Reaching for Titan & the Rings with Cassini Radio Science

Essam Marouf & the Cassini Radio Science Team

Cassini CHARM Presentation
September 25, 2007

Cassini Radio Science Team

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- US Universities
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  - Andrew Nagy (U. of Michigan)
- Italy
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  - Luciano Iess (Universita' di Roma, Roma)
- Associate Team Members
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  - Paul Schinder (Cornell U. & NASA/GSFC)

Radio Science Subsystem (RSS): Downlink Configuration

From Cassini

To the Deep Space Network (DSN)

- X, S: 70 m
- Ka, X: 34 m BWG

$$\frac{\Delta f}{f} \sim 10^{-14}$$

Downlink ↓

Three Sinusoids Coherent in Phase (Crystal Oscillator-- USO)

$$\frac{\Delta f}{f} \sim 10^{-13}$$

	λ (cm)	P_t (W)	S/N (dB-Hz)
Ka↓	0.94		48
X↓	3.6	19	54
S↓	13	10	42

Goldstone, CA: 70 m

EM: Cassini RSS

Radio Science Observations During the Cassini Tour (7/1/2004 - 6/30/2008)

- Downlink (1-way) Observations:
  - Radio Occultation Observations of Saturn's Rings
  - Radio Occultation Observations of Saturn's and Titan's Atmospheres and Ionospheres
  - Bistatic Scattering Observations of Titan's Surface

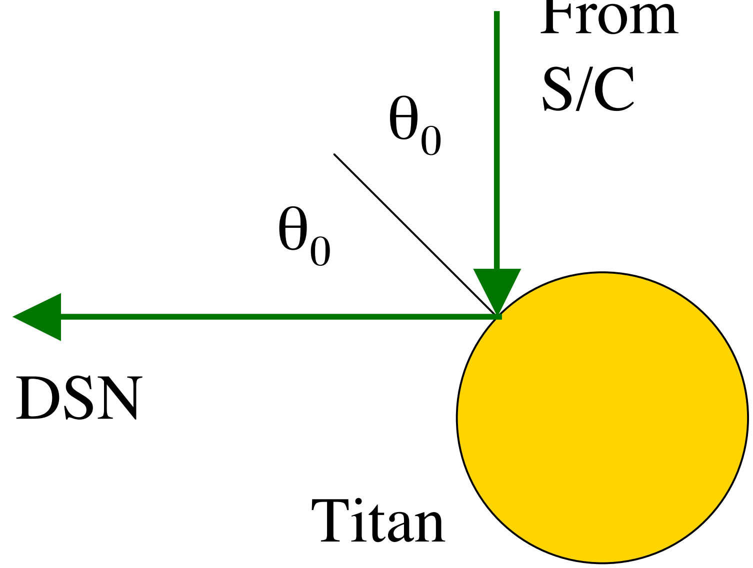
- Uplink/Downlink (2-way) Observations:
  - Gravity Field Observations of Saturn, Titan, and the major Satellites

Cassini

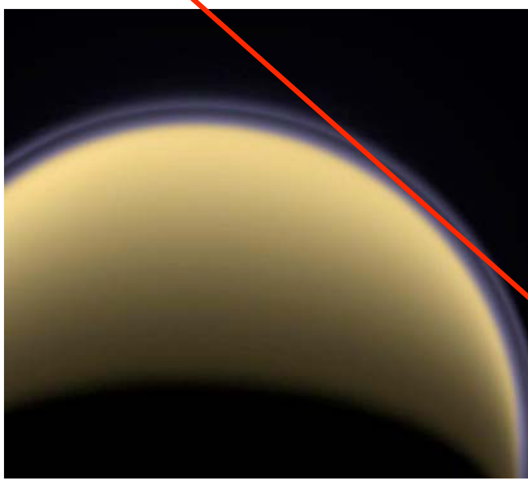
RSS Titan Downlink Observations

1- Atmospheric/Ionospheric Occultation

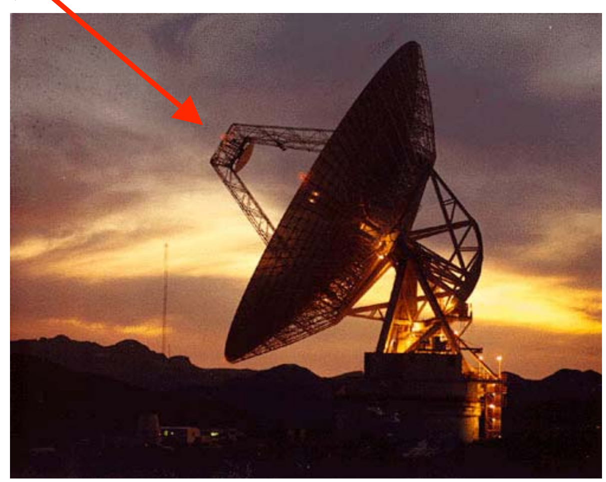
2- Bistatic Scattering From Titan's Surface



X/S/Ka-Bands: RCP



Titan's Atmosphere



DSN

X/S : 70 m
Ka/X: 34 m
RCP & LCP

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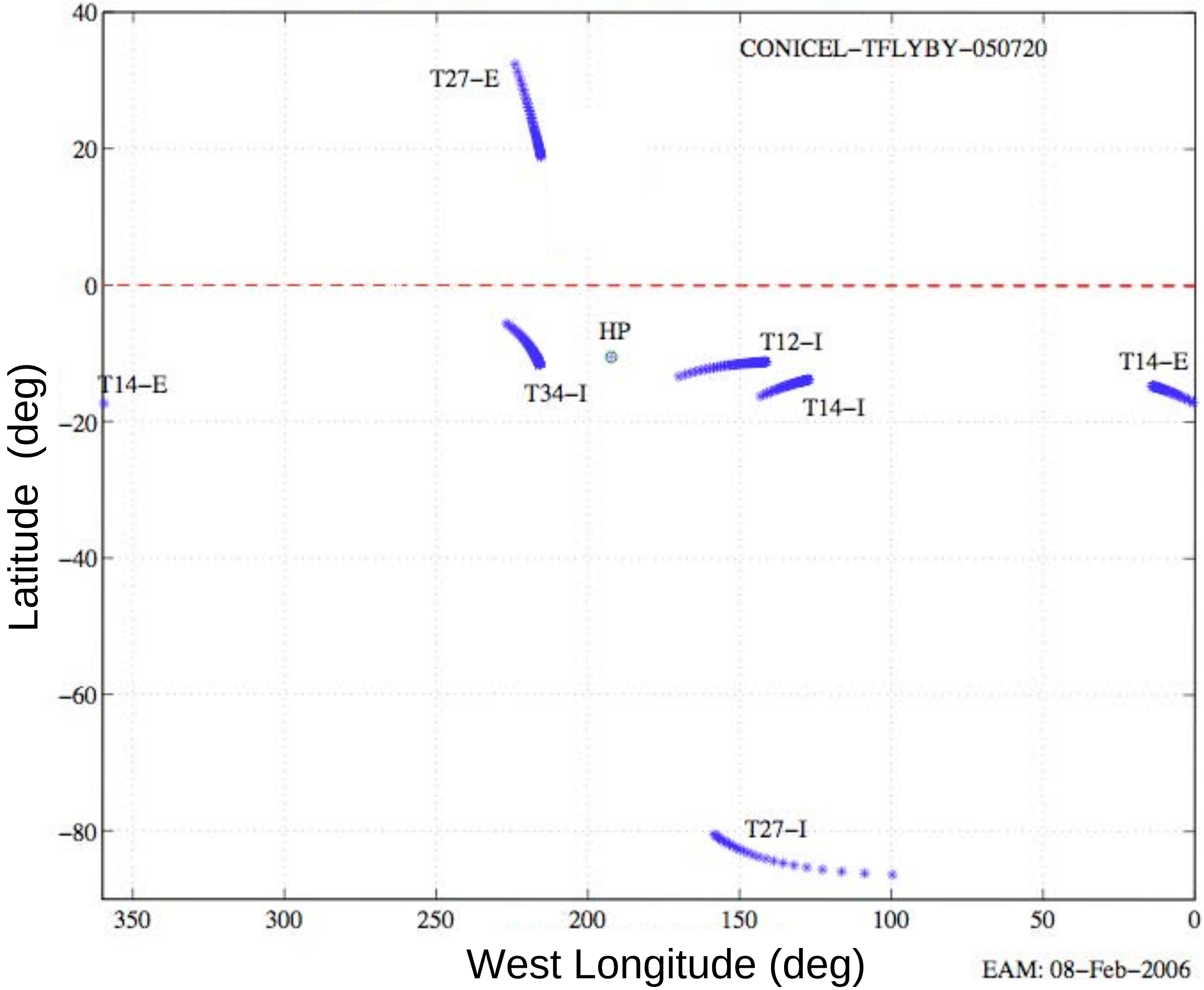
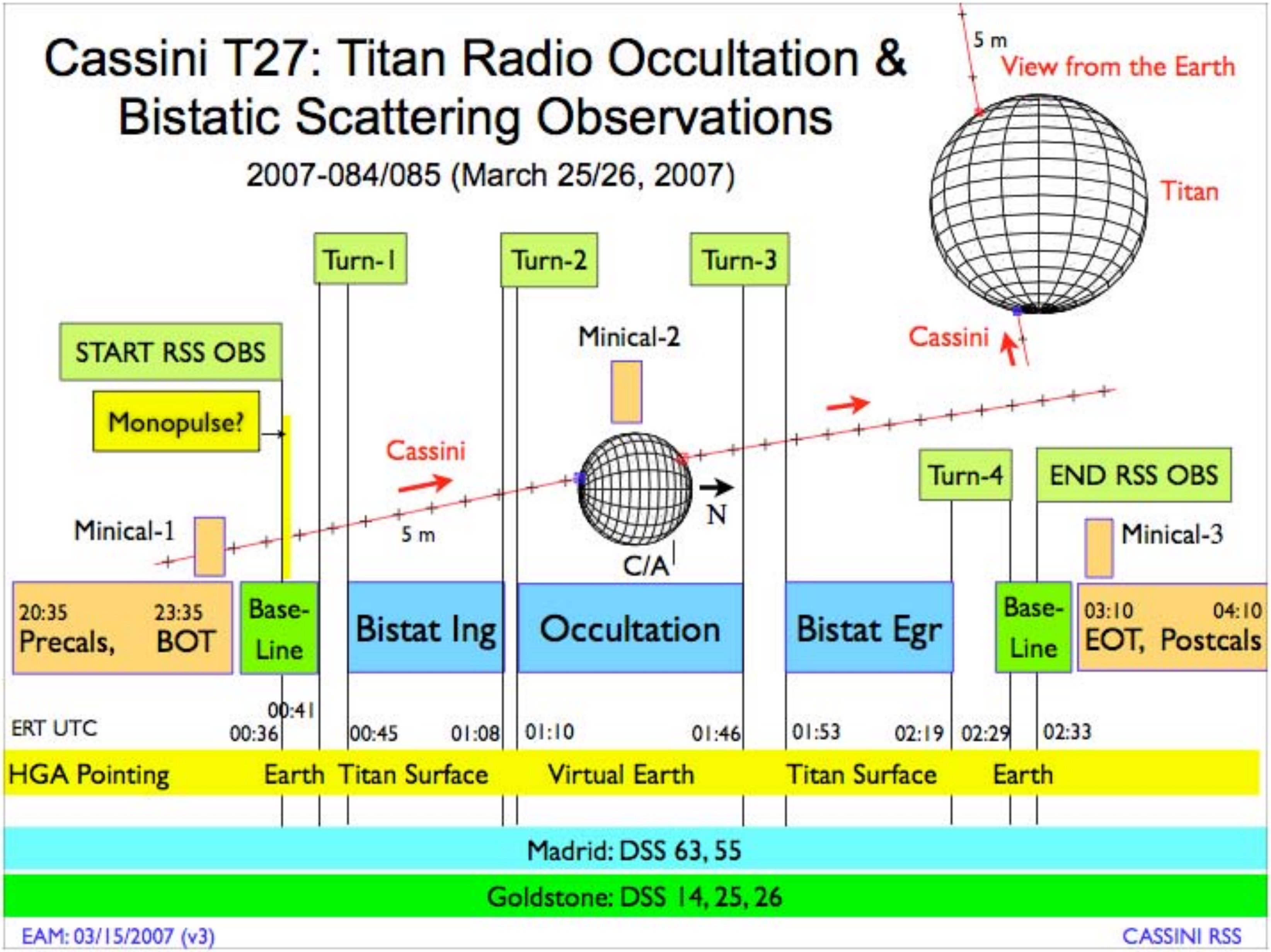
Titan Bistatic: Ground Tracks

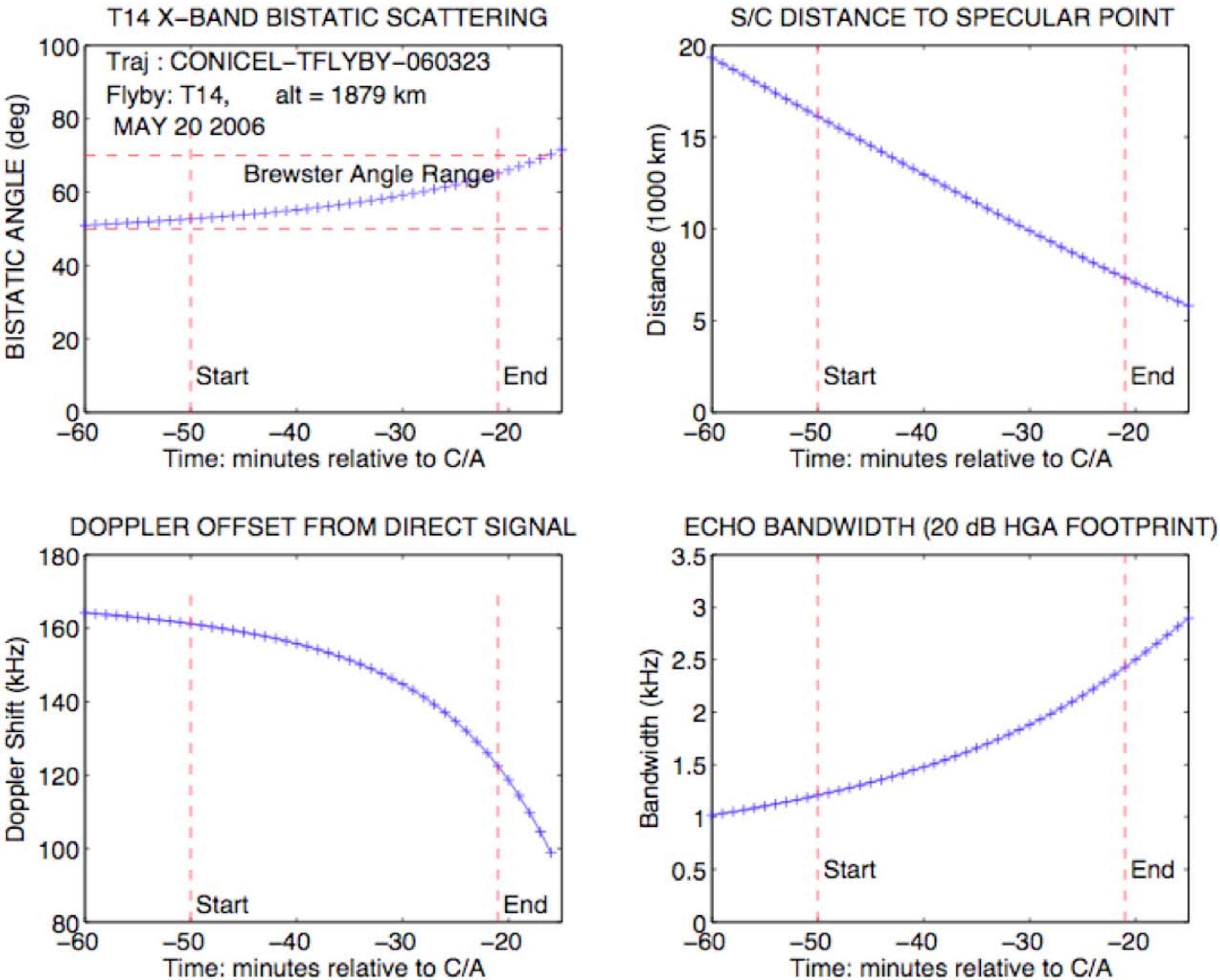


Bistatic Examples from T14 & T27

saturn.jpl.nasa.gov



Cassini T27: Titan Radio Occultation &
Bistatic Scattering Observations
2007-084/085 (March 25/26, 2007)
5 m
View from the Earth
Titan
Cassini
Turn-1
Turn-2
Turn-3
START RSS OBS
Monopulse?
Minical-2
Cassini
5 m
N
C/A
Minical-1
Turn-4
END RSS OBS
Minical-3
20:35
23:35
Precals,
BOT
Base-Line
Bistat Ing
Occultation
Bistat Egr
Base-Line
03:10
04:10
EOT, Postcals
ERT UTC
00:36
00:41
00:45
01:08
01:10
01:46
01:53
02:19
02:29
02:33
HGA Pointing
Earth
Titan Surface
Virtual Earth
Titan Surface
Earth
Madrid: DSS 63, 55
Goldstone: DSS 14, 25, 26
EAM: 03/15/2007 (v3)
CASSINI RSS



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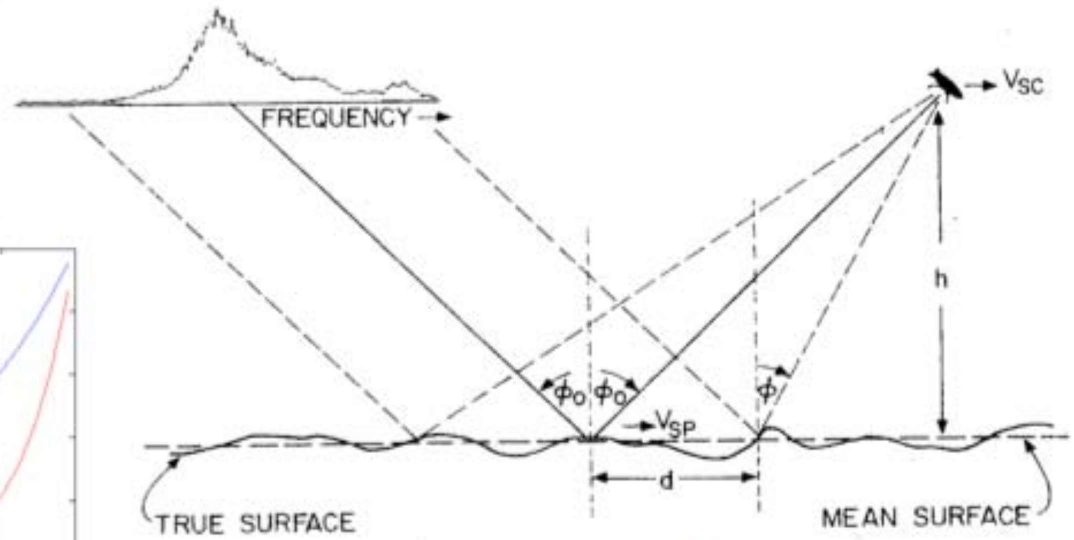
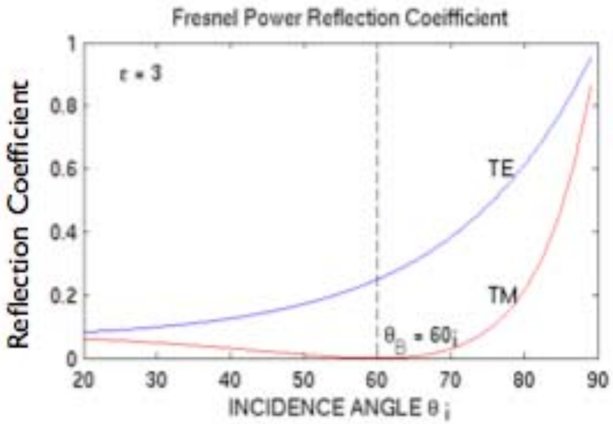
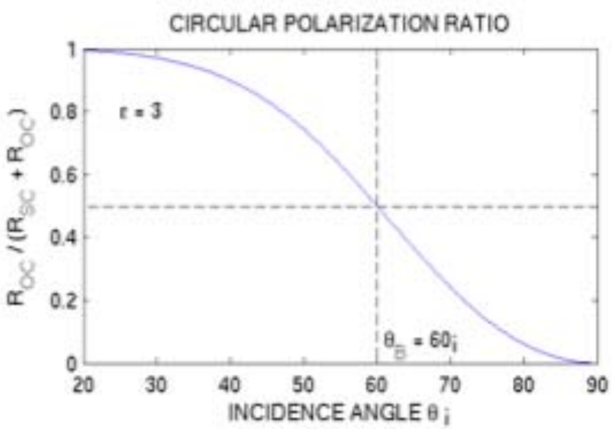
Bistatic Scattering: Objectives



From Simpson *et al*. 1977





Surface Roughness

Surface Dielectric Constant

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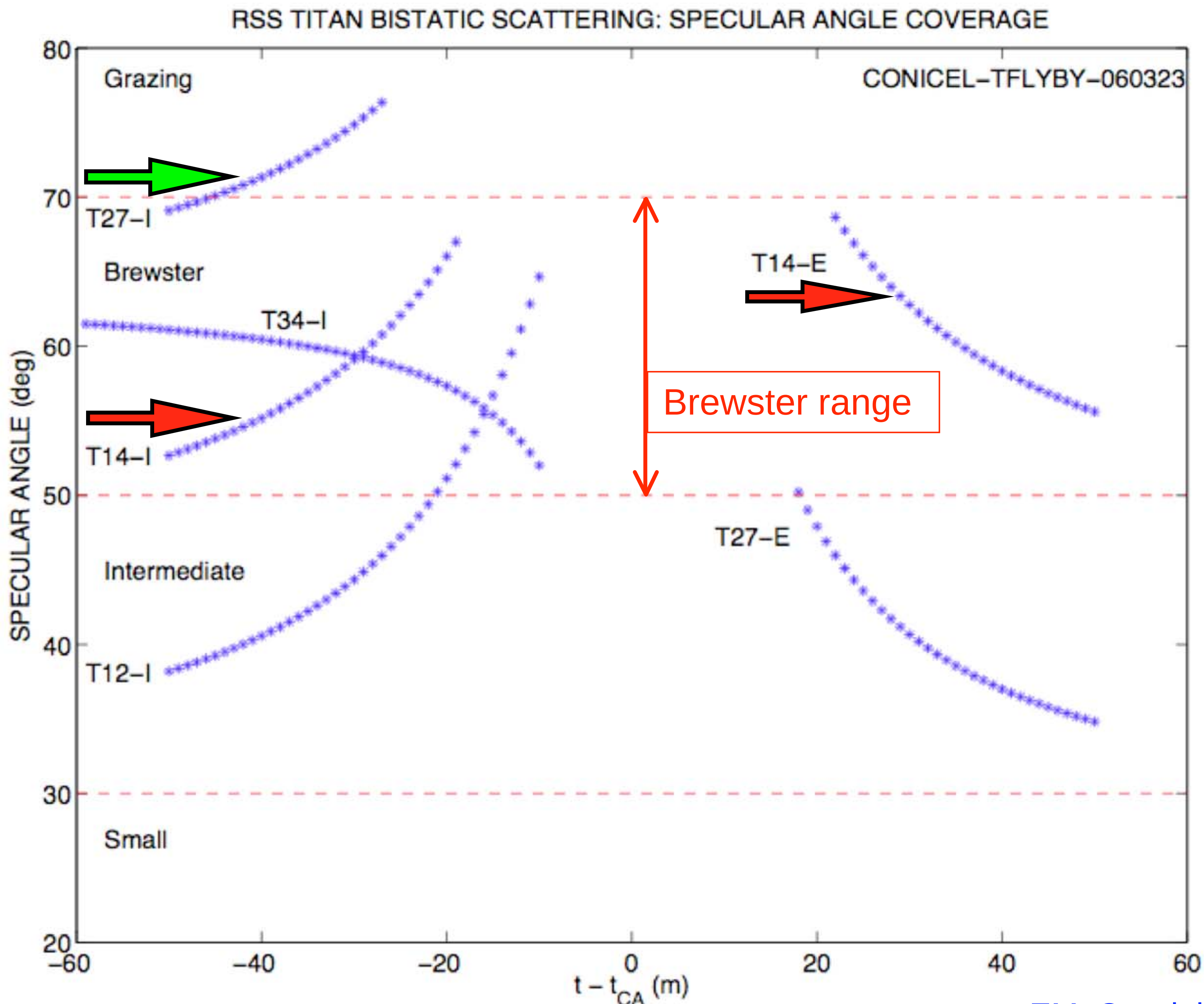
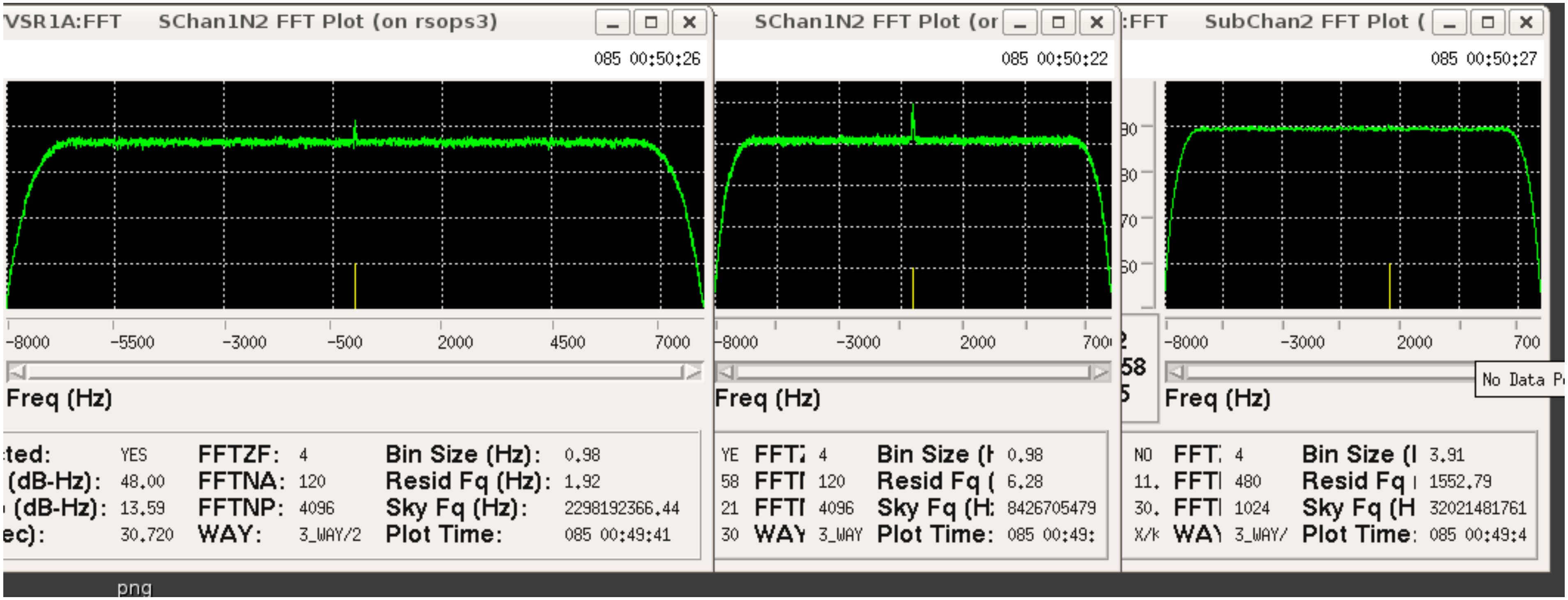


EM: Cassini RSS

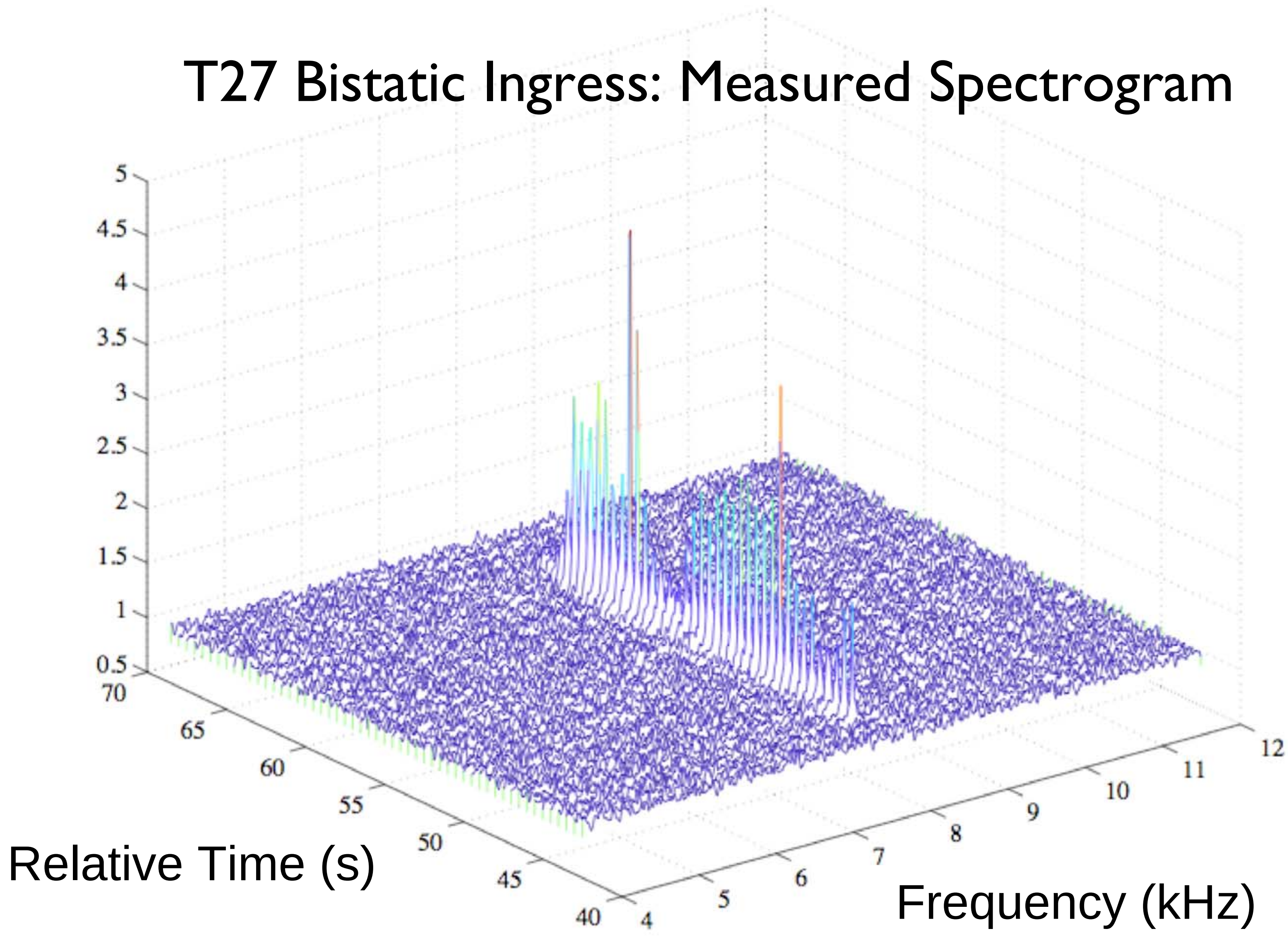
T27 Bistatic Ingress: Real-Time Spectra

S-Band X-Band Ka-Band

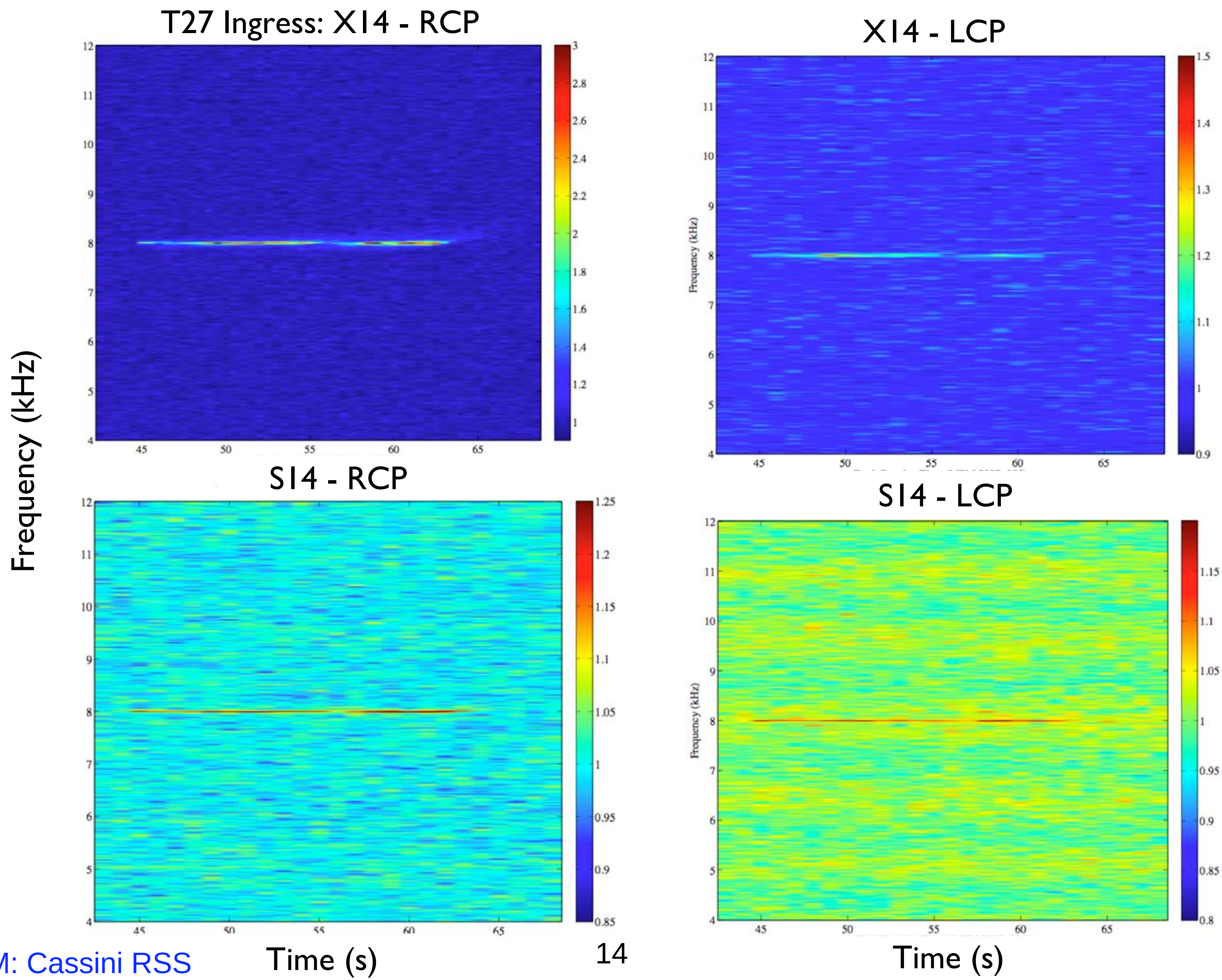


16 kHz Bandwidth, ~30 s average

T27 Bistatic Ingress: Measured Spectrogram

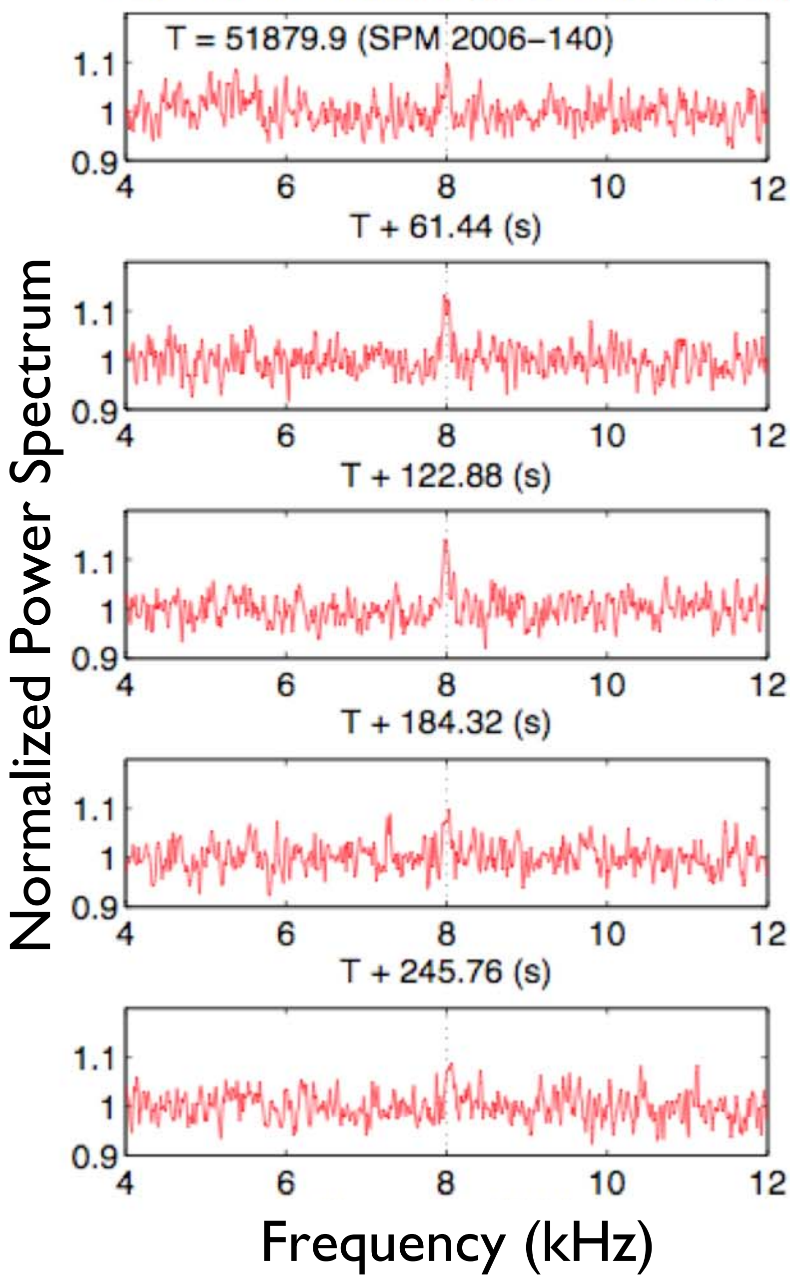


EM: Cassini RSS

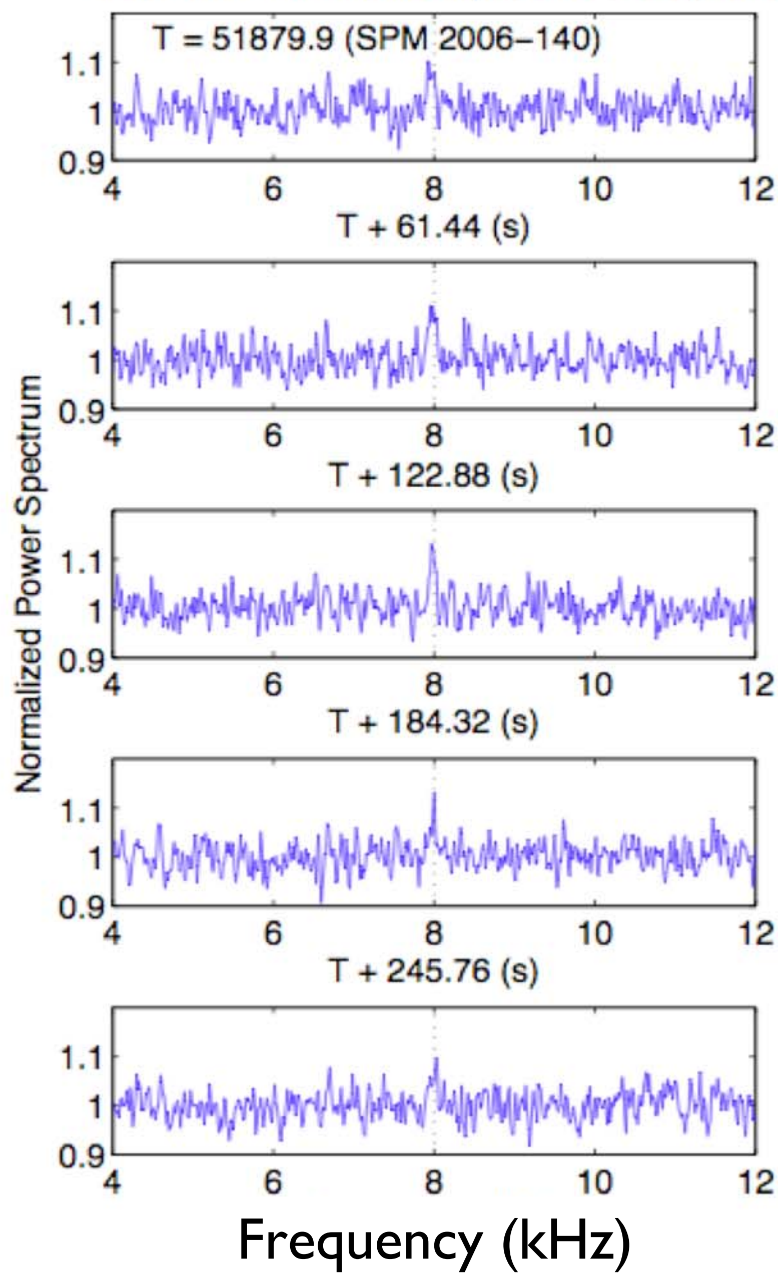


EM: Cassini RSS

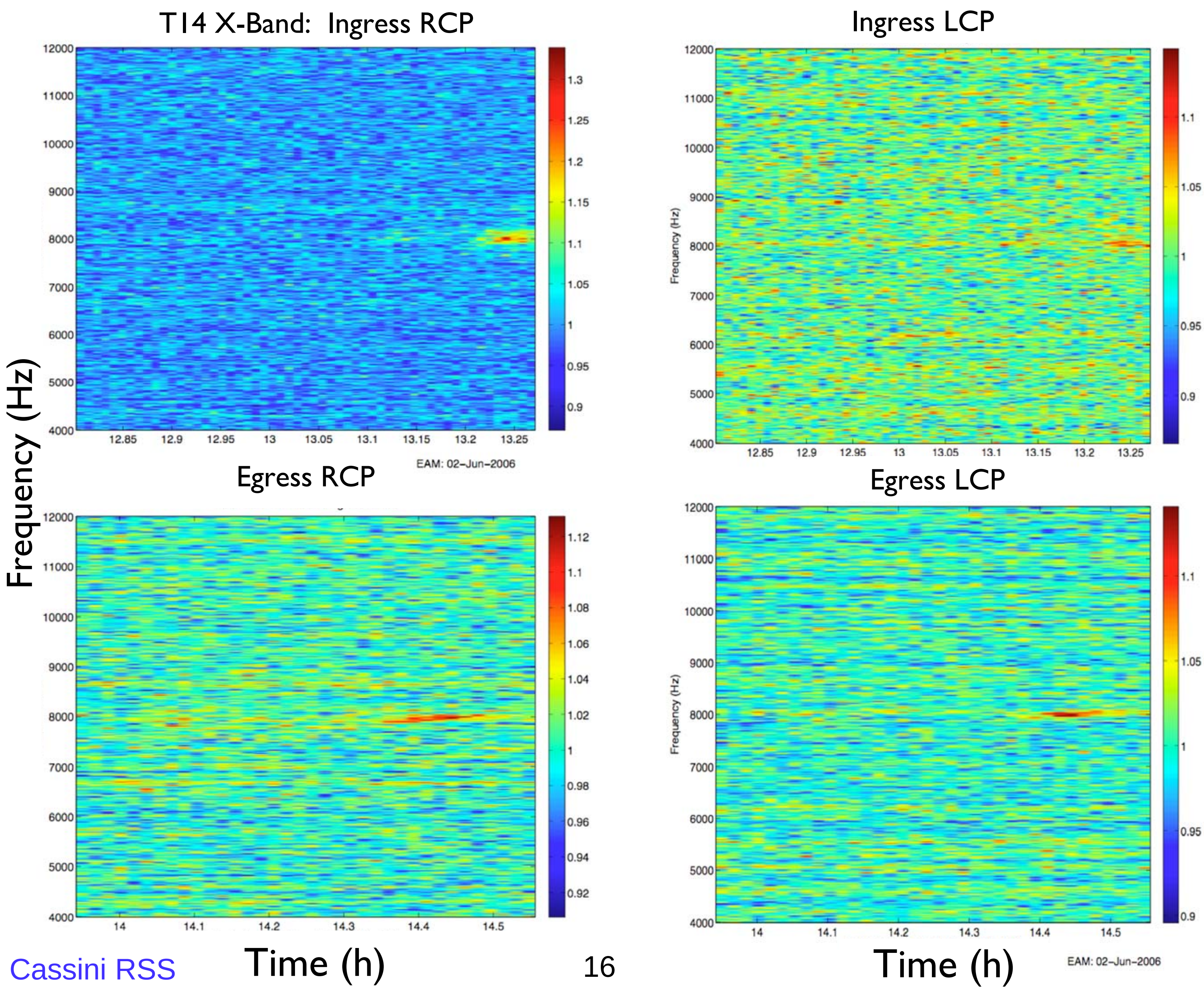
T14 Egress: LCP



T14 Egress: RCP

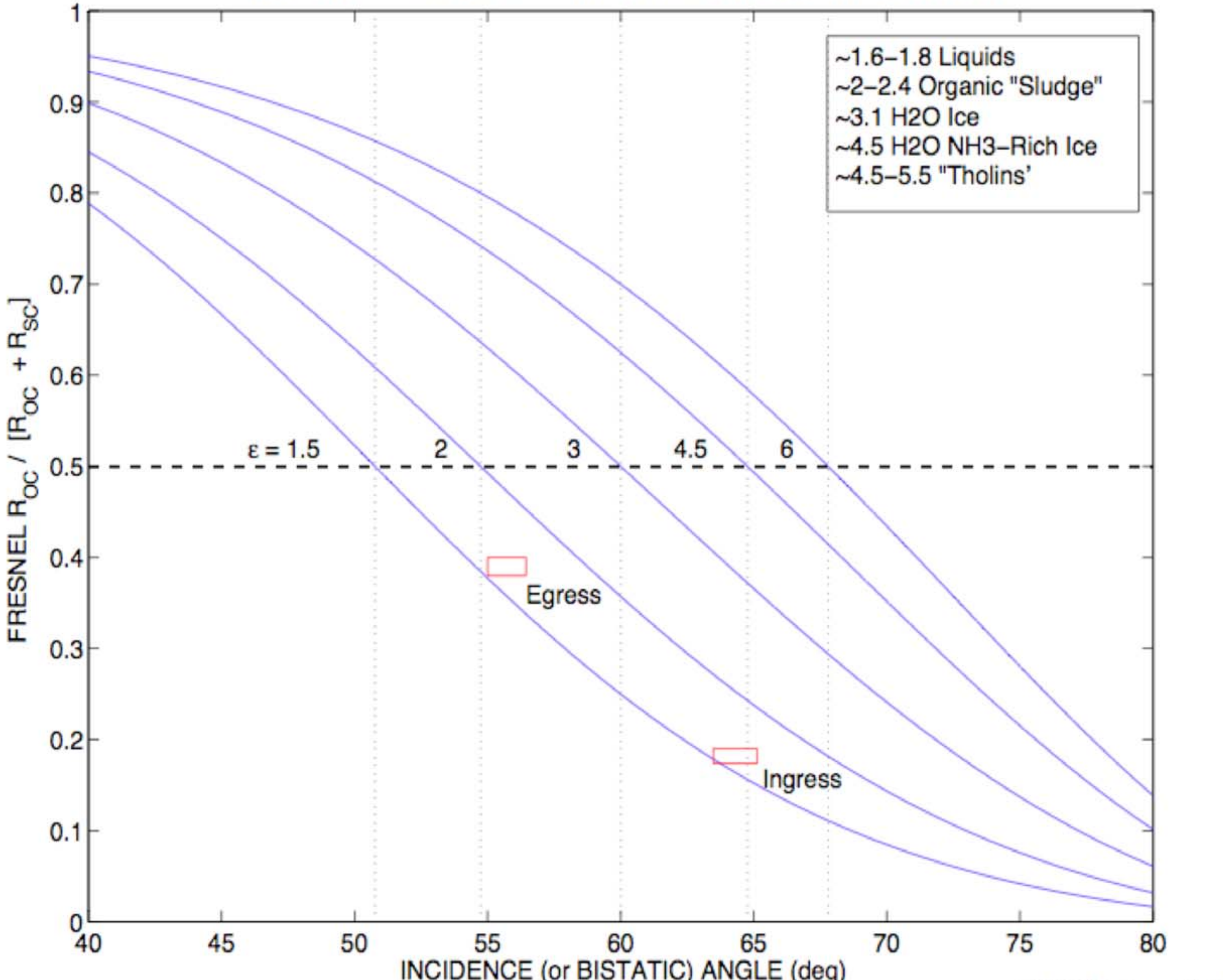


EM: Cassini RSS



EM: Cassini RSS

Liquid Hydrocarbons?



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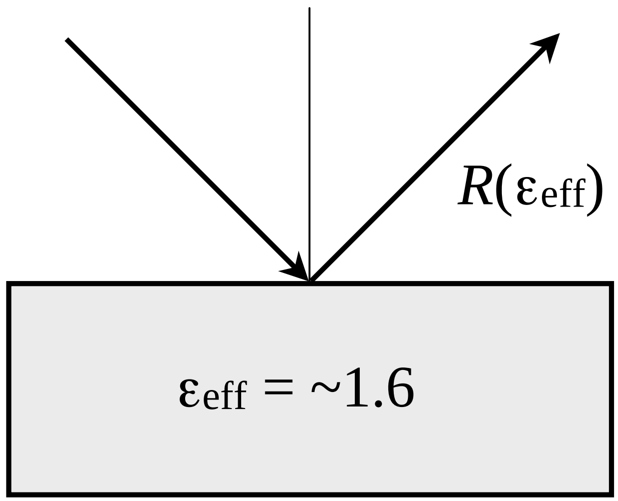
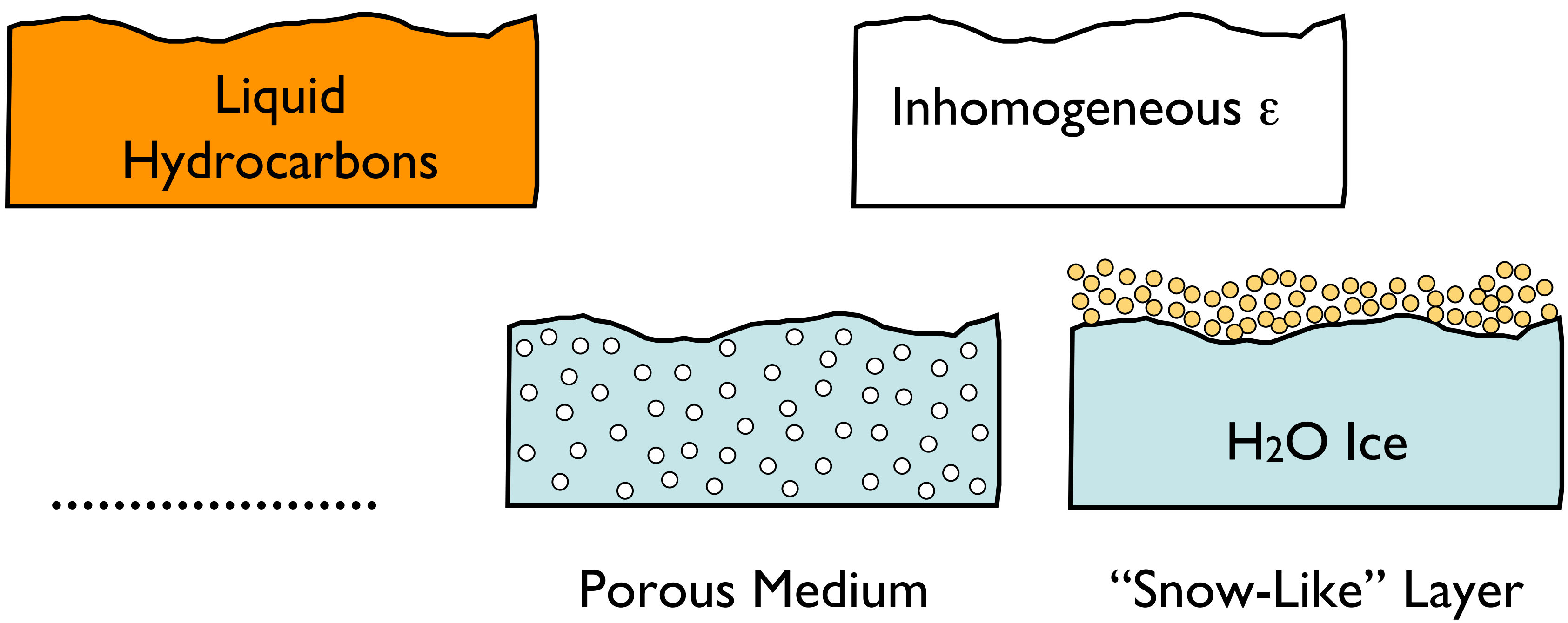
Alternatives





T31 Occultation Geometry: May 27, 2007

$\Delta t = 300$ (s)

flyby−alt = 2284 (km)

V−ing = −2.9 (km/s)

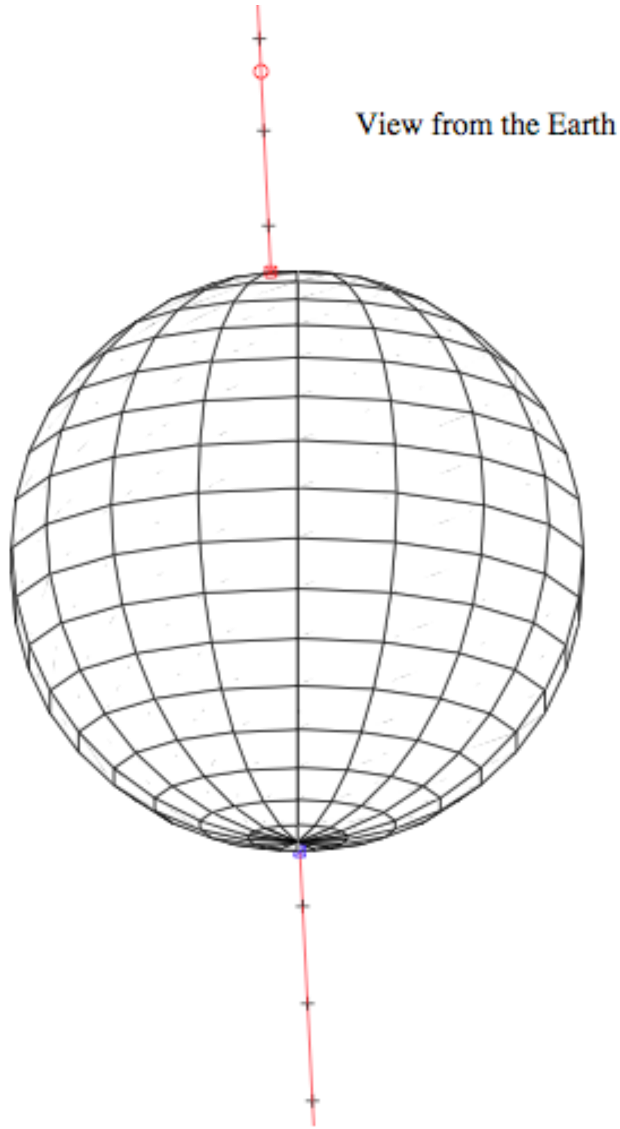
V−egr = 2.9 (km/s)

D−ing = 14938.7 (km)

D−egr = 5597.5 (km)

m−ing = 11 (mdeg/s)

m−egr = 29.2 (mdeg/s)

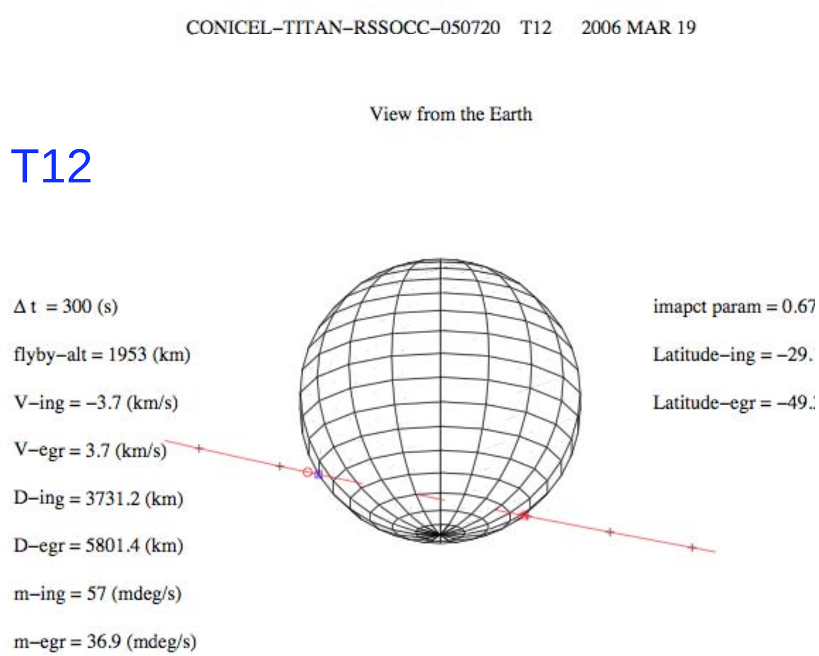


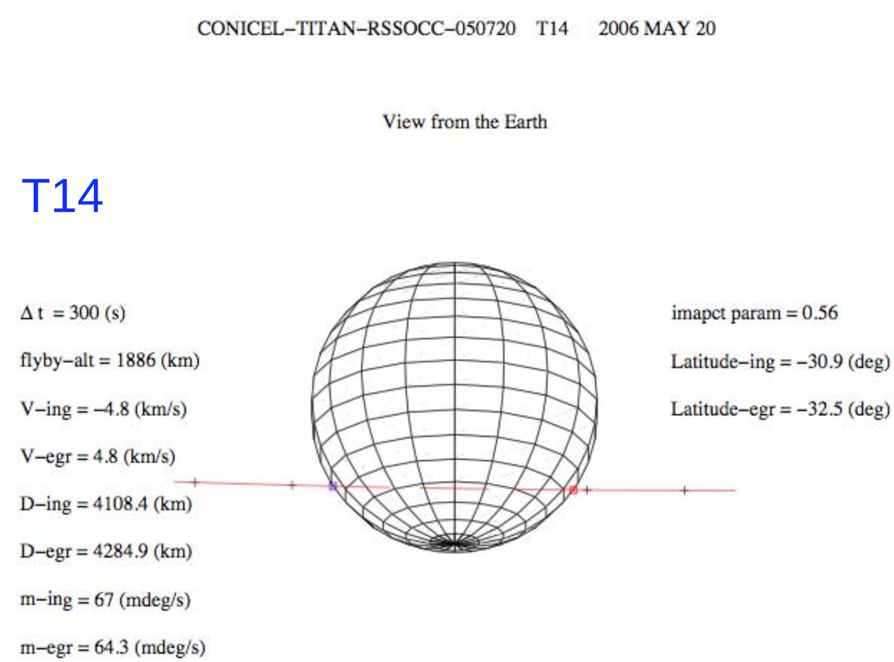
imapct param = 0.04

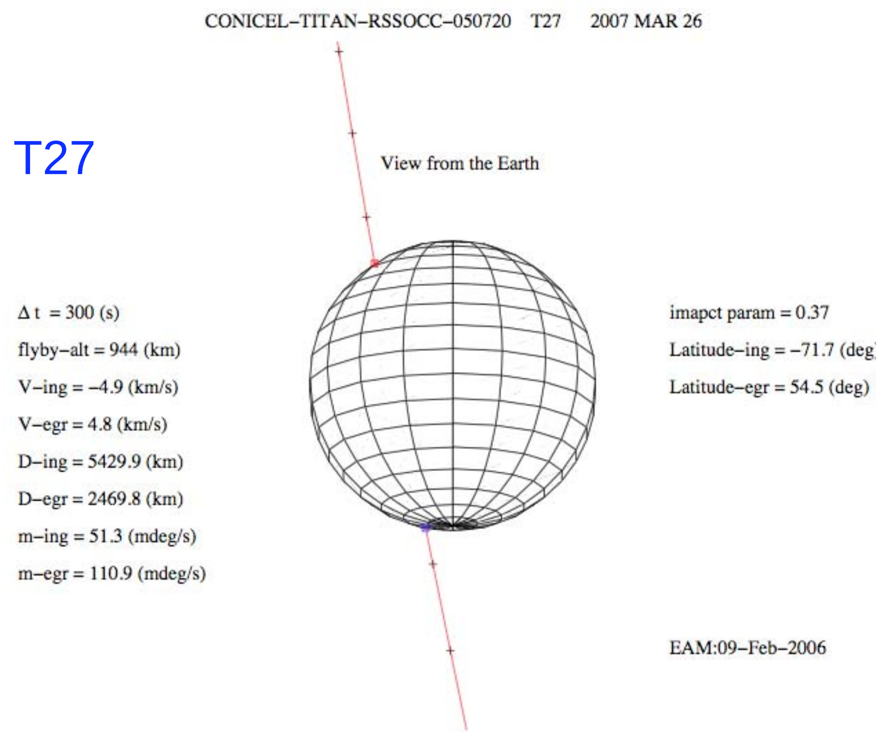
Latitude−ing = −75.4 (deg)

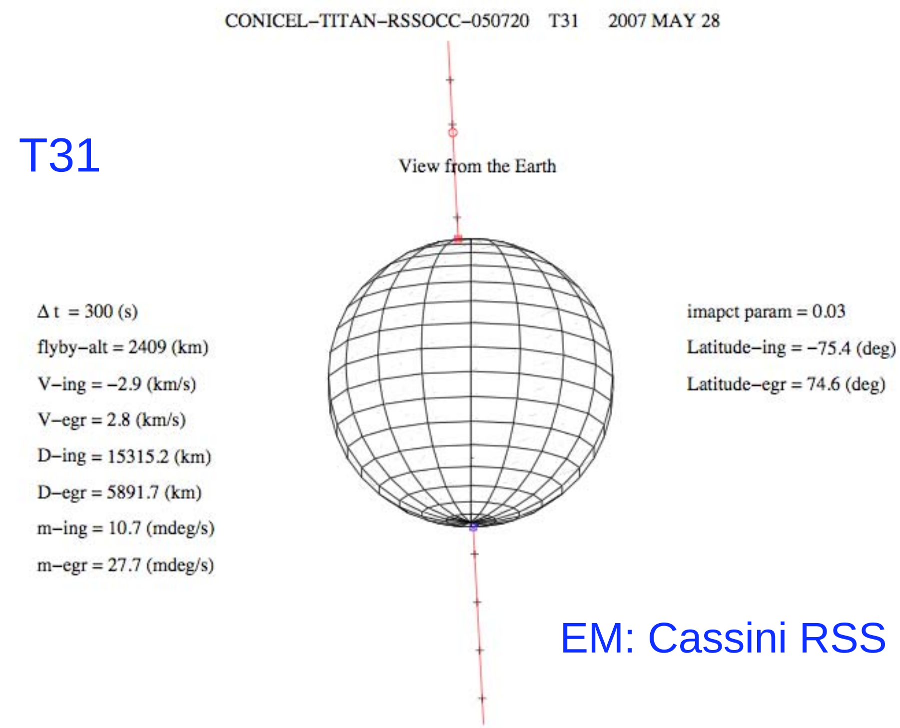
Latitude−egr = 74.6 (deg)

EAM: Cassini RSS









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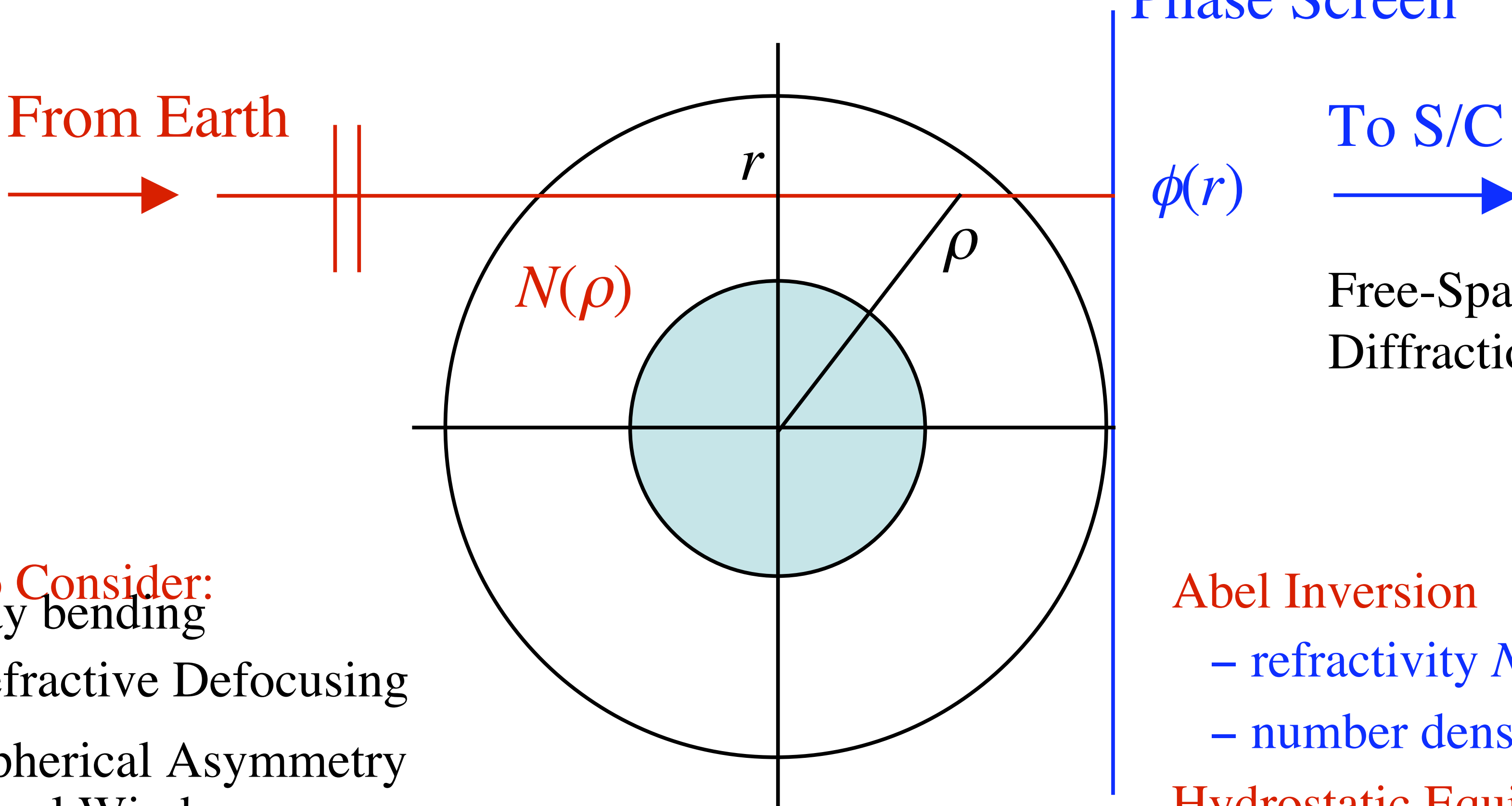
Atmospheric Occultation



To Consider:

Ray bending

Refractive Defocusing

Spherical Asymmetry

Zonal Winds

Absorption

Scattering

$$\phi(r) = \int_{-\infty}^{\infty} \frac{N(\rho)\,\rho\,d\rho}{\sqrt{\rho^2 - r^2}}$$

Abel Inversion

– refractivity $N(r)$

– number density $n(r)$

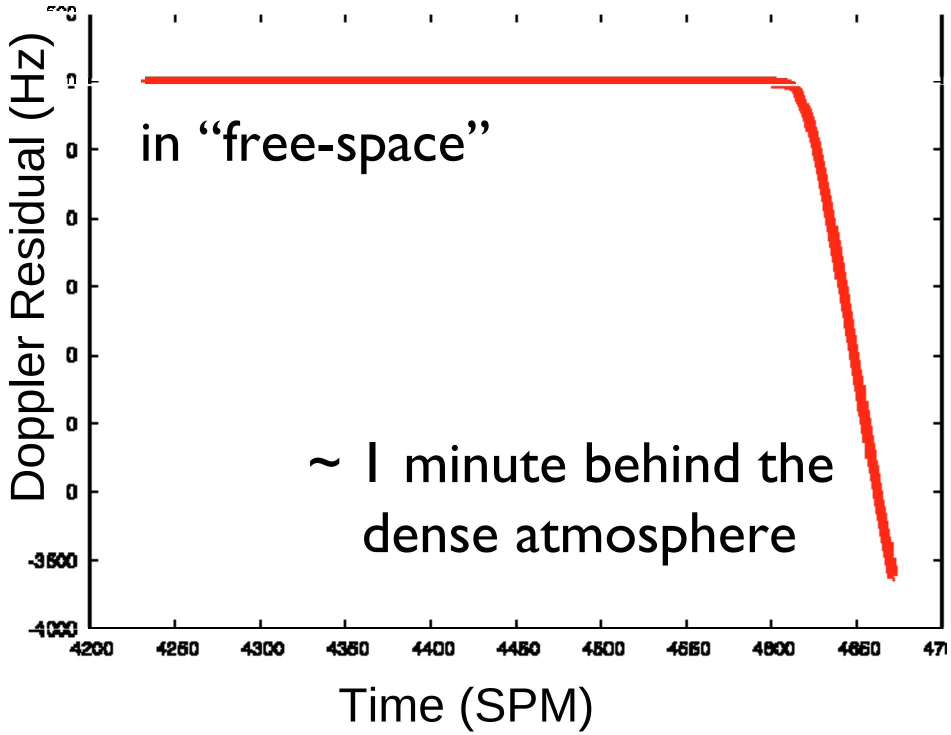
Hydrostatic Equilibrium

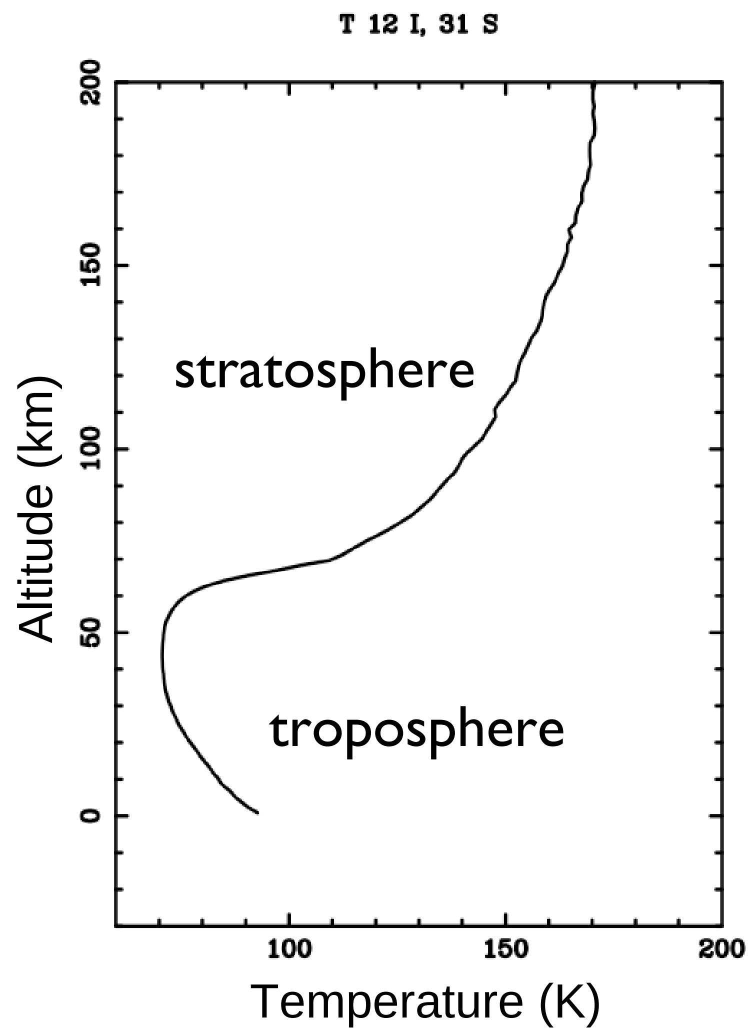
– pressure $p(r)$

Equation of State

– temperature $T(r)$

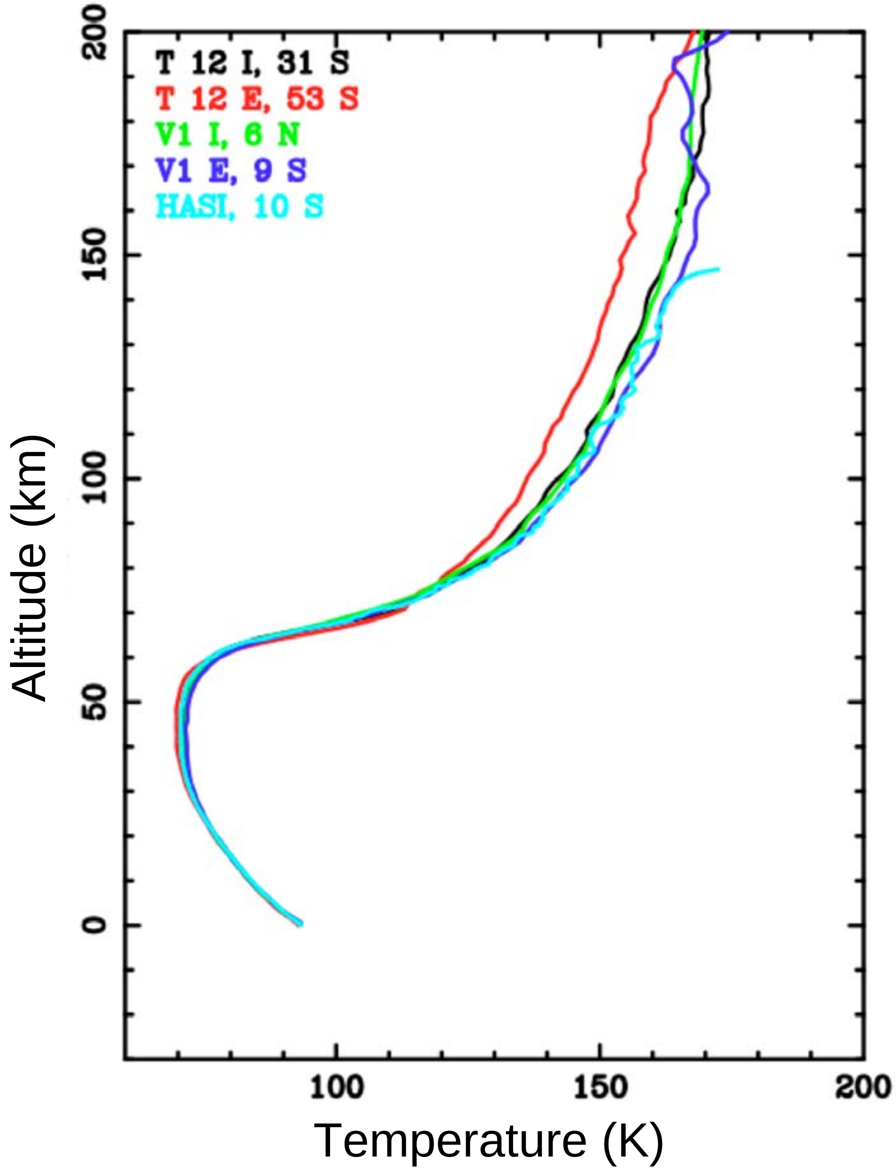
Frequency Residuals & Temperature Profile
T12 ingress, X63





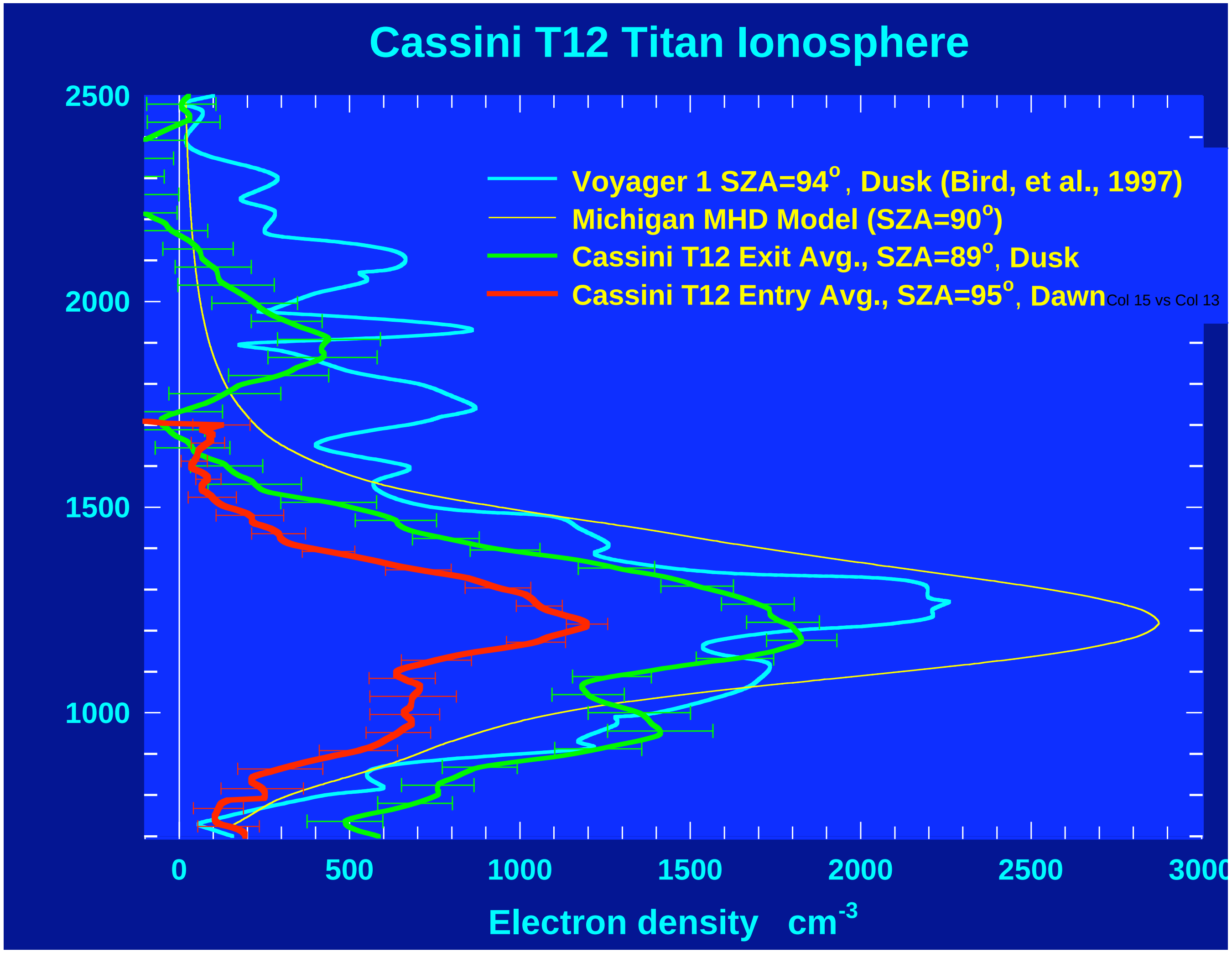
PS: Cassini RSS

Titan Temperature Profile: Cassini, HASI, Voyager Comparison

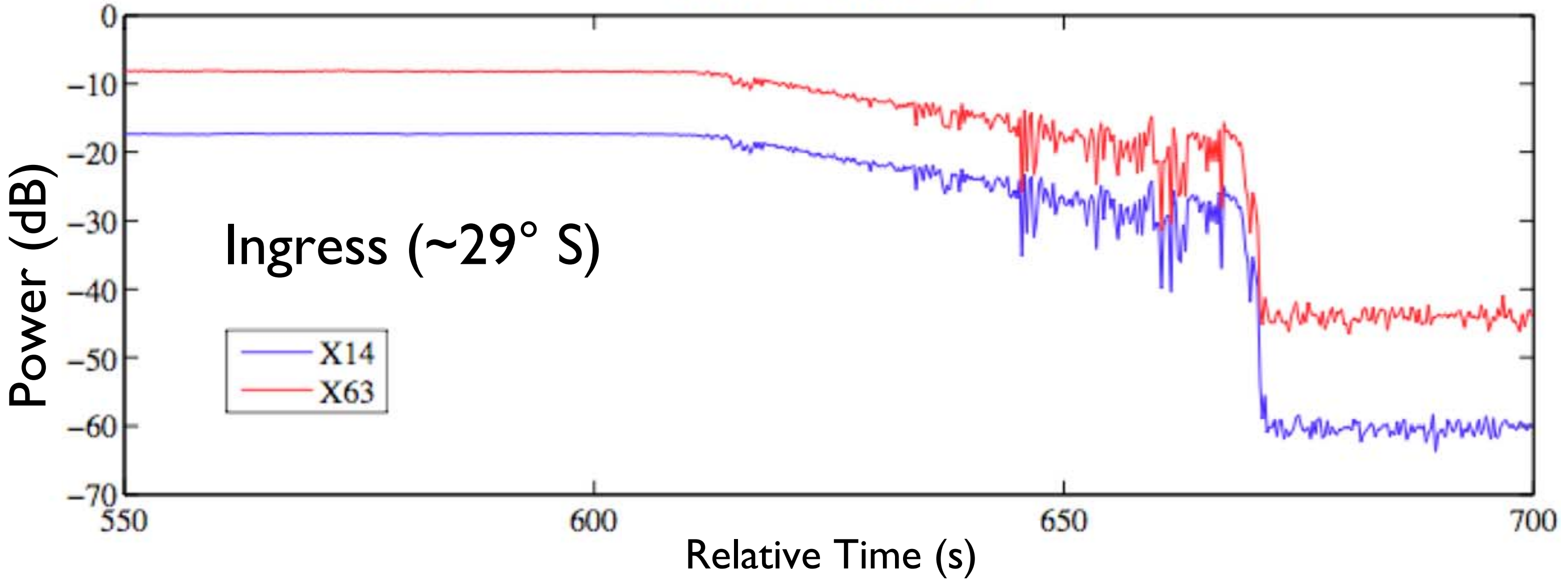


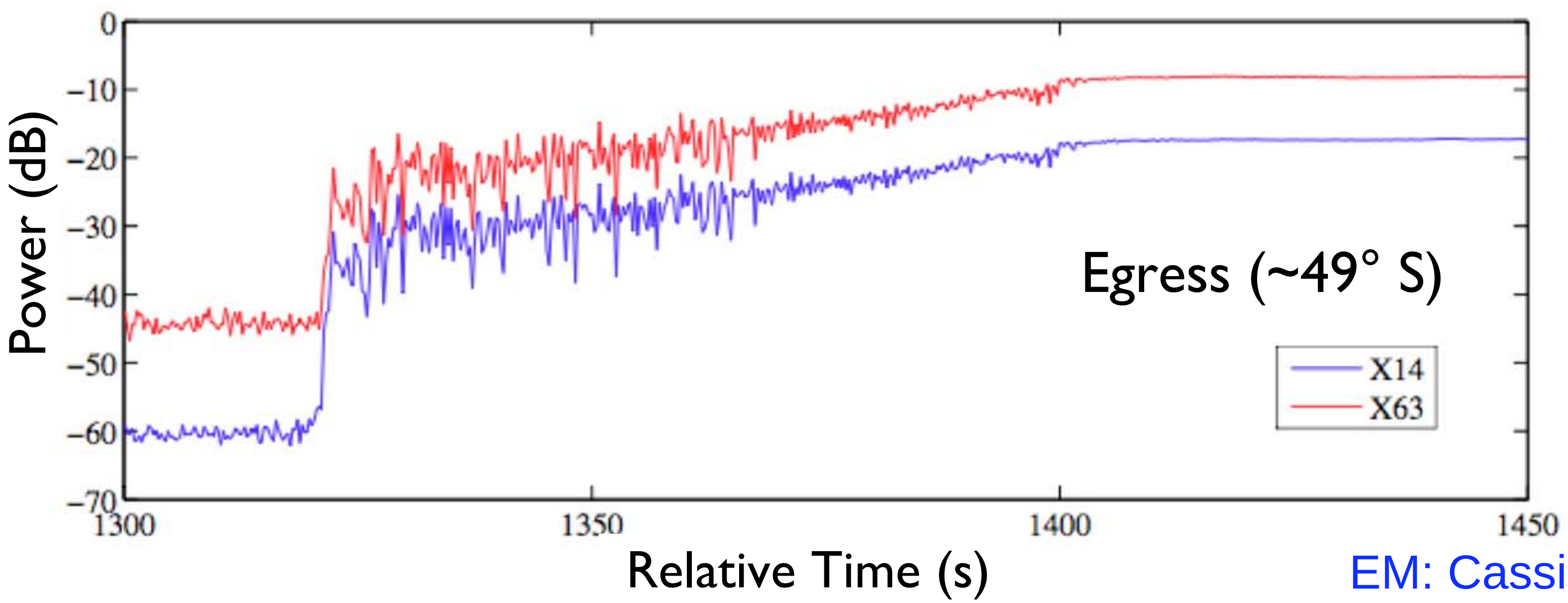
PS: Cassini RSS

Measured Frequency Residuals are also used to recover the electron number density in the ionosphere



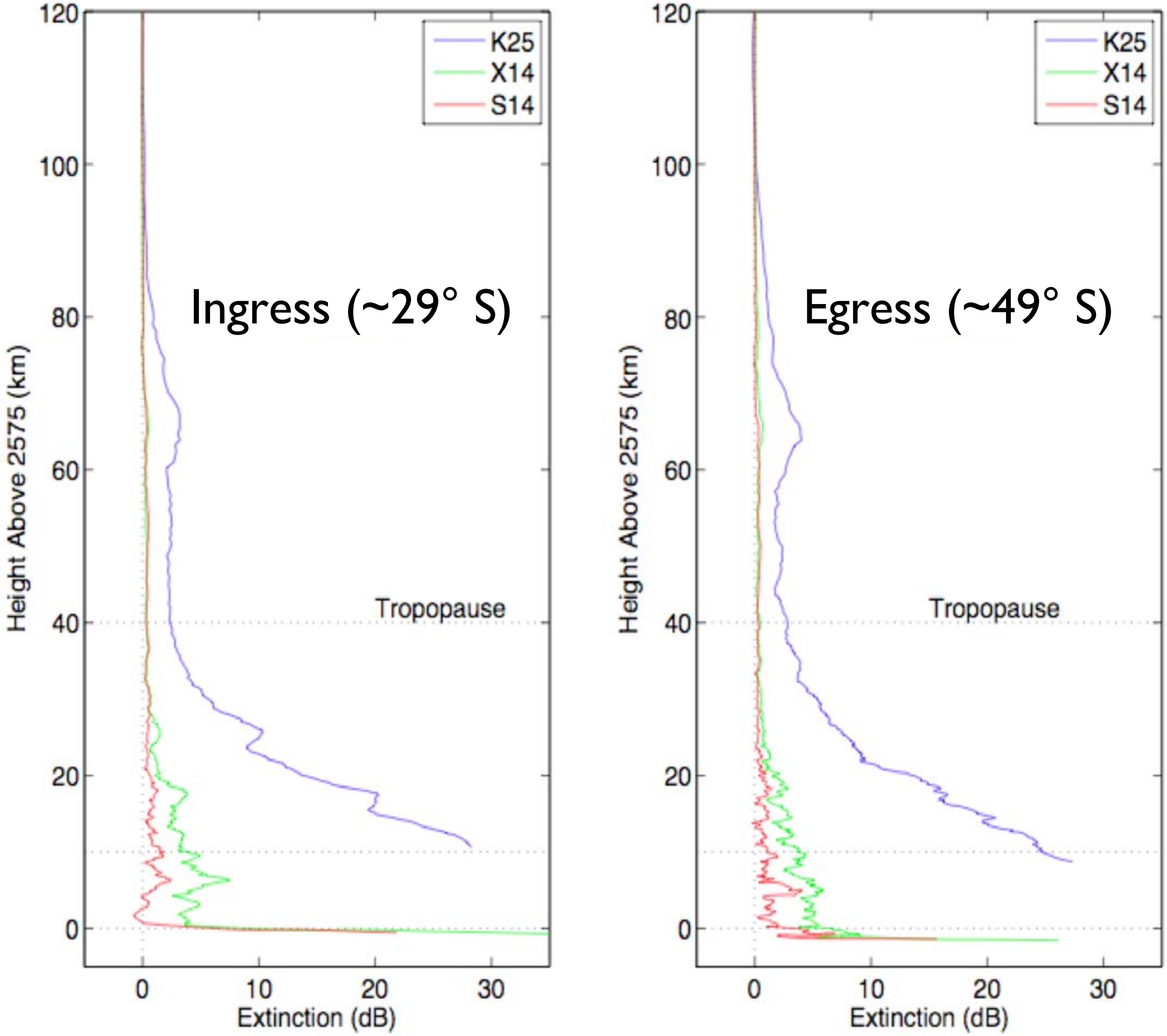
Measured Signal Intensity: T12





EM: Cassini RSS

S/X/Ka Extinction Profiles: T12



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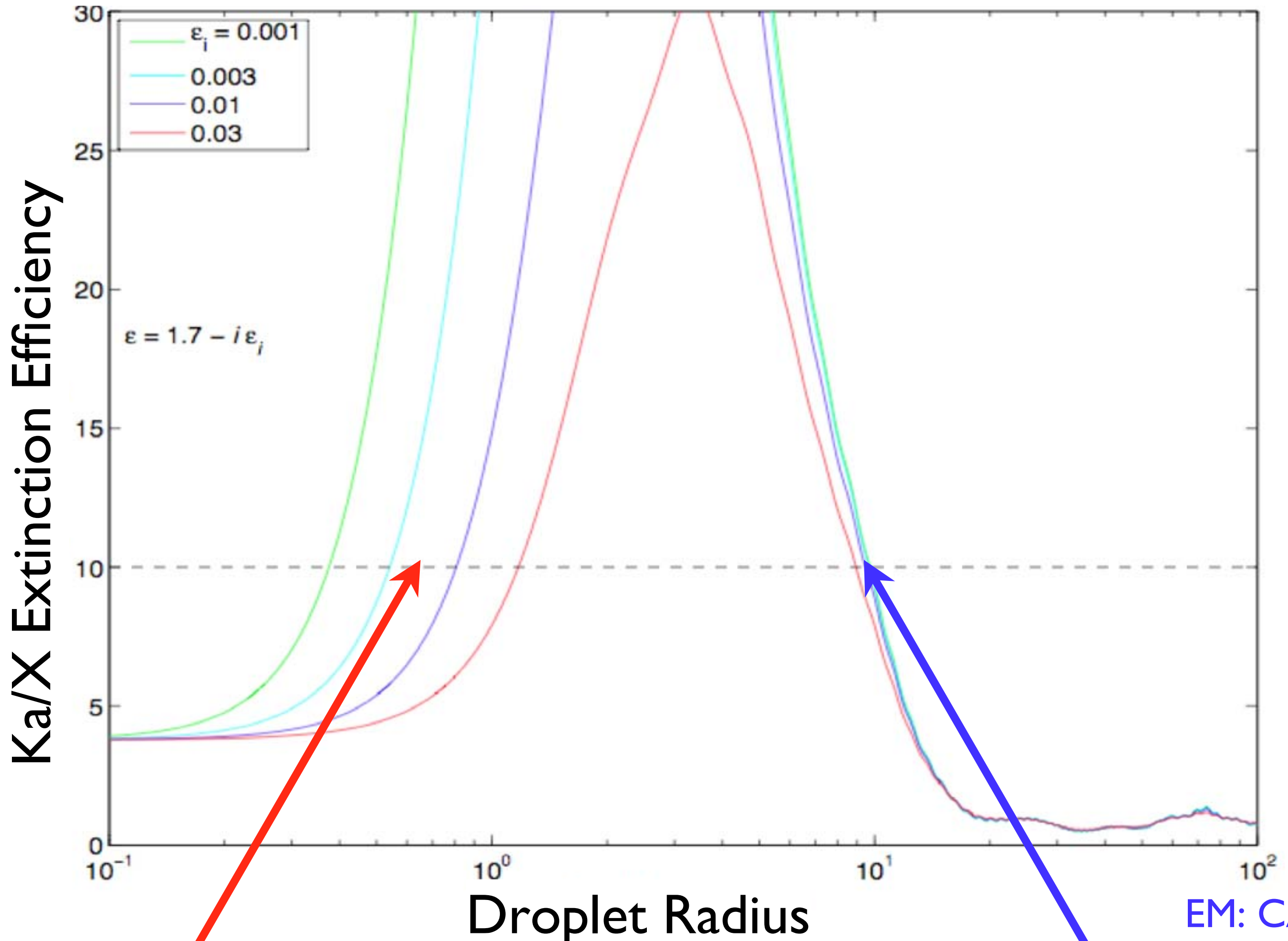
Extinction Due to Tropospheric Raindrops?



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radius ~ 0.1 to 1 mm
- large number density is implied
- very large ORS normal optical depth
- must be discounted

radius ~ 10 mm
- small ORS normal optical depth (<0.05)
- very large droplet sizes implied
- inconsistent with finite S-band extinction

N_2-N_2 , N_2-CH_4 Collision Induced Gaseous Absorption

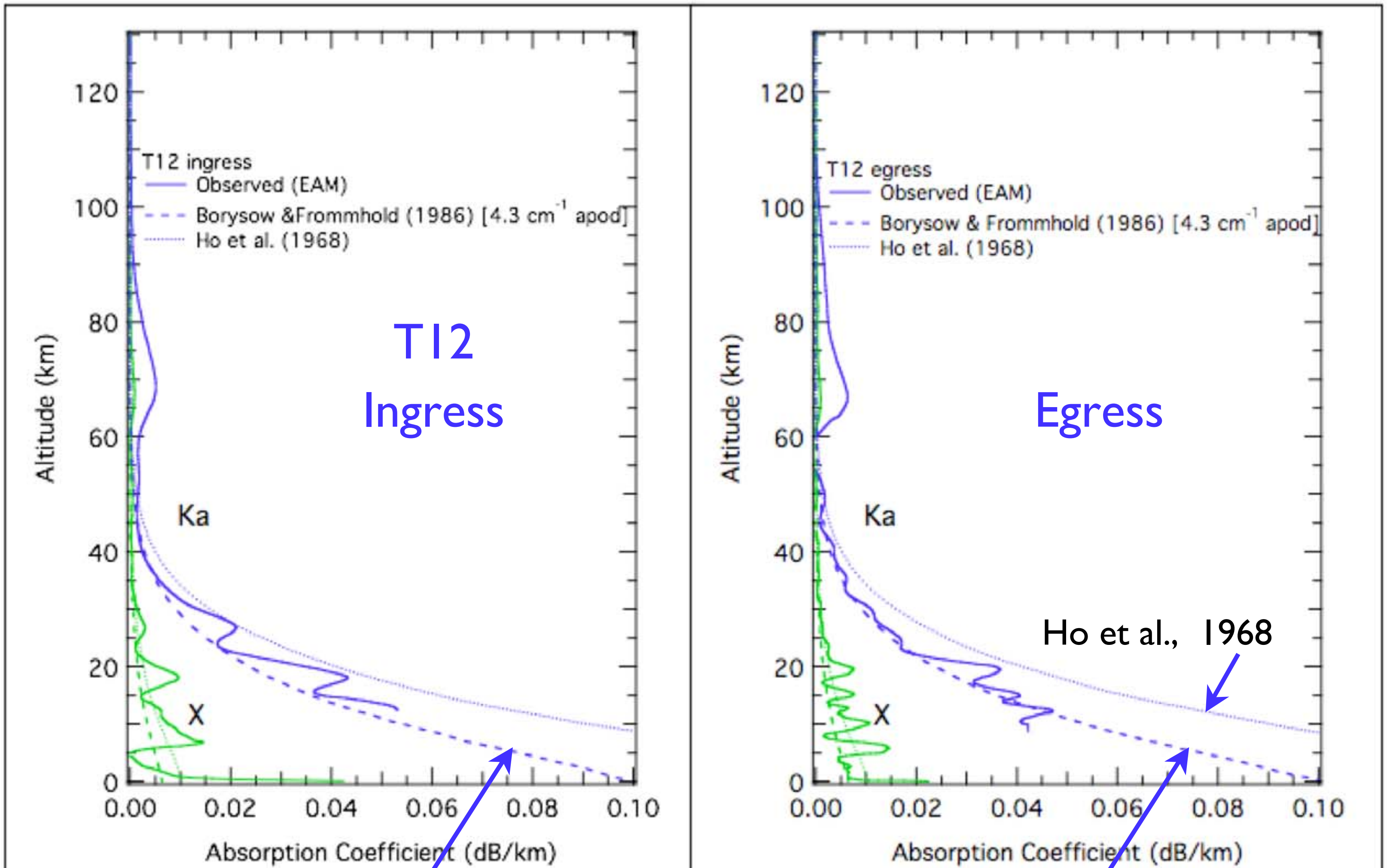


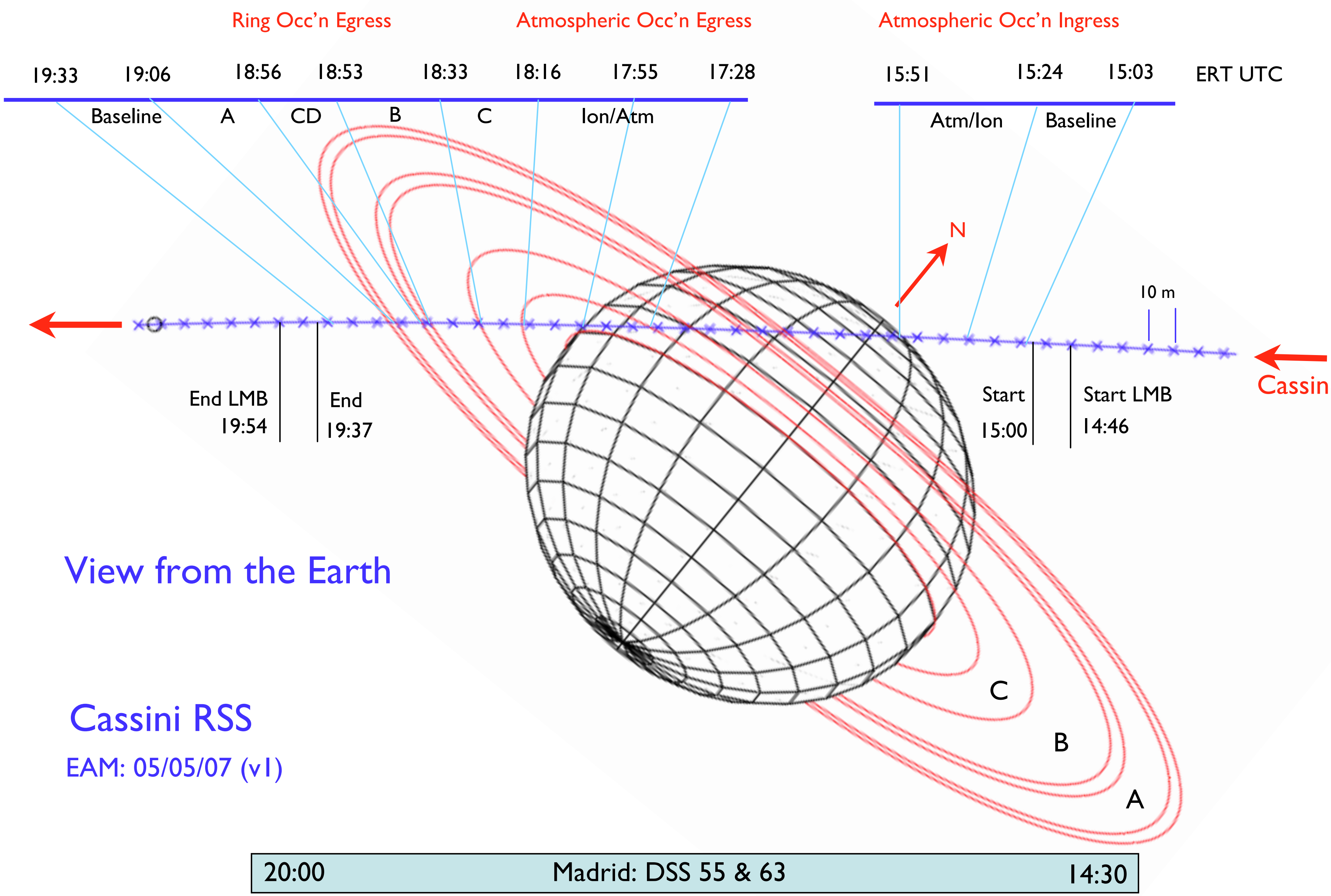
Fig. 2

Borysow & Frommhold 1986 as Adapted by Mike Flasar

- nicely envelopes the absorption coefficient from below
- residual microwave absorption mechanism ?

Rev 44: RSS Saturn's Ring & Atmospheric Occultations

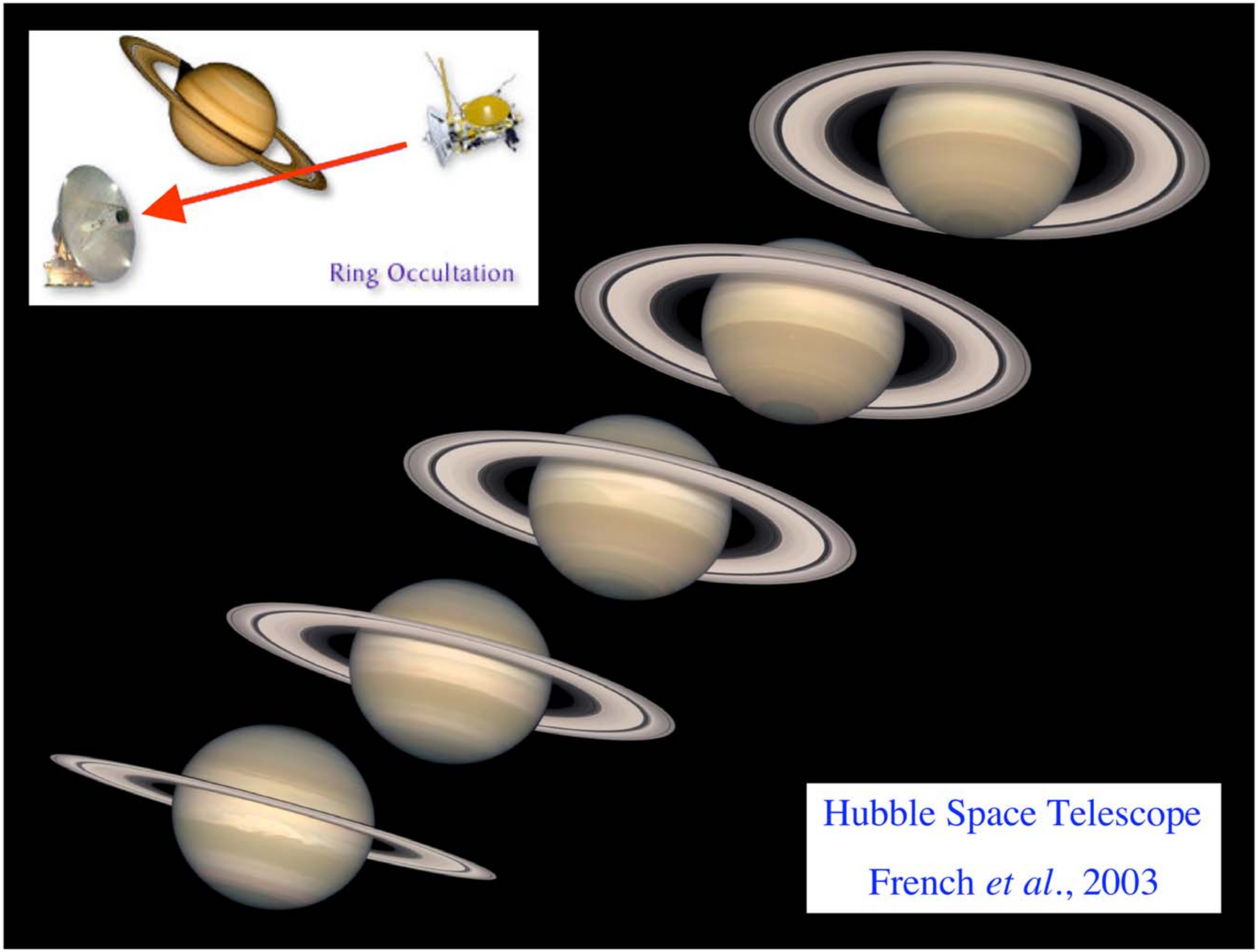
May 10, 2007 (DOY 130)

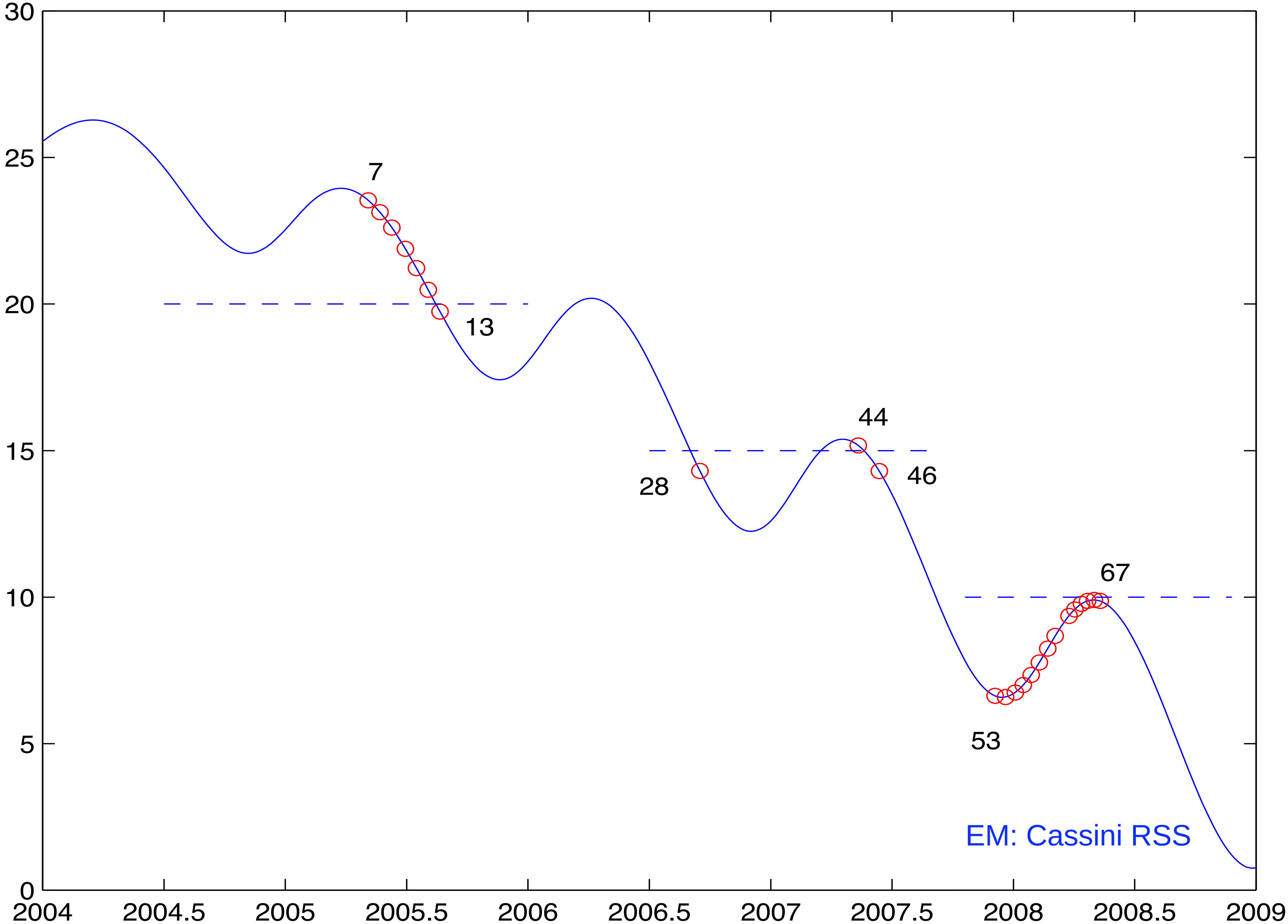


View from the Earth

Cassini RSS

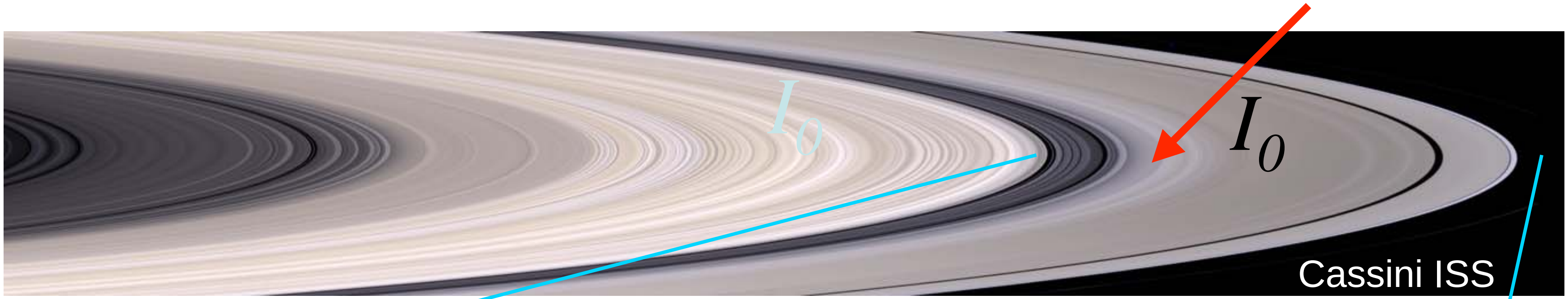
EAM: 05/05/07 (v1)

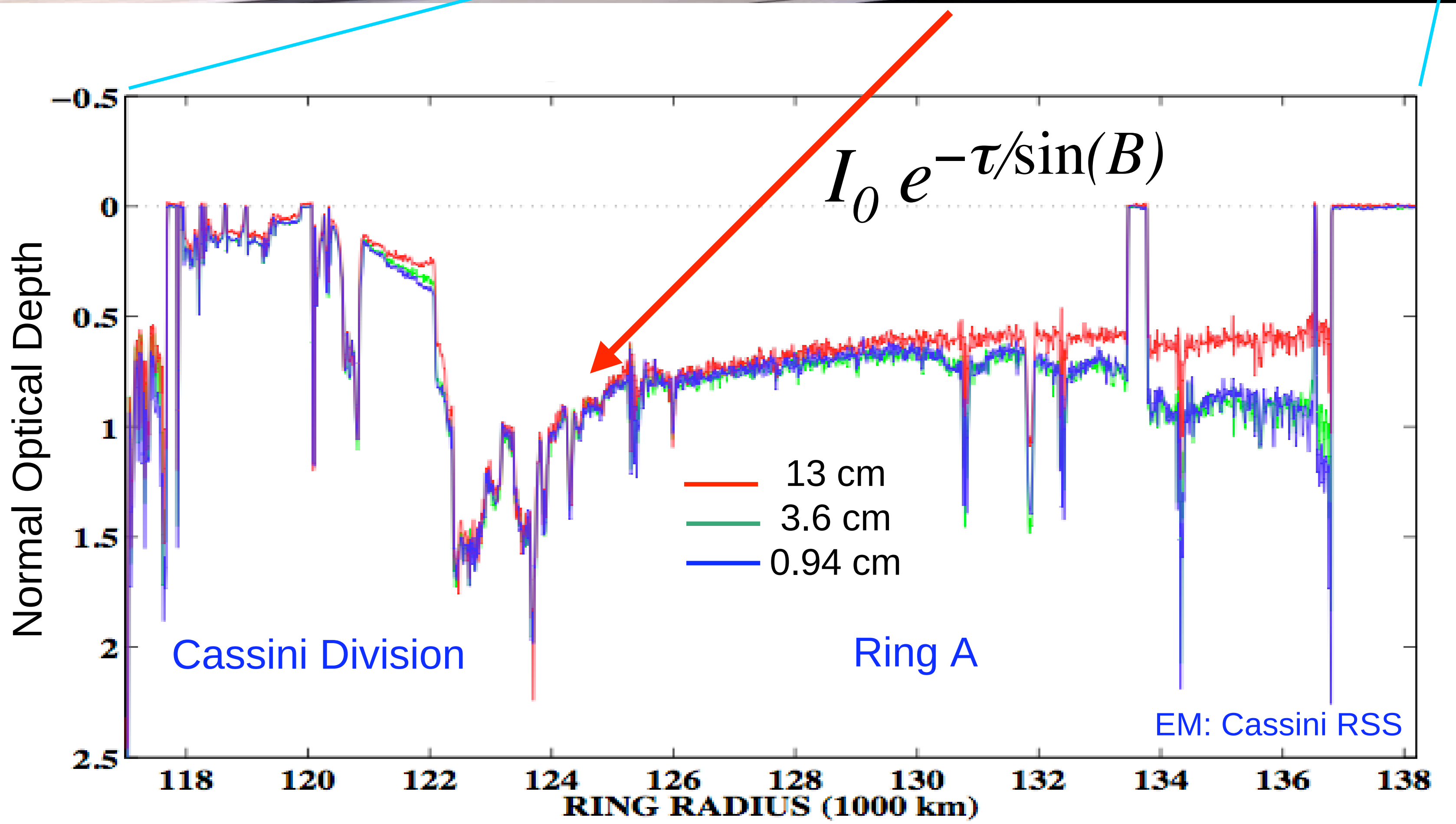

Ring Occultation
Hubble Space Telescope
French *et al.*, 2003



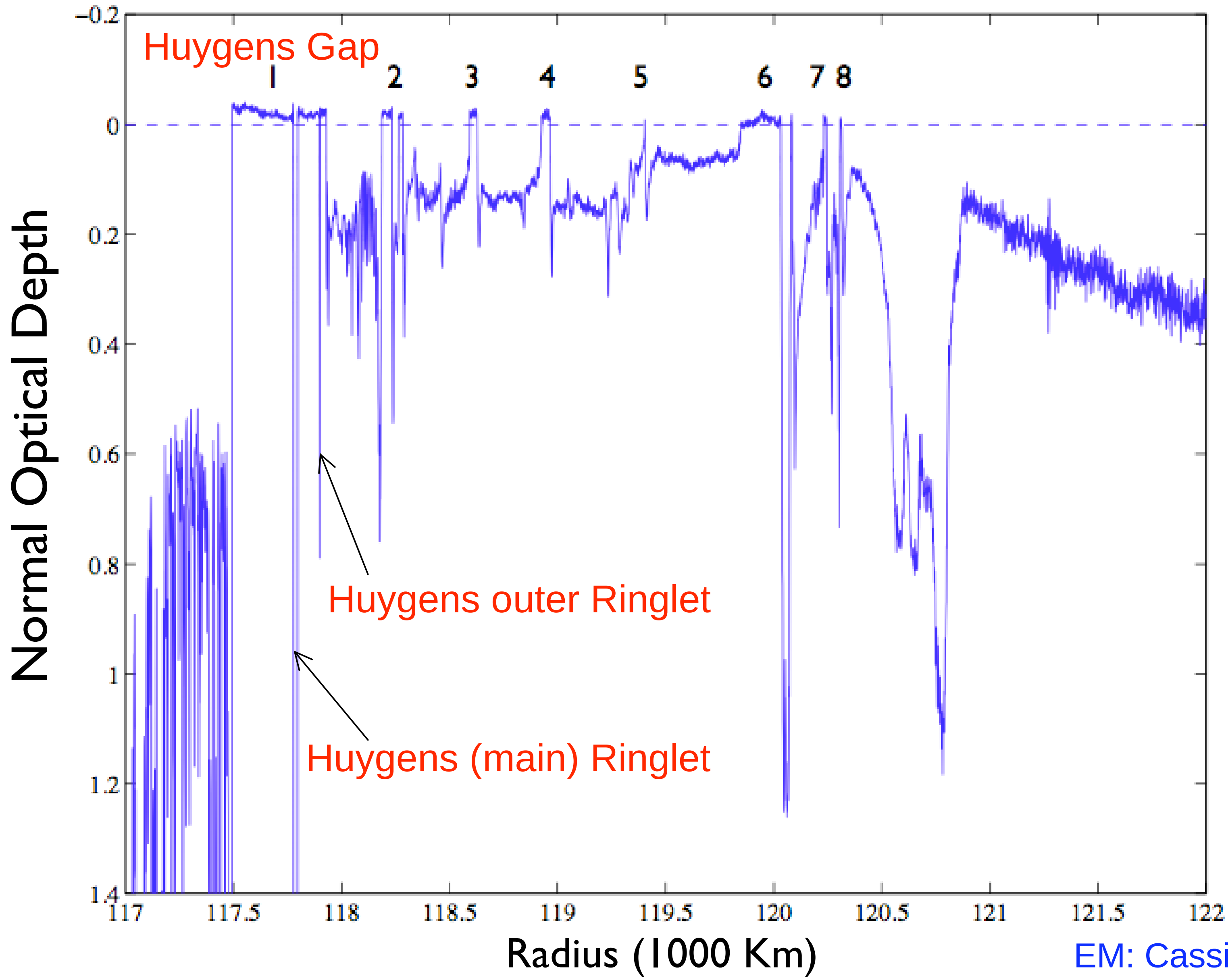
30
25
20
15
10
5
0
2004
2004.5
2005
2005.5
2006
2006.5
2007
2007.5
2008
2008.5
2009
7
13
28
44
46
53
67
EM: Cassini RSS

Profiling Ring Structure by Cassini Radio Occultation





Cassini Division: Gaps & Narrow Ringlets

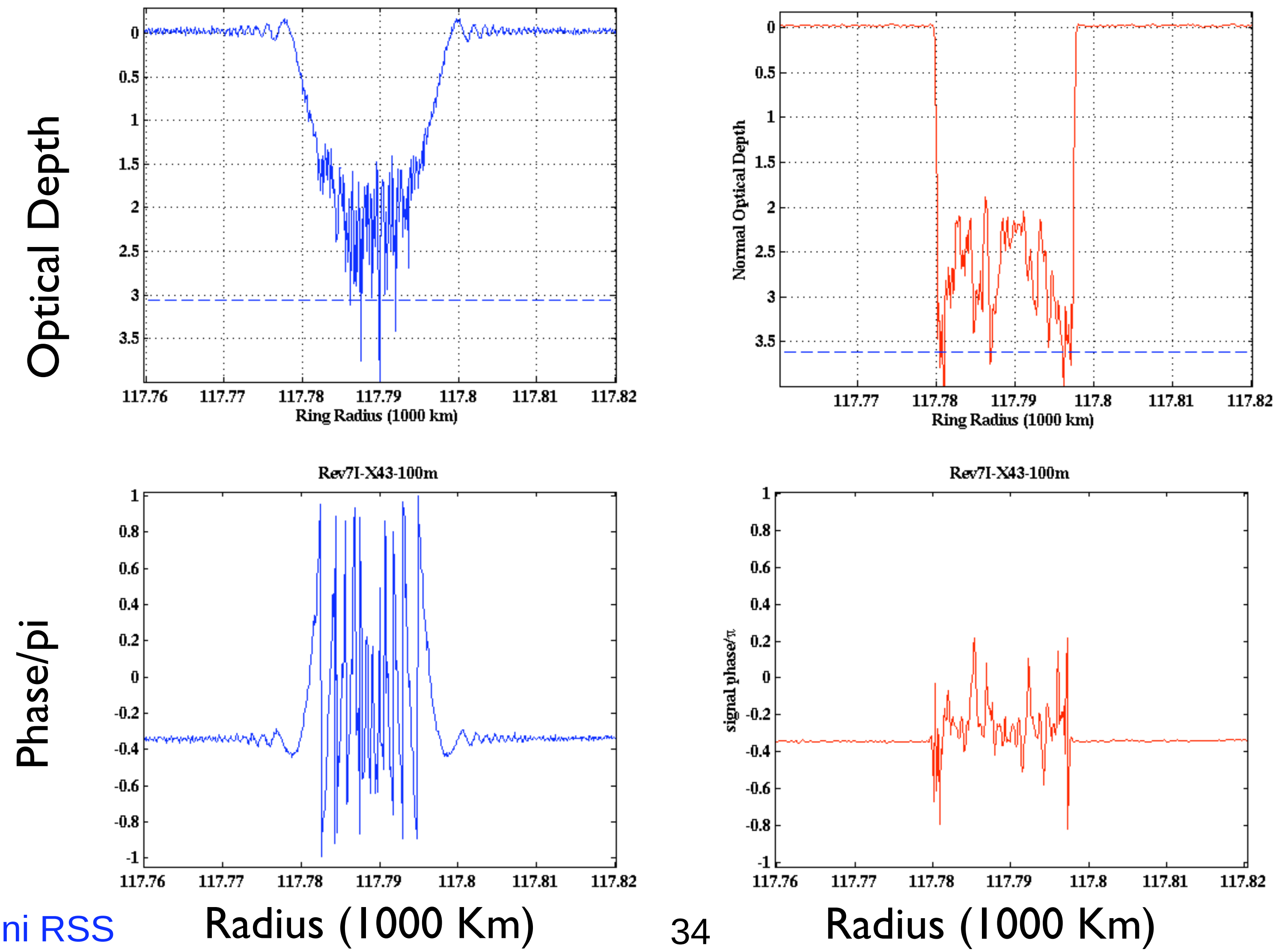


EM: Cassini RSS

Holographic Reconstruction of Diffraction Effects

Example of the Huygens Gap Main Ringlet

Measured | **Reconstructed**



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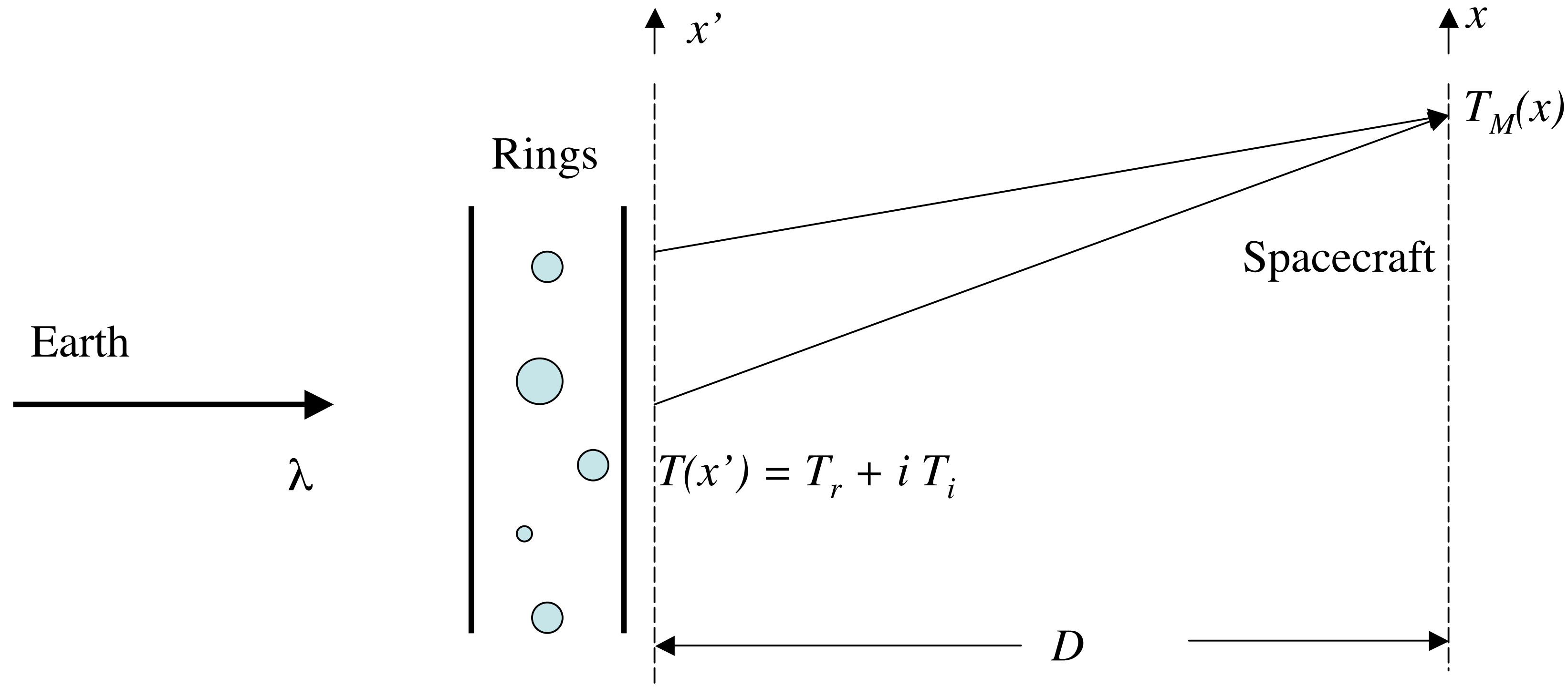
Fresnel Diffraction & Holographic Reconstruction



- -Inverse Fresnel Transform
- -Diffraction Reconstruction
- -Diffraction Correction
- -Back-Propagation
- -Deconvolution

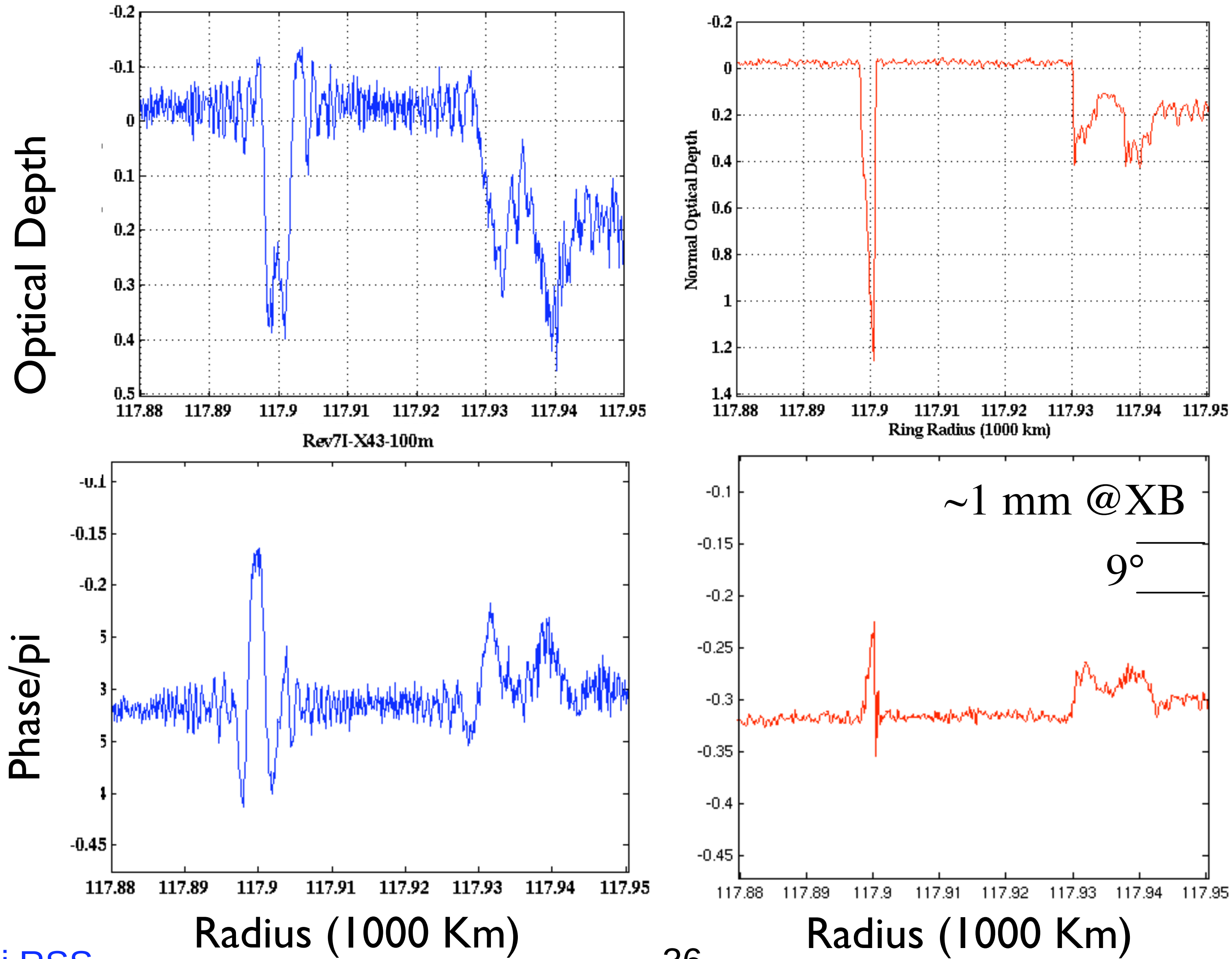
$$T_M(x) = \frac{1-i}{2F}\int_{-\infty}^{\infty} T(x')\ \exp[i\frac{\pi}{2}(\frac{x-x'}{F})^2]\ dx'$$

$$T(x') = \frac{1+i}{2F}\int_{-\infty}^{\infty} T_M(x)\ \exp[-i\frac{\pi}{2}(\frac{x'-x}{F})^2]\ dx$$

Holographic Reconstruction of Diffraction Effects

Example of the Huygens Gap Outer Ringlet

Measured | Reconstructed



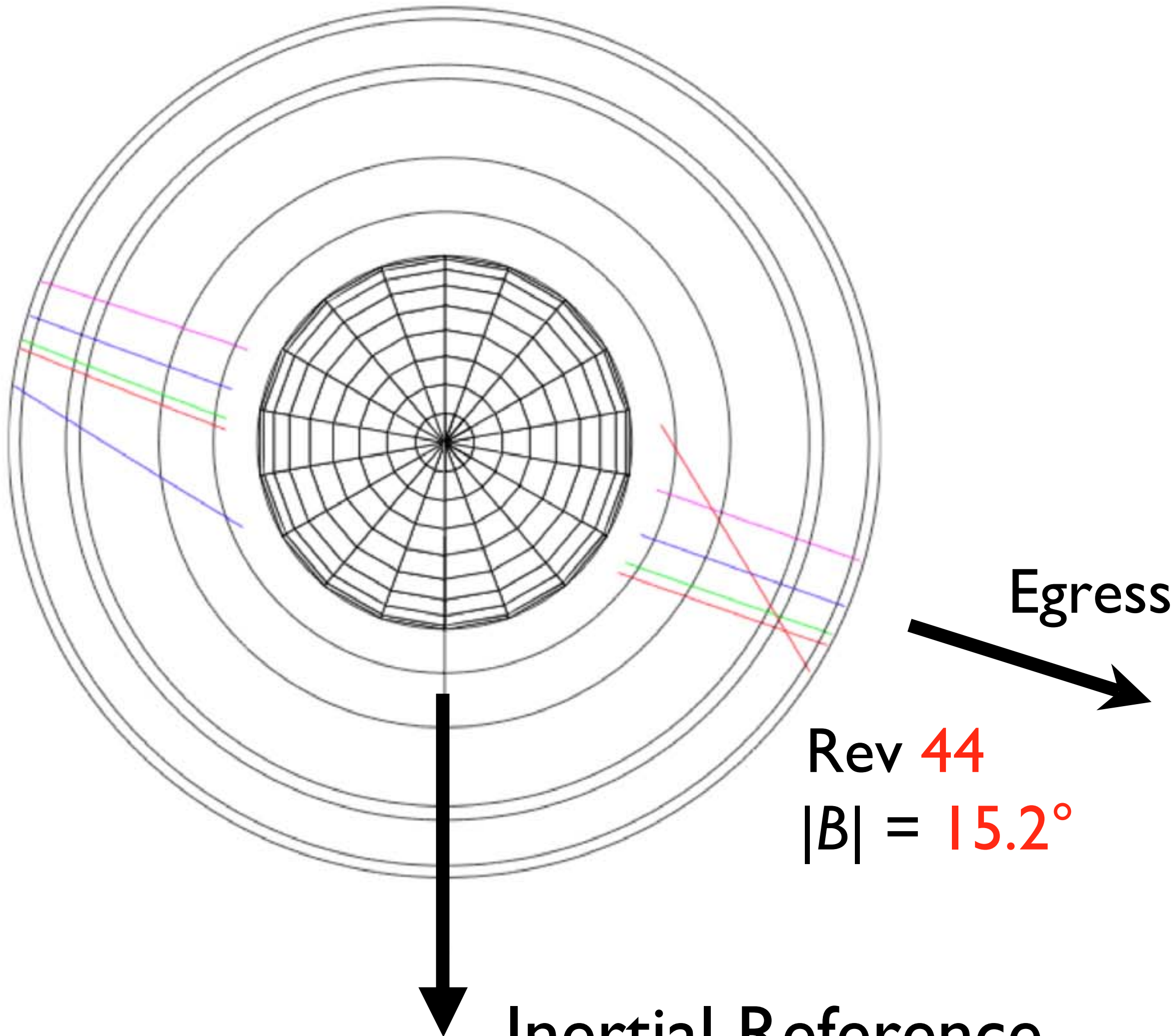
EM: Cassini RSS

Multiple Observation Longitudes

(15 completed; 10 are shown)

View from Saturn's North Pole

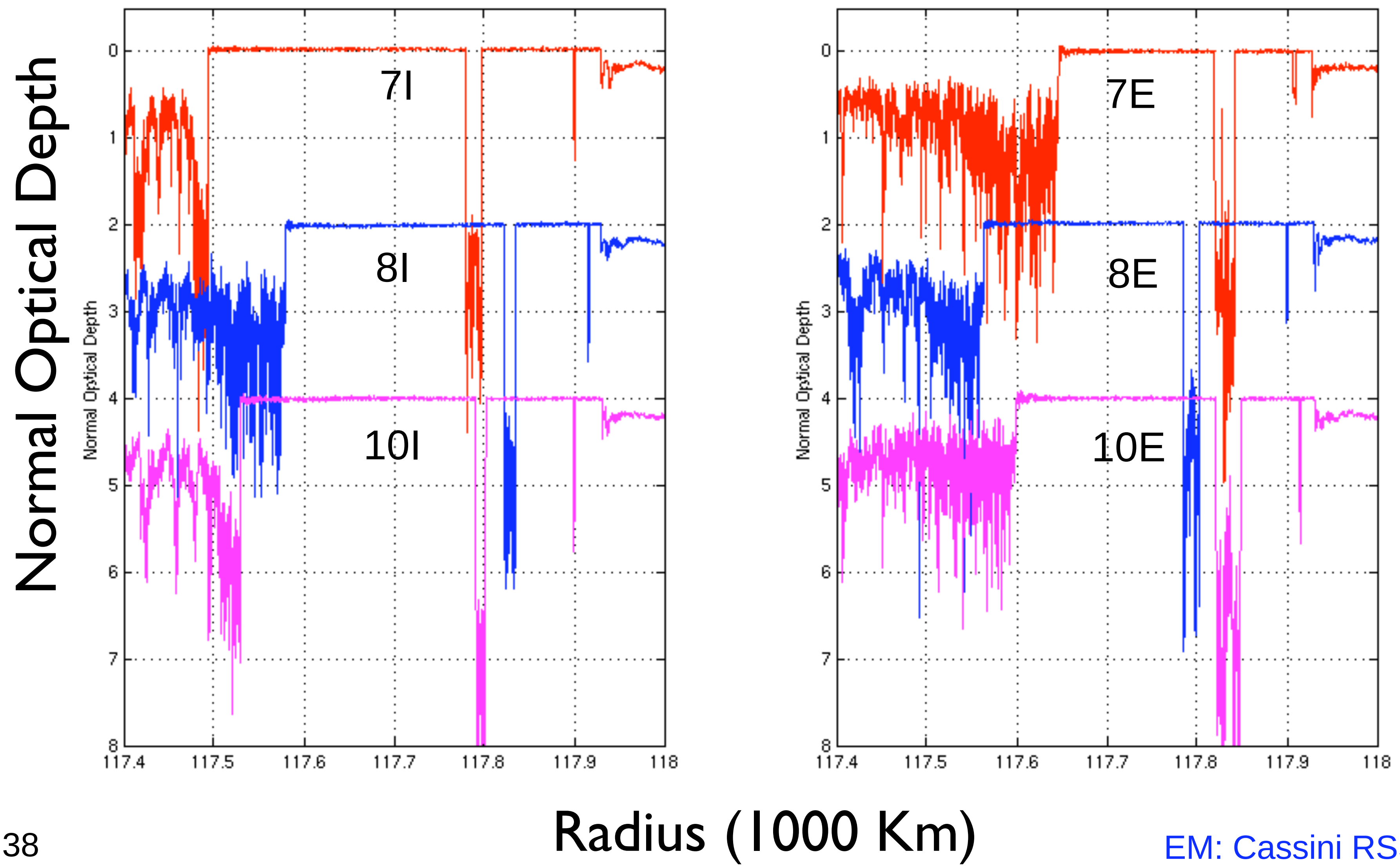
Rev	$\|B\|$ =
12	20.5°
10	22.0°
8	23.2°
7	23.6°
46	14.4°



EM: Cassini RSS

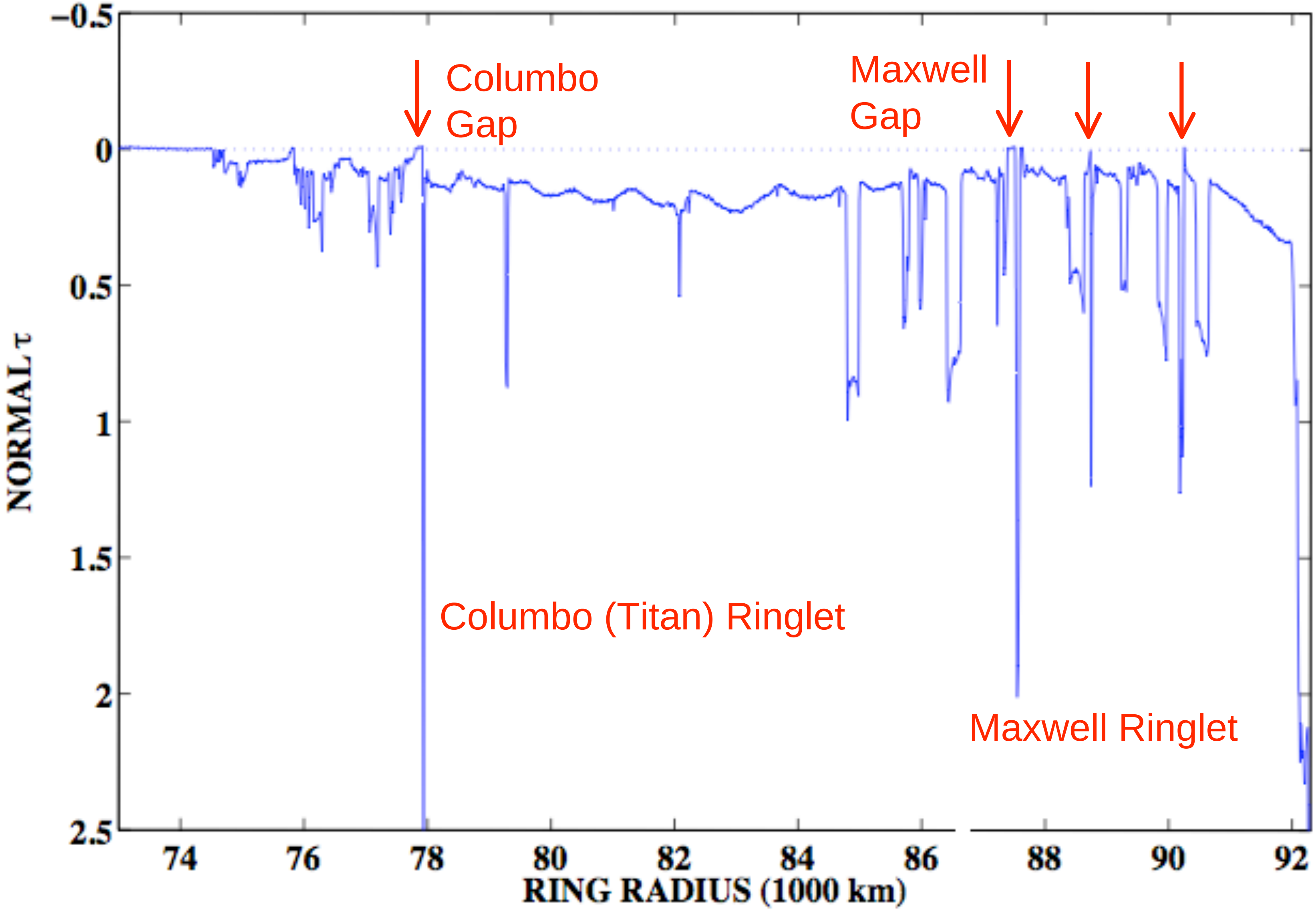
Why Multiple Longitude Occultations are Valuable?

Example of the Huygens Gap & Two Ringlets (400 m resolution)



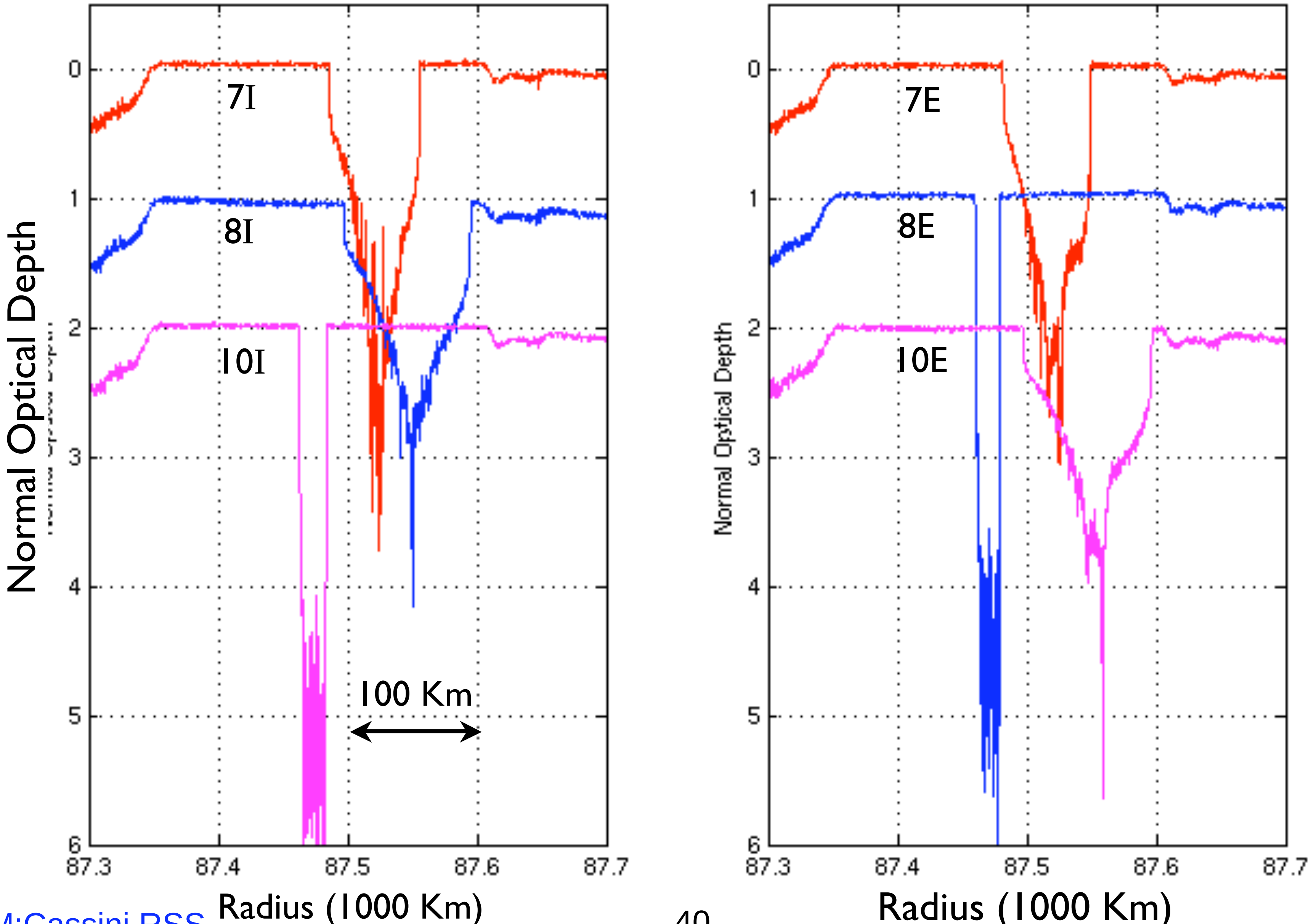
EM: Cassini RSS

Gaps & Embedded Ringlets in Ring C (10 km res)



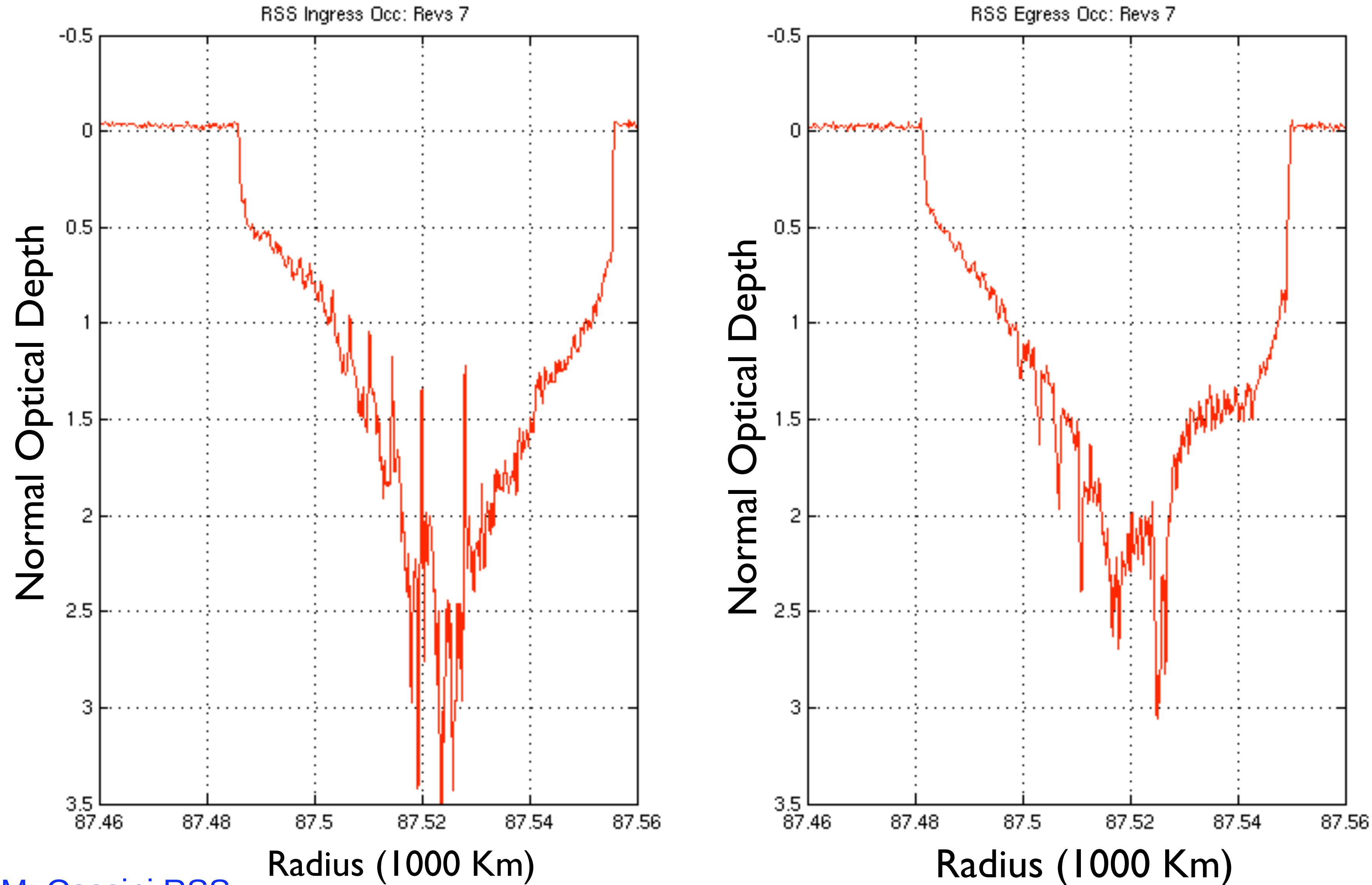
EM: Cassini RSS

Gaps and Embedded Ringlets: The Maxwell Gap in Ring C



EM:Cassini RSS

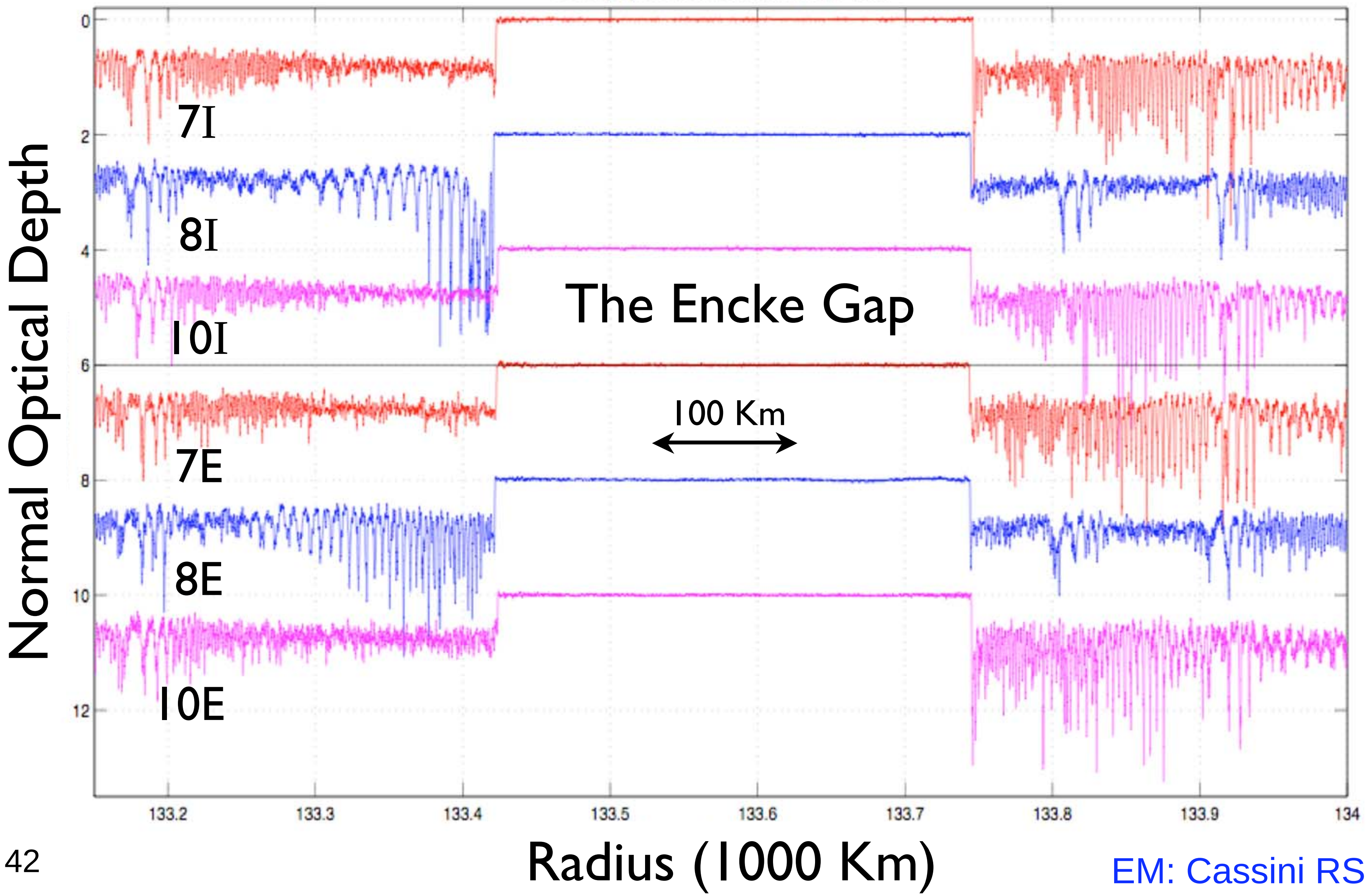
The Maxwell Ringlet: Edge Wave? (400 m res)



EM: Cassini RSS

Structure Due to Gravitational Interactions with Embedded Satellites

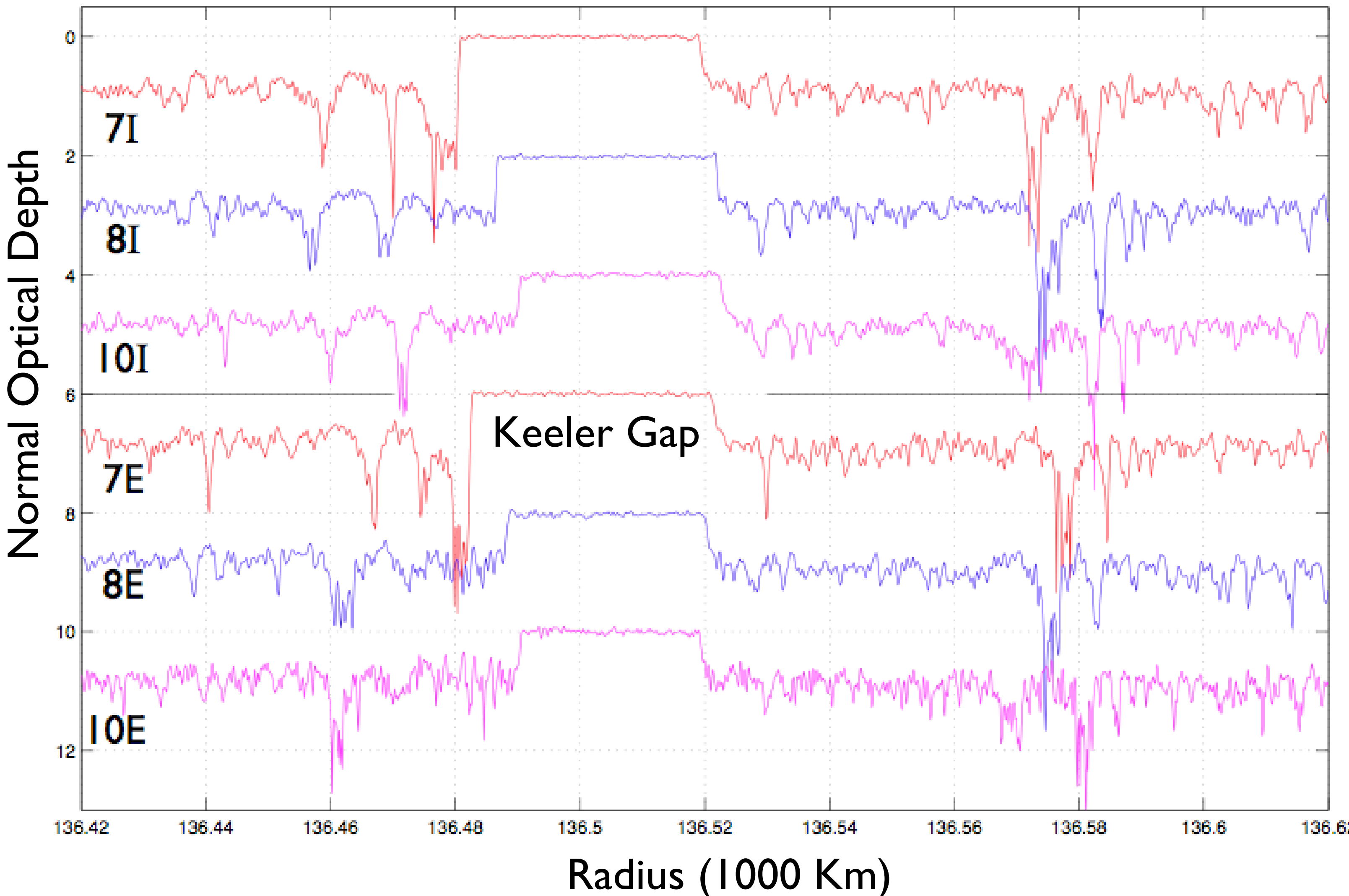
The Encke Gap: Pan's Wake



EM: Cassini RSS

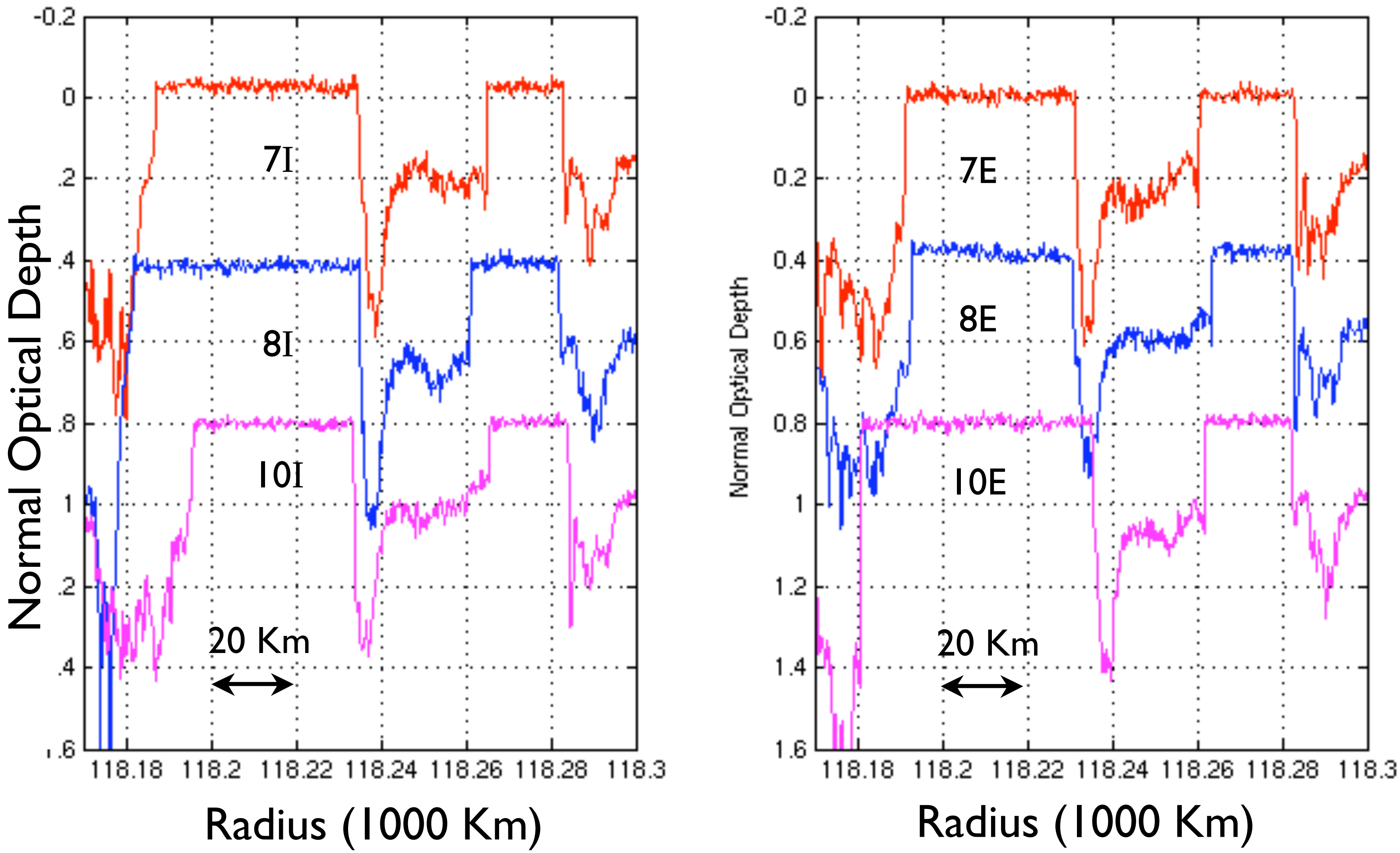
Structure Due to Gravitational Interactions with Embedded Satellites

The Keeler Gap: Daphnis' wake is not as obvious



EM:Cassini RSS

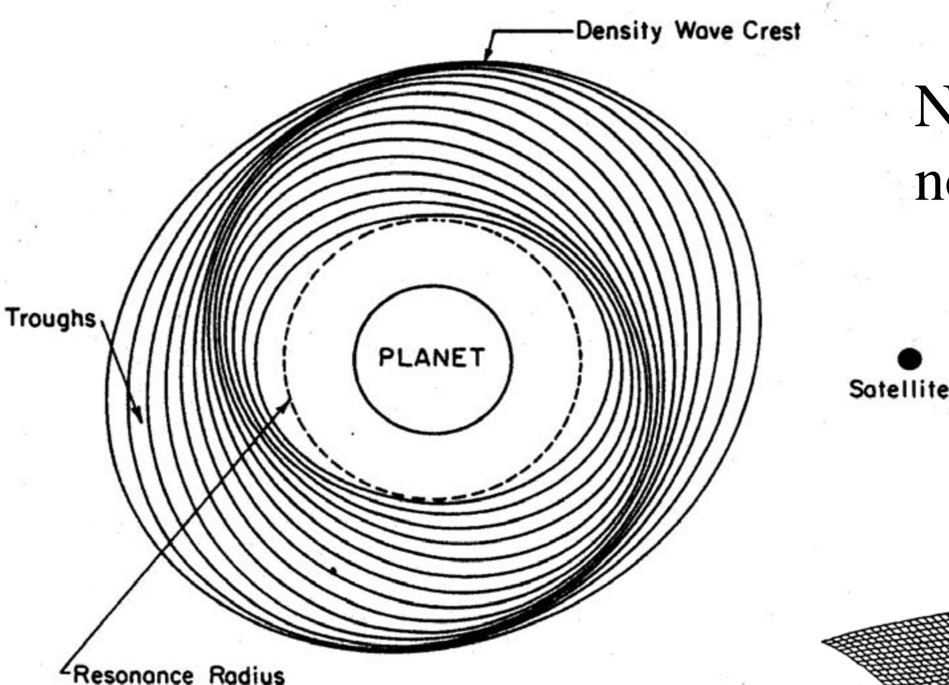
Gap Width Variations in the Cassini Division: Embedded Satellites?



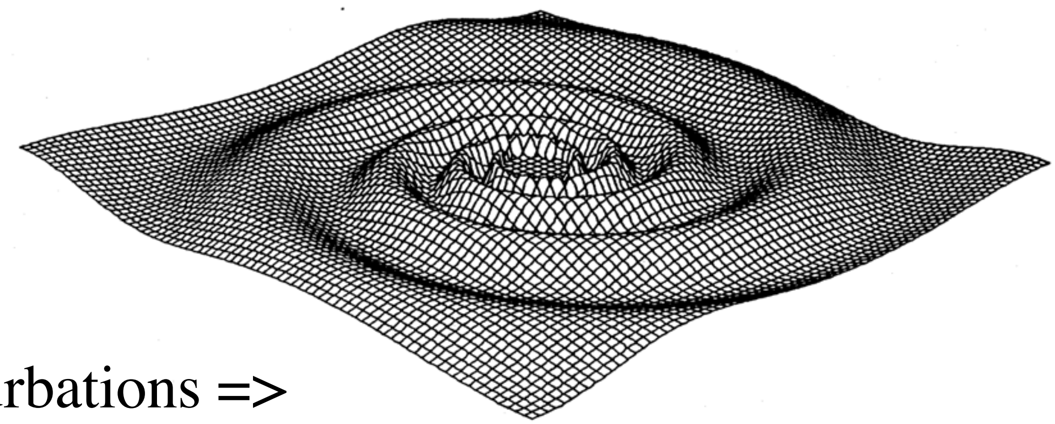
EM: Cassini RSS

Structure Driven by Resonant Interaction with Exterior Satellites

Streamlines Perturbations => Density & Bending Waves



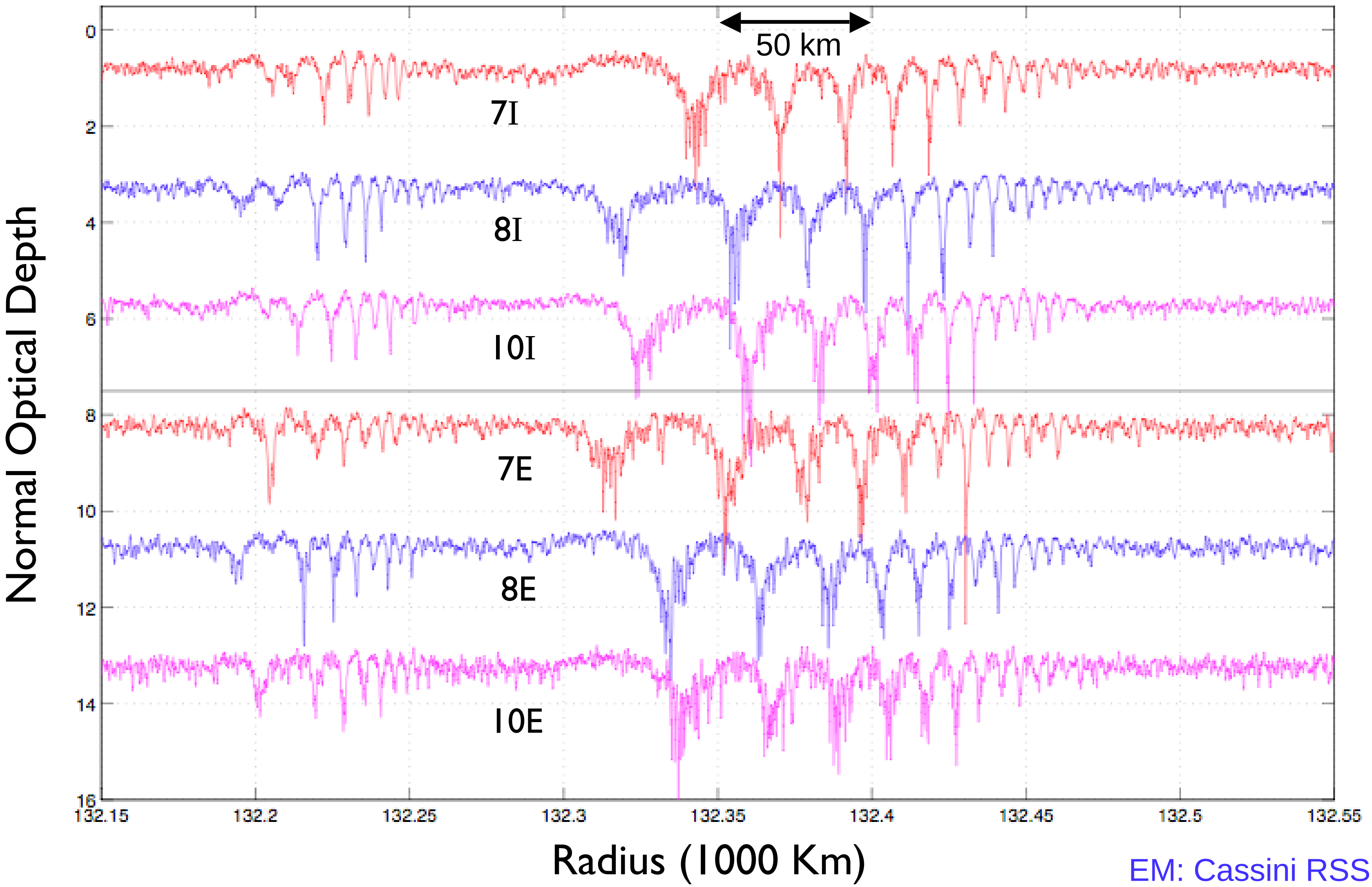
Number density perturbations =>
normal optical depth perturbations



Signal path length perturbations =>
normal optical depth perturbations

Structure Due to Resonant Interactions with External Satellites

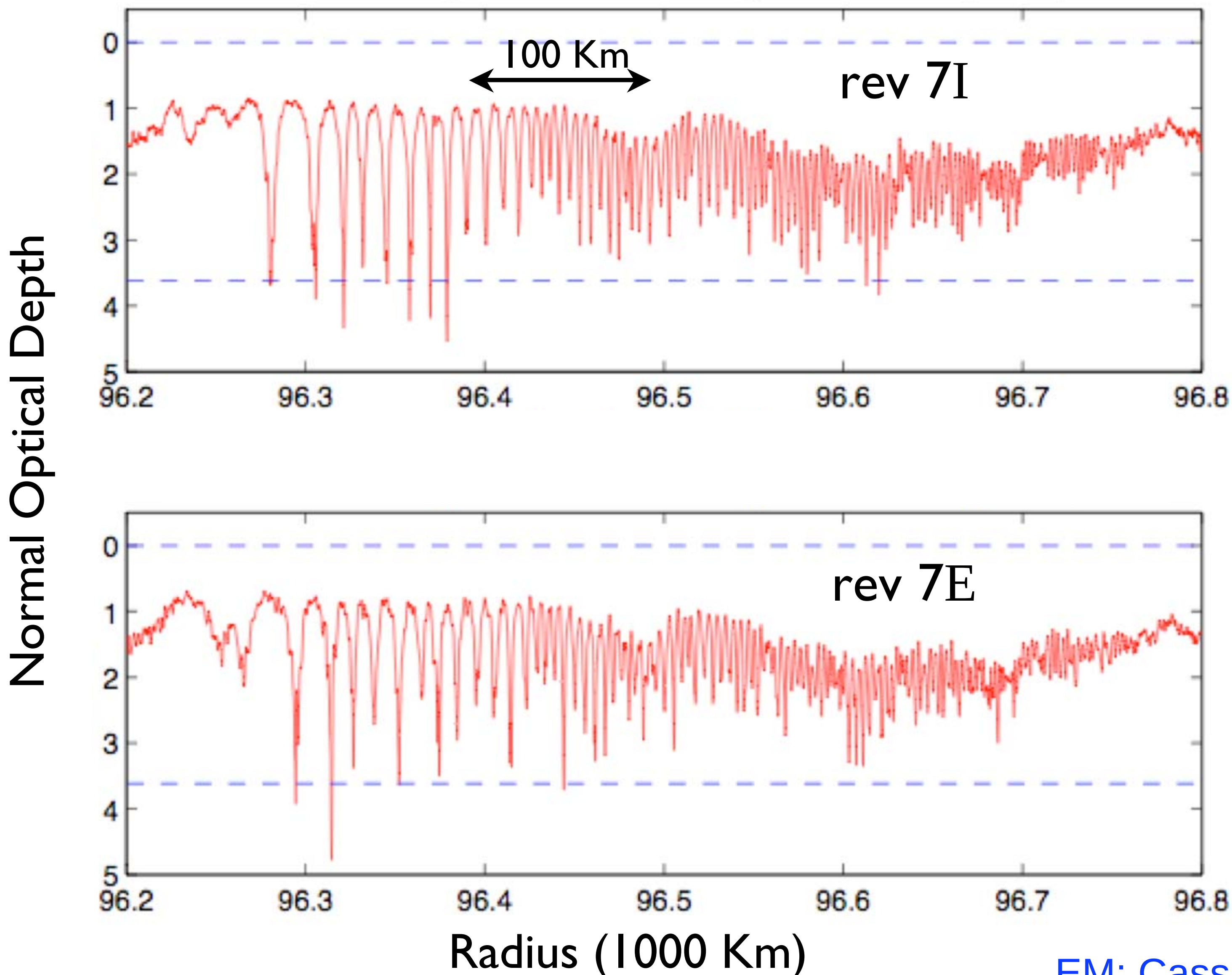
Ring A: Mimas 5:3 Density Wave



EM: Cassini RSS

Structure Due to Resonant Interactions with External Satellites

Ring B: Co-orbital Satellites 2:1 Density Wave



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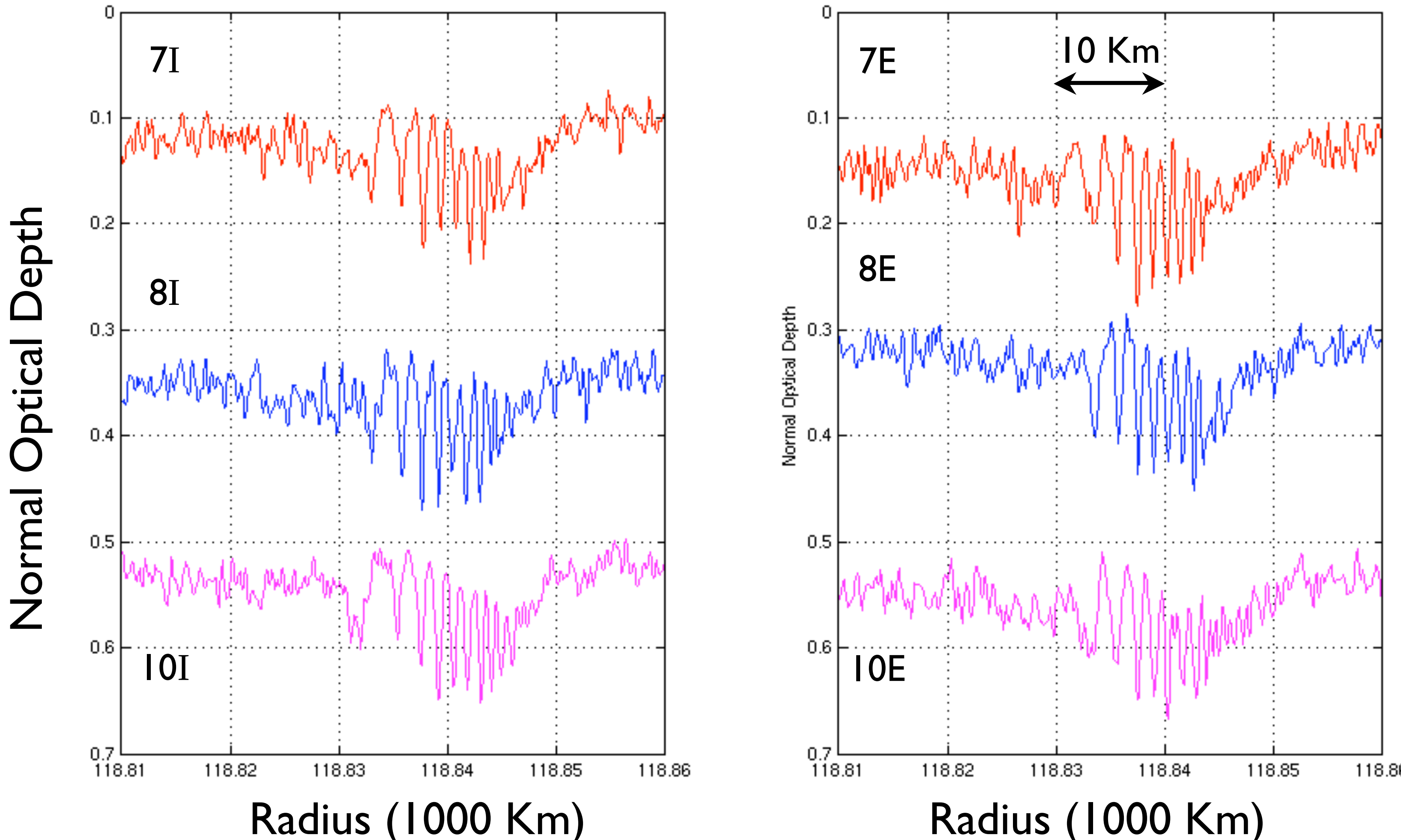
Structure Due to Resonant Interactions with External Satellites

Cassini Division: Atlas 5:4 Density Wave



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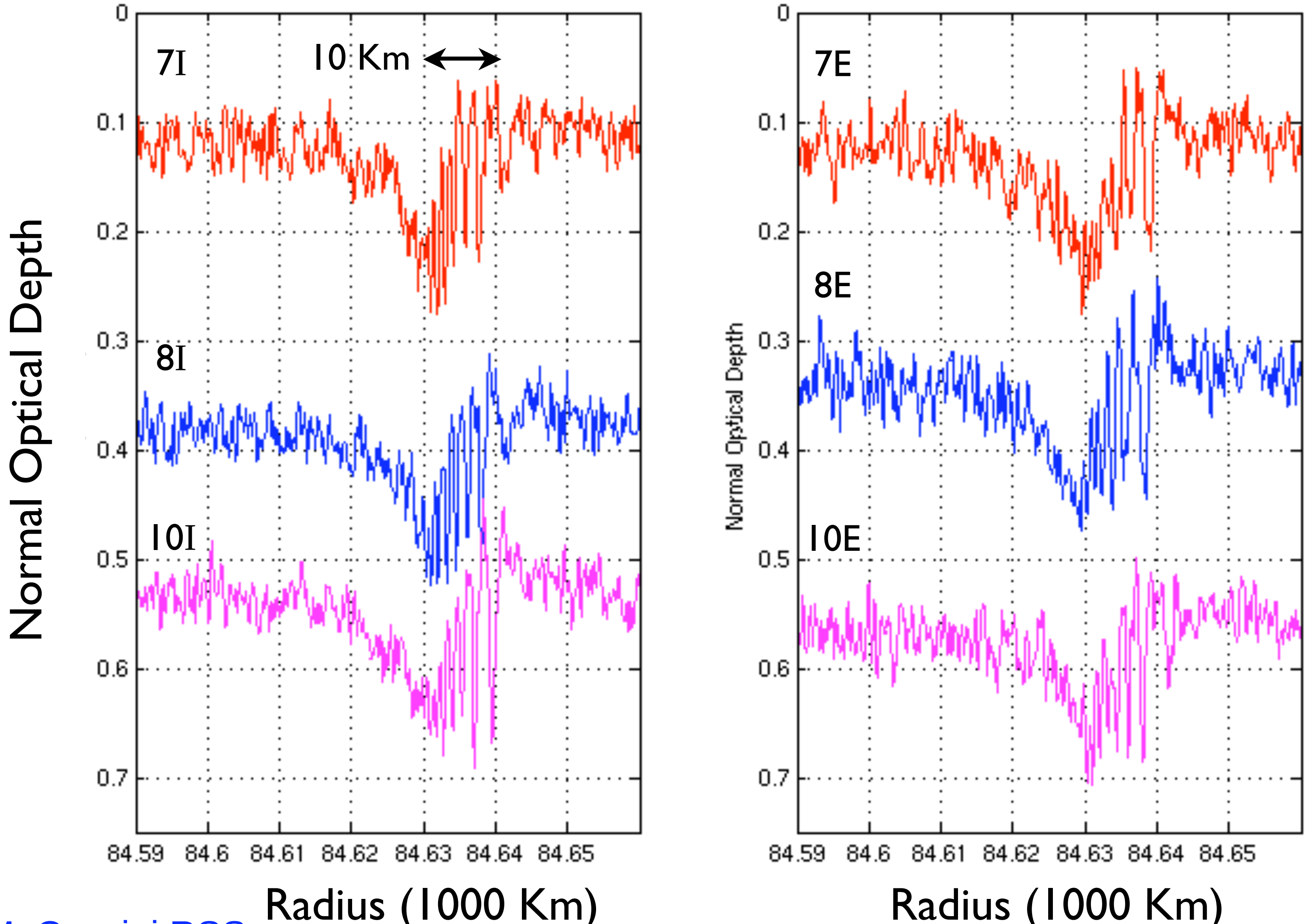
Structure of Unknown Origin: Resonant Interactions with Saturn?

Ring C: The “Rosen Waves”



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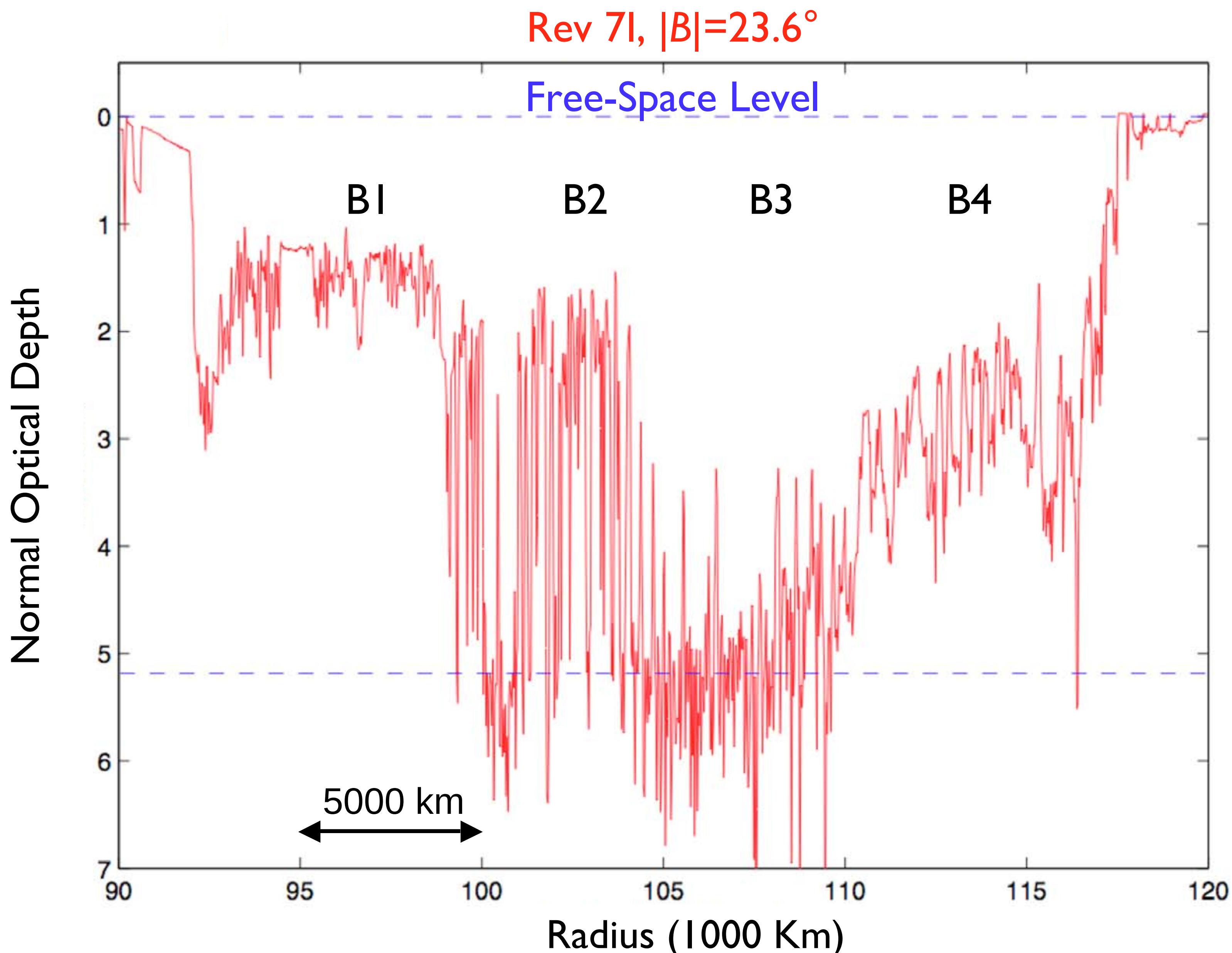
Enigmatic Ring B (20 Km res)



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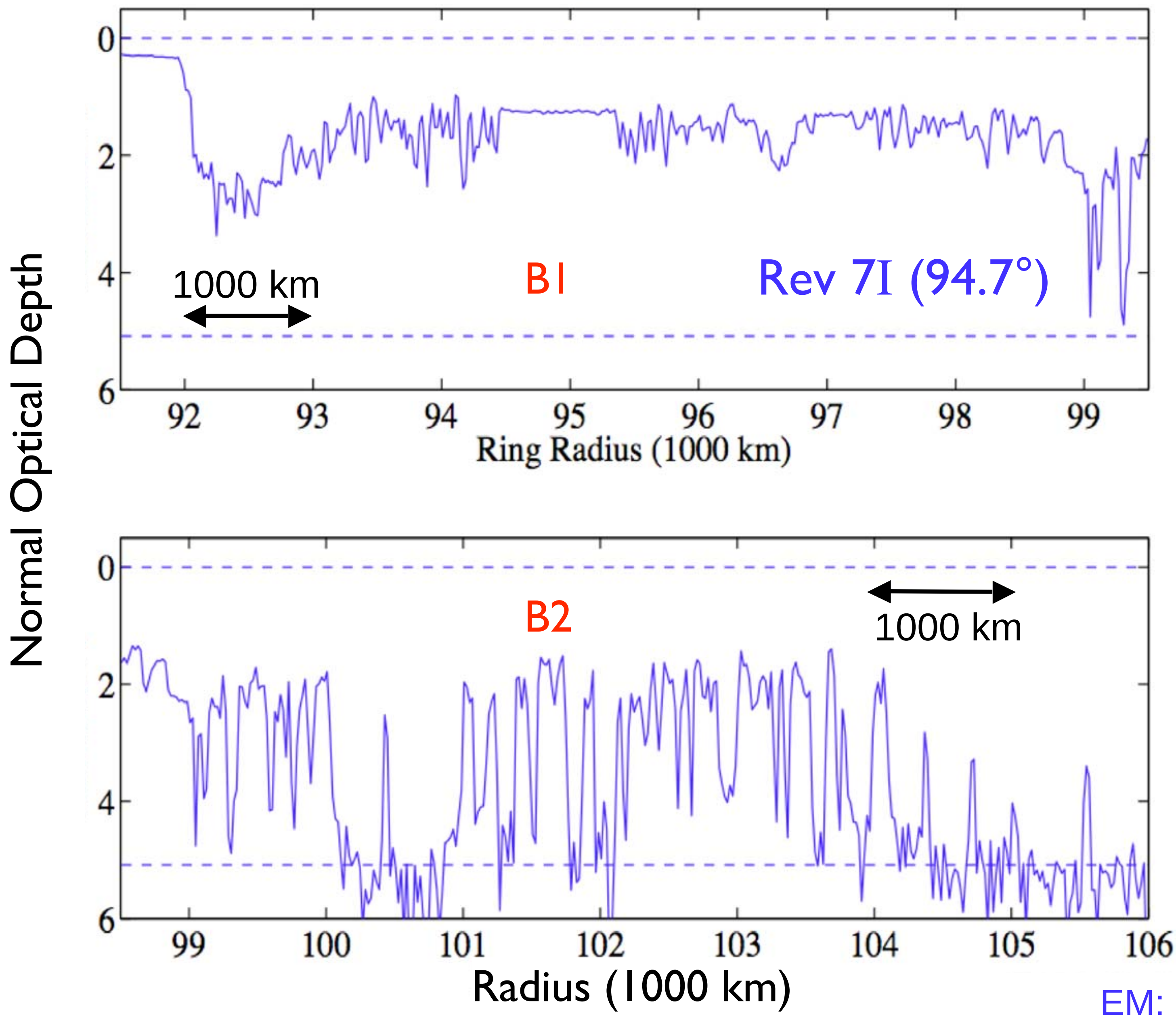
Structure of Regions B1& B2 (20 km res)



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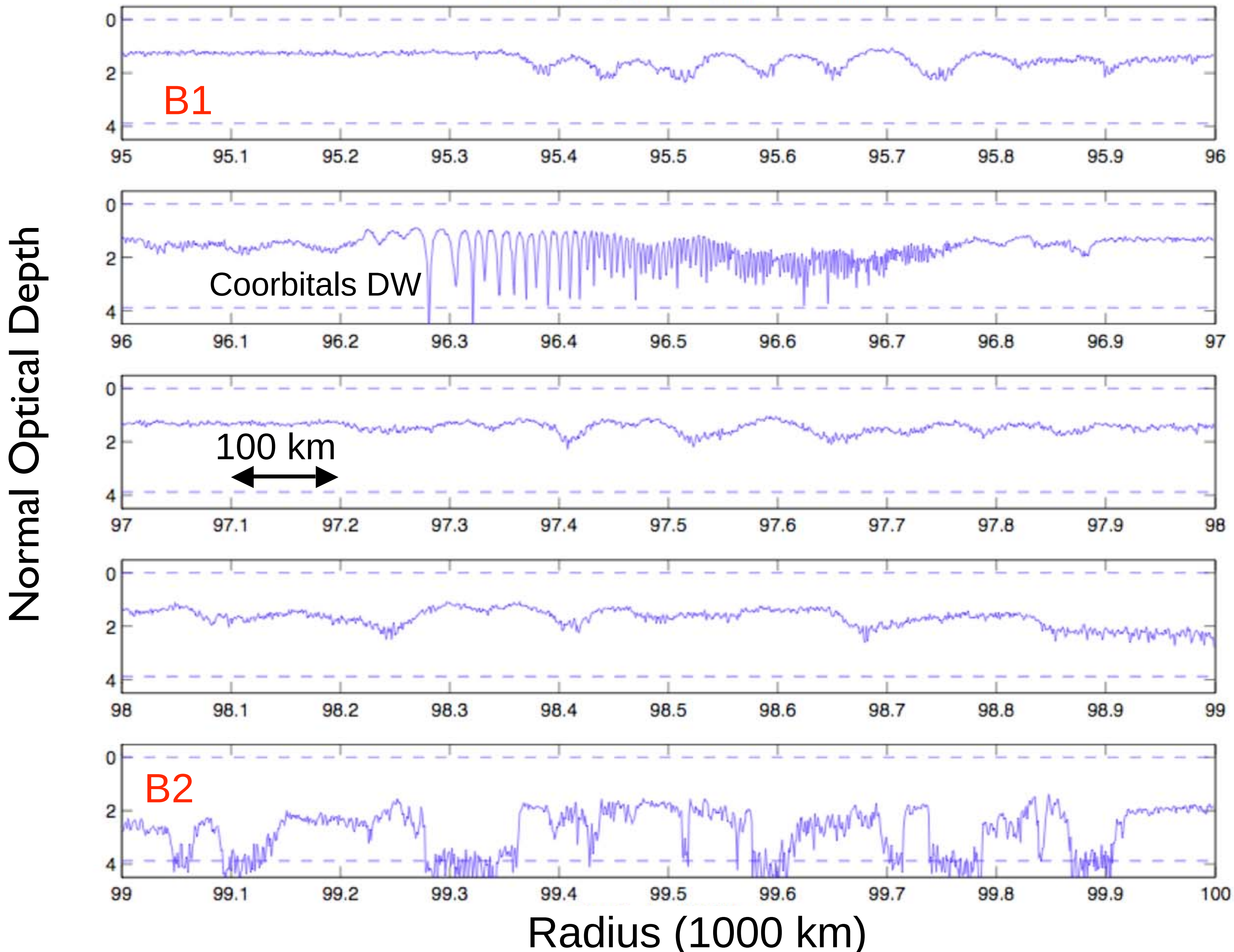
Detail from Region B1 (1 km res)



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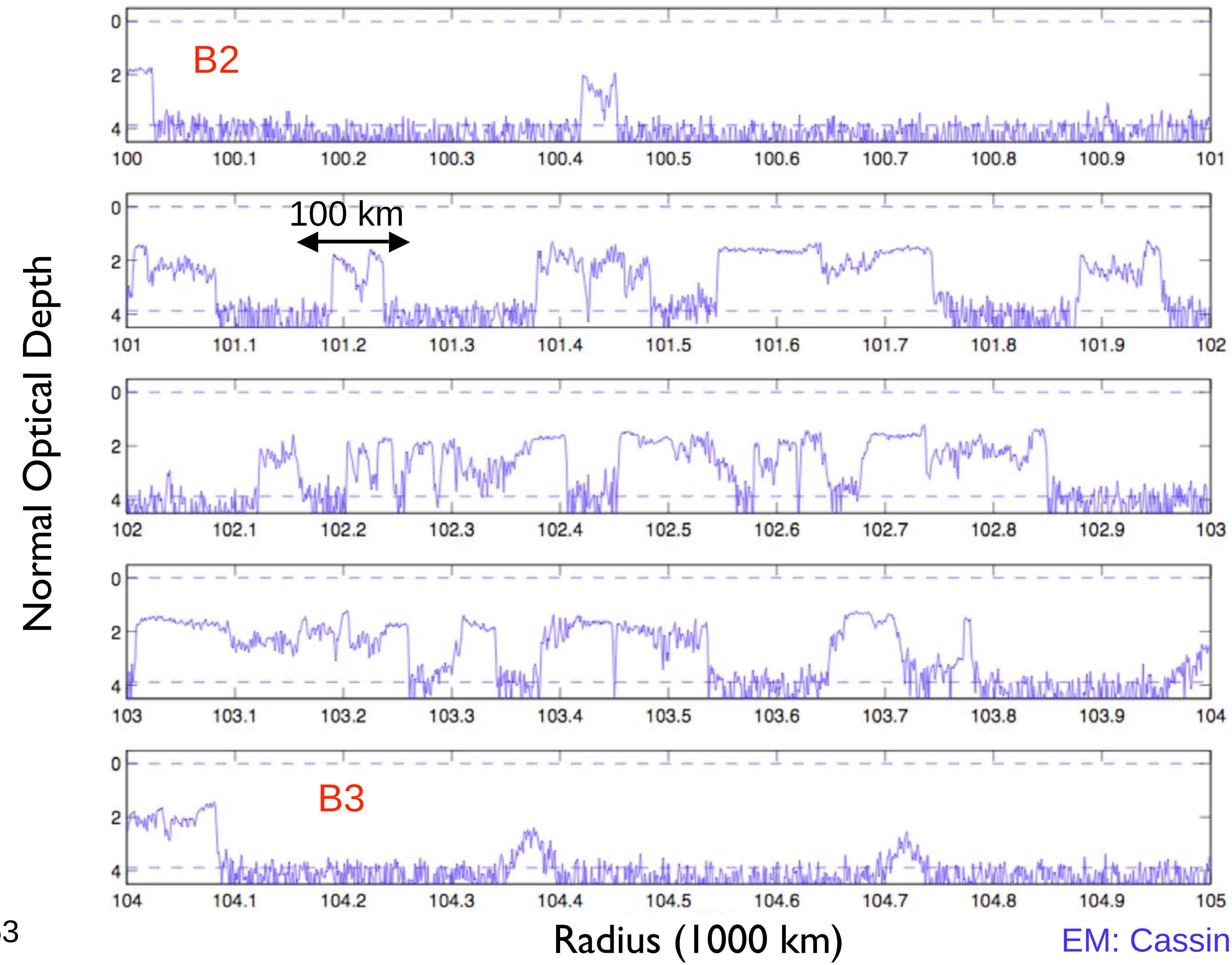
Details from Remarkable Region B2 (1 km res)



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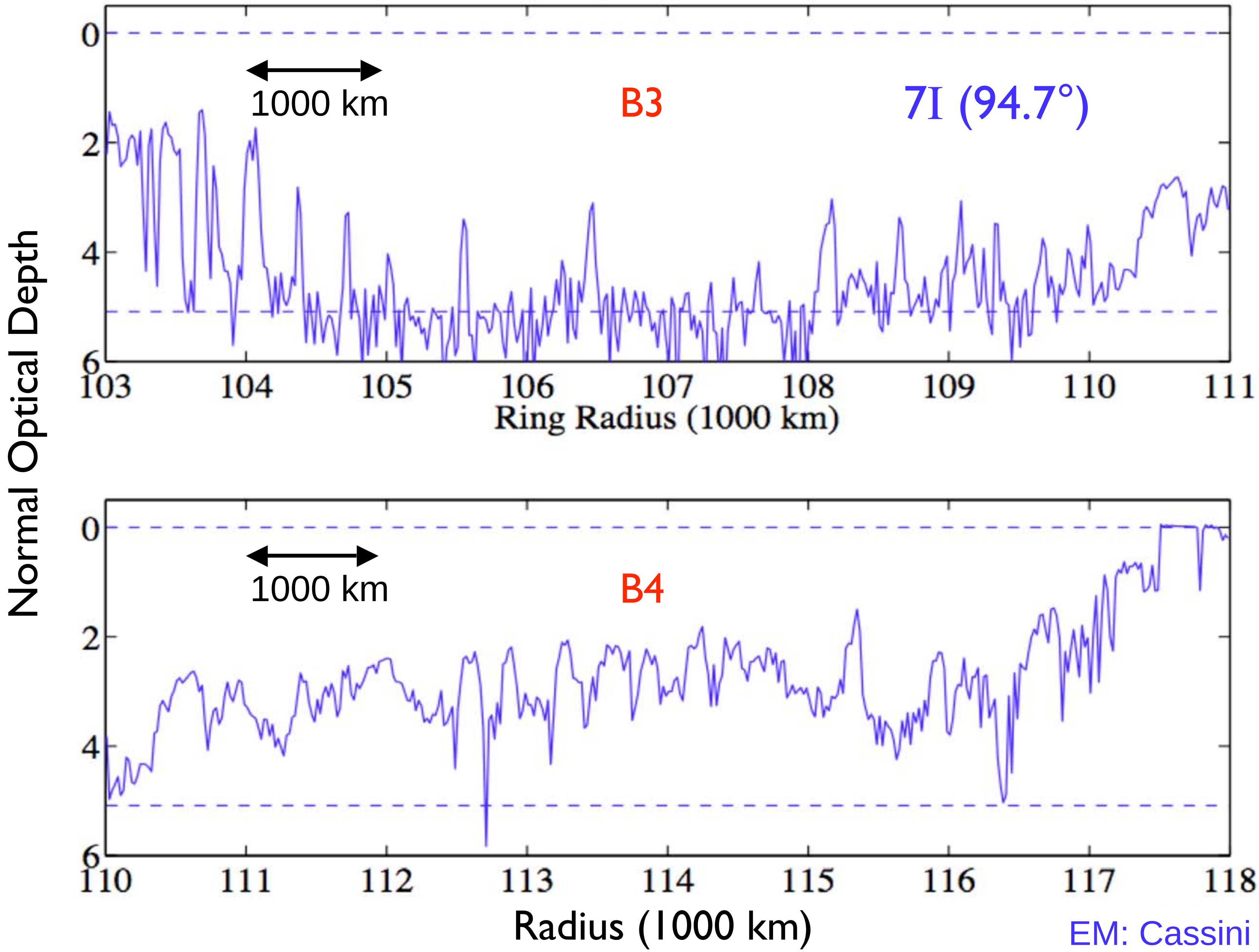
Structure of Regions B3 & B4 (20 km res)



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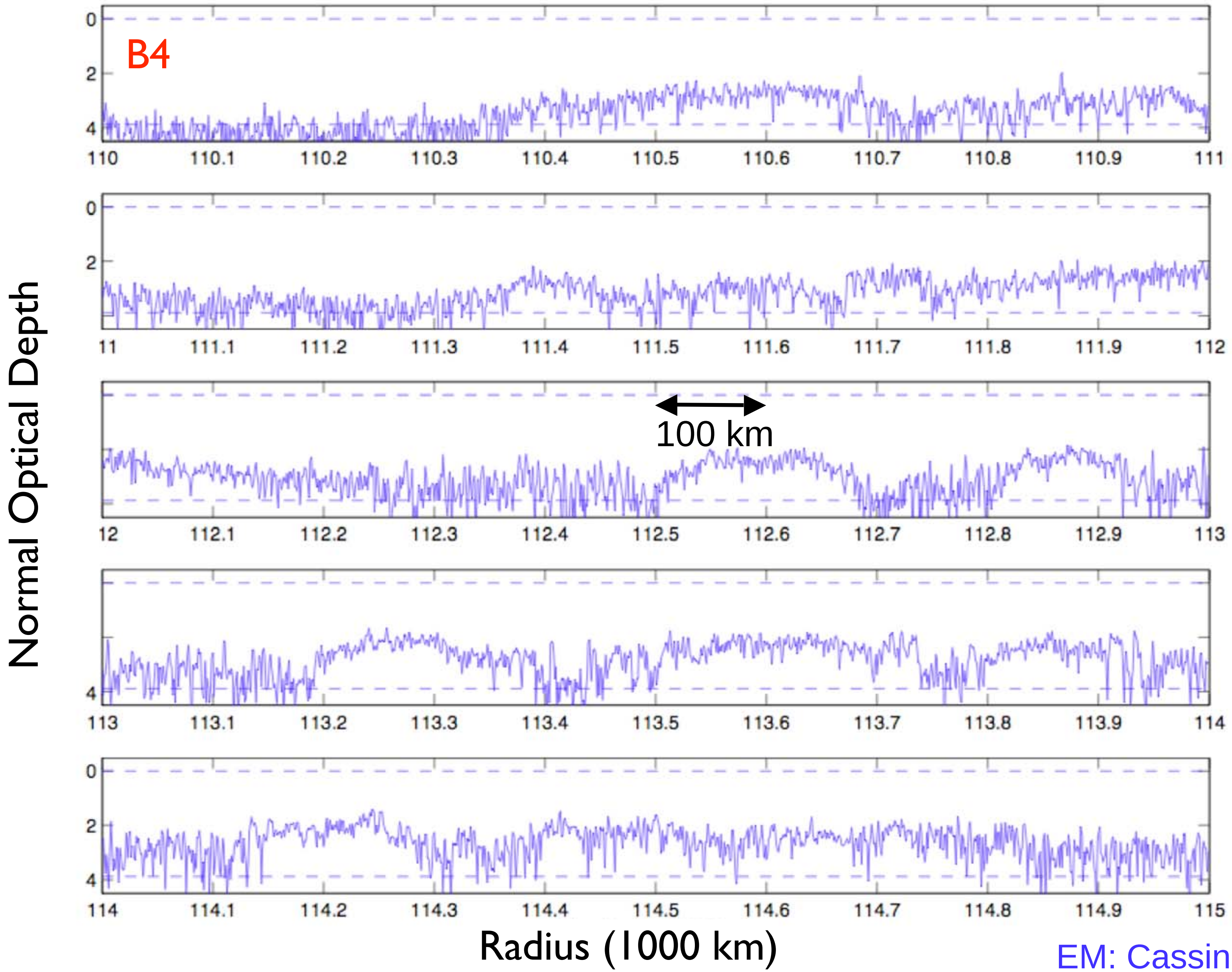
Detail from Region B4 (1 km res)



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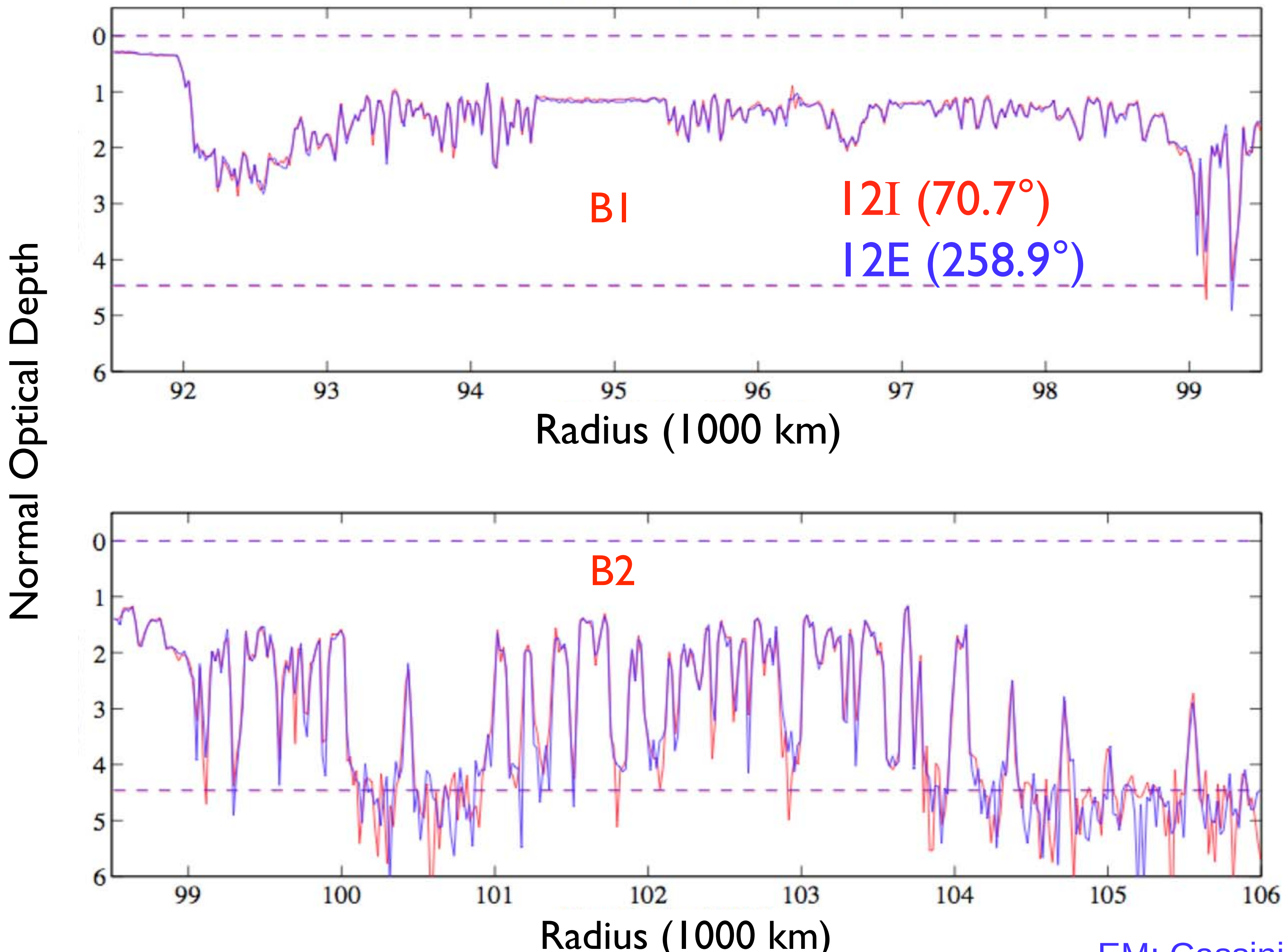
Near-Circular Symmetry of Ring B (20 km res)



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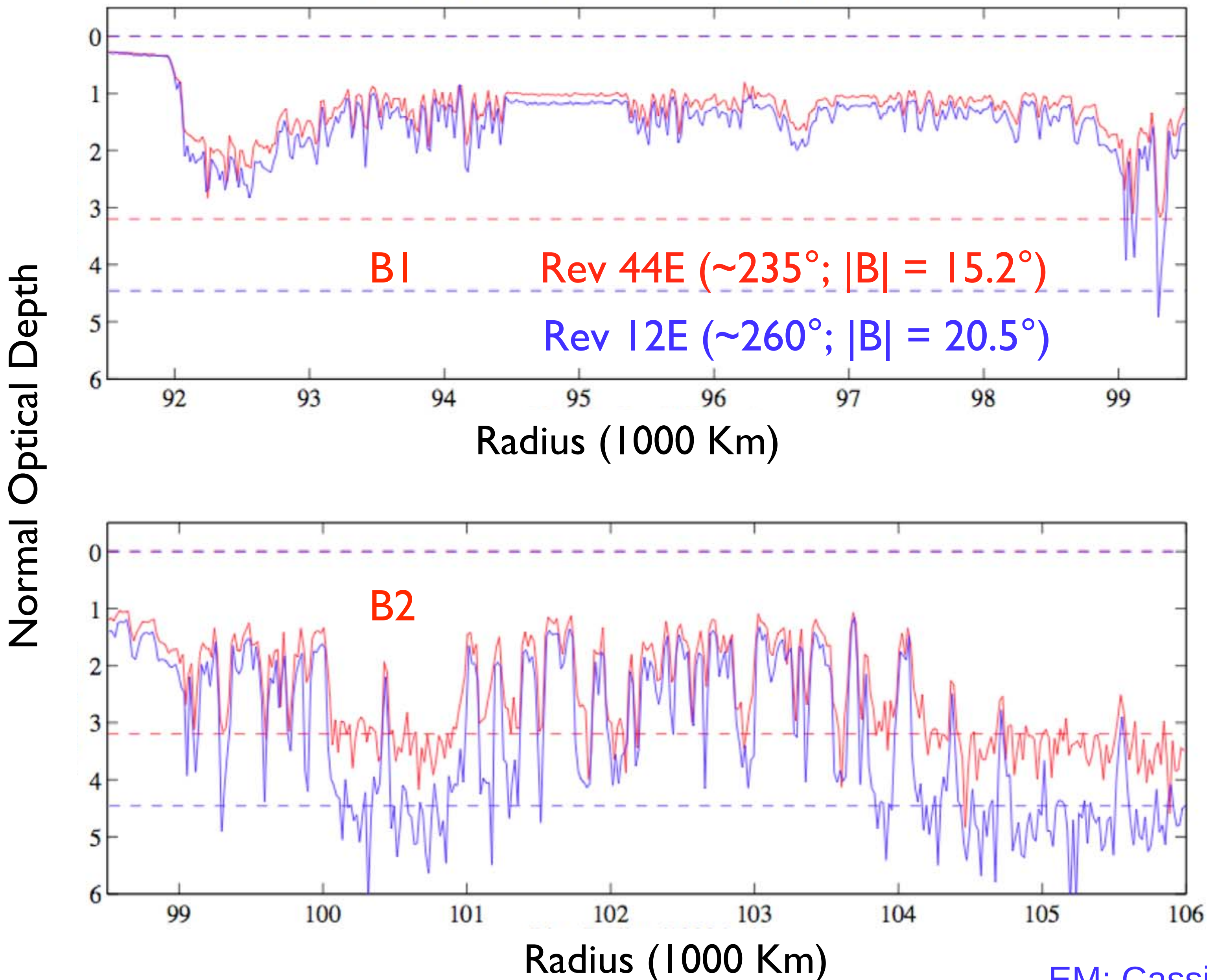
Azimuthal Asymmetry of Ring B (20 Km res)



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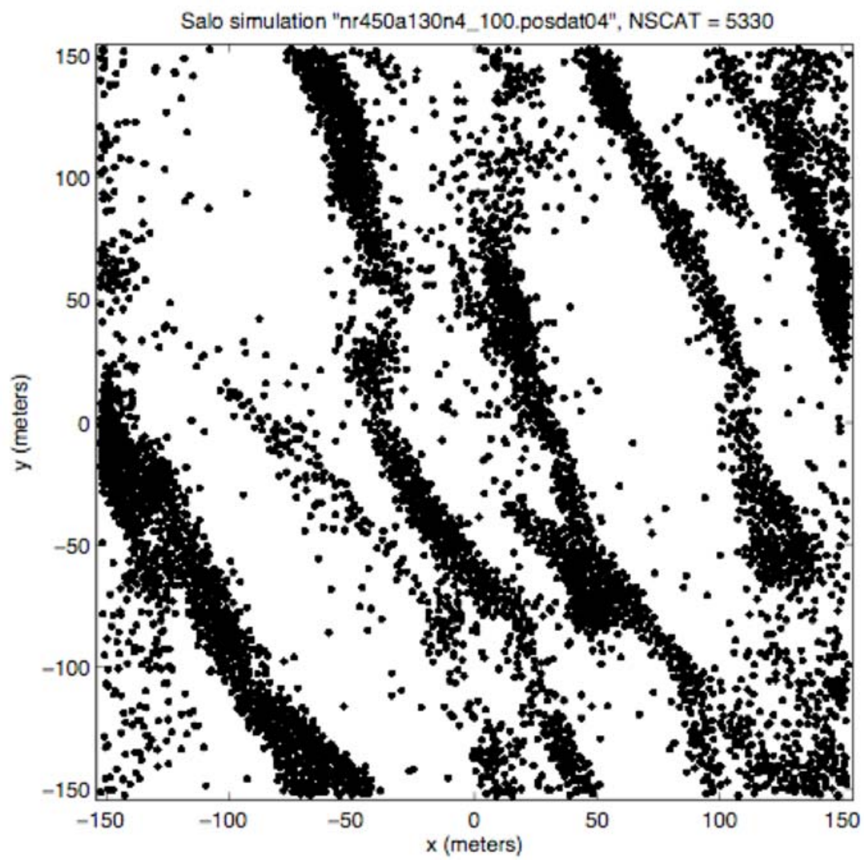
Ring "Microstructure": Particles & Particle-Aggregates Level

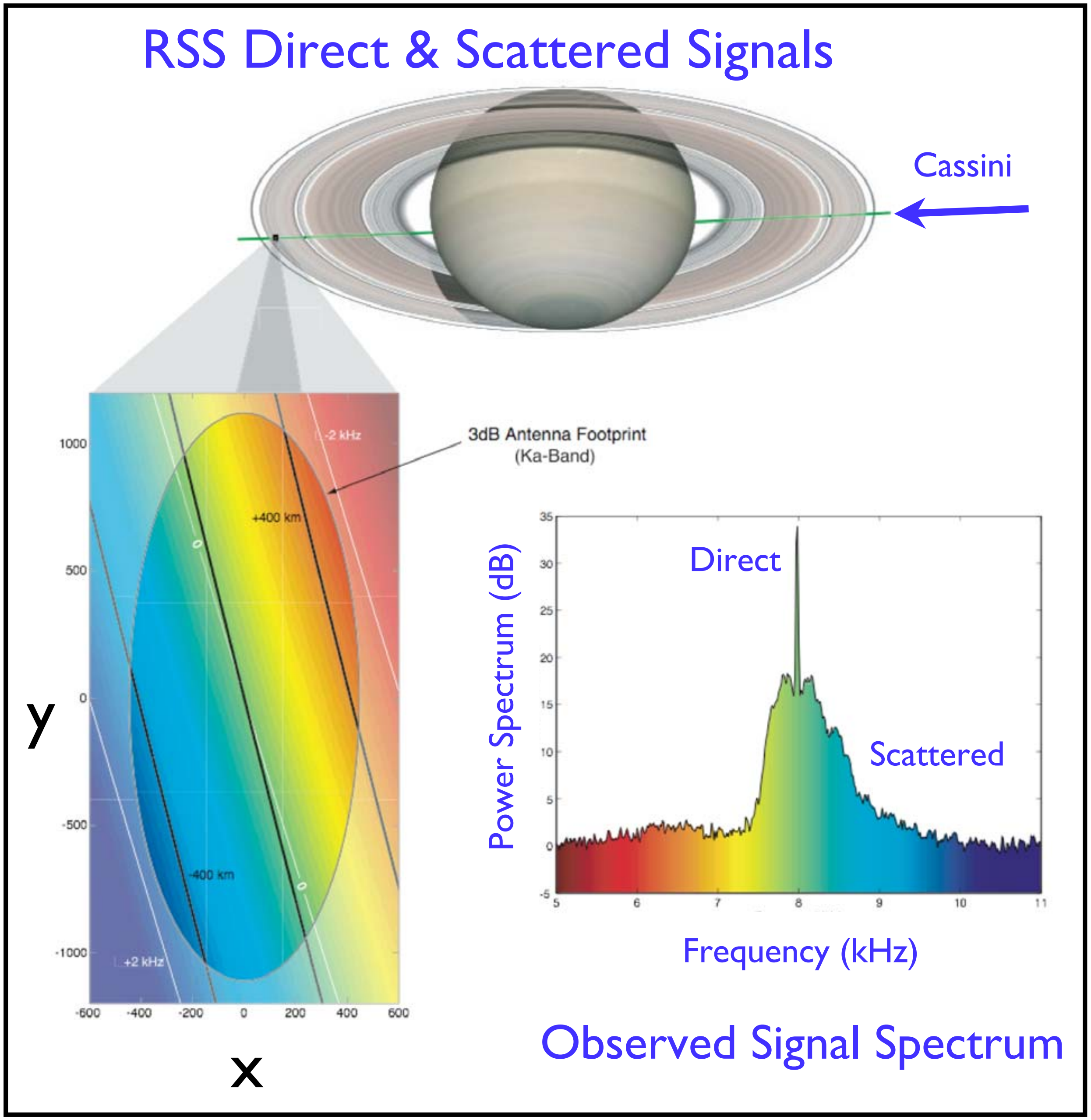
"Classical" (Isotropic) Ring Model

Artist Conception

Gravitational-Wakes Ring Model



Salo et al., 2004



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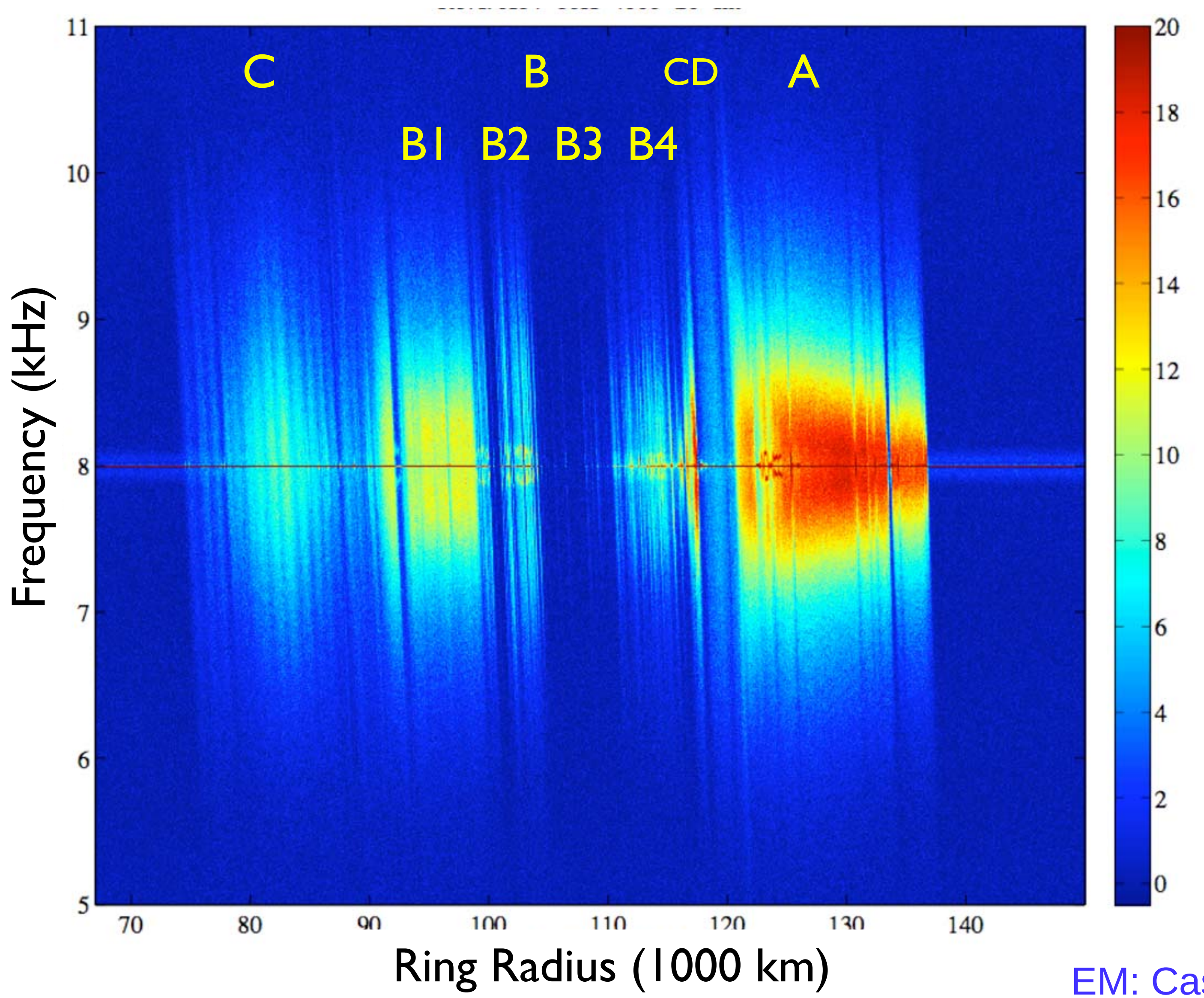
Spectrograms of Scattered Signal: a complementary story about the rings microstructure is yet to be told !



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