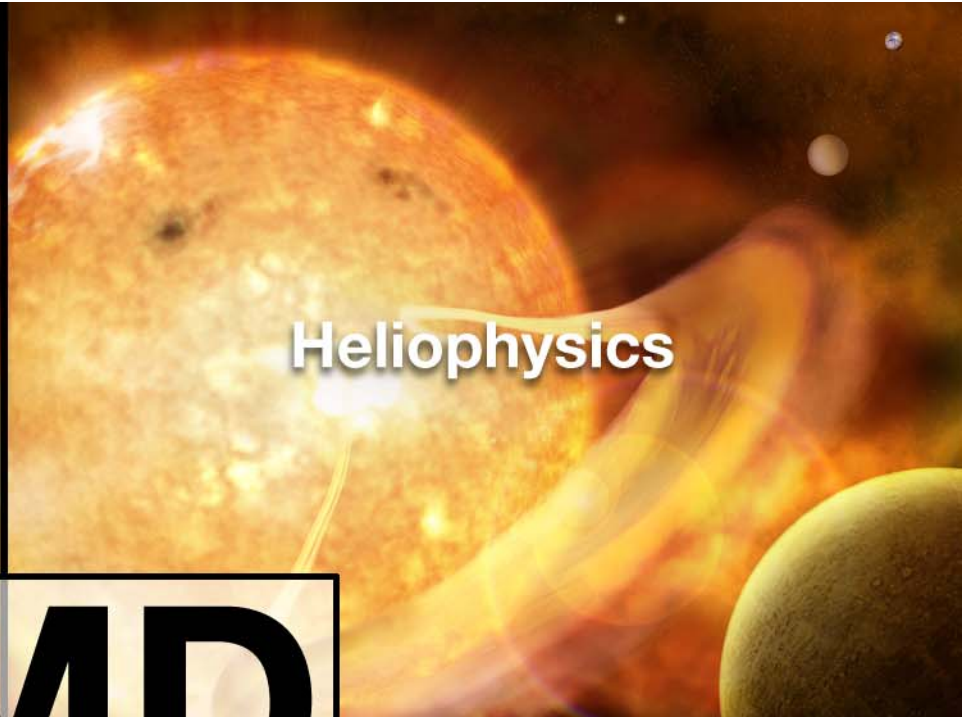


# NASA Update

- Science Mission Directorate structure
- Budget update
- Astrophysics missions timeline
- Beyond Einstein Program: Who's on first?
- JDEM Concept Studies
- Fever charts
- Recent Astrophysics Results



**Earth Science**

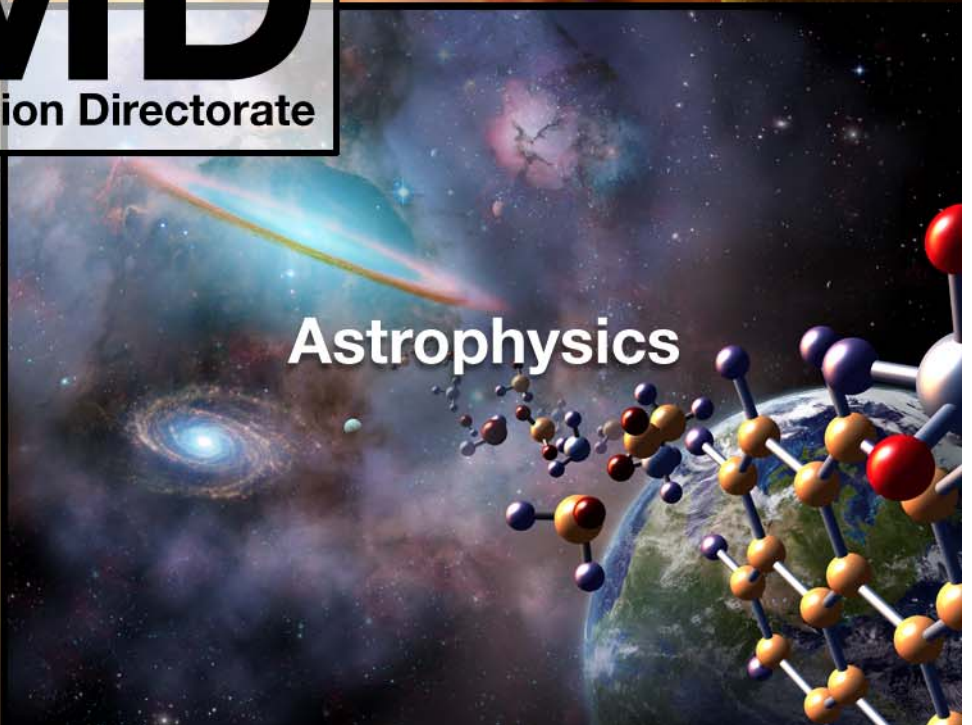


**Heliophysics**

**SMD**  
Science Mission Directorate





**Planetary Science**



**Astrophysics**

# SMD Programs

## Science Mission Directorate

 Division  
 Program

### Planetary Science Division

New Frontiers

Mars Exploration

Discovery

Solar System Research

Cassini

### Earth Science Division

Earth System Science Pathfinder

Earth Systematic Missions

Applied Sciences

Earth Science Research

ESS Multimission Ops

Other Agency Support Programs

### Astrophysics Division

Hubble Space Telescope

Navigator

James Webb Space Telescope

SOFIA

GLAST

ISSC: Herschel/Planck

Universe Research

Beyond Einstein

### Heliophysics Division

Living with a Star

Solar Terrestrial Probes

New Millennium

Explorer

Deep Space Mission Systems

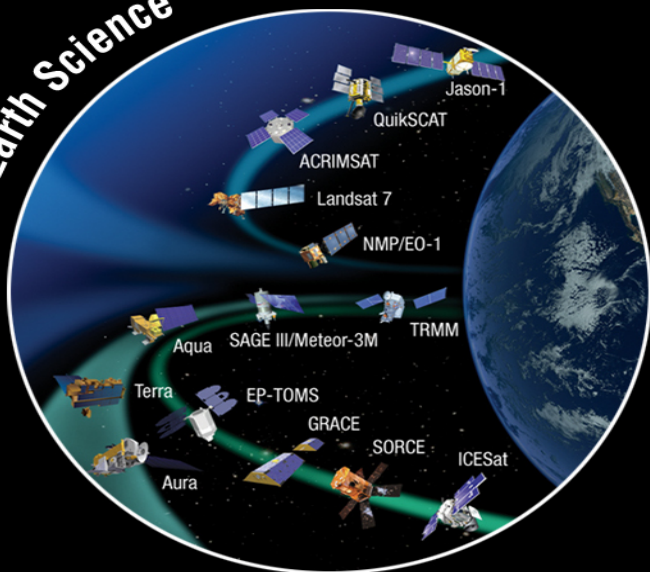
Ground Network

Heliophysics Research

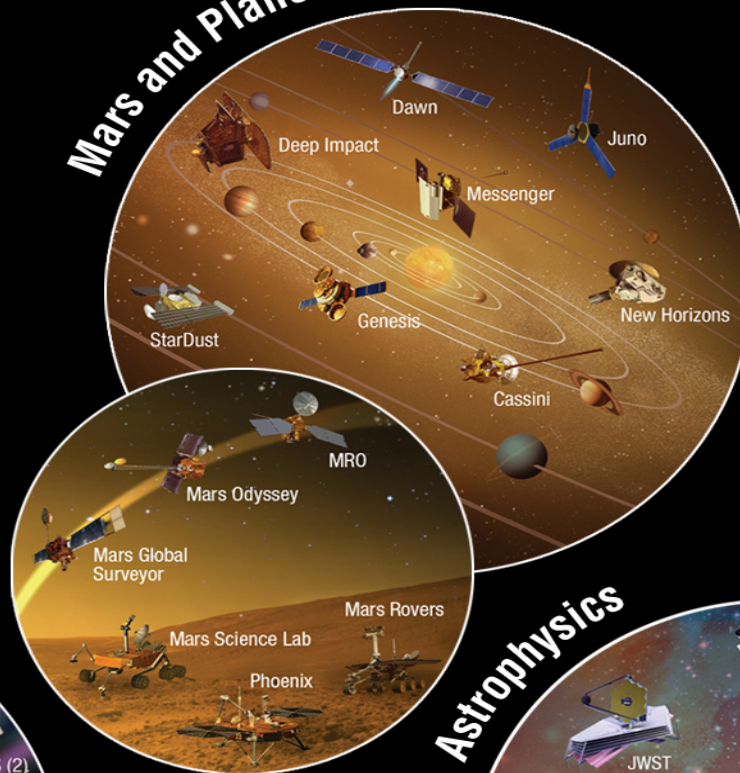


# NASA Science Missions

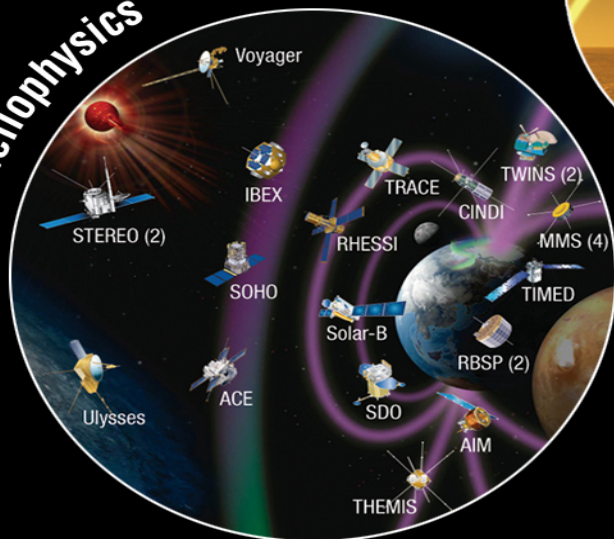
## Earth Science



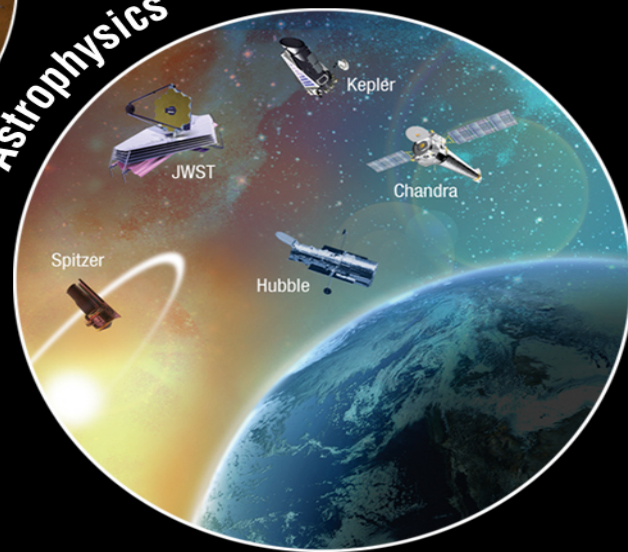
## Mars and Planetary Science



## Heliophysics



## Astrophysics





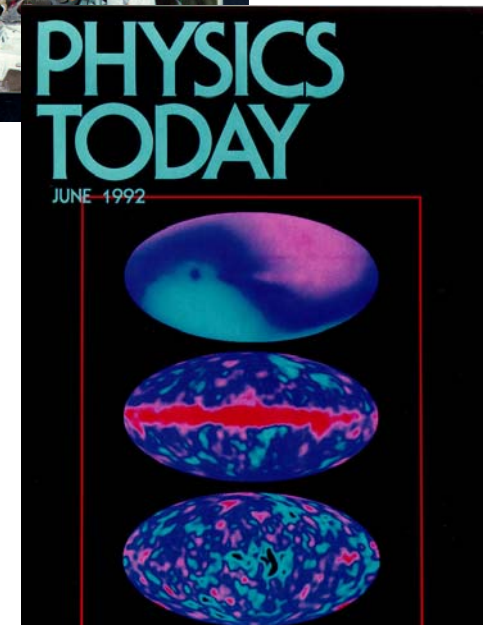
# 2006 Nobel Prize in Physics



- **John C. Mather and George F. Smoot**
  - Goddard Space Flight Center
  - University of California, Berkeley

**“for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation”**

- Awarded only occasionally for astrophysical topics:
  - Davis, Koshiba & Giacconi (2002)
  - Hulse & Taylor (1993)
  - Chandrasekhar & Fowler (1983)
  - Penzias & Wilson (1978)
  - Hans Bethe (1967)
- Award ceremony in Stockholm on December 10.





## 2006 Balzan Prize for Astronomy and Astrophysics

- **Paolo de Bernardis**, Italy and **Andrew Lange**, USA
  - Fisica Spaziale Università degli Studi di Roma La Sapienza
  - Physics Department, California Institute of Technology

**"For their contributions to cosmology, in particular the Boomerang Antarctic balloon experiment."**

- Details about the Prize are available at:

<http://www.balzan.com/en/preistraeger/preistraeger06.cfm>

- "One of the highest awards for science, culture and achievement, ranking close to the Nobel Prize"

- This prize comes with 1 Million Swiss Francs
- Awarded only occasionally for **Observational Astronomy and Astrophysics**

- Reinhard Genzel (2003)
- Fred Hoyle and Martin Schwarzschild (1994)
- Martin Rees (1989)
- Jan Oort (1984)

- Award ceremony in Rome on November 2



04-27-00 issue



# FY2007 NASA Budget Update

- Presidential Budget Request issued in February, 2006 (see next slides).
- House and Senate appropriation subcommittees governing NASA have both prepared legislation with differing (but non-conflicting) earmarks.
- Senate version contains an extra \$1B to NASA as “emergency” funding to offset Hurricane Katrina losses and also those following from the loss of the Columbia Shuttle.
- Final Conference bill (House+Senate) must be passed; Continuing Resolutions beginning in October, 2006.





# FY 2007 President's Budget (The Universe Budget Changes)

	<u>FY 2006</u>	<u>FY 2007</u>	<u>FY 2008</u>	<u>FY 2009</u>	<u>FY 2010</u>	<u>TOTAL</u>
FY 2006 PRESIDENT'S BUDGET	1,512.2	1,531.5	1,539.4	1,495.0	1,406.7	7,484.9
FY 2007 PRESIDENT'S BUDGET	1,507.9	1,509.2	1,500.9	1,307.9	1,276.1	7,101.9
Changes	(4.3)	(22.3)	(38.5)	(187.2)	(130.6)	(382.9)
James Webb Space Telescope (JWST)	(7.5)	70.6	164.0	153.9	163.6	544.6
Hubble Space Telescope (HST)	77.9	118.5	159.0	(8.8)	25.3	371.9
Gamma-ray Large Space Telescope (GLAST)	26.5	18.7	1.3	9.5	3.5	59.5
Discovery (Kepler)	19.7	24.2	53.1	0.3	(1.1)	96.2
Universe Explorers (incl WISE)	(15.4)	(8.5)	26.7	45.1	9.4	57.3
International Space Science Collab. (Herschel, Planck)	0.0	(2.5)	(15.3)	0.3	4.0	(13.5)
Navigator (SIM, TPF, Keck)	(54.0)	(118.5)	(223.9)	(155.2)	(172.5)	(724.1)
Beyond Einstein (LISA, Con-X, Einstein Probes)	(41.3)	(62.7)	(143.1)	(166.6)	(95.3)	(509.0)
Stratospheric Observatory for Infrared Astronomy (SOFIA)	(0.3)	(57.1)	(59.4)	(60.2)	(60.4)	(237.4)
Universe Research	(9.9)	(5.0)	(0.1)	(5.4)	(7.5)	(27.9)



# The Astrophysics: Content of FY07 Budget

	FY06	FY07	FY08	FY09	FY10	FY11
<b>FY 07 President's Budget</b>	<b>1,507.9</b>	<b>1,509.2</b>	<b>1,500.9</b>	<b>1,307.9</b>	<b>1,276.1</b>	<b>1,309.7</b>
Navigator	145.5	128.1	170.6	276.9	261.6	347.0
SIM	117.0	98.5	139.0	236.2	222.5	302.2
Keck Interferometer / Single Aperture	9.6	10.2	9.6	8.4	7.0	7.0
TPF	3.4					
Corporate / Other	15.5	19.4	22.0	32.3	32.1	37.8
<b>James Webb Space Telescope</b>	<b>364.0</b>	<b>443.1</b>	<b>492.6</b>	<b>380.9</b>	<b>353.0</b>	<b>305.0</b>
Hubble Space Telescope	268.6	336.7	302.2	161.4	120.3	138.5
Development	166.5	216.2	178.9	55.0	45.4	45.7
Operations and Data Analysis	87.0	102.0	106.0	97.0	68.0	85.0
Corporate	15.1	18.5	17.3	9.4	6.9	7.8
Stratospheric Observatory for Infrared Astronomy (SOFI)	48.0					
Gamma-ray Large Space Telescope (GLAST)	125.9	85.4	25.2	28.8	29.3	30.4
Discovery (Kepler / Corporate)	137.5	100.8	69.9	13.8	13.4	13.0
Explorer (Universe)	85.4	67.6	86.1	56.7	19.0	4.6
WISE	69.7	53.9	71.7	44.8	8.8	4.3
Swift, Suzaku	10.9	10.0	9.5	8.6	9.1	
Corporate	4.8	3.7	4.9	3.3	1.1	0.3
<b>Universe Research</b>	<b>305.8</b>	<b>306.6</b>	<b>309.2</b>	<b>297.4</b>	<b>288.9</b>	<b>259.6</b>
Research and Analysis	65.1	54.4	54.0	56.0	53.9	55.9
Chandra	58.4	63.0	65.1	64.7	65.1	65.0
Spitzer	74.3	76.6	75.7	71.7	66.4	35.9
Other Missions / Data	68.1	71.2	70.8	59.2	58.4	59.2
Balloons	22.8	24.5	25.8	28.5	28.8	29.0
Corporate / Other	17.1	16.9	17.8	17.3	16.3	14.6
ISSC (Herschel / Planck)	13.0	19.6	23.6	38.9	38.5	36.3
Beyond Einstein	14.1	21.2	21.4	53.0	152.2	175.4



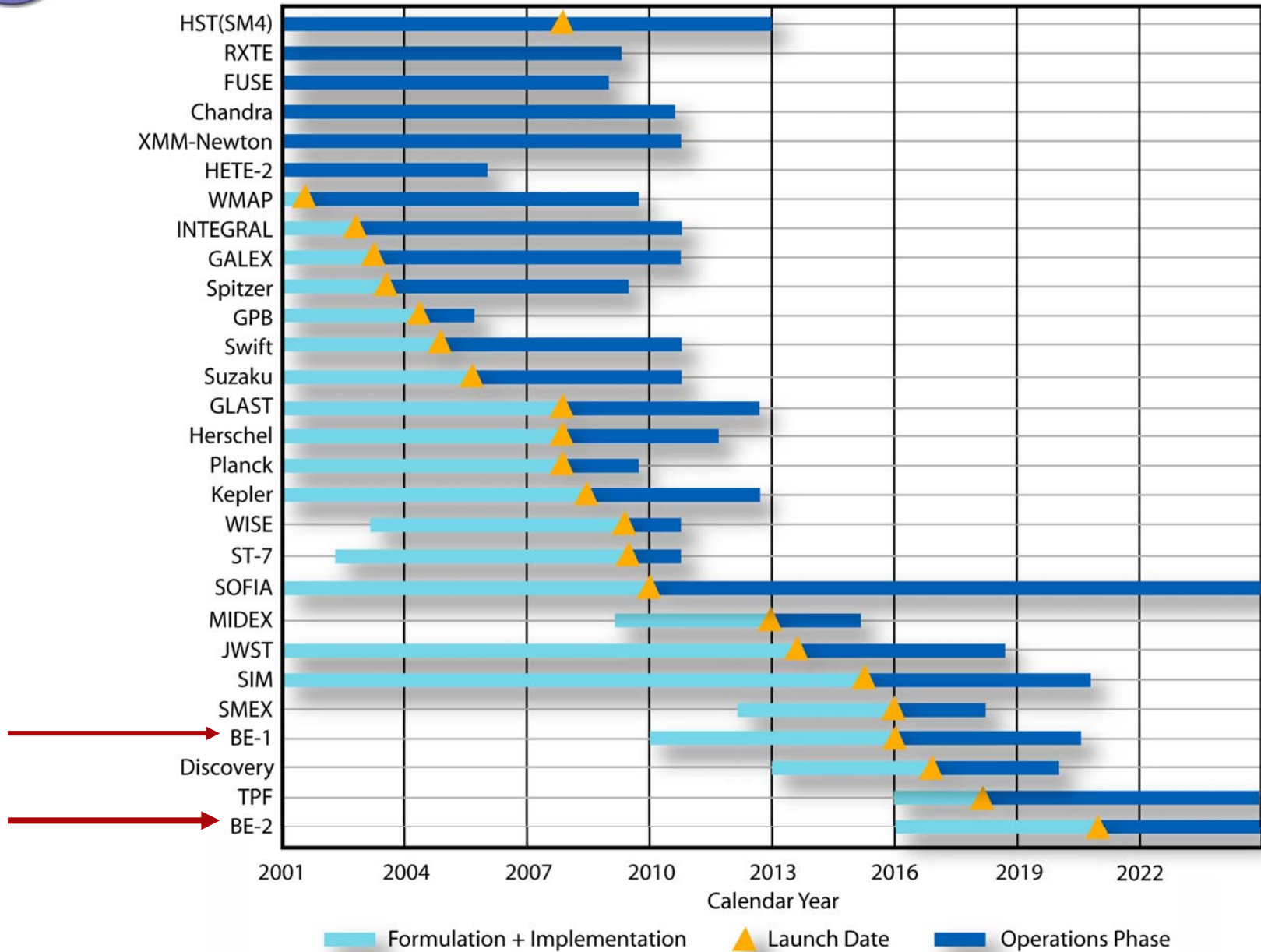
# From the President's Budget Request for FY2007

QuickTime™ and a  
TIFF (LZW) decompressor  
are needed to see this picture.





# Astrophysics Division Missions Timeline (from SMD Science Plan)

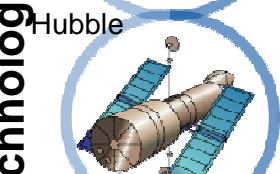
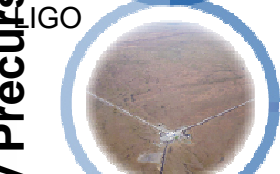
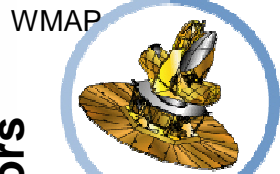




# Beyond Einstein Program

BEYOND Einstein

Science and Technology Precursors



microwave background detection

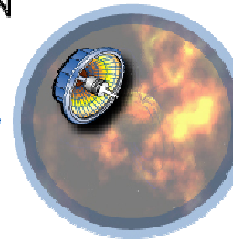
gravitational wave detectors

optical imaging

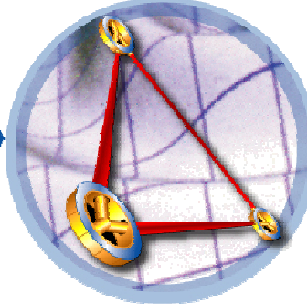
x-ray imaging

mega-channel electronics

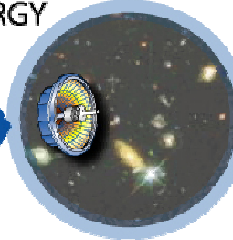
INFLATION PROBE



LISA



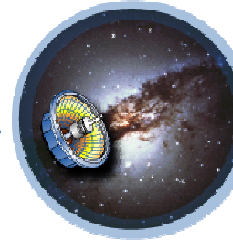
DARK ENERGY PROBE



CONSTELLATION-X



BLACK HOLE FINDER PROBE



big bang physics

space interferometry, gravitational wave detection

space interferometry

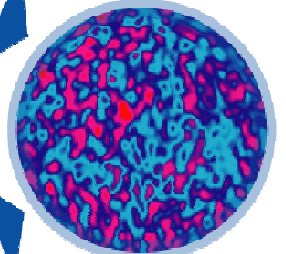
dark energy physics

dark matter physics

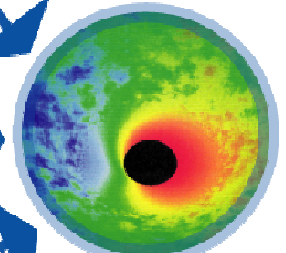
black hole physics

black hole census

BIG BANG OBSERVER



BLACK HOLE IMAGER



GREAT OBSERVATORIES

PROBES

VISIONS



# NRC Committee to Assess the Beyond Einstein Program

- Original 2004 ordering of Beyond Einstein missions was LISA (launch in 2013), Con-X (launch in 2018), with Einstein Probes initiating as funds were provided (JDEM, Inflation Probe, Black Hole Finder Probe).
- FY05 Presidential Budget delayed LISA and Con-X by a year, and deferred the Einstein Probes to beyond the budget horizon.
- Intense focus on Dark Energy has created programmatic pressure to consider placing JDEM at top of BE queue.
- Funding reductions in FY07 Presidential Budget have placed LISA, Con-X on low level of technology development only, with funding wedge for one new BE start in 2009.
- NASA/SMD and DOE/HEP requested the NRC/Space Studies Board (SSB) and Board of Physics and Astronomy (BPA) to convene a panel to recommend which of the BE missions should fly first (with no additional prioritization). The report is due in September, 2007.
- The subsequent Decadal Survey (results available by 2010) would prioritize the remaining BE missions, along with the entire Astrophysics Division mission suite.



## Tasks of the NRC Beyond Einstein Committee

1. To assess the five proposed Beyond Einstein missions (Constellation-X, LISA, JDEM, Inflation Probe, and Black Hole Finder Probe) and recommend which of these five should be developed and launched first, using a funding wedge that is expected to begin in FY2009. The criteria for these assessments include
  1. Potential scientific impact within the context of other existing and planned space-based and ground-based missions;
  2. Realism of preliminary technology and management plans, and cost estimates.
2. To assess the Beyond Einstein missions sufficiently so that they can act as input for any future decisions by NASA or the next Astronomy and Astrophysics Decadal Survey on the ordering of the remaining missions. This second task element will assist NASA in its investment strategy for future technology development within the Beyond Einstein Program prior to the results of the Decadal Survey.



## NRC Beyond Einstein Committee (cont.)

- “Determining which of the five Beyond Einstein missions should be selected for this [FY2009] start involves several factors, scientific impact being of primary importance, but also including technological readiness and mission partnership issues.”
- Cost realism is an issue, as seen in the previous A&A Decadal Survey estimates:
  - Con-X: 2nd-ranked Major Initiative (\$800M)
  - LISA: 2nd-ranked Moderate Initiative (\$250M for US contribution)
- NASA/SMD and DOE/HEP are jointly funding this NRC effort.
- The SSB and BPA have already received funds for the study; the first meeting of the committee will be in early November, 2006. The final report is due September 8, 2007.
- Several town hall meetings will be held by the Committee to solicit input from the community on the Beyond Einstein mission priorities.





# Joint Dark Energy Mission (JDEM) Concept Studies

- Call for JDEM Concept Studies in NASA's 2005 ROSES (Research Opportunities in Space and Earth Science) Announcement; proposals were due in March, 2006; selections made in August, 2006; FY07 start.
- Each award provides ~\$2M (total) for a 2-year period for concept development and final report preparation.
- 3 proposals selected out of 6 submitted:
  - **SuperNovae / Acceleration Probe - Lensing (SNAP-L)**; Saul Perlmutter; deep survey of 7.5 deg<sup>2</sup> with 2000 Type Ia SNe out to  $z=1.7$ ; wide survey of 1000 deg<sup>2</sup> for weak-lensing mapping.
  - **Advanced Dark Energy Physics Telescope (ADEPT)**; Charles Bennett; wide survey of  $10^8$  galaxies in  $H\alpha$ ,  $1 < z < 2$ , to observe baryon acoustic oscillations; will also measure 1000 Type Ia SNe.
  - **Dark Energy Space Telescope (DESTINY)**; Tod Lauer; deep survey of 3 deg<sup>2</sup> with 3000 Type Ia SNe,  $0.4 < z < 1.7$ ; wide survey of 1000 deg<sup>2</sup> for weak-lensing mapping.
- Each mission meets the finding of Dark Energy Task Force, "*no single technique can answer the outstanding questions about dark energy; combinations of at least two of these techniques must be used to full realize the promise of future observations.*"



## JDEM Concept Studies (continued)

- Intent of JDEM Concept Studies:
  - Help develop multiple mission concepts and competitive collaborations.
  - Learn what science can be returned for a JDEM cost cap of \$600M.
- Concept study reports due at beginning of FY09, which is when the Beyond Einstein NASA funding ramp begins.
- A joint DOE/NASA Announcement of Opportunity for the JDEM mission may be issued as early as FY08, with proposals due in FY09. (This assumes JDEM is selected to be the first BE mission.)
- DOE/HEP continues to support SNAP and generic dark energy research at the level of several million \$.



## Science Mission Directorate Science Plan

- The 2005 NASA Authorization Act mandates the delivery of “a plan to guide the science programs of NASA through 2016.”
- Astrophysics Chapter is derived from the Universe Division Roadmap (2005), which was never published (but is available on the web).
- Currently we are on Version 4.0 of the Science Plan, with only minor modifications expected before the final product goes to Congress.
- Comments on the Plan have generally been very positive:
  - NRC Committee on Review of NASA Science Mission Directorate Science Plan (Thomas Young, Chair): *“Some portions of the plan, such as that concerning astrophysics, do a truly excellent job of outlining why NASA carries out its scientific missions.”*
  - NASA Science Associates Group: *“This draft is a very good document which reflects a tremendous amount of work by the NASA Science Mission Directorate staff... The draft plan, therefore, “answers the mail” in responding to Congress with considerable justification for the approach the agency is taking.”*
  - NAC/Astrophysics Subcommittee (David Spergel, Chair): *“We are concerned that the draft document did not reflect budget realities and was not consistent with the President’s budget and proposed changes.”*



## **NASA Authorization Act for 2005 (S.1281)**

### **Title I Section 101**

(d) SCIENCE.— (1) IN GENERAL.—The Administrator shall develop a plan to guide the science programs of NASA through 2016.

(2) CONTENT.—At a minimum, the plan developed under paragraph (1) shall be designed to ensure that NASA has a rich and vigorous set of science activities, and shall describe— (A) the missions NASA will initiate, design, develop, launch, or operate in space science and earth science through fiscal year 2016, including launch dates; (B) a priority ranking of all of the missions listed under subparagraph (A), and the rationale for the ranking; and (C) the budget assumptions on which the policy is based, which for fiscal years 2007 and 2008 shall be consistent with the authorizations provided in title II of this Act.

(3) CONSIDERATIONS.—In developing the science plan under this subsection, the Administrator shall consider the following issues, which shall be discussed in the transmittal under paragraph (6): (A) What the most important scientific questions in space science and earth science are. (B) How to best benefit from the relationship between NASA's space and earth science activities and those of other Federal agencies. (C) Whether the Magnetospheric Multiscale Mission, SIM-Planet Quest, and missions under the Future Explorers Programs can be expedited to meet previous schedules. (D) Whether any NASA Earth observing missions that have been delayed or cancelled can be restored. (E) How to ensure the long-term vitality of Earth observation programs at NASA, including their satellite, science, and data system components. (F) Whether current and currently planned Earth observation missions should be supplemented or replaced with new satellite architectures and instruments that enable global coverage, and all-weather, day and night imaging of the Earth's surface features. (G) How to integrate NASA earth science missions with the Global Earth Observing System of Systems.

(4) CONSULTATION.—In developing the plan under this subsection, the Administrator shall draw on decadal surveys and other reports in planetary science, astronomy, solar and space physics, earth science, and any other relevant fields developed by the National Academy of Sciences. The Administrator shall also consult widely with academic and industry experts and with other Federal agencies.

(5) HUBBLE SPACE TELESCOPE.—The plan developed under this subsection shall address plans for a human mission to repair the Hubble Space Telescope consistent with section 302 of this Act.

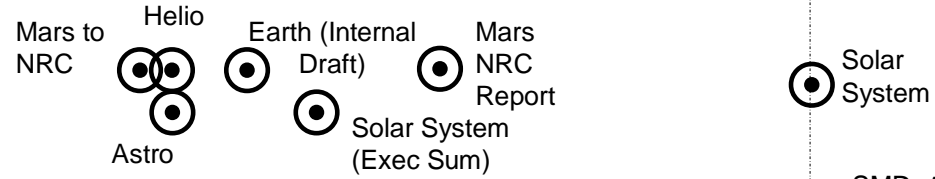
(6) SCHEDULE.—The Administrator shall transmit the plan developed under this subsection to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate not later than 1 year after the date of enactment of this Act. The Administrator shall make available to those committees any study done by a nongovernmental entity that was used in the development of the plan.



JAN 06 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

SMD Science Plan Schedule 10/5/06

Roadmaps



SMD Management Review



Draft of Common Elements Sections



Roadmap Presentations to Subcommittees



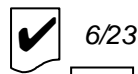
Status / Content Presentation to NAC / SC



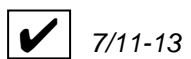
Draft of Science Division Sections



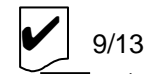
Draft 3 for SC, Subcommittees, NRC, Industry review



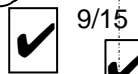
Meeting of SSB ad hoc Review Committee



Draft 3.5 for Sept. Subcommittee Meetings



Comments from NRC, NSAG, etc.



Draft 4 for NAC/SC, Other Agency Review



Final Discussion with NAC / SC



Table top review with PA&E

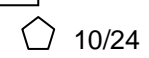
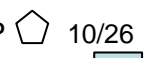
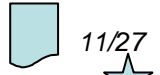


Table top review with OMB, OSTP



*SSB report on impacts of FY07 request*

Draft for Agency & OMB clearance



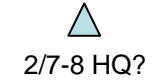
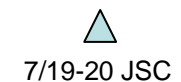
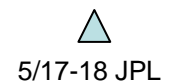
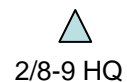
**Deliver to Congress**



AGU 12/11-15



NAC Science Committee



Science Subcommittees

Chairs telecon - 4/7



5/3-4 Conference



7/6-7 21



5 mtgs in mid, late Sept



**Key**

- ⊙ Roadmap
- ☒ SMD Review
- Draft
- ▭ Presentation
- ⬠ Table Top Review
- ▲ Meetings
- ★ Delivery

*Italics = change from prior version of the schedule*



# Astrophysics Division Developmental Missions Status

<i>Project</i>	<i>Launch</i>	<i>June</i>	<i>July</i>	<i>Aug</i>	<i>STATUS</i>
<b>Keck Intrfrmrtr</b>	N/A	Y	Y	Y	Technical effort focuses on nulling and support for highest priority science.
<b>Keck Outrigger</b>	N/A	R	R	R	Outriggers not funded in FY07- Looking at options.
<b>SOFIA</b>	TBD	R	R	R	Schedule delays for 1st test flight and ORR, reduce budget for FY06, no budget in FY07 & beyond. Agency PMC Sep 14, 2006, accepted prog office plan.
<b>LBTI</b>	Jun 2007 init. capability	G	G	G	Replan due to delays in telescope readiness complete.
<b>GLAST</b>	NET Nov 2007	Y	Y	Y	LAT TVAC successfully completed, at SASS for Obs I&T. GBM/Obs I&T continues. Budget reserves and launch date rebaseline DPMC scheduled for Oct 18.
<b>HST SM-4</b>	NET Jan 2008	G	G	G	Awaiting SM-4 decision and manifest date.
<b>Herschel</b>	Feb 2008	G	G	G	All hardware development has been completed.
<b>Planck</b>	Feb 2008	G	G	G	All hardware development has been completed.
<b>Kepler</b>	2008	Y	Y	Y	Continued technical issues. Completion of CDR near.
<b>WISE</b>	2009	R	Y	Y	WISE given new funding planning numbers for Oct 13 Delta Mission Confirmation Review.
<b>JWST</b>	NET 2013	G	Y	Y	Recent State Department policy change affecting TAAs w/ ESA threatens schedule.
<b>SIM</b>	NET 2015	G	G	G	Real-time control subsystem received 9 new brassboards. This has enabled validation of the largest (18 node) ring bus topology to date.
<b>LISA</b>	TBD	G	G	G	Preparation underway for upcoming NRC review.
<b>Con-X</b>	TBD	G	G	G	Preparation underway for upcoming NRC review.
<b>TPF</b>	TBD	G	G	G	Plans for FY07 activities under development. To be delivered to HQs for review & approval by the end of September.
<b>Balloons</b>	on-going	Y	Y	Y	Successful FIRST( Far-IR Spectroscopy of the Troposphere) conventional balloon mission (9-18-06) including an underflight of CALIPSO. ULDB dev funding issue.
<b>MSC</b>	N/A	G	G	G	Keck Obs archive ingested 1.2 TB data. Archive public mid-July, registered with NVO.



# Astrophysics Division Operating Missions Status

	<i>Launch/EOM</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>STATUS</i>
<b>HST</b> (Extended)	<b>4-25-90</b> <b>2010</b>	<b>G</b>	<b>G</b>	<b>Y</b>	ACS Hi-Res Camera Power issue under study. ACS observations on hold since event on 9/23 - rest of HST operating nominally.
<b>Rossi XTE</b> (Extended)	<b>12-30-95</b> <b>2-28-09</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>FUSE</b> (Extended)	<b>6-24-99</b> <b>9-30-08</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>Chandra</b> (Extended)	<b>7-19-99</b> <b>7-19-10</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>XMM-Newton</b> (Extended)	<b>12-9-99</b> <b>9-30-10</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>WMAP</b> (Extended)	<b>6-30-01</b> <b>9-30-09</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>Integral</b> (Extended)	<b>10-17-02</b> <b>9-30-10</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>GALEX</b> (Extended)	<b>4-28-03</b> <b>9-30-10</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>Spitzer</b> (Extended-Prime)	<b>8-25-03</b> <b>3-31-09</b>	<b>G</b>	<b>Y</b>	<b>G</b>	S/C recovered from safemode 8/31 -- 13 days of science time lost.
<b>GP-B</b> (DA mode)	<b>4-20-04</b> <b>8-30-05</b>	<b>G</b>	<b>G</b>	<b>G</b>	FY07 data analysis cost extension approved by Division. S/C ops to be taken over by USAFA - Space Act Agreement in concurrence cycle for SMD signature.
<b>Swift</b> (Prime)	<b>11-20-04</b> <b>9-30-10</b>	<b>G</b>	<b>G</b>	<b>G</b>	
<b>Suzaku</b> (Prime)	<b>7-9-05</b> <b>9-30-10</b>	<b>G</b>	<b>G</b>	<b>G</b>	



# Recent Cover Stories



September 4, 2006



September 2006



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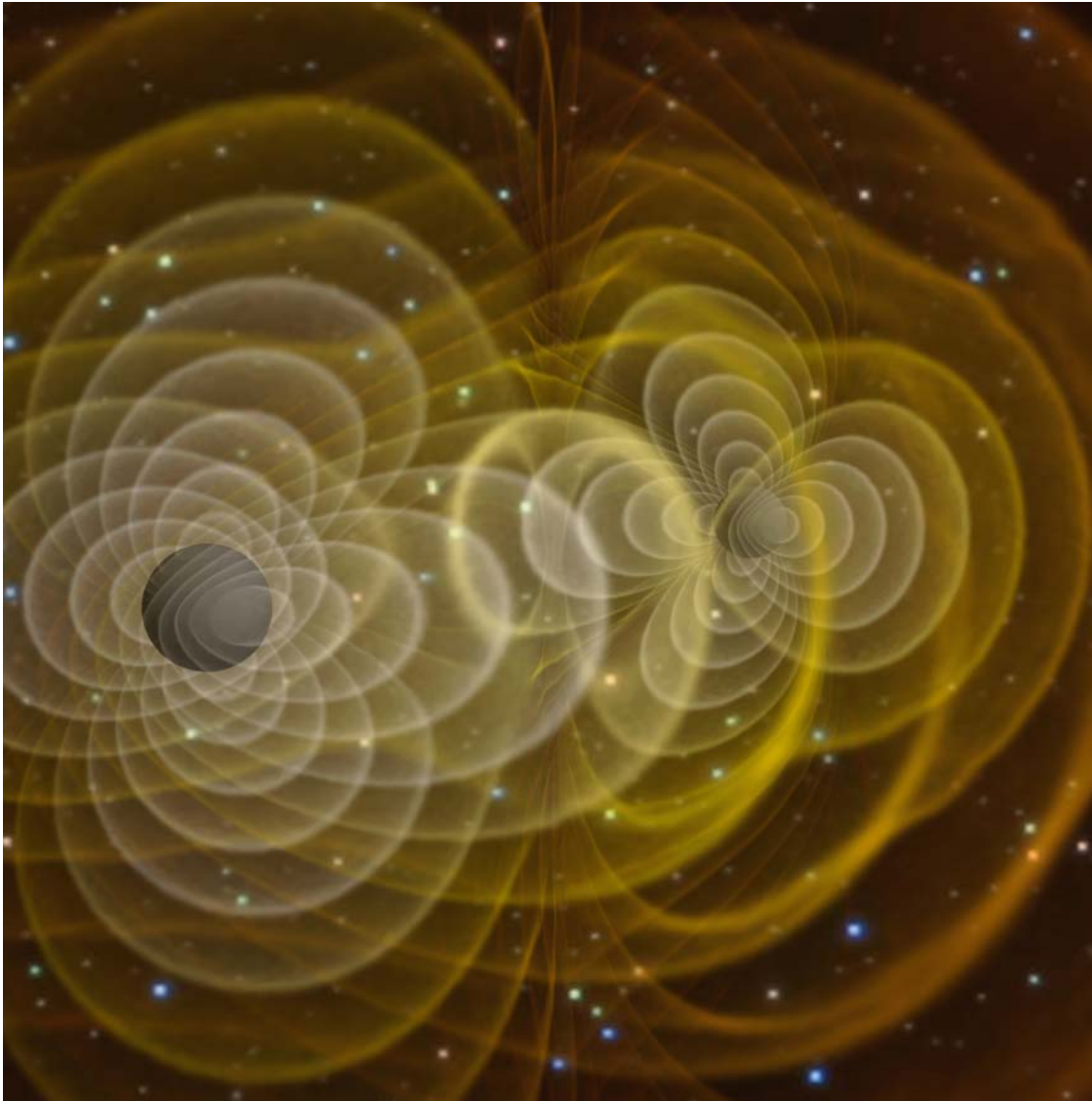
November 2006







## Gravitational Waves (from SMD Science Plan)



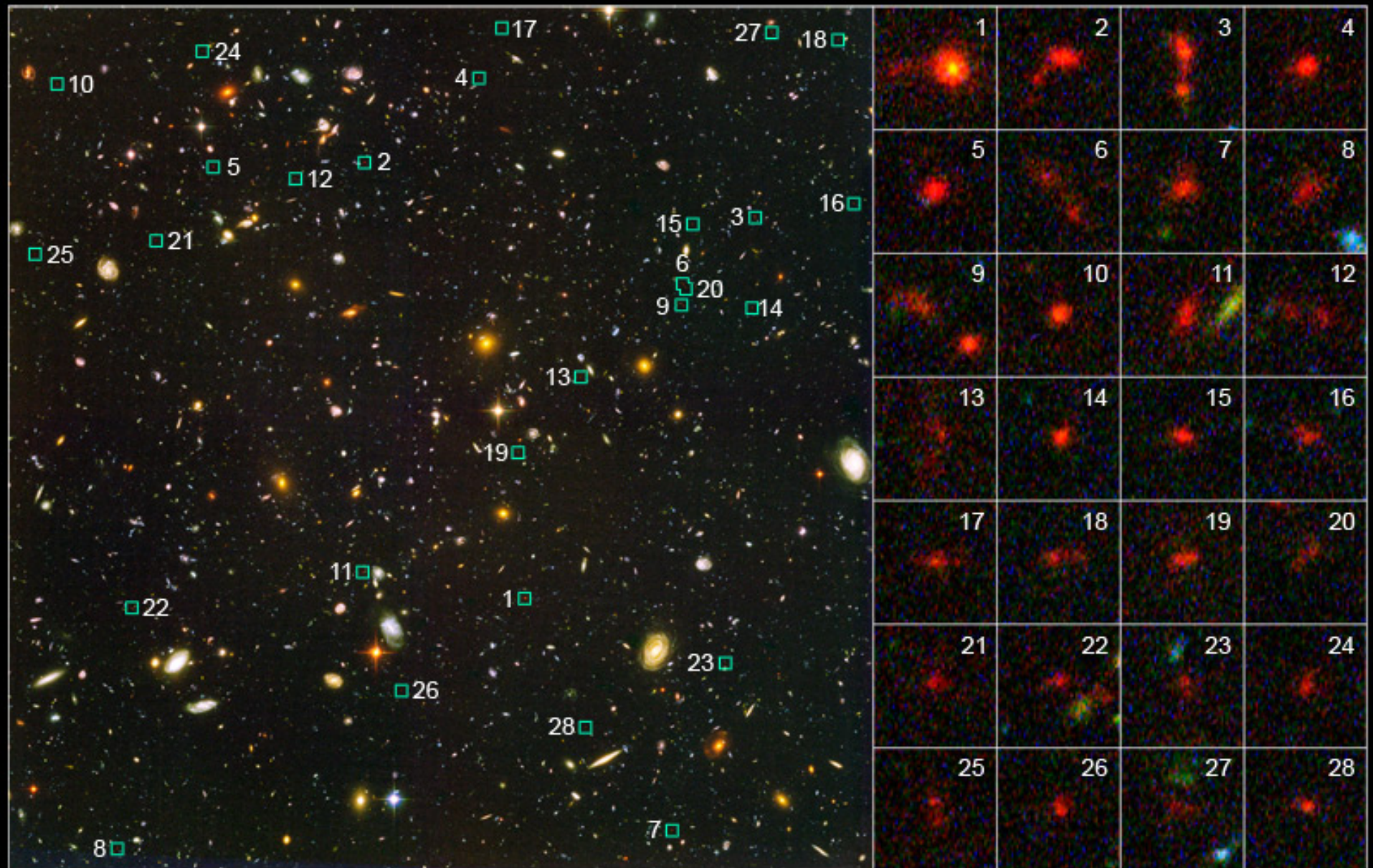
Researchers crunched Einstein's theory of general relativity on the Columbia supercomputer at the NASA Ames Research Center to create a three-dimensional simulation of merging black holes. This was the largest astrophysical calculation ever performed on a NASA supercomputer. The simulation provides the foundation to explore the universe in an entirely new way, through the detection of gravitational waves by the LISA mission.



NASA/JPL-Caltech/Yale Univ.

# Distant Galaxies in the Hubble Ultra Deep Field

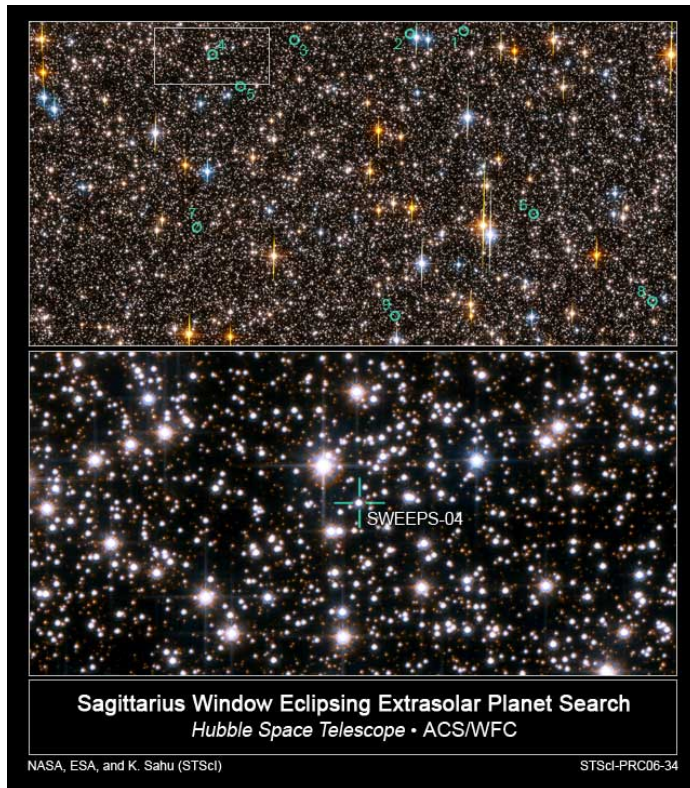
HST ■ ACS/WFC



NASA, ESA, R. Bouwens and G. Illingworth (University of California, Santa Cruz)

STScI-PRC06-12

# HST - 16 Candidate Planets at the Center of Our Galaxy



This discovery is the culmination of the Sagittarius Window Eclipsing Extrasolar Planet Search (SWEEPS). **The Hubble Space Telescope (HST) was used to look farther than has ever successfully been searched for extrasolar planets**, looking at 180,000 stars in the crowded central bulge of our galaxy 26,000 light-years away.

**Five of the newly discovered planets represent a new extreme type of planet not found in any nearby searches.** Dubbed Ultra-Short-Period Planets (USPPs), these worlds whirl around their stars in less than one Earth day, and would be heated to a temperature of 3,000 F.

HST could not view directly the 16 newly found planet candidates. Astronomers used Hubble's Advanced Camera for Surveys to search for planets by measuring the slight dimming of a star due to the passage of a planet in front of it, an event called a *transit*. The planet would have to be about the size of Jupiter to block enough starlight, about one to 10%, to be measurable by HST. (They are called *candidates* because they are too distant to study for follow-up evidence, such as the wobble of the star caused by the planet.)

**The planets tend to be found with stars high in heavier elements**, supporting theories that higher elements are needed in star systems for planets to form.

When extrapolated to the entire galaxy, HST's data provides strong evidence for the existence of **about 6 billion Jupiter-sized planets in the Milky Way.**

