Current overarching science questions in solar physics and challenges for future ground-based telescopes

Courtesy of Stefano Ferro

HELLENIC ASTRONOMICAL SOCIETY

Queen's University Belfast

David B. Jess

The 13th Hellenic Astronomical Conference

3rd July 2017

Upcoming Ground-based Facilities

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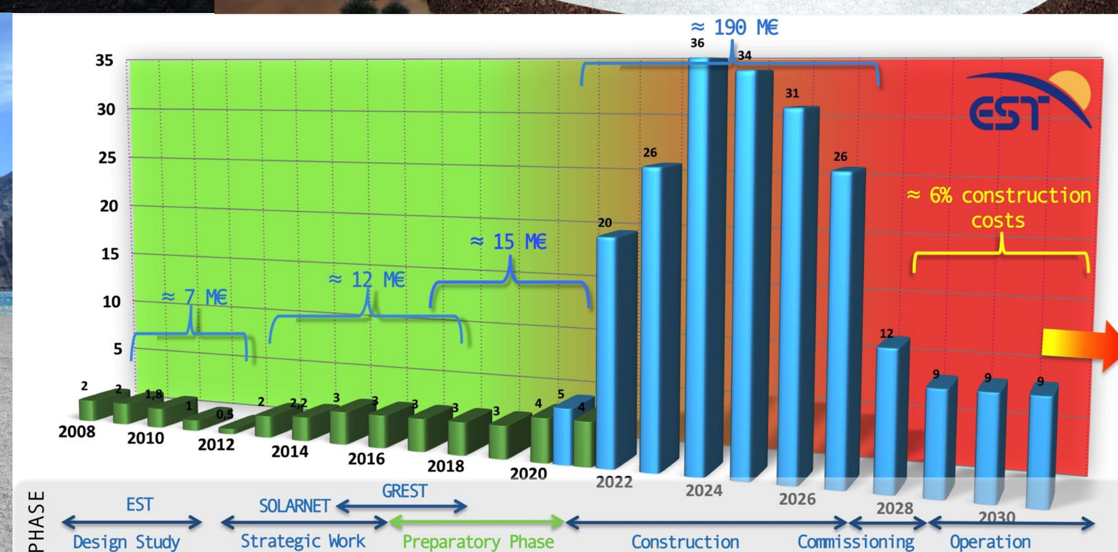
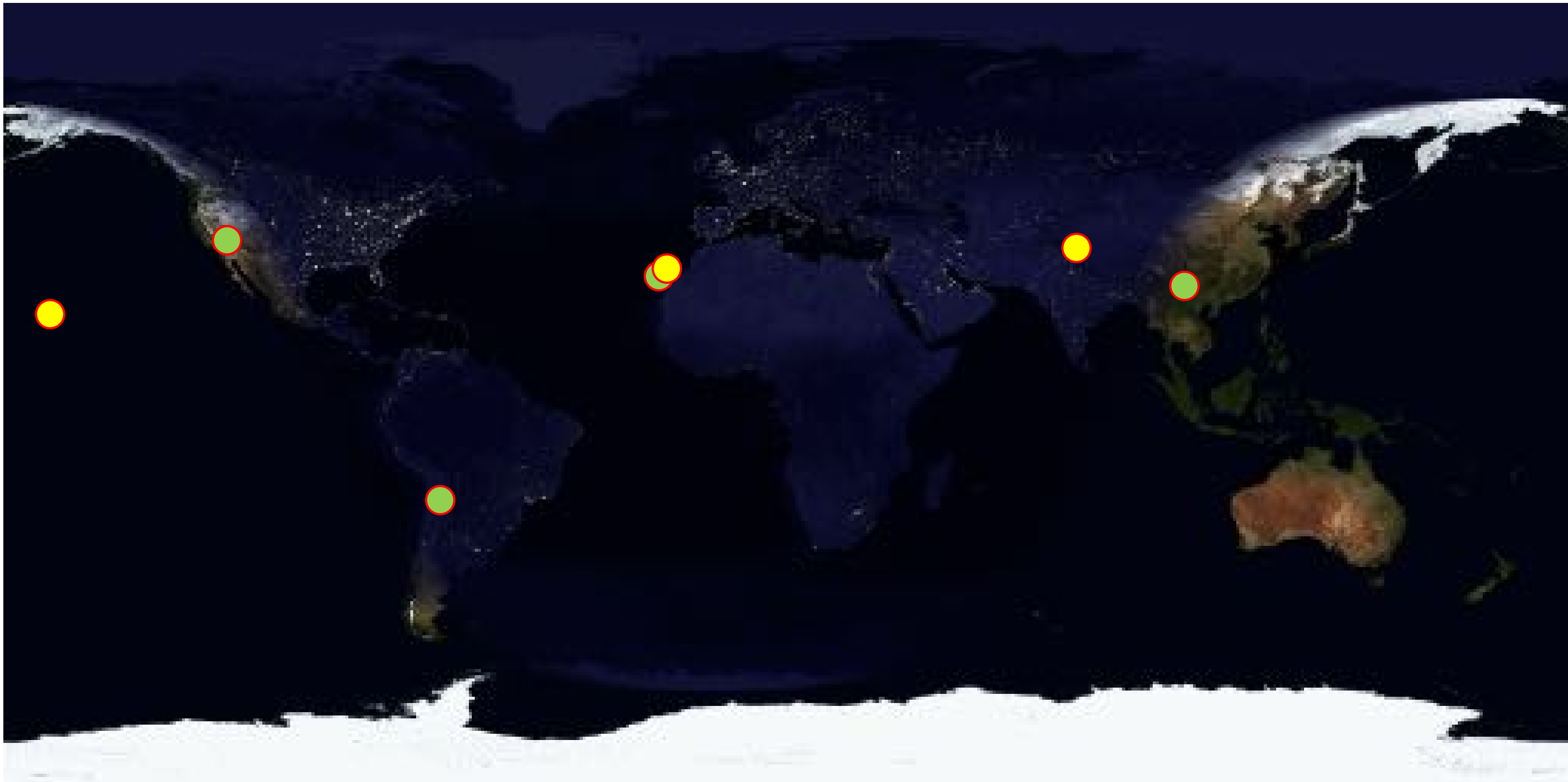
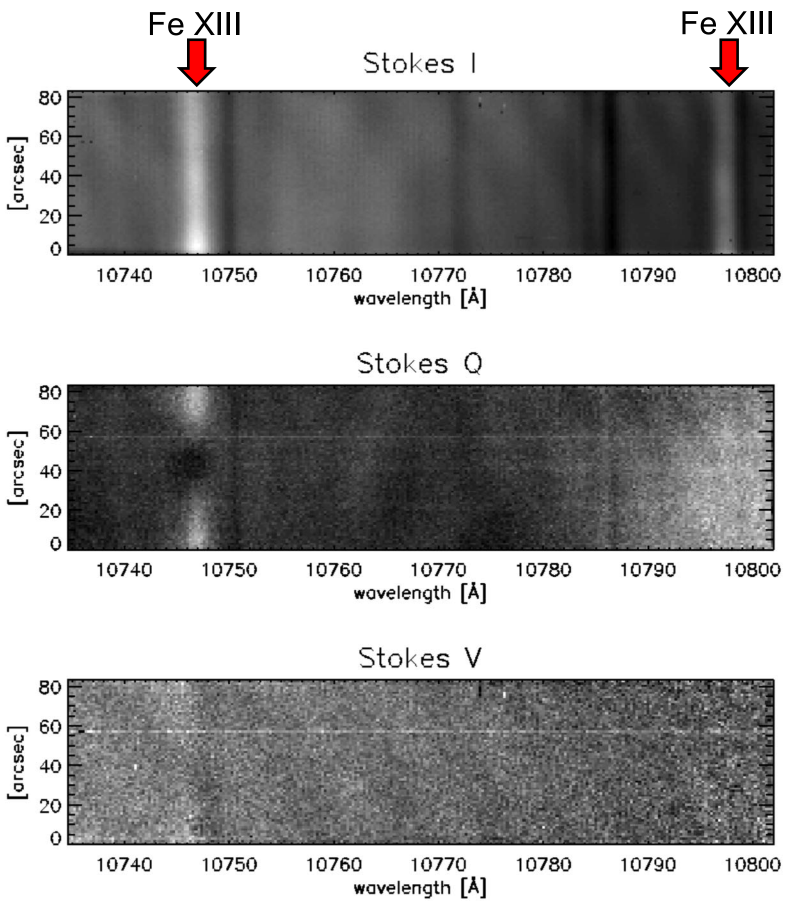


Upcoming Ground-based Facilities

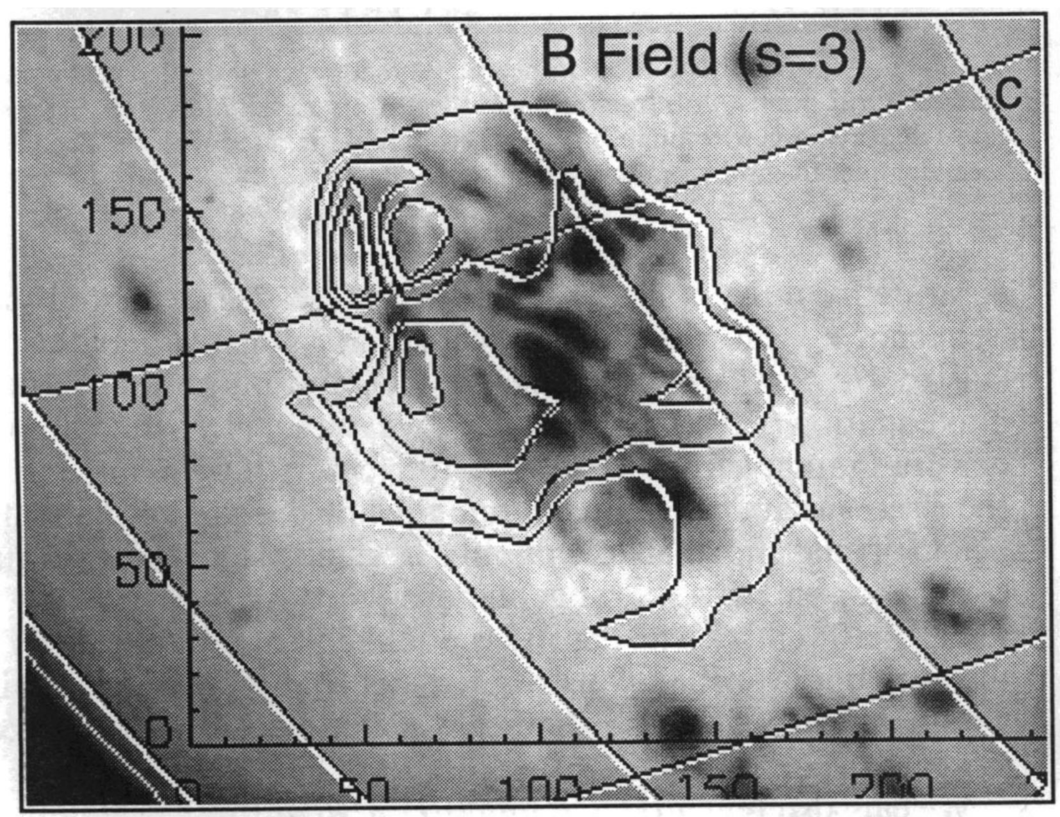


Overarching Theme

- Magnetically dominated solar atmosphere, *but difficult to directly measure fields in the corona*
- Spectropolarimetric and radio observations are challenging due to signal-to-noise and resolution/cadence drawbacks



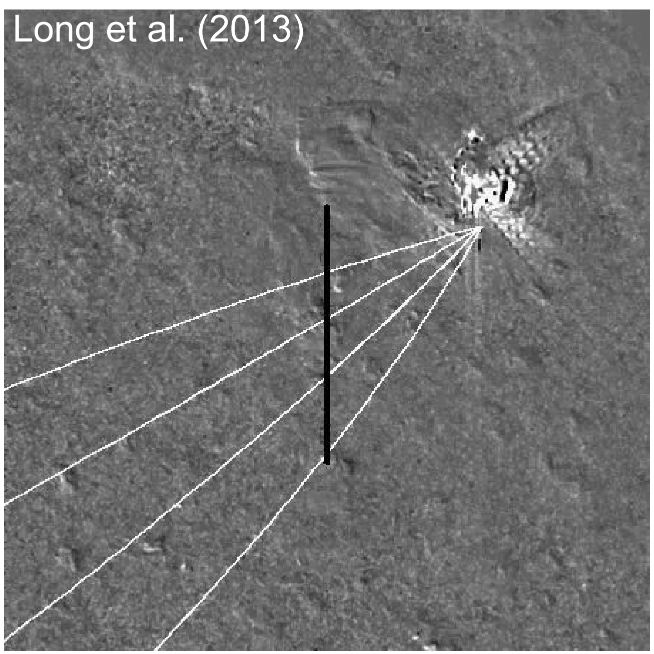
Lin et al. (2000)

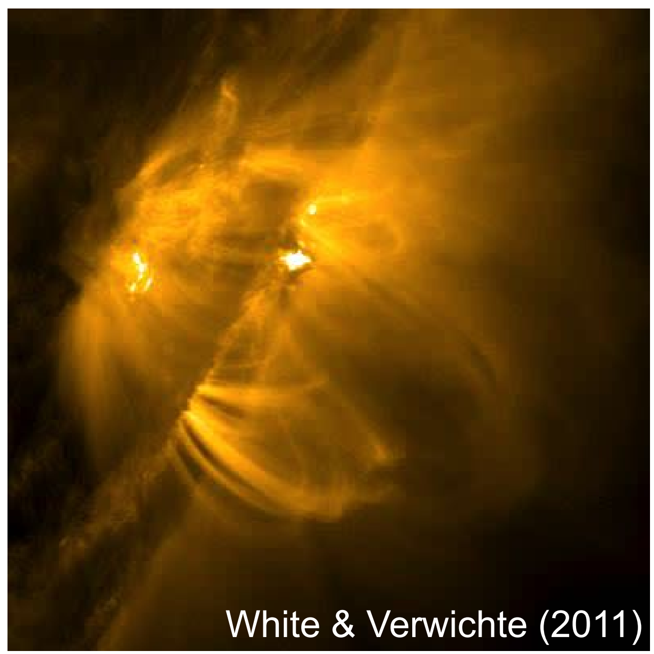


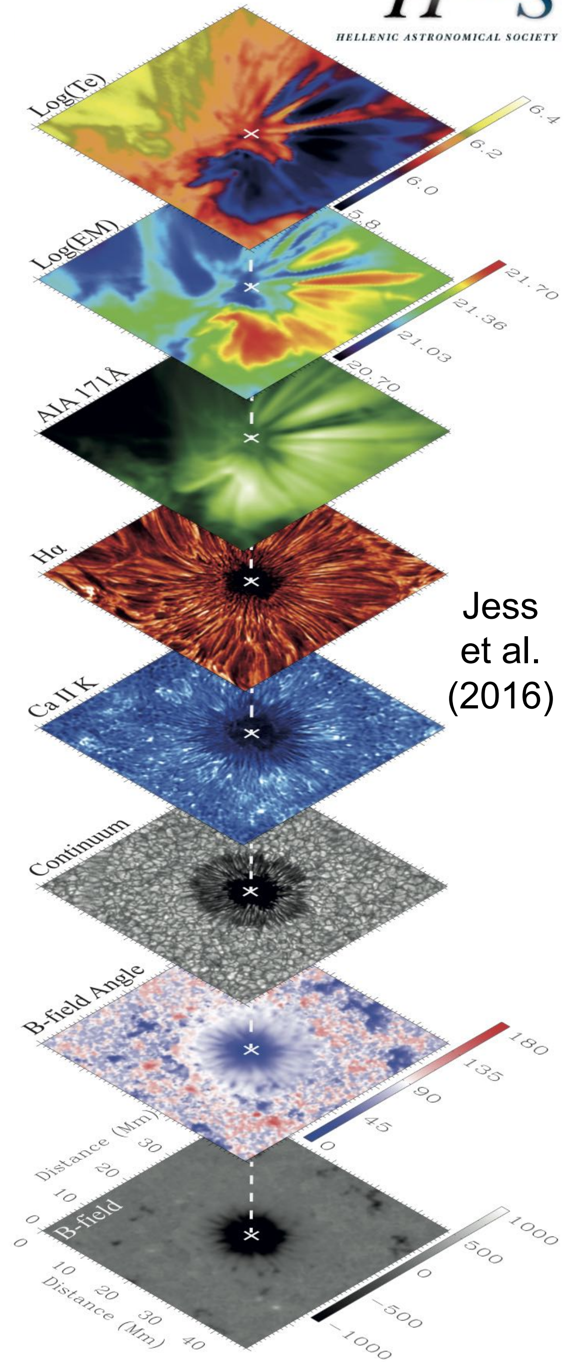
Gary & Hurford (1993)

Magnetic Fields in the Solar Corona

- Liu et al. (2011) – fast mode waves after a flare
  → B ~ 8 G (coronal funnel)
- White & Verwichte (2011) – transverse loop oscillations
  → B ~ 3 – 19 G (coronal loop)
- Long et al. (2013) – propagation of EIT waves
  → B ~ 2 – 6 G (quiet Sun)
- Jess et al. (2016) – seismology of slow mode waves
  → B ~ 2 – 35 G (sunspots)







Jess et al. (2016)

Insights with DKIST

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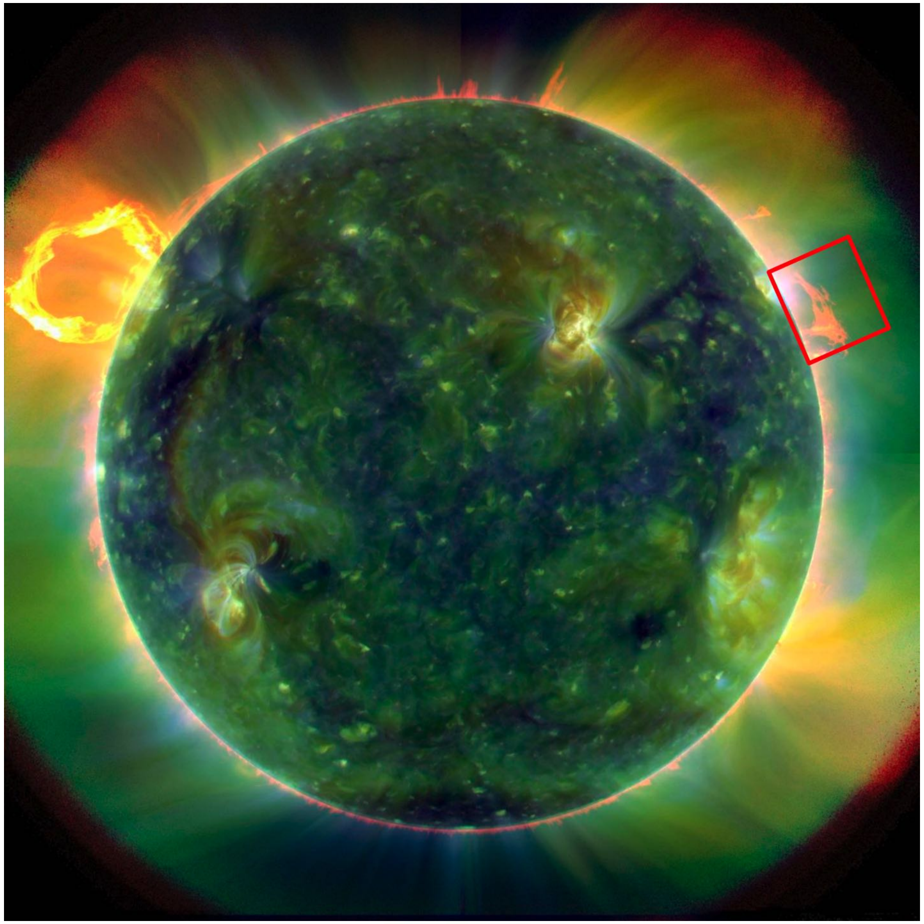
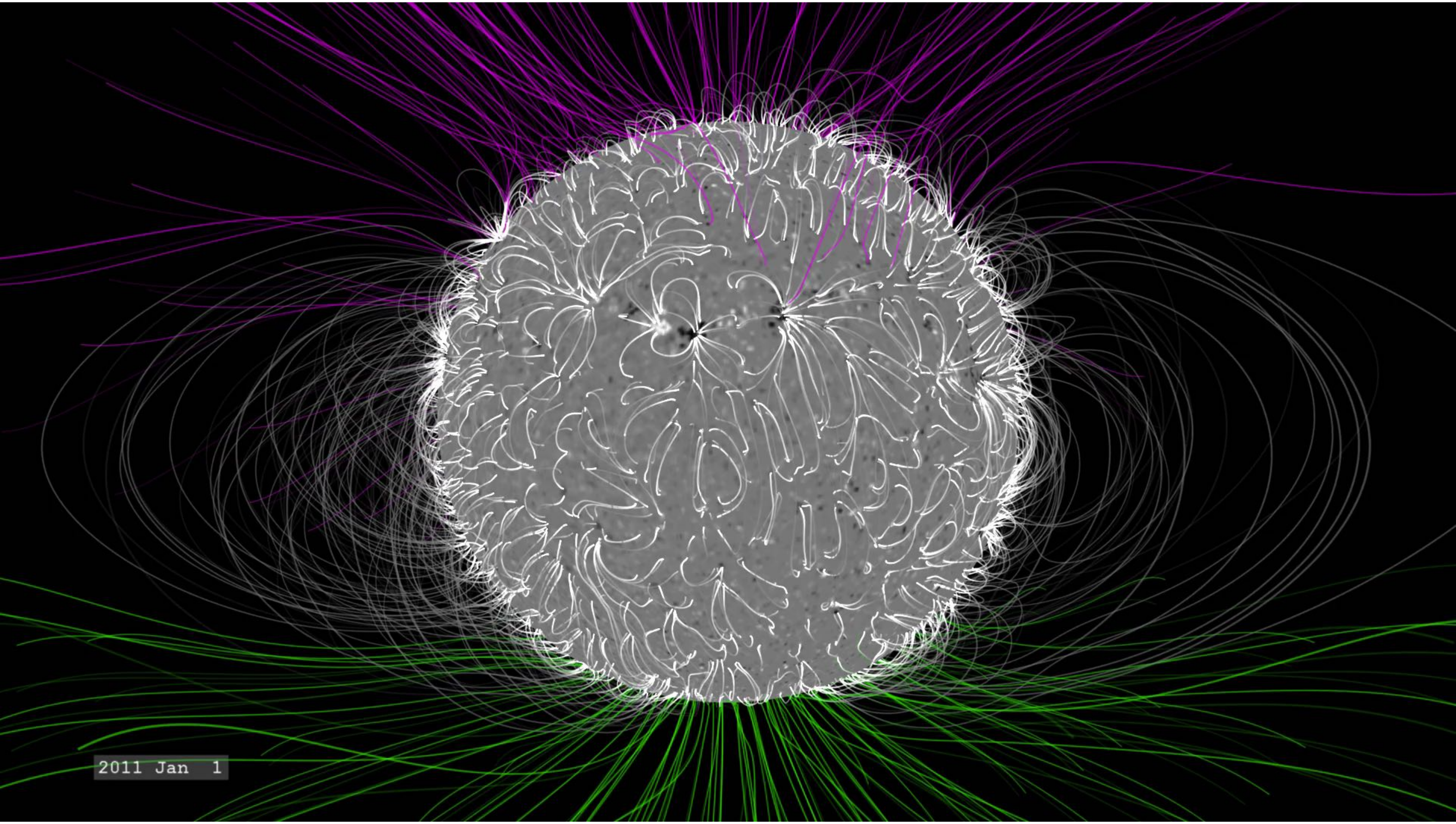
Cryo-NIRSP (coronal mode)

Grating	Echelle – 32 line/mm
Wavelengths	1000 – 5000 nm
Spectral resolution	30,000
Pixel scale	0.12" arcsec along slit 0.5" arcsec slit width
Field of view	4' slit with 3' scan
Polarimetric accuracy	5×10^{-4}
Sampled lines	He I, S IX, Si X, Fe XII, CO, Mg VIII

Fehlmann et al. (2016)



Magnetic Field Connectivity

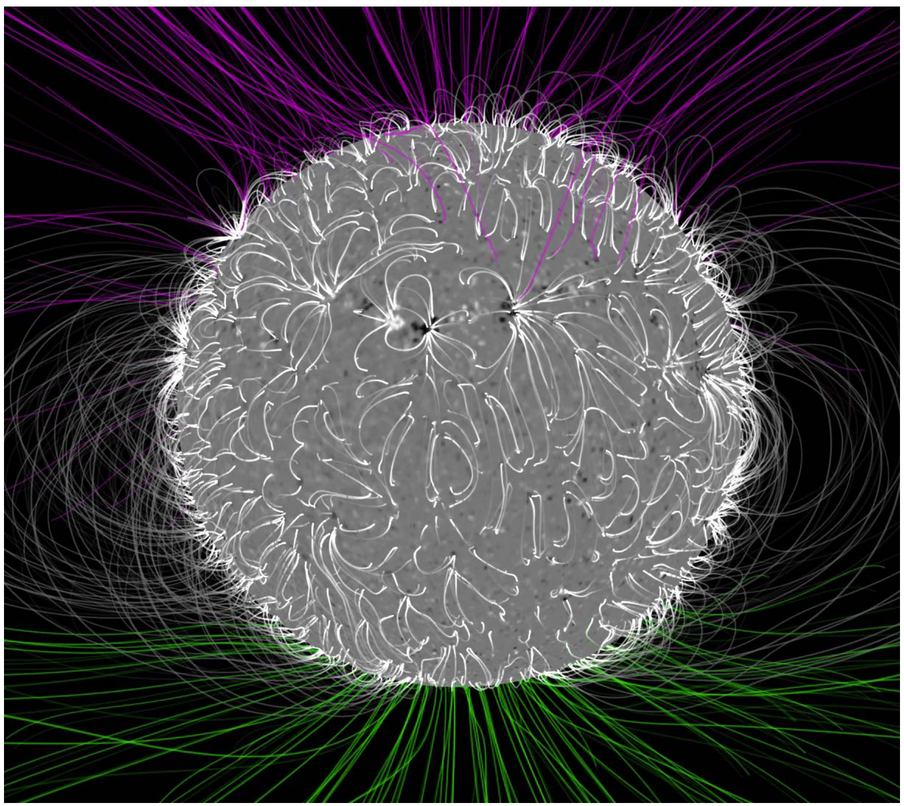


courtesy of NASA's Scientific Visualization Studio

Magnetic Field Connectivity

- Magnetically dominated atmosphere, *but not without complexities…*
  - Difficulty defining lower-boundary configurations (Georgoulis et al. 2012)
  - Violation of the force-free assumption? (Metcalf et al. 2008)
  - 20° – 40° misalignment angles (DeRosa et al. 2009)
  - Insufficient spatial resolution? (DeRosa et al. 2015)

Aschwanden et al. (2016)



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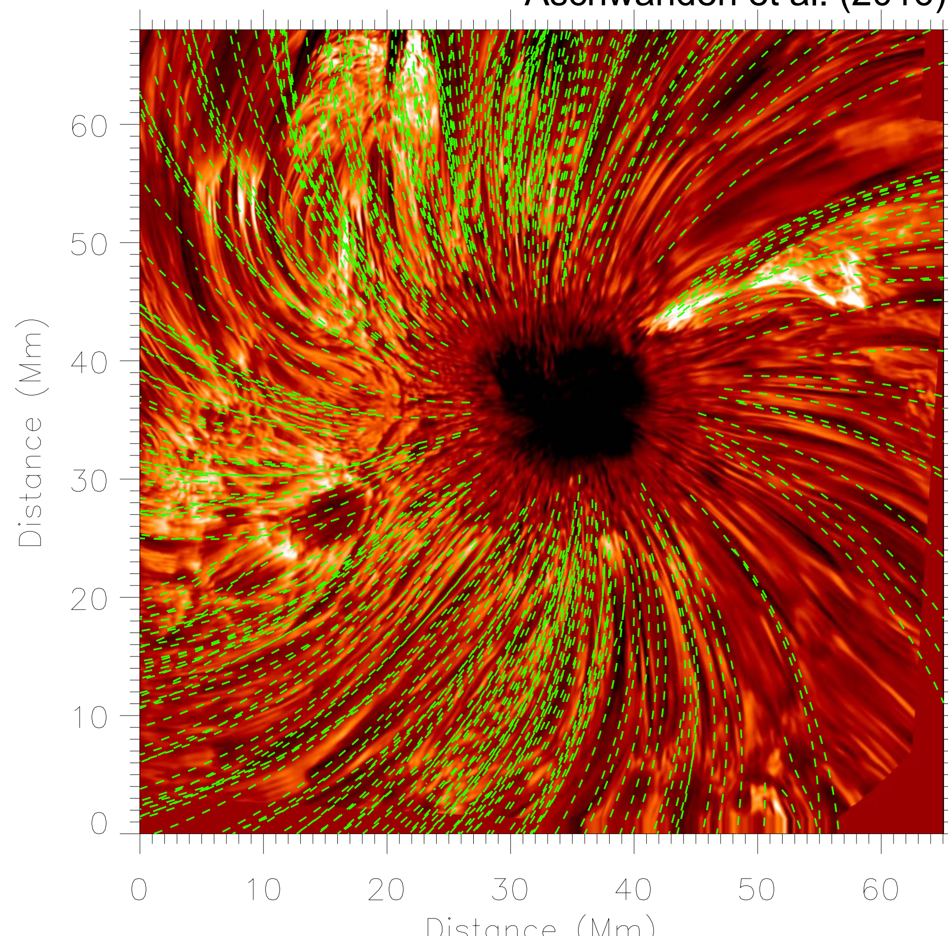
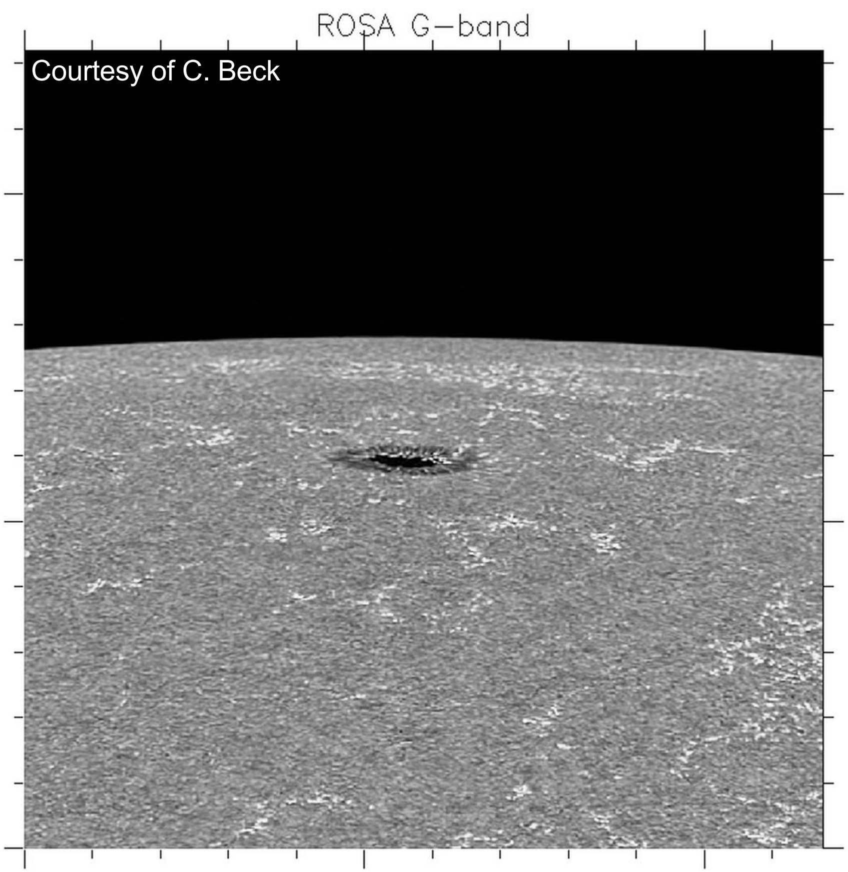
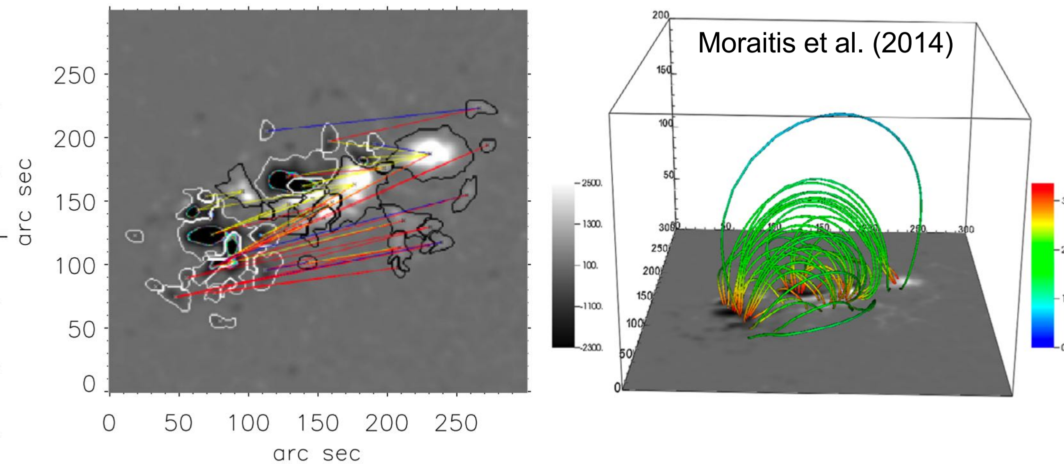


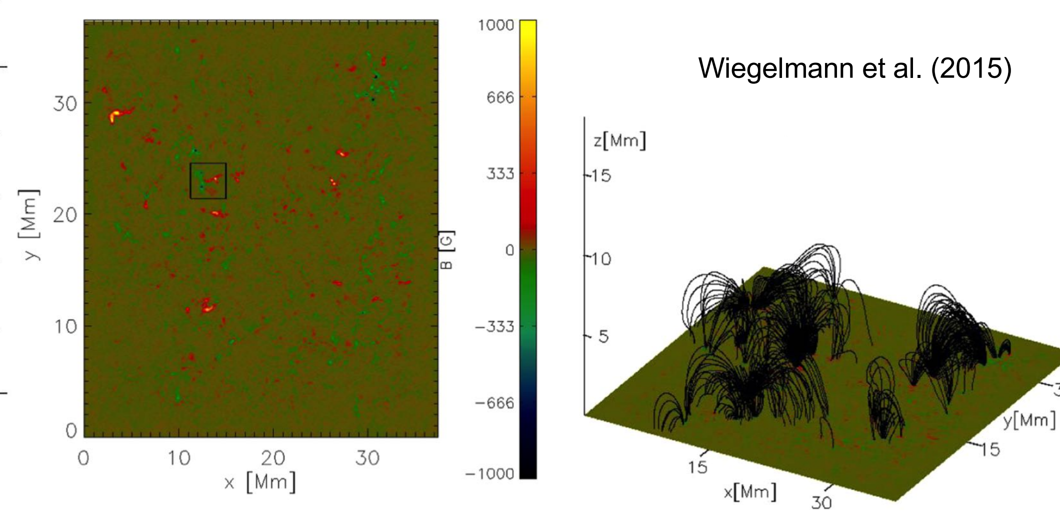
Magnetic Field Connectivity

- Need vector magnetograms from the chromosphere
  - He I 10830Å or Ca II 8542Å from DST/SST/GREGOR/etc.
  - Use as mid-level constraints for magnetic field extrapolation codes





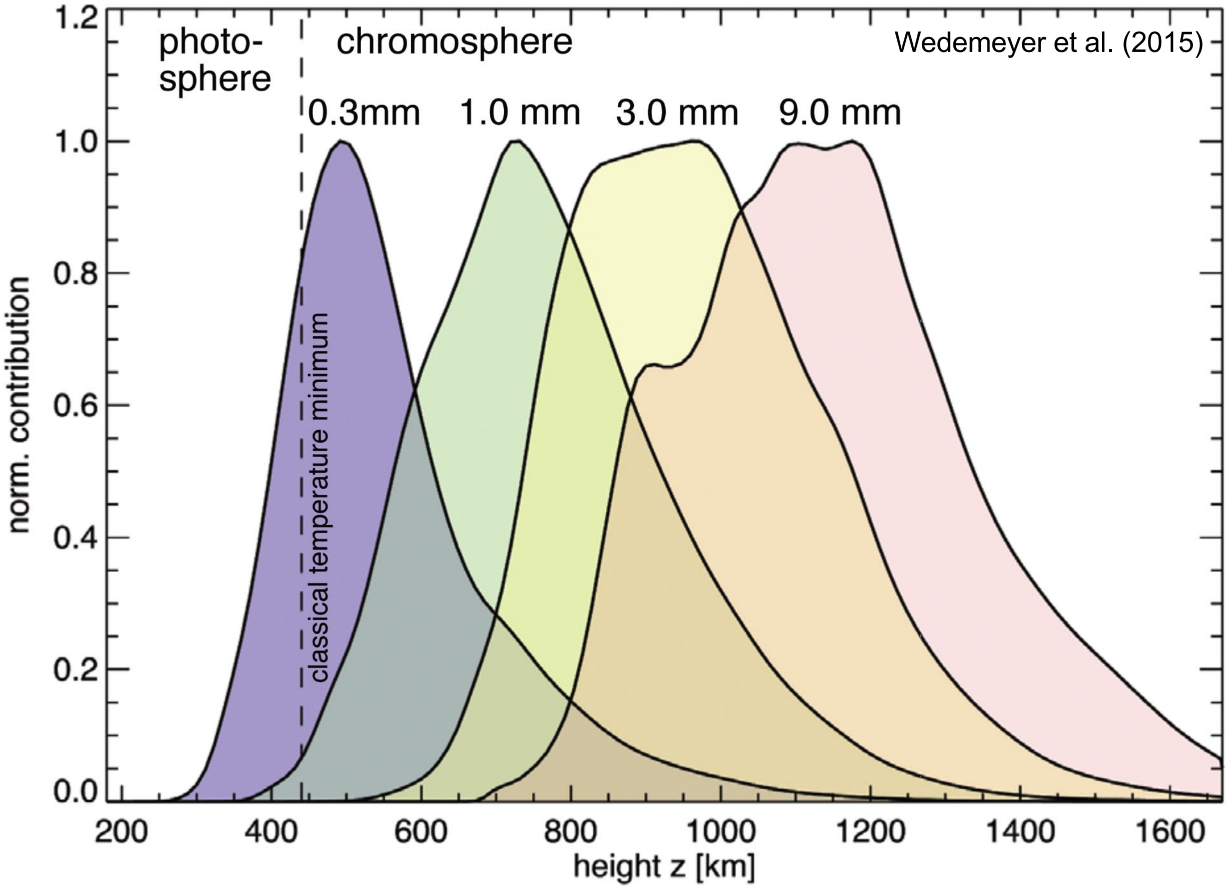
Moraitis et al. (2014)



Wiegelmann et al. (2015)

Insights with ALMA

- Need vector magnetograms from the chromosphere
  - Effective formation height of the millimeter continuum radiation increases with height from the temperature minimum at the shortest wavelengths
  - Brightness temperature spectrum responds to the magnetic field along the line of sight due to the dependence of the free-free opacity on the local magnetic field strength
  - ALMA temperature and magnetic field diagnostics to test force freeness
  - 0.3 mm - 8.6 mm (35 GHz - 950 GHz) Receivers for longest λ yet to be installed



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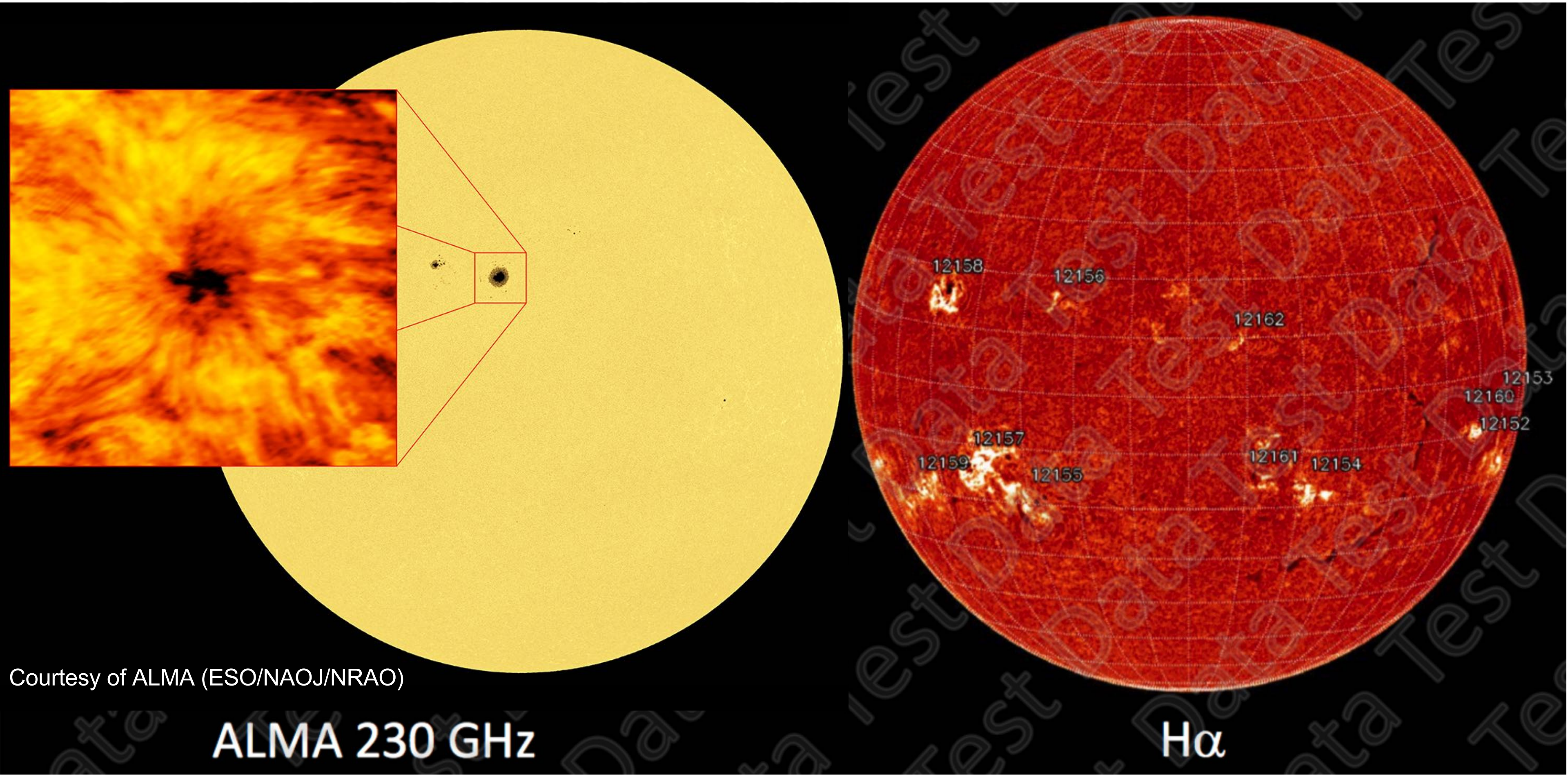

Wedemeyer et al. (2015)

Insights with ALMA

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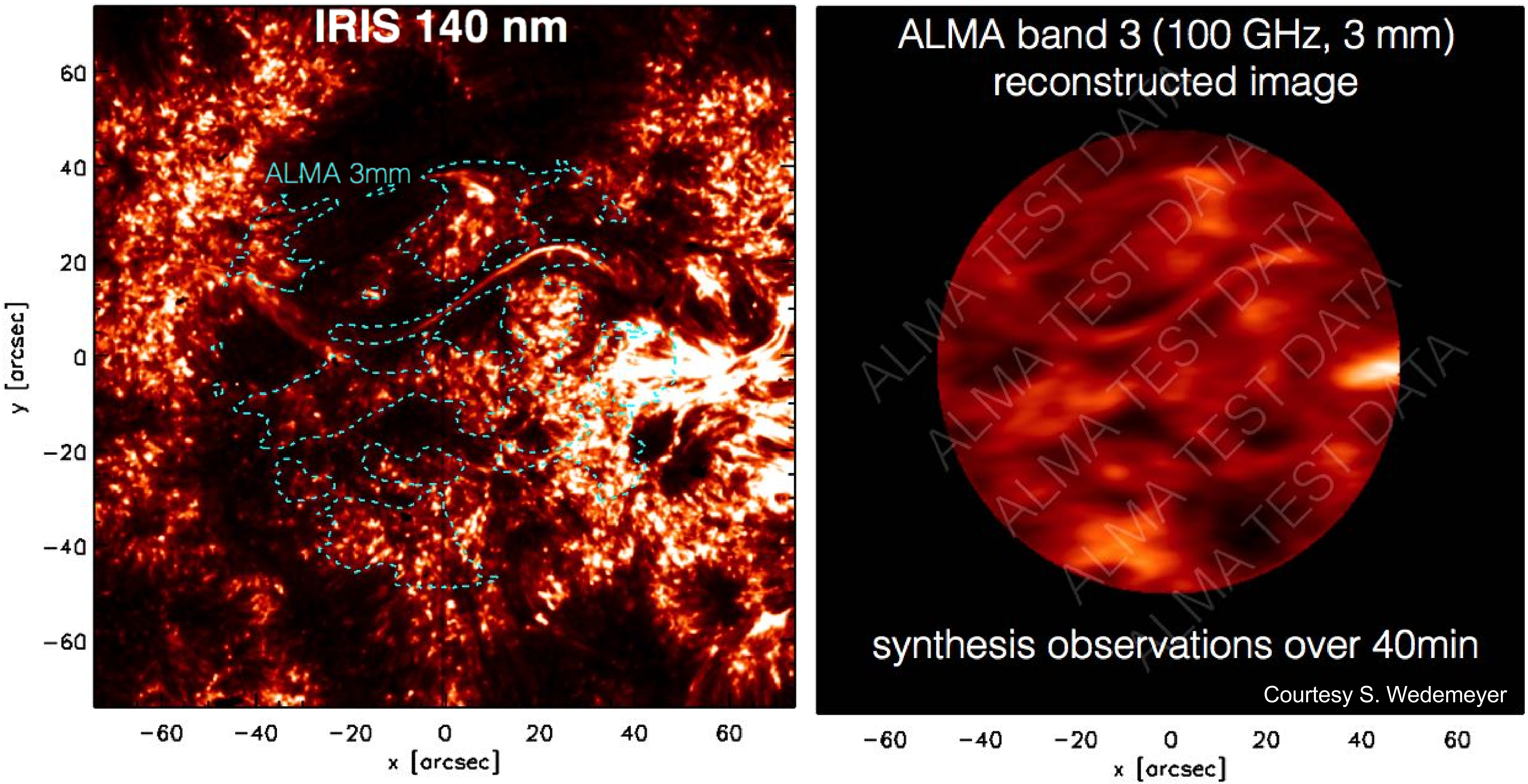
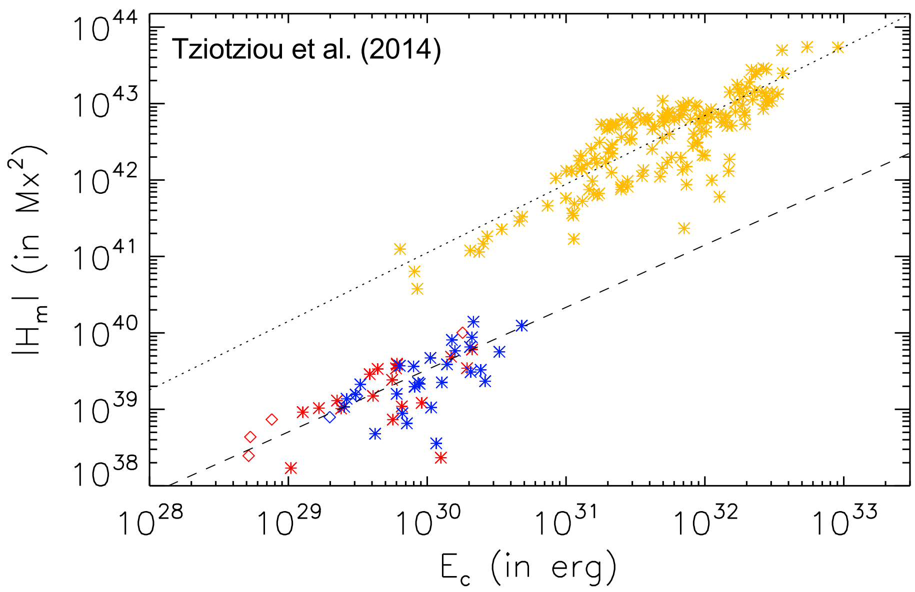


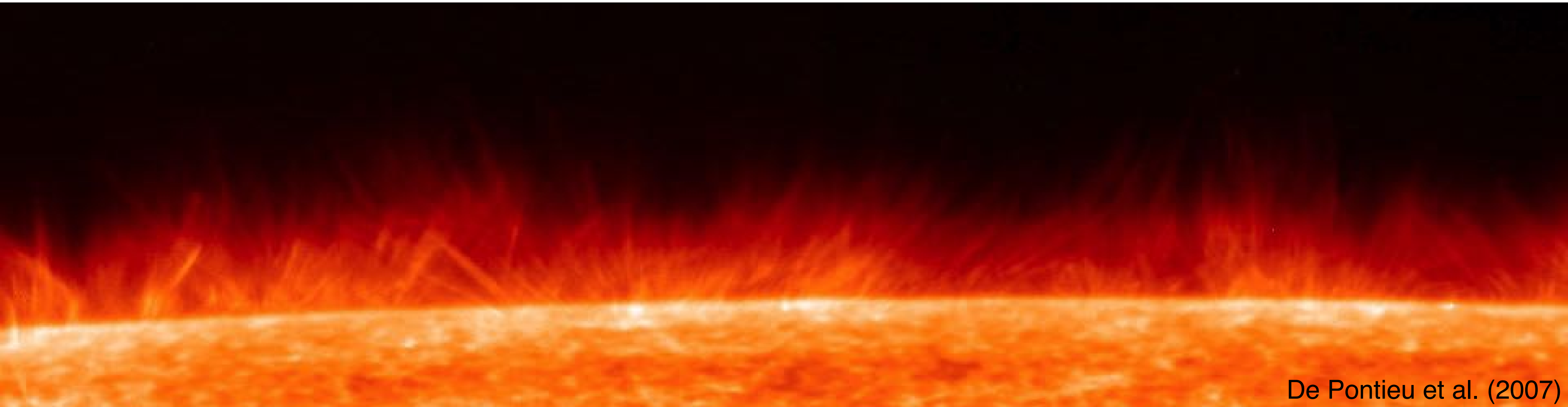
Free Energies

- Evidence for enough free energy in the quiet Sun to power fine-scale structures (~10^{36} erg; Tziotziou et al. 2014)

- De Pontieu et al. (2011) found for chromospheric (spicule) jets:
  - Mass flux ~ 1.5×10^{-9} g/cm^2/s
  - Energy flux ~ 2×10^{6} erg/cm^2/s

- Coronal counterparts rapidly propagate upwards – strong upflows? Or wave related?





De Pontieu et al. (2007)

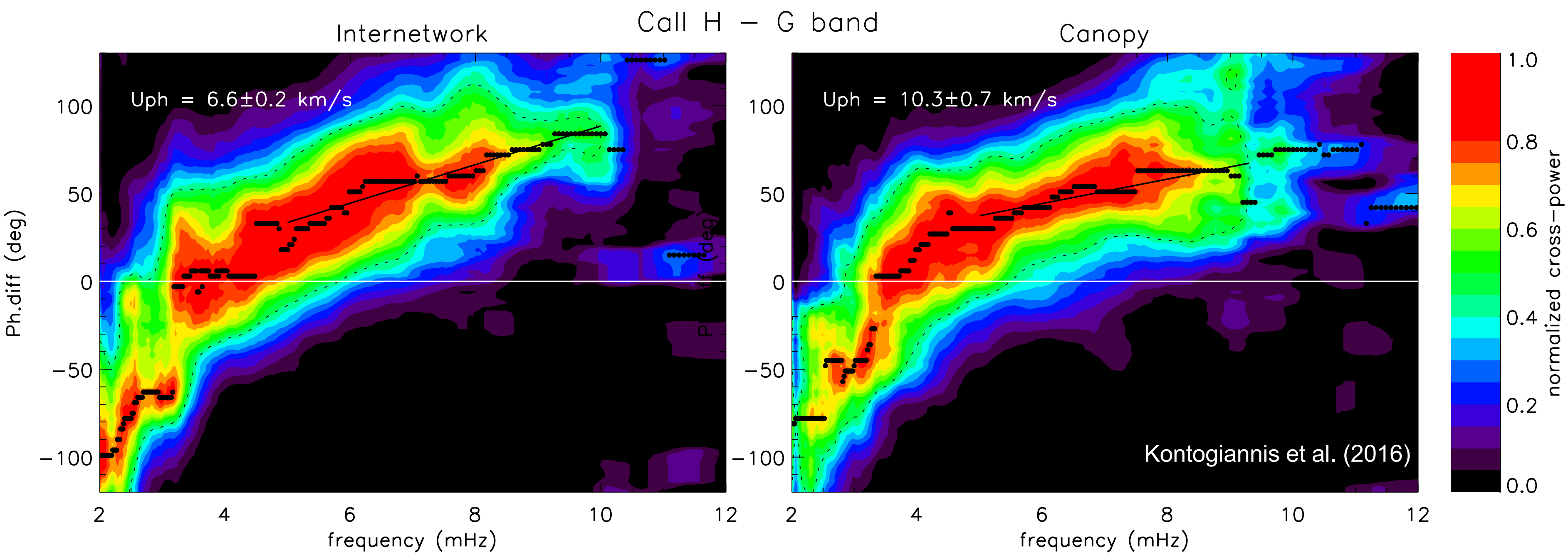
Waves Guided by Magnetic Fields

- Magnetic topology affects (slow magneto-acoustic) wave propagation by modifying the acoustic cut-off frequency (Bel & Leroy 1977):

$$f_c \propto \frac{\cos\theta}{\sqrt{T}}$$

- Chromospheric regions demonstrate a wealth of propagating/standing waves alongside evidence for mode conversion (Jess et al. 2012)

- Cut-off frequencies <5.2 mHz suggests the presence of small-scale, ***unresolved*** inclined magnetic fields (Kontogiannis et al. 2016)



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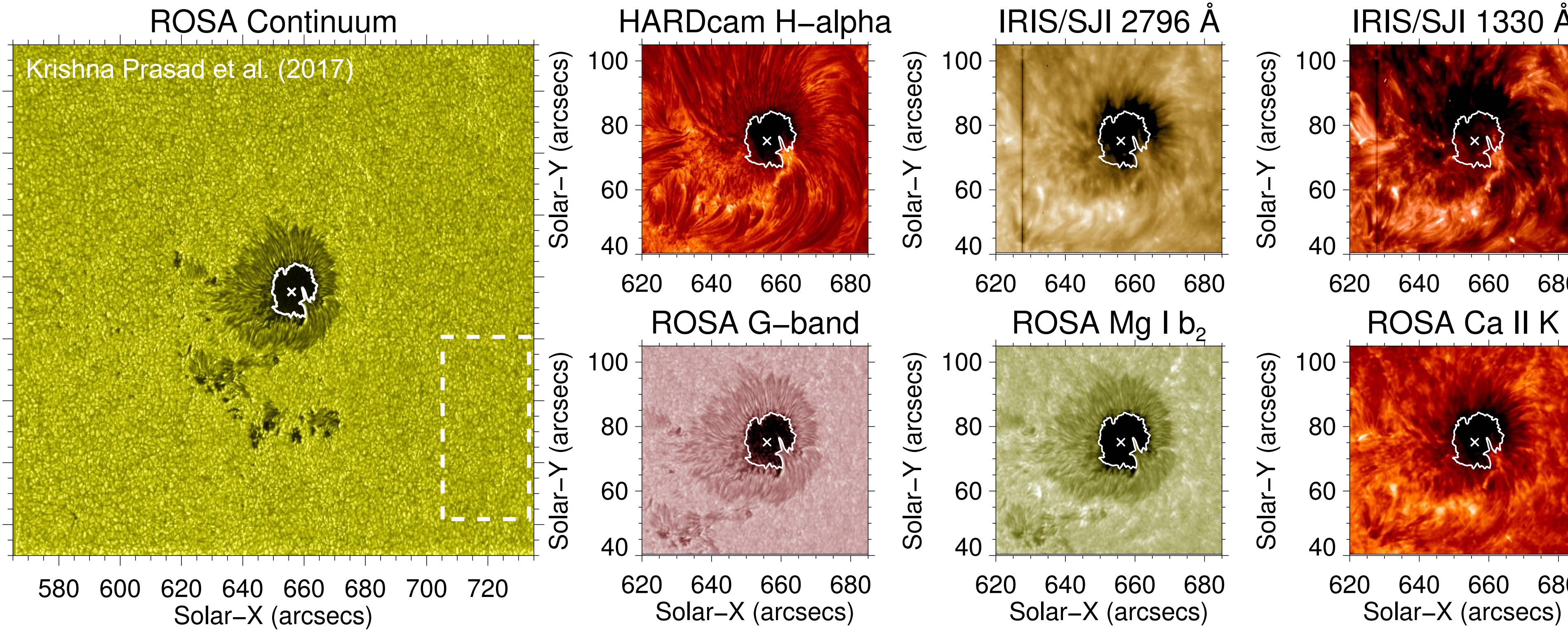
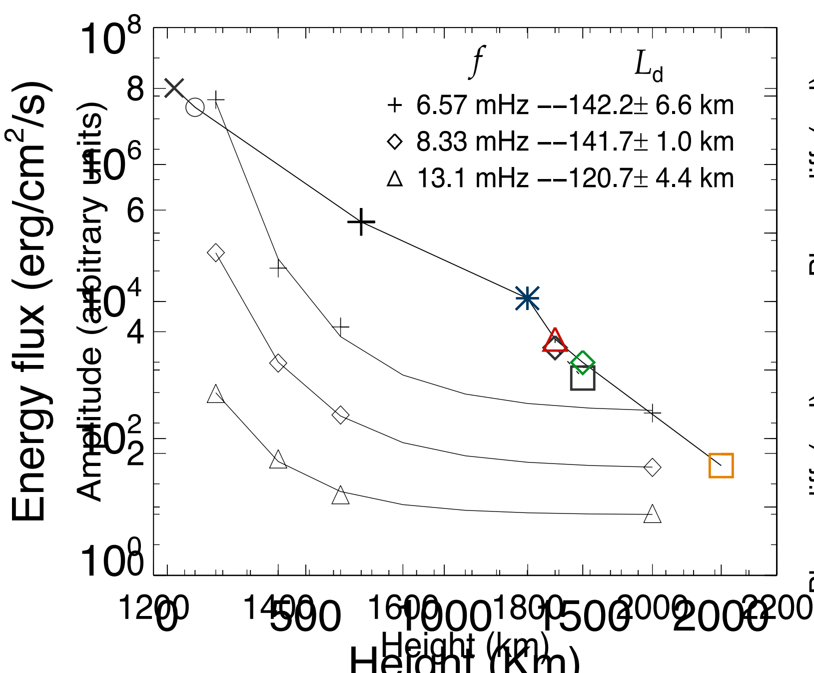
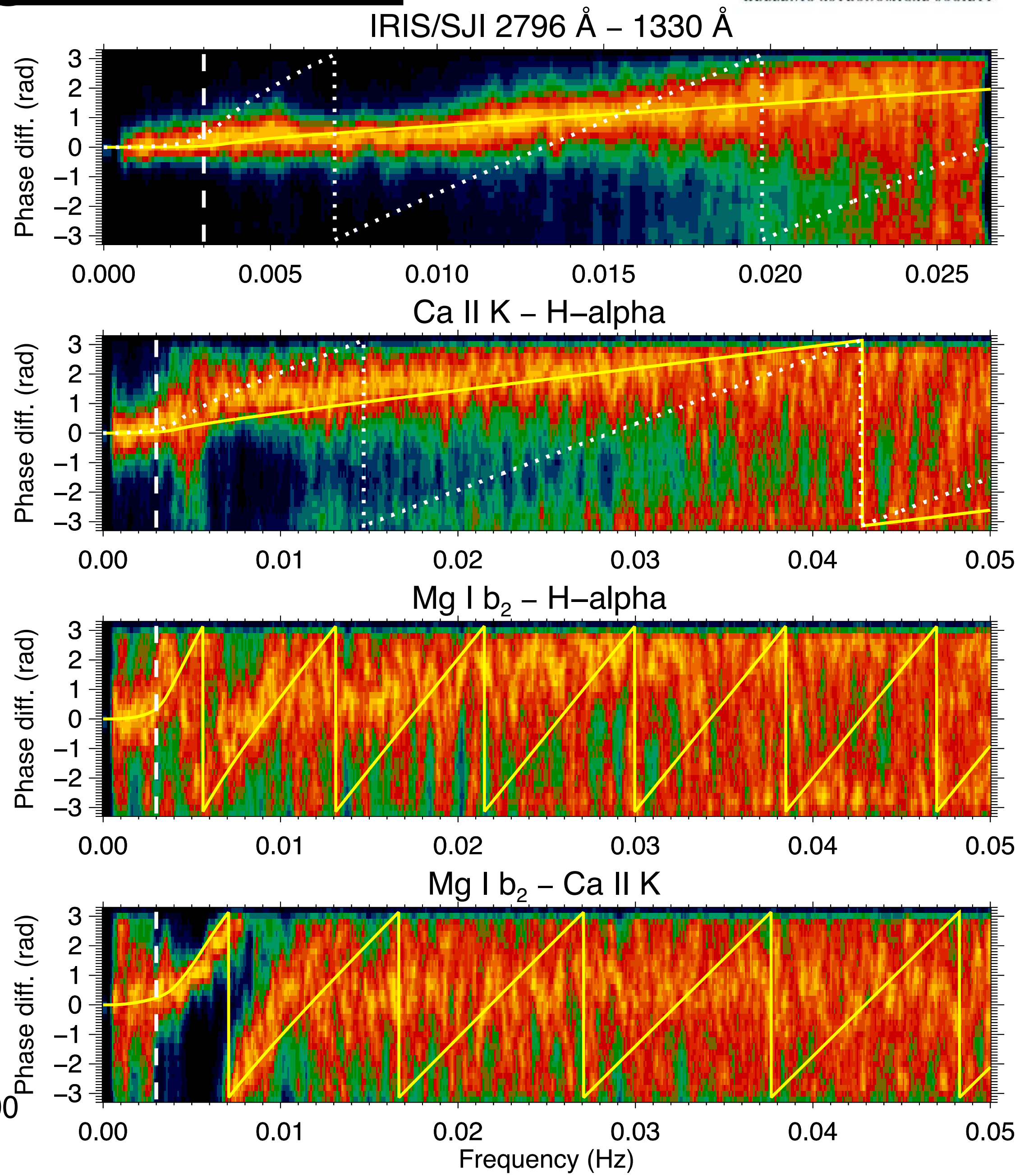


- Krishna Prasad et al. (2017) employed:
  - 3-hour dataset ⟹ high frequency resolution (~0.09 mHz)
  - High cadence (up to 1s) ⟹ high Nyquist frequency (500 mHz)
  - High spatial resolution (up to 0.09 arcsec/pixel) ⟹ large pixel numbers (up to 3×10^8)

Waves Guided by Magnetic Fields

- Clear evidence for coherent upwardly propagating magneto-acoustic waves
- Frequency-dependent damping is consistent with coronal studies, where thermal conduction dominates (e.g., $\propto P^2$; Ofman & Wang 2002)
- *But can thermal conduction still dominate in the cooler lower atmosphere?*



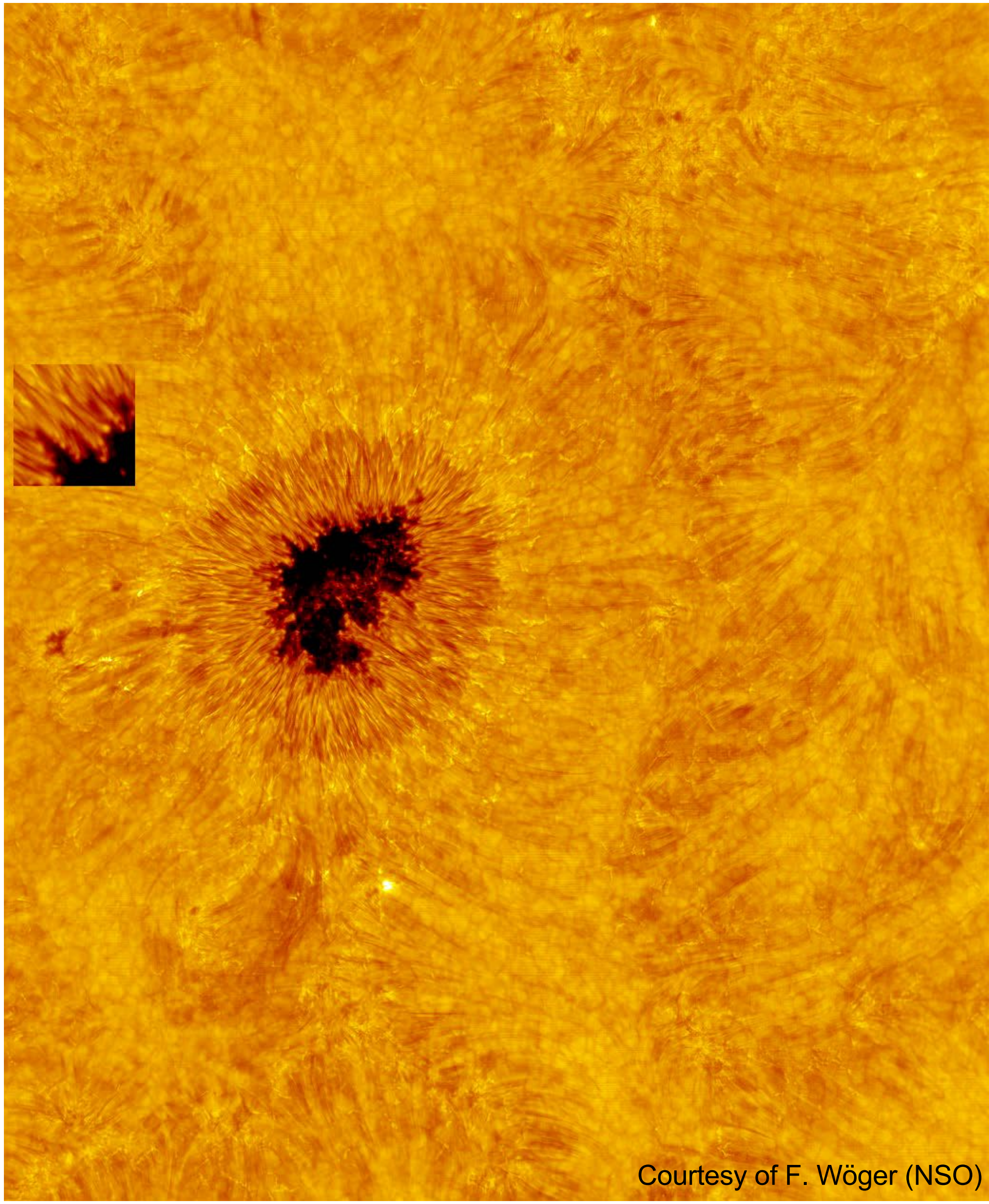


Insights with DKIST

Visible Broadband Imager (VBI)

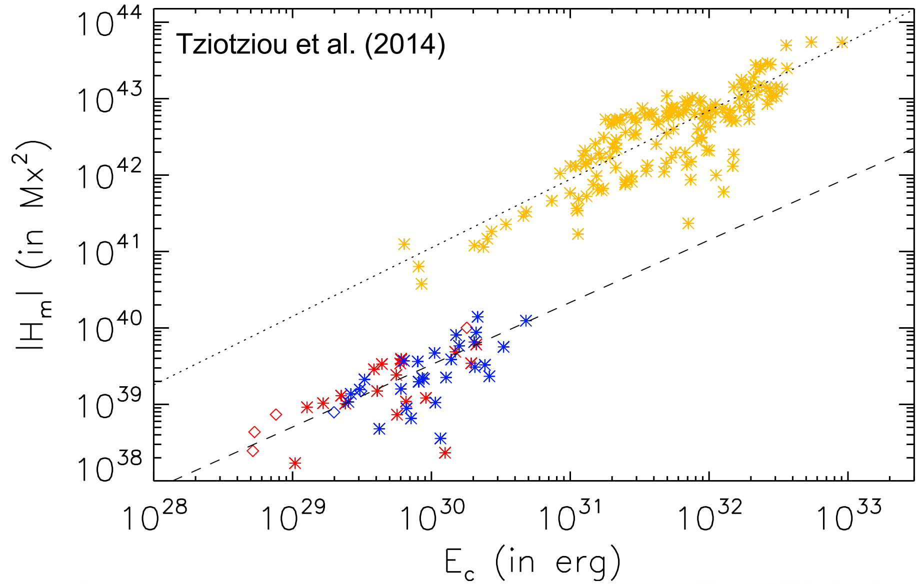
Spectral range	393.3 nm – 486.4 nm (***blue channel***) 656.3 nm – 705.8 nm (***red channel***)
Pixel scale	0.011" arcsec/pixel (blue) *8 km/pixel* 0.017" arcsec/pixel (red) *12 km/pixel*
Field of view	2' × 2' with 27s cadence
Relative photometry	$2 \times 10^{-2} I_0$
Filters	Ca II K, G-band, Hβ, Hα, TiO, blue/red continua

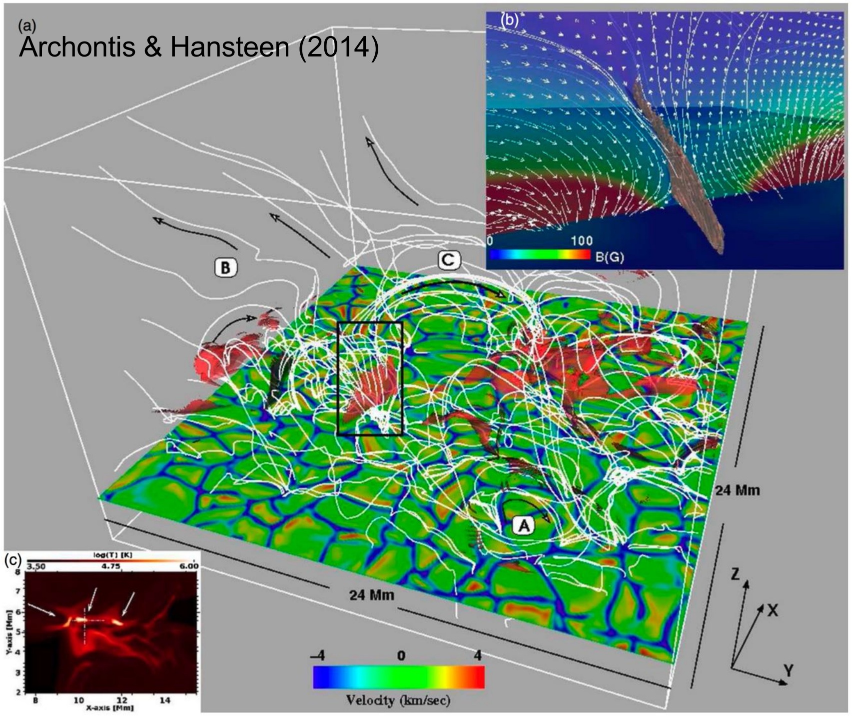
Wöger et al. (2016)

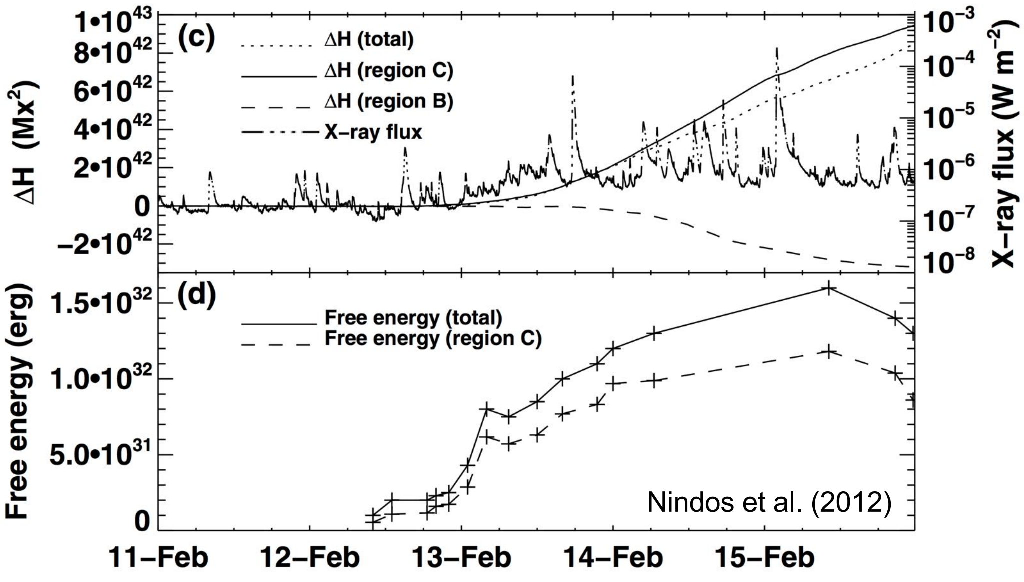


Free Energies

- Often treated as a proxy for solar activity and potential CMEs and space weather (e.g., Aschwanden et al. 2016)
- Nindos et al. (2012) found the increase of magnetic free energy and accumulated helicity during flux emergence contributed to the observed eruptions
- Eruptive events leading to EUV/X-ray jets with energies consistent with lower energy microflares ($10^{25} – 10^{27}$ erg; Archontis & Hansteen 2014)
- *Can small-scale fields provide more understanding of nanoflare activity?*







Overarching Questions:

- Future observatories and facilities will push our understanding with better resolution, polarimetric precision and the ability to track phenomena across a multitude of temperatures:
  - *Magnetic field topology*
  - *Waves vs flows – atmospheric connectivity*
  - *Reconnection events and associated space weather*