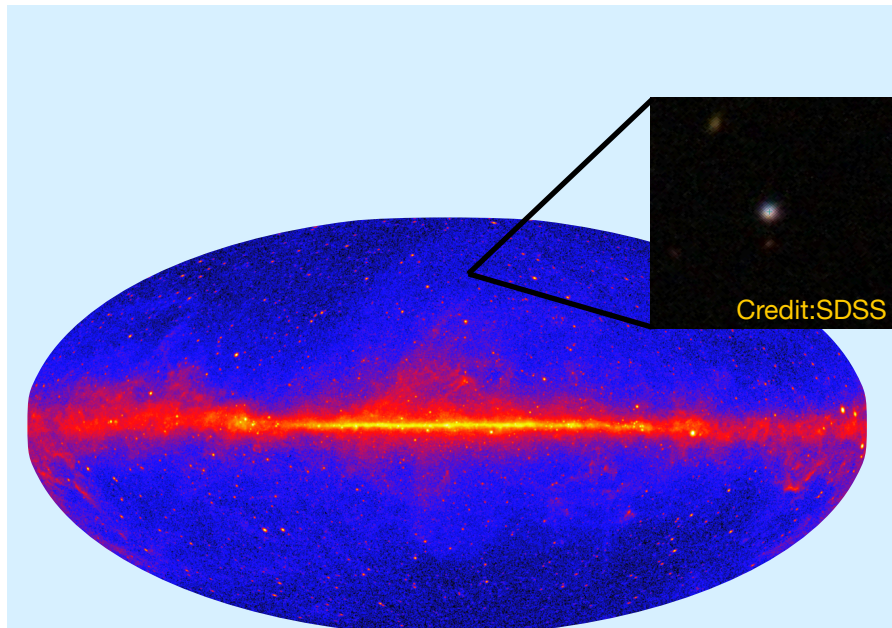


PKS 1502+106

High-energy neutrinos from a faraway active galaxy

X Rodrigues, S Gao, S Garrappa, A Franckowiak, V Paliya, and W Winter



Credit: SDSS

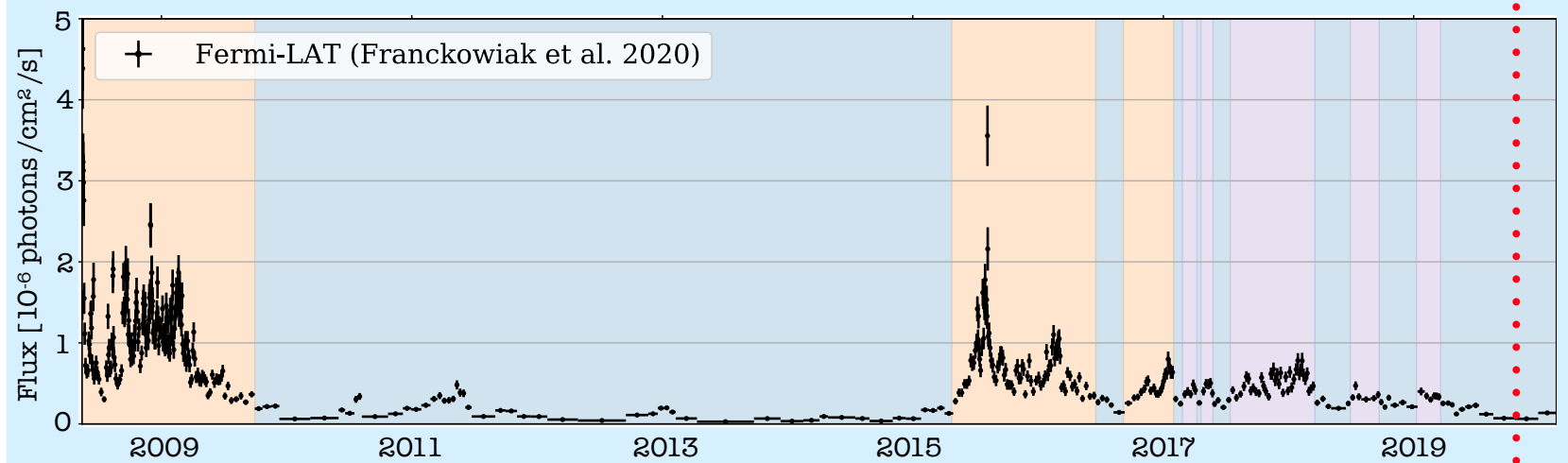
Credit: NASA/DOE/Fermi-LAT

PKS 1502+106 is a flat-spectrum radio quasar (FSRQ). The **supermassive black hole** in its core launches a **relativistic jet** in the direction of Earth, leading to the observation of powerful and highly variable multi-wavelength emission from non-thermal processes

In spite of its high redshift of 1.82, it is **among the 15 brightest** sources in the gamma-ray sky

On July 30, 2019, the **IceCube detector**, located in the South Pole, observed a **neutrino** with an estimated energy of **300 TeV** from the direction of **PKS 1502+106**

At the time the source was in a **quiescent state** of weak gamma-ray activity



Flux [10^{-9} photons/cm²/s]

2009 2011 2013 2015 2017 2019

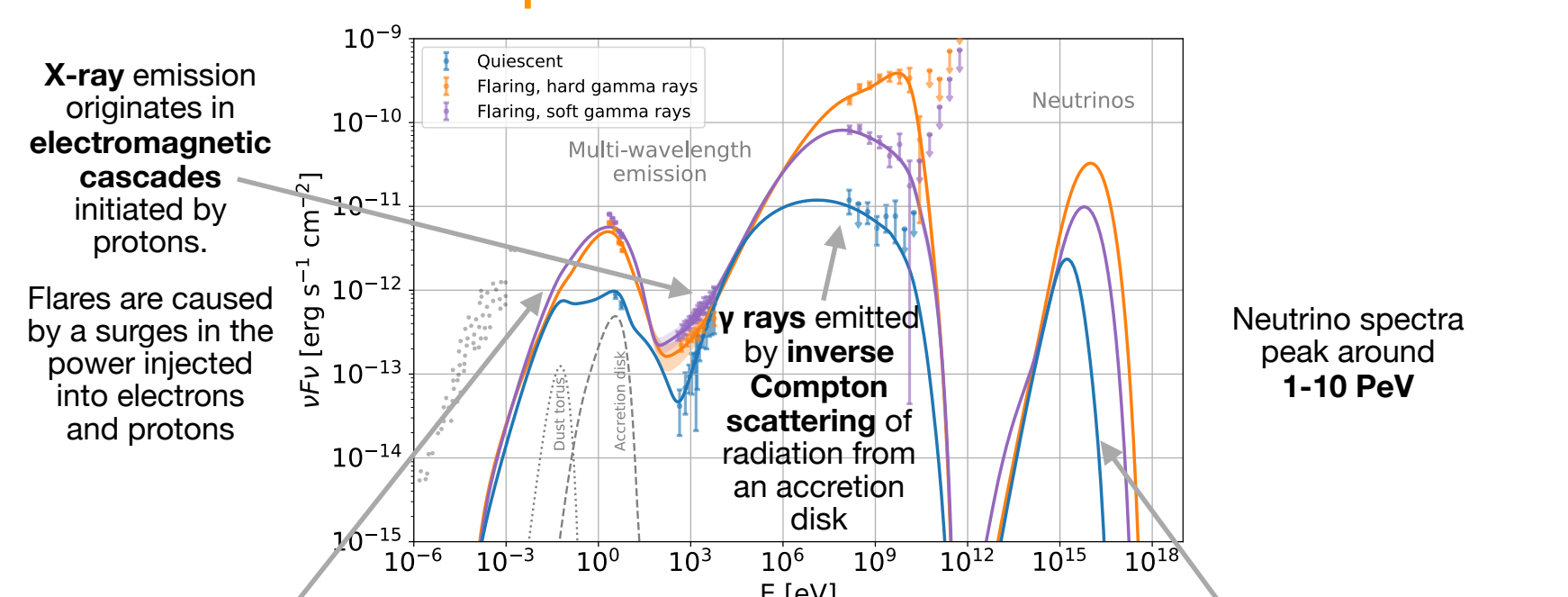
+ Fermi-LAT (Franckowiak et al. 2020)

Neutrino detection (IC-190730A)

In 11 years of gamma-ray data we can identify three different states:

- Quiescent state (low gamma-ray flux)
- Flaring with hard gamma-ray spectrum
- Flaring with soft gamma-ray spectrum

Leptohadronic model



X-ray emission originates in **electromagnetic cascades** initiated by protons. Flares are caused by a surge in the power injected into electrons and protons

Multi-wavelength emission

Neutrinos

Neutrino spectra peak around **1-10 PeV**

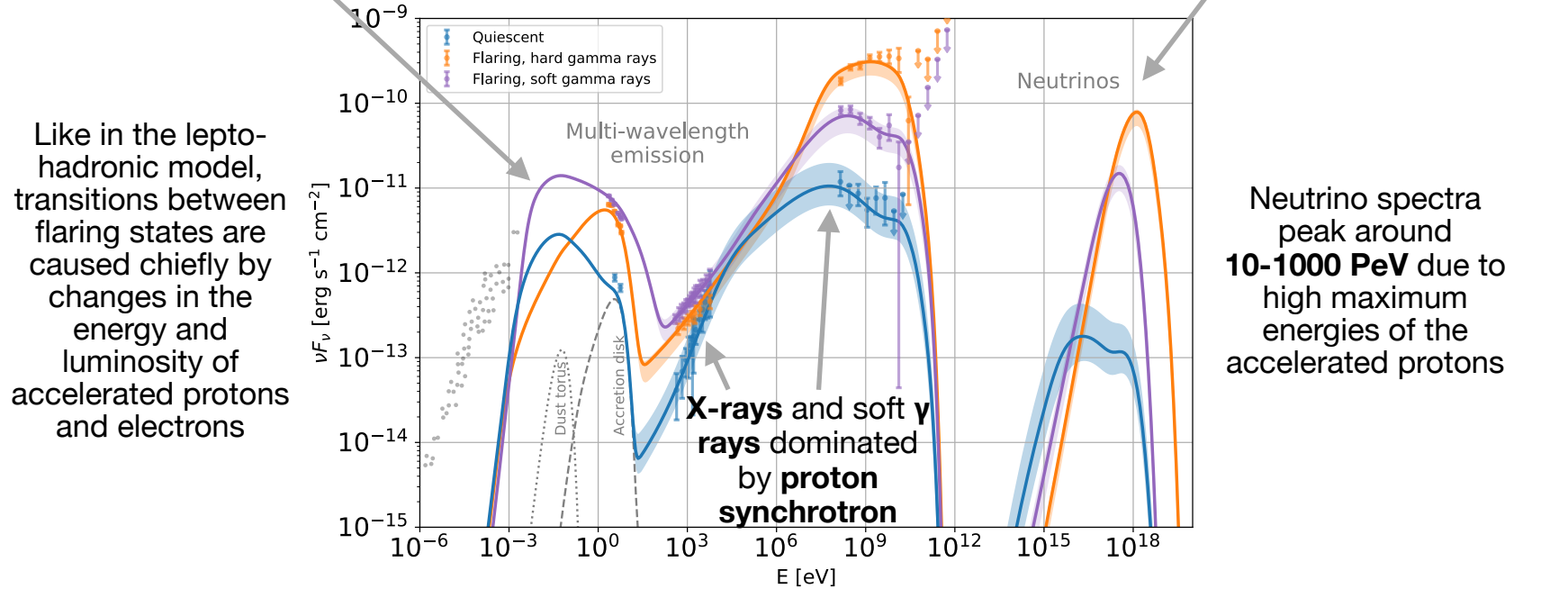
γ rays emitted by **inverse Compton scattering** of radiation from an accretion disk

Variable optical emission originates in **synchrotron radiation** by electrons

We can explain the photon emission from the source by numerically modeling the **photo-interactions** of **electrons and protons** accelerated in a single zone in the relativistic jet (see also Rodrigues et al. 2019, ApJ 874 L29)

Neutrinos are produced through **photo-pion** interactions by high-energy **protons**

Proton synchrotron model



Like in the leptohadronic model, transitions between flaring states are caused chiefly by changes in the energy and luminosity of accelerated protons and electrons

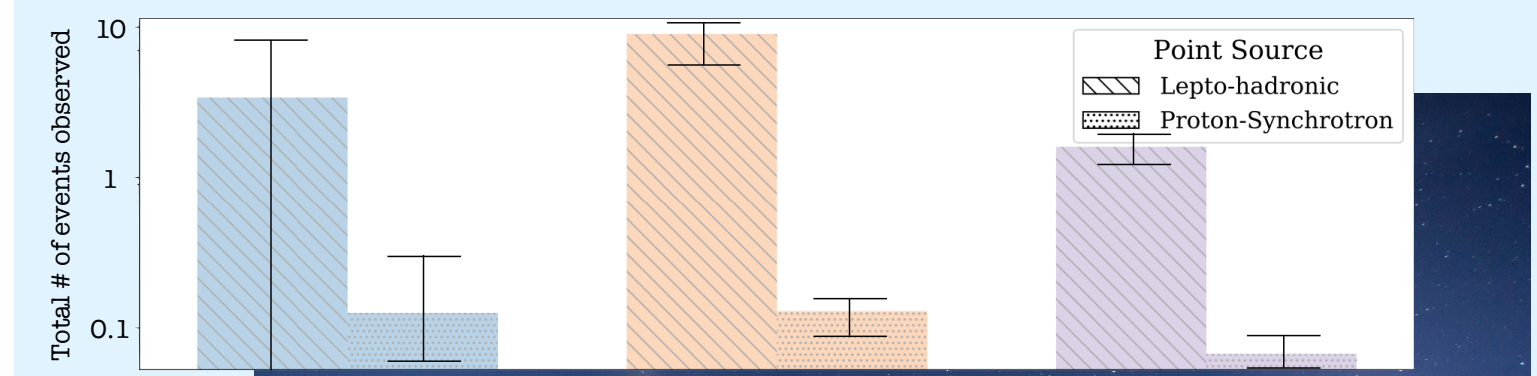
Multi-wavelength emission

Neutrinos

Neutrino spectra peak around **10-1000 PeV** due to high maximum energies of the accelerated protons

X-rays and soft γ rays dominated by **proton synchrotron**

The models can be used to predict the expected number of neutrino events detected by IceCube from this source over the course of 11 years




Total # of events observed

10 1 0.1

Quiescent state (low gamma-ray flux) Flaring hard gamma rays Flaring soft gamma rays

Point Source Lepto-hadronic Proton-Synchrotron



In both models **high-energy protons** can help explain the multi-wavelength emission from PKS 1502+106, leading to the **co-production of high-energy neutrinos**.

While neither model favours the emission of neutrinos during the quiescent state, they both **support the hadronic nature** of the emission of PKS 1502+106 and its **potential as a neutrino source**.

The results suggest that with increasing statistics, **more correlations** should be expected with sources of this kind.

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