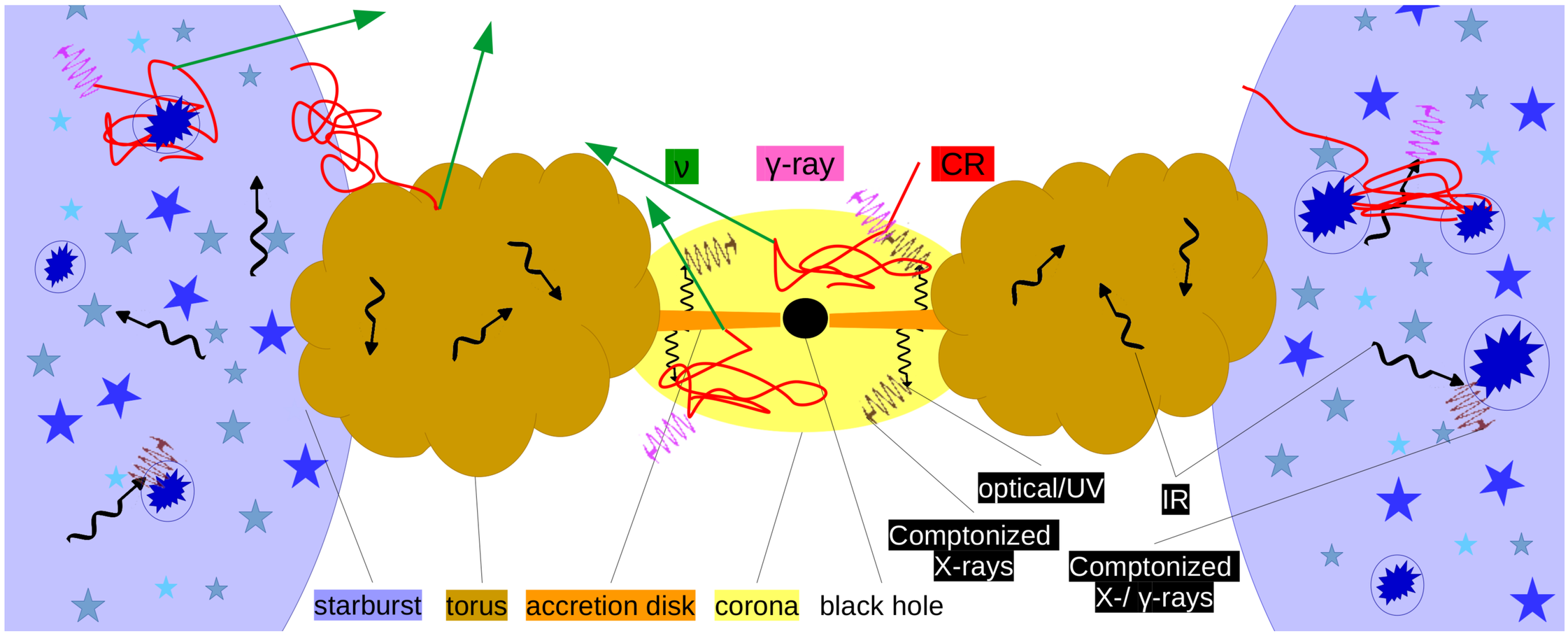
# An AGN-starburst composite multi-messenger model of NGC 1068

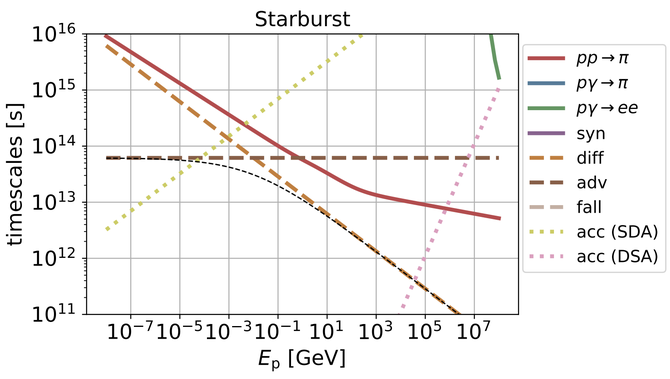
Björn Eichmann*, Ralf-Jürgen Dettmar*, and Julia Becker-Tjus*

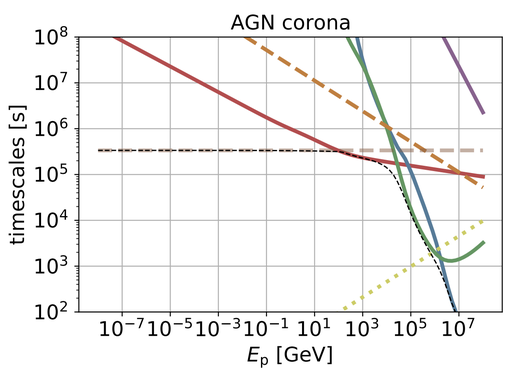
*Ruhr Astroparticle and Plasma Physics Center (RAPP Center), Ruhr-Universität Bochum, Institut für Theoretische Physik IV, 44780 Bochum, Germany

## There is an *AGN* in its center *and* a circumnuclear *starburst*...



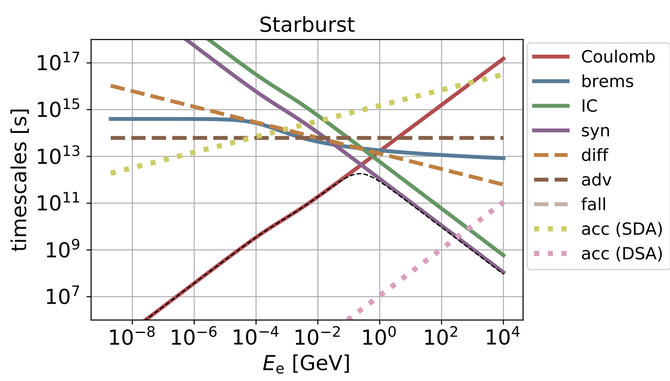

## ...where cosmic-ray protons and electrons act completely different.

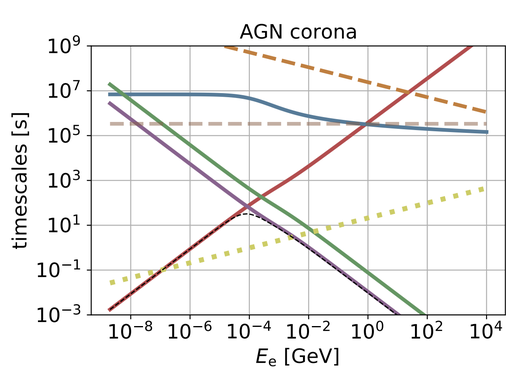



### Protons:

- Can reach hundreds of TeV in both regions but due to different acceleration processes.
- Starburst is not a proton calorimeter, whereas only protons with a kinetic energy $\lesssim 100\,\mathrm{GeV}$ leave the AGN corona by falling into the black hole before loosing its energy.
- Photohadronic losses constrain the maximal energies only in the AGN corona region.




### Electrons:

- Can reach TeV energies in the starburst region, but in the AGN corona stochastic diffusive acceleration has to compete with Coulomb losses at sub-keV energies and synchrotron/ inverse Compton losses above some MeV.
- Both regions are perfect electron calorimeters.

## Multi-messenger SED of NGC 1068

Using the differential proton and electron density, that results from the simplified, two-zone, steady-state transport equation

$$-\frac{\partial}{\partial E}\left(\frac{E\,n(E)}{\tau_{\mathrm{cool}}(E)}\right) = q(E) - \frac{n(E)}{\tau_{\mathrm{esc}}(E)}\,,$$

we determine the nonthermal leptonic and hadronic emission of these particles from radio to gamma-ray energies, including:

- the maximal energy constraints from the (previous) timescale analysis;
- the same total number of injected protons and electrons;
- the secondary electrons/ positrons from hadronic interactions;
- the opacity of the AGN corona (synchrotron-self and free-free absorption at $E \lesssim 1\,\mathrm{meV}$, and $\gamma\gamma$-pair attenuation at $E \gtrsim 1\,\mathrm{GeV}$)

This model essentially mergers the AGN corona model by Murase et al. [1] with the starburst model by Eichmann & Becker-Tjus [2] using the therein mentioned parametrization and target photon fields (see Fig. 1).

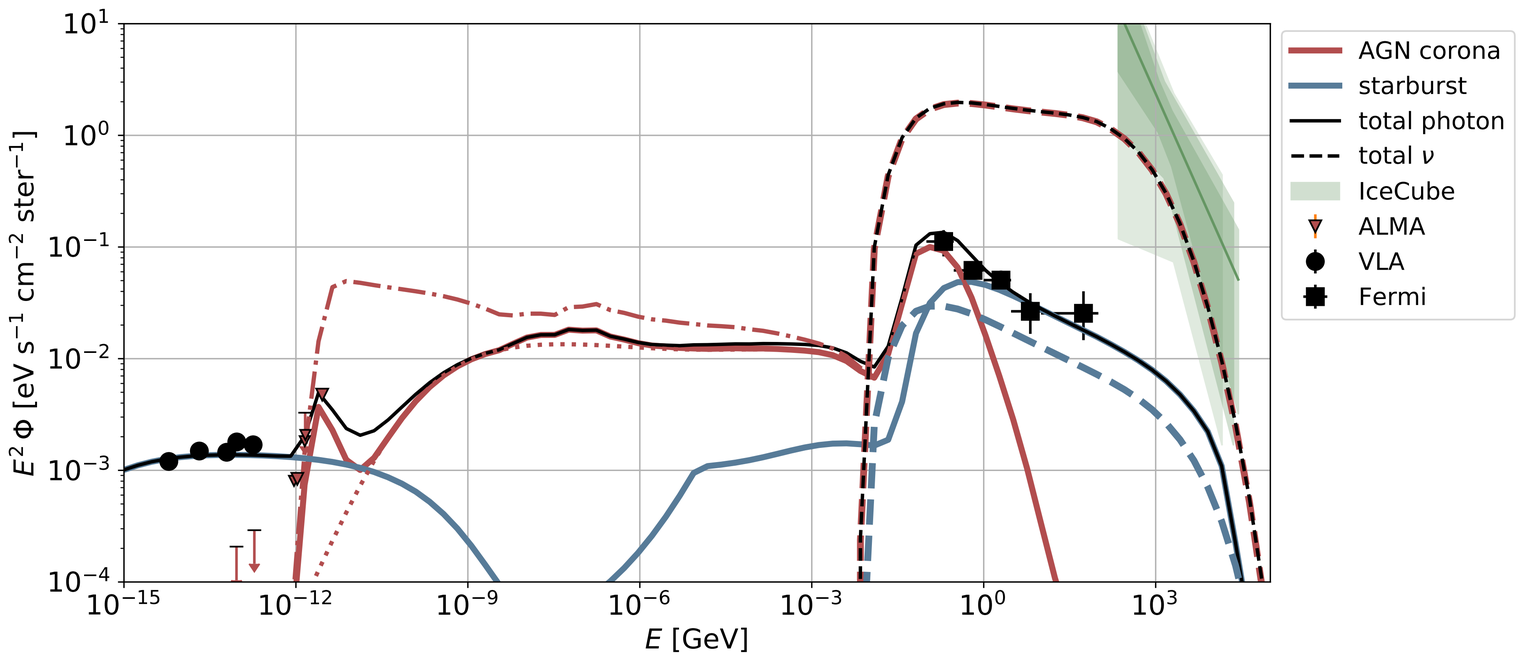



Fig. 1: Model predictions for *photons (solid/ dotted lines)* and *neutrinos (dashed lines)* with respect to the data (small red markers and upper limits refer to a beam size of $\sim 10\,\mathrm{mas}$, and large black markers indicate a beam size of $\gtrsim 10\,\mathrm{as}$). The light grey area indicates the thermal disk- and torus emission as well as Comptonized X-rays of the AGN corona, and the dark grey area indicates the thermal IR emission of the starburst region. The red dotted (dash-dotted) line indicates the total photon SED by the AGN corona in the case of vanishing primary electron ($E^{(\mathrm{e})}_{\mathrm{max}} = 100\,\mathrm{MeV}$).

### Conclusions:

Using typical parameters of NGC 1068 we can show — without any parameter fine-tuning — that:

- only the total non-thermal emission by the starburst *and* the AGN corona yields a good agreement to the radio/ IR and gamma-ray data;
- the high-energy neutrino emission by the AGN corona provides a good agreement to the IceCube measurements;
- a significant amount of primary electrons (up to $\sim 1\,\mathrm{MeV}$) is needed to explain the onset of the IR flux of the inner parsecs of NGC 1068, as observed by the ALMA experiment.

... or to make a long story short: Both starburst *and* AGN corona are needed to understand the emission from NGC 1068.

## References

[1] Kohta Murase, Shigeo S. Kimura, and Peter Mészáros. *Phys. Rev. Lett.*, 125(1):011101, 2020.

[2] B. Eichmann and J. Becker Tjus. *Astrophys. J.*, 821:87, 2016.