NASA’s Great Observatories
“an astronomical Mount Rushmore”
Why do astronomy in space?

• No atmospheric blurring
• Wider accessible wavelength range
• Instrumental stability
• No clouds/daylight (timing)
HUBBLE

Past

...future?
Some HST Science highlights

- Structures of distant galaxies
- Hubble constant from Cepheid variable stars
- Black holes in (almost all) galactic nuclei
- Protoplanetary material near young stars
- Gravitational lenses
- Intergalactic gas and its history
- Stuff scattered all the way through the textbooks
And just lately...

- Oddly compact massive galaxies in the early Universe
- Lensed galaxies even farther back
- Galaxy-star cluster demographics
- Host galaxies and scattered quasar light
Interacting Galaxies

Hubble Space Telescope • ACS/WFC • WFPC2

NASA, ESA, the Hubble Heritage (AURA/STScI)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)
Gravitational Lenses in the COSMOS Survey

Hubble Space Telescope • ACS/WFC

0038+4133
0211+1139
5921+0638
0018+3845
0013+2249

Double Einstein Ring SDSSJ0946+1006

Hubble Space Telescope • ACS/WFC

NASA, ESA, C. Faure (Zentrum für Astronomie, University of Heidelberg), J.-P. Kneib (Laboratoire d’Astrophysique de Marseille)

NASA, ESA, R. Gavazzi and T. Treu (University of California, Santa Barbara), and the SLACS Team

SYSci-PIC08-04
Instrument history

1990: FGS  HSP  FOS  GHRS  FOC  WF/PC
1993: FGS  CoSTAR  FOS  GHRS  FOC  WFPC2
1997: FGS  CoSTAR  NICMOS  STIS  FOC  WFPC2
2002: FGS  CoSTAR  NICMOS  STIS  ACS  WFPC2
2008: FGS  COS  NICMOS  STIS  ACS  WFC3
Hubble status, August 2008

- Space Telescope Imaging Spectrograph dead (only high-res/small-region spectrometer)
- 3 of 6 gyros (RSUs) functional (3 normally needed, 2-gyro mode now in use with restricted pointing)
- Battery capacity decreasing (useless circa 2010)
- Estimated 50% failure time on above: end of 2008
- Instrument/transmitter power cycling now reduced by rescheduling/eliminating parallel imaging
- Advanced Camera for Surveys (ACS) wide-field camera out
Shuttle status

- “Safe haven” means standby orbiter
- Need for on-orbital shuttle inspection
- Orbital mechanics: 28.5-degree inclination, getting heaviest payloads highest from Cape Canaveral, restricted options now
- STS-125 (HST SM-4) scheduled for October; pacing item was external tank for standby orbiter
**STS-125 Launch Windows** (all times are Central Daylight Time unless noted otherwise; some windows overlap two calendar days; unlike ISS missions, the window runs from planar open to protect a PD-3 rendezvous for HST grapple, and ends on planar close for a targeted rendezvous altitude of 350 statute miles (564 km); there is no preferred in-plane launch time; the launch time is at planar opening; all windows run about 62-66 minutes in length; times will be updated by Flight Dynamics and Flight Design; additional launch opportunities are available, no beta cutout)

| Oct. 5   | 2:02:14am |  |  |  |  |  |
|----------|-----------|  |  |  |  |  |
| Oct. 6   | 1:31:38am |  |  |  |  |  |
| Oct. 7   | 1:01:03am |  |  |  |  |  |
| Oct. 8   | 12:34:49am|  |  |  |  |  |
| Oct. 9   | 12:04:11am|  |  |  |  |  |
| Oct. 9/10| 11:33:35pm (9th CT)  | 12:33:35am (10th ET) |  |  |  |  |
|          | 12:33:35am (10th CT) | 1:39:51am (10th ET) |  |  |  |  |
| Oct. 10/11| 11:03:54pm (10th CT) | 12:03:54am (11th ET) |  |  |  |  |
|          | 12:03:54am (11th CT) | 1:09:13am (11th ET) |  |  |  |  |
| Oct. 11/12| 10:36:45pm (11th CT) | 11:36:45am (12th ET) |  |  |  |  |
|          | 11:36:45am (12th CT) | 1:28:36am (12th ET) |  |  |  |  |
| Oct. 12/13| 10:06:08pm (12th CT) | 11:06:08am (13th ET) |  |  |  |  |
|          | 11:06:08am (13th CT) | 1:28:36am (13th ET) |  |  |  |  |
| Oct. 13  | 9:35:33pm | 10:41:47pm |  |  |  |  |
| Oct. 14  | 9:09:20pm | 10:11:09pm |  |  |  |  |
| Oct. 15  | 8:38:41pm | 9:40:34pm |  |  |  |  |
| Oct. 16  | 8:08:05pm | 9:14:23pm |  |  |  |  |
| Oct. 17  | 7:37:30pm | 8:43:43pm |  |  |  |  |
| Oct. 18  | 7:11:16pm | 8:13:08pm |  |  |  |  |
| Oct. 19  | 6:40:38pm | 7:42:31pm |  |  |  |  |
Final (SM4) servicing mission

- >2 prior STS flights had “acceptable” foam shedding
- COS, WFC3, STIS and ACS repairs, batteries, gyros
- Now manifested as STS-125 (last non-ISS flight)
- Deorbit module status unclear
It’s still popular!
(Figure: Dynamics of Cats/Cosmic Variance blogs)
Next up: JWST
James Webb Space Telescope

- Launch 2013, on Ariane V, to L2 region
- 6.5m deployable primary
- 0.6-20 microns (far red to mid-IR)
- Key problems: formation of galaxies, first stars, maybe planets
- Spacecraft weight/mirror area ratio roughly that of Hubble mirror alone!
Compton Gamma-Ray Observatory
Compton Gamma-Ray Observatory

- Distribution, distance of gamma-ray bursts
- Gamma-ray blazars, relativistic beaming
- Microquasars
- Radioisotopes in interstellar medium
- Successors: Swift, INTEGRAL, GLAST
And at other wavelengths...

Chandra and its complement XMM-Newton

Chandra X-ray Observatory
The galactic-center black hole and its attendants
Hot gas between galaxies
The history of black holes – a Chandra deep field
Spitzer Space Telescope
Spitzer Space Telescope

- Warm launch, radiative cooling
- Cryogen management, 3 years of 5+ so far
- Earth-trailing heliocentric orbit
- 2 cameras, 2 spectrographs, 3.6-160 μm
- Shortest-wavelength cameras could operate indefinitely
Direct detection of IR from two "hot Jupiters" during eclipses, two wavelengths give temperature estimates.

Temperatures of extrasolar planets

![Graphs and plots related to temperature estimation of extrasolar planets.](image)
Across the spectrum - now

FarIR  MidIR  nearIR  opt  UV  farUV  X-ray  gamma

Spitzer  Hubble  GALEX  INTEGRAL  CQROT  WMAP  Akari  GLAST  XMM-Newton  Hubble  Swift  Chandra
Multispectral Greatest Hits

- Intergalactic gas
- Starburst galaxies
- High-redshift galaxies
- Evaporating planets
- Protoplanetary disks
- Growth of black holes
- Complexity of stardeath

- Gamma-ray bursts
- Supernova chemistry
- Quasar jets
- Stripped galaxies
- Pregalactic lumps
- Galaxy history
- Relativistic jets
A panchromatic view - spiral galaxy M81
A new Universe to explore

• The full electromagnetic spectrum
• Open international competition for observations
• Public data archives (without mailing tapes!)
• The beginnings of the Virtual Observatory
• But astronomers think about facilities differently from NASA and ESA...
More just as great

• ESA’s XMM-Newton
• GALEX, Akari, Swift
• Practically everybody’s INTEGRAL
• On the runway: SOFIA
• Almost on the pad: ESA’s Herschel
• And of course – NASA/ESA JWST
• On the ground and meant to stay there: ALMA, GMT, LSMT, ELT, OWL...
GALEX
(Galaxy Evolution Explorer)

Ultraviolet imaging and spectroscopic survey of the sky – the first to be so deep and wide.
GALEX+SDSS and bimodal galaxy properties
Akari
(JAXA's TSFKA Astro-F)
Far-Infrared Image of the Orion Region and the Milky Way

AKARI/Far-Infrared Surveyor (wavelength: 140 μm)

11th July, 2007
Swift – catching gamma-ray bursts on the fly!
X-ray supernova flash in NGC2770

X-ray

SN 2007uy

UV/Optical

SN 2008D

X-ray supernova flash in NGC2770
SOFIA – Stratospheric Observatory for Infrared Astronomy - NASA/DLR
International Gamma-Ray Laboratory (INTEGRAL)
It really *is* international:

ESA mission
Russian launch
NASA communication
Radioactive $^{26}$Al in the Galaxy
- first results from SPI/INTEGRAL -

Map of Galactic $^{26}$Al as obtained from COMPTEL

radioactive decay in the galactic centre region

synthesis of new elements by super-massive stars in the Cygnus constellation

© 2003 the SPI collaboration
Al-26 mass:
2.8 solar masses

Massive SN rate: 1.9/century
ESA Herschel Space Telescope
3.5m Far-IR optimized
Ariane 5 launch (w/Planck)
2009
L2 halo orbit
3 instruments
3 years’ cryogens
60-670 µm range
Gamma-Ray Large Area Space Telescope (GLAST) Fermi
GLAST burst monitors at MSFC right before shipping to Phoenix for integration

(Vela – early returns)

Soup to nuts: everything works!
- timing
- background rejection
- alignment

- precise ephemerides of many pulsars provided by Parkes, Jodrell Bank, Green bank, Nançay, Arecibo, Hartbeeshoek, Urumqi, RXTE, XMM...

- good timing of the EGRET pulsars

- selecting on-pulse shows point source
- evaluate PSF
- alignment of LAT to sky (fit to several point sources)

(Richard Dubois)
Across the spectrum - soon

FarIR MidIR nearIR opt UV farUV X-ray gamma