Searching for high-energy and very-high-energy emission from novae with Fermi-LAT and MAGIC

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Outline

- **Introduction**
  - **Novae**
  - **The Fermi Gamma Ray Space Telescope**
- **Fermi-LAT observations of novae**
- **Are novae VHE sources?**
  - **LAT and MAGIC observation of V339 Del**
- **Conclusions**

White Dwarfs in close binary systems

Compact cataclysmic variable:

WD + Main Sequence

↓

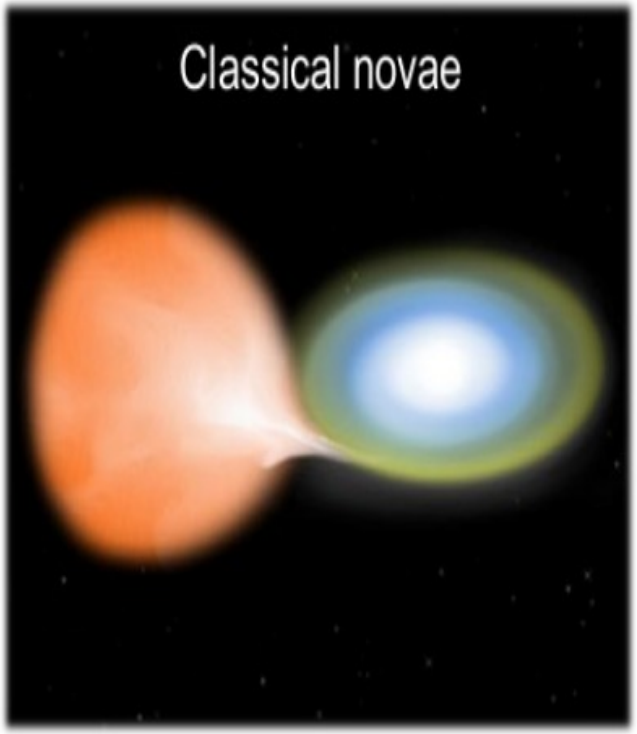
Roche lobe overflow

Symbiotic system:

Massive WD + Red Giant

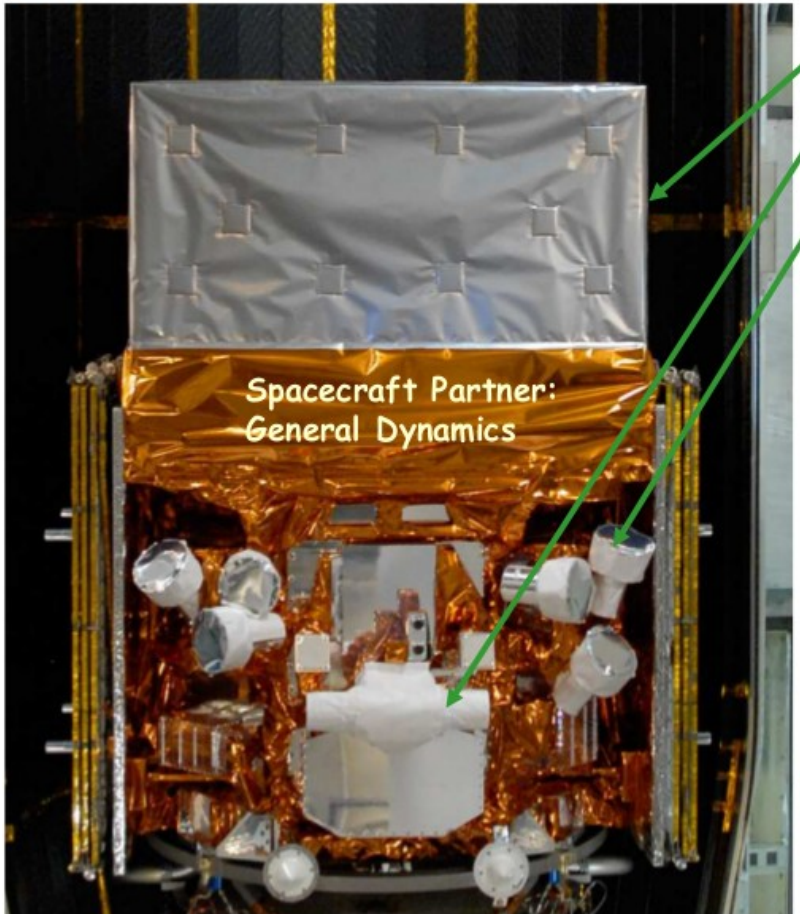
↓

accretion from a red giant wind



Hydrogen burning in degenerate conditions on top of the white dwarf

The Fermi observatory



Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

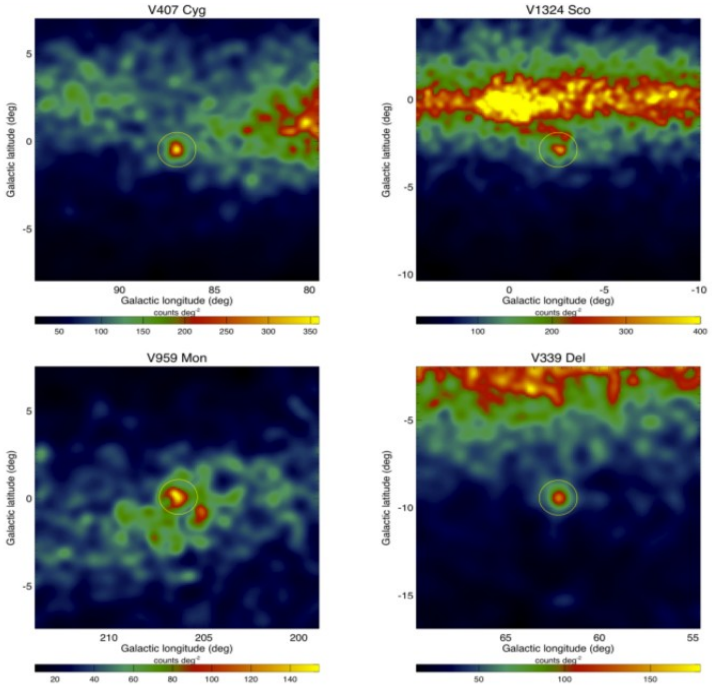
KEY FEATURES

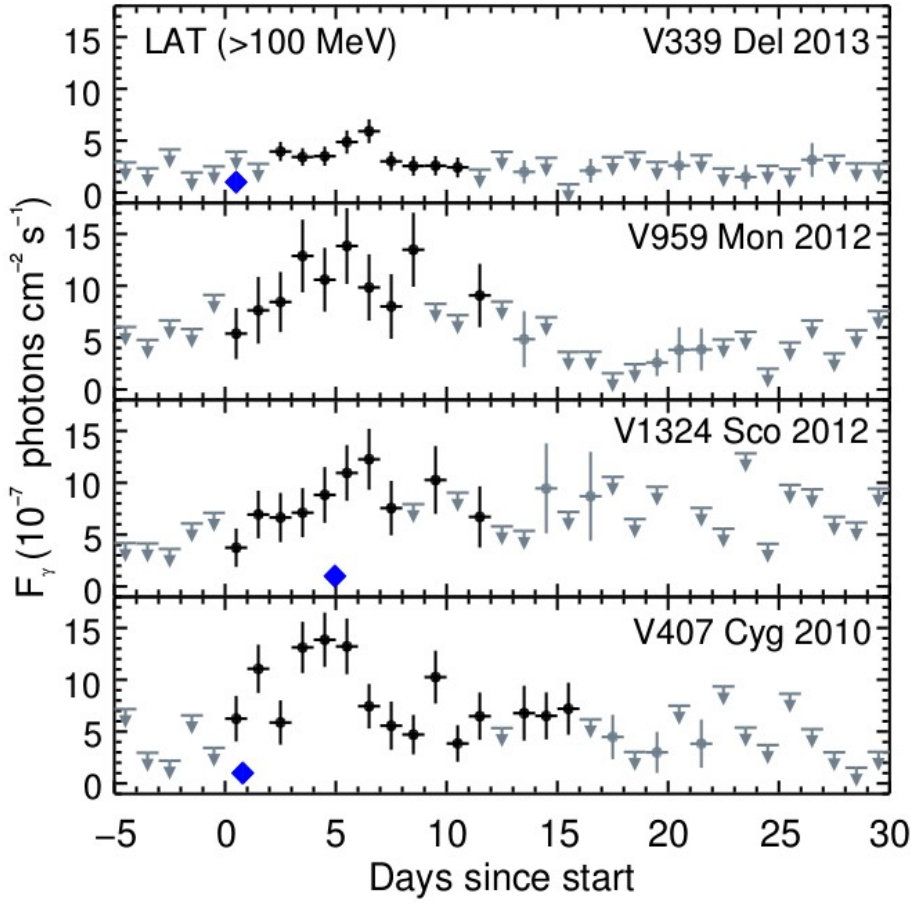
- **Huge field of view**
  - –LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV. **Total of >7 energy decades!**
- Large leap in all key capabilities. Great discovery potential.

➨ **Perfect observatory to study transients events!**

LAT observations of novae

- **3 classical, 1 symbiotic**
- **All are within 4-6 kpc**
- **Gamma ray flux rises after the optical peak reaching max values ~ 10^{-6} ph cm^{-2} s^{-1}**
- **Gamma-ray emission lasts for 2-3 weeks**



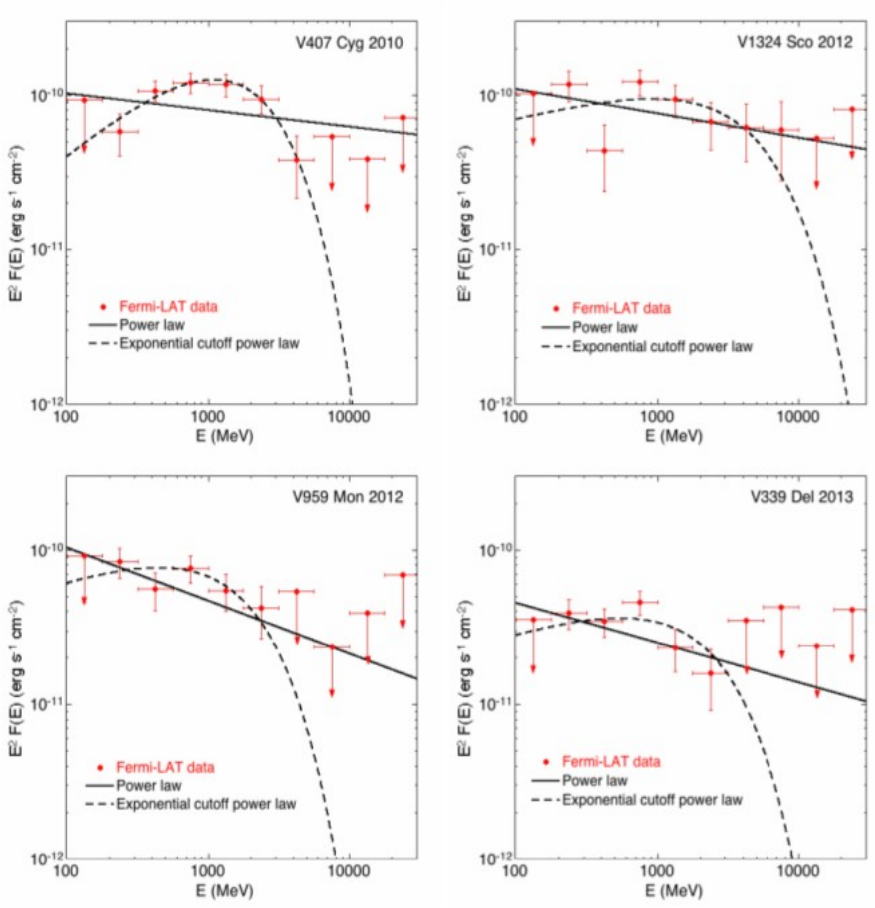


Ackermann et al. (2014)

LAT observations of novae

Spectral analysis

- **PL vs PL*expcut:**
  2-4 sigma significance improvement!
- **GeV spectra modeled**
  - **PL index ~ 1.2-1.9**
  - **E cut-off ~ 1-4 GeV**
- **No significant spectral variability detected**



Ackermann et al. (2014)

Novae @ HE and VHE

- **Origin of GeV emission:**

  Hadronic model

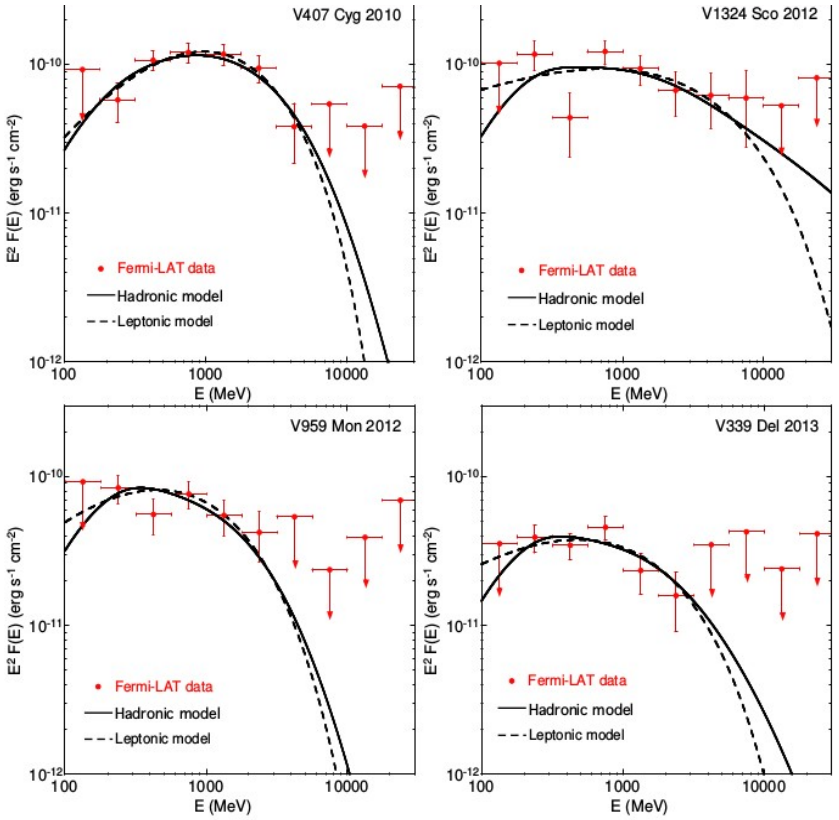
  - **pi zero decay**

    HE protons collide with nuclei in the ejecta and/or in the companion star wind

  Leptonic Model

  - **IC and/or Bremsstralhung**
  - **HE electrons in the ejecta front layers**
  - **target photons emitted by the nova photosphere or by the RG companion**

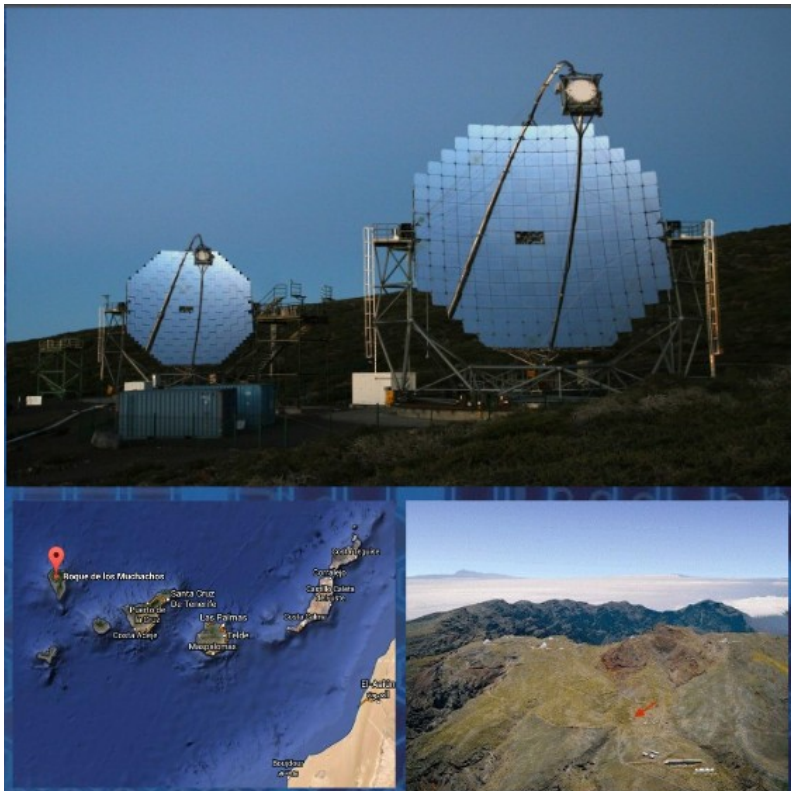
- **Origin of possible TeV emission: protons accelerated in same conditions as electrons**
  - **Lower energy loss**
  - **gamma-rays from pp interactions (pi 0 decay)**



Ackermann et al. (2014)

The MAGIC Telescope

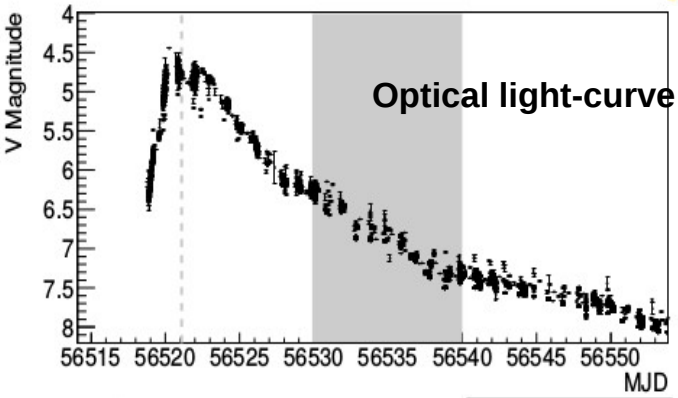
- **Two 17m diameter IACTs**
- **Located in Roque de los Muchachos, La Palma, Canary Islands, at 2200 m a.s.l.**
- **First telescope in operation since 2004, stereo system since 2009**
- **Trigger energy threshold: ~50 GeV**
- **Sensitivity: (0.67+/-0.04)%**
  of Crab Nebula flux (>290 GeV)
- **Angular resolution: ~0.1 deg**

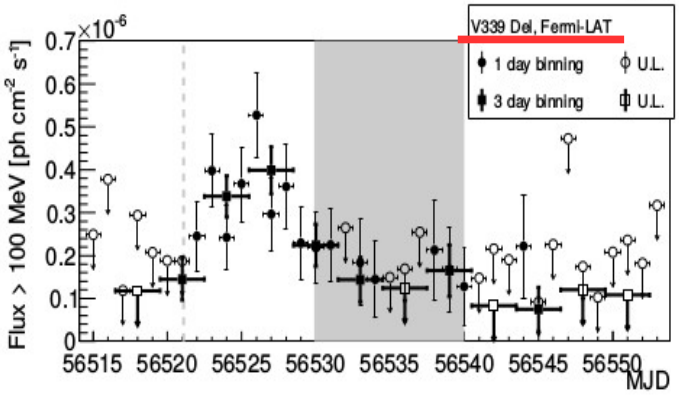


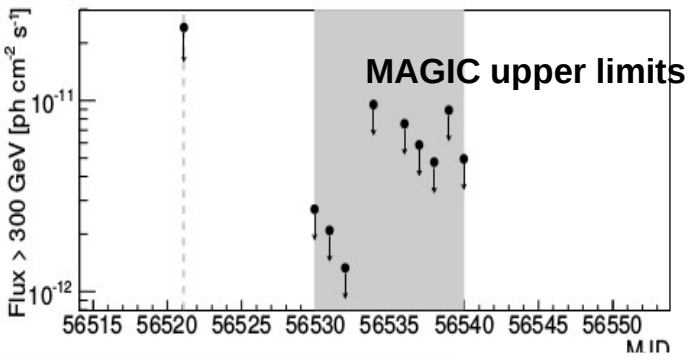
MAGIC observations

- **Since 2012 MAGIC has a follow-up program on novae**

- **Three observations performed so far:**
  - **YY Her**
    symbiotic nova, April 2013
  - **ASASSN-13ax**
    dwarf nova, July 2013
  - **V339 Del**
    classical nova, August 2013







Ahnen et al. (2015)

V339 Del – LAT results

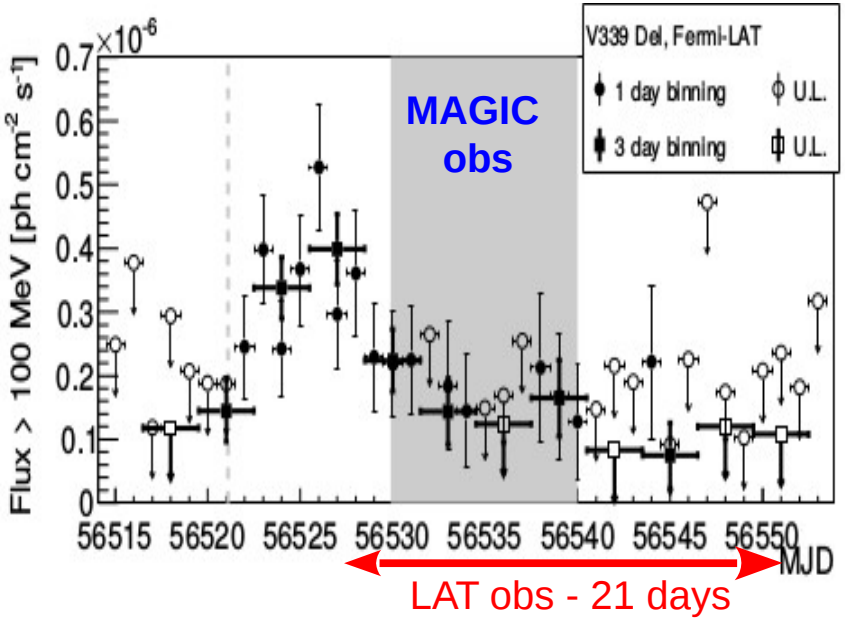
- **Light-curve**
  - 1-day and 3-day bins
  - 95% c.l. upper limits for TS<4
  - power-law with fixed index of 2.3

- **Spectral fits**
  - MAGIC obs period (~7σ)
  - LAT decaying phase (~11σ)

    Index = 1.44 +/- 0.29

    Cutoff Energy = 1.6 +/- 0.8 GeV

    Flux = (0.13 +/-0.03) 10^{-6} ph cm^{-2} s^{-1}

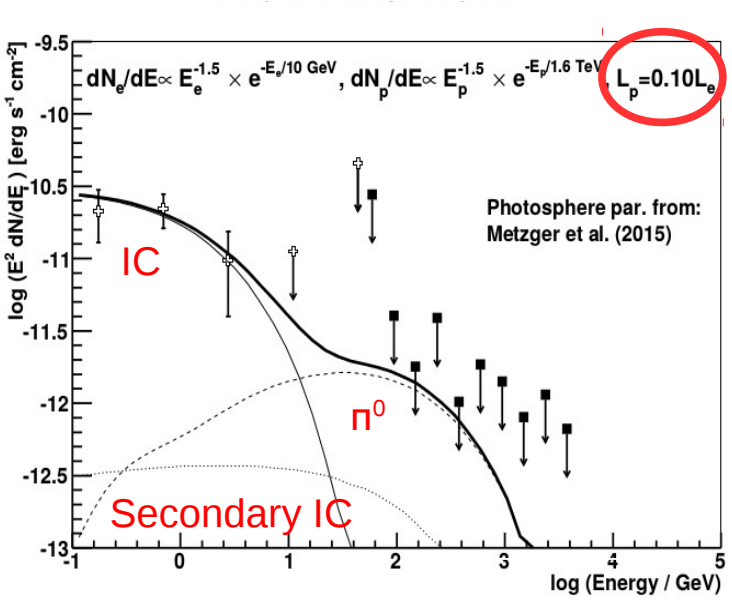


3.3σ improvement over a simple power-law adding the exponential cut-off

Ahnen et al. (2015)

Modelling the VHE emission

- **TeV emission model follows a modification of the model used for V407 Cyg in Sitarek and Bednarek (2012)**
- **LAT spectrum can be described mostly by IC scattering of the thermal photons in the nova's photosphere by electrons.**
- **The expected hadronic component overpredicts MAGIC observations at ~ 100 GeV for the case $L_p = L_e$**
- **MAGIC ULs can place a limit on L_p/L_e**
- **Results unchanged when considering different radiation field parameters from different measurements**



Ahnen et al. (2015)

Conclusions

- **No VHE emission observed from V339 Del**
- **GeV spectrum from LAT provides fit for accelerated electron population**
- **TeV upper limits from MAGIC constrain emission from co-accelerated protons**
  - **L_p ~< 15% of L_e**
  - **Detection of neutrino emission is unlikely**
- **Future GeV and TeV observations planned as interesting novae arise**

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Thanks for your attention!

Back up

Nova phtosphere

- **Estimate the parameters of nova photosphere @ 10 days from optical detection:**

Table 1. Parameters characterizing the optical emission of V339 Del (photosphere temperature $T_4 \times 10^4$ K, radius $R_{ph,13} \times 10^{13}$ cm and luminosity L) according to the two scenarios assumed in the modeling of the GeV and TeV emission.

	T_4	$R_{ph,13}$	$L/L_\odot$
Metzger et al. (2015)	0.7	1.2	6×10^4
optical+UV	1.3	0.4	8×10^4

Ahnen et al. (2015)

Modelling the TeV emission

- **0riginal scenario applied to V407 Cyg (symbiotic nova):**
  - **GeV γ-ray emission attributed to IC of the electrons on the strong radiation field in the vicinity of the red giant companion star.**
- **For V339 Del: radiation field of the companion star is not as strong:**
  - **The photosphere of the nova provides a dominant target for the IC process.**
- **Parameters of the photosphere (Metzger et al. 2015) + the break in the GeV spectrum at ~ 1.6 GeV:**
  - **protons accelerated at least up to ~ 1.6 TeV (1.1 TeV for opt+UV fit of photosphere).**
- **The acceleration can be also limited by the dynamic time (but tis effetc dominates only on longer time scales):**
  - **accelerated protons will mostly cool down due to energy losses in hadronic interactions.**
  - **The normalization of both components is determined by Lp /L e , i.e. the ratio of the total power of accelerated protons to that of electrons.**
- **We consider that the electrons and protons accelerated in Fermi-like acceleration obtain a power-law energy spectrum with a spectral index of 1.5.**
- **The spectra of electrons and protons cut-off at energies determined by equations 2 and 8 in Ahen et al., 2105.**

Wich effects could lower the Lp /Le ratio ?

- **The increased power in electrons compared to protons may be related to how particles with different mass are injected in the acceleration process:**
  - **Energetic e + e − pairs from nuclear decays produced in the nova explosion could inject them preferentially into the shock acceleration process.**
  - **Schlickeiser (2003): in a low-beta plasma acceleration of electrons is preferred over protons if the particles are accelerated out of a thermal popolation.**