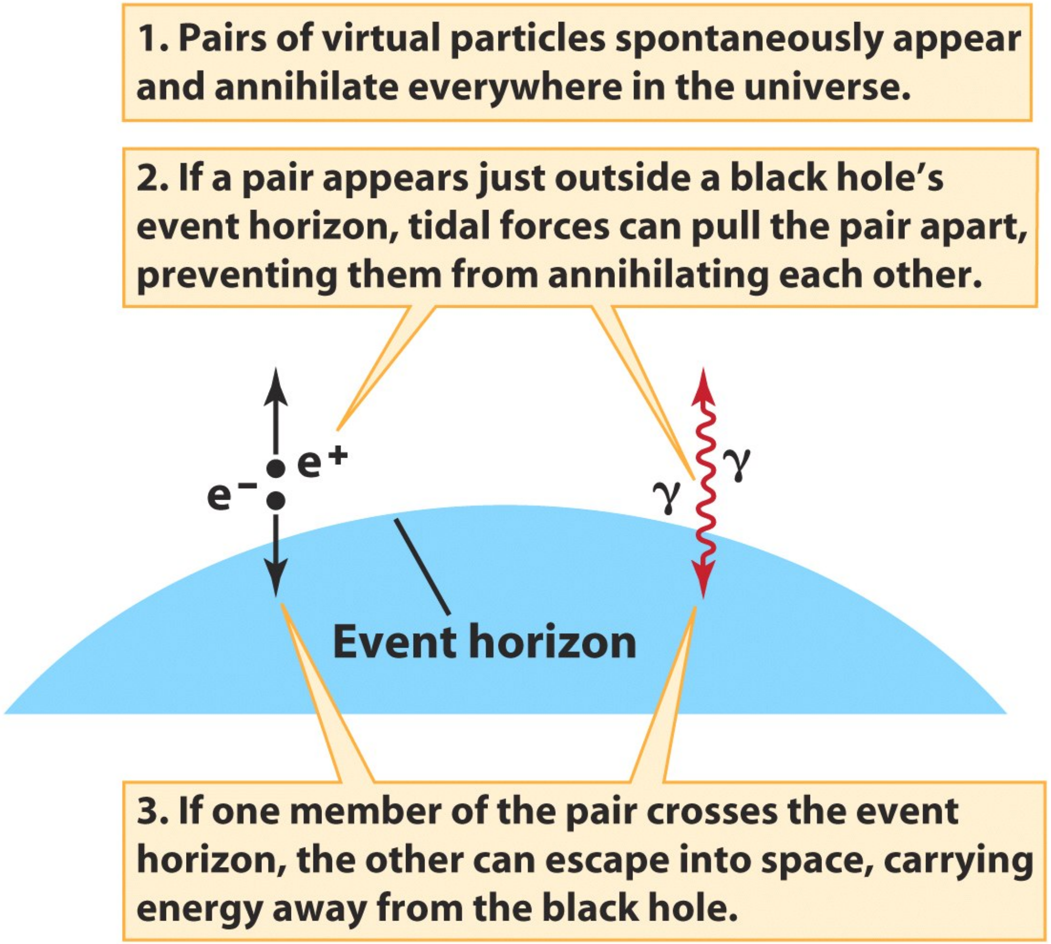
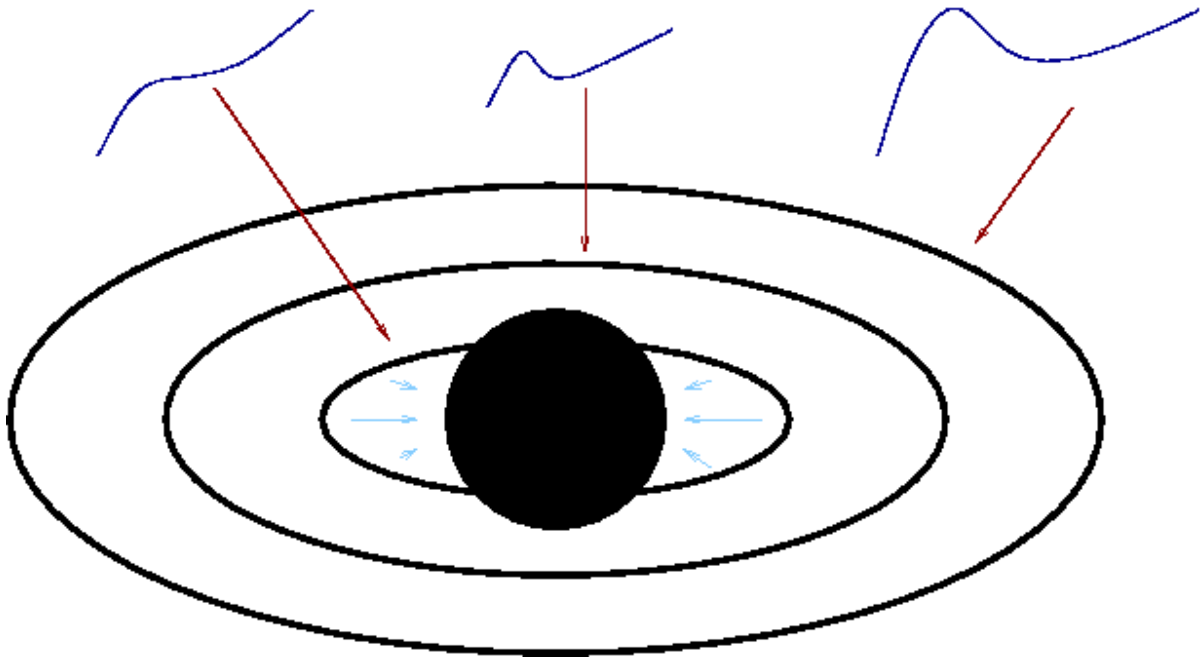
Hawking radiation



Extremely low luminosity (undetectable), but may cause evaporation of micro-BH (formed at Big Bang?)

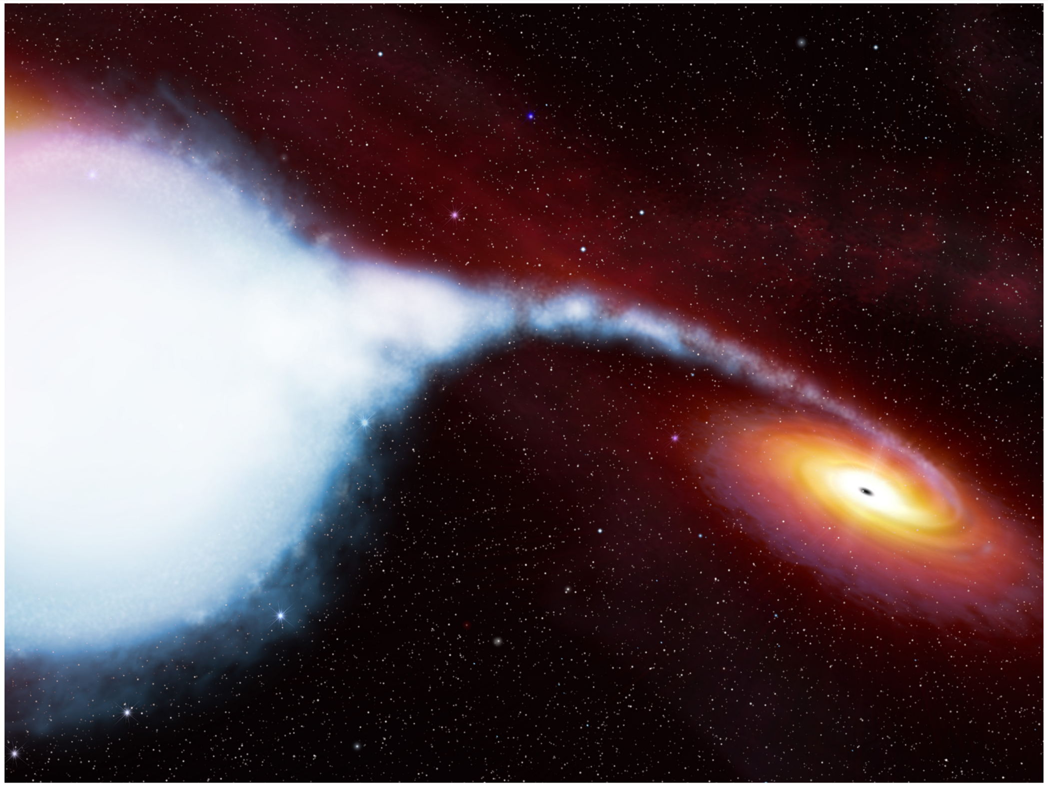
Some orbits and their potentials



By altering angular momentum, we get **stable orbits** at different radii: stable circular orbit at a minimum of potential.

At $R = 6GM/c^2 = 3R_S$ the minimum becomes a point of inflection ⇒ **Innermost Stable Circular Orbit (ISCO)**

Accretion efficiency



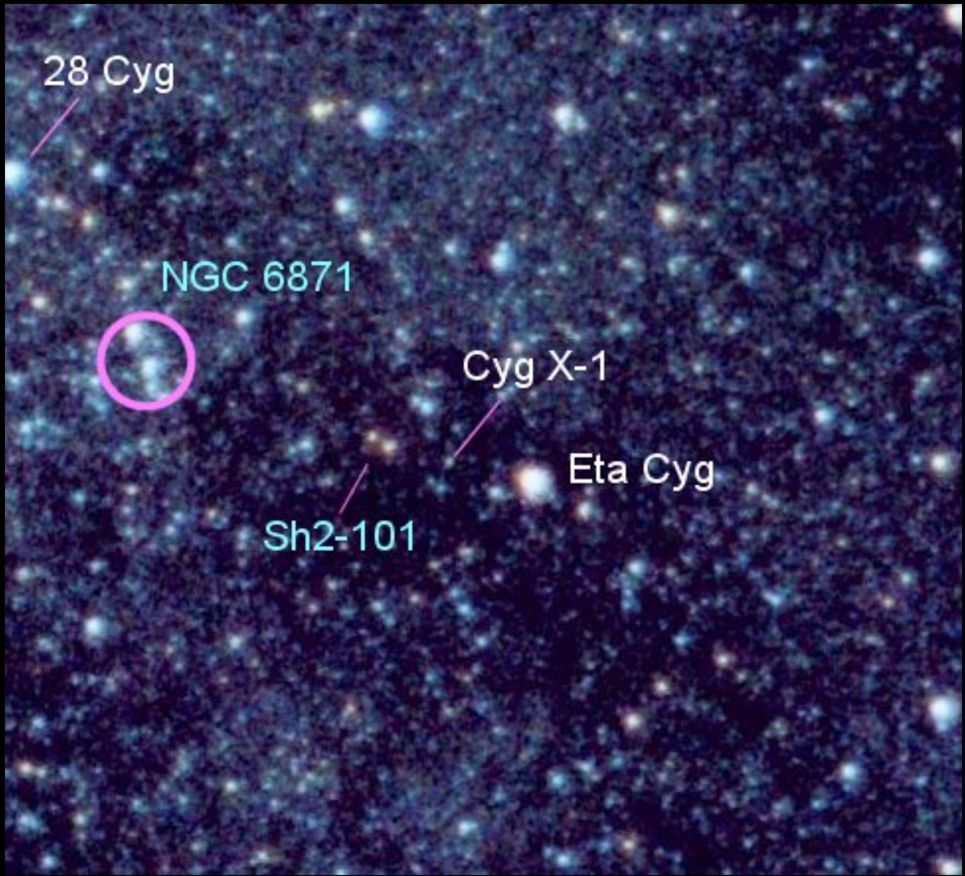
Gravitational energy at ISCO ($R_{ISCO} = 3R_S \sim 100$ *km for a 10* $M_\odot$ *BH*):

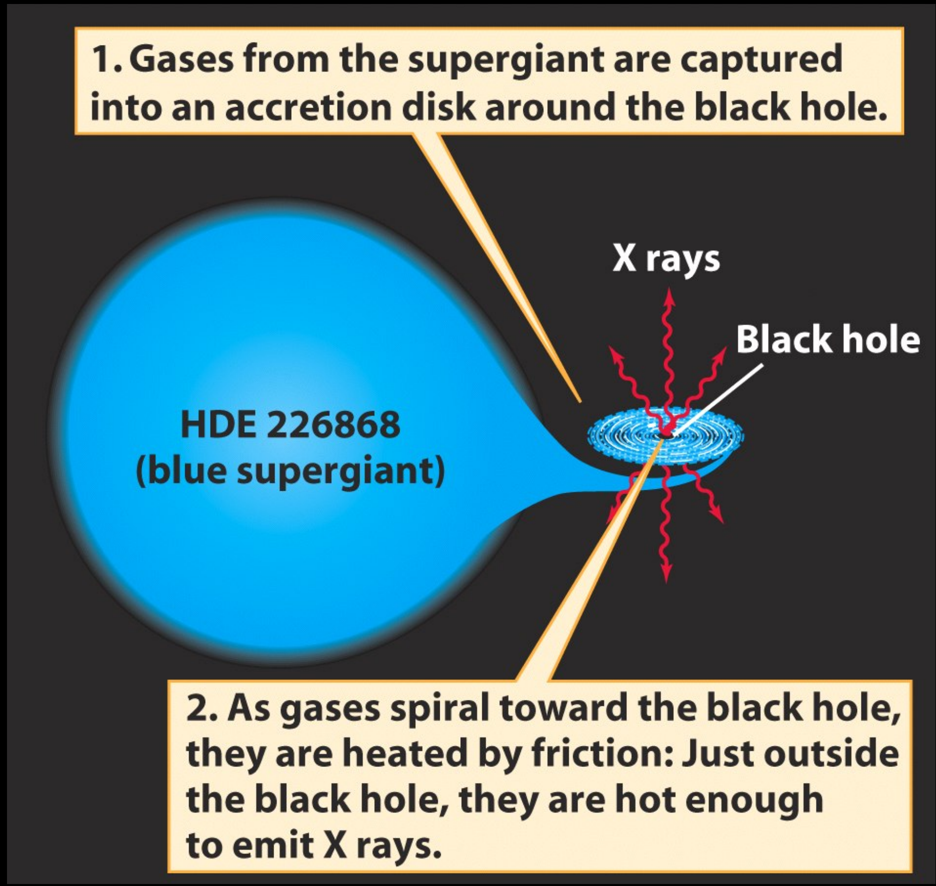
$$E_G \sim GmM/3R_s = GmMc^2/6GM = mc^2/6$$

Efficiency: $E_G/mc^2 \sim$ 1/6 **~ 20%** » 0.7% (nuclear fusion)

Stellar mass BHs

Bright X-ray sources when in accreting binary systems





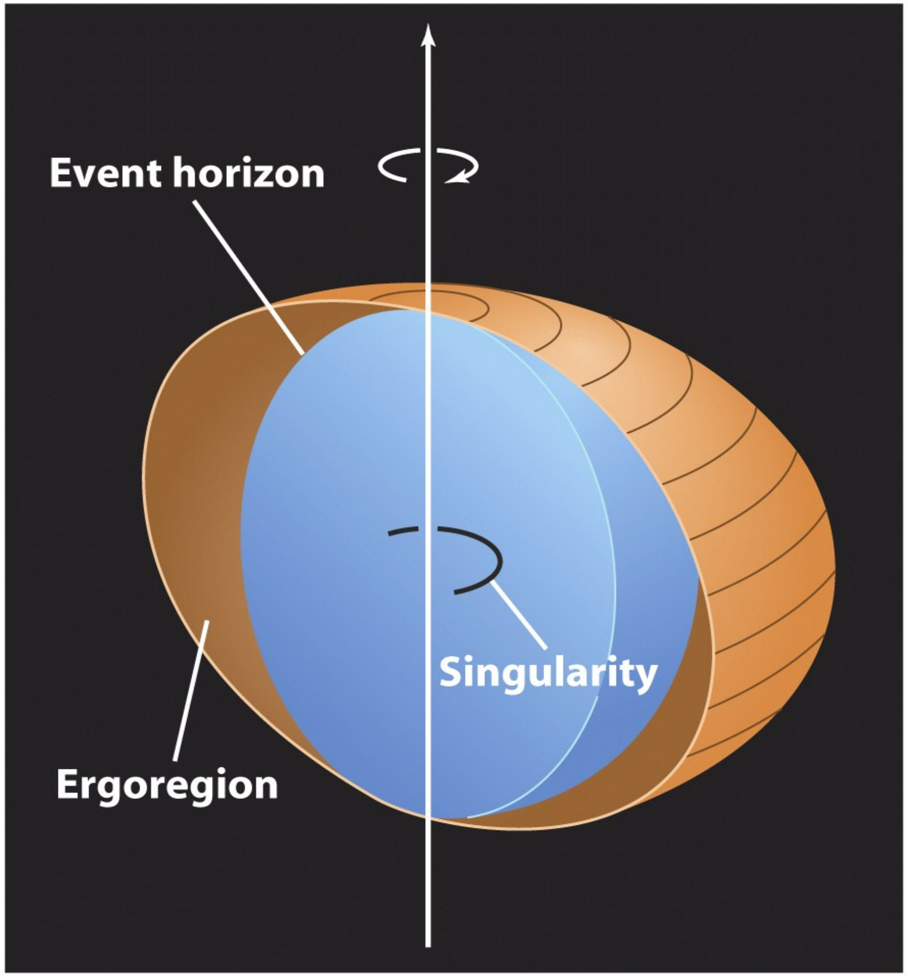
Cyg X-1: X-ray variability on <1 s timescale; M ~ 15 $M_\odot$

Rotating black holes (Kerr BH)

- A rotating black hole has an **ergosphere** around the outside of the event horizon
- In the ergosphere, space and time themselves are dragged along with the rotation of the black hole
- If maximum spin ($a_*=1$): event horizon at

$$R=GM/c^2=1/2\ R_S\ ;$$

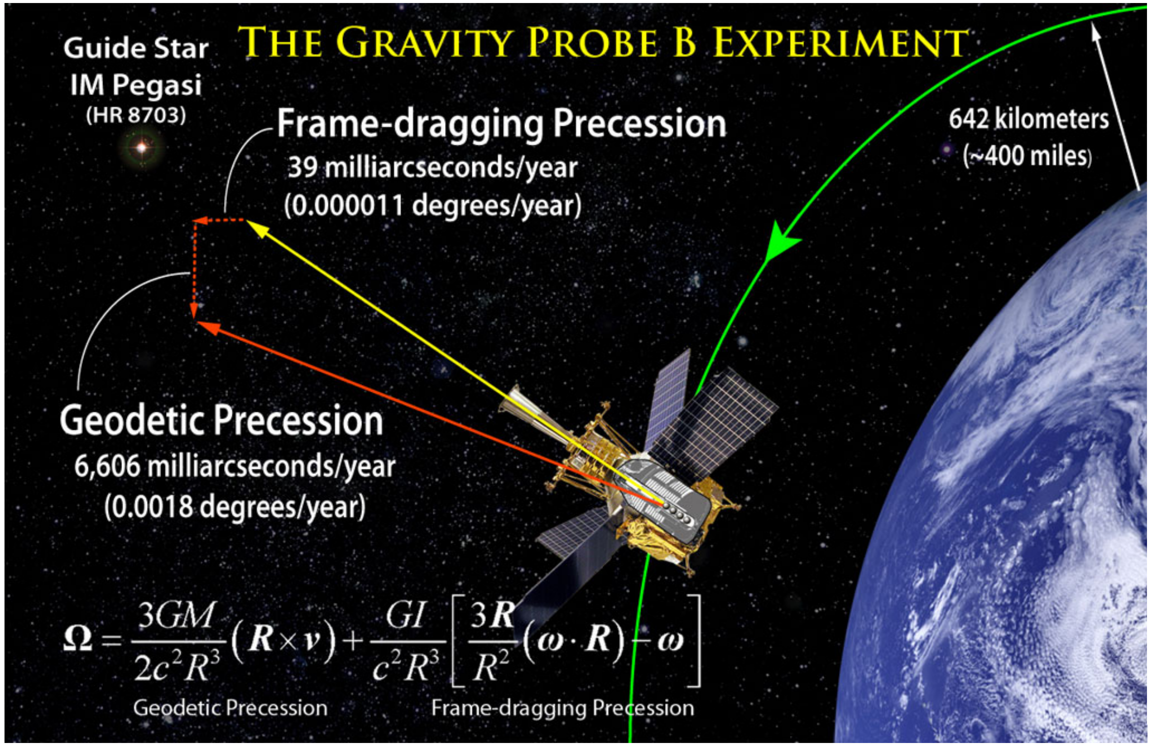
$$R_{ISCO}=GM/c^2=R$$

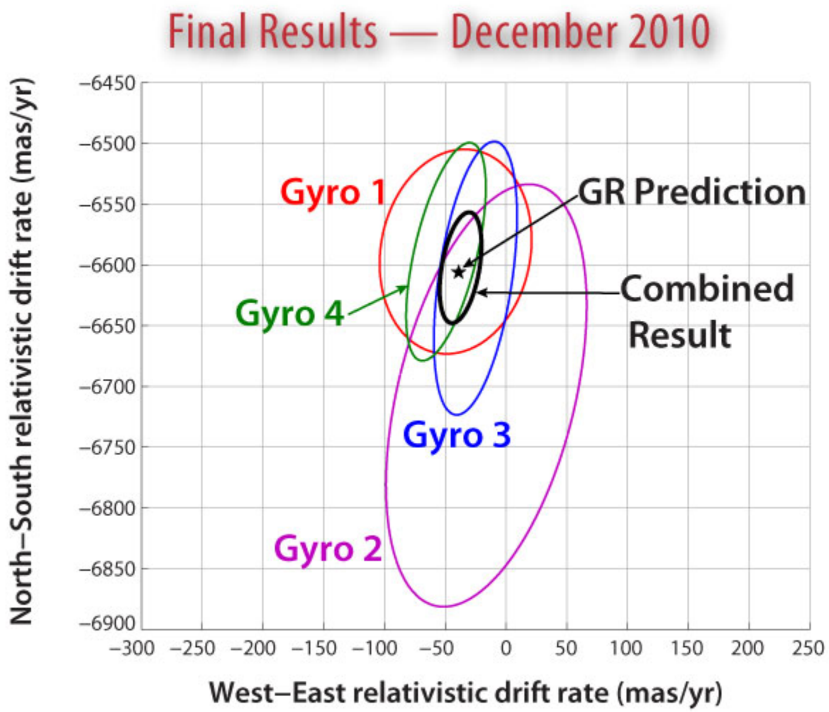


A rotating mass has a tendency to pull space-time along with it

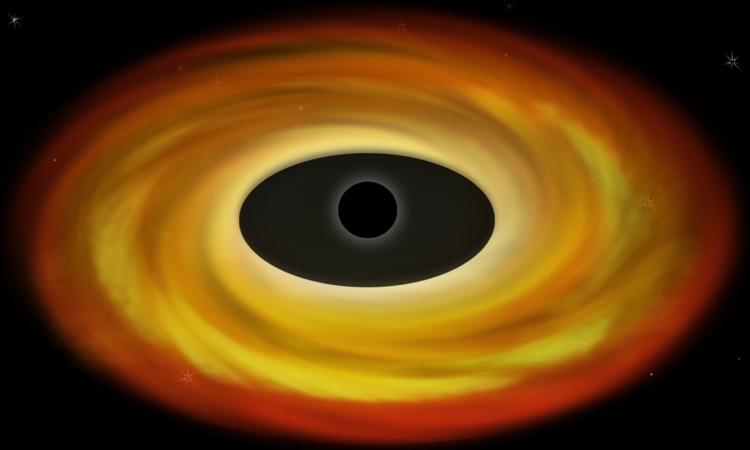
Gravity Probe B

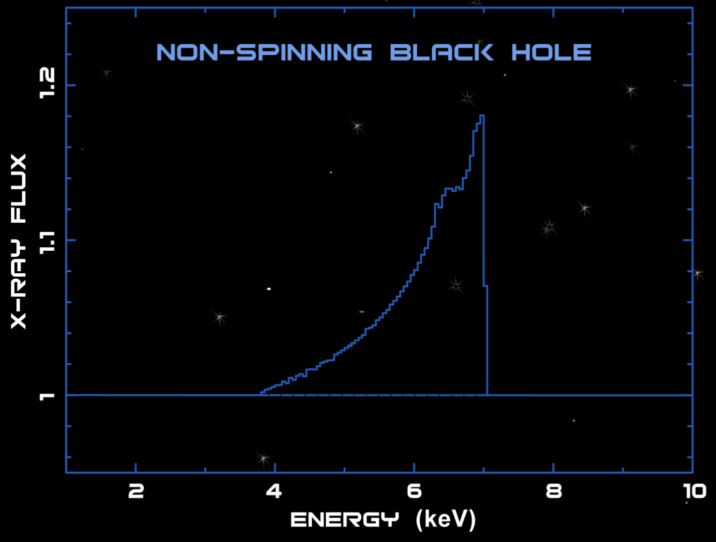
Launched 20 April 2004 to test geodetic and frame-dragging GR effects, by means of cryogenic gyroscopes in Earth orbit



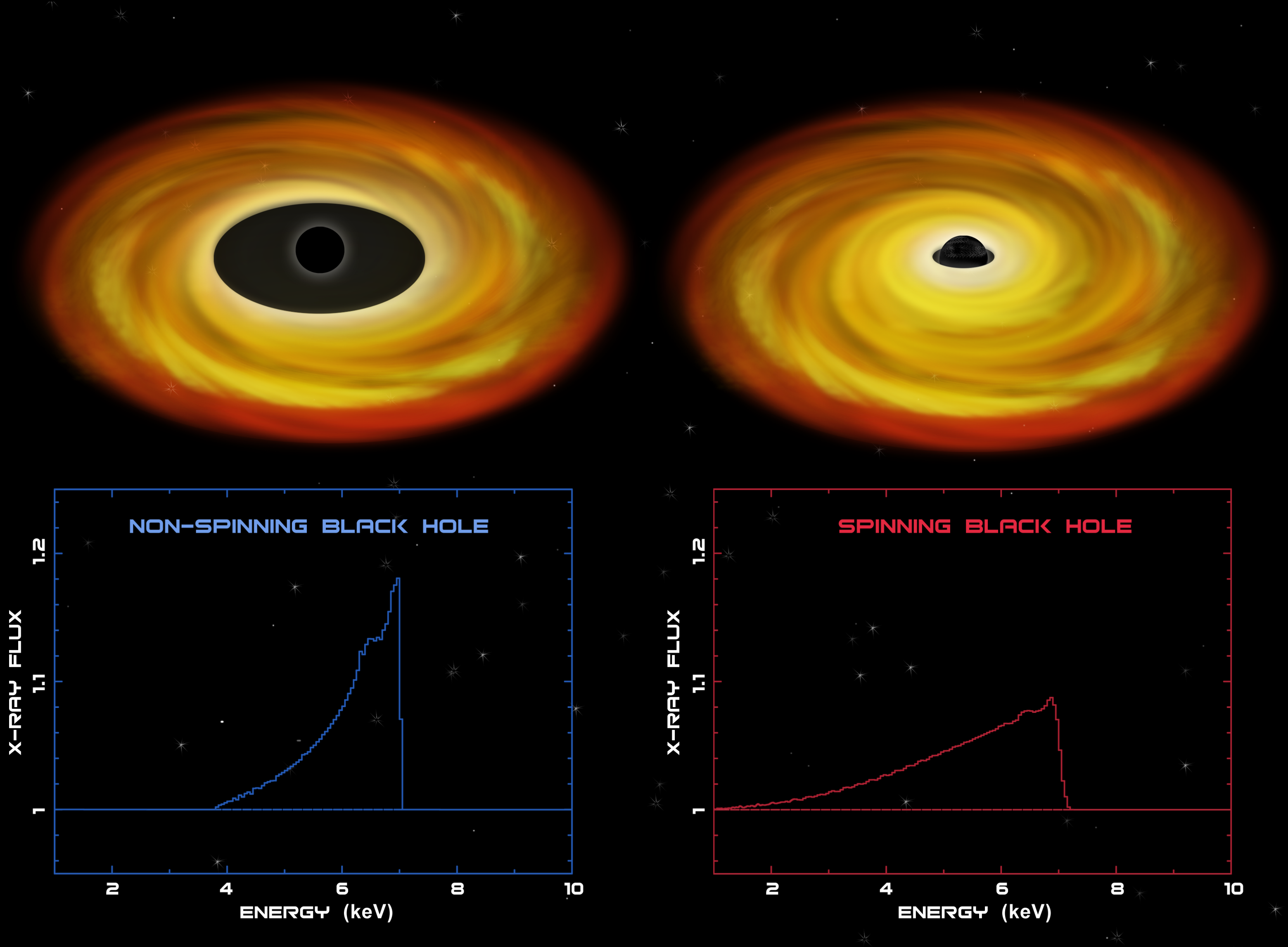


Relativistic line

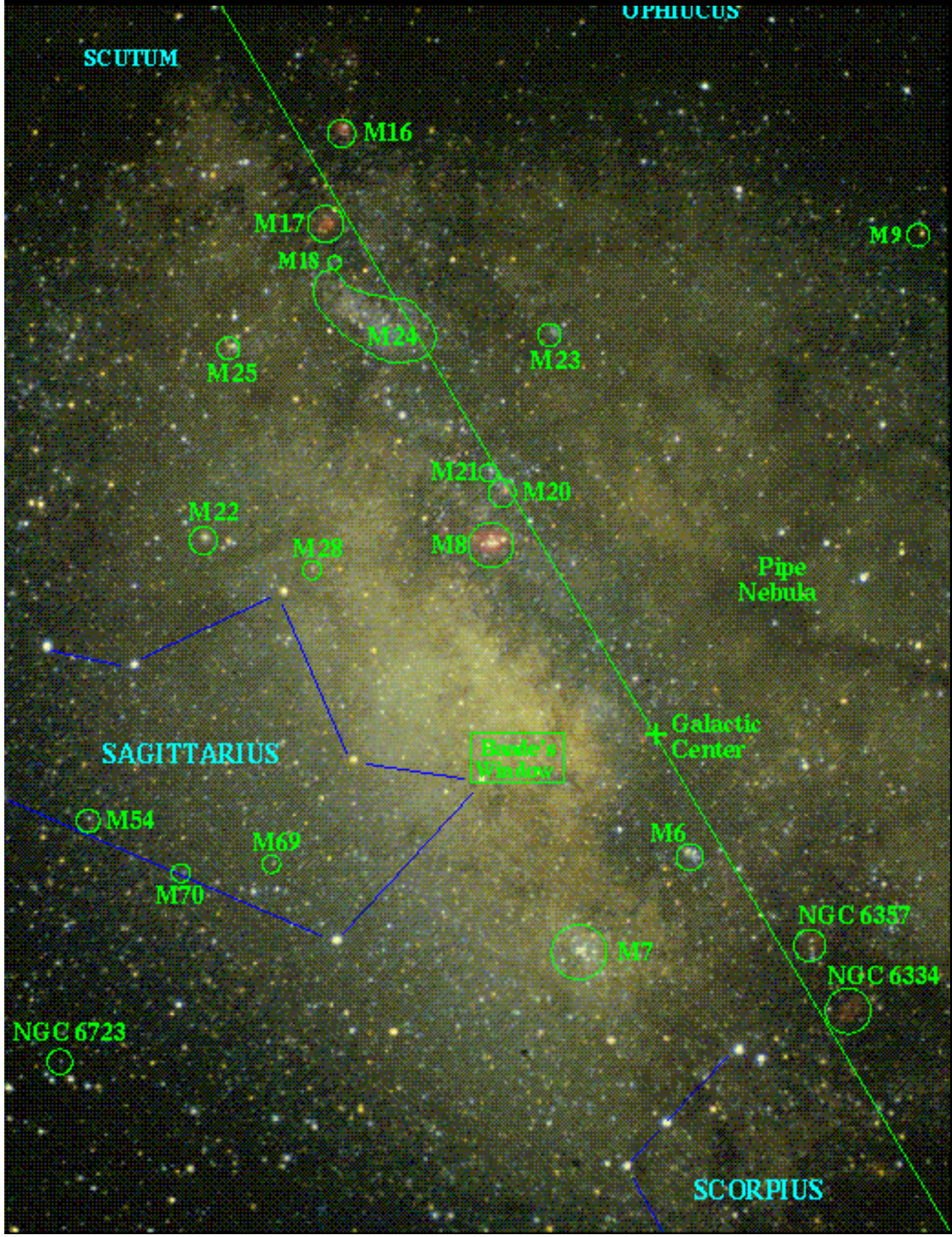




Relativistic line



The biggest nearby BH: Sgr A*



Center of our galaxy: radio source Sgr A*

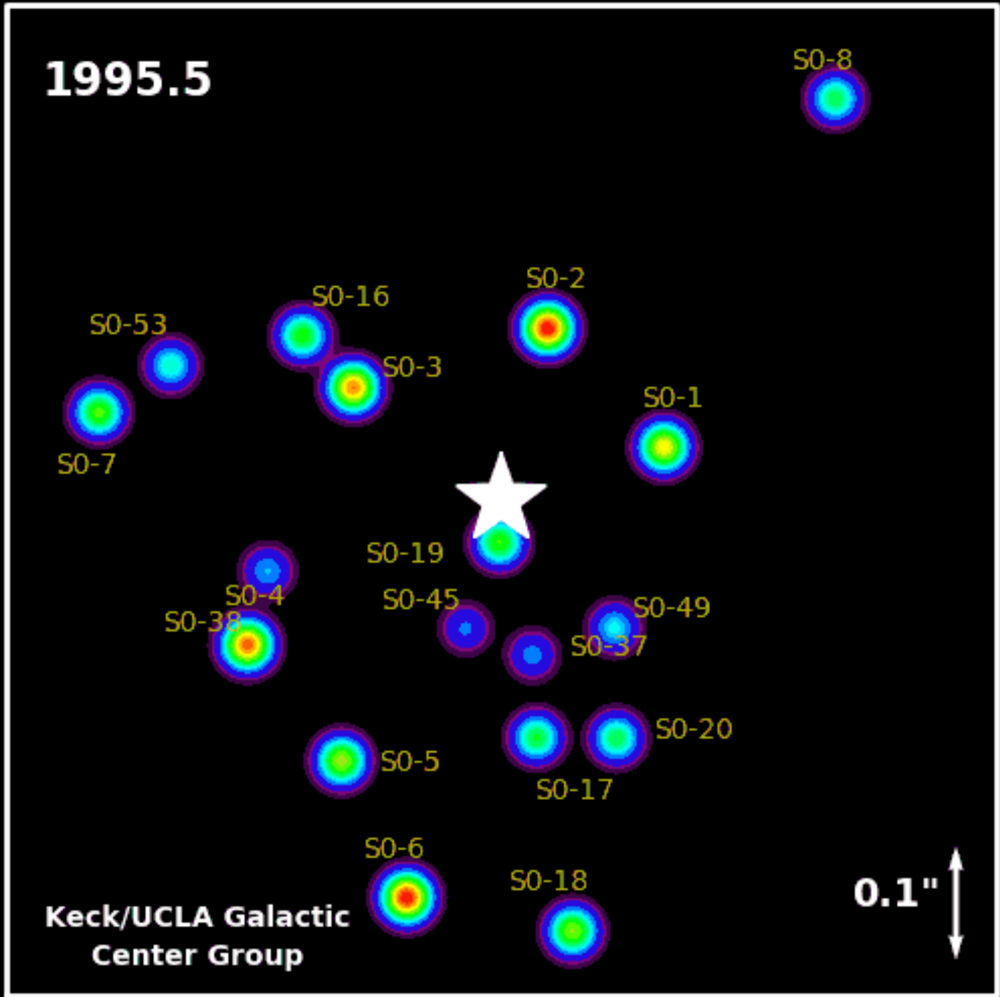
Distance: 8 kpc

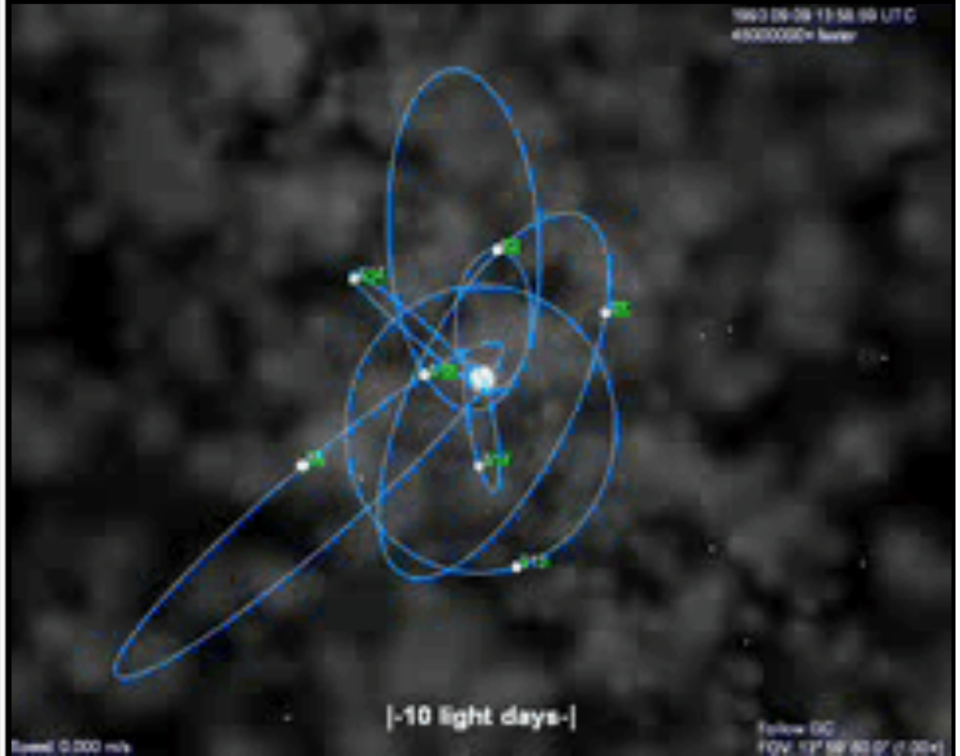
Highly obscured in optical

Dense central star cluster visible in infrared

Photo/illustration from A. Tanner, UCLA

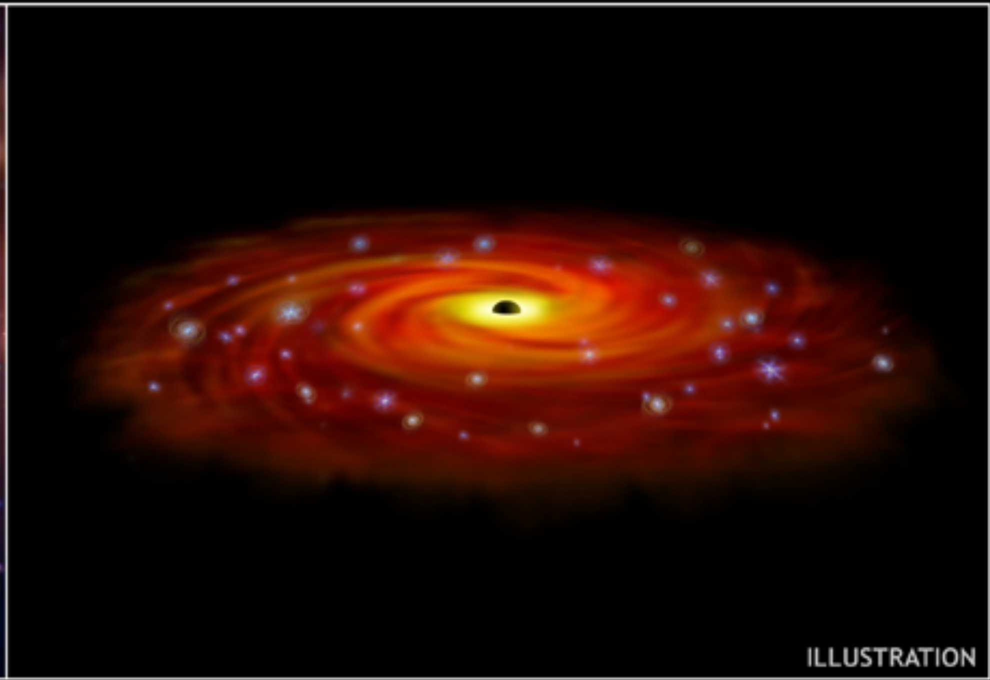
The mass of Sgr A*

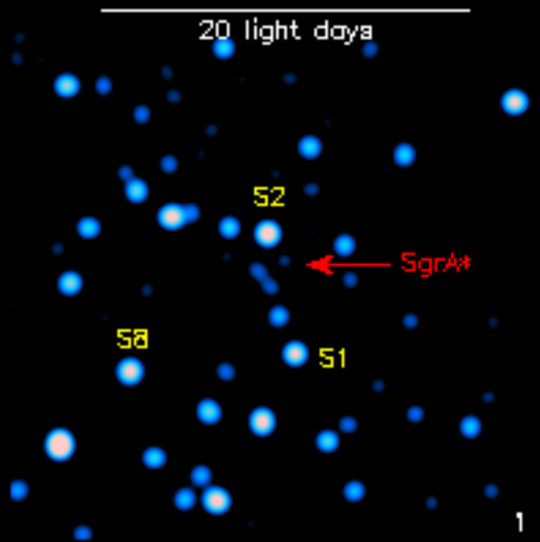




Mass = $4 \times 10^6\ M_\odot$; $R_S \sim 10^7$ km $\sim 10\ R_\odot \sim 1/15$ AU

Is Sgr A* "black"?





SgrA is a variable point source in radio, IR, X-rays (obscured in optical/UV)

Accreting at a very low rate ⇒ very low luminosity

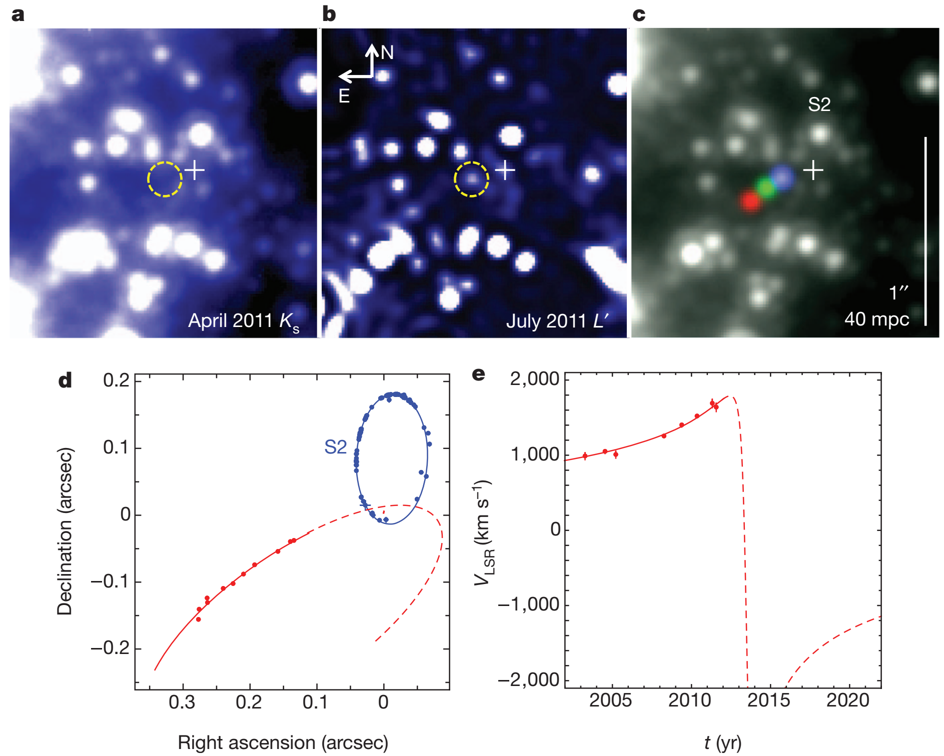
LETTER

***Nature* 481, 51–54 (05 January 2012)**
Received 25 August 2011 Accepted 17 October 2011
Published online 14 December 2011
doi:10.1038/nature10652

A gas cloud on its way towards the supermassive black hole at the Galactic Centre

S. Gillessen[1], R. Genzel[1,2], T. K. Fritz[1], E. Quataert[3], C. Alig[4], A. Burkert[4,1], J. Cuadra[5], F. Eisenhauer[1], O. Pfuhl[1], K. Dodds-Eden[1], C. F. Gammie[6] & T. Ott[1]

Measurements of stellar orbits[1–3] provide compelling evidence[4,5] that the compact radio source Sagittarius A* at the Galactic Centre is a black hole four million times the mass of the Sun. With the exception of modest X-ray and infrared flares[6,7], Sgr A* is surprisingly faint, suggesting that the accretion rate and radiation efficiency near the event horizon are currently very low[3,8]. Here we report the presence of a dense gas cloud approximately three times the mass of Earth that is falling into the accretion zone of Sgr A*. Our observations tightly constrain the cloud's orbit to be highly eccentric, with an innermost radius of approach of only ~3,100 times the event horizon that will be reached in 2013. Over the past three years the cloud has begun to disrupt, probably mainly through tidal shearing arising from the black hole's gravitational force. The cloud's dynamic evolution and radiation in the next few years will probe the properties of the accretion flow and the feeding processes of the supermassive black hole. The kilo-electronvolt X-ray emission of Sgr A* may brighten significantly when the cloud reaches pericentre. There may also be a giant radiation flare several years from now if the cloud breaks up and its fragments feed gas into the central accretion zone.



Large Flare from Sgr A* Detected by Swift

ATel #5006; *N. Degenaar, M. T. Reynolds, J. M. Miller (Michigan), J. A. Kennea (Penn State), R Wijnands (Amsterdam)*
on ***25 Apr 2013; 00:54 UT***
Credential Certification: Mark Reynolds (markrey@umich.edu)

Subjects: Radio, Infra-Red, X-ray, AGN, Black Hole, Transient

Referred to by ATel #: 5009, 5011, 5013, 5014, 5016, 5020, 5025, 5046

We report the detection of a large X-ray flare from a position consistent with Sgr A* during regular monitoring observations of the Galactic center with Swift.

In a 1ks observation on 2013-04-24 (17:34UT) a large flare is detected. Using an 10" radius extraction region centred on the known radio position, we measure a count rate of 0.11+/-0.1 ct/s. Comparing to the long term X-ray lightcurve of Sgr A* accumulated by Swift from 2006-2011 (Degenaar et al., 2013), the flare is consistent with the largest count rate detected from Sgr A* by Swift to date.

A total of 122 counts are detected during the observation facilitating basic spectral fitting. Assuming a fixed column density of 9.1e22 cm^-3 (see Degenaar et al. 2013) and fitting with a power-law in the 2 - 10 keV bandpass, we measure

Gamma: 2.1+/-0.5
norm: 0.018 +0.019 -0.01

where the errors are at the 90% confidence level, resulting in an absorbed flux of 2.1e-11 erg/s/cm^2 (2-10 keV), or a luminosity of ~ 1.6e35 erg/s for an assumed distance of 8 kpc. These properties are consistent with the most luminous X-ray flares previously observed from Sgr A*, e.g., Degenaar et al. (2013), Nowak et al. (2012), Porquet et al. (2003, 2008), Baganoff et al. (2001).

Swift is carrying out a daily monitoring campaign throughout 2013 to study the evolution of the X-ray properties of Sgr A* as it interacts with the G2 cloud (Gillessen et al., 2012, 2013). All observations are promptly analyzed and the resulting X-ray lightcurve will be made publicly available at the link below. Bright flares (Lx > 1e35 erg/s) will be reported to the community in further telegrams.

If you would like to receive an automated email update of large flares, please email swift.sgra 'at' gmail.com to be added to the mailing list.

Swift Sgr A Monitoring Campaign Website*

Continued Swift Monitoring of the Galactic Center Flare

ATel #5016; *M. T. Reynolds, N. Degenaar, J. M. Miller (Michigan), J. A. Kennea (Penn State), R. Wijnands (Amsterdam) on behalf of a larger collaboration*
on ***26 Apr 2013; 20:36 UT***
Credential Certification: Mark Reynolds (markrey@umich.edu)

Subjects: Radio, Infra-Red, X-ray, AGN, Black Hole, Transient

We report the result of a long Swift observation of the galactic center flaring source (atel #5006, #5008, #5011, #5013, #5014) undertaken last night (2013-04-25; obsid: 00554491001; Exptime: 11.2 ks). Continued elevated X-ray emission consistent with the position of Sgr A* is detected, where a count rate of 0.095+/-0.003 ct/s is measured from a 10" radius region centred on the radio position of Sgr A*.

The measured intensity is consistent with a roughly constant level of approximately 0.1 ct/s over the past 48 hrs from this source, e.g., atel #5006.

Extracting the source spectrum from this region and background from an annulus extending from 20"-50" from the position of Sgr A*, we have a total of 1060 net counts. All fits are reported in the 2-10 keV bandpass and errors where quoted are at the 90% confidence level.

The source spectrum is intrinsically soft and thermal-like. Fixing the column density to that measured towards Sgr A* (9.1e22 cm^-2), we find curved residuals when the spectrum is fit with a power-law (Gamma ~ 2). Allowing the column density to vary results in an improved fit but the resulting spectral tends towards Gamma ~ 4.

Our nominal best fit model is a simple blackbody

Nh: 9.1e22 cm^-2
kT: 1.06+/-0.06 keV
norm: (4.1+/-0.2)e-4

though alternative models that naturally produce curvature in the 2 -- 10 keV band pass also return acceptable fits, e.g., Bremsstrahlung. The normalization implies an emission region with a radius of ~ 16m (d/8kpc)^2.

The spectrum does not reveal any evidence for the presence of Fe K emission intrinsic to the source, suggesting the tentative Fe K line detection reported in atel #5011 originates in the diffuse gas that permeates the GC region, e.g., Baganoff et al. (2003), Nowak et al. (2012).

Inspection of the lightcurve reveals the source to be highly variable, with typical variations at the 10% level. There is no evidence for any periodicity and/or eclipses as might be exected from an X-ray binary in the lightcurve. The resulting power spectrum is featureless and consistent with stochastic variability from this source.

The observed spectral shape is not consistent with that typically observed from NS & BH LMXB at luminosities ~ 1e35 erg/s. If this spectrum were due to emission from a NS/BH LMXB, such high temperatures are only observed from sources accreting at a significant fraction of the Eddington limit ~0.1 LEdd, which implies a line-of sight source lying at a distance far in excess of the galactic center.

Given the positional coincidence with Sgr A* and the unusual spectrum, it is possible that we are observing emission from Sgr A* at a low Eddington fraction. If so, the current event is the longest and most energetic accretion event observed from Sgr A* in modern times.

```
TITLE:   GCN CIRCULAR
NUMBER:  14443
SUBJECT: Trigger 554491: Swift detection of a spike possibly from Sgr A*
DATE:    13/04/25 19:49:55 GMT
FROM:    Scott Barthelmy at NASA/GSFC  <scott@milkyway.gsfc.nasa.gov>

S. D. Barthelmy (GSFC), J. A. Kennea (PSU),
H. A. Krimm (CRESST/GSFC/USRA), V. Mangano (INAF-IASFPA),
C. B. Markwardt (NASA/GSFC), F. E. Marshall (NASA/GSFC) and
A. Maselli (INAF-IASFPA) report on behalf of the Swift Team:

At 19:15:25 UT, the Swift Burst Alert Telescope (BAT) triggered and
located a transient position consistent with Sgr A* (trigger=554491).
Swift did not slew immediately because the current target had a higher merit
value.  The slew was delayed by 15 min.  The BAT on-board calculated location
is  RA, Dec 266.412, -28.990 which is
   RA(J2000)  =  17h 45m 39s
   Dec(J2000) = -28d 59' 22"
with an uncertainty of 3 arcmin (radius, 90% containment, including
systematic uncertainty).  The BAT light curve shows shows a single 64 msec bin.
The peak count rate was ~2500 counts/sec (15-350 keV), at ~0 sec
after the trigger.

The BAT position is within 65 arcsec of the galactic center and Sgr A*.  Given
the recent activity reported from Sgr A* (ATEL #5006), it's quite possible that
this is the source of X-ray flaring.  Also, this is a confused region, so
we cannot rule out other candidates.

The XRT began observing the field at 19:31:27.6 UT, 962.8 seconds after
the BAT trigger. Using promptly downlinked data we find an X-ray source
located at RA, Dec 266.41715, -29.00866 which is equivalent to:
   RA(J2000)  = 17h 45m 40.12s
   Dec(J2000) = -29d 00' 31.2"
with an uncertainty of 4.1 arcseconds (radius, 90% containment). This
location is 69 arcseconds from the BAT onboard position, within the BAT
error circle. This position may be improved as more data are received;
the latest position is available at http://www.swift.ac.uk/sper. This
position is 3.2 arcseconds from that of Sgr A*, and is consistent with
being that source. The X-ray source shows an elevated emission level,
consistent with that reported from observations taken yesterday in
ATEL #5006.

UVOT took a finding chart exposure of 150 seconds with the White filter
starting 967 seconds after the BAT trigger. No credible optical counterpart has
been found in the initial data products. The 2.7'x2.7' sub-image covers 100% of
the XRT error circle. The typical 3-sigma upper limit has been about 19.6 mag.
No correction has been made for the large,
but uncertain extinction expected.
```


Swift/BAT detection of an SGR-like flare from near Sgr A*

ATel #5009; *J. A. Kennea (PSU), H. Krimm, S. Barthelmy, N. Gehrels, C. Markwardt, J. Cummings, F. Marshall (GSFC), T. Sakamoto (AGU), N. Degenaar, M. T. Reynolds, J. M. Miller (Michigan), C. Kouveliotou (MSFC)*
*on **26 Apr 2013; 02:48 UT***
Credential Certification: Jamie A. Kennea (kennea@astro.psu.edu)

Subjects: X-ray, Black Hole, Soft Gamma-ray Repeater, Transient

Referred to by ATel #: 5011, 5032, 5033, 5035, 5037, 5046

Degenaar et al (ATEL #5006) recently reported elevated X-ray emission from Sgr A* detected in daily monitoring by Swift XRT, which has persisted for at least a day (Dwelly and Ponti, ATEL #5008). We report here on observations of Sgr A* triggered by the detection of a short flare by Swift BAT on April 25, 2013 at 19:15:25UT (Barthelmy et al., GCN #14443).

Although Sgr A* has been shown to flare in X-rays repeatedly (e.g. Degenaar et al., 2013), continued elevated X-ray emission is unprecedented, leading to speculation that this and the BAT flare may be related to an interaction with the G2 cloud (Gillessen et al., 2012, 2013). However, the short timescale of the flare is difficult to reconcile given the mass of Sgr A* Based on the BAT data we suggest the flare may be a new soft-gamma repeater (SGR) near Sgr A*. This is based on (1) the short duration (30 msec) of the flare, (2) the persistent emission from this region recently detected by XRT (Degenaar et al., ATel #5006; Dwelly & Ponti, ATel #5008), (3) the blackbody spectrum and energy cutoff at 46 keV and 4) the high density of magnetar candidates (30% of the total population) in a longitude range of 30 degrees from the center along the plane towards the Scutum galactic arm. We note at this time we have been unable to detect any periodicity in the XRT data in the typical SGR range (2-12 s).

If this is a new SGR, the angular separation between it and Sgr A* would have to be relatively small (conservatively <4 arcsec). Alternatively the X-ray counterpart of the BAT flare could be below the level of XRT detectability.

We encourage follow-up of Sgr A* during this period of high X-ray emission. In particular we recommend observations by Chandra, to unambiguously determine if the enhanced emission is from Sgr A* or from an unresolved transient.

Swift monitoring of Sgr A* is on-going. Results of this monitoring can be seen online at the following web page: http://swift-sgra.com/

NuSTAR discovery of a 3.76 second pulsar in the Sgr A* region

ATel #5020; *Kaya Mori, Eric V. Gotthelf (Columbia University), Nicolas M. Barriere (UC Berkeley), Charles J. Hailey (Columbia Univerity) , Fiona A. Harrison (Caltech), Victoria M. Kaspi (McGill University), John A. Tomsick (UC Berkeley), Shuo Zhang (Columbia University)*
on ***27 Apr 2013; 05:40 UT***
Credential Certification: Jules Halpern (jules@astro.columbia.edu)

Subjects: X-ray, Neutron Star, Soft Gamma-ray Repeater, Transient, Pulsar

Referred to by ATel #: 5025, 5027, 5032, 5033, 5035, 5037, 5040, 5043, 5046

Following detection of flaring from the Galactic center (ATel #5006, #5008, #5011, #5013, #5014) we initiated a 40 ks NuSTAR X-ray observation of Sgr A* on 2013 April 26, 1:00:06 UT. From an initial 21 ks of data that spanned 64 ks we detected enhanced X-ray emission in the 3-10 keV X-ray band approximately 3 times greater than previous NuSTAR survey observations of the same field. The count rate increased to 0.38 cts/s/module within a 30 arcsecond radius aperture around the Sgr A* as compared to 0.11 cts/s/module in the 2012 October observation.

A blackbody plus power-law spectral model yields a temperature of kT = 0.85 keV and photon index of Gamma = 3.2 and is statistically preferred over a single power-law. The 3-10 keV unabsorbed flux is 2.4e-11 erg/cm2/s corresponding to a luminosity of 1.8e35 erg/s at d=8 kpc.

For a preliminary timing analysis we searched a total of 16,497 photon arrival times extracted from the combined pair of Focal Plane Modules on-board NuSTAR using a 30 arcsecond radius aperture centered on the peak X-ray emission. The arrival times were binned into a 2 ms resolution light curve and searched for coherent pulsations using an FFT to the Nyquist frequency. We find a complex signal around 3.76 seconds with power at odd harmonics. A refined Z^2_3 analysis gives a preferred period of P=3.7635417(80) seconds corresponding to a pulse profile with three resolved peaks each 0.6 s wide, dominated by a single strong peak. A summary plot is available at http://www.astro.columbia.edu/~eric/sgra_transient_timing.ps

The bursting, timing, and spectral properties strongly suggest a previously unknown magnetar undergoing an outburst. Further observations are planned to follow the flux and spectral evolution as well as to measure the spin-down rate and to search for additional bursts. NuSTAR has triggered additional ToO observations. Additional radio observations of the field, particularly to search for radio pulsations, are encouraged.

NuSTAR Pulsar Summary Plot

Chandra localization of the soft gamma repeater in the Galactic Center region

ATel #5032; *N. Rea (CSIC-IEEC), P. Esposito, G. L. Israel (INAF), A. Papitto (CSIC-IEEC), A. Tiengo (IUSS/INAF), F. Baganoff (MIT), D. Haggard (Northwestern/CIERA), S. Mereghetti, M. Burgay, A. Possenti (INAF), S. Zane (MSSL), on behalf of a larger collaboration*
on ***30 Apr 2013; 21:53 UT***
Distributed as an Instant Email Notice Transients
Credential Certification: Nanda Rea (rea@ieec.uab.es)

Subjects: X-ray, Soft Gamma-ray Repeater, Pulsar

Referred to by ATel #: 5035, 5037, 5040, 5046

We have observed the new X-ray pulsar discovered near the Galactic Center using the High Resolution Camera (HRC-S) onboard the Chandra X-ray Observatory on April 29, 2013 for ~10ks.

In a preliminary analysis we detected the new soft gamma repeater at a count rate of ~0.087 c/s . The new source position is:

RA 17:45:40.19, Dec: -29:00:30.37 (with a 0.3" 1sigma statistical error; not boresight corrected).

This position lies at ~3" from the best Chandra position of SgrA* (Nowak et al. 2012), which is instead not detected in our observation. Furthermore, we confirm the spin period of ~3.76s, and the triple-peaked pulse profile, as observed by NUSTAR (Mori et al. 2013, Atel #5020).

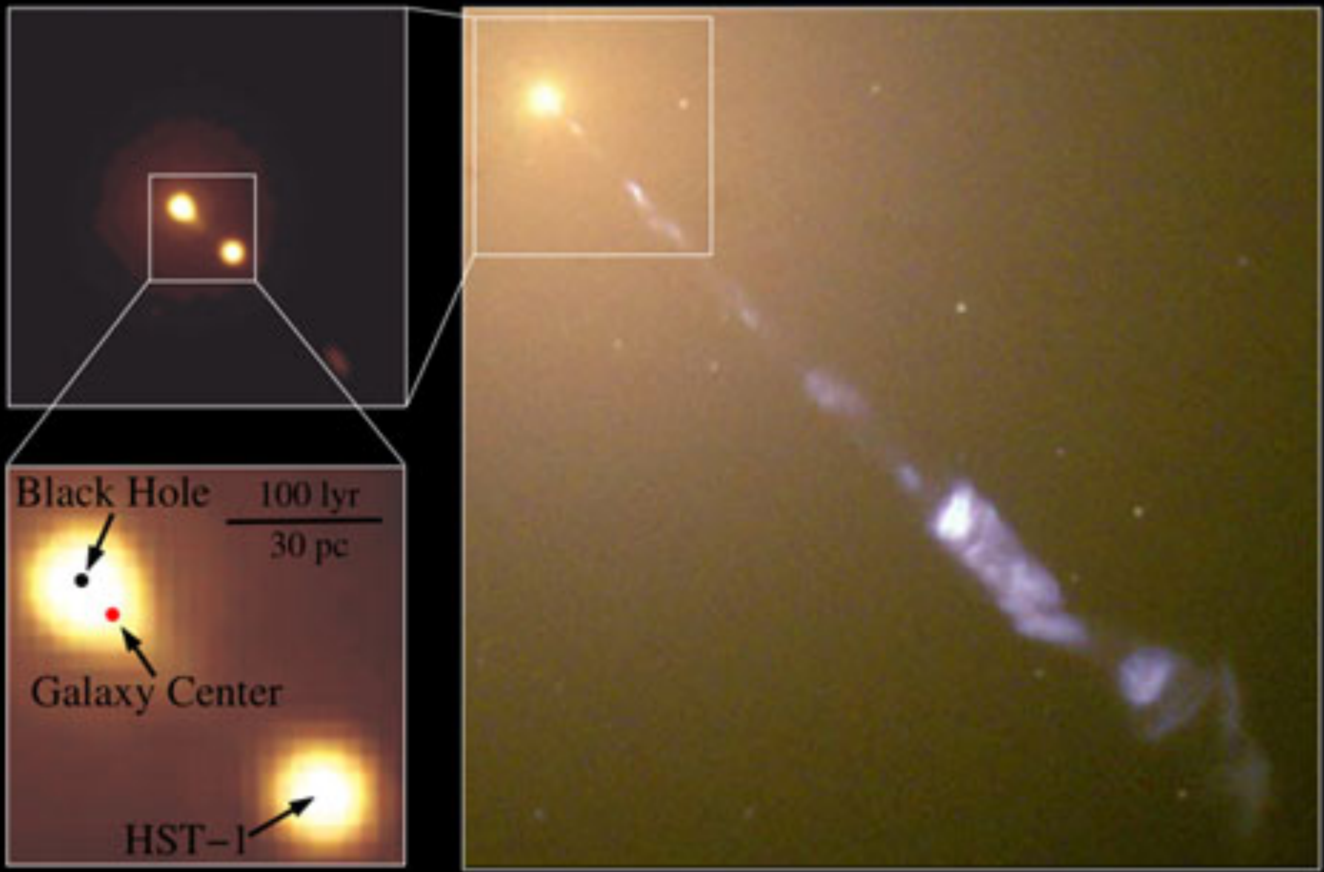
This observation confirms the presence of a new soft gamma repeater as responsible for the SGR-like flare observed by Swift-BAT (Kennea et al. 2013, Atel #5009), while SgrA* does not appear to be in a X-ray flaring active state.

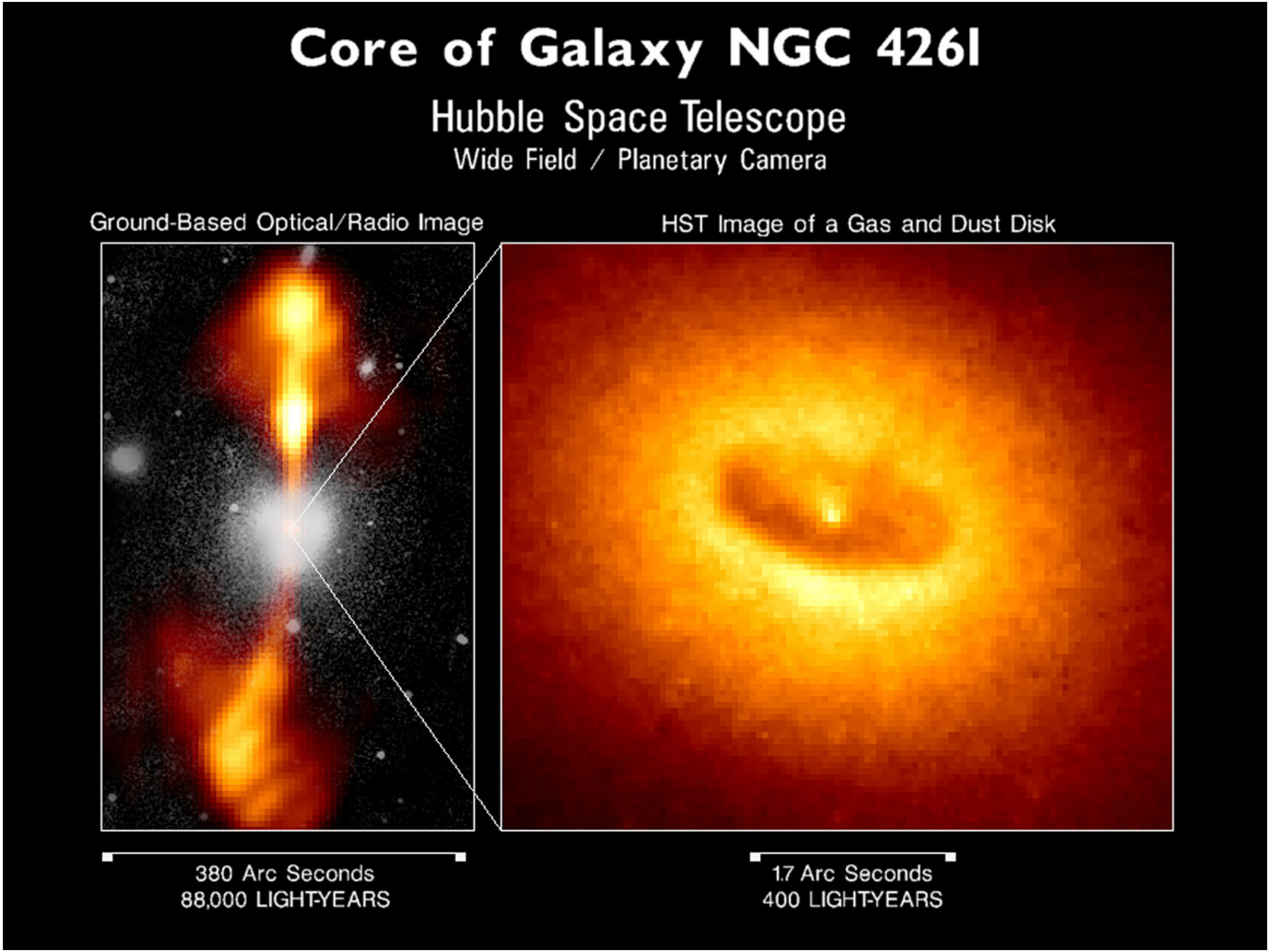
Further Chandra observations are planned to follow this new source during its outburst decay.

Chandra image: left image is the new HRC-S observation; right image is an archival ACIS-S image (obsid:13017)

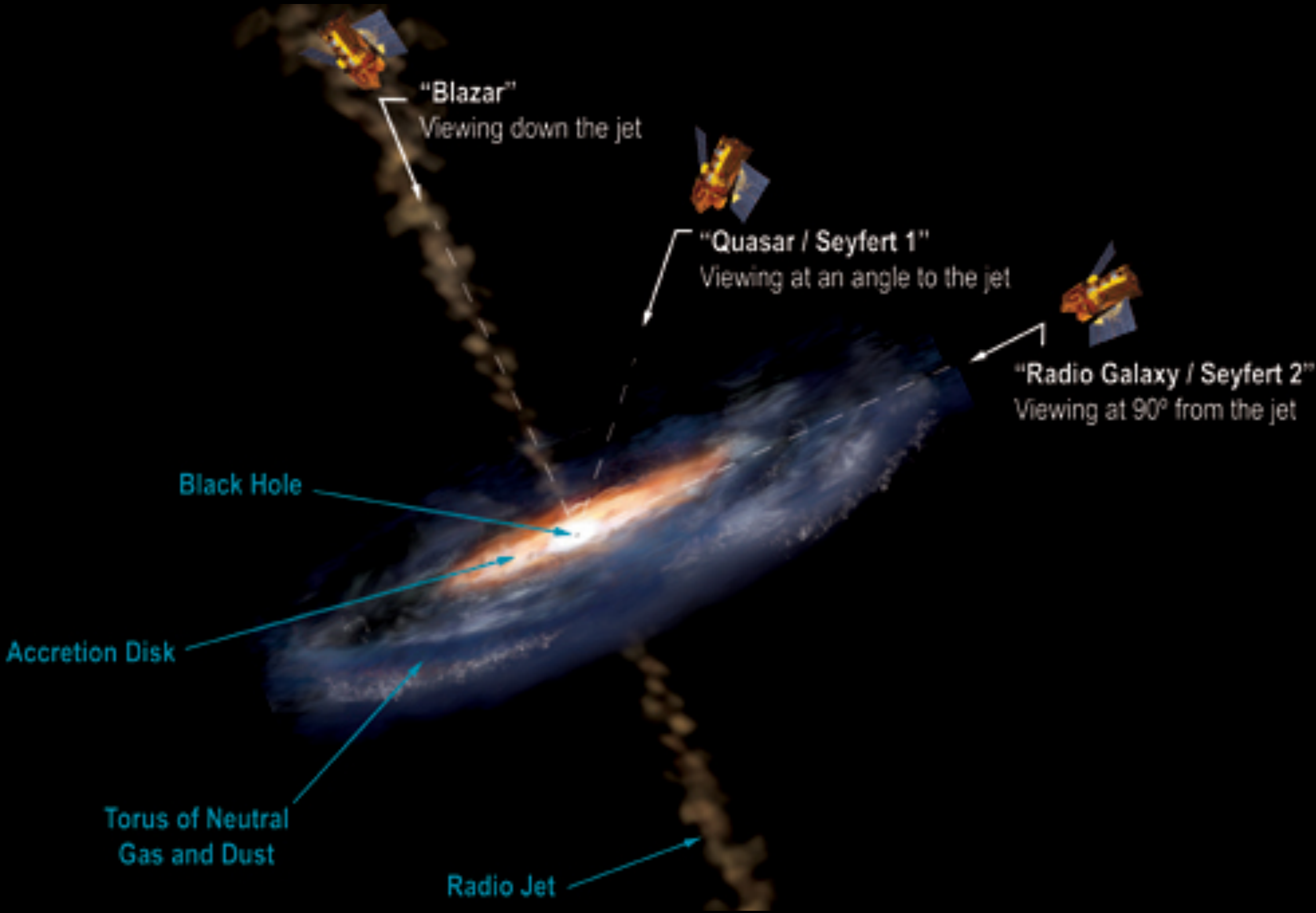
Active Galactic Nuclei (AGN)

Accreting supermassive BHs (up to billions of Solar masses) at the center of galaxies



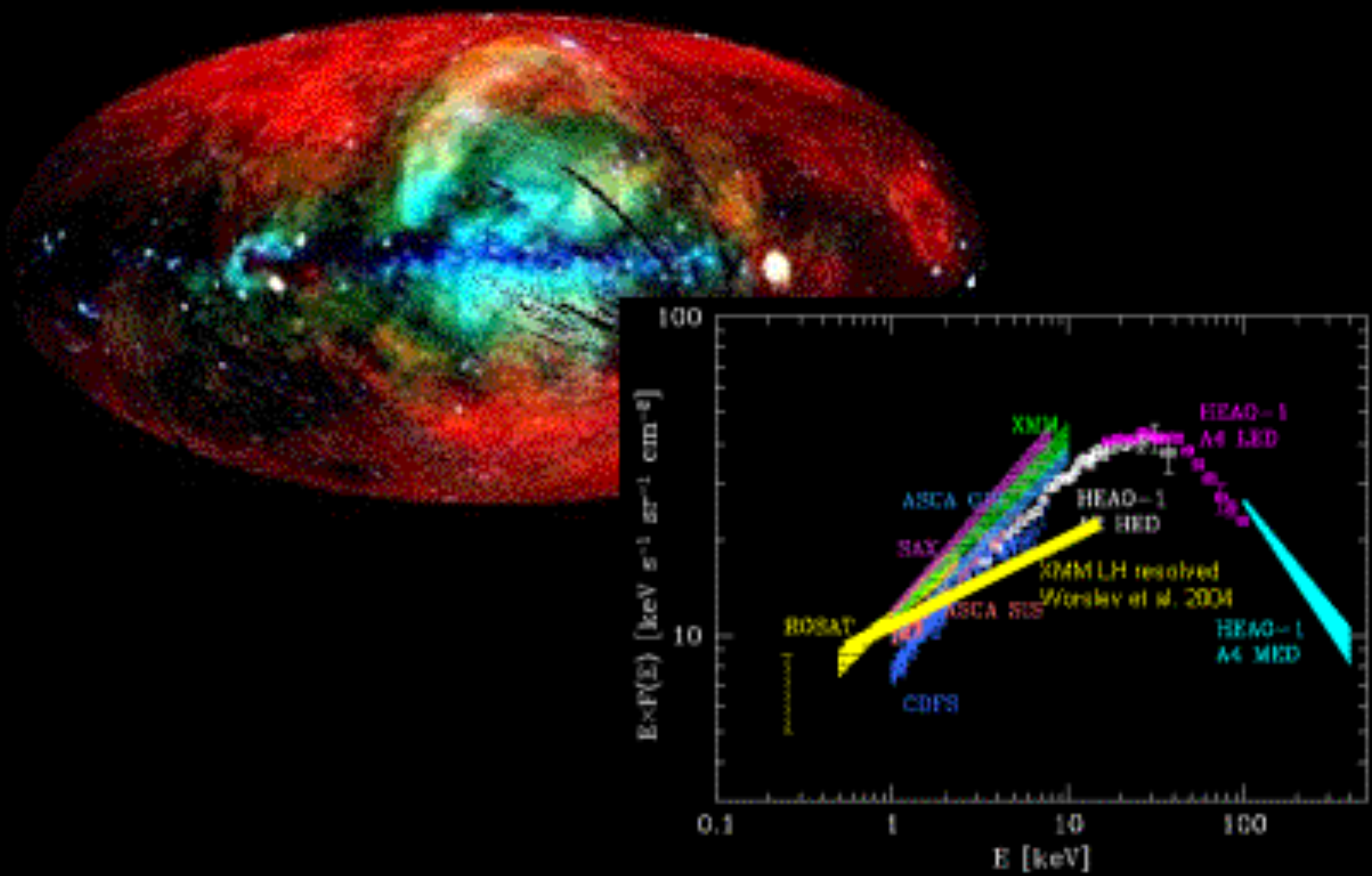

Core of Galaxy NGC 4261
Hubble Space Telescope
Wide Field / Planetary Camera
Ground-Based Optical/Radio Image
HST Image of a Gas and Dust Disk
380 Arc Seconds
88,000 LIGHT-YEARS
1.7 Arc Seconds
400 LIGHT-YEARS

AGN classes



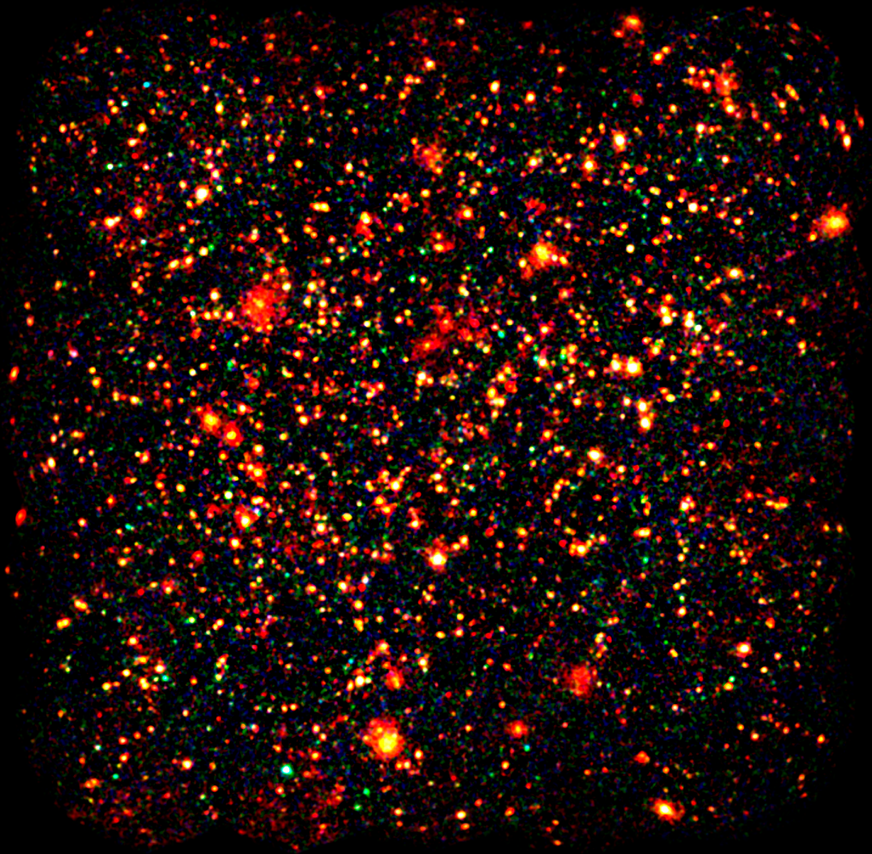
"Blazar"
Viewing down the jet
"Quasar / Seyfert 1"
Viewing at an angle to the jet
"Radio Galaxy / Seyfert 2"
Viewing at 90° from the jet
Black Hole
Accretion Disk
Torus of Neutral
Gas and Dust
Radio Jet

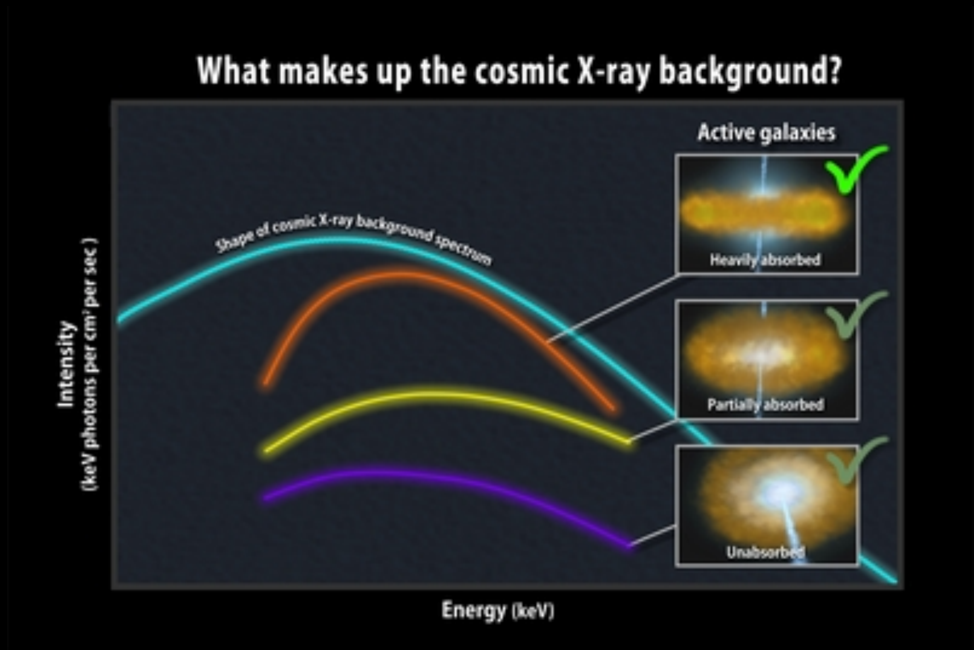
The Cosmic X-ray Background (CXB)



Removing discrete X-ray sources, residual diffuse emisssion

CXB and AGNs





CXB is due to unresolved X-ray emission from distant AGNs