The ASCA Program
Senior Review Presentation

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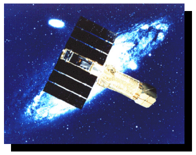
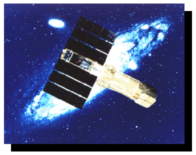


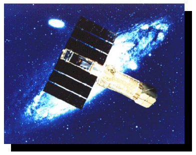
Some Highlights Since August 1996: Part 1

- Confirmed the relativistic accretion disk origin for the broad iron K line from AGN
- Possible 60,000s periodicity from the Seyfert I IRAS 18325-5926
- Observation of X-ray Baldwin effect in AGN
- Evidence for highly relativistic outflows from three narrow line Seyfert I galaxies
- Constraints on Ω_o from 0.29 to 0.57 from redshift 0.3-0.6 cluster temperature measurements
- Use of the Sunyaev-Zel'dovich effect to give a direct measure of Hubble constant in the range 42-61 km/s/Mpc

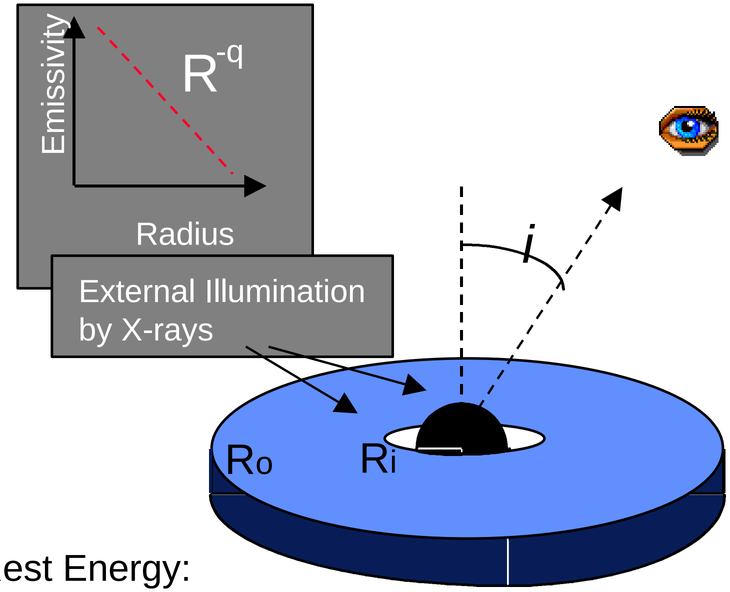


Some Highlights Since August 1996: Part 2

- X-ray detection of dark cluster at z=1 with M/L of 3300
- Discovery of plerions and magnetars in many supernova remnants
- Observation of abundance variations during stellar flares
- Discovery of pervasive high temperature emission from pre-main sequence stars
- Discovery of resonant absorption lines in two micro-quasars
- Observation of different low energy line emission patterns from LMXRB
- Catalogs of over 1000 new serendipitous 1-10 keV sources



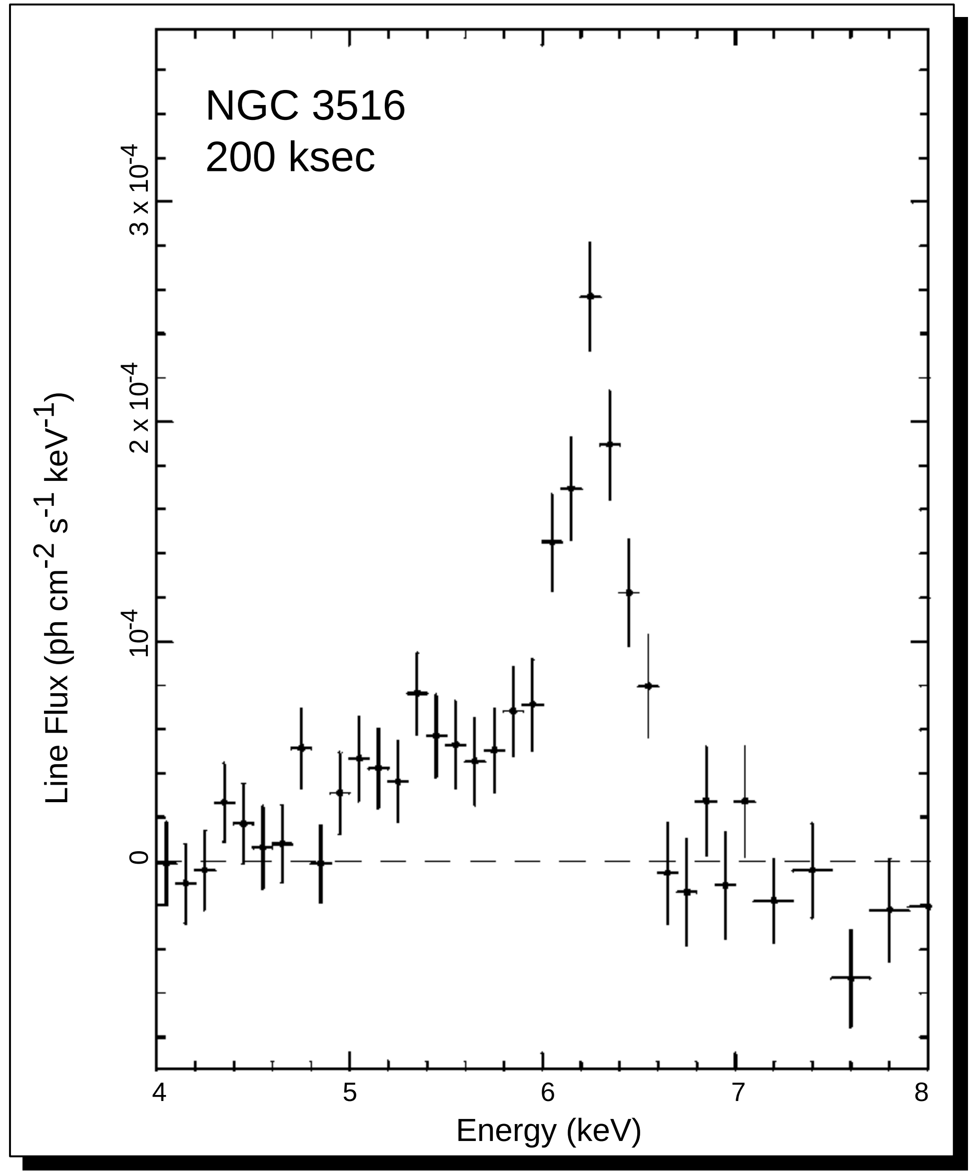
Probing black holes in AGN with ASCA



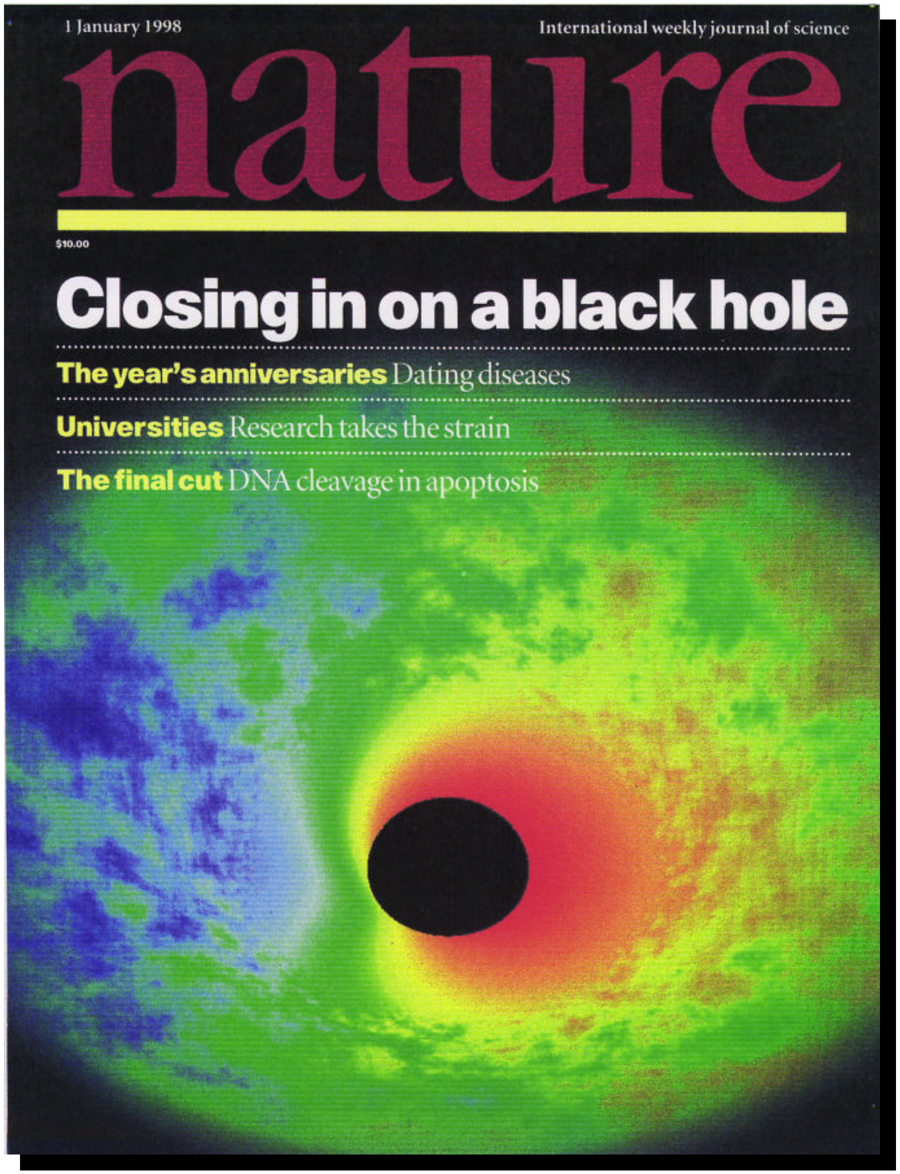
Rest Energy:
E = 6.4 - 6.9 keV

DISK LINE MODEL

- Line emission from Fe Kα has broad (Fabian et al., 1994; Mushotzky et al 1995) and asymmetric (Tanaka et al., 1995) profile
- Line arises in an accretion disk, the profile indicates distortion due to strong gravitational effects close to the black hole
- Study of sample of Seyfert 1s showed E = 6.4 keV; width implies velocities ~ 40,000 km/s; disk oriented face-on (Nandra et al 1997)

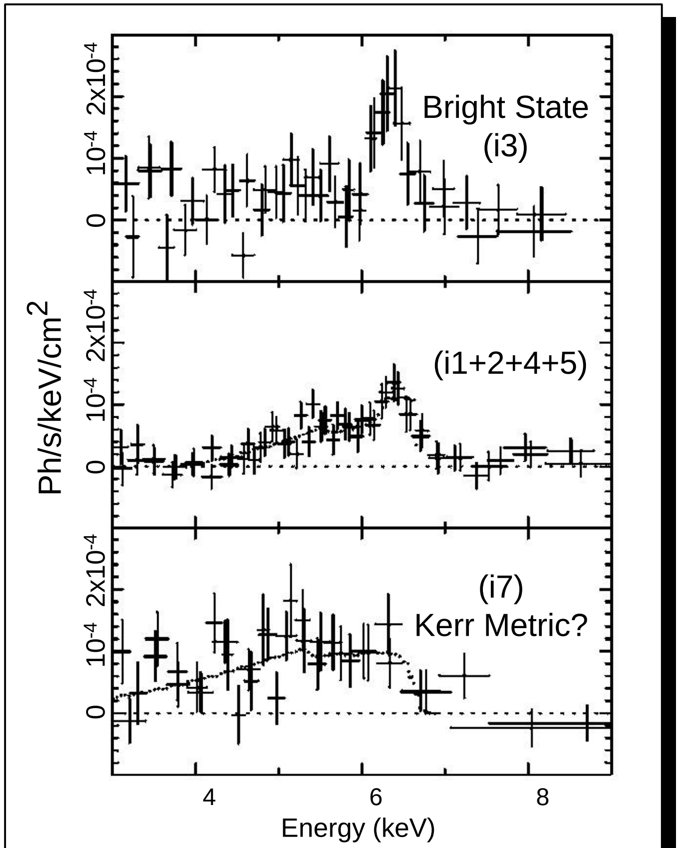


Closing in on Supermassive Black Holes in AGN



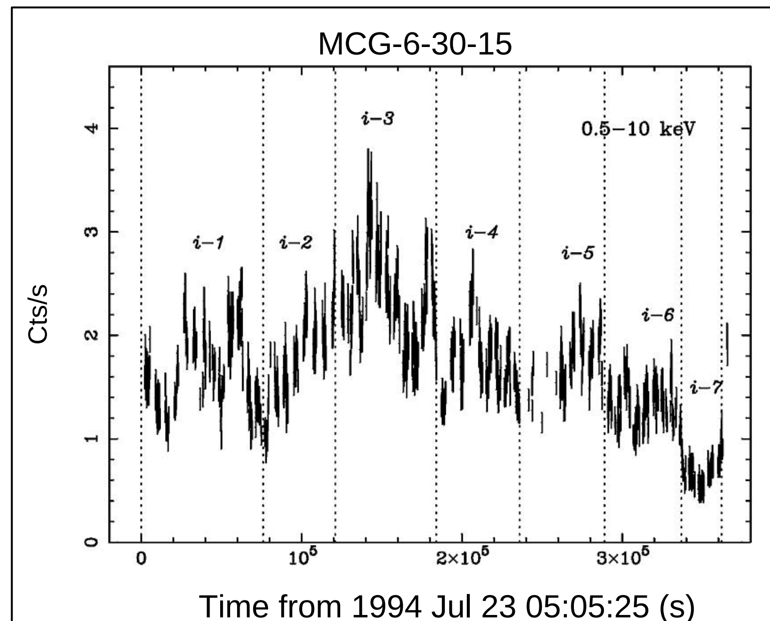
- Bromley, Miller, and Pariev (1998) use the minimum frequency at which significant line emission is detected to tighten constraints on the inner radius for line emission
- $R_{in} < 2.6 \pm 0.3\ R_s$ at 95% confidence
- Reynolds and Begelman (1997) find conditions where disk is emissive within $3R_s$ (dependant on accretion rate and source luminosity) BUT if their conditions are not met then emission from within $3R_s$ constrains the black hole rotation.
- In MCG-6-30-15 hole rotation > 23 ± 17% of theoretical maximum

Relativistic Fe Line Profile Variations



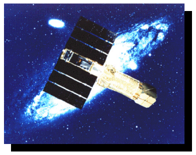
Iwasawa et al., 1998

- Four-day observation of MCG-6-30-15
  - Variations in line seen on time scales of 10,000 s
  - Core of line correlates with continuum while red wing is anticorrelated
- **But** some epochs show rapid variation (few 1000 s) where wing variations DO correlate with flares
- Different regions dominate at different times
- May be due to occultation? (Weaver & Yaqoob 1998; McKernan & Yaqoob 1998)



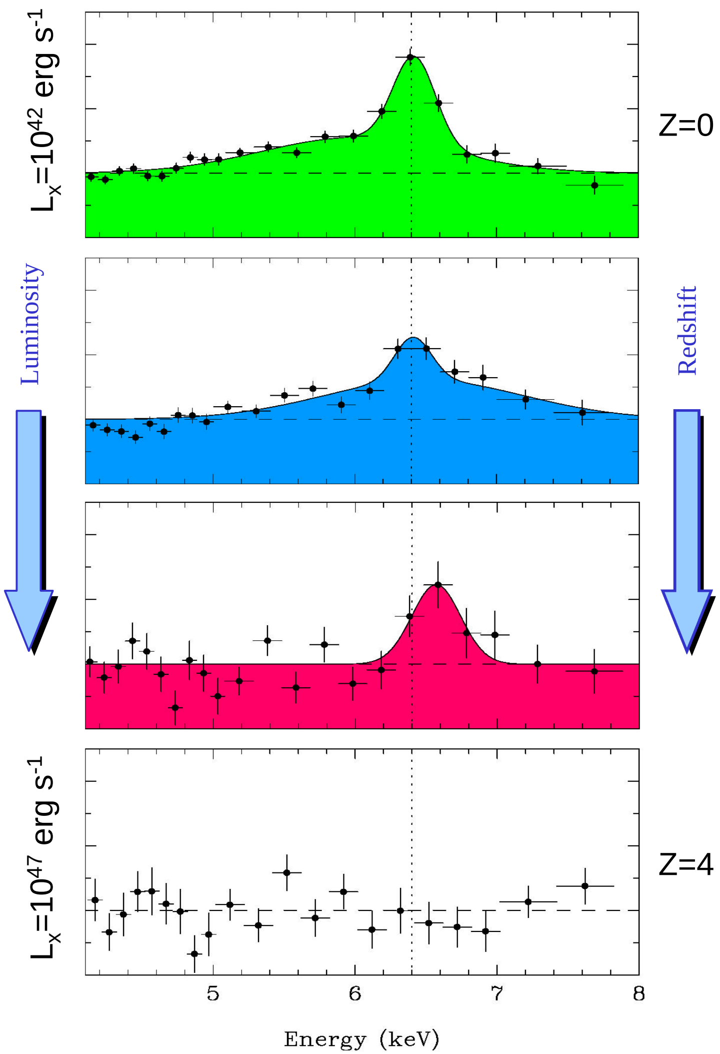
- NGC 7314, red-wing tracks continuum over 10^5 s (Yaqoob et al. 1996)
- NGC 3516 line varies with no change of profile over one year (Nandra et al. 1996)

ASCA

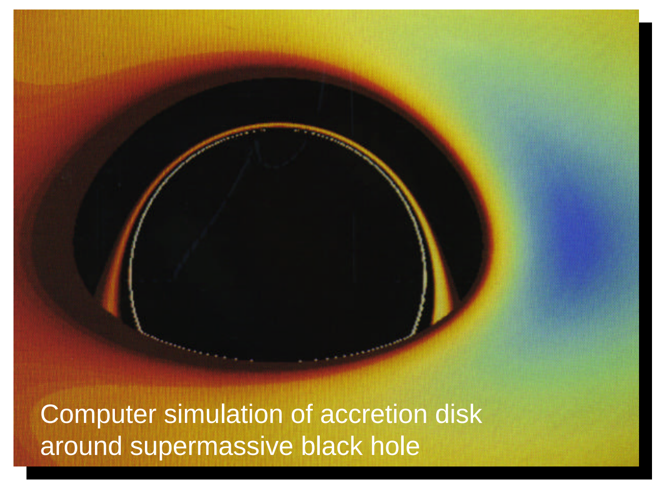


On the Dependence of Iron K-line Profiles with Luminosity in Active Galactic Nuclei

Nandra, K., George, I.M., Mushotzky, R.F., Turner, T.J., Yaqoob, T,
1997 ApJL 488, 164

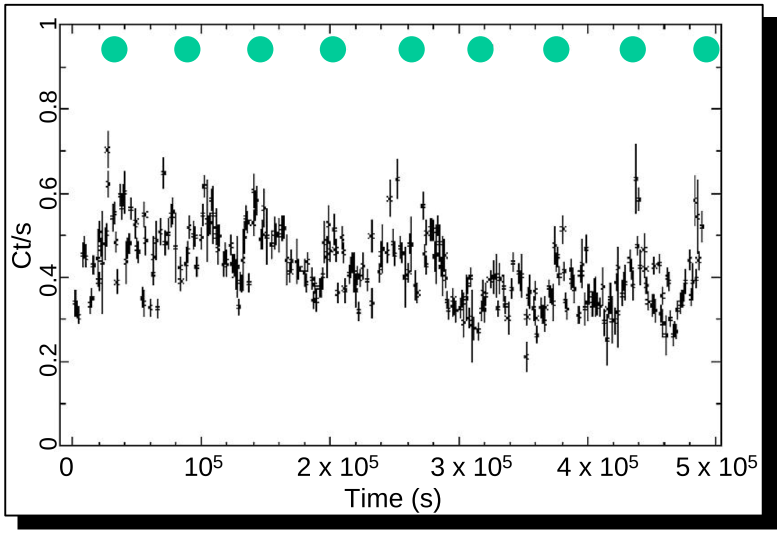


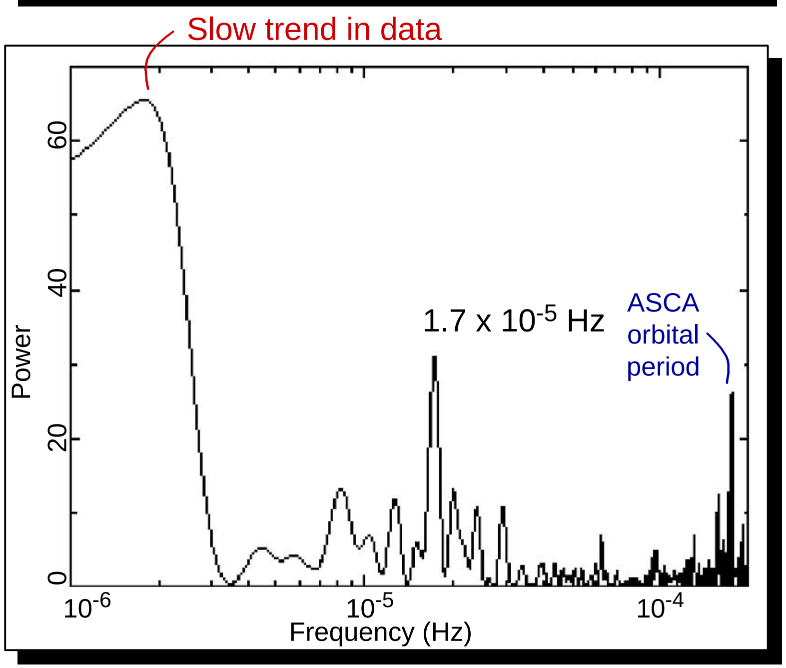
- Gravitational time dilation close to supermassive black hole in active galaxies distorts iron emission line observed in X-rays.
- ASCA data obtained for objects ranging from nearby objects to powerful quasars close to the edge of the observable universe.
- Black hole signature reduces in strength as the source power and redshift increase, eventually disappearing.
- Effect probably due to the intense radiation of the quasars stripping away electrons from the iron atoms, suppressing the emission line.
- Data allow investigation of the physical conditions around supermassive black holes and their evolution through cosmological time.


Computer simulation of accretion disk around supermassive black hole

ASCA

X-ray Periodicity in SY I Galaxy IRAS 18325-5926



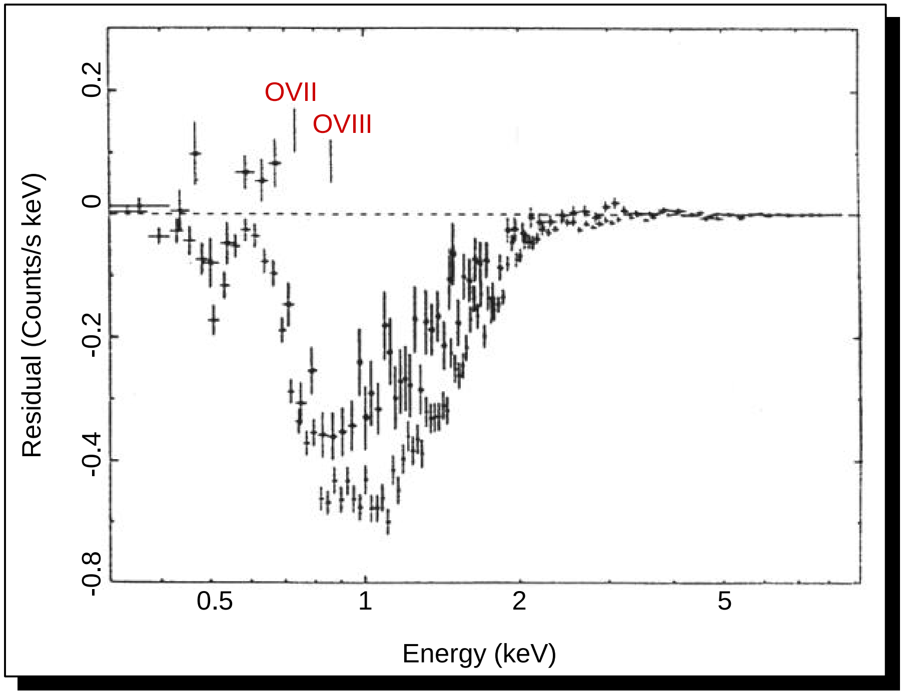


- Possible 16-hour period detected
- Five-day ASCA observation revealed 9 cycles with 14% amplitude
- Orbital period at 5 R_s implies 200 million $M_\odot$ black hole
- Requires Confirmation

Iwasawa et al. (1998)

Warm Absorber Variations in Seyfert 1 Galaxies

Detailed Edge Structure



Ionized gas exists in the line-of-sight to at least 50% of AGN (Reynolds, 1997; George et al., 1998), with typical column density ~10^{22} cm^{-2}.

OVII and *OVIII* edges were detected in MCG-6-30-15 (Fabian et al., 1994); however, the location of the warm absorber has been unclear.

Further progress can be made from consideration of the variability of the warm absorber.

A four-day observation of MCG-6-30-15 showed the *OVIII* edge to deepen as the continuum flux diminished (Otani et al., 1996) while the *O VII* edge was constant. These authors showed that two zones of ionized gas could explain all the ASCA observations of this source.

The outer zone dominates the *OVII* edge and has a long recombination time, consistent with an origin in the narrow-line-region. The inner zone produces most of the *OVIII* edge and has a recombination time < 10,000 s, responding more directly to changes in nuclear flux. This gas may exist in the broad-line-region, < 10^{17} cm from the nucleus.

Archival Survey of Seyfert 2 Galaxies

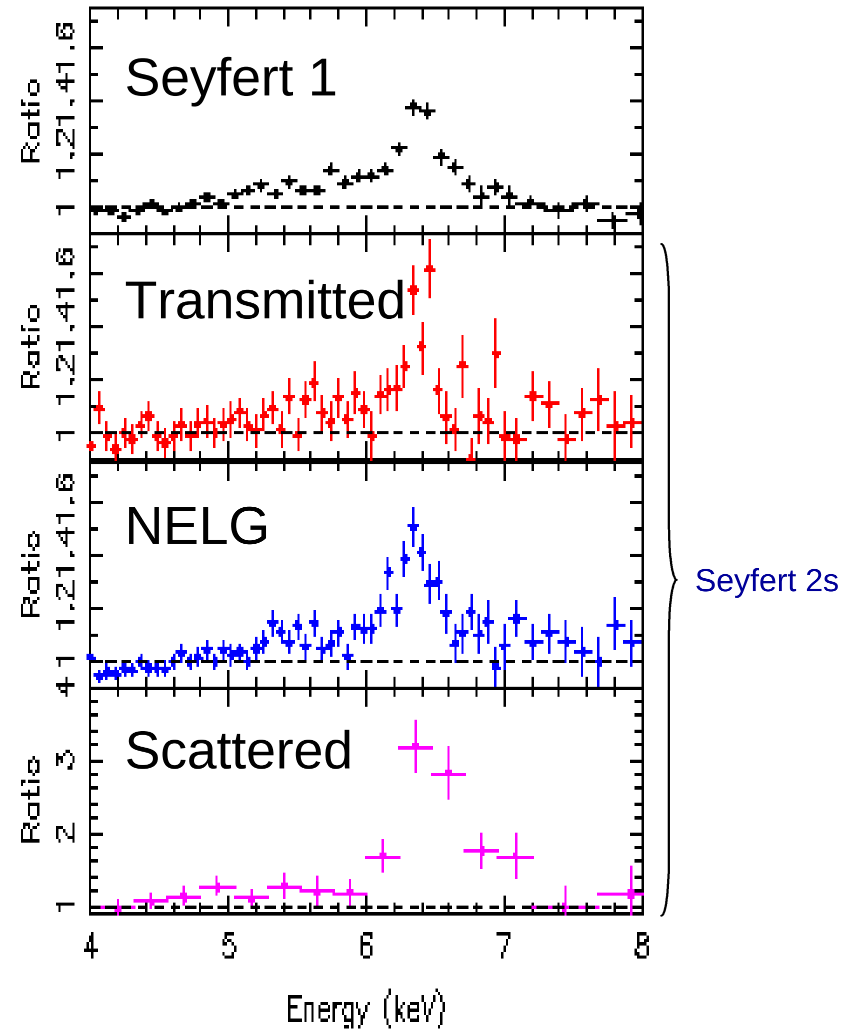
Detailed survey of ASCA archives to compare compare line profiles of different AGN

The iron Kα emission line in Seyfert 2 galaxies is asymmetric, indicating a strong contribution from the accretion disk.

The profile from Compton-thick sources shows line of high EW, with some contribution from ionized material but also a red wing at the same level as in Seyfert 1 galaxies. This is expected if the scatterer sees a face-on disk (but we are looking at the source edge-on).

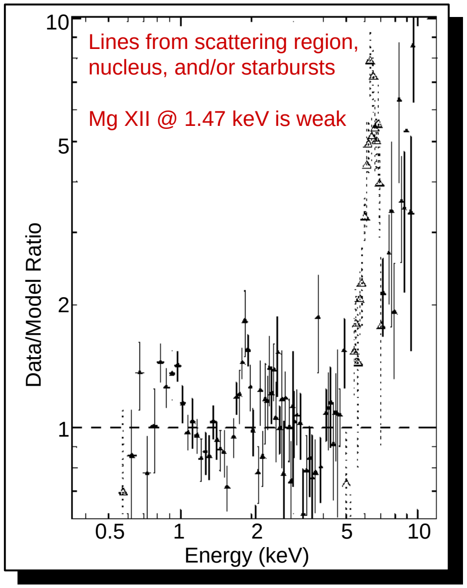
However, profiles in the Compton-thin sources also show a remarkable similarity to those from Seyfert 1 galaxies, indicating a face-on orientation of the inner disk in both cases.

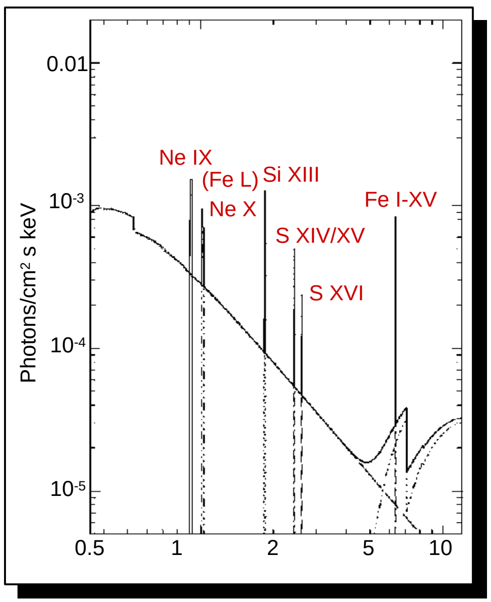
This is a problem for unification models, as there must be a population of sources where the inner disk is oriented edge-on.



Turner et al. (1997 a,b,c)

Line Emission in NGC 6240





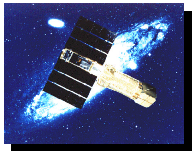
NGC 6240 is an ultraluminous IRAS galaxy, the optical spectrum is that of a type-2 Seyfert galaxy.

ASCA detects line emission from ionized species of Ne, Si, S, and Fe with EWs ~ 50-100 eV (Turner et al., 1998).

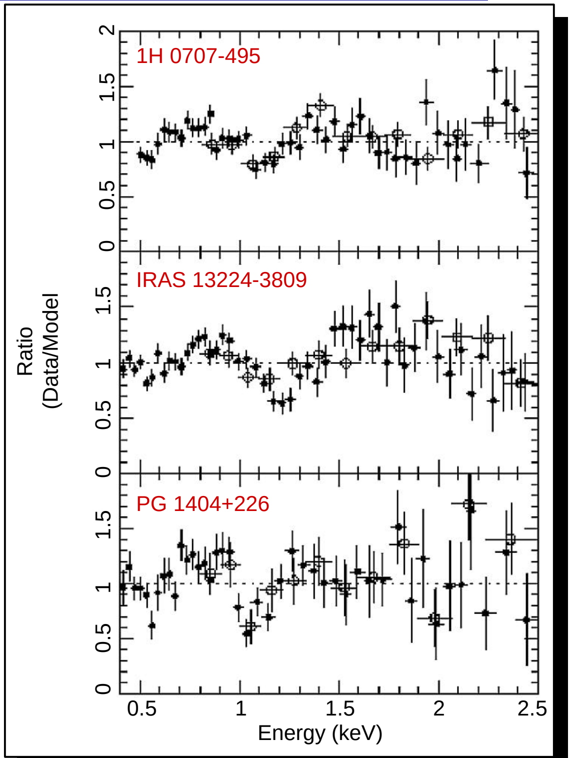
The absorbed hard X-ray component, and strong Fe Kα at 6.4 keV indicates the presence of an obscured AGN. The observed emission is the sum of starburst (35%) and nuclear activity.

Seven of 25 Seyfert-2 galaxies show line emission other than Fe Kα, most were H-like and He-like species like those observed in NGC 6240. Such lines were also seen in sources with little or no starburst activity (e.g., Mrk 3) and so some of these may be attributable to gas photoionized by the active nucleus. More detailed measurements of these faint sources can constrain conditions in the reprocessing gas and find the best targets for observation by AXAF.

Netzer, Turner, & George (1998)



Unexpected and Intriguing Spectral Features



Leighly, Mushotzky, & Nandra (1997)

Absorption features close to 1 keV are reported for three Narrow-Line Seyfert 1 galaxies.

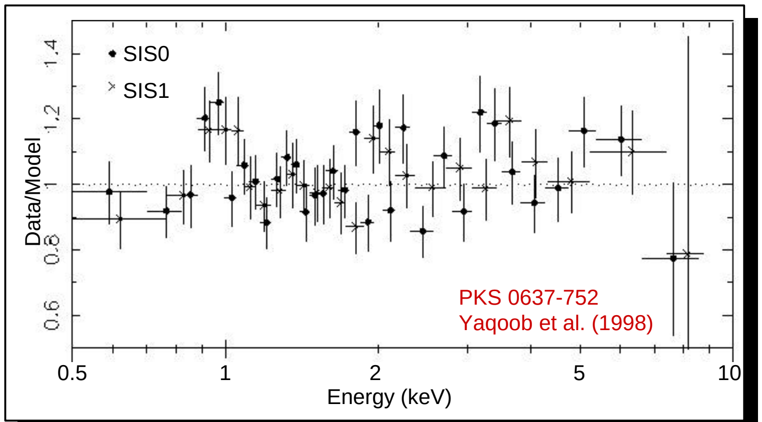
Rest-frame absorption features due to oxygen are common (Reynolds et al., 1997; George et al., 1998) and these features have been interpreted as oxygen absorption in a highly relativistic outflow.

Fits to absorption edges imply velocities of outflow are 0.2-0.3c (c.f., the gas in the jets in SS433 at 0.26*c*).

Blueshifted edges due to an outflowing absorber are also seen in UV data from broad-absorption-line (BAL) quasars, however those have much lower velocities.

The luminous ($L_X \sim 10^{46}$ erg/s) radio-loud quasar PKS 0637-752 (z = 0.654) shows an unabsorbed spectrum, no evidence for emission from Fe Kα (EW < 80 eV). A unique emission line of EW 60 eV is observed at a rest-energy E = 1.60 ± 0.07 keV.

Faint sources observed just before and after this show no such feature. The background level is a factor of 12 weaker than this feature at this energy. No obvious explanation in terms of emission from foreground sources. The feature is also evident in PSPC data.

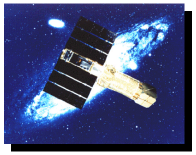


PKS 0637-752
Yaqoob et al. (1998)

Assuming no bulk motion, the energy could lead to an association with ionized Mg, Fe, or Ni, but the presence of any of these would predict observable lines from more abundant elements.

Association with Si *XIII* (which is commonly seen in Seyfert 2 and starburst galaxies) would infer inflow with v ~ 0.05*c*.

ASCA observations of samples of AGN have lead to these exciting discoveries and will reveal the most promising targets for AXAF observations.



ASCA Observations of Active Galactic Nuclei: The next few years.....

We have not exhausted the scientific potential of ASCA for studies of AGN.

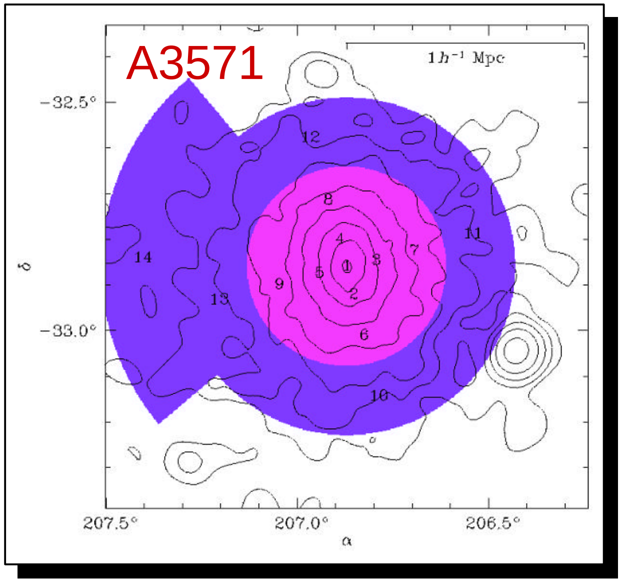
ASCA can provide as much scientific progress in the next few years, as has been made since launch

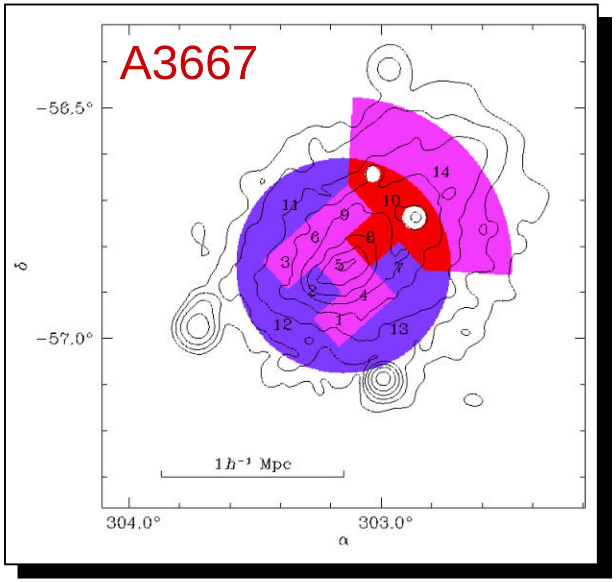
Change observing strategy to fulfill ASCA’s potential - go to large programs

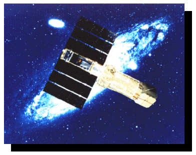
Only 4 AGN have been observed for > 200 ksec!!!! These have provided some of the richest returns

Temperature Mapping Clusters of Galaxies

- Temperature maps produced using GIS data for Abell 3571 and Abell 3667 illustrate the two types of temperature distributions observed
- Abell 3571 is almost isothermal with a mild decrease in temperature with increasing radius
- Abell 667 shows evidence for a stronger merger with a non-axisymmetric temperature distribution
  - In regions 8 and 10, the gas has been shock-heated to temperatures above the mean value for the cluster
- Note that the isointensity contour plots of the two clusters are not significantly different
  - The spatially-resolved temperature data is required to identify the merger

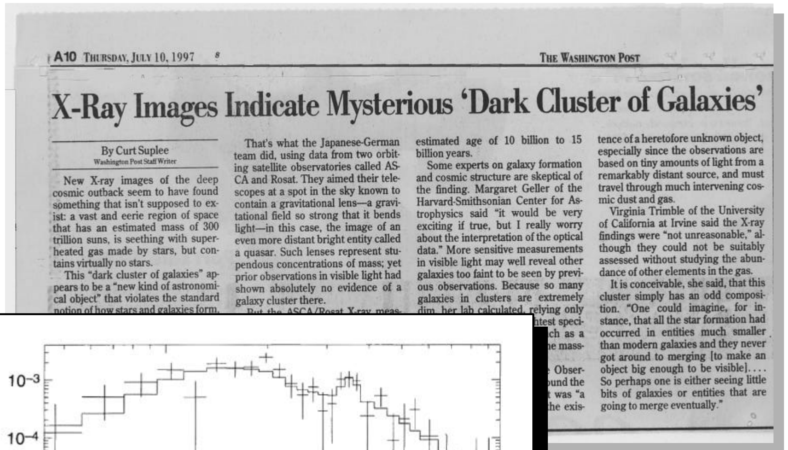






Discovery of a Dark Cluster

The gravitationally lensed QSO MG2016+112 indicated the presence of a cluster



A10 Thursday, July 10, 1997 — The Washington Post

X-Ray Images Indicate Mysterious 'Dark Cluster of Galaxies'

By Curt Suplee
Washington Post Staff Writer

New X-ray images of the deep cosmic outback seem to have found something that isn't supposed to exist: a vast and eerie region of space that has an estimated mass of 300 trillion suns, is seething with superheated gas made by stars, but contains virtually no stars.

This "dark cluster of galaxies" appears to be a "new kind of astronomical object" that violates the standard notion of how stars and galaxies form.

That's what the Japanese-German team did, using data from two orbiting satellite observatories called ASCA and Rosat. They aimed their telescopes at a spot in the sky known to contain a gravitational lens—a gravitational field so strong that it bends light—in this case, the image of an even more distant bright entity called a quasar. Such lenses represent stupendous concentrations of mass; yet prior observations in visible light had shown absolutely no evidence of a galaxy cluster there.

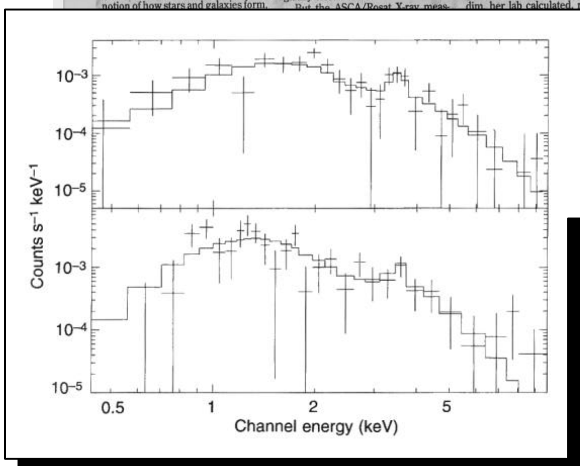
... estimated age of 10 billion to 15 billion years.

Some experts on galaxy formation and cosmic structure are skeptical of the finding. Margaret Geller of the Harvard-Smithsonian Center for Astrophysics said "it would be very exciting if true, but I really worry about the interpretation of the optical data." More sensitive measurements in visible light may well reveal other galaxies too faint to be seen by previous observations. Because so many galaxies in clusters are extremely dim, her lab calculated, relying only ...

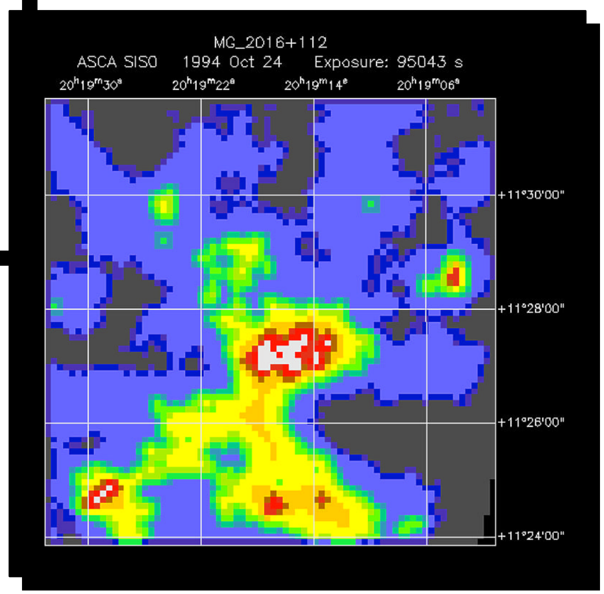
... tence of a heretofore unknown object, especially since the observations are based on tiny amounts of light from a remarkably distant source, and must travel through much intervening cosmic dust and gas.

Virginia Trimble of the University of California at Irvine said the X-ray findings were "not unreasonable," although they could not be suitably assessed without studying the abundance of other elements in the gas.

It is conceivable, she said, that this cluster simply has an odd composition. "One could imagine, for instance, that all the star formation had occurred in entities much smaller than modern galaxies and they never got around to merging [to make an object big enough to be visible]. . . . So perhaps one is either seeing little bits of galaxies or entities that are going to merge eventually."

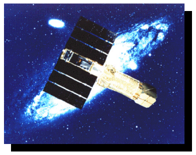


- ASCA discovered an X-ray source AX J 2019+1127 showing typical cluster spectrum
- Iron K line shows redshift corresponding to z=1
- Iron abundance of 0.96-2.95 sets important new limit on epoch of metal enrichment

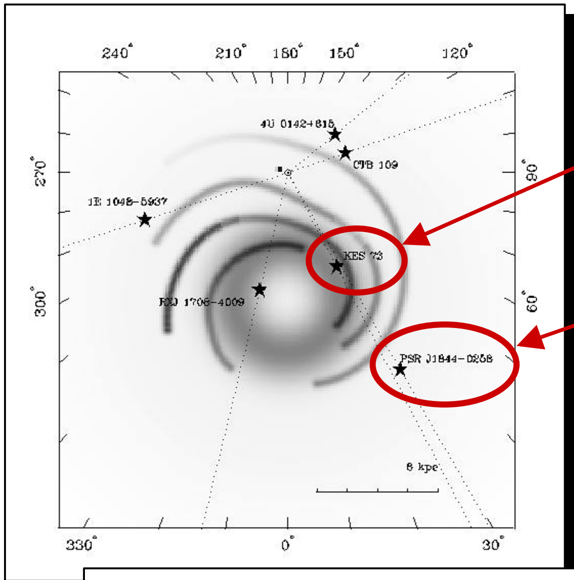


- Follow up ROSAT HRI demonstrated source is extended
- Cluster is centered on a giant elliptical galaxy
- The cluster is *Dark* with M/L of 3300

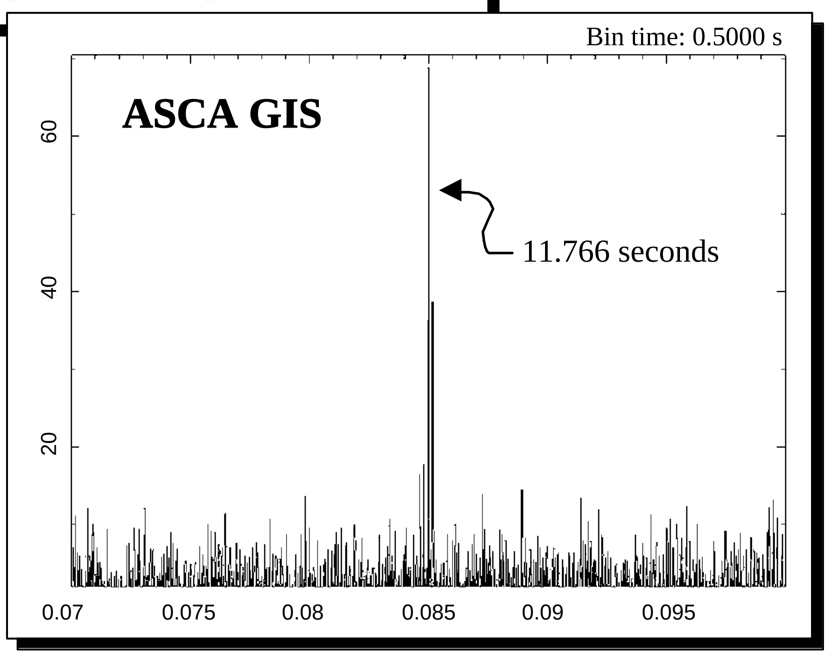
This may be a new class of *X-ray Bright, Optically Dark* Cluster



Discovery of Anomalous X-ray Pulsars in Supernova Remnants



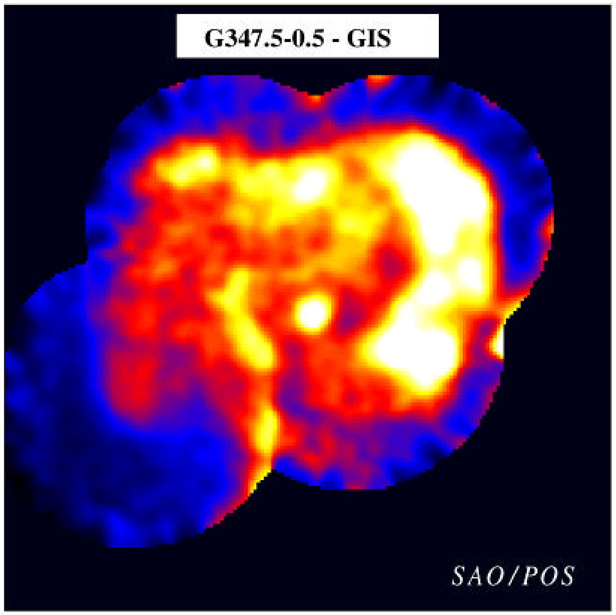
- ASCA X-ray observations reveal 12-second pulsar in Kes 73 (Vasisht & Gotthelf, 1997, *ApJL*, 486,129)
- Another similar pulsar AX 1845-0258 recently discovered by Gotthelf & Vasisht (1998)
- Especially remarkable since surrounding supernova remnant is very young (< 2000 years)

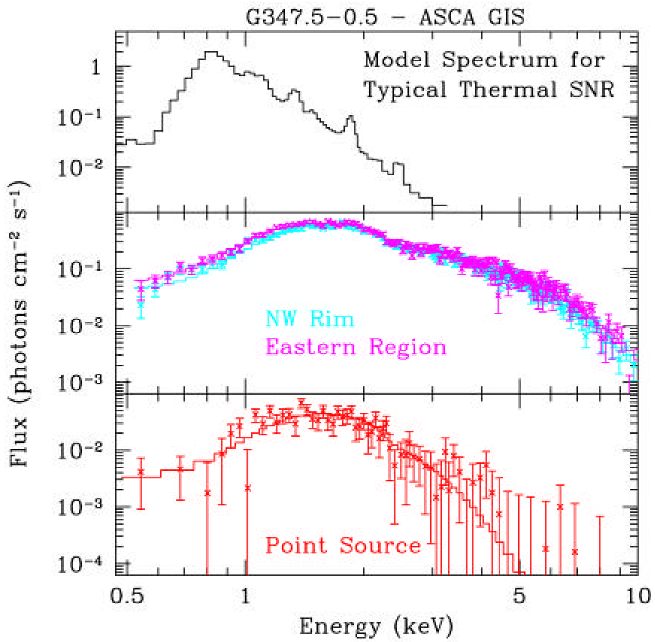


- Further evidence for Magnetars -- neutron star pulsars with enormous magnetic field (**B** ~ 7 x 10^{14} G)
  - this large **B**-field required to spin down the neutron star to the observed rate for inferred age of the remnant
  - may explain puzzling lack of fast pulsars associated with supernova remnants

Non-Thermal Emission in SNRs

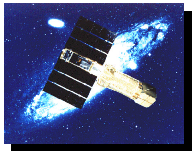
ASCA Observations of G 347.5-0.5 (Slane et al., 1998)



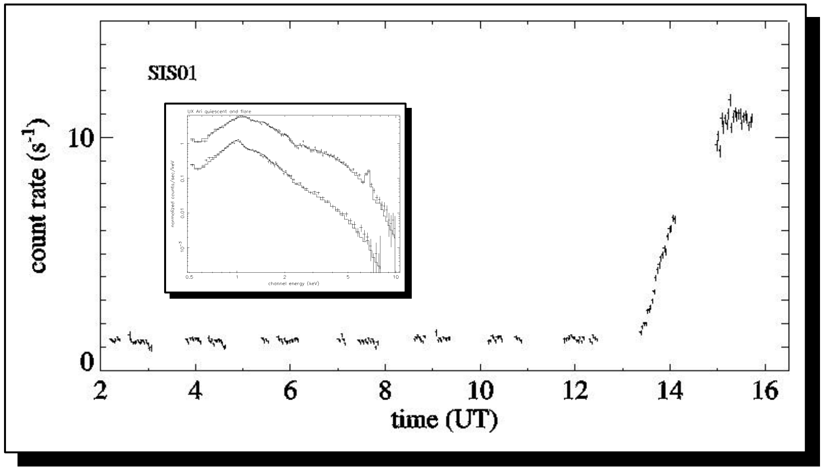


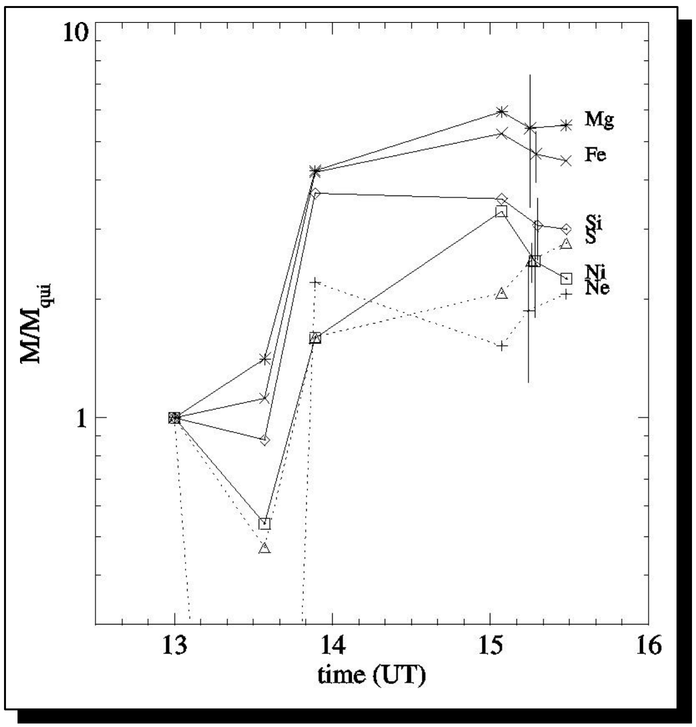
- Complete ASCA mapping of remnant carried out
  - Non-thermal emission confirmed for NW region; N_H = (8.1± 0.4) X 10^{21} cm^{-2}, α = 2.41 ± 0.05; identical power law spectrum obtained for SW region
  - Eastern region shows non-thermal spectrum as well but with slightly flatter spectrum (α = 2.17 ± 0.05) and lower absorption (N_H = (5.6 ± 0.5) x 10^{21} cm^{-2})

- Point source in field has no optical counterpart brighter than B = 18.5 within 20”
  - Blackbody spectrum (kT = 370 eV, R = 5.5 D_{10} km) ==> possibly a NS



Stellar Coronae Variable Abundances

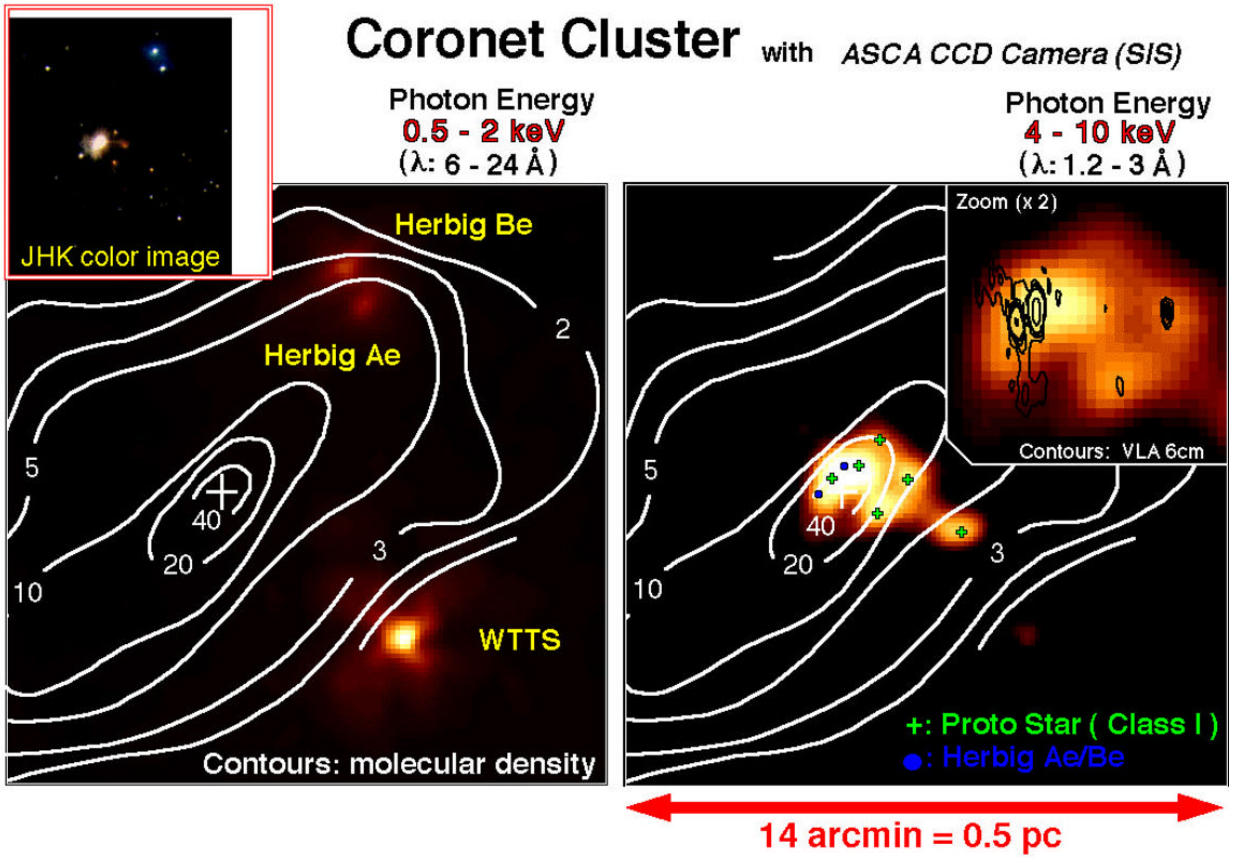




- **Stellar Coronae Variable Abundances**
  - Large flare detected by ASCA from UX Ari (Guedel et al., 1998)
  - Plasma heated to in excess of 50 million degrees
  - Iron K line appears during the flare spectrum
  - Iron and other abuncances increase by factor of 5
  - Confirms earlier ASCA coronal under-abundances in quiescent emission
  - Gravitational settling of heavy elements may be responsible
- **Very few flares have been caught be ASCA**
  - longer observations requires to catch different flare types
  - monitor before and after coronal abundances

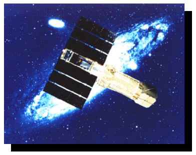
R CrA Dark Cloud Observed by ASCA

X-ray images of R CrA dark cloud obtained with CCD camera (SIS 0+1) onboard the ASCA satellite. The overlaid contours (Loren et al., 1983, *ApJ* 270, 620) represent the H_2 volume densities in units of 10^4 cm^{-3}.

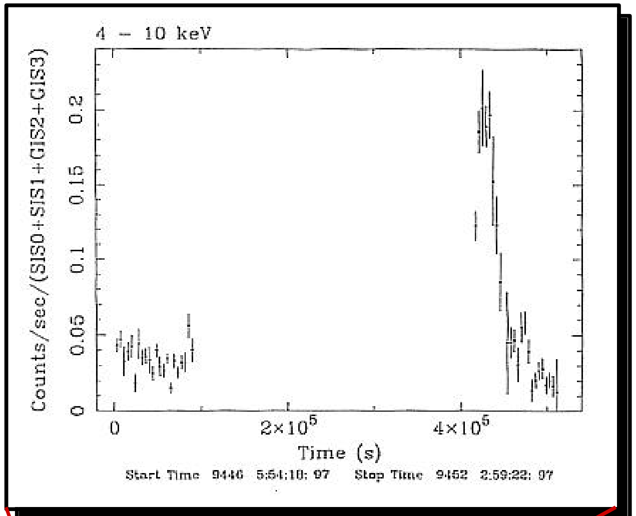


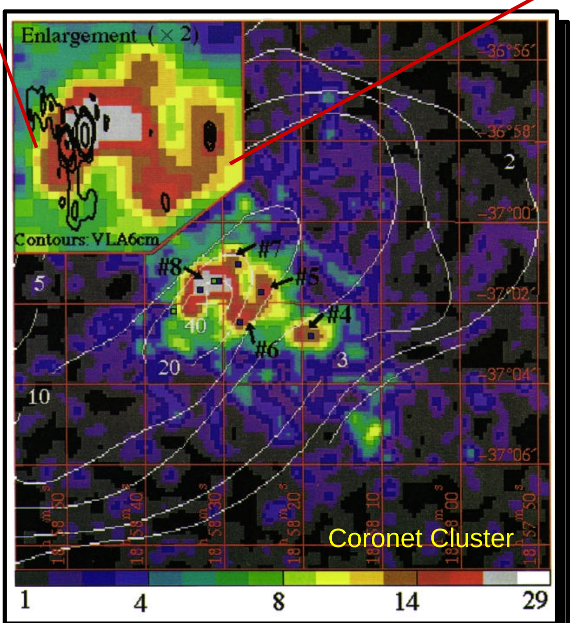
Left: Image in the 0.5-2 keV band The south west source is a TTS CrA 1 discovered with the Einstein satellite (Walter, Kuhi, 1981, *ApJ* 250, 254), while the two closely spaced source to the northwest are HD176386 and TY CrA.

Right: Image in the 4-10 keV band. The green crosses are embedded Class I infrared sources, while the blue closed circles are Class II and III sources. inset: VLA radio continuum map (Brown 1987, *ApJ* 322, L31) superposed on the cluster of hard X-ray sources.



X-rays and Winds From Protostars

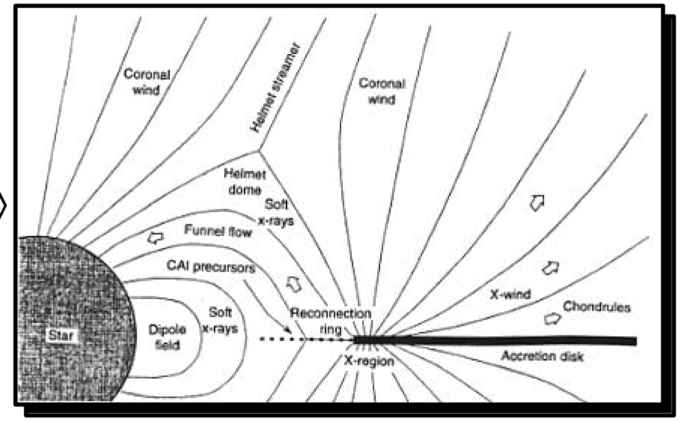




ASCA and ROSAT observations show that protostars

- emit more X-rays (hard and soft) than young Sun-like stars
- X-ray flares observed by ASCA have same temperature as quiescent emission (6 keV) and show broad iron K line

X-rays probably caused by the time dependent interaction of young star magnetosphere with an accretion disk



X-rays provide the crucial link that may unify disparate phenomena involving protostars: magnetic activity, winds and jets, extinct radioactivity in meteorites

Flares produced by such fluctuations may be responsible for

- flash heating of chrondrules found in chrondritic meteorites
- production of short lived radioactivities through bombardment of primitive rocks by solar cosmic rays

Shu et al., (5 September 1997) *Science* 277, 1475

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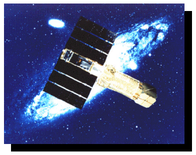
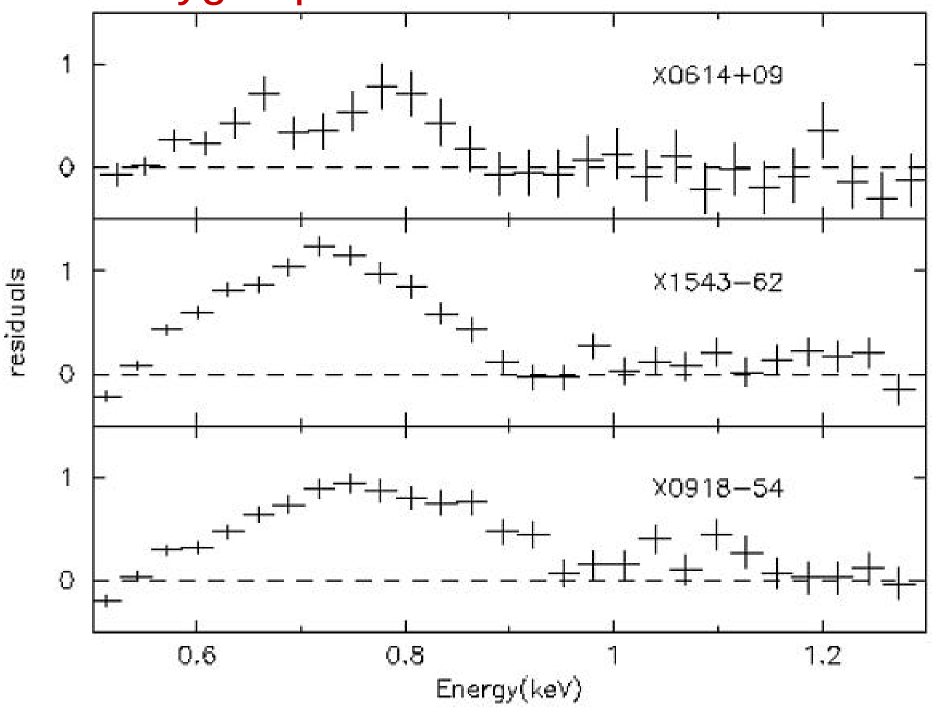


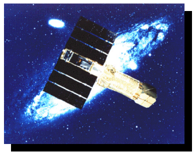
Low Mass X-ray Binary Low Energy Line Emission

A systematic survey of LMXRB is being made with the ASCA SIS to classify low energy line emission patterns (Angelini et al., 1998)

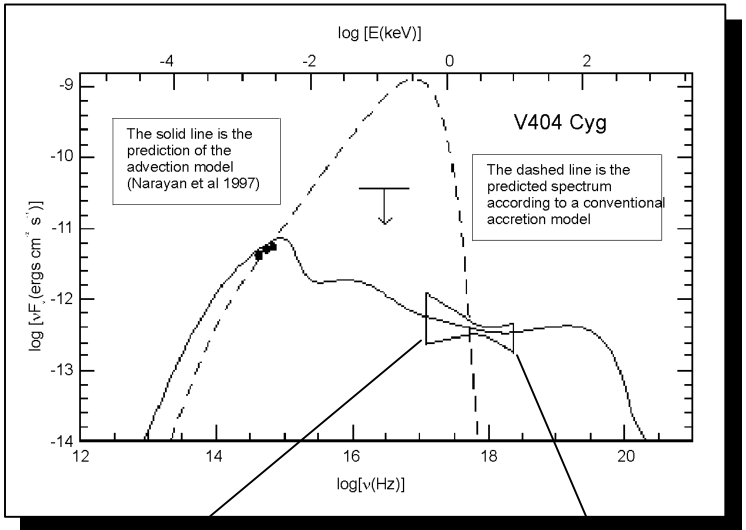
Oxygen pattern from three LMXRB

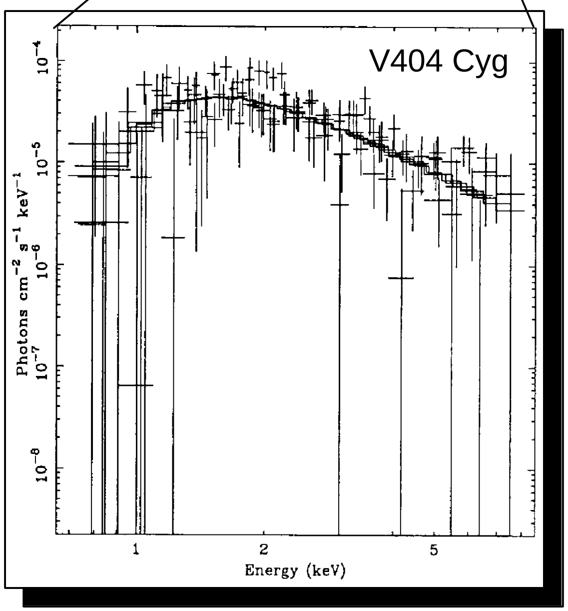


- Low column densities required to detect 0.5-1.5 keV spectrum
- Seven objects surveyed so far and show four distinct line patterns from different sources
  - Broad iron L pattern at 1.1 keV (Cyg X-2)
  - Broad oxygen pattern at 0.6-0.9 keV (X0614+09, X1543-62, X0918-54)
  - Strong Neon emission at 1 keV (4U1626-67)
  - No line emission (several systems)
- May be caused by different abundances or different conditions in accretion disk corona



Evidence for Advection Dominated Accretion Flows in Black Hole X-ray Transients



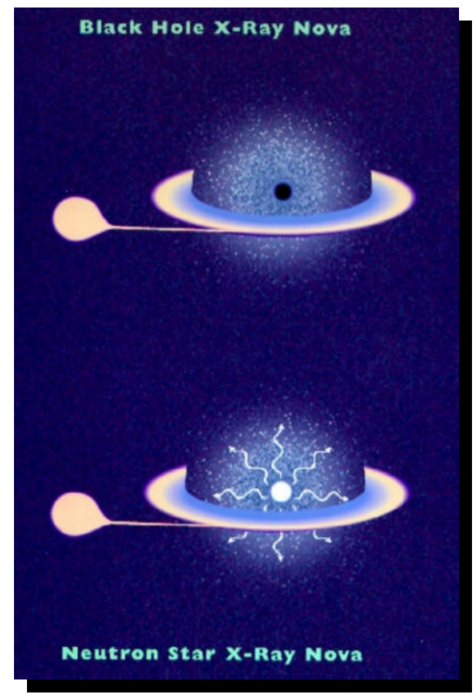


Energy released through viscosity

Thin disk → Almost entirely radiated

ADAF → Almost entirely stored in the gas

- At low $\dot{M}$, accretion disk may find "hot" ADAF solution
  - time to radiate larger than infall time
- Black hole transients in quiescence may be in this regime
- ASCA observations of black holes in quiescence show spectrum that is consistent with ADAF model



Narayan, McClintock, et al. (1996)

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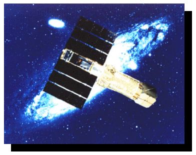
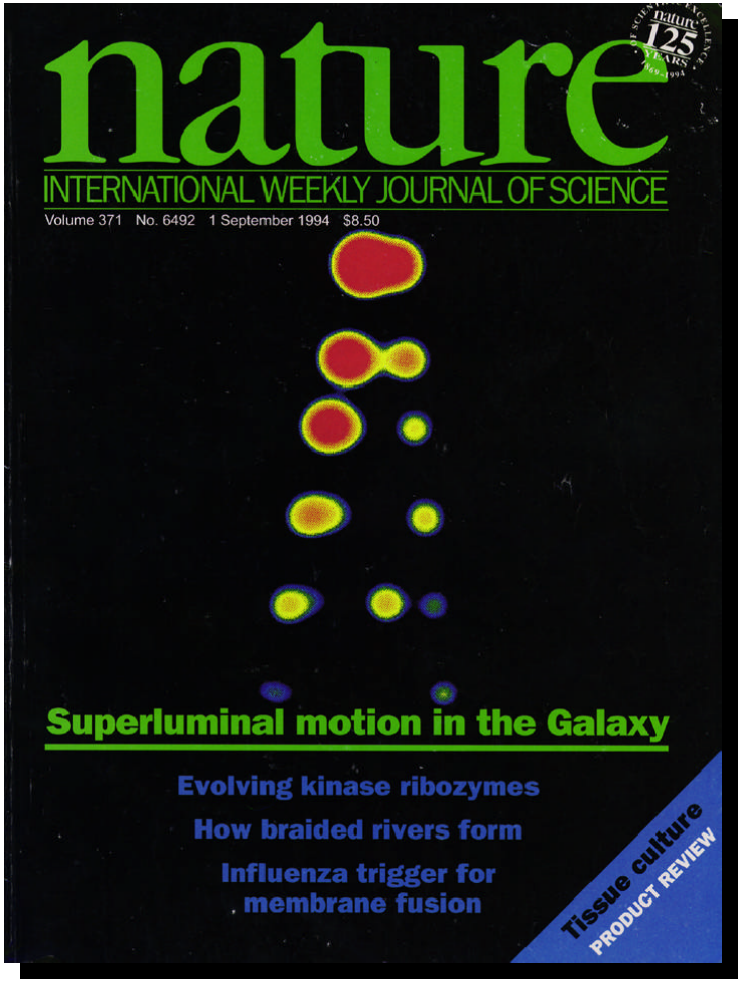


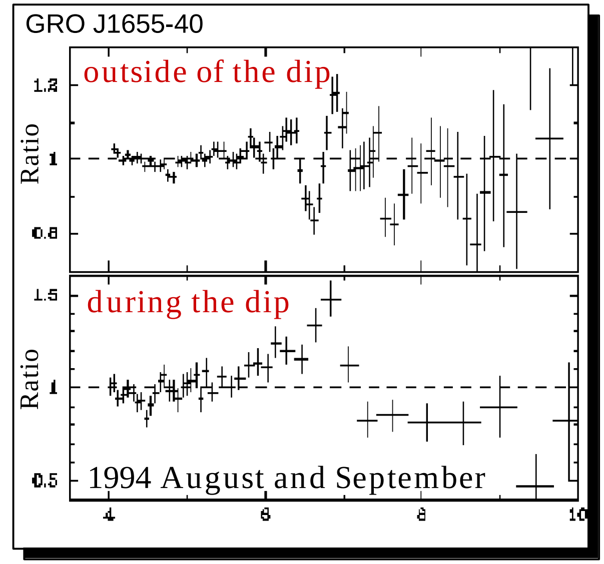
Resonance Lines in Microquasars

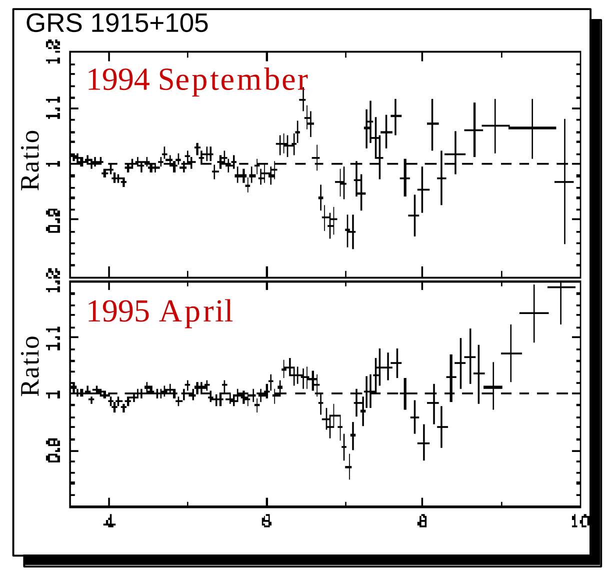


Two superluminal sources in our Galaxy

- 0.92 *c* jets from black holes
- GRS 1915+105 and GRO J1655-40

- Resonant absorption lines from He-like and H-like iron that may be unique X-ray signature of jet sources?
- Direct evidence for presence of highly ionized plasma with $N_H \sim 10^{23}$ H cm^{-2}
- Viewing central X-ray source through outflow or corona above the accretion disk





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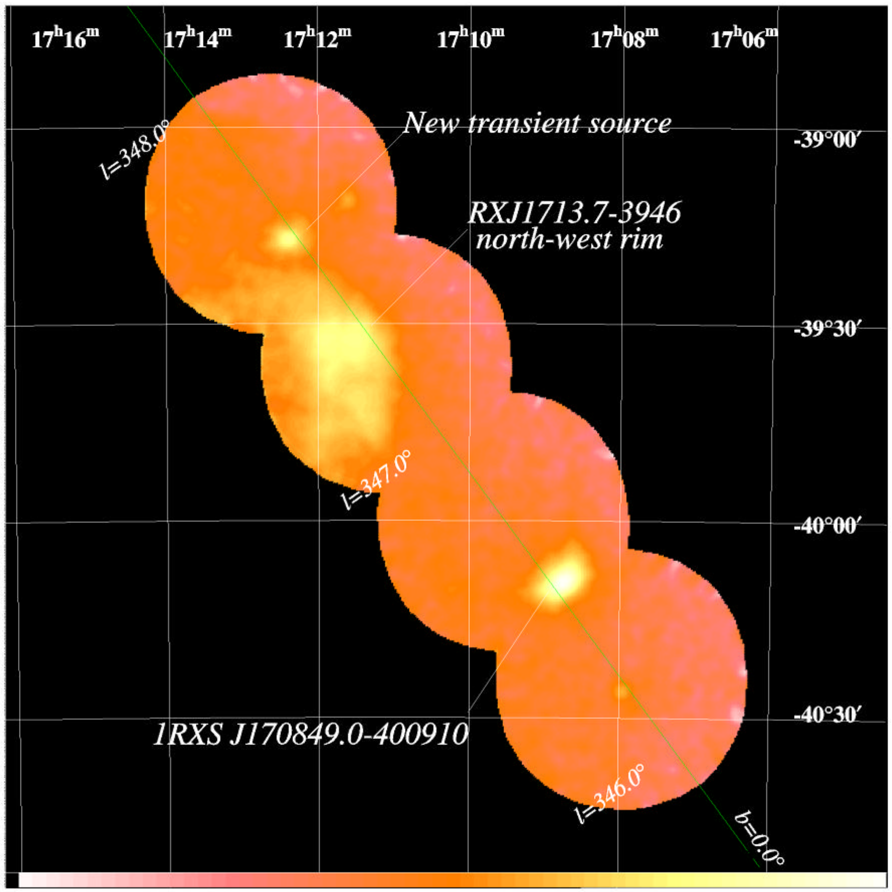
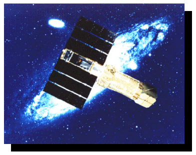
ASCA Galactic Plane Survey

ASCA galactic plane survey is being made as apart of the Japanese program



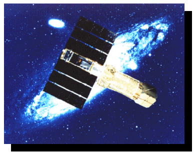
SNR G347.5-0.5 GIS2+3 Mosaic Image (0.7-10 keV)

- 6-hour snapshot exposures
- Revealing many new supernova and pulsars
- This example shows
  - 11s X-ray pulsations discovered by ASCA from RXS J170849.0-400910 (Sugizaki et al., 1997)
  - Non-thermal X-rays from SNR RXJ1713.7-3946 (Koyama et al., 1997)



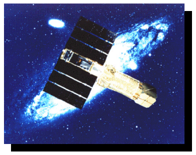
ASCA Capabilities, Status, and Future Program

- ASCA continues to perform well
  - CCD degradation is still modest with current resolution of 170 eV, compared to 130 eV after launch
  - GIS shows no degradation and provides wide field of view 2-10 keV survey capability
  - orbit is expected to last until late 2001/early 2002
  - After Astro-E launch in Feb 2000 ASCA will switch to 1-2 week observations
- ASCA is a complementary facility to the upcoming major X-ray observatories
  - collecting area at iron K is 50% more than that of AXAF
  - provides pathfinder observations
  - flexible time allocation for TOOs and multi-wavelength observations
  - unique capability to make extended 1-2 week observations
  - continue to survey key regions of the sky
  - ***Astro-E will reuse much of the ASCA software so that ASCA operations post-2000 appended to Astro-E at very modest cost***



Science Goals for Future AOs: Part II

- Use large FOV and high quantum efficiency of ASCA GIS to
  - Survey local poor clusters and Groups
  - Search for more non-thermal SNRS
  - Make 2-10 keV surveys of select regions of the sky (e.g., LMC)
- Long observations of stars to study flares and binary modulations
- Systematic effort to acquire complete sample of spectra of CVs
- Long multiwavelength campaigns on Intermediate Polars and Polars to constrain emission regions
- Make first detailed study of line emission and absorption variability in X-ray binaries



Science Goals for Future AOs: Part I

- Monitor flux/profile variations in Fe Kα lines -> distinguish between Kerr hole, or other (e.g., occultation) models for profile variations, tighten constraints on black hole mass, spin.
- Search for X-ray periods in other AGN, re-examine IRAS18325-59 to determine whether the period changes
- Determine time scales of variability (days-weeks) for absorption features -> constrain gas location, density, study multiple zones
- Observe well-defined samples of AGN - improve understanding of correlations
- Find interesting objects for AXAF

ASCA is **satellite of choice** for these studies:

Good spatial resolution (minimize source contamination important for attribution of periods to AGN); mature mission can now invest in long programs

Good spectral resolution (monitor changes in spectral features)