

Solar Radiation Physical Modeling: Tools for understanding and forecasting solar EUV and UV irradiance variations

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SRPM Project Goals

- **Diagnosis** of physical conditions through the solar atmosphere; energy balance of radiative losses and mechanical heating.

- **Evaluating** proposed physical processes to determine the solar atmosphere structure and spectrum at all spatial and temporal scales.

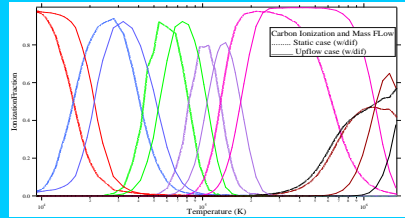
- **Synthesizing** solar irradiance spectrum and its variations to improve the above and produce complete and quantitative physical models.

- **Forecasting** spectral irradiance at any time and position in the Heliosphere. Weekly and monthly forecast is now becoming possible.

Layers of the solar atmosphere

- Photosphere (using average 1D models and external 3D simulations)
 - Slow motions (few km/s) dominated by convection overshoot
 - Weak ionization
 - All particles are unmagnetized
 - Plasma beta > 1
 - At or near LTE
- Chromosphere (using average 1D models and 3D MHD simulations)
 - Motions and inhomogeneities change from weak to strong
 - Weak ionization ($n_p \ll n_e \sim 10^{-4} n_H$)
 - Ions unmagnetized, electrons magnetized (implies tensor conductivity)
 - Plasma beta crosses 1 somewhere within the chromosphere
 - Needs to consider full non-LTE radiative transfer radiative losses
- Corona (will use results from groups carrying coronal loops modeling)
 - Motions and inhomogeneities are very strong
 - Highly ionized
 - All species are magnetized
 - Plasma beta $\ll 1$
 - Non-LTE effects are extreme and but optically thin applies
 - Particle transport is large and probably large departures from Maxwellian

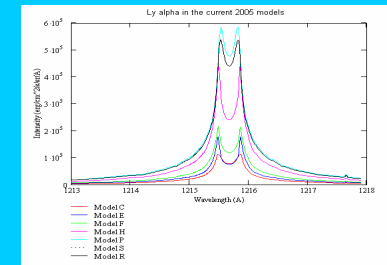
SRPM Flow Scheme



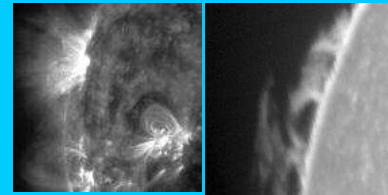
$$n_{lev}, n_{ion}, \dots (x, y, z, t)$$

Intermediate
Parameters

Emitted
Spectrum

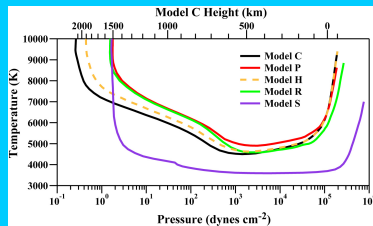


$$I(\lambda, \mu, \varphi, t)$$

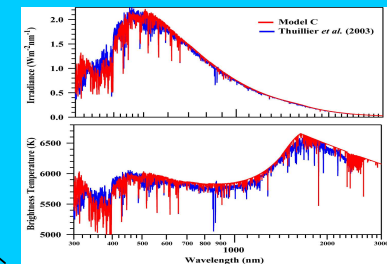


Physical Models
& Processes

Observed
Spectrum



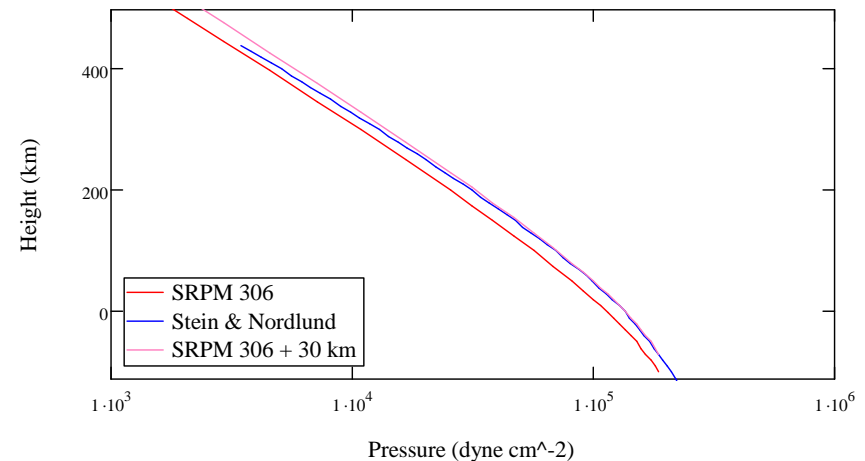
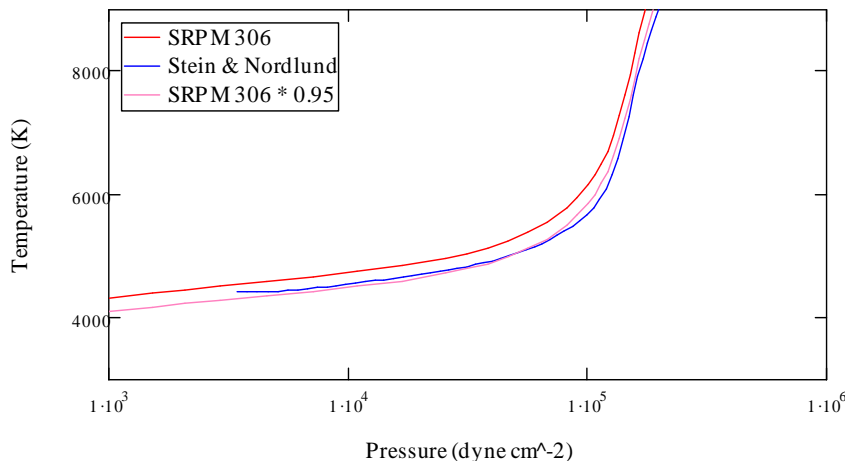
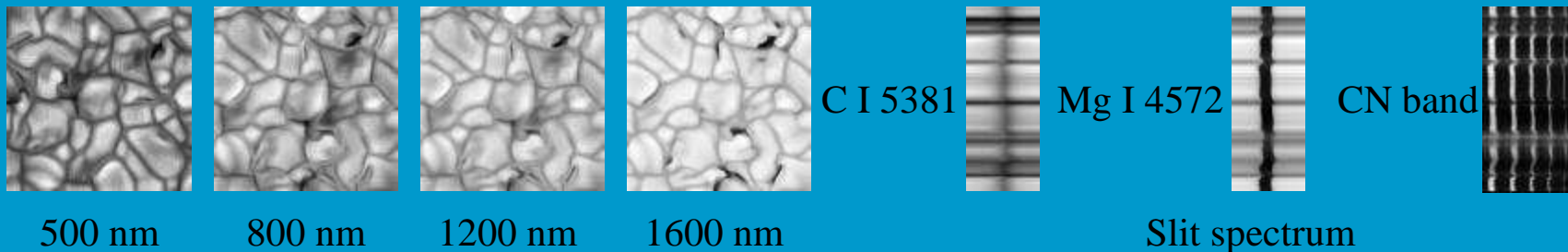
$$T, n_e, n_h, U, \dots (x, y, z, t)$$



$$I(\lambda, \mu, \varphi, t)$$

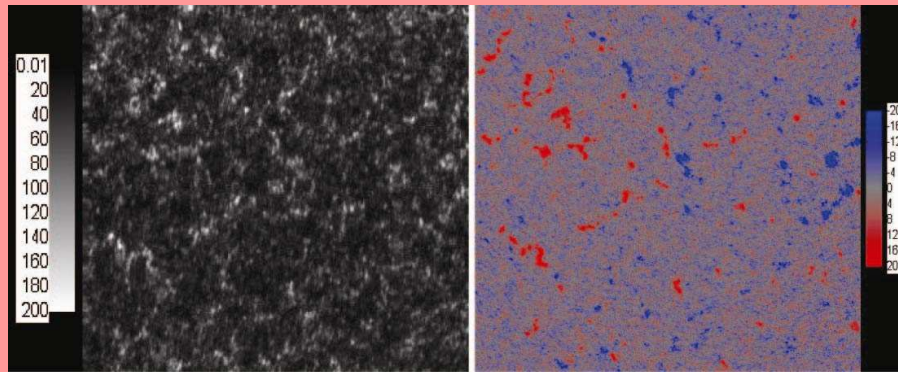
Photosphere (radiation/convection)

Stein & Nordlund 2000 convection simulations snapshots
SRPM absolute radiance, wavelength and CLV dependence



Comparison of spatial averages with semi-empirical models
points to improvements in average models and in simulations

Solar Chromosphere (radiation/plasma heating)

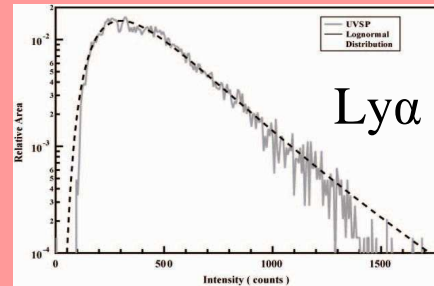


UV (1540 Å) continuum

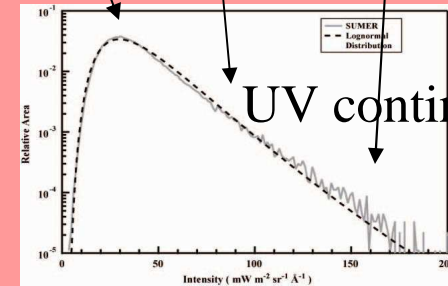
MDI magnetogram

Discrete set of features assigned to various heating levels.

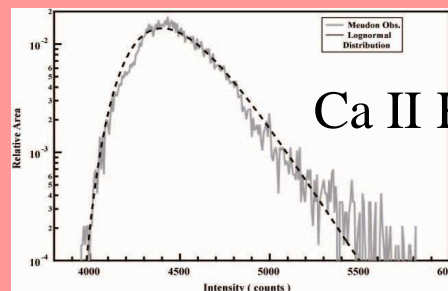
Log-normal distribution of heated areas in quiet Sun, probably due to similar distribution of magnetic features.



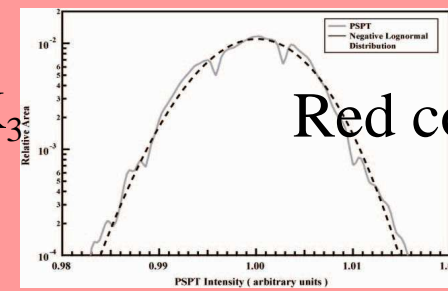
Ly α



UV continuum



Ca II K₃



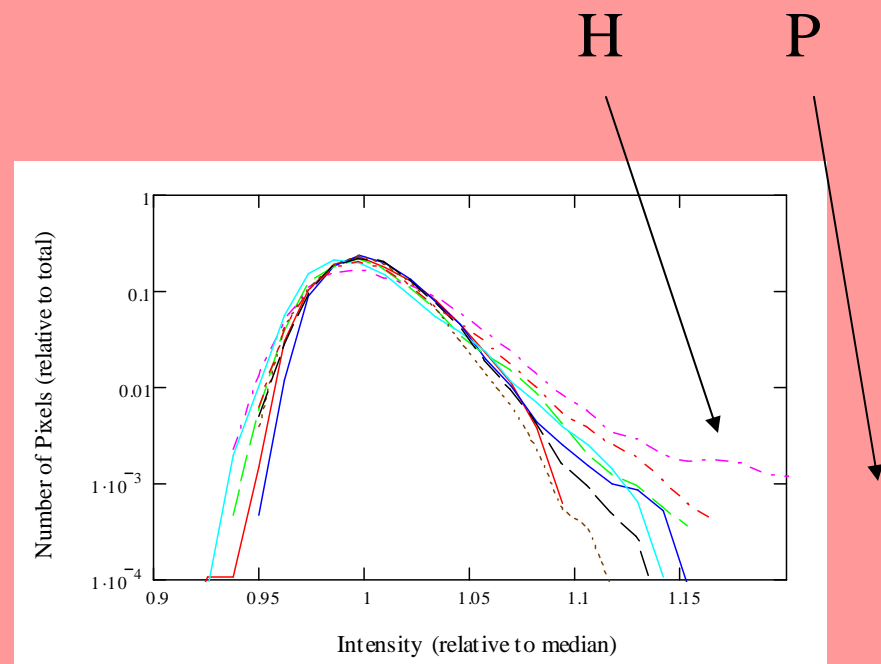
Red cont.

Active Sun chromospheric features

Sunspot umbra and penumbra taken from continuum images, but plage and network pixels from Ca II K data.



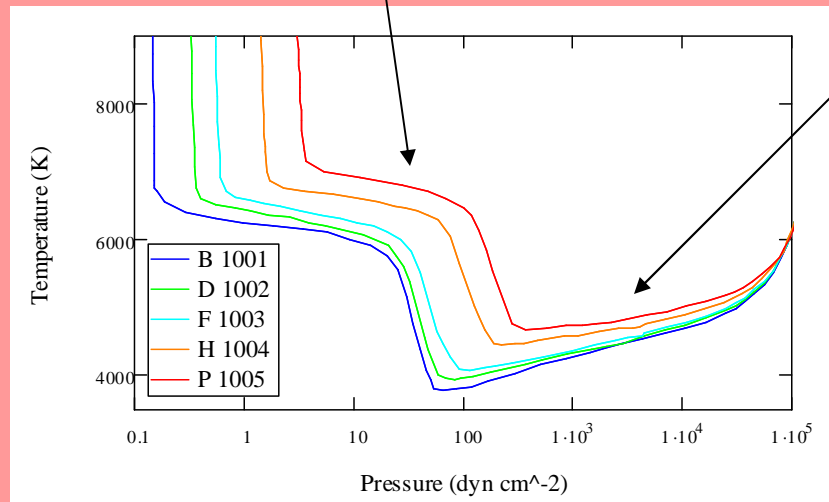
Super-heated (plage) features in active regions are discretized by two components.



A set of models discretizes the distribution of heated areas (other models for sunspot umbra & penumbra are not shown here)

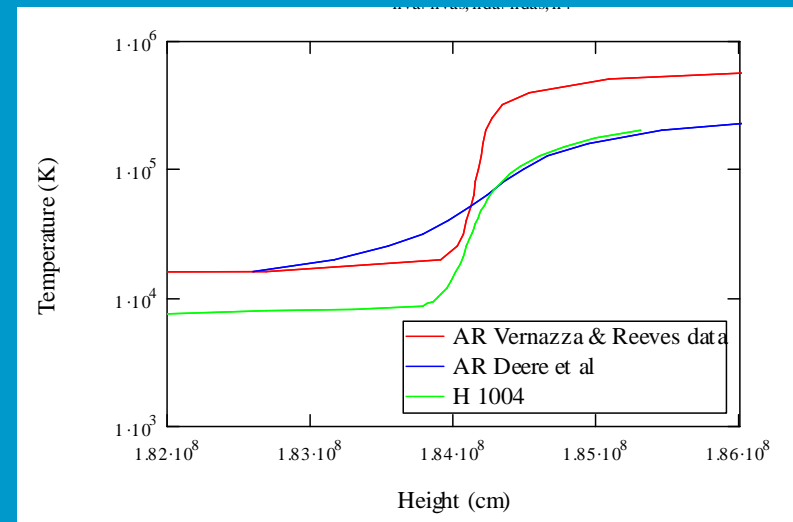
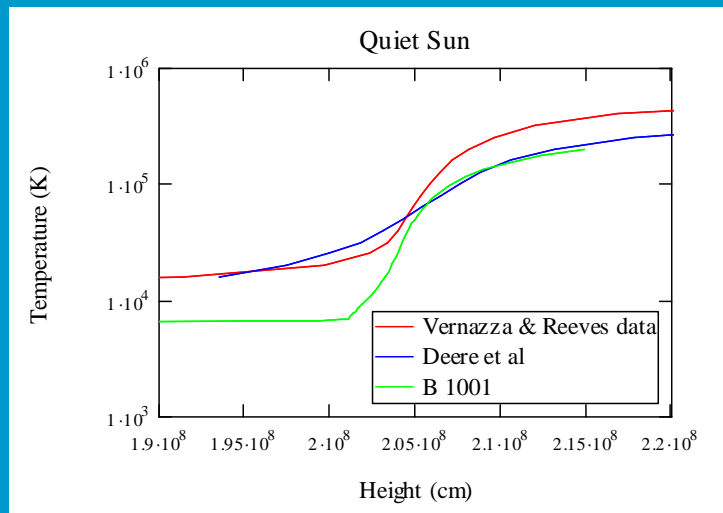
Upper chromosphere

Lower chromosphere



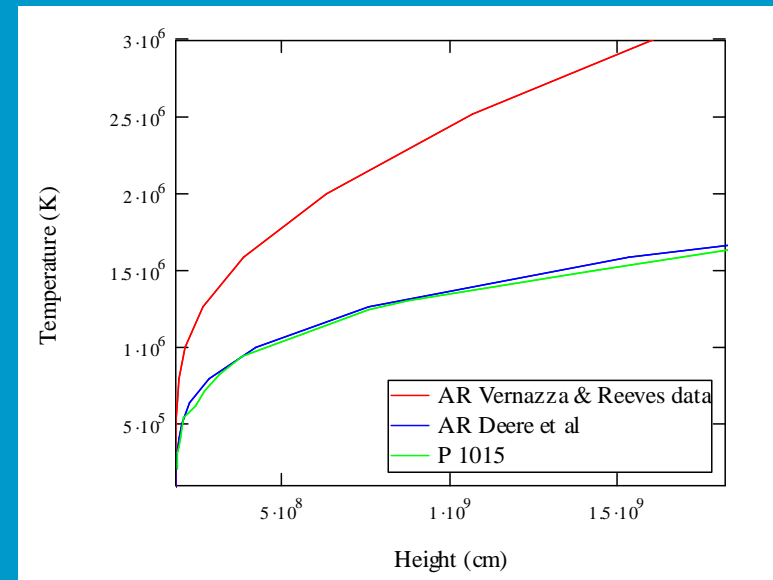
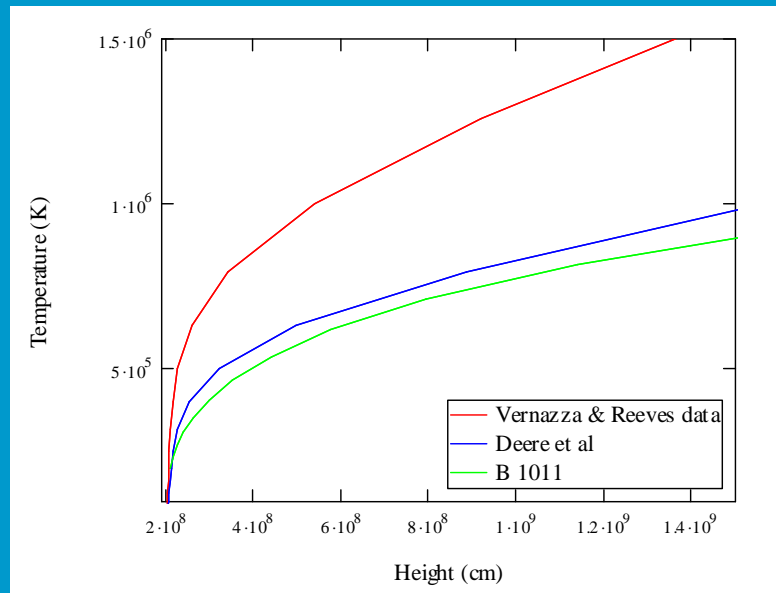
Semi-empirical, in-pixel. NLTE radiative transfer models built to account for the radiance observations.

Transition region (radiation/conduction+diffusion+flows)



The low transition-region ($T < 200,000$ K) is strongly affected by optically thick NLTE radiative transfer and particle diffusion effects up to $\sim 60,000$ K. Above that the energy balance model is close to the DEM standard curves for comparable abundances (note that SRPM uses abundances similar to Dere values).

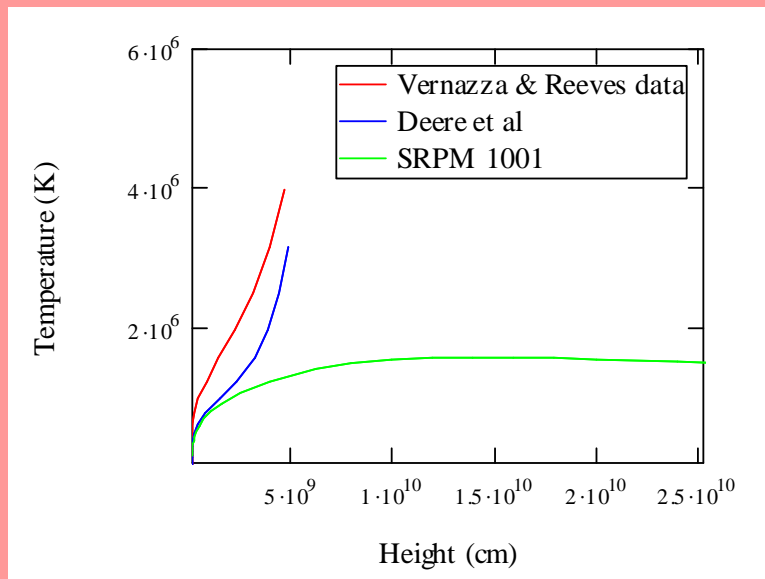
Upper transition-region



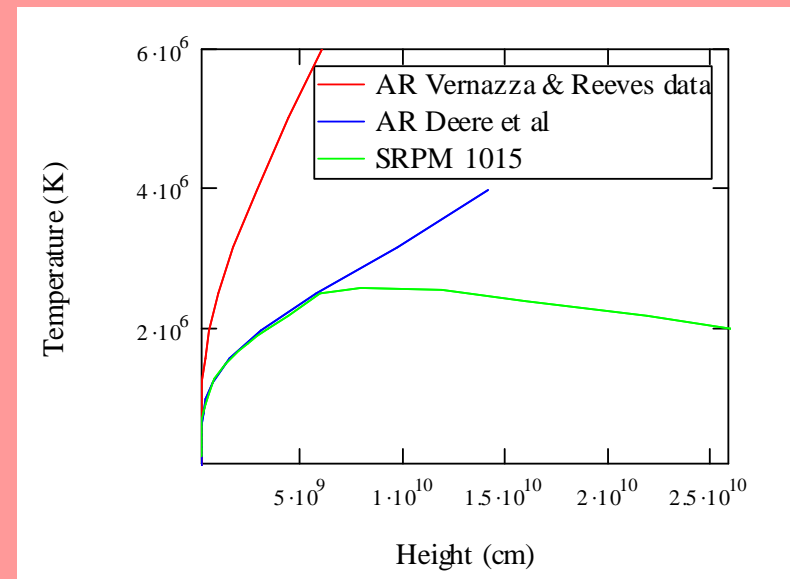
Upper transition-region ($T > 200,000$ K) energy balance models are also close to the DEM ones with similar abundances. In the energy balance models conduction dominates at the bottom but local energy dissipation becomes important at the top.

Corona and upper transition region (radiation+conduction+solar wind)

Quiet



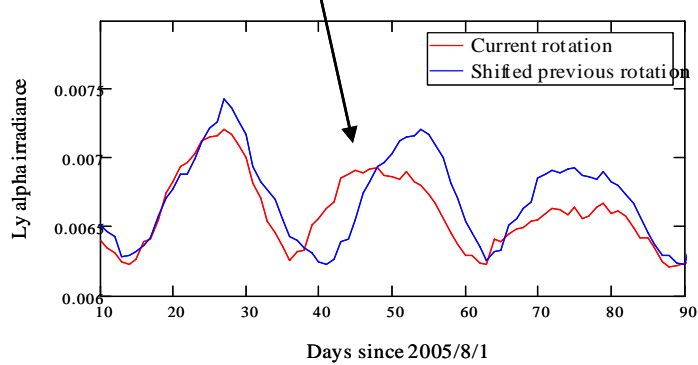
Active



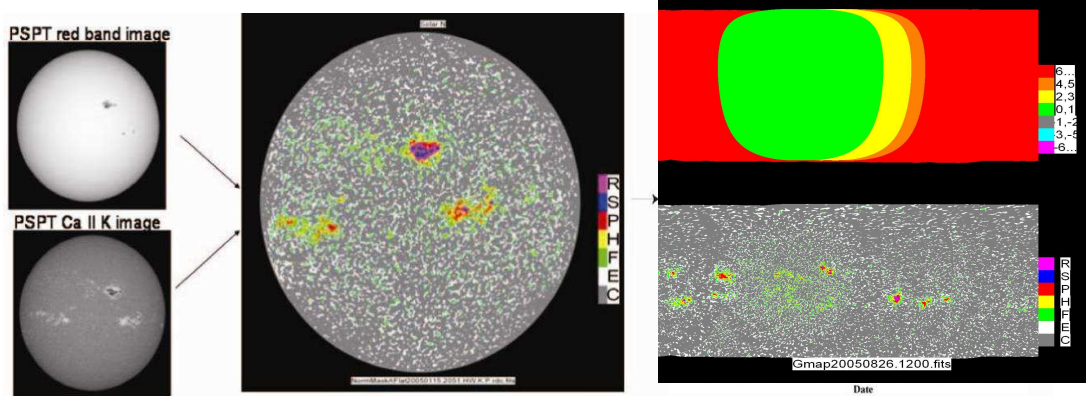
The temperature reaches a maximum value (local energy dissipation is essential) and decreases again in the heliosphere. DEM cannot handle this behavior. Solar wind and coronal holes are features to consider. In active regions, groups of hot loops are the key feature.

Tools for forecasting solar irradiance

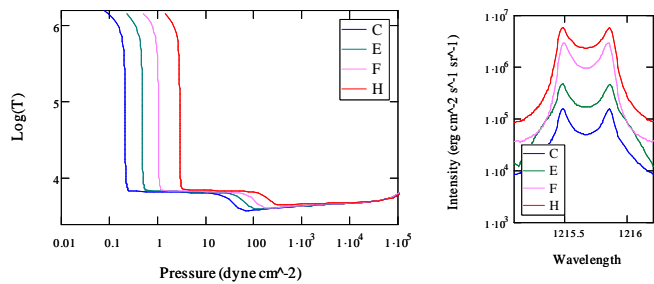
Assuming previous curve is bad



Images of the near-side produce daily masks of features

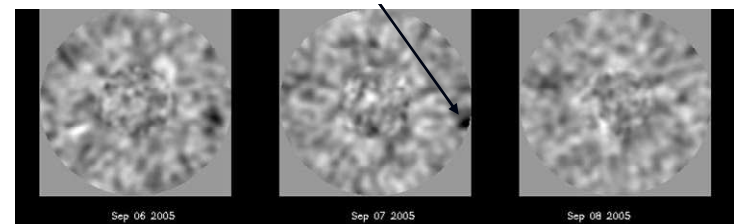
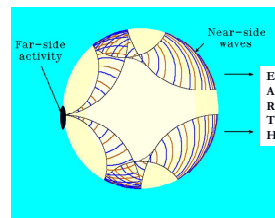


Using atmospheric models the spectrum is computed for any day

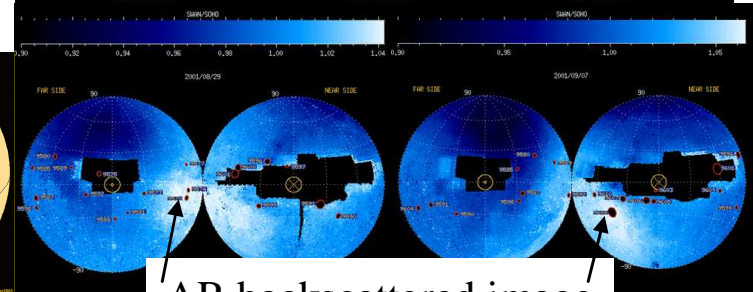
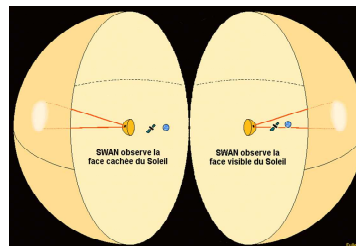


Synoptic masks are refined by applying trends and far-side imaging:

AR helioseismic image



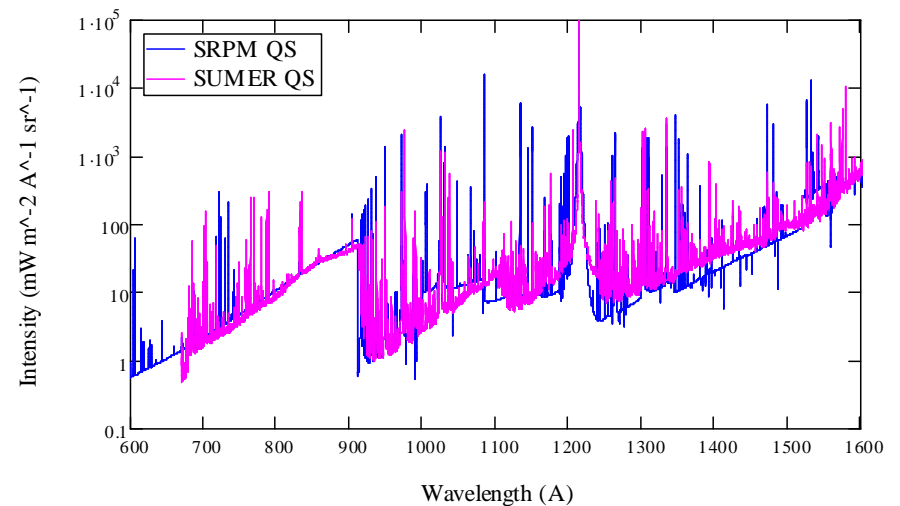
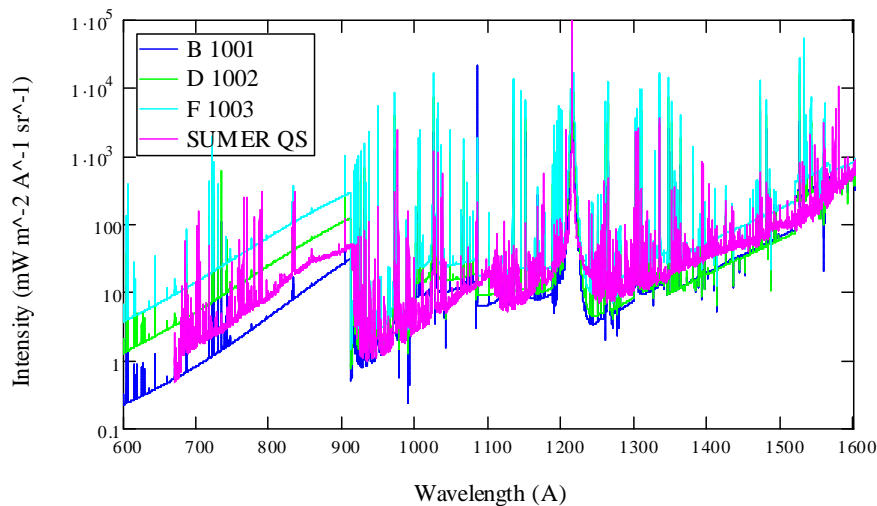
Without refinement the synoptic mask features obsolescence makes it bad



AR backscattered image

EUV radiance spectra of solar features

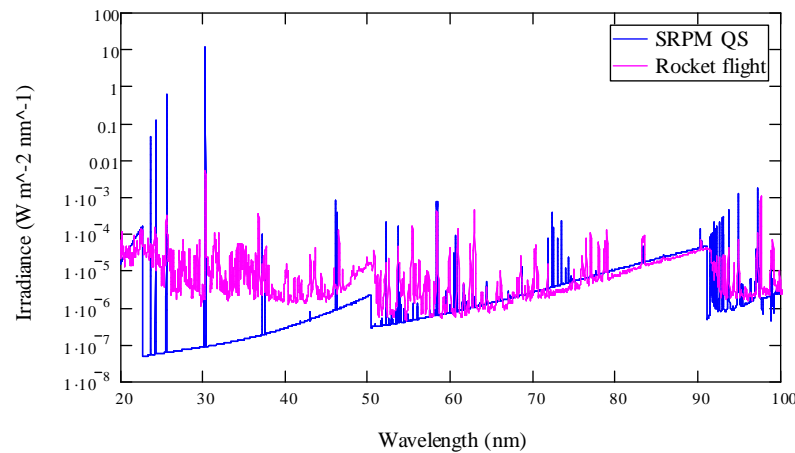
Features radiance spectra → Combined QS radiance spectrum



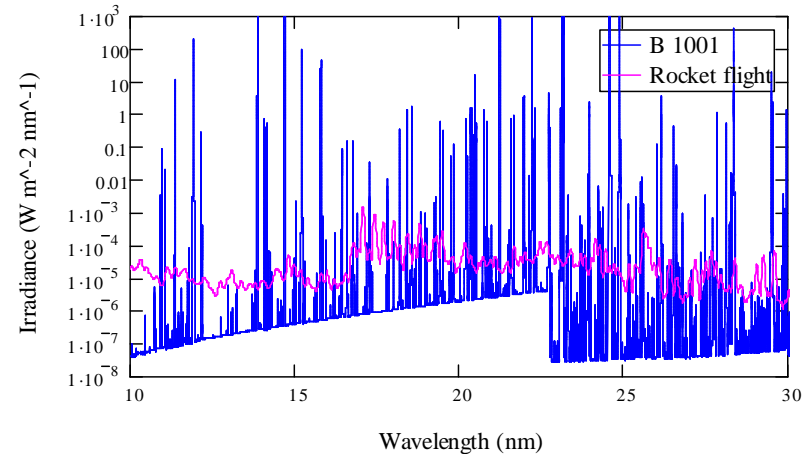
The models computed radiance matches the SOHO/SUMER spectra as the models were built for that. They provide other spectral ranges and extremely high resolution too. The QS combination of models (0.75 B+0.22 D+0.03 F) nearly matches the average QS in Curdt et al. atlas. (Preliminary spectra, work in progress..)

EUV irradiance spectra

Chromospheric

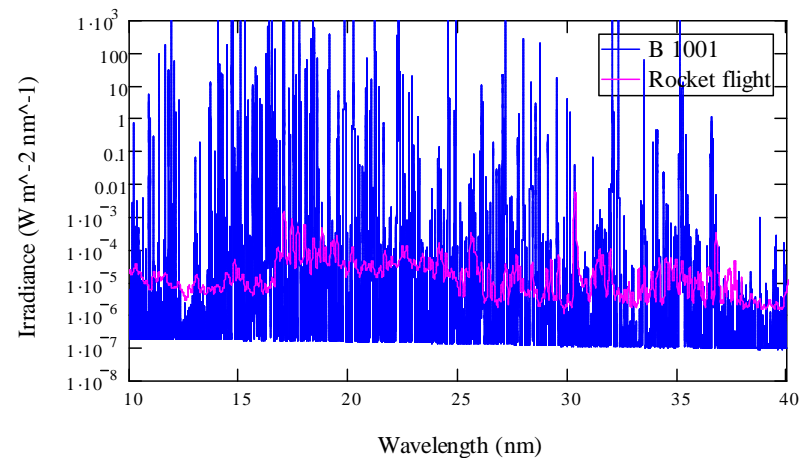


+Lower transition-region



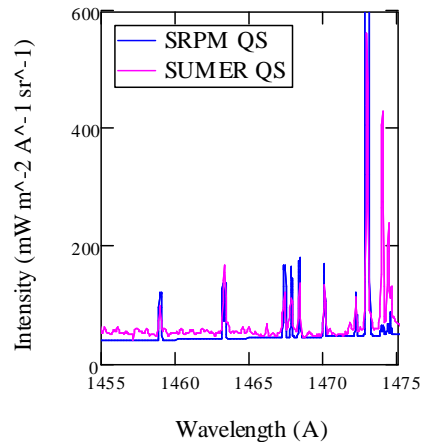
The irradiance from a uniform disk is higher and lower for each feature but the combination at wavelengths longer than 50 nm is close to the recent Rocket flight during practically quiet Sun conditions. Shorter than 50 nm coronal/upper TR lines form a pseudo continuum.

Corona-upper TR only

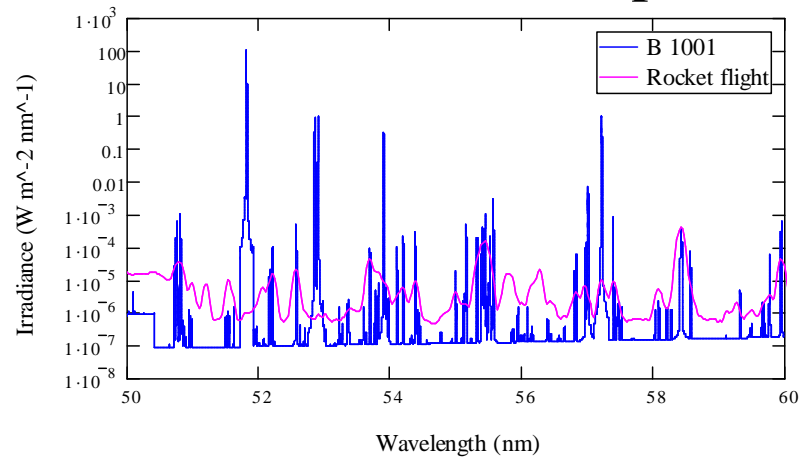


High resolution examples

Chromospheric radiance example



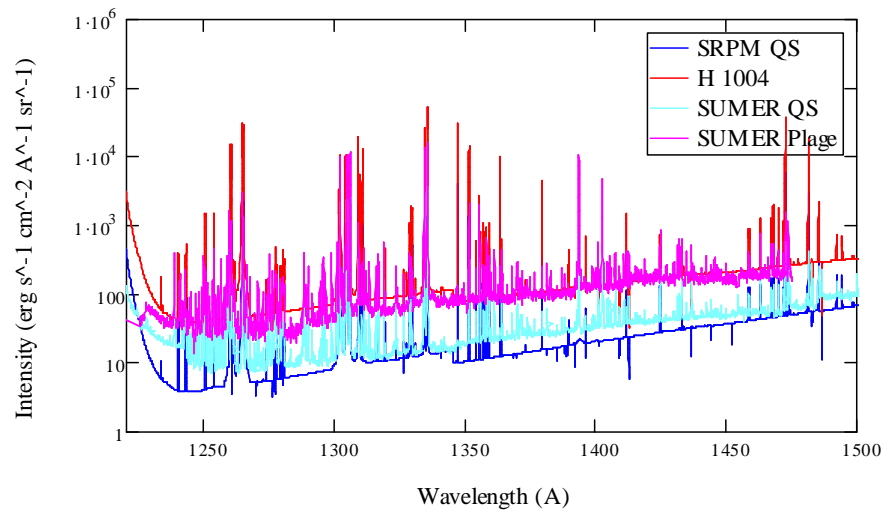
Low transition-region irradiance example



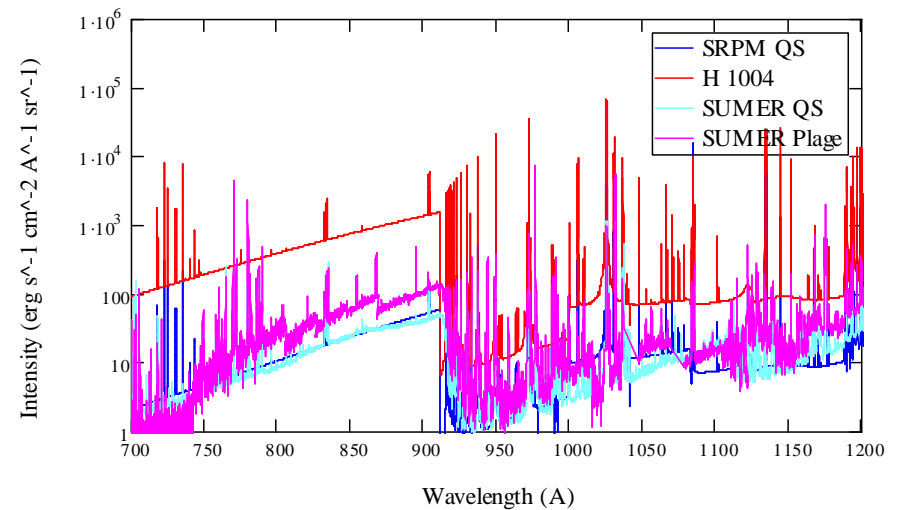
In general there is good agreement on lines but individual lines can be off because of uncertainties in atomic data (mainly collisional excitation rates). Also, so far we have not completed the runs for the spectra of upper transition-region+coronal parts of the models which contribute many lines.

Preliminary Active Region

Chromospheric



Lower transition-region



The UV chromospheric continuum matches fine in model P. However, improvement is needed in the lower transition-region of the active region models.