Progress Report of WG5 (and related) activities:
The Bs Challenge

Spiros Patsourakos, University of Ioannina, Greece

ISEST 2018 WORKSHOP
24-28 September 2018, Hvar, Croatia

The Bs challenge: Statement of the WG
(from ISEST description)

The presence of **southward** magnetic fields in ICMEs are the most important factor in producing **geomagnetic storms**.

WG5 aims to understand and reconstruct the possible flux rope **magnetic structure** of CMEs/ICMEs from observations and models. It also aims to **predict** the **intensity** and the duration of the **Bs** in ICMEs **upon arriving at the Earth**.

DIFFICULTIES ….

State of the Art

Radio diagnostics of CME coronal & IP magnetic field by Faraday rotation (e.g.,Bird et al. 1985; Jensen & Russel 2008, Liu+ 2007, Jensen+2010; Liu+ 2007; Bisi+ 2016; Kooi+ 2017) & gyrosynchrotron emission (e.g., Bastian+2001;Tun & Vourlidas 2013; Carley+2017) are difficult & rare

Advent of methods to **infer** the CME magnetic field in the corona/IP

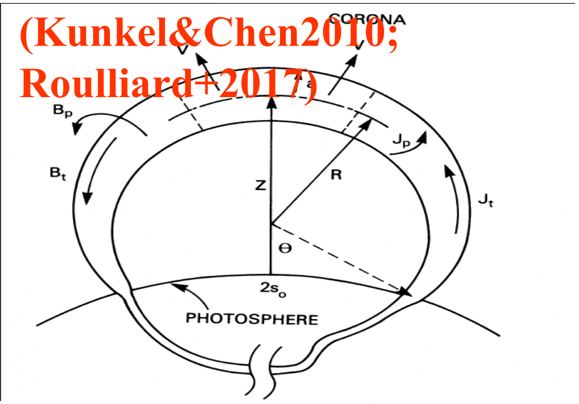
Emergence of magnetized CME heliospheric propagation models for space-weather predictions (EUHFORIA, COIN-TVD, ENLIL, SUNSANOO); constraints by coronal CME b-field inferences

Sun-to-Earth CME simulations (AWSoM, MAS thermodynamic): genesis& propagation

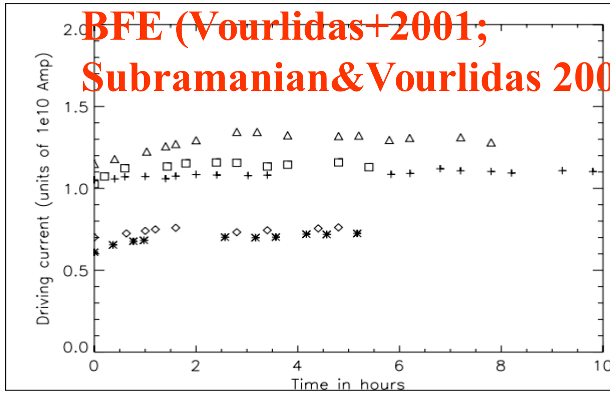
Development of **statistical framework** to compare Bz-predictions with observations

Many Models of CME Magnetic Field Infererence

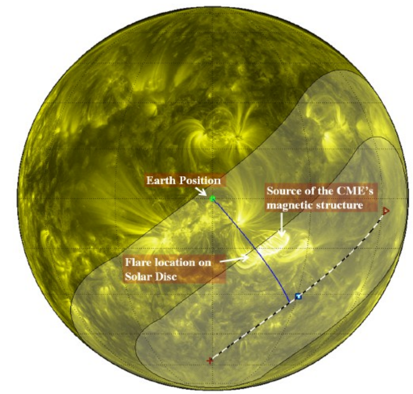
HELIO-XM (Kunkel&Chen2010; Roulliard+2017)



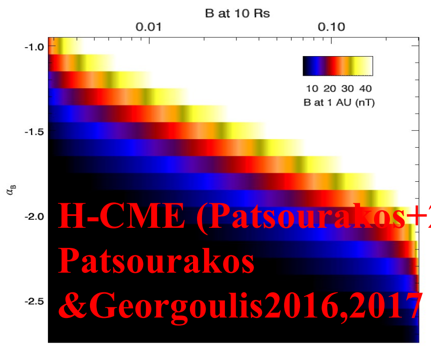
BFE (Vourlidas+2001; Subramanian&Vourlidas 2009)



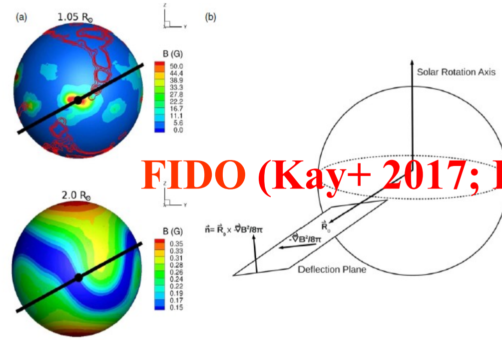
BZ4CAST (Savani+ 2015, 2016)



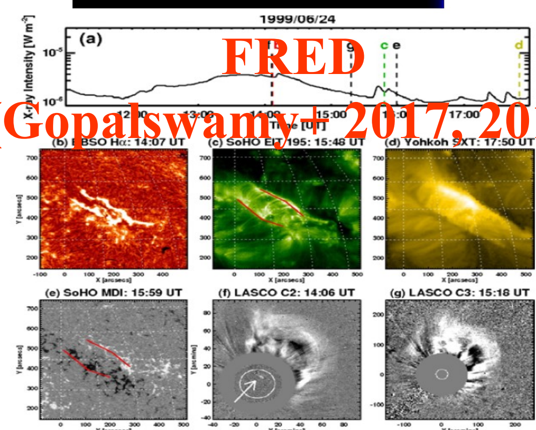
H-CME (Patsourakos+2016; Patsourakos &Georgoulis2016,2017



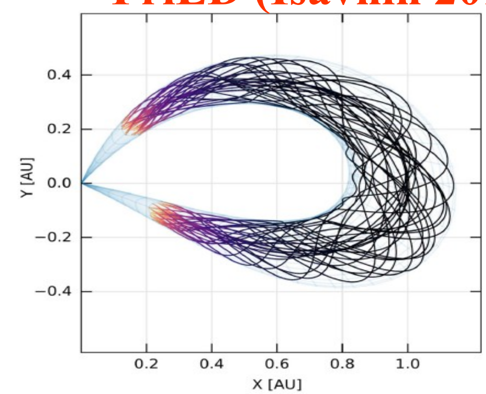
FIDO (Kay+ 2017; Kay&Gopal 2017b)



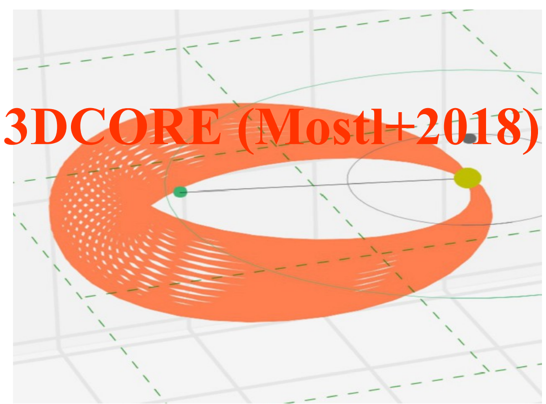
FRED (Gopalswamy+ 2017, 2018)



FriED (Isavnin 2016)



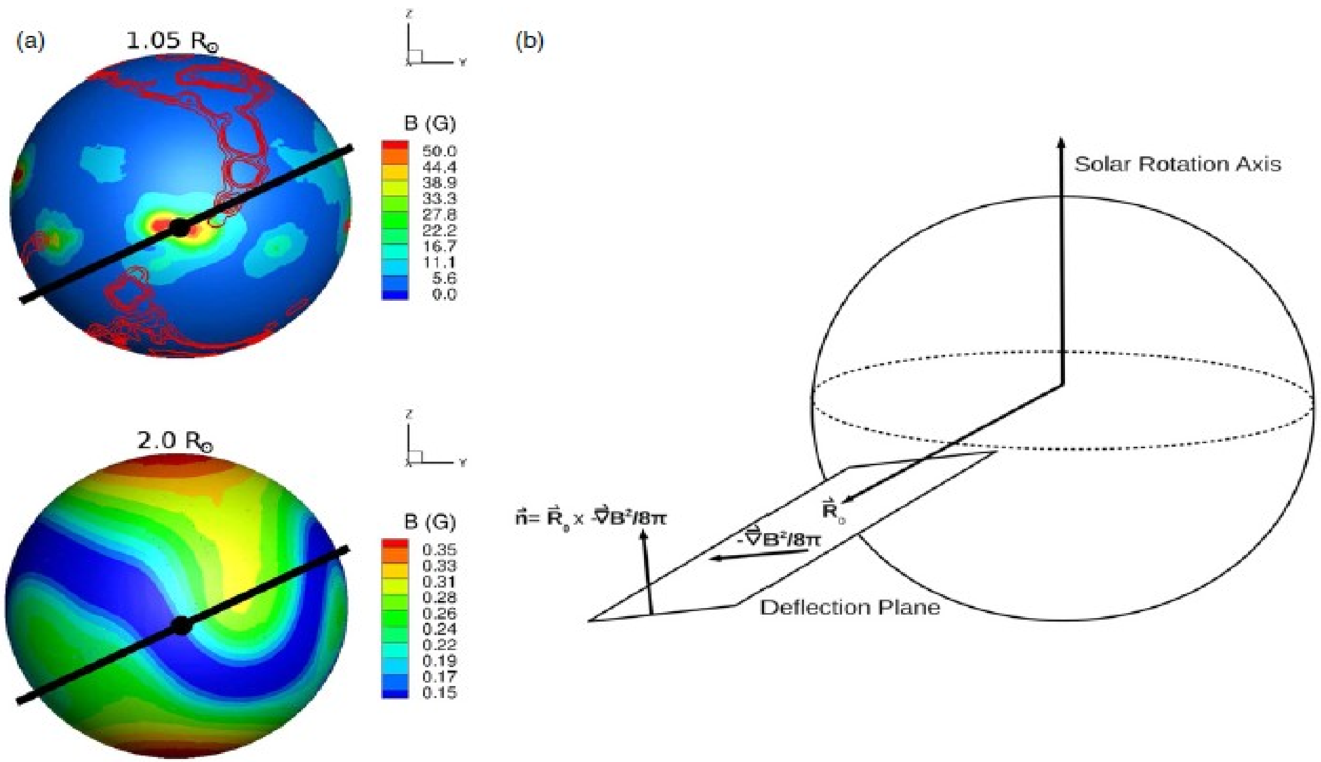
3DCORE (Mostl+2018)



FIDO (Kay+2017; Kay&Gopalswamy 2017)

ForeCAT semi-analytical data-constrained model (Kay+2013,2014,2015)

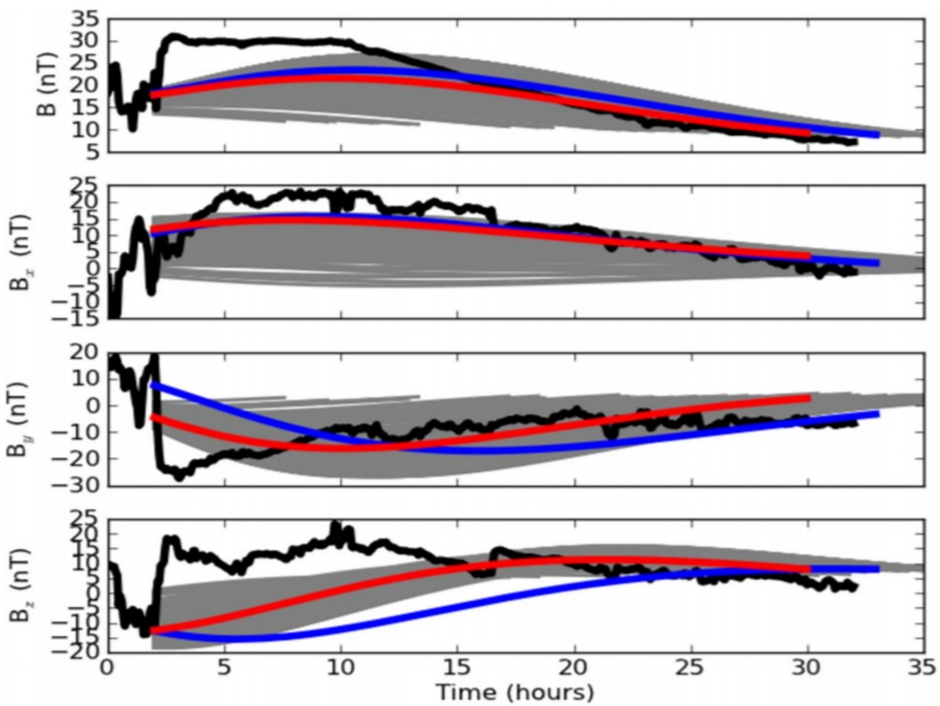
magnetic forces acting on CMEs --> **near-Sun CME deflection + rotation**



LFF cylindrical model + flux conservation --> B CME @ 1 AU

FIDO (Kay+2017; Kay&Gopalswamy 2017)

Applied to 49 events



black ---> observations

blue --> no deflection/rotation

red ---> model

ballpark agreement

gray --> uncertainties

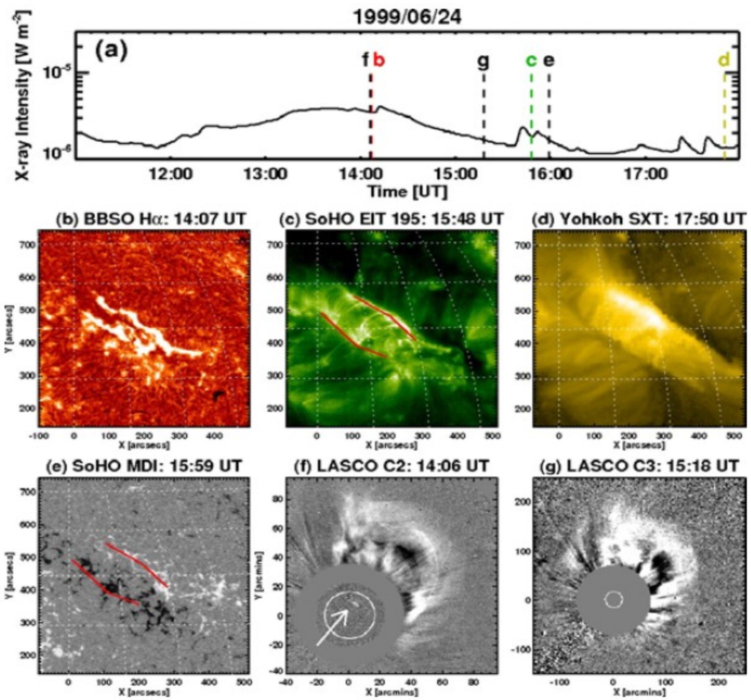
5 deg (lat); 10 deg (lon,tilt)

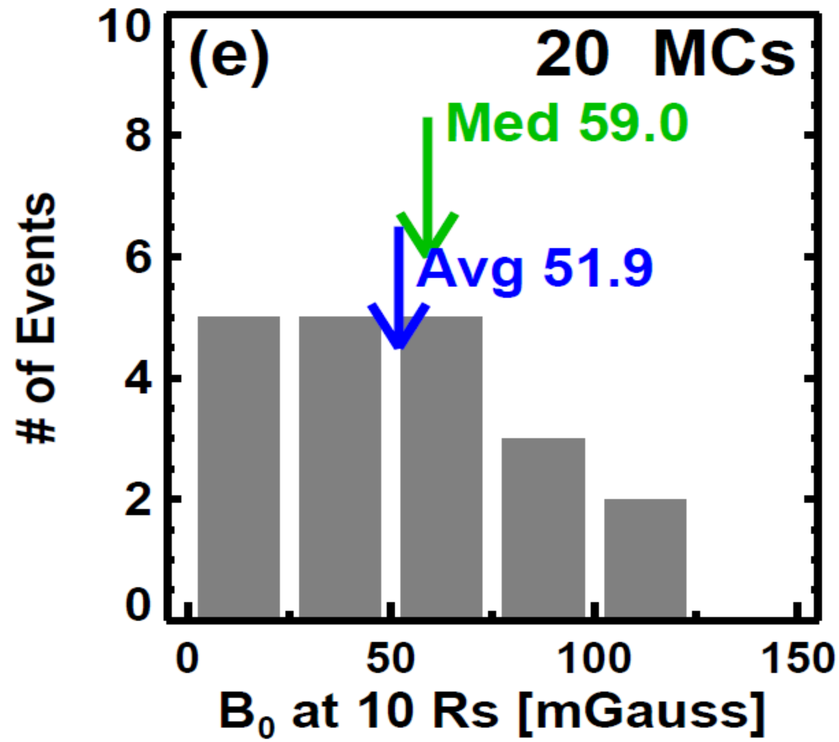
B sensitive to uncertainties of CME location/orientation

--> **C. Kay talk**

Uses in-situ observations @ 1 AU for near-Sun CME |B|

FRED (Gopalswamy+ 2017, 2018)

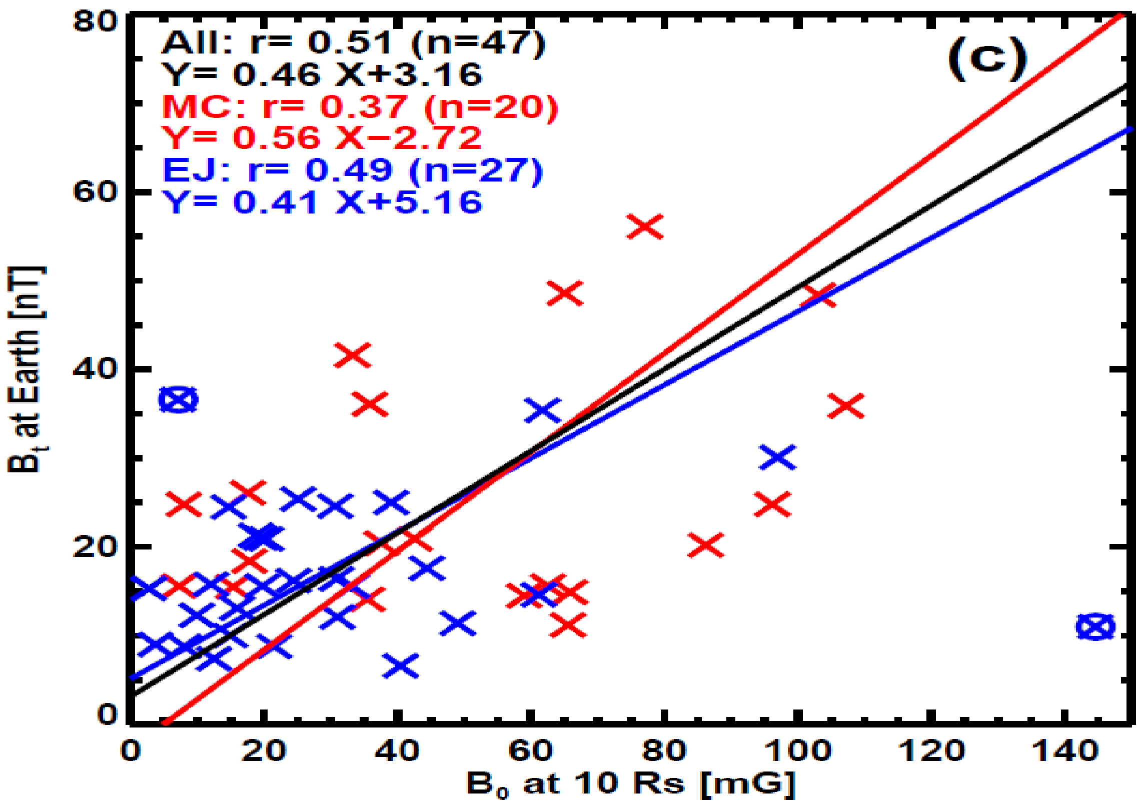




Calculate reconnected flux in post-eruption arcades + fit flux rope model to corresponding CMEs from LASCO observations of 54 CMEs

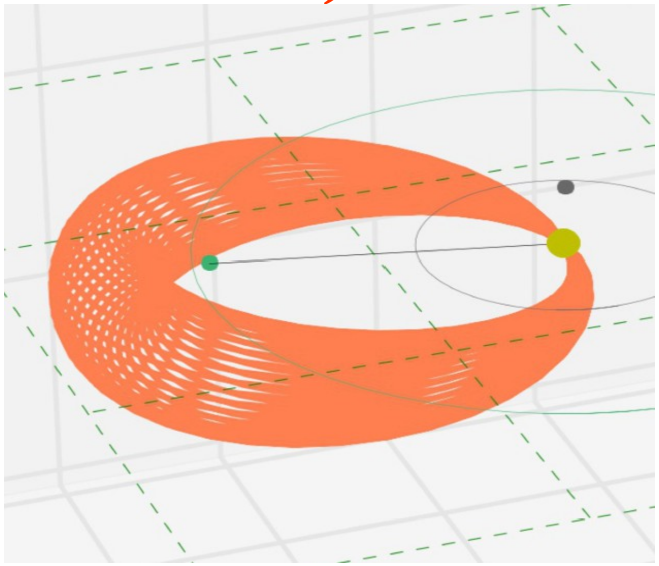
Apply constraints to cylindrical LFF model ---> **CME magnetic field at 10 Rs** (> ambient)

FRED: Coronal and IP attributes (Gopalswamy+ 2017,2018)



correlation btw near-Sun BCME + MC axial field

3DCORE (Mostl+2018)

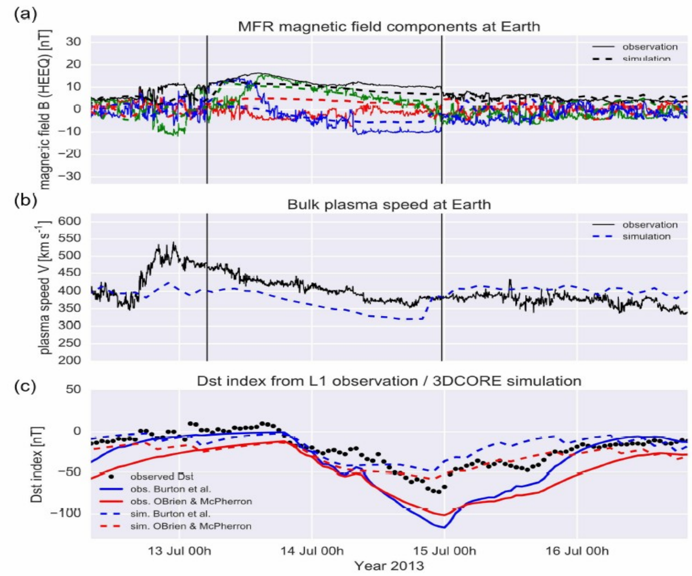


Stack 2D Gold-Hoyle sections to a 3D tapered torus & flux conservation

drag-force model Vrsnak + 2013 --> kinematics

applied to a case study

Ballbark agreement + ToA



Uses in-situ observations @ **Messenger** to determine near-Sun CME |B|

H-CME (Patsourakos+2016)

For LFF cylindrical flux rope (Lundquist 1950) :
Dasso, Mandrini, Demoulin et al. 2003 →

$$B_0 = \sqrt{\frac{2.405 H_m}{4\pi L R J}}$$

L, R → CME length+ radius from GCS
modeling of CMEs with STEREO (Thernisien et al 2009)

Hm → from photospheric magnetic/flow obs & extrapolations (e.g., Valori et al. 2017) ; conserved (e.g., Berger 1985)

Near-Sun CME magnetic field B_0

Extrapolation of coronal CME b-field to 1 AU

Use a power-law of the radial distance r:

$$B_0(r) = B_*(r/r_*)^{\alpha_B}$$

αB → [-2.7, -1.0] from Demoulin & Dasso 2009

αB is a free parameter used to match the in-situ observations

Parametric Studies of H-CME *(Patsourakos& Georgoulis 2016,2017)*

Generate *10^4 synthetic CMEs by*
by taking random samples from the observed AR Hm (Tziotziou+ 2012) & CME geometrical parameter (Thernisien+2009;Bosman+ 2012) distributions

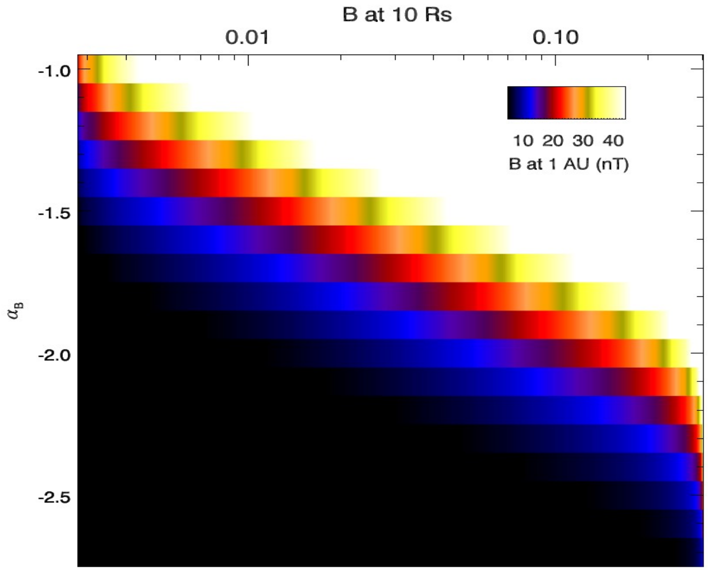
↓

Determine near-Sun B for the 10^4 synthetic CMEs*

↓

Extrapolate CME b-field to 1 AU for different αB for the 10^4 synthetic CMEs

Parametric Studies of H-CME (*Patsourakos& Georgoulis 2016,2017*)

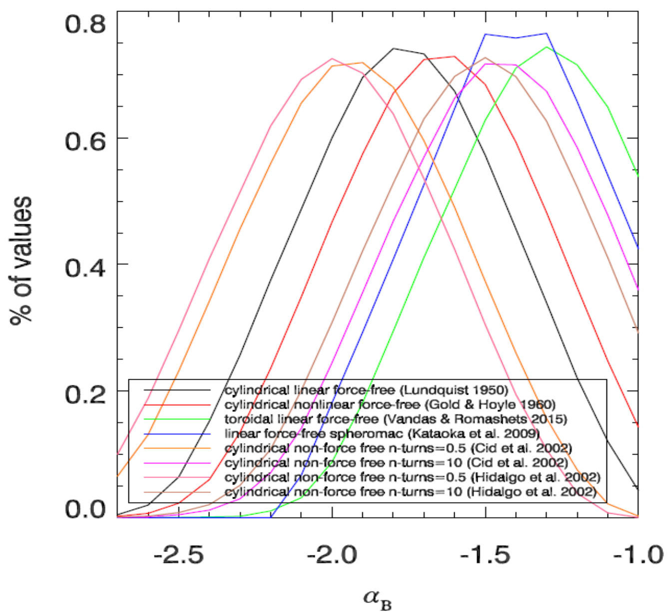


LFF cylindrical model

color --> extrapolated to 1 AU CME magnetic field

black+white ---> outside range of MC observations (Lynch+2003; Lepping+ 2006)

region around αB~-1.6 fits reproduces the bulk of MC observations

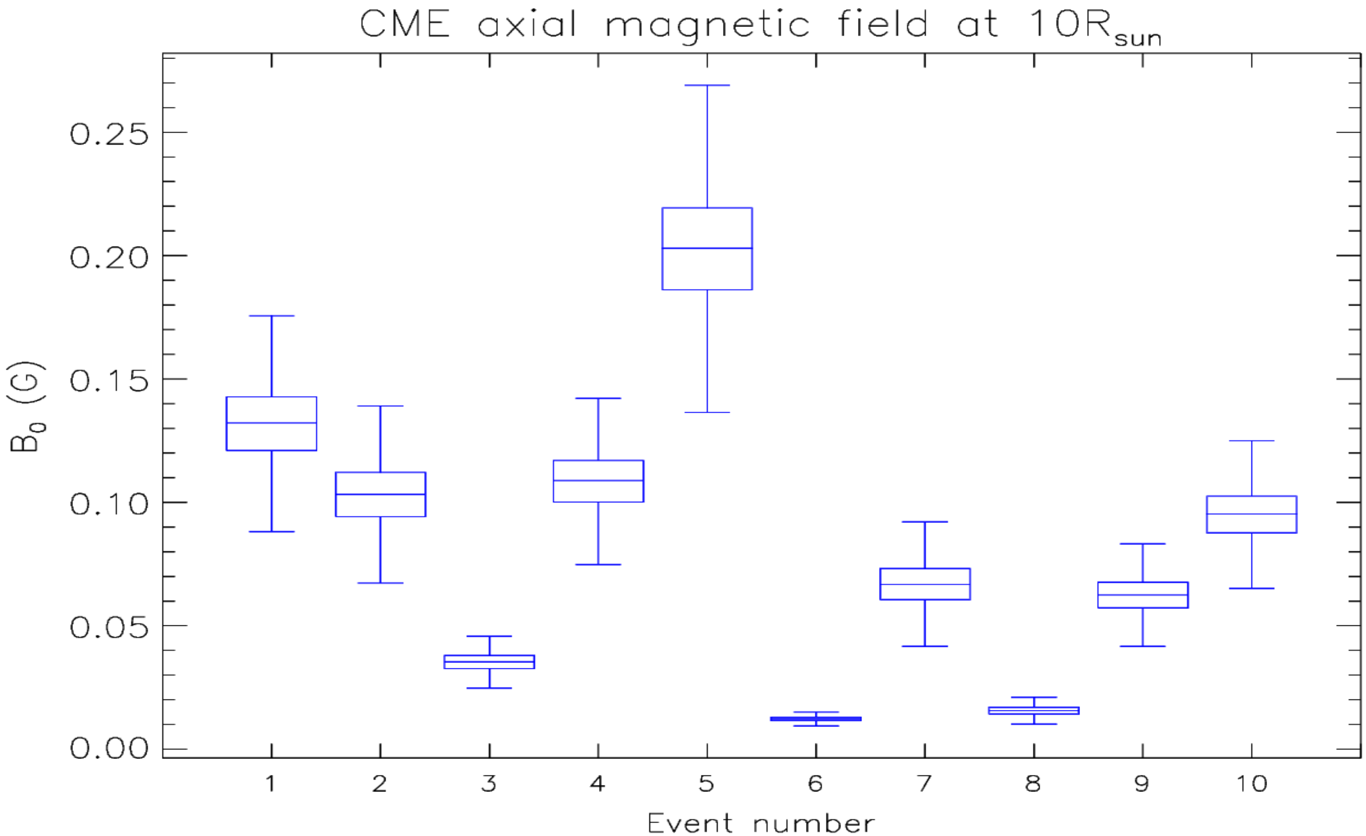


extension to various CME models (e.g., non-force-free, spheromac etc)

% of predicted values within the range of MC observations as a function of α_B

robustness of models for specific α_B-range is used

H-CME application to 10 CMEs (Petroulea+2018)



ISEST event list 10 C-X class flares (Hess&Zhang 2017)

assess uncertainties in derived magnetic fields

x10 range in |B|; higher than ambient

Summary of CME b-field inference models (Vourlidas+2018)

Model	HELIO-XM	BFE	BZ4CAST	H-CME	FiDO	Fried	FRED	CORE3D
shape	torus	cylinder	cylinder	cylinder/torus/spheromac	torus	torus	torus	torus
principle	hoop force	CME energetics	hemispheric helicity rule & region of influence	magnetic helicity conservation	force balance	flux conservation along 3D torus	reconnected flux	populate 3D torus with 2D magnetic sections
Near-Sun magnetic field	non-force-free	force-free	force-free	force-free/non-force-free	force-free	force-free	force-free	force-free
|B| near-Sun	Y	Y	CCMC simul of sheath	Y	N	N	Y	N (@ Messenger)
near-Sun deflections	N	Y	Y	Y	Y	Y	N	Y
IP propagation	radial	radial	radial	radial	radial	radial	radial	radial
|B| IP evolution	force-balance	flux conservation	CCMC simulation	power-law with varying αB	flux conservation	flux conservation	flux conservation	flux conservation
B vector	Y	N	Y	N	Y	Y	N	Y

HELIO-XM: Kunkel & Chen (2010); Roulliard & Lavarra (2017)
BFE: Vourlidas et al. (2001); Vourlidas & Subrahmanian 2007
BZ4CAST: Savani et al. (2015,2016)
H-CME: Patsourakos et al. (2016); Patsourakos & Georgoulis (2016,2017)
FIDO: Kay et al. (2017); Kay & Gopalswamy (2017)
Fried: Isavnin (2016)
FRED: Gopalswamy et al. (2017,2018)
CORE3D: Mostl et al. (2018)

no perfect model; pros + cons

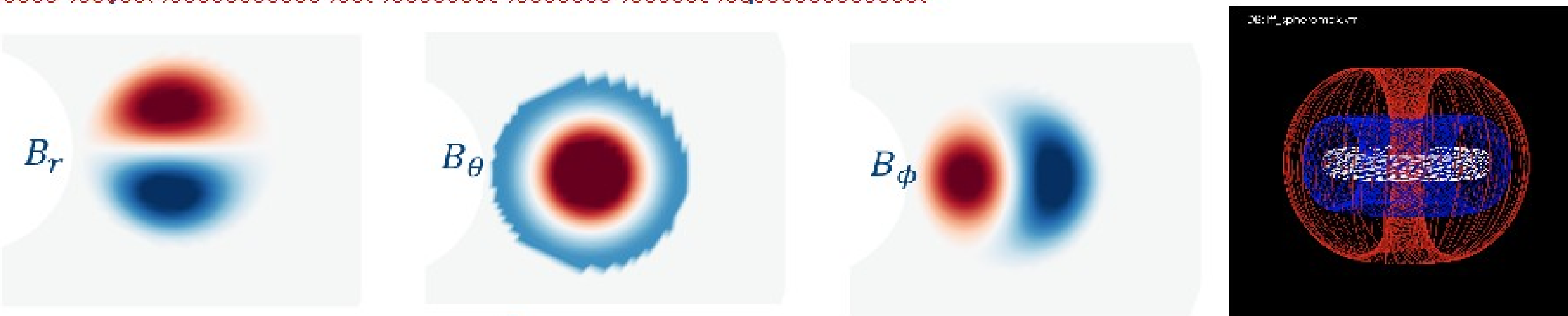
Mostly "fit" in-situ
(|**B**|coronal from in-situ observations, radial fall-off of B parametrized to match in-situ, sheath-region,used instead of flux rope)

models **capture** the distribution of **B in its components at 1 AU**

Empirically-Constrained Heliospheric CME Models

EUHFORIA: Spheromak CME

Flux rope modeled as Linear Force Free Spheromak



CME kinematics
Cone model

inner boundary @ 20 Rs

- Start time of CME
- Propagation velocity of CME
- Latitude of centre of CME source region
- Longitude of centre of CME source region
- Half-width of CME
- Density of CME
- Temperature of CME
- Title angle of the CME
- Helicity of the CME
- Total toroidal flux

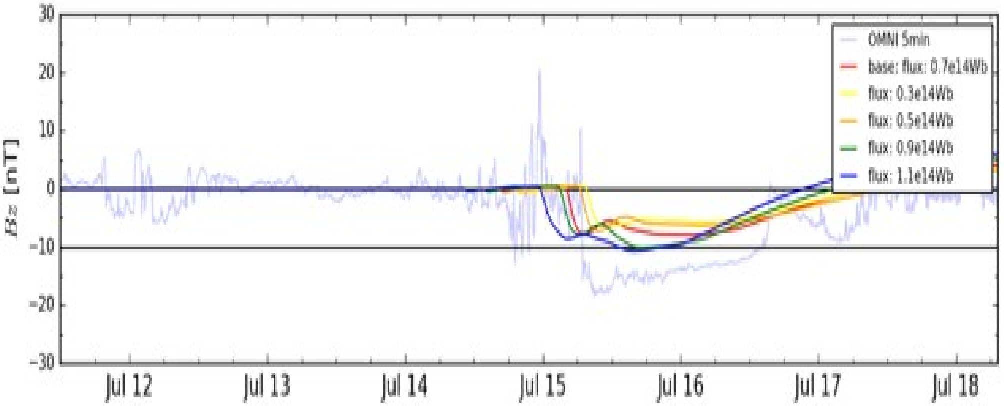
Flux rope parameters

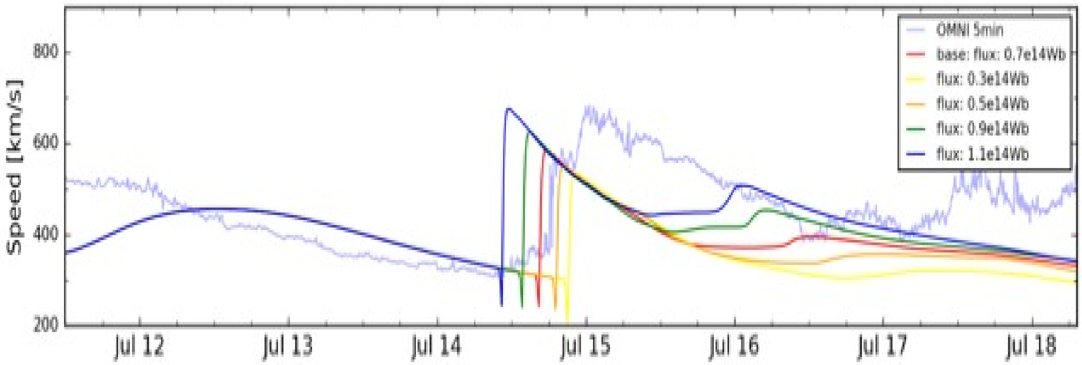
Talks by C.Scolini; D. Odstrcil ENLIL; F. Chen COIN-TVD

Parameter study using EUHFORIA (Verbeke+2018)

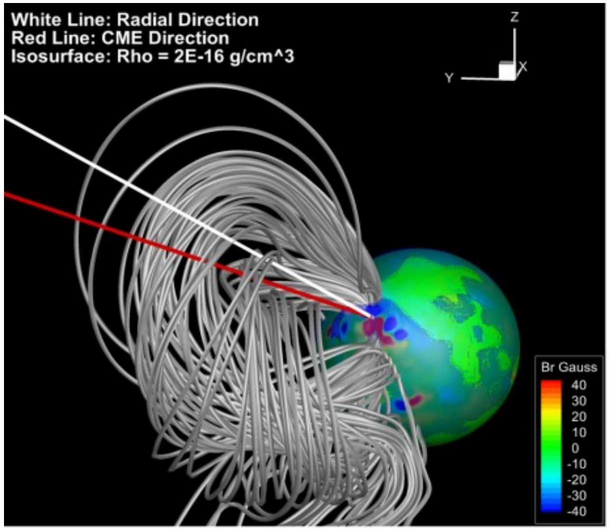
Use **FRED coronal magnetic field** to **initialize** the model for the major CME of 12 July 2012

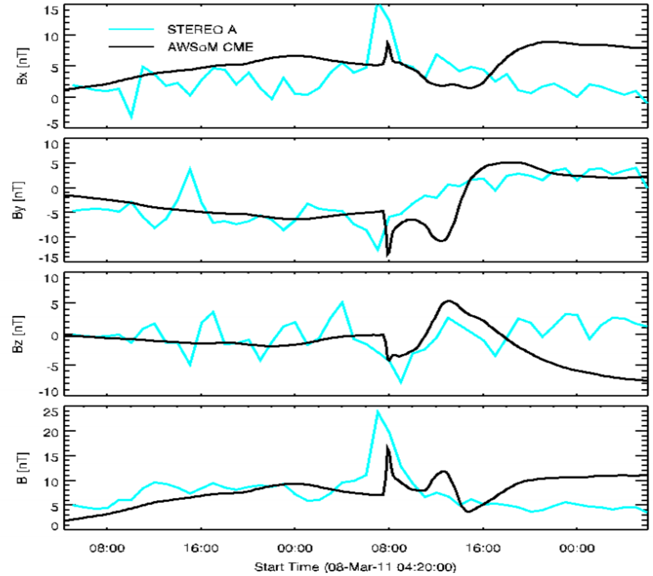
change the **CME axial flux** by a factor ~ **7 --> significant changes in B** at **1 AU** & ToA





Sun-to-Earth MHD CME simulations

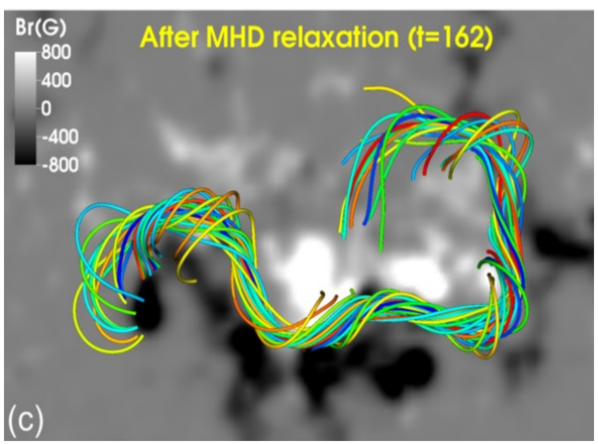


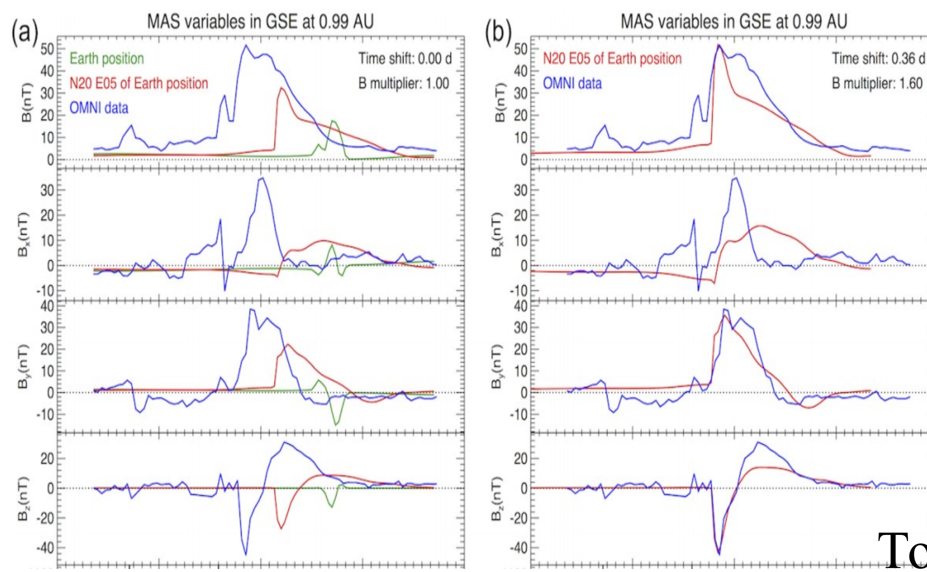


recovers shock structure

Jin+2017a,2017b
talk by M. Jin

unstable flux rope





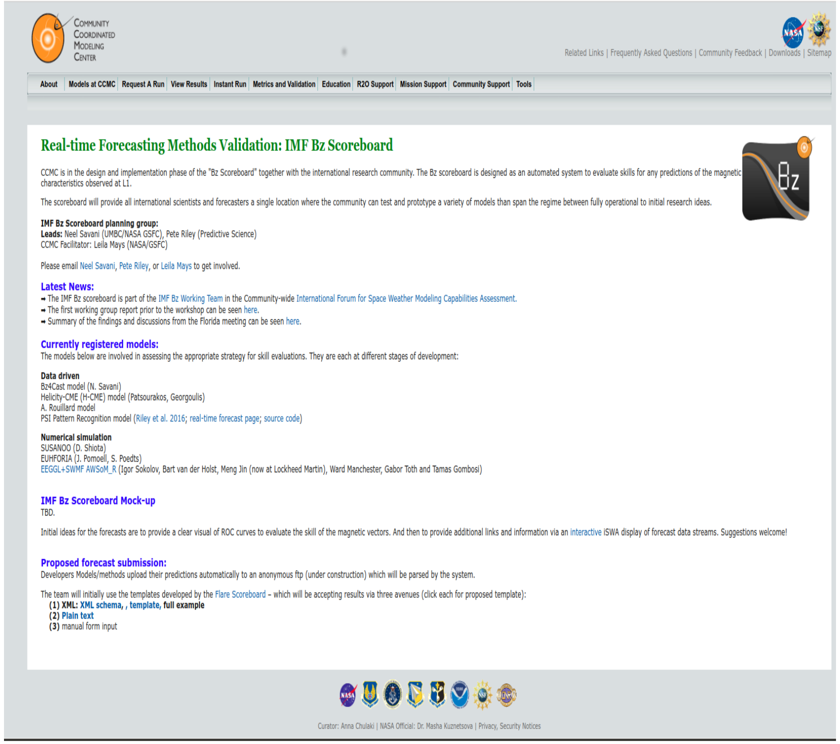
Torok+2018

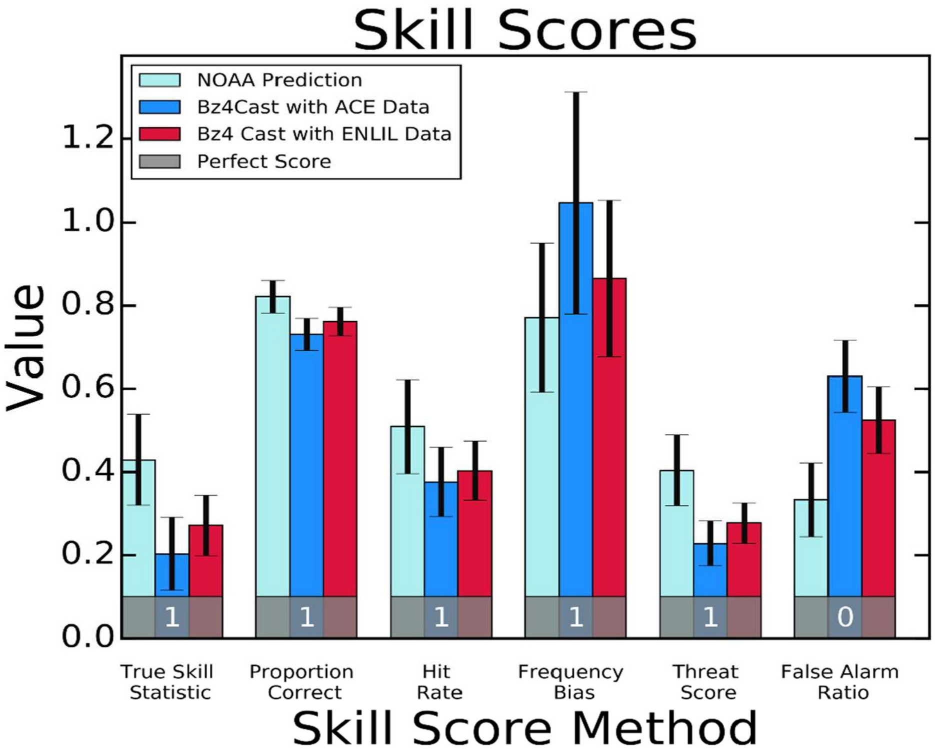
energize stable flux rope w/ boundary flows

x1.6 |**B**| + shift by 20 deg N to match in-situ

Standardizing Bz forecasting models

Build a common framework to compare Bz models with observations (e.g., various skill scores, ROC curves etc; widely used in weather & flare forecasting)

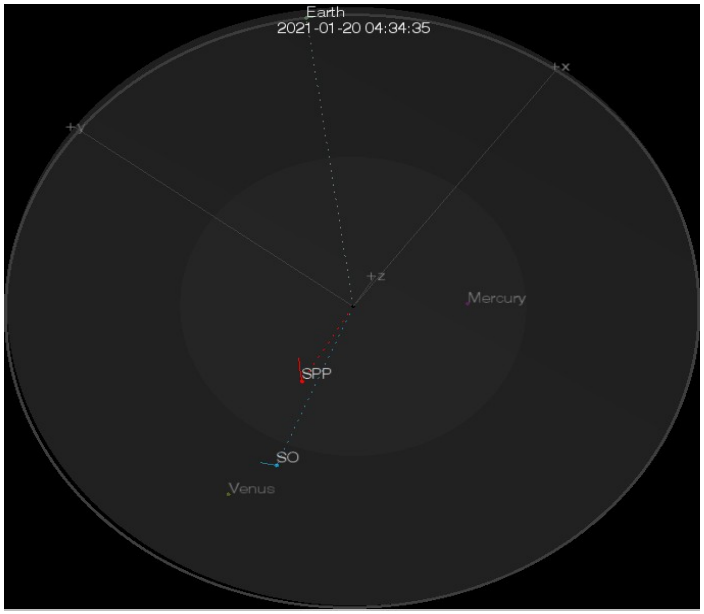


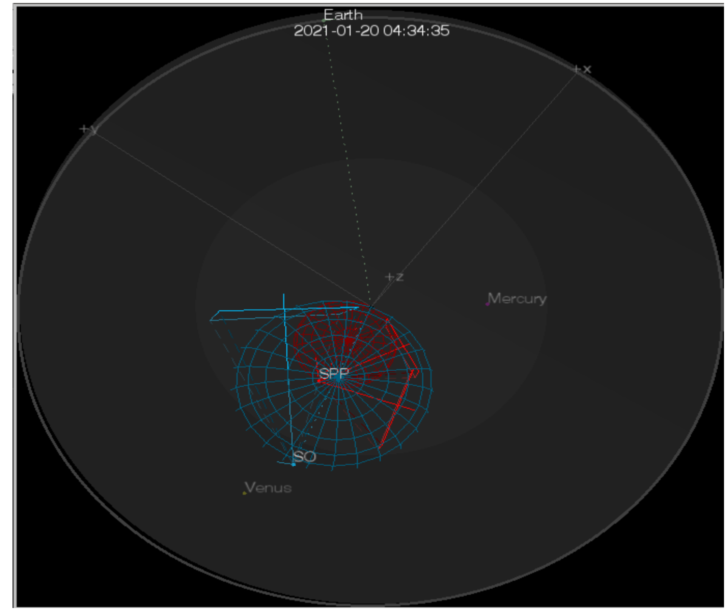


IMF Bz scoreboard @ CCMC
Savani, Riley, Mays

B4CAST model (Savani+2015;2016) achieves similar scores as NOAA forecasters (Austin& Savani 2018)

Coming up soon: PSP & SoLO observations

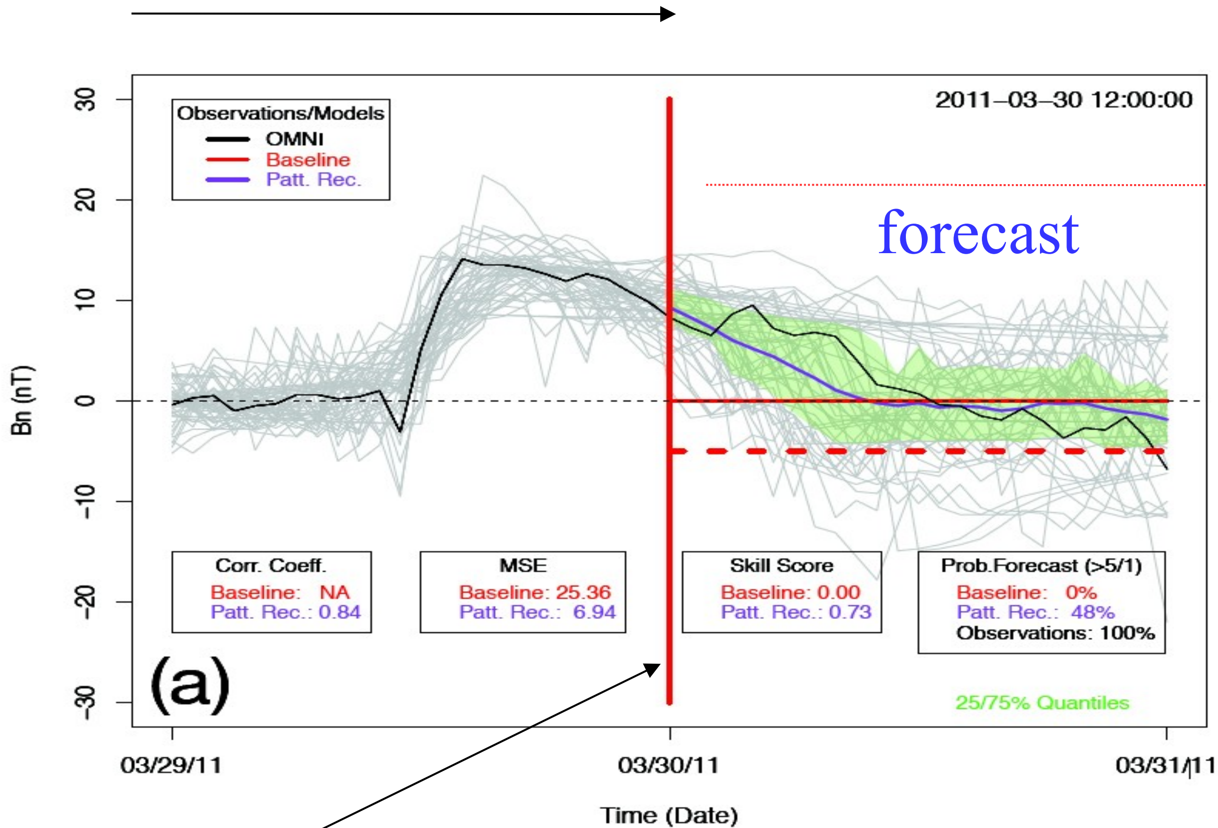




track CMEs along the SC line with:
remote sensing from both SolO (METIS&SolO HI) & PSP (WISPR)
+ source region from PHI+SPICE+EUI(HRI)
& in-situ

validate near-Sun CME B-field inferences & determine its nature (LFF?, NLFF?
Nieves-Chinchilla talk on ICME models)
determine radial fall-off of B from corona to IP
better understand & characterize background solar wind

Bz prediction w/ pattern recognition (Riley+ 2017)



Set **reference time** & **define window dt in past**

Search 10 years of in-situ data for 50 best dt-long intervals & use their next dt for forecast

Good match between forecast + observations

Part of the MC should be already observed

Outlook

Test various existing models on the same events & exploit any radio available

Assess uncertainties of observational inferences & impact on heliospheric simulations

Come up with hybrid schemes

Consider complex set-ups (e.g., multiple CMEs, shocks)

Exploit the PSP & SoLO data-stream

Major element of ISEST follow-up