



Heat-death by Volcano: How Venus went rogue?

M.J. Way¹⁻³, R.E. Ernst^{4,5} & J.D. Scargle⁶

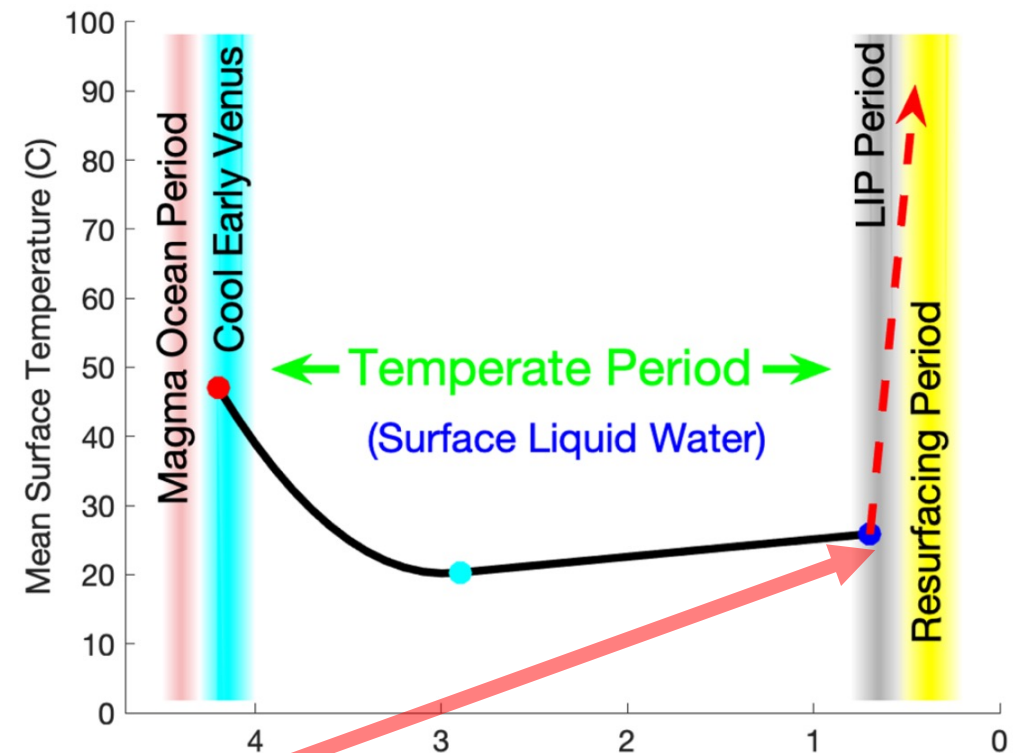
- 1. NASA Goddard Institute for Space Studies, New York, USA
- 2. GSFC Sellers Exoplanet Environments Collaboration
- 3. Theoretical Astrophysics, Dept. of Physics & Astronomy, Uppsala University, Sweden
- 4. Carleton University, Ottawa, Canada; 5. Tomsk State University, Tomsk, Russia
- 6. Astrobiology and Space Science Division, NASA Ames Research Center, California, USA

EGU 2022: Way, Ernst, Scargle

Recent GCM work has proposed a temperate climate history of Venus

Two problems with this early happy habitable Venus model remain:

1. How would a Venus-like world transition from temperate to hothouse?
 - I. Increasing insolation won't work
 - II. Large scale volcanism?



The GREAT CLIMATE TRANSITION (GCT)

EGU 2022: Way, Ernst, Scargle

Recent GCM work has proposed a temperate climate history of Venus

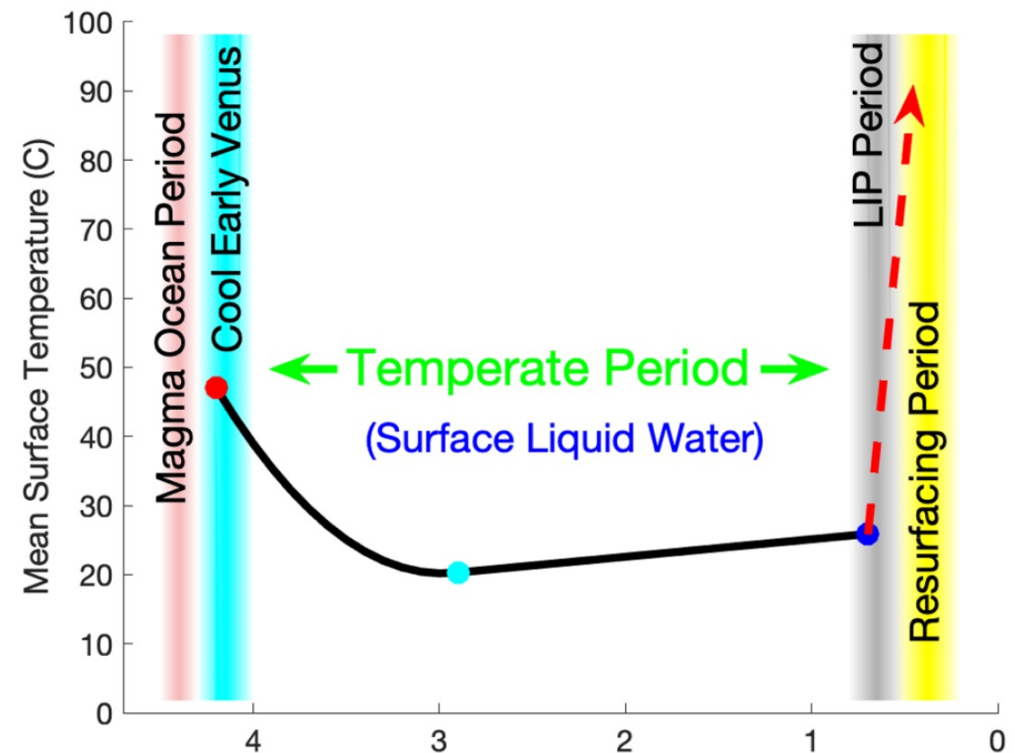
Two problems with this early happy habitable Venus model remain:

1. **How would a Venus-like world transition from temperate to hothouse?**

- I. Increasing insolation won't work
- II. **Large scale volcanism?**

2. **Where is the oxygen?**

- I. Upper atmosphere photodissociation of water oceans
- II. H escape is possible
- III. Oxygen escape is too low (Persson et al. 2020)
- IV. Perhaps resurfacing plays a role in Oxygen absorption? (Warren & Kite 2021 LPSC No. 2548)



EGU 2022: Way, Ernst, Scargle

Hypothesis

Venus' GREAT CLIMATE TRANSITION was driven by the
Environmental Impacts of
Multiple Large Igneous Provinces (LIPs)
occurring at the same time

We used the Earth's record of LIPs to estimate this likelihood

560 Continental & Ocean LIPs over 2800 Myr (Ernst et al. 2021)

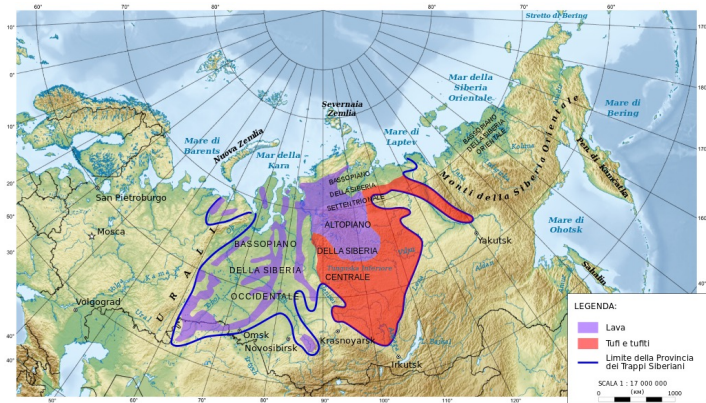
EGU 2022: Way, Ernst, Scargle

LARGE IGNEOUS PROVINCES (LIPs)

Large mainly basaltic events on Earth that cause dramatic climate change

Example: 252 Ma Siberian Traps LIP caused end-Permian mass extinction--- where 90% of life was wiped out

(e.g. LIP Mass Extinction events: Wignall 2011, Nature, 477, 285–286)



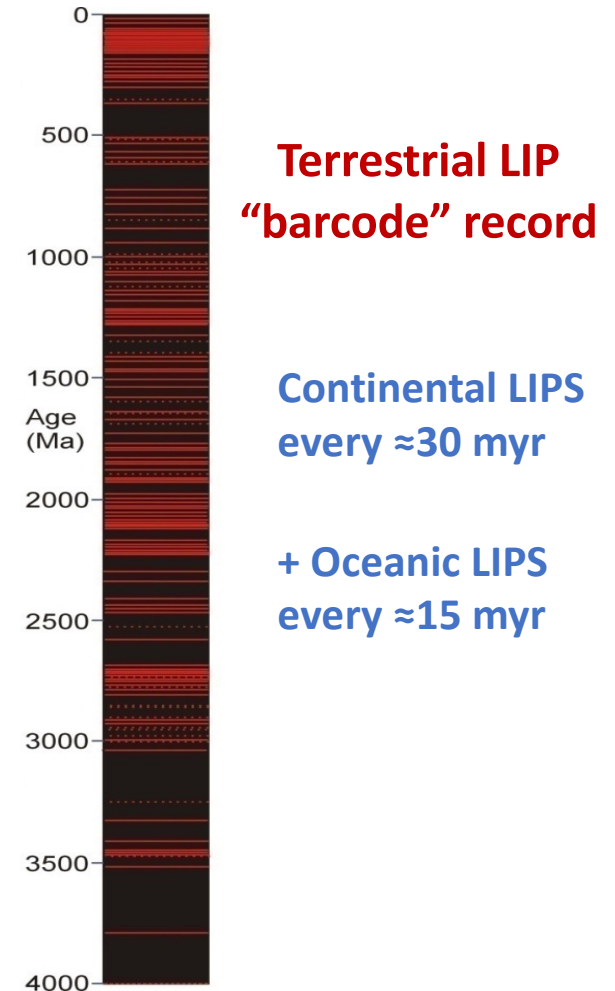
Credit: Kaidor,(wikimedia.org) CC BY-SA 3.0

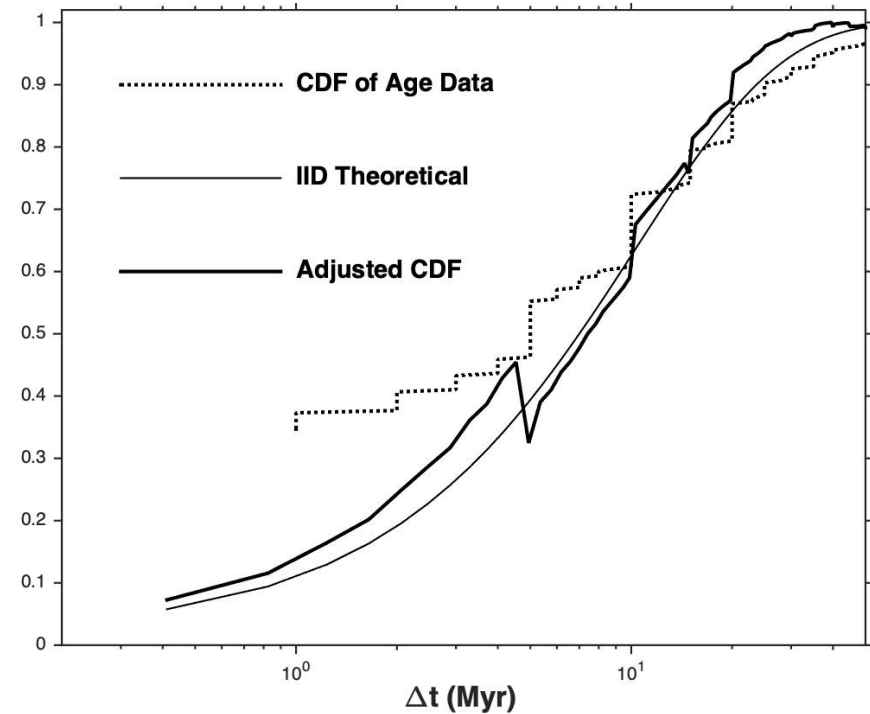
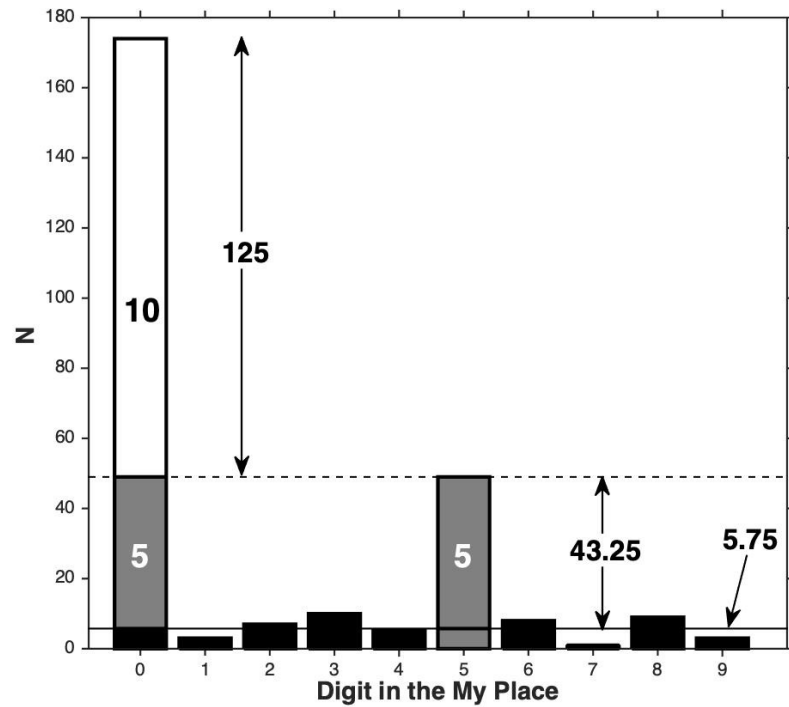


Credit: OlgaChuma (wikimedia.org) CC BY-SA 3.0

See Ernst LIP Commission website: <http://www.largeigneousprovinces.org/>

EGU 2022: Way, Ernst, Scargle





Fixing the rounding of dates in LIP data

Cumulative Distribution Function: Random!

EGU 2022: Way, Ernst, Scargle

Expected number of LIP clusters simultaneous to within time Δt in Myr
In the Earth record over 2800 Myr.

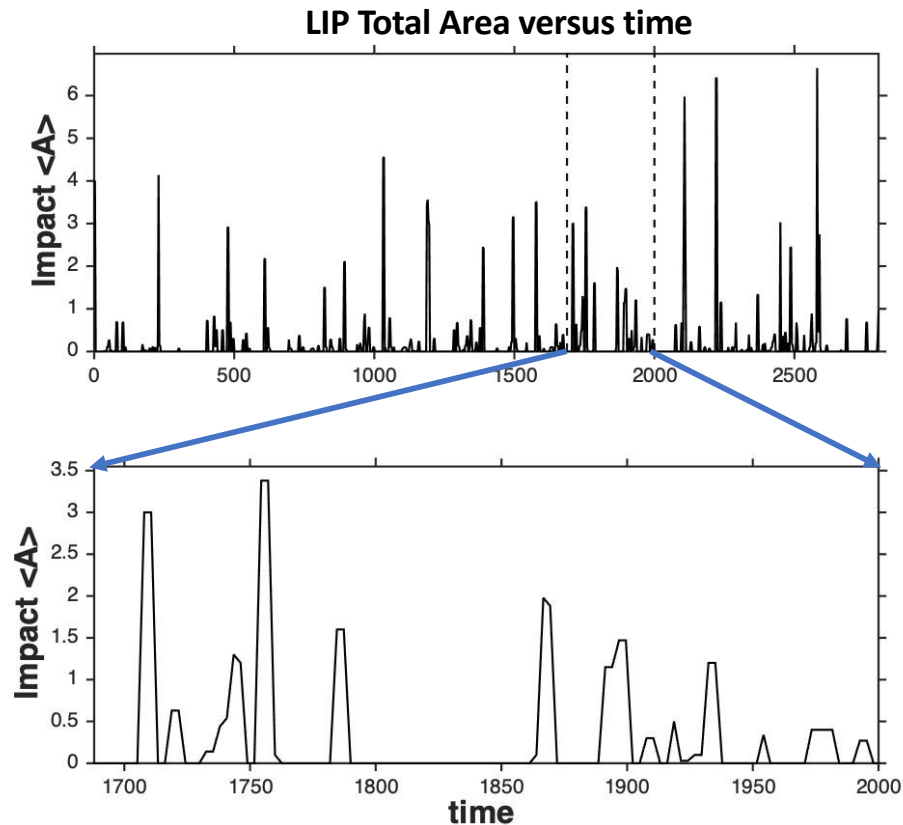
multiplicity	(1) N(k=1)	(2) close pair rate relative to LIP rate	(3) Waiting time (Myr)	(4) Prob of at least one
pair $\Delta t = 0.1$	11	2.0%	252	0.9999...
$\Delta t = 1$	101.5	18.1%	28	0.9999...
triple $\Delta t = 0.1$	0.11	.02%	25,345	0.1046
$\Delta t = 1$	9.8	1.7%	285	0.9999
quad $\Delta t = 0.1$.0007	.0001%	3,800,660	0.0007
$\Delta t = 1$	0.64	0.11%	4354	0.4746

The takeaway: Using Earth's LIP record (Ernst et al. 2021), pairs and triplets of simultaneous LIPs (with ≈ 1 Myr separation) are very common over our 2800 Myr Earth history

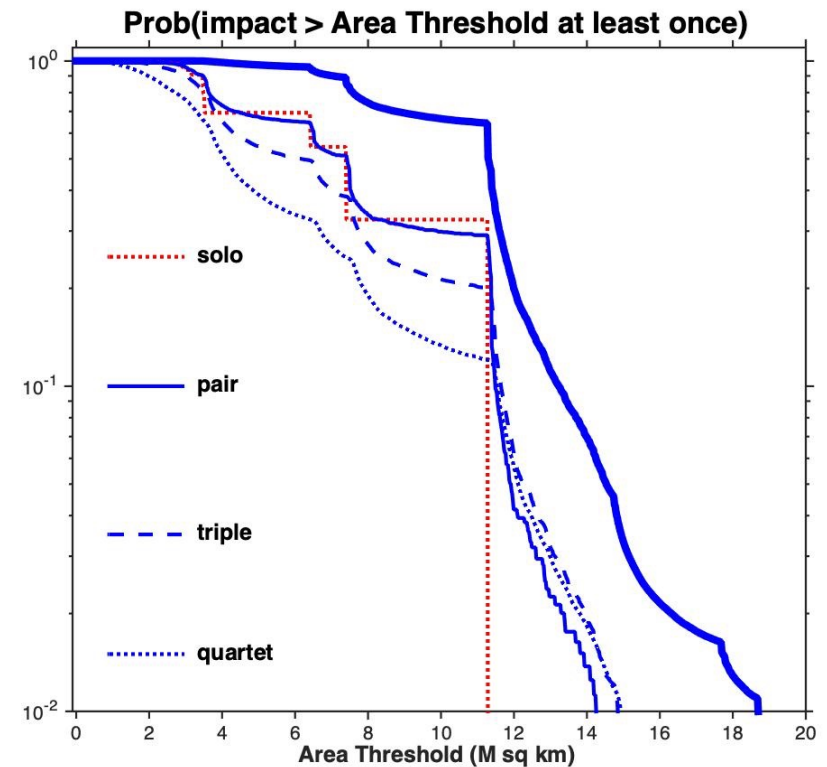
- Many pairs are expected,
- At least one triplet is likely
- Quadruplets are unlikely.

EGU 2022: Way, Ernst, Scargle

Alternative analysis using ensemble of 1024 simulations based on Earth LIP data



Average over 1024 simulated histories of LIP events.
Bottom: Zoomed in portion shows overlapping LIPs



Thin lines are the contributions of
solo events, event pairs, triplets and quartet

EGU 2022: Way, Ernst, Scargle

HEAT DEATH OF VENUS-EARTH TYPE PLANETS

- We assume Venus' rate of LIP magmatism was comparable to Earth's

EGU 2022: Way, Ernst, Scargle

HEAT DEATH OF VENUS-EARTH TYPE PLANETS

- We assume Venus' rate of LIP magmatism was comparable to Earth's
- Earth's LIPs occur approximately randomly and uniformly over time.

HEAT DEATH OF VENUS-EARTH TYPE PLANETS

- We assume Venus' rate of LIP magmatism was comparable to Earth's
- Earth's LIPs occur approximately randomly and uniformly over time.
- On average, simultaneous LIP pairs and triples are expected over 2,800 Myr, yielding enhanced environmental impacts

HEAT DEATH OF VENUS-EARTH TYPE PLANETS

- We assume Venus' rate of LIP magmatism was comparable to Earth's
- Earth's LIPs occur approximately randomly and uniformly over time.
- On average, simultaneous LIP pairs and triples are expected over 2,800 Myr, yielding enhanced environmental impacts
- Modelling underway to estimate the specific background conditions for multiple LIP events leading to a runaway greenhouse state

EGU 2022: Way, Ernst, Scargle

HEAT DEATH OF VENUS-EARTH TYPE PLANETS

- We assume Venus' rate of LIP magmatism was comparable to Earth's
- Earth's LIPs occur approximately randomly and uniformly over time.
- On average, simultaneous LIP pairs and triples are expected over 2,800 Myr, yielding enhanced environmental impacts
- Modelling underway to estimate the specific background conditions for multiple LIP events leading to a runaway greenhouse state
- If such a simultaneous LIP model explains Venus' Great Climate Transition, then a runaway greenhouse event could be in Earth's future

EGU 2022: Way, Ernst, Scargle

HEAT DEATH OF VENUS-EARTH TYPE PLANETS

- We assume Venus' rate of LIP magmatism was comparable to Earth's
- Earth's LIPs occur approximately randomly and uniformly over time.
- On average, simultaneous LIP pairs and triples are expected over 2,800 Myr, yielding enhanced environmental impacts
- Modelling underway to estimate the specific background conditions for multiple LIP events leading to a runaway greenhouse state
- If such a simultaneous LIP model explains Venus' Great Climate Transition, then a runaway greenhouse event could be in Earth's future
- For Future: Size Matters: Need to take into account estimated size of LIP

EGU 2022: Way, Ernst, Scargle

HEAT DEATH OF VENUS-EARTH TYPE PLANETS

- We assume Venus' rate of LIP magmatism was comparable to Earth's
- Earth's LIPs occur approximately randomly and uniformly over time.
- On average, simultaneous LIP pairs and triples are expected over 2,800 Myr, yielding enhanced environmental impacts
- Modelling underway to estimate the specific background conditions for multiple LIP events leading to a runaway greenhouse state
- If such a simultaneous LIP model explains Venus' Great Climate Transition, then a runaway greenhouse event could be in Earth's future
- For Future: Size Matters: Need to take into account estimated size of LIP
- See Way, Ernst, Scargle (2022) PSJ 3:92 (<https://doi.org/10.3847/PSJ/ac6033>)

EGU 2022: Way, Ernst, Scargle