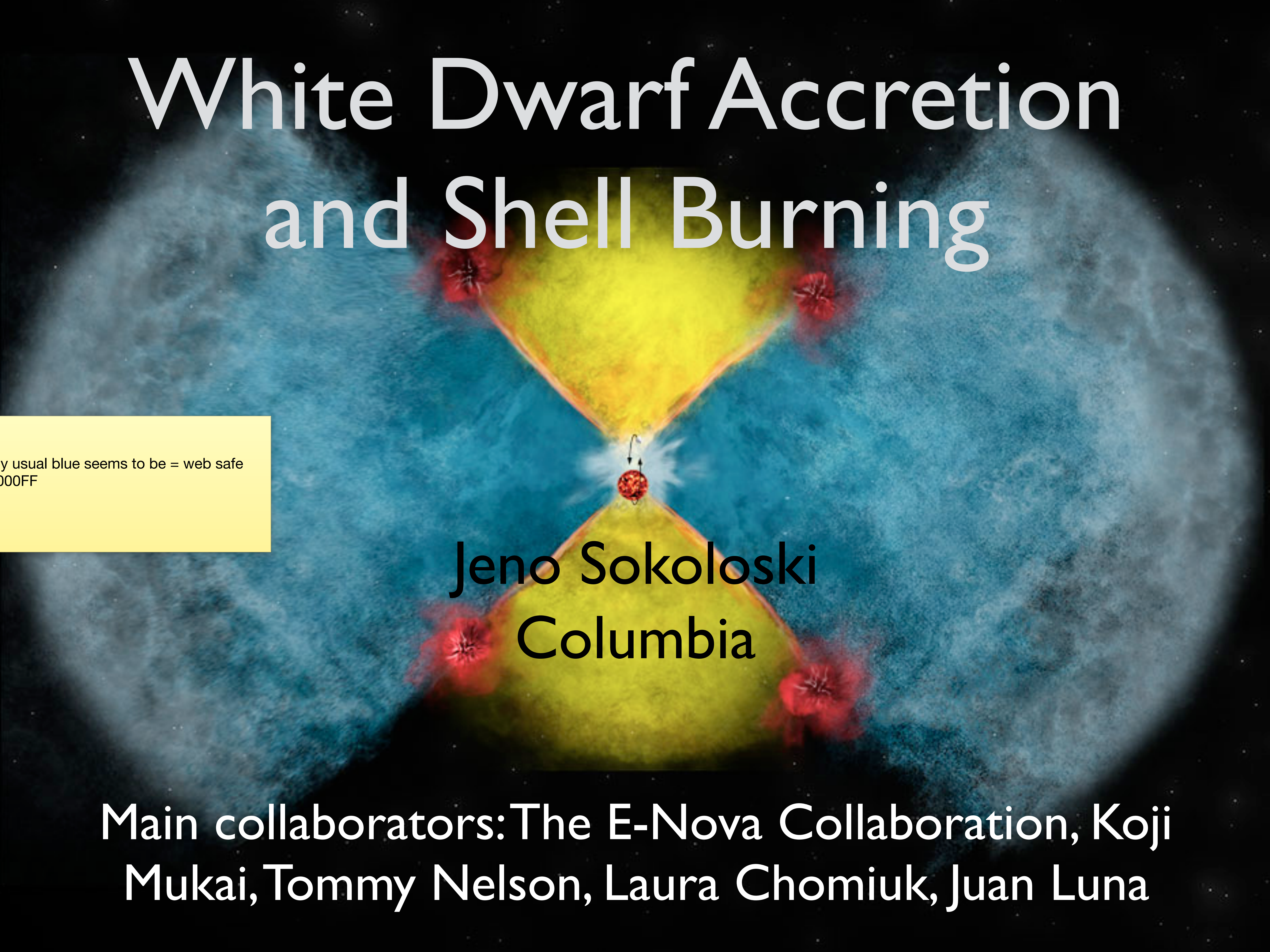
White Dwarf Accretion and Shell Burning



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000FF

Jeno Sokoloski
Columbia

Main collaborators: The E-Nova Collaboration, Koji Mukai, Tommy Nelson, Laura Chomiuk, Juan Luna

X-Rays from White Dwarf

Before we dive into any discussio
symbiotics, symbiotic outbursts,
known population, we need to cla
symbiotics that effects almost eve
absence of quasi-steady shell bu

Shock heating of accretion flows:

$$T_{ps} = \frac{3}{16}\frac{\mu m_p}{k_B} v_s^2 = 4 \times 10^7 \left(\frac{v_s}{1700\ \mathrm{km\ s^{-1}}}\right)^2 \frac{\mu}{0.6}\ \mathrm{K}$$

In outflows or innermost accretion regions

Shell burning: $E_{burn}/E_{nuc} \sim 50$

In contrast to neutron stars, white dwarfs produce more energy from nuclear burning than accretion (for a given amount of fuel).

Novae

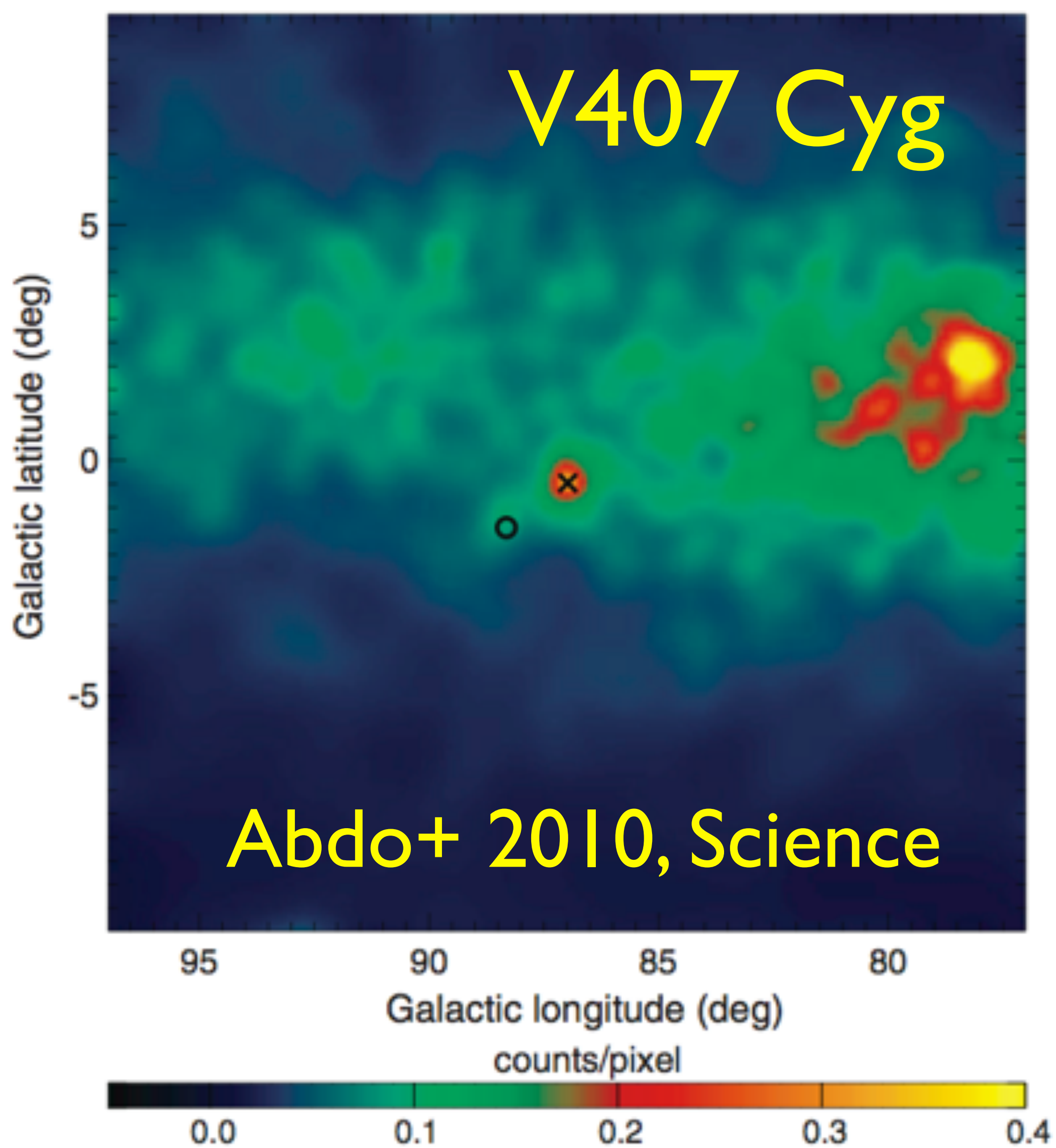
Quasi-steady b

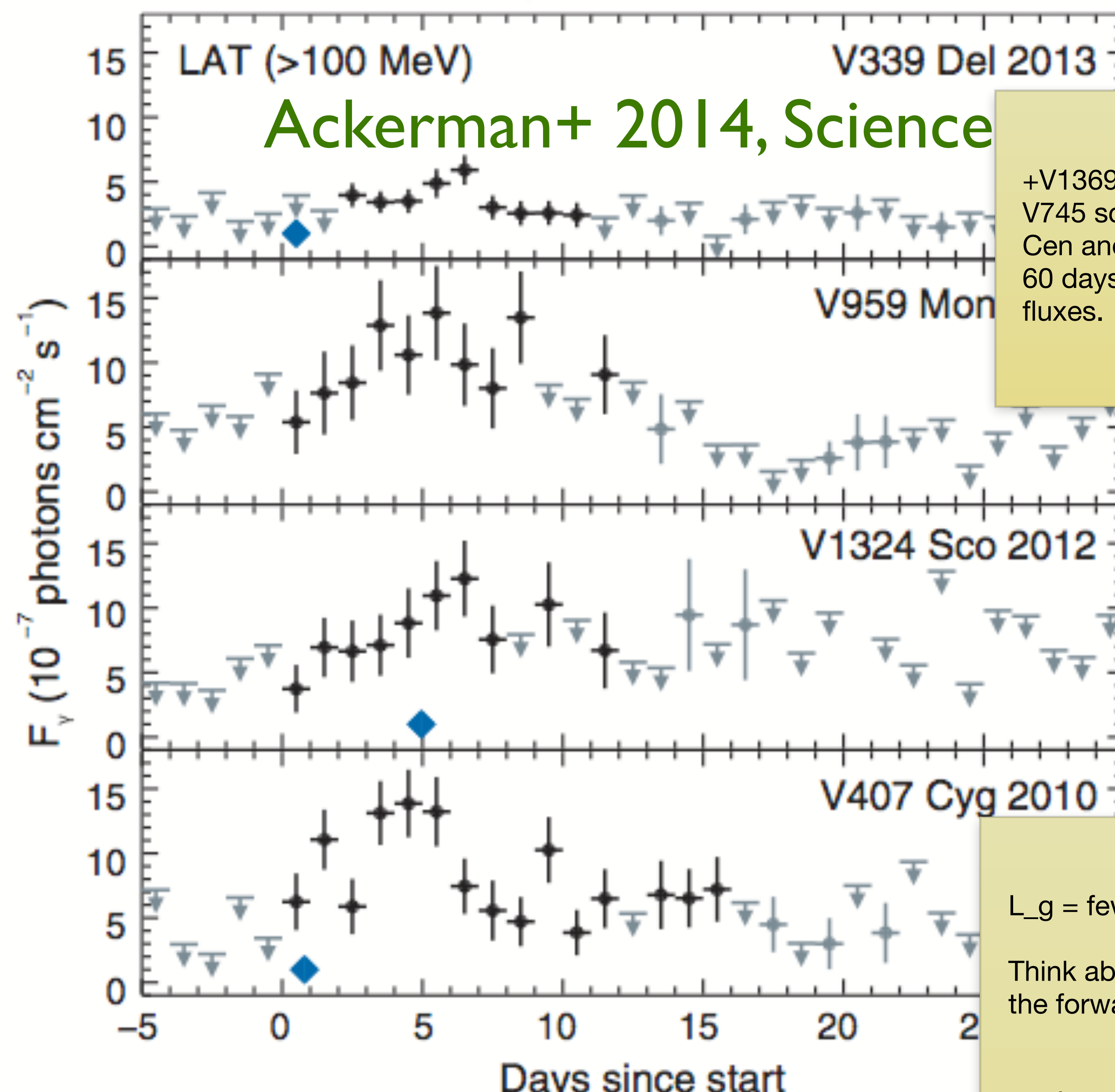
Much of what is known about magnetic accretion and the accretion-disk BL in CVs comes from X-ray observations, including CCD and grating observations with Chandra. Chandra has been particularly impactful when its high spatial resolution has been used to observer populations e.g., in GCs and other galaxies (as by, e.g., Dave Pooley and Rosanne).

It [is/would be] hard for me to exaggerate the degree to which this finding that novae produce gamma-rays has surprised the nova and high-energy communities.

White dwarfs produce γ-rays!?!

Fermi Detects Normal Novae





+V1369 Cen, N Sgr
V745 sco
Cen and Sgr detec
60 days after 1st de
fluxes.

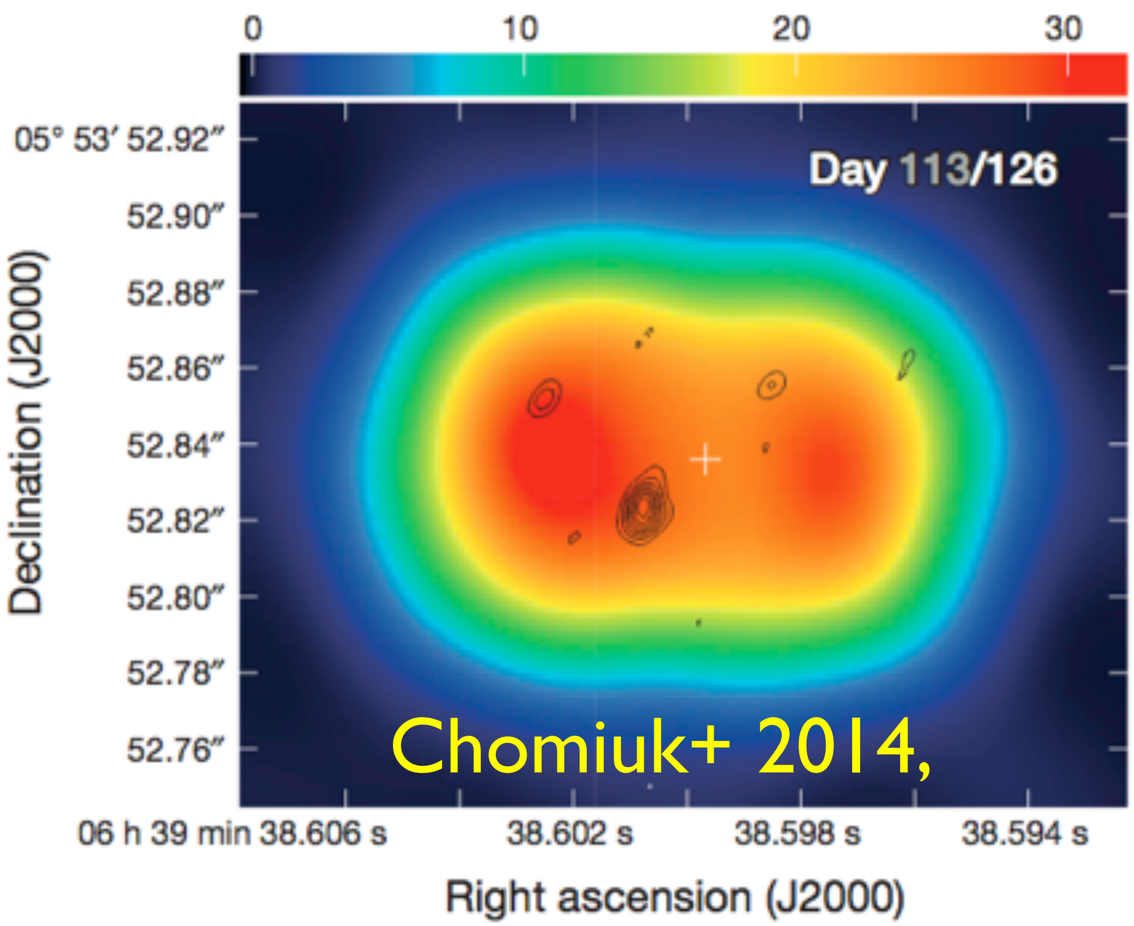
L_g = few x 10^35 e

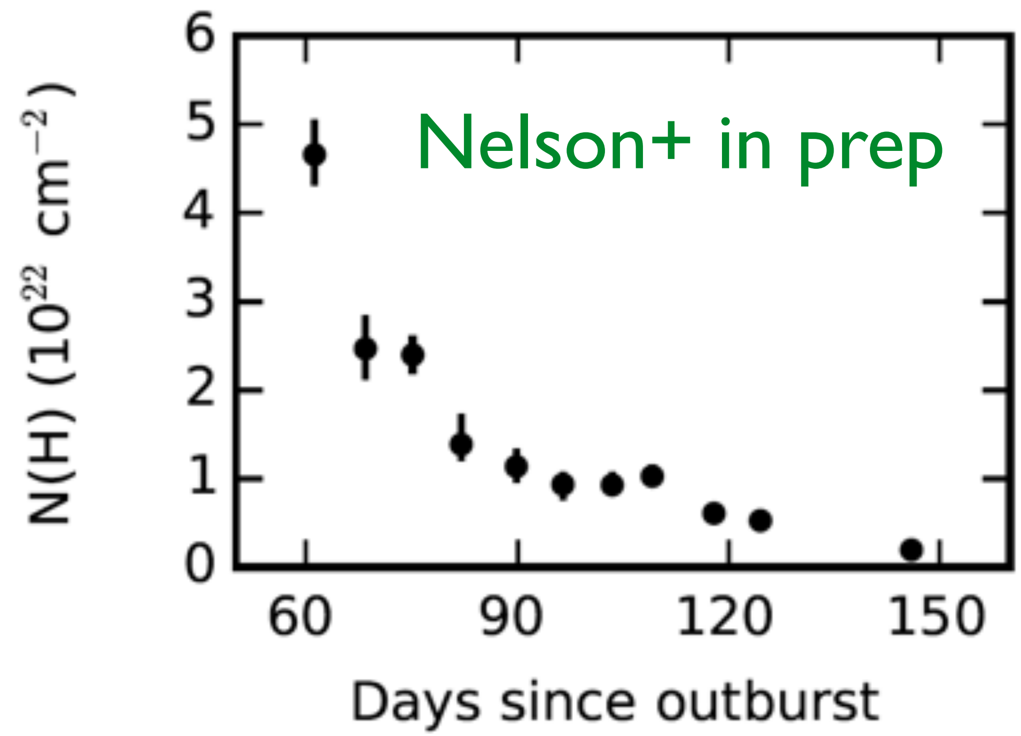
Think about Tommy
the forward shock to

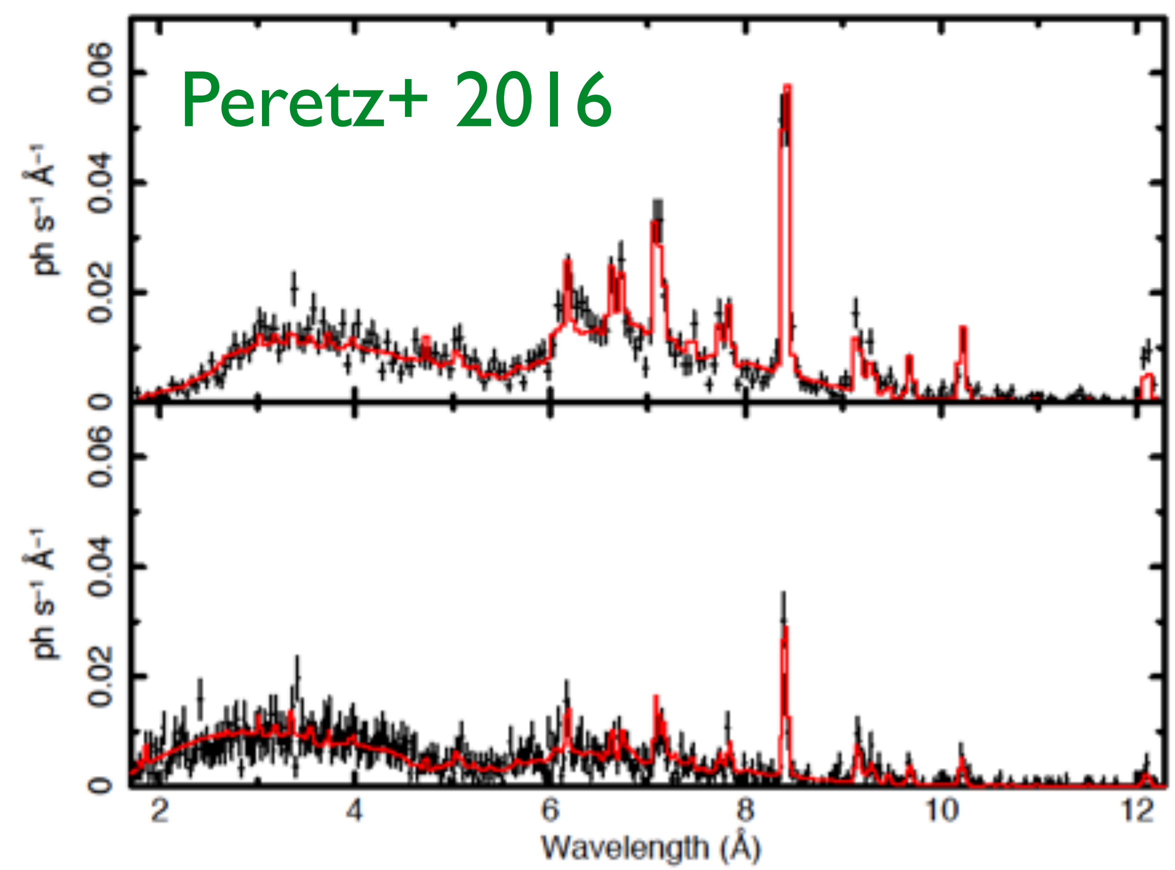
total energies, fractio
Prob. later...)

Unexpected: Flow speeds non-relativistic. Radioactive decays → lines with E ~ MeV.

Finding the γ-ray shocks: V959 Mon

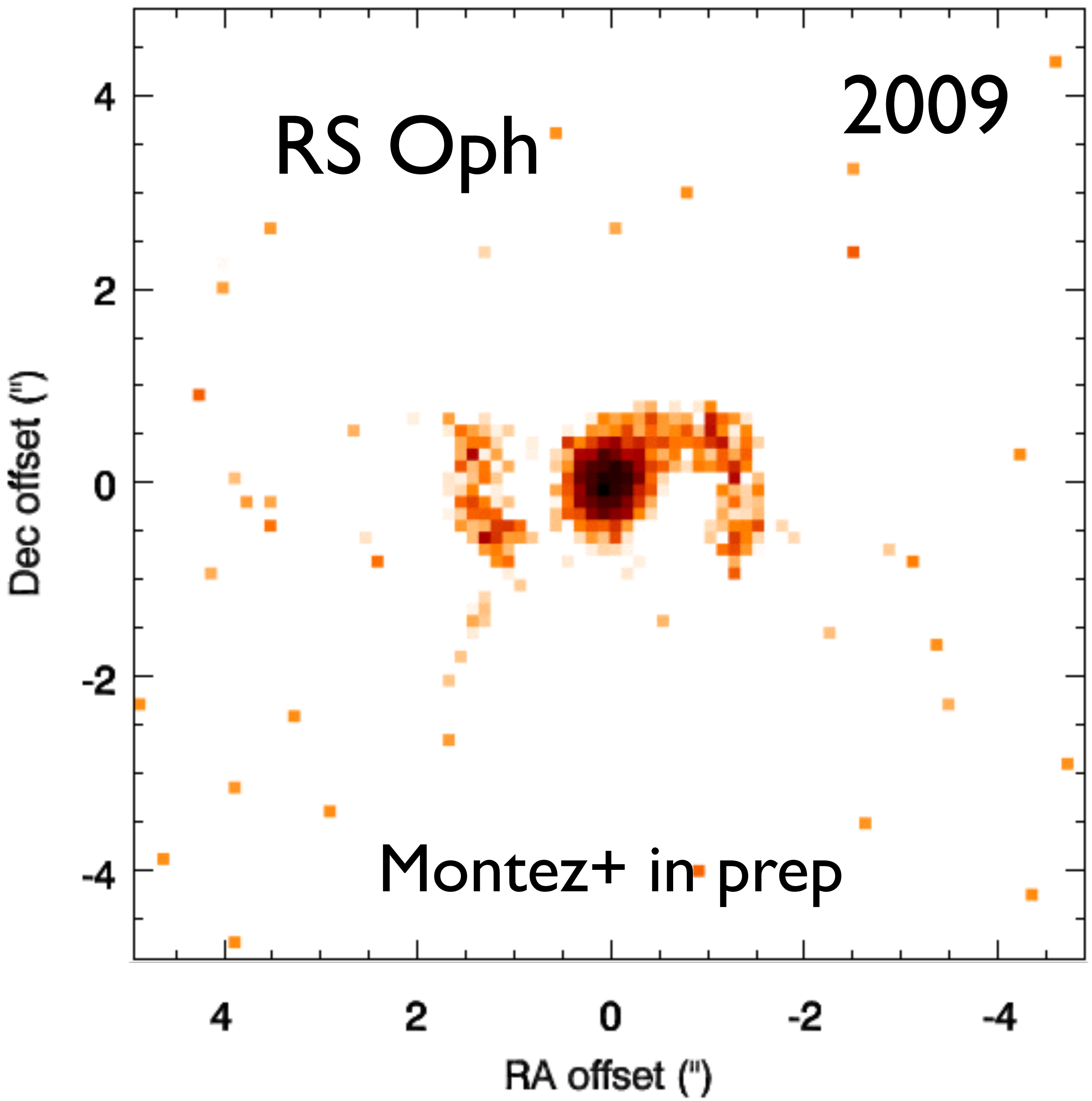






X-rays probe the same shocks that accelerate particles.

Direct Imaging



Need to image sub-arcsec scales to uncover internal shocks in γ-ray novae.

See also Mukai & Still (2003).

Invest in Nearby Novae

- Fermi detects one nova/yr.
- Assume it will operate for 10 yr.
- We have about 10 chances to understand nova γ-rays.
- We may only get one we can image.
- We should be aggressive.

Result: origin of γ-rays and solutions to long-standing questions of mass ejection and binary stellar evolution.

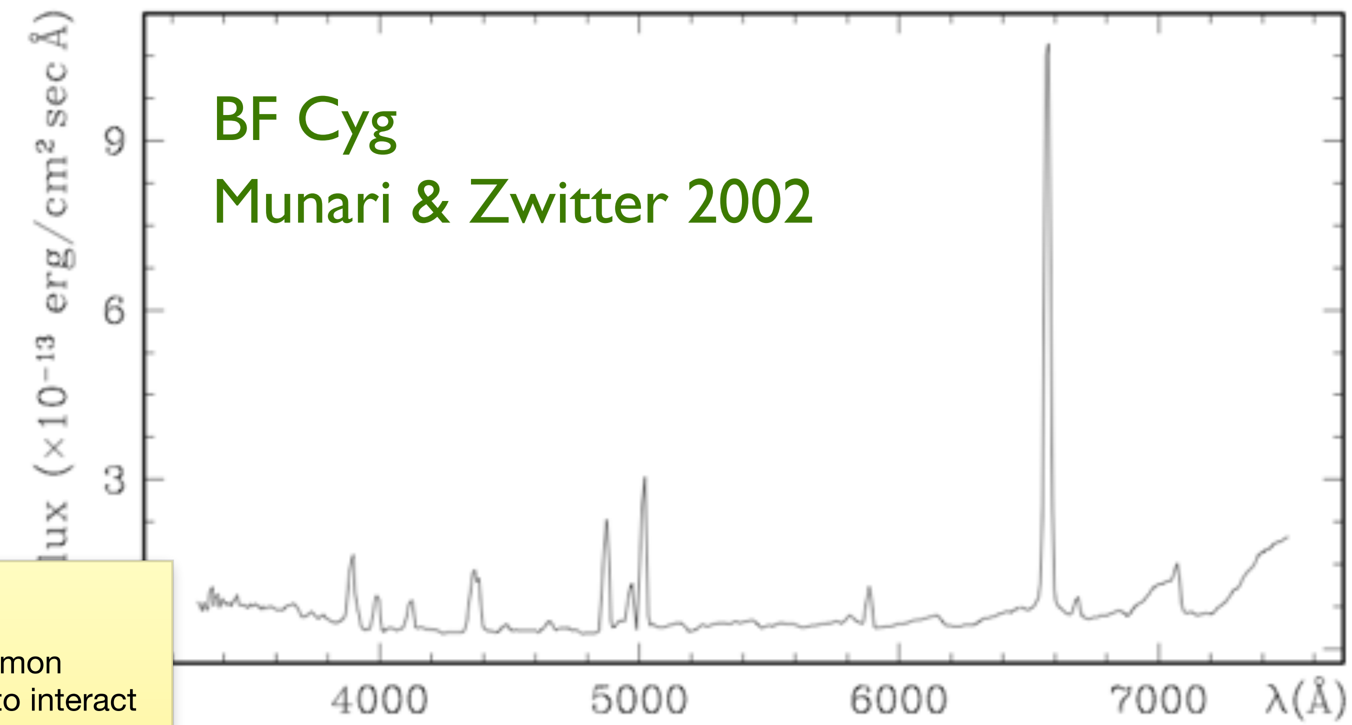
Shell burning makes some symbiotic stand out.

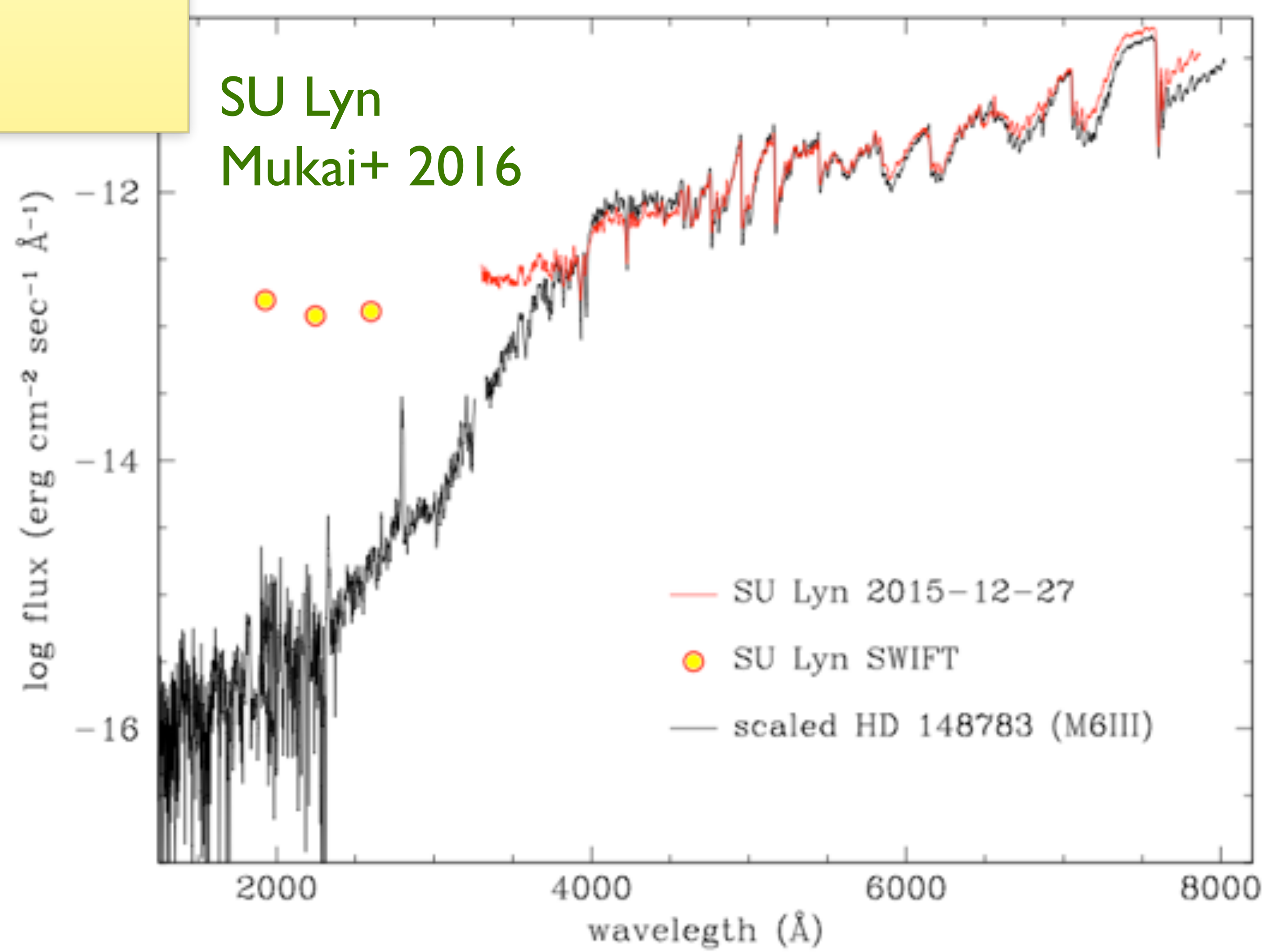
Wide white dwarf binaries

- Half of low-mass stars are in binaries. The distribution of initial orbita periods pea around 100

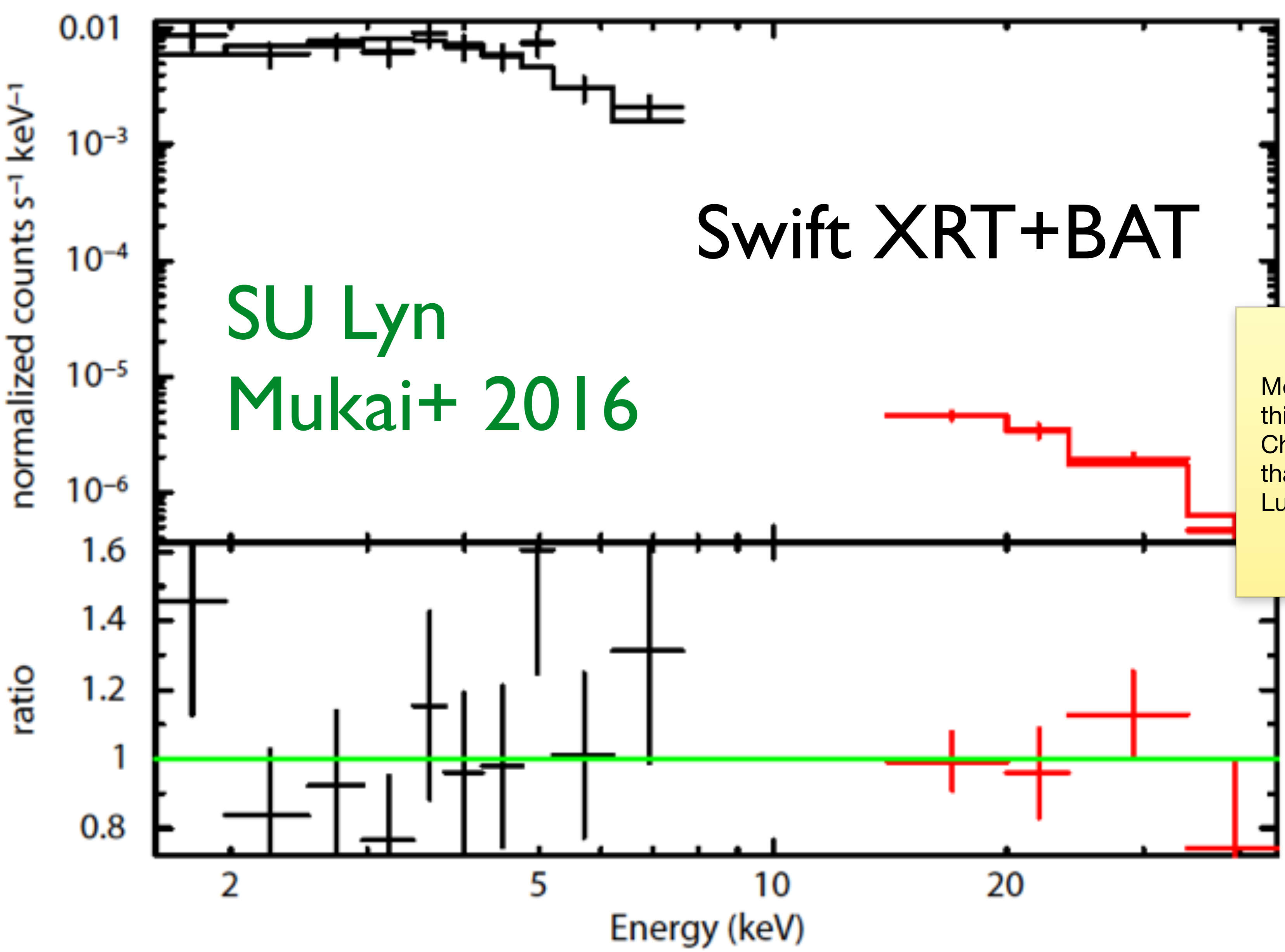
Wide enough to escape common envelope, but close enough to interact at some point.

- Where are all the wide, interacting, low-mass binaries?





X-rays from non-burning symbiotics



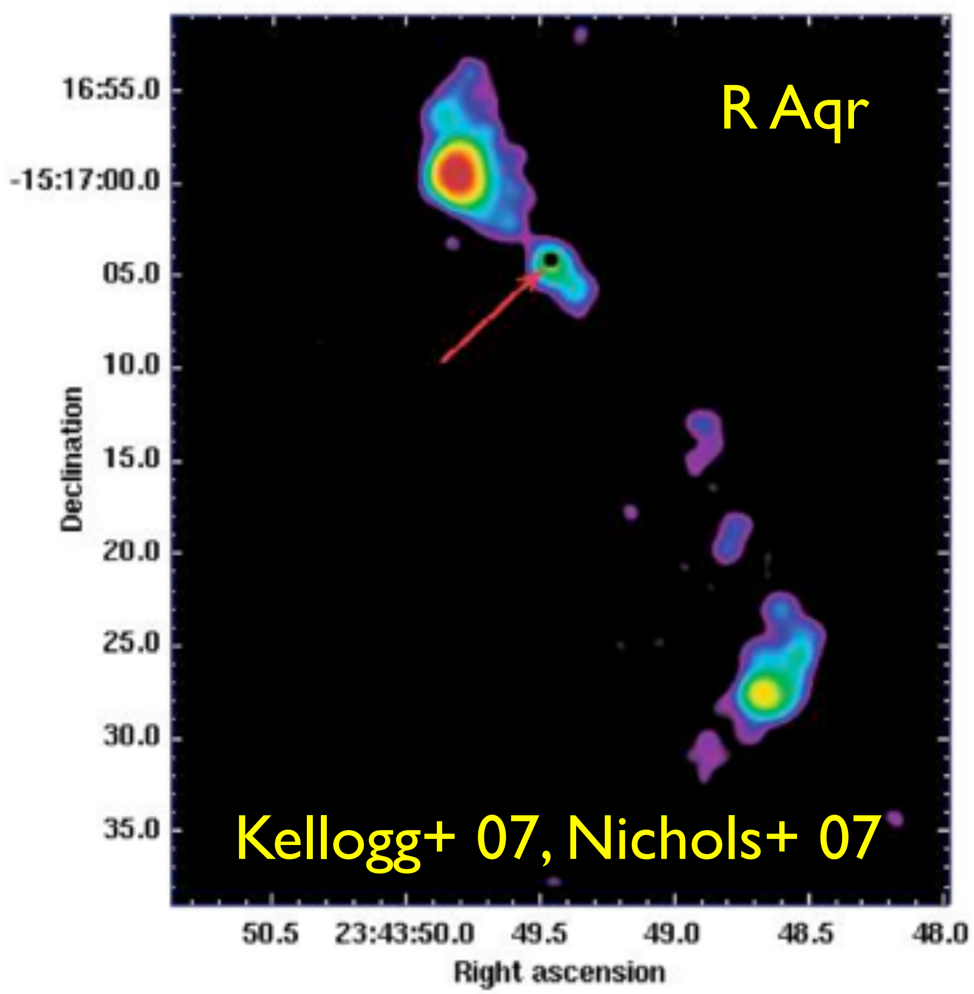
d=650 +- 10% parsec (Mukai+2016)
Detected serendipitously with Swift
during an X-ray high state.

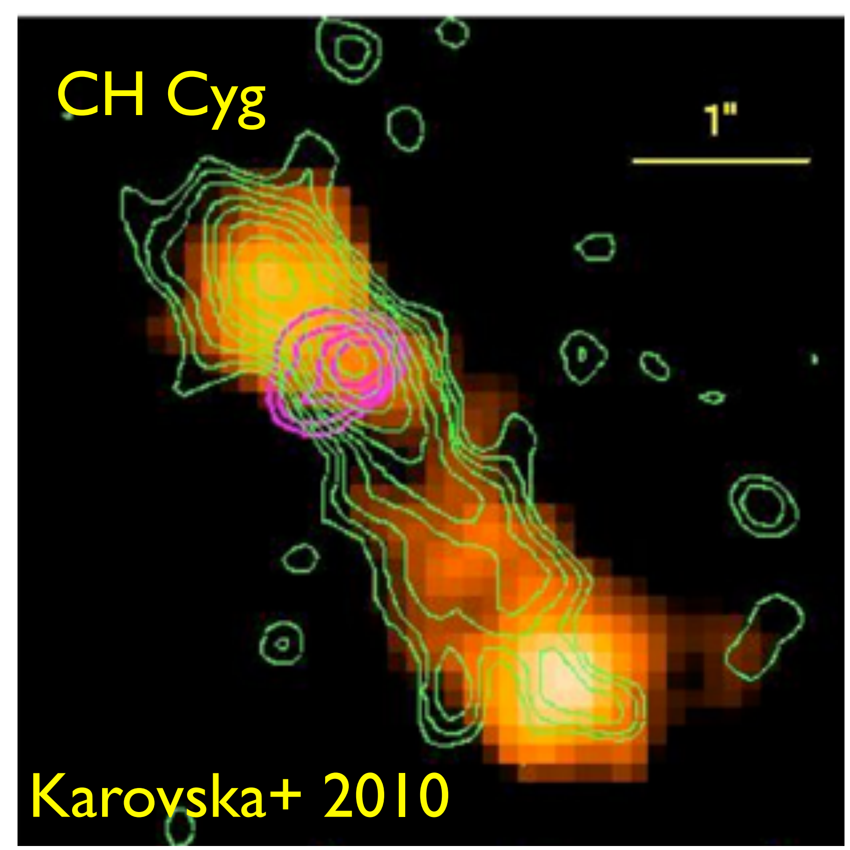
Mention RT Cru? <- How my interest in this population began: with a 25 ks DDT Chandra observation (and a 25k grant that supported then-SAO predoc Juan Luna). We found: …

X-ray emission from $>10^{-9}$ M_{sun}/yr accreting onto a 1 M_{sun} white dwarf.

Insight from a new population

- UV excess, X-rays, variability, astrometric wobble.
- More non-burning than burning symbiotics (Mukai +16). Total space density could rival that of CVs.
- Elucidate binary stellar evolution, accretion physics, disk winds and jets.





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Distances for R Aq

Conclusions

- Working closely with other observatories, Chandra is poised to make multiple, major discoveries relating to accreting white dwarfs.
- One will almost certainly relate to shocks, γ-ray production, and how novae erupt, especially if Chandra observes nearby novae aggressively.
- Chandra is also likely to help find, and probe accretion physics with, a new population of interacting, jet-producing white dwarf binaries.

Nova γ-rays

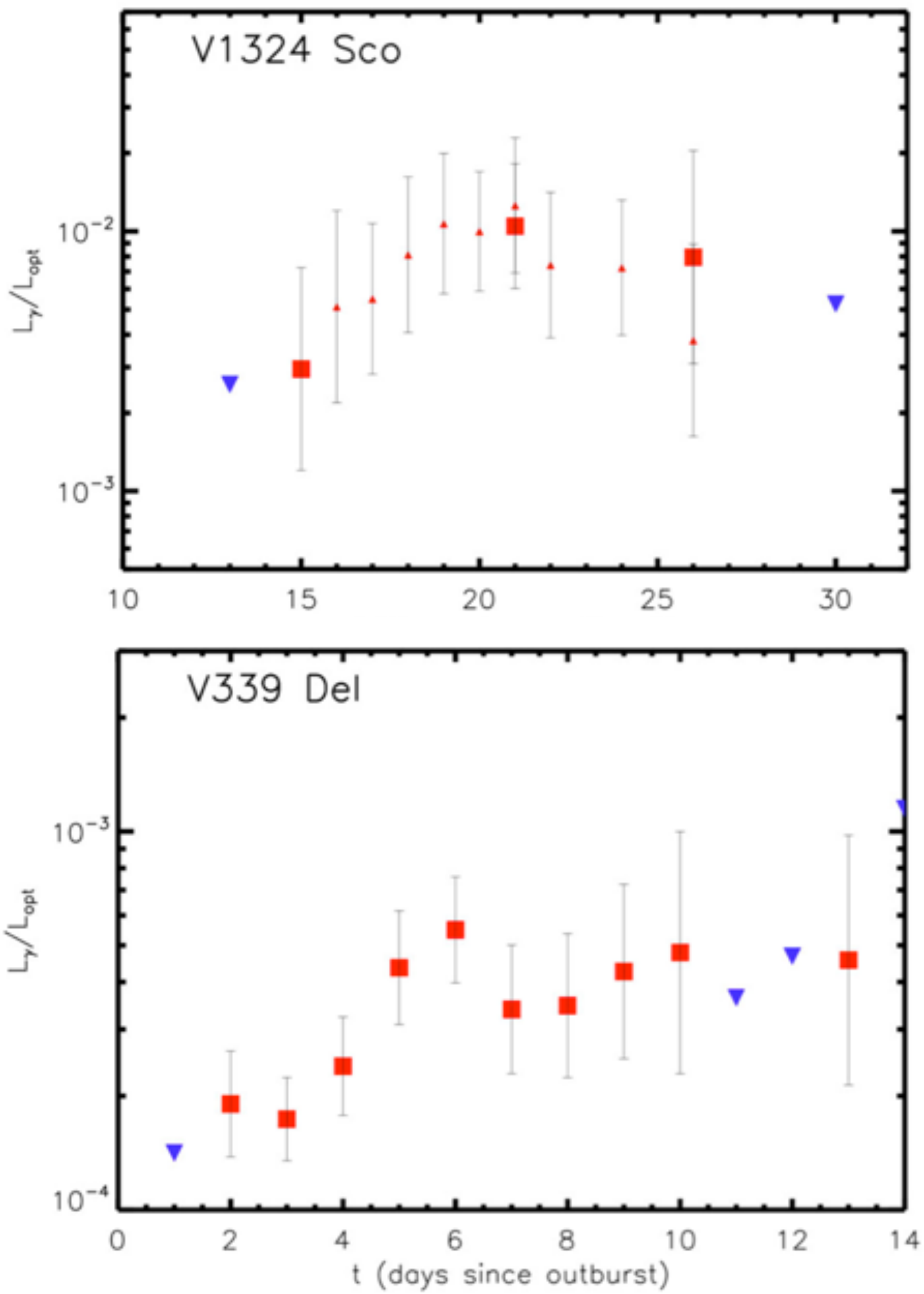
1. Overturns old picture of novae.

$L_{LAT} \sim 10^{35}$ erg/s → $L_{\gamma} \sim 10^{36}$ erg/s → L_{shock} $\sim 10^{38}$ erg/s $\sim L_{opt/UV}$ (Metzger+ 2014, 2015)

2. New regime for particle acceleration.

Both possible mechanisms for generating GeV emission require particle acceleration in shocks.

Hadronic scenario likely for γ-rays



Metzger+ (2015)

If shocks radiative and $\varepsilon_\gamma < 0.2$:

e_nth is the acce
efficiency.

V1324 Sco: $\varepsilon_{nth} > 0.1 - 0.01$

V339 Del: $\varepsilon_{nth} > 10^{-3}$

Since $\varepsilon_{nth} \sim 10^{-5} - 10^{-3}$ for leptonic scenario (e.g., Morlino & Caprioli 2012, Kato 2015, Park+ 2015), hadronic more likely.

Probing particle acceleratio[n]

w/ novae

Metzger+ (2014, 2015)

X-rays reprocessed because outer ejecta neutral (and post-FS gas dense and cool).

Shock energetics from O/UV luminosities ->

Shocks are radiati[ve]

$t_{cool} < t_{expansion}$

Shock power → X-rays → optical/[UV]

From Lgamma = L_sh e_nth e_gamma

$L_\gamma < L_{opt}\ \varepsilon_{nth}\ \varepsilon_\gamma$

$\varepsilon_{nth} > (L_\gamma / L_{opt})$ (...

Got interesting / meanin[gful] findings because relativi[stic particles] trapped (all converted to [gamma] rays).

M15 eq19: protons experience > 1 collision on ave until after a time t_pp = 8wks (Mej/1e-4)^{1/2} (v/1000 km/s)^{-3/2}.

V1324 Sco: $\varepsilon_{nth} > 0.01$

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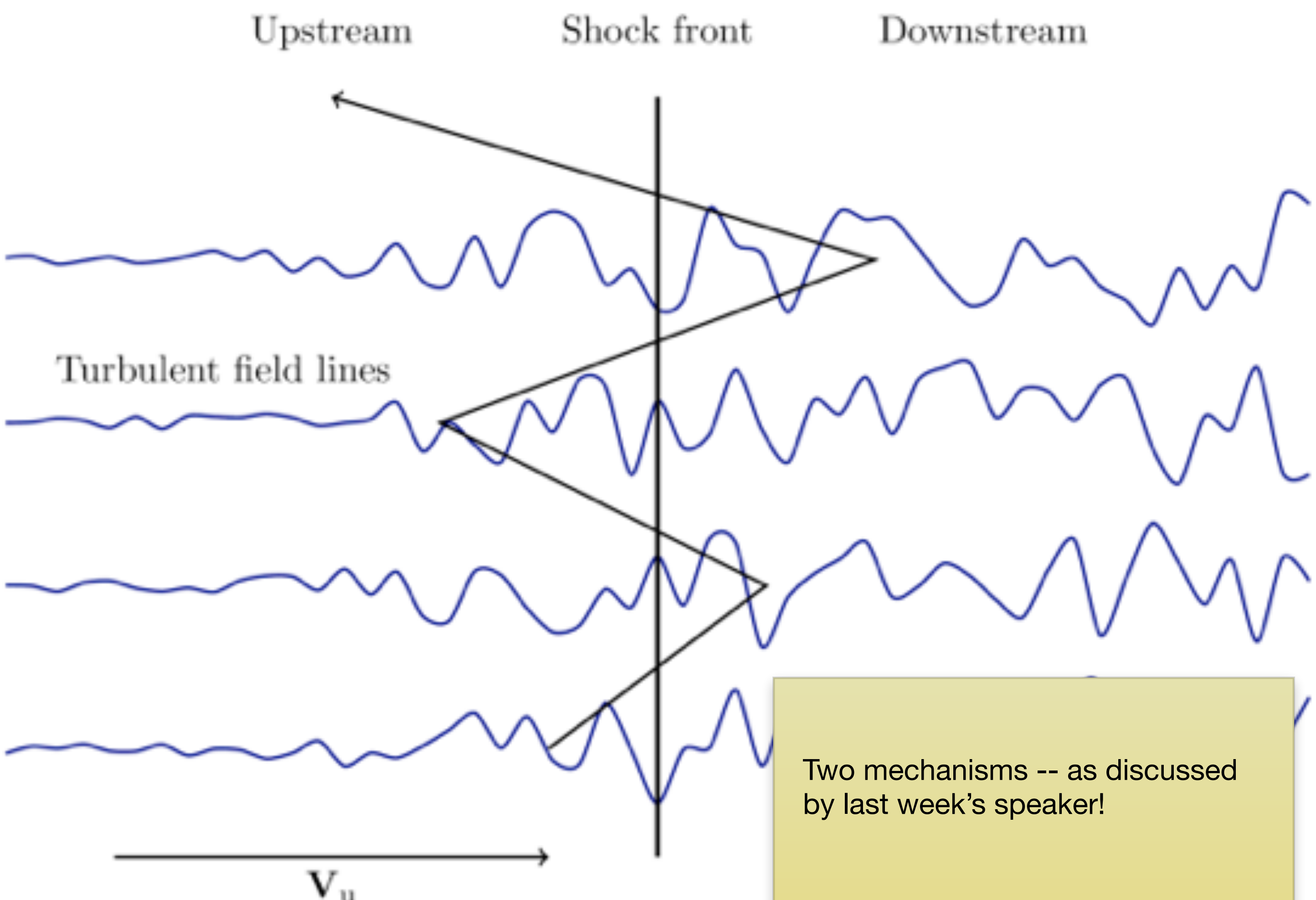
$\varepsilon_{nth} \sim 10^{-5} - 10^{-3}$ for leptonic scenario (e.g., Morlino & Caprioli 2012, Kato 2015, Park+ 2015), so hadronic more likely.

Diffusive shock acceleration

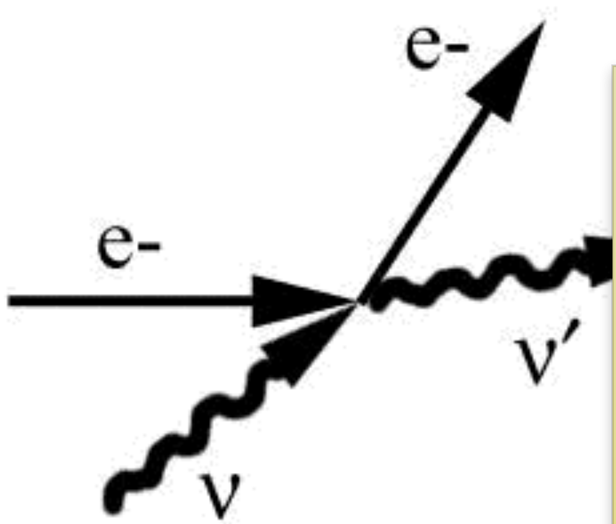


Two mechanisms -- as discussed by last week's speaker!

Fermi 1949, PR;
Bell 1978, MN

(Image courtesy Mark Pulupa.)

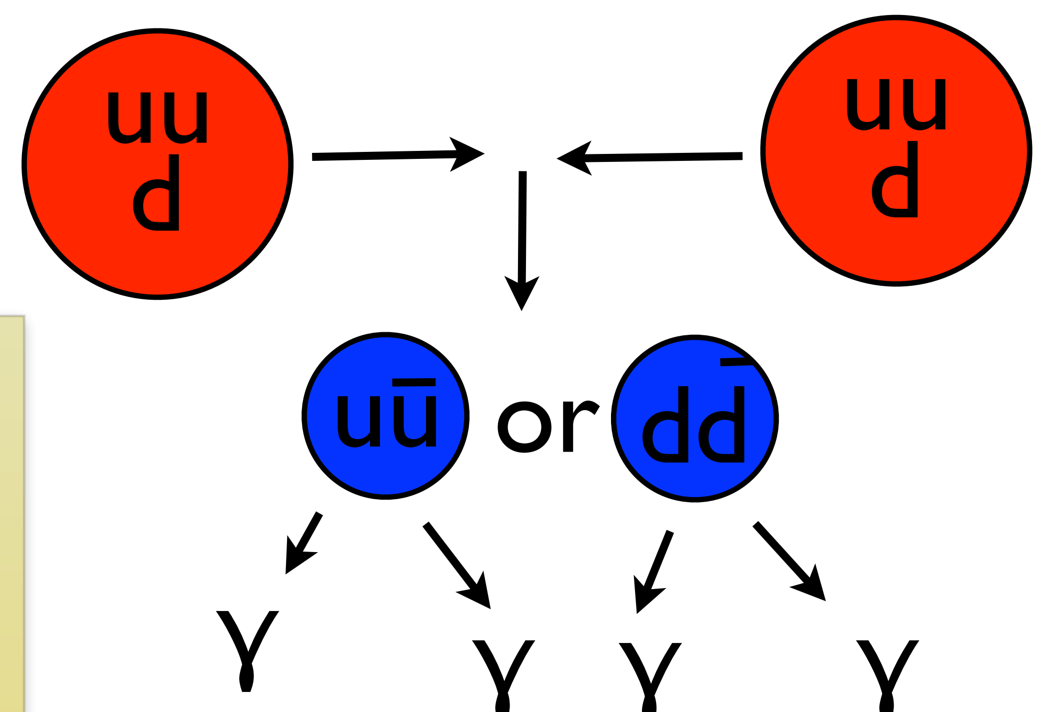
Inverse Compton scattering



current gamma-ray observations consistent with both mechanisms...

, A&A

π^0 decay



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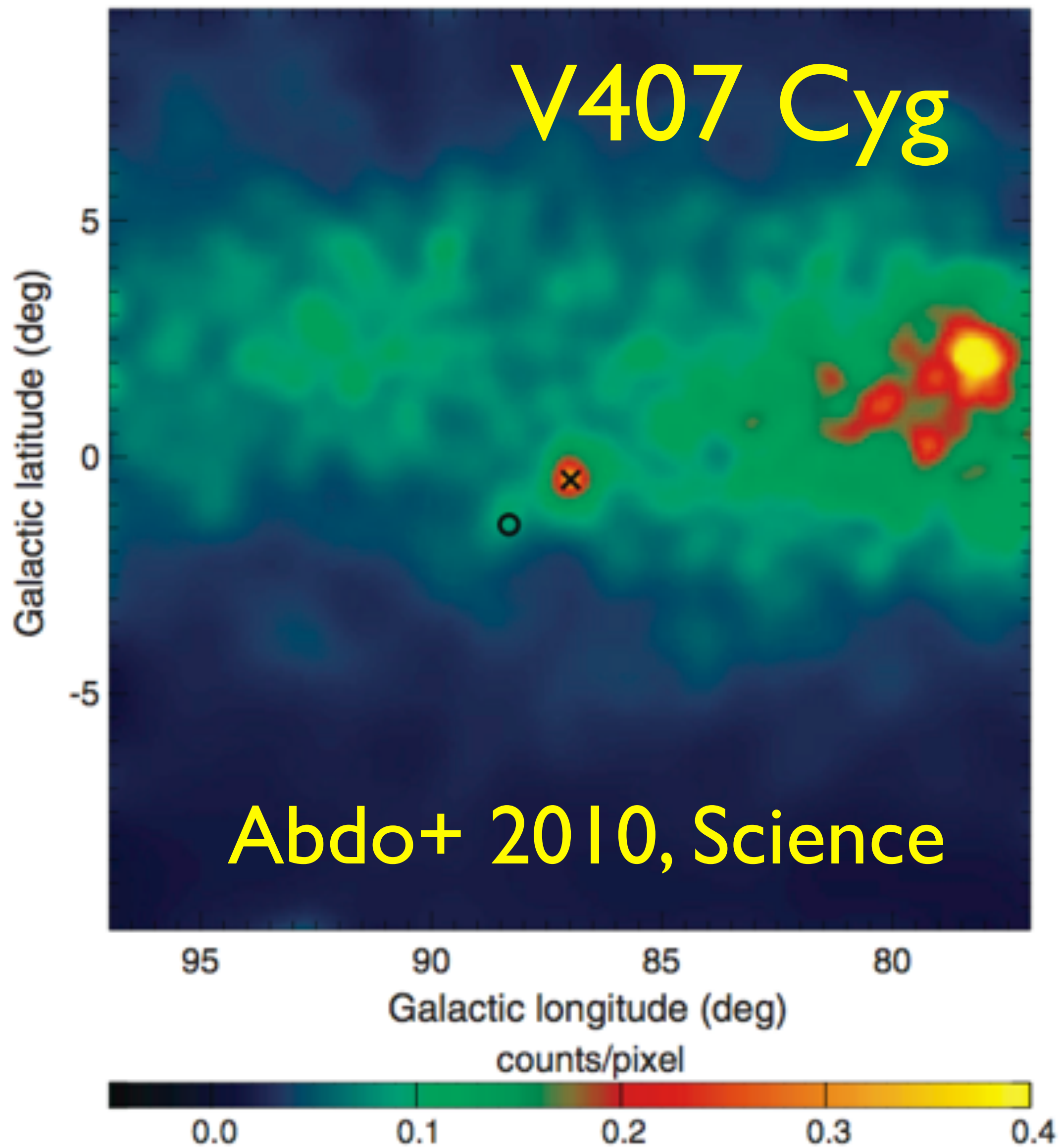

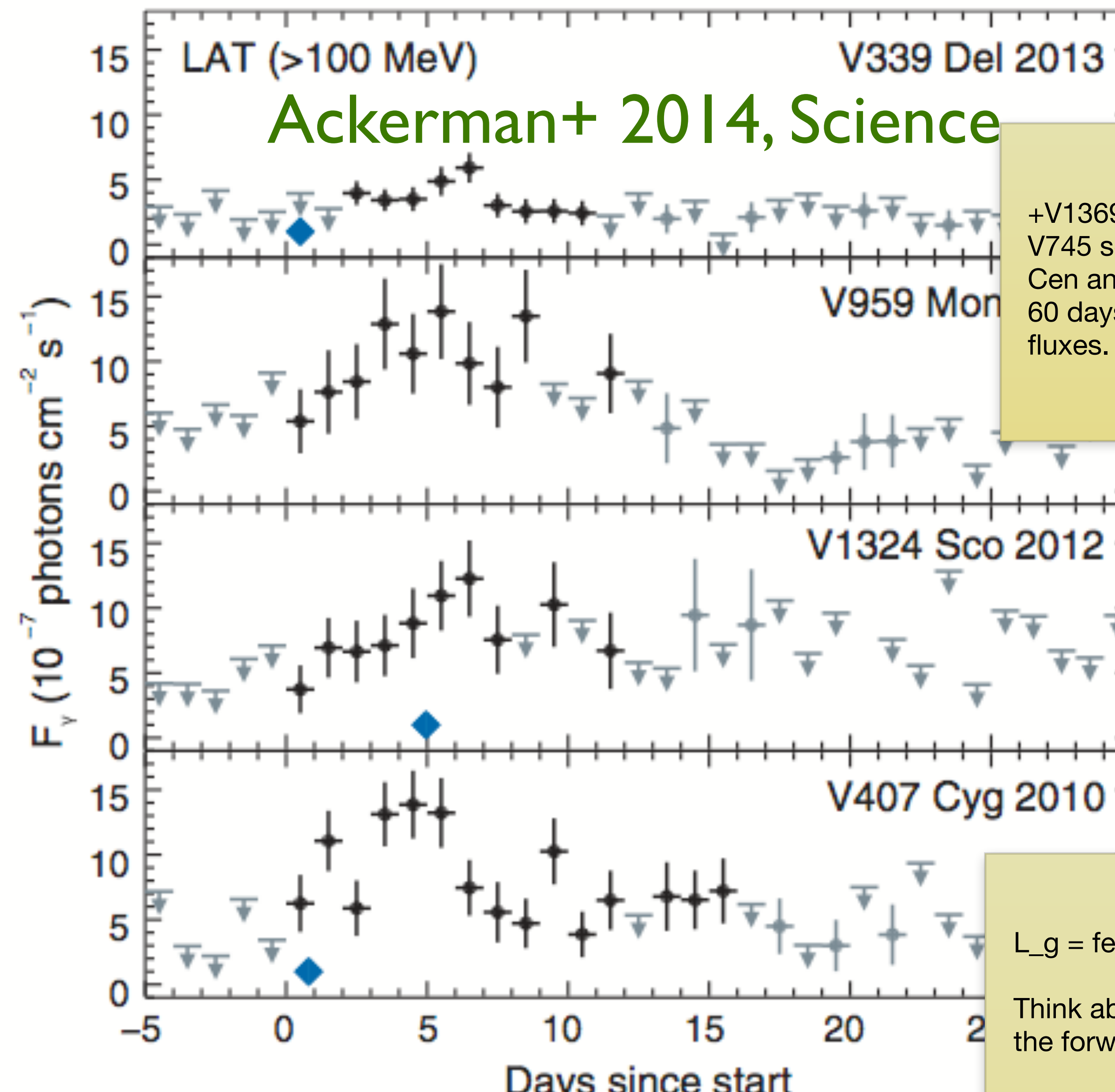

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L_g = few x 10^35 e

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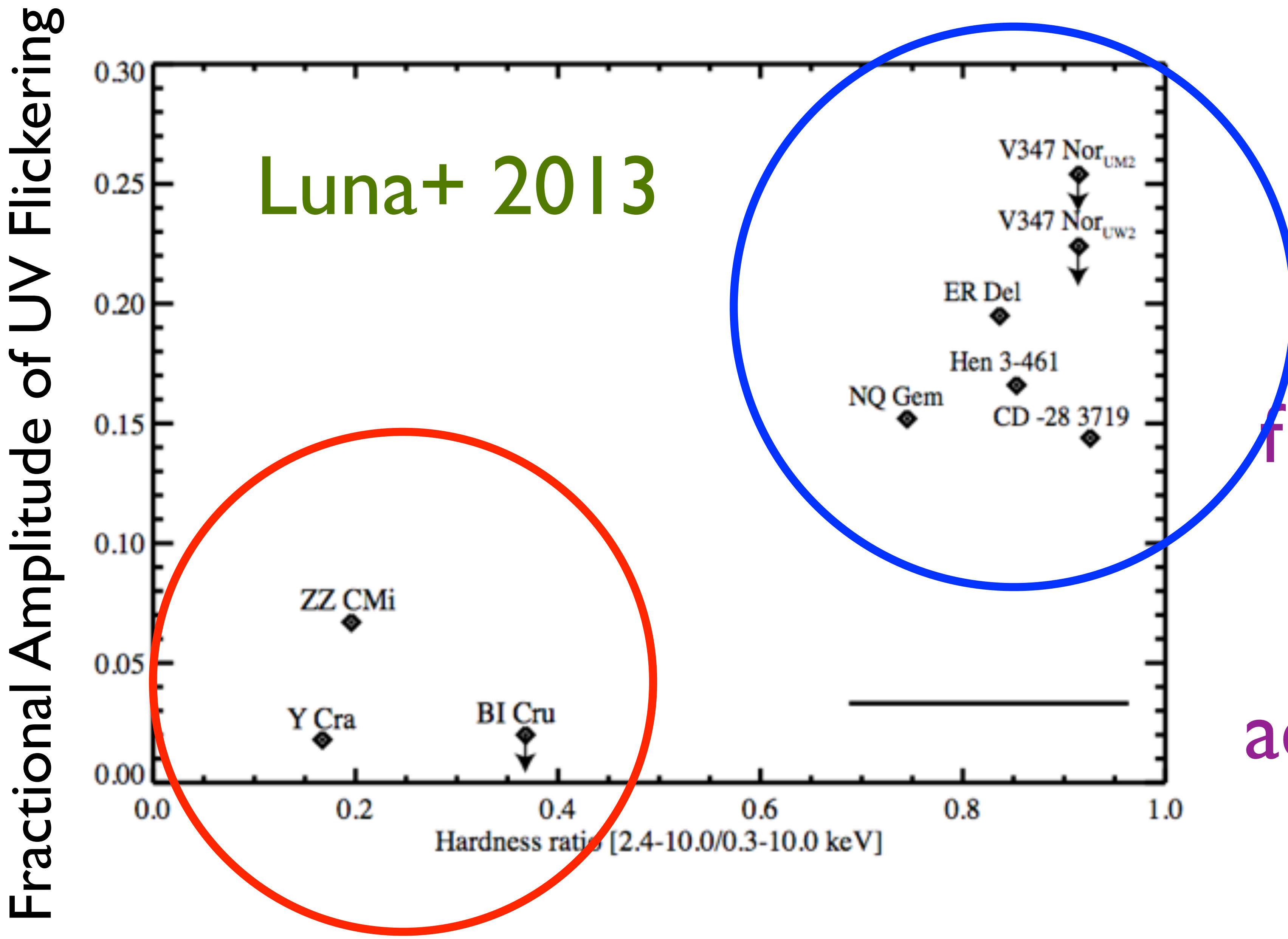
Prob. later...)

- Ubiquity: 3 out of 4 CN within 4 kpc
- Similarity of γ-rays: flux, spectrum, timing
- Diversity: 2/7 embedded, X-rays, radio and optical LCs

X-rays as Probe of Shell Burning

➡ Symbiotics without SBWDs can produce hard X-rays. In others, FUV flux from SBWD cools BL.

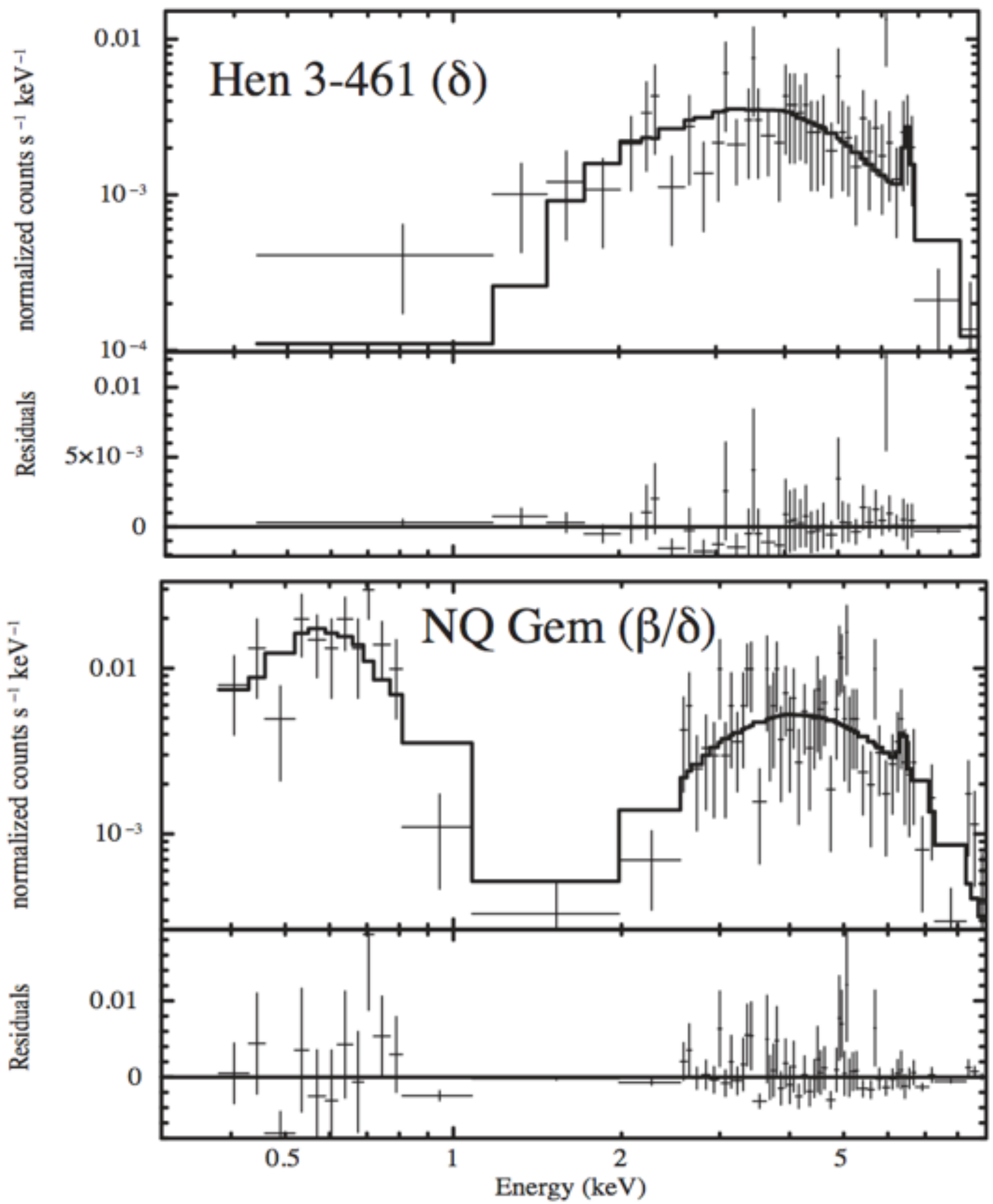


Corre[lation] between X-ray hardness and UV flickering supports idea that SS with hard X-rays are accretion powered.

Often termed `symbiotic like' or `weakly symbiotic'

Flickering associate with disk accretion, and some of the known accretion-powered symbiotics

Swift Survey of Symbiotics

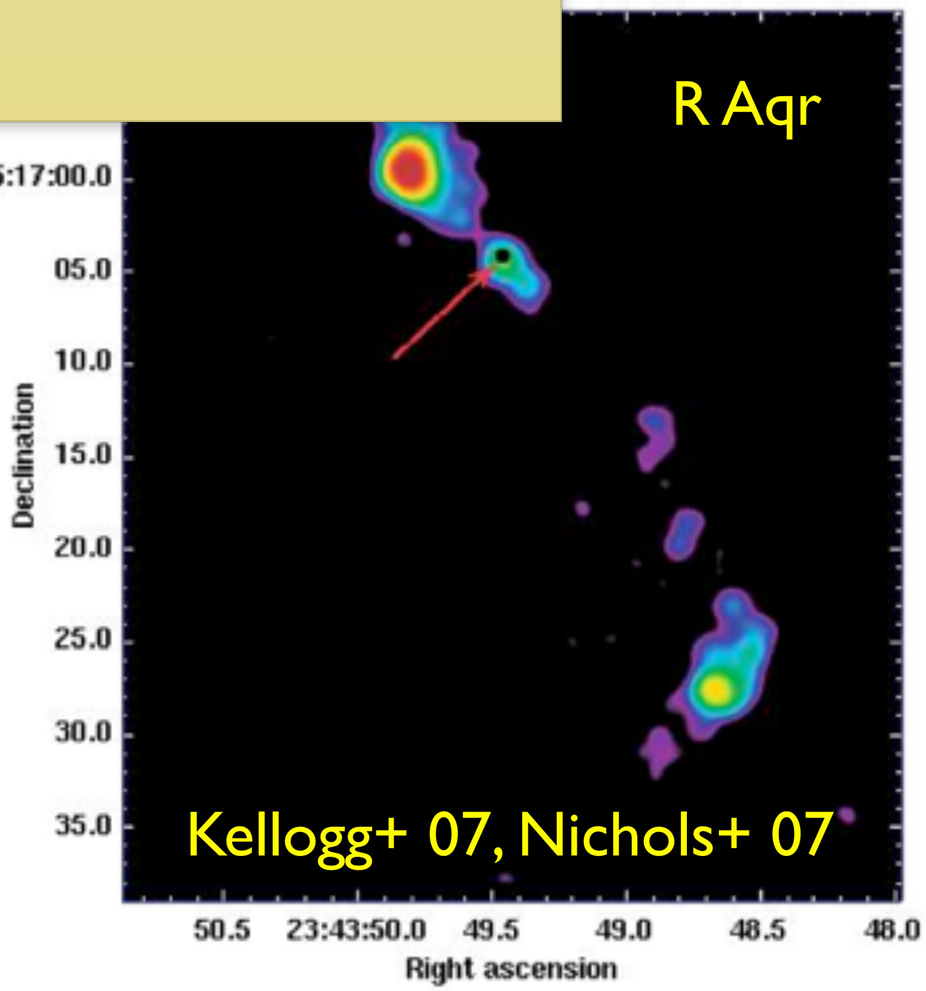


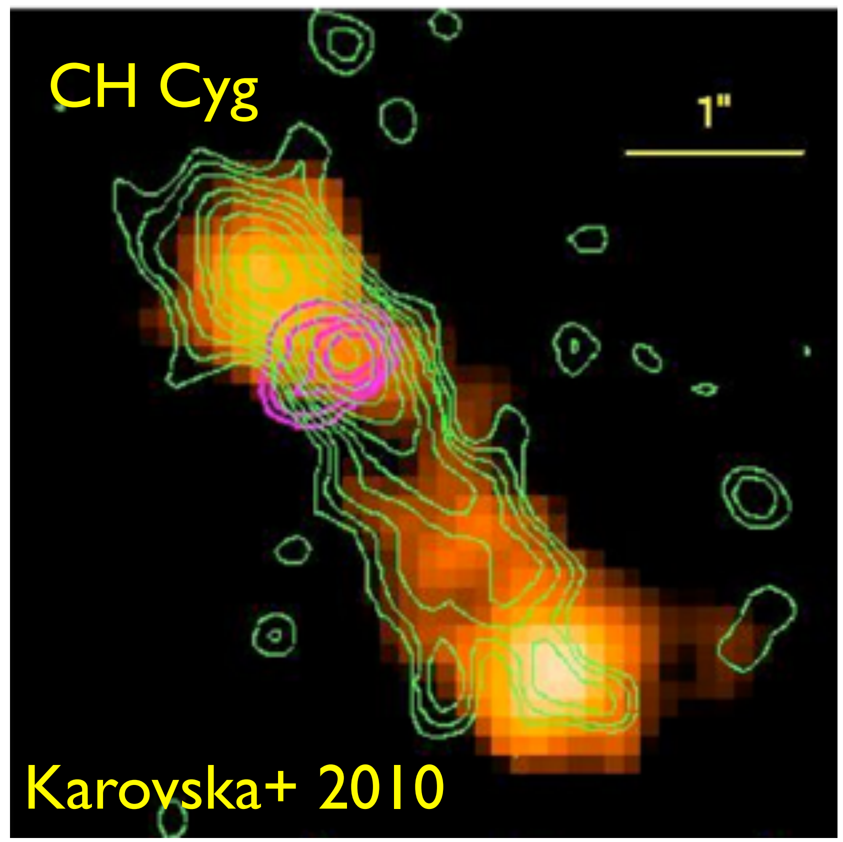
- 41 SS observed with XRT for ~10 ks each.
- 10 new X-ray sources detected, all with emission above 2 keV.
- Identification of hard X-ray emission from accretion.
- 2/3 of our detections from top 1/3 of distance-sorted list.
- XRT did not detect some nearby, optically bright targets.

Southwest inner jet (which appeared between 2000 and 2004) produced radio synchrotron emisison, whereas outer knots are typically thermal. (Previous synch jet to the NE in 1987).

Between 2000 and 2004, when the new jet was produced, the hard x-ray emission from the boundary layer strengthened.

biotics as Nanoquasars





(See also Galloway & Sokoloski '04; Sokoloski & Kenyon '03; Crocker+ '01, '03)

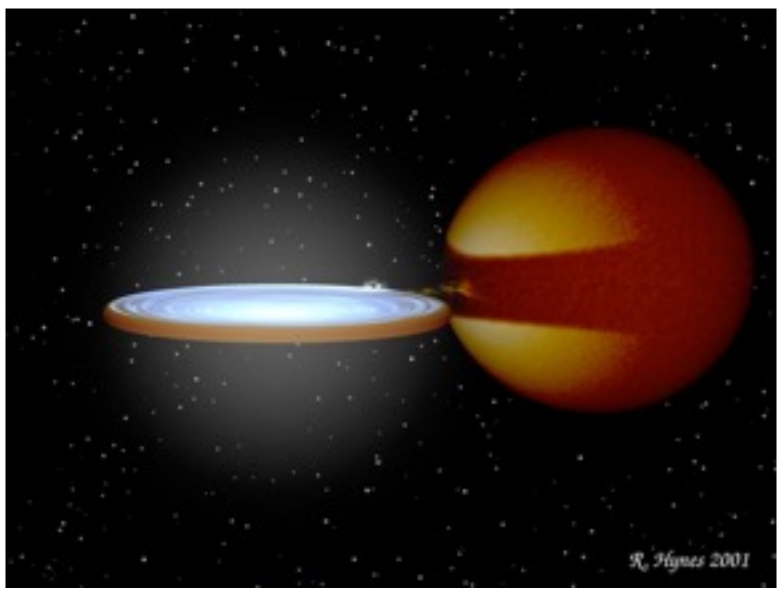
- 10^2 - 10^3 km/s
- 10^3 AU
- transient
- disk-jet link
- precessing
- therma

non-ther

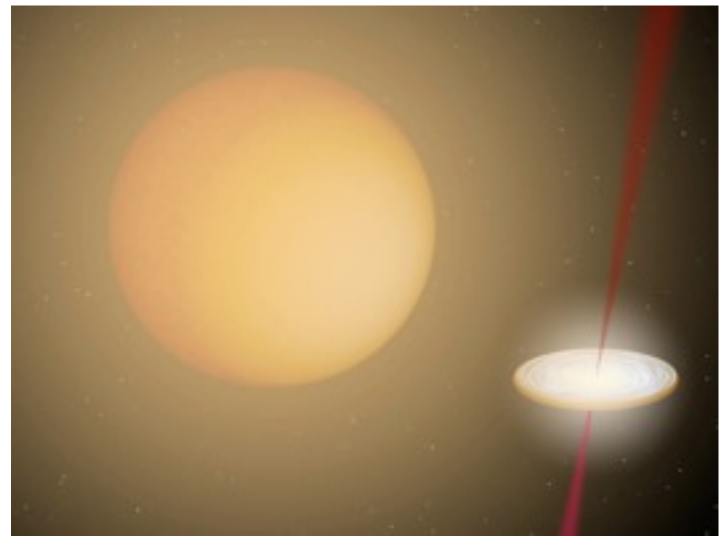
magenta contours are
emission; green conto
HST [OIII] flux; color is
(0.2-2keV) X-rays

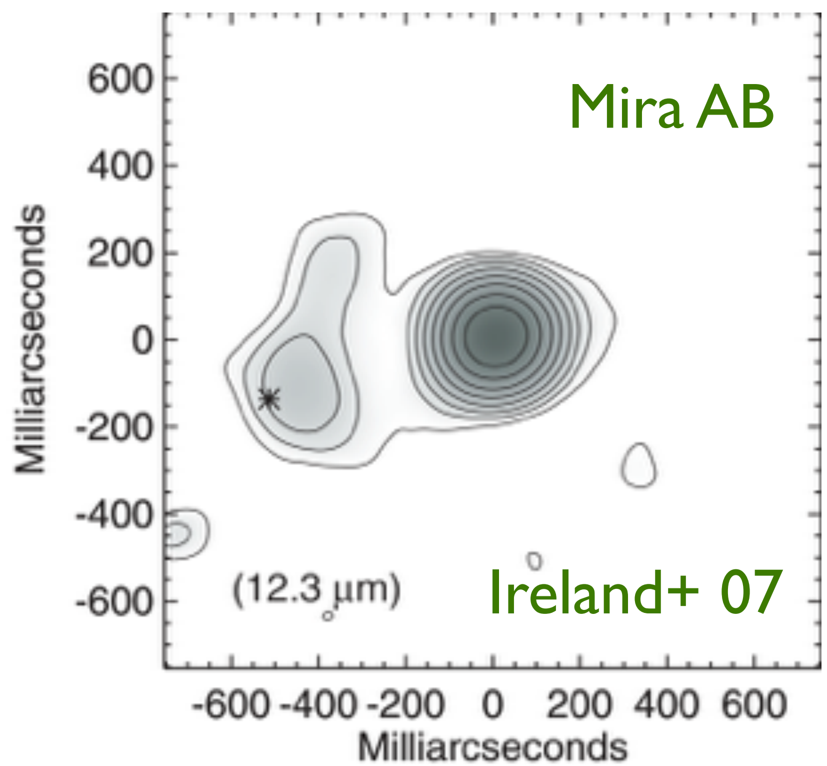
Jets spatially resolved in the radio, optical, and X-rays (e.g., Brocksopp+ '04).

Large, wind-fed disks



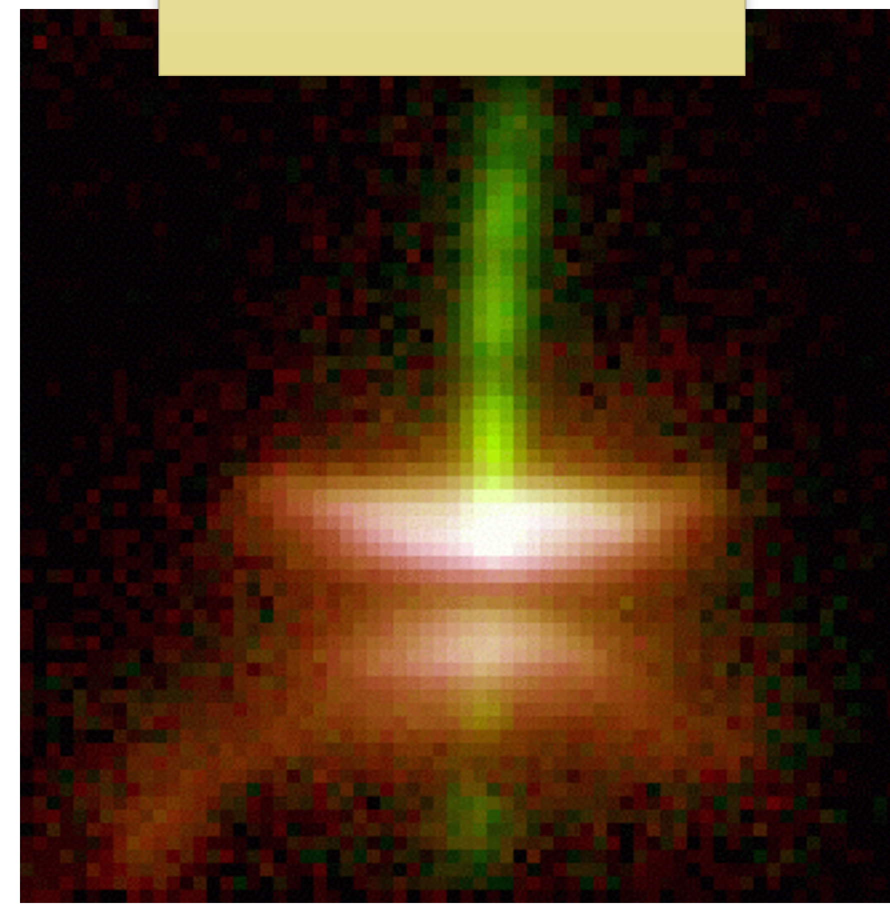
~10^{10} cm





~10^{13} - 10^{14} cm

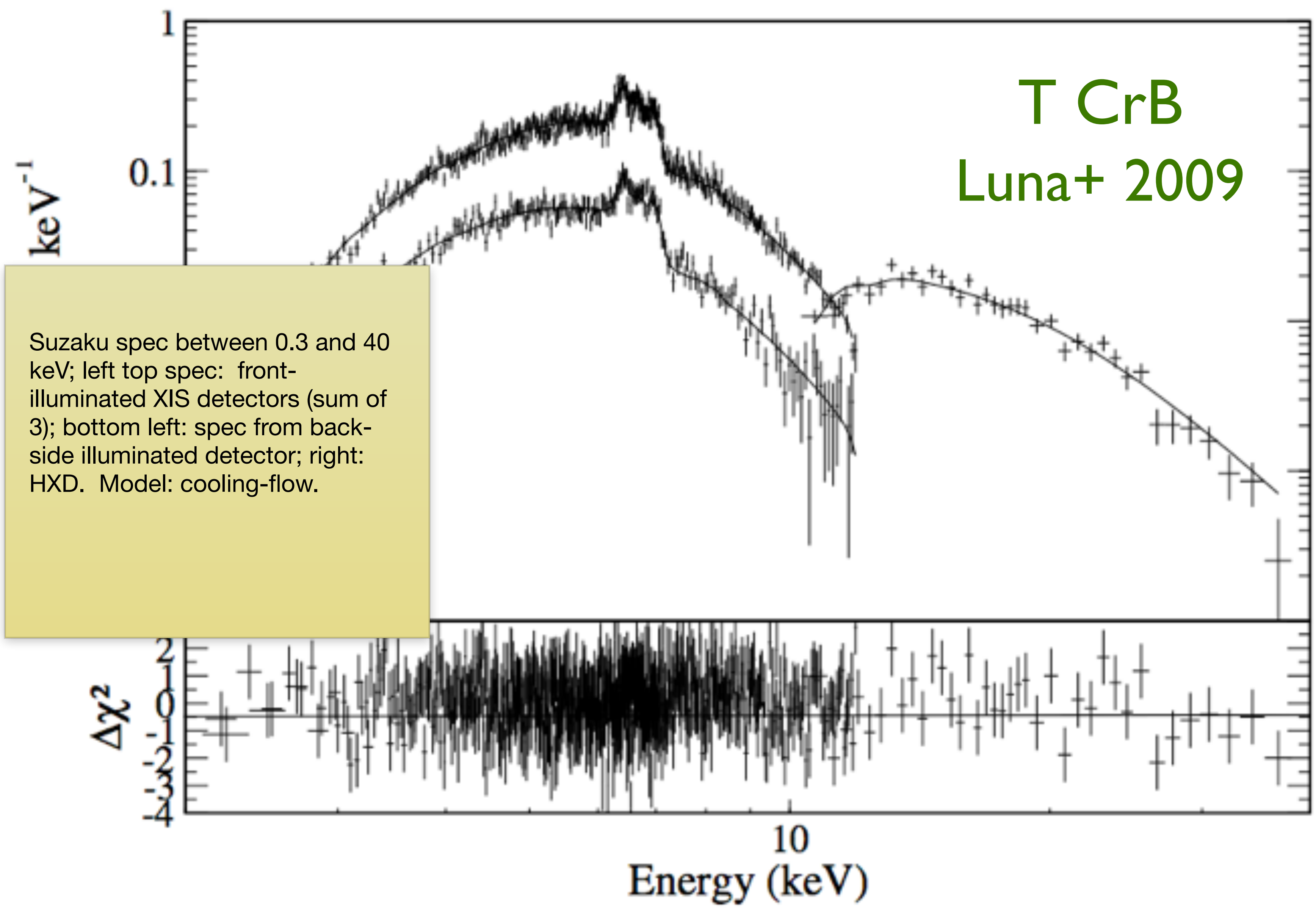
HST image of HH 30; dark lane is



10^{15} - 10^{16} cm

Disk accretion in WD symbiotics

➡ With X-rays and flickering UV emission, we are finally finding the disks (e.g., Luna+ 13).



X-rays:

- Flickering
- Cooling-flow
- Reflection (NuSTAR; Nelson, Mukai+)

UV:

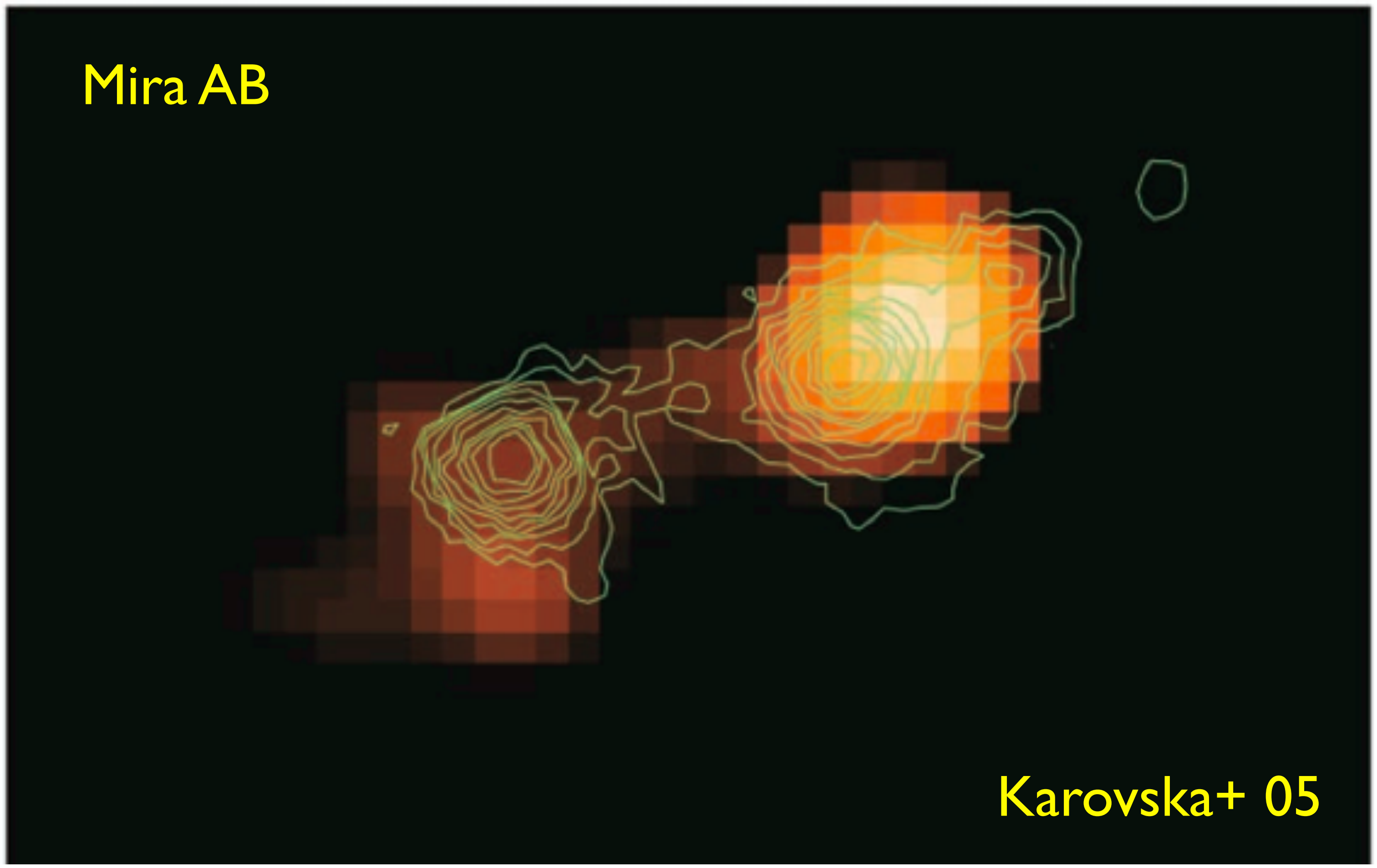
Flickering

(See also Ezuka+ '98, Luna & Sokoloski '07, Nichols+ 07, Kennea+ 09, Eze+ '10)

Key question: accretion rate

Is it high, as expected for 'wind Roche lobe overflow'?

(Mohamed & Podsiadlowski 07)



Contours from HST 3729A image. Color = chandra.

➡ No. No evidence for pervasive accretion rates near wind loss rates. Typically 10^{-9} to 10^{-8} Msun/yr (e.g., Sokoloski & Bildsten '10).