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Evidence of external influences on planetary climates

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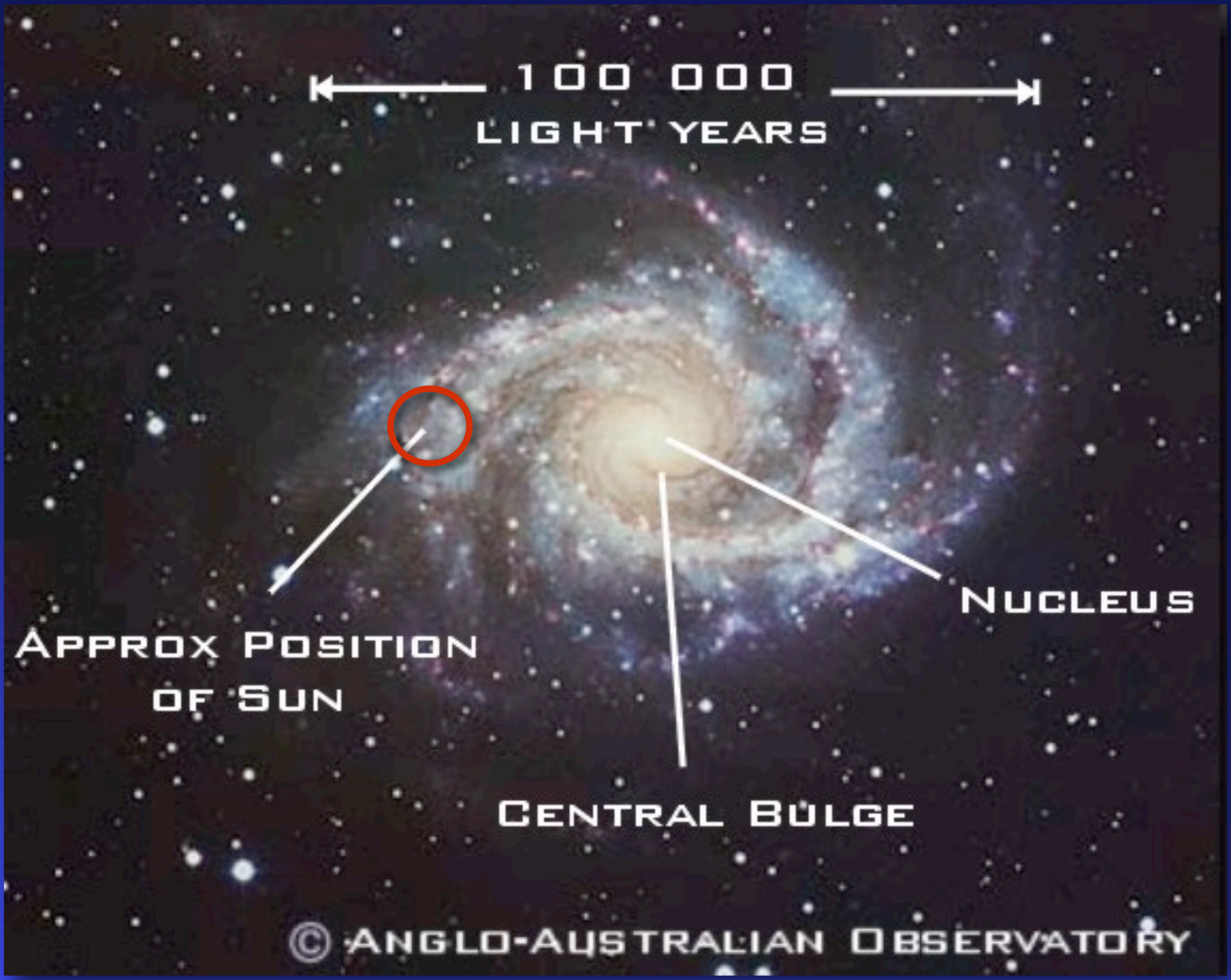
Outline

- Introduction
- External influences
- Variability of influences
- Reconstruction of long-term solar variability
- Summary and conclusions

Introduction

NGC 2997



Galaxy:
- stars: 10^{11}
- age: ~7 Gy

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Formation of the Sun and the planetary disk

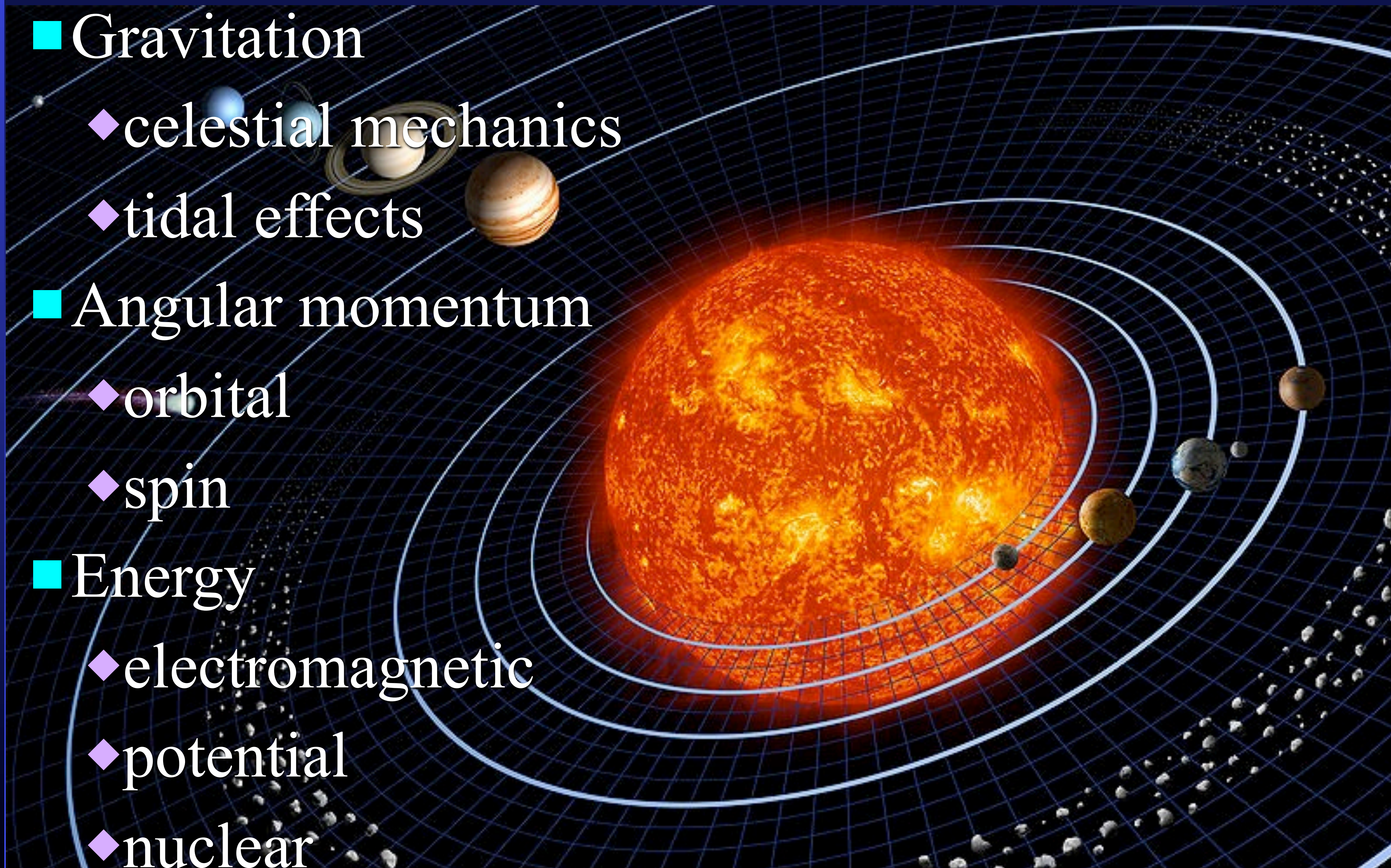
Lee Hartmann

	Mass	Angular momentum
Sun	99.8%	2%
Planets	0.2%	98%

NASA: http://cougar.jpl.nasa.gov/HR4796/anim.html

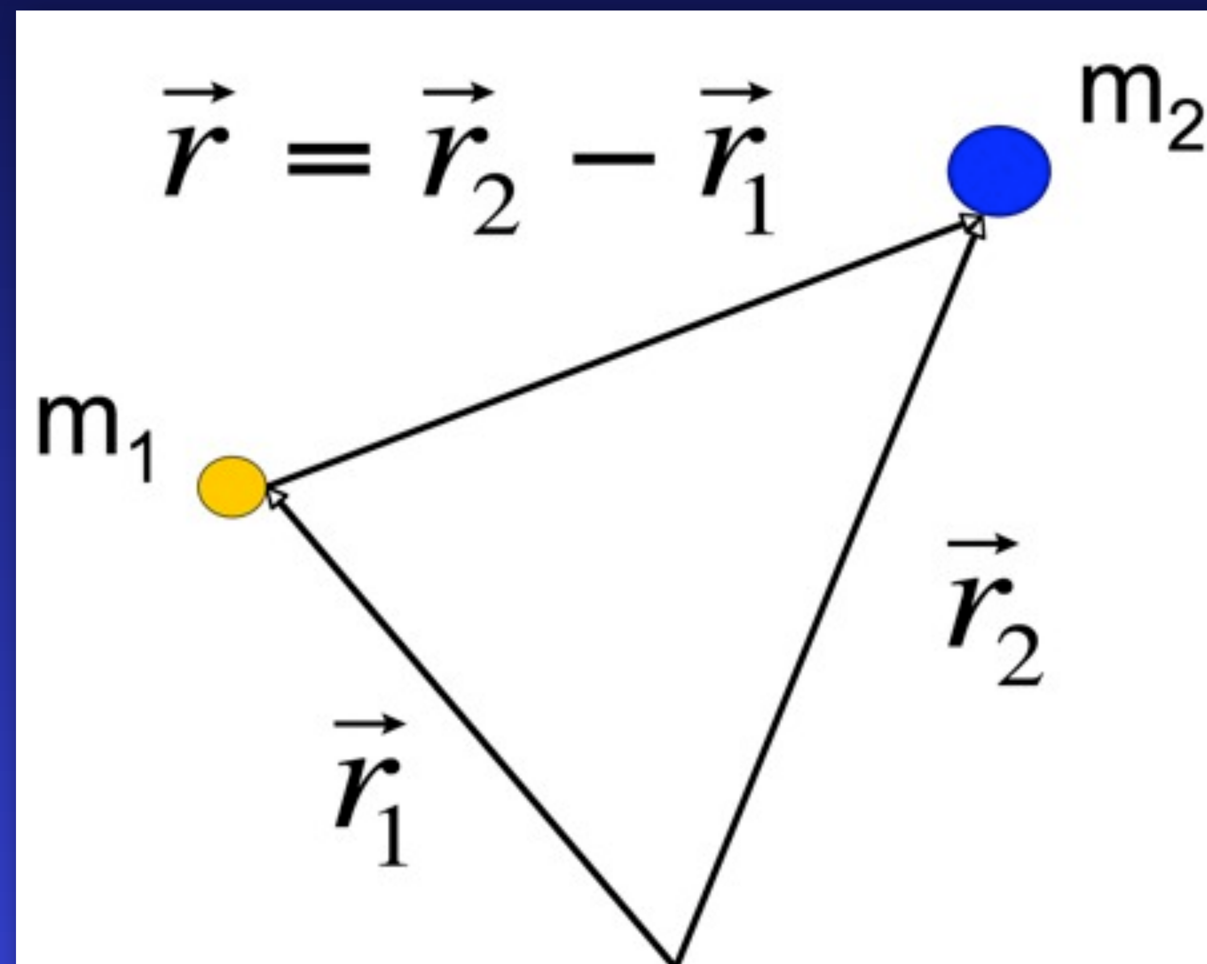
Coupled system: gravitation, conservation of angular momentum, electromagnetic radiation, particles, magnetic fields

External Influences



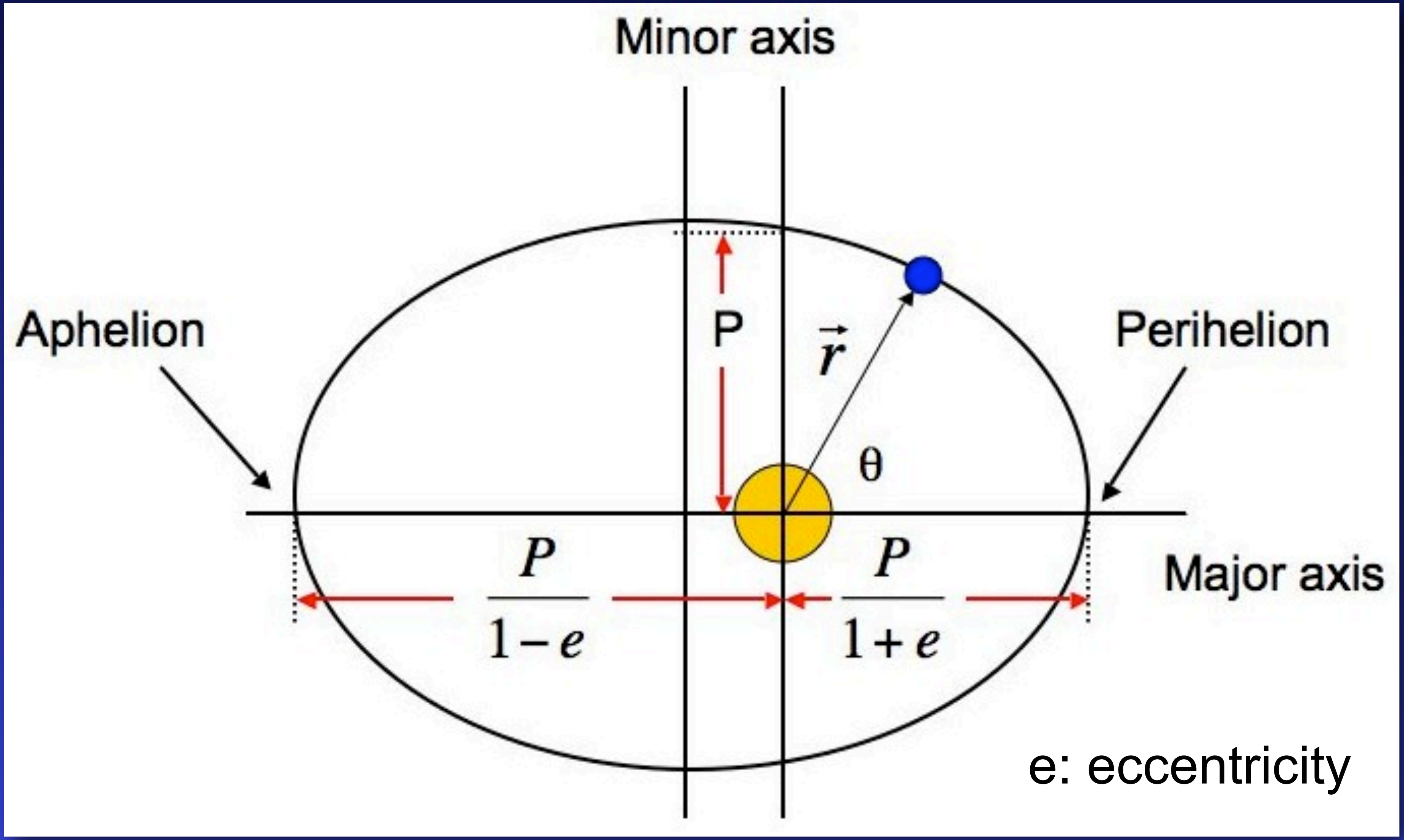
- Gravitation
  - celestial mechanics
  - tidal effects
- Angular momentum
  - orbital
  - spin
- Energy
  - electromagnetic
  - potential
  - nuclear

Gravitation



$$\vec{F}_{12} = -G\frac{m_1\, m_2}{r^2}\vec{e}_r$$

Elliptical orbit



$$r(\theta) = \frac{P}{1 + e \cdot \cos(\theta)}$$

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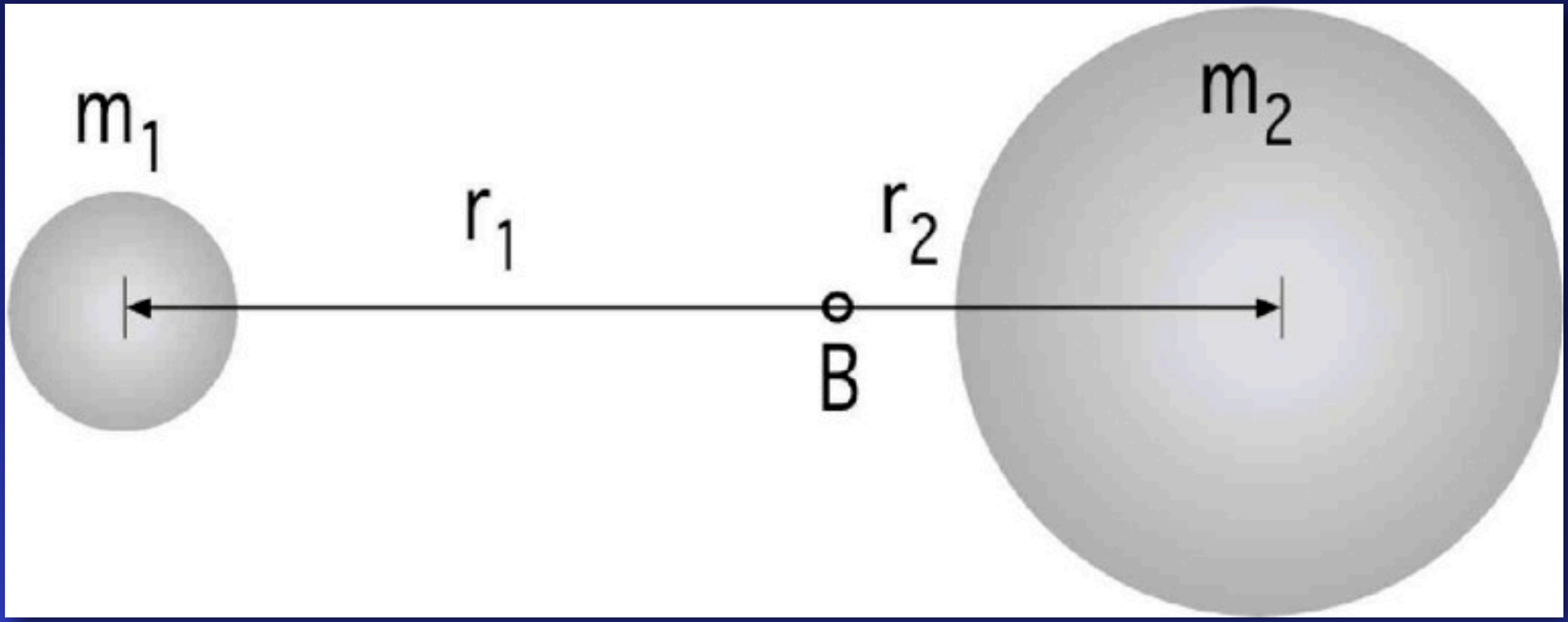
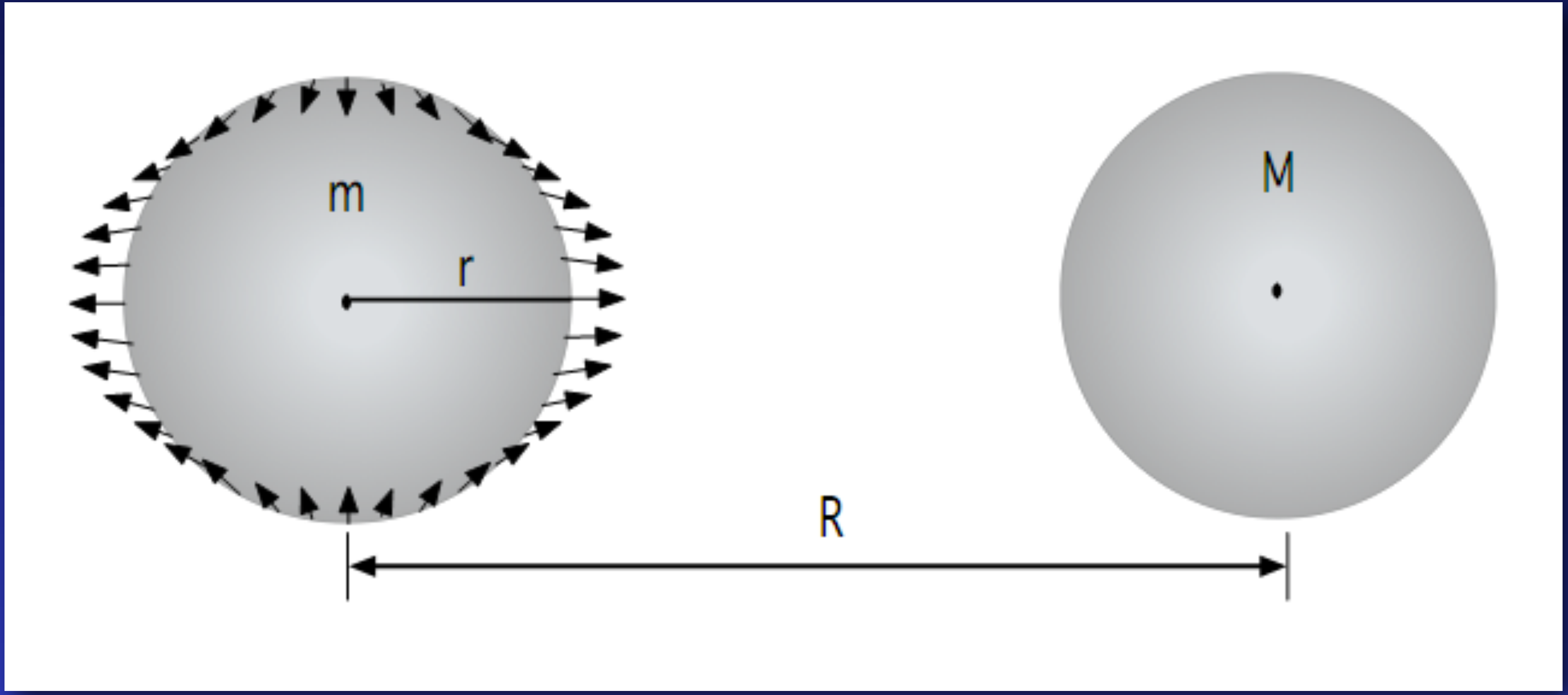
Barycenter



$$r_2 = \frac{a}{1 + \frac{m_2}{m_1}}$$

Tidal Effects



$$a_g \approx \pm\gamma \frac{2\,M}{R^2}\frac{r}{R}$$

Angular momentum

Orbital angular momentum

$$L_{\mathrm{orb}} = m\, r^2\, \omega$$

Spin angular momentum

$$L_{\mathrm{spin}} = \frac{4\,\pi\, m\, R^2}{5\, P_{\mathrm{spin}}}$$

$$\omega = 2\,\pi / P_{\mathrm{orb}}$$

Angular momenta in the solar system

Body	Mass (kg)	Orbital Radius (10^9 m)	Orbital Period (Days)	Spin Radius (10^6 m)	Spin Period (Days)	L_{orbital} (10^{40} Js)	L_{Spin} (10^{40} Js)
Sun	$1.99\ 10^{30}$			696	27		93.08
Mercury	$3.30\ 10^{23}$	58	88	24.4	58.6	0.09	$8.74\ 10^{-9}$
Venus	$4.87\ 10^{24}$	108	225	6.05	243	1.84	$1.91\ 10^{-9}$
Earth	$5.97\ 10^{24}$	150	365	6.38	1	2.68	$6.33\ 10^{-7}$
Mars	$6.42\ 10^{23}$	228	687	3.4	1	0.35	$1.93\ 10^{-8}$
Jupiter	$1.90\ 10^{27}$	778	4333	71.5	0.41	1930.70	0.061
Saturn	$5.68\ 10^{26}$	1429	10760	60.3	0.44	784.14	0.012
Uranus	$8.68\ 10^{25}$	2871	30685	25.6	0.72	169.61	0.0002
Neptune	$1.02\ 10^{26}$	4504	60190	24.8	0.67	250.07	0.0002
Pluto	$1.27\ 10^{22}$	5914	90800	1.17	6.39	0.04	$7.09\ 10^{-12}$

Energy

- Electromagnetic
- Particle
- Potential
- Geothermal

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Source of Solar Energy

$2\ 10^8$ NPP

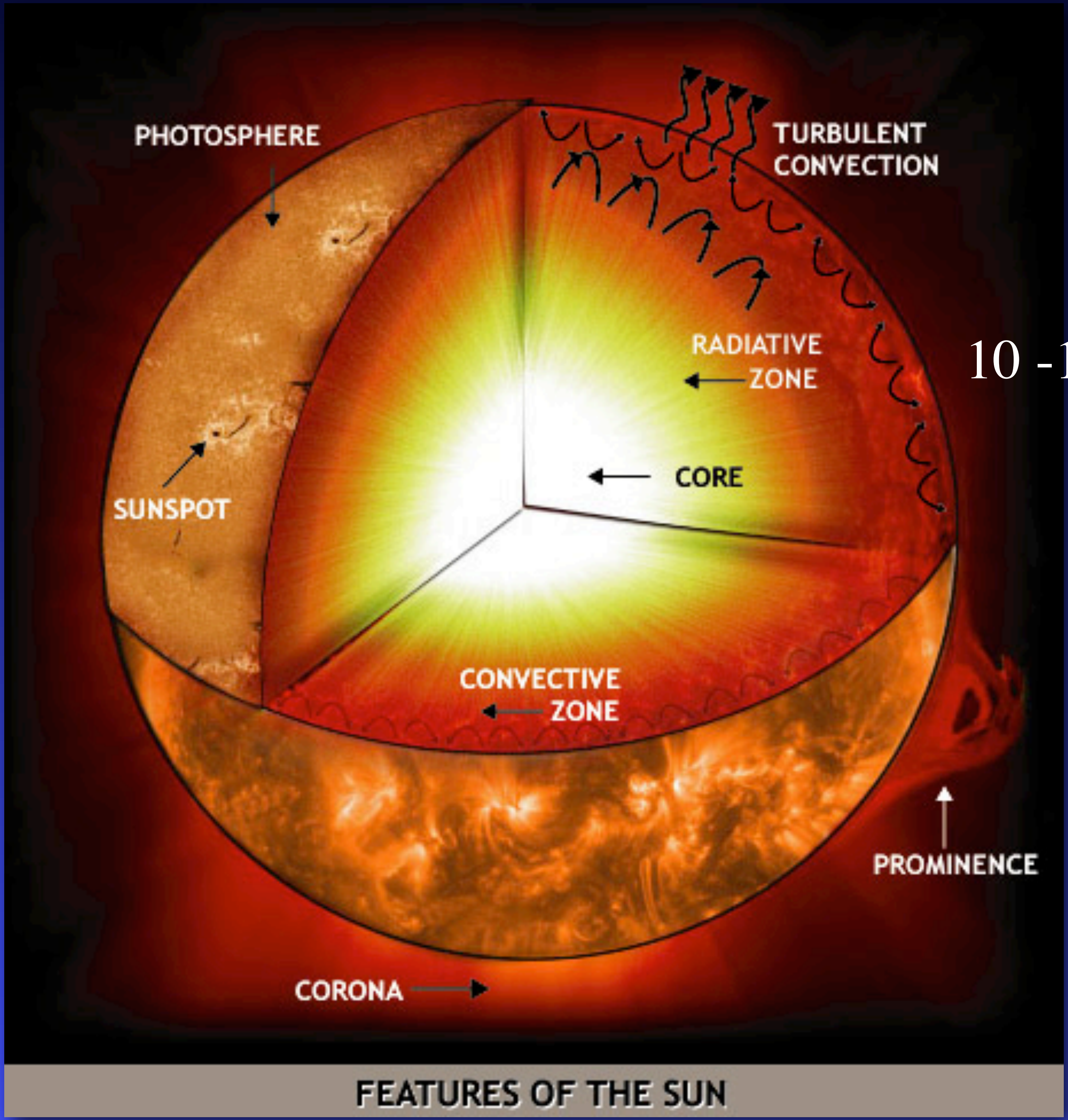
$2\ 10^{17}$ W

Power: $4\ 10^{26}$ W

Potential energy: $2\ 10^{41}$ J --> 20 My (Kelvin - Darwin)

Nuclear energy: $4\ 10^6$ Tons/sec --> 10 Gy

Energy



10 -170 kyr

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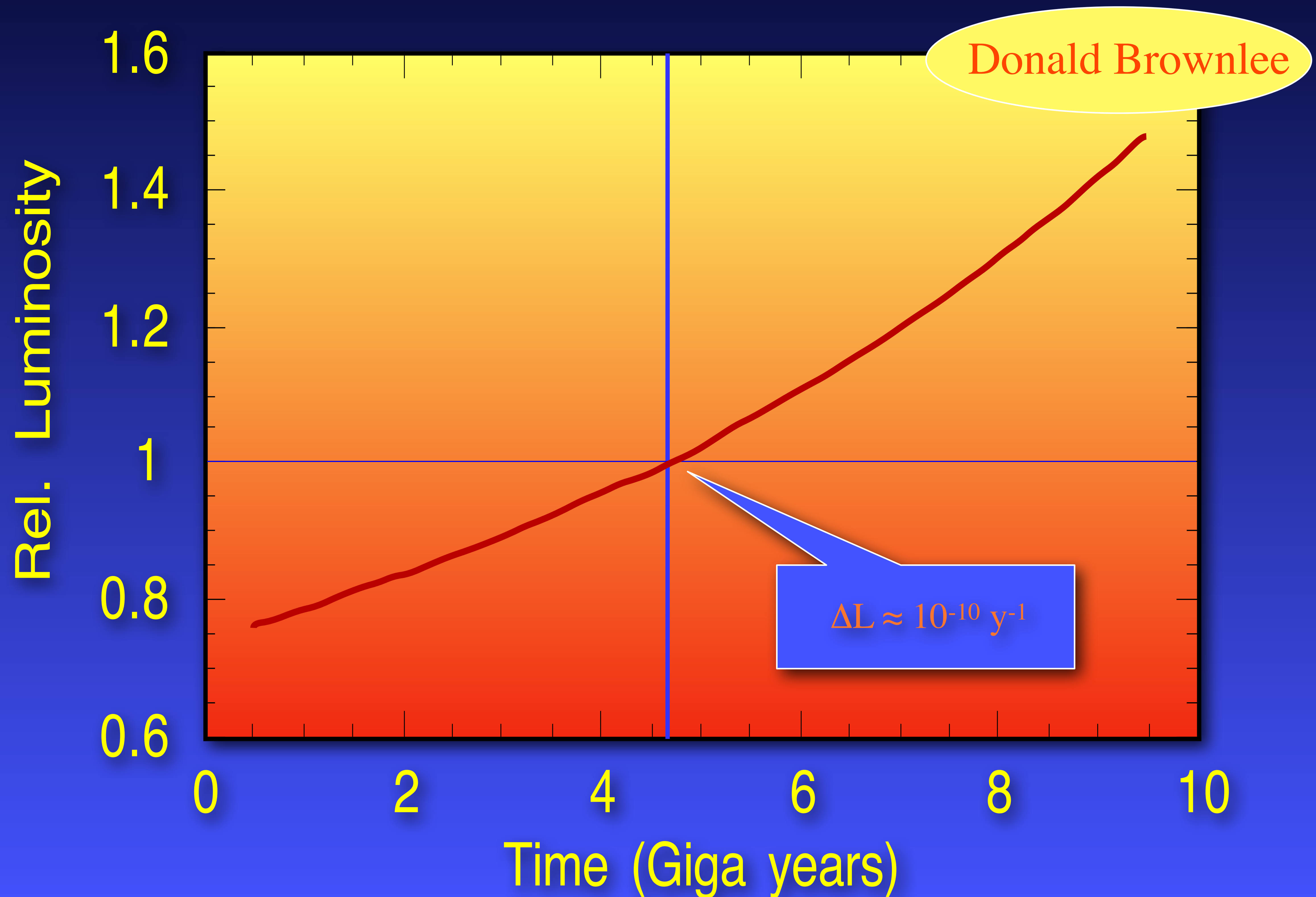
Evolution of solar Luminosity



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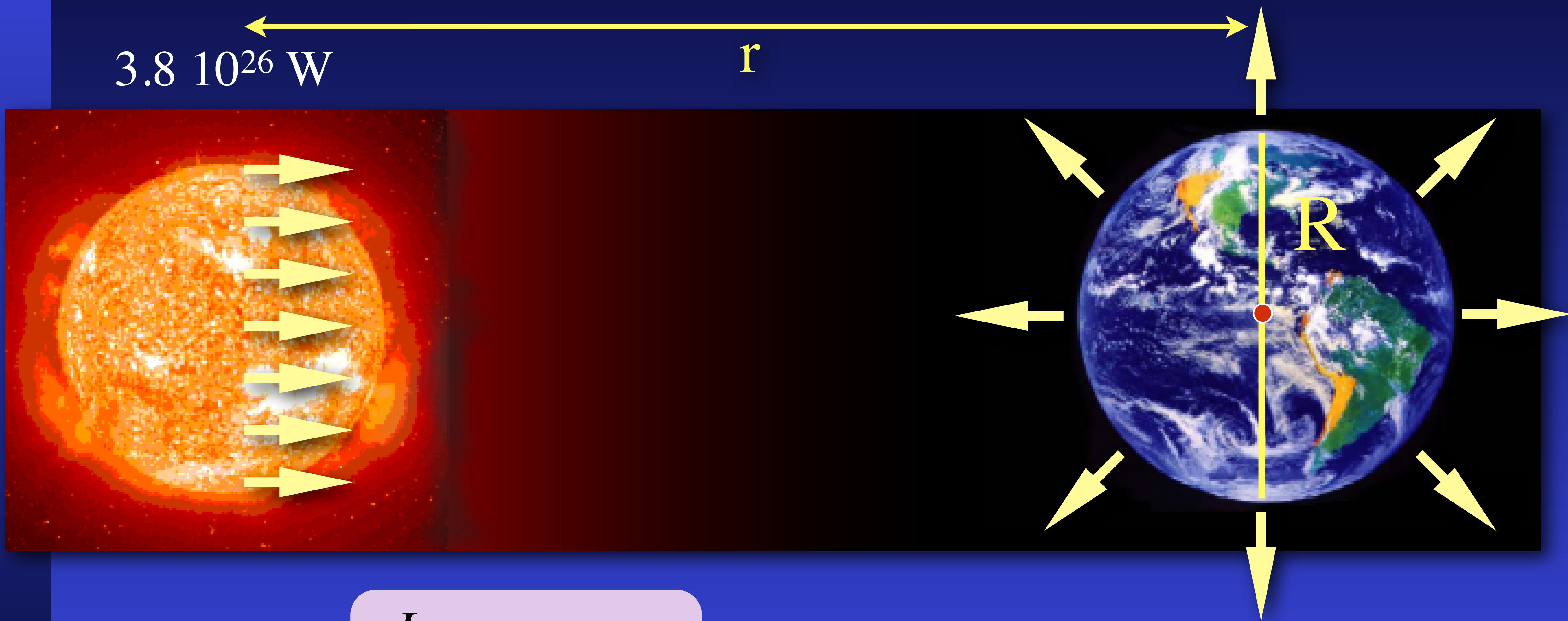
Climate: Energy and its Distribution



Absorption: $\frac{L}{4\pi r^2} \cdot \pi R^2 (1-a)$

Emission: $4\pi R^2 \cdot \sigma T^4$

L: Luminosity
a: Albedo
σ: Stefan-Boltzmann

$$T = \sqrt[4]{\frac{L(1-a)}{16\pi r^2 \sigma}}$$

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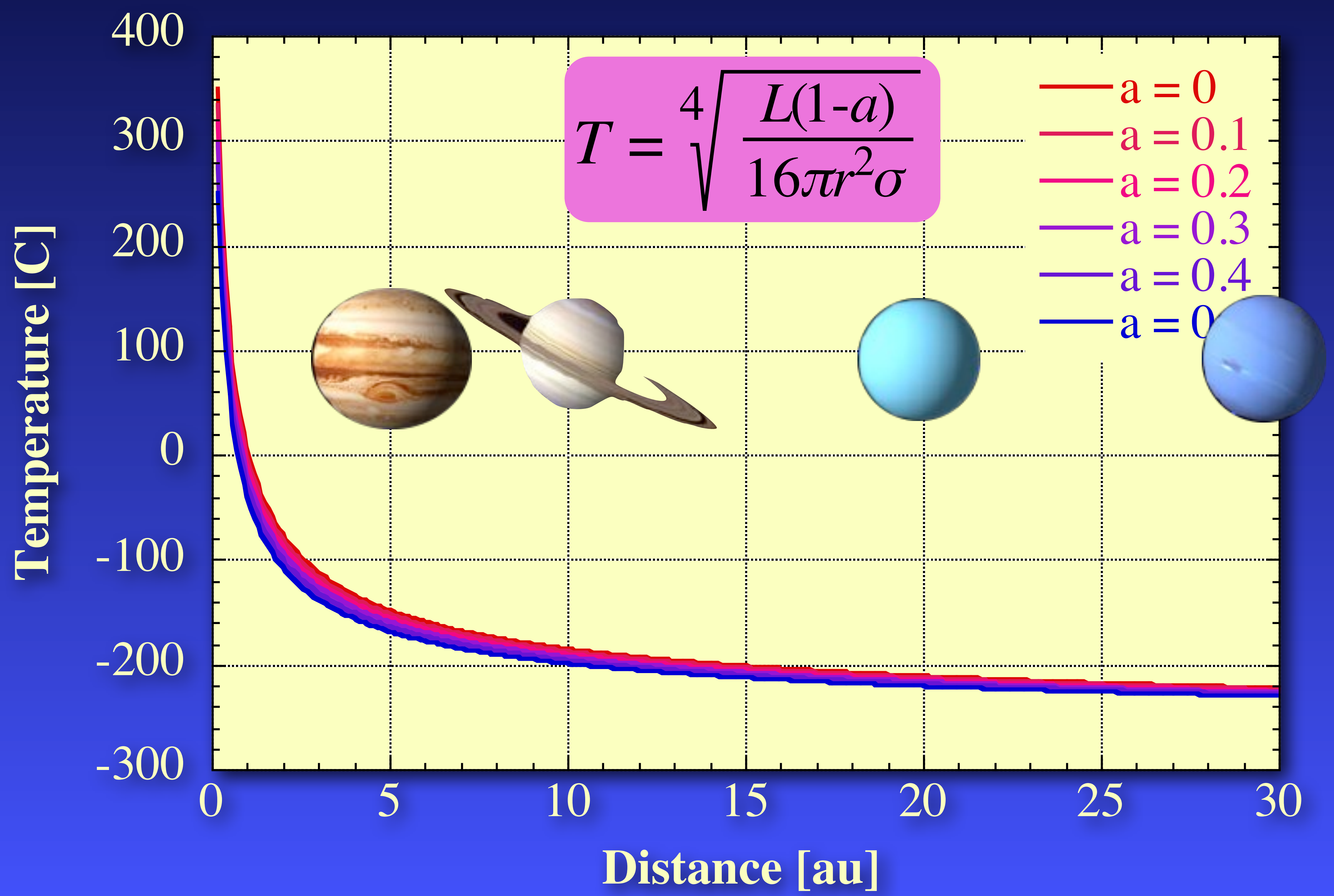
Black body temperatures of planets



Temperatures calculated - observed

Planet	Distance (AU)	Temperature (°C) $a = 0.5$ $L = 0.8$	$a = 0.3$ $L = 1$	$a = 0.1$ $L = 1.2$	Observed
Mercury	0.38	77	130	175	180 to 420
Venus	0.72	-10	30	66	460
Earth	1	-50	-18	11	15
Mars	1.52	-95	-65	-40	-87 to 5
Jupiter	5.2	-175	-160	-150	-130
Saturn	9.54	-200	-190	-180	-180
Uranus	19.18	-220	-215	-210	-210
Neptune	30.06	-230	-225	-220	-210

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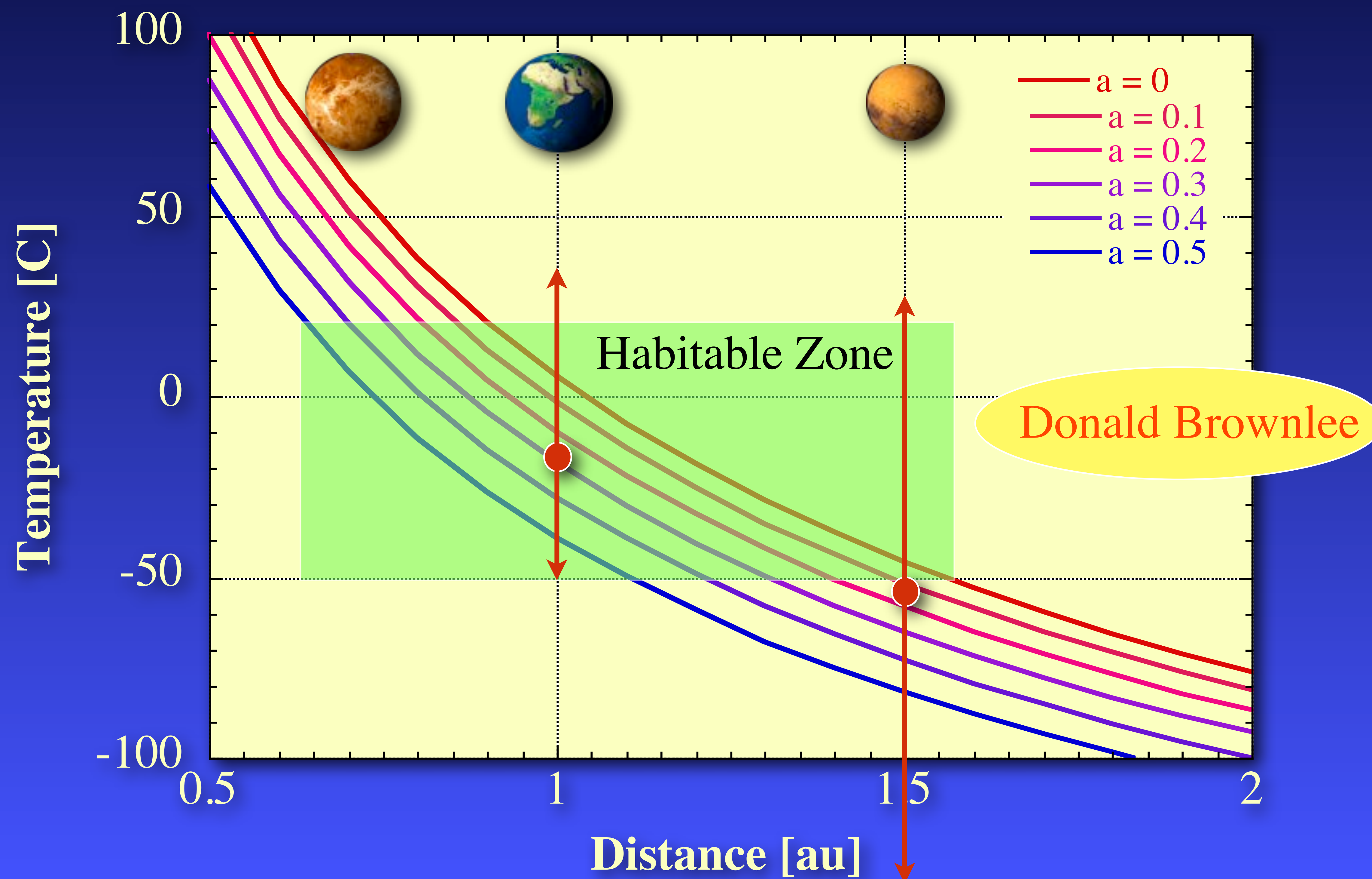
The inner planets



Dependencies

$$T = \sqrt[4]{\frac{L(1\text{-}a)}{16\pi r^2\sigma}}$$

Luminosity

$$\frac{dT}{T} = \frac{1}{4}\frac{dL}{L}$$

Albedo

$$\frac{dT}{T} = -\frac{1}{4}\frac{da}{1\text{-}a}$$

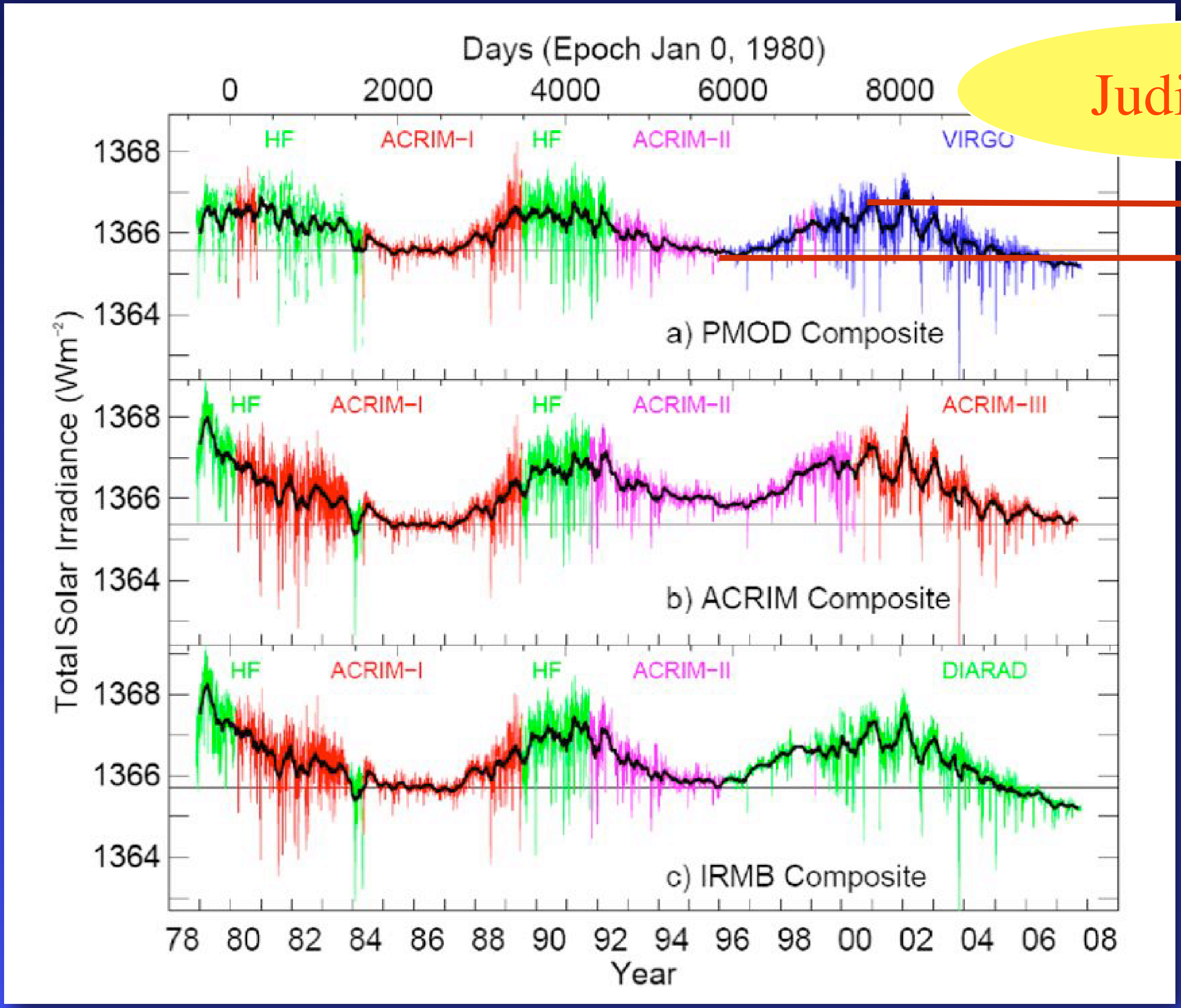
Distance

$$\frac{dT}{T} = -\frac{1}{2}\frac{dr}{r}$$

Variability of influences

$$T = \sqrt[4]{\frac{L(1-a)}{16\pi r^2 \sigma}}$$

$$dT/T = 1/4\, dL/L$$



Judith Lean

1 ‰ 1.5 K

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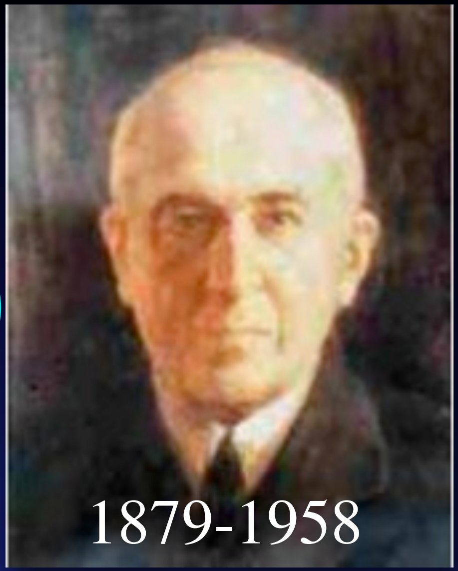
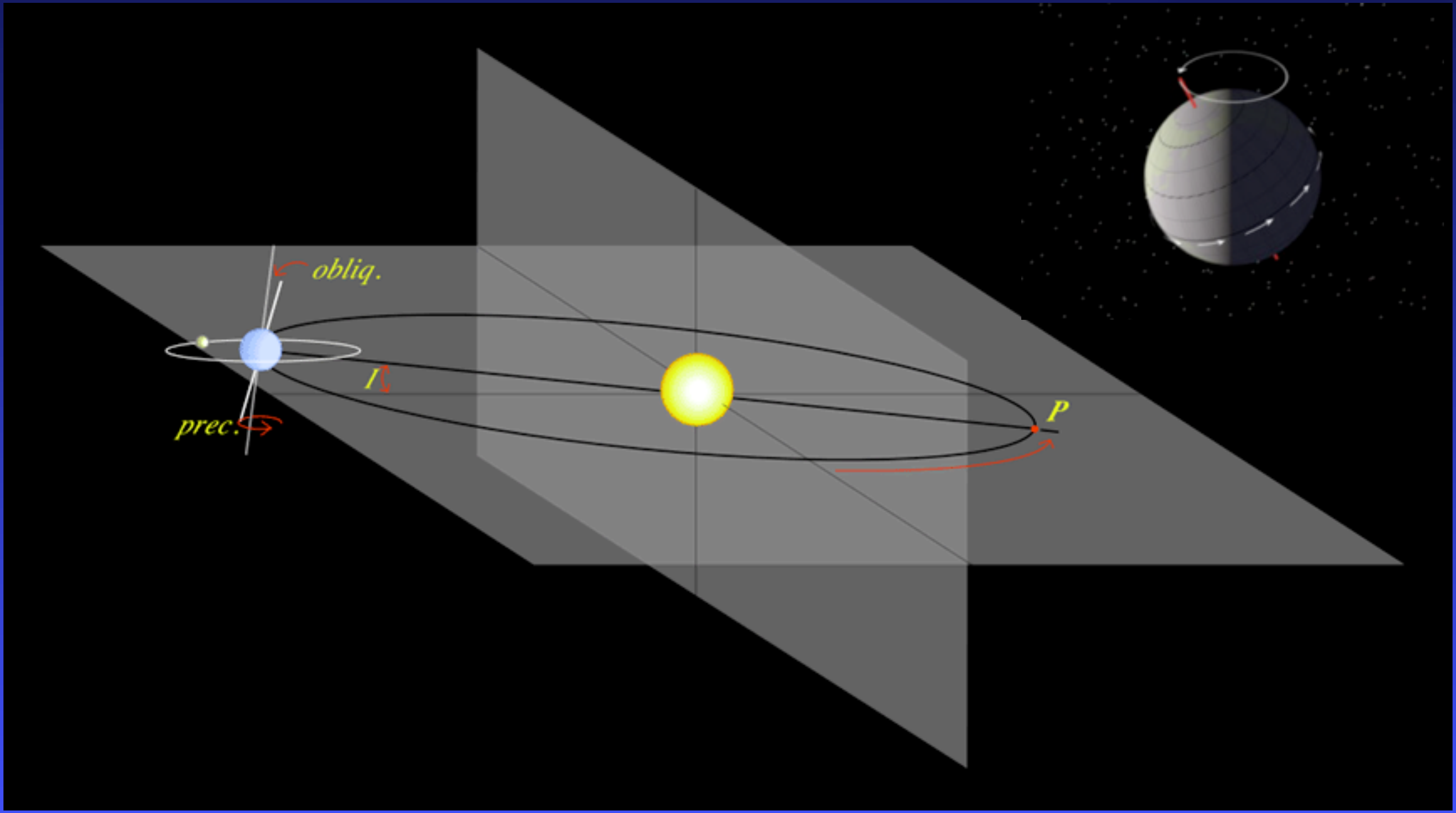
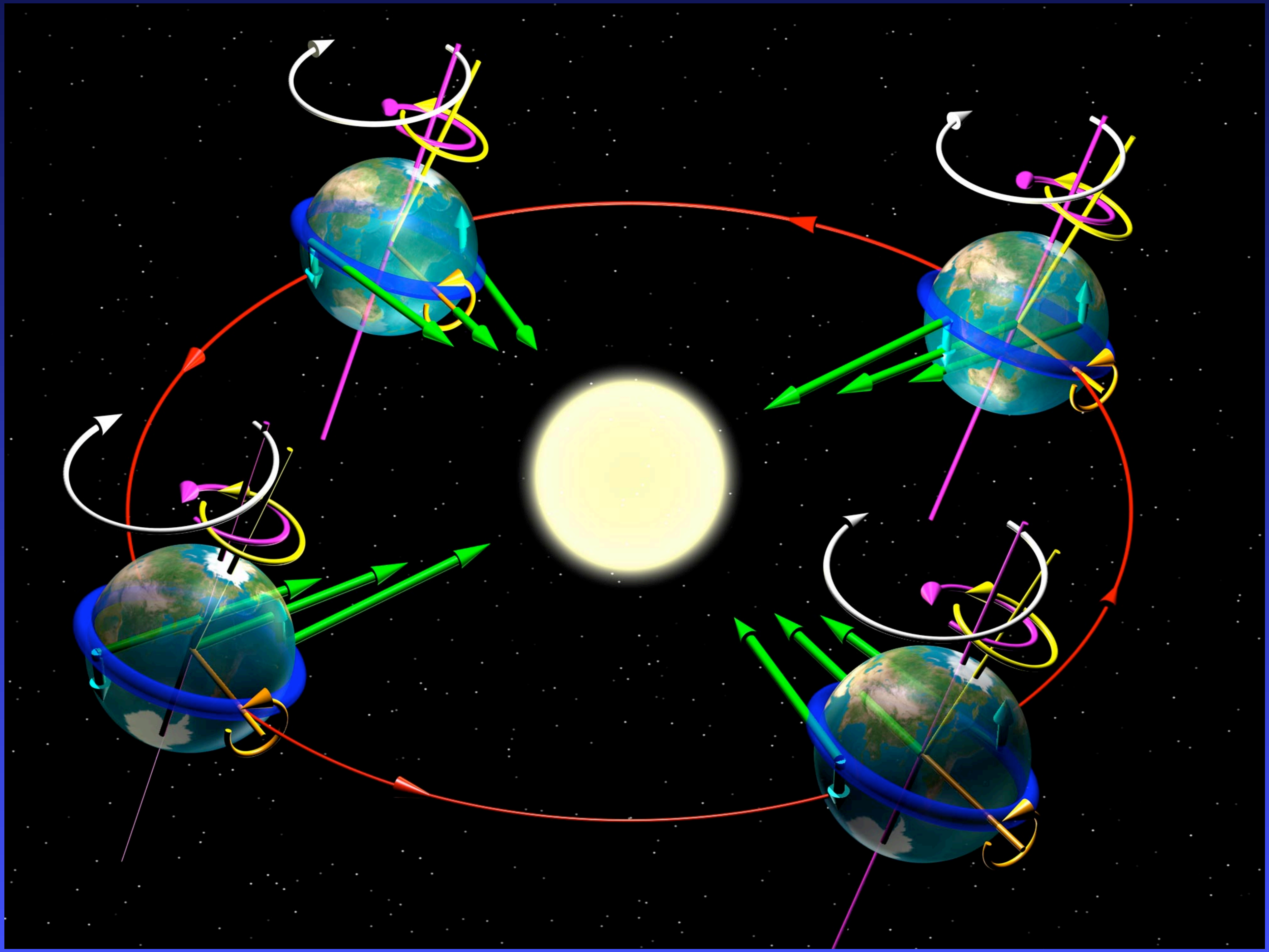
Orbital variability (Milankovic)





Tidal force



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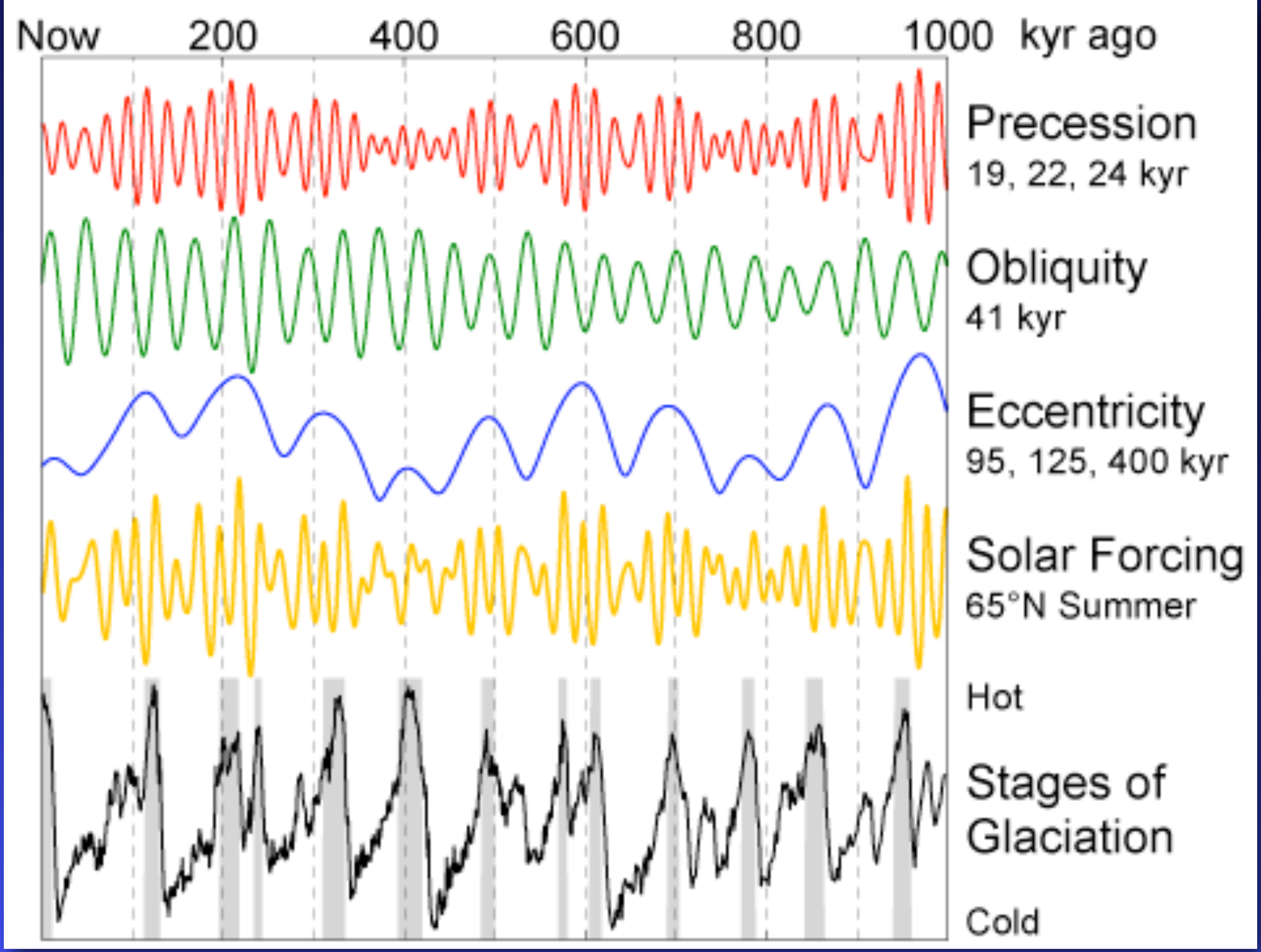
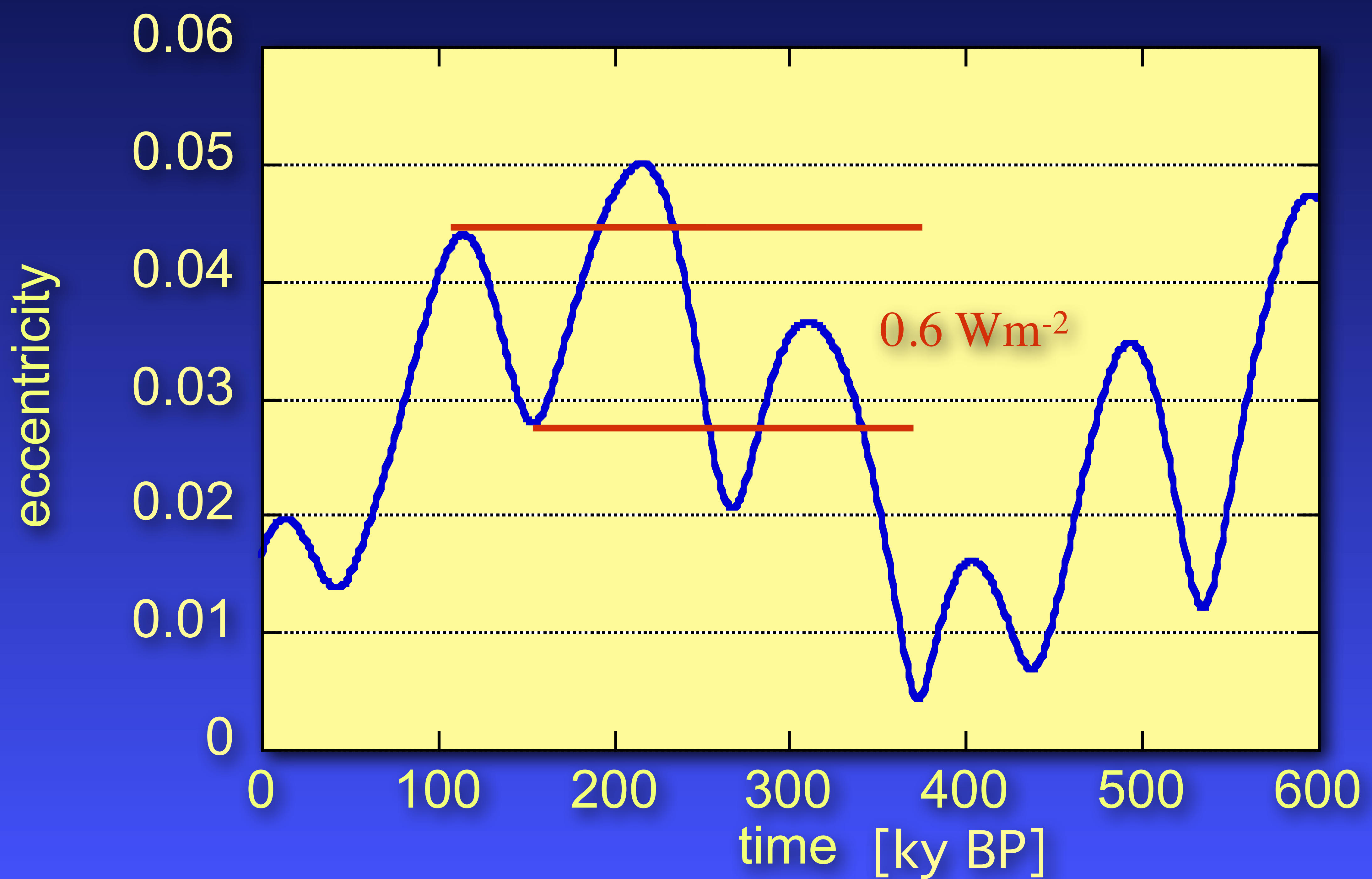
Orbital parameters and insolation

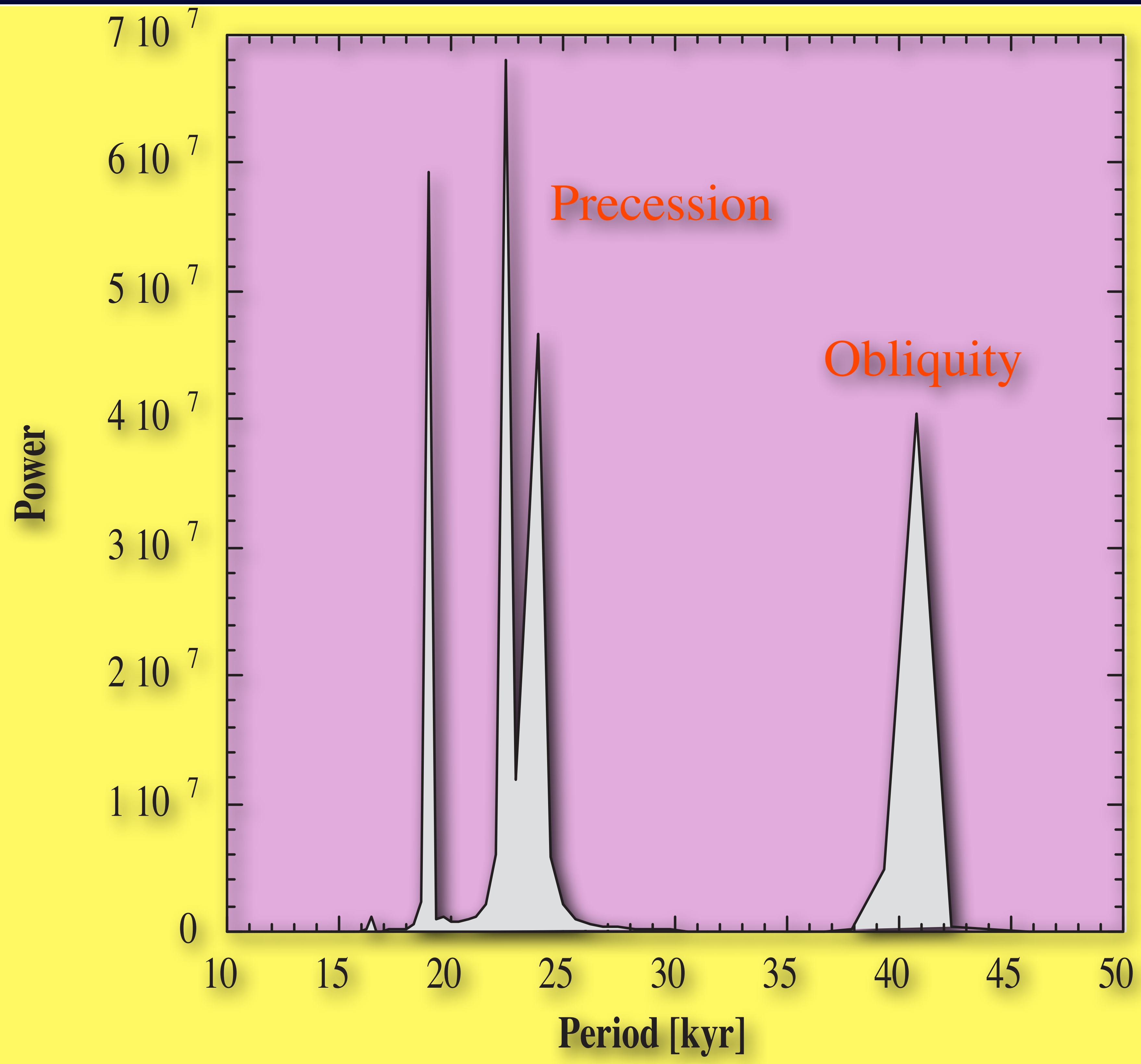


Eccentricity

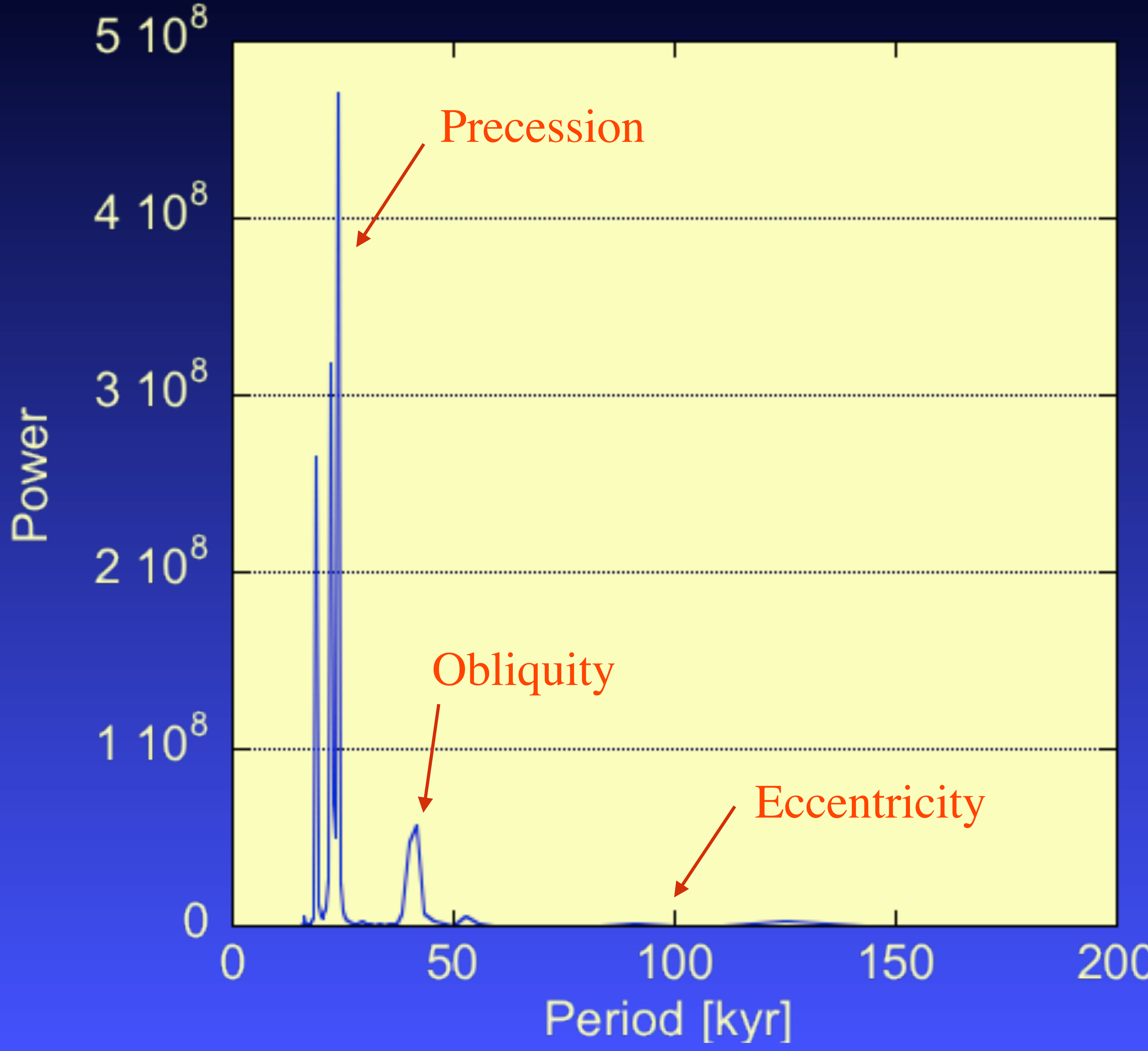
$$\frac{dS}{S} = \frac{e^2}{1-e^2}\,\frac{de}{e}$$



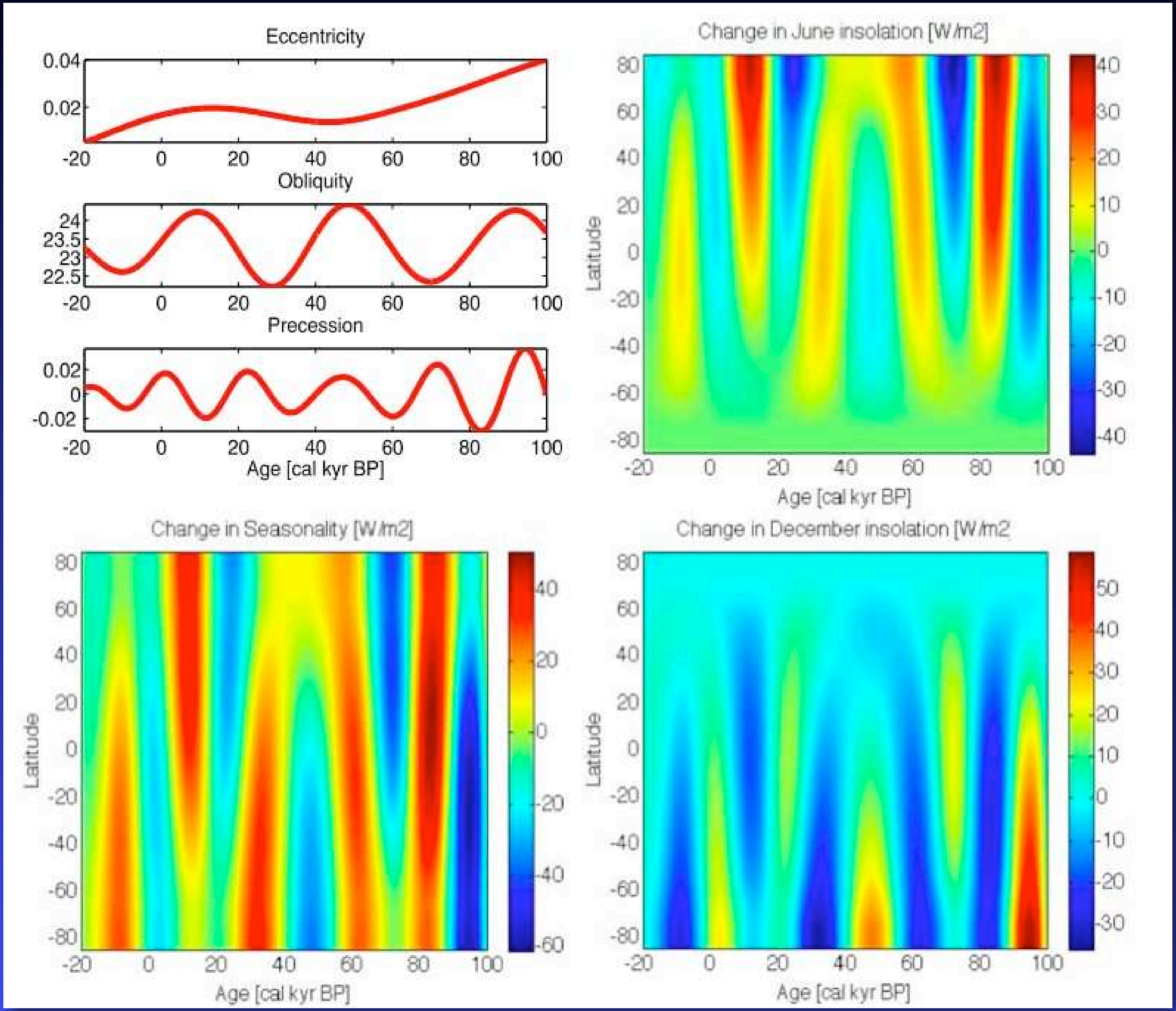
Power spectrum of insolation



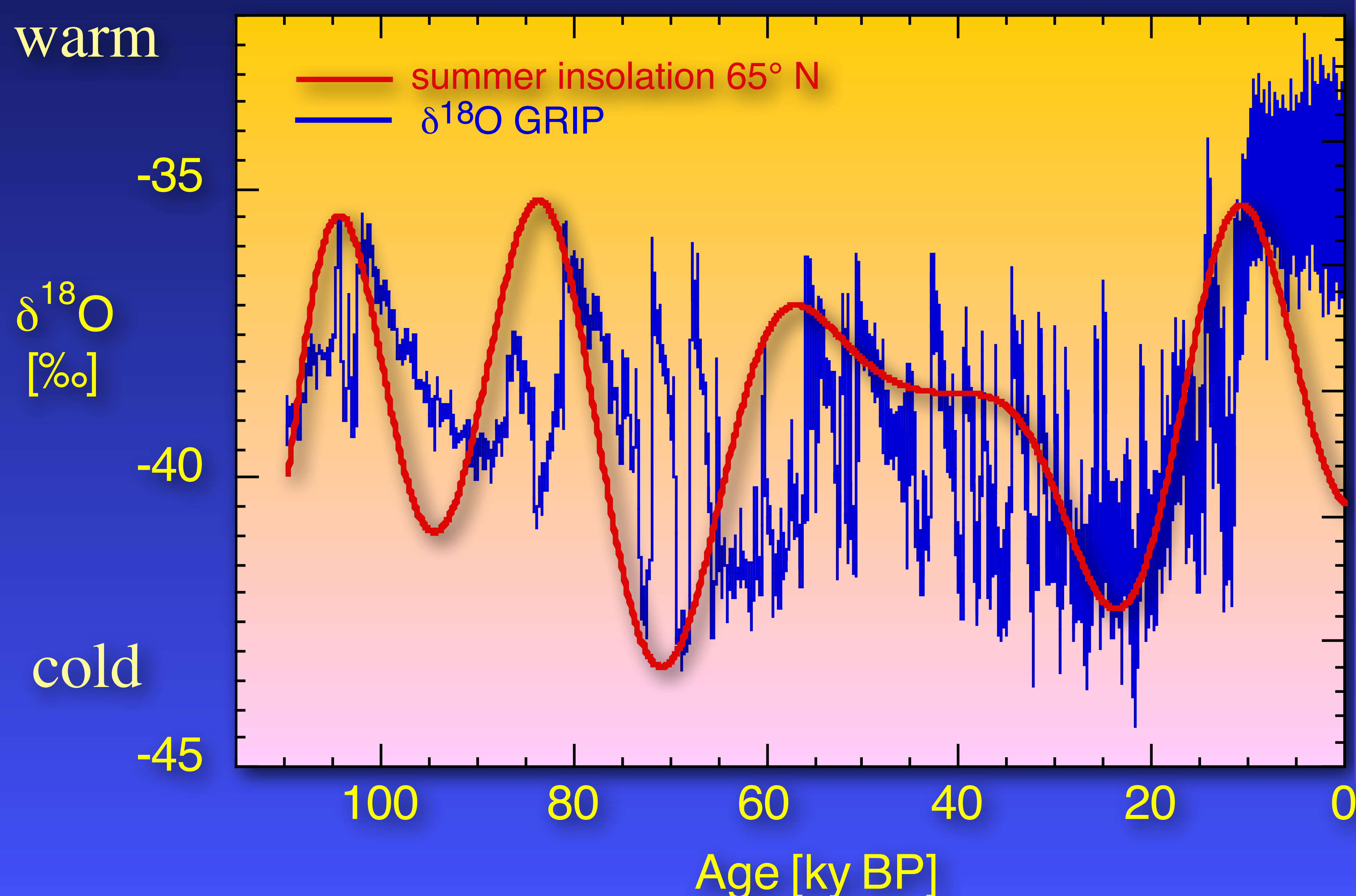
Power Spectrum



Orbital Forcing (Milankovic)



Orbital forcing and δ^{18}O in ice



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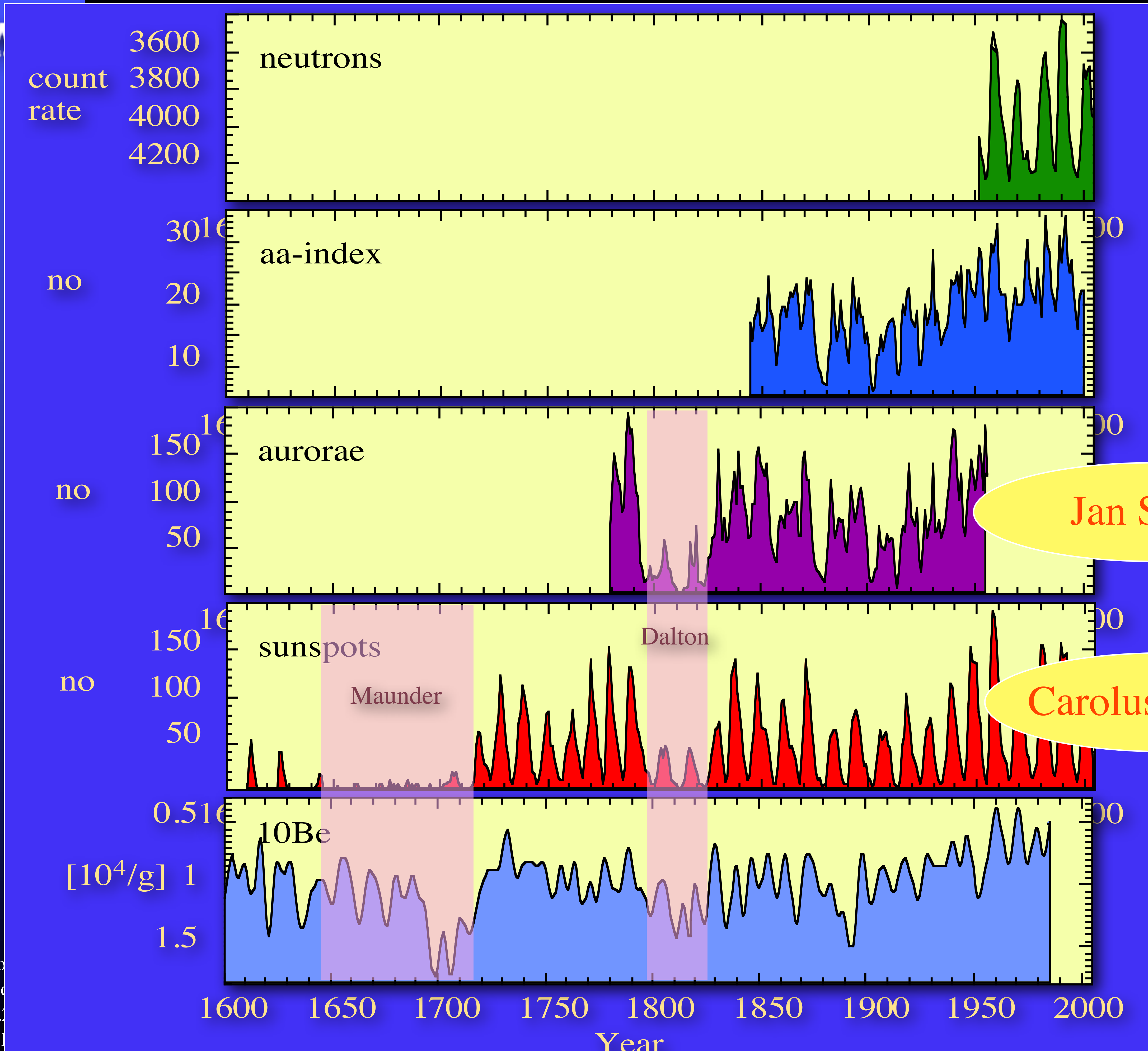


Climax

Mayaud, 1973

Jan Sojka

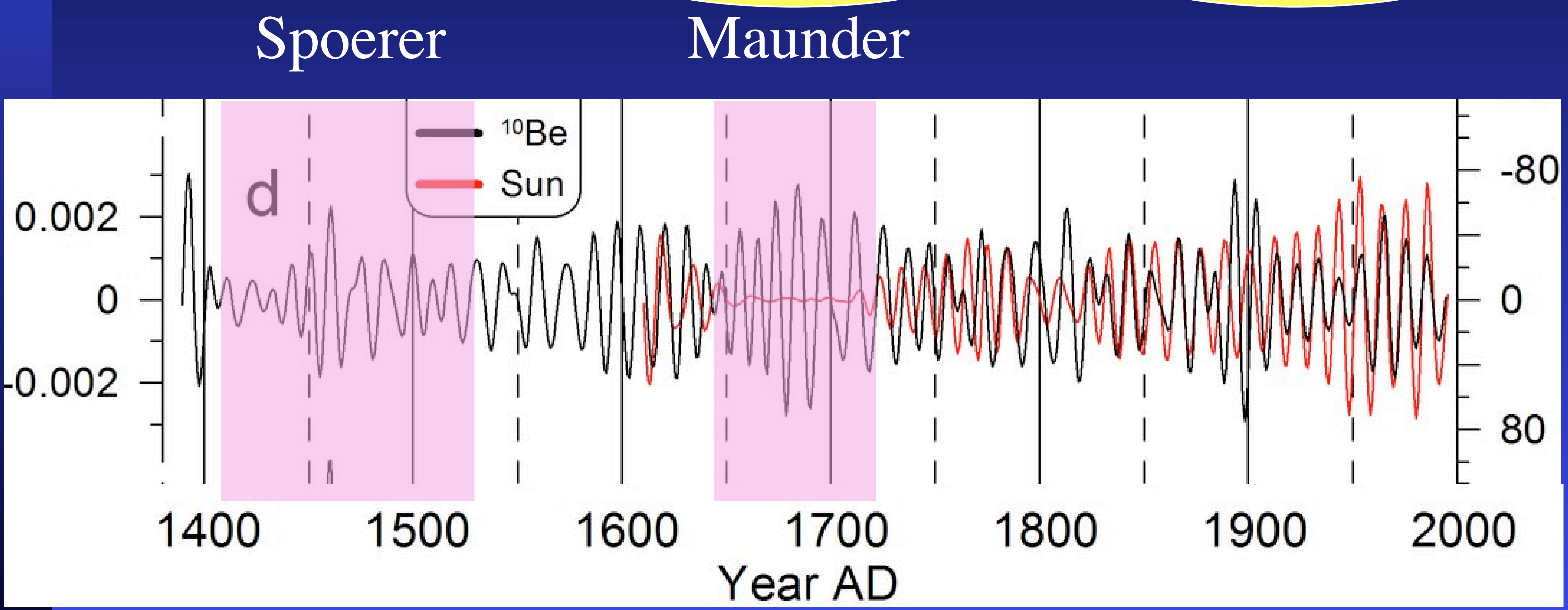
Carolus Shrijver

Beer et al., 1990

^{10}Be NGRIP - Sunspots (8-16 y)

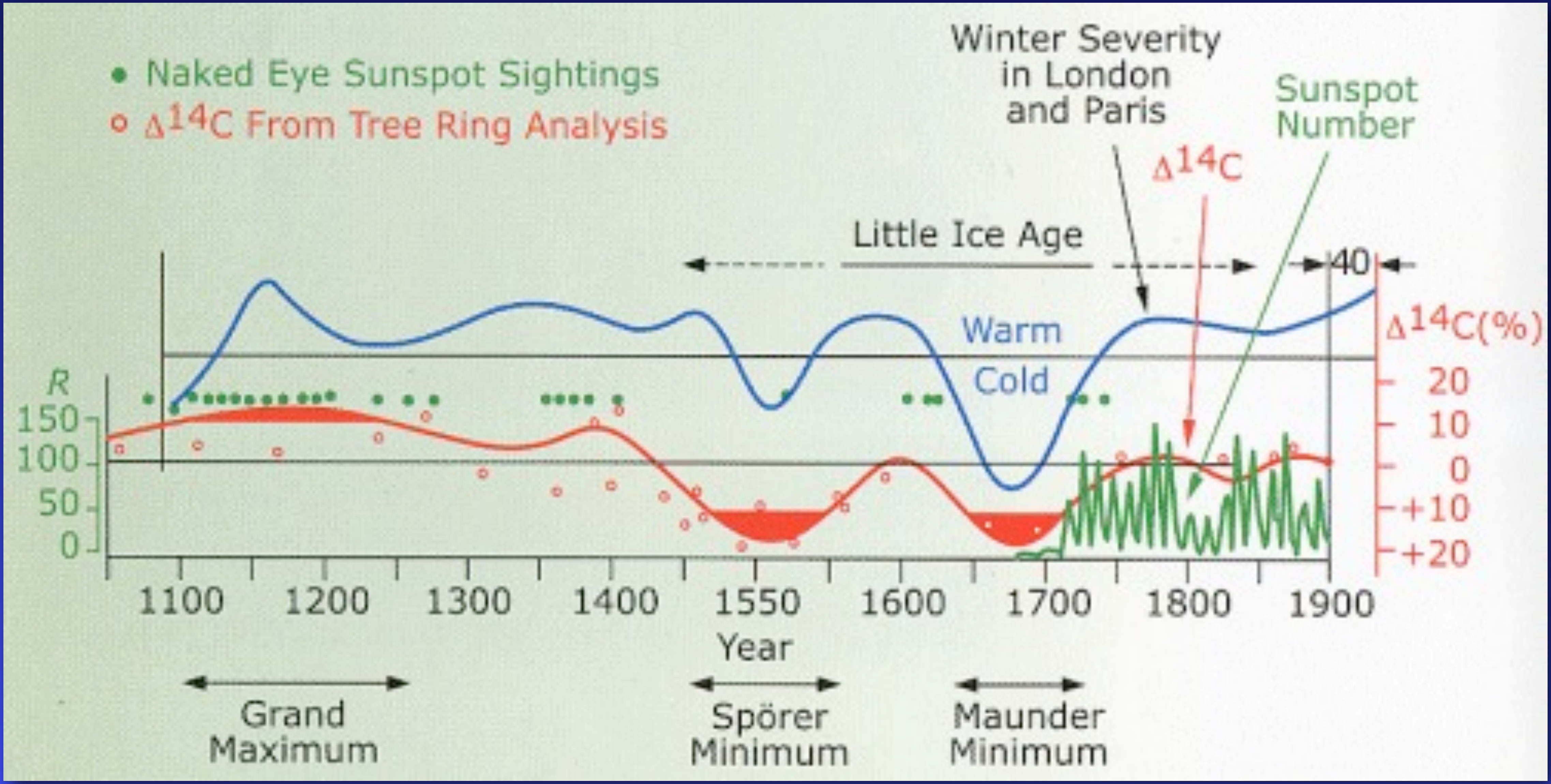
Randy Jokipii

Paul Charbonneau



Bergren et al., GRL 36, 2009

Solar Forcing and Climate Change



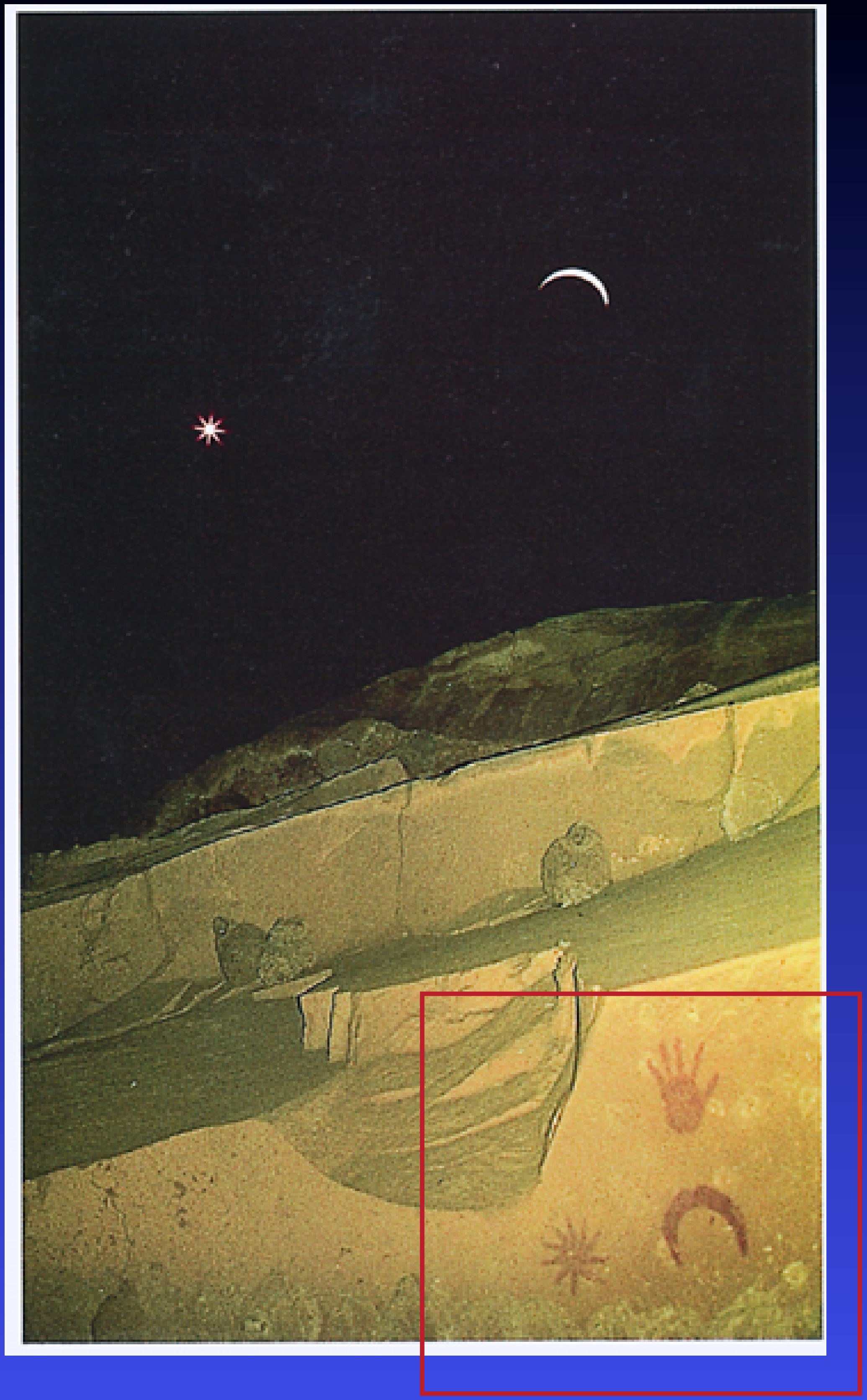
Eddy, The Maunder Minimum, Science 192, 1976

Solar forcing and climate change: documentary evidence (Jack Eddy)

Luke Clement

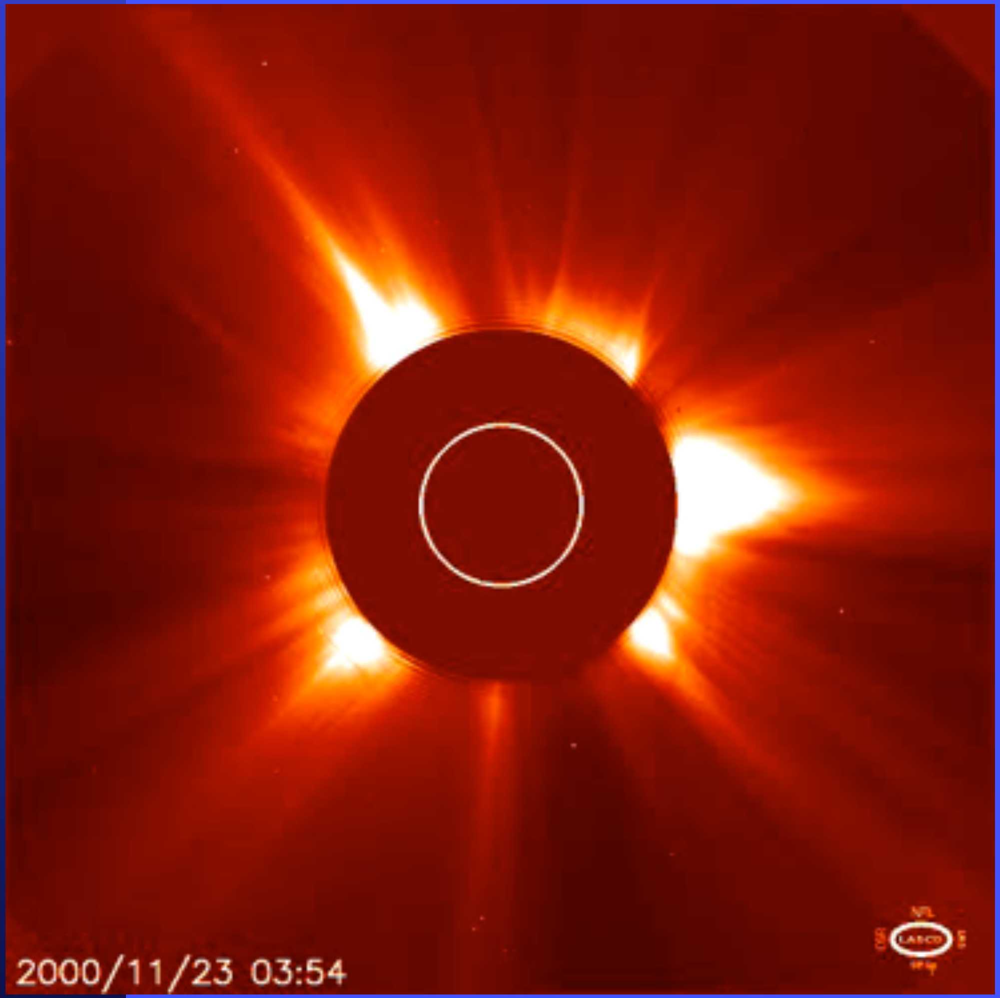
Supernova 1006

A new star, likely the brightest supernova in recorded human history, appeared in planet Earth's sky in the year 1006 AD (©Tezel)

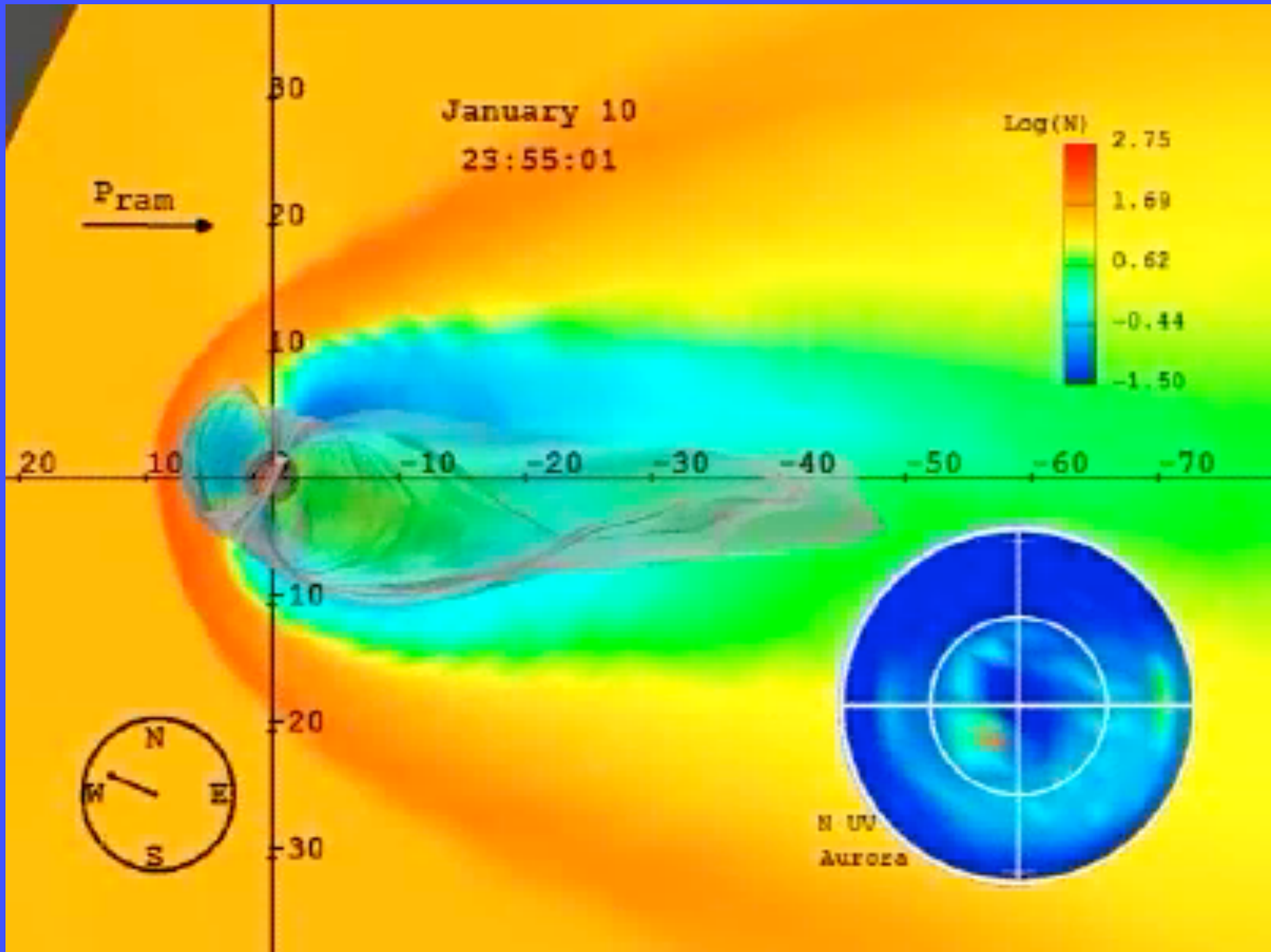


Anazasi painting

Solar and Geomagnetic Modulation



Solar wind emission



Solar wind - geomagnetic field interaction

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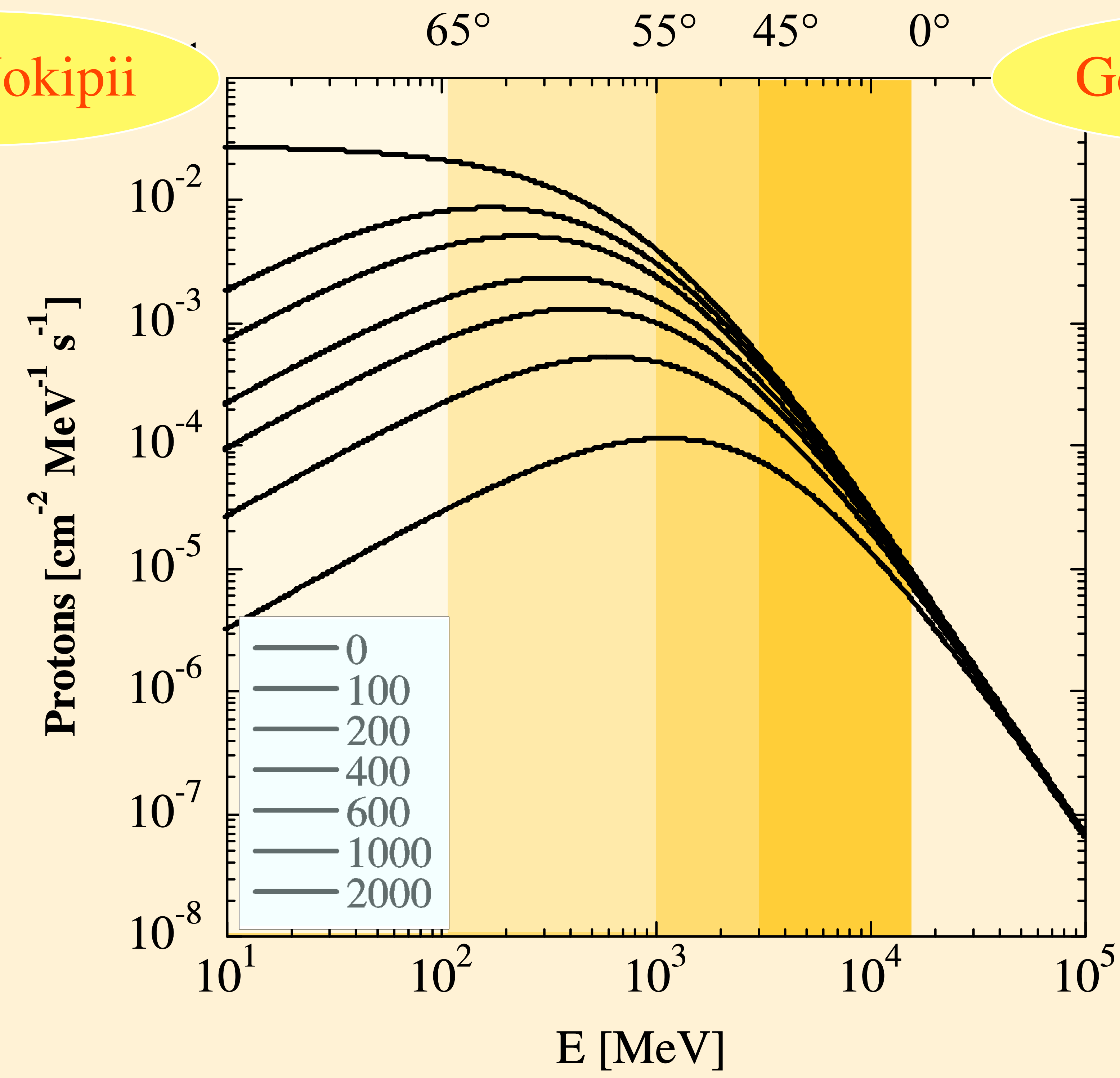
Solar and Geomagnetic Modulation

Randy Jokipii

George Siscoe



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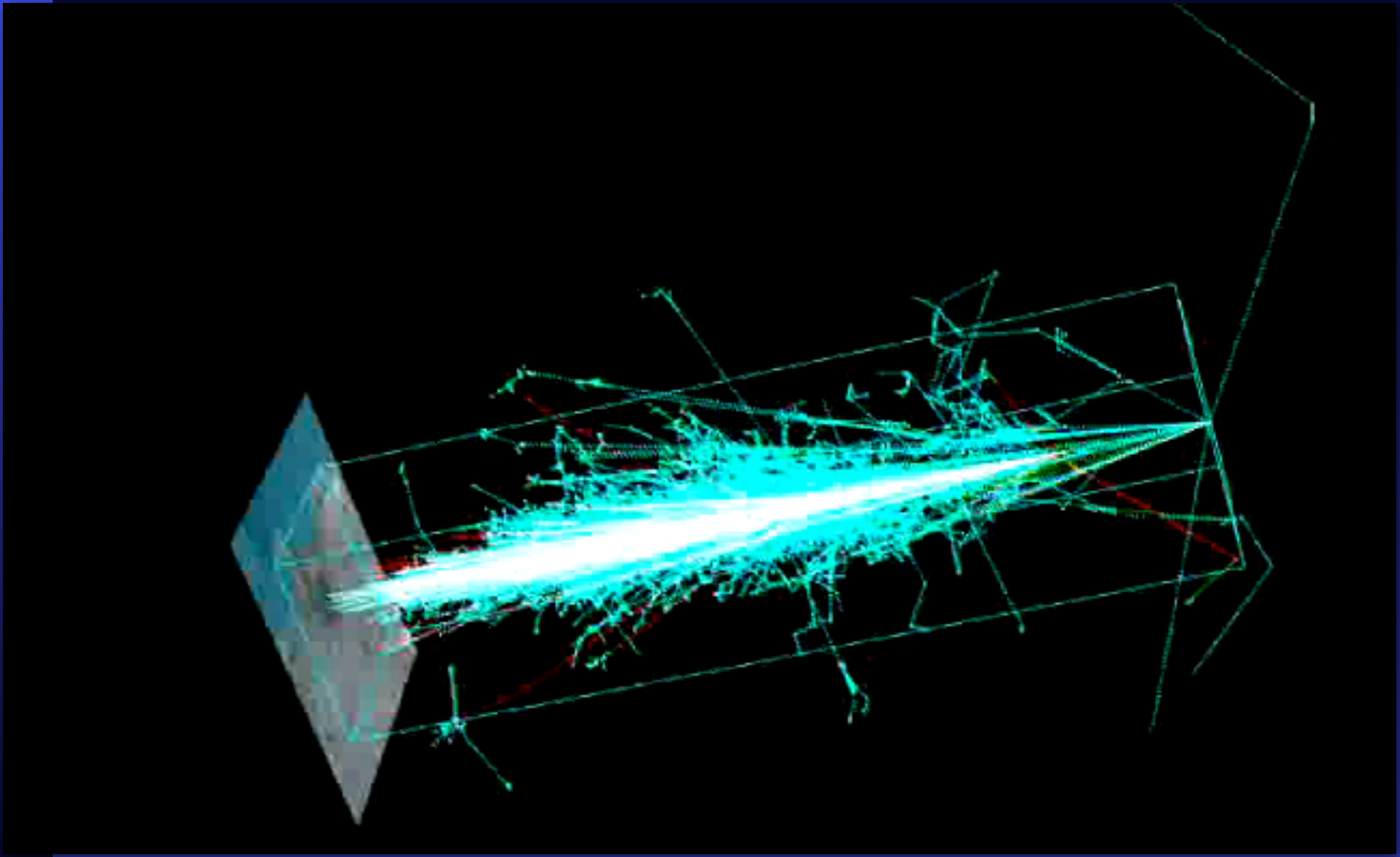
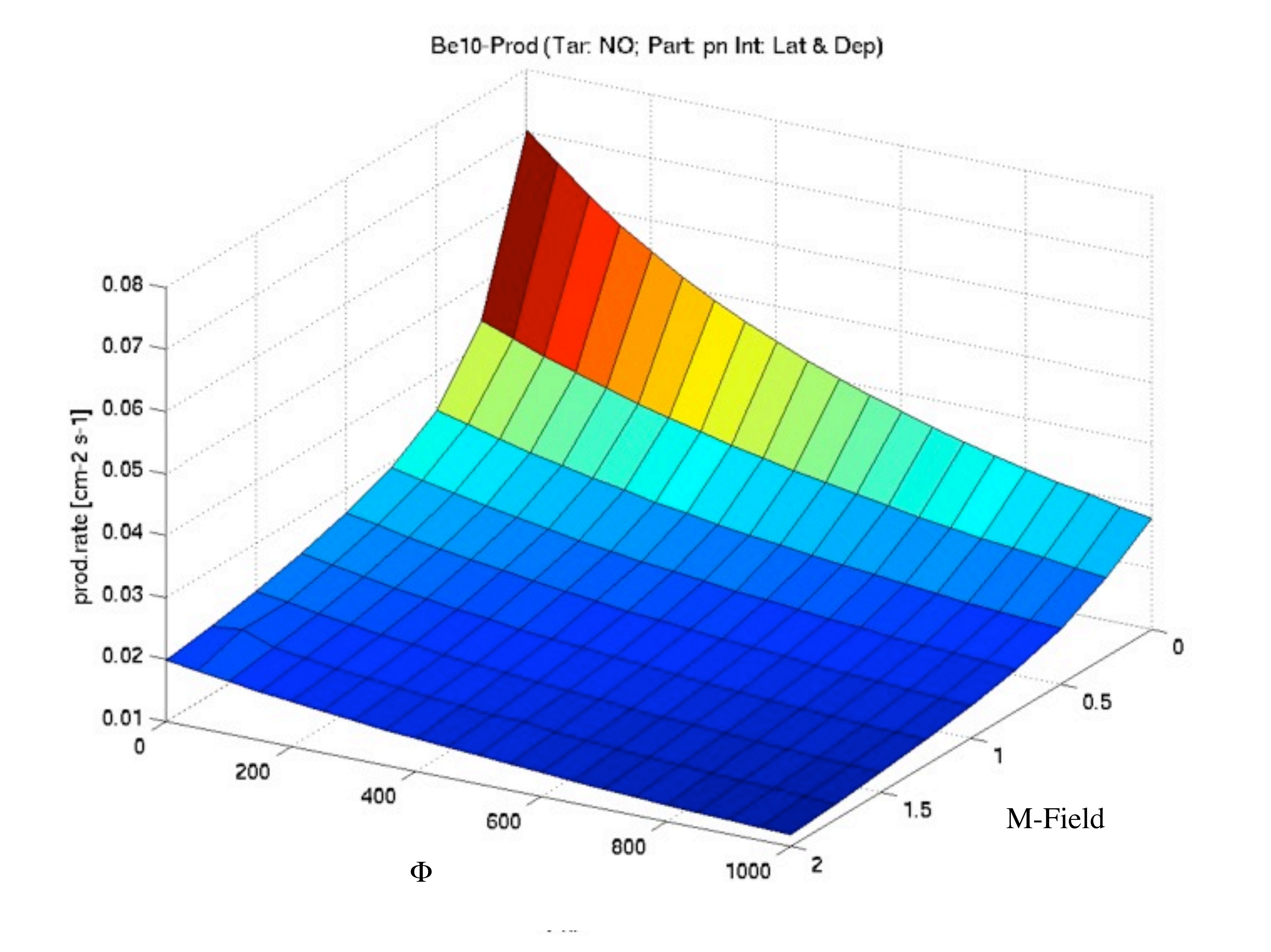
Monte Carlo Simulation



http://astro.uchicago.edu/cosmus/projects/aires/

Mean ^{10}Be-Prod. (Φ, M-Field)



(Masarik & Beer)

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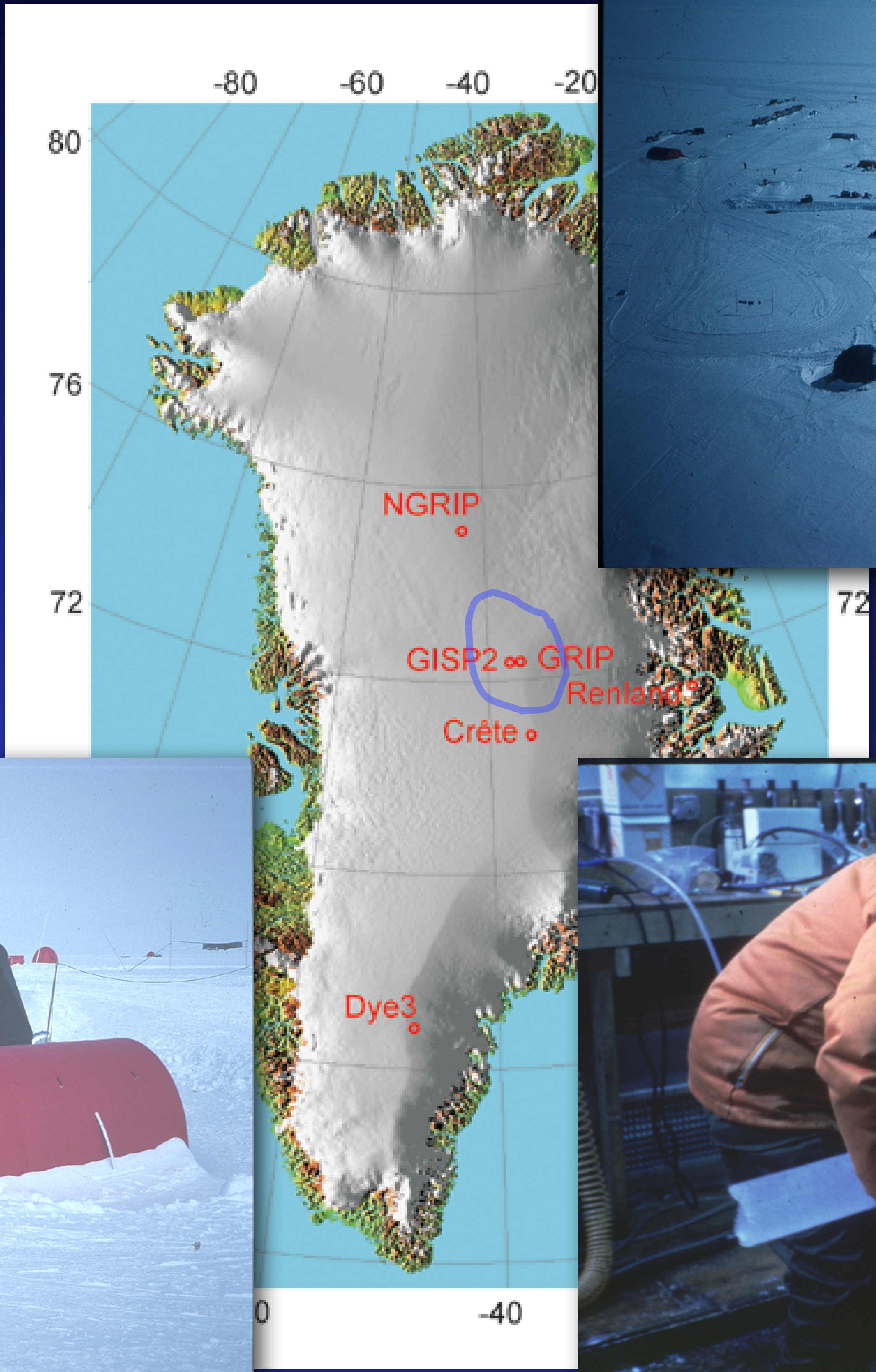
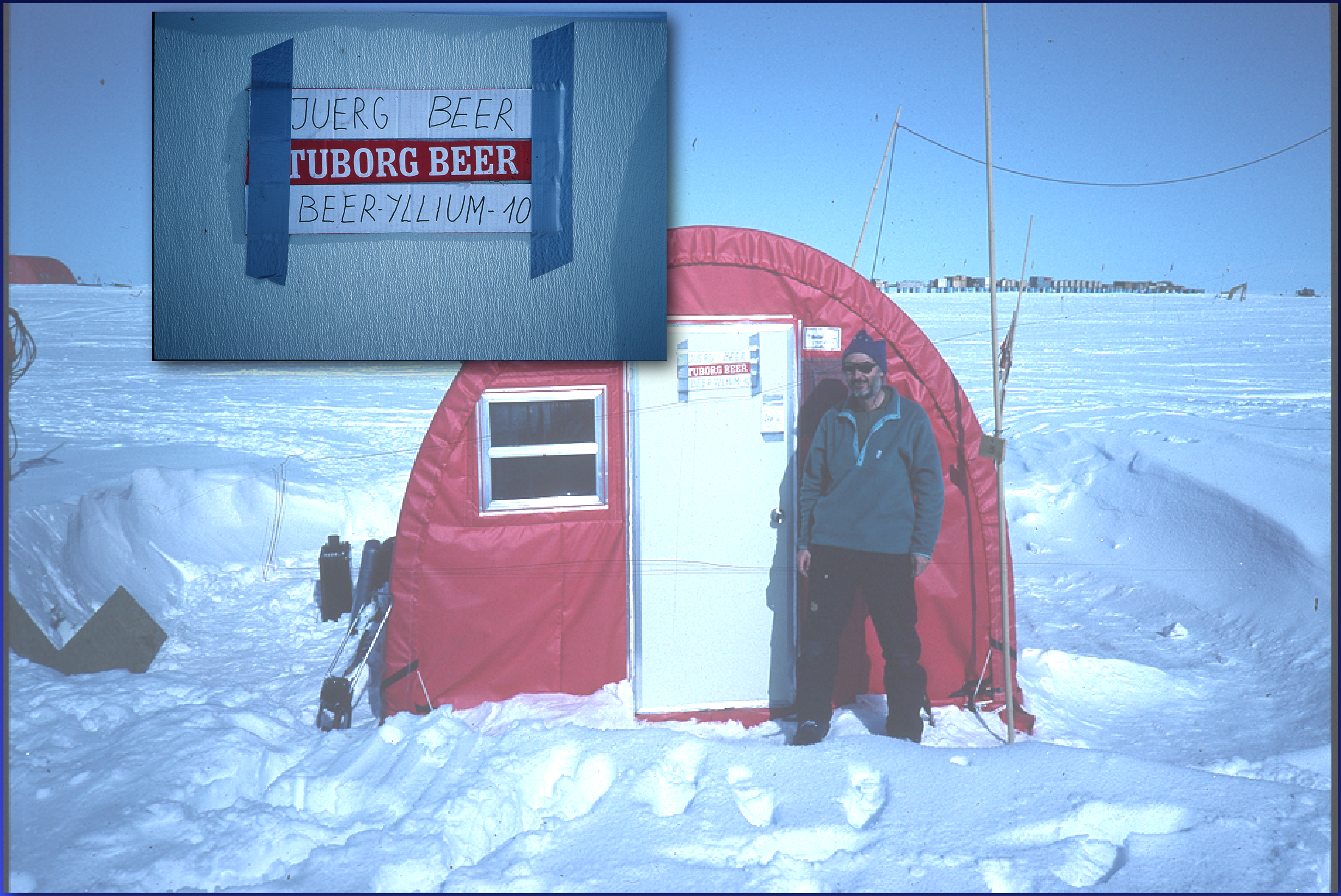
GRIP Ice Core



Lab at Summit



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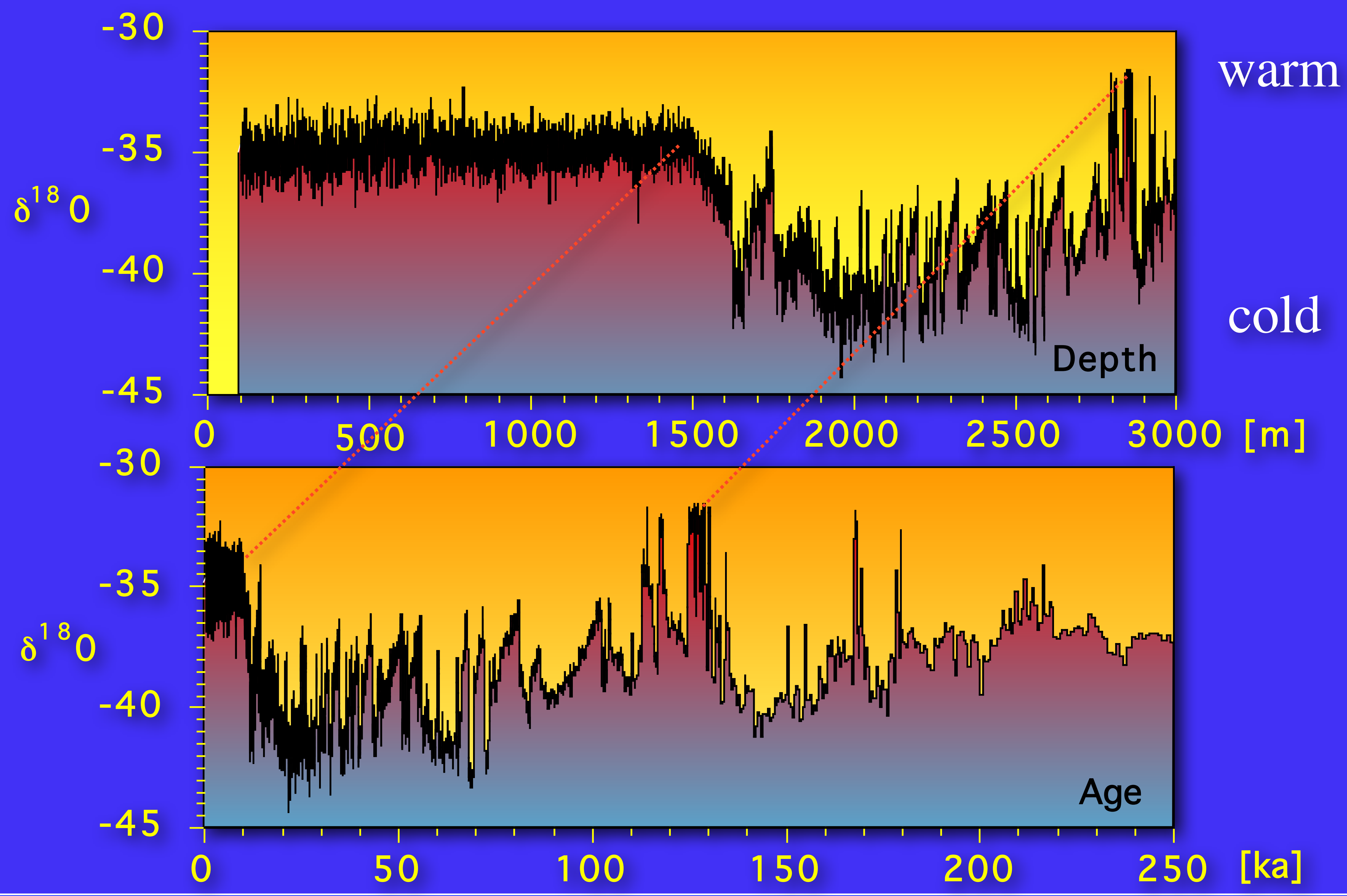
$\delta^{18}O$ versus Depth and Age: Dating



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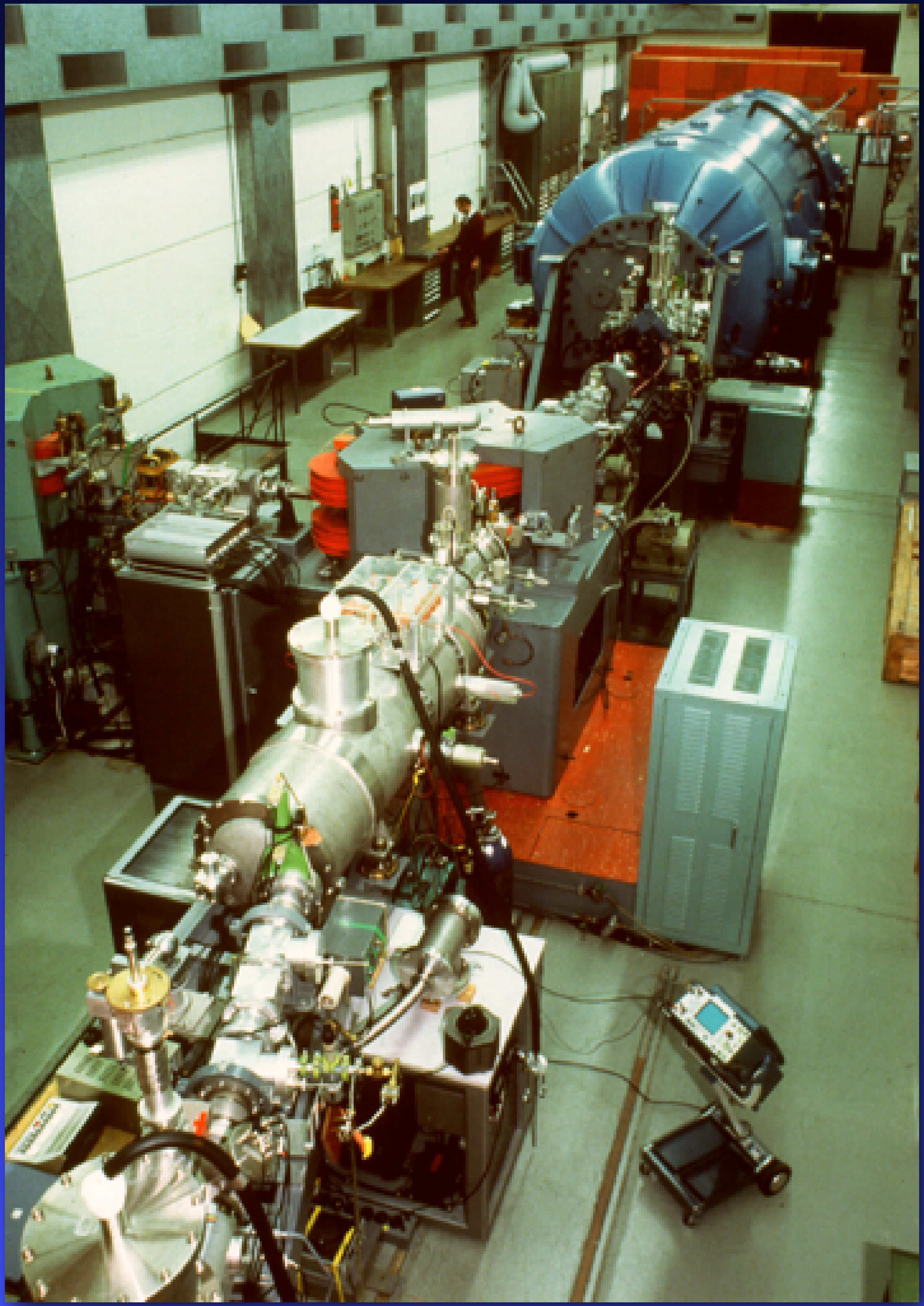
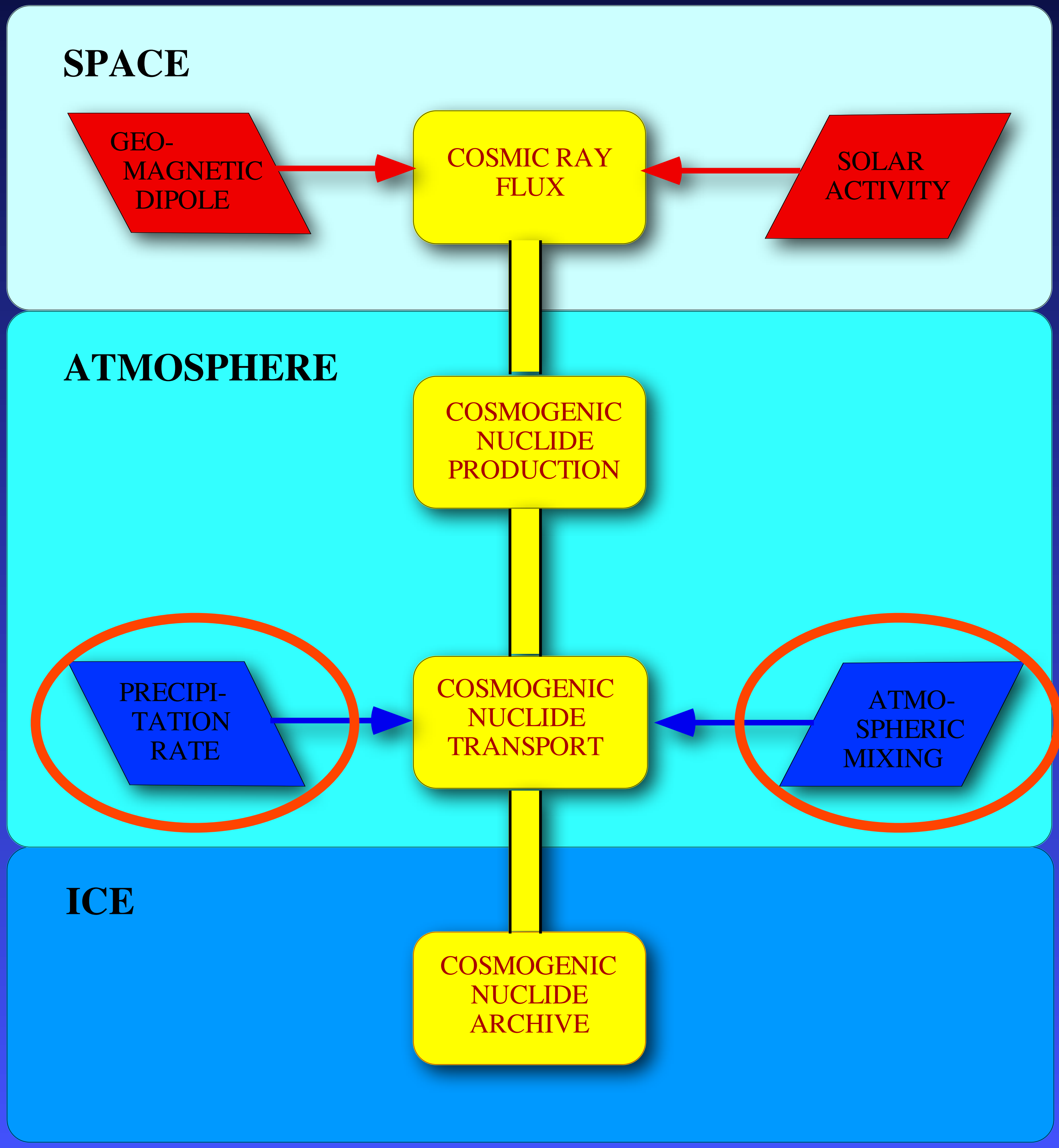
Accelerator Mass Spectrometer ETH

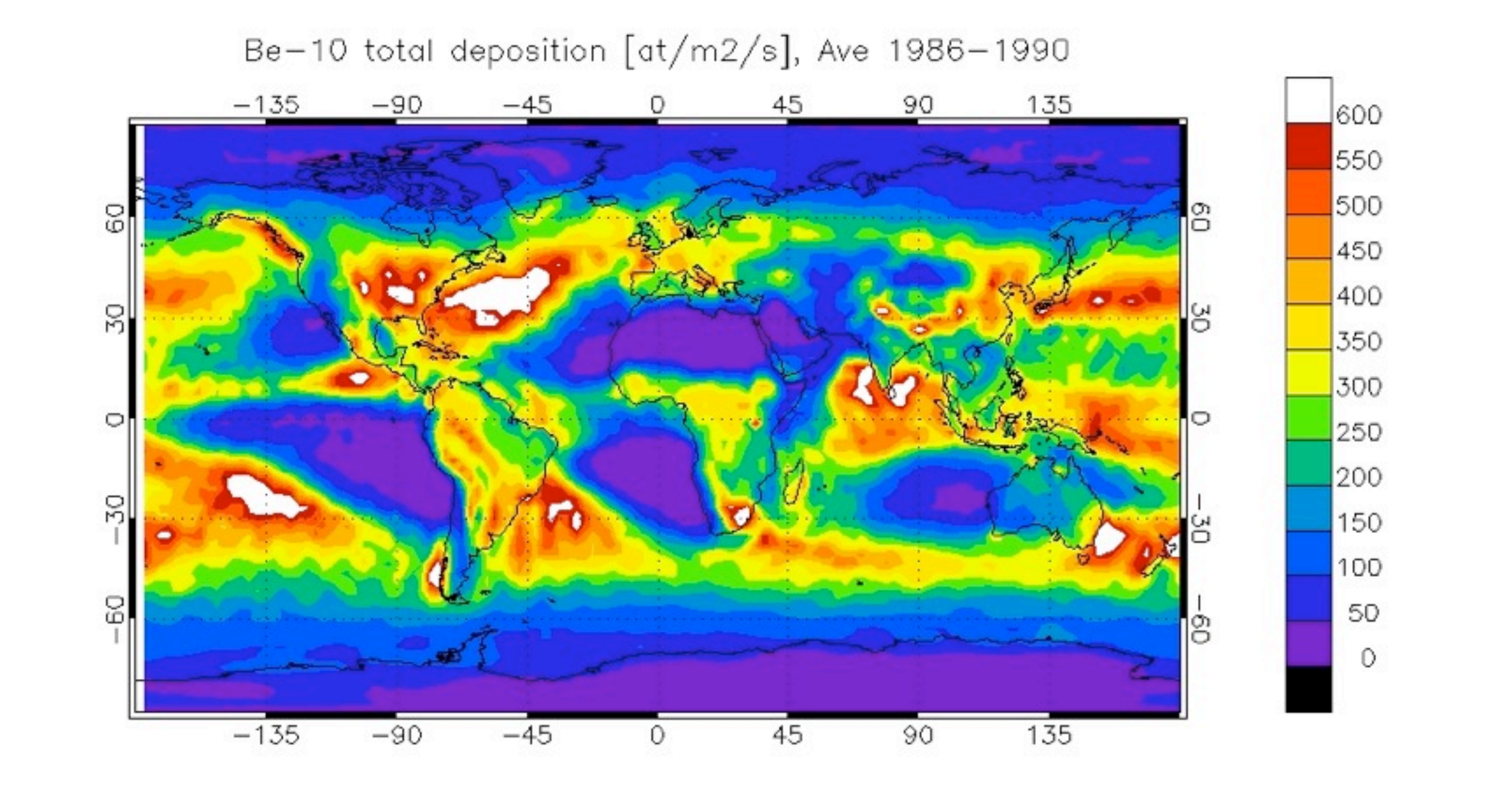


- Acceleration: 6 MV
- 1 Mio ^{10}Be atoms
- $^{10}Be/^{9}Be > 10^{-14}$
- <1 kg of ice

Information from cosmogenic radionuclides

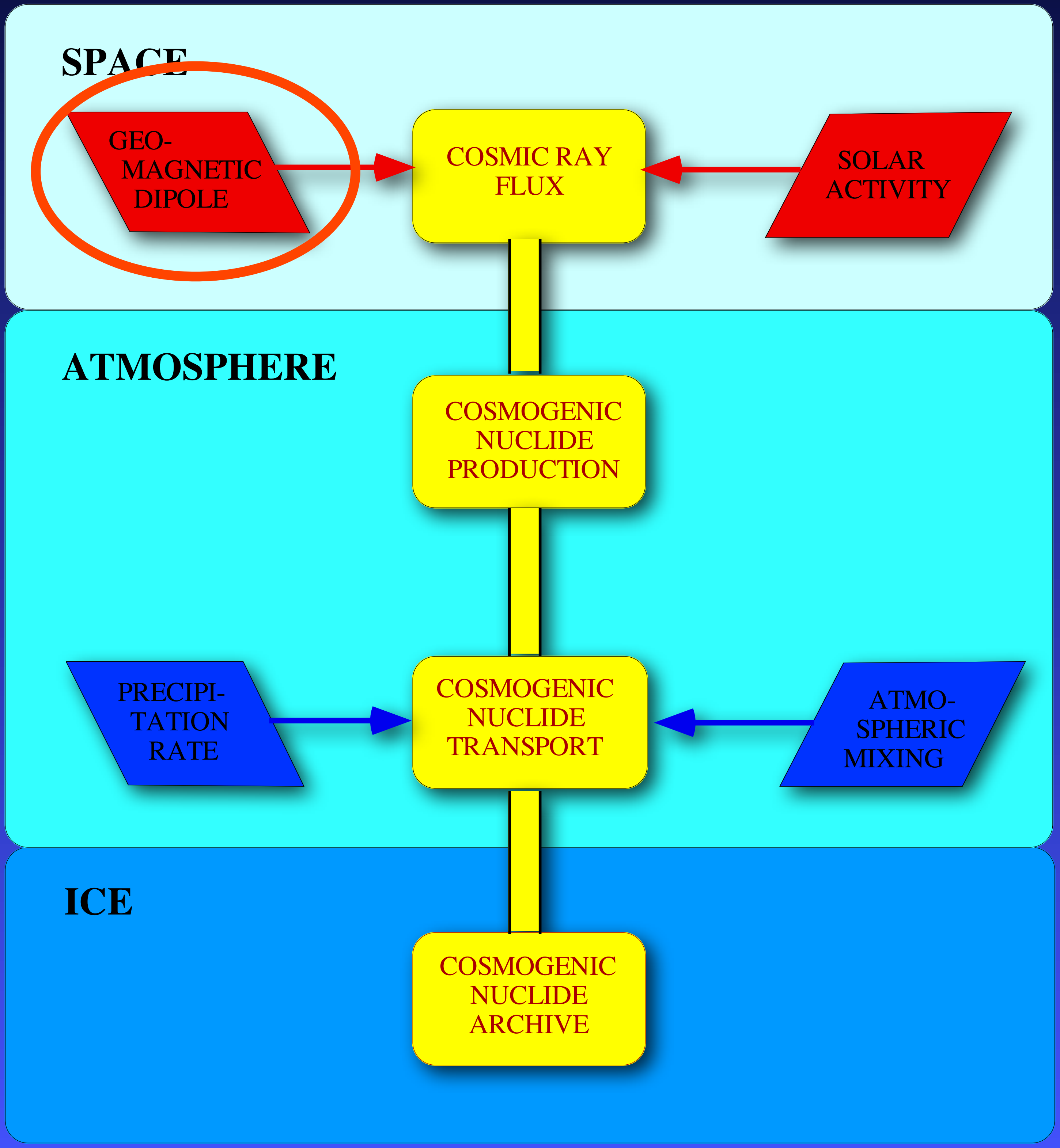


Global ^{10}Be Deposition Flux



Heikkilä et al, 2008

Information from cosmogenic isotopes



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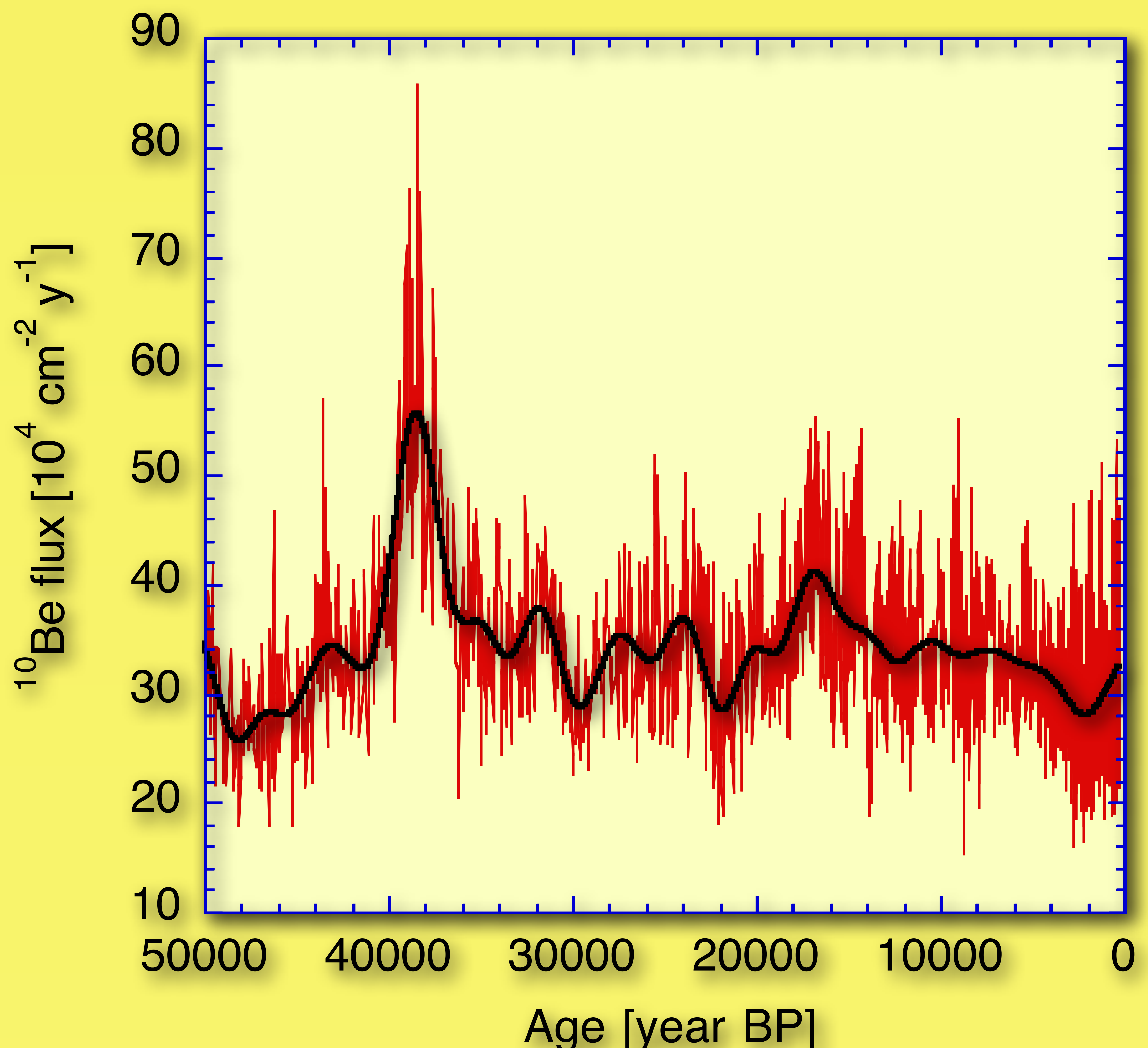
^{10}Be flux from GRIP



Muscheler, R., et al., EPSL, 219, 325-340

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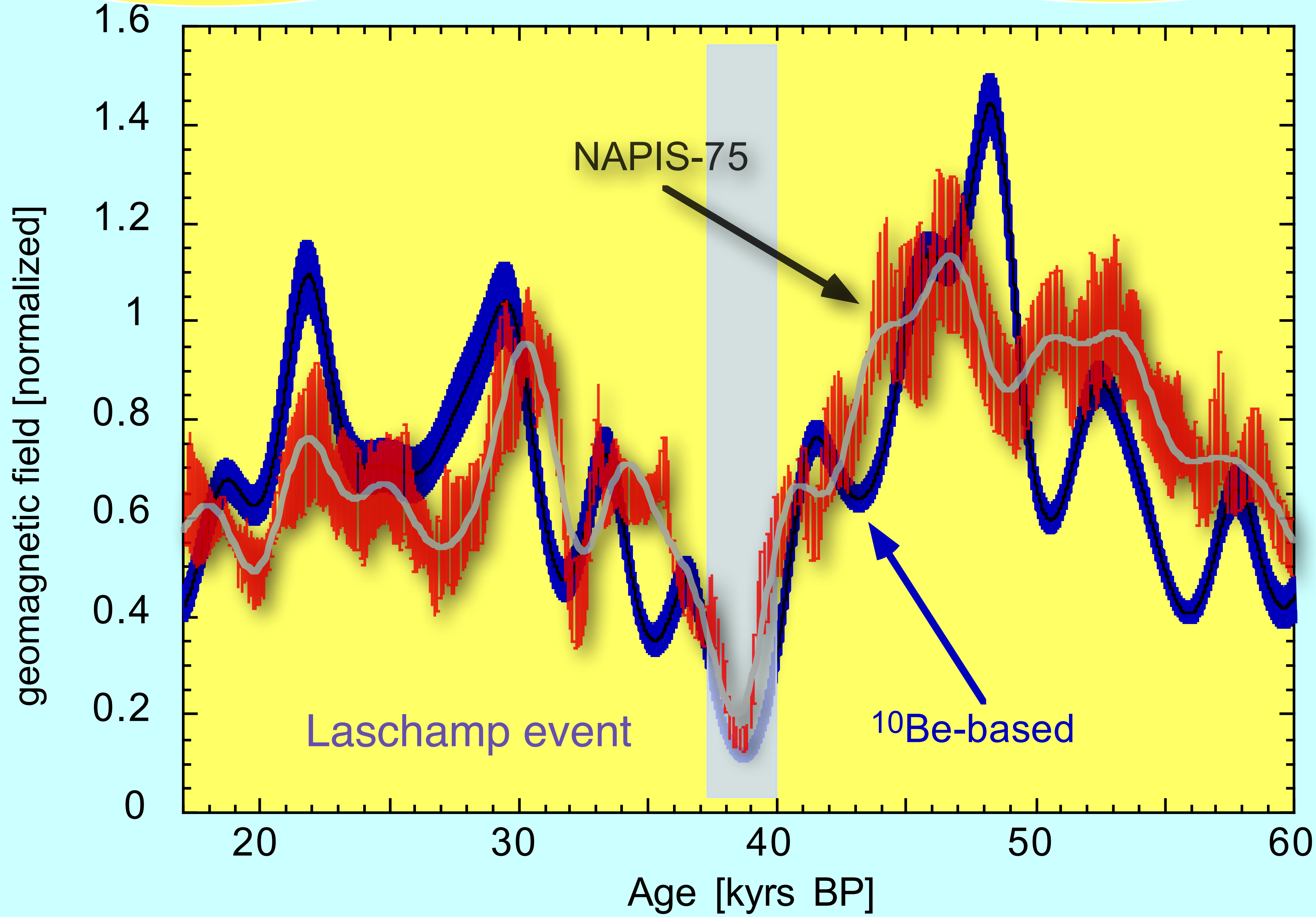
Paleomagnetic Field Reconstruction

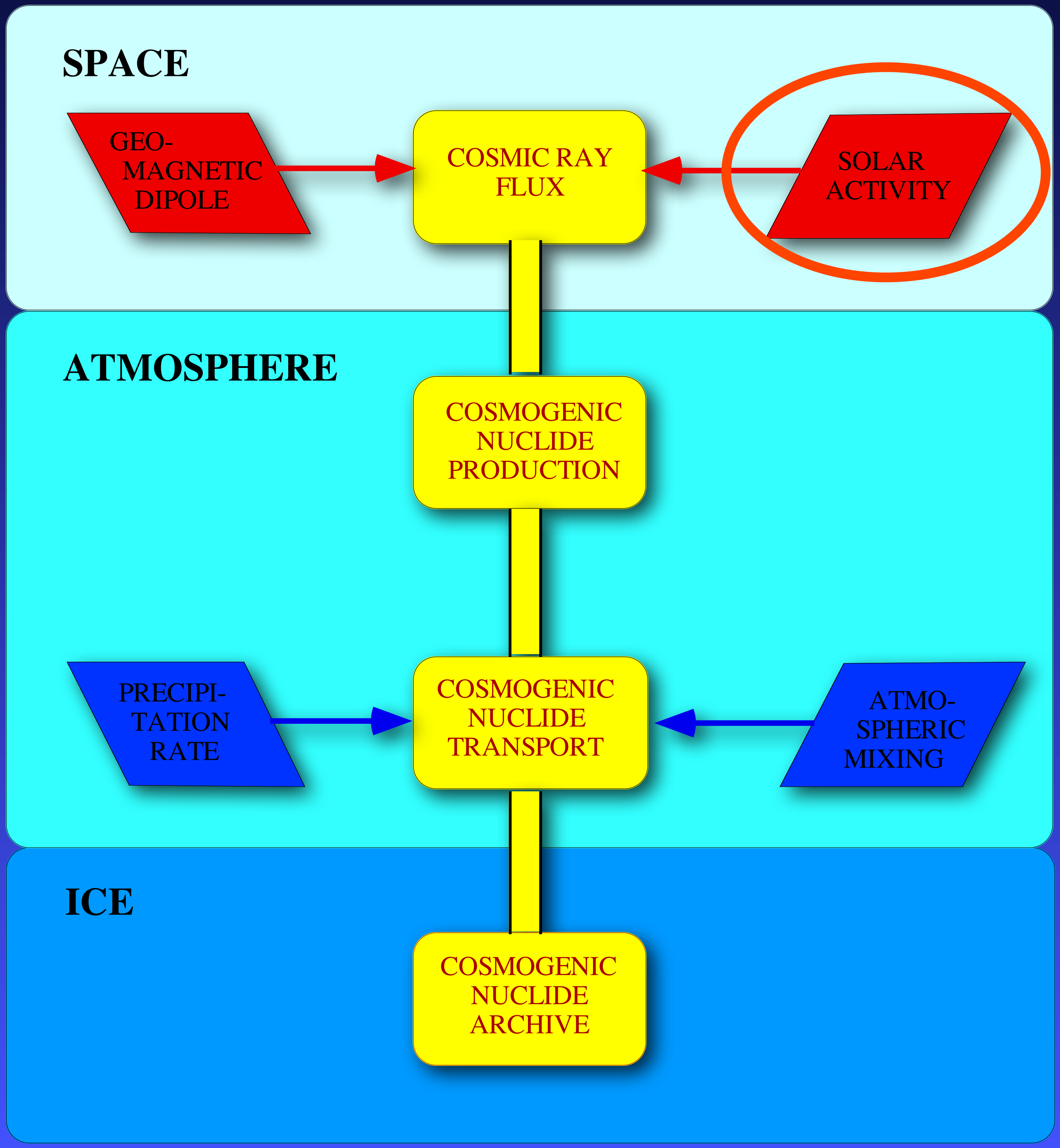
Ulrich Christensen

Jan Sojka

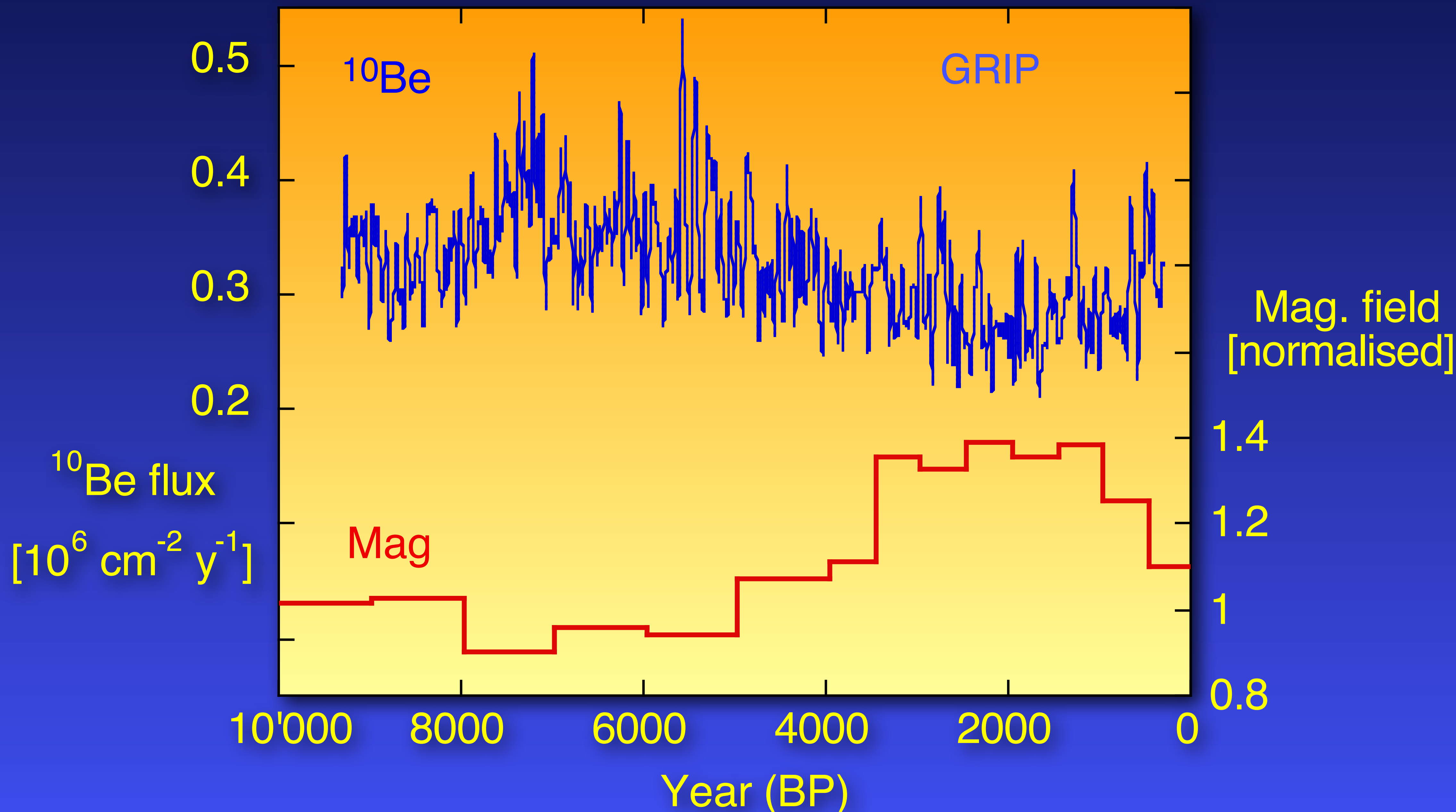


NAPIS-75: Laj et al. Phil. Trans. R. Soc. Lond. A 358 (2000) 1009-1025

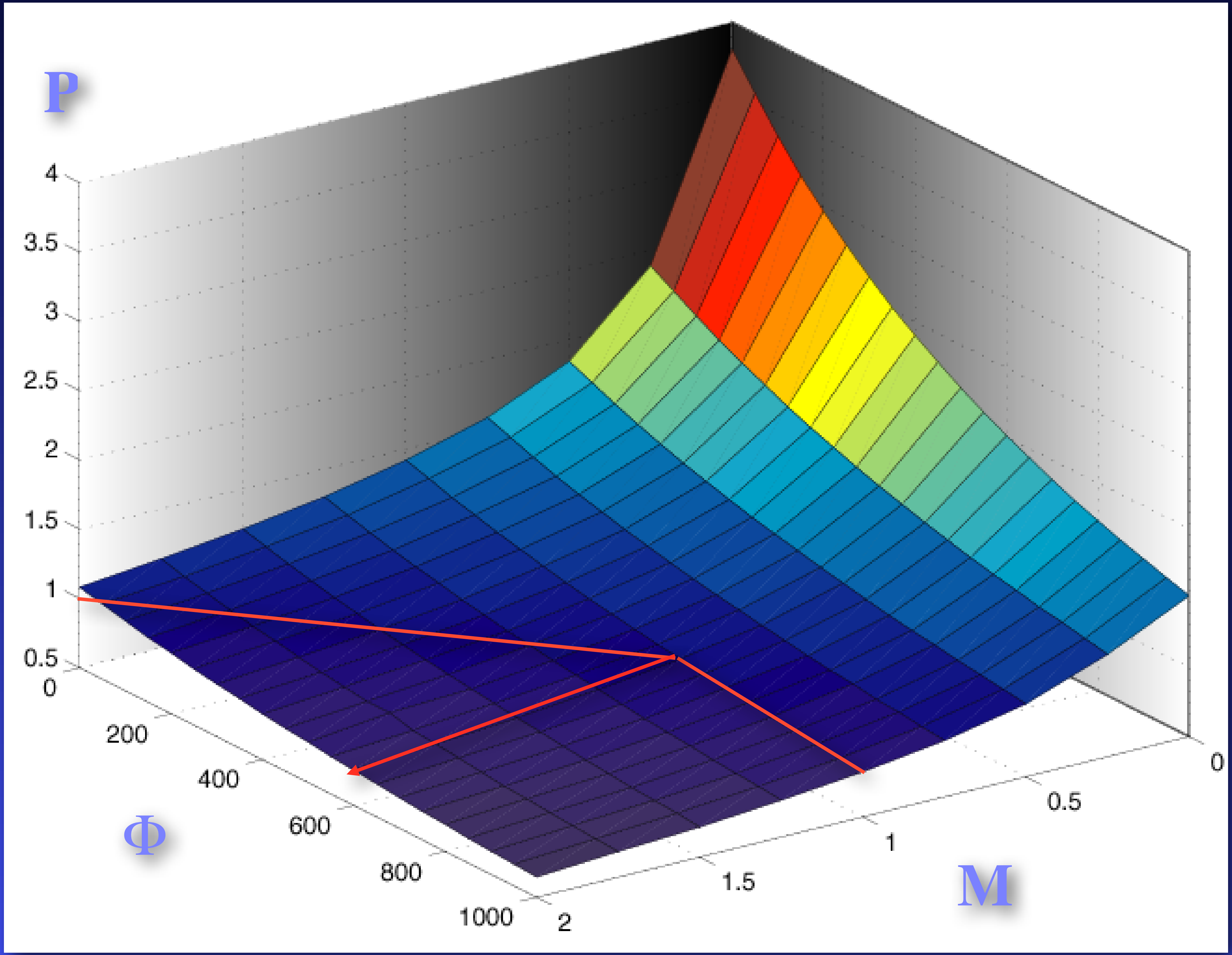
Information from cosmogenic isotopes



Extraction of the Solar Signal



Modulation of the ^{10}Be production rate



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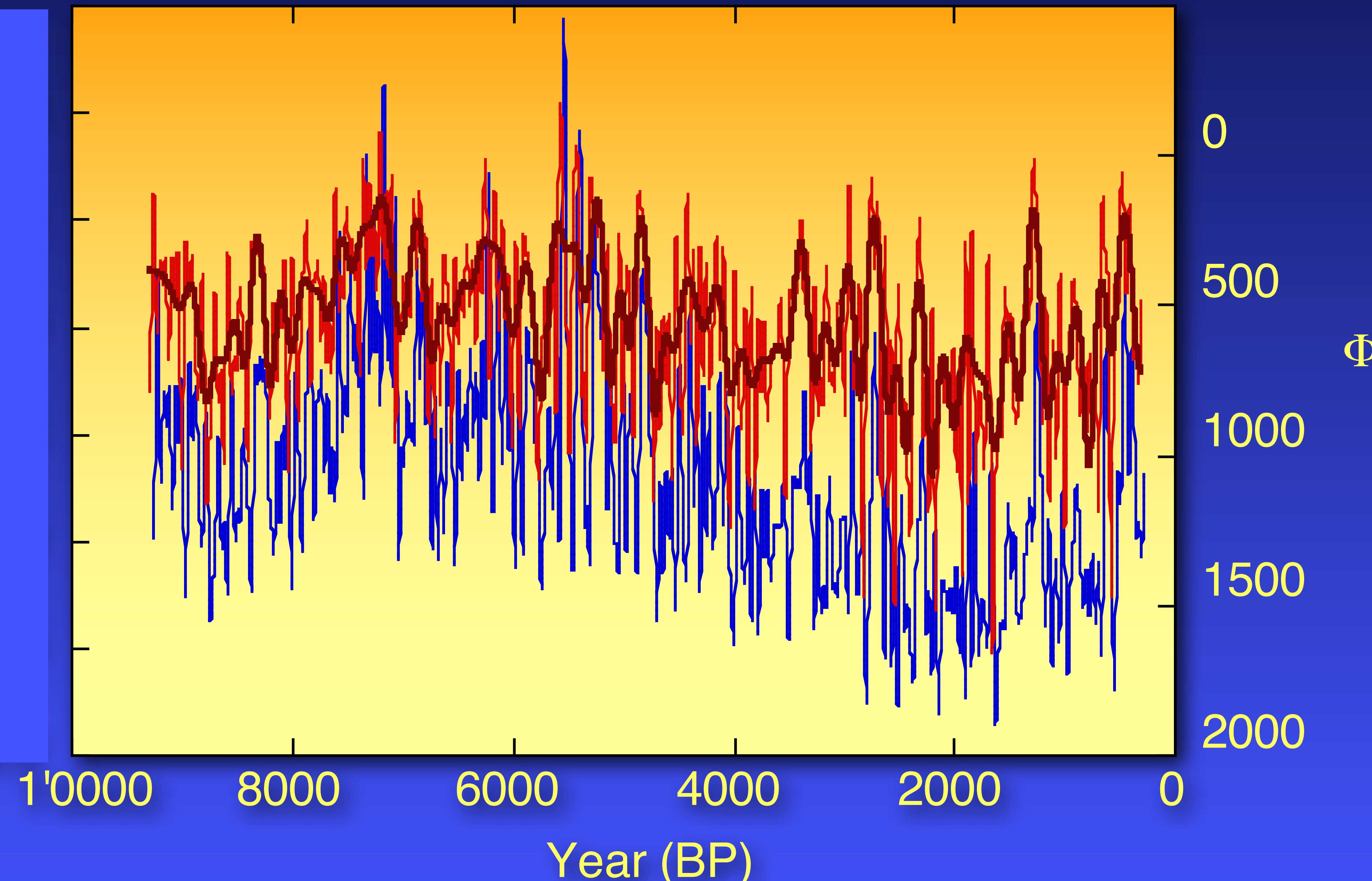
Conversion of ^{10}Be flux into Φ



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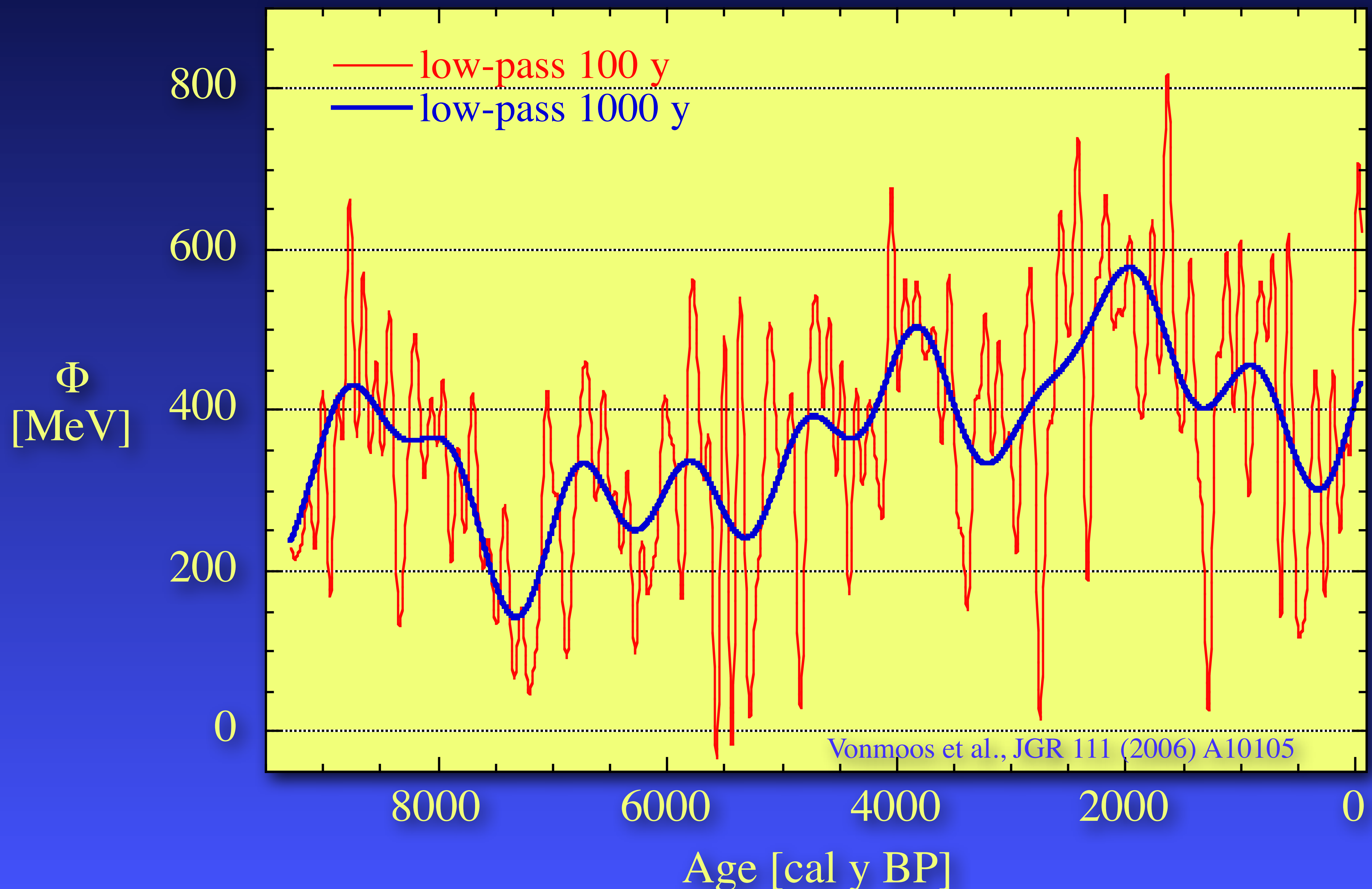
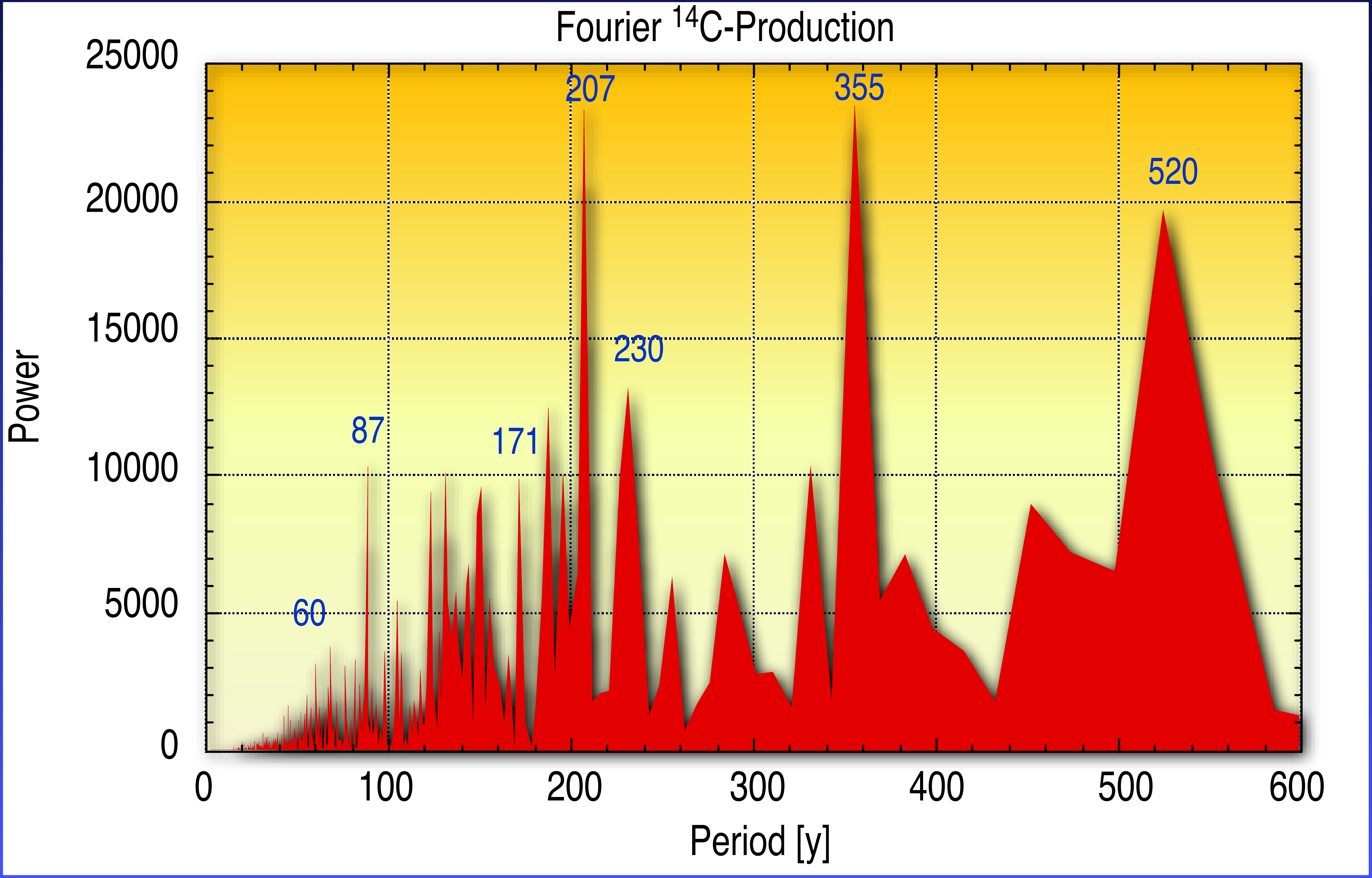
History of solar activity



^{14}C Power Spectrum



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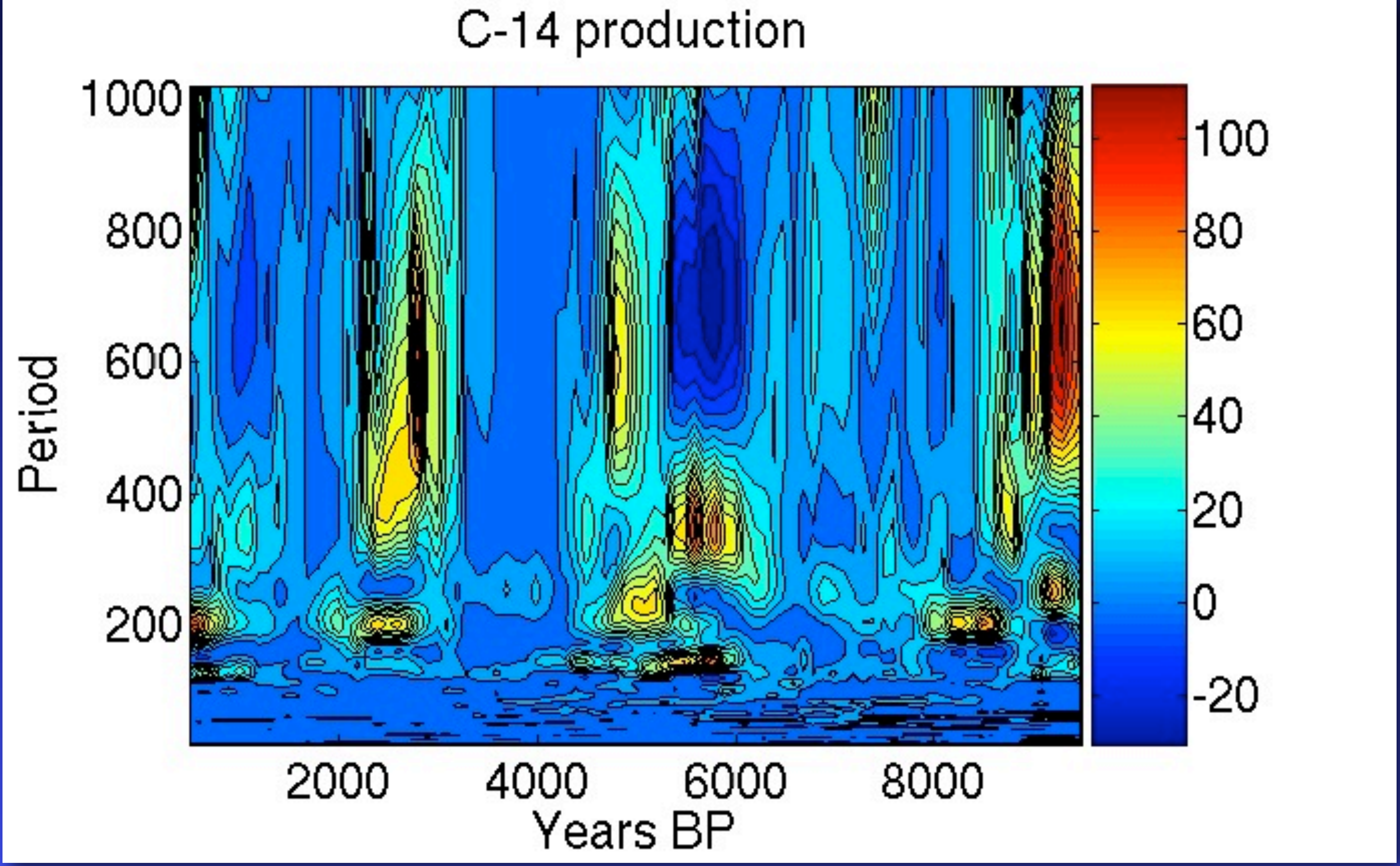
Fourier spectrum of ^{14}C production (1 ky windows)



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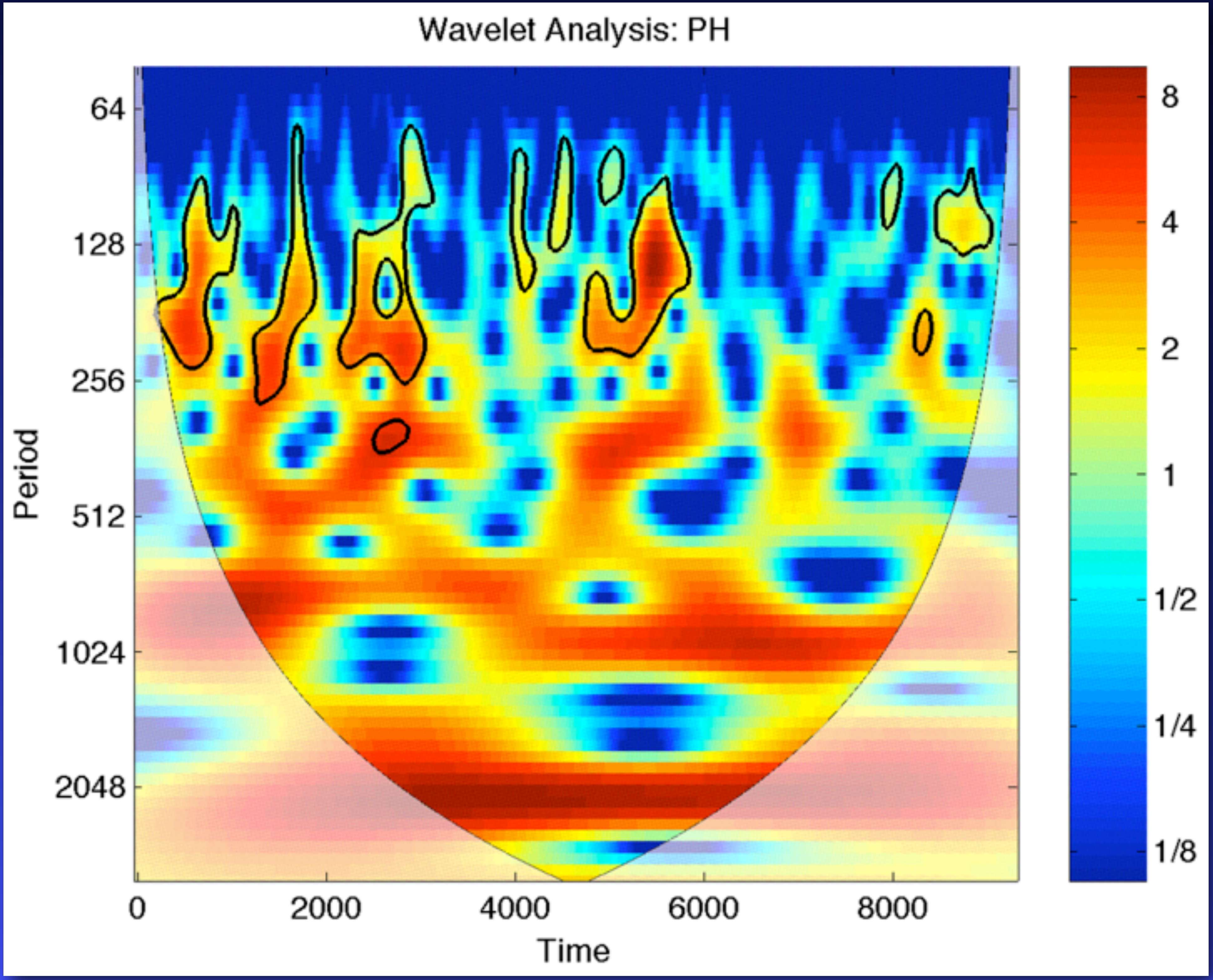
Wavelet analysis: ^{14}C-production



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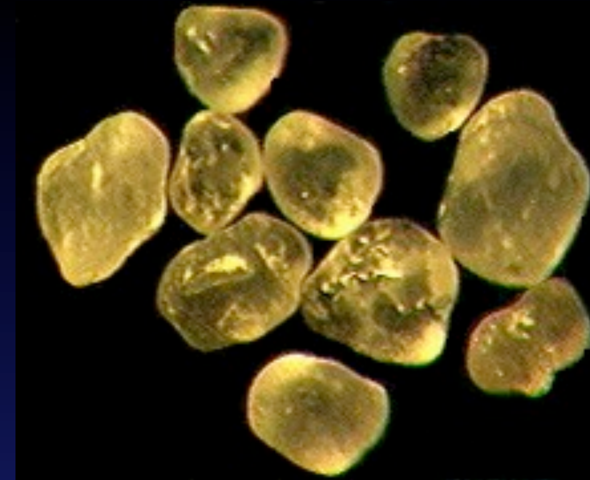
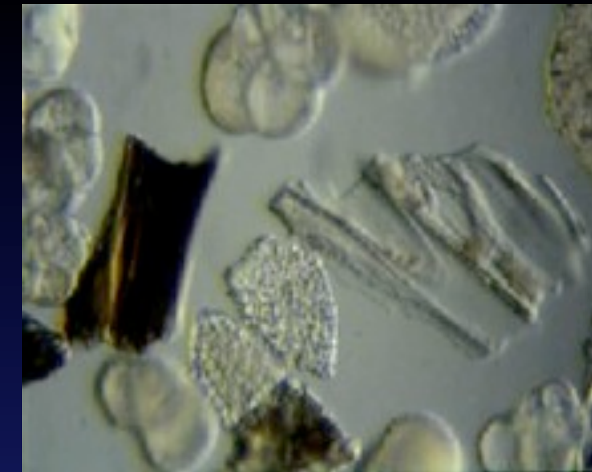
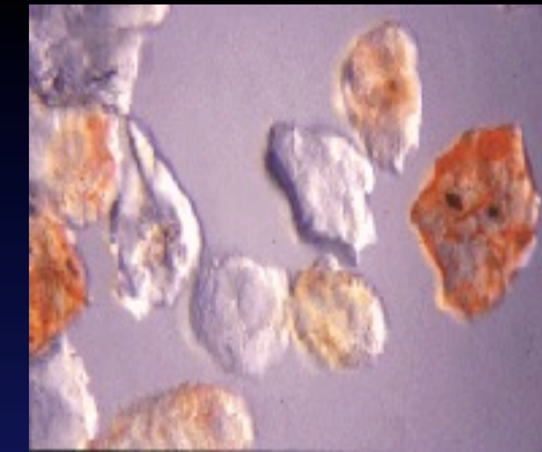
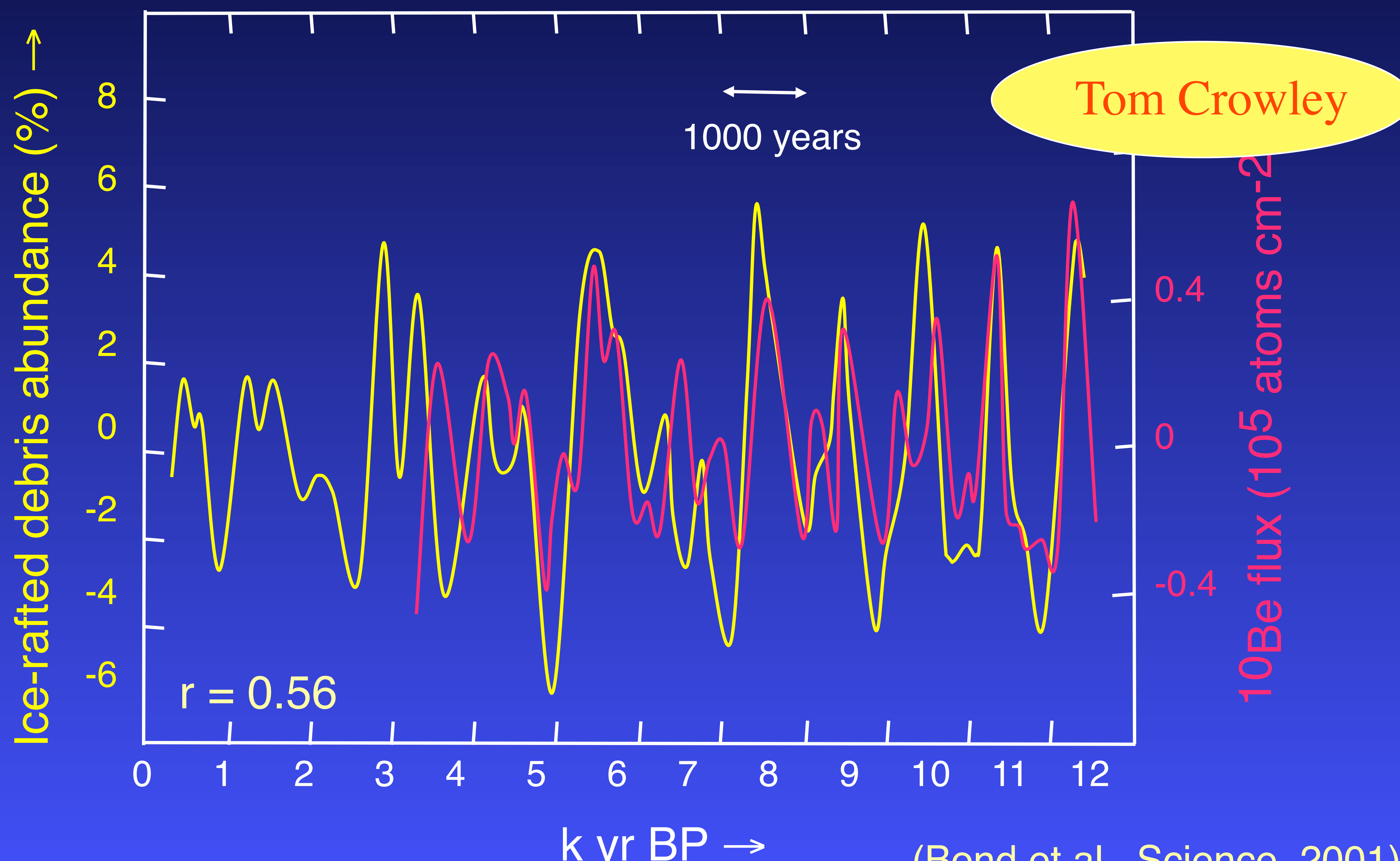
Solar cycles

Cycle / Period	Φ	$\Delta^{14}C$	$Q^{14}C$
Hallstatt	2194	2275	2424
	982	984	957
De Vries, Suess	207	208	208
	352	350	350
	704	714	713
	497	512	512
	105	105	105
Gleissberg	86	87.9	87.0

(Bond et al., Science, 2001)

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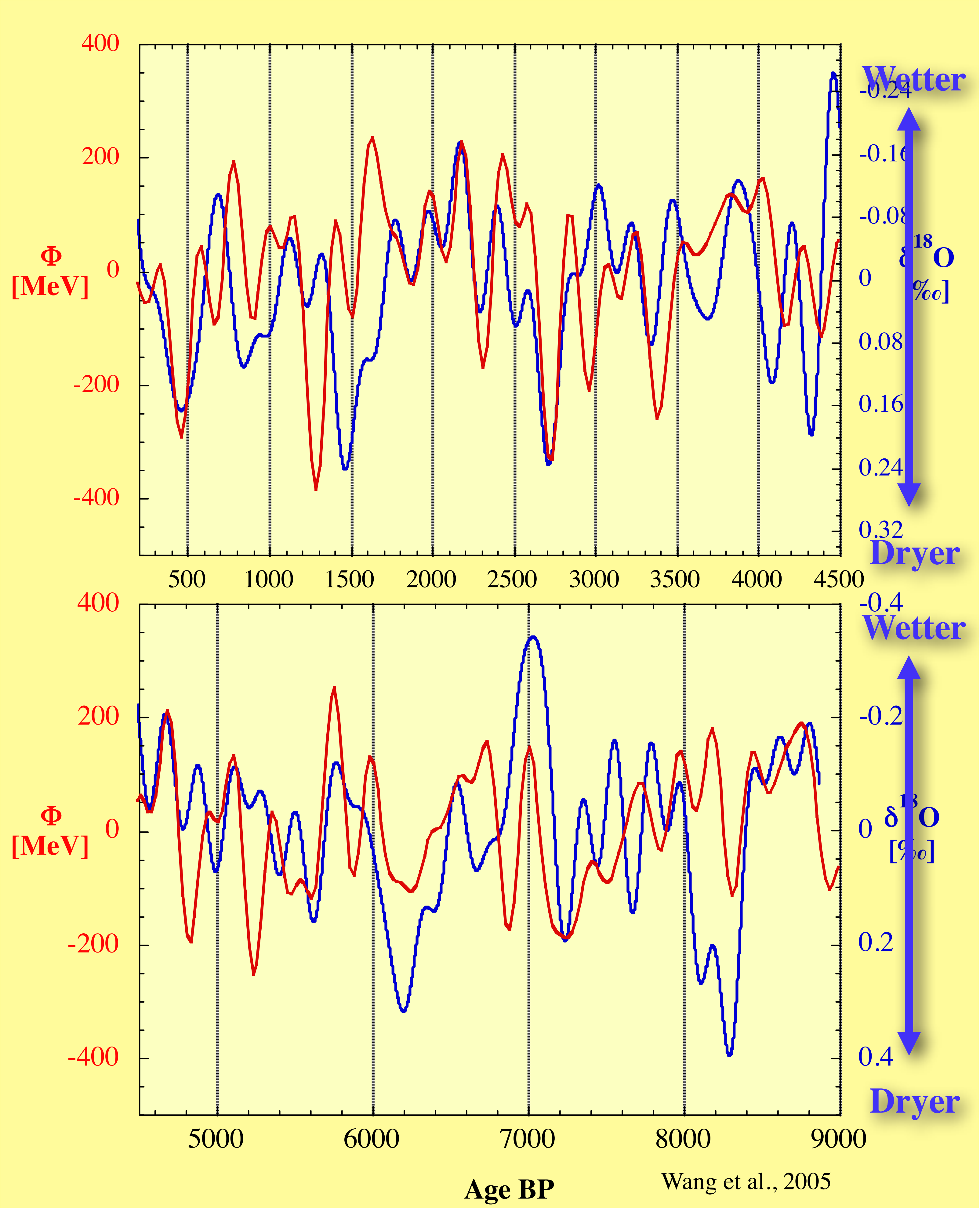
Stalagmite from Dongge Cave, China



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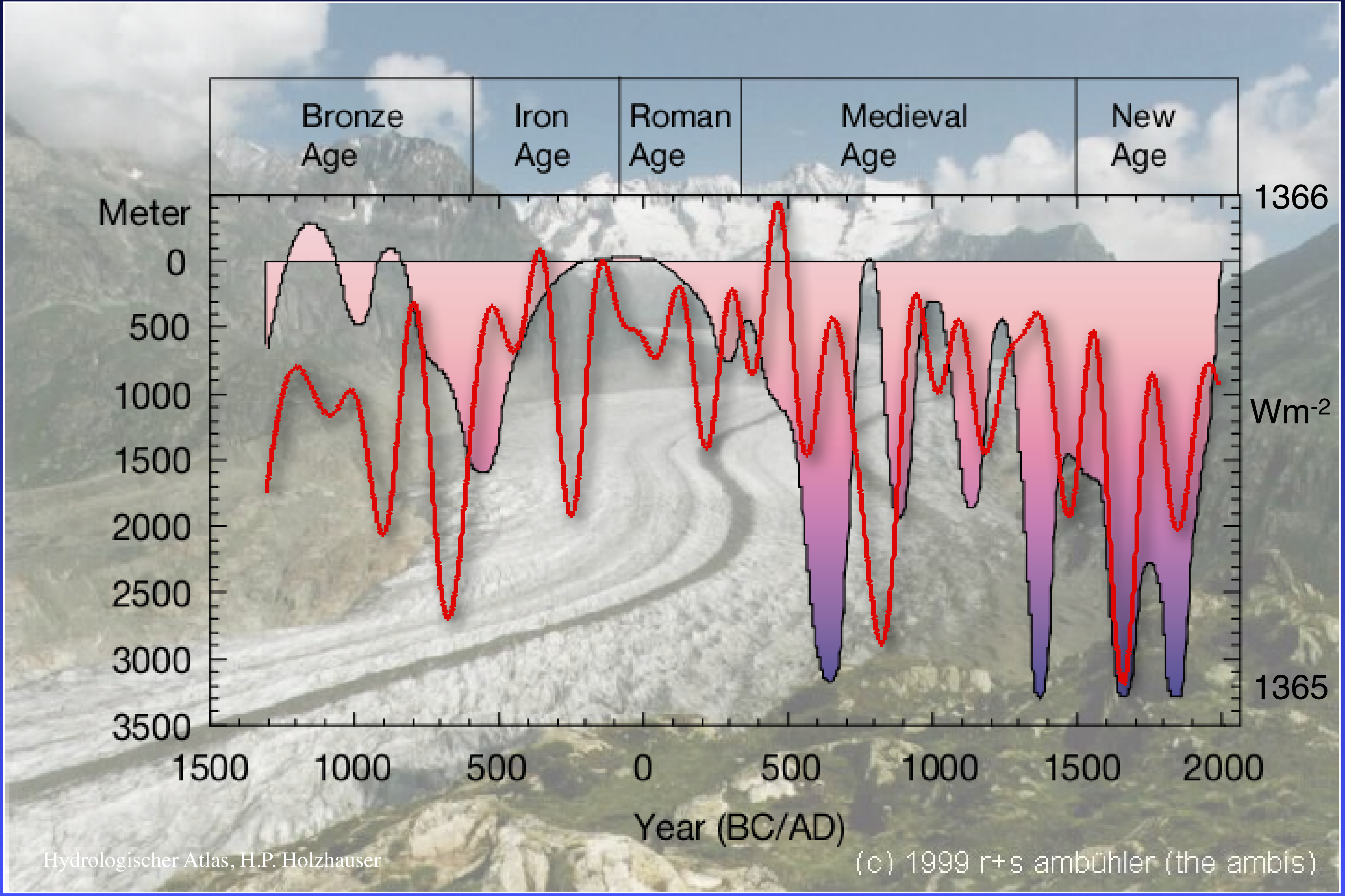
Evidence from glacier (Aletsch)

Length of the Aletsch glacier

Holzhauser et al., Holocene 15(2005)789



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eawag aquatic research

Summary and conclusions-1

- Solar system: coupled
- External influences:
  - gravity
  - angular momentum
  - energy (photons, particles, magnetic fields)
- Planetary climate:
  - distance from Sun
  - albedo
  - composition of atmosphere

Summary and conclusions-2

- Variability general
  - time scales: minutes - million years
  - feed backs (non-linear coupled system)
  - models
- Variability specific
  - orbital parameters
  - solar activity (forcing)
  - long-term variability

Summary and conclusions-3

- Cosmogenic radionuclides
  - time range: 100,000 y
  - time resolution: >1 y
  - atmospheric transport processes
  - geomagnetic dipole field
  - solar activity
    - cycles (11, 87, 207, 2200,....)
    - grand minima
    - implications for solar dynamo
    - solar forcing and climate change

The last view......

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