Role of Heating on Solar Wind Velocity and Temperature profiles

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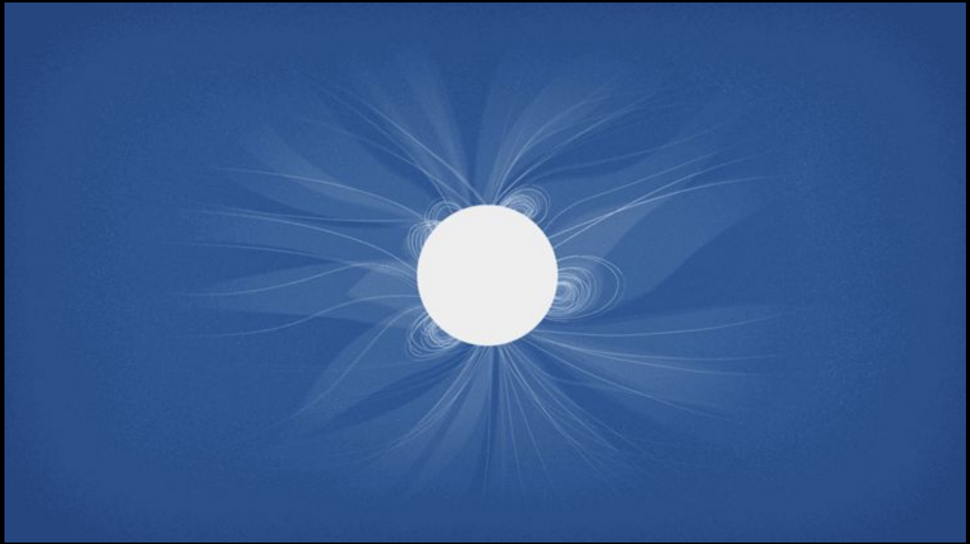
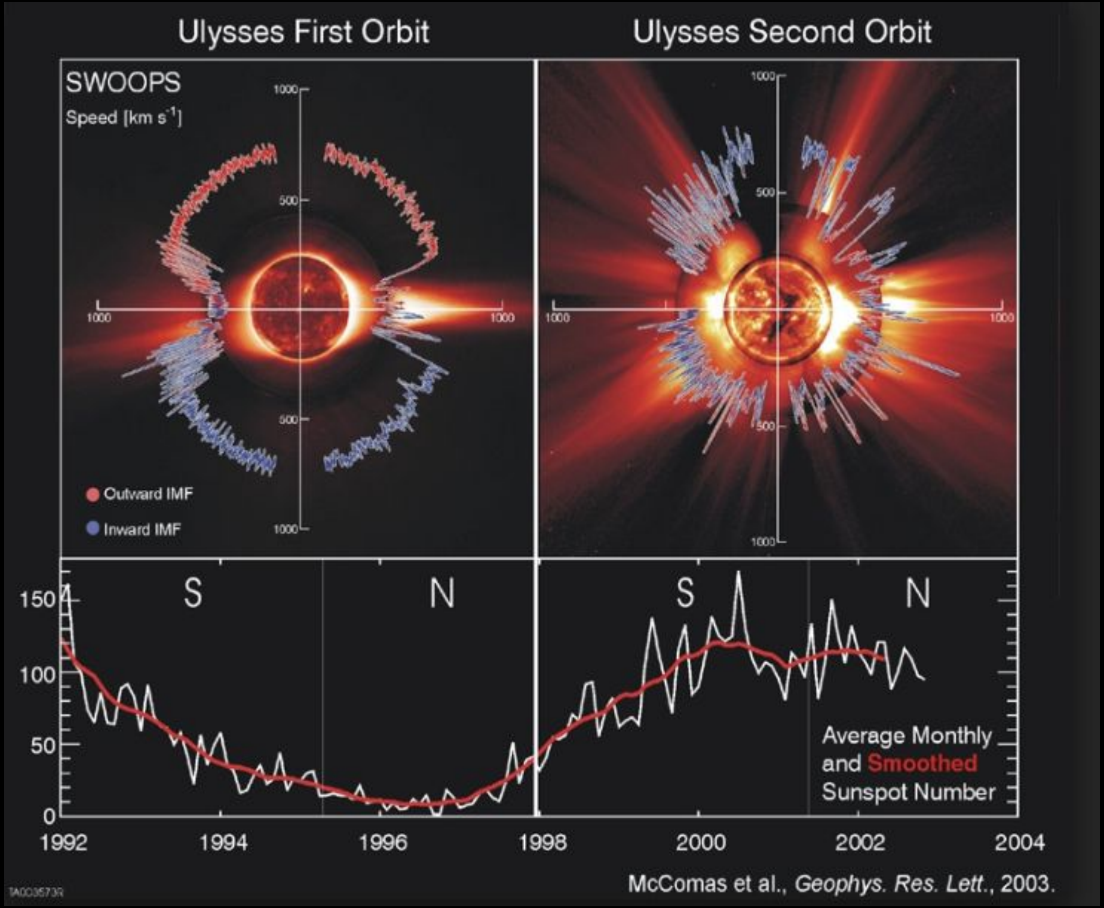
Solar Wind:



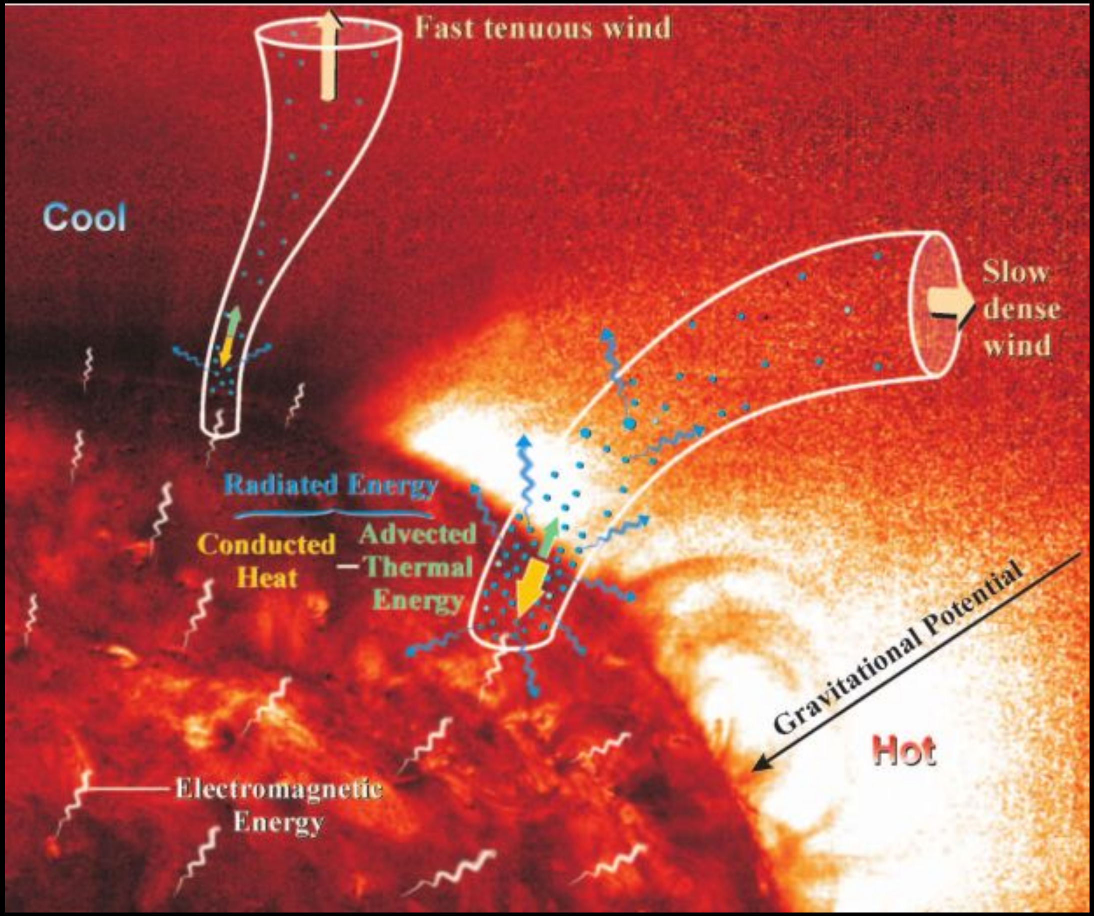
- ➢ Solar Corona is very hot
- ➢ Pressure is higher than ambient interstellar medium.
- ➢ Upper Corona expands into the interstellar space, accelerates and forms the solar wind.
- ➢ It contains waves, turbulence and energetic particles.
- ➢ In closed magnetic field, plasma is trapped
- ➢ In open magnetic field, plasma can expand into interplanetary space.

Variation of the Solar Wind Speed:



- ➢ At minimum: fast wind in coronal hole in polar caps; slow wind at low latitude.
- ➢ At maximum: fast and slow wind stream distributed all over the surface.
- ➢ Strong link between wind properties and the solar cycle.

Observational Properties of the Solar Wind:



- ➢ Fast wind is in the open field regime, which is generally cool.
- ➢ Slow, dense wind is from the hot region.

(Schwadron & McComas 2003)

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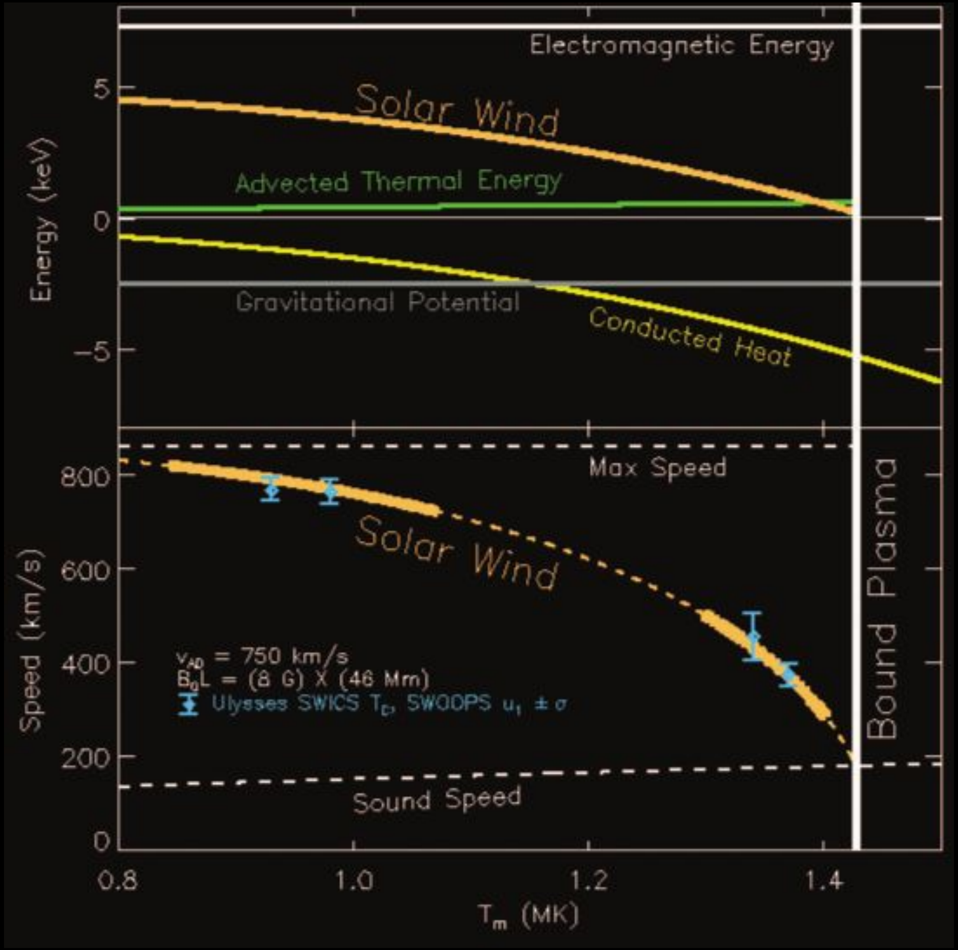
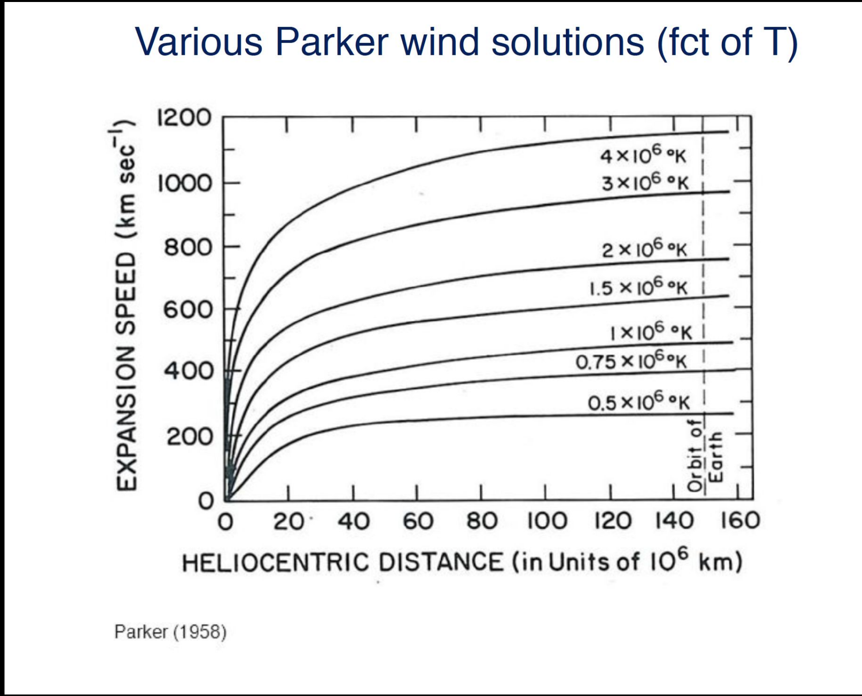


- ➢ Wind energy decreases with temperature at the base of the corona.
- ➢ Speed of the solar wind also decreases with temperature at the base of the corona.
- ➢ Our aim is to explain these properties from the numerical model of solar wind.

(Schwadron & McComas 2003)

Parker Wind Model:

In 1955, Parker first proposed that the Sun possesses a wind.

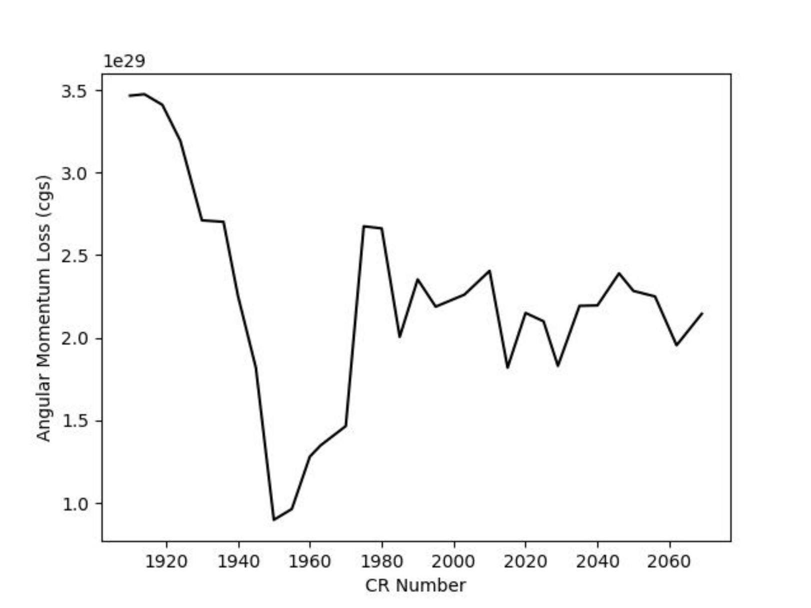


Solar wind is launched by magnetic heating of the corona and accelerated by coronal pressure there.

- ➢ Solar wind speed increases with temperature.
- ➢ However, in reality this is not the case. Fast wind is observed to originate from cool coronal hole regime. So, there is a discrepancy between model and the observations.

Polytropic Solar Wind Model:

We solve MHD equations with an initial polytropic wind profile to model the solar wind. We use PLUTO MHD code for this purpose.



- ➢ Polytropic wind model can explain the observed mass loss and angular momentum loss.
- ➢ However, polytropic wind model is thermally driven. It means if temperature at the base of the corona is high, speed of solar wind speed is also high.

Modelling of the Solar Wind with Alfven Wave:

$$\frac{\partial}{\partial t}\rho + \nabla \cdot \rho \mathbf{v} = 0,$$

$$\frac{\partial}{\partial t}\rho \mathbf{v} + \nabla \cdot (\rho \mathbf{v}\mathbf{v} - \mathbf{B}\mathbf{B} + \mathbf{I}p) = -\rho \nabla \Phi,$$

$$\frac{\partial}{\partial t}(E + \rho\Phi) + \nabla \cdot ((E + p + \rho\Phi)\mathbf{v} - \mathbf{B}(\mathbf{v}\cdot\mathbf{B})) = Q,$$

$$\frac{\partial}{\partial t}\mathbf{B} + \nabla \cdot (\mathbf{v}\mathbf{B} - \mathbf{B}\mathbf{v}) = 0,$$

We solve these MHD equations with an initial Parker wind profile to model the solar wind. However, there is now an extra source term due to alfven wave.

Our model is axisymmetric. So, it is 2.5D model of solar wind.

$$p = p_{\rm th} + \mathcal{E}/2 + B^2/2$$

$$E \equiv \rho e + \rho v^2/2 + B^2/2 + \mathcal{E}$$

Here, E is the total energy, m is the mass density, B is the magnetic field, P is the pressure.

Source term in the energy equation is made of four components: $Q = Q_h + Q_w - Q_c - Q_r,$

Qh, Qc and Qr corresponds to heating, thermal conduction and radiative cooling. Qw is an extra heating source term in our model which is due to Alfven wave.

Modeling Alfven Wave Heating Mechanism:

- ➢ We introduce two populations of parallel and antiparallel alfven wave in our solar wind model.
- ➢ We model this velocity propagation following WKB theory (Bachelor 1971, Tu & Marsh 1993) .

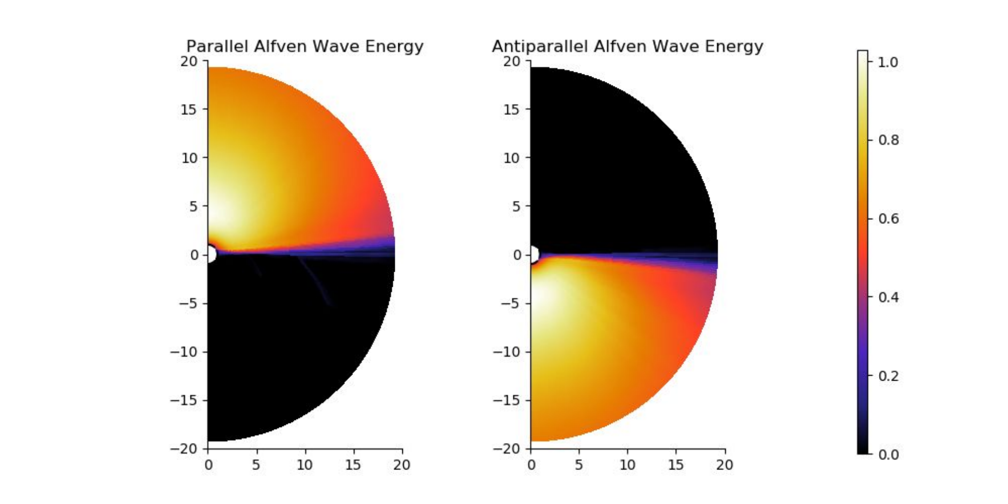
$$\frac{\partial \mathcal{E}^{\pm}}{\partial t} + \nabla \cdot ([\mathbf{v} \pm \mathbf{v_a}]\mathcal{E}^{\pm}) = -\frac{\mathcal{E}^{\pm}}{2}\nabla \cdot \mathbf{v} - Q_w^{\pm},$$

$$\mathcal{E}^{\pm} = \rho \frac{|z^{\pm}|^2}{8}$$

$$\mathbf{z}^{\pm} = \delta \mathbf{v} \pm \frac{\delta \mathbf{b}}{\sqrt{4\pi\rho}}$$

$$Q_w = Q_w^{+} + Q_w^{-},$$

$$Q_w^{\pm} = \frac{\rho}{8}\frac{|z^{\pm}|^3}{\lambda}$$

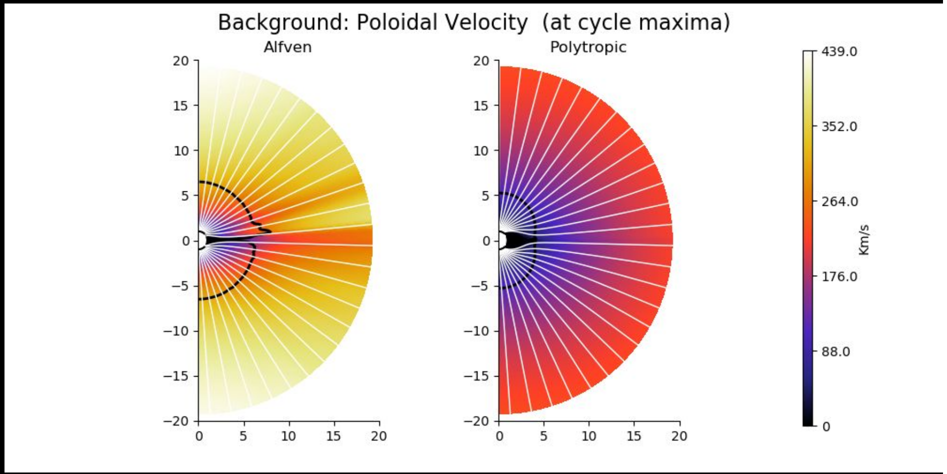


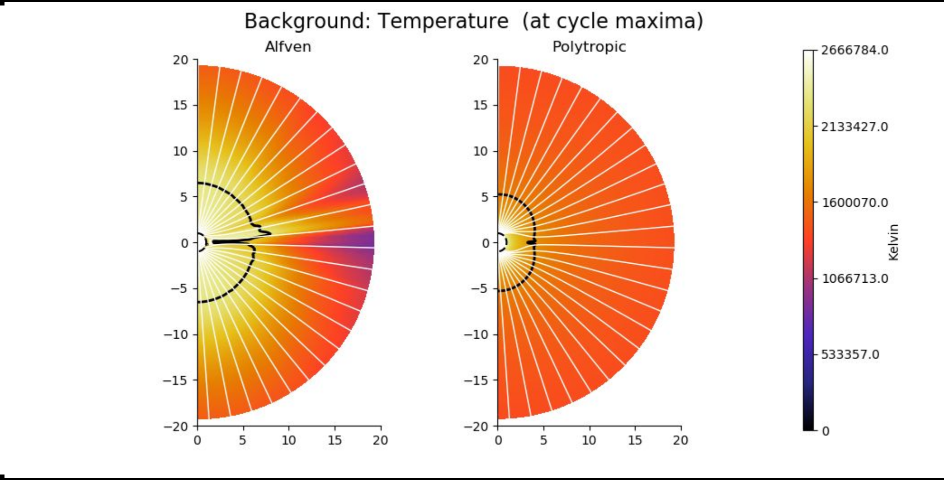
$\mathbf{z}^{\pm}$ is the elasser variable. Q is the dissipation energy. This term follows Kolmogorov cascading phenomenology with dissipation length. Counter propagating Alfven wave is necessary for development of turbulence. We model the rate for creation of counter propagating wave due to reflection by dissipation length λ

See Reville et al. 2018 for Alfven wave heating mechanism. (also see Tu & Marsh 1995, Lionello et al. 2014)

Results from Solar Wind Model with Alfven Wave:

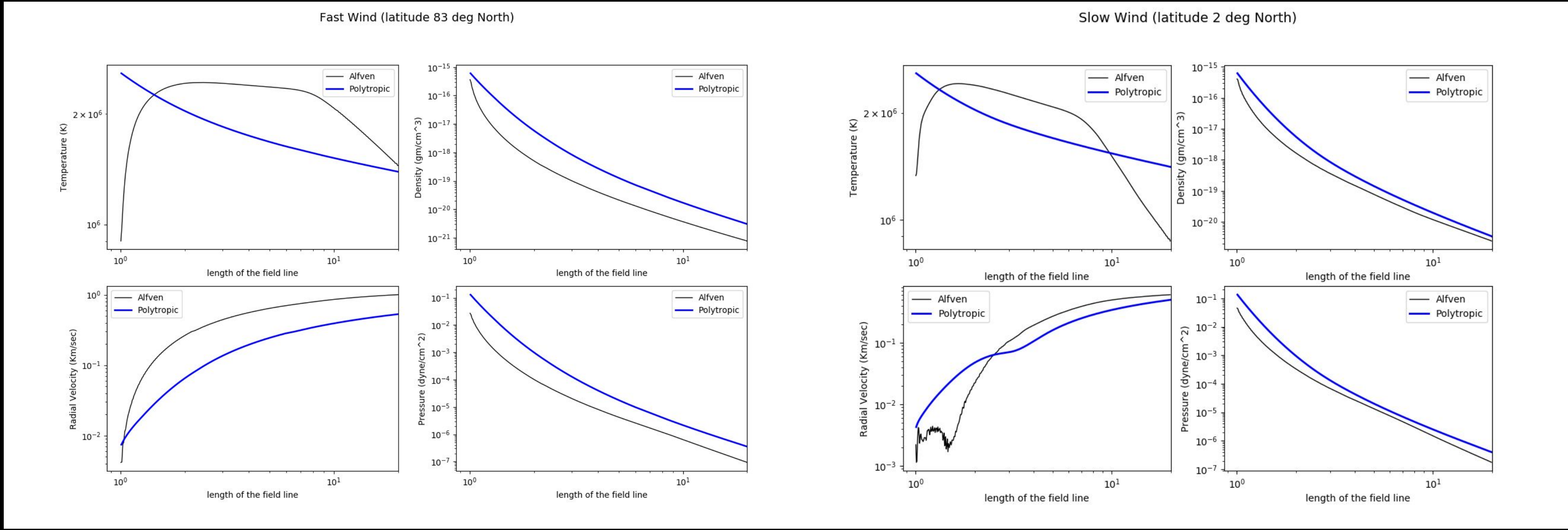
At Cycle Maxima:



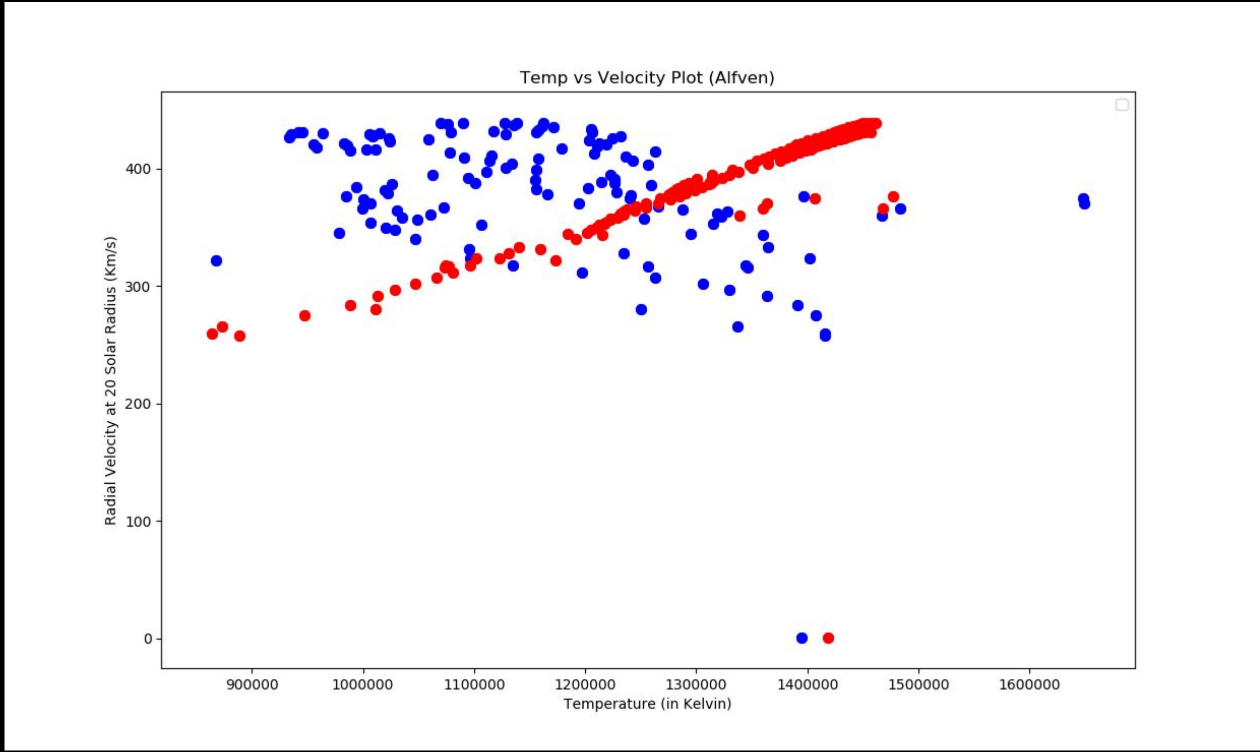


- ➢ In polytropic case, solar wind velocity is very high near the equator, i.e., streamer region. Temperature is also high in that region.
- ➢ While in the model which also considers heating due to Alfven wave, solar wind speed is slow near the equator, i.e., in the streamer region. Temperature is also low in that region.

Comparison of different profiles along the open field line in fast and slow wind regime:



Temperature and Wind Speed Relationship:



Blue denotes temperature is taken at the base of the corona.

Red denotes temperature is taken near 20 solar radius.

- Wind Speed decreases with the temperature at the base of the Corona.
- Our Model with Alfven wave resolve the discrepancy between the theory and observation.

Summary:

- We have developed an improved solar wind model based on Alfven wave heating (Also see Reville et al. 2018).

- We are now also able to run our 2.5 D solar wind model upto 1AU. We will now be able to compare our result with HELIOS mission data.

- We are now in process for comparison of our results obtained from new Alfven wave heating based solar wind model and the polytropic solar wind model.

- We have to also analyze different properties of Alfven wave in the solar wind.

- We are in process of developing 3D model of solar wind.