Physics 535 – Lecture 24
Physics of Lightning

Constraints on Charge lowered to ground

3/21/16

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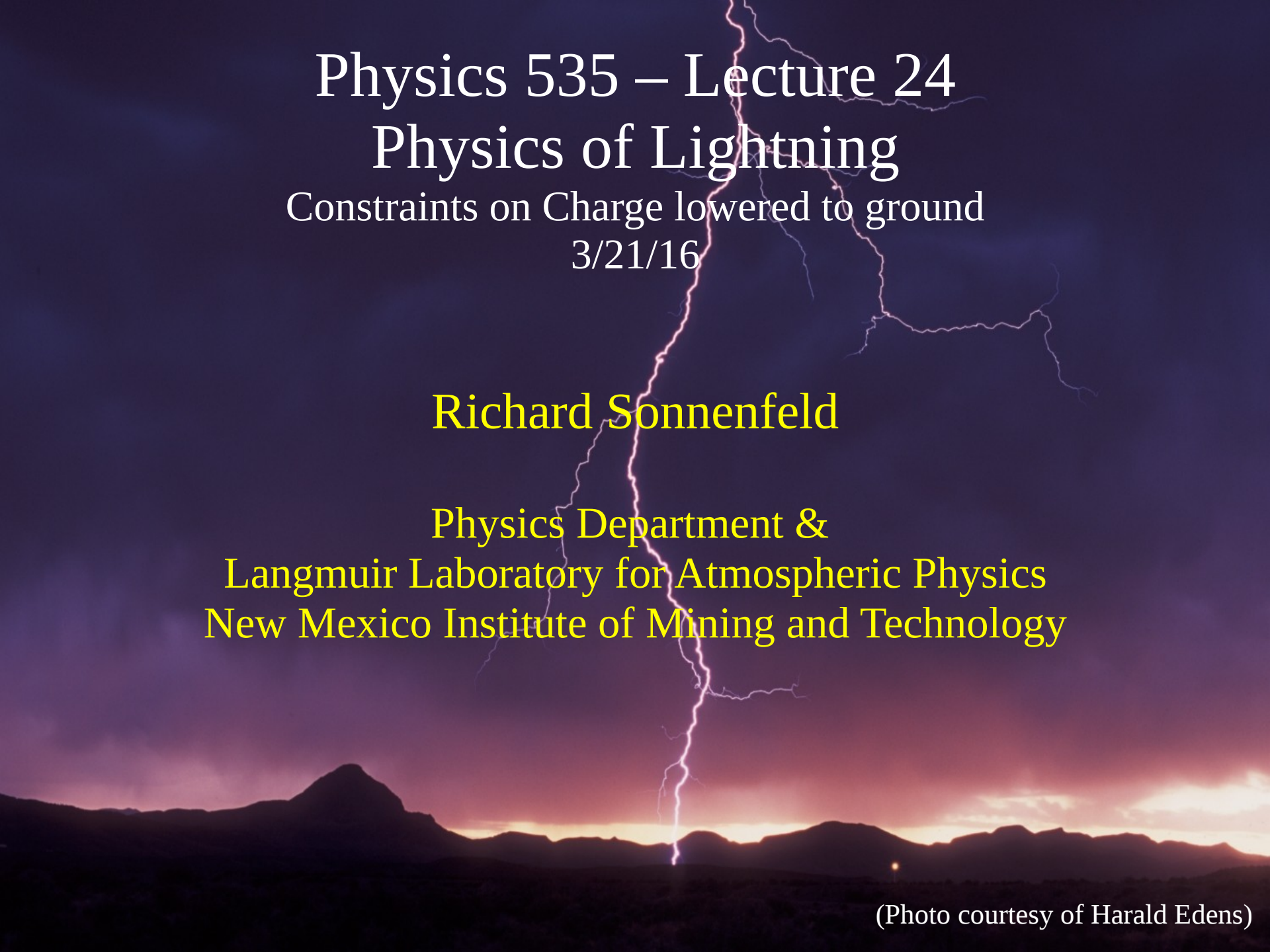
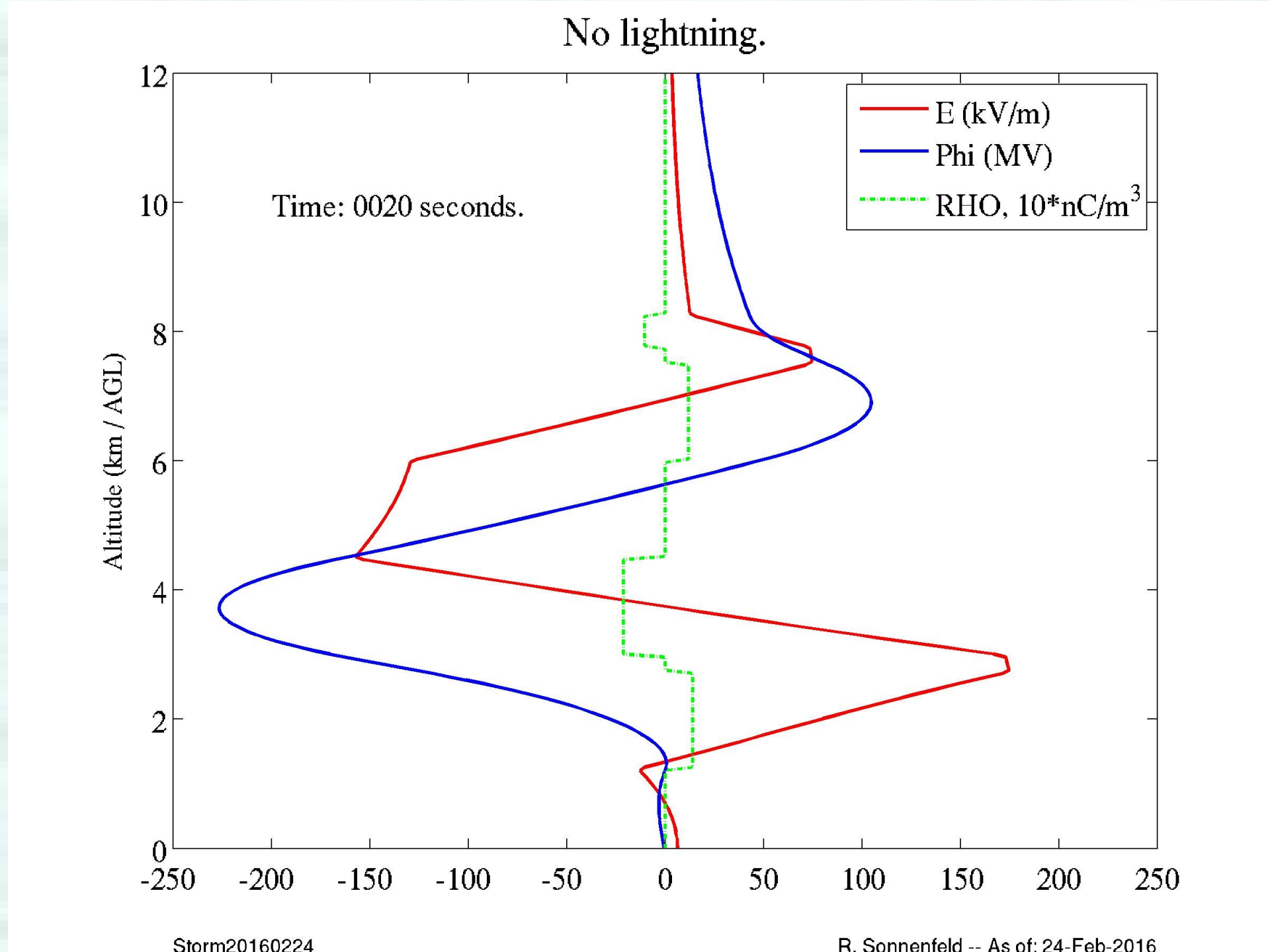


(Photo courtesy of Harald Edens)

HW Review

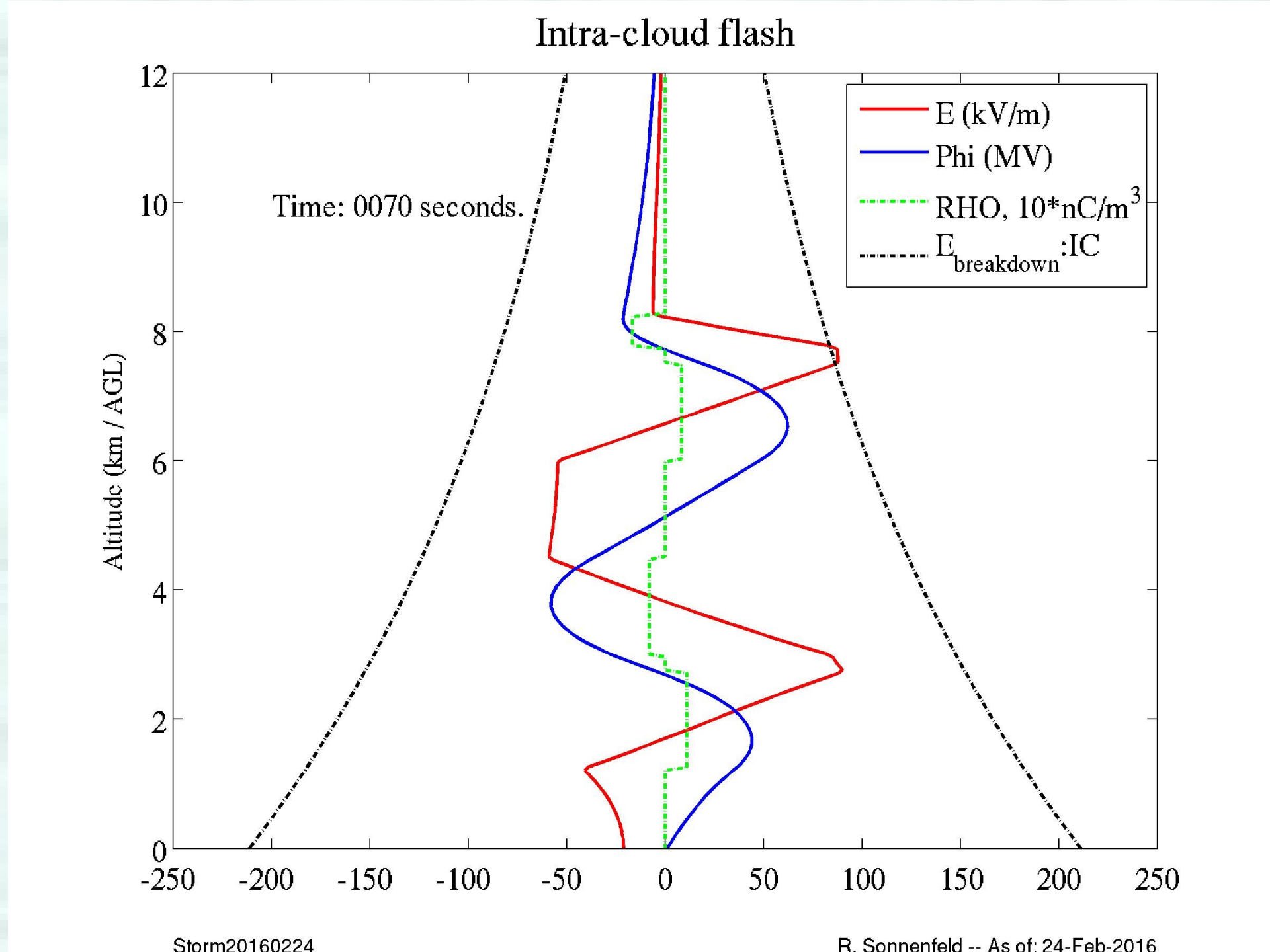

No lightning.
Time: 0020 seconds.
E (kV/m)
Phi (MV)
RHO, 10*nC/m3
Altitude (km / AGL)
12
10
8
6
4
2
0
-250
-200
-150
-100
-50
0
50
100
150
200
250
Storm20160224
R. Sonnenfeld -- As of: 24-Feb-2016

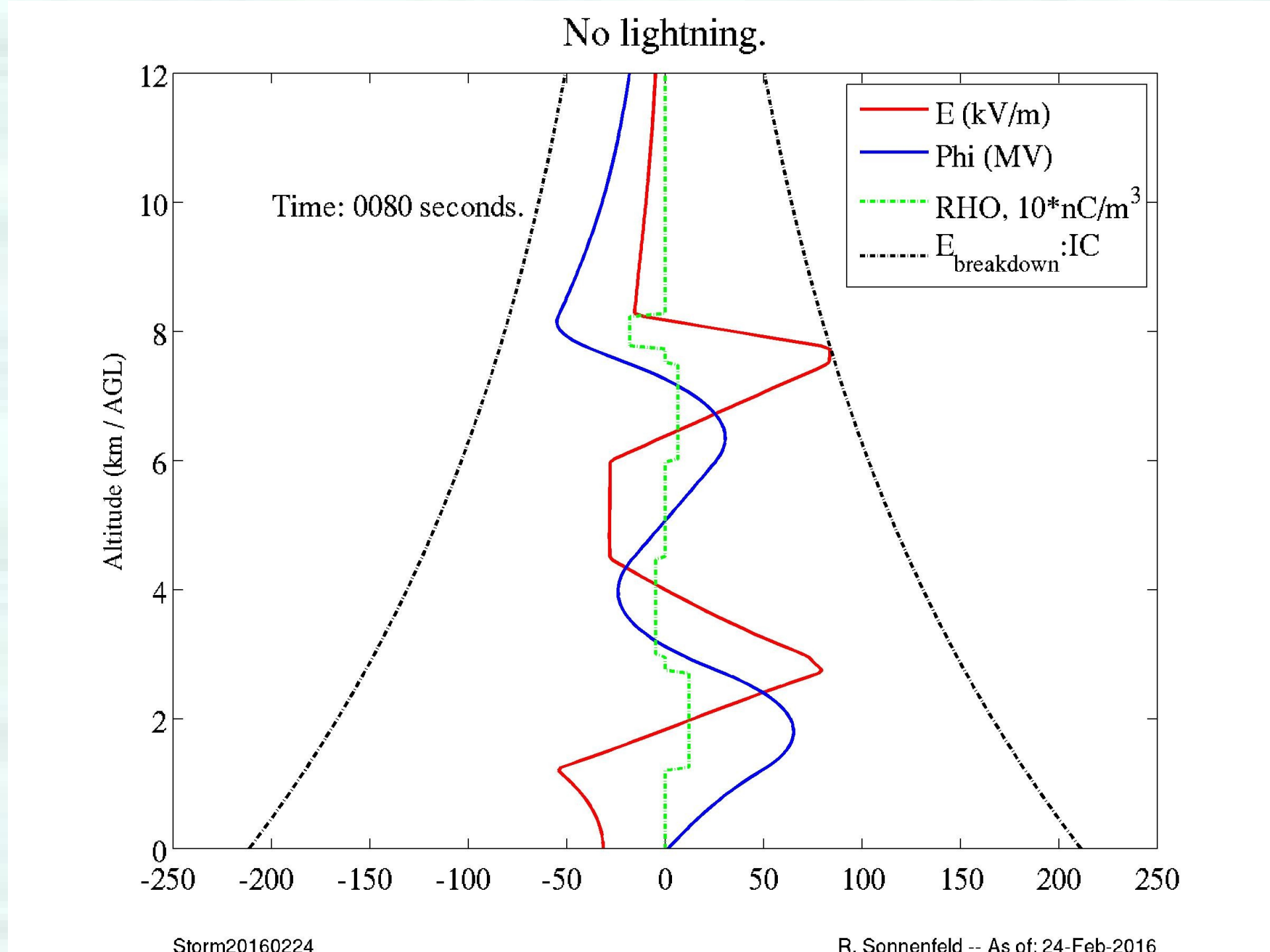
We made a model that showed us where in a thunderstorm a lightning flash might originate.

Kasemir showed us how to determine how far a flash might propagate.

None of the models have allowed for the fact that the flash itself changes the charge structure of the storm.

What happens if we account for this?


Intra-cloud flash
Time: 0070 seconds.
E (kV/m)
Phi (MV)
RHO, 10*nC/m3
Ebreakdown:IC
Altitude (km / AGL)
12
10
8
6
4
2
0
-250
-200
-150
-100
-50
0
50
100
150
200
250
Storm20160224
R. Sonnenfeld -- As of: 24-Feb-2016


No lightning.
Time: 0080 seconds.
E (kV/m)
Phi (MV)
RHO, 10*nC/m3
Ebreakdown:IC
Altitude (km / AGL)
12
10
8
6
4
2
0
-250
-200
-150
-100
-50
0
50
100
150
200
250
Storm20160224
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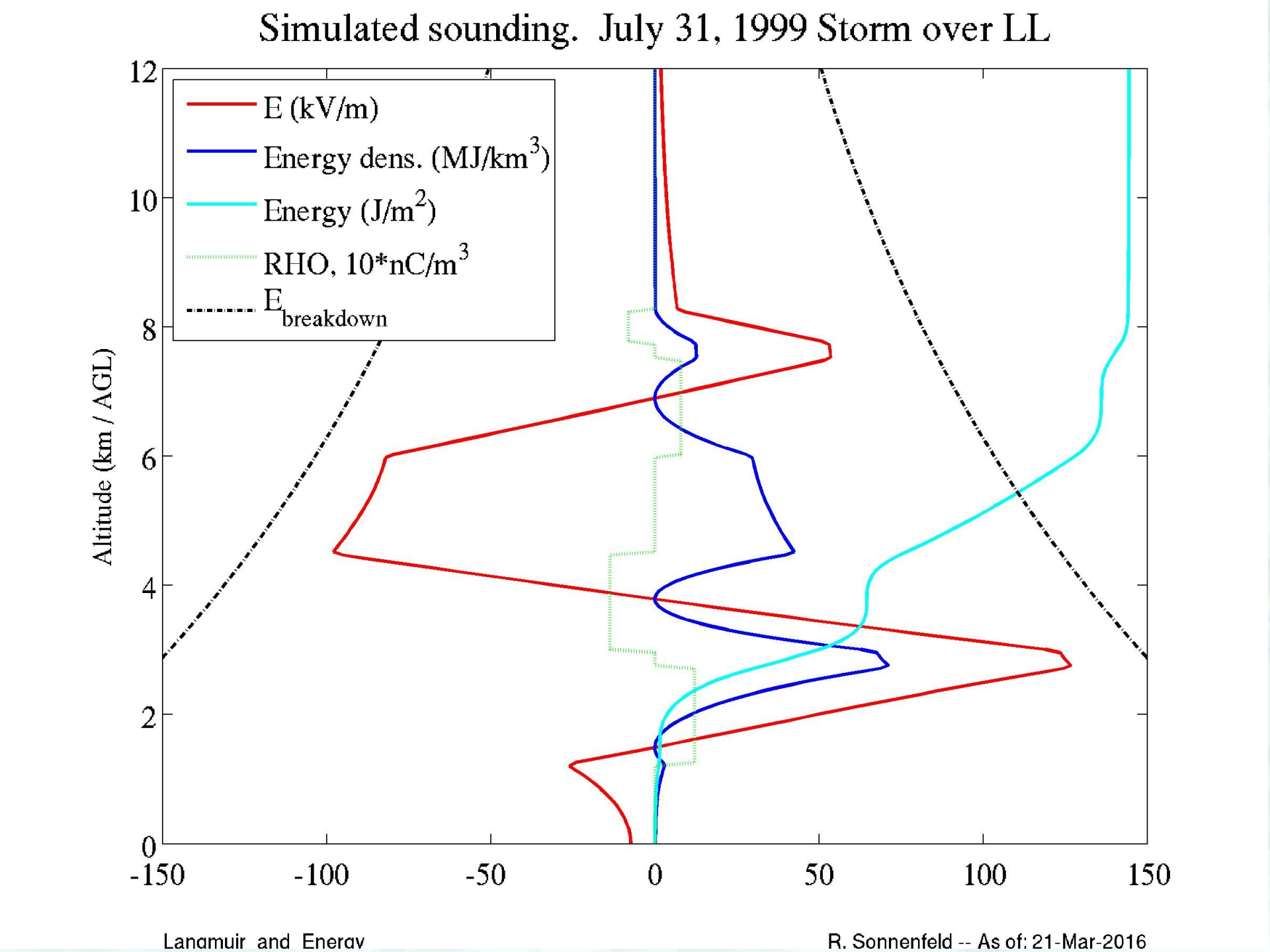

Simulated sounding. July 31, 1999 Storm over LL
E (kV/m)
Energy dens. (MJ/km3)
Energy (J/m2)
RHO, 10*nC/m3
Ebreakdown
Altitude (km / AGL)
0
2
4
6
8
10
12
-150
-100
-50
0
50
100
150
Langmuir and Energy
R. Sonnenfeld -- As of: 21-Mar-2016

Assumption --

Marshall & Stolzenburg “Electrical Energy Constraints on Lightning”

A lightning flash must decrease the total electrical energy of the Storm.

Model is 1-D, which assumes that as a flash propagates through an altitude, it extends horizontally enough to change the field over all the points at that altitude.

In that case, we can calculate the total energy of the storm before and after the flash.

$$\Delta U = \int_0^H u(z)_f \, dz - \int_0^H u(z)_i \, dz$$

$$u(z) = \frac{1}{2} \epsilon_0 E(z)^2$$

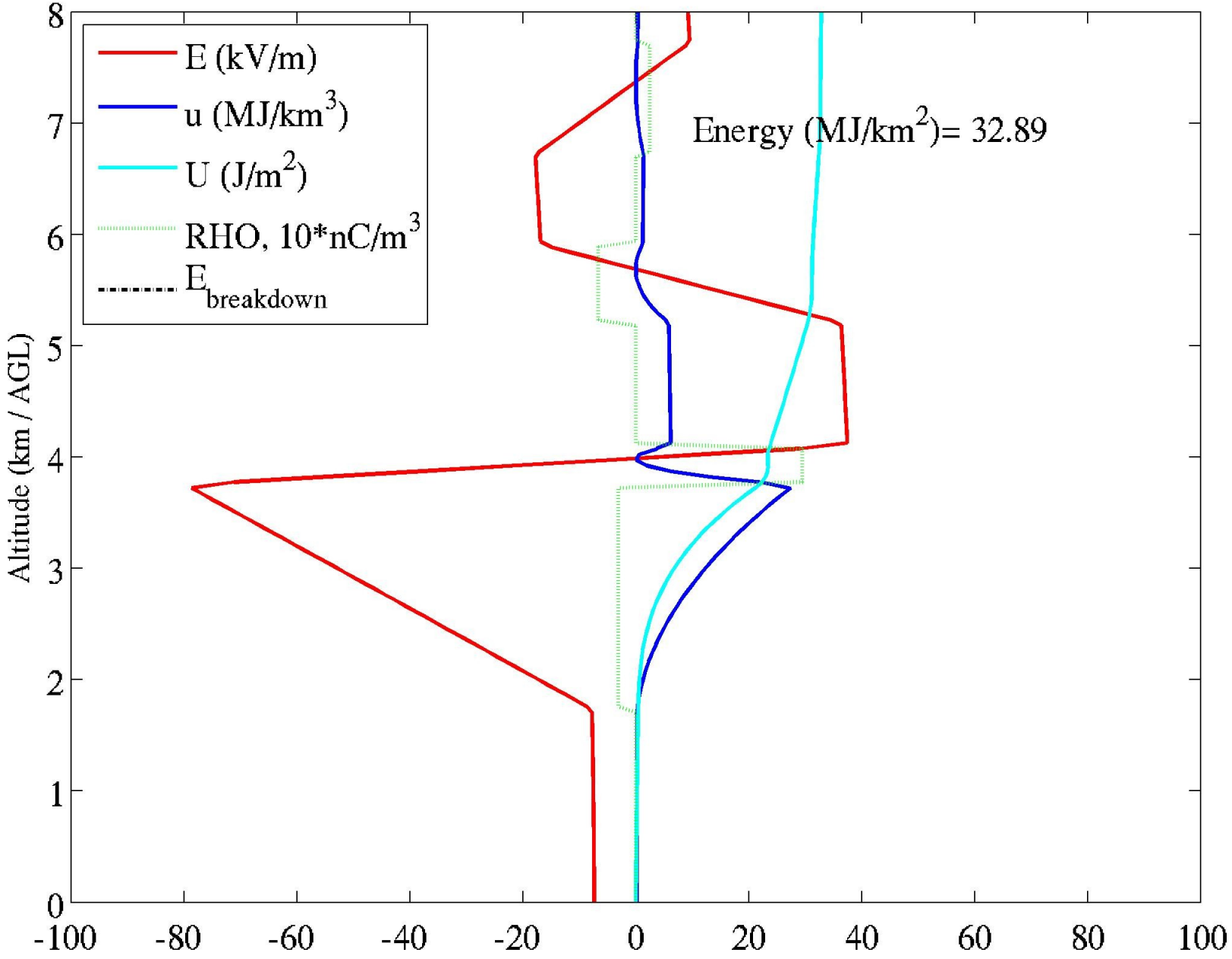
Parameters --

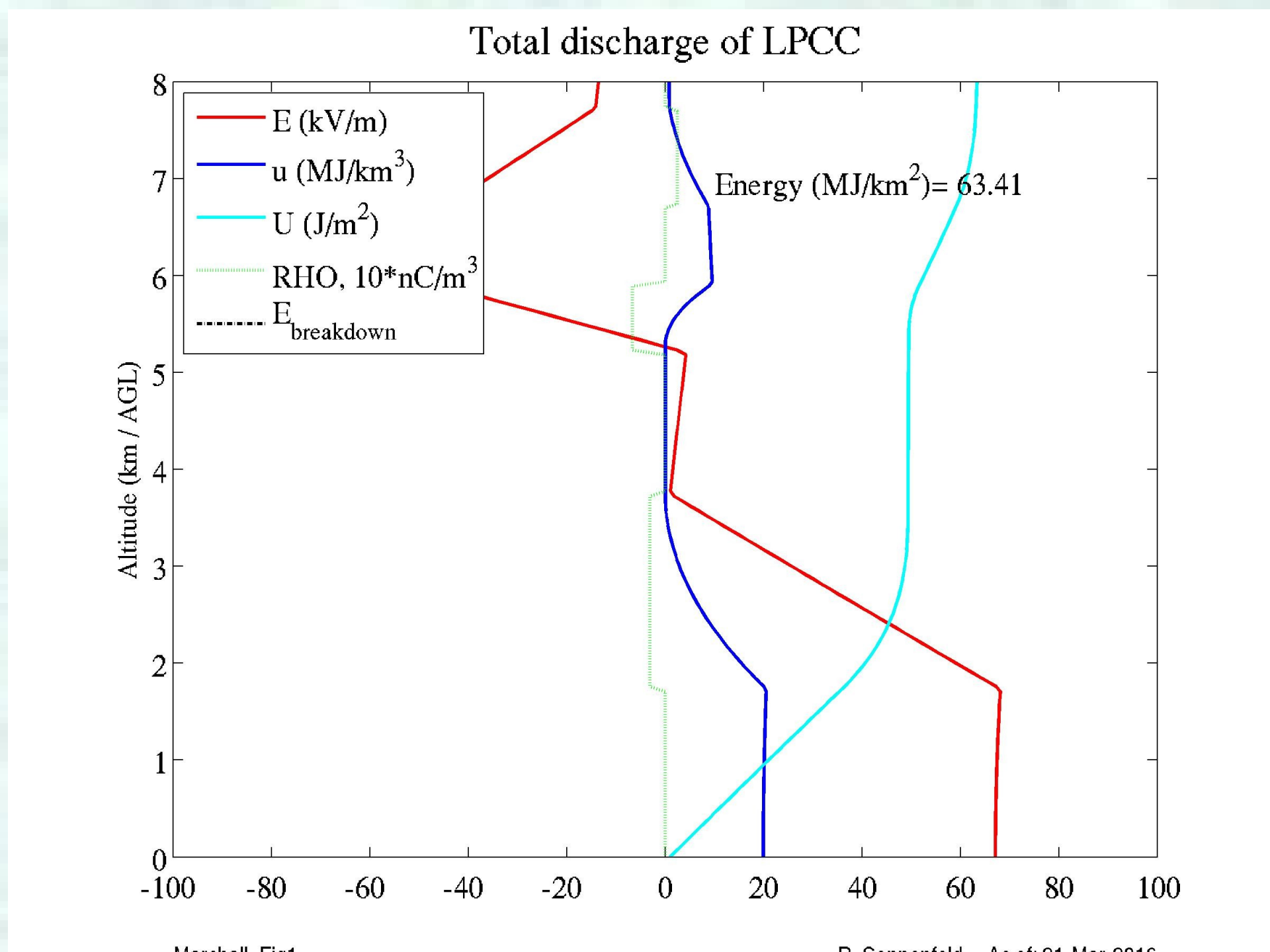
Marshall & Stolzenburg “Electrical Energy Constraints on Lightning” – Figure 1

Four Charge Layers (all altitudes are MSL, and AGL)
Radii of charge layers assumed infinite

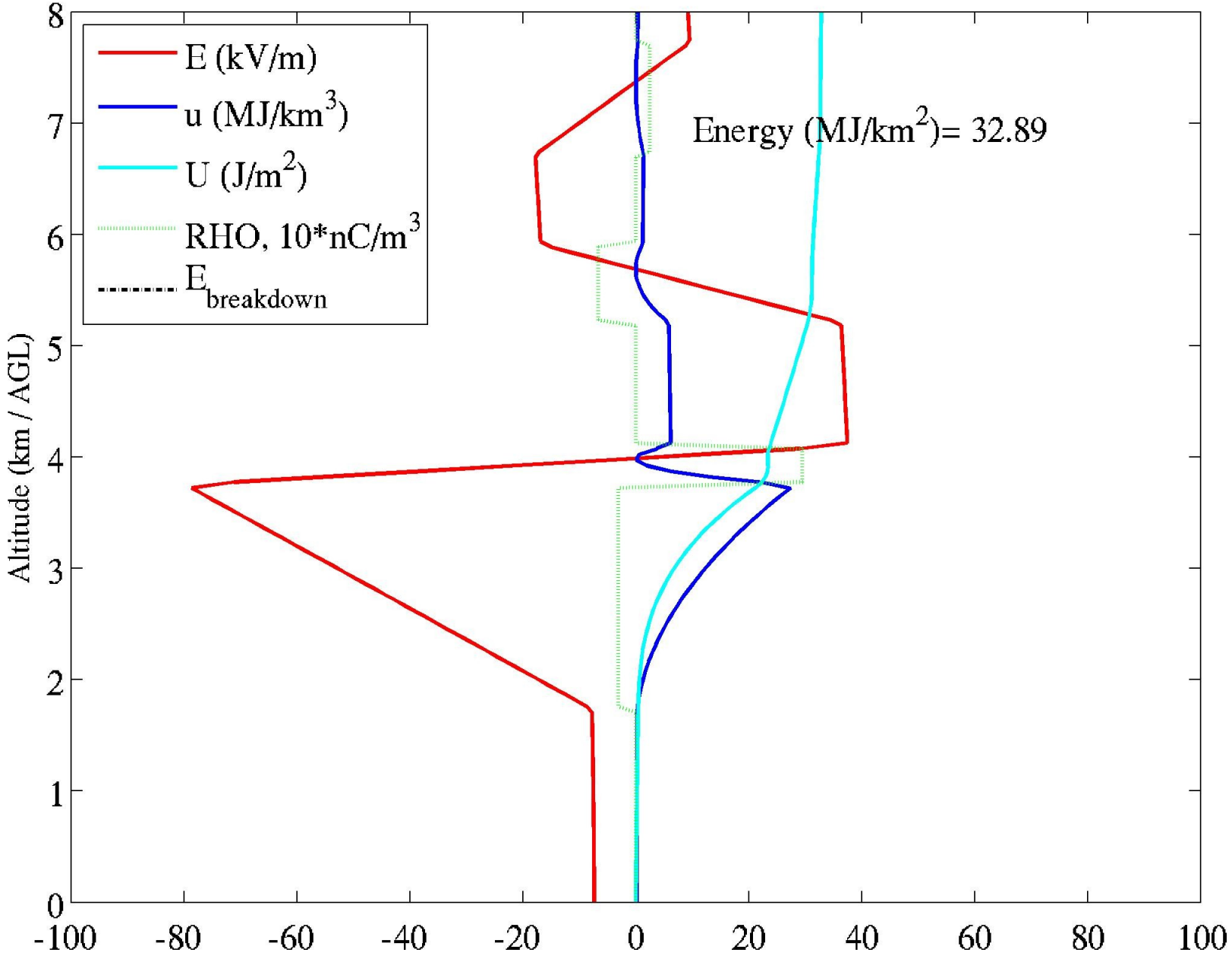
UP	0.25 nC/m^3	6.7-7.7 km
MN	-0.66 nC/m^3	5.2-5.9 km
LP	+0.25 nC/m^3	3.75-4.1 km
LN	-0.31 nC/m^3	1.75-3.75 km

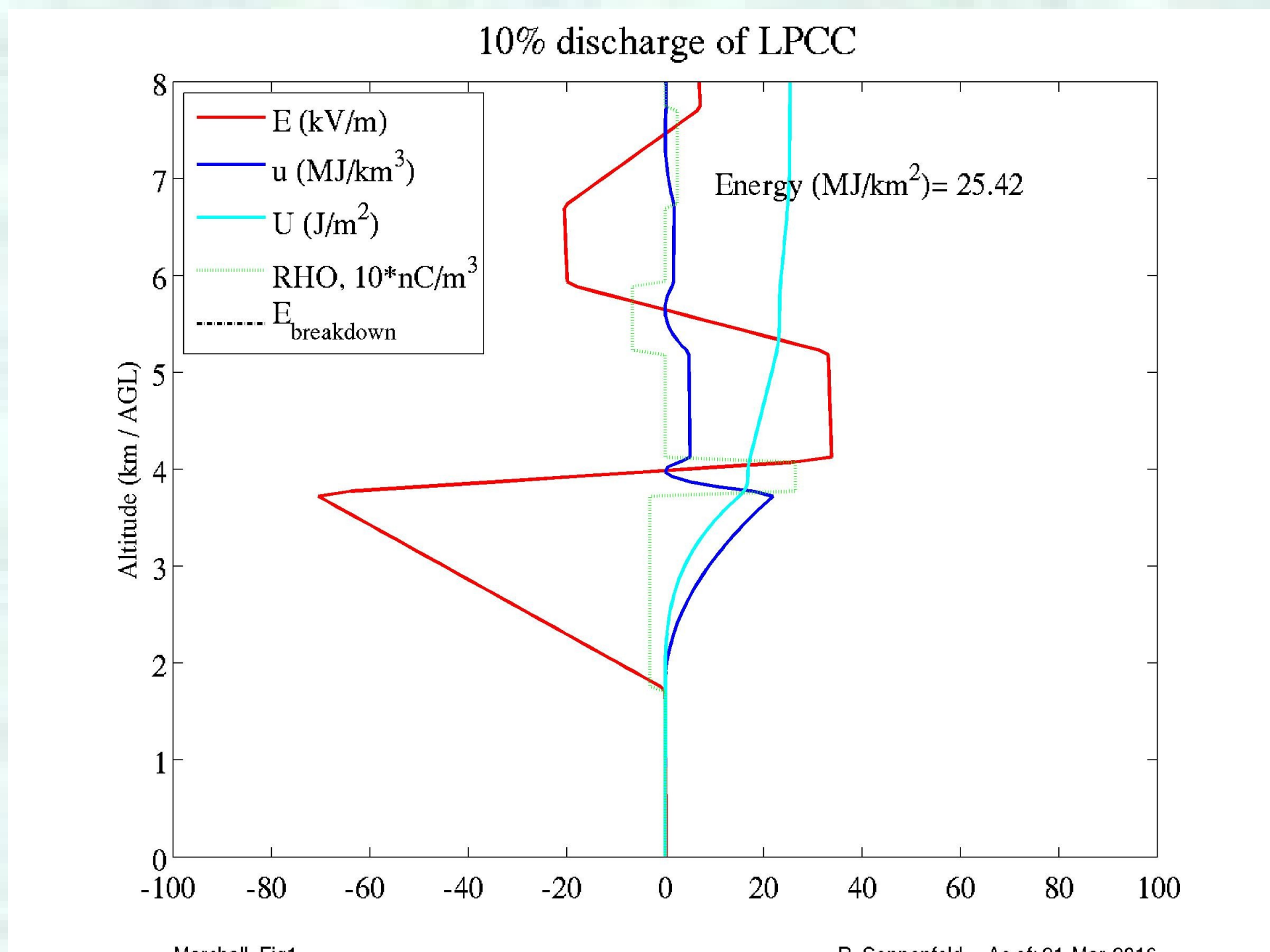
Marshall 2002, Fig. 1

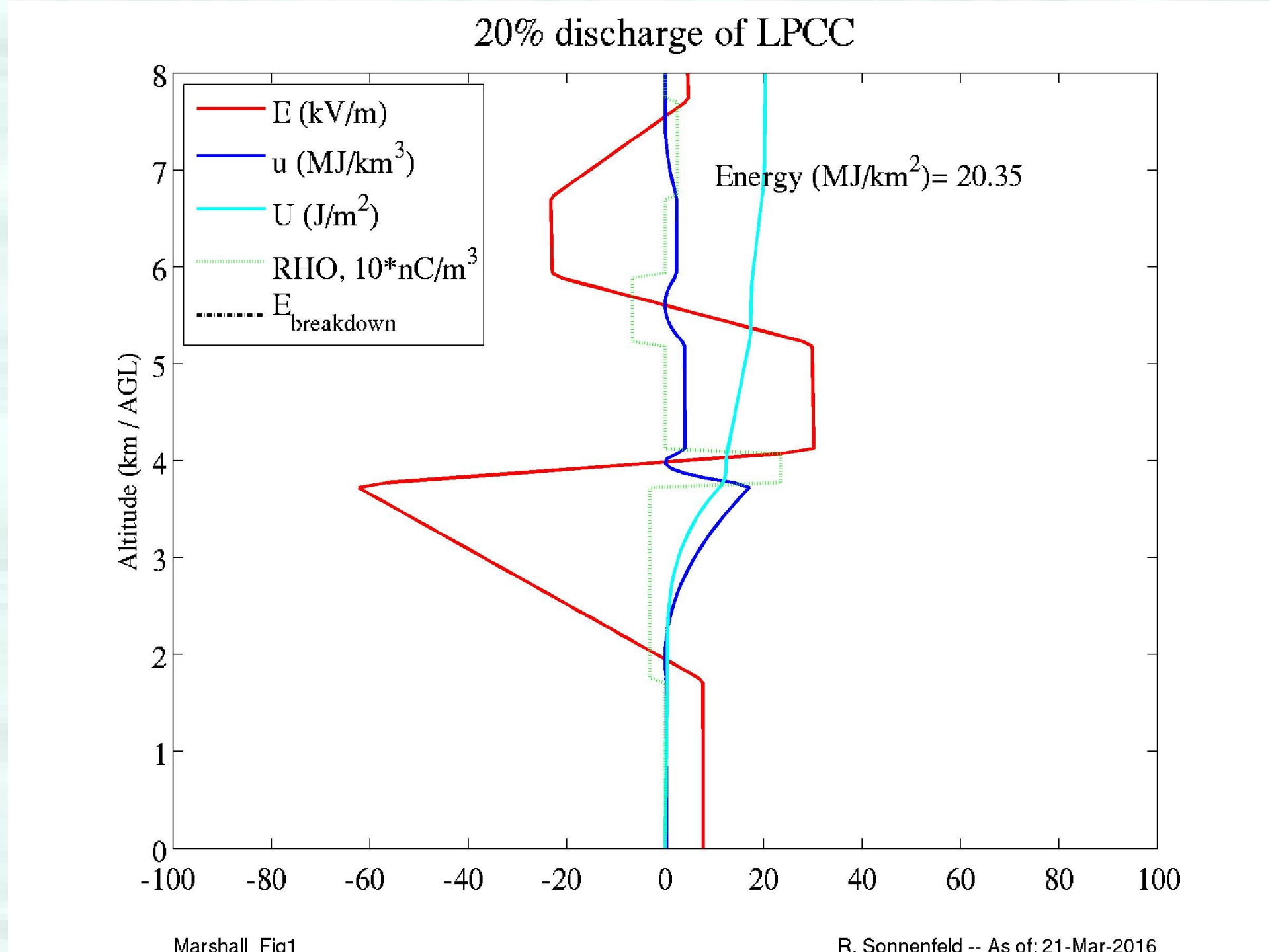


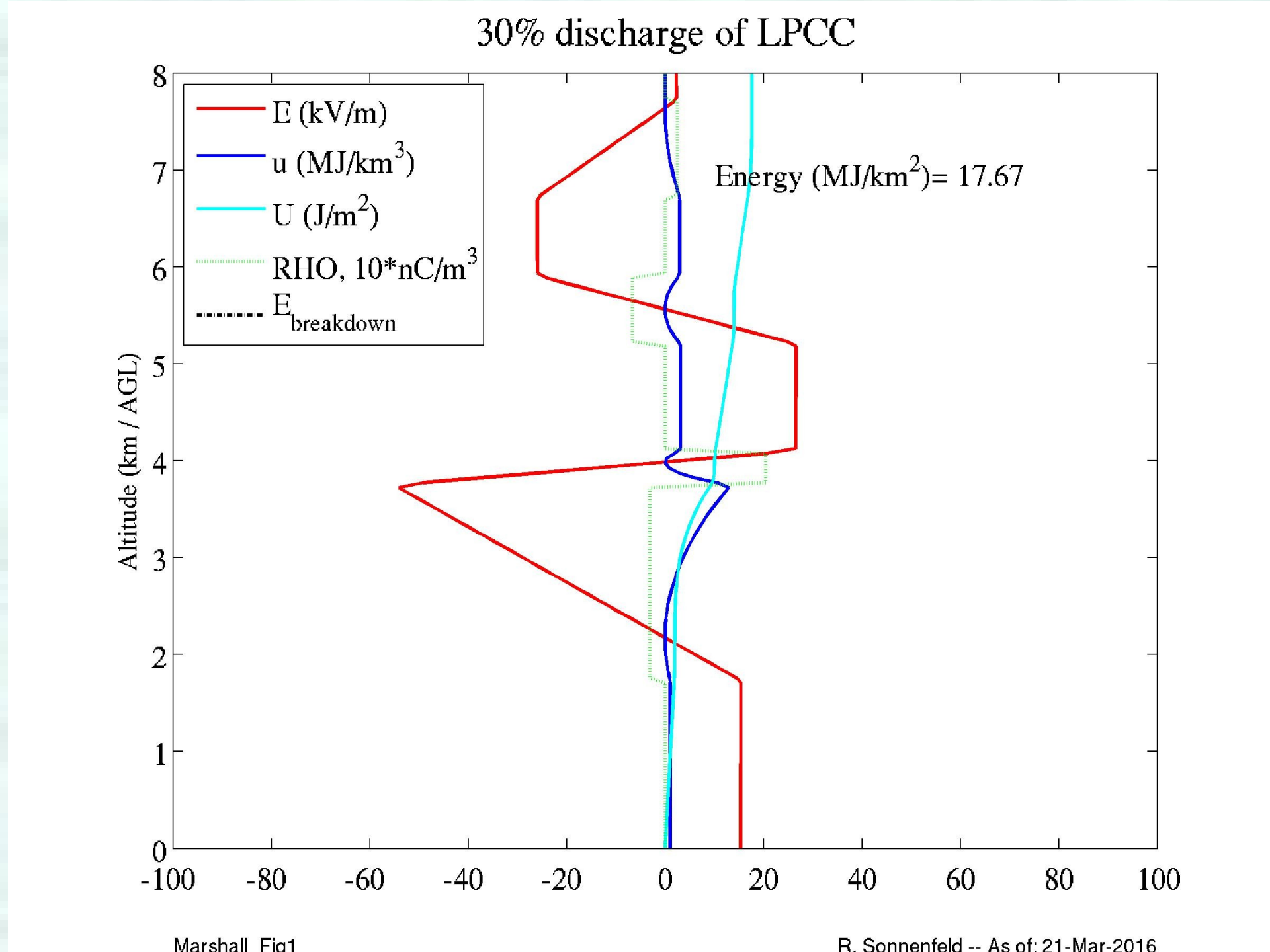

Total discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 63.41
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100

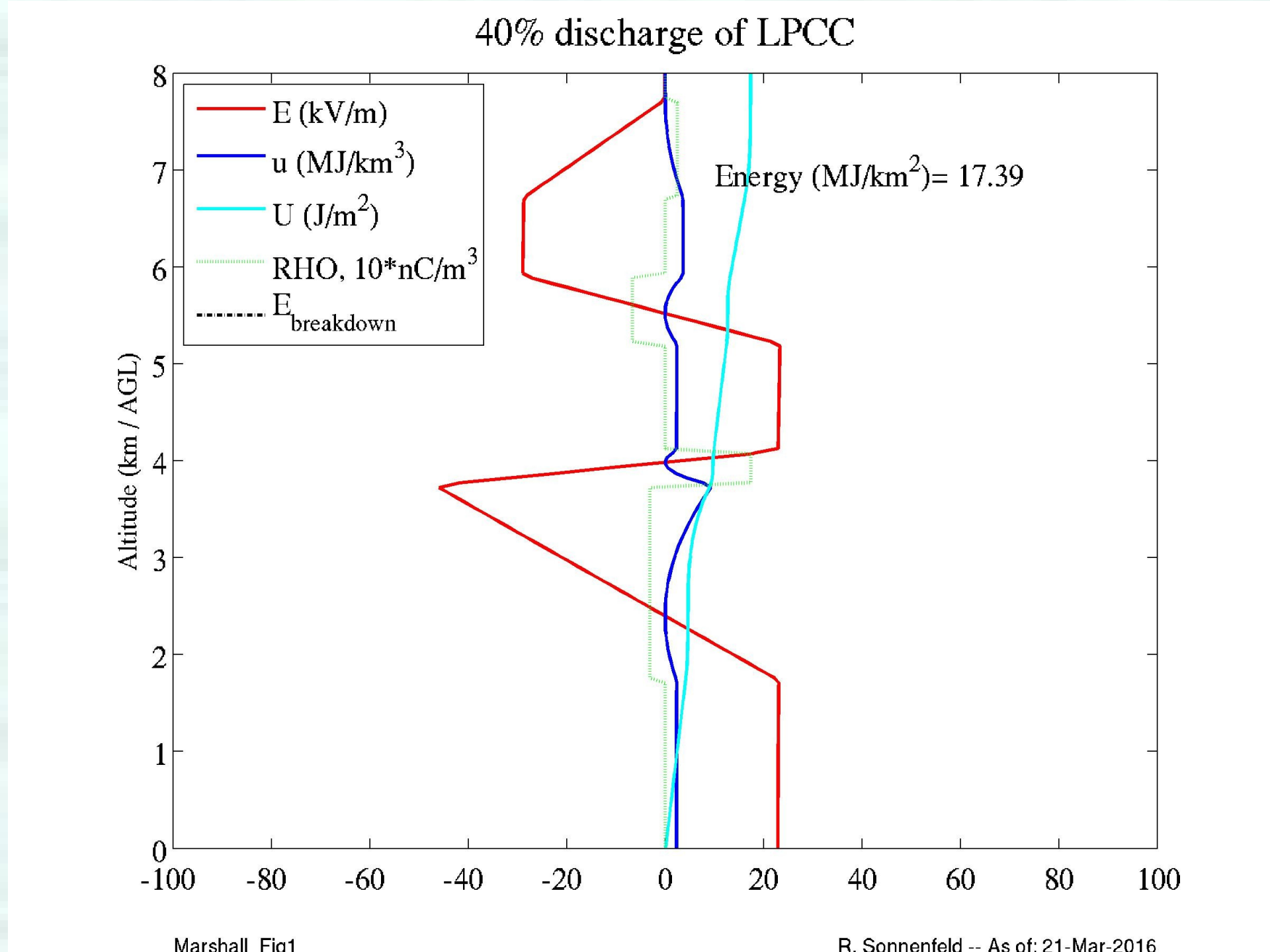
Marshall 2002, Fig. 1

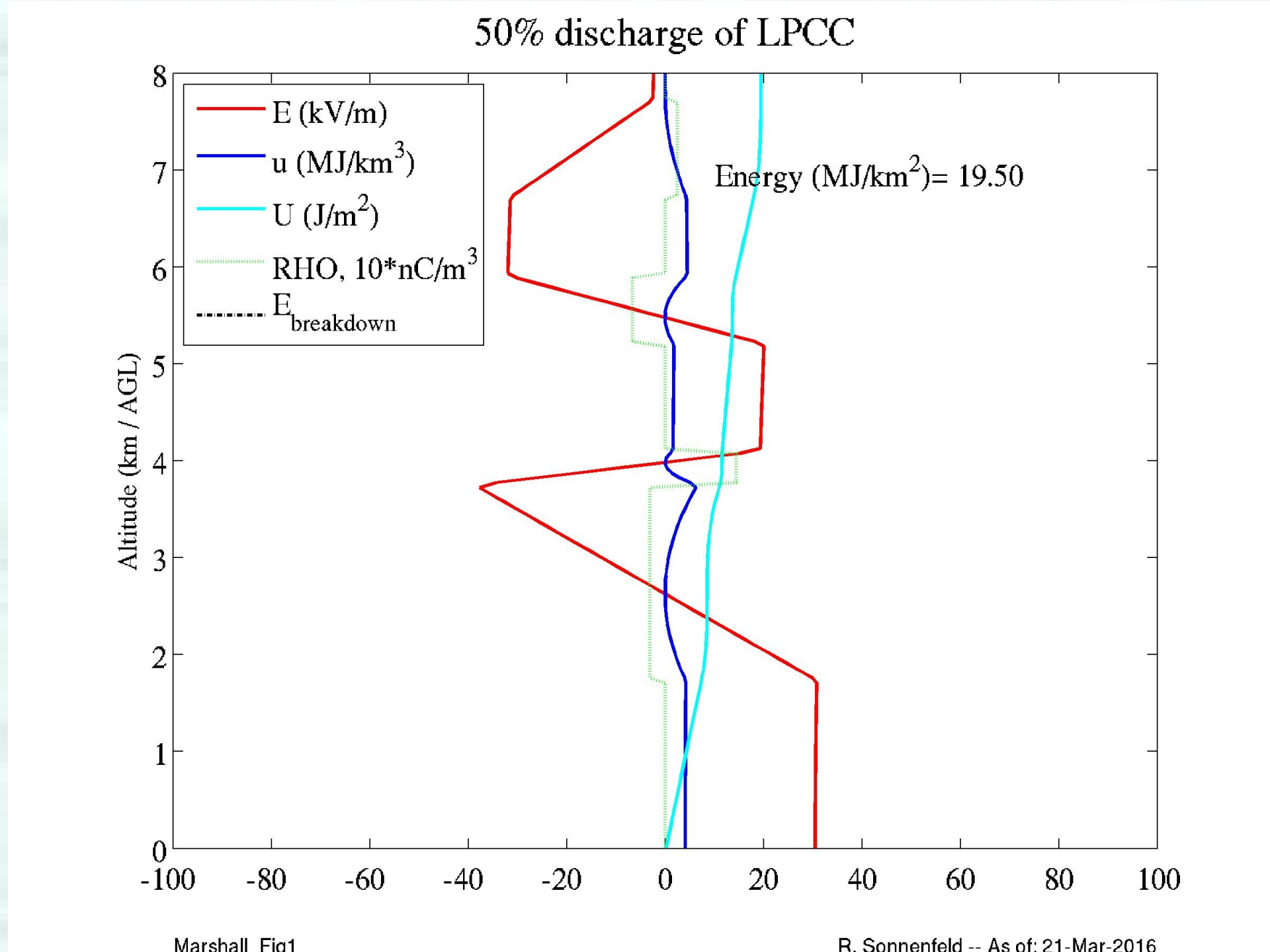


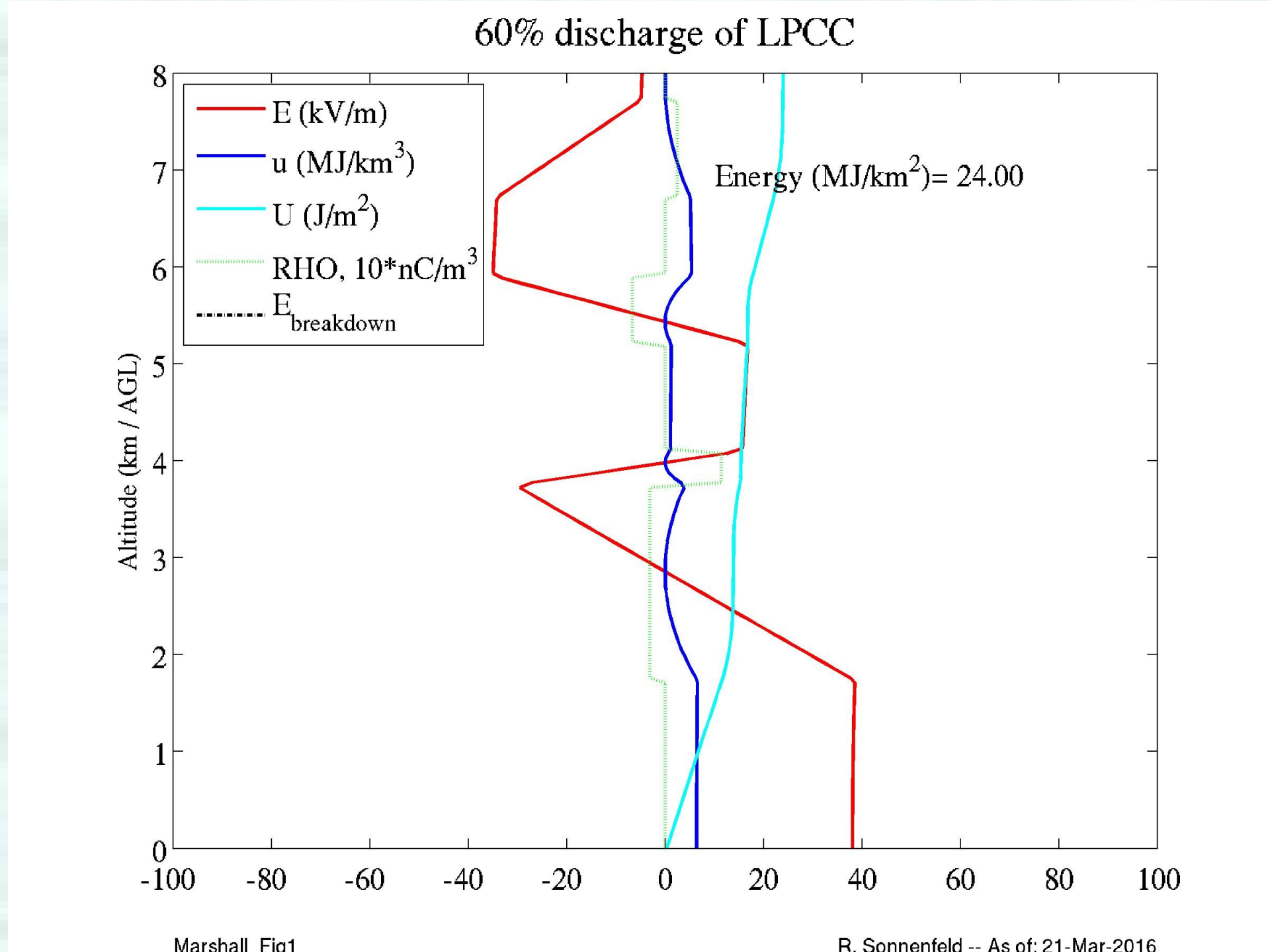

10% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 25.42
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100


20% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 20.35
Altitude (km / AGL)
8
7
6
5
4
3
2
1
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall, Fig1
R. Sonnenfeld -- As of: 21-Mar-2016


30% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 17.67
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall_Fig1
R. Sonnenfeld -- As of: 21-Mar-2016


40% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 17.39
Altitude (km / AGL)
8
7
6
5
4
3
2
1
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall_Fig1
R. Sonnenfeld -- As of: 21-Mar-2016


50% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 19.50
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall_Fig1
R. Sonnenfeld -- As of: 21-Mar-2016


60% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 24.00
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall, Fig1
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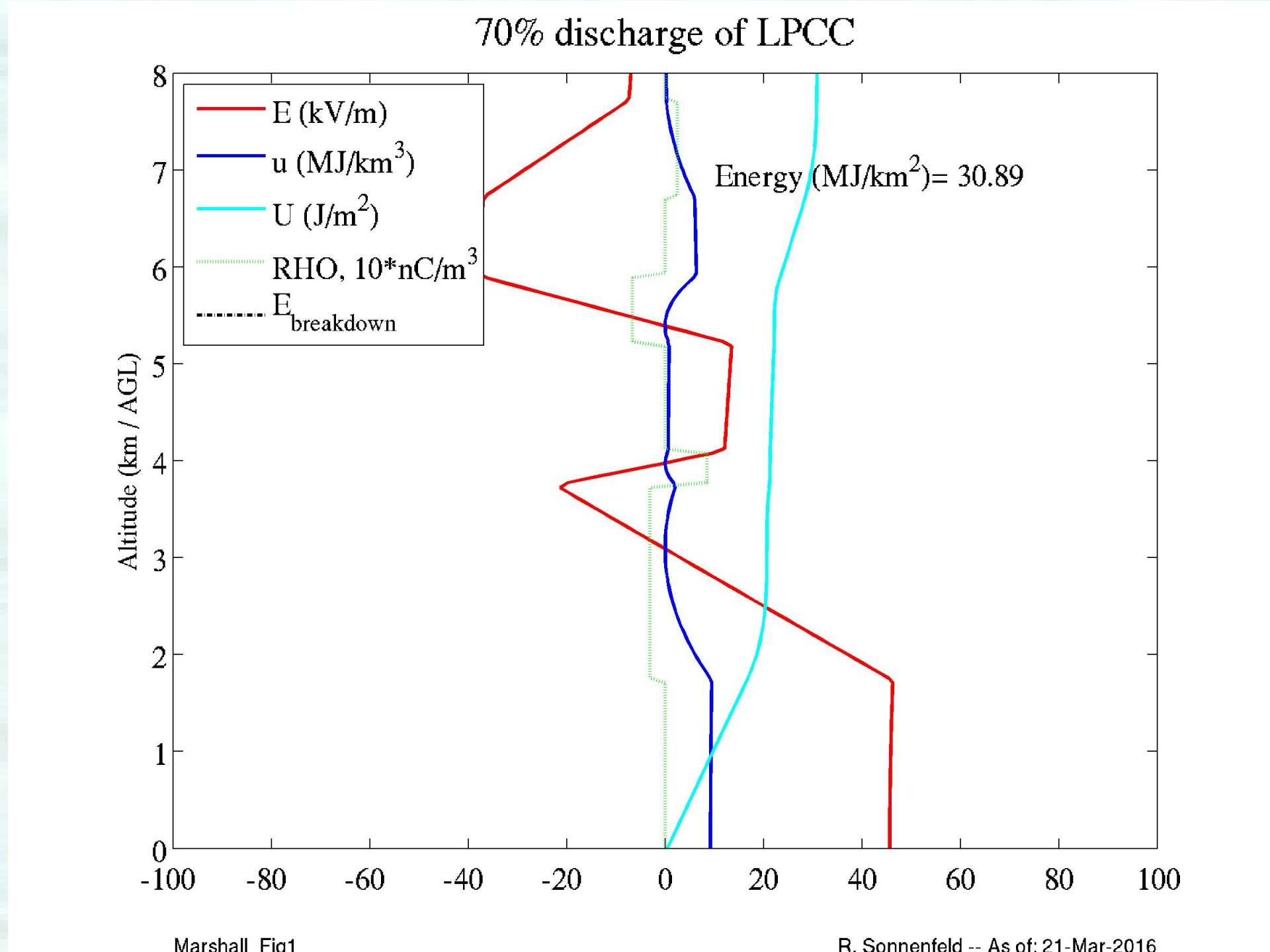
70% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 30.89
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall_Fig1
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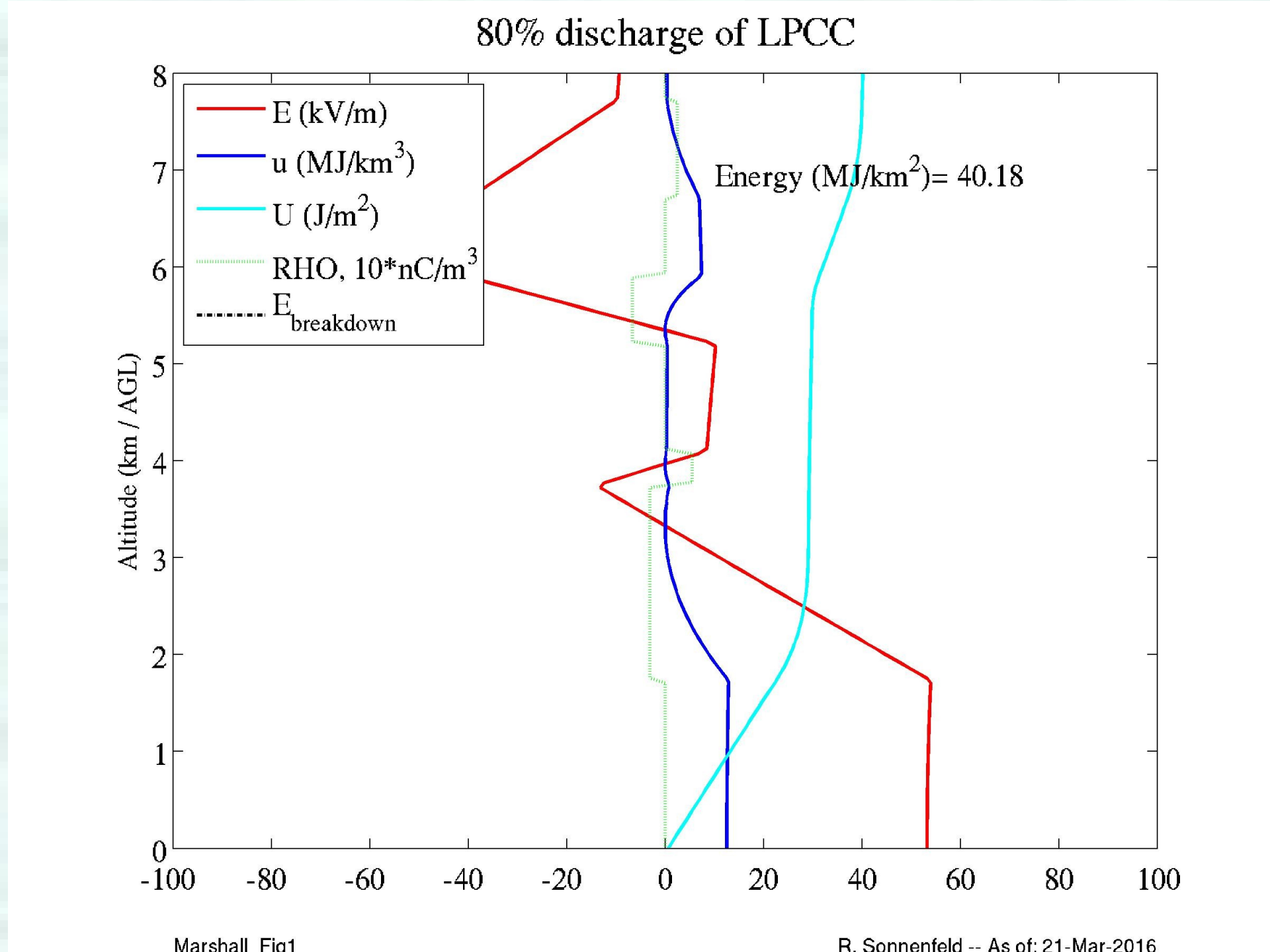
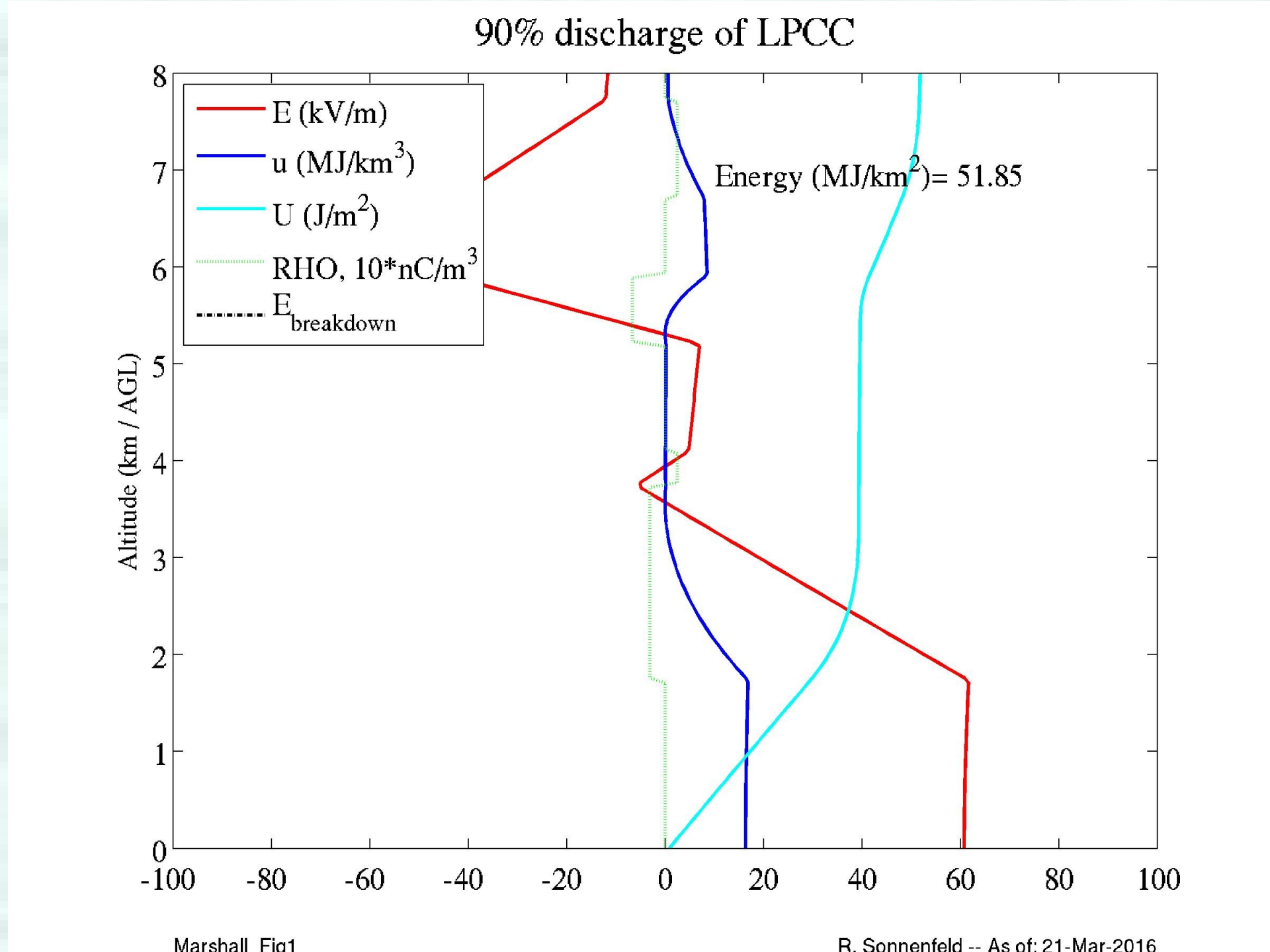

80% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 40.18
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall_Fig1
R. Sonnenfeld -- As of: 21-Mar-2016


90% discharge of LPCC
E (kV/m)
u (MJ/km3)
U (J/m2)
RHO, 10*nC/m3
Ebreakdown
Energy (MJ/km2)= 51.85
Altitude (km / AGL)
0
1
2
3
4
5
6
7
8
-100
-80
-60
-40
-20
0
20
40
60
80
100
Marshall_Fig1
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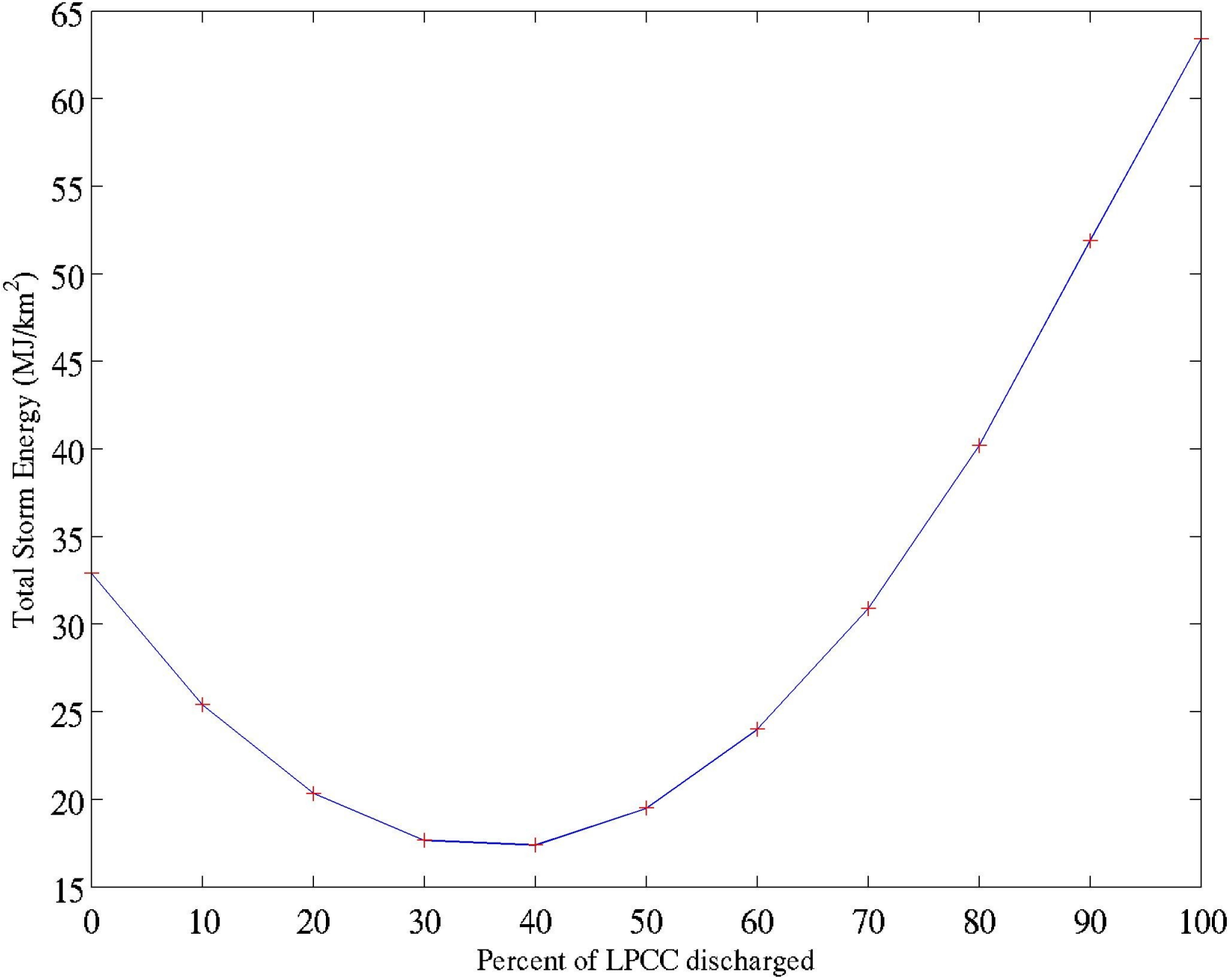
65
60
55
50
45
40
35
30
25
20
15
Total Storm Energy (MJ/km^2)
0
10
20
30
40
50
60
70
80
90
100
Percent of LPCC discharged

Conductivity and UV light