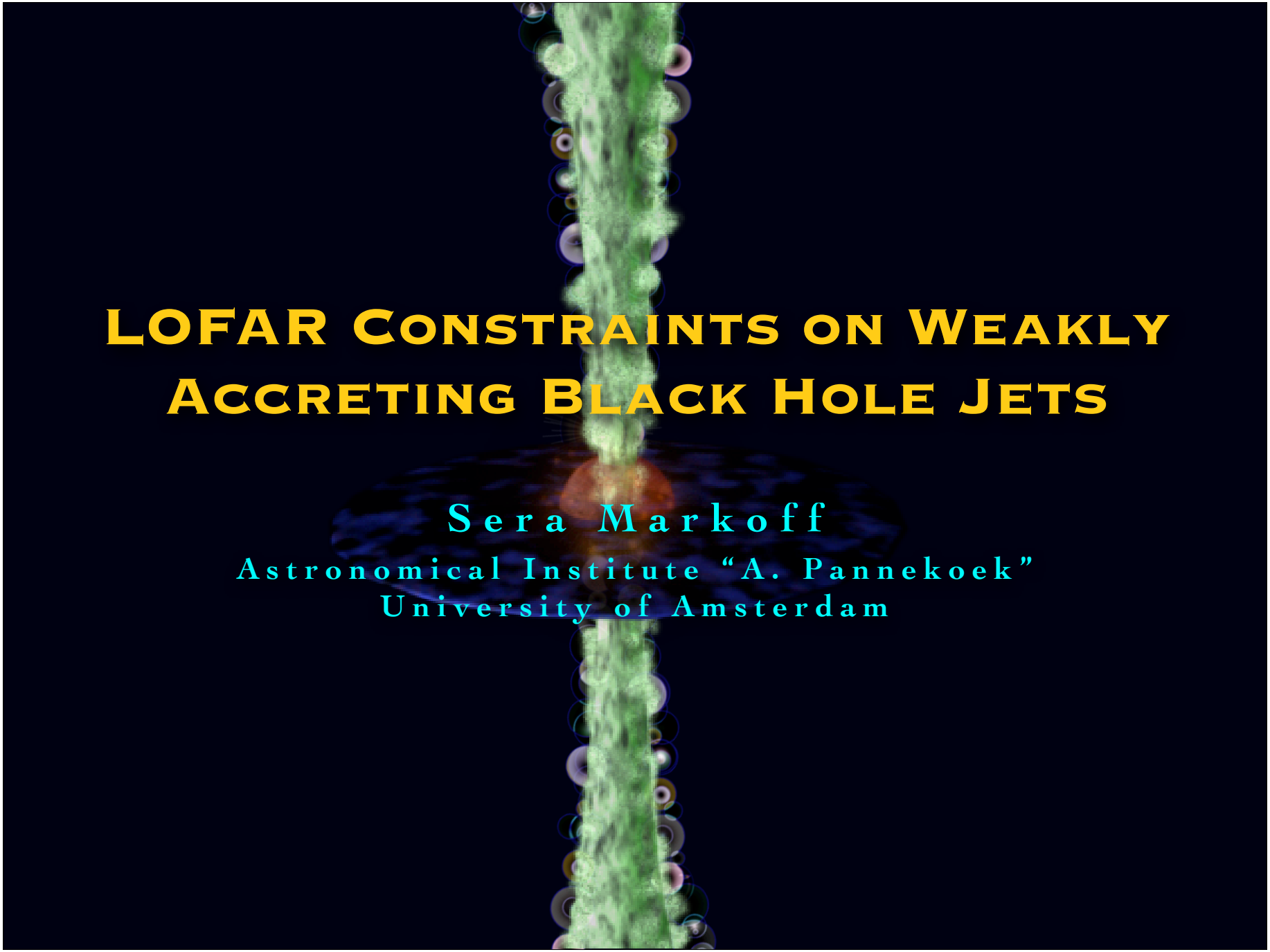
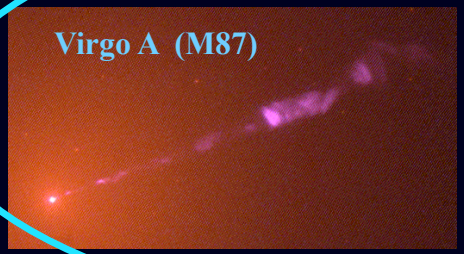


LOFAR Constraints on Weakly Accreting Black Hole Jets

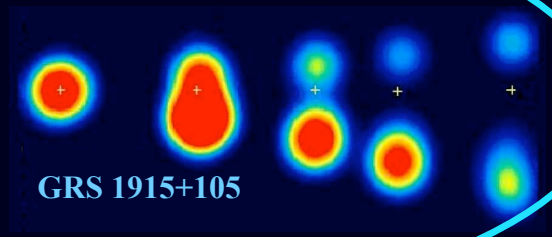
Sera Markoff
Astronomical Institute "A. Pannekoek"
University of Amsterdam

Jets appear in many astronomical objects

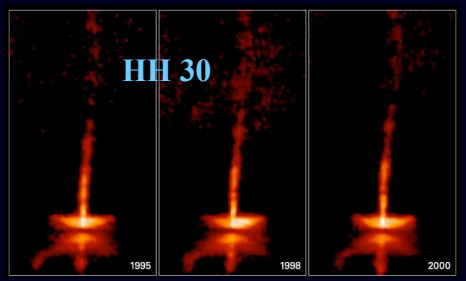
SUPERMASSIVE BLACK HOLES



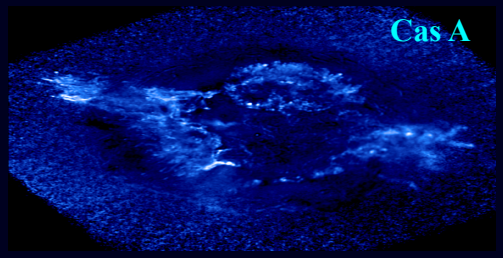
STELLAR-MASS BLACK HOLES



FORMING STARS



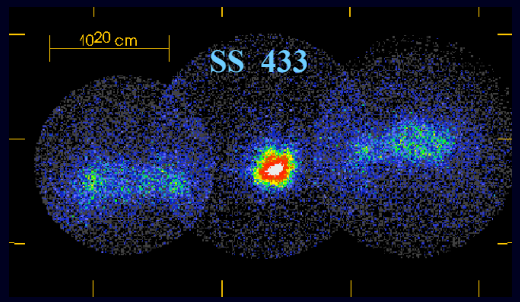
DYING STARS



DEAD STARS

R AQUARII

CRAB PULSAR

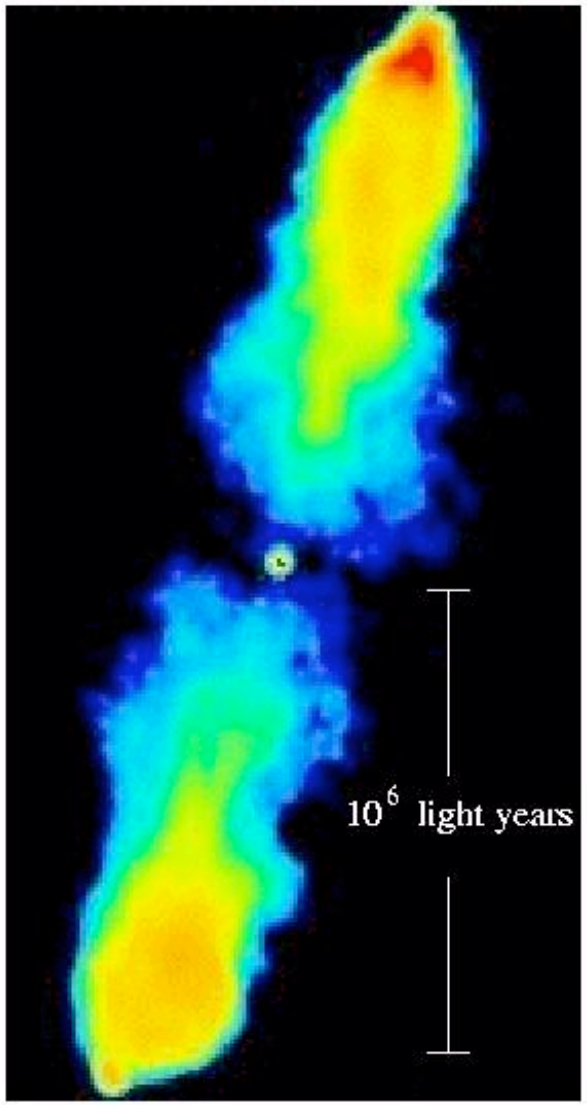


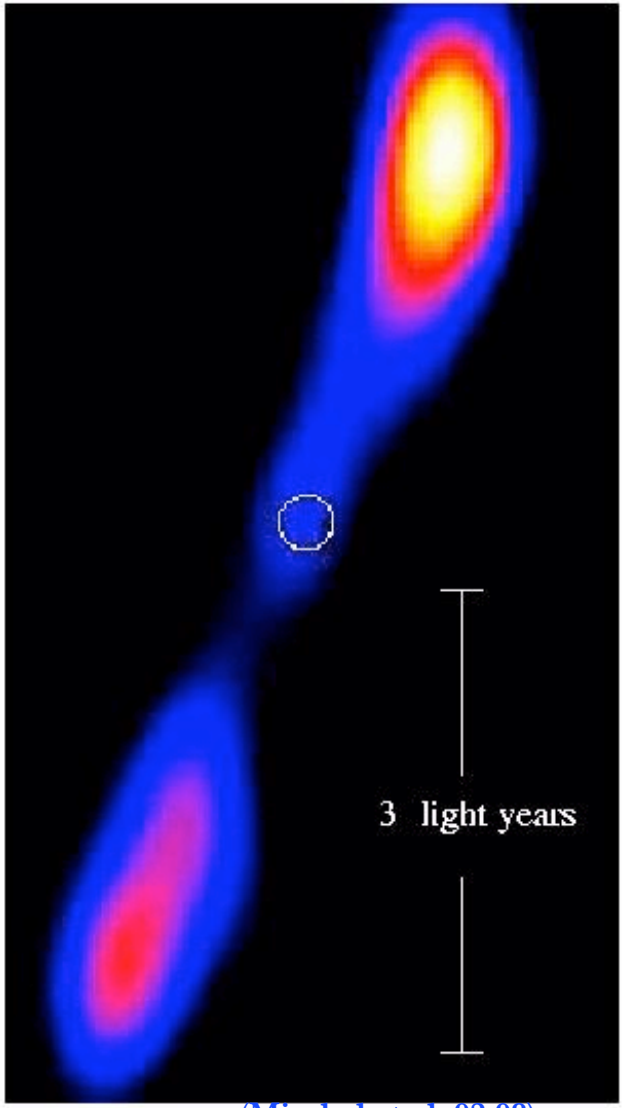
Fundamental Questions

- Why do jets form? What are the conditions near the black hole leading to jet creation, collimation etc.? Does the black hole play a special role or could it be anything in there?
- Jet structure/geometry/bulk velocity
- Jet intrinsic physics: Matter (e^-p vs e^+e^-) vs. Poynting flux dominated?
- Is BH physics generic? If yes, should scale predictably between stellar/galactic systems

Accreting BHs with Jets - Mass (Size) Scales

QUASAR (AGN) MICROQUASAR (XRB)



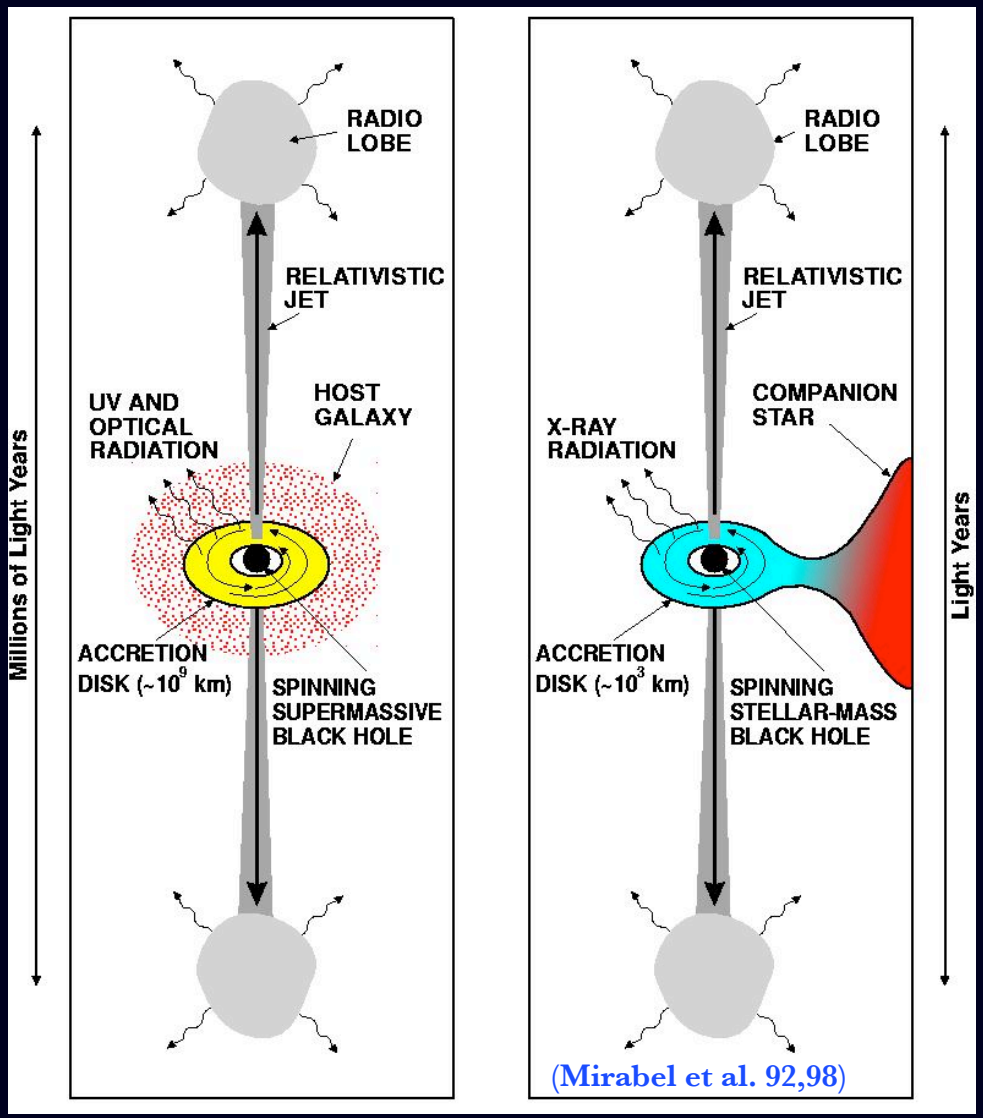


(Mirabel et al. 92,98)

Comparing accretion across the mass scale

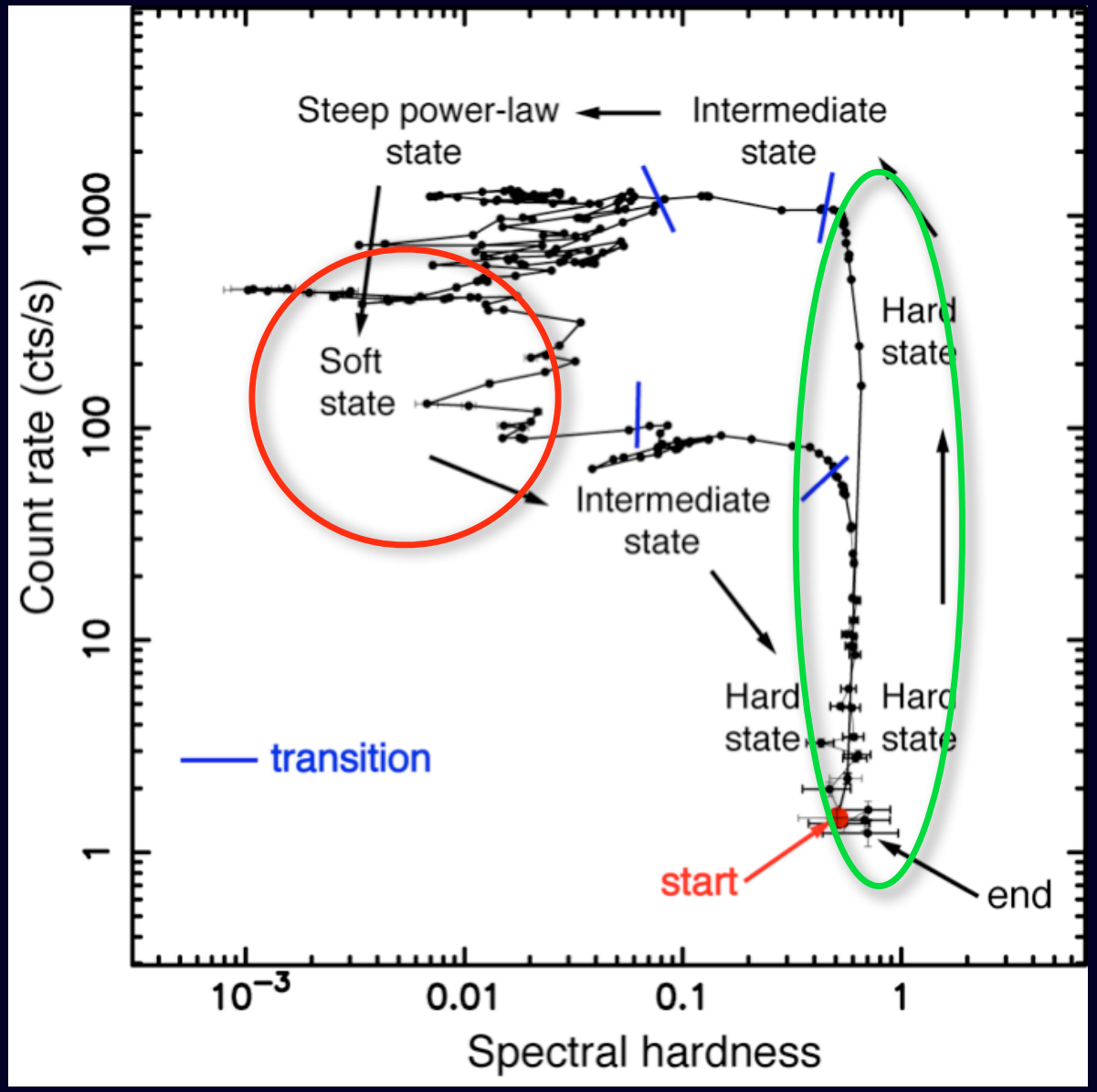
QUASAR (AGN) MICROQUASAR (XRB)

10^{4-5} yrs!



1 day

XRB accretion states

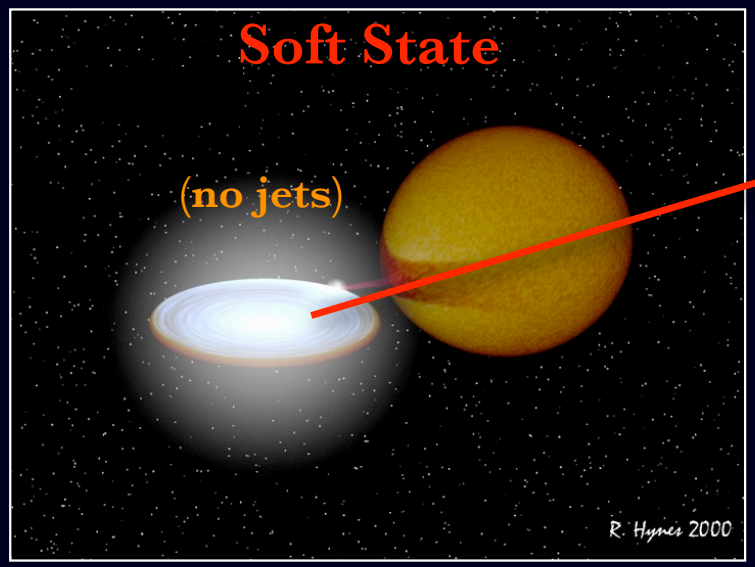


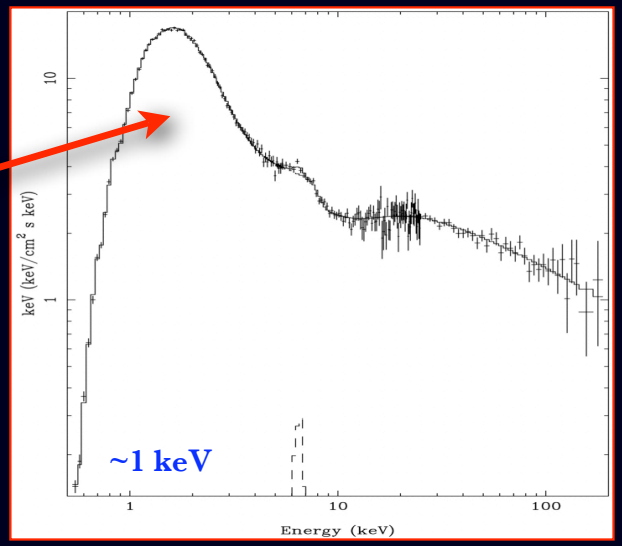
(Homan & Belloni 2004)

(BH) XRB Accretion States

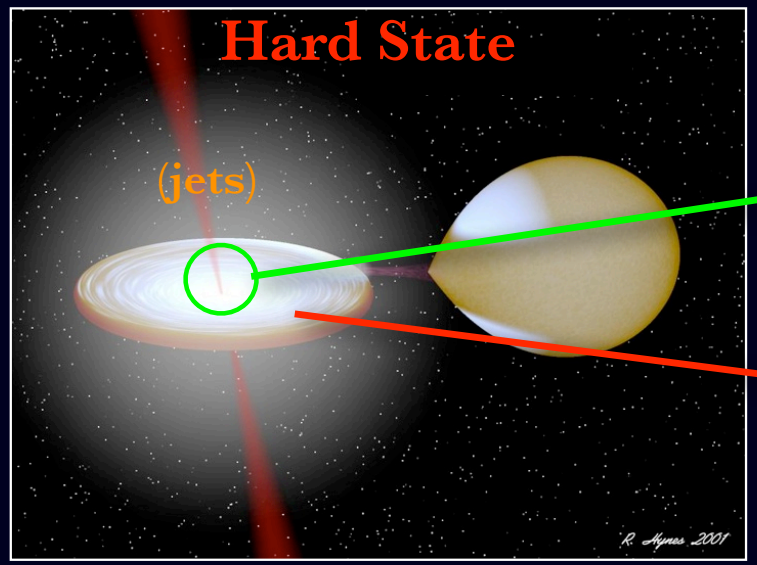
Luminosity

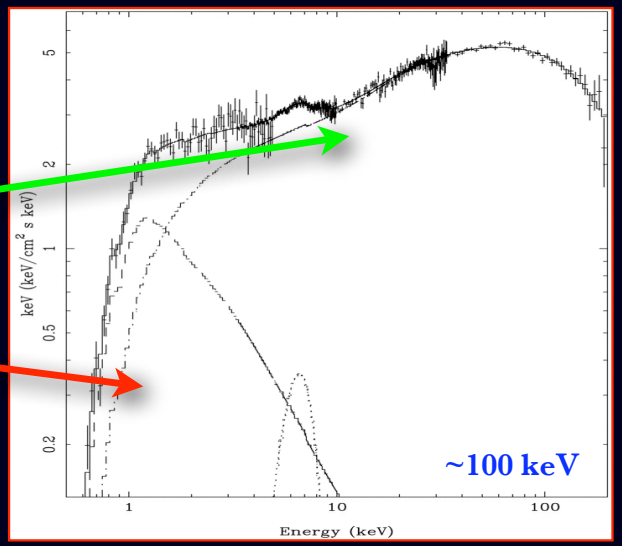
≈ L_{Edd}



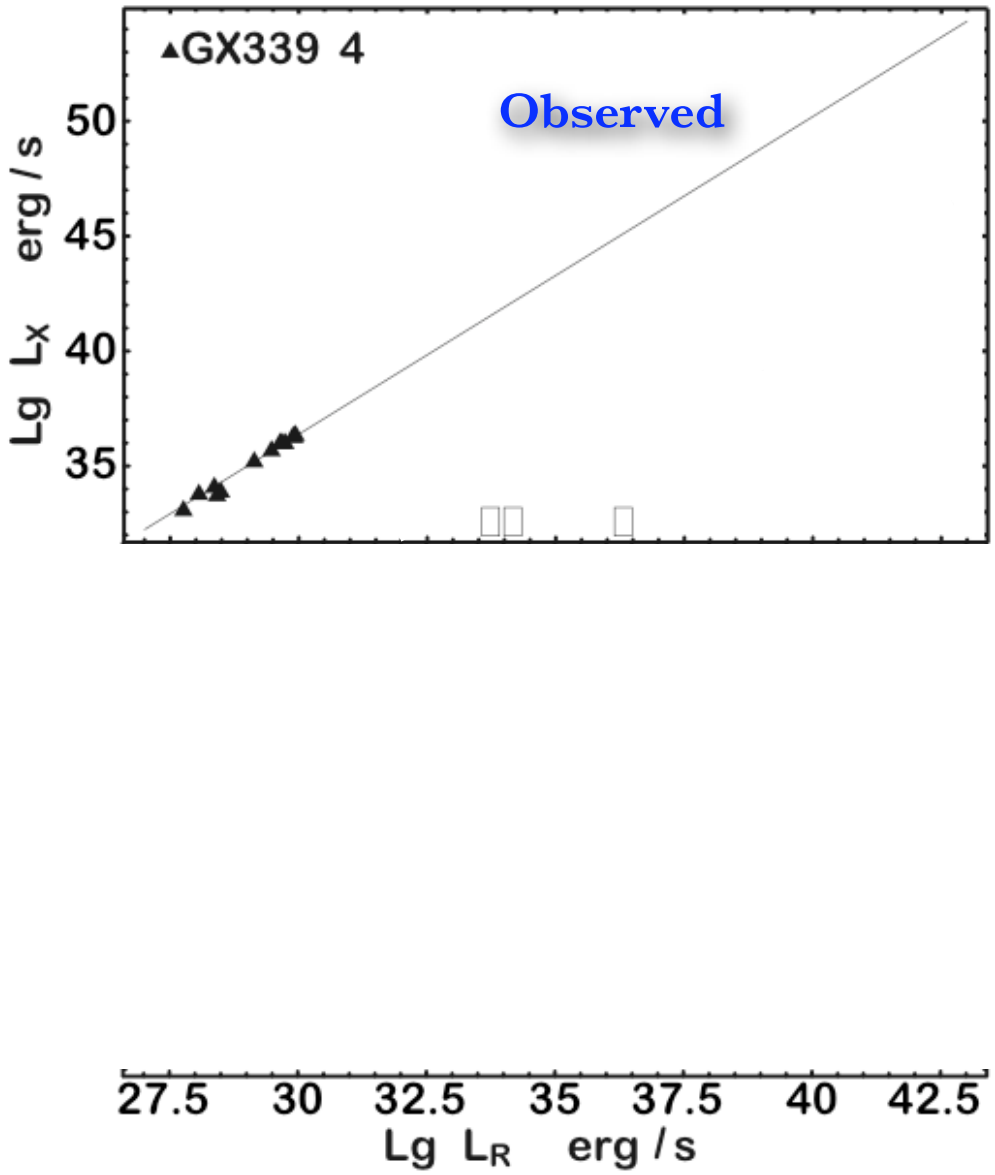


« L_{Edd}



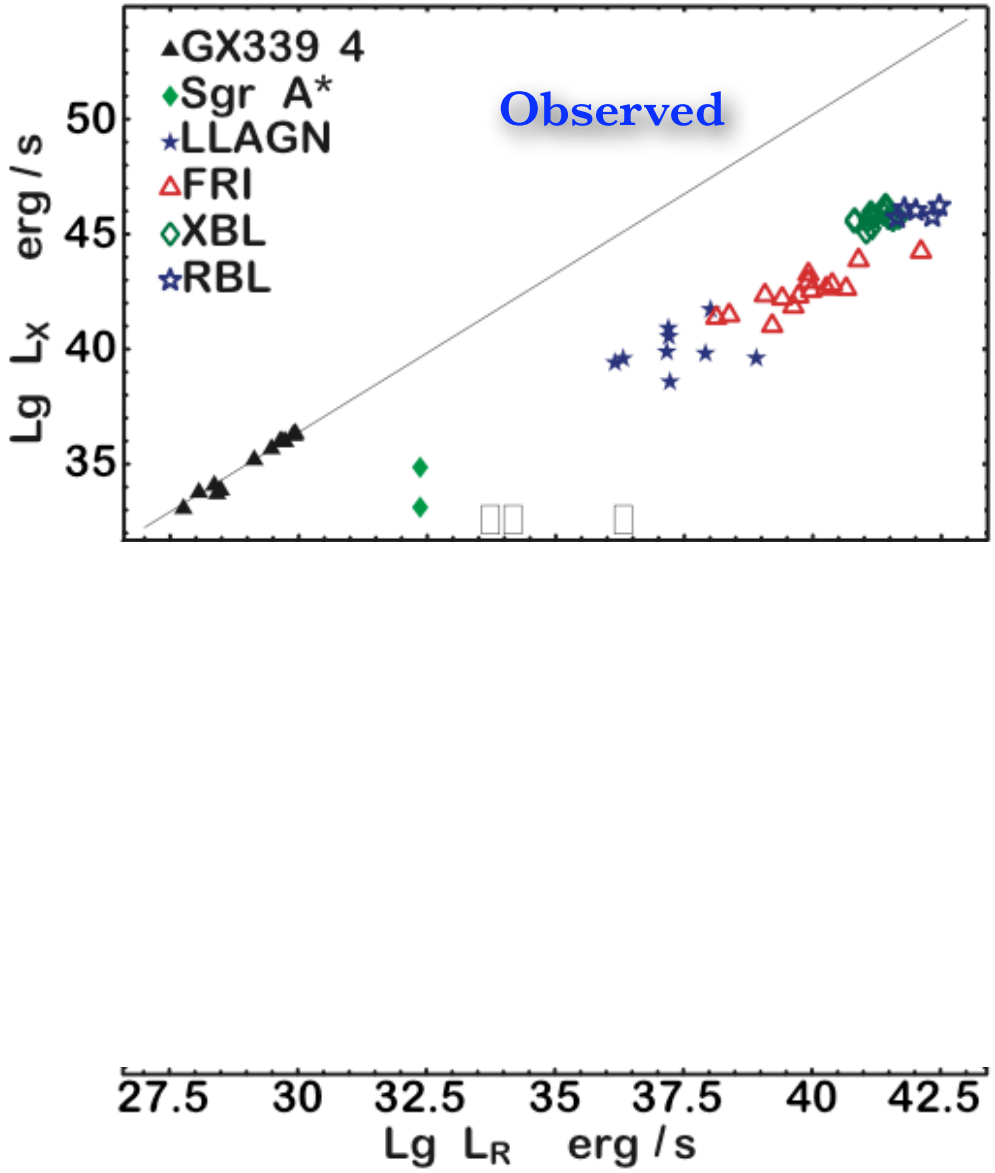


Fundamental plane of BH accretion!



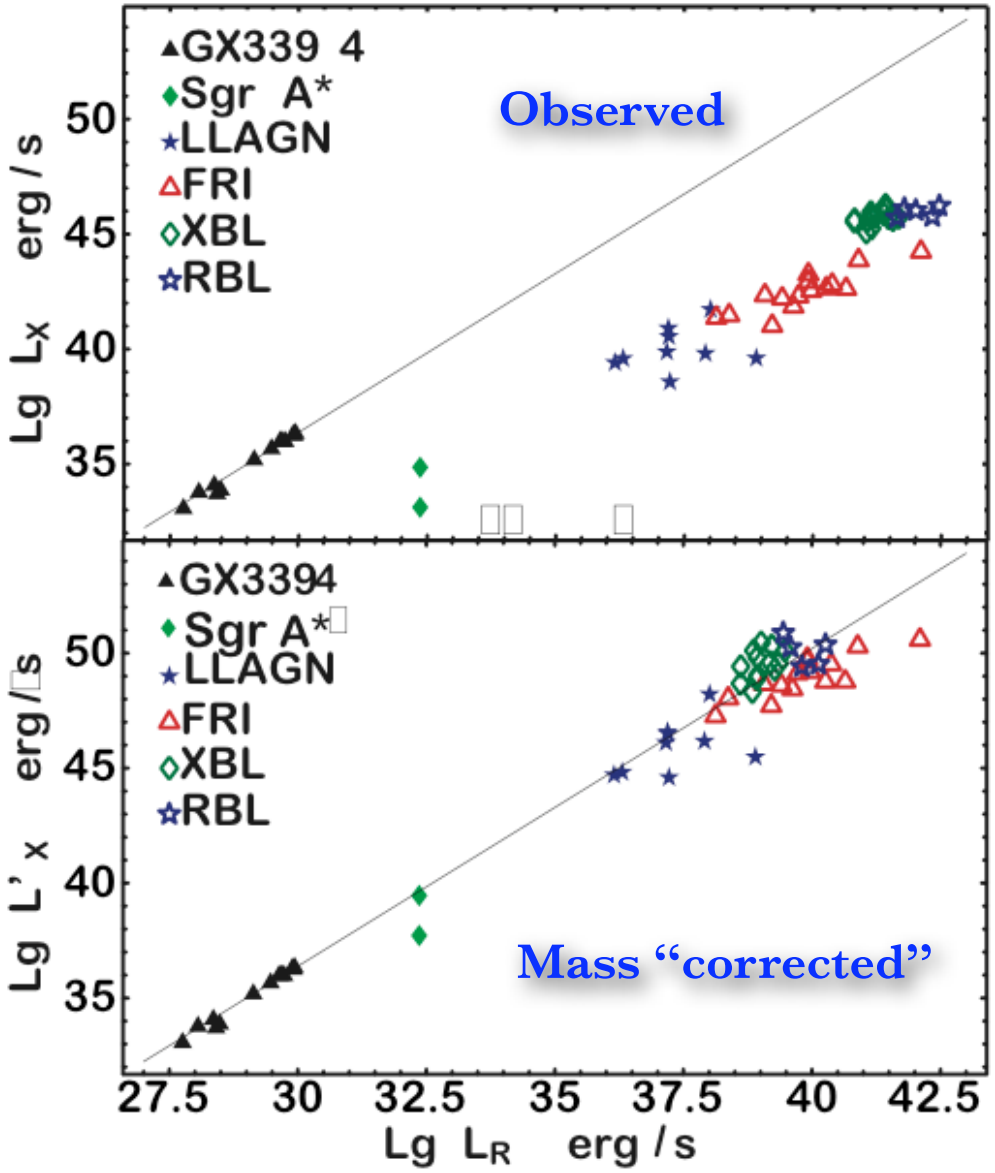
(Falcke, Körding & Markoff 2004
Merloni,Heinz & diMatteo 2003)

Fundamental plane of BH accretion!



(Falcke, Körding & Markoff 2004
Merloni,Heinz & diMatteo 2003)

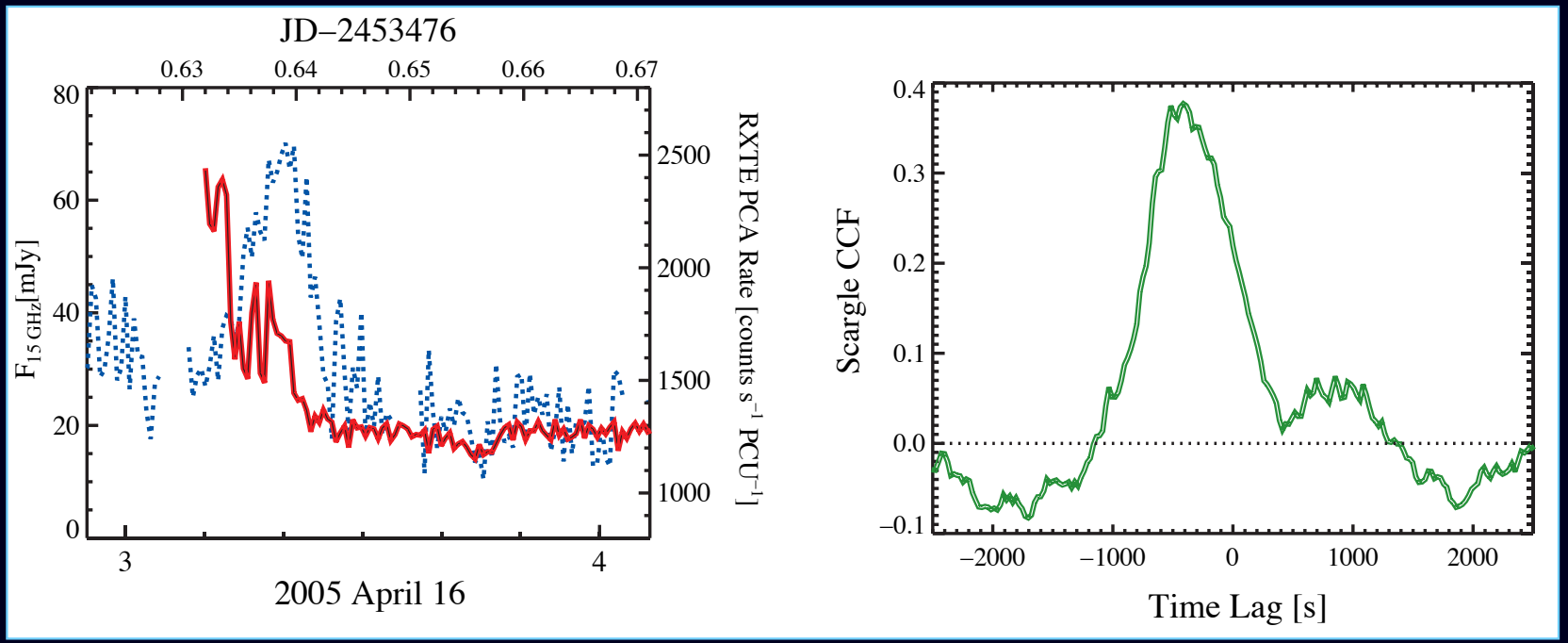
Fundamental plane of BH accretion!



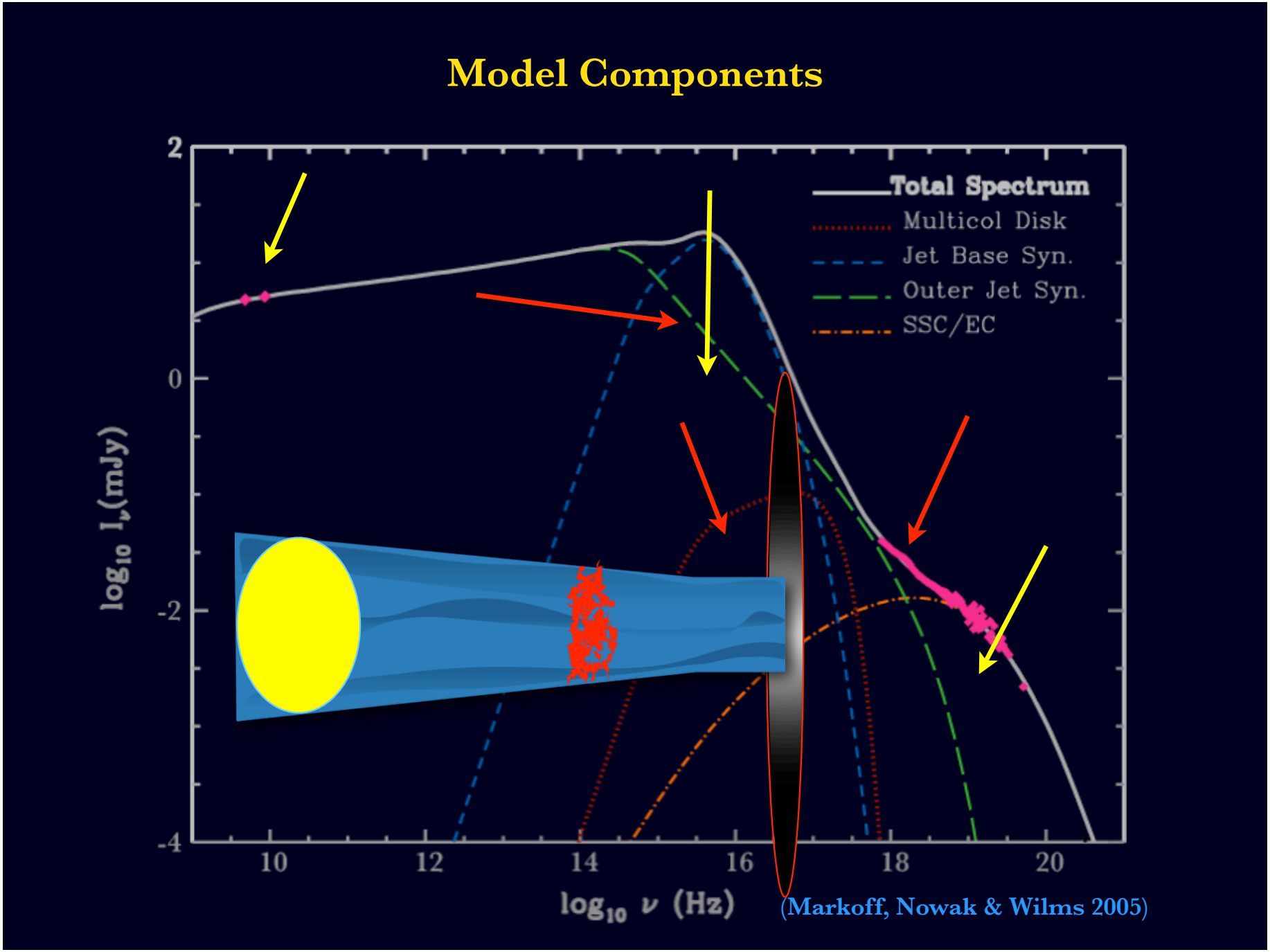
(Falcke, Körding & Markoff 2004
Merloni,Heinz & diMatteo 2003)

Jet structure/plasma flow

- **Measuring lags between frequencies, and amplitude/shape decay/evolution of flare events**
  - **Gives information about plasma velocities and internal physics, e.g., Cyg X-1: (Wilms et al. 2007)**

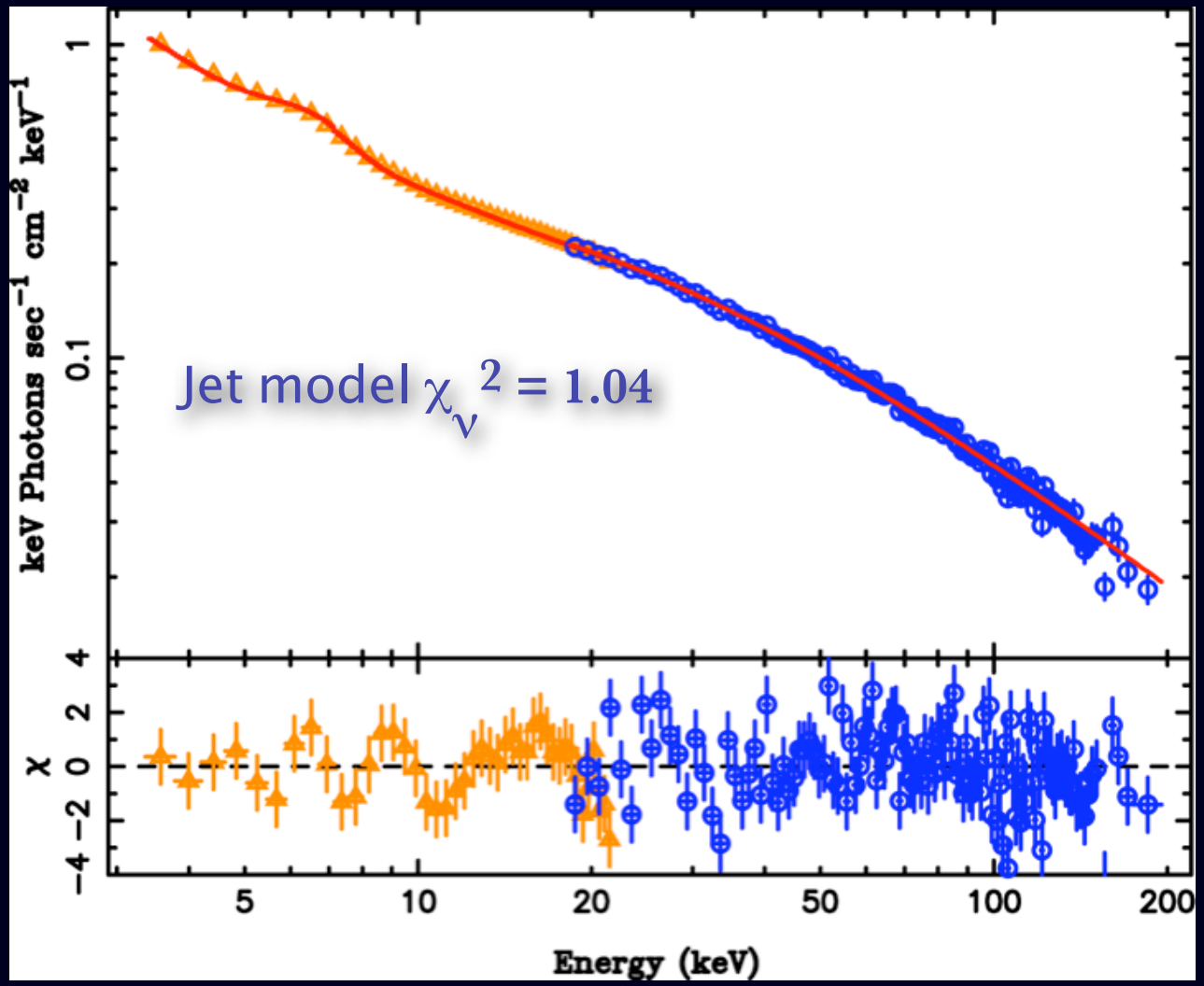


Model Components



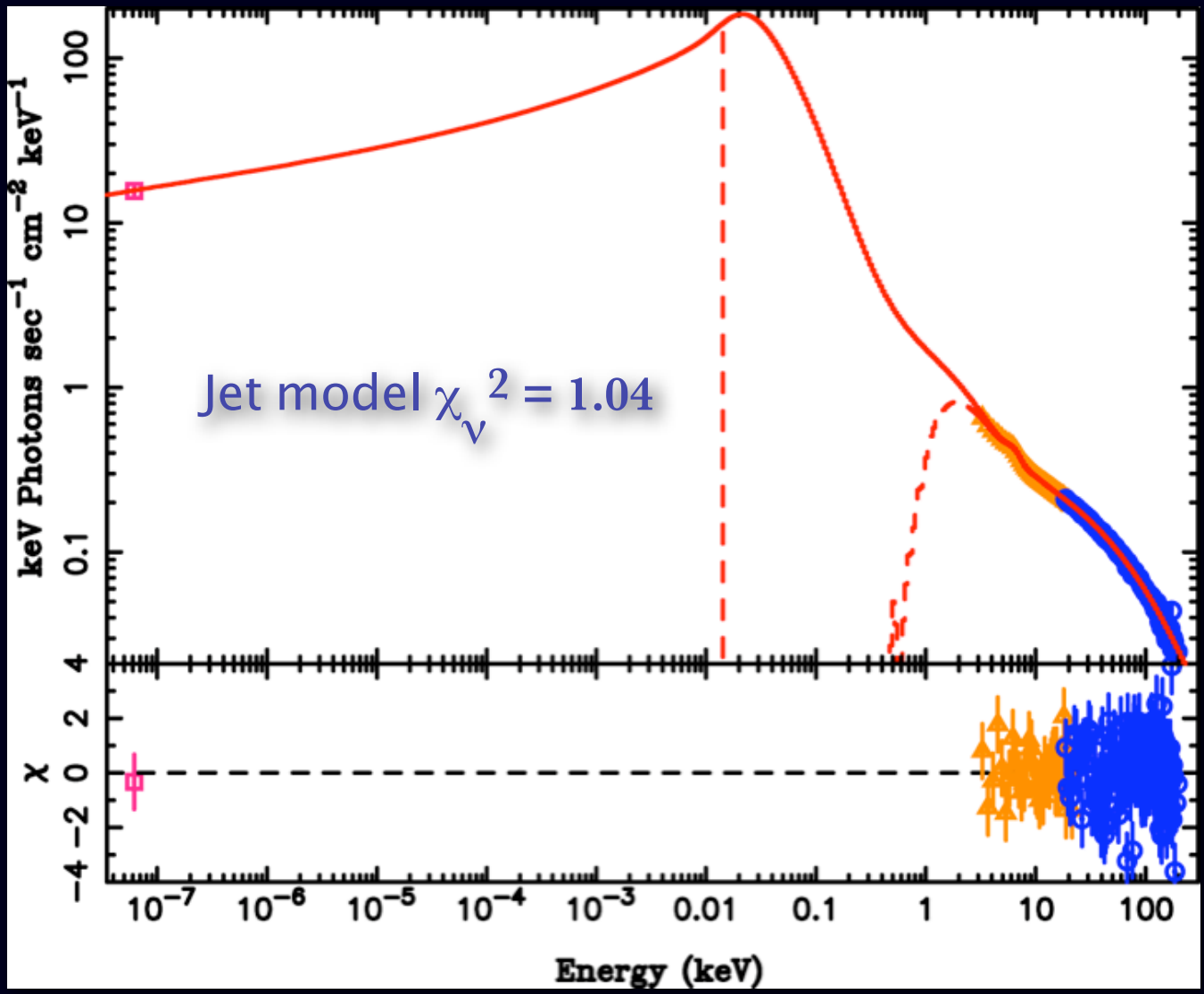
(Markoff, Nowak & Wilms 2005)

Radio/Xray only: Cyg X-1 spectrum



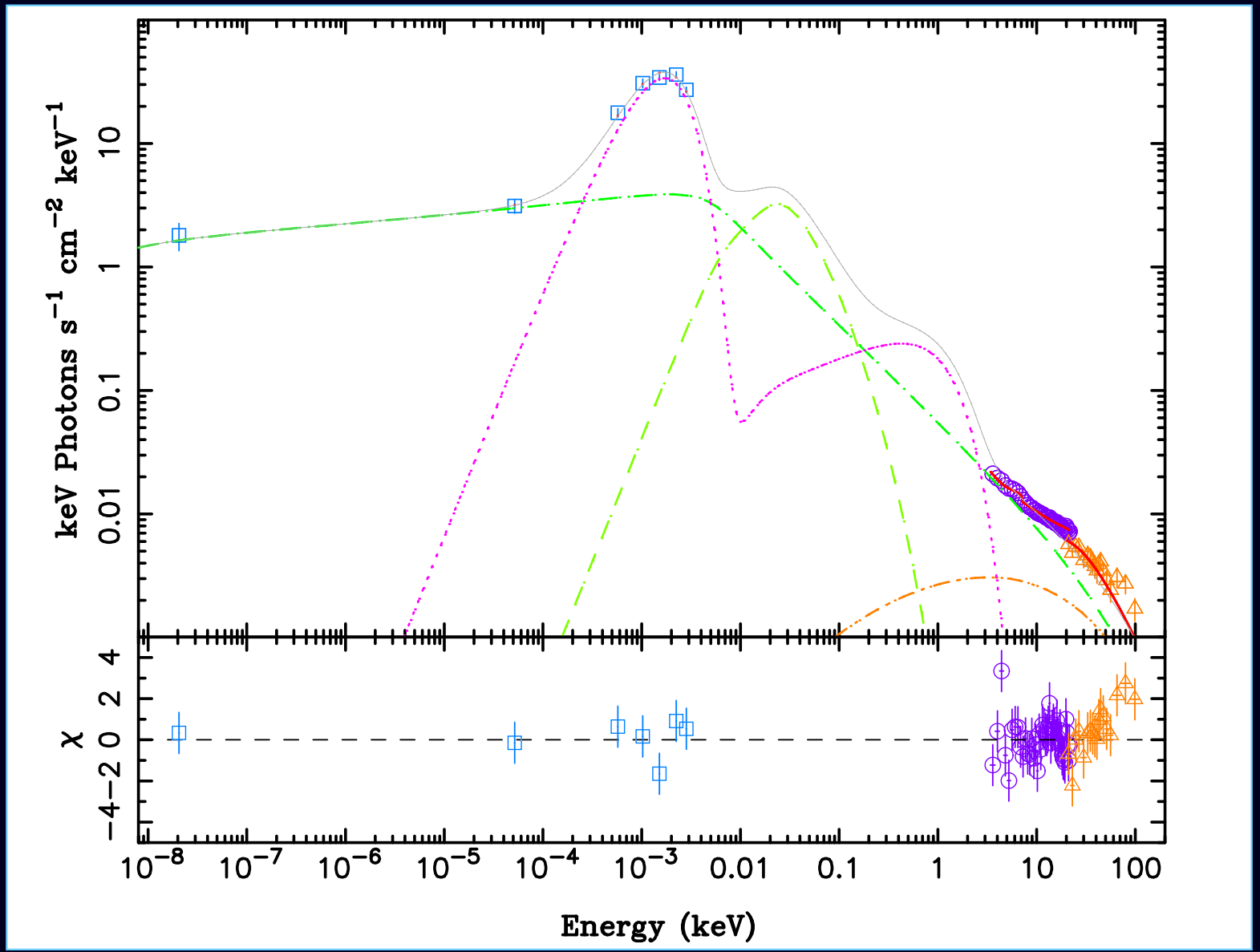
(Markoff & Nowak 2004; Markoff, Nowak & Wilms 2005)

Radio/Xray only: Cyg X-1 spectrum



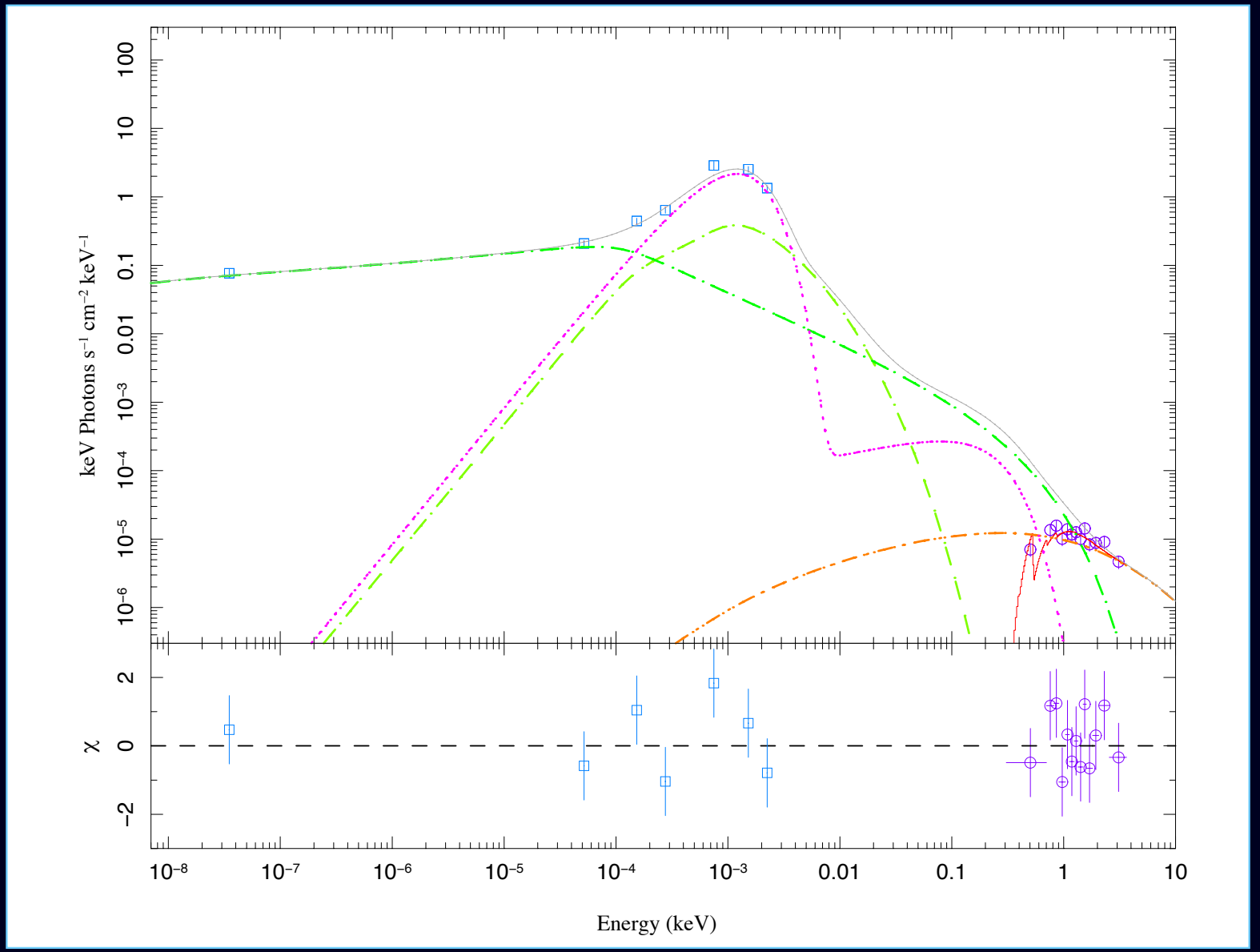
(Markoff & Nowak 2004; Markoff, Nowak & Wilms 2005)

New constraints from IR/Optical I: GRO J1655-40



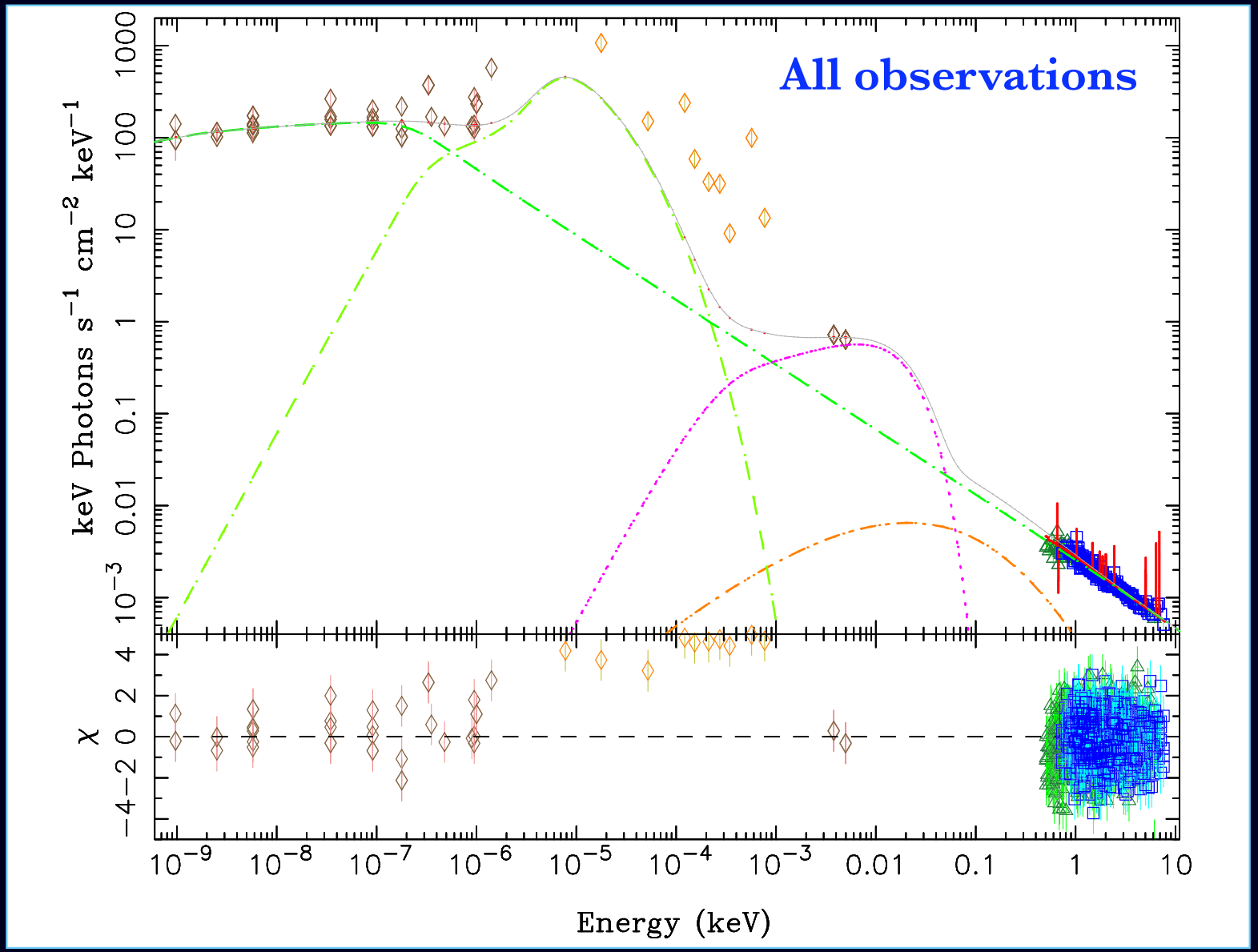
(Migliari et al. 2007)

New constraints from IR/Optical II: A0620-00



(Gallo et al. 2007)

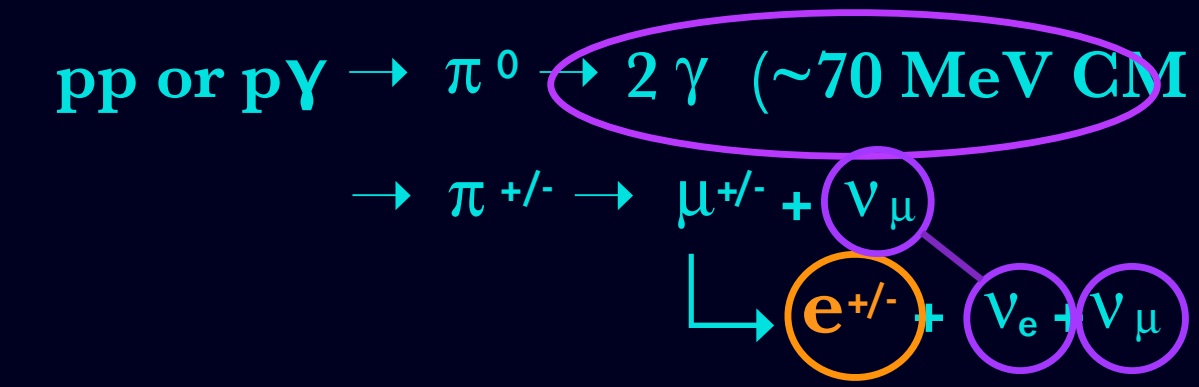
M81* simultaneous campaign



(Markoff et al. 2007)

"Multimessenger" = multiwavelength

★ **If protons accelerated in the jets, additional contribution from hadronic interactions**



☛ **Submitted proposals to trigger MAGIC and IceCube with first bright LOFAR transients, as well as mutual monitoring of known sources**

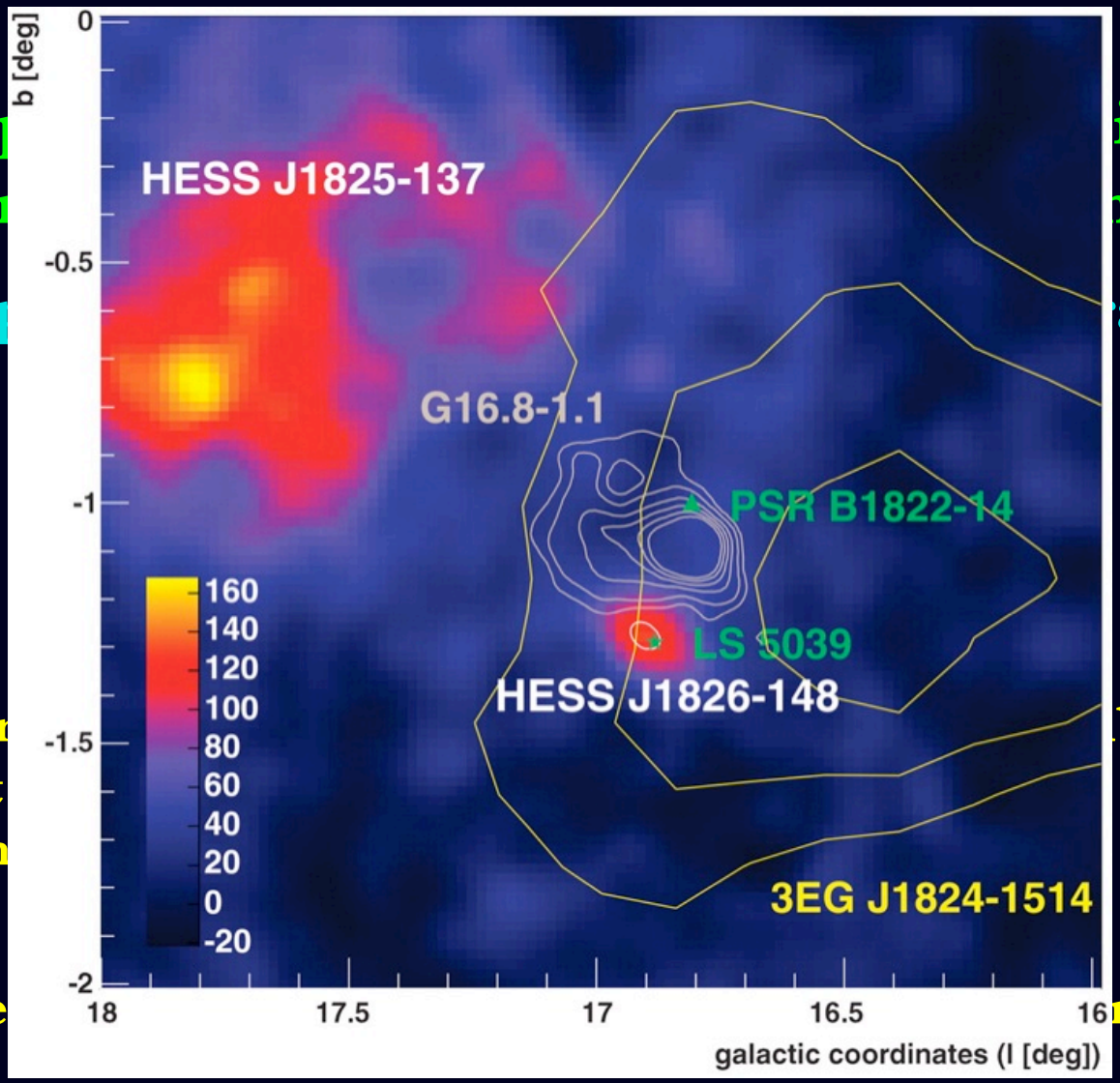
☛ **Will directly address questions about particle acceleration and internal energetics/matter content**

"Multimessenger" = multiwavelength

★ If p… …ional
co… …ns
p… …ame)

☛ Subr… …be with
first
mon…

☛ Will …
acce… …nt

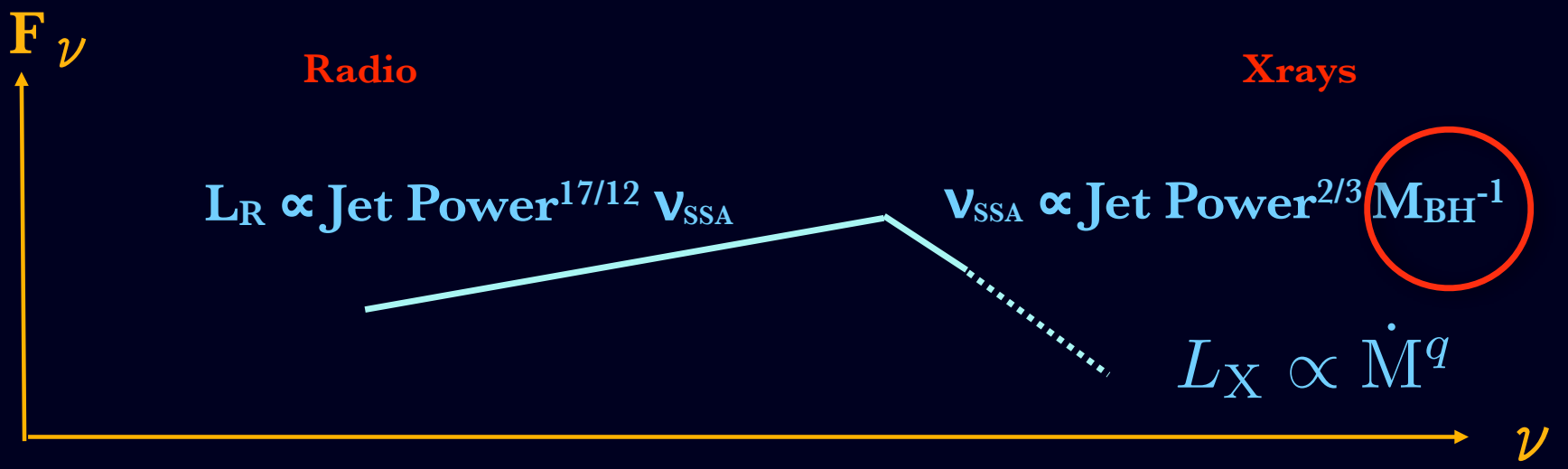


Summary

- **LOFAR promises significant progress in understanding jet physics in accreting black holes ➠ exploiting multi-λ and 8 orders of magnitude in mass/power scales!**
  - ➠ ***RSM:*** **helping understand radio-dominated states**
  - ➠ ***Low-ν alone:*** **jet energetics, e^- distribution, prompt synchrotron**
  - ➠ ***LOFAR in combination with multiwavelength*** **: new constraints on bulk velocity, geometry, emission mechanisms**
  - ➠ ***LOFAR/γ-ray*****: expanding spectrum on both ends, determination of hadronic component? Eventually in combination with direct neutrino detections?**
  - ➠ ***Spectral fitting*****: constraints on geometry and plasma conditions very close to BH ➠ clues about jet formation**

A few extra slides

Predictions for radio/X-ray correlations



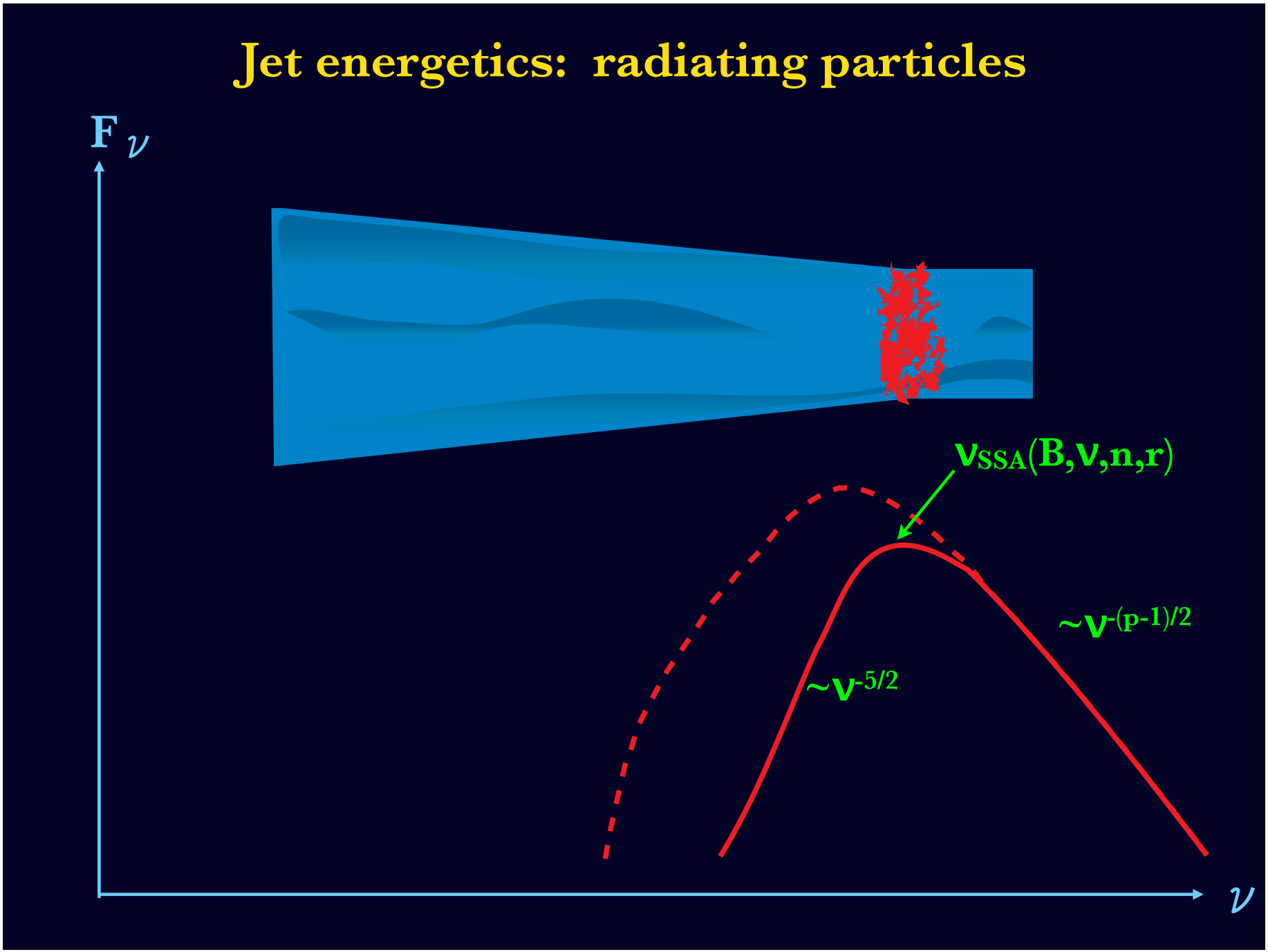
For objects with the *same* mass:

$$L_{\rm R} \propto L_{\rm X}^{m} \qquad m = \frac{\frac{17}{12} - \frac{2}{3}\alpha_{\rm R}}{q} \approx \frac{1.4}{q}$$

Synchrotron: q=2, ADAF/RIAF: q=2-2.3,
Radiatively efficient disk/corona: q=1 ➠ problematic

(Markoff et al. 2003, Merloni, Heinz & diMatteo 2003, Falcke, Körding & Markoff 2004)

Jet energetics: radiating particles



Jet energetics: radiating particles