

幻の加速機構



# Introduction

遠心力加速というアイデア 〜とても期待されたアイデア〜



電磁誘導で共回転

遠心力で吹き飛ぶ







中性子星合体

AGN Kerr BH or 降着円盤

# **1.17. A RECONNER DRIGHT A RECONNER DRIGHT A REFERENCE A RECONNECTION A REFERENCE A RECONNECTION A REFERENCE A**



gal force increases up to some critical value to break up the ideal-MHD, and the plasma



# 遠心力加速問題

### $\frac{1}{2}$   $\frac{1}{2}$  (振り回すという) 粒子加速が起こるか? の問題 電磁場のエネルギー flux : EME 粒⼦のエネルギー flux : KE  $\sigma$  = EME / KE high sigma : Poynting energy dominant low sigma: Kinetic energy dominant <sup>μ</sup> 磁気モーメント Ω 自転角速度 c 光速

実際には分布がある σ(θ)

# Model

- 相対論的な電磁流体⼒学で記述
- 中心にダイポール磁場:軸対象
- 定常問題





- パルサー発見後、これらの方程式系は非常に熱心に研究された。 (e.g. Michel 1969; Goldreich and Julian 1970; Li and Melrose 1994; Begalman and Li 1994; Takahashi and Shibata 1998,… AGN jet のコン テンツでも注目された) <sub>field-aligned eq. + trans-field eq. を連立して解くのはハードルが高すぎて</sub> 誰もできていない。
- •磁力線に沿った流れを解くと→遠心力加速は起こらない (Poynting energy dominant wind になる)  $\gamma \approx = \sigma_0^{-1/3}$ . eg. if  $\sigma_0 = 10^6$ ,  $\gamma \approx = 100$ .  $v_{\varphi} = \Omega_{*}\varpi + \kappa B_{\varphi}$
- •ただし  $\left| \textit{B}_{\text{p}}\varpi^{\textit{2}}\right|$  が減少する時、反比例して加速 → AGN jetに応用

数値的に解いて解決できるか? RMHD simulation から

open field line の流れでは遠心力加速は起 こらないのは正しい

磁場が弱くなる Y-point , equatorial current sheet 近傍では遠心力加速が 起こるようだ。 この領域は数値計算上いろいろ問題 を起こす場所ではっきりしない。 加速の効率も決まらない。 **→ RMHDのアプローチは放置状態** 

磁力線と速度場、 流体のエネルギー/電磁場のエネルギーの図



Komisarov 2006  $\mathcal{L}$  is the contours show the magnetic flux function,  $\mathcal{L}$  the arrows show the flux function, and the colour image  $\mathcal{L}$ 

 $\mathbf{S}$  is the poloidal electric current density multiplied by r2; Bottom left panels: The magnetic flux show the magnetic flux 遠心力加速が起こる場所がある。  $t_{\rm c}$ the magnetic  $t_{\rm c}$  is  $\sim$  the color velocity, and the colour image shows B2. simulationで結果が出ない)  $\mathbf{1}$  on the azimuthal angle was introduce introduce introduce introduce in order to reduce in order to reduce in E>B の扱いが問題 (sRMHD

では、Particle simulationでは (PIC simulation)

# PICで磁気圏全体をsimulation ?

Wada, T. & Shibata, S. 2007, mnras, 376, 1460. doi:10.1111/j.1365-2966.2007.11440.x

その後、雨後の筍のように盛んになった。



Wada and Shibata, 2007)

### PIC simulation の例



Hu, R. ¥& Beloborodov, A.~M.¥ 2022, ¥apj, 939, 42. doi:10.3847/1538-4357/ac961d



 $-1$  $-2$  $-3$  $-4$  - $\mathcal{D}$ ejection of plasmoids  $x/R_{\star}$ the light cylinder is comparable to RLC in our simulation. This  $+$  creation is achieved by the state by the state  $\mathbf{r}$ 0.2 0.4  $0.6$ 0.8  $0.0$ 

3

 $\overline{2}$ 

 $\theta$ 

**Figure 12.** Average  $\phi$  velocity of an emitted photon.

outer gap も再現

 $\mathfrak{F}(\mathcal{N})^{\circ}$  $\bullet$  creation are still below those in real objects. るためいろいろ とが何かわかったという状況で くみられたがた イドの放出が (Lyubarsky 1990), and the equatorial current sheet outside  $\ell$ PICsimulation は author ごとに条件が異なるためいろいろな現象が起 simulation shows that the charged layer along the separatrix  $\mathbf{r}$ きて、はっきりしたことが何かわかったという状況ではない。Y- $C_{\alpha}$  can be surface charge  $\alpha$  $\overline{\phantom{a}}$  noint if  $\overline{\phantom{a}}$  if  $\overline{\phantom{a}}$   $\overline{\phantom{a}}$ point 近傍で、プラズモイドの放出が広くみられたがなぜプラズモ  $\lambda$   $\kappa$   $\kappa$   $\mu$   $\kappa$   $\lambda$   $\kappa$   $\mu$ イドが出るか説明できない。  $\sim$   $\sim$   $\sim$   $\sim$   $\sim$ were initially formed at the Y-point and later grew through  $\mathcal{F}$  and  $\mathcal{F}$  and  $\mathcal{F}$  and  $\mathcal{F}$  are  $\mathcal{F}$ mately spans light orange,  $\overline{0.25}$ 

プニブフルポ温担の仮宝しま 12  $\Gamma$  or  $\sqrt{\pi}$  (the  $\ell$  /  $\pi$  ) in the  $\pm$   $\pm$   $\pm$ PICではE//加速も起きてプラズマ生成過程の仮定(setting)とも関わり複雑

 $1.0$ 

#### cyaation (force fied moder) **Figure 2.** Calculation domain and imposed boundary conditions. See text pulsu.  $\sharp$ 羽 = pulsar equation (force free model) trans-field equation + 慣性無視 = pulsar equation (force free model)  $I - \sigma P$ とても流⾏った



![](_page_14_Figure_0.jpeg)

![](_page_15_Picture_0.jpeg)

本研究の結果

基本的アイデア(2023.12) the open field region due to the poloidal current, which circulates

 $\text{ideal-MHD} \rightarrow \text{iso-rotation law}$ ideal-MHD  $\rightarrow$  iso-rotation law

$$
v_{\varphi} = \Omega_* \varpi + \kappa B_{\varphi}
$$

where is a scalar function to be determined. The open magnetic r-point こ<sub>得</sub>い电加眉ツキには、toroidal ซxx Y-point と薄い電流層の中では、toroidal 磁場が ⼩さくなっていて

$$
\boxed{\boldsymbol{v}_{\varphi} = \Omega \varpi \rightarrow c} \quad \Box - \nu \triangleright \textcolor{blue}{\text{D} \boxplus \textcolor{red}{\text{F}} \textcolor{blue}{\text{D}} \textcolor{red}{\text{F}} \textcolor{blue}{\text{F}}}
$$

![](_page_16_Picture_5.jpeg)

ローレンツ因⼦の発散

に近いことが起こって  $\frac{1}{1}$ .<br>…ねる。そのような<br>…カドリフト雷流の 閉じた磁場を開く遠心カドリフト電流の犭<br>の噴出が矛盾なく説明できることを示せる<br>- ^ 3. is the magnetiza-stage **→**field-aligned eqs.を解く。 に近いことが起こっている。このような流れの行ってとかこう:<br>閉じた磁場を開く遠心カドリフト電流の発生と、重くなった共回転プラズマ  $\bigtriangledown$  field-aligned eqs.を解く。 に近いことが起こっている。そのような流れの存在を示そう! の噴出が矛盾なく説明できることを示せる?

![](_page_17_Figure_0.jpeg)

ideal-MHD が成立しているとして、 MHD eq.の field-aligned equations を解くことにする。

> Flow A と Flow B を考える

Figure 3. Two types of field-alined flows. The solid curves indicate the magnetic field lines. The dashed curves are field-aligned flows; Flow A locates outside of the current layer, while flow B runs inside the current layer. The  $\tau\sigma$ -axis indicates the axial distance. The thin dashed line  $x_A$  is the Alvéen surface. The thin dotted line  $\tau = R_L$  is the ligh cylinder.

![](_page_18_Picture_0.jpeg)

constant along the field line. The field line along the field line. The field line are all determined by the f

a set of boundary conditions and the conditions and the flow passes and the flow passes  $\mathcal{L}$ 

a set of boundary conditions and the condition that the flow passes

**3 CONCLUSIONS**

a set of boundary conditions and the conditions and the flow passes  $\mathcal{L}$ 

of solutions is obtained as contours of (*,* ) for a given set of

plane. The Bernoulli function (*,* ) has a form (Okamoto 1978;

(1 − )/, where <sup>A</sup> is the value of at the Alfvén point. A family

Camenzind 1986; Takahashi 1991),

The force-free solution may be a good approximation for the field

The last numbered section should briefly summarise what has been

sections, we will take a slightly deeper MHD approach.

sections, we will take a slightly deeper MHD approach.

sections, we will take a slightly deeper MHD approach.

facilities used etc. Try to keep it short.

third-party data analysed in the article. The statement should describe

articles published in MNRAS. Data Availability Statements provide

Julian density. However, in the case of dense plasma, magnetohydro-

sections, we will take a slightly deeper MHD approach.

third-party data analysed in the article. The statement should describe

articles published in MNRAS. Data Availability Statements provide

the article. This data analysed in the article. The statement should describe in the statement should describe

articles published in MNRAS. Data Availability Statements provide

done, and describe the final conclusions which the authors draw from

The last numbered section should briefly summarise what has been

a standardised format for readers to understand the availability of data

![](_page_19_Picture_0.jpeg)

The poloidal magnetic field would be som  $t$ the star, and changes to something like radial near and beyond the radial near  $t$ light cylinder. Mimicking this, a simple funct as *follows* $\hat{\beta}$ . The magnetic stream function for  $B_{\rm E} R_{\rm I}^3$  $\frac{3}{L}$ sin  $\frac{\partial^2 f_T}{\partial x_{mcg}(\psi)}$  where  $\frac{\partial^2 f_T}{\partial x^2}$  spherical mas of a  $\frac{1}{M_{\text{ini}}}$ been used. For the dipole field, we have  $\hat{B}$  $\hat{B}_{\text{dip}}(x) = (\psi/B_{\text{L}}R_{\text{L}}^2)$  $\vec{r}$  $4-3(\psi x/B_{L} R_{L}^{2})$ 2/3  $1/2$ *,* (11)  $\Gamma$ <sub>p</sub> and  $\dot{A}$  the solution fall we whether the solution of  $\dot{A}$ <u>satisfies the boundary conditions.</u> In the boundary conditions. In the must change in the must change in the must<br>The must change in the most change in the must change in the must change in the must change in the must ch  $\lim_{x\to 0} \frac{1}{x}$  from  $\lim_{x\to 0} \frac{1}{x}$  $T$  is the only parameter that determines the flow poloidal  $\overline{\omega}$   $\overline{\omega}$  $\sigma K_I^2$  $\overline{\mathcal{B}}$  $\frac{4\pi m_{CS}^2(\psi)}{1}$  $\frac{1}{2}$  where  $\frac{1}{2}$  $2\tilde{M}$  $\overline{\mathcal{L}}$ inj  $h$  $\widehat{\Omega(\psi)}$ **\** ≈ **Y**max  $\mathcal{N}$ inj *,* (10)  $\hat{B}$  =  $B_p \varpi^2$  $B_L R_L^2$ , 遠心力加速がないradial flow だと 1で一定  $\text{Adj}_p(x) = (\psi / D \text{L} \Lambda_L)$  |  $+ - \text{J}(\psi x / D \text{L} \Lambda_L)$ value at the injection point. The injection point  $\Gamma$ **Figure 7.** Left panels: The particle energy  $\frac{1}{2}$  $\mathbf{d}$  (dashed line) as functions of log . Rright panels: The azimuthal velocity panels: The azimuthal velocity  $\mathbf{d}$  $\overline{\phantom{a}}$ 磁気圏の磁場のエネルギー密度と 刀氏スヌのエネルは一年頃の質 poloidal 磁場の 令回は107  $40<sup>3</sup>$ 遠心力加速がないradial flow だと 1で一定 Y-point に侵入すると小さくなる

where  $x = \varpi / R_{L}$ . Since  $\hat{B}$  $\hat{\mathsf{S}}$ is constant for radial field, it gradually changes to a constant  $n = \pi / P$   $\sum_{i=1}^{\infty} P_i$   $\sum_{i=1}^{\infty} P_i$ where  $x = \omega / n_L$ . Since *b* is constant for the

## B hat の変化でさまざまな流れの性質が変わる

![](_page_21_Figure_1.jpeg)

![](_page_21_Figure_2.jpeg)

Figure 3. Two types of field-alined flows. The solid curves indicate the magnetic field lines. The dashed curves are field-aligned flows; Flow A locates outside of the current layer, while flow B runs inside the current layer. The  $\varpi$ -axis indicates the axial distance. The thin dashed line  $x_A$  is the Alvéen surface. The thin dotted line  $\omega = R_L$  is the ligh cylinder.

**Figure 5.** Models of  $\hat{B}(x) \propto B_p \omega^2$  for the flow A, B and C.

![](_page_22_Figure_0.jpeg)

![](_page_23_Figure_0.jpeg)

![](_page_24_Figure_0.jpeg)

## Flow B

![](_page_25_Figure_1.jpeg)

**Figure 3. The same as Figure 7, but for the flow B.** The centrifugal drivers **/YY / For You?** mate the Lorentz factor to open the mate  $+$  , we we also have the conservation proposition of the combined the combined theory and DC. Ļ 14  $\frac{1}{2}$ . In the contract of  $\frac{1}{2}$ .  $\frac{1}{2}$ .  $\frac{1}{2}$ . In the contract of  $\frac{1}{2}$ . In the contract of  $\frac{1}{2}$ .  $T$ **/ The Main Street** the condition to open the magnetic field lines, we have the magnetic field lines, we h  $2\frac{1}{1}$ p point and the conservation of p of the cases. The set results seems to show different faces. Δ **FILL**  $\frac{\Delta V}{\Delta \phi}$ (21361) (/)<sup>2</sup> magnetic field decreases. If = 0, there is no decrease, but if it is (H) **V RY B**<br>P **page**  $\vec{p}$ LUI<br>LUI **13 22 32 42 61 147 15 21 21 22 32 43** IF ACTIONS IN CHAR UNITY OF A LINE OF A **Religion in the expression indicates the expression indicates the expression indicates the expression indicates UNITY OF STATE OF LAST FACTOR**  $p$  ,  $p$  ,  $p$  is about unity. The factor  $p$  is about unity. ducts of the Alfvestation of mate the Lorenz factor to opening radical conseiler during de ENFE example, we use = 0*.*01, <sup>d</sup> = 1*.*2, and = 0*.*1, as shown in Figure 5. The value of 0 is set to be the same as the flow A, i.e., The centrifugal drift velocity is the centrifugal dr the condition to open the magnetic field lines, we have the magnetic field lines, we have the magnetic field l  $2\frac{1}{2}$ p , where the conservation  $p$ , we arrive at  $p$ , we arrive at  $p$ 磁場の磁路 公共に通り ヘッド 磁場は開けるか︖ **放電に吊りでおす** *Bp <i>O***utin AP** M *Bp* **B**  $\overline{B}$ 304  $\frac{1}{2}$ global<br>global at the outer edge of the current loop. With the second in the second in the With the Y-point in mind, we find the Y-point is only the Y-point place where the centrifugal acceleration can take place higher latitudes. **Ity is**  $\Delta$  co-rotationcould be **be** takes de  $\begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$  currentlm tha in**index** ig di **that** 2 FIS ESULT OF **Y-Point** <u>i ji </u> only the world centrifugal acceleration acceleration acceleration and the current sheet is possible to an and that is possible zin take parties **place. 194**  $\frac{1}{2}$ utrich and chen zathlich allen and **GROSC 3015; HARS CRIMINAL ISP 4156** a do Santa Branse a self-consistent structure of the centrifugal wind.  $L_{\bullet}$   $\sim$  1  $\sim$   $\alpha$  between  $\alpha$   $\sim$   $\alpha$  between  $\alpha$   $\alpha$   $\alpha$   $\alpha$ Pote to kinetic vicinity is converted to kinetic energy in the vicinity of the vicinity of the vicinity of the **PIUQ KUNILIZ GRICY NIGHT IS ALIGNED IN ALIGNED IS** magnetosphere, depending on the code prescriptions. It is interesting that Hu and Hu mate the Lorenz factor to open in the centrifugal and the centrifugal acceleration. interesting feature of their simulations is ejection of plasmoids. In the following the centrifugal acceleration that is  $p$  and  $p$  in a vicinity of the  $\alpha$  -point. It will be super-fast for the super-fast flows pro-fast flows pro-fast flows pro-fast flows pro-fast flows provide the azimuthal drift control open to a simulate control of the control open the control of the control of We will propose a series and consistent structure of the centrifugal wind. The centrifugal wind structure of the centrif sections, we will take a slightly deeper MHD approach. 2. Structure of the current sheet of the control of the current sheet of the current sheet of the current sheet **3 FEAD AT 15 FEARS** The last number of last number of the last number of the last number of the last number of the summarise who has been assessed to the last number of the last number of the last number of the last number of the last number done, and described the final conclusions which the authors draw from the authors of the authors draw from the the state of the state **ACKNOWLEDGEMENTS**  $4242$ **provide** the second contract of the s  $\frac{1}{2}$ provided the provided and the pro-We expect a thin layer as  $\frac{1}{2}$  we all  $\frac{1}{2}$  we are the solution of  $\frac{1}{2}$ L. If (Y/Δ) (Y/L) ≈ 1, <sup>c</sup> ≈ max/M. This value of the Lorentz factor is just the Lorentz is the Lorentz maximum of the Lorentz factor obtained if the Poynting energy is converted to kinetic energy. **DRIFT CURRENT** It would be nice to open up for your manner, when I is a self-consistent manner, may guessΔthe Larmore radius of the accelerated particles. This may be the case if the plasma density is near or less than the case in the case of the Goldreich-The last numbered section should briefly summarise what has been done, and describe the final conclusions which the authors draw from their work. **ACKNOWLEDGEMENTS 2.1 Structure of the current sheet 3 CONCLUSIONS** The last numbered section should briefly summarise what has been  $\frac{1}{2}$  in Fig. , and describe the final conclusions which the authors draw from  $\frac{1}{2}$  , and  $\frac{1}{2}$  the working of the work. We that that a thin layer as  $\frac{1}{10}$  we are  $\frac{1}{10}$  with  $\frac{1}{10}$   $\frac{1$ L. If (Y/Δ) (Y/L) ≈ 1, <sup>c</sup> ≈ max/M. This value of the Lorentz factor is the Lorentz factor is the Lorentz factor in the Lorentz factor of the Lorentz factor is the Lorentz factor in the Lorentz factor to opening the Lorentz factor in the Lorentz factor is the Lorentz factor o factor obtained if the Post is converted to kinetic energy is converted to kinetic energy. It would be nice to find Δ and Y in a self-consistent manner, it to the Poynting to It would be nice to find a<br>It would be nice to find considering the magnetic inside the magnetic resorts in the current layer.  $\frac{1}{2}$  and  $\frac{1}{2}$  accelerations of the acceleration particles. The acceleration particles. The acceleration particles is  $\frac{1}{2}$ be the case if the plasma density is near or less Julian density. dinamical process may determine the thickness sections, we will take a slightly deeper 2.1 Structure of the current sheet video the agrift current to open the current to open the contract of current to open the contract of contract o mate the Lorentz factor to open these a me many in the magnetic the centrifugal drift current. The region we consider it is the vicinity  $\sigma$  of  $\sigma$  shown in  $\sigma$  as  $\sigma$  as  $\sigma$  as shown in Figure 2. In the following sections, we have  $\sigma$ use the cylindrical coordinate (*, ,* ) with the unit vectors denoted by the centrifugal drift velocity, which has opposite die between die koning on the charge sign, would be twee significant would be the charge sign, would be a sign of **ACTIONS** The Acknowledgements section is not numbered. Here you can thank helpful colleagues, actions and the funding agencies, the funding agencies, the funding agencies, the funding a facilities used etc. Try to keep it short. **DATA AVAILABILITY AVAILABILITY AVAILABILITY AVAILABILITY AVAILABILITY AVAILABILITY AVAILABILITY AVAILABILITY A**  $\mathcal{L}_{\text{D}}$  does an describe the final conclusions which the authors draw from the authors draw from the authors draw from  $\mathcal{L}_{\text{D}}$ their work. **ACK MANUSCRIPT (1994)**  $T$ here  $\frac{1}{2}$ helpful colleagues, acknowledge funding agencies, telescopes and It would be nice to find a self-consistent manner in a self-consistent manner of the self-consistent manner, a considering the magnetic inside the magnetic inside the current layer. One current layer in the current layer may guessary and the acceleration of the acceleration of the acceleration of the acceleration of the acceleration be the case if the case if the plasma density is near or less than the plasma density is near or less than the<br>Less than the plasma density is near or less than the Goldreich-Contract of the Goldreich-Contract of the Gold Indrical conversions Care under ENTERN BAY 15 MILLEN DENSITY OF DENSITY CONTROL dinamical process may determine the thickness  $\frac{1}{2}$ **ACCEPTED ACTS AND ACCEPTANCE OF ACTS** The Act of th helpful colleagues, acknowledge funding agencies, telescopes and facilities used etc. Try to keep it short.  $d$  done, and describe the final conclusions which the authors draw from  $\alpha$ their work. **ACKNOWLEDGEMENTS** It would be nice to find a self-consistent manner of the nice to find  $\alpha$ ch of contracted the magnetic the magnetic theorem may guessΔthe Larmore radius of the accelerated particles. This may be the case if the plasma density is near or less than the plasma density is near or less than the Gold response 3 **19 STRUCTURE** Suppose a flow running just outside of the equatorial current layer, and  $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$  $\mathcal{I}$  is in the flow  $\mathcal{I}$  of  $\mathcal{I}$ that the azimuthal velocity would be  $\mathbf{t} = \nabla \mathbf{t}$  $\mathbb{Z}$  , in the equator in the current layer, in the current layer, indicated by B in the current layer, in faire a have a is small. Such a flow may have a  $e^{\frac{1}{2} \left( \sum_{i=1}^{n} \frac{1}{i} \right)}$  $w(\mathbf{u}, \mathbf{v})$  the current density as from the equator, we might obtain thickness of the current layer. <sup>p</sup> is the poloidal field strength outside the current layer,  $\mathcal{A}$  is a typical this condition, we have the Lorentz this condition, we have the local term of  $\mathcal{A}$ factor to open the magnetic field, ≈  $\frac{1}{2}$ p )<br><u>I</u><br><u>L</u> 2  $H$  $\boldsymbol{\mu}$ Δ **Y**  $\begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ =  $\sum_{i=1}^n$  $\frac{1}{2}$  $^{\prime}$  $\overline{\mathbf{A}}$ Y **EAN** d<br>D *.* (4) WE EXPECT A THIN LAYER, AND LAYER, AND  $\mathbb{R}^N$  say  $\mathbb{Z}^N$  ,  $\mathbb{Z}^N$  ,  $\mathbb{Z}^N$  ,  $\mathbb{Z}^N$  $\mathcal{L}$  is just expected one if  $\mathcal{L}$  is the Poisson intervals energy is converted on  $\mathcal{L}$ to kinetic energy. The condition  $\mathbb{R}^n$ It is a self-consistent to find  $\mathbb{E}$  in a self-consistent to find  $\mathbb{E}$ manner, considering the magnetic inside the magnetic inside the current of the current of the current of the current of layer. One may guess that Δ would be some thing like the Larmor radius of the accelerated particles. This may be the case if the plasma density is near or less than the Goldreich-Julian density. However,  $i$ n the case of dense plasma, magneto $i$ determine the thickness Δ. **3 STRUCTURE OF THE CURRENT SHEET**  $\mathbf{L}$  is the function of the equatorial current layer. We call it the flow A as is shown Figure 3. Since the flow A is inside 可以 アイビリ式 きょうしょく アンディアング アイストライン あんじょう しょうかい アイストライン アイディアン アイディアン アイアンドライバー しゅうしょう しょうかい しゅうしょう

only the contract of the contract of

**3 CONCLUSIONS**

# flow 中の密度減少を防ぐには、Y-point でinjectすればよいだろう

![](_page_27_Figure_1.jpeg)

B hat の変化でさまざまな流れの性質が変わる

![](_page_28_Figure_1.jpeg)

Figure 5. Models of  $\hat{B}(x) \propto B_p \omega^2$  for the flow A, B and C.

![](_page_29_Picture_0.jpeg)

![](_page_30_Picture_0.jpeg)

1-
$$
\lambda = 10^{-6}
$$
 O<sup>1</sup>/<sub>9</sub>  
\n1000  
\n1000  
\n0.8  
\n0.9  
\n0.8  
\n0.1  
\n0.0  
\

![](_page_32_Figure_0.jpeg)

## flow D で加速が起こる。これもMHD flow で説明されるはず。 磁場はダイポール的→加速は起きない remind that…

10000 1000 10  $0.2$  $0.6$  $0.8$  $0.4$ 

![](_page_34_Figure_0.jpeg)

![](_page_35_Figure_0.jpeg)

Figure 12. The Lorenz factor (solid line) and the energy of result of the end of the plasma. the flow (dashed line) as functions of  $\log \xi$ , and the azimuthal velocity as a function of *x* for Flow D.

![](_page_36_Figure_0.jpeg)

![](_page_37_Figure_0.jpeg)

![](_page_38_Figure_0.jpeg)

![](_page_38_Figure_2.jpeg)

**Figure 13.** Plasmoids formed by magnetic reconnection in the equatorial outflow. The snapshot was taken at  $t = 213.2 R<sub>s</sub>/c$ , at the end of the simulation. Top:<br>electron density  $n_e$ . Bottom: contours of the normalized

Fast critical ポイントが Alfven critical point に縮退した rast chitical ハイフィカ Aliven chitical point に<sub>Tinue</sub>とした<br>ため、current sheet の厚さや到達するローレンツ因子 にw、current sneet v<sub>パ子</sub>。<br>がもとまらなくなった。 reconnection process による。 厚みをgyro radius 〜 慣性長で評価すれば見積もれる。 (*eB*L*R*L)<sup>2</sup> /JCV)、Current Sneet Vカ<sub>子</sub> C 1<sup>9</sup>±5連 9 つローレノン凶丁<br>がちナキらかくかった

$$
\gamma \approx \frac{\gamma_{\max}}{(2\mathcal{M})^{1/2}}, \text{ and } \frac{\Delta}{R_{\text{L}}} \approx \frac{1}{(2\mathcal{M})^{1/2}}.
$$

結論: 相対論的遠心力風の構造 1 *flow* 

![](_page_40_Figure_1.jpeg)

![](_page_40_Figure_2.jpeg)

![](_page_41_Figure_0.jpeg)

![](_page_42_Picture_0.jpeg)

field-aligned eq. + trans-field eq. を連立して解くのはハードルが高 すぎて誰も試みていない。

### いよいよこれを実⾏する時がやってきた︕ 歴史に残る仕事になる。

### GS方程式を解くバートを共同してくれる方、いませんか?

aligned equation の trans-fast flow は解けるプログラムは出てきている。