Simultaneous X-ray and Radio Observations of Seyferts, and Disk-Jet Connections

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Summary

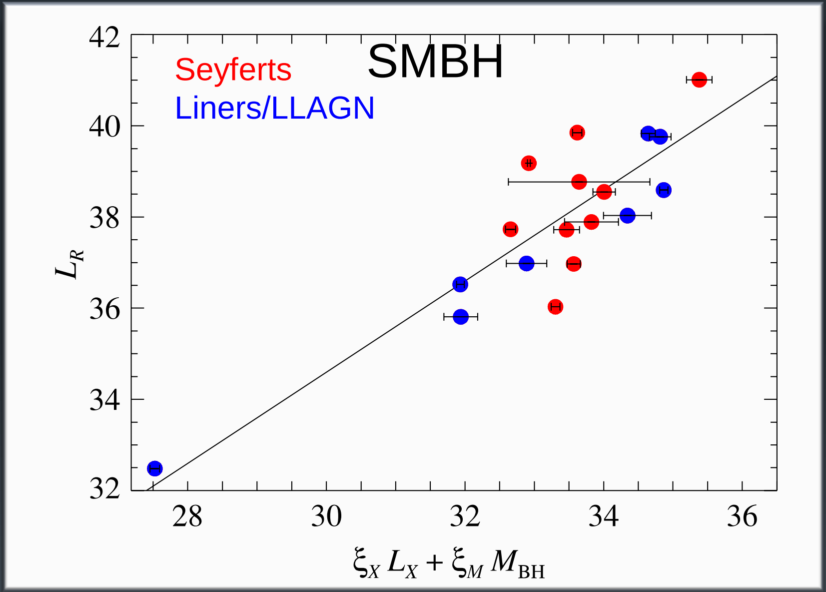
- The Fundamental Plane of Black Hole Accretion:
  - Physical Link Between Jet Production, Black Hole Mass and Mass Accretion Rate
- Seyferts are Interesting Sources to Explore this Disk-Jet Connection
  - Clear Variability on Short Timescales
  - Jet Production Although Typically Radio Quiet
- Seyferts Might Probe a Different Disk-Jet Coupling
  - as Compared to the Other AGN on the Fundamental Plane, Which are at Lower Eddington Fractions
- There is a Necessity for Simultaneous Observations
  - For a Variety of Different Sources and Viscous Timescales

The Fundamental Plane of Accretion onto Black Holes

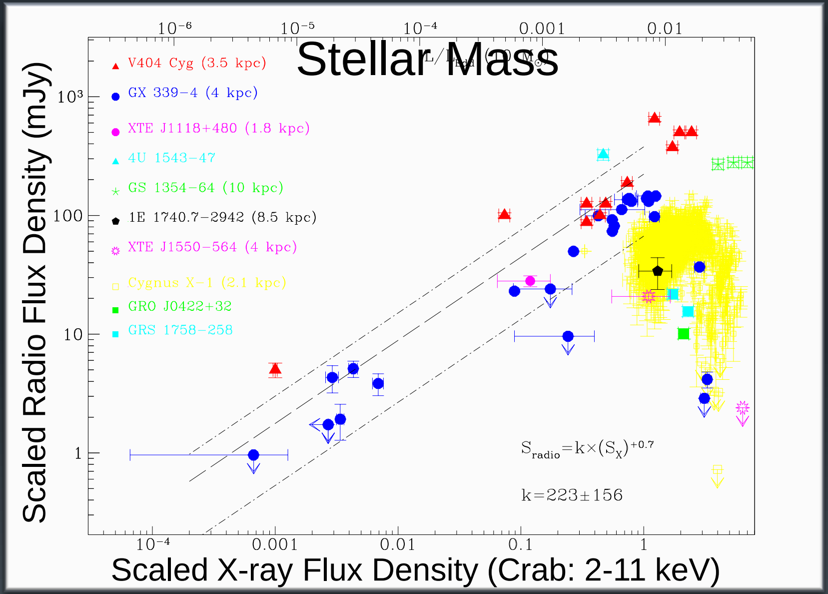
- X-ray Luminosity: Mass Accretion Rate
  - Stellar Mass peak in X-ray (T ~ 10^7K)
  - Supermassive peak in UV (T ~ 10^5 K)

$$T \propto M^{-1/4}$$

- Inverse Compton Scattering off of Corona leads to power-law distribution of photons in X-ray band
- Radio Luminosity: Jet Production via Synchrotron Radiation



Gultekin, K., et al., 2009, ApJ, 706, 404



Gallo, E., et al. 2003, Nature, 436, 819

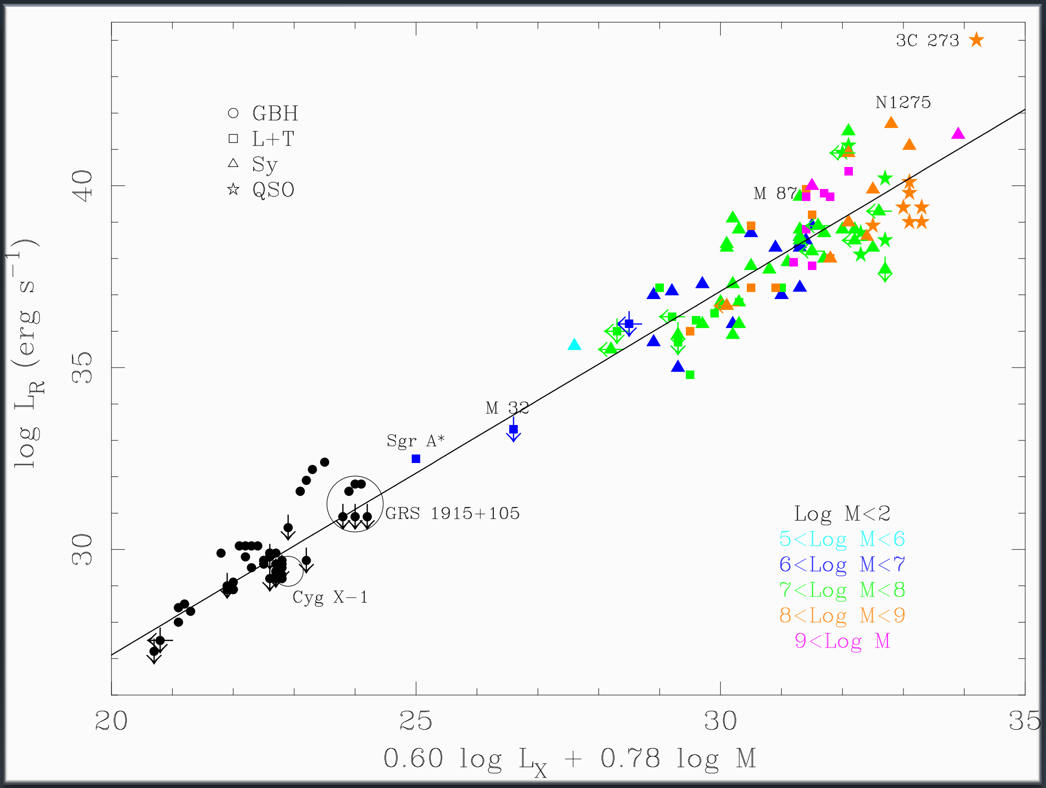
Jet Production is Dependent on Mass Accretion Rate and Mass of the Black Hole

Pressing Questions to Be Answered

- How Are Jets Launched?
  - Role of Magnetic Fields
  - Growth of the Black Hole
- How Does the Accretion Rate and the Jet Power Influence Coevolution Between the Galaxy and the BlackHole?
  - Feedback Mechanism
  - Impact on Star Formation
  - Gas Enrichment

Understanding the Scatter

- What are driving the uncertainties?
  - Distances
  - Mass
  - **Intrinsic Variability-**
    - **Variations in Mass Accretion Rate**
    - **Stellar-Mass Black Hole State Dependent**



Merloni, A., et al., 2003, MNRAS, 345, 1057

See also, Falcke, H., et al., 2004, A&A,414, 895

Timescales

- Dynamical Timescales

$$t_{dyn} \approx \frac{R}{v_\phi}$$

- Thermal Timescales

$$t_{therm} \approx t_{dyn}\alpha^{-1}$$

- Viscous Timescales

$$t_{vis} \approx t_{dyn}\alpha^{-1}\left(\frac{H}{R}\right)^{-2}$$

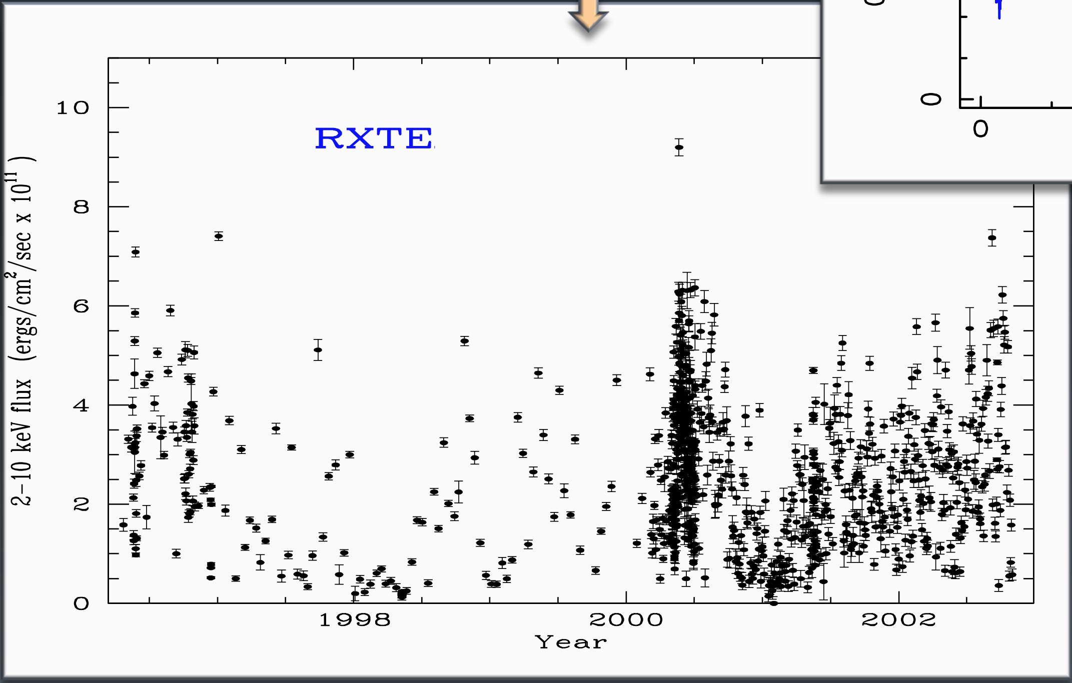
	Stellar-Mass (10 $M_\odot$, 25 R_g)	**Super-massive (10^7 $M_\odot$, 25 R_g)**
Dynamical	6×10^{-3} s	2 hrs
Thermal (α=0.1)	6×10^{-2} s	20 hrs
Viscous (H/R = 0.1)	6 s	2 months

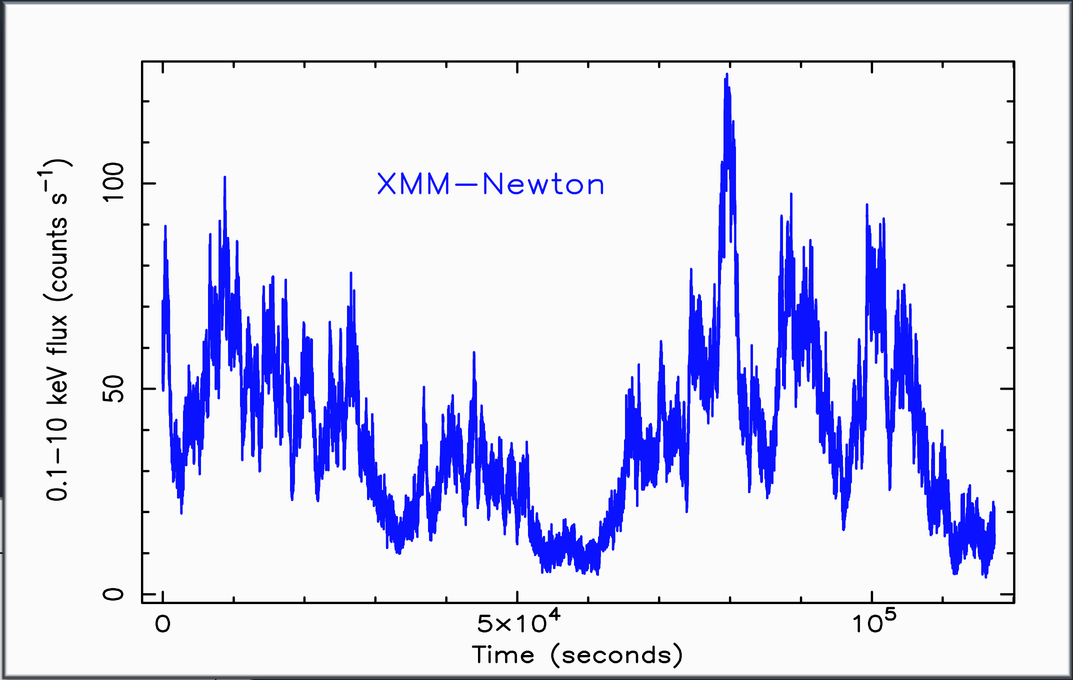
Characterizing Seyfert Variability

Why Choose Seyferts?

- Highly variable
- Radio Quiet but NOT Silent
- Viewing angle to the central engine is not obscured by disk or boosted by the jet
- Monitoring Timescales are feasible within a few months

- Viscous: Months





- Dynamical : Hours

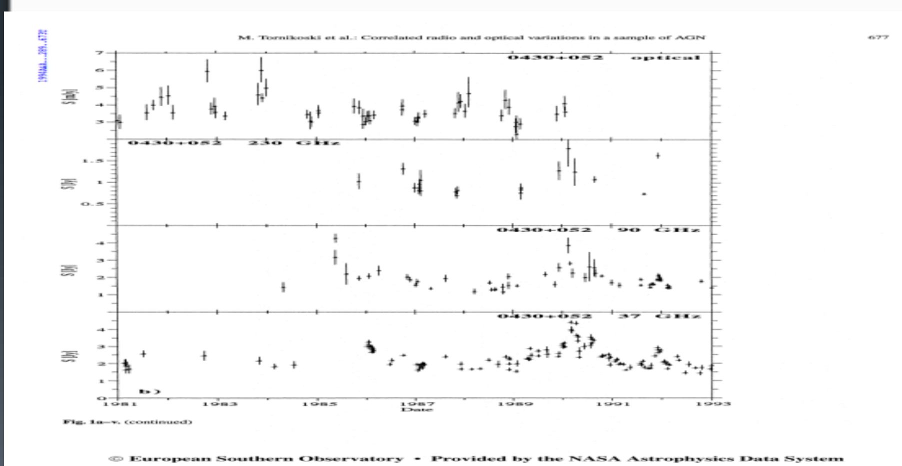
NGC 4051

McHardy, I., et al., 2004, MNRAS, 348, 783

Radio Variability

- Viscous Timescales –months/years
- Tends to be less variable than the X-ray
- Emission could be coming from further away and/or in a larger region
  - Variations are on longer timescales and lower amplitude

3C 120



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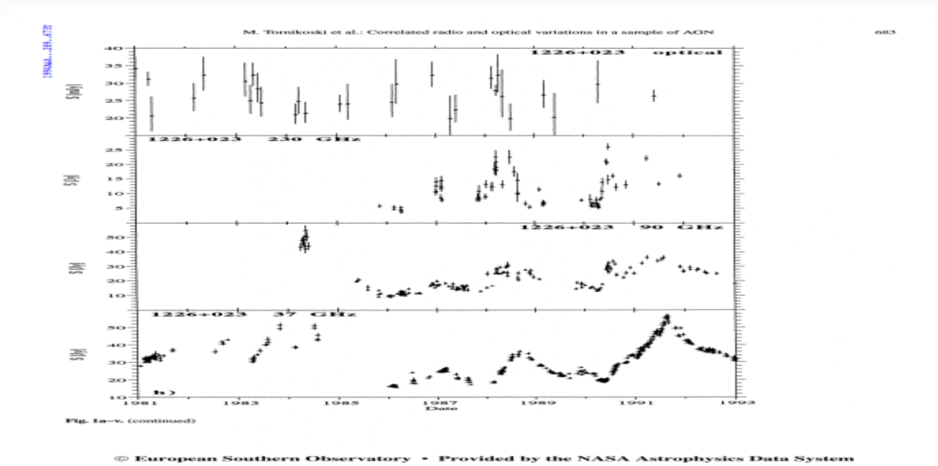


Tornikoski, M., et al., 1994, A&A, 289, 673

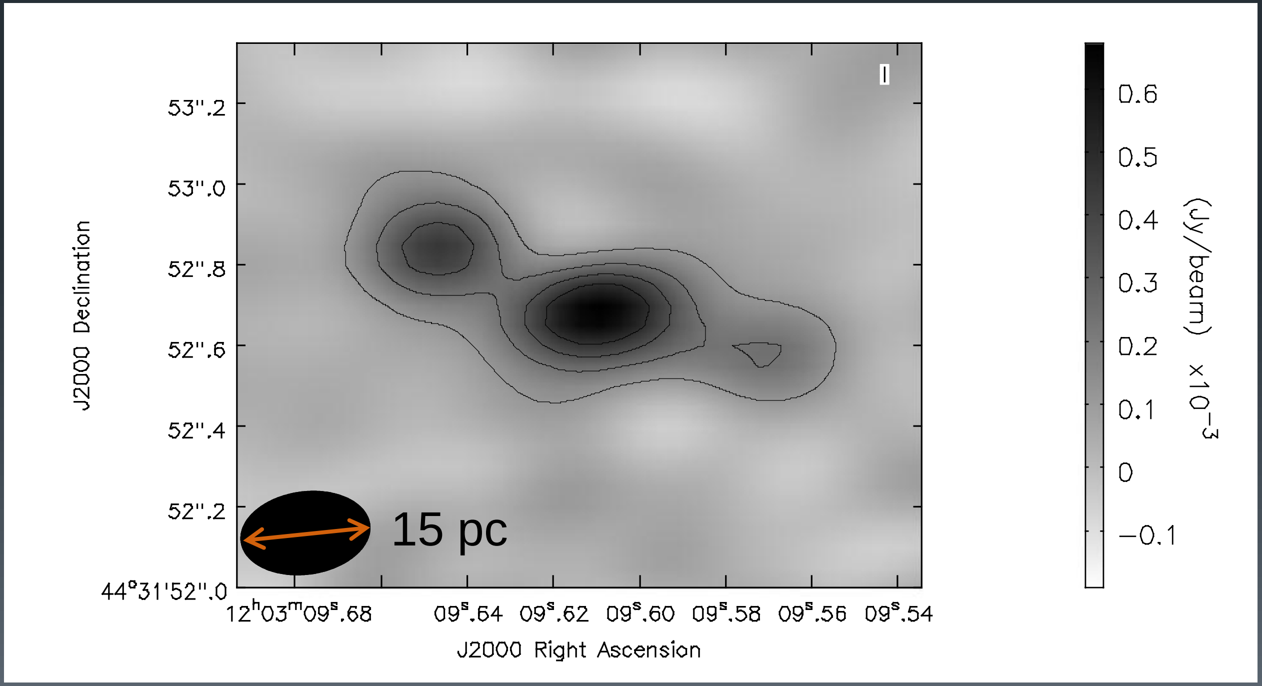
NGC 4051

- Nearby Seyfert-1 Galaxy (10 Mpc)
- High X-ray Variability
- M = 1.73 x 10^6 $M_\odot$

(Denney et al. 2009)

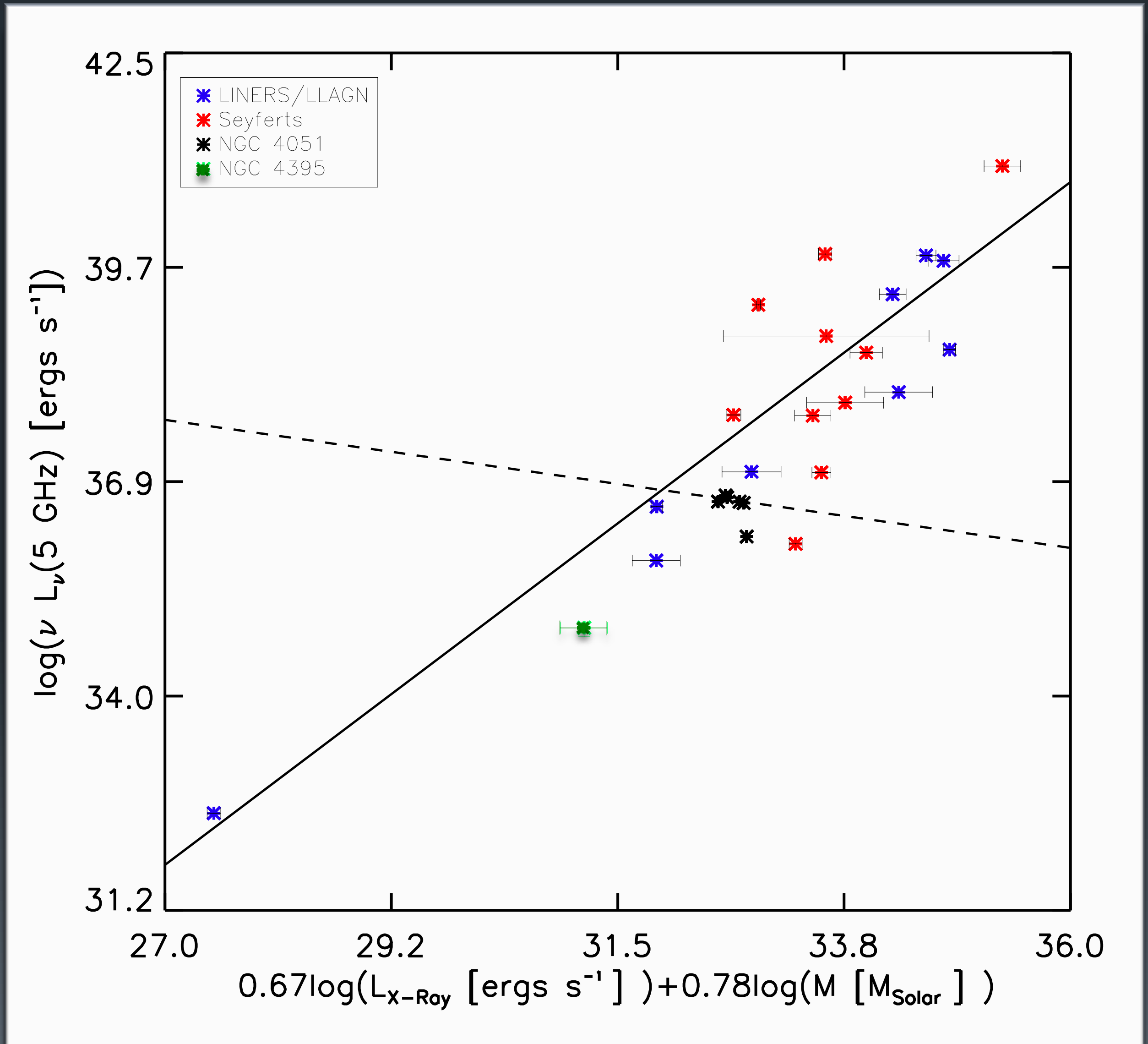
- Nearly Simultaneous 6 VLA at 8 Ghz and 8 *Chandra* X-ray
- A configuration – jet-like structures observed

King, A. L., et al. 2011, ApJ, 729, 19



Compared to the Fundamental Plane

- Large Scatter Driven by X-ray Variability
- Do Higher Accretion Rates Follow a Separate Disk-Jet Connection?

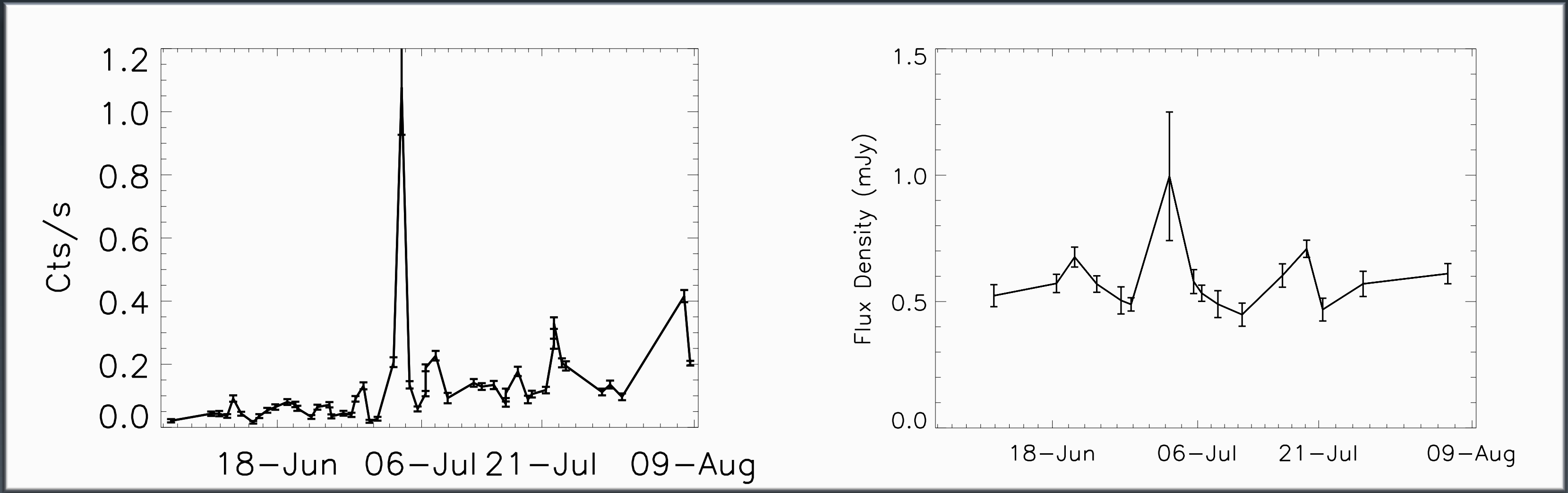


King, A. L., et al. 2011, ApJ, 729, 19

Gultekin, K., et al., 2009, ApJ, 706, 404

NGC 4395

- Nearby Dwarf Galaxy (4.3 Mpc)
- $M = 3 \times 10^5 M_\odot$
- Nearly Simultaneous EVLA at 8.4 GHz and 30 *Swift* X-ray
- Highly Variable X-ray, Less Variable Radio



King, A.L., et al., 2012, ApJ *In Prep*

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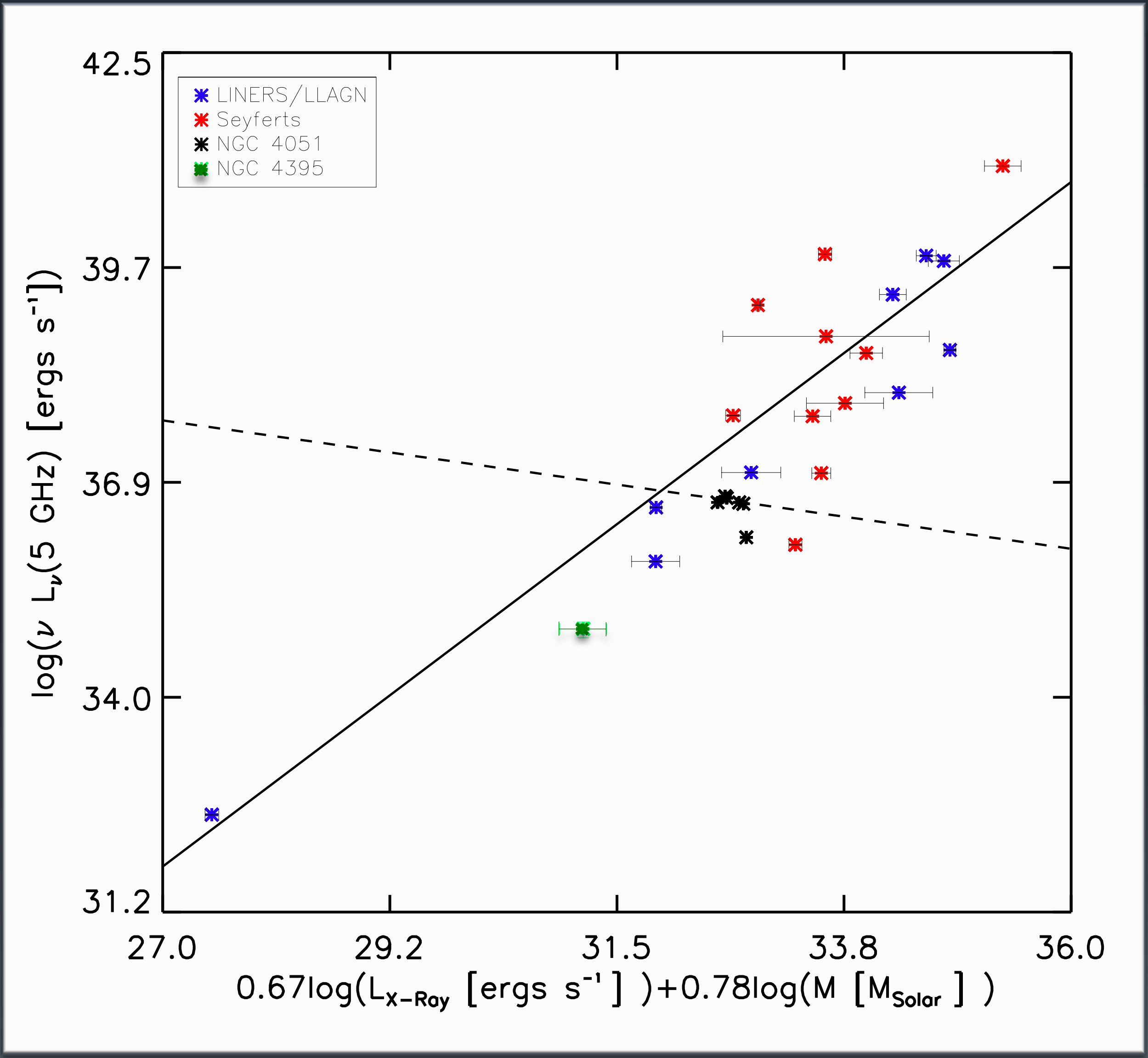

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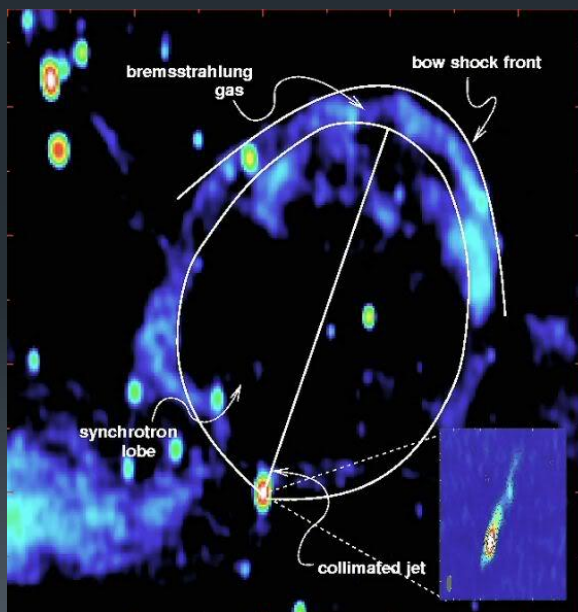
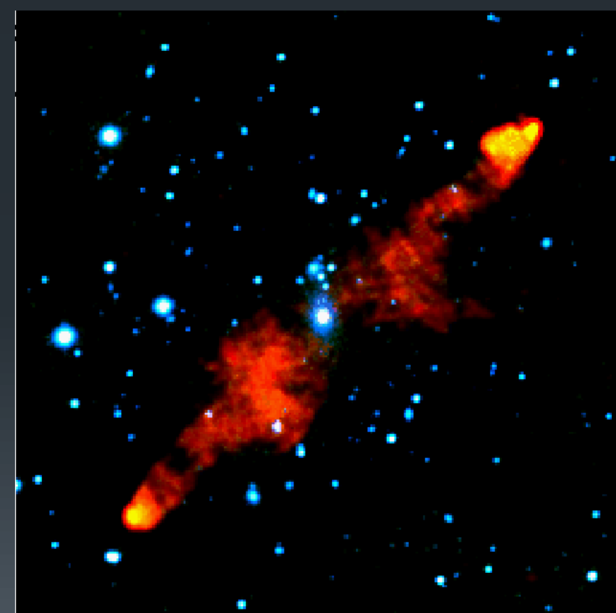
References

How Do We Observe Jets?

- X-ray and Radio Cavities
- Radio Emission via non-thermal processes: Synchrotron

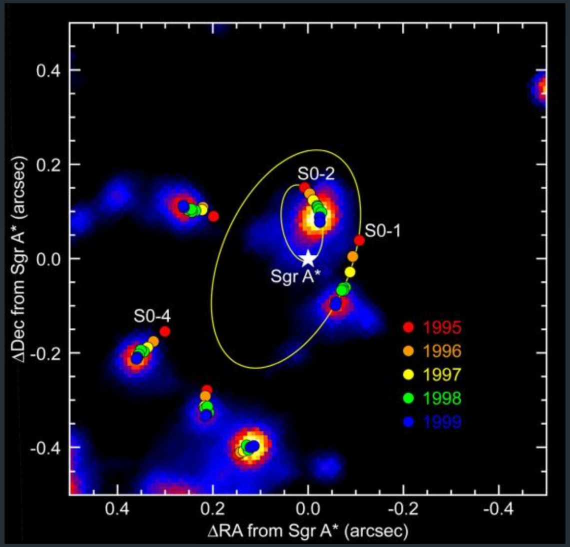


Cygnus X-1: Gallo et al. 2005



PKS 2356-61: ATCA image by A. Koekemoer, R. Schilizzi, G. Bicknell and R. Ekers

Mass & Mass Accretion Rate

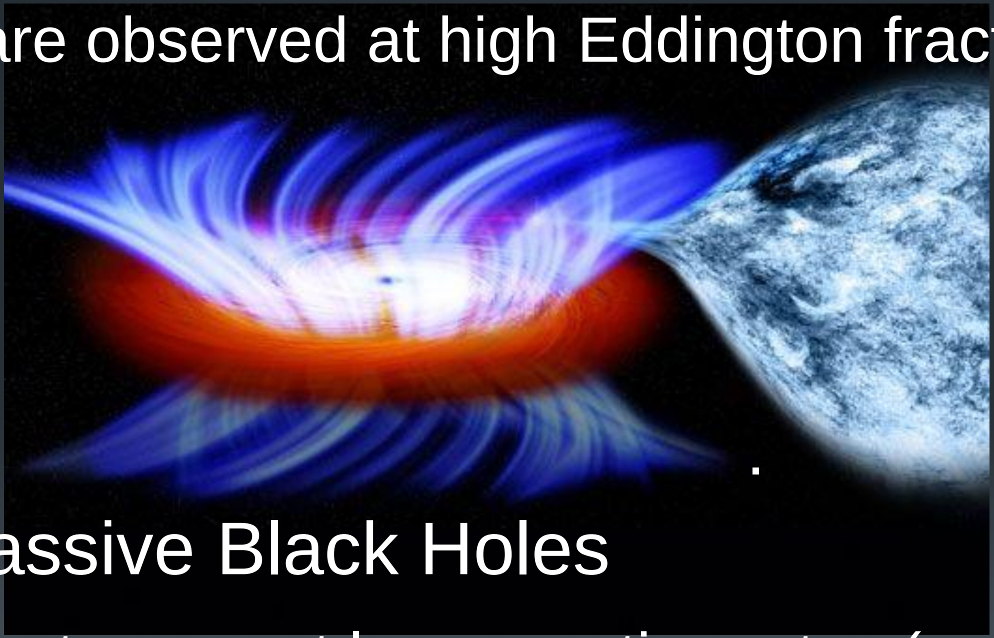


- **Mass**
  - Dynamical Masses
  - Mass-Luminosity Relation
  - M-σ relation
- **Mass Accretion Rate**
  - Expect material accreting onto

    Black Hole can also supply material for the Jet
  - Peak of Spectral Energy Distribution (SED)
    - Ultra-violet for Supermassive Black Holes
    - X-ray for Stellar Mass Black Holes
  - Non-thermal component: X-ray
    - Power-law – generated from Inverse Compton Scattering of photons off of e^- in the Corona

State Dependence

- In Stellar-Mass Black Holes jets are only observed at low accretion rates
  - Winds are observed at high Eddington fractions

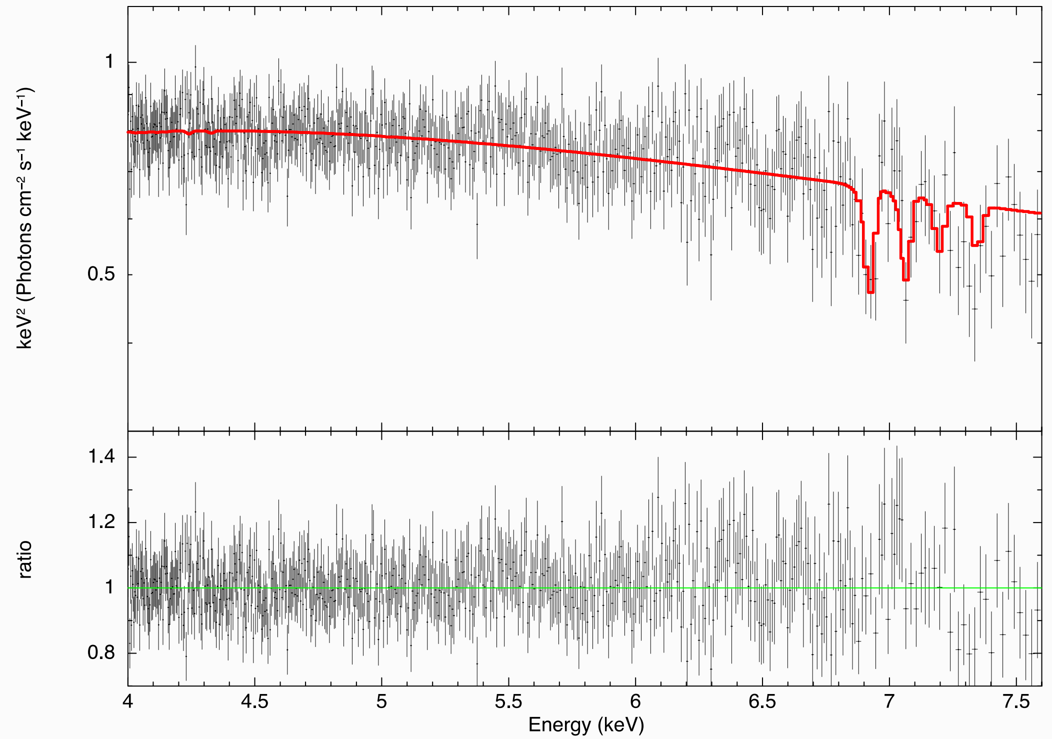


- Supermassive Black Holes
  - Jets are stronger at low accretion rates (e.g., M87)
  - Winds and Jets are both at ~10^{-2} M_{Edd} (e.g, NGC 4051)

Ultra-Fast Outflows of Black Hole Candidate IGR J17091

- State Dependent
  - High/Soft State
- Simultaneous EVLA Observations
  - No Radio Detection
- Highly Ionized, $\log(\xi) = 3.3$
- v_{out}~10,000 km/s
- $\dot{M}_{out} = 0.4\text{-}20\ \dot{M}_{acc}$
- "Micro-Quasar"

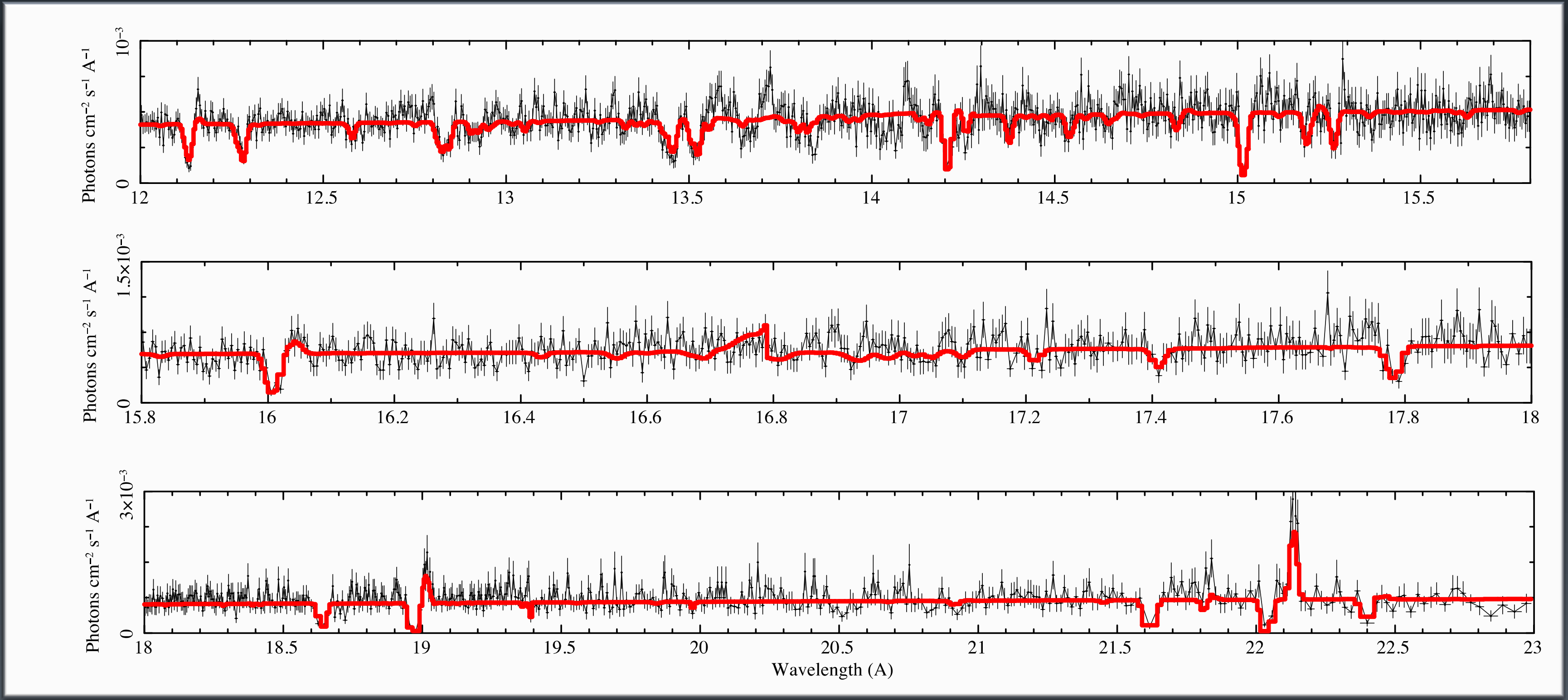
King, A. L., et al. 2012, ApJ, 746, L20.



Warm Absorbing X-ray Winds

- X-ray Absorption Features
  - Highly ionized, Located closest to the Black Hole

NGC 4051 *Chandra HETG Spectra*   **King, A. L., et al., 2012, ApJ, 746, 2.**



Conclusions:

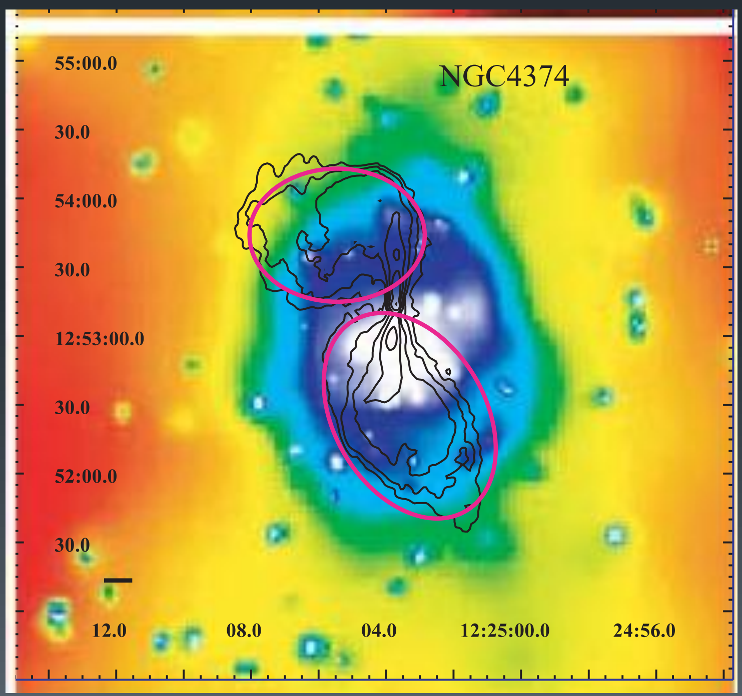
- The Fundamental Plane Suggests a Link Between Black Hole Mass, Mass Accretion Rate and Jet Production
- Sources are Intrinsically Variable
  - Due to Mass Accretion Rate
  - Occurs Especially in High Energy Photons
  - Demands the Necessity for Simultaneous Observations
- Outflow Transition Begins at High Accretion Rates
  - Accretion Driven Winds Tend to Dominate

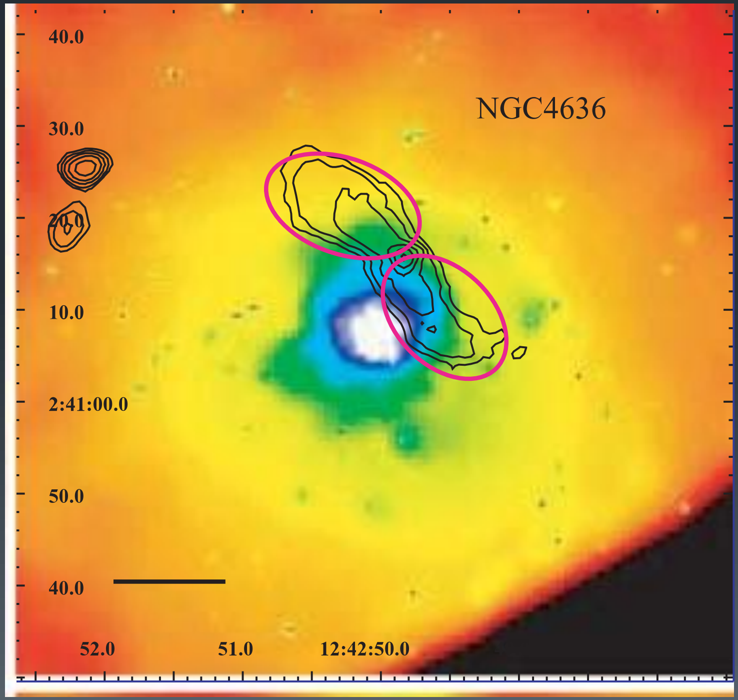
Accretion Disk Winds

- Warm Absorbing Winds in AGN and Seyferts
  - Example: NGC 4051 has wind originate within $R < 10^5\ R_g$ (within BLR)
- Stellar-Mass Black Hole Winds
  - Example: GRO 1655-40 Magnetically Driven
- Driving Processes:
  - Thermal – Stellar Mass
  - Radiative – AGN
  - Magnetic – Stellar Mass and AGN

Jet Power: Traced via Jet Cavities

- $P_{jet} \approx E/t_{age}$
- $E = \gamma_2/(\gamma_2-1)PV$, $t_{age} = R/c_s$





Allen et al. 2006