# Gamma-ray Emission from Microquasars

Guillaume Dubus (IPAG)

image credit
NASA / GSFC

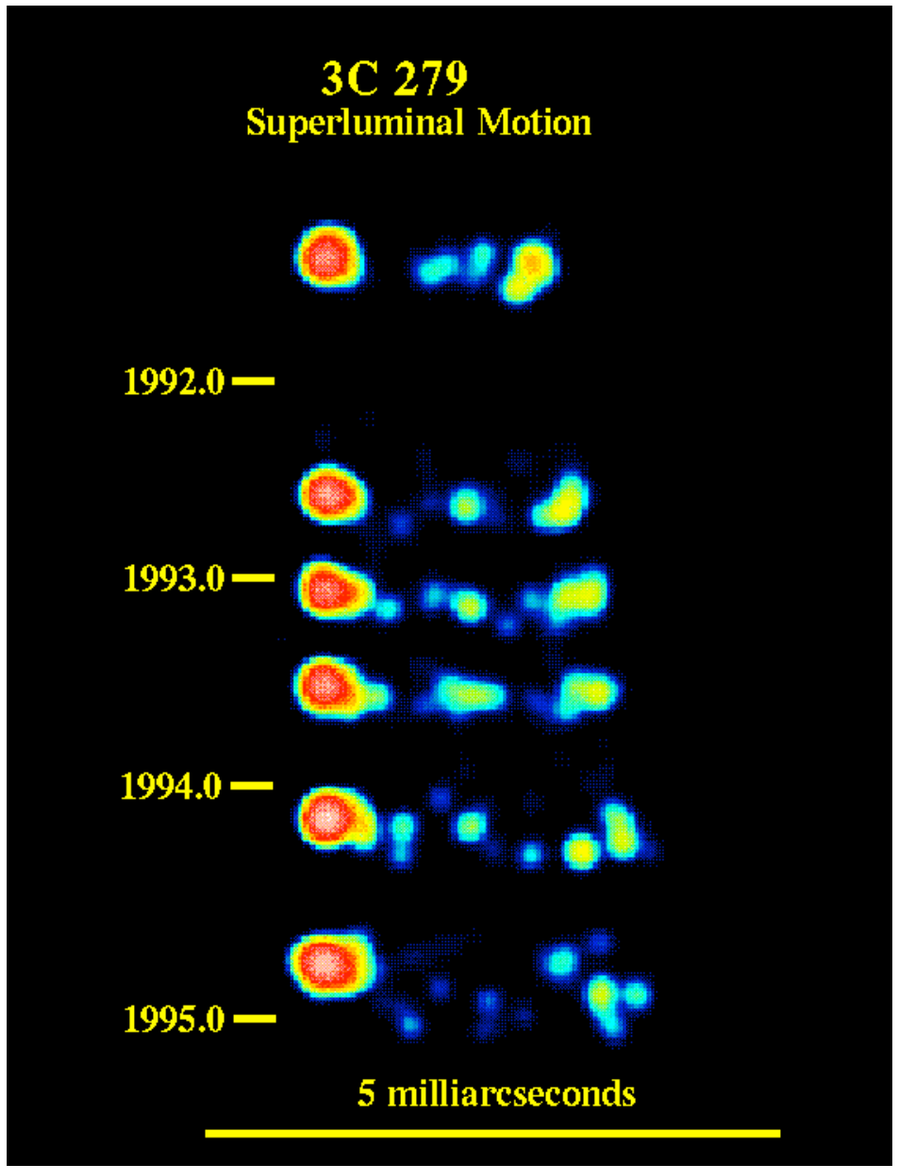
IPAG
Institut de Planétologie et d'Astrophysique de Grenoble
cnrs
UNIVERSITÉ GRENOBLE ALPES

Simulating the evolution and emission of relativistic outflows
Meudon, 28-29 novembre 2019

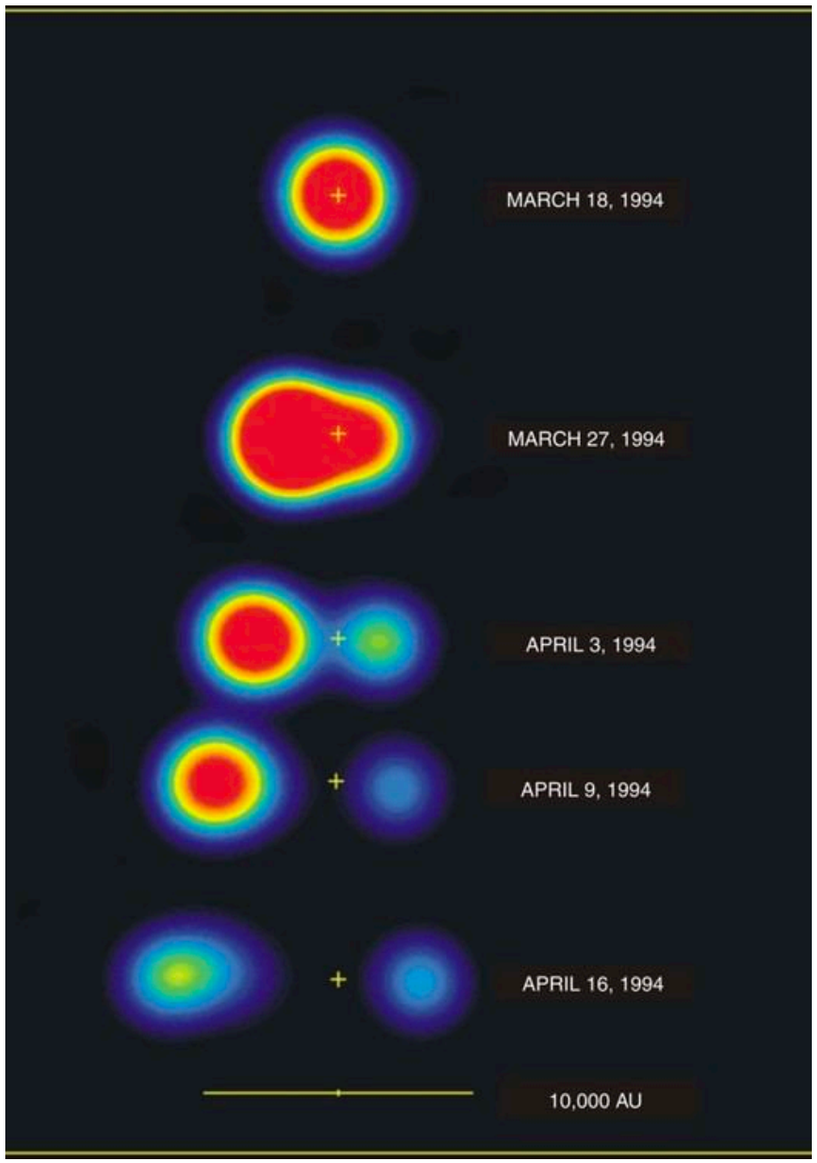
# Scaling relativistic jets

Superluminal radio jets in AGNs and X-ray binaries

Werhle + 2001




Mirabel & Rodríguez 1994



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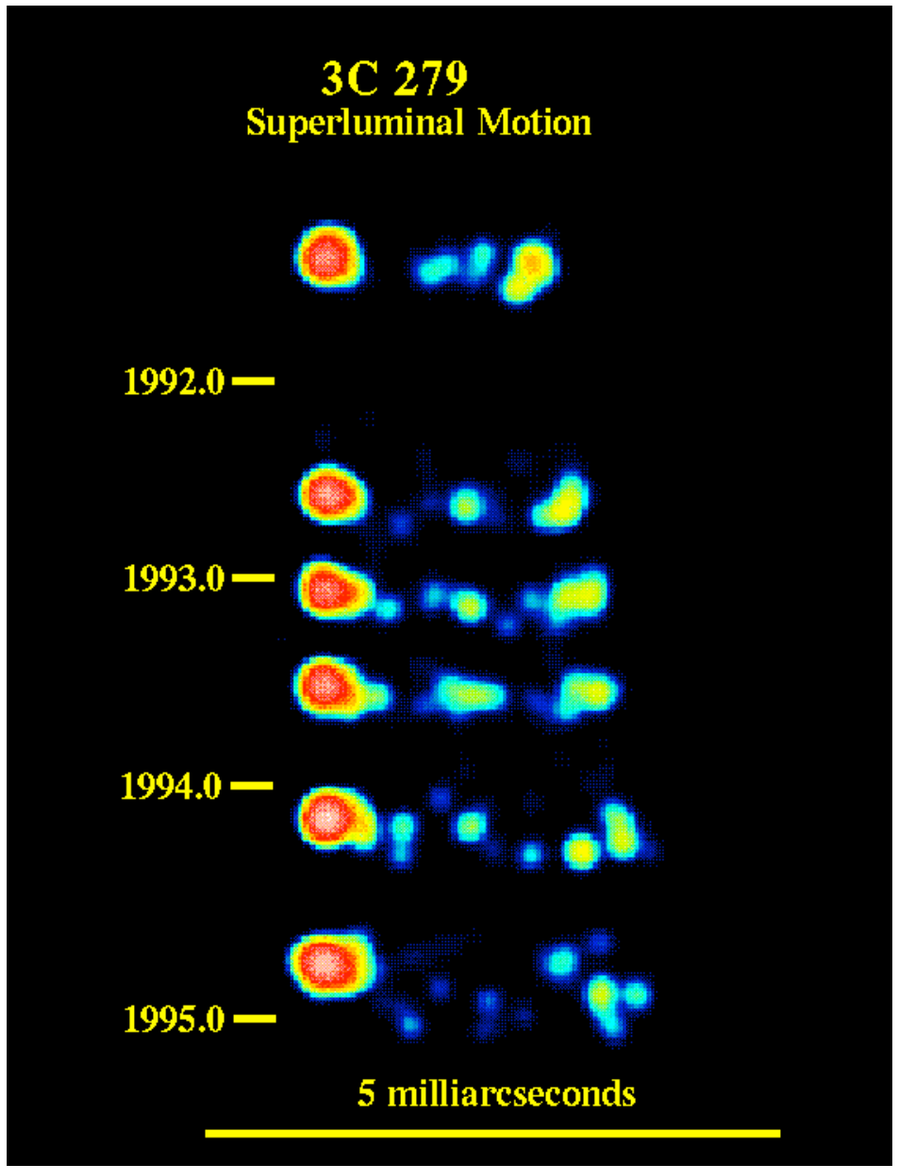
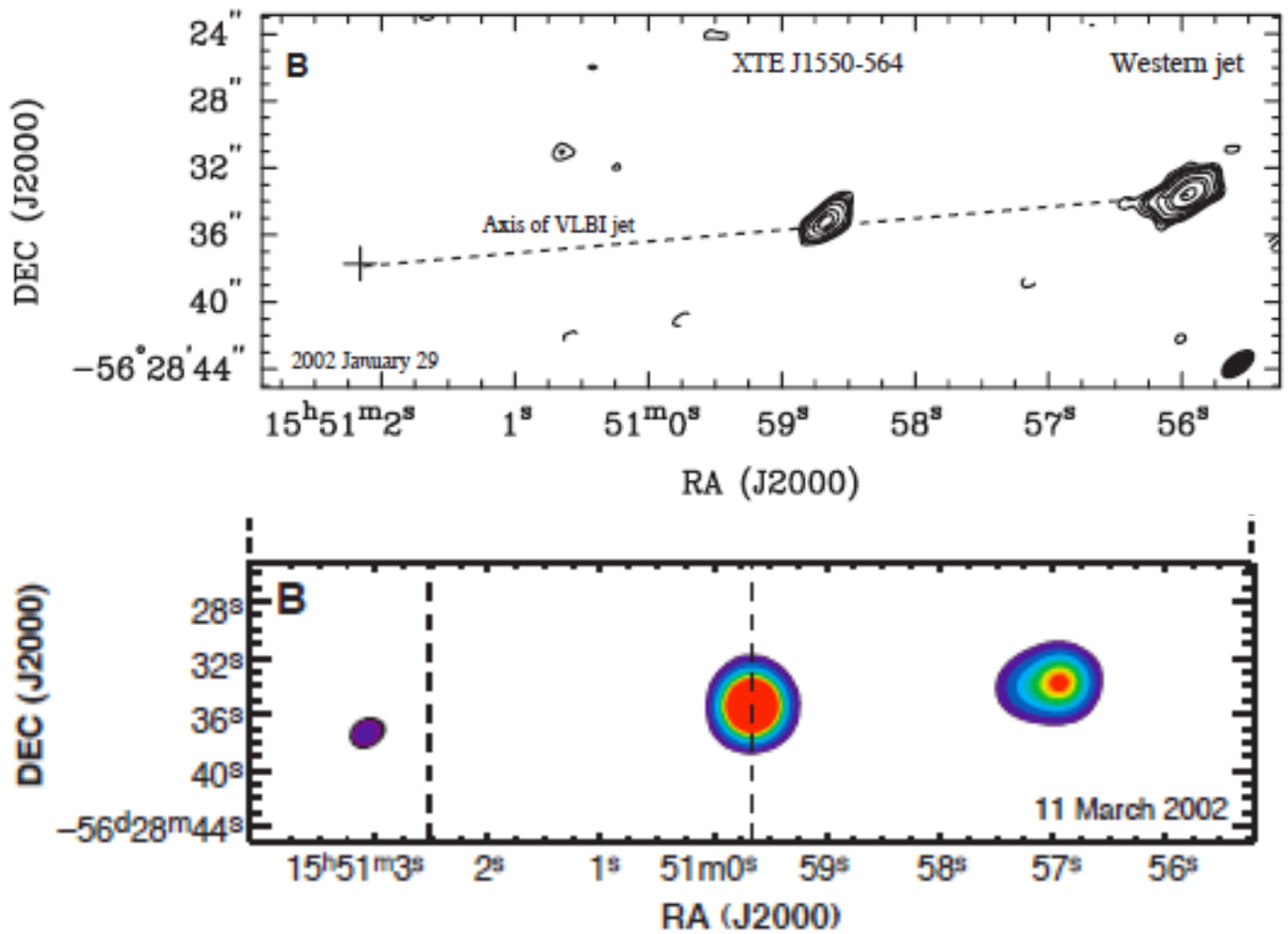



Corbel+ 2002 X-ray jet emission on pc scale




Evidence for TeV electrons in microquasars

# Scaling relativistic jets

Superluminal radio jets in AGNs and X-ray binaries

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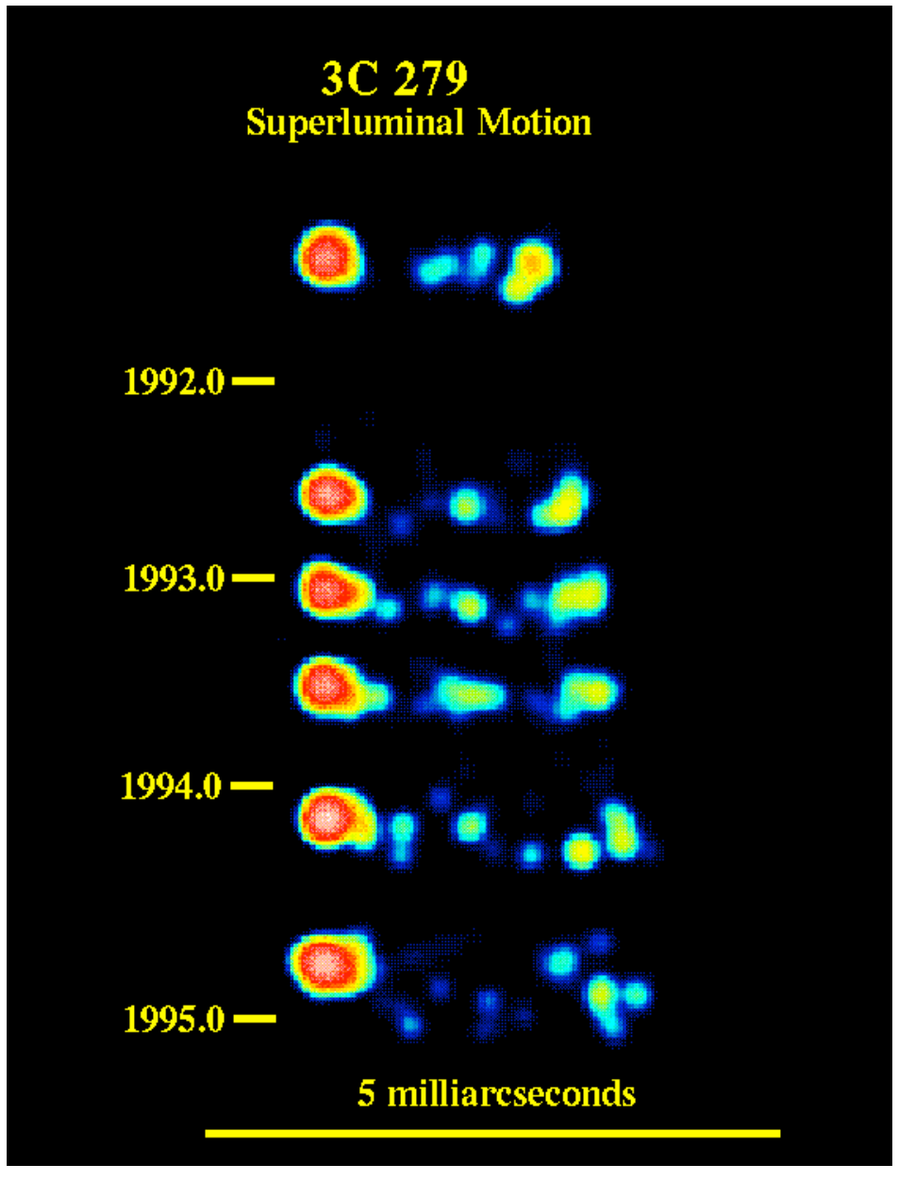
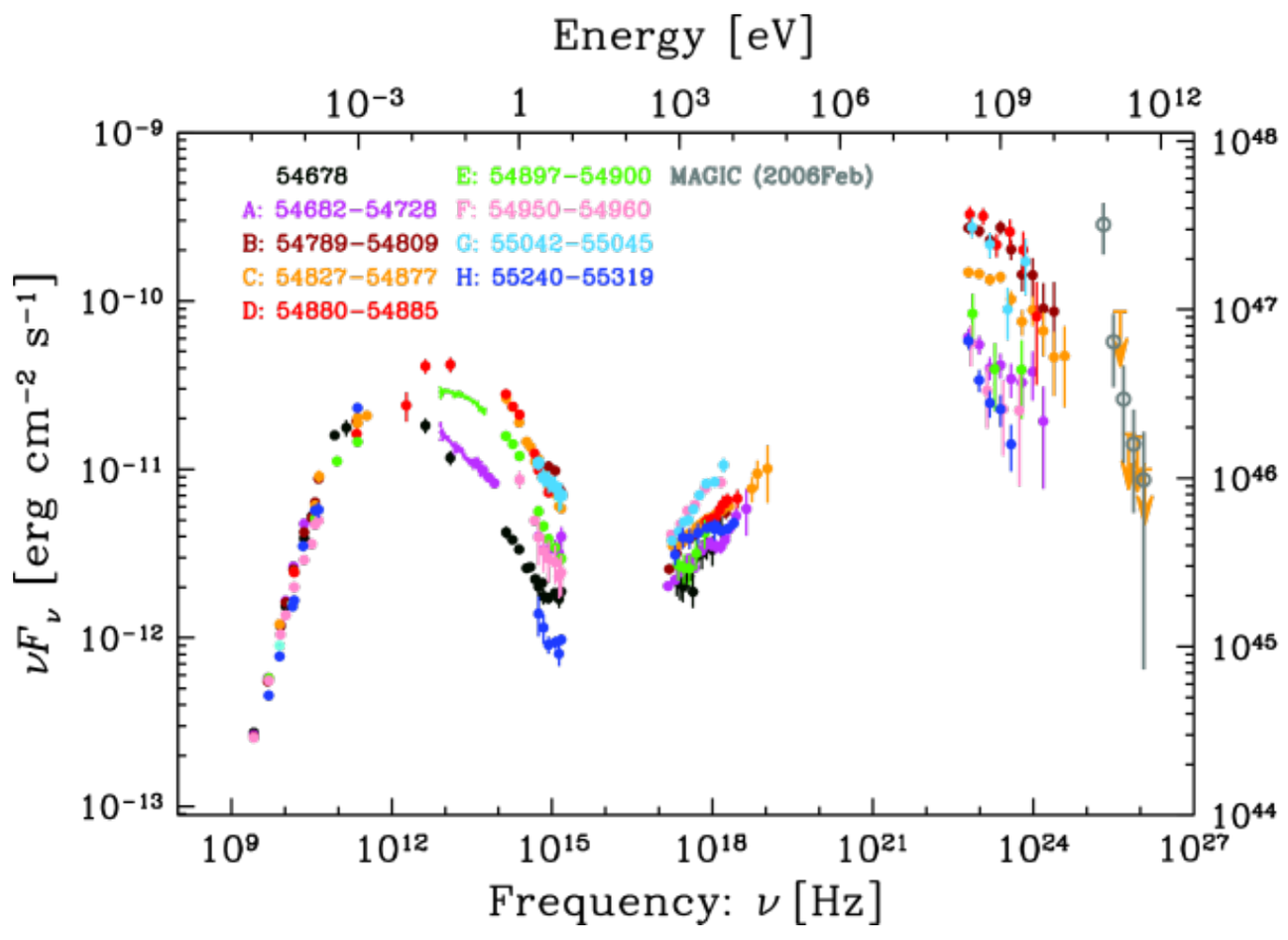
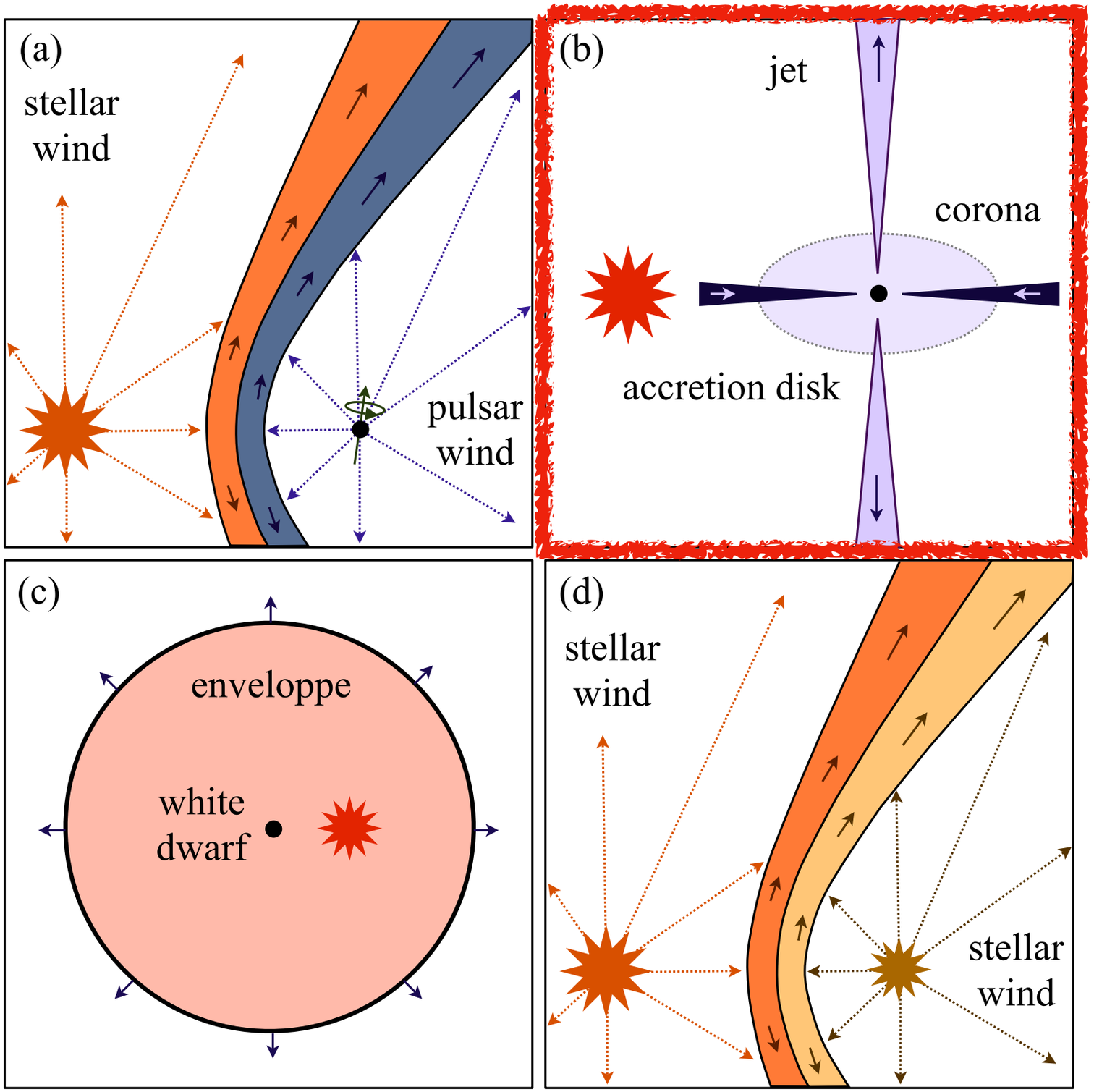



Hayashida + 2012 Spectral Energy Distribution of 3C 279




Gamma-ray emission from microquasars ?

# Binaries detected in (V)HE gamma rays




GD 2013, 2015

"secure" microquasar detections > 100 MeV:

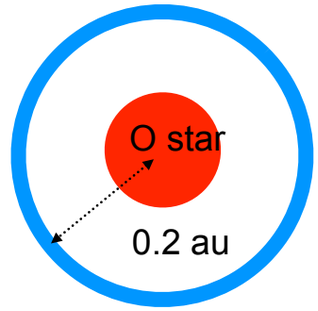
Cyg X-3
Cyg X-1
SS 433

(V404 Cyg)

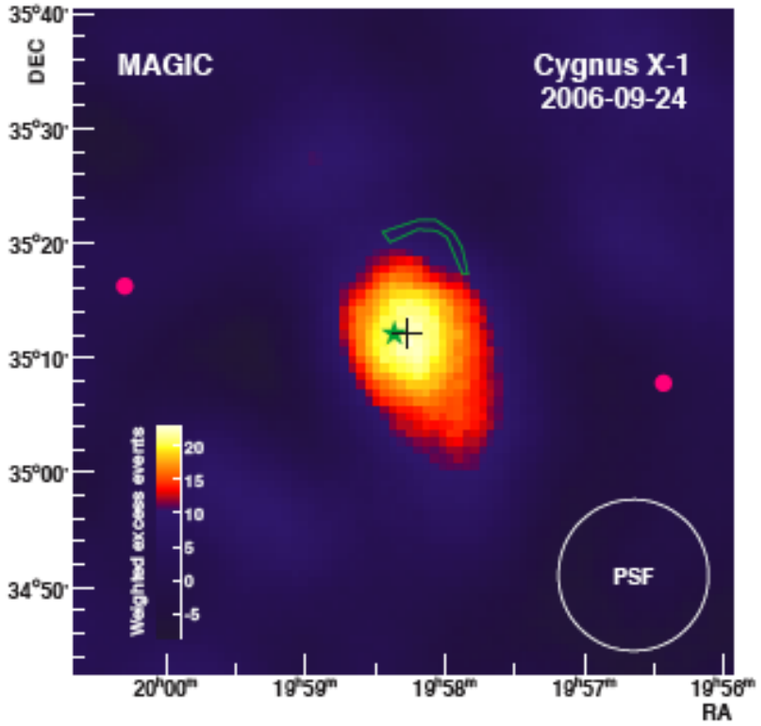
# Cyg X-1 : gamma rays from a microquasar

A 15 Msol black hole in 5.6 day orbit around 25 Msol supergiant, 2kpc

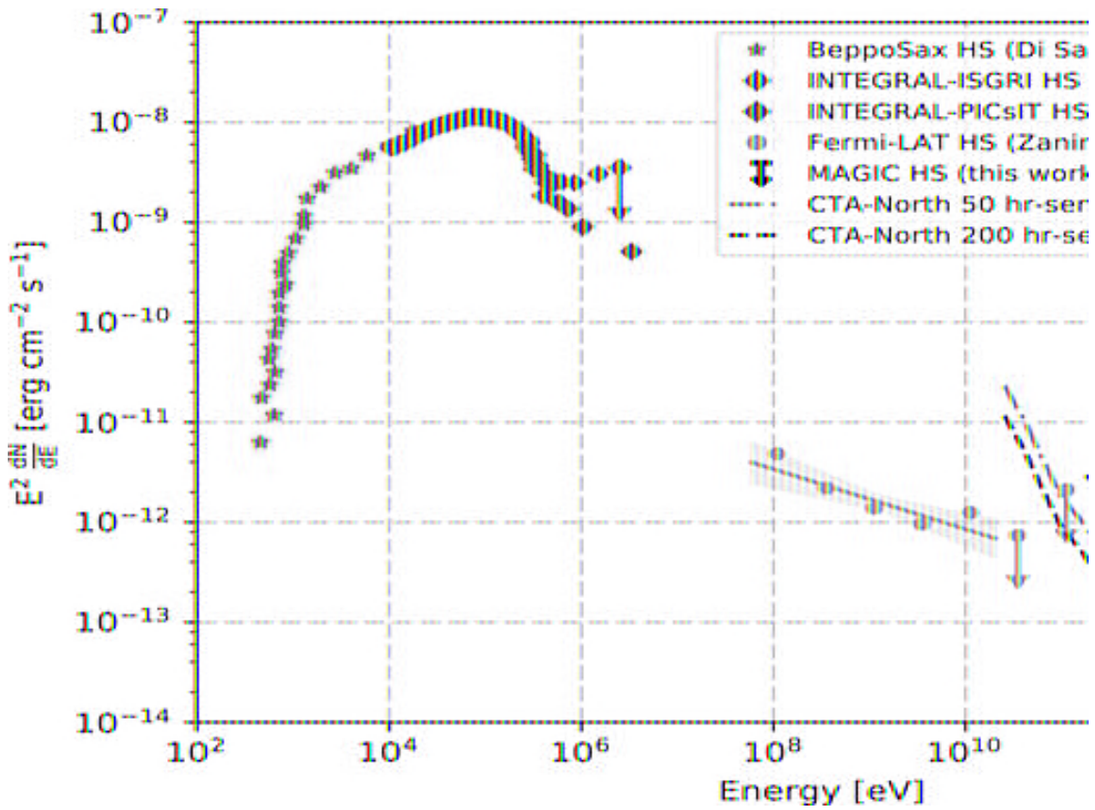
Unconfirmed VHE emission, $L_{VHE} < 10^{-6}\ L_{edd}$ or $< 10^{-4}\ P_{jet}$




MAGIC coll. 2007, 1 day flare ?



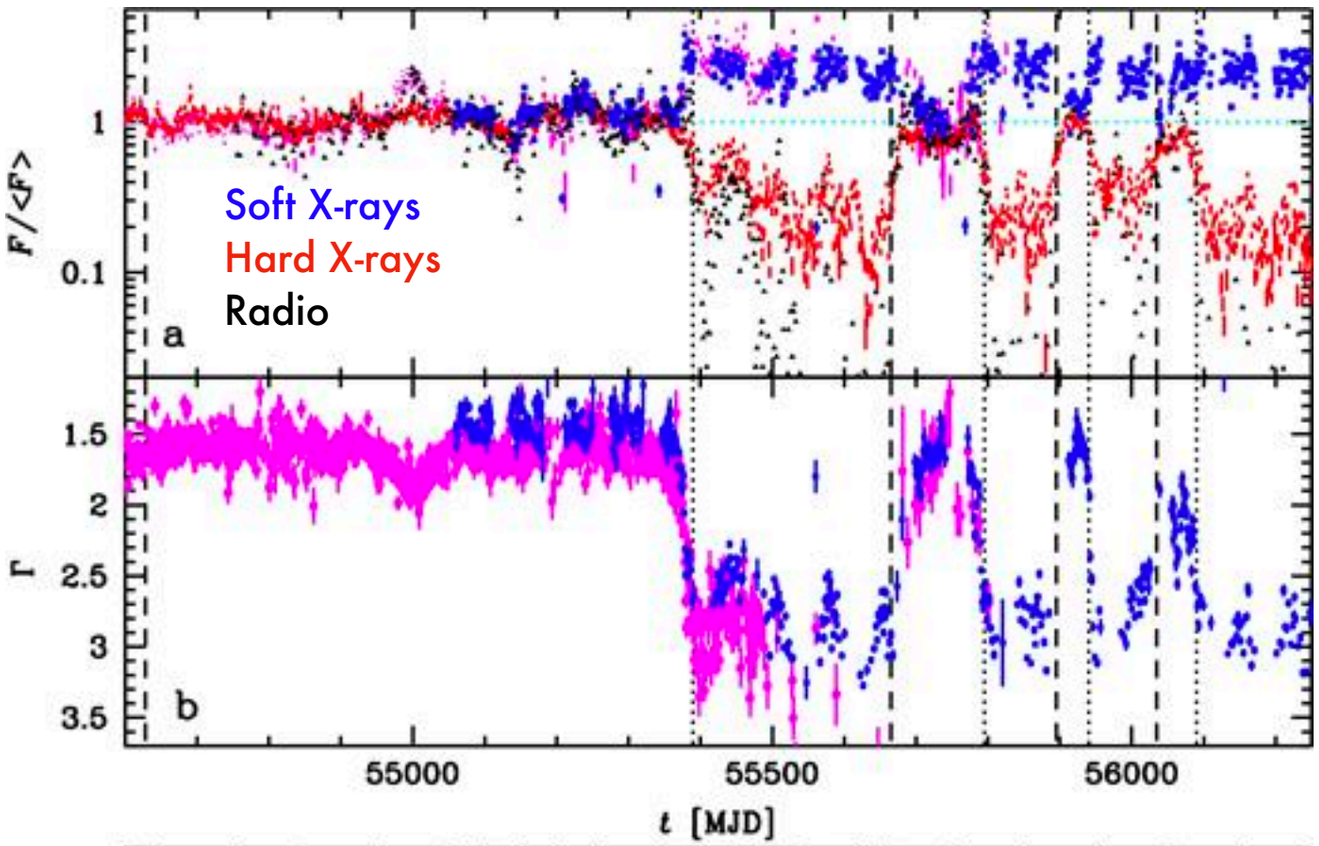

MAGIC coll. 2017 UL with 100hr of add. Data



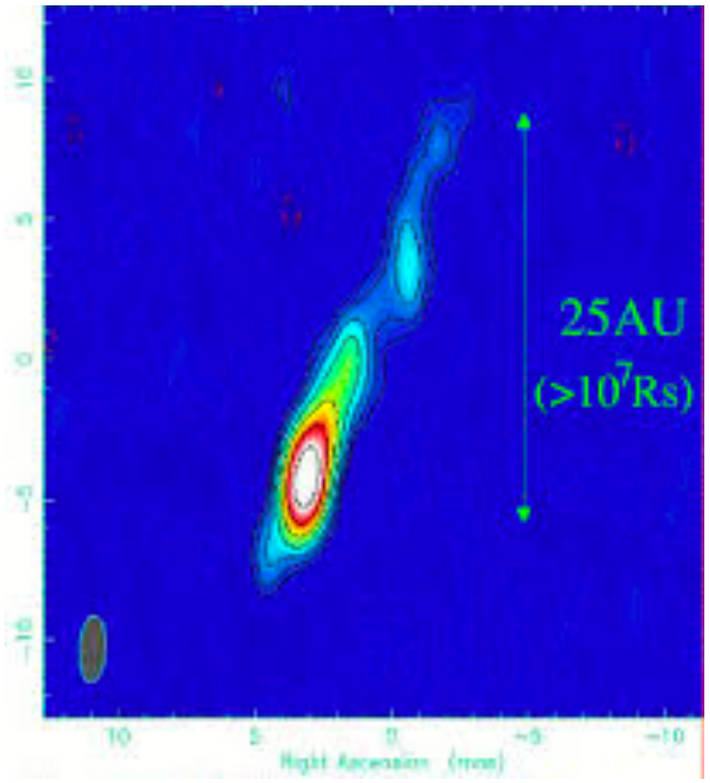
# Hard X-ray state of Cyg X-1

**High-energy** gamma-ray emission when selecting hard X-ray state associated with a jet

Zdziarski+ 2017, Zanin+ 2016




compact jet Stirling+2001

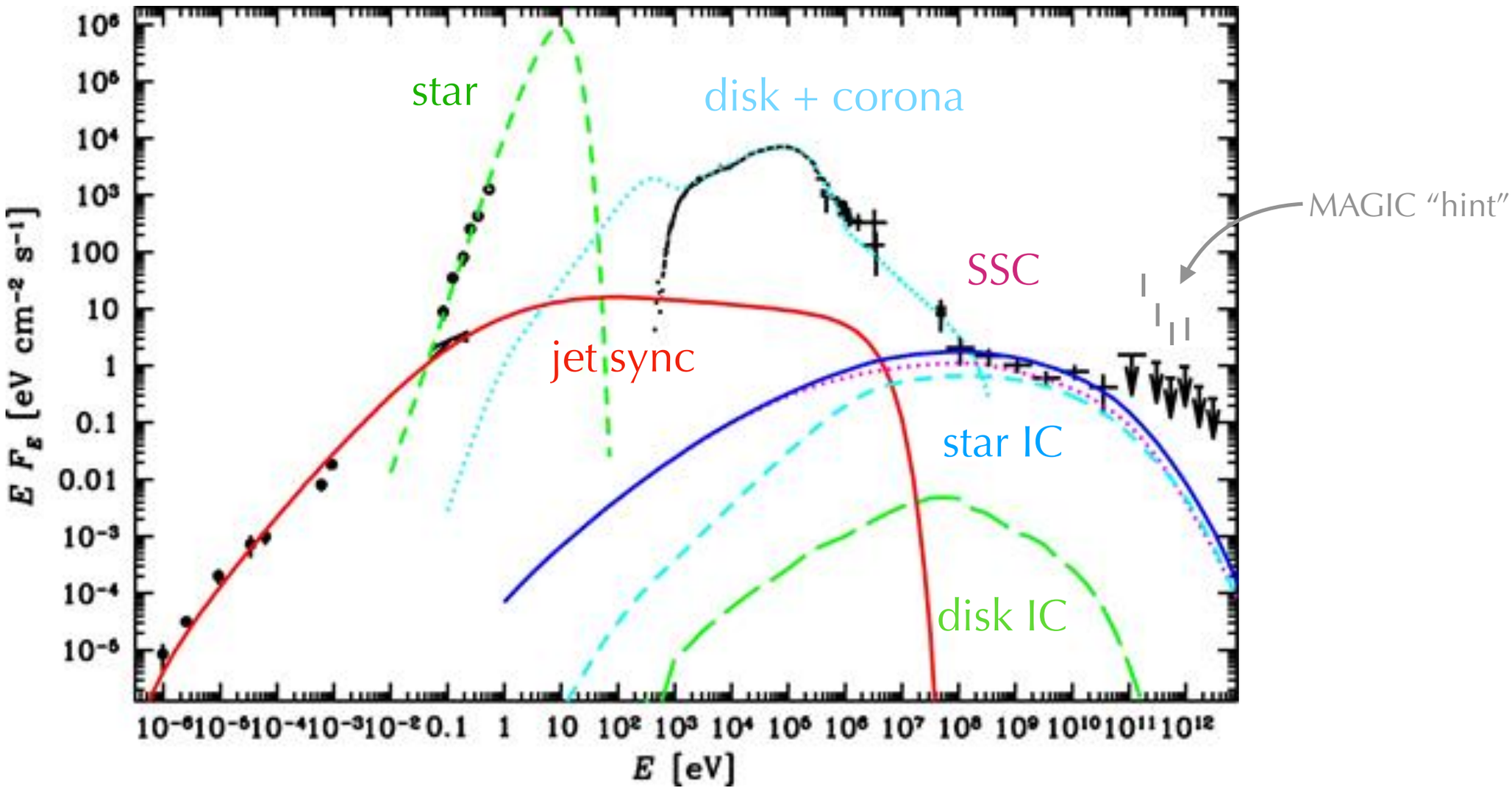



Gamma-ray detection from 40 MeV to 60 GeV, with L~5x10$^{33}$ erg s$^{-1}$

# Constraining jet physics with Cyg X-1

*weak* **orbital modulation** suggests SSC in clumpy jet so as to overcome star IC emission

Zdziarski+ 2017



# Cyg X-3

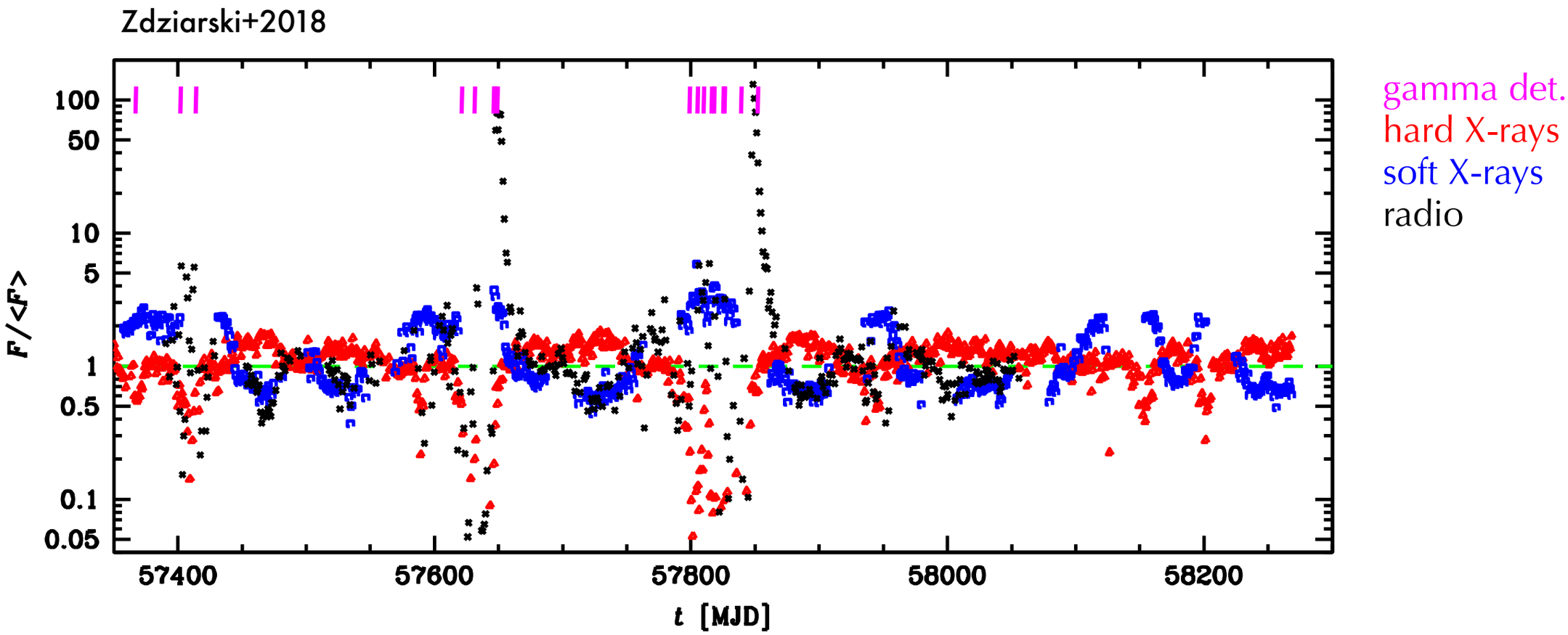
low-mass BH (?) in **4.8 hour** orbit with Wolf-Rayet

image credit
NASA / GSFC

# Cyg X-3

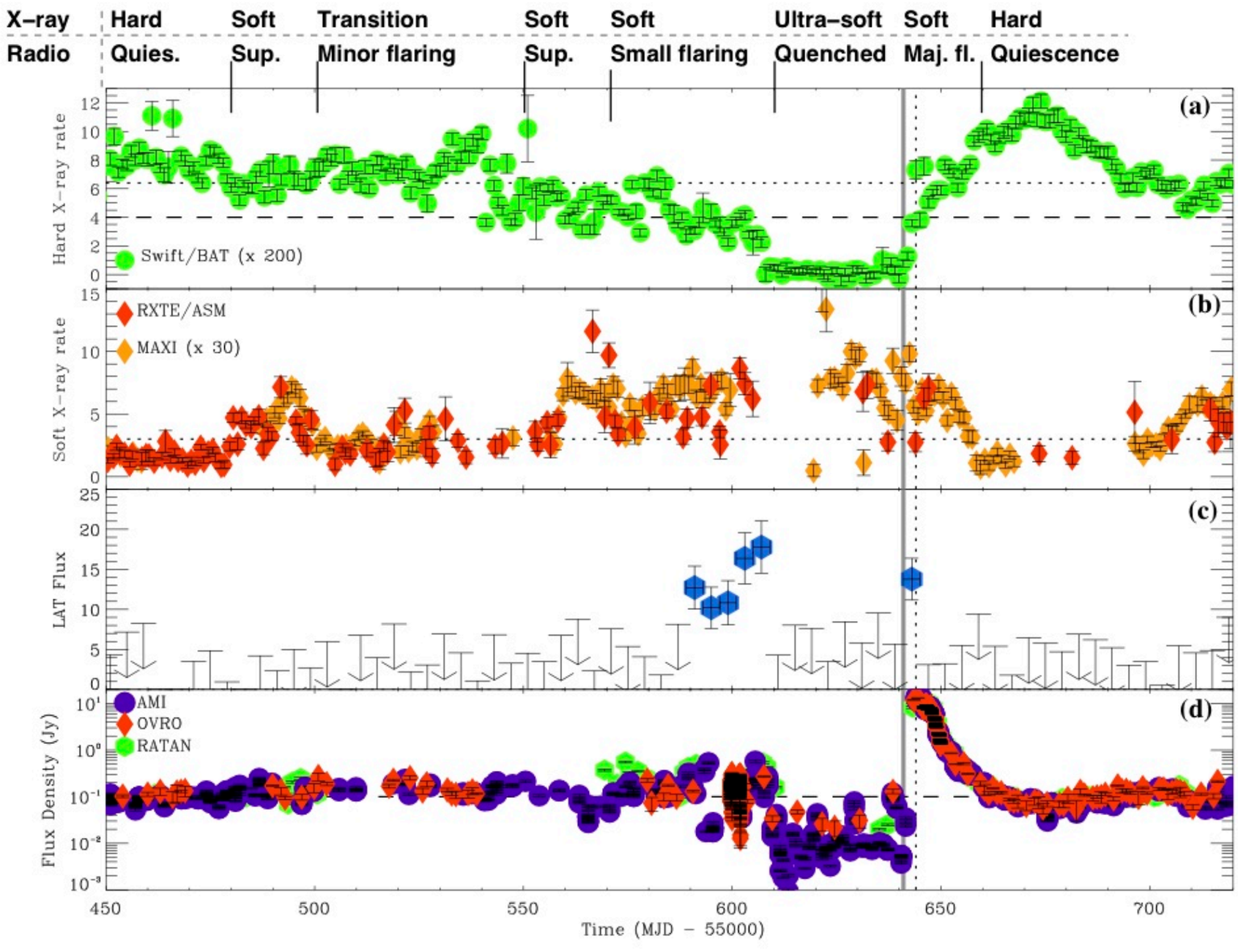
Gamma-ray detections clearly related to X-ray spectral state

About 1000x more luminous in gamma rays than Cyg X-1 with L~5x10$^{36}$ erg s$^{-1}$



# Linking accretion, acceleration, ejection

Corbel et al. 2012



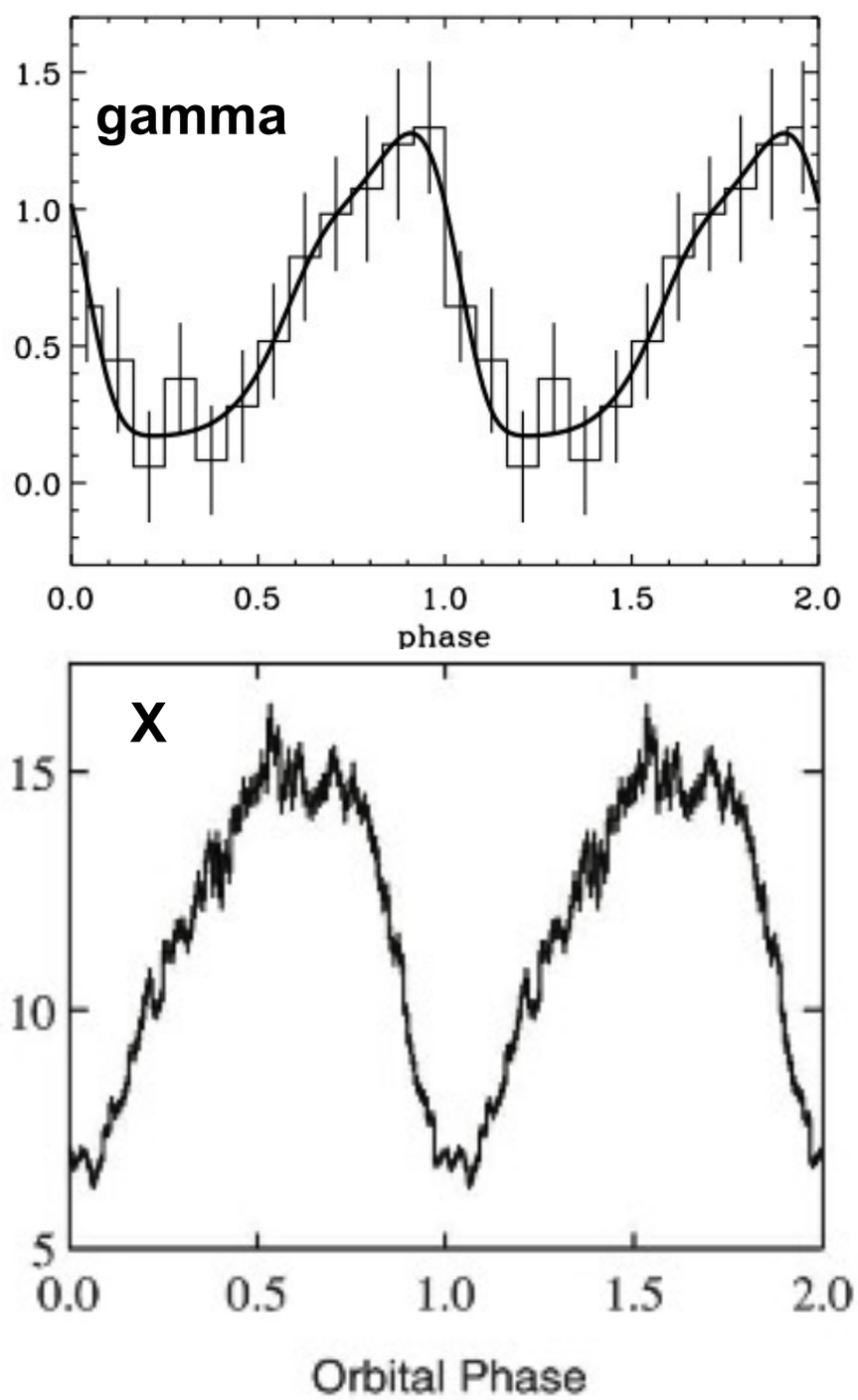

Accretion

non-thermal / thermal

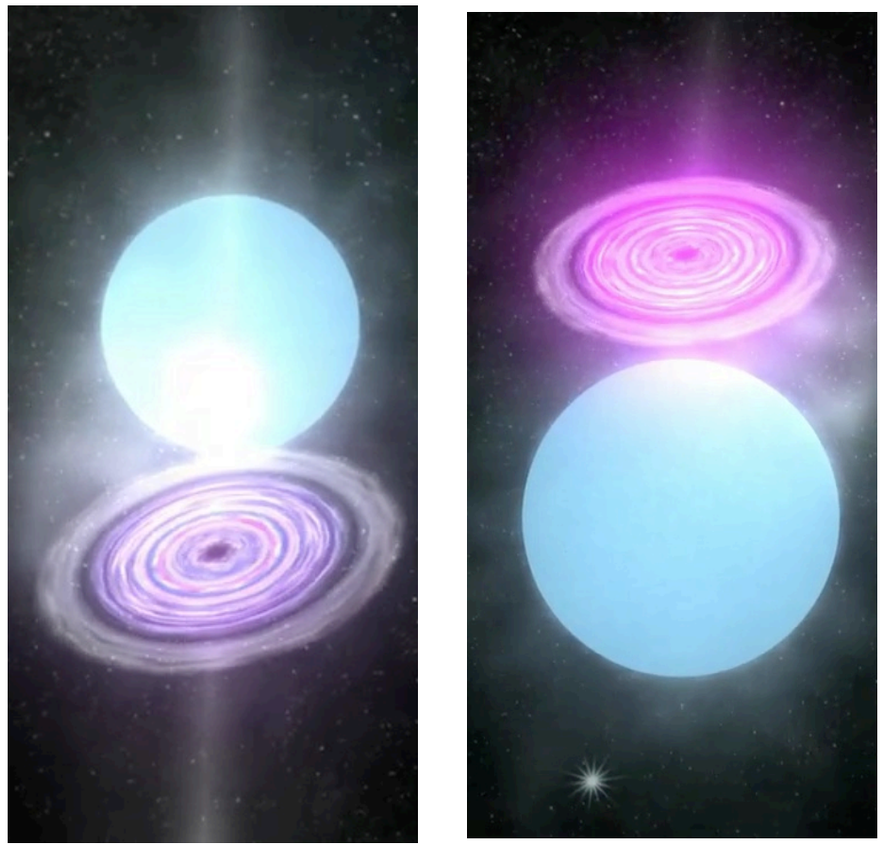
Ejection

# Gamma-ray orbital variability

Fermi-LAT+ 2009 Cyg X-3 4.8 hour orbit



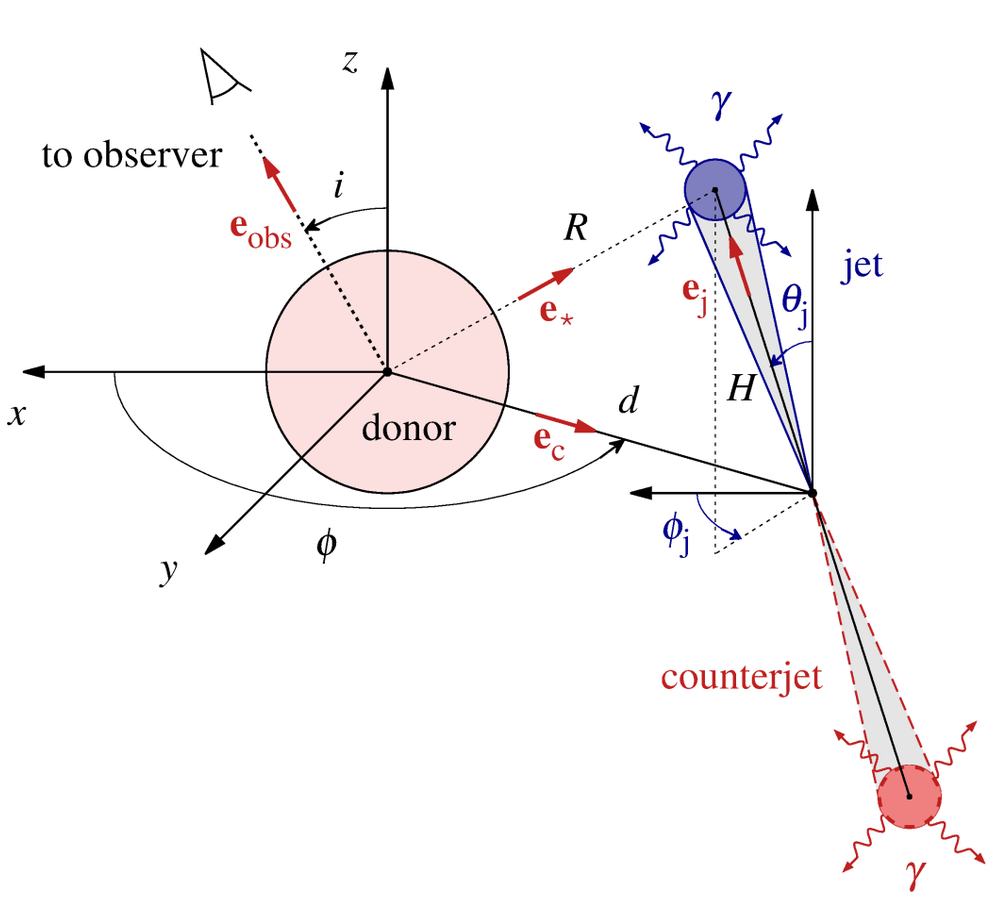

inverse Compton on star photons

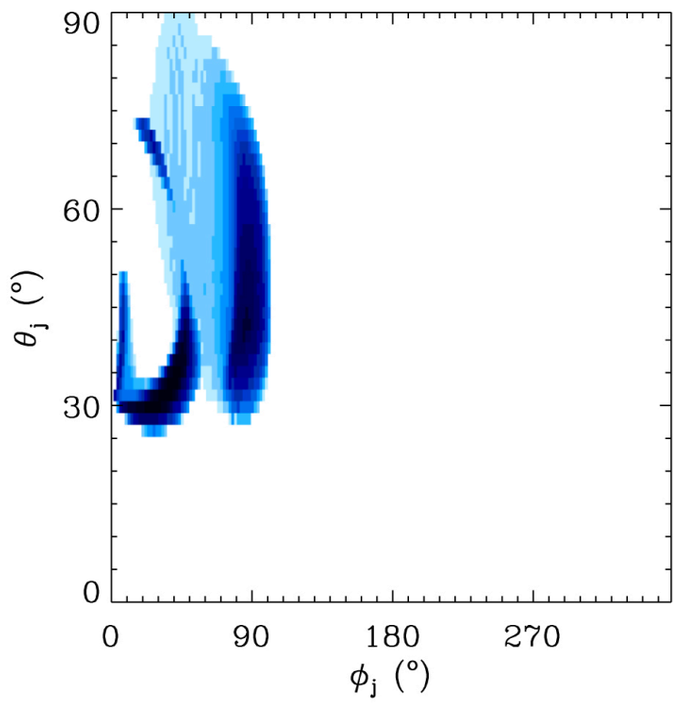


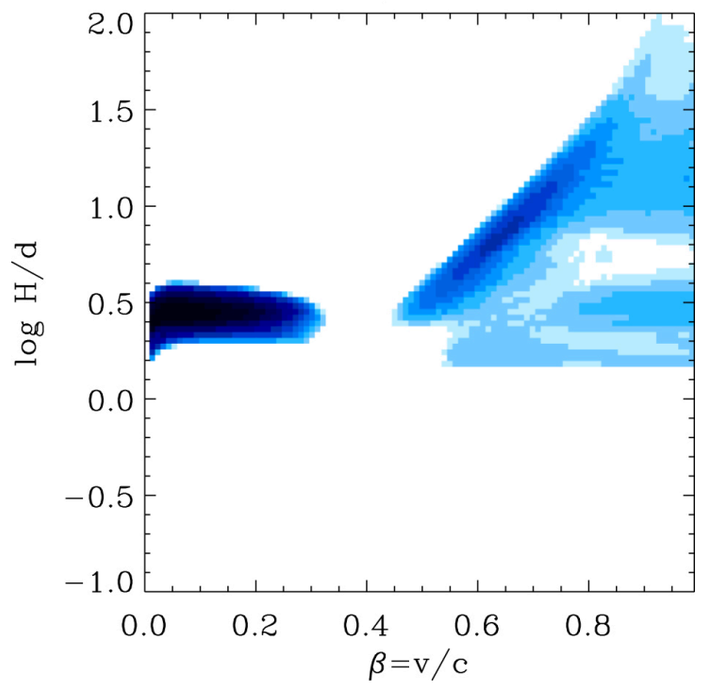
GD, Cerutti, Henri 2010

# Gamma-ray emission model

- Emission located beyond system, ~ 3 orbital separations
- Jet is inclined, mildly relativistic, close to line-of-sight, no sign of precession in gamma



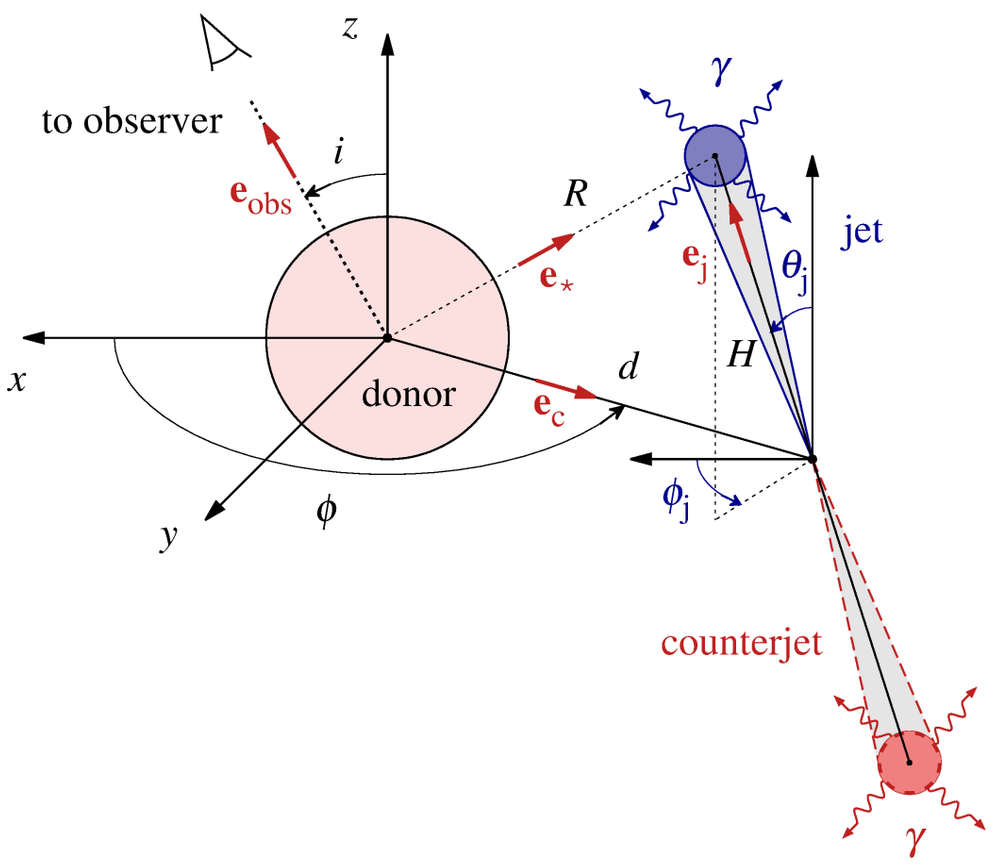



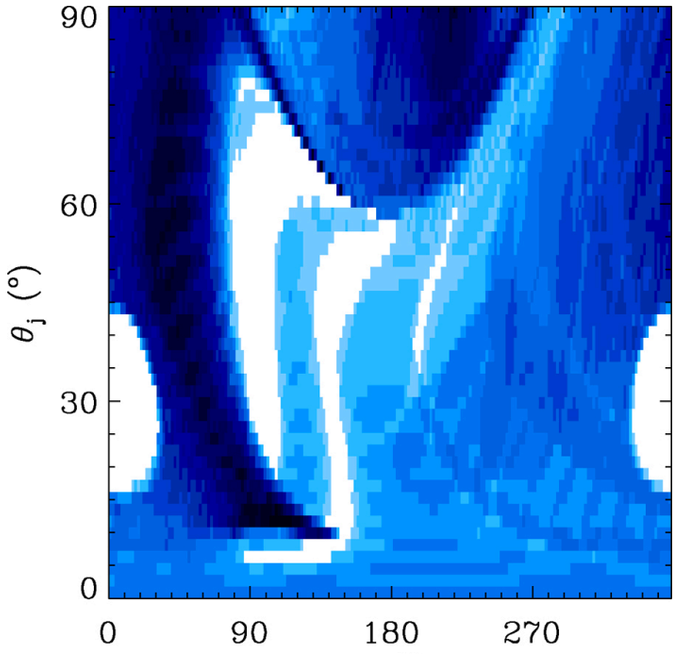

location of statistically acceptable fits

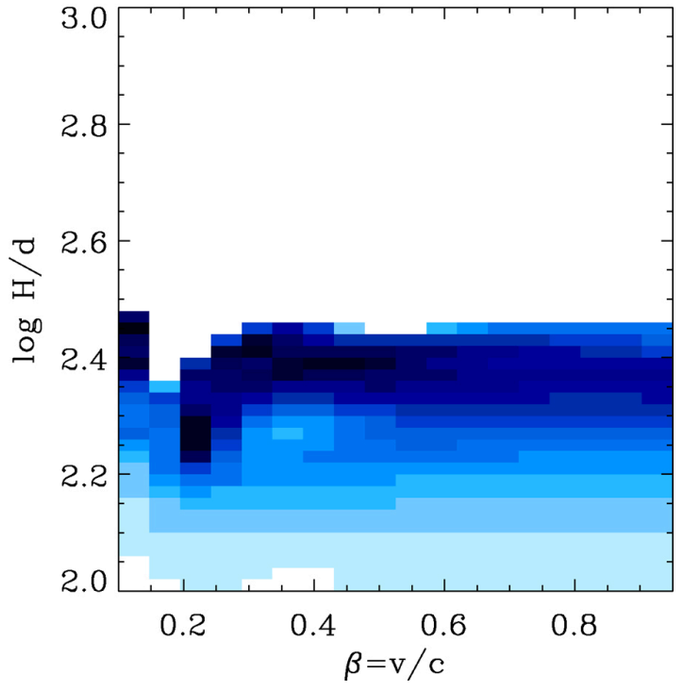
Zdziarski +2018

# Radio modulation

- Radio orbital modulation due to free-free absorption in Wolf-Rayet wind
- Radio emission zone ~ 3 AU from system



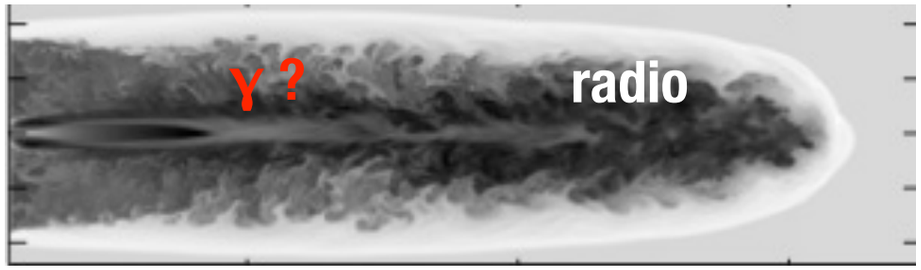




location of statistically acceptable fits

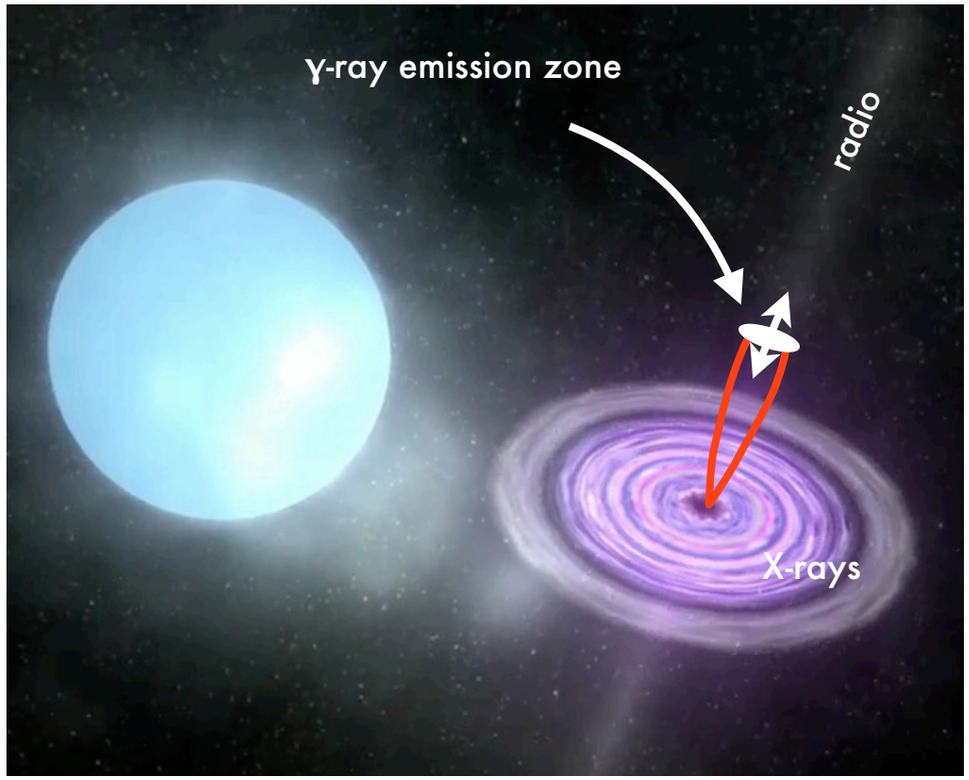
**Zdziarski +2018**

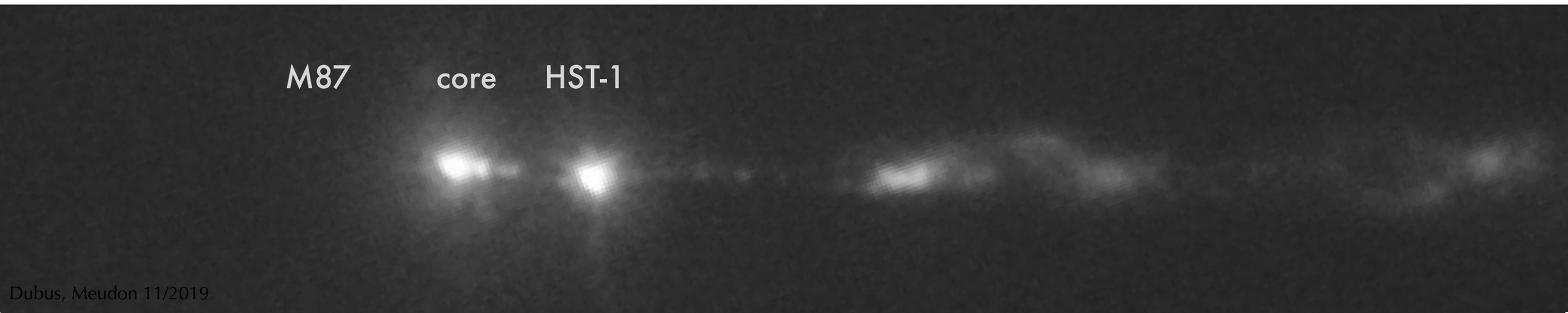
# Acceleration region ?

Recollimation shock ? Relationship to the conditions in the corona, radio jet?

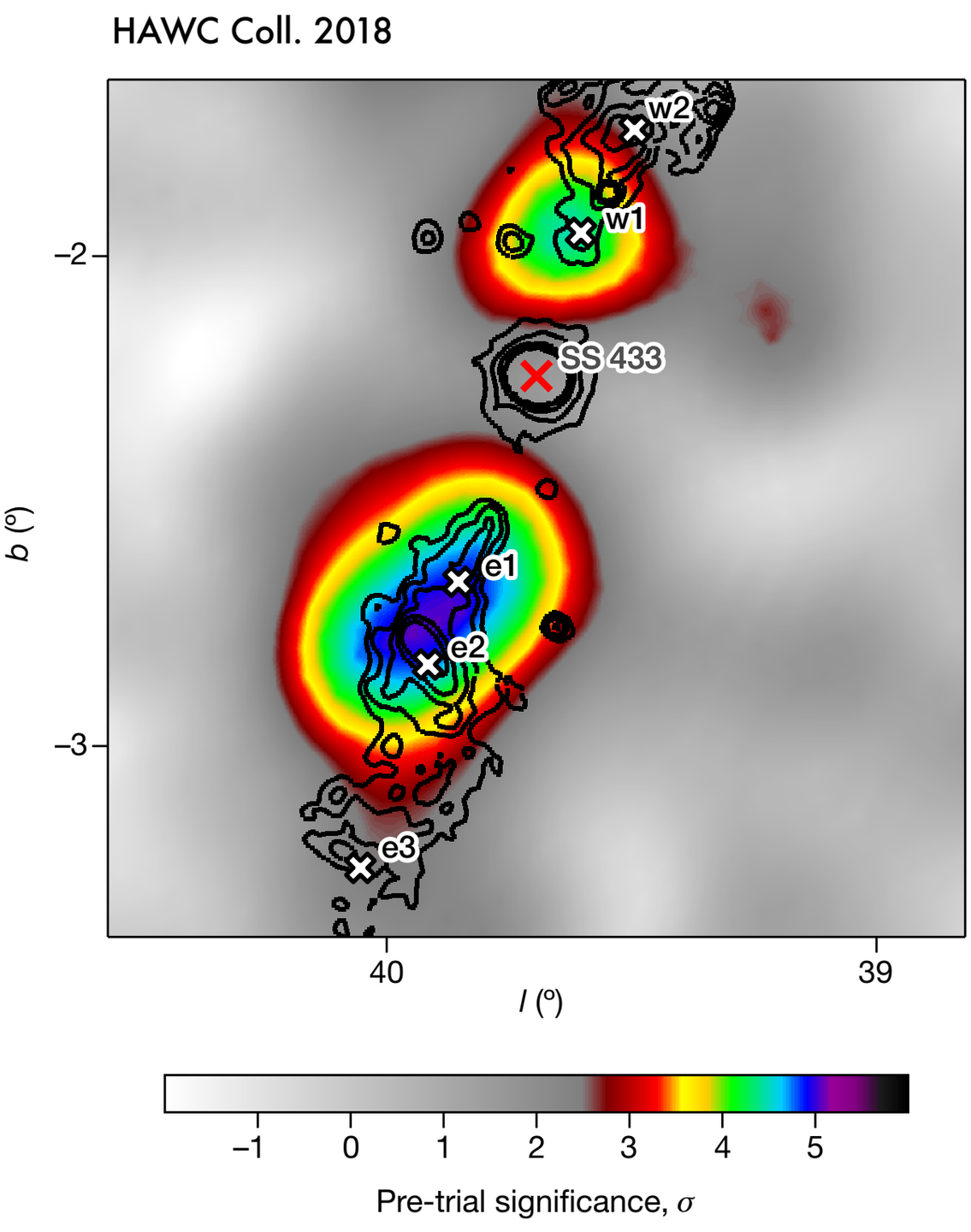



Perucho et al. 2010

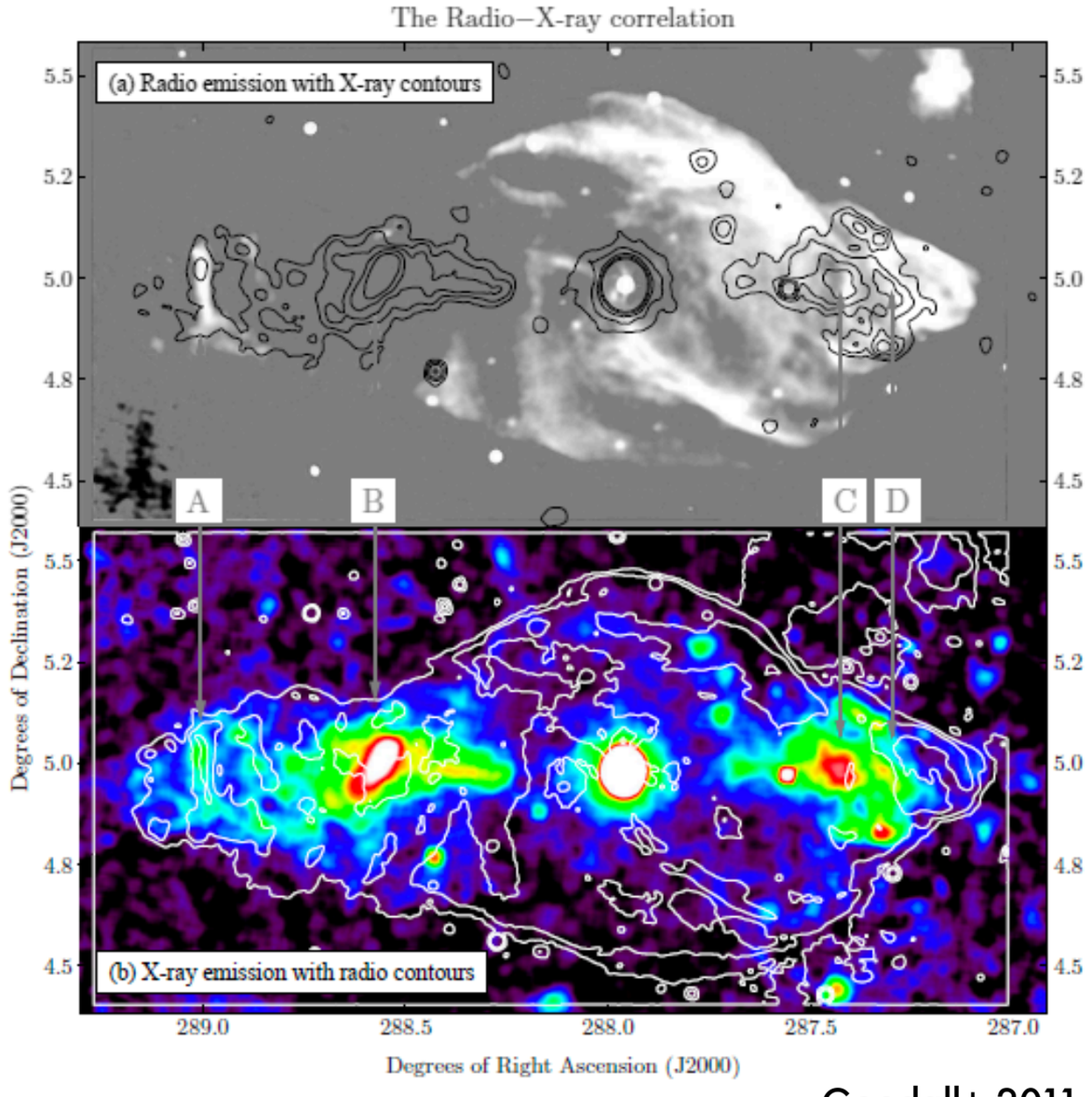


# SS433 gamma ray at termination shock ?

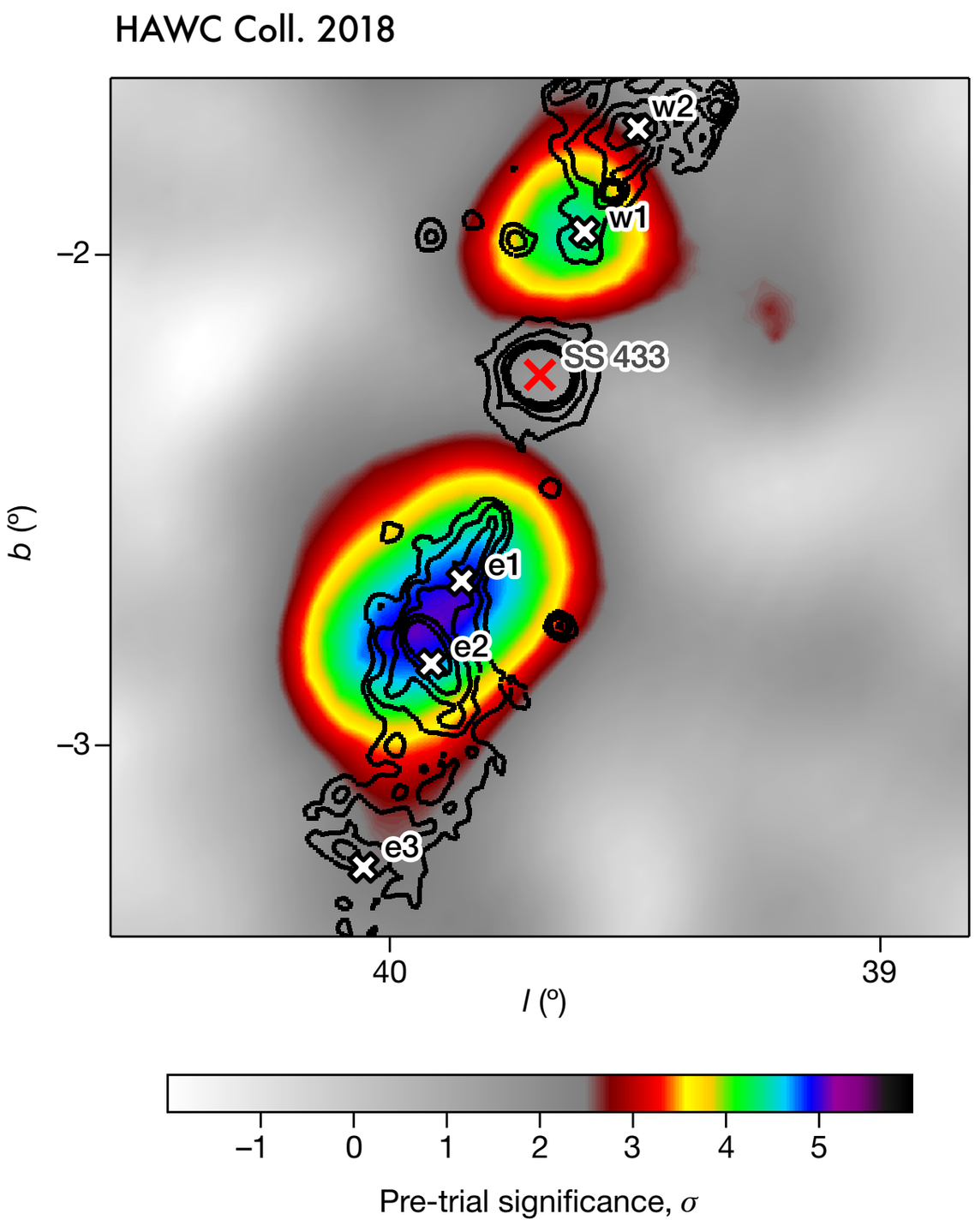



- BH or NS in 13 day orbit with highly-evolved massive star, super Edddington, $P_{jet}$~$10^{39}$ erg/s




Goodall+ 2011

# SS433 gamma ray at termination shock ?




- BH or NS in 13 day orbit with highly-evolved massive star, super Edddington, $P_{jet}$~$10^{39}$ erg/s
- **HAWC >25 TeV emission** in termination region
  - > 100 TeV e- up scattering CMB (<1% Pjet)
  - pp emission unlikely (>100% Pjet)
  - particle acceleration at termination shock ?
  - GeV emission: unsettled

# Gamma rays from microquasars

- Variable GeV emission from **Cygnus X-3, Cygnus X-1**, and (tentatively) V404 Cyg
- GeV luminosity (very) low compared to X-ray luminosity, no microblazar
- GeV emission **related to X-ray state**
  - link between non-thermal coronal emission & jet ?
- GeV likely emitted far in the jet on scales ~ orbital separation
  - need to avoid pair production on disc or corona X-ray photons
  - a natural outcome of upscattering stellar photons even with continuous injection
  - non-thermal injection: reconnection ? shear ? internal shocks ? recollimation shocks ?
- $>$ 25 TeV at jet termination in **SS433**
  - jet energy injected back into ISM

# Evidence for gamma rays from V404 Cyg

- 9 Msun + low mass comp. 6.4 day orbit
- super Eddington outburst in 2015
- **Single Fermi-LAT detection** associated with period of brightest radio/X-ray activity, notably strong jet ejection.
- Pair production opacity requires GeV emission on scale > orbit
- L(>100 MeV) ~ 2 x $10^{35}$ erg $s^{-1}$

Loh et al. 2016