Very high-energy emission from microquasars

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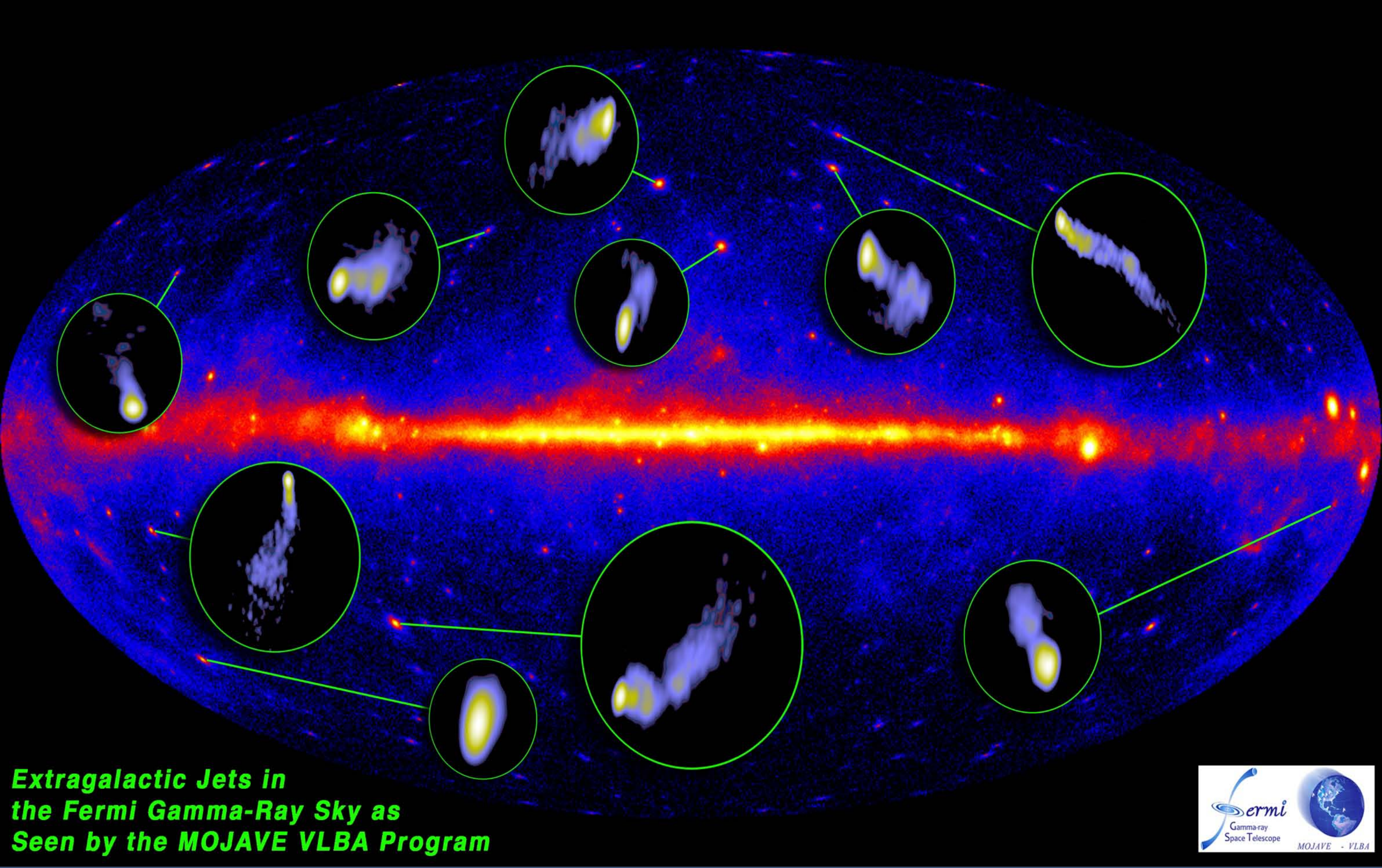
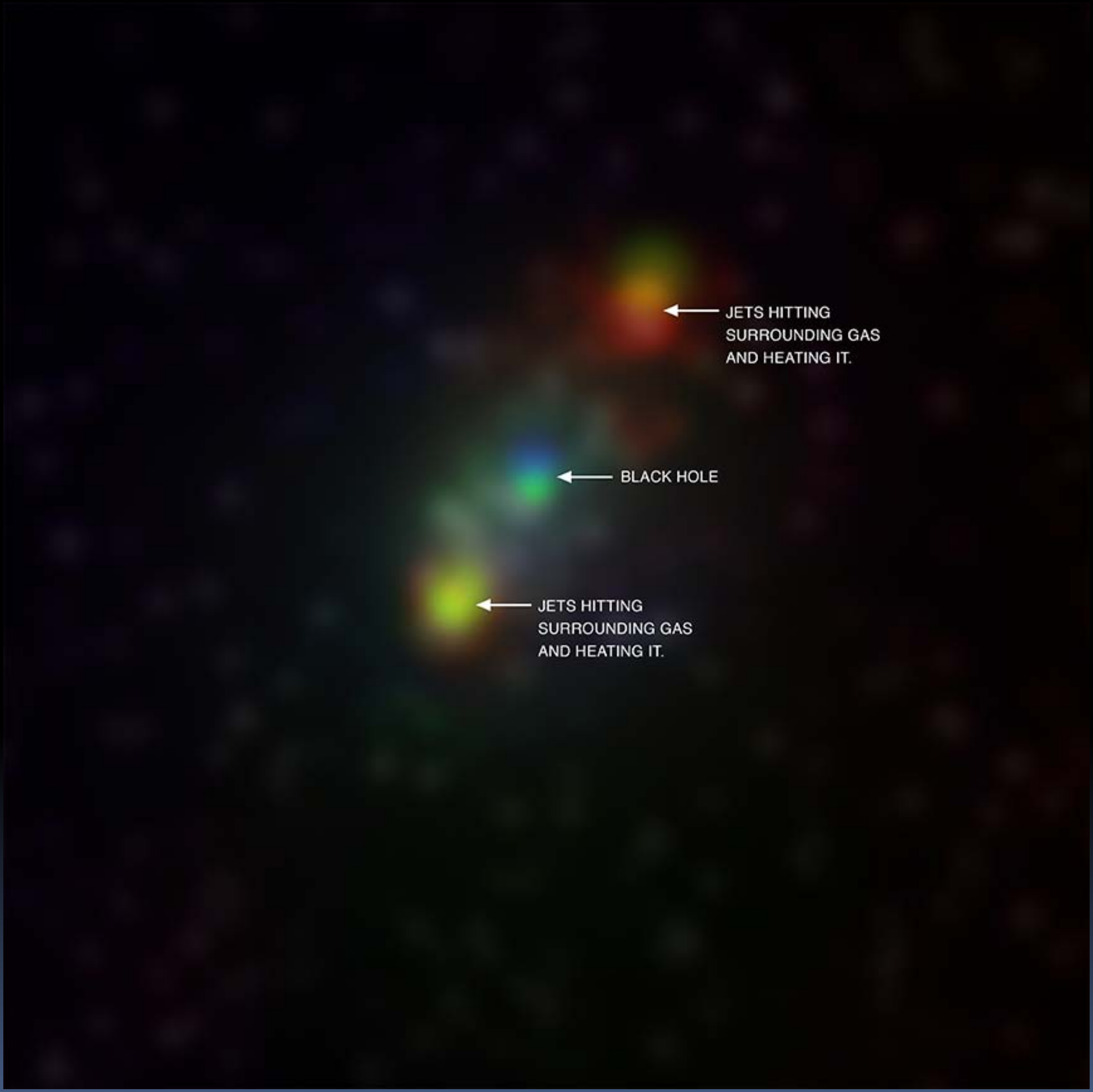
Heidelberg, November 30 – December 3, 2010



Extragalactic Jets in the Fermi Gamma-Ray Sky as Seen by the MOJAVE VLBA Program

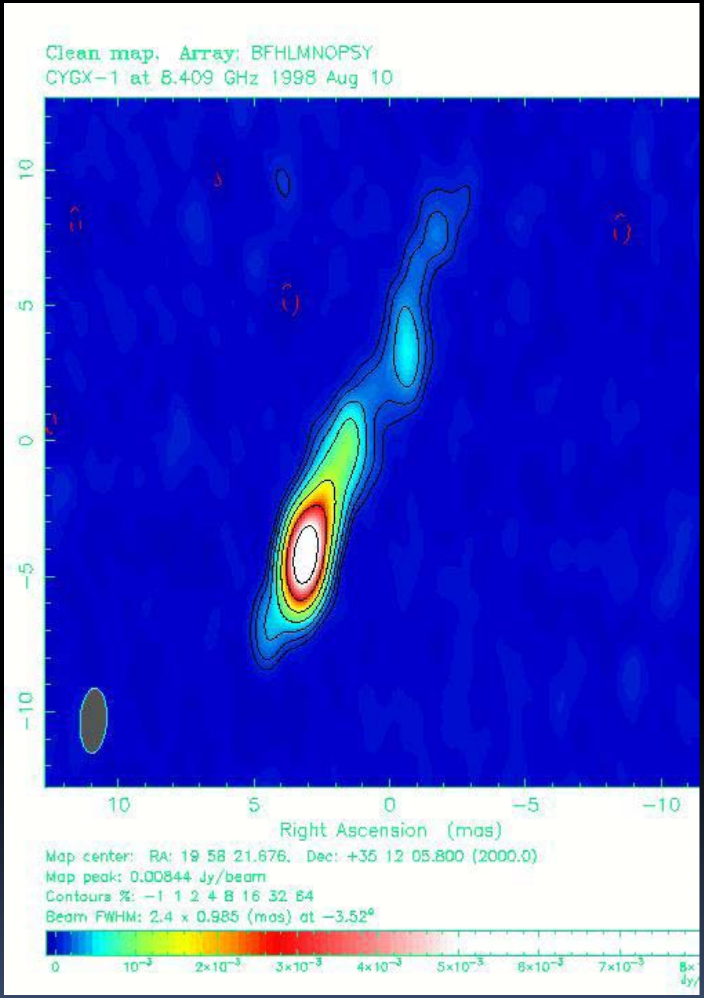
AGNs produce gamma-ray emission

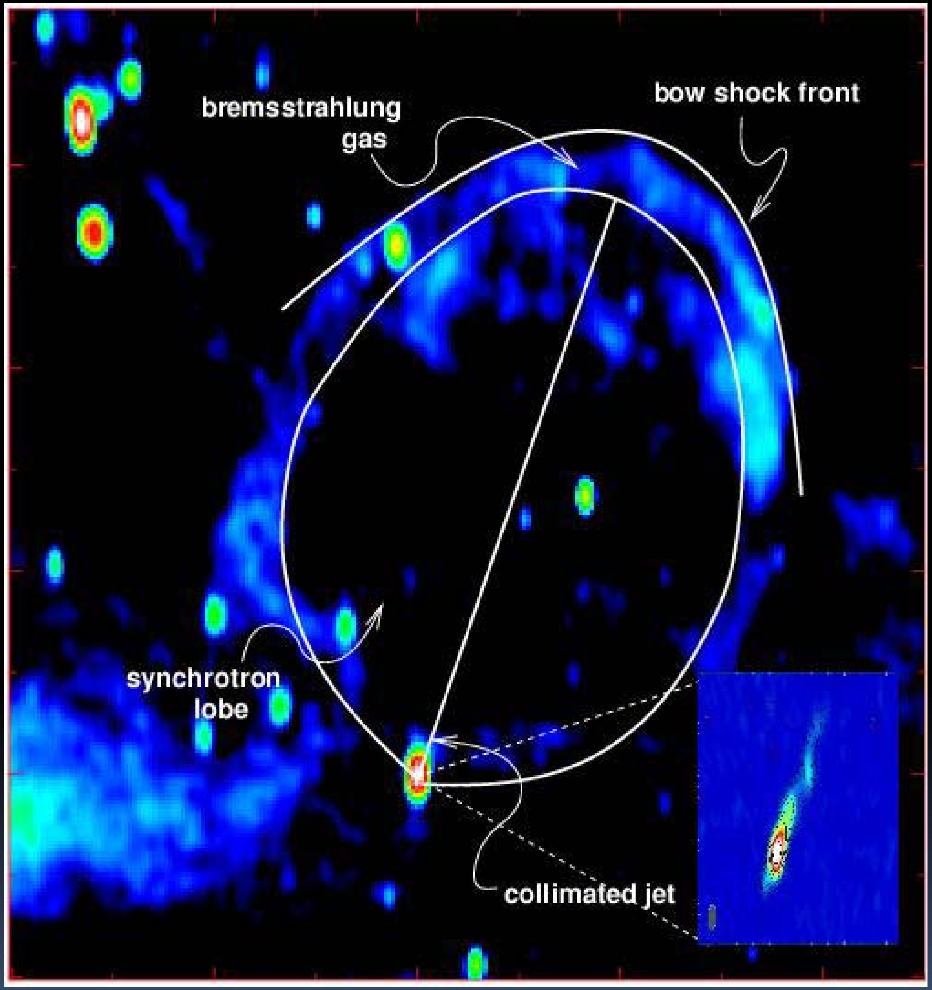
Stellar black holes can also produce jets



NGC 7793: Pakull et al. (2010)

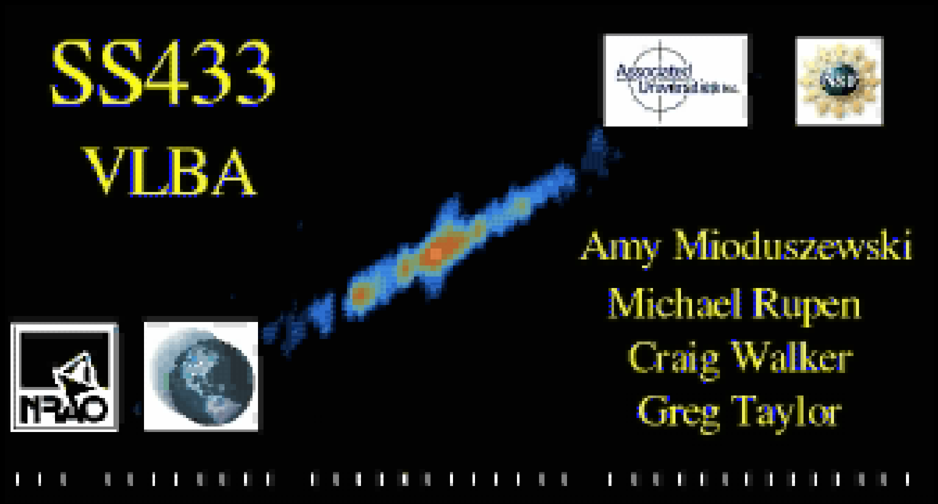
Stellar black holes can also produce jets



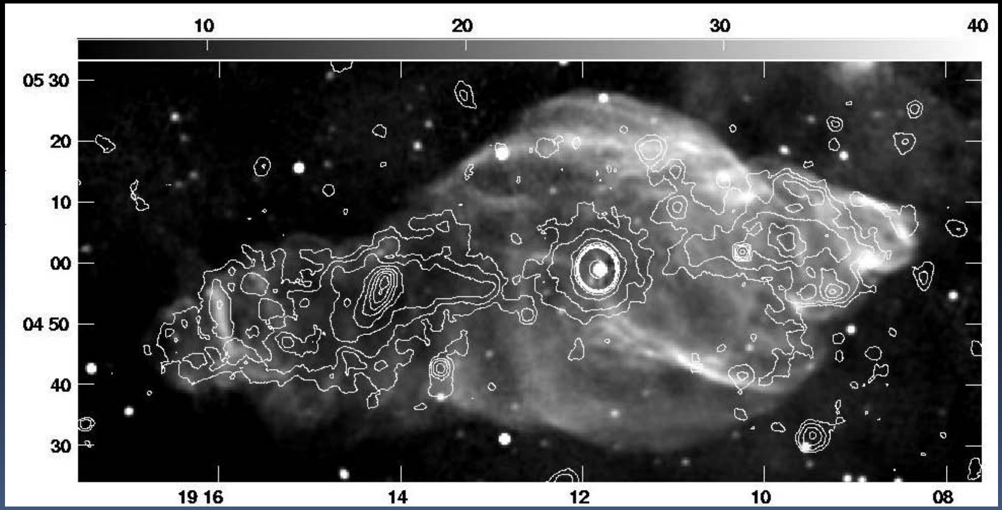


Cygnus X-1: Stirling et al. (2001), Gallo et al. (2005)

Stellar black holes can also produce jets



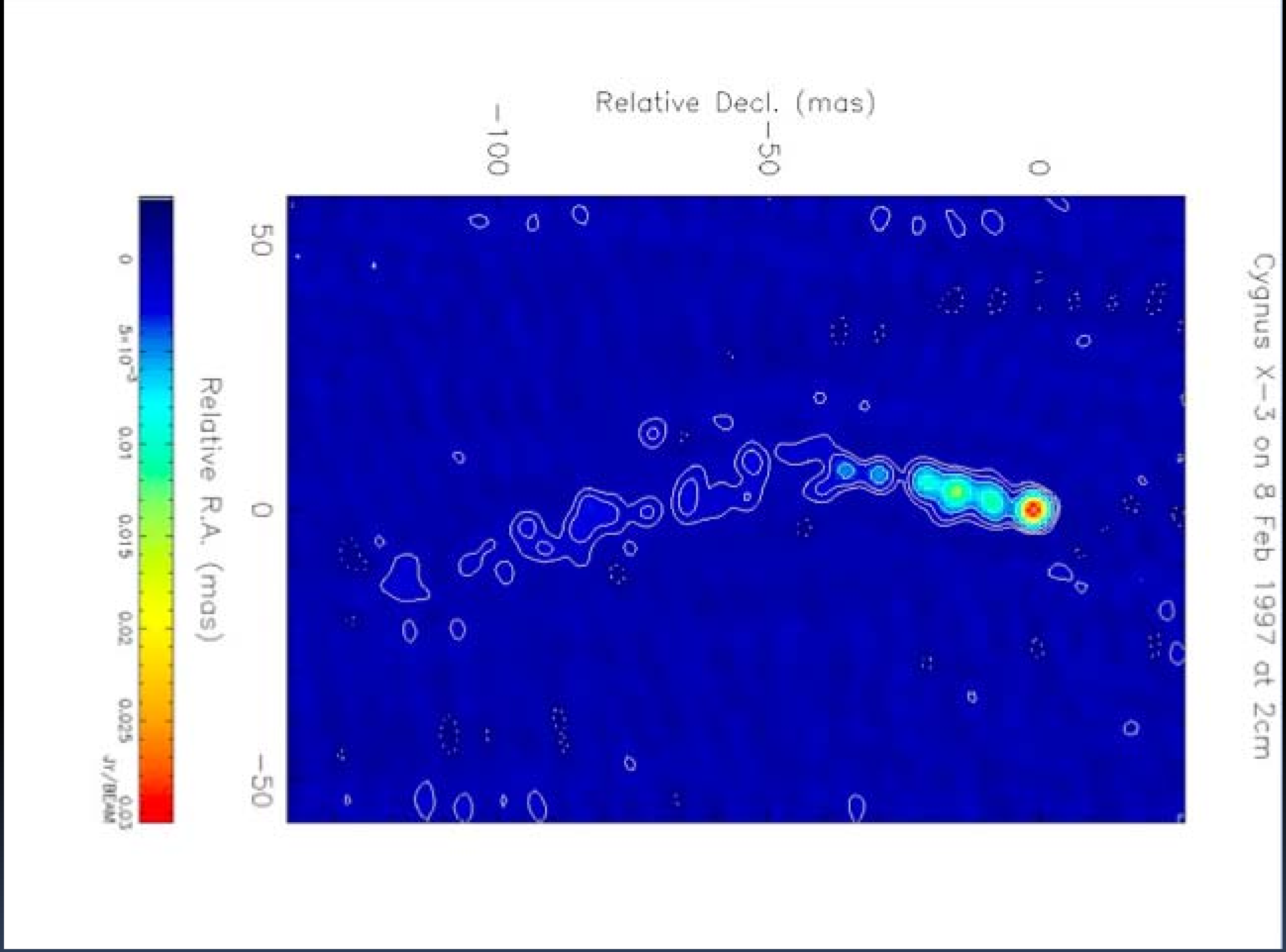
- ATOMIC NUCLEI MOVING AT 0.26c
- MECHANICAL LUMINOSITY > 10^{39} erg/sec
- NON RADIATIVE JETS = “DARK” JETS
- >50% OF THE ENERGY IS NOT RADIATED



Radio (Dubner et al); X-rays (Brinkmann et al)

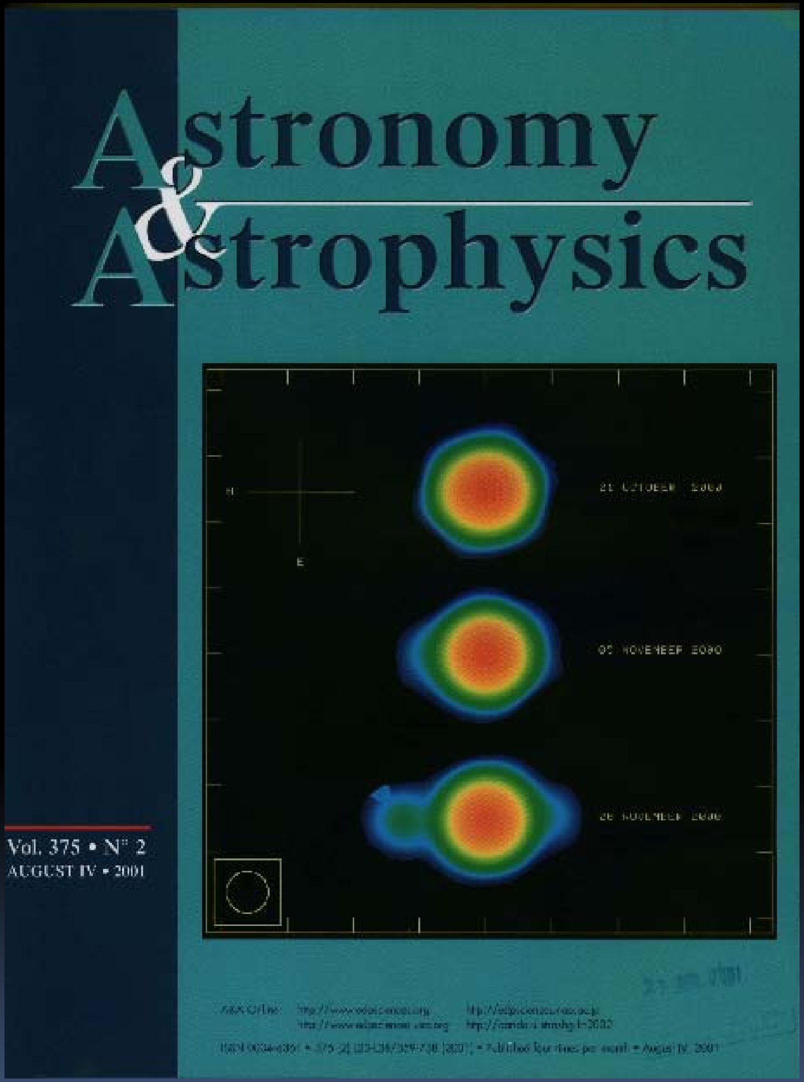
SS 433

Stellar black holes can also produce jets



Cygnus X-3: **Mioduzewski et al. (2001)**

Stellar black holes can also produce jets



Astronomy & Astrophysics

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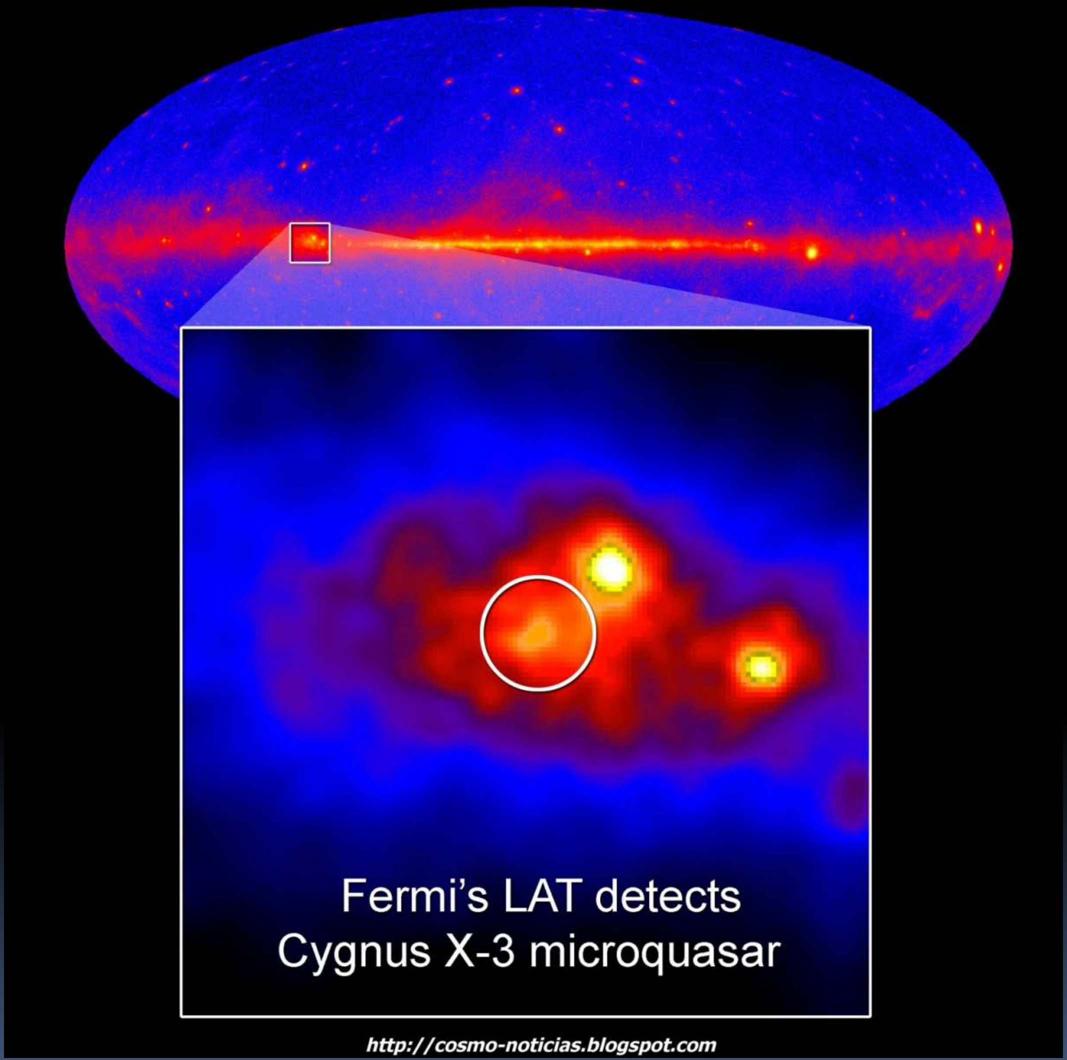
AUGUST IV • 2001

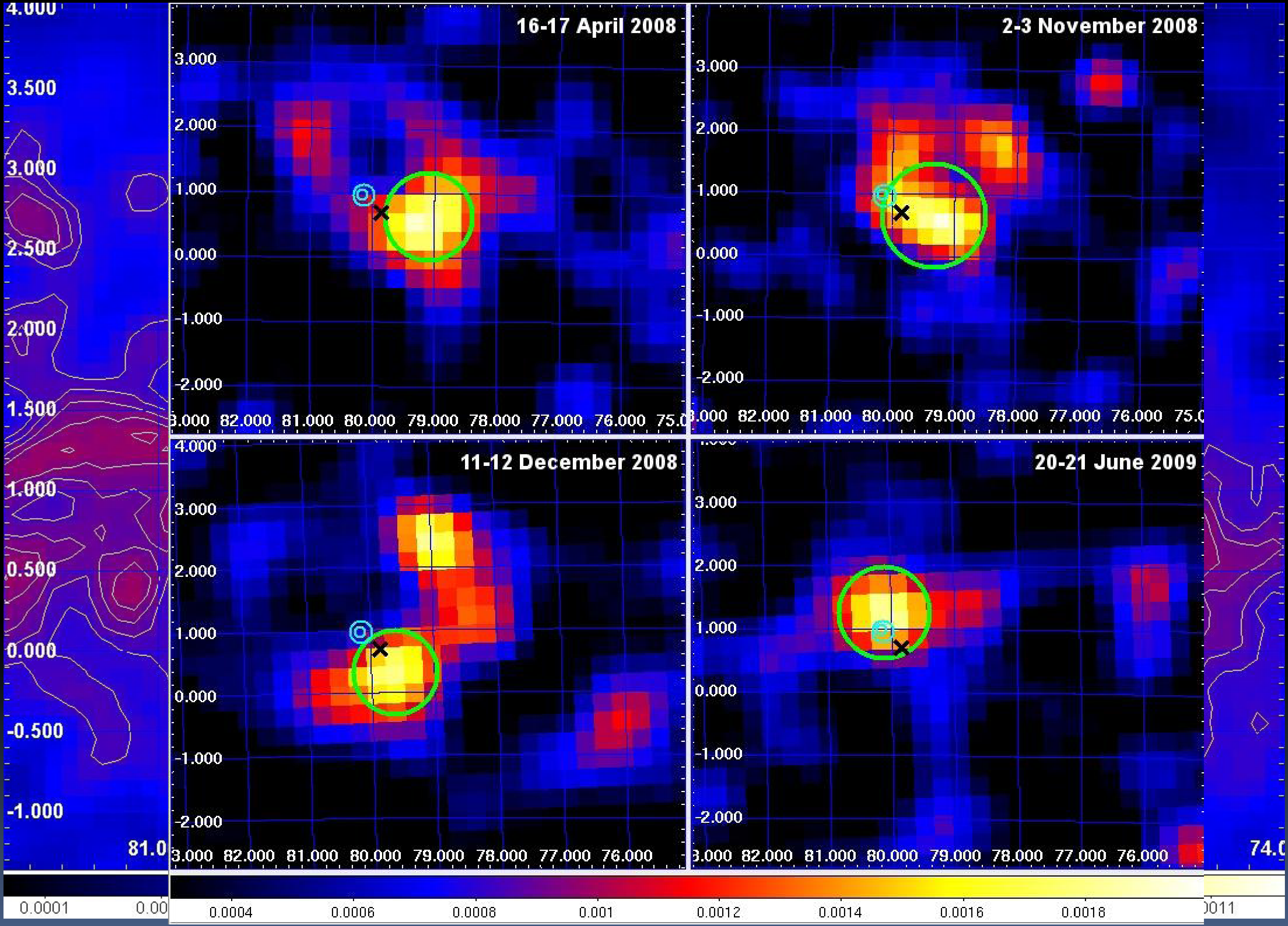
Cygnus X-3: **Martí, Paredes, et al. (200**1)

…and gamma-rays



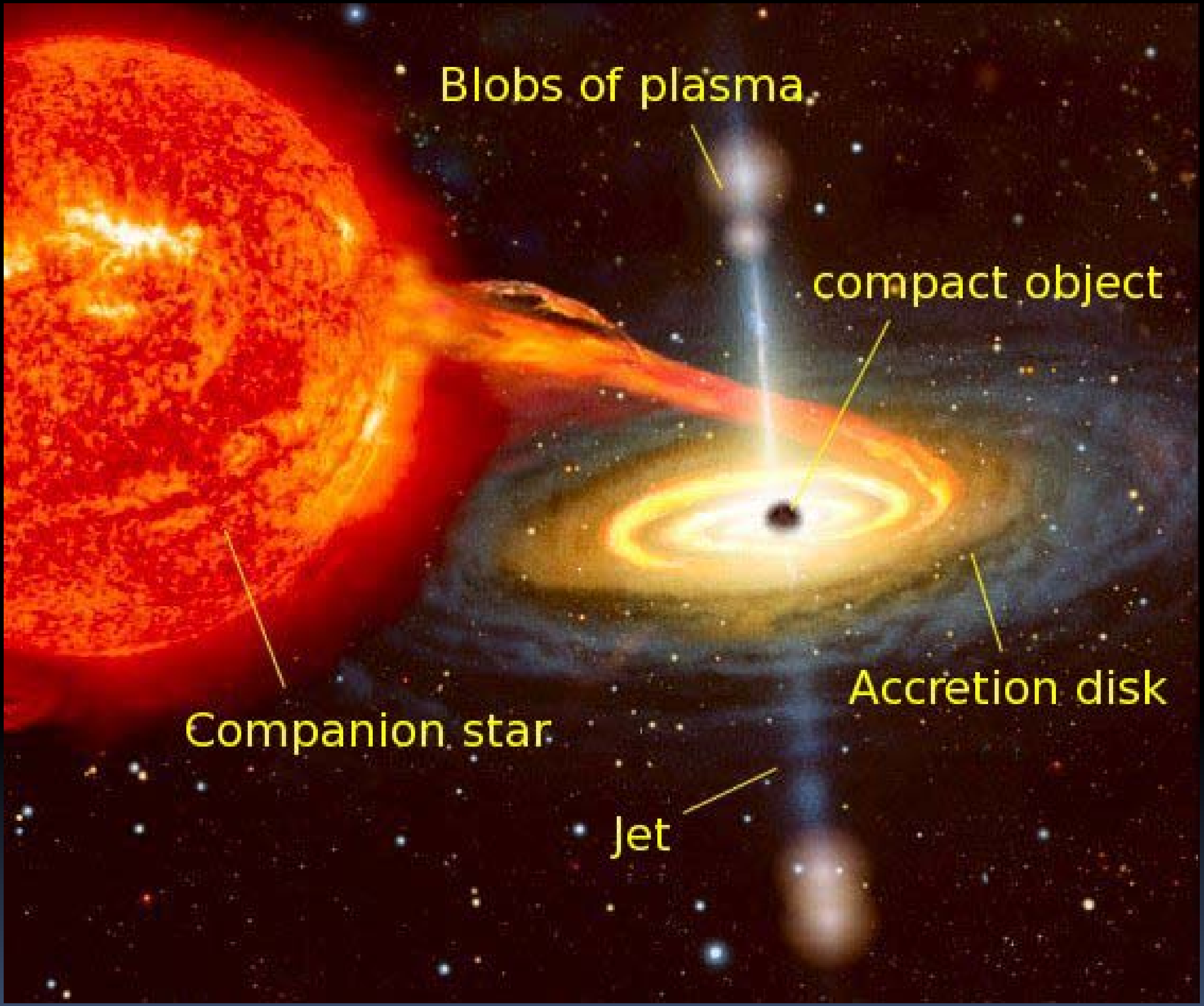
Cygnus X-3: **Fermi collaboration (2009)**

…and gamma-rays



Cygnus X-3: **AGILE collaboration (2009)**

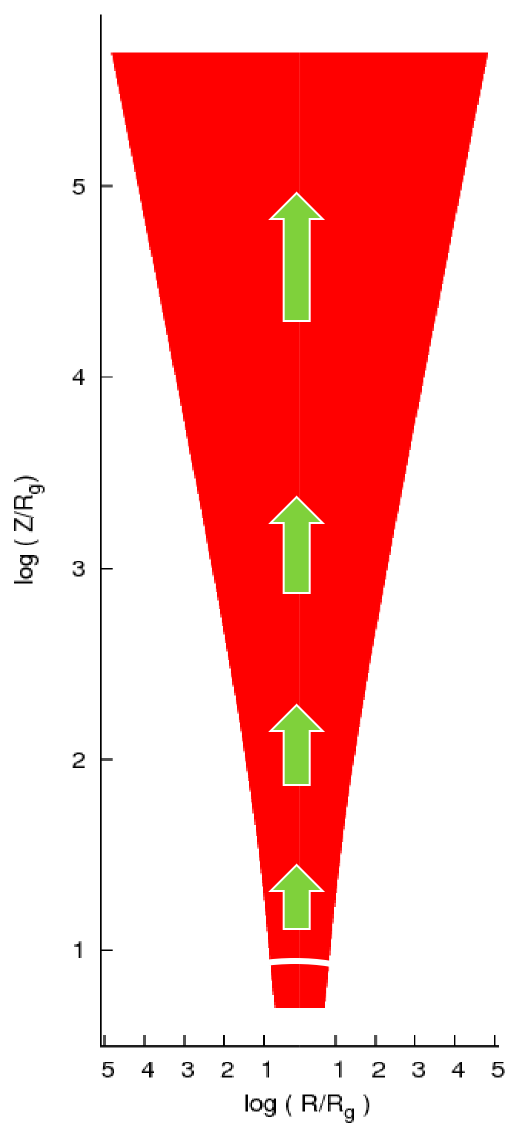
Galactic accreting black holes can also produce jets



A “basic” jet model (in a nutshell)

Physical conditions near the jet base are similar to those of the corona (e.g. Bosch-Ramon et al. 2006; Romero & Vila 2008, 2009; Vila & Romero 2010)

- The jet launching region is quite close to the central compact object (few R_g)
- Thermal plasma injected at the base, equipartition b/w particles and magnetic field to start with.
- Jet plasma accelerates longitudinally due to pressure gradients, expands laterally with sound speed (Bosch-Ramon et al. 2006)
- The plasma cools as it moves outward along the jet. Solve the continuity equation for cooling of the electron and proton energy distributions



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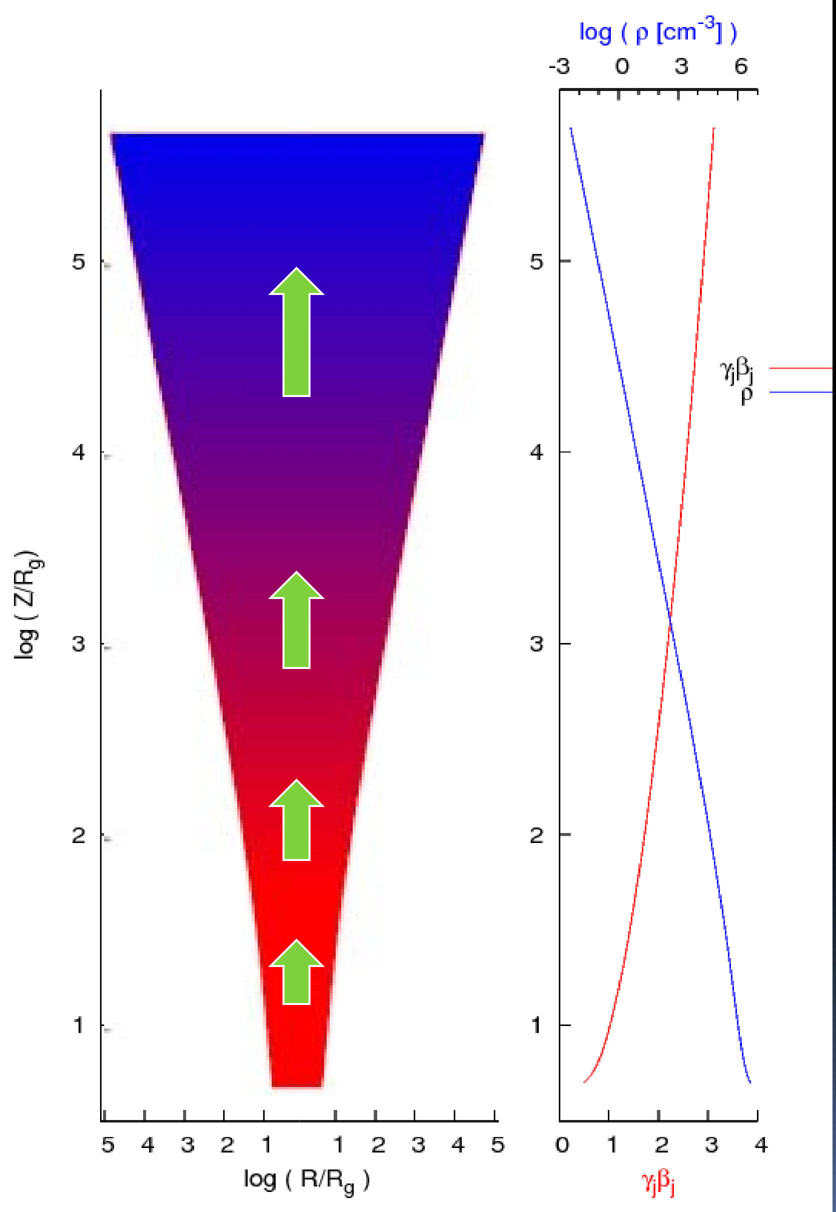
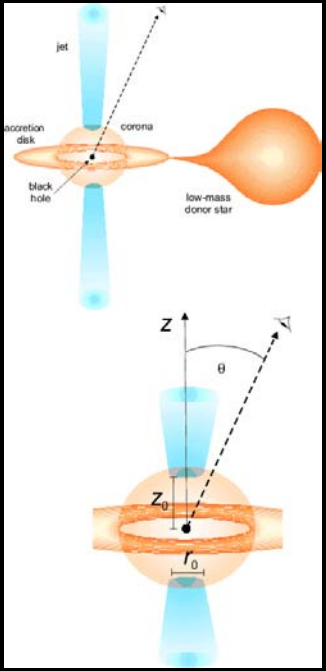
$$\nu_b \frac{\partial N(E,z)}{\partial z} + \frac{\partial \left[b(E,z) N(E,z) \right]}{\partial E} + \frac{N(E,z)}{T_d(E)} = Q(E,z).$$



Jet model



Conical jet, perpendicular to binary orbit

Mildly relativistic outflow

Moderate viewing angle

Compact acceleration/emission region

✓ Content of relativistic particles

$$L_{jet} = 0.1 L_{acc}$$

Falcke & Biermann (1995)

Körding *et al.* (2006)

$$L_{rel} = 0.1 L_{jet} \approx 2\times10^{37}\,\mathbf{erg\ s^{-1}}$$

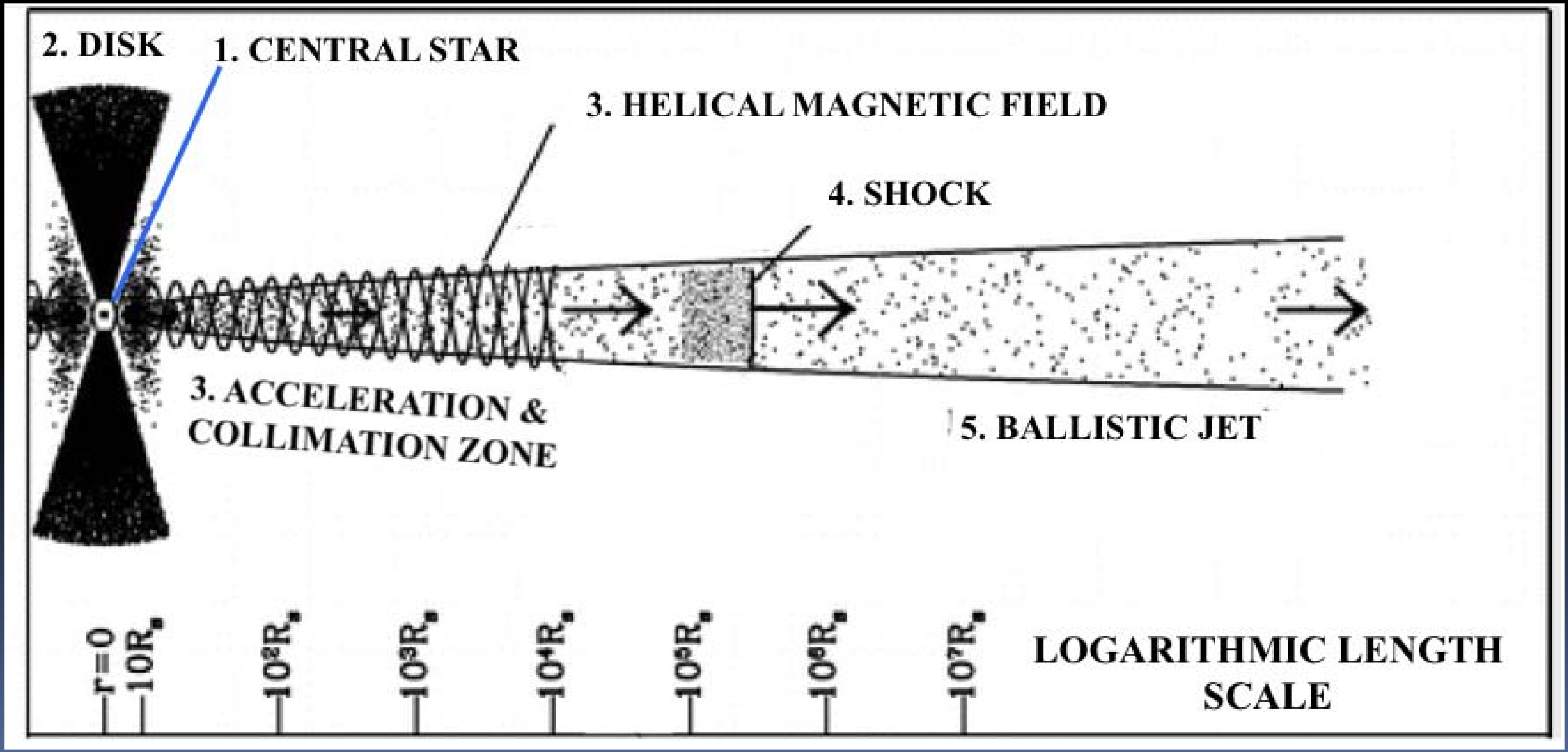
$$L_{rel} = L_p + L_e \quad L_p = a L_e$$

✓ Magnetic field close to equipartition (at the base)

$$\frac{B_0^2}{8\pi} = U_{\rm jet}^{\rm kin}(z_0) \Rightarrow B_0 \approx 10^7\,G$$

$$B(z) = B_0\left(\frac{z_0}{z}\right)^{-m} \qquad 1 \le m \le 2$$

Shocks develop when the magnetic energy decreses and charged particles are re-accelerated by a Fermi-like mechanism (alternatives: converter mechanism – Derishev , local magnetic reconnection – Lyubarsky). Power-law populations of non-thermal particles are injected. These particles will interact with the local fields, producing non-thermal radiation.



Radiative models

Leptonic

Hadronic

A hadronic model for jets is a model that represents radiative processes triggered by protons or other nuclei. There is not such a thing as a *purely hadronic radiative model* in astrophysics. All models are actually lepto-hadronic, since relativistic hadronic interactions unavoidably lead to meson production and the subsequent injection of leptons in the system.

Proton microquasar jet model

(Romero et al. 2003; Aharonian et al. 2006; Romero & Vila, 2008, 2009; Vila & Romero 2010)

Interaction of relativistic *p* and *e*$^-$ with

magnetic field

radiation fields

in the jet

- Synchrotron radiation $p,\ e^- + B \to p,\ e^- + \gamma$
- Inverse Compton (IC) $e^- + \gamma \to e^- + \gamma$
- Proton-proton inelastic collisions $p + p \to p + p + a\,\pi^0 + b(\pi^+ + \pi^-)$
- Photohadronic interactions (*p*γ) $p + \gamma \to p + e^+ + e^-$

$$e^\pm + B \to e^\pm + \gamma$$

$$\pi^o p \to 2\gamma \to p + a\pi^o + b(\pi^+ + \pi^-)$$

$$\pi^{\cdot}\ p + \gamma \to n + \pi^+ + a\pi^o + b(\pi^+ + \pi^-)\ \ _{\iota}(\nu_\mu)$$

Particle losses

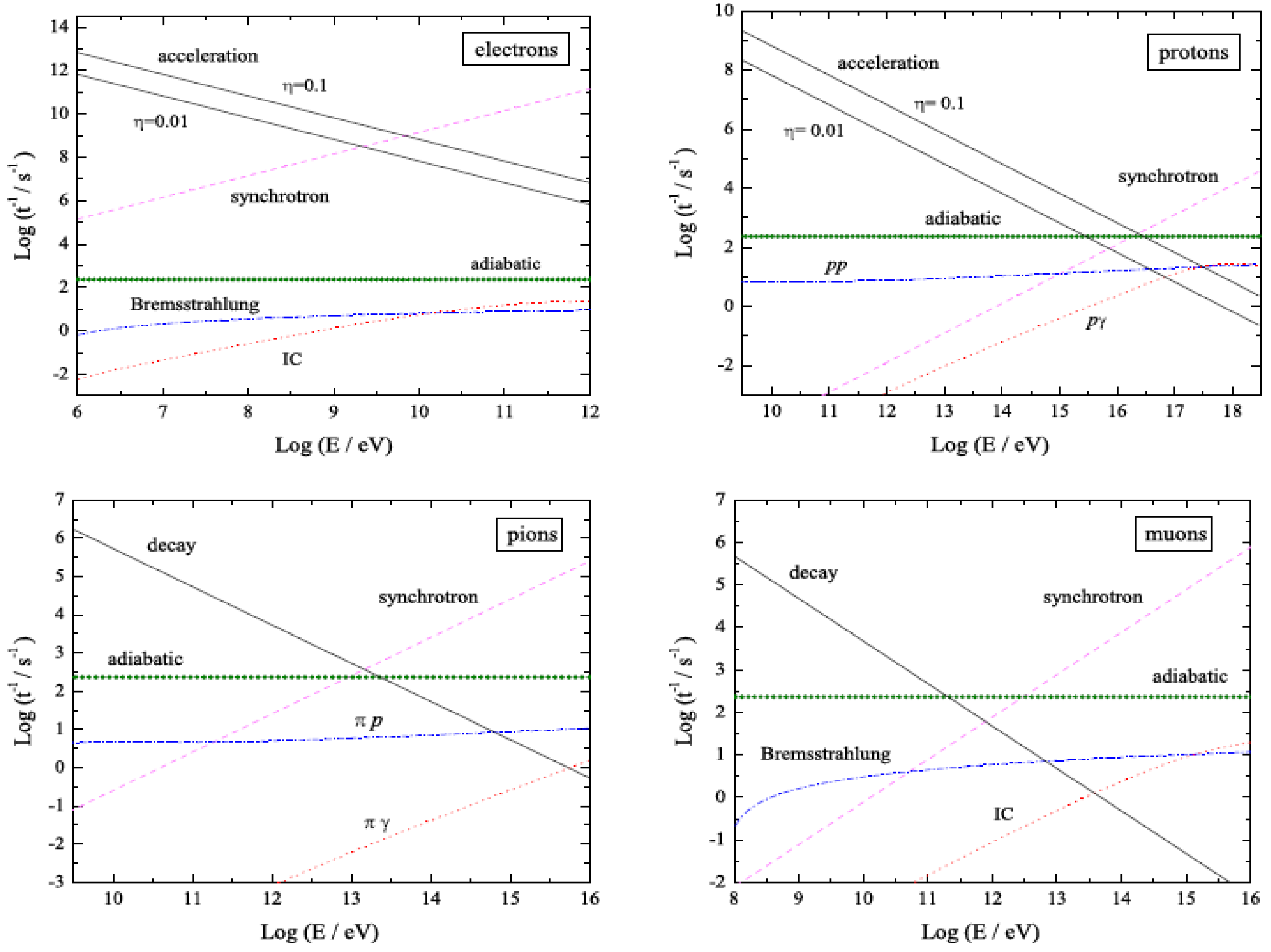


Fig. 1. Acceleration and cooling rates at the base of the jet for primary protons and electrons, and secondary pions and muons, calculated for representative values of the model parameters (proton-to-lepton energy ratio $a = 1000$, and primary injection spectral index $\alpha = 1.5$). The acceleration efficiency parameter η is indicated.

Spectral energy distributions

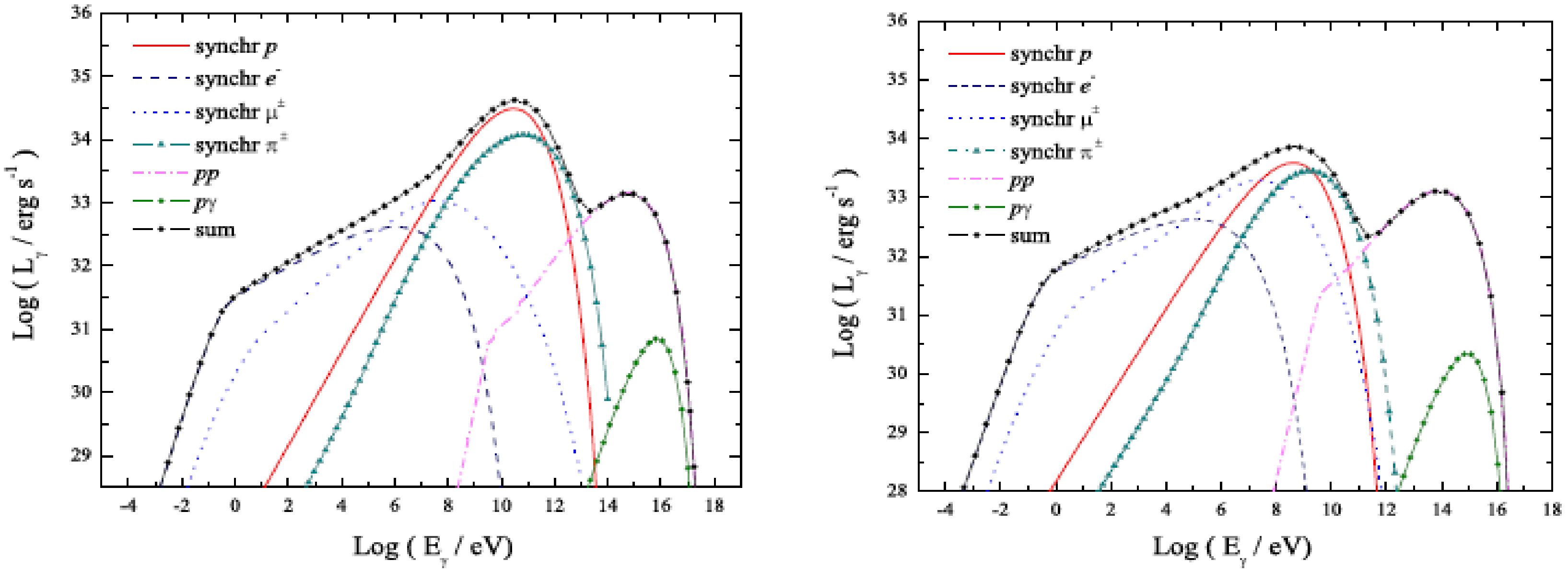
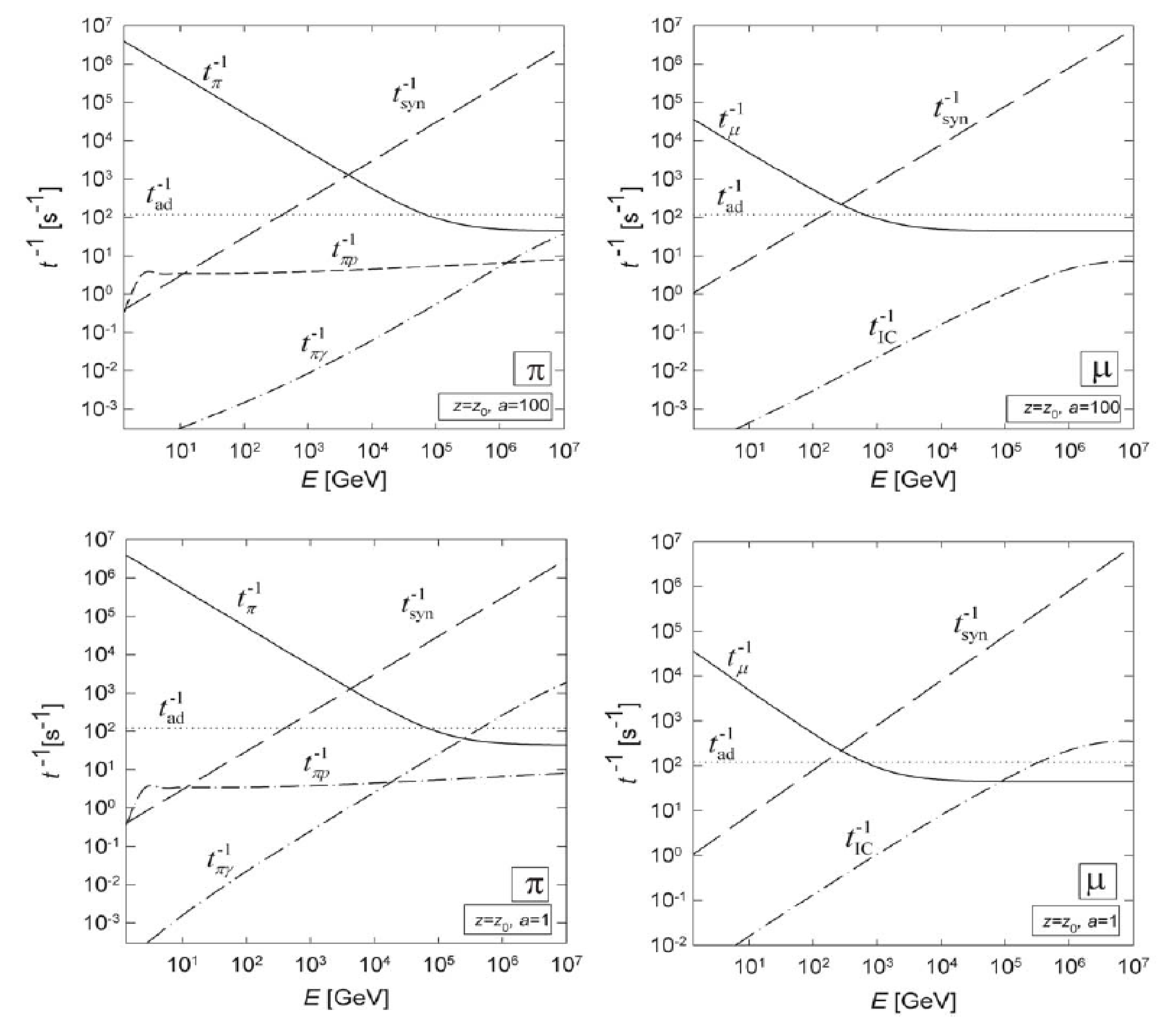


Fig. 2. Spectral energy distributions of a proton-dominated microquasar ($a = 1000$). Each panel corresponds to a different acceleration efficiency ($\eta = 0.1$ on the left, $\eta = 0.01$ on the right).

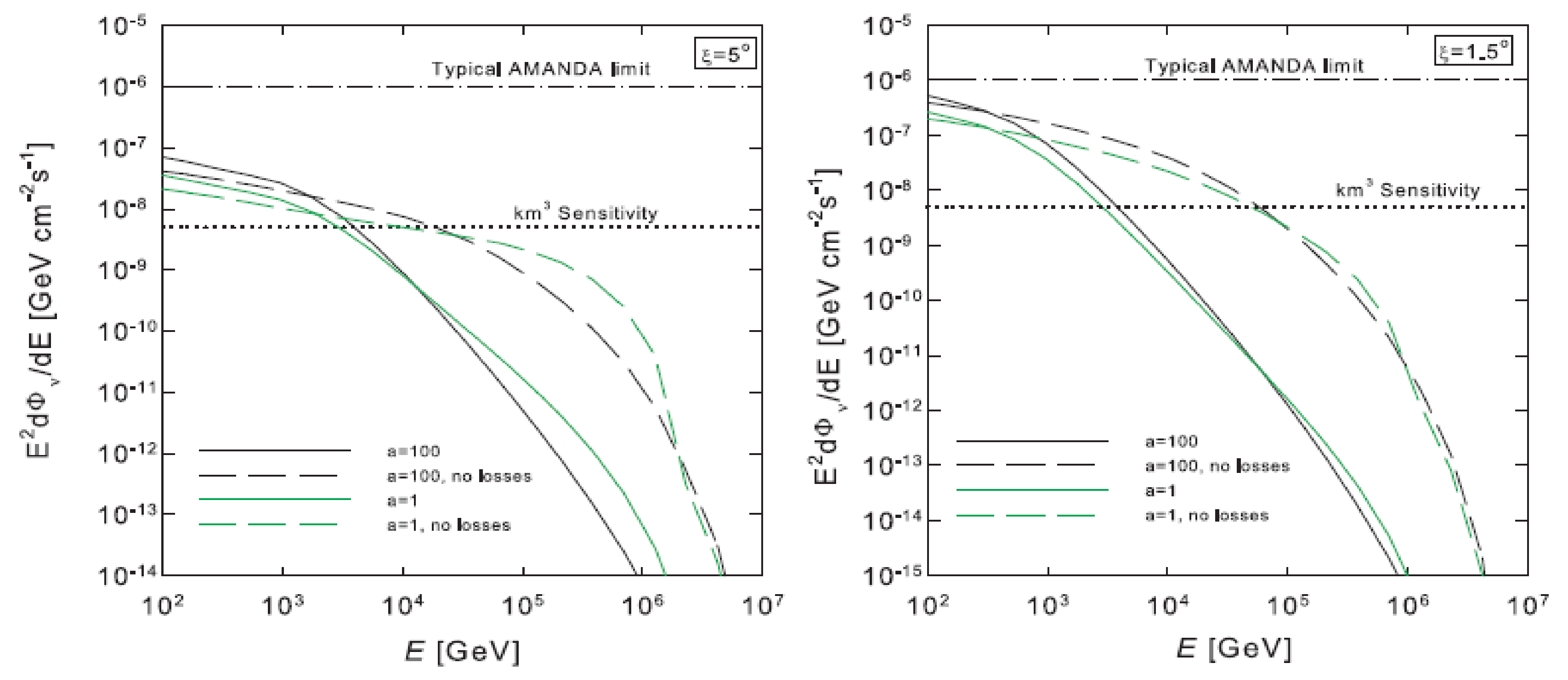
Romero & Vila, A&A, 494, L33 (2009)

Magnetic field effects on neutrino



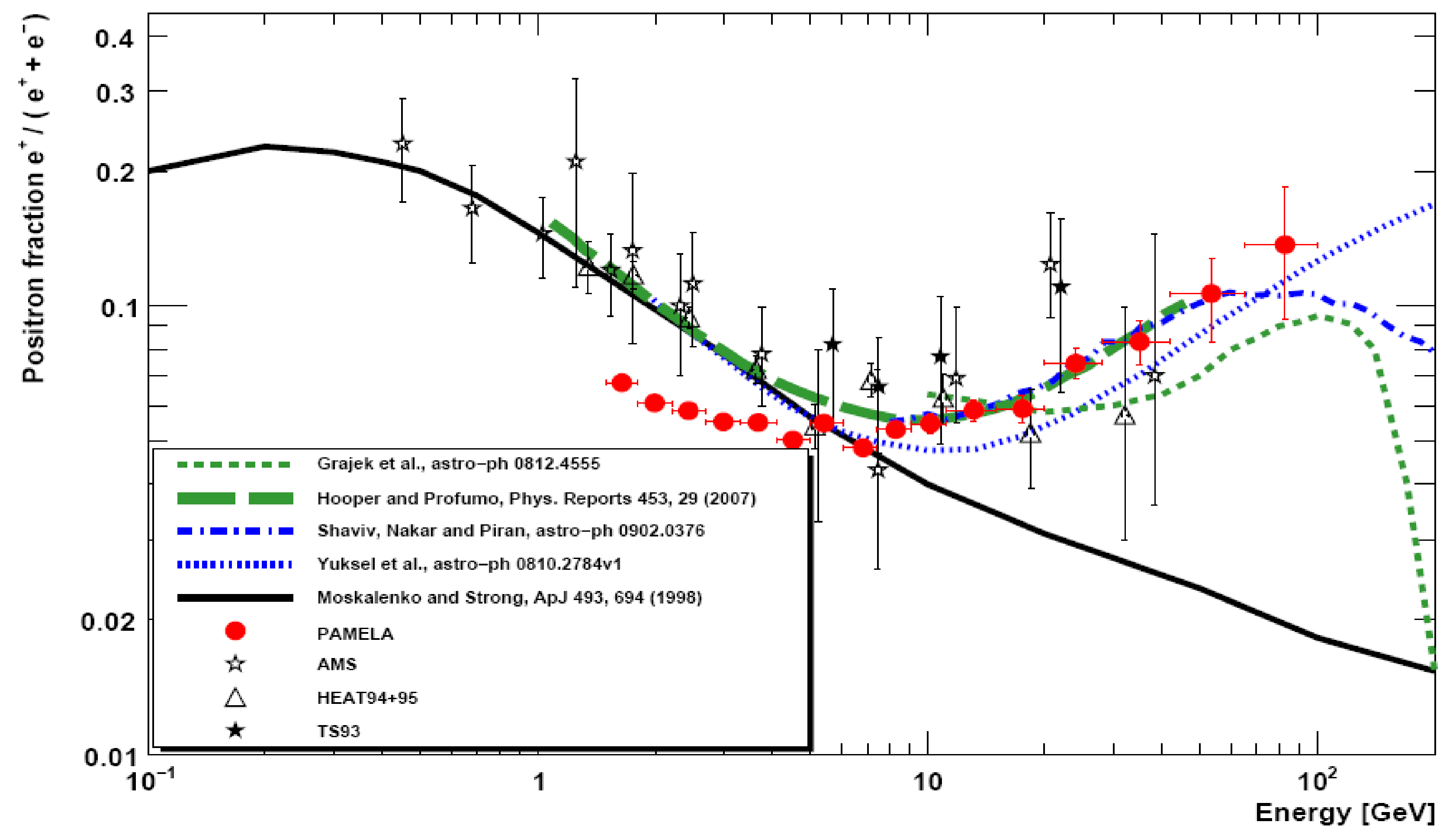
Reynoso & Romero A&A, 493, 1 (2009)

Magnetic field effects on neutrino production

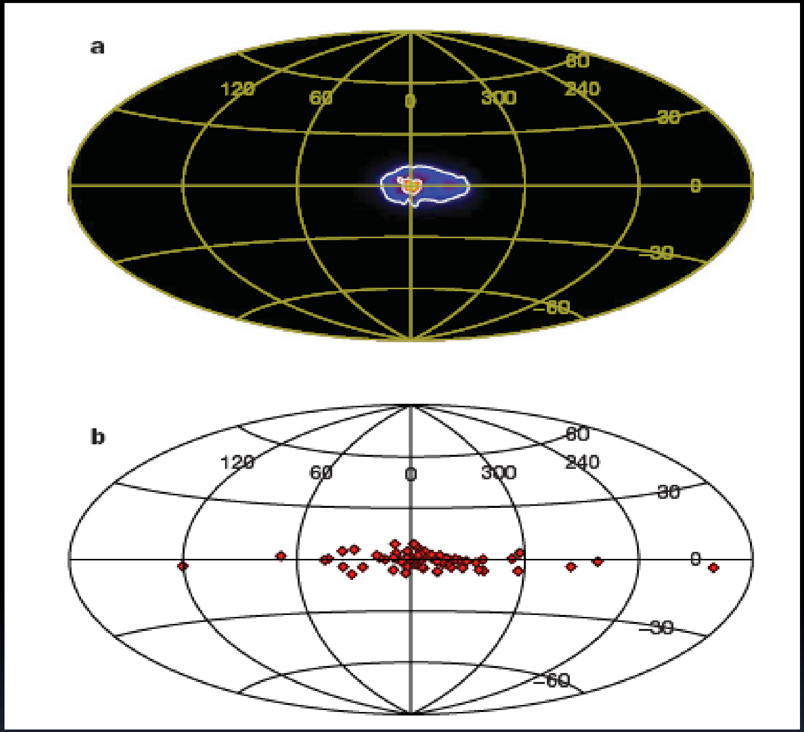


Reynoso & Romero A&A, 493, 1 (2009)

PAMELA positron fraction



Positrons are copiously produced by internal absorption and charged muon decays in MQs jets



Annihilation line distribution

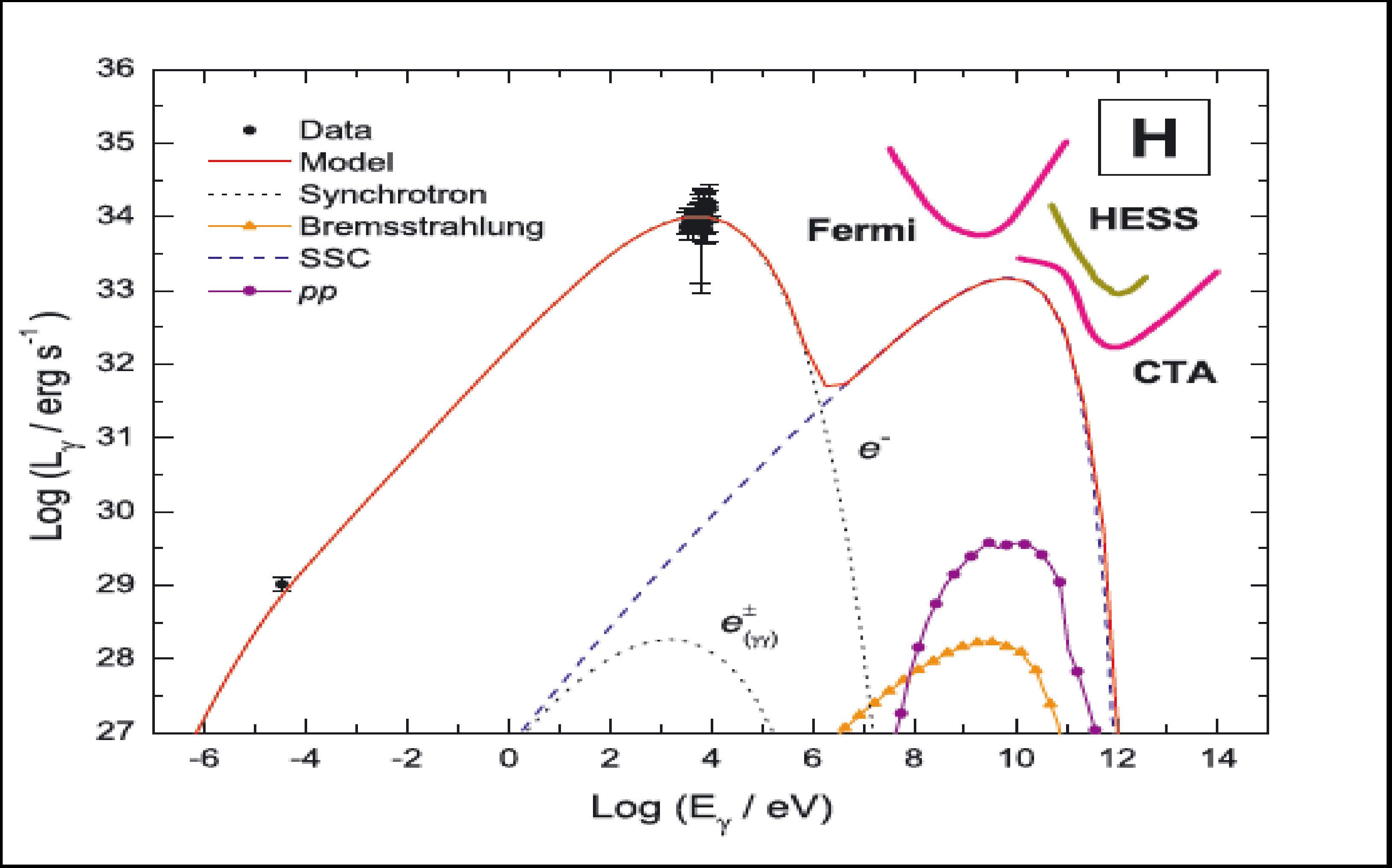
LMXRBs distribution

INTEGRAL results (Weidenspointener et al., Nature 451, 159, 2008)

Models with a=100 produces around 10^{42} positrons/s

Lepto/hadronic models for LMXRB

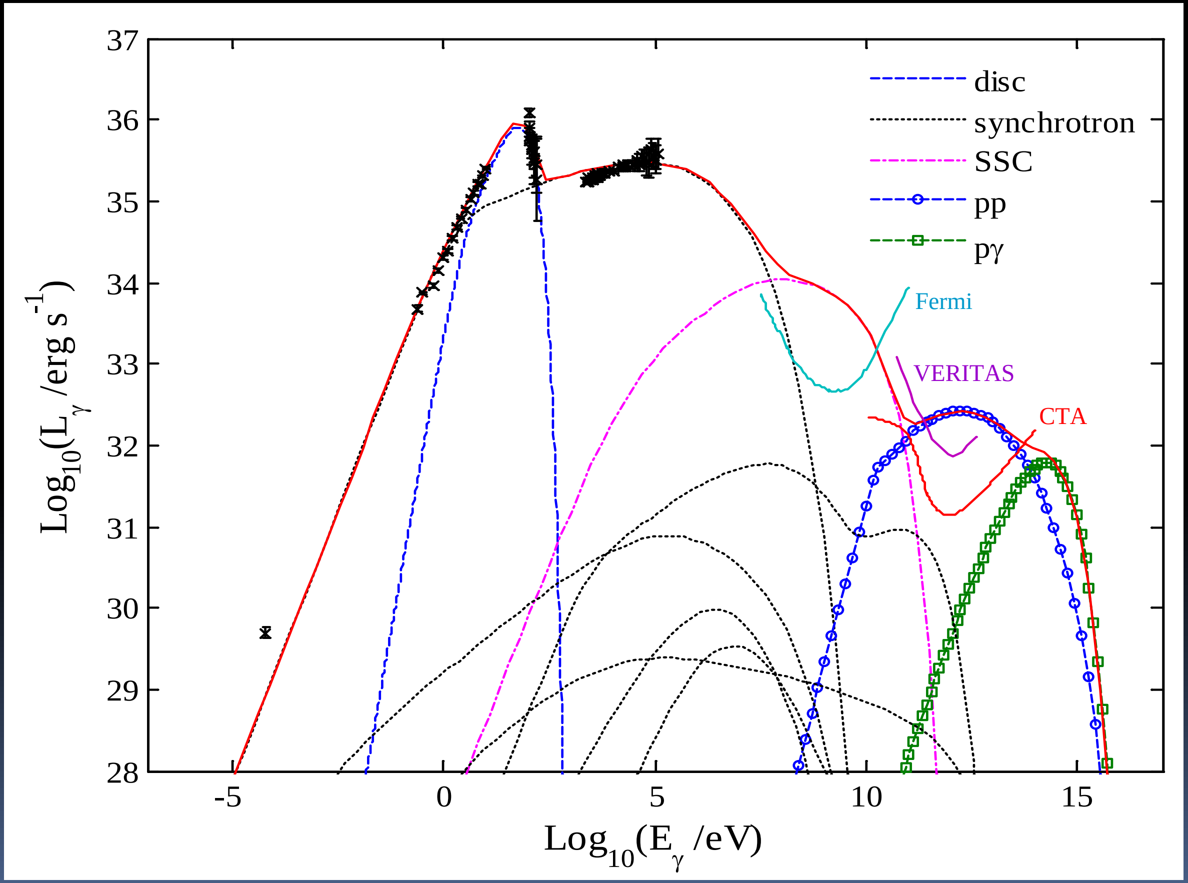
(Vila & Romero, MNRAS 403, 1457, 2010)



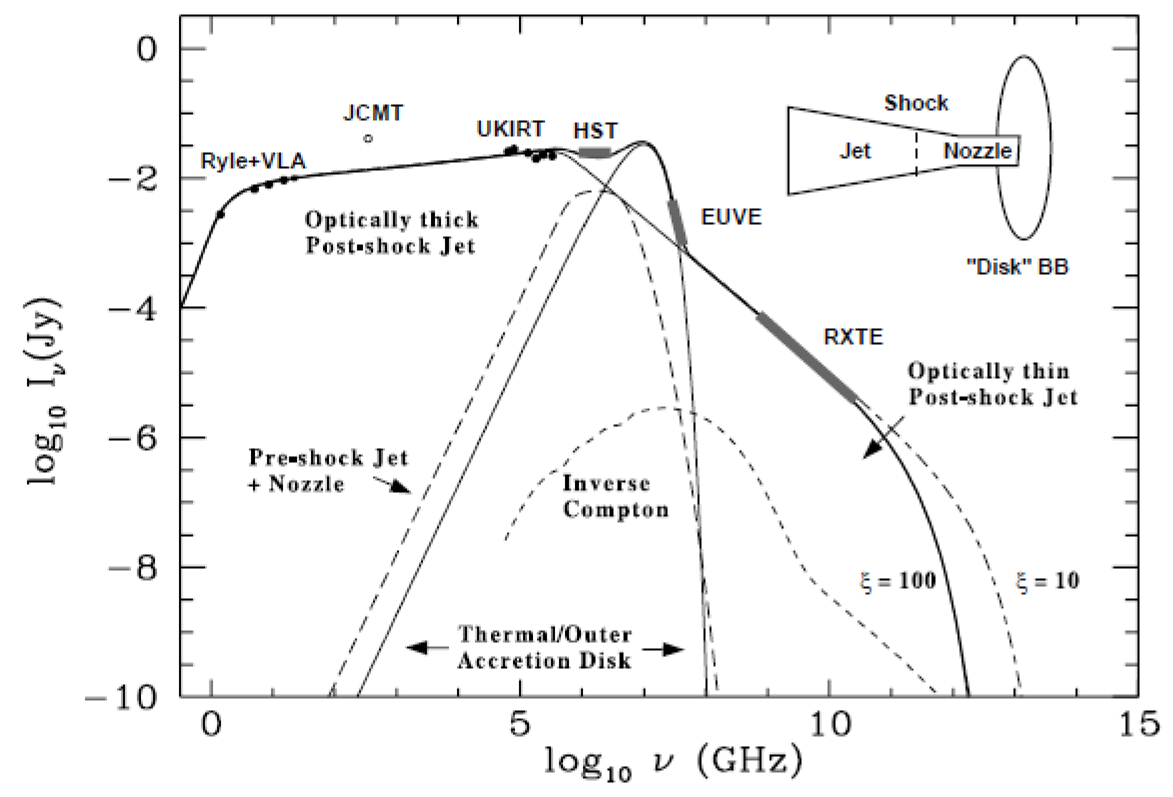
GX 339-4

An application – Vila & Romero, extended-zone model, 2011
Fit to the spectrum of the LMMQ XTE J1118+480

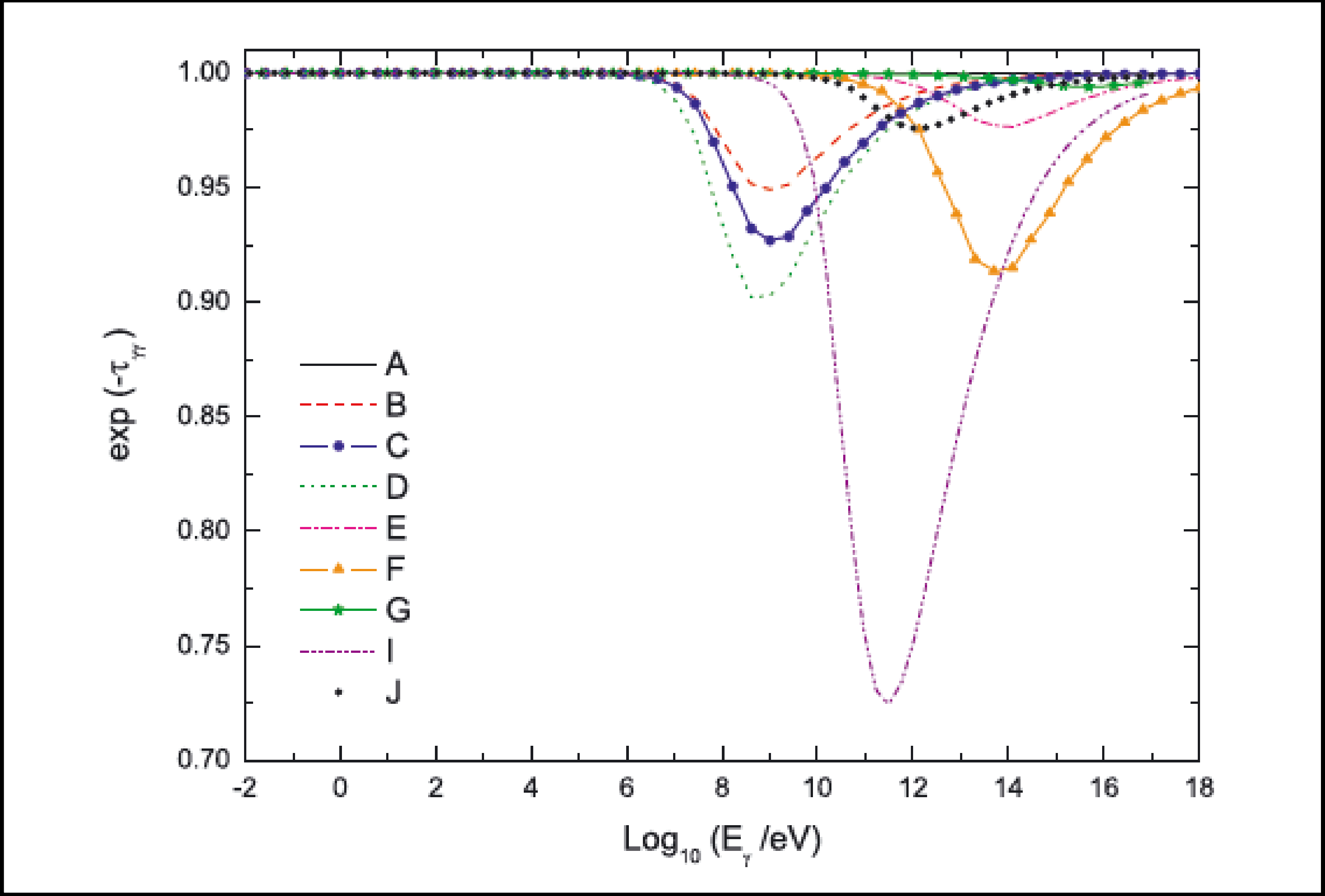
2000 outburst



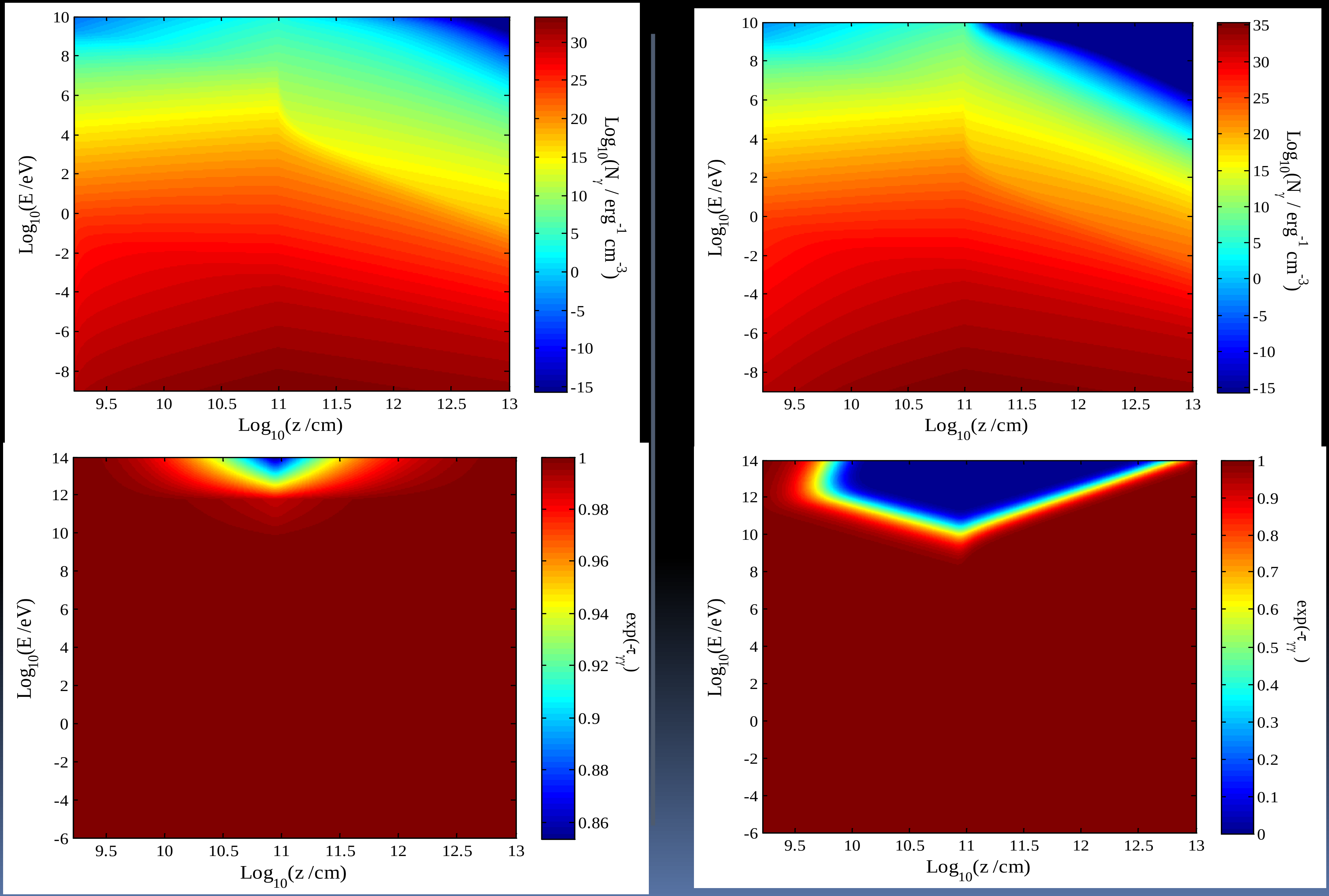
Markoff et al. 2001, A&A



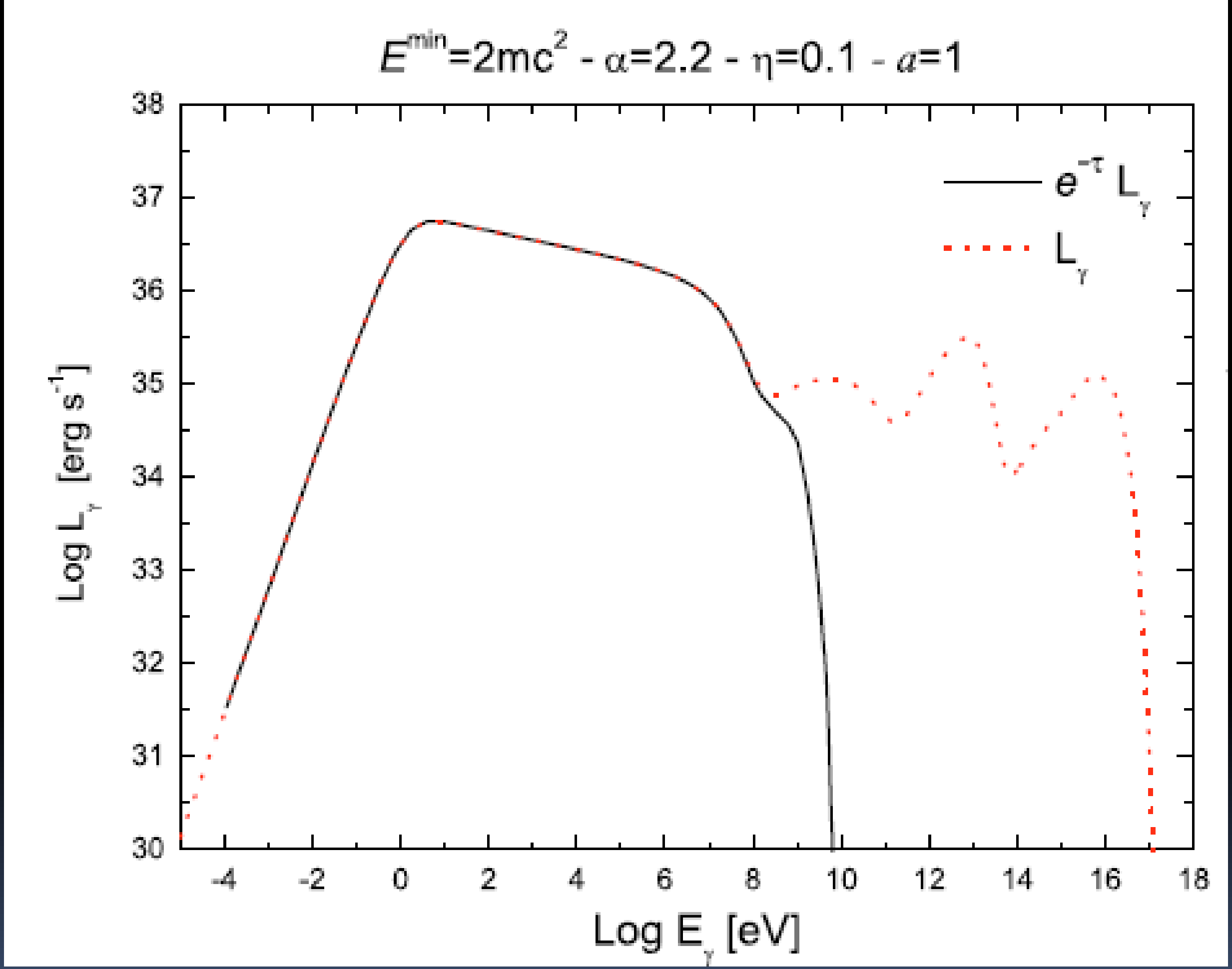
Internal absorption (Vila & Romero, 2010)



Absoption effects: γγ annihilation (Vila & Romero 2011)

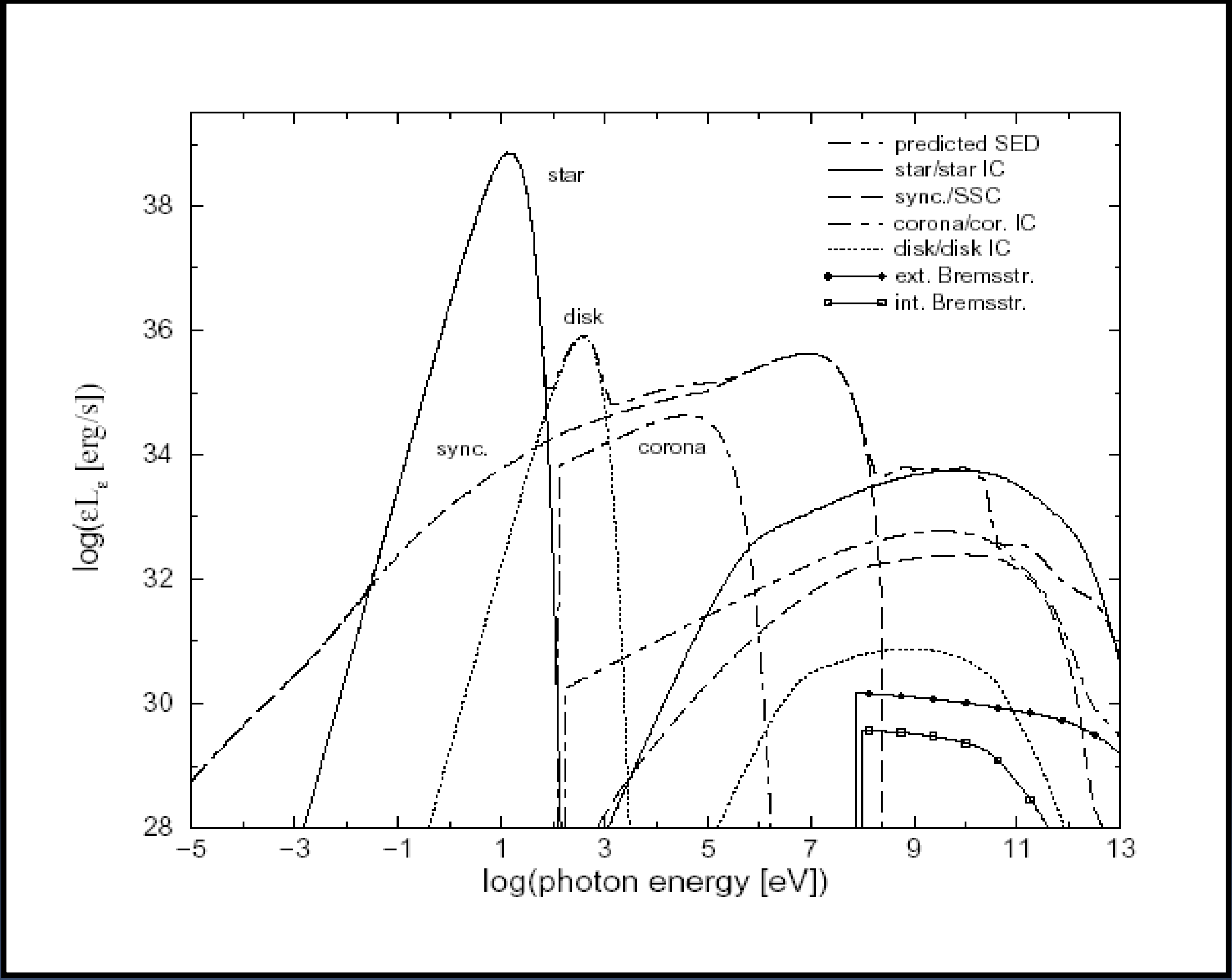


“Dark” HE MQ (Romero & Vila 2008)



However, a strong neutrino source…

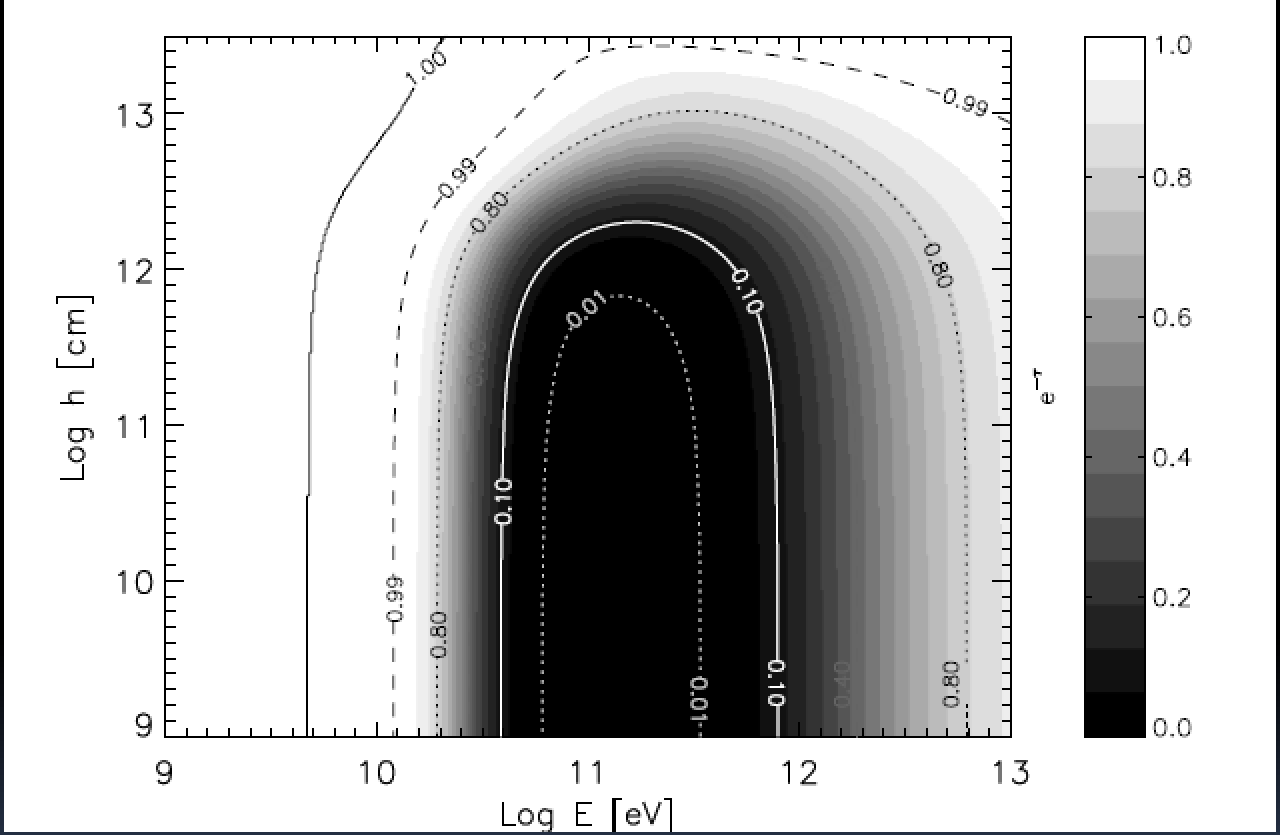
High-mass donor star



Bosch-Ramon, Romero, Paredes, 2006, A&A 447, 263

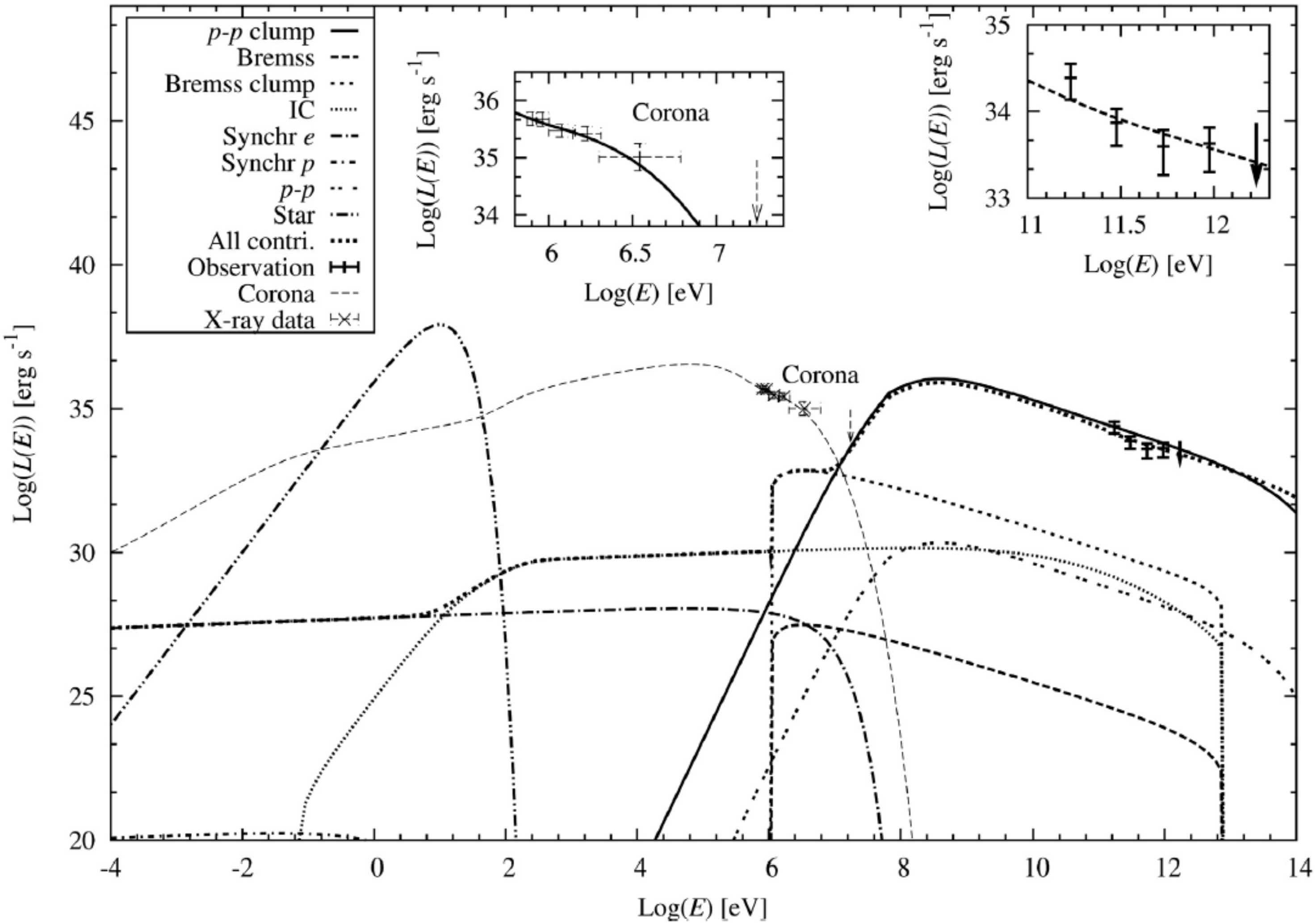
High-mass donor star: Cygnus X-1

External absorption



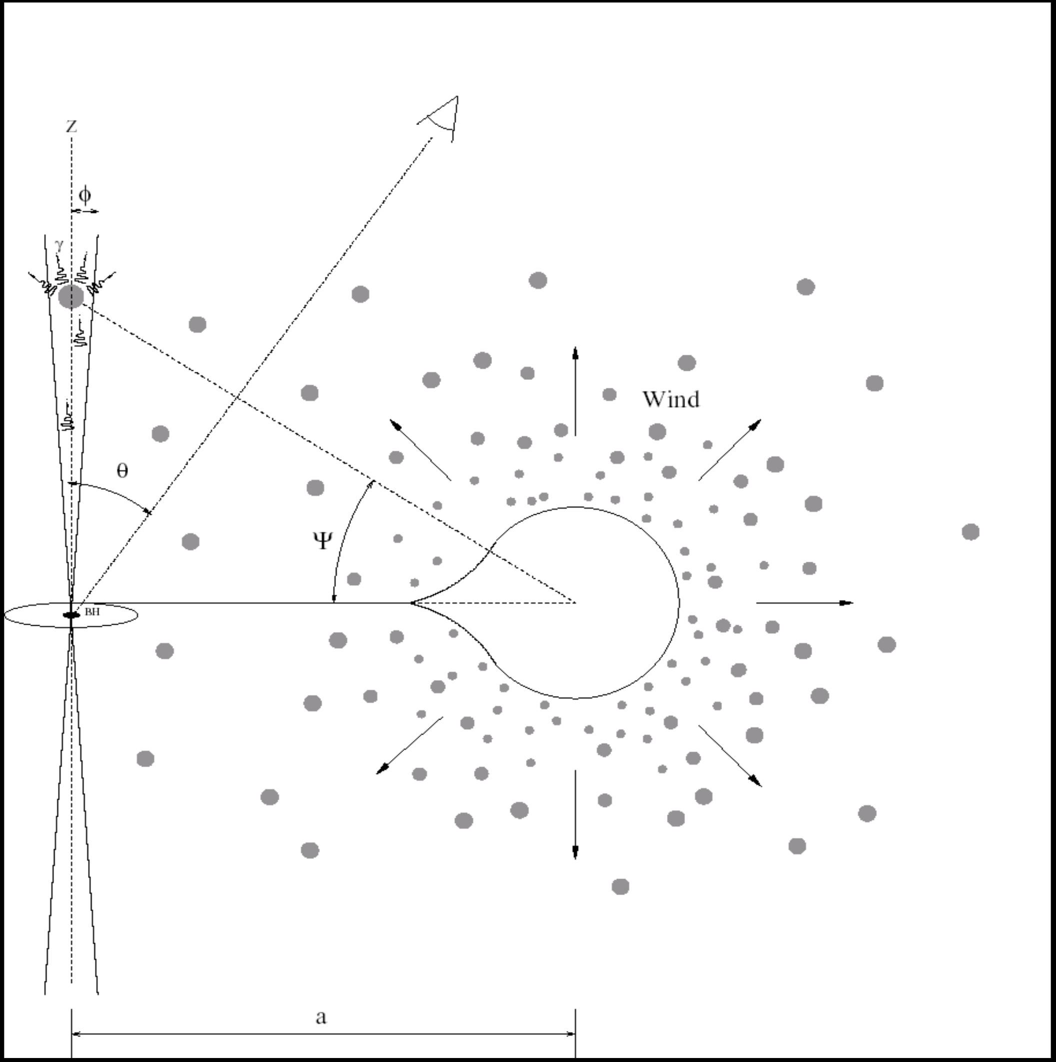
Romero, del Valle, & Orellana, 2010, A&A 518, A12; see also
Bosch-Ramon, Khangulyan & Aharonian, 2008, A&A, 489, L21

G. E. Romero et al.: Gamma-ray flares in Cyg X-1



$Z > 10^{12}$ cm

A microquasar with a clumped wind



Araudo, Bosch-Ramon & Romero A&A, 503, 673 (2009), Owocki et al. 2009, ApJ, 696, 690 (2009)

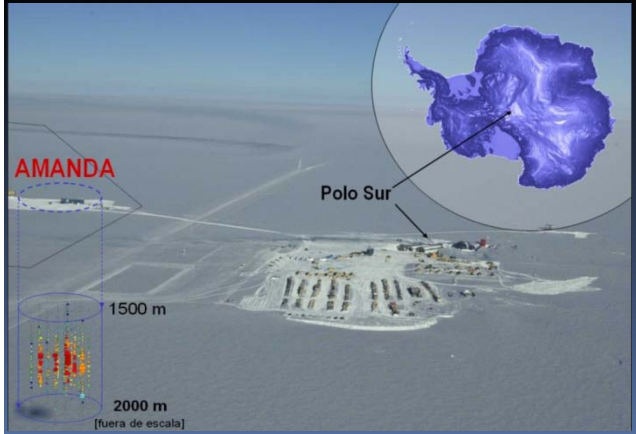
Final comments

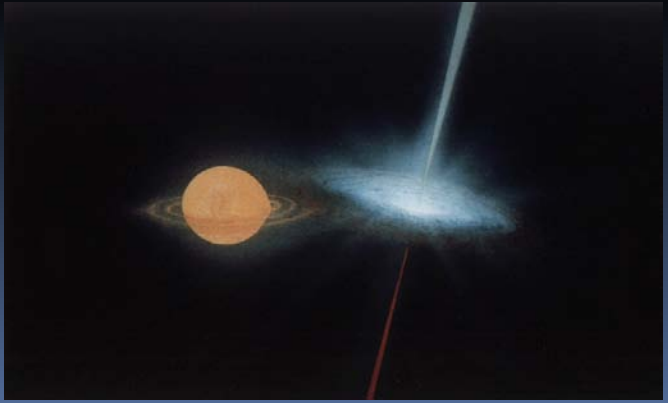
- MQs produce gamma-rays, likely in the jets.

- The consistency of the models presented can be tested with present and future gamma-ray and neutrino observations (IceCube, Fermi, CTA…).

- MQs can be sources of comic rays up to energies of the order of the knee.

- MQs can also be an important source of positrons in the Galaxy.

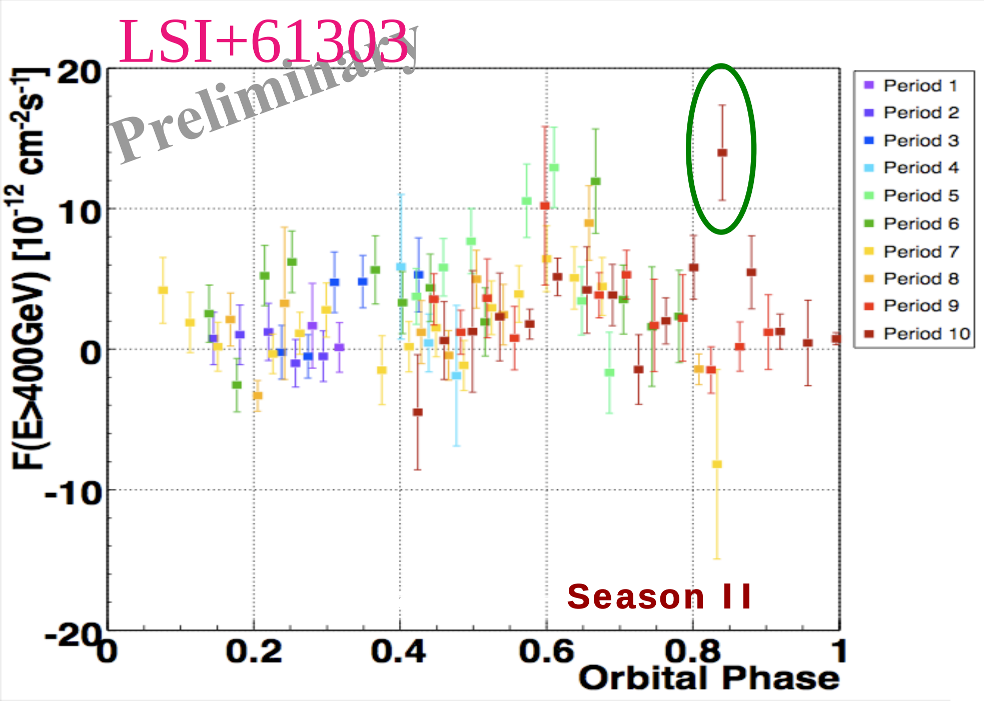




Thank you

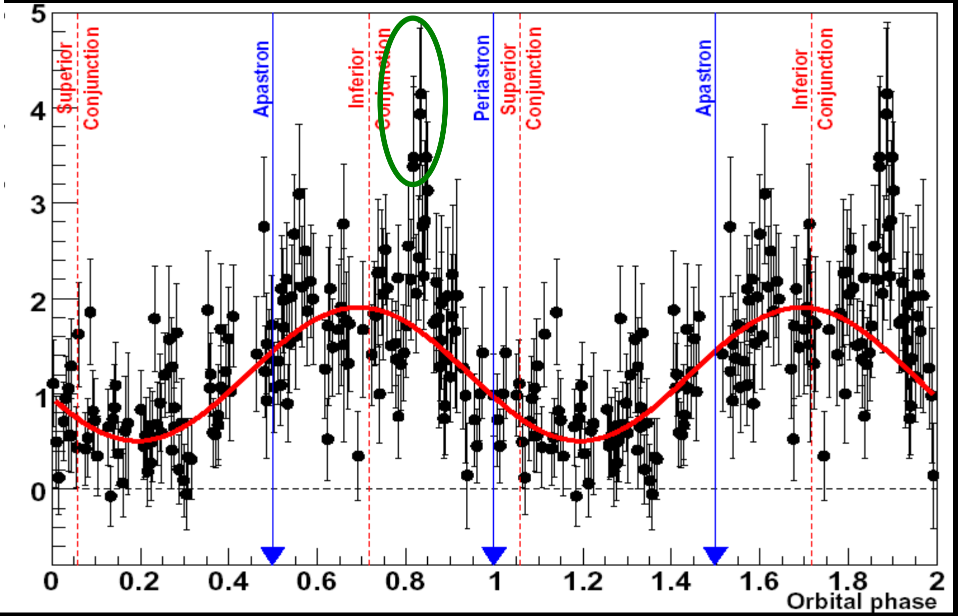
MAGIC

LSI+61303

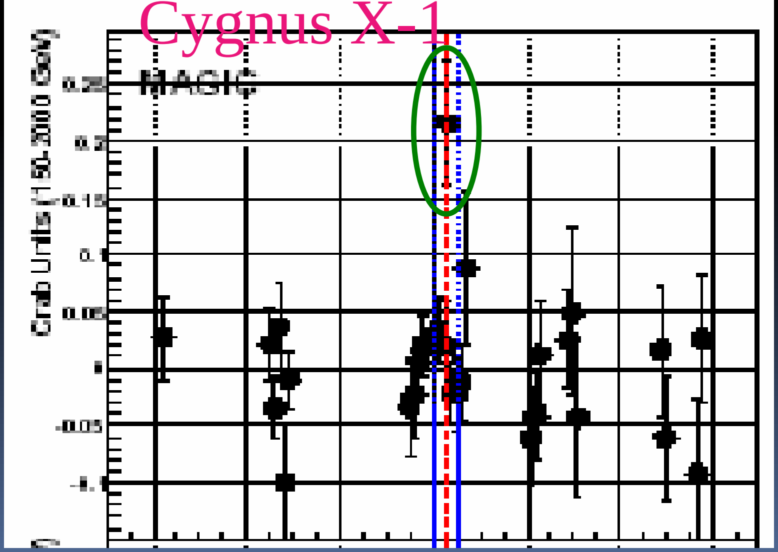


HESS

LS 5039



Cygnus X-1

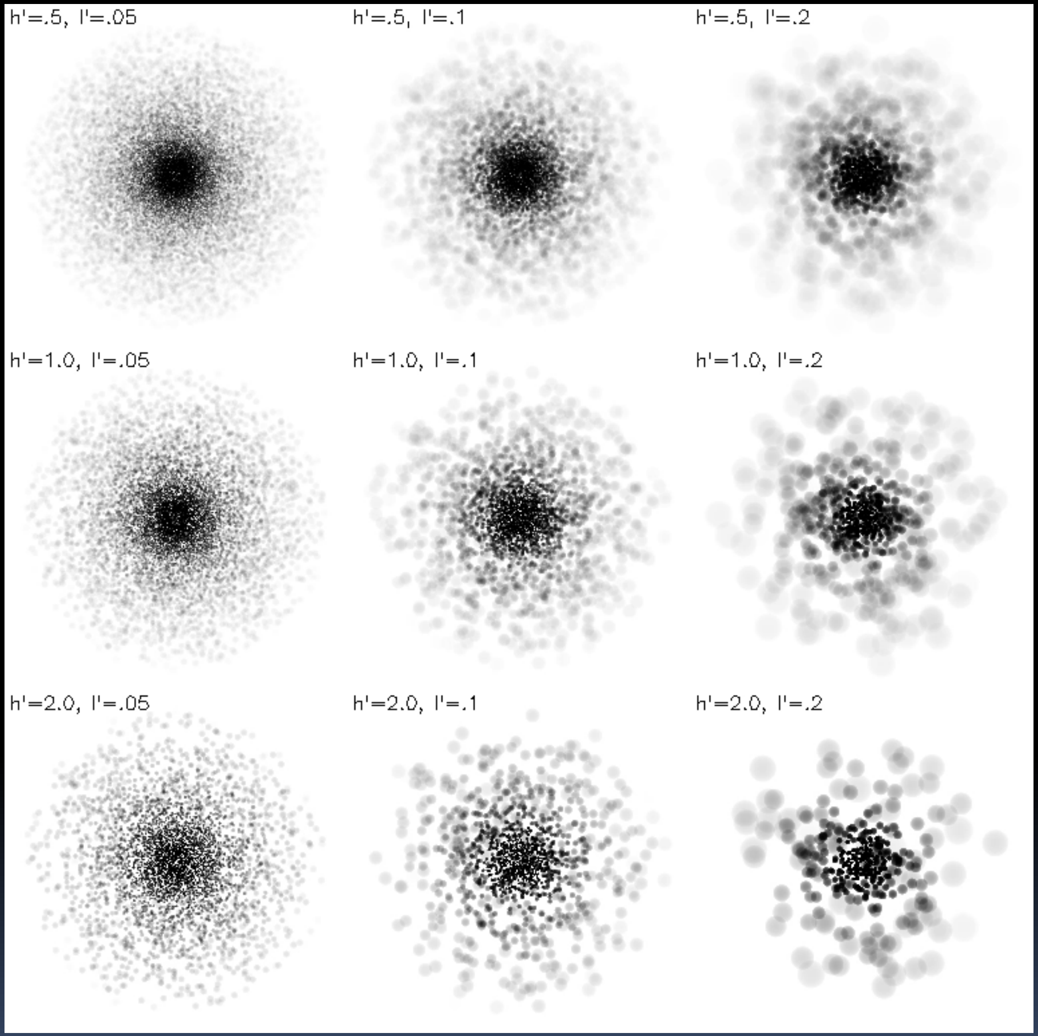


Flaring TeV emission?

If the wind has a clumpy structure, then jet-clump interactions can produce rapid flares of gamma-rays

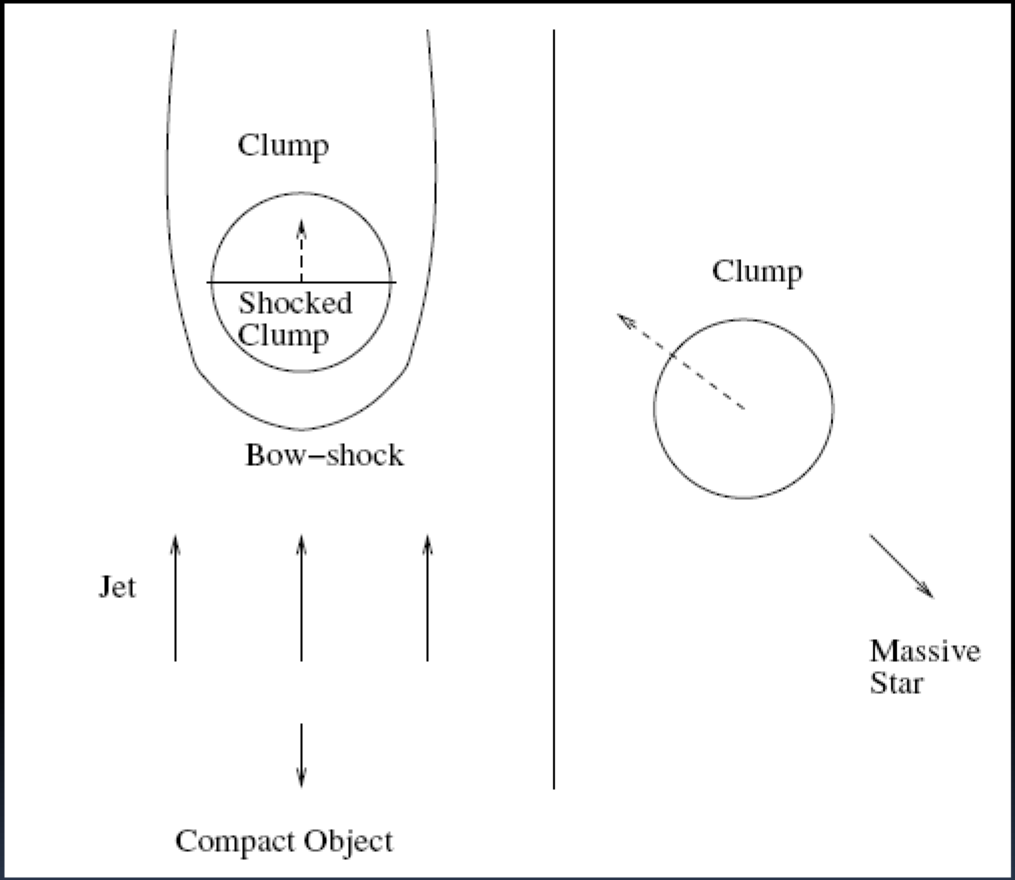
Romero et al. 2007, astro-ph/0708.1525

Effects of the stellar wind



Owocki et al. 2009, ApJ, 696, 690

A microquasar with a clumped wind



Araudo, Bosch-Ramon & Romero A&A, 503, 673 (2009)

A microquasar with a clumped wind

Insta

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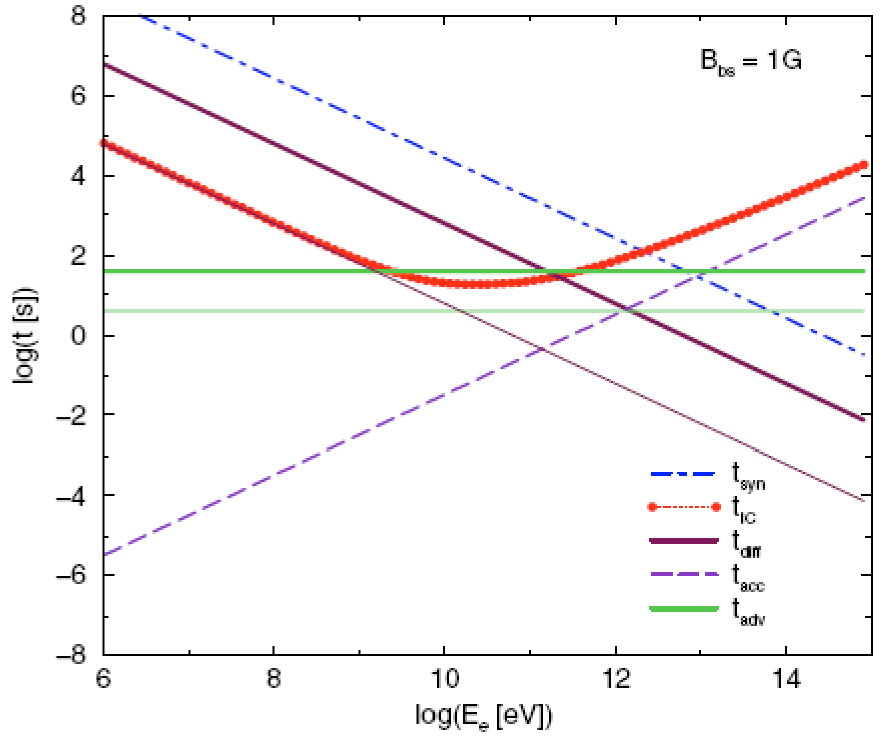

Fig. 3. Acceleration and radiative loss (synchrotron and IC) time for electrons in the bow-shock region. The advection and diffusion times are shown for $R_c = 10^{10}$ (thin line) and 10^{11} cm (thick line). This figure corresponds to the case B_{bs} = 1 G.

Local particle re-acceleration

Araudo, Bosch-Ramon & Romero A&A, 503, 673 (2009)

A microquasar with a clumped wind

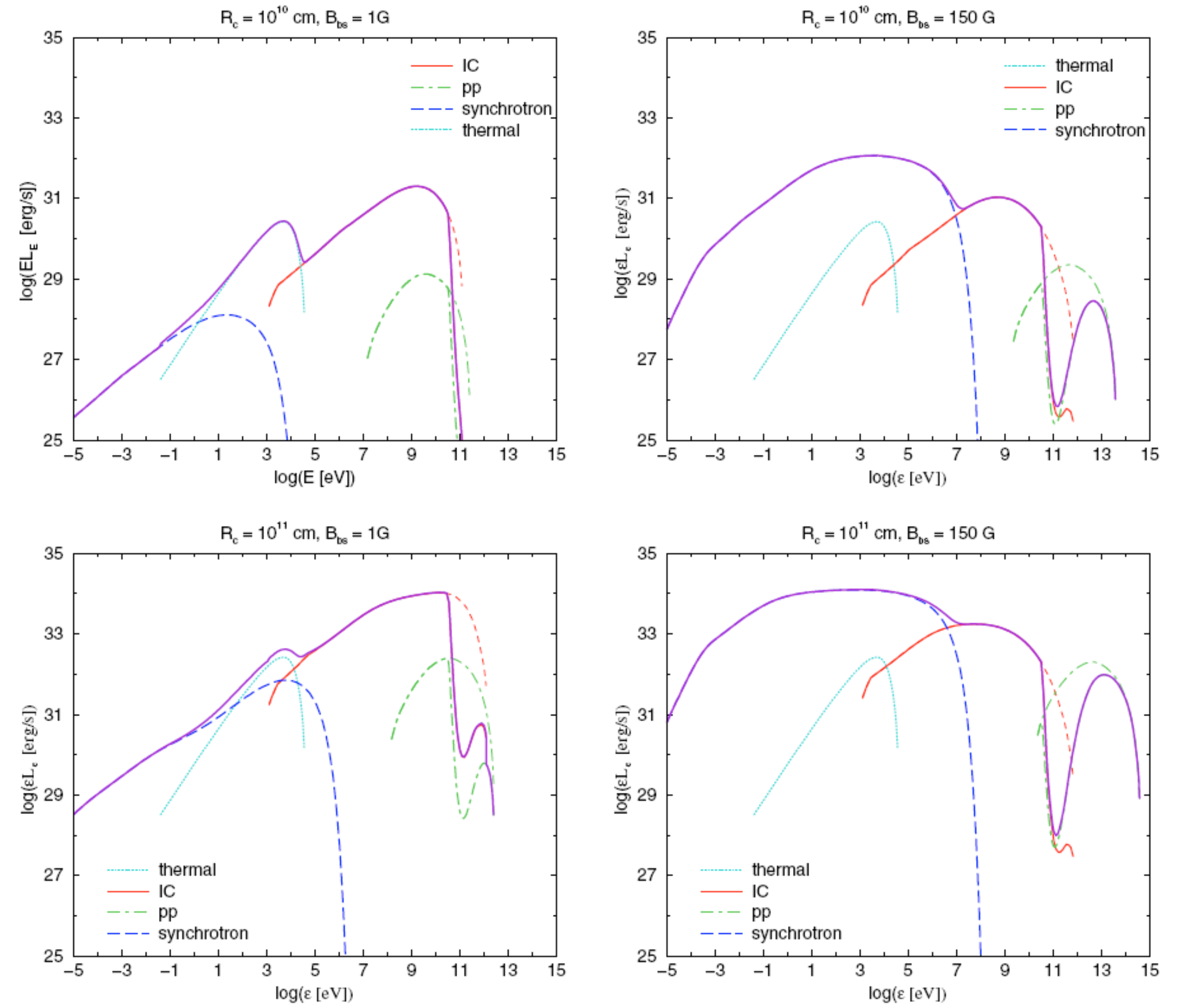

Fig. 7. SEDs for different values of B_{bs} and R_c; the curves of both absorbed and unabsorbed (thin lines) IC and pp radiation are shown.

Araudo, Bosch-Ramon & Romero A&A, 503, 673 (2009)