

# Karadeliklerde dönem geişlerinin ok bantlı gzlemlerle araştırılması

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**TÜBİTAK**

Nick Kylafis, Chris Nixon, Greg Salvesen'a katkılarından dolayı teşekkür ederim. Bu alışmanın önemli bir kısmı 2014-2015 misafir araştırmacı olarak bulunduğum JILA-CU Boulder'da gerçekleştirilmiştir.

**TÜBİTAK BİDEB + ARDEB 115F488**

# Çalışmanın önemi

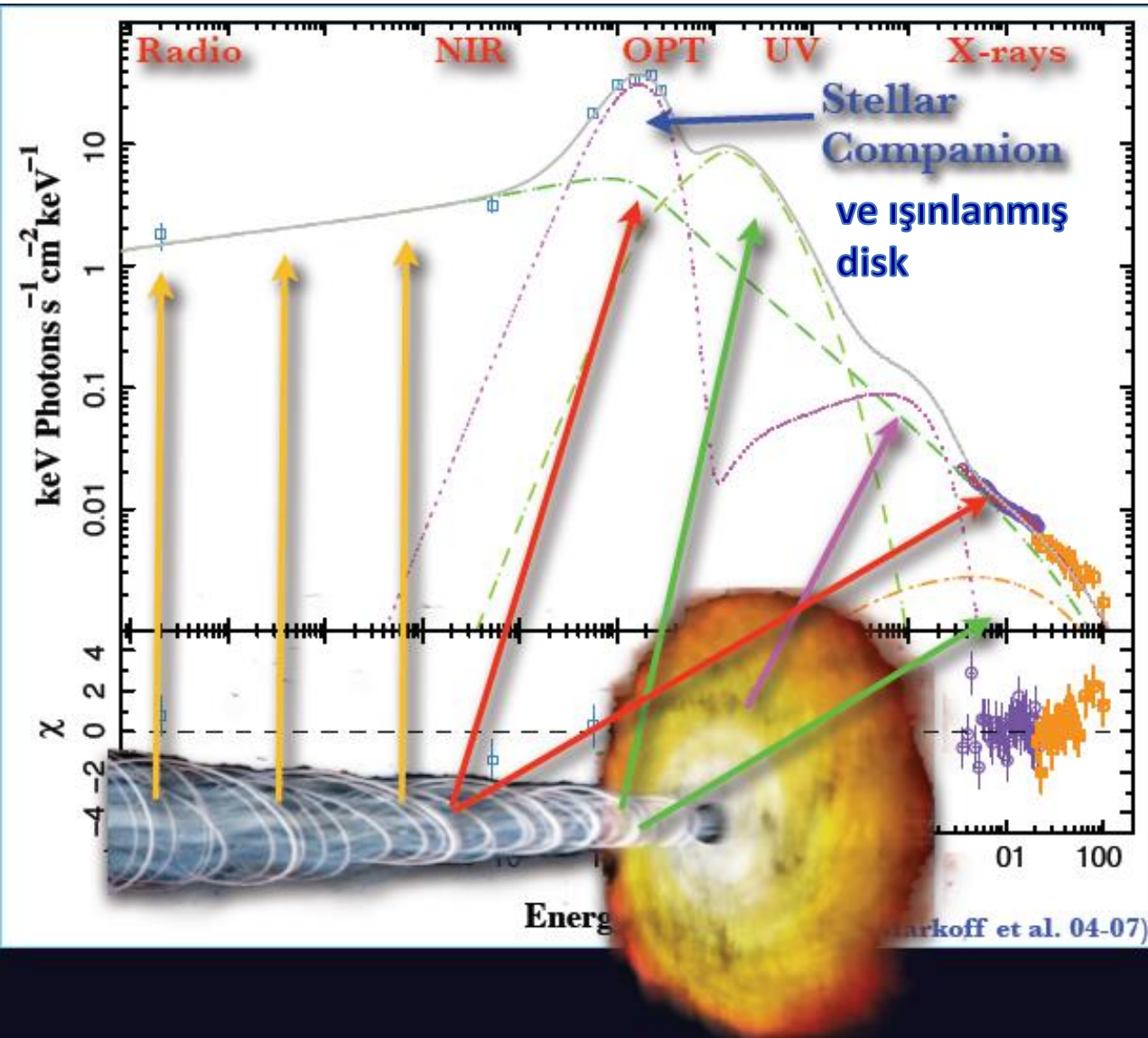
- Karadeliklerde, sert ve yumuşak dönem geçişleri sırasında yapılan çok bantlı gözlemler bu kaynakların kütle aktarım özellikleri konusunda yeni ve önemli bilgiler elde etmemizi sağlar.
- Bazı ilginç özellikler (balistik radyo jetleri, bazı QPO çeşitleri) sadece dönem geçişleri sırasında gözlenir.
- Erzurum'da yapımı devam eden kızılötesi teleskop DAG dönem geçişlerindeki fotometrik (günlük ve hızlı) ve tayfsal çalışmalarla jet oluşumu ve yok olması ve jet/rüzgar ilişkisi üzerine önemli katkılarda bulunabilir.

# “Dönem geçişi” nedir?

- Bir kaynağın “gözlemsel özelliklerinden” bir ya da birkaç tanesindeki “ani ve büyük” değişim:
  - “gözlemsel özellik”:
    - Her hangi bir gözlem bandındaki (optik, radyo vs) akı ya da tayfın biçimi
    - saniye altı zamansal özellikler (güç tayfının etkin değeri, biçimi, QPO’ların ortaya çıkması)
  - “ani ve büyük”: dönem geçişi önceki evrimin genel değişimine kıyasla çok daha hızlı ve çok daha büyük bir değişim.
- Böylesine ayrıntılı bir mikro analiz madde aktarımı fiziğini çok iyi anlamamızı sağlayabilir ama gereksinimleri de büyüktür:
  - 1. Zamansal çözünürlüğü iyi bir X ışını uydusu ile günlük gözlemler (RXTE mükemmel bir uyduydu, Swift işe yarayabilir, LOFT kabul edilseydi mükemmel olurdu)
  - 2. Radyo, kızılötesi ve optik teleskoplarla her gün yapılan gözlemler.

# Neden çok bantlı gözlemler gereklidir?

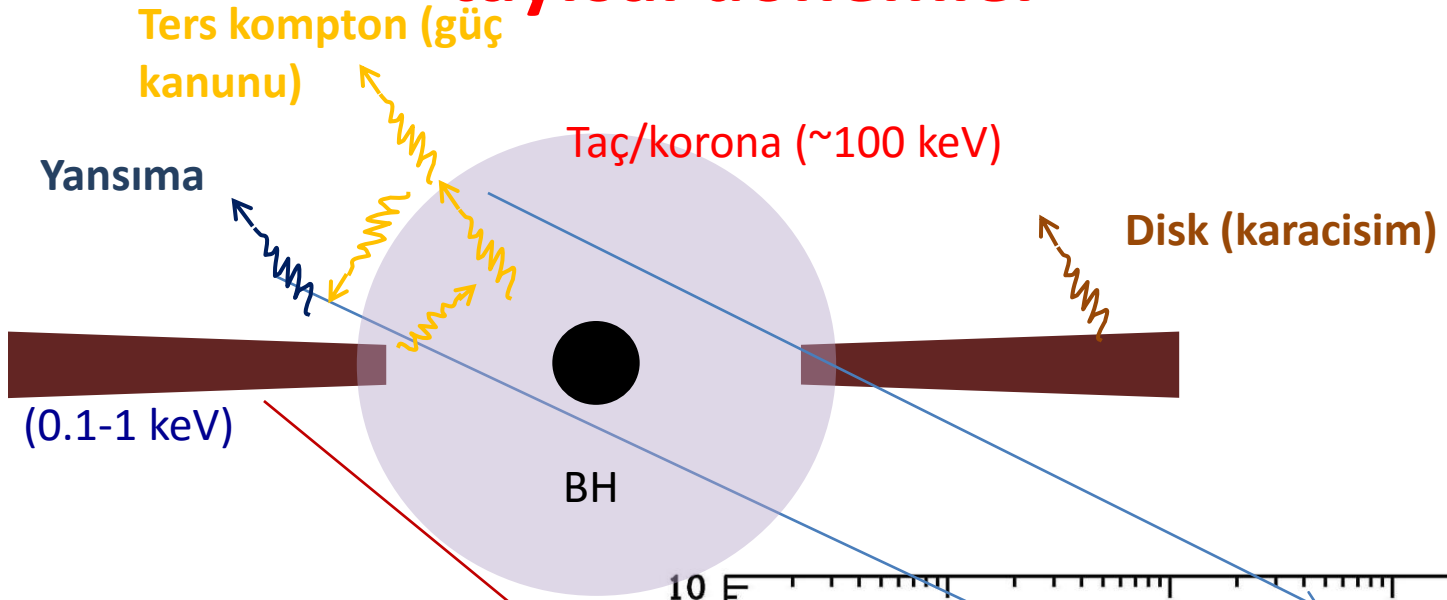
GRO J1655-40, Migliari et al. 2007



- Sıkı (compact) konik jetlerden radyo bandında frekansa karşı düz ya da yükselen, ve yakın/orta kızılötesinde kırılarak frekansa karşı azalan tayf beklenir.

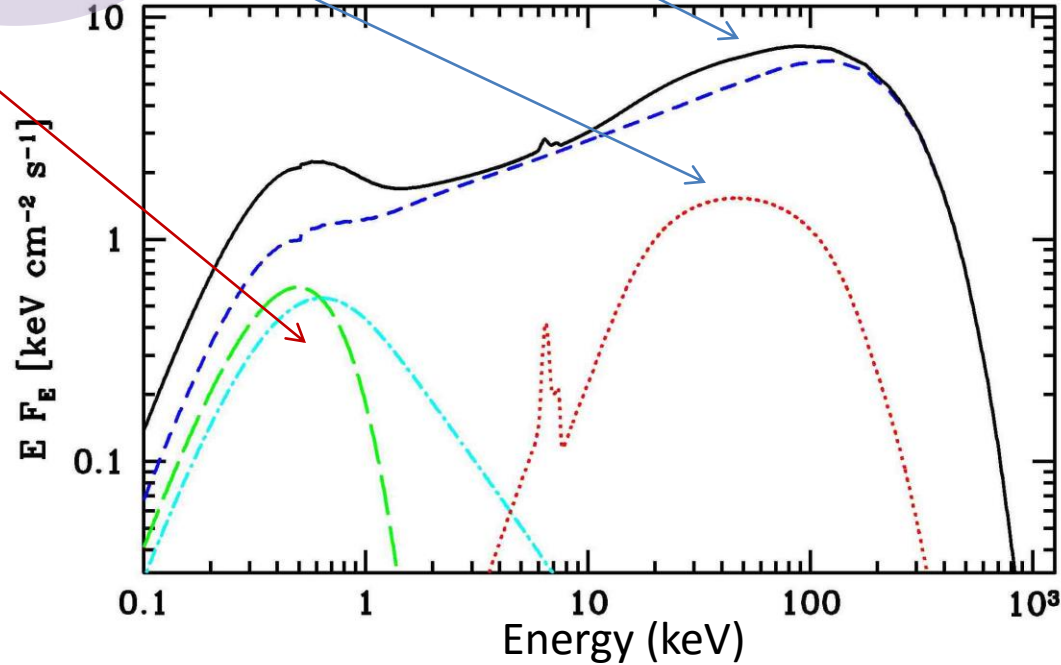
Madde aktarımı ve fırlatımı ile ilgili tüm bileşenleri birbirinden ayırabilmenin tek yolu aynı anda yapılan çok bantlı gözlemlerdir.

# Karadeliklerden gelen x ışınları ve tayfsal dönemler



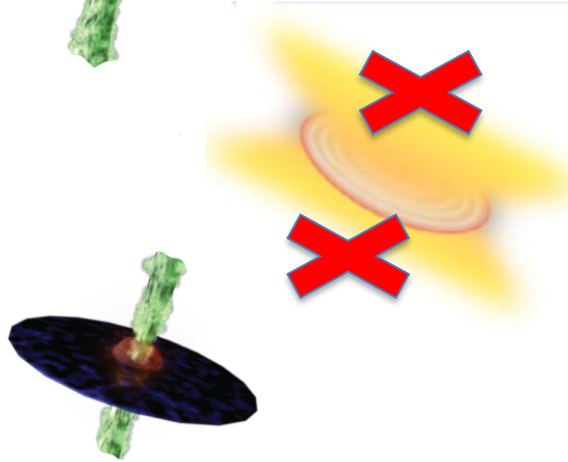
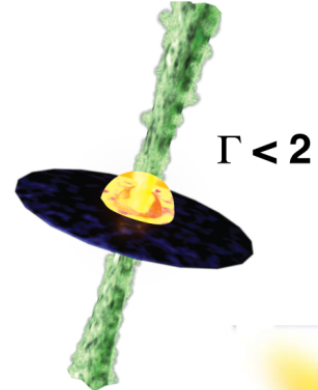
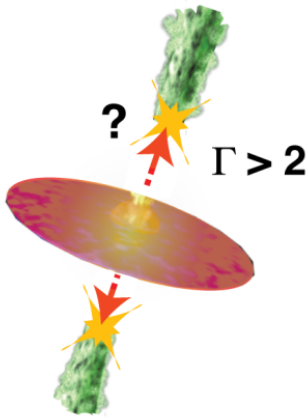
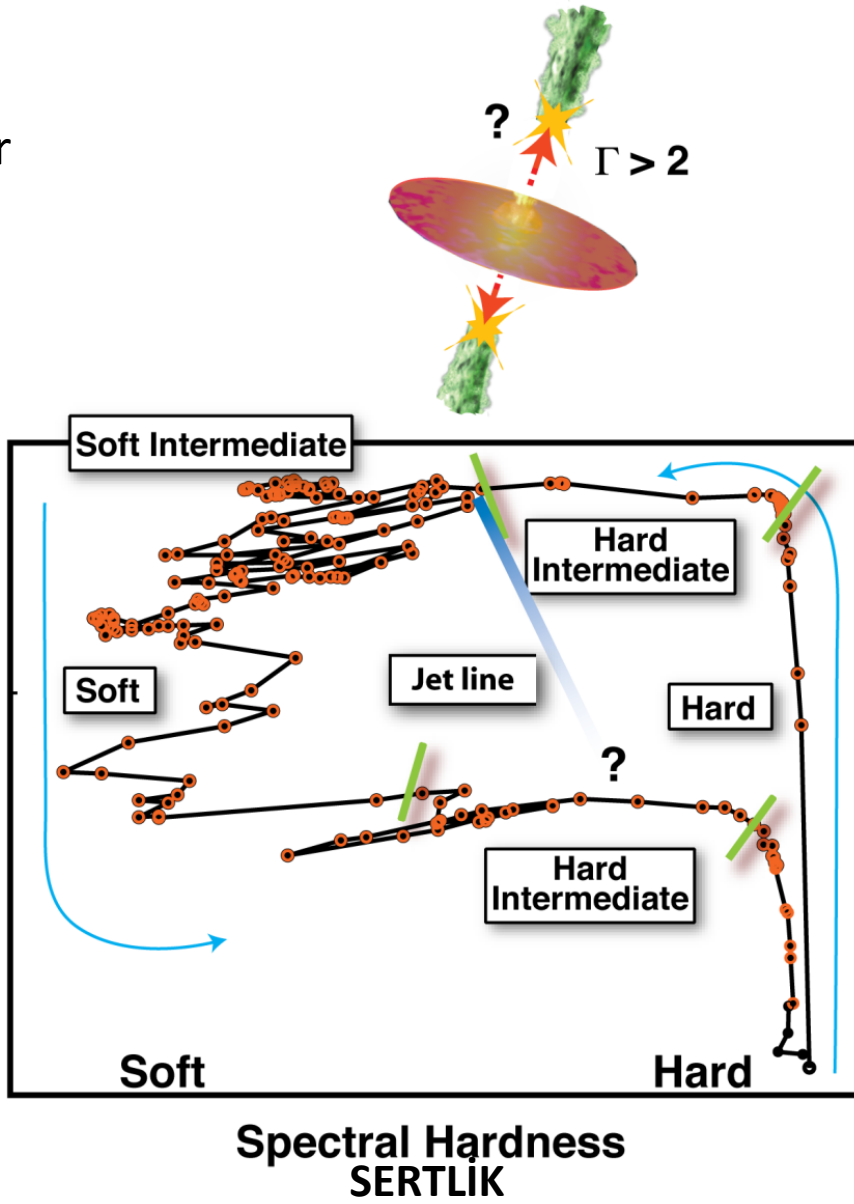
model:  
disk-karacisim (diskbb) +  
Ters kompton sert X-ışınları (güç kanunu)+  
+yansımalar  
+demir çizgisi

SERT DÖNEM: Ters kompton ışıması baskın  
YUMUŞAK DÖNEM: Disk karacisim ışıması baskın

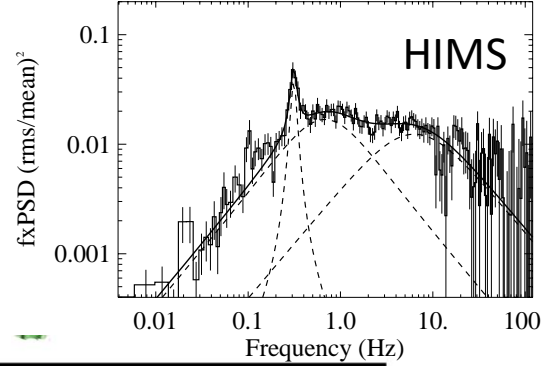
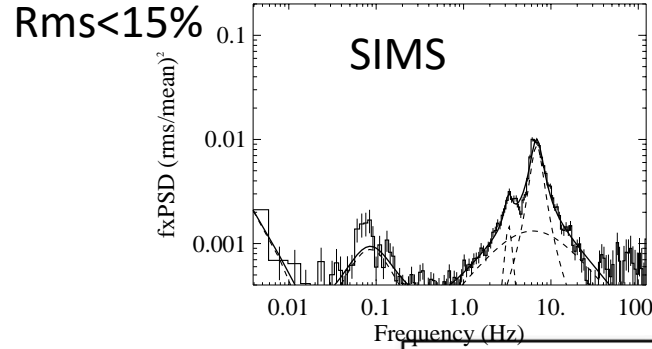


# Karadelik parlaması dönemlerinin genel özellikleri I

disk görüş açısı da önemlidir

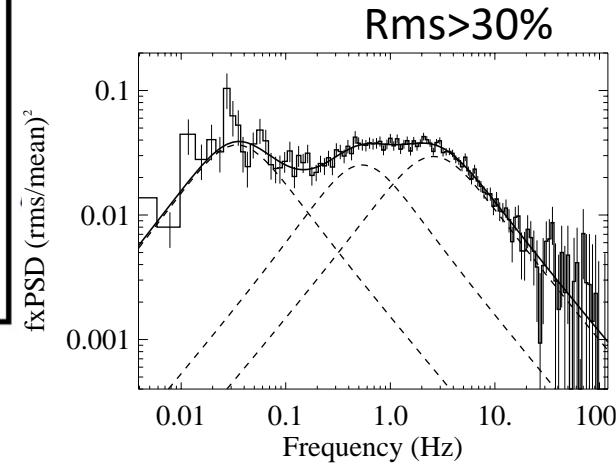
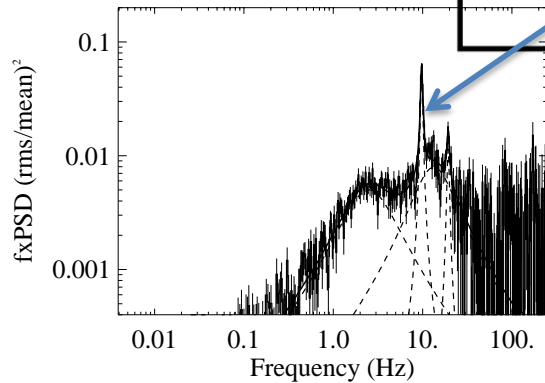
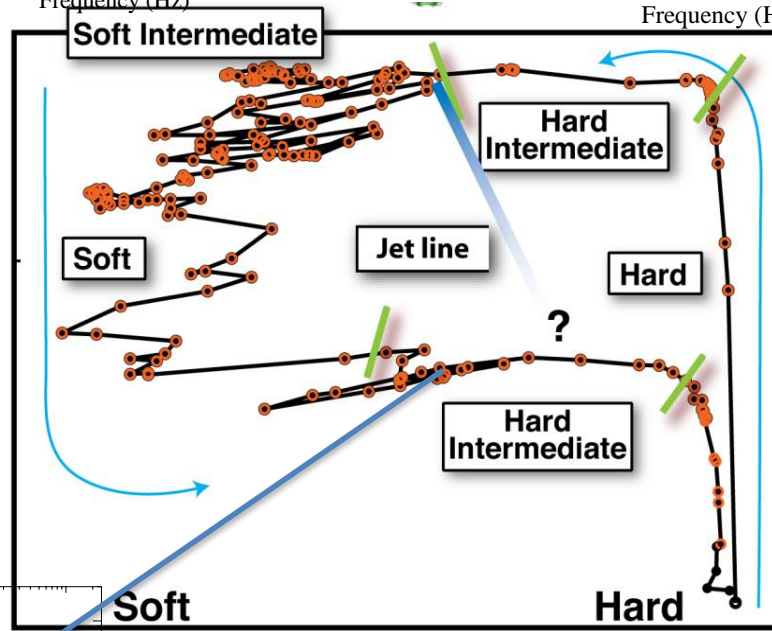
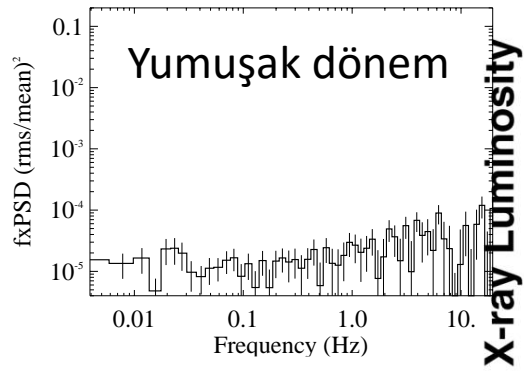


# Güç tayfları ve dönemler



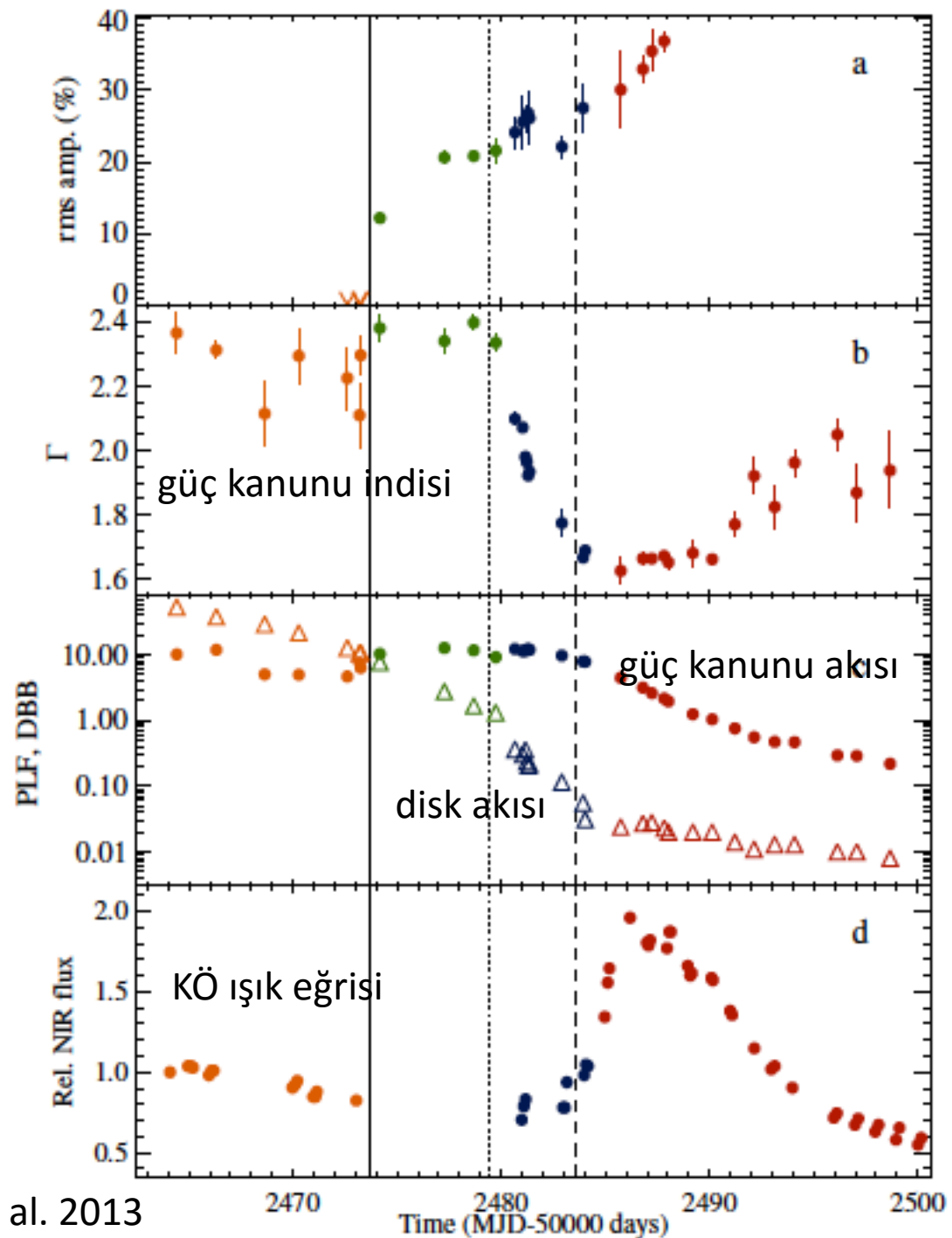
Rms>15-30%

Rms<5%



# Yöntem

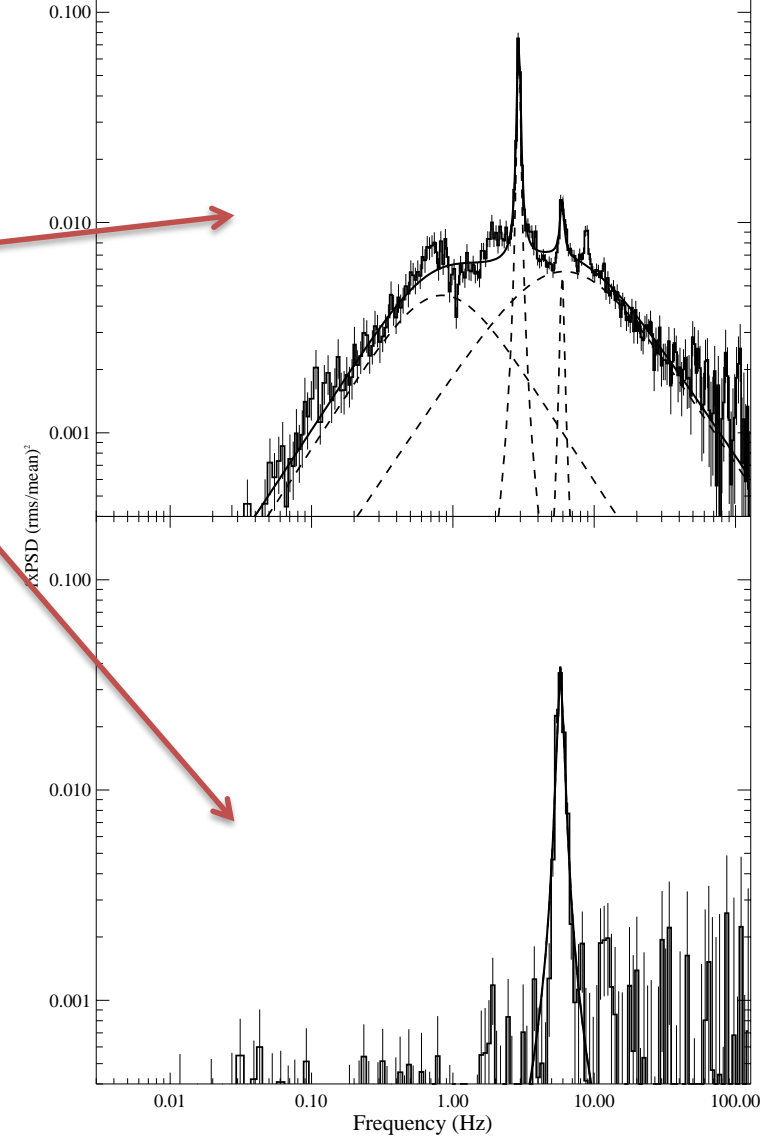
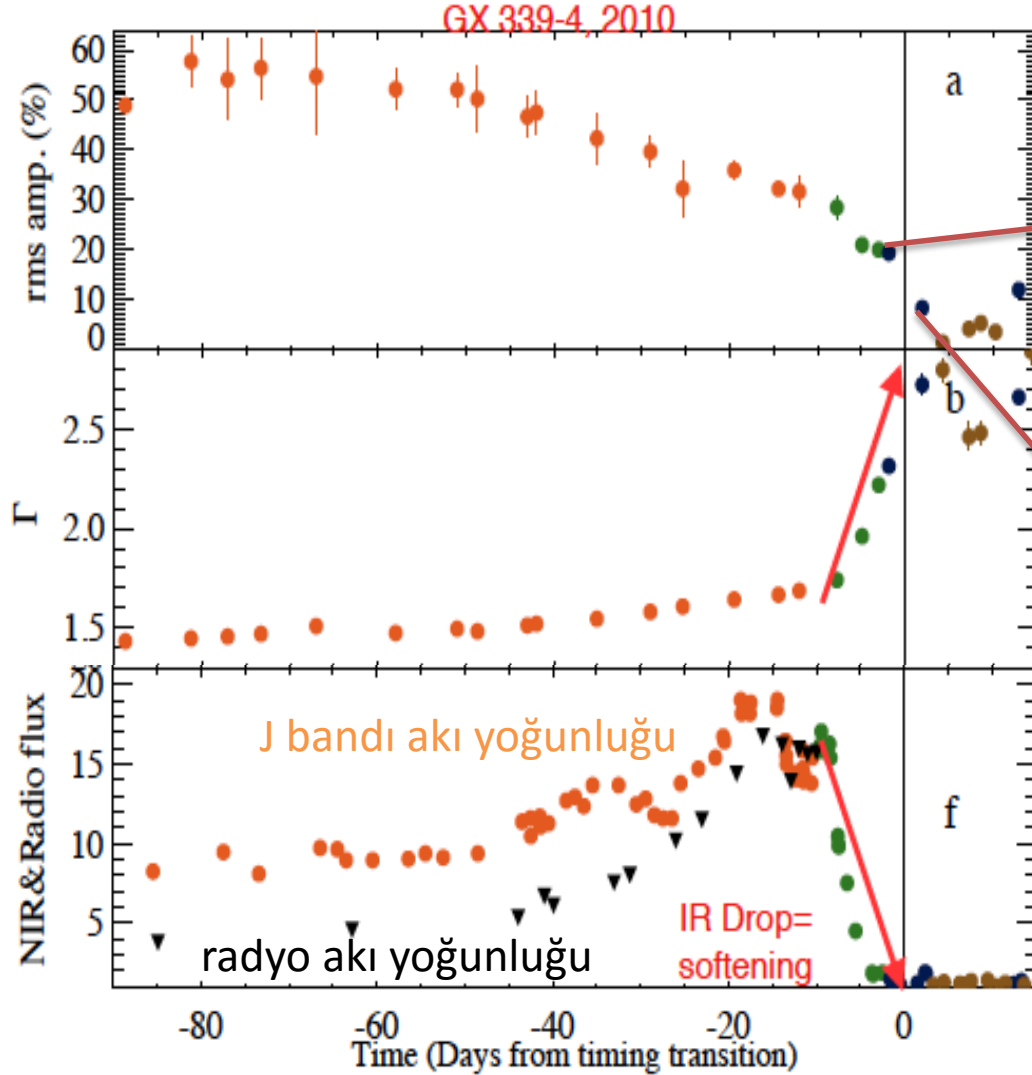
- Tüm X-ray gözlemleri için tayf disk+güç kanunu ile modellenir.
- Güç tayfından etkin değer ve QPO'lar bulunur (varsa).
- Parametreler zamana karşı çizdirilir.
- Çok bantlı gözlem sonuçları (Optik, KÖ ve/veya radyo akısı) eklenir.
- Ani değişimler kontrol edilerek dönem geçişleri bulunur.





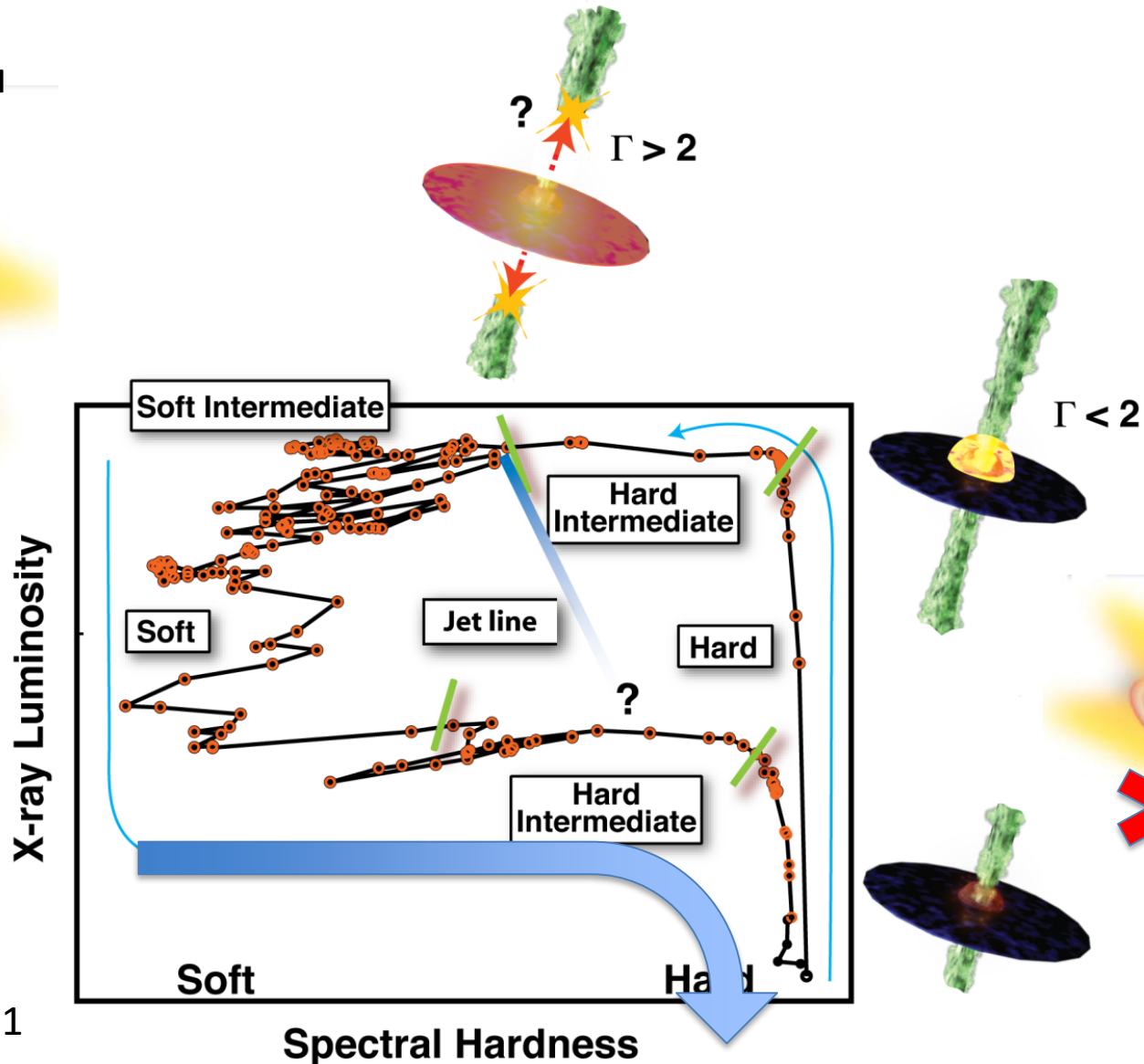
# Parlamanın çıkışı sırasında dönem geçişlerin sırası:

1. X-ray tayfında yumuşama ve aynı anda KÖ düşüş – jet sönüyor.
2. Güç tayfında gözlenen bir geçiş
3. Akabinde konuşmanın konusu olmayan ara geçişler.



# Karadelik dönem geçişleri, sönüm dönemi

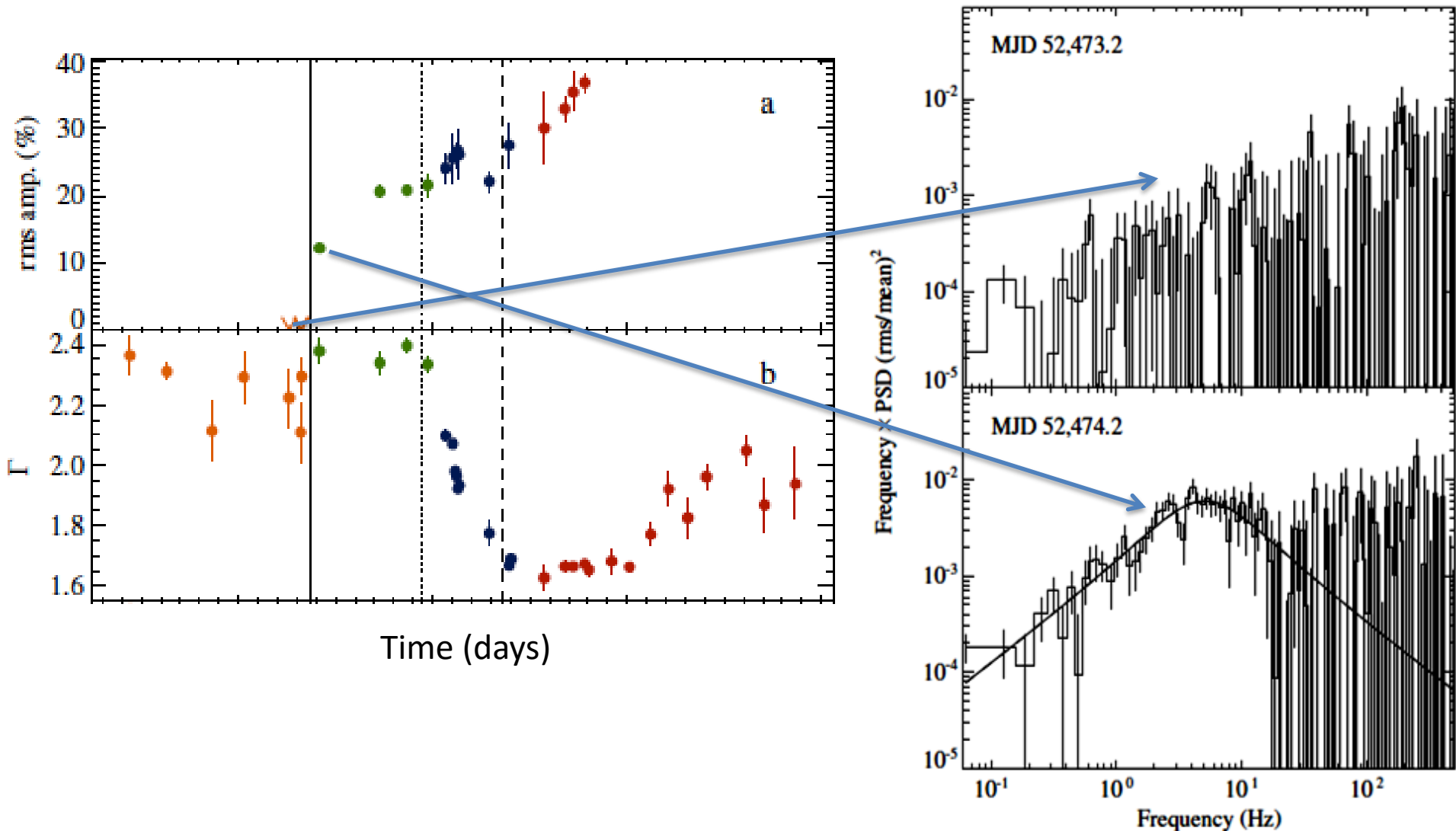
disk rüzgarları



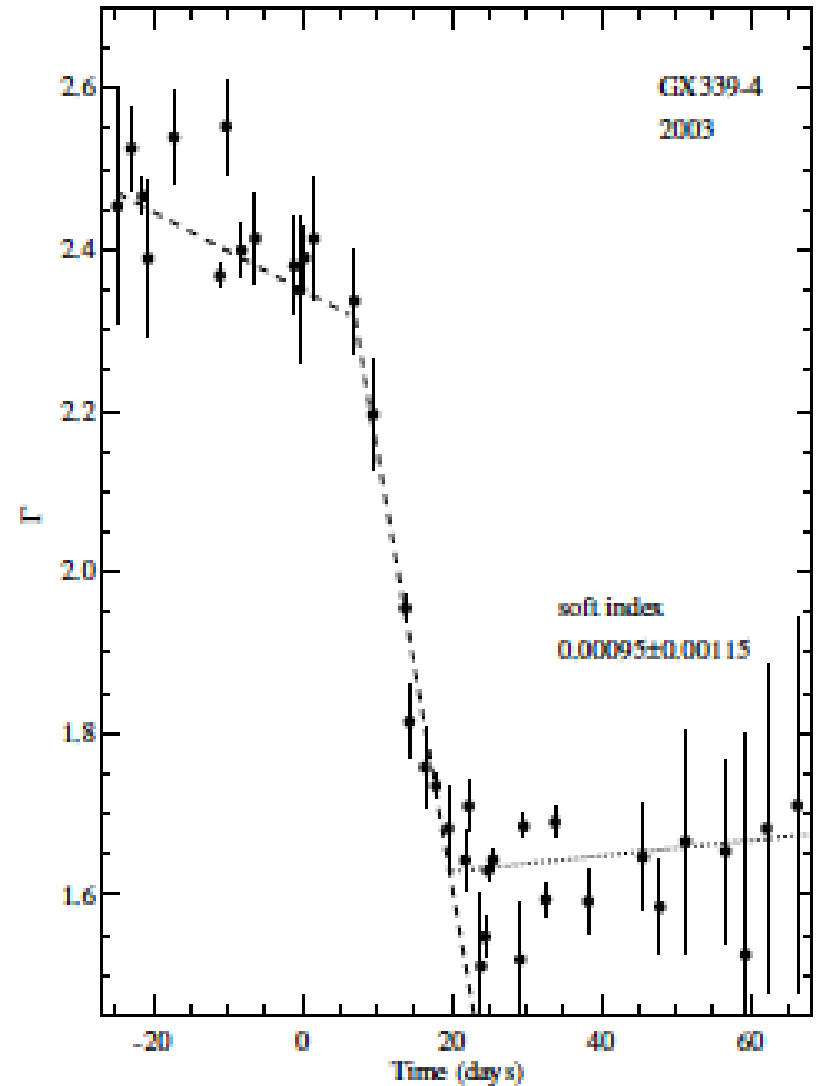
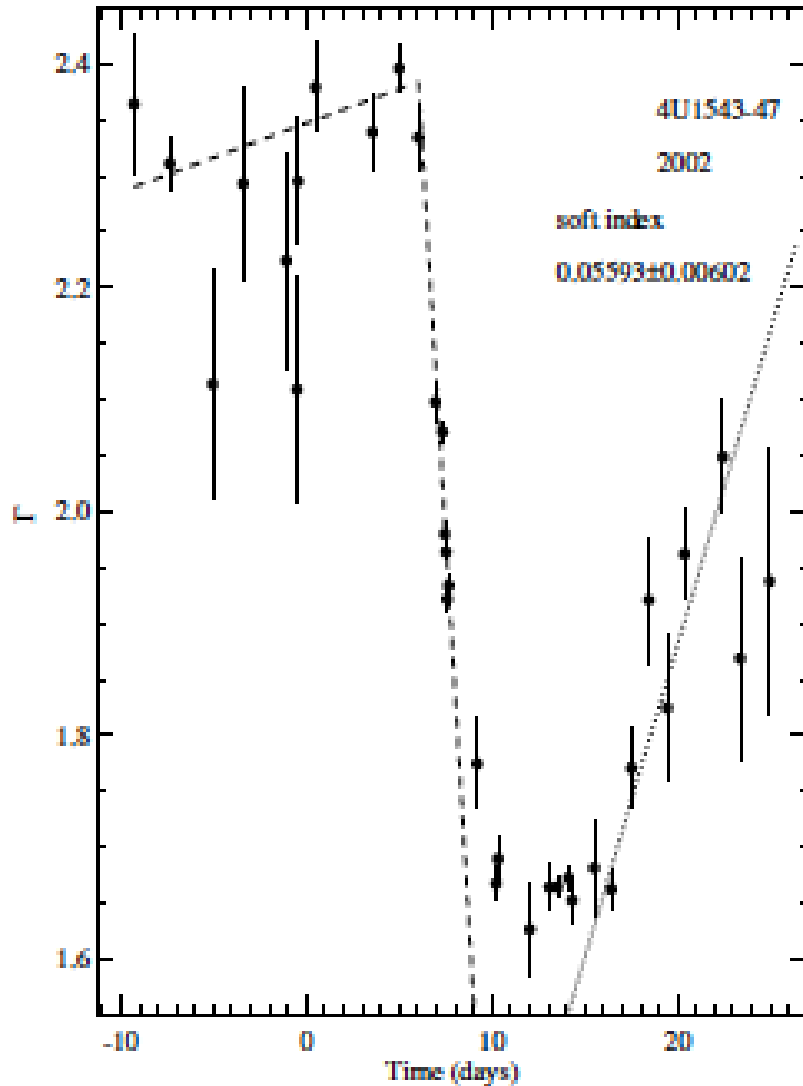
Sönme!  
Russell et al. 2011

# Sönüm döneminde geçişlerin sırası:

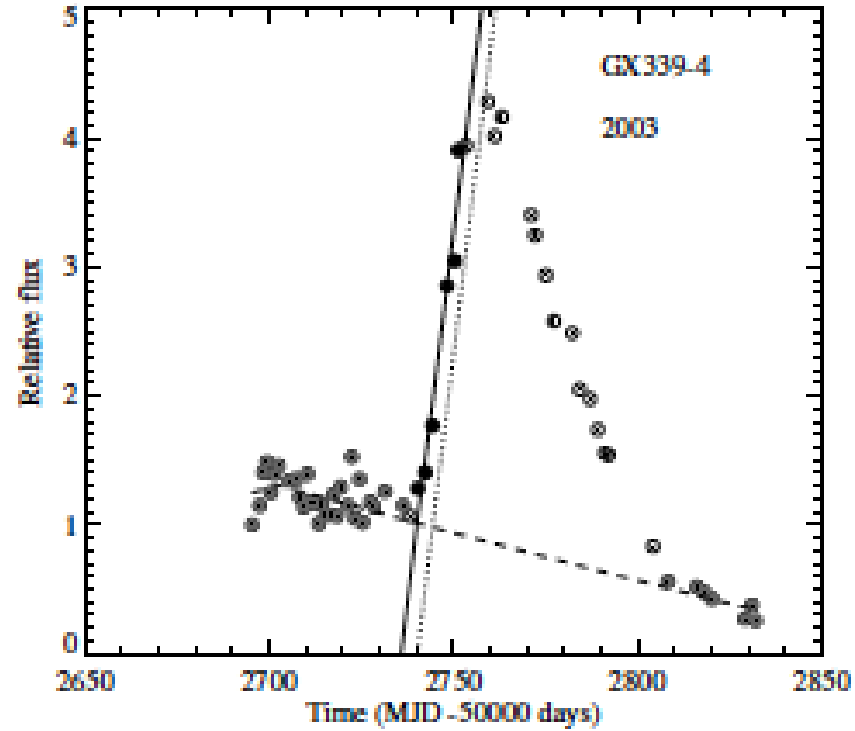
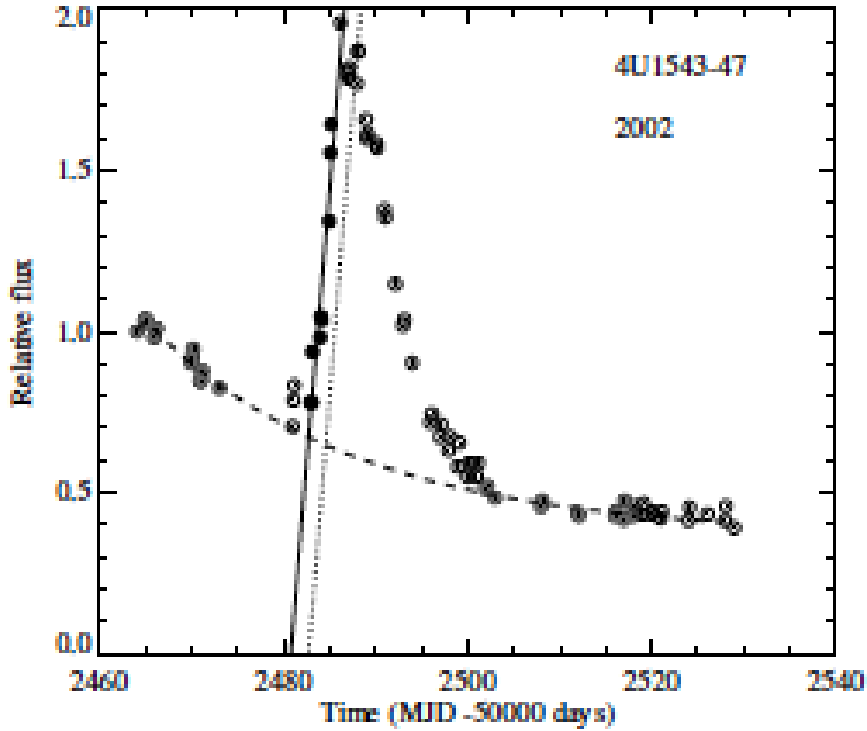
## 1. Zamansal (güç tayfı) dönem geçişi



## 2. Enerji tayfı güç indisi, tayfsal sertleşme

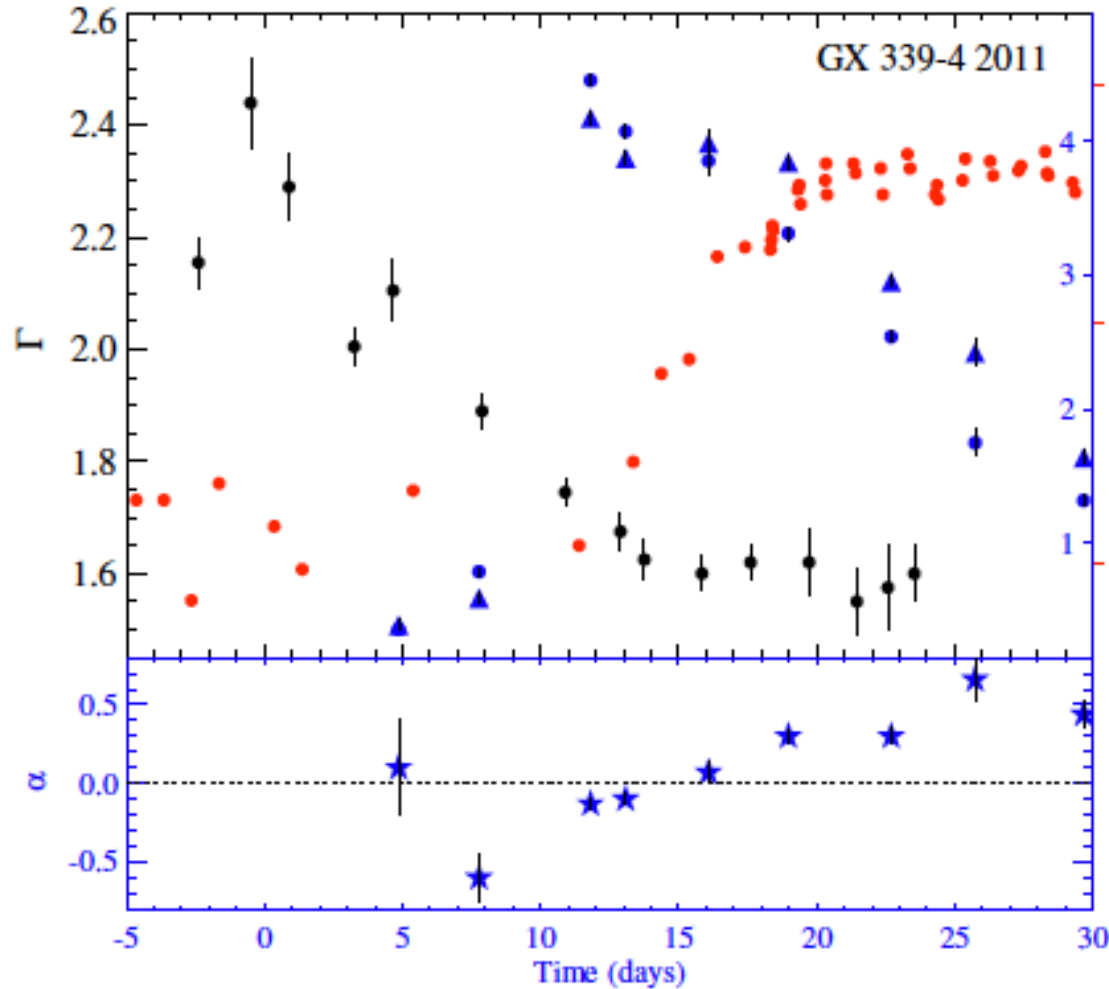


# 3. Sıkı jet geçişi, O/KÖ parlama



KÖ parlamasının jet kaynaklı olduğunu nereden biliyoruz?

# KÖ akı artışı = jet oluşumu?



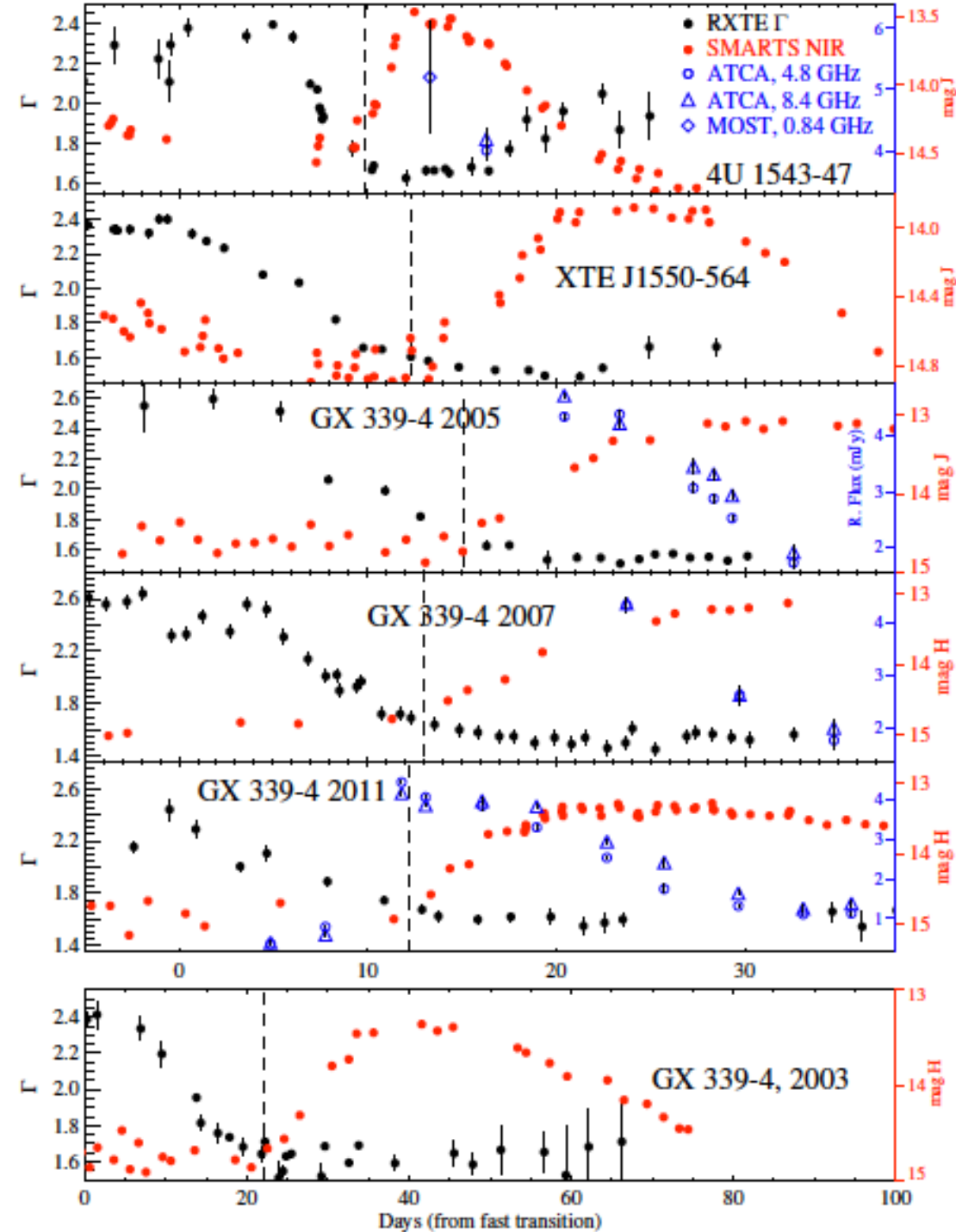
- RXTE güç kanunu indisi
- SMARTS J kadir
- 4.8 GHz radyo
- ▲ 8.4 GHz radyo

radyo verisi  
Corbel et al. 2013

# İnceleyebdiğimiz bütün kaynaklar

Benzer kızılötesi/radyo/X-ray tayf bağıntısı.

Alternatif açıklama da mevcut:  
Veledina & Poutanen 2012  
Poutanen & Veledina 2014  
sıcak kütle aktarım modeli.



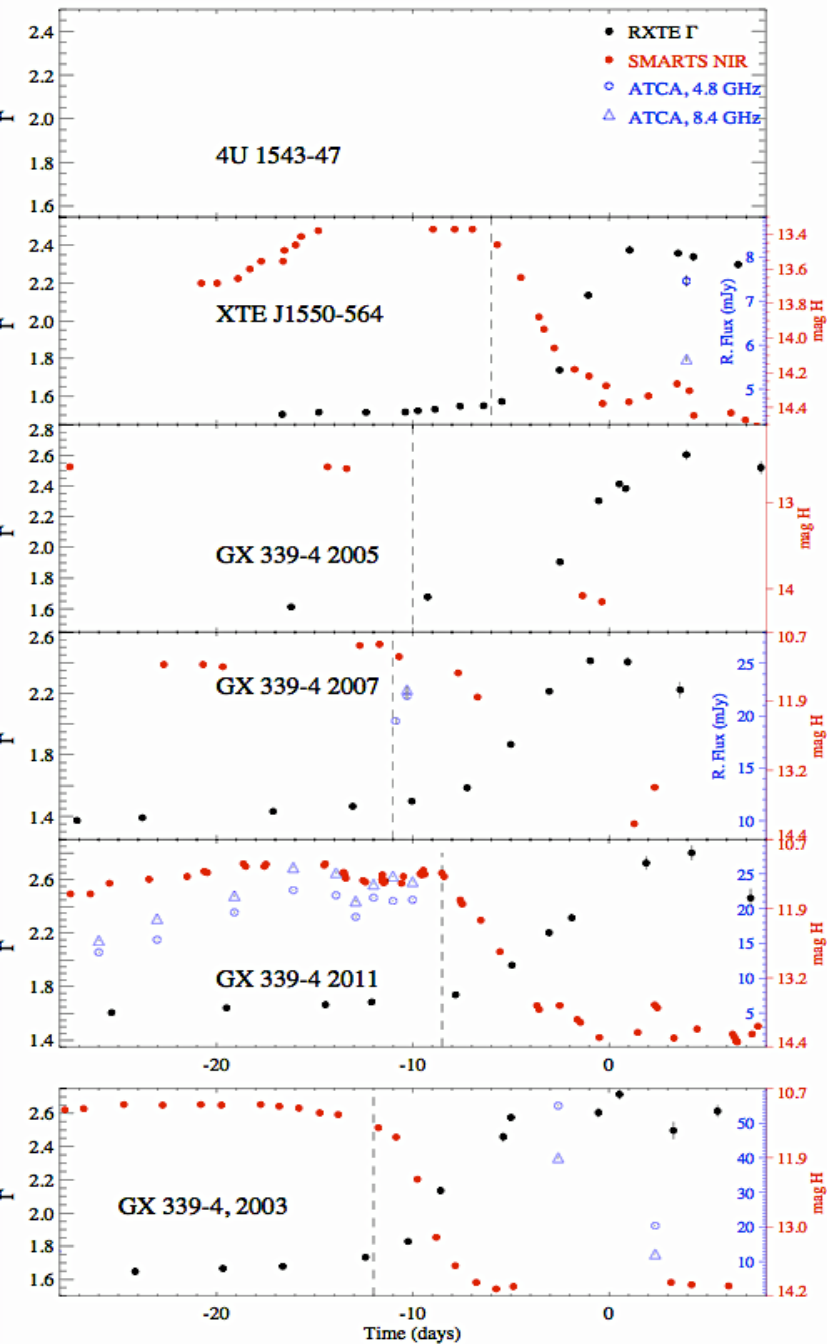
# Histeresis, parlamanın çıkış ve sönüş dönemindeki farklar

## YÖNTEM:

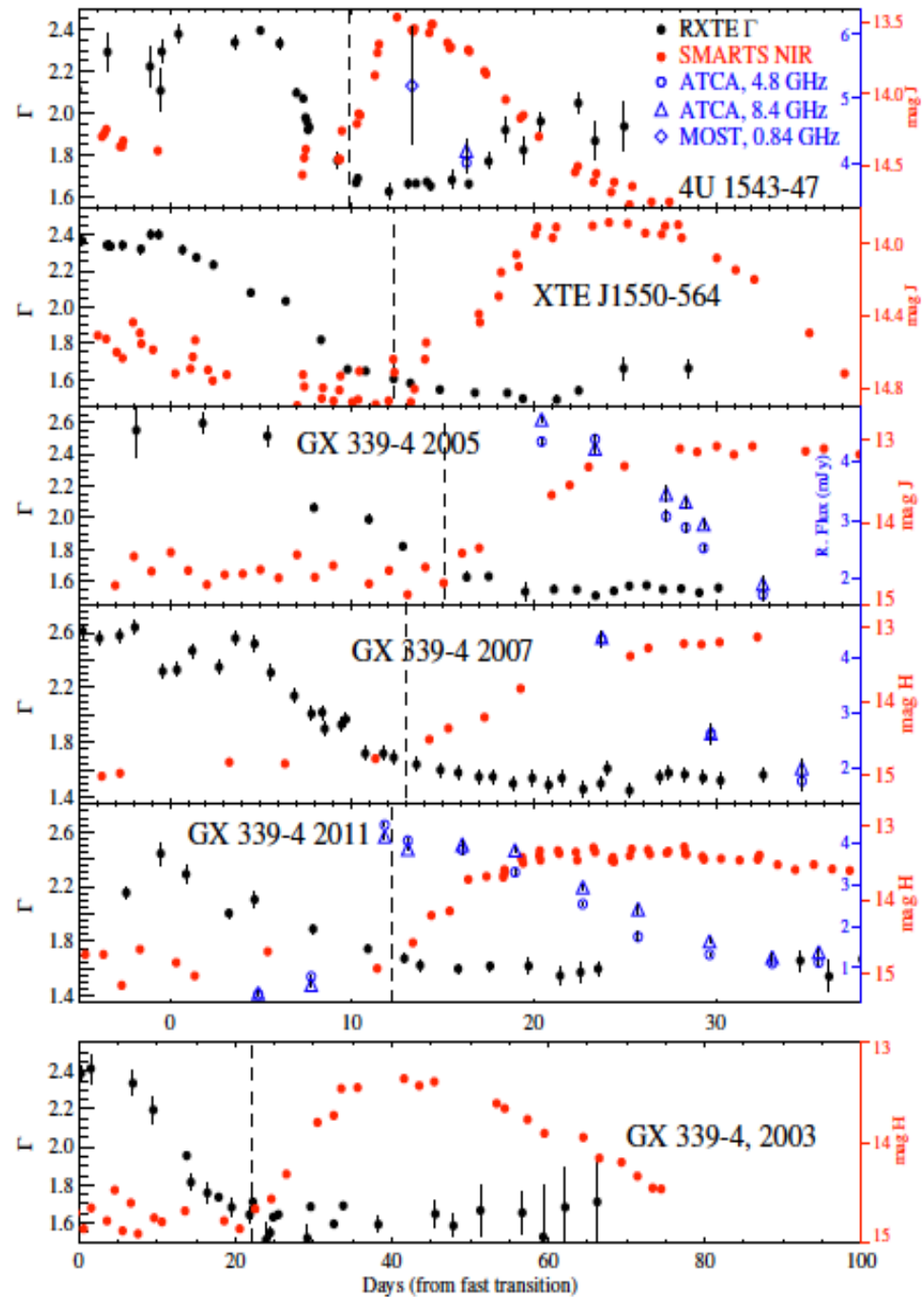
- Güç kanunu indisi ( $\Gamma$ ) koronanın sıcaklığını ve büyüklüğünü betimler, düşük indisler daha sıcak ve daha büyük korona demektir.
- KÖ ve radyo akısı jetten gelen ışınımı betimler.
- Radyo tayfının indisi jetin ne kadar sıkı olduğunu (jetin çıkış açısını) betimler, düz ya da frekansa göre artan akı daha sıkı jet demektir.



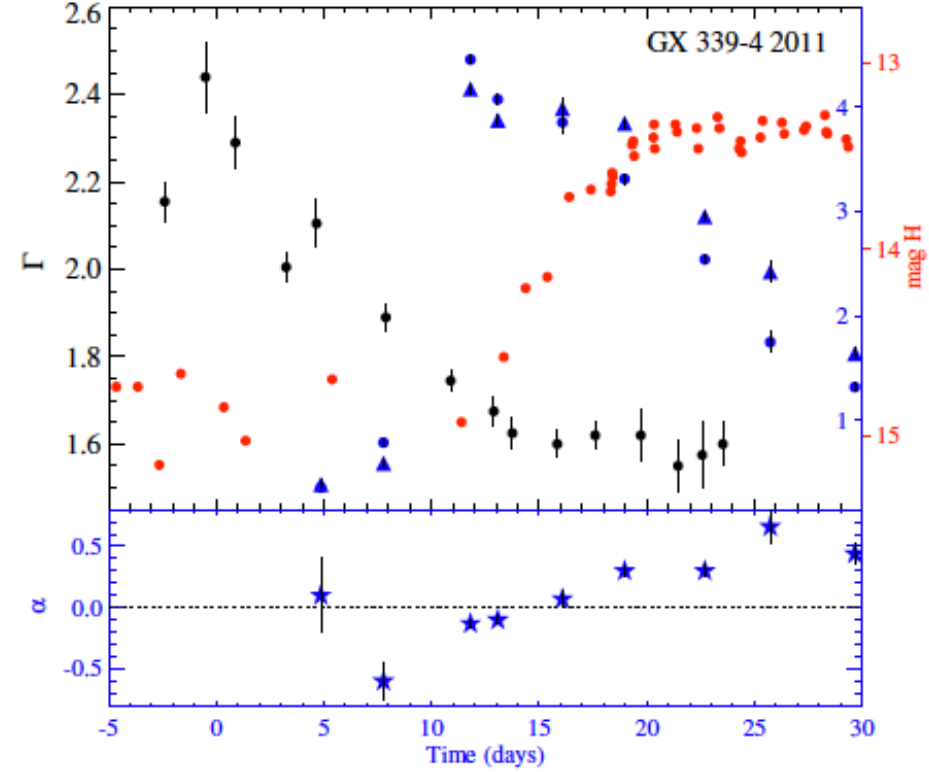
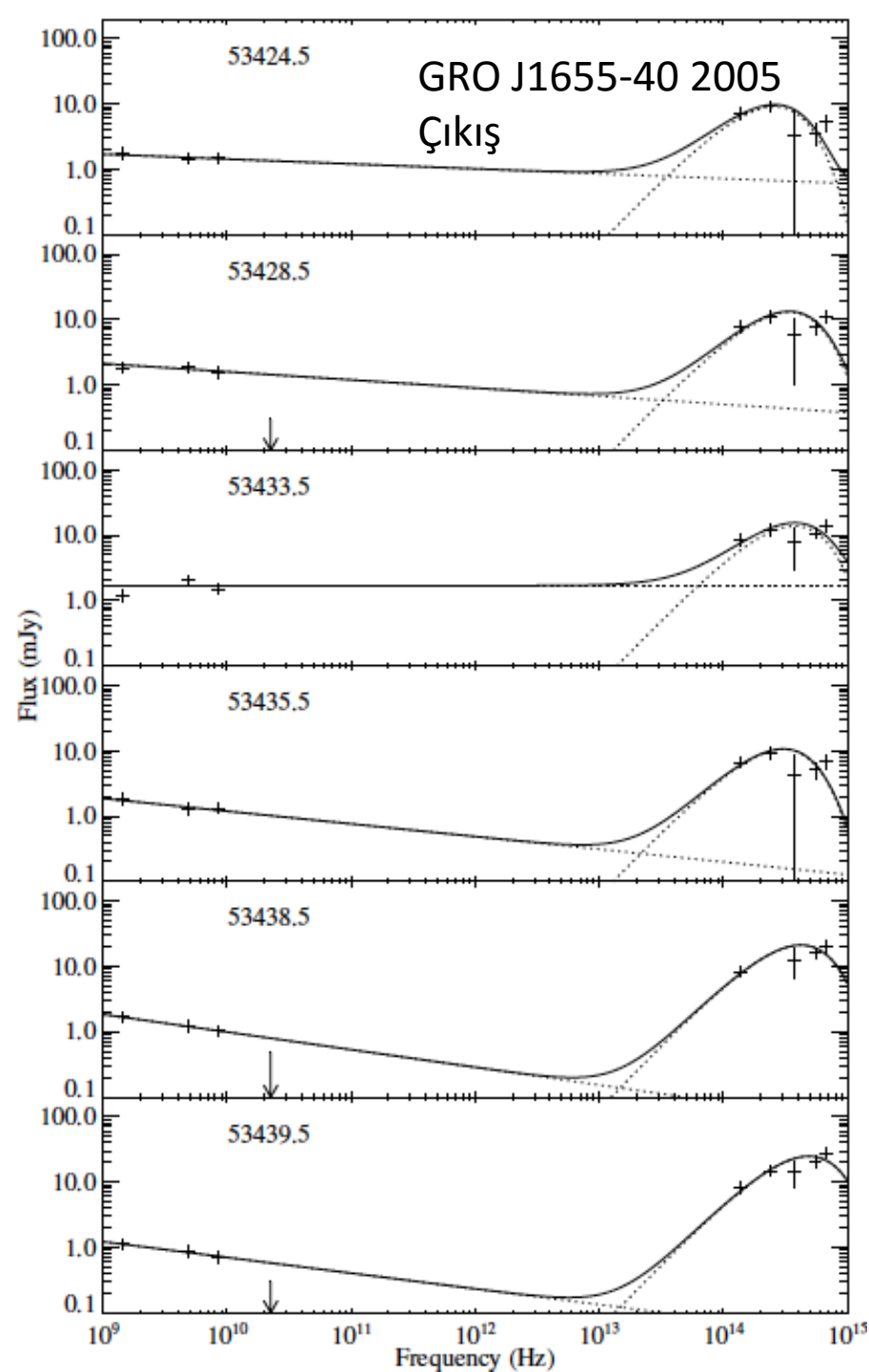
# ÇIKIŞ



# SÖNÜŞ



# Çıkış ve sönüş, radyo evrimi.

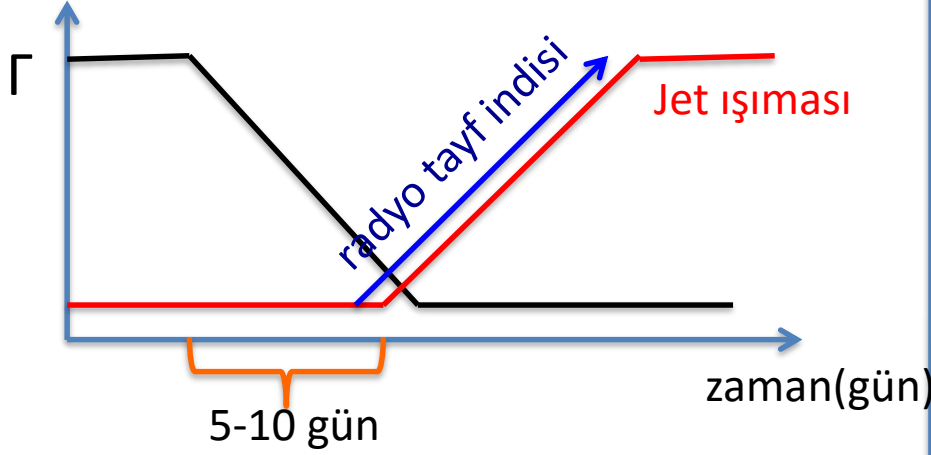


Çıkış : jet açısı büyüyor,  
sönüş jet açısı küçülüyor?

Kalemci et al. MNRAS 2016, kabul edildi.  
H 1743-322 de benzer özellik gösteriyor.

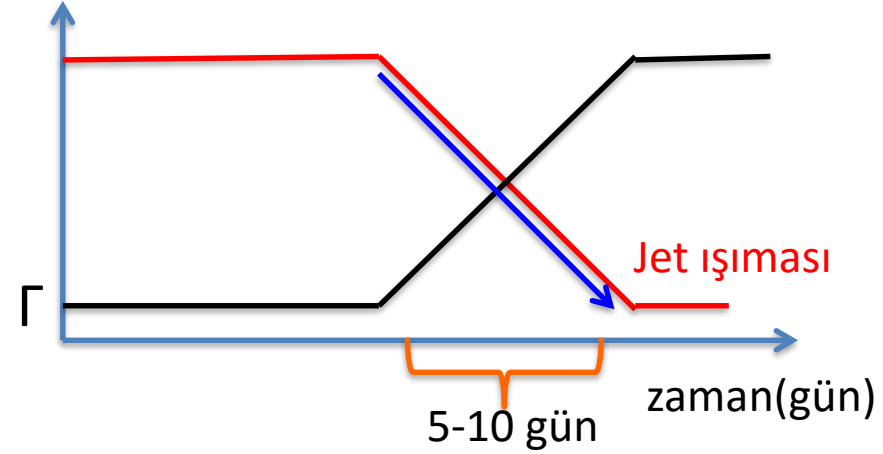
# Sıkı jetler ve dönem geçişleri

sönüm döneminde jet oluşumu

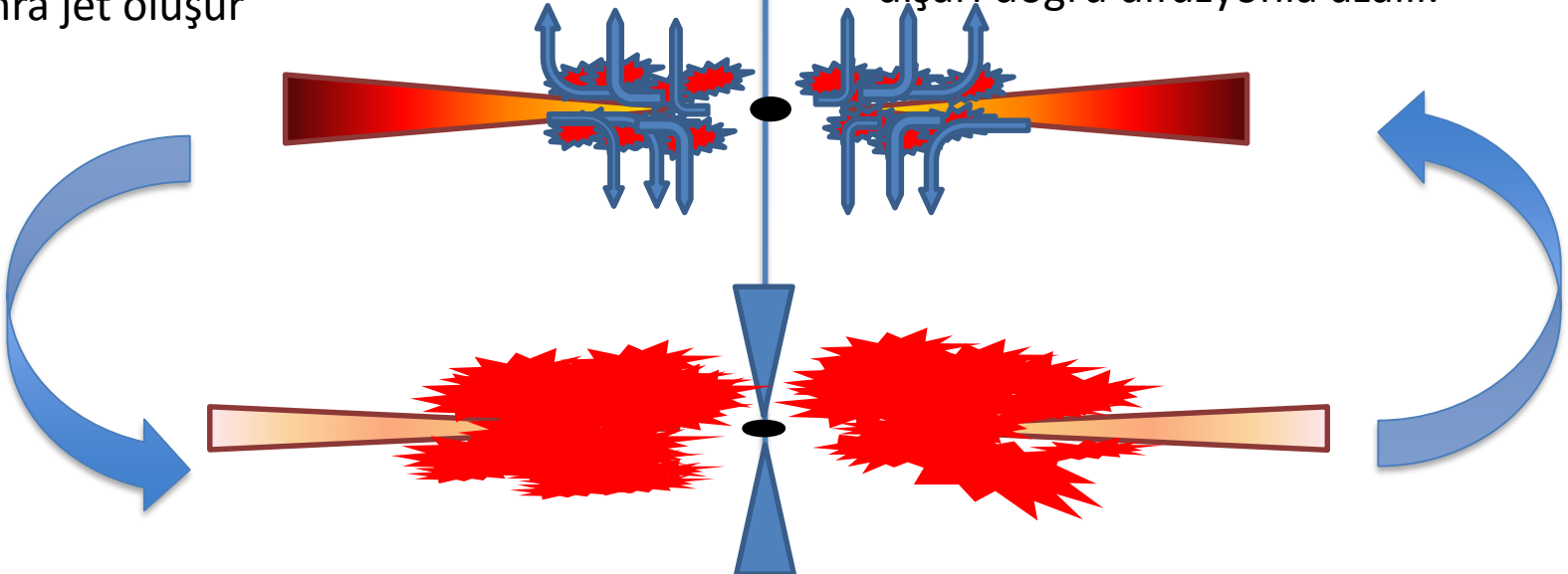


Manyetik akının birikmesinden sonra jet oluşur

çıkış döneminde jetin yok olması



Manyetik akı yenilenmediği için hemen dışarı doğru difüzyonla azalır.

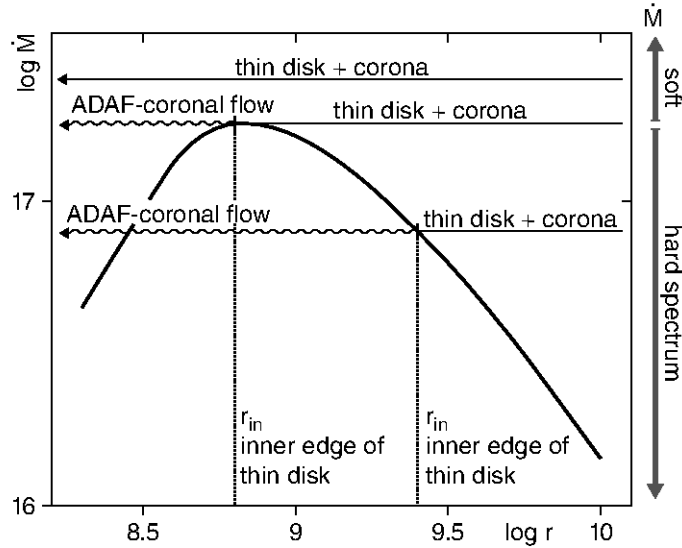


# Dönem geçiş modelleri

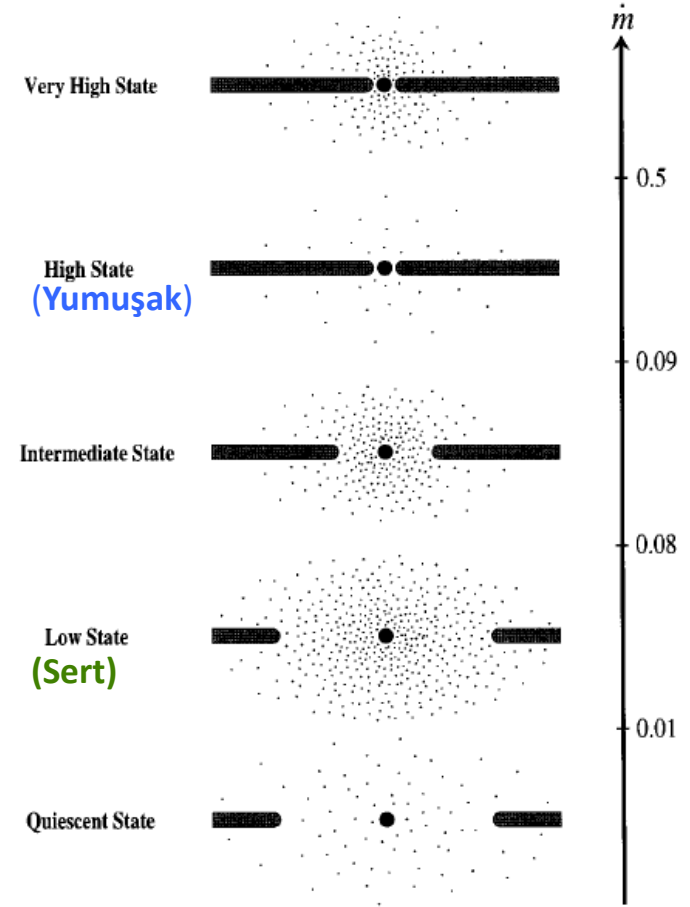
- biraz da kuramlara bakalım....

# İlk fikir: Dönemleri yığılma hızı $dM/dt$ belirler

- Teori: Termal etkiler düşük madde yığılma hızlarında iç diskin buharlaşmasına sebep olur. İnce diskin iç kısmı korona haline gelir. Maddenin az ışınım yaparak doğrudan karadeliğe aktığı modellere ADAF denir. Sert x ışınlarında ışınım ters Compton saçılması ile meydana gelir.



Meyer et al. 2000

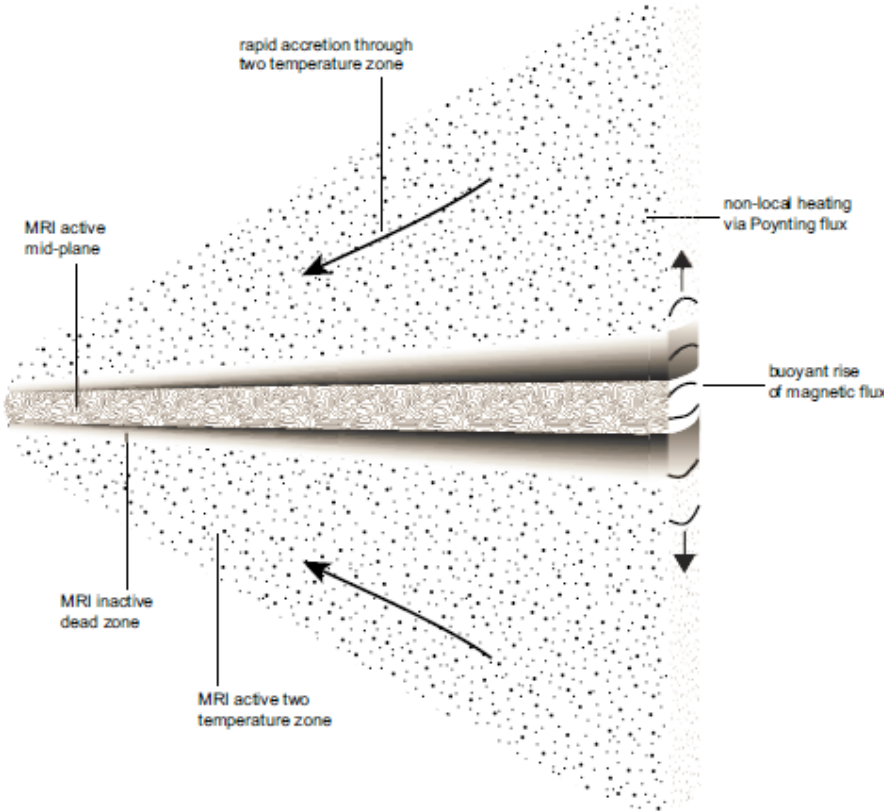


Esin, McClintock, & Narayan 1997

Yuan & Narayan 2014 Review: "buharlaşma" modeli (Meyer & Meyer-Hosmeister 1994; Liu et al. 1999, 2011; Meyer et al. 2000, 2007; Ró z ań ska & Czerny 2000; Spruit & Deufel 2002; Mayer & Pringle 2007; Taam et al. 2012); "türbülent difüzyon" modeli (Honma 1996, Manmoto & Kato 2000, Manmoto et al. 2000); "büyük vizkozite" modeli (Gu & Lu 2000, Lu et al. 2004). Yeni çalışma: Wu et al. 2016

# Manyetik alan yaratımı ve aktarımına dayanan modeller

MRI organize toroidal alan yaratır.



MRI aktif alt bölge termal ışınım yapar  
MRI aktif üst bölge termal +  
termal olmayan Komptonize ışınım,  
rüzgar ve jetleri oluşturur  
Üst ve alt bölgeden gelen ışınımın kuvveti  
dönemi belirler:

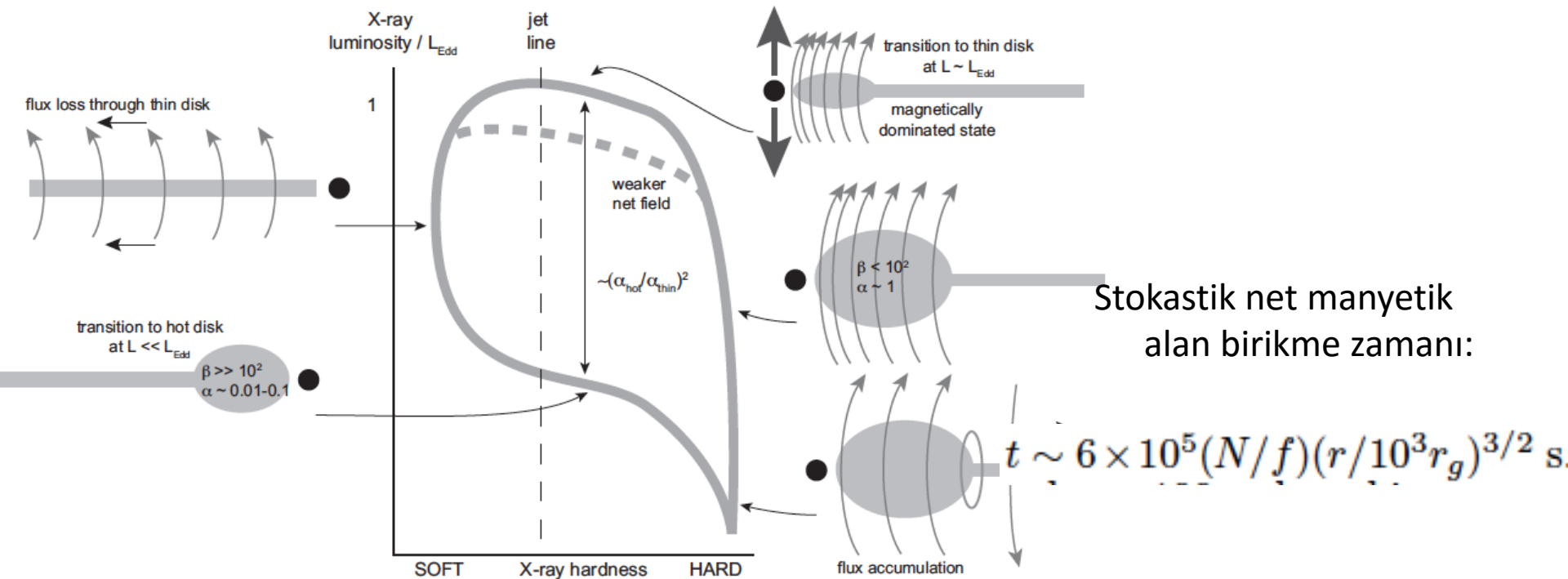
Alt bölge hakim: yumuşak dönem  
Üst bölge hakim: sert dönem  
İkisi de etkili: ara dönemler

- Begelman, Armitage, Reynolds 2015, Salvesen et al. 2016

# Poloid manyetik alanın kaynağı?

## İkincil yıldız?

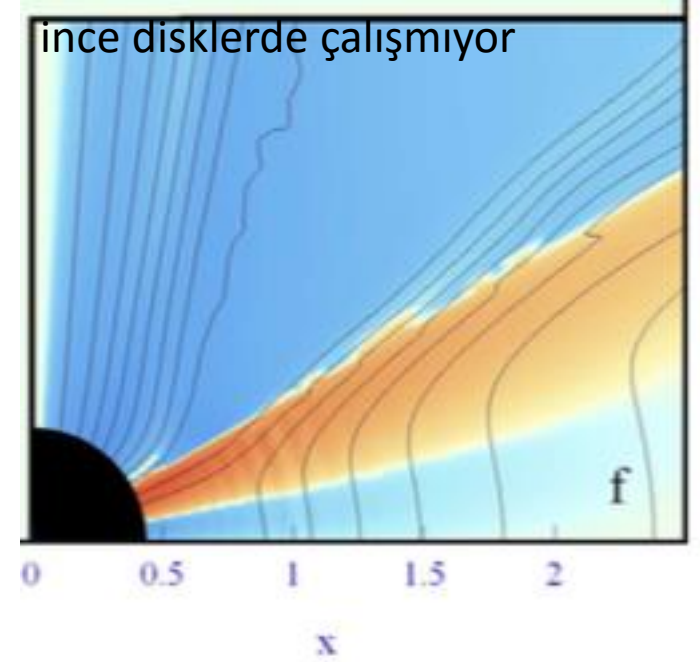
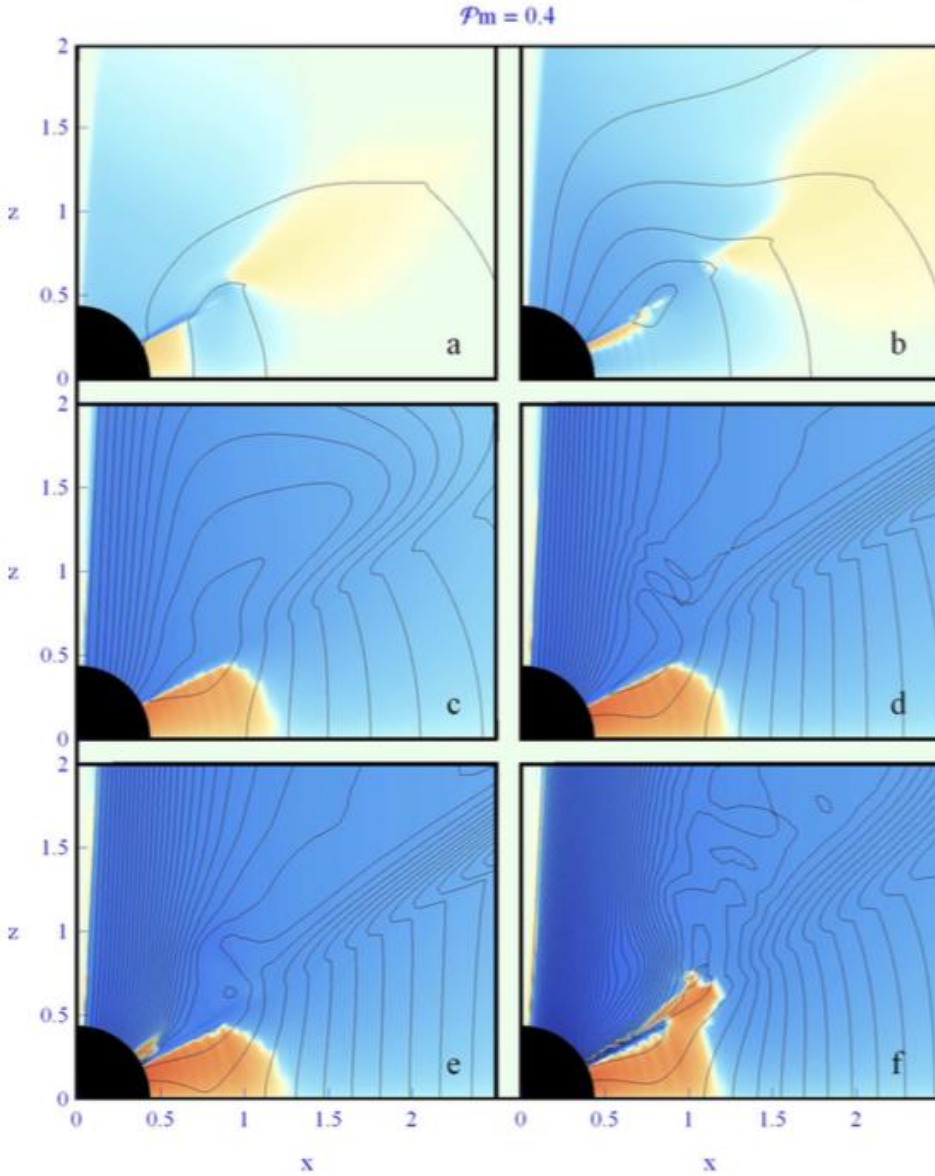
## Adveksiyon/stokastik birikme?



Karadeliklere uygun parametrelerle bu model jetleri fırlatacak yeterli manyetik alanın oluşma zaman skalası 10-20 gün, gözlemlerle uyumlu!

# Poloid manyetik alanın kaynağı?

## Poynting-Robertson mekanizması?



Contoupoulos&Kazanas

Kylafis & Belloni 2014

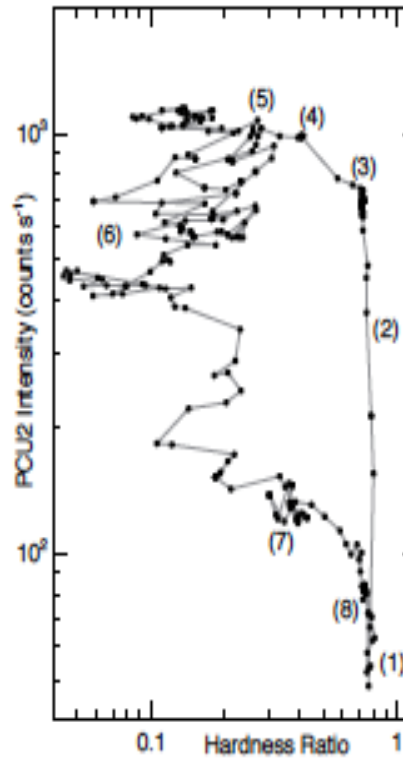
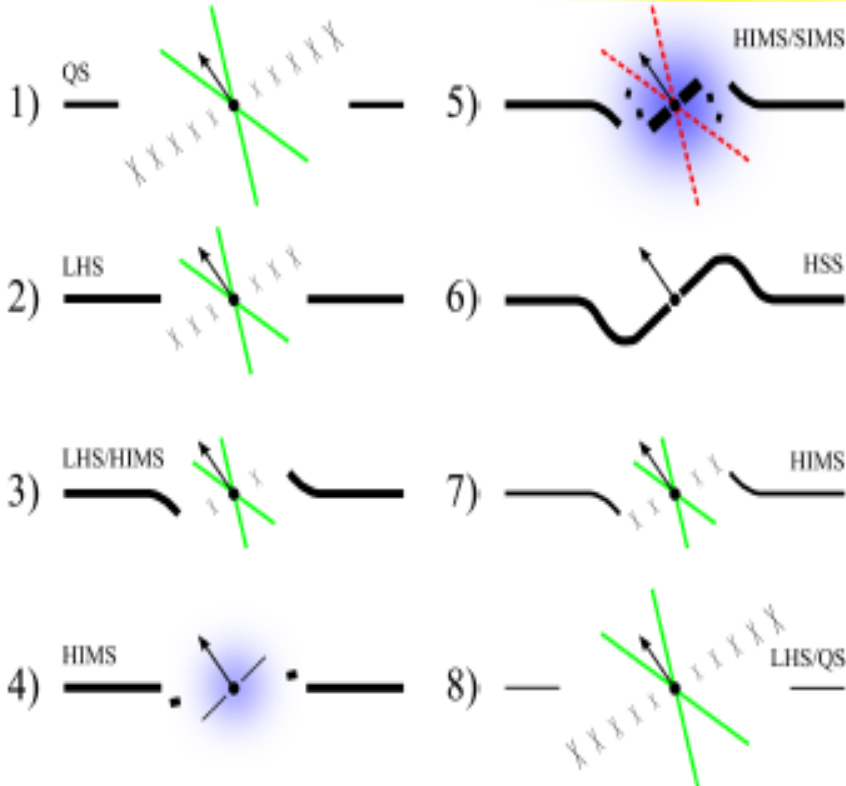
ADAF+jet models: Cao et al 2015,

Ye et al. 2015

Poloid B falanı ISCO etrafındaki hızlı elektronların radyasyonla etkileşimden oluşur  
Contoupoulos 2015



# Disk kırılması...



Dönen karadeliklerde disk ve spin ekseninin farkı sonucu ortaya çıkan disk kırılması dönem geçişlerinin bazı özelliklerini açıklayabilir.

Nötron yıldızlarında çalışmaz. Özellikle bazı kaynaklarda ara geçişlerde etkili olabilir (Kalemci 2016)

Nixon & Salvesen 2013

# Sorular

- Sertlik/parlaklık diyagramının üst dalında dönem geiş parlaklığını ne belirler?
- Sönüm dönemindeki dönem geiş parlaklığı tüm kaynaklar için sabit midir? Öyleyse neden?
- Çıkış dönemindeki balistik jet tam olarak ne zaman oluşur? Bu jetin X ışını zamansal ve tayfsal bağımlılığı nedir?
- Dönem geişlerinde manyetik alanın rolü nedir? Poloidal manyetik alanın kaynağı nedir?

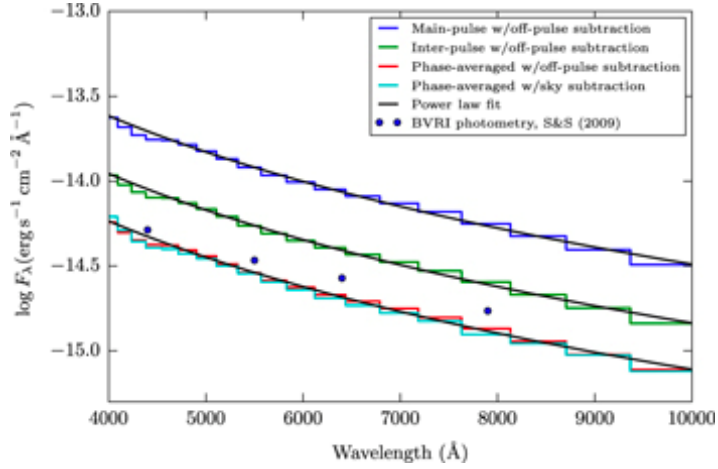
## İleriye bakış

- Veriler teoriden çok ileride.
- Modelleme bize çok şey söyleyecek.
- SKA + LOFT? + LSST + KÖ (DAG!) günlük gözlemler yeni ufuklar açacak.

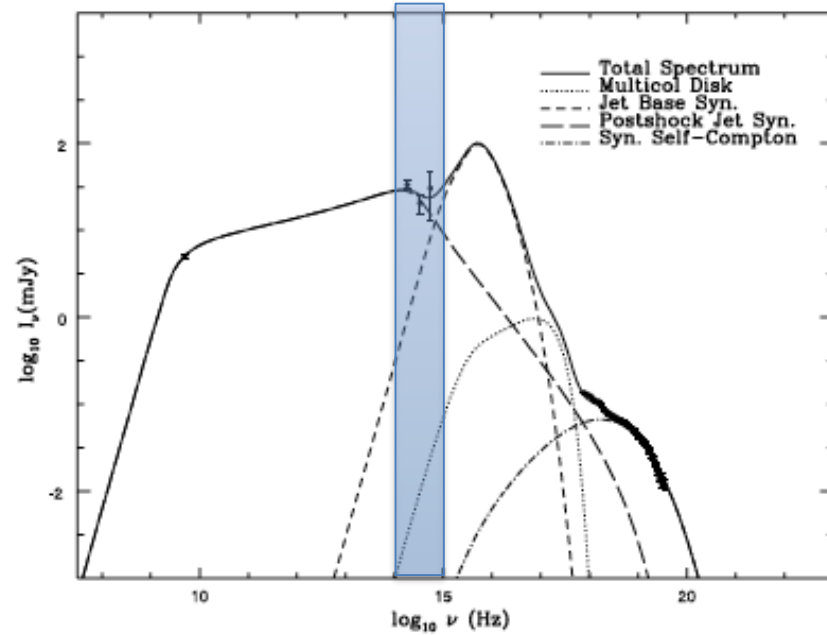
# Karadelikler ve DAG

- Yüku çekenerler:
  - 1.3m SMARTS – avantaj: Şili’de
  - Faulkes 2m - avantaj: 2 yarımküre, 2 teleskop.  
dezavantaj: kızılötesi yok.
  - Diğerleri: Çok küçük (50-60 cm) ya da fazla zaman ayıramayacak kadar büyük!
- Rüya 1: 4m çap + MKID + dönem geçişi boyunca her gün gözlem
- Rüya 2: 4m + saniye altı hızlı KÖ zamansal ölçümler (MKID ya da başka özel alet)

# DAG + MKID odak düzlemi algılayıcısı



ARCONS faza bağımlı Crab tayfı!  
Noktalar B, V, R, I fotometri



SED modellemesi, GX 339-4. Homan 2002  
Optik kızılötesi: SMARTS

SED kırılma noktası nerede = jetin toplam gücü

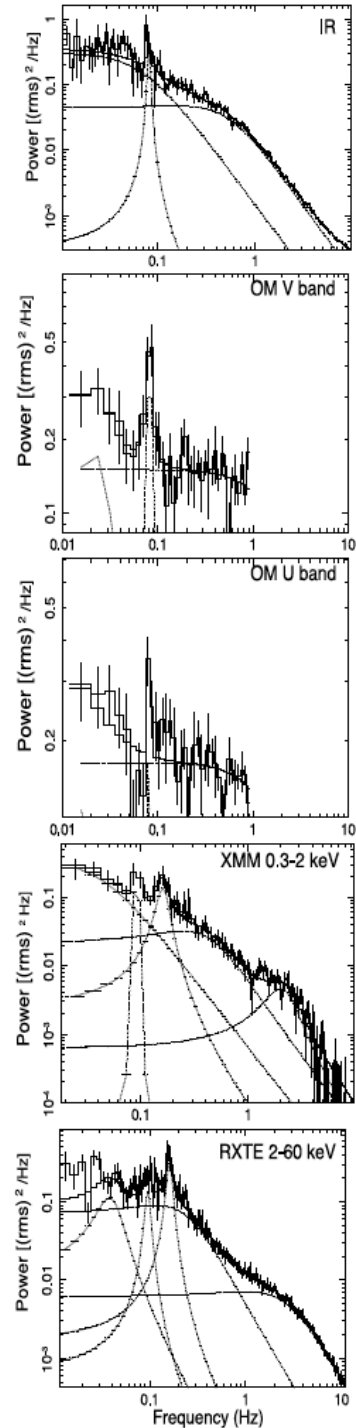
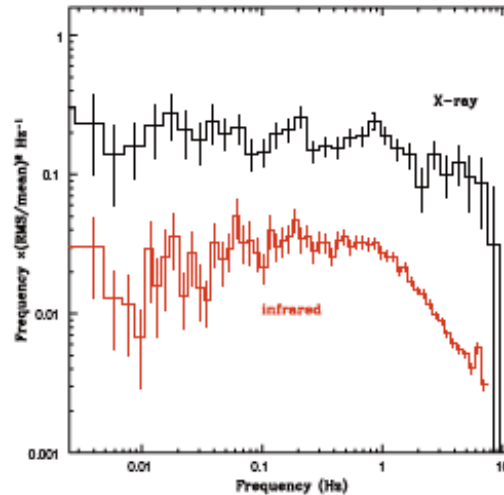
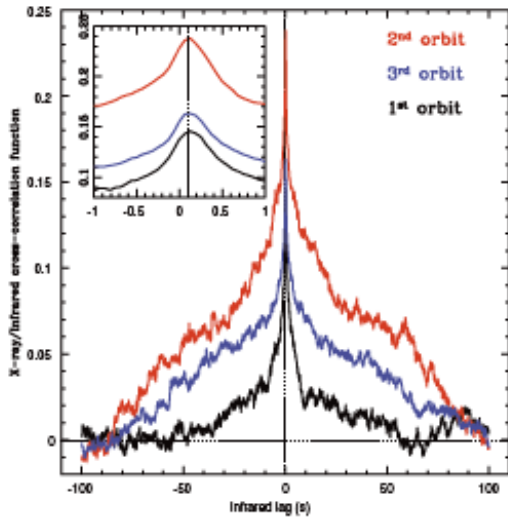
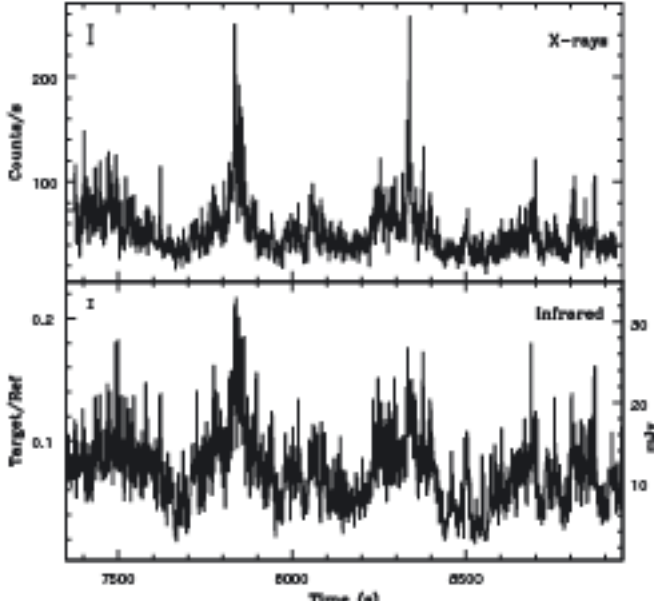
Jetin karadeliğe yakın kısmında sinkrotron ışınması var mı? = jetin yapısı, fiziği

# Çok hızlı IR fotometri

Casella 2010

Kalamkar 2016

VLT üzerinde ISAAC  
KÖ 2 makale, optik 2 makale!



- **DAG'ı heyecanla bekliyorum ....**

# EXTRA SLIDES

# Models

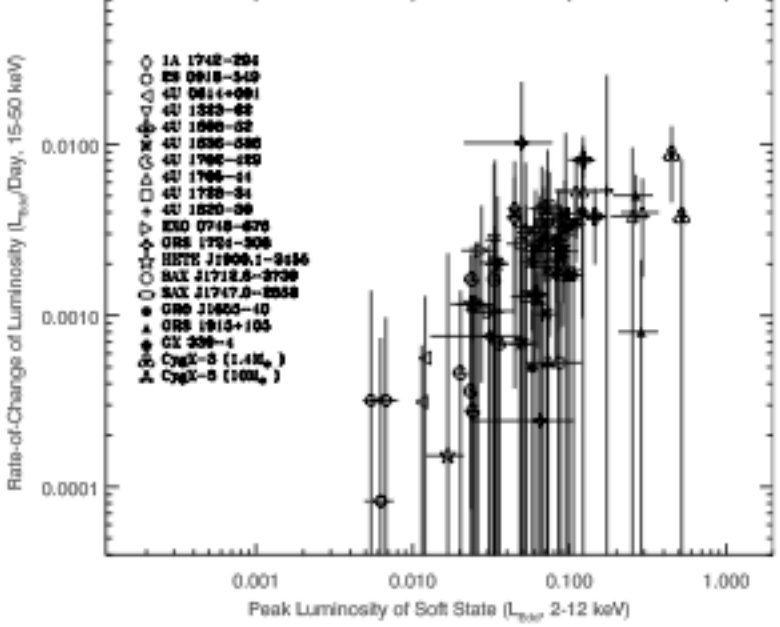
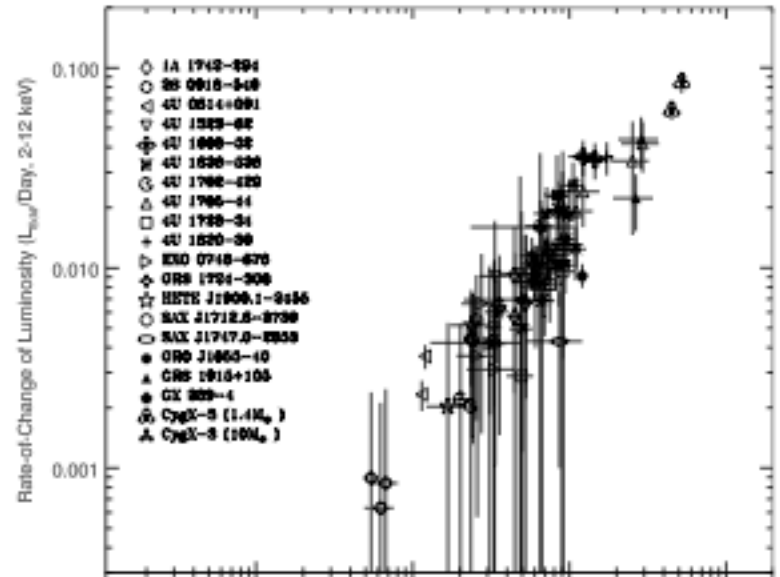
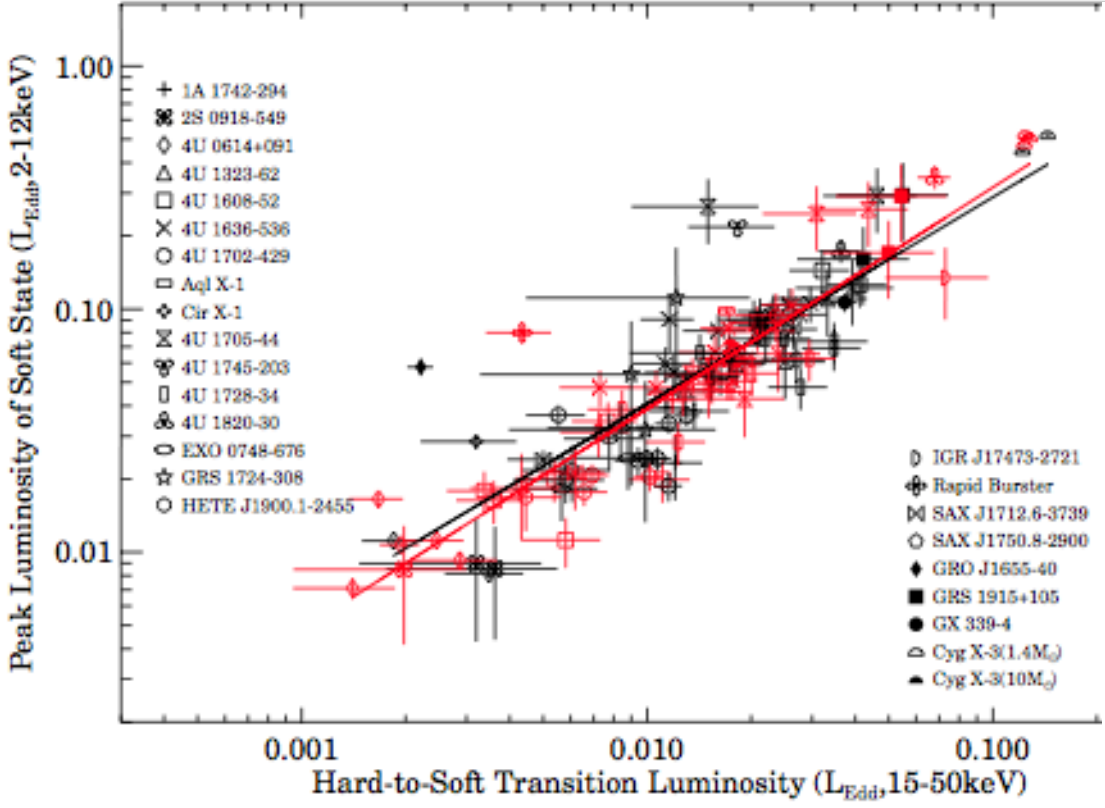
- CENBOL? – TCAF is the name of actual model
- just check NS / WD connection
- can fit data in all states, but require that the optically thick disk be away.



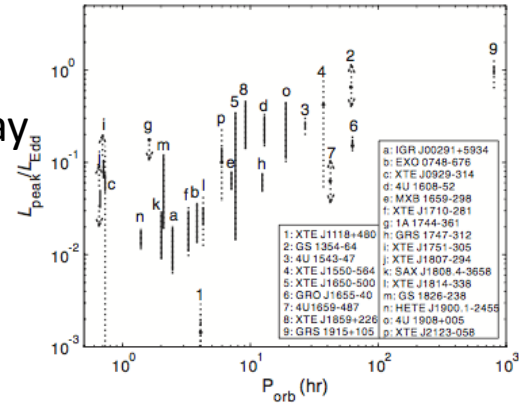
# MACRO-STUDIES

- Including many neutron star and BH sources macro studies of state transitions have been conducted (important to set general accretion trends) using all sky monitors.

Hard to soft state transitions of NSs and BHs, a correlation with no turn over. (Tan, Yu& Yan 2010)  
 Hard to soft transition depends on how fast the soft luminosity rises. (Yu & Yan, ApJ 2009)  
 Peak X-ray luminosity increases with increasing orbital period.



Black hole rise and decay timescales > that of NS  
 Yan et al. 2014



# complications

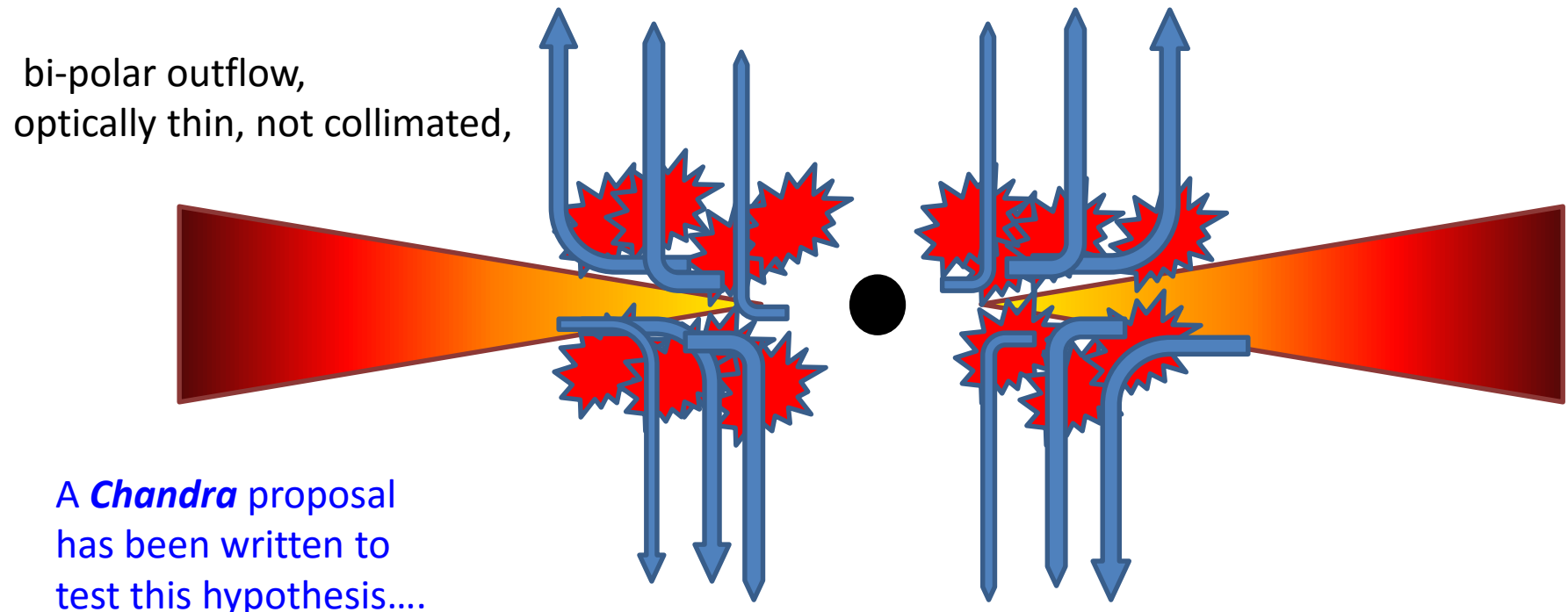
- geometry, iron line – gapped disk model...
- origin of QPOs, broad band timing
- effect of winds
- warped disks?

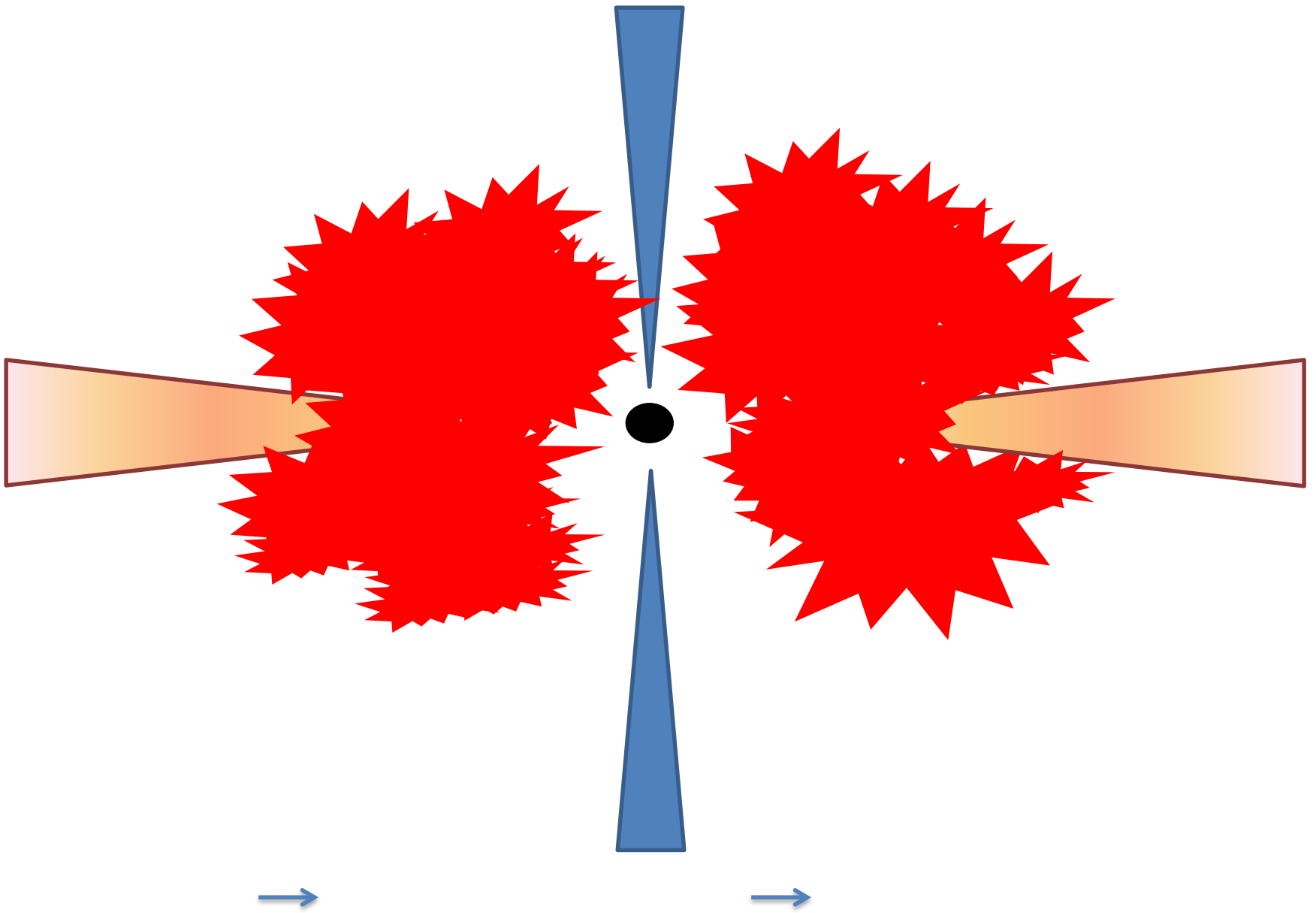
# DISCUSSION and INTERPRETATION I

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.

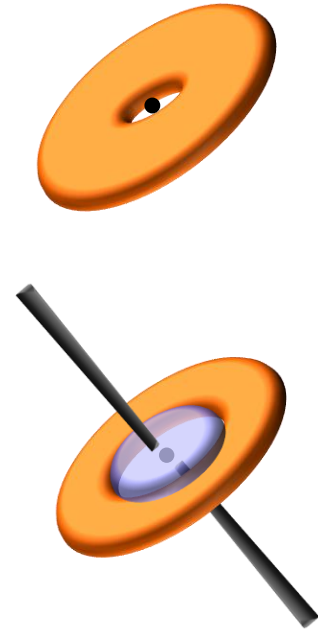
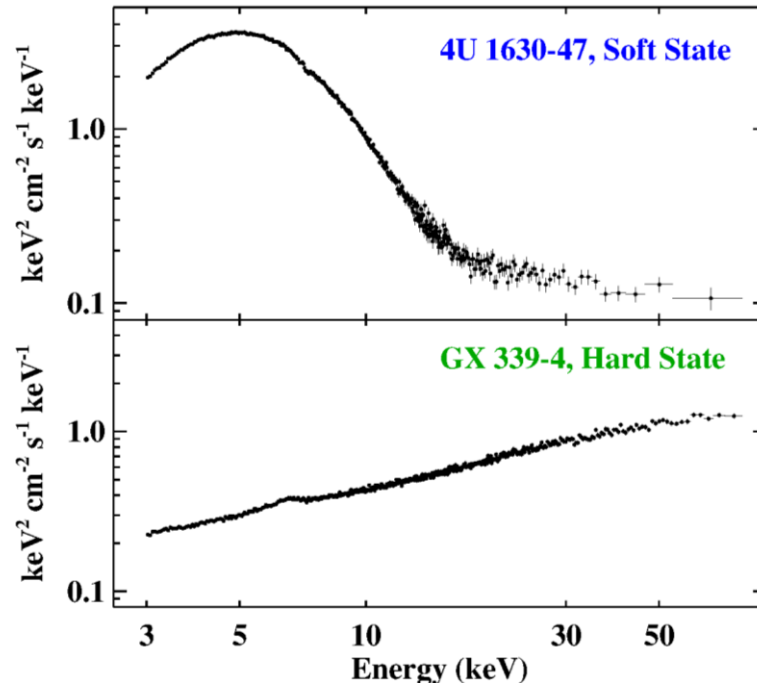
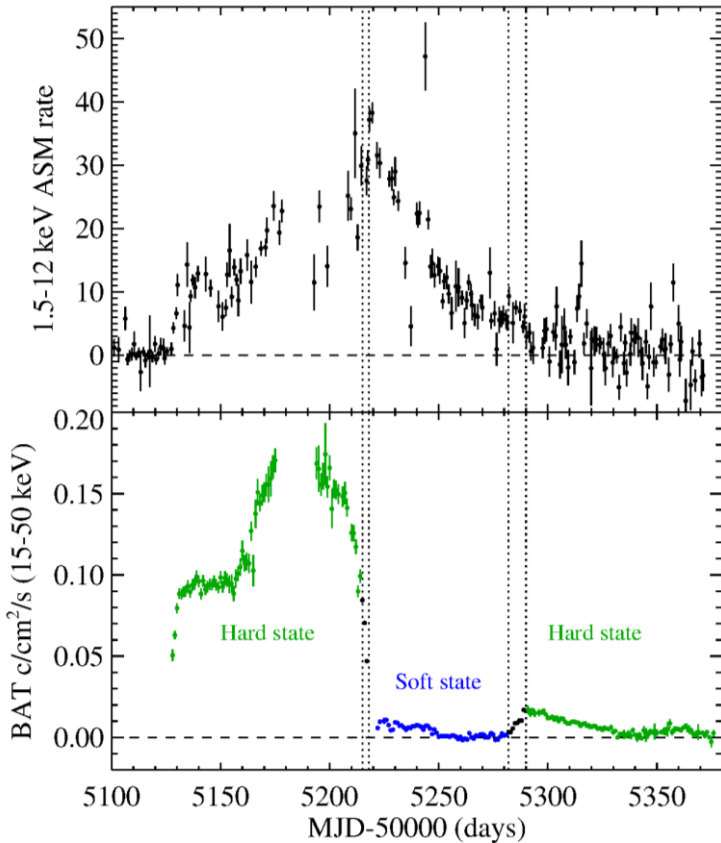




Disk flux goes down, corona scale height increase, effective transport of B field + effective collimation, all ingredients necessary for compact jet formation. BUT...

## DISCUSSION and INTERPRETATION II

# 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:  $\sim 1$  keV thermal plus power-law
- Hard state:  $\Gamma \sim 1.4-1.8$  power-law

Explains hysteresis and jet behavior, ties states to puffed up disk, standard ADAF

- In hard states the inner part of the accretion disk is ADAF-like, the **Cosmic Battery** (Contopoulos & Kazanas 1998) works efficiently, and a compact jet is **always** present (Kylafis et al. 2012).
- Then, the jet line is approached.
- The Cosmic Battery does not work efficiently in the thin disk. Also, the thin disk cannot sustain the high magnetic field that was created in the thick disk.
- The magnetic field recombines and produces huge eruptions (**eruptive jet**), as it is observed.

# 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

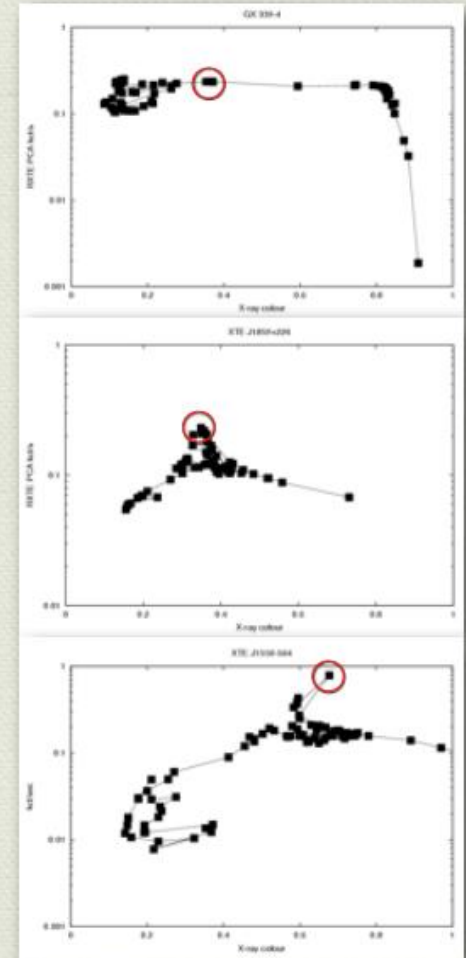
- Begelman & Armitage 2014
- Cao 2015, magnetic outflows increasing radial velocity, helping ADAF survive.
- Kylafis had similar ideas

# 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....

# Transient ejections

- ◆ Major flares or ejections
- ◆ Always intermediate
- ◆ Only in hard to soft
- ◆ Precisely at HIMS-SIMS transition?
- ◆ Noise disappears - jet appears
- ◆ Not causal

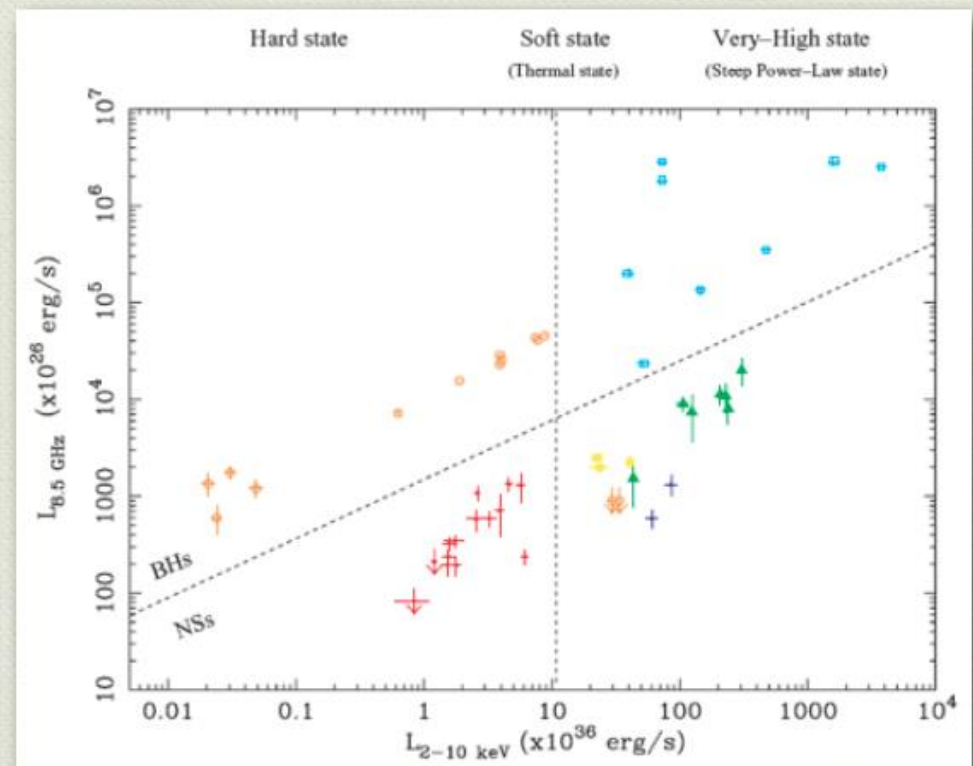
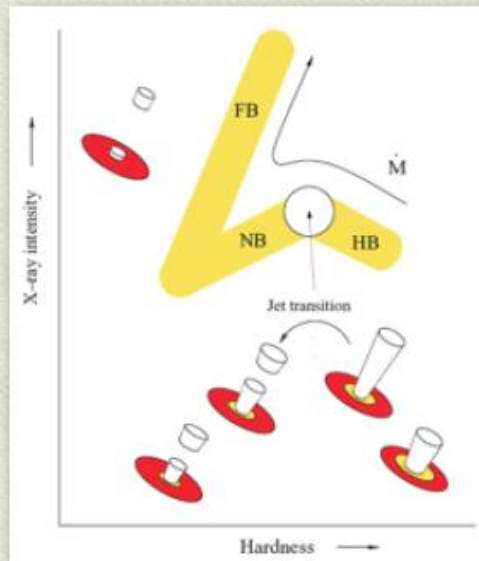


Fender, Belloni & Gallo (2004)

# Neutron star binaries

- ◆ Hard-state correlation: similar to black holes, but radio-quiet (factor 30)
- ◆ Plus ejections

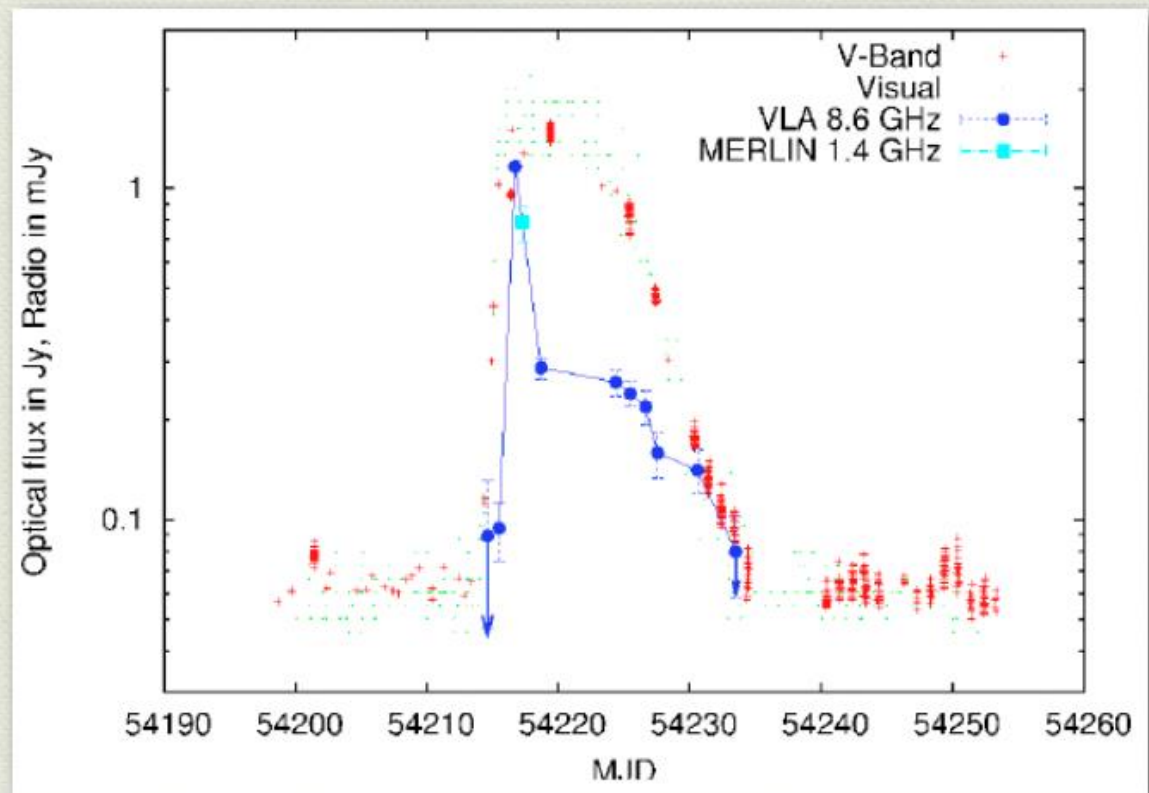
Migliari & Fender (2006)



# White dwarfs!

- ◆ SS Cygni
- ◆ Dwarf nova
- ◆ Radio flare
- ◆ At transition!

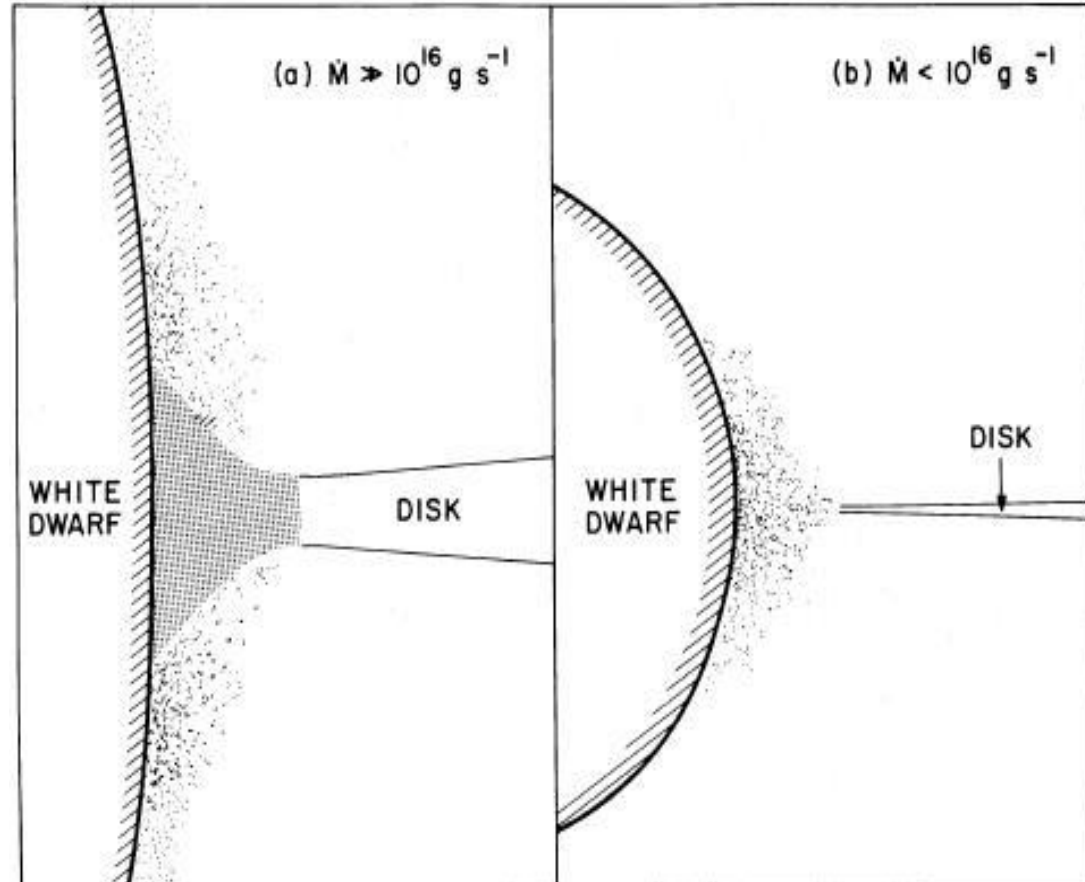
Kording et al. (2008)



- H1743 quenching
- Miller jones 2011.

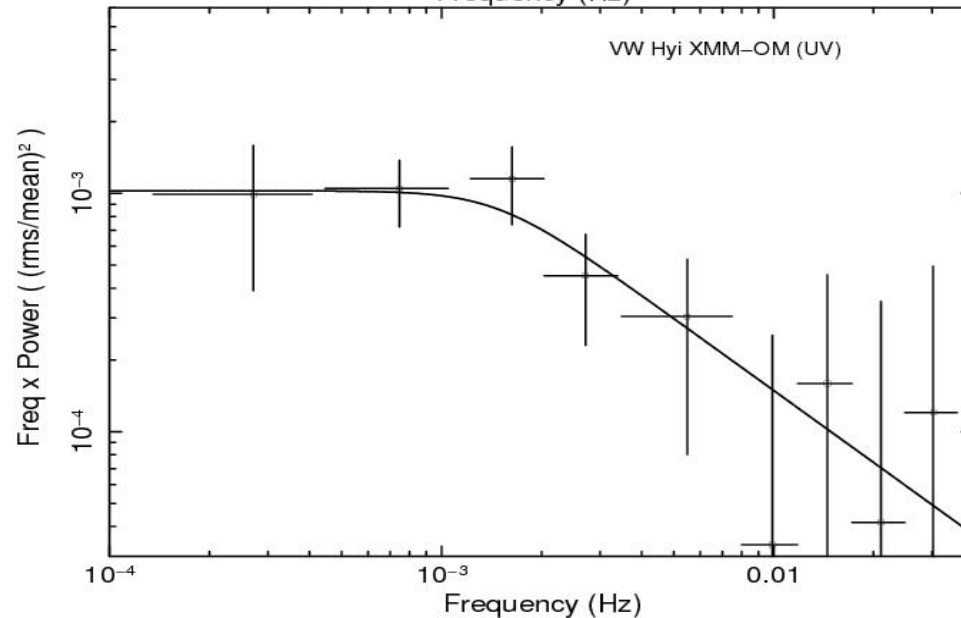
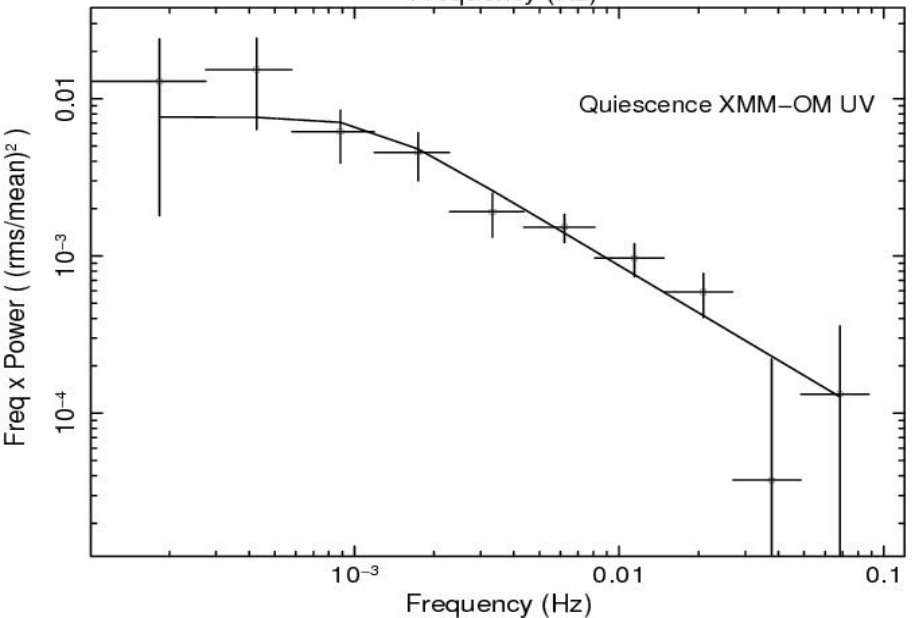
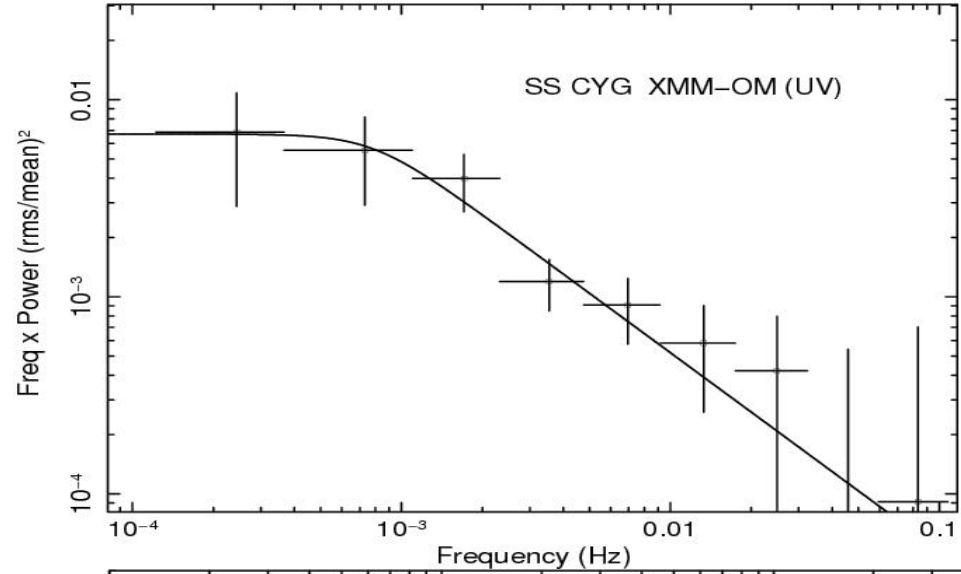
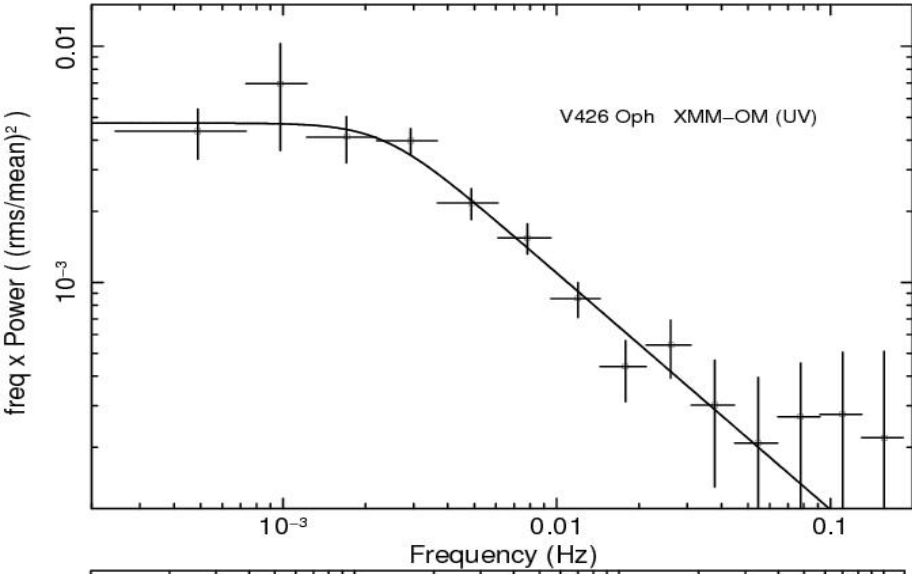
# X-ray Emission from Nonmagnetic CVs

- Boundary Layer (BL)
- $L_{BL} \approx L_{disk} = GM_{wd} \dot{M}_{acc} / 2R_{wd}$   
 $= L_{acc} / 2$  **matter decelerates from Keplerian velocities to the slowly rotating WD  $L_{BL} \approx L_x$**
- (Patterson & Raymond 1985; Narayan & Popham 1993, Popham & Narayan 1995, Godon et al. 1995, Hertfelder et al. 2013 )
- **Optically thick BL**
- **→ Soft X-rays  $\sim 10^5$  K**
- **$\dot{M} > 10^{-9} M_{\odot} / \text{yr}$**
- **Optically thin BL**
- **→ Hard X-rays  $\sim 10^8$  K**
- **$\dot{M} < 10^{-9} M_{\odot} / \text{yr}$**



# UV Power Spectra

XMM-Newton OM  
UVW1 filter 240-340  
nm



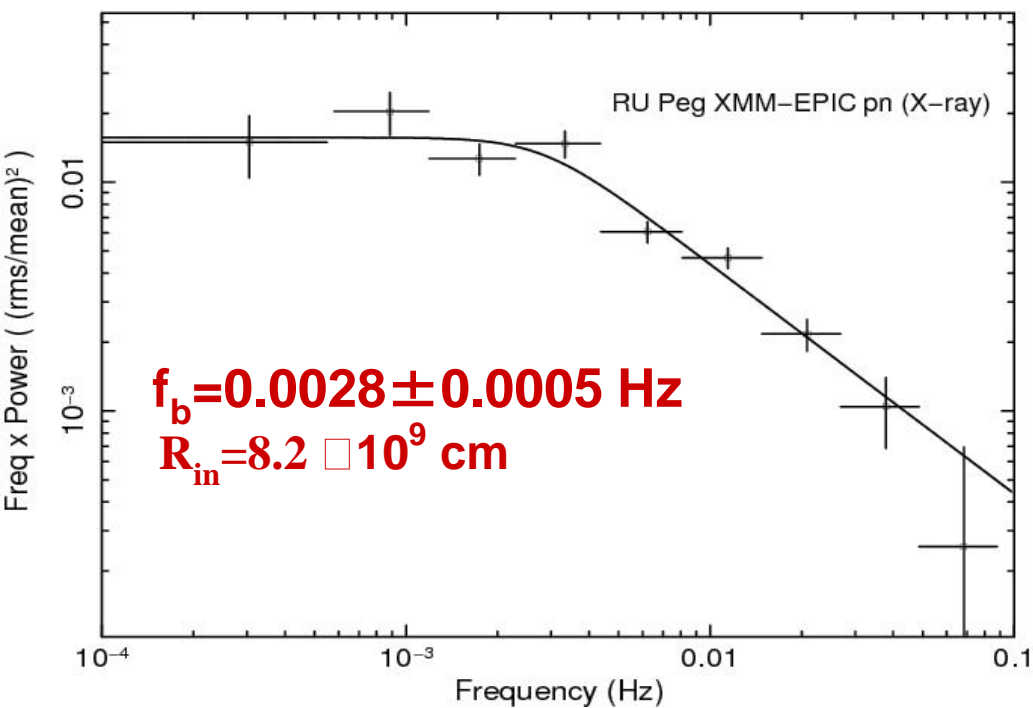


# RU Peg

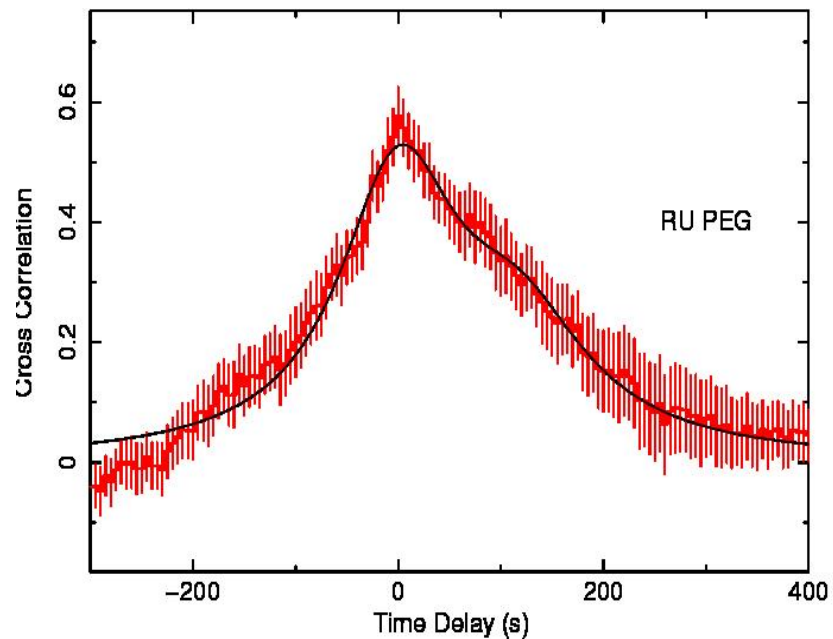
50 d, 20 d

8.99 hr

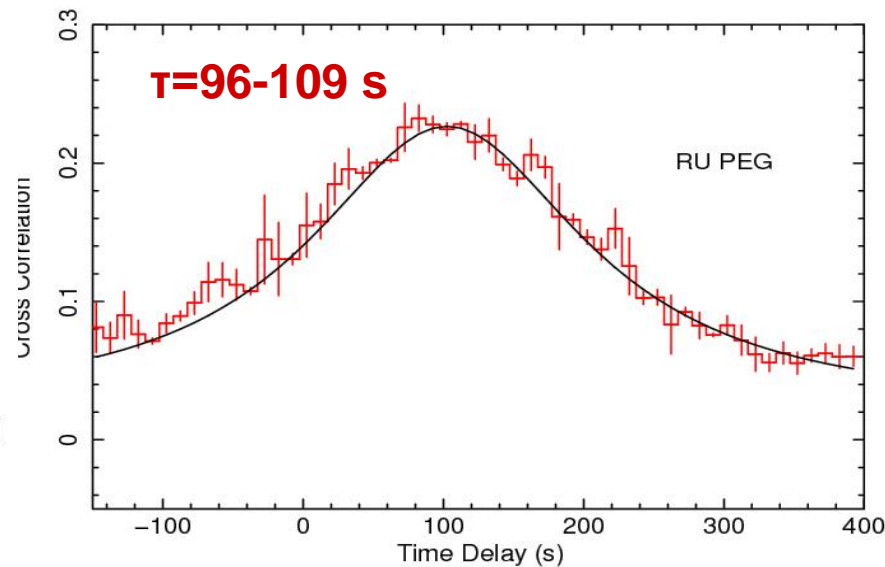
~31 keV



Balman & Revnivtsev 2012



Balman et al. 2011



# Conclusions

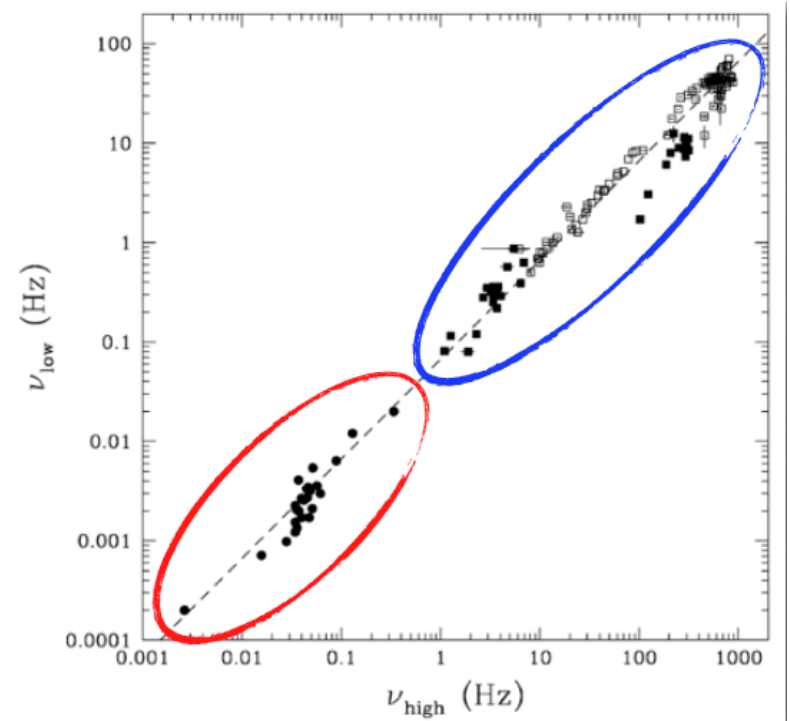
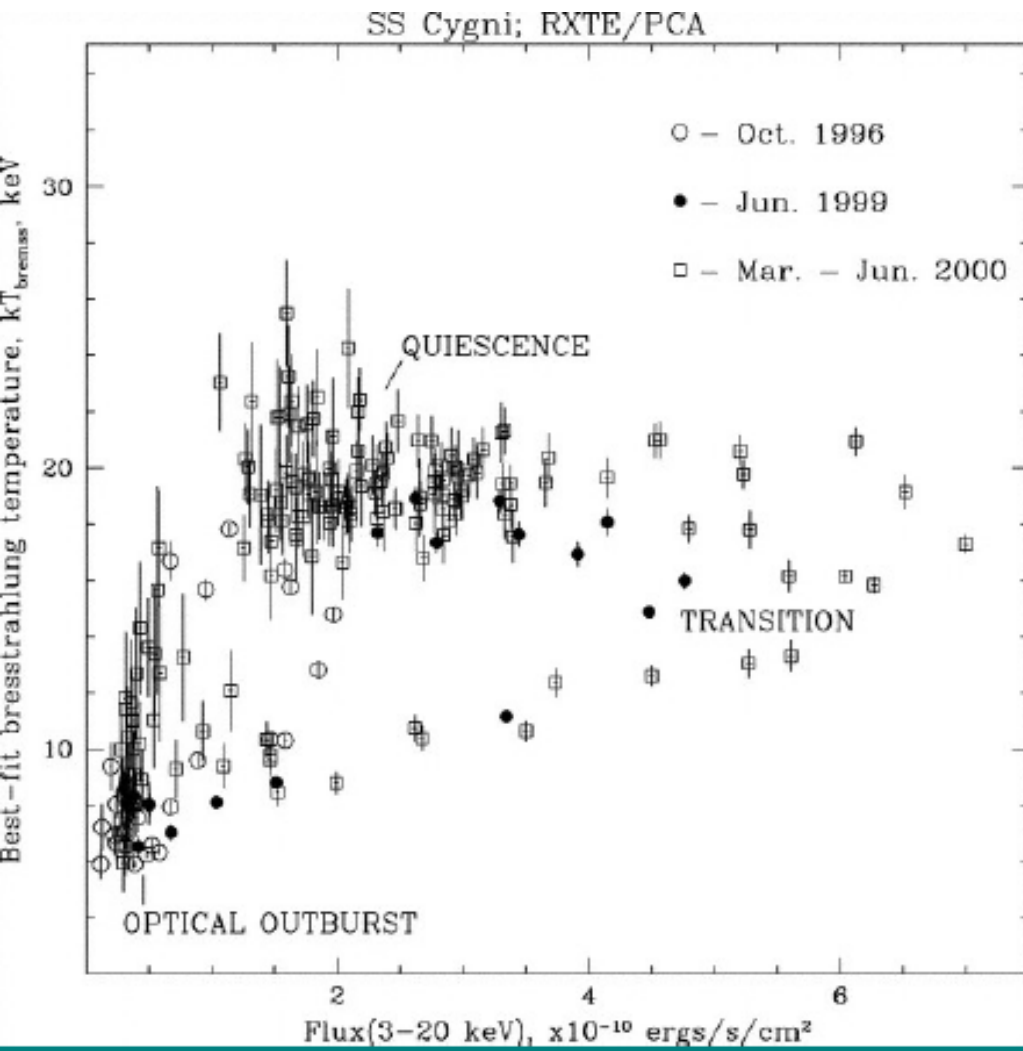
- There is large scale truncation in the Disks of Dwarf Novae (DN) in at least 9 systems with radii in a range  $R_{tr} \approx 3-10 \times 10^9$  cm. The Magnetic CVs (MCVs) show rather smaller truncation radii  $\sim 0.9-1.9 \times 10^9$  cm (Revnivtsev et al. 2011).

Suggest that most of these systems (DN) have truncated disks with hot coronal flows dominating in the inner disks (e.g. ADAF-

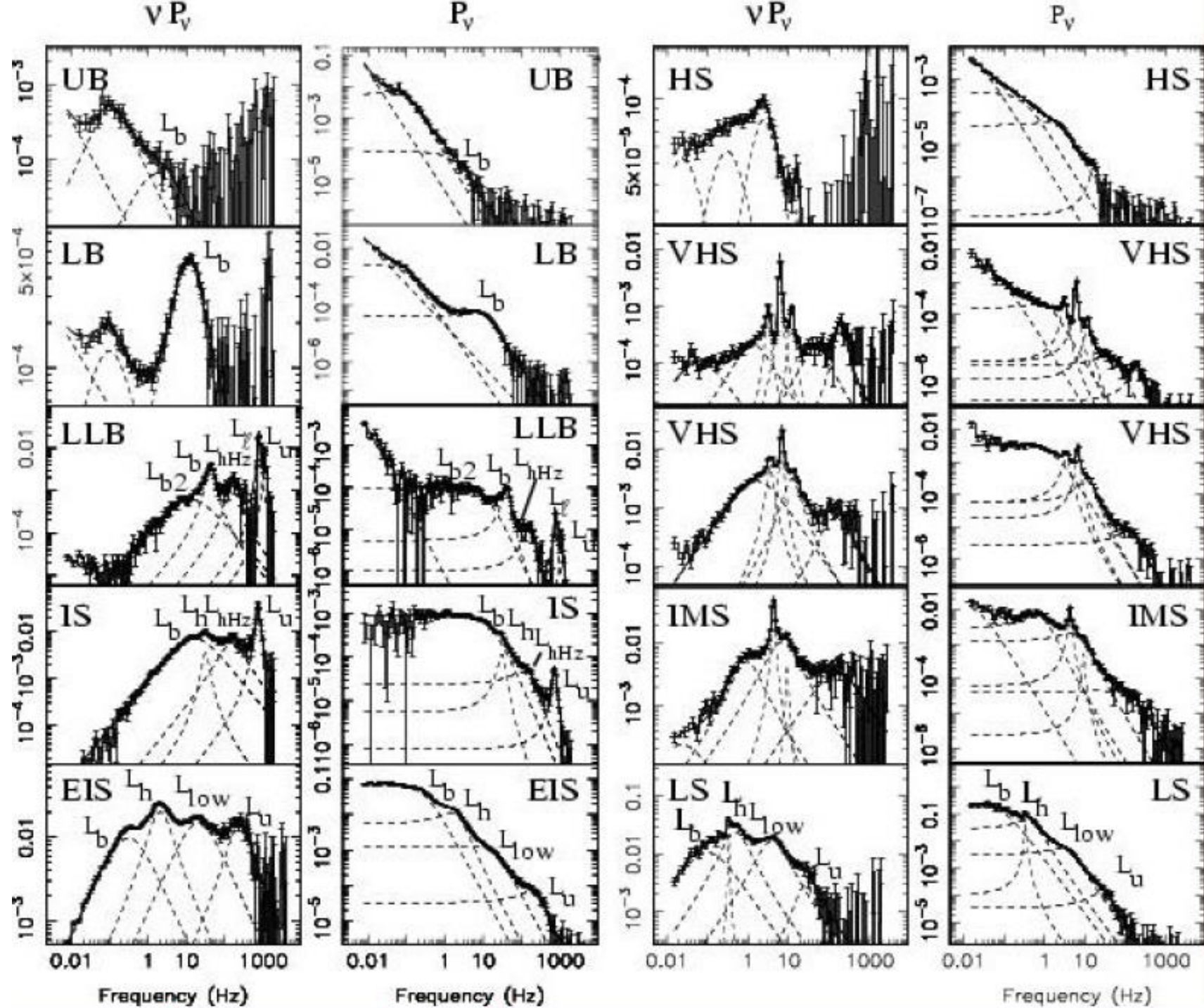
- Time delays in X-ray disk (corona) of 96-181 sec in 5 objects are found (Balman & Revnivtsev 2012). These are consistent with matter propagation timescales onto the WD in truncated nonmagnetic CV disks. This value is about 6-8 sec for the magnetic CV, Intermediate Polar EX Hya.

- Suggest that the  $\alpha$  parameter in DNe is  $\sim 0.1-0.3$  compared with delay times in MCVs
- There is evidence that the disk truncation varies with accretion rate changes in quiescence and outburst.

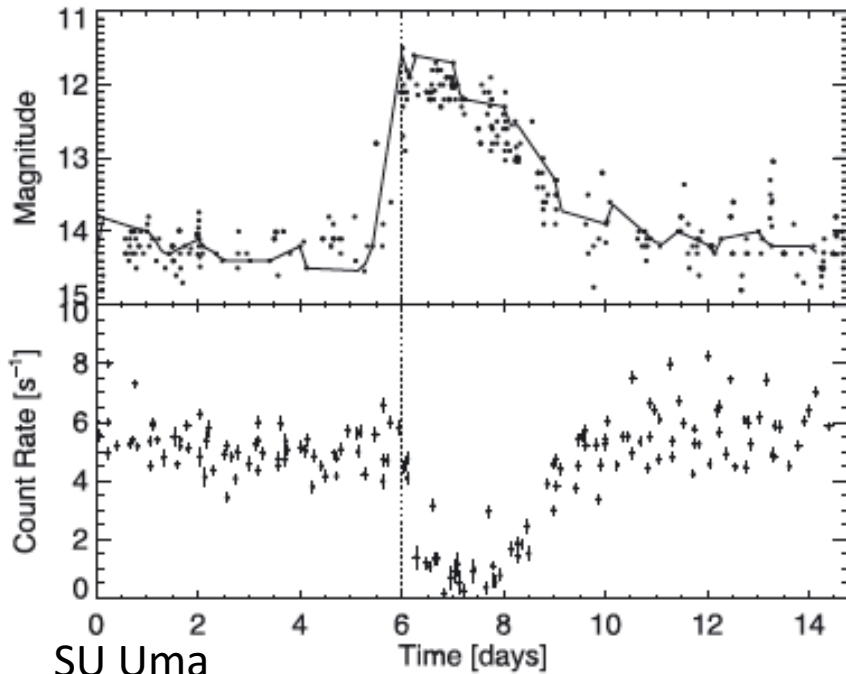
# White dwarfs



Warner, Woudt & Pretorius 2003.

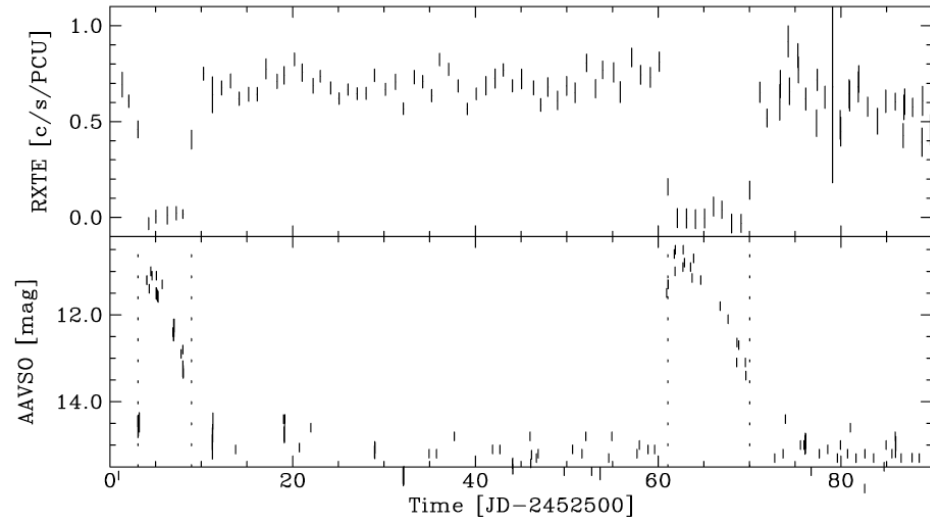


# Is SS Cyg the prototype?



SU Uma

Collins&Wheatley 2010



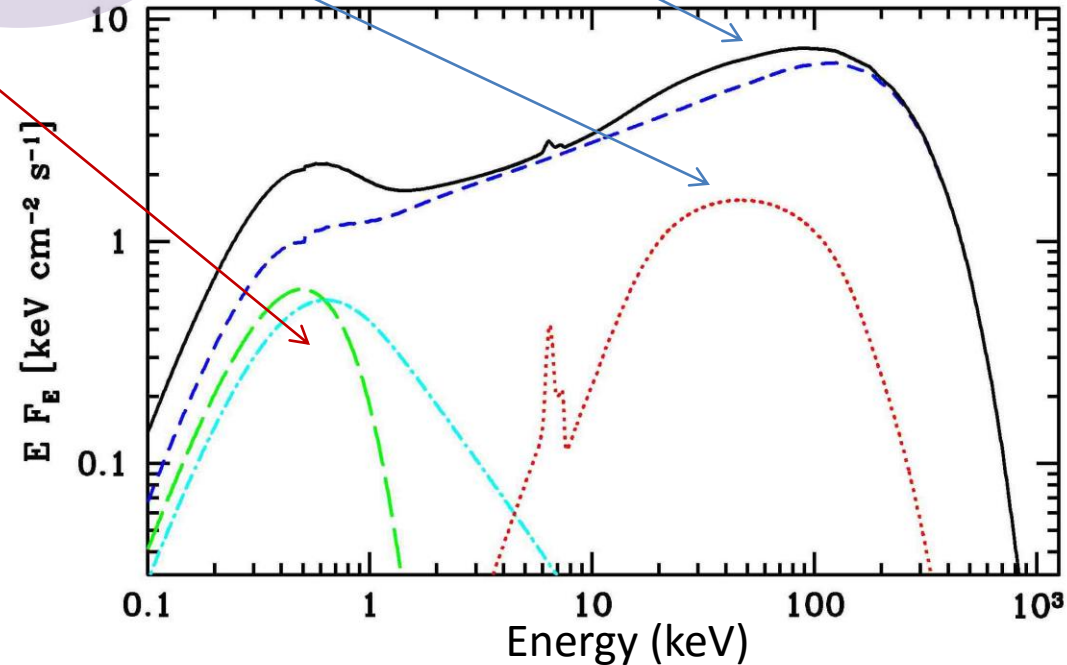
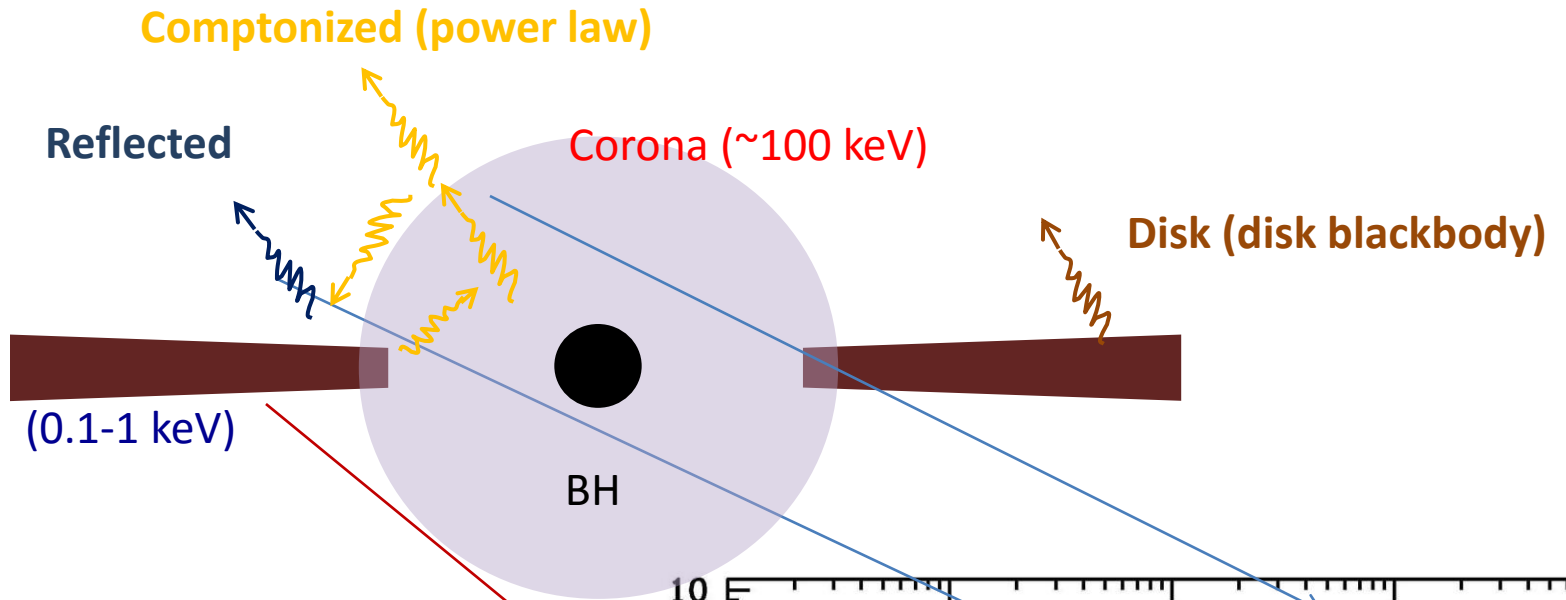
WW Cet, Fertig 2011

## Fertig 2011

### SS CYGNI PARADIGM

Object	X-ray suppression	Spectral softening	X-ray delay	Recovery at late decline	Enhancement—rise	Enhancement—decline
SS Cyg .....	Yes	Yes	Yes	Yes	Yes	Yes
SU UMa .....	Yes	Yes	Yes	Yes	No	No
VW Hyi .....	Yes	Yes	No?	Yes	No	Maybe
WW Cet .....	Yes	?	No?	Yes	No	No
U Gem .....	No	?	Yes	Yes	?	?
GW Lib .....	No	No	?	?	?	?

# X-ray emission from black holes

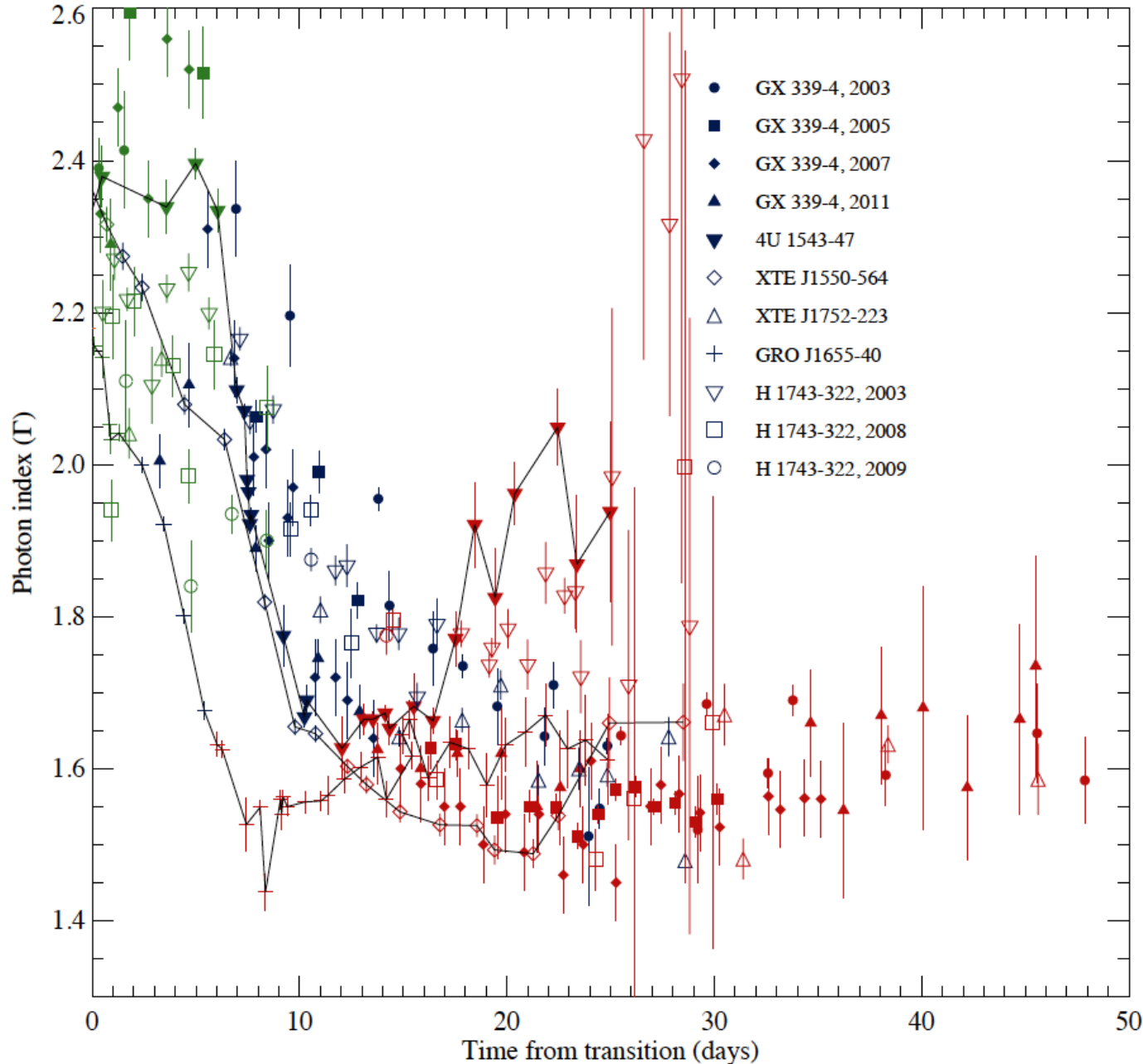


Phenomenological model:

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

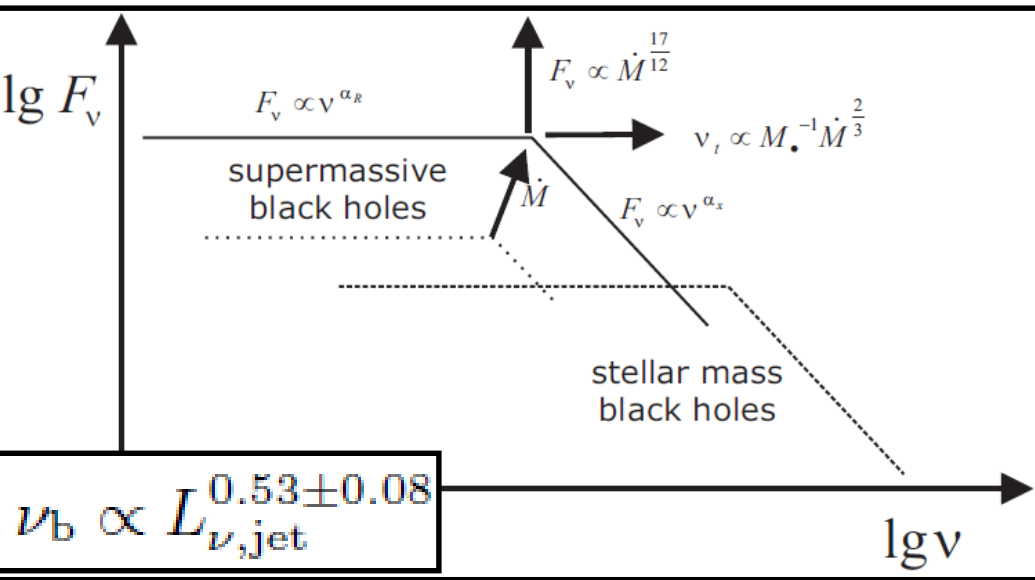
# Softening

?

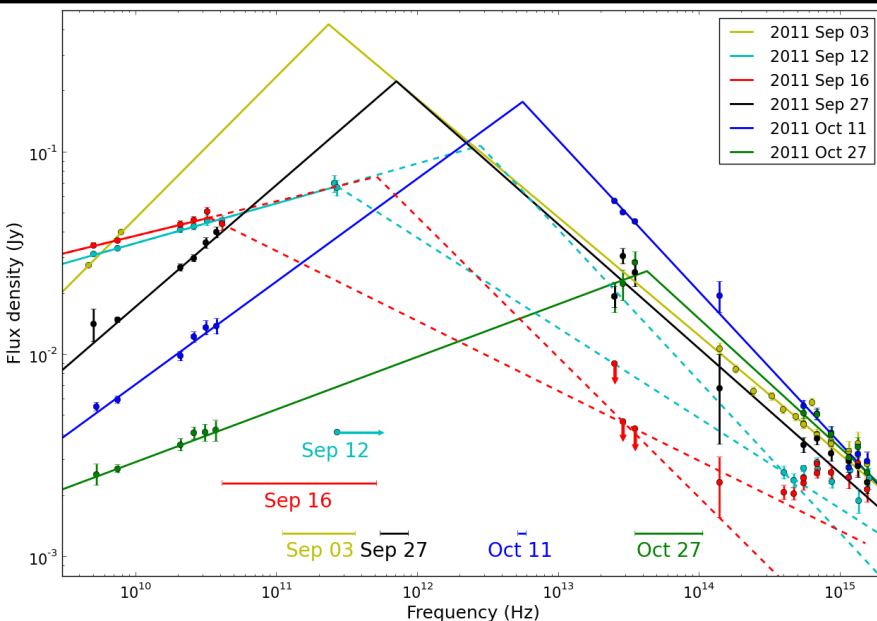


- sources for which the flux drops rapidly (and the index change rapidly) show softening.

# For the jets already formed...



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

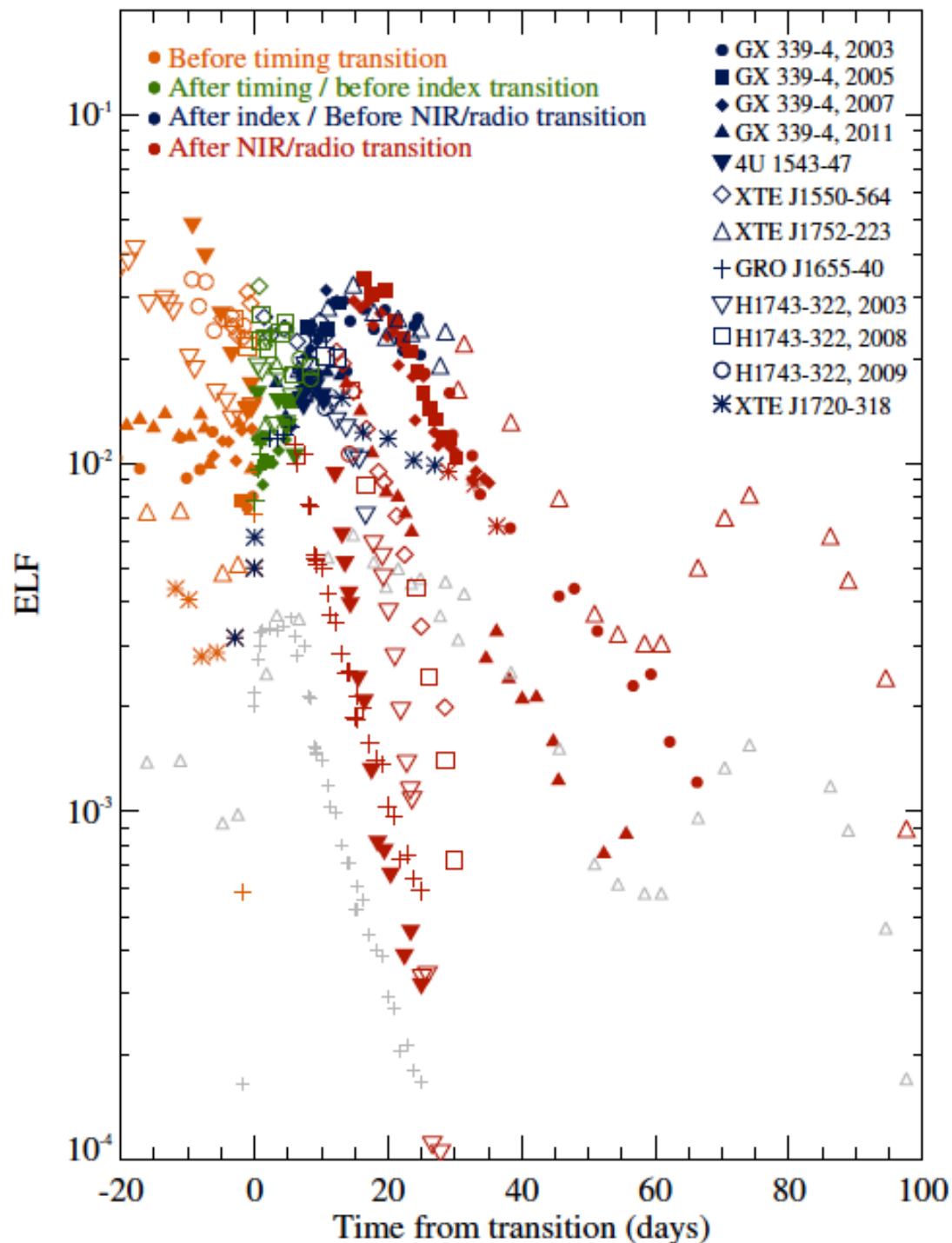


Falcke & Biermann 1995,  
 Heinz et al. 2003,  
 Markoff et al. 2003,  
 Falcke et al. 2004:

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/ $L_{\text{Edd}}$

Jets appear at around a few %  $L_{\text{Edd}}$

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

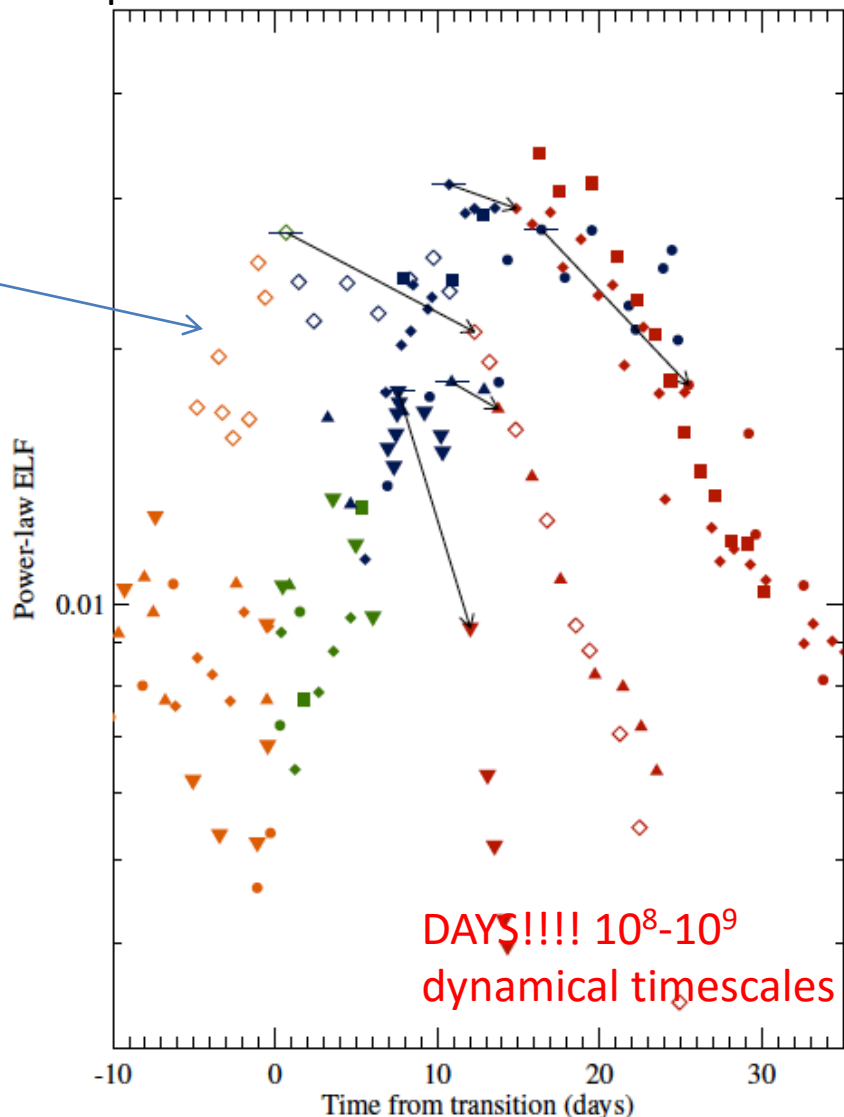
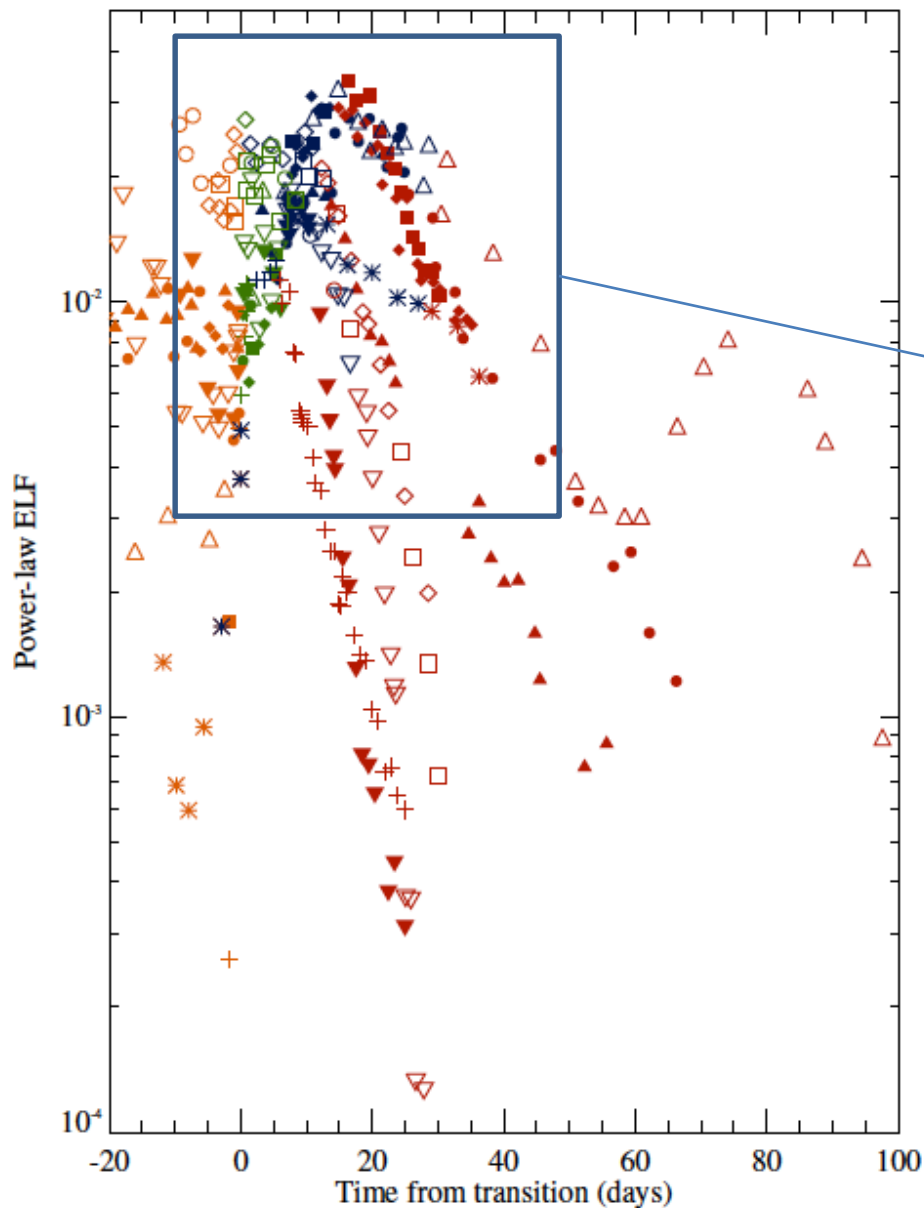
\*For sources with no distance  
information 8 kpc used.

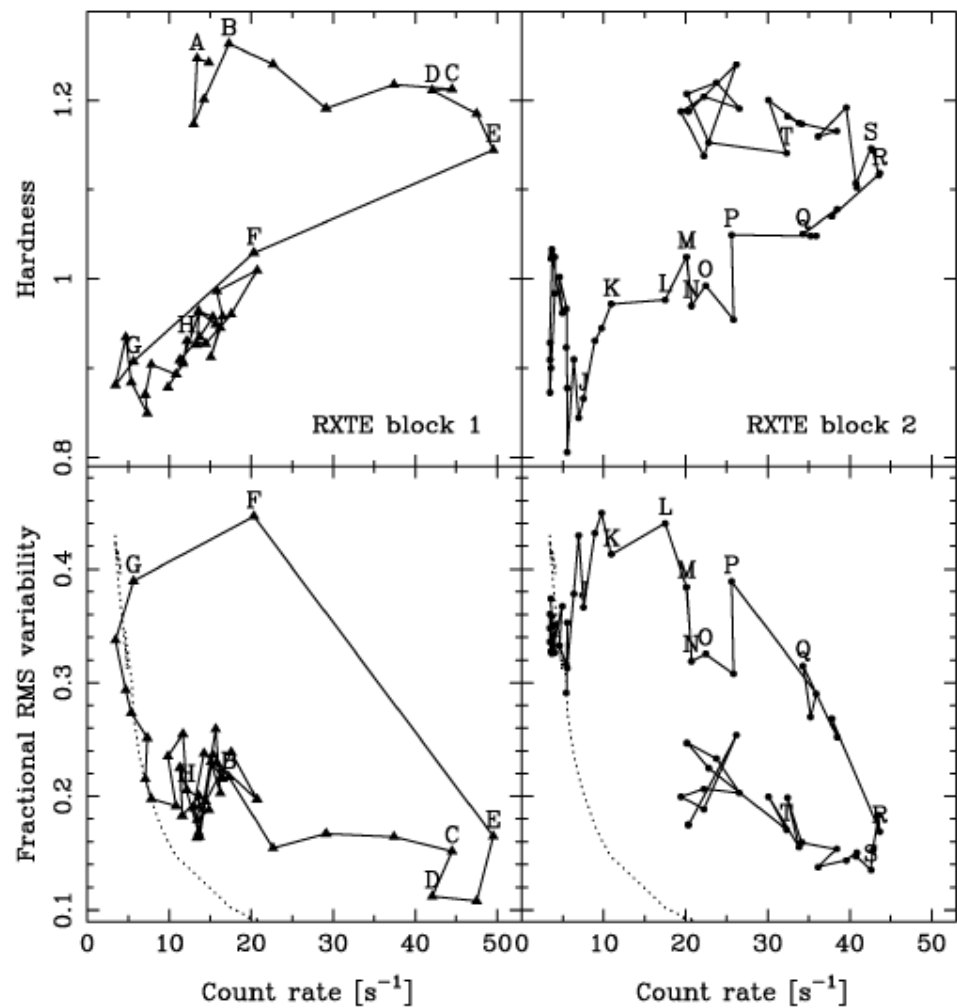
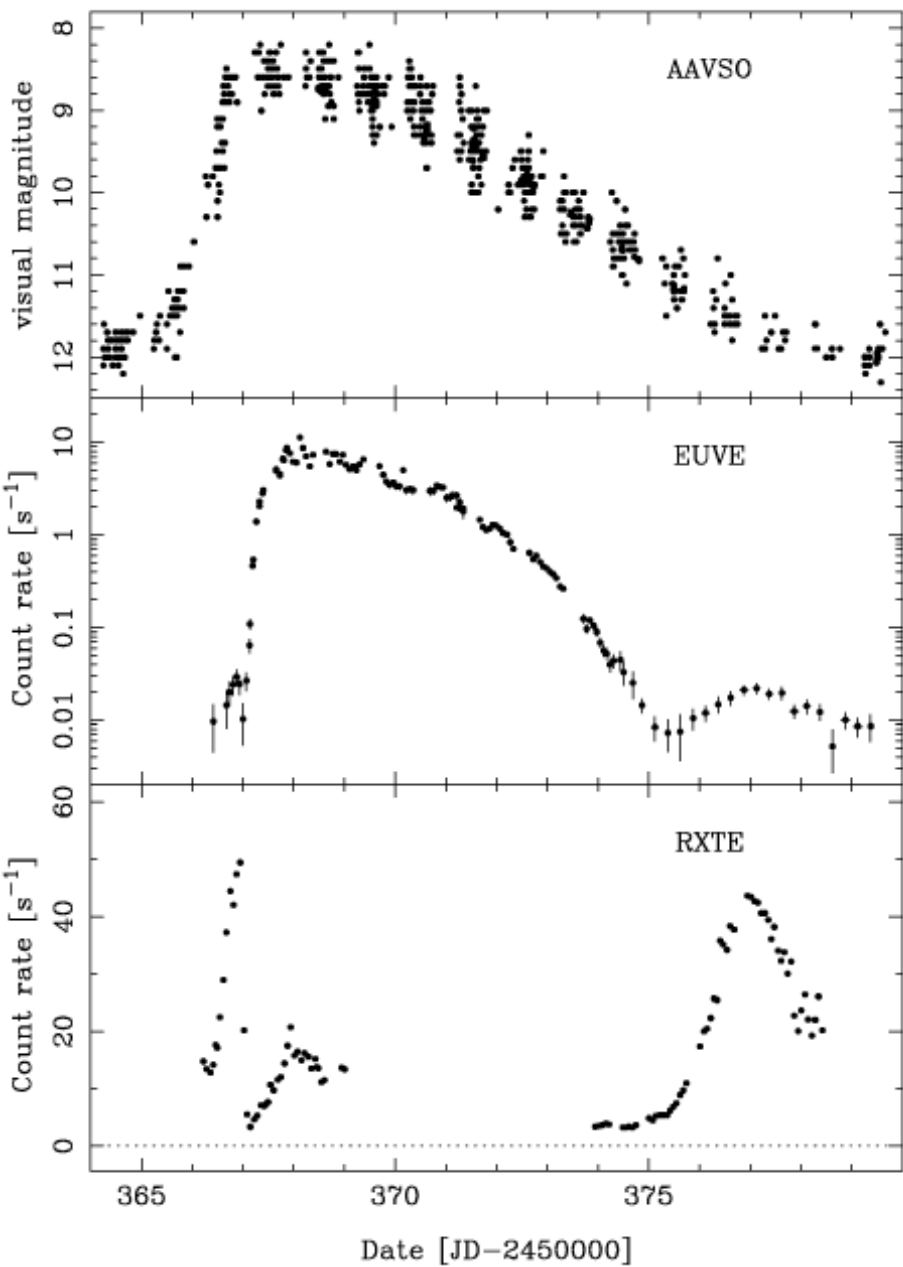
For sources with no mass information  
 $8M_{\odot}$  used (Ozel et al 2010, Kreidberg 2012)

# Evolution of power-law vs disk luminosity

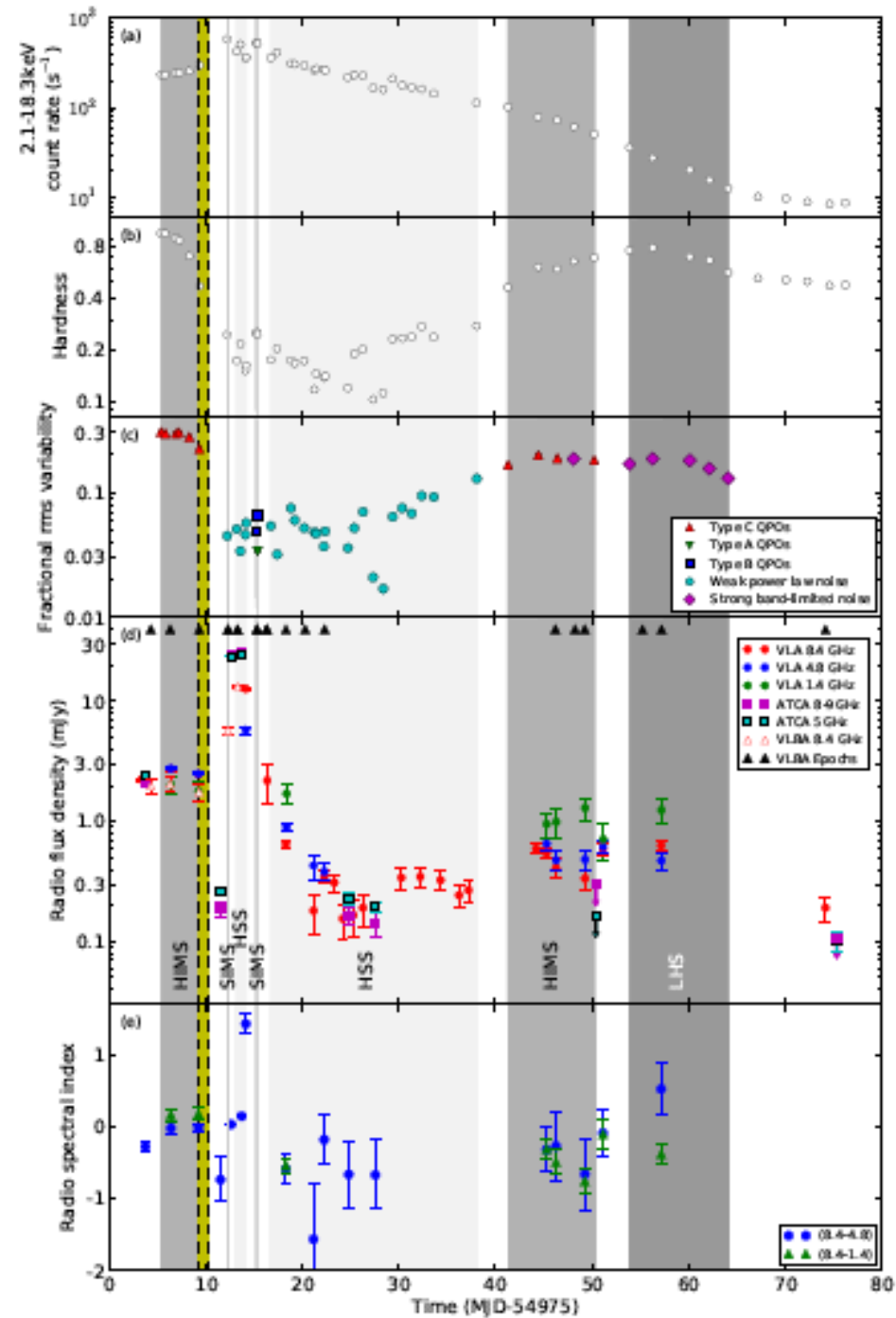
Power – law luminosity

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



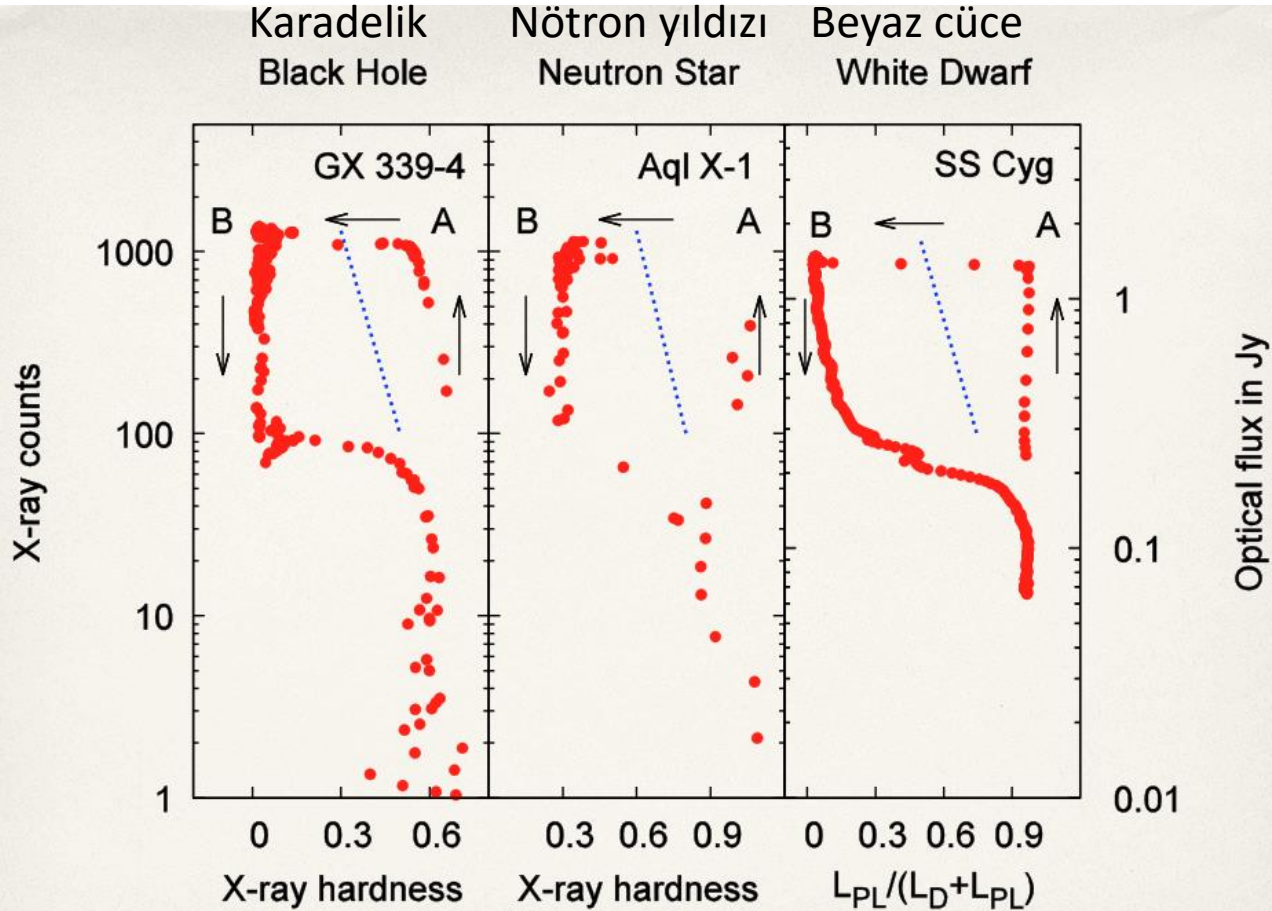


# H1743-322 2009



Miller-Jones et al. 2012.

# Nötron yıldızları ve hatta beyaz cücelerde bazı durumlarda (düşük manyetik alan) benzer evrim gözlenir.



The jet line in the Hardness-Intensity Diagram (Kording *et al.* 2008)

# Nötron yıldızları karadelik karşılaştırması

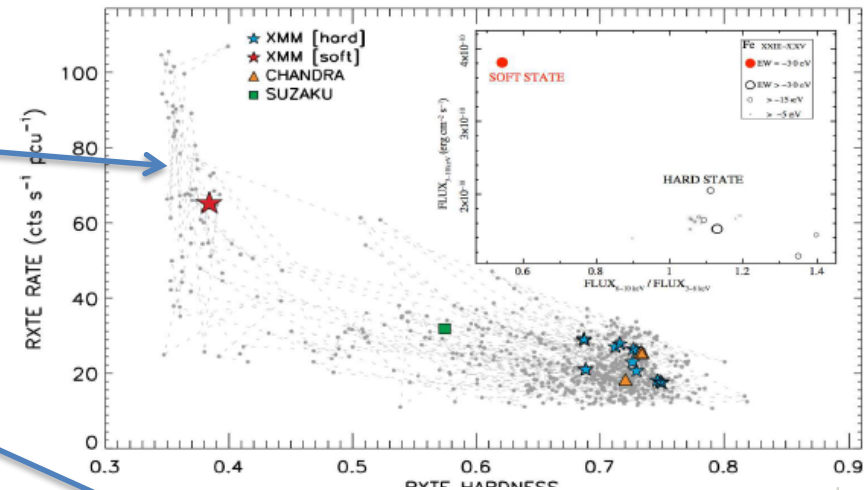
Ponti 2014

## Döneme bağlı

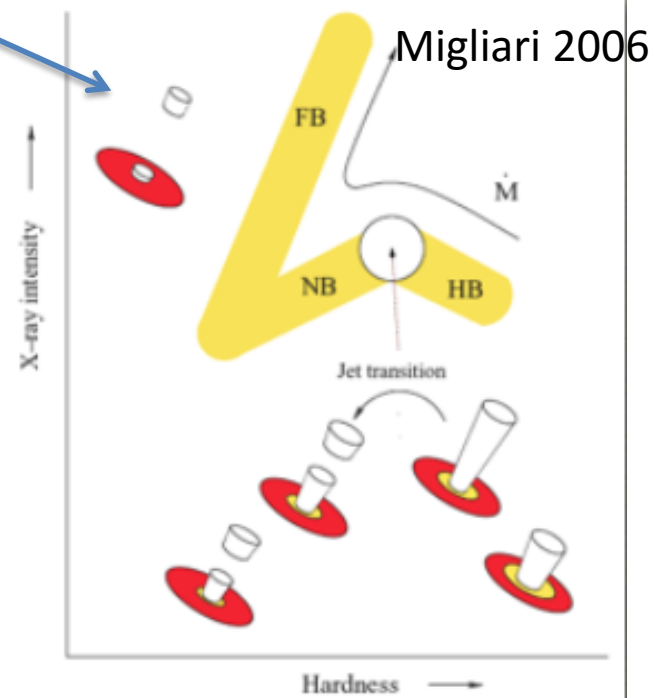
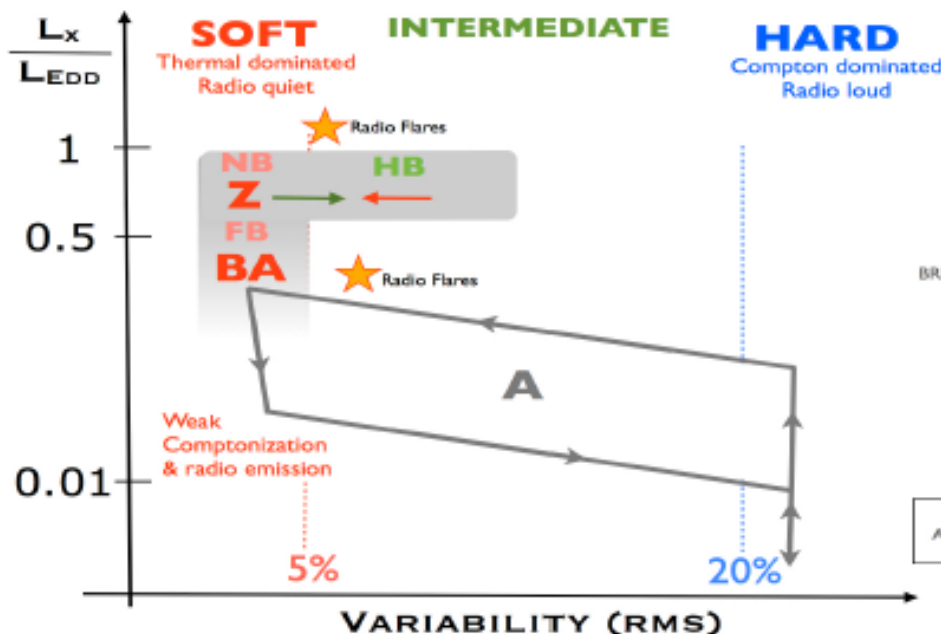
Disk rüzgarı

Jets (sert dönem daha zayıf, yumuşak dönemde var)

Zamansal özelliklerde histeresis



Munoz-Darias 2014

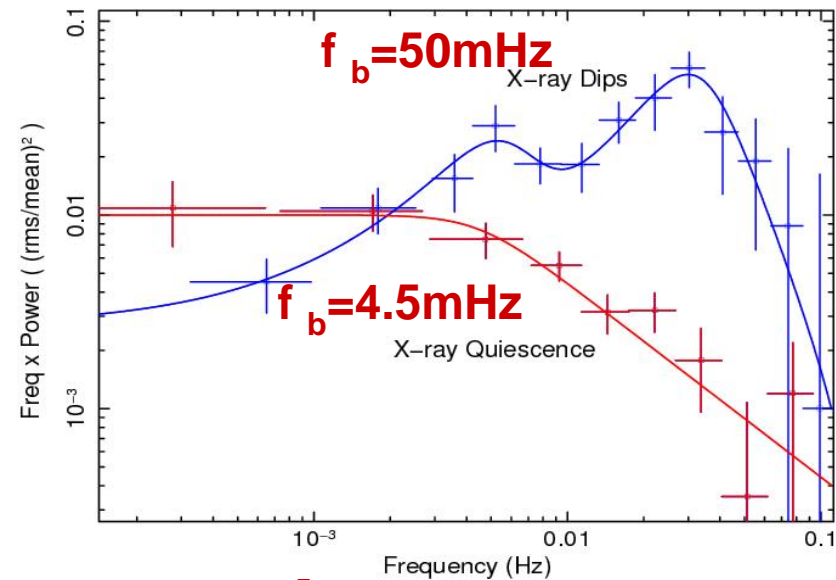
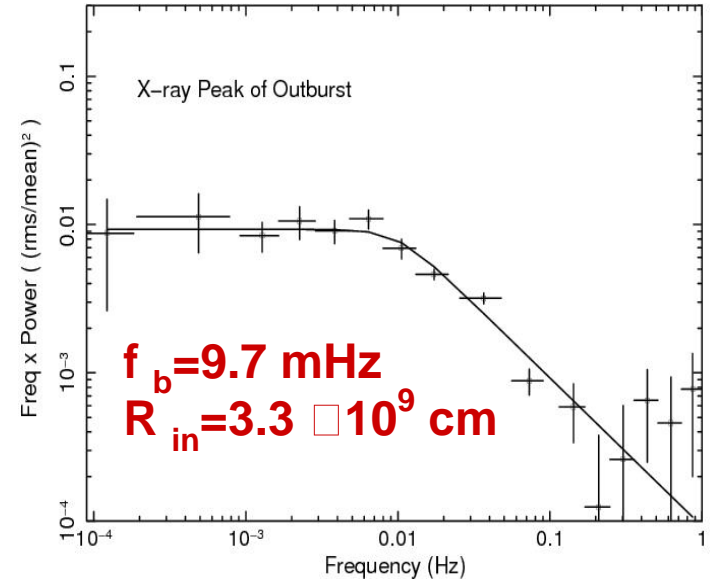
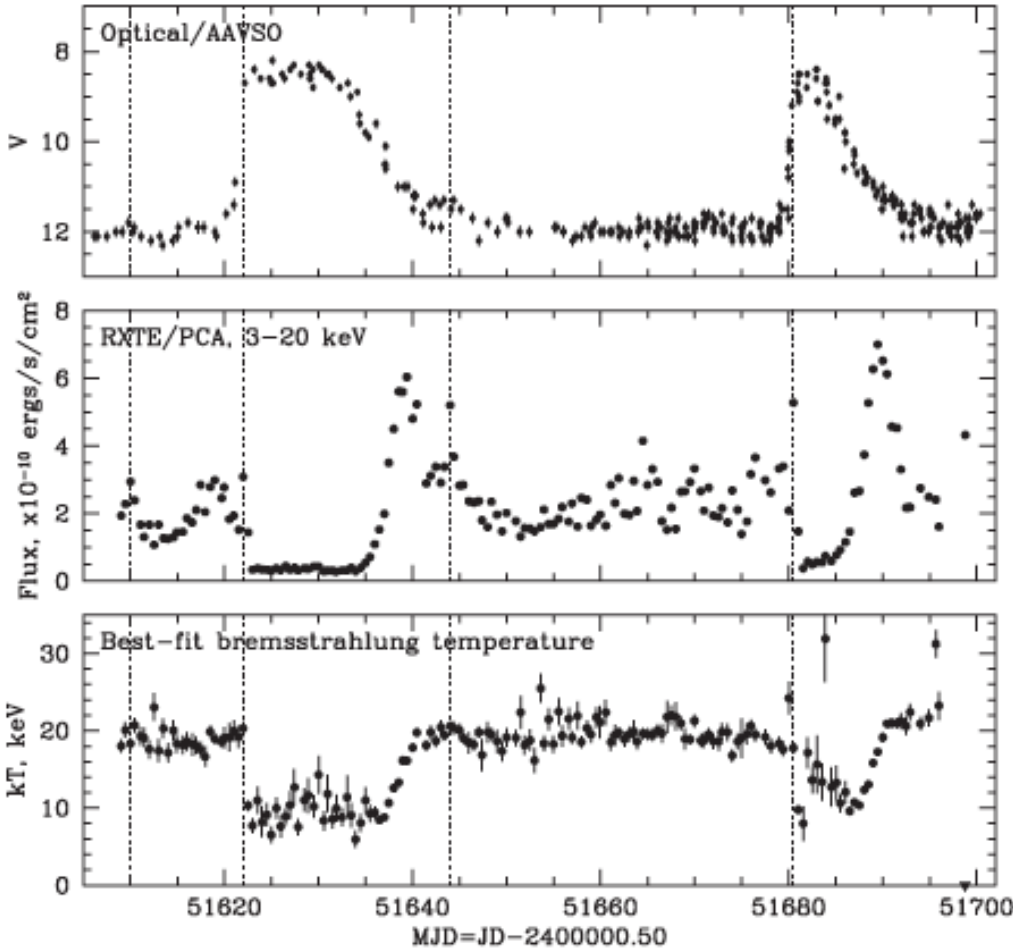


Migliari 2006

# Beyaz Cüceler biraz daha muğlak

Balman & Revnivtsev 2012

SS Cygni, March–June, 2000

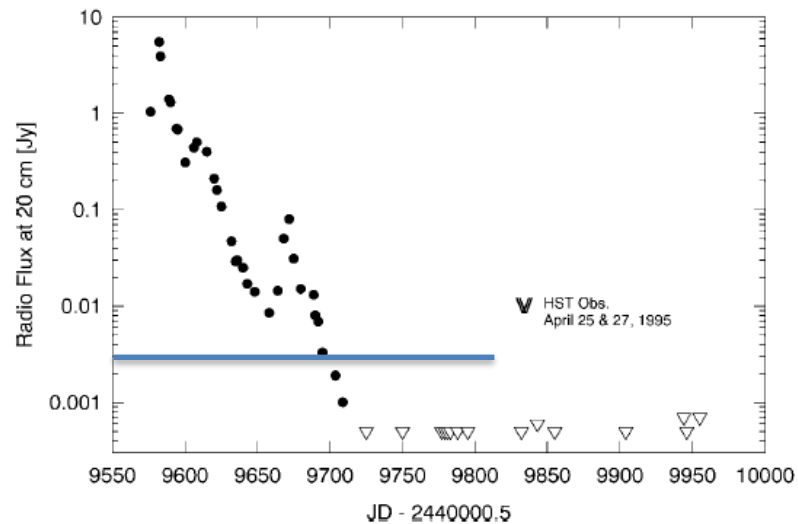
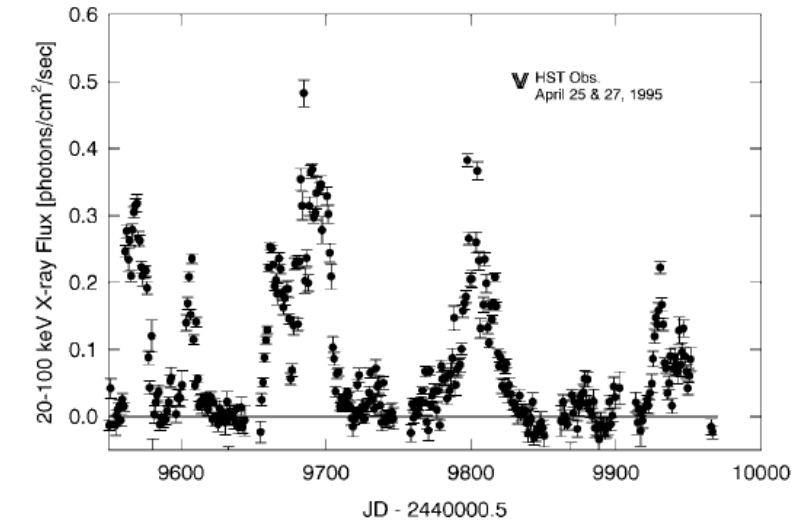
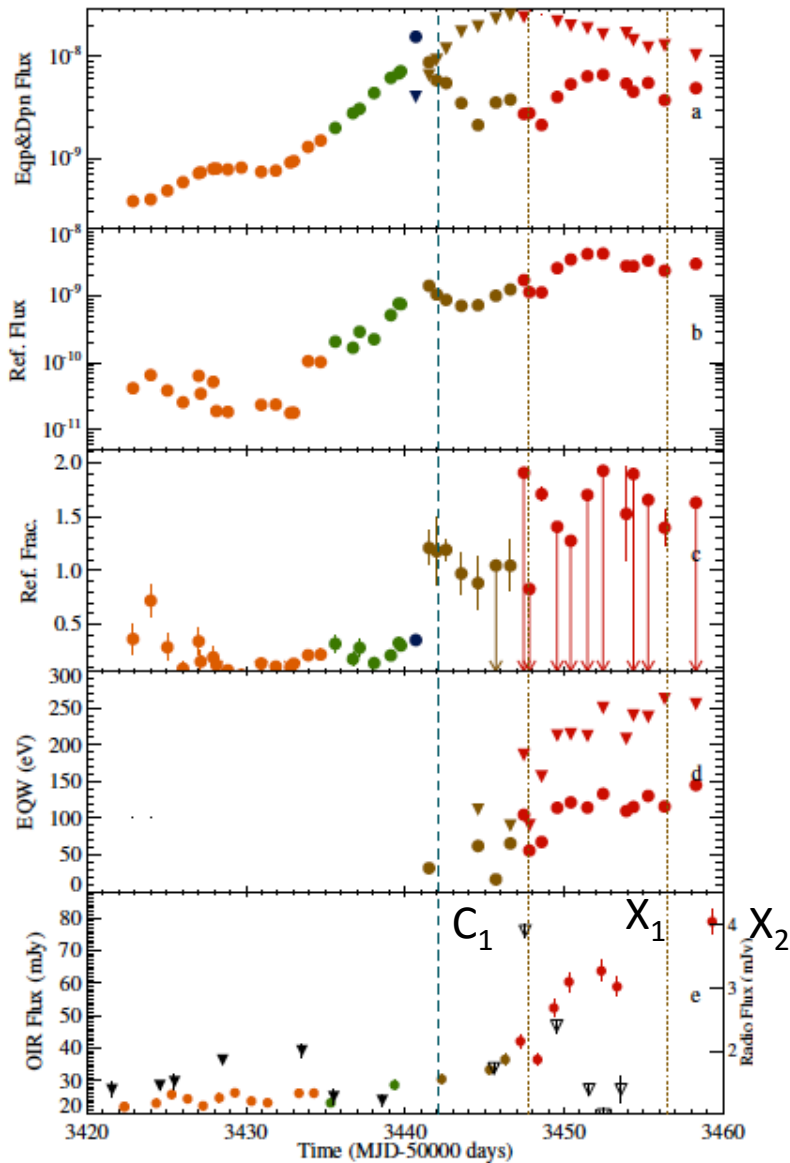


$R_{in} = 1.1 \times 10^9 \text{ cm} \Rightarrow 5.5 \times 10^9 \text{ cm}$

McGowan et al. 2004; (see also Wheatley et al. 2003)

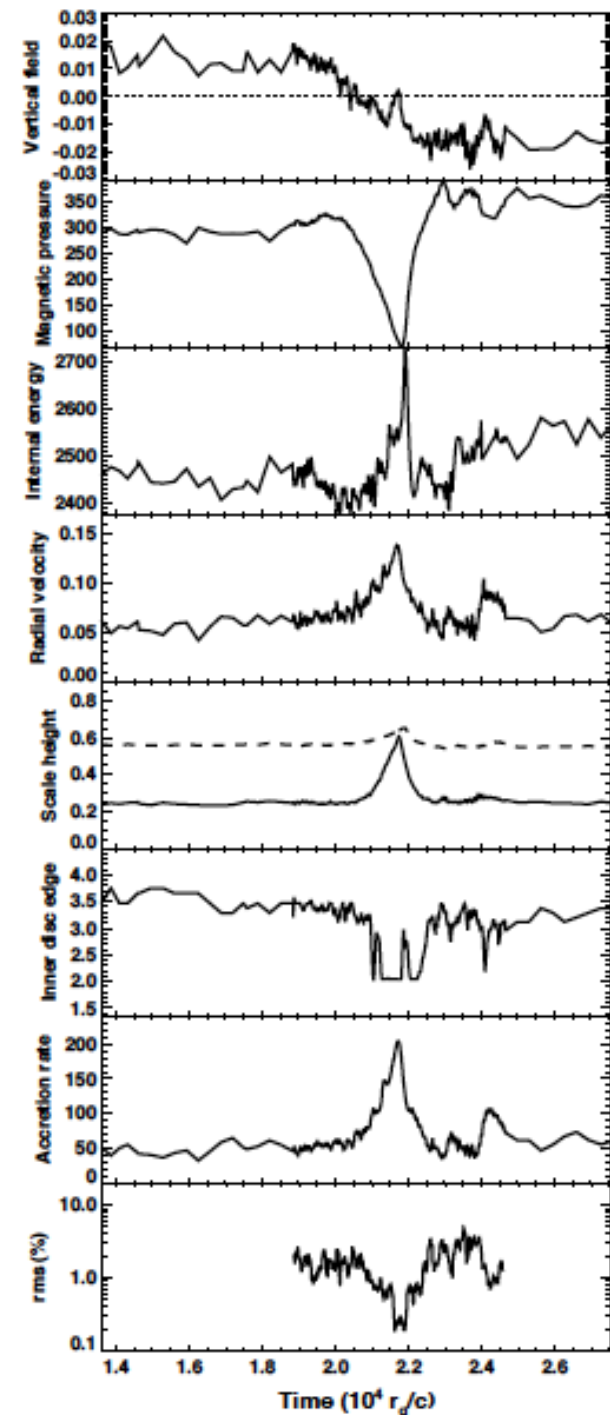
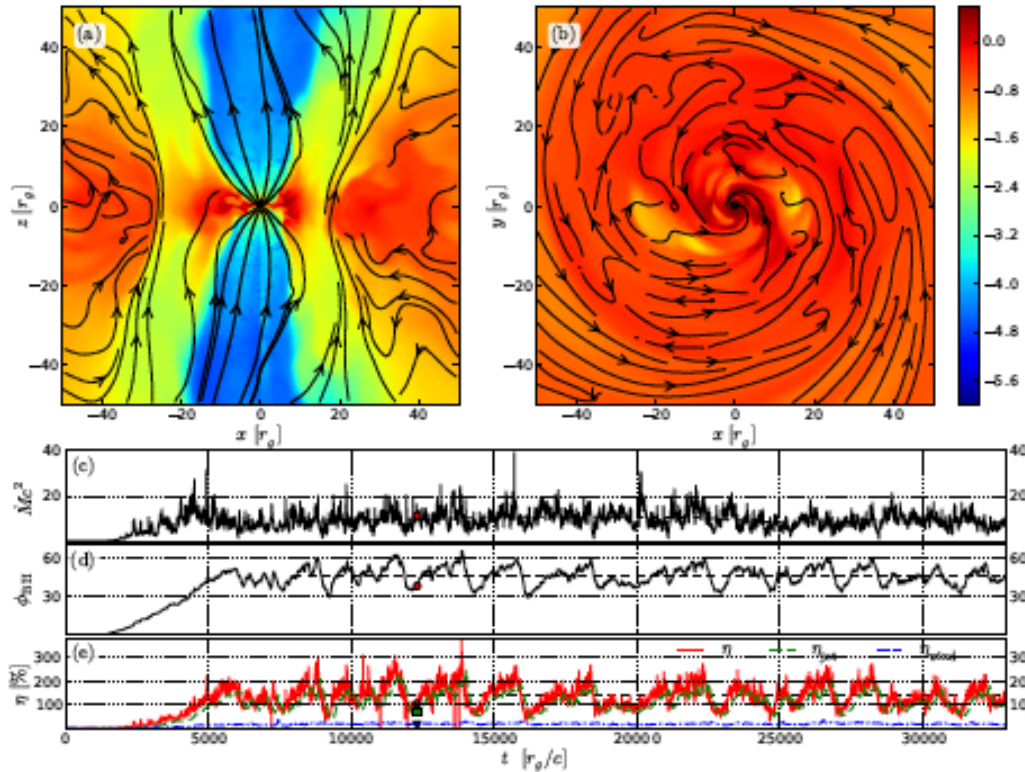
# GRO J1655-40 state transitions....

## Wind and (opt. thin) jet at the same time!





# Manyetik alanı hapseden diskler ve manyetik alan flip



Tchekhovskoy et al. 2012

See also Li & Yan 2015

Igumenshev 2009

Dexter et al. 2013.