AEG Inland Empire

Back to the Future:
(How) Can the Past Inform the Future?

Andy Ridgwell

University of California – Riverside
University of Bristol

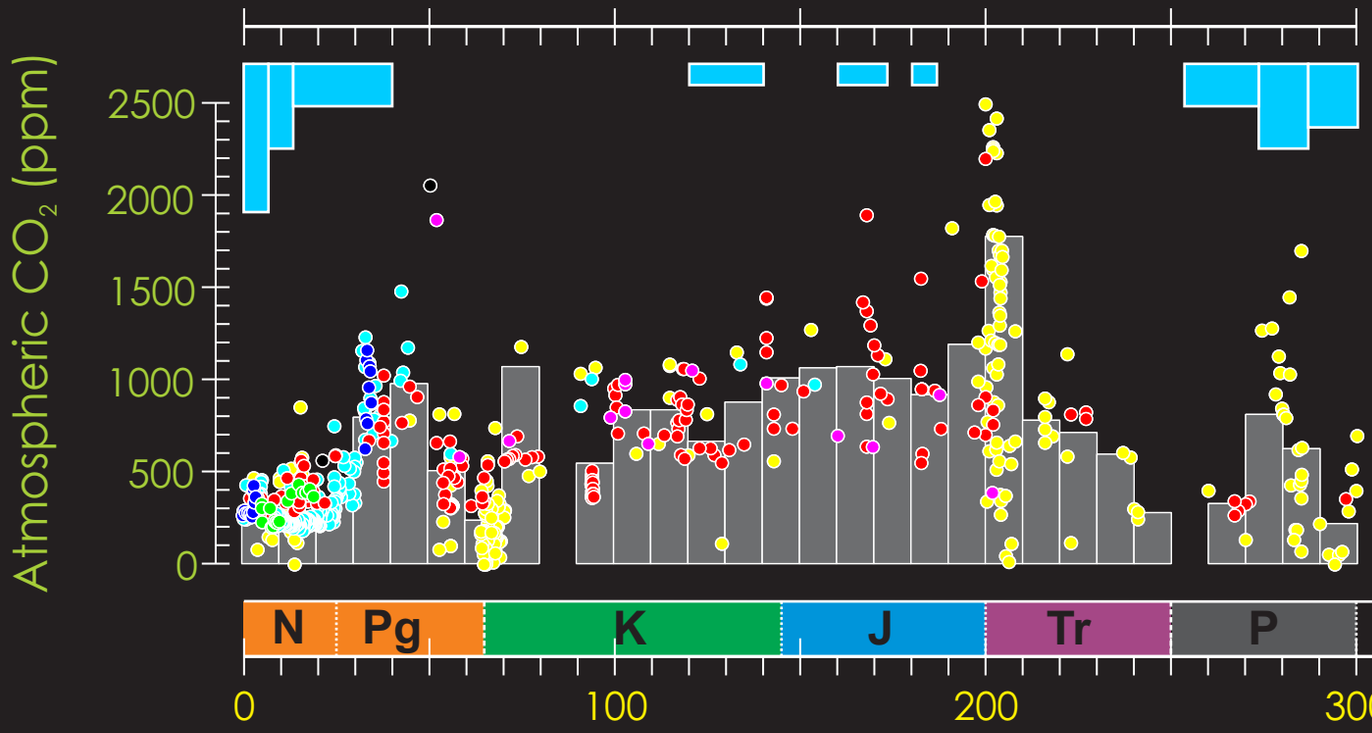
vs.

Why?

?

??

?



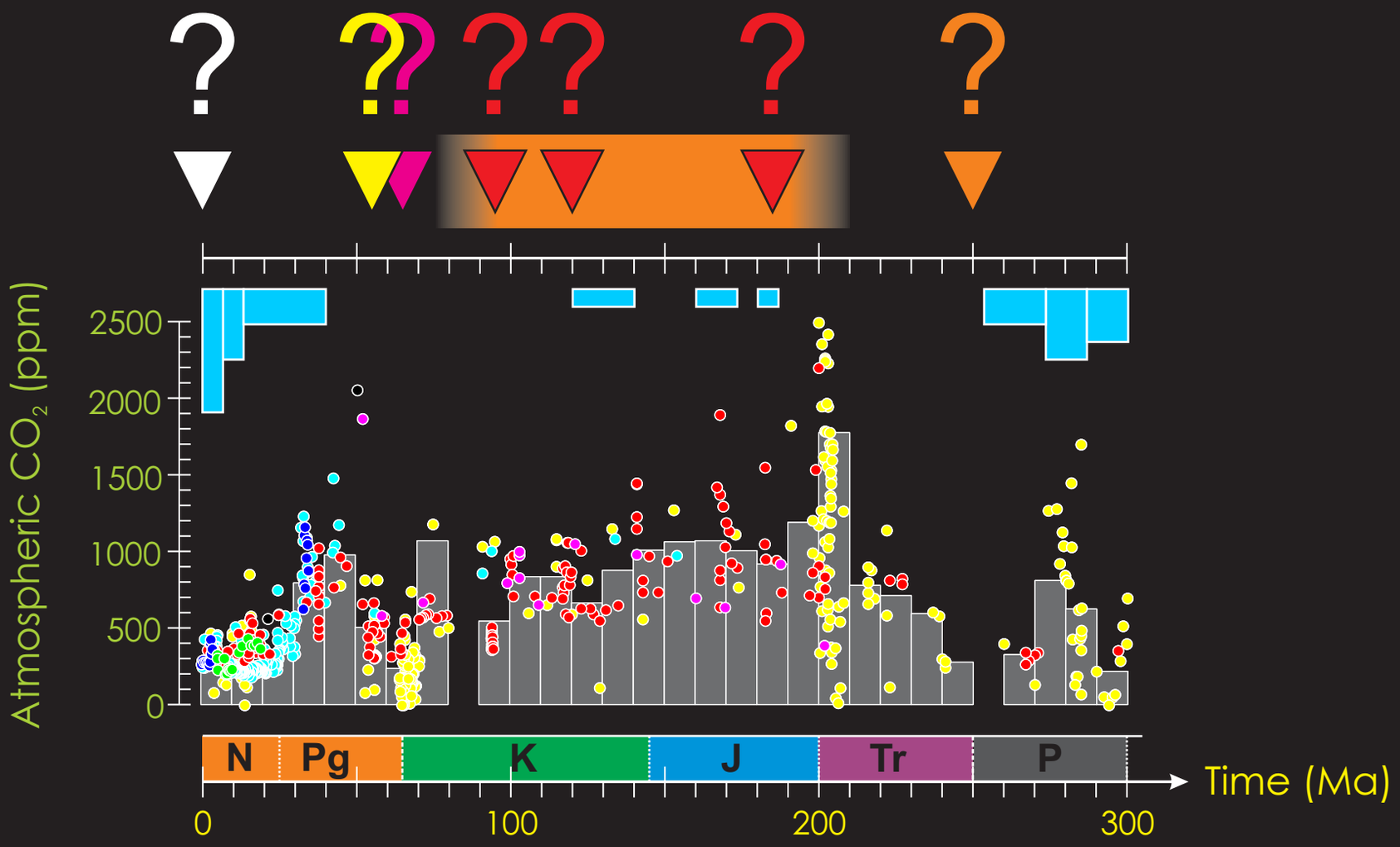
Occurrence of
ice ages (relative intensity)

source; *Crowell* [1999]

From: *Hönisch et al.* [2012]

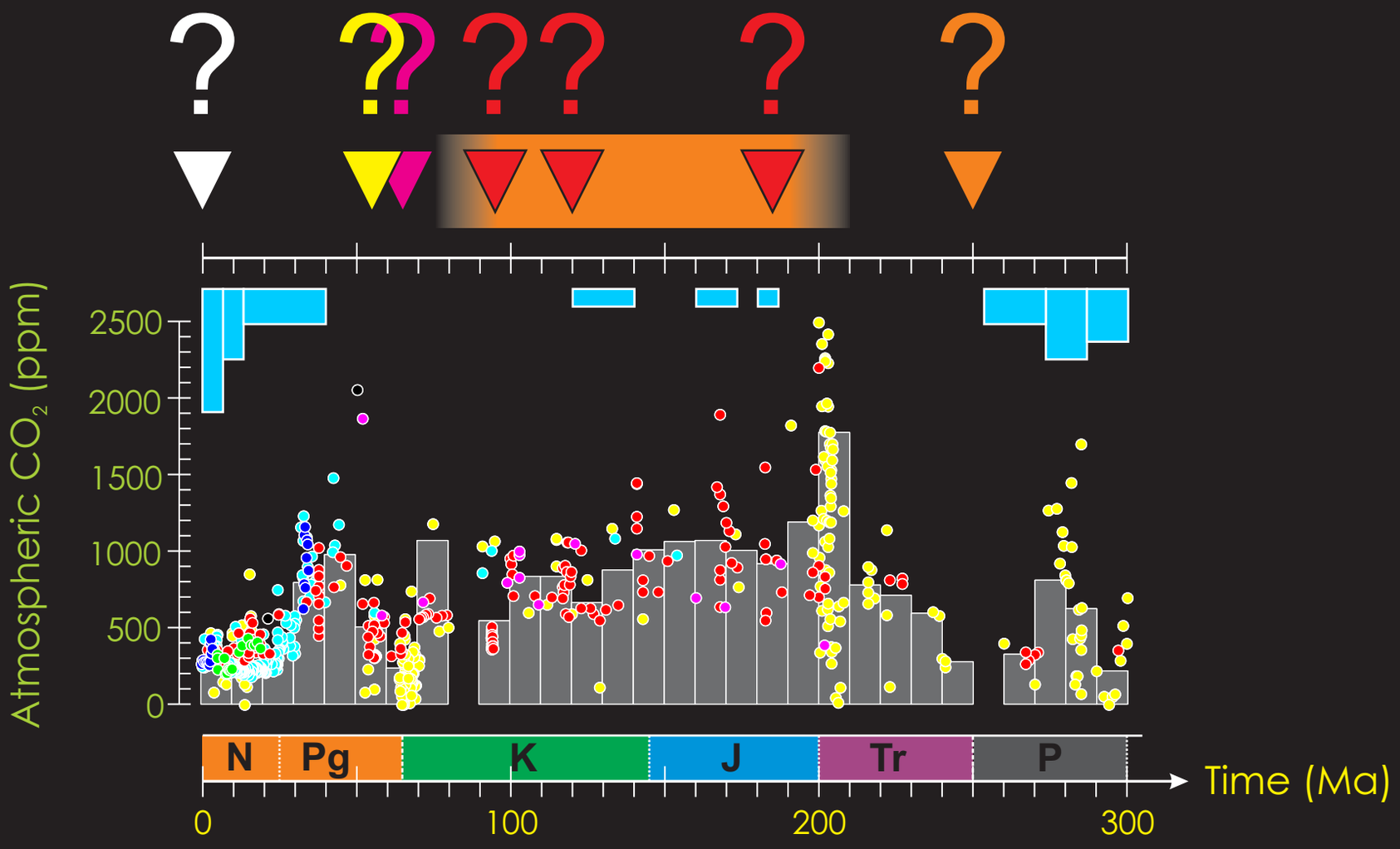
Reason #1 – *fun*

(aka: gaining fundamental insights into the casues and consequences of key events in the evolution of the Earths environment and life)



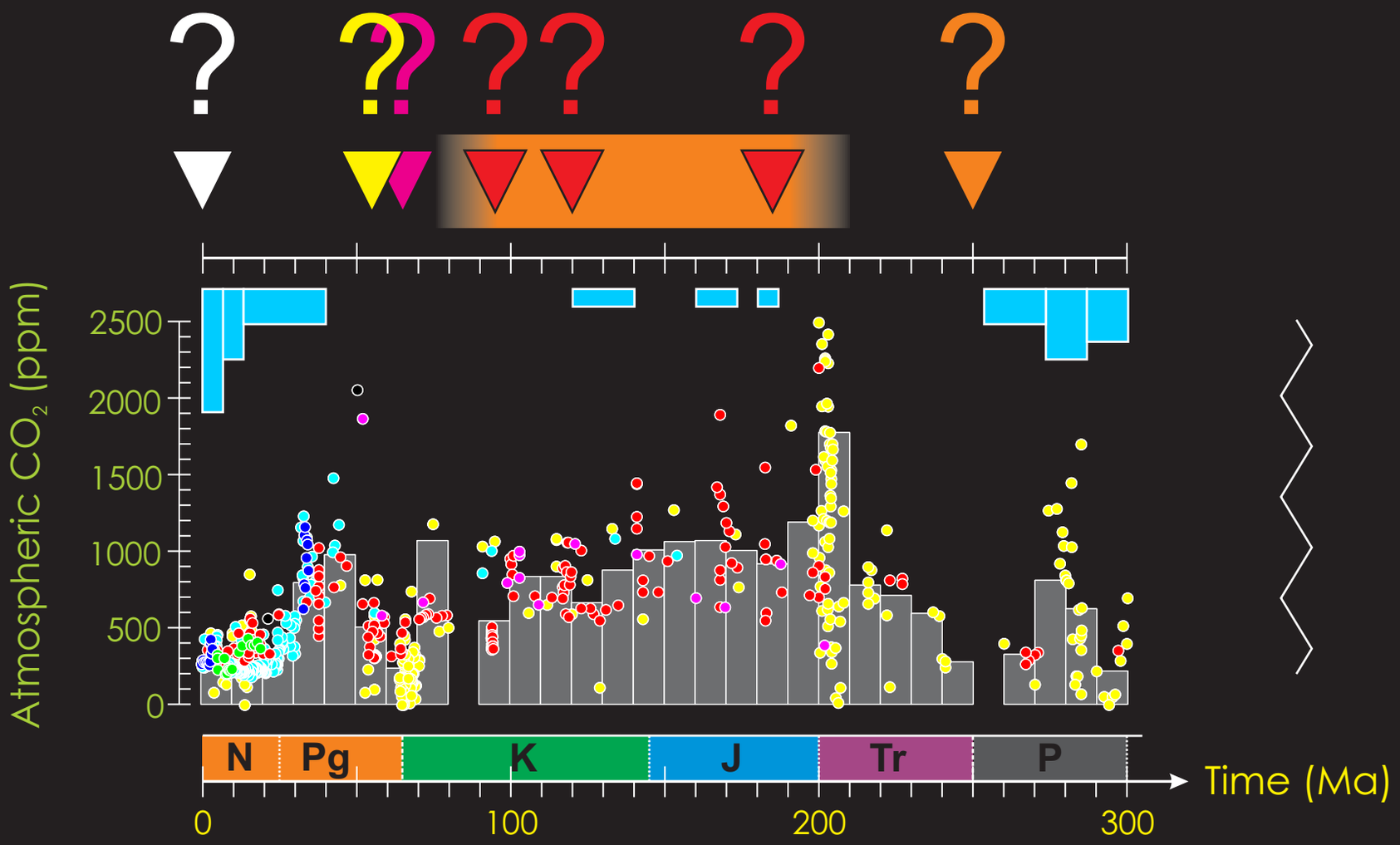
Reason #2 – 'practical uses'

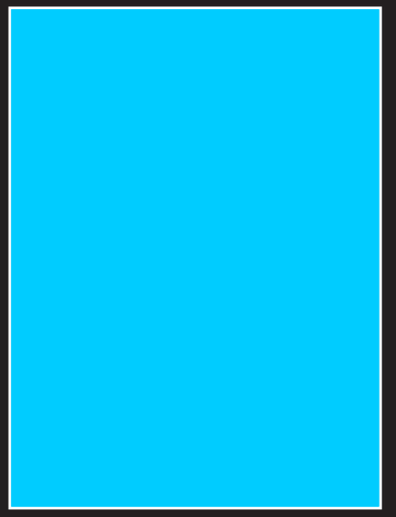
(e.g. understanding and improving prediction of petroleum reservoirs; subsurface movement of groundwater, contaminants, petroleum, etc.)



Reason #3 – for NSF-friendly ‘future relevance’

(the opposite of ‘fun’?)





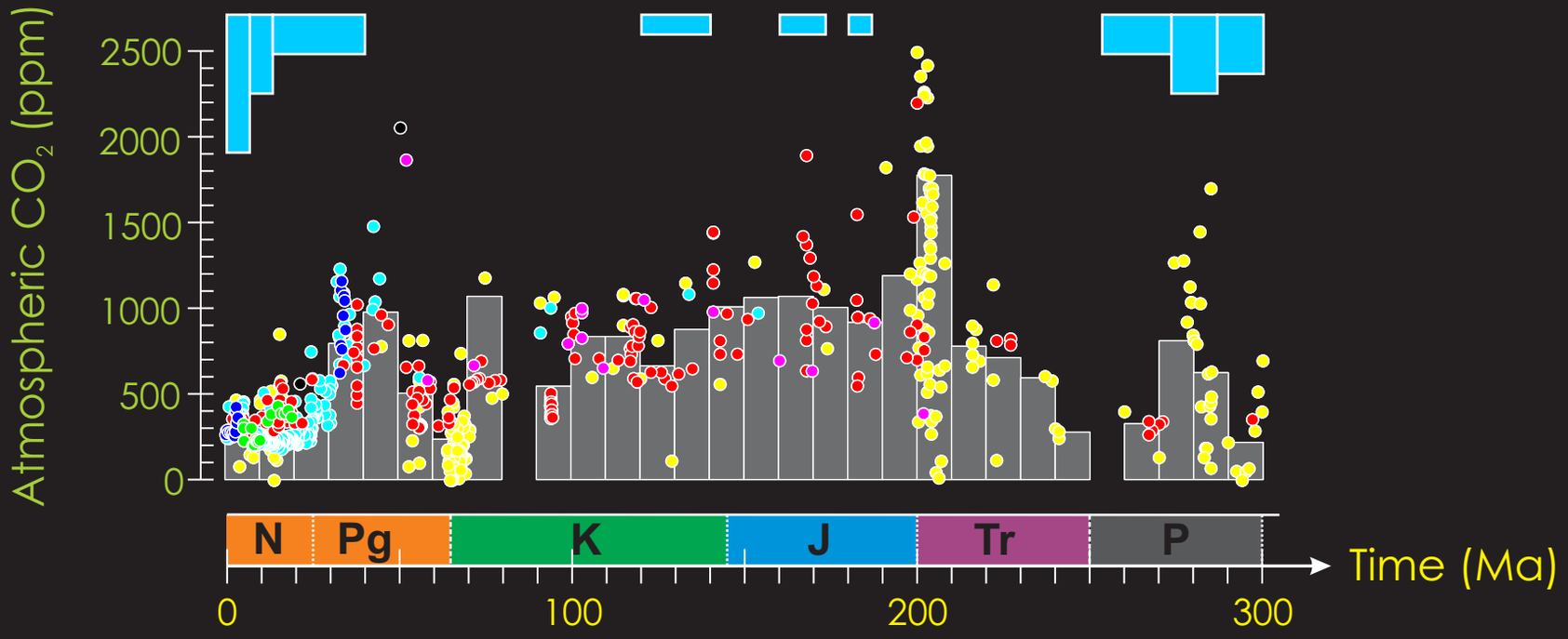
what exactly about 'the future'?

(and hence can, and in what way, the past inform the future?)

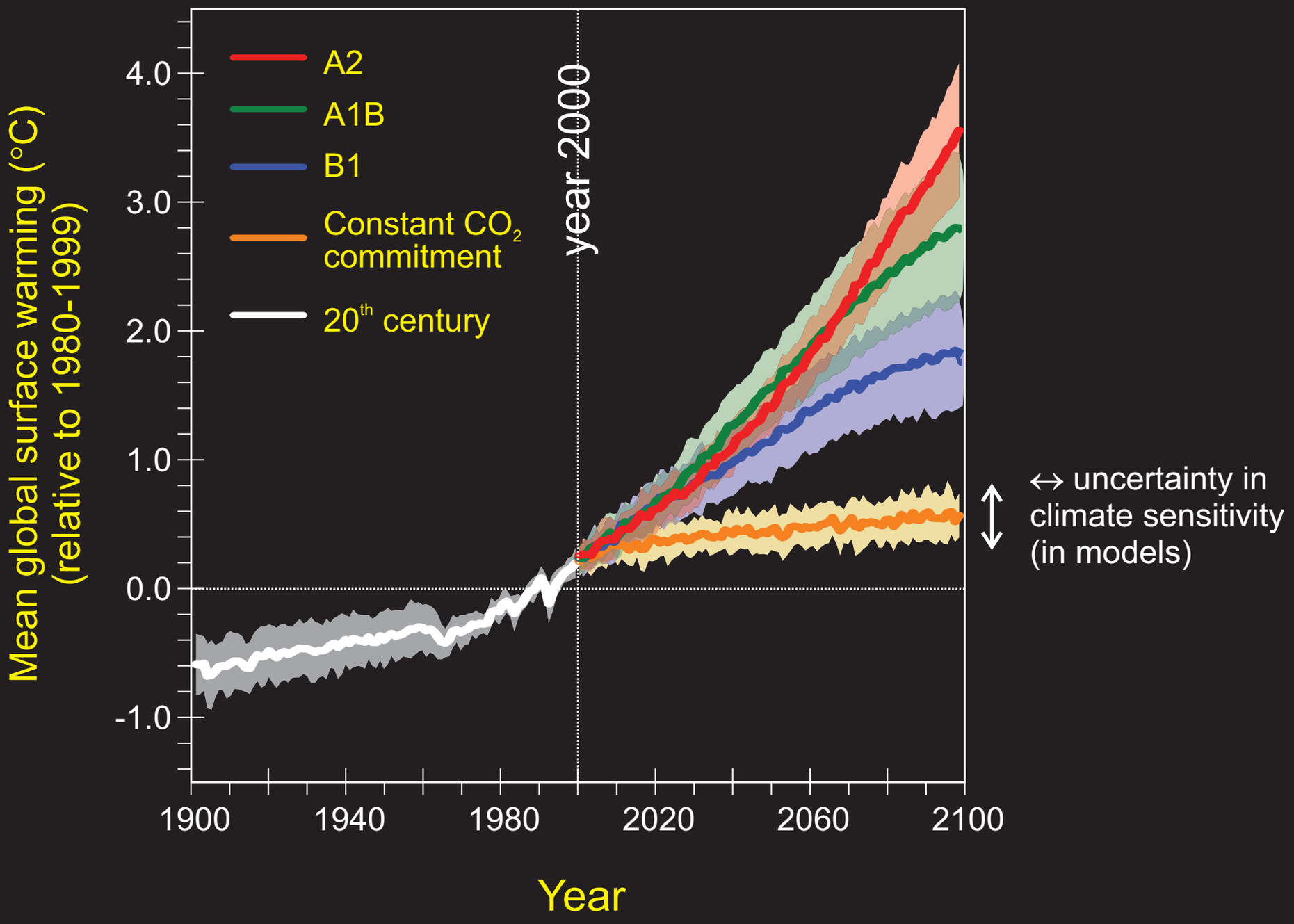
- ~~Outcome of the next Presidential 'Debate'?~~
- ~~Superbowl 2017?~~
- Climate sensitivity (λ).

The equilibrium global mean annual surface air temperature warming associated with a doubling of atmospheric CO_2.

$\Delta T = \lambda \times \Delta F$, where $\Delta F \sim 5.35 \times C/C_0$ (W m^{-2}) ($\Delta F \sim 3.71$ W m^{-2} for a doubling of CO_2)



Why?


A2
A1B
B1
Constant CO_2 commitment
20th century
year 2000
Mean global surface warming (°C)
(relative to 1980-1999)
4.0
3.0
2.0
1.0
0.0
-1.0
1900
1940
1980
2020
2060
2100
Year
↔ uncertainty in climate sensitivity (in models)

Why?

what exactly about 'the future'?

- ~~Outcome of tonght's Presidential 'Debate'?~~
- ~~Superbowl 2017?~~
- Climate sensitivity.
- (a) The strength of positive carbon cycle feedbacks with a warming climate (vegetation and soil carbon, peat, permafrost, methane hydrates), and the mechanistic nature of these feedbacks (e.g. increased carbon metabolism respiration vs. increased incidence of wildfires).

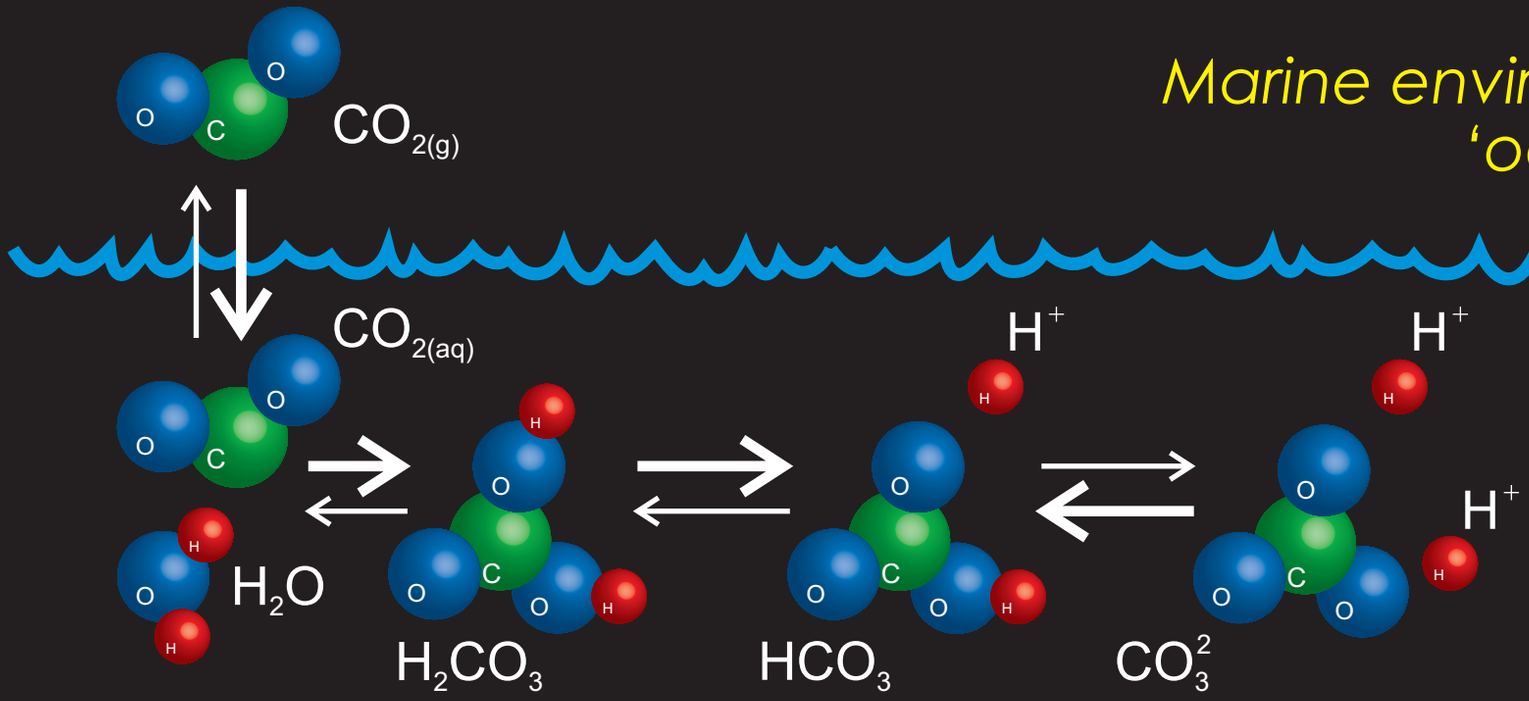
  (b) The strength of negative carbon cycle feedbacks with a warming climate and higher atmospheric CO_2 (silicate weathering, weathered nutrient supply and availability, marine (or soil) organic carbon preservation and burial, deep-sea carbonate dissolution ('compensation')).

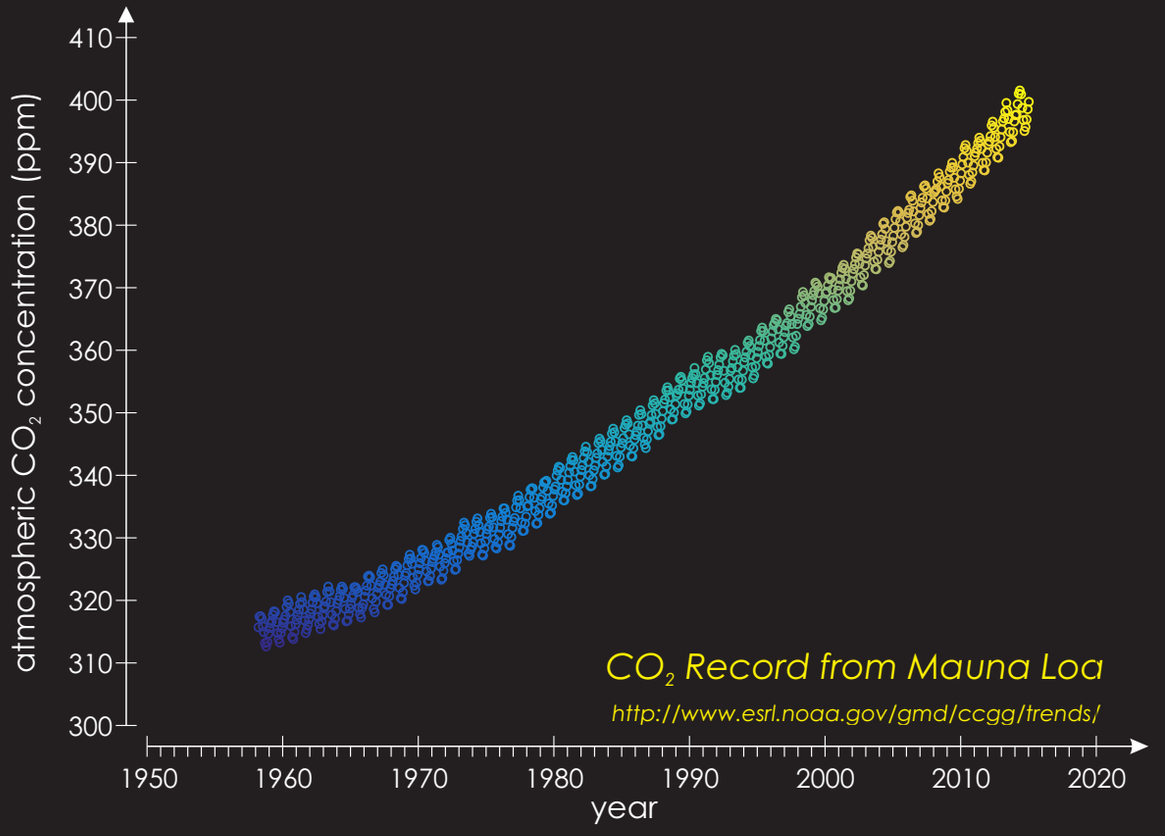
Why?

what exactly about 'the future'?

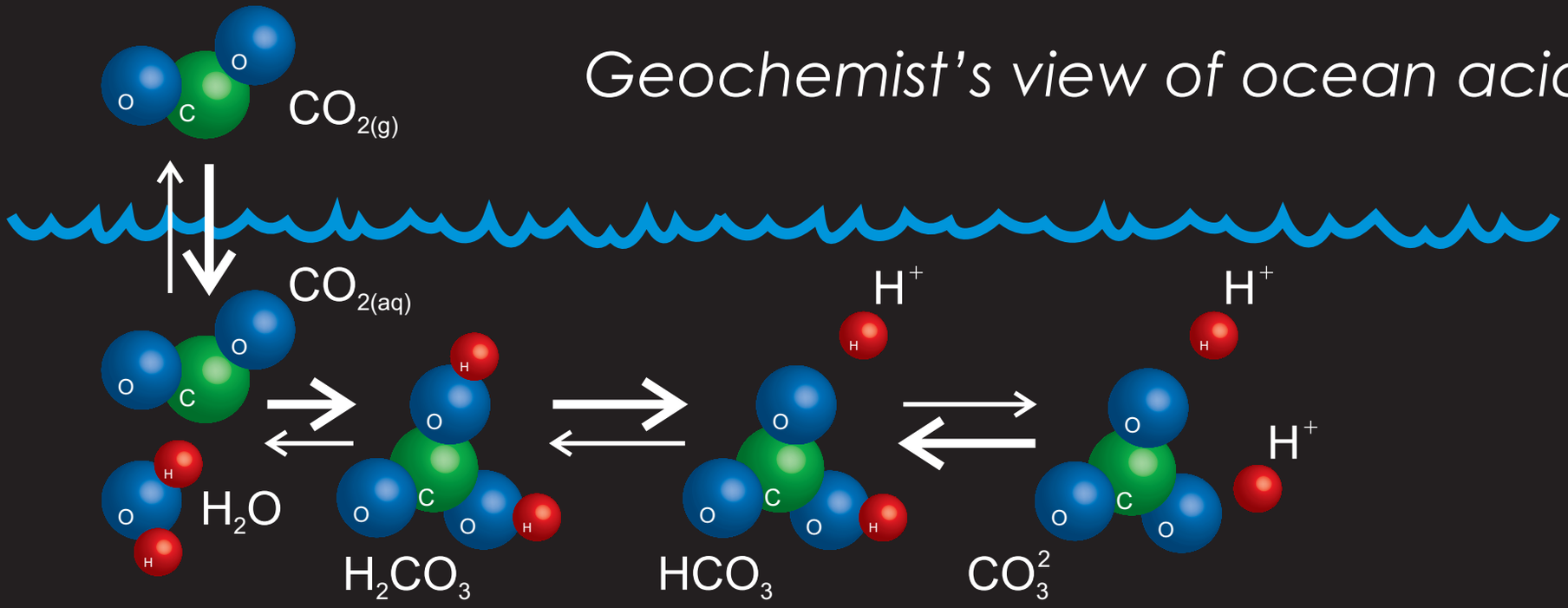
- ~~Outcome of tonght's Presidential 'Debate'?~~
- ~~Superbowl 2017?~~
- Climate sensitivity.
- (a) The strength of positive carbon cycle feedbacks with a warming climate (vegetation and soil carbon, peat, permafrost, methane hydrates), and the mechanistic nature of these feedbacks (e.g. increased carbon metabolism respiration vs. increased incidence of wildfires).
  (b) The strength of negative carbon cycle feedbacks with a warming climate and higher atmospheric CO_2 (silicate weathering, weathered nutrient supply and availability, marine (or soil) organic carbon preservation and burial, deep-sea carbonate dissolution ('compensation')).
- Ecological and extinction sensitivity to climate change and ocean acidification.

Marine environmental change: 'ocean acidification'





Geochemist's view of ocean acidification



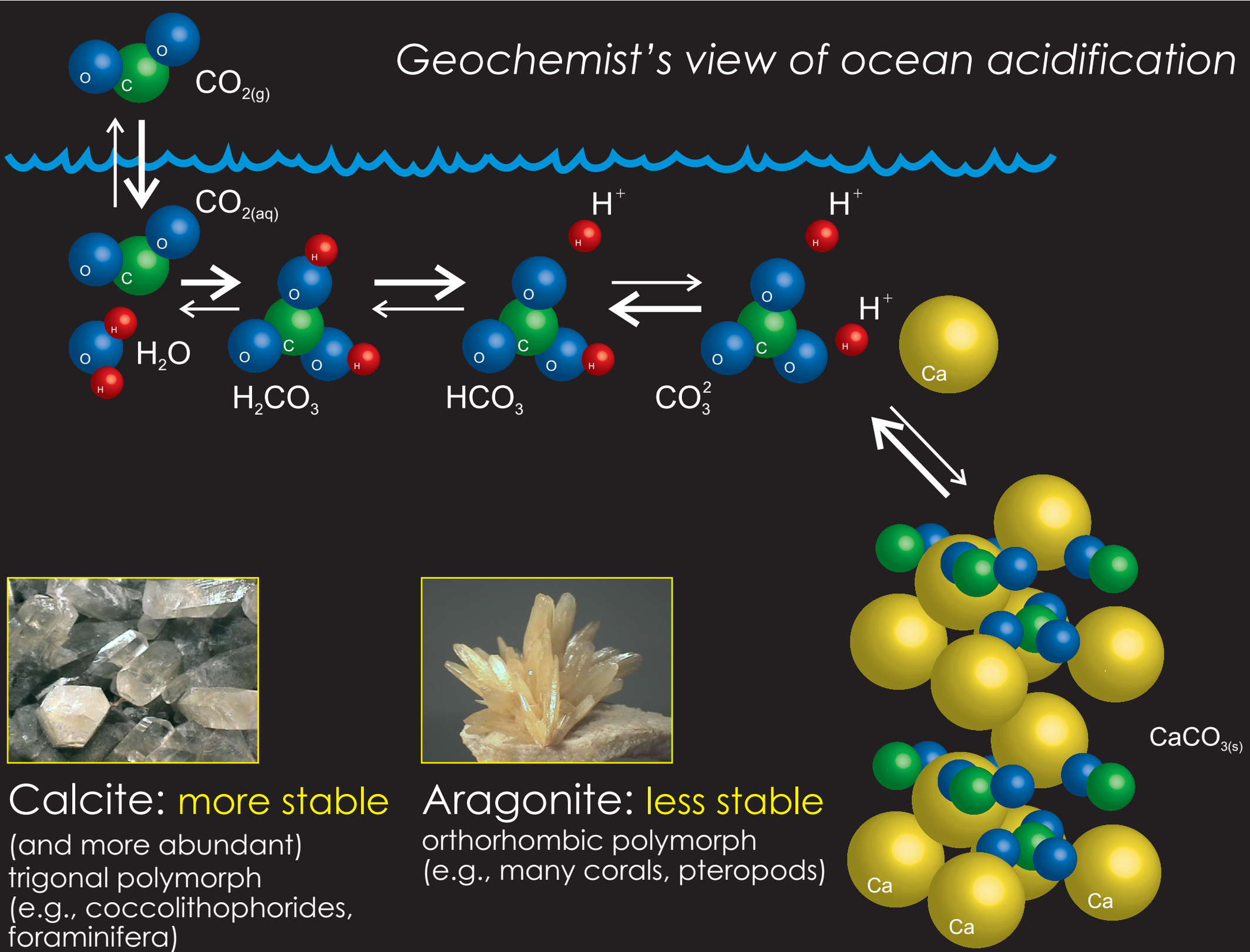
When CO_2 dissolves in seawater, the equilibrium distribution of dissolved carbon between $CO_{2(aq)}$, HCO_3^-, and CO_3^{2-}, is perturbed.

To a first approximation, the net outcome can be written:

$$CO_{2(aq)} + CO_3^{2-} + H_2O \rightarrow 2HCO_3^-$$

(However, a small part of the resulting HCO_3^- dissociates into CO_3^{2-} and H^+, which is where the 'acidification' in ocean acidification comes from.)

Geochemist's view of ocean acidification



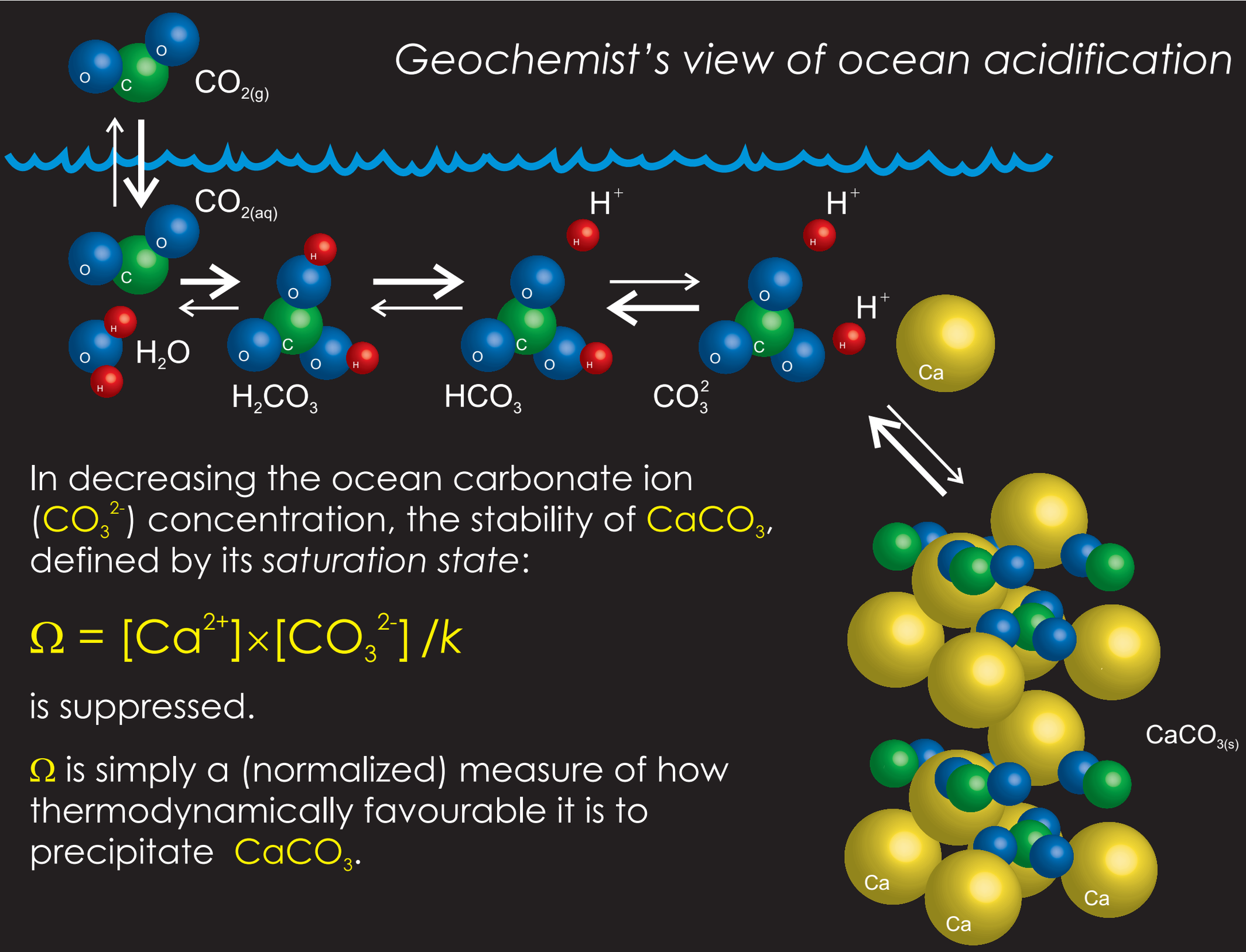
Calcite: more stable

(and more abundant)
trigonal polymorph
(e.g., coccolithophorides, foraminifera)

Aragonite: less stable

orthorhombic polymorph
(e.g., many corals, pteropods)

Geochemist's view of ocean acidification



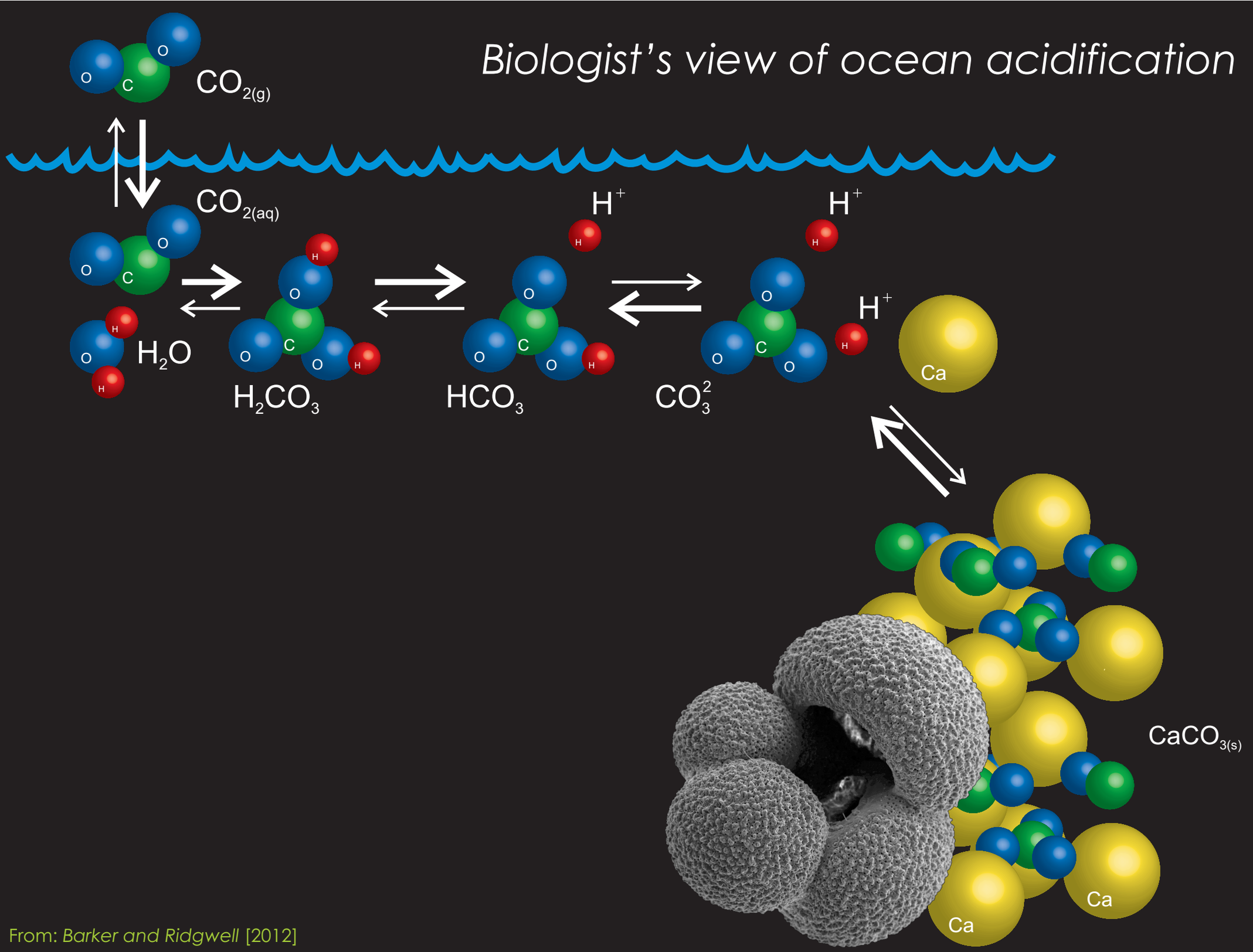
In decreasing the ocean carbonate ion (CO_3^{2-}) concentration, the stability of $CaCO_3$, defined by its *saturation state*:

$$\Omega = [Ca^{2+}] \times [CO_3^{2-}] / k$$

is suppressed.

Ω is simply a (normalized) measure of how thermodynamically favourable it is to precipitate $CaCO_3$.

Biologist's view of ocean acidification

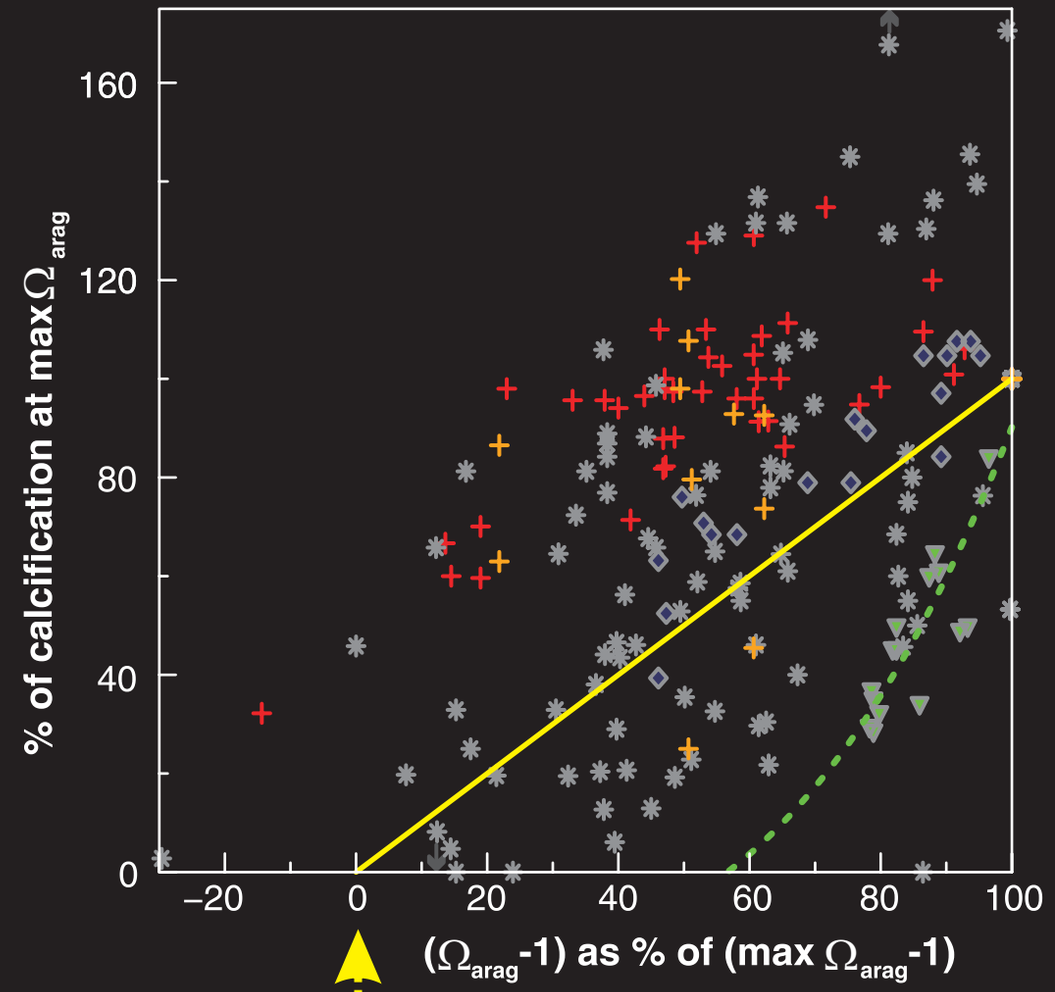


From: *Barker and Ridgwell* [2012]

Ocean Acidification

decreasing *p*H, saturation

decreasing calcification



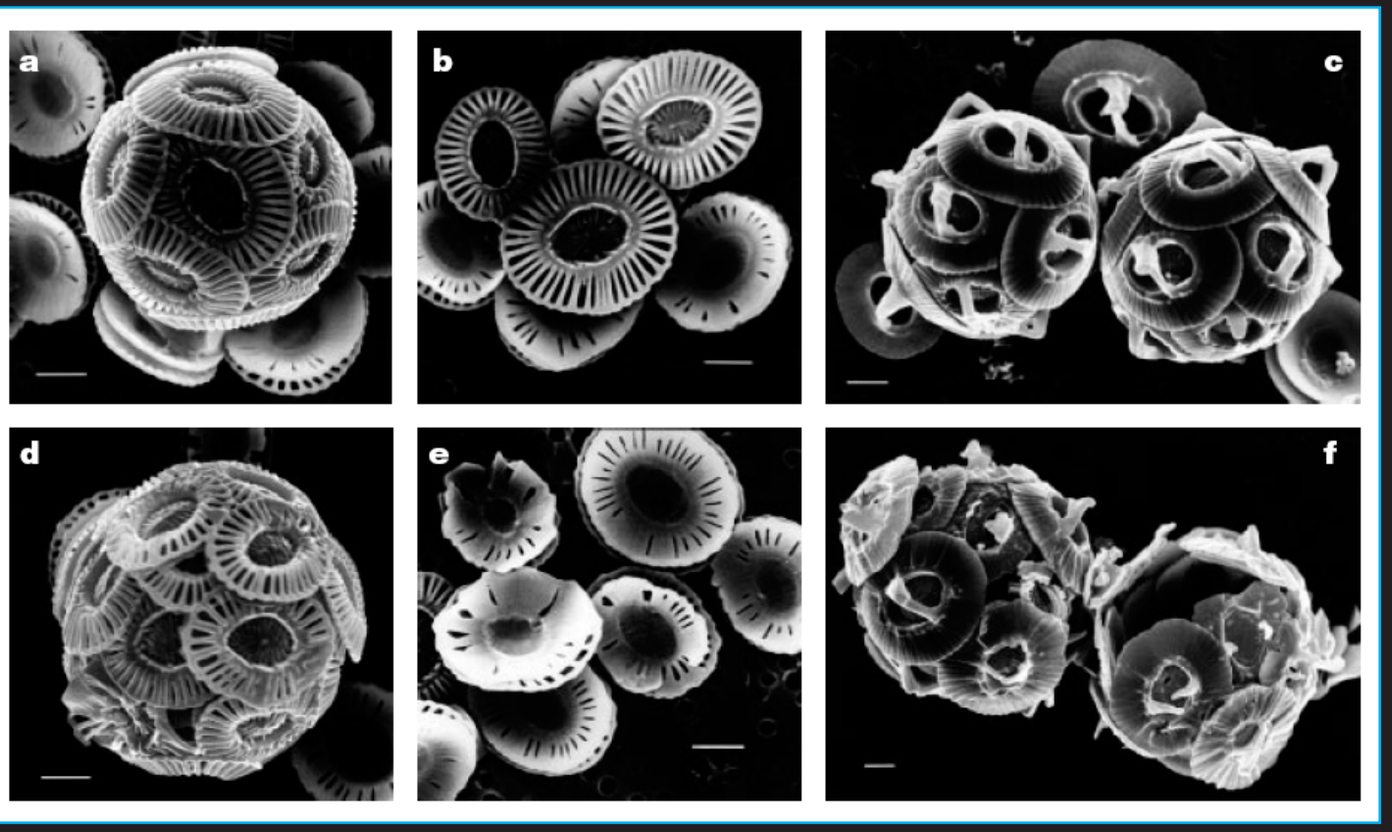
under-saturated

over-saturated

Ω = 1.0

Pandolfi et al. [2011] (*Science*)

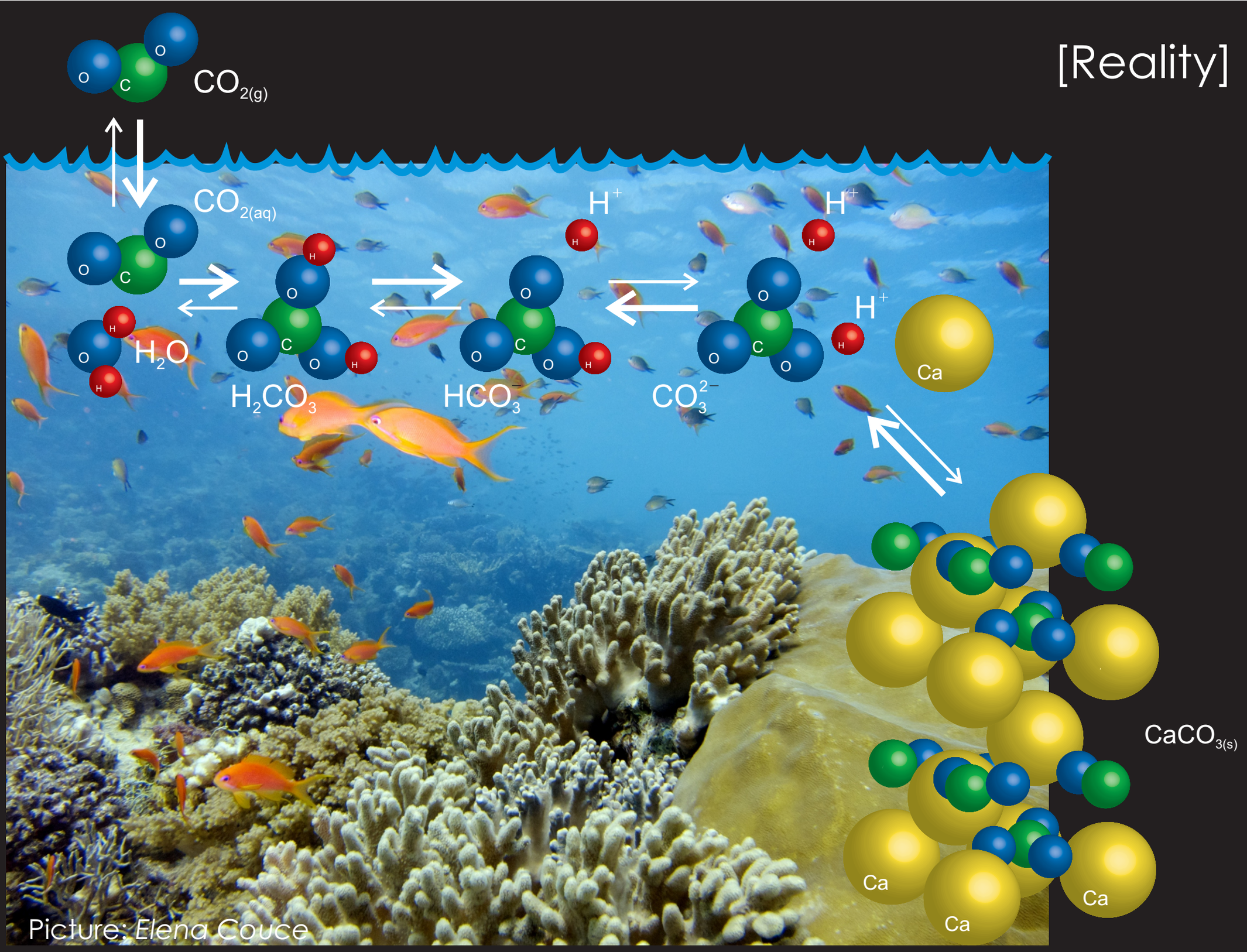
Ocean Acidification



low CO_2 (high pH)

high CO_2 (low pH)

SEM micrographs of coccolithophorids under different CO_2 conditions
Riebesell et al. [2000] (*Nature* 407)


[Reality]
$CO_{2(g)}$
$CO_{2(aq)}$
H_2O
H_2CO_3
HCO_3^-
CO_3^{2-}
H^+
H^+
H^+
Ca
Ca
Ca
Ca
$CaCO_{3(s)}$
Picture: *Elena Couce*


[Reality]


Google


JOIDES Resolution

['Joides Resolution']

143 m

vs.

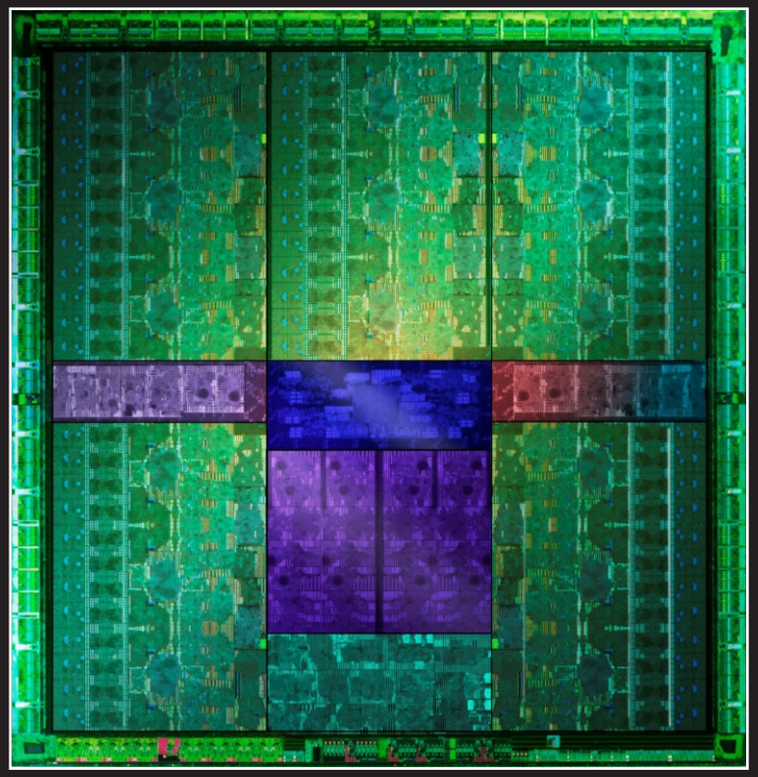
143 m

Lies, damn lies, and computer models

[Intel 'knights landing';
8e9 x 14 nm transistors;
>60 processing cores]

143 m

vs.

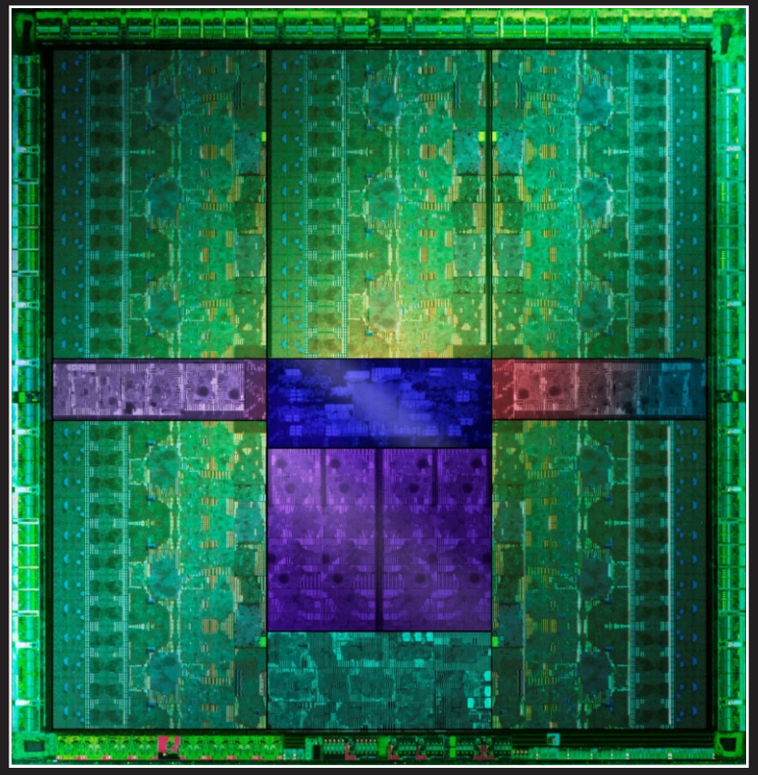


0.026 m

Lies, damn lies, and computer models

'ASCI Q', ca. year 2003
~7 teraflops

vs.

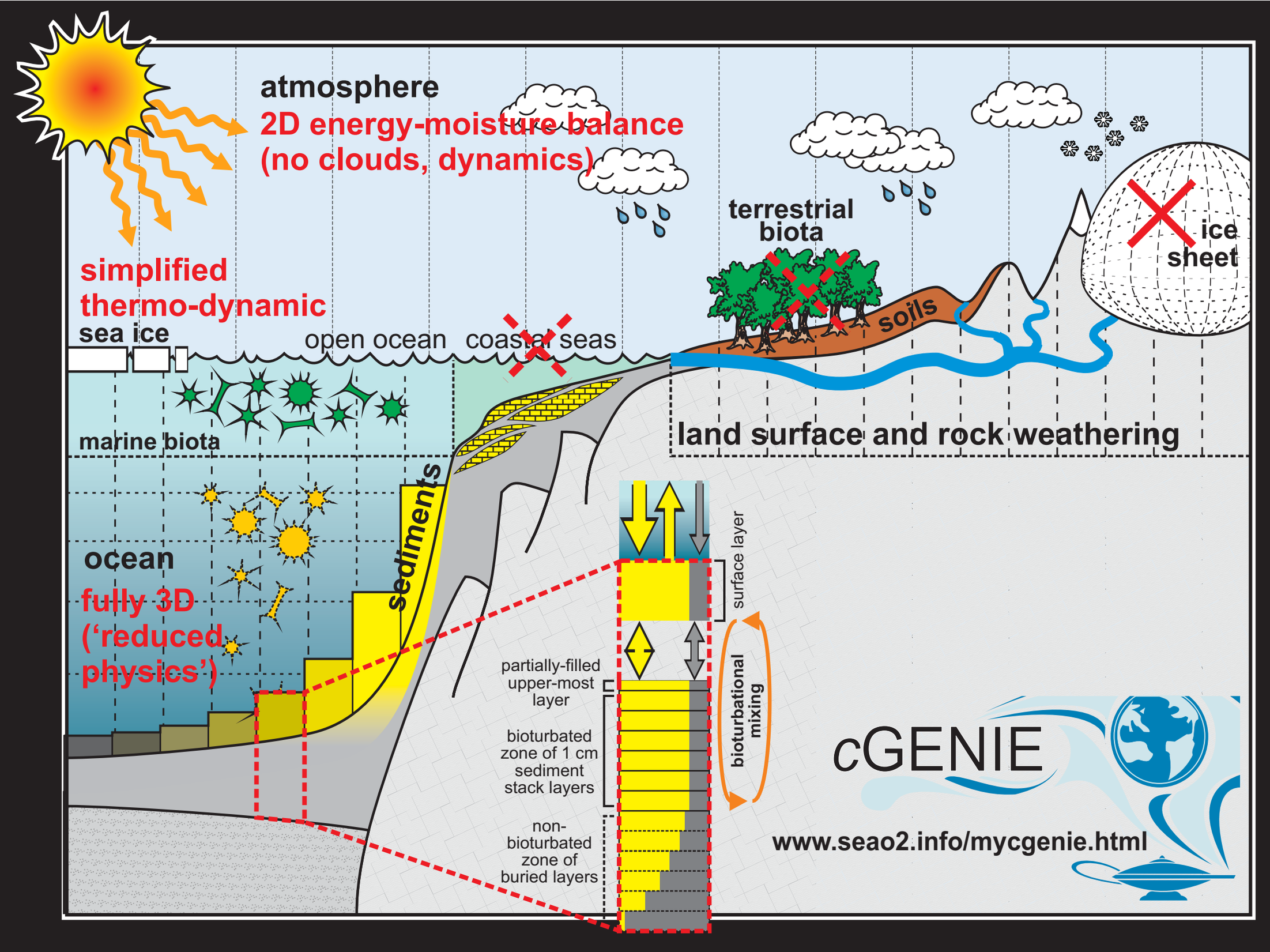


6 teraflops
(6e9 floating point operations per second)

vs.

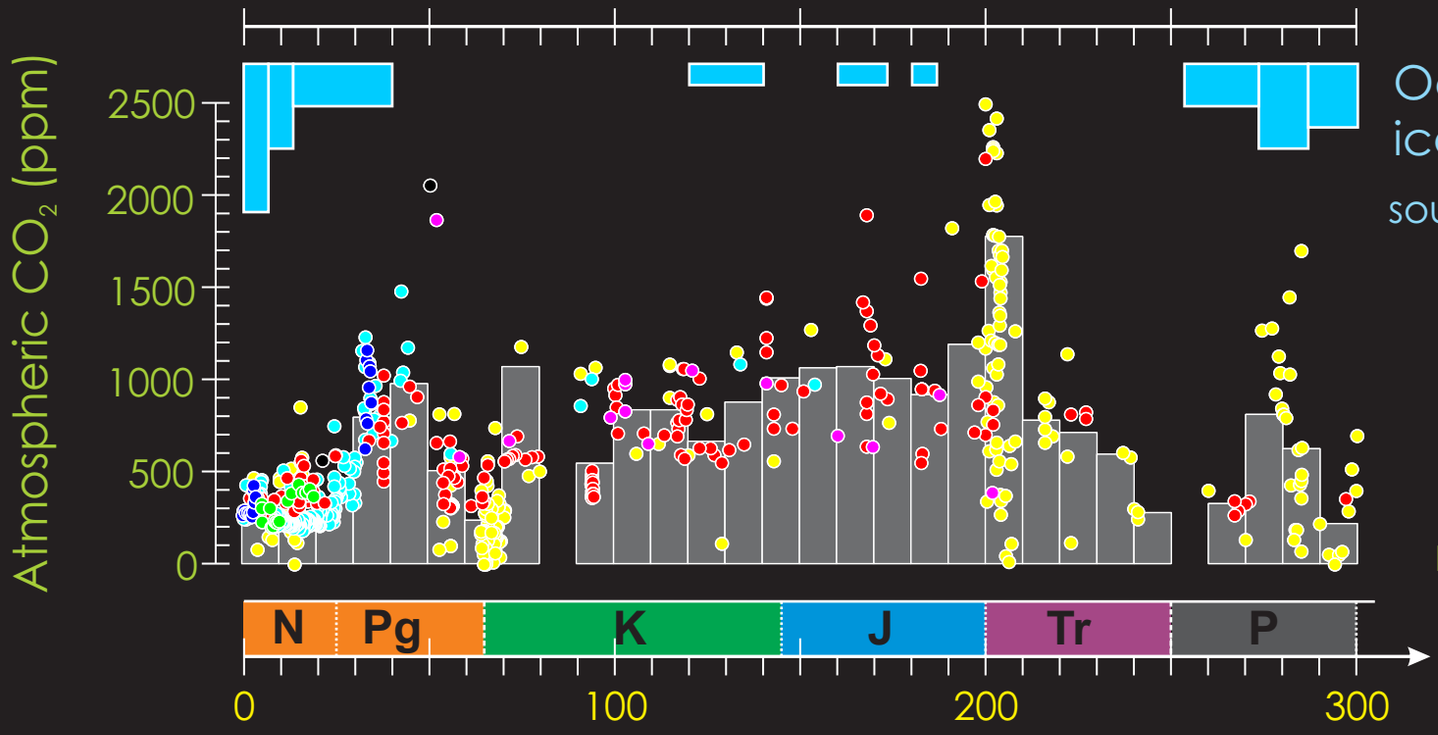
1 bash-per-second

1 bash-per-second


atmosphere
2D energy-moisture balance
(no clouds, dynamics)
simplified
thermo-dynamic
sea ice
open ocean
coastal seas
terrestrial
biota
soils
ice
sheet
land surface and rock weathering
marine biota
sediments
ocean
fully 3D
('reduced
physics')
surface layer
partially-filled
upper-most
layer
bioturbated
zone of 1 cm
sediment
stack layers
non-
bioturbated
zone of
buried layers
bioturbational
mixing
cGENIE
www.seao2.info/mycgenie.html

Paleo-analogues – the question of rate

an OA analogue?



Occurrence of
ice ages (relative intensity)

source; *Crowell* [1999]

From: *Hönisch et al.* [2012]

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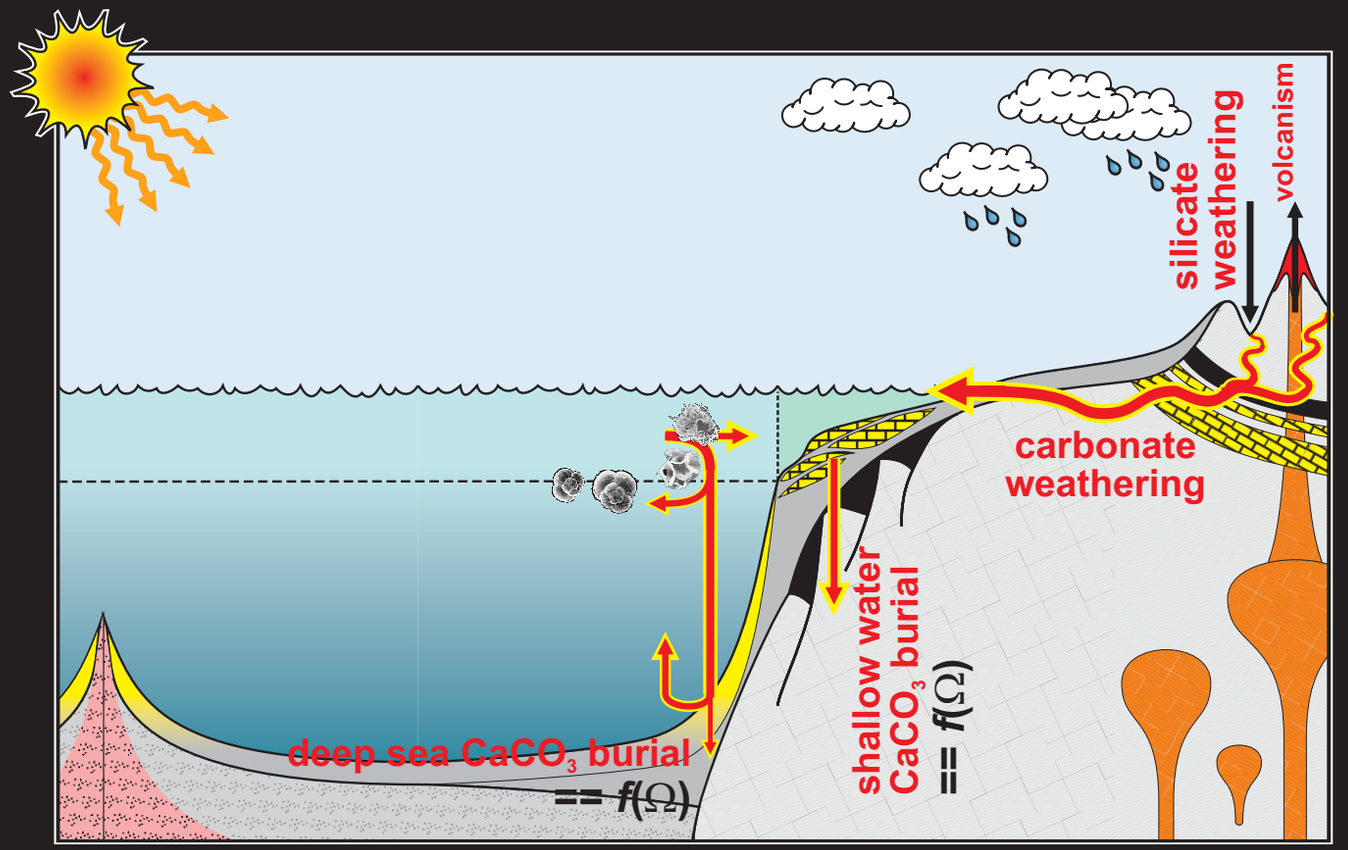
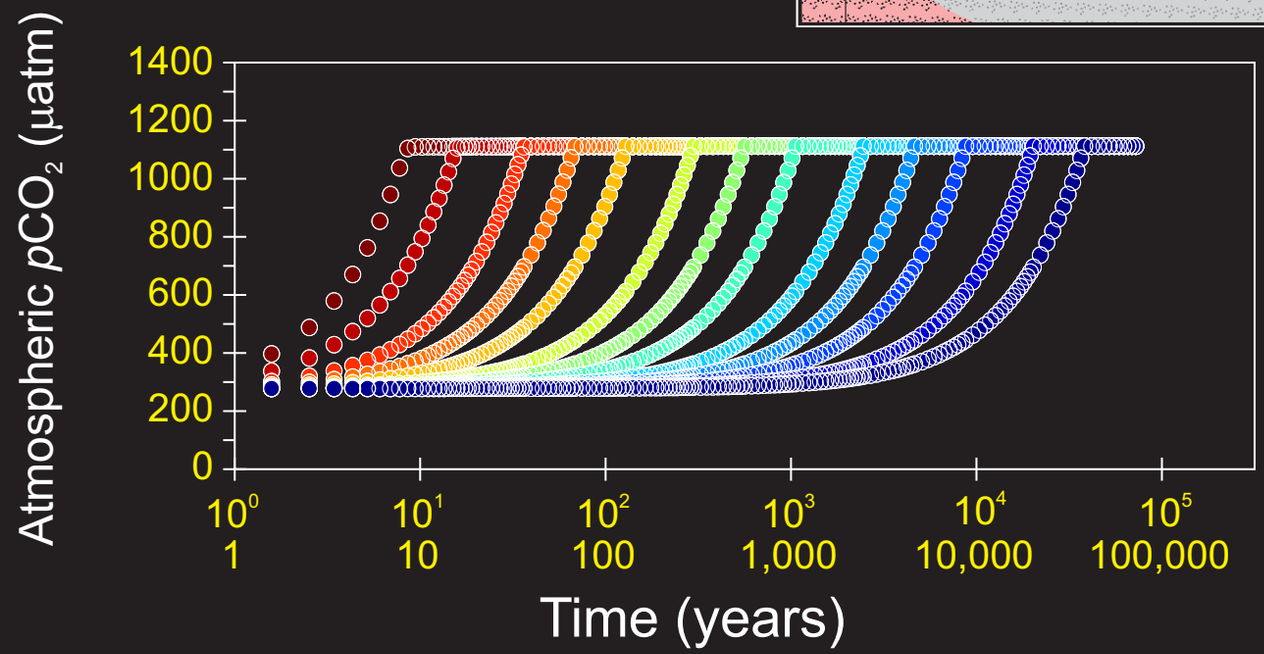
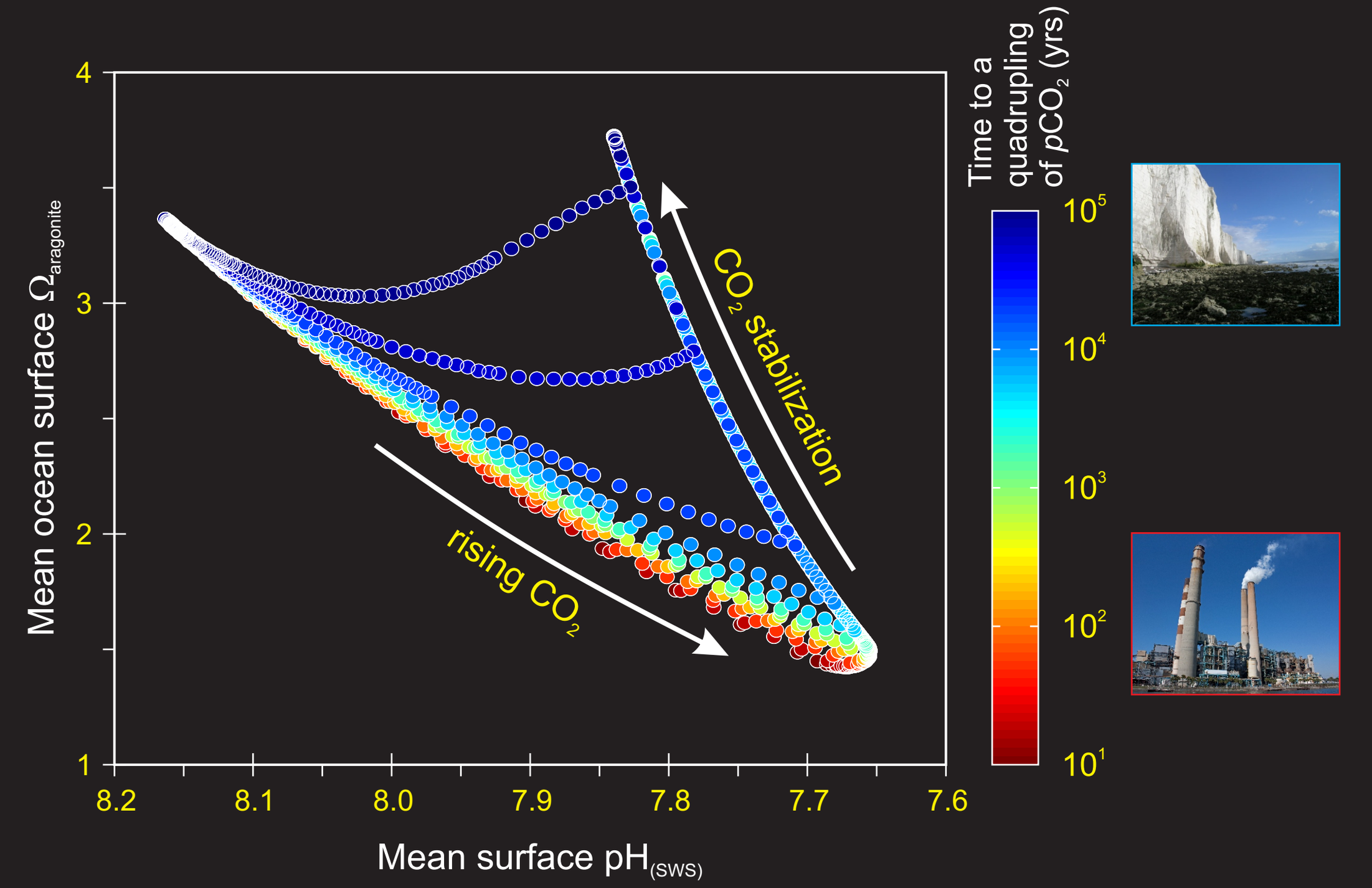




From: *Hönisch et al.* [2012] (*Science*)

Paleo-analogues – the question of rate



From: *Hönisch et al.* [2012] (*Science*)

Paleo-analogues – the question of rate

pH saturation

pH saturation

‘slow’
(quasi steady-state)

‘fast’
(geologically abrupt)

Rate of change (or magnitude of CO_2 emissions)

Paleo-analogues – which ... ?

Total carbon release (gC)
proxy for magnitude of environmental perturbation

10^{20}

10^{19}

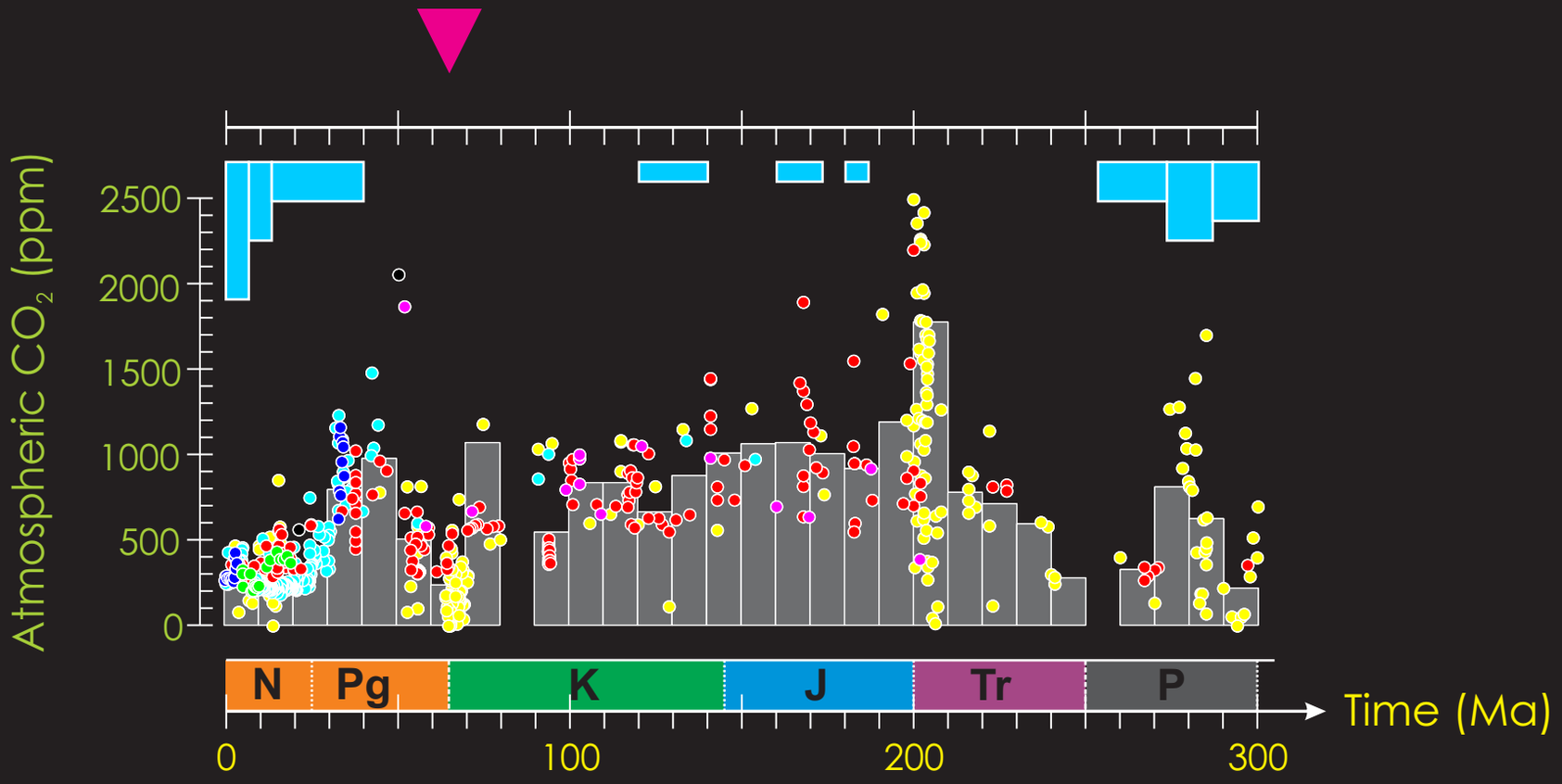
10^{18}

future
ca. 1000-5000 PgC
over centuries

10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}

Event (onset) duration (yrs)
proxy for 1 / (rate of change)

Paleo-analogues – which ... ?



Paleo-analogues – which … ?

Problems: *much* faster rate of change than the Anthropocene, and with a qualitatively different driver/perturbation

Total carbon release (gC)
proxy for magnitude of environmental perturbation

10^{20}
10^{19}
10^{18}

?
?
?
?
?

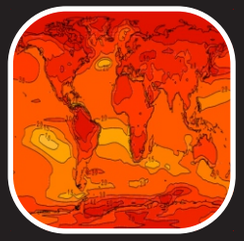
end K
< 1000 PgC
<= years

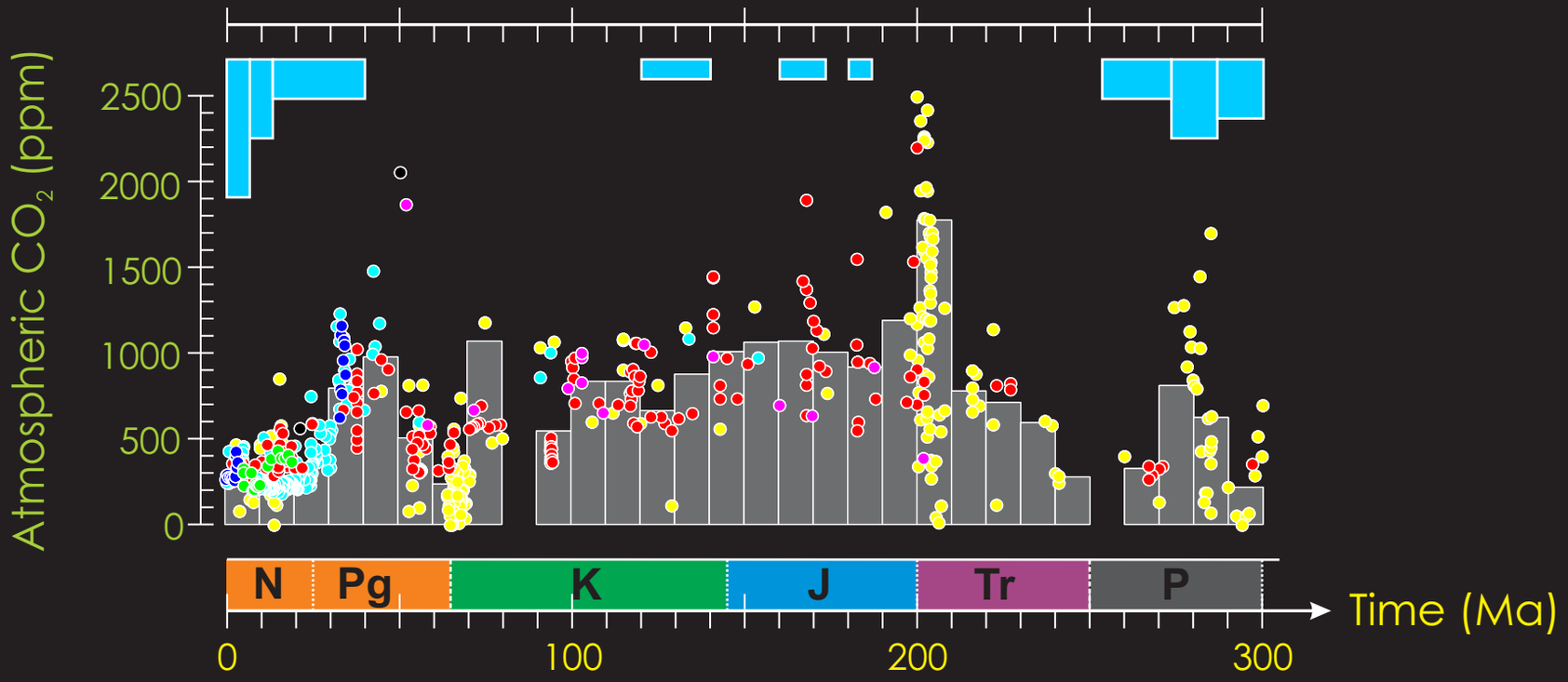
ca. -1.5 to -2.0 ‰ $\Delta\delta^{13}C$ in (pelagic) marine sediments
ca. -1.5 to -3.0 ‰ $\Delta\delta^{13}C$ in terrestrial sediments

10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}

Event (onset) duration (yrs)
proxy for 1 / (rate of change)

Paleo-analogues – which ... ?





Paleo-analogues – which ... ?

Problems: Too 'slow' (but impossilbe to be completely sure), too large a perturbation(?)

Total carbon release (gC)
proxy for magnitude of environmental perturbation

10^{20}
10^{19}
10^{18}

end Permian
ca. 30,000-100,000 PgC
over 10-100 kyr

? ? ? ? ? ? ? ? ? ?

future
ca. 1000-5000 PgC
over centuries

10^0 10^1 10^2 10^3 10^4 10^5

Event (onset) duration (yrs)
proxy for 1 / (rate of change)

Paleo-analogues – which ... ?

Total carbon release (gC)
proxy for magnitude of environmental perturbation

10^{20}
10^{19}
10^{18}

? ? ? ? ? ? ? ? ? ?

? ? ? ? ?

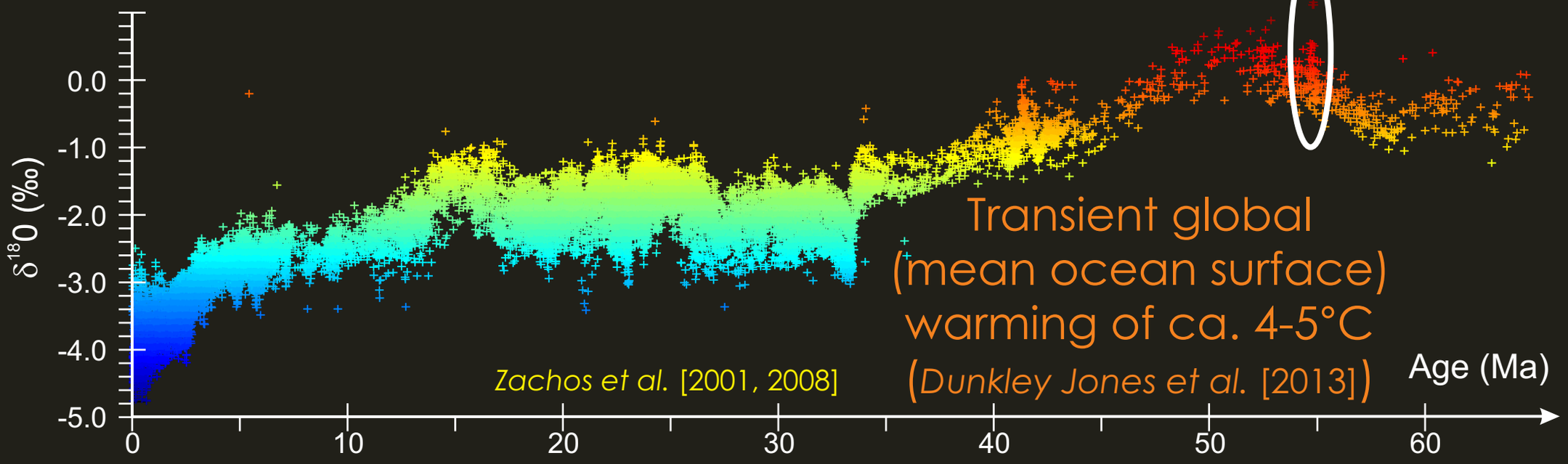
end K
< 1000 PgC
<= years

ca. -1.5 to -2.0 ‰ $\Delta\delta^{13}C$ in (pelagic) marine sediments
ca. -1.5 to -3.0 ‰ $\Delta\delta^{13}C$ in terrestrial sediments

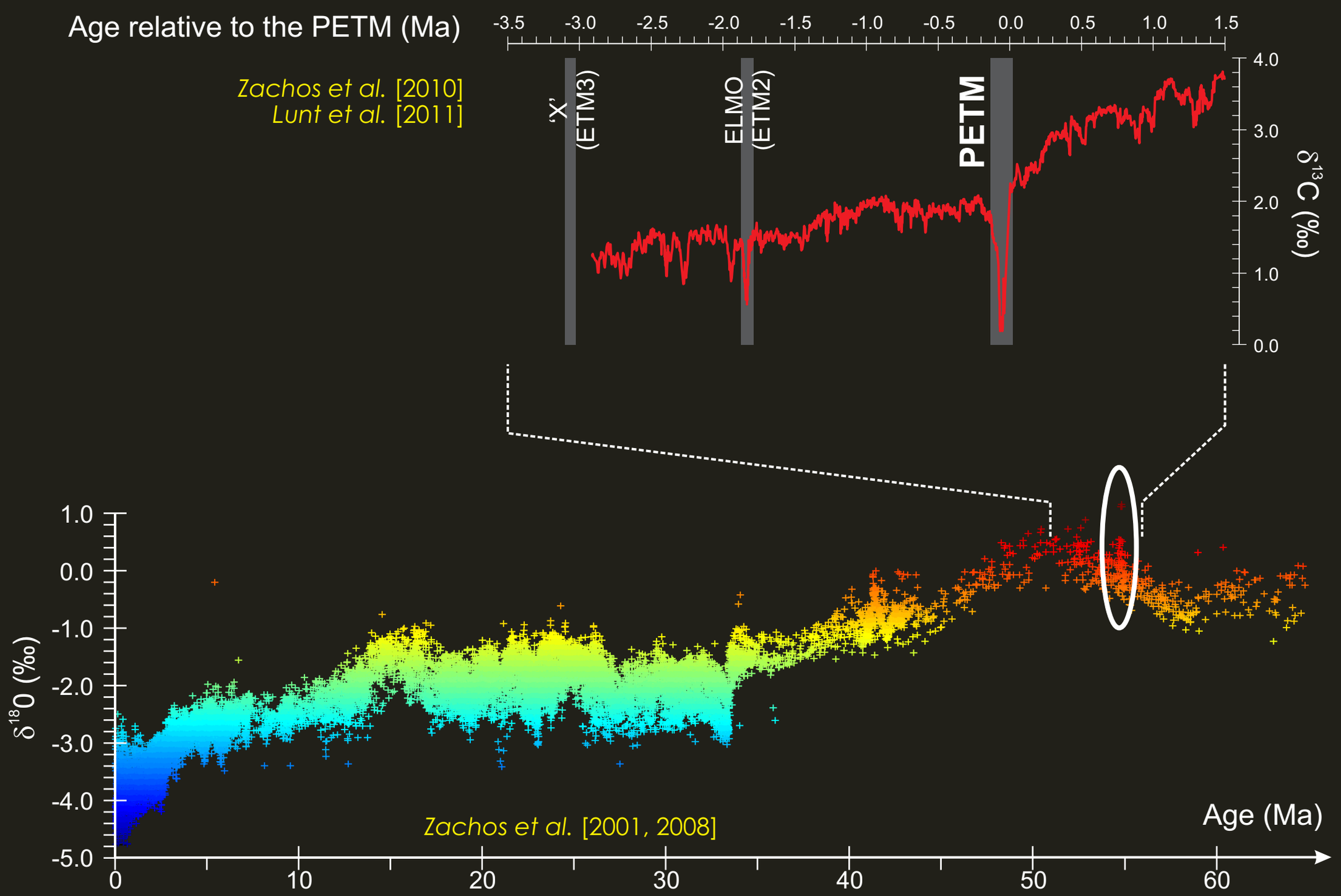
10^0 10^1 10^2 10^3 10^4 10^5

Event (onset) duration (yrs)
proxy for 1 / (rate of change)

Paleo-analogues – the PETM?



Paleo-analogues – the PETM?



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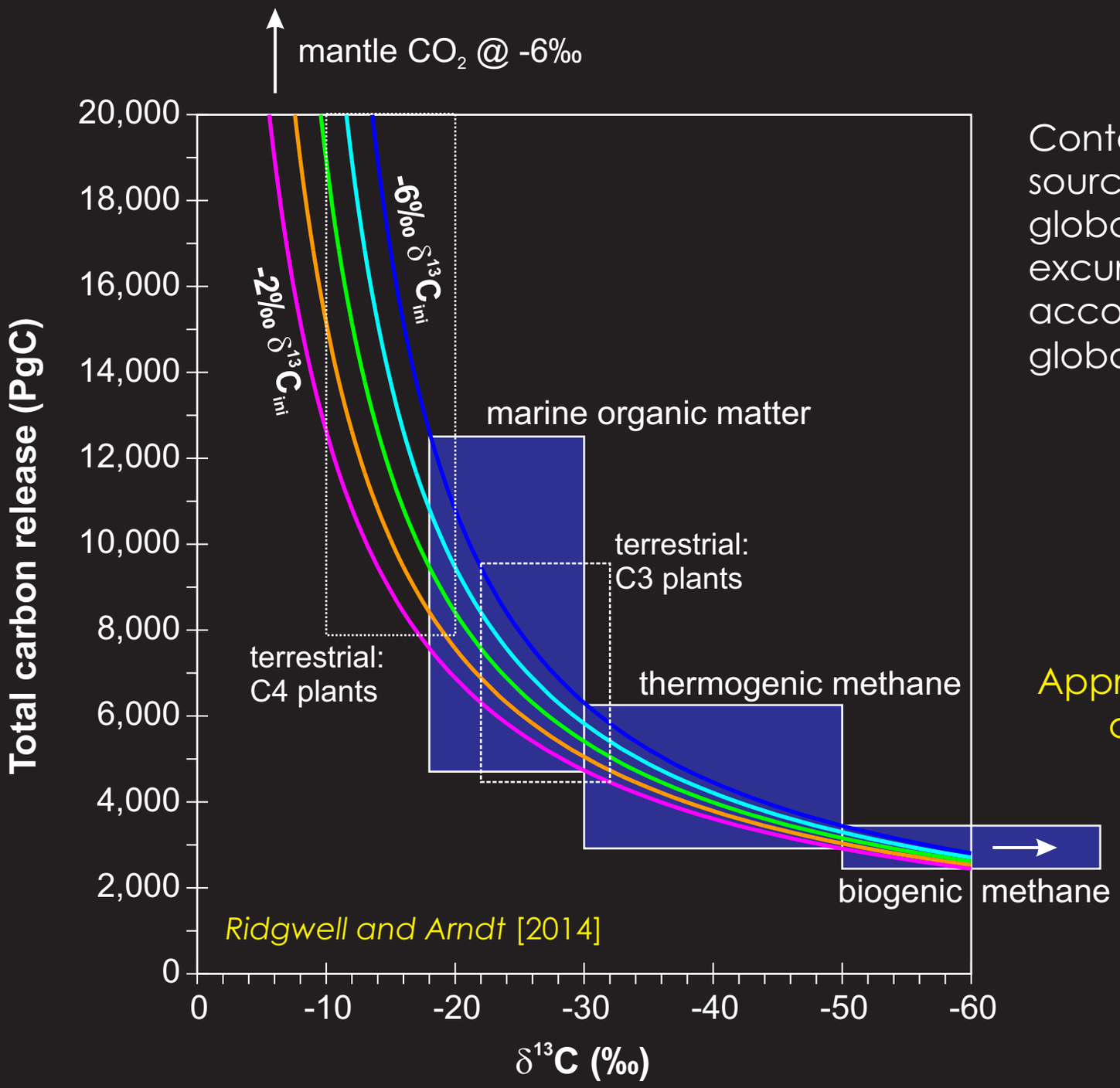
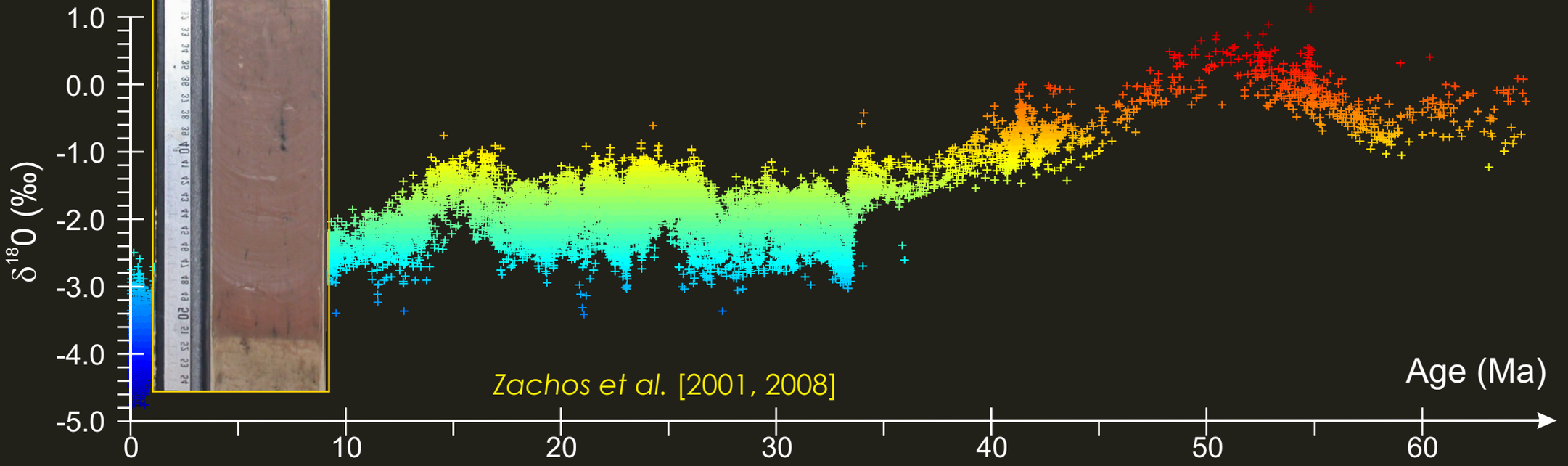


Contours of carbon release vs. source isotopic signature for a global -4‰ carbon isotopic excursion. Contours differ according to the initial mean global $\delta^{13}C$.

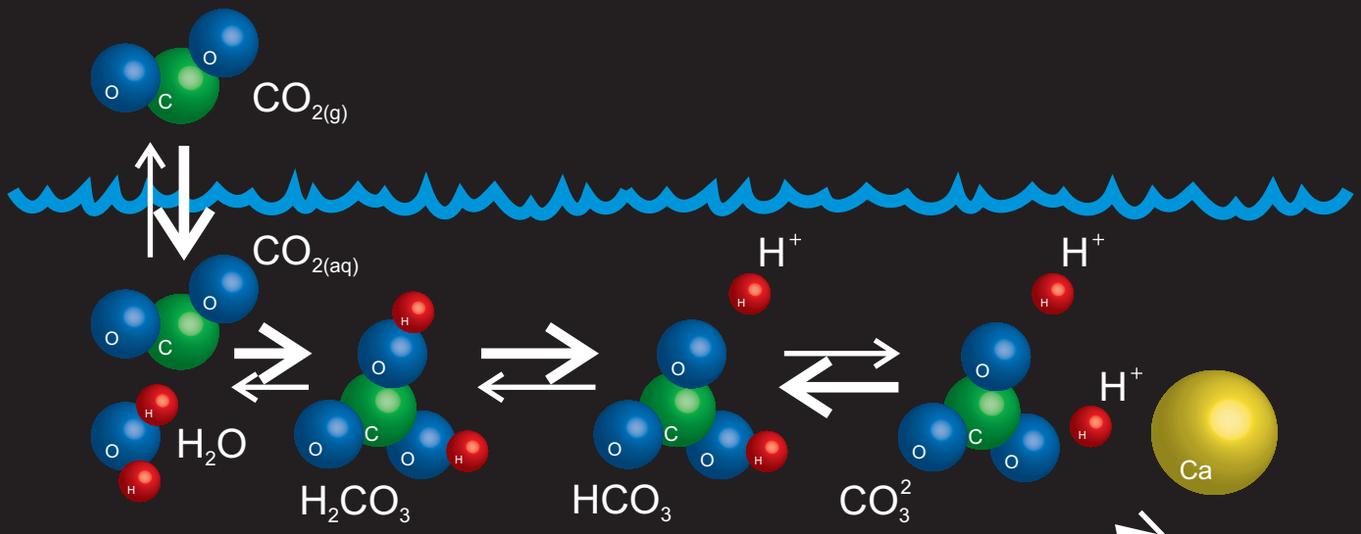
Approx. societally-relevant range of (rapid) carbon release

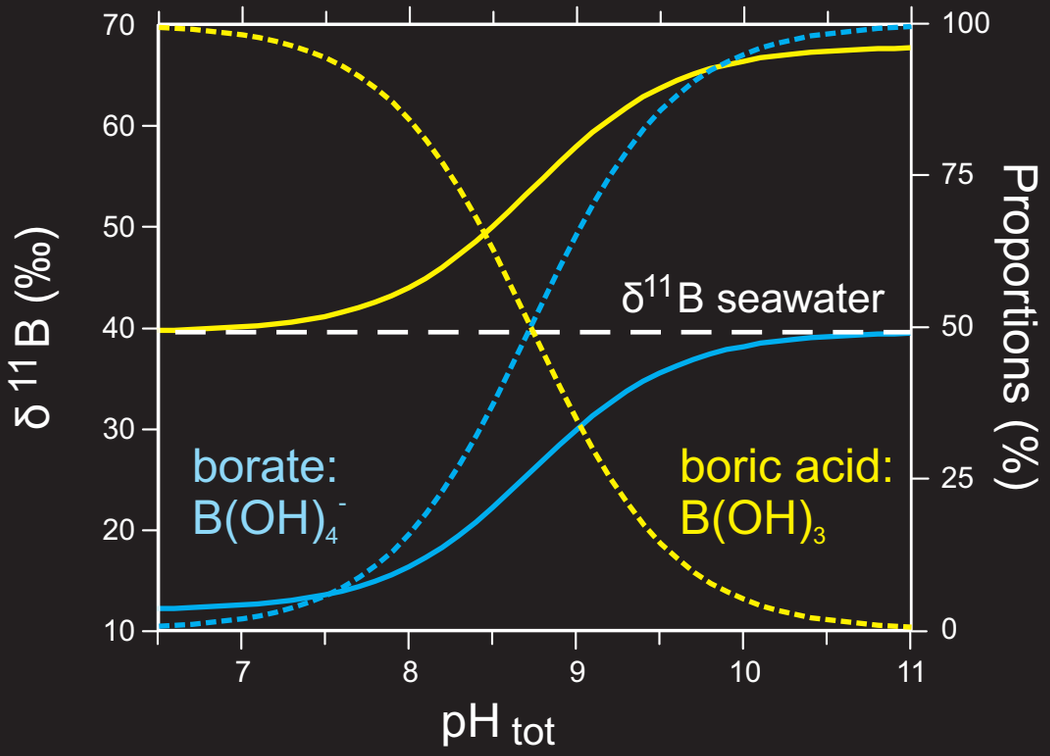
Paleo-analogues – the PETM?

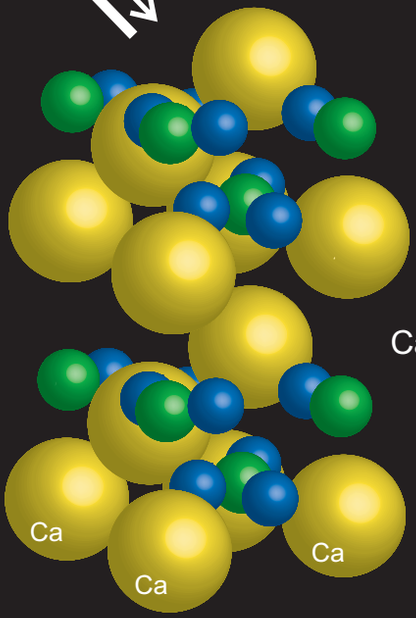
Age relative to the PETM (Ma)



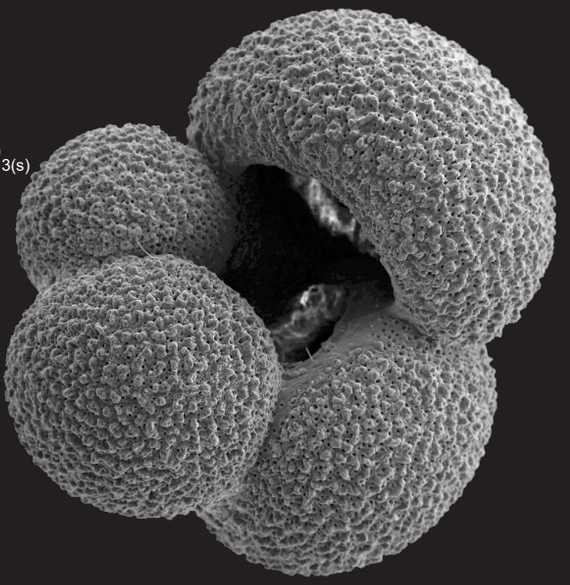
Boron, isotopes, and paleo pH







$CaCO_{3(s)}$



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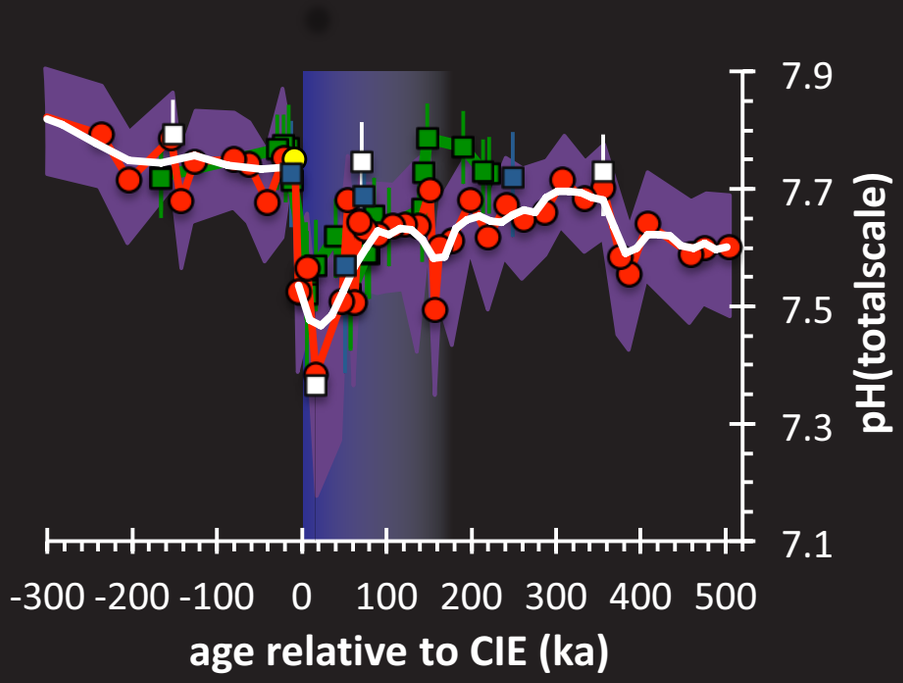
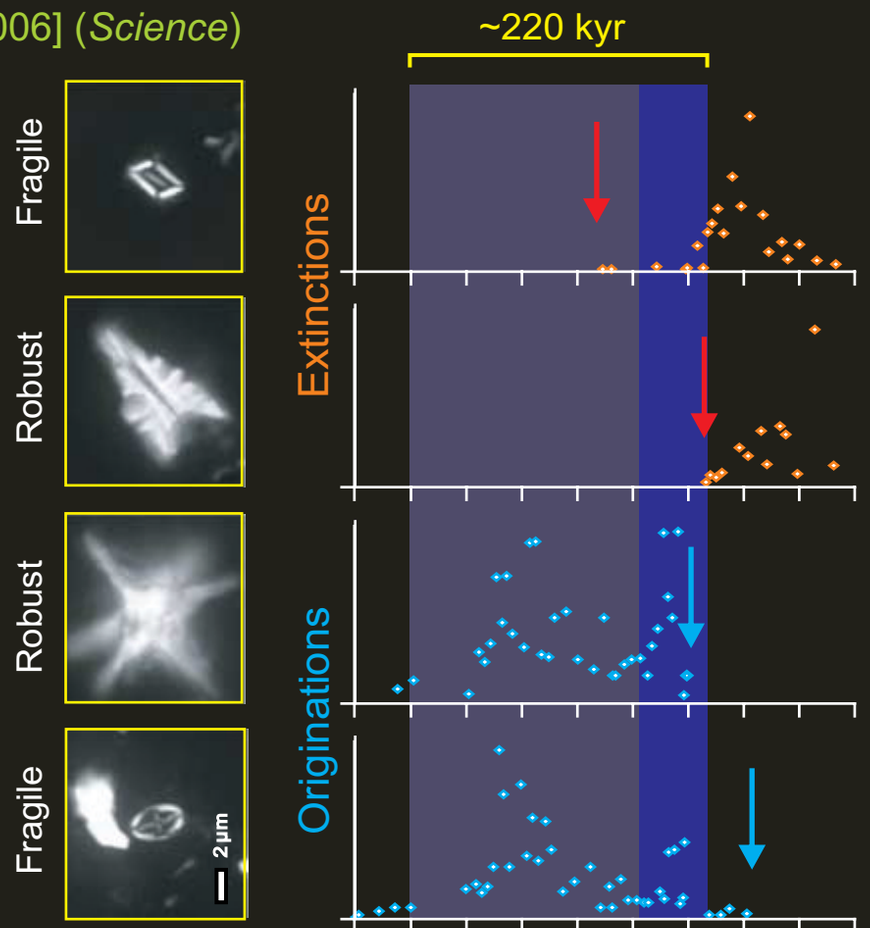


Site 401 (NE Atlantic) [in revision]

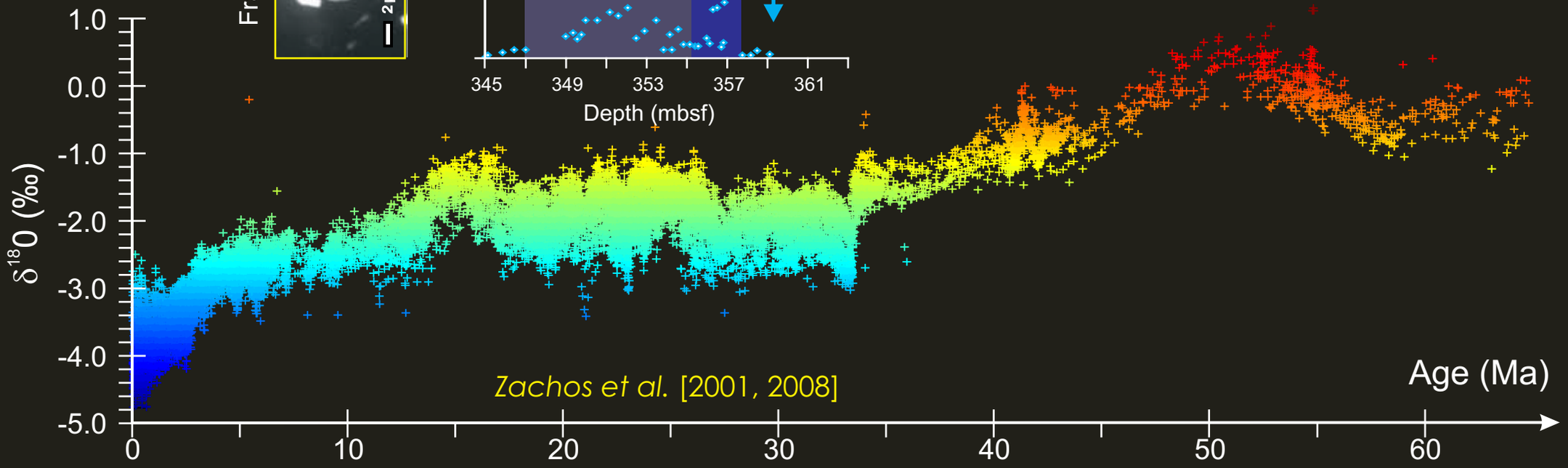
Site 865 (Eq. Pacific) Site 1263 (ES Atlantic) Site 1209 (N Pacific) [*Penman et al.*, 2014]

Paleo-analogues – the PETM?

Gibbs et al. [2006] (*Science*)



observed nanoplankton assemblage response to environmental change across the PETM



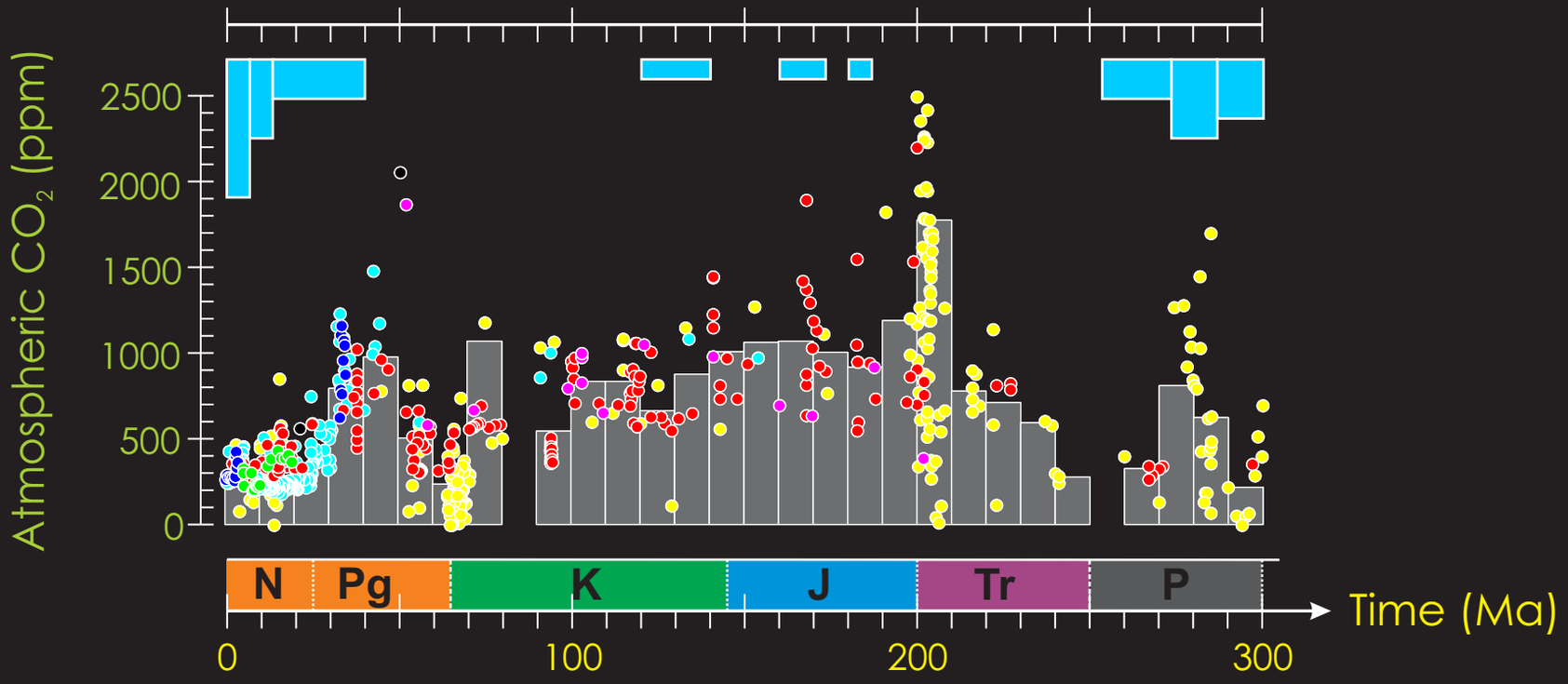
Zachos et al. [2001, 2008]

Paleo-analogues – the PETM?

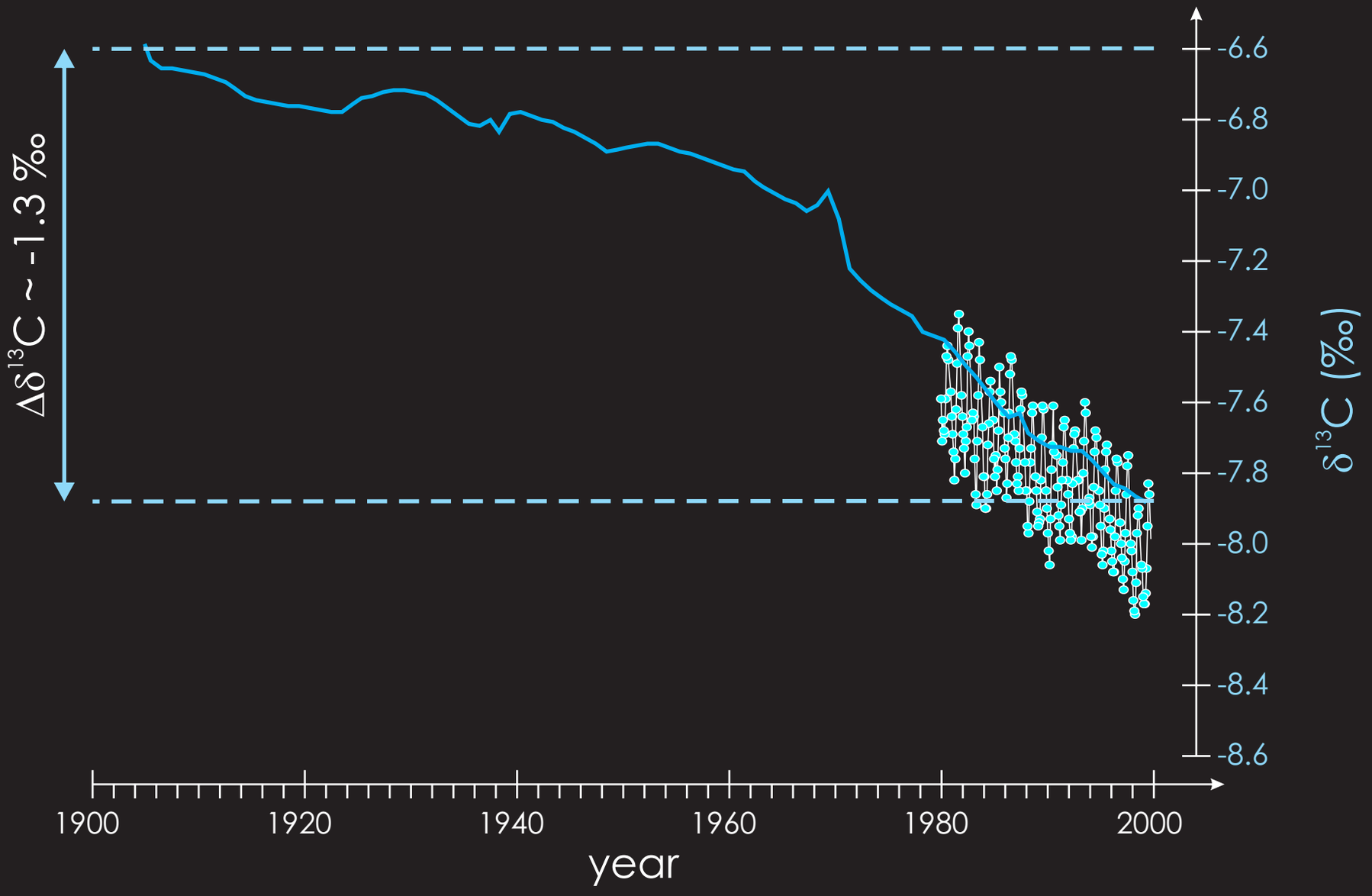
'triggers'

carbon cycle feedbacks

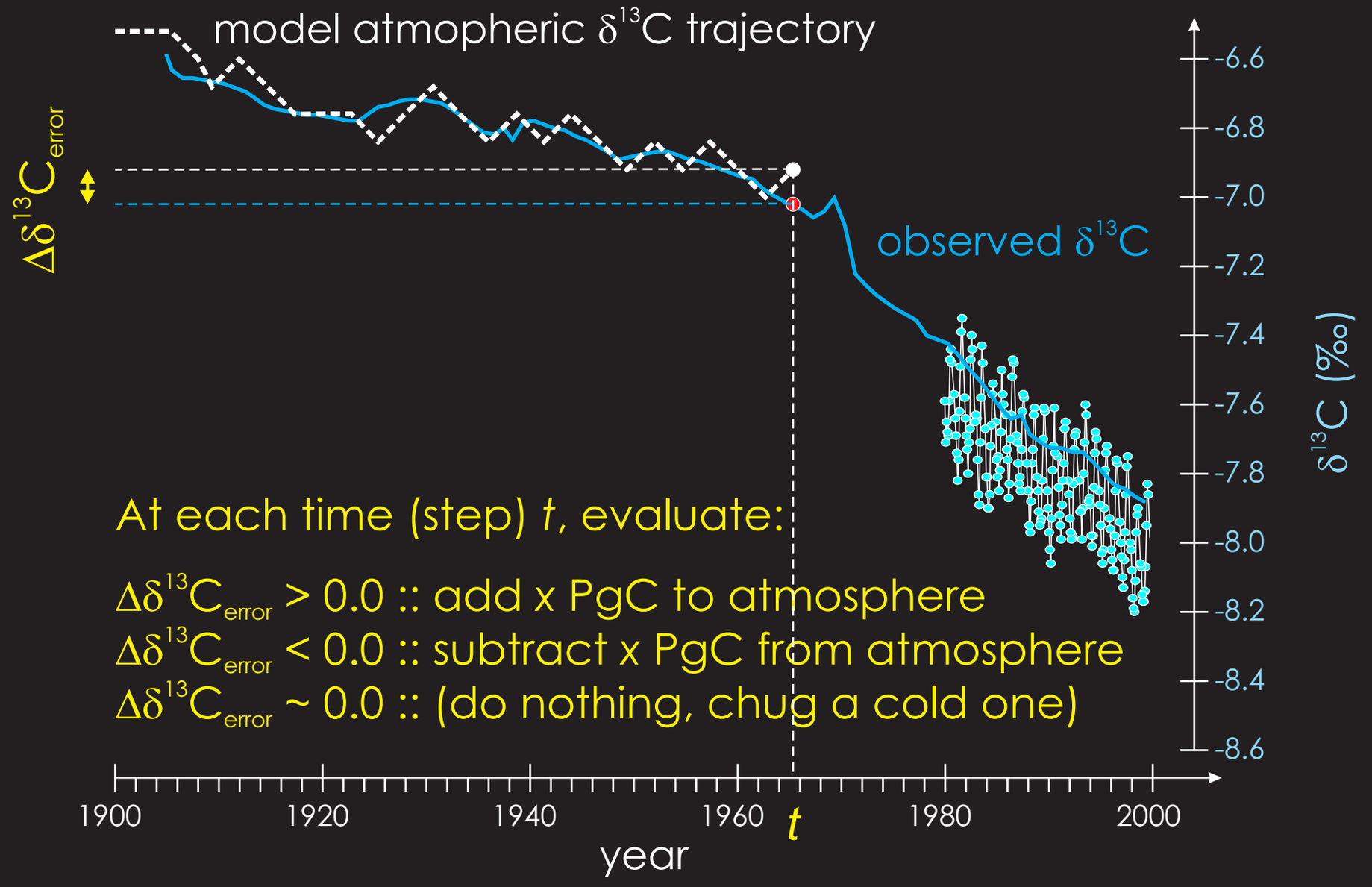
?



Methods


$\Delta\delta^{13}C \sim -1.3$ ‰
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6
$\delta^{13}C$ (‰)
1900
1920
1940
1960
1980
2000
year

Methods


model atmopheric δ13C trajectory
observed δ13C
Δδ13Cerror
δ13C (‰)
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6
1900
1920
1940
1960
1980
2000
t
year
At each time (step) t, evaluate:
Δδ13Cerror > 0.0 :: add x PgC to atmosphere
Δδ13Cerror < 0.0 :: subtract x PgC from atmosphere
Δδ13Cerror ~ 0.0 :: (do nothing, chug a cold one)

Methods

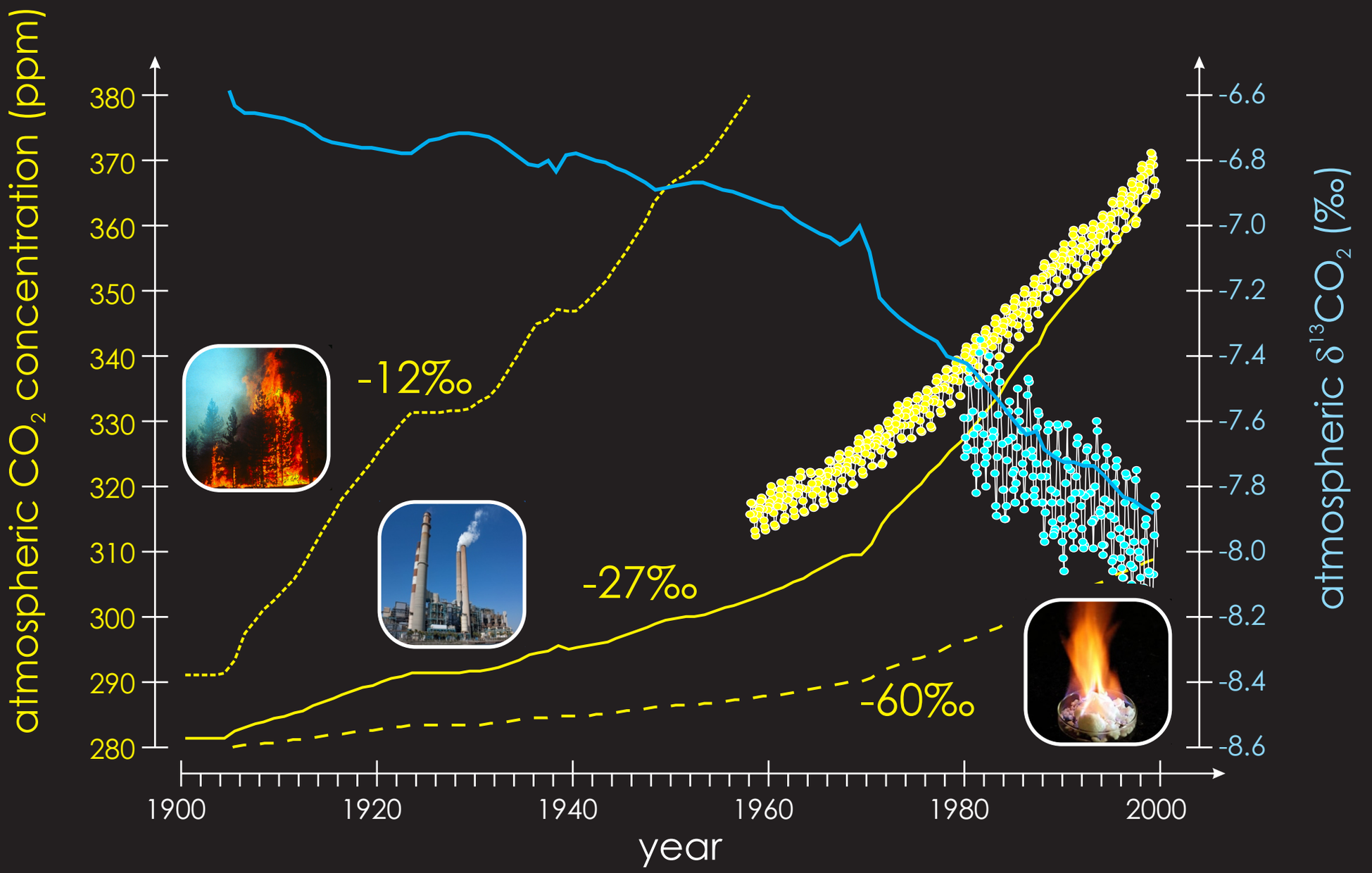
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6

$\delta^{13}C$ (‰)

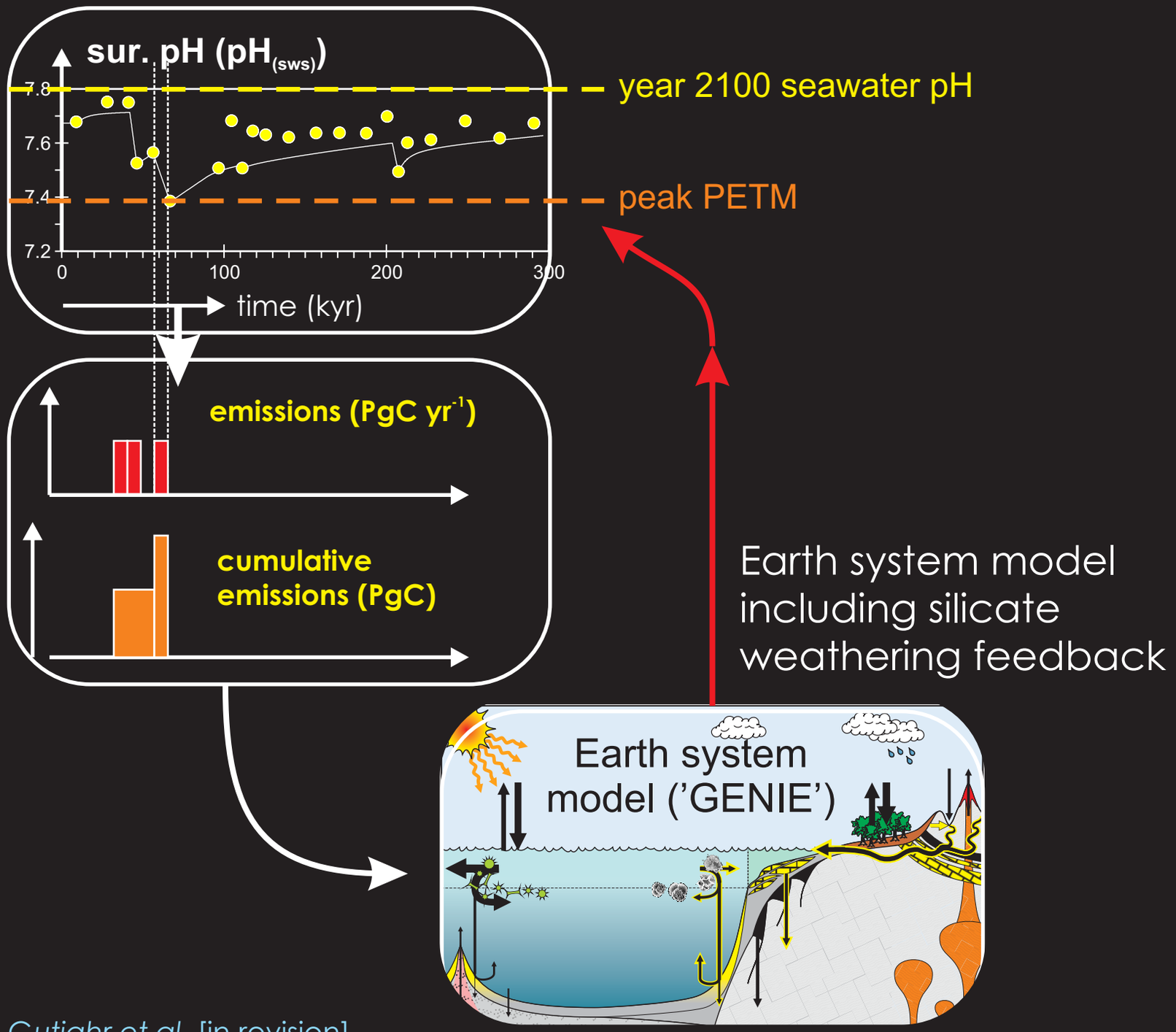
1900
1920
1940
1960
1980
2000

year

Methods

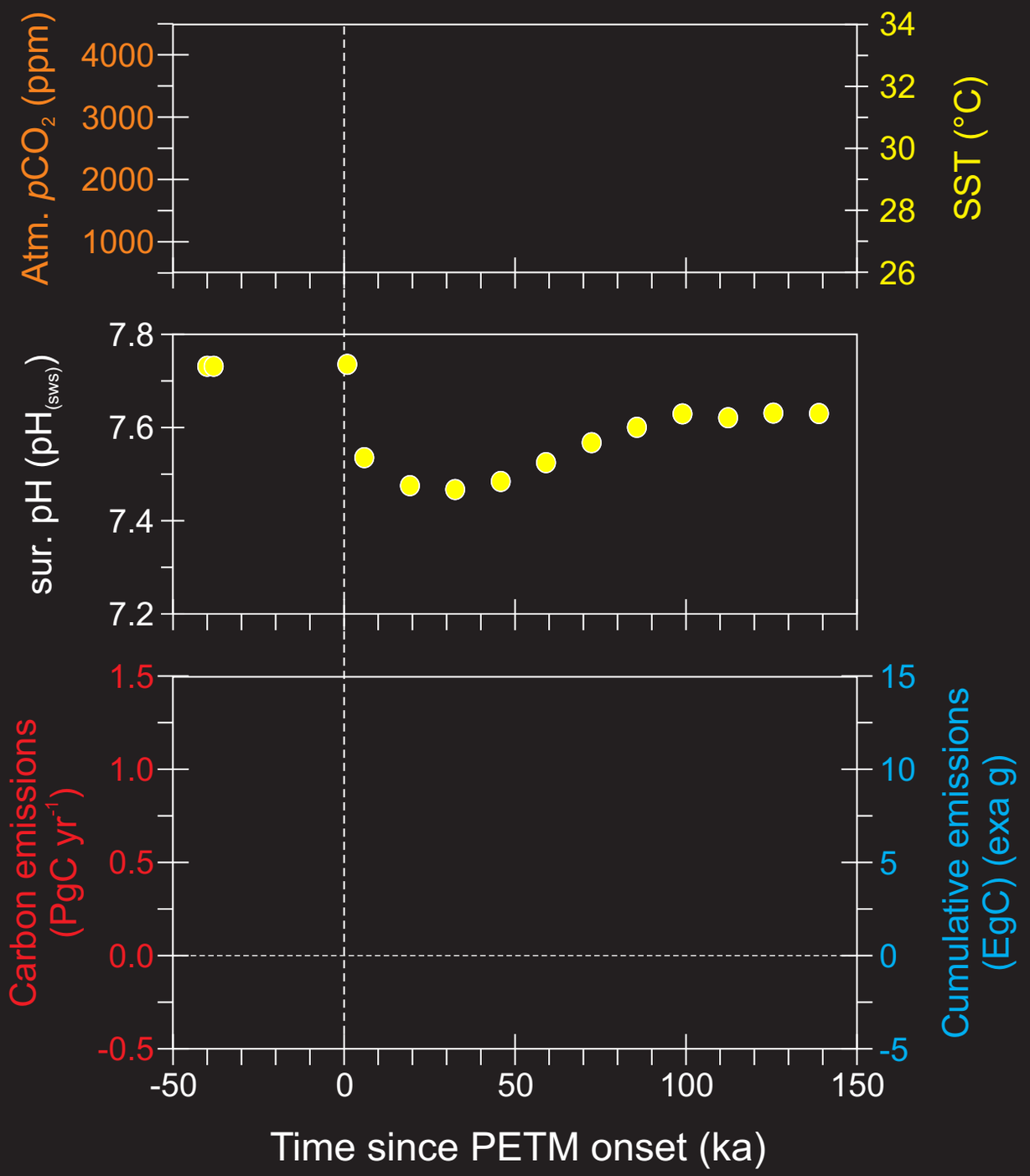

atmospheric CO_2 concentration (ppm)
380
370
360
350
340
330
320
310
300
290
280
-12‰
-27‰
-60‰
atmospheric $\delta^{13}CO_2$ (‰)
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
-8.4
-8.6
1900
1920
1940
1960
1980
2000
year

Assimilating surface ocean pH change (only)

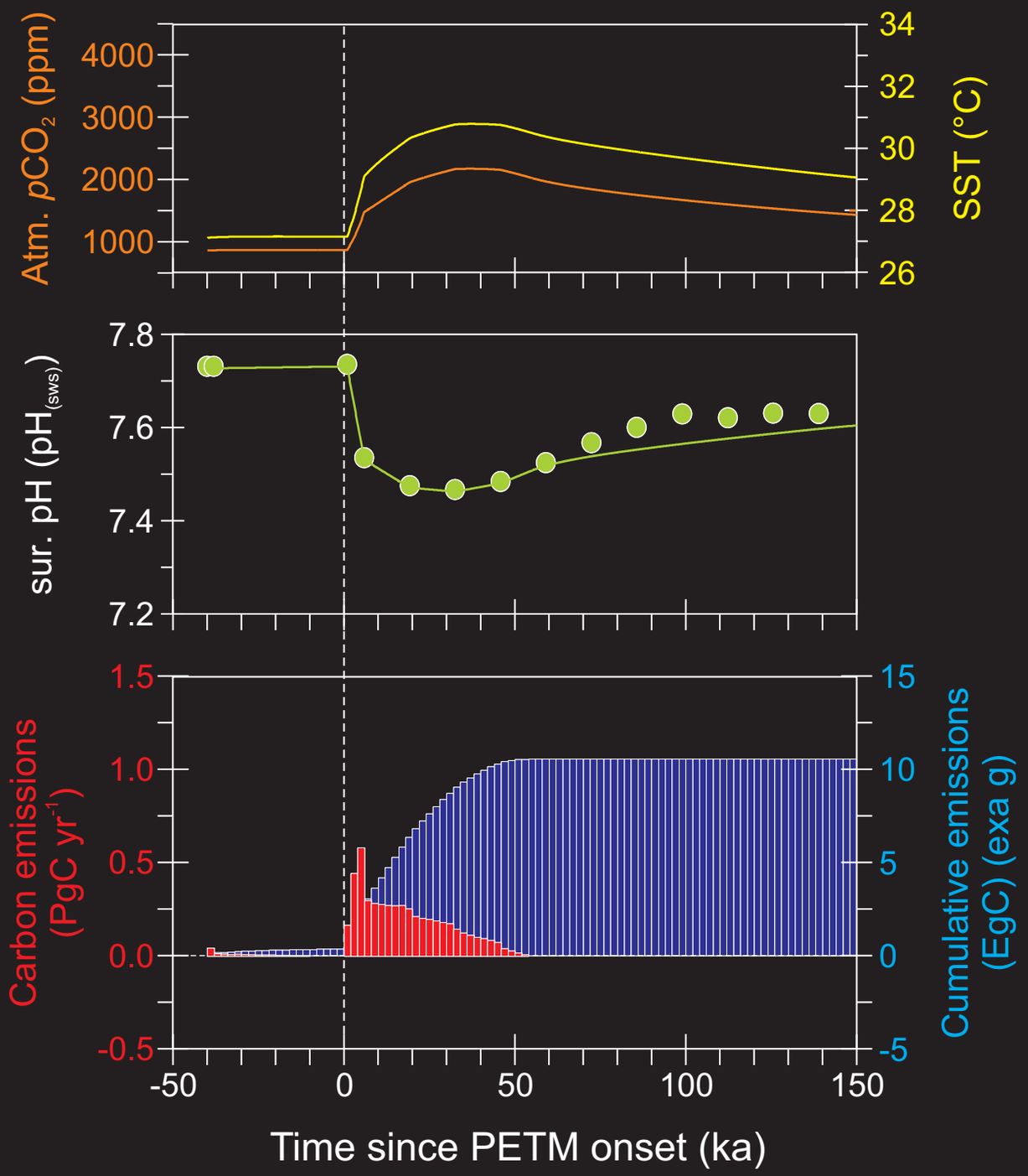


Gutjahr et al. [in revision]

Assimilating surface ocean pH change (only)



Assimilating surface ocean pH change (only)



Paleo-analogues – which ... ?

Total carbon release (gC)
proxy for magnitude of environmental perturbation

10^{20}
10^{19}
10^{18}

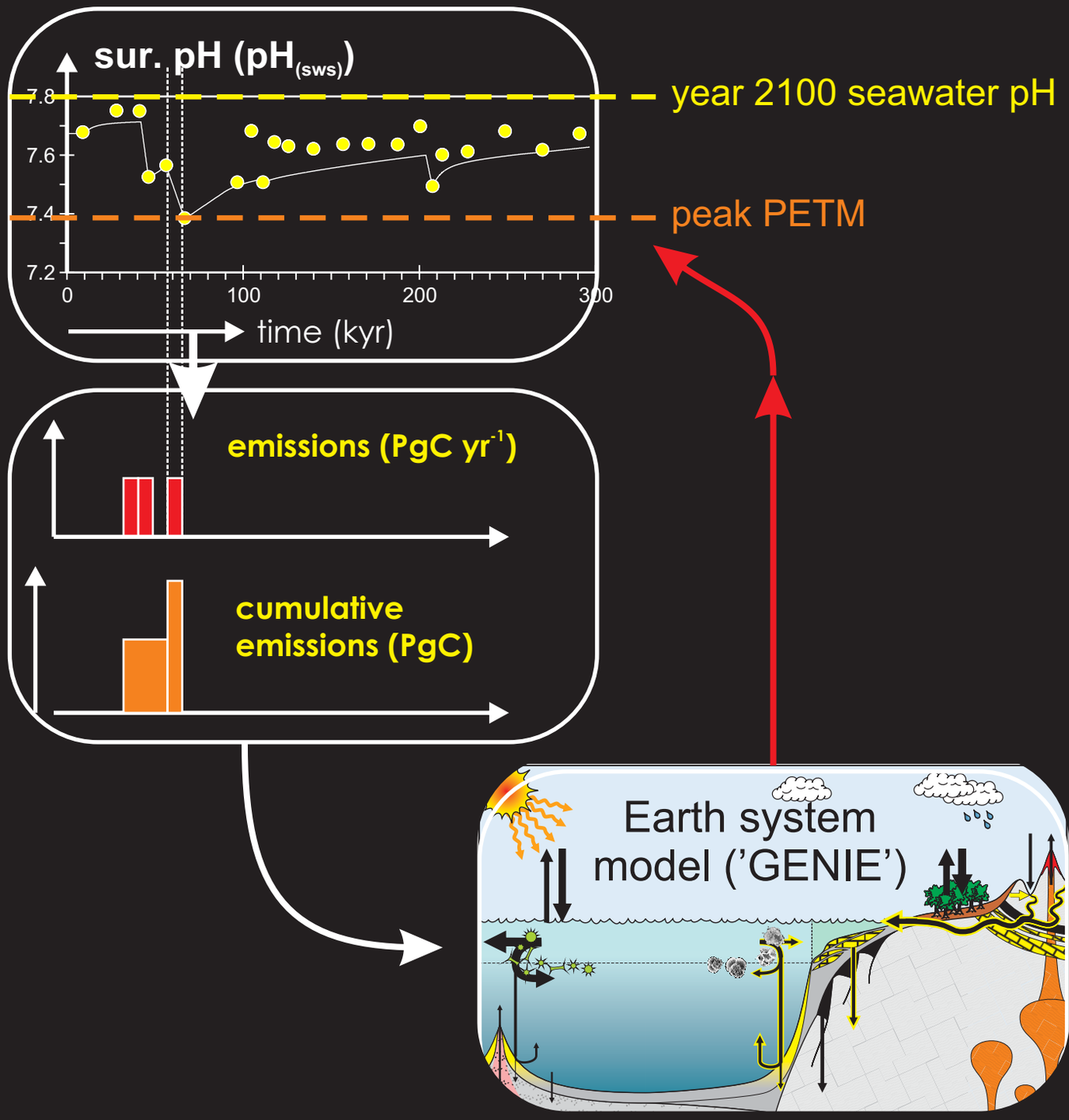
This study:
12,000 PgC
over 20 kyr

future
~1000-5000 PgC
over centuries

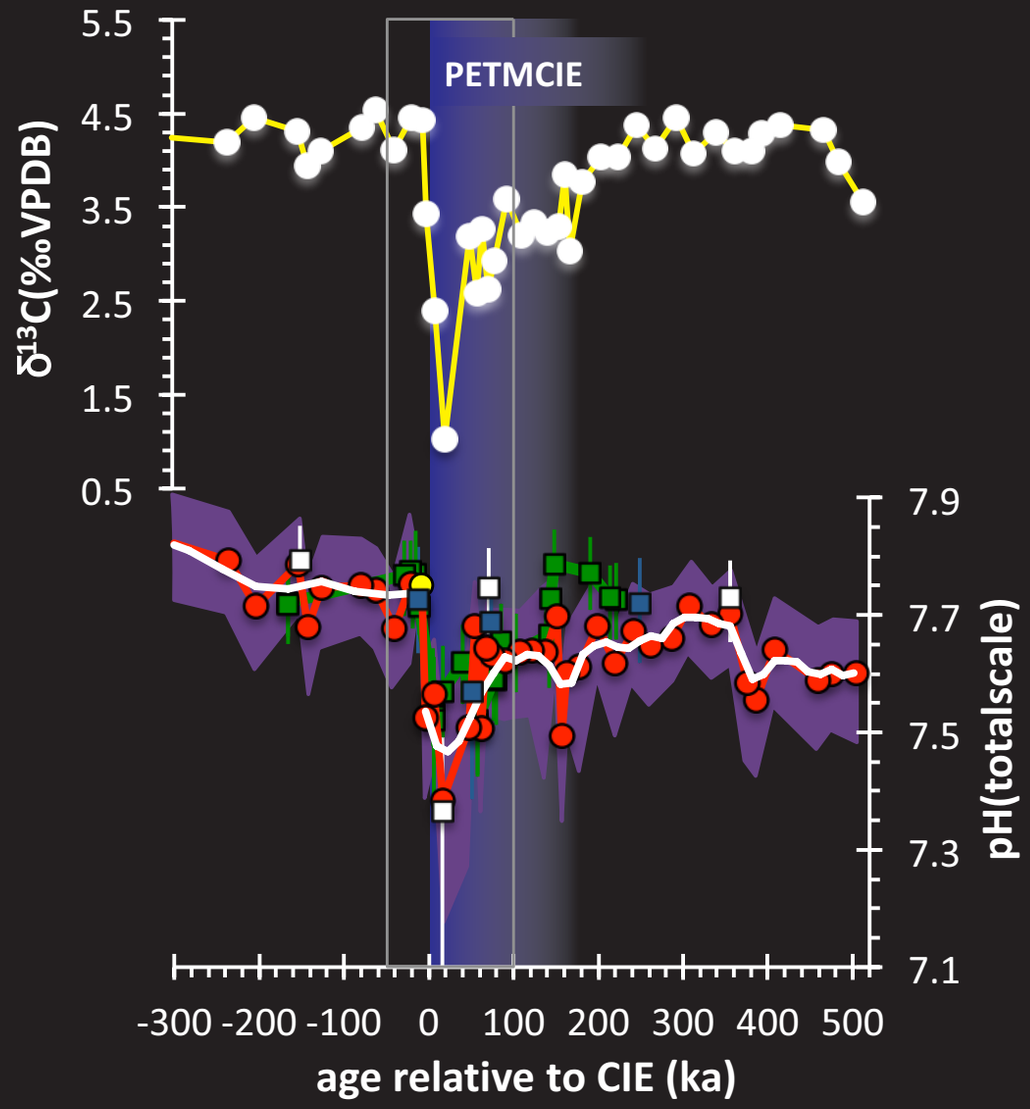
10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}

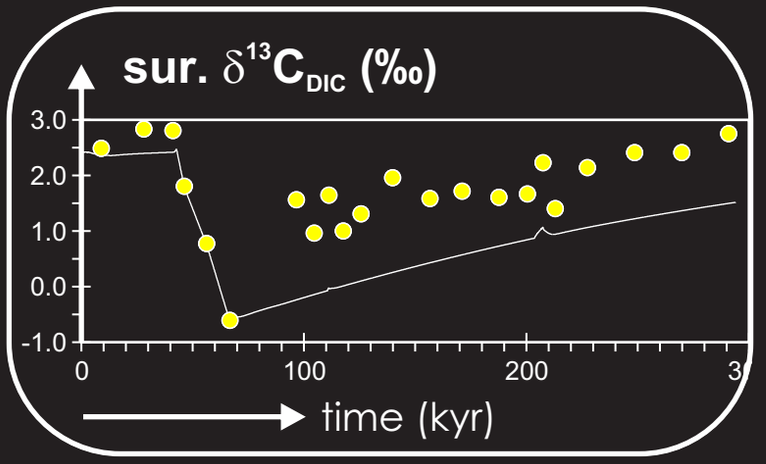
Event (onset) duration (yrs)
proxy for 1 / (rate of change)

Assimilating surface ocean pH change (only)



Assimilating surface ocean pH and $\delta^{13}C$

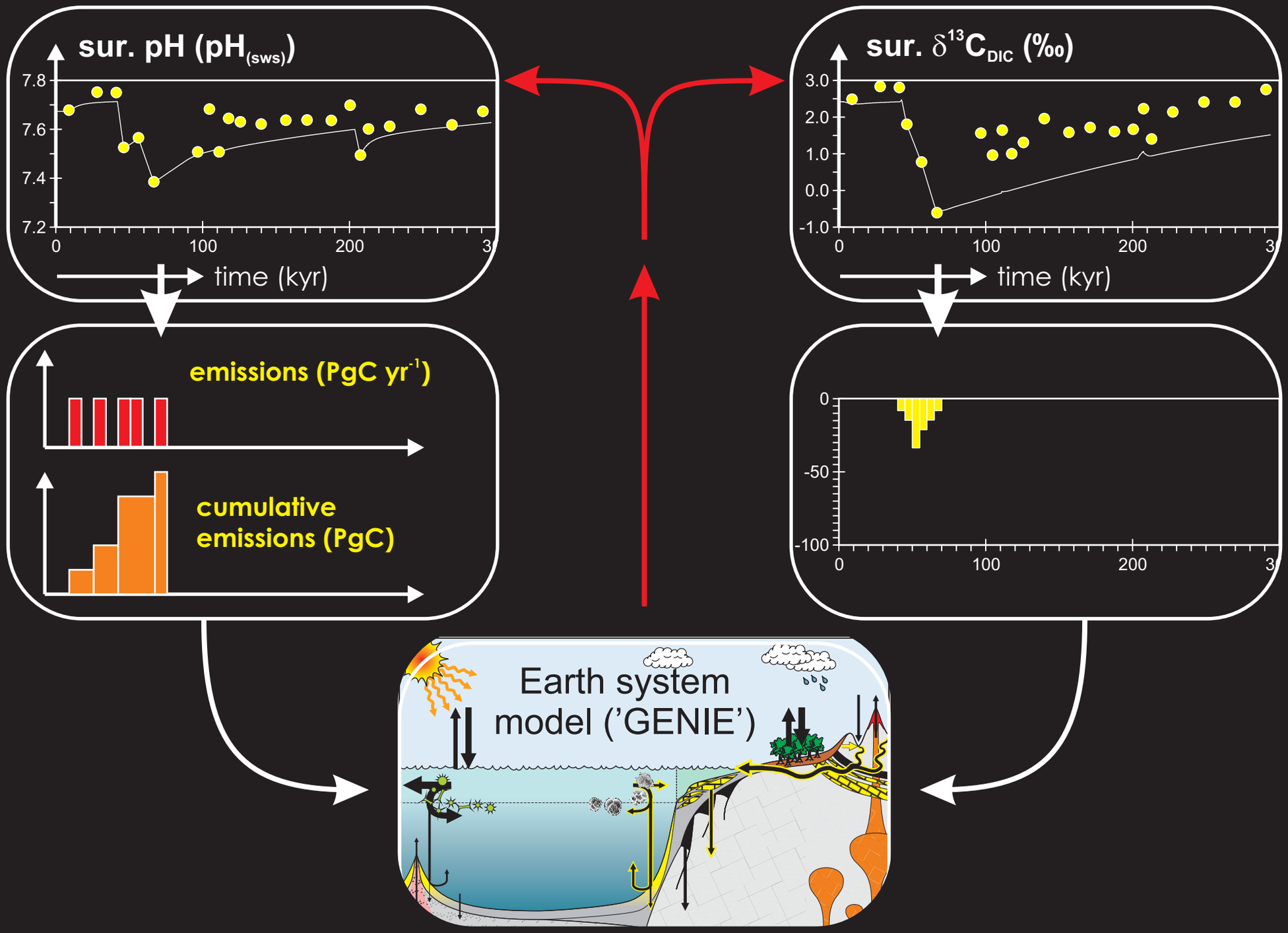




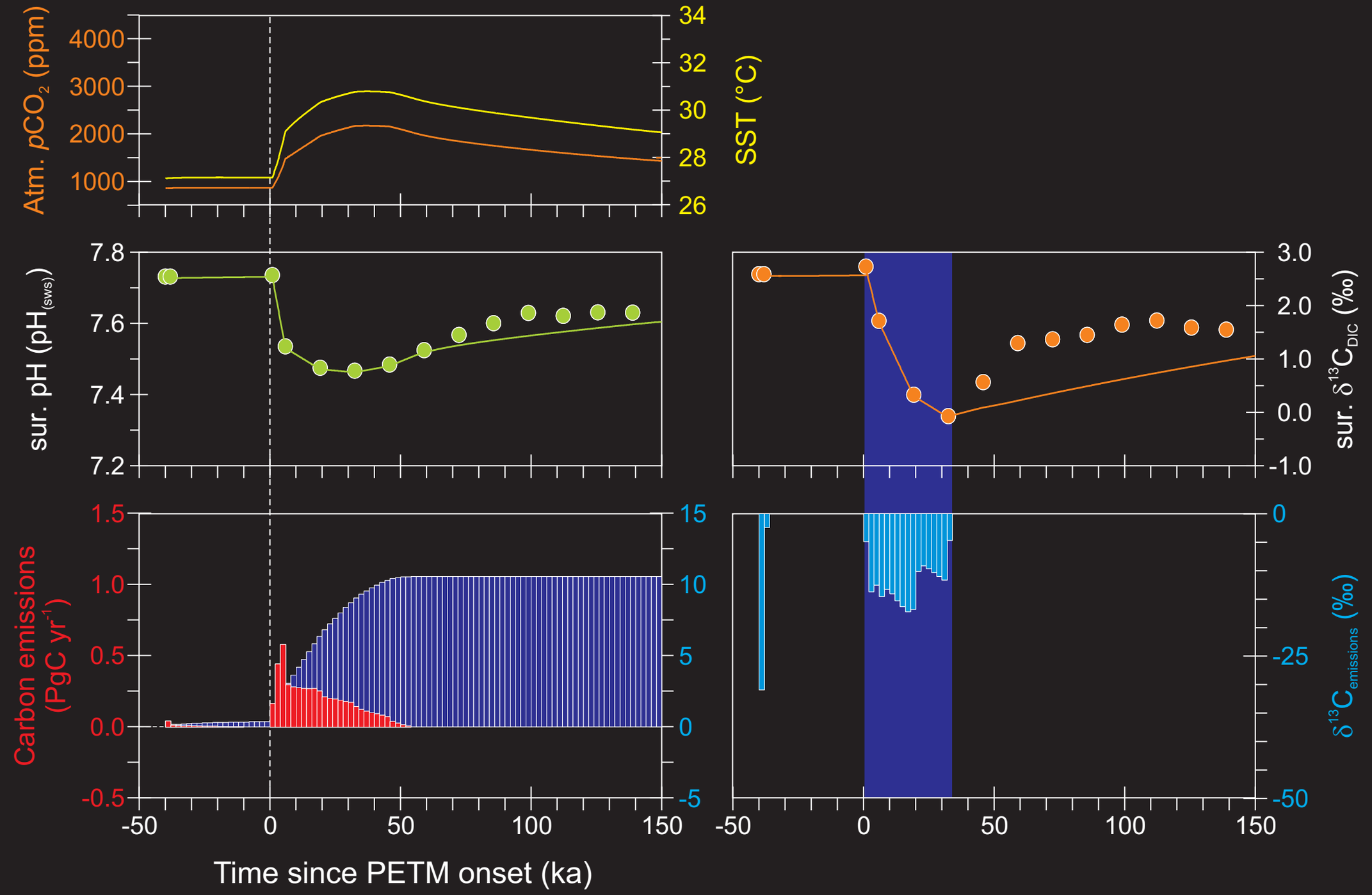
Site 401 (NE Atlantic) [unpublihed]

Site 865 (Eq. Pacific) Site 1263 (ES Atlantic) Site 1209 (N Pacific) [*Penman et al.*, 2014]

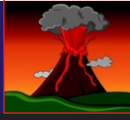
Assimilating surface ocean pH and $\delta^{13}C$



Assimilating surface ocean pH and $\delta^{13}C$



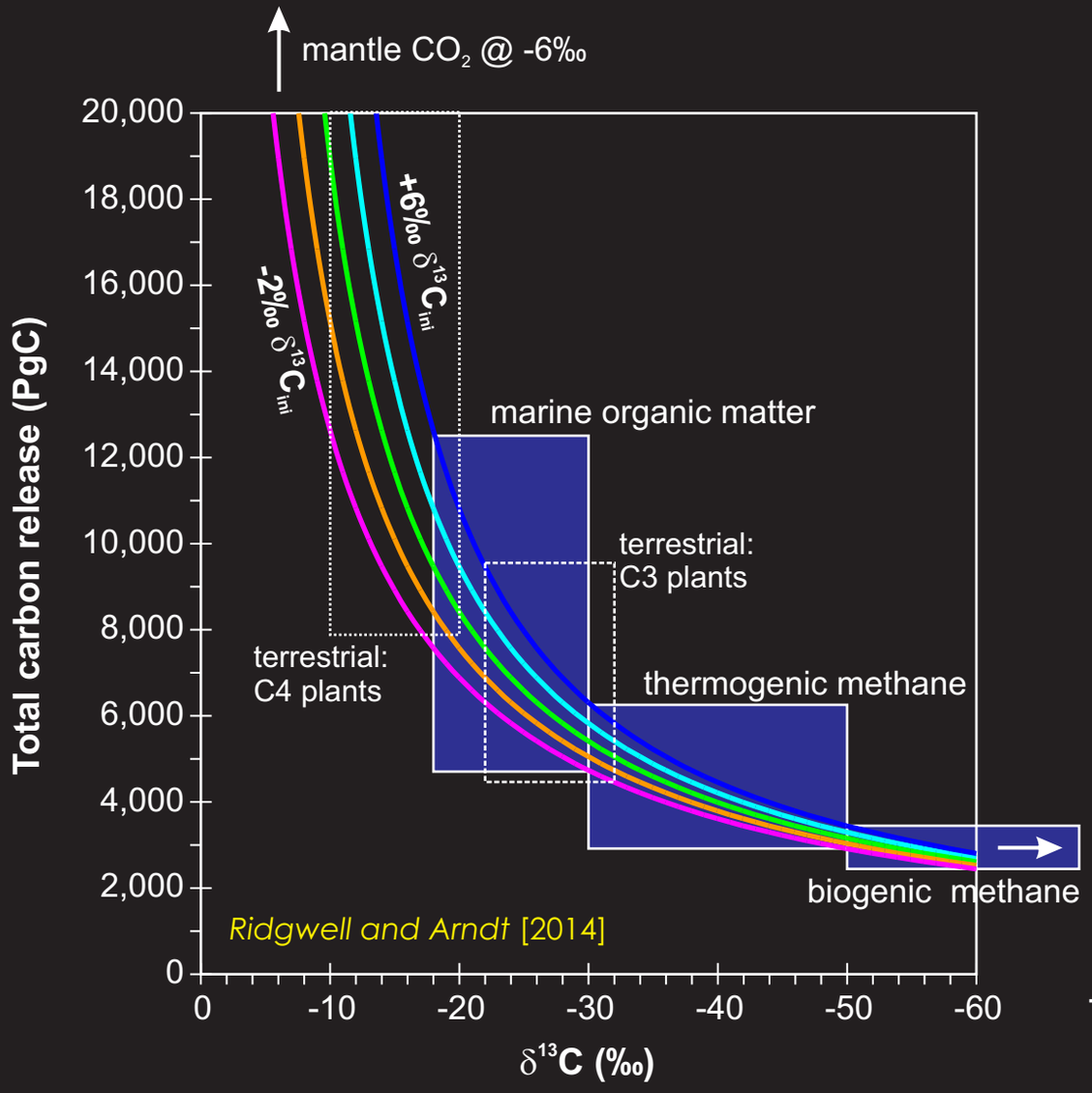
Assimilating surface ocean pH and $\delta^{13}C$

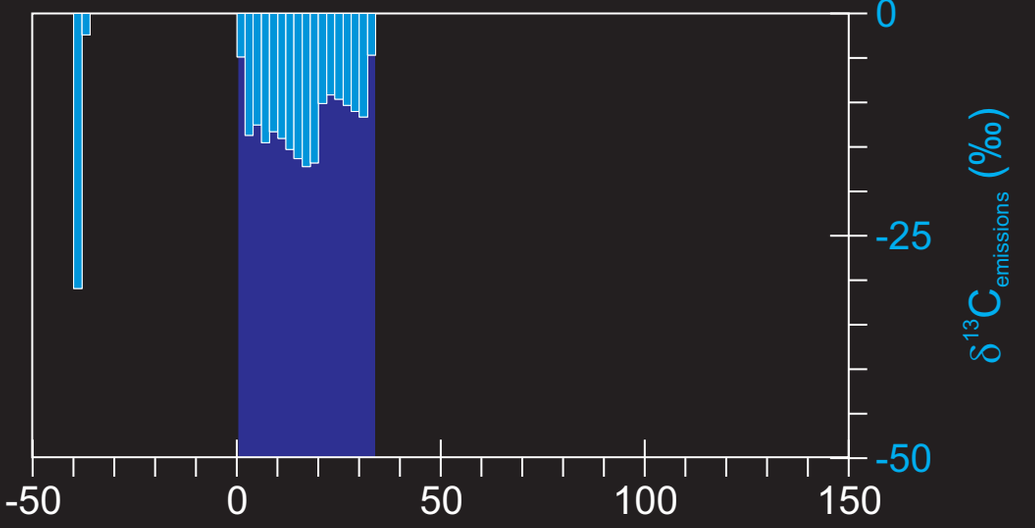


+

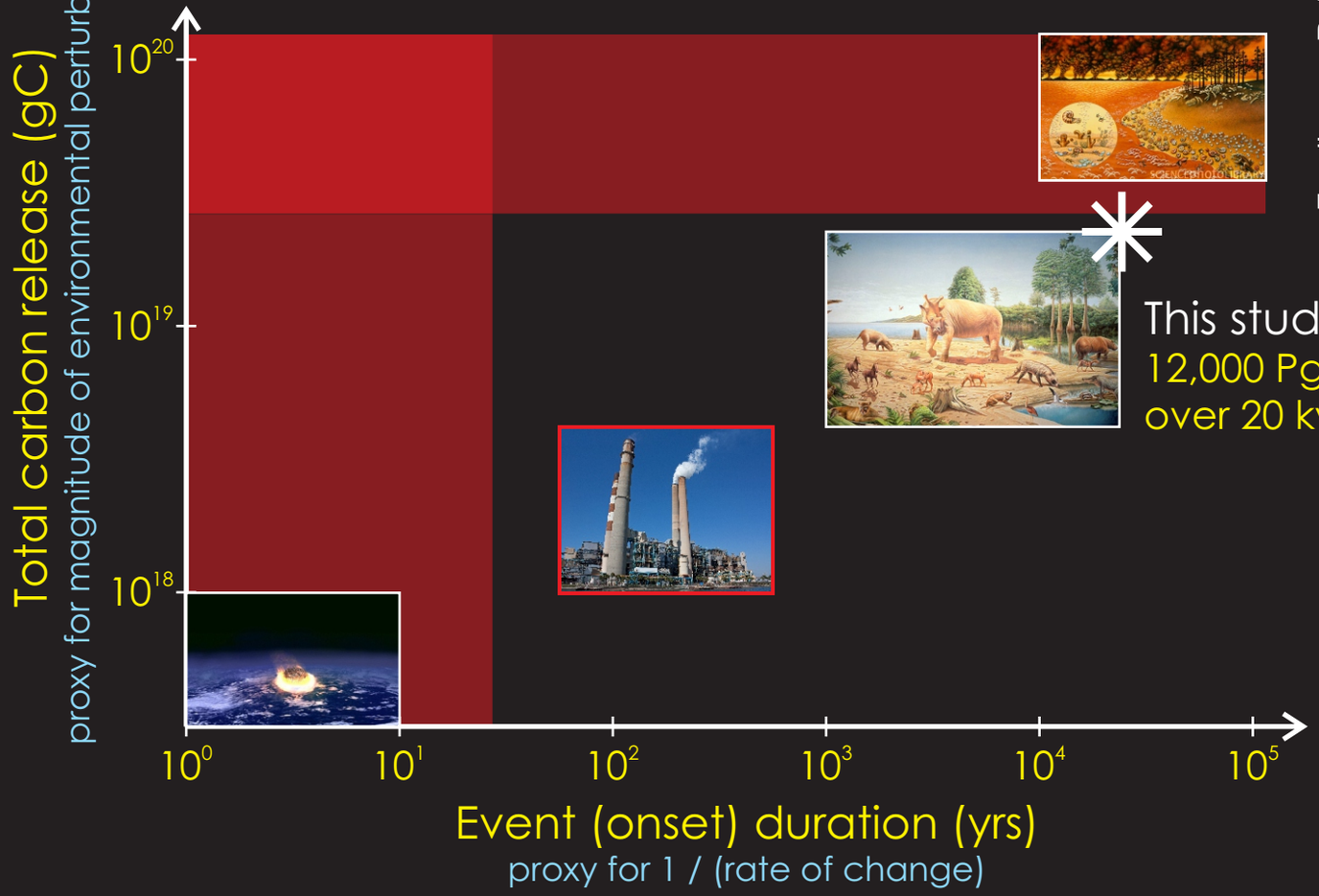
OR

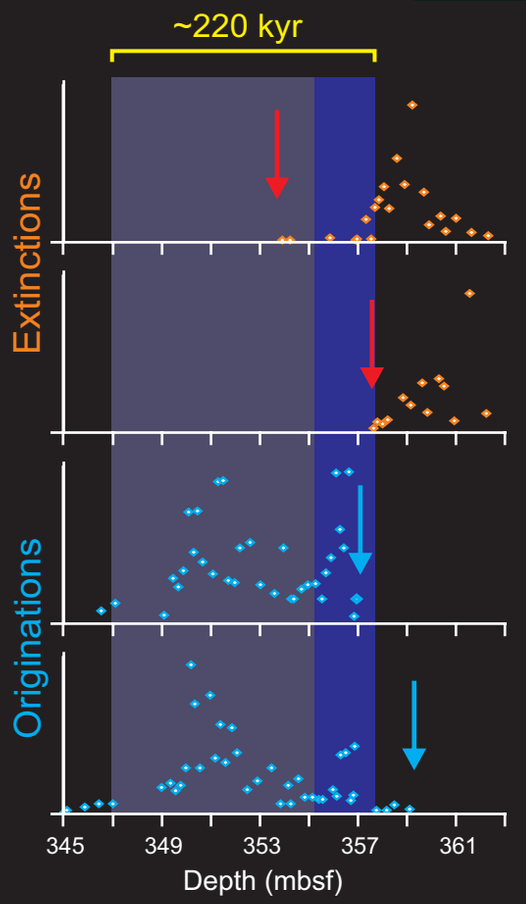
+



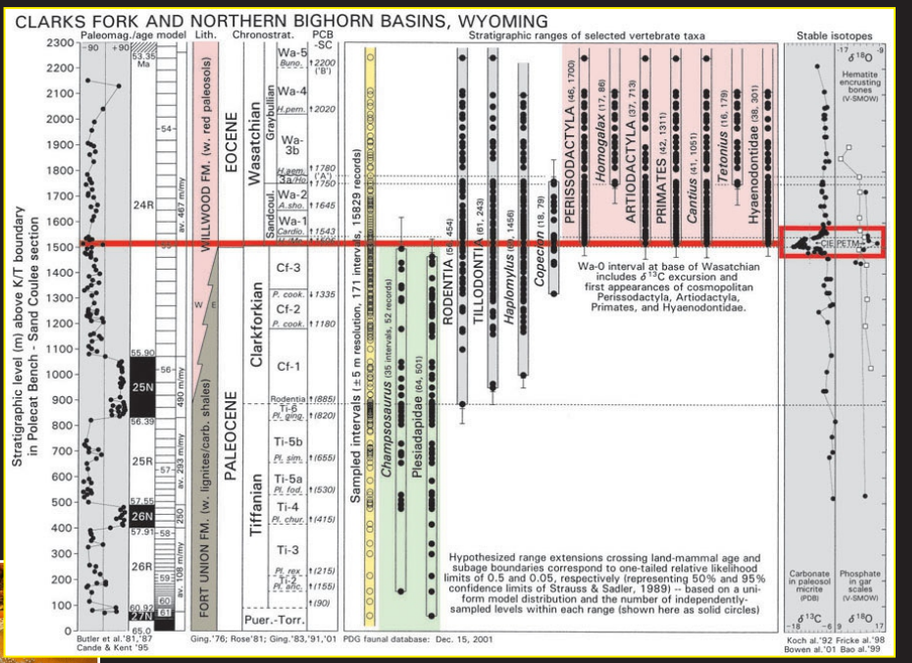


Conclusions #1a – ecological sensitivities

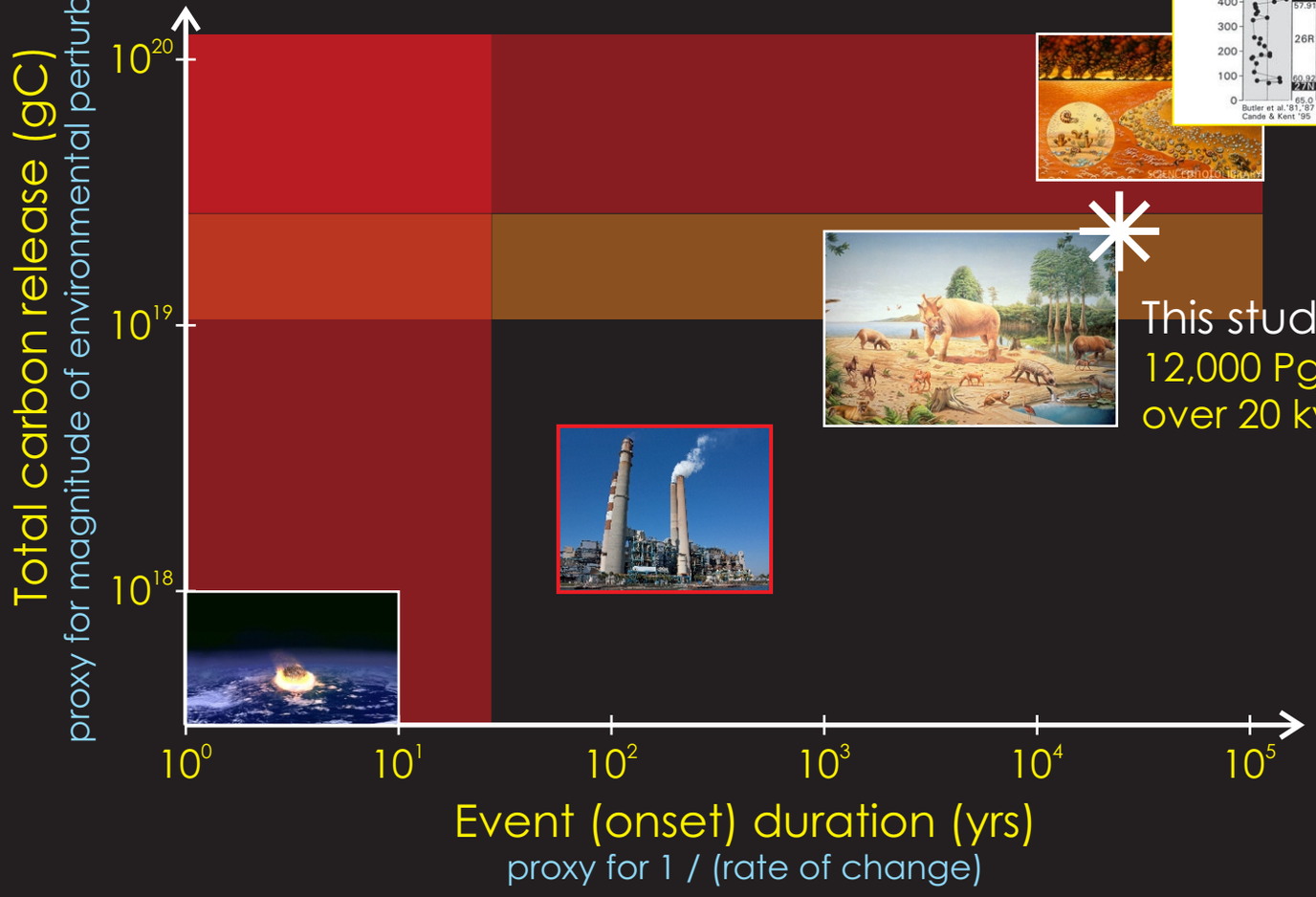




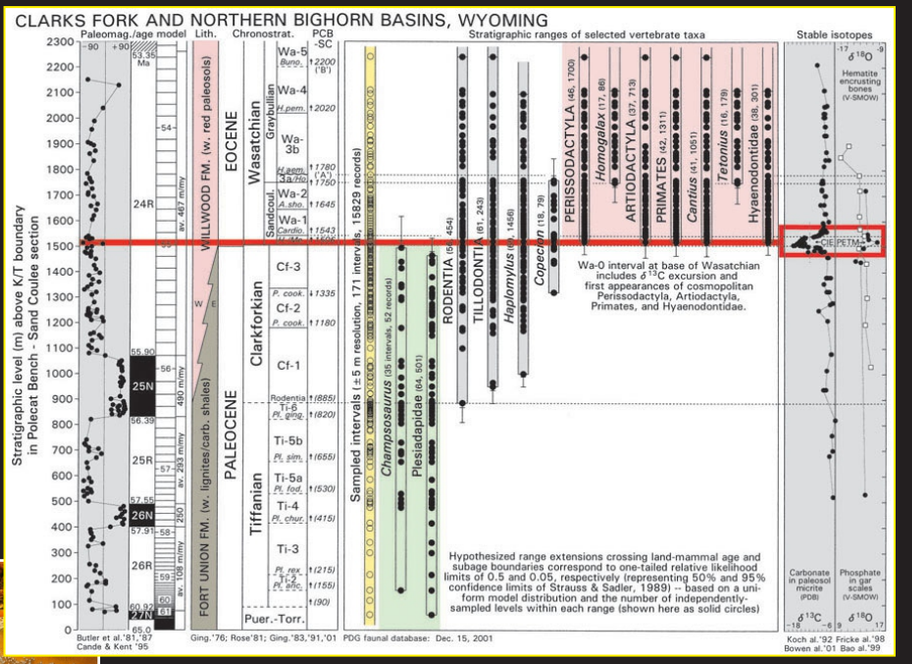
Conclusions #1b – ecological sensitivities



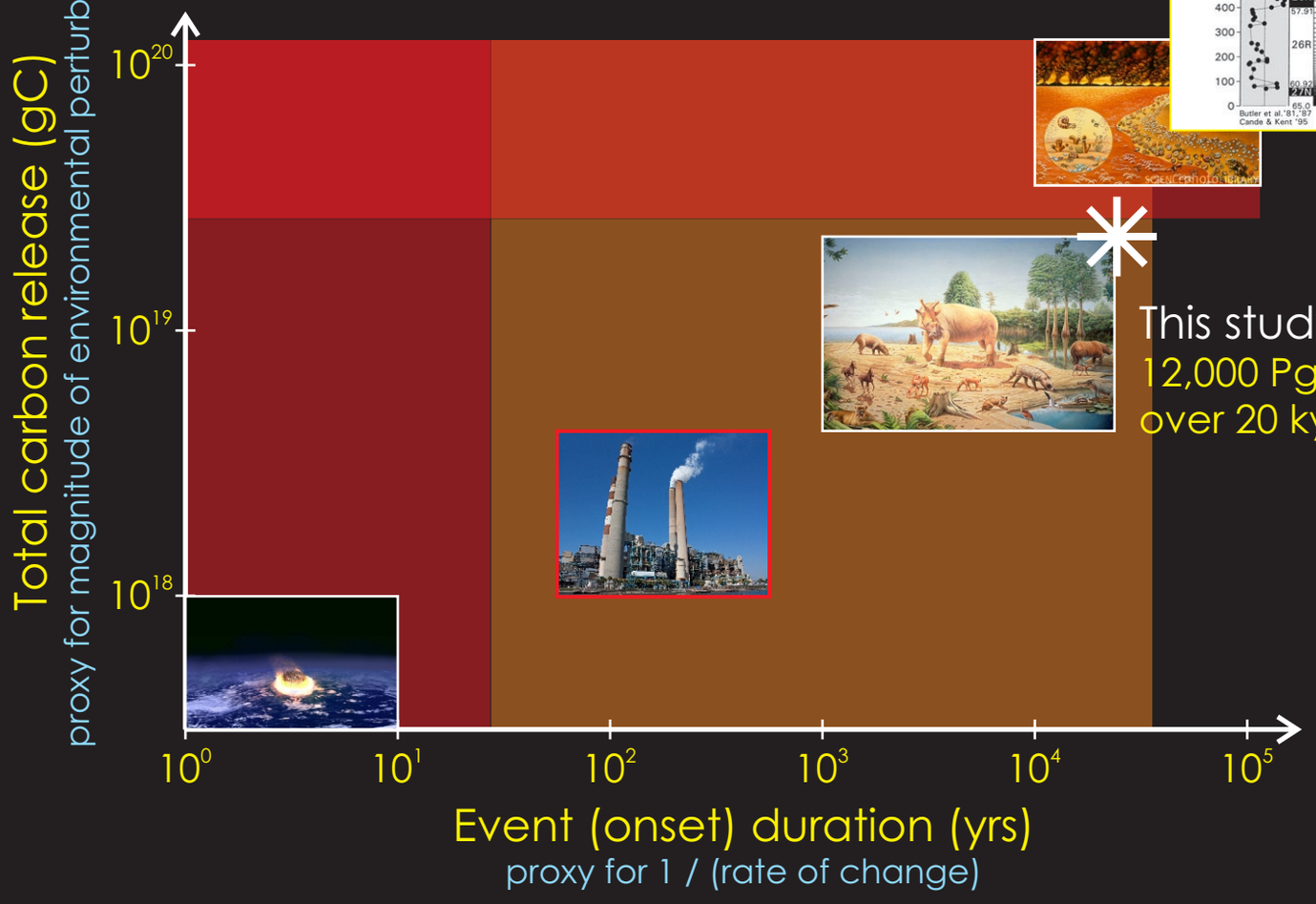
[*Philip D. Gingerich*]



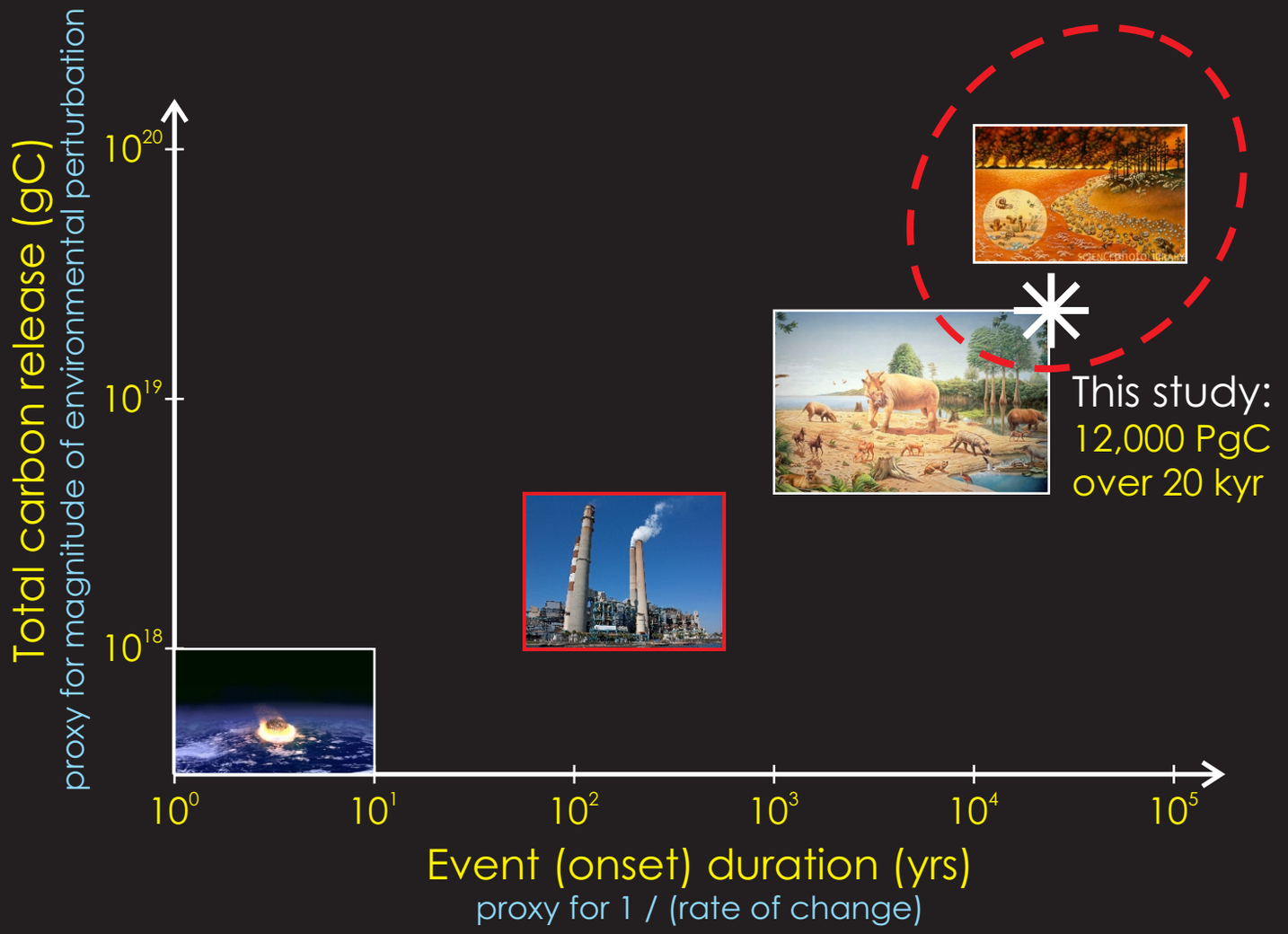
Conclusions #1c – ecological sensitivities



[*Philip D. Gingerich*]



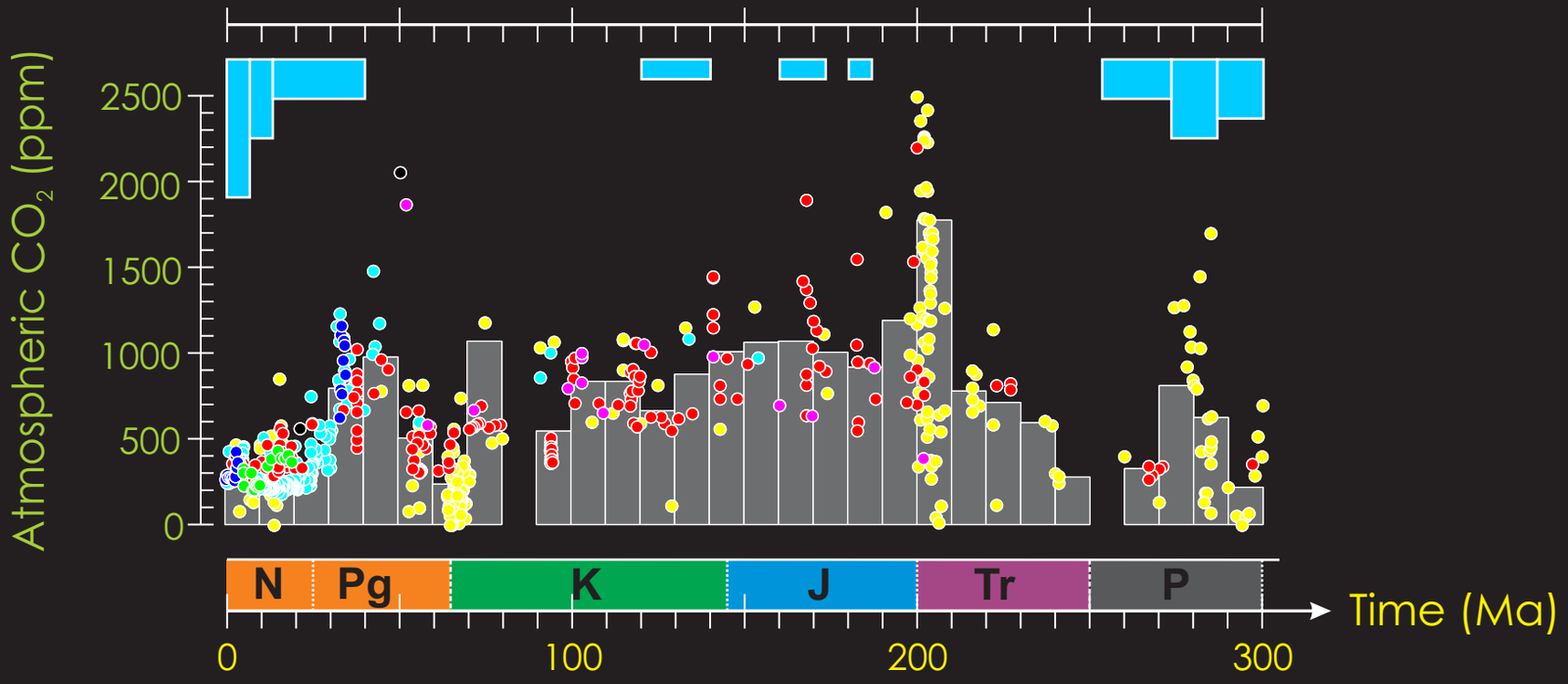
Conclusions #2 – role of carbon cycle feedbacks



Conclusions #3 ...

the 'ideal' event?

- A transient environmental perturbation in the absence of massive volcanism and/or bolide impact ...
- ... or sufficient proxy data to back-out the contribution of volcanism. (Not obvious (to me) how direct environmental change can be backed out of an impact-dominated event.)
- Comparable onset time-scale to modern.



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