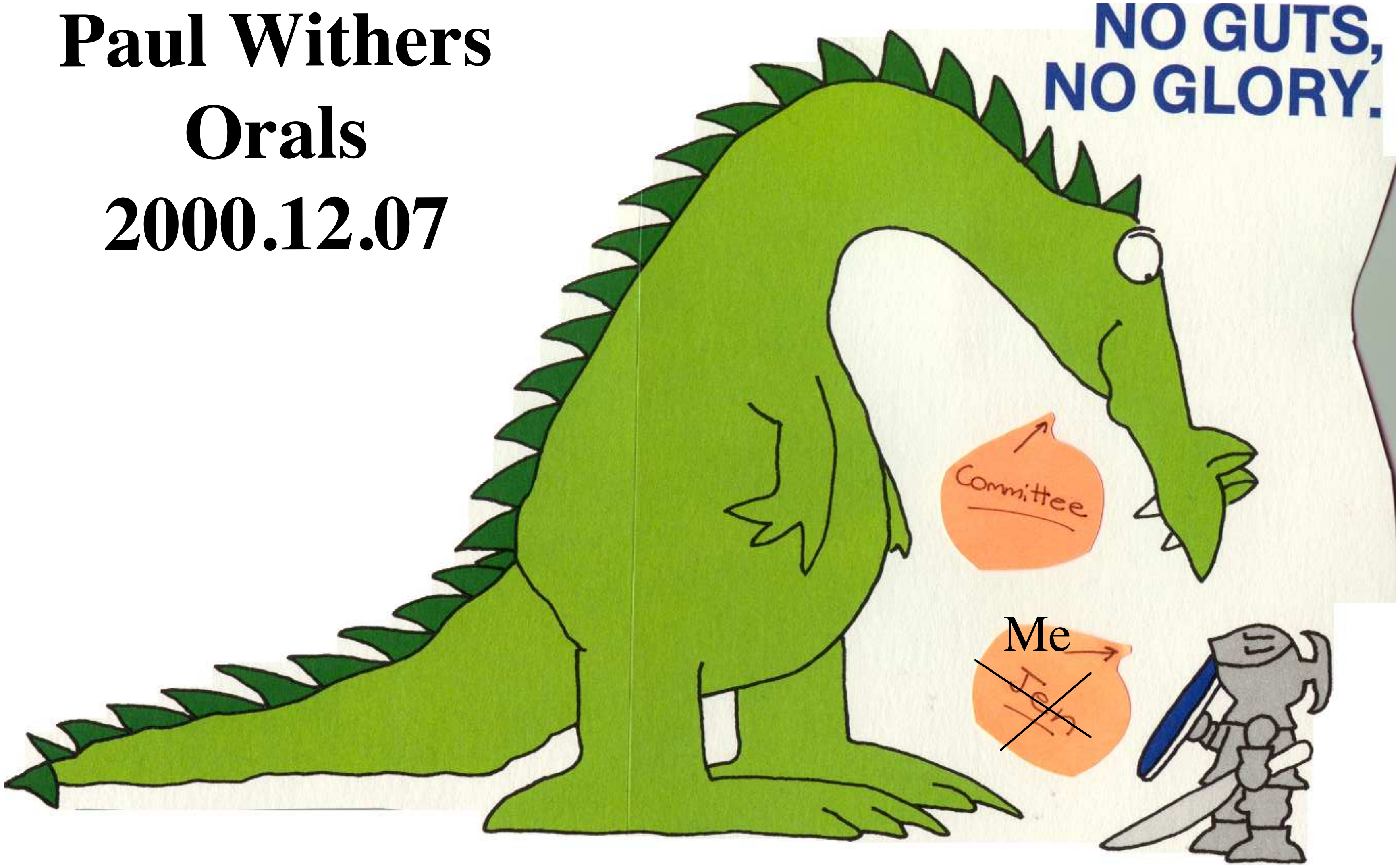
Paul Withers
Orals
2000.12.07



Classes

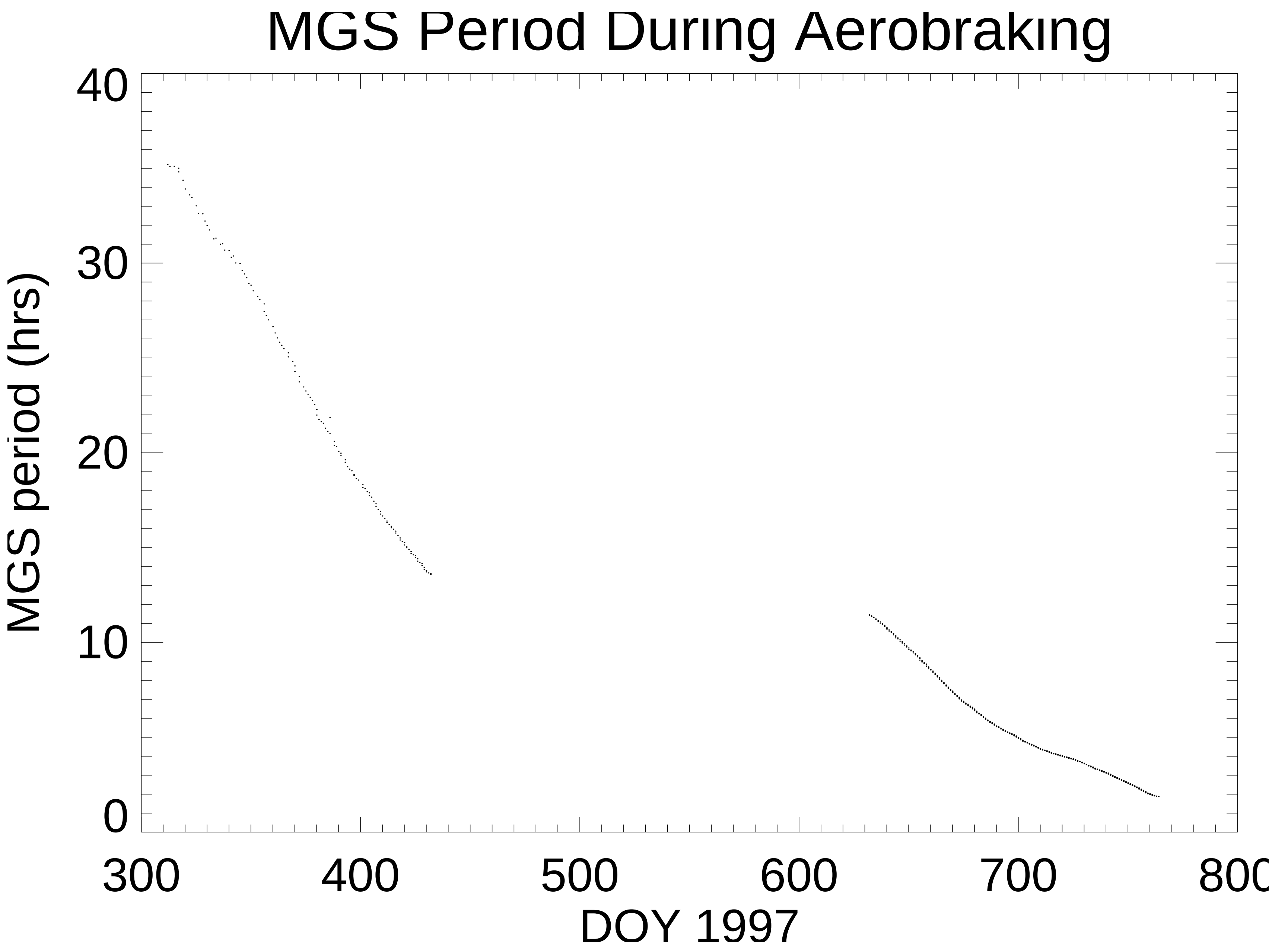
- Atmospheres, Hunten
- Chemistry, Lewis
- Chemistry, Drake
- Surfaces, Melosh
- Geophysics, Melosh
- Physics, Hubbard
- Physics, Jokipii
- Terrestrial Planets, Drake and Melosh
- Remote Sensing, McEwen
- Thermodynamics, Ganguly

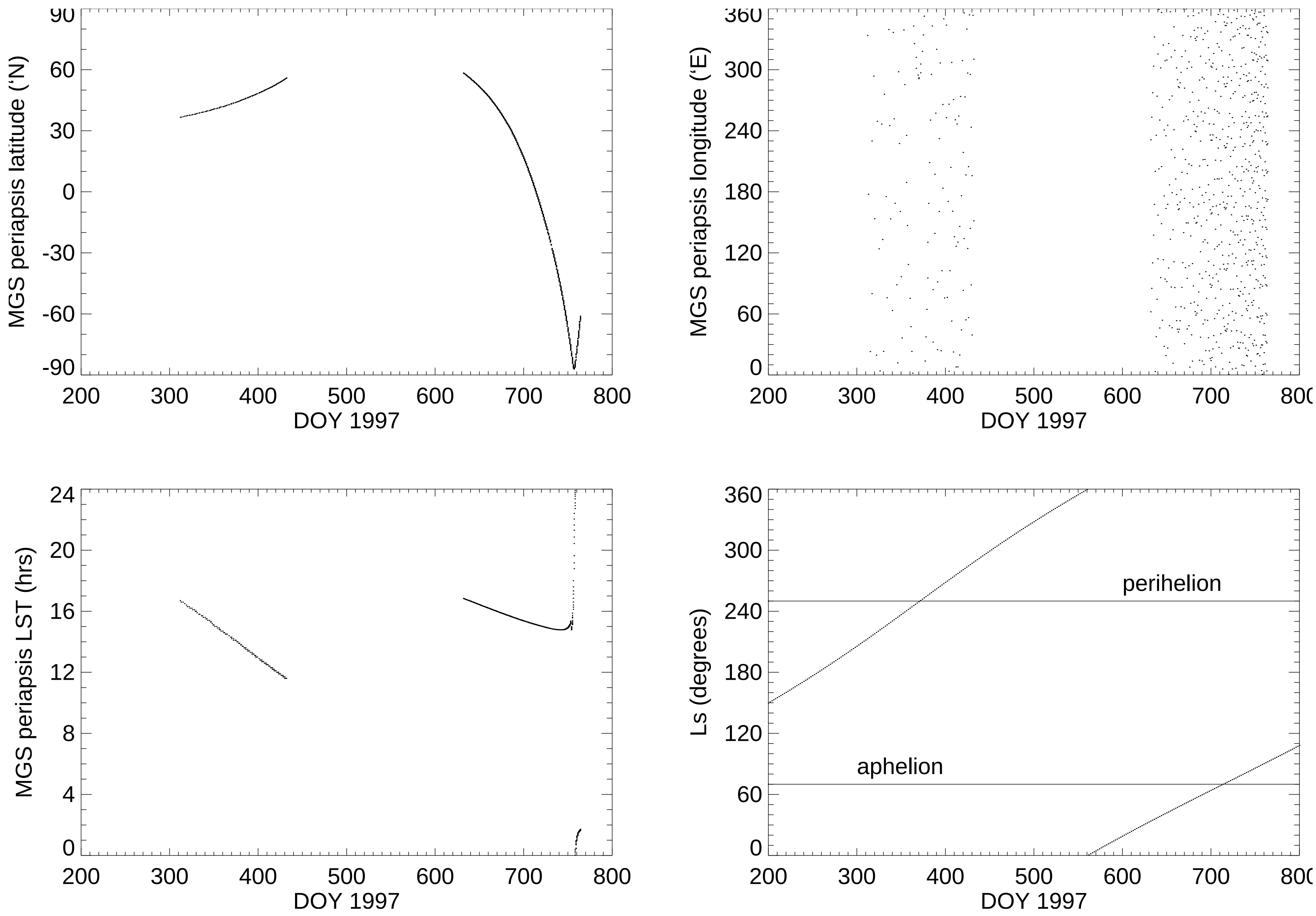
- Meteorites, Boynton
- Volcanology, Kring
- Outer Planets, Hubbard

Research

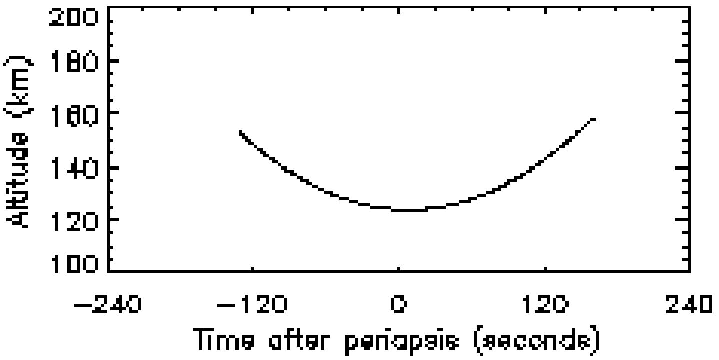
- Martian upper atmosphere (main)
- Recent lunar impact (backup)
- Ridges on Mars - summer with MOLA
- Simple climate models - Ralph’s entropy ideas

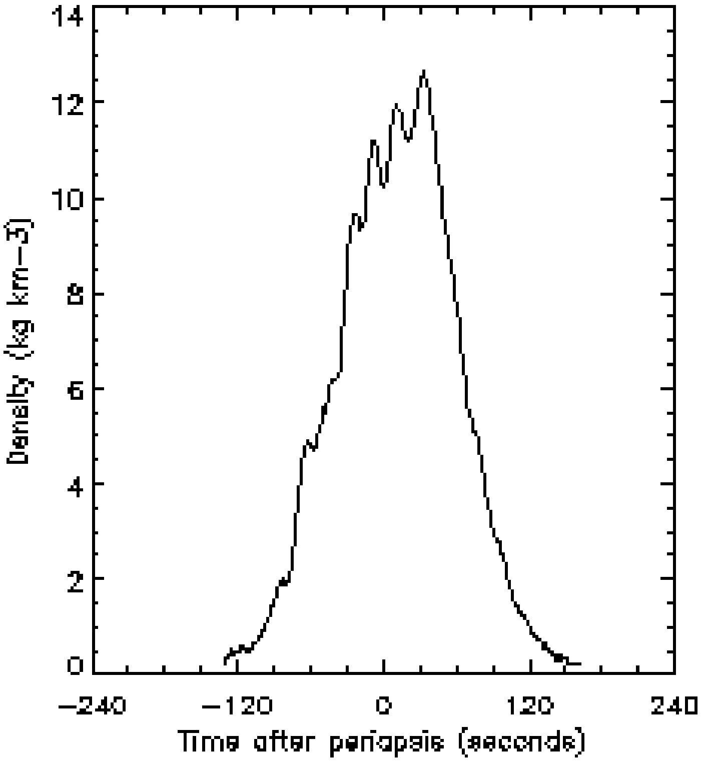
- 1 conference talk, 2 conference posters
- Recent lunar impact paper about to be accepted by Meteoritics
- Coauthor on a few papers currently under review or in press
- Coauthor on a few conference presentations

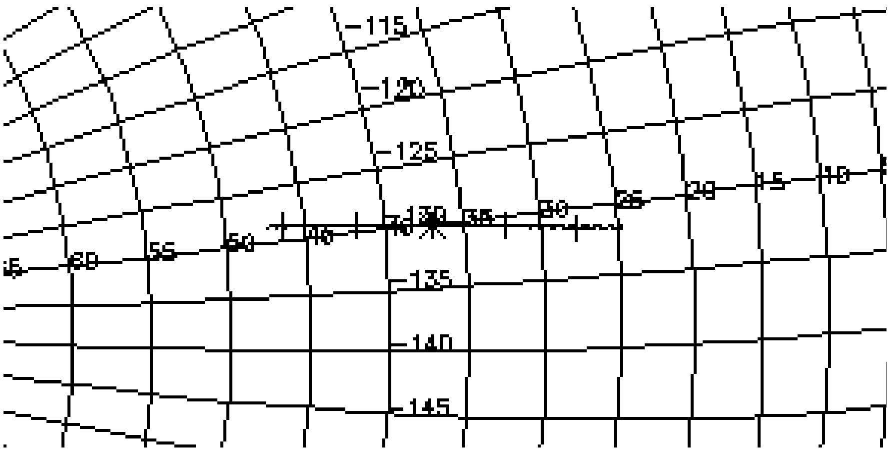

MGS Period During Aerobraking
MGS period (hrs)
0
10
20
30
40
300
400
500
600
700
800
DOY 1997



MGS periapsis latitude ('N)
90
60
30
0
-30
-60
-90
200
300
400
500
600
700
800
DOY 1997
MGS periapsis longitude ('E)
360
300
240
180
120
60
0
DOY 1997
MGS periapsis LST (hrs)
24
20
16
12
8
4
0
DOY 1997
Ls (degrees)
perihelion
aphelion
DOY 1997


Altitude (km)
200
180
160
140
120
100
−240
−120
0
120
240
Time after periapsis (seconds)


Density (kg km−3)
14
12
10
8
6
4
2
0
−240
−120
0
120
240
Time after periapsis (seconds)


−115
−120
−125
−135
−140
−145
60
55
50
25
20
15
10

Accelerometer

$$\mathbf{a}_{\mathbf{meas}} = \mathbf{a}_{\mathbf{bias}} + \mathbf{a}_{\mathbf{aero}} + \mathbf{a}_{\mathbf{grav}} + \mathbf{a}_{\mathbf{ACS}}$$
$$+ \omega \times (\omega \times \mathbf{r}) + \omega \times \dot{\mathbf{r}} + \mathbf{a}_{\mathbf{panel}}$$

a_{meas} = instrument output

a_{bias} = instrument bias

a_{aero} = aerodynamic drag forces

a_{grav} = gravitational gradient between instrument and spacecraft centre of mass

a_{ACS} = Attitude Control System, thrusters

$\omega \times (\omega \times \mathbf{r}) + \omega \times \dot{\mathbf{r}}$ = angular motion of instrument about centre of mass

a_{panel} = translation of instrument due to solar panel vibration

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Results of the Mars Pathfinder atmospheric structure investigation

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Atmospheric density ρ is related to the aerodynamic deceleration of a spacecraft through the aerodynamic drag equation:

$$\rho = -\frac{2m}{C_D A}\frac{a_v}{V_R^2} \qquad (1)$$

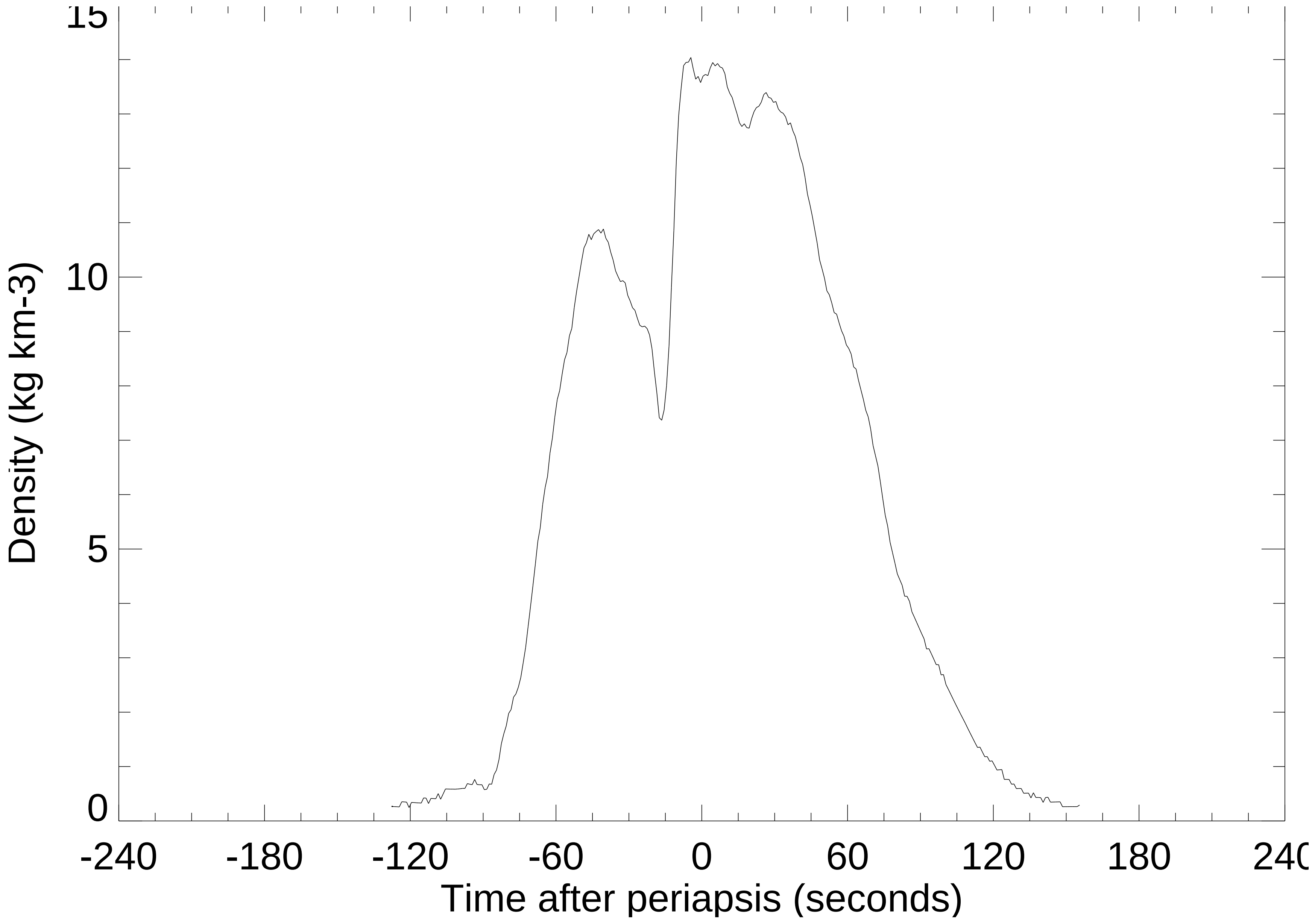
Atmospheric pressure p is then derived from the density by integrating the equation of hydrostatic equilibrium, and the atmospheric temperature T is determined from the ideal gas law with knowledge of the mean molecular weight μ as in the following equations:

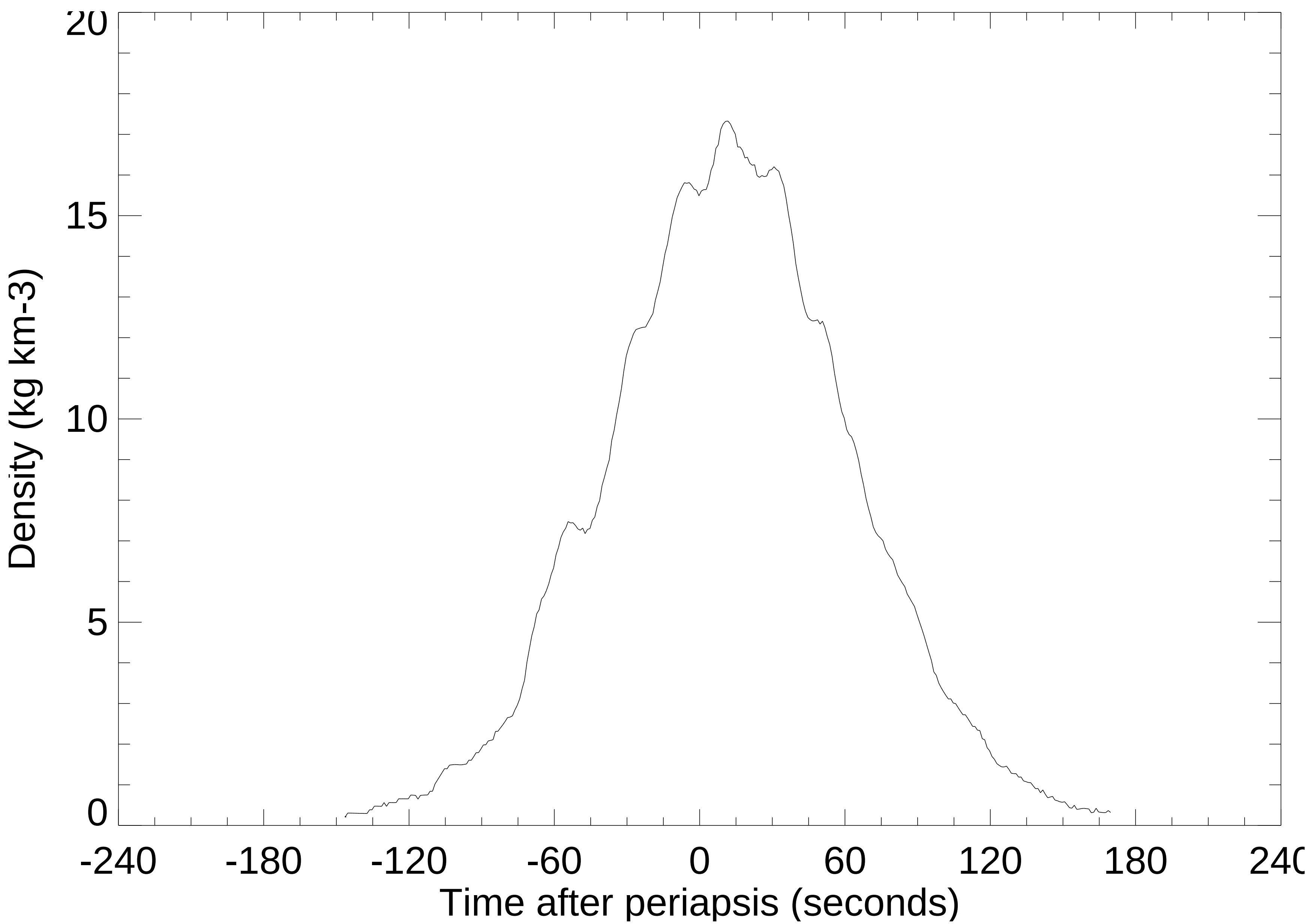
$$p(z) = -\rho(z_0)\,g\left(\frac{d}{dz}\ln\rho\right)^{-1}_{z_0} - \int_{z_0}^{z}\rho g\,dz \qquad (2)$$

$$T(z) = \frac{p(z)\mu(z)}{\rho(z)R_U} \qquad (3)$$

Known anomalies

- Nearly instantaneous changes in acceleration
- Excessive solar panel vibration
- Other oscillatory variations

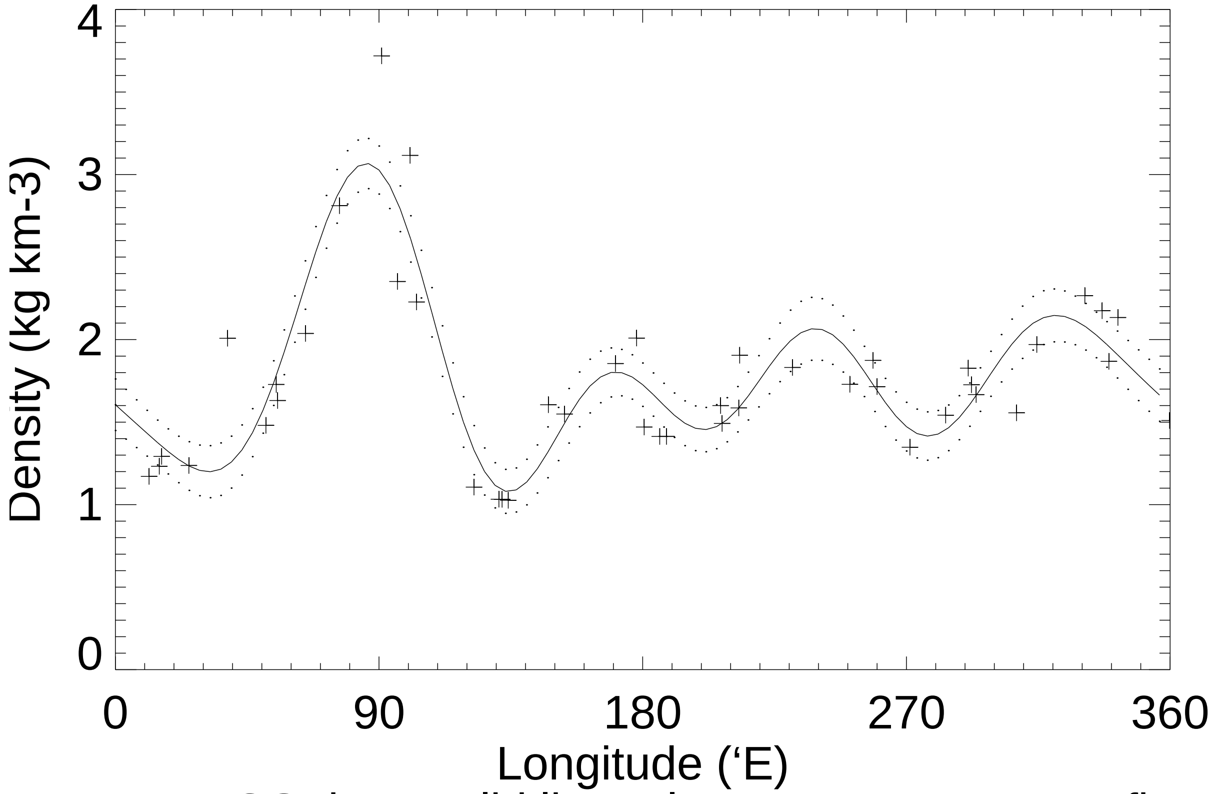

15
10
5
0
-240
-180
-120
-60
0
60
120
180
240
Density (kg km-3)
Time after periapsis (seconds)


Density (kg km-3)
0
5
10
15
20
-240
-180
-120
-60
0
60
120
180
240
Time after periapsis (seconds)

Derived p, T

- $\rho=\rho_0 \exp(-z/H)$
- $H=mg/kT$
- $p = \rho kT/m$
- Assumes hydrostatic eqm and constant temperature over a rather large region.
- Will say nothing more about p, T.

Wave-5 fit to inbound densities at 130km
Phase 2, 10 to 20 ‘N, 40 second data, daytime



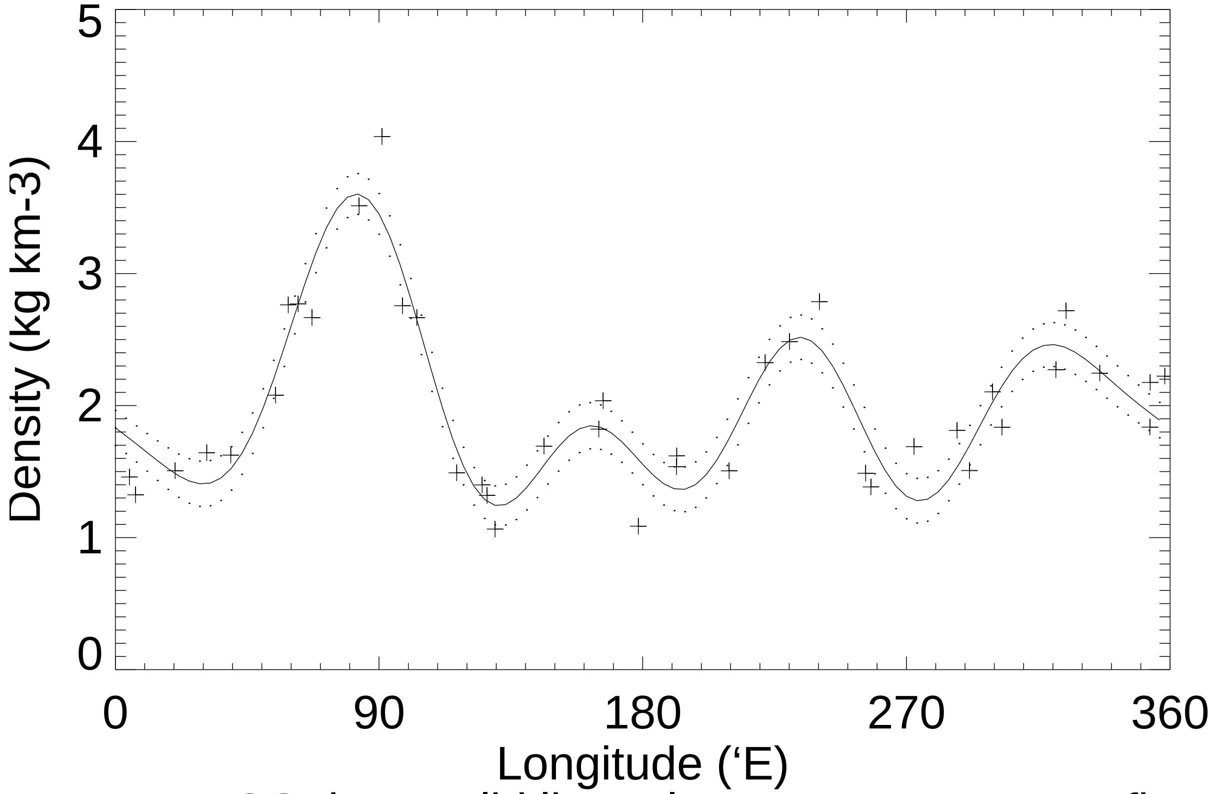
+ = MGS data, solid line = least squares wave-5 fit,
dotted lines = 1 sigma uncertainty in fit

Mean density	=	1.786 * (1 +/- 0.001)
Normalized Wave 1 amplitude	=	0.074 * (1 +/- 0.030)
Normalized Wave 2 amplitude	=	0.164 * (1 +/- 0.013)
Normalized Wave 3 amplitude	=	0.246 * (1 +/- 0.009)
Normalized Wave 4 amplitude	=	0.161 * (1 +/- 0.015)
Normalized Wave 5 amplitude	=	0.131 * (1 +/- 0.019)
Wave 1 phase	=	60.963 * (1 +/- 0.027)
Wave 2 phase	=	88.438 * (1 +/- 0.004)
Wave 3 phase	=	86.376 * (1 +/- 0.002)
Wave 4 phase	=	76.638 * (1 +/- 0.003)
Wave 5 phase	=	20.088 * (1 +/- 0.011)

Statistics neglects errors in the data

Wave phases are first maximum east of 0‘E

Wave-5 fit to outbound densities at 130km
Phase 2, 10 to 20 ‘N, 40 second data, daytime

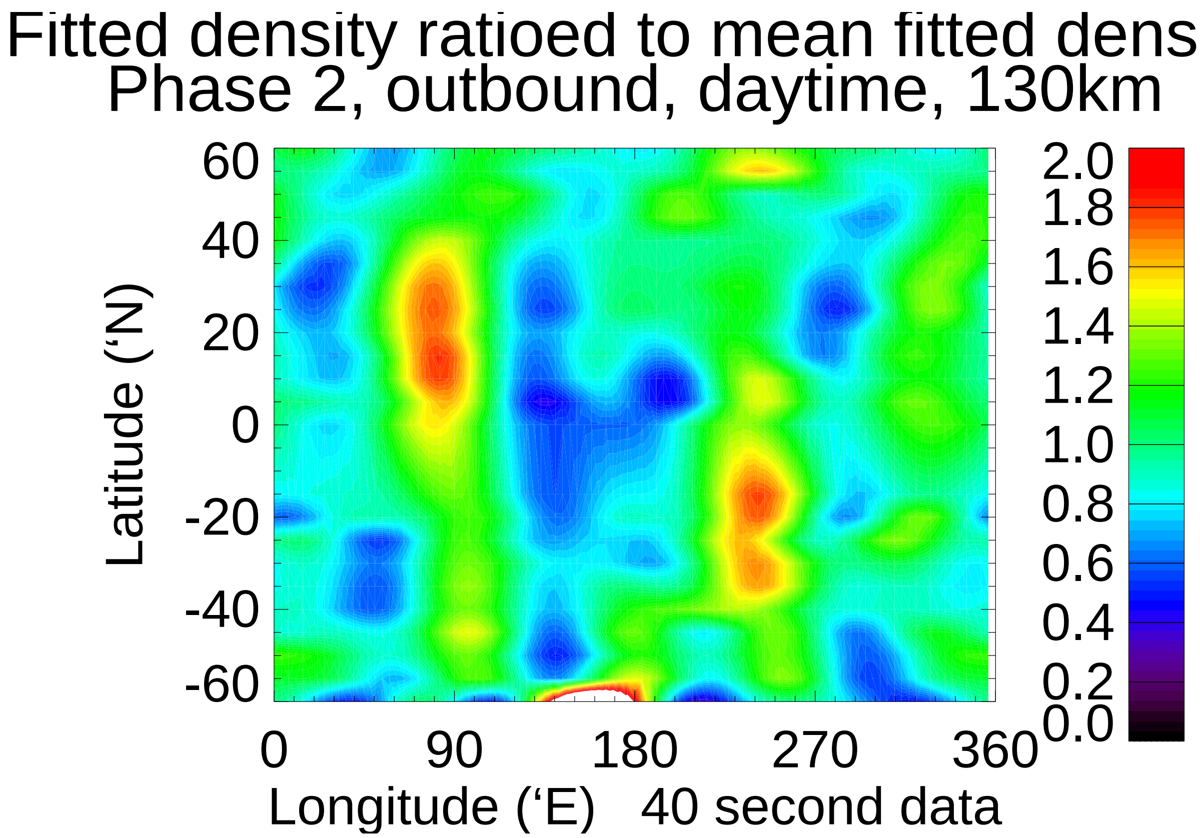


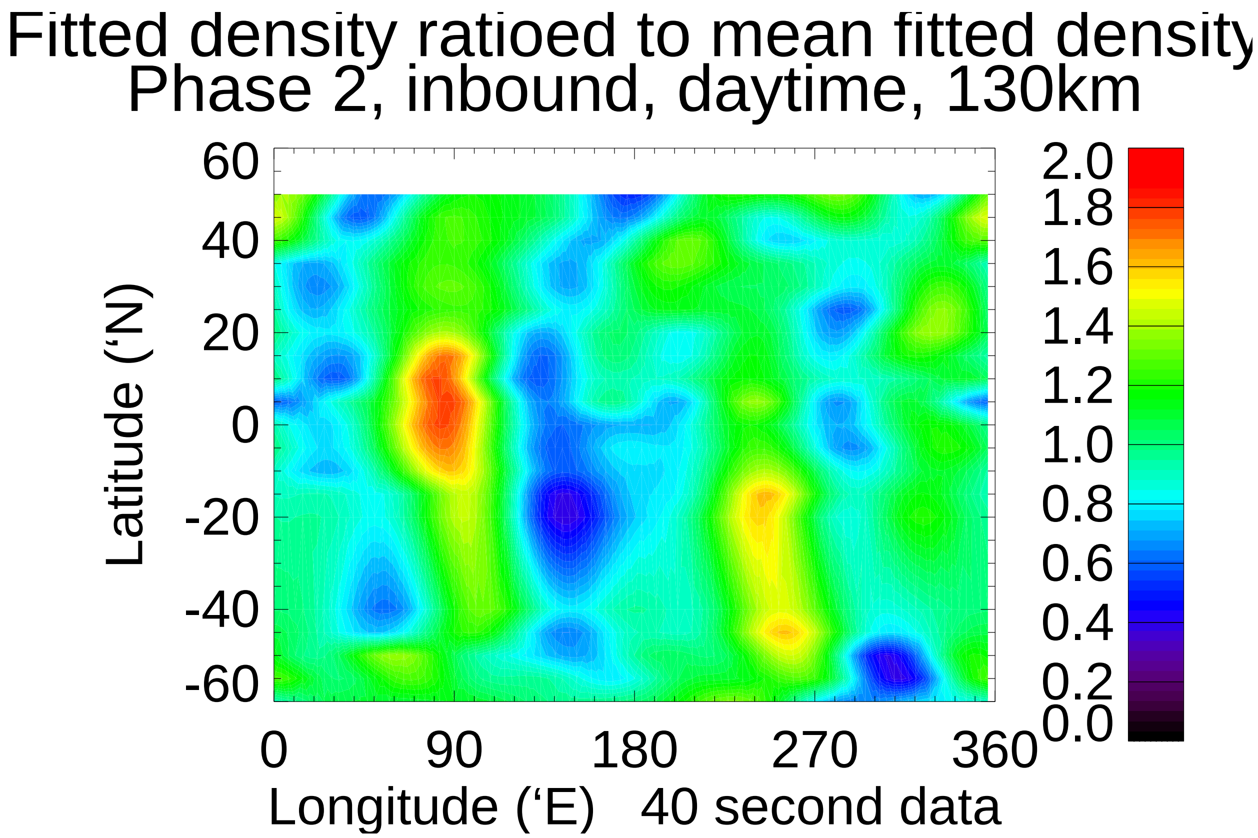
+ = MGS data, solid line = least squares wave-5 fit,
dotted lines = 1 sigma uncertainty in fit

Mean density	=	1.995 * (1 +/- 0.001)
Normalized Wave 1 amplitude	=	0.130 * (1 +/- 0.018)
Normalized Wave 2 amplitude	=	0.179 * (1 +/- 0.013)
Normalized Wave 3 amplitude	=	0.271 * (1 +/- 0.010)
Normalized Wave 4 amplitude	=	0.172 * (1 +/- 0.014)
Normalized Wave 5 amplitude	=	0.165 * (1 +/- 0.014)
Wave 1 phase	=	53.042 * (1 +/- 0.019)
Wave 2 phase	=	82.208 * (1 +/- 0.005)
Wave 3 phase	=	87.354 * (1 +/- 0.002)
Wave 4 phase	=	69.309 * (1 +/- 0.003)
Wave 5 phase	=	16.046 * (1 +/- 0.010)

Statistics neglects errors in the data

Wave phases are first maximum east of 0‘E


Fitted density ratioed to mean fitted density
Phase 2, outbound, daytime, 130km
Latitude ('N)
60
40
20
0
-20
-40
-60
0
90
180
270
360
Longitude ('E)
40 second data
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0


Fitted density ratioed to mean fitted density
Phase 2, inbound, daytime, 130km
Latitude ('N)
60
40
20
0
-20
-40
-60
0
90
180
270
360
Longitude ('E)   40 second data
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0

Possible Studies

- Obtain wave amplitudes and phases as a function of latitude, LST, Ls, and altitude.
- Compare with topography, thermal inertia, albedo, …
- Coupled MGCM-MTGCM runs.
- RS electron density peak, RS lower atmosphere profiles, TES non-sunsynchronous lower atmosphere profiles, TES sunsynchronous lower atmosphere profiles, MHSA, mapping orbit perturbations.
- Dust storms, solar flares.
- Structure in individual profiles.
- Orbit-rotation resonance gives repeat coverage, study intrinsic atmospheric variability.

Tidal theory

- Conservation of mass, momentum, and energy plus ideal gas law.
- Some reasonable assumptions
- Some unreasonable assumptions
- Linearise
- $X = X^{\sigma, s}(\theta, z) \exp i(\sigma t + s\phi)$
- θ shape from $\Theta_n^{\sigma, s}$, z shape from $h_n^{\sigma, s}$

Detailed Plan

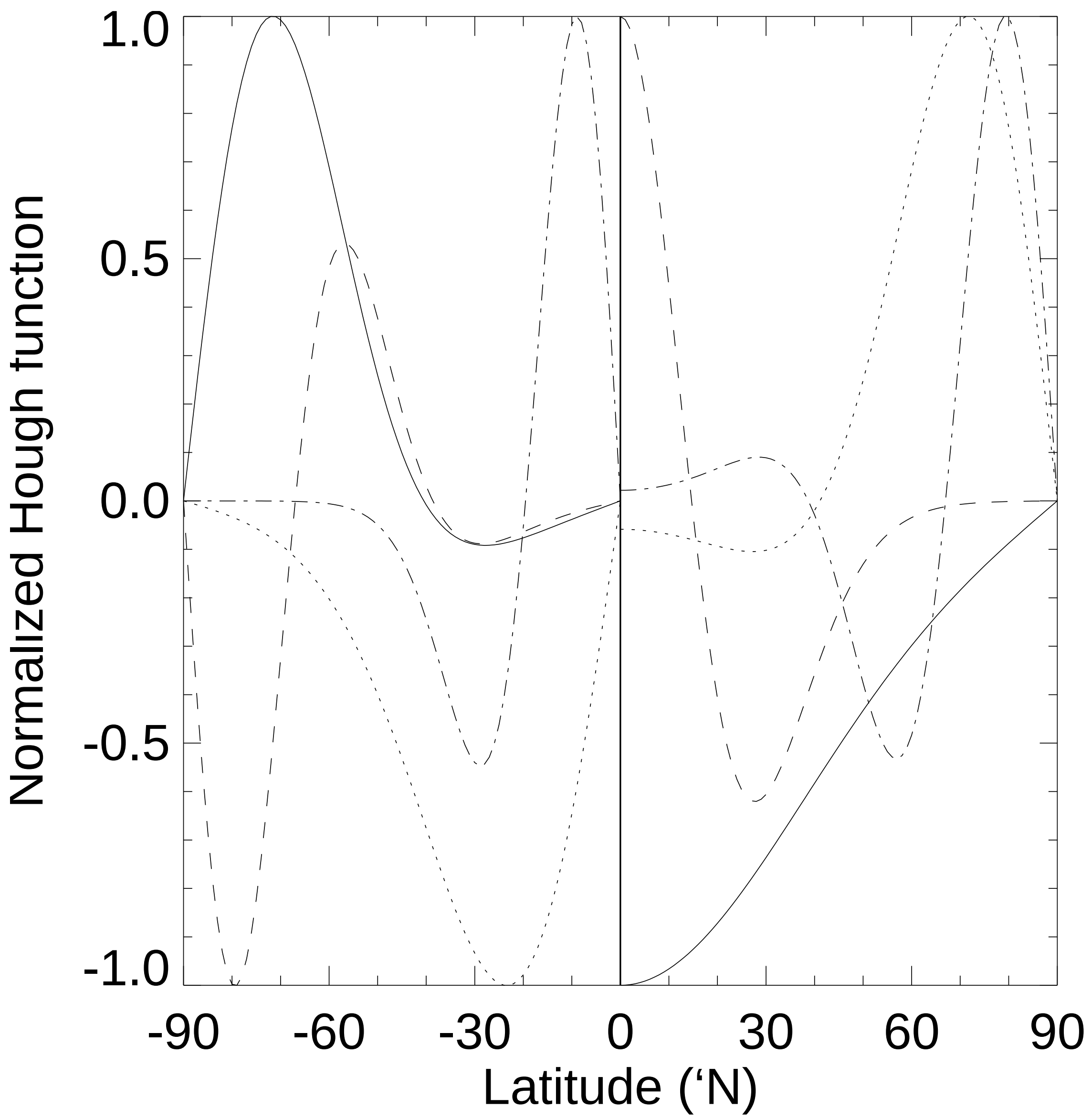
Identify tidal modes that are plausible sources of zonal structure.

1 - Test each $\Theta_n^{\sigma, s}$ for reasonable latitudinal shape and ability to propagate vertically.

2 - Compare day/night data where possible, identifying temporal frequencies.

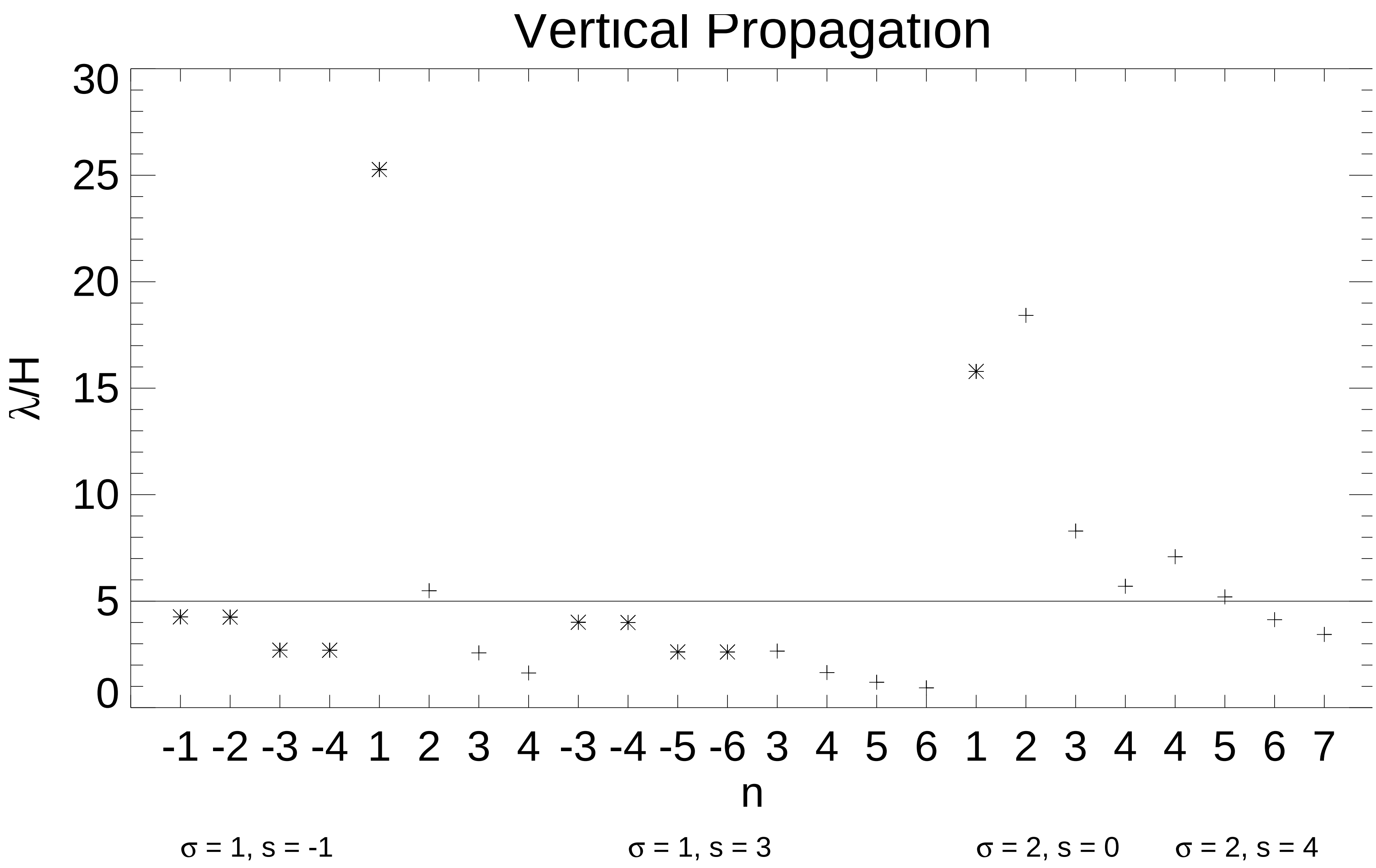
3 - Compare vertical wavelengths in individual profiles to those of each $\Theta_n^{\sigma, s}$.

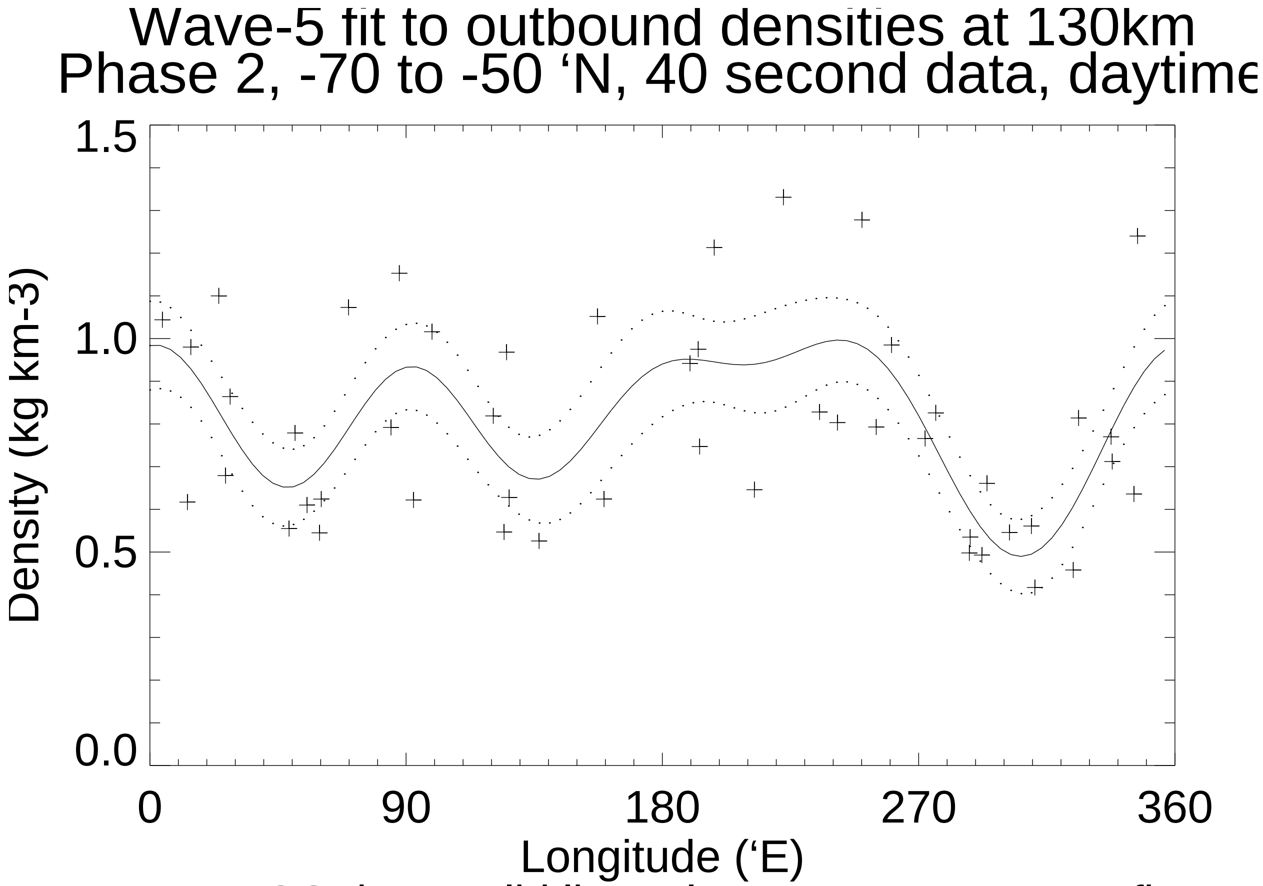
Quantify intrinsic variability at resonances.



σ = 1, s = -1

Asymmetric	Symmetric
n = -1 : Solid	n = 1 : Solid
n = 2 : Dotted	n = -2 : Dotted
n = -3 : Dashed	n = 3 : Dashed
n = 4 : Dot Dash	n = -4 : Dot Dash


Vertical Propagation
λ/H
30
25
20
15
10
5
0
-1 -2 -3 -4 1 2 3 4 -3 -4 -5 -6 3 4 5 6 1 2 3 4 4 5 6 7
n
σ = 1, s = -1
σ = 1, s = 3
σ = 2, s = 0
σ = 2, s = 4



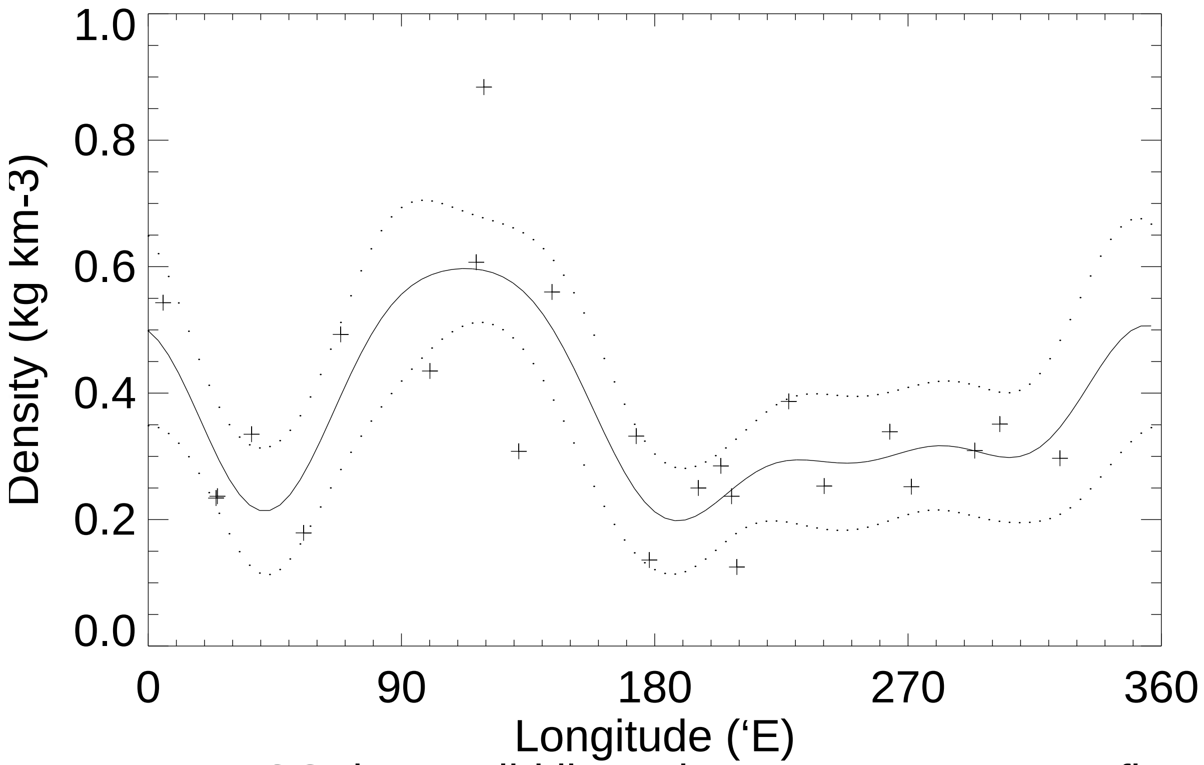
+ = MGS data, solid line = least squares wave-5 fit,
dotted lines = 1 sigma uncertainty in fit

Mean density	= 0.811 * (1 +/- 0.001)
Normalized Wave 1 amplitude	= 0.087 * (1 +/- 0.028)
Normalized Wave 2 amplitude	= 0.142 * (1 +/- 0.016)
Normalized Wave 3 amplitude	= 0.129 * (1 +/- 0.017)
Normalized Wave 4 amplitude	= 0.136 * (1 +/- 0.018)
Normalized Wave 5 amplitude	= 0.022 * (1 +/- 0.089)
Wave 1 phase	= 179.533 * (1 +/- 0.008)
Wave 2 phase	= 34.082 * (1 +/- 0.014)
Wave 3 phase	= 112.600 * (1 +/- 0.003)
Wave 4 phase	= 87.092 * (1 +/- 0.003)
Wave 5 phase	= 21.518 * (1 +/- 0.074)

Statistics neglects errors in the data

Wave phases are first maximum east of 0‘E

Wave-5 fit to inbound densities at 130km
Phase 2, -70 to -50 ‘N, 40 second data, nighttime

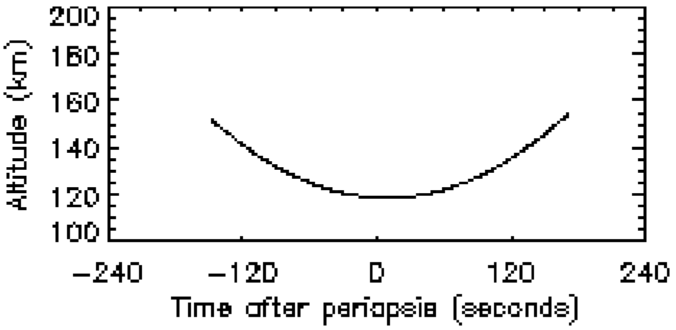


+ = MGS data, solid line = least squares wave-5 fit,
dotted lines = 1 sigma uncertainty in fit

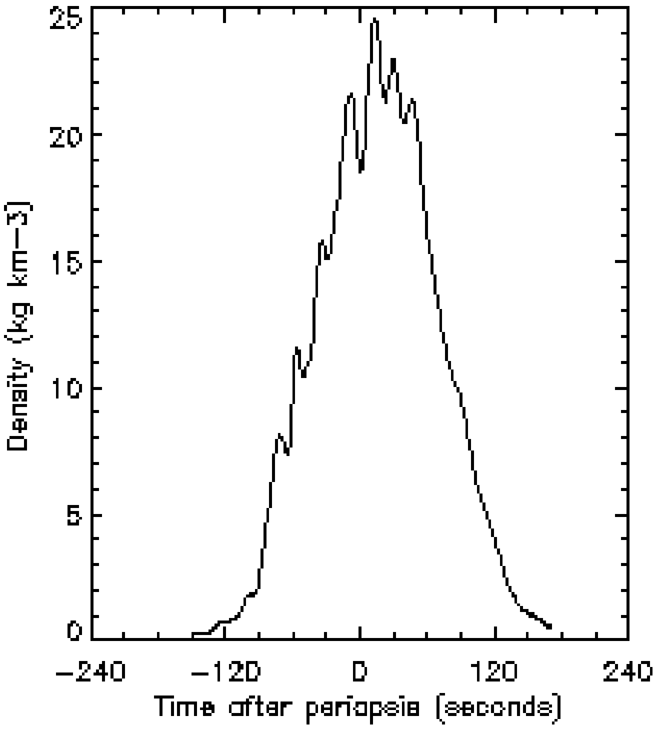
Mean density	=	0.369 * (1 +/- 0.003)
Normalized Wave 1 amplitude	=	0.253 * (1 +/- 0.024)
Normalized Wave 2 amplitude	=	0.262 * (1 +/- 0.021)
Normalized Wave 3 amplitude	=	0.265 * (1 +/- 0.022)
Normalized Wave 4 amplitude	=	0.070 * (1 +/- 0.087)
Normalized Wave 5 amplitude	=	0.095 * (1 +/- 0.059)
Wave 1 phase	=	80.593 * (1 +/- 0.021)
Wave 2 phase	=	123.210 * (1 +/- 0.006)
Wave 3 phase	=	113.963 * (1 +/- 0.004)
Wave 4 phase	=	87.416 * (1 +/- 0.014)
Wave 5 phase	=	0.484 * (1 +/- 1.562)

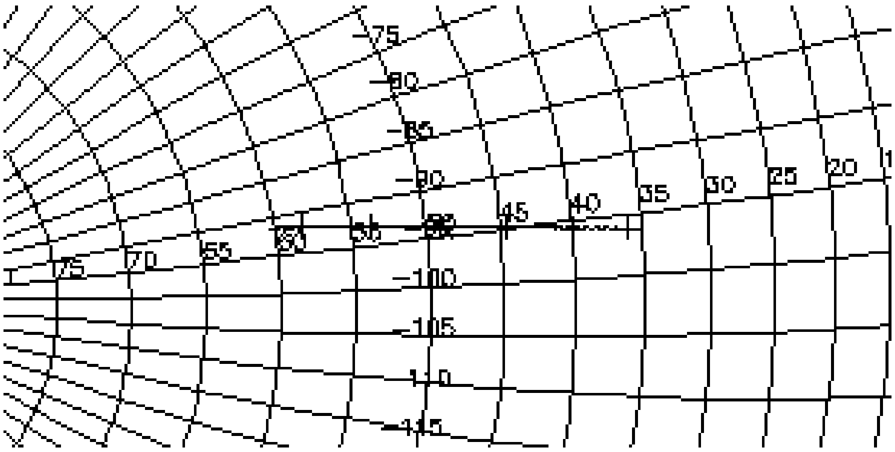
Statistics neglects errors in the data

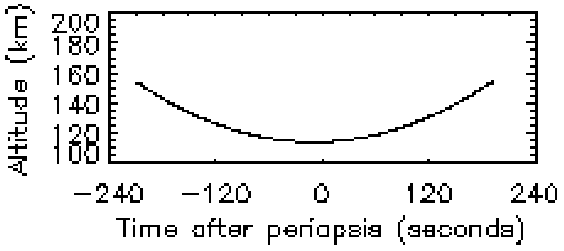
Wave phases are first maximum east of 0‘E



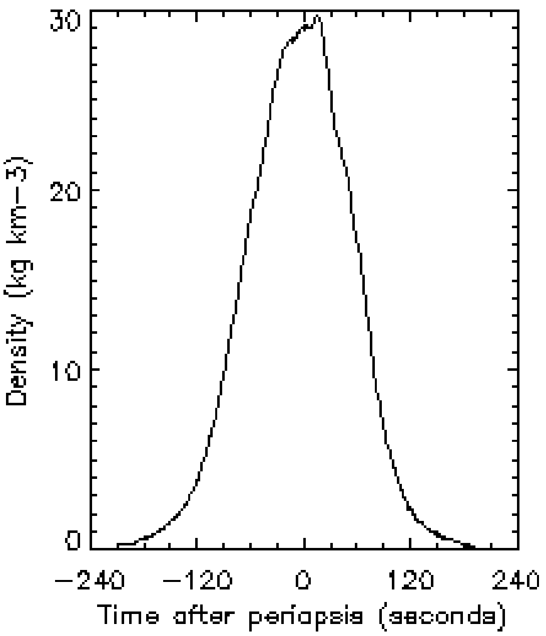
P122, wiggles

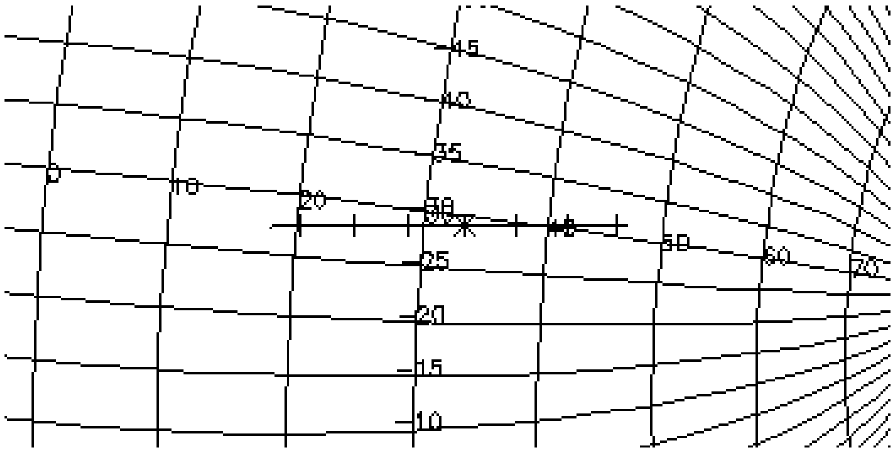


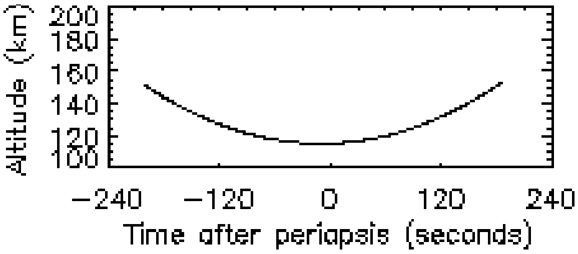



Altitude (km)
200
180
160
140
120
100
−240
−120
0
120
240
Time after periapsis (seconds)

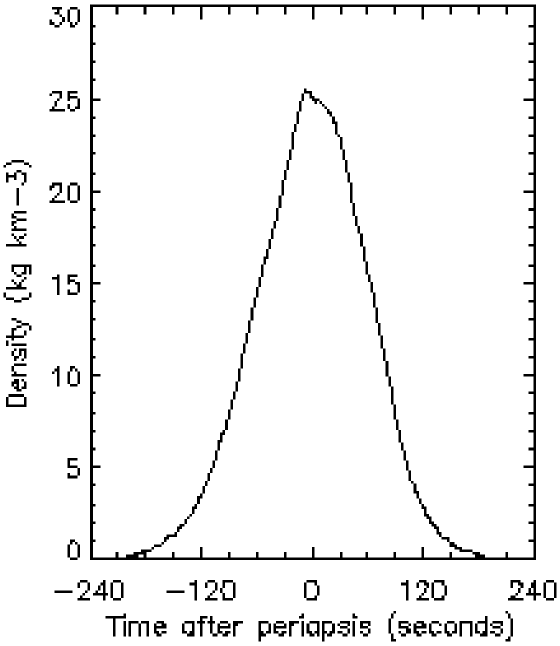
P714, 4:1

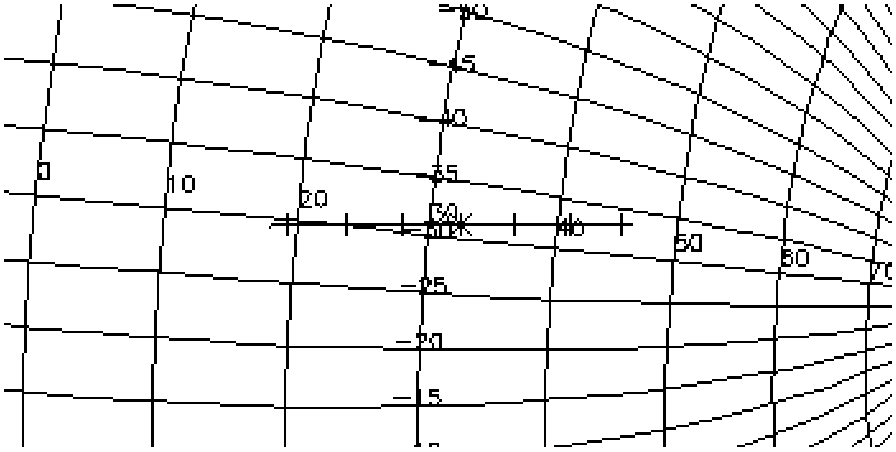

Density (kg km−3)
30
20
10
0
−240
−120
0
120
240
Time after periapsis (seconds)

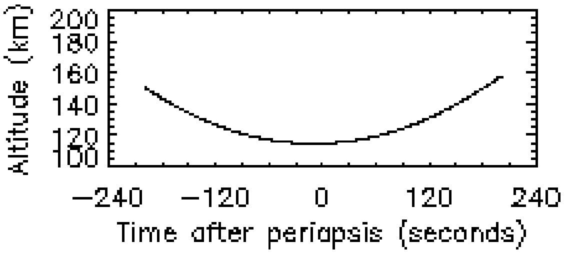



Altitude (km)
200
180
160
140
120
100
−240
−120
0
120
240
Time after periapsis (seconds)

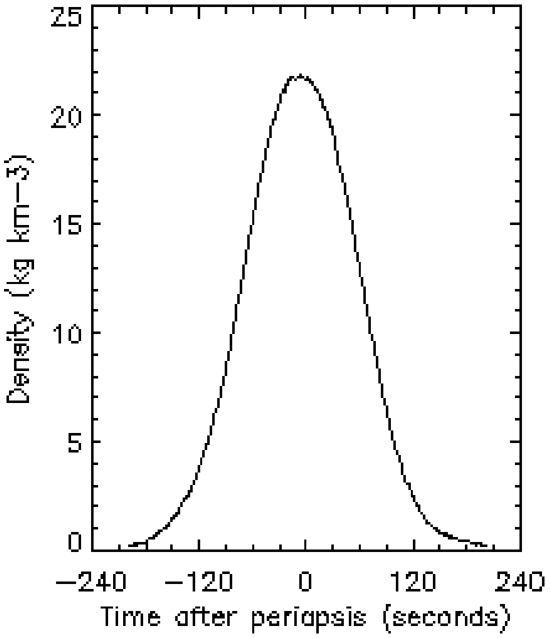
P718, 4:1

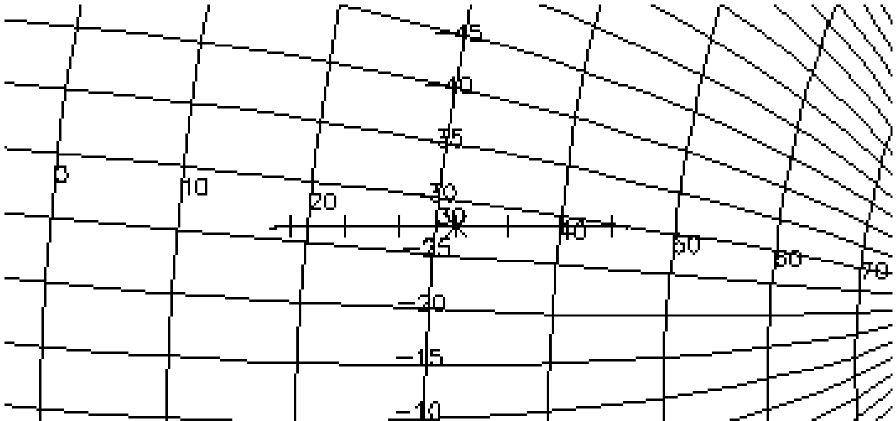

Density (kg km−3)
30
25
20
15
10
5
0
−240
−120
0
120
240
Time after periapsis (seconds)


−45
−40
−35
0
10
20
40
50
60
−25
−20
−15


Altitude (km)
200
180
160
140
120
100
−240
−120
0
120
240
Time after periapsis (seconds)

P722, 4:1


Density (kg km−3)
25
20
15
10
5
0
−240
−120
0
120
240
Time after periapsis (seconds)


−45
−40
−35
−30
−25
−20
−15
−10
0
10
20
30
40
50
60
70