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怀柔观测基地
Huairou Solar Observing Station, CAS

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Coronal Magnetic Field Measurements from EUV wavelengths

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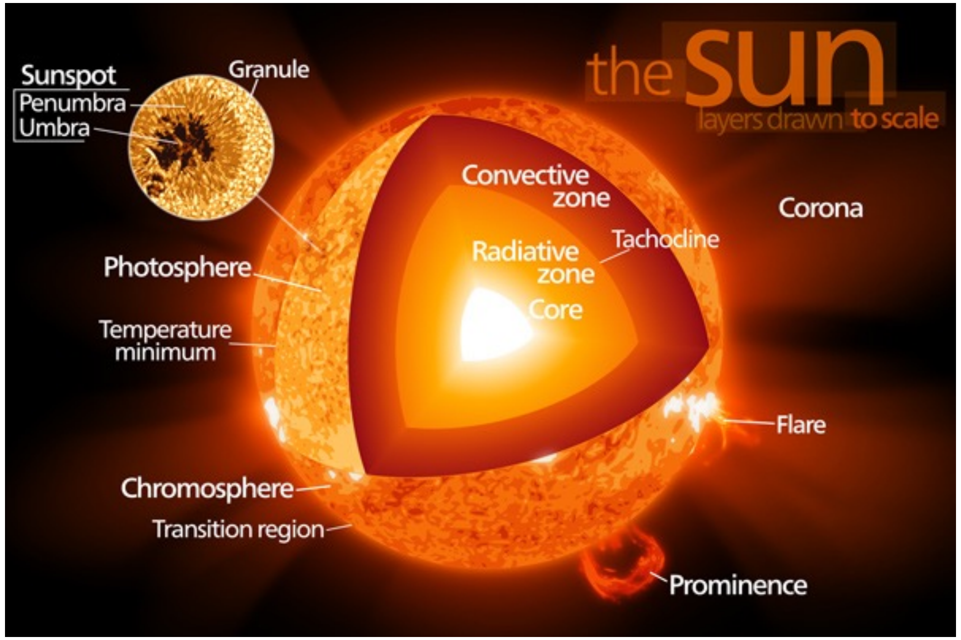
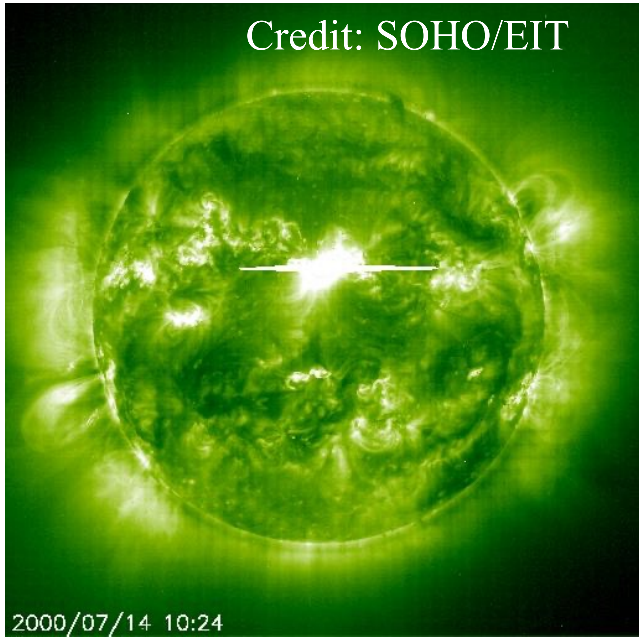
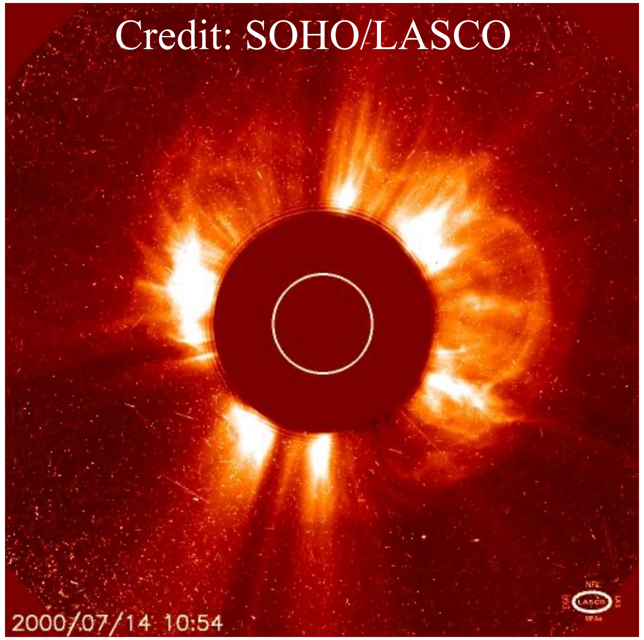
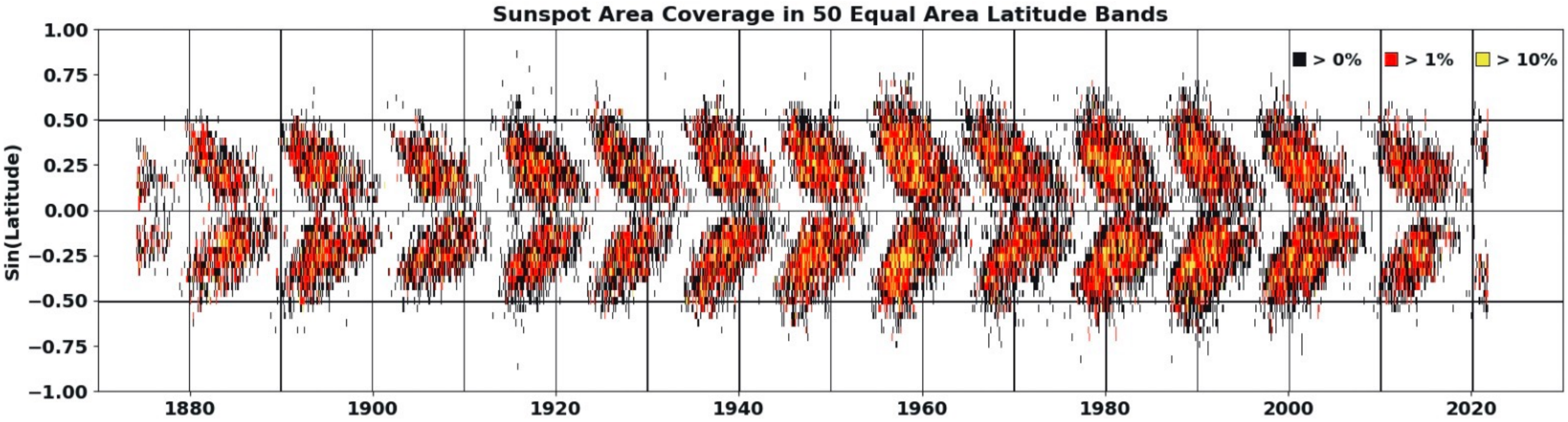
LMSAL/SETI Institute: Meng Jin

Magnetized solar atmosphere



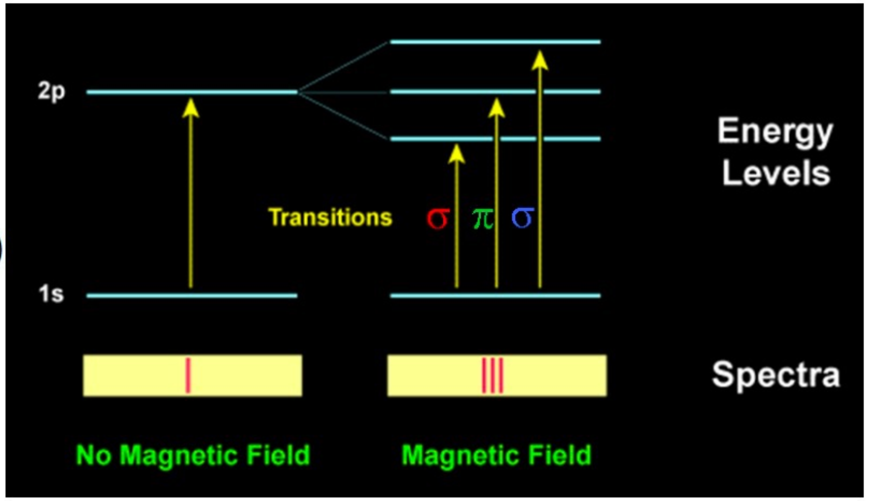




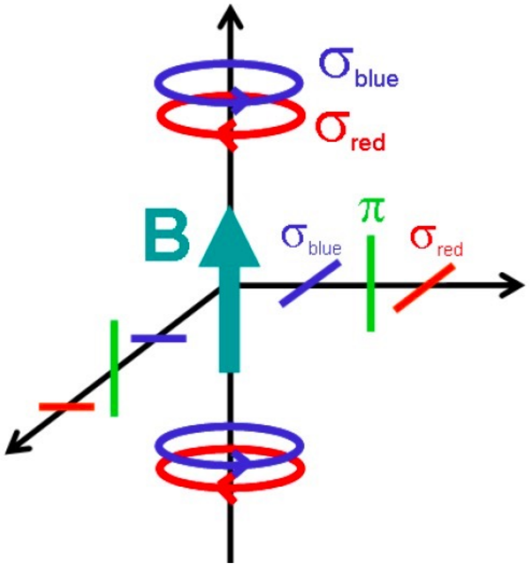


Schematic of Zeeman splitting and polarization of the π and σ components Reiners, LRSP, 9,1, (2012)

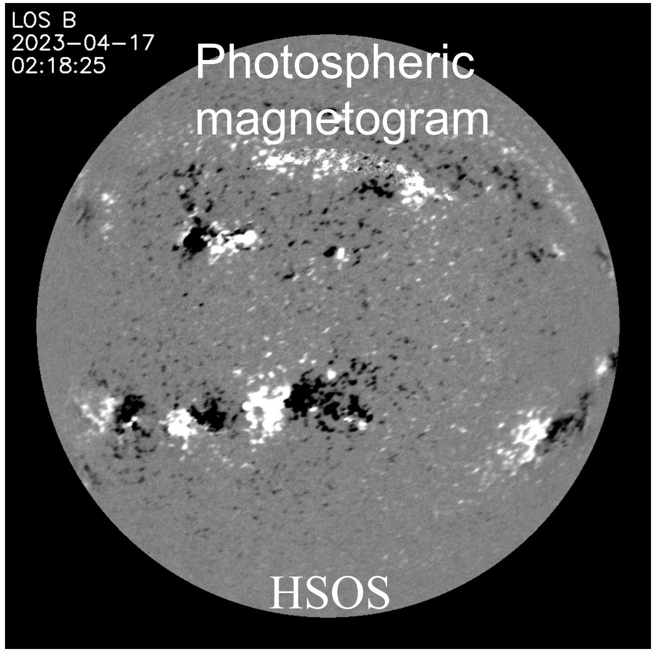
(a)



(b)



Accurate and routine measurements of solar magnetic field achieved at the photospheric level (e.g., Huairou Solar Obs. Station, SDO/HMI, ASOS-FMG)



Coronal magnetogram

?

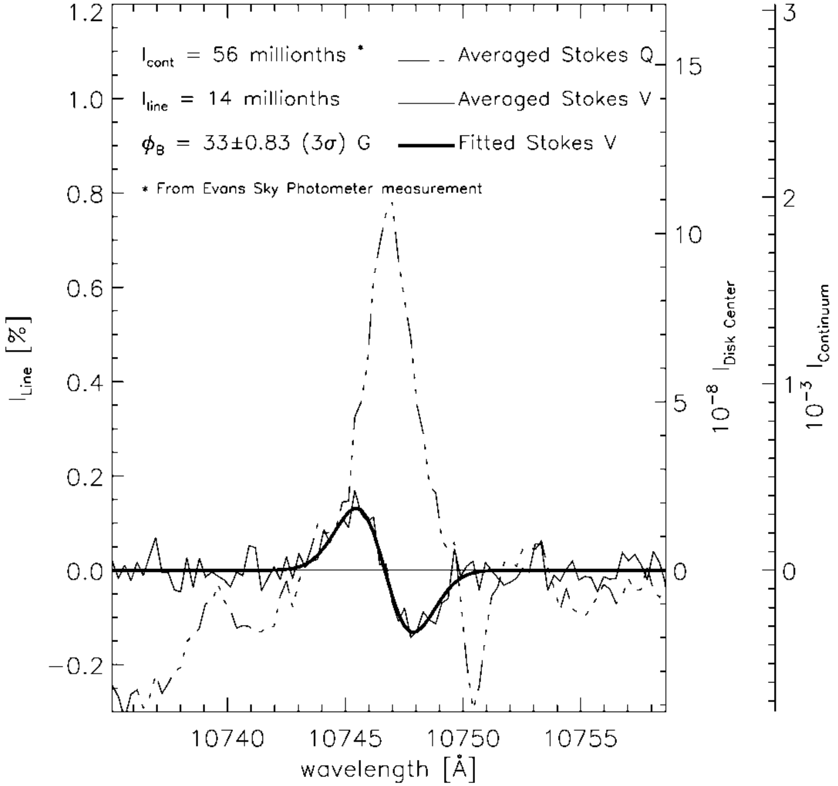
weak field
High temperature

Spectropolarimetry of the visible and near-infrared coronal emission lines

(Lin et al. 2000, ApJ; Lin et al. 2004, ApJL; Tomczyk et al. 2008, SoPh; Liu & Lin 2008, ApJ; Li et al. 2017, ApJ)

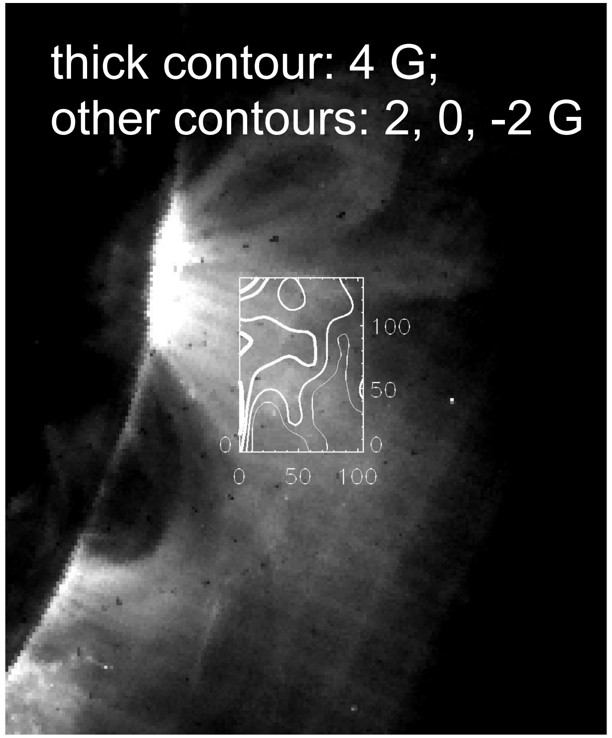
$$V = -kB_{\rm LOS}\,\partial I/\partial\lambda$$

Lin et al. 2000, ApJ



Averaged Stokes Q and V profiles of Fe XIII 1074.7 nm line

Lin et al. 2004, ApJL

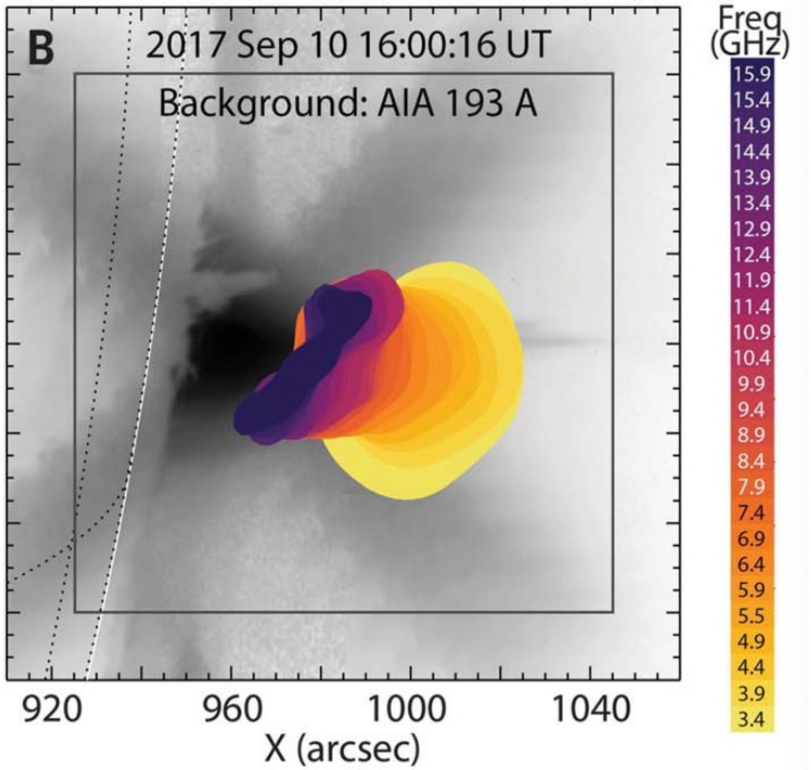


Contour map of the measured coronal magnetic field strength using Fe XIII overplotted on the EUV Imaging Telescope Fe XV image

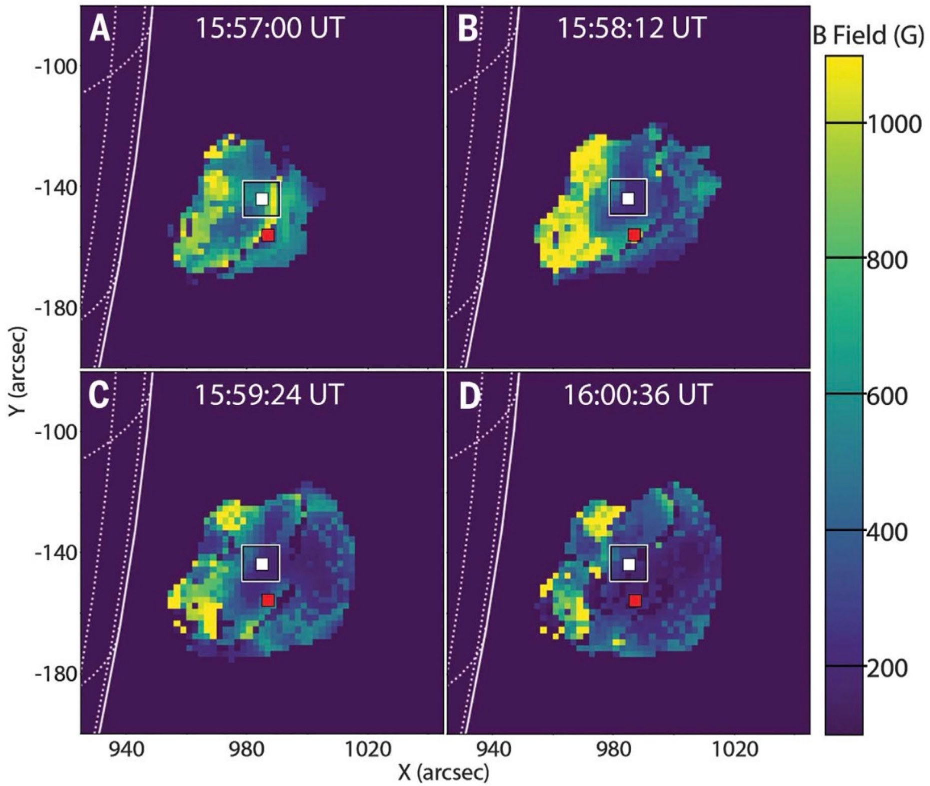
70 minutes of integration time; need larger aperture to achieve higher S/N.

Radio imaging observations (Vasanth et al. 2014, SoPh; Chen et al.Tan et al. 2012, ApJ; Chen et al. 2020, NatAs; Fleishman et al. 2020, Science)

Fleishman et al. 2020, Science



Microwave observations taken with EOVSA overplotted on the AIA 193 Å



Evolving maps of the coronal magnetic field.

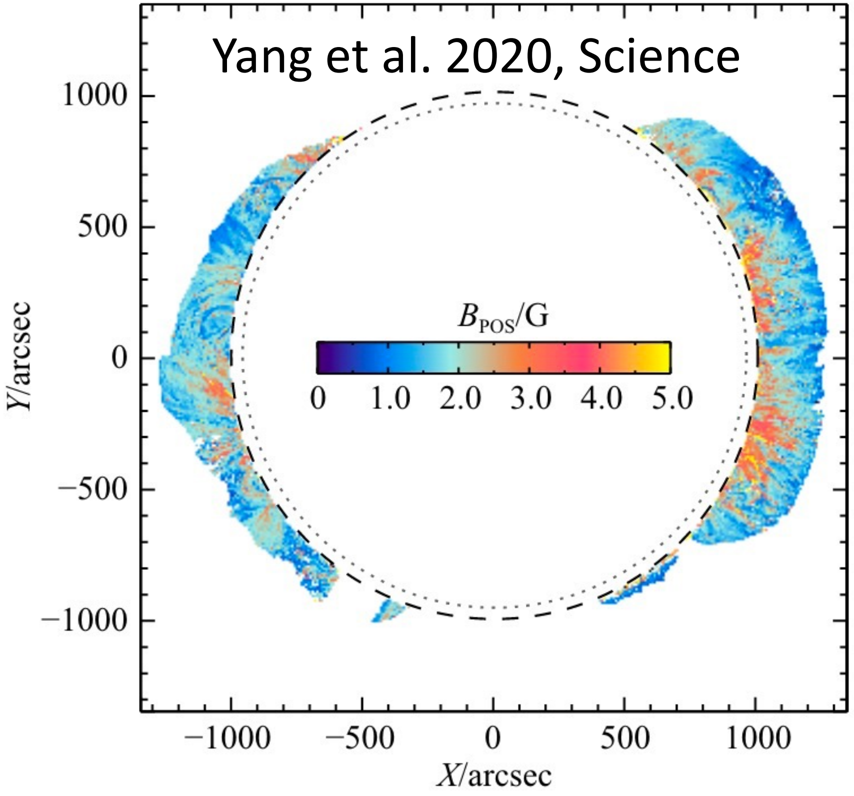
diversity of emission mechanisms; variability in different regions and at different frequency ranges; need high temporal, spatial and spectral resolutions

Magnetoseismology (Nakariakov & Ofman 2001 ; Chen et al. 2011 ; Long et al. 2017; Magyar & Van Doorsselaere 2018; Yang et al. 2020, Science; 2020, ScChE)

Coronal Multi-channel Polarimeter, CoMP

$$c_{\mathrm{k}} = \frac{B}{\sqrt{\mu_0 \langle \rho \rangle}}$$

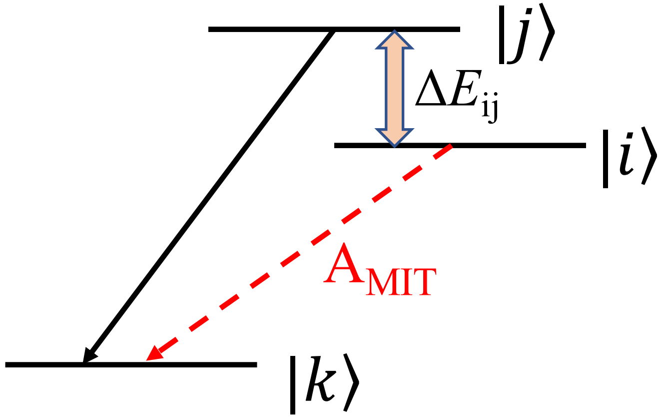
- c_{k} : phase speed: wave-tracking technique
- $\langle \rho \rangle$: mass density: Fe XIII 1079.8 /1074.7nm intensity ratio for electron density
- *B*: plane of sky component of coronal magnetic field strength



Global map of coronal magnetic field obtained through magnetoseismology using CoMP observations

Only the POS component of B in off-limb corona; Cannot be applied to regions affected by solar eruptions

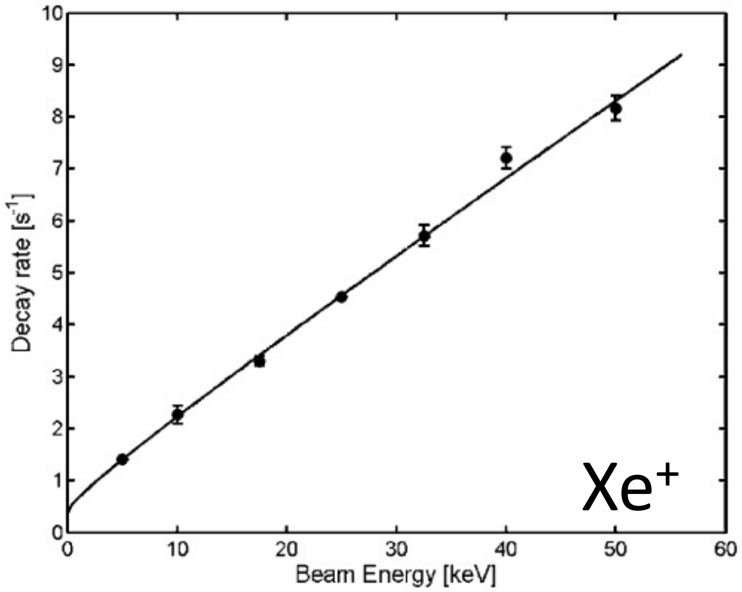
Magnetic-field Induced Transition



- mixing states i and j; a "new" transition channel $i \rightarrow k$: magnetic-field induced transition (MIT)

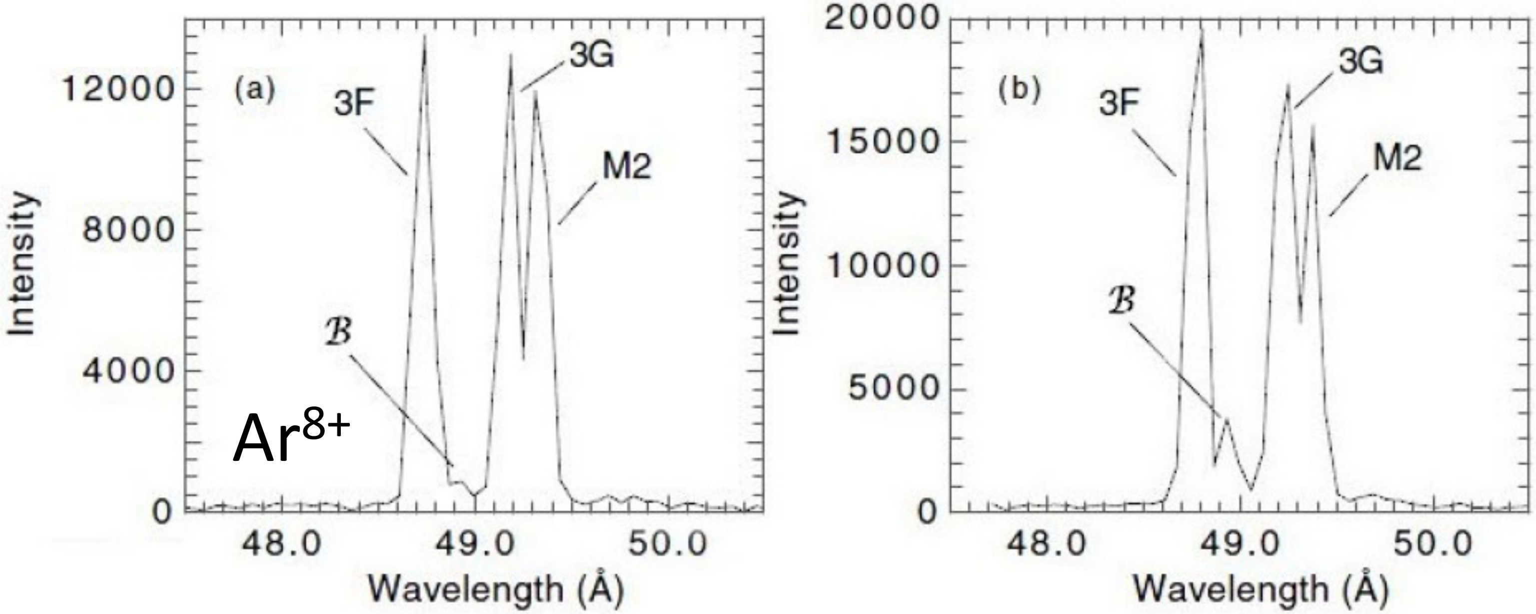
$$A_{MIT}(i \rightarrow k) \propto A(j \rightarrow k) \frac{B^2}{\lambda^3 (\Delta E_{ij})^2}$$

Schef et al. 2005, PRA @ Ion Storage Ring



change in lifetime

Beiersdorfer et al. 2003, PRL @ Electron Beam Ion Trap

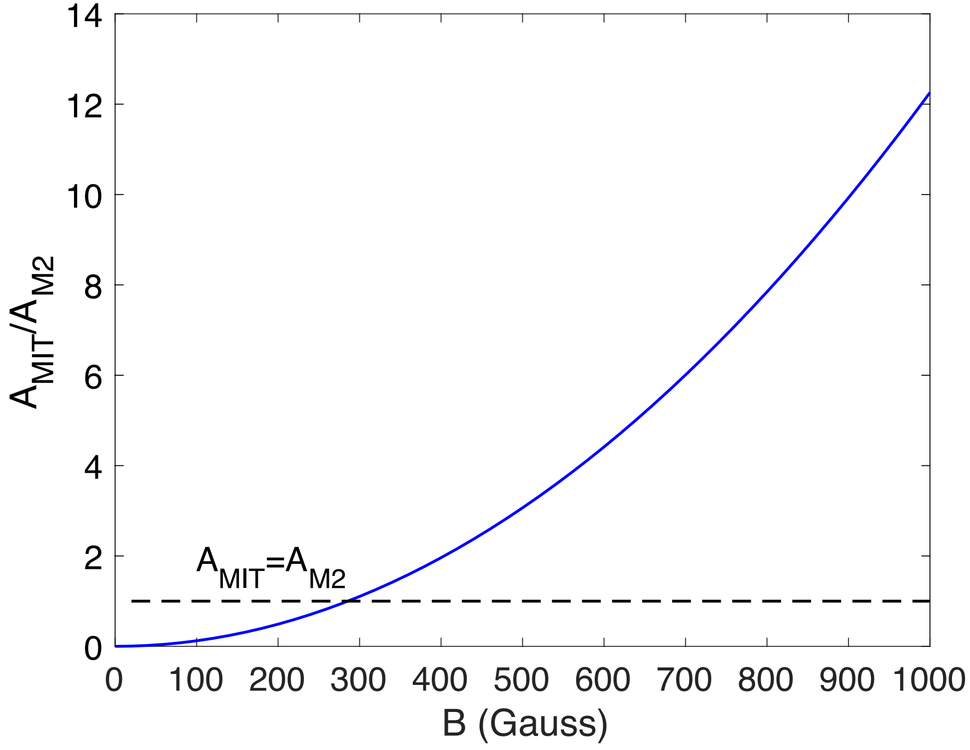


change in spectral features/line ratios

EUV magnetic-induced transition in Fe X

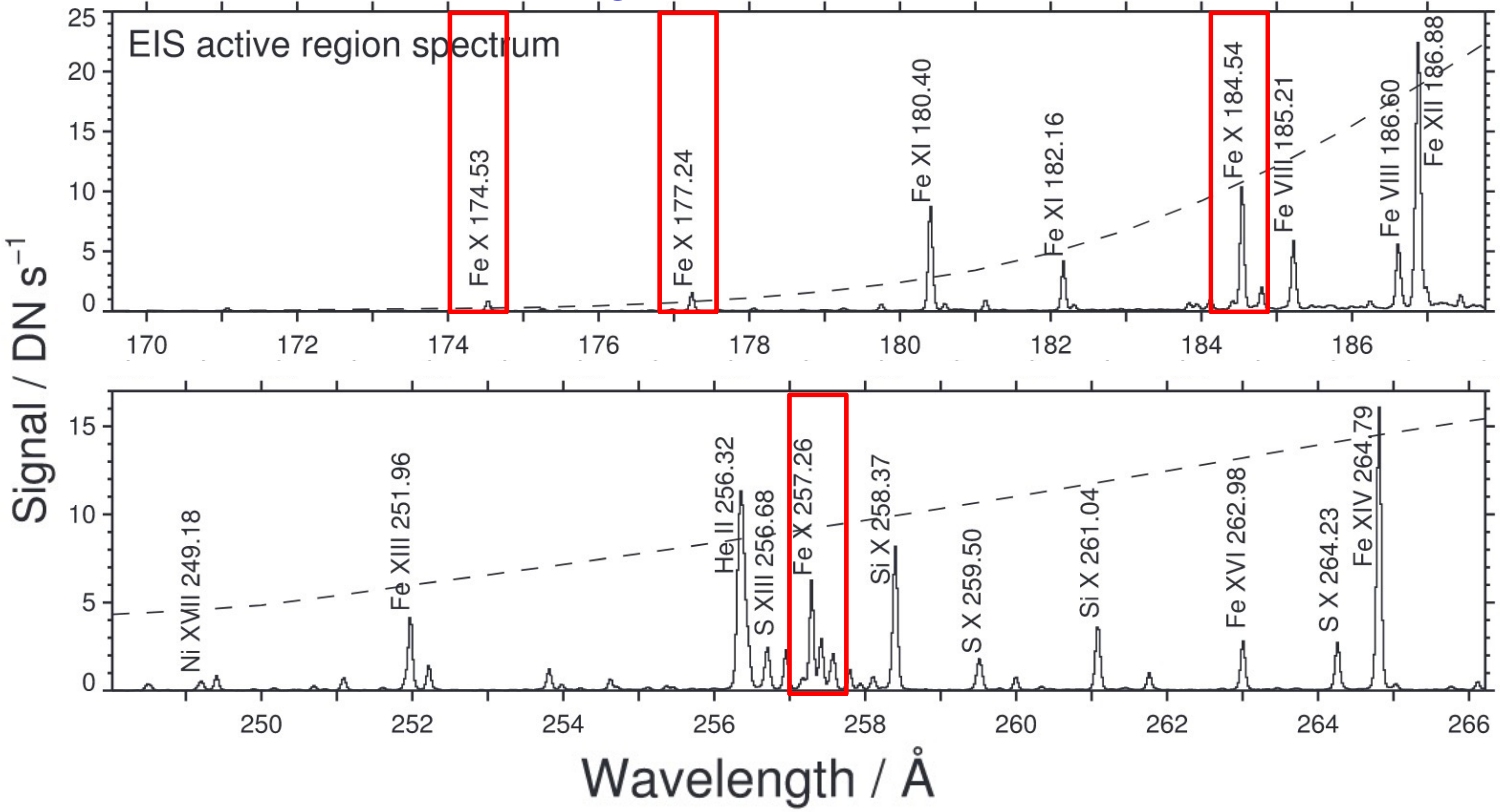
-- close degeneracy between short- and long-lived levels (Li et al. 2015, 2016, ApJ)

Li et al. 2021, ApJ



A_{MIT}/A_{M2} as a function of B

Young et al. 2007, PASJ

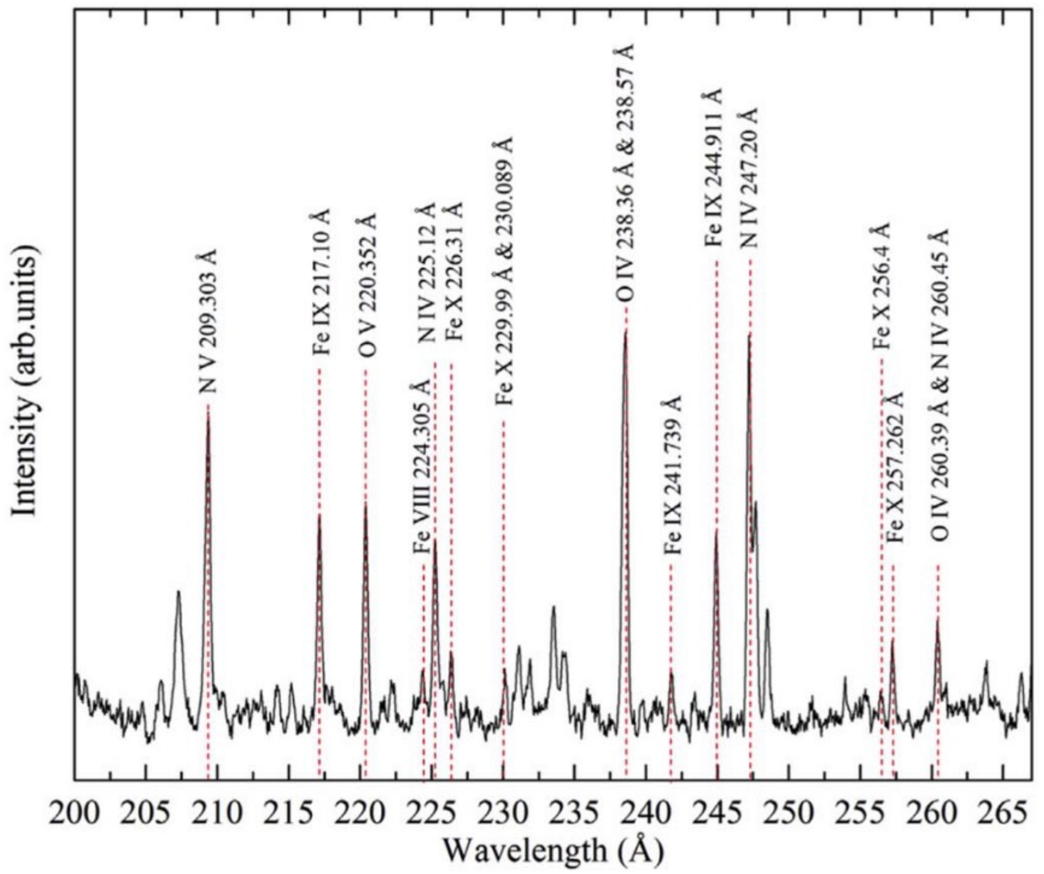


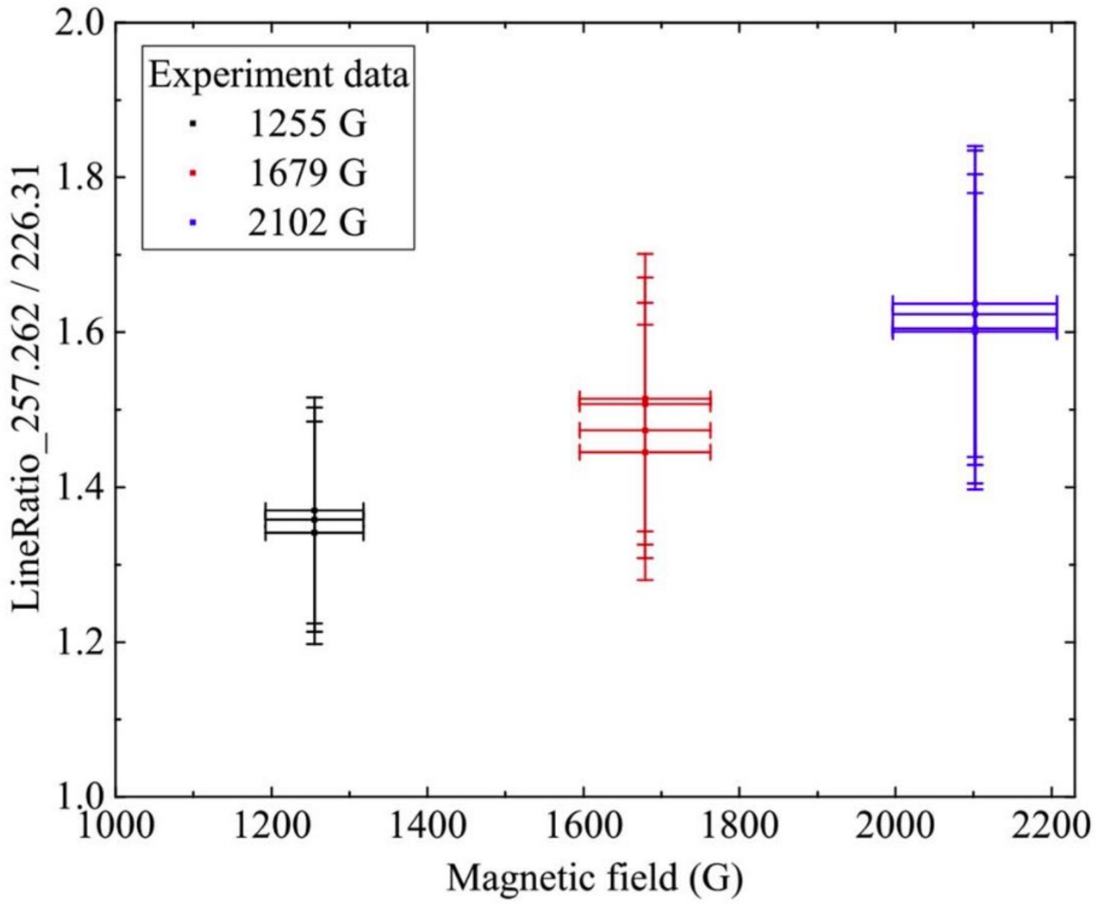
Portion of Fe X spectrum from Hinode/EIS

Compare the observed 257/Ref. from EIS with theoretical predictions Line Ratio, LR(T,N,B)

Laboratory measurement of MIT in Fe X at different magnetic fields@SH-Htsc EBIT

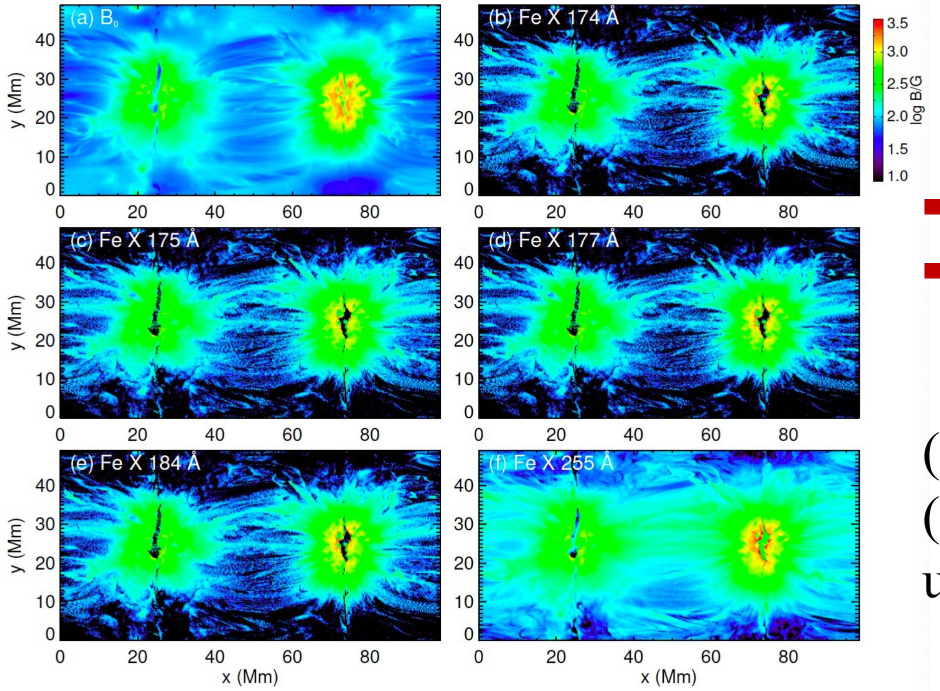
Xu et al. 2022, ApJ





Forward modeling with 3D MHD models—solar corona

Disk-center



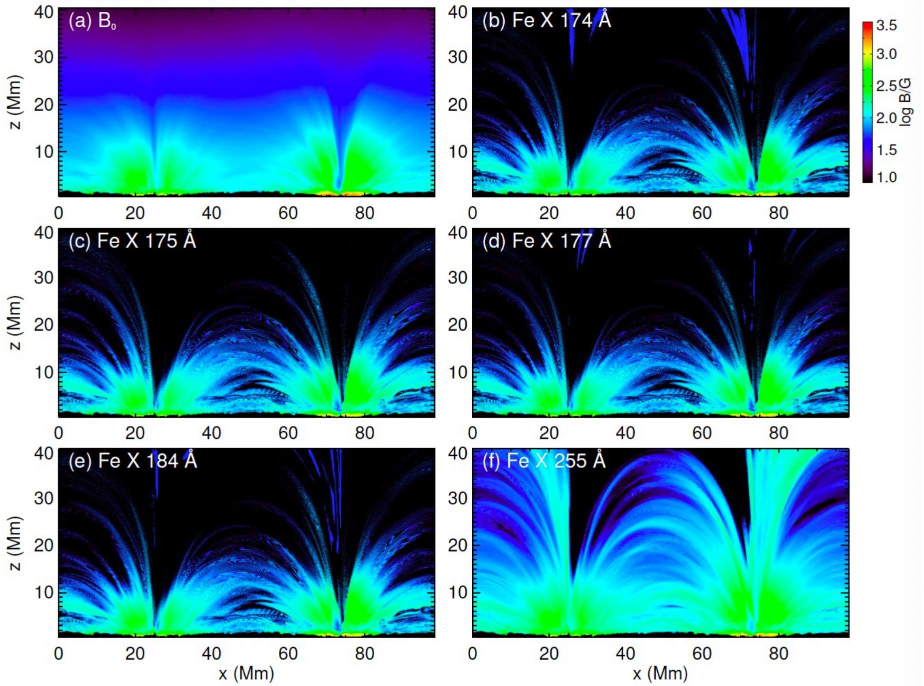
Chen et al. 2021, ApJ

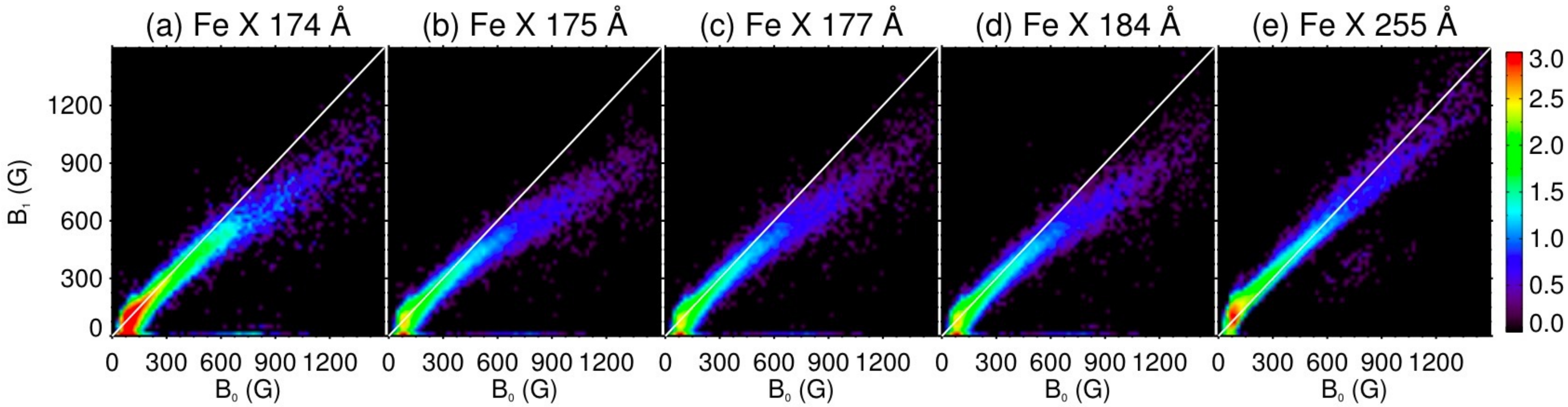
- Density: Fe X 175/174
- Temperature: 184/345

(a): B_0

(b)-(f): B_{MIT} derived using different ref. lines

Off-limb





Forward modeling with 3D MHD models—stellar coronae

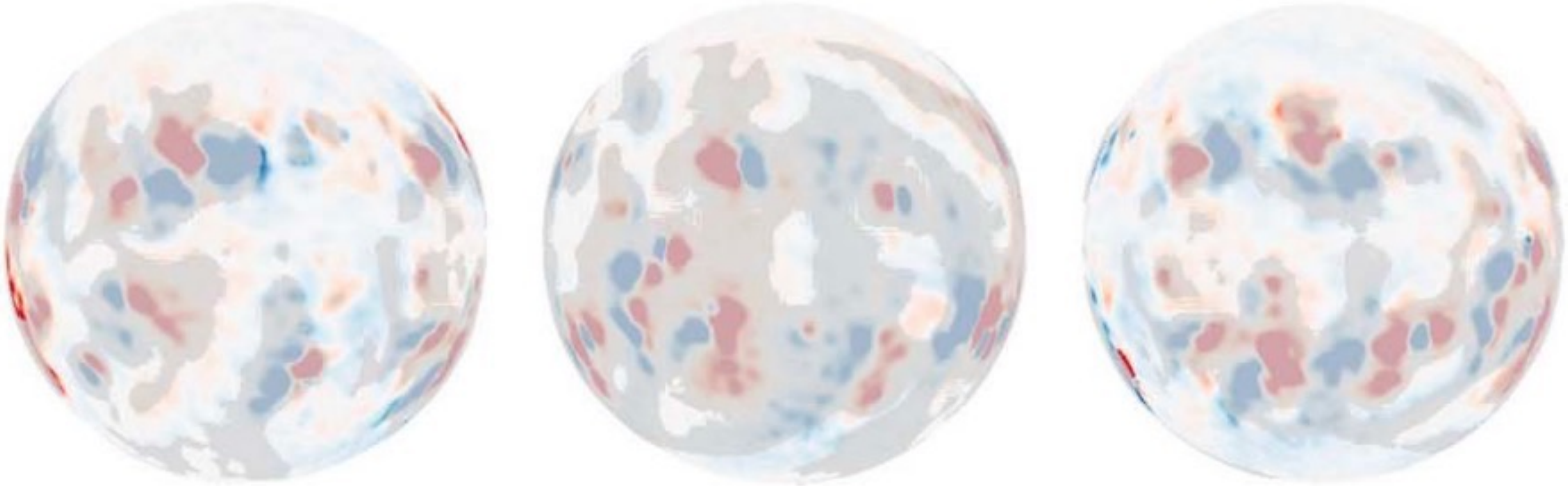
Liu et al., 2022, ApJ

emissivity-weighted average field strength :

$$B_0(i, e_{th}) = \frac{\int_{V'(i,e_{th})} B \cdot e_{174} dV}{\int_{V'(i,e_{th})} e_{174} dV}$$

e_{th}: emissivity threshold

B_0=B_1



Best fitted V' (gray isosurface) for different LOS directions

The measured field strength from MIT diagnostic technique largely reflects the average field strength in stellar active regions.

Hinode/EIS Measurements of Solar Coronal Magnetic Fields

Hinode/EIS (since 2007):

170 – 210 Å (SW)

250 – 290 Å (LW)

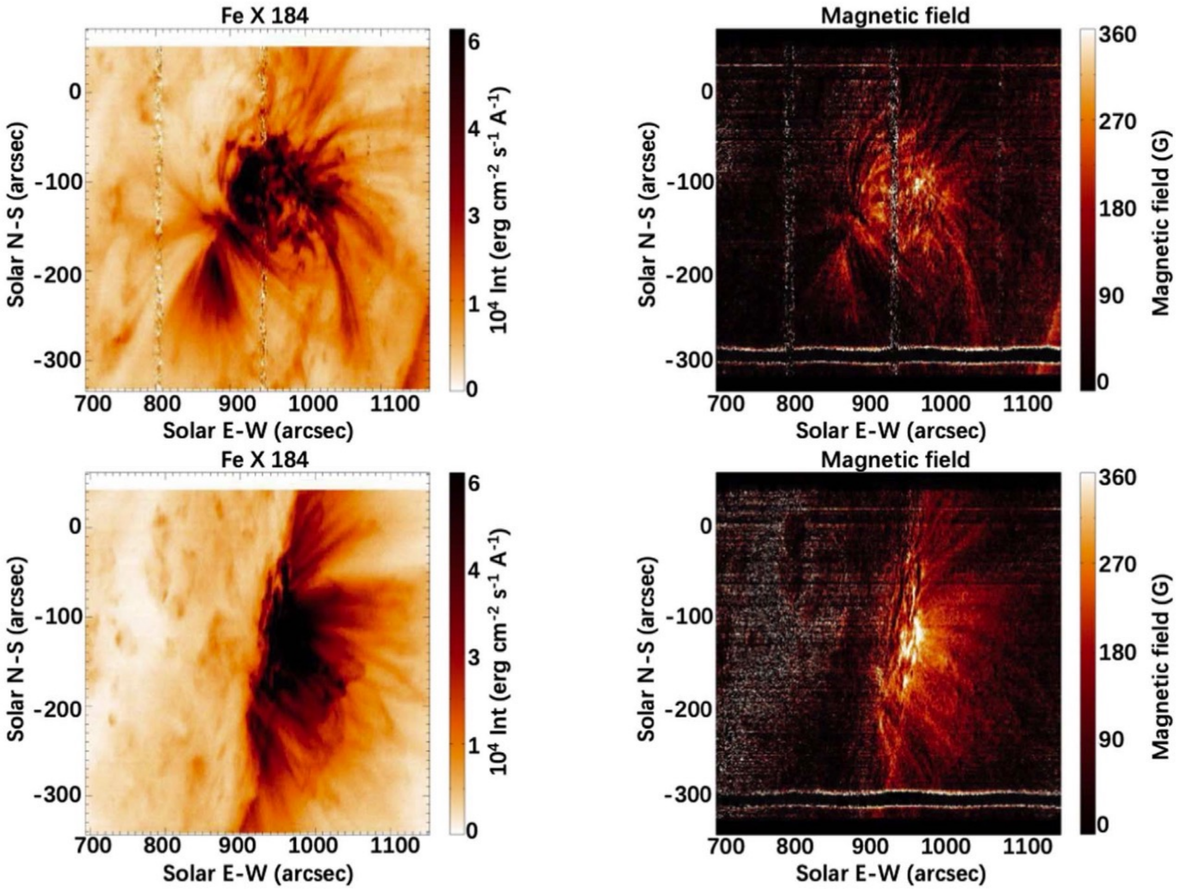
- reference line: 184 Å
- Density: Fe X 174/175 Å
- log T/K = 6.0
- Weak-field regime

Landi et al. 2020, ApJ

AR10978

Disk-center observation

Off-limb observation



Summary

EUV in Fe X

Theoretical investigation	Forward modeling	Laboratory measurement	Hinode/EIS observations

Pros and Cons:

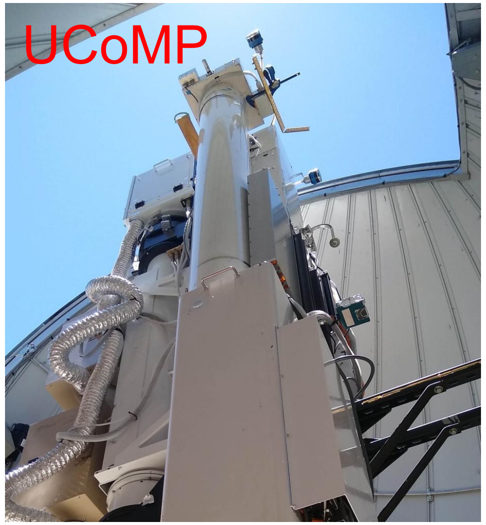
- Spectroscopic method
- Both disk-center and off-limb measurements
- Only intensity but not direction measurement

Future perspective

- Improve on: theoretical model + EIS observations + instrument
- Search for other potential MIT lines
- Combination of different techniques

Spectropolarimetry

magnetoseismology



radio observations

- Atomic physics + Astrophysics: “unexpected” transitions

Thanks for your attention!