地球系统数值模拟装置项目（地球系统模式数值模拟系统）日地空间环境模式分系统培训

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太阳大气观测

太阳表面-地球轨道（1AU）的三维空间

三维磁流体力学数值模型

运动学模型

模拟太阳风在太阳日冕到地球空间中的传播演化过程

输出整个日地空间和地球附近的太阳风磁场与等离子体基本参数的时空变化

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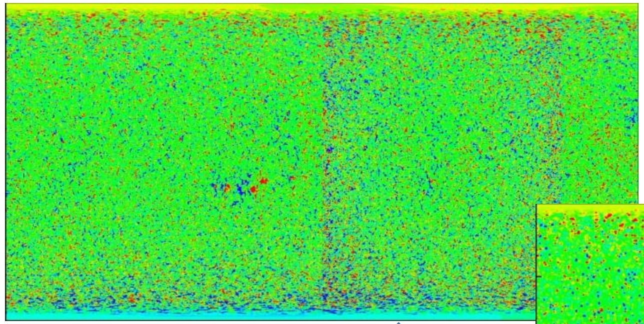
光球磁图处理

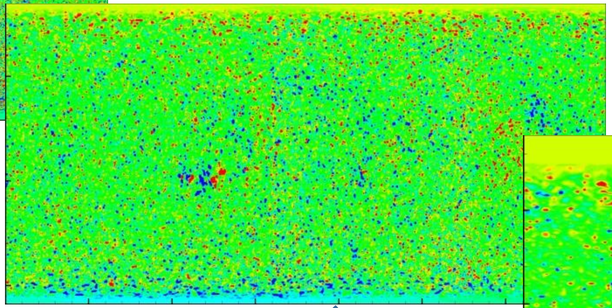
通过对不同数据源的光球磁图进行处理，获得给定网格的平滑后的光球磁场，作为模式的输入。

- ✓ 使用开源的FITSIO库读取fits文件，可处理一般的fits文件（GONG）和RICE压缩的fits文件（HMI）。
- ✓ 可从fits文件头中获取分辨率、起始卡灵顿坐标等信息，在后续处理中使用。

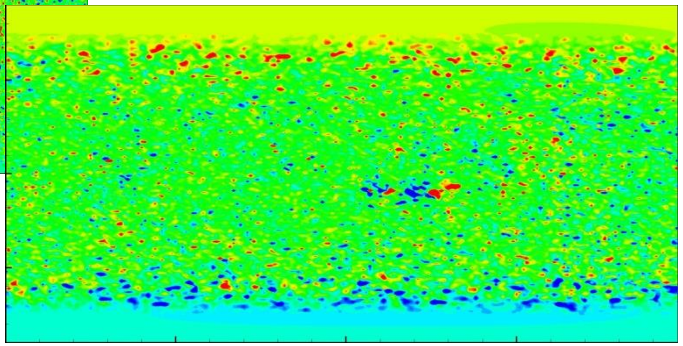
HMI原始磁图 （$\phi, \sin\lambda$）网格，3600× 1440



HMI平滑磁图（$\phi, \sin\lambda$）网格，3600× 1440



HMI插值磁图（ϕ, λ）网格，360× 180



PFSS外推

基本假设： $\nabla \times \mathbf{B} = 0$

定义： $\mathbf{B} = -\nabla\Phi$

$\nabla \cdot \mathbf{B} = 0 \quad \rightarrow \quad \nabla^2\Phi = 0$

内边界($1R_s$)：观测B_r

外边界(R_{SS}): $B_\theta = 0 \; B_\phi = 0$

R> R_{SS} :

基本假设：磁场只有B_r分量

$$B_r = B_{r(R=R_{SS})}\left(\frac{R_{SS}}{R}\right)^2$$

$$B_\theta = 0$$

$$B_\phi = 0$$

$$\mathrm{B_r(r,\theta,\phi)} = \sum_{n=1}^{Nmax}\sum_{m=0}^{n}\frac{1}{a_n - 1}[a_n(n+1)r^{-(n+2)} + nr^{n-1}]P_m^n(\theta)\,G_{nm}^p(\phi)$$

$$\mathrm{B_\theta(r,\theta,\phi)} = \sum_{n=1}^{Nmax}\sum_{m=0}^{n}\frac{-1}{r}f_n(r)\frac{dP_m^n(\theta)}{d\theta}G_{nm}^p(\phi)$$

$$\mathrm{B_\phi(r,\theta,\phi)} = \sum_{n=1}^{Nmax}\sum_{m=0}^{n}\frac{1}{r\sin\theta}mf_n(r)P_m^n(\theta)\,G_{nm}^m(\phi)$$

$$G_{nm}^p(\phi) = g_m^n\cos m\phi + h_m^n\sin m\phi$$

$$G_{nm}^m(\phi) = g_m^n\cos m\phi - h_m^n\sin m\phi$$

g_m^n和h_m^n由输入的光球磁场概图给定。

应用纯径向假设和磁通量守恒，源表面外磁场的计算方法为：

$$\mathrm{B_r(r,\theta,\phi) = B_r(R_{SS},\theta,\phi)}\left(\frac{\mathrm{R_{ss}}}{r}\right)^2，\mathrm{B_\theta(r,\theta,\phi) = 0.0}，\mathrm{B_\phi(r,\theta,\phi)}$$

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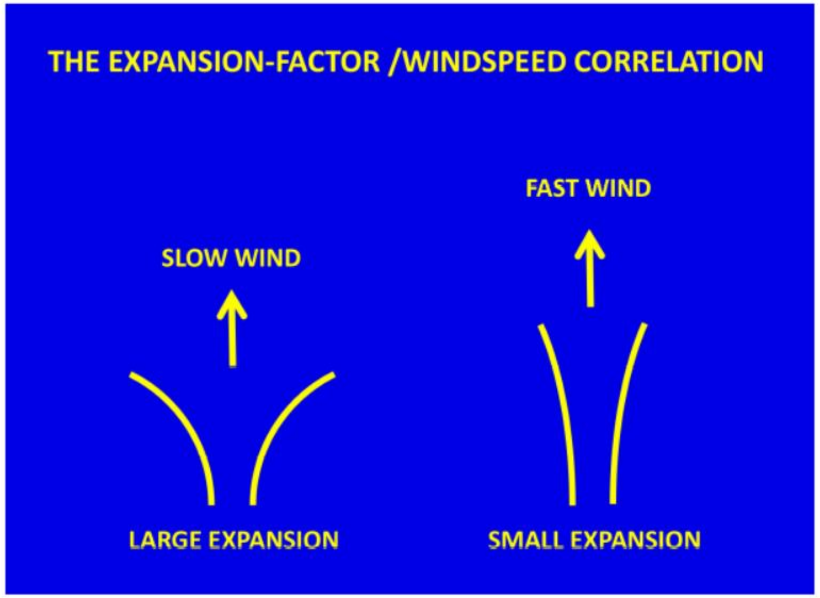
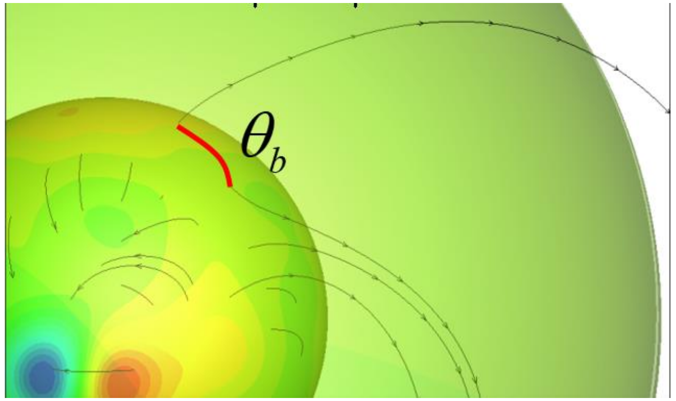
WSA模型

利用三维磁场数据，追踪磁力线，给出磁力线足点信息，并根据WSA模型计算太阳风速度在源表面上的分布。





$$V = V_s + \frac{V_f}{(1+f_s)^{a_1}}\left[a_2 - a_3 \exp\left(-\left(\frac{\theta_b}{a_4}\right)^{a_5}\right)\right]^{a_6}$$

MHD方程

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0$$

$$\frac{\partial \rho \boldsymbol{v}}{\partial t} + \nabla \cdot \left(\rho \boldsymbol{v}\boldsymbol{v} + \left(p + \frac{\boldsymbol{B}^2}{2\mu_0}\right) I - \frac{\boldsymbol{B}\boldsymbol{B}}{\mu_0}\right) = \boldsymbol{f} - \boldsymbol{B}(\nabla \cdot \boldsymbol{B})$$

$$\frac{\partial E}{\partial t} + \nabla \cdot \left(\left(E + p + \frac{\boldsymbol{B}^2}{2\mu_0}\right)\boldsymbol{v} - \frac{\boldsymbol{B}\boldsymbol{B} \cdot \boldsymbol{v}}{\mu_0}\right) =$$
$$Q_E + \boldsymbol{f} \cdot \boldsymbol{v} - (\boldsymbol{B} \cdot \boldsymbol{v})(\nabla \cdot \boldsymbol{B})$$

$$\frac{\partial \boldsymbol{B}}{\partial t} + \nabla \cdot (\boldsymbol{v}\boldsymbol{B} - \boldsymbol{B}\boldsymbol{v}) = -\boldsymbol{v}(\nabla \cdot \boldsymbol{B}) + \eta \nabla(\nabla \cdot \boldsymbol{B})$$

$$\boldsymbol{f} = \rho\left[\frac{GM}{r^3}\vec{r} + \boldsymbol{\omega} \times (\boldsymbol{\omega} \times \vec{r}) + 2\boldsymbol{\omega} \times \boldsymbol{v}\right]$$

- 太阳共转坐标系中的理想MHD方程，外力项包括重力、离心力和科里奥利力。
- Q_E 为体积加热项，将日冕加热/太阳风加速的过程参数化，通过磁场拓扑结构获得，用以产生快慢太阳风结构。 Q_E的级算由加热引子模块完成。
- 添加了相关的源项，控制磁场散度误差。

体积加热

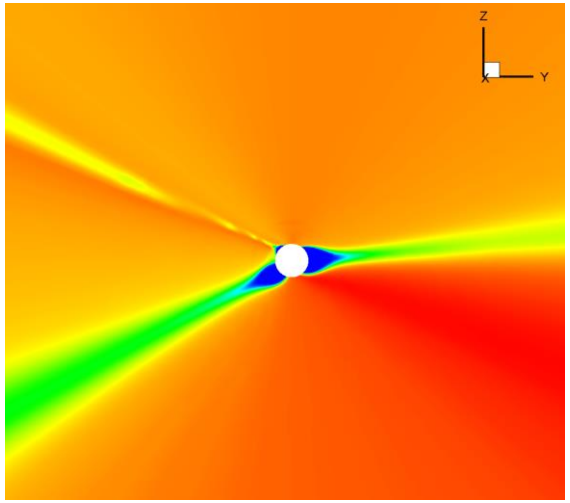
根据初始磁场位型计算加热因子，实现日冕加热和太阳风加速，产生结构分明的快慢太阳风结构。

$$\frac{\partial E}{\partial t} + \nabla \cdot \left(\left(E + p + \frac{\boldsymbol{B}^2}{2\mu_0} \right) \boldsymbol{v} - \frac{\boldsymbol{B}\boldsymbol{B} \cdot \boldsymbol{v}}{\mu_0} \right) = \boldsymbol{f} \cdot \boldsymbol{v} - (\boldsymbol{B} \cdot \boldsymbol{v})(\nabla \cdot \boldsymbol{B}) + Q_E$$

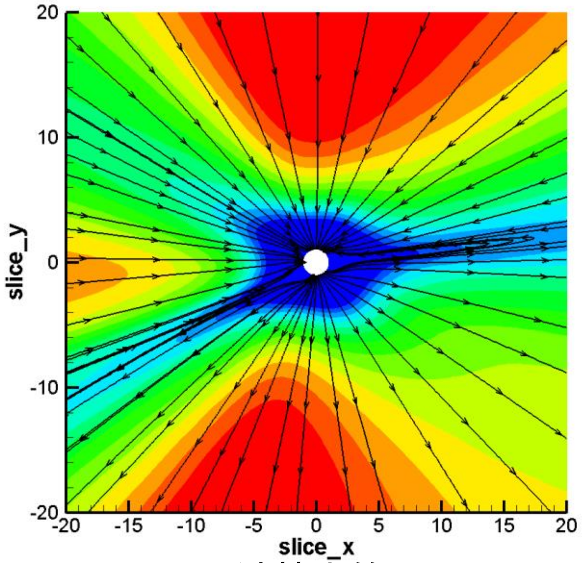
$$\mathrm{Q_E} = Q_0 \exp - \frac{r}{L_1} + Q_1^0 Q_1^*(r-1) \exp - \frac{r}{L_2}$$

$$Q_1^* = \frac{1}{(1+f_s)^{2/9}} \left[1 - \exp\left(- \left(\frac{\theta_b}{2} \right)^2 \right) \right]^3$$

f_s、 θ_b通过实时追踪计算结果中的磁力线，确定足点信息后给定。



加热因子系数在太阳附近的分布图



计算出的
快慢太阳风结构和磁力线

磁场散度误差 $\nabla\cdot B$的处理

$$\frac{\partial \boldsymbol{B}}{\partial t}+\nabla\times(\boldsymbol{v}\times\boldsymbol{B})=0 \quad\Rightarrow\quad \frac{\partial \boldsymbol{B}}{\partial t}+\nabla\cdot(\boldsymbol{vB}-\boldsymbol{Bv})=0 \qquad (\nabla\cdot B=0)$$

$$\frac{\partial \mathbf{B}}{\partial t}+(\nabla\cdot\mathbf{u})\mathbf{B}+(\mathbf{u}\cdot\nabla)\mathbf{B}-\boxed{(\nabla\cdot\mathbf{B})\mathbf{u}}-(\mathbf{B}\cdot\nabla)\mathbf{u}=0$$

● 磁场散度误差带来的问题

◆产生与磁力线方向平行的非物理的洛伦兹力，进而给出非物理的解。

◆由能量($E=\frac{1}{2}\rho v^2+\frac{p}{\gamma-1}+\frac{1}{2}B^2$)计算压强时，导致负压的出现。

● 处理措施

添加相关源项，使得磁场散度误差在产生后，通过对流和耗散效应控制。

添加源项等效于 $\frac{\partial}{\partial t}(\boldsymbol{\nabla}\cdot\boldsymbol{B})+\nabla\cdot(\boldsymbol{v}\boldsymbol{\nabla}\cdot\boldsymbol{B})=\eta\nabla^2(\boldsymbol{\nabla}\cdot\boldsymbol{B})$

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MHD方程数值解法

$$\frac{\partial \mathbf{U}_{\mathrm{i,j,k}}}{\partial \mathrm{t}} + \frac{1}{\mathrm{V}_{\mathrm{i,j,k}}} \sum_{l=1}^{6} \mathbf{F}_{\mathrm{l}} \cdot \boldsymbol{\Omega}_{\mathbf{l}} = \int_{V} \mathbf{S}_{\mathrm{i,j,k}}\, dV$$

$$\mathrm{U}^{\mathrm{n}+\frac{1}{2}} = U^{n} + \frac{1}{2} \Delta t R(U^{n})$$

$$\mathrm{U}^{\mathrm{n+1}} = U^{n} + \Delta t R(U^{n+\frac{1}{2}})$$

使用线性重构和MC限制器，使格式的空间重构精度达到2阶，且计算保持稳定。

$$\mathbf{W}_{\mathrm{i}+\frac{1}{2},\mathrm{j,k}} = \mathbf{W}_{\mathrm{i,j,k}} + \left(\frac{\partial \mathbf{W}}{\partial x}\right)_{i,j,k} \left(x_{i+\frac{1}{2},j,k} - x_{i,j,k}\right)$$

$$\left(\frac{\partial \mathbf{W}}{\partial x}\right)_{i,j,k} = \sigma_{\mathrm{i}}\left(2\frac{|W_{i+1,j,k} - W_{i,j,k}|}{x_{i+1,j,k} - x_{i,j,k}}, \frac{|W_{i+1,j,k} - W_{i-1,j,k}|}{x_{i+1,j,k} - x_{i-1,j,k}}, 2\frac{|W_{i,j,k} - W_{i-1,j,k}|}{x_{i,j,k} - x_{i-1,j,k}}\right)$$

$$\sigma_{\mathrm{i}} = \begin{cases} sign\left(W_{i+1,j,k} - W_{i,j,k}\right) & \left(W_{i+1,j,k} - W_{i,j,k}\right)\left(W_{i,j,k} - W_{i-1,j,k}\right) > 0 \\ 0 & \left(W_{i+1,j,k} - W_{i,j,k}\right)\left(W_{i,j,k} - W_{i-1,j,k}\right) < 0 \end{cases}$$

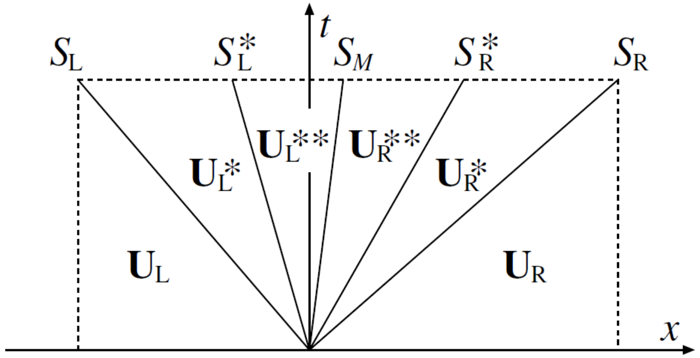
$$\mathbf{W}_{\mathbf{L}} = \mathbf{W}_{\mathrm{i,j,k}} + \left(\frac{\partial \boldsymbol{W}}{\partial x}\right)_{i,j,k} \left(x_{i+\frac{1}{2},j,k} - x_{i,j,k}\right)$$

$$\mathbf{W}_{\mathbf{R}} = \mathbf{W}_{\mathrm{i+1,j,k}} + \left(\frac{\partial \boldsymbol{W}}{\partial x}\right)_{i+1,j,k} \left(\mathrm{x}_{\mathrm{i}+\frac{1}{2},\mathrm{j,k}} - \mathrm{x}_{\mathrm{i+1,j,k}}\right)$$

Lax-Friedrich解子 $$f(U_L,U_R)=\frac{1}{2}\left[\hat{f}(U_L)+\hat{f}(U_R)-\frac{1}{2}|\lambda_{max}|_{LR}(U_R-U_L)\right]$$

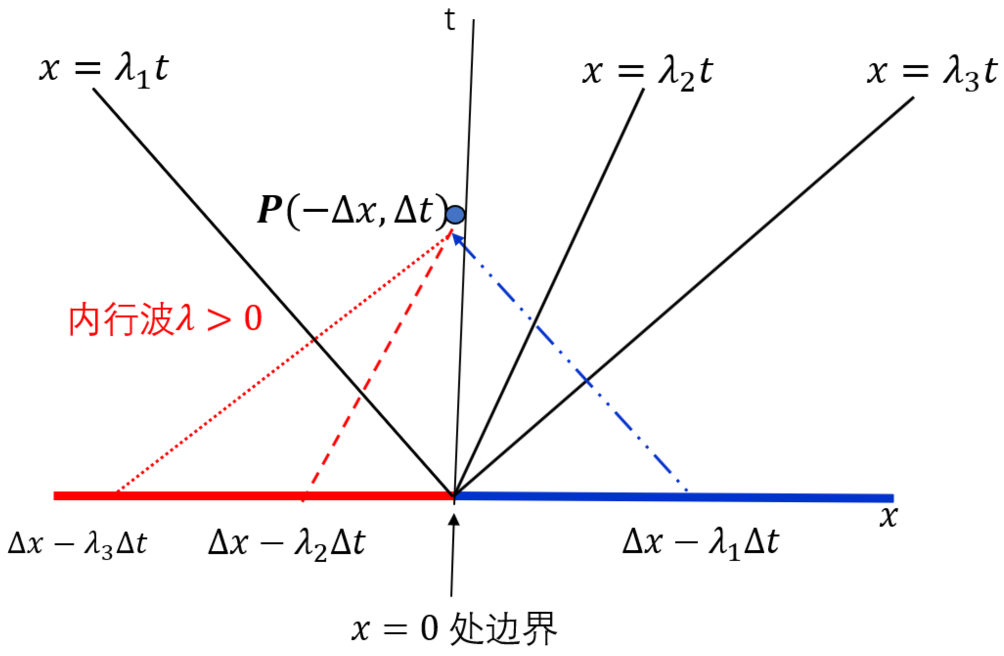
$$\boldsymbol{f}(\boldsymbol{U_L},\boldsymbol{U_R})=\begin{cases}\hat{\boldsymbol{f}}(\mathbf{U_L}) & \mathrm{S_L}>0\\ \boldsymbol{f}^* & S_L<0<S_R\\ \hat{\boldsymbol{f}}(\mathbf{U_R}) & \mathrm{S_R}<0\end{cases}$$

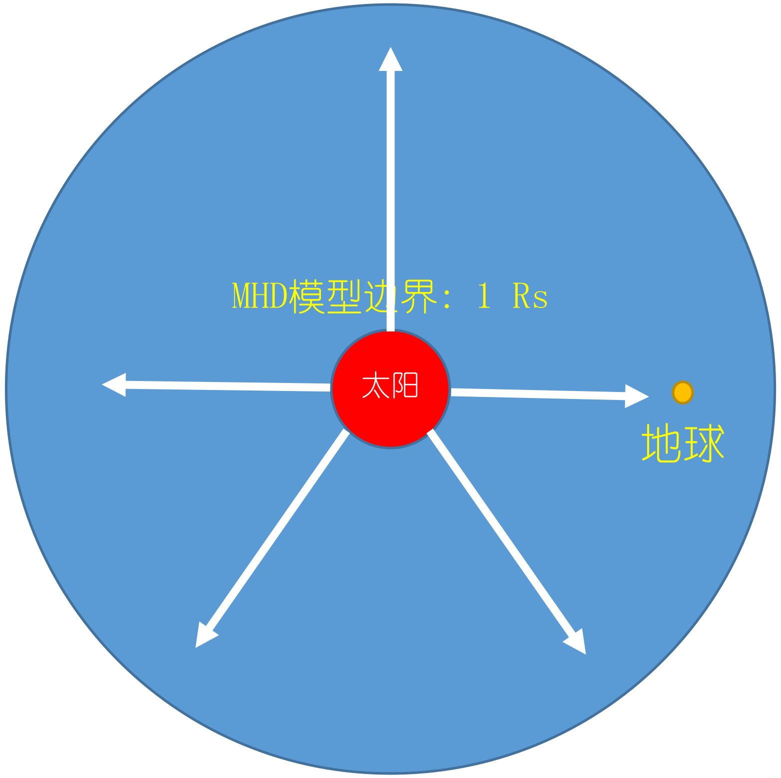
HLLD解子 $$\boldsymbol{f}(\boldsymbol{U_L},\boldsymbol{U_R})=\begin{cases}\hat{\boldsymbol{f}}(\mathbf{U_L}) & \mathrm{S_L}>0\\ \boldsymbol{f}_L^* & S_L<0<S_L^*\\ \boldsymbol{f}_L^{**} & S_L^*<0<S_M\\ \boldsymbol{f}_R^{**} & S_M<0<S_R^*\\ \boldsymbol{f}_R^* & S_R^*<0<S_R\\ \hat{\boldsymbol{f}}(\mathbf{U_R}) & \mathrm{S_R}<0\end{cases}$$



边界处理

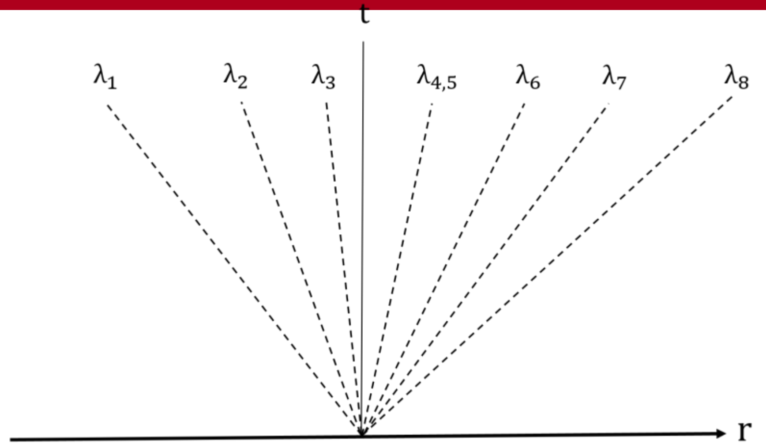
通过特征边界处理方法，根据边界的物理性质和计算区域内的信息，确定边界上太阳风参数的值。





外行波：
求解特征方程

$$\mathbf{l}\frac{\partial \mathbf{W}}{\partial t} + \lambda \mathbf{l}\frac{\partial \mathbf{W}}{\partial r} = \boldsymbol{S_{bd}} = \mathbf{l}\left(-\frac{\mathbf{A}_\theta}{r}\frac{\partial \mathbf{W}}{\partial \theta} - \frac{\mathbf{A}_\phi}{r\sin\theta}\frac{\partial \mathbf{W}}{\partial \phi} + \boldsymbol{S}_W\right)$$



MHD特征系统：8个特征波

内行波：
给定物理条件，输入观测信息

$$\frac{\partial B_r}{\partial t} = 0$$

$$u_r\frac{\partial B_\phi}{\partial t} + B_\phi\frac{\partial u_r}{\partial t} - B_r\frac{\partial u_\phi}{\partial t} = 0$$

$$B_r\frac{\partial u_\theta}{\partial t} - u_r\frac{\partial B_\theta}{\partial t} - B_\theta\frac{\partial u_r}{\partial t} = 0$$

$$\frac{\partial\left(\frac{p}{\rho^\gamma}\right)}{\partial t} = 0$$

$$\frac{\partial(\rho v_r)}{\partial t} = 0$$

$$\mathfrak{L}_1 = v_r\left(\frac{\partial \rho}{\partial r} - \frac{1}{a^2}\frac{\partial p}{\partial r}\right)$$

$$\mathfrak{L}_2 = v_r\left(\frac{\partial B_r}{\partial r}\right)$$

$$\mathfrak{L}_3 = (v_r - c_s)\left(-\frac{c_s\alpha_s}{2a^2}\frac{\partial v_r}{\partial r} - \frac{Mc_f\alpha_f\beta_\theta}{2a^2}\frac{\partial v_\theta}{\partial r} - \frac{Mc_f\alpha_f\beta_\phi}{2a^2}\frac{\partial v_\phi}{\partial r} - \frac{\alpha_f\beta_\theta}{2a\sqrt{\rho}}\frac{\partial B_\theta}{\partial r} - \frac{\alpha_f\beta_\phi}{2a\sqrt{\rho}}\frac{\partial B_\phi}{\partial r} + \frac{\alpha_s}{2a^2\rho}\frac{\partial p}{\partial r}\right)$$

$$\mathfrak{L}_4 = (v_r + c_s)\left(\frac{c_s\alpha_s}{2a^2}\frac{\partial v_r}{\partial r} + \frac{Mc_f\alpha_f\beta_\theta}{2a^2}\frac{\partial v_\theta}{\partial r} + \frac{Mc_f\alpha_f\beta_\phi}{2a^2}\frac{\partial v_\phi}{\partial r} - \frac{\alpha_f\beta_\theta}{2a\sqrt{\rho}}\frac{\partial B_\theta}{\partial r} - \frac{\alpha_f\beta_\phi}{2a\sqrt{\rho}}\frac{\partial B_\phi}{\partial r} + \frac{\alpha_s}{2a^2\rho}\frac{\partial p}{\partial r}\right)$$

$$\mathfrak{L}_5 = (v_r - |b_r|)\left(-\frac{\beta_\phi}{2}\frac{\partial v_\theta}{\partial r} + \frac{\beta_\theta}{2}\frac{\partial v_\phi}{\partial r} - \frac{M\beta_\phi}{2\sqrt{\rho}}\frac{\partial B_\theta}{\partial r} + \frac{M\beta_\theta}{2\sqrt{\rho}}\frac{\partial B_\phi}{\partial r}\right)$$

$$\mathfrak{L}_6 = (v_r + |b_r|)\left(\frac{\beta_\phi}{2}\frac{\partial v_\theta}{\partial r} - \frac{\beta_\theta}{2}\frac{\partial v_\phi}{\partial r} - \frac{M\beta_\phi}{2\sqrt{\rho}}\frac{\partial B_\theta}{\partial r} + \frac{M\beta_\theta}{2\sqrt{\rho}}\frac{\partial B_\phi}{\partial r}\right)$$

$$\mathfrak{L}_7 = (v_r - c_f)\left(-\frac{c_f\alpha_f}{2a^2}\frac{\partial v_r}{\partial r} + \frac{Mc_s\alpha_s\beta_\theta}{2a^2}\frac{\partial v_\theta}{\partial r} + \frac{Mc_s\alpha_s\beta_\phi}{2a^2}\frac{\partial v_\phi}{\partial r} + \frac{\alpha_s\beta_\theta}{2a\sqrt{\rho}}\frac{\partial B_\theta}{\partial r} + \frac{\alpha_s\beta_\phi}{2a\sqrt{\rho}}\frac{\partial B_\phi}{\partial r} + \frac{\alpha_f}{2a^2\rho}\frac{\partial p}{\partial r}\right)$$

$$\mathfrak{L}_8 = (v_r + c_f)\left(\frac{c_f\alpha_f}{2a^2}\frac{\partial v_r}{\partial r} - \frac{Mc_s\alpha_s\beta_\theta}{2a^2}\frac{\partial v_\theta}{\partial r} - \frac{Mc_s\alpha_s\beta_\phi}{2a^2}\frac{\partial v_\phi}{\partial r} + \frac{\alpha_s\beta_\theta}{2a\sqrt{\rho}}\frac{\partial B_\theta}{\partial r} + \frac{\alpha_s\beta_\phi}{2a\sqrt{\rho}}\frac{\partial B_\phi}{\partial r} + \frac{\alpha_f}{2a^2\rho}\frac{\partial p}{\partial r}\right)$$

特征向量的形式相对繁杂

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- HI
- photosphere_mag
- plot
- kinetic
- data
- external_libs
- corona
- math_utility
- run
- clean.sh
- compile.sh

corona目录为日冕部分的太阳风传播模拟和磁流体力学数值计算代码；

HI为行星际部分的太阳风传播模拟和磁流体力学数值计算代码；

kinetic为运动学模型代码；

math_utility为通用的数学计算功能；

photosphere_mag为处理光球磁场概图的代码；

plot为可视化后处理代码；

run为运行目录；

external_libs为依赖的外部库

data为运行需要的部分外部数据

clean.sh为清除运行结果和已编译的目标文件、可执行文件的脚本；

compile.sh为编译脚本

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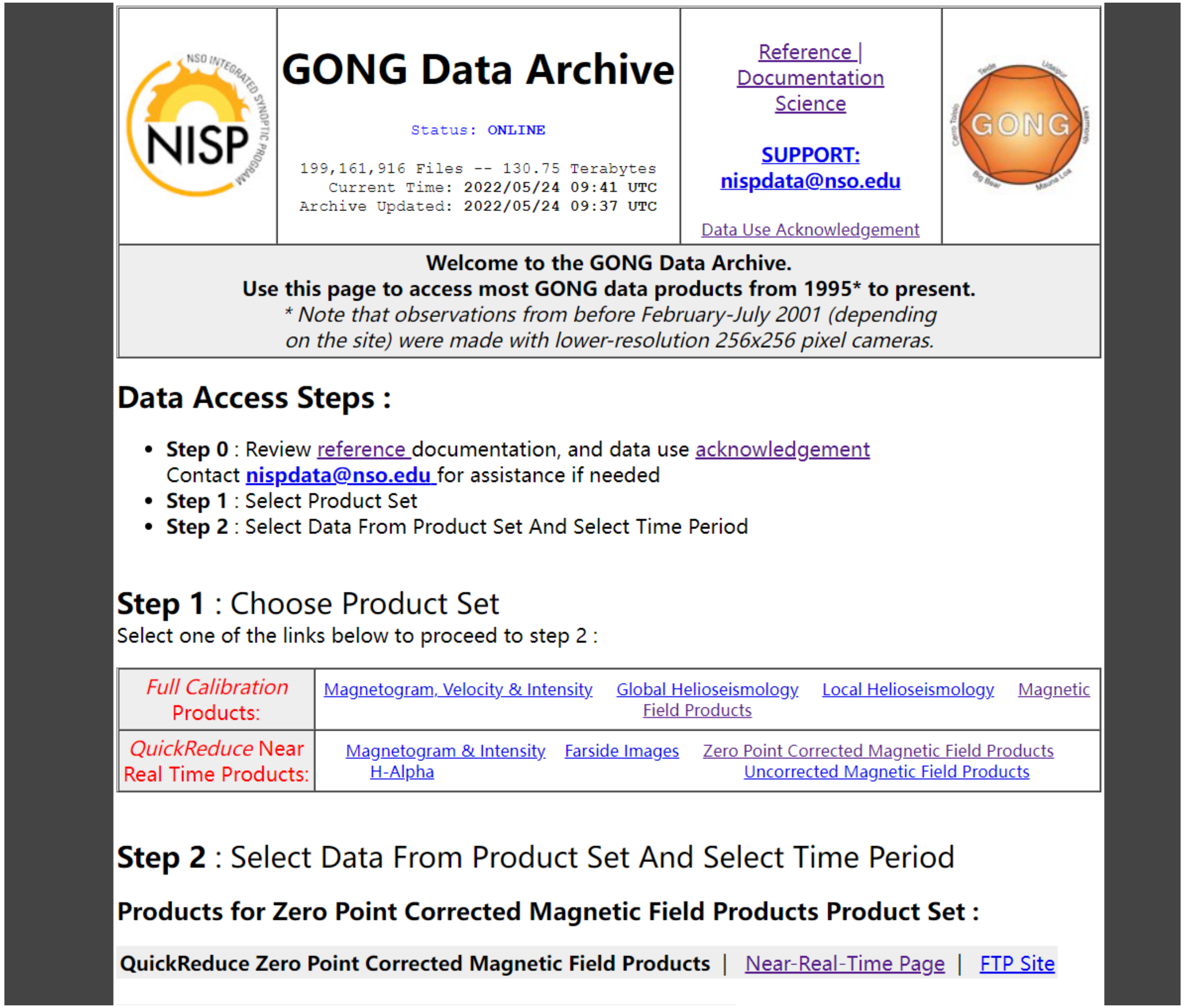
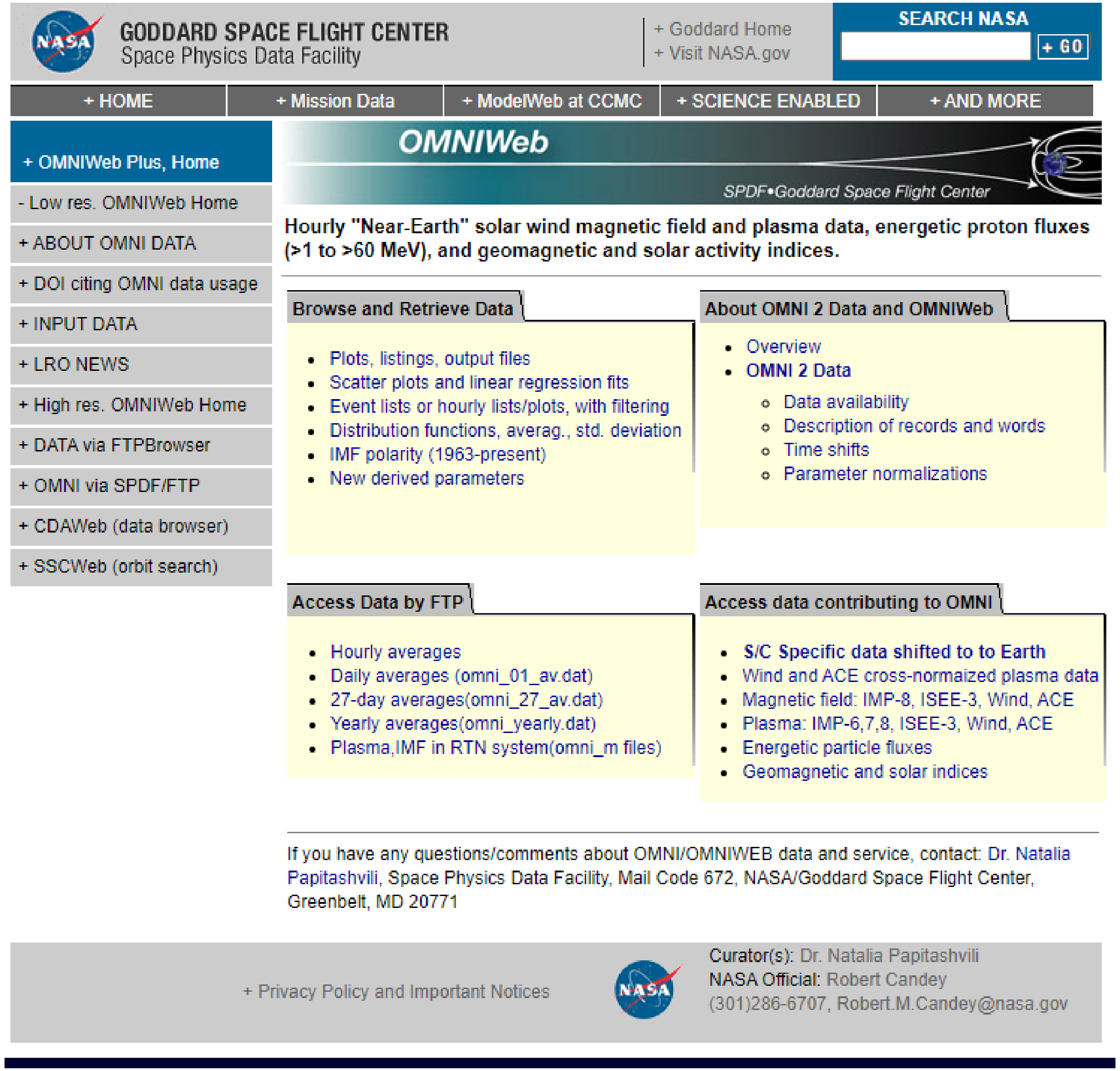
光球磁场数据

https://gong2.nso.edu/archive/patch.pl?menutype=zeroPoint



1AU观测数据



https://spdf.gsfc.nasa.gov/pub/data/omni/low_res_omni/

安装FITSIO库

FITSIO库用于读取太阳磁场概图的FITS格式文件。在 https://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html 下载最新的FITSIO库安装包，或使用模式软件包内附带的cfitsio-3.49.tar.gz，解压到程序目录下的external_libs目录中编译安装。

目前，程序目录中external_libs/cfitsio-3.49已经有在“寰”平台上编译安装好的FITSIO库。编译和运行中的动态库目录也已经指向该目录。如需更新或重新编译，按照以上步骤操作完成后，检查compile.sh中LD_LIBRARY_PATH环境变量、fitsio_path变量和运行目录中sub_run.sh中的LD_LIBRARY_PATH环境变量与新编译完成后的库路径是否一致。

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拷贝OMNI数据

将下载好的OMNI局地观测数据拷贝到运行目录的data/omni_low_reso目录中。

生成新的运行目录

将默认的run目录整体拷贝并重命名成其他目录名

设置编译器名称和运行目录名称

默认的编译器为mpif90，根据上一节设置的环境，这个编译器会使用ifort编译器作为基本fortran编译器，并在编译过程中自动调用mpi环境，因此串行和并行过程的代码皆使用此编译器。如需修改，可改变compile.sh中的FC变量名。

如果修改运行目录，则需要将compile.sh和clean.sh中的run_dir变量修改为相应的目录名称。

编译公用数学功能

在模式目录下输入./compile.sh math进行编译，等待编译完成。

编译paramesh库

在模式目录下输入./complie.sh paramesh进行编译，等待编译完成

设置FITSIO库路径

将compile.sh中fitsio_path变量设置为FITSIO库的安装目录。

编译模式其他部分

在模式目录下输入./compile.sh all进行编译，完成编译后可执行文件会拷贝到设置的运行目录下。

背景太阳风的MHD模拟

按照系统安装与配置的说明，完成代码的编译，生成可执行文件并检查所有动态库都已经指向了正确的路径。以下以运行目录为run为例，介绍本功能的配置和使用方法。

ftp:// gong2.nso.edu/mnt/oQR/nqs中根据需要模拟的太阳自转周（卡灵顿周）编号，下载相应的磁场概图，并上传到run/input_synoptic目录中。

```
2. 10.64.201.3 (hcli)
[hcli@login03 input_synoptic]$ ls
copy.bat                                  mrnqs081203t2237c2077_000.fits.gz
mrbqs080404t1154c2068_096.fits.gz         mrnqs081231t0627c2078_000.fits.gz
mrbqs080404t2354c2068_090.fits.gz         mrnqs180113t1425c2199_000.fits.gz
mrbqs081212t0554c2077_011.fits.gz         mrnqs180209t2245c2200_000.fits.gz
mrmqs081203t2237c2077_000.fits.gz         mrnqs180309t0640c2201_000.fits.gz
mrnqs080111t1709c2065_000.fits.gz         mrnqs180405t1353c2202_000.fits.gz
mrnqs080208t0128c2066_000.fits.gz         mrnqs180502t2007c2203_000.fits.gz
mrnqs080306t0938c2067_000.fits.gz         mrnqs180530t0127c2204_000.fits.gz
mrnqs080402t1711c2068_000.fits.gz         mrnqs180626t0617c2205_000.fits.gz
mrnqs080429t2333c2069_000.fits.gz         mrnqs180723t1112c2206_000.fits.gz
mrnqs080527t0449c2070_000.fits.gz         mrnqs180819t1638c2207_000.fits.gz
mrnqs080623t0925c2071_000.fits.gz         mrnqs180915t2244c2208_000.fits.gz
mrnqs080720t1401c2072_000.fits.gz         mrnqs181013t0525c2209_000.fits.gz
mrnqs080816t1912c2073_000.fits.gz         mrnqs181109t1232c2210_000.fits.gz
mrnqs080913t0114c2074_000.fits.gz         mrnqs181206t2003c2211_000.fits.gz
mrnqs081010t0757c2075_000.fits.gz         plt
mrnqs081106t1508c2076_000.fits.gz
[hcli@login03 input_synoptic]$ pwd
/data/hcli/space/run/input_synoptic
[hcli@login03 input_synoptic]$
```

使用vi或其他编辑器，设置CR_time配置文件

```
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!Carrington Rotation (CR) Setting
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!====================================================================
!Carrington Rotation Number
!====================================================================
2077     ! CR_num
!====================================================================
!Start date of the CR
!====================================================================
2008     ! CR_yr_s    --- Year
11       ! CR_m_s     --- Month
20       ! CR_d_s     --- Day
6        ! CR_h_s     --- Hour
!====================================================================
!End date of the CR
!====================================================================
2008     ! CR_yr_e    --- Year
12       ! CR_m_e     --- Month
17       ! CR_d_e     --- Day
14       ! CR_h_e     --- Hour
~
~
```

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使 用 vi 或 其 他 编 辑 器 ， 设 置 corona_parameters配置文件。

2. 10.64.201.3 (hcli)

```
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!Corona Grid and Parallel Block Setting
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!====================================================================
!Process numbers
!====================================================================
2          ! pe_comp_total   ----   grid components
5          ! pe_r_total      ----   r direction
4          ! pe_th_total     ----   th direction
6          ! pe_ph_total     ----   ph direction
!====================================================================
!Grid number in each pe -- th and ph direction
!====================================================================
10         ! N_th    ----   th direction
20         ! N_ph    ----   ph direction
!====================================================================
!Blocks in radi direction
!====================================================================
2          ! d_size1    ---   pe number in block 1
2          ! d_size2    ---   pe number in block 2
1          ! d_size3    ---   pe number in block 3
10         ! nrsize1    ---   block 1 - grid number in each pe
20         ! nrsize2    ---   block 2 - grid number in each pe
50         ! nrsize3    ---   block 3 - grid number in each pe
```

```
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!Physical Parameters
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
1.3        ! T0        --- Bottom Temperature Unit: 10^6 K
1.5        ! N0_S      --- Bottom Number Density Unit: 10^14 cm^-3
0.030      ! Exp_para1 --- Q1 in the volume heating term
0.015      ! Exp_para2 --- Q2 in the volume heating term
0.0        ! M_para    --- M0 in the momuntum source term
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!Coronal Running Time Parameters
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
-60.0      ! t_ini_cese --- Start time. Negative value to start a new run
90.0       ! tmax       --- maximum running time in physical hours
20.0       ! dt_out_cese --- output interval
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
!CME parameters
!%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
.false.    ! if_CME       --- if add CME
```

使用vi或其他编辑器，设置HI_parameters配置文件

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
HI settings Setting
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
====================================================================
Numerical Settings
====================================================================
1         ! TVD_RK=1,STD_RK=2    --- temporal discretization method
true.     ! if_div_Powell        --- switch of Powell source term
true.     ! if_div_diff          --- switch of divB diffusion
.2        ! div_diff_para        --- divB diffusion para
false.    ! if_GLM               --- switch of GLM Method
3         ! GLM_FORM   1:GLM_ORI, 2:EGLM, 3:EGLM_GI --- GLM form
====================================================================
Inner Boundary Settings
====================================================================
5.0       ! r_sphere0            --- most inner radius of the grid
1.5       ! update_r             --- boundary radiu s of the HI model
====================================================================
Time  Settings
====================================================================
201.0     ! t_ini_amr            --- Start time. Negative value to start a new run
01.0      ! tmax                 ---
2.0       ! dt_out_amr
01.5      ! time_dependent_start_time
```

使用vi等编辑器打开sub_run.sh，修改相关运行资源设置，参考slumr
一般的脚本设置方法。

使用 sbatch sub_run.sh命令向系统提交任务

等待任务运行结束，在corona_result目录中下载日冕可视化结果，在HI_reuslt目录中下载行星际部分的可视化结果。在insitu_result中下载地球附近的太阳风时序数据结果。

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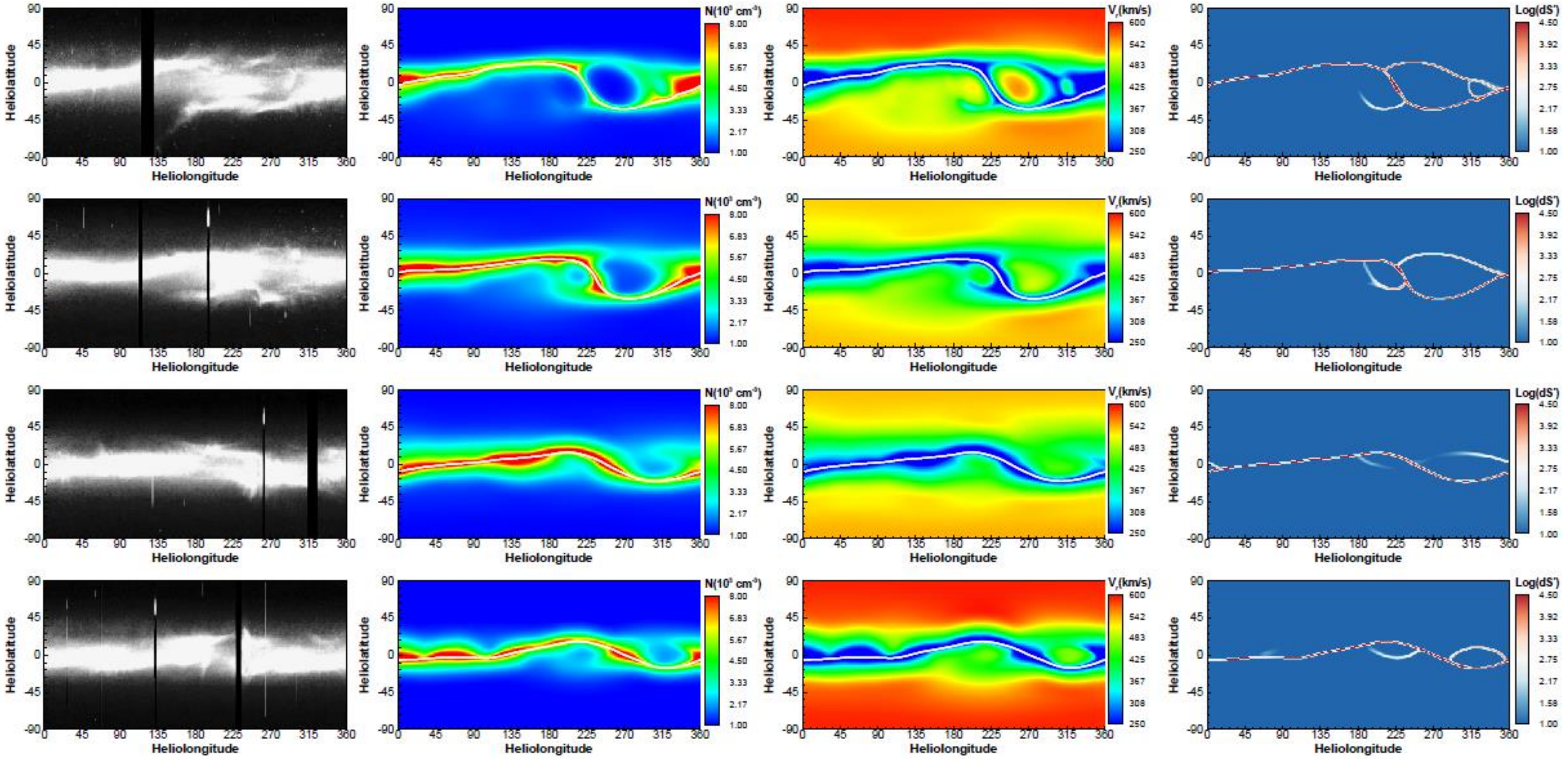
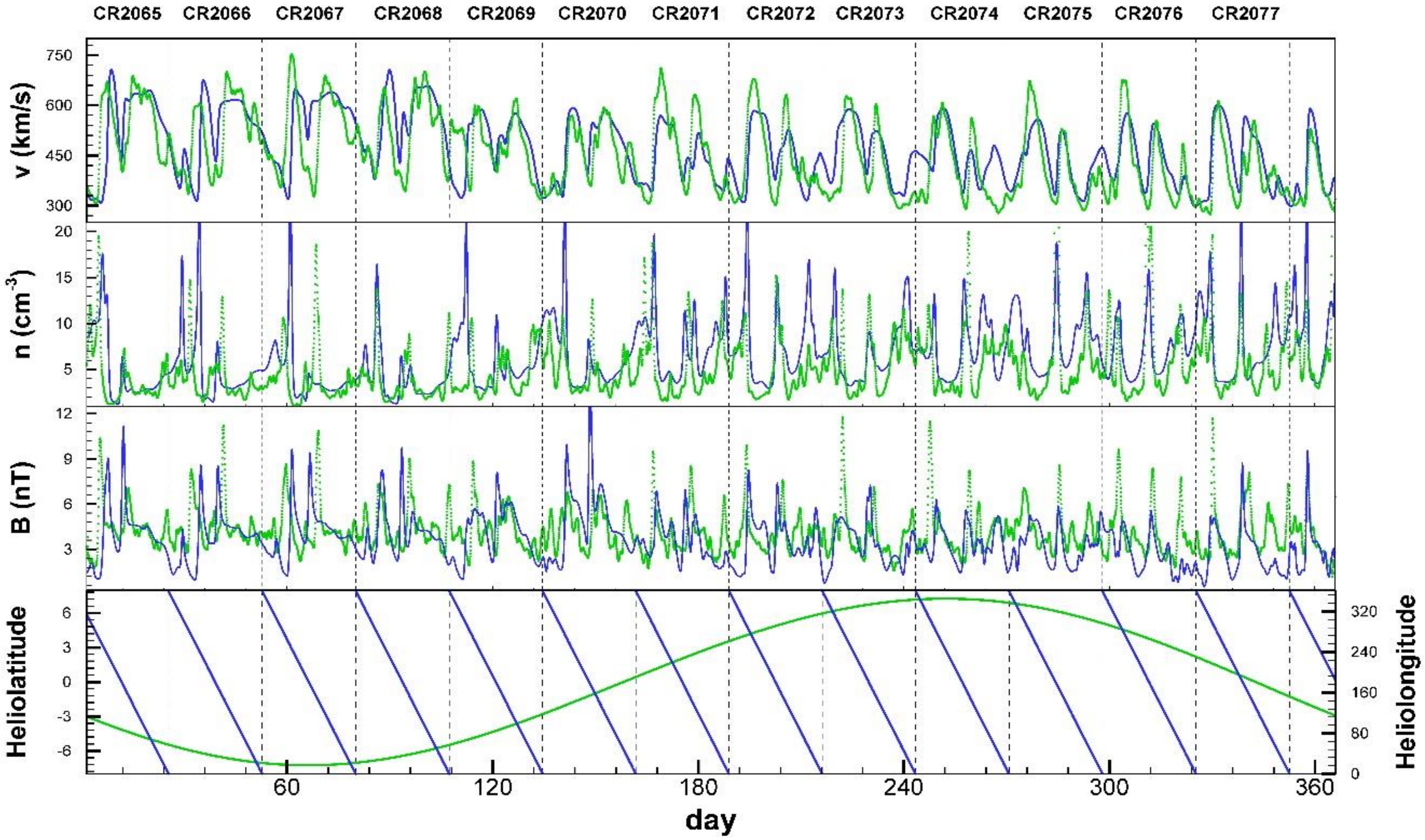
2008年日冕-行星际背景态

CR2065 CR2069 CR2074 CR2077



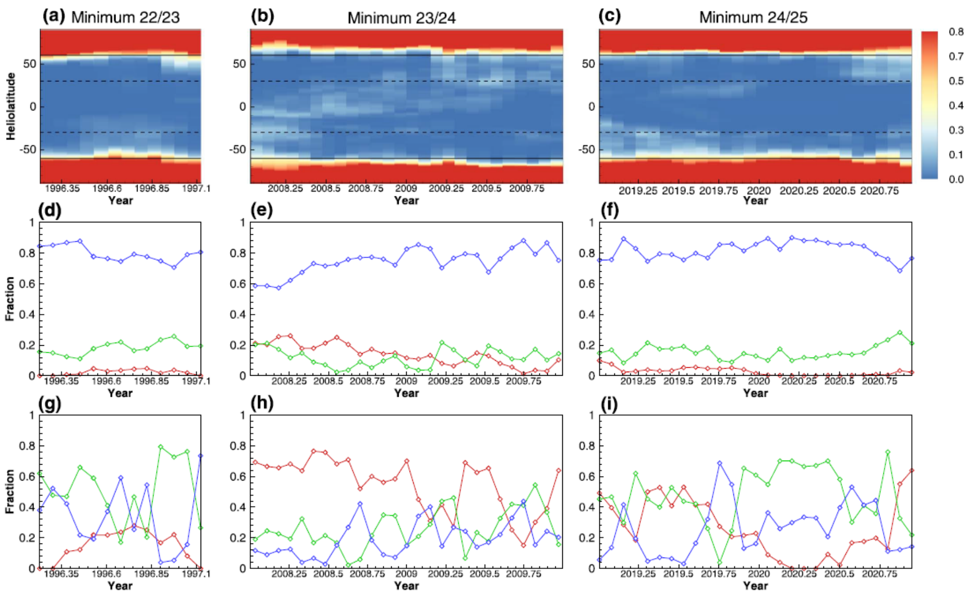
10Rs日冕结构概图

- 极区被性质均一、源自极区冕洞的高速太阳风占据，赤道附近的高速流源自低纬冕洞和极区冕洞向赤道的延伸部分。
- 冕流带附近是慢速太阳风带。伪冕流附近的太阳风速度虽然低于极区，但大部分情况下高于冕流带附近。

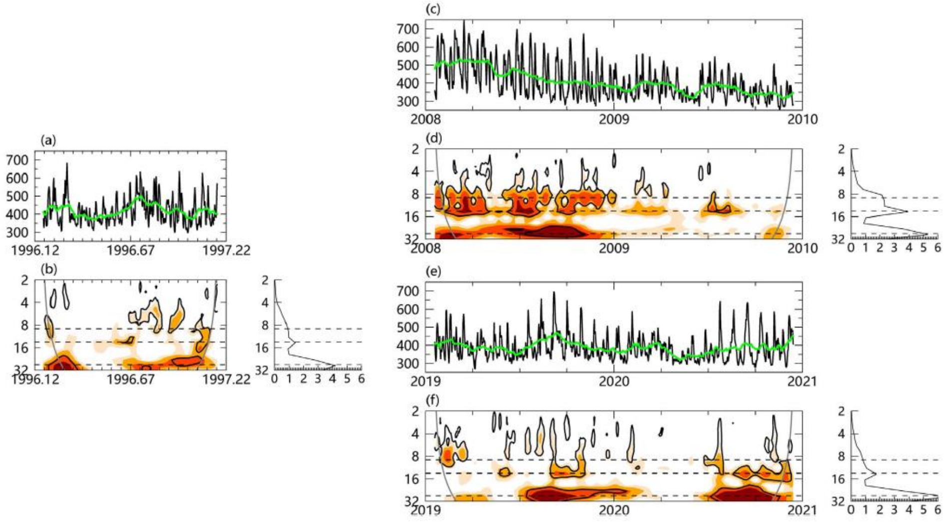

CR2065 CR2066 CR2067 CR2068 CR2069 CR2070 CR2071 CR2072 CR2073 CR2074 CR2075 CR2076 CR2077
v (km/s)
n (cm^{-3})
B (nT)
Heliolatitude
Heliolongitude
day

第24/25太阳极小期日冕行星际结构异常的研究

- 利用分系统模式软件，对刚刚结束的第24/25太阳周极小期的日冕结构和行星际太阳风参数进行了分析，希望由此弄清该太阳极小期是否仍然存在异常特征。
- 从本工作的分析看，24/25极小期是一个部分反常的极小期，而一般极小期特征的恢复有可能来自于极区磁场的增强。



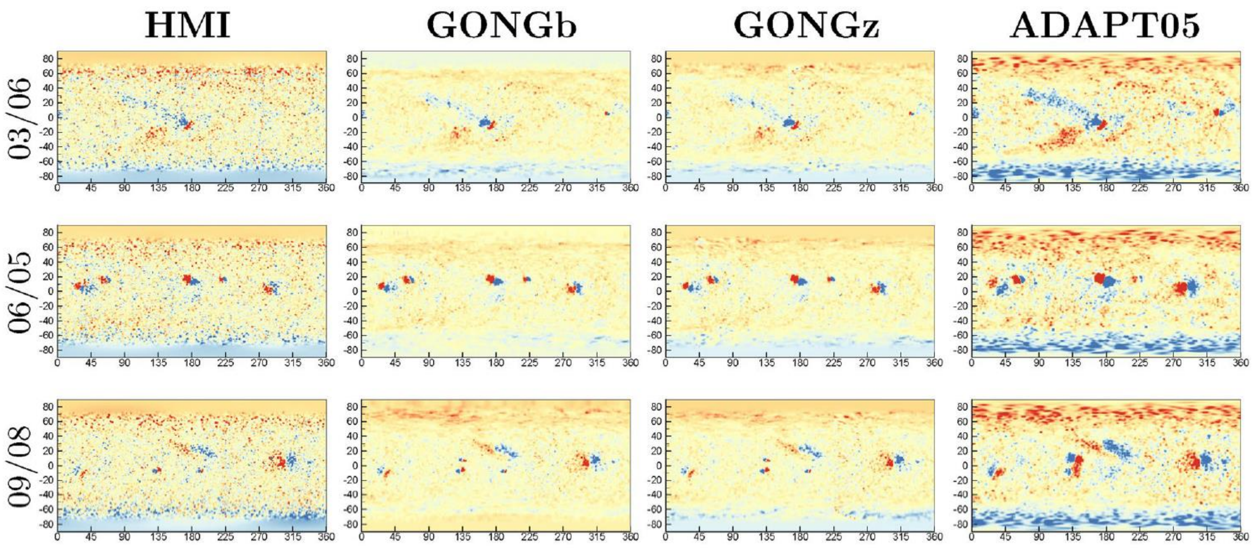
几个太阳极小期的冕洞分布的对比



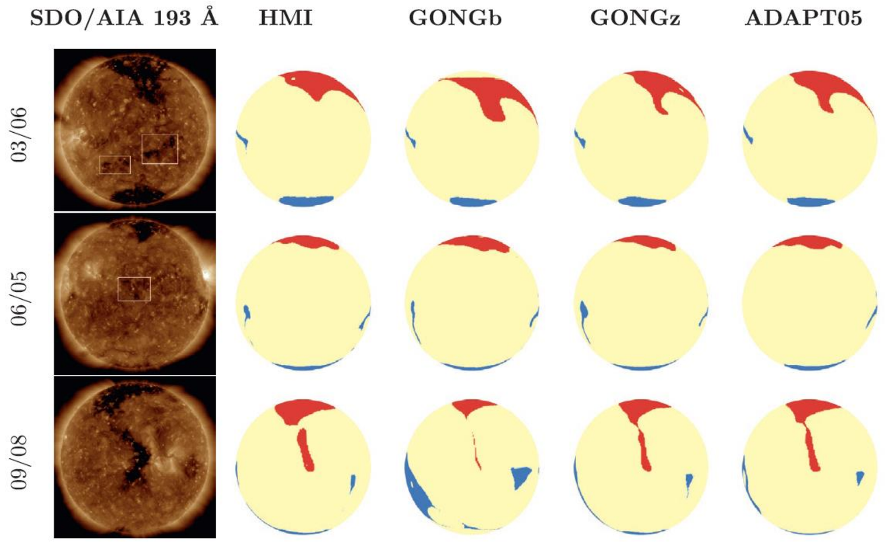
几个太阳极小期的太阳风速度变化及其谱分析

观测输入对日冕行星际模式结果影响情况分析

- 针对目前常用于模拟的磁场概图，驱动模式产生的日冕行星际磁场结构，系统分析了模式结果的差异及与磁图数据质量的关联。
- 以往较为可靠的GONGb概图出现了明显的缺陷，原因可能是未校正的零点误差。本工作为空间天气模式误差来源分析和业务运行流程提供了重要的结论。



各数据源的磁图给出的光球磁场分布对比



SDO/AIA 193A极紫外观测与模式结果给出的太阳表面开场区结构的对比。

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谢　谢