STARS

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The Solar Analogy

The Forest: X-rays across the HR diagram

- heating mechanisms
- coronal structure
- fundamental parameters

The Trees: Spectral analysis

- Low-res spectra:
  temperatures, fluxes, and metallicity
- High-res spectra:
  temperature distributions, emission measures, abundances

The Roots: The Sun

THE NEAREST STAR

- Sun-Earth Connection
  - "space weather" affects satellites
  - activity affects climate
- Solar corona
  - hot (million-degree) plasma
  - dominated by magnetic loop structures
  - dynamic environment
- Stellar coronae
  - ubiquitous, and copius
  - tuning the Sun

STELLAR X-RAY EMISSION

- Why do the exist, how are they heated?
  - Magnetic reconnection?
  - Alfvénic wave heating?
  - ¿?
- What determines coronal structure?

  Simple answer: Magnetic fields

  Correct answer:
- What are the fundamental parameters?
  - Dynamo activity: Rotation and convection
  - Age: evolution, mass-loss
  - Composition: Radiative loss function
  - Gravity: field topology and stability
  - Environment: binary companions

Spectra
Or, How do we find out what we want to know?

Thermal Emission
– optically thin emission from collissionally excited plasma in local thermal equilibrium

Low-resolution spectra
– dominant temperatures
– metallicity

High-resolution spectra

- Select lines spanning temperature range of interest
- Measure fluxes of selected lines
- Infer the emission measure distribution (and **error bars!**)

$$\begin{aligned} I_{ul} &= AK_{ul} \int_{\Delta T_{ul}} G_{ul}(n_e, T) n_e^2(T)\, dV(n_e, T) \\ &= AK_{ul} \int_{\Delta T_{ul}} G_{ul}(T) \left\{ n_e^2(T) \frac{dV(T)}{d\log T} \right\} d\log T \end{aligned}$$

- Rinse, lather, repeat
- [X/Fe] via lines and [Fe/H] via continuum

Coronal Loops

Energy Balance:

$$E_H + \mathcal{F} \cdot \mathbf{v} = \nabla \cdot \mathbf{F_c} - E_R + \nabla \cdot \left(\left[\frac{1}{2} \rho v^2 + U \right] \mathbf{v} + \rho \mathbf{v} \right)$$

where E_H is the local heating function, $\mathcal{F}$ is the volume force exerted by gravity and momentum deposition, $\mathbf{v}$ is the flow velocity, $\mathbf{F_c}$ is the conductive flux, $F_c(s) = -\kappa T^{5/2} \frac{dT}{ds}$, $E_R \propto \frac{P(T}{T^2}$ is the radiative loss, $\rho = m_H n_e$ is the density, U is the thermal energy density. The gradient in the pressure p is balanced by gravity. For large pressure scale heights, $\frac{dp}{ds} = 0$ and $\mathbf{v} = \mathbf{0}$,

$$E_H + E_R - \nabla \cdot \mathbf{F_c} = 0$$

Scaling laws

$$T_{max} \propto (p_0 L)^{\frac{1}{3}}$$

$$E_H \propto p_0^{7/6} L^{-5/6}$$

$$n_e^2 \frac{ds}{d \log T} \propto T^{3/2}$$