Winds and high energy flares in GRO J1655-40

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Motivation

- Reanalyzed multiwavelength data of 2005 outburst rise of GRO J1655-40 with the initial motivation of investigating hysteresis in spectral state transitions.

- Led to surprising (re-)discoveries:
  - Hard X-ray flares in the soft state
  - Iron absorption features (from a wind) together with optically thin radio flare (jet).

OUTLINE

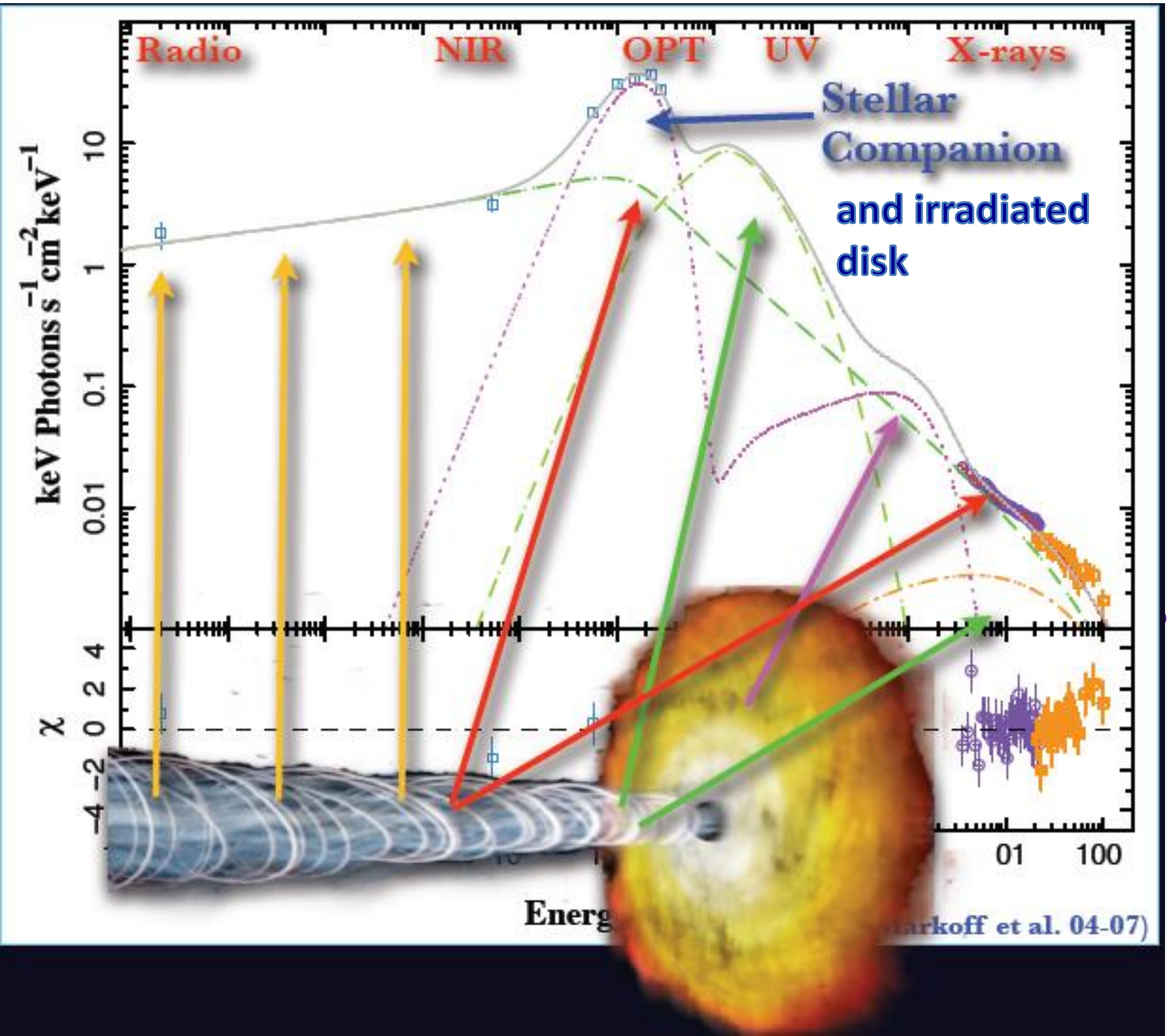
- Introduction

- GRO J 1655-40 in 2005
  - Hard X-ray flares in soft state
  - Iron lines with radio jets…

- Future look to some wind studies with the eXTP

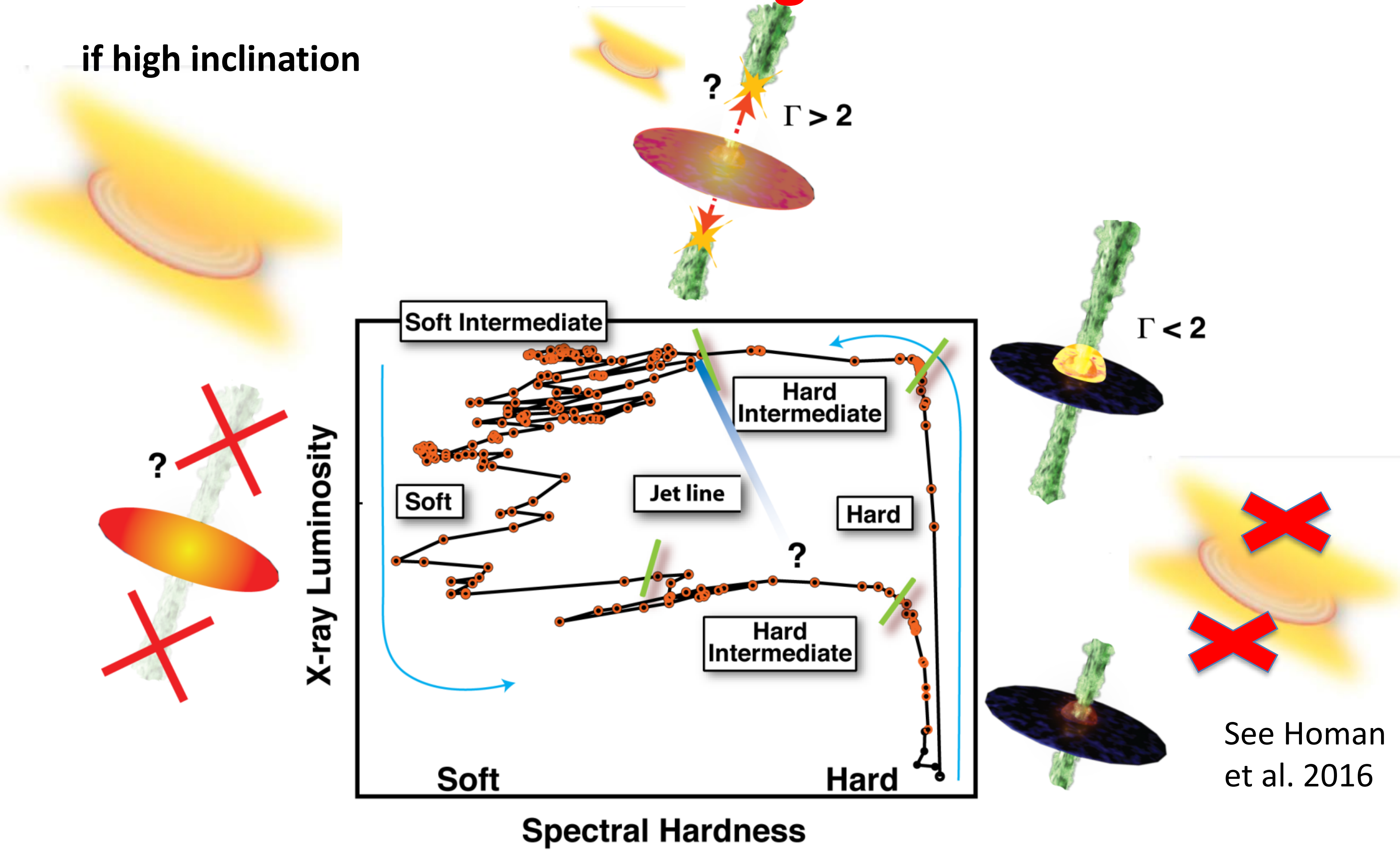
Why multi-wavelength studies?

GRO J1655-40, Migliari et al. 2007



- **Steady compact jet:** flat to inverted radio spectrum up to a break in the Near/mid infrared > Conical Jet.
- We need to disentangle jet from the companion+disk +corona emission.

Black hole states and transitions, the multiwavelength view



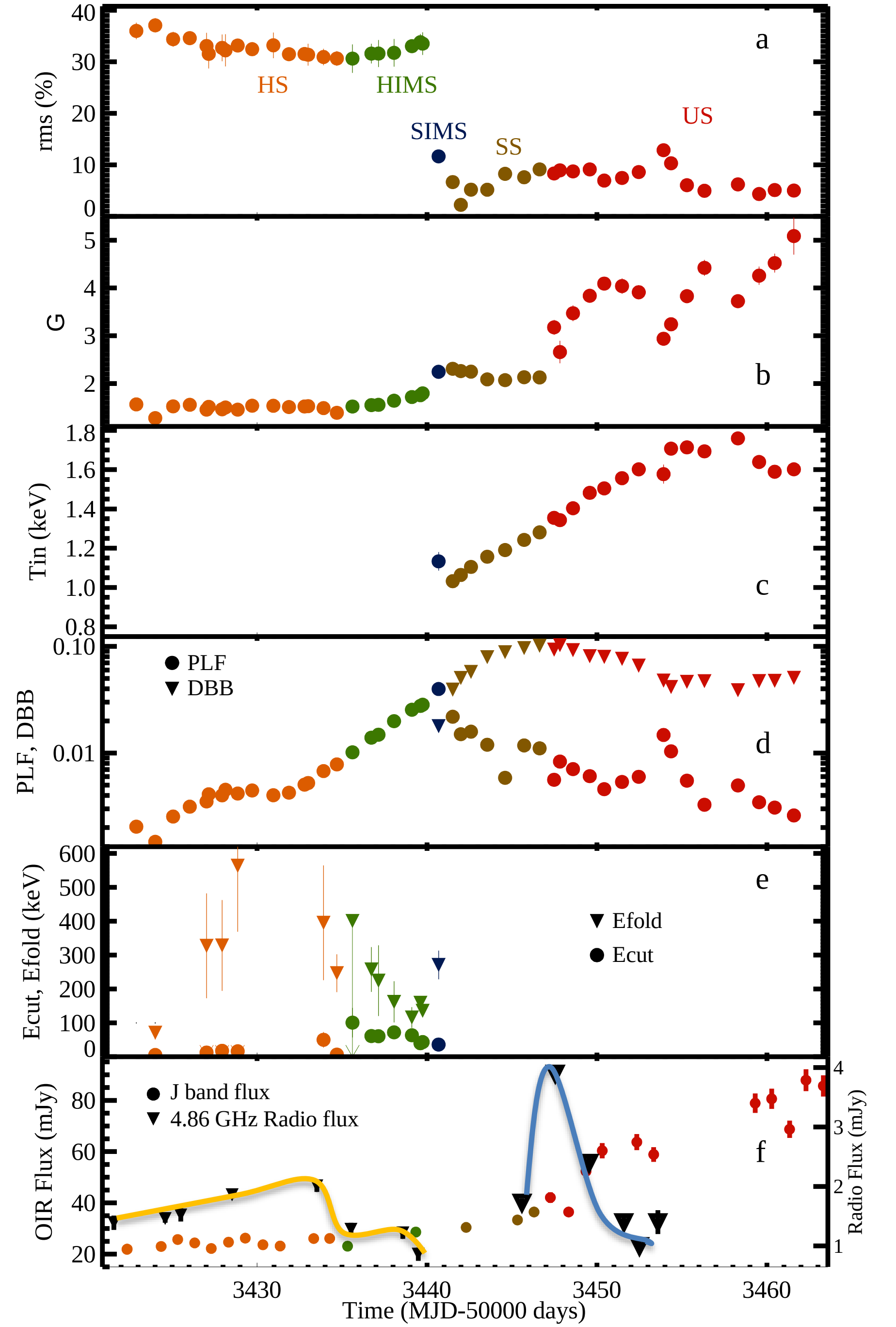
See Homan et al. 2016

GRO J1655-40, a special dataset

- Well determined distance and mass
- Very rich multiwavelength dataset
  - Third source showing relativistic jets (Hjellming & Rupen 1995)
  - First radio – hard X-ray correlation (Harmon et al. 1995)
  - First magnetically driven winds – Miller et al (but also see Netzer 2006)
  - First mid-IR detection of (jet / disk/ combination) with Spitzer (Migliari et al. 2006)
  - Rich near-infrared behavior (Shidatsu et al. 2016, Uttley & Klein-Wolt 2015)
  - Rich X-ray phenomenology (many references!)
  - High frequency QPO pair (Strohmayer 2001), low frequency QPOs deep in the hard state together with compact jet (Dincer et al. 2014).

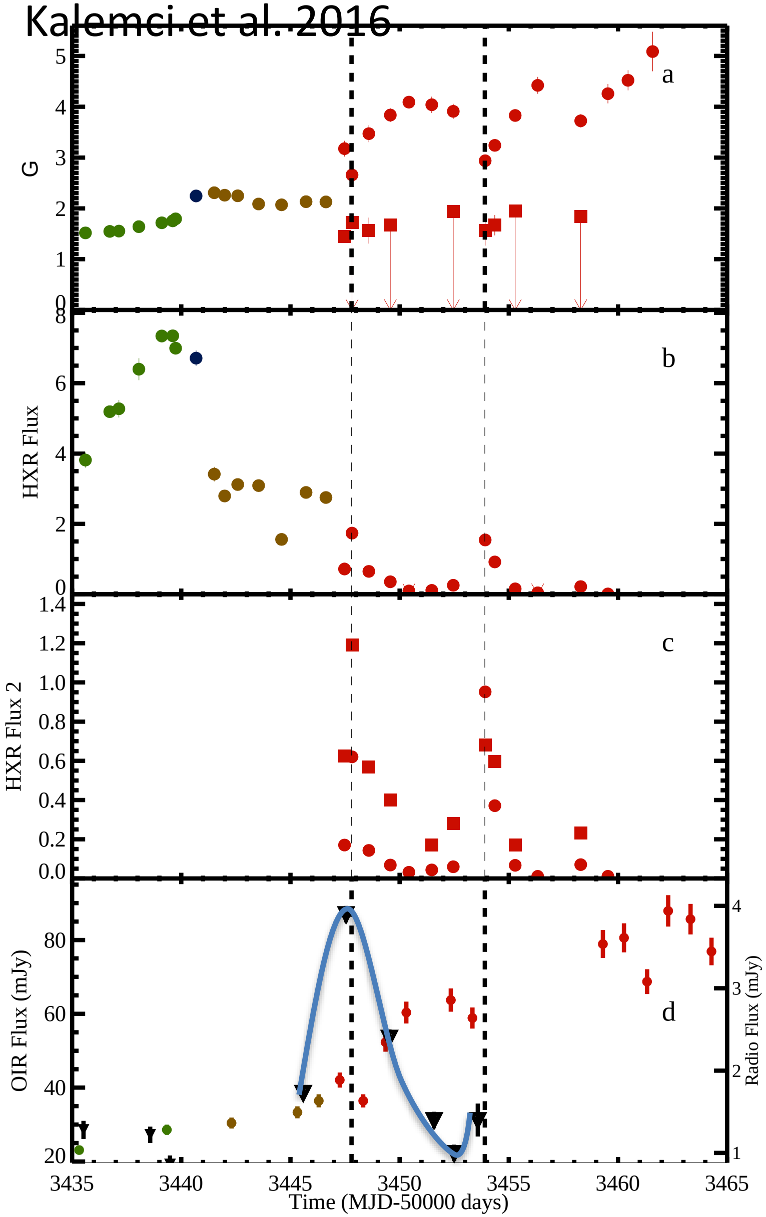
GRO J1655-40, an archival MW study

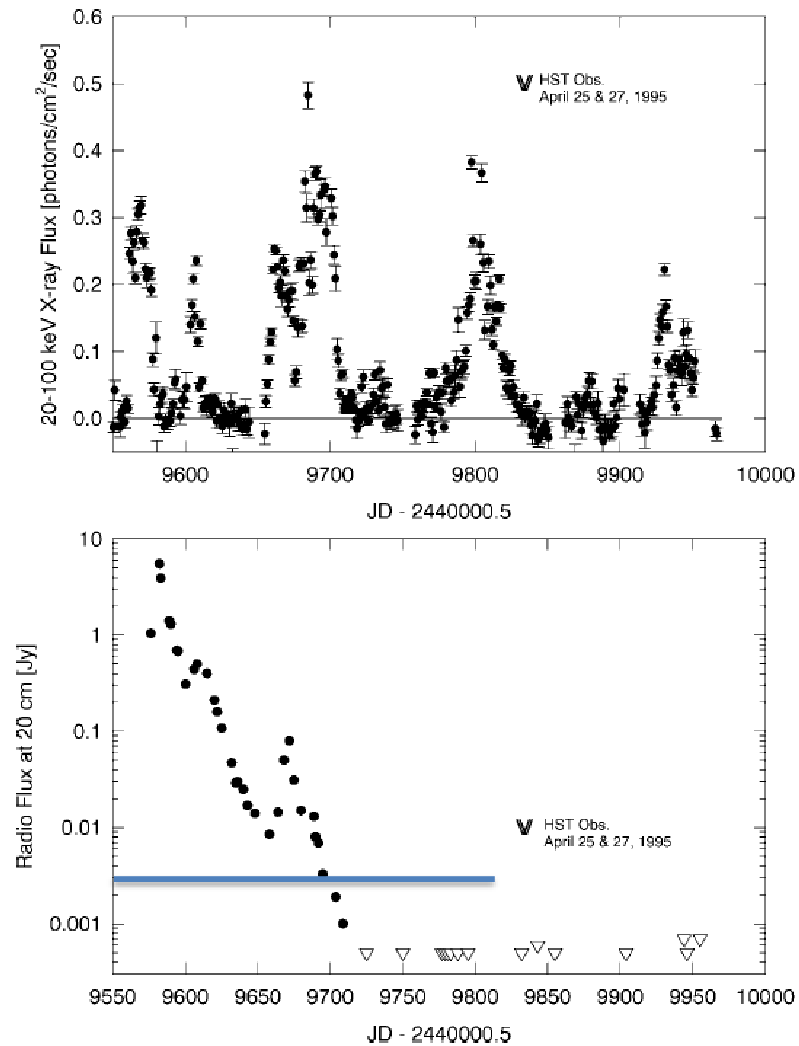
- Reanalyzed RXTE in X-rays, SMARTS in optical/NIR, and VLA in radio during **outburst rise**.
- Modelled RXTE PCA+HEXTE spectra with phenomenological, as well as Comptonization models (*eqpair*).
- Characterized state transitions, using timing and spectral data.
- Published recently in MNRAS, Kalemci et al. 2016



GRO J1655-40, 2005, Hard X-ray flares

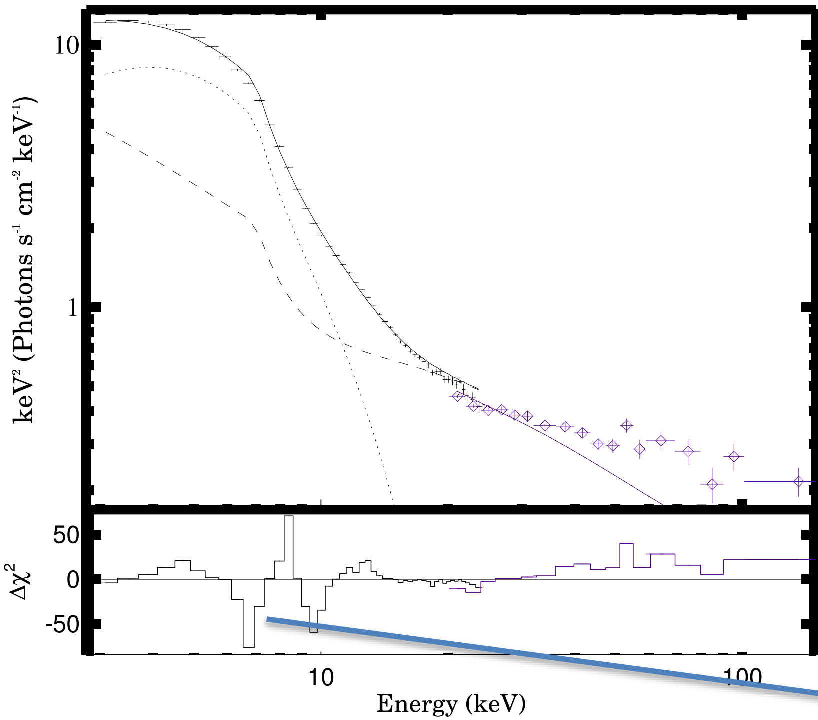
Kalemci et al. 2016

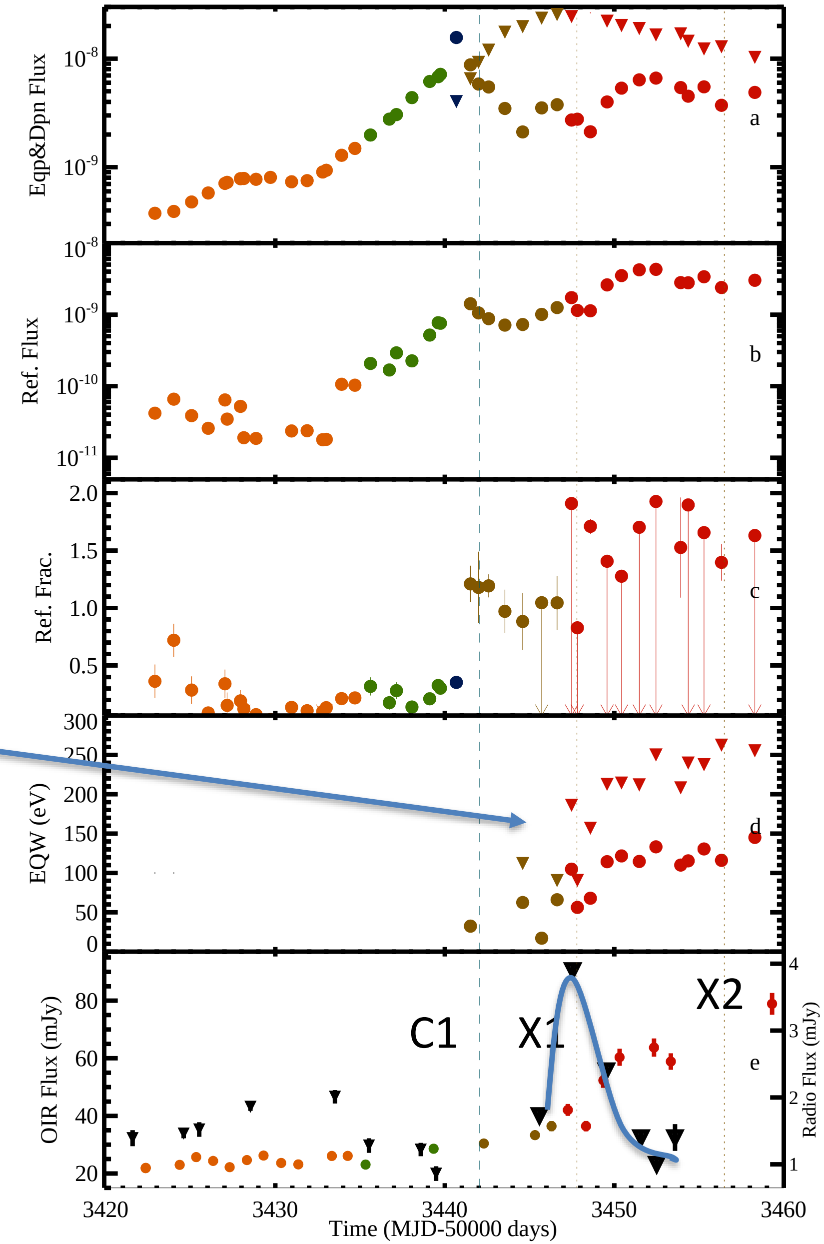




Tavani et al. 1996

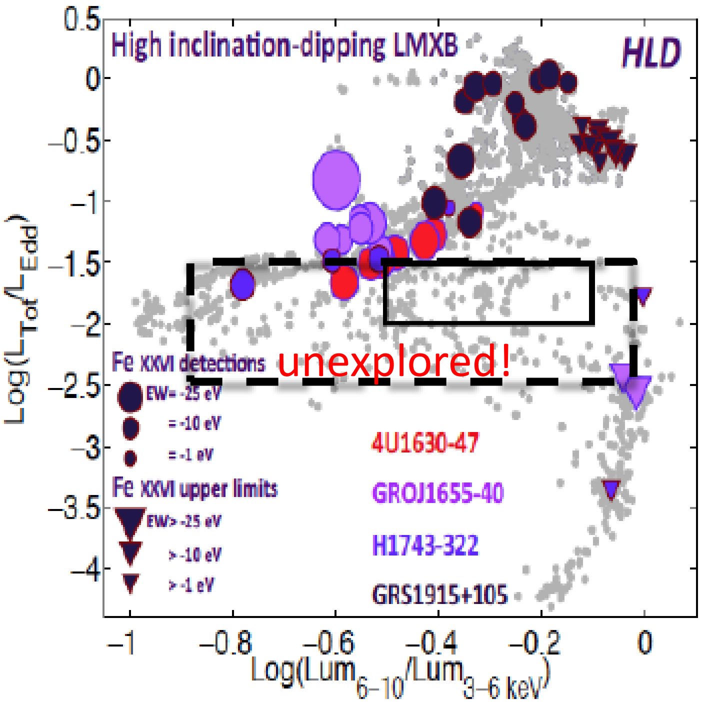
Winds with radio flare



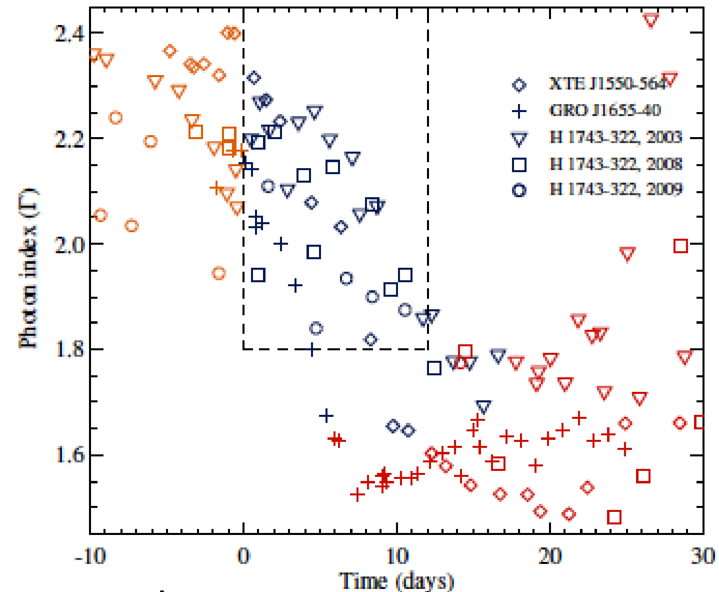


Iron absorption line energies and equivalent widths consistent with what XMM-Newton detected in the ultrasoft state (Diaz-Trigo et al. 2007). Figure also shows the need for a high energy component.

What can be done with the eXTP?



Ponti et al. 2012

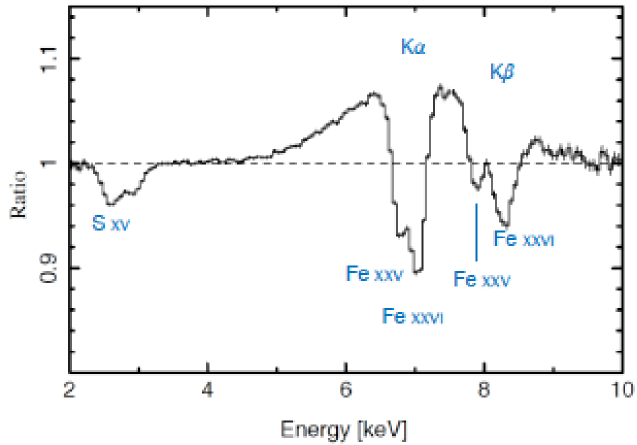


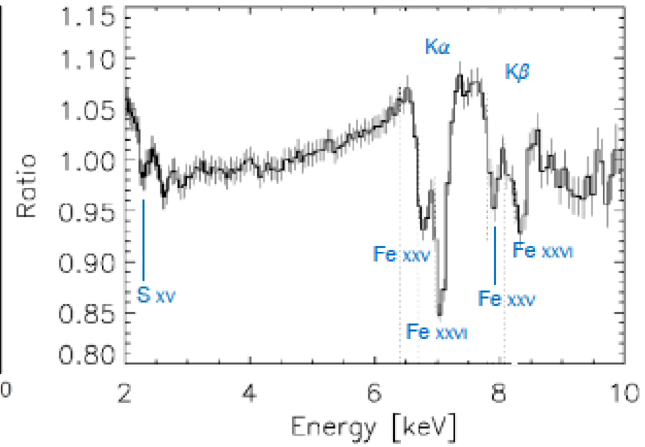
Kalemci et al 2013

- Wind detections are scattered – with Chandra and XMM-Newton (and Athena and X-ray Surveyor) difficult to schedule.
- Fundamental questions: how do winds form and die? How are they related to jet formation and quenching? Are they always thermal in origin but could they sometimes be magnetic?
- To be able to monitor wind related structures in X-rays **everyday** with mid-resolution will answer some of these questions and provide important insight onto origin of winds.

Future with eXTP

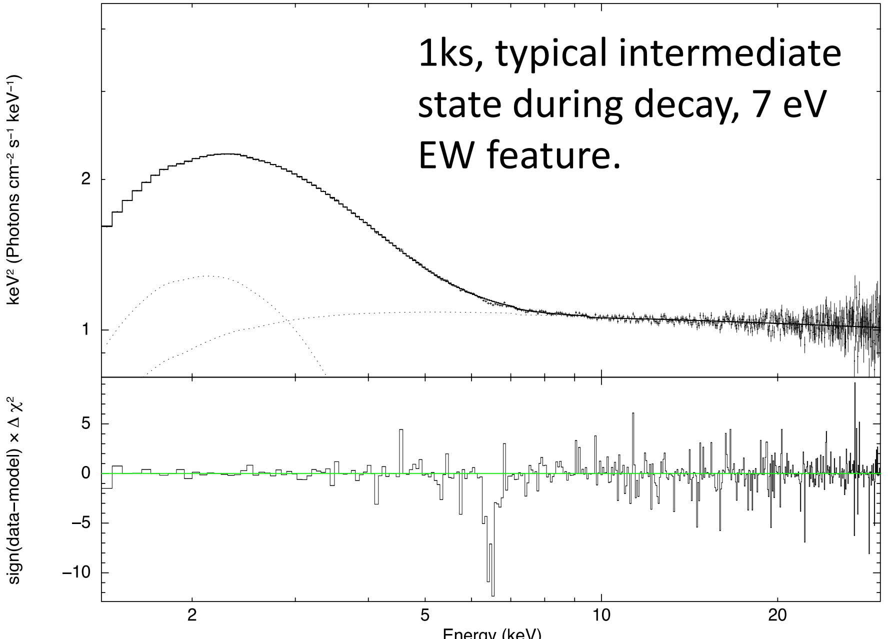
1. Wind absorption features as observed in GRO J1655-40 during outburst rise will be detected in < 100s with LAD on eXTP allowing precise determination of wind formation and its relation to X-ray spectrum and compact jets. Determination of line centroid 0.1 -0.3% error.





comparison of 3ks eXTP LAD and 80 ks XMM-Newton

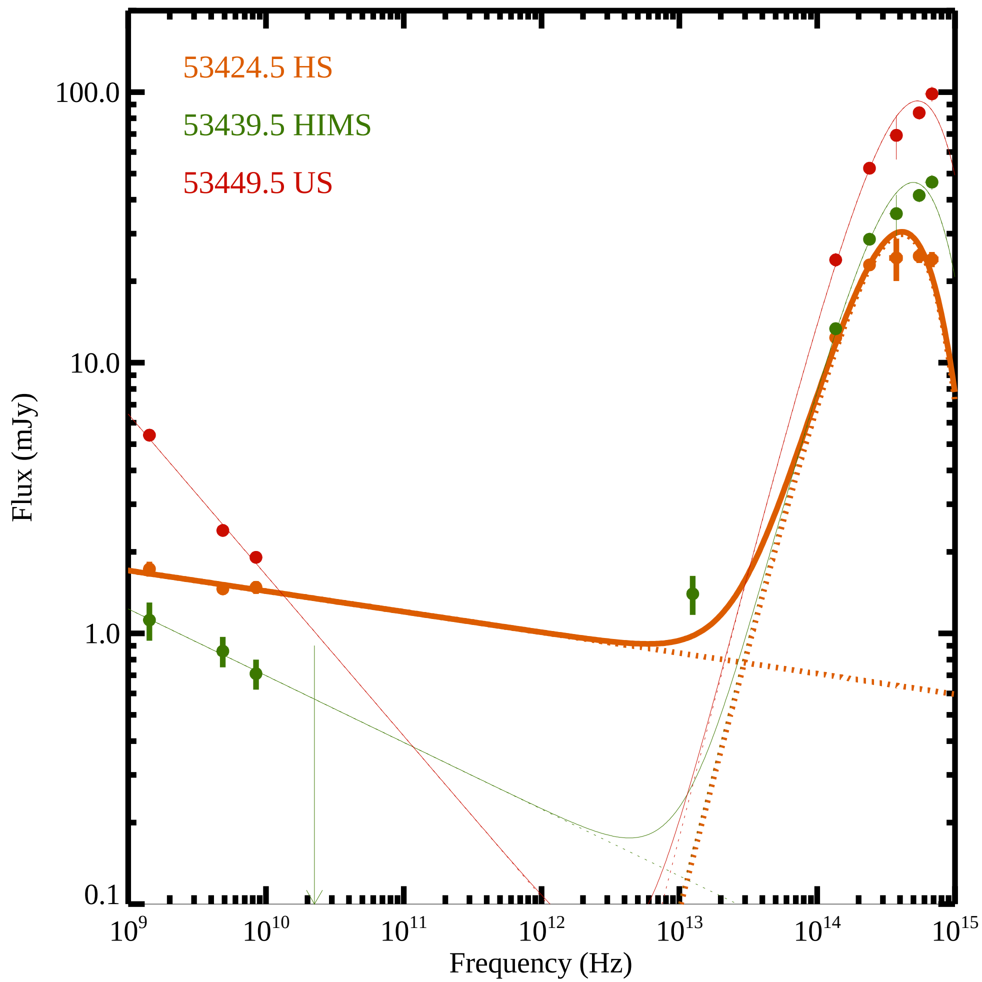
2. Wind absorption features stronger than 5 eV EW will be detected during outburst decay in an intermediate state in less than 1 ks with eXTP LAD for a typical flux level of a few x 10^{-9} ergs cm^{-2} s^{-1} . Such detections will allow relating winds to jet formation.

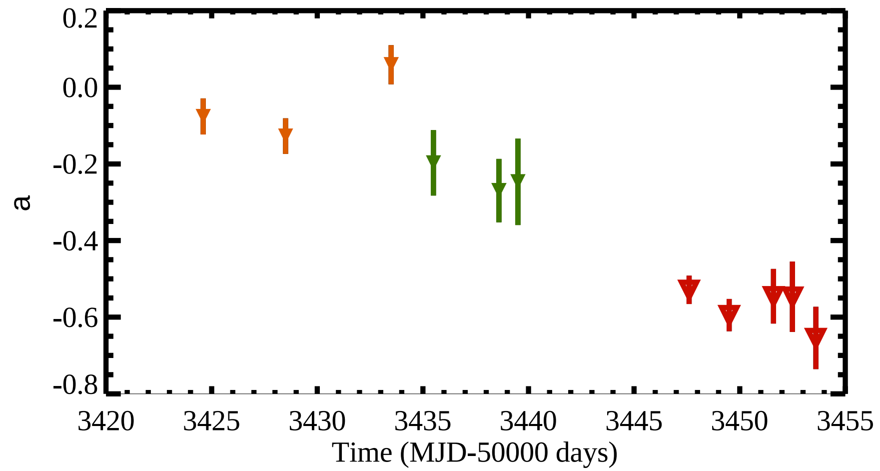


Conclusions

- The quality of GRO J1655-40 data provides us a glimpse of what awaits us with the eXTP in terms of observatory science.
- Thanks to better energy resolution the eXTP will provide much better constraints on wind structures, and will allow us to find how winds and jets are related when they are (either of them) first forming.

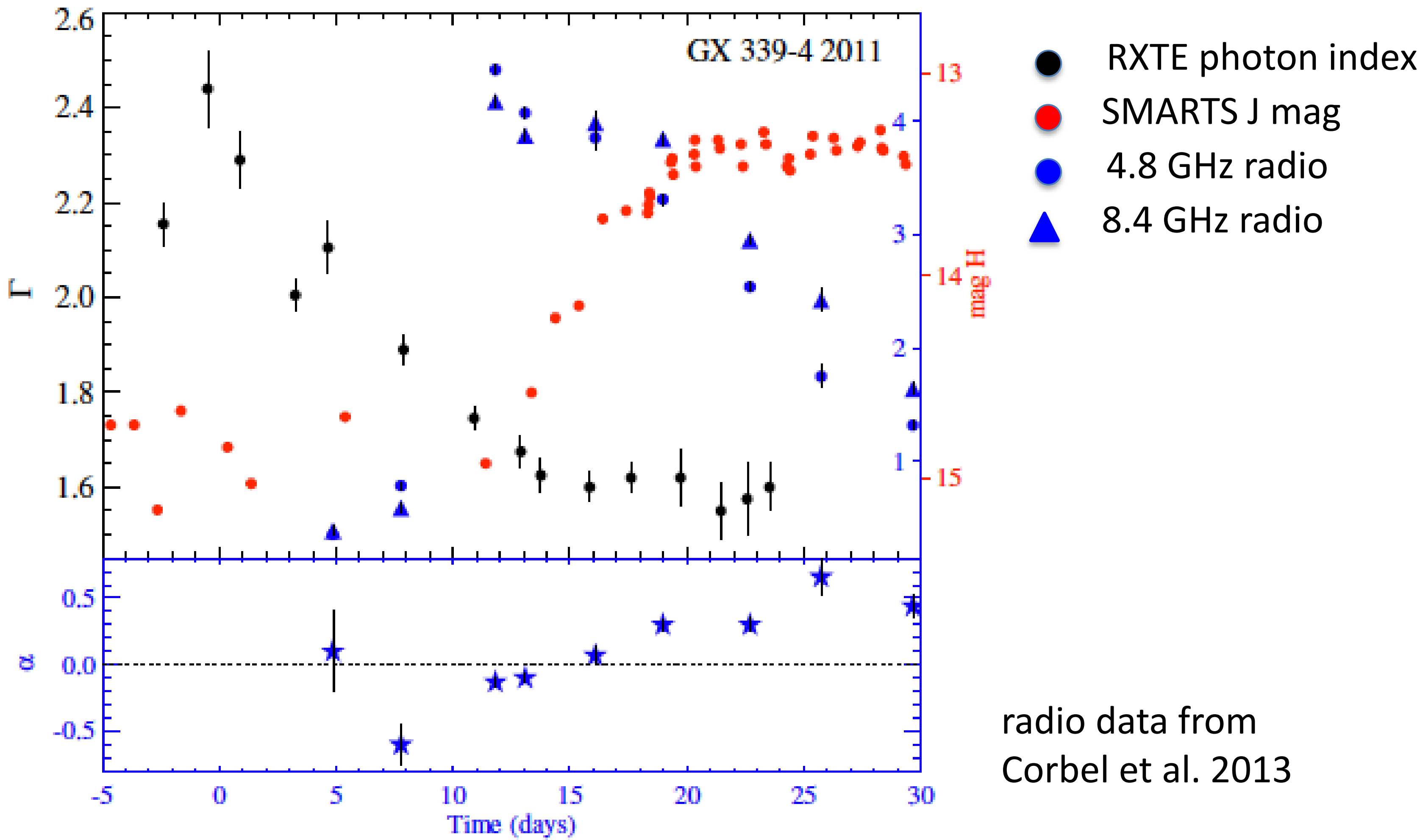
Multi-wavelength transition during rise



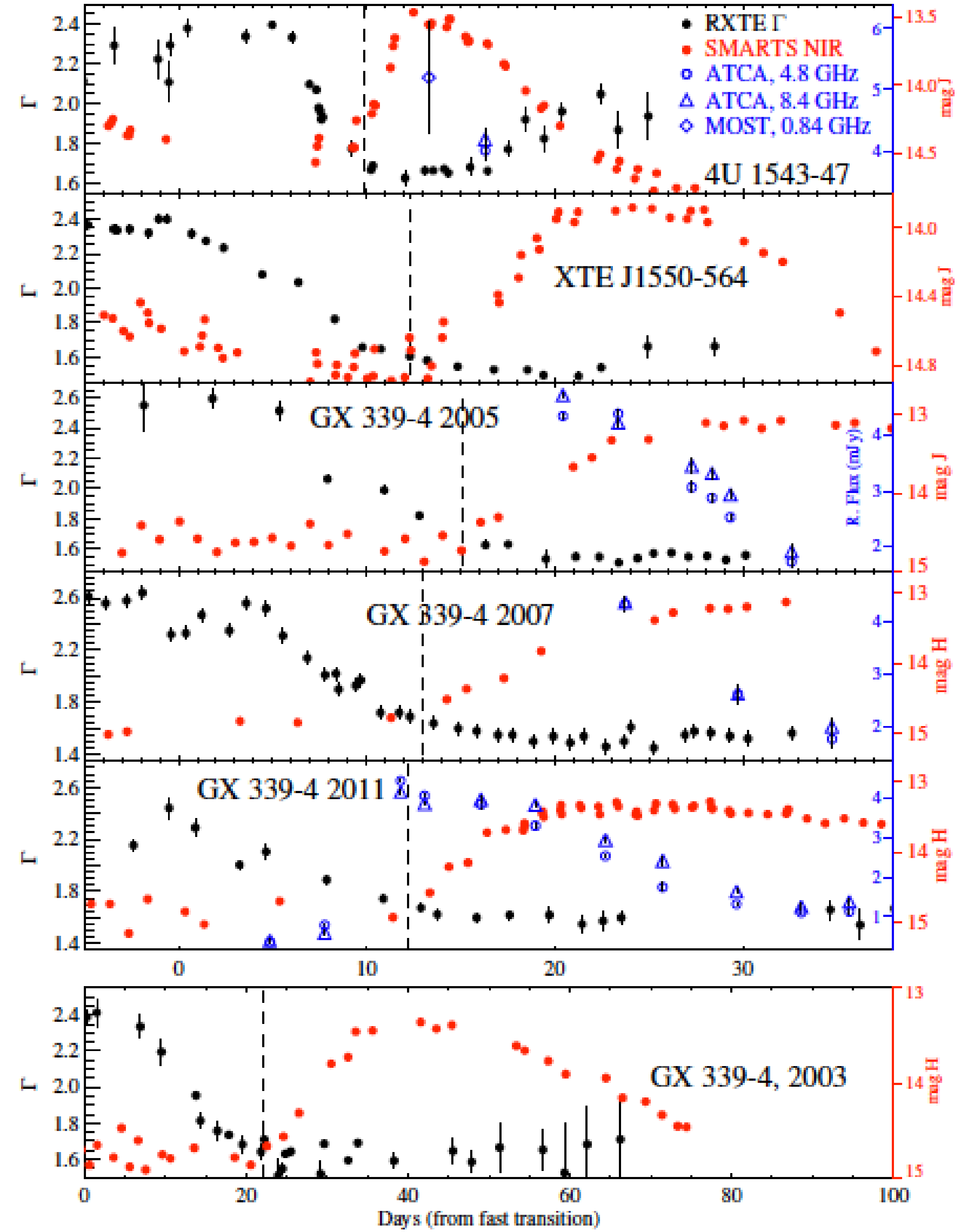


- Concentrate on radio evolution for this source as the near-infrared to optical dominated by strongly irradiated accretion disk.
- Radio is compact jet dominated in the HS and HIMS, and optically thin jet dominated in the US.
- The evolution indicates opening up of the jet angle as the radio spectral index drops.

What about outburst decays?



radio data from
Corbel et al. 2013



All sources we investigated

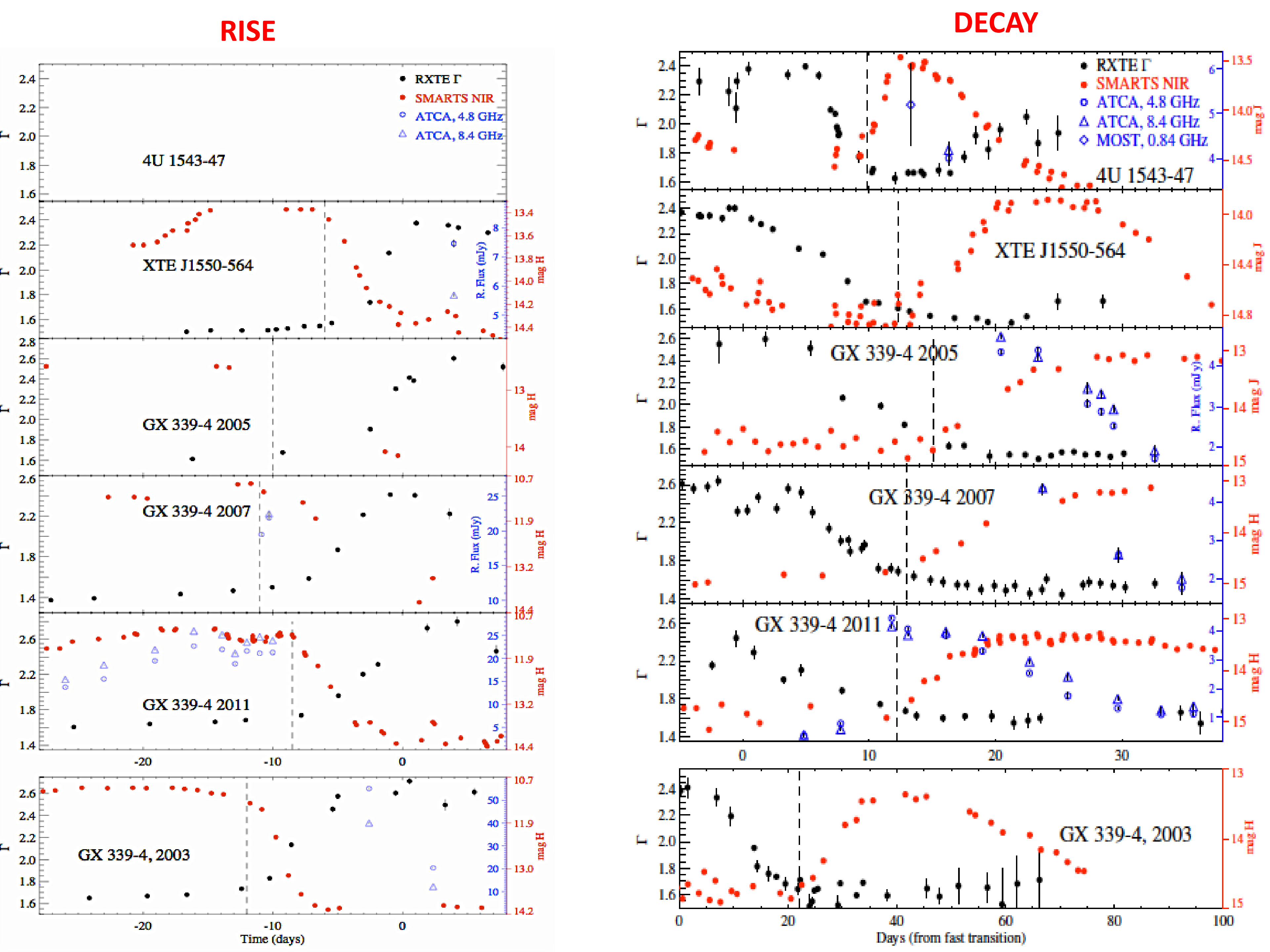
Similar rebrightinings, in other sources and outbursts with similar spectral index behavior!

Natural to assume that the NIR brightening is jet related, but also see
Veledina & Poutanen 2012
Poutanen & Veledina 2014
hot accretion flow model.

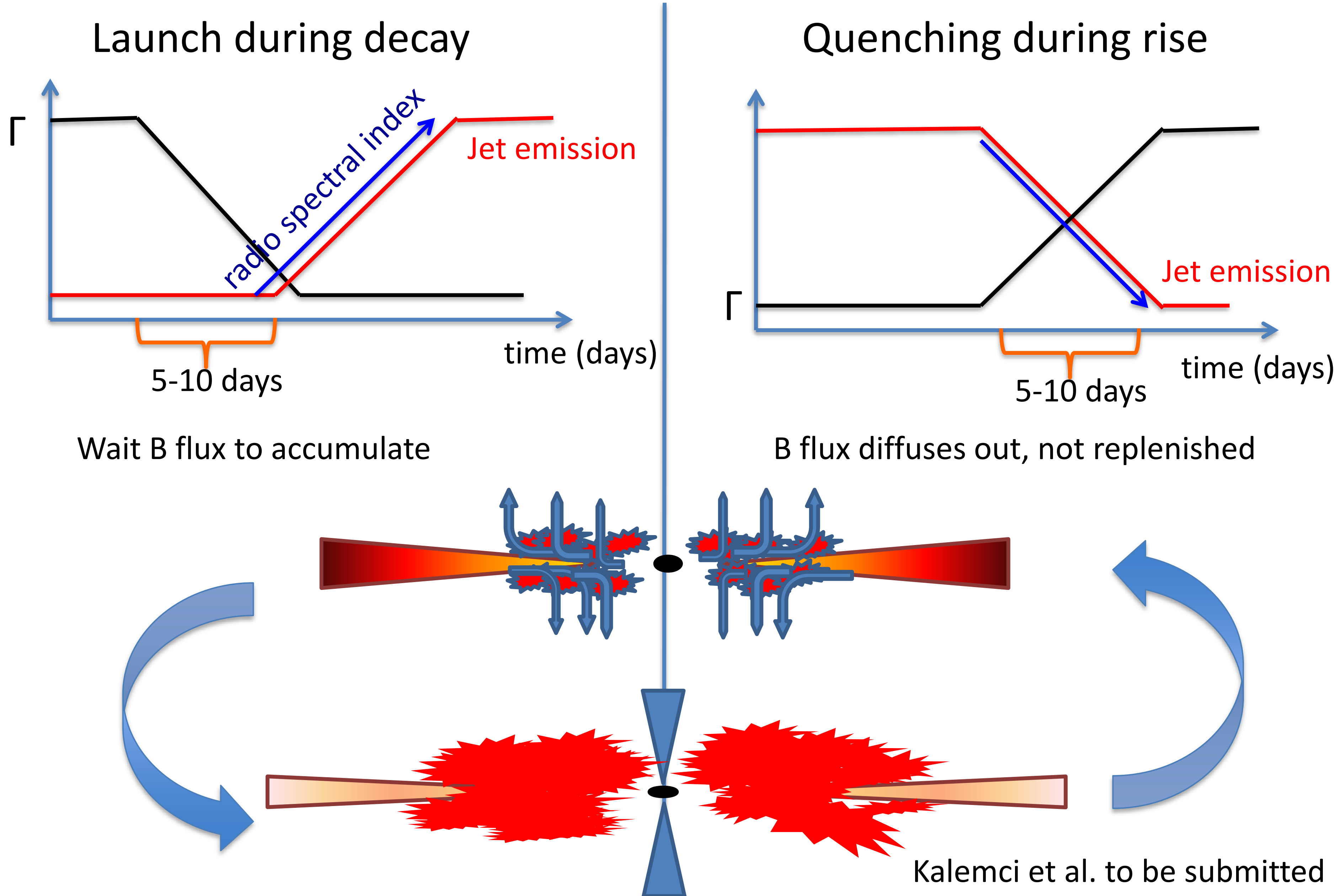
Kalemci et al. 2013

Comparison of rise and decay sequence

- spectral index (Γ) as a proxy for strength of corona, formation of geometrically thick medium
- NIR and radio flux as a proxy for jet emission
- Radio spectral index as a proxy for jet collimation.

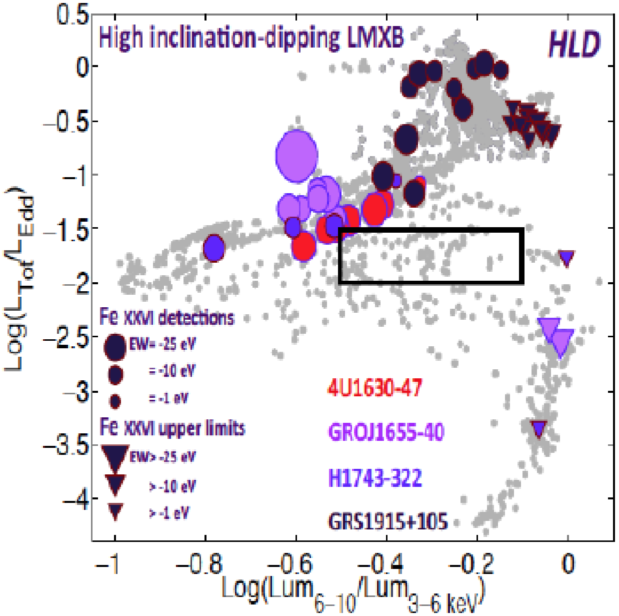

RISE
DECAY
RXTE Γ
SMARTS NIR
ATCA, 4.8 GHz
ATCA, 8.4 GHz
MOST, 0.84 GHz
4U 1543-47
XTE J1550-564
GX 339-4 2005
GX 339-4 2007
GX 339-4 2011
GX 339-4, 2003
Γ
R. Flux (mJy)
mag H
mag J
Time (days)
Days (from fast transition)

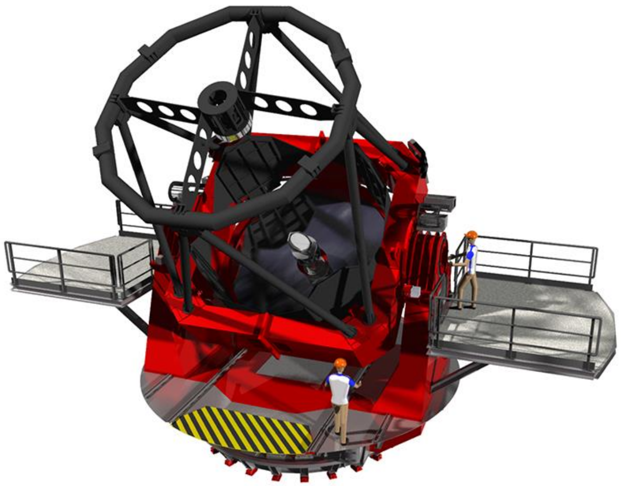
A new hysteresis...



Future outlook II

- Extended future
  - Prepare for Athena and eXTP with "WINDS of change". Why don't we observe winds in the hard state?
  - Surveys – LSST, SKA + SMARTS / DAG NIR complete and excellent MW coverage of state transitions!





DAG Telescope with possible MKID focal plane instrument

Elevated Disks and State Transitions

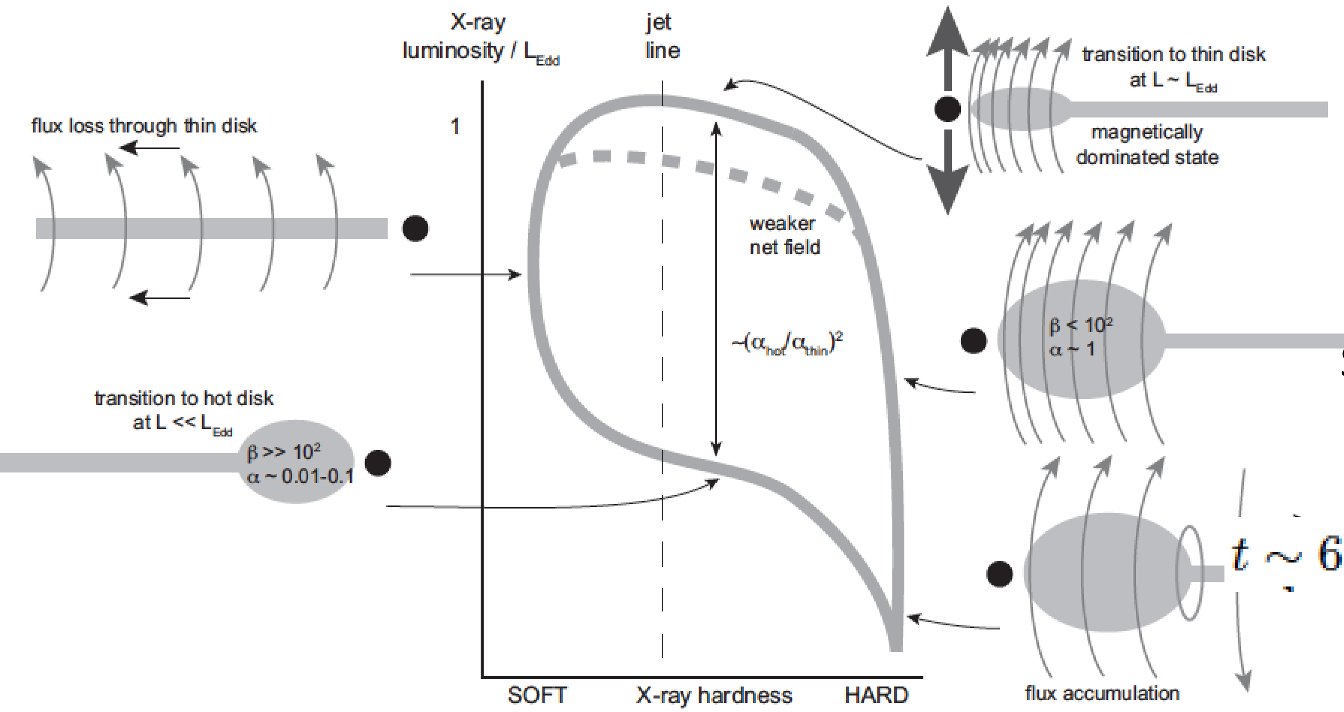
Elevated disks are geometrically thicker, and accretes faster, and thermally and viscously stable.

The result:

- MRI active lower zone produces thermal emission
- MRI active upper zone produces thermal + nonthermal Comptonized emission, winds, jets
- Upper vs. lower luminosity ratio determines state
  - Lower dominates: soft state
  - Upper dominates: hard state
  - Both comparable: intermediate state

(Begelman et al. 15)

Origin of the poloidal field?
The secondary star?
Advection/stochastic accumulation?



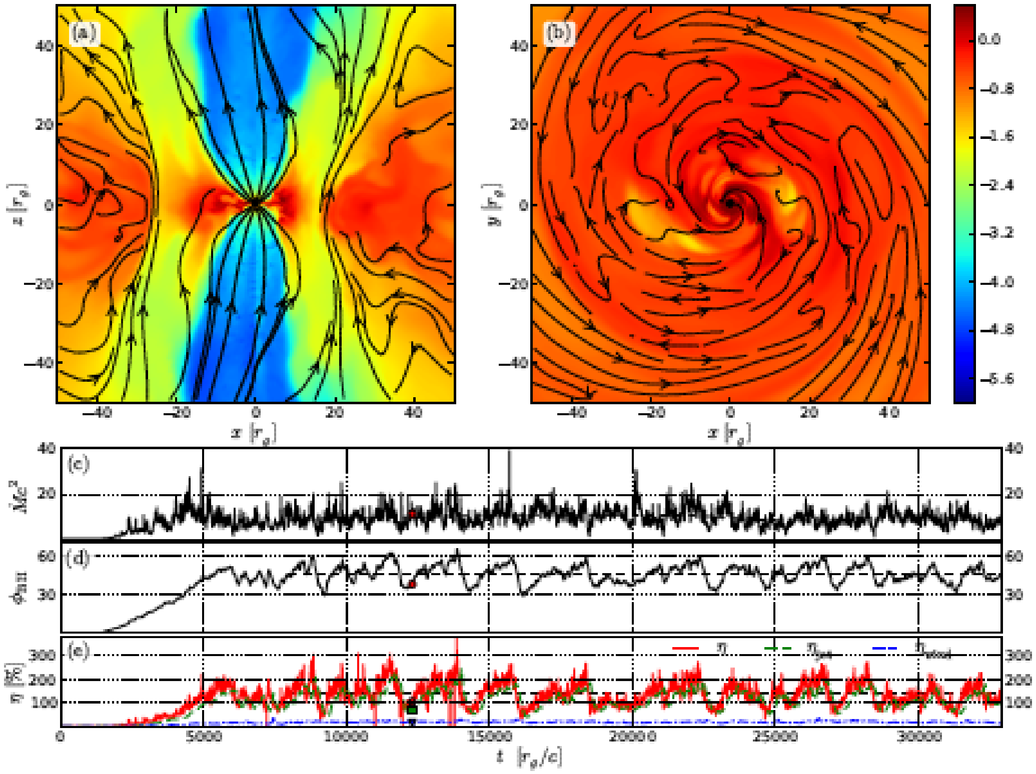
Stochastic net magnetic field accumulation timescale:

$$t \sim 6 \times 10^5 (N/f)(r/10^3 r_g)^{3/2} \text{ s}$$

with typical parameters, it takes 10-20 days to obtain magnetic fields high enough to produce jets, it is the right time scale!

Begelman & Armitage 2014

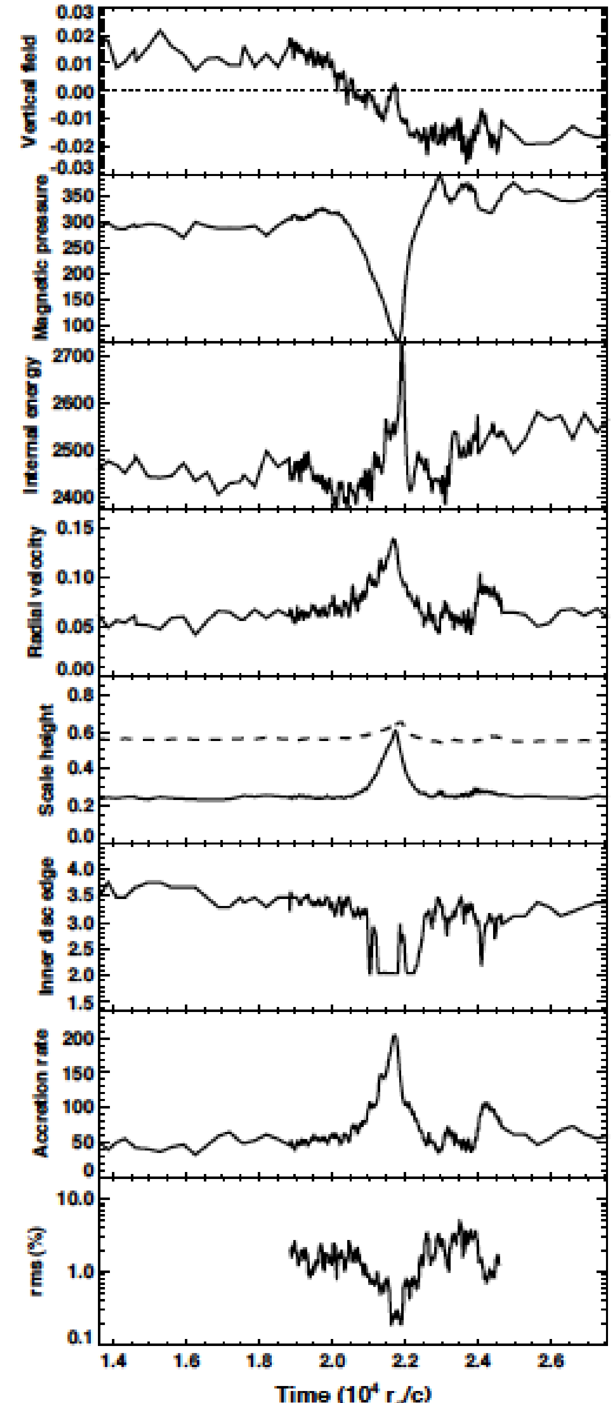
Magnetically arrested disks and field flipping



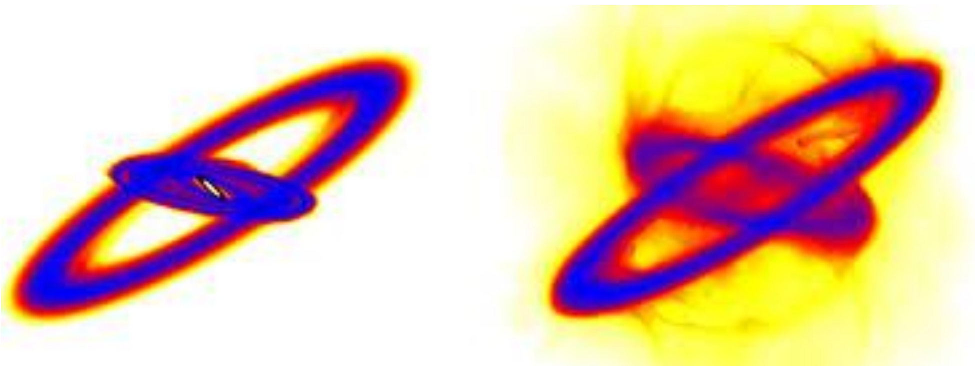
Tchekhovskoy et al. 2012

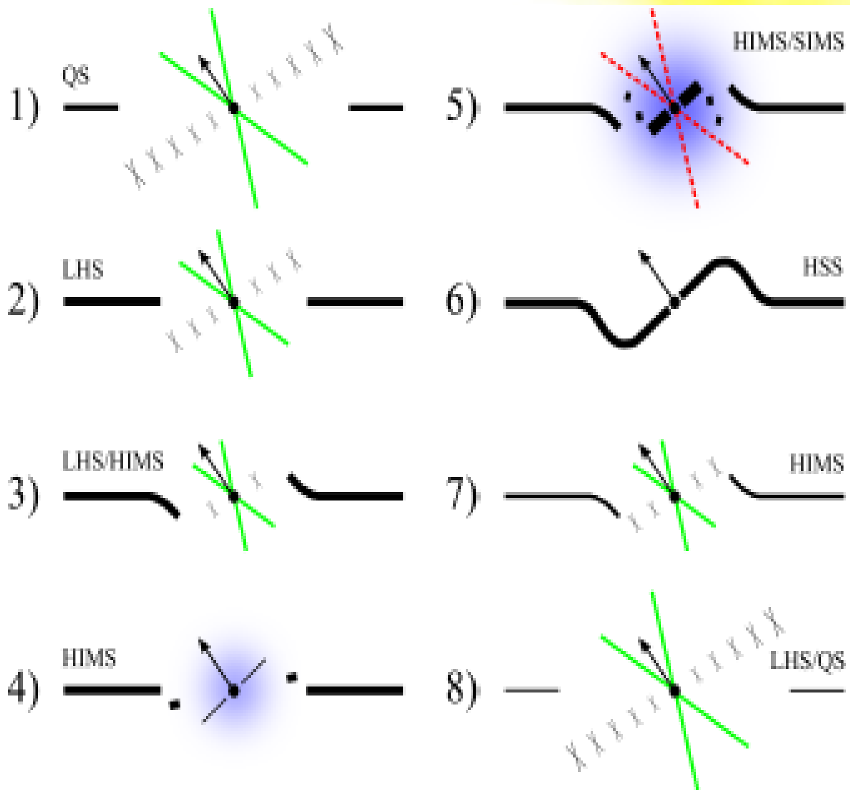
See also Li & Yan 2015

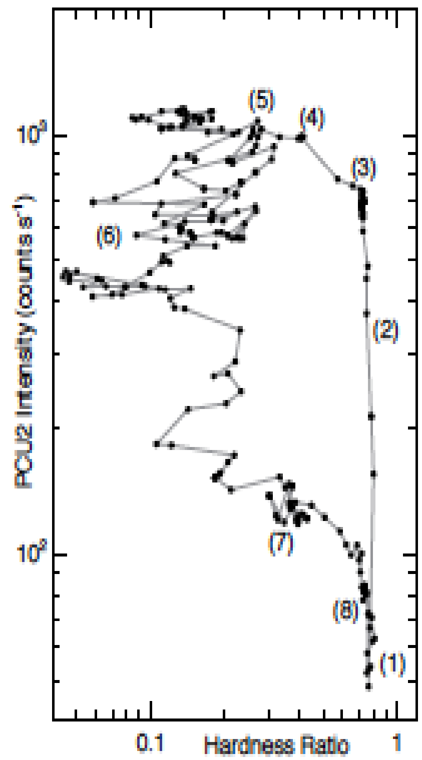
Igumenschev 2009
Dexter et al. 2013.



Disk breaking….







Could only explain BH outbursts with disk/spin misalignment, not valid for NSs and BHs but,

May explain:
Quick HIMS/SIMS transitions.

Nixon & Salvesen 2013

Questions

- What determines the transition luminosity in the upper branch?
- Is the transition luminosity constant during the decay?
- When is the optically thin jet actually launched during the rise, how is it related to timing and spectral changes?
- What is the role of B field in state changes, and where is it created?
- How do you reconcile truncated disk models with iron line transition radius measurements?
- What is the role of boundary layer in launching jets in WDs and NSs?
- Can a single mechanism explain major properties of state transitions in BHs, WDs and NSs?

Outlook

- Phenomenology is way ahead of theory…
- Expecting big breakthrough in simulations.
- SKA + LOFTish + LSST + IR monitoring would open up new insights.

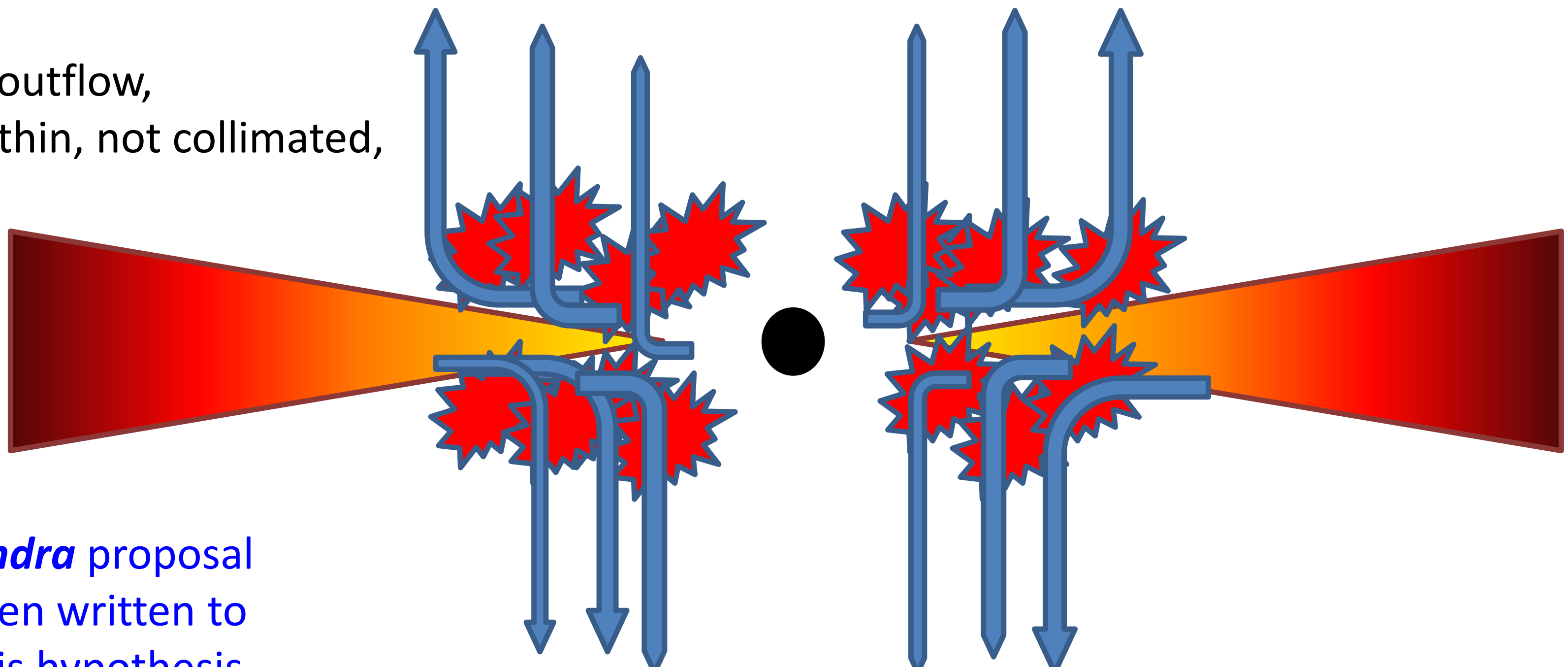
DISCUSSION and INTERPRETATION I

Observing compact jet requires:

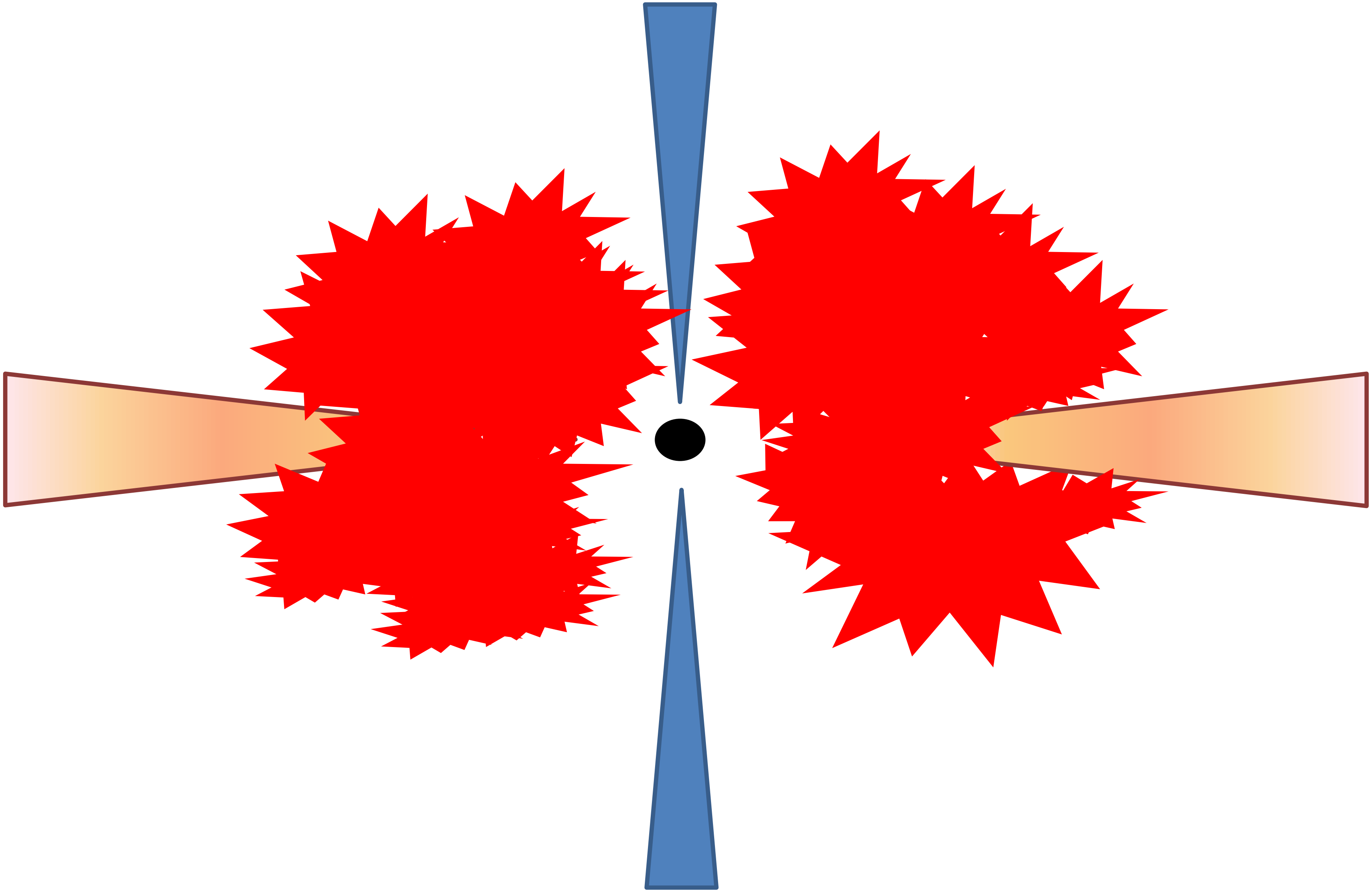
1. Transport of ordered magnetic field (Beckwith 2009, McKinney 2012),
2. Effective collimation,
3. Radiative processes (shocks, etc, Fragile et al. 2012)

Optically thin radio emission: Outflows, in terms of wind/or not so collimated structures may occur as soon as we see the changes in X-ray spectral and temporal parameters, basically the corona cannot collimate outflows.

bi-polar outflow,
optically thin, not collimated,



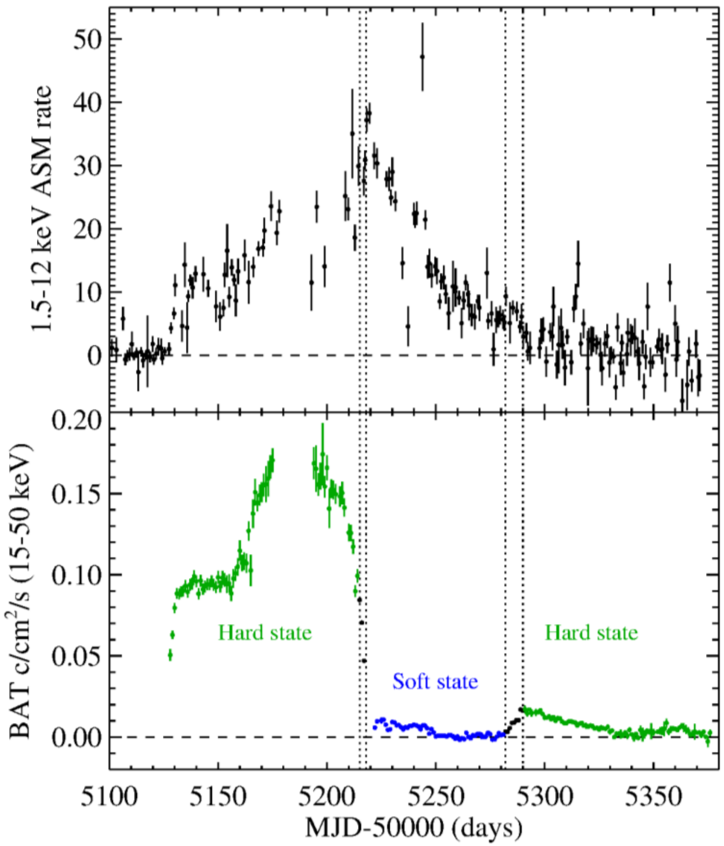
A ***Chandra*** proposal has been written to test this hypothesis....

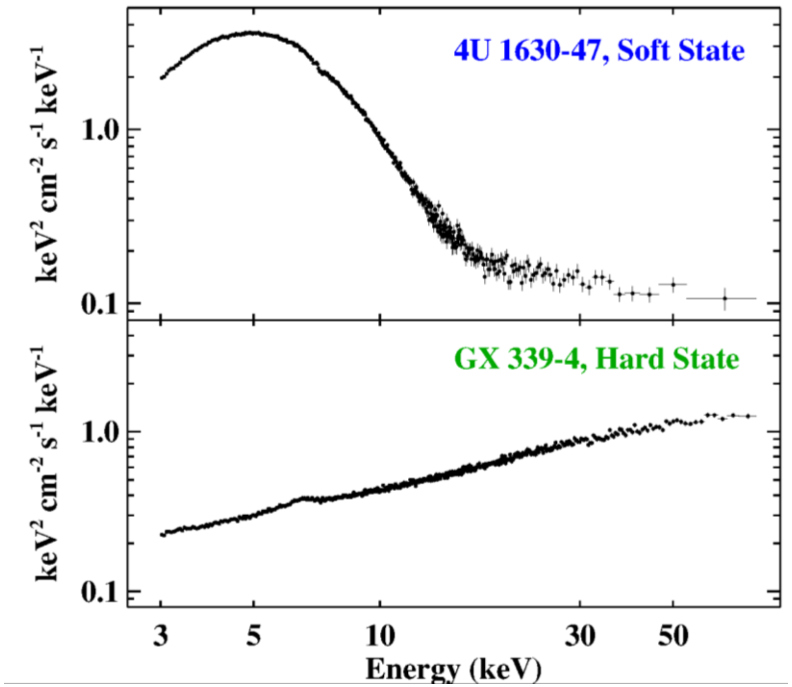


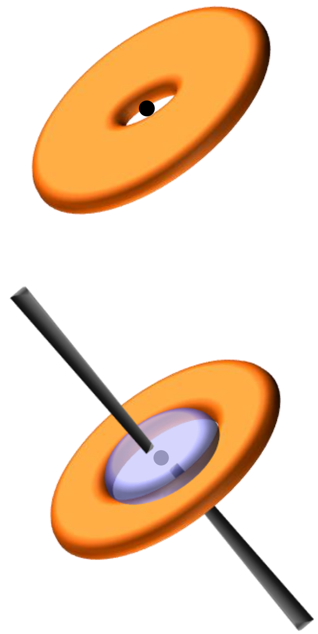
DISCUSSION and INTERPRETATION II

Disk flux goes down → corona scale height increase → effective transport of B field + effective collimation, all ingredients necessary for compact jet formation. BUT...

Spectral state transitions







3-79 keV *NuSTAR* spectra
(King et al. 2014; Fuerst et al. 2015)

- Sudden transitions during an outburst from XTE J1752-223

- Soft state: ~1 keV thermal plus power-law
- Hard state: Γ ~ 1.4-1.8 power-law

What is the source of ordered B field?

- Outer disk, companion star?
  - high B companion (Shuang-Lian and Yan 2015)
- Thick disk/thin disk boundary:
  - Begelman & Armitage 2014
  - RP cosmic battery (Contopoulos & Kazanas 98)

Hysteresis and state transitions

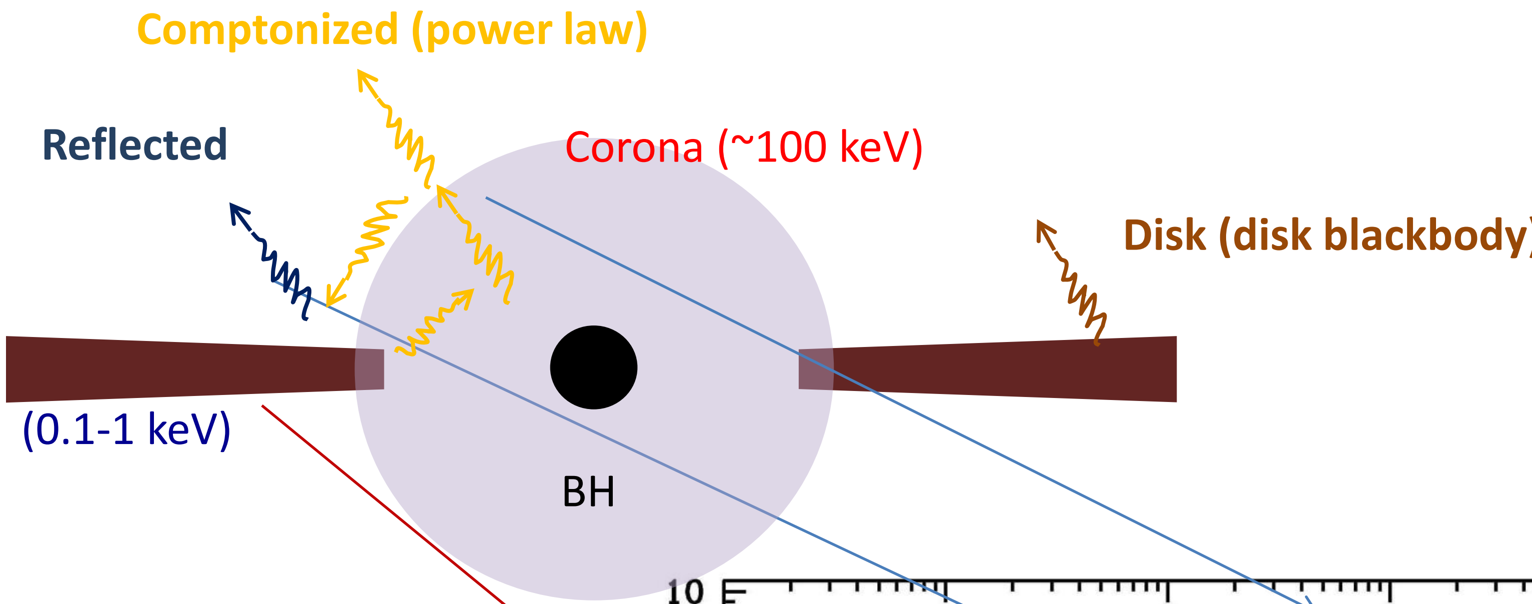
- Begelman & Armitage 2014
- Kylafis had similar ideas

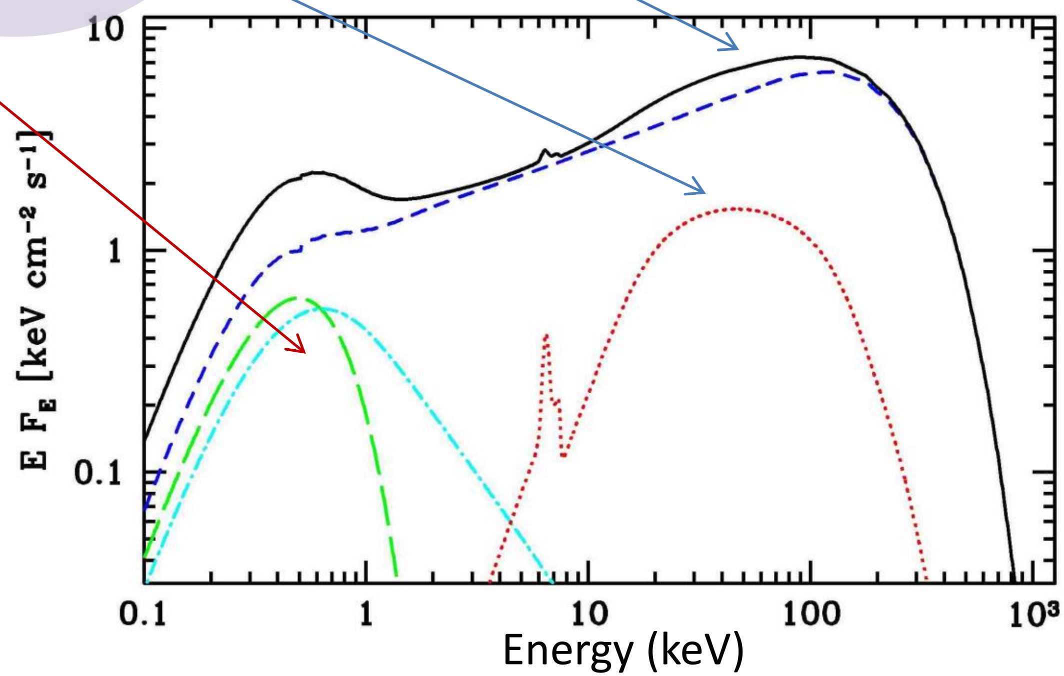
- Cao 2015, magnetic outflows increasing radial velocity, helping ADAF survive.

Interpretation in terms of B field accumulation-transport models

- The magnetic field normally diffuses out in the soft state when the optically thick disk moves all the way to ISCO.
- During the hard state, magnetic field in the inner region is continuously replenished (perhaps by the mechanism described in Begelman & Armitage 2014 or PRCB).
- As the inner disk forms, the easy transport is hampered, and B field decreases, reducing collimation and decreasing radio/infrared flux, which is consistent with what we observe during the rise. This would happen as soon as disk starts to move in because the field is already present in the inner regions. While during the rise we need to wait until enough B field is accumulated.
- The **prediction** is then the softening should also lead to radio spectrum becoming optically thin….

X-ray emission from black holes

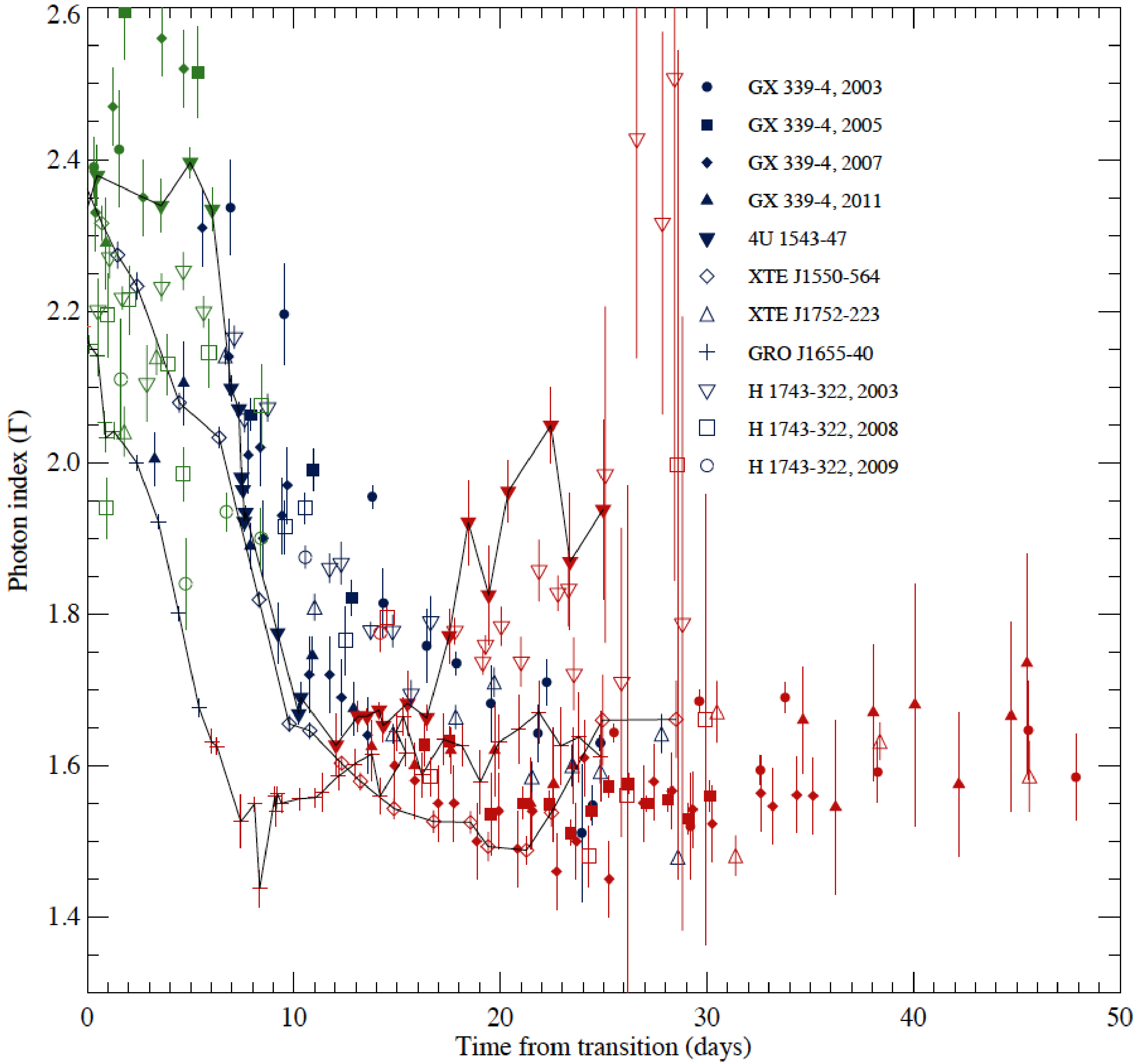




Phenomenological model:

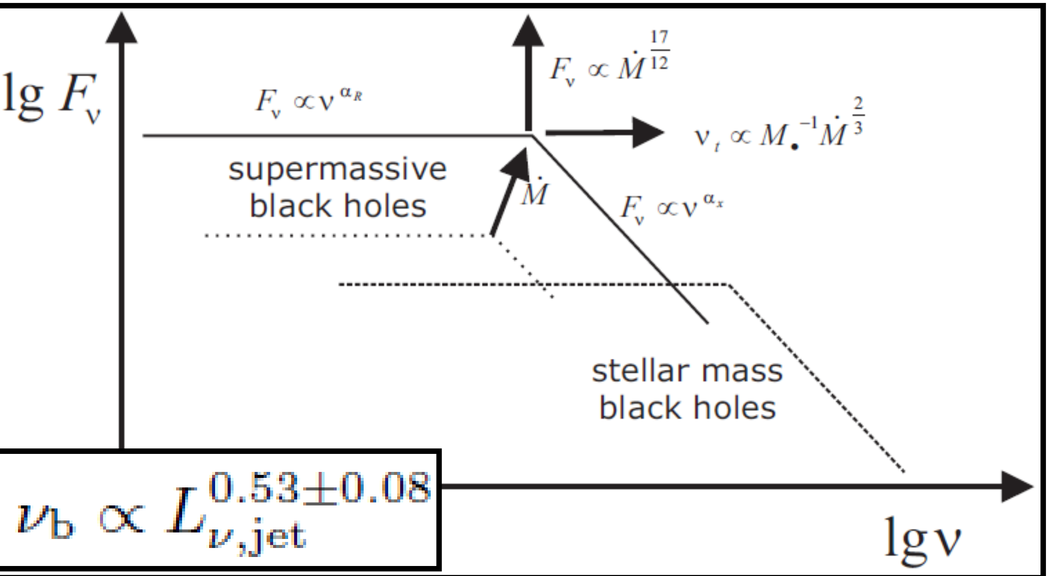
disk-blackbody (diskbb) +
Comptonized hard X-rays (power-law)+
+reflection
+iron line and edges

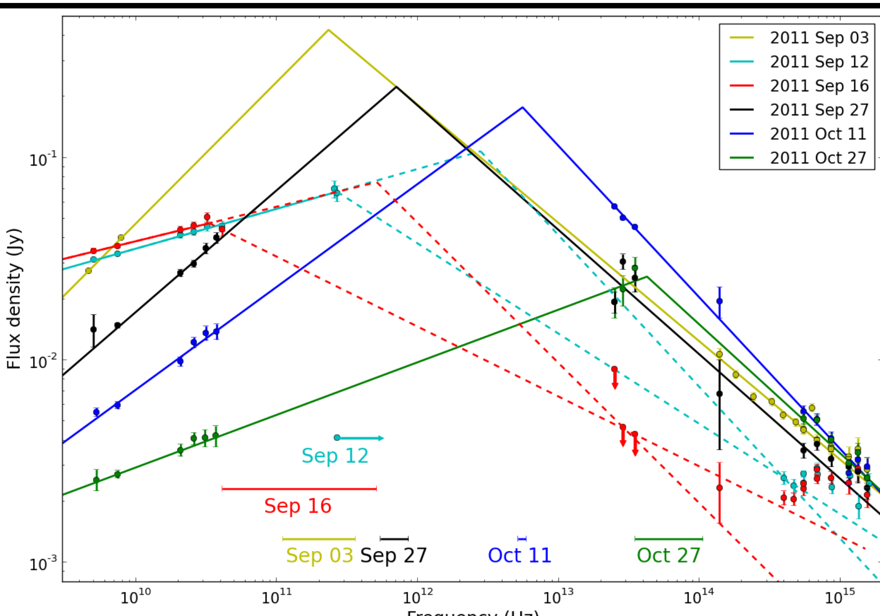
Softening ?



- sources for which the flux drops rapidly (and the index change rapidly) show softening.

For the jets already formed…



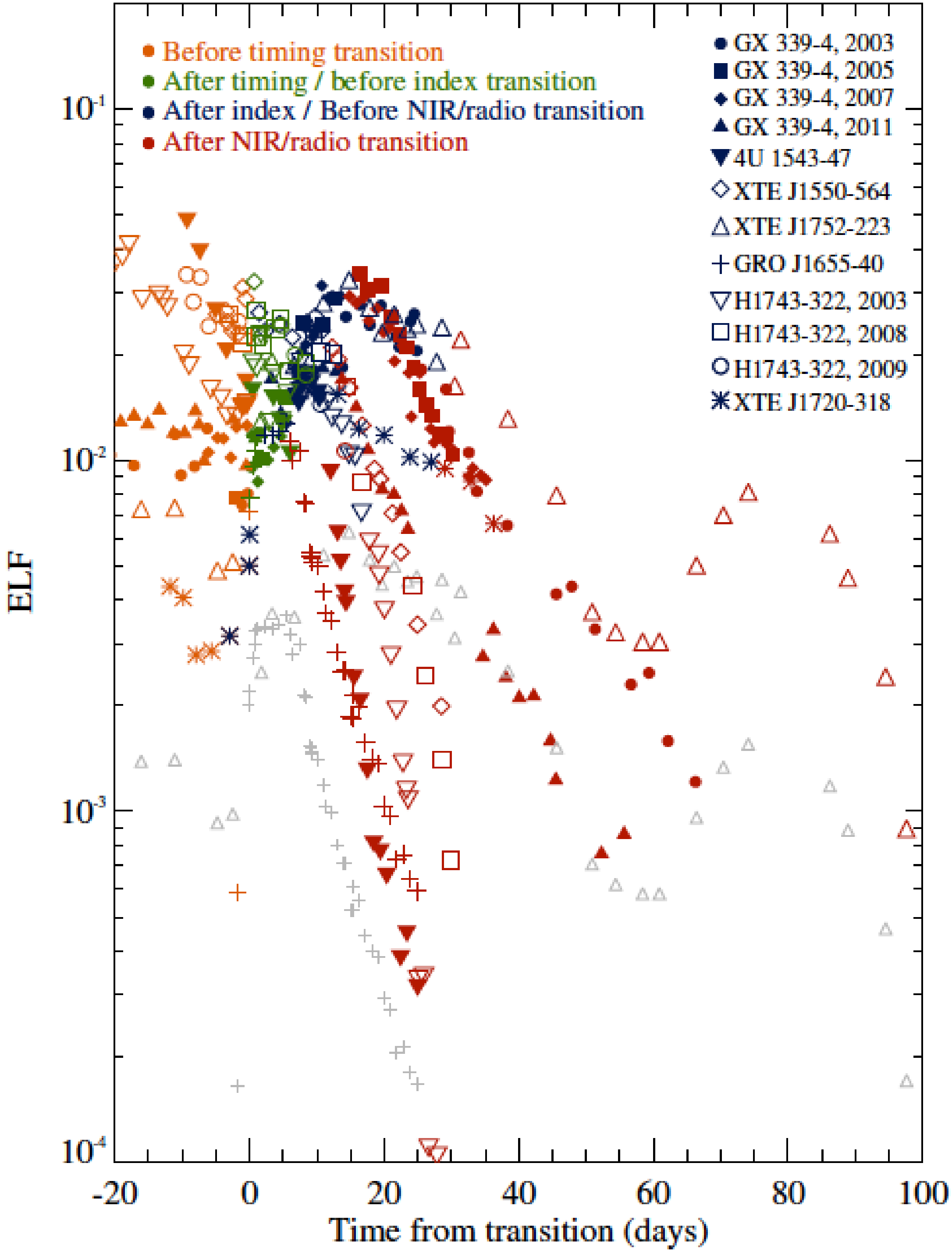


Falcke & Biermann 1995,
Heinz et al. 2003,
Markoff et al. 2003,
Falcke et al. 2004:

- Simple scaling predicts break in the SED going to higher frequencies with increasing jet power. We should see radio before the NIR.

MAXI J1836-194 – it is a failed outburst….
The compact jet was always there.
Russell 2013

All sources



well covered 5 sources, 8 decays +
not so well covered 2 sources, 4 decays

ELF: 3-200 keV Luminosity/L_{Edd}

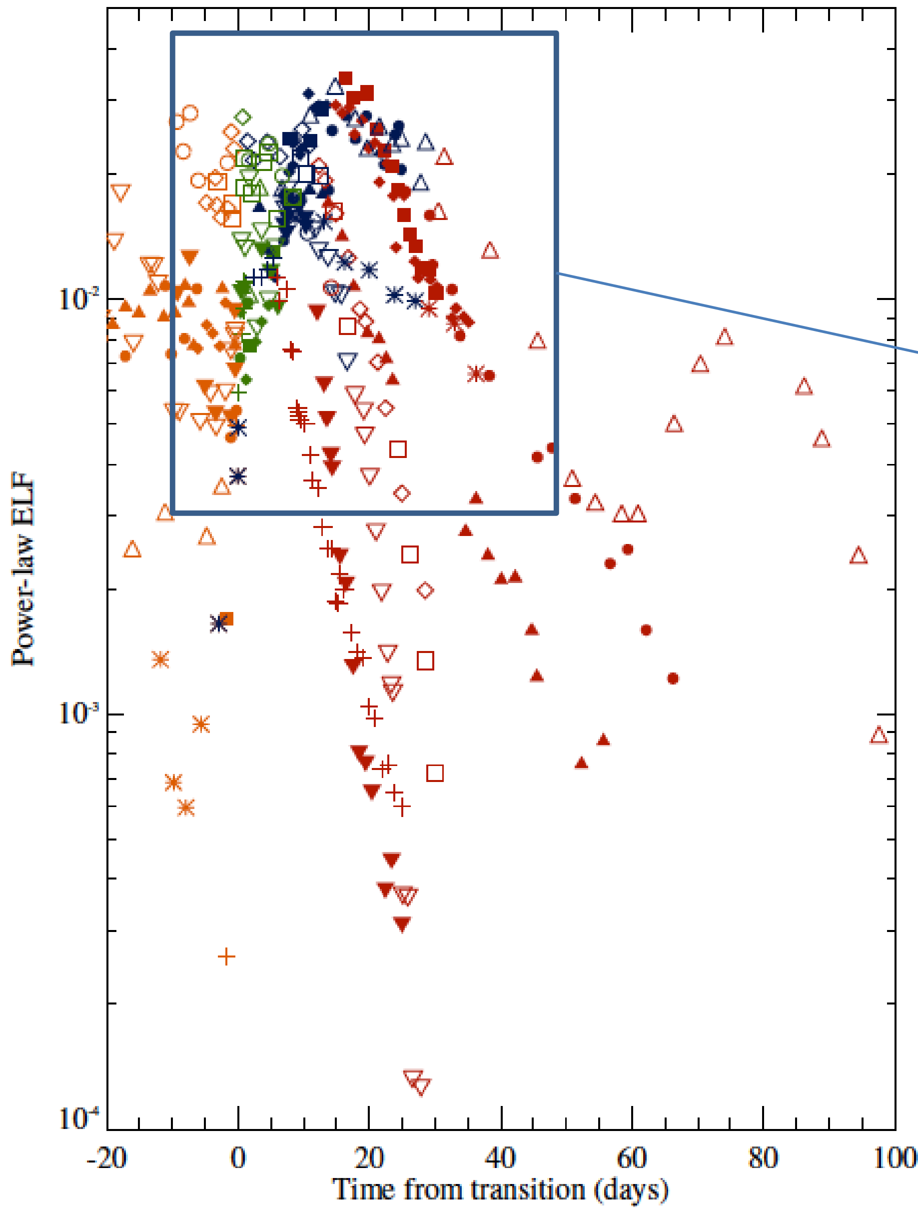
Jets appear at around a few % L_{Edd}

The delay between index transition (spectral hardening) and compact jet appearing is 5-25 days...

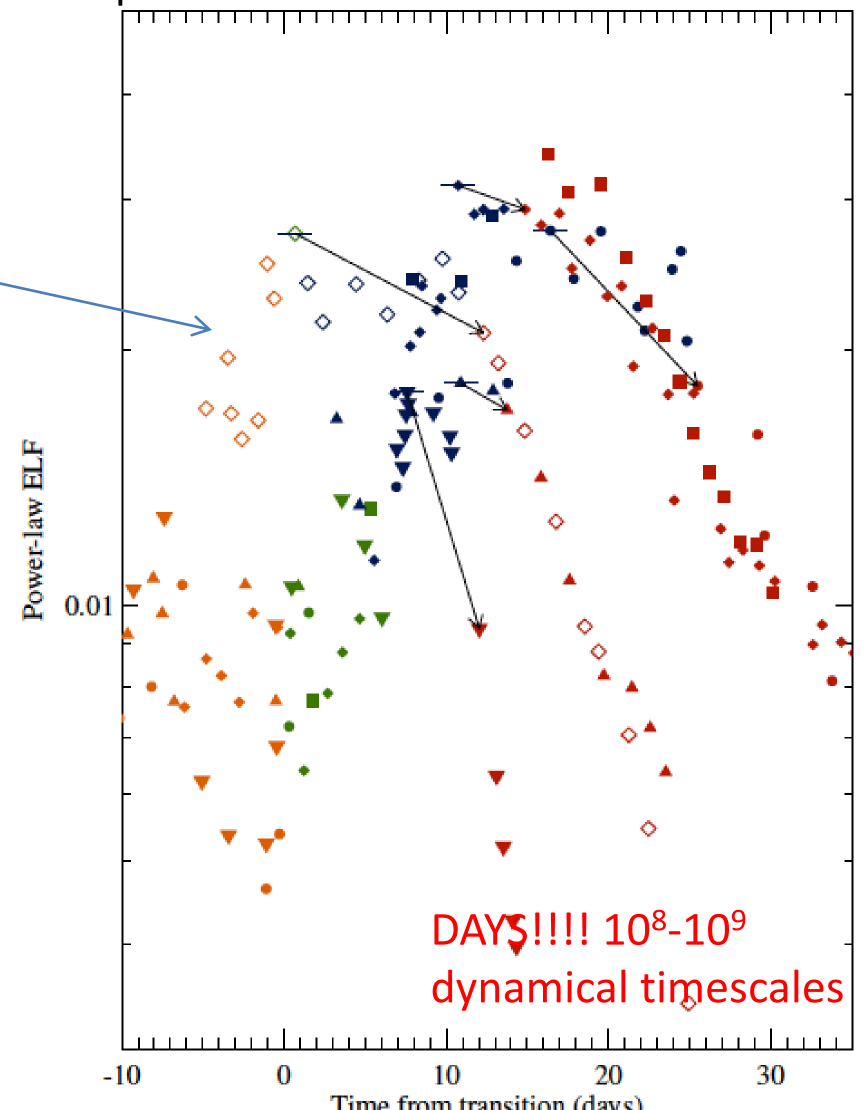
*For sources with no distance information 8 kpc used.
For sources with no mass information $8M_{\odot}$ used (Ozel et al 2010, Kreidberg 2012)

Evolution of power-law vs disk luminosity

Power – law luminosity

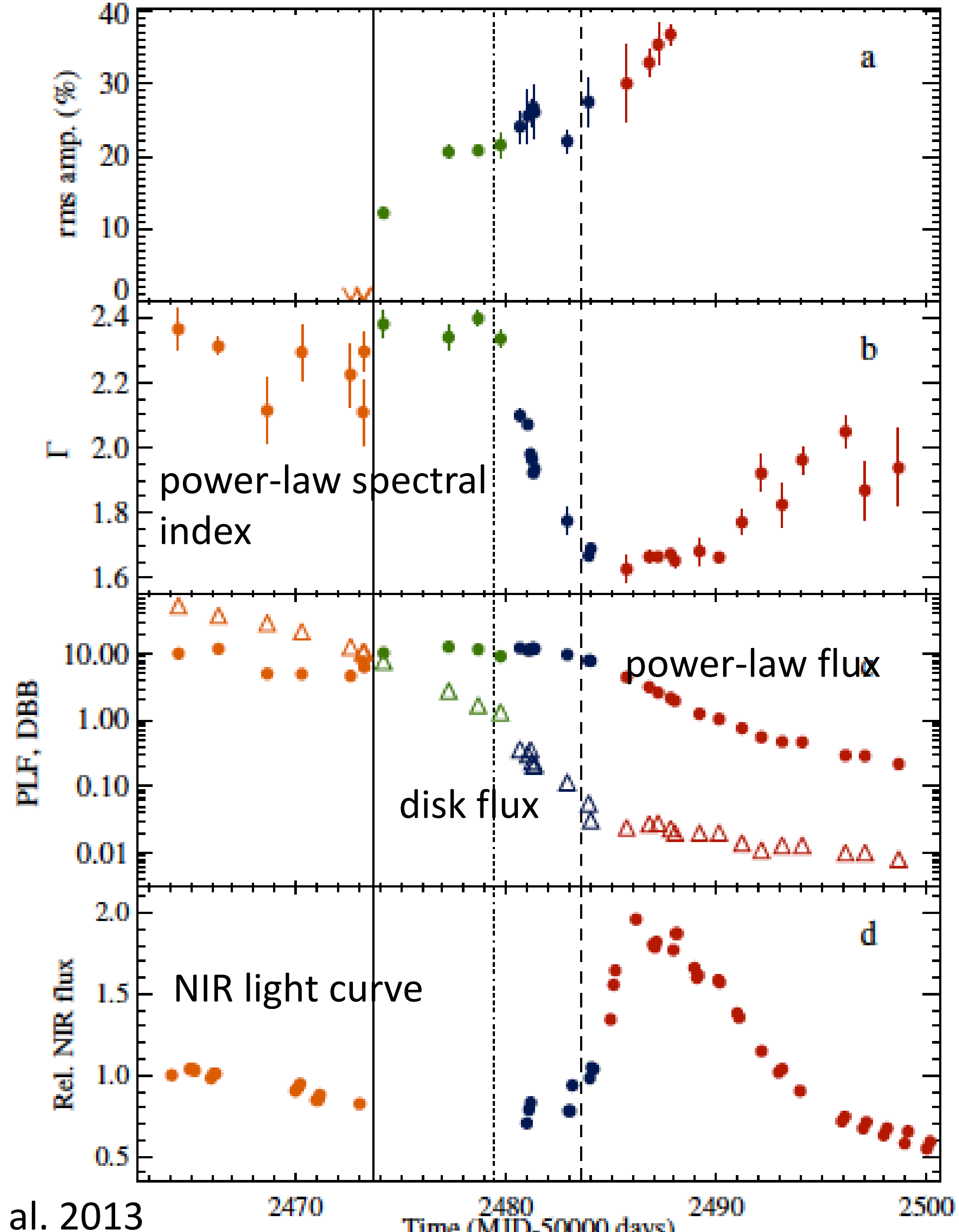


Power law flux increases rapidly with the timing transition, but often the compact jets are observed **DAYS** after the power law ELF peaks...



Method

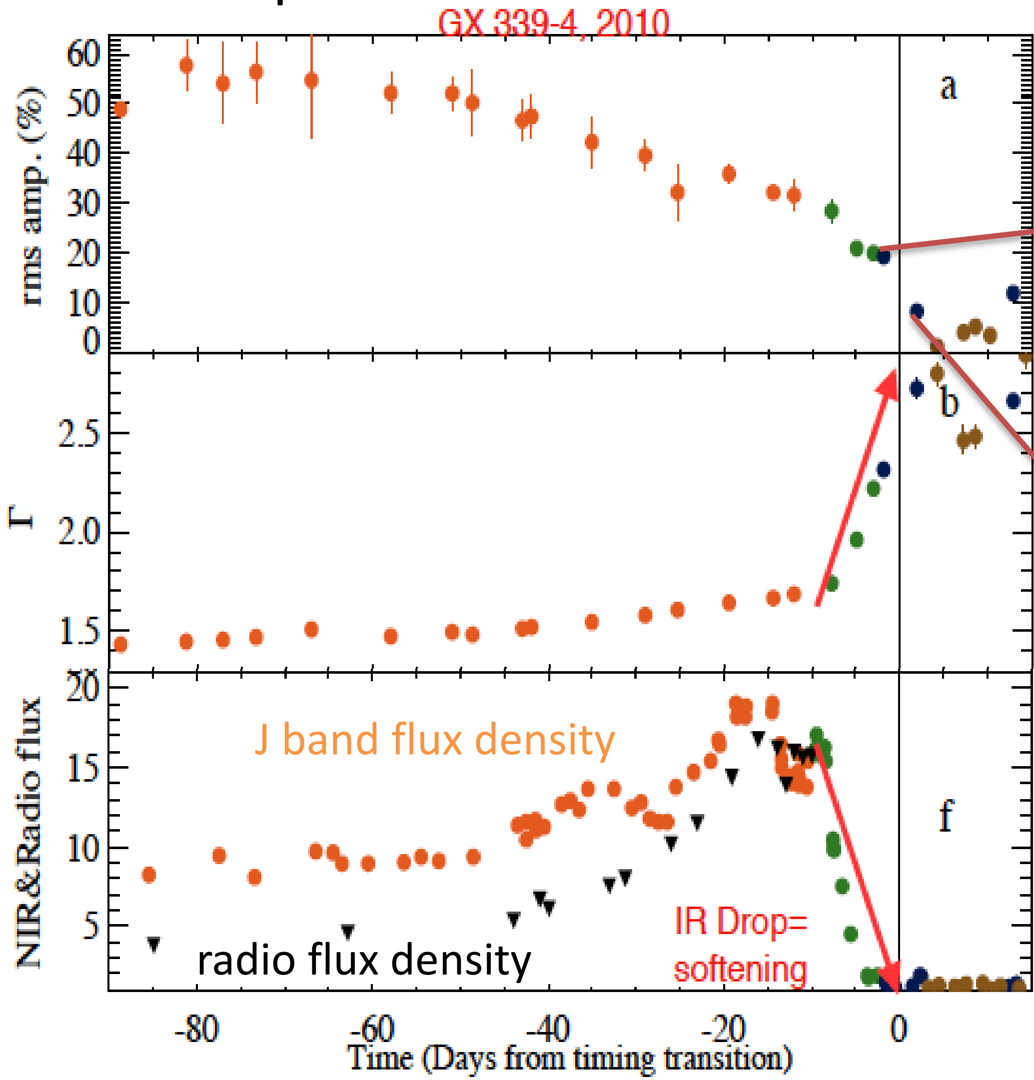
- For each X-ray observation, fit disk+power-law, or your favorite model
- Find rms amplitude of variability using power spectra, get QPO information (if possible)
- Plot parameters as a function of time
- Add multiwalength observation (IR, optical radio)
- Find transitions.

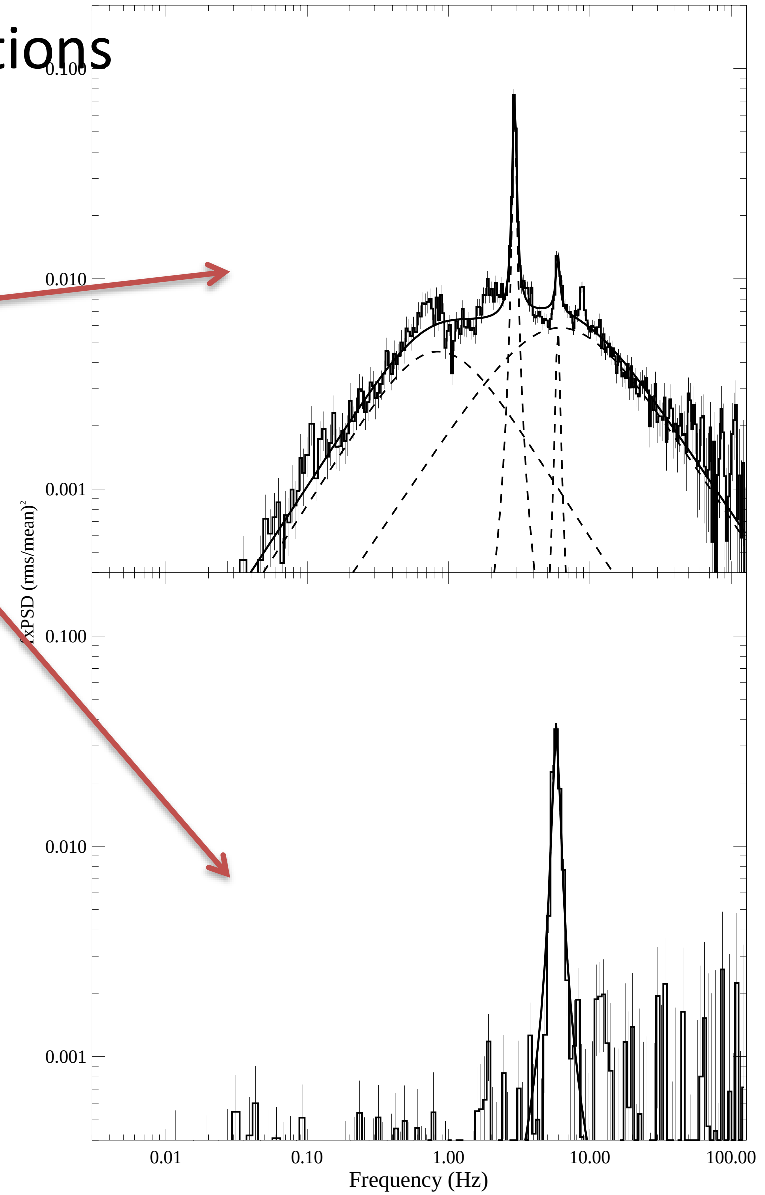


Kalemci et al. 2013

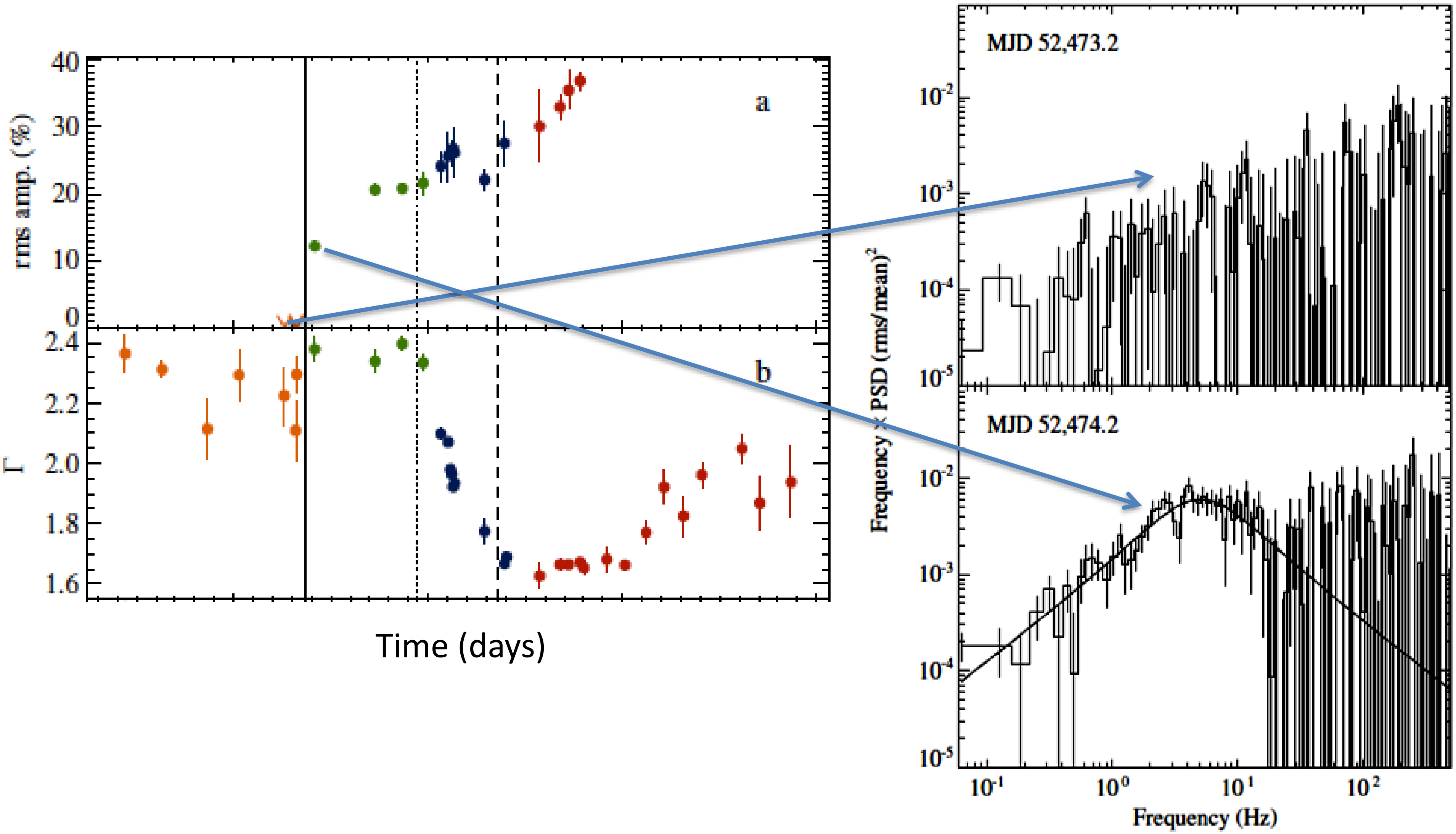
TRANSITION SEQUENCE in OUTBURST RISE:

1. Softening and IR drop simultaneously – compact jet turning off.
2. A transition in timing.
3. Complicated HIMS – SIMS –SS transitions

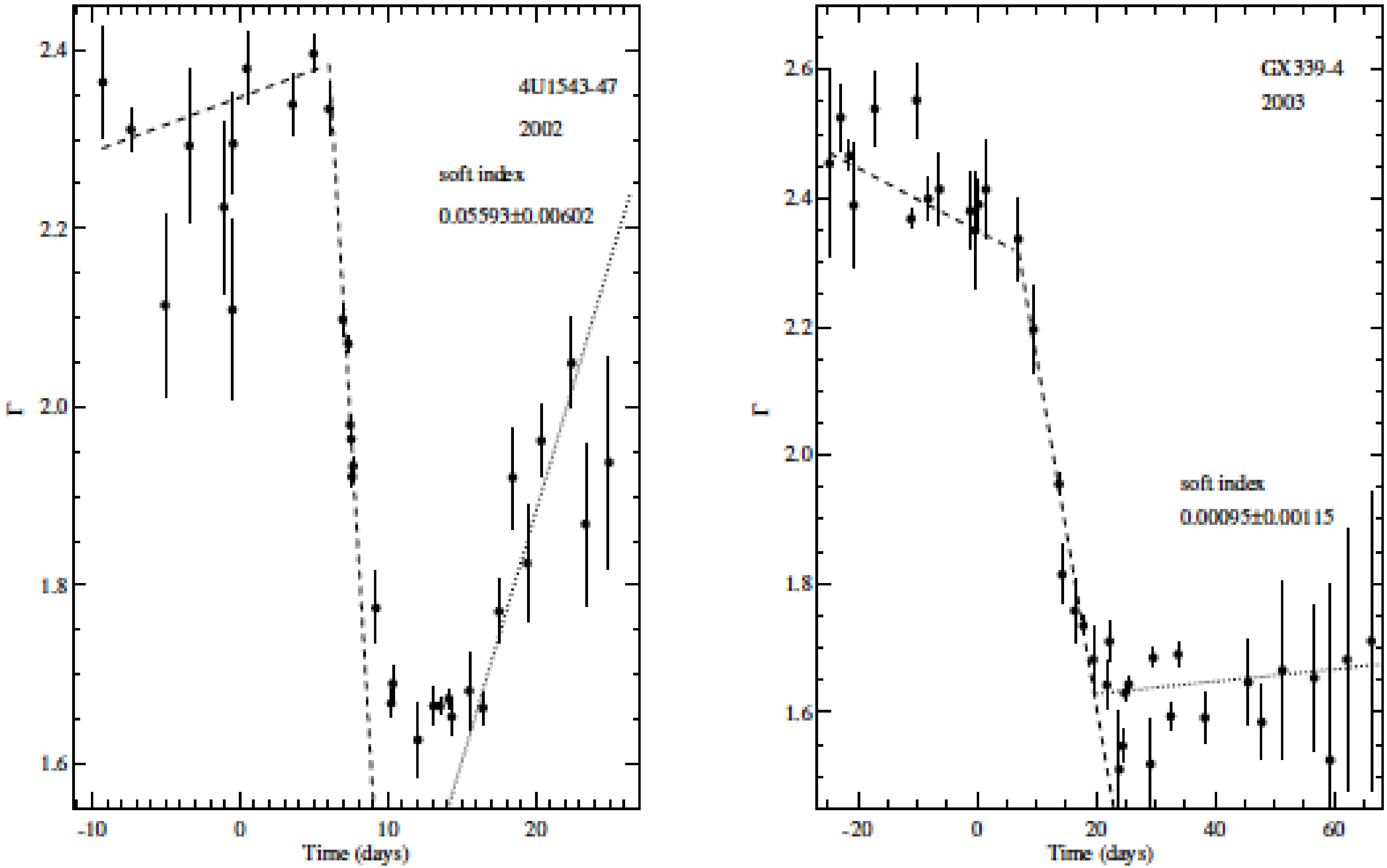




Transition sequence during decay:
1. Timing transition

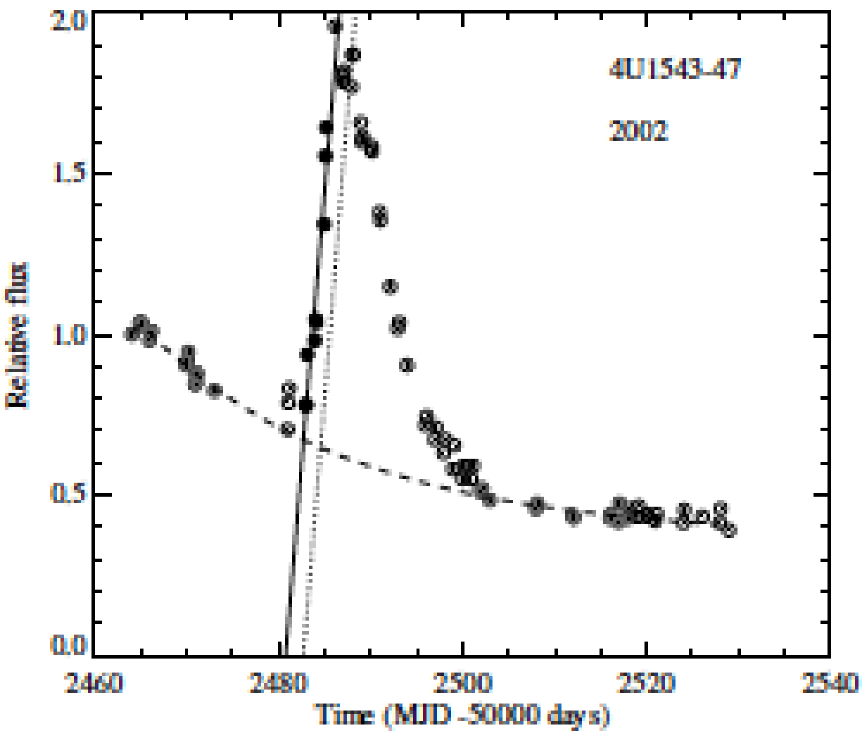


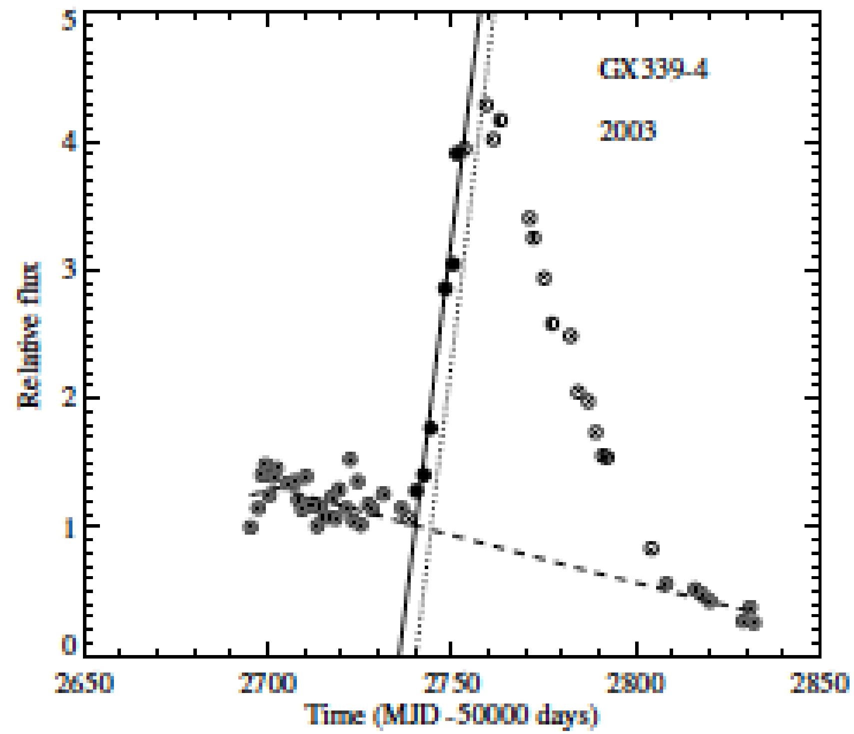
2. Index transition, spectral hardening



3. Compact jet transition, OIR brightening

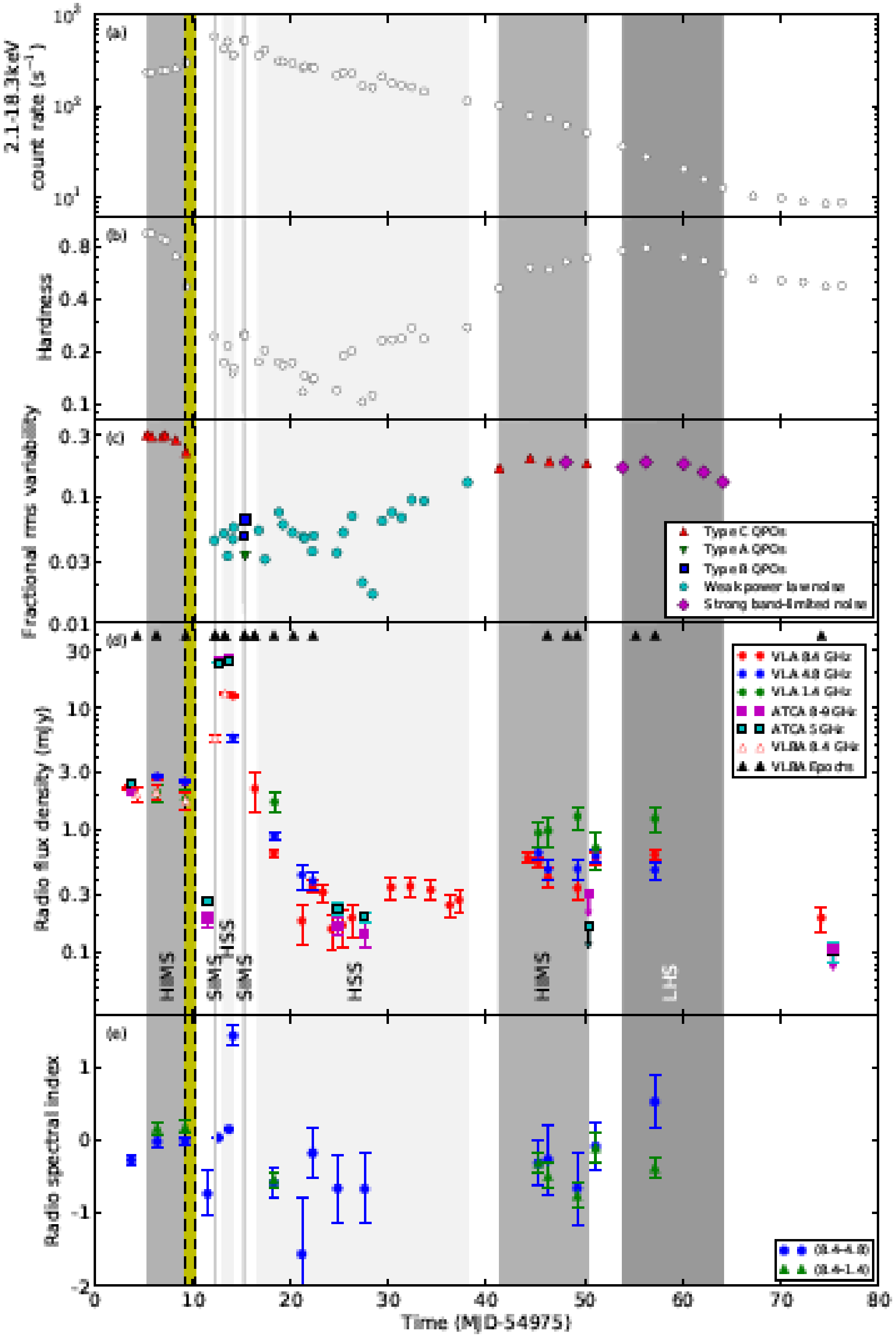
Fit increase in near-infrared fluxes, or, first radio observation with flat to inverted spectrum





How do we know near infrared rise correspond to compact jet formation?

H1743-322 in 2009



Miller-Jones et al. 2012.

X-ray states and timing

Timing is a better proxy for determining intermediate states, Belloni et al.