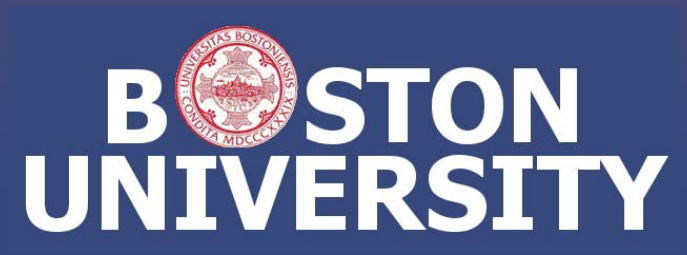
Ionospheric Layers of Mars and Earth

Michael Mendillo



ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Planetary and Space Science ▮▮▮ (▮▮▮▮) ▮▮▮–▮▮▮

Planetary and Space Science

www.elsevier.com/locate/pss

Short communication

Ionospheric layers of Mars and Earth

Henry Rishbeth[a,b,*], Michael Mendillo[a]

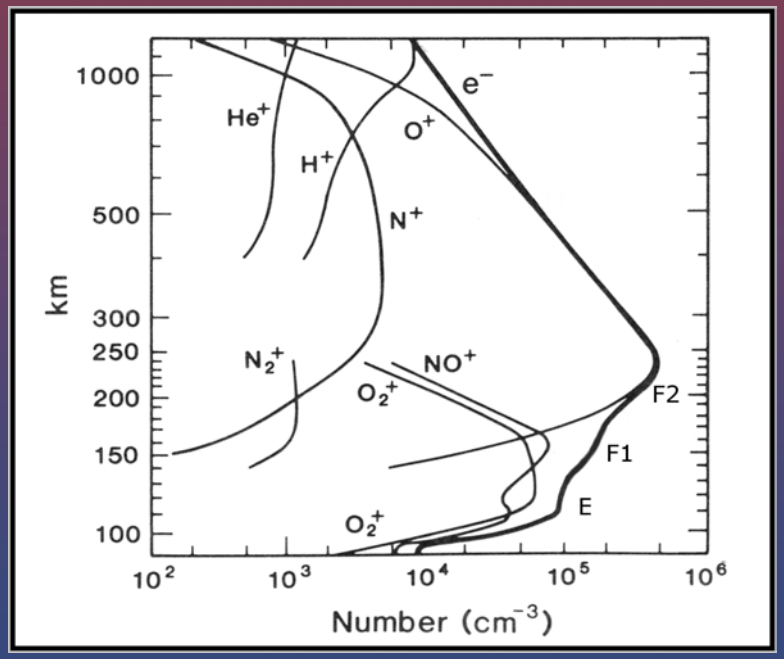
[a] Center for Space Physics, Boston University, Boston, MA 02215, USA

[b] Department of Physics and Astronomy, School of Physics and Astronomy, University of Southampton, Highfield, Southampton, Hampshire SO17 1BJ, UK

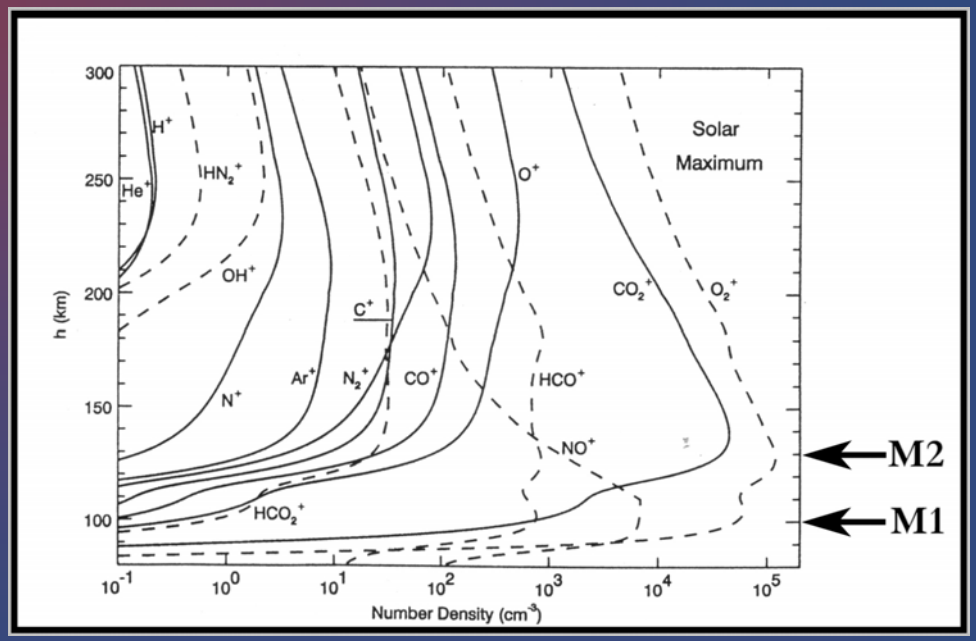
Received 11 September 2003; received in revised form 24 February 2004; accepted 24 February 2004

EARTH

MARS



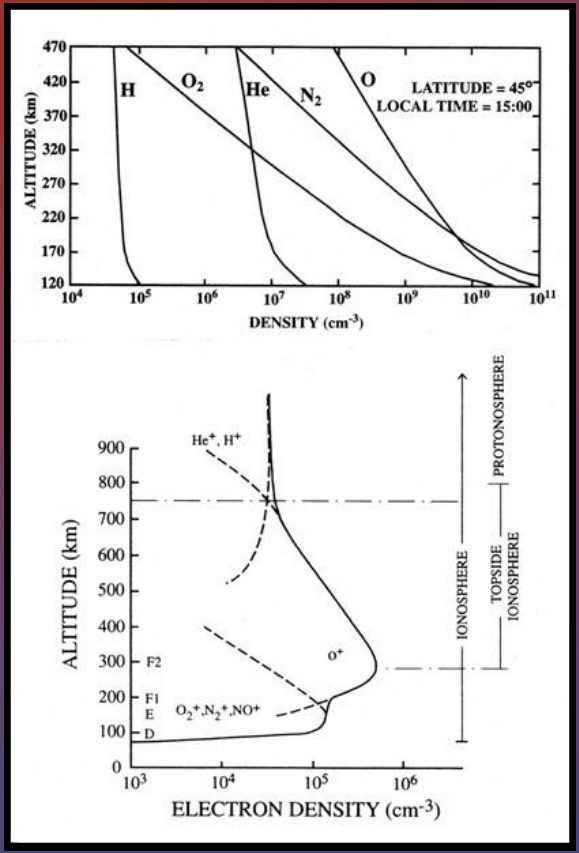
(after Johnson, 1969)



From Krashopolsky, JGR, 2002

COMPARATIVE ATMOSPHERES/IONOSPHERES*

EARTH



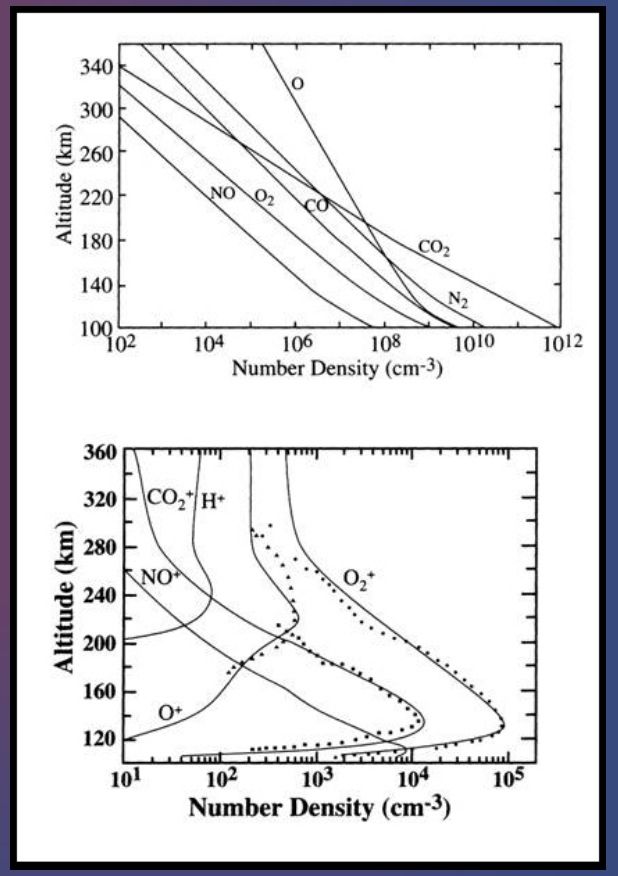
E-Region

$h_mE \approx 110$ km

$[N_2] \approx$ few x10^{11} cm^{-3}

$[\ e^-\ ] \approx 10^5$ cm^{-3}

MARS



Maximum

$h_mM_2 \approx 135$ km

$[CO_2] \approx 10^{11}$ cm^{-3}

$[\ e^-\ ] \approx 10^5$ cm^{-3}

* Schunk and Nagy (2000): IONOSPHERES, Physics, Plasma Physics, and Chemistry; Camb. Univ. Press

Photo-Chemical Equilibrium

	EARTH	MARS
Production (P_o) :	$N_2 + h\nu \xrightarrow{k_1} N_2^+ + e^-$	$CO_2 + h\nu \xrightarrow{k_3} CO_2^+ + e^-$
Transformation :	$N_2^+ + O \xrightarrow{k_2} NO^+ + N$	$CO_2^+ + O \xrightarrow{k_4} O_2^+ + CO$
Loss (L):	$NO^+ + e^- \xrightarrow{\alpha_1} N + O$	$O_2^+ + e^- \xrightarrow{\alpha_2} O + O$

For $P_o = L$:

$$P_o = \alpha N_e^2$$

Chapman Theory

$$\left(\frac{\eta S}{eH}\right)\cos\chi = \alpha N\dot{e}^2$$

where

η=ionization efficiency

($\#e^- / cm^3 / h\nu$ absorbed)

S=Solar Ionizing Flux

$= S_1(1AU)/d^2(AU)$

H=Scale Height of ionizable gas

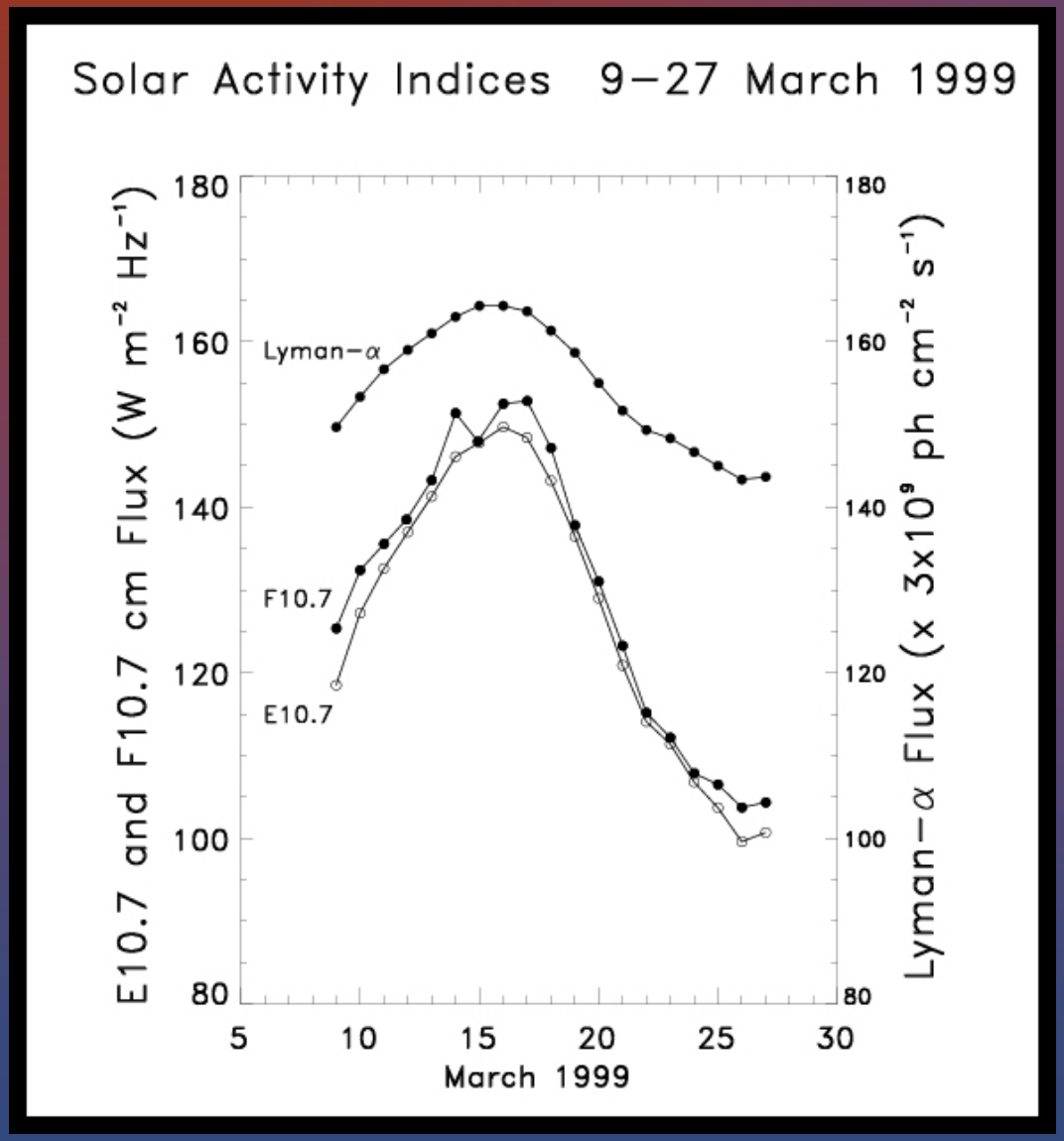
e =2.718...

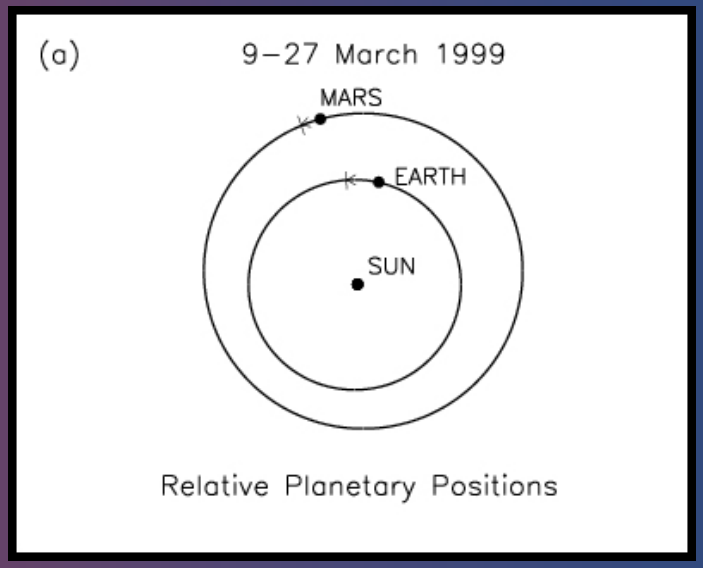
χ = Solar zenith angle

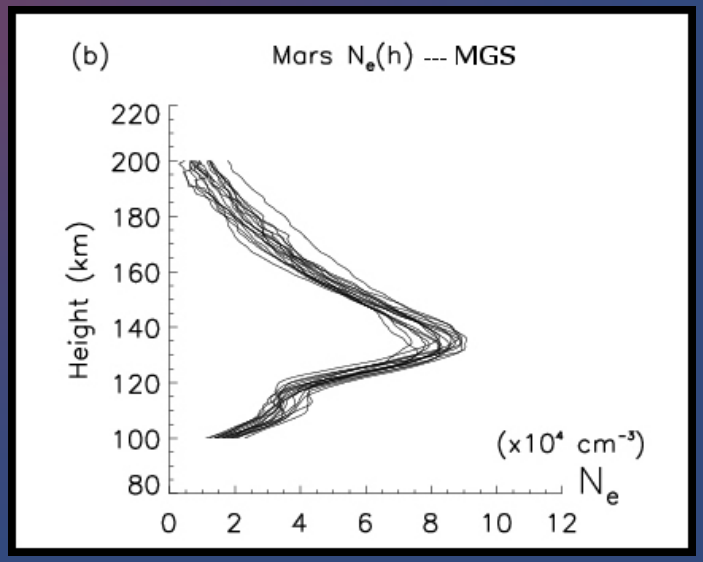
$$\underbrace{\frac{\eta S_1}{e\alpha H}}_{\text{Ionospheric Layer Index}} = \underbrace{N\dot{e}^2\, d^2 \sec\chi}_{\Theta\ (\text{observed})} \quad (\#2)$$

Θ (theory) (#1)

Case Study Period --- Mars near Opposition during a month of pronounced Solar Activity







Ionospheric layer index at six stations for 9-27 March 1999

Station	Geographic Coordinates	Θ (E)	θ (E)	Θ (F1)	θ (F1)
Chilton	52°N,2°W	29 ± 3	0.042	117 ± 9	0.19
Eglin	30°N,87°W	32 ± 6	0.100	133 ± 42	0.15
Ahmedabad	23°N,73°E	24 ± 2	0.106	146 ± 20	0.35
Hobart	43°N,147°E	35 ± 5	0.114	134 ± 2	0.43
Port Stanley	52°N,58°W	29 ± 4	0.080	165 ± 23	0.50
Zhongshan	69°N,76°W	24 ± 6	0.108	120 ± 24	0.89
Average		29 ± 4	0.092	136 ± 24	0.42

Ionospheric layer index Θ for F1, M2, E and M1 layers from Eq. (2) versus solar flux index $E_{10.7}$ in flux units (10^{-22} W m^{-2} Hz^{-1}).

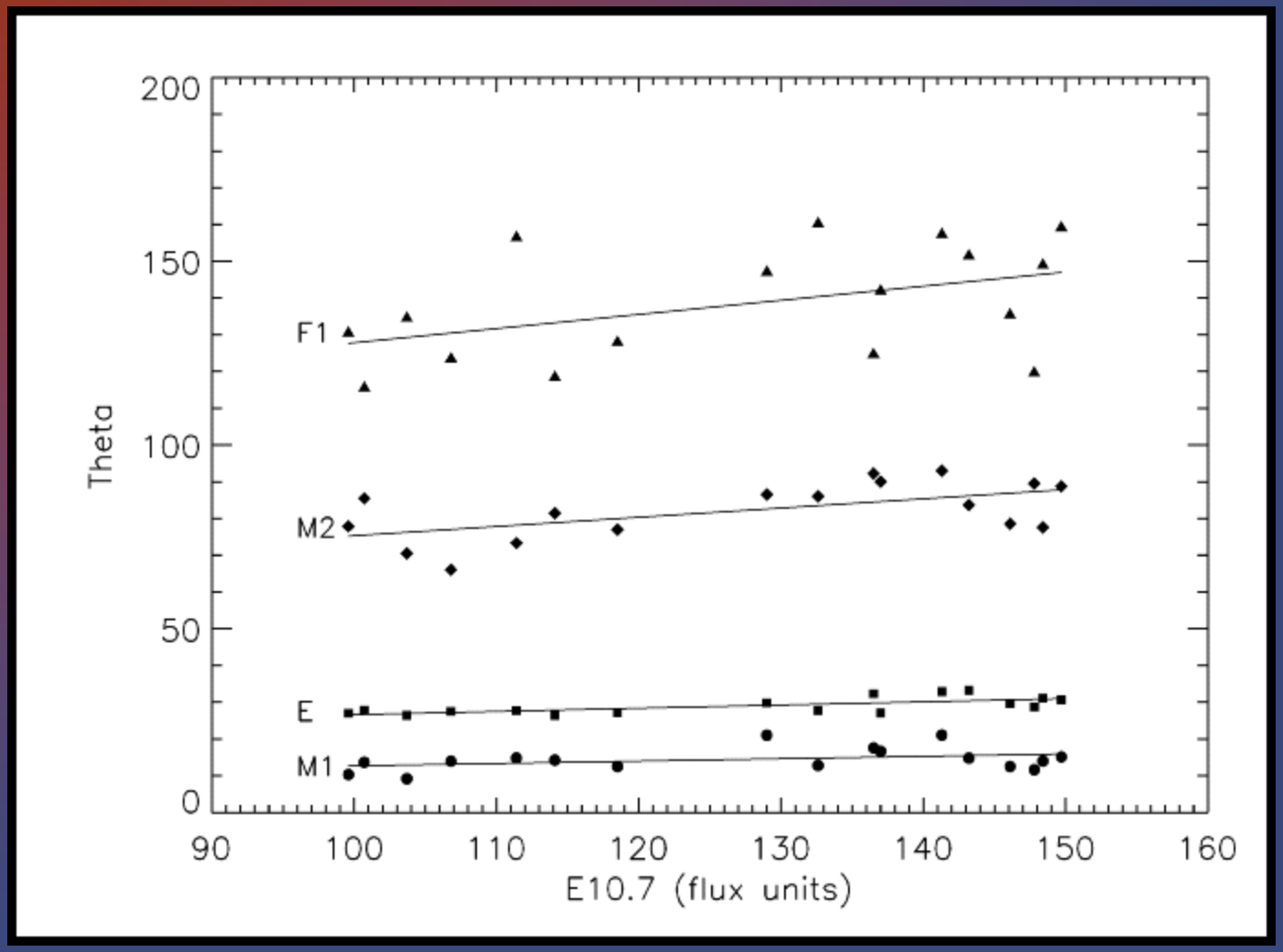


Photo-Chemical Equilibrium

	EARTH	MARS
Production (P_o) :	$N_2 + h\nu \xrightarrow{k_1} N_2^+ + e^-$	$CO_2 + h\nu \xrightarrow{k_3} CO_2^+ + e^-$
Transformation :	$N_2^+ + O \xrightarrow{k_2} NO^+ + N$	$CO_2^+ + O \xrightarrow{k_4} O_2^+ + CO$
Loss (L):	$NO^+ + e^- \xrightarrow{\alpha_1} N + O$	$O_2^+ + e^- \xrightarrow{\alpha_2} O + O$

For $P_o = L$:

$$P_o = \alpha N_e^2$$

Chapman Theory

$$\left(\frac{\eta S}{eH}\right)\cos\chi = \alpha N\dot{e}^2$$

where

η=ionization efficiency

$(\#e^- / cm^3 / h\nu$ absorbed)

S=Solar Ionizing Flux

$= S_1(1AU)/d^2(AU)$

H=Scale Height of ionizable gas

e =2.718...

χ = Solar zenith angle

$$\underbrace{\frac{\eta S_1}{e\alpha H}}_{\text{Ionospheric Layer Index}} = \underbrace{N\dot{e}^2\, d^2 \sec\chi}_{\Theta\ (\text{observed})} \quad (\#2)$$

Θ (theory) (#1)

Mars/Earth comparison of ionospheric layers, showing:

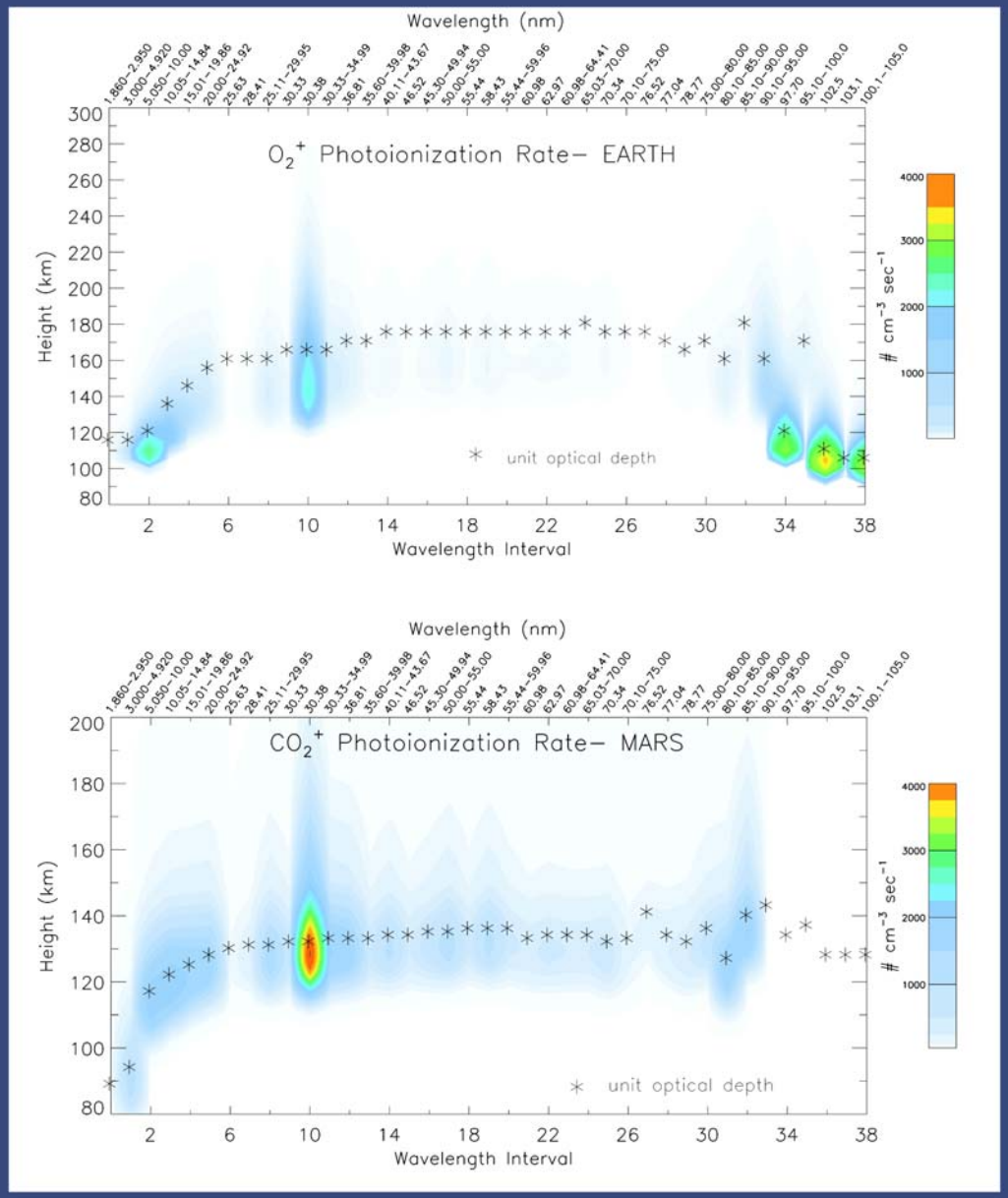
- layer heights h_m
- 'ionospheric layer index' Θ at solar flux $E_{10.7}$ = 125
- slope $\theta = d\Theta/dE_{10.7}$
- correlation coefficient between Θ and E10.7
- scale height H
- atmospheric pressure p at height h_m corrected to overhead sun

Layer	Height (km)	Θ	θ	Correlation	H (km)	$\log_{10}$ p (mb)
F1	170	137 ± 14	0.38	0.45	36	-5.4
M2	134 ± 3	82 ± 6	0.25	0.59	12	-5.8
E	110	29 ± 2	0.087	0.70	10	-4.3
M1	111 ± 3	14 ± 3	0.065	0.37	8	-4.8

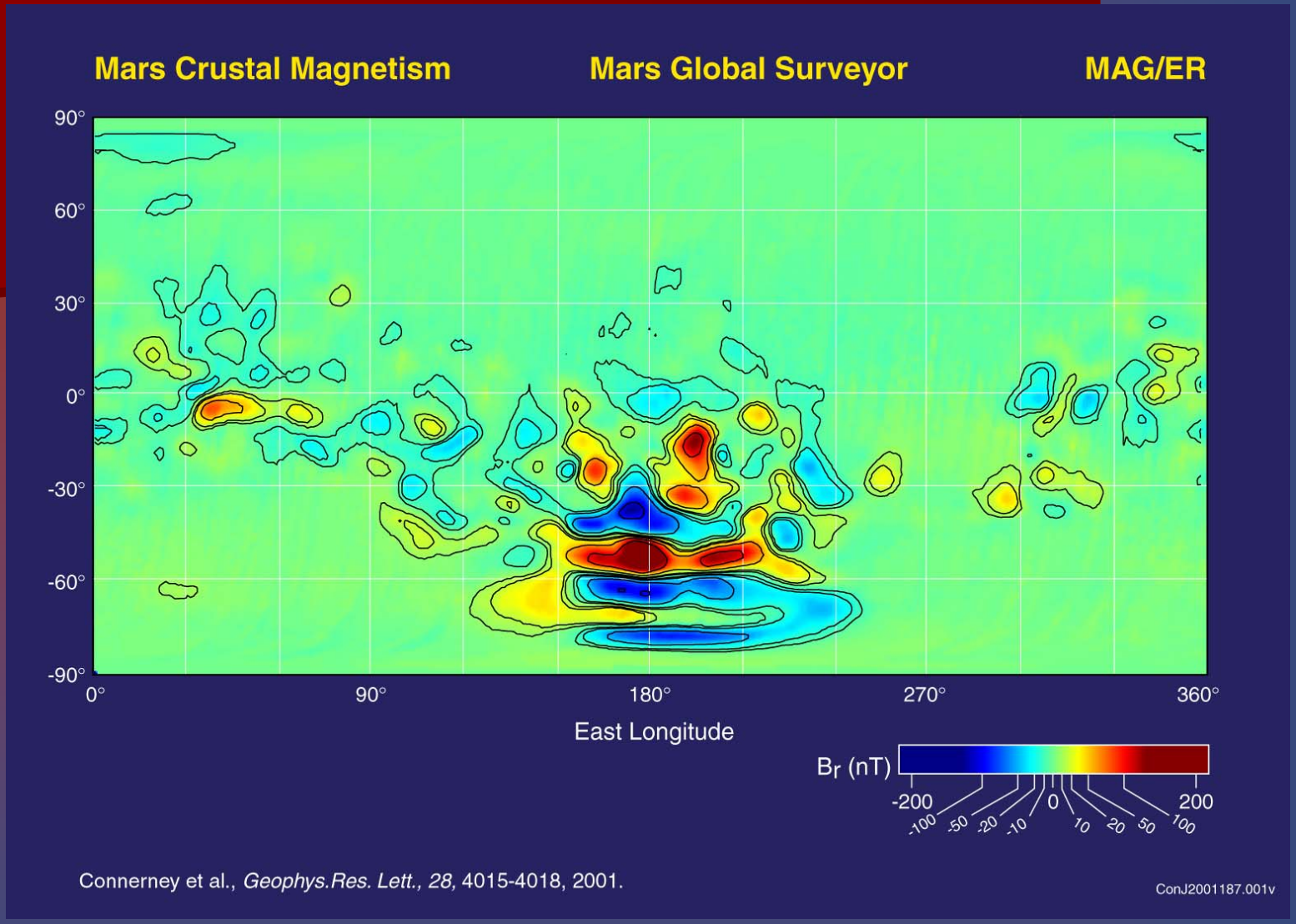
Photo-production vs. λ

EARTH

MARS

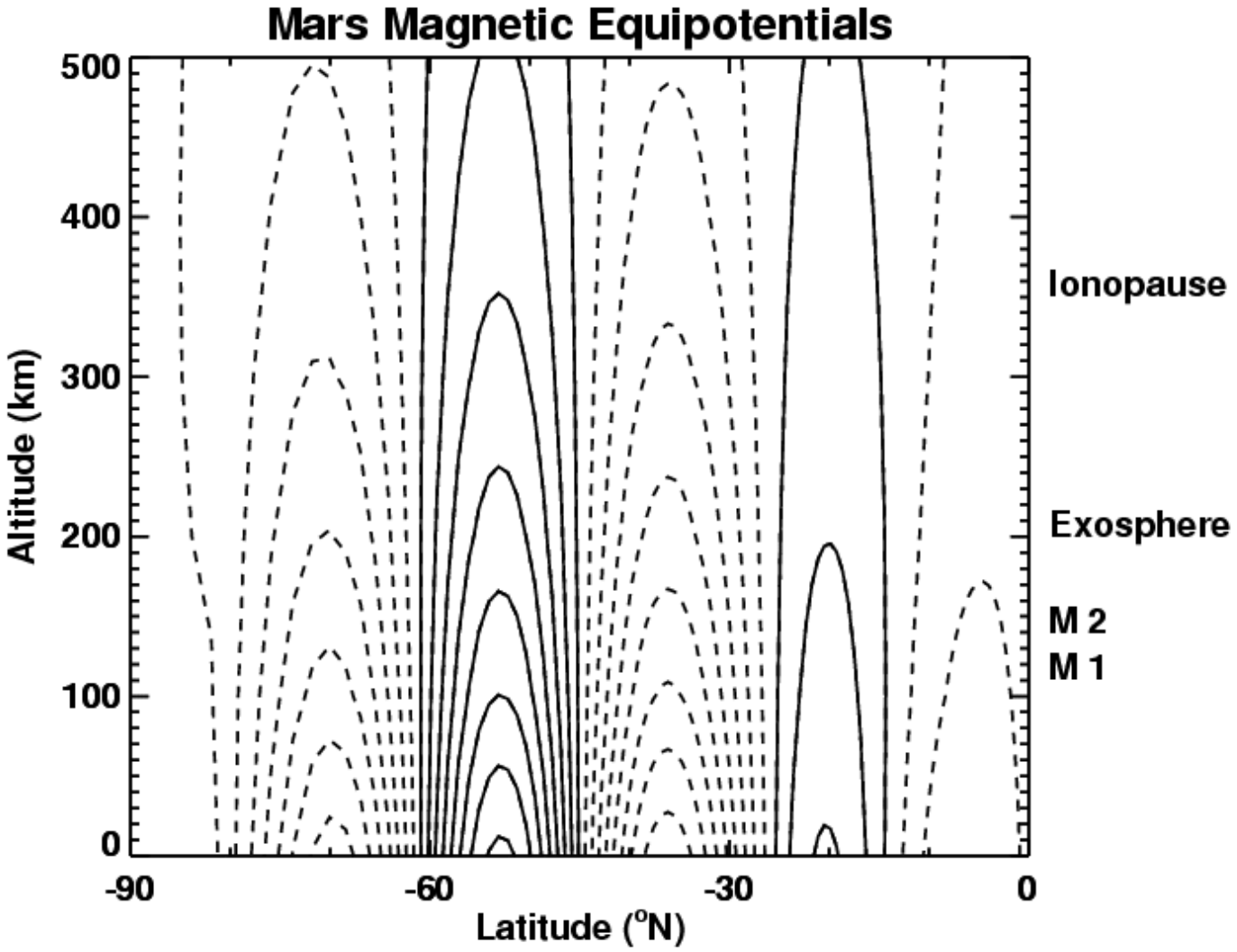


The End



BOSTON UNIVERSITY

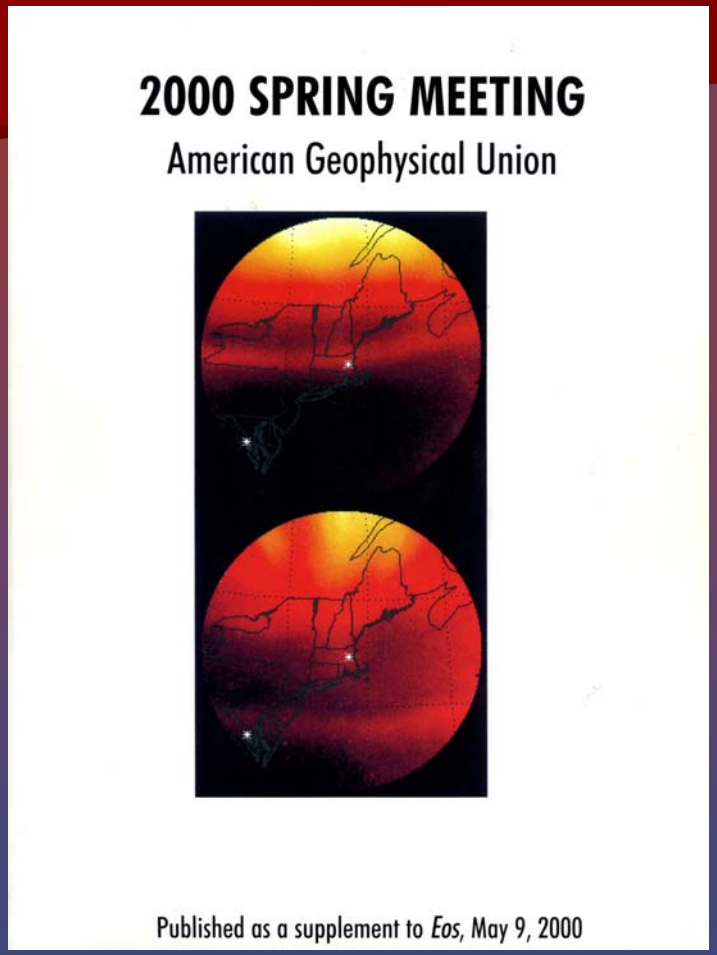
Imaging science



BOSTON UNIVERSITY

Imaging science

Imaging Magnetospheric Boundaries at Ionospheric Heights



- Diffuse Aurora and Stable Auroral Red (SAR) Arcs track Plasma Sheet and Ring Current Movements from L = 4 to L = 2.
- The CEDAR Imager at Millstone Hill -- over a solar cycle of Multi-spectral Imaging at a Sub-Auroral Site

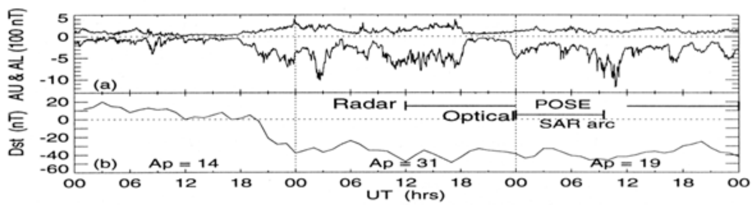
C S P

BOSTON UNIVERSITY

Imaging science

CHAINS-AND-CLUSTERS in AERONOMY
(ISRs-FPIs-ASIs)
--In the decade of the 1990s, one paper was published using data from 3 ISRs, 1 FPI and 1 ASI

PI ET AL.: DYNAMICAL EFFECTS OF GEOMAGNETIC STORMS AND SUBSTORMS 7415



		Local Time Sectors:	← Daytime →		← Nighttime →		
	Geomagnetic Conditions:	Substorm Activity	#1 Recovery	#1 Post-event	#2 Onset	#2 Expansion	Recovery
Electrodynamics	(c) Sondre Stromfjord:	E-meridional:	North	Quiet (N)	South	South with δE(N)	North
		E-zonal:	East	Quiet (E)	West	East δE(E)	
	(d) Millstone Hill	E-zonal:	Pene-tration	Over-shielding	Shielded	Pen. O-S with δE(E)	Quiet (E)
	(e) Arecibo	E-zonal:	Shielded		Shielded	Pen. O-S	Quiet (E)
		E-meridional:	Shielded		Pene-tration	O-S	Quiet
Thermosphere	(f) Millstone Hill	U_m - meridional:	δU_m (south) by ion-drag; L.S.G.W's by auroral activity.		$\delta U_m(S)$ TAD	$\delta U_m(S)$ by Joule heating	
	Arecibo	U_m - meridional:	δU_m (south); L.S.G.W's.		L.S.G.W's	$\delta U_m(N)$ MTM	$\delta U_m(S)$ by iondrag and Joule heating
Ionosphere	(g) Millstone Hill	N(h), TEC:	Minimal Changes		h_mF2 ascent		
	Arecibo	N(h), TEC:	Diurnal double maxima in TEC caused by dynamics		Wave-like Disturb.	h_mF2 Midnight Collapse	

27 October 28 October, 1992

What happened to the dream?