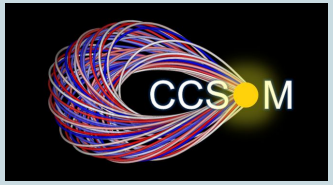

The effect of AMR on the advanced magnetized CME model

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[3] Institute of Physics, University of Maria Curie-Skłodowska, Lublin, Poland

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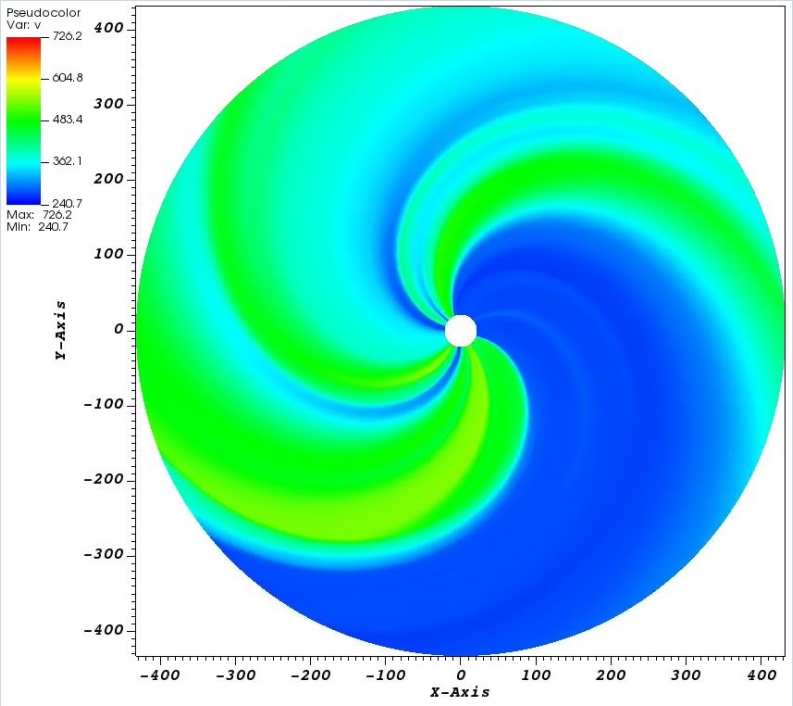
Icarus (Verbeke et al., 2022)

New heliospheric model in ***MPI-AMRVAC*** (Xia et al., 2018)

- Ideal MHD equations (polytropic index γ=1.5)
- Model of the Solar wind from **0.1AU** to **2AU**
- Input: Solar wind data generated from a magnetogram
- Reference frame co-rotating with the Sun

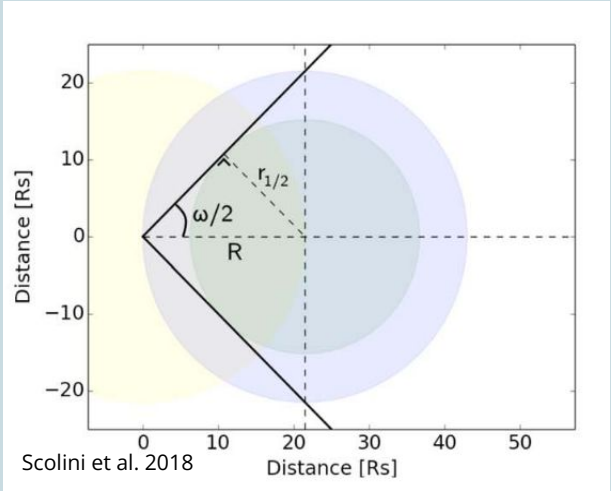


Icarus (Verbeke et al., 2022)

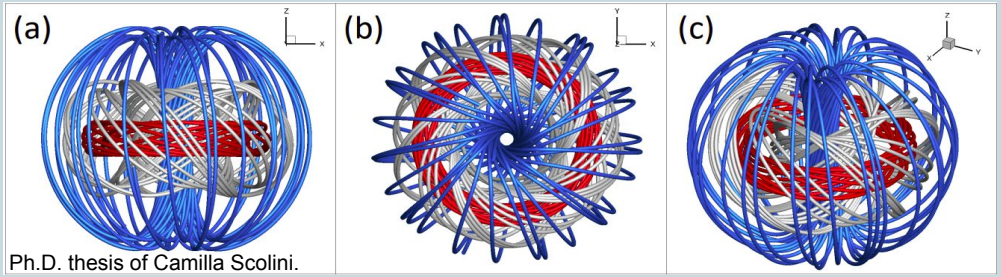
New heliospheric model in *MPI-AMRVAC* (Xia et al., 2018)

- Propagation of the Coronal Mass Ejections (**CMEs**) in the domain
  - Cone model
  - Magnetized CME model

Cone CME



Spheromak



Icarus (Verbeke et al., 2022)

New heliospheric model in *MPI-AMRVAC* (Xia et al., 2018)

- Propagation of the Coronal Mass Ejections (**CMEs**) in the domain
  - Cone model
  - Magnetized CME model
- Advanced Techniques:
  - Radial grid Stretching
  - Adaptive Mesh Refinement (AMR)

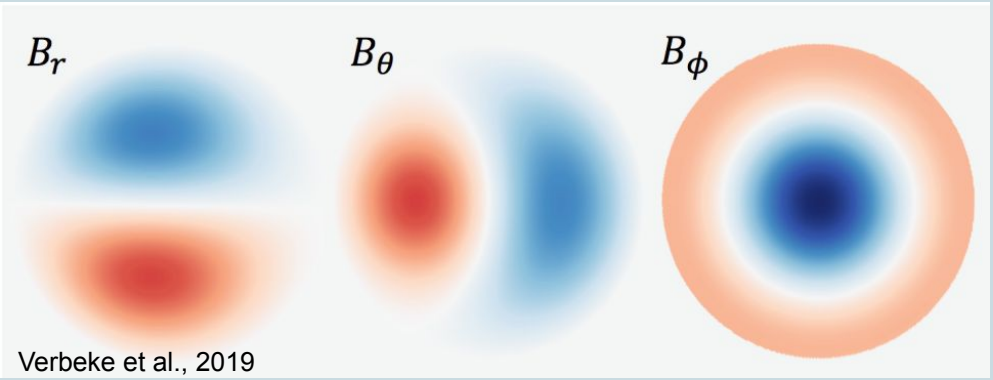
Linear Force-Free Spheromak (LFFSpheromak(Shiota&Kataoka, 2016))

$$B'_r = 2B_0 \frac{j_1(\alpha r')}{\alpha r'} cos\theta',$$

$$B'_\theta = -B_0 \left[\frac{j_1(\alpha r')}{\alpha r'} + j'_1(\alpha r') \right] sin\theta',$$

$$B'_\phi = H \cdot B_0 j_1(\alpha r') sin\theta'.$$

Magnetic field is divergence free and force-free

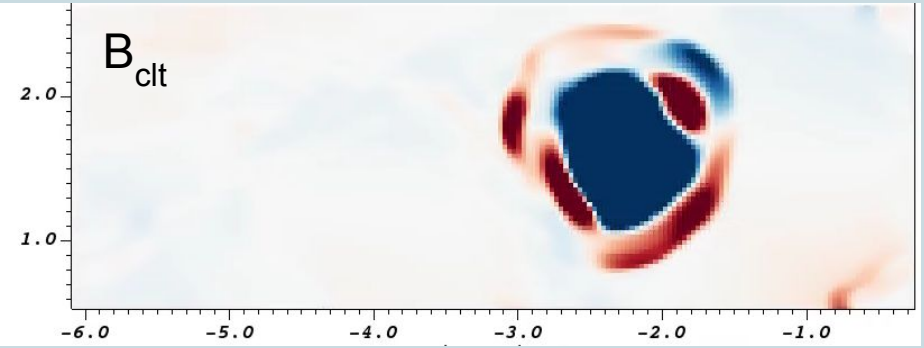


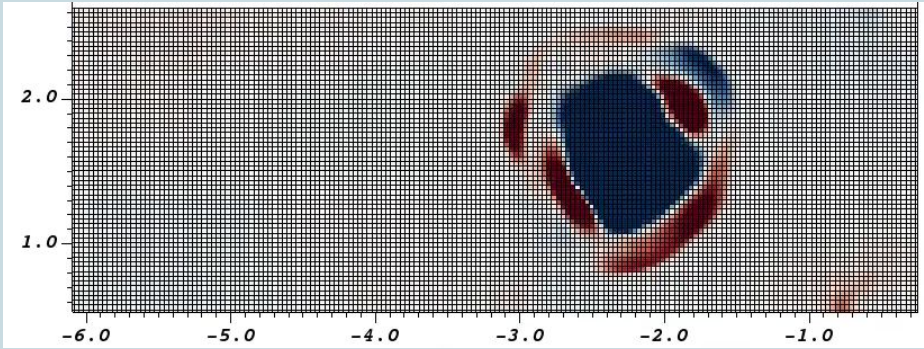
Verbeke et al., 2019

Magnetic field components of an LFFS model with tilt angle τ_{CME} of 90.0 [deg] in the meridional plane in HEEQ coordinates. **Red** and **blue** correspond to **positive** and **negative** magnetic field components, respectively.

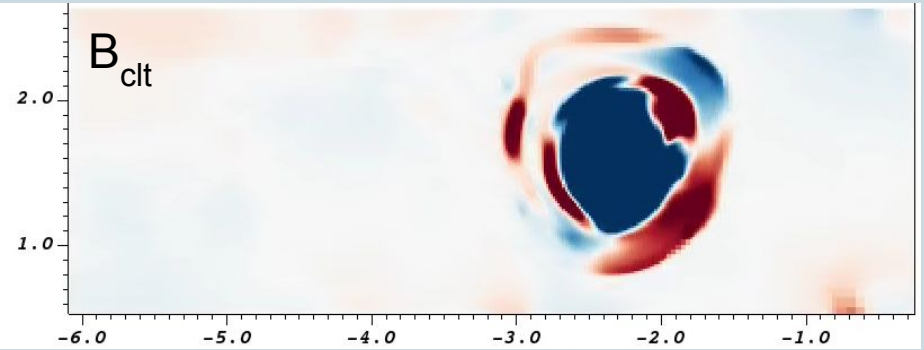
Adaptive Mesh Refinement (AMR) on spheromak

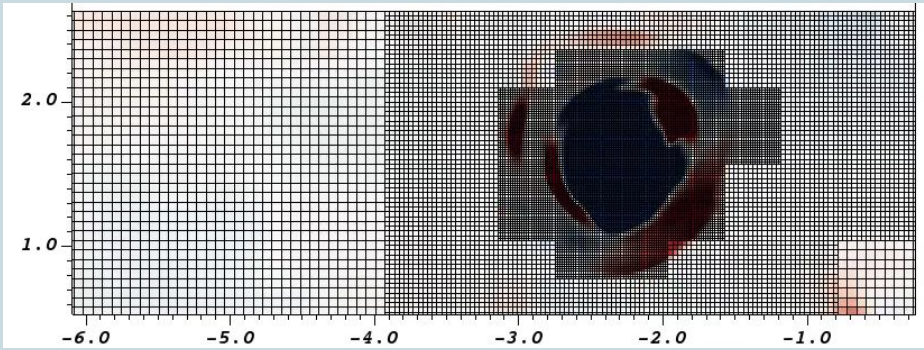
Middle Resolution





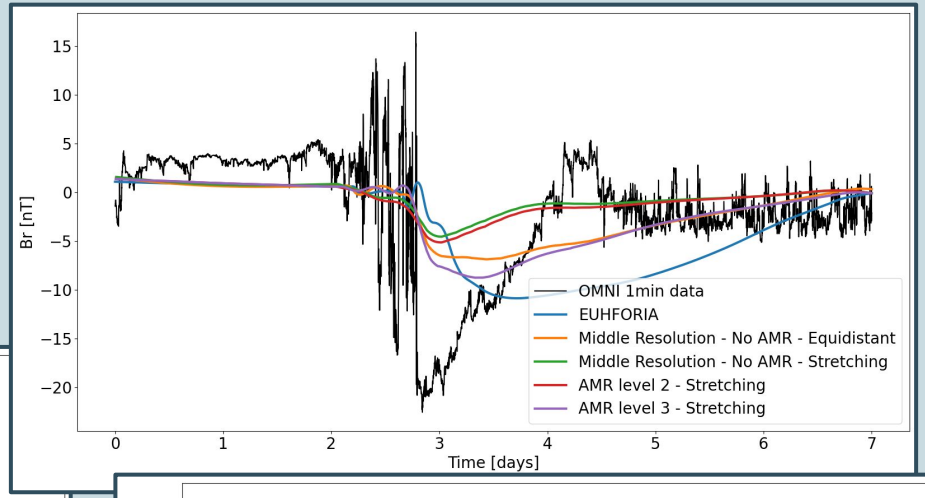
AMR level 3

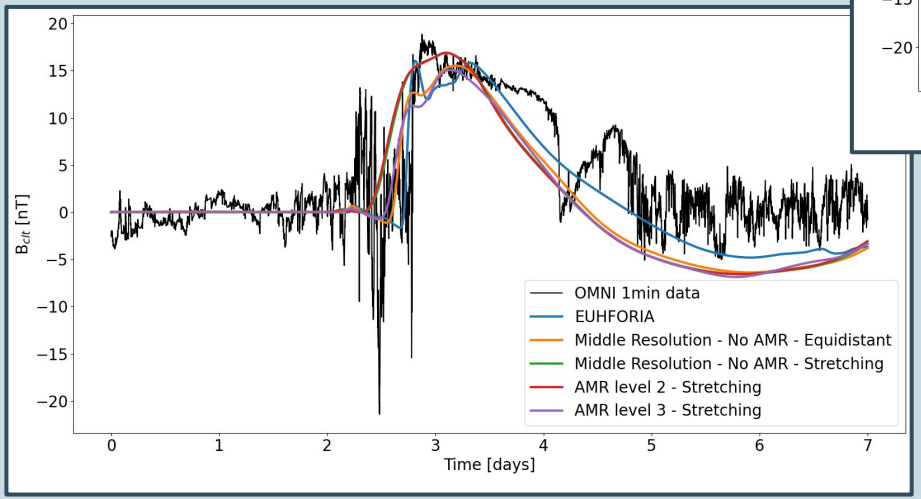


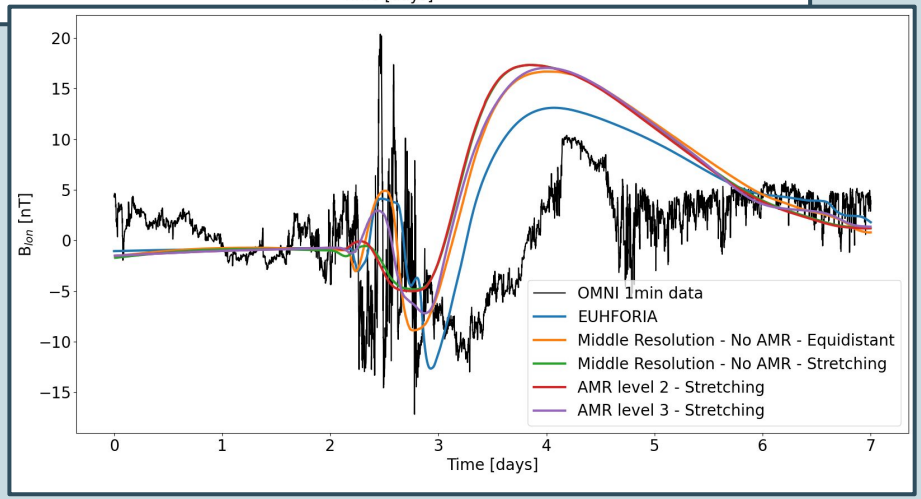


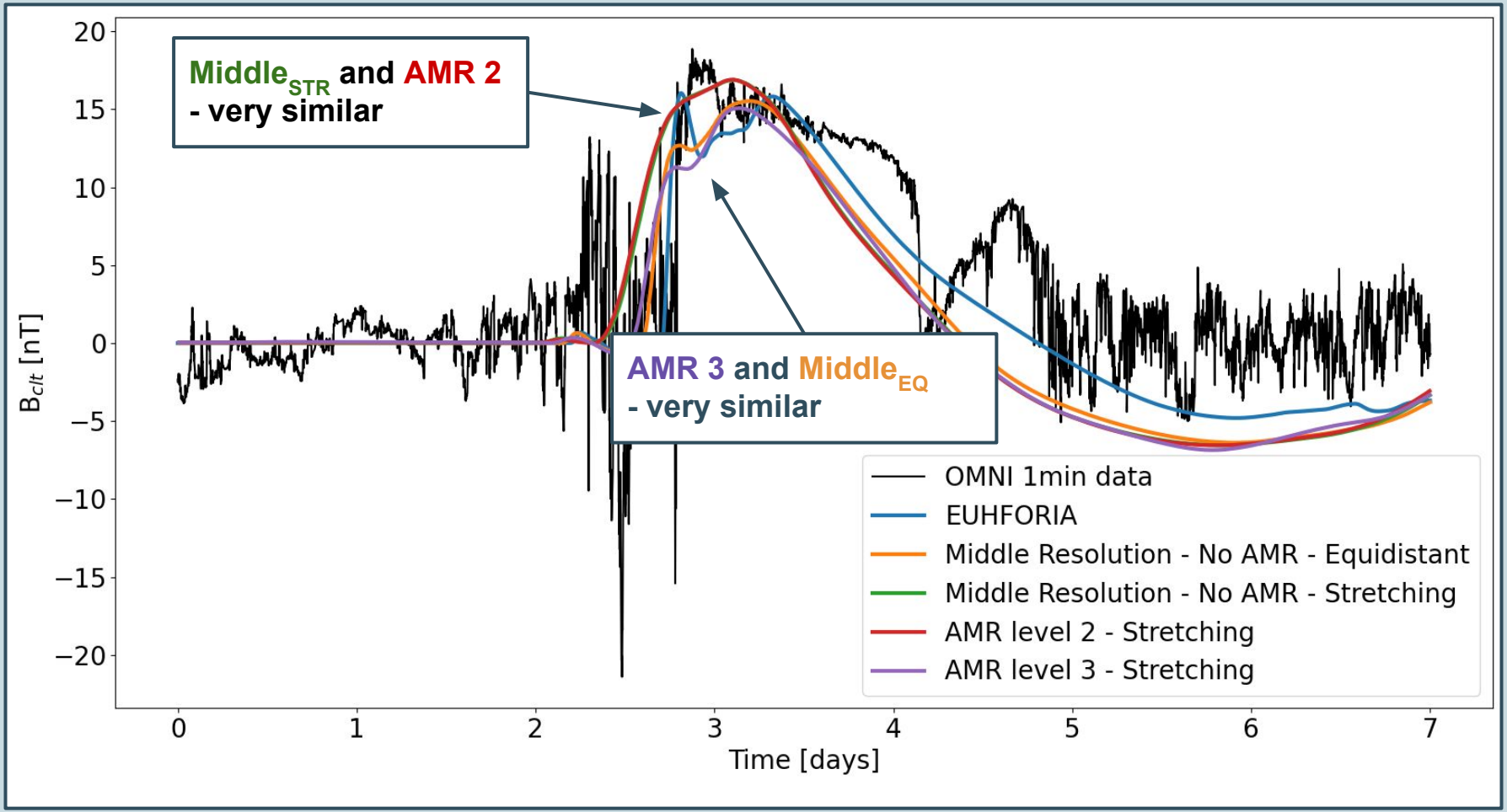
Time series at Earth

CME event: July 12th, 2012 from the NOAA AR 11520.








Middle$_{STR}$ and AMR 2
- very similar
AMR 3 and Middle$_{EQ}$
- very similar
OMNI 1min data
EUHFORIA
Middle Resolution - No AMR - Equidistant
Middle Resolution - No AMR - Stretching
AMR level 2 - Stretching
AMR level 3 - Stretching
B_{clt} [nT]
Time [days]
20
15
10
5
0
−5
−10
−15
−20
0
1
2
3
4
5
6
7

Speed up

	EUHFORIA (Middle resolution)	Icarus (Middle) Equidistant	Icarus (Middle) Stretched	AMR 2	AMR 3
Wall-clock times	18h 2m	6h 9m	1h 3m	0h 14m	0h 38m

Simulations are performed on **1 node only (with 36 CPUs)** on the Genius cluster at the Vlaams Supercomputing Centre.

Speed up factors

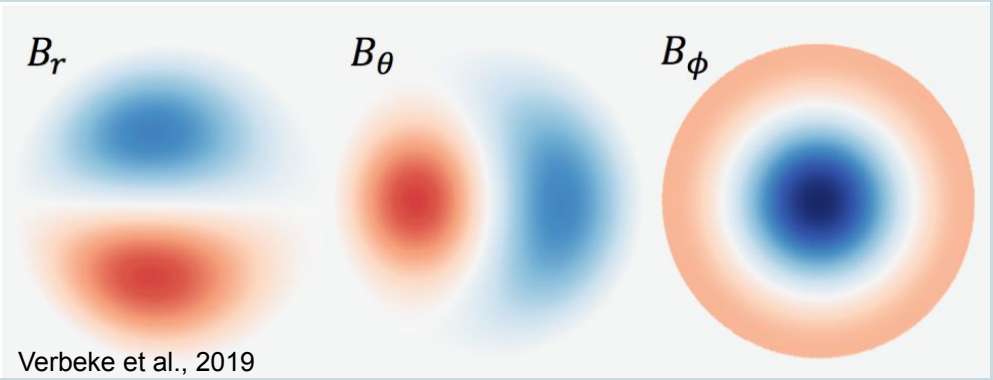
	Icarus (Middle)	EUHFORIA
AMR 2	**26**	**77.3**
AMR 3	**9.7**	**28.5**

Linear Force-Free Spheromak (LFFSpheromak(Shiota&Kataoka, 2016))

$$B'_r = 2B_0 \frac{j_1(\alpha r')}{\alpha r'} cos\theta',$$
$$B'_\theta = -B_0 \left[\frac{j_1(\alpha r')}{\alpha r'} + j'_1(\alpha r') \right] sin\theta',$$
$$B'_\phi = H \cdot B_0 j_1(\alpha r') sin\theta'.$$

$$B_r(r,\theta,\phi) = \left(\frac{\Delta}{r}\right)^2 b_r(\Delta,\theta,\phi),$$
$$B_\theta(r,\theta,\phi) = \frac{\Delta}{r}\frac{d\Delta}{dr} b_\theta(\Delta,\theta,\phi),$$
$$B_\phi(r,\theta,\phi) = \frac{\Delta}{r}\frac{d\Delta}{dr} b_\phi(\Delta,\theta,\phi).$$

Gibson&Low, 1998



Verbeke et al., 2019

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Summary & Future work

- New heliospheric model - Icarus (Verbeke et al., 2022)
- Advanced techniques
  - Grid Stretching
  - Adaptive Mesh Refinement
- CME models
  - Cone CME
  - Magnetized CME
- *Advanced Gibson & Low model - **Ongoing***

Thank You!

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