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Modeling the Thermodynamic State of a Coronal Mass Ejection (CME) Using Its Kinematics in the Heliosphere

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1. Introduction and Motivation

BACKGROUND:

- Some internal properties of CMEs have also been measured near and beyond 1 AU from their in situ observations by instruments on board the Voyager, Ulysses, Helios, Wind, ACE, and STEREO spacecraft (Burlaga et al. 1981; Richardson & Cane 1995; Lepri et al. 2001; Wang & Richardson 2004; Liu et al. 2005, 2006; Jian et al. 2008).
- Some internal CME plasma properties are measured using EUV spectral observations from the ultraviolet coronagraph spectrometers (UVCS), coronal Diagnostic Spectrometer, and solar ultraviolet measurements of emitted radiation instruments on the SOHO spacecraft (Raymond 2002; Ciaravella et al. 2003; Kohl et al. 2006; Lee et al. 2009).

METHODS and AIMS:

- The only attempt to infer the internal state of a CME during its propagation has been done by Wang et al. (2009) by developing a Flux Rope Internal State (FRIS) model. In our recent study (Mishra & Wang 2018), we improve the FRIS model and use the equations of thermodynamics to derive the polytropic index, internal forces, absorbed heat, heating rate, entropy and entropy changing rate of the CME of 2008 December 12.

2. Flux Rope Internal State (FRIS) Model for the CMEs

We begin with the assumption that a CME is an axisymmetric cylindrical flux rope in the local scale which is undergoing a self-similar expansion within the cross-section.

Derivation of FRIS model

Conservation of total mass and angular momentum of the CME

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Equation of motion using momentum conservation equation

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Equations of Thermodynamics

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Lorentz and Thermal pressure force

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Equation of motion in terms of measurable parameters of the flux rope

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Putting additional constraints give equation (1), fitting of which to the measurements of CME kinematics gives unknowns

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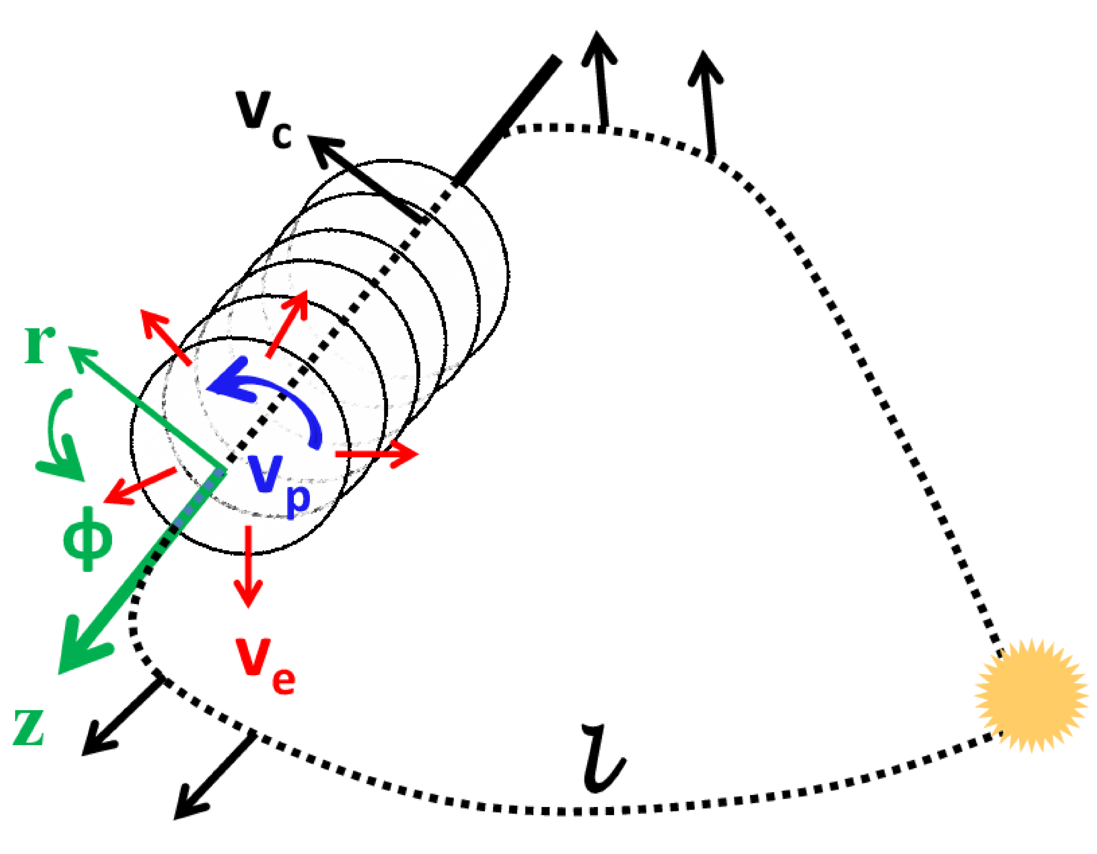
Estimating internal thermodynamic parameters of a flux-rope CME

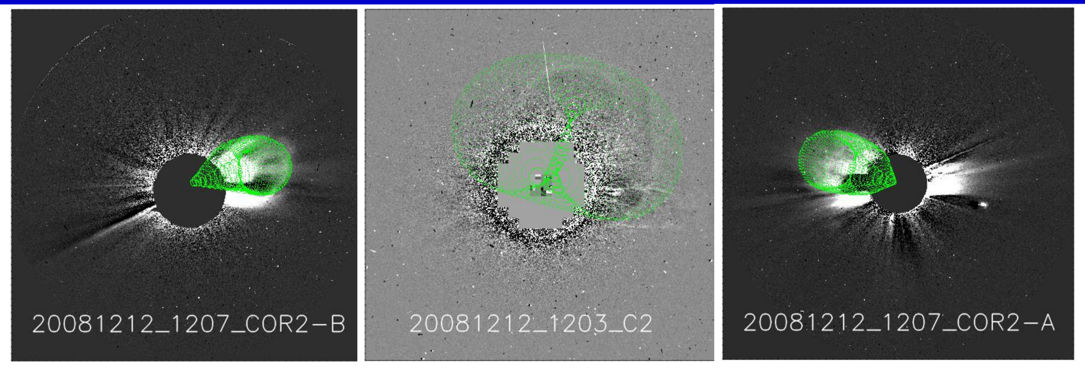


$$
\begin{aligned}
(LR^2)^{\gamma-1} = L^{\gamma-1}R^{\gamma-1}[c_5 a_e + \{(\gamma-1)c_4 a_e v_c \\
- c_3 c_5 L^{-1} + c_4 \frac{da_e}{dt} L \Big\} R^{-1} \\
+ \{(2-\gamma)c_3 c_4 v_c L^{-1} + (\gamma-1)c_4 a_e v_e L\} R^{-2} \\
+ \{(2-\gamma)c_3 c_4 v_e - c_2 c_5 L - c_1 c_5\} R^{-3} \\
+ \{(1-\gamma)c_1 c_4 v_c - \gamma c_2 c_4 v_c L\} R^{-4} \\
+ \{(4-\gamma)c_1 c_4 v_e L + (4-\gamma)c_2 c_4 v_e L^2\} R^{-5}],
\end{aligned}
$$

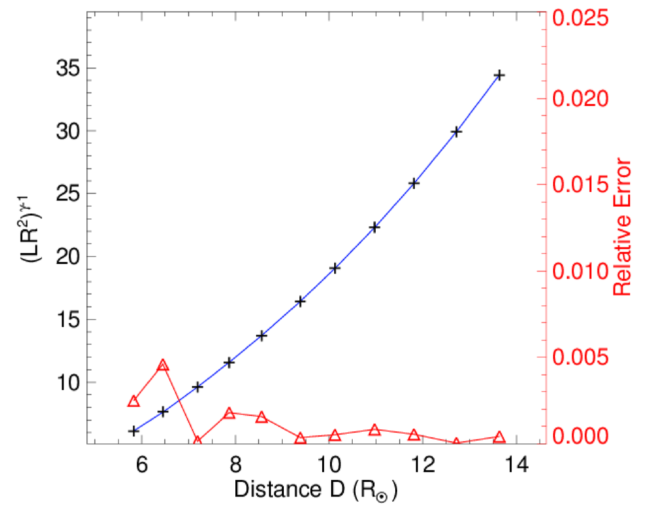
---- equation (1)

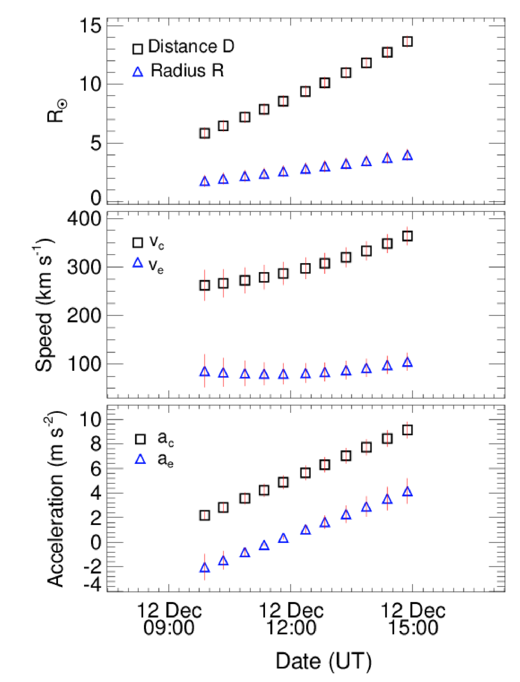
where, h=heliocentric distance of CME leading edge, L= distance of flux-rope axis from solar surface, R= radius of cross-section of flux-rope, v_c = propagation speed, v_e = expansion speed, a_e = expansion acceleration, γ = adiabatic index, c_1- c_5 are constants to be determined by fitting the equation.

3. Reconstruction of 2008 December 12 CME



R = (a/(1+a))*h
a = R/L
L = h – R – 1 Rs

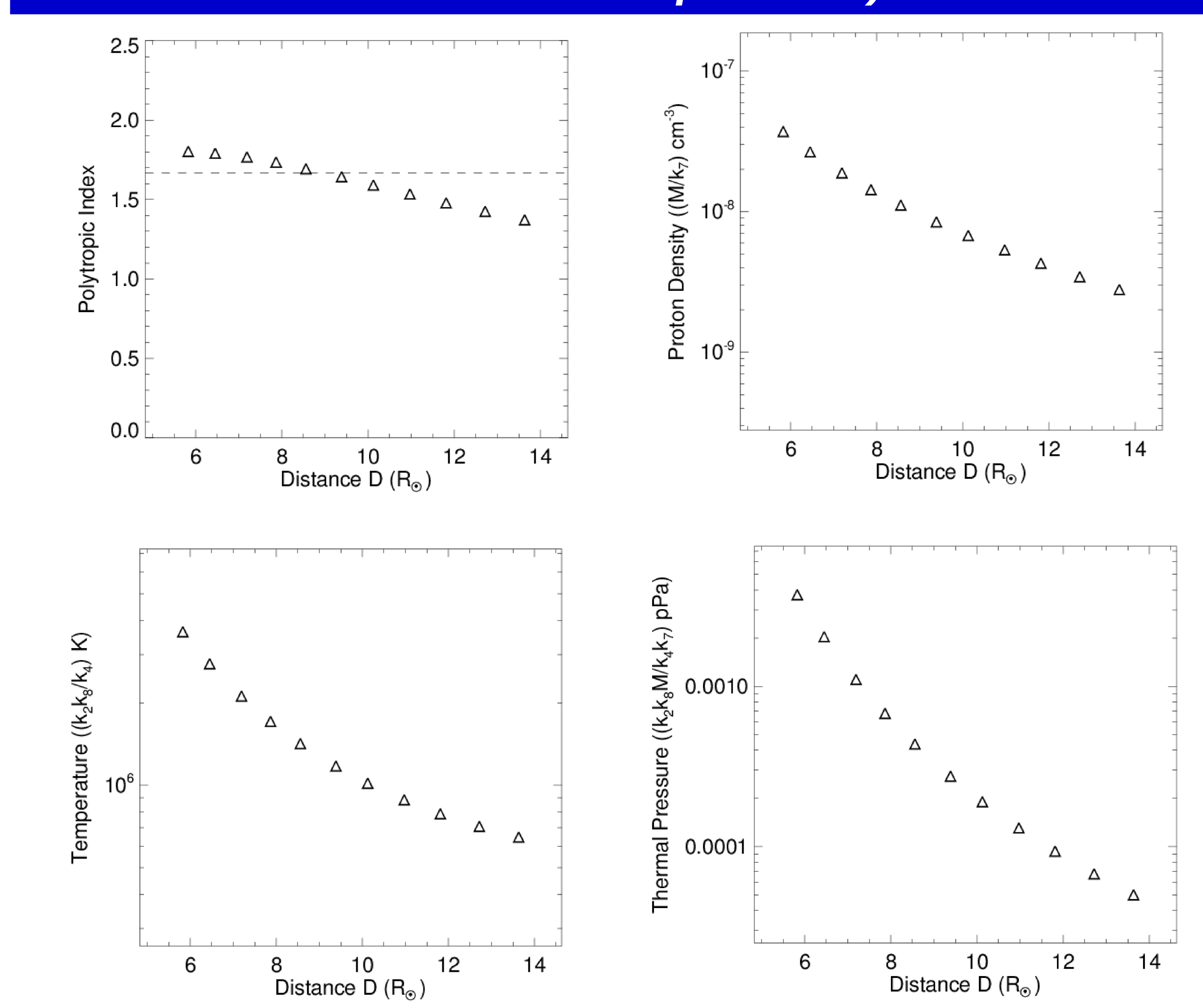




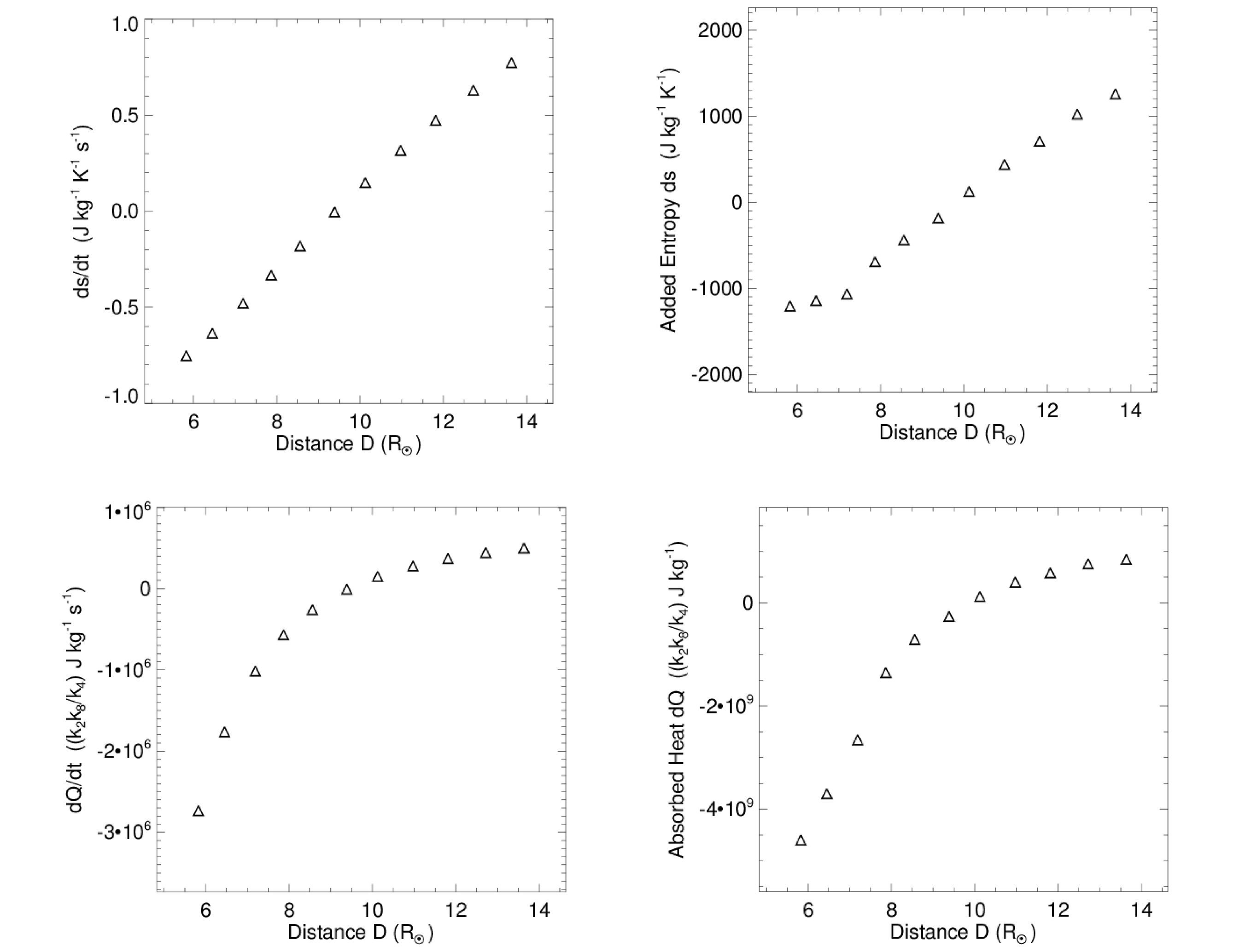
4. Application of the FRIS model to the CME

4.1 Thermodynamic process

(Polytropic index, Density, Temperature, and Thermal pressure)

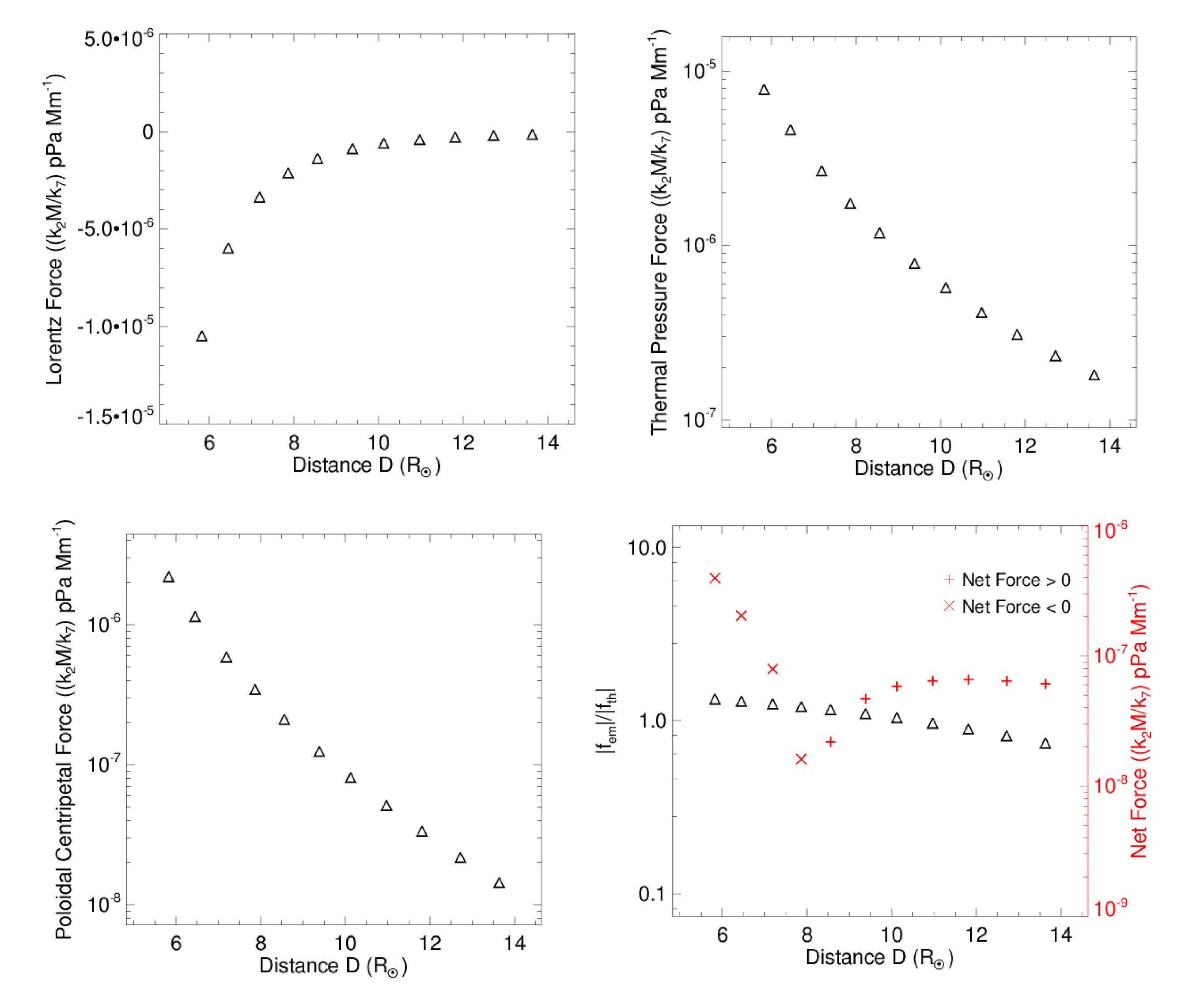


Absorbed heat (dQ), Heating rate (dQ/dt), Entropy (s) and Entropy changing rate (ds/dt)



4.2 Dynamic Process

(Lorentz, Thermal and Centrifugal Forces)



5. Conclusions

- Our study suggests that the CME released heat before it reached an adiabatic state and then absorbed heat.
- The thermal force inside the CME is the internal driver of CME expansion while the Lorentz force prevented the CME from expanding.
- The centrifugal force due to poloidal motion decreased with fastest rate, and the Lorentz force decreased slightly faster than thermal pressure force as the CME moved away from the Sun.

Acknowledgements and Contact

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For further information, please visit http://iopscience.iop.org/article/10.3847/1538-4357/aadb9b/meta, and contact **Wageesh Mishra** at wageesh@ustc.edu.cn