The Greenhouse Effect
What it is, how it works and how it can be exploited to solve our environmental crisis

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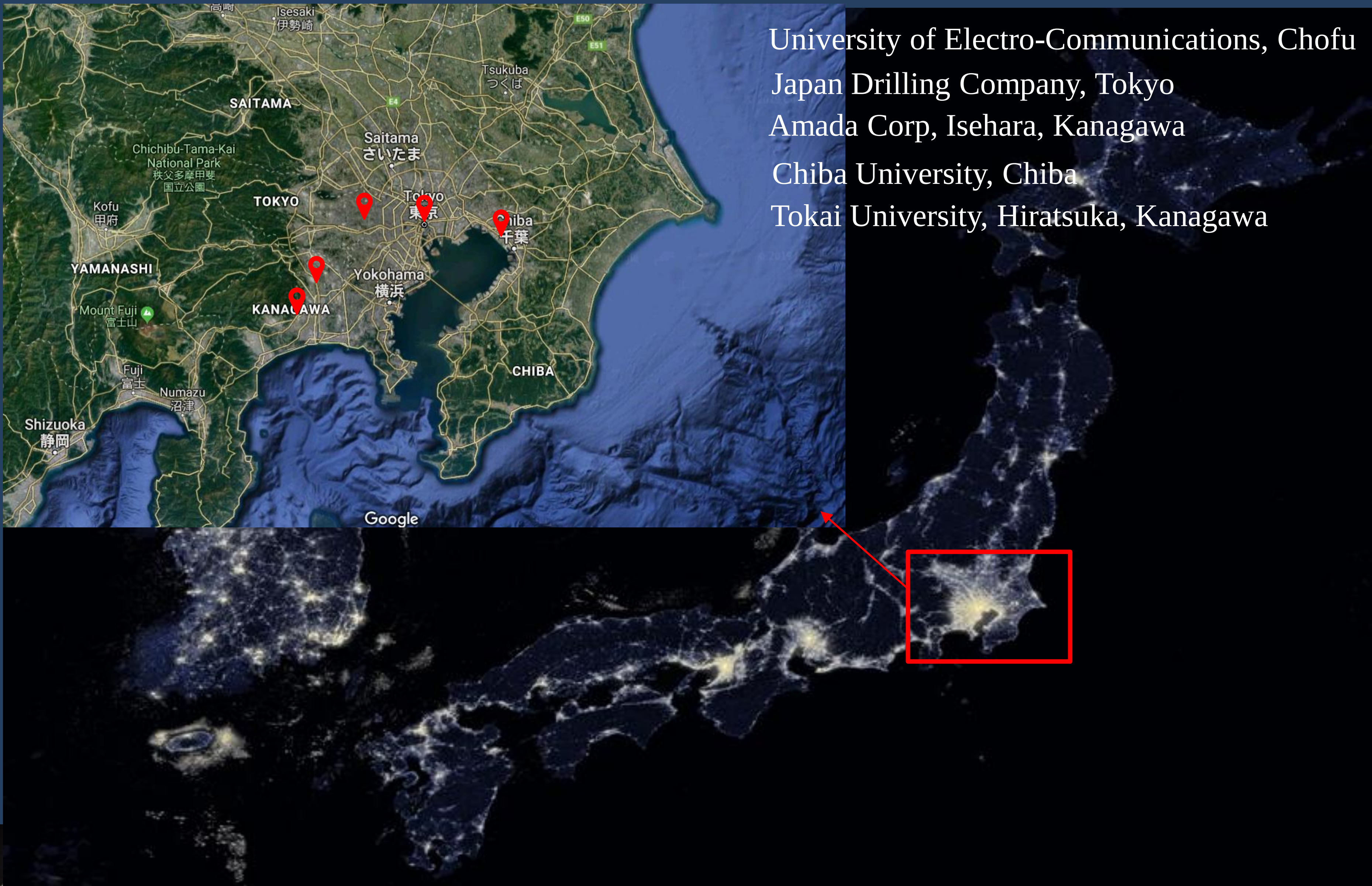
5 October 2019

Université de Moncton

- Created in 1963
- Nearly 5 000 students on 3 campuses
  [Moncton (main campus), Shippagan, Edmundston]

My Life in Japan

University of Electro-Communications, Chofu
Japan Drilling Company, Tokyo
Amada Corp, Isehara, Kanagawa
Chiba University, Chiba
Tokai University, Hiratsuka, Kanagawa



Outline

- The greenhouse effect on Earth
- Methane hydrate and solar power: two abundant resources in Japan
- How the greenhouse effect is used for harnessing solar energy

The Radiative Balance of the Earth with the Sun

Each m^2 of the Earth receives 340 W of radiant energy, of which **240 W** are absorbed

⇒ In steady state: the Earth loses an equal amount of energy

⇒ This happens through **radiative transfer**

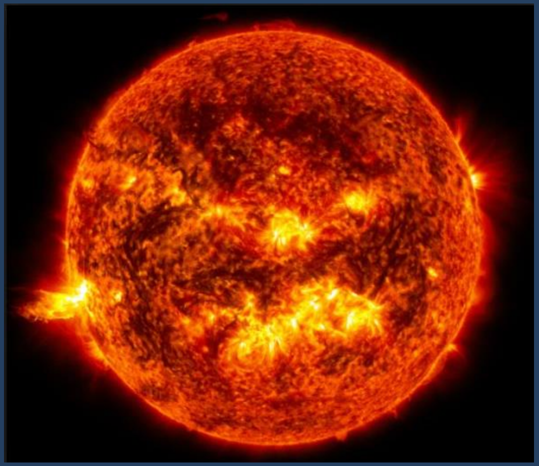
The Earth viewed from Apollo 10 (18 May 1969)

In reality, we are not in steady state : 237W are reemitted!

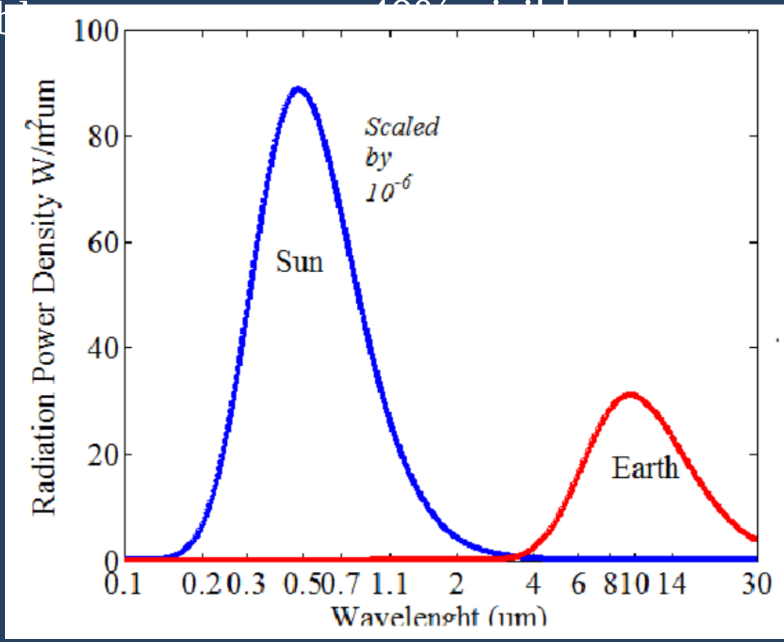
Thermal Radiation

T=35 °C
Mid-IR at λ=10 μm

T=2000 °C
Lots of IR, 5% visib

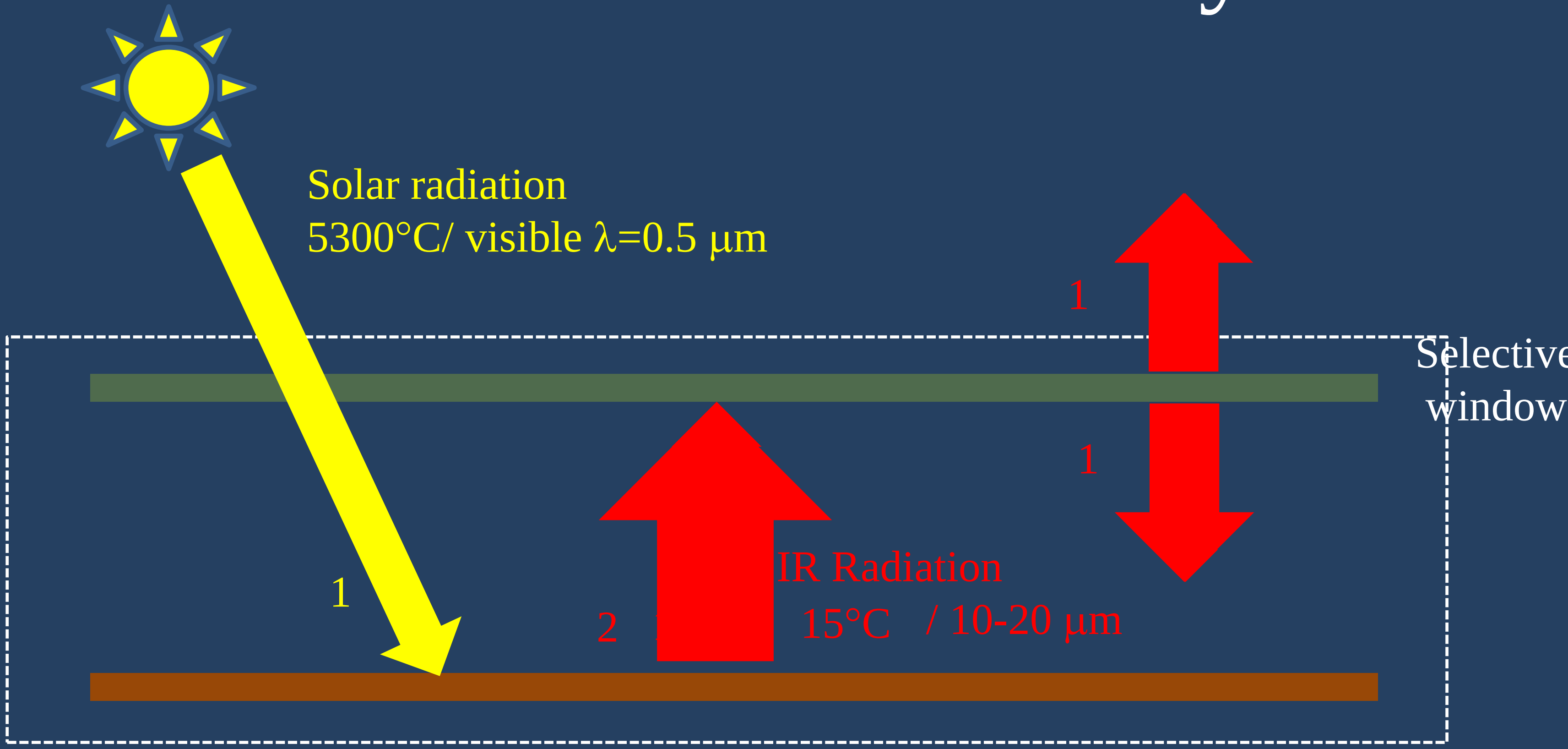


T=5300 °C



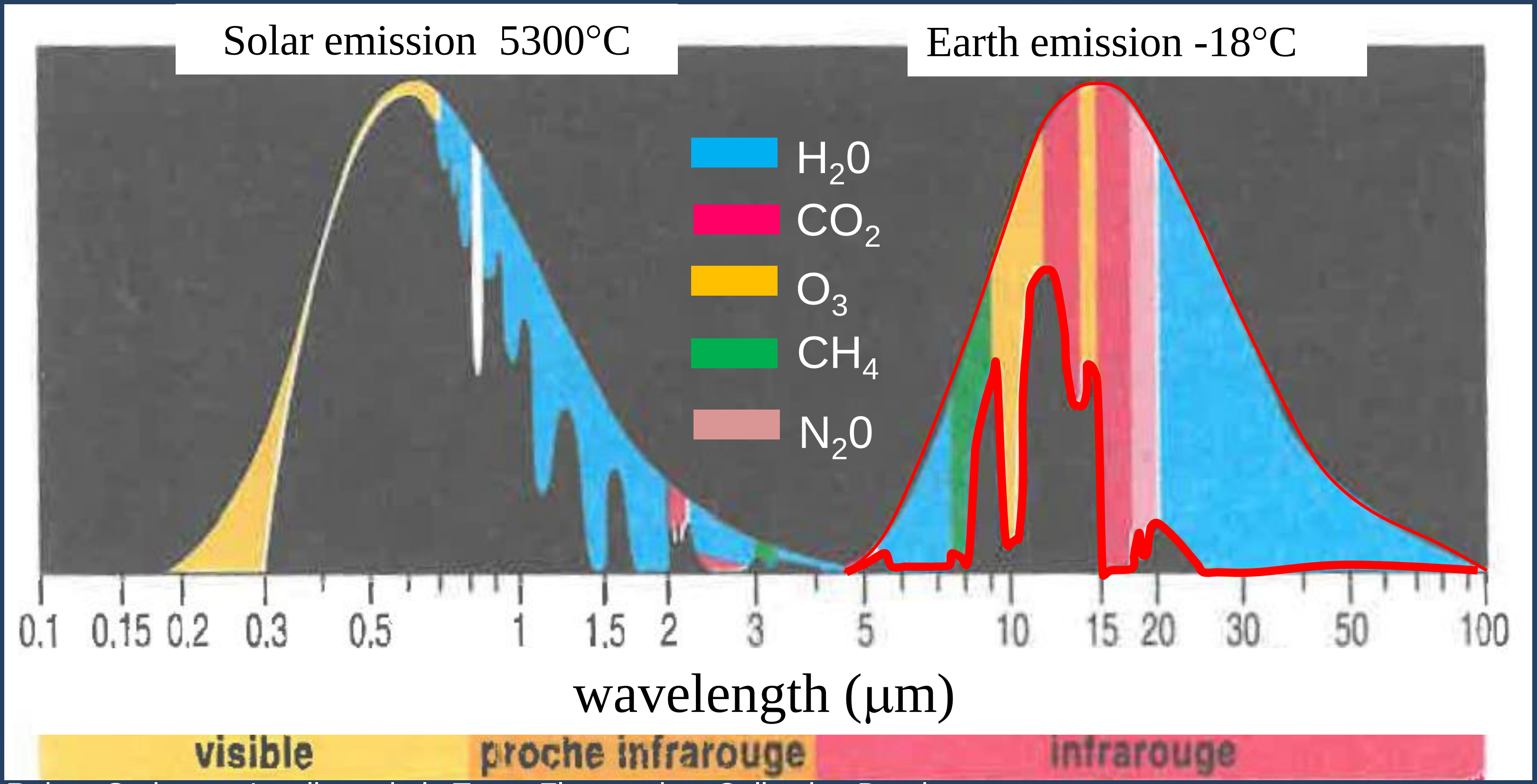
- Bodies at a lower temperature emit at a longer wavelengths

The Greenhouse Effect: a Toy Model



- The surface of the Earth receives 560 W/m^2 (instead of 240 W/m^2)
- Seen from space, the total radiation remains the same: hence, the GHE has no effect on the Earth's apparent temperature

The Greenhouse Gases



Robert Sadourny, Le climat de la Terre, Flammarion, Collection Domino

- Water vapor is the main contributor to the warming effect.
- Greenhouse gases heats up the surface of the Earth to 15°C

The Faint Sun “Paradox”

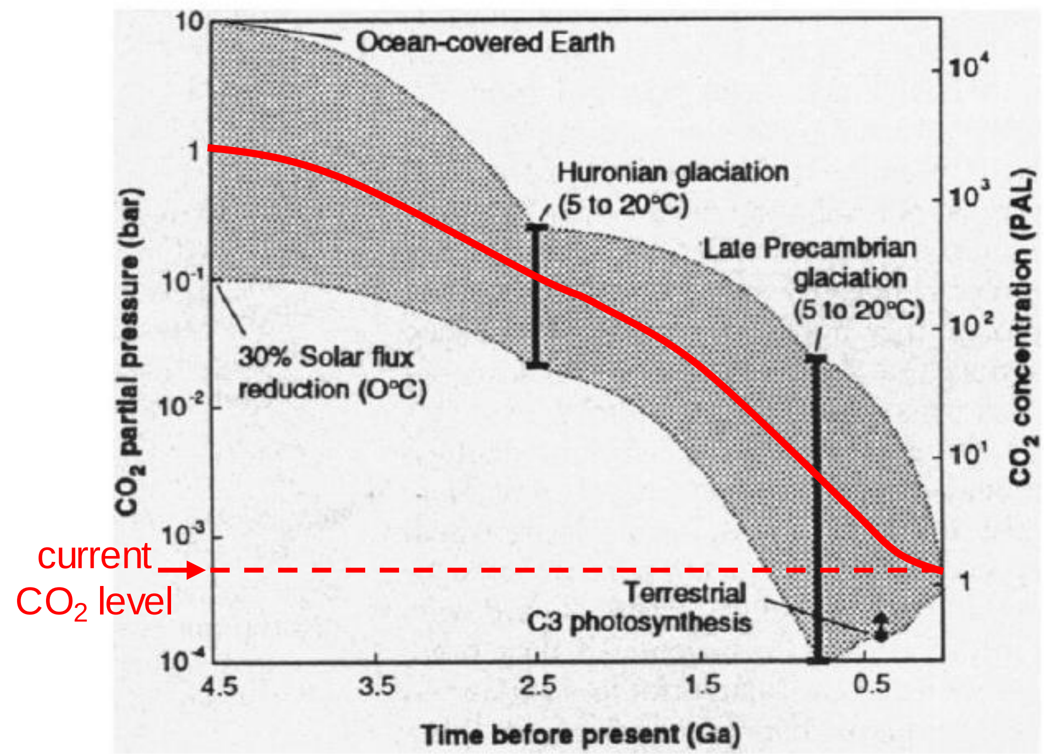
- 4.5 billion years ago, solar power was 30% lower than now
- With an atmosphere similar to nowadays, temperatures would have been much lower
- Frozen oceans => life could not have developed

Earth’s Early Atmosphere

James F. Kasting

SCIENCE • VOL. 259 • 12 FEBRUARY 1993

Much higher partial pressure of CO_2 is believed to have maintained the surface temperature higher than the freezing point. This circumstance is believed to have played a key role in the emergence of life.



The rise of oxygen in Earth's early ocean and atmosphere

Timothy W. Lyons[1], Christopher T. Reinhard[1,2,3] & Noah J. Planavsky[1,4]

20 FEBRUARY 2014 | VOL 506 | NATURE | 307

The rapid increase of carbon dioxide concentration in Earth's modern atmosphere is a matter of major concern. But for the atmosphere of roughly two-and-half billion years ago, interest centres on a different gas: free oxygen (O_2) spawned by early biological production. The initial increase of O_2 in the atmosphere, its delayed build-up in the ocean, its increase to near-modern levels in the sea and air two billion years later, and its cause-and-effect relationship with life are among the most compelling stories in Earth's history.

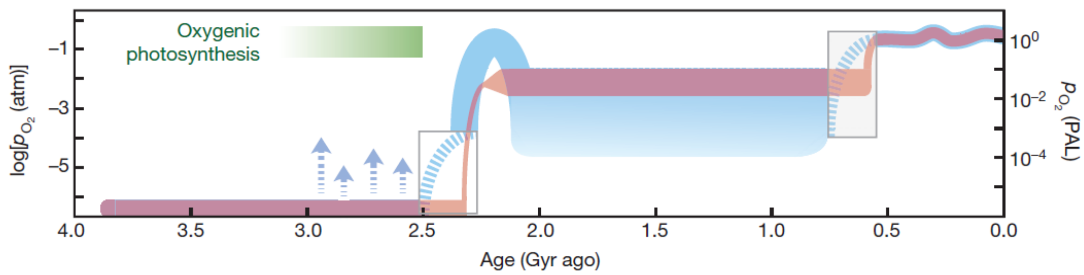


Figure 1 | Evolution of Earth's atmospheric oxygen content through time. The faded red curve shows a 'classical, two-step' view of atmospheric evolution[95], while the blue curve shows the emerging model (p_{O_2}, atmospheric partial pressure of O_2). Right axis, p_{O_2} relative to the present atmospheric level (PAL); left axis, log p_{O_2}. Arrows denote possible 'whiffs' of O_2 late in the Archaean; their duration and magnitude are poorly understood. An additional frontier lies in reconstructing the detailed fabric of 'state changes' in atmospheric p_{O_2}, such as occurred at the transitions from the late part of the Archaean to the early Proterozoic and from the late Proterozoic to the early Phanerozoic (blue boxes). Values for the Phanerozoic are taken from refs 96 and 97.

Cyanobacterias => Photosynthesis =>

- Production of oxygen
- Elimination of CO_2

Late Proterozoic Low-Latitude Global Glaciation: the Snowball Earth

JOSEPH L. KIRSCHIVINK

(1992) The Proterozoic biosphere : a multidisciplinary study. Cambridge University Press, New York

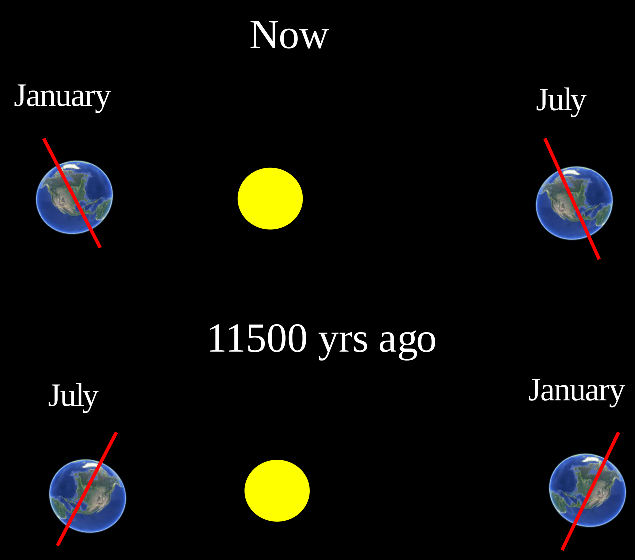
Circa 650 million years ago

The Earth’s Orbit Around the Sun

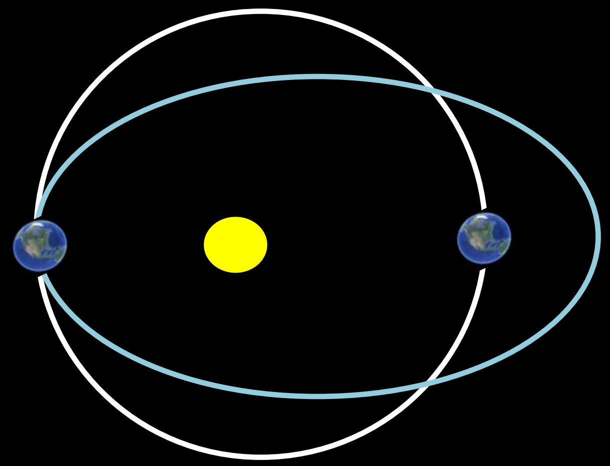
- The Earth’s axis of rotation is tilted with respect to the orbit around the sun
- The orbit is elliptical: it is closest to the sun in January
- Precession, changes in the tilt and eccentricity drive strong climate variations, e.g. glaciation periods, etc.

Tilt
Period: 41 kyrs

Precession
Period: 23 kyrs



Eccentricity
Period: 100 kyrs



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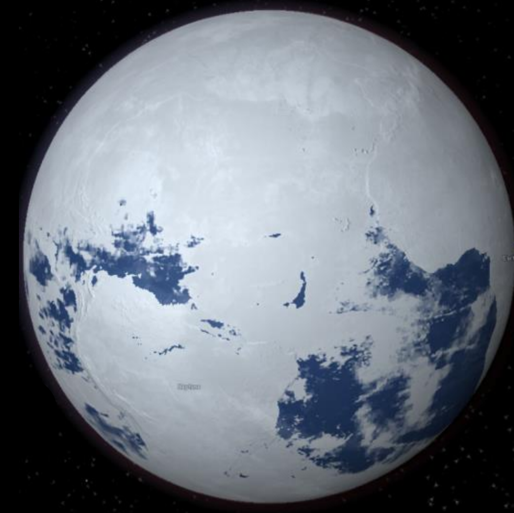


- Initial cooling may be due to a combination of:
  - Catastrophic event (ex.: volcanic eruption, meteorite)
  - Circumstances in the Earth's orbit
  - Solar variations

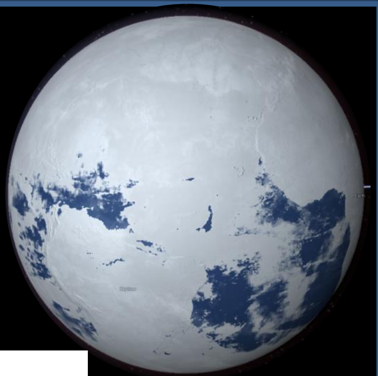
- Positive feedback mechanism:

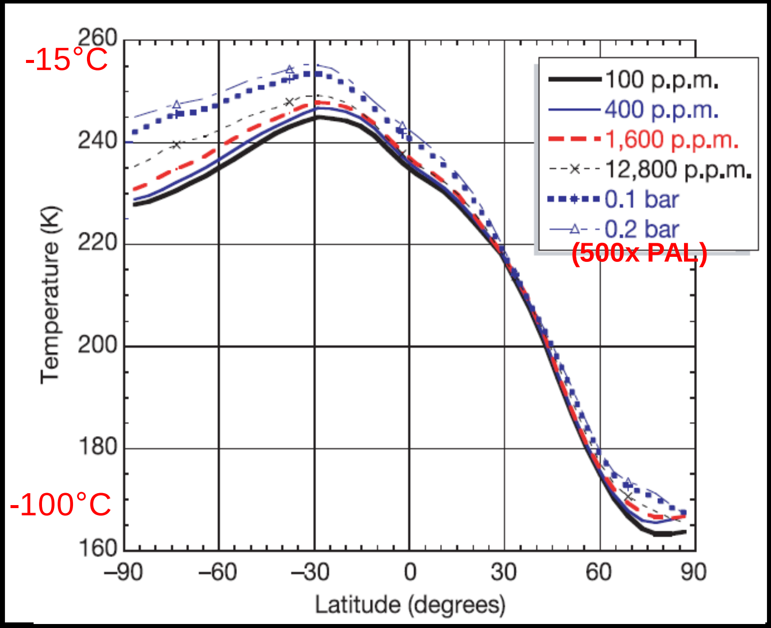
- Deglaciation would have taken place due to rise of CO_2 concentration from volcanic emissions.

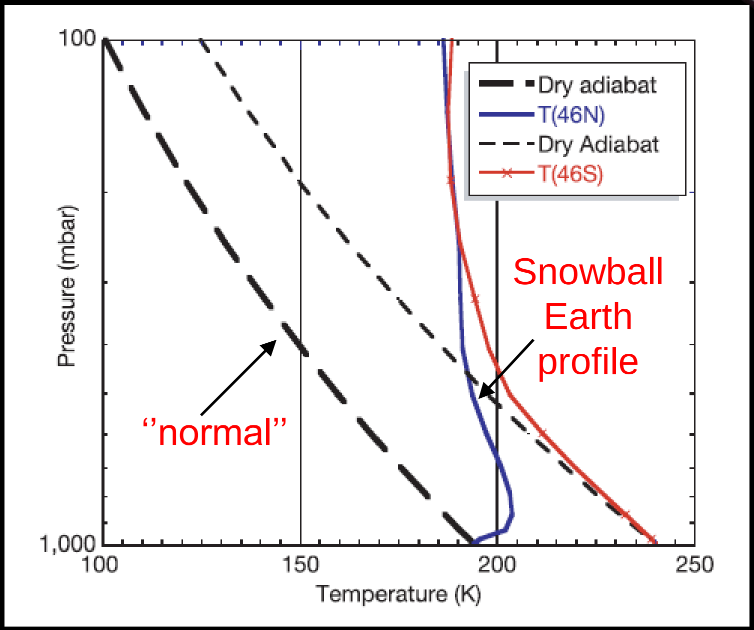
High levels of atmospheric carbon dioxide necessary for the termination of global glaciation

Raymond T. Pierrehumbert

NATURE | VOL 429 | 10 JUNE 2004 | www.nature.com/nature







- The CO_2 concentration required to trigger deglaciation is VERY high.
- The reason for CO_2 being so ineffective is the quasi-absence of vertical temperature gradient in the atmosphere.
- Hence, CO_2 generated by volcanic outgassing as the only root cause is questionable.

The Snowball Earth: Mechanism for Deglaciation

Dust Aerosol Important for Snowball Earth Deglaciation

DORIAN S. ABBOT

Department of Geophysical Sciences, University of Chicago, Chicago, Illinois

ITAY HALEVY

Department of Earth and Planetary Sciences, Harvard University, Cambridge, Massachusetts

Toward the snowball earth deglaciation…

Guillaume Le Hir · Yannick Donnadieu ·
Gerhard Krinner · Gilles Ramstein

Clim Dyn (2010) 35:285–297

nature Vol 453|29 May 2008|**doi:10.1038/nature06961**

Snowball Earth termination by destabilization of equatorial permafrost methane clathrate

Martin Kennedy[1], David Mrofka[1] & Chris von der Borch[2]

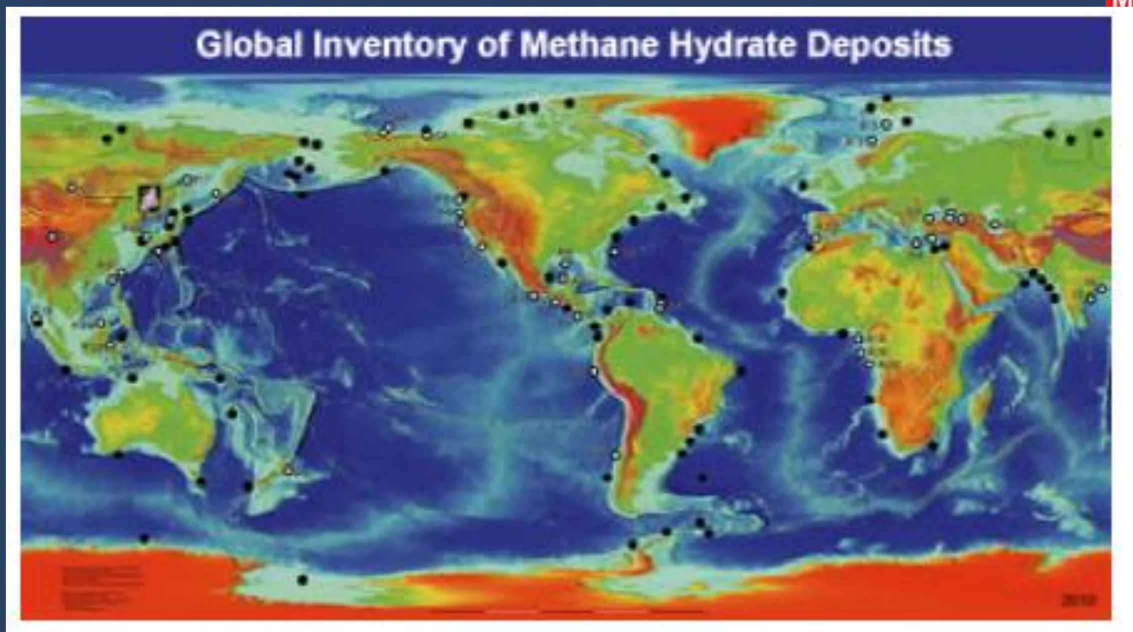
- Small particles producing additional warming and increasing the absorption by snow
- Large-scale destabilization of methane hydrate is another possibility

Methane Hydrate

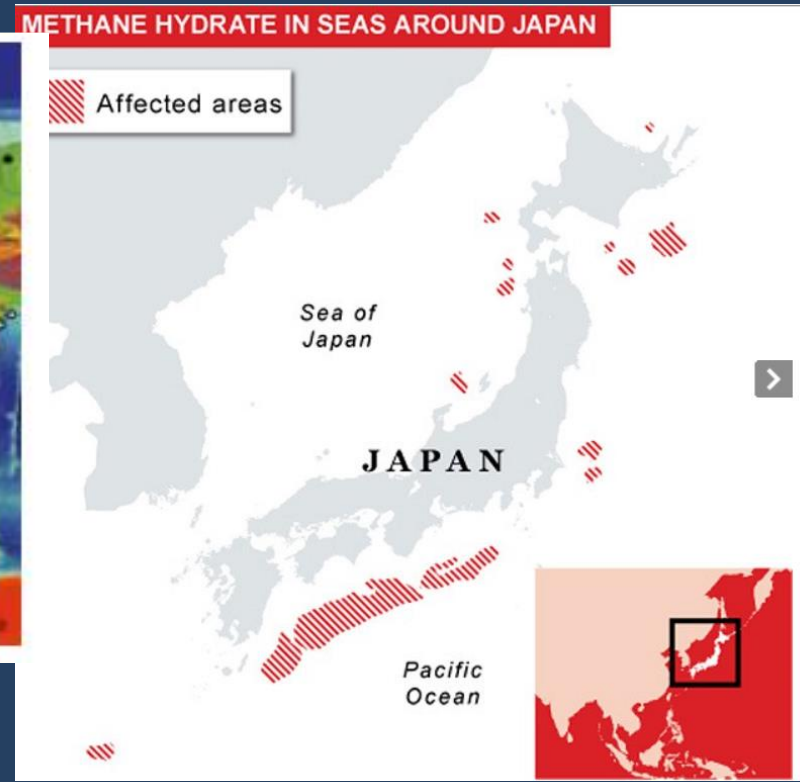
A solid cage of H_2O molecules entraps a CH_4 molecule

- 1 m^3 contains the equivalent of 164 m^3 of CH_4
- Floats on water and melts at the water surface temperature **(unstable once released)**
- CH_4 has 60 times the warming potential of CO_2

Methane Hydrate: an Abundant Energy Resource in Japan's Territorial Waters



[2] **A Global Inventory of Natural Gas Hydrate Occurrence**: Keith A. Kvenvolden and Thomas D. Lorenson, Pacific Coastal & Marine Science Center, United States Geological Survey.



If 10% of the methane were released to the atmosphere within a few years, impact on the Earth's surface radiation budget would be equivalent to an increase in atmospheric CO_2 by a factor of 10.

Japan and Methane Hydrate

Japan extracts gas from methane hydrate in world first

12 March 2013 Ref. BBC (March 2013)

China and Japan find way to extract 'combustible ice' from seafloor, harnessing a legendary frozen fossil fuel

Ref. National Post (May 2017)

"At last, Japan found an important resource on its territory that could help make it an energetically independent country!"

Solar Energy for the Production of Electricity

- Accessible and abundant (>10^{17} W)
(world energy consumption < 10^{15} W)
- No GHG emission

- Intermittent source
- panels do not store energy

=> should used in combination with other power generation methods or with batteries

Magnesium and Solar Power as a Sustainable Source of Energy

Proposed par Yabe et al., Appl. Phys. Lett. 89, 261107 (2006)

$$Mg + H_2O \rightarrow MgO + H_2 + 359\ \mathrm{kJ/mol}$$

$$H_2 + 1/2\ O_2 \rightarrow H_2O + 241\ \mathrm{kJ/mol}$$

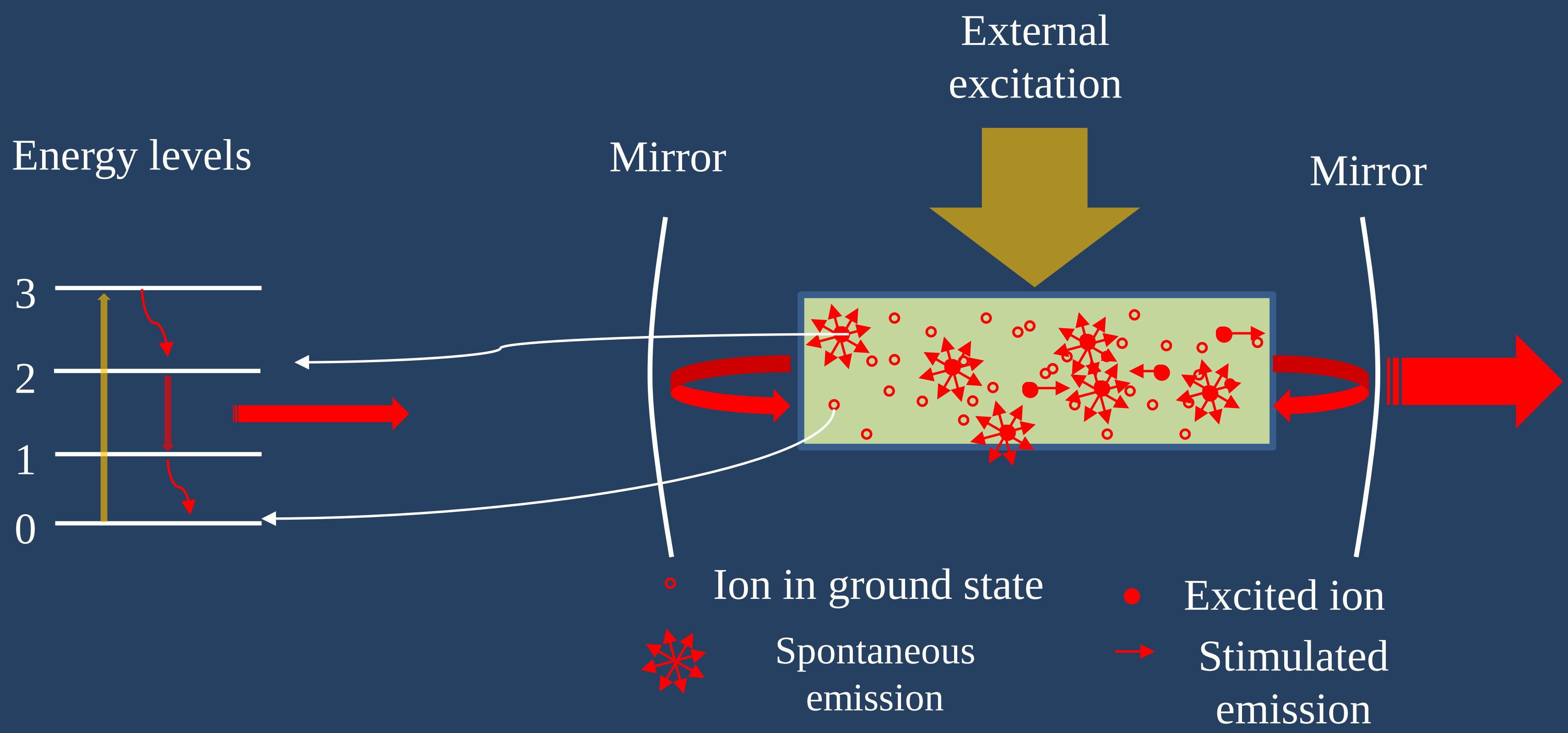
heating at 4000K

Mg: 43 GJ/m^3 Lithium battery: 1-3 GJ/m^3 Gasoline: 34 GJ /m^3

Not feasible just by concentrating solar radiation

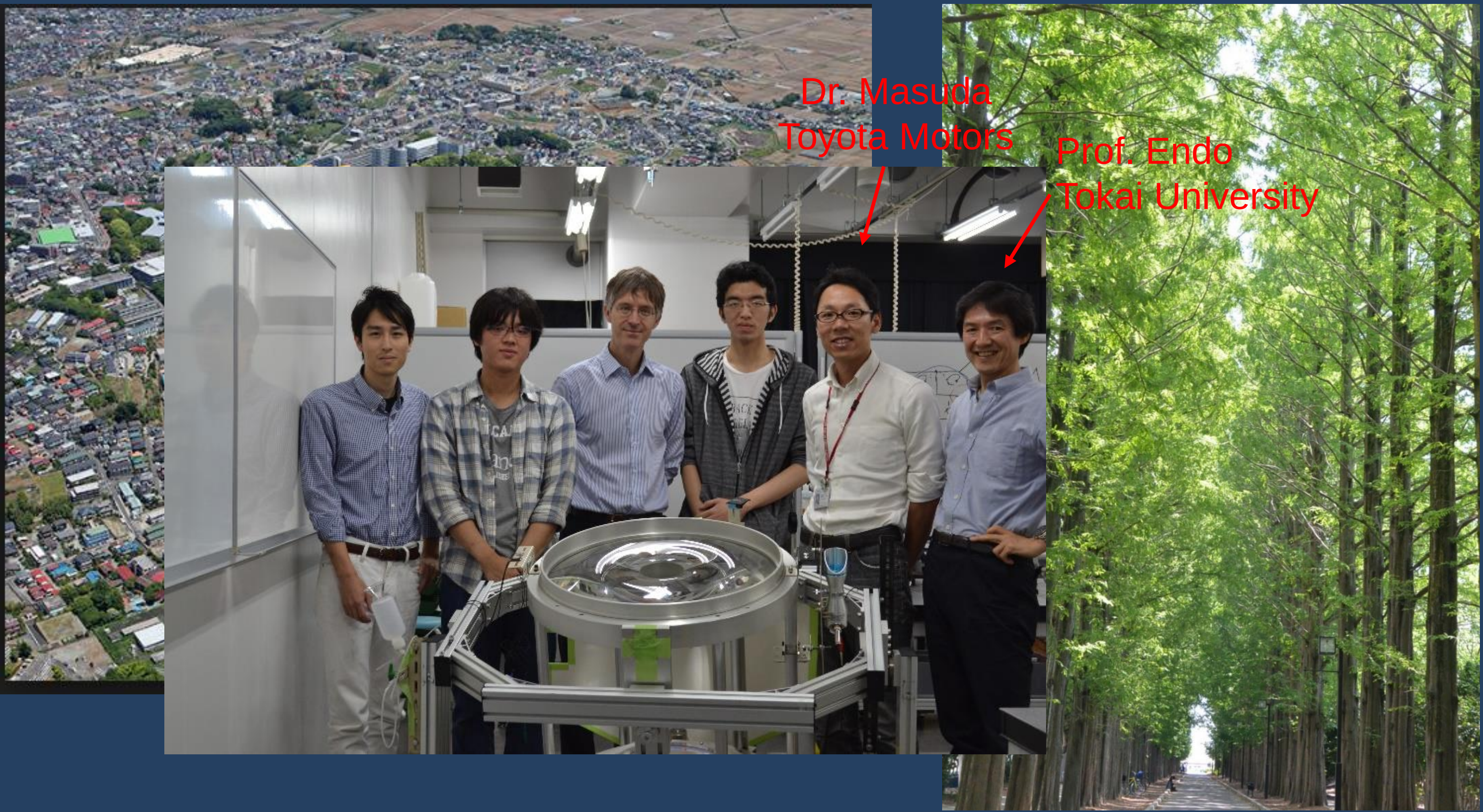
Solution: convert solar power into coherent emission that can be concentrated more tightly

The Laser in a Nutshell



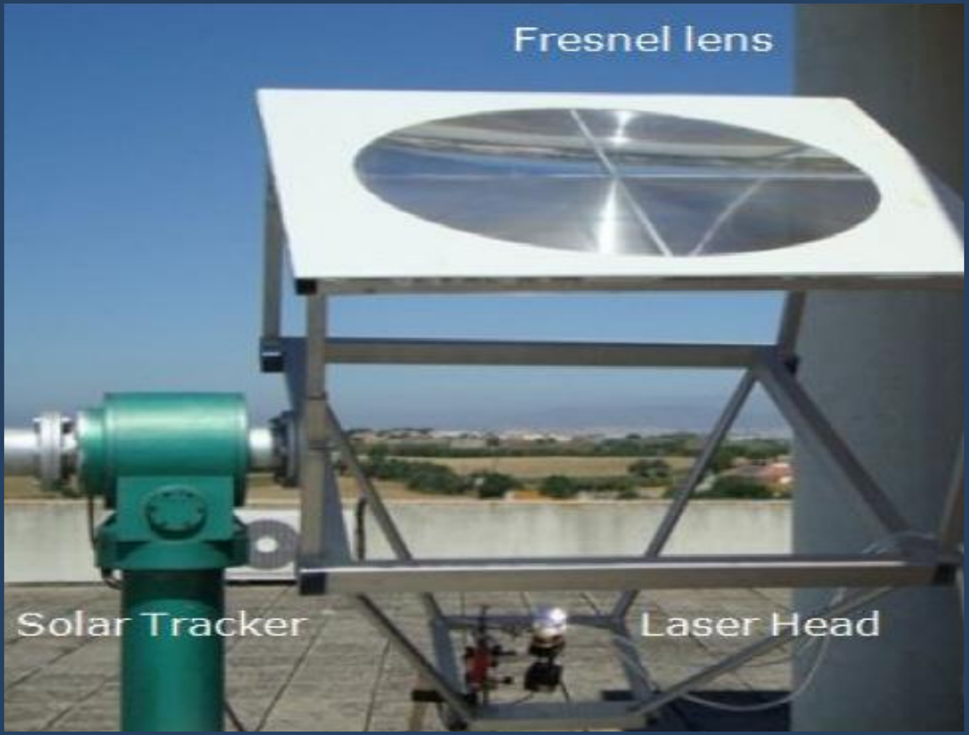
With a near IR laser, a power density of 1 kW/mm^2 can easily be reached by focusing just a few mW.

The Solar-Pumped Laser
Developed at Tokai Univ. (Prof. Endo 2013-2019)



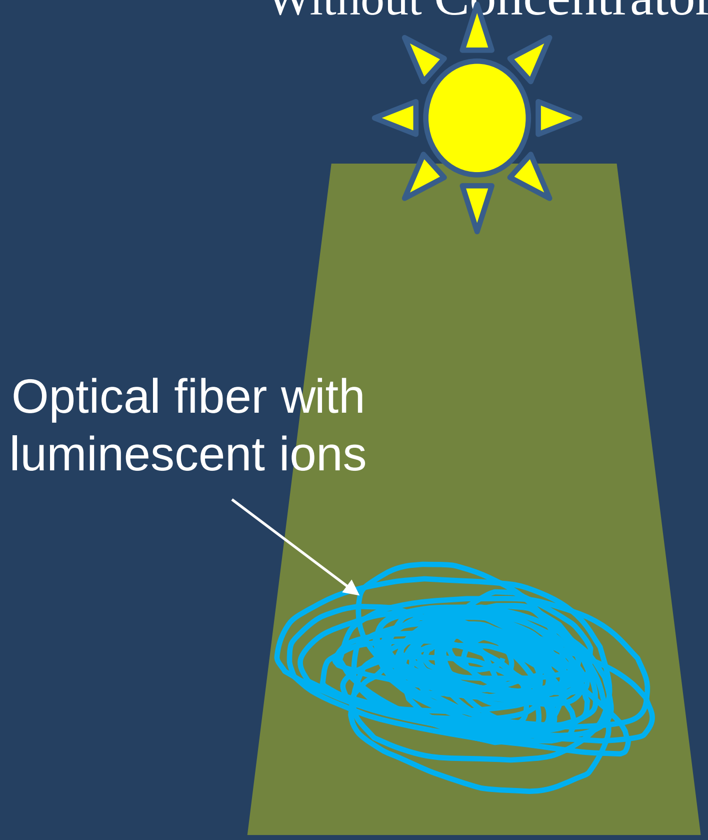
Solar Pumped Lasers

Conventional design using large concentrator

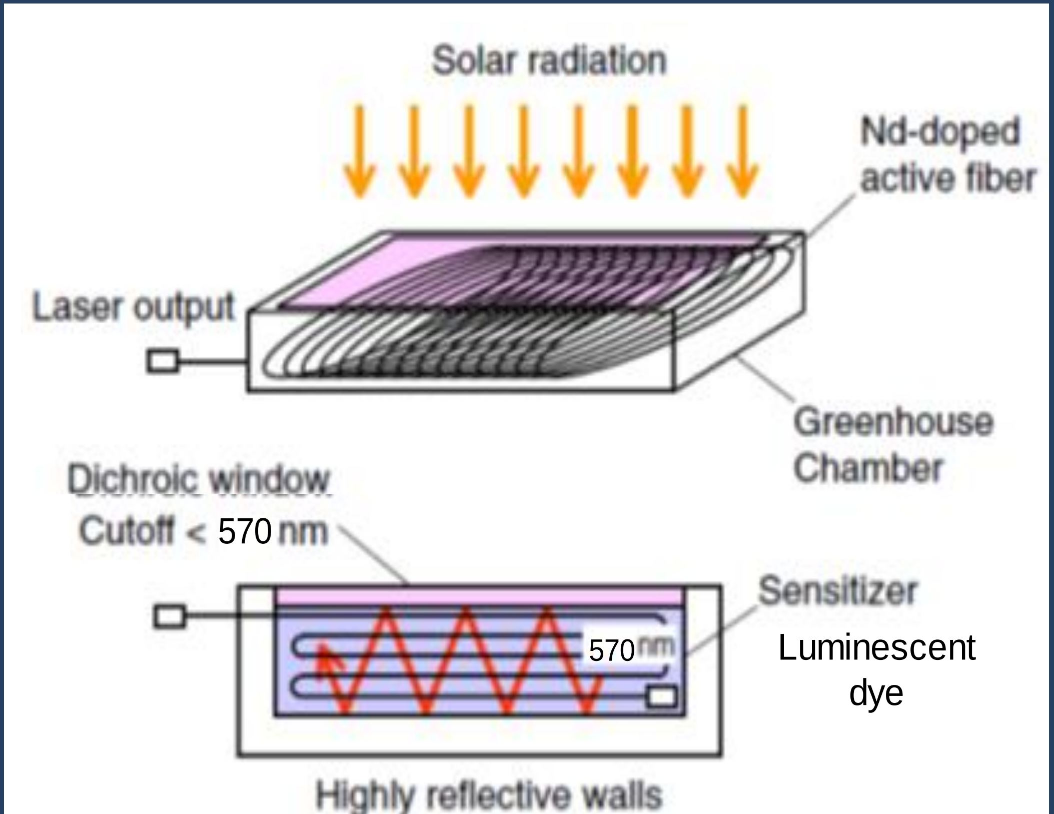


Liang, Almeida, Opt. Express, 19(27), 2640-2645, 2011

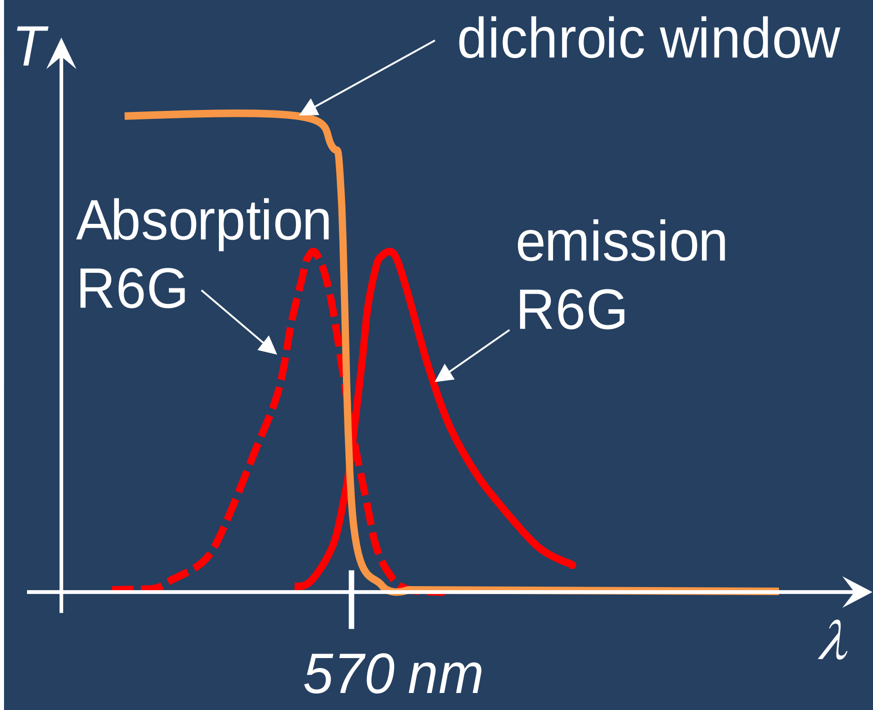
Our idea: Transverse Excitation Without Concentrator



A Fiber Laser Inside a Greenhouse Chamber



Bisson, Ueda, APLS 2004, paper TuE-B4
Endo, Bisson, Jpn. J. Appl. Phys. 2012



Applications

- Sustainable energy cycle of magnesium

(or other metal fuels)

- Airborne applications
  - Autonomous laser gyroscope
  - Hydrogen from water splitting for fuel cells.
  - …

Physicists should work on projects with scholars in different fields

I am eager to collaborate with you

Conclusion

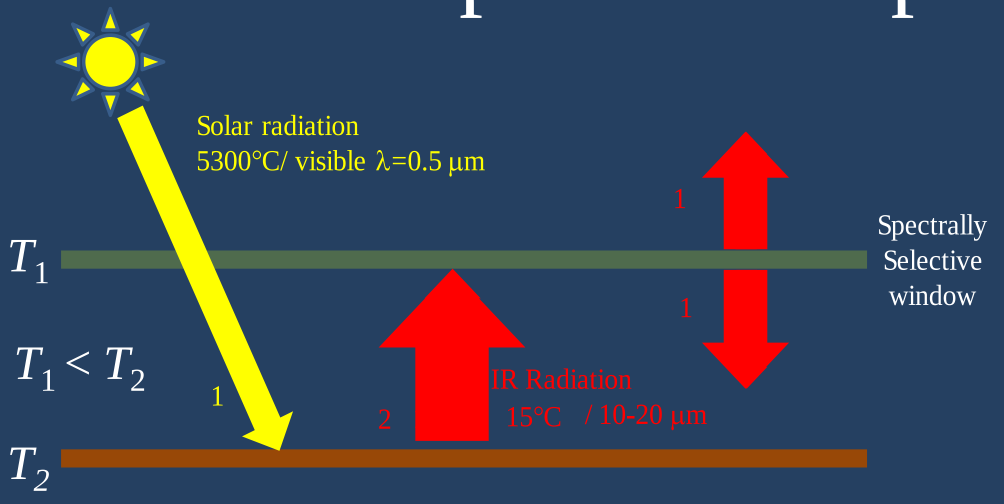
- Greenhouse gases have kept the surface of the early Earth warm enough for liquid water to exist and life to develop
- Japan is actively pursuing the exploitation of methane hydrate and solar energy.
- Lasers could help harness solar energy for several purposes

Aknowledgements

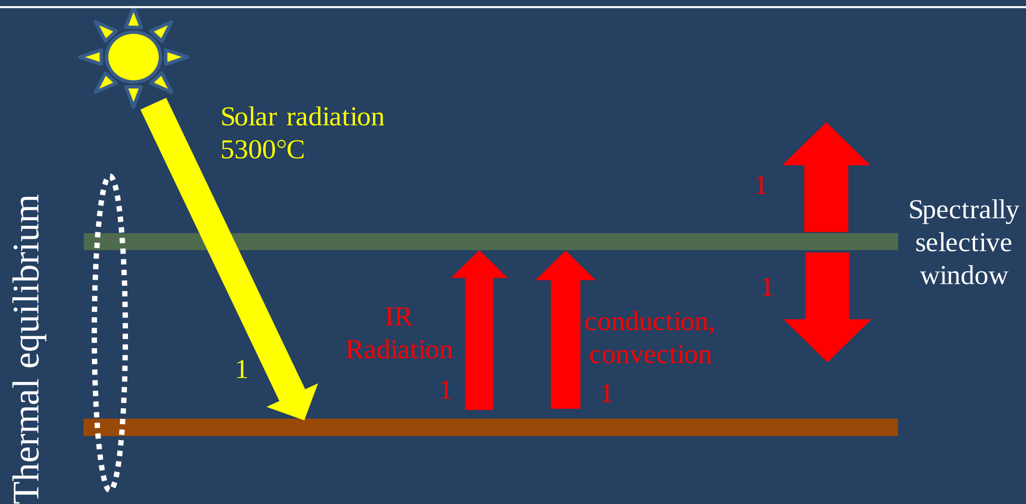
- Masamori Endo, Tokai University, Hiratsuka, Japan
- Taizo Masuda, Toyota Motors.

Thank you!

The Greenhouse Effect and the Vertical Atmospheric Temperature Distribution



Vertical temperature gradient => Existing GHG-induced surface heating



No vertical temperature gradient => No GHG-induced surface heating