# Constraining the coronal magnetic field from ground- and space-based observations

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# Solar flares & Coronal mass ejections

- Key ingredients:
  - **current-carrying magnetic fields**: free magnetic energy + magnetic helicity
  - **specific magnetic topologies**: current sheets + reconnection

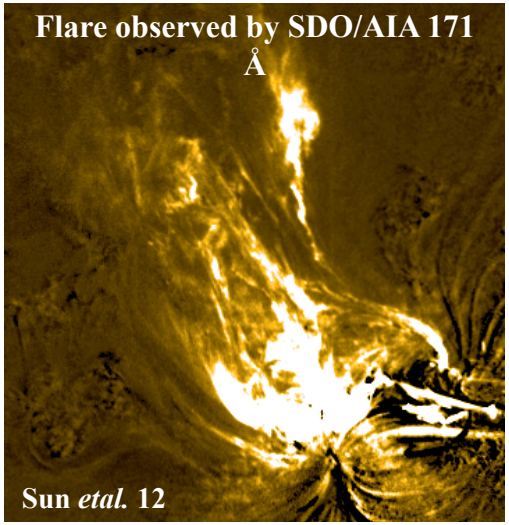
  Démoulin *etal.* 96; Schrijver *etal.* 11; Pevtsov *etal.* 14

- Several mechanisms identified & well understood:
  - ideal (e.g., Kink, Torus) & resistive (e.g., Tearing) instabilities

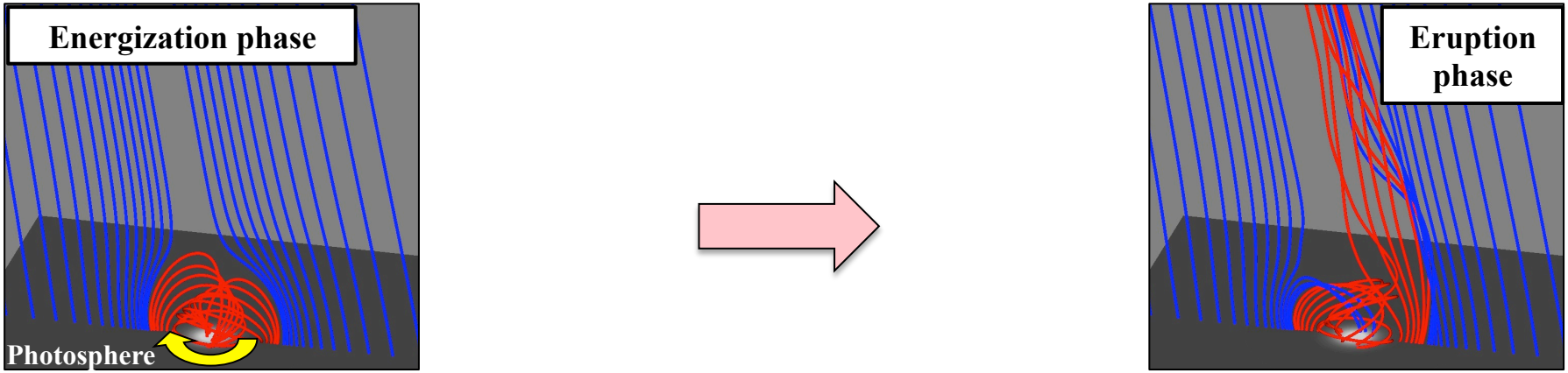
  Aulanier *etal.* 10; Janvier *etal.* 11; Barta *etal.* 13; Amari *etal.* 14; Zuccarello *etal.* 15

- **But still not able to produce accurate flare/CME forecasts**

  Falconer *etal.* 11; Al-Ghraibah *etal.* 15; Bobra & Couvidat 15; Korsós *etal.* 15




**3D MHD model of a coronal jet**




**Pariat, Dalmasse, DeVore *etal.*, 15**

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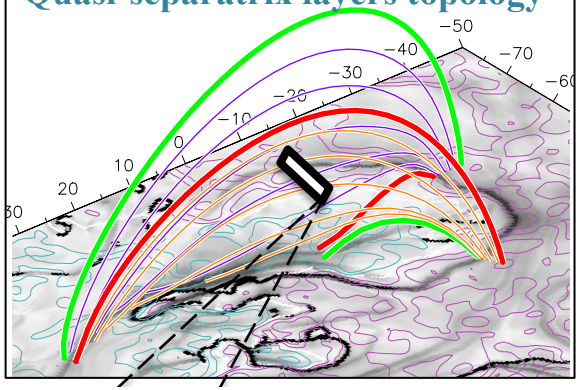
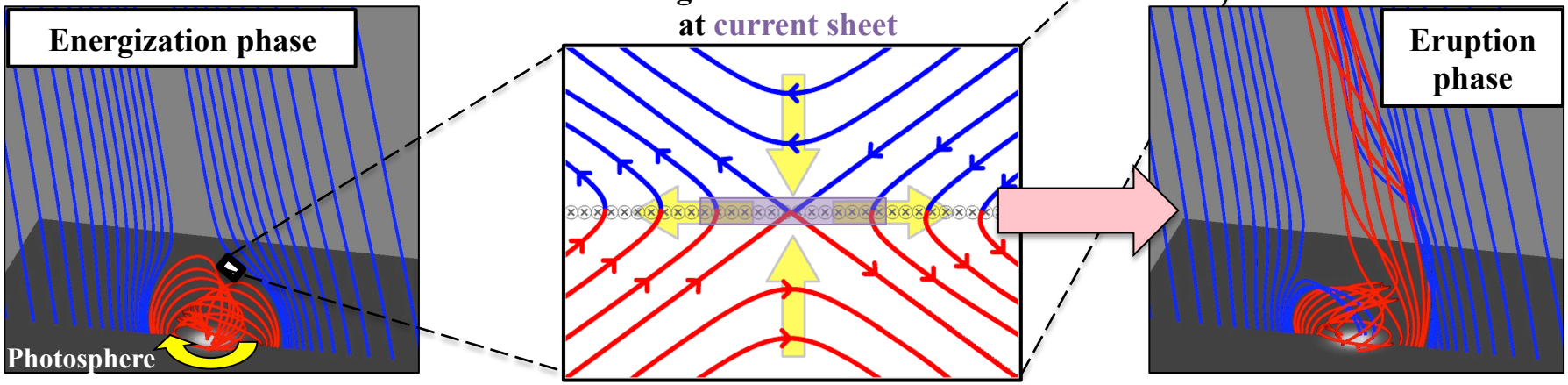
Quasi-separatrix layers topology




Dalmasse, Chandra, Schmieder *etal.*, 15

3D Null-point (B=0) topology

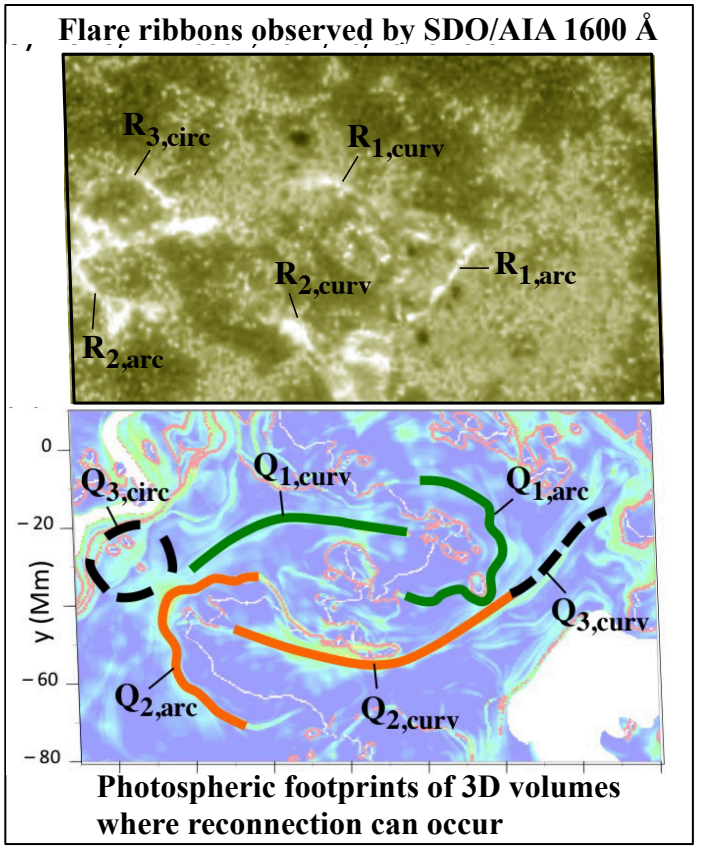



Pariat, Dalmasse, DeVore *etal.*, 15

# Solar flares & Coronal mass ejections

- **No accurate flare/CME forecasts = don't know B 3D in the solar atmosphere**

- 3D magnetic field in ARs = reconstruction from photospheric data (force-free assumption):
  - **no unique solution for current-carrying fields**
  - well suited for, e.g., flare signatures wrt magnetic topology, flux of magnetic helicity in 3D
  - **practictal use limited to analyze the role of key 3D quantities for flare/CME prediction**

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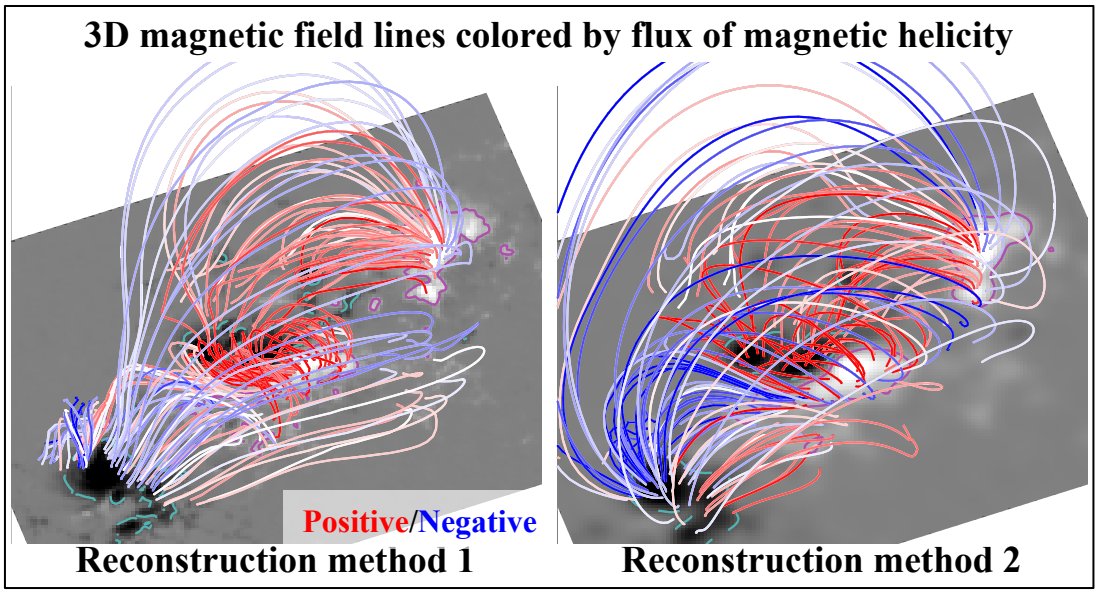


**Dalmasse, Jing, Pariat *etal.*, in prep.**

Schmieder *etal.* 97; DeRosa *etal.* 09; Masson *etal.* 09; Wiegelmann & Sakurai 12; Zhao *etal.* 16

# Data to constrain magnetic field reconstructions

- Most models = photospheric polarimetry + EUV loops only
- But more could be used:
  - e.g., EUV / White-light / X-ray / Hα emission
  - **Chromospheric polarimetry** (e.g., Ca II 8542 Å, He I 10830 Å):
    - e.g., VTT+TIP-II, GRIS+TIP-II
    - Future: CHROMAG, BBSO, DKIST, EST
  - **Coronal polarimetry** (e.g., Fe XIII 10747 Å, Fe XIV 5303 Å, Radio ~1-20 GHz):
    - e.g., CoMP-S, JVLA, MUSER, NoRH
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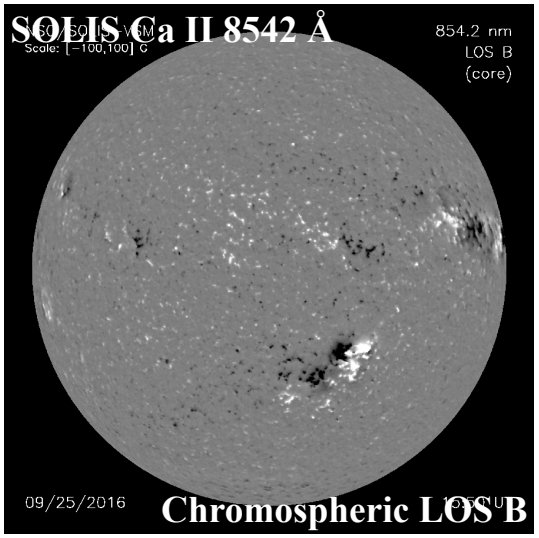


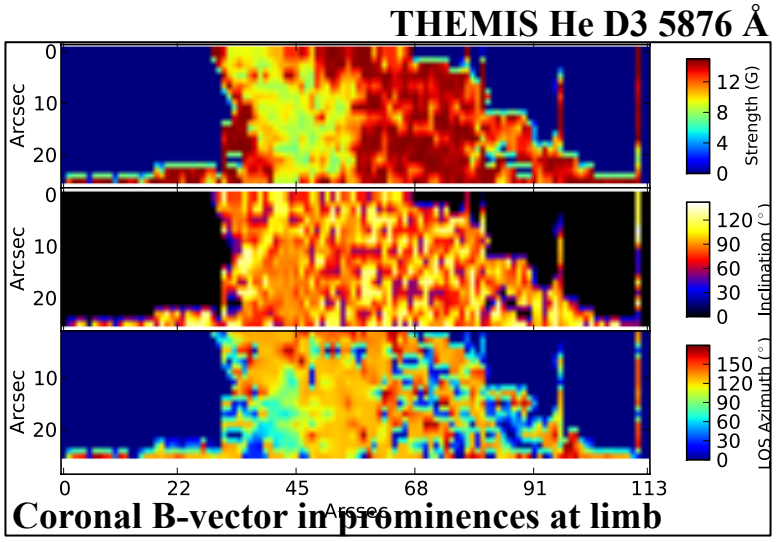


Schmieder, Tian, […], Dalmasse *etal.* 14

Bommier & Molodij 02; Pariat *etal.* 04;
Yelles Chaouche *etal.* 12; Rachmeler *etal.* 13; ;
Balthasar *etal.* 14; Pevtsov *etal.* 14b; Wang *etal.* 15;
Levens *etal.* 16; Miyawaki *etal.* 16

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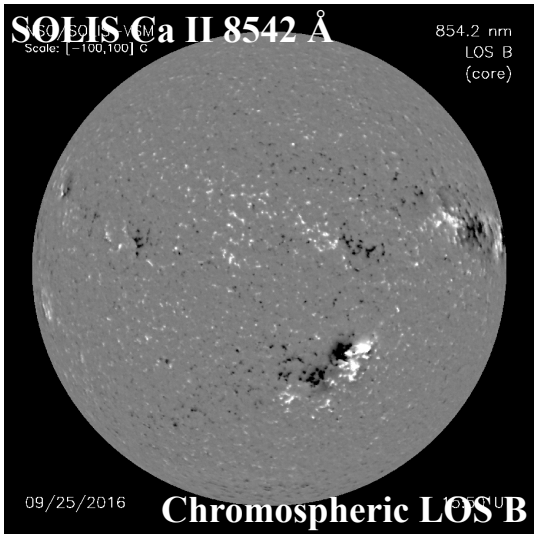


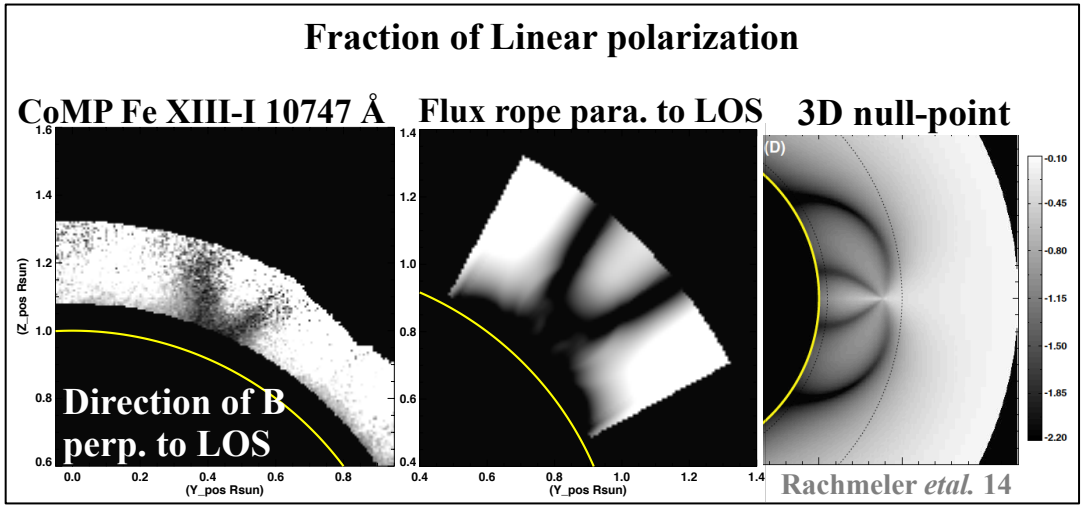


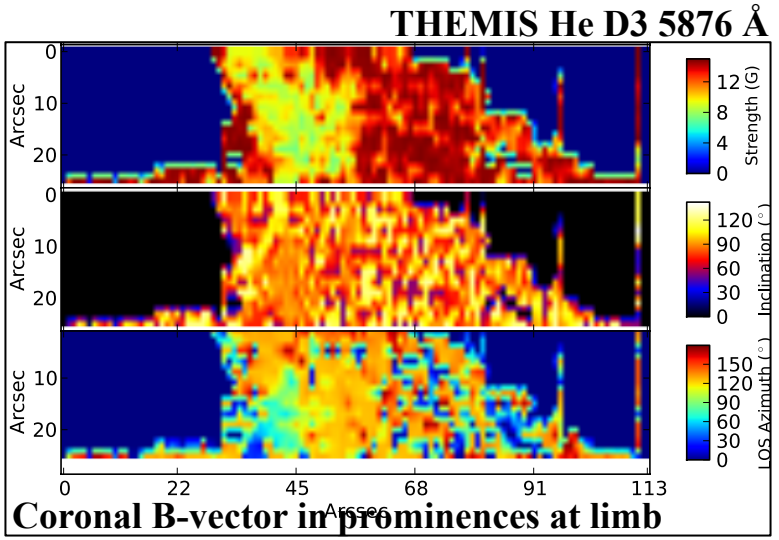

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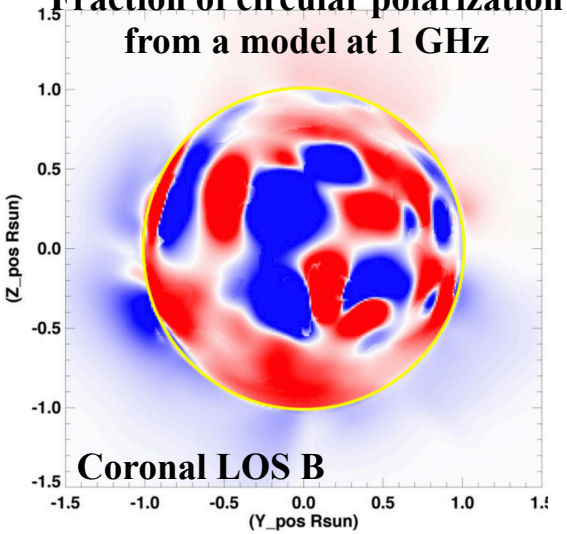
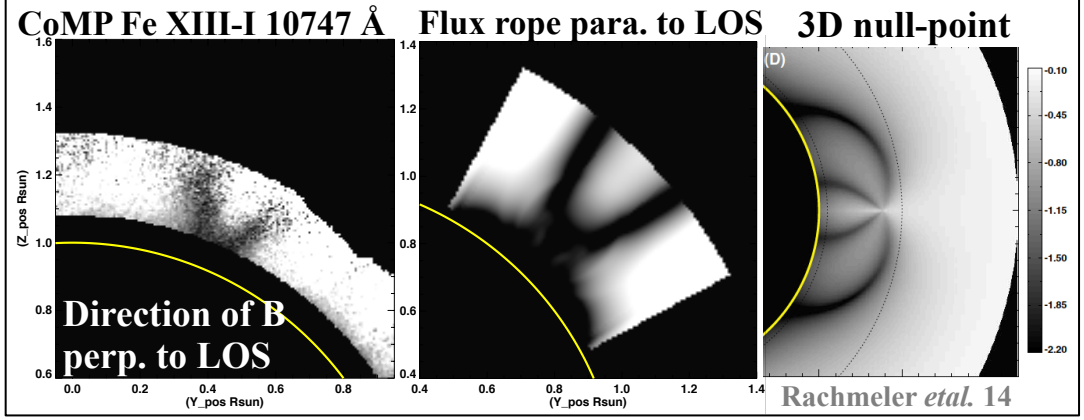
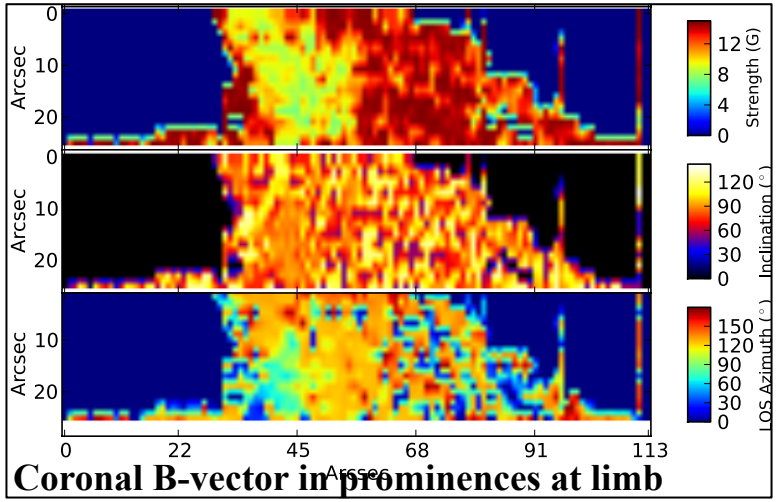
**Fraction of circular polarization from a model at 1 GHz**




**Fraction of Linear polarization**




**THEMIS He D3 5876 Å**




Schmieder, Tian, […], Dalmasse *etal.* 14

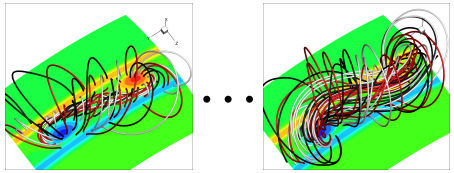
# Data-constrained magnetic field reconstruction

- Including more observations = not straightforward:
  - optically thick chromosphere but limited information/accuracy on height
  - optically thin corona = LOS-integrated signal

- Proposed solution = **Data-Optimized Coronal Field Model** (DOCFM project):

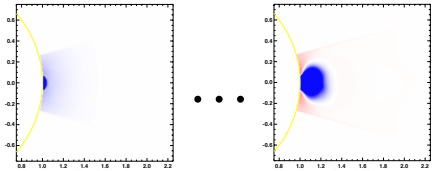
**Step 1: Model**

Generate magnetic field model for a sparse grid of parameter values



**Step 2: FORWARD**

Create synthetic observations for grid of models using forward modeling



Gibson *etal.* 16

**Step 3: Optimization with ROAM**

Compare synthetic observations from grid of models to real observations + find set of best-fit parameters

**Dalmasse, Nychka, Gibson *etal.*, 16;**
**Dalmasse, Nychka, Flyer, in prep**

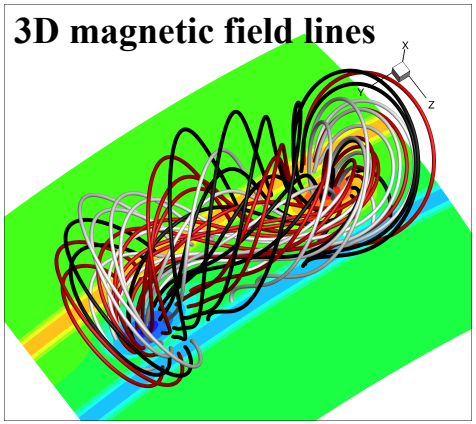
**Step 4: Iterate**

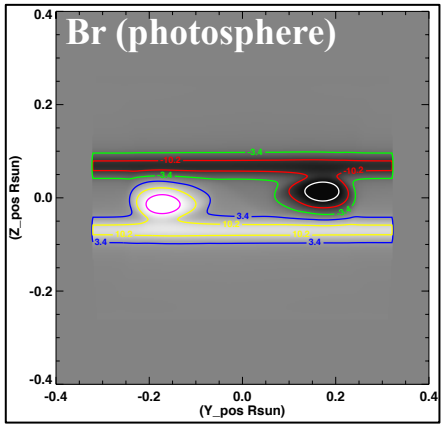
Iterate on a refined region of the model's parameter space

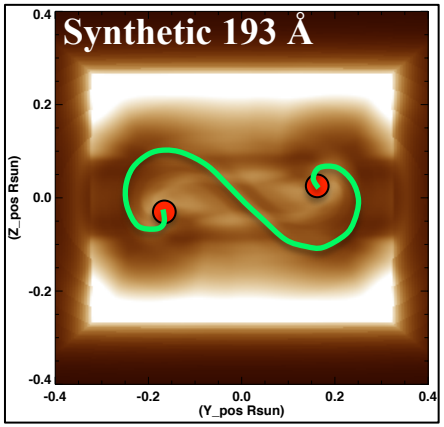
https://www2.hao.ucar.edu/hao-science/data-optimized-coronal-field-model-docfm
https://www2.hao.ucar.edu/modeling/FORWARD-home

# Setup for synthetic test bed

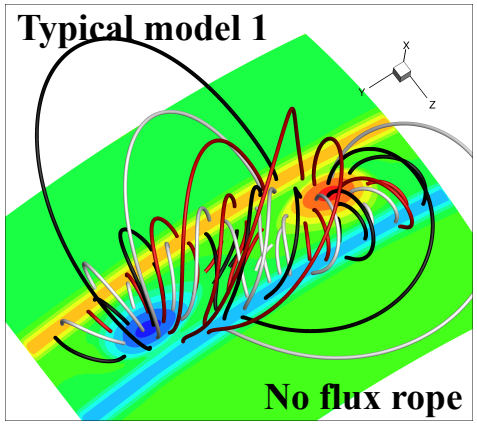
- Current focus = model-data fitting of flux ropes (CME precursors)
- Ground truth = 3D MHD model of a flux rope

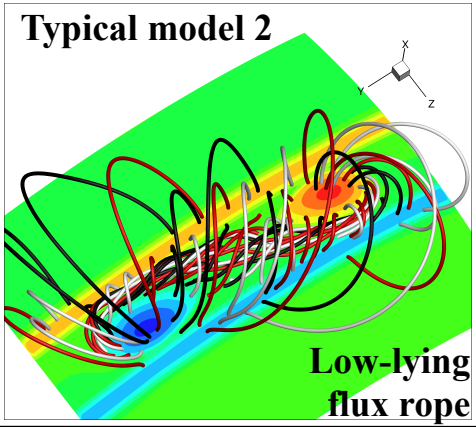


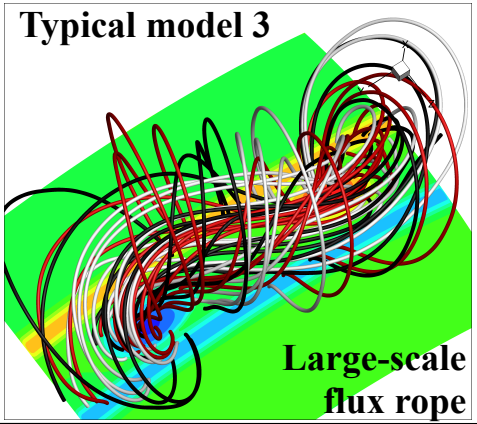




- Reconstruction model = flux rope embedded in current-free magnetic field **(van Ballegooijen 04; Savcheva *etal.* 12)**
  - space-based data: photospheric magnetogram + EUV emission
  - 2 parameters = poloidal (P) and axial (A) fluxes
  - sparse parameter grid: **6x6=36 sets of (P ; A)** for ROAM, **P = [$10^6$ ; $10^{11}$] Mx, A = [$10^{16}$ ; $10^{21}$] Mx**

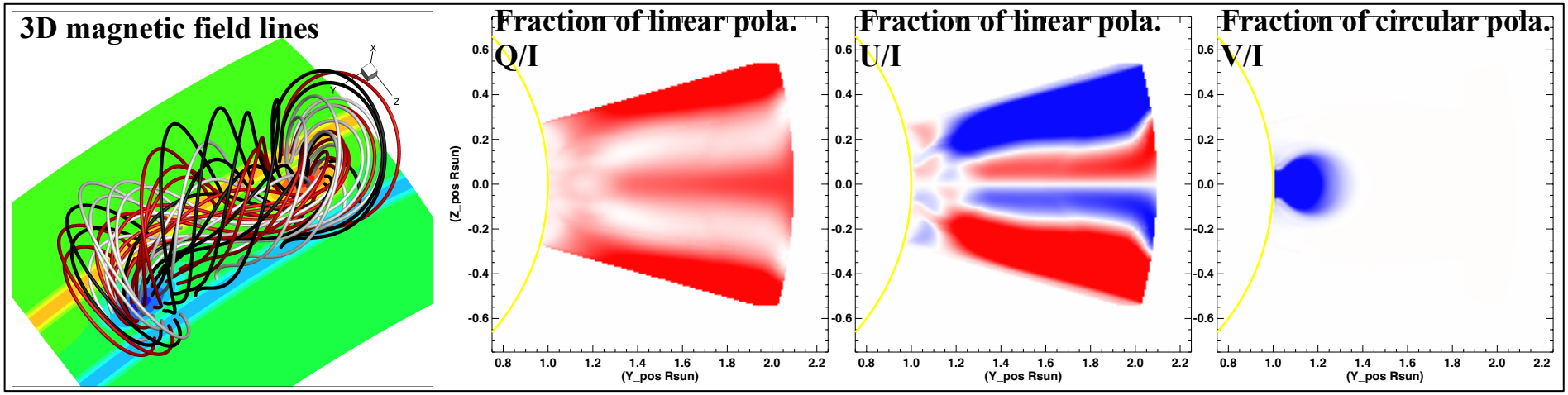


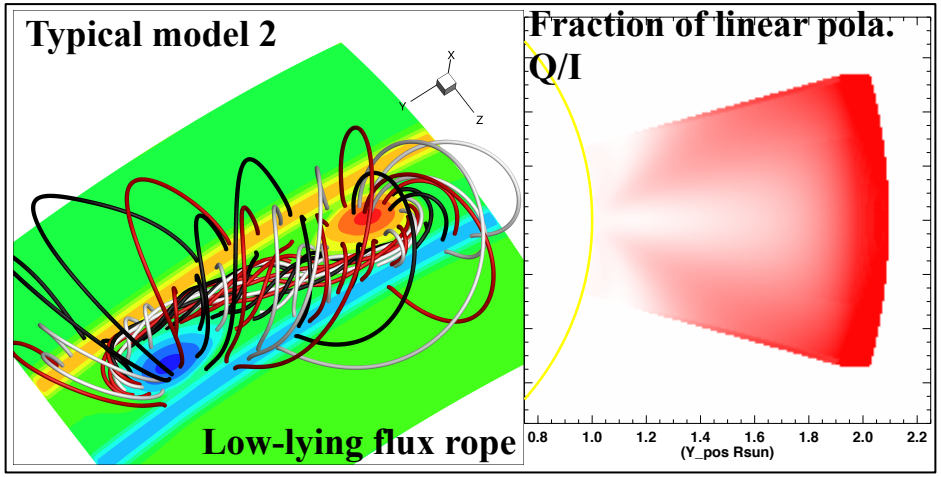



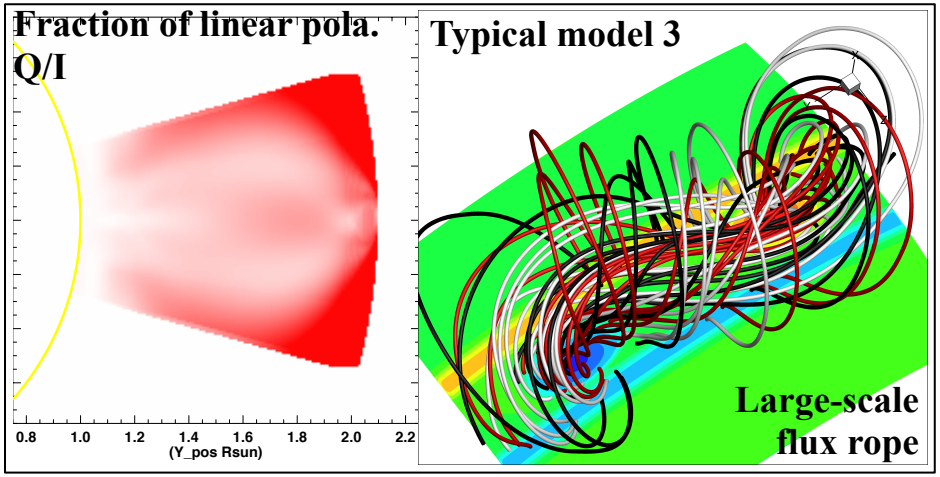
# Synthetic observations for test bed

- Current focus = CoMP-like coronal polarimetric measurements, here Fe XIII-I 10747 Å
- Ground truth:




- 2 of the 36 reconstructed models:



# Early results from test bed

| Oracle test | Model-data fitting tests (no iteration) | | |
|---|---|---|---|
| $\min_{(P,A)} \left( \sum_m \left( \mathrm{B}_m(P,A) - \mathrm{B}_m^{\mathrm{GT}} \right)^2 \right)$ | $\min_{(P,A)} \left( \sum_k \left( \mathrm{Y}_k(P,A) - \mathrm{Y}_k^{\mathrm{GT}} \right)^2 \right)$ | | |
| ($B_r$, $B_\theta$, $B_\varphi$) | (I, Q, U, V)-10747 Å | (I, Q, U)-10747 Å | (I, Q, U,)-10747 Å & (I, V)-1 GHz |
| $P_{best\text{-}fit} = -3.7 \times 10^9$ Mx<br>$A_{best\text{-}fit} = 7.7 \times 10^{20}$ Mx | $P_{best\text{-}fit} = -3.0 \times 10^9$ Mx<br>$A_{best\text{-}fit} = 8.6 \times 10^{20}$ Mx | No minimum in considered (P ; A)-space | $P_{best\text{-}fit} = -4.0 \times 10^9$ Mx<br>$A_{best\text{-}fit} = 7.9 \times 10^{20}$ Mx |

- Minimization using $\log_{10}$(P ; A): 8% accuracy in $\log_{10} \approx$ 20% accuracy in normal units

- Still need:
  - to create model for best-fit solutions
  - error quantification for magnetic field & quantities relevant to flaring activity and forecasts

- **But very promising preliminary results**

# Conclusions & perspectives

- **Data-Optimized Coronal Field Model** project:
  - currently in development with very promising early results
  - scientific questions to be addressed by DOCFM:
    - **What instabilities trigger and drive solar flares and CMEs?**
    - **What quantities control the evolution of flares/CMEs and could be used for forecasting?**

- **Future instruments and data that will help:**
  - **Solar Orbiter**: photospheric polarimetry + EUV at a different viewpoint
  - **FASR**: polarimetry in range [.05 ; 20] GHz = middle-chromosphere to upper corona
  - **DKIST**: polarimetry in range [380 ; 5000] nm = photosphere to corona
  - **EST**: polarimetry from photosphere to upper chromosphere

- **What else do we need?**
  - Forward modeling:
    - chromospheric polarimetry at limb (in progress with A. López Ariste for He D3) + on-disk
    - UV/EUV coronal polarimetry (collab. with N.E. Raouafi & S. Fineschi for H I Lyα)
  - Instruments/data:
    - ground-based IR polarimeters with large field-of-view (**U-CoMP**, **CLIMSO**, **COSMO**)
    - space-based, off-limb, UV/EUV polarimeters as was proposed in **MASC** (**MAGIC**; **Auchère etal.**) and **INSTANT** (**MAGIC**; **Lavraud etal. 16**) proposals