Tsunami from Plume-Forming Collisional Airbursts

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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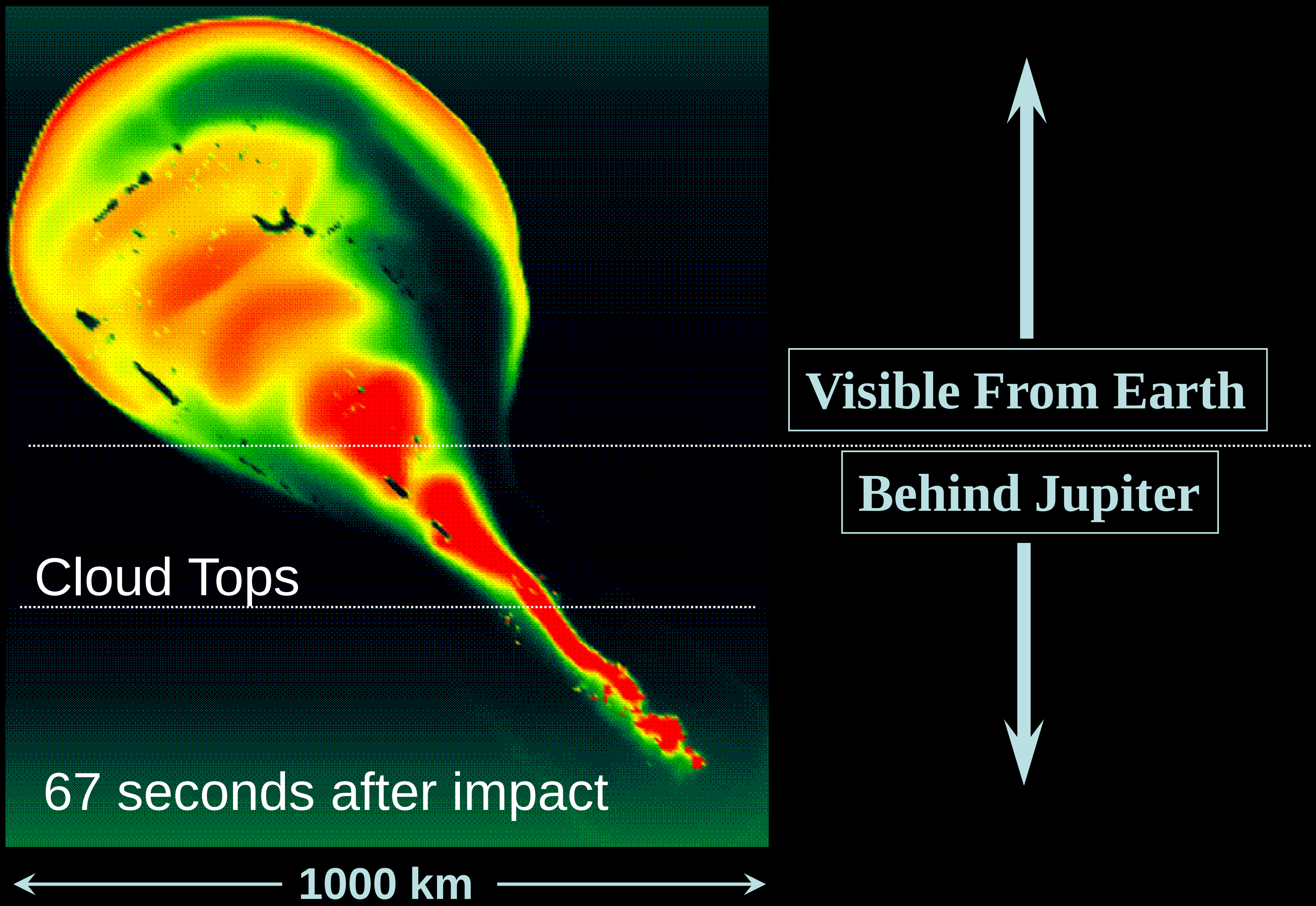
First direct observation of atmospheric collision:

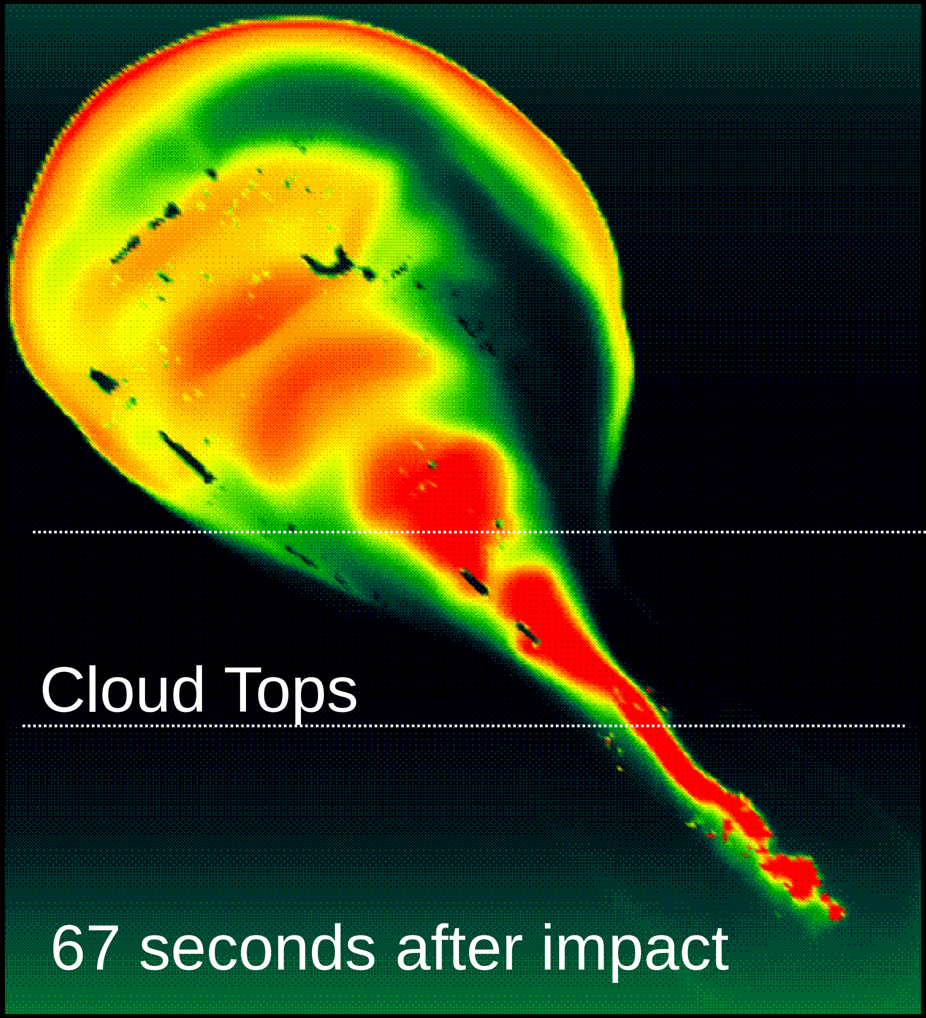
Shoemaker-Levy 9 comet crash: Jupiter, 1994

“Point source” explosion is not a good airburst approximation

Plumes from collisional airbursts: Emergent phenomenon
Discovered in 1993 by computation of Shoemaker-Levy 9

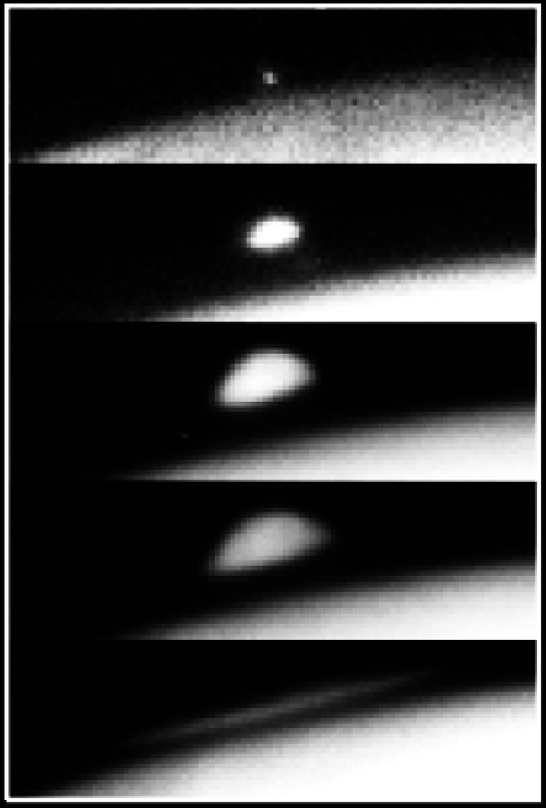


Airburst is a line explosion that ejects a plume: Observational validation by Shoemaker-Levy 9 impact



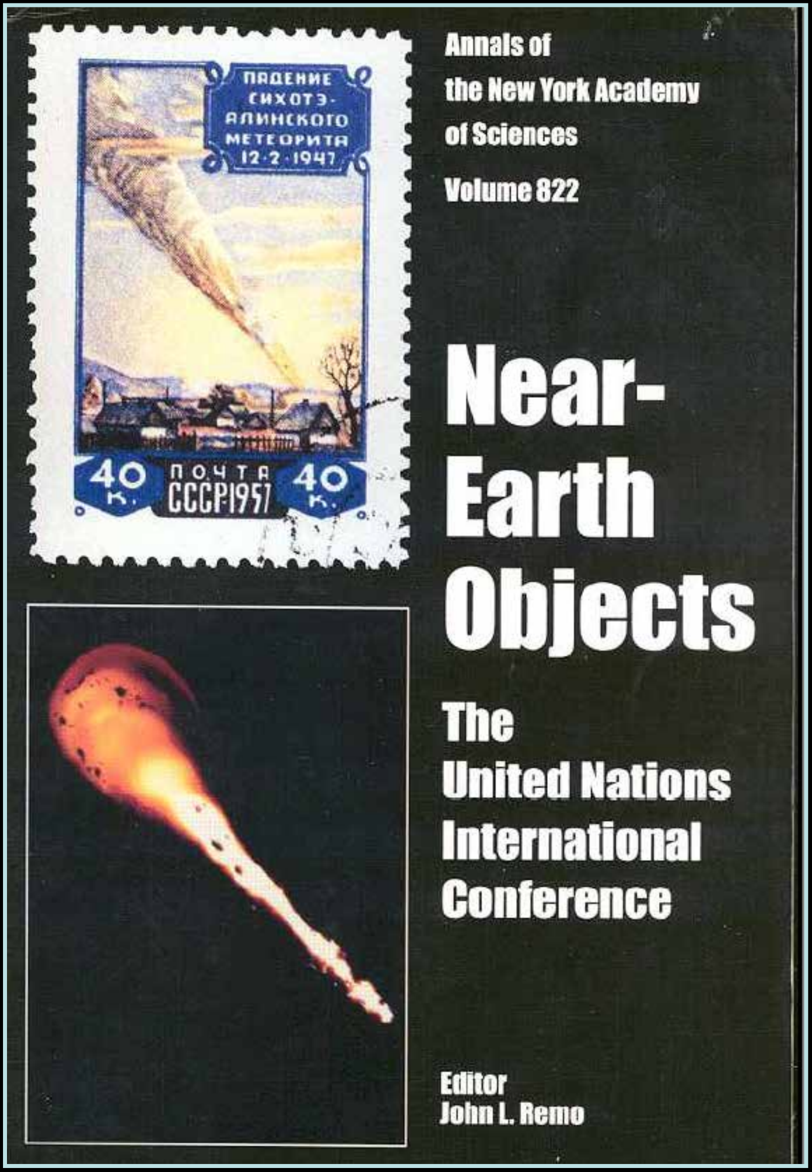
1000 km

Impact G

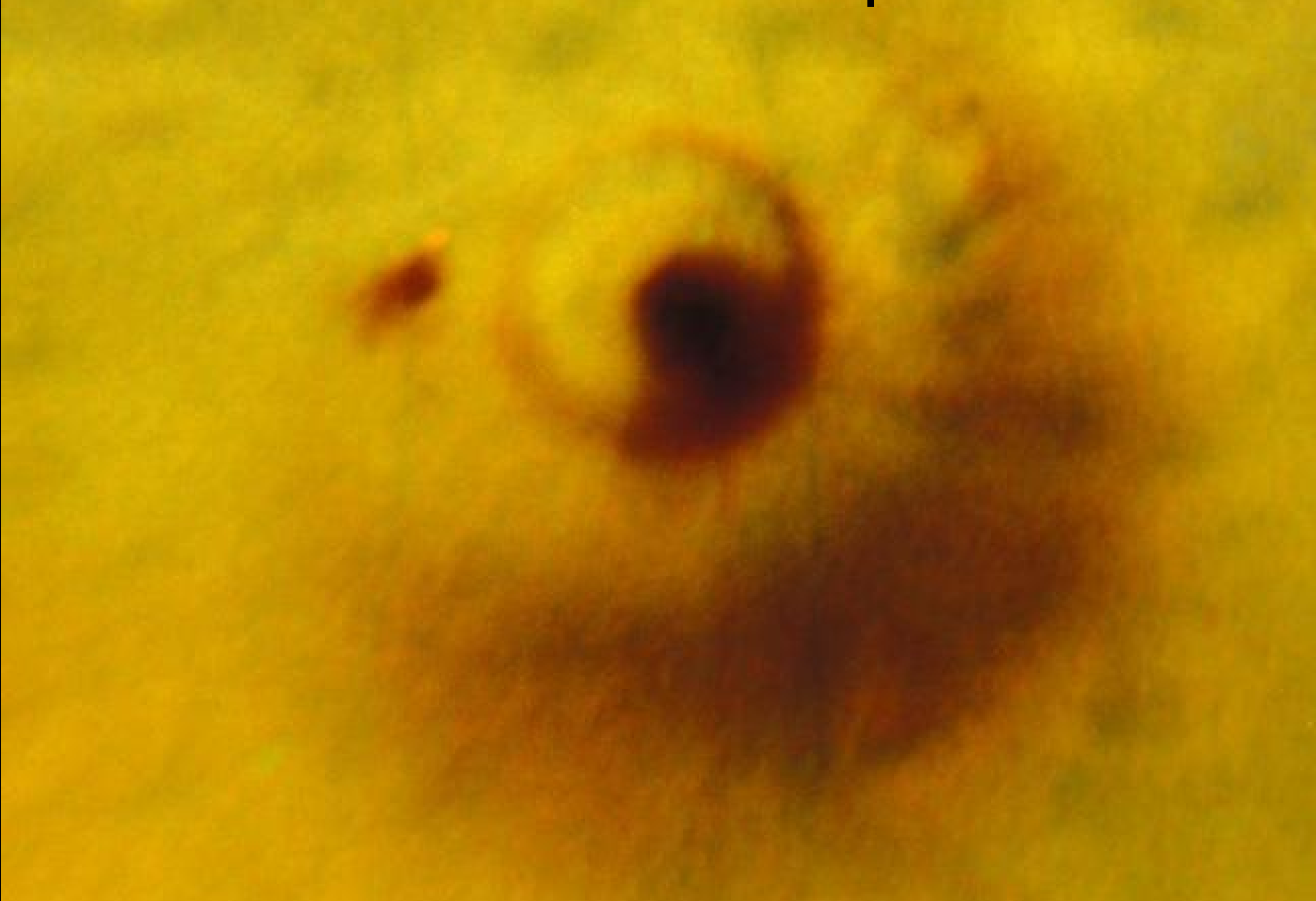


Hubble Space Telescope Image

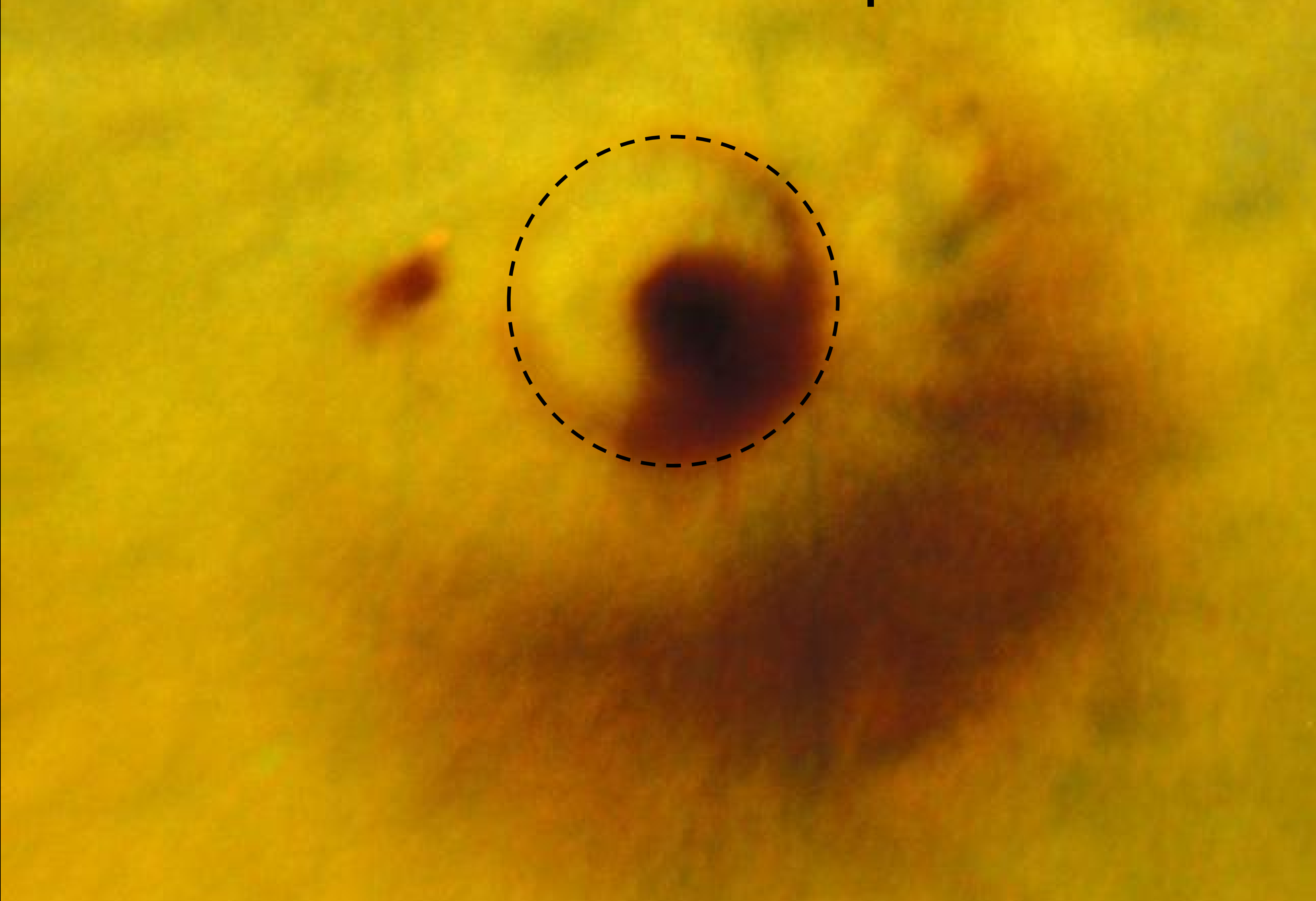
Plumes and line explosions on Earth



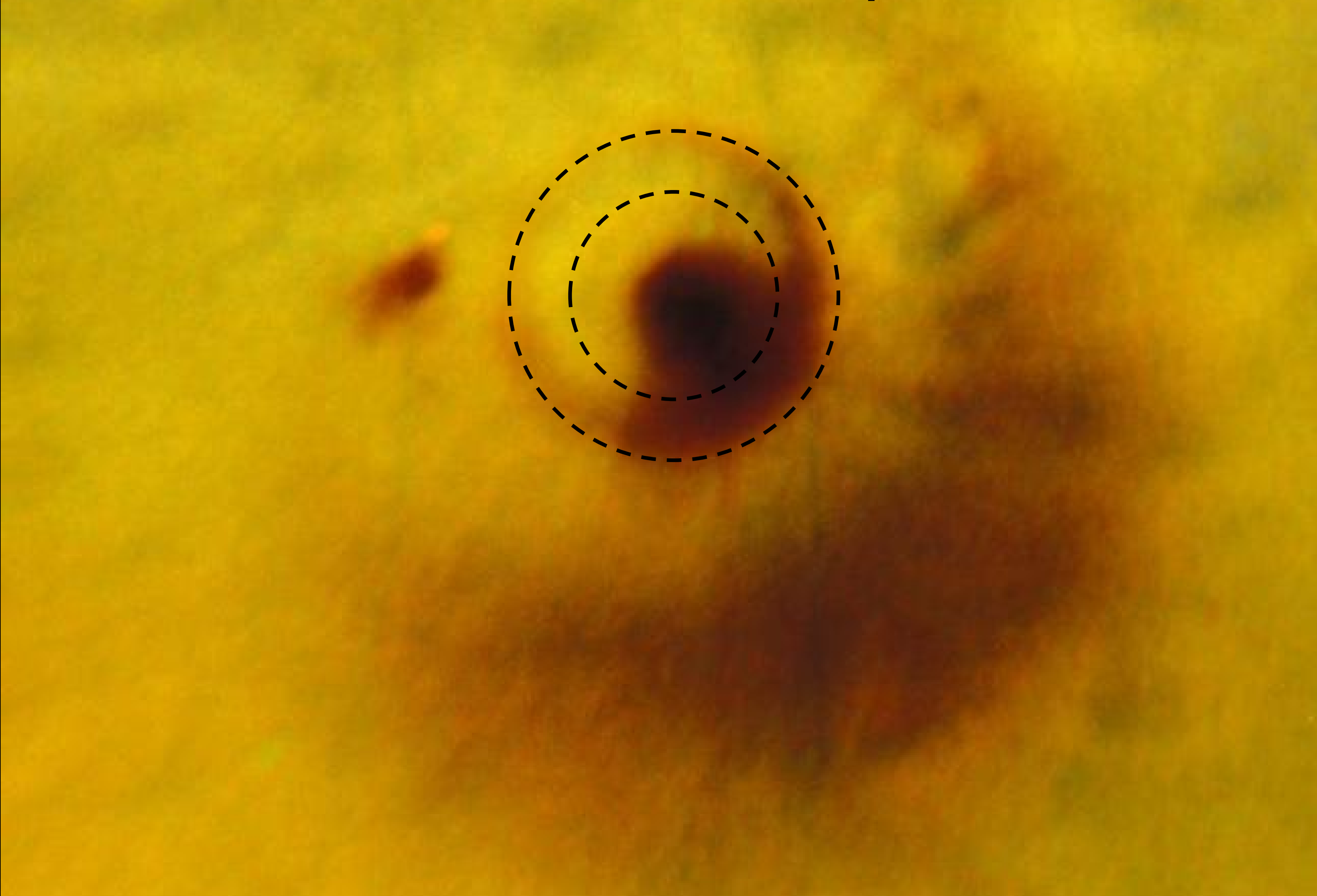
“Tsunami” on Jupiter



“Tsunami” on Jupiter

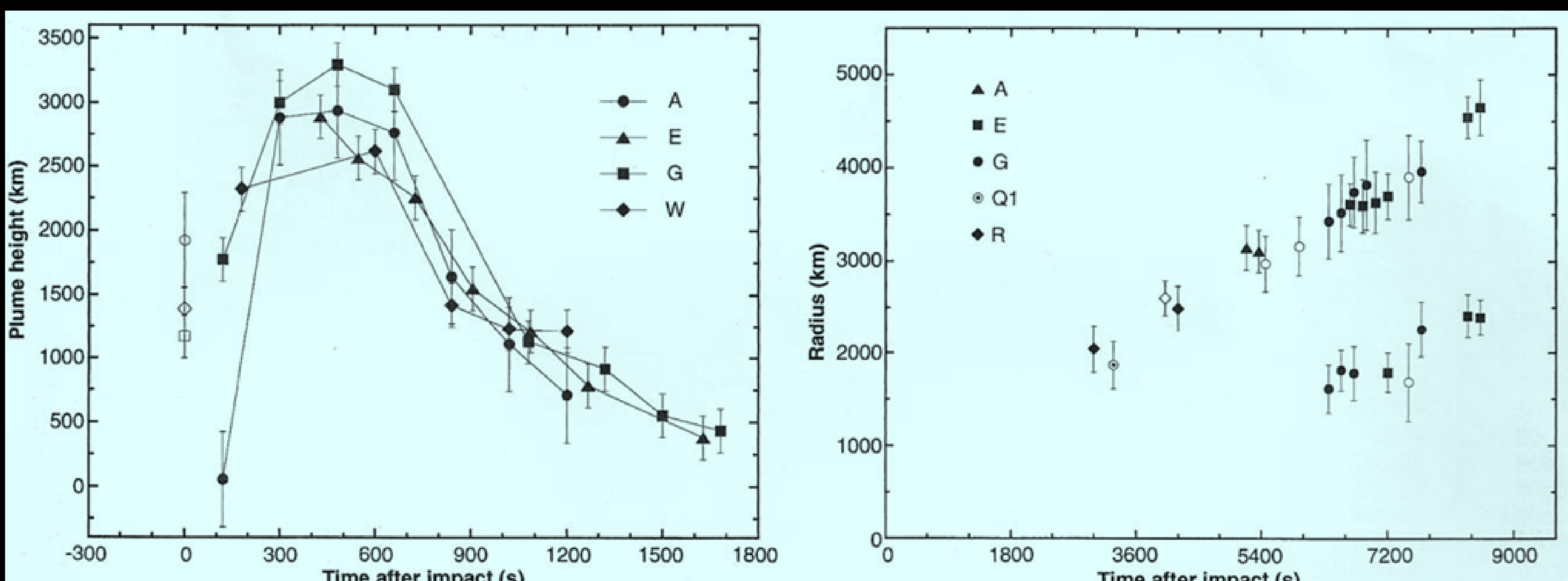


“Tsunami” on Jupiter



Hammel, Heidi B. et al.,
"HST Imaging of Atmospheric Phenomena
Created by the Impact of Comet Shoemaker-Levy 9"
Science, 267 (1995): 1288-1296.

Waves: "In images taken within 3 hours of the larger impacts, we detected transient 'rings' that are most likely caused by atmospheric waves. The most dramatic example was the multiple ring system created by the large G fragment. The circularity of the rings suggests that they are waves; debris features are asymmetric."

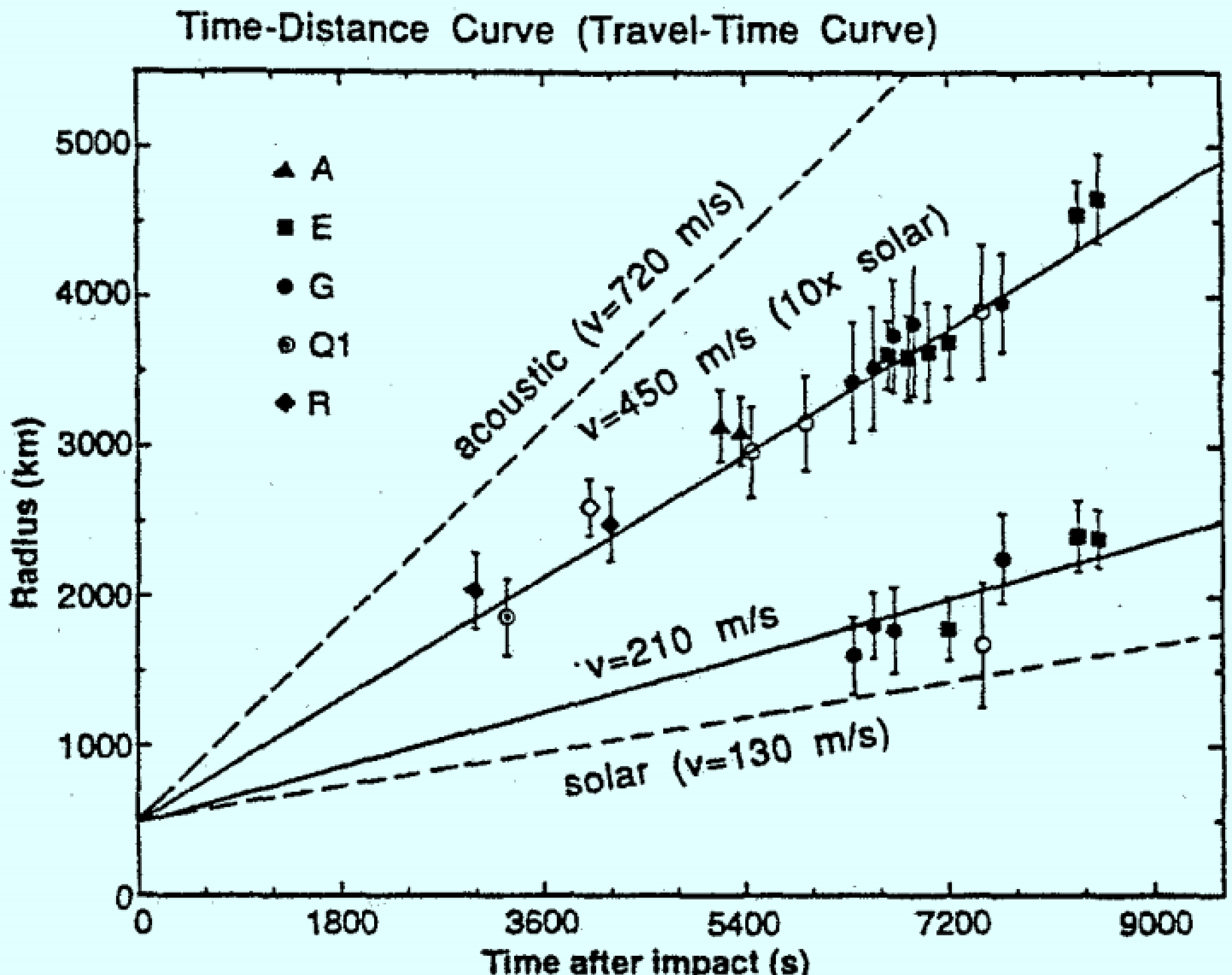


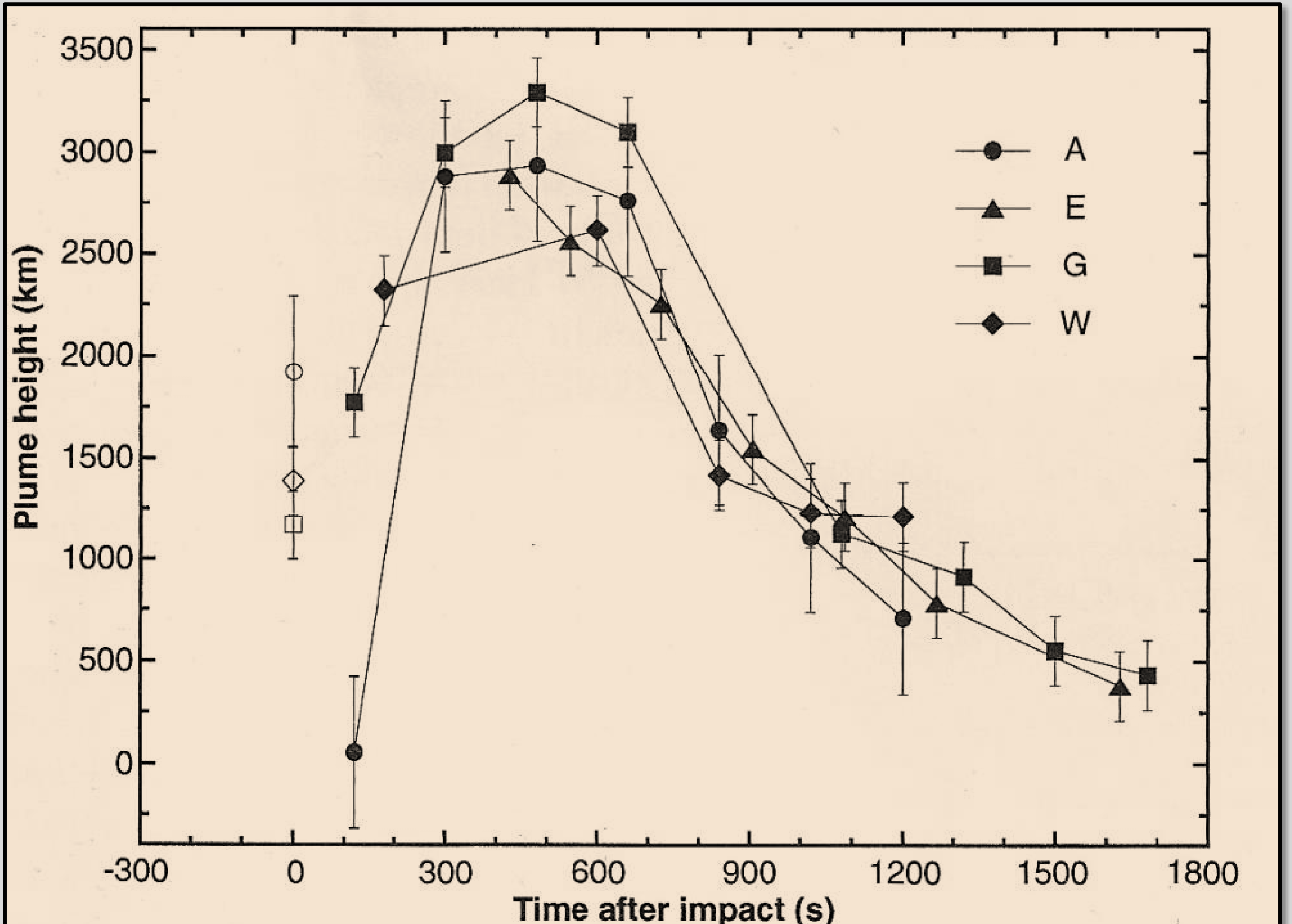
Ingersoll, Andrew P., and Hiroo Kanamori,
"Waves from the Shoemaker-Levy 9 impacts."
The Collision of Comet Shoemaker–Levy 9 (1995): 329-345.

“Images of Jupiter taken by the Hubble Space Telescope (HST) reveal two concentric circular rings surrounding five of the impact sites from comet Shoemaker-Levy 9 (SL9). The rings are visible 1.0 to 2.5 hours after the impacts. The outer ring expands at a constant rate of 450 ms^{-1}. The inner ring expands at about half that speed. The rings appear to be waves….”

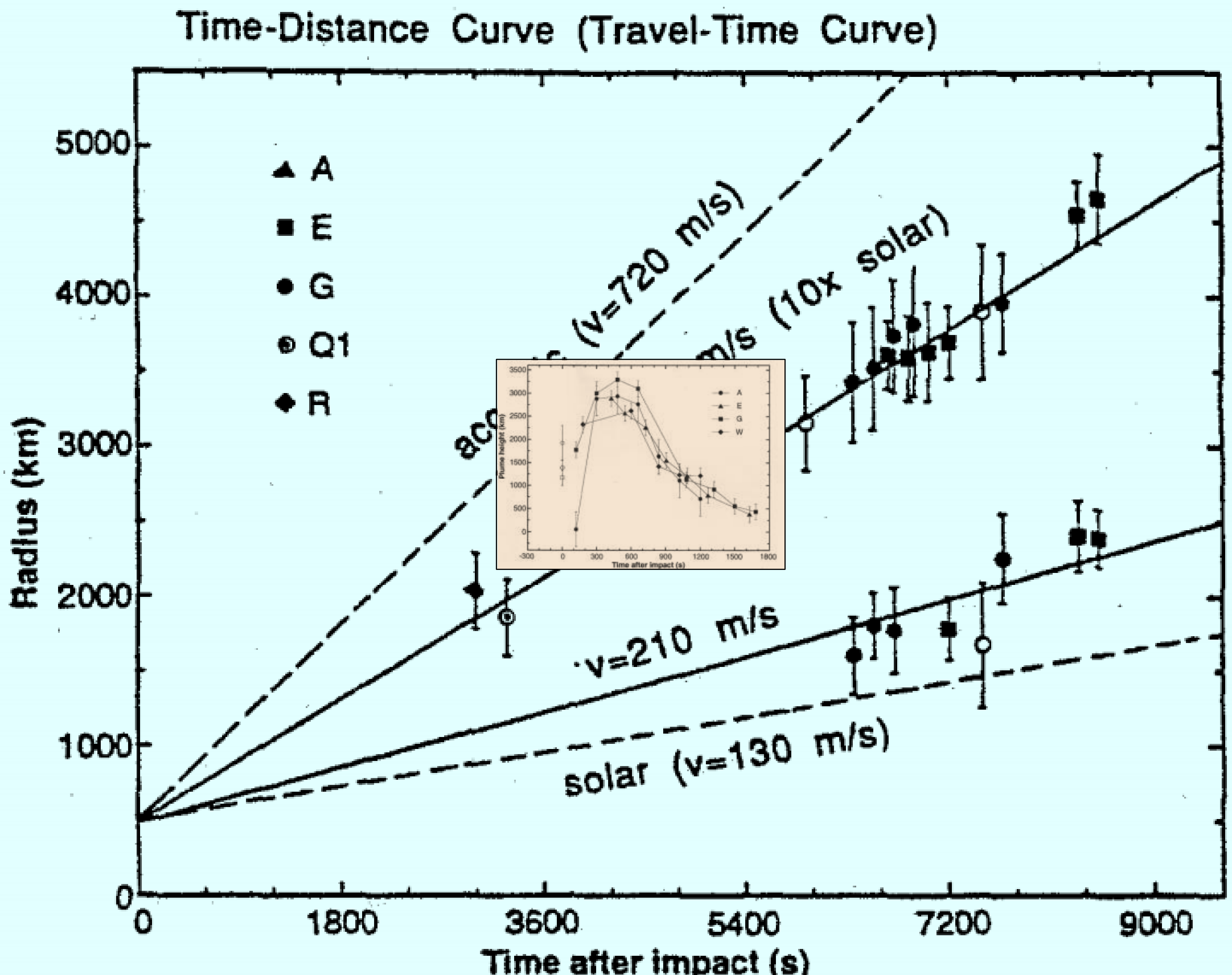
Ingersoll and Kanamori have argued that internal gravity waves trapped in a stable layer within the putative water cloud are the only waves that can match the observations.

A. P. Ingersoll & H. Kanamori: *Waves from the SL9 impacts*




3500
3000
2500
2000
1500
1000
500
0
Plume height (km)
-300
0
300
600
900
1200
1500
1800
Time after impact (s)
A
E
G
W

A. P. Ingersoll & H. Kanamori: *Waves from the SL9 impacts*



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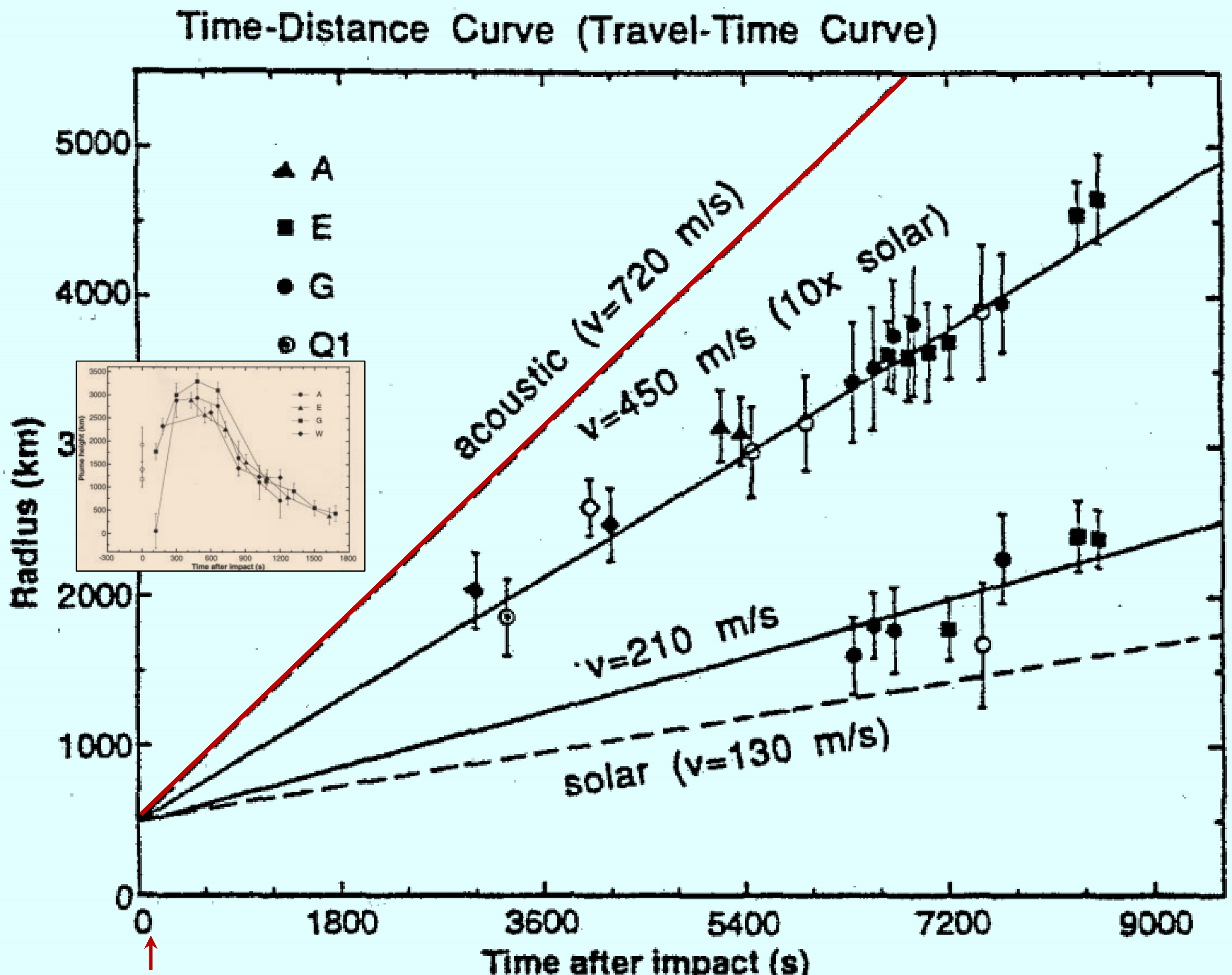

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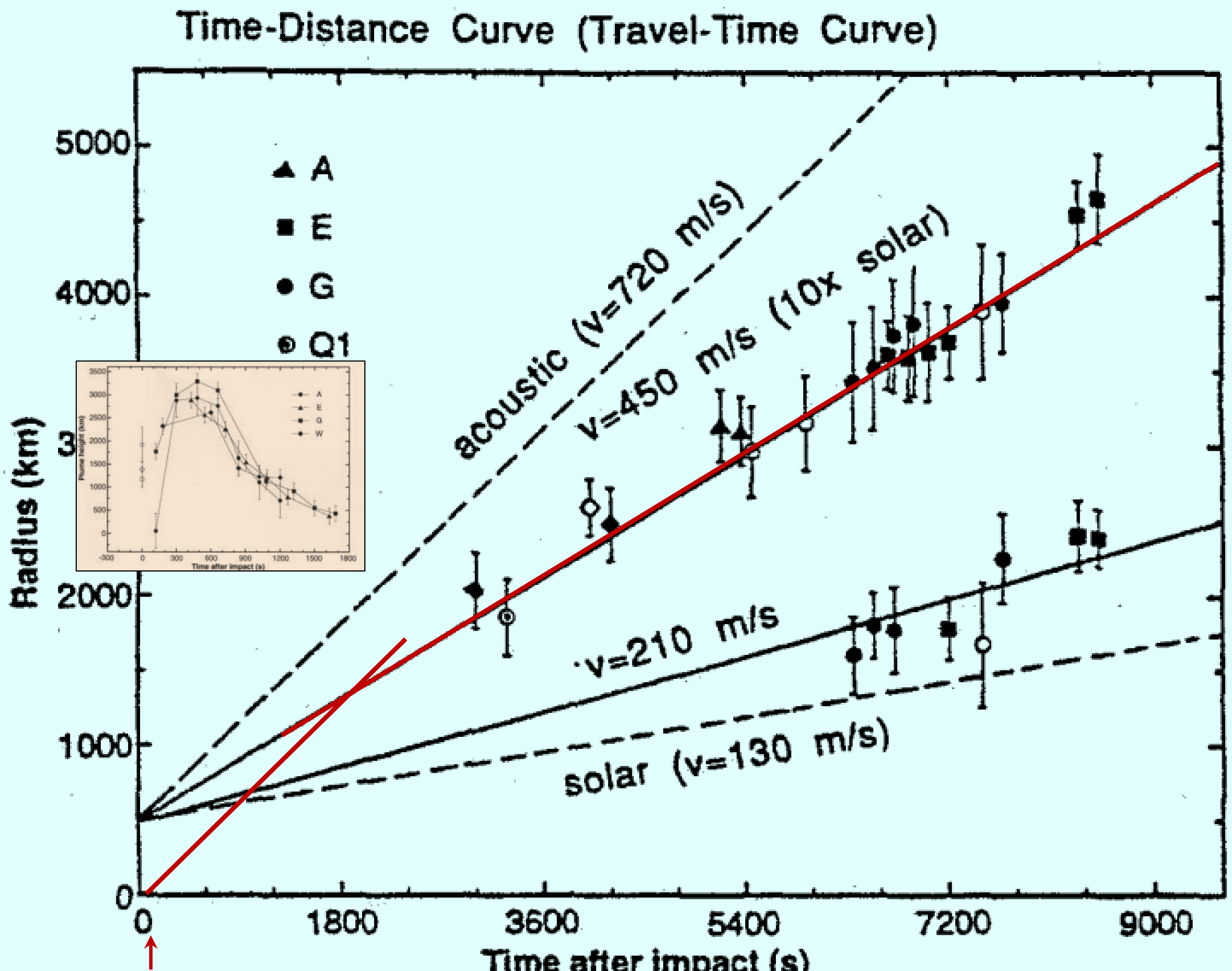
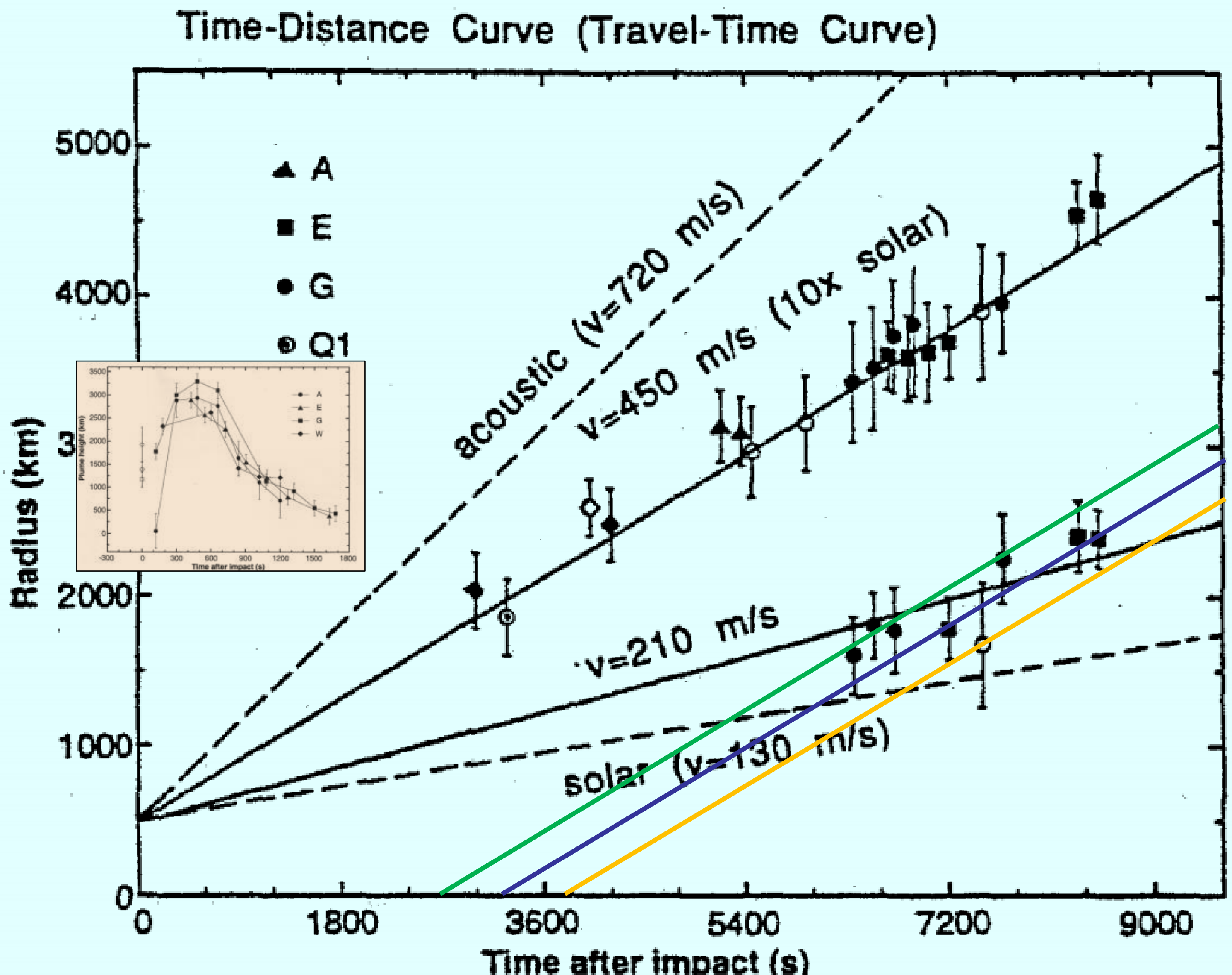
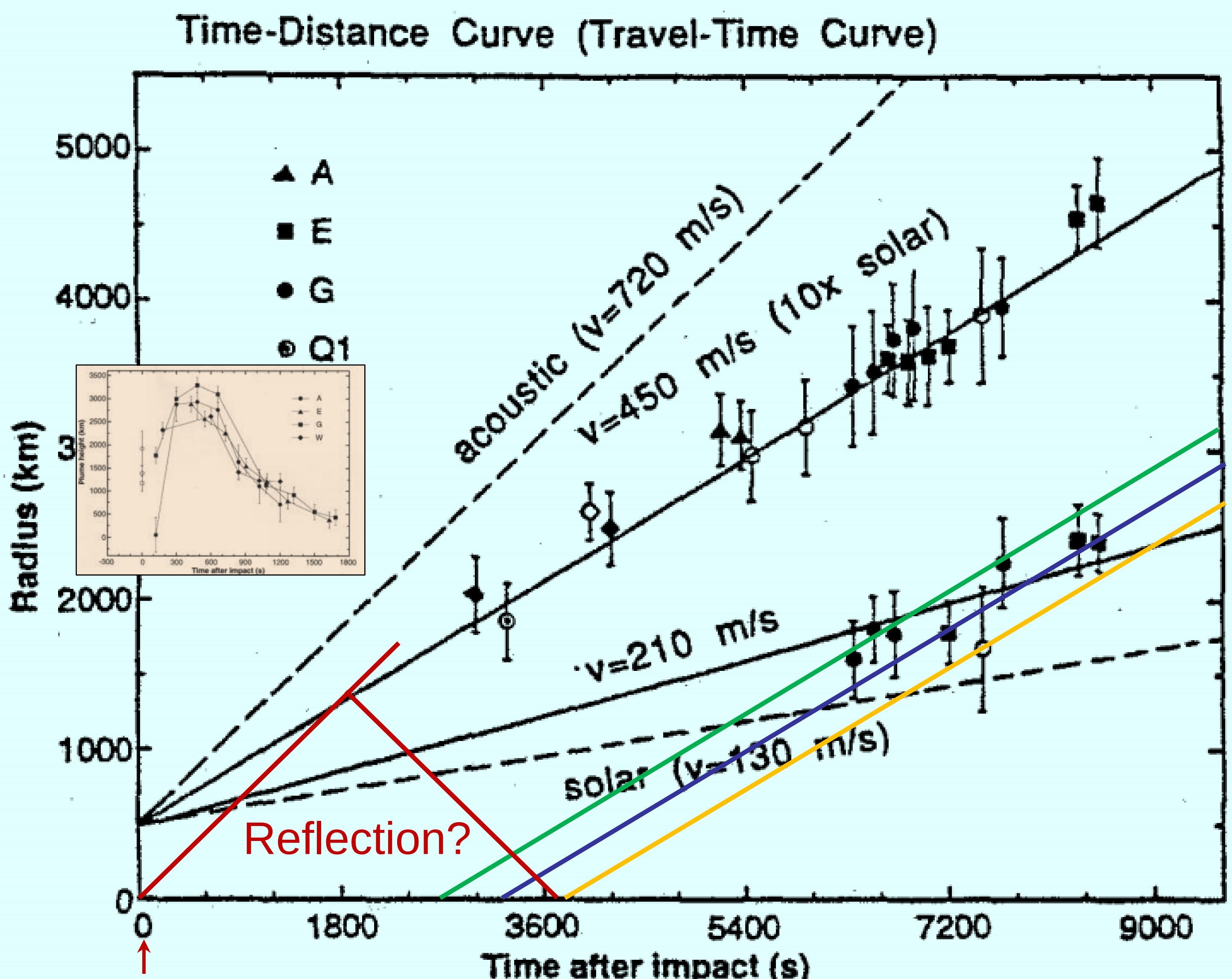


A. P. Ingersoll & H. Kanamori: *Waves from the SL9 impacts*



A. P. Ingersoll & H. Kanamori: *Waves from the SL9 impacts*



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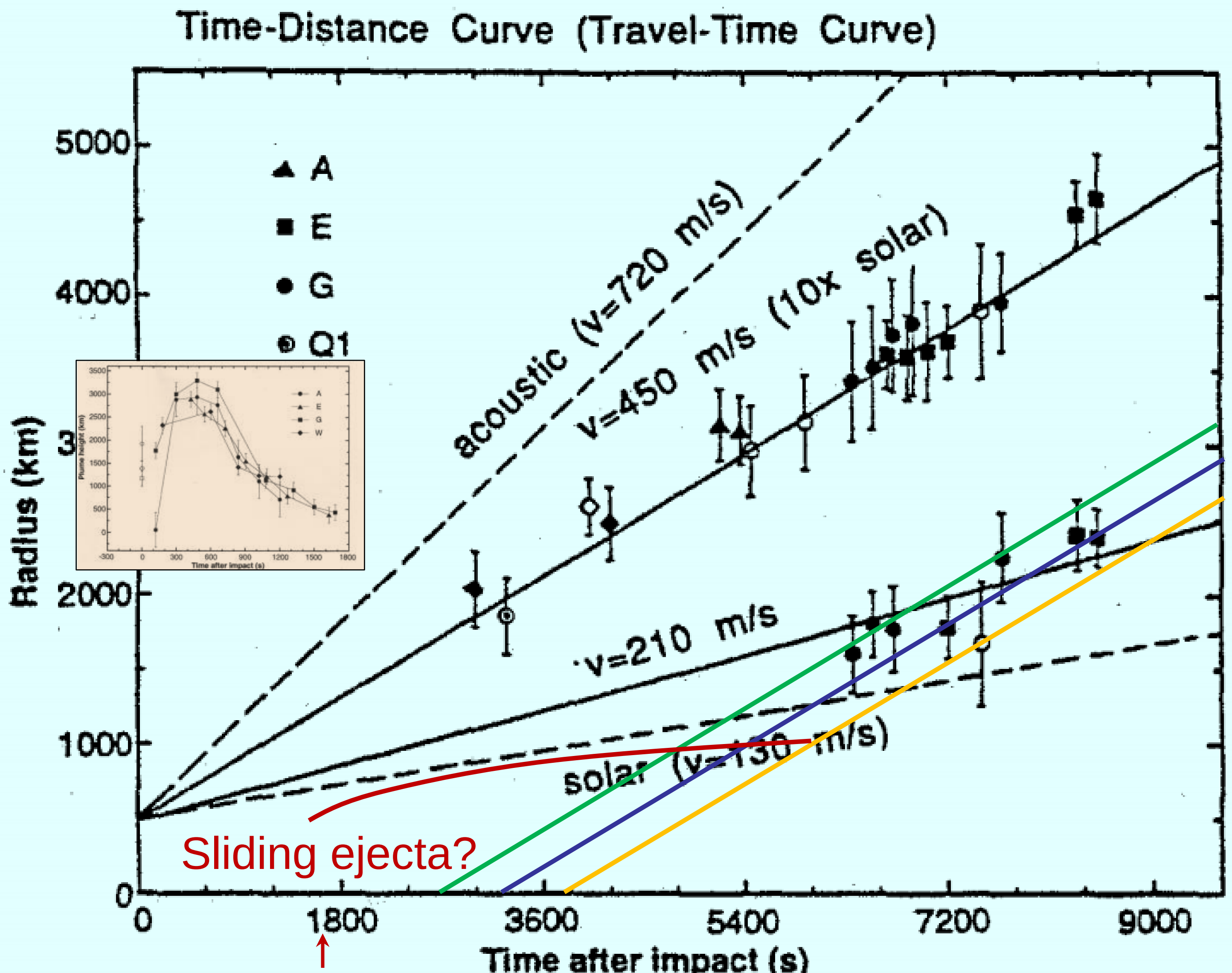
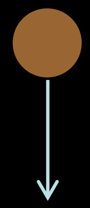


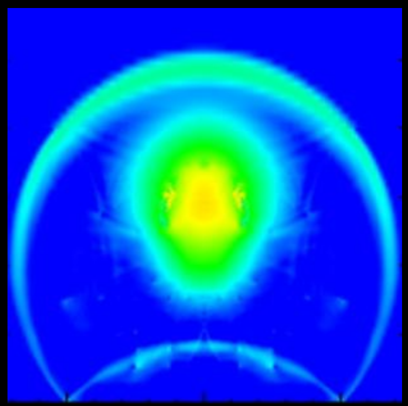
Tunguska Yield Estimates

Three ways to generate seismic impulse: $7x10^{18}$ dyne-cm

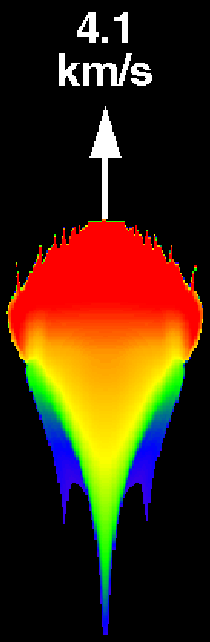
The earth has a β for seismic coupling time scale



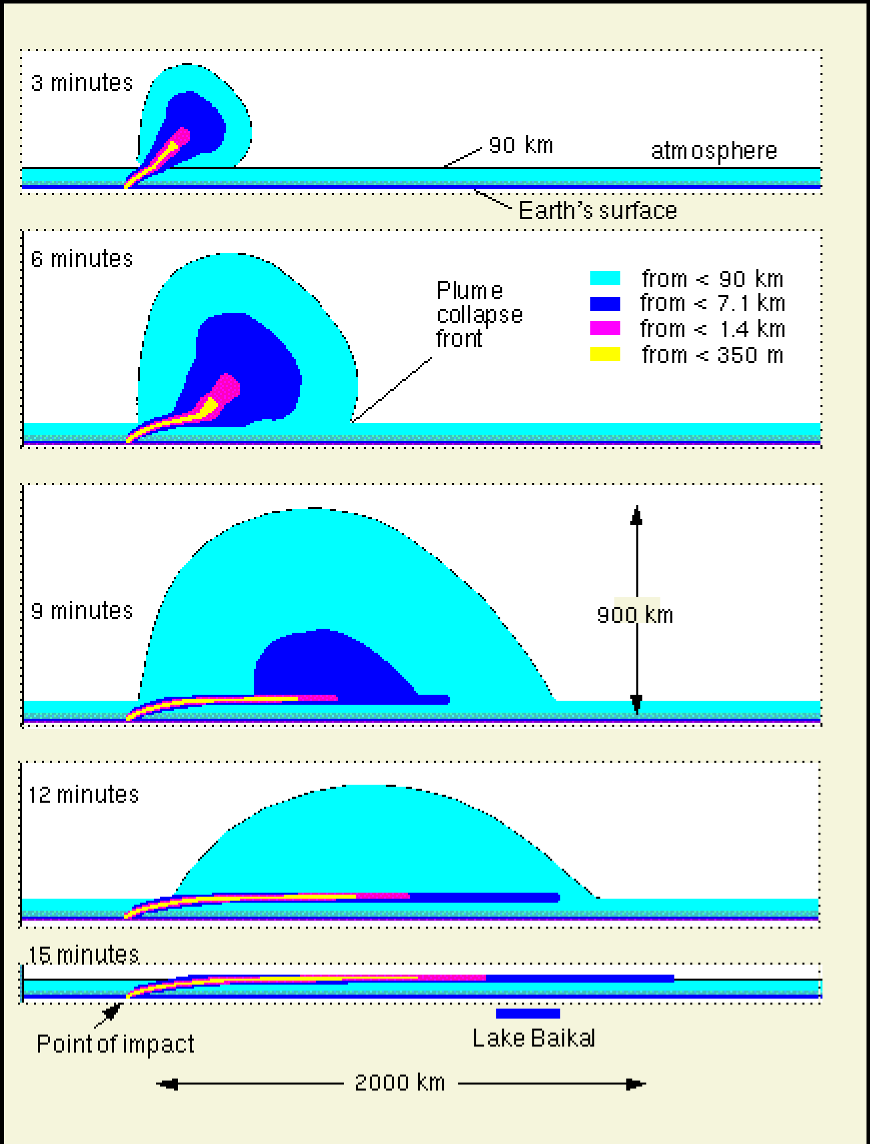
1000 Mton β = 1
Turco et al., 1982



12.5 Mton β ≈ 80
Ben-Menahem,1975

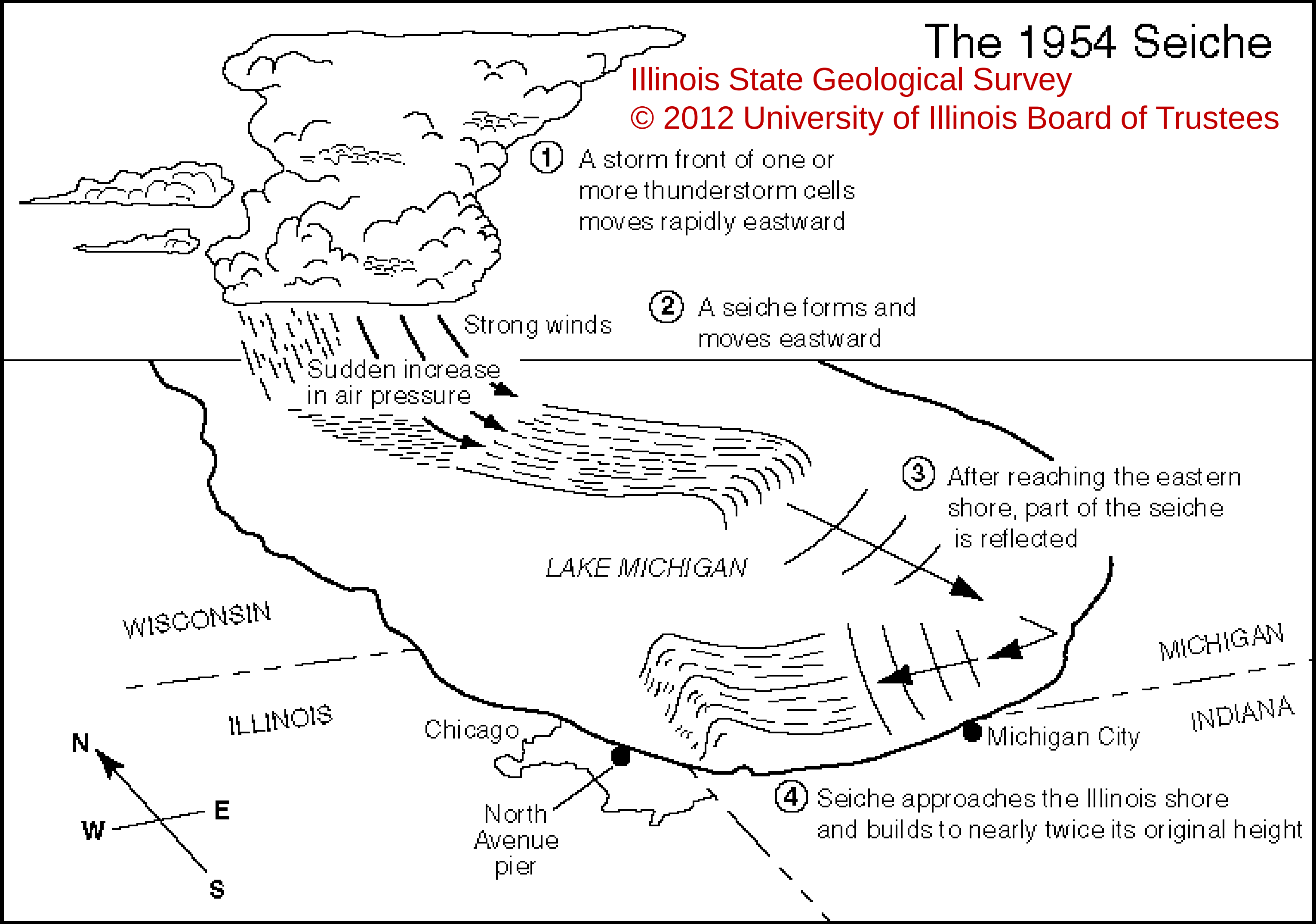


3 Mton β ≈ 300
Boslough & Crawford,1997



Distribution of bright night skies,
June 30 – July 1, 1908
(I.T Zotkin & A.L. Tchijevsky)

Meteotsunami

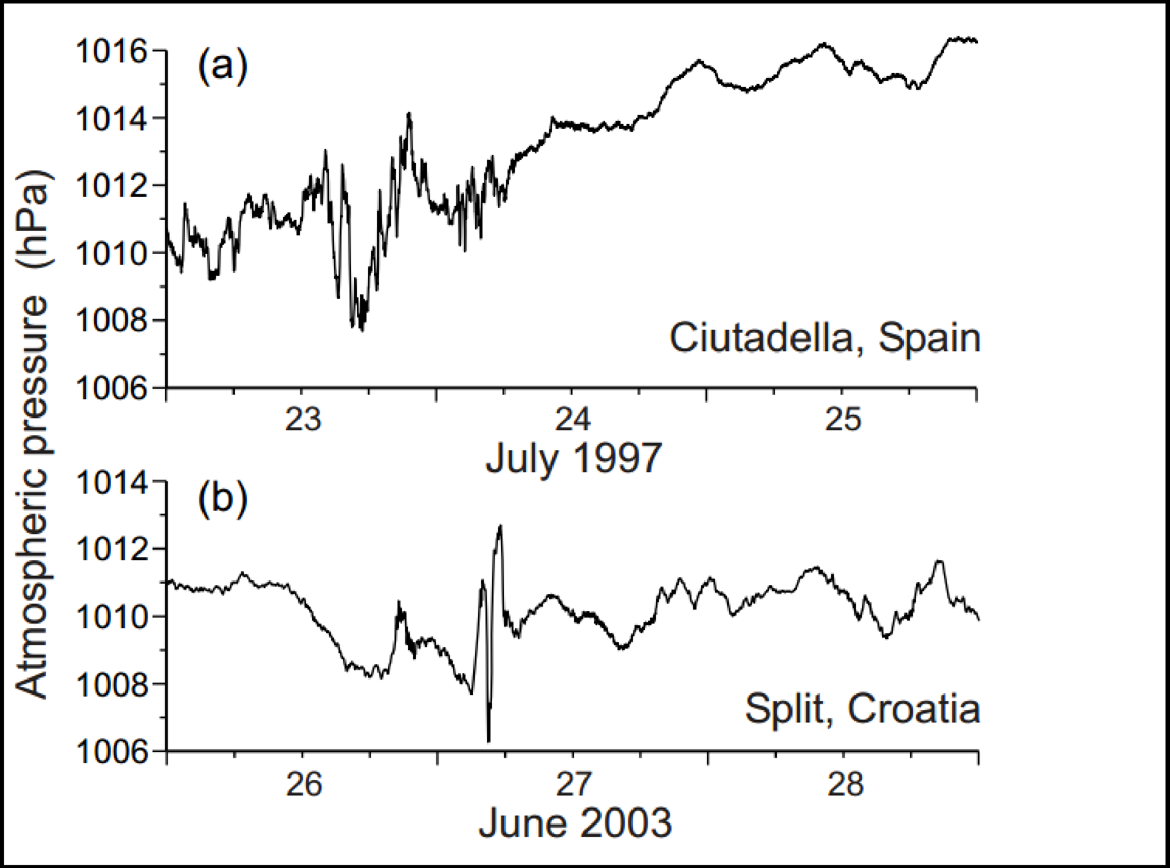


The coast was inundated up to 50 meters inland and unexpectedly swept many fishermen off of the Montrose Harbor piers, killing seven.

Rissaga a Ciutadella (2006)

S. Monserrat et al.,
"Meteotsunamis: atmospherically induced destructive ocean waves in the tsunami frequency band."
Nat. Hazards Earth Syst. Sci., 6, 1035–1051, 2006

"…even during the strongest events, the atmospheric pressure oscillations at these scales typically reach only a few hPa that correspond only to a few cm of sea level change."



S. Monserrat et al.,
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"…even during the strongest events, the atmospheric pressure oscillations at these scales typically reach only a few hPa that correspond only to a few cm of sea level change."

3 Mton Tunguska-scale impact

Plume impulse = $7 \cdot 10^{18}$ dyne-s within 1 minute
(Boslough & Crawford, (1997)

Mean force for 60 s = $1.2 \cdot 10^{17}$ dynes

Area within sound speed of epicenter at 60 s = 1200 km^2

Mean overpressure = 10 mbar = 10 hPa

S. Monserrat et al.,
"Meteotsunamis: atmospherically induced destructive ocean waves in the tsunami frequency band."
Nat. Hazards Earth Syst. Sci., 6, 1035–1051, 2006

> "Consequently, these atmospheric fluctuations can produce a significant sea level response only when some form of resonance occurs between the ocean and the atmospheric forcing."

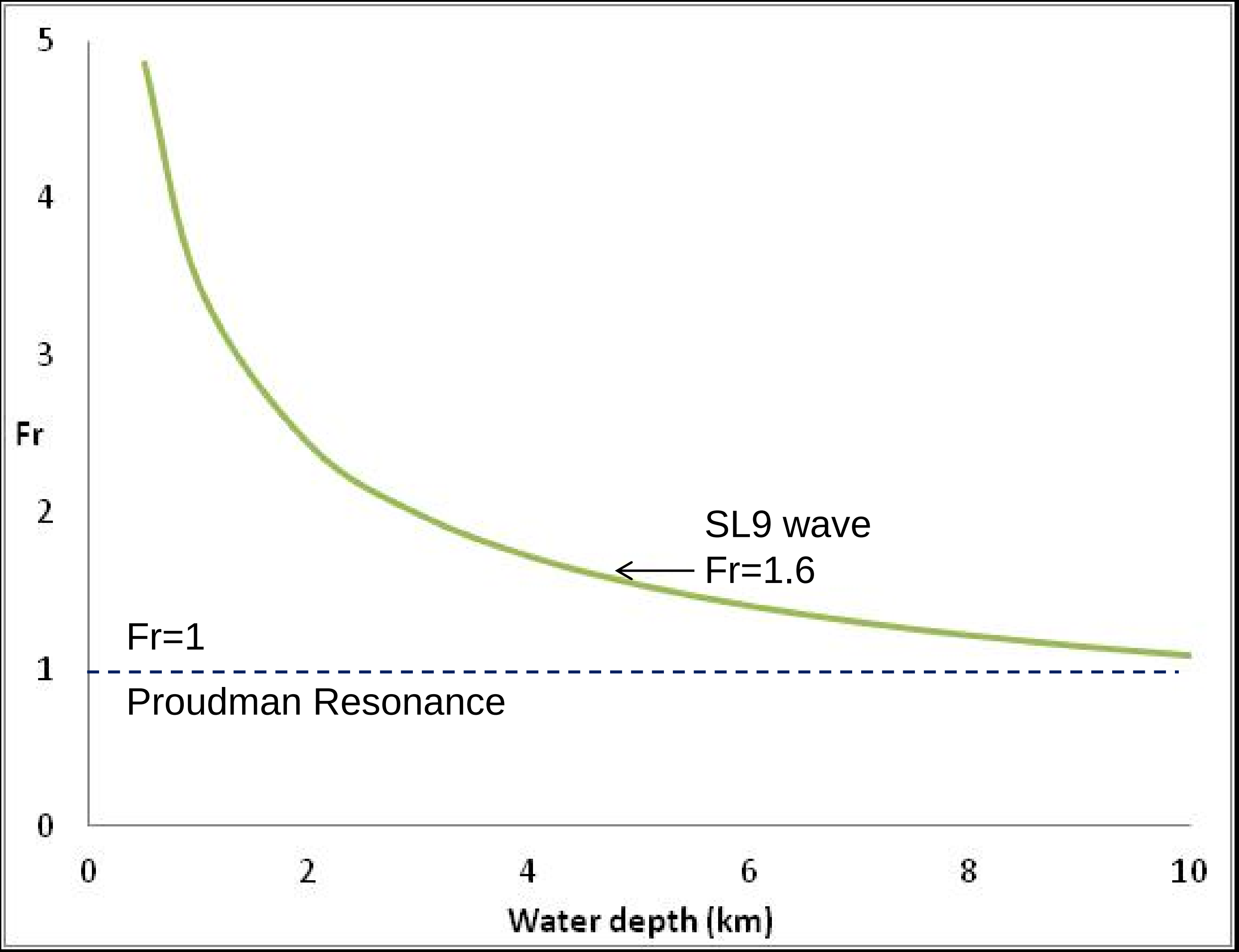
Proudman resonance

U=c, i.e. the atmospheric disturbance translational speed (U) equals the longwave phase speed $c= \sqrt{gh}$ of ocean waves

Froude number (Fr = U/c)

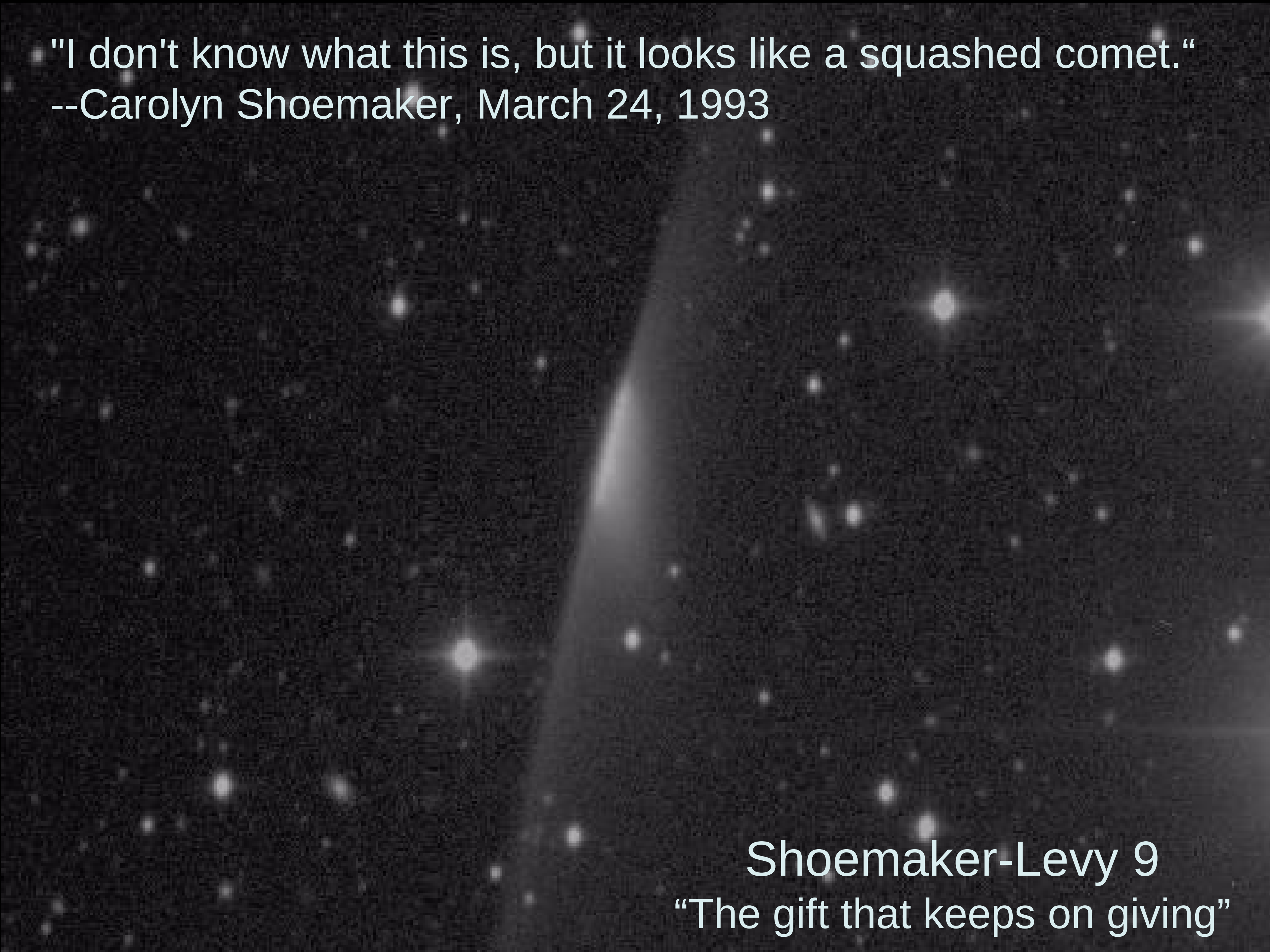
Coupling is strong when Fr ≈ 1.0

4.6-km deep ocean has same Fr as Jupiter



Conclusion

- Tunguska-scale plume-forming impact can generate reaction impulse that raises atmospheric pressure over a large area on time scale sufficiently close to the Proudman resonance in deep water (>4 km) to produce dangerous meteotsunami.
- This effect needs to be quantified and included in NEO hazard assessment.


"I don't know what this is, but it looks like a squashed comet."
--Carolyn Shoemaker, March 24, 1993
Shoemaker-Levy 9
"The gift that keeps on giving"