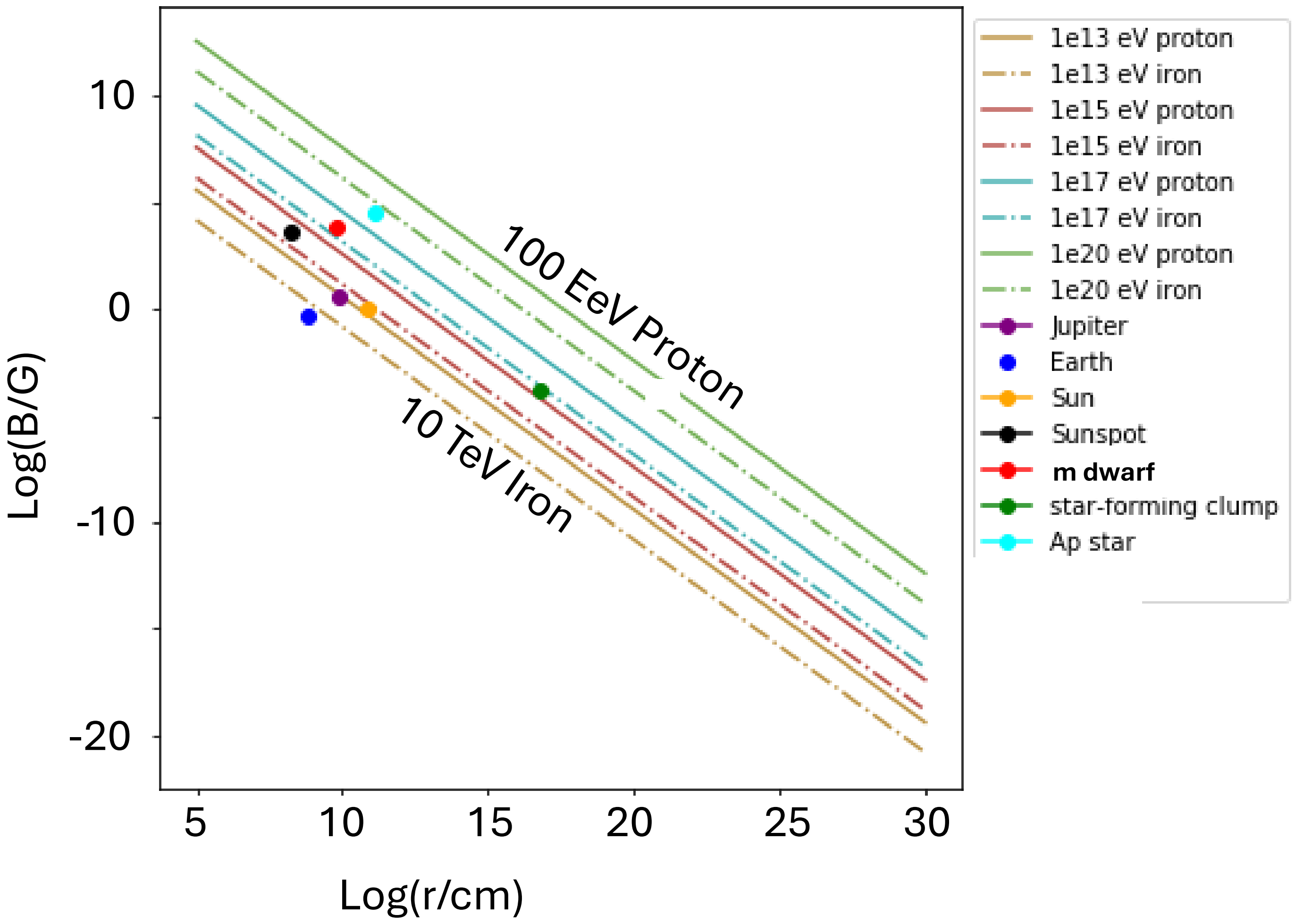
Evaluating the Potential of Low Mass Stars as Sources of TeV Cosmic Rays

Kathryn Plant

Jet Propulsion Laboratory
California Institute of Technology

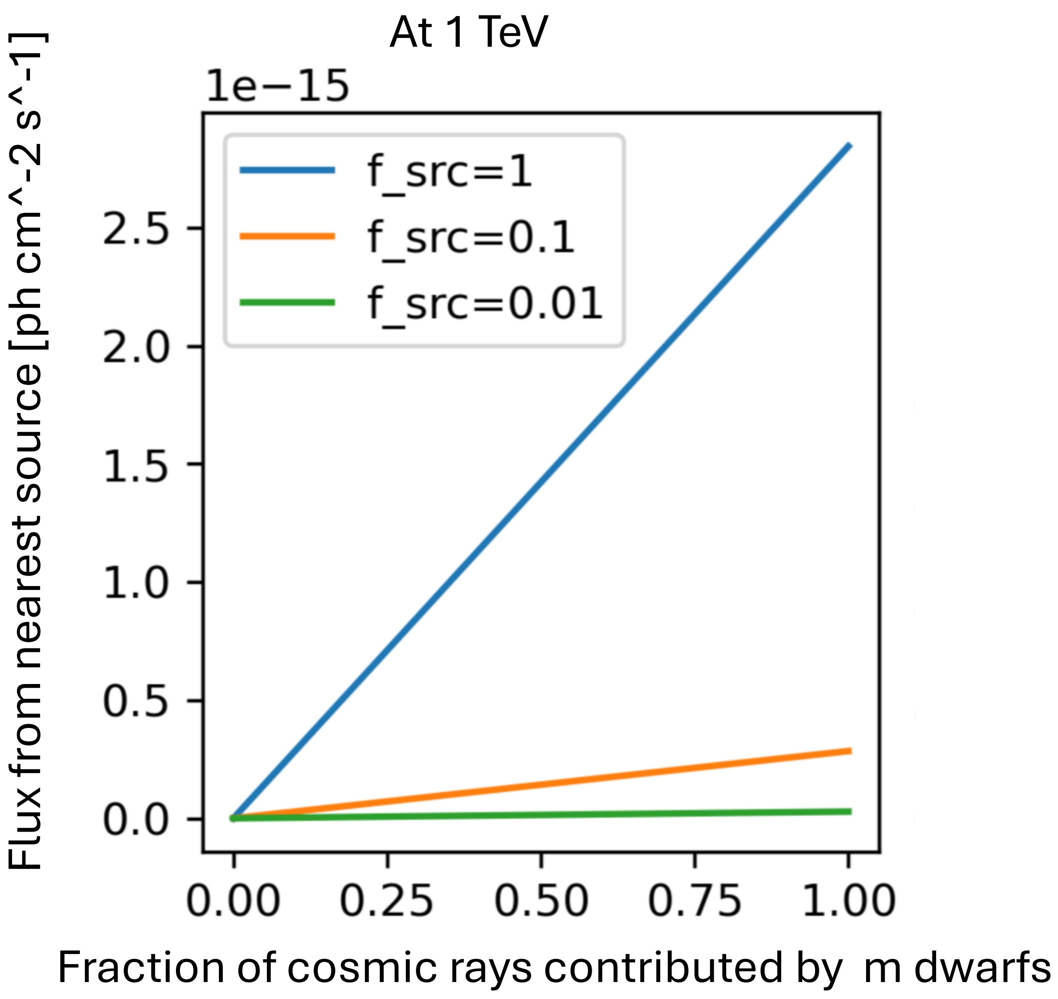
What if there were a faint but abundant source class of Galactic cosmic rays?

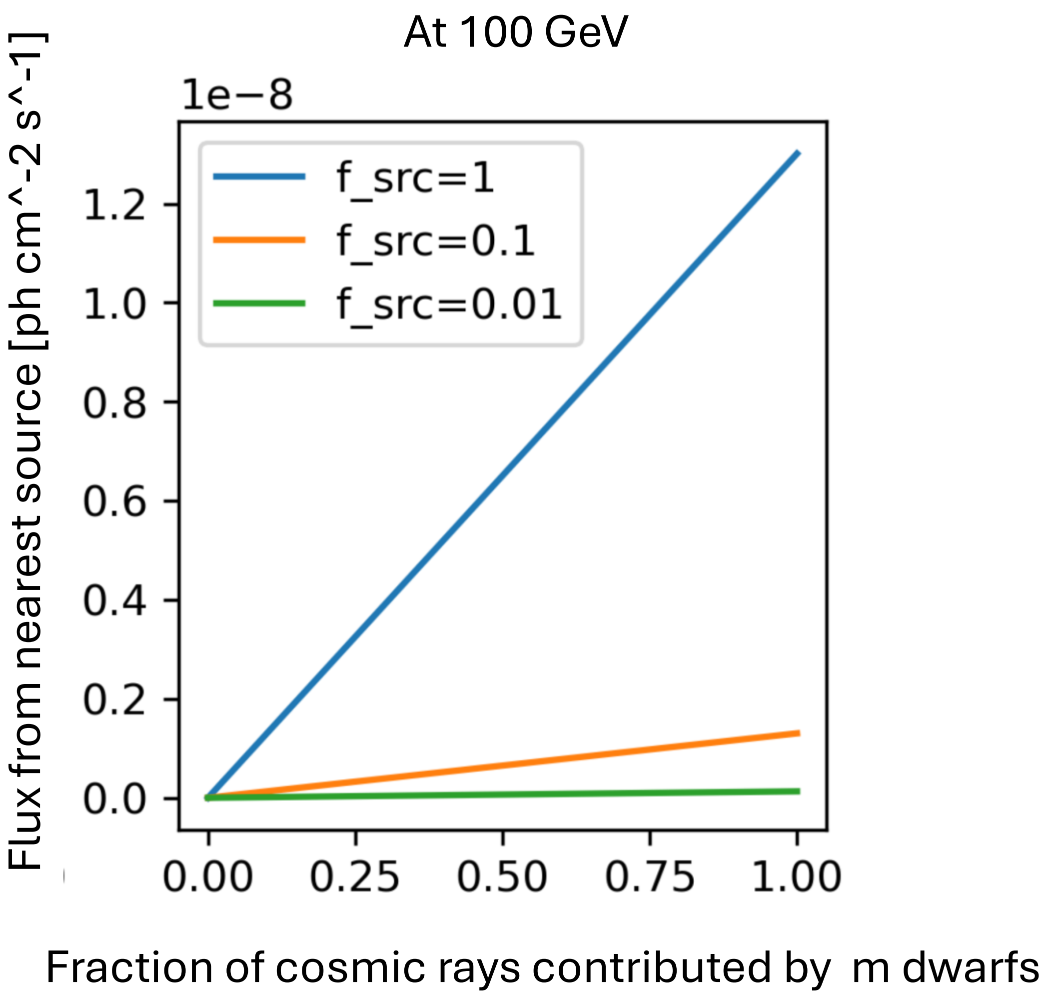
Hillas plot featuring stars and planets



- Most stars are M dwarfs
- kilogauss magnetic fields

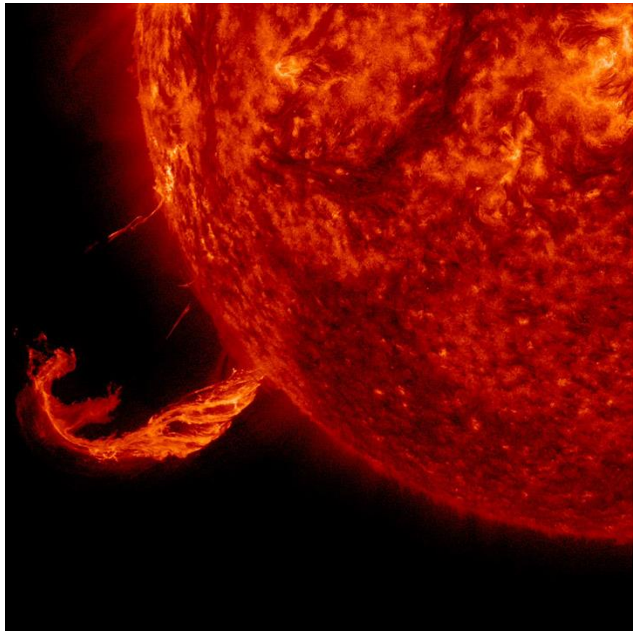
An abundant source class could contribute a large fraction of the cosmic ray flux without individual detectable gamma ray sources.





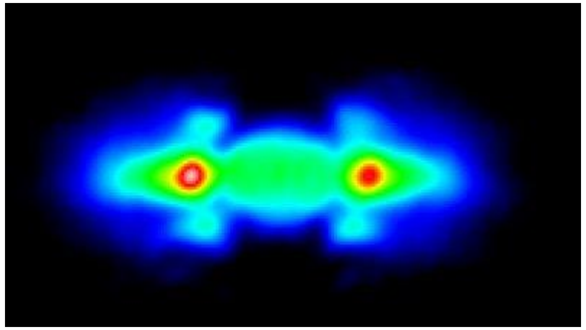
M dwarf Magnetic Activity

- Complex Small-scale fields
- Coronal & chromosphere activity



- Large-scale dipolar fields
- Aurora

Jupiter Lband image



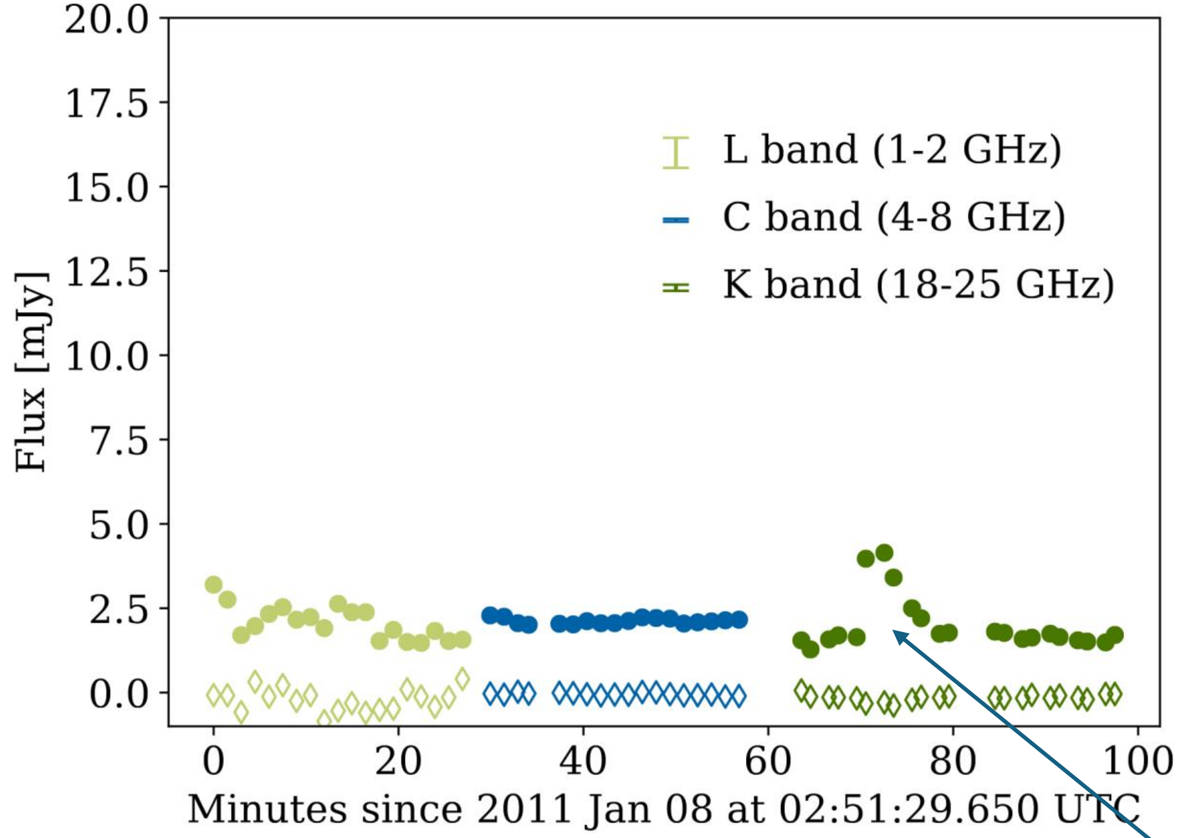
Source: ATNF

Image credit: Credits: NASA, ESA

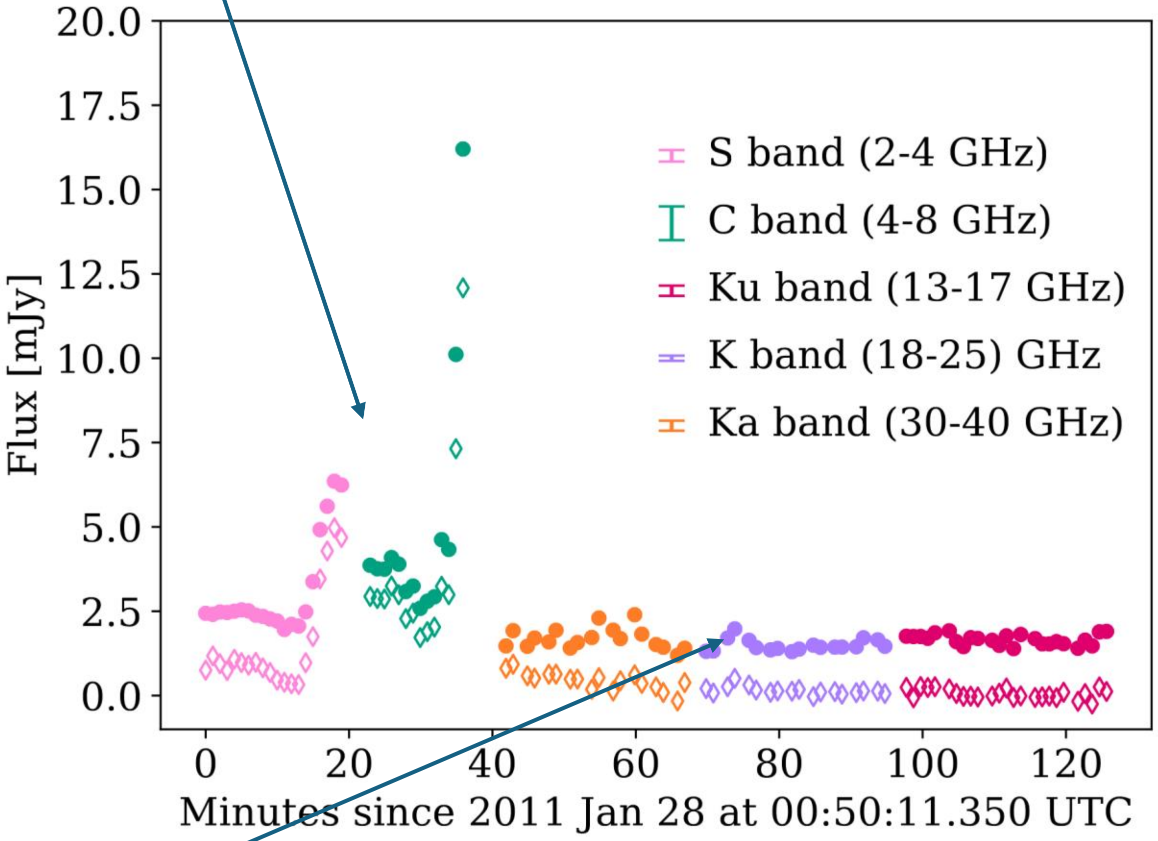
Radio Light Curves illustrating auroral and coronal activity

Electron cyclotron maser, RCP = X mode

January 8 2011



January 28 2011

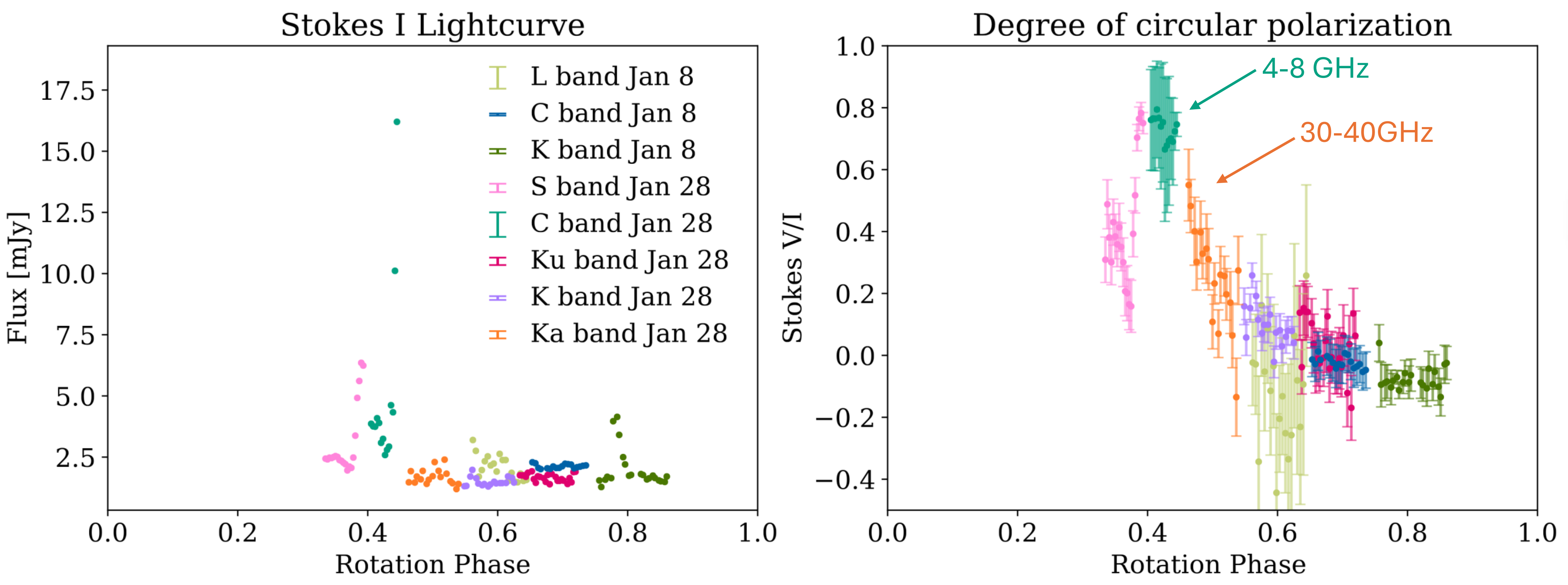


● Stokes I
◊ Stokes V

Flares

Plant, Hallinan, and Bastian 2024 ApJ

Radio Light Curves illustrating auroral and coronal activity



Strong X mode polarization at Ka band → Gyrosynchrotron unlikely

Plant, Hallinan, and Bastian 2024 ApJ

Particle energy limit estimates
1. Scaling from Earth's van Allen Belts

Dipole moment

radius

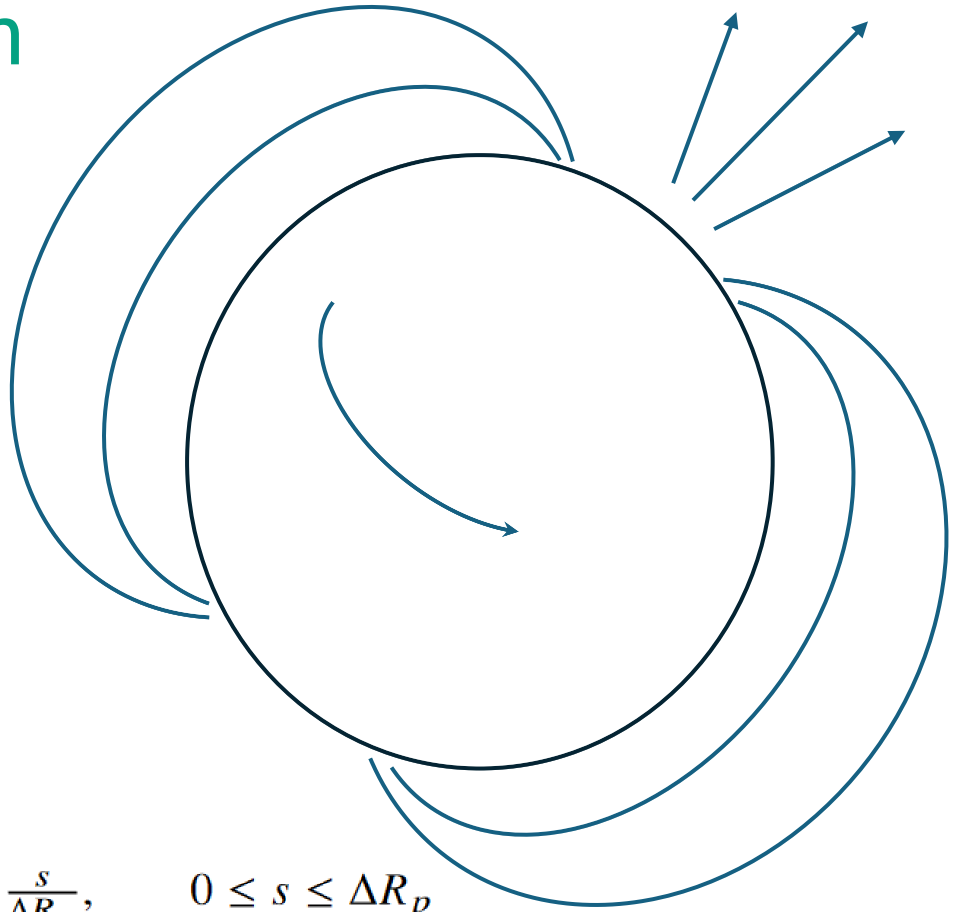
$$E_{\rm max} = E_{\rm Earth\_Max} \frac{\mu}{\mu_{\rm Earth}} \frac{r}{r_{\rm Earth}}^{-2}$$

Earth:
Van Allen Belts maximum observed: ~500 MeV
R= 6.37 × 10^8cm
μ = 8 × 10^25 Gcm−3

M Dwarf:
R = 9.7 × 10^9cm
μ = 3.7 × 10^33Gcm−3
E~0.1 PeV ?

Calculation scaled from Pizzella 2018

Particle energy limit estimates
2. Polar cap acceleration mechanism



- Ikhsanov and Biermann 2006 estimated particle flux and maximum energy for a rapidly rotating white dwarf
- Here, I adapt that for an m dwarf
  - rotation period = 0.23 days
  - dipole field strength 2 kG
- Result: maximum proton energy ~TeV
- Proton flux from all m dwarfs = 10^-9 cm^2 s^-1

$$E_{\parallel} = E_{AS} \times \begin{cases} \frac{s}{\Delta R_p}, & 0 \le s \le \Delta R_p \\ 1, & \Delta R_p \le s \le R \\ \sqrt{2R/r}, & s > R \end{cases}$$

$$E_{AS} = \frac{1}{8\sqrt{3}} (\frac{\Omega R}{c})^{5/2} B_0$$

Conclusion

- There are plausible scenarios for m dwarfs to be sources of TeV cosmic rays, but they would likely be faint sources.
- Even the nearest individuals may be difficult to detect as gamma ray sources.