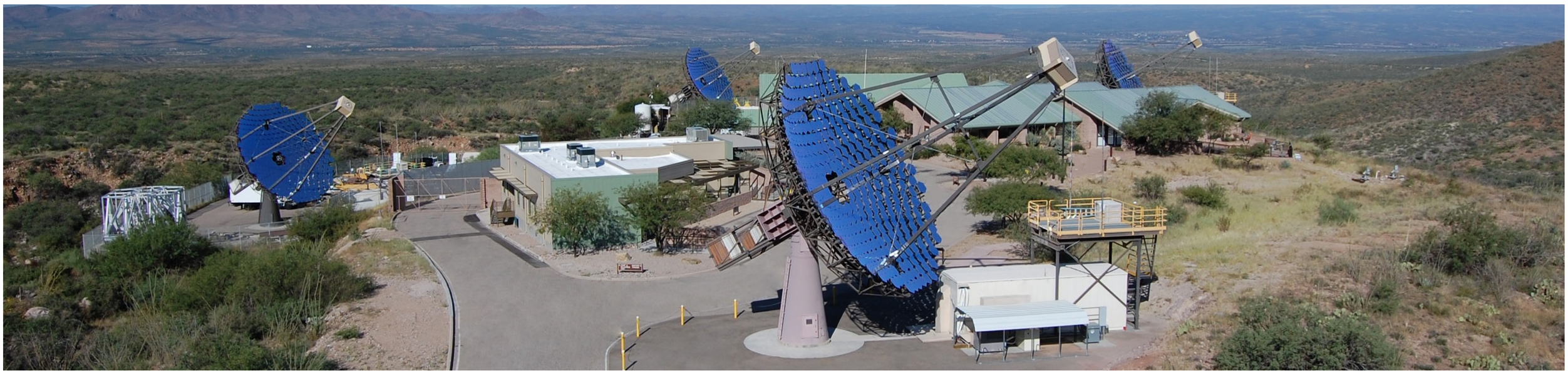

Upper limits on the VHE γ-ray flux from the ULIRG Arp 220 and other galaxies with VERITAS.

Henrike Fleischhack[1] for the VERITAS collaboration[2]

[1] henrike.fleischhack@desy.de
[2] https://www.veritas.sao.arizona.edu

Star formation & the FIR-radio-GeV correlation

A correlation between FIR and radio emisssion has been measured for many galaxies [1]; a similar correlation between FIR and GeV emission has been found, albeit within a smaller sample [2]. These correlations can be explained because the emission in all these wavelengths is correlated with the star formation rate:
A high rate of star formation leads to a large number of O and B type stars, which emit mainly in the UV. Regions of high star formation are relatively dense in gas or dust. Thus, the UV radiation is absorbed and re-emitted in the IR band.
Massive stars are short-lived and explode as supernovae. In the remnants they leave behind, electrons and positrons can be accelerated to high energies. Electrons then emit radio waves due to synchrotron processes. Highly accelerated protons and electrons also cause the emission of γ rays in the GeV to TeV range (e.g. through pion production or inverse compton upscattering of ambient photons).
Some galaxies experience periods with high rates of star formation (starburst). These galaxies are considered good candidates to look for VHE (very high energy, 100 GeV$<E<$100 TeV) γ-ray emission due to the processes described above.

The ULIRG Arp 220

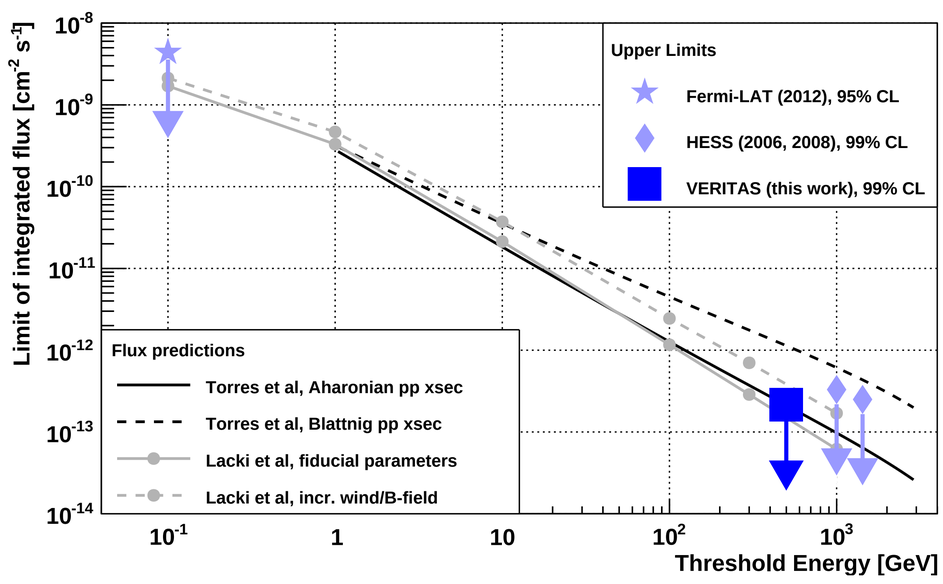

Figure 1: Predictions of the integral γ-ray flux from Arp 220[1, 3] and measured upper limits [2, 4, 5]

- Result of a merger of two galaxies. Two cores with high star formation rate.
- Good candidate for (V)HE γ-ray emission, detailed model predictions available [1, 3, 6].
- Observed by VERITAS in 2012; no evidence for VHE γ-ray emission was found.
- Upper limit on integral flux: F $< 2.24 \cdot 10^{-9}$ m^{-2} s^{-1} above 500 GeV at 99% CL

3C 321 — the Death Star Galaxy

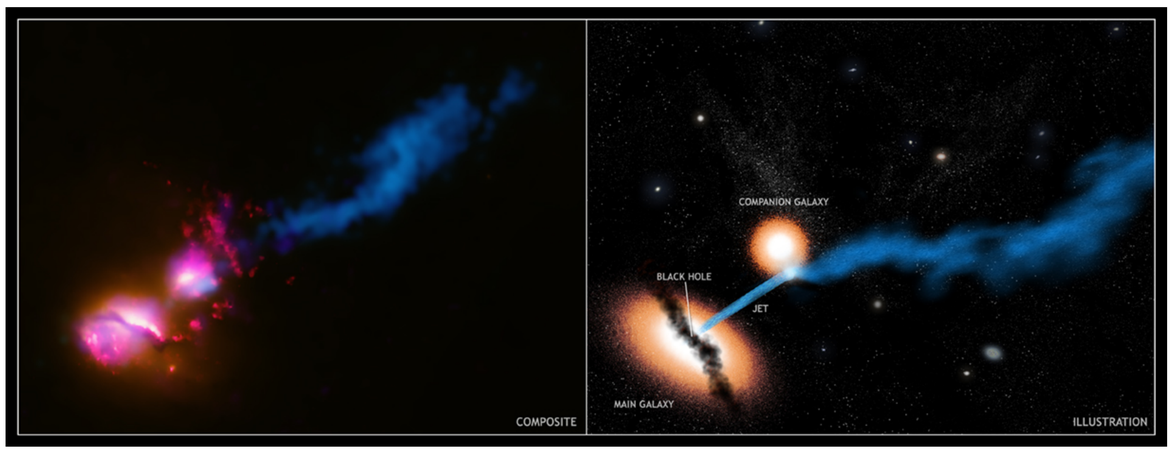

Figure 2: 3C 321: Multiwavelength composite image and artist's impression. Image credit:X-ray: NASA/CXC/CfA/D.Evans et al.; Optical/UV: NASA/STScI; Radio: NSF/VLA/CfA/D.Evans et al., STFC/JBO/MERLIN http://chandra.harvard.edu/photo/2007/3c321/

- Two merging active galaxies, on of the jets interacting with companion galaxy.
- Imaged in many wavelengths from radio and X-ray[7].
- Interaction region possible site for particle acceleration.
- Observed by VERITAS in 2008 (pointing at 3C 321) and 2012 (pointing at Arp 220, $\sim 1°$ away from 3C 321; no evidence for VHE γ-ray emission was found.
- Upper limit on integral flux: F $< 1.9 \cdot 10^{-9}$ m^{-2} s^{-1} above 500 GeV at 99% CL.

IRAS 17208-0014

- Very luminous, dense ULIRG.
- Observed by VERITAS in 2011/12.
- No evidence for VHE γ-ray emission.
- Upper limit on integral flux: F $< 1.82 \cdot 10^{-9}$ m^{-2} s^{-1} above 600 GeV at 99% CL.

IC432

- Starburst galaxy close to Local Group.
- Observed by VERITAS in 2010.
- No evidence for VHE γ-ray emission.
- Upper limit on integral flux: F $< 2.76 \cdot 10^{-8}$ m^{-2} s^{-1} above 500 GeV at 99% CL.

VERITAS instrument and obervations

- Very Energetic Radiation Imaging Telescope Array System [8].
- Array of four imaging atmospheric Cherenkov telescopes at the Fred Lawrence Whipple Observatory (FLWO) in southern Arizona (31 40N, 110 57W, 1.3km a.s.l.).
- Sensitive to energies from 85 GeV to >30 TeV.
- Systematic uncertainty on the integral flux: $\sim 30\% - 40\%$ (for spectral index -2.5 to -3.0).

Source	Observing period [MJD]	Livetime [h]	Mean zenith angle [°]
Arp 220	55987–56046	31	16
IRAS 17208-0014	55678–56008	14	34
IC342	55528–55572	3	37
3C321	54503–56046	41	17

Table 1: Overview over the VERITAS data analyzed for this paper.

Summary & Conclusions

- No evidence for VHE γ-ray emission from 3C 321, Arp 220, IRAS 17208-0014, or IC342.
- Upper limits on the integral flux have been set, VERITAS ULs most constraining at VHE so far.
- Arp 220 seems like a good candidate, but flux predictions vary.
- Most optimistic models have been ruled out.
- Need next-generation IACTs to either discover ULIRGs or further constrain models.

Source	E_{min} [GeV]	N_{ON}	N_{OFF}	α	$A_{eff} \cdot T$ [m^2 s]	Flux ($E > E_{min}$) [m^{-2} s^{-1}]
Arp 220	500	45	282	0.17	$8.35 \cdot 10^9$	$\leq 2.24 \cdot 10^{-9}$
IRAS 17208-0014	600	16	124	0.17	$4.76 \cdot 10^9$	$\leq 1.82 \cdot 10^{-9}$
IC342	500	37	174	0.18	$0.94 \cdot 10^9$	$\leq 27.6 \cdot 10^{-9}$
3C321	500	52	363	0.17	$7.23 \cdot 10^9$	$\leq 1.90 \cdot 10^{-9}$

Table 2: 99% confidence level upper limits on the integral flux of the four galaxies studied here, measured by VERITAS. A power law spectrum is assumed for all sources, with an index of -3.0 for 3C321 and index -2.5 for the three star forming galaxies.

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See PoS(ICRC2015)745 for more details.

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