Interplanetary CMEs and PUNCH

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Working Group 2A

- Important questions about CMEs that PUNCH can address:
  - How do CME propagate through the heliosphere?
  - How does CME structure evolve; both magnetic and plasma?
  - How can we predict CMEs' out-of-ecliptic magnetic fields?
  - What is the role of CMEs for the IMF? IMF evolution.
  - Magnetic reconnection through and above the Alfven surface.
  - Association with CIRs.
  - We need to better understand CME shocks and SEPs: at Earth, at other planets and for man in space (Moon, Mars, asteroids)

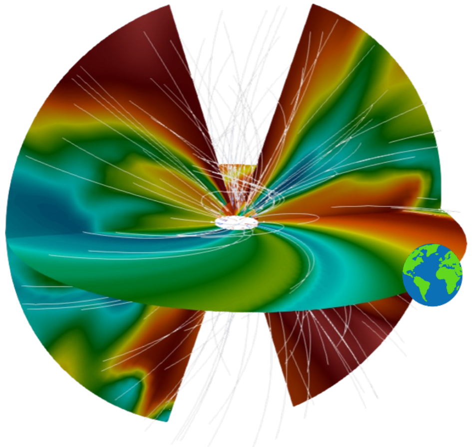
In preparation for launch…

GAMERA
Grid Agnostic MHD for Extended Research Applications

https://civspace.jhuapl.edu/gamera/

- We do not have PUNCH data at the moment!
- But we *do* have MHD simulations that we can use to mimic data for pre-launch analysis

Global Solar Wind 0.1-1 AU



(Merkin et al. 2016)

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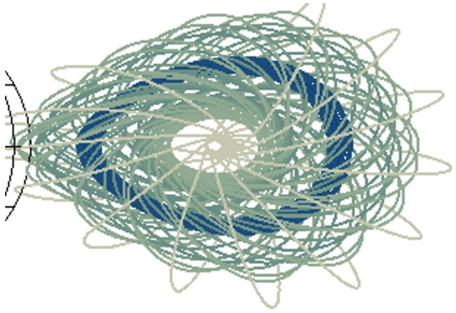
Gibson & Low flux rope model



(Gibson & Low, 1998)

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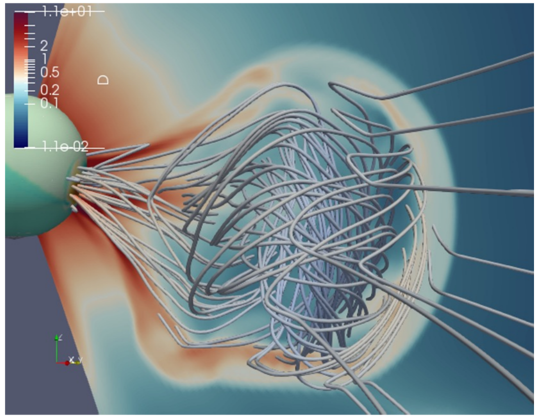
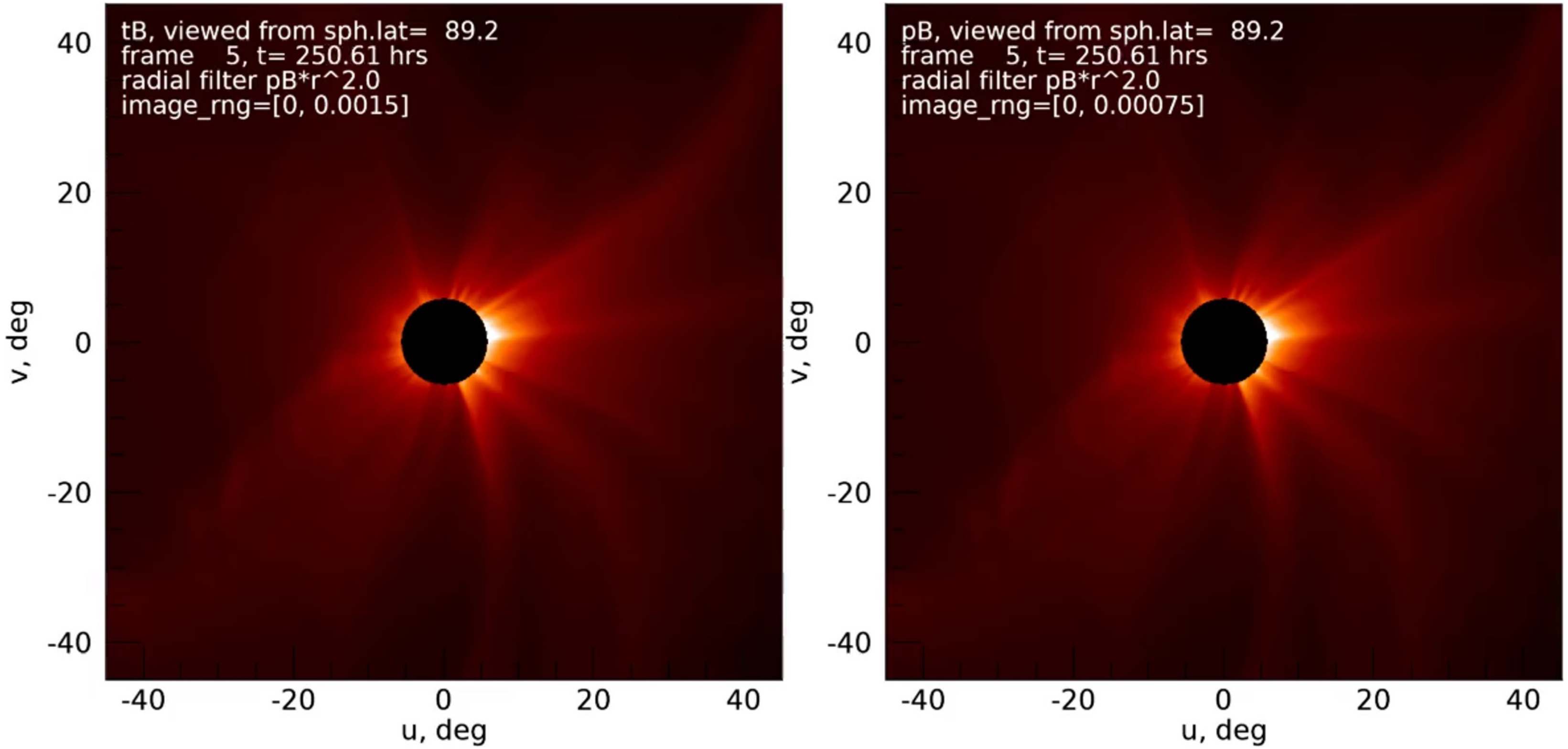
CME in the inner heliosphere



Synthetic data: aka "CME Challenge v2.0"

- Synthetic PUNCH-like data using GAMERA MHD simulation
- pB, tB in PUNCH-like field-of-view and projection



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  - CME0: reference case: all properties of CME are known a priori
    - can be used to test CME reconstruction/flow tracking methods
  - CME1-CME3: validation cases: properties are disclosed upon request
    - can be used for *validation* of established methods

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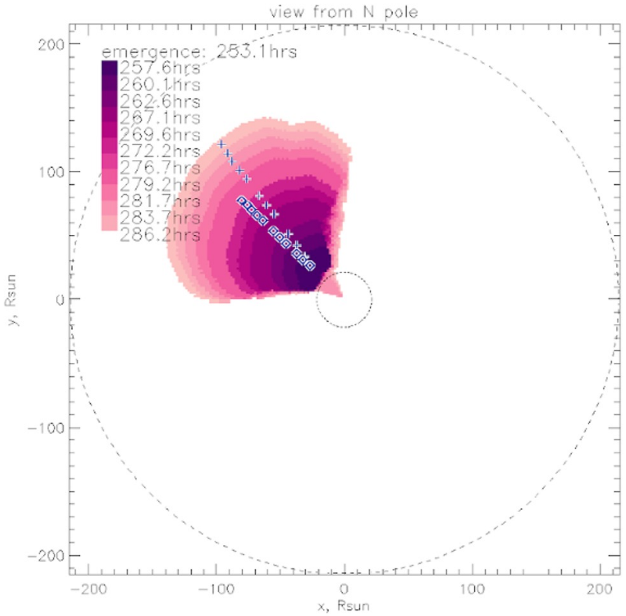
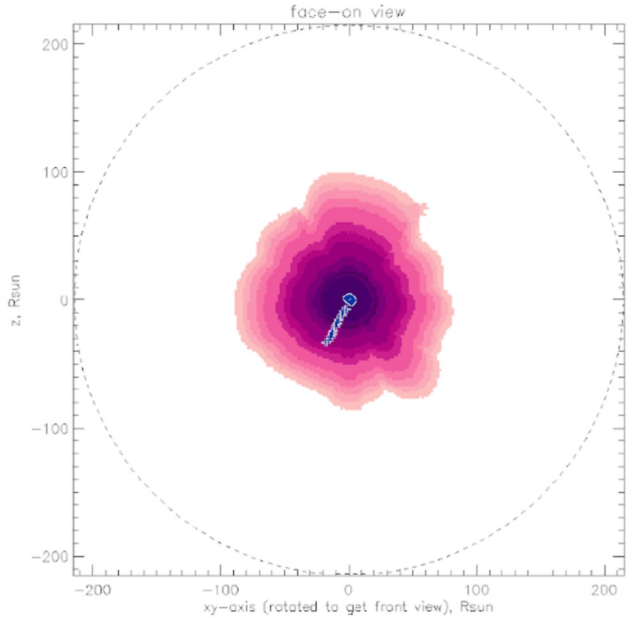
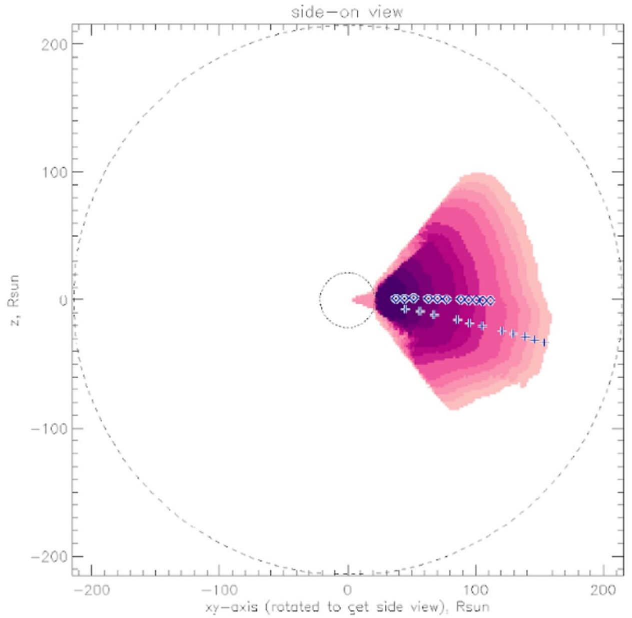
CME0



View from N pole



Face-on (“halo”) view



Side-on (“limb”) view

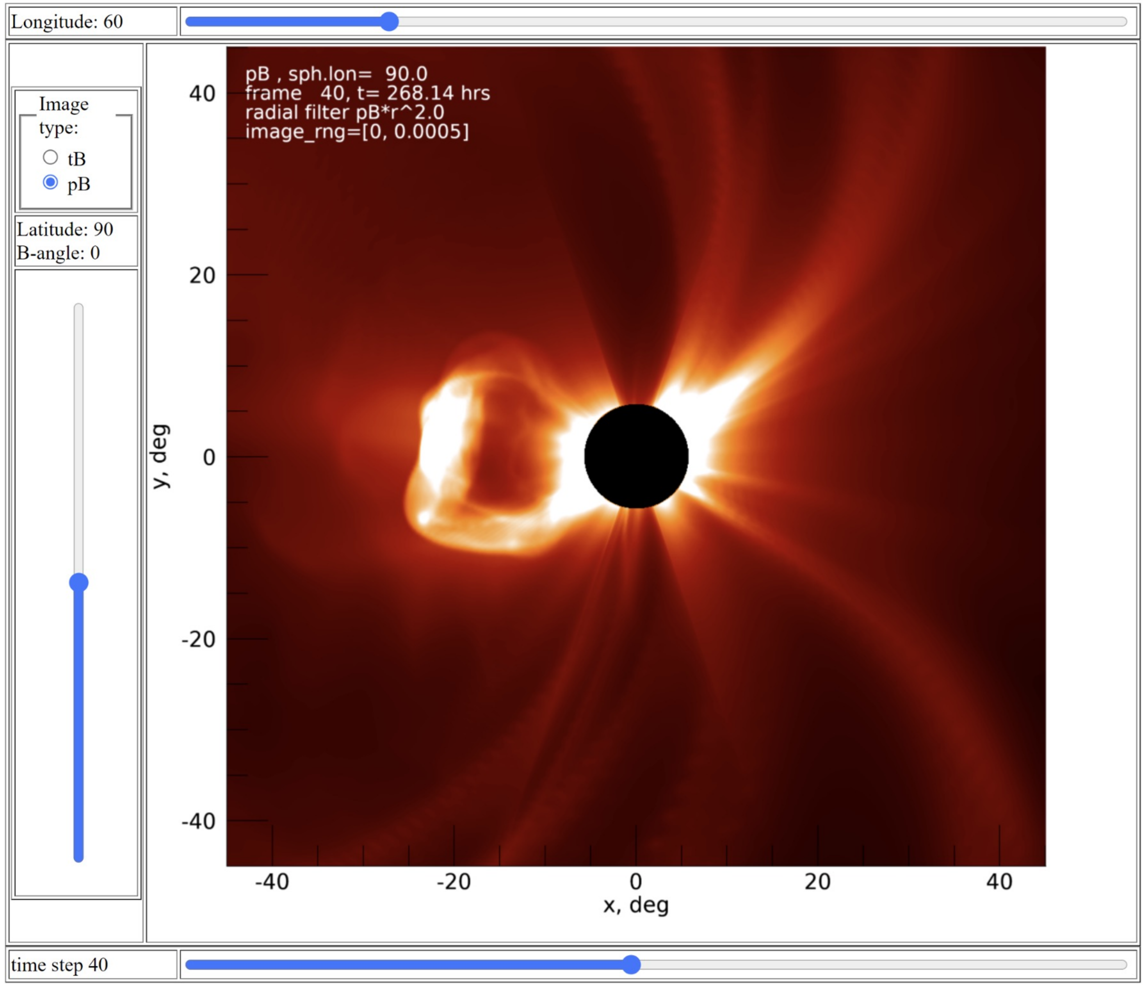
“CME Challenge” ? “CME Challenge v2.0”

- updates in CME injection algorithm, in pB synthesis, in ground truth parameters, and in data products

	v1.0	v2.0 (current)
Number of events	CME0-CME2	CME0-CME4
Viewing angles (w.r.t. the observer)	30°, 60°, 90° (W limb)	-60°, 0°, 30°, 90° (E and W limbs)
“4pi” coverage	--	all events
In situ	--	all events, 4pi
Storage	Google drive, got to know the link -- available upon request	Easy to find! HAO website (some data) & Globus (all data) – stay tuned!
MHD cube that we store	density only, until CME reaches 1AU	All MHD variables (e.g.: have **B** cubes for comparisons); 3D cube to 1AU plus 1AU shell data for CME passage

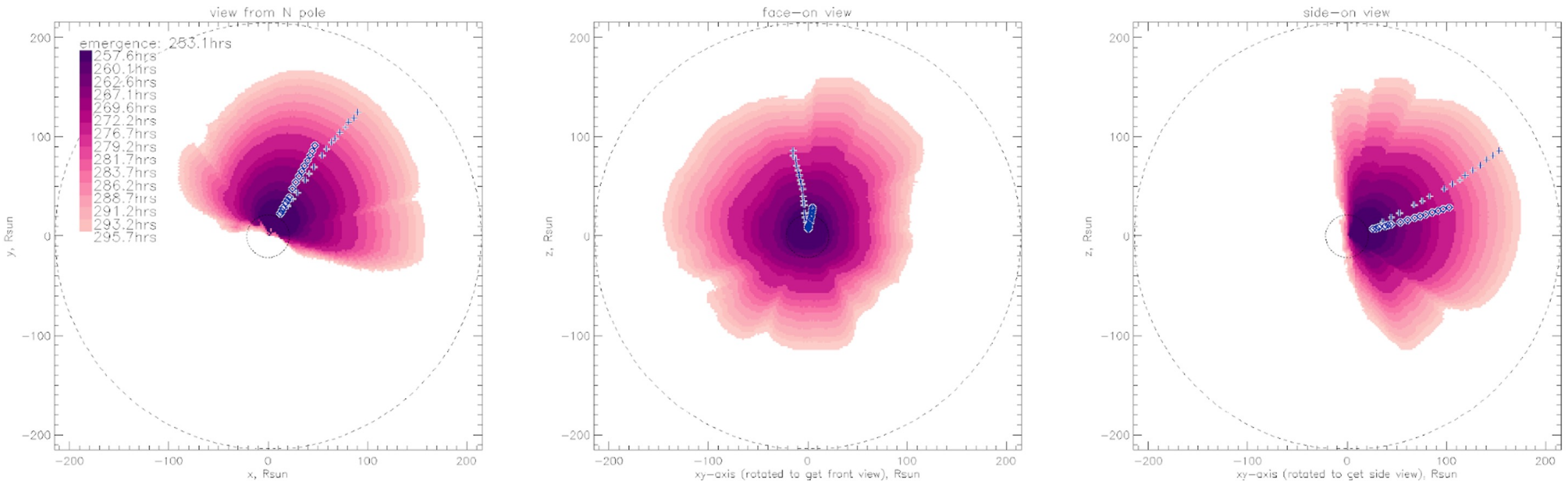
“4pi” data product: the idea

- Interactive webpage for quick preview on HAO website; FITS files in Globus
- Observer is not moving with Earth (hovering in space, motionless, w.r.t. distant stars)
- Observer can be anywhere around the Sun
- Observer has PUNCH-like coronagraph plus *in-situ* trace of solar wind



“Ground truth” data product: why need it?

- CMEs interact with the solar wind:
  - They slow down
    (e.g.: CME0 has starting Vr=1700 km/s, but fitted to the volume data Vr~755 km/s)
  - The trajectory may get deflected
  - CMEs expand non-uniformly in the wind
  - CME imaging observations often include “snow-plow” wind material
  - We record all those, plus the shape of the CME volume with time



CME Challenge v2.0 current status:

- Simulations: done
- PUNCH-like projections: done
- Ground truth: done
- 4pi coronagraph: done for CME0, in progress for the rest
- 4pi in situ: in progress
- Globus storage: done
- HAO webpage: in progress

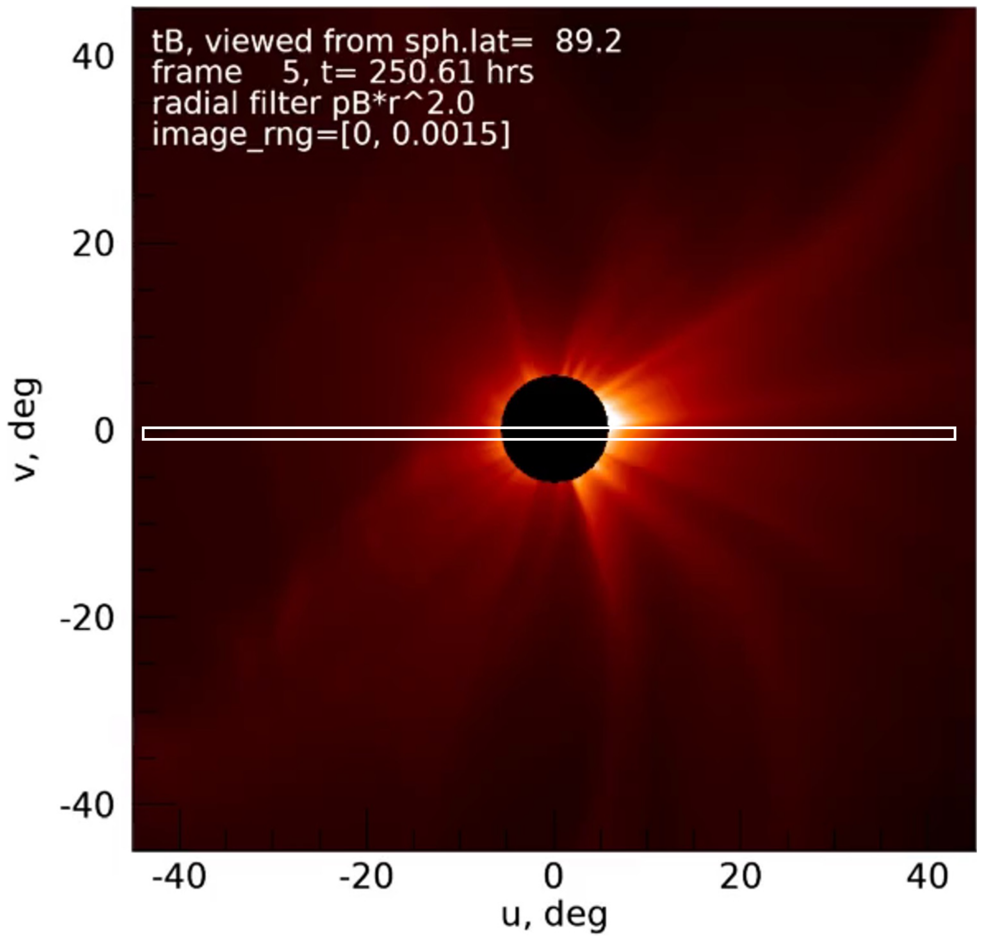
A few notes on subsequent slides…

That cover fine points in interpreting these data:

- On projections
- On *what* is that we see
- On *how* is that we see it

Note on projections

- PUNCH will have a *very* wide field of view



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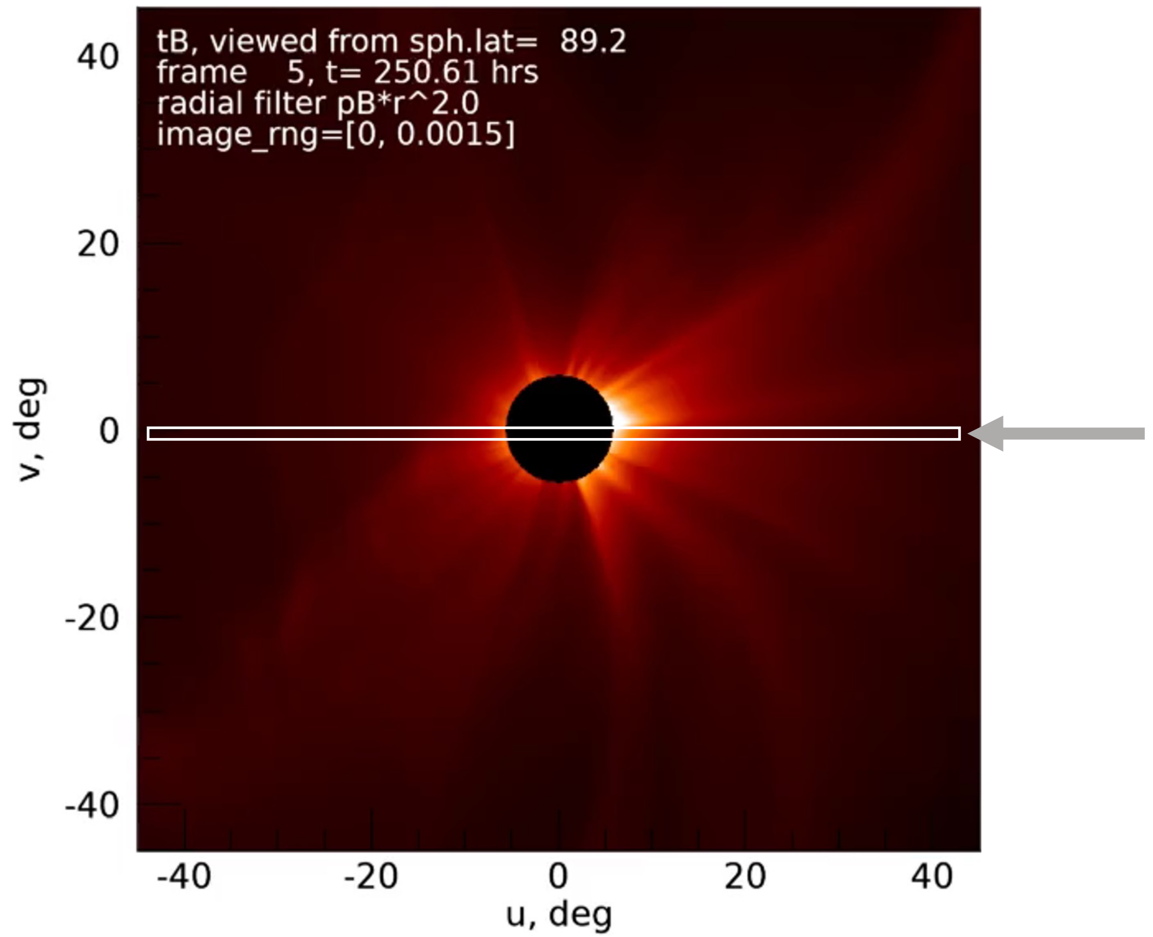
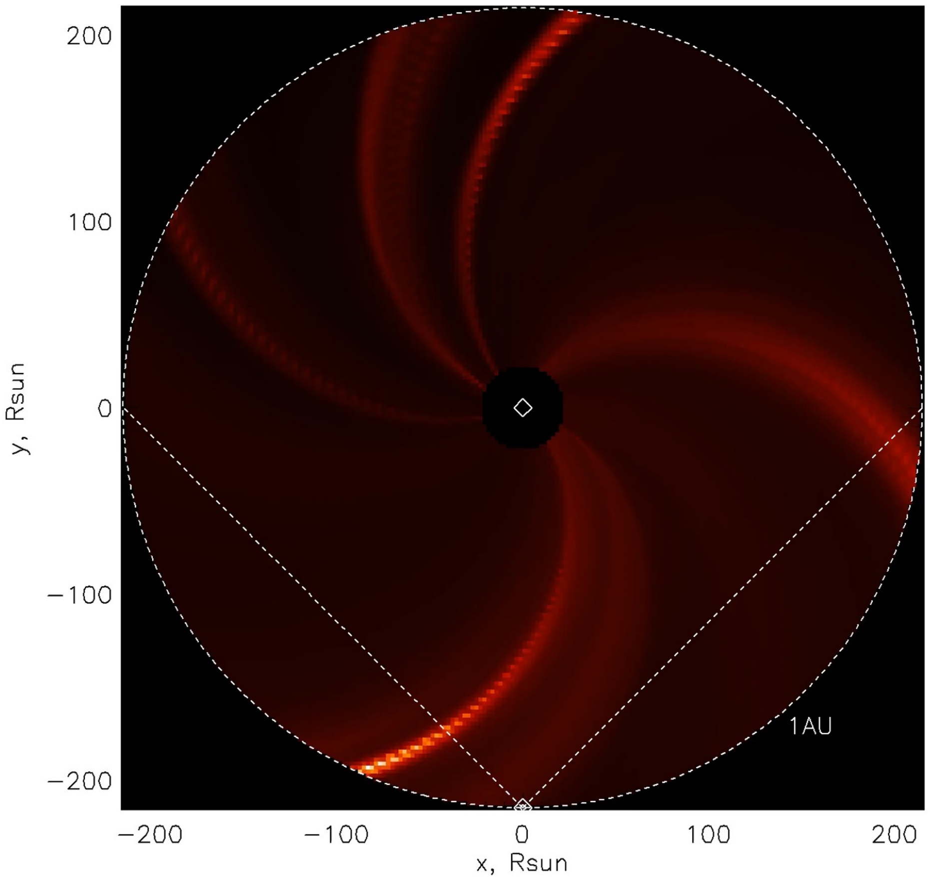
- So, it'll have a somewhat unusual projection (for heliospheric obs.)



density *slice* at equator (vignette: r^2)



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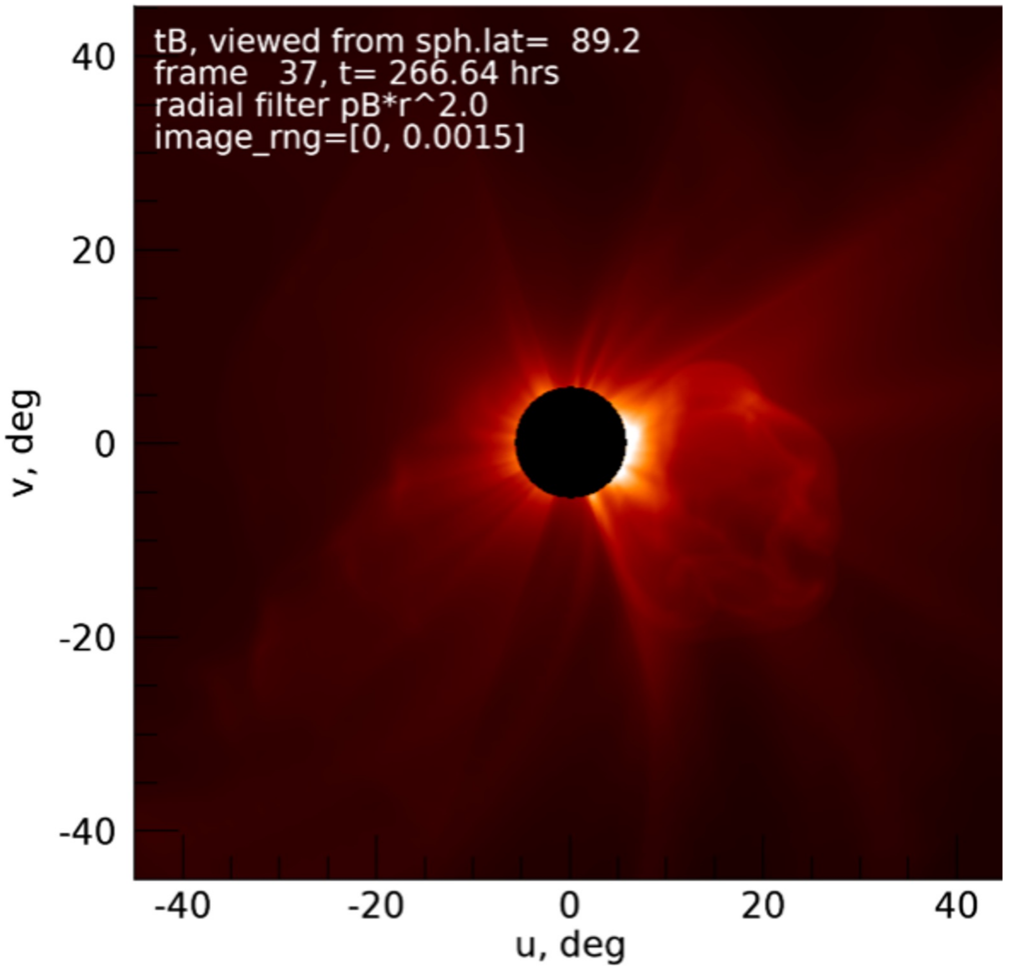

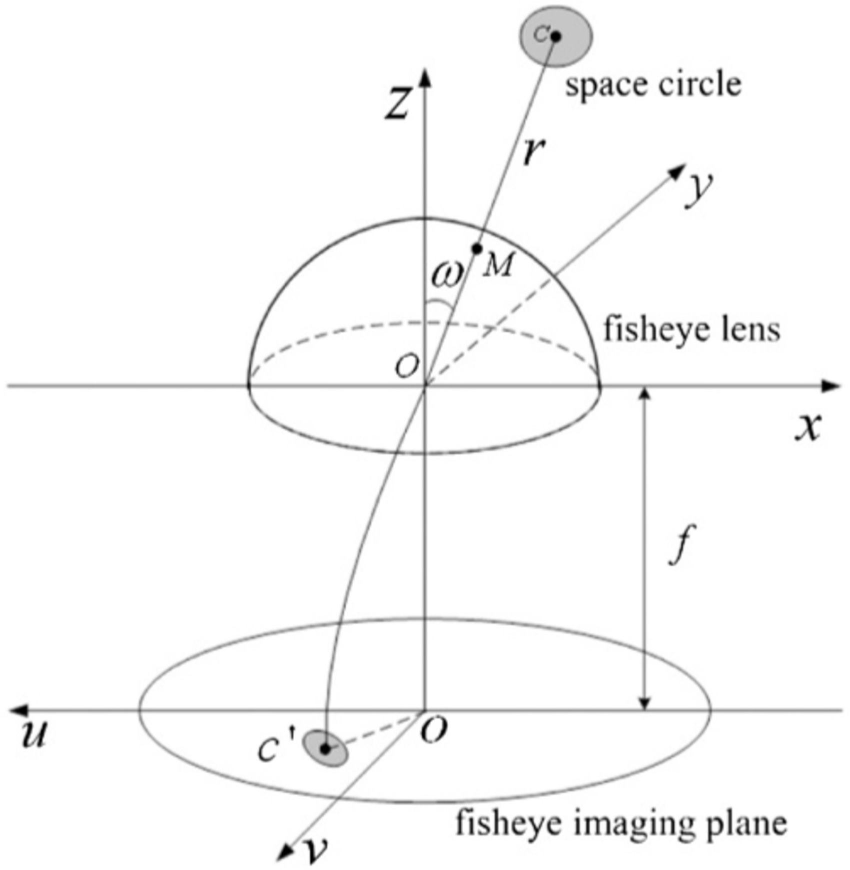

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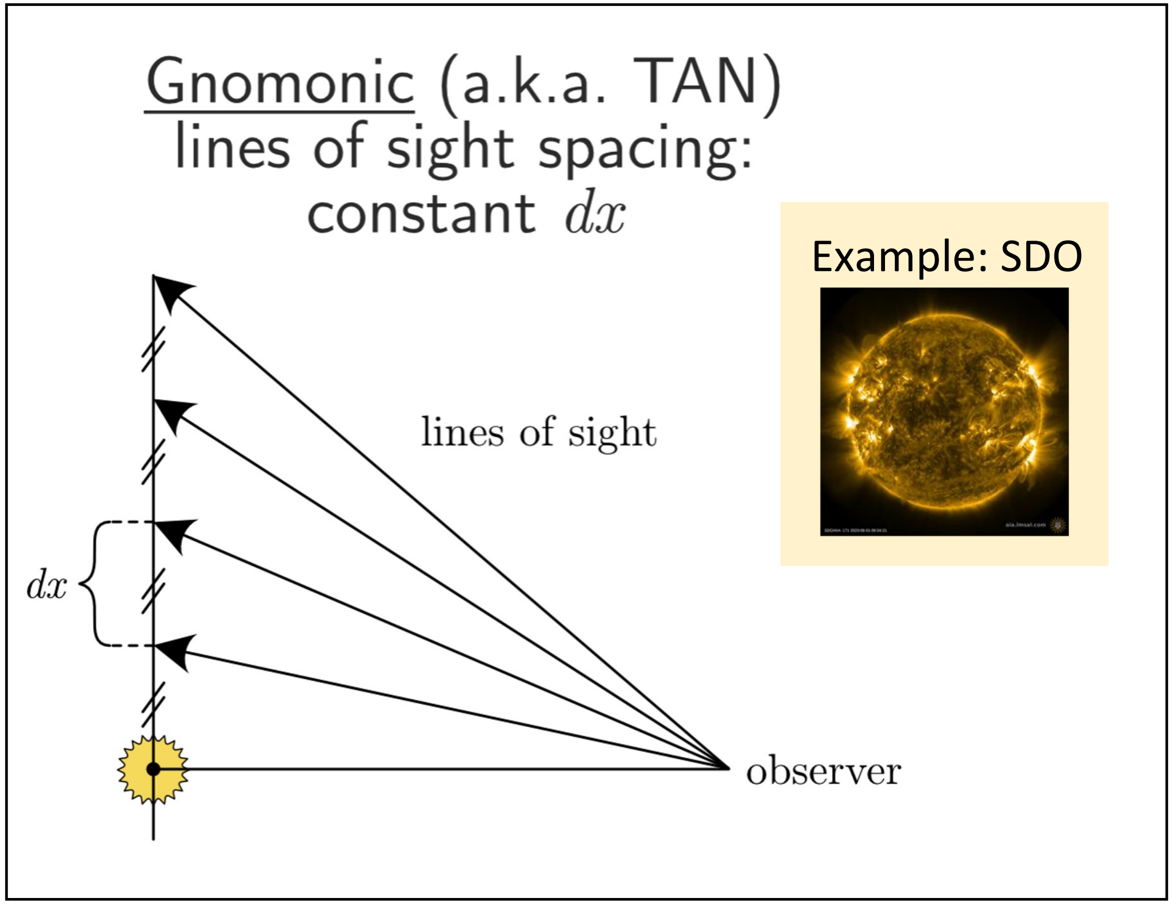
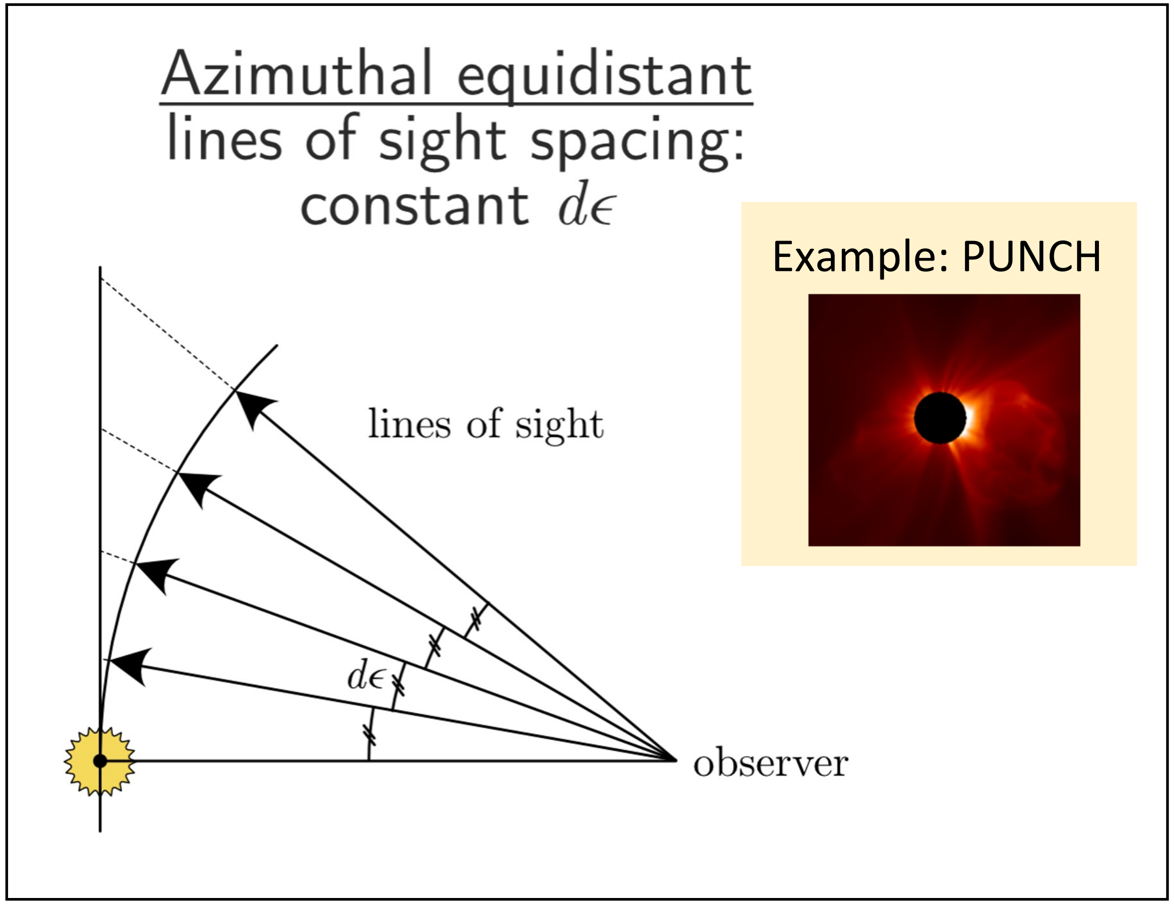
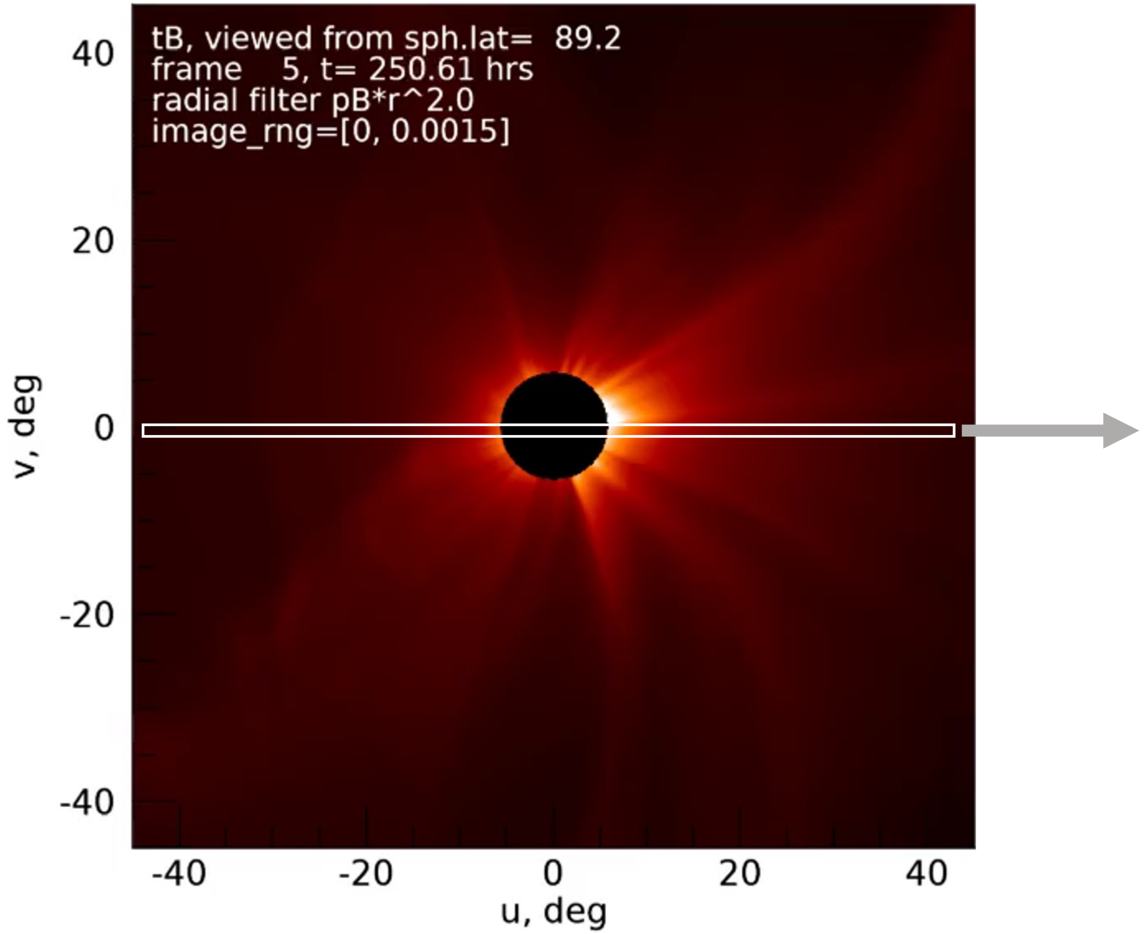




Thomson scattering

- …so, lines of sight.
  What do we integrate along the lines of sight?



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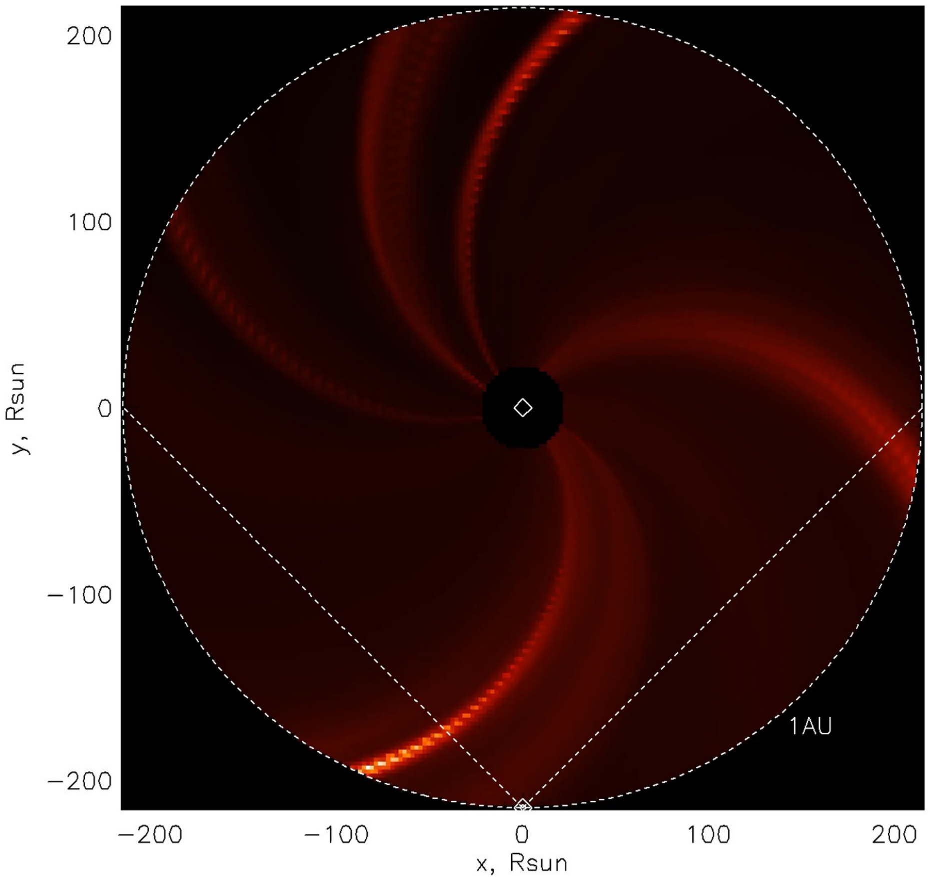

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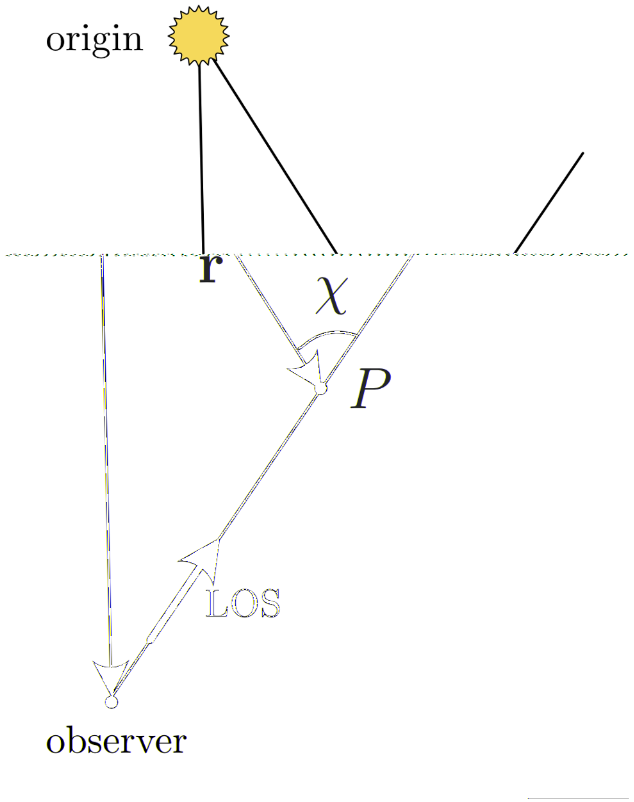

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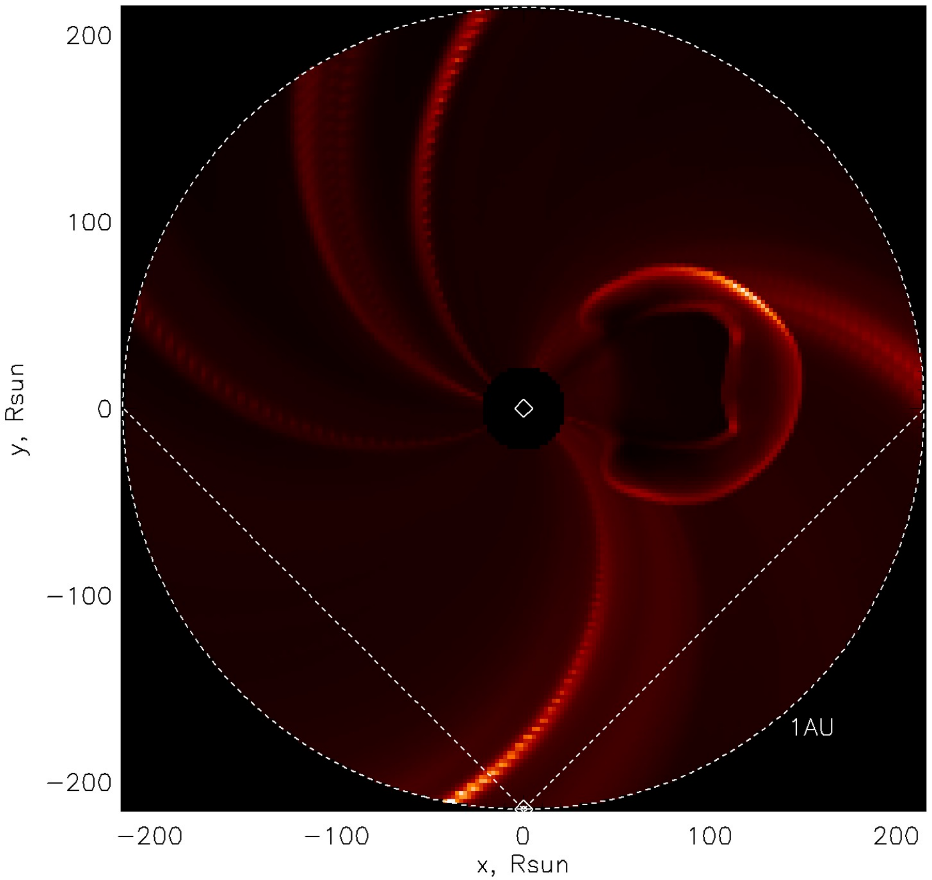

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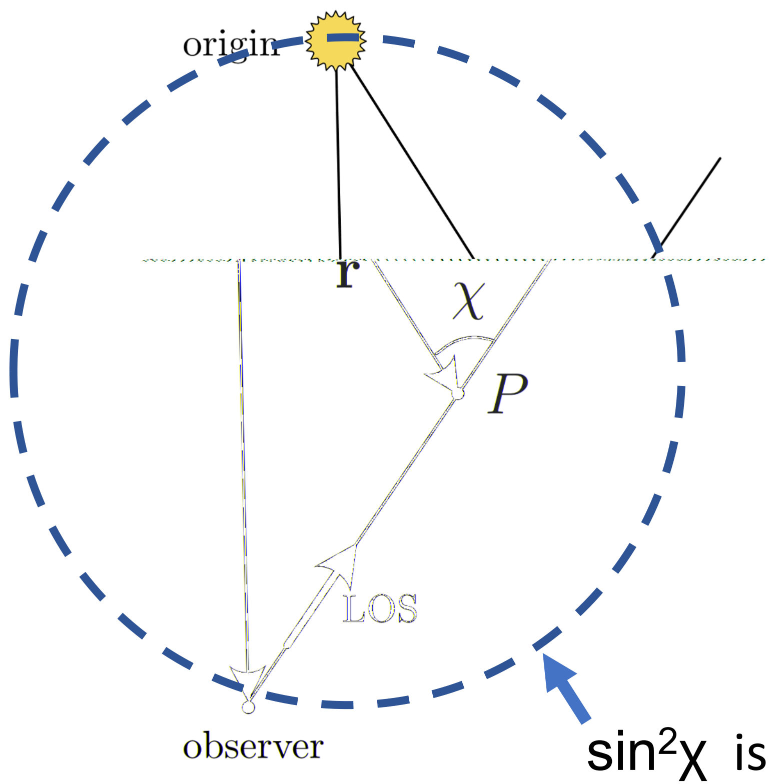

$$tB = C_0 \int_0^\infty N(l)\left[2\left[(1-u)C + uD\right] - \sin^2\chi\left[(1-u)A + uB\right]\right] dl$$

$$pB = C_0 \int_0^\infty N(l)\sin^2\chi\left[(1-u)A + uB\right] dl$$

N(l) – density

A,B,C,D – functions of *r* , not the observer (aka “van de Hulst coefficients”)

$\sin^2\chi$ – function of scattering angle, depends on observer

$\sin^2\chi$ is the biggest at Thomson sphere

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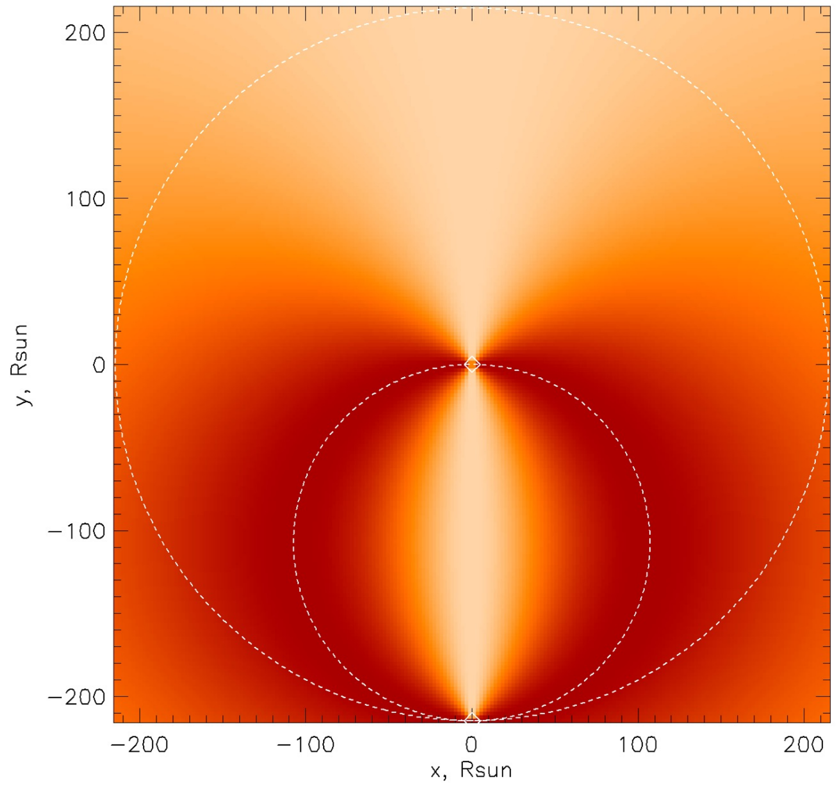

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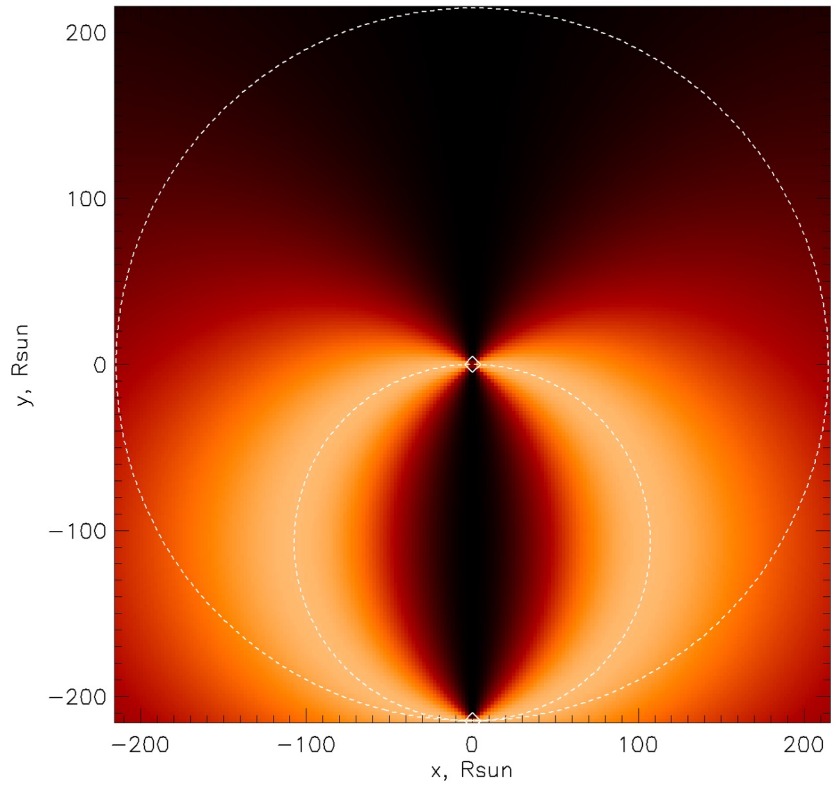

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- We have to integrate density along the line of sight *times* some geometric factors:

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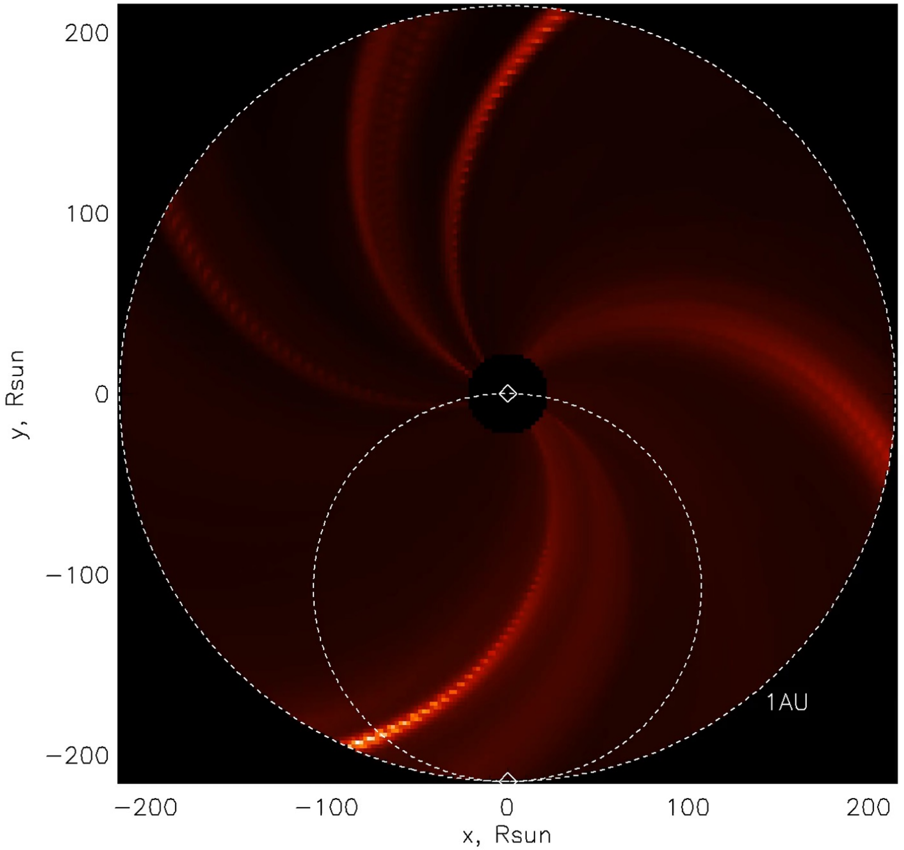

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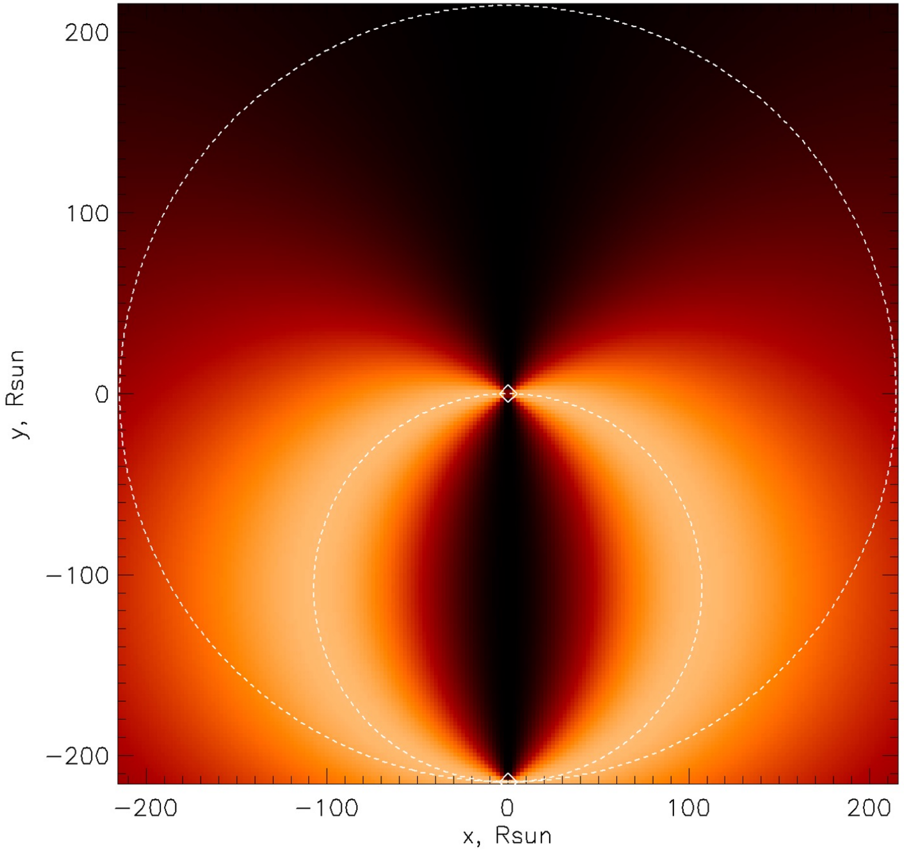

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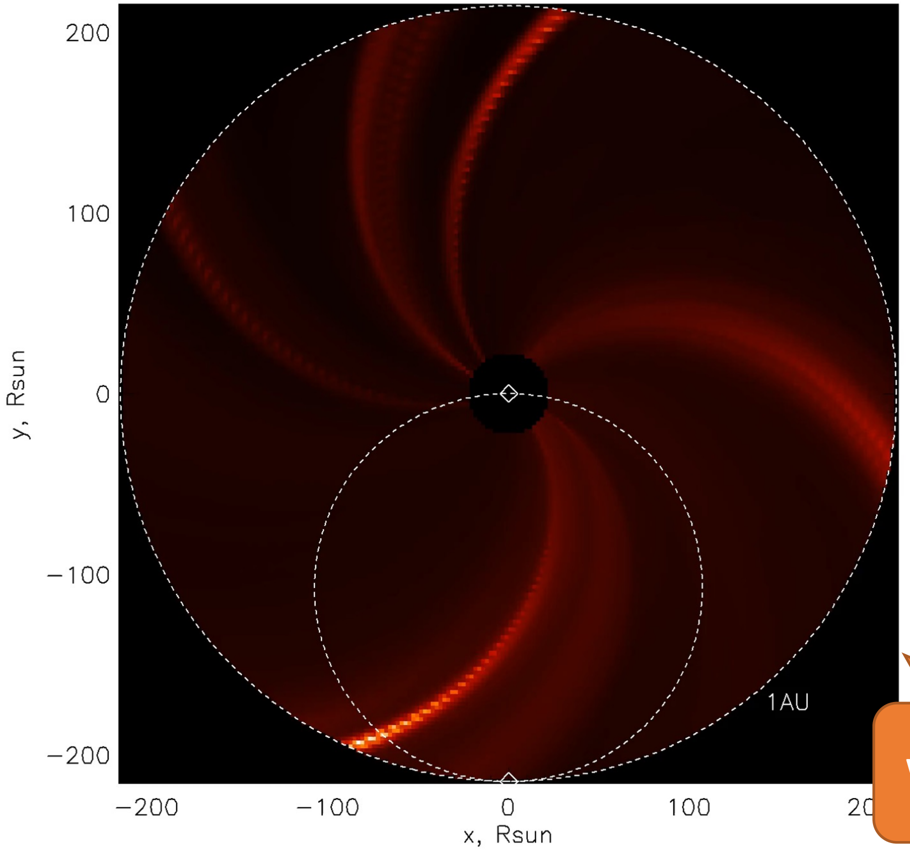
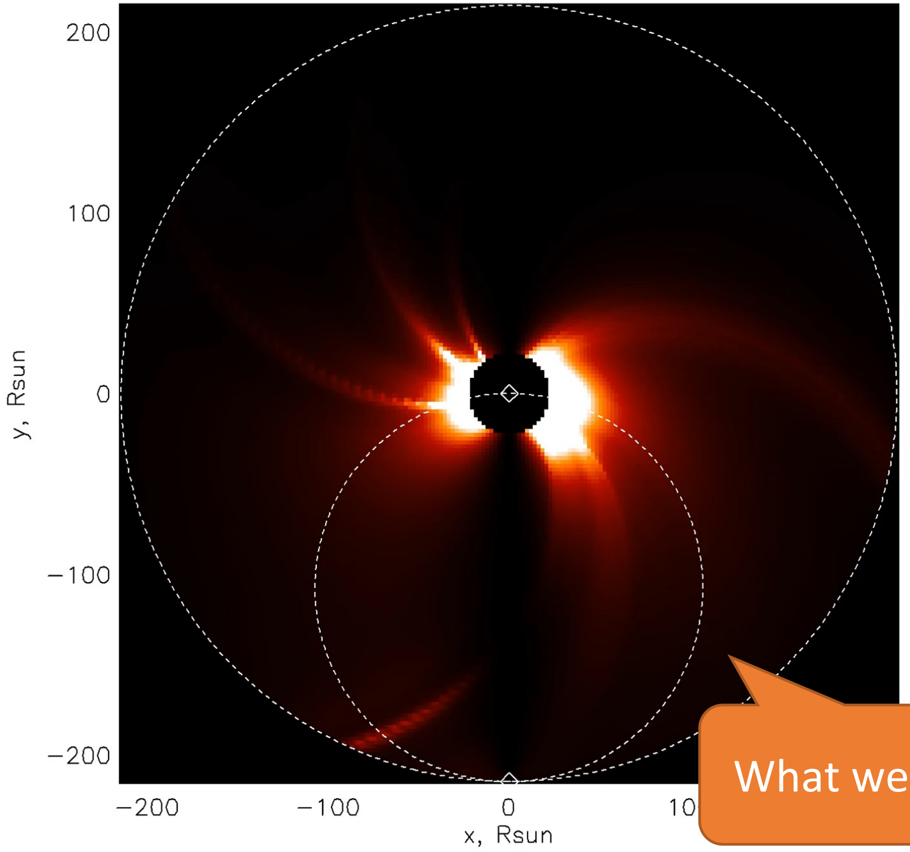


What we want

(vignette: r^2)



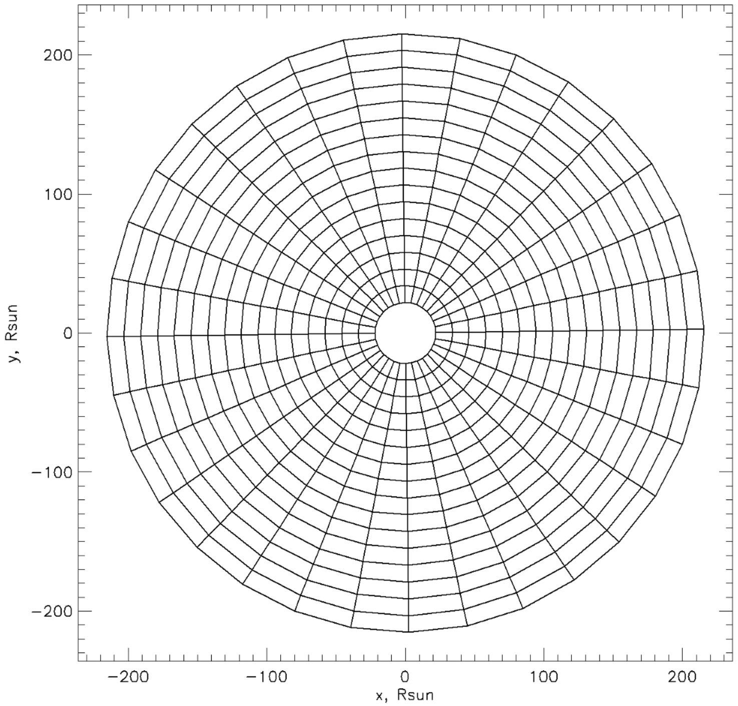
What we have

Finally…

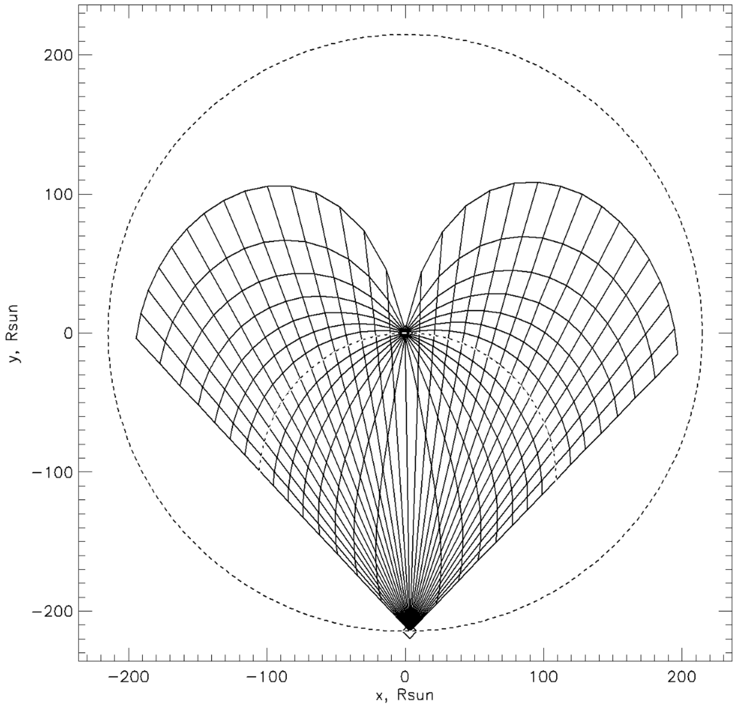
- For ***very*** fine features (i.e., turbulence, small-scale flows)
- and for *numerical simulations* (in general), as opposed to observations,

  a line-of-sight grid may be worth thinking about

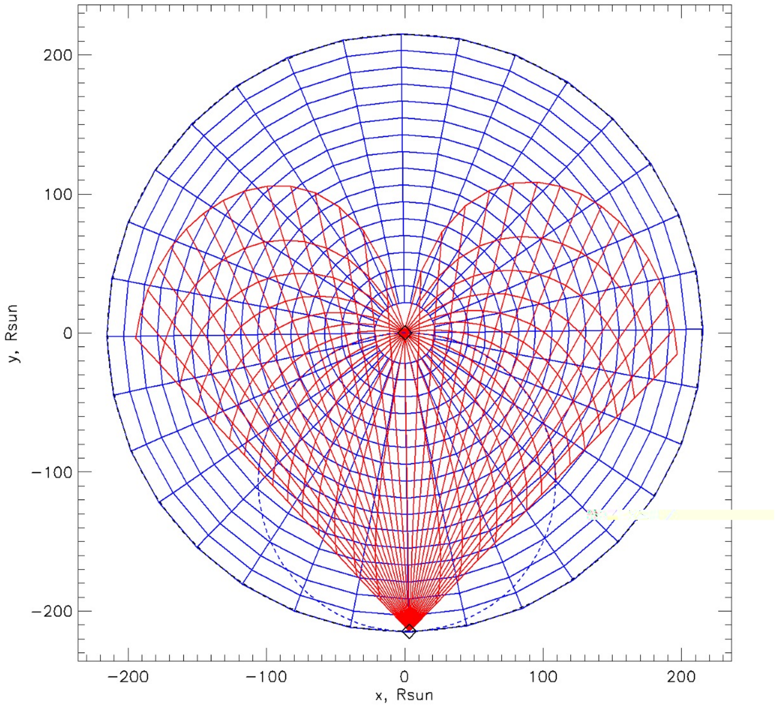
GAMERA grid



Line of sight grid



Both – **Moiré**, possibly?



- (normally not an issue with large structures like CMEs and with finer grids ☺)

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–note that projections and Thomson scattering effects do also apply to real PUNCH data!

So we have to learn how to analyze given these effects!

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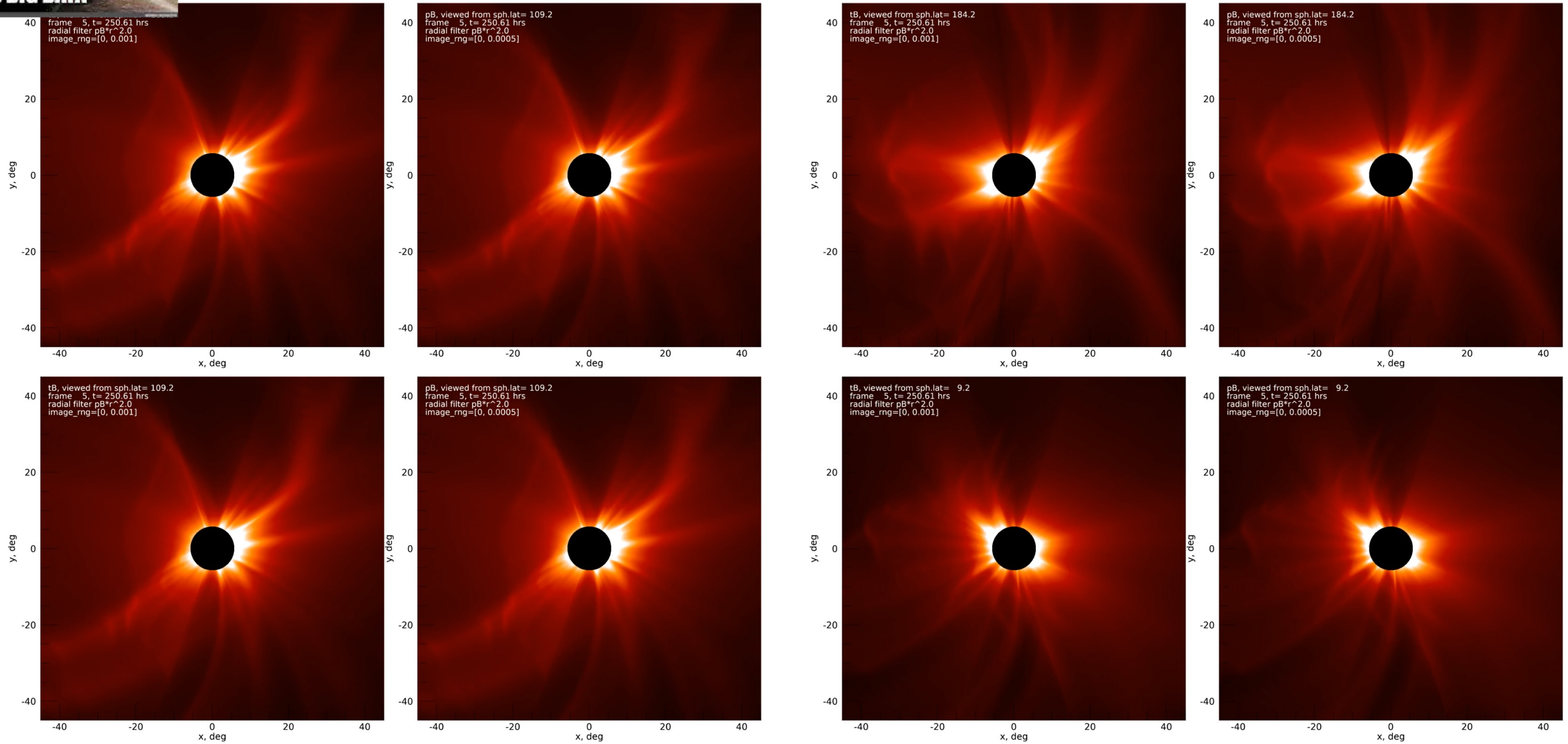
This is BIG DATA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pB, viewed from sph.lat= 109.2
frame 5, t= 250.61 hrs
radial filter pB*r^2.0
image_rng=[0, 0.0005]
tB, viewed from sph.lat= 184.2
frame 5, t= 250.61 hrs
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x, deg
y, deg

Thank you! ☺️