磁気流体プラズマ乱流中の渦構造とダイナミクス

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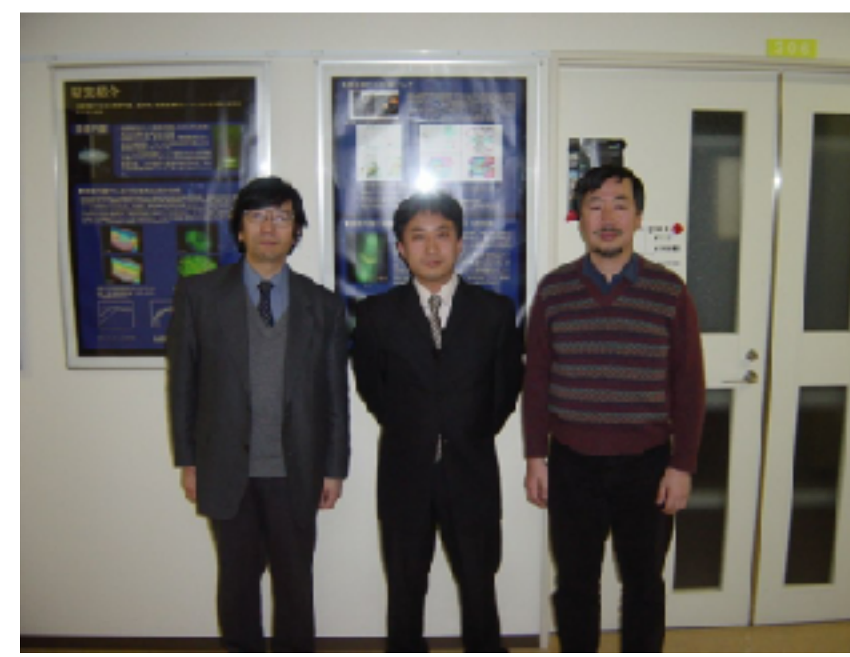
(理研)

Vincent van Gogh's *The Starry Night (1889)*
the view from the window of his asylum room at Saint-Rémy-de-Provence

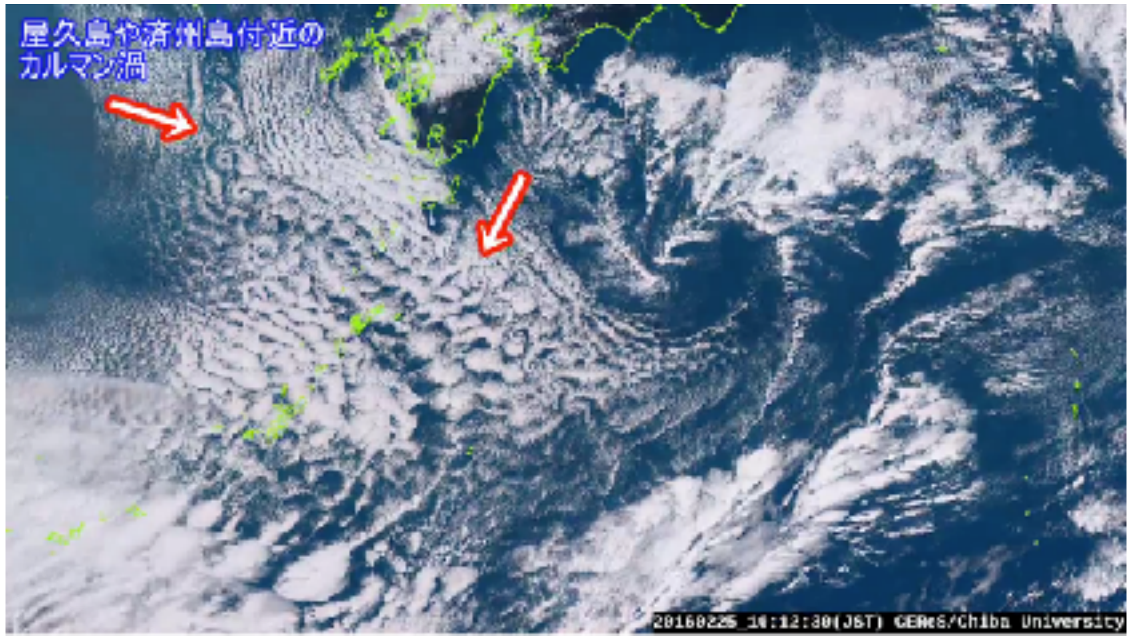
1998年

2003年



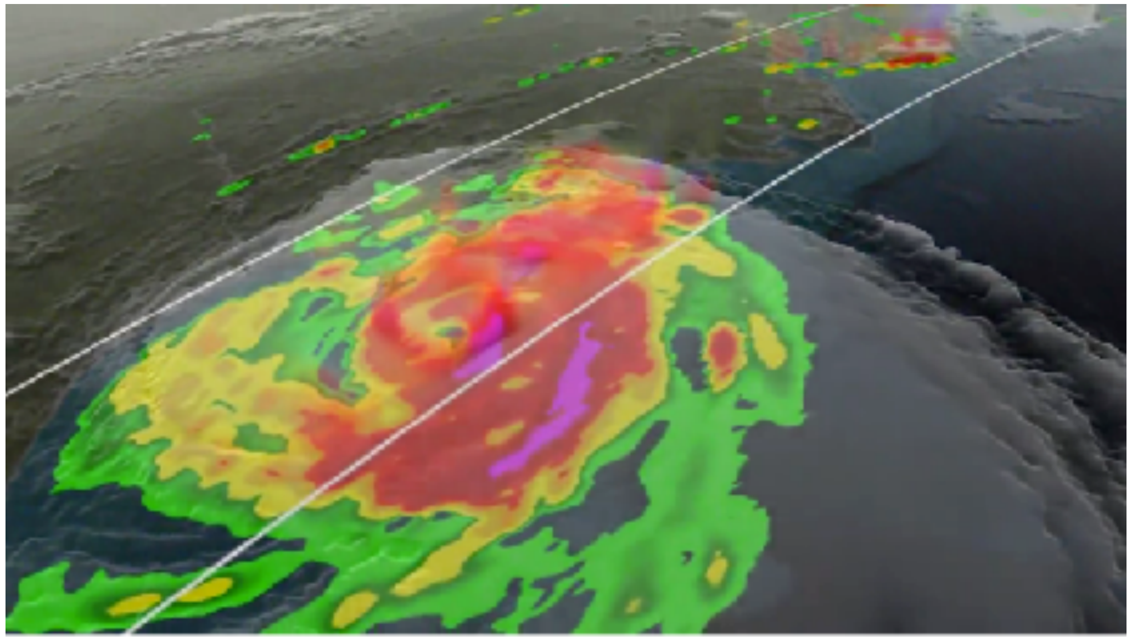
2004年

Karman vortex



CEReS NICT JMA HIMAWARI Visualization Team on YouTube

Tropical cyclone (Hurricane, Typhoon)

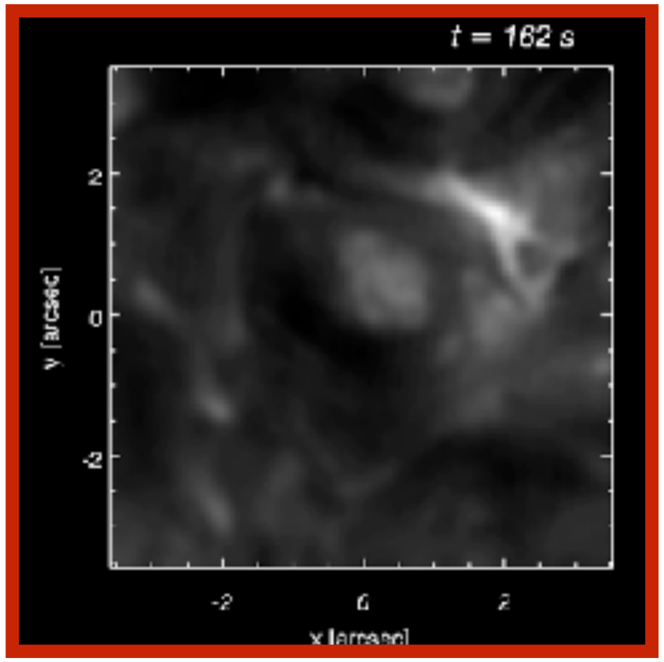


https://en.wikipedia.org/wiki/Tropical_cyclone

Wingtip vortex

https://en.wikipedia.org/wiki/Wingtip_vortices

太陽”磁気”トルネード

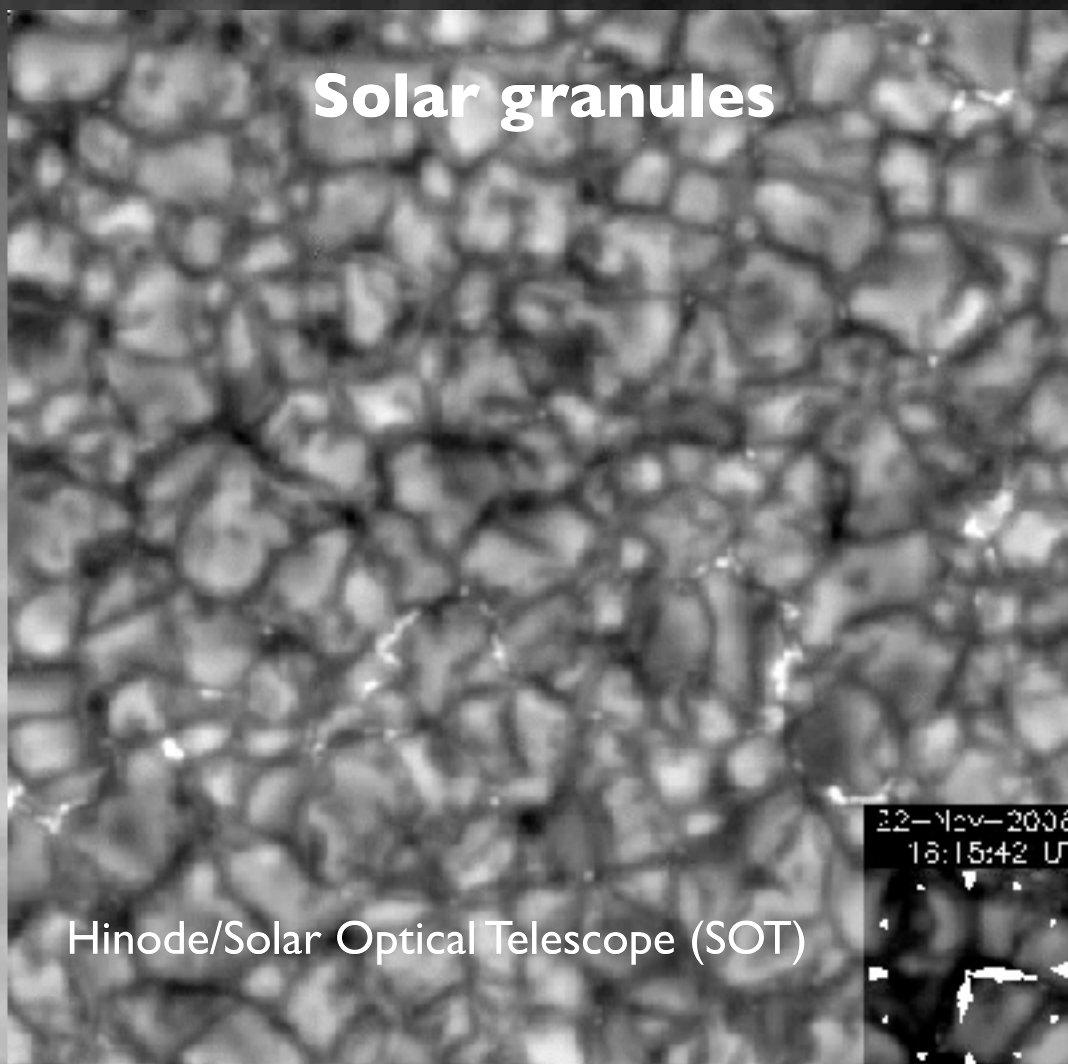


Ca II 854.2 nm -CRISP@SST
(Wedemeyer-Böhm & Rouppe van der Voort 2009)

Wedemeyer-Böhm et al. 2012

Solar Chromosphere

Spicules = Dynamical fibrils



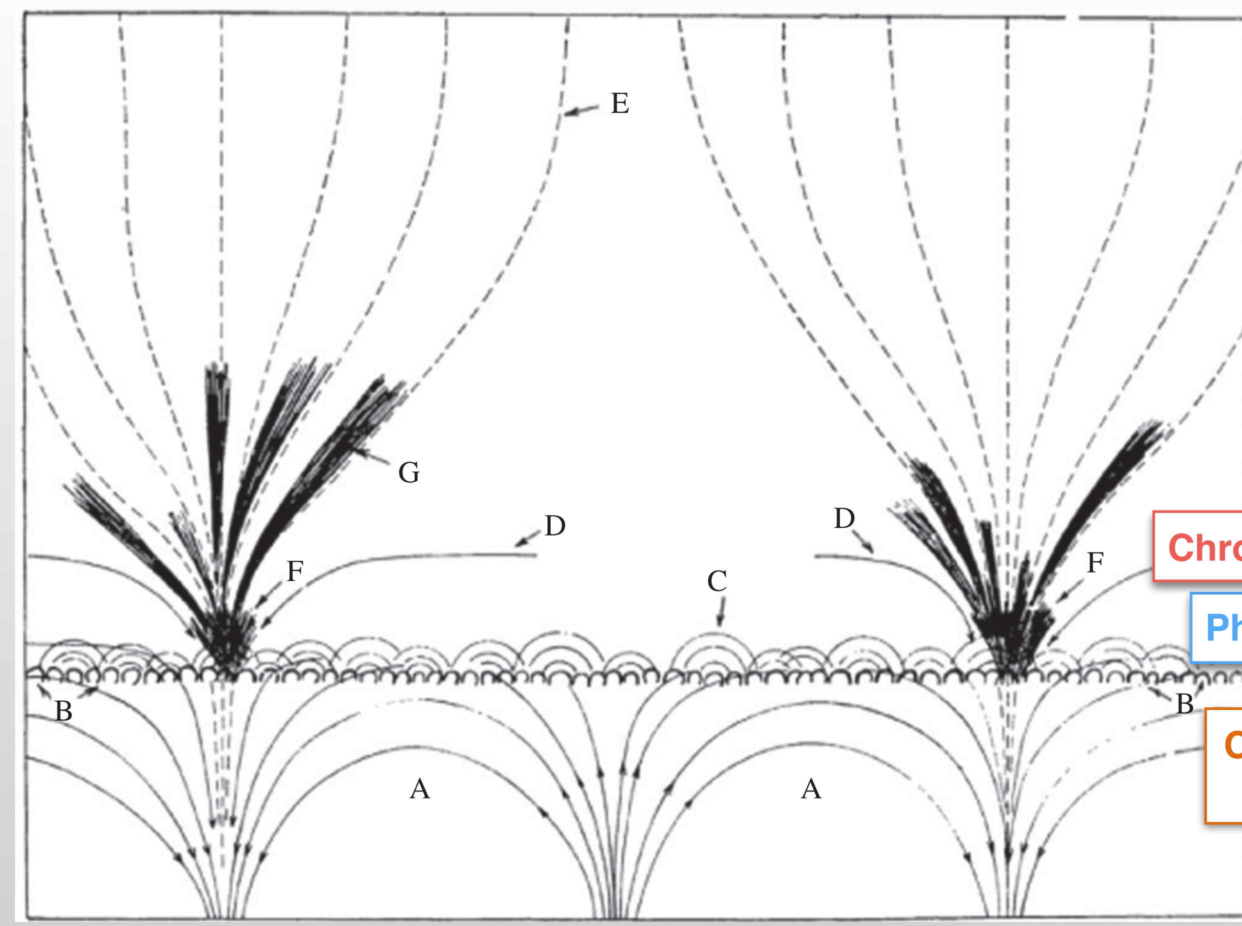


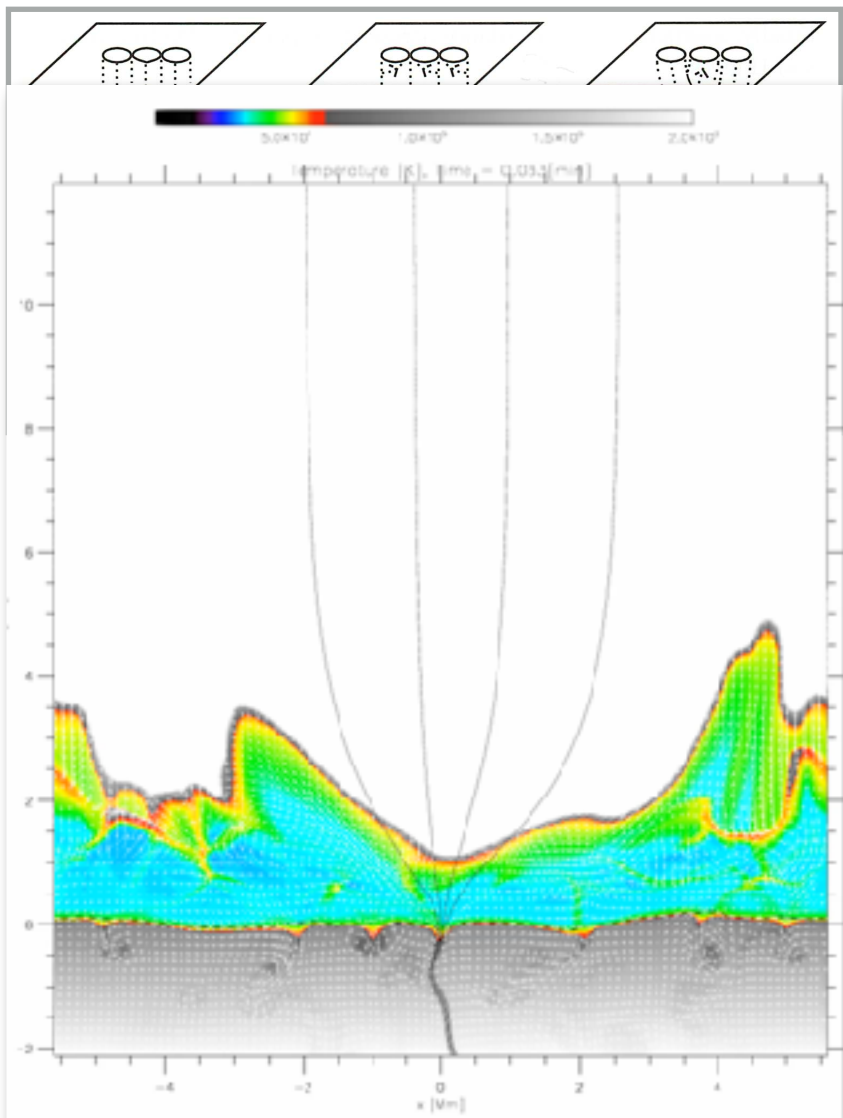
Figure 1. Sketch of the granulation–supergranulation–spicule complex in cross section. A, Flow lines of a supergranulation cell. B, Photospheric granules. C, Wave motions. D, Large-scale chromospheric flow field seen in Hα. E, [Magnetic] lines of force, pictured as uniform in the corona but concentrated at the boundaries of the supergranules in the photosphere and chromosphere. F, Base of a spicule 'bush' or 'rosette', visible as a region of enhanced emission in the Hα and K-line cores. G, Spicules. [...] The distance between the bushes is 30 000 km. Reproduced with permission from Noyes [15], including this caption.

Rutten 2012

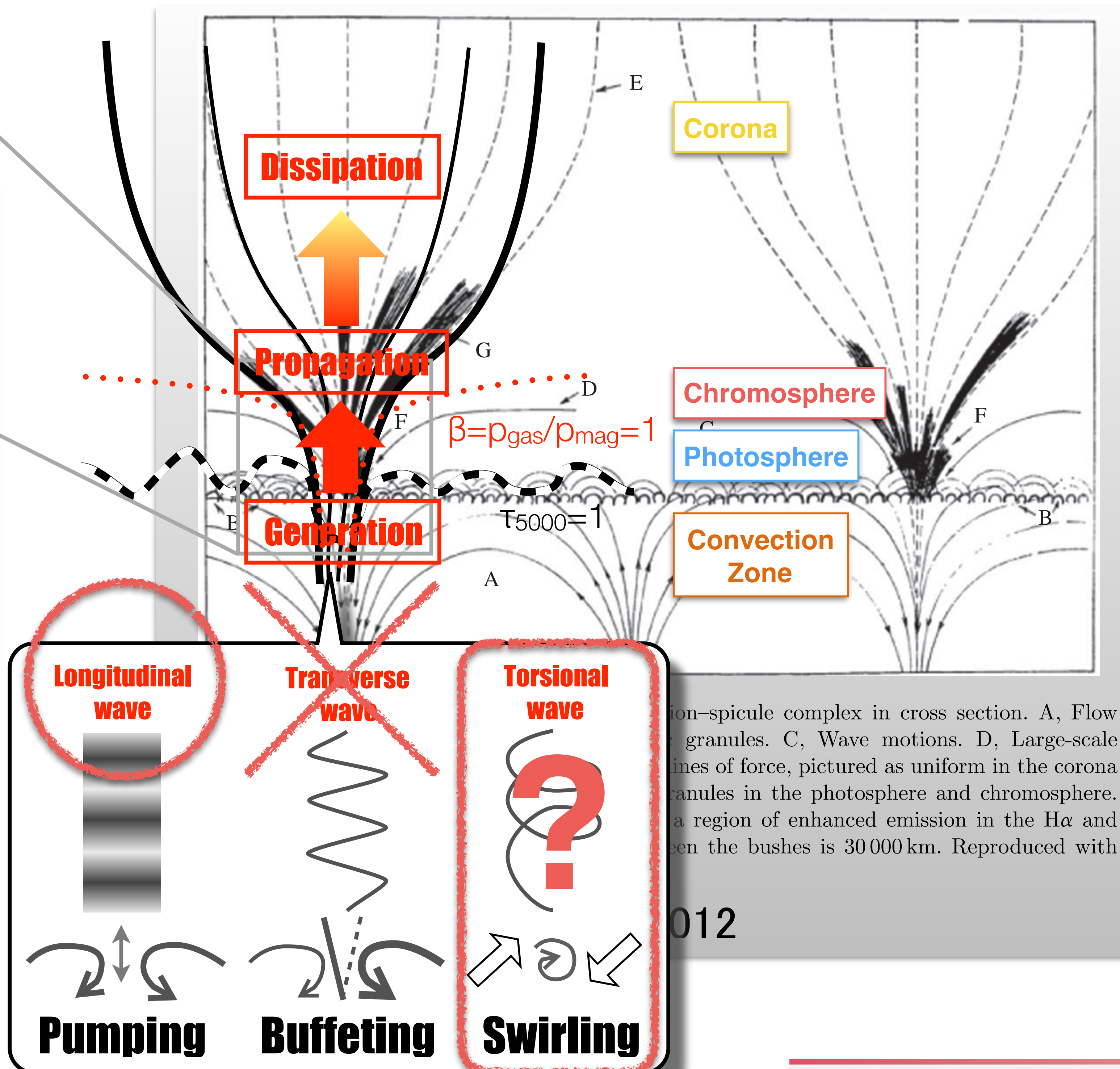
Hinode/Ca II H BFI movie (courtesy by Mats Carlsson)

Magnetic flux tube as magnetic portal

Current sheets will form at the boundary of field lines.



YK et al. 2016



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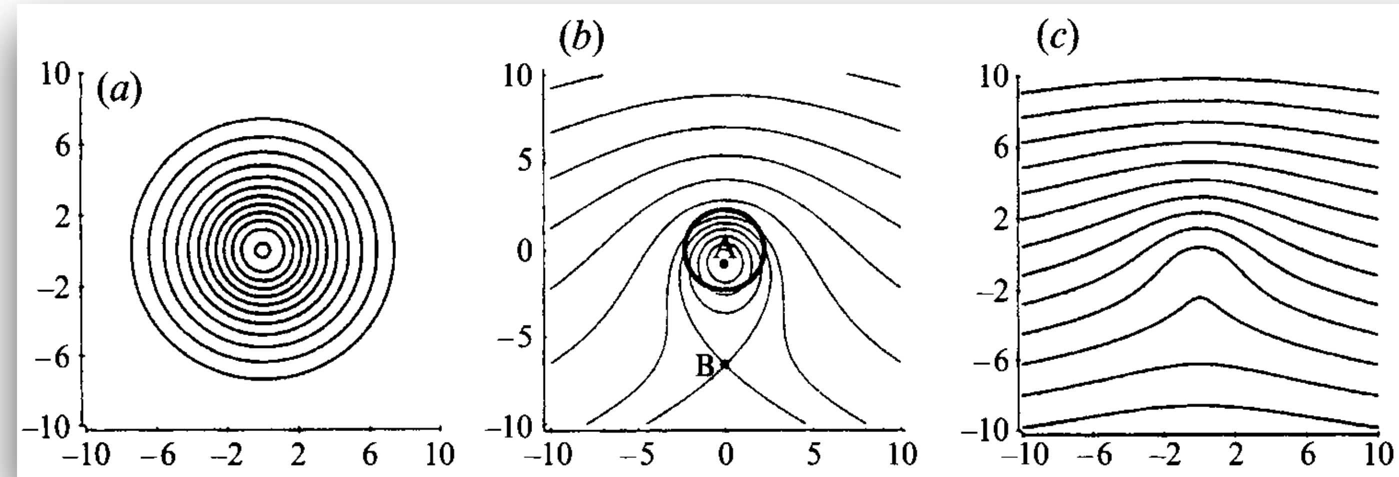
平成26年度発足 文部科学省 科学研究費補助金 新学術領域研究 Hadean Bioscience 冥王代生命学の創成

How to find a vortex?

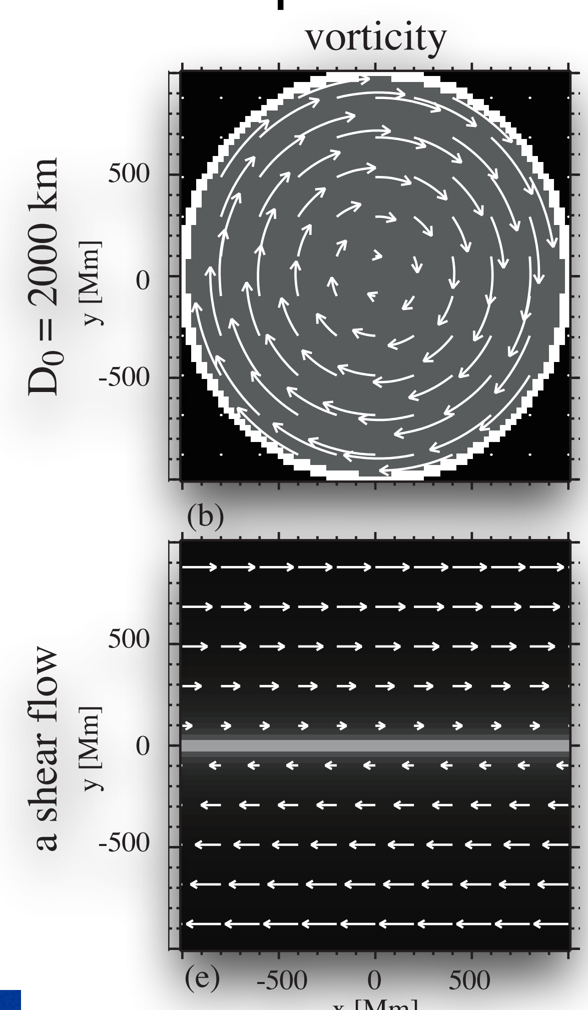
- Streamlines
- Vorticity magnitude
- Local pressure minimum



Rest frame

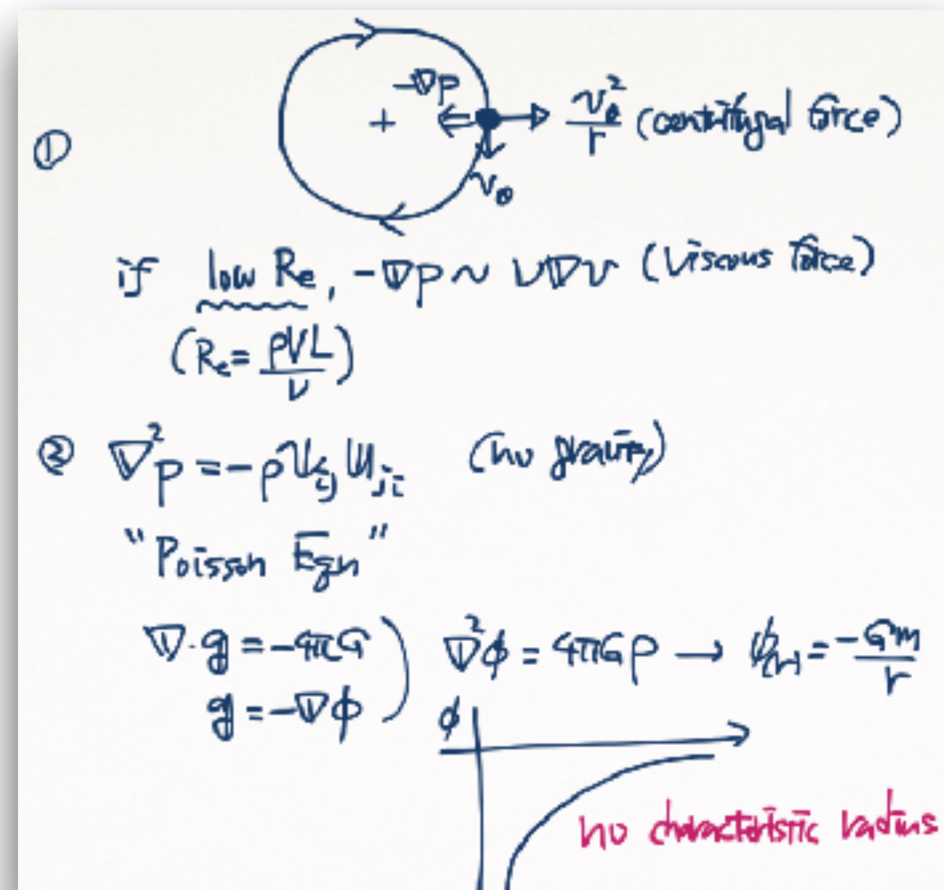
Slow co-moving frame

Fast co-moving frame



$$\nabla \times \boldsymbol{v} = \boldsymbol{\omega}$$

YK & Wedemeyer 2017

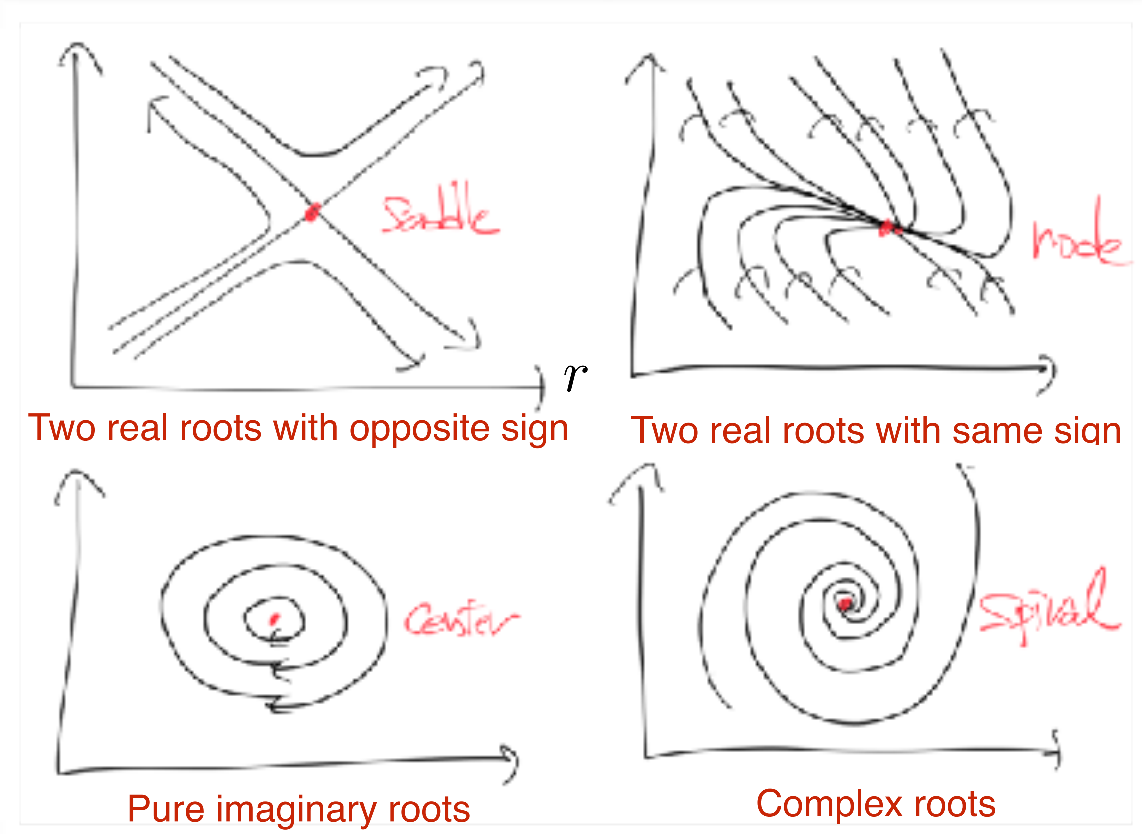


Recent measures of a vortex

by an imaginary part of eigenvalue of the velocity gradient tensor “Swirling Strength”= 渦巻度 (Moll et al. 2011)

$$\frac{dv}{dr} = \frac{N}{D}$$

The singular point analysis/classification on the differential equations



Two real roots with opposite sign

Two real roots with same sign

Pure imaginary roots

Complex roots

Consider the velocity gradient tensor, $\mathcal{D}_{ij}$

$$\mathcal{D}_{ij} = \frac{\partial v_{\mathrm{i}}}{\partial x_{\mathrm{j}}} \tag{2}$$

If λ are the eigenvalues of $\mathcal{D}_{ij}$, then

$$\left[\mathcal{D}_{ij} - \lambda I\right] e = 0 \tag{3}$$

where e is the eigenvector.

The eigenvalues can be determined by solving the characteristic equation

$$\det\left[\mathcal{D}_{ij} - \lambda I\right] = 0 \tag{4}$$

which, for a velocity flow in two-dimensional space $\boldsymbol{v} = (v_{\mathrm{x}}, v_{\mathrm{y}})$, can be written as

$$\lambda^2 + P\lambda + Q = 0 \tag{5}$$

where $P = -\mathrm{tr}(\mathcal{D}_{ij})$ and $Q = \det(\mathcal{D}_{ij})$. Equation (5) has the following canonical solutions:

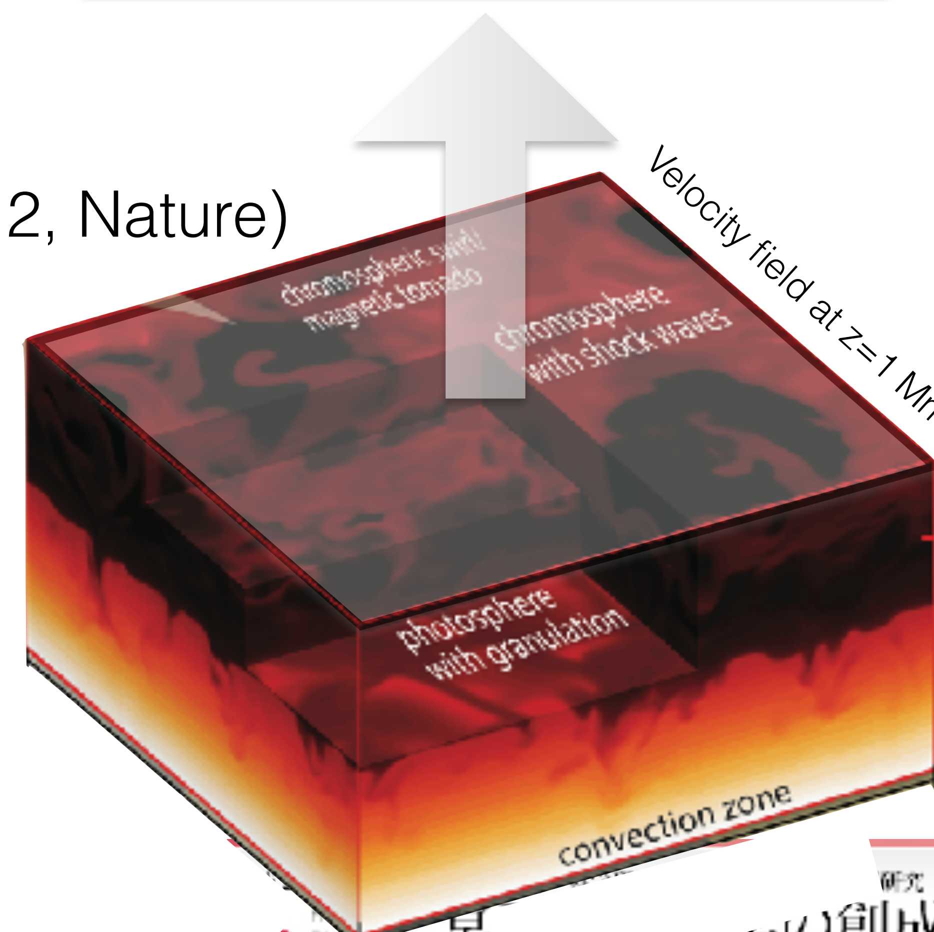
$$\lambda = \frac{-P \pm \sqrt{P^2 - 4Q}}{2}. \tag{6}$$

Testing a new detection algorithm

YK & Wedemeyer 2017 A&A

- A new 3D numerical simulation by using CO^5BOLD
  - CO^5BOLD (Freytag et al. 2008)
    - Fortran90+OpenMP
    - MHD: HLLC solver with the Janhunen source terms.
    - Long-characteristic Radiation Transfer
    - Equations of State assuming LTE
  - Initial model (similar to Wedemeyer-Böhm et al. 2012, Nature)
    - **$|B_0|$ = 50G** (strictly vertical)
    - Horizontal extent: 8.0 Mm x 8.0 Mm (11” x 11”)
    - Vertical extent: -2.4 Mm to **+2.4 Mm**
    - Δx=28 km in horizontal direction (286^3 meshes)

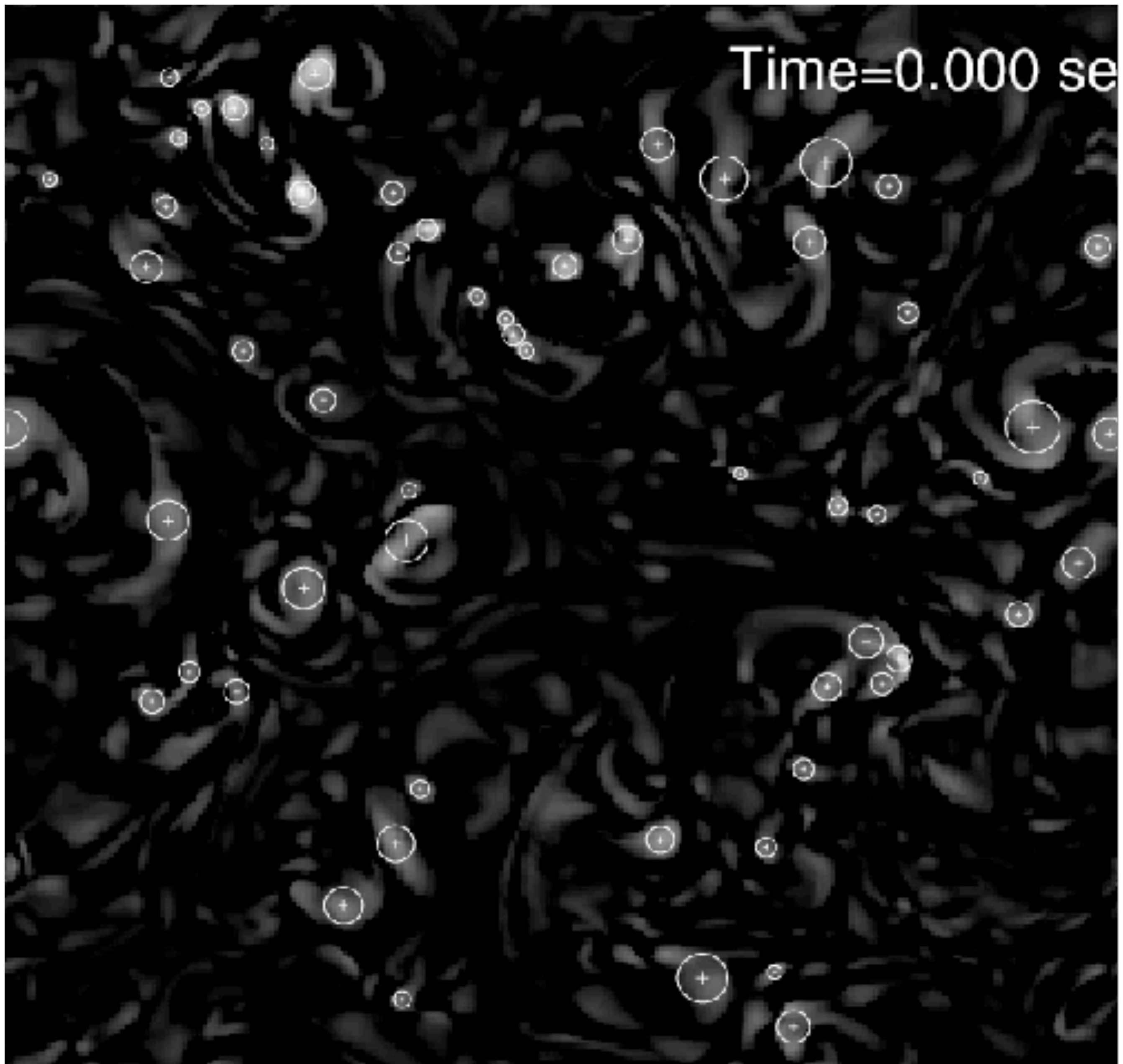
The velocity field at z=1 Mm is used as an input for testing the detection algorithm



渦巻度と渦度の比較

YK & Wedemeyer 2017 A&A

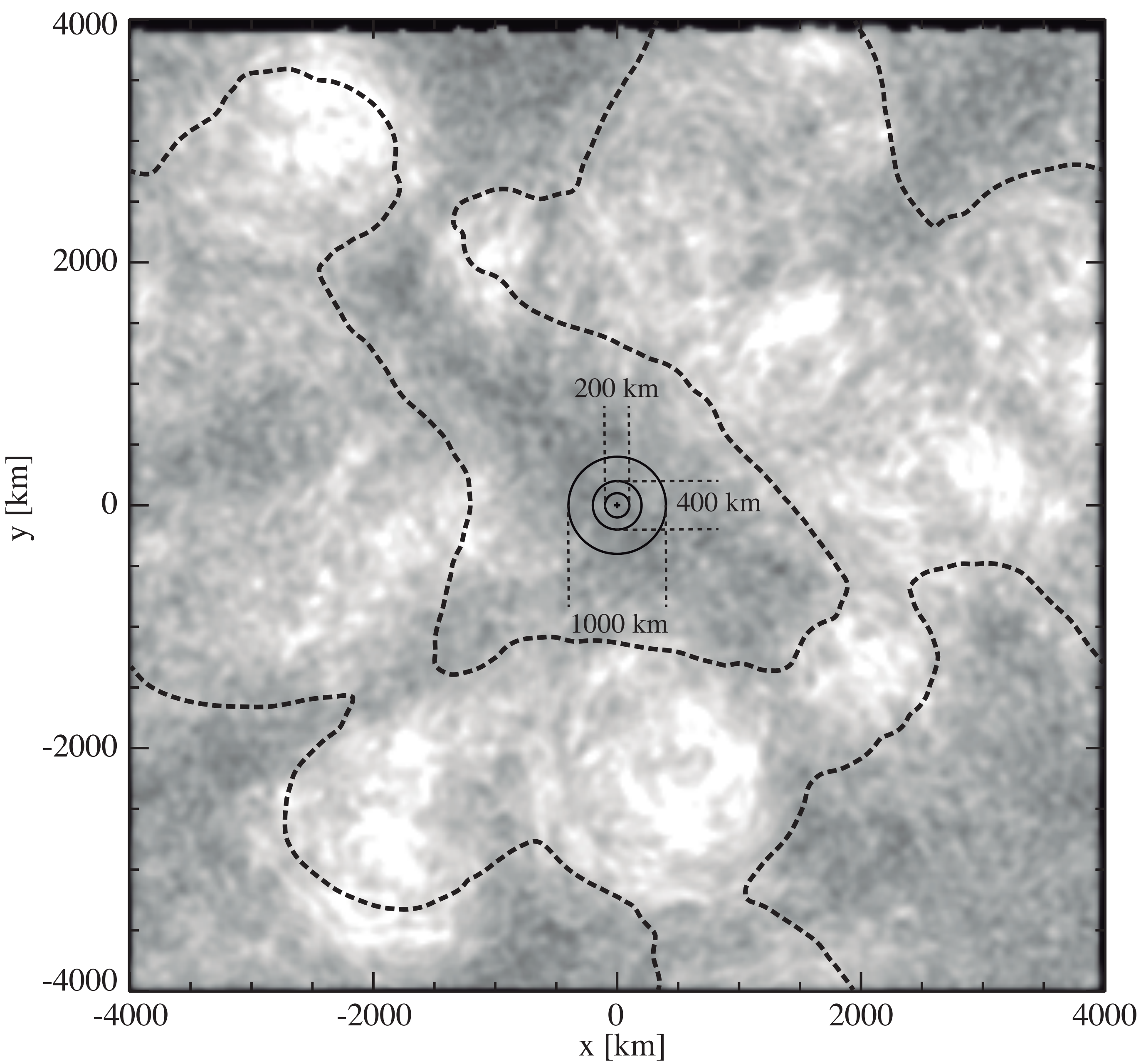
渦巻度

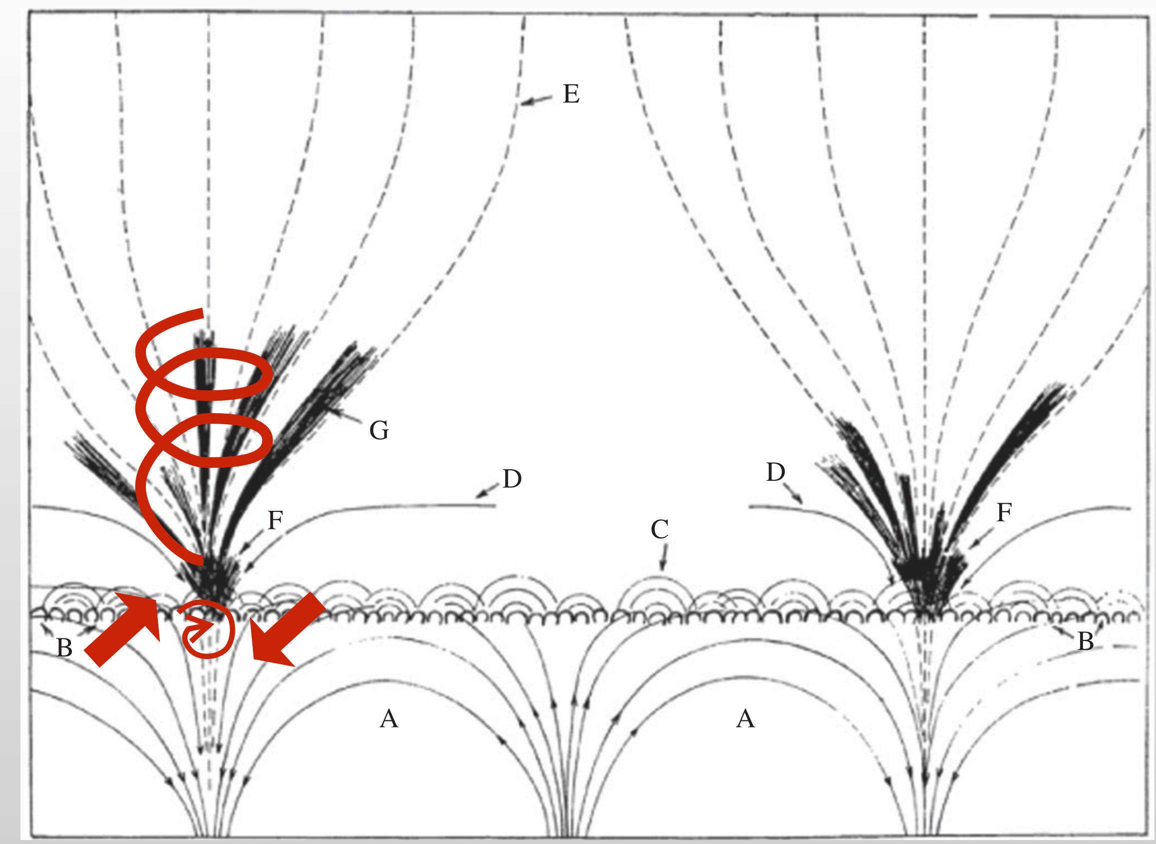


渦度

渦巻度と磁場強度の位置相関

YK & Wedemeyer 2017 A&A





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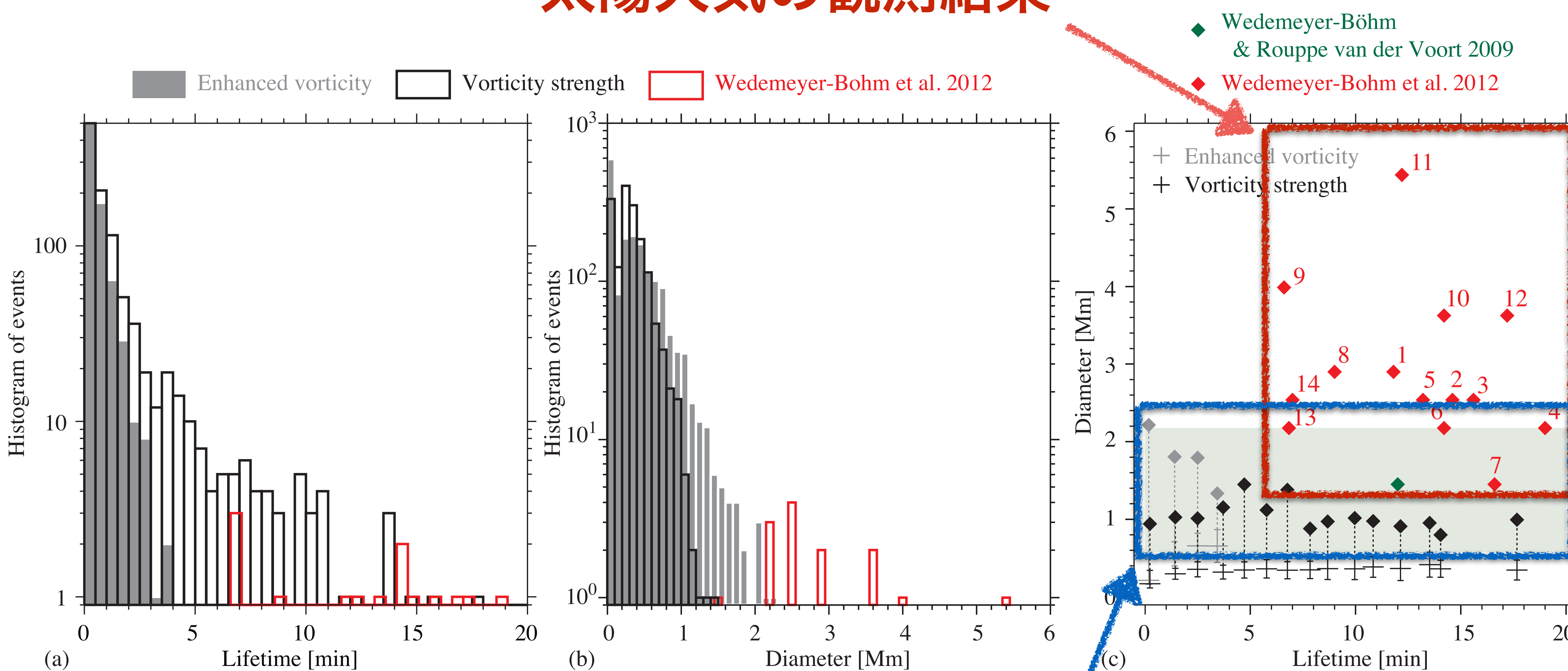
Rutten 2012

太陽観測と輻射磁気流体モデルの比較

YK & Wedemeyer 2017 A&A

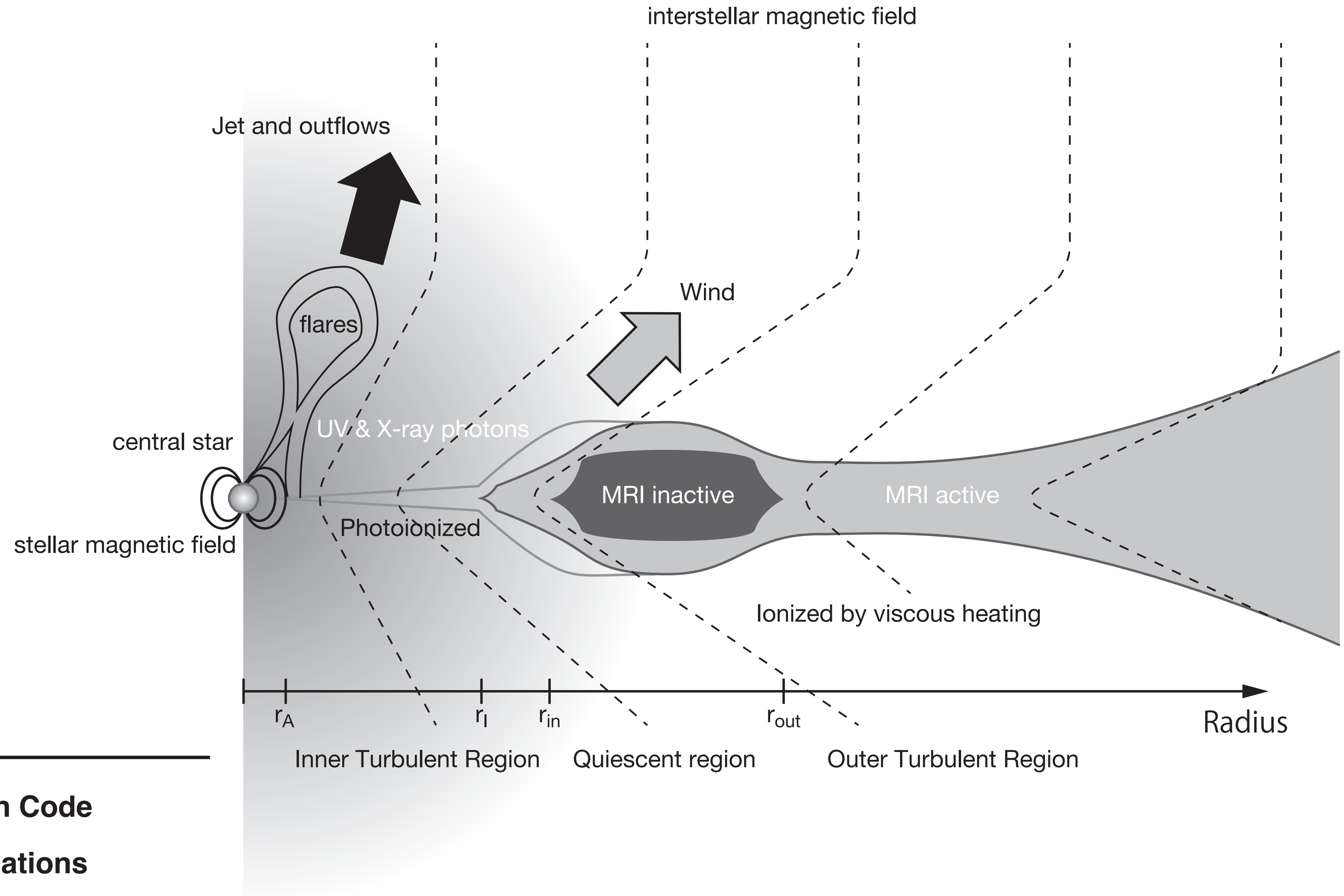
太陽大気の観測結果

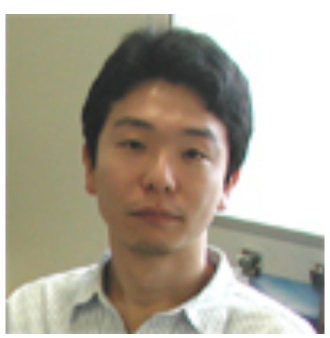


太陽モデルの計算結果

原始惑星系円盤の渦構造と惑星形成

Toward Simulation of Protoplanetary Disk





CANS+

Magnetohydrodynamic Simulation Code

CANS+: Assessments and Applications

Yosuke MATSUMOTO[1,2], Yuta ASAHINA[3], Yuki KUDOH[1], Tomohisa KAWASHIMA[3,4], Jin MATSUMOTO[5], Hiroyuki R. TAKAHASHI[3], Takashi MINOSHIMA[6], Seiji ZENITANI[4], Takahiro MIYOSHI[7], and Ryoji MATSUMOTO[1]

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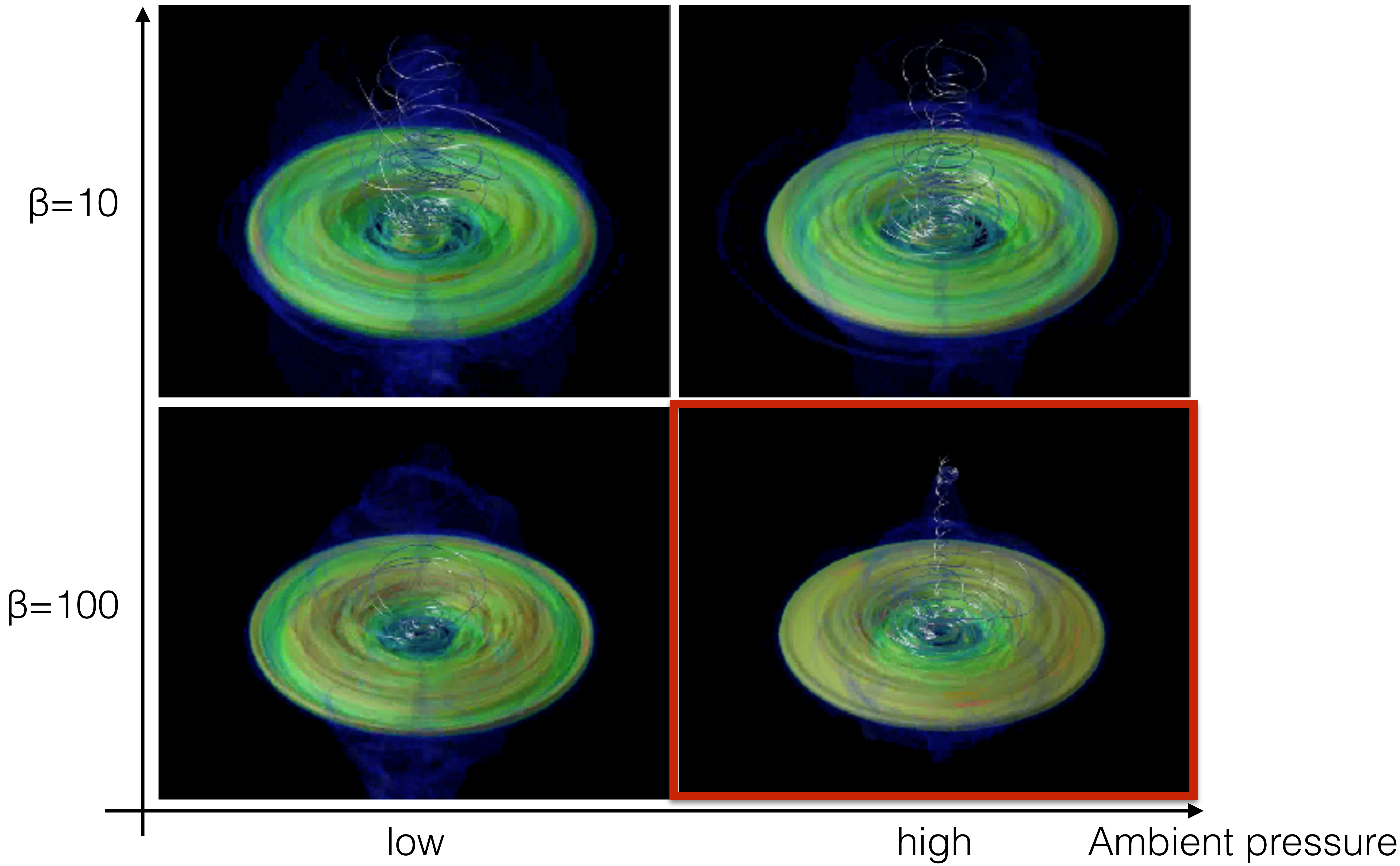
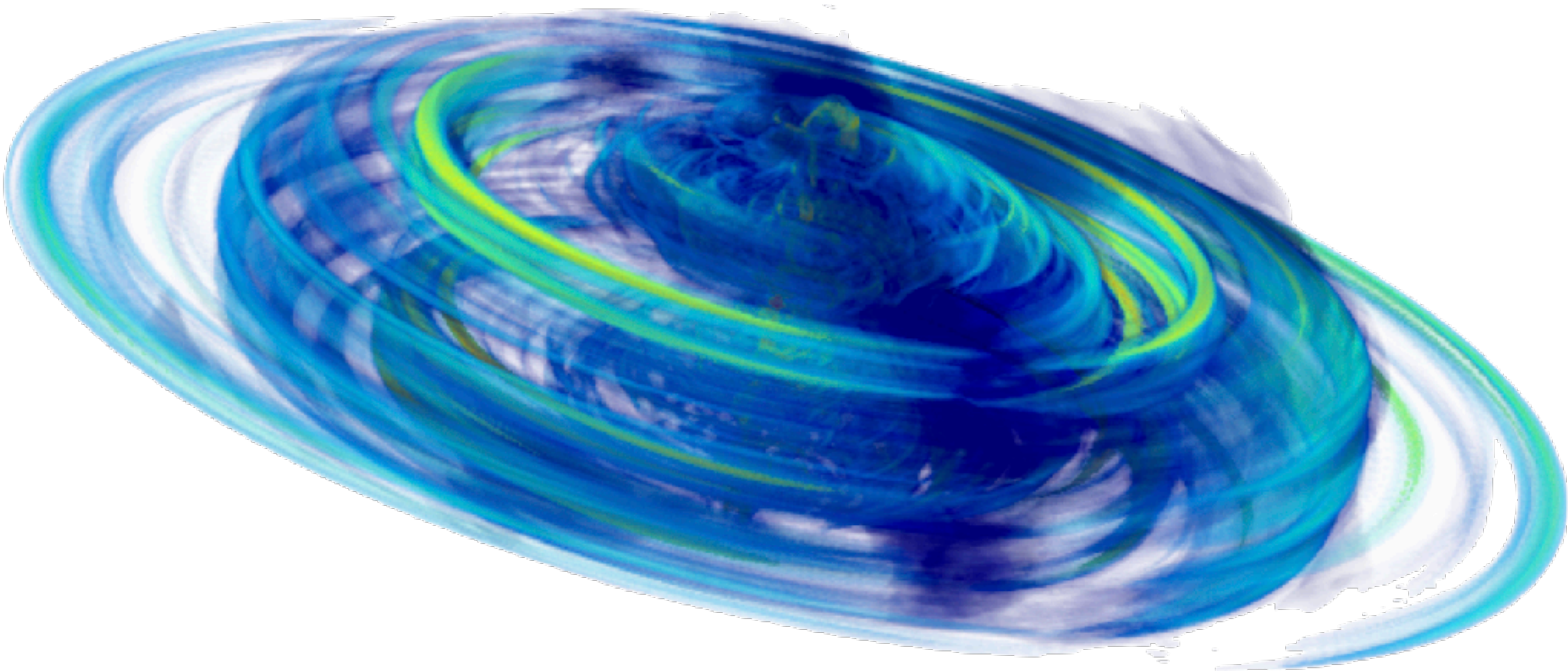
Hadean Bioscience 冥王代生命学の創成

Revisiting simulations of magnetic tower jet



降着円盤の渦巻度構造



まとめ

- 渦構造を同定する物理量：**渦巻度（速度勾配テンソルの固有値の虚部成分）**
- 太陽コロナ加熱の主犯とみられる**太陽トルネード**はまだ観測では見つかり難い小さい構造のモノが沢山存在する
- 降着円盤の**渦巻度**分布は**乱流粘性**（〜α粘性の起源）と相関するかどうか？【今後の研究】

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（領域略称名：冥王代生命学、領域番号：２６０５）