Solar Wind Iron Ions with STEREO/PLASTIC: Kinetic properties and charge state abundances

P. Bochsler[1], R. Karrer[1], H. Daoudi[1], L. Blush[1], A. Opitz[1,5], P. Wurz[1], A.B. Galvin[2], L. Ellis[2], C. Farrugia[2], L.M. Kistler[2], E. Möbius[2], M.A. Popecki[2], K.D.C. Simunac[2], K. Singer[2], B. Klecker[3], and R. F. Wimmer-Schweingruber[4]

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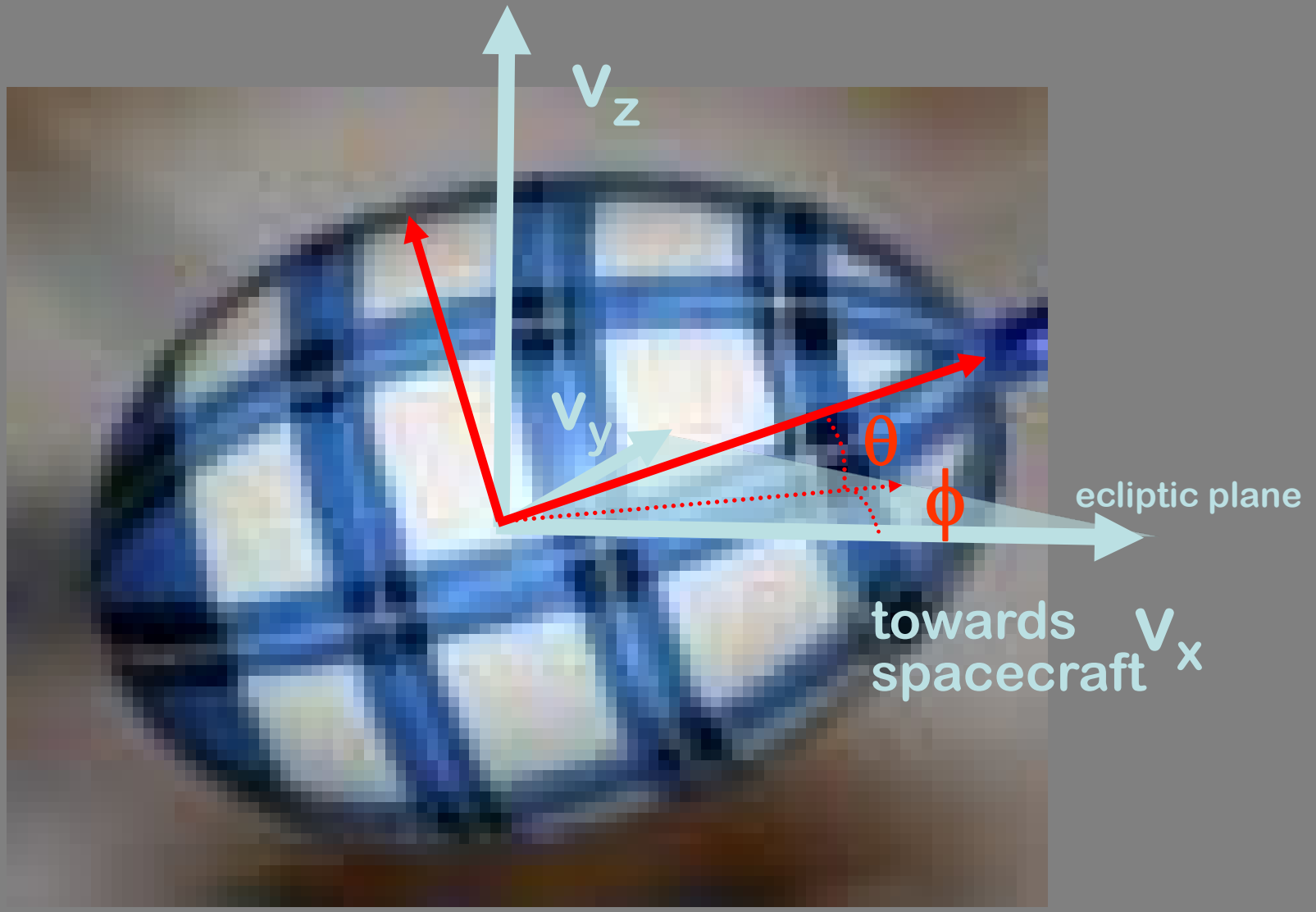
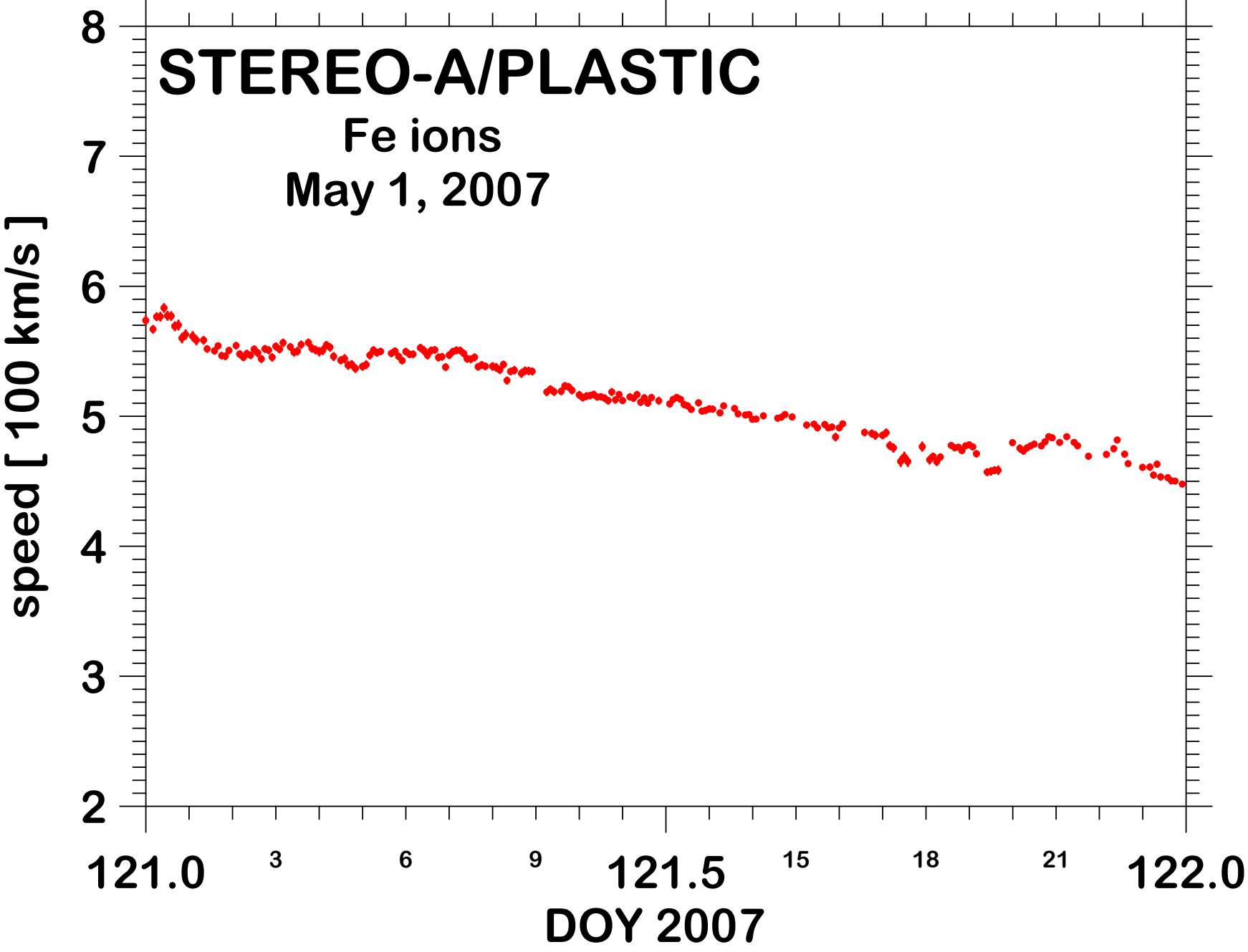
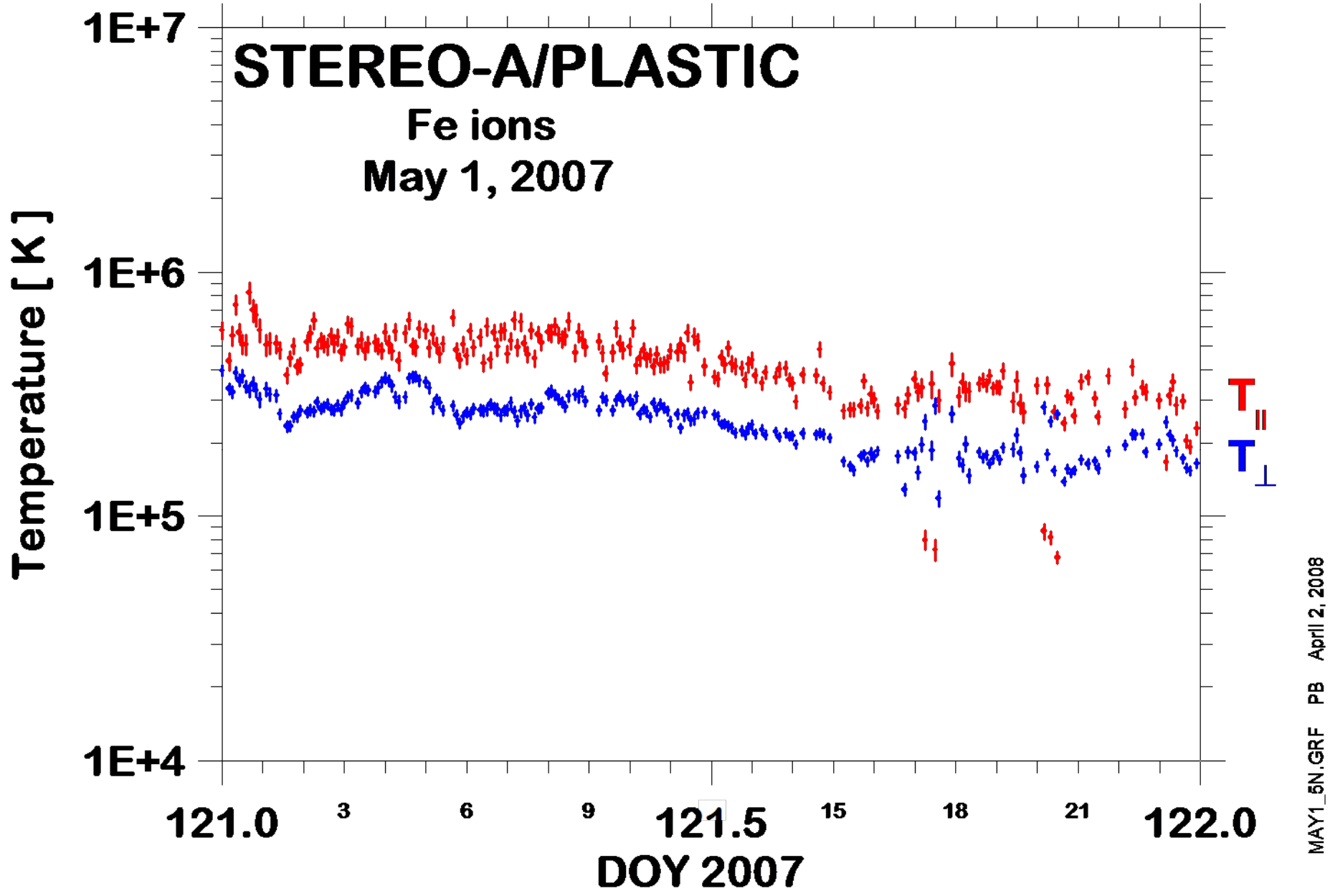
[4]Institute for Experimental and Applied Physics, Christian-Albrechts-Universität, Kiel, Germany
[5]CESR, Toulouse, France

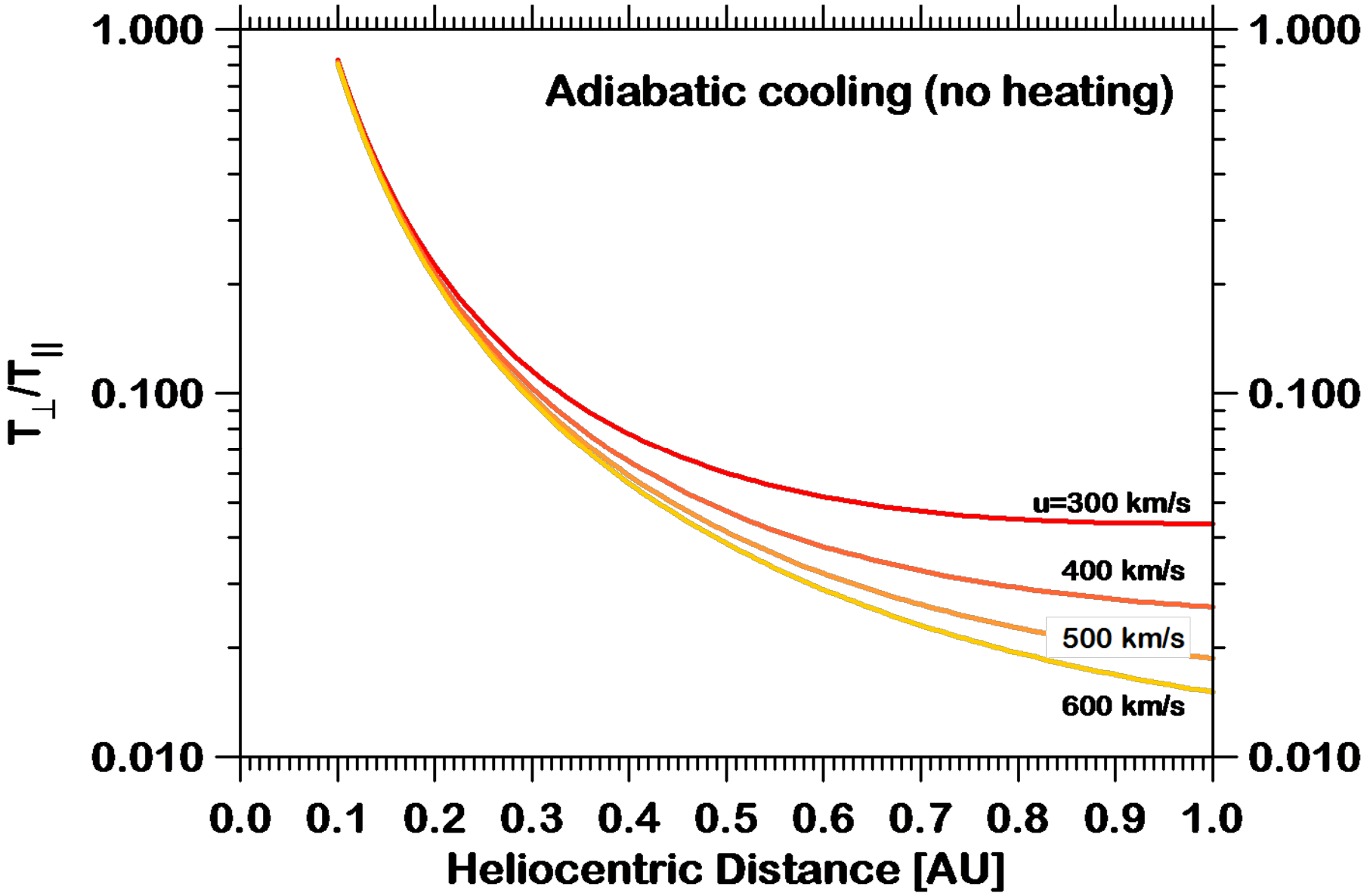
Two case studies

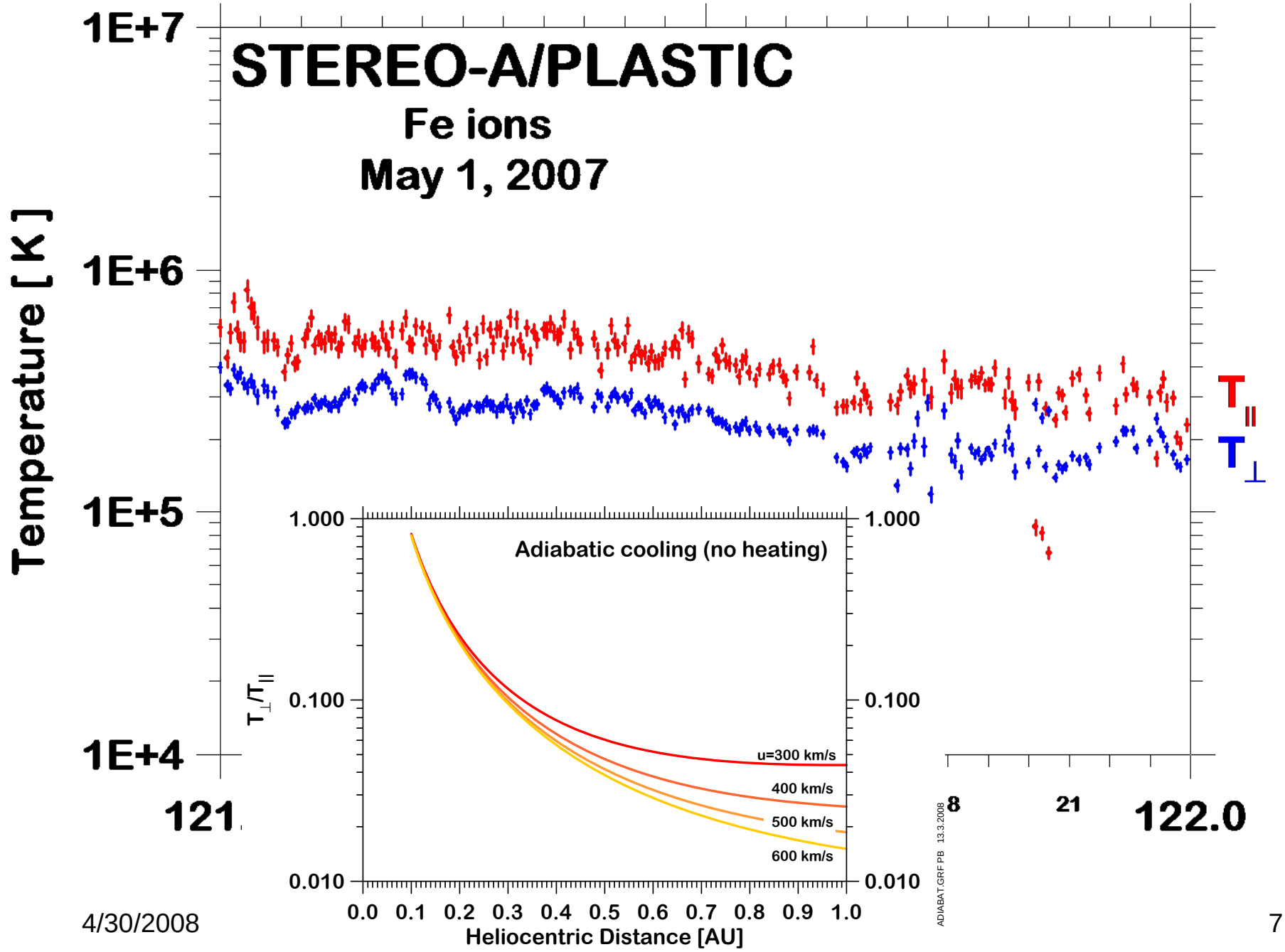

V_z
V_y
θ
ϕ
ecliptic plane
towards spacecraft
V_x

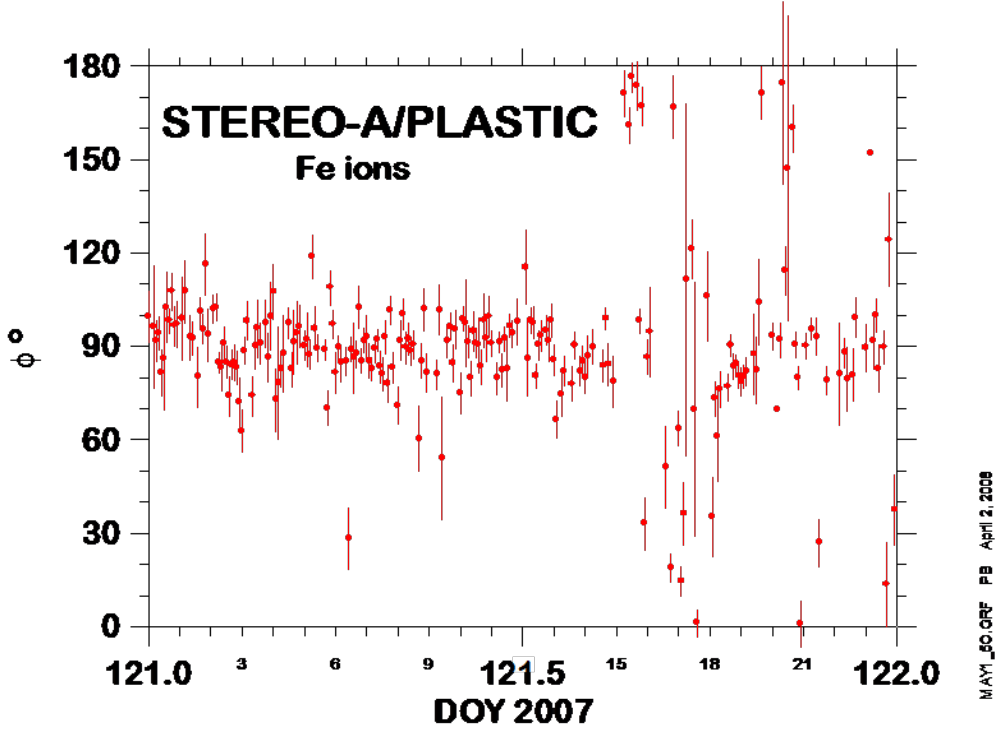


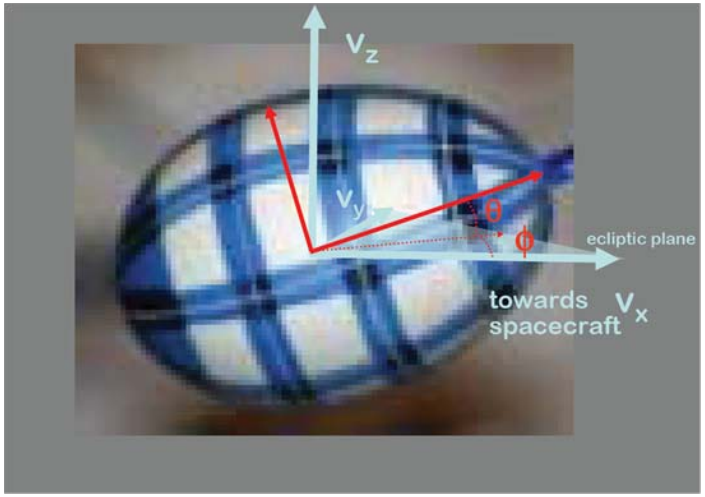
MAY1_5M.GRF PB April 2, 2008

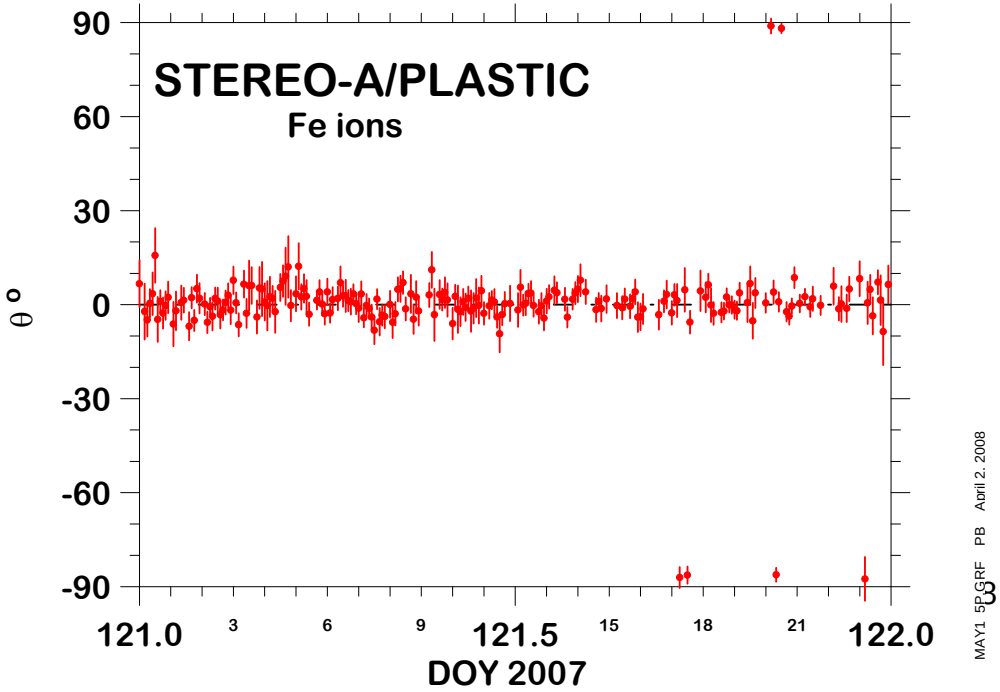

STEREO-A/PLASTIC
Fe ions
May 1, 2007
Temperature [K]
1E+7
1E+6
1E+5
1E+4
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007
T||
T⊥
MAY1_5N.GRF PB April 2, 2008

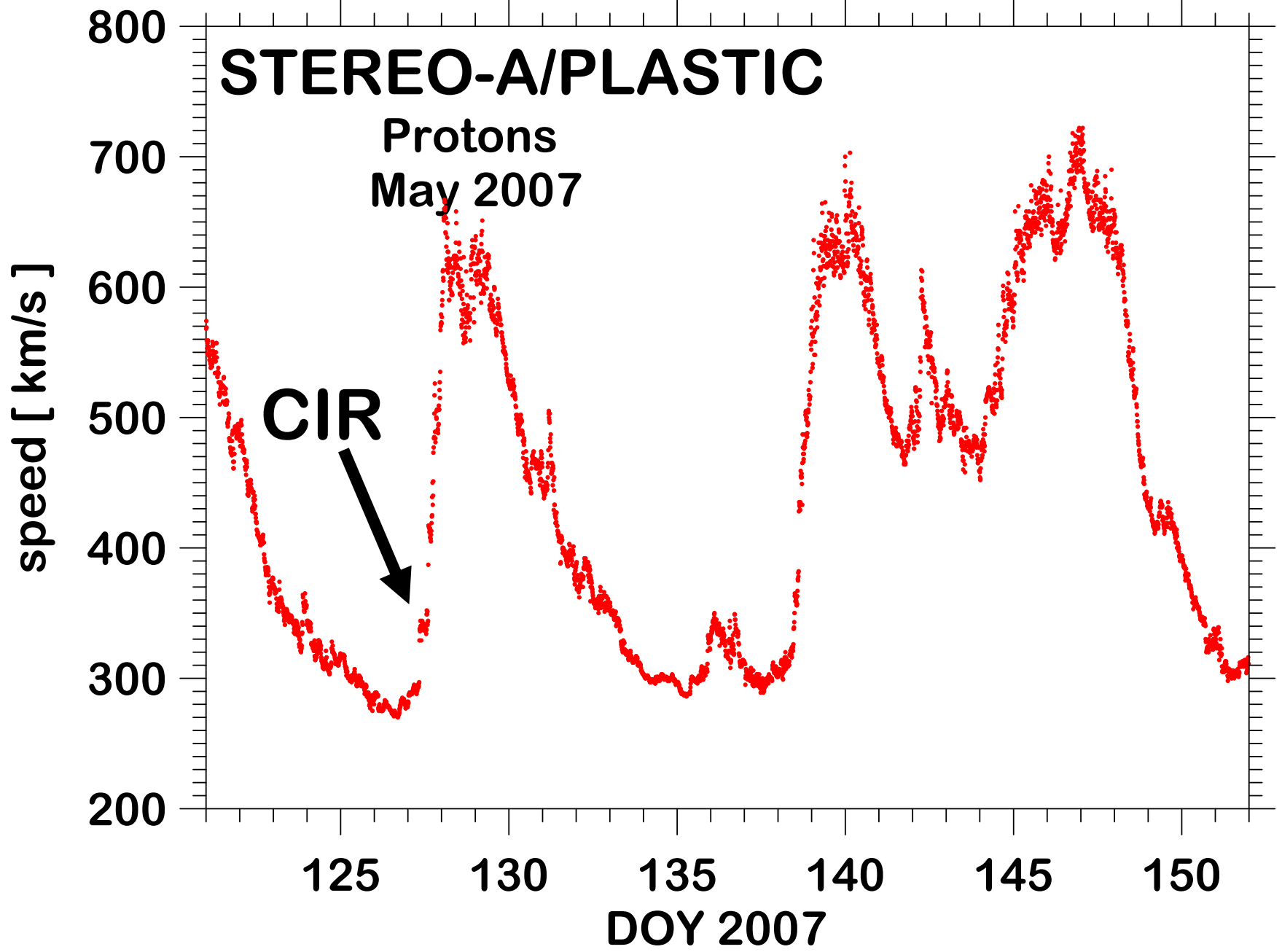

Adiabatic cooling (no heating)
$T_\perp/T_{||}$
1.000
0.100
0.010
u=300 km/s
400 km/s
500 km/s
600 km/s
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Heliocentric Distance [AU]
ADIABAT.GRF PB 13.3.2008


STEREO-A/PLASTIC
Fe ions
May 1, 2007
Temperature [K]
1E+7
1E+6
1E+5
1E+4
T||
T⊥
121
122.0
Adiabatic cooling (no heating)
T⊥/T||
1.000
0.100
0.010
u=300 km/s
400 km/s
500 km/s
600 km/s
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Heliocentric Distance [AU]
ADIABAT.GRF PB 13.3.2008
MAY1_5N.GRF PB April 2, 2008

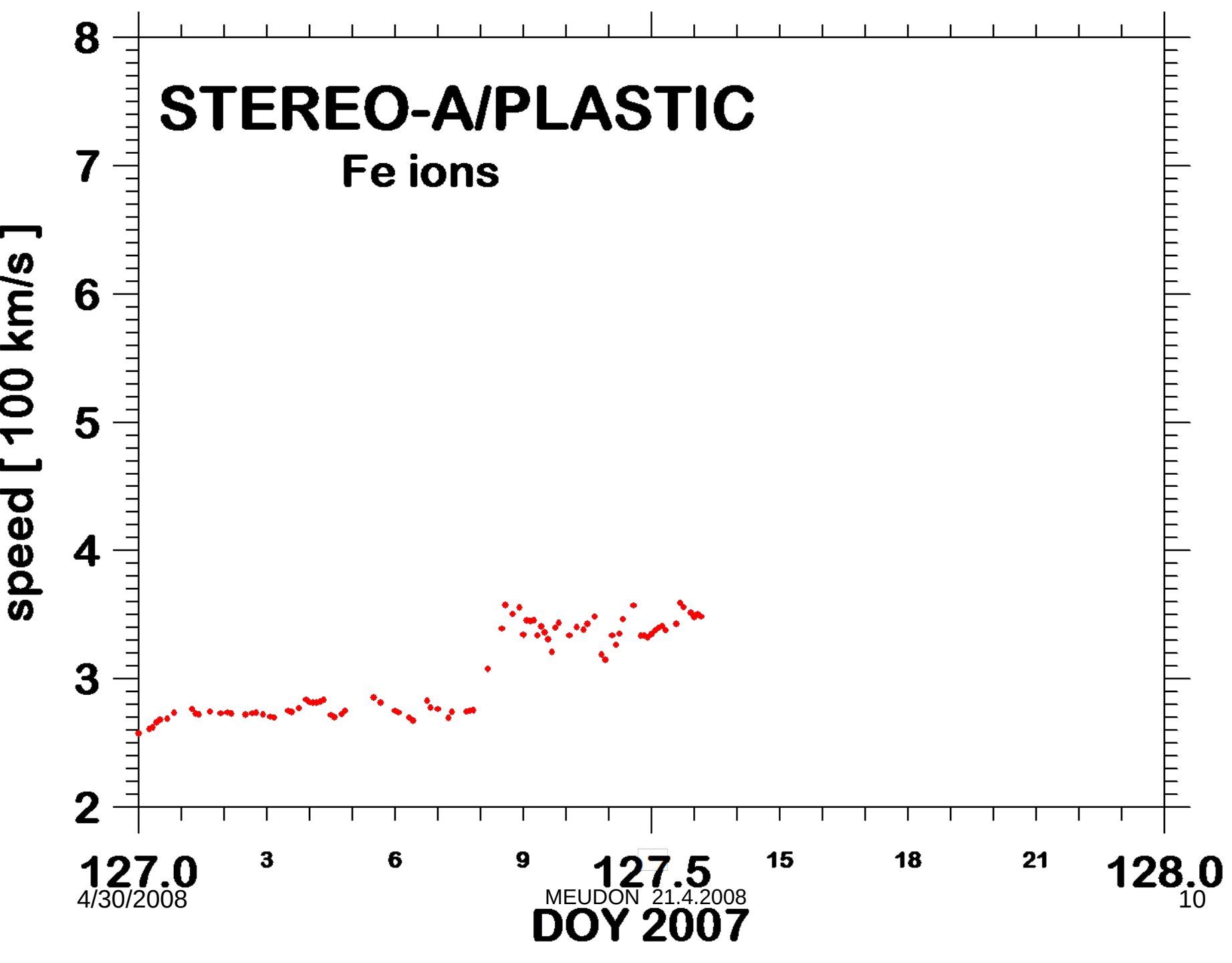

STEREO-A/PLASTIC
Fe ions
φ °
180
150
120
90
60
30
0
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007
MAY1_50.GRF PB April 2, 2008

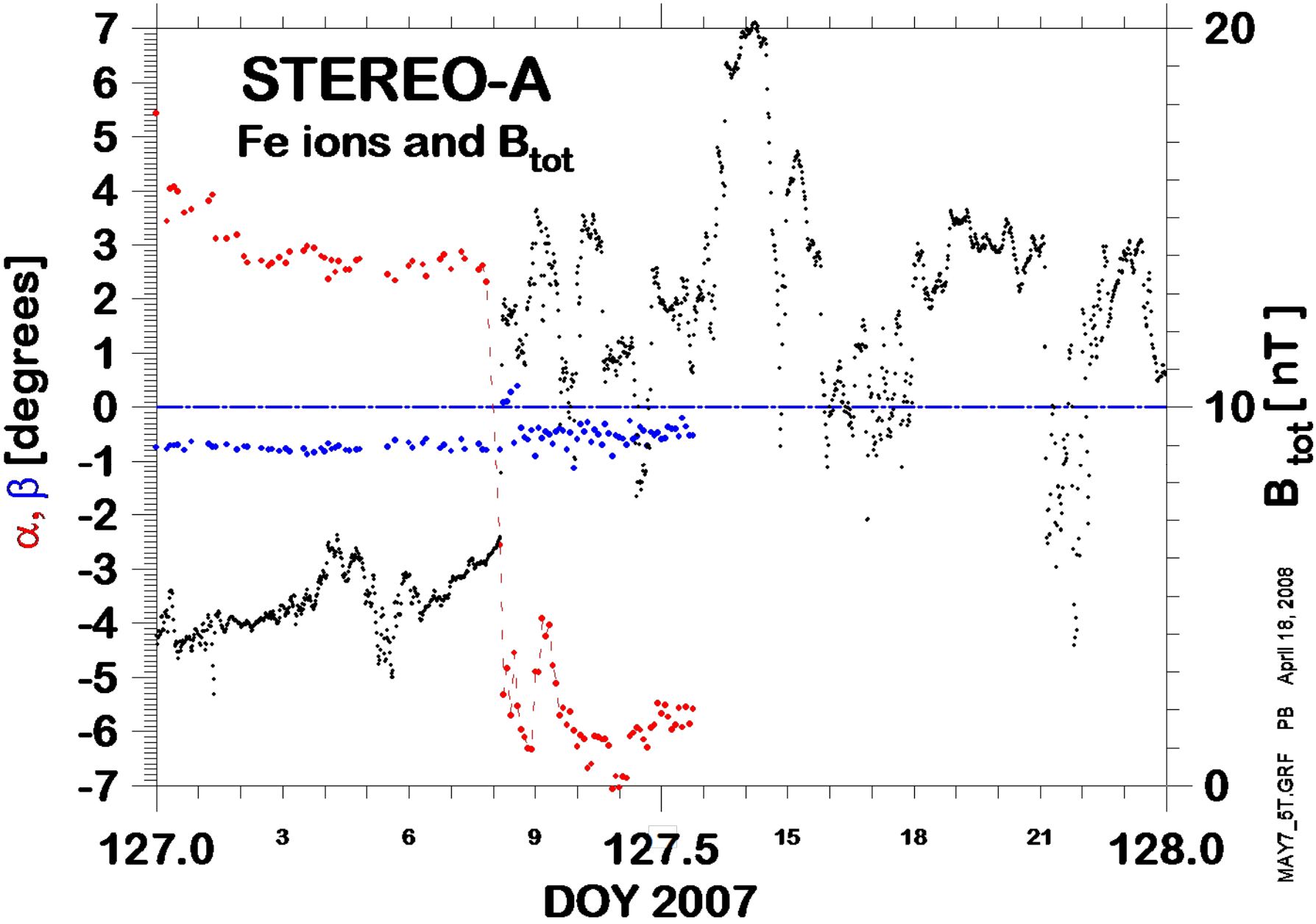

V_z
V_y
θ
φ
ecliptic plane
towards spacecraft
V_x

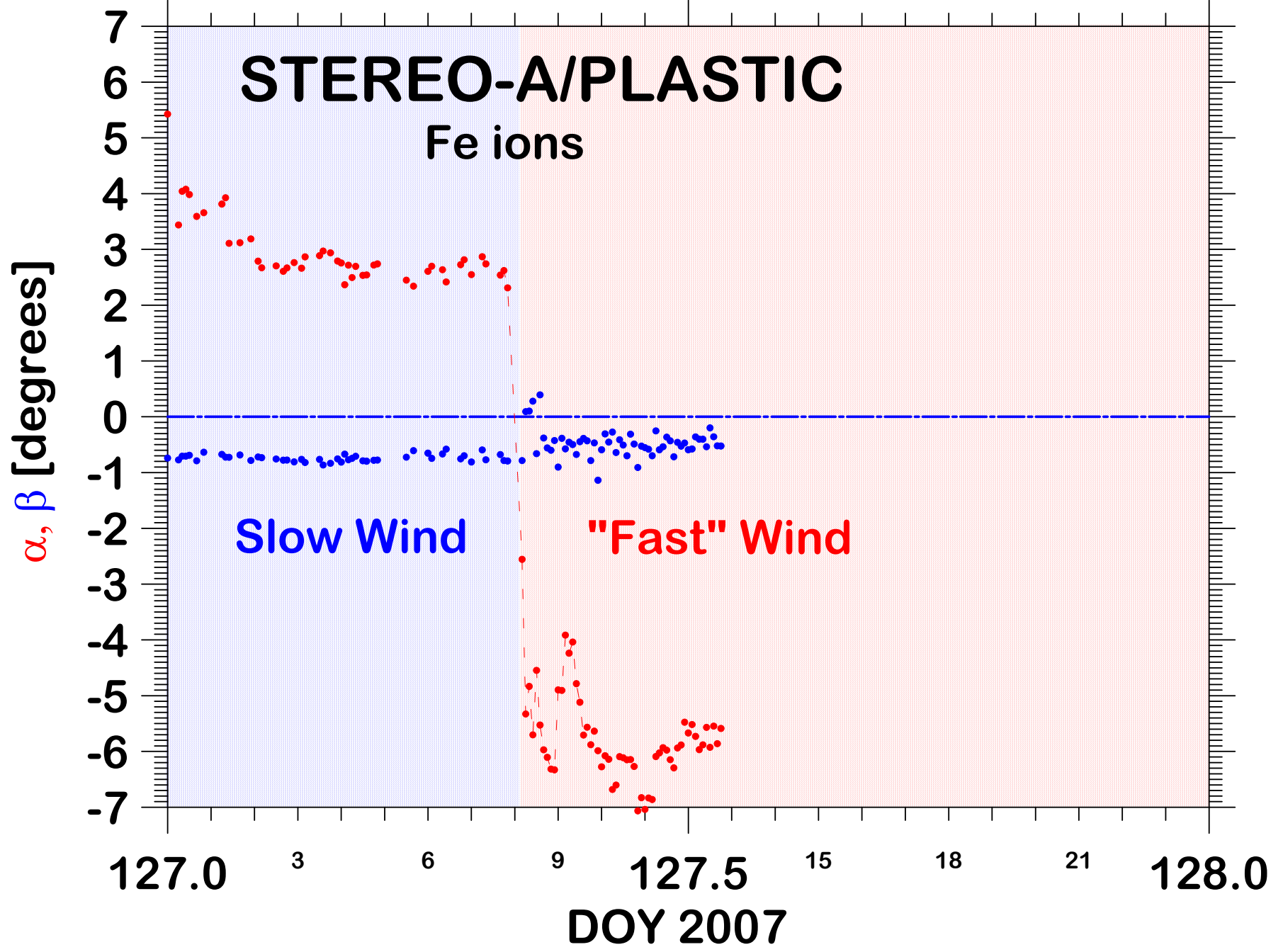

STEREO-A/PLASTIC
Fe ions
θ °
90
60
30
0
-30
-60
-90
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007
MAY1_5PGRF PB April 2, 2008

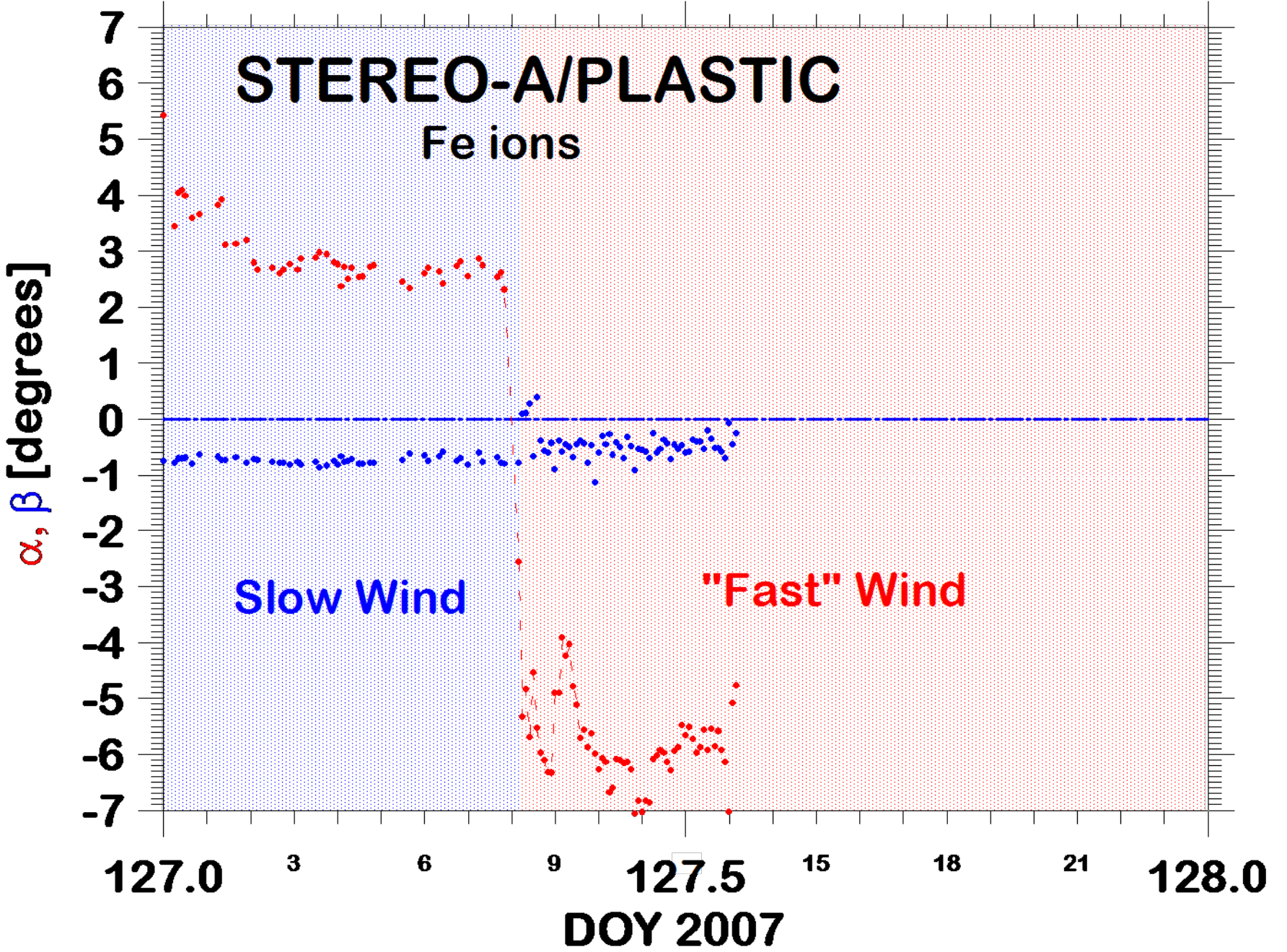


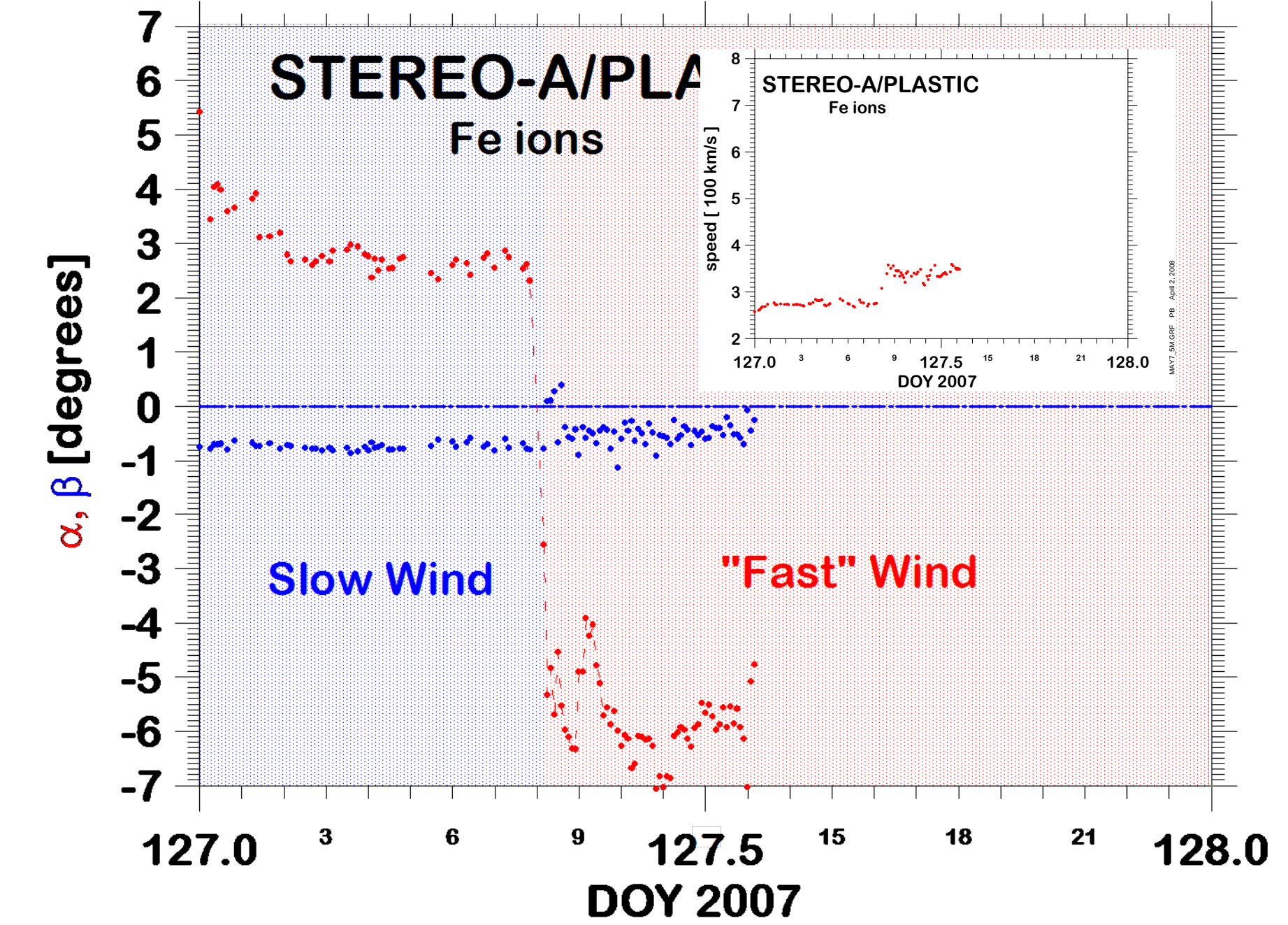
MAY_P.GRF PB April 18, 2008

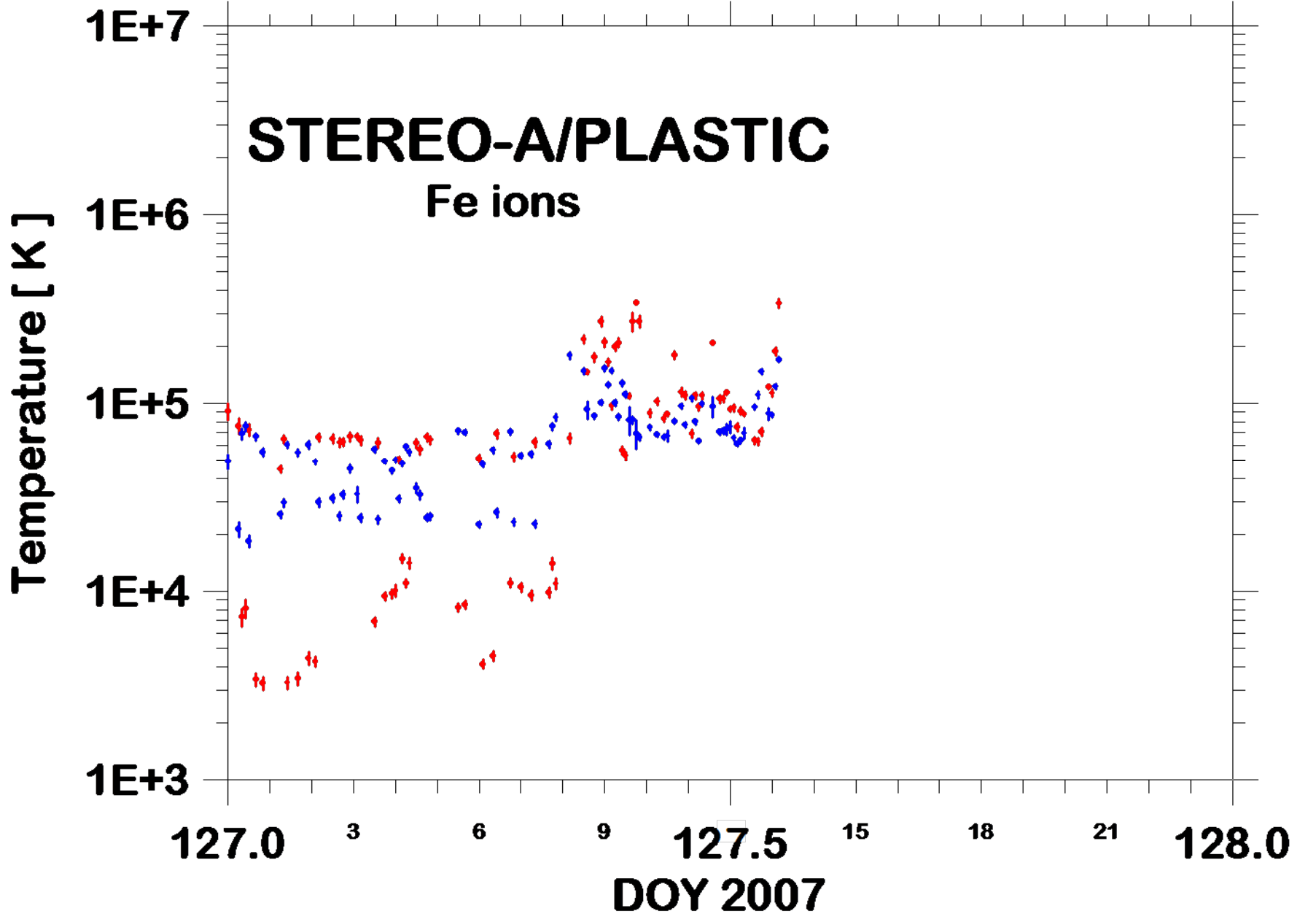

STEREO-A/PLASTIC
Fe ions
speed [100 km/s]
8
7
6
5
4
3
2
127.0
3
6
9
127.5
15
18
21
128.0
DOY 2007


STEREO-A
Fe ions and B tot
α, β [degrees]
B tot [nT]
DOY 2007
127.0
127.5
128.0
MAY7_5T.GRF PB April 18, 2008


STEREO-A/PLASTIC
Fe ions
Slow Wind
"Fast" Wind
α, β [degrees]
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
127.0
3
6
9
127.5
15
18
21
128.0
DOY 2007
MAY7_5R.GRF PB April 11, 2008

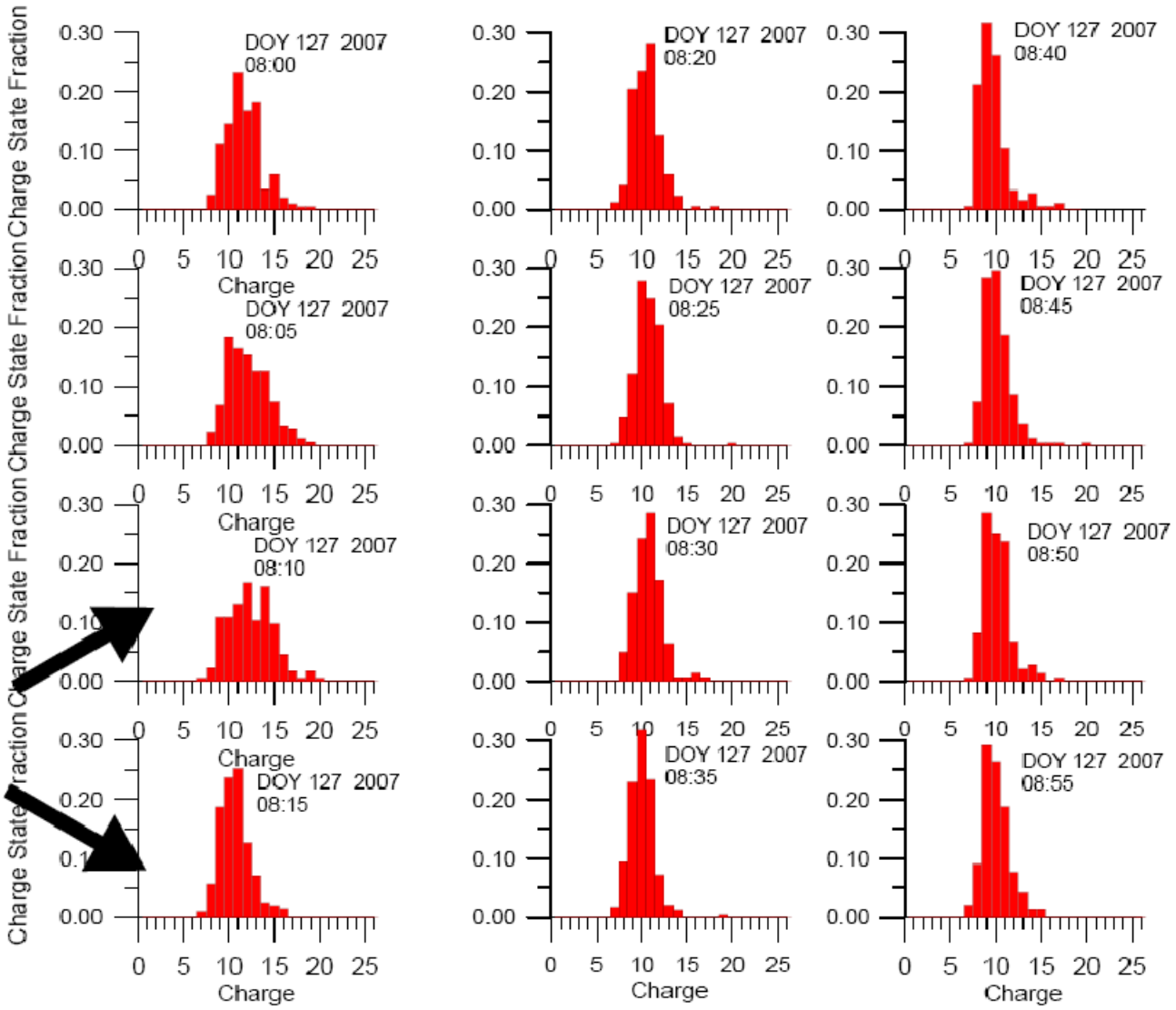

STEREO-A/PLASTIC
Fe ions
α, β [degrees]
Slow Wind
"Fast" Wind
DOY 2007
MAY7_5R.GRF PB April 11, 2008


STEREO-A/PLA
Fe ions
STEREO-A/PLASTIC
Fe ions
speed [100 km/s]
DOY 2007
MAY7_5M.GRF PB April 2, 2008
α, β [degrees]
Slow Wind
"Fast" Wind
DOY 2007
MAY7_5R.GRF PB April 11, 2008

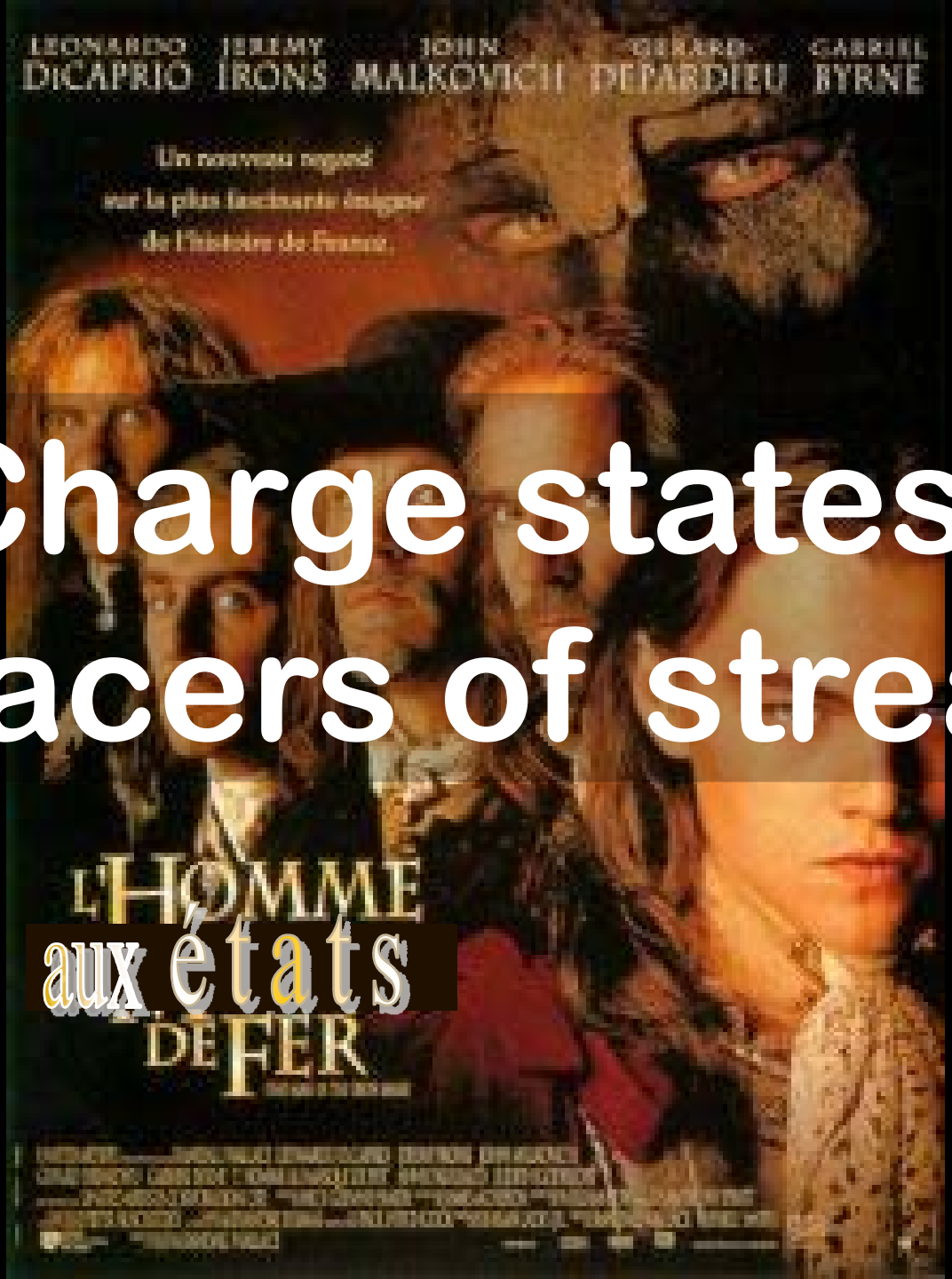

STEREO-A/PLASTIC
Fe ions
Temperature [K]
1E+7
1E+6
1E+5
1E+4
1E+3
127.0
3
6
9
127.5
15
18
21
128.0
DOY 2007
MAY7_5N.GRF PB April 8, 2008

STEREO-A/PLASTIC

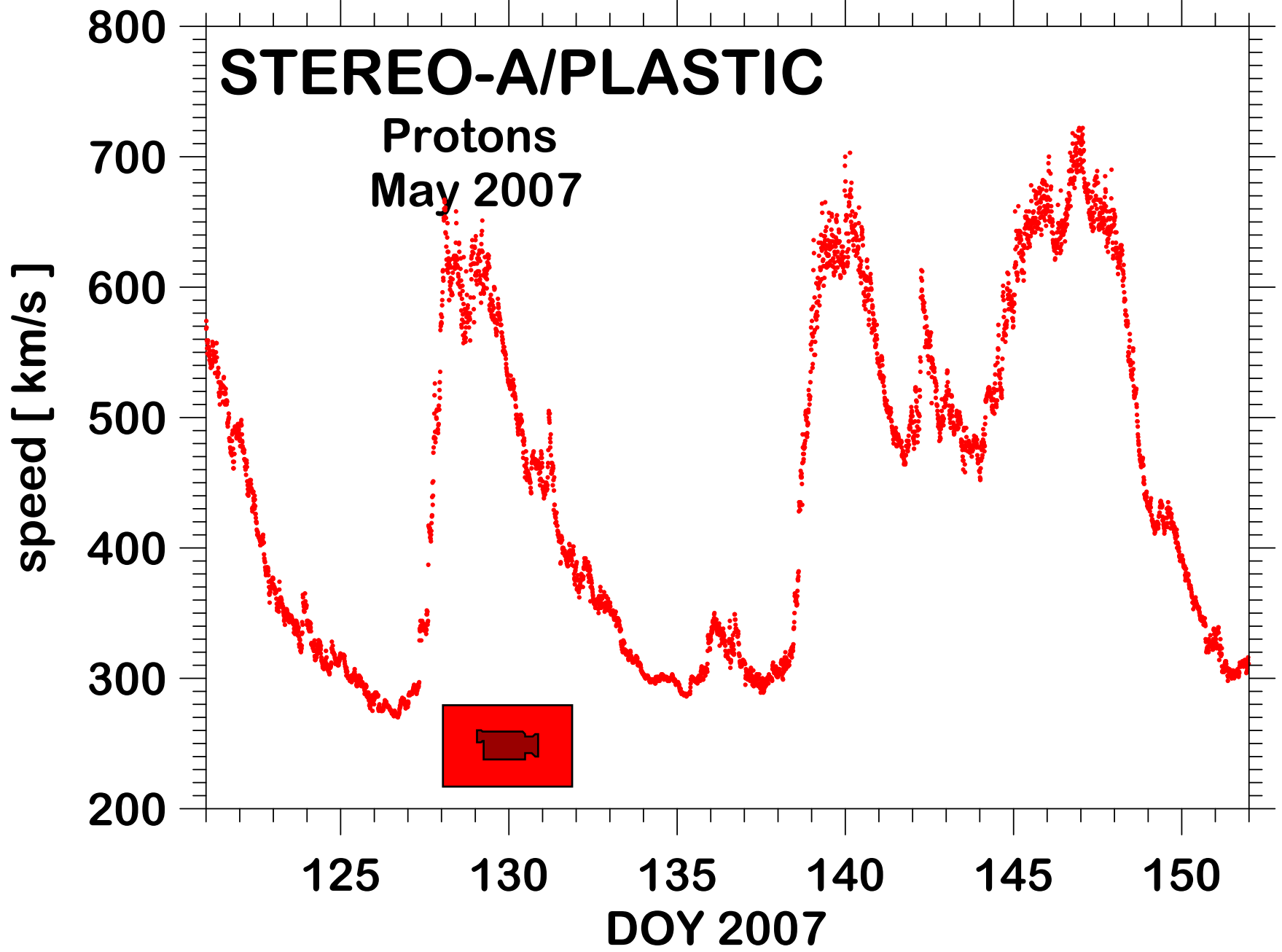
DOY 127, 2007 08:00 - 09:00 UT



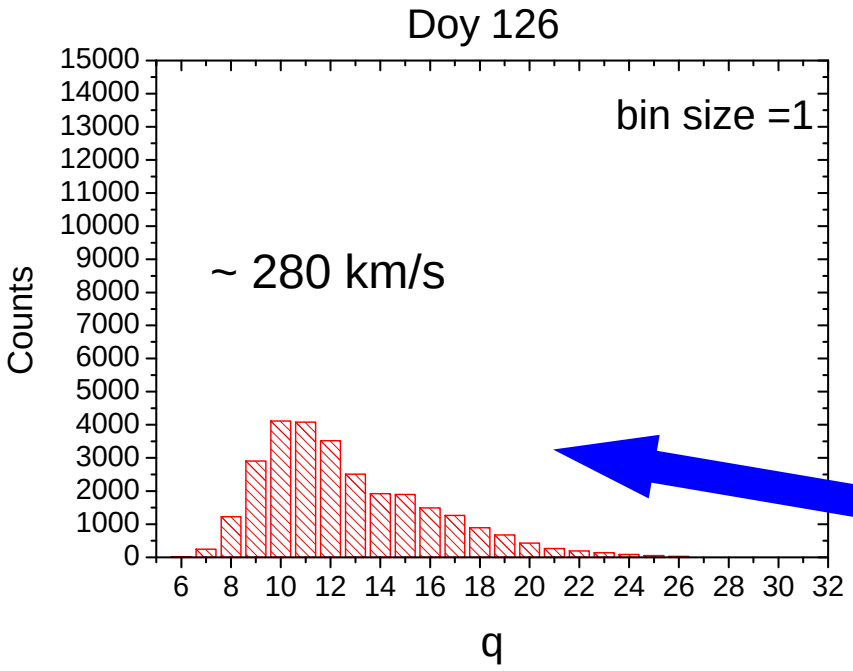
Transition in CIR

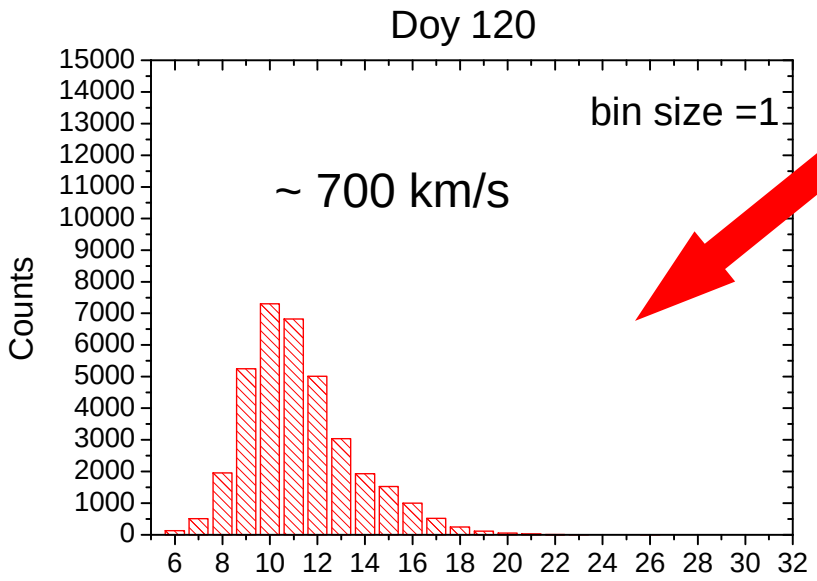


Charge states as tracers of streams



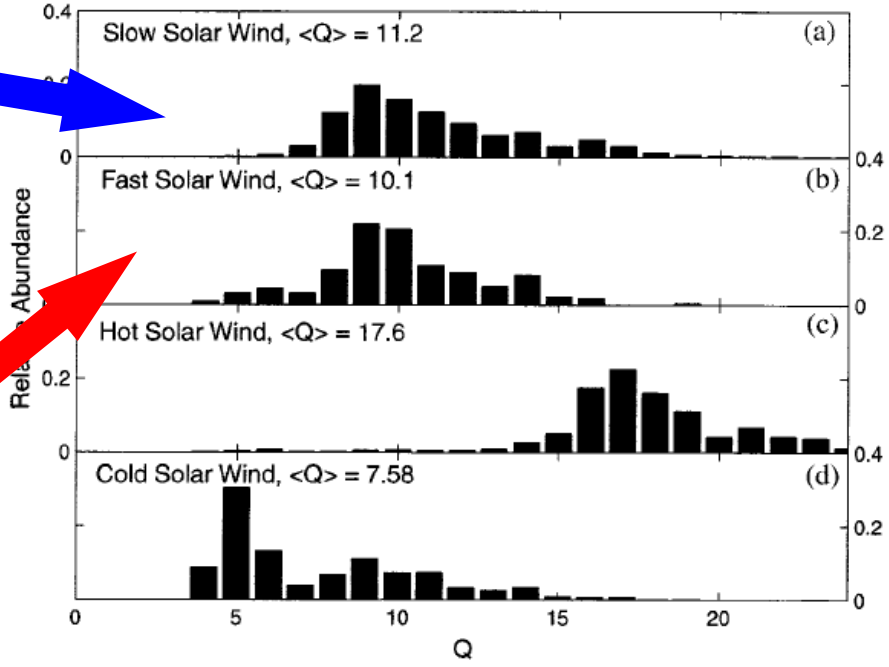
MAY_P.GRF PB April 18, 2008



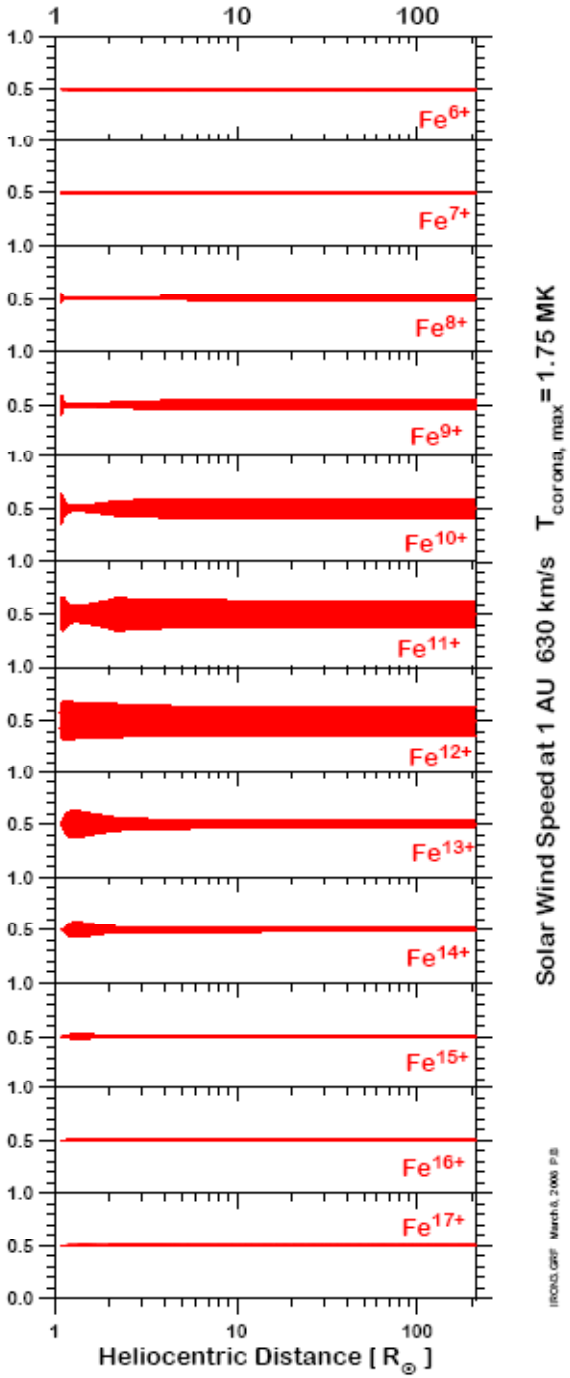


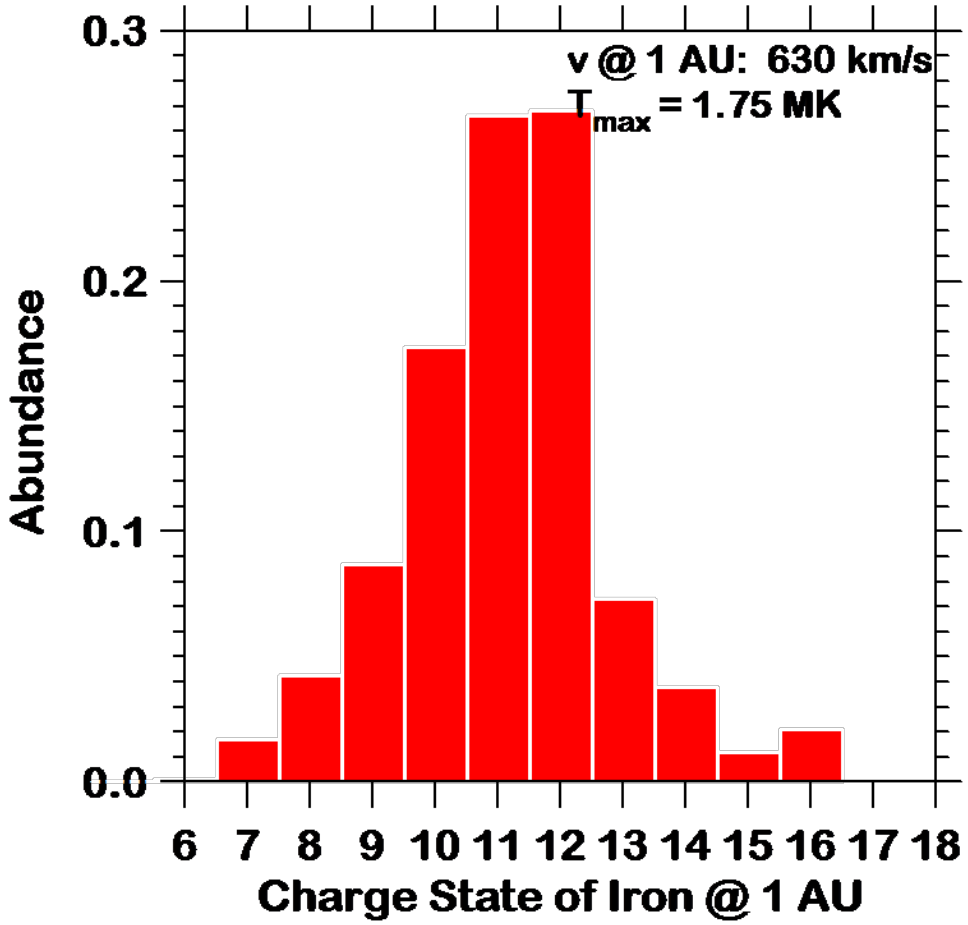
Iron charge distribution as an identifier of interplanetary coronal mass ejections

S. T. Lepri,[1] T. H. Zurbuchen,[1] L. A. Fisk,[1] I. G. Richardson,[2,3] H. V. Cane,[3] and G. Gloeckler[1,2]

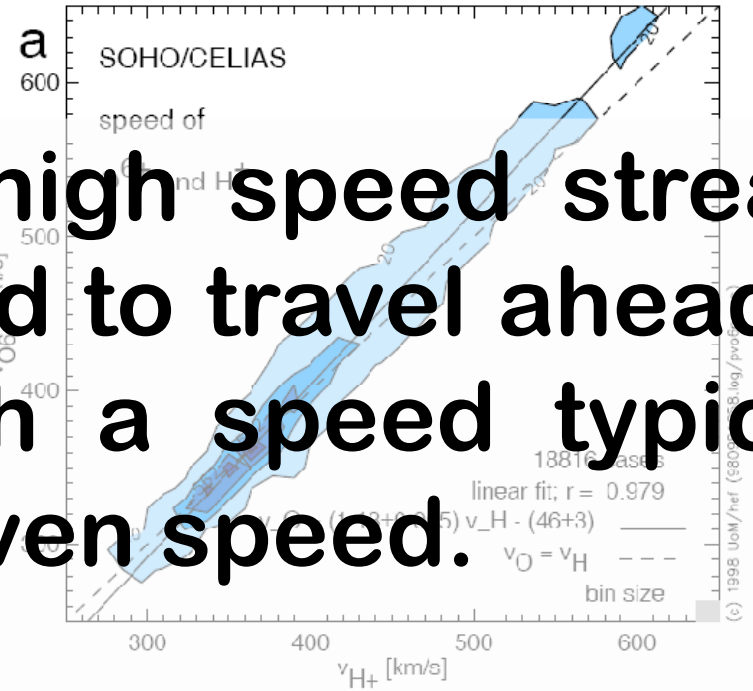


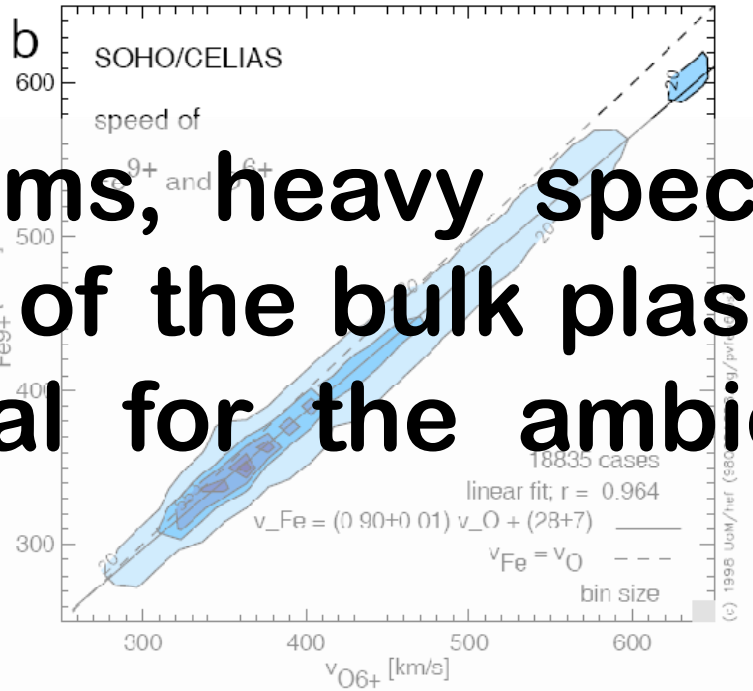
Theoretical Model

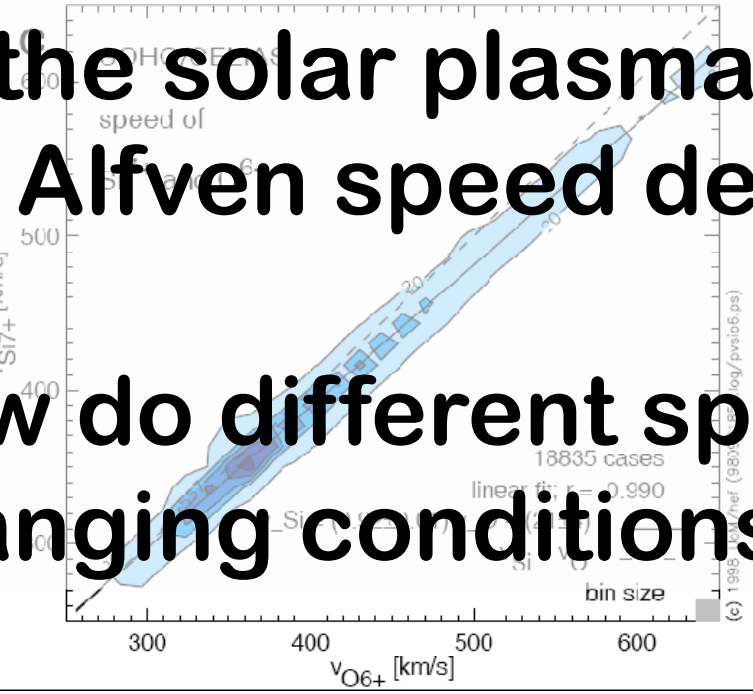


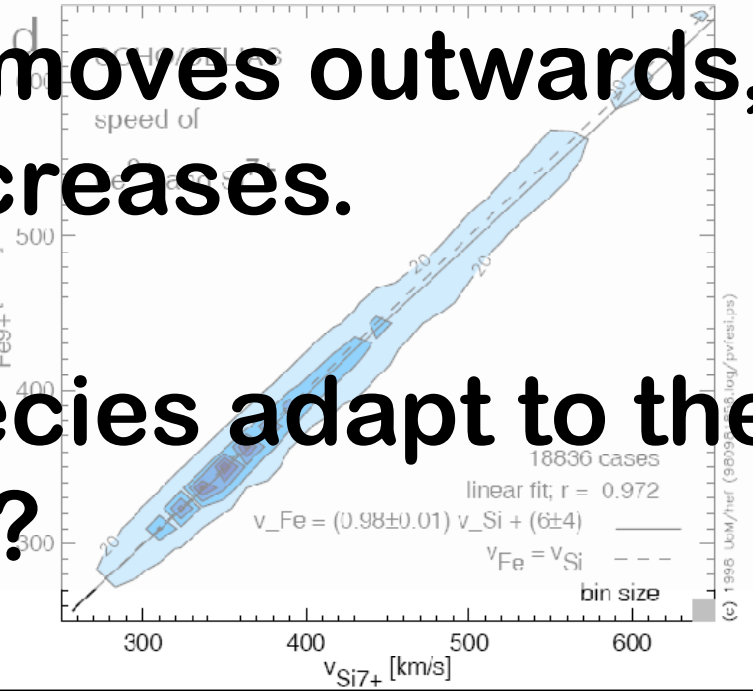


Speeds of different species





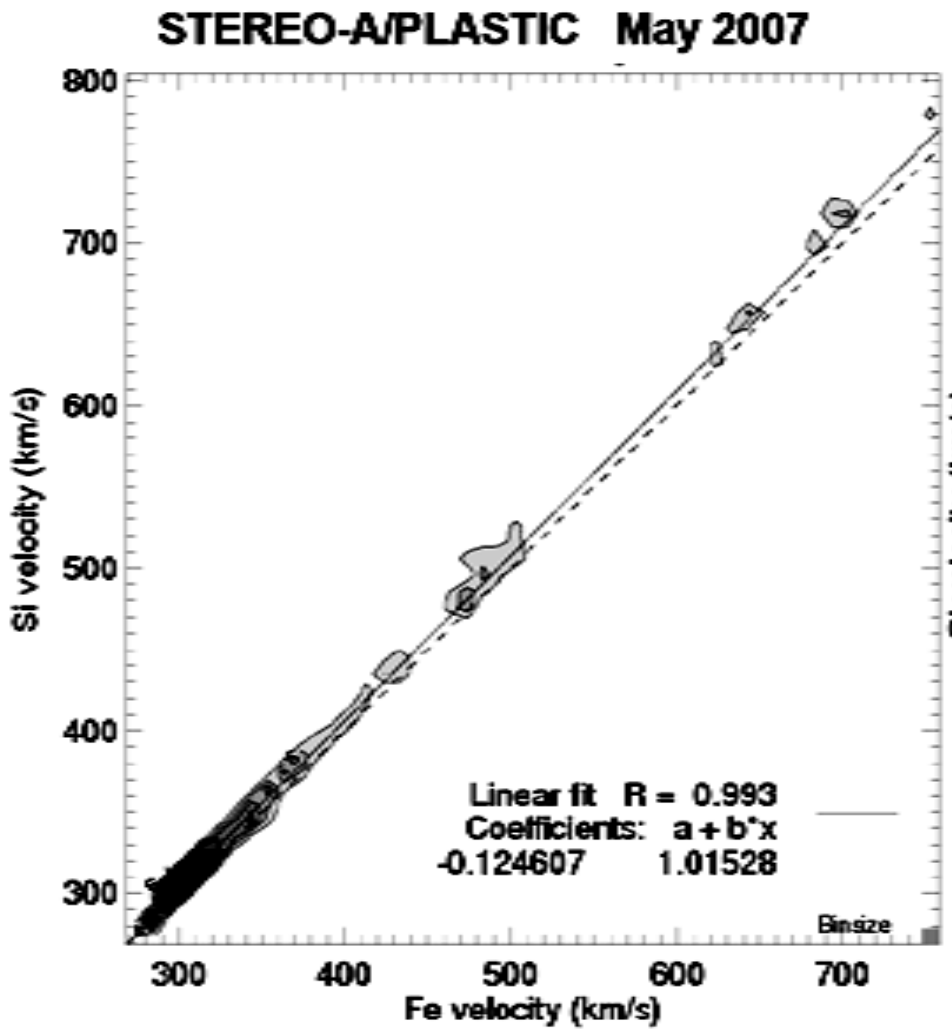


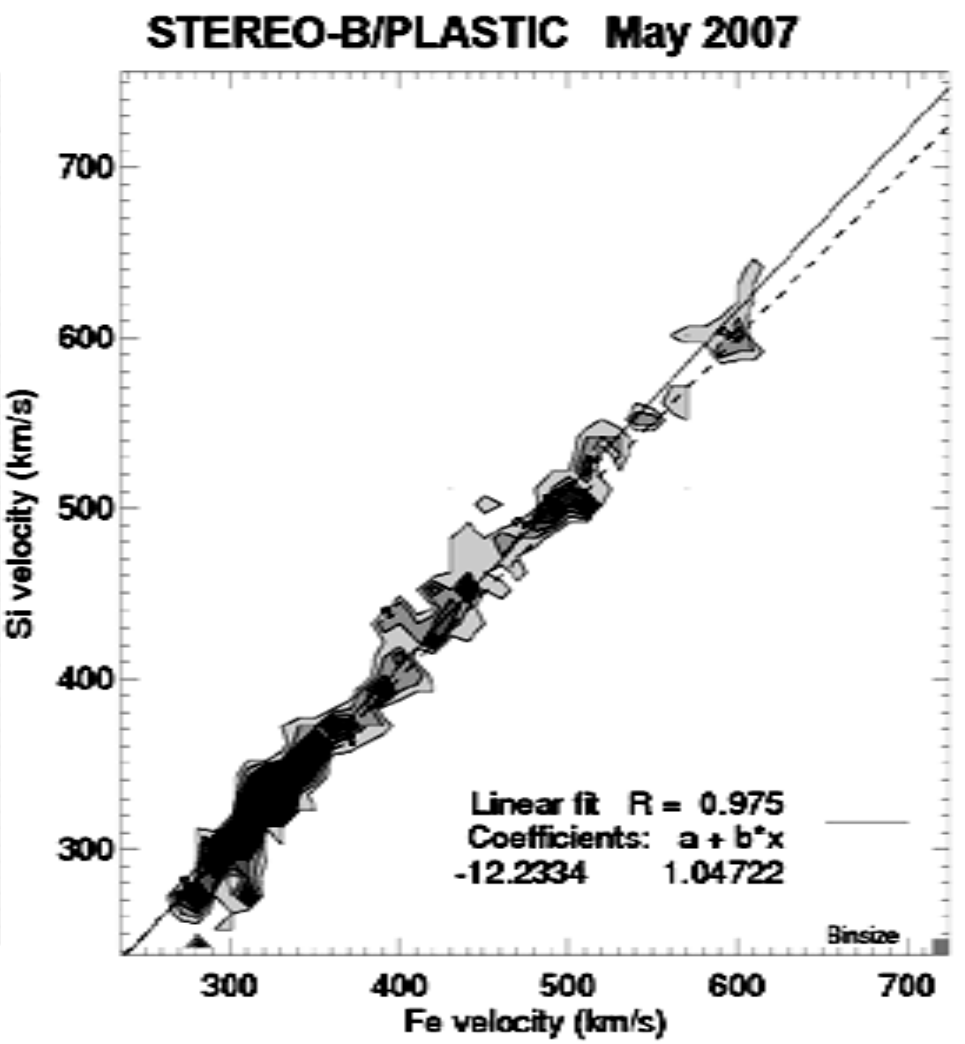


In high speed streams, heavy species tend to travel ahead of the bulk plasma with a speed typical for the ambient Alfven speed.

As the solar plasma moves outwards, the Alfven speed decreases.

How do different species adapt to the changing conditions?


STEREO-A/PLASTIC May 2007
Si velocity (km/s)
Fe velocity (km/s)
Linear fit R = 0.993
Coefficients: a + b*x
-0.124607 1.01528
Binsize

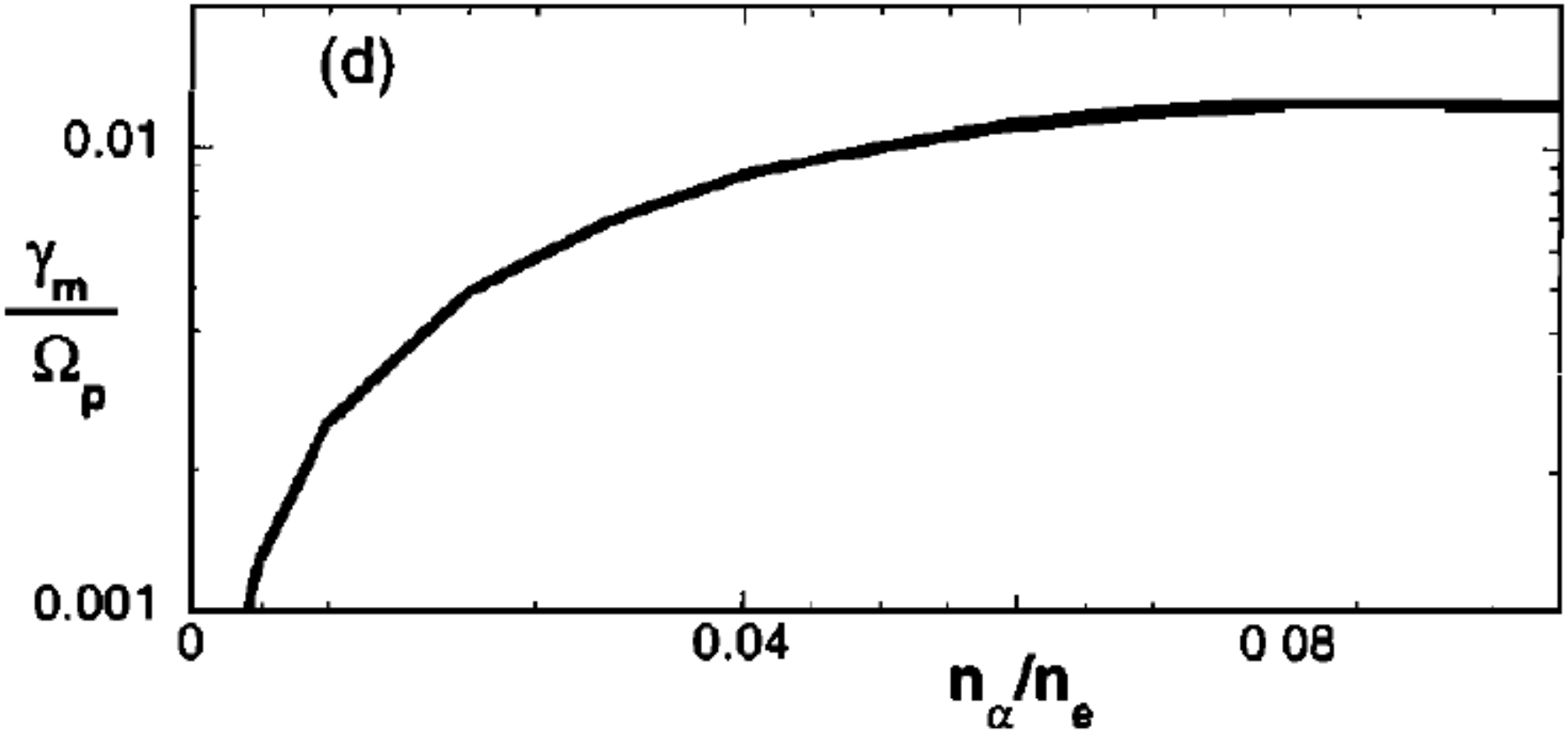

STEREO-B/PLASTIC May 2007
Si velocity (km/s)
Fe velocity (km/s)
Linear fit R = 0.975
Coefficients: a + b*x
-12.2334 1.04722
Binsize

Conclusions:

- In situ particle data from STEREO is unique!

- Need help
  - from other instruments waves and fields
  - from theorists and modelers

Growth rate of magnetosonic instability



Alpha/proton magnetosonic instability in the solar wind
S. Peter Gary, Lin Yin, Dan Winske and Daniel B. Reisenfeld
J. Geophys. Res. 105 (2000) 20,989-20996

Summary:

Hefti et al. (2000, and earlier Schmid et al. and Bochsler) claimed that Si is slower in high-speed winds than O, and He.

Hefti et al. find Fe to be slightly faster than Si in high speed wind

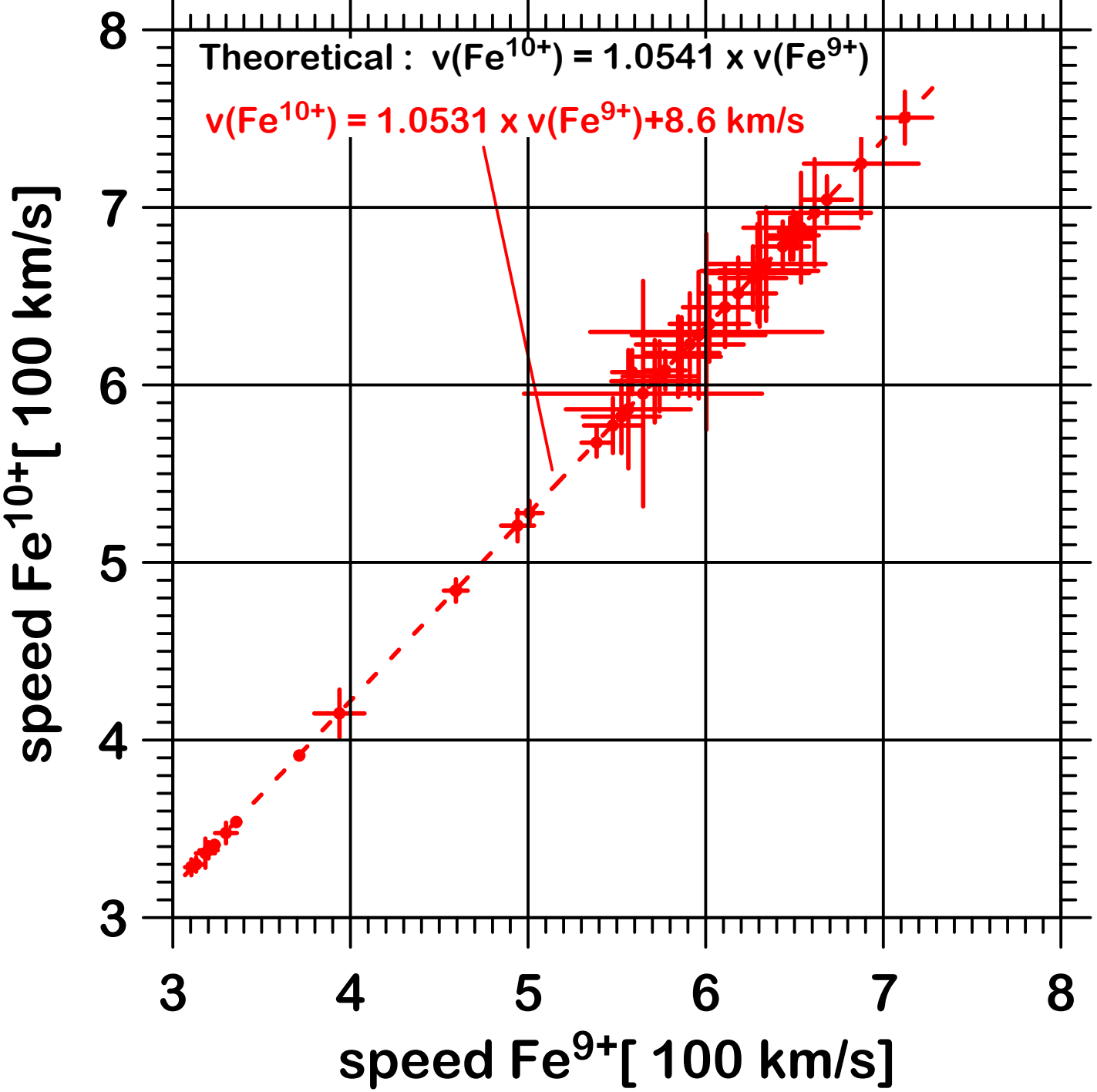
Heavy species are always faster than protons

Hefti tried to explain the preferential deceleration of heavies by Coulomb collisions (although Coulomb collisions are rather inefficient at large heliocentric distances in fast solar wind).

Gary et al. investigated the role of magnetosonic (and other) instabilities in decelerating heavy species compared to protons. At least in the case of alpha particles this seems to work.

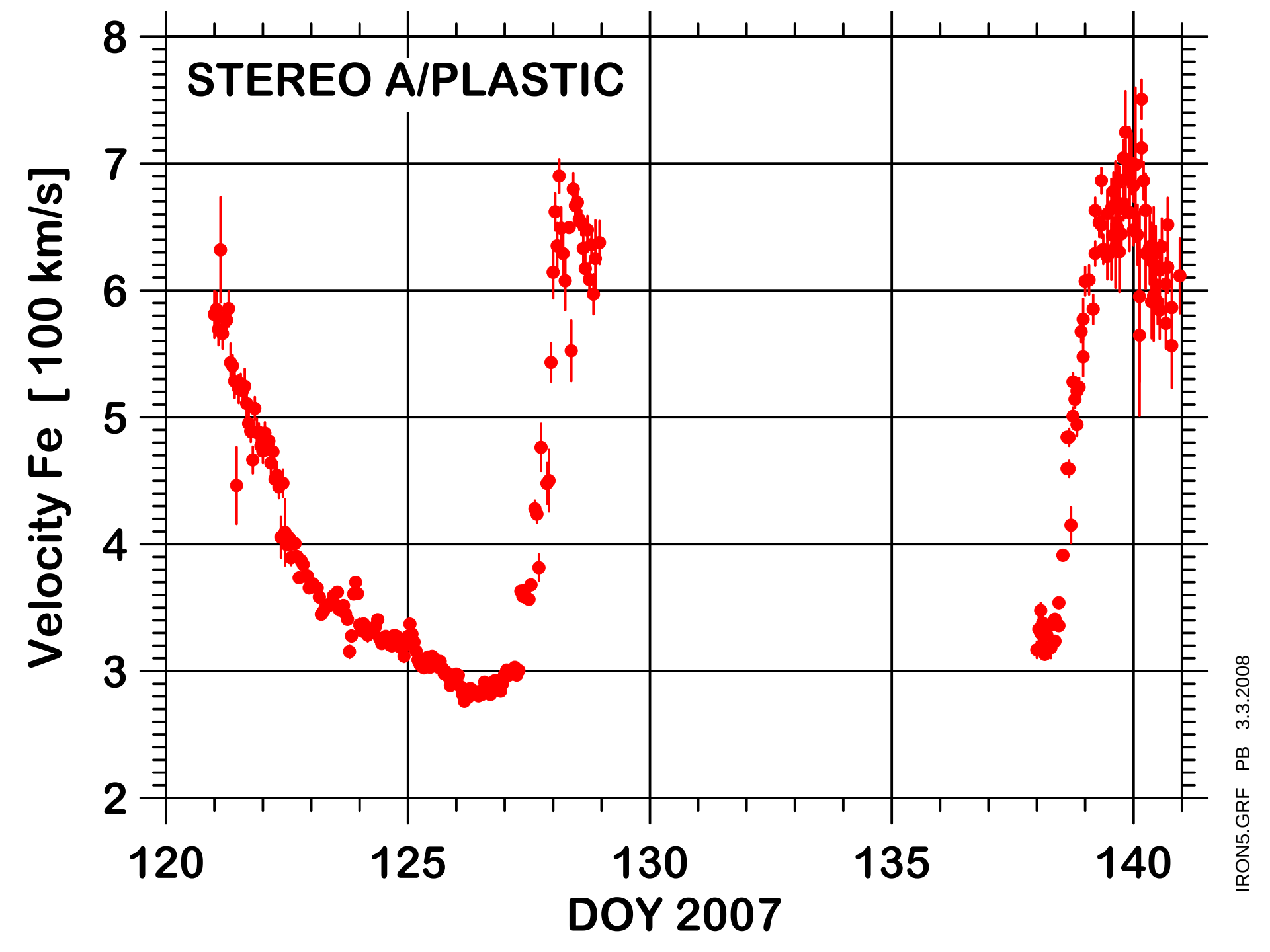
What happens to heavies? Do they create their own instabilities, or are they just decelerated together due to the instabilities of alphas?

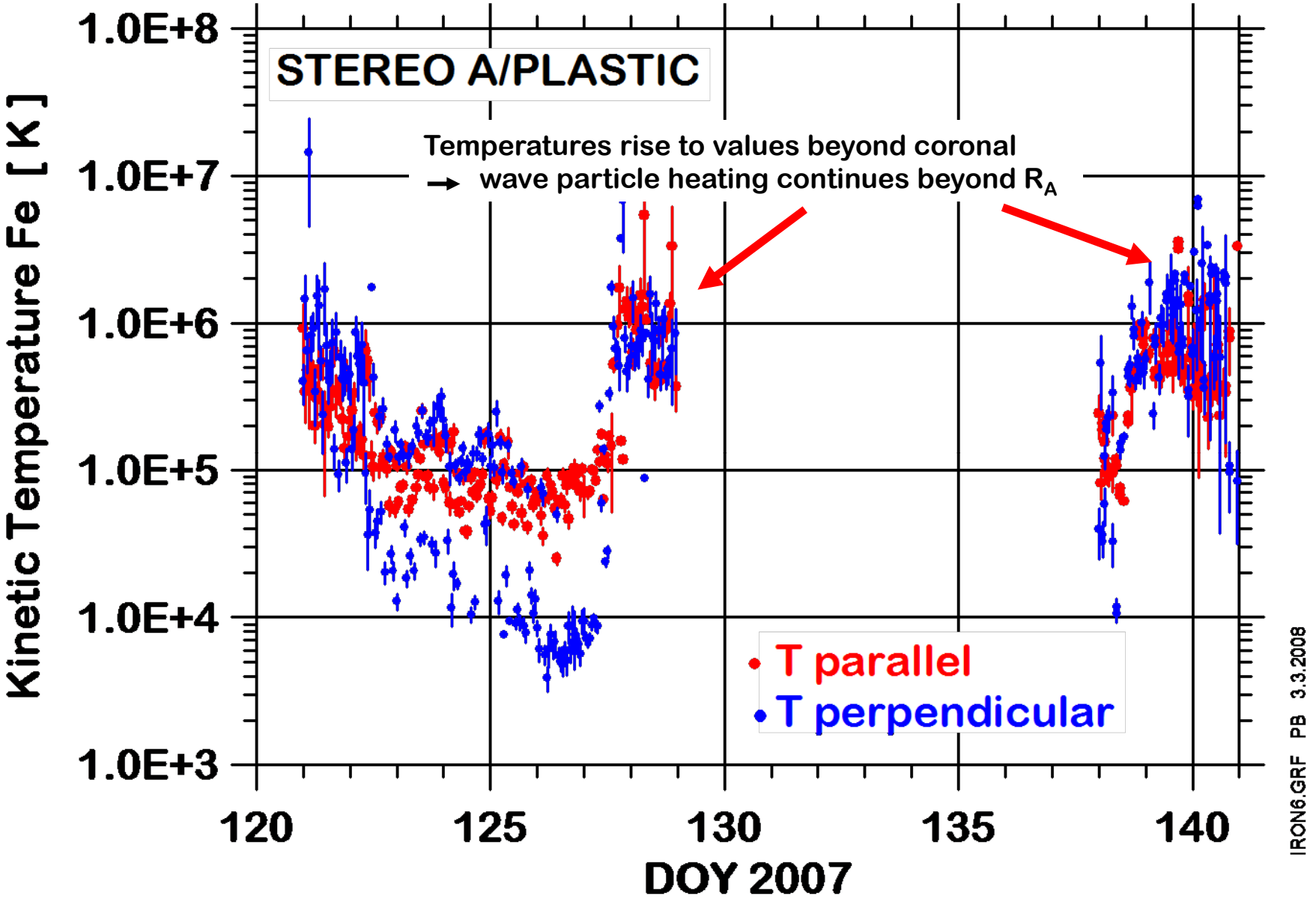
How do instabilities work in detail? Wave spectrum?

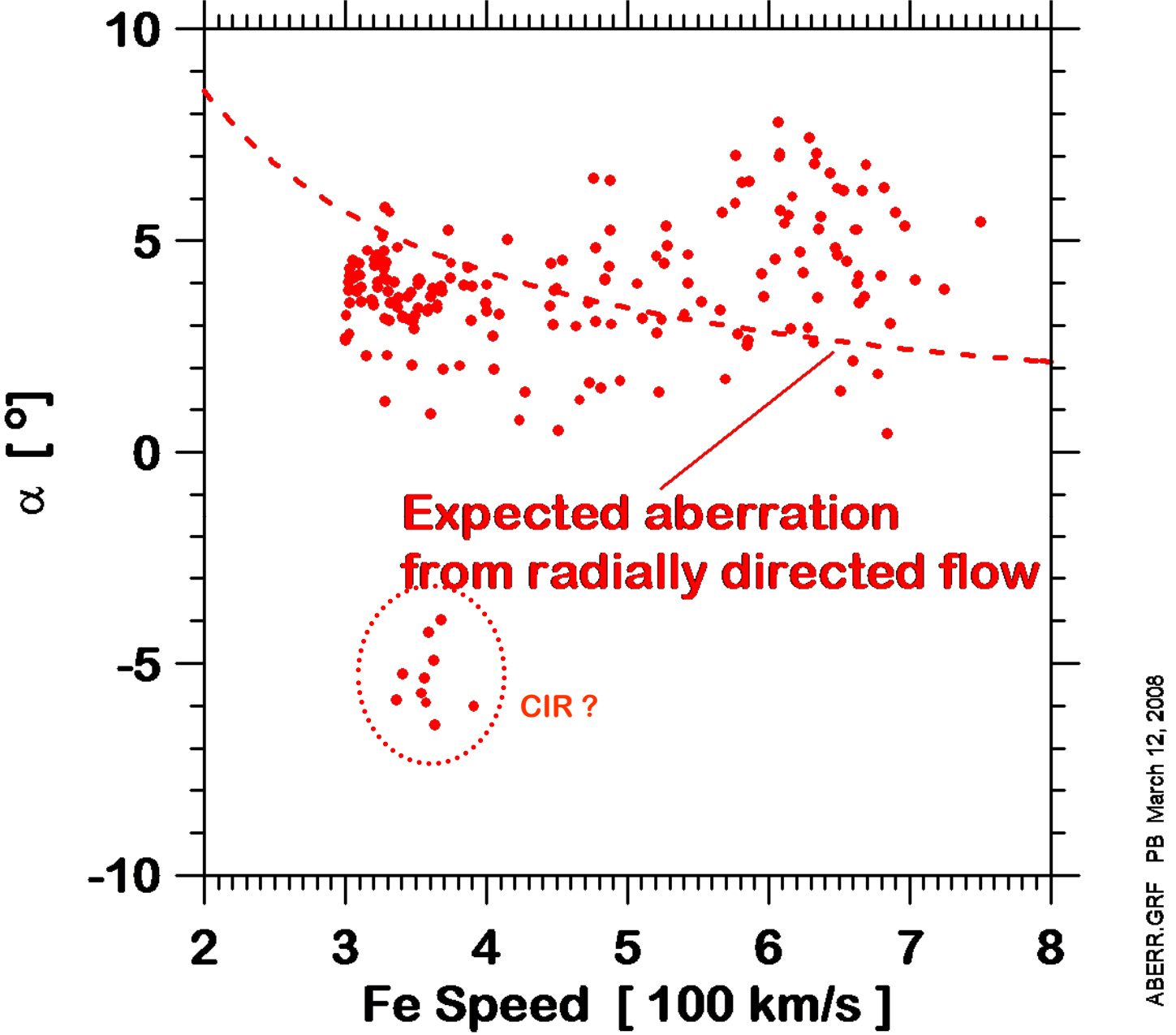


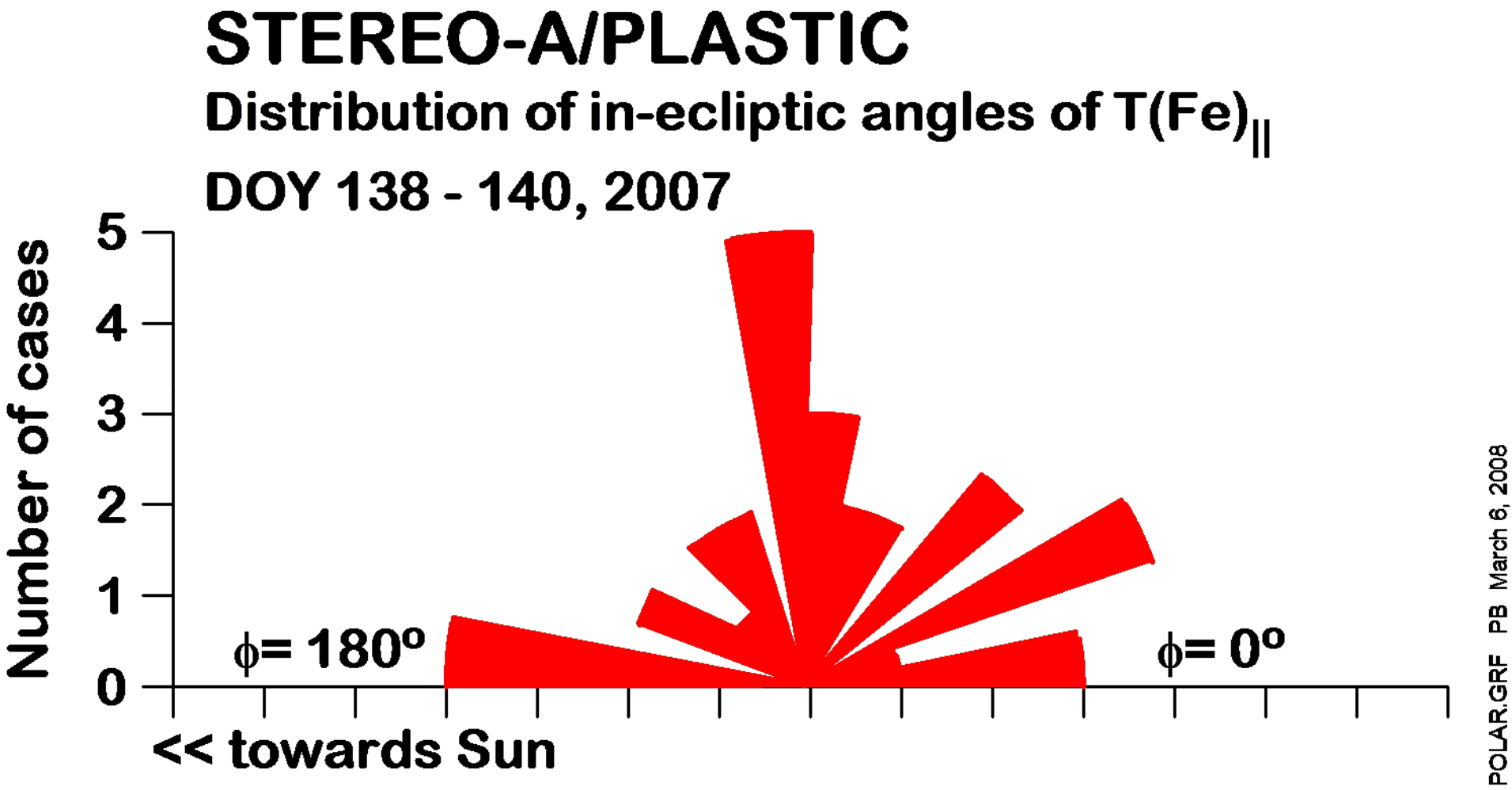
PHA Events
with anomalously
large TOF signals

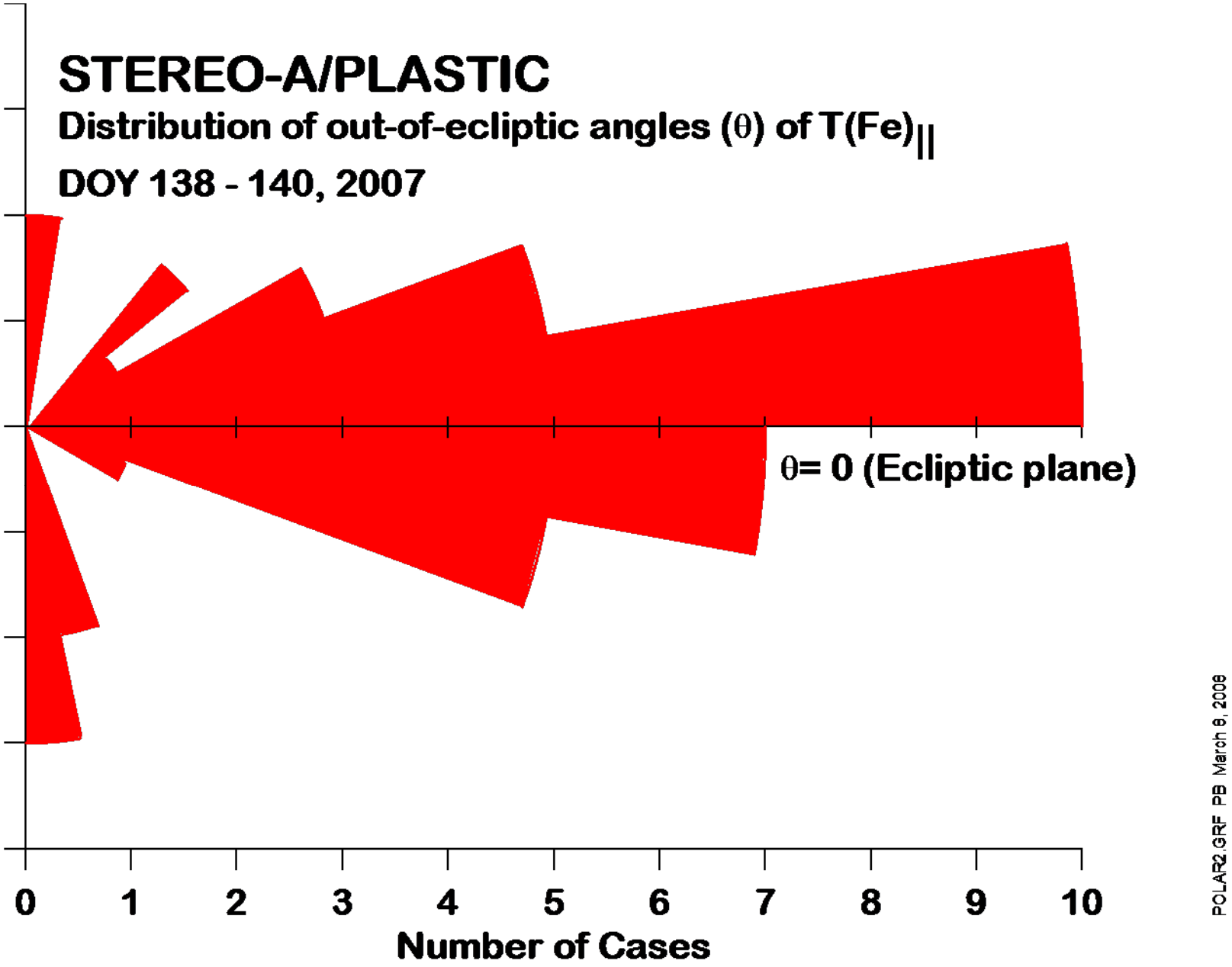
COR10_9.GRF PB 4.3.2008


STEREO A/PLASTIC
Velocity Fe [100 km/s]
8
7
6
5
4
3
2
120
125
130
135
140
DOY 2007
IRON5.GRF PB 3.3.2008


STEREO A/PLASTIC
Temperatures rise to values beyond coronal
wave particle heating continues beyond R_A
T parallel
T perpendicular
Kinetic Temperature Fe [K]
1.0E+8
1.0E+7
1.0E+6
1.0E+5
1.0E+4
1.0E+3
120
125
130
135
140
DOY 2007
IRON6.GRF PB 3.3.2008


10
5
0
-5
-10
α [°]
2
3
4
5
6
7
8
Fe Speed [100 km/s]
Expected aberration
from radially directed flow
CIR ?
ABERR.GRF PB March 12, 2008


STEREO-A/PLASTIC
Distribution of in-ecliptic angles of T(Fe)||
DOY 138 - 140, 2007
Number of cases
0
1
2
3
4
5
ϕ= 180°
ϕ= 0°
<< towards Sun
POLAR.GRF PB March 6, 2008


STEREO-A/PLASTIC
Distribution of out-of-ecliptic angles (θ) of T(Fe)||
DOY 138 - 140, 2007
θ= 0 (Ecliptic plane)
0
1
2
3
4
5
6
7
8
9
10
Number of Cases
POLAR2.GRF PB March 6, 2008

Adiabatic invariants:

$$\frac{d}{dt}\left(\frac{T_{||}B^2}{n^2}\right)=0$$

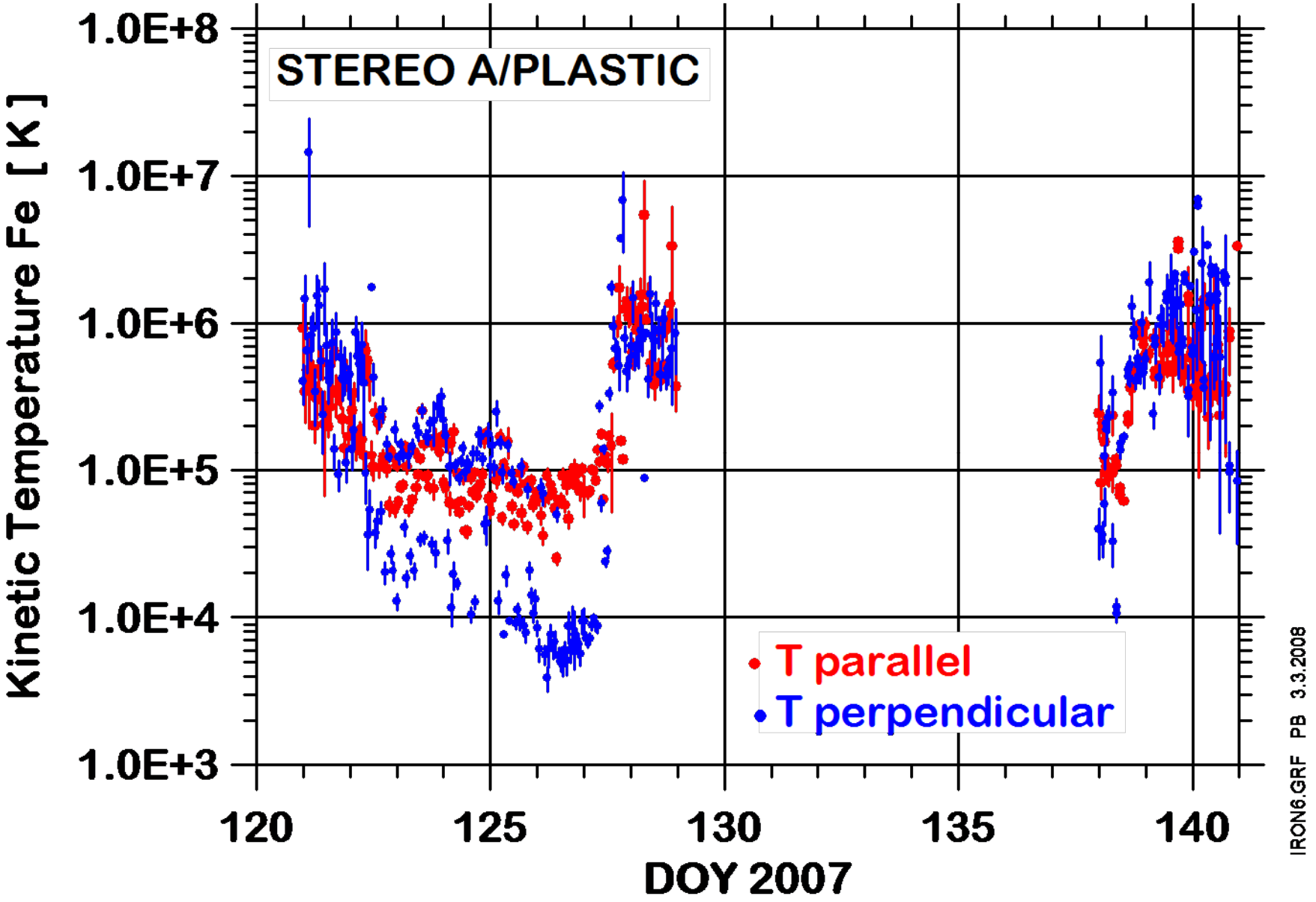
$$\frac{d}{dt}\left(\frac{T_{\perp}}{B}\right)=0$$

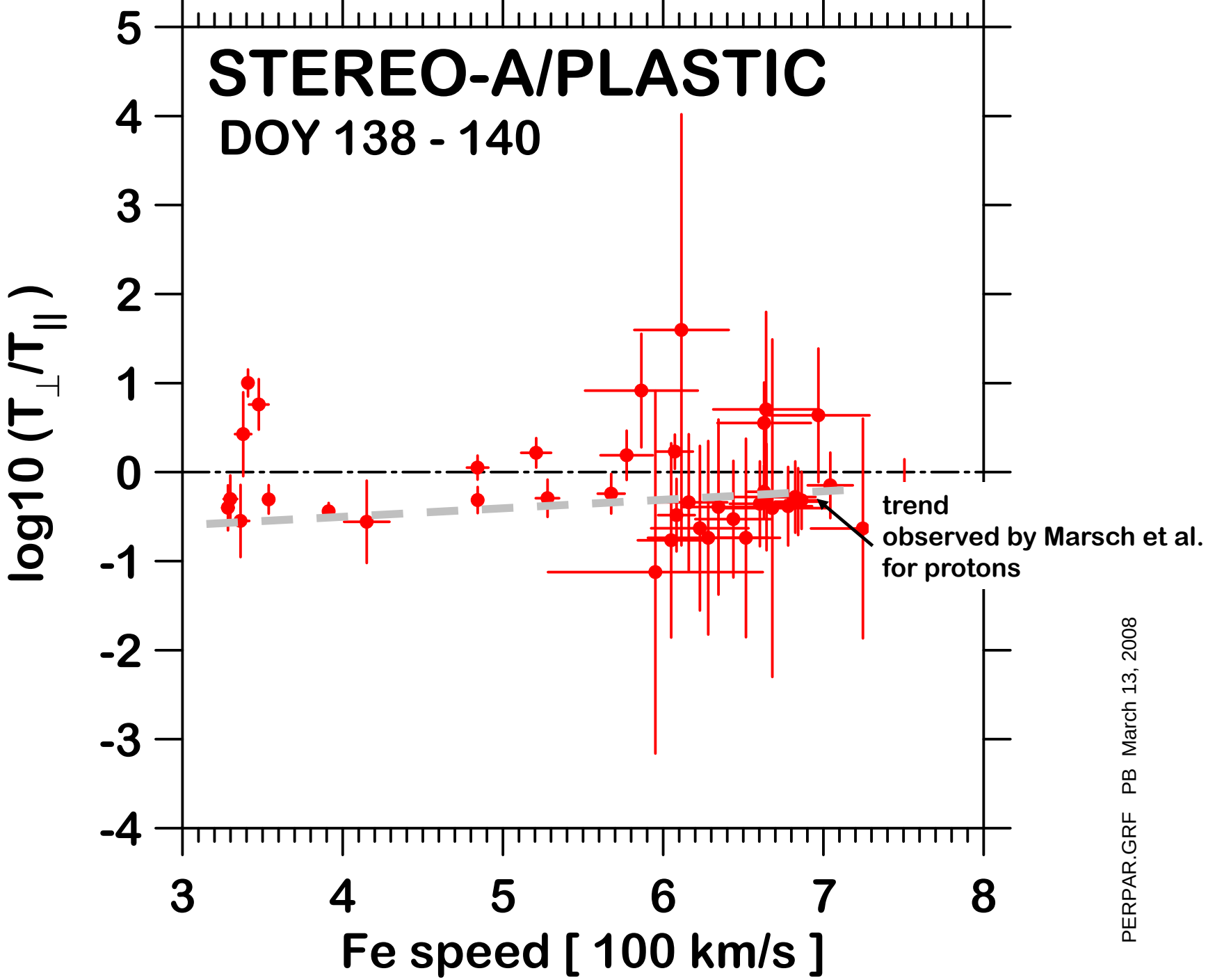
$$\frac{T_{\perp}}{T_{||}} \propto \frac{B^3}{n^2}$$

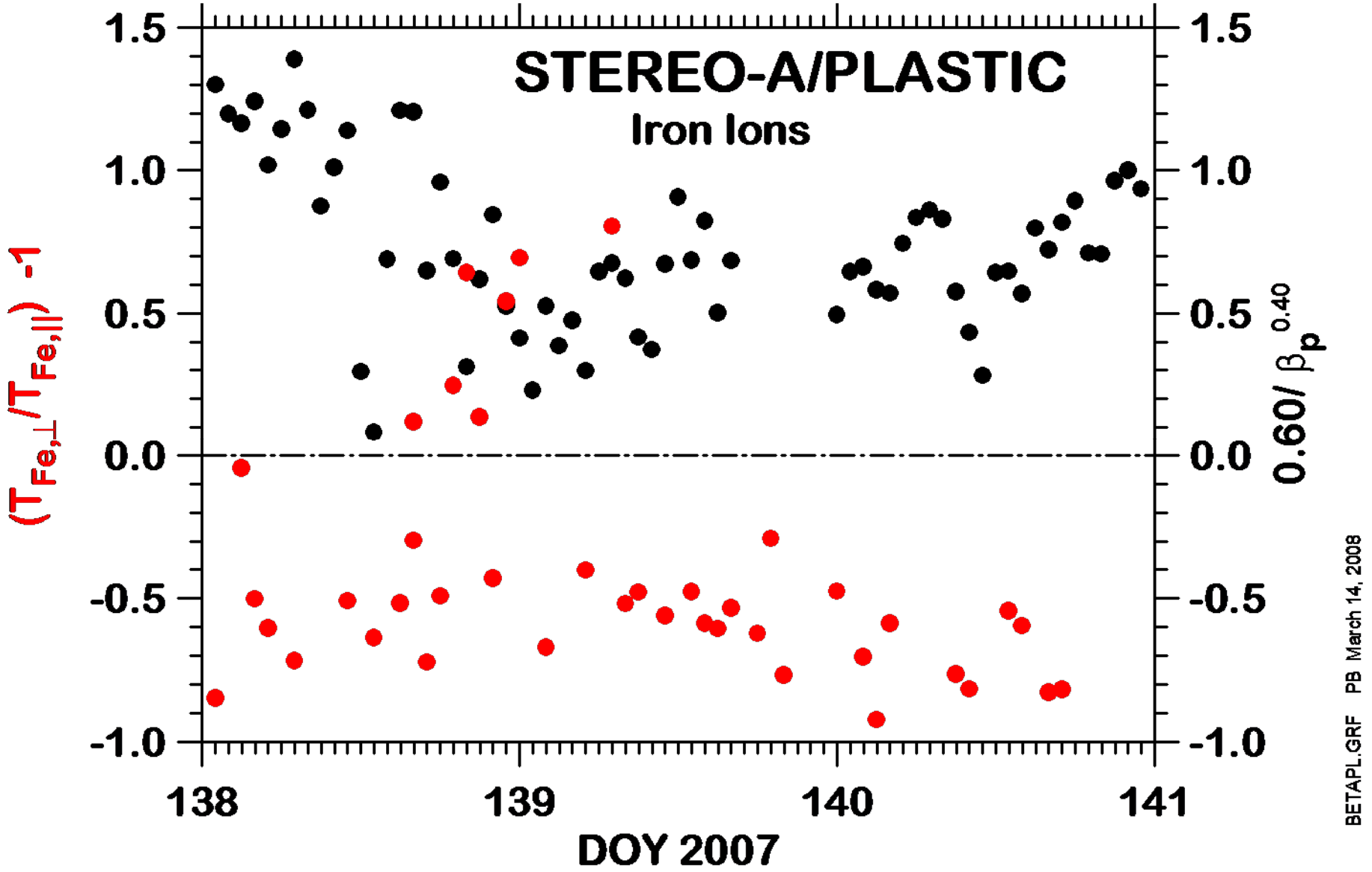
For constant solar wind speed u, B $\propto$ Parker spiral, no heating:

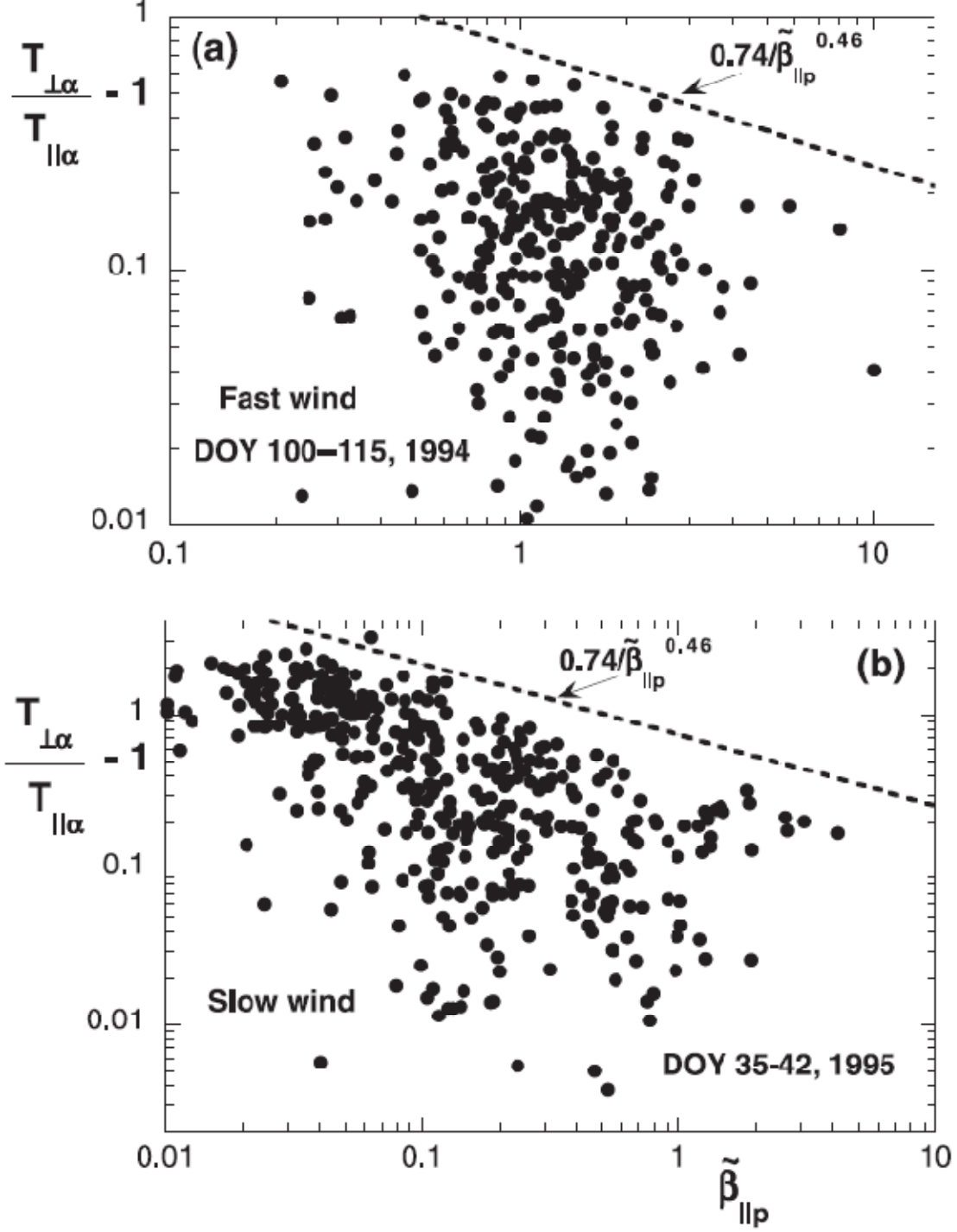
$$n \propto r^{-2} \qquad B \propto \frac{1}{r^2}\sqrt{1+\frac{\omega^2 r^2}{u^2}\sin^2\theta}$$

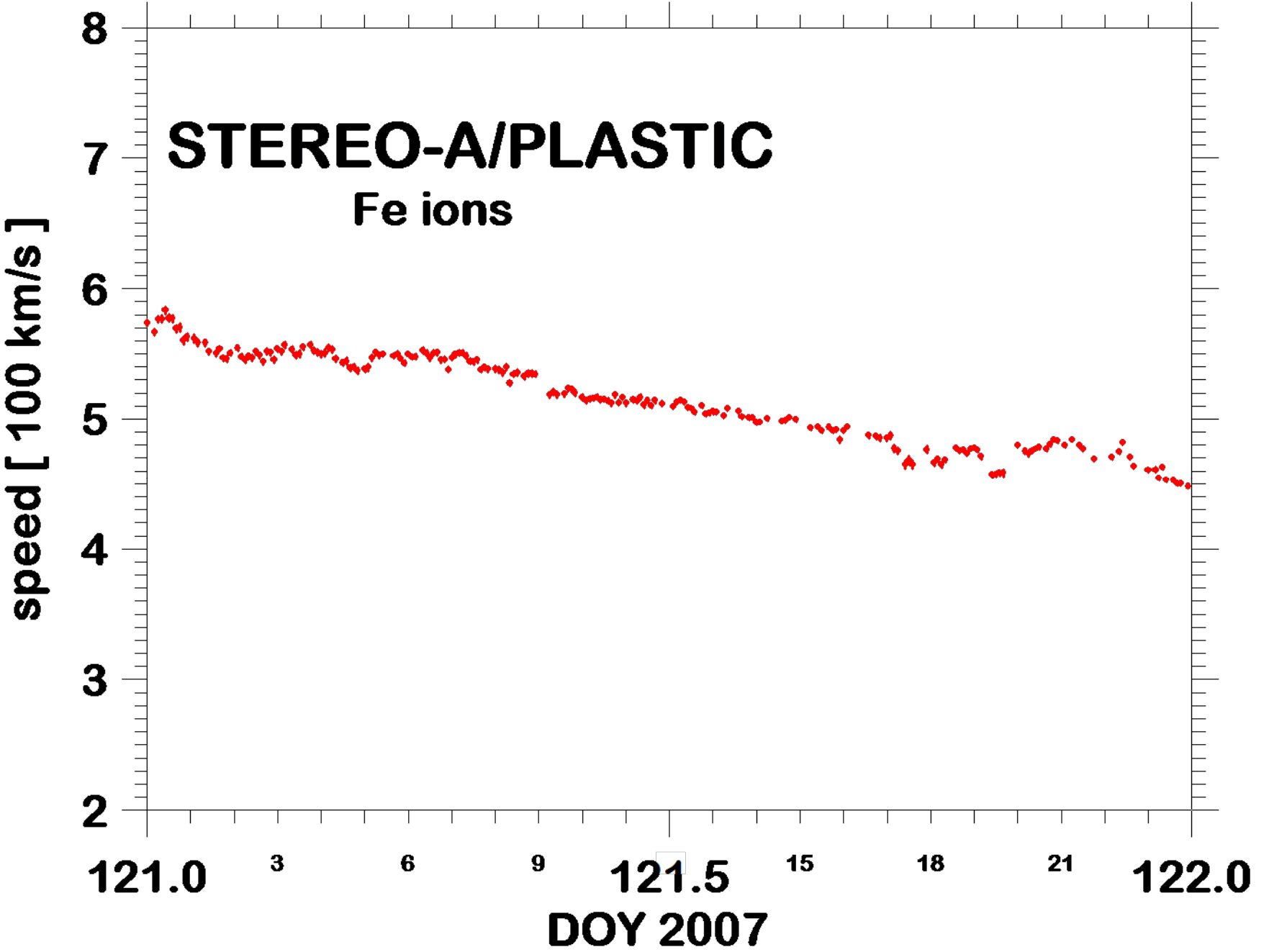
$$\frac{T_{\perp}}{T_{||}} \propto \frac{B^3}{n^2} \propto \frac{1}{r^2}\left(1+\frac{\omega^2 r^2}{u^2}\sin^2\theta\right)^{3/2}$$

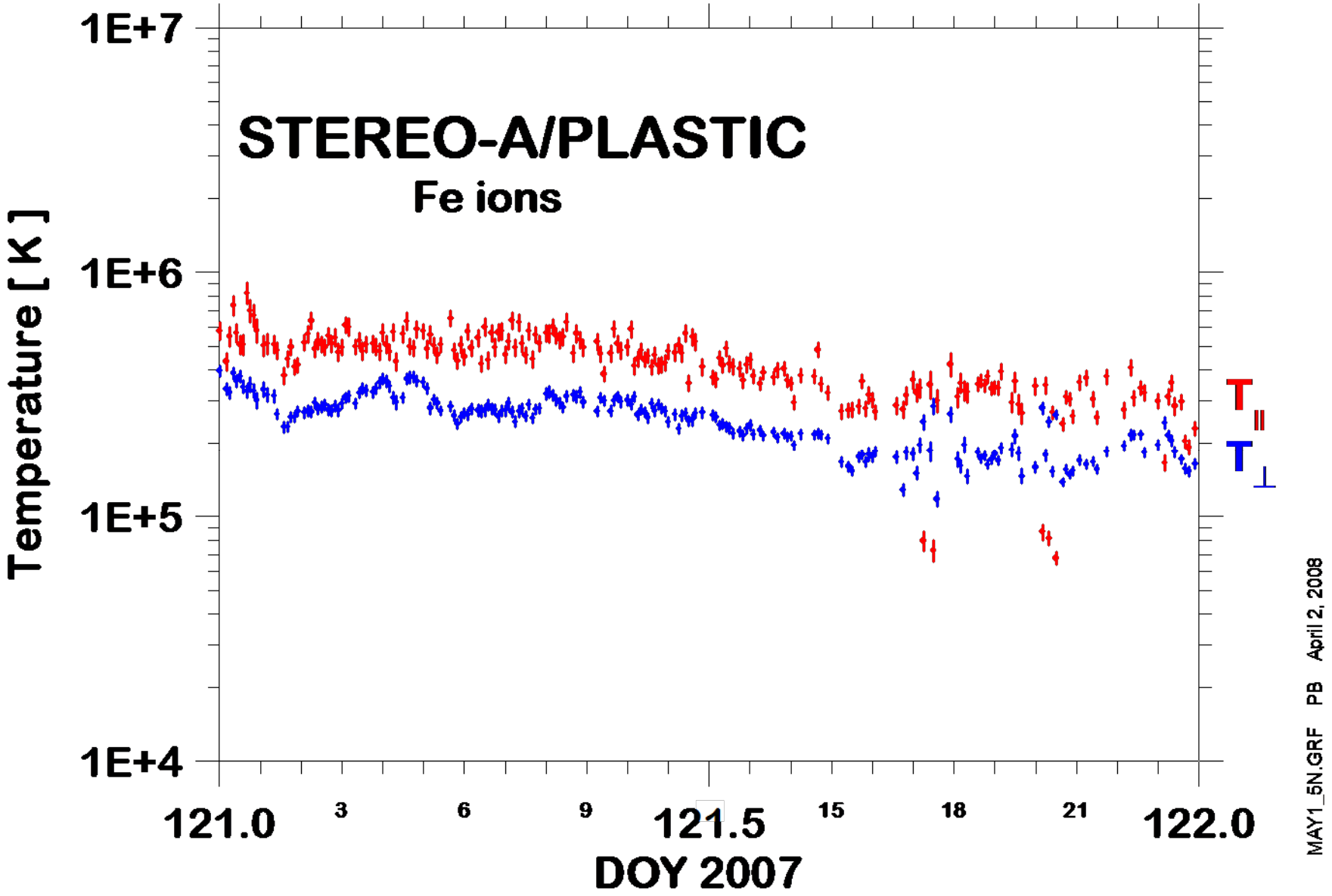

STEREO A/PLASTIC
Kinetic Temperature Fe [K]
1.0E+8
1.0E+7
1.0E+6
1.0E+5
1.0E+4
1.0E+3
120
125
130
135
140
DOY 2007
T parallel
T perpendicular
IRON6.GRF PB 3.3.2008

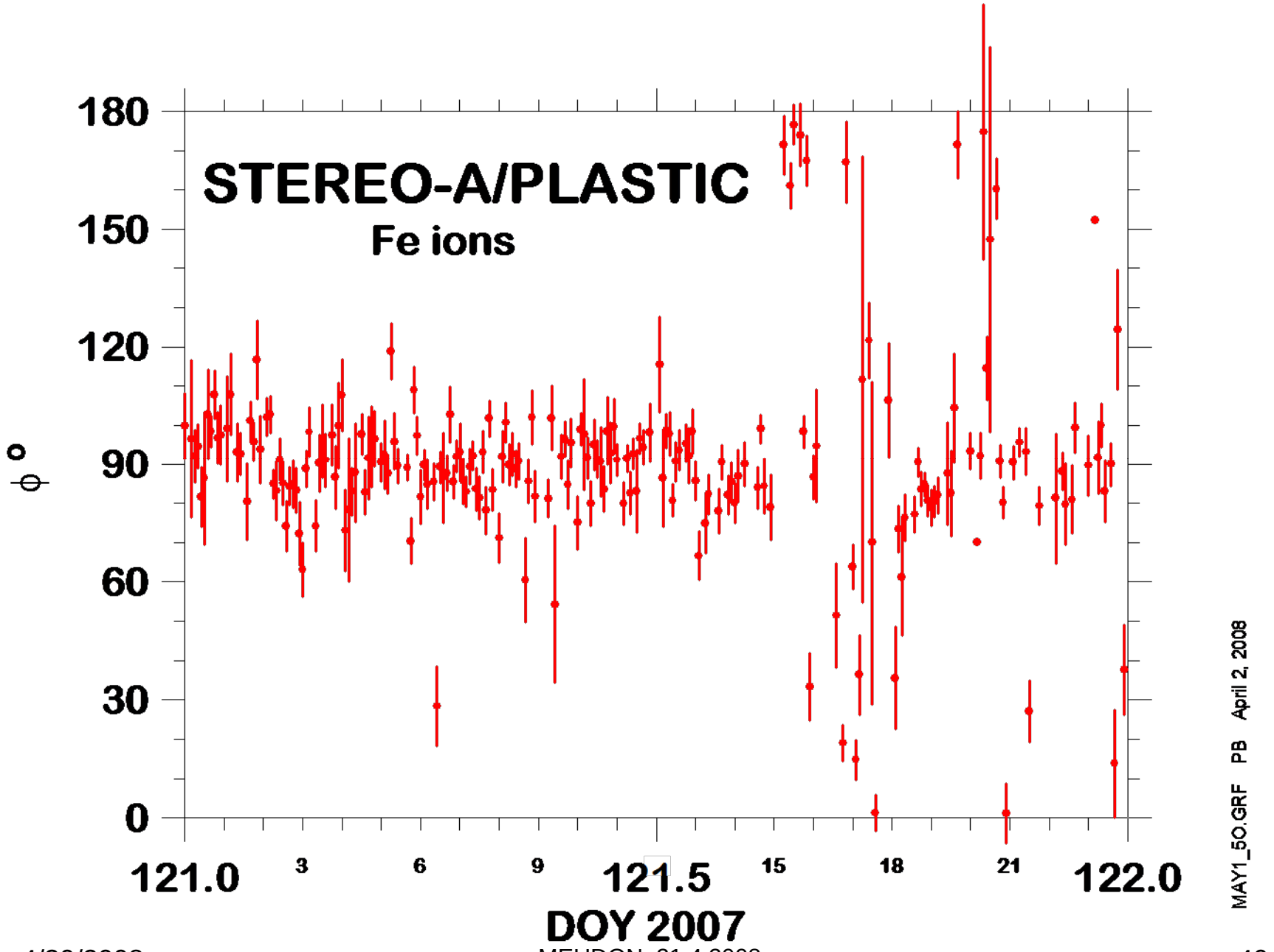

STEREO-A/PLASTIC
DOY 138 - 140
log10 (T⊥/T||)
5
4
3
2
1
0
-1
-2
-3
-4
3
4
5
6
7
8
Fe speed [100 km/s]
trend
observed by Marsch et al.
for protons
PERPAR.GRF PB March 13, 2008

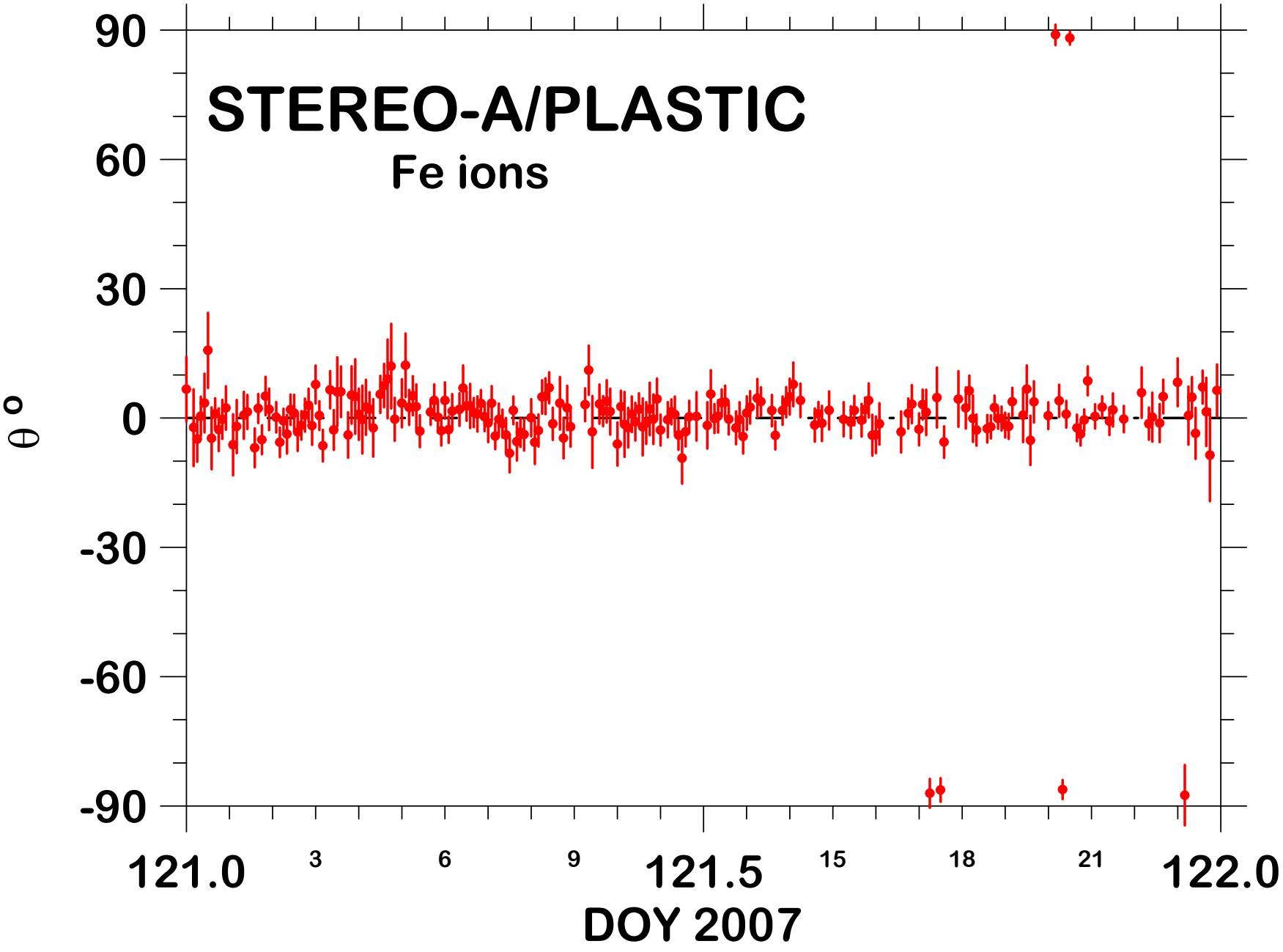

STEREO-A/PLASTIC
Iron Ions
$(T_{Fe,\perp}/T_{Fe,\parallel})$ -1
$0.60/\beta_p^{0.40}$
DOY 2007
1.5
1.0
0.5
0.0
-0.5
-1.0
138
139
140
141
BETAPL.GRF PB March 14, 2008

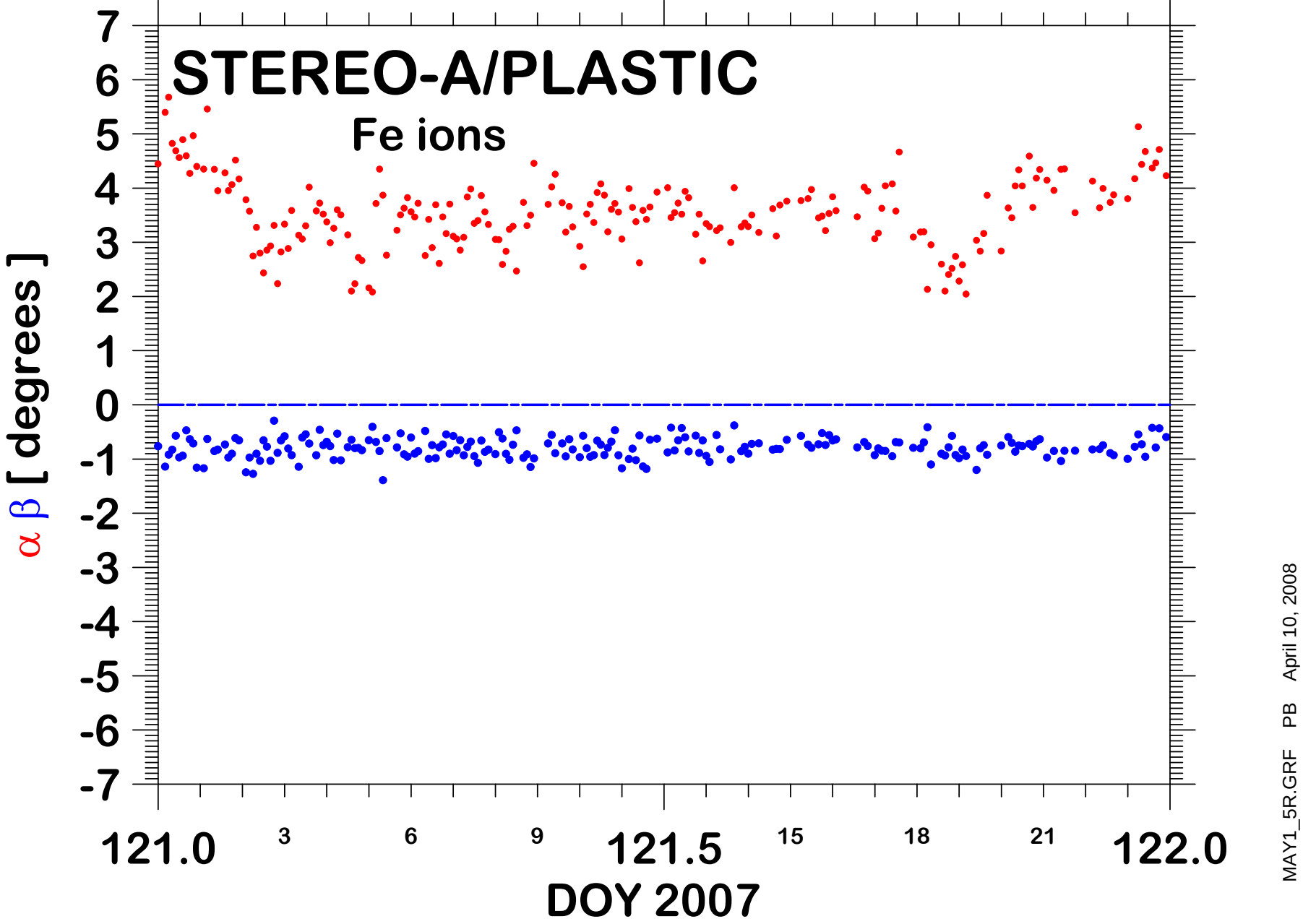

(a)
$0.74/\tilde{\beta}_{\|p}^{0.46}$
$\frac{T_{\perp\alpha}}{T_{\|\alpha}} - 1$
Fast wind
DOY 100–115, 1994
1
0.1
0.01
0.1
1
10
(b)
$0.74/\tilde{\beta}_{\|p}^{0.46}$
$\frac{T_{\perp\alpha}}{T_{\|\alpha}} - 1$
Slow wind
DOY 35-42, 1995
0.01
0.1
1
10
$\tilde{\beta}_{\|p}$

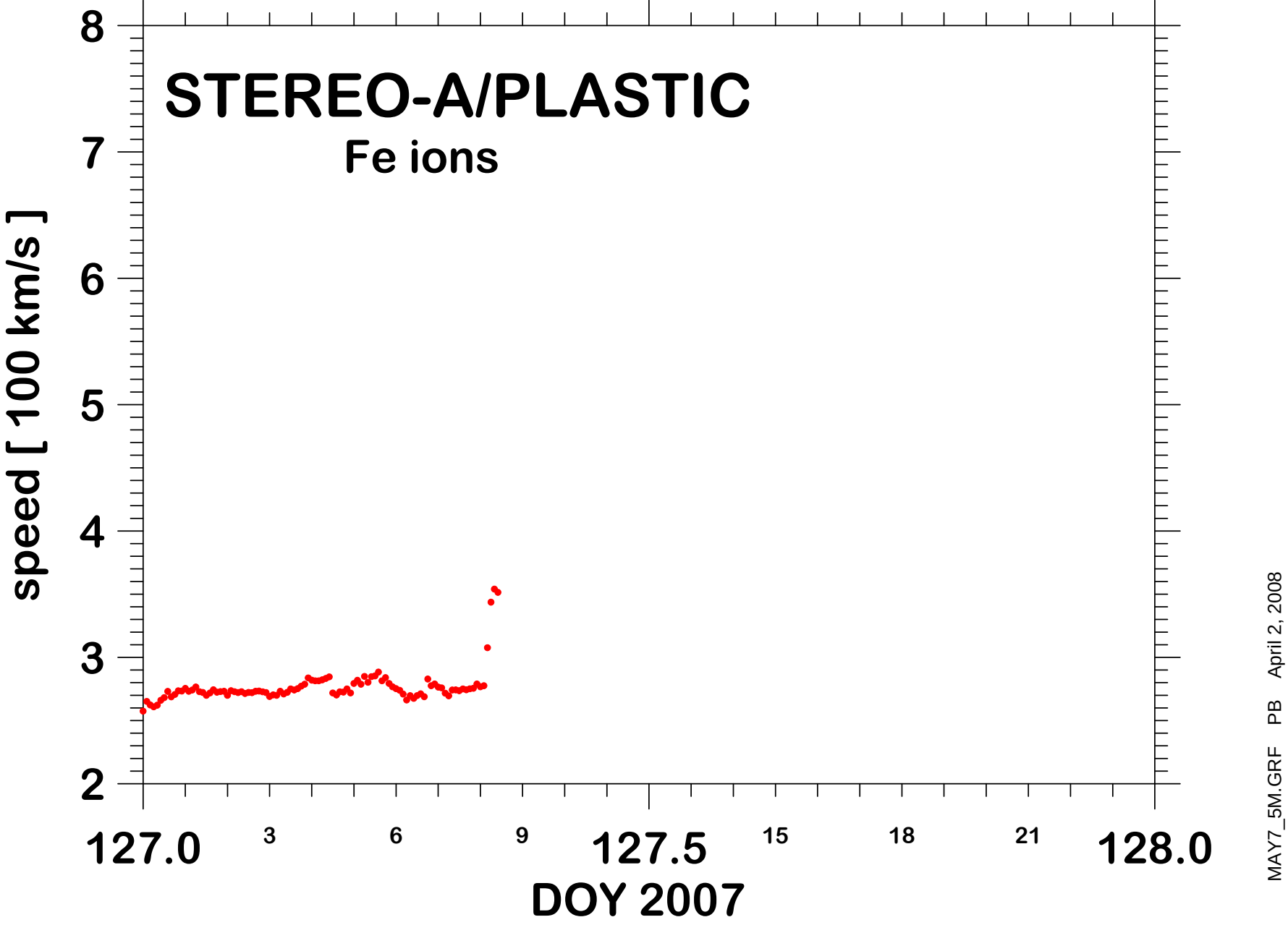

STEREO-A/PLASTIC
Fe ions
speed [100 km/s]
8
7
6
5
4
3
2
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007
MAY1_5M.GRF PB April 2, 2008


STEREO-A/PLASTIC
Fe ions
Temperature [K]
1E+7
1E+6
1E+5
1E+4
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007
T||
T⊥
MAY1_5N.GRF PB April 2, 2008

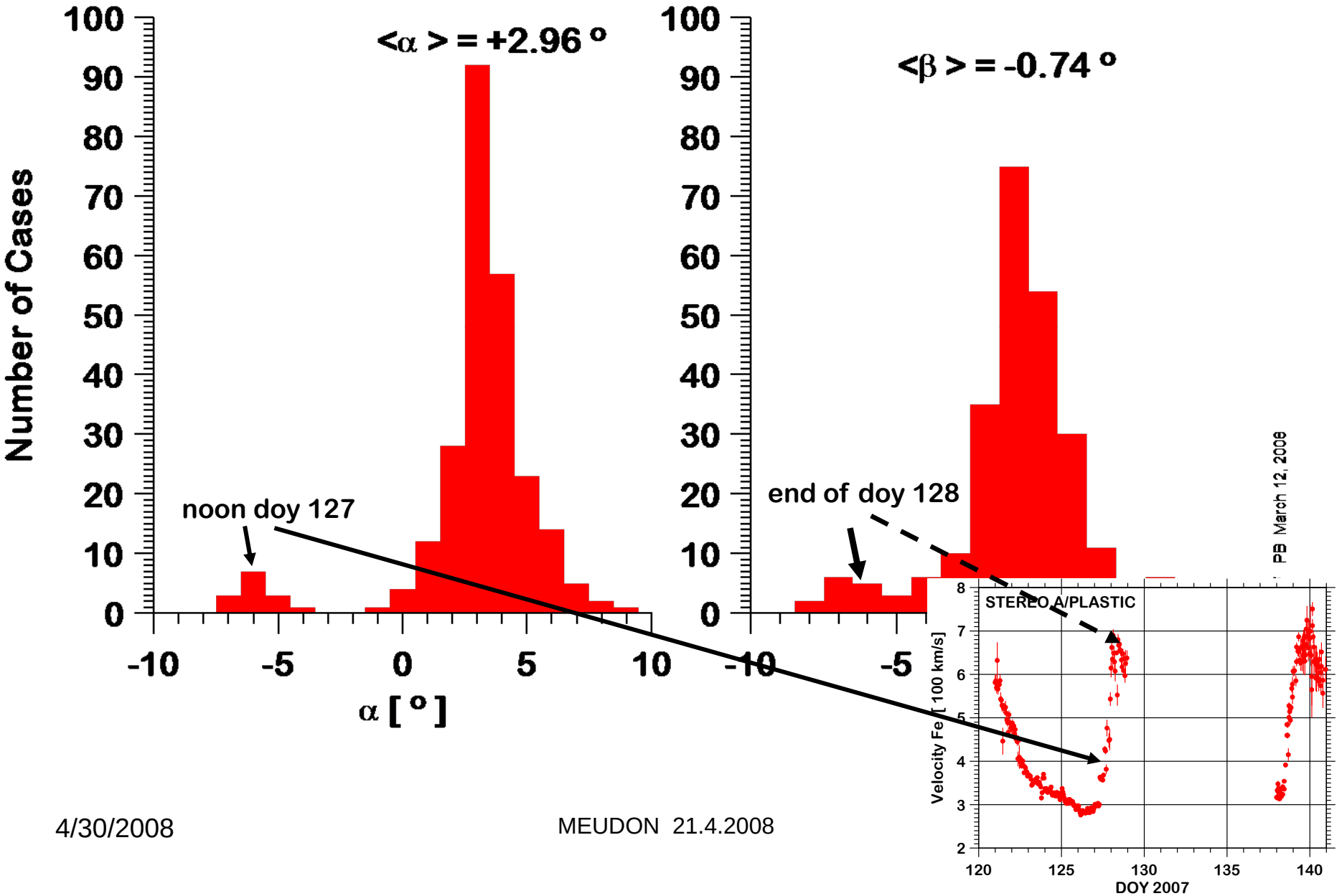

STEREO-A/PLASTIC
Fe ions
180
150
120
90
60
30
0
φ°
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007
MAY1_5O.GRF PB April 2, 2008


STEREO-A/PLASTIC
Fe ions
θ °
90
60
30
0
-30
-60
-90
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007


STEREO-A/PLASTIC
Fe ions
α β [degrees]
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
121.0
3
6
9
121.5
15
18
21
122.0
DOY 2007
MAY1_5R.GRF PB April 10, 2008


STEREO-A/PLASTIC
Fe ions
speed [100 km/s]
8
7
6
5
4
3
2
127.0
3
6
9
127.5
15
18
21
128.0
DOY 2007
MAY7_5M.GRF PB April 2, 2008

STEREO-A/PLASTIC May 2007 (253 hourly averages)



4/30/2008

MEUDON 21.4.2008

Priorities

- Extend analysis to larger data set
- Use Hagar's criteria to identify iron ions
- Generalize data reduction including all charge states
- Combine analysis with fields and waves
- Wave-field interaction (simulations?)