Heating of the Magnetically Closed Corona

Annual Progress Report: 2021 Oct 1 – 2022 Sept 30

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Core Team Members (on proposal):
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Affiliate Team Members (joined later):
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1. Work Package Description

Our work package is an ambitious, carefully planned, and closely integrated research program to make major progress on one of the most important problems in space science: the heating of the magnetically closed corona. Our immediate objectives are to determine when, where, and why impulsive heating events known as nanoflares occur, and how the plasma responds to produce the inhomogeneous thermal structure of the corona. A long-term goal is to construct physics-based models of the solar spectral irradiance, both for space weather applications and for understanding the origin and development of life throughout the universe. We use a combination of numerical simulations, theory, and observations to investigate the many physical effects and highly disparate and coupled spatial scales that are involved. Magnetic reconnection – a fundamental process – is at the heart of the problem, and by studying nanoflares, we are gaining insights into many other heliophysical and astrophysical phenomena. We support the broader Heliophysics community through our scientific advances and leadership, by training undergraduate and graduate students and postdocs, by organizing scientific meetings, by serving on committees, by developing numerical tools for community use, and by assisting instrument and mission planning.

2. Progress

We have made excellent progress during the reporting period as evidenced by the 21 research papers submitted and/or accepted[1], the 12 directly relevant decadal survey white papers submitted, and the 45 presentations given. We provide details below using the Year 1 table of milestones and deliverables included in the proposal.

[1] Additional papers published during the period but accepted previously are not included in the total.

<u>Year 1:</u>

S[2]: Single current sheet simulations with (1) thinning and (2) line-tying.

We performed simulations of thinning current sheets and analyzed the results. We found that reconnection does not begin until the sheet thins to a size where the growth rate of the fastest tearing mode approximately equals the thinning rate. This is crucial for understanding how stress and energy build up in magnetic fields before it is explosively released. This knowledge provides a basis for predicting the energies of nanoflares, CMEs, jets, etc. We presented preliminary results at meetings and are about to write a paper on the work.

We performed simulations of reconnection in equilibrium current sheets where the guide component of the magnetic field is line tied at the boundaries. This is the situation with nanoflares. We found that line tying alters the reconnection and can prevent it from occurring depending on the separation of the boundaries, i.e., depending on the length of the reconnecting "loops." We presented preliminary results at meetings and are about to write a paper on the work.

S: Synthetic spectral line profiles from single-sheet simulations with constant-T boundary

Meaningful predictions of spectral line profiles require that field-aligned thermal conduction be included in the simulations. We discovered that standard numerical techniques allow unrealistically large cross-field conduction that can significantly impact the results. We therefore developed a new technique that avoids these difficulties. It has generated considerable interest in the computational MHD community, and we are planning to publish a paper on it. The technique will allow us to move ahead with confidence as we compare our single current sheet and multi-strand simulations with actual observations.

MM: Multi-strand simulations with realistic driving (translation and rotation).

We developed improved boundary conditions for driving in our workhorse LaRe3D MHD code. We formulated a driving pattern motivated by photospheric convection that includes both translational and rotational components. We performed and analyzed initial test simulations, and the results look good. We will perform production runs in the near future.

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[2] Letter designations refer to spatial scale and approach and point to sections in the proposal - S: small-scale (Sec. 3.1); MM: meso-scale MHD (Sec. 3.2); MH: meso-scale hydro (Sec. 3.3); MA: meso-scale analytical (Sec. 3.2); M: meso-scale observations; L: large-scale (Sec. 3.4)

We wrote a paper on our “cooling model.” This model provides a method of computing synthetic observations from MHD simulations that could not otherwise be compared with real observations because they do not include radiation, thermal conduction, and the connection between the corona and lower solar atmosphere. Many models are of this type. We applied the model to our previously published ARMS multi-strand simulation with rotational driving. We found that the diffuse component of the corona can be explained by random uncorrelated nanoflares, while bright coronal loops can be explained by collective effects resulting in localized nanoflare “storms.”

We performed a multi-strand simulation with rotational driving in an expanding magnetic field geometry and studied the height distribution of nanoflare reconnection. We found that reconnection occurs preferentially near the footpoints, which is one prerequisite for thermal nonequilibrium (see below). We published the results.

MM: Adding TRAC to LaRe3D and ARMS.

We implemented our Transition Region Adaptive Conduction (TRAC) method in the LaRe3D and ARMS codes. This method allows the crucial energetic and dynamic coupling between the corona and lower atmosphere to be accurately treated with far less computational resources – crucial to massive MHD simulations. We are sharing this method with the community.

MA: Semi-analytical model of diffuse corona (overlapping loops).

We found that the power-law slope of the spatial distribution of coronal brightness in an image is related to the distribution of the magnetic strand diameters assumed to be responsible for the emission. More work is required before the results can be published.

MH: Nanoflare hydro simulations to determine conditions required for TNE.

We performed many ARGOS 1D hydrodynamic simulations assuming nanoflare heating with different frequency (occurrence rate) distributions and different height distributions. We determined the frequency and height requirements for thermal non-equilibrium (TNE) and developed a physical explanation for the results. We discovered an interesting regime in which TNE does not occur even though the standard “rules” indicate that is should. We explained this with a resonance effect that happens when the nanoflare frequency matches the sound travel time along the loop. We presented the results at meetings and will perform a few additional simulations before writing a paper.

MH: Improvements to EBTEL.

We made two major improvements to our EBTEL hydro code. We added kinetic energy and non-uniform cross-sectional area. We published two papers on the improvements. EBTEL is widely used by the international community.

M: Observed time lags in quiet Sun using EIS/Hinode spectral line data for
M: comparison with nanoflare hydro and multi-strand simulations (years 2 and 3).

We measured the time lags and plan to publish the results in the coming year.

L: Models of one observed active region using different nanoflare properties and
L: comparison with AIA imaging observations.

This work was postponed pending improvements to GX_Simulator (see below). Peter Young is the lead on this effort and his commitment was reduced when he accepted the position of acting Division Deputy Directory. We have hired a postdoc to fill the gap.

L: Improvements to GX_Simulator

We implemented an option for nanoflares with different frequency and energy distributions. Previously the nanoflares were homogeneous at a fixed frequency – either very low or very high frequency. Observations indicate a broad distribution of frequencies within active regions, including low, high, and intermediate. A draft of the paper has been written.

L: Solar spectral irradiance workshop.

We decided to not hold a workshop this year. Instead, we organized a highly successful spectral irradiance session at the Triennial Earth-Sun Summit. We also formed a new International Space Weather Action Team (ISWAT) subgroup (S2-6) on Origins of the Spectral Irradiance and its Intermediate Timescale Variability. Samuel Schonfeld and James Klimchuk are the Co-Leads. We submitted a section on Physics Based Models of the Solar Spectral Irradiance for a draft review paper connected with ISWAT.

We performed additional important research on coronal heating that was not explicitly spelled out in the proposal table of milestones and deliverables. Topics include:

Spectral line profiles associated with the plasma response to nanoflare energy release (distinct from line profiles associated with the reconnection itself, as discussed above). We used HYDRAD 1D hydrodynamic simulations to generate synthetic profiles which will later be compared to actual profiles observed by EIS, IRIS, and the EUNIS rocket.

The role of spicules in producing hot coronal plasma. We used simulations to show that spicules can account for only a very small fraction of the observed plasma. “Traditional” coronal heating is the dominant cause.

The dependence of the reconnection rate on 3D structure. We used single current sheet simulations to show that 3D effects slow the rate of reconnection and heating, demonstrating that 2D results must be treated with caution.

The dependence of heating on driver frequency. We used multi-strand simulations to show that low-frequency (nanoflare) driving produces stronger heating than high-frequency (wave) driving.

Universal scaling laws for solar and stellar heating.

Energy release when long field lines reconnect with the short field lines of small bipoles. This scenario applies to coronal holes and the quiet Sun and possibly – to a lesser extent – active regions.

Additional topics can be found in our list of publications and presentations.

3. Changes Required or Problems Encountered

As noted above, Peter Young’s commitment was reduced due to his new role as acting Division Deputy Director. We have hired a new postdoc, Shanwlee Sow Mondal, to pick up the slack. She will start in January.

4. Budget Performance

We underspent this year due to Peter Young’s new status and because we traveled less than anticipated. We will use the carry over funds to help support the new postdoc. Slow reporting by contractor institutions has produced a difference between costed and approved funds.

5. New Proposals Relevant to the Work Package

Under review: “Response of the Solar Atmosphere to Impulsive Energy Input” submitted to HGI by J. Brosius (N. Viall and A. Daw CoI’s). They will compare simulated and observed line profiles for a wide range of explosive phenomena: flares, microflares, nanoflares. They will the RADYN 1D hydrodynamic simulation code, which specializes in optically thick radiation from the chromosphere. The work package effort has concentrated on optically thin emissions from the corona and transition region.

Under Review: “Understanding the Birth and Death of Solar Coronal Plumes” submitted to HGIO by P. Kumar (V. Uritsky CoI). This proposal concerns structures in coronal holes, but the magnetic reconnection involved is relevant to the quiet Sun.

Not selected: “Response of the Solar Atmosphere to Impulsive Energy Release” submitted by W. Barnes (N. Viall CoI)

6. Research Papers[3]

(submitted or accepted[4])

1. "Static and Dynamic Solar Coronal Loops with Cross-Sectional Area Variations," Cargill, P. J., Bradshaw, S. J., Klimchuk, J. A., & Barnes, W. T. 2022, MNRAS, 509, 4420

2. *"Solar Irradiance Variability for the Galileo Solar Space Telescope Mission: Concept and Challenges," Carlesso, F., Rogriguez Gomez, J. M., Barbosa, A., Vieira, L., & Dal Lago, A. 2022, Front. Phys., 10:869738*

3. "Impact of 3D Structure on Magnetic Reconnection," Daldorff, L. K. S., Leake, J. E., & Klimchuk, J. A. 2022, ApJ, 927, 196

4. "(When) Can Wave Heating Balance Optically Thin Radiative Losses in the Corona?", De Moortel, I., & Howson, T. A. 2022, ApJ, in press

5. "Probing the Physics of the Solar Atmosphere with the Multi-Slit Solar Explorer (MUSE): I. Coronal Heating," De Pontieu, B., De Moortel, I. et al. 2022, ApJ, 926, 52

6. "Forward Modelling of Heating within a Coronal Arcade," Fyfe, L. E. , Howson, T. A., De Moortel, I. 2021, A&A, 656, A120

7. "The Effects of Driving Time Scales on Coronal Heating in a Stratified Atmosphere," Howson, T. A., & De Moortel, I. 2022, A&A, 661, A144

8. "Signatures of Coronal Heating in MHD Simulations Without Radiation or a Lower Atmosphere," Klimchuk, J. A., Knizhnik, K. K., & Uritsky, V. M. 2022, ApJ, in press

9. "The Location and Angle Distribution of Magnetic Reconnection in the Solar Corona," Knizhnik, K. J., & Cabral-Pelletier, L. C. 2022, ApJ, 973, 93

10. "Quasi-periodic Energy Release and Jets at the Base of Solar Coronal Plumes," Kumar, P., Karpen, J., Uritsky, V., DeForest, C., Raouafi, N., & DeVore, C. R. 2022, ApJ, 933, 21

11. "The Effect of Nanoflare Flows on EUV Spectral Lines," Lopez Fuentes, M., & Klimchuk, J. A. 2022, ApJ, 939, 17

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[3] Entries for affiliate team members (not on the original proposal) are italicized

[4] Additional papers published during the period of performance but accepted before its start (2021 Oct 1) are not included

12. “The Coronal Veil,” Malanushenko, A., Rempel, M., Cheung, M., DeForest, C., & Klimchuk, J. 2022, ApJ, 927, 1

13. “Flows in Enthalpy Based Thermal Evolution of Loops,” Rajhans, A., Tripathi, D., Bradshaw, S. J., Kashyap, V. L., & Klimchuk, J. A. 2022, ApJ, 924, 13

14. “Center to Limb Variation of Transition Region Doppler Shift in Active Regions,” Rajhans, A., Tripathi, A., Kashyap, V. L., & Klimchuk, J. A. 2022, ApJ, submitted

15. “Contribution of Spicules to Solar Coronal Emission,” Sow Mondal, S., Klimchuk, J. A., & Sarkar, A. 2022, ApJ, 937, 71

16. *“Universal Scaling Laws for Solar and Stellar Atmospheric Heating: Catalog of Power-law Index Between Solar Activity Proxies and Various Spectral Irradiances,” Toriumi, S., Airapetian, V., Namekata, K., & Notsu, Y. 2022, ApJ Supp., 262, 46*

17. *“Universal Scaling Laws for Solar/Stellar Atmospheric Heating,” Toriumi, S., & Airapetian, V. 2022, ApJ, 927, 179*

18. “Planning the Future Space Weather Operations and Research Infrastructures,” Cohen, C., Viall, N. M., et al. 2022, Proceedings of the Nat. Acad. Sci., Eng., Med.

19. “An Analysis of Spikes in Atmospheric Imaging Assembly (AIA),” Young, P. R., Viall, N. M., Kirk, M. S., Mason, E. I. & Chitta, L. P. 2021, SoPh, 296, 181

20. “Properties of EUV Imaging Spectrometer (EIS) Slot Observations,” Young, P. R., & Ugarte-Urra, I. 2022, SoPh, 297, 87

21. “Scattered Light in the Hinode/EIS and SDO/AIA Instruments Measured from the 2012 Venus Transit,” Young, P. R. & Viall, N. M. 2022, ApJ, 938, 27

7. Decadal Survey White Papers of Direct Relevance

1. “Cool Multiphase Plasma in Hot Environments,” Antolin, P., Johnston, C. D., Klimchuk, J. A. et al.

2. “Quantifying the Sun’s Magnetic Stress with the Photospheric Flows,” Attie, R., Tremblay, B., Kirk, M., Schuck, P., Pesnell, D., Upton, L., Klimchuk, J., Viall, N., and Thompson, B.

3. “The Case for Comprehensive Spectroscopic Measurements of the Sun: Understanding Solar Flares and Coronal Heating”, Brosius, J., Young, P., Klimchuk, J., Kucera, T., and Daw A.

4. “CLARO Solar Coronal Polarization Diagnostics with H I Ly-alpha,” Cassini, R., Viall, N. M., et al.

5. “The Next Decade of Solar Ultraviolet Spectral Irradiance – Continuity, Modeling, and Physics,” Chamberlin, P., Jones, A., Klimchuk, J., Kopp, G., Mason, J., Thiemann, E., Warren, H., Woods, T.

6. “Major Scientific Challenges and Opportunities in Understanding Magnetic Reconnection and Related Explosive Phenomena in Heliophysics and Beyond,” Ji, H., Karpen, J., Klimchuk, J., et al.

7. “Heating of the Magnetically Closed Corona and Physical Models of Solar and Stellar Spectral Irradiances,” Klimchuk, J., Work Package Team, others

8. “Measuring Nonthermal Properties of Weak Transients in the Quiescent Solar Corona,” Mondal, S., Chen, B., Yu, S., Klimchuk, J., Chhabra, S., Chen, T.

9. “Observing Coronal Microscales and their Connection with Mesoscales,” Rabin, D., Klimchuk, J., Viall, N., De Moortel, I., et al.

10. “Firefly: The Case for a Holistic Understanding of the Global Structure and Dynamics of the Sun and Heliosphere,” Raouafi, N., Viall, N. M., et al.

11. “Fundamentals of Impulsive Energy Release in the Corona,” Shih, A., Klimchuk, J., et al.

12. “Mesoscale Dynamics are the Key to Unlocking the Universal Physics of Multiscale Feedback,” Kepko, L, Viall, N. M., et al.

8. Presentations[5]

1. "Preliminary Application of EUNIS Soft X-Ray and EUV Imaging Spectroscopy to EIS Radiometric Calibration," Brosius, J., Daw, A., Landi, E., Rabin, D., and Schmit, D. (Hinode-14/IRIS-11 Joint Science Meeting; virtual at George Mason Univ.; 10/25/21)

2. "First Imaging Spectroscopy of 92-115 Angstrom Solar Soft X-rays by EUNIS: Implications for Solar Coronal Heating," Brosius, J., Daw, A., Rabin, D., Landi, E., and Schmit, D. (AGU Fall Meeting; New Orleans; 12/13/21)

3. “Application of EUV and SXR Spectra from the EUNIS Sounding Rocket to Solar Coronal Heating,” Brosius, J., Daw, A., Rabin, D., Landi, E. (Goddard UV Symposium; 4/5/22)

[5] Only those with team members as first author are included. There are many additional presentations with team members as coauthor.

4. “Application of EUV and SXR Spectra from the EUNIS Sounding Rocket to Solar Coronal Heating,” Brosius, J., Daw, A., Rabin, D., Landi, E. & Schmit, D. (poster; Triennial Earth-Sun Summit; Bellevue, WA; 8/8/22)

5. “Signatures of Type III Solar Radio Bursts from Nanoflares: Modeling,” Chhabra, S., Klimchuk, J., & Gary, D. (invited; NASA MSFC Journal Club; 10/15/21)

6. “Study of Type III Radio Bursts in the Closed Corona and the Solar Wind from Small-Scale Reconnection: Observations (highlighted),” Chhabra, S., Klimchuk, J. A., Gary, D. E. (Fall AGU Meeting; New Orleans; 12/14/21)

7. “Magnetic Reconnection in 3D vs. 2D and Dependence on Magnetic Shear,” Daldorff, L., Leake, J., & Klimchuk, J. (Fall AGU Meeting; New Orleans; 12/14/21)

8. “Implication of Line Tied Magnetic Field on Magnetic Reconnection in the Closed Corona” Daldorff, L., Leake, J., & Klimchuk, J. (Magnetic Reconnection 2022; Monterey, CA; 5/16/22)

9. “Magnetic Reconnection in 3D vs. 2D and Dependence on Magnetic Shear,” Daldorff, L., Leake, J., & Klimchuk, J. (10th Coronal Loops Workshop; Paris; June 28 – July 1, 2022)

10. “Magnetic Reconnection in 3D vs. 2D and Dependence on Magnetic Shear,” Daldorff, L., Leake, J., & Klimchuk, J. (Triennial Earth-Sun Summit; Bellevue, WA; 8/9/22)

11. "Hot Spectroscopy: Co-ordinated EUNIS-2021, IRIS, and Hinode Observations of AR 12824," Daw, A., Schmit, D., Rabin, D., Brosius, J., and Landi, E. (Hinode-14/IRIS-11 Joint Science Meeting; virtual at George Mason Univ.; 10/25/21)

12. “Aspects of MHD Wave Heating in the Complex Solar Atmosphere,” De Moortel, I. (seminar; Manchester Univ.; 2/16/22)

13. “Aspects of MHD Wave Heating in the Complex Solar Atmosphere,” De Moortel, I. (seminar; Leeds Univ.; 3/10/22)

14. “(When) Can Wave Heating Balance Optically Thin Radiative Losses in the Corona?”, De Moortel, I. (10th Coronal Loops Workshop; Paris; 6/29/22)

15. “A Fast and Accurate Method to Capture the Solar Corona/Transition Region Enthalpy Exchange in Multi-Dimensional Magnetohydrodynamic Simulations,” Johnston, C., De Moortel, I., Daldorff, L, Leake, J., Klimchuk, J., et al. (AGU Fall Meeting; New Orleans; 12/13/21)

16. “Multi-Dimensional Modeling of the Transition Region and Application to Thermal Non-Equilibrium,” Johnston, C. D. (Invited; Workshop on What Solar Observations Can Teach us about Multiphase Plasmas across Astrophysical Scales; Orléans, France; 6/15/22)

17. “A Fast Multi-Dimensional MHD Formulation of the Transition Region Adaptive Conductive (TRAC) Method,” Johnston, C. D., Hood, A. W., De Moortel, I., & Daldorff, L. K. S. (10th Coronal Loops Workshop; Paris; 6/28/22)

18. “A Fast and Accurate Method to Capture the Solar Corona/Transition Region Enthalpy Exchange in Multi-Dimensional Magnetohydrodynamic Simulations,” Johnston, C. D., Hood, A. W., De Moortel, I., & Daldorff, L. K. S. (Triennial Earth-Sun Summit; Bellevue, WA; 8/8/22)

19. “A Fast Multi-Dimensional MHD Formulation of the Transition Region Adaptive Conduction (TRAC) Method," Johnston,C. D., Hood, A. W., De Moortel, I & Daldorff, L. K. S. (Invited; 2022 Solar MHD Meeting; Eastbourne, UK; 8/9/22)

20. “Coronal Heating,” Klimchuk, J. A. (invited seminar; PMOD/WRC, Davos, Switzerland; 12/7/21)

21. “Coronal Heating: A Coupled Multi-Scale Problem,” Klimchuk, J. A. (**honorary Parker Lecture**; Fall AGU Meeting; New Orleans; 12/13/21)

22. “Computing Emission Signatures from Coronal MHD Models Without a Realistic Atmosphere,” Klimchuk, J. A., Knizhnik, K., & Uritsky, V. (Fall AGU Meeting; New Orleans; 12/16/21)

23. “Heating of the Magnetically Closed Corona,” Klimchuk, J., Daldorff, L., Brosius, J., & Johnston, C. (HISFM Showcase, 4/7/22)

24. “The Role of 3D Complexity in Magnetic Reconnection,” Klimchuk, J., Daldorff, L., & Leake, J. (invited; given by L. Daldorff as Klimchuk could not attend for medical reasons; Magnetic Reconnection 2022; Monterey, CA; 5/20/22)

25. “Alfven Waves From Interchange Reconnection at Streamer-Coronal Hole Boundaries,” Klimchuk, J. (invited; Viall Work Package Team Meeting; GSFC; 6/3/22)

26. “Cross Sections of Coronal Loop Flux Tubes,” Klimchuk, J., & DeForest, C. (10th Coronal Loops Workshop; Paris; 6/30/22)

27. “Observational Signatures of Coronal Heating in MHD Simulations Without Radiation or a Lower Atmosphere,” Klimchuk, J., Knizhnik, K., & Uritsky, V. (poster; 10th Coronal Loops Workshop; Paris; 6/28/22)

28. "Coronal Heating: A Coupled Multi-Scale Problem," Klimchuk, J. (invited colloquium; Institut d'Astrophysique Spatiale, Paris; 7/4/22)

29. "Investigations of Coronal Heating at GSFC," Klimchuk, J. (Solar Lab meeting; GSFC; 7/14/22)

30. "Observational Signatures of Coronal Heating in MHD Simulations Without Radiation or a Lower Atmosphere," Klimchuk, J., Knizhnik, K., & Uritsky, V. (Triennial Earth-Sun Summit; Bellevue, WA; 8/8/22)

31. "Cross Sections of Coronal Loop Flux Tubes," Klimchuk, J., & DeForest, C. (poster; Triennial Earth-Sun Summit; Bellevue, WA; 8/8/22)

32. "Magnetospheric Nanoflares?", Klimchuk, J. (LWS team meeting; Huntsville, AL; 10/12/22)

33. The Role of 3D Complexity in Magnetic Reconnection," Klimchuk, J., Daldorff, L., & Leake, J. (LWS team meeting; Huntsville, AL; 10/14/22)

34. "Coronal Heating: Globally and Within Campfires," Klimchuk, J. (invited; Solar Orbiter "Atmospheric Heating" Science Working Group; virtual; 10/17/22)

35. "Modeling of Condensations in Active Region Loops Produced by Nanoflares," Kucera, T., Klimchuk, J., & Luna, M. (Solar Orbiter Science Meeting; Belfast; Sept 12-15, 2022)

36. "Simulations of Thermal Non-Equilibrium Caused by Nanoflares," Kucera, T., Klimchuk, J., & Luna, M. (10th Coronal Loops Workshop; Paris; June 28 – July 1, 2022)

37. "Simulations of Thermal Non-Equilibrium Caused by Nanoflares," Kucera, T., Klimchuk, J., & Luna, M. (poster; Triennial Earth-Sun Summit; Bellevue, WA; 8/8/22)

38. "Onset of Magnetic Reconnection in the Solar Corona," Leake, J., Klimchuk, J., & Daldorff, L. (Fall AGU Meeting; New Orleans; 12/15/21)

39. "The Onset of Magnetic Reconnection in Dynamically Evolving Coronal Current Sheets," Leake, J., Daldorff, L., & Klimchuk, J. (Triennial Earth-Sun Summit; Bellevue, WA; 8/9/22)

40. "Coronal Microscale Observatory (CMO)," Rabin, D., Viall, N. M., Klimchuk, J. A., et al. (UV Science at Goddard Workshop; Greenbelt)

41. "A Study of Small-Scale Brightenings using EUV Data from SPICE onboard Solar Orbiter," Rodriguez Gomez, J. M., Young, P., & Kucera, T. (EGU General Assembly 2022; Vienna; 5/23/22)

42. “Answering the Outstanding Questions of Solar Wind Physics,” Viall, N. M. (invited; St. Andrews University; 3/16/22)

43. “Outstanding Questions of Coronal Heating and Solar Wind Physics,” Viall, N. M. (invited; Triennial Earth-Sun Summit; Bellevue, WA; 8/8/22)

44. “CHIANTI: An Atomic Database and Software Package for UV Spectroscopy,” Young, P. (Goddard UV Symposium; 4/4/22)

45. “An Analysis of Spikes in Atmospheric Imaging Assembly (AIA) Data,” Young, P., Viall, N. M., et al. (Triennial Earth-Sun Summit; Bellevue, WA; 8/8/22)