Very-High-Energy Gamma-Ray Astrophysics

Garret Cotter
(garret.cotter@physics.ox.ac.uk)

Very-high-energy astrophysics

Gamma-rays are electromagnetic radiation of very short wavelength (shorter and more energetic than X-rays) and are of interest to astronomers for many reasons. At present, much is being learned about sources that might emit gamma-rays; detections have been made from stars in an advanced stage of evolution (including pulsars and X-rays binaries) and from energetic sources outside our Milky Way (active galaxies). Gamma-rays can provide information about these particle accelerators in space, producing the energetic charged particles which are the progenitors of the gamma-rays. As such, they give us a completely different view of the universe from other types of radiation.

Fig. 1: The CHEC-S camera.

The Cherenkov Telescope Array (CTA)

CTA will be formed of Large, Medium and Small Size Telescopes (LSTs, MSTs and SSTs respectively). There will be about 70 of the SSTs on CTA's southern site in Chile, covering an area of several square kilometres and providing sensitivity to photons in the energy range from 1TeV to >100 TeV. The Oxford group is part of CTA-UK, which is working with colleagues across the world to build the cameras for the SSTs. The development of such an instrument requires input at many levels, this includes lab testing of hardware, development of analysis techniques and software, and matching simulations to lab data. There will also be opportunities to work with the camera during observation runs.

The High Energy Stereoscopic System (H.E.S.S.)

The Oxford group holds membership of the current flagship ground-based gamma-ray instrument, H.E.S.S. in Namibia. As such, students have access to H.E.S.S. data and can go to perform observing shifts on site.

GRBs and other transients

H.E.S.S. (along with MAGIC, one of the other gamma-ray telescopes) recently made headlines due to their detection of a gamma-ray burst (GRB) from the ground (the first time this had been achieved at TeV energies). This opens up a new window for the study of these highly energetic, short lived objects. H.E.S.S. is also running follow up observations on neutrino and gravitational wave detections.

Deep Learning

Cherenkov telescopes rely on machine learning techniques to perform event classification and reconstruction. We have a leading role in developing new techniques for this based on Convolutional Recurrent Neural Networks (CRNNs) .

Theory & Data Analysis

AGN Modelling

Active Galactic Nuclei (AGN) are powered by supermassive black holes residing in galactic centres, with the energy manifesting as highly collimated relativistic streams of charged particles, or jets. If the jet points towards us, the emission is greatly amplified by relativistic effects. These objects emit across the entire electromagnetic spectrum, and work undertaken at Oxford has been very successful when modelling such emission, with the jet geometry outlined in the figure below.

Jet Simulations

Space and time-resolved simulations of AGN jets help us understand the production of particles at the highest energies. At Oxford we simulate these environments in which we are able to track the trajectories of single particles on the computer. Despite most jet properties being best described by leptonic models, there most likely is a small fraction of hadronic constituents residing in AGN jets as well. These highly relativistic hadrons may not only contribute to the highest-energy gamma-rays by interacting with the source environment but also produce high-energy neutrinos which are observed at the IceCube neutrino detector at the South Pole.

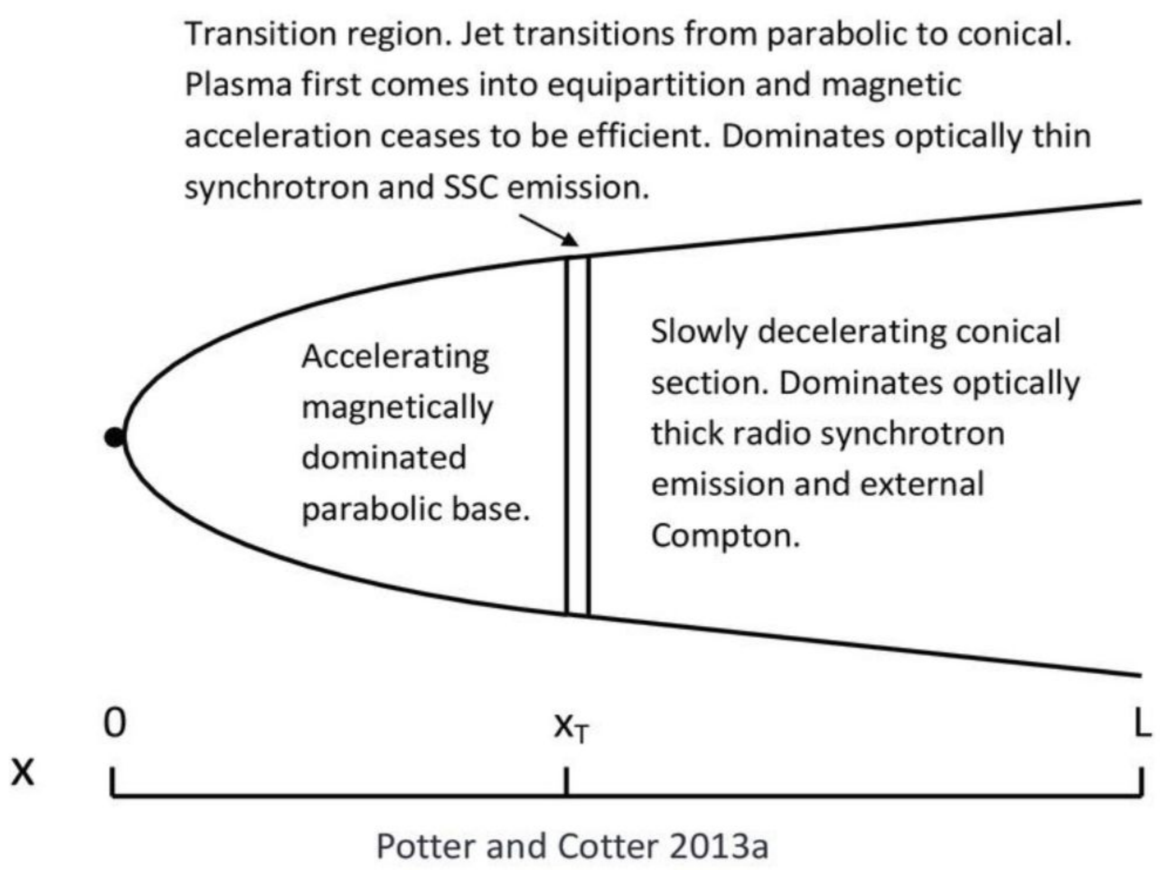

Fig. 2: Potter & Cotter jet geometry

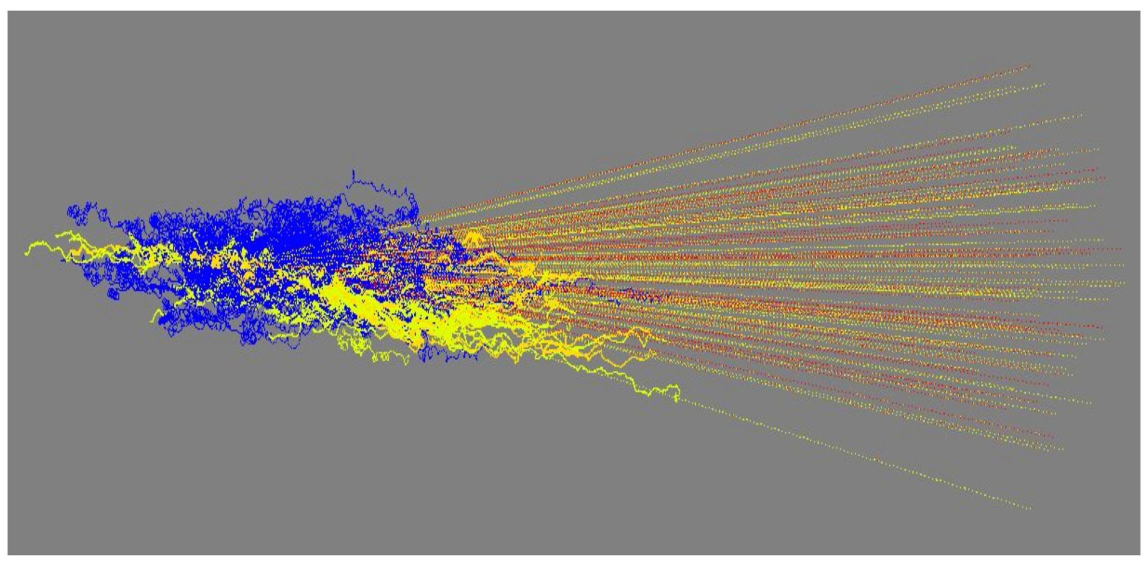

Fig. 3: 3D Simulation of a jet with hadronic (blue) and leptonic (yellow) constituents. The straight lines are secondary neutrinos and gamma-rays propagating along the jet direction.

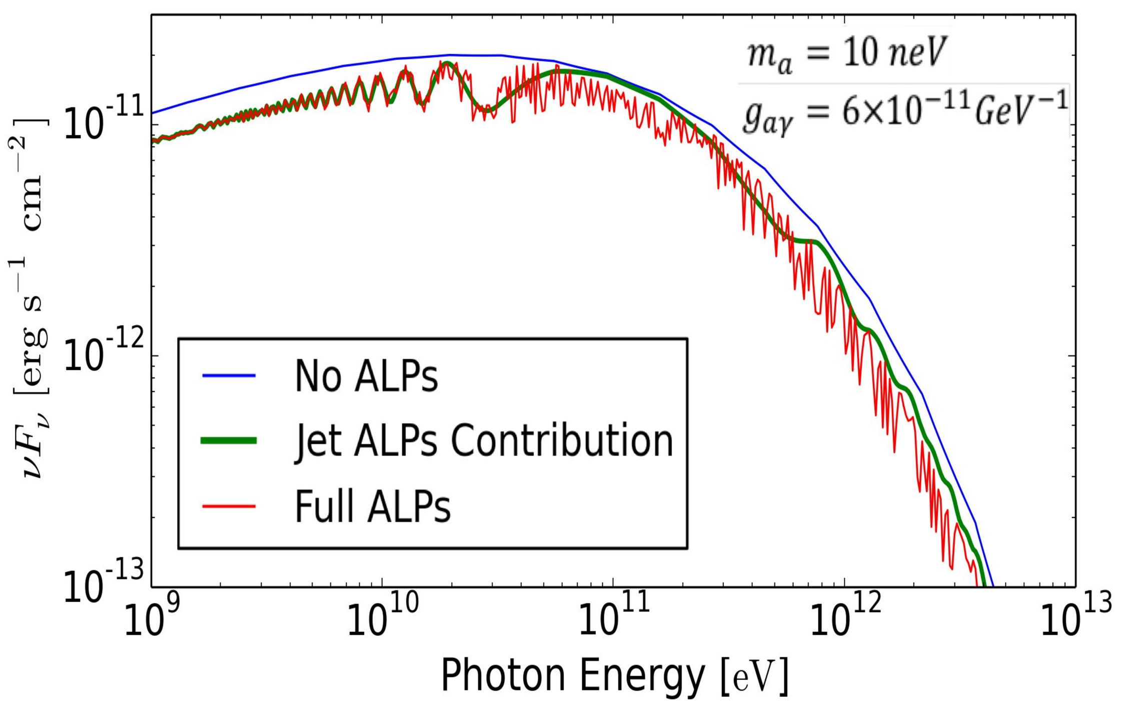

Fig. 4: Simulated Mrk 501 spectrum showing oscillations produced by ALP-photon mixing.

Axionlike Particles (ALPs)

Gamma-rays observations of jets can be used to probe physics beyond the Standard Model. For instance, theorised very light axionlike particles (dark matter candidates) mix with photons in a magnetic field and so could leave observable signatures in blazar spectra (see Fig. 4). By simulating gamma ray spectra of blazar Mrk 501 including ALP-photon mixing we have found that the jet is an important mixing region for ALPs and that the details of jet magnetic field structure is important for future blazar ALP searches. Many of the current limits on ALP properties come from gamma-ray observations, and this work is especially relevant with CTA coming online soon with an order of magnitude sensitivity improvement.

Opportunities

There are various opportunities for DPhil study in the VHE astrophysics group, including: astrophysical theory and modelling, hardware and calibration, simulations and data analysis, and camera software development.

Being part of a large collaboration means you will have the frequent ability to travel for collaboration meetings and so on. There's also the opportunity to spend up to a year at collaborating institutes through the STFC's long term attachment scheme.

See also:
https://www.cta-observatory.org/
https://www.mpi-hd.mpg.de/hfm/HESS/
https://www.arxiv.org/abs/1709.07997