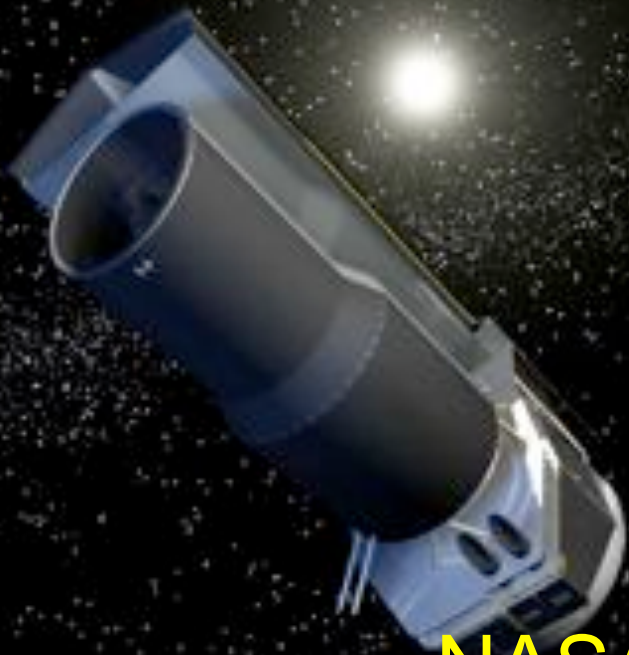
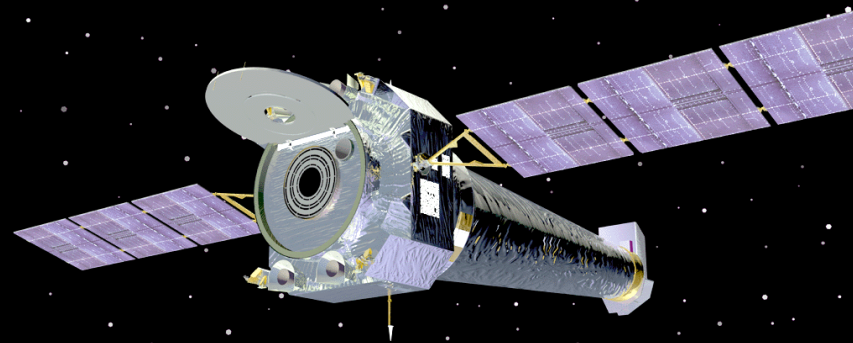


Spitzer



Chandra



NASA's Great Observatories  
*"an astronomical Mount Rushmore"*



Compton



Hubble

# 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...

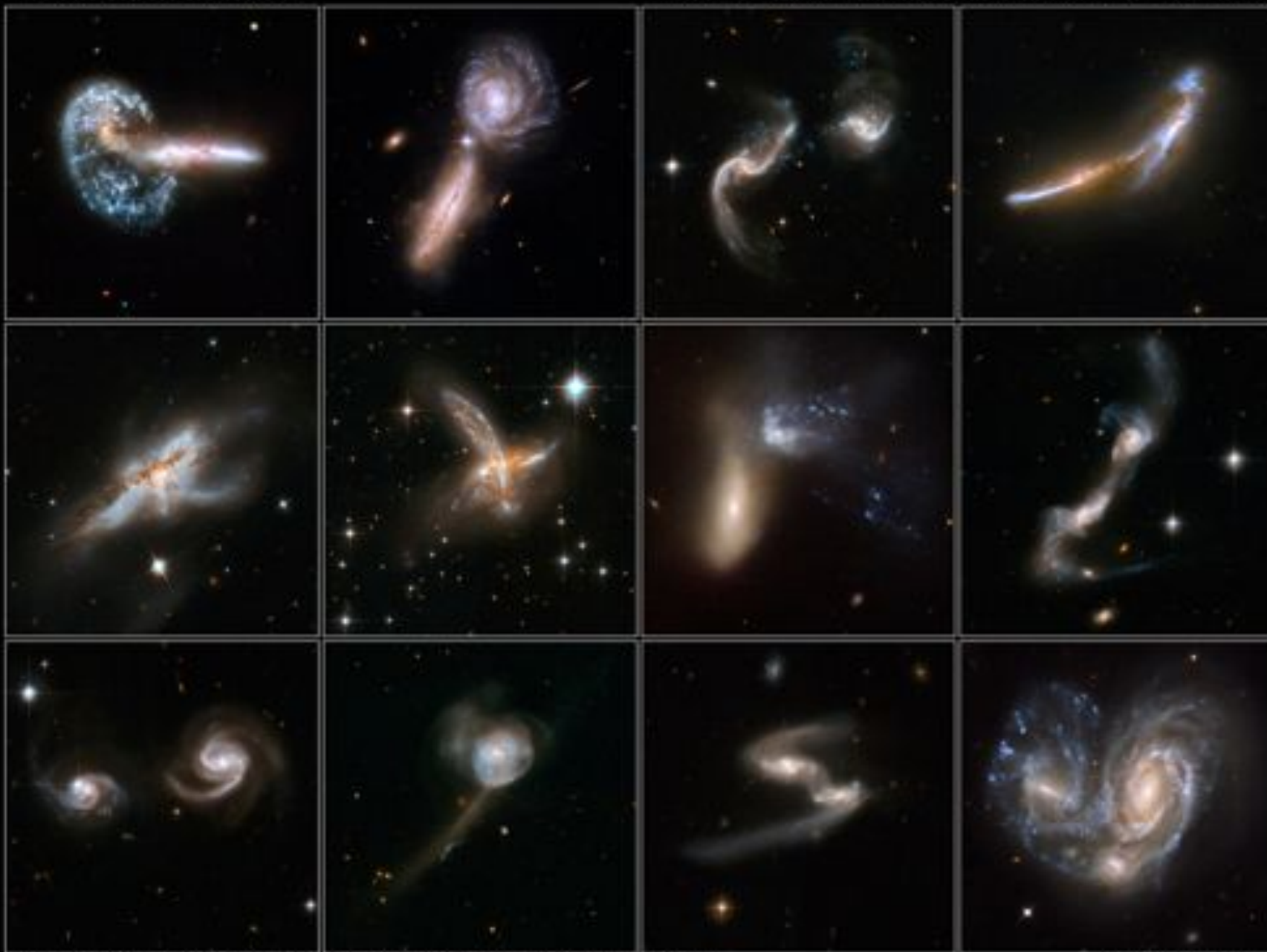
- Oddly compact massive galaxies in the early Universe
- Lensed galaxies even farther back
- Galaxy-star cluster demographics
- Host galaxies and scattered quasar light





# Interacting Galaxies

Hubble Space Telescope • ACS/WFC • WFPC2





INTERACTING GALAXIES

HUBBLE SPACE TELESCOPE





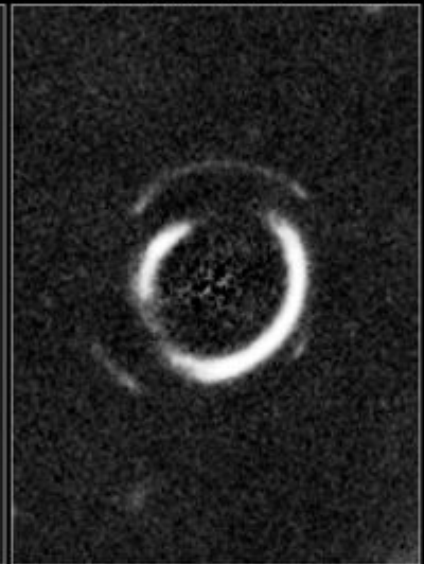
# Gravitational Lenses in the COSMOS Survey

Hubble Space Telescope • ACS/WFC



Double Einstein Ring SDSSJ0946+1006

Hubble Space Telescope • ACS/WFC



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

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

STScI-PRC08-04

STScI-PRC08-04





# Instrument history

1990: FGS HSP FOS GHRS FOC WF/PC

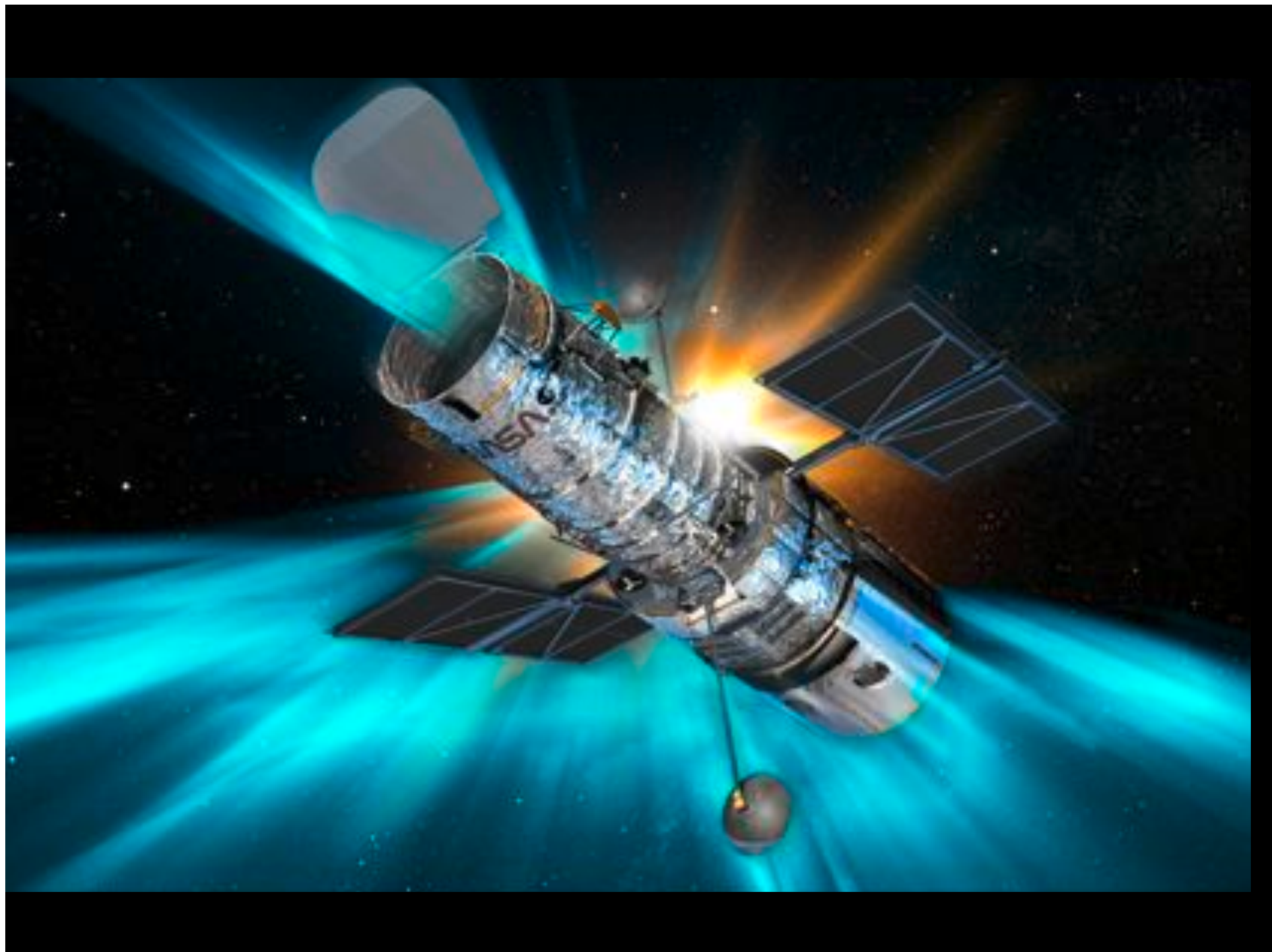
1993: FGS CoSTAR FOS GHRS FOC WFPC2

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



August 1, 2008

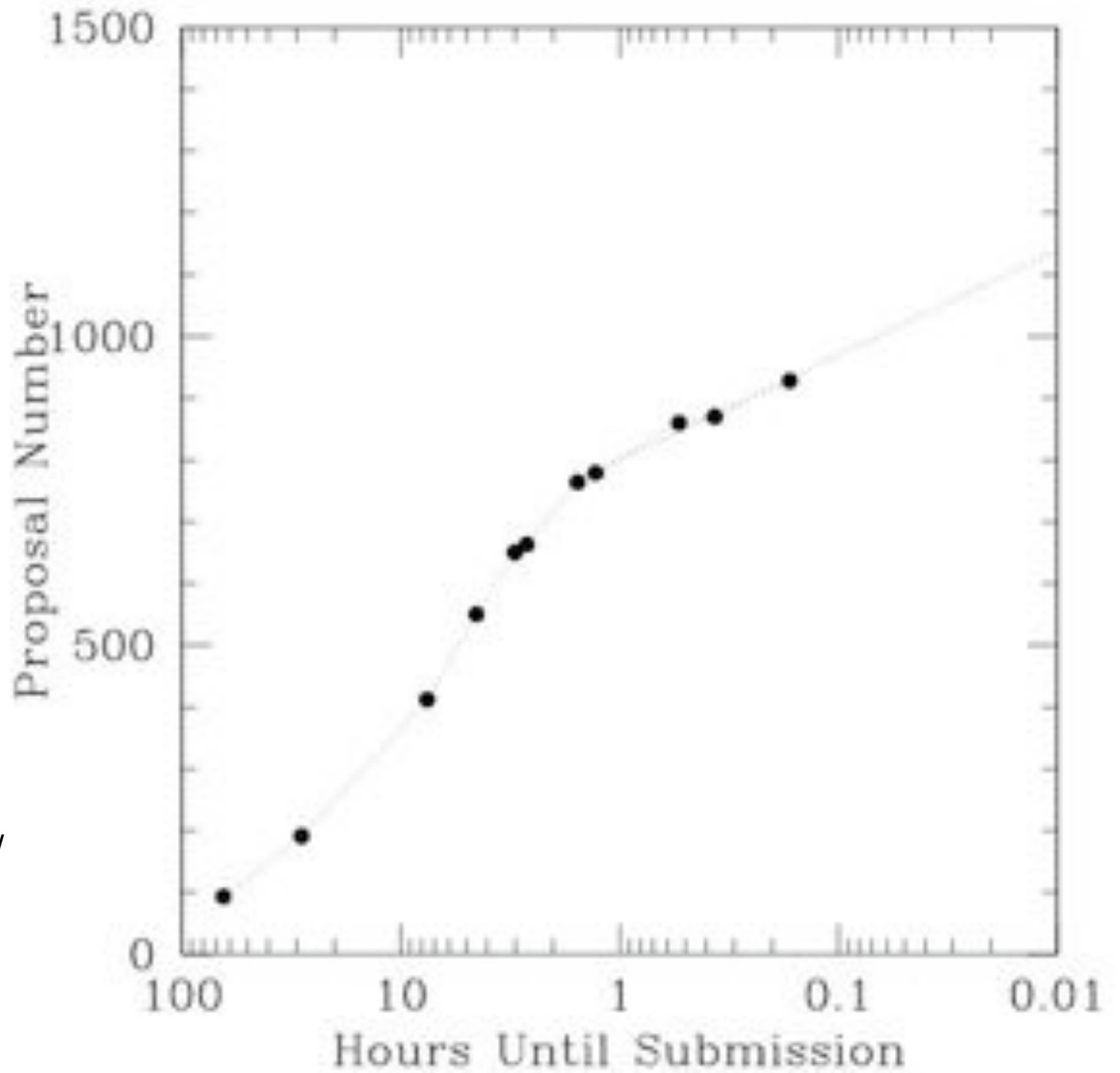
**STS-125 LAUNCH WINDOWS** (all times are Central Daylight Time unless noted otherwise; some windows overlap two calendar days; unlike ISS missions, the window runs from planar open to protect a FD 3 rendezvous for MS7 grapple, and ends on planar close for a targeted rendezvous altitude of 350 statute miles (704 nm); 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 cutoff)

	<u>Planar Open</u>	<u>Planar Close</u>
Oct. 5	2:02:14am	3:04:06am
Oct. 6	1:31:38am	2:37:55am
Oct. 7	1:01:03am	2:07:16am
Oct. 8	12:34:49am	1:36:39am
Oct. 9	12:04:11am	1:06:04am
Oct. 9/10	11:33:35pm (9 <sup>th</sup> CT) 12:33:35am (10 <sup>th</sup> ET)	12:39:51am (10 <sup>th</sup> CT) 1:39:51am (10 <sup>th</sup> ET)
Oct. 10/11	11:03:54pm (10 <sup>th</sup> CT) 12:03:54am (11 <sup>th</sup> ET)	12:09:13am (11 <sup>th</sup> CT) 1:09:13am (11 <sup>th</sup> ET)
Oct. 11/12	10:36:45pm (11 <sup>th</sup> CT) 11:36:45pm (11 <sup>th</sup> ET)	11:38:36pm (11 <sup>th</sup> CT) 12:38:36am (12 <sup>th</sup> ET)
Oct. 12/13	10:06:08pm (12 <sup>th</sup> CT) 11:06:08pm (12 <sup>th</sup> ET)	11:08:02pm (12 <sup>th</sup> CT) 12:08:02am (13 <sup>th</sup> 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	8:13:06pm
Oct. 19	6:40:36pm	7:42:31pm

# Final (SM4) servicing mission

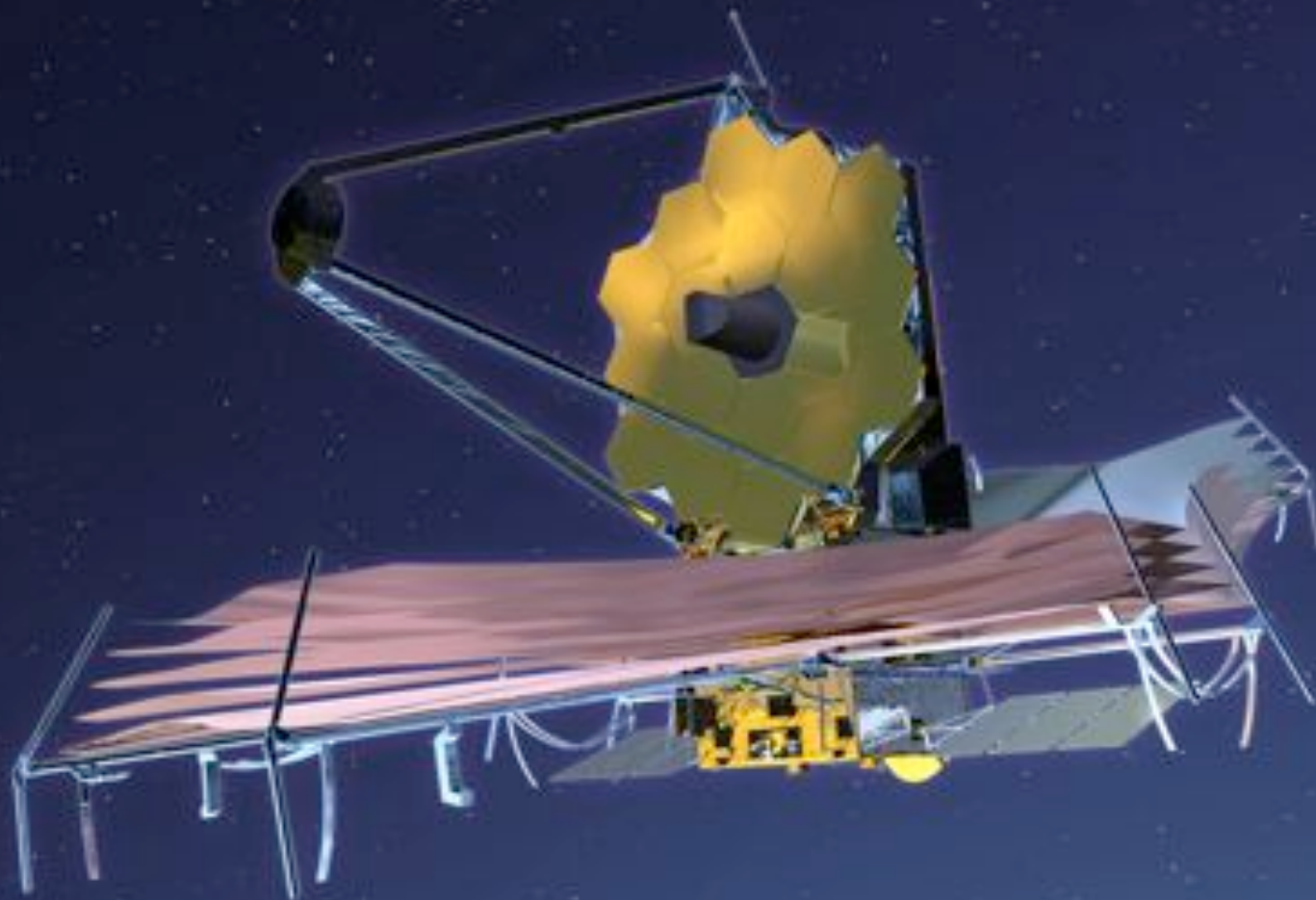
- >2 prior STS flights had “acceptable” foam shedding
- COS, WFC3, STIS and ACS repairs, batteries, gyros
- Now manifested as STS-125 (last non-ISS flight)
- Deorbit module status unclear





It's still popular!  
(Figure:  
Dynamics of Cats/  
Cosmic Variance  
blogs)

Next up: JWST

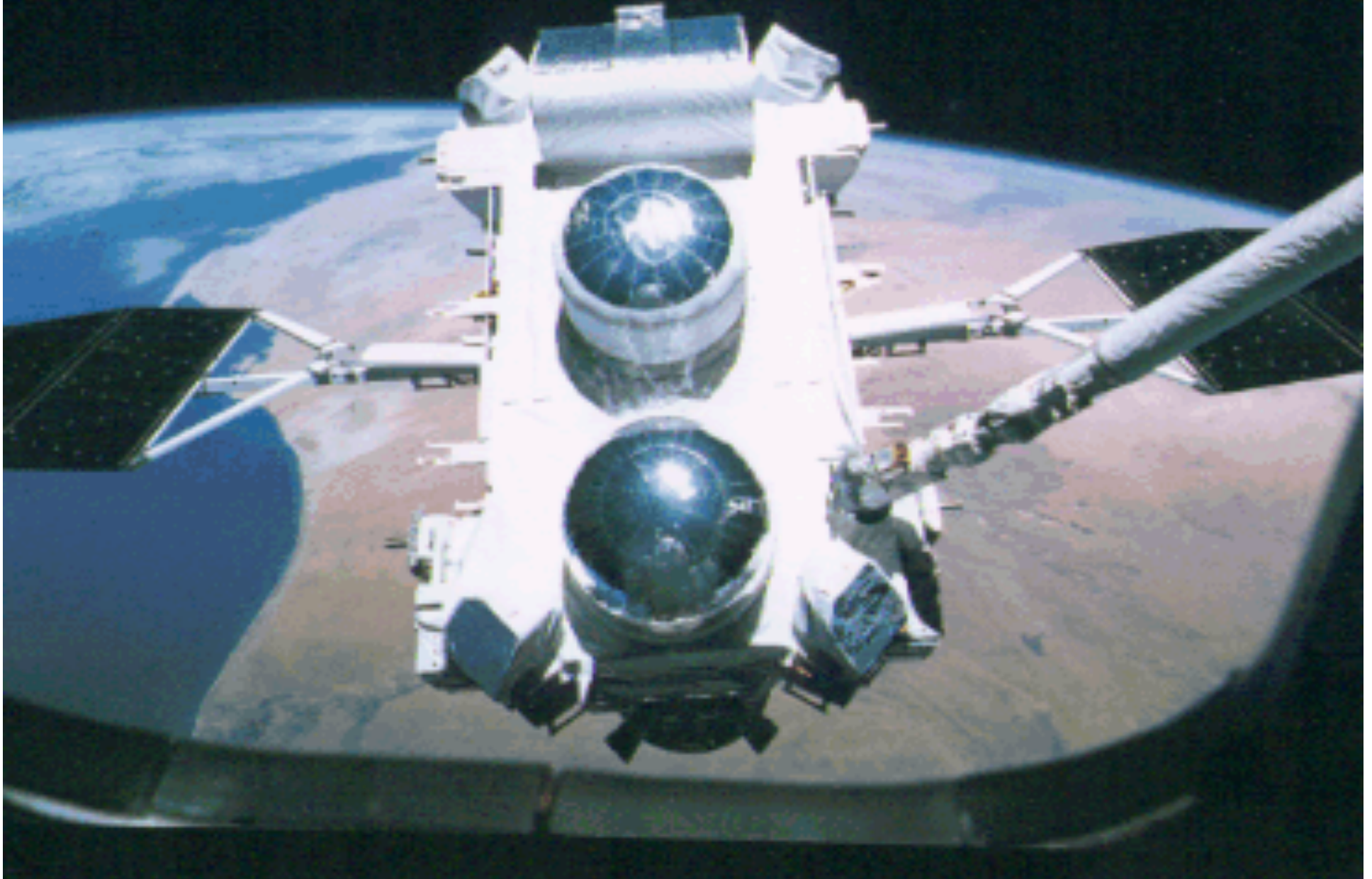




# James Webb Space Telescope

- 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!

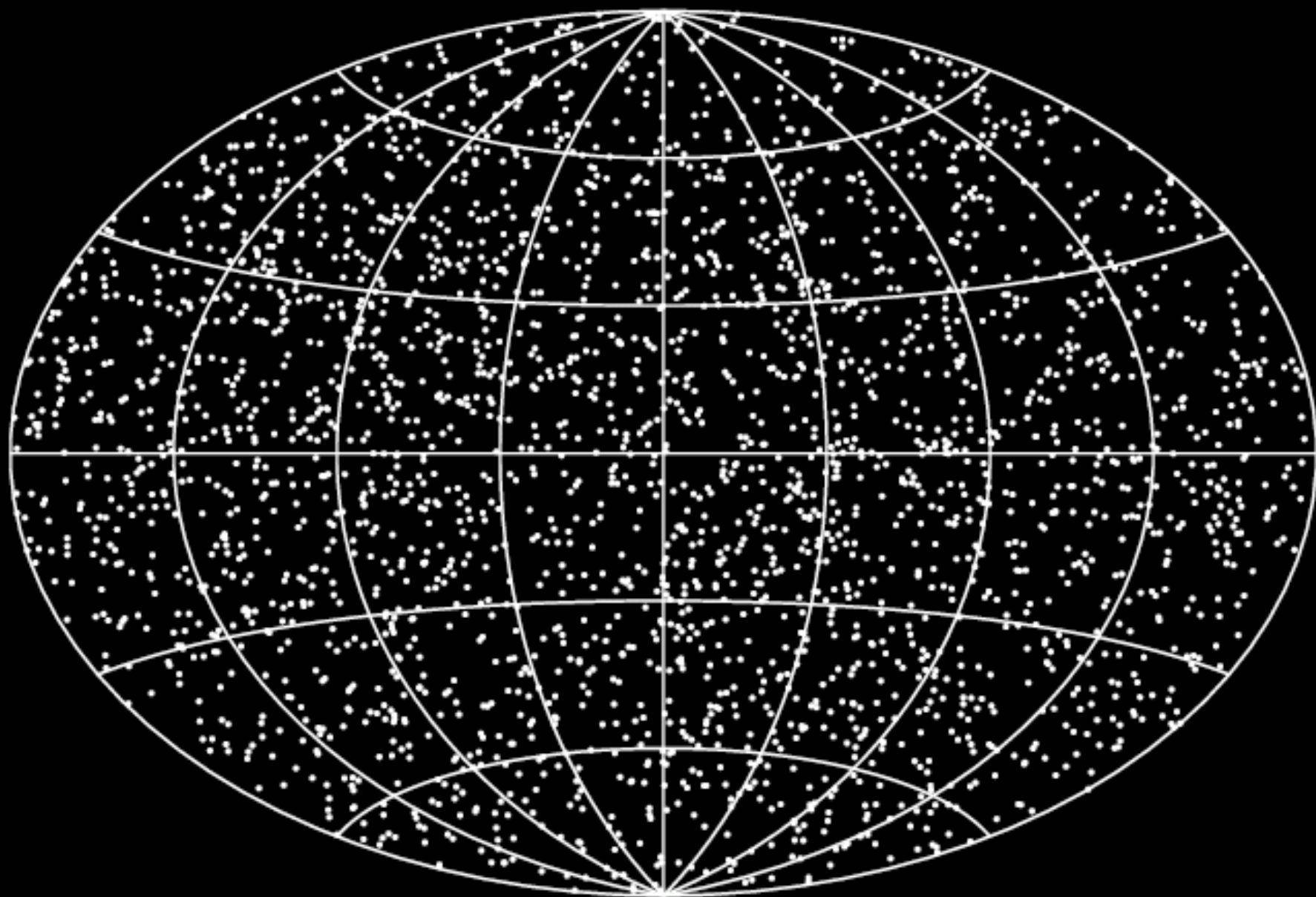
# Compton Gamma-Ray Observatory



# Compton Gamma-Ray Observatory

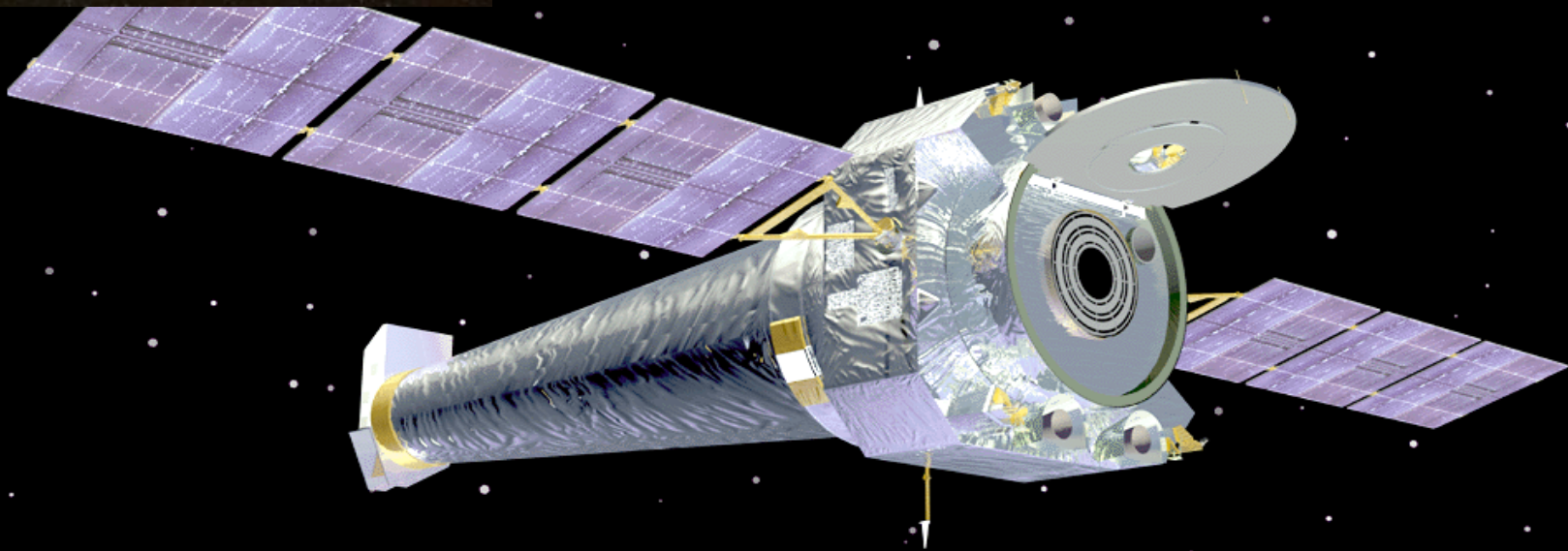
- Deployed April 1991 by STS-37 *Atlantis* crew. Deorbited mid-2000.
- Distribution, distance of gamma-ray bursts
- Gamma-ray blazars, relativistic beaming
- Microquasars
- Radioisotopes in interstellar medium
- Successors: Swift, INTEGRAL, GLAST

# 2704 Gamma-Ray Bursts in Galactic Coordinates





# Chandra X-ray Observatory

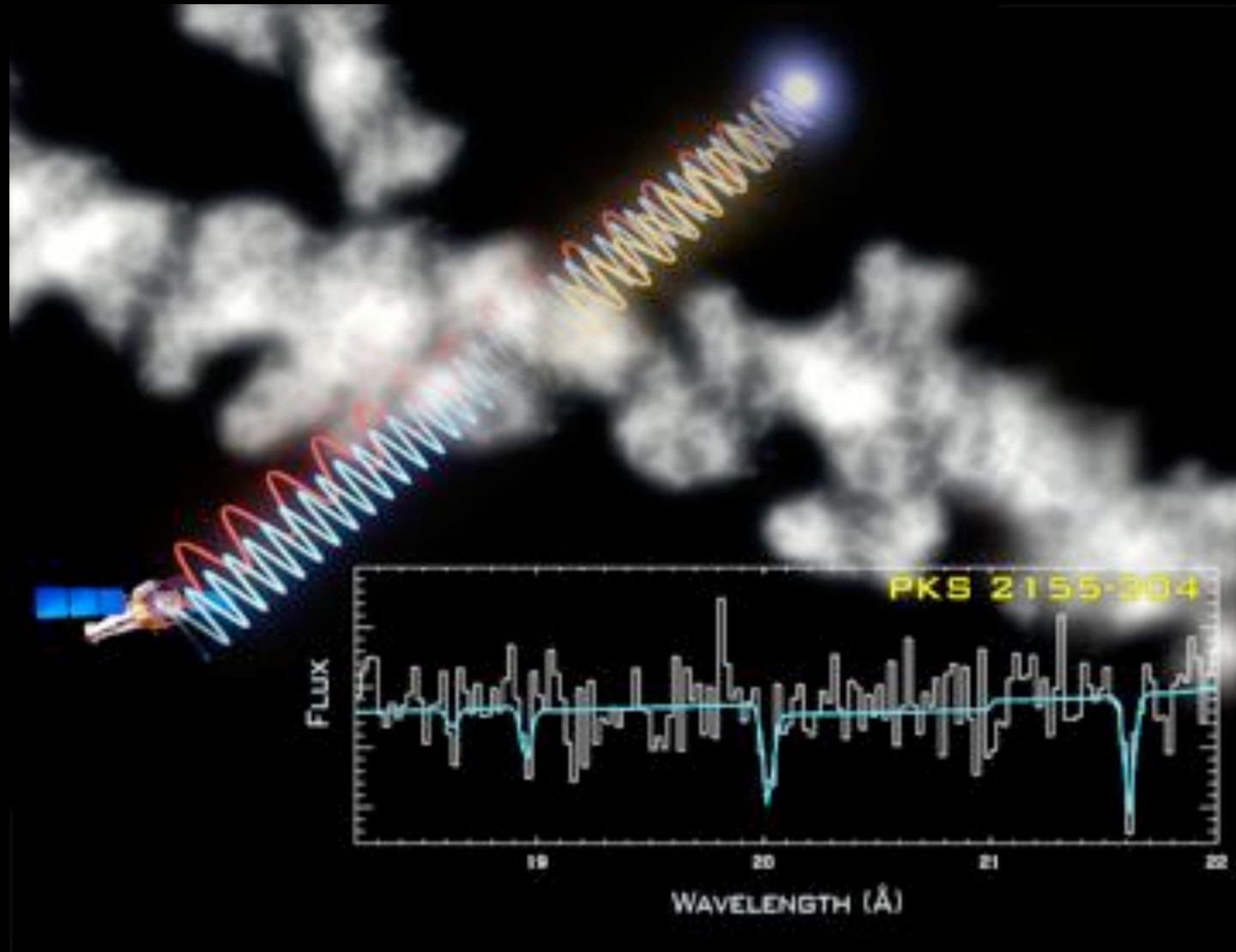




# The galactic-center black hole and its attendants



# Hot gas between galaxies



# The history of black holes – a Chandra deep field





COMPOSITE

X-RAY

RADIO

OPTICAL







# Spitzer Space Telescope

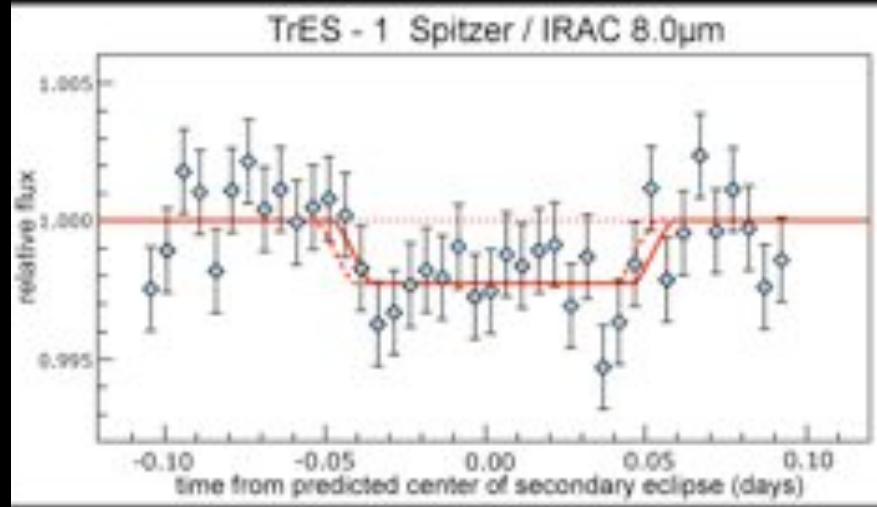
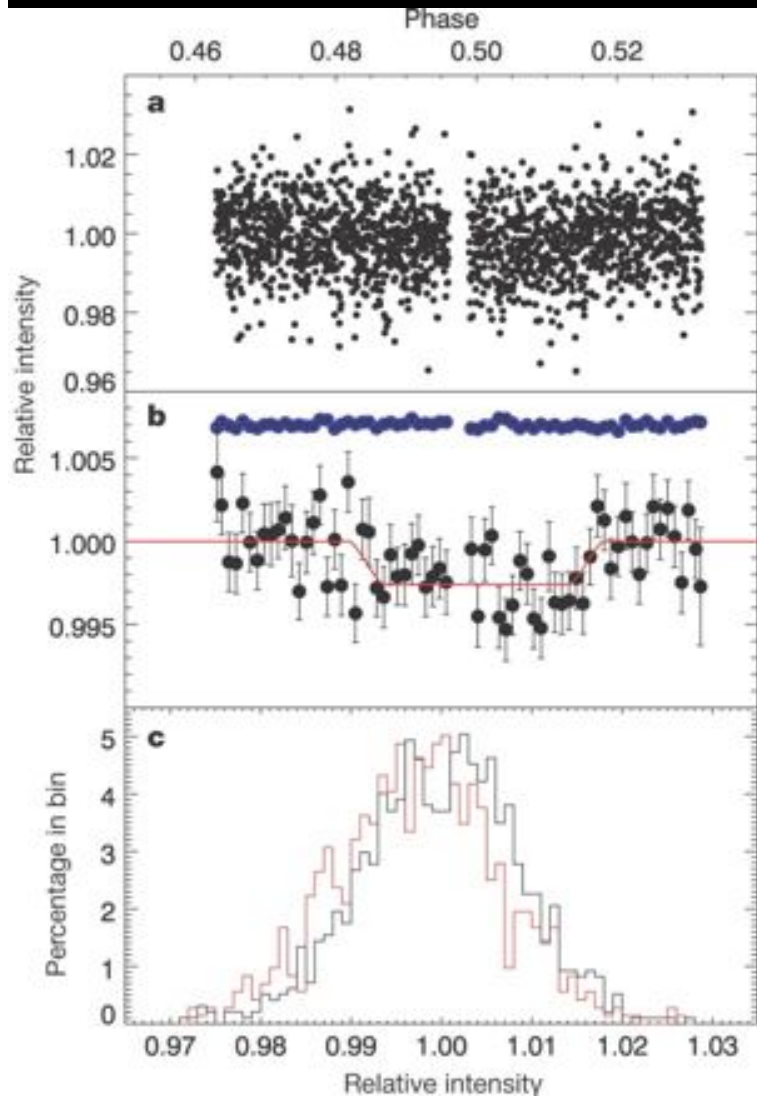


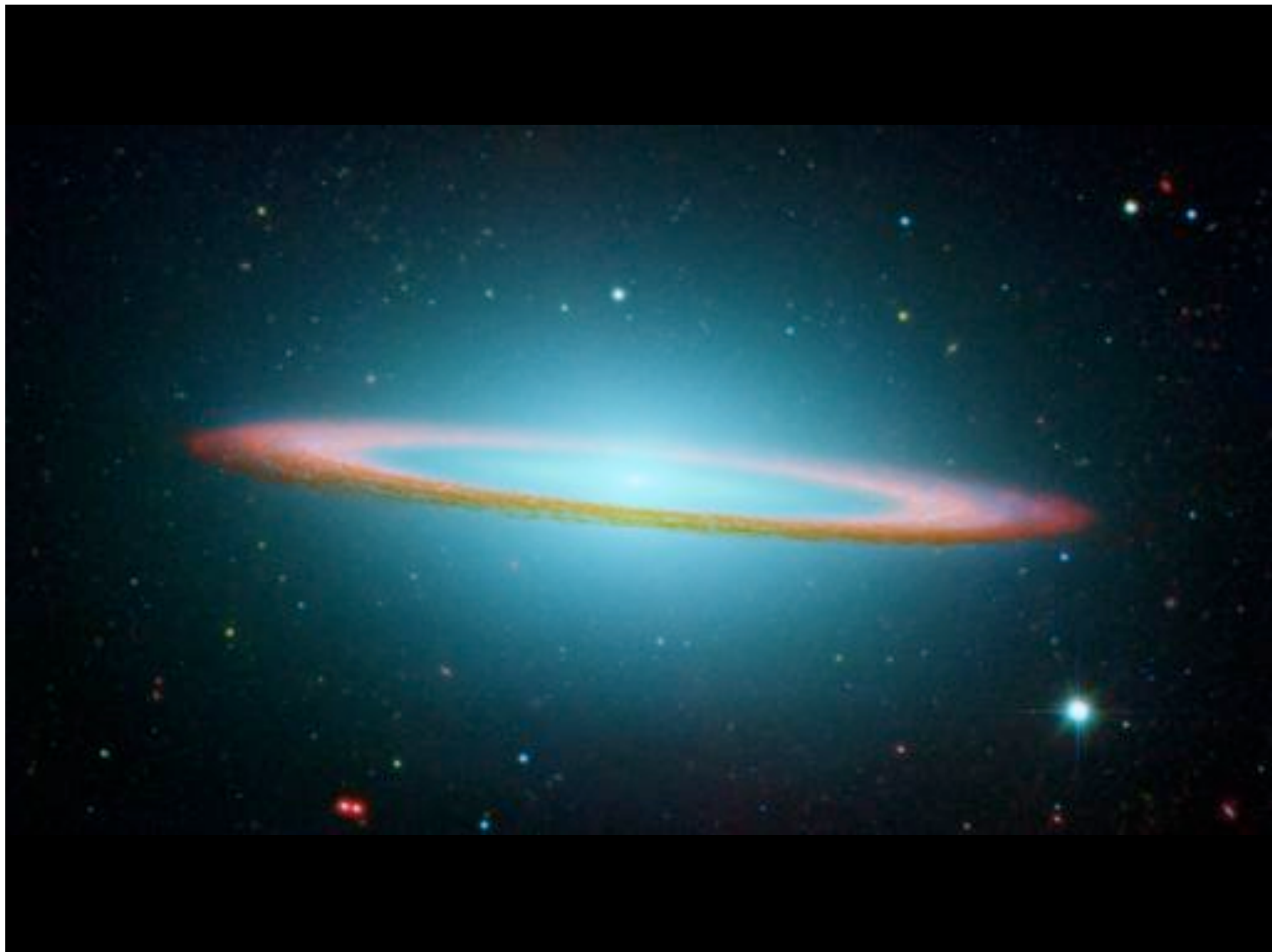
# Spitzer Space Telescope



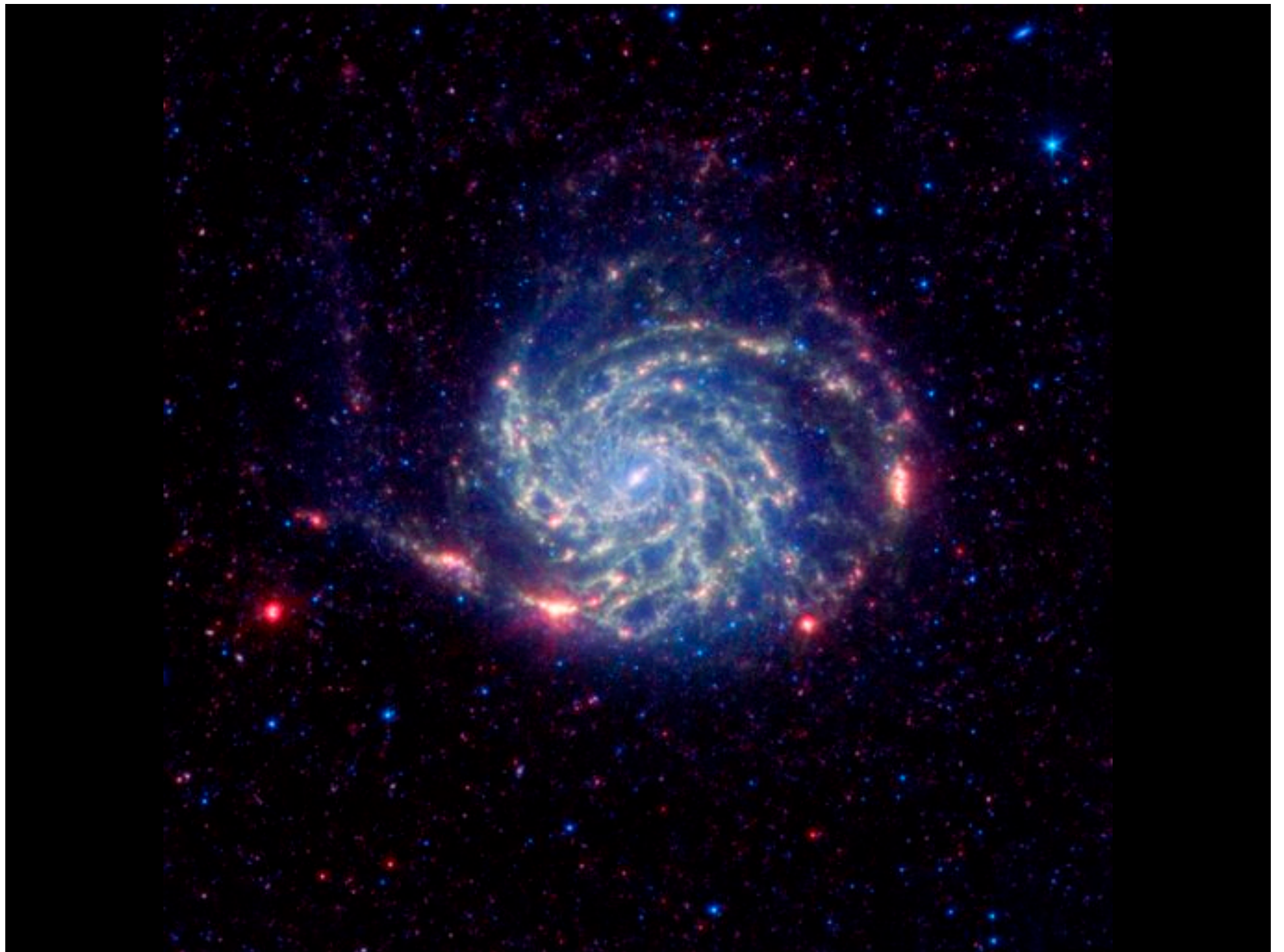
- Warm launch, radiative cooling
- Cryogen management, 3 years of 5+ so far
- Earth-trailing heliocentric orbit
- 2 cameras, 2 spectrographs, 3.6-160  $\mu\text{m}$
- Shortest-wavelength cameras could operate indefinitely

# Temperatures of extrasolar planets











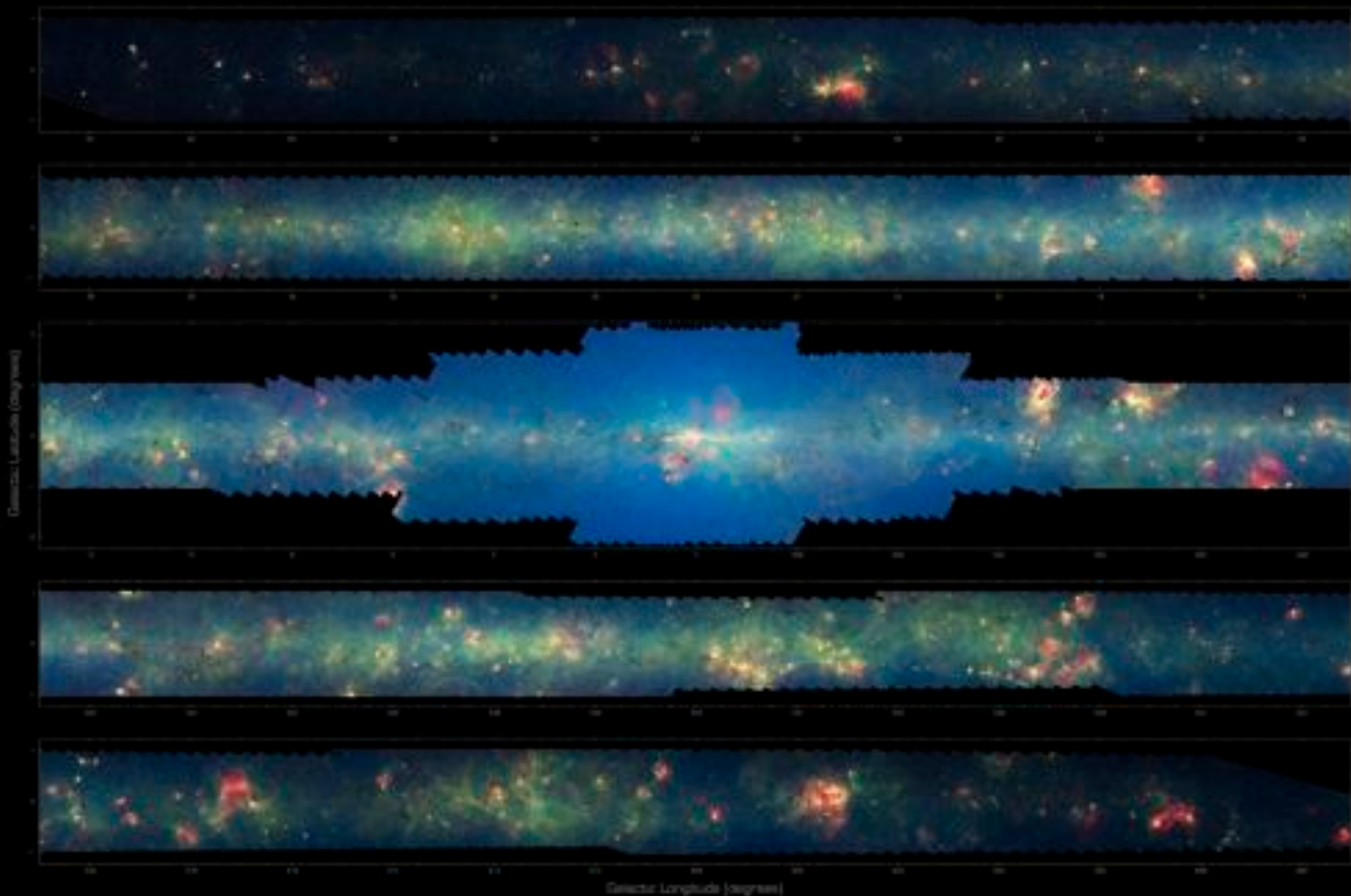


**The Center of the Milky Way Galaxy**

NASA / JPL-Caltech / S. Stolovy (Spitzer Science Center/Caltech)

**Spitzer Space Telescope • IRAC**

ssc2006-02a

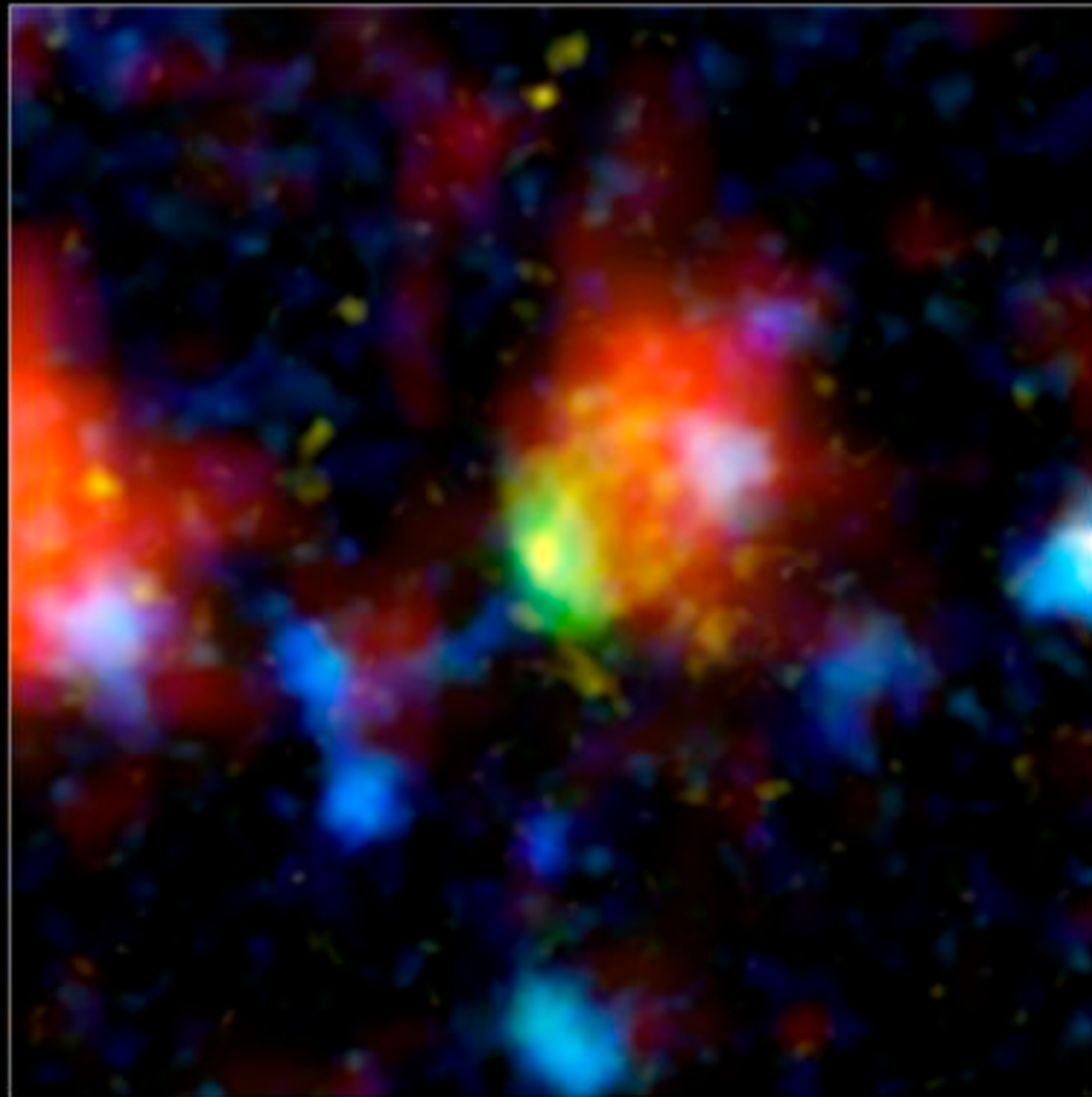


**The Infrared Milky Way: GLIMPSE/MIPSGAL Spitzer Space Telescope • IRAC • MIPS**

NASA / JPL-Caltech / E. Churchwell (Univ. of Wisconsin), GLIMPSE Team & S. Carey (SSC-Caltech), MIPSGAL Team 66c2008-11a







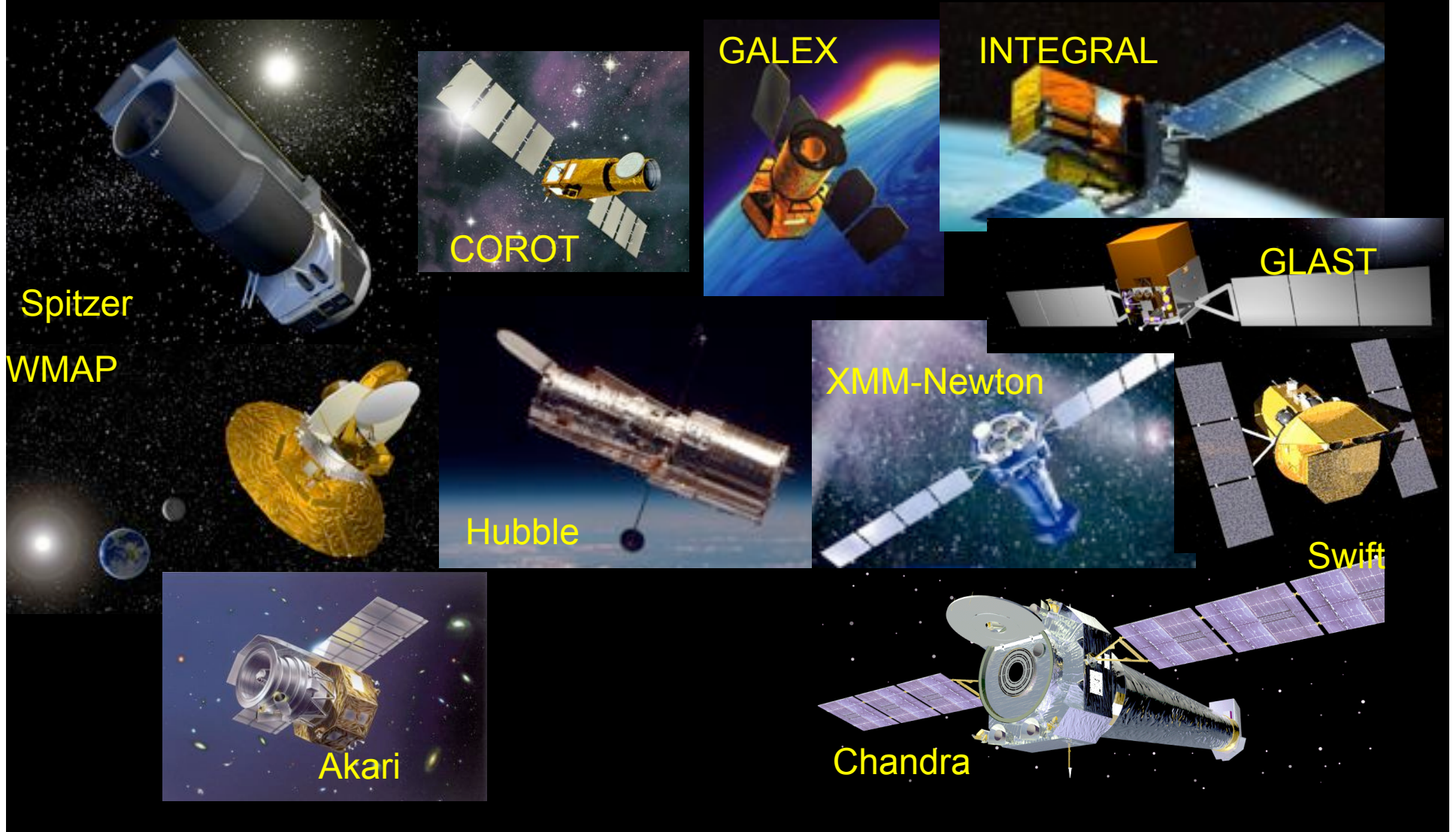
Distant Starburst Galaxy ( $z=4.5$ ) Spitzer Space Telescope • IRAC,  
Subaru, Hubble

NASA / JPL-Caltech / Subaru / STScI / P. Capak (SSC-Caltech)

ssc2008-12a

# Across the spectrum - now

FarIR MidIR nearIR opt UV farUV X-ray gamma

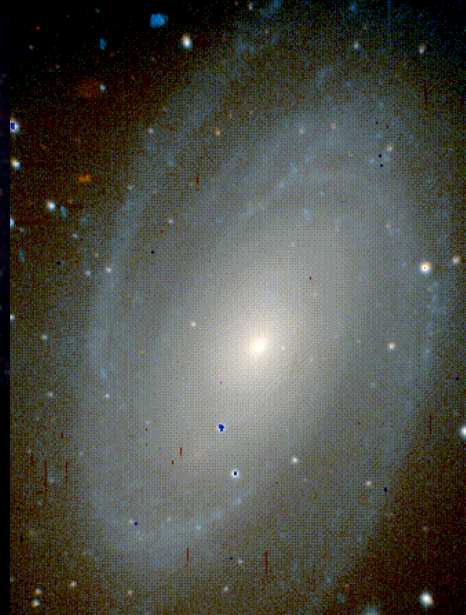
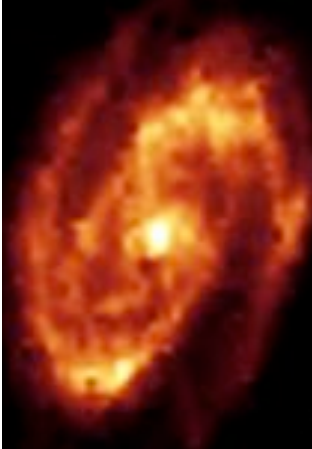
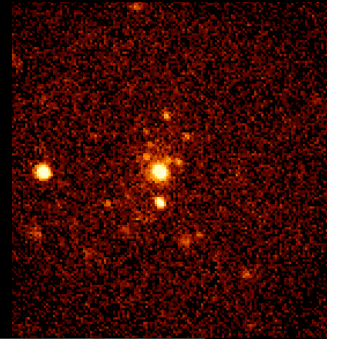
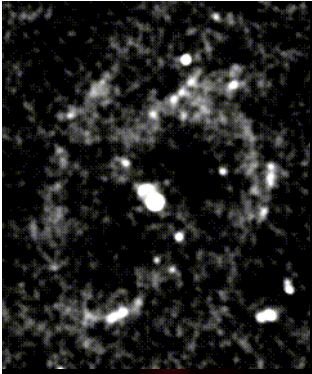




# Multispectral Greatest Hits

- 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
- Pregelactic 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...

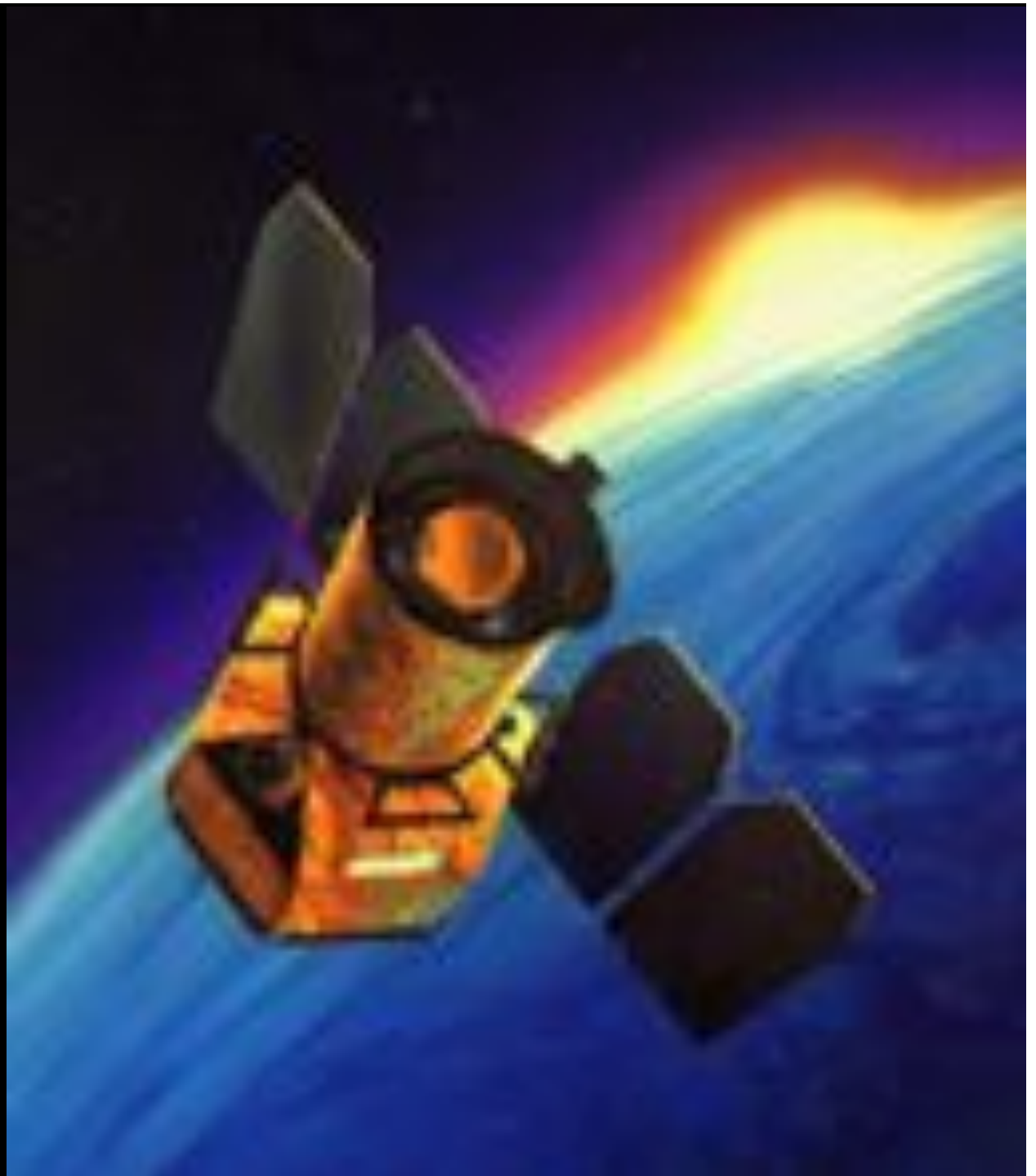
# More just as great

- 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...

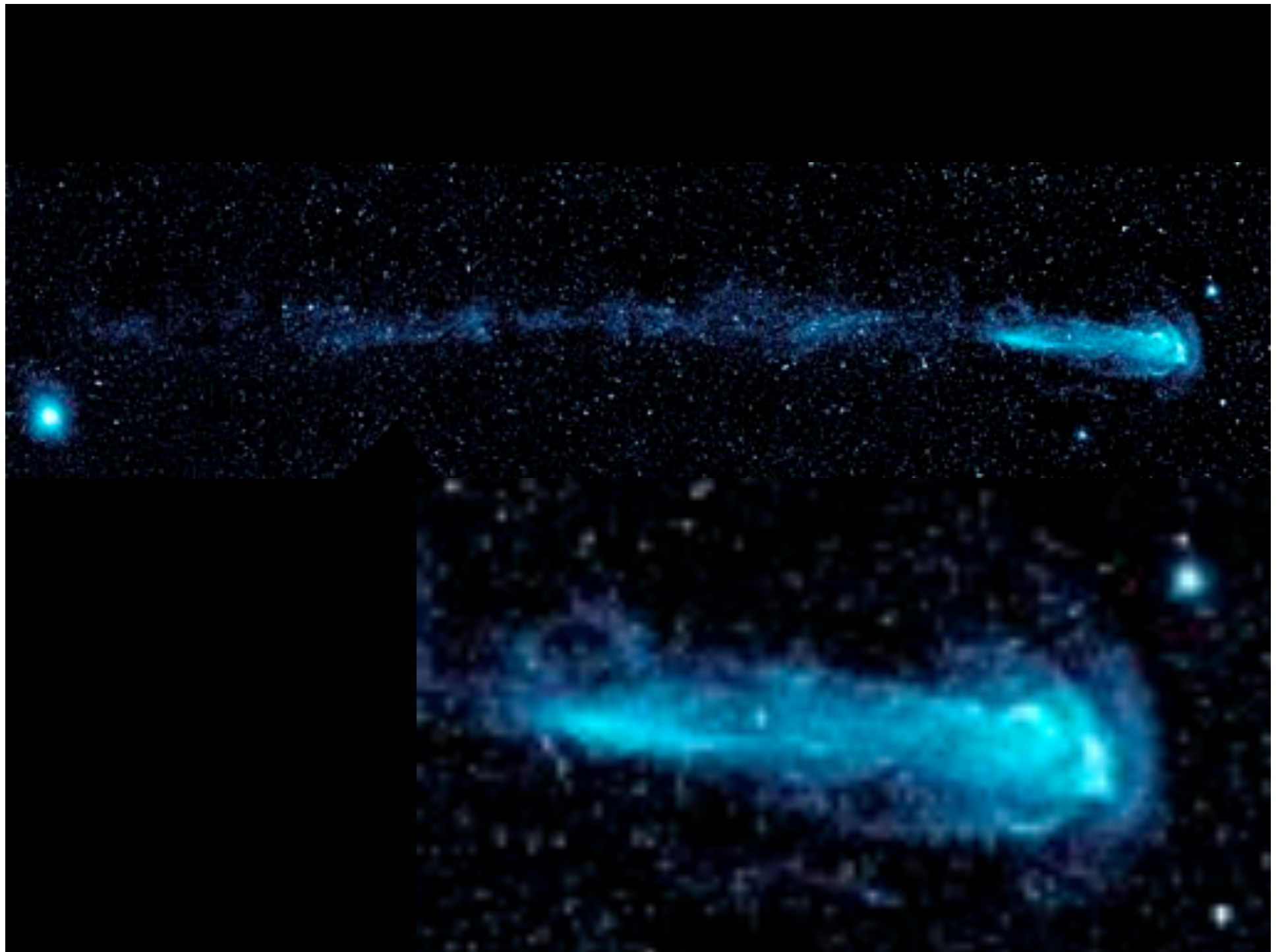


**GALEX**  
(Galaxy Evolution  
Explorer)

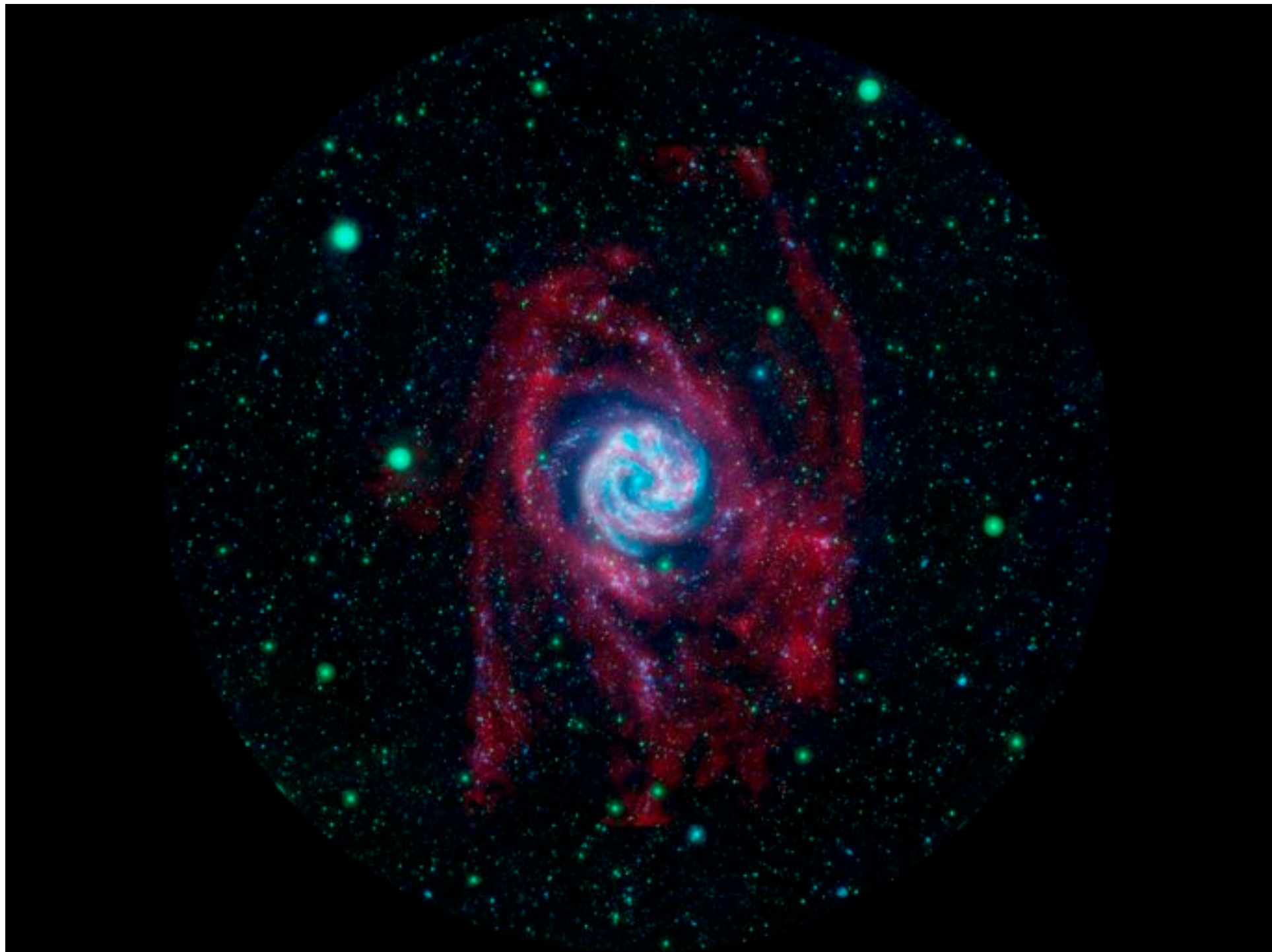
Ultraviolet imaging and  
spectroscopic survey of  
the sky – the first to be  
so deep and wide.



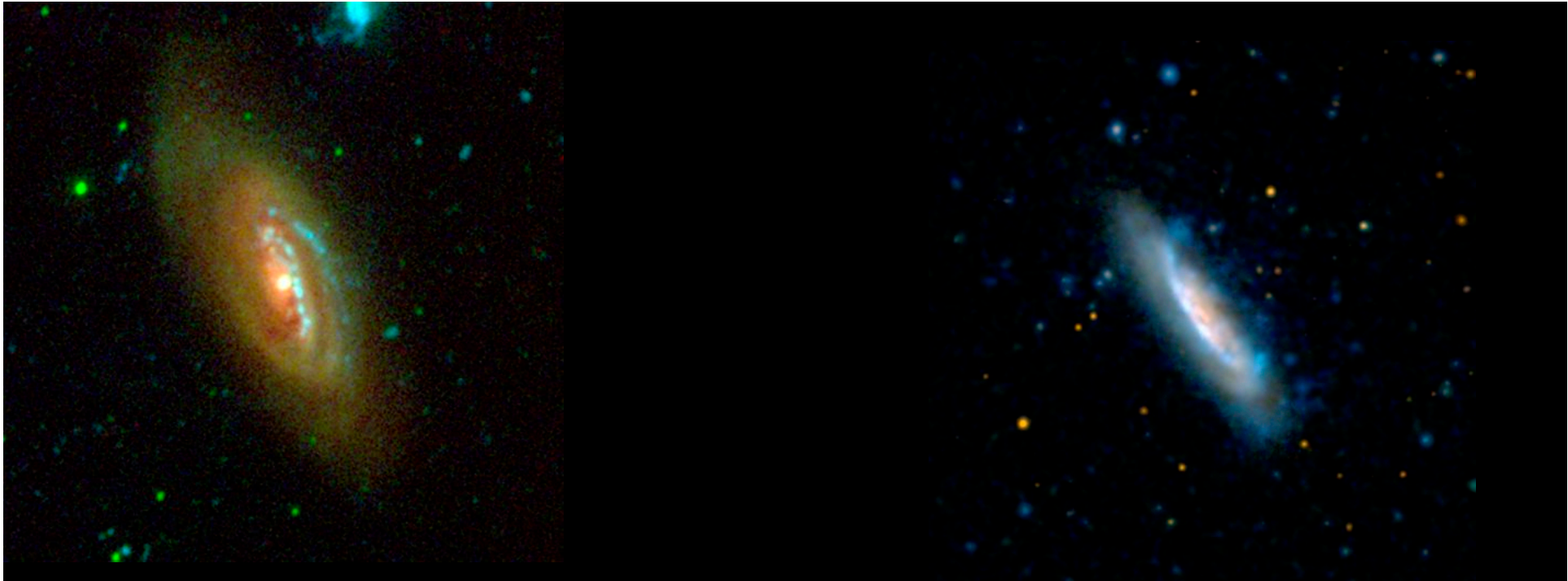




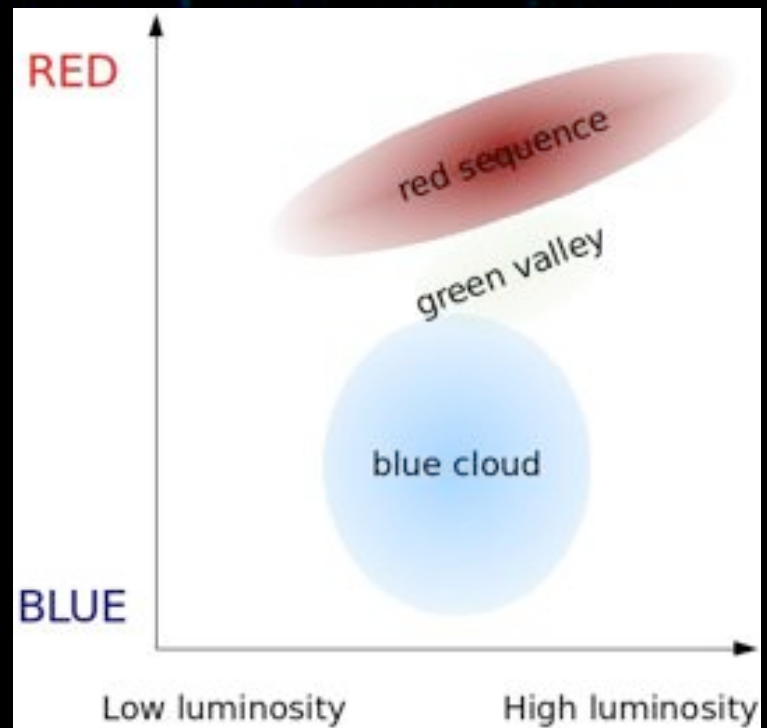






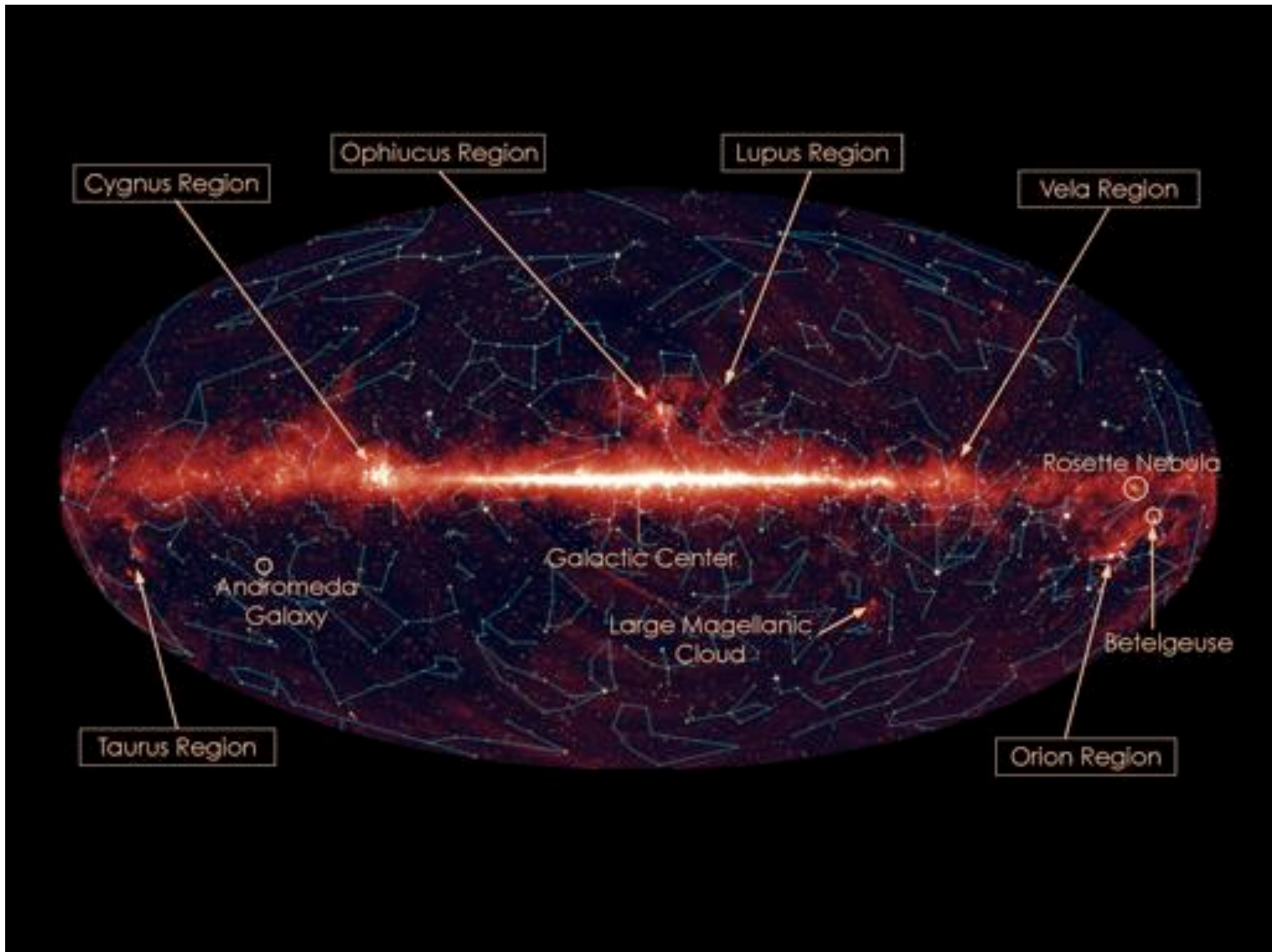


GALEX+SDSS and bimodal galaxy properties





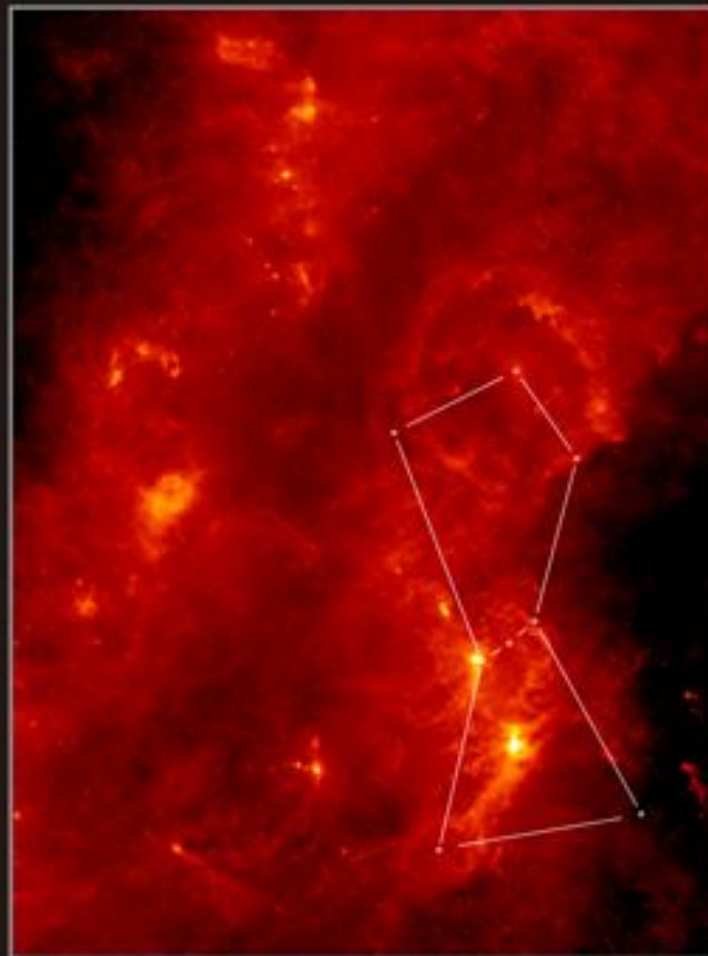
Akari  
( JAXA's TSFKA Astro-F)







## Far-Infrared Image of the Orion Region and the Milky Way



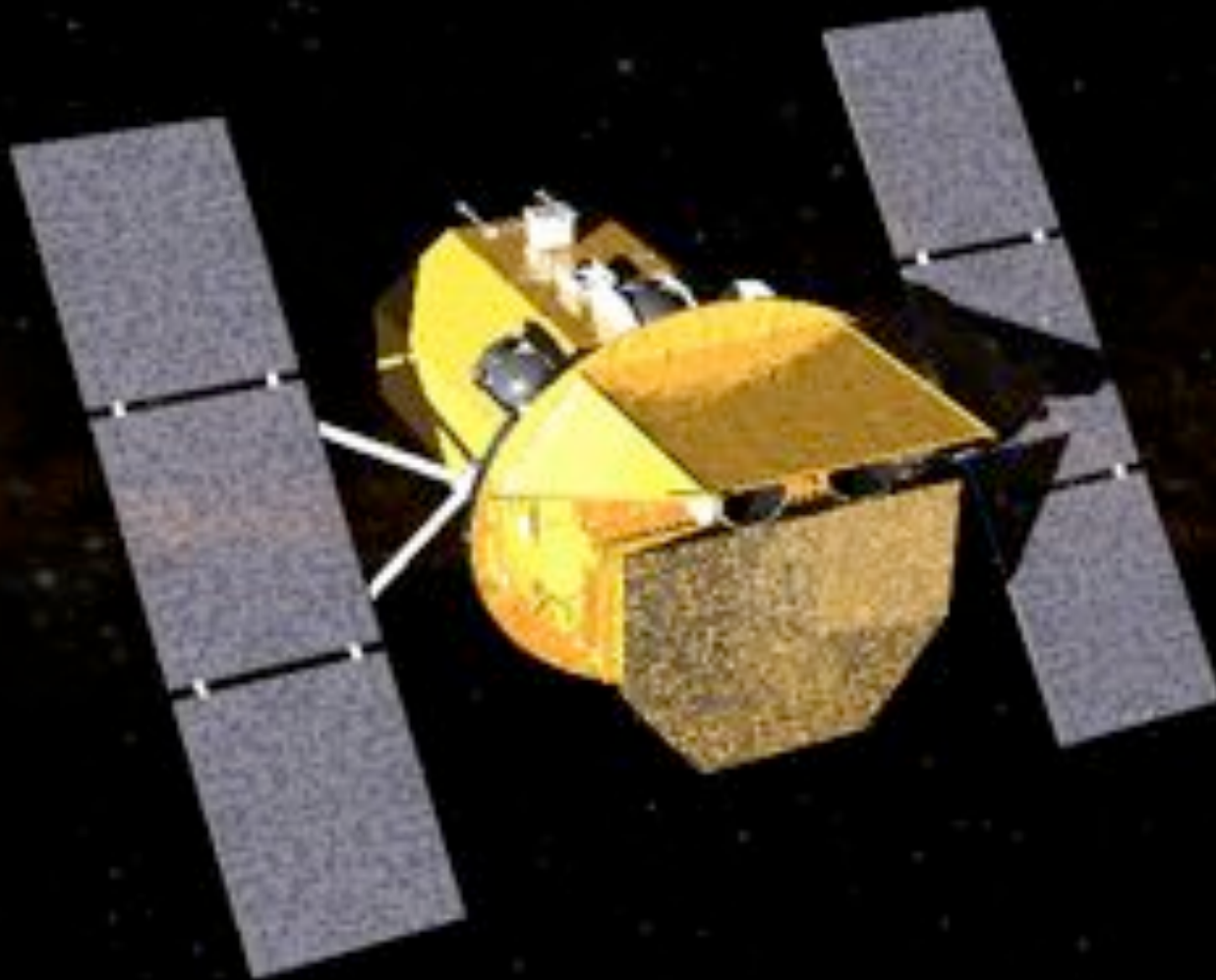
AKARI/Far-Infrared Surveyor (wavelength:  $140 \mu\text{m}$ )



11th July, 2007



Swift – catching gamma-ray bursts on the fly!



X-ray

SN 2007uy

An X-ray image showing a diffuse, irregularly shaped orange and red emission region. A yellow arrow points from the text 'SN 2007uy' to a specific spot within this region.

UV/Optical

A UV/Optical image of a galaxy, showing a bright, elongated, blueish-white structure. A yellow arrow points from the text 'SN 2007uy' in the X-ray panel to a specific spot on the galaxy's surface.

SN 2008D

An X-ray image showing a bright, circular, orange and red emission region. A yellow arrow points from the text 'SN 2008D' to the center of this region.

X-ray supernova flash in NGC2770

A UV/Optical image of a galaxy, showing a bright, elongated, blueish-white structure. A yellow arrow points from the text 'SN 2008D' in the X-ray panel to a specific spot on the galaxy's surface.

# SOFIA – Stratospheric Observatory for Infrared Astronomy - NASA/DLR









# International Gamma-Ray Laboratory (INTEGRAL)



It really *is* international:

ESA mission

Russian launch

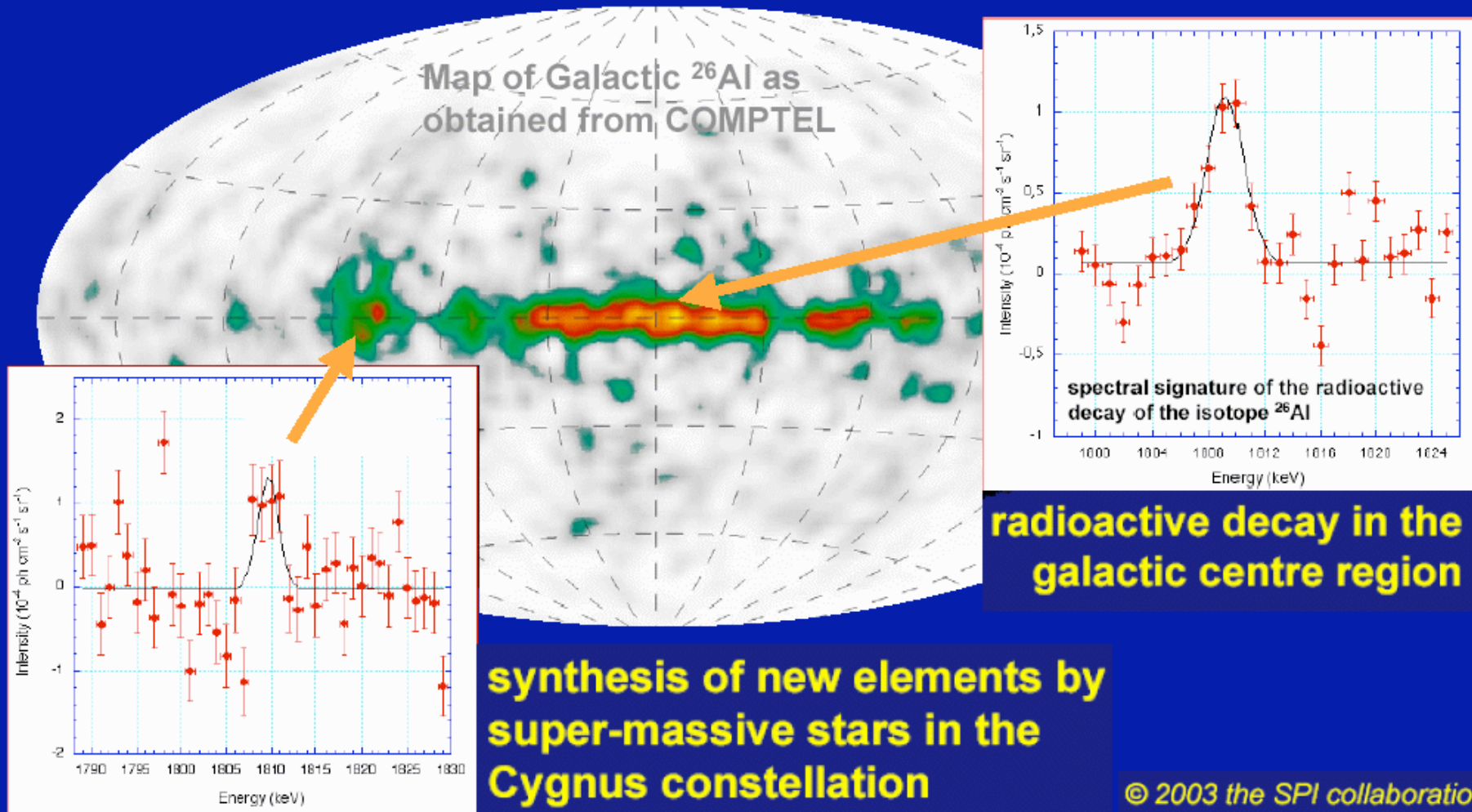
NASA communication



# Radioactive $^{26}\text{Al}$ in the Galaxy

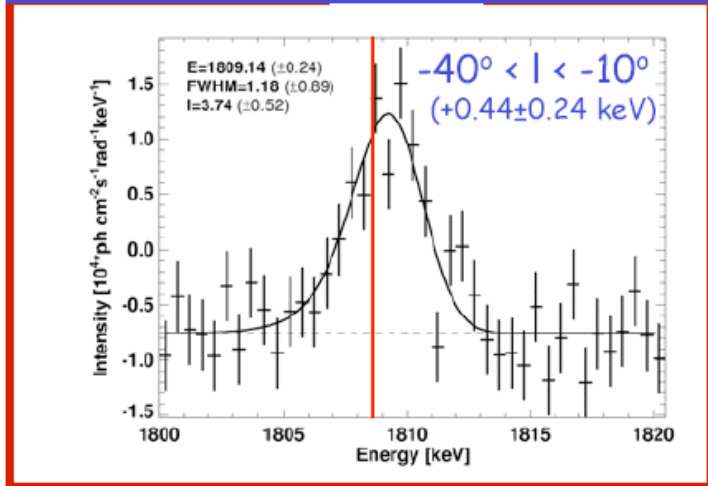
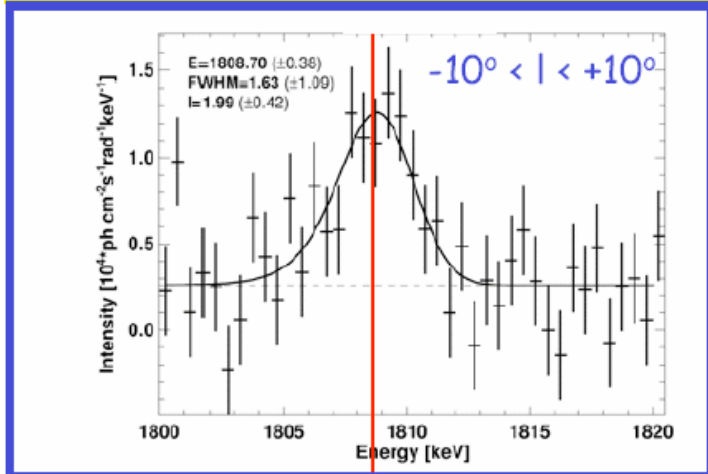
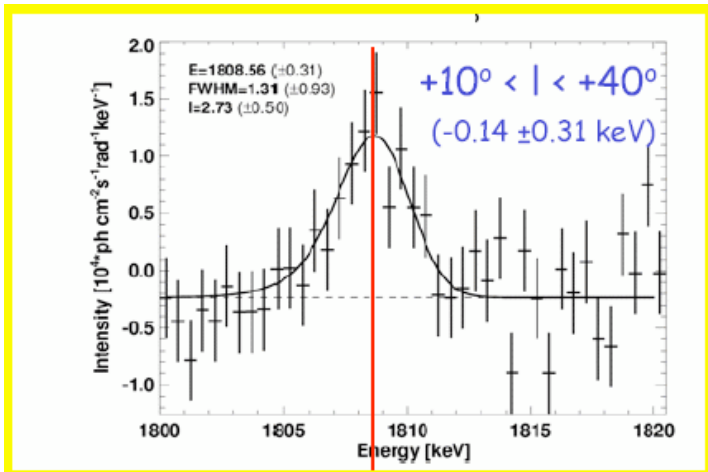
- first results from SPI/INTEGRAL -

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

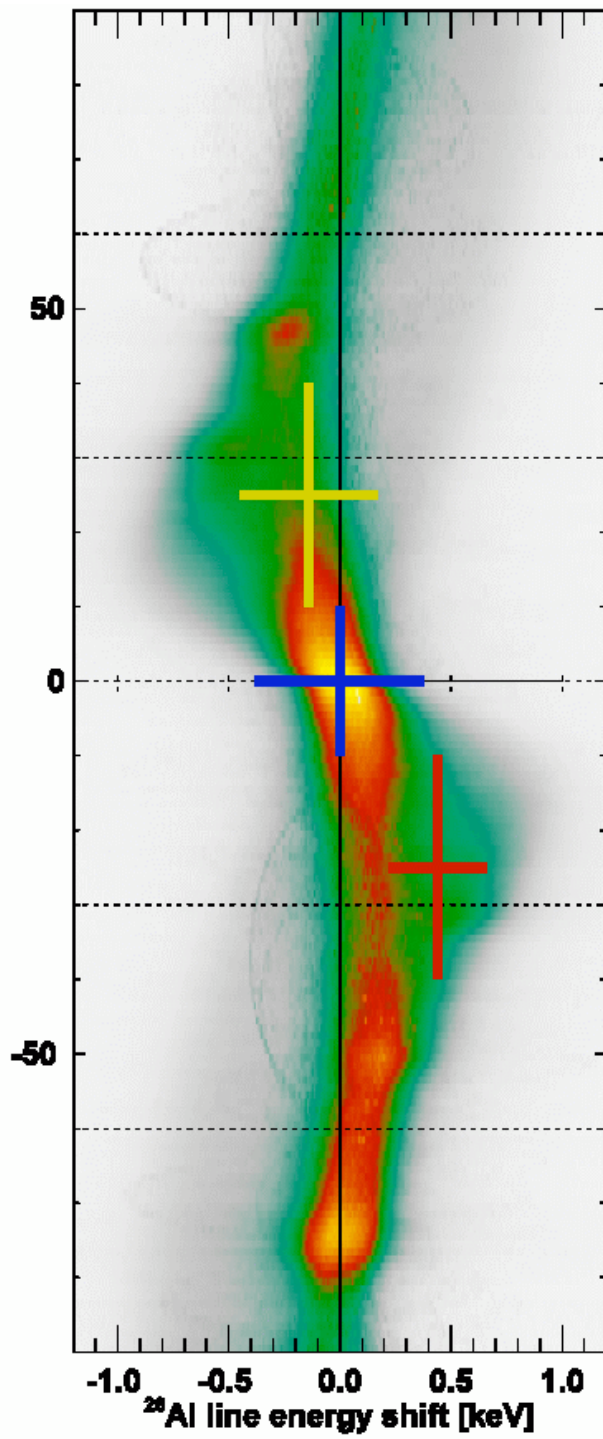


© 2003 the SPI collaboration





Galactic longitude [deg]

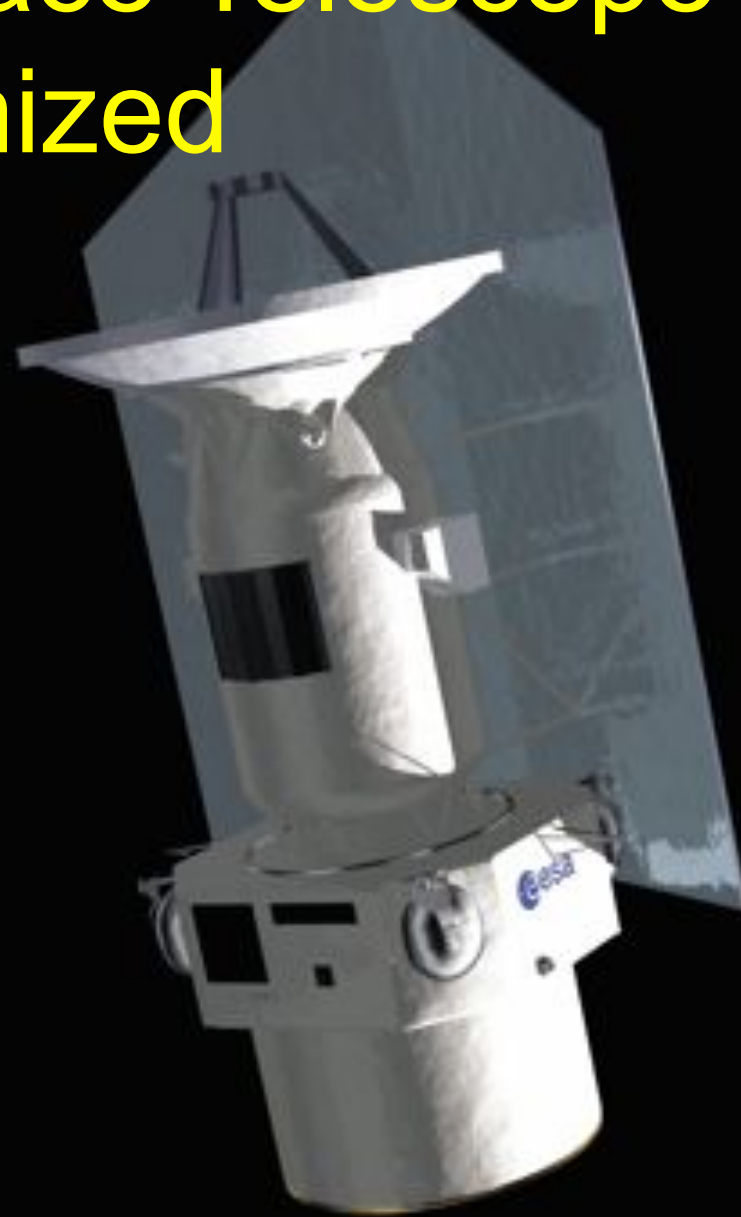


Al-26 mass:  
2.8 solar masses

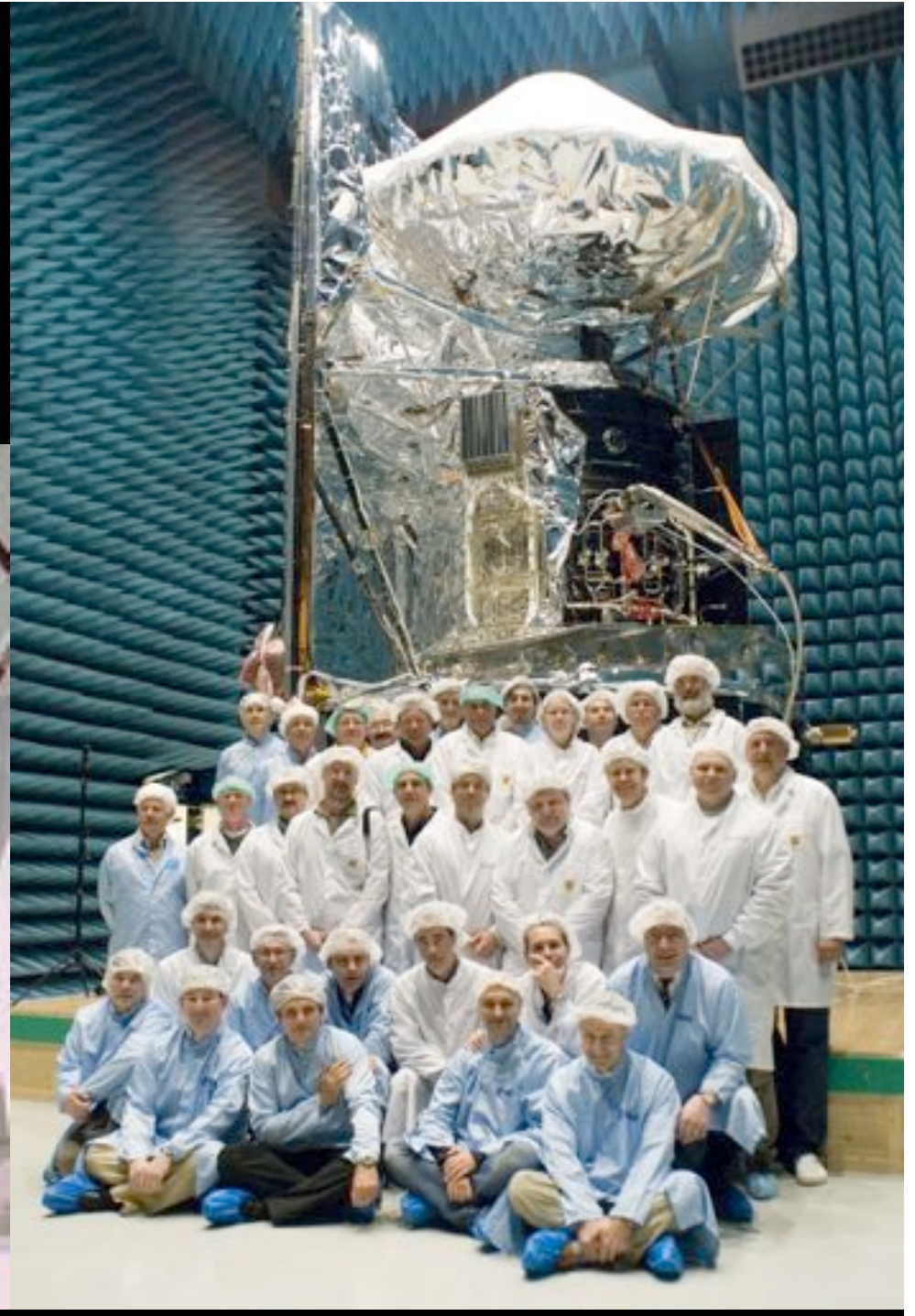
Massive SN rate: 1.9/  
century



ESA Herschel Space Telescope  
3.5m Far-IR optimized  
Ariane 5 launch  
(w/Planck)  
2009  
L2 halo orbit



3 instruments  
3 years' cryogenics  
60-670  $\mu\text{m}$  range



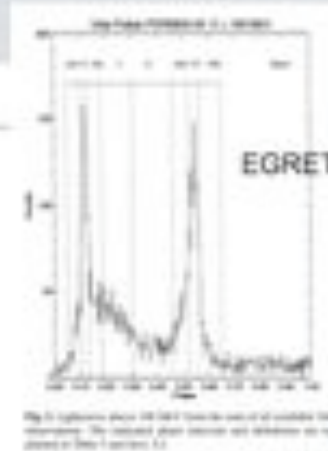
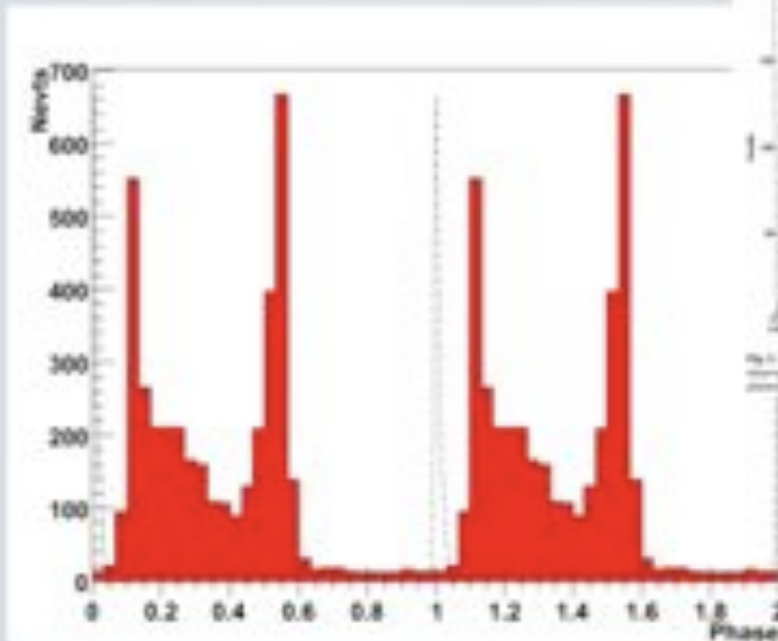
# Gamma-Ray Large Area Space Telescope (~~GLAST~~) Fermi



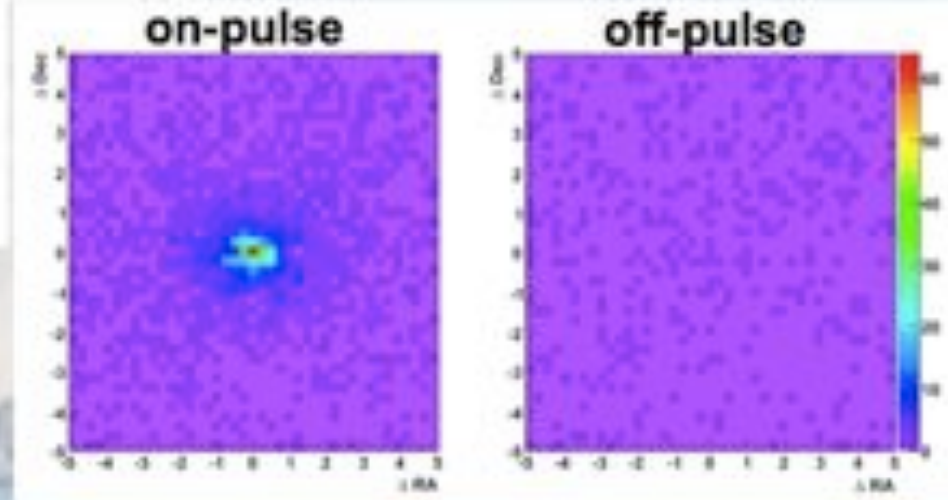




# Vela – early returns



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



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

- good timing of the EGRET pulsars

(Richard Dubois)

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



# Across the spectrum - soon

FarIR MidIR nearIR opt UV farUV X-ray gamma

