Data Driving our way to 2032

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Outline

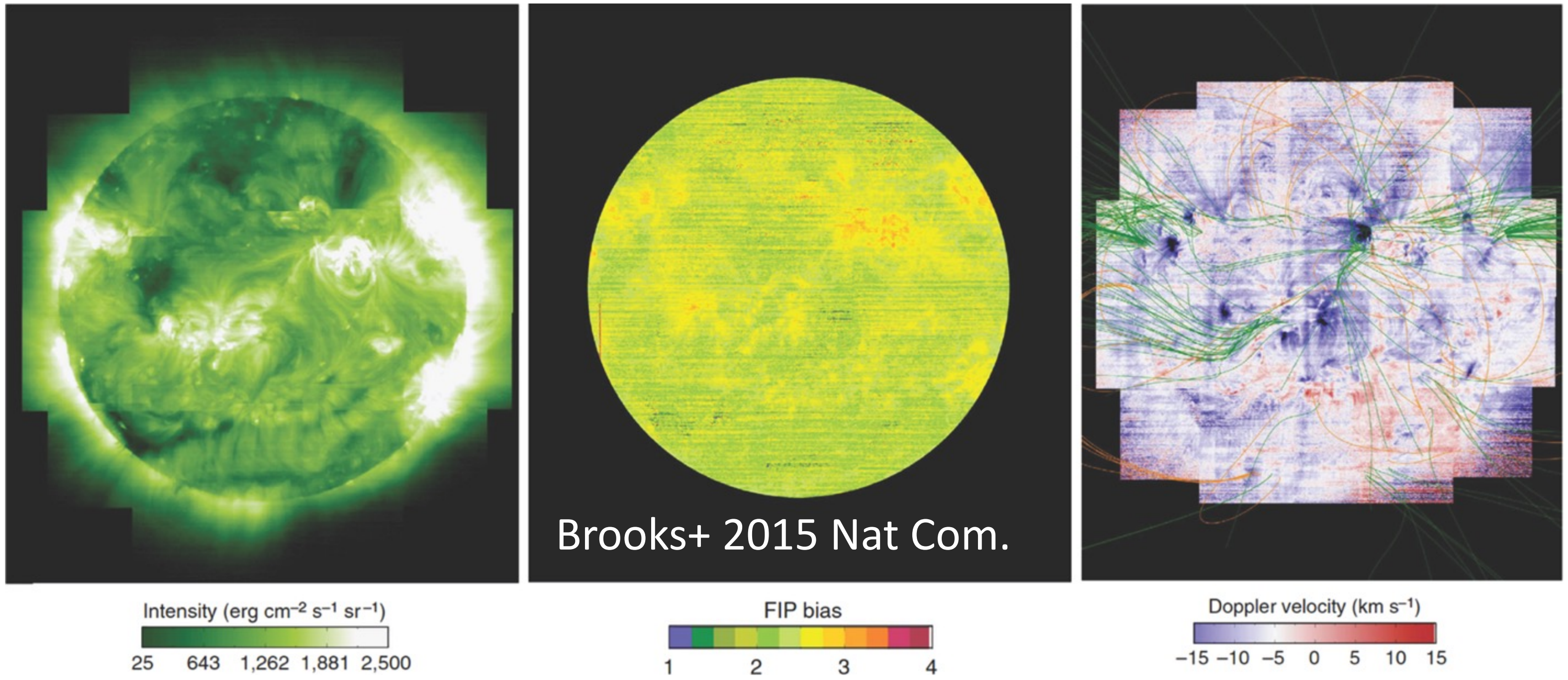
1. Problems we want to solve
2. Why data driving is the Right Way
3. Necessary focus on the lower, driving boundary
4. A vast sea of unknowns

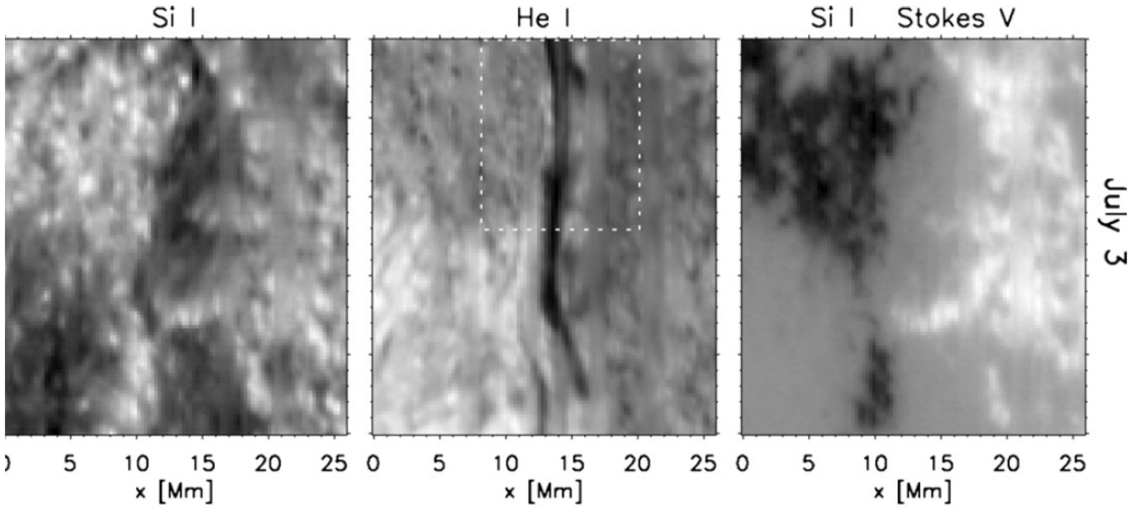
Kumar+2017 A&A 603

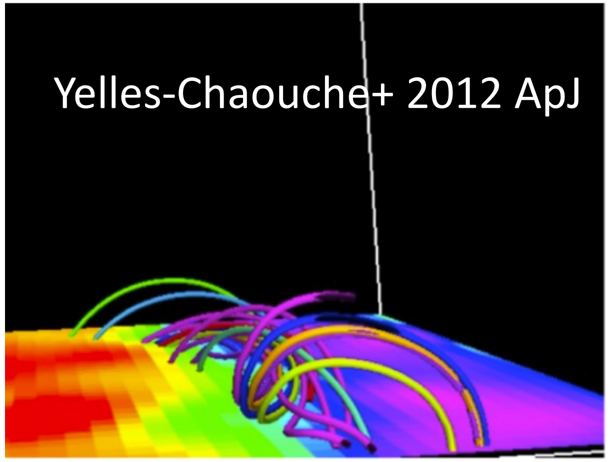
Problems we want to solve

- Heating
- Eruptions
- Solar Wind(s)

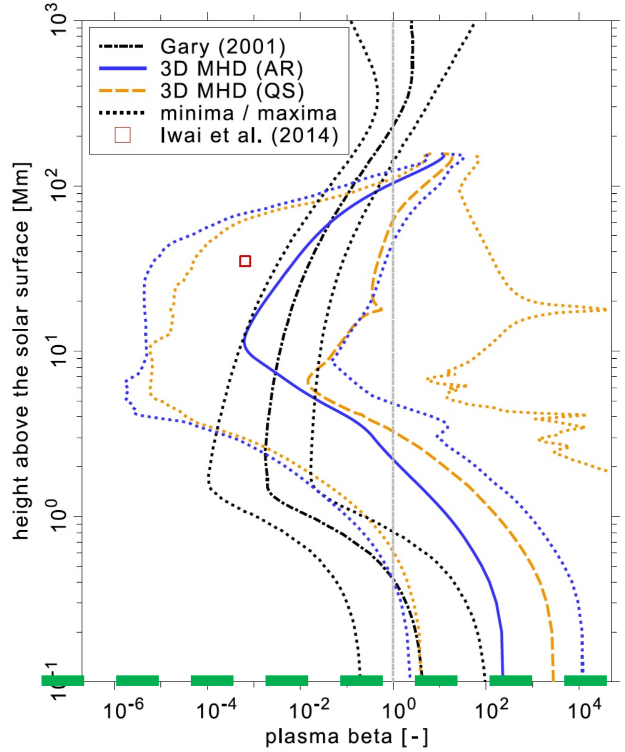
These all require knowledge of global magnetic field + plasma configuration



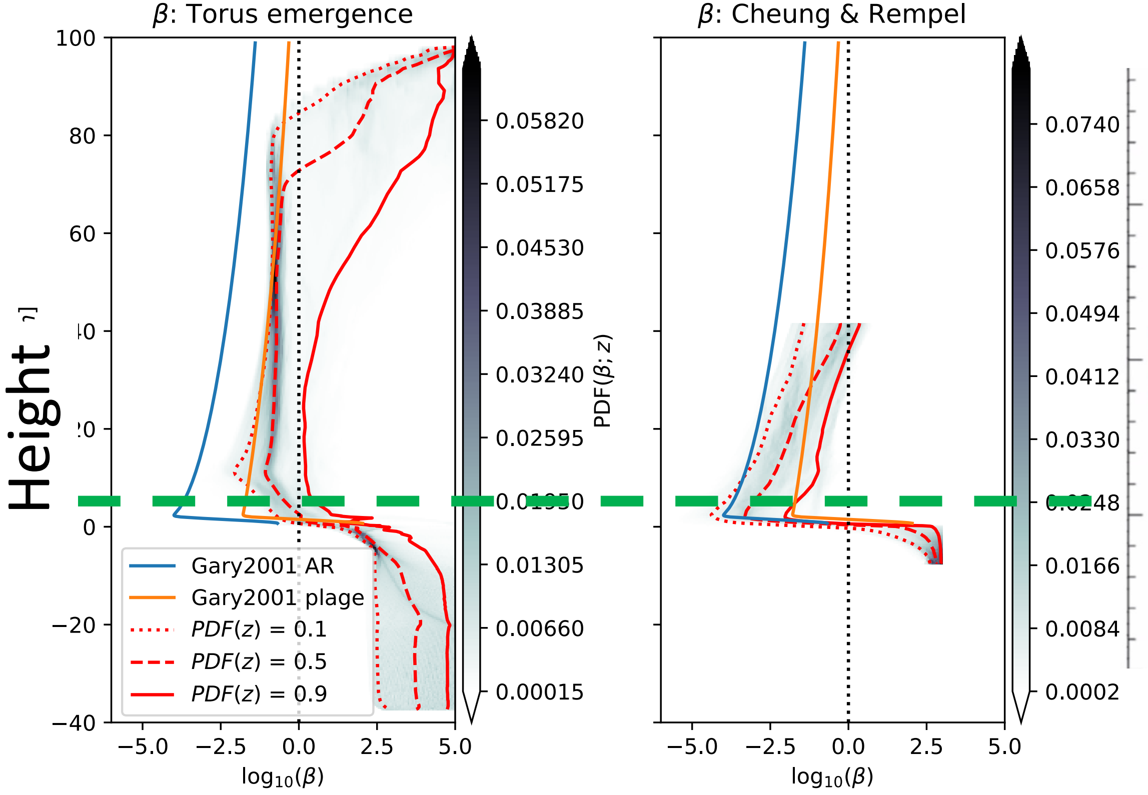




Why data-driving is the way

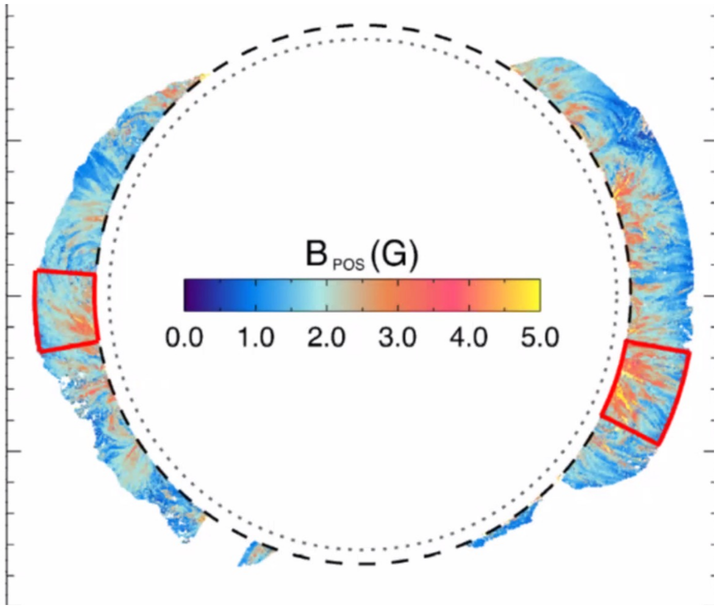


Bourdin 2017, A&A



Tarr+ 2022; Knizhnik+ 2021; Cheung, Rempel+ 2019

From Tomczyk's talk, Yang+2020



- From spectral-inversions, always going to have gaps in spatial coverage
- Dynamic modeling can fill in those gaps

Much of the corona is:

- Low-ish beta (Gary 2001, Peter+2015, Bourdin 2017, …)
- Probably <u>not</u> force free (**Peter+ A&A 2015 584**, Warnecke+2017)
- We don't have enough constraints for accurate static extrapolations
- Dynamic evolution provides additional strong constraints

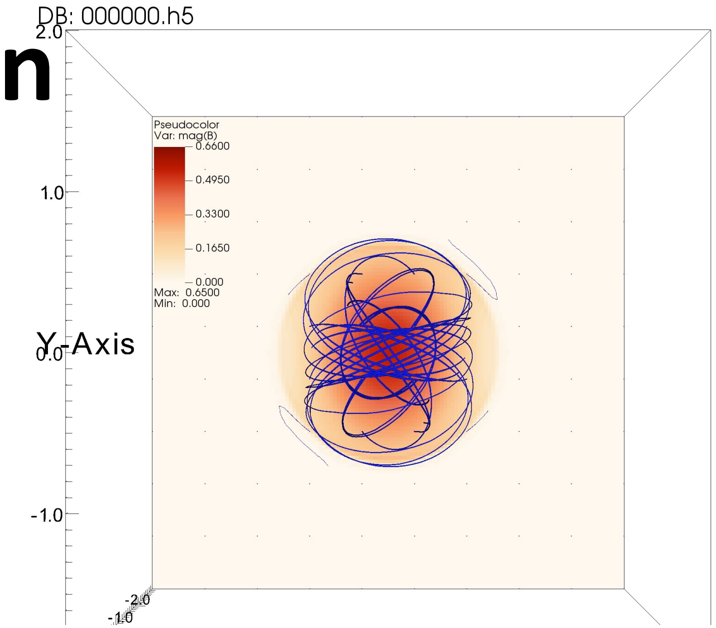
The lower boundary has all the action

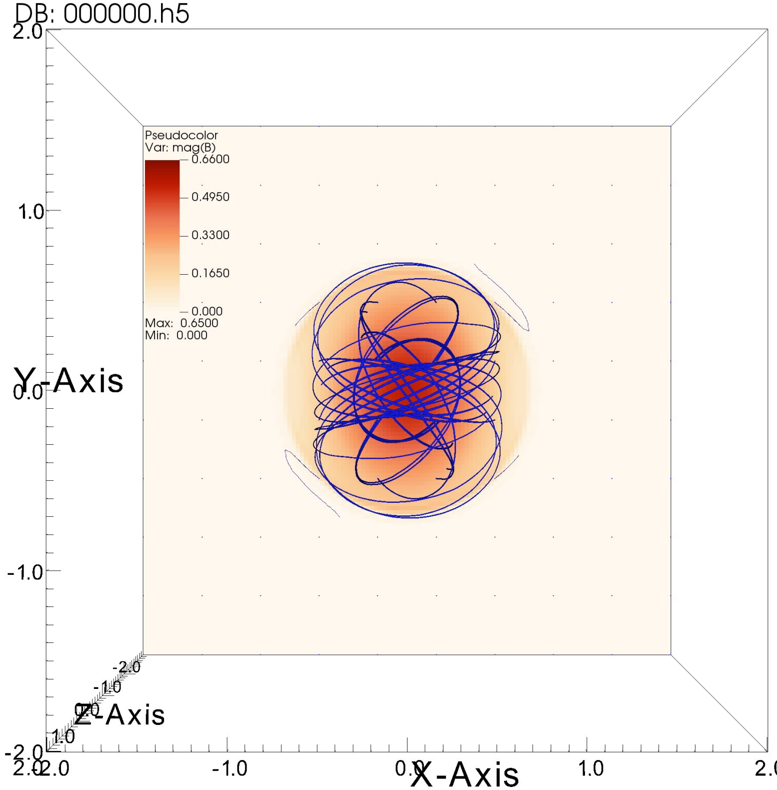
MHD equations are hyperbolic (mostly), and the BC is open:

Have to set the <u>values</u> of all fields and their <u>derivatives</u> in order to get a unique, stable solution (Cauchy BCs, Morse & Feshbach Ch 6.)

Big implications for what observations we need!

- Need spectral lines with broad enough formation height and enough spectral resolution
- Validation through multi-line observations
- Need for 3D spectral inversions
- The combination of Si I + HeI lines at 1.08um were made for this; also 1.5um FeI line





Data-driving challenges and unknowns

- What's the "right" boundary condition?
    - Implementing a BC is the explicit encoding of assumptions about the external universe. What assumptions are the right ones to make (**energy flux, helicity flux,** …)? If our best fix is on the values, what do we use to set the derivatives?
- How dependent is the solution on the initial condition ?
    - (how long does the model remember it's initial state)
- Really need a multi-fluid approach
    - (but step 1 is demonstrate that it works for single-fluid MHD)
- We are going to get multiple things wrong:
    - What is it OK it ignore and what is it best to focus on?
        - **Temporal cadence? Spatial resolution? Sensitivity of solution to different observables?**
    - How do we fix things once they are known to be wrong? (change the initial condition and re-run?)
        - (Data assimilation/copy the weather forecasters; see Benoit's talk)

Model Coupling? e.g., convection <-> low atmosphere <-> solar wind + Fluid <-> kinetic throughout?

Multiple types of validation

1. self-validation :

- Interior solution is deterministic, so any data driven method should be able to reproduce an arbitrary subvolume of its own simulation.
- Focus on getting the physics at the boundary correct and the details of the dynamics correct. THEN it's a matter of how much and what information you can leave out and still accurately reproduce energy? helicity? current distributions?

2. external validation:

- Large-scale coronal fields and plasma properties (COSMO)
- Location and properties of filaments/prominences (ngGONG)
- Details of magnetic field configuration (DKIST)
- |B| as function of "height" (FASR)
- Which comparisons are most useful? I think still currently unknown.

3. Need to support 3D inference from diverse observations, both for getting good initial conditions and for model<->observation comparison down-the-line. Lot of progress (multi-line inversions using, e.g., Hazel2, tomographic inversions)

4. Defining uncertainties is going to be a real issue