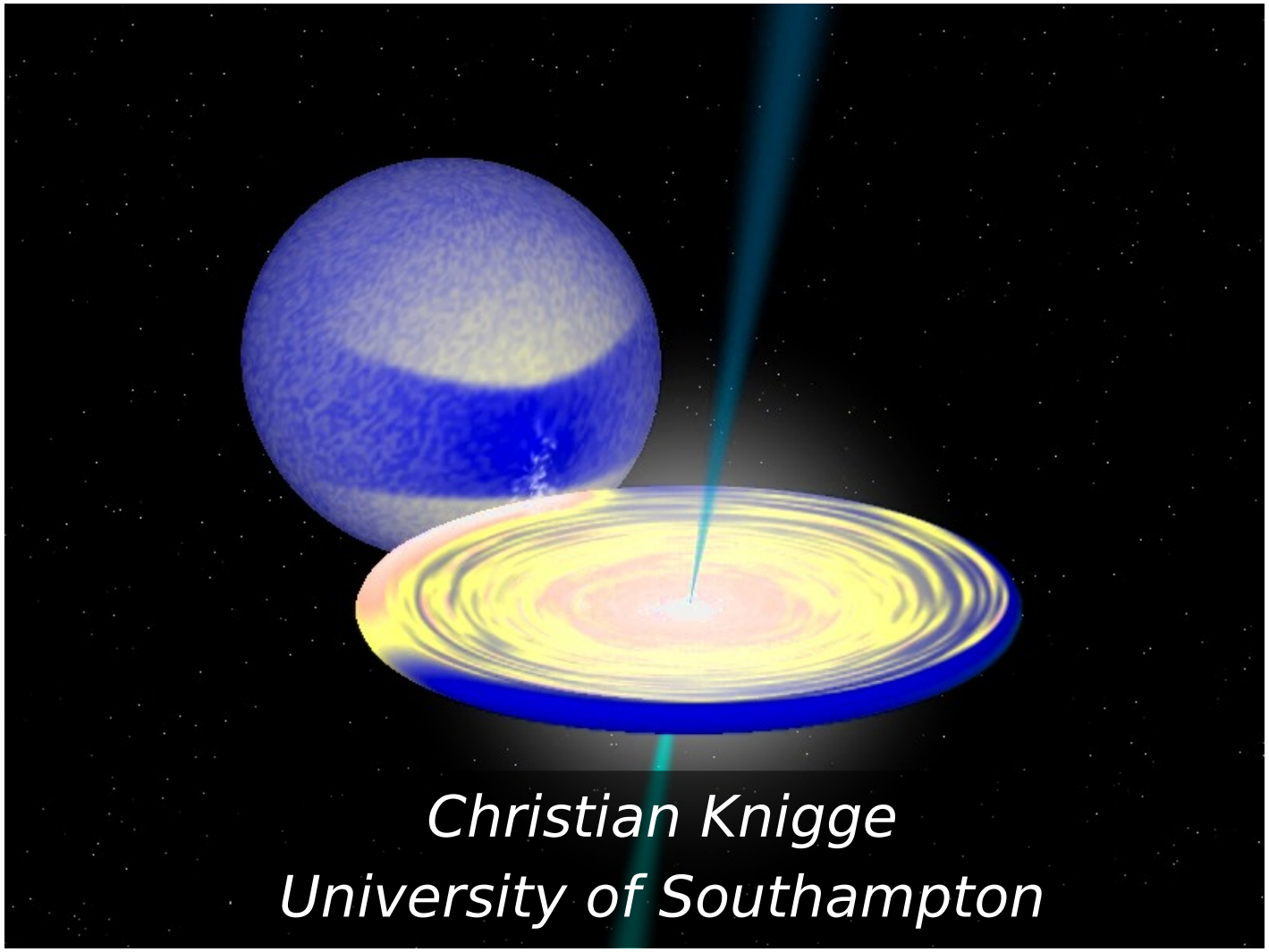
# Accreting White Dwarfs as Laboratories for the Universal Nature of Disk Accretion

## From Phenomenology to Physics




Rob Hynes (LSU)

**Christian**

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# *Outline*

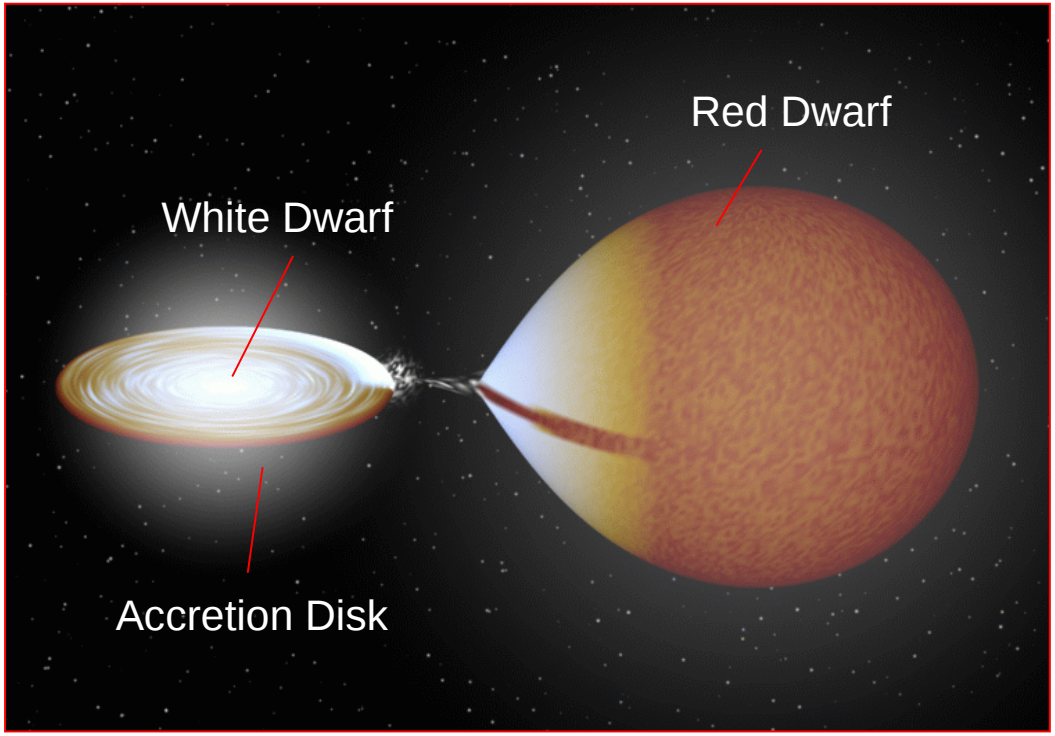
- Introduction
  - ***White Dwarfs*** vs **Neutron Stars & Black Holes** vs **YSOs**

- The Universal Phenomenology of Disk Accretion:
  - Outbursts, Variability, Outflows

- From Phenomenology to Physics
  - A Sketch of A Great Observatories Legacy Campaign

# *Accreting White Dwarfs: A Primer*

## *The Physical Structure of "Cataclysmic Variables"*

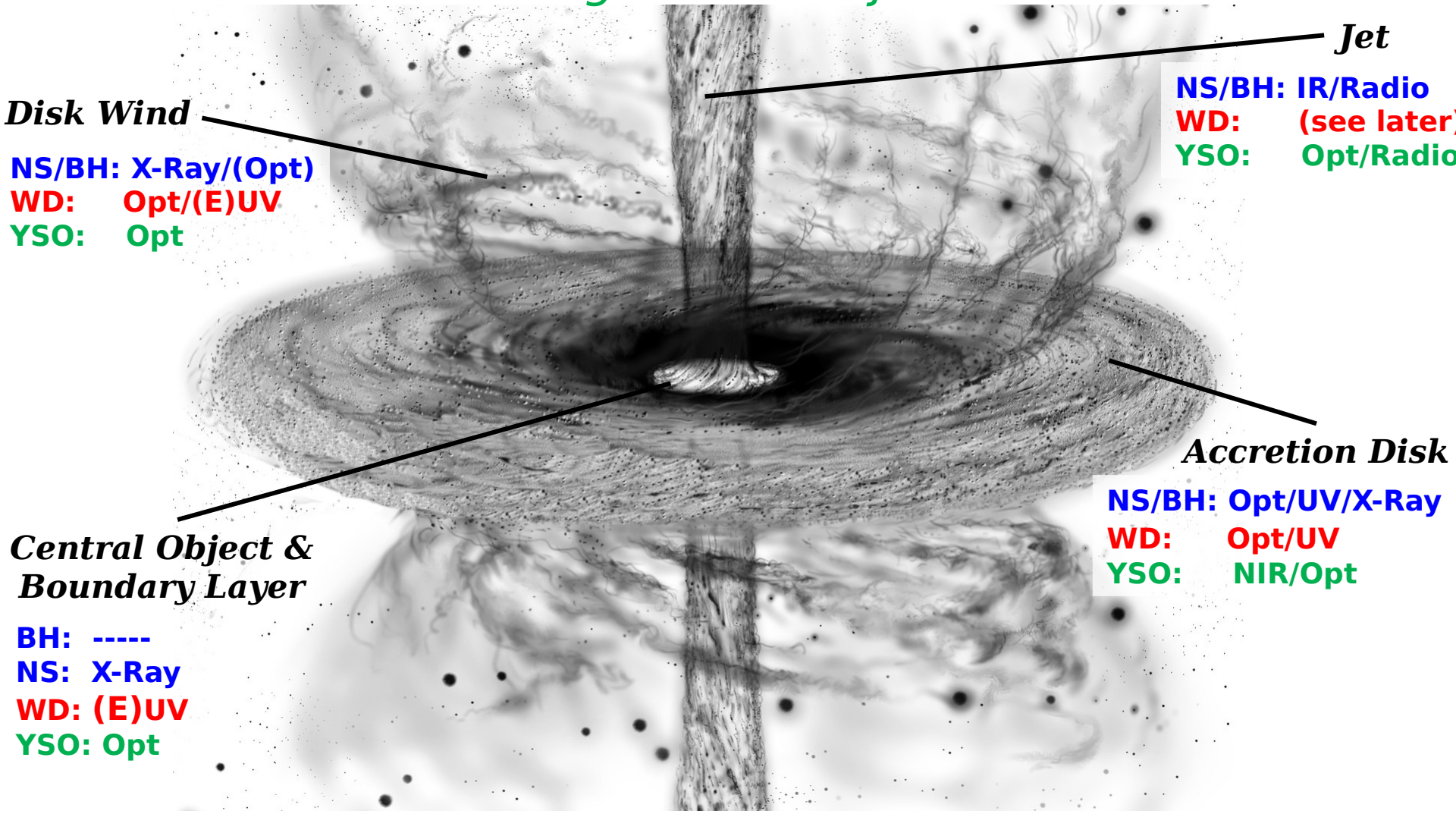



Credit: Rob Hynes

- White dwarf primary
- "Main-sequence" secondary
- 75 mins < $P_{orb}$ < 6 hrs
- Roche-lobe overflow
- Accretion usually via a disk
  - "non-magnetic" CVs
- Excellent accretion laboratories
  - bright
  - numerous
  - nearby
  - convenient time-scales

But can we really expect accreting white dwarfs to teach us anything useful about neutron stars, black holes or YSOs?

# Accreting White Dwarfs vs Neutron Stars and Black Holes vs Young Stellar Objects





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# *The Universal Phenomenology of Disk Accretion*

## *Outbursts*

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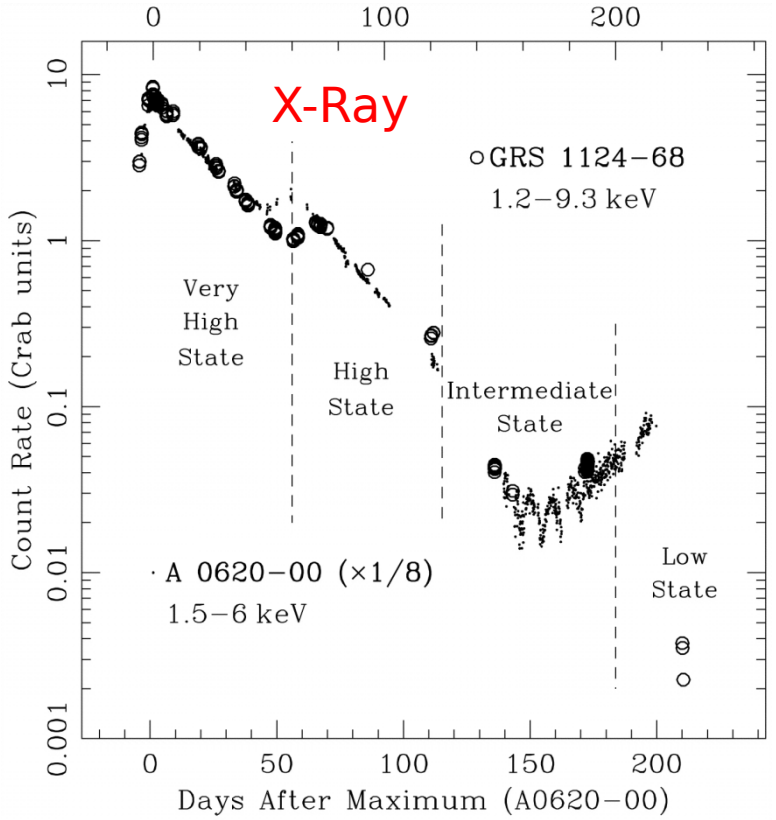
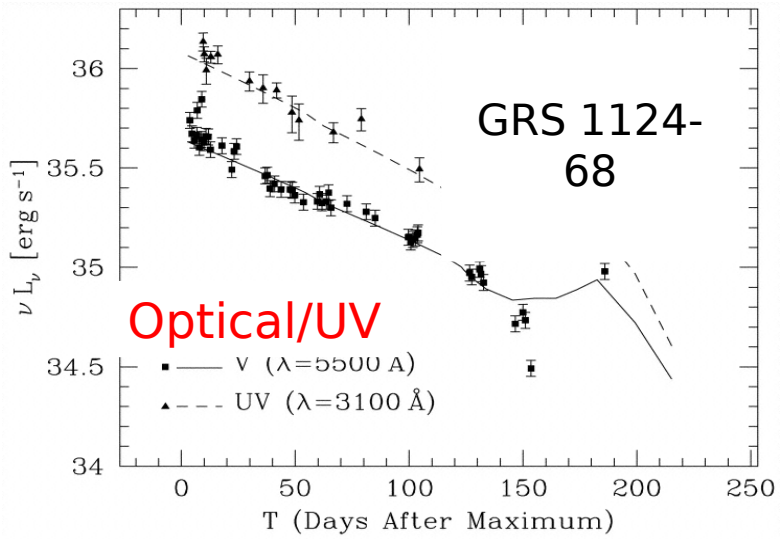
# The Universal Phenomenology of Disk Accretion

## Outbursts: Neutron Stars and Black Holes




Esin et al. 2000

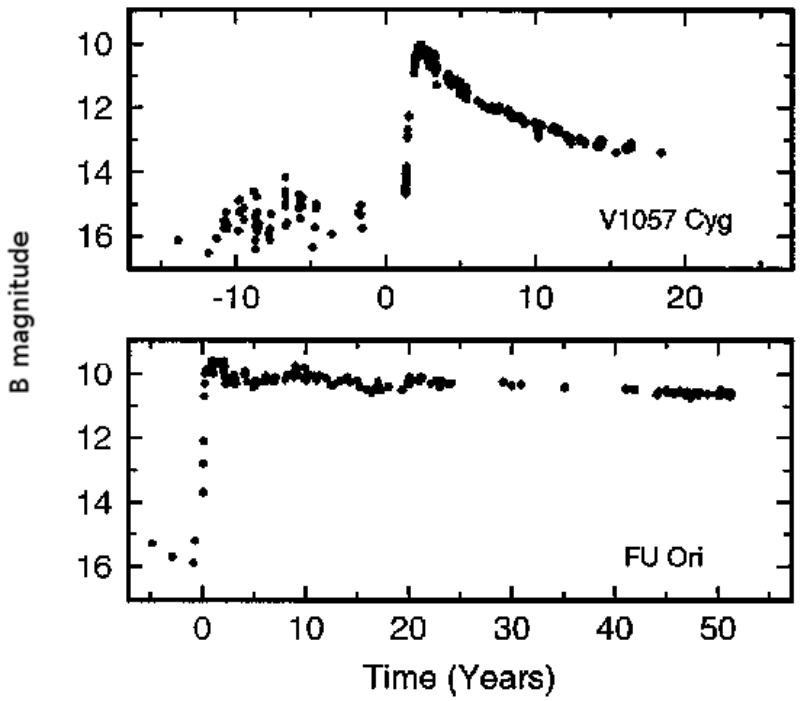
- Many accreting neutron stars and black holes exhibit outbursts
  - X-ray transients



# The Universal Phenomenology of Disk Accretion

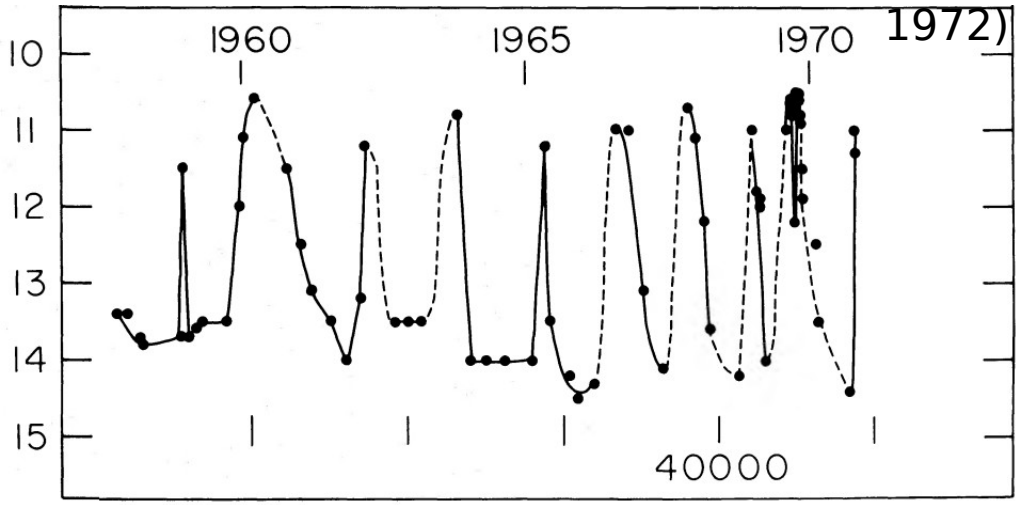
## Outbursts: Young Stellar Objects

Hartmann & Kenyon 1996



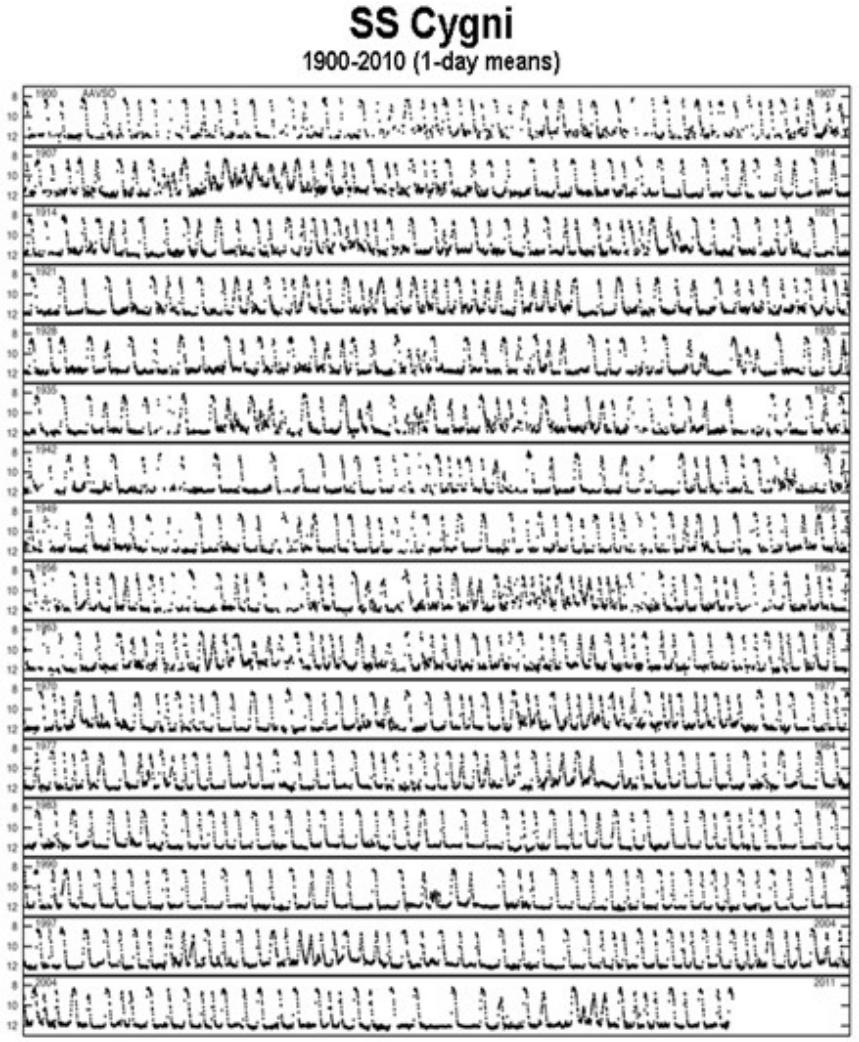

- Accreting YSOs also show transient behaviour
  - FUOr and EXOr eruptions

Herbig 1977
(based on Meininger 1968, 1972)

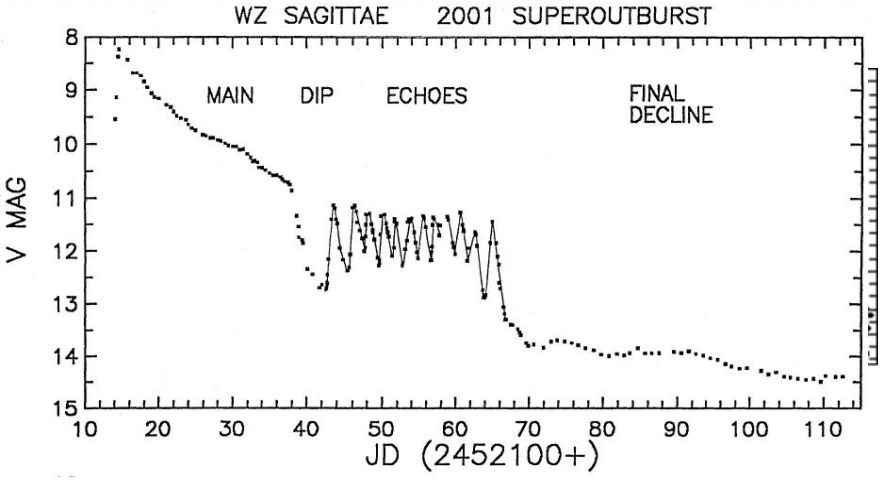


# The Universal Phenomenology of Disk Accretion

## Outbursts: Accreting White Dwarfs




- Most accreting WDs do the same
  - Dwarf Novae

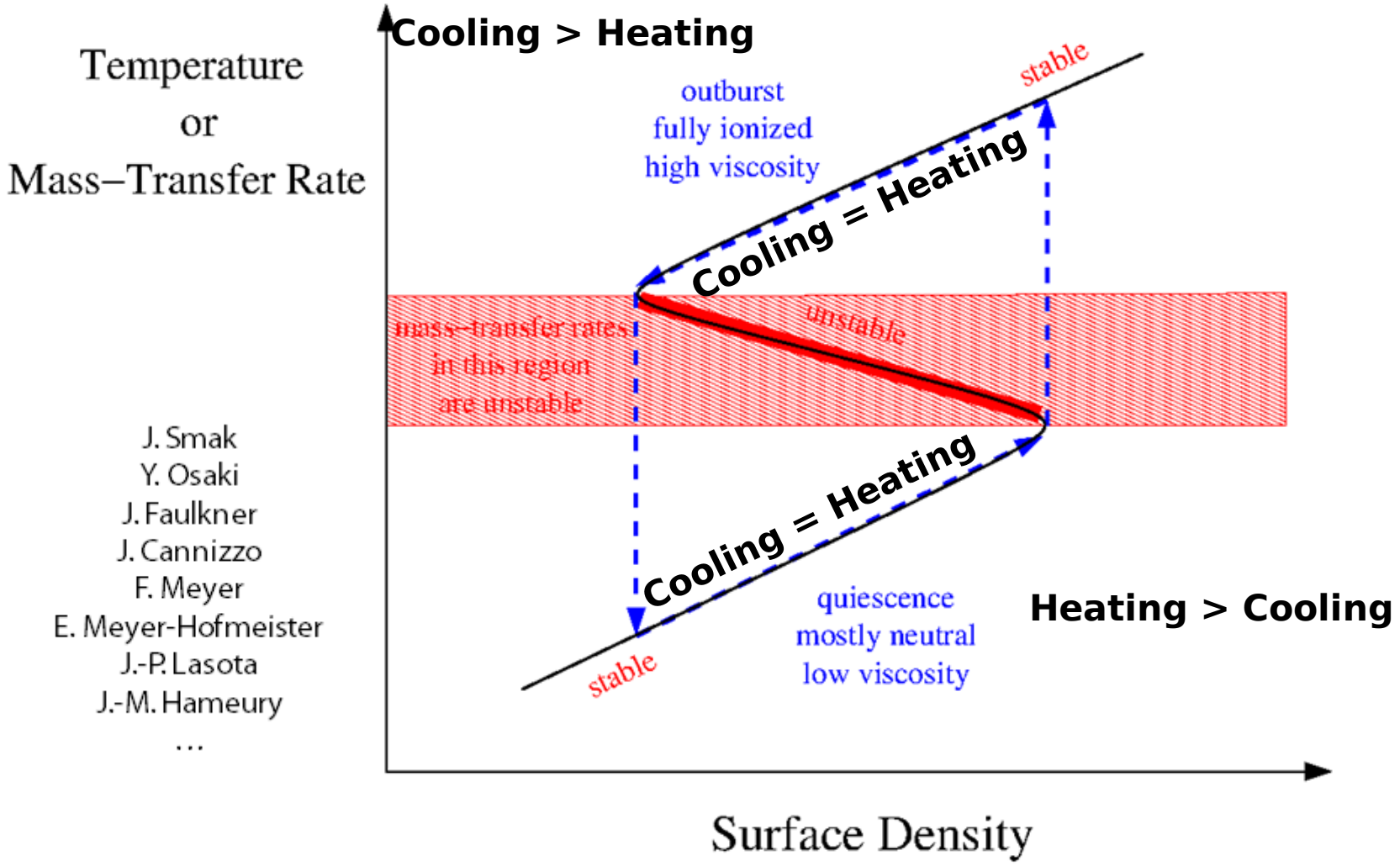



Patterson et al. 2002

- In fact, DNe are the prototypes!
- The underlying physics is thought to be the same in many (all?) settings

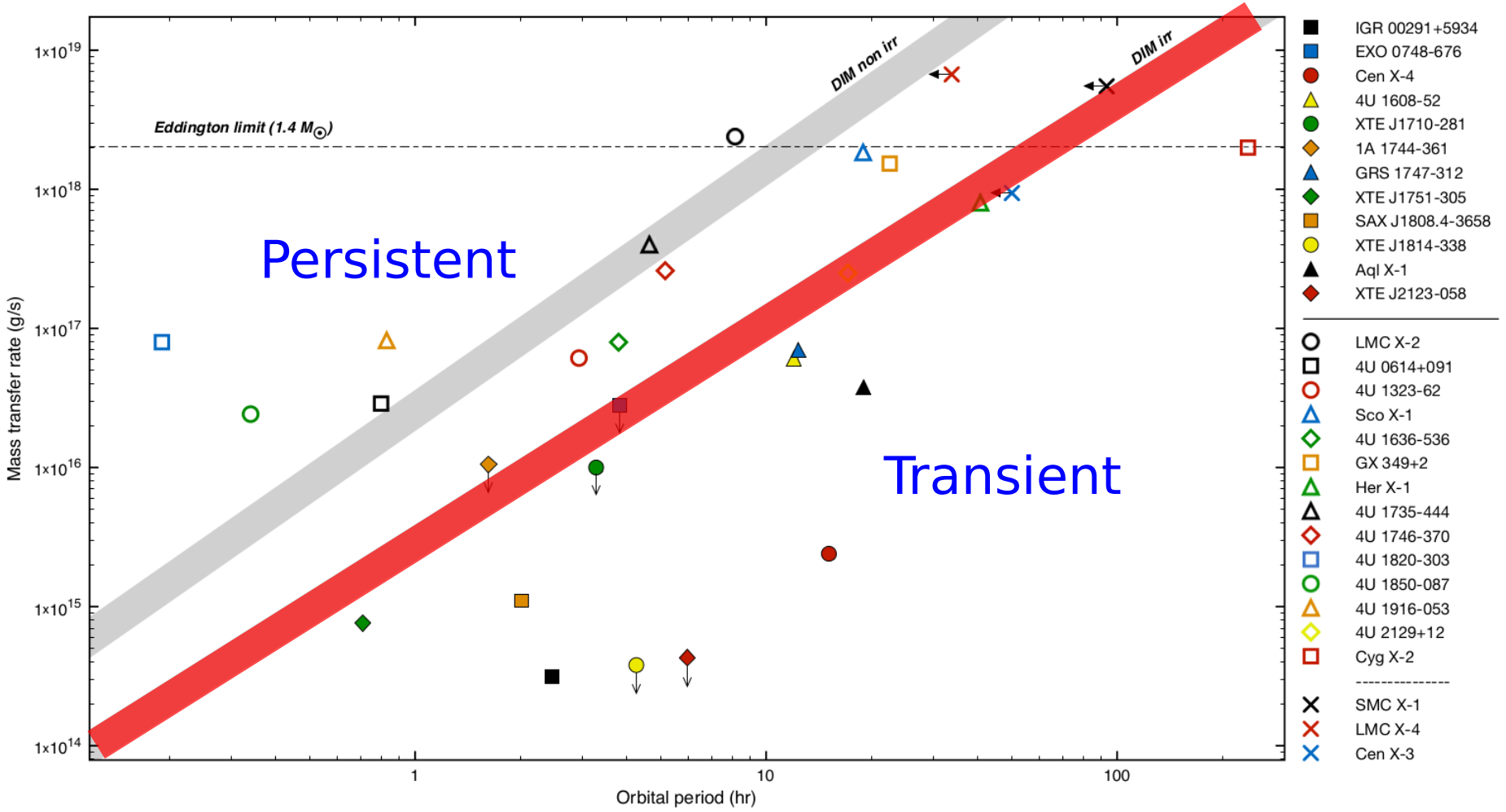
# The Universal Phenomenology of Disk Accretion

## The Physics of Outbursts



# *Does the DIM Work?* **Yes!**

## *Neutron Stars*




Coriat et al. (2012)

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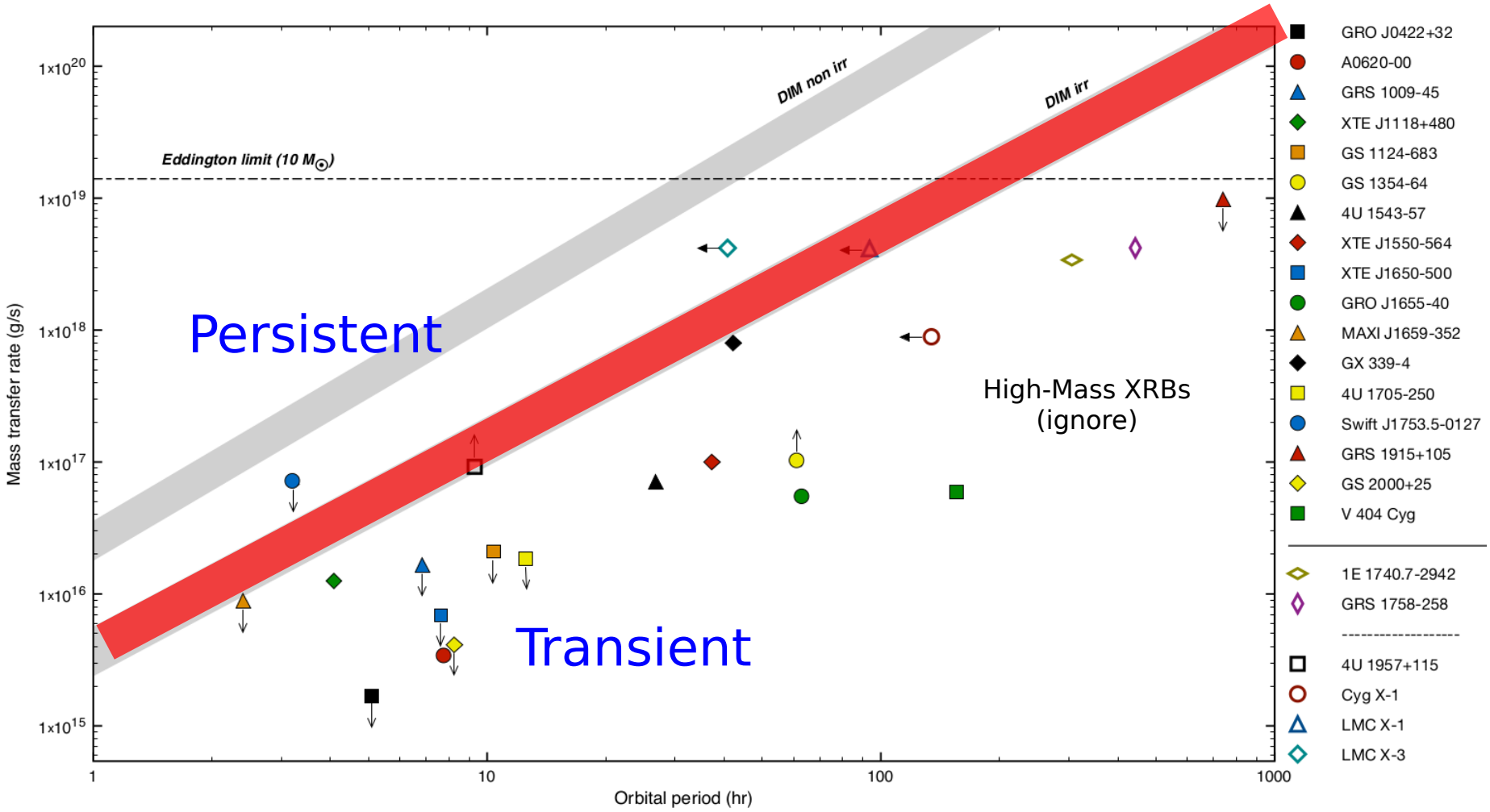
# *Does the DIM Work?* **Yes!**

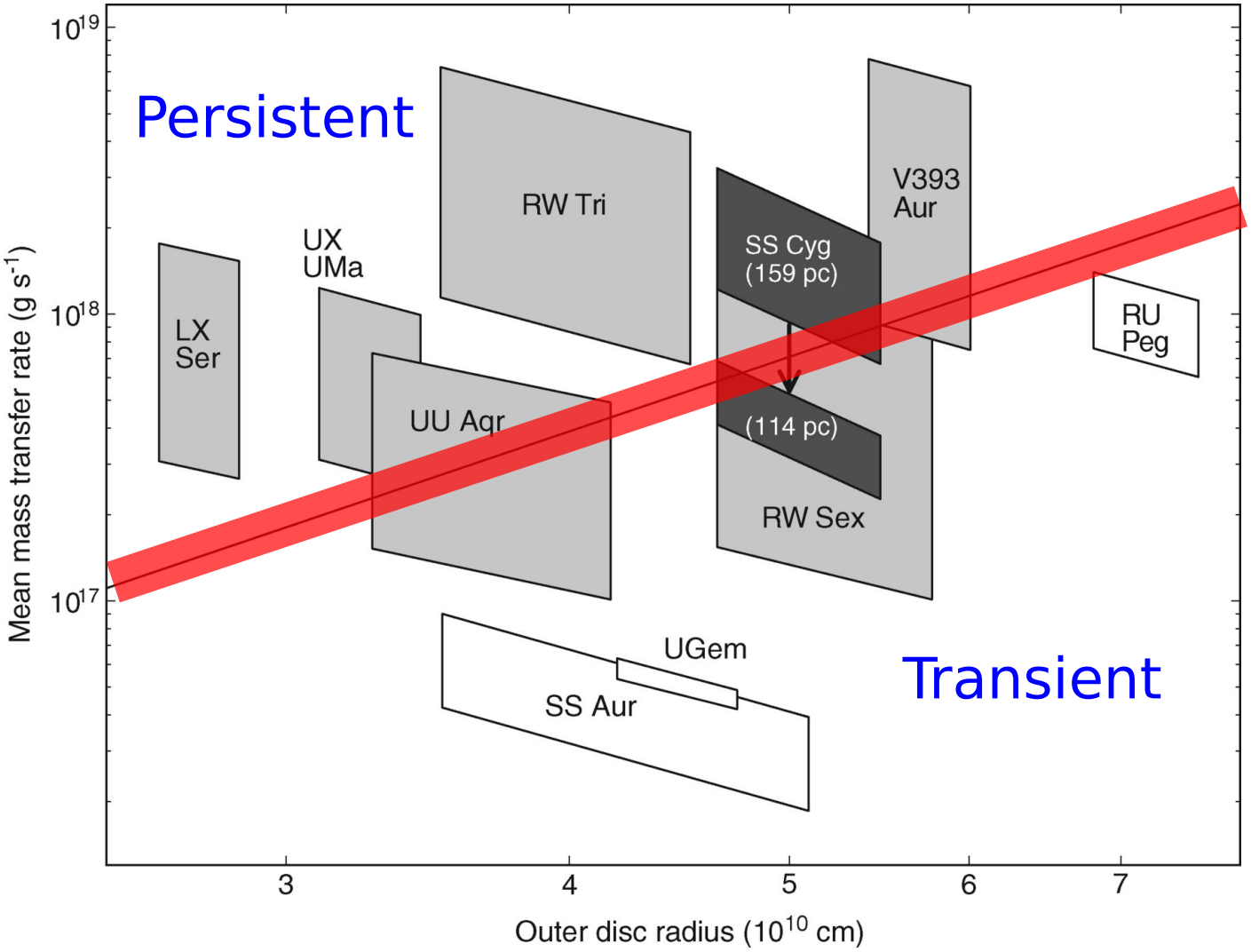
## *Black Holes*




Coriat et al. (2012)

# *Does the DIM Work?* **Yes!**

## *White Dwarfs*

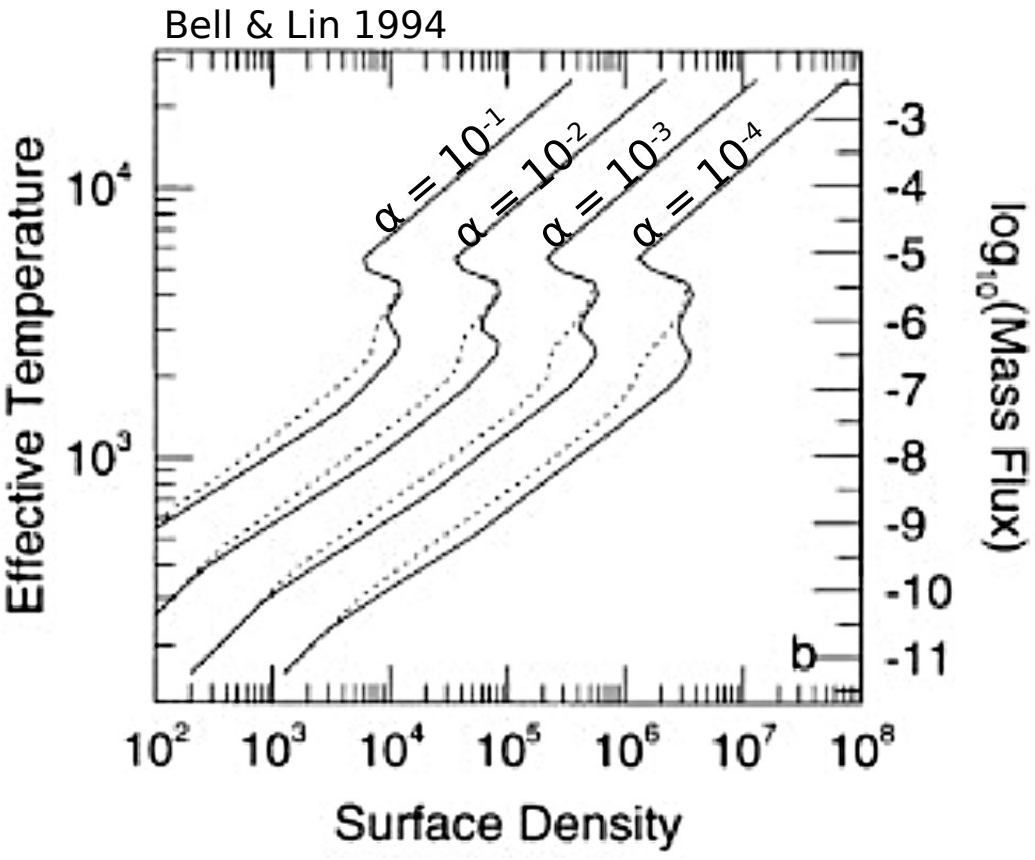



Schreiber & Lasota (2007)

Miller-Jones et al. (2012)

# *Does the DIM Work?*

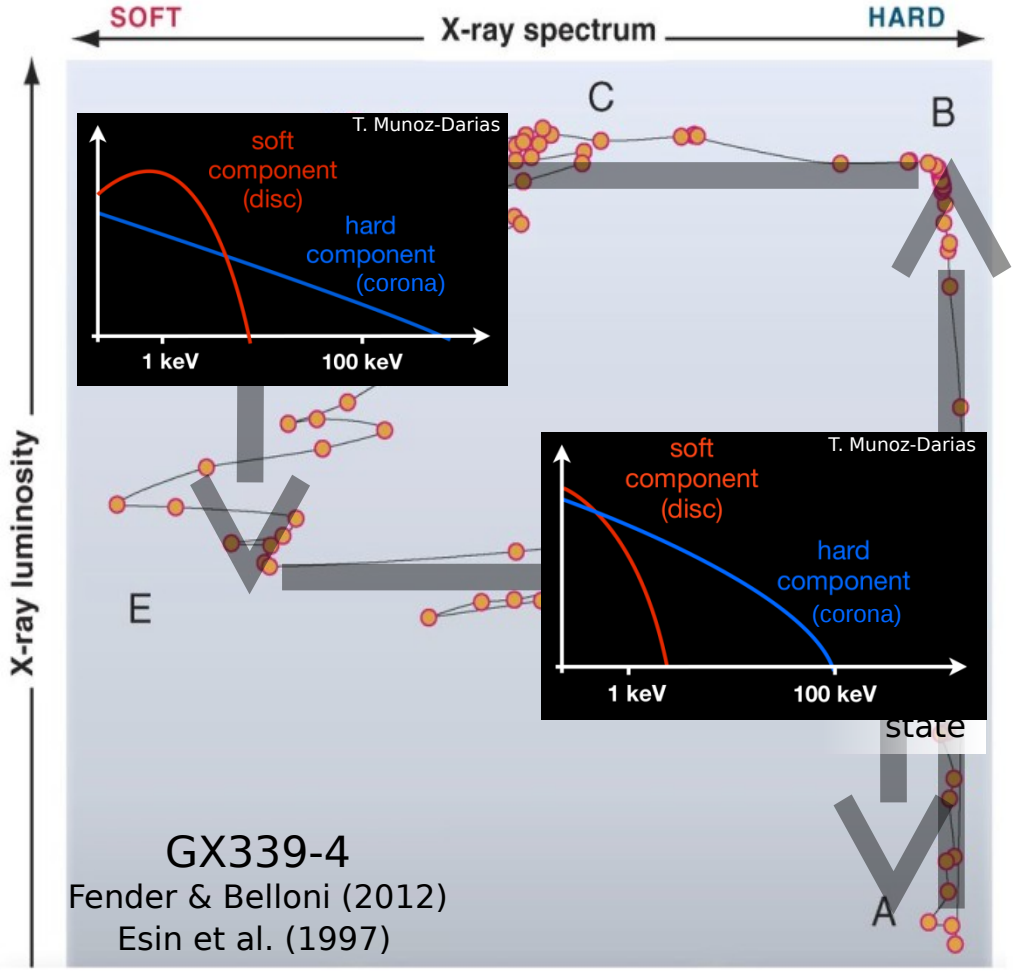
## *YSOs*




- Maybe… (Bell+94,05)
- …but
  - $\tau_{FUOr} \approx$ decades ⇒ $\alpha \leq 10^{-4}$
  - low α ⇒ high Σ
  - high Σ ⇒ gravitational instability
- Modifications & Alternatives
  - MRI+GI (eg Martin & Lubow 11,13)
  - Planets (eg Lin+85, Clarke+05)
  - GI+Fragmentation (eg Vorobyov+05,06,09,10)
  - Close Encounters (e.g. Bonnell & Bastian 92)

# The Universal Phenomenology of Disk Accretion:

## Hysteresis & State Transitions: Neutron Stars and Black Holes

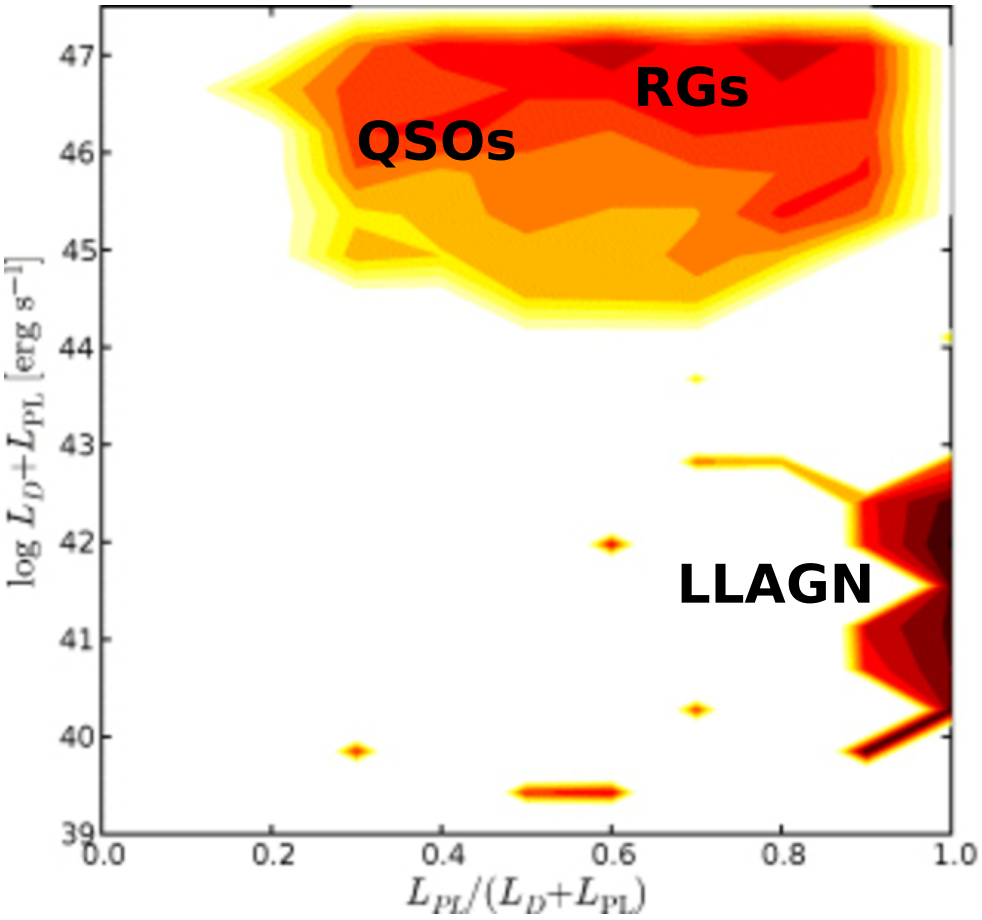



- Recent insights from NSs and BHs (Fender, Belloni & Gallo 2004)
  - X-ray transients execute a q-shaped path in the X-ray hardness vs intensity plane

→ **Hysteresis**

# The Universal Phenomenology of Disk Accretion:

## Hysteresis & State Transitions: Neutron Stars and Black Holes

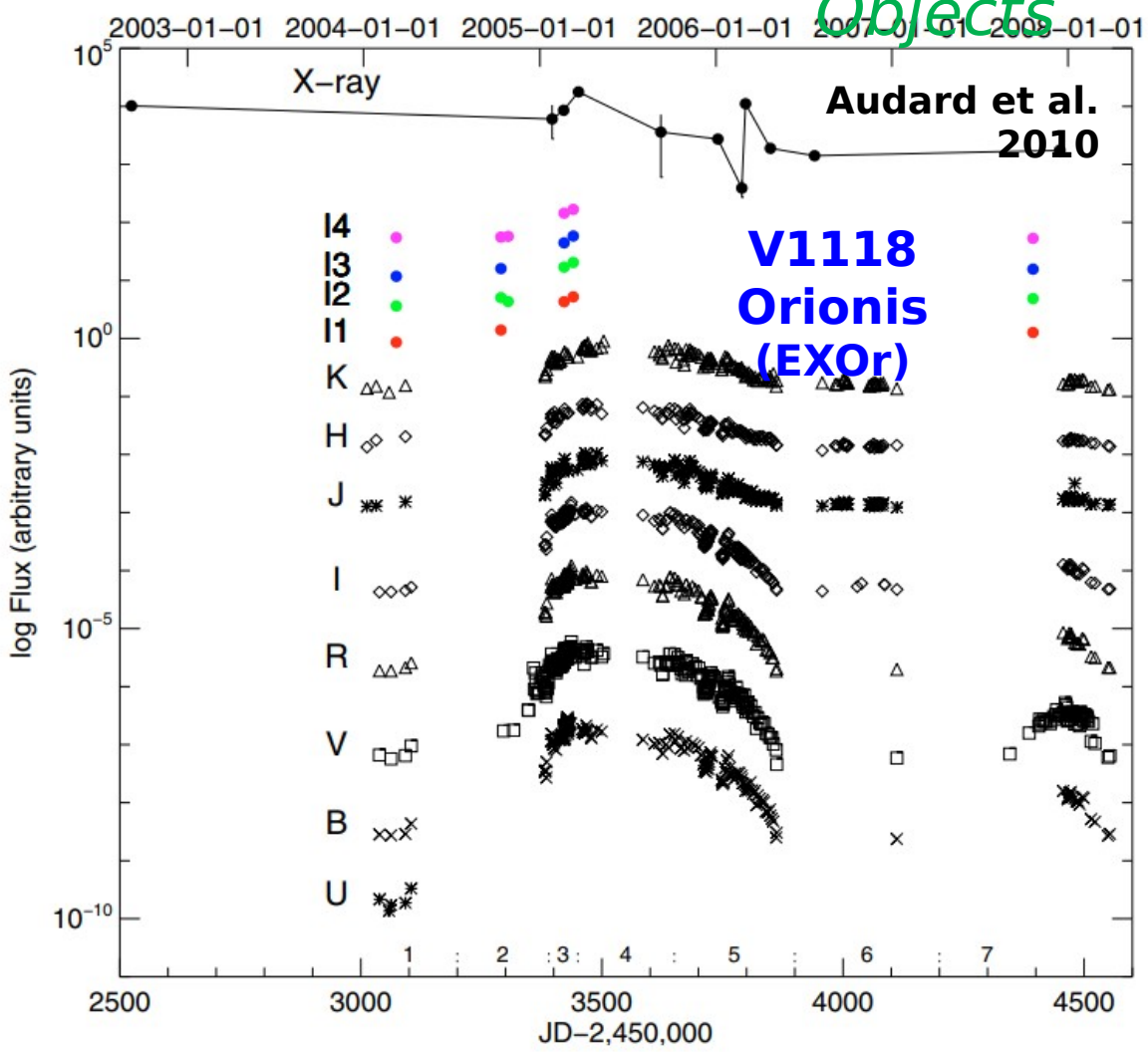



- Recent insights from NSs and BHs (Fender, Belloni & Gallo 2004)
  - X-ray transients execute a q-shaped path in the X-ray hardness vs intensity plane

    → **Hysteresis**
  - Generalized "disk-fraction/luminosity" diagram (DFLD) may also apply to AGN (Koerding, Jester & Fender 2006)

# The Universal Phenomenology of Disk Accretion:

## *Hysteresis & State Transitions: Young Stellar Objects*

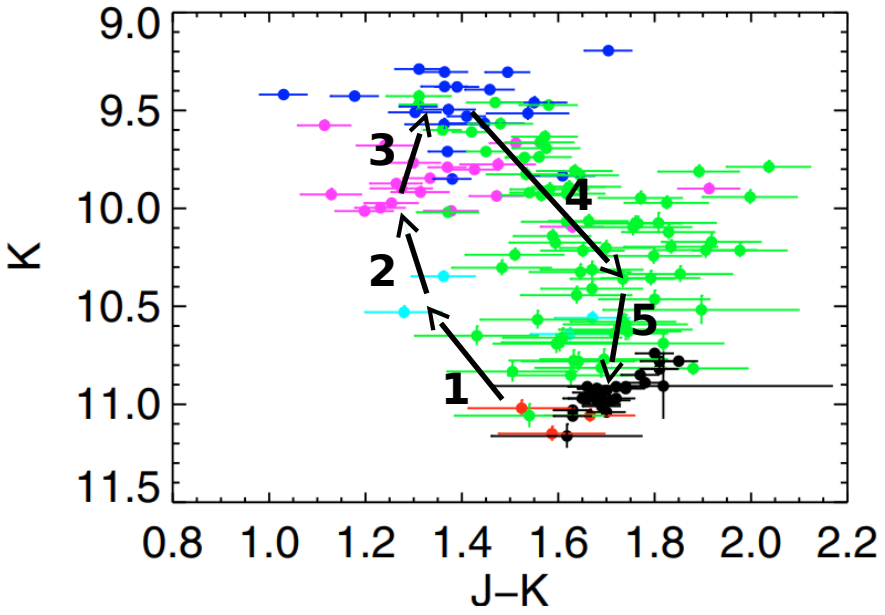



- Do FUOrs and EXOrs display hysteresis?

# The Universal Phenomenology of Disk Accretion:

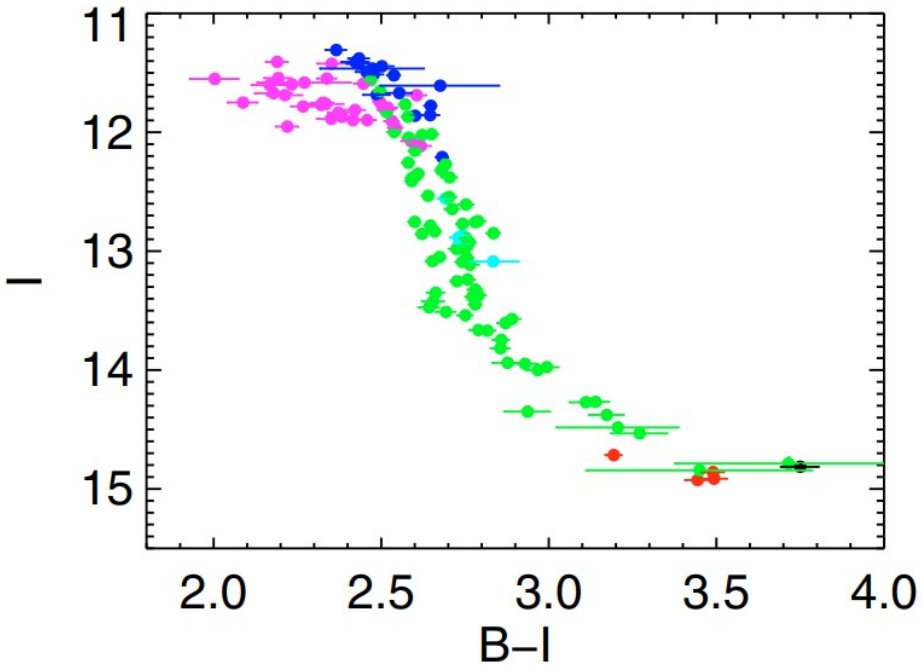
## *Hysteresis & State Transitions: Young Stellar Objects*

**Near-IR: Yes?**




- Do FUOrs and EXOrs display hysteresis?
  - Open question (?)

**Optical: No?**

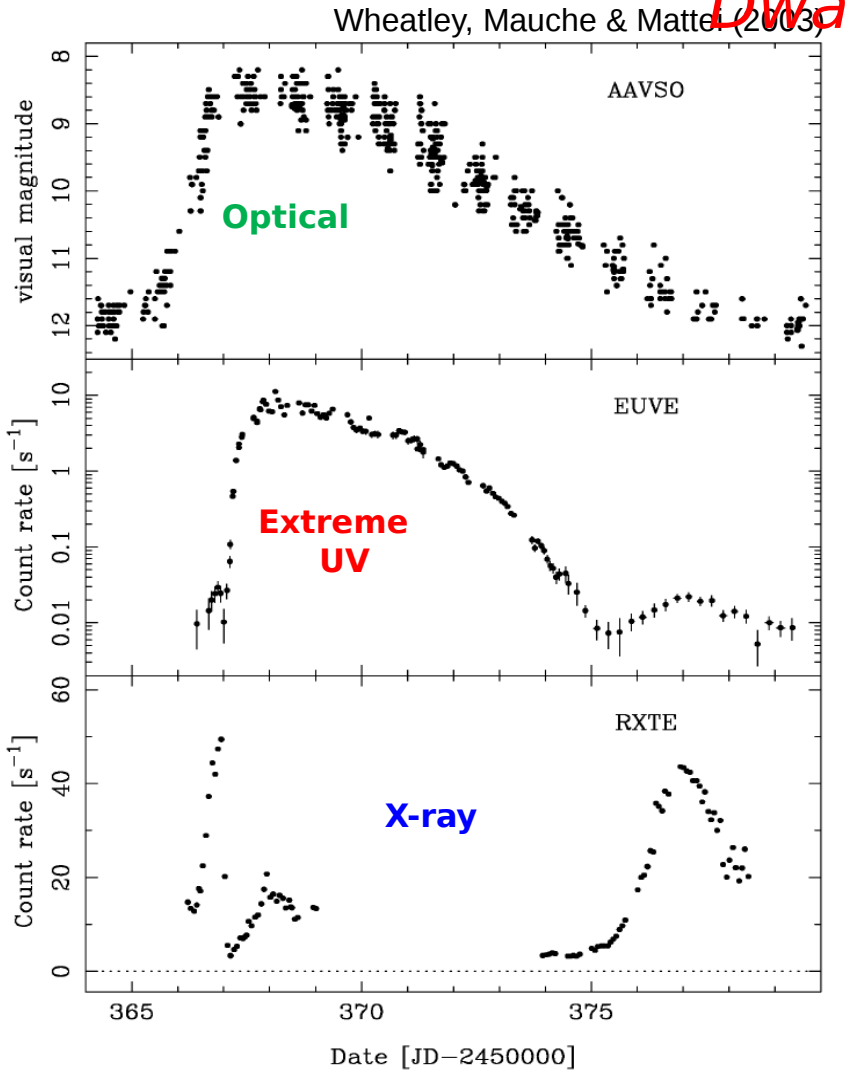



**V1118 Orionis (EXOr)**

**Audard et al. 2010**

# The Universal Phenomenology of Disk Accretion:

## Hysteresis & State Transitions: Accreting White Dwarfs




- Do transient accreting WDs – i.e. dwarf novae – show hysteresis?
  - Remarkably few simultaneous multi-wavelength observations!
  - Multi-wavelength coverage matters!
  - **Best available data set: SS Cyg**
    - Disk: UV / Opt
    - Corona / BL($\tau < 1$): X-ray
    - BL ($\tau > 1$): EUV / X-ray

Let's take a look at the behaviour in different bands….


- Disk: UV / Opt
- Corona / BL: X-ray
- BL : EUV / X-ray



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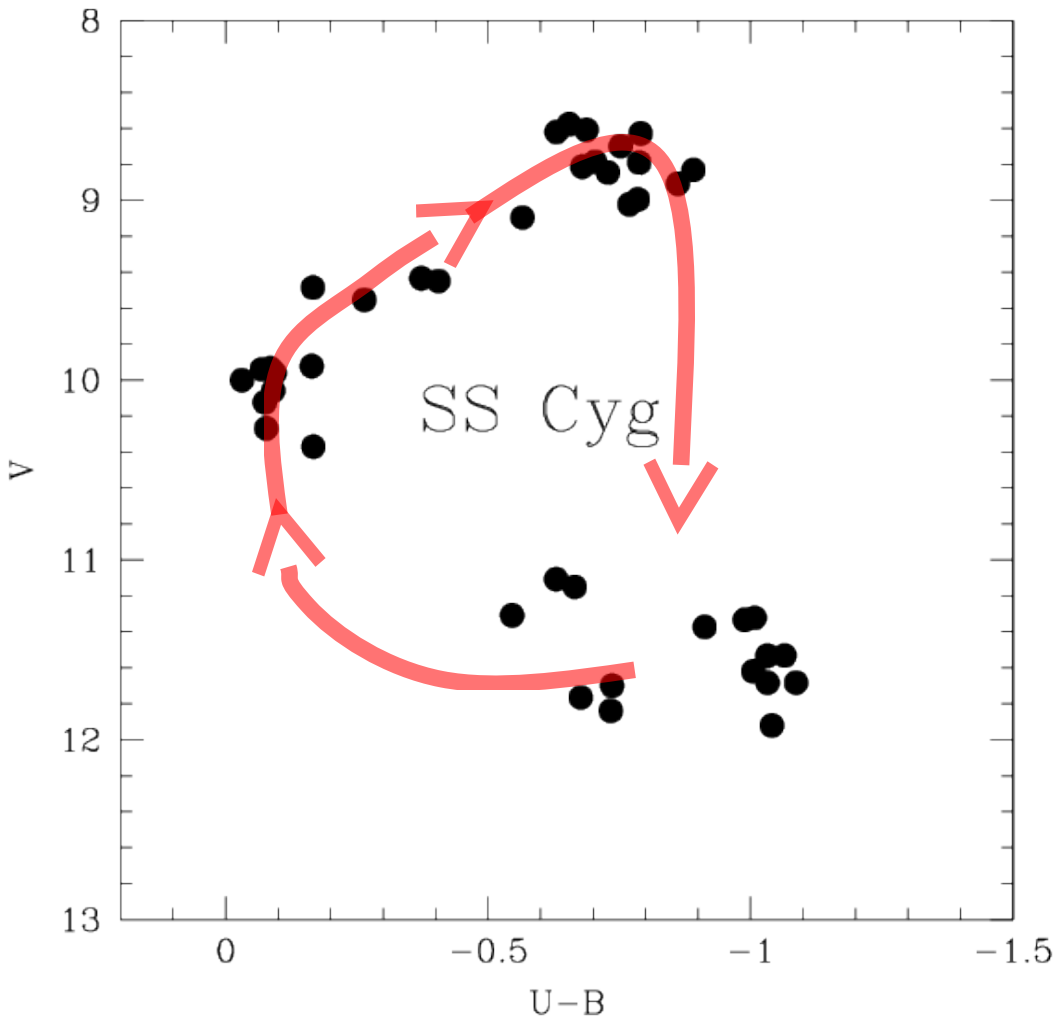
# The Universal Phenomenology of Disk Accretion:

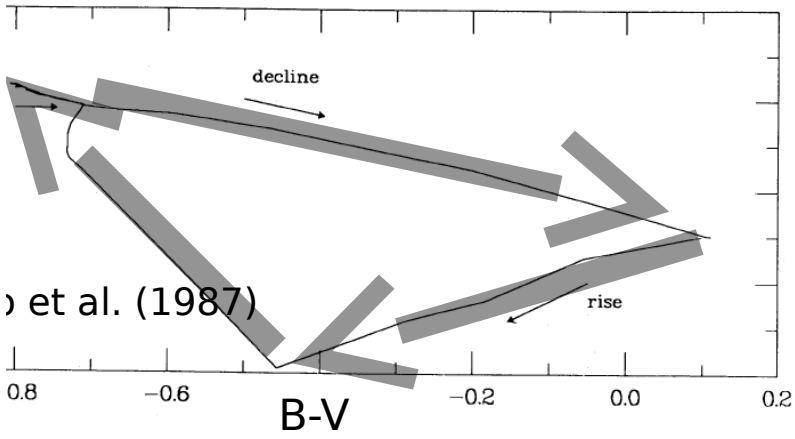
## Hysteresis & State Transitions: Accreting White Dwarfs




Do transient accreting WDs – i.e. dwarf novae -- show hysteresis?

- Optical colours do!
  (Bailey 1980, Echevaria & Jones 1983)

- Opposite sense to HID in




et al. (1987)

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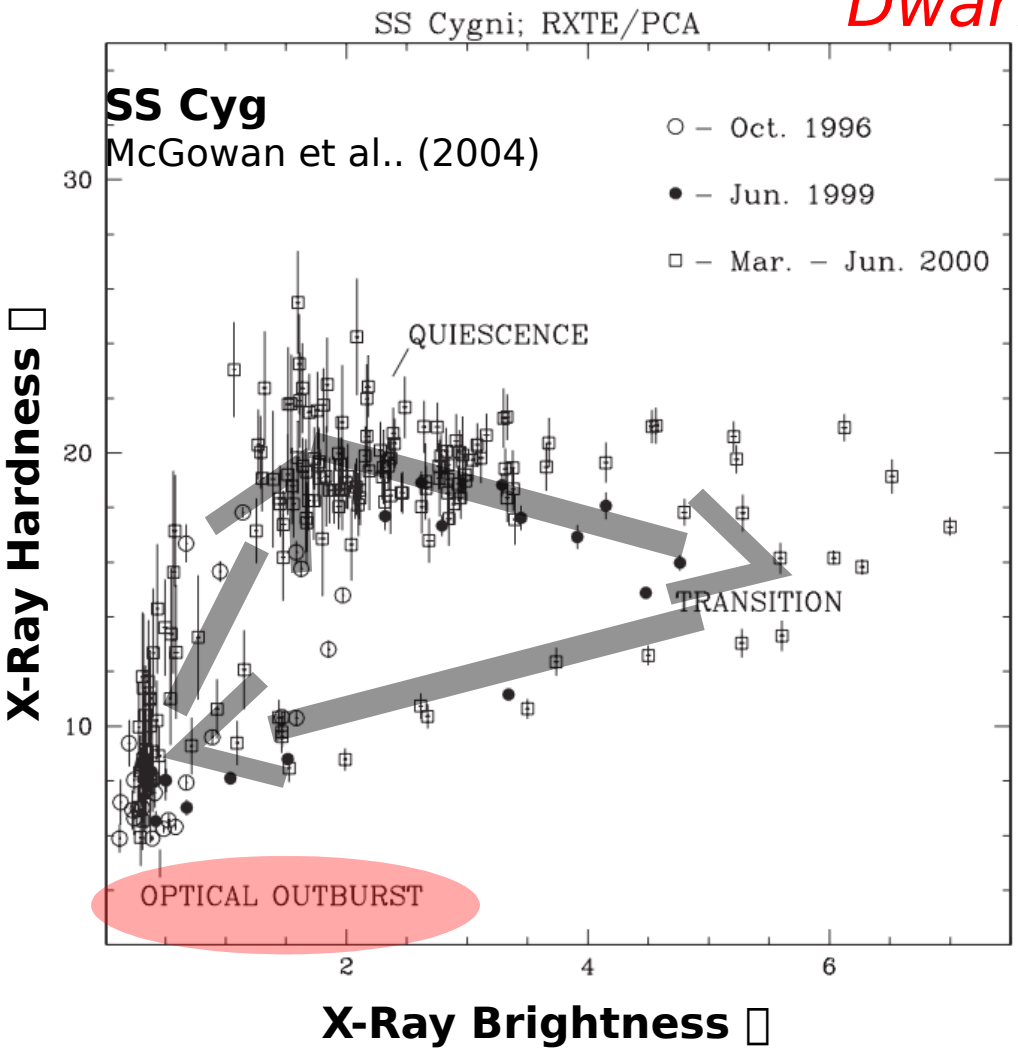
# The Universal Phenomenology of Disk Accretion:

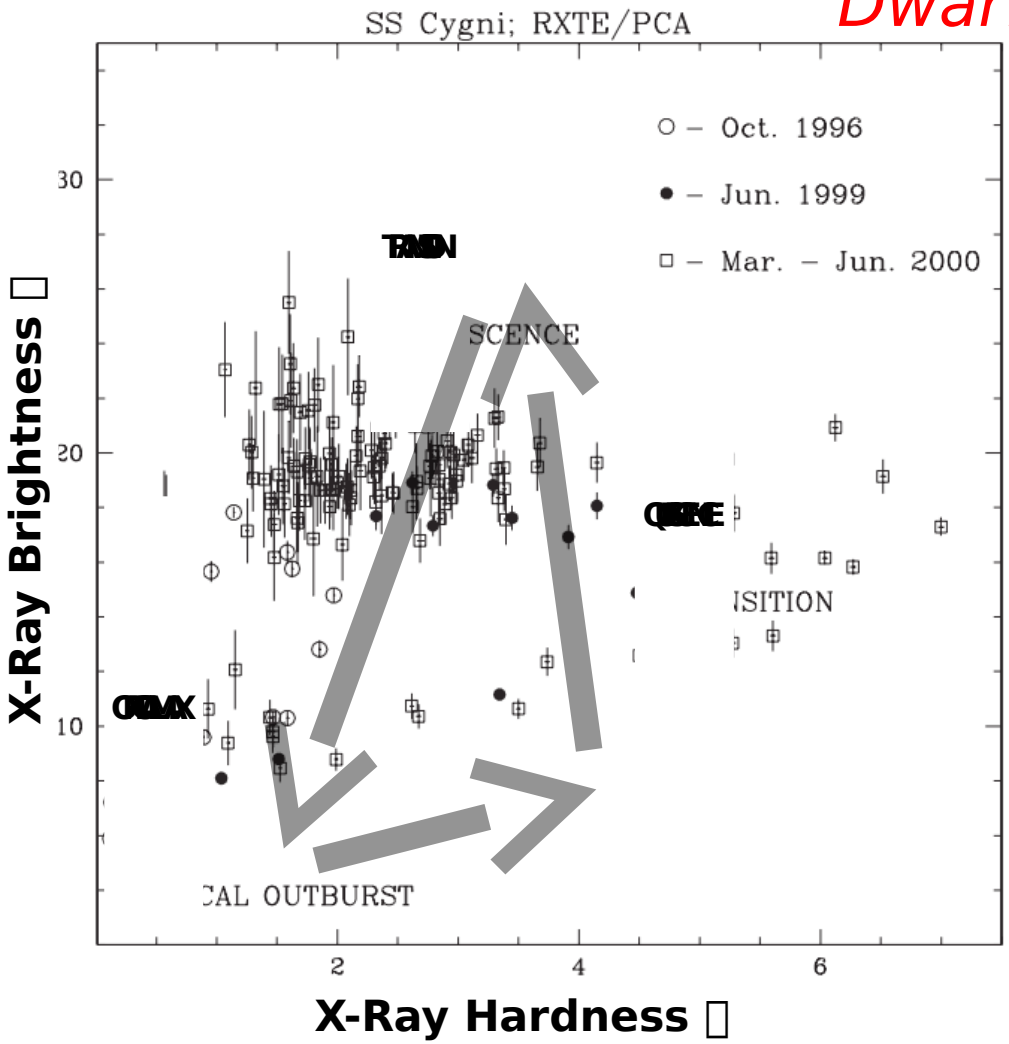
## Hysteresis & State Transitions: Accreting White Dwarfs




- Do transient accreting WDs – i.e. dwarf novae -- show hysteresis?
  - Optical colours do! (Bailey 1980, Echevaria & Jones 1983)
    - Opposite sense to HID in XRBs
    - Broadly consistent with DIM (Cannizzo et al. 1987)
  - X-rays do as well! (McGowan et al. 2004)

# The Universal Phenomenology of Disk Accretion:

## Hysteresis & State Transitions: Accreting White Dwarfs

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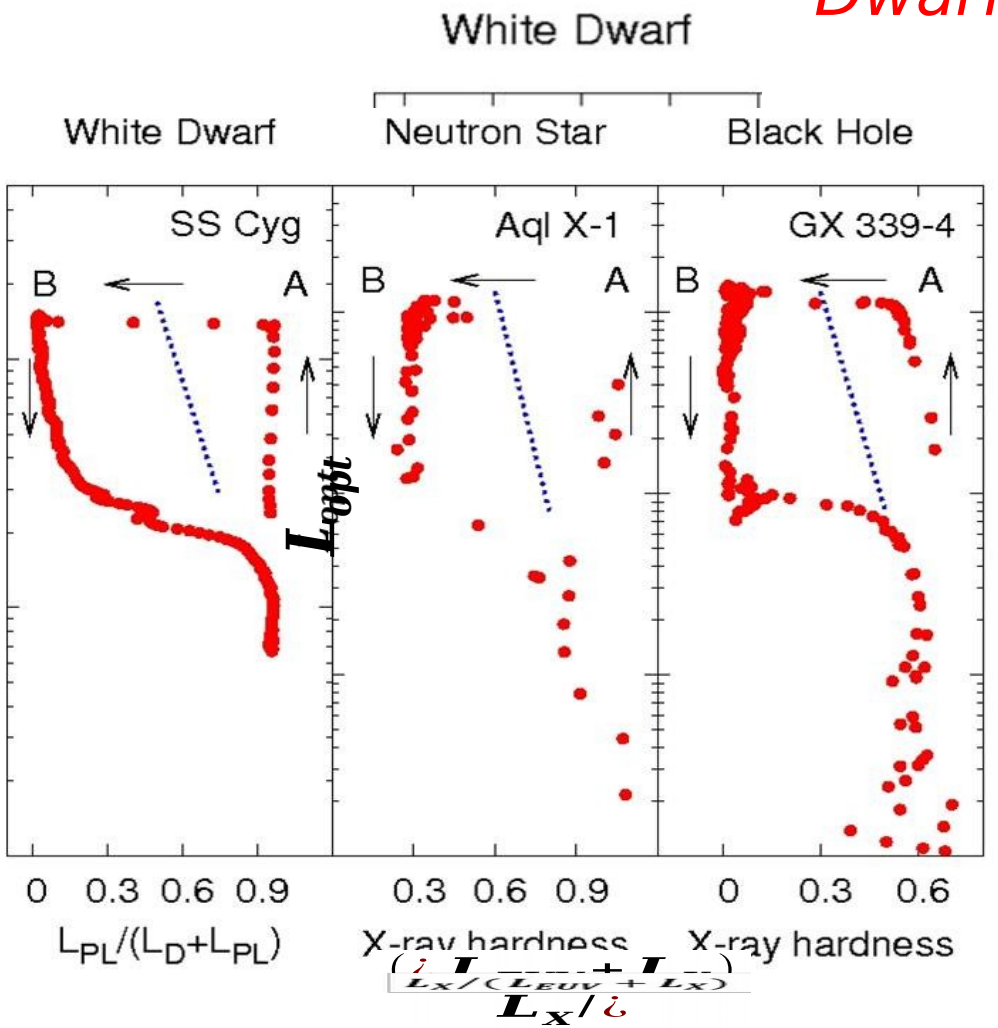
    - Opposite sense to HID in XRBs
    - Broadly consistent with DIM (Cannizzo et al. 1987)
  - X-rays do as well! (McGowan et al. 2004)
    - Same sense as HID in XRBs
- But what is the "right" diagram for comparison to

# The Universal Phenomenology of Disk Accretion:

## *Hysteresis & State Transitions: Accreting White Dwarfs*




- Only one attempt to construct a multi-λ DFLD for accreting WDs (Koerding et al. 2008, Science)
  - **Remarkably similar to NS/BH XRBs**

…but possibly wrong?
(Hameury, Lasota, Knigge & Koerding 2017)

# *The Universal Phenomenology of Disk Accretion*

## *Variability*

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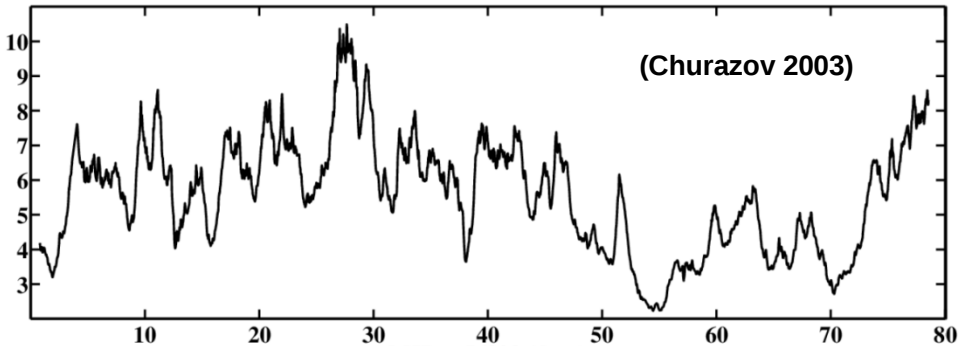
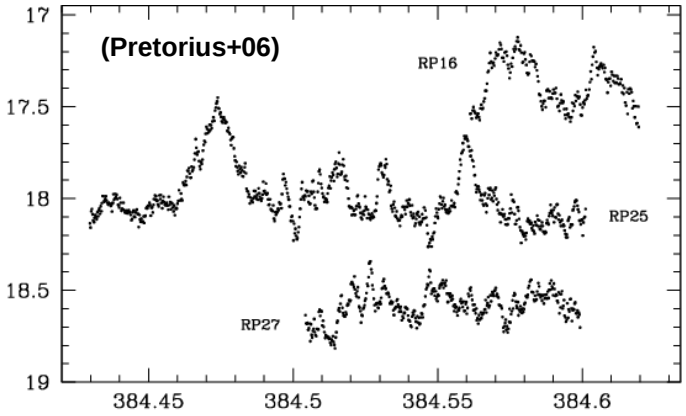
# *The Universal Phenomenology of Disk Accretion: Aperiodic Variability*

- All types of accreting systems display aperiodic variability ("flickering")

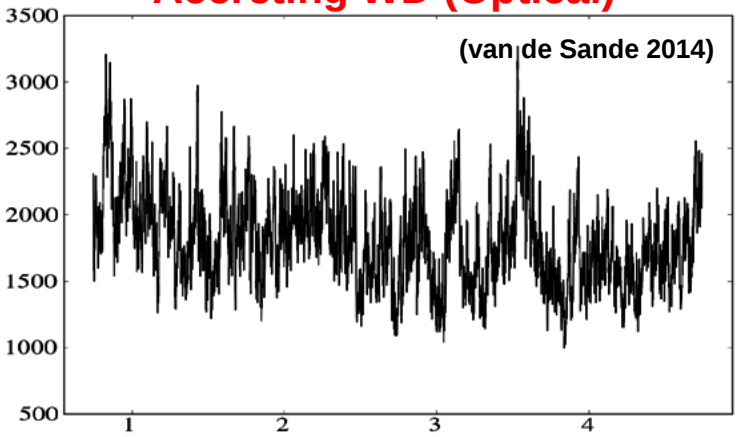
**Accreting YSO (Optical)**



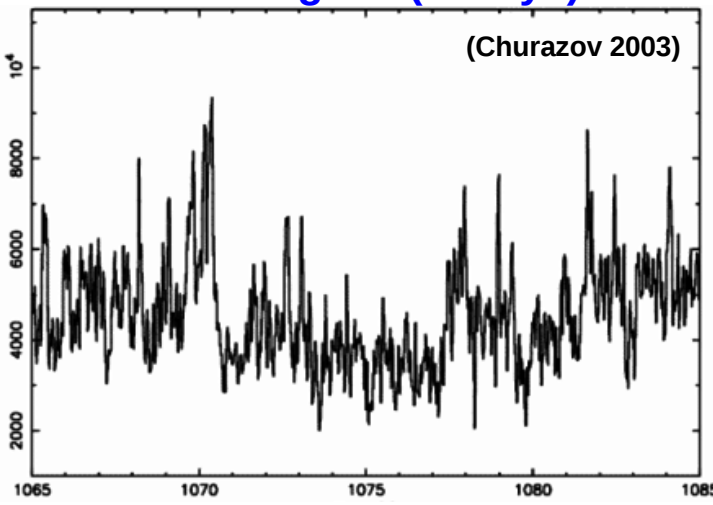




**Accreting WD (Optical)**

**Accreting WD (Optical)**




**Accreting BH (X-Rays)**

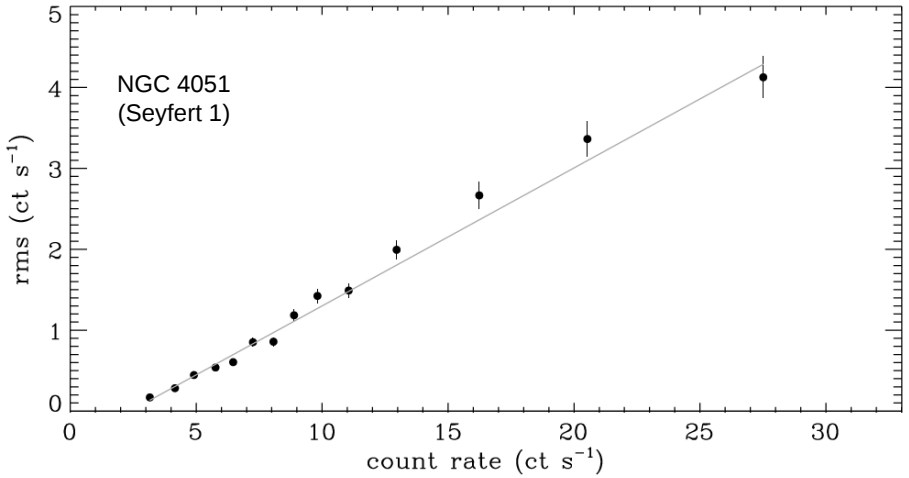


# The Universal Phenomenology of Disk Accretion:

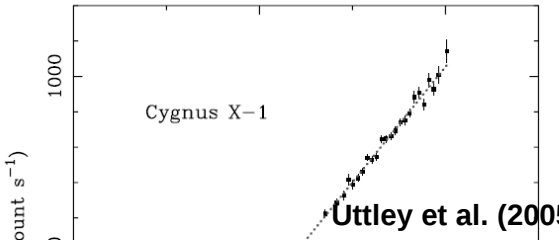
## Aperiodic Variability: Neutron Stars and Black Holes

- Key discovery in XRBs and AGN: **"rms-flux relation"**
  - Rules out "additive" (e.g. shot-noise) models
  - Applies on all time-scales ⇒ log-normal flux distribution

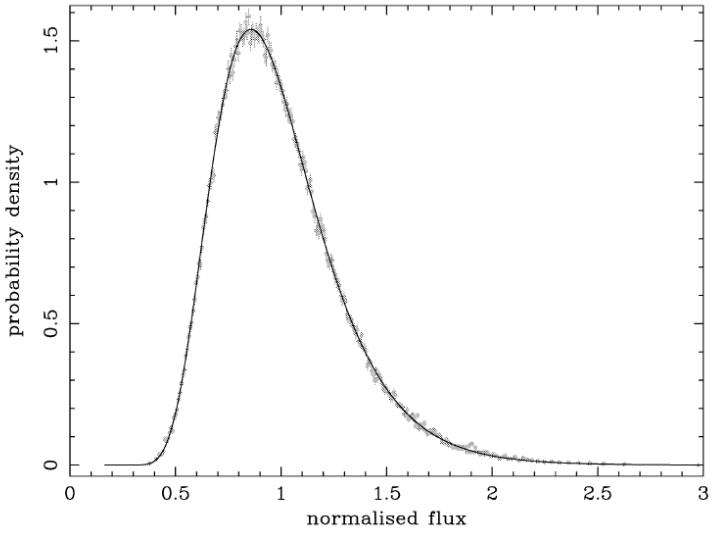
**AGN (Vaughan et al. 2011)**

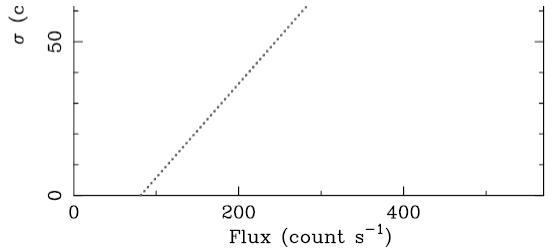



**Black Hole XRB (Uttley & McHardy 2001)**




**Uttley et al. (2005)**

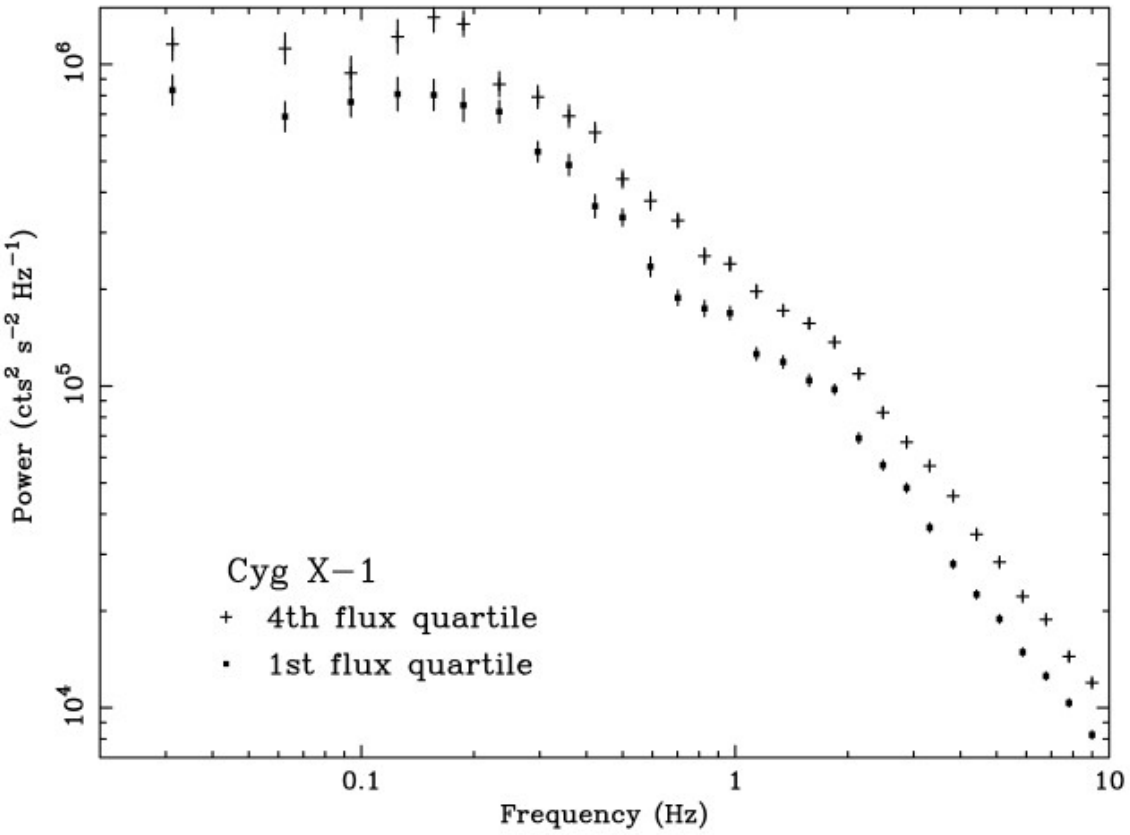


# The Universal Phenomenology of Disk Accretion:

## Aperiodic Variability: Neutron Stars and Black Holes

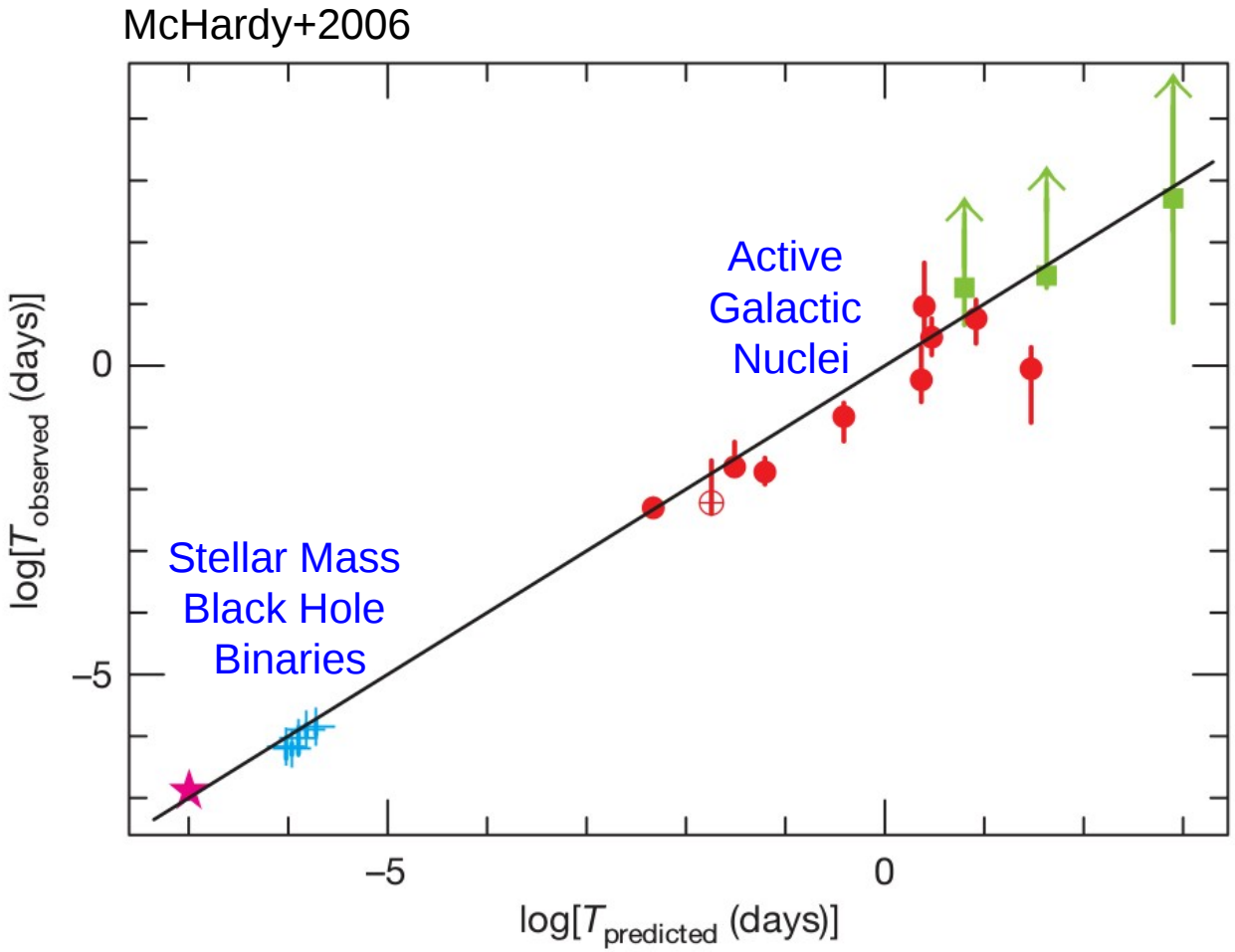
Uttley & McHardy 2001




- Flickering is characterized by broken power-law PSDs
  - “red noise”
- What sets the break frequency?

# *The Universal Phenomenology of Disk Accretion:*

## *Aperiodic Variability: Black Holes*




- $\nu_{break}$ scales with
  - $M_{BH}$
  - Accretion rate
- Connects LMXBs and AGN
  - **8 orders of magnitude!**
- But is it definitely $M_{BH}$ ?
  - **$R_{ISCO} \sim M_{BH}$**
  - For BHs, size and mass are ***degenerate*** !

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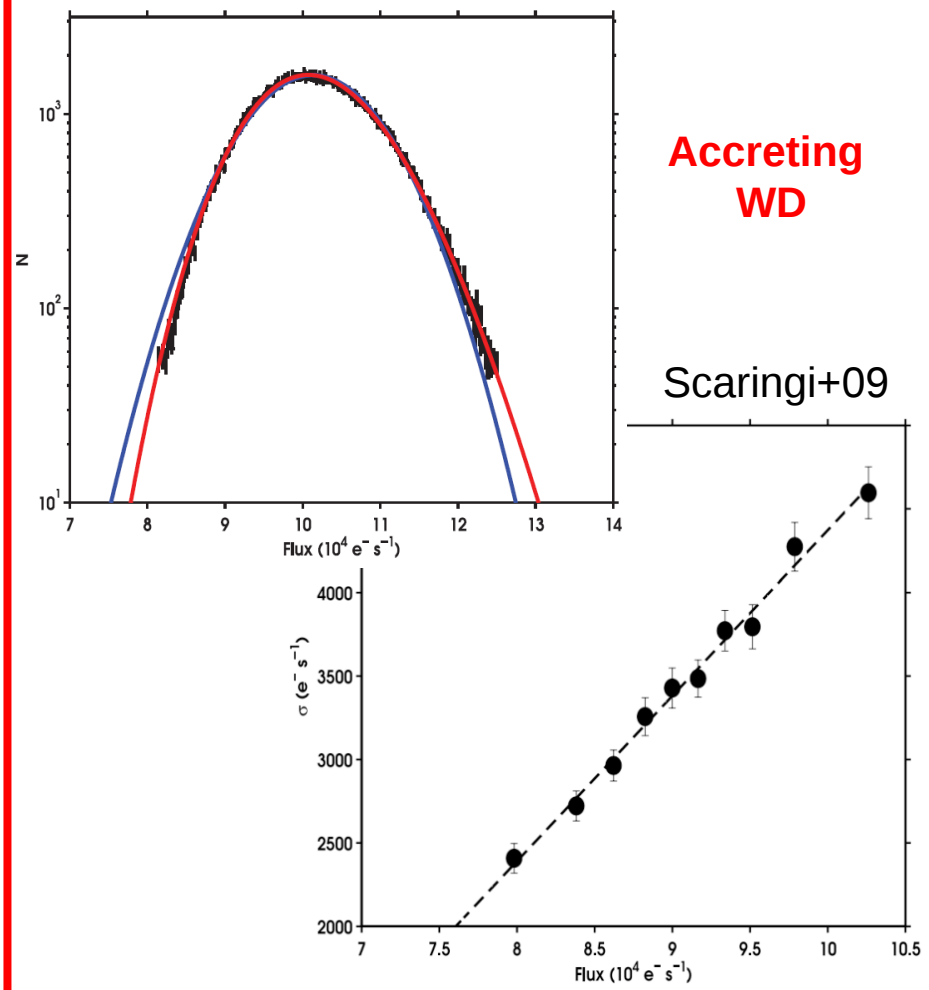
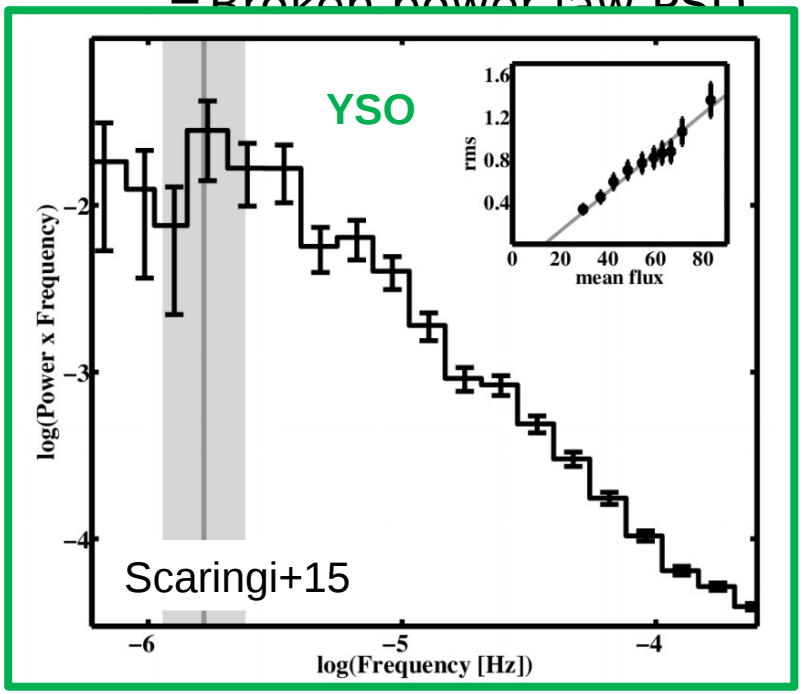
# The Universal Phenomenology of Disk Accretion:

## Aperiodic Variability: Accreting White Dwarfs and YSOs



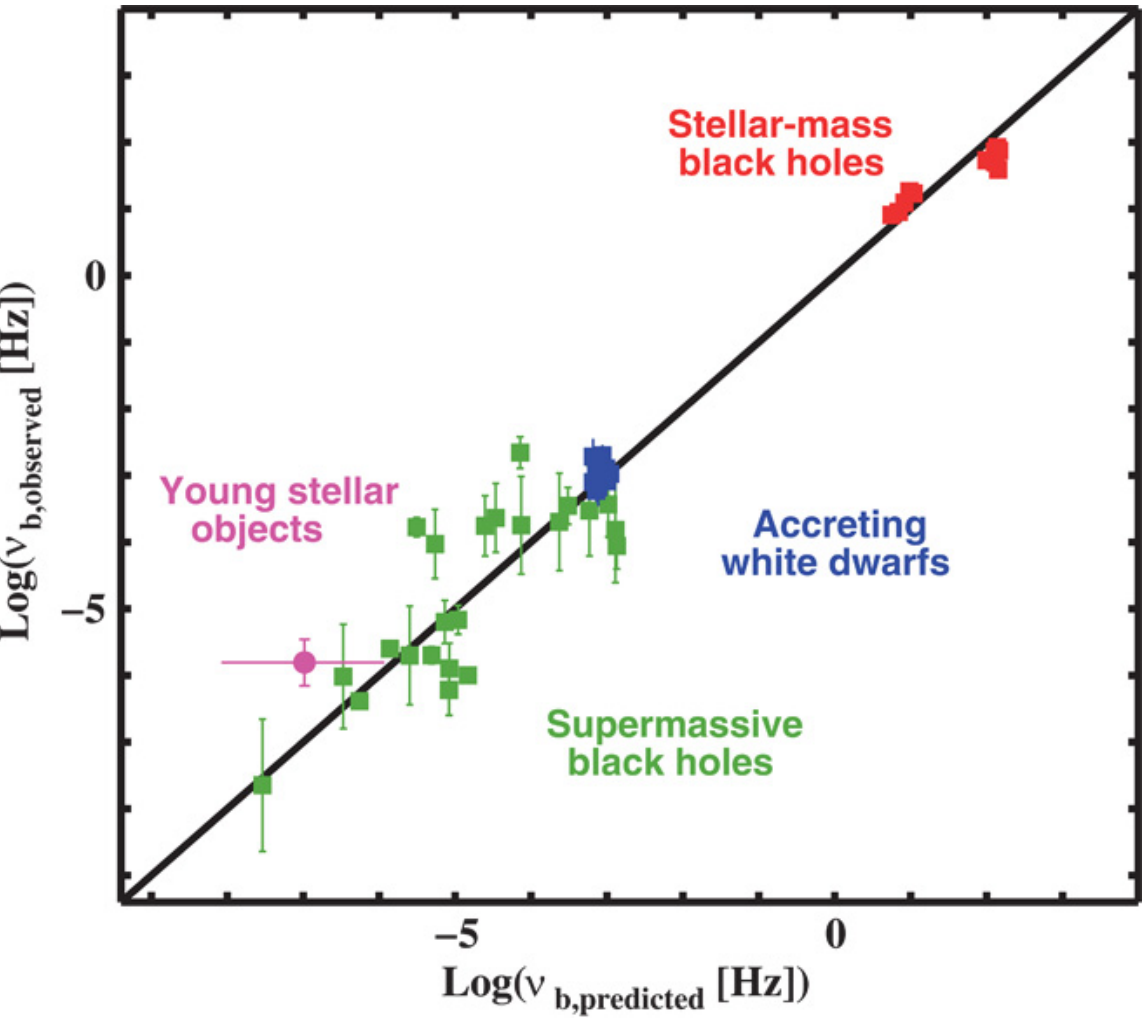

- Accreting WDs and YSOs display the **same** phenomenology!
  - RMS-flux
  - Log-normality
  - Broken power law PSD



# The Universal Phenomenology of Disk Accretion:

## Aperiodic Variability: Black Holes, White Dwarfs, YSOs

Scaringi+15




- Both WDs and YSOs fit on the BH scaling relation!
- They break the M-R degeneracy  $\nu_{break}$ scales with
  - ***Inner Disk Radius***
  - Accretion rate

# The Universal Phenomenology of Disk Accretion:

## *Quasi-Periodic Variability: Black Holes, Neutron Stars & White Dwarfs*

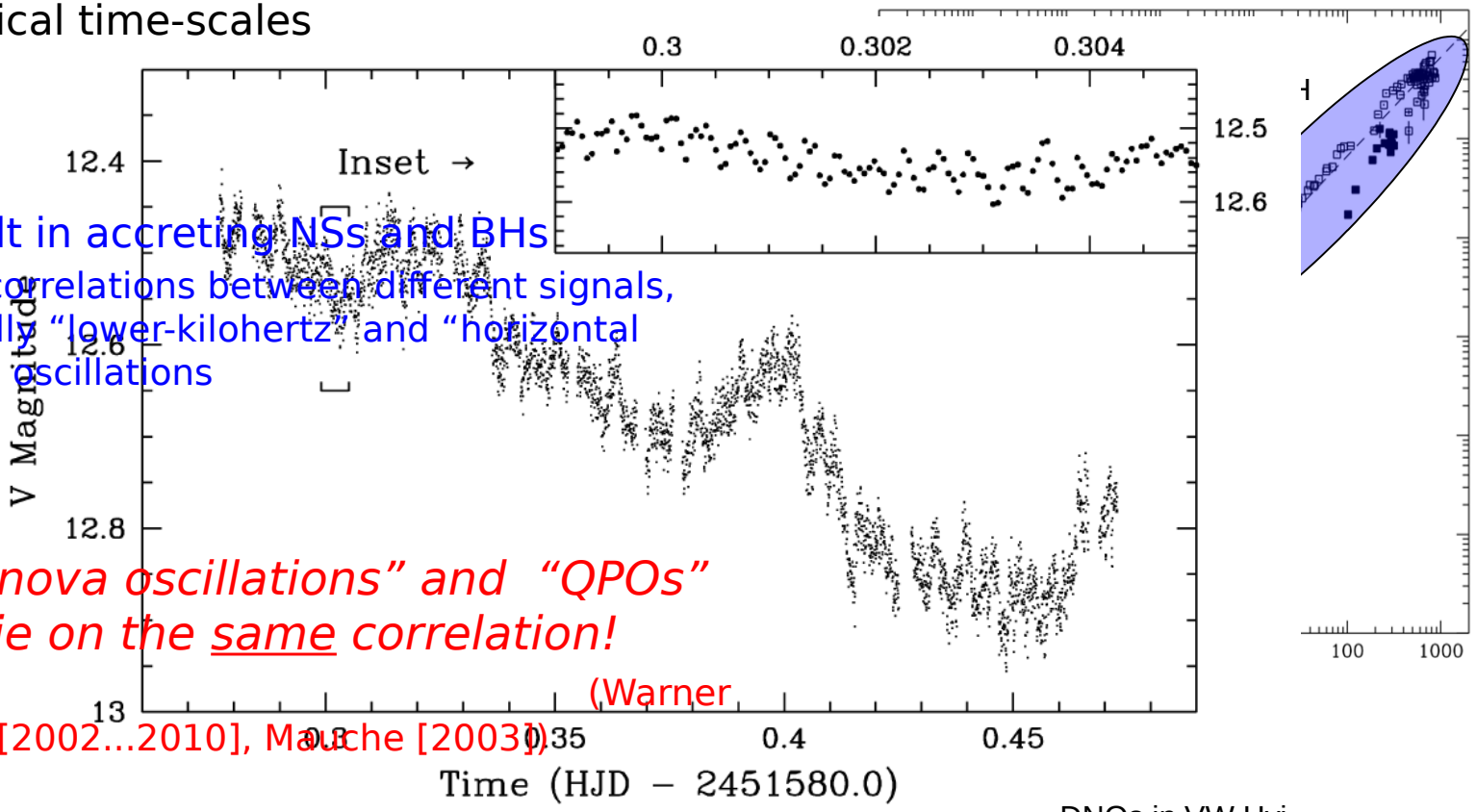
- Like BH and NS XRBs, accreting WDs also exhibit (quasi-) periodic oscillations on ~dynamical time-scales

- Key result in accreting NSs and BHs
  - strong correlations between different signals, especially "lower-kilohertz" and "horizontal branch" oscillations

- *"Dwarf-nova oscillations" and "QPOs" in CVs lie on the same correlation!*

(Warner & Woudt [2002...2010], Mauche [2003])

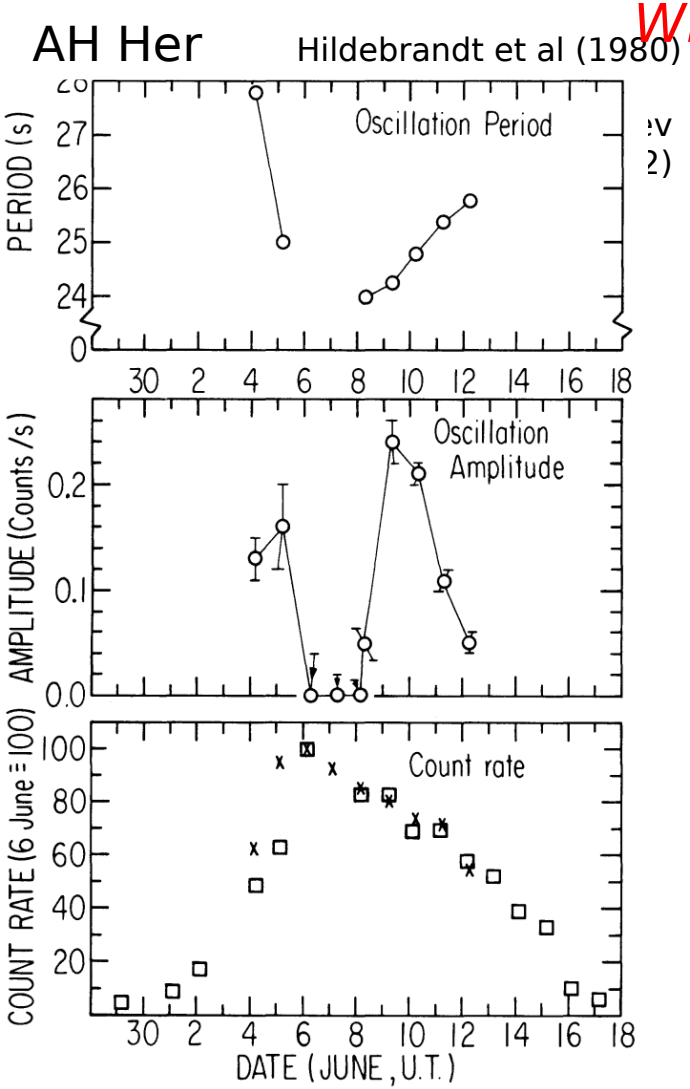
Warner & Woudt 2004




DNOs in VW Hyi
Woudt & Warner (2002)

# The Universal Phenomenology of Disk Accretion:

## *Quasi-Periodic Variability: Black Holes, Neutron Stars & White Dwarfs*




- As with accreting BHs and NSs, variability properties of CVs depend on accretion state
  - X-ray power spectra change during outburst
  - Optical DNOs become faster and brighter during outburst, but disappear near maximum
    - Ram-pressure quenching of magnetosphere?
  - Multi-λ behaviour and connections to other system properties remain largely unknown!

# *The Universal Phenomenology of Disk Accretion*

## *Outflows*

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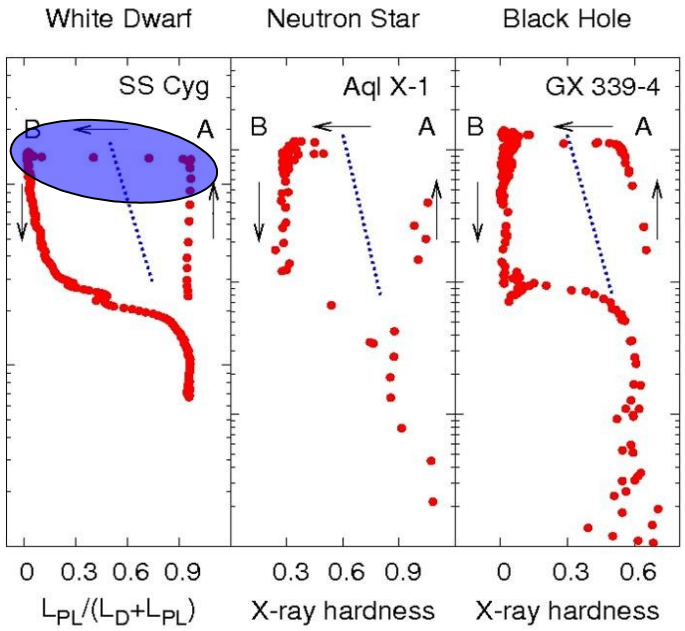
# The Universal Phenomenology of Disk Accretion

## Jets: *Black Holes, Neutron Stars* & *Accreting White Dwarfs*

- Relativistic radio jets are seen in all transient NS/BH systems
- Strong connection to outbursts/states (Fender, Belloni & Gallo 2004, ....)
  - Steady jets exist only in the hard state
  - Near outburst peak, spectrum softens and jet ultimately disappears
  - Hard  soft transition is accompanied by radio flares
    - transient ballistic jet ejection episode
- What about accreting WDs?
  - **Are CVs capable of launching jets?**
    - Early searches all negative, but focused on high-state systems




Koerding et al. (2008)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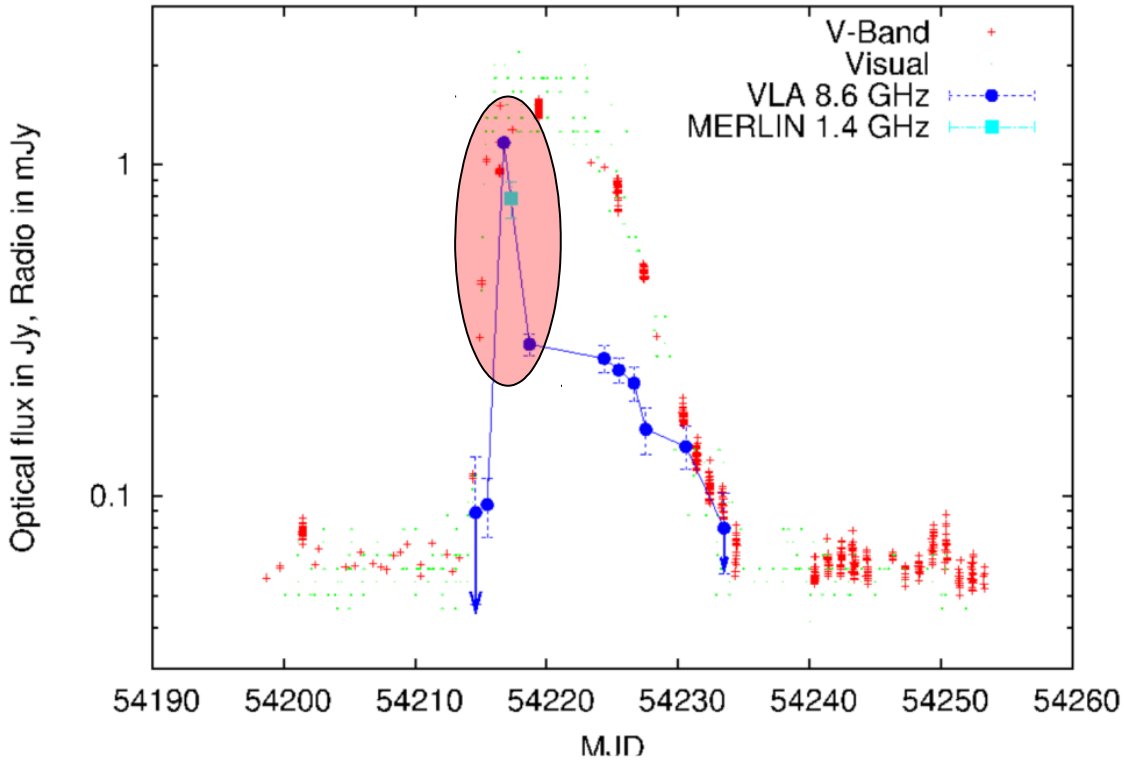
# *The Universal Phenomenology of Disk Accretion*

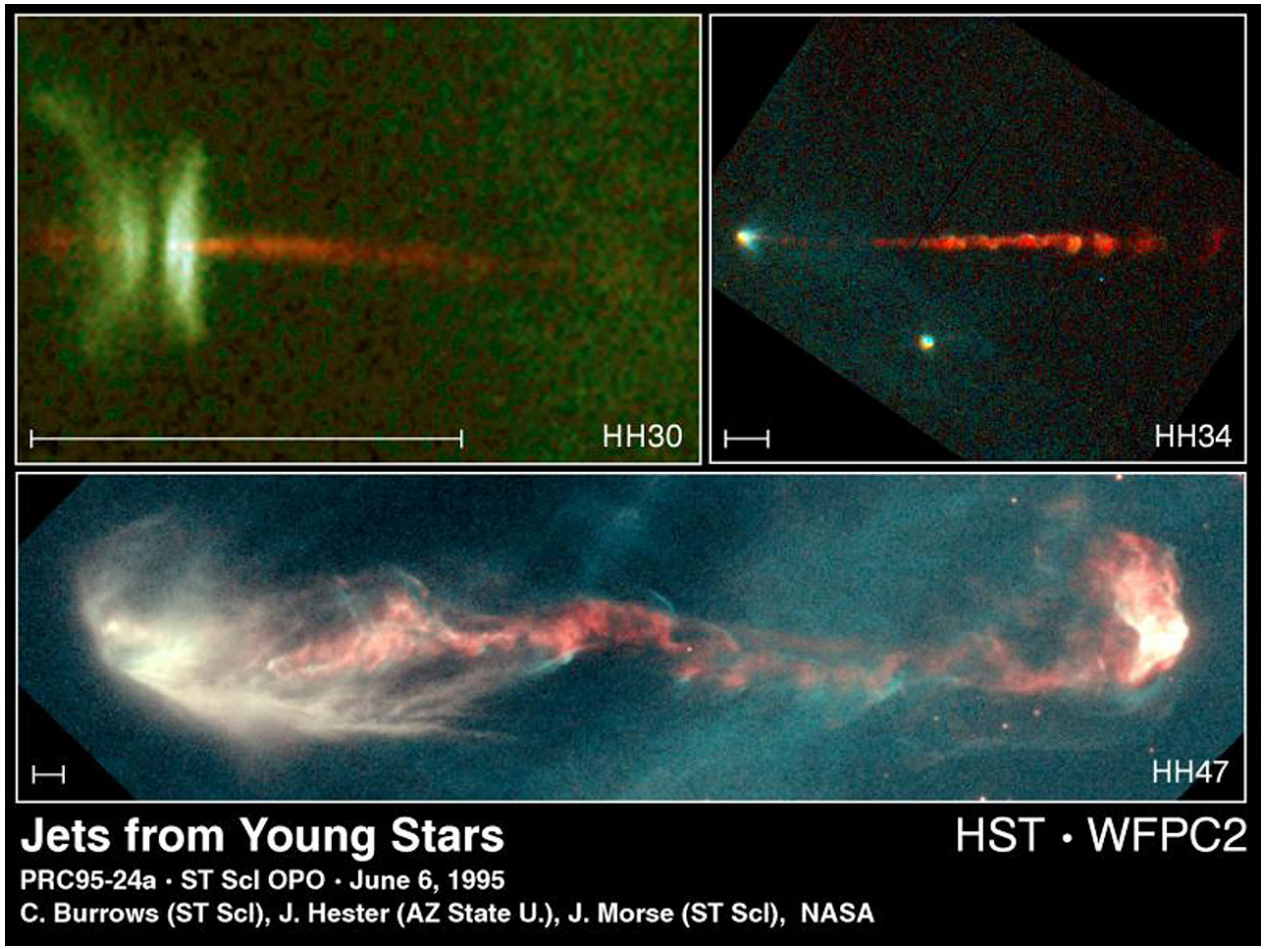
## *Jets: Accreting White Dwarfs*

- First attempt: the proto-typical dwarf nova SS Cygni
  - **Disovery of the first jet in a CV via detection of a radio flare**
    (Koerding, Rupen, Knigge, Fender et al. 2008, Science)



# *The Universal Phenomenology of Disk Accretion*

## *Jets: Young Stellar Objects*

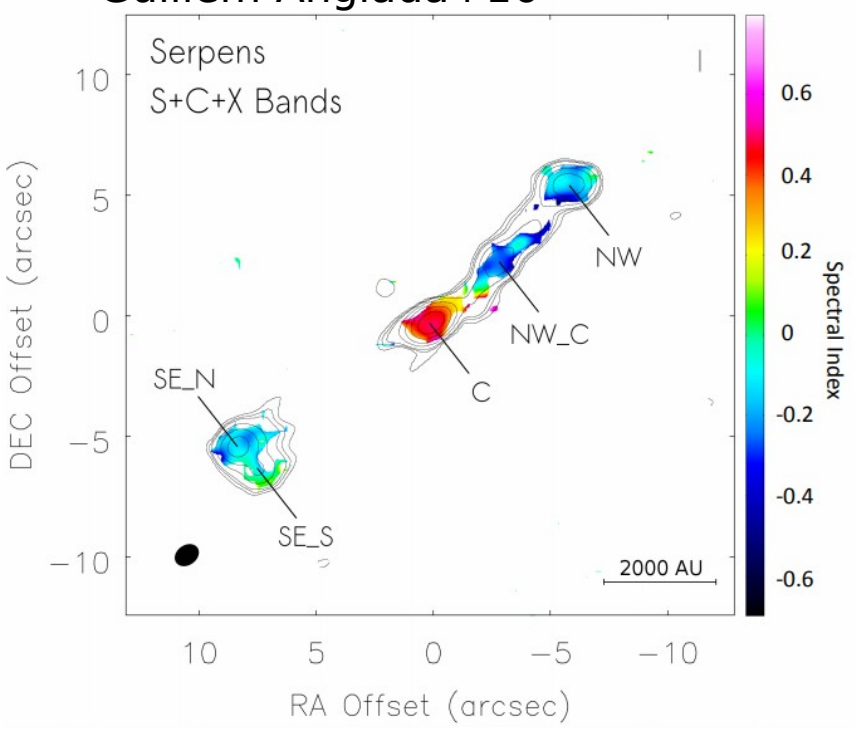



Jets are (of course) also seen in YSOs

# *The Universal Phenomenology of Disk Accretion*

## *Jets: Young Stellar Objects*

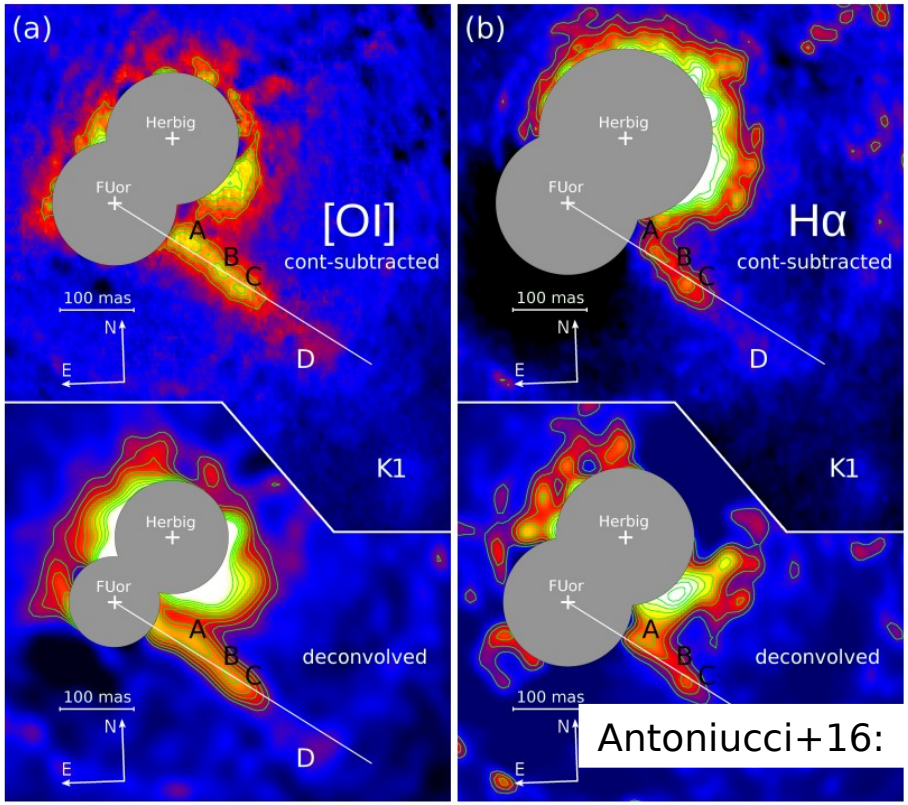
Guillem-Anglada+16




This even includes non-thermal (synchrotron) radio jets!

But relation to “state” is unclear!

A Resolved Jet in the FUOr Z CMa




Antoniucci+16:

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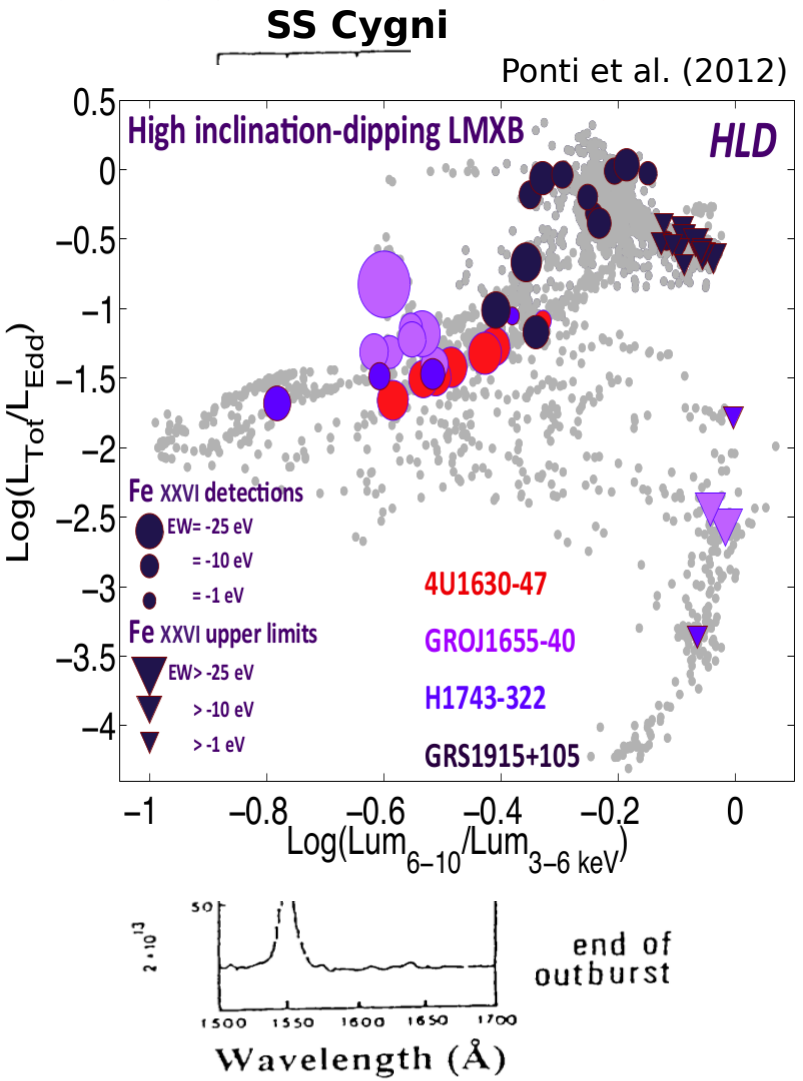
# The Universal Phenomenology of Disk Accretion

## Disk Winds: Black Holes, Neutron Stars & White Dwarfs

- Recent insights from BH XRBs (Ponti et al. 2012)
  - High-inclincation LMXBs show blue-shifted X-ray absorption lines, but only in high/soft(ish) states
    - Never in hard/jet states
    - ***Hard-to-soft transition accompanied (caused?) by switch from collimated jet → disk wind***
    - ***Hard-to-soft transition accompanied (caused?) by switch from collimated jet → disk wind***
- Relation to accreting white dwarfs?
  - Disk winds are present in all high-$\dot{M}$ CVs !
    - blue-shifted UV absorption lines in low-i systems
    - uneclipsed UV emission lines in high-i systems
- Relation to accreting white dwarfs?
  - In DNe, wind-formed blue-shifted UV absorption only develops near outburst maximum
  - Disk winds are present in all high- CVs !
    - blue-shifted UV absorption lines in low-i systems → ***analogous to XRBs?***
    - uneclipsed UV emission lines in high-i systems





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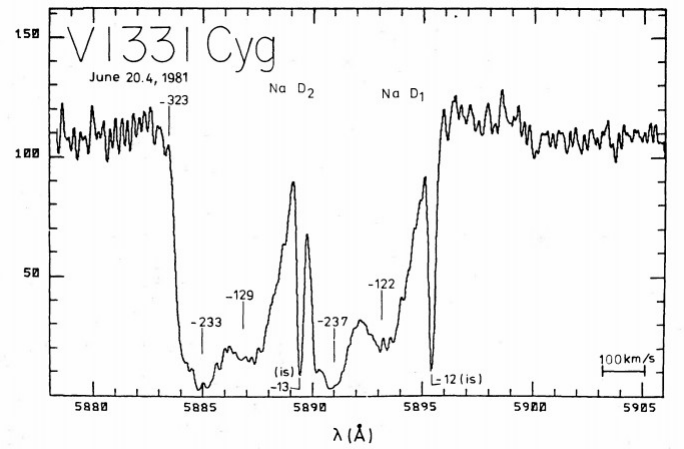
# The Universal Phenomenology of Disk Accretion

## Disk Winds: Young Stellar Objects

A T Tauri Disk Wind

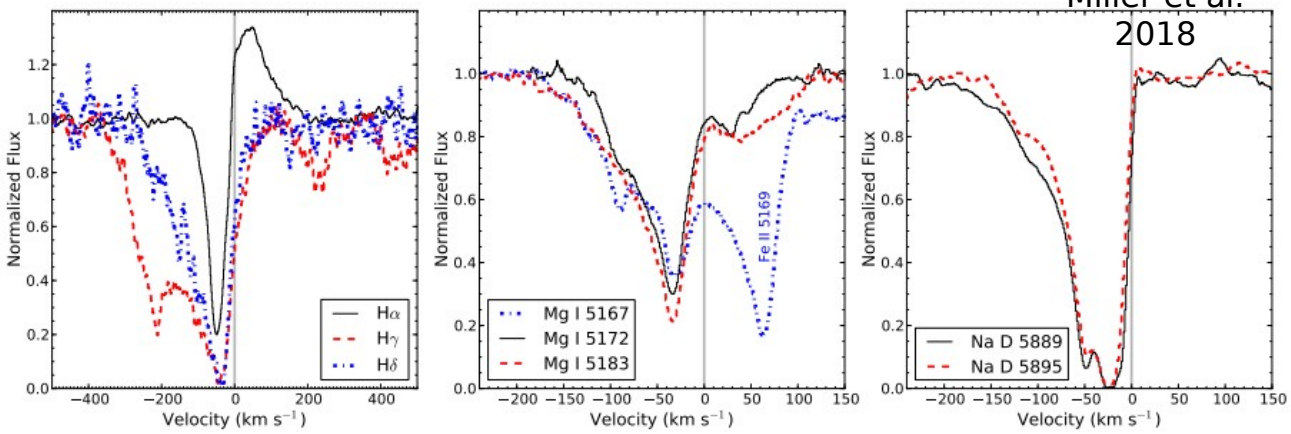
Mundt 1984




- Disk winds are also seen in YSOs
  - Optical P Cygni lines
- Present in both TTaus and FUOrs
  - **No "state" dependence?**
  - Is the apparent state dependence in BHs, NSs and WDs definitely real?

A FUOr Disk Wind

Miller et al. 2018



*From Phenomenology to Physics*

# *GOALS: The Great Observatories Accretion Legacy Survey*

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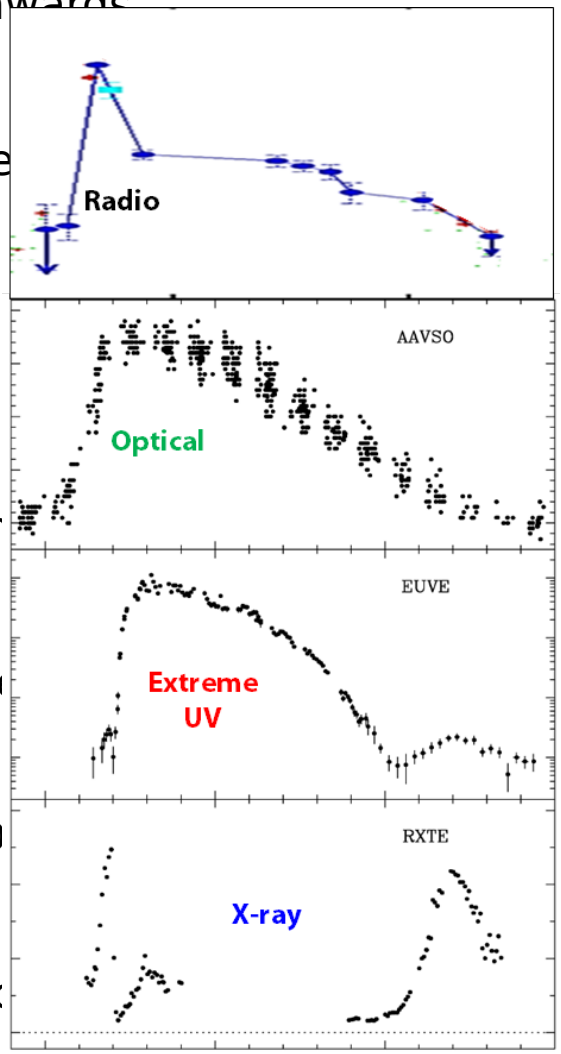
# *Anatomy of an Erupting Accretion Disk*

## *Dissecting a Dwarf Nova Outburst*

- Disk annulus becomes unstable, sending a heating wave inwards
  - **Optical** monitoring allows approximate timing to be predicted *(AAVSO, CBA)*
- Flickering and DNOs strengthen and speed up as disk moves inwards
  - High-speed **optical**, **UV** and **X-ray** photometry *(ULTRACAM, HST, Swift, XMM, Chandra)*
- X-rays from BL/corona brighten as $\dot{M}$ onto WD increases
  - Time-resolved **X-ray** photometry/spectroscopy *(Chandra, XMM, NuSTAR, INTEGRAL, Swift)*
- Disk wind is launched once disk is sufficiently hot and bright
  - Time-resolved **EUV**, **UV** and **optical** spectroscopy *(Chandra, HST, Swift, ground-based)*
- Strong radio flare due to jet ejection when inner disk reaches centre
  - **Radio** and **infrared** monitoring *(VLA, ground-based)*
- DNOs are quenched as magnetosphere is crushed onto WD
  - High-speed **optical**, **UV** and **X-ray** photometry *(ULTRACAM, HST, Swift, XMM, Chandra)*
- BL emission switches from X-ray to EUV as it becomes optically thick
  - Time-resolved **X-ray** and **EUV** spectroscopy *(Chandra, XMM, NuSTAR, INTEGRAL, Swift)*

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# *What would this answer?*

## *Predictions and Open Questions*

- Are jets and disk winds causally connected?
  - Do radio flares precede or follow the development of UV wind lines?
- Do jet ejection and oscillation quenching signal the disk reaching WD
  - Does DNO quenching coincide with radio flares?
- Does the BL become optically thick at the same point?
  - Does the X-ray  EUV switch coincide with radio flares or DNO quenching?
- Is there still a hot corona after the switch?
  - Are there residual hard X-rays in outburst?
- Is flickering PSD a good tracer of the inner disk edge?
- How does the rms-flux relation evolve?
- Are there lags between variability in different wavebands?
- Do disk winds signatures dominate UV and optical spectra?
- When and how do disk winds turn off?
- What is the total amount of accreted and ejected material?

# *We can actually do this!*

- Requires roughly 1-2 weeks ~ 0.5–1Msec ~ 100-200 HST orbits
  - big, but not ridiculous
- Coordinated observations from radio to X-ray
  - ground-based, VLA, HST, Swift, Chandra, XMM-Newton, NuSTAR, INTEGRAL, ...
- Can probably be scheduled as non-disruptive ToO
  - several weeks notice
- Observatories seem up for the challenge!
- Need critical mass across the accretion community!
  - **if you are interested, get in touch!**