Modeling the Structured Solar Wind with STRIA

Trestan Simon[1], Steven Cranmer[1], Chris Gilly[2], Sarah Gibson[3]

[1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO
[2]NorthWest Research Associates, Boulder, CO
[3]National Center for Atmospheric Research, Boulder, CO

Introduction

STRIA, a three-dimensional time-dependent density model of the structured solar wind in development since 2021 (Gilly et al., 2021), has been expanded to further support the interpretation of PUNCH/NFI data and flow-tracking efforts. STRIA synthesizes total brightness (*tB*) and polarization brightness (*pB*) images of the upper corona and inner heliosphere within the field of view of NFI by modeling the region as a set of discrete, spherically expanding, co-rotating flux tubes wound by the Parker spiral with each flux tube assumed to connect to one open supergranule on the solar surface. Using this model, we investigate foreshortening of estimated blob velocities as well as the statistical properties of observable density fluctuations over time with and without blobs. We analyze both inflowing and outflowing blobs in order to improve our understanding of the kinematics of flows in the vicinity of the Alfvén surface.

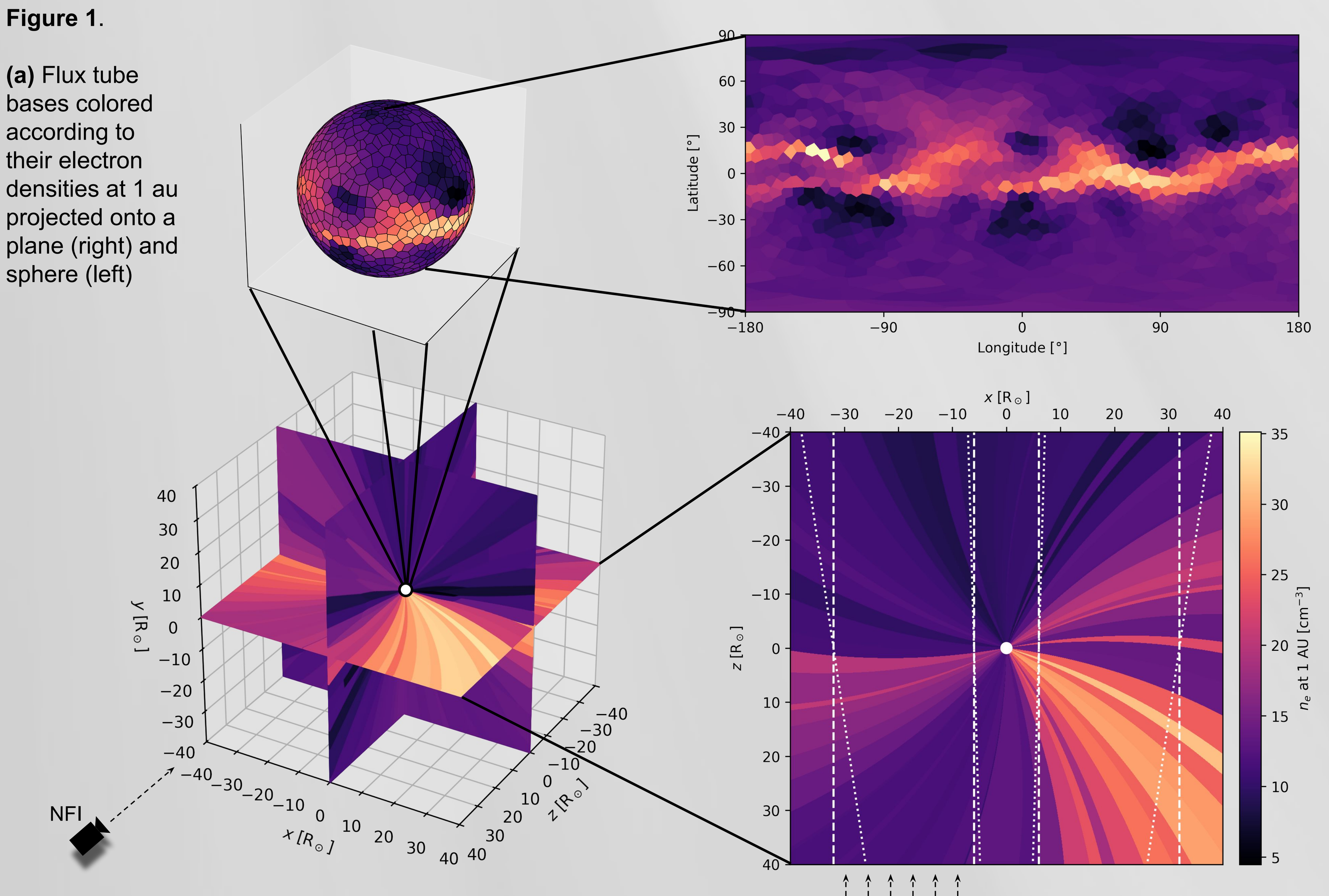
Building STRIA

- The central axes of ~1000 flux tubes (based on the number of open supergranules) are distributed across a Sun-centered sphere
- The boundaries of each flux tube are drawn along lines equidistant from the flux tube's central axis and the closest neighboring flux tubes' central axes, producing a Voronoi tessellation (see Fig. 1a)
- Away from the Sun, the flux tube areas expand spherically while the central axes are wound by the Parker spiral (see Fig. 1b-c)
- Electron densities along the length of each tube are determined by a shared radial dependence modified by a unique electron density given at 1 au and inferred from coronal rotational tomography (Morgan & Cook, 2020; see Fig. 3 for examples)
- Electron densities can be enhanced by compact blobs confined to individual flux tubes with predefined radial velocities

Synthesizing tB, pB, and τ Images

- Because NFI's field of view (FOV) is close to the Sun, we assume that all observing rays are parallel and establish a Cartesian coordinate system with the Sun at the origin, the *x*-axis toward the observer, the *y*-axis toward solar west, and the *z*-axis toward solar north
- *tB* and *pB* values along a given line of sight (LOS) correspond to the I and Q Stokes parameters, respectively, for the light produced by Thomson scattering of unpolarized light from the solar disk off of free electrons in the model's flux tubes (see Fig. 2)
- The complement of the scattering angle, or τ, is derived from the fractional polarization, pB/tB (Gibson et al., 2026)

Figure 1.



(a) Flux tube bases colored according to their electron densities at 1 au projected onto a plane (right) and sphere (left)

(b) Cuts along Cartesian planes colored according to the density of intersected flux tubes expanding spherically with distance from the Sun at the origin

(c) Equatorial plane cut with real and parallel NFI FOV bounds (dotted and dashed lines)

Figure 2.

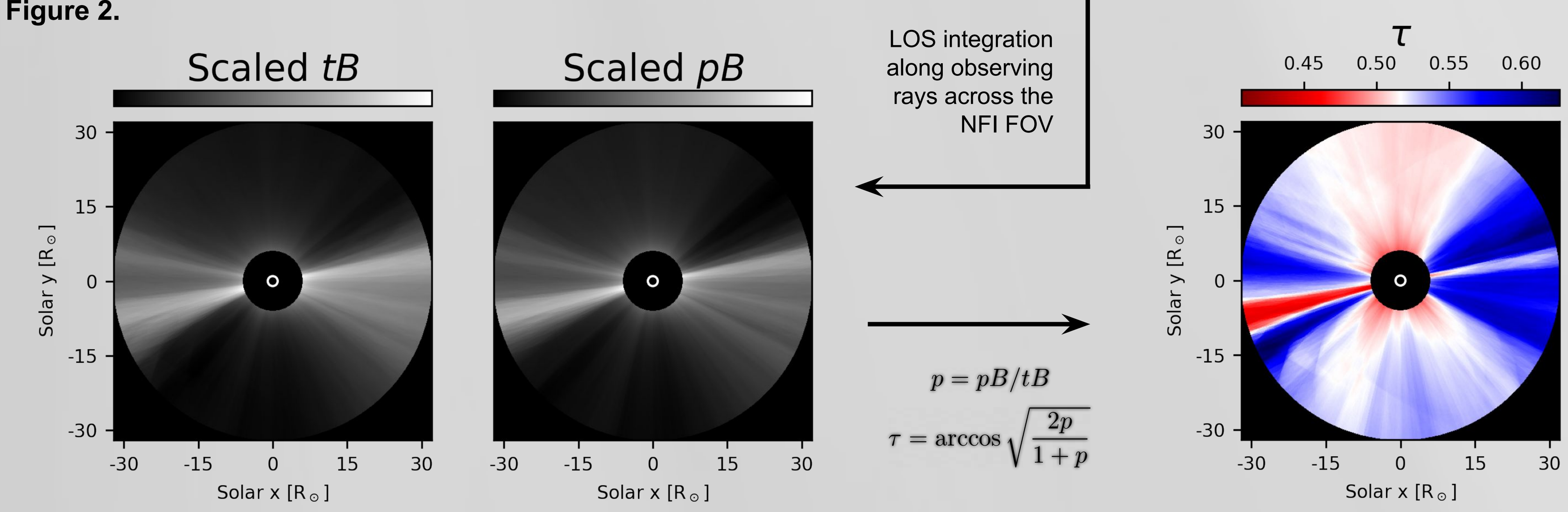
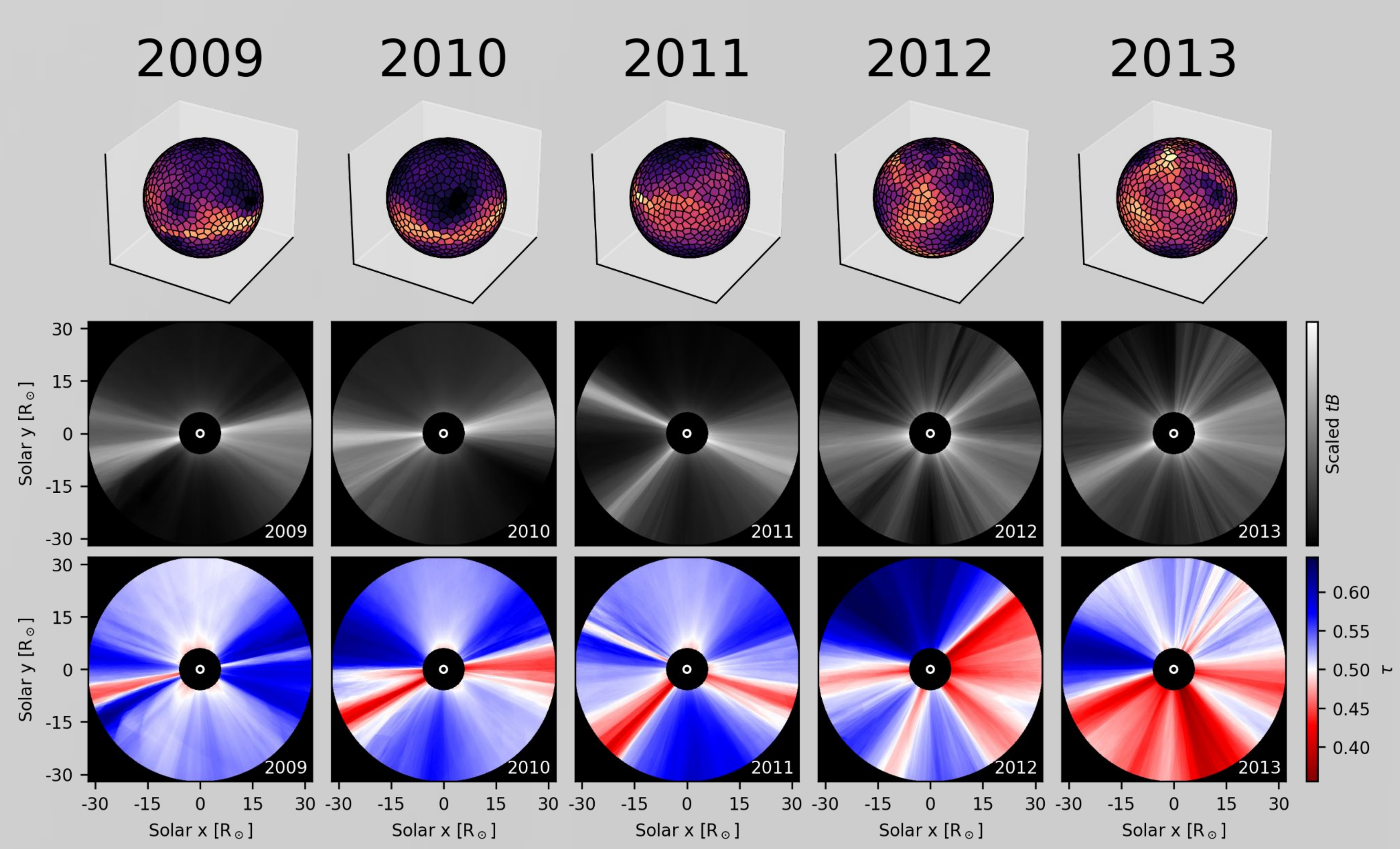


Figure 3. Flux tube bases colored according to density (1st row) and the corresponding synthetic *tB* (2nd row) and τ (3rd row) coronagraph imagery generated with STRIA using electron density data obtained at different points during the ascending phase of solar cycle 24 (Morgan & Cook, 2020) showcases how STRIA reproduces the appearance of different streamer configurations.



Blob Tracking

- Plane-of-sky (POS) positions of blob centroids are approximated using the peaks of the background-subtracted *tB* data in synthetic j-maps
- The POS angle of the blob is approximated using the background-subtracted τ value at the centroid (Gibson et al., 2026)
- Using the POS position and angle we can obtain the 3D position and velocity of the blob (see Fig. 4 and 5)

Figure 4. Example blob tracking for a compact 10x density enhancement starting above the Alfvén surface (~10 solar radii) in a flux tube with a POS angle of ~35° and following the trajectory of an inward-propagating Alfvén wave (Cranmer et al., 2023)

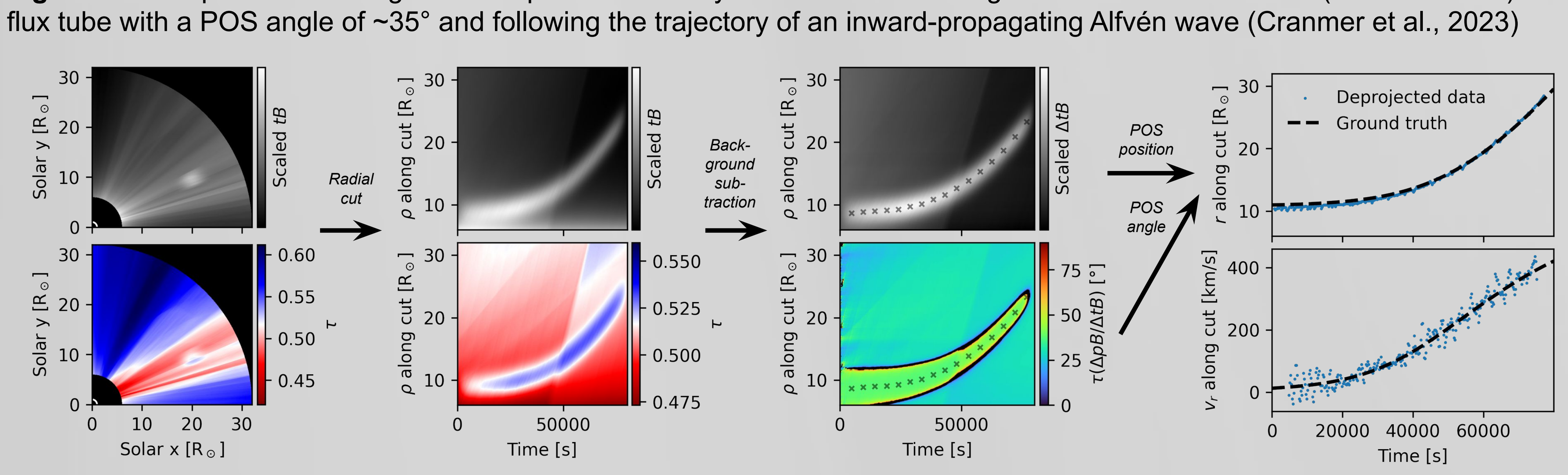


Figure 5. (a, b) Applying our blob tracking procedure to a large number of different blobs distributed throughout the NFI FOV and comparing the results with the ground truth reveals that errors in position (left column) and velocity (right column) are dominated by projection effects. **(c)** The radial dependence of the flux tube densities also shifts blob centroids sunward.

(a) Errors using the POS data as true position and velocity

(b) Errors after deprojecting the POS data

(c) Errors after deprojecting and correcting for tube density

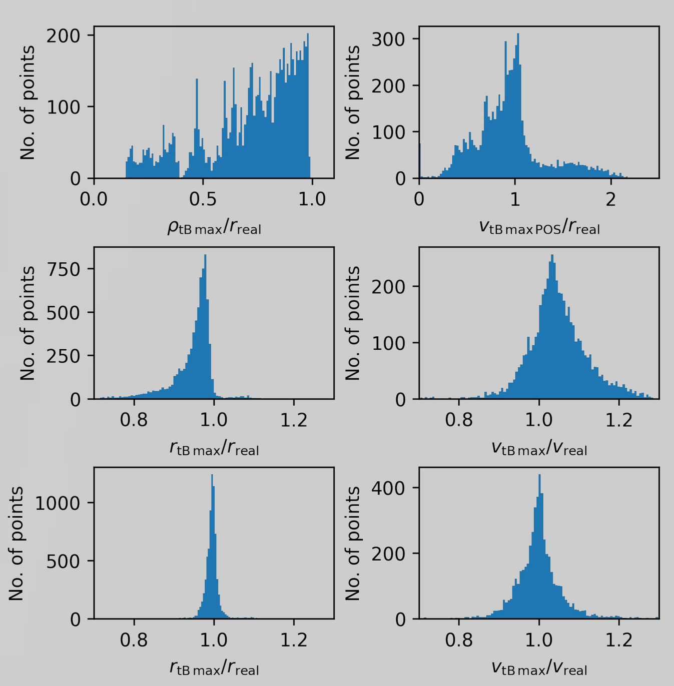
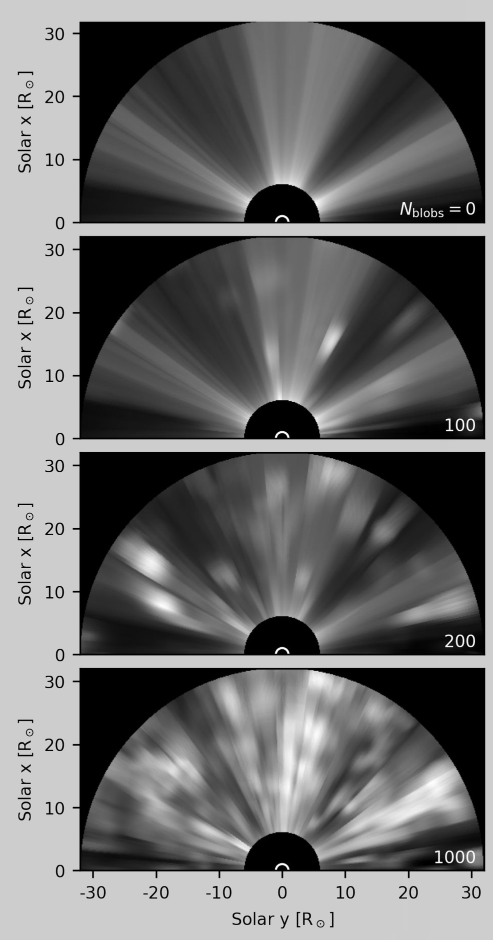


Figure 6. STRIA can produce complicated test cases for tracking algorithms by simulating many blobs in the FOV simultaneously. Synthetic time series observations made with and without blobs can also be used to determine how solar rotation and blobs contribute to observable density fluctuations.



Discussion

- We have expanded the STRIA density model of the structured solar wind to support NFI flow tracking efforts relevant to studying the Alfvén surface.
- We have obtained distributions of the errors in radial velocity estimates for large samples of blobs within the NFI FOV using a simple tracking algorithm (see Fig. 5a). This procedure can be repeated using other tracking algorithms to help determine the statistical properties of position and velocity error for compact density enhancements observed in real NFI data.
- We have investigated factors influencing foreshortening of blob radial positions and the impacts this foreshortening has on velocity estimates (see Fig. 5b-c).
- In the future, we will investigate the low-level observable density fluctuations from flux tube rotation with and without blobs (see Fig. 6)

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