Cygnus X-1: The First Black Hole

Jon M. Miller

On behalf of the High Energy Group at The University of Michigan

Riccardo Giacconi Memorial Symposium, May 30, 2019

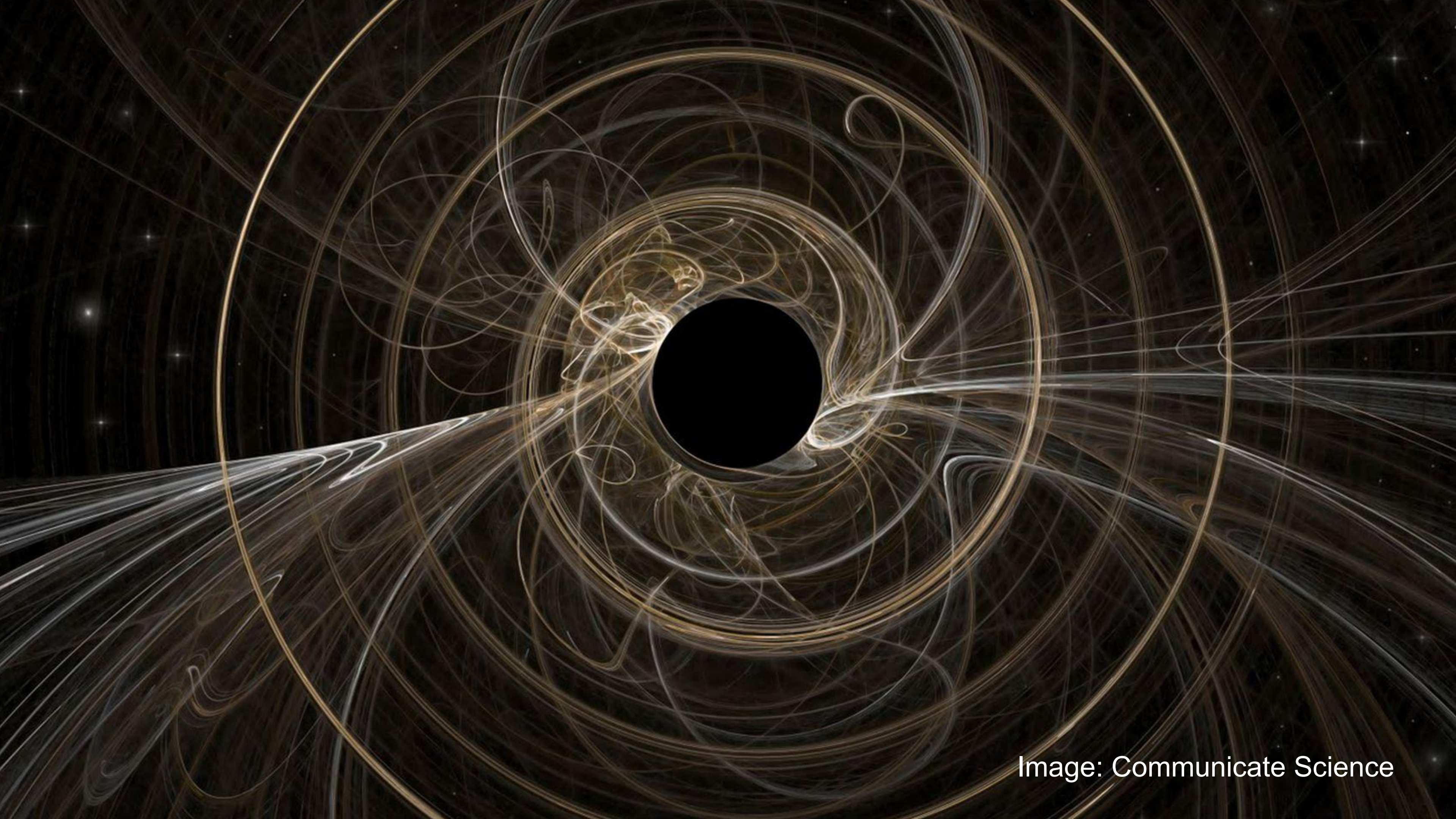
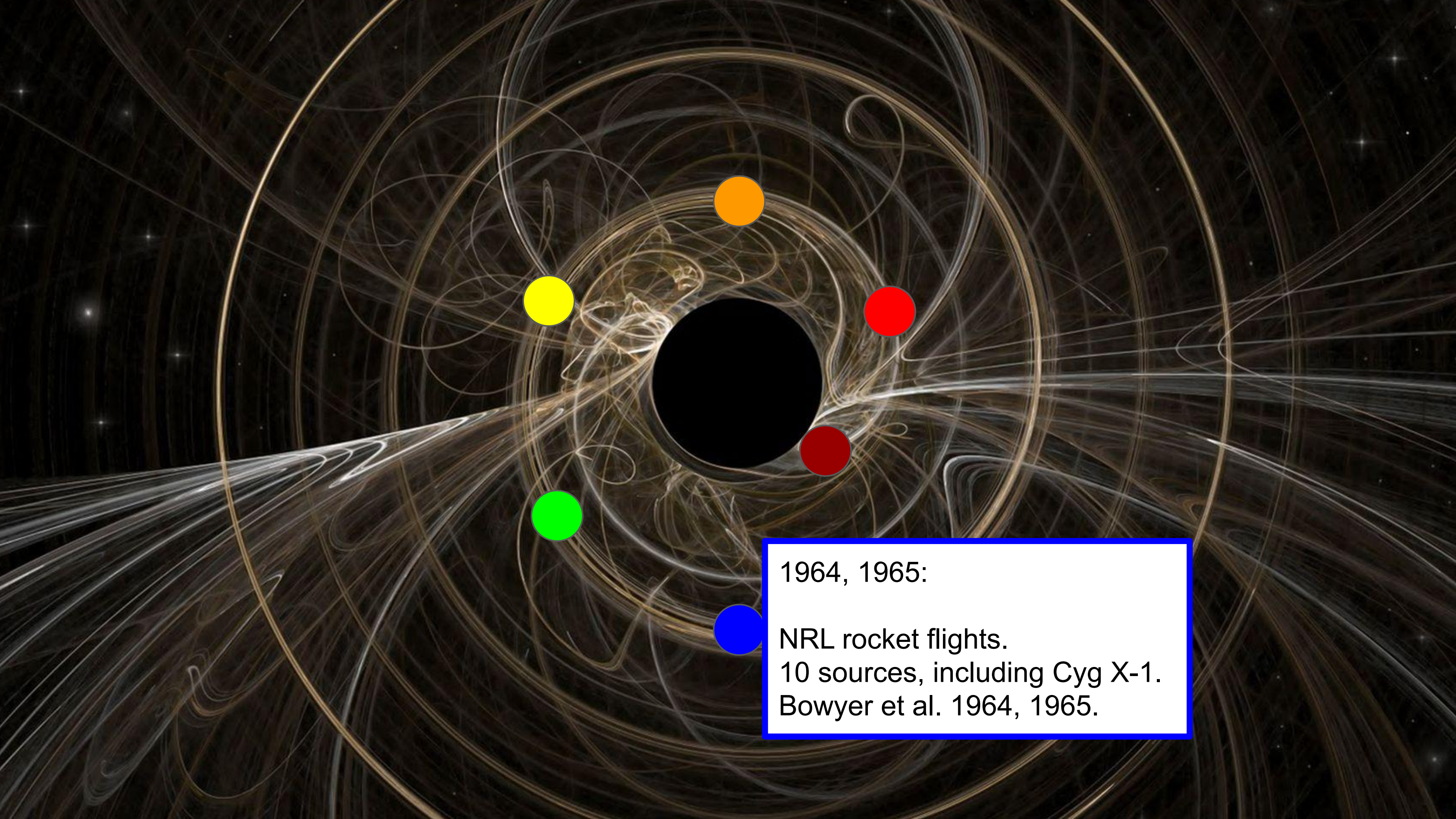


Image: Communicate Science

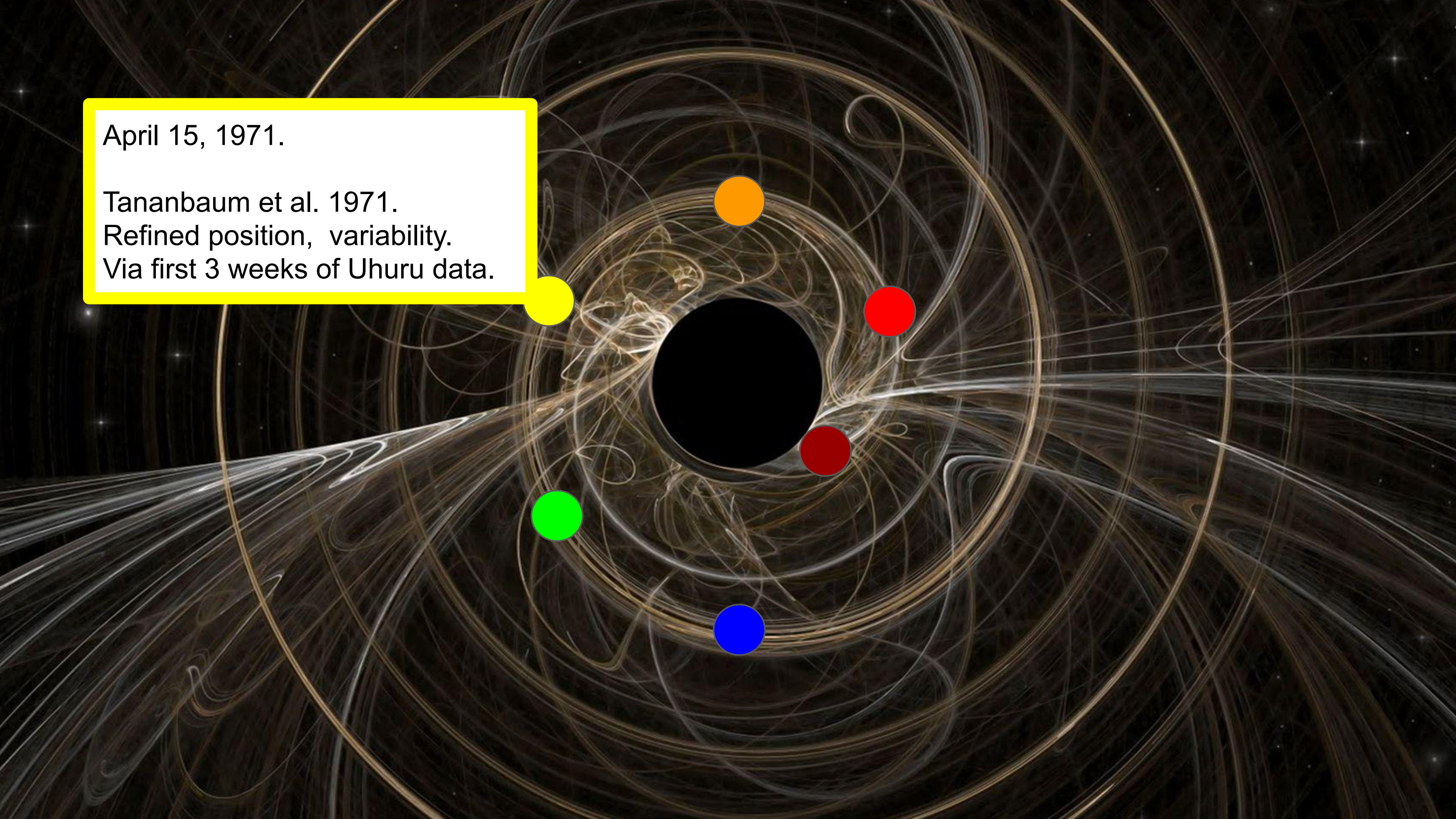


1964, 1965:

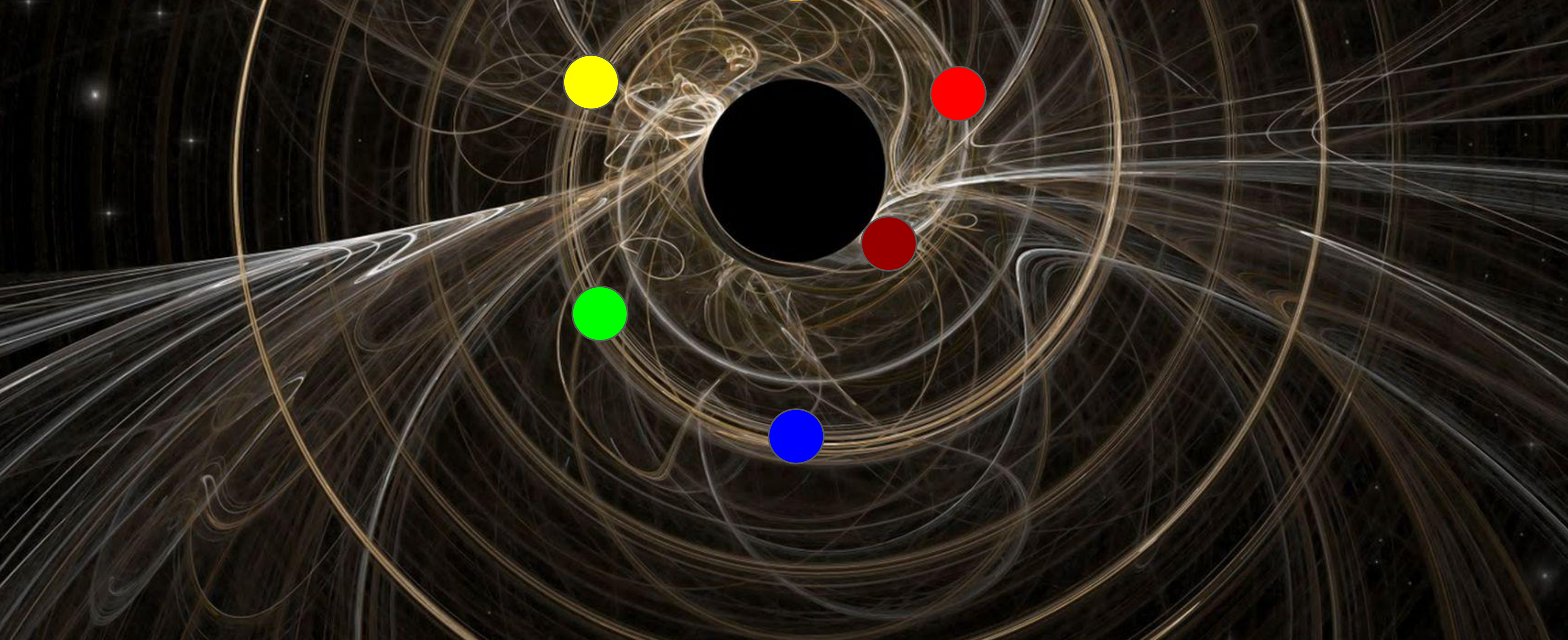
NRL rocket flights.
10 sources, including Cyg X-1.
Bowyer et al. 1964, 1965.

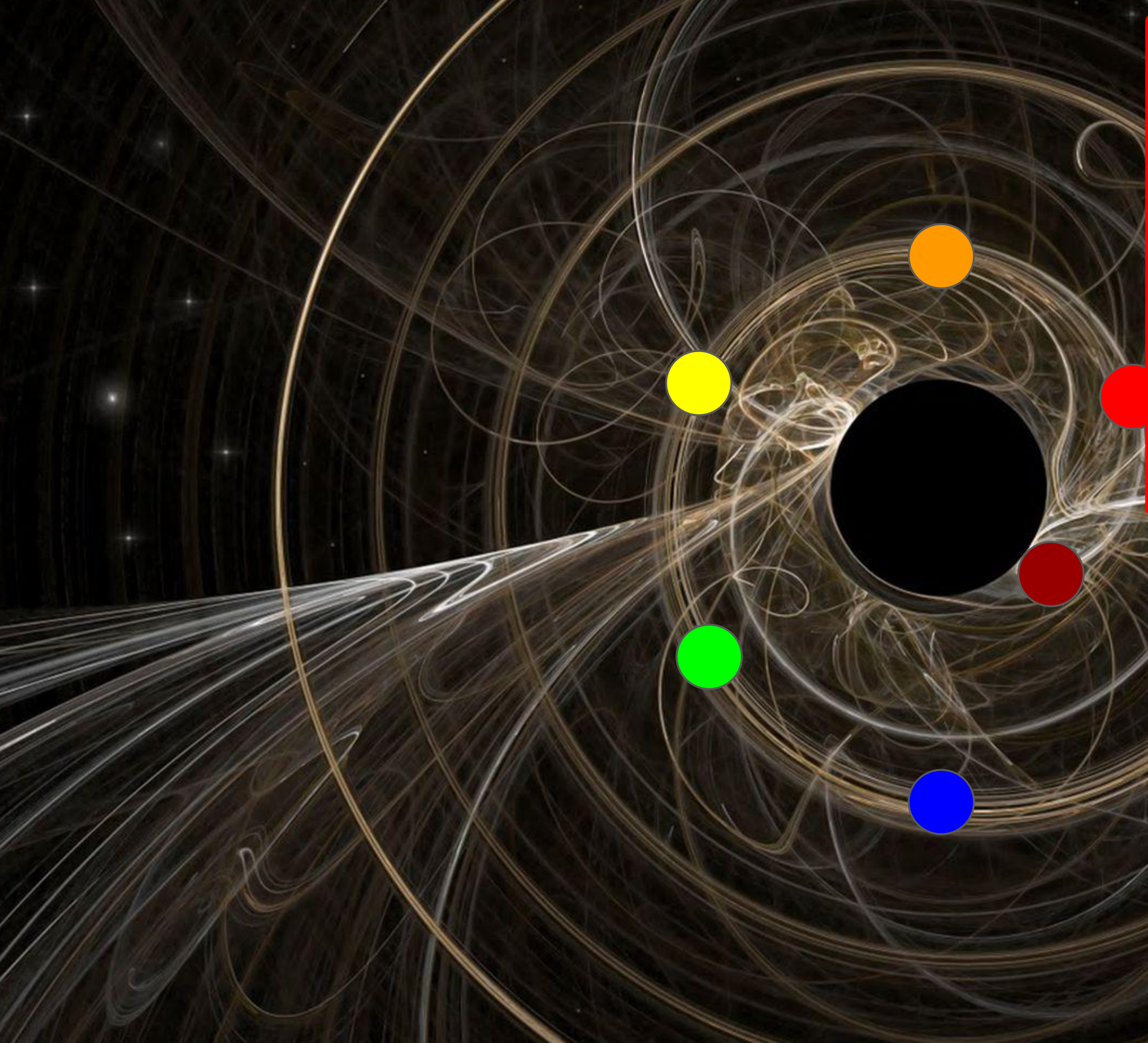
December 12, 1970.

Giacconi launches Uhuru,
X-ray astronomy.


April 15, 1971.
Tananbaum et al. 1971.
Refined position, variability.
Via first 3 weeks of Uhuru data.

April 28-29, 1971.
Westerbork observes Cyg X-1 (Braes & Miley 1971).
Variable radio source. Small error box.
HD 226868 suggested as counterpart.



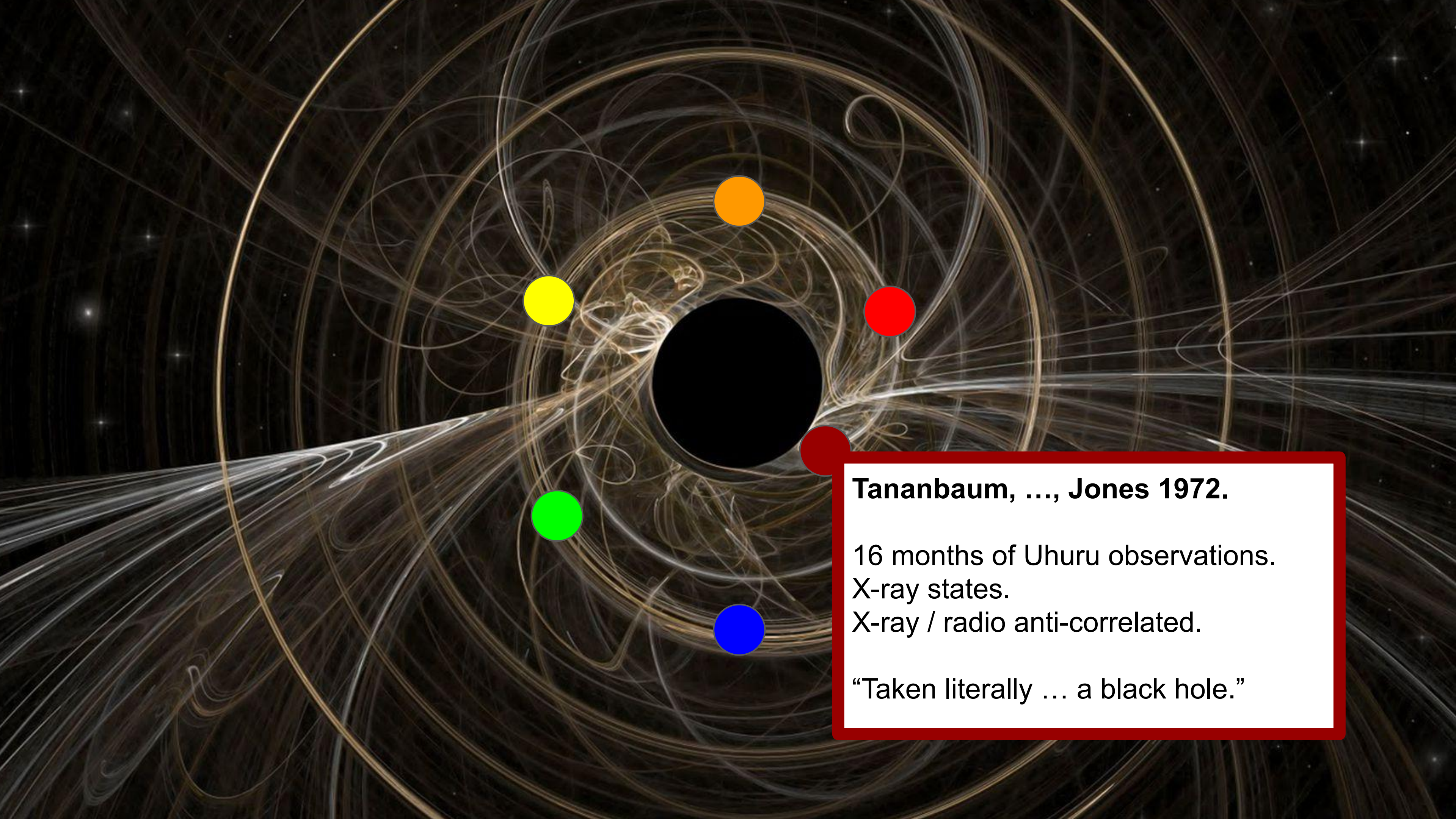


August 12, 1971: B0Ib counterpart.
(Murdin & Webster 1971).

Nov. 17, 1971:
5.6-day period, mass function.
(Webster & Murdin 1972).

Bolton et al. 1972 confirms.

Suggestions of black hole nature.



Tananbaum, …, Jones 1972.

16 months of Uhuru observations.
X-ray states.
X-ray / radio anti-correlated.

“Taken literally … a black hole.”

Early Uhuru: Tananbaum et al. 1971

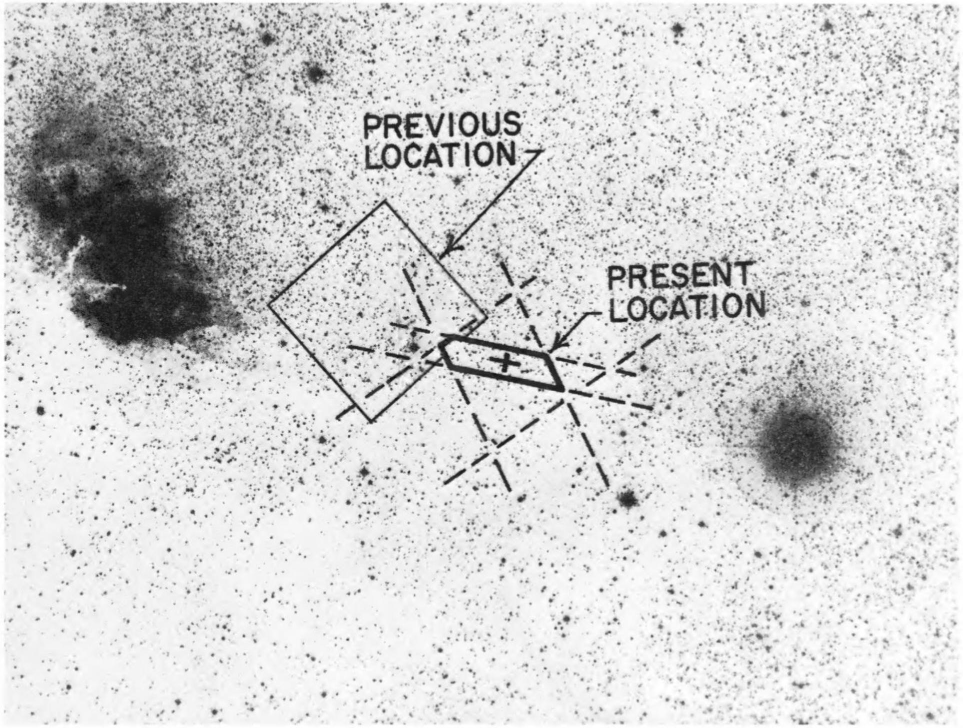


PLATE L3

FIG. 4.—Enlargement of a *Palomar Sky Survey* print containing the *Uhuru* location error box for Cyg X-1. *Dashed lines*, the bands of position obtained on three separate days. Their common intersection is shown with heavier lines, and the center of the *Uhuru* X-ray location is marked with a cross. The coordinates of the center are $\alpha(1950) = 19^h55^m59^s$, $\delta(1950) = 35°2'52''$. Error box of the previous X-ray location of Giacconi *et al.* (1967) is also shown as the larger box in the figure.

OBSERVATION OF A CORRELATED X-RAY–RADIO TRANSITION IN CYGNUS X-1

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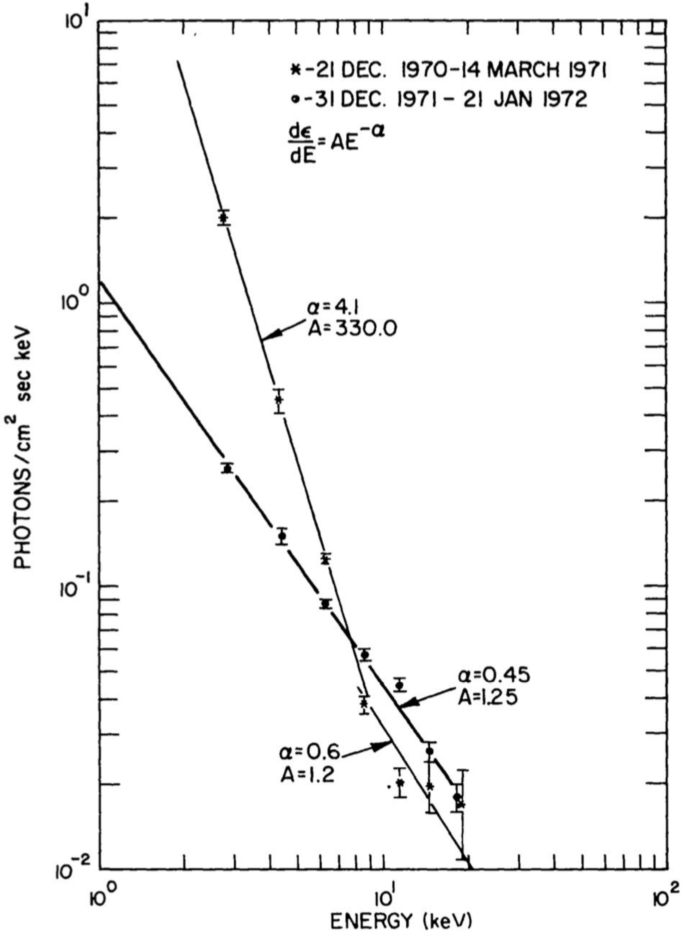
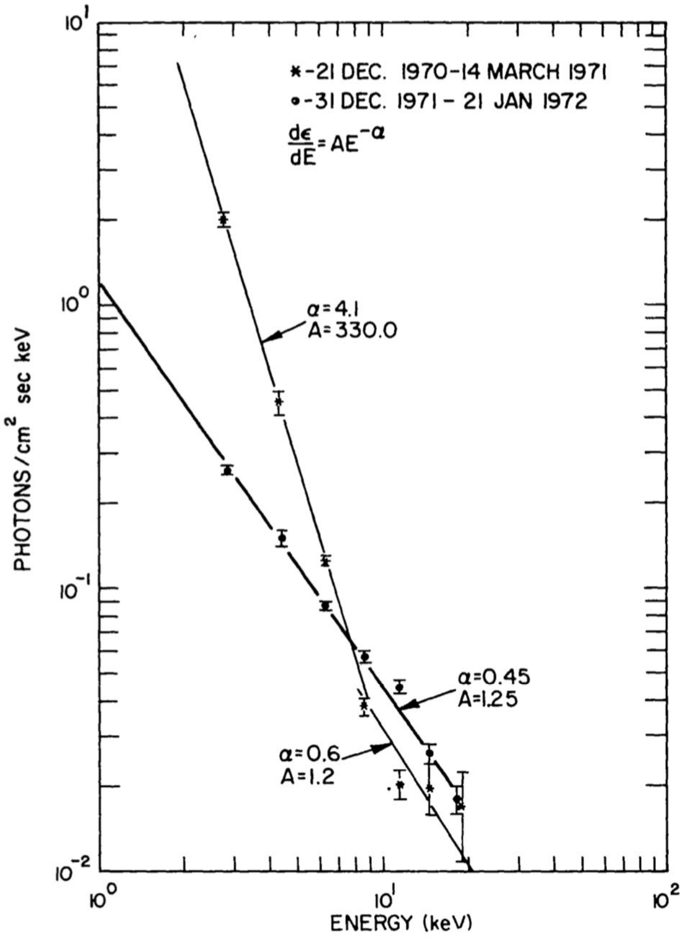
Received 1972 July 24

ABSTRACT

Analysis of 16 months of *Uhuru* data on Cyg X-1 has shown a remarkable transition in the source which occurred during 1971 March and April. The average X-ray intensity in the 2–6-keV energy range decreased by about a factor of 4, the average X-ray intensity in the 10–20-keV band increased by a factor of 2, and a weak radio source suddenly appeared. This simultaneous X-ray and radio behavior provides strong evidence for the identification of the radio source with Cyg X-1. *Uhuru* also monitored Cyg X-1 for 35 consecutive days during 1971 December and 1972 January. The data were analyzed for an effect due to a binary system. Although large-scale fluctuations were present, no periodicity was found.



- Black hole "states".
- Accretion disks.
- Disk-jet connections.
- Feedback.
- Evolution.
- Connections to AGN types.



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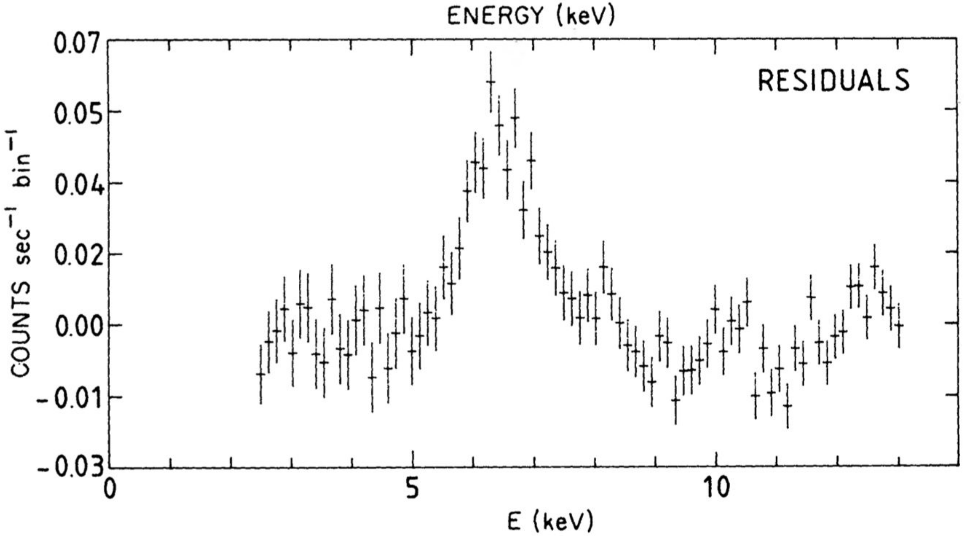
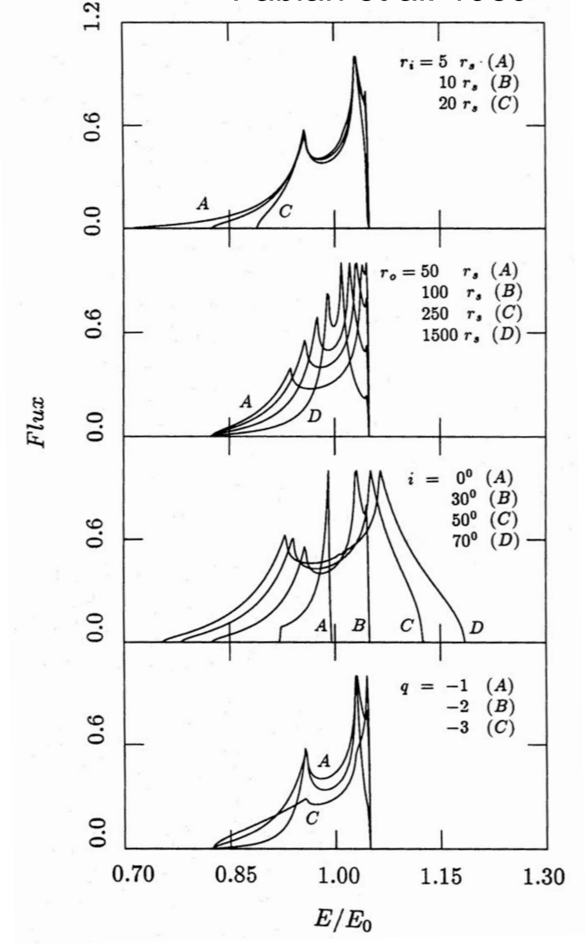
The first relativistic Fe K line

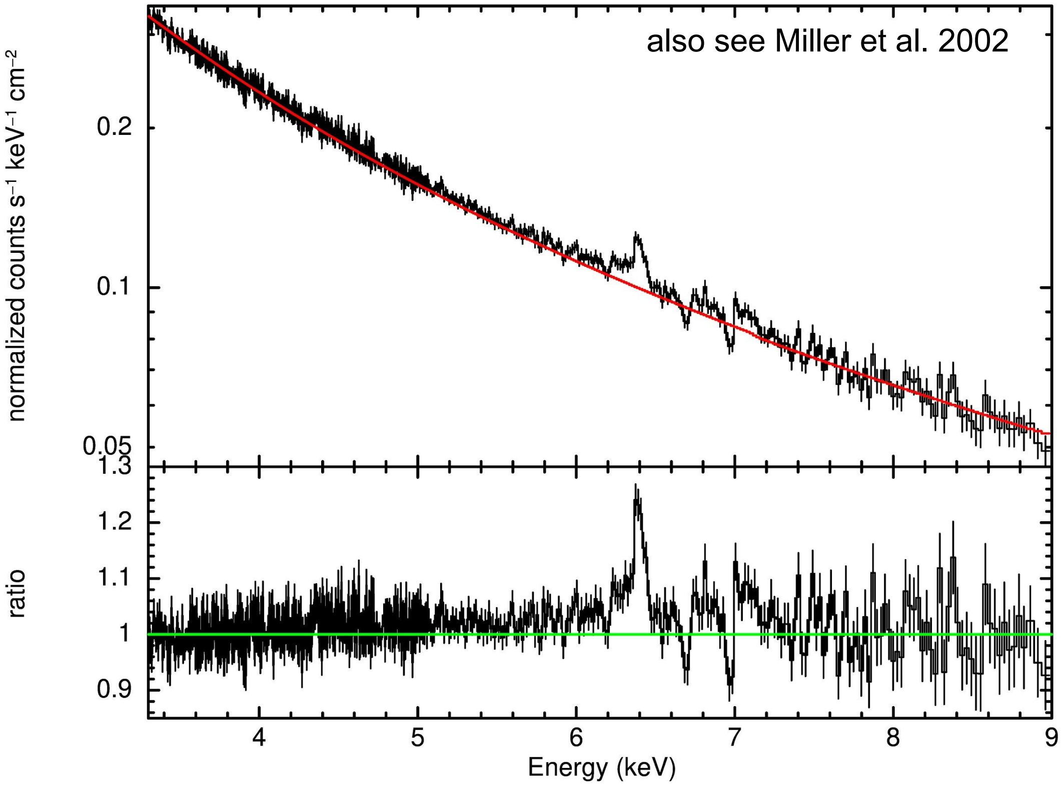


Cygnus X-1 (EXOSAT) Barr, White, & Page 1985

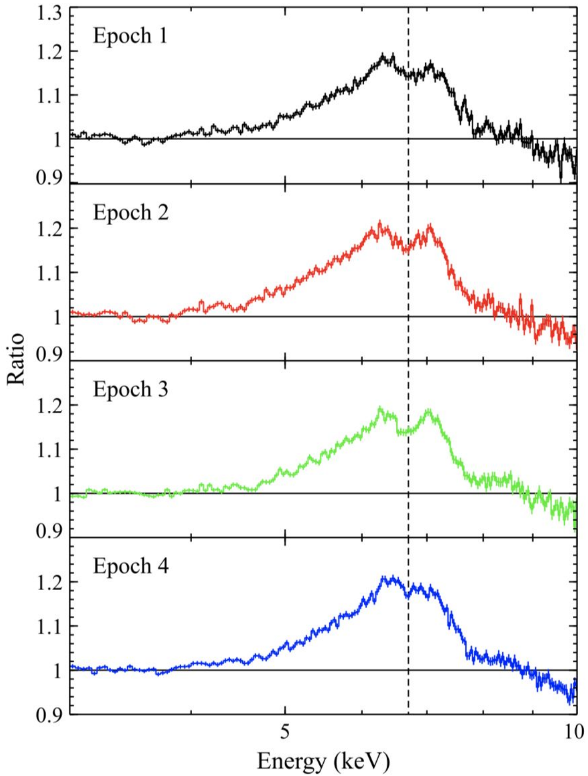
Fabian et al. 1989



Cygnus X-1: Chandra and NuSTAR



Walton et al. 2016



X-ray-Radio Connections: Disks and Jets

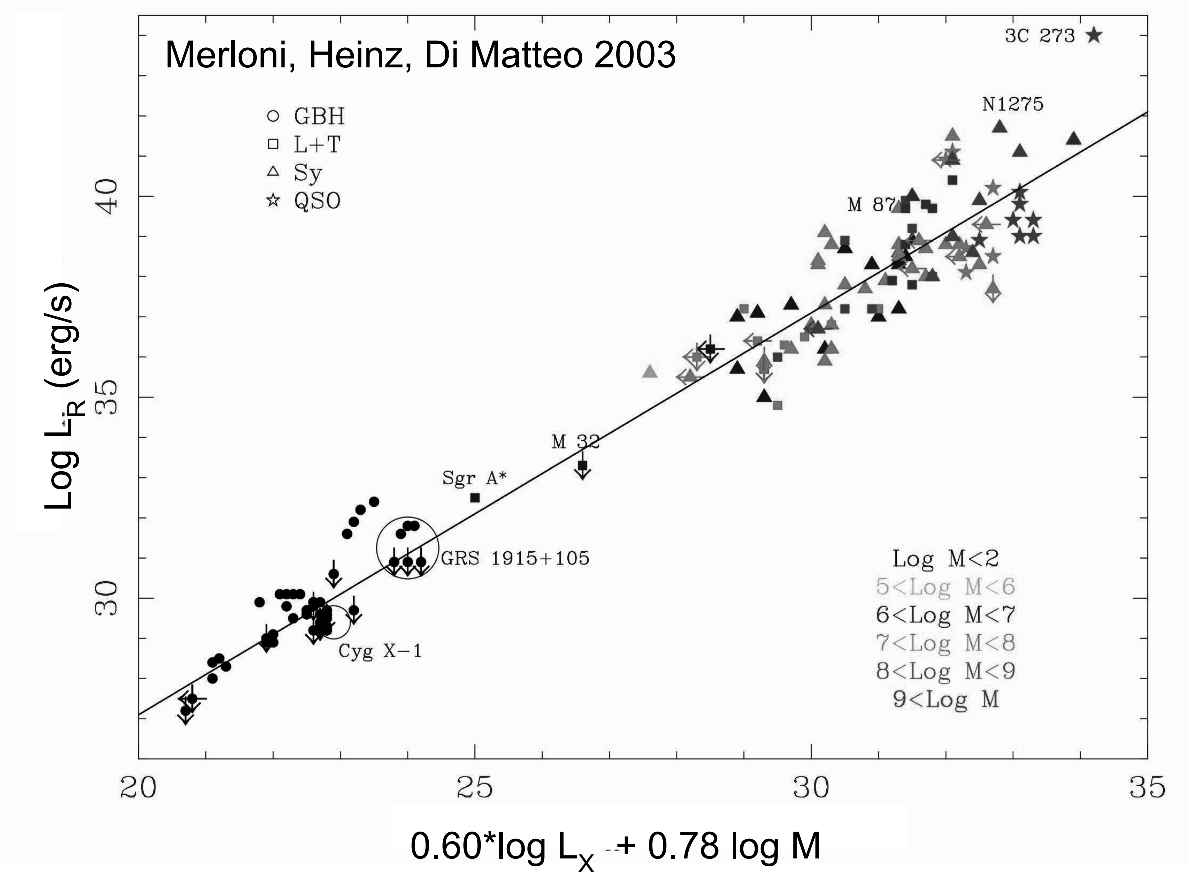
The “fundamental plane” of black hole accretion.

Stellar-mass black holes, including Cygnus X-1:

Elena Gallo et al. 2003.

Tananbaum ++ 1972 really the point of origin.

Now a subfield unto itself.



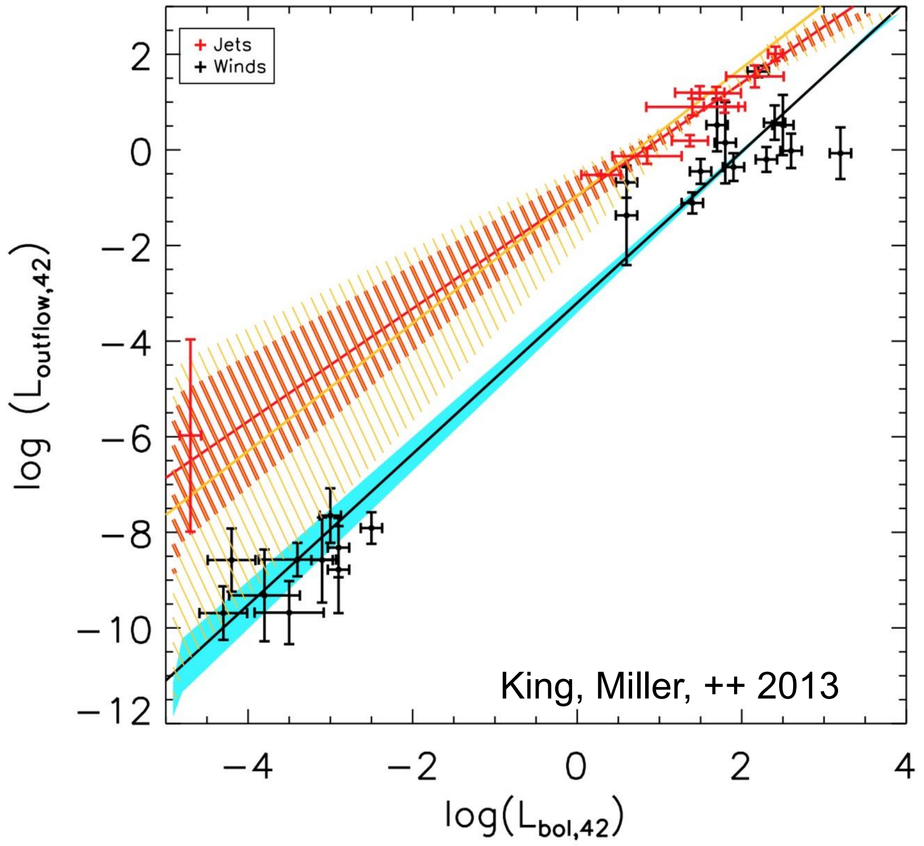
X-ray-Radio Connections: Disks, Winds, and Jets

Winds and jets may be regulated in the same way.

Extends across the black hole mass scale.

Potentially a complete recipe for feedback:

Radiation + winds + jets.



The Impact of Cygnus X-1: raw numbers

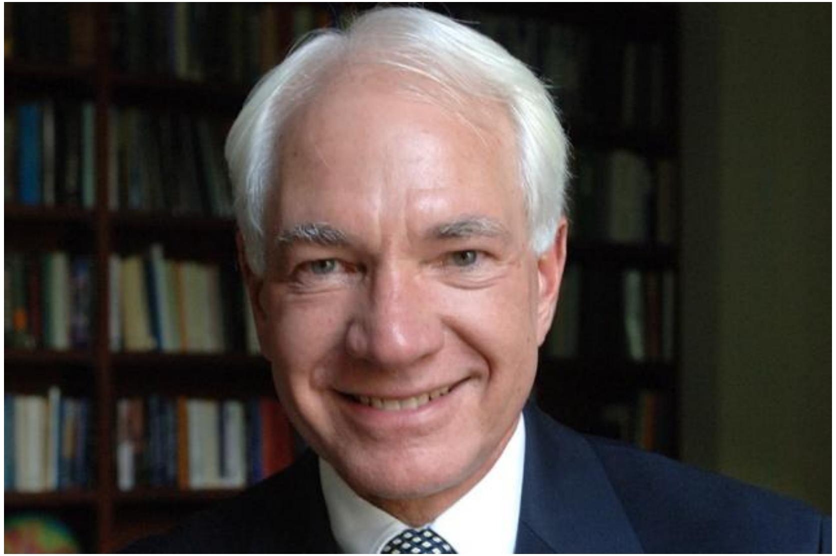
Search term(s)	hits	citations
Cygnus X-1	*2802*	*50,720*
black hole + X-ray	19,130	398,000
black hole + X-ray + disk	7920	224,850
black hole + X-ray + state	4338	102,170
black hole + X-ray + radio	4035	95,880
black hole + Chandra	3640	48,055

Claude Canizares

Cygnus X-1 was an X-ray astronomer's dream come true!

A clean binary system, very bright optically as well as in X-rays, and with enigmatic rapid, chaotic variability clearly distinct from the pulsating sources like Her X-1.

Of course, it also soon became the strongest candidate for a stellar mass black hole.



(MIT News Photo)

Roger Blandford

The demonstration that the rapidly variable X-ray source Cyg X-1 provided very strong circumstantial evidence for the actual existence of black holes stood out, even in a steady stream of enduring astronomical and cosmological discoveries at that time.

In retrospect, it was an excellent early example, like the discovery of quasars, of what we now call multi-wavelength astronomy with radio and optical observations complementing the technical brilliance and acute insights of Riccardo, Harvey and their colleagues.

(Stanford University News photo)

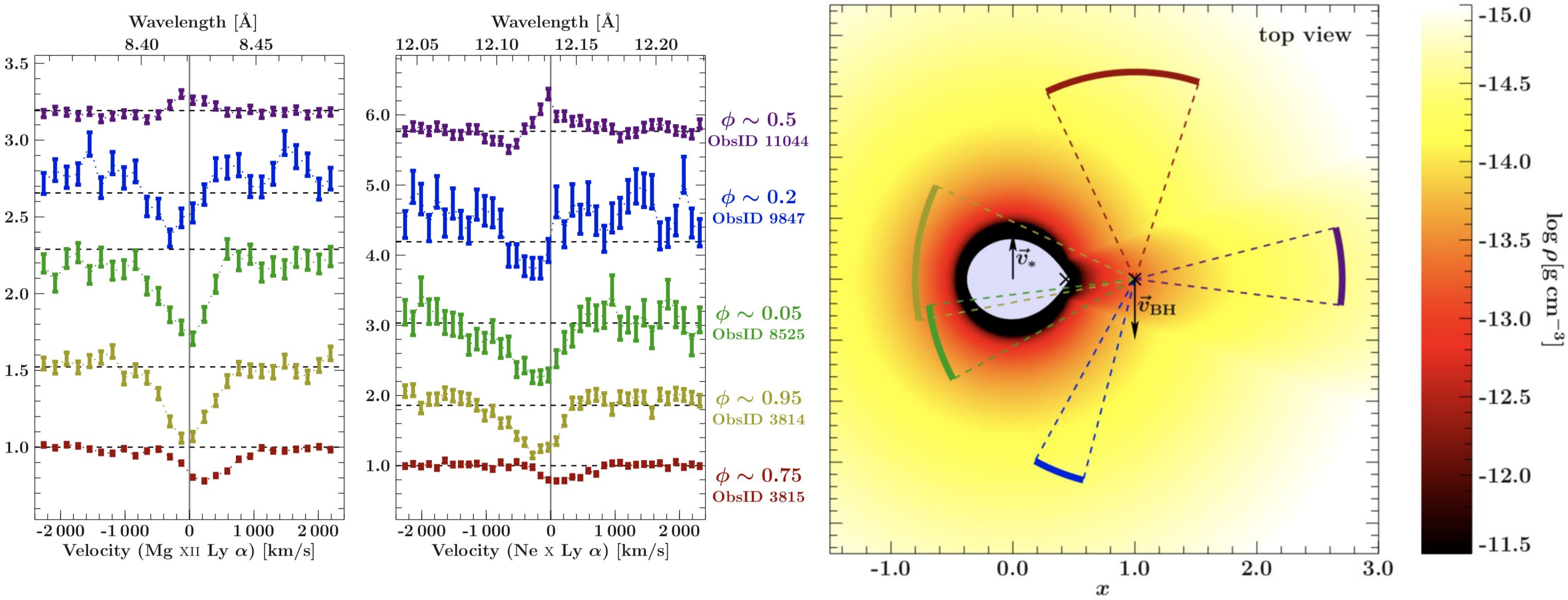
I did not have the honor of knowing Riccardo Giacconi.

But, the field and scientists that he launched … have made science possible for me, and for and countless others.

I am especially grateful to Harvey Tananbaum.

Thank you, Harvey, and Dr. Giacconi, and many more.

Chandra: The O9.7 Iab Companion Wind



Ivica Miskovicova et al. 2016

RESOLVING THE COMPOSITE Fe Kα EMISSION LINE IN THE GALACTIC BLACK HOLE CYGNUS X-1 WITH *CHANDRA*

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T. Di Matteo,[4] H. L. Marshall,[1] C. R. Canizares,[1] D. Pooley,[1] and W. H. G. Lewin[1]
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ABSTRACT

We observed the Galactic black hole Cyg X-1 with the *Chandra* High Energy Transmission Grating Spectrometer for 30 ks on 2001 January 4. The source was in an intermediate state, with a flux that was approximately twice that commonly observed in its persistent low/hard state. Our best-fit model for the X-ray spectrum includes narrow Gaussian emission line ($E = 6.415 \pm 0.007$ keV, FWHM$= 80^{+28}_{-19}$ eV, $W = 16^{+3}_{-2}$ eV) and broad-line ($E = 5.82^{+0.06}_{-0.07}$ keV, FWHM$= 1.9^{+0.5}_{-0.3}$ keV, $W = 140^{+70}_{-40}$ eV) components, and a smeared edge at 7.3 ± 0.2 keV ($\tau \sim 1.0$). The broad-line profile is not as strongly skewed as those observed in some Seyfert galaxies. We interpret these features in terms of an accretion disk with irradiation of the inner disk producing a broad Fe Kα emission line and edge, and irradiation of the outer disk producing a narrow Fe Kα emission line. The broad line is likely shaped predominantly by Doppler shifts and gravitational effects, and to a lesser degree by Compton scattering due to reflection. We discuss the underlying continuum X-ray spectrum and these line features in the context of diagnosing the accretion flow geometry in Cyg X-1 and other Galactic black holes.