宇宙線で繋ぐ文明・地球環境・太陽系・銀河
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# 宇宙線による星間・初期惑星でのアミノ酸生成
# Formation of Amino Acids in Interstellar and Early Planetary Environments by Cosmic Rays

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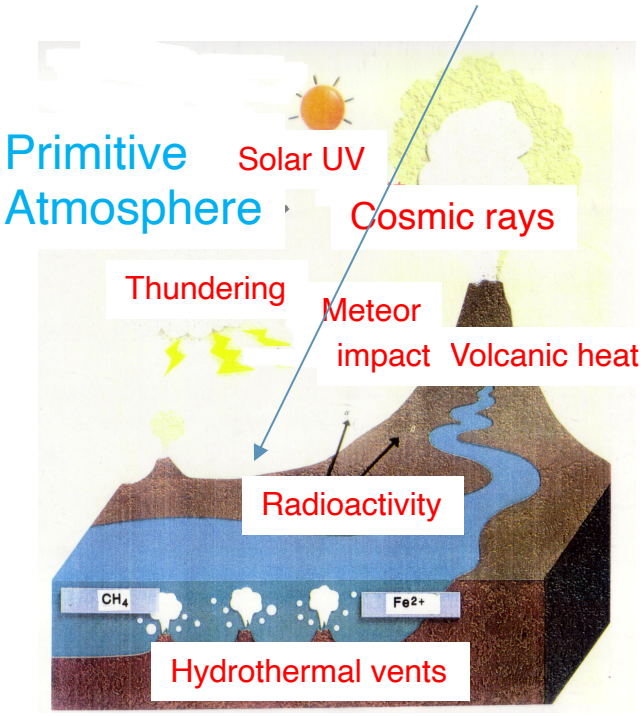
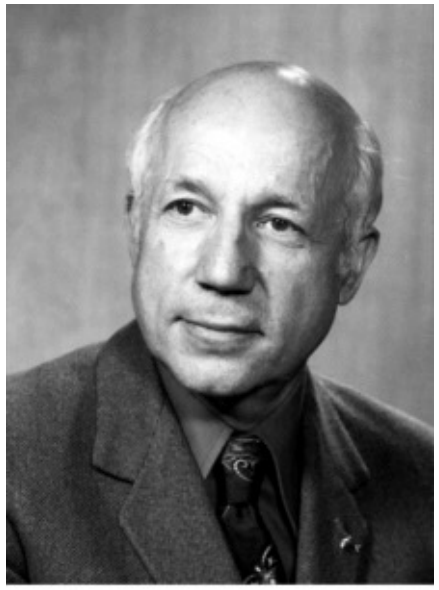
# Outline

1. Miller's Experiment and Conventional Scenario of Chemical Evolution
2. Cosmic Ray Production of Amino Acid Precursors in Molecular Clouds
3. Cosmic Ray Production of Amino Acid Precursors in Early Atmosphere
4. Origin of Bio-homochirality by Cosmic Ray?
5. Conclusion and future prospect

# Origins of Life: Experimental Approaches to Prebiotic Chemistry

Atmosphere ➡ Non-reducing *vs.* Strongly-reducing



- ✓ Composition of early Earth atmosphere?
- ✓ Energy for prebiotic synthesis?

Calvin

$CO_2$, $H_2O$, $Fe^{2+}$ → HCHO, HCOOH

(Garrison et al. 1951)

Miller

$CH_4$, $NH_3$, $H_2$, $H_2O$ → Amino acids

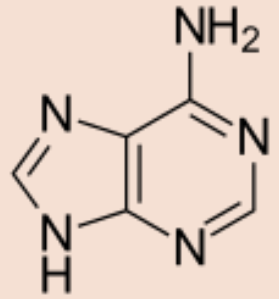
(Miller, 1953)

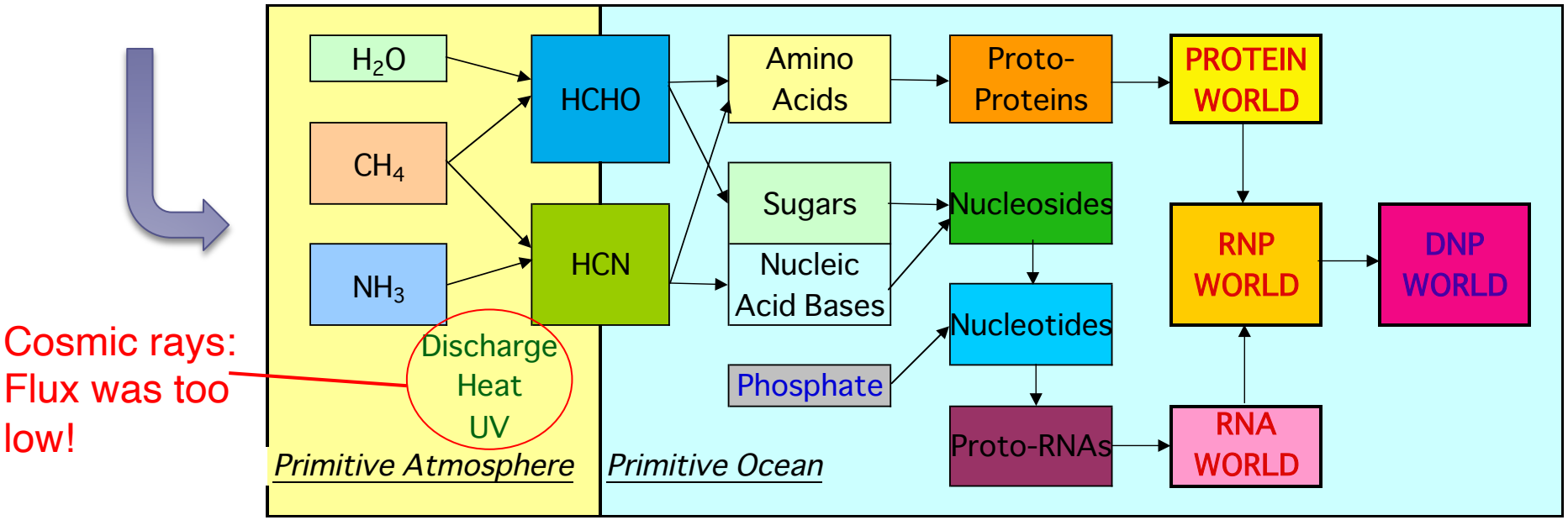
Energy ➡ Radiation ($\alpha$-rays irradiation) Thundering (Spark Discharges)

# The Classical Scenario of Chemical Evolution

- Miller (1959) proposed amino acid formation via the Strecker synthesis *
- Oro (1960):
  Adenine synthesis from HCN solution**
- Orgel et al. (1970s-80s):
  Abiotic syntheses of oligonucleotides

*$HCN + RCHO + NH_3$
$\rightarrow NH_2\text{-}CHR\text{-}CN$
$\rightarrow NH_2\text{-}CHR\text{-}COOH$
$2\ H_2O$ (amino acid)

**HCN
$\rightarrow NHCH{=}CN$
$\rightarrow NH_2CH(CN)_2$
$\rightarrow \quad \rightarrow \quad \rightarrow \ldots$
$\rightarrow$ 
(adenine, $C_5H_5N_5$)



# Origins of Bioorganics for the First Life

$CH_4$
$NH_3$
$H_2$
$H_2O$

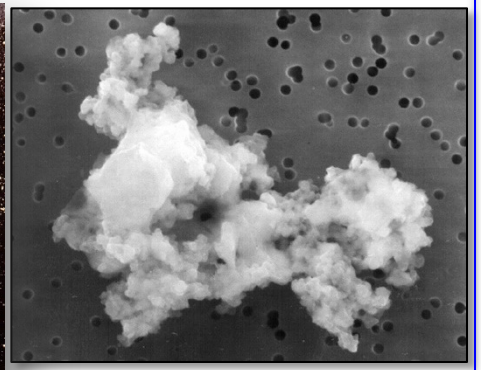
Miller's Experiment (1953)

Primitive earth atmosphere was not strongly reducing, but only slightly reducing (1980s～)

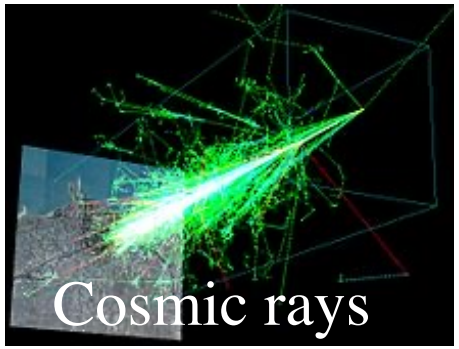
$CO_2$
CO
$N_2$
$H_2O$

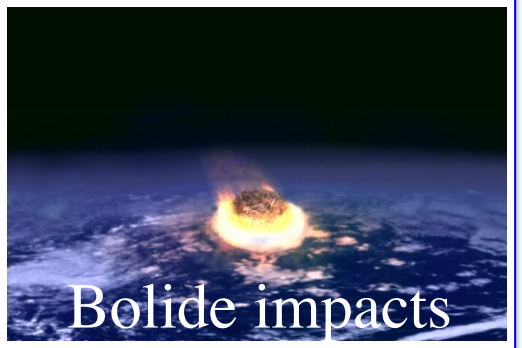
Formation of Amino acid by thundering or solar UV was difficult.

## Delivery of extraterrestrial organics

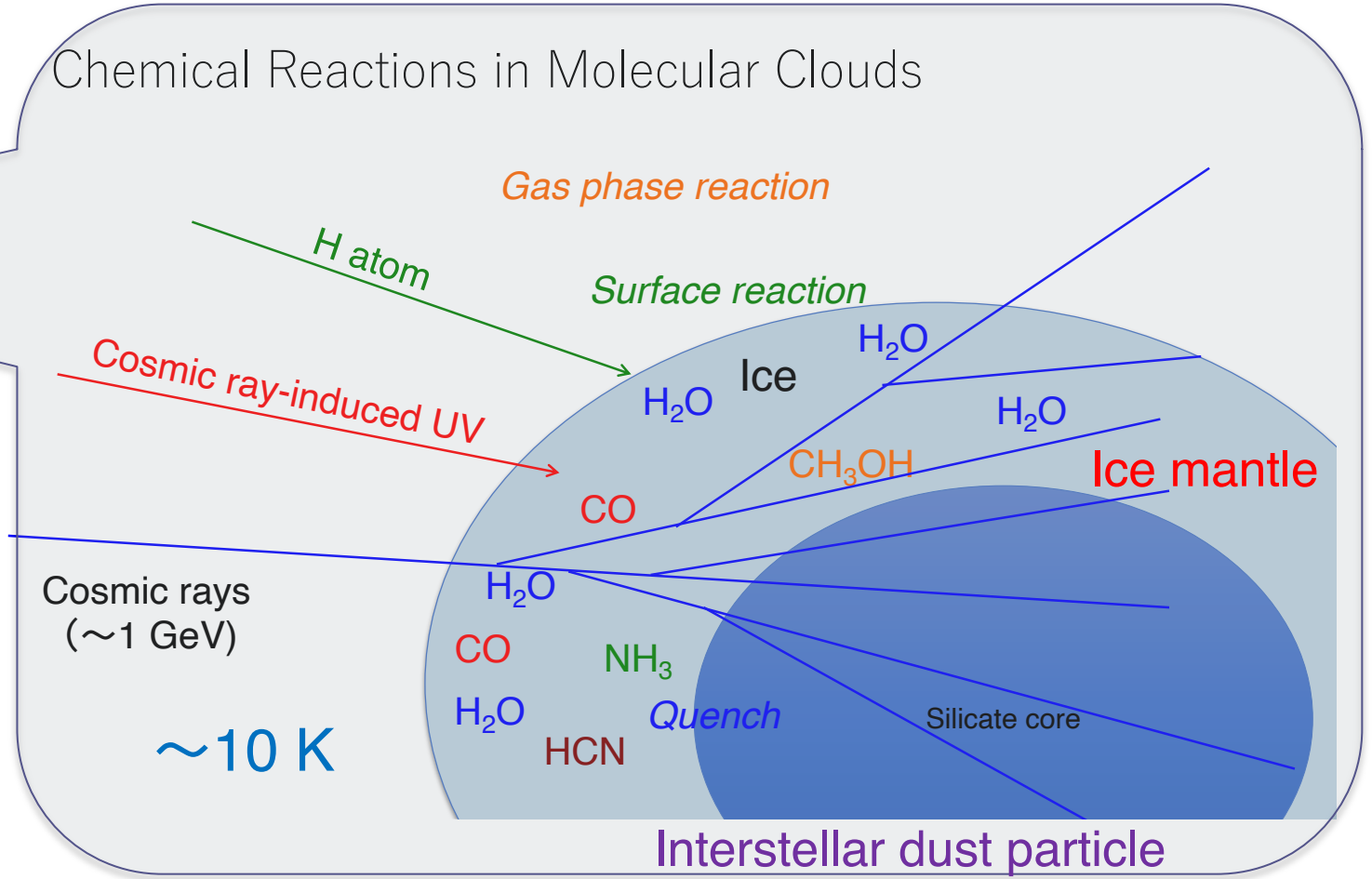
## Contribution of alternative energies



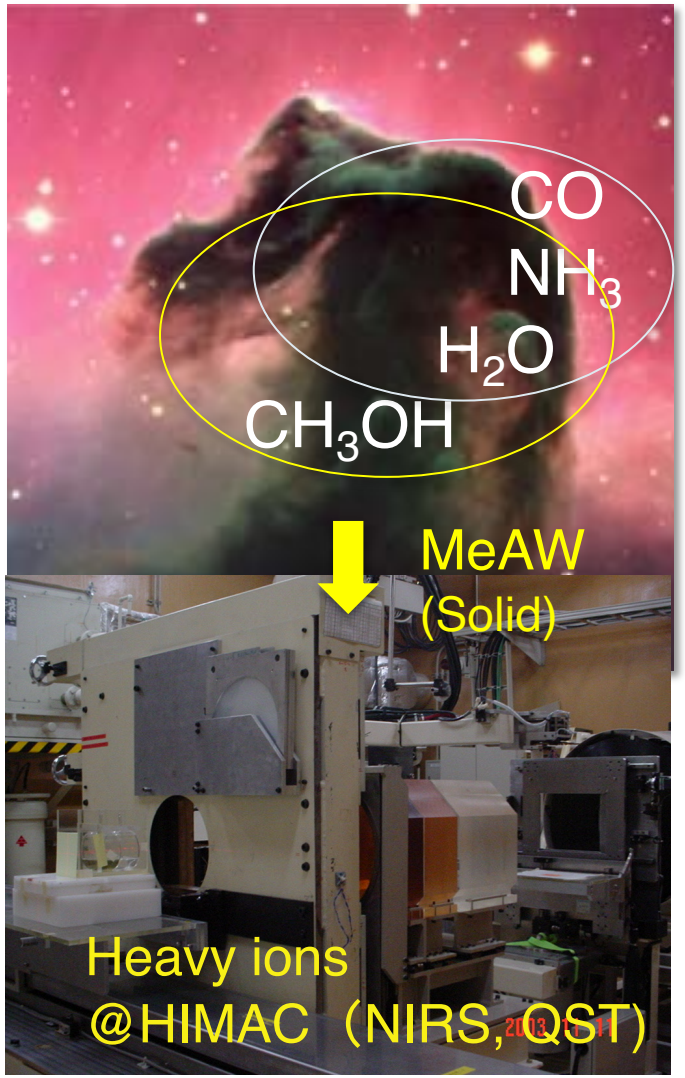
# Possible Formation Sites of Complex Organics: Interstellar Dust Particles in Molecular Clouds

Horsehead Nebula © ESO

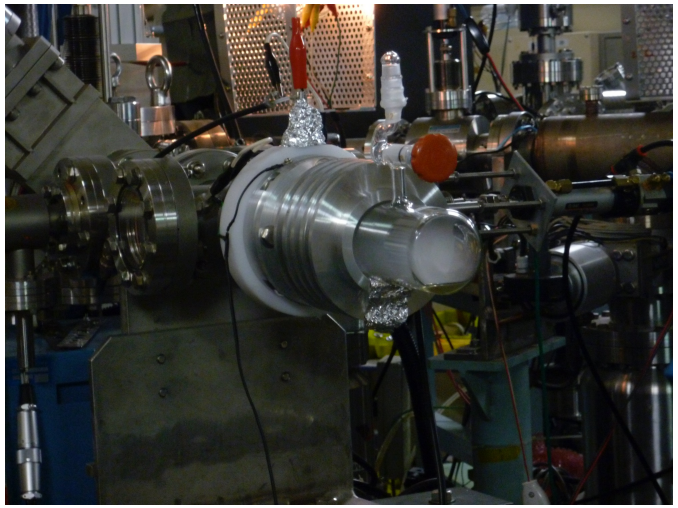



Canonical Greenberg Model:
Cosmic rays are too high an energy to induce reactions

# Amino Acid Formation Experiments: Particles Irradiation of Simulated Interstellar Media




CAW
(Gas)



Protons
@Tandem Accelerator
(Tokyo Tech)

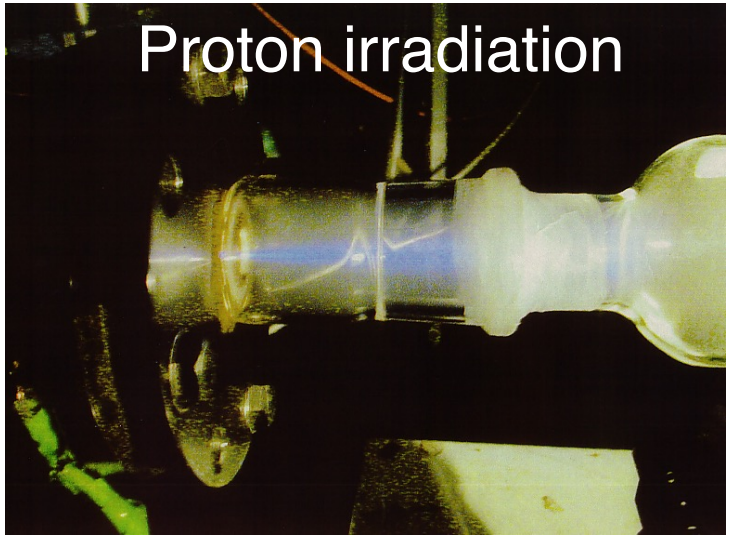
- ✓ Frozen mixtures of $H_2O$, $CH_3OH$ & $NH_3$ (100: 10: 1) gave amino acid precursors by irradiation with 290 MeV/u (3.48 GeV) carbon ions.
- ✓ Mixtures of CO, $NH_3$ and $H_2O$ gave amino acids precursors and nucleic acid bases in high yield.

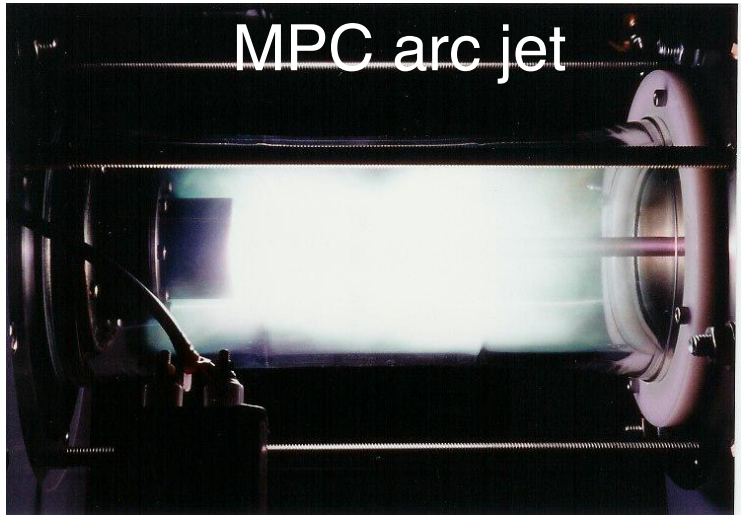
# Endogenous Production: Possible Formation of Bioorganics in Primitive Earth Atmosphere

Materials :
Weakly-reducing gas mixtures
($CO_2$, CO, $N_2$, $H_2O$)*
Energies:
Cosmic rays (Proton irradiation)
Bolide impacts (MPD arc jet)

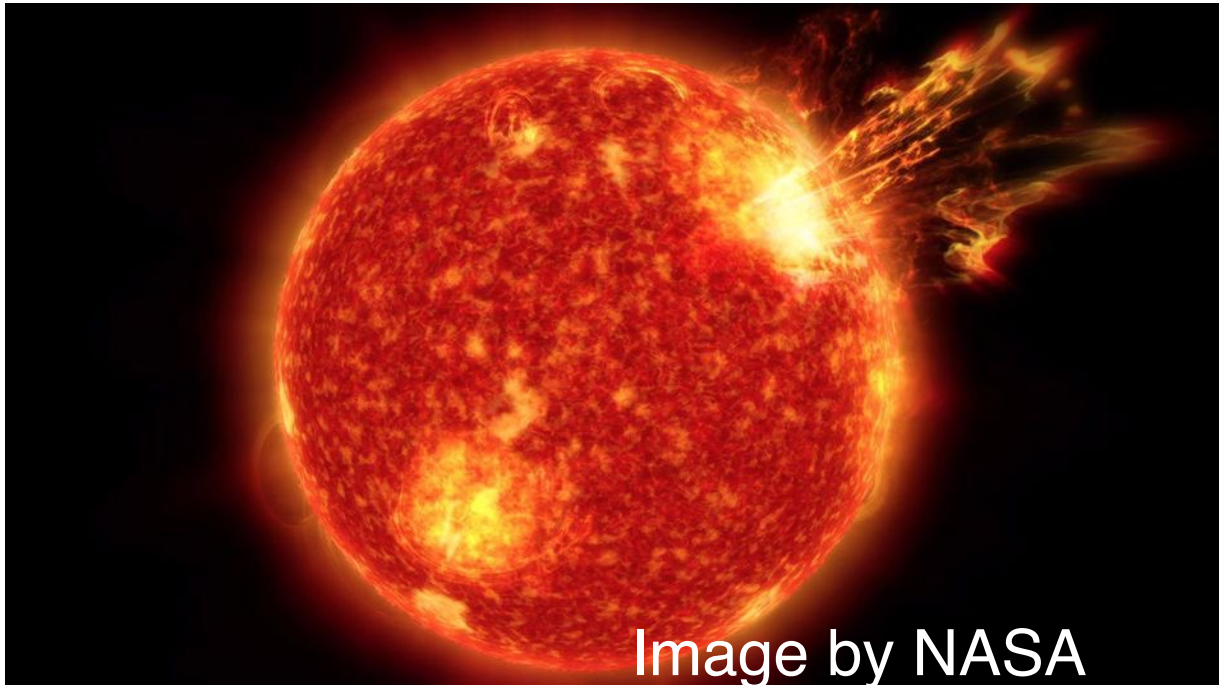
*Kasting, OLEB,1990

Amino acid precursors and nucleic acid bases are produced (Miyakawa+ PNAS 2002)



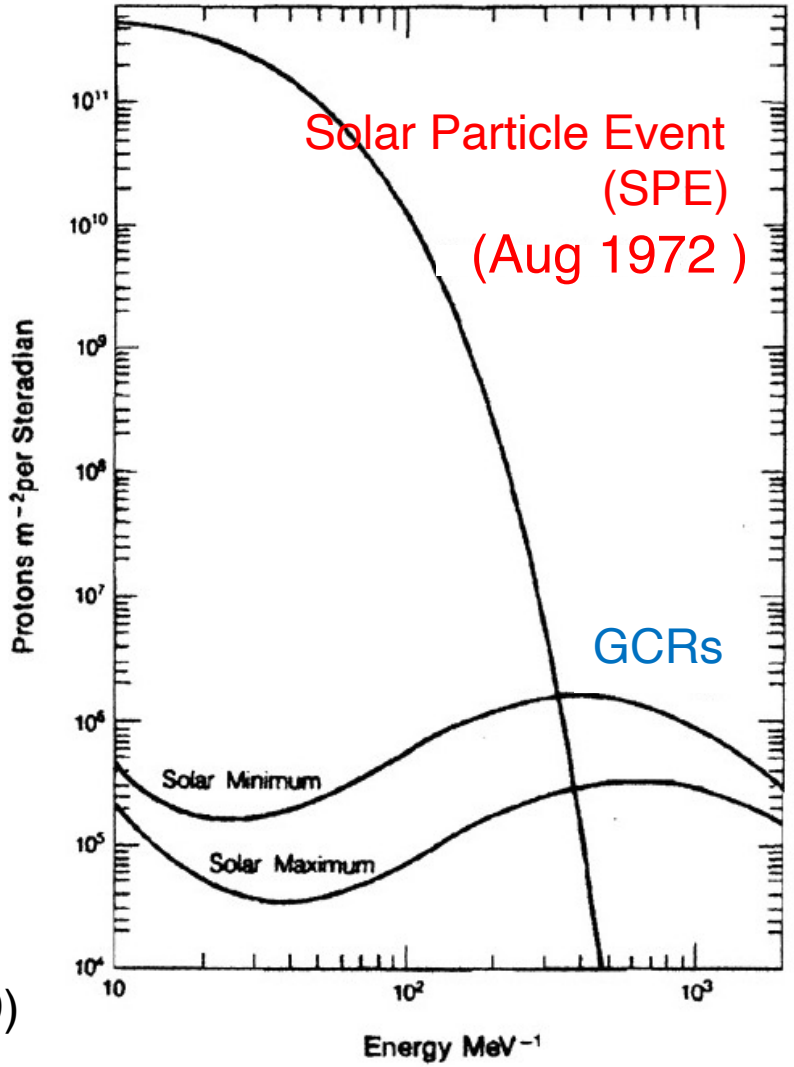
# Solar / Stellar Energetic Particles (SEPs) from Solar Flares/Coronal Mass Ejections




- ✓ Superflares were found in Solar-type Stars (Maehara+, 2012)
- ✓ Extreme solar flares shot out by the young suns

$E$(SPEs) = $10^4 \sim 10^5$ $E$(GCRs) (Airapetian+, 2019)

Airapetian+, 2016



# Endogenous Production of Amino Acids and Organic Carbon at 4 Billion Years Ago

GCRs energy flux*:

0.5 kJ $m^{-2}$ $yr^{-1}$ $2\pi^{-1}$

G-value of @5 % CO Atmosphere**:

Amino acids: $5 \times 10^{-3}$

Organic carbon: 0.3

Production rate

Amino acids: $10^{10}$ g $yr^{-1}$

Organic carbon: $10^{11}$ g $yr^{-1}$

SEPs energy flux***:

10 MJ $m^{-2}$ $yr^{-1}$ $2\pi^{-1}$

G-value of @5 % CO Atmosphere*:

Amino acids: $5 \times 10^{-3}$

Organic carbon: 0.3

Production rate

Amino acids: $10^{14}$ g $yr^{-1}$

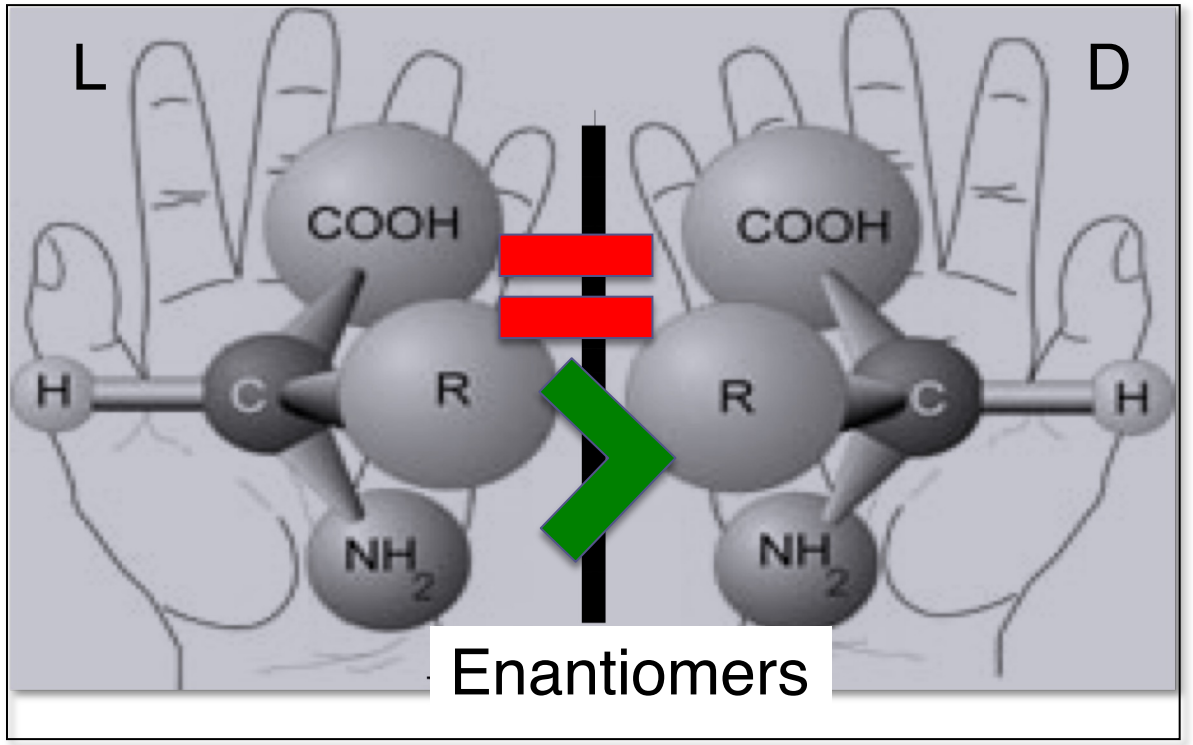
Organic carbon: $10^{15}$ g $yr^{-1}$

*Kobayashi+, OLEB, 1998)

**315 Torr $CO_2$, 35 Torr CO, and 350 Torr $N_2$ with water vapor was irradiated with 2.5 MeV protons.

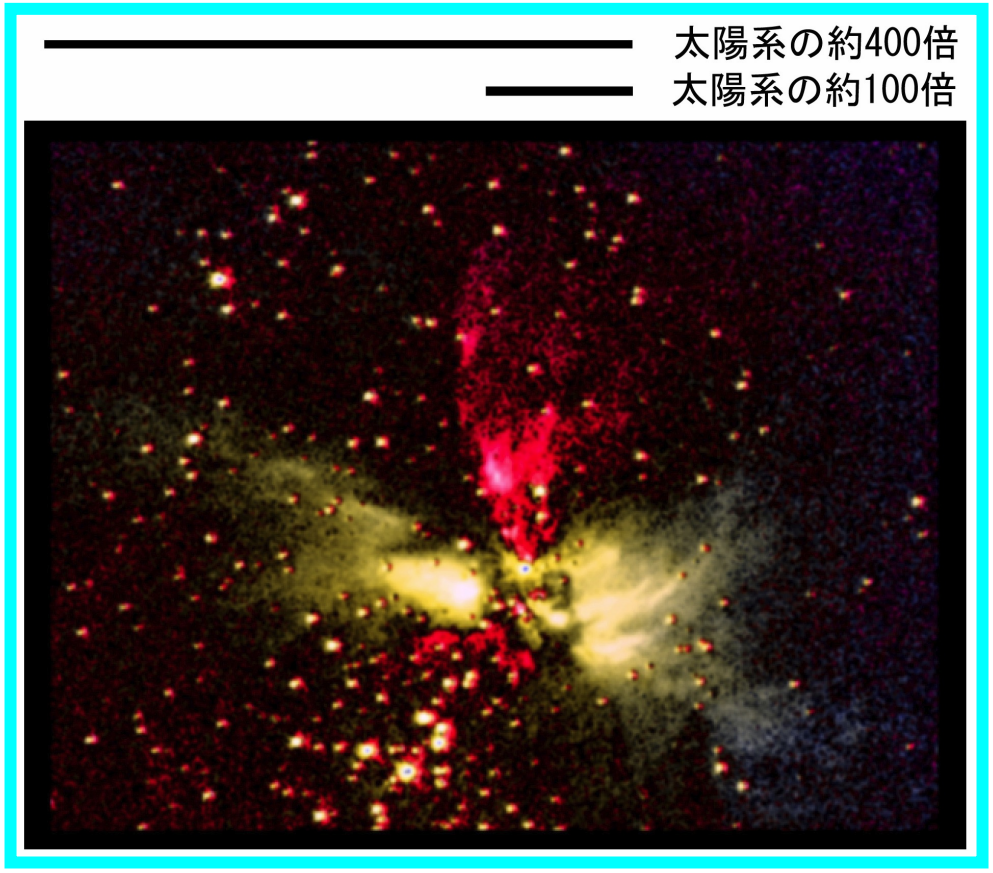
***Our estimation that SEPs flux was 4-5 orders of magnitude larger than GCRs.

# Origins of Bio-Homochirality

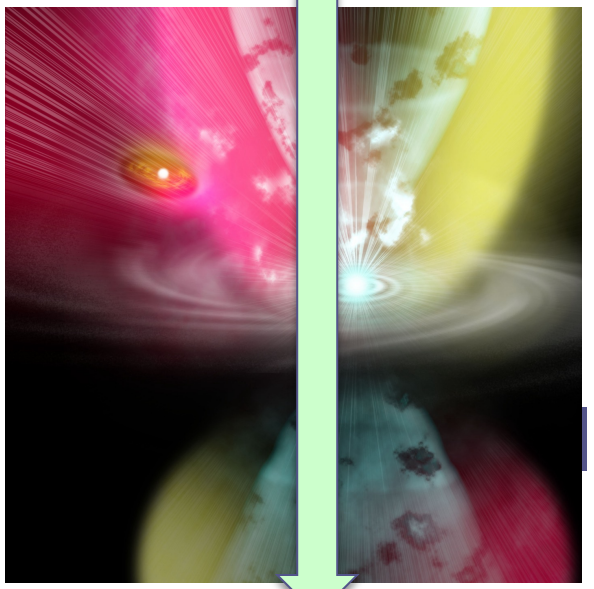




Cronin and Pizzarello, 1997

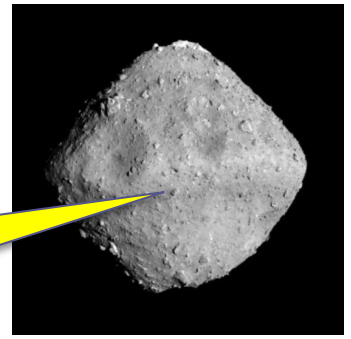
# Formation of Seeds of Homochirality
## (1) Circularly Polarized Light in Space




L–AA = D–AA



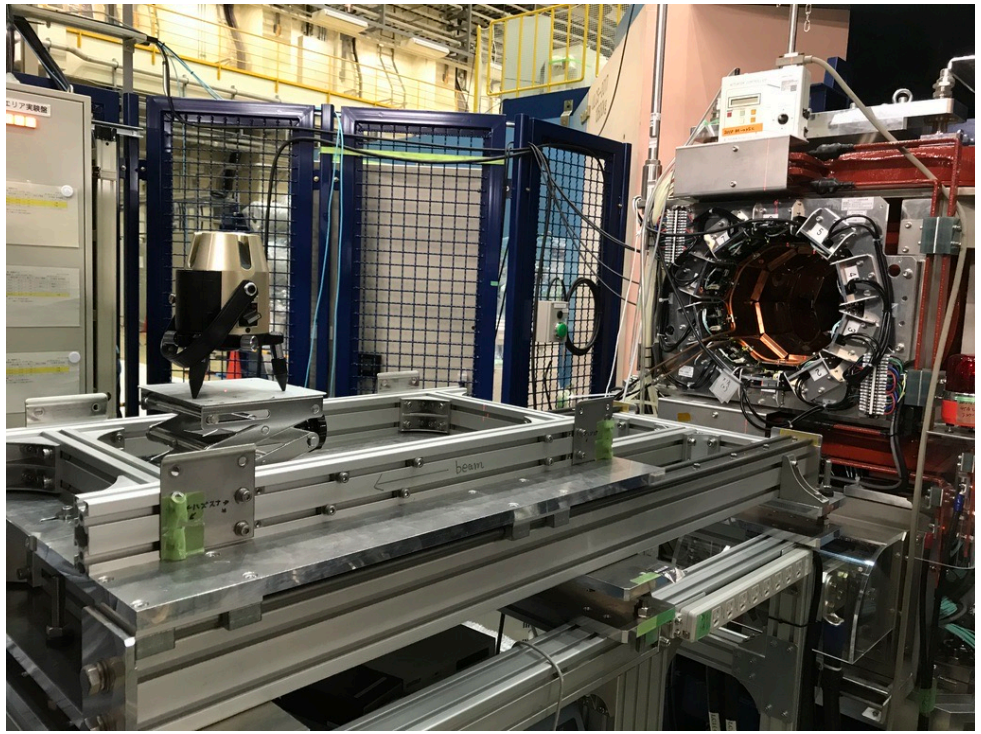
L–AA > D–AA



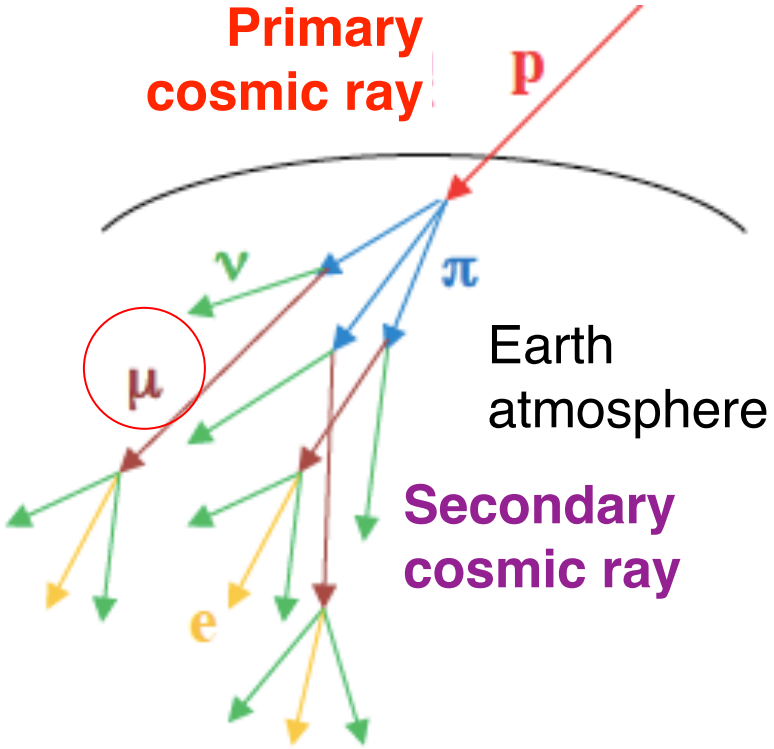
Circular polarized light is distributed over the area of 100 times larger than the solar system.

(Takano+, EPSL, 2007)

# Formation of Seeds of Homochirality
# (2) Spin-Polarized Muons in planetary atmosphere and in space



Muon Irradiation @ J-PARC



# Garakuta World Hypothesis: Chemical Evolution from Non-Life ($L$=0) to Life ($L$=1)

Extraterrestrial Life

*No Relics on the Earth!*

Non-Life

Garakuta Molecule

Auto-catalytic molecule?

Garakuta Life

RNA World?

Commonote (Earth)

Extant Life (Earth)

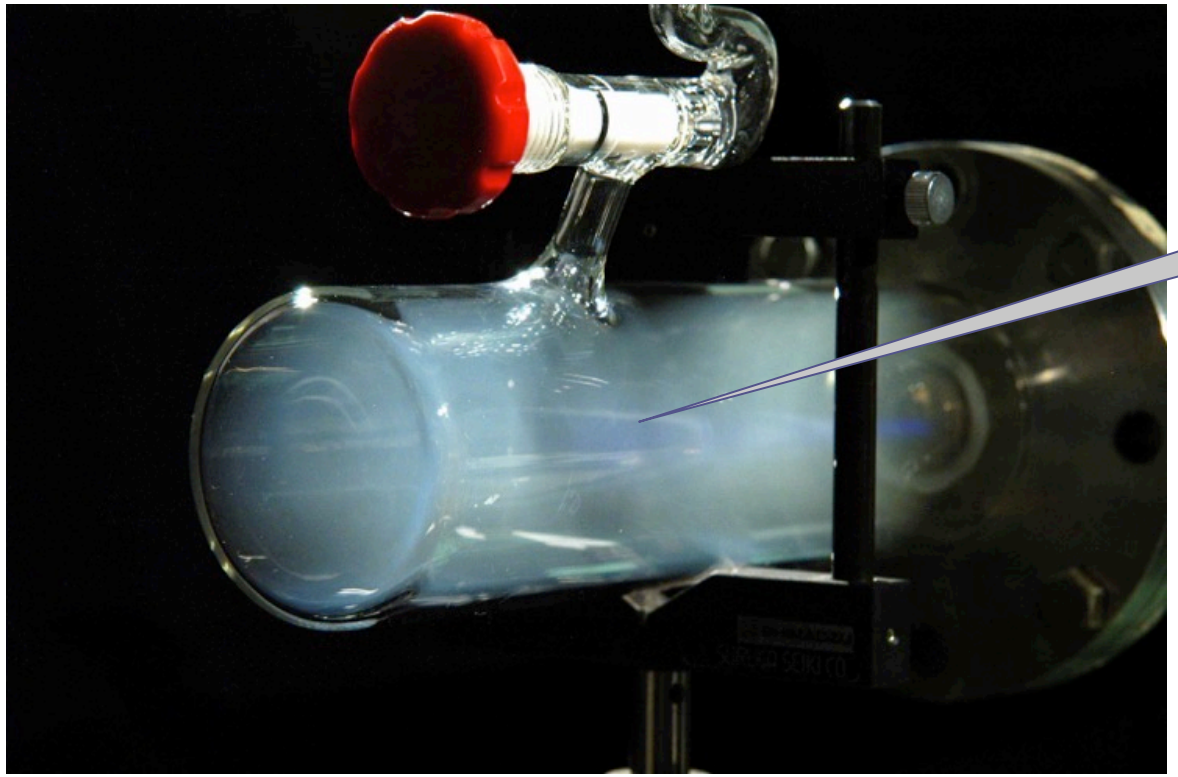
Proteinoid microspheres?

0 $10^{-10}$ $10^{-8}$ $10^{-6}$ $10^{-4}$ $10^{-2}$ 1 1

$L$

(Life 1.0)

# Formation of Complex Organics (*Tholins*) in Simulated Titan Atmosphere by Cosmic Rays



$N_2 + CH_4$

Complex solid organics (*tholins*) were formed, which yielded amino acids and bases after hydrolysis (Taniuchi+, Anal. Sci., 2013)

Dragonfly mission
（landing in 2036? ）© NASA

# *Thank you for your attention!*

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