13th Asia-Oceanic Meteorological Satellite Users' Conference
(S6: Space Weather @ 11:30 on 2023-Nov-09)

Solar Activity and Space Weather

KASI's Ongoing Studies to Understand and Predict Solar Flares

Sung-Hong Park and Young-Sil Kwak

Korea Astronomy and Space Science Institute (KASI)

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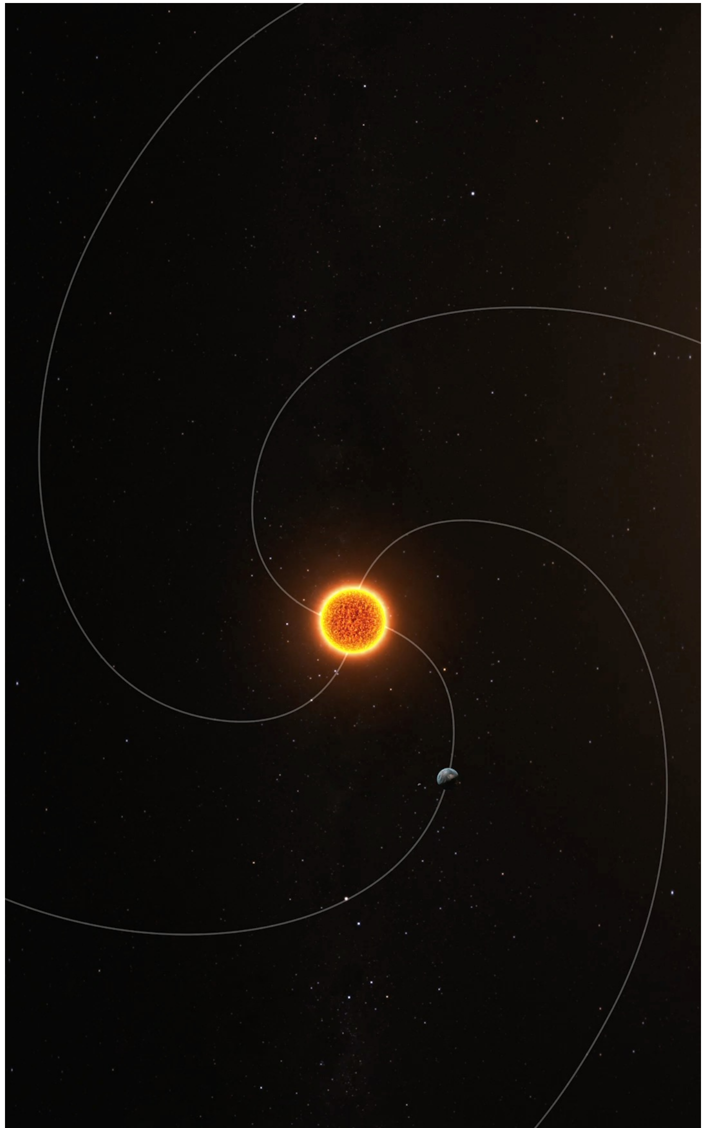
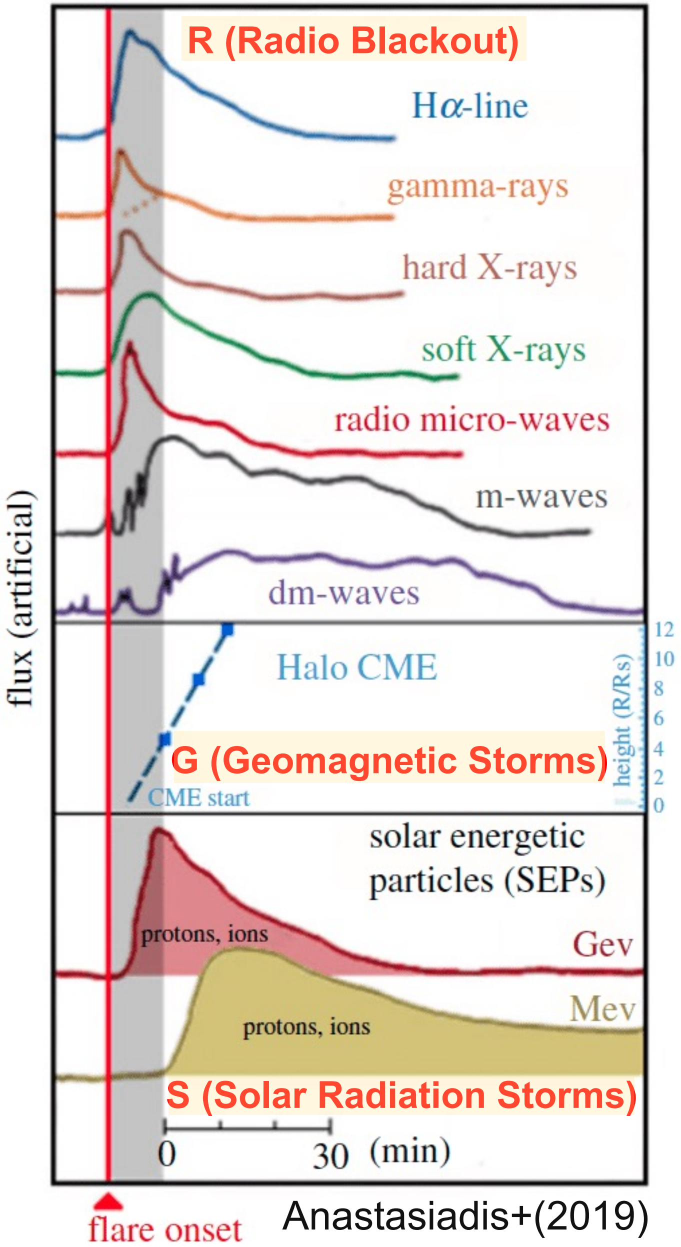
1. Introduction: solar activities and their impacts on space weather



Credit: NASA's Goddard Space Flight Center Conceptual Image Lab



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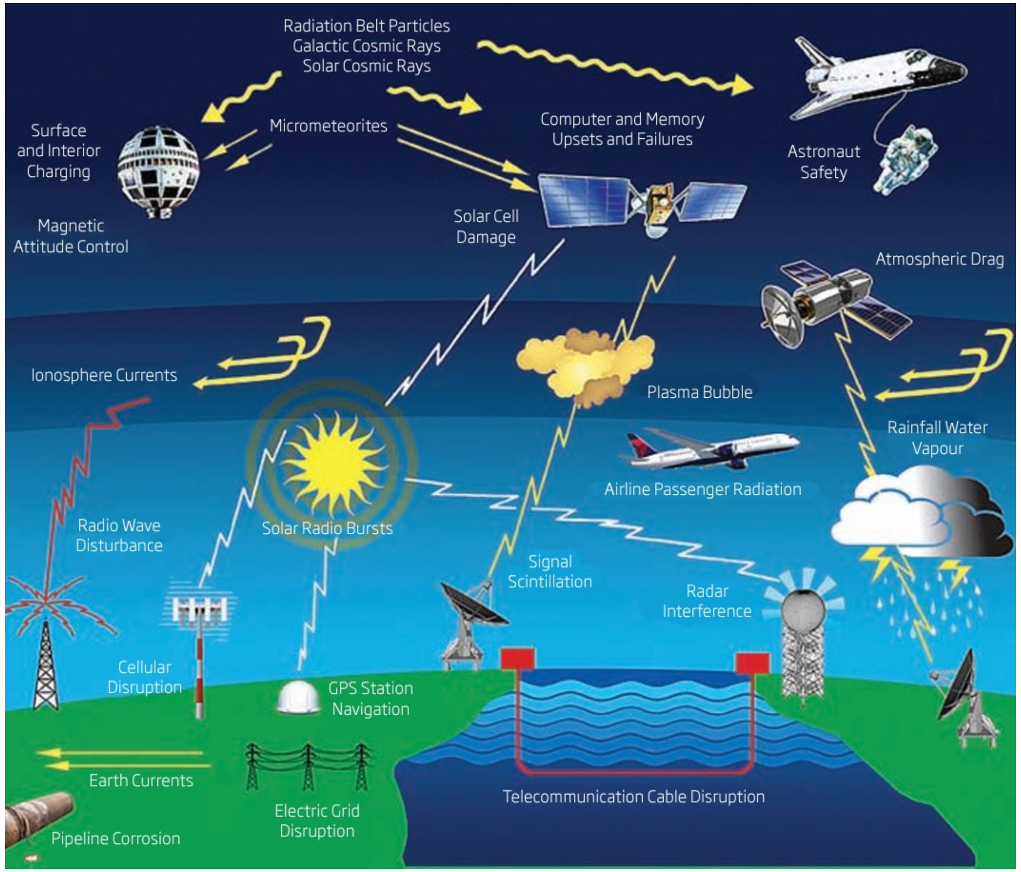
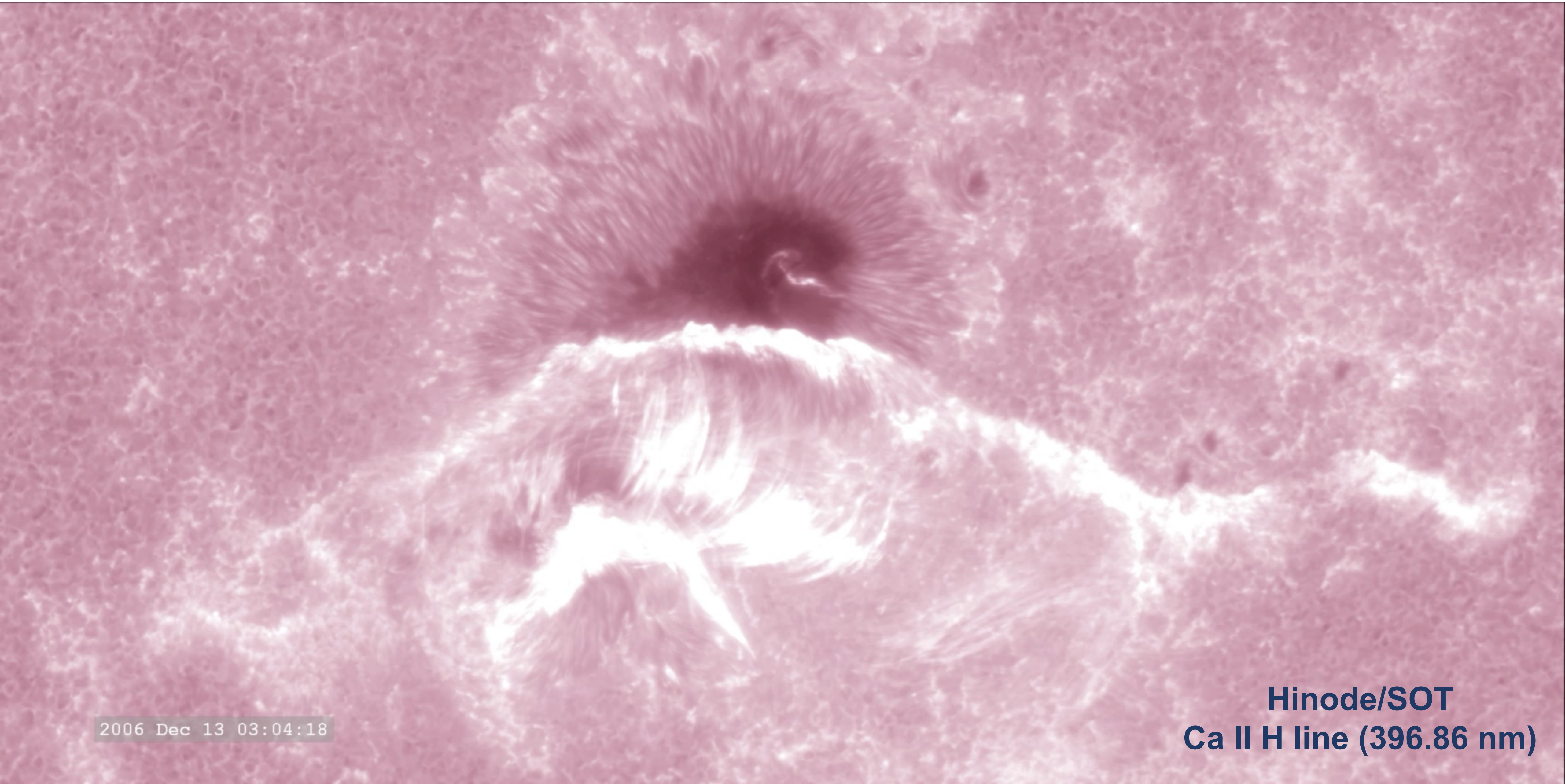
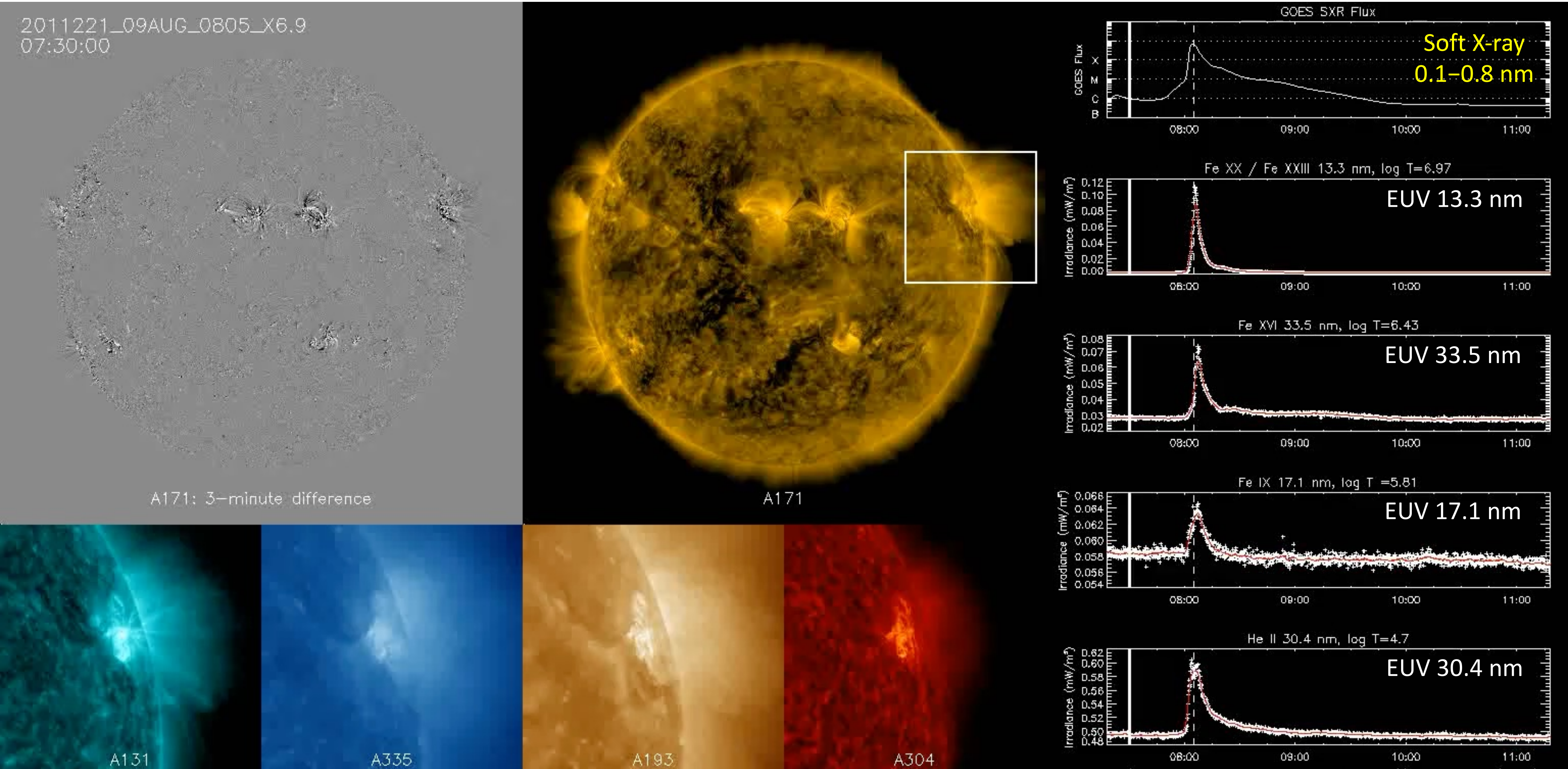


Credit: L. J. Lanzerotti

1. Introduction: solar flares

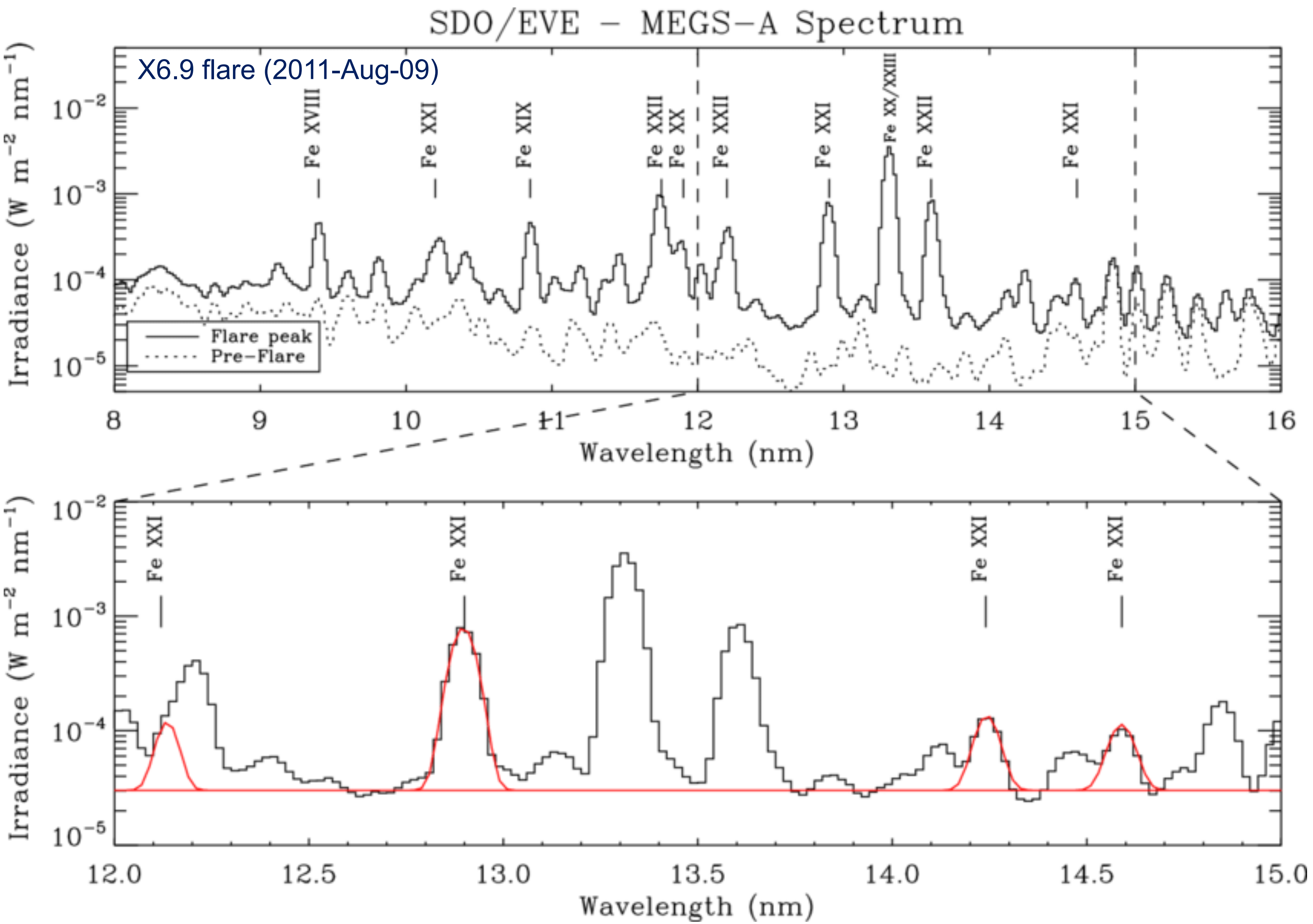


1. Introduction: X-ray and EUV emissions from a flare

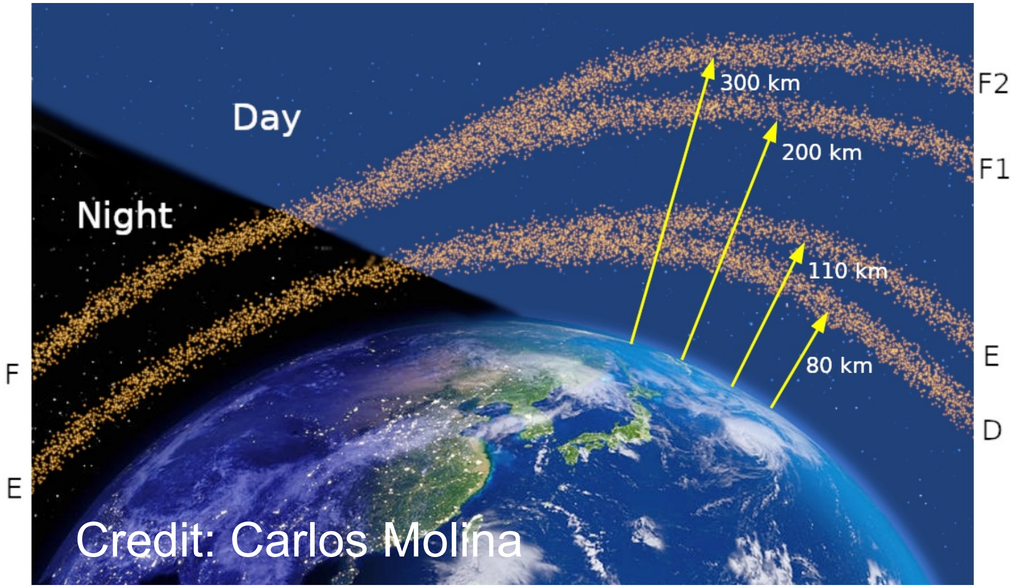


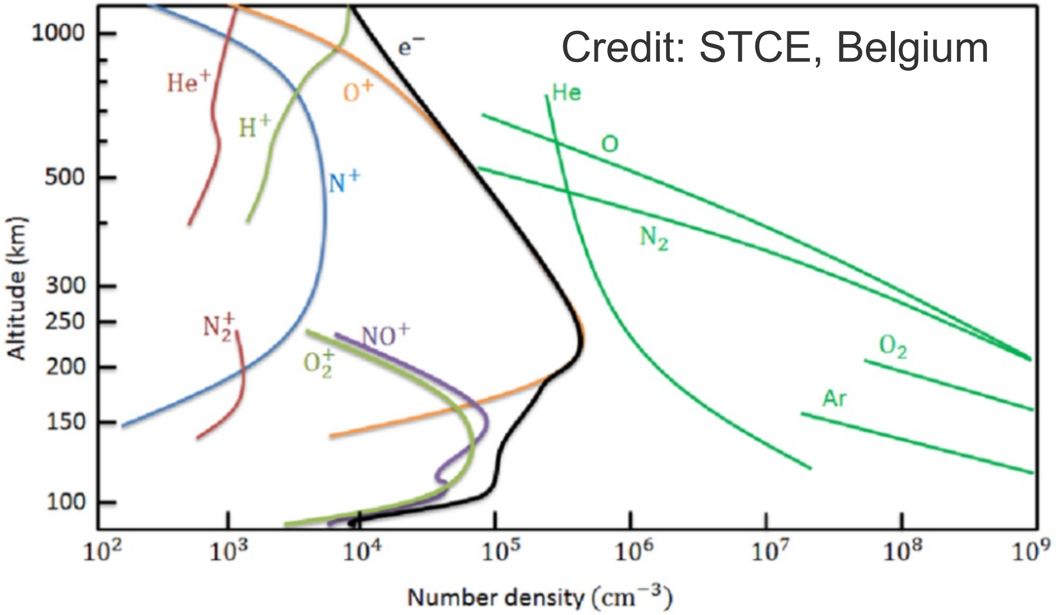
Courtesy of NASA/SDO and the AIA, EVE, & HMI science teams. http://lasp.colorado.edu/home/eve

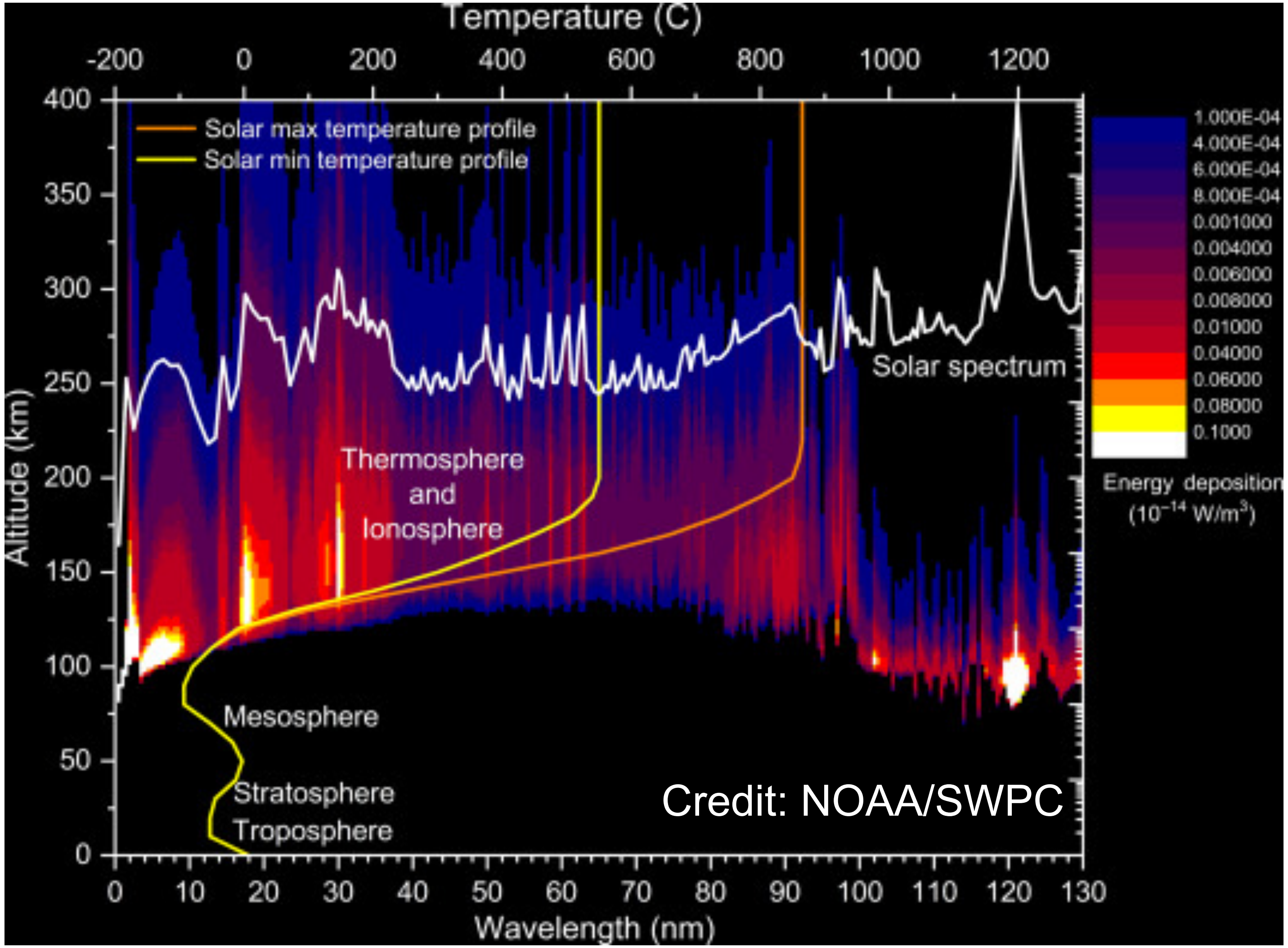
1. Introduction: EUV spectrum during a flare (Milligan+2012)



1. Introduction: ionospheric response to solar flare irradiance







2. Daily forecasts of flaring activity of the Sun

- **Fully automated** and **operational**
  : Issued daily at 00:00 UT if either NASA's Solar Dynamics Observatory (SDO) near-real-time (NRT) data or NOAA's Solar Region Summary (SRS) is available

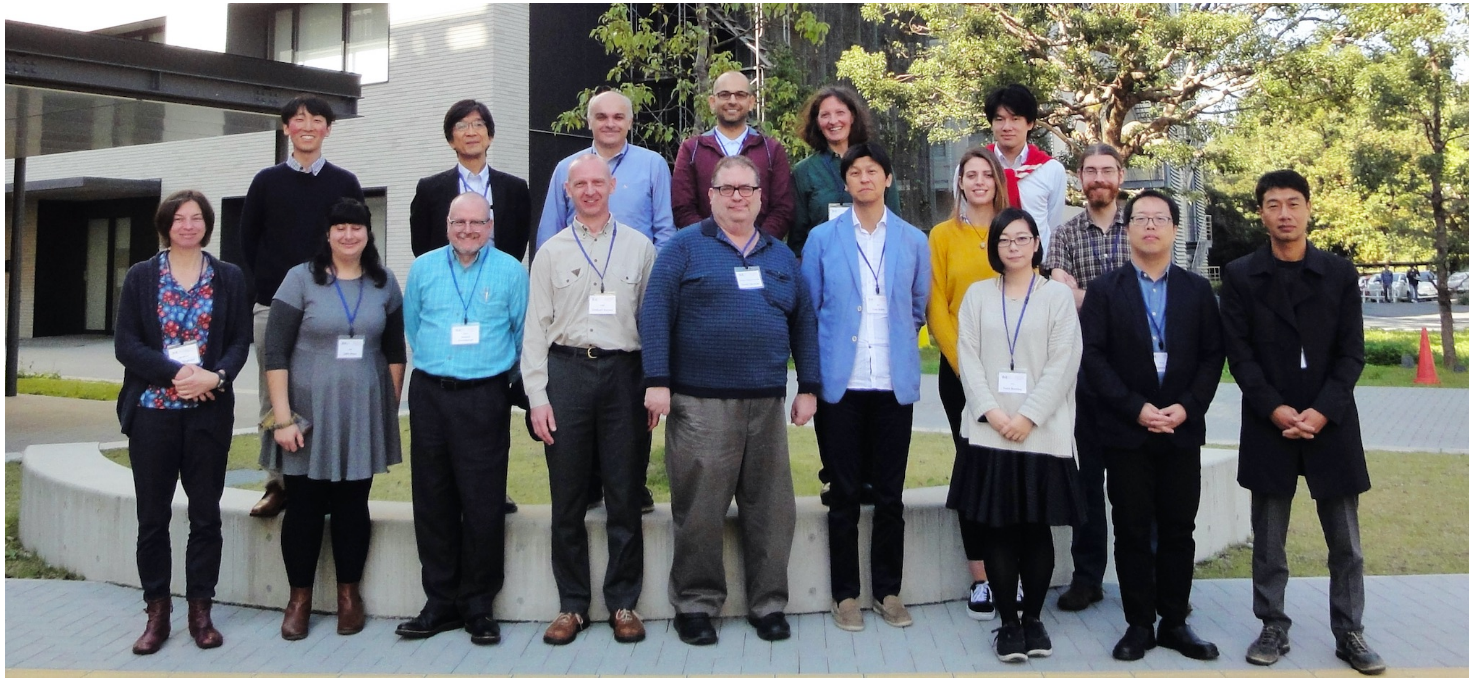
- **Three forecast windows**: 0−24 hr, 24−48 hr and 48−72 hr from the issuance time

- **Event definitions**: NOAA/GOES C-, M-, and X-class

- **Methods**: Poisson statistics with
  1) dH/dt: transport rate of magnetic helicity via the photospheric surface of active regions
  2) McIntosh sunspot classification

2. Daily forecasts of flaring activity of the Sun

- **Common challenge**: flares near or partially occulted by the solar limb (Park+2020)



Flare Forecasting Model Evaluation Workshop in 2017

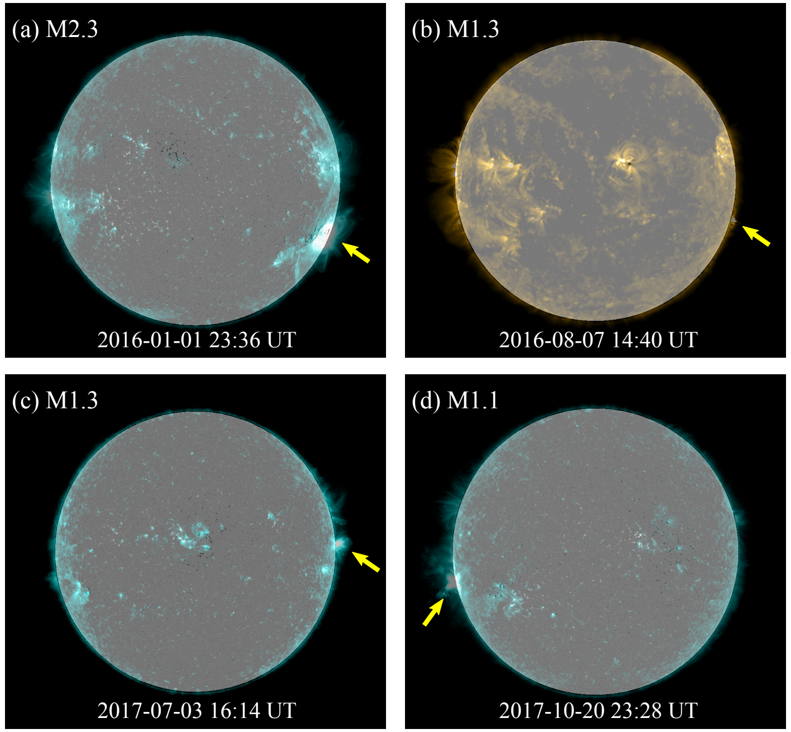


Table 6. Summary for Limb Flares on Four Event-days

Flare			Source Region	
#	Start Time	Peak Flux	NOAA Number	Location
1	2016-01-01 23:10 UT	M2.3	12473	S25 W82
2	2016-08-07 14:37 UT	M1.3	None†	S12 W70§
3	2017-07-03 15:37 UT	M1.3	None†	N02 W85
4	2017-10-20 23:10 UT	M1.1	12685	S12 E88§

- During the testing interval of 2016 to 2017, there were four M1.0+ event-days (of 26 event-days, or 15%) for which all flare forecasting models failed to provide a “yes” forecast with the probability threshold of 0.5.

2. Daily forecasts of flaring activity of the Sun

- **Under way to update** the forecasting methods with **differential emission measure** (DEM; n_e^2 along the line-of-sight for a given temperature range) from solar full-disk EUV NRT images obtained by the Atmospheric Imaging Assembly (AIA) onboard SDO.

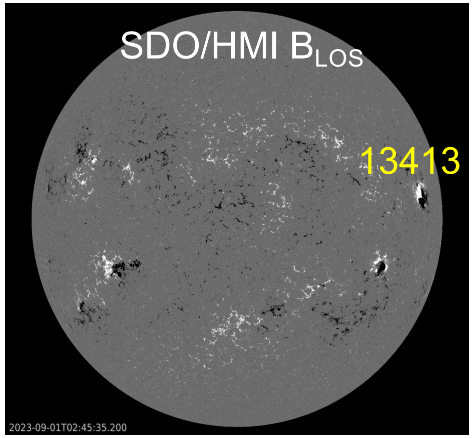
: DEM maps derived from AIA NRT data using the regularized inversion by Hannah & Kontar (2012, 2013)

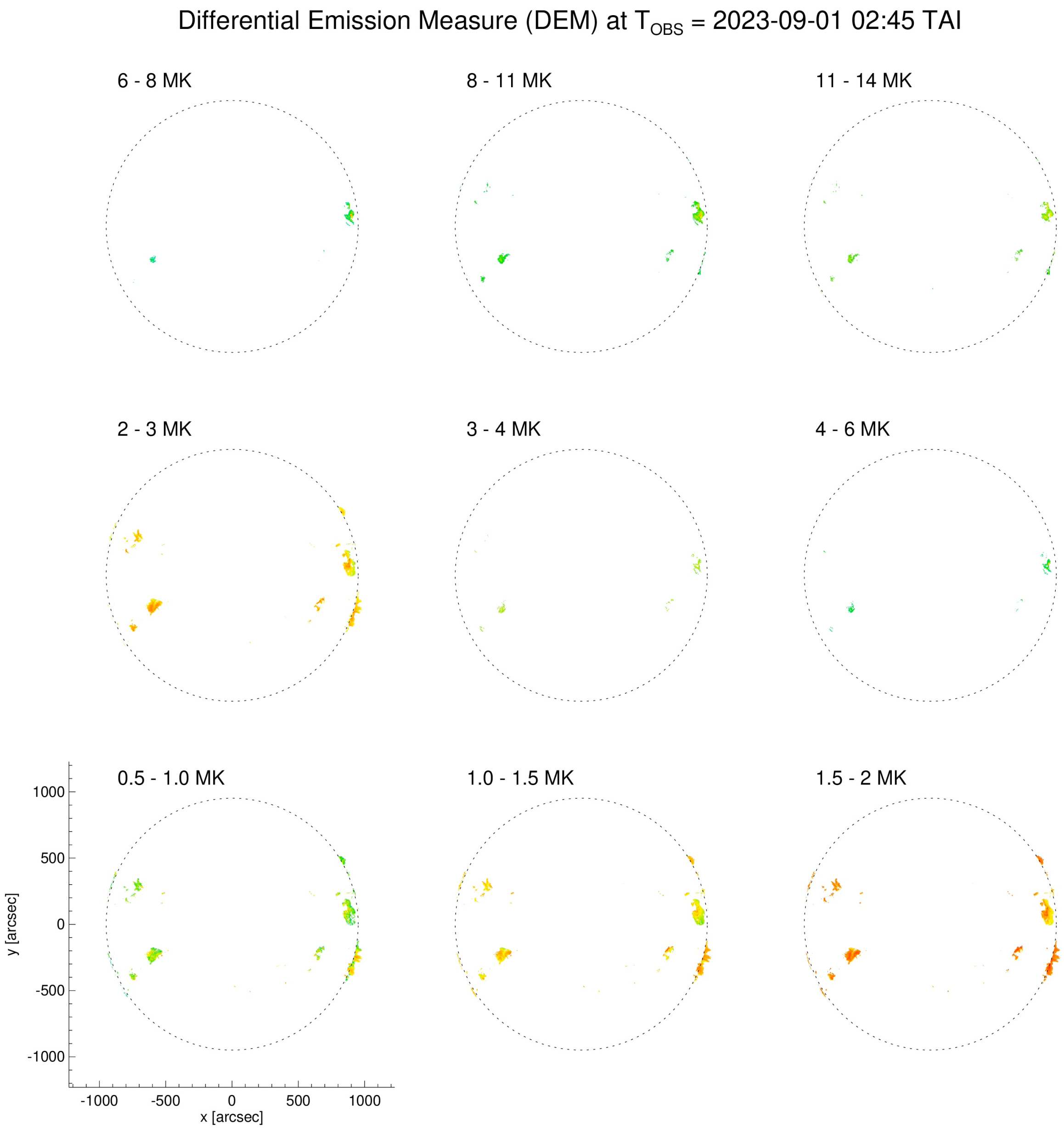
: For example, M1.2 flare in AR13413 (with an S1 proton flux) → start 02:54 UT / peak 04:47 UT

: Enhancement of DEM (particularly, T ≳ 10 MK) right before and around the GOES flare start time

: Reasonable calculation time (typically, a few min) of DEM for all AR pixels of a solar full-disk image

: Under investigation with various flare events



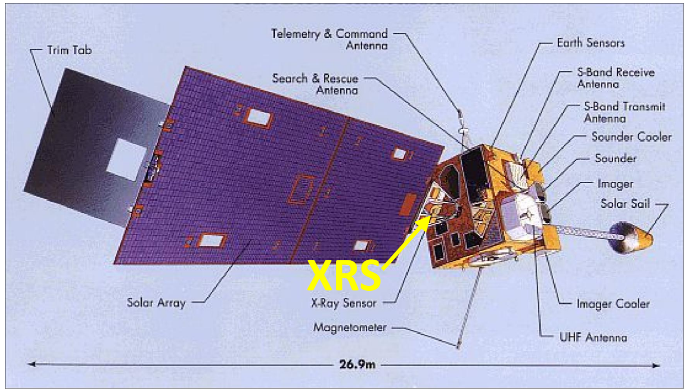


3. Deep learning model for solar flare irradiance translation: motivation

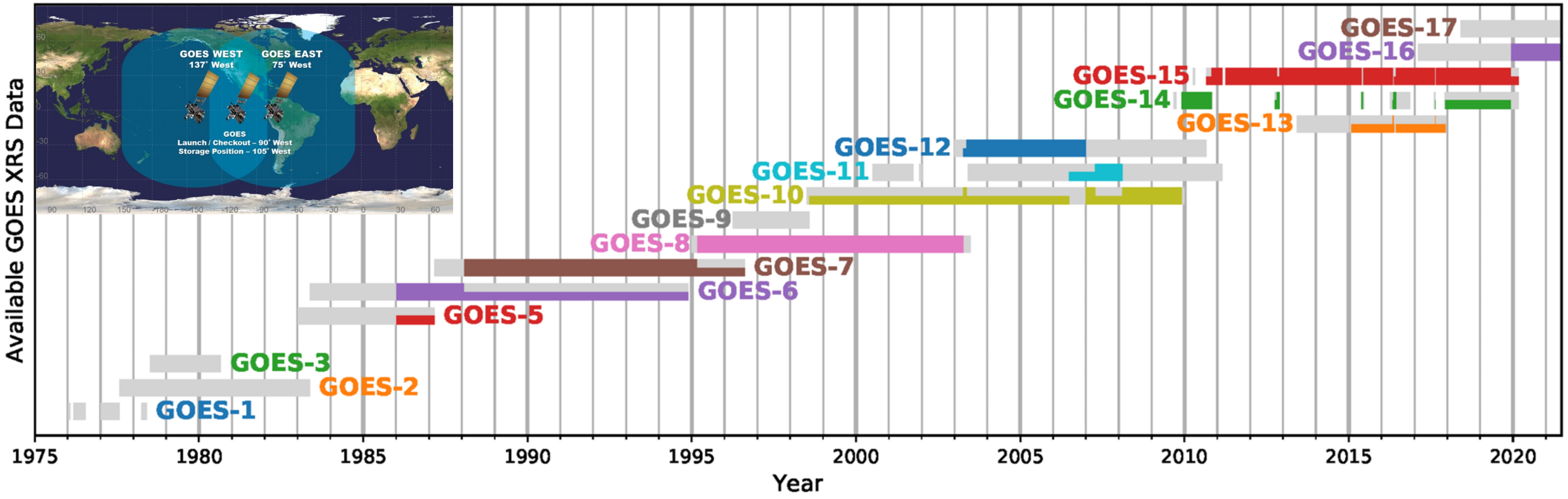
- Crucial to have EUV spectral irradiance measurements of solar flares
  - Solar plasma diagnostics → understanding of energy release, coronal heating, …
  - Modeling the ionospheric response to flares → space weather applications (forecast)

- Limited with a small number of solar EUV spectrometers operated in space so far (e.g., SDO/EVE since 2010): mission lifetime, wavelength range, …

- NOAA's GOES/X-ray Sensor (XRS) measurements of soft X-ray irradiance since 1975
  - Two channels: 0.05−0.4 nm (short), 0.1−0.8 nm (long)
  - Cadence: 2 or 3 sec



GOES-18 (lunched in 2022)



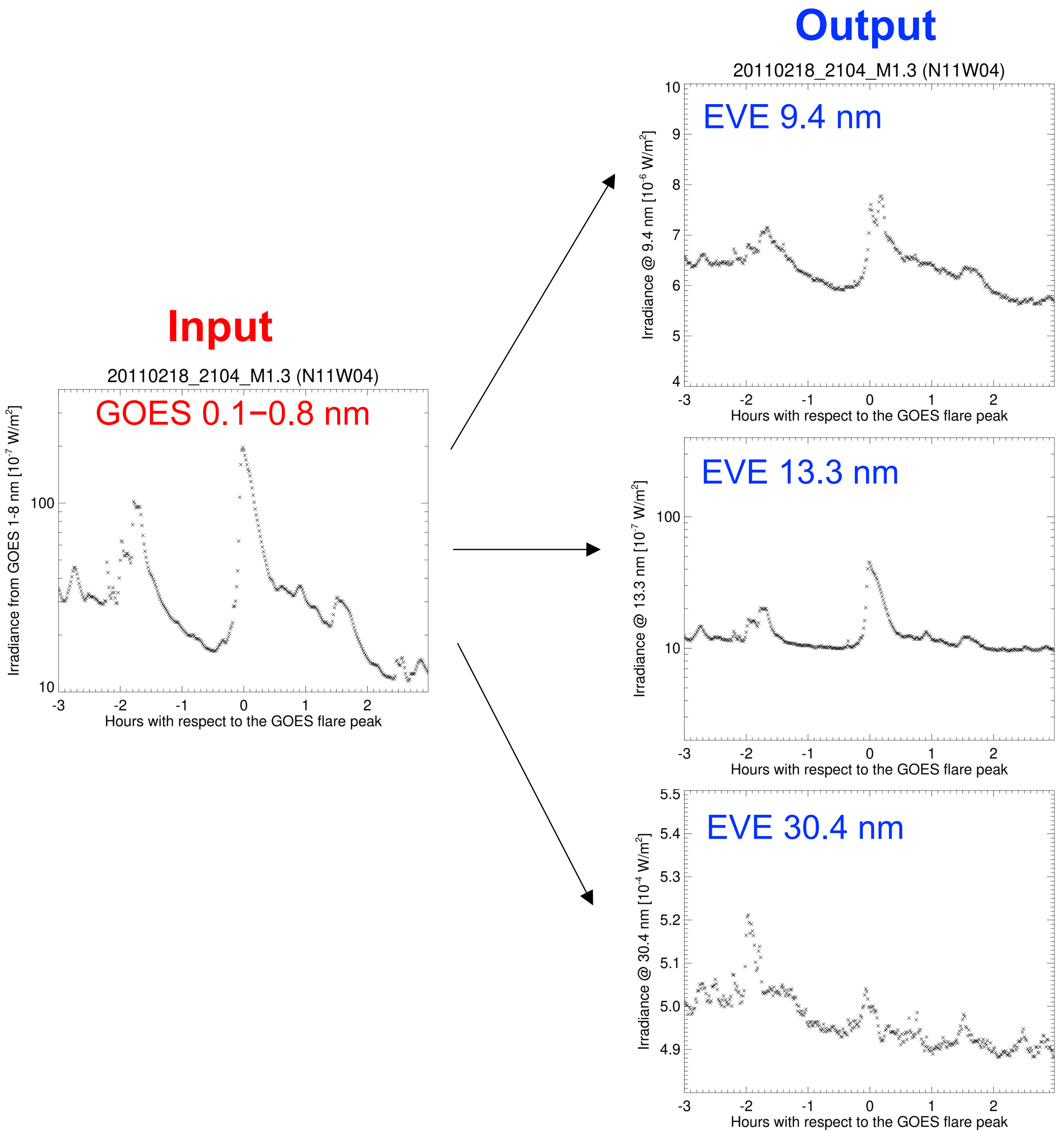
3. DL model for solar flare irradiance translation: goal

- Developing a deep learning (DL) model that can generate irradiance in EUV channels from GOES soft X-ray irradiance measurements of a given flare
  : ***Solar flare irradiance translator*** (SFIT, soft X-ray → EUV)

- Applications of the developed model
  - A statistical studies of solar flares: EUV properties, plasma temperatures/densities
  - A case study of an ionospheric response to EUV irradiance during a flare event (e.g., comparing ionosphere models with/without flare EUV input)

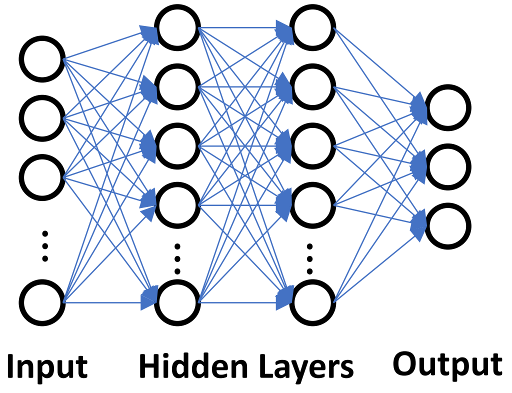
3. DL model for solar flare irradiance translation: dataset

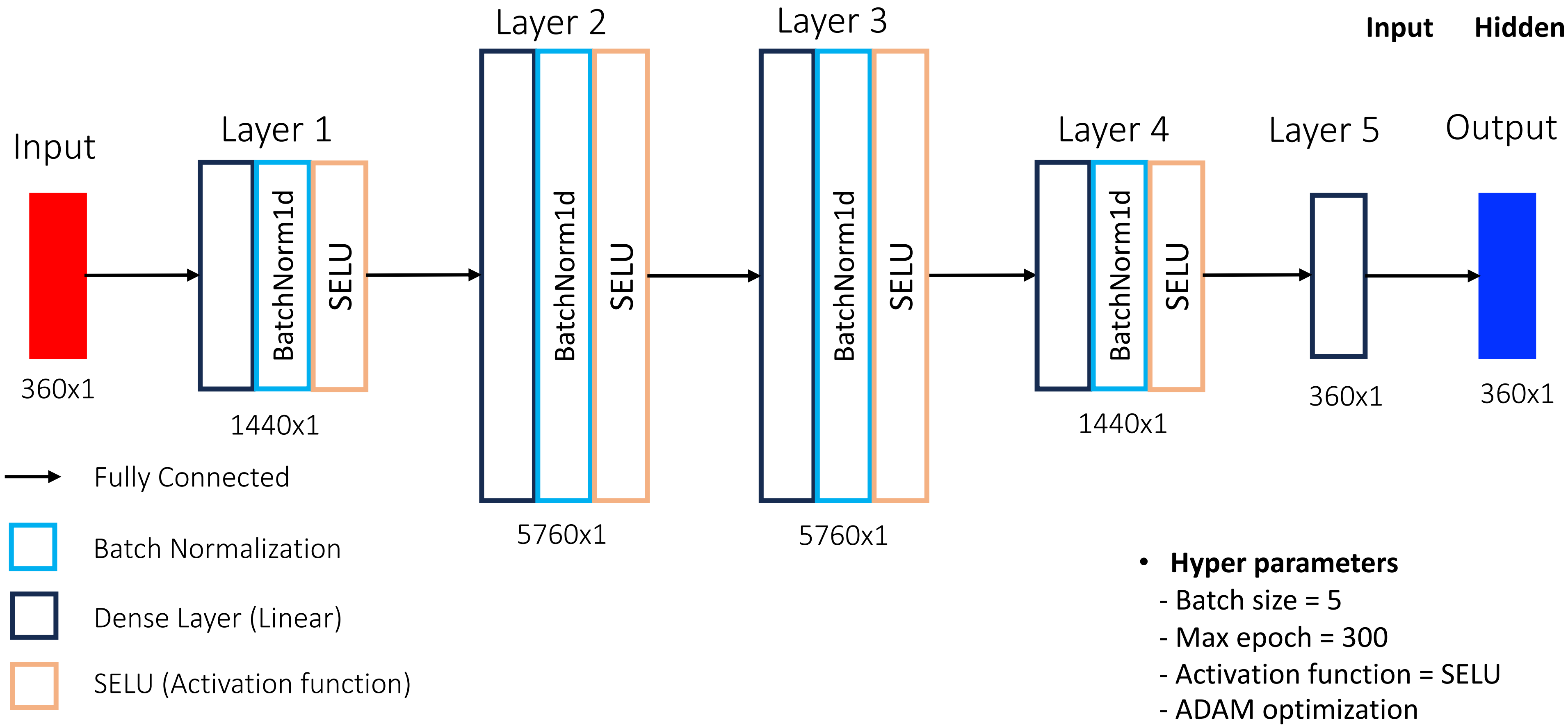
- **Event definition**
  : A total of 1,993 flare events larger than the GOES C2.0 peak flux from the SDO/EVE flare catalog (2010 − 2014)
- **Input data**
  : GOES/XRS (0.1−0.8 nm channel) 1-min average irradiance time series over 6 hours (±3 hours from the GOES flare peak)
- **Output data**
  : SDO/EVE/MEGS 1-min average irradiance time series for three flare emission lines (9.4, 13.3, 30.4 nm) among a total of 30
- **Preprocessing**
  : interpolation for data gaps as well as suspicious points (outliers)



3. DL model for solar flare irradiance translation: model

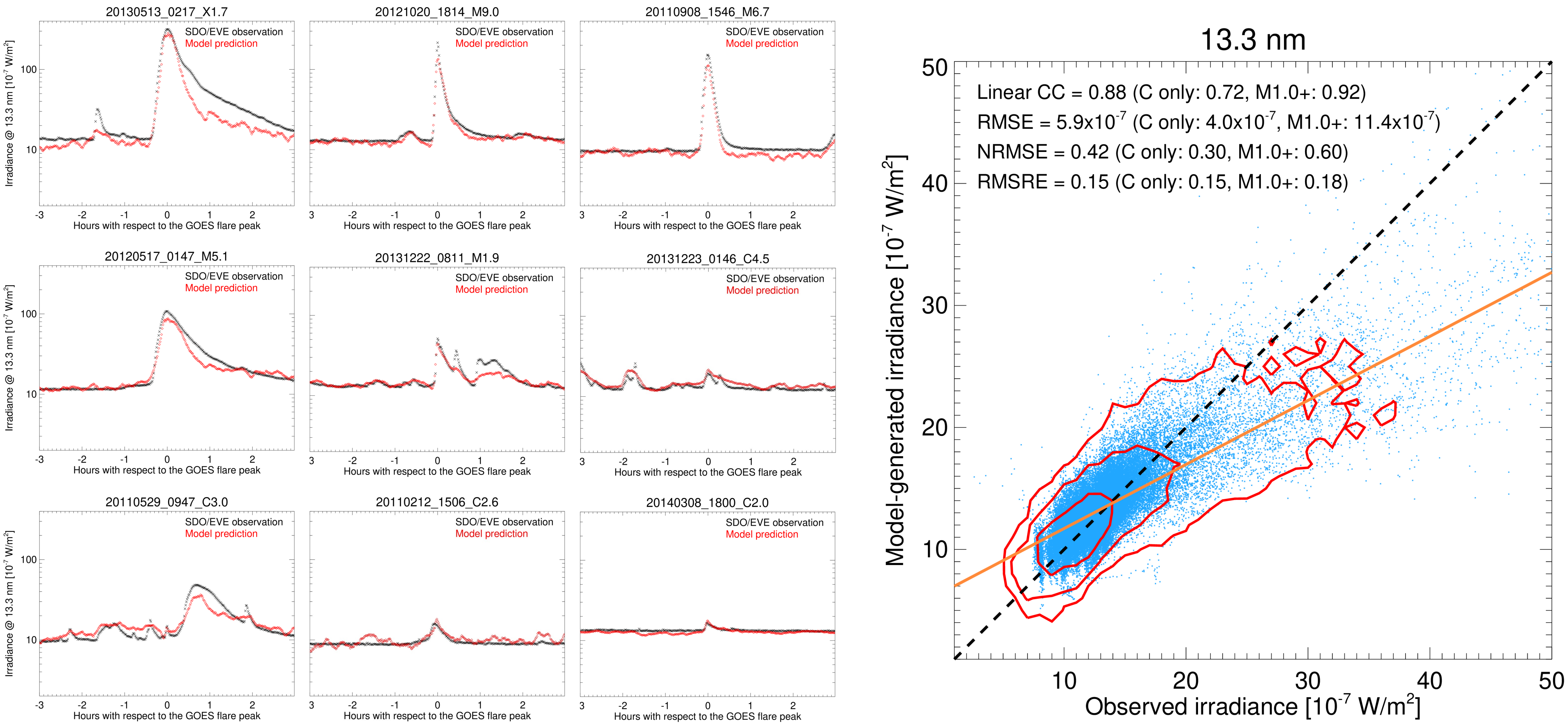
- Fully Connected Layer (FLC) is a sort of Multi-layer Perceptron (MLP) characterized by densely interconnected neurons, where each neuron in the previous layer is connected to every neuron in the next layer.



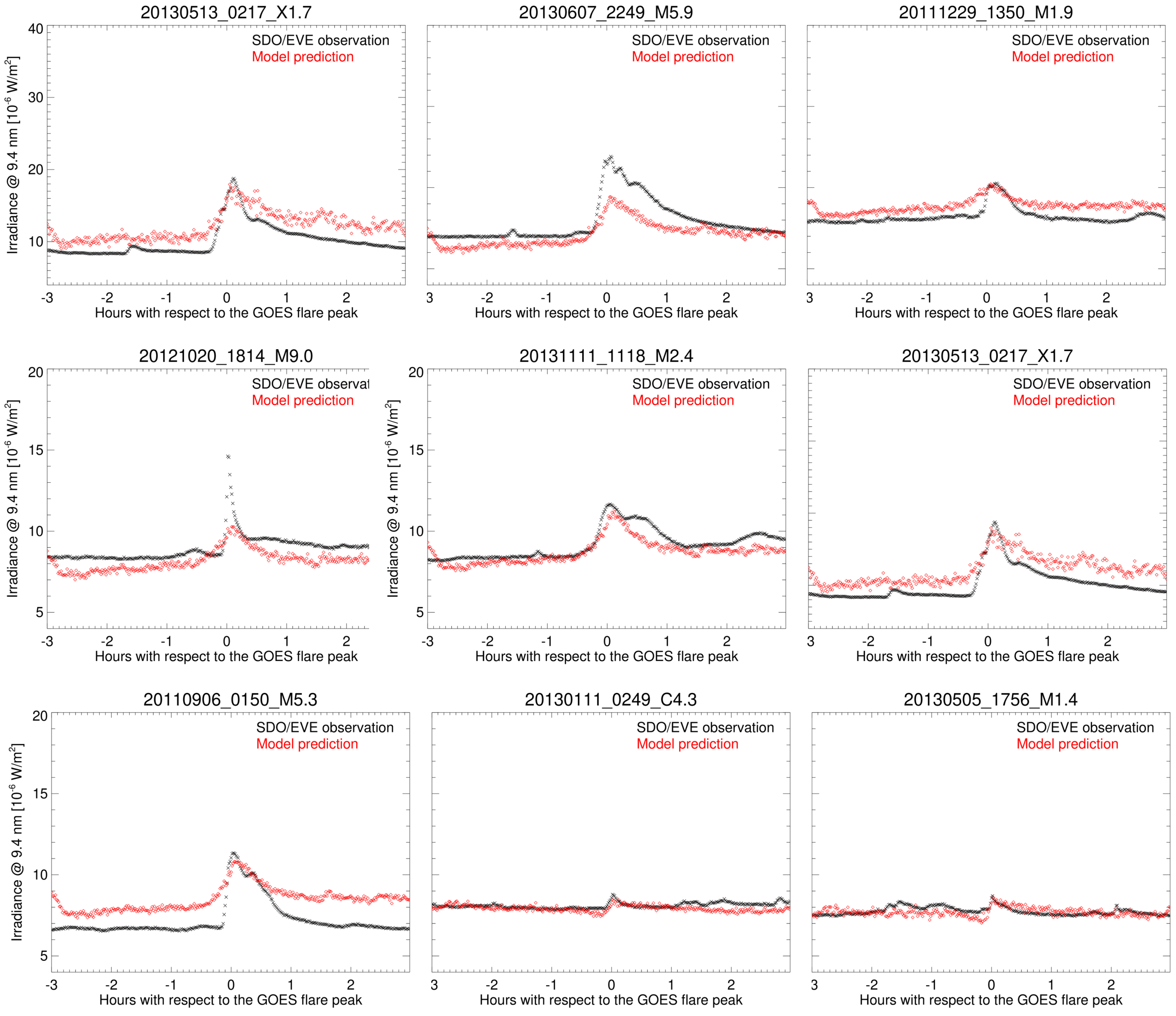


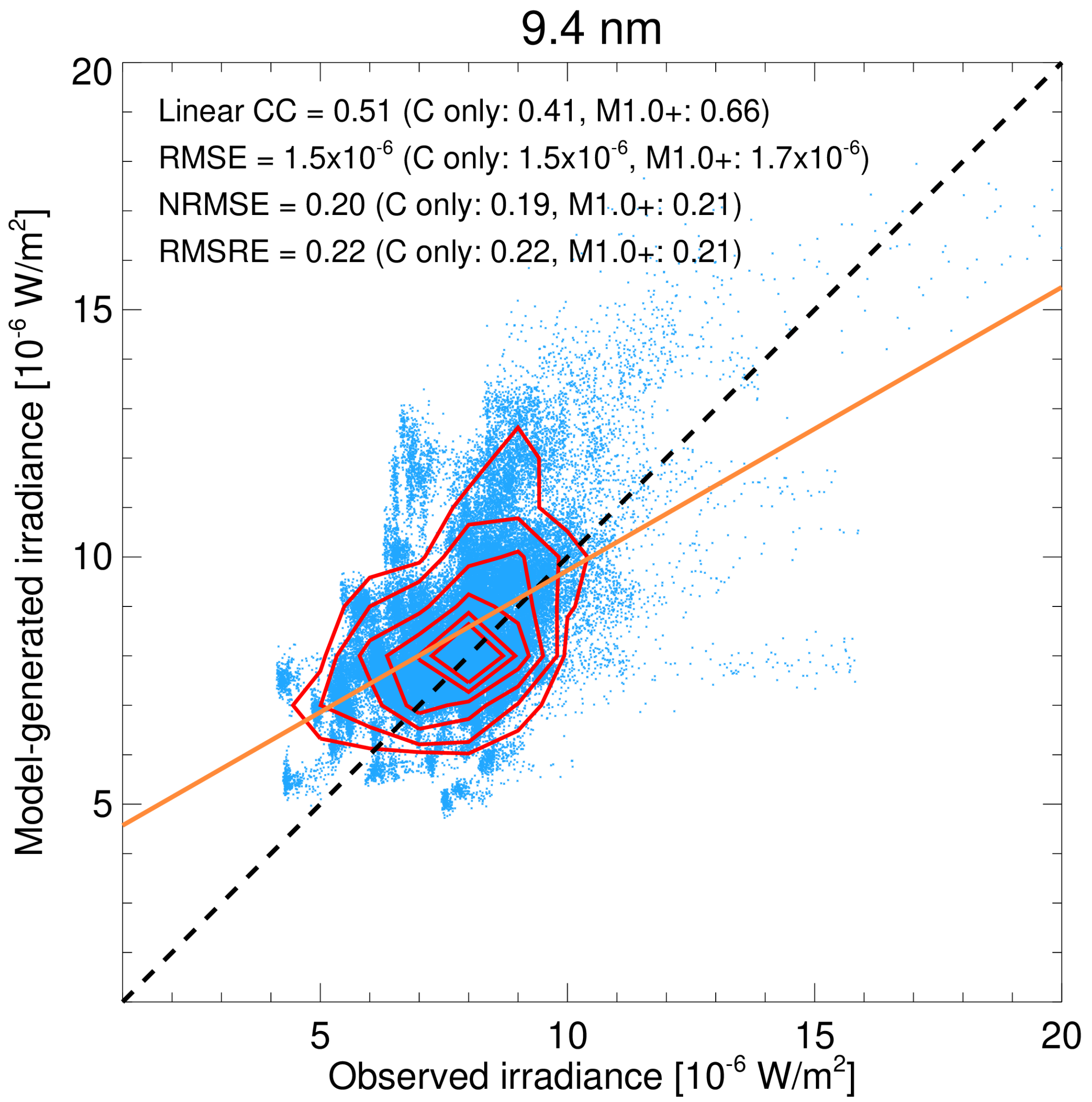
- **Hyper parameters**
  - Batch size = 5
  - Max epoch = 300
  - Activation function = SELU
  - ADAM optimization

3. DL model for solar flare irradiance translation: results I. 13.3 nm

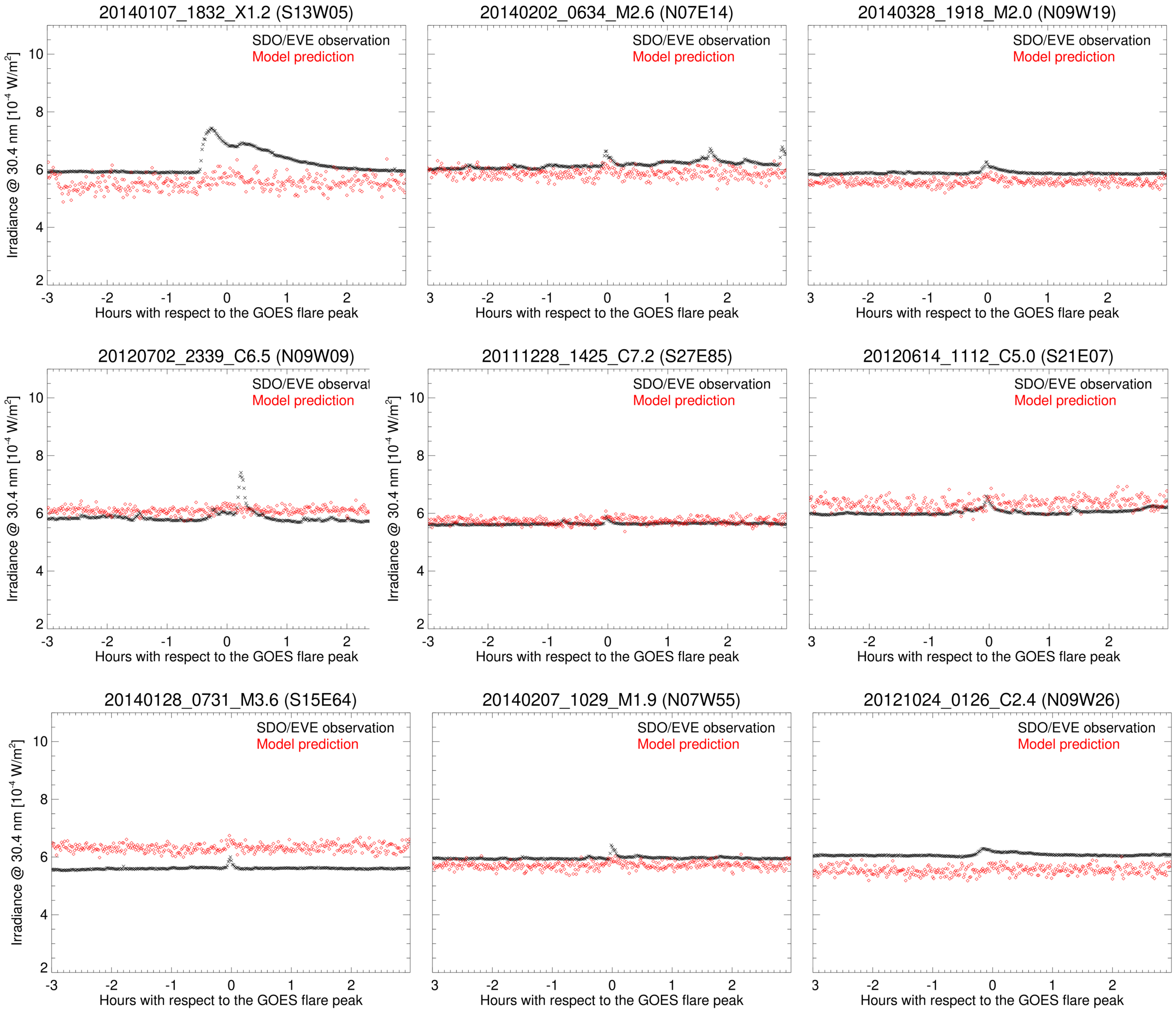


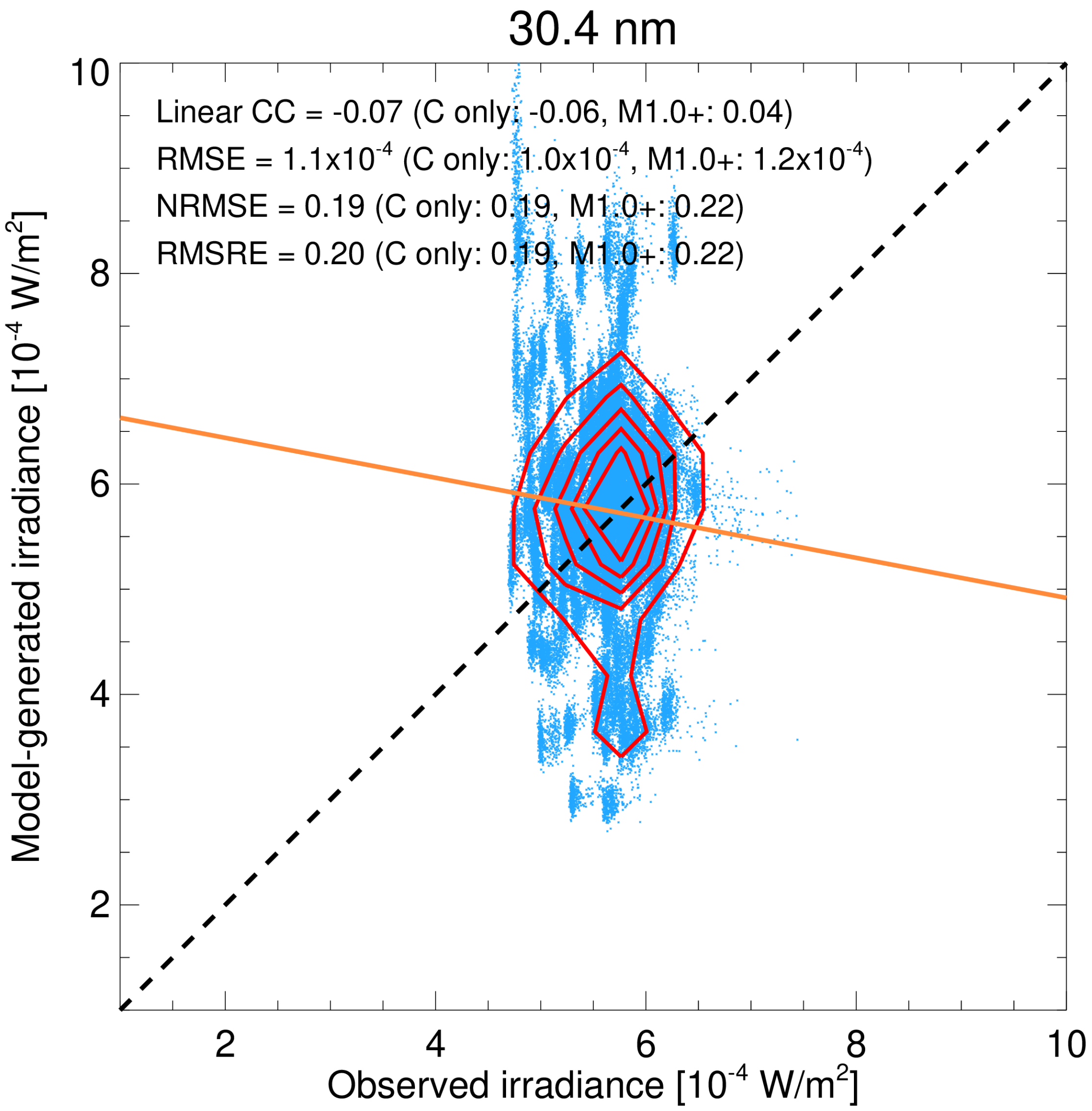
3. DL model for solar flare irradiance translation: results II. 9.4 nm





3. DL model for solar flare irradiance translation: results III. 30.4 nm





Summary and discussion

- Various studies are being carried out at KASI to better understand and predict solar flares, mainly using:
  1) large datasets obtained with persistent observations from space such as NASA’s SDO and NOAA’s GOES
  2) recent techniques of data science (such as deep learning)

- One of the key elements for the flare study would be to construct a comprehensive (but fundamental only), consistent and easy-to-use science database from observations and simulations.

- In this context, an international-community-wide effort is required to efficiently design the database and future space (e.g., off-Sun-Earth line) missions such as an L4 mission under the feasibility study by KASI.