Simulating the directional detection of dark matter

Ciaran A. J. O'Hare, Anne M. Green, Phys. Rev. D **90**, 123511 (2014).

Particle Theory Group, University of Nottingham

What is dark matter?

Dark matter is an unknown particle introduced to explain why there appears to be so much more mass in the Universe than is accounted for by what we can observe in the form of stars and galaxies. There is now a wealth of evidence for dark matter from many independent sources including: galaxy rotation speeds, gravitational lensing by galaxy clusters, and the cosmic microwave background.

What do we know?

- it is massive (has gravitational influence)
- it does not interact with photons (is invisible)
- it must be non-relativistic (is cold, not hot)

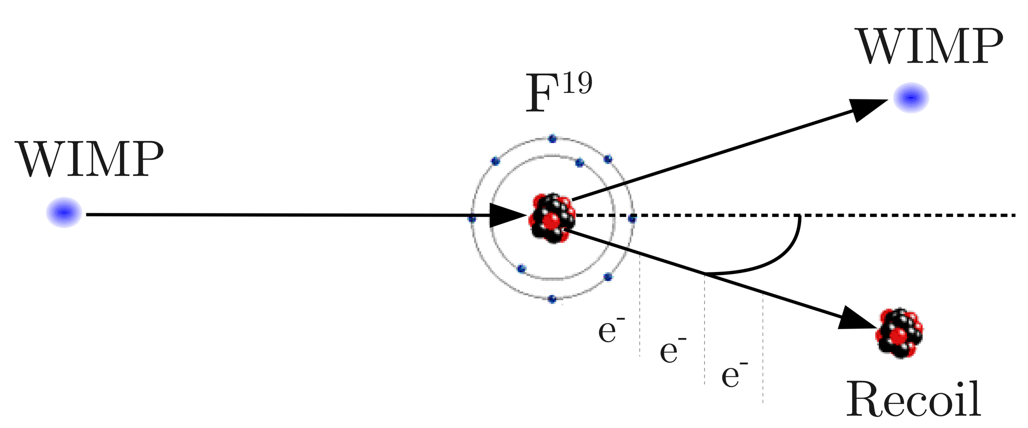
We do not know of any particle possessing these properties hence we must look to theoretical extensions to the standard model of particle physics to find a candidate.

WIMPs

The best motivated group of dark matter candidates is a broad and generic class known as Weakly Interacting Massive Particles or **WIMPs**. These particles are their own antiparticle and have a number of candidates in extensions to the standard model such as supersymmetry.

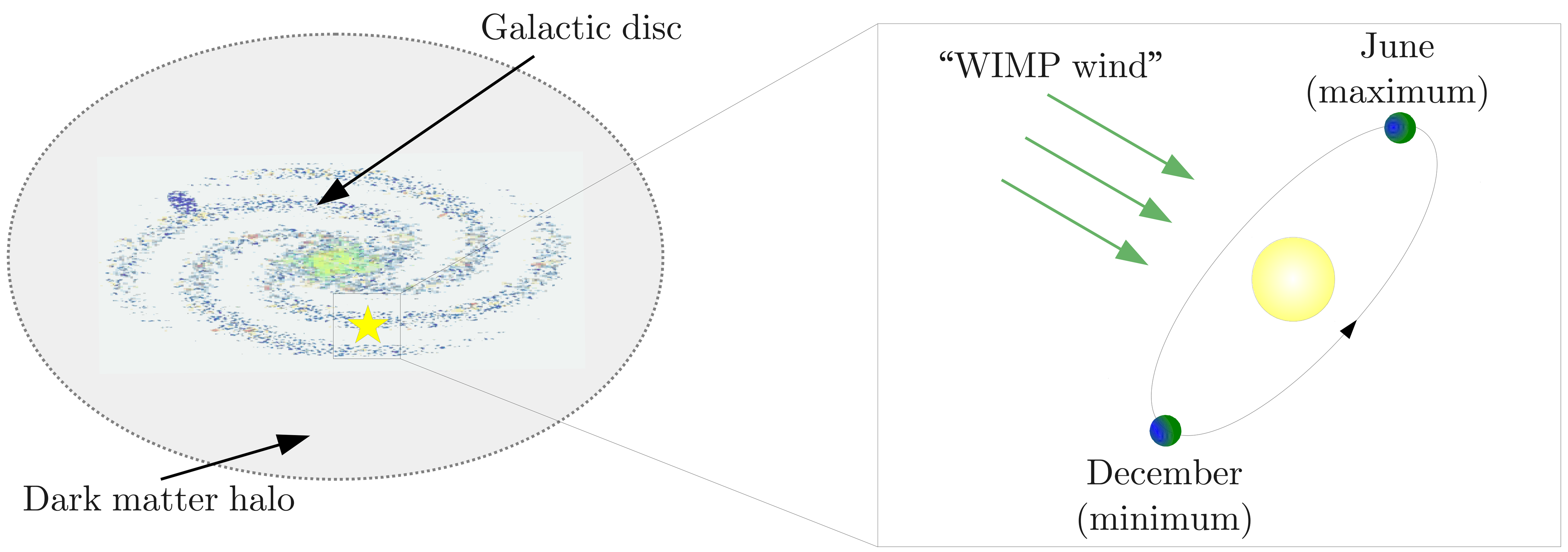
Detecting WIMPs

WIMPs should interact with everyday matter by scattering elastically off nuclei. The signature of such an interaction taking place is a spontaneously recoiling nucleus with an energy of a few keV. Detecting such recoils is extremely challenging as there are many contaminating backgrounds also causing recoils in this range of energies.



Smoking gun signals

To distinguish a recoil caused by a dark matter particle from one caused by something in the lab, the direction of the recoil and also the time at which it occured can be used. Because the Galactic disc is embedded inside a non-rotating dark matter halo we expect to feel a **wind of WIMPs** from a particular direction in the sky (the constellation of Cygnus). The orbit of the Earth with respect to this wind will then cause the event rate to modulate over the course of the year, with a maximum occuring during June.

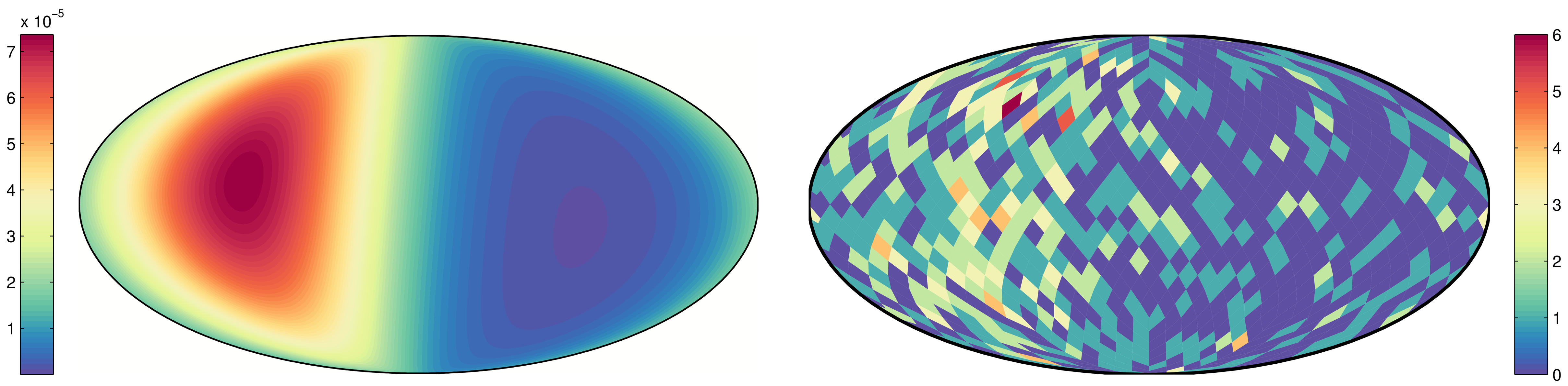


The simulation

We have developed a simulation to establish the science potential of future directional detectors. We have modelled our simulation on a forecast of the **MIMAC** detector in Modane, France, using Fluorine-19 as a target nucleus in a low-pressure time projection chamber. The goal of the simulation has been to test the power of statistical tests on spherical data (e.g. rotational symmetry, median direction) in analysing mock recoil data and how they can be used to study the astrophysics of WIMPs in the local dark matter halo.

Underlying recoil pattern

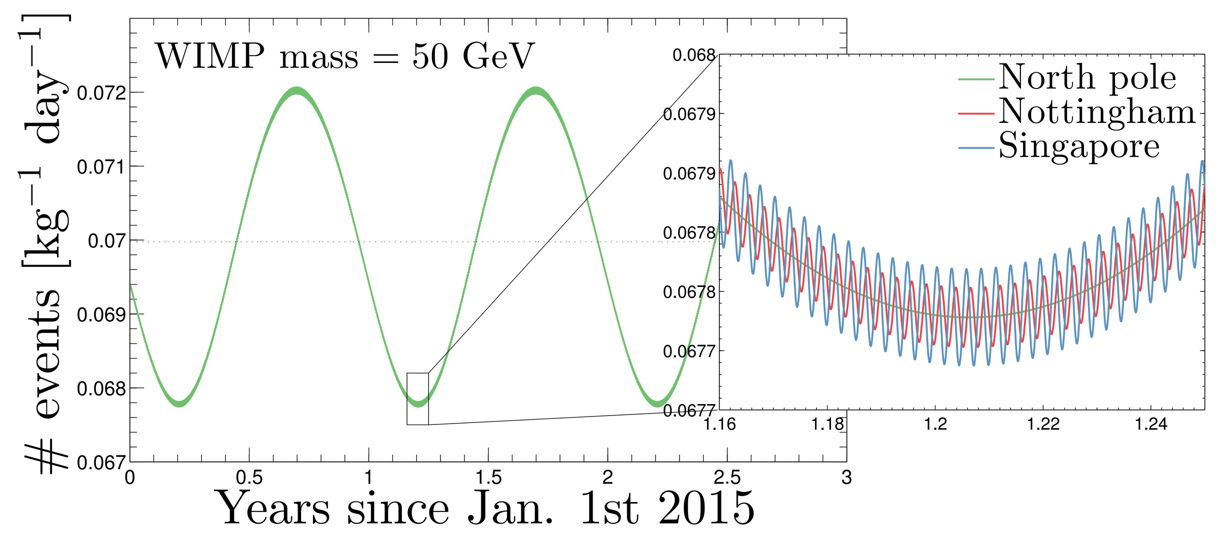
Simulated data



The above plots are 2D projections of the 3D all-sky recoil data in the analytic (left) and simulated (right) cases. The left hand plot has an infinite exposure and perfect angular resolution and can detect the full range of energies whereas the right hand has only a 10 kg yr exposure and finite angular resolution (seen here as pixels of equal angular area) and can only detect down to a minimum recoil energy of 5 keV.

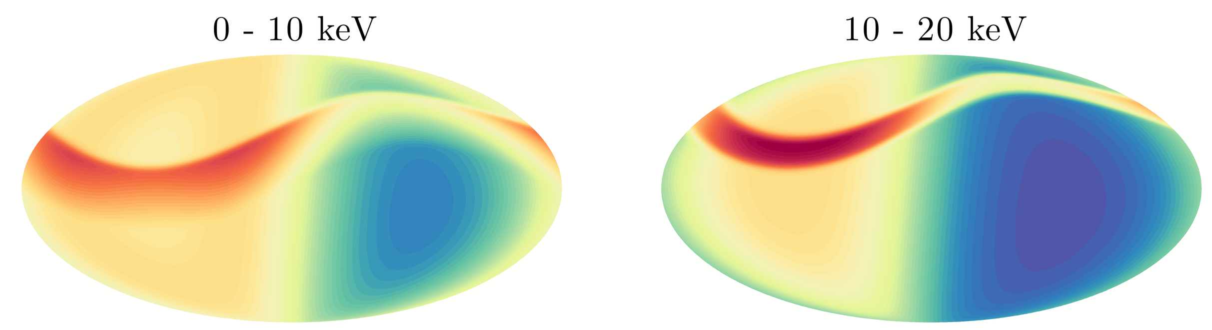
Annual/daily modulation

By modelling the orbit of the Earth and its rotation we can see an annual and daily oscillation in the event rate that is also dependent on the location of the detector:



Tidal streams

Accretion of dark matter from smaller satellite galaxies by the Milky Way gives rise to streams of dark matter sweeping round the Galaxy similar to ocean currents. One of these, the **Sagittarius stream**, is expected to pass near the Earth and would leave a distinctive signature in the expected signal (below). Using our statistical tests we have found that with only modest exposure times ($\mathcal{O}(10)$ kg yr) such a feature is detectable by future detectors. However, the window of recoil energies measurable by an experiment limits the range of different streams detectable on Earth moreso than the underlying dark matter halo alone.



Summary

We have developed a simulation to predict signals expected in the next generation of directional detector, in particular signals from non-standard halo models such as ones including tidal streams. We have incorporated a number of experimental constraints and have applied special statistical tools to analyse the simulated data.