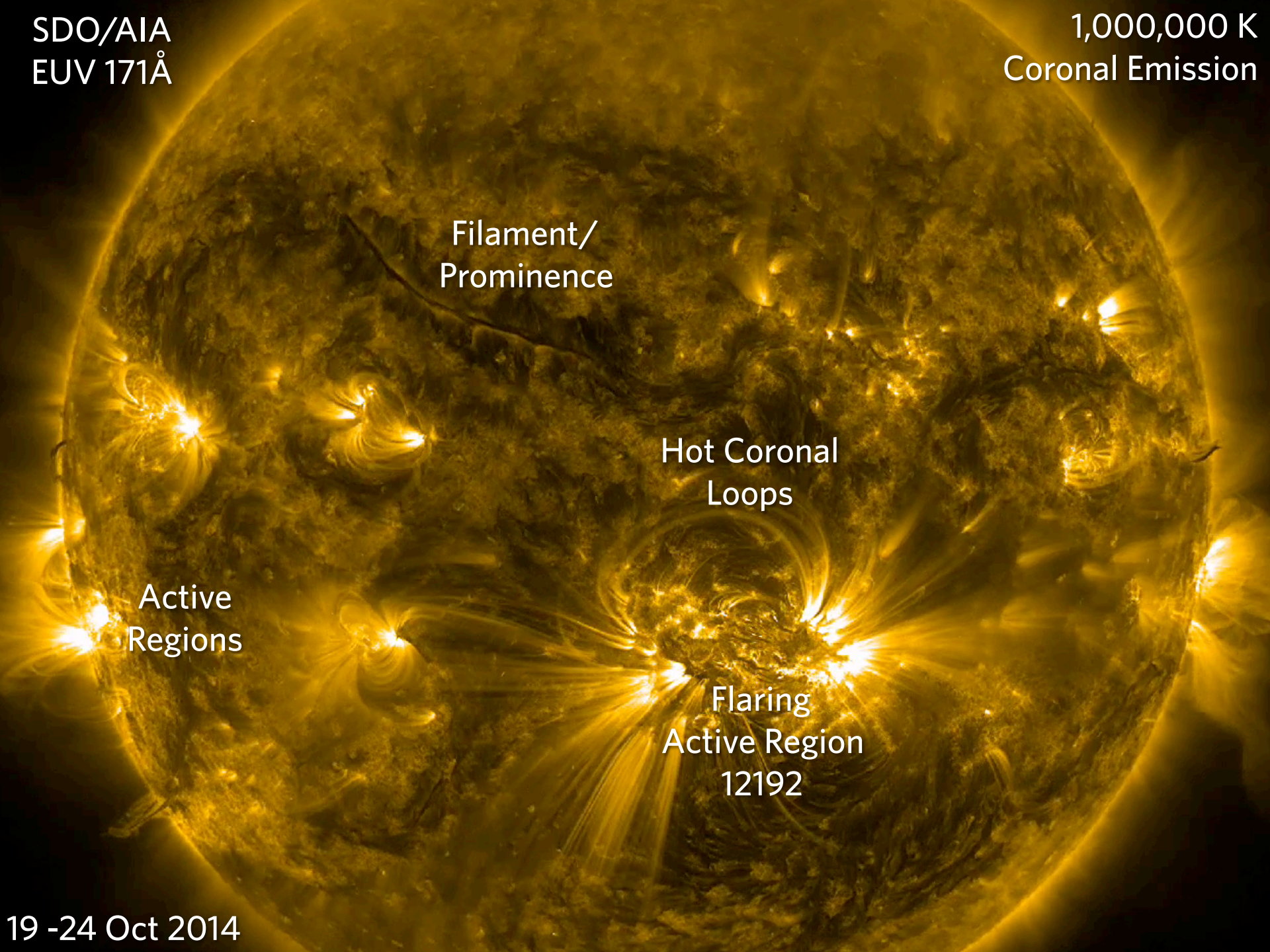
Iain G. Hannah iain.hannah@glasgow.ac.uk http://www.astro.gla.ac.uk
Lyndsay Fletcher, Eduard Kontar, Nicolas Labrosse, Alec MacKinnon, Hamish Reid, Enrique Perez, Nicolas Bian, Natasha Jeffrey, Paulo Simoes & many students


SDO/AIA
EUV 171Å
1,000,000 K
Coronal Emission
Filament/
Prominence
Hot Coronal
Loops
Active
Regions
Flaring
Active Region
12192
19 -24 Oct 2014

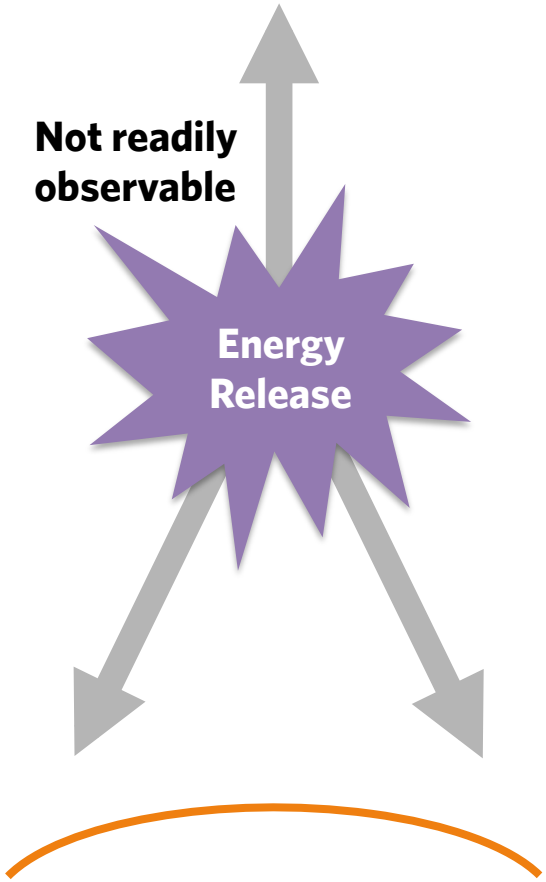
What are these phenomena?

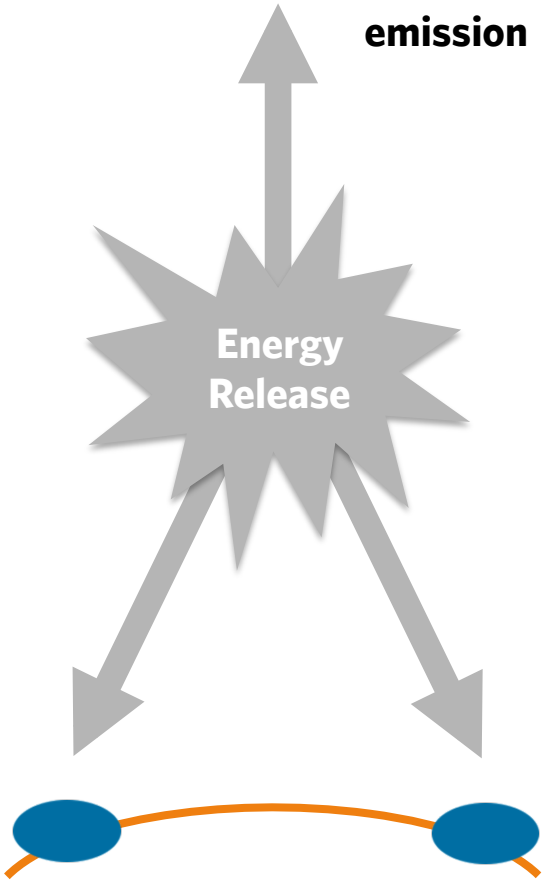
- All due to solar magnetism
  - Associated with active regions/sunspots
  - But cannot observe the detailed magnetic field changes

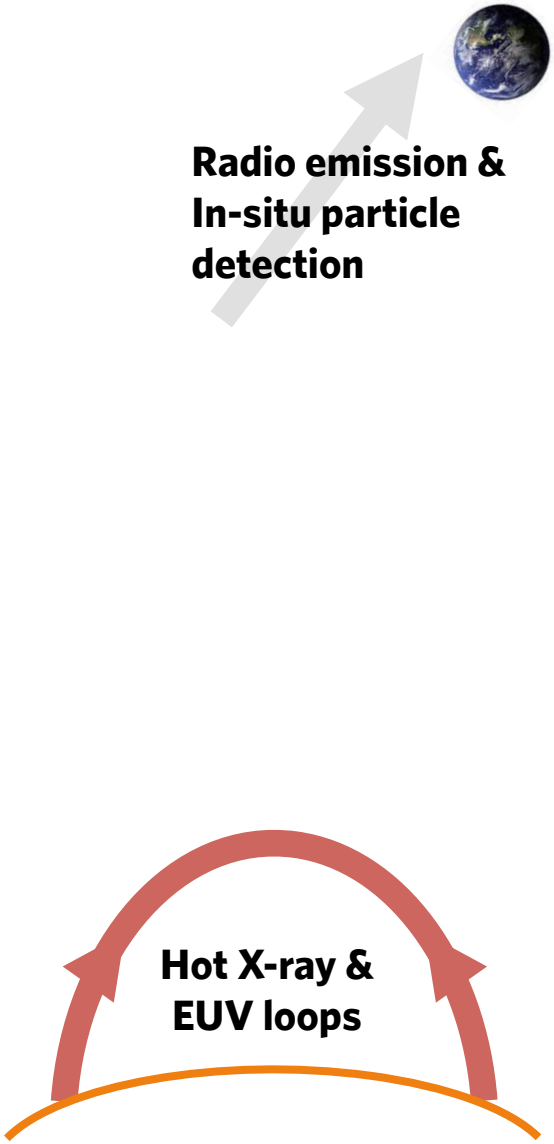
- How is the energy so rapidly & efficiently released from the magnetic field ?
  - Into heating, particle acceleration, waves, eruptions

- What are the quantitative details/physics ?
  - In flares, prominences/filaments, coronal mass ejections (CMEs)

Simplified flare picture







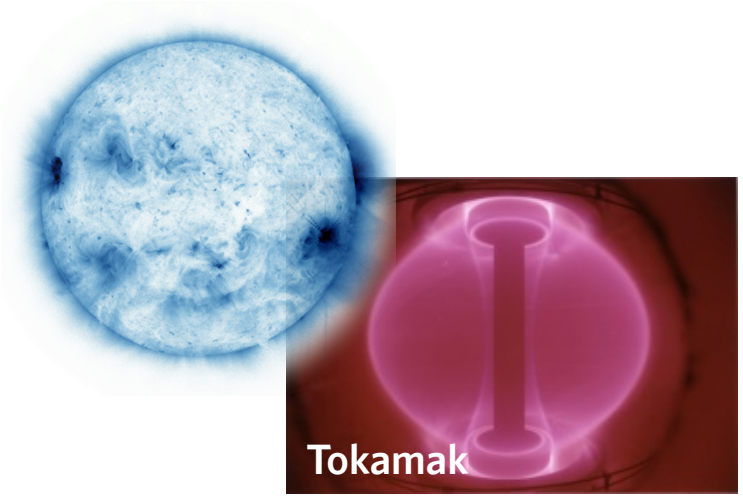
How do we do study this?

- **Multi-messenger astronomy**
  - Combining together multi-wavelength and particle data
  - Substantial amounts of (big) data from ground & space
  - Use advanced spectral fitting, image processing, feature recognition, image reconstruction techniques

- **Models/Simulations**
  - From back of envelope calculations to supercomputers
  - Simulating transport and response of atmosphere
  - Does it match the multiple observed signals?
  - What physical processes dominate?
  - What physics are we missing?

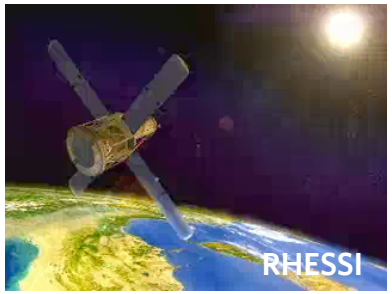
Why study these phenomena ?

- Learn how Sun & stars work
  - Applicable to laboratory and astrophysical plasmas

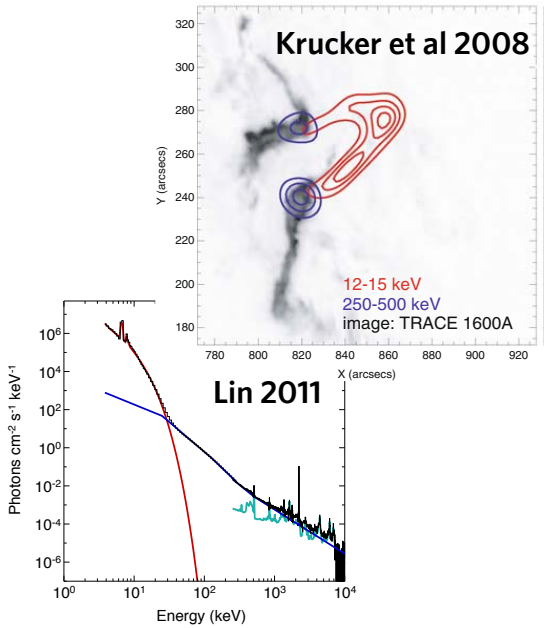


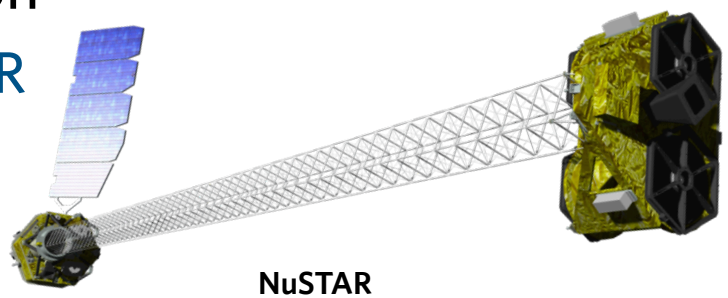
- Space Weather & Solar Storms
  - Expensive threat to us & our tech
    - UK risk register: 4th most important
    - Met Office Space Weather Operations Centre
    - Big events & regular strain
  - Flares: immediate -> radio/GPS blackout
  - CMEs: few days later -> satellite/ spacecraft & power grid damage

X-rays: RHESSI & NuSTAR



- X-rays: hottest material and accelerated electrons in flares
  - Glasgow leading for >40 years (Brown 1971)
- NASA's RHESSI Imaging Spectrometer
  - Observed >96,000 flares since 2002 launch
  - High spatial, energy & temporal resolution
  - Rotation Modulation Collimators
  - Indirect imaging -> image reconstruction
- NASA's NuSTAR astrophysics mission
  - Highly sensitive direct imager of HXR
  - Launched 2012
  - Just started solar observations

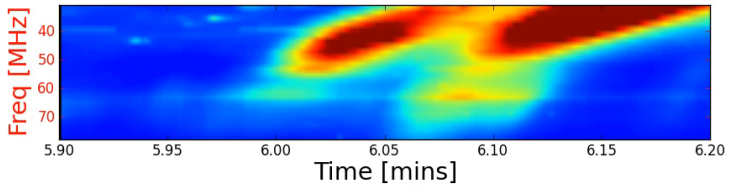


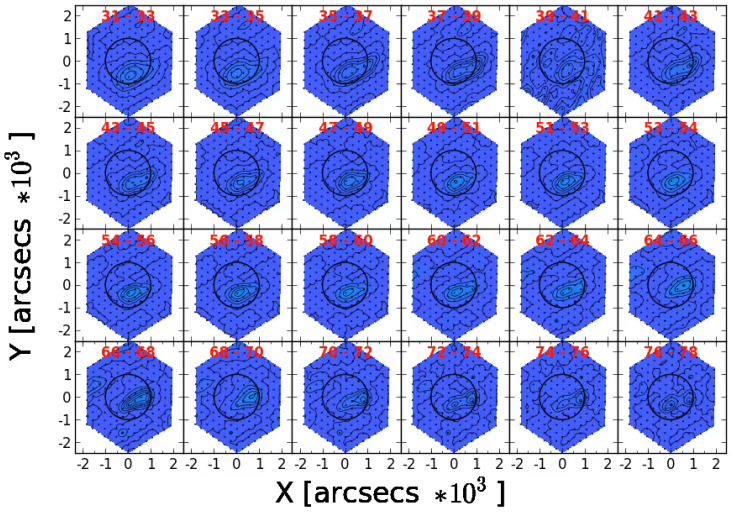


Radio: LOFAR

- Radio: electrons ejected outwards, producing plasma waves & radio emission

- LOw Frequency Array of interferometry radio telescopes across Europe (10 -240 MHz)
  - Solar obs using LOFAR Core in the Netherlands
  - Incredibly high temporal & frequency resolution
- Substantial computing task to correlate & reconstruct the data

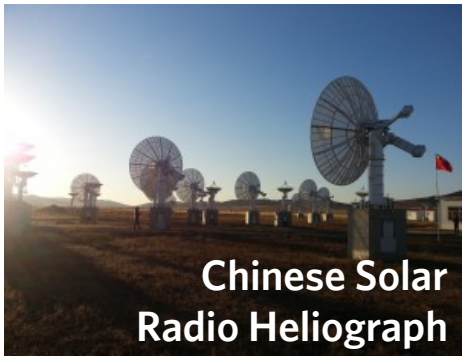




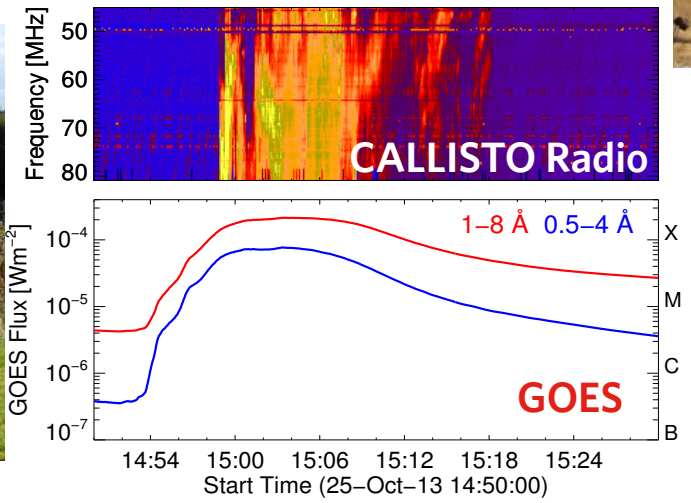
Reid

Radio: Radio Sun & Glasgow

- Radiophysics of the Sun
  - FP7/Marie Curie International Research Staff Exchange Scheme
  - EU (Warwick, Glasgow, Czech Republic, Poland), Russia (Pulkovo, Irkutsk), China (Beijing)



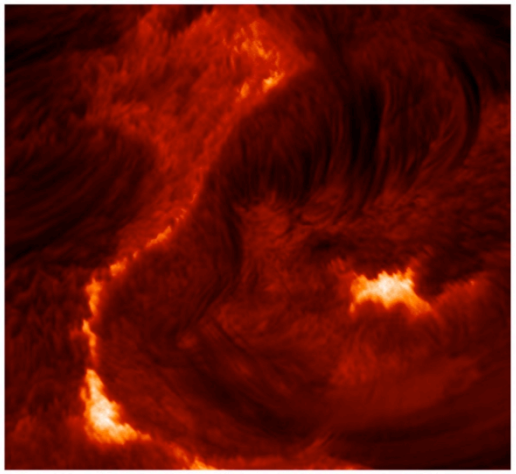
- Also observable in Glasgow



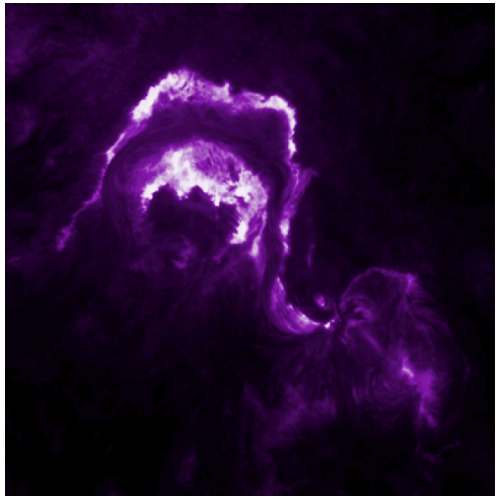
F-CHROMA

Flare **Chr**omospheres: **O**bservations, **M**odels and **A**rchives

- 7-institute, €2.4M EC-funded project
  - GU-Led: Lyndsay Fletcher PI
- Focused study of physical processes in the chromosphere during flares
  - The dense solar atmosphere



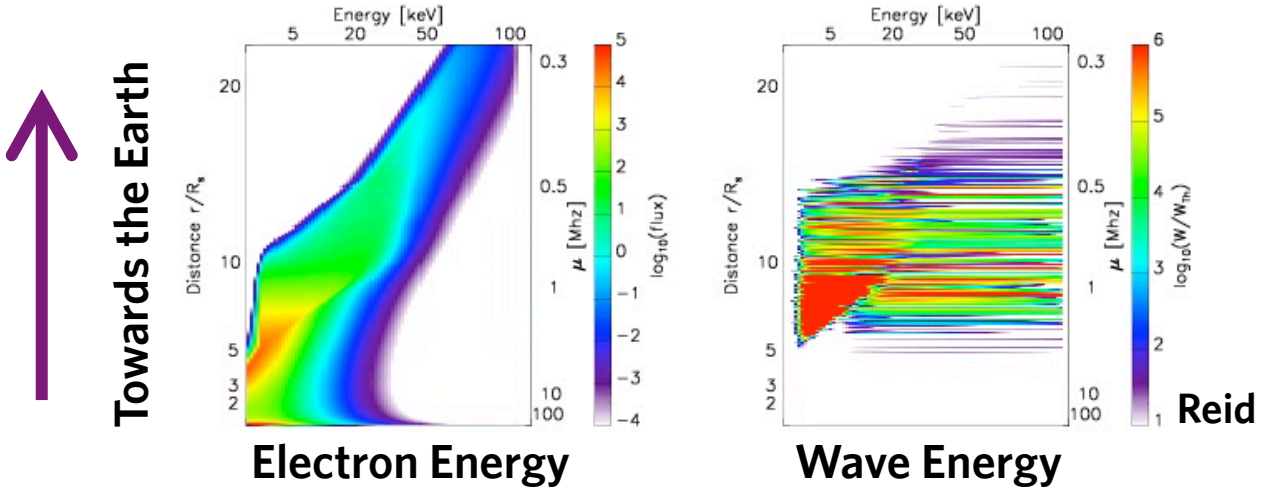
- Why the chromosphere?
  - Most complicated, many physics puzzles
  - Source of most of a flare's radiation
  - Rich in plasma diagnostics
    - Can illuminate physics of energy transport & dissipation



Modelling & Simulations

See Duncan's talk next

- Electron beam & wave-particle interactions
  - Changes energy & generates radio emission
  - Run on local cluster and DiRAC II supercomputer



Electron Energy

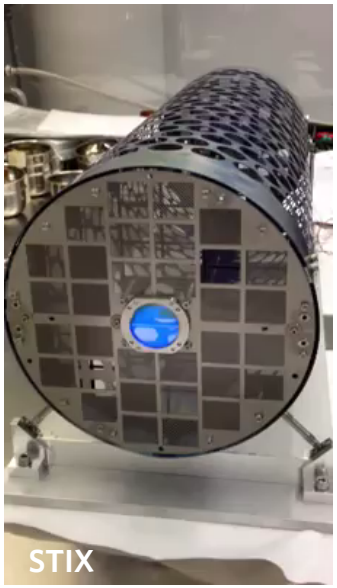
Wave Energy

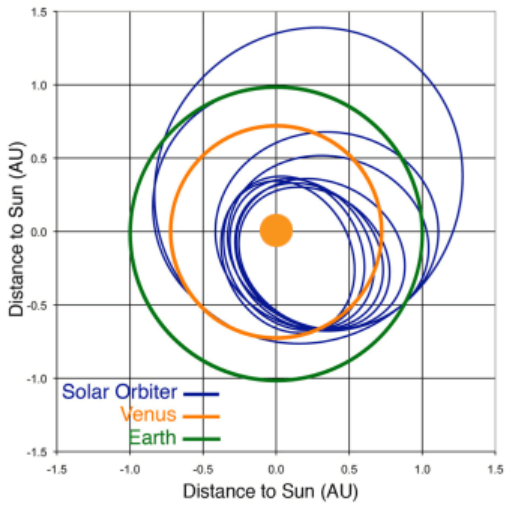
- RADYN simulation code:
  - Dynamics & emission from flare-heated solar atmosphere
  - Developed in Oslo & NASA/GSFC

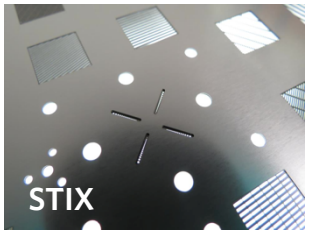
ESA's Solar Orbiter/STIX

- Suite of remote and in-situ instruments (2017+)
  - Gets to <0.3 AU
- Glasgow has several science Co-Is on STIX X-ray telescope
  - PI: FHNW, Switzerland
  - RHESSI successor, imaging spectrometer 4 - 150 keV
- Glasgow also science Co-Is on
  - EUI: Extreme UV Imager
  - RPW: Radio & Plasma Waves

solar orbiter



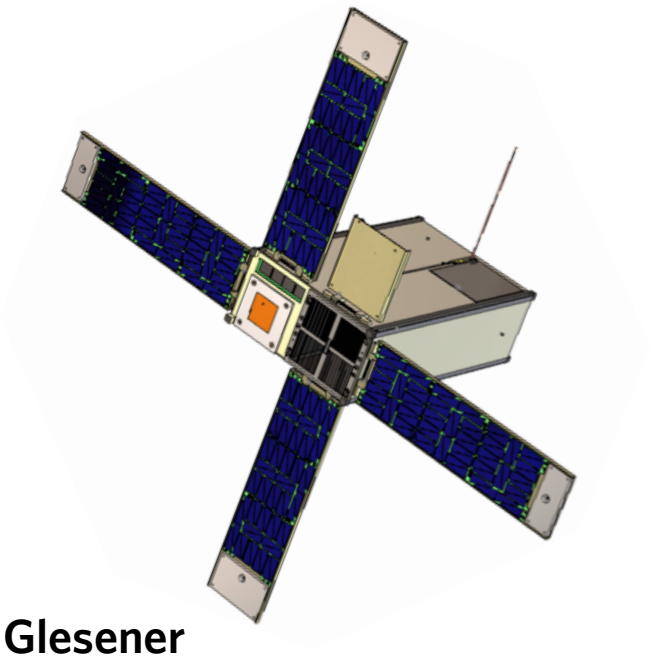




X-ray Cubesat & Small Satellites ?

- For science and/or monitoring ?
  - One example is MinXSS from LASP/CU Boulder (Jan 2015)
    - 3U Cubesat Grad Student X-ray spectrometer
    - Proposed followup of CubIXSS 6U X-ray imager

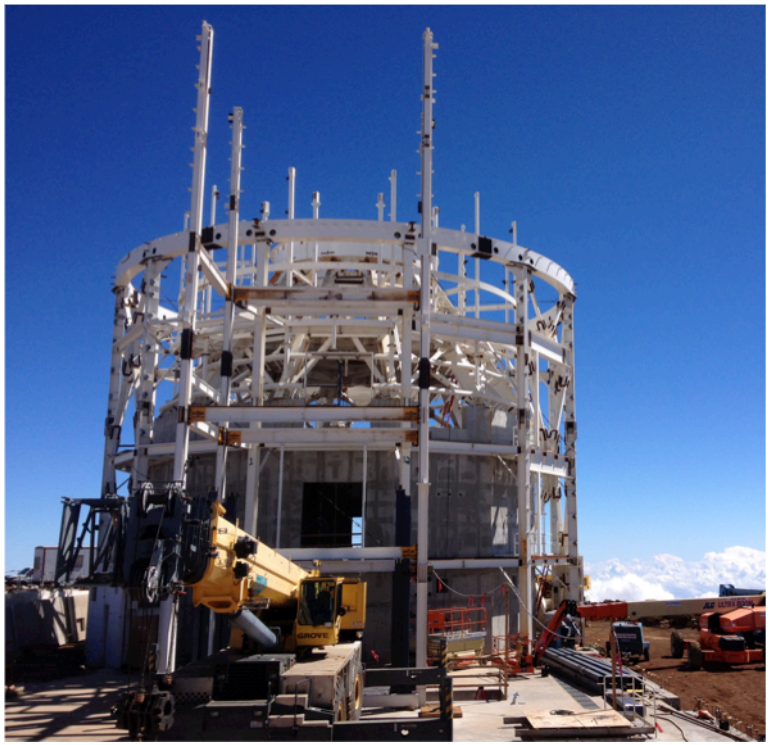
- MiXI from Berkeley/FHNW
  - Proposed Miniature X-ray Imager
  - Based on RHESSI & SO/STIX tech
  - X-ray Imaging spectrometer
  - Complements SO/STIX (2017+)



Glesener

DKIST

- Daniel K. Inouye Solar Telescope
  - Biggest solar telescope: 4m primary mirror
  - Under construction on Haleakala mountain, Hawai'i (2019)
- Goals:
  - Measure the magnetic field in the Sun's corona
  - Study structure & evolution of the Sun's surface at a scale of 35km
  - Investigate solar dynamo & build-up of solar flares and ejections
- GU role on Science Working Group & camera proposal



26-Oct-2014, Fletcher

Summary

- Studying the Sun important scientifically, economically & politically

- Need to combine multi-messenger space and ground based observations with modelling/simulations
  - Glasgow group and our collaborations at forefront
  - This talk just a brief summary – doing other things as well

- Our work is driving direction of future observations
  - New space and ground based telescopes
  - Small satellite opportunities for science & monitoring

- http://www.astro.gla.ac.uk