# Signatures of Time-dependent Heating in Active Regions and the Slow Solar Wind

Organizers: Steve Bradshaw, Will Barnes (Rice University); Nicki Viall (GSFC)

Scene setting speakers:

**Vanessa Polito** (CfA) addressed signatures of heating in the solar corona from remote sensing observations

**Sue Lepri** (U. Michigan) reviewed in-situ measurements of slow solar wind properties that might be related to coronal heating

Major Questions:

1. How are active region loops connected / related to solar wind streamers?
2. What role does reconnection play in transporting plasma from closed coronal loops into the slow solar wind?
3. What are the primary observable signatures of impulsive heating in active regions?
4. Do signatures of heating in active regions persist into the slow solar wind?
5. How can future instruments (PSP, SO) best be utilized to detect predicted signatures?
6. What models are needed to understand the relationship between closed and open regions?

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## 1. How are active region loops connected / related to solar wind streamers?

Hints from observations of coronal rain in closed loop systems underlying streamers: thermal non-equilibrium leads to formation of condensations which, as they fall, may give rise to outward propagating pressure / density disturbances. Density variations affect reconnection rate between closed loops and streamer ($1/\sqrt{\rho}$), which modulates the interaction between these regions (also relevant to Q2). **[Emily Mason]**

## 2. What role does reconnection play in transporting plasma from closed coronal loops into the slow solar wind?

Possible interchange reconnection between closed / open field at active region / coronal hole boundaries (e.g. Del Zanna et al. 2011, Bradshaw et al. 2011) can provide a path for hot dense plasma originating on closed loops onto open field; the resulting strong pressure gradient drives a strong outflow (and associated rarefaction wave) which is consistent with the properties of persistent blue-shifts observed at active region boundaries (also relevant to Q1). **[Vanessa Polito]**

## 3. What are the primary observable signatures of impulsive heating in active regions?

Time-lag plots (Viall & Klimchuk 2012, 2017), which correlate signatures in the SDO/AIA coronal channels that are sensitive to different wavelengths / temperatures, are broadly consistent with what is expected from nanoflare (impulsive) heating (Bradshaw & Viall, 2016). Questions remain concerning the frequency with which plasma is re-energized ("trains" of nanoflares) and how that might be related to local properties of the corona ($\bar{B}, n$ etc.). **[Vanessa Polito]**

Blue-shifts in Si IV emission observed by IRIS in active region moss brightenings are consistent with weak electron beams depositing energy (thermalizing) below the height (equivalently temperature) at which Si IV is formed (Testa et al. 2014). **[Vanessa Polito]**

Nanoflare-train model estimates of the emission measure (EM) gradient (in log space) cool-ward of the temperature of peak EM (Reep et al., 2012; Cargill 2014; Barnes et al. 2016a,b) produce the observed range of measured gradients (summarized in Bradshaw et al. 2013).

## 4. Do signatures of heating in active regions persist into the slow solar wind?

Higher $O^{7+}$ / $O^{6+}$ ratios are expected from higher temperature sources such as active regions than the quiet sun (QS) or coronal holes (CH). Such ratios are readily measured in the slow solar wind. **[Sue Lepri]**

The fast solar wind is <u>generally</u> associated with lower charge states (consistent with its CH source region) than the slow wind, which is strongly indicative of different sources (Liewer et al. 2004). **[Sue Lepri]**

The FIP effect can be measured in-situ. Photospheric abundances are measured in the fast wind because its source is photospheric (CH). A relatively strong enhancement of low FIP elements is observed in the slow wind, again indicates a different source. Try to correlate FIP enhancement measured in-situ in the slow wind with candidate source region FIP enhancements to identify / isolate the source (Brooks and Warren, 2011; Brooks et al. 2015). **[Sue Lepri]**

<u>Major caveat</u>: it is still extremely difficult (impossible?) to identify particular coronal source regions of slow wind properties measured in-situ. Observational reasons due to limited fields of view and cadence of remote sensing instruments; complex physics along the propagation path between the corona and in-situ site. **[Tim Horbury, Nicki Viall]**

## 5. How can future instruments (e.g. PSP, SO) best be utilized to detect predicted signatures?

At present, we have very poor information concerning the outer corona (see **Barbara Thompson**'s plenary talk), which PSP and SO should make a substantial contribution to improving. **[Nicki Viall]**

Ground-based observations taken during eclipses are providing a growing data set. Freeze-in distances for ion populations have been constrained from 5 – 10 $R_{sun}$ to within 2 $R_{sun}$. More data is on the way! **[Benjamin Boe]**

In-situ measurements of charge states closer to the sun can complement these measurements and help to verify above the constraints (e.g. by measuring ion populations to 8 $R_{sun}$). Measurements of charge state ratios taken at shorter radial distances will reduce errors / uncertainties when tracing back to source regions (shorter paths).

In-situ measurements of particle distributions (e.g. Maxwellian vs. Kappa) taken closer to the sun should be more “pristine” since less time / opportunity for coronal source distributions to be modified (e.g. by kinetic processes in wind). Perhaps sufficient to better estimate particle distributions in the inner corona?

## 6. What models are needed to understand the relationship between closed and open regions?

The vast range of spatial and temporal scales that need to be addressed makes a consistent and physically valid treatment from (at least) the photosphere to 1 AU well beyond the capability of any existing single model and computational resources.

There are capable models within the regimes for which they have been designed. There exists plenty of scope for models (and modelers!) to better complement one another. Progress is feasible via the intelligent combination of hydrodynamic, MHD, and kinetic approaches, where appropriate.

Summary: the enormous complexity of connecting properties of the slow wind measured in-situ with remotely-sensed possible source regions, and all of the associated ambiguities (e.g. even potential confusion between fast and slow wind), should encourage one to move away from the traditional way of thinking of the solar wind.

Rather than discriminating between "fast" and "slow" solar wind, separate it in terms of its source region: e.g. coronal hole wind vs. "other" wind. **[Tim Horbury]**

Unfortunately, the session concluded before we could arrive at a definition less coarse than "other" – perhaps next time!

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