Microbiology in CELS

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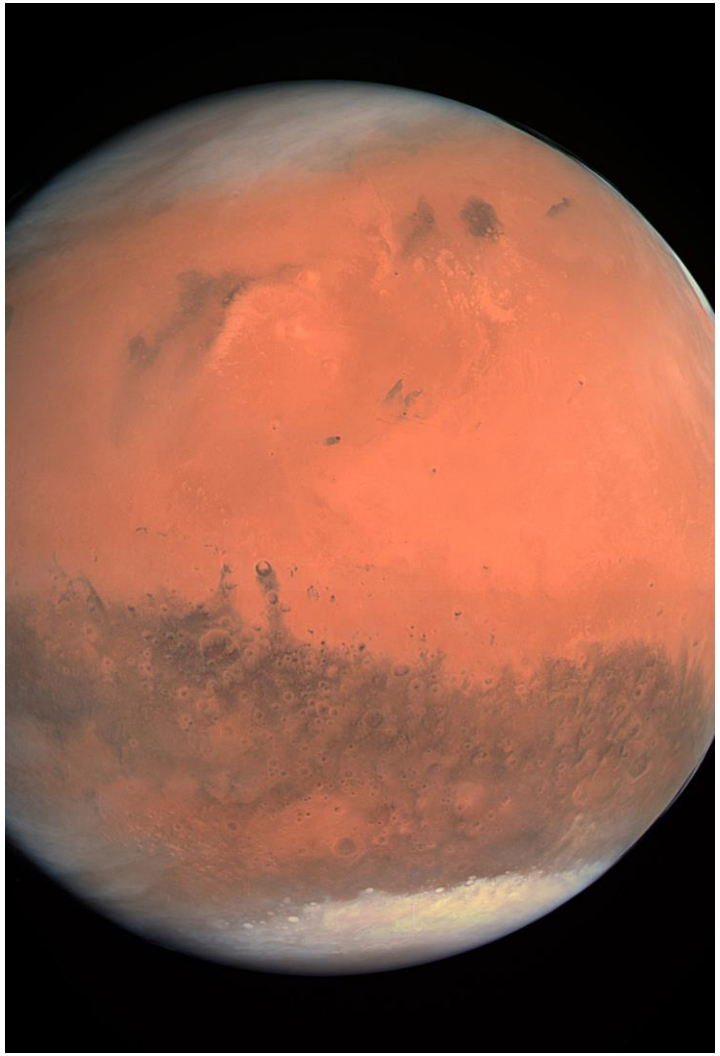


Plan

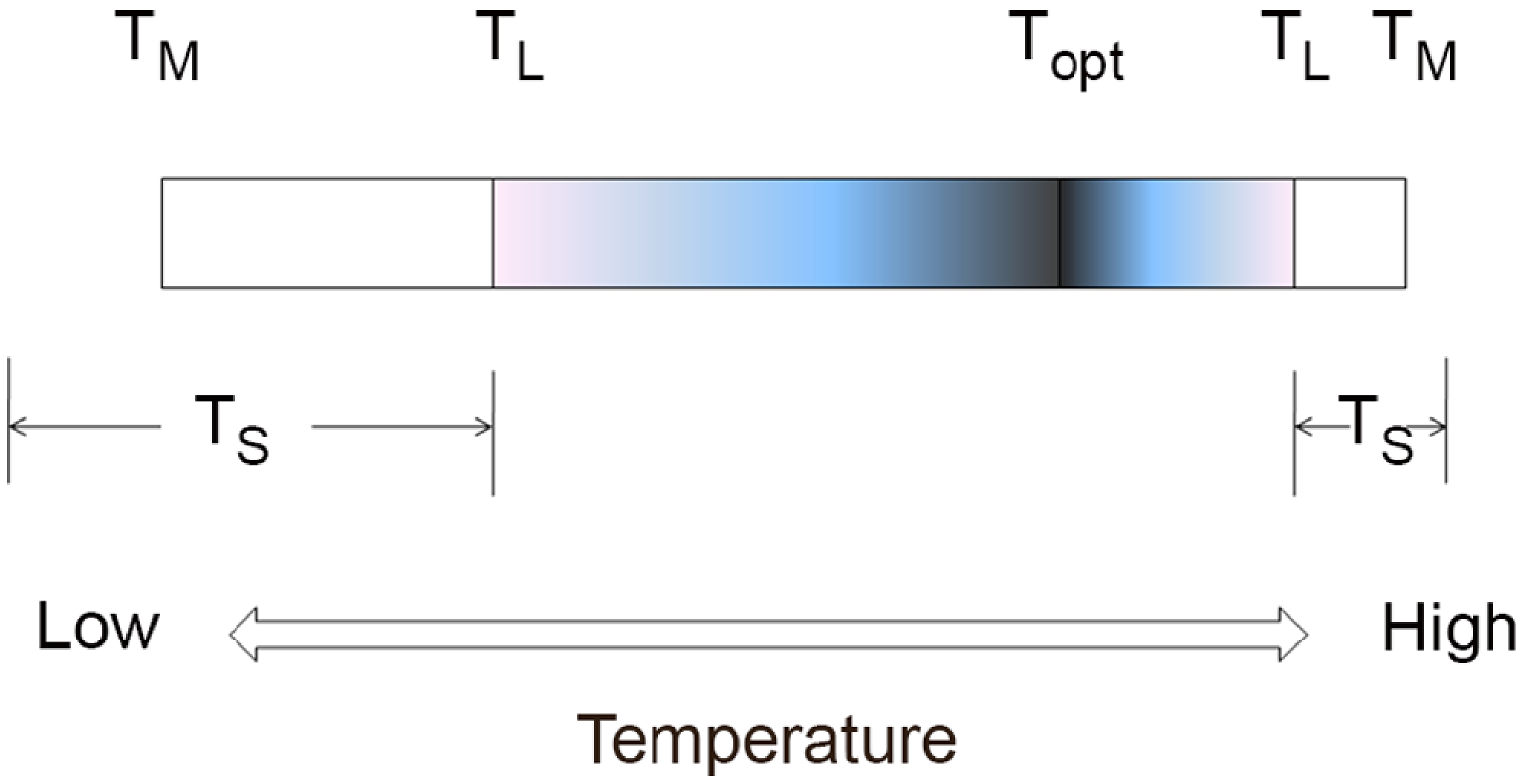
- Limitations for life on Earth
- Challenges for Earth organisms on Mars
- Possibilities for Earth organisms on Mars
- Adapting Earth microorganisms to Martian conditions
- Microbial biosignatures for detection of life on exoplanets
- Bacteria and cloud formation

Requirements for life as we know it

- Elements
  - Carbon, nitrogen, phosphorus etc
- Energy source
  - Light
  - Chemical
    - Electron donor
    - Electron acceptor
- Liquid H_2O

Limits for life

- Survival
- Activity
- Growth/reproduction



T_S: limit for survival
T_M: limit for metabolism
T_L: limit for completion of life cycle

Record-breaking extremophilic bacteria and archaea

Limits for **activity**

		Lower limit	Optimum	Upper limit
Hyperthermophile	*Geogemma barossii*	85^{o}C	???^{o}C	130^{o}C
Psychrophile	*Planococcus halocryophilus*	-25^{o}C	25^{o}C	37^{o}C
Acidophile	*Picrophilus oshimae*	pH -0.06	pH 1.1	pH 4
Alkaliphile	*Alkaliphilus transvaalensis*	pH 8.5	pH 10	pH 12.5[a]
Barophile	MT41	500 atm	700 atm	>1000 atm
Halophile	*Halobacterium salinarum*	15%	25%	32% (saturation)

[a]A variety of β-proteobacteria, *Bacillus spp.*, and *Clostridium spp.* are found at pH 13.2 in Lake Calumet, SE Chicago

Main problems for life on Mars

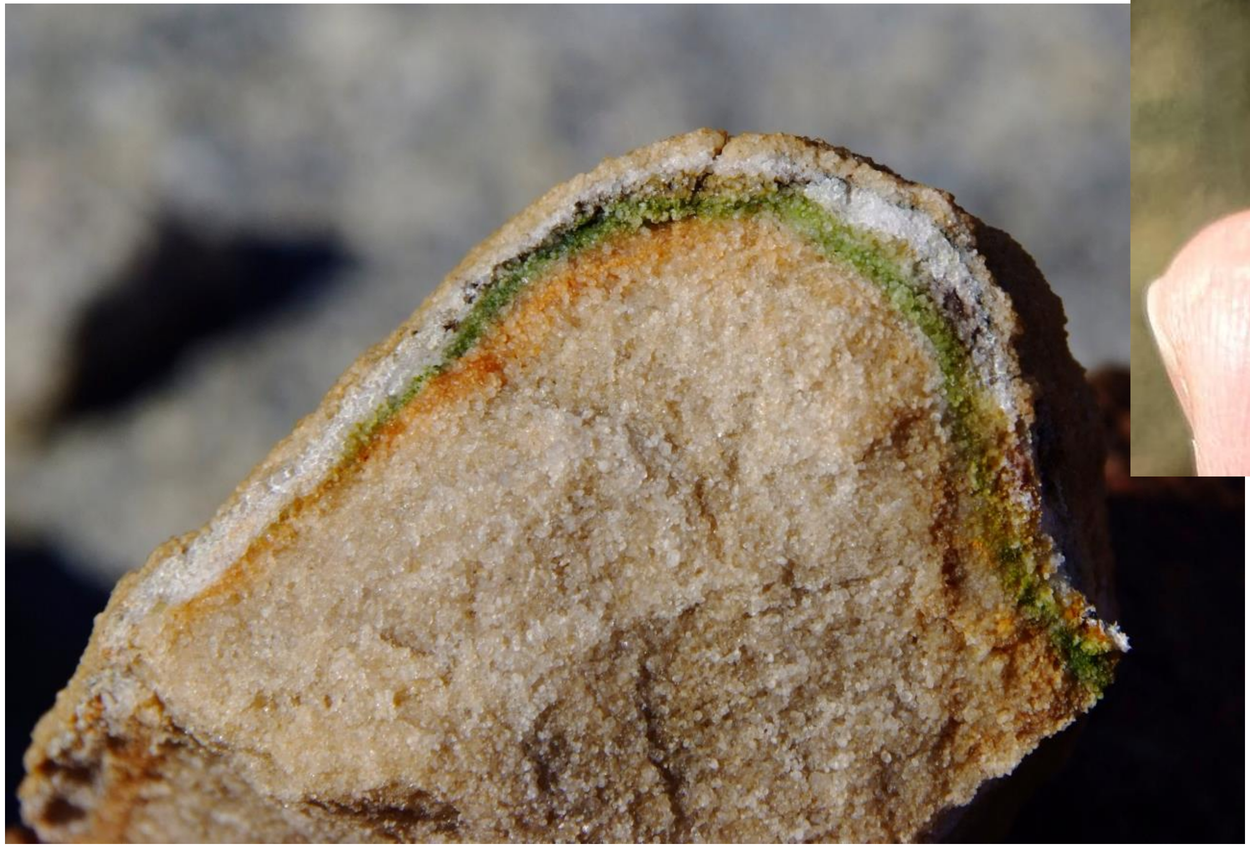
- Very little water
- Very low temperatures
- Difficult to obtain chemical energy
- High UVC radiation level
- Low atmospheric pressure

Possibilities for life known on Earth to obtain energy on Mars

Light energy (40% of Earth)

Chemical energy

Protection from drying out:
Endolithic and hypolithic cyanobacteria



Chroococcidiopsis sp.

Possibilities for life known on Earth to obtain chemical energy on Mars

- Electron donors
  - Organics from meteoric infall (total of 8.6×10^6 kg yr^{-1} ~ 60 μg m^{-2} yr^{-1})
  - Ferrous iron (Fe^{++})
  - Carbon monoxide (CO), 750 ppm
  - Hydrogen (H_2), 0.8 ppm
  - Methane (CH_4), <0.001 ppm
- Electron acceptors
  - Ferric iron (Fe^{+++})
  - Perchlorate (ClO_4^-), 0.5 solid wt%
  - Sulphate (SO_4^{2-}), 1.3 solid wt%
  - Oxygen (O_2), 1,700 ppm
  - Carbon dioxide (CO_2), 960,000 ppm

Mars analogs on Earth

Atacama Desert

- Moderate temperatures
- Annual precipitation down to 1-3 mm
- Highest level of UVA and UVB radiation on Earth
- Up to 0.3 wt% perchlorate

Mars, Gale Crater

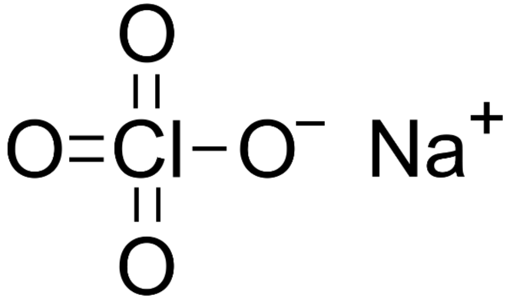
- Mean annual temp. -60°C
- No precipitation
- High UVA, UVB and UVC radiation
- 0.5 wt% perchlorate

McMurdo Dry Valleys

- Mean annual temp. -20°C
- Annual precipitation <100 mm

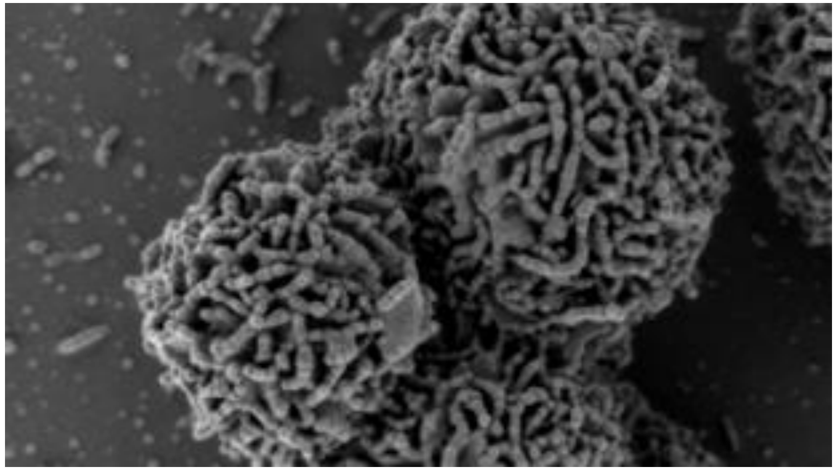
Perchlorate

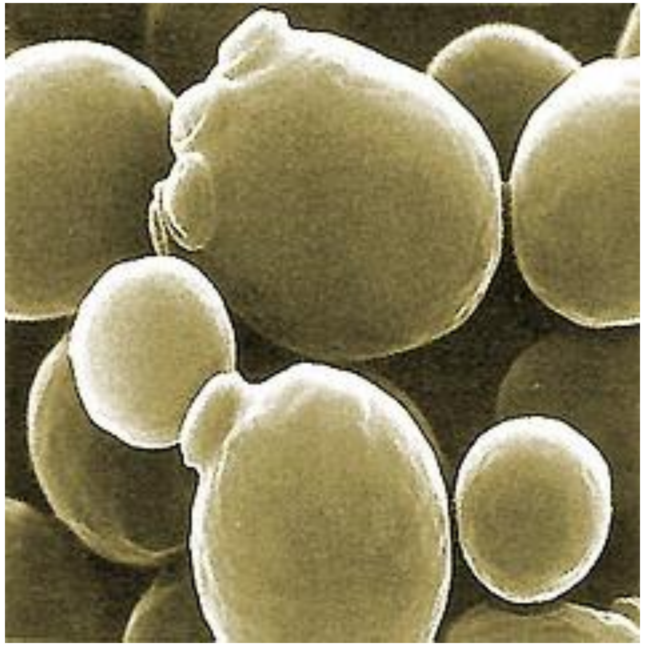
- Deliquescent
- An electron acceptor
- Made naturally in the Earth atmosphere
- Used in rocket propellants, fireworks, flares, etc.
- Toxic to humans
    - affects the thyroid gland
- Toxic to plants and (some) microorganisms
    - competitive uptake by nitrate reductase leads to highly reactive chlorite



Microbial perchlorate tolerance records

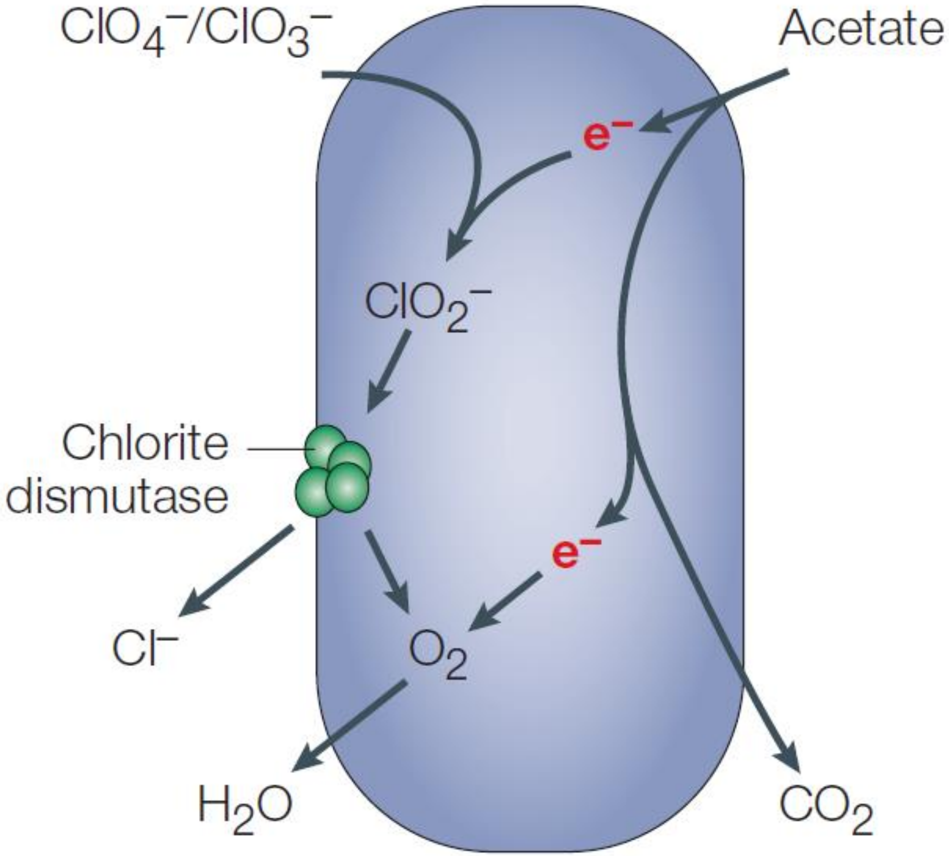
- Bacteria: *Planococcus halocryophilus* and *Halobaculum sp.* 12 % $NaClO_4$
- Fungi: *Debaryomyces hansenii* 23 % $NaClO_4$





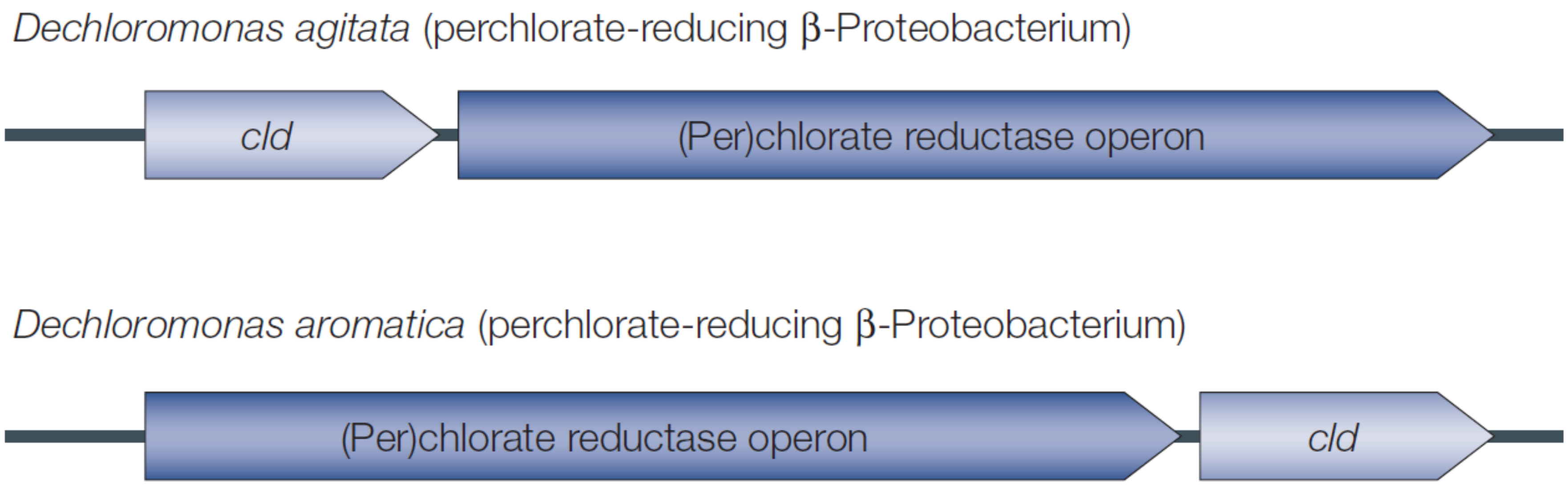
Heinz et al. 2019 Astrobiology 19:1377-1387; Heinze et al. 2020 Life 10:53

Using perchlorate as an electron acceptor: Bacterial perchlorate-reduction



Youngblut et al. 2016 Annu. Rev. Microbiol. 70:435–57

Usual organization of perchlorate reductase operon and chlorite dismutase gene *cld* in bacterial genomes



Bacterial perchlorate reduction

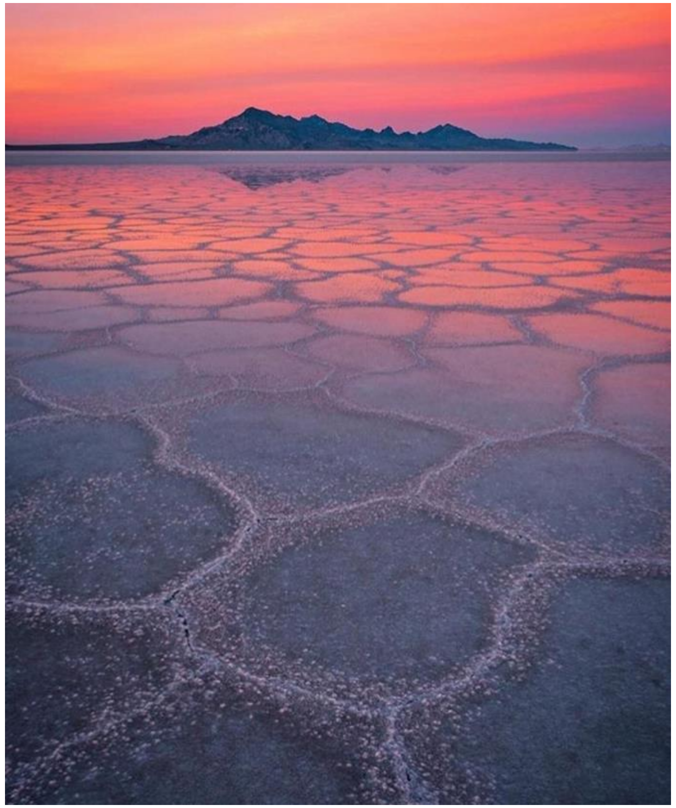
Besides simple organic compounds, perchlorate is known to be an electron acceptor coupled to oxidation of e.g.:

- Hydrogen
- Carbon monoxide

Carbon monoxide oxidation coupled to perchlorate

The archaea *Halobaculum sp.* WSA2 from salt flats in Utah can

- tolerates 12 % Na-perchlorate
- performs $CO + ClO_4^- \rightarrow CO_2 + ClO_3^-$
- consumes CO down to 2 ppm using perchlorate as electron acceptor



Myers and King 2017 Front Microbiol 8:2571

Biosignatures:
Organic volatiles produced by microorganisms in thawed permafrost soil

Table 1 The most emitted compounds

Compound	Emission rate (nmol g^{-1} dw soil h^{-1})	Relative abundance (%)
Ethanol	1.345	51.2
Methanol	0.673	25.6
Acetaldehyde	0.198	7.5
Acetone	0.134	5.1
Formaldehyde	0.103	3.9
Acetonitrile	0.062	2.4
2-Butanone	0.023	0.9
2-Butene/2-methyl-1-propene	0.010	0.4
Propyne/1.2-propadiene/cyclopropene	0.009	0.3
Cyclopropane/propene	0.008	0.3

Kramshøj et al. 2018 Nature Comm 9:3412

Bacteria in the atmosphere of Earth

Large global emission of bacteria into the atmosphere:
$7.5*10^{15}$–$3.3*10^{16}$ viable bacteria per sec

Bacteria in the dry atmosphere

- **10^4-10^5 cells per m^3**
- Residence times: days-weeks
- Extreme environment: desiccation, UV radiation, low temperature, low concentration of nutrients

Bacteria in clouds

- **1500 - 430 000 cells per ml**
- 20% of time in cloud droplets
- Favorable compared to dry air
- Harsh environment: low temperature, low concentration of nutrients, cycles of drying and wetting or freezing and thawing

Bacteria and cloud formation

- Bacteria and non-biological cloud condensation nuclei have similar size: 0.1-1 μm
- In lower troposphere (<5 km altitude): Bacteria and non-biological cloud condensation nuclei have similar abundance
- Large bacteria and bacterial aggregates may form “Giant CCN”
- *Pseudomonas syringae* and some other bacterial species produce ice-nucleating proteins

Thank you for your attention