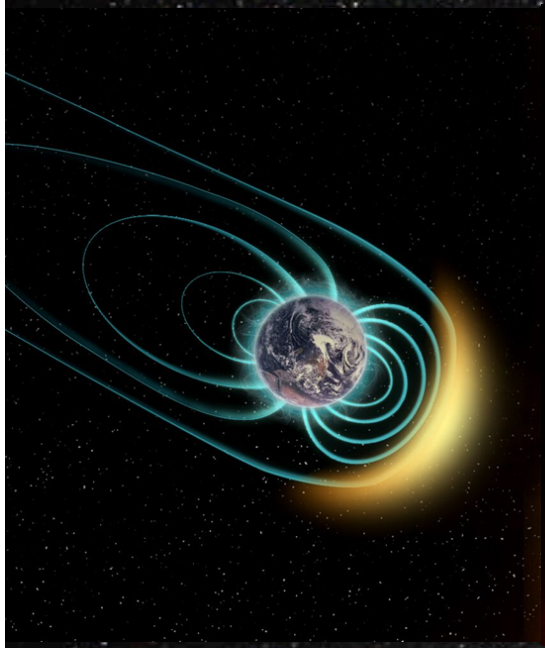
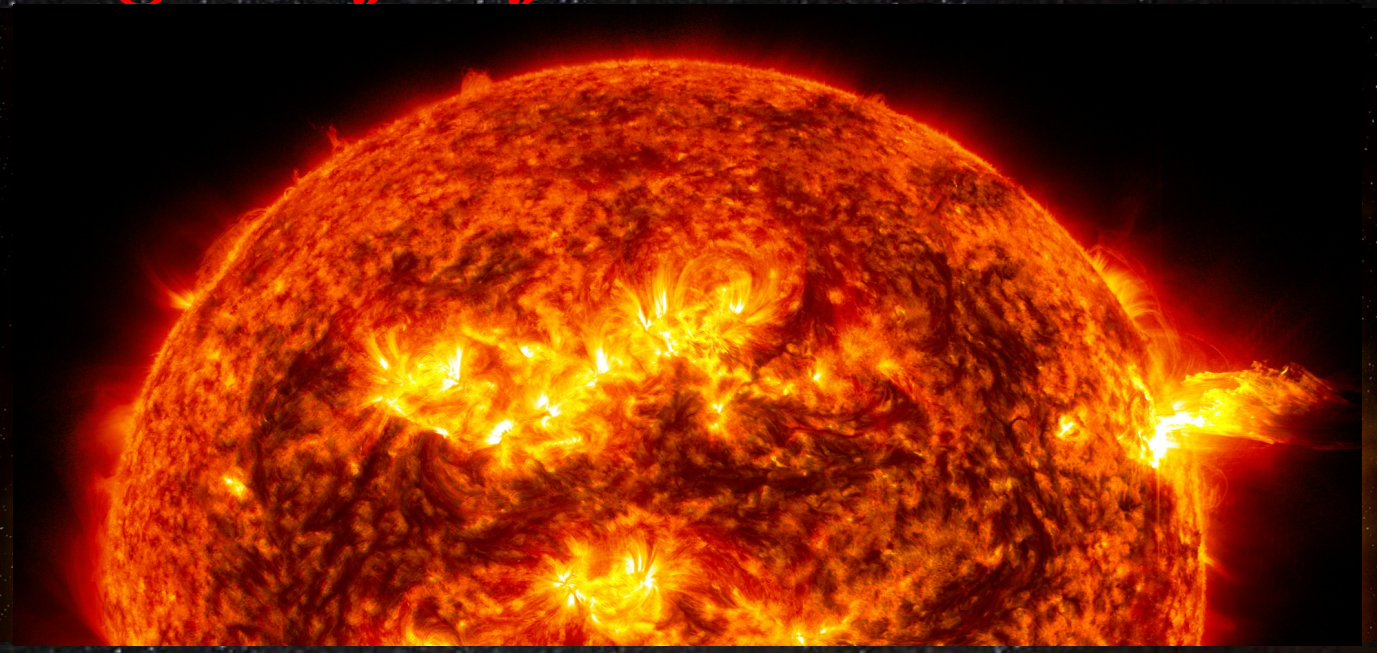
NAI/NExSS STG ISSI EON

Activity of the Young Sun and The Origin of Life On Earth





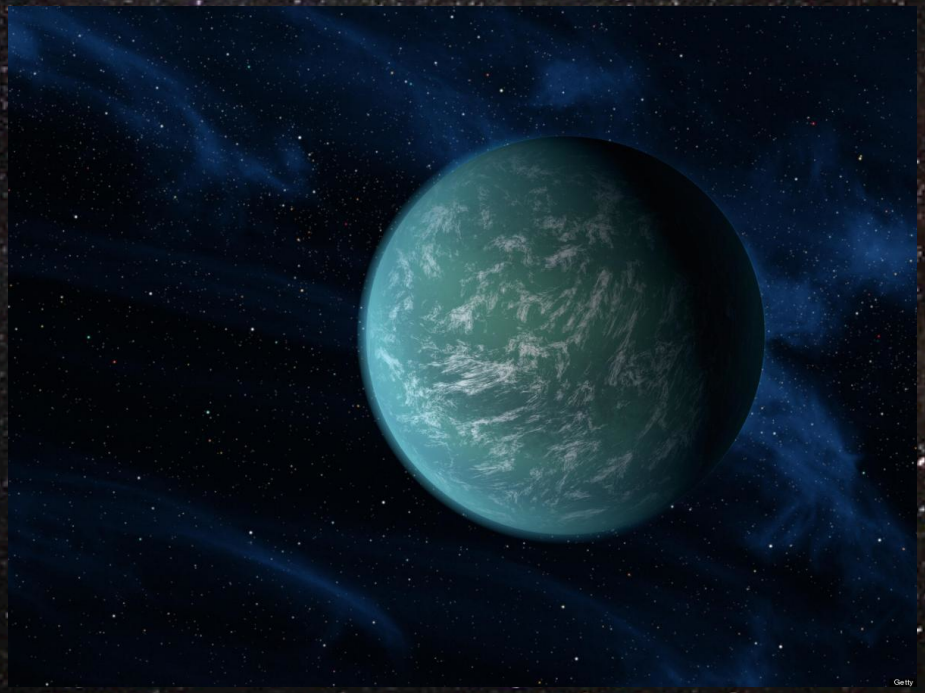
Vladimir Airapetian (CUA/GSFC) & The Dream Team

Danchi, Glocer, Gronoff, Hebrard, Khazanov, Usmanov, Dong, France, Lloyd, Sojka, Del Genio, Jackman, Liemohn, Mlynzcak, Zank, Kobayashi, Carpenter, Rabin, Chen

USNO Scientific Colloquium, 01/26/17

THE BIG QUESTION

ARE WE ALONE IN THE UNIVERSE?
HOW COMMON IS LIFE?



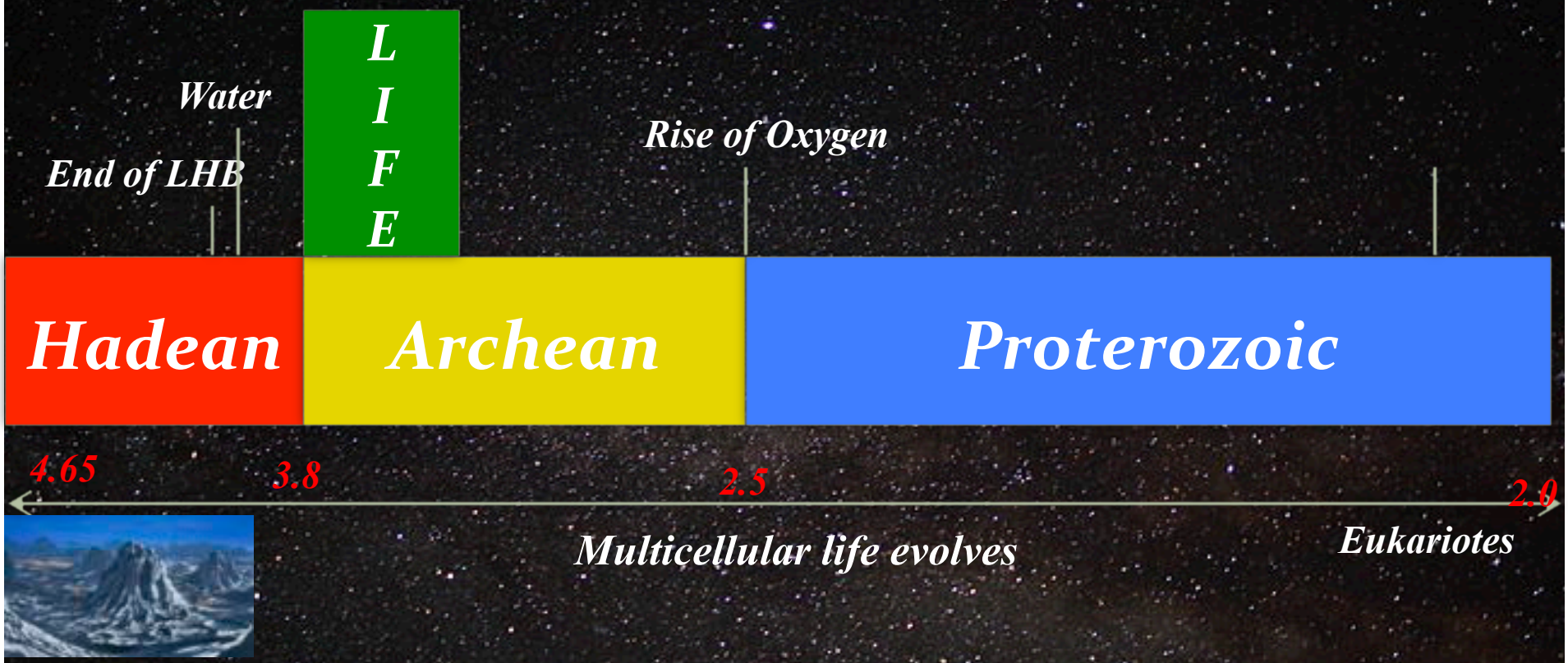
IT TAKES A VILLAGE or A DREAM TEAM TO ANSWER THESE QUESTIONS !

NAI/NExSS Team: Mission to Young Earth 2.0

How To Find a Planet Habitable With Life?

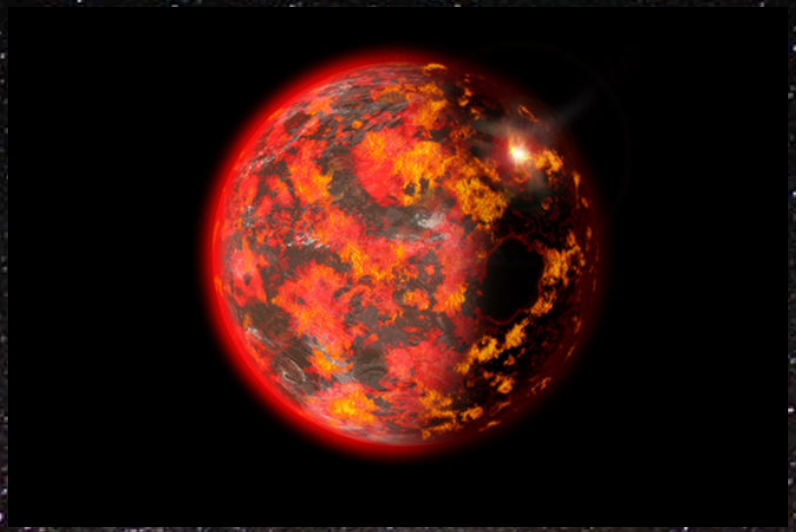
- ***How did life form and evolve on early Earth?***
  Search for life in the Universe starts at our own planet and the Solar System.
- ***What is the role of a host star on the origin and evolution of life on exoplanets?***
- ***How can life be detected ?***

How Old Is Life?



"Hadean" from Hades, the Greek god of the underworld.

Hadean Earth -The First 0.8 Gyr



Accretion, H/He atmosphere

0

0.1 Gyr
magma ocean

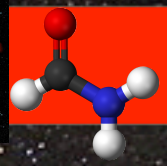
N_2, CO_2, CH_4
H_2O, SO_2

0.2- 0.3 Gyr

Stable hydrosphere
Oceans

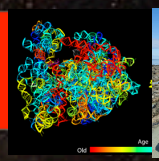
LHB

Prebiotic chemistry



0.5 Gyr

RNA world

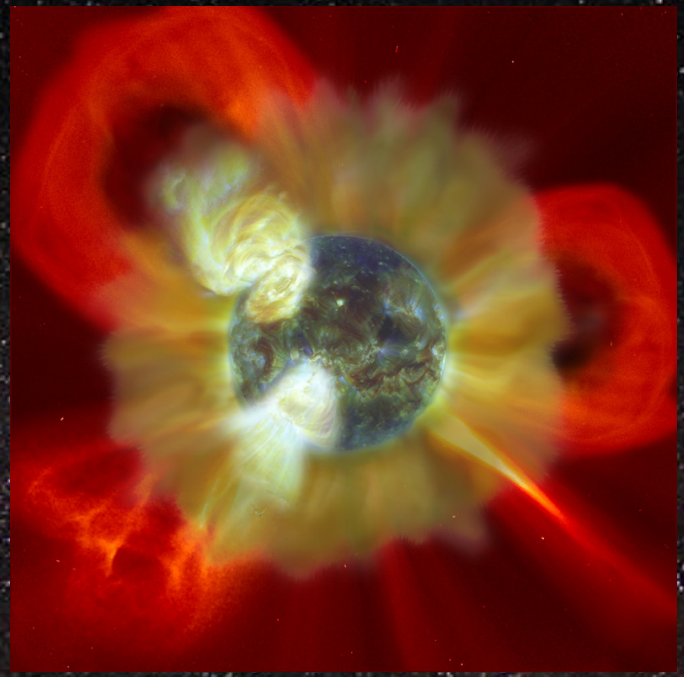


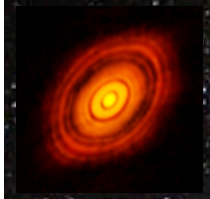
0.8 Gyr

Fossilized mats of cyanobacteria
Zirkons

Magnetic field

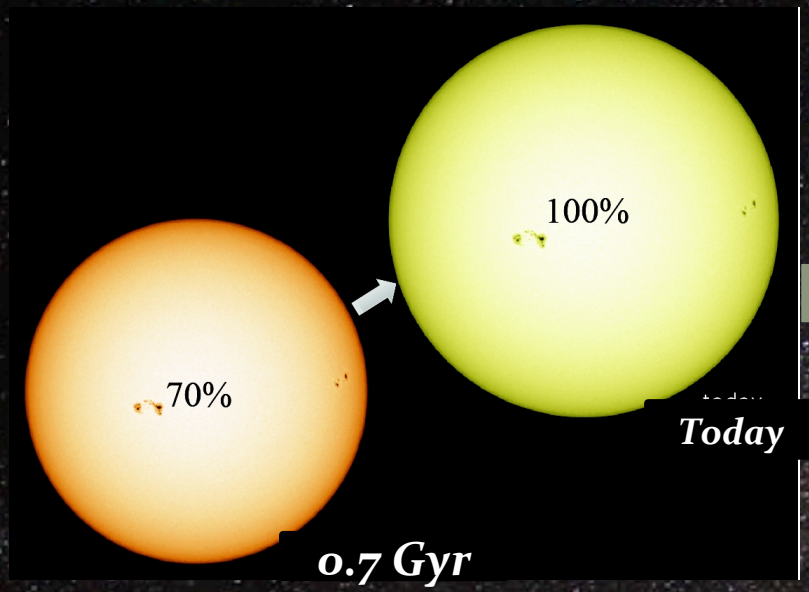
Hadean Sun-The First 0.5 Gyr

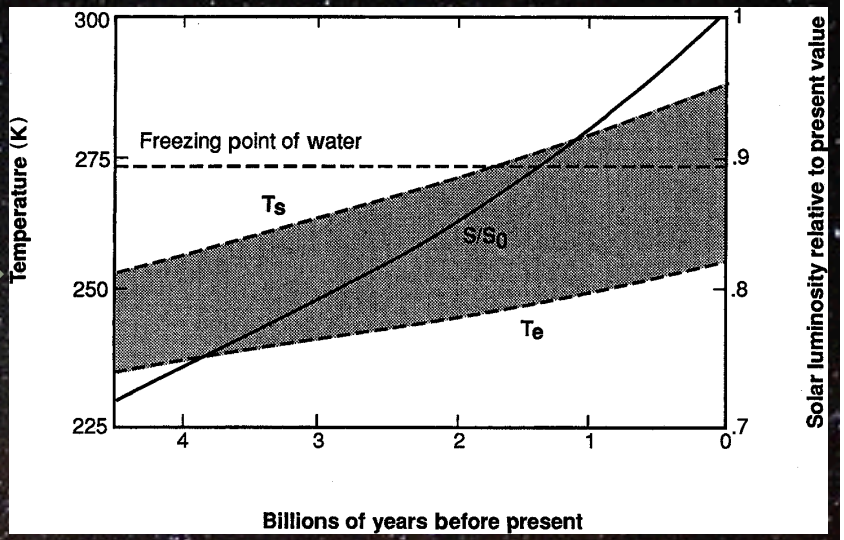




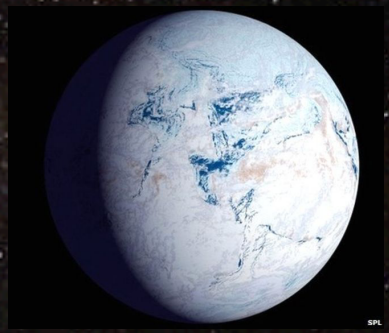
0 ***T Tau phase*** ***Faint Explosive Sun*** ***0.5 Gyr***

The Young Sun Was Also a Fain Star

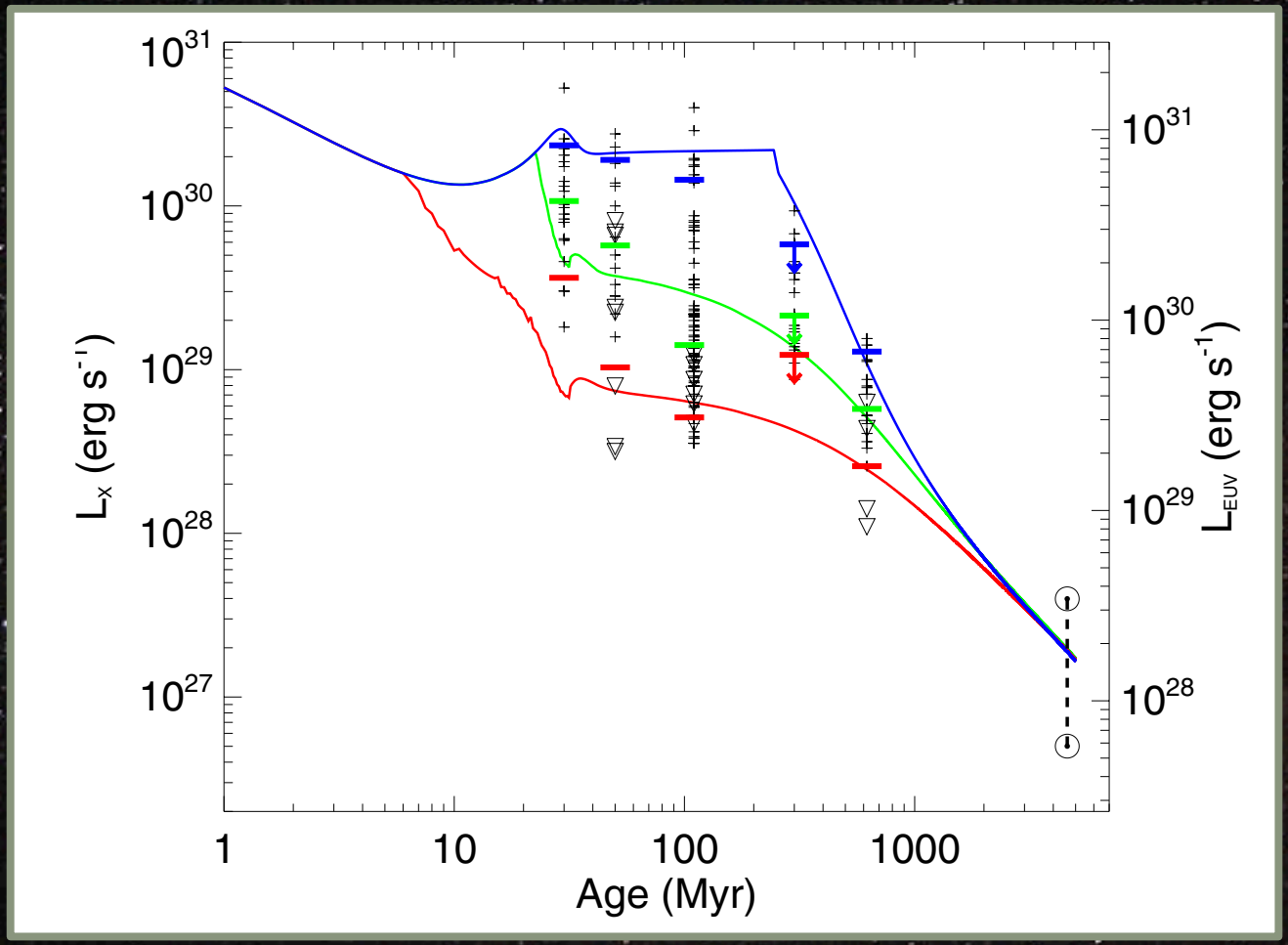




- *30% fainter*
- *Earth and Mars are icy balls*
- *Earth and Mars should not be habitable*
- *Faint Young Sun paradox*

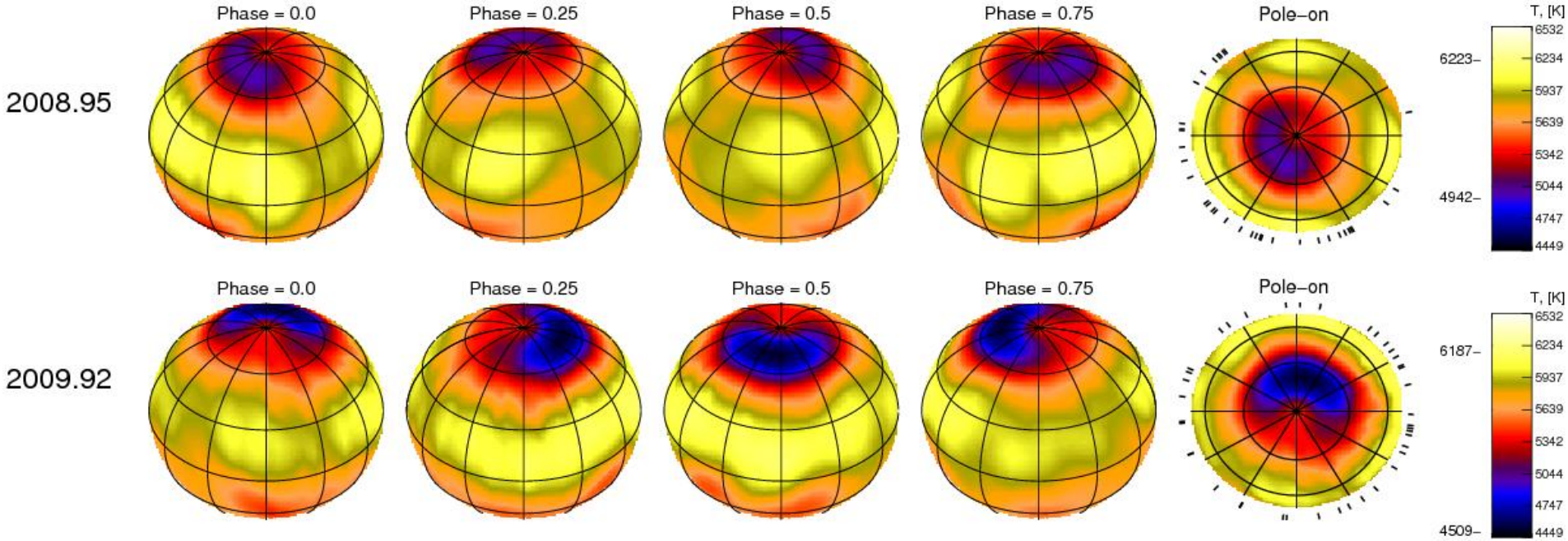


The young Sun was an X-ray star



Tu et al.2015

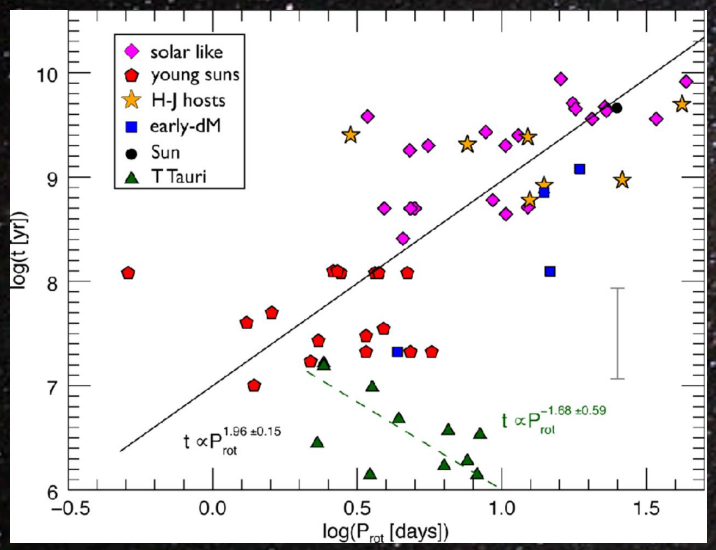
Huge sunspots covering 10-15 % of the surface area, AF Lep

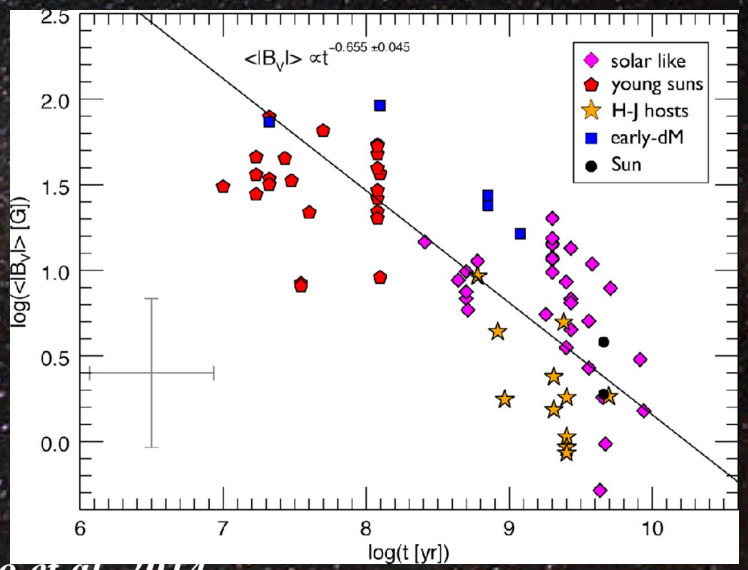


Temperature maps of AF Lep (P=1 d) (Järvinen et al. 2015. NOT)

Magnetism of The Young Sun

Longitudinal surface magnetic field from Stokes V and I LSD profiles for a number of high-g sepctral lines

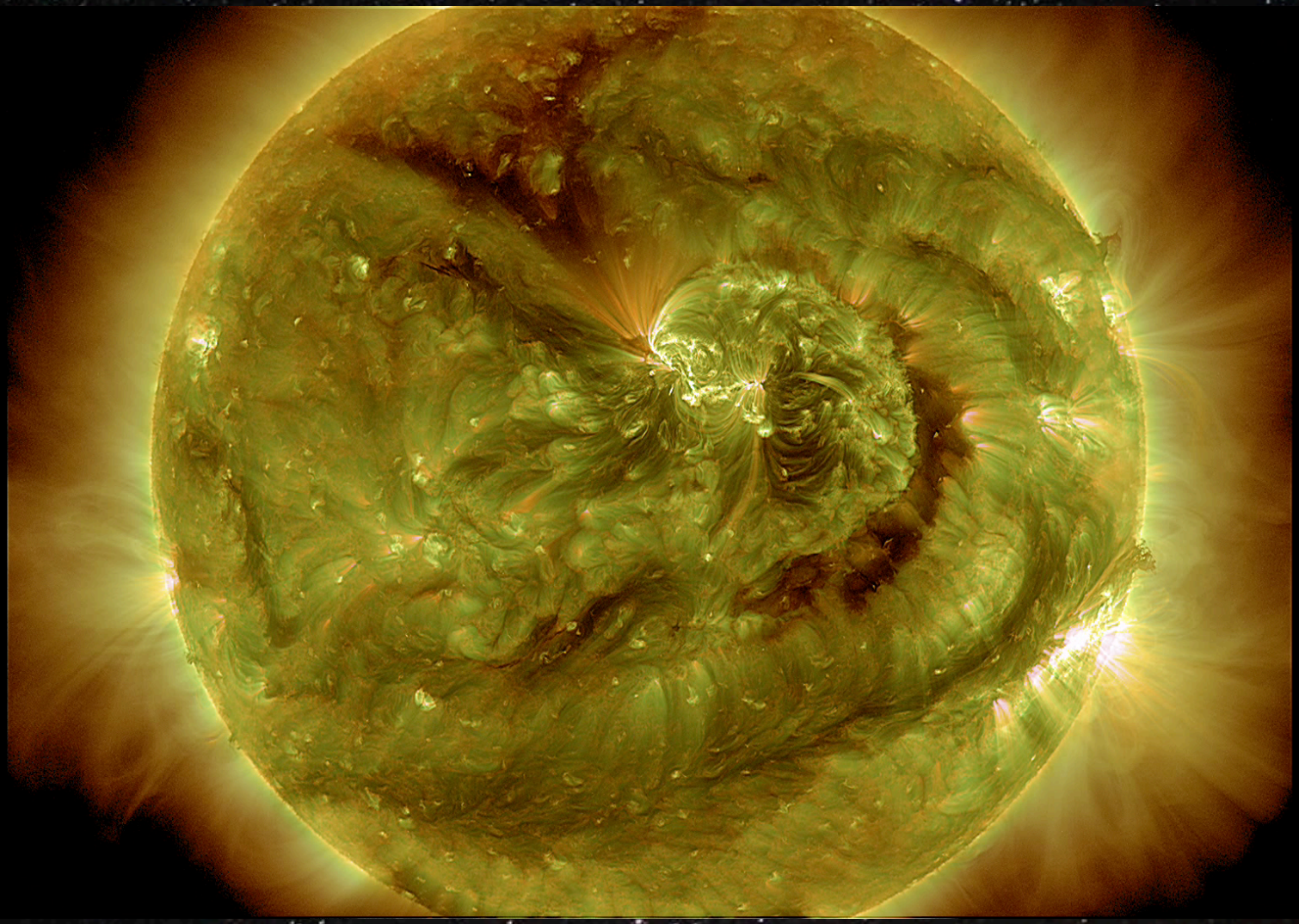




Marsden et al. 2014; Vidotto et al. 2014

Correlation between age t and rotation period Prot for the stars, indicating that the non-accreting stars follow the Skumanich law ($t \sim P_{rot}^2$)

Our Sun is a Magnetically Active Star

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IBEX Satellite Finds Ribbon-Like Structure At Edge Of Heliosphere
ScienceDaily (Oct. 16, 2009) — The invisible structures of space are becoming less so, as scientists look out to the far edges of the solar wind bubble that separates our solar system from the interstellar cloud through which it flies. Using the High Energy Neutral Atom Imager, led by Los Alamos National Laboratory, the NASA Interstellar Boundary Explorer (IBEX) mission has sent back data that indicates a "noodle soup" of solar material has accumulated at the outer fringes of the heliosphere bubble.
As the solar wind streams out far
IBEX-Hi (0.9-1.5 keV)
Voyagers 1 and 2 reached the termination shock in 2005 and 2007, respectively, taking point
SMITHSONIAN COLLECTOR'S EDITION
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IS THE SUN HEATING UP?
PLUS:
OUR VERY OWN BLACK HOLE
EINSTEIN'S DILEMMA
METEORITE MESSAGES
INVASION OF THE NEUTRINOS
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NASA to Reveal New Details About Solar System's Edge
by SPACE.com Staff
Date: 28 September 2010 Time: 02:27 AM ET
SHARE THIS PAGE
Artist's impression of NASA's IBEX spacecraft exploring the edge of our solar system. Image NASA/GSFC
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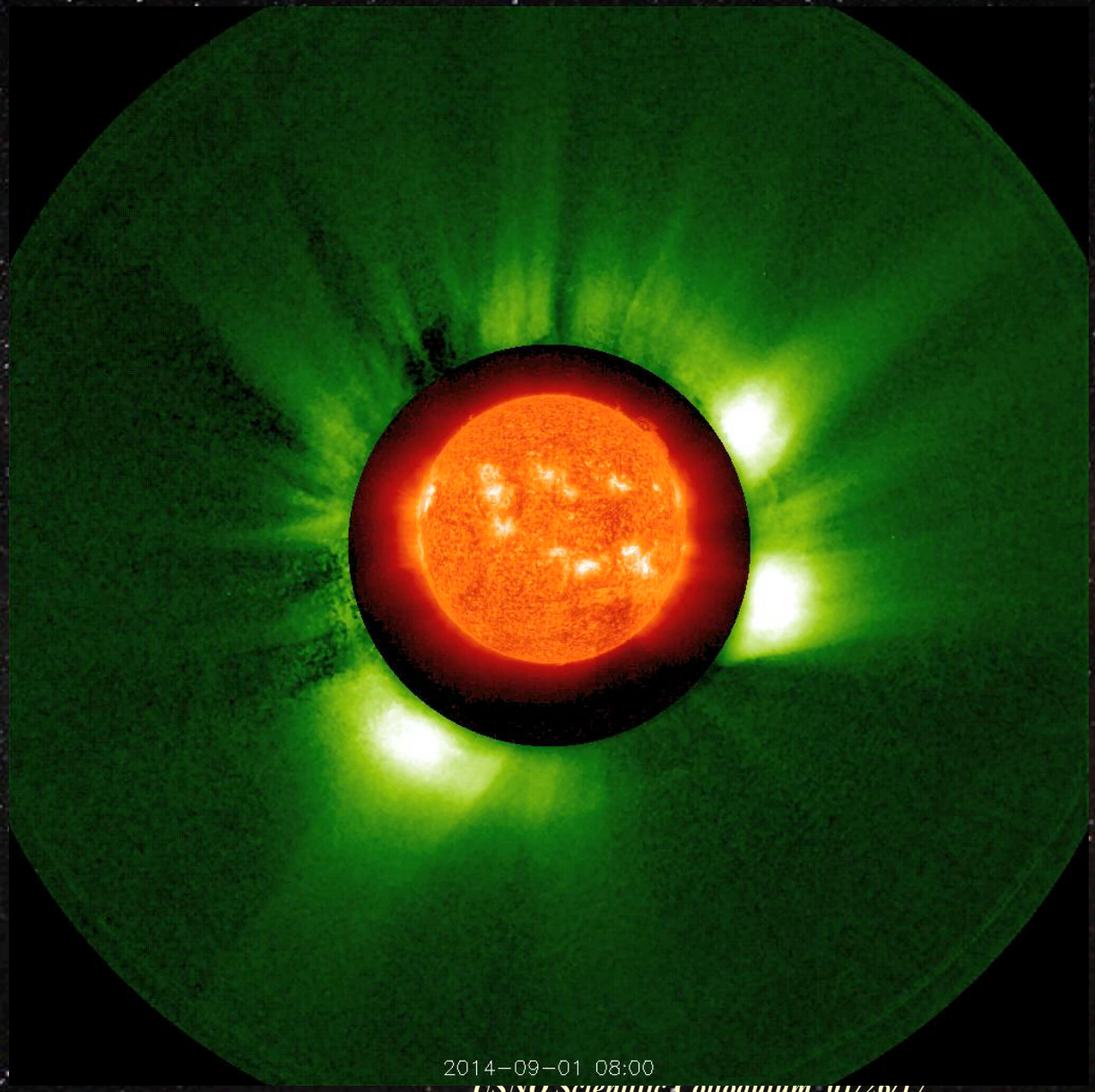
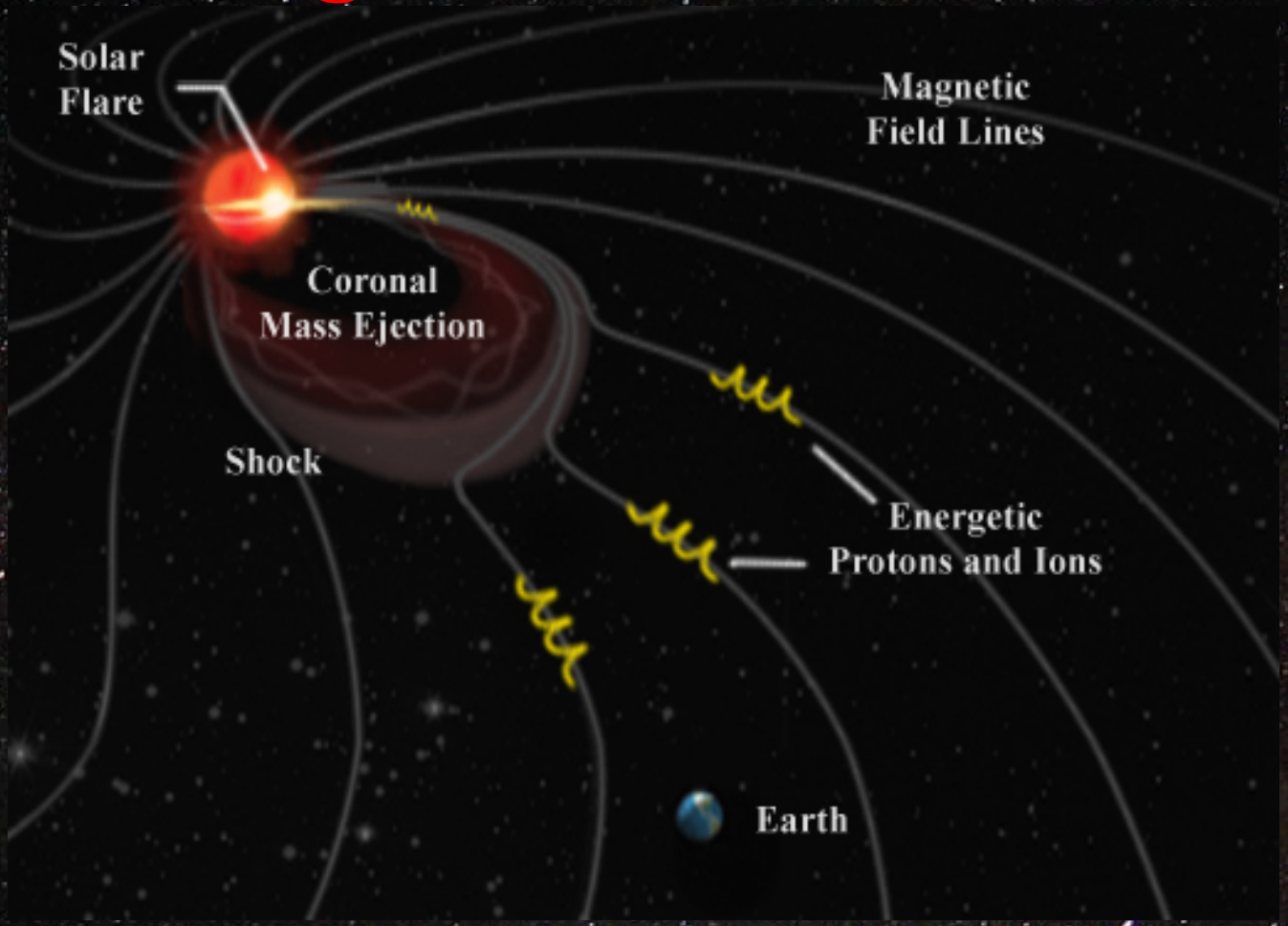
UPDATE: NASA has rescheduled this announcement for Thursday, Sept. 30, at 12 p.m. EDT.
NASA will gather scientists together Wednesday (Sept. 29) to announce new findings about the edge of our solar system from a spacecraft gazing at the region from its orbit around Earth.
The space agency will hold an afternoon teleconference to discuss the latest discoveries by its Interstellar Boundary Explorer spacecraft, which is studying the edge of the solar system from an orbit about 200,000 miles (322,000 km) above Earth.

Sept 1, 2014 CME (STEREO Behind)

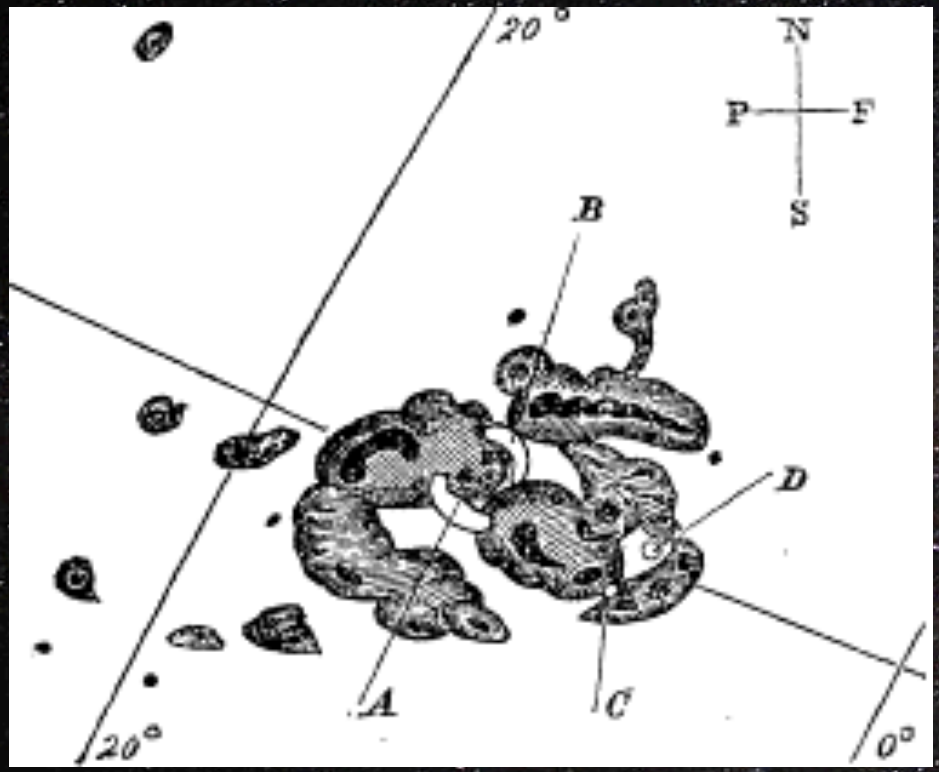


Solar Energetic Particle (SEP) Events



Typically about 10% of CME kinetic energy goes into SEPs
Similar to flare energy
Expect Ground Level Enhancement events (GLEs) are associated with energetic CMEs

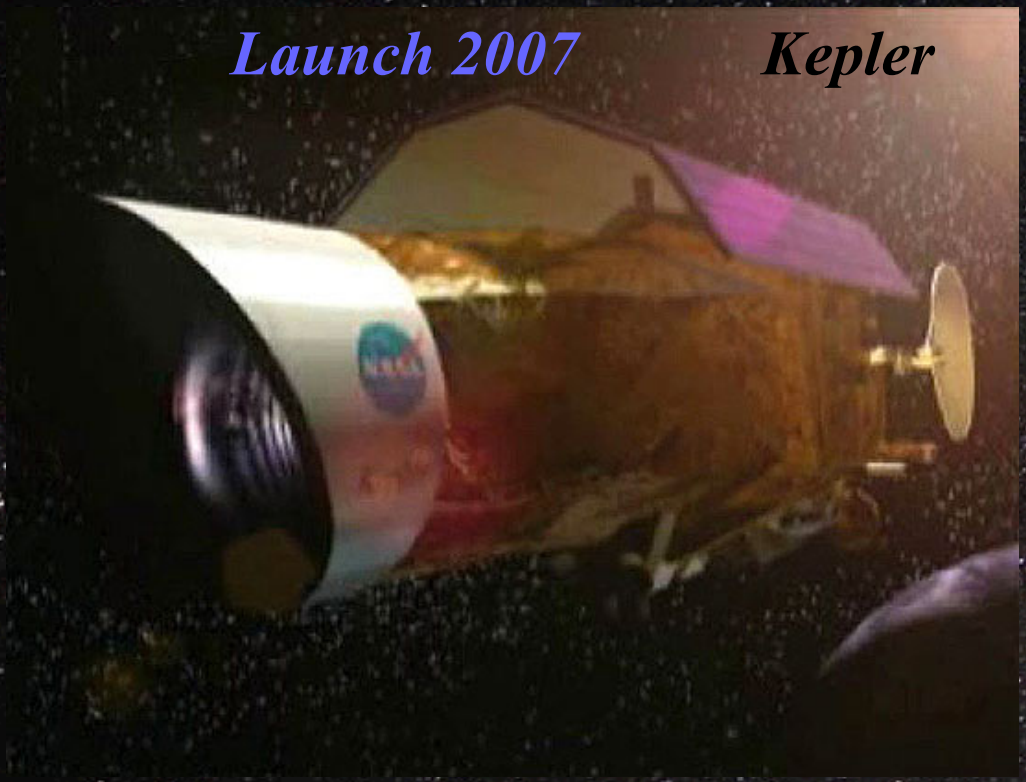
Extreme CMEs: Carrington Event, Sept 1-2, 1859



- *Giant spots, flare and CME event*
- *Most severe SW event in history*
- *Lasted Eight days long*
- *Aurorae at equatorial latitudes*
- *Global telegraph network disrupted, operators suffered electric shocks*
- *Magnetometers driven off scale*
- *Energy in CME ~2 x 10^{33} erg*
- **Frequency – 250 events/d 4 Gyr ago**
- *~ 1 per 300 yr today!*
- *What to expect?*

$E_{flare} = 2 \times 10^{33}$ erg $= 0.1\ E_{cme}$

Surprises from Kepler Mission



Photometry: stellar brightness changes caused by transiting terrestrial planets

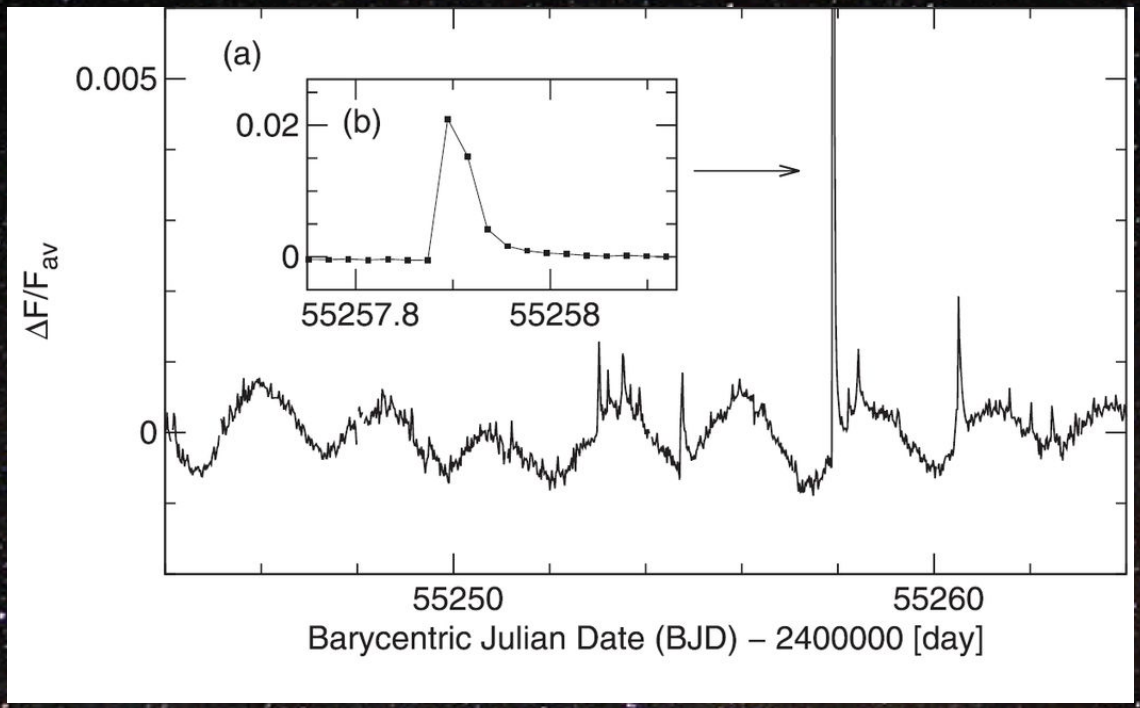
Variability range in mmag

Monitoring 150,000 stars at 30 min cadence for 4 years!

Over 4000 planet candidates

And a very surprising discovery of superflares on host stars

Superflare Renaissance



Superflares E > 10^{33} ergs from K-M stars

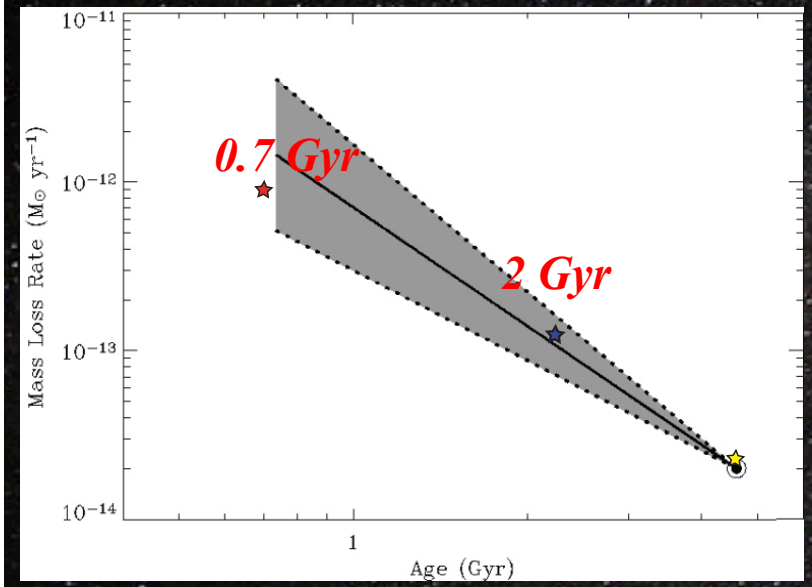
$dN/dE \sim E^{-2}$

R~ 0.1 d^{-1} at $E_f \sim 5 \times 10^{34}$ ergs

R~ 25 d^{-1} at $E_f \sim 5 \times 10^{33}$erg - Super Carrington events!

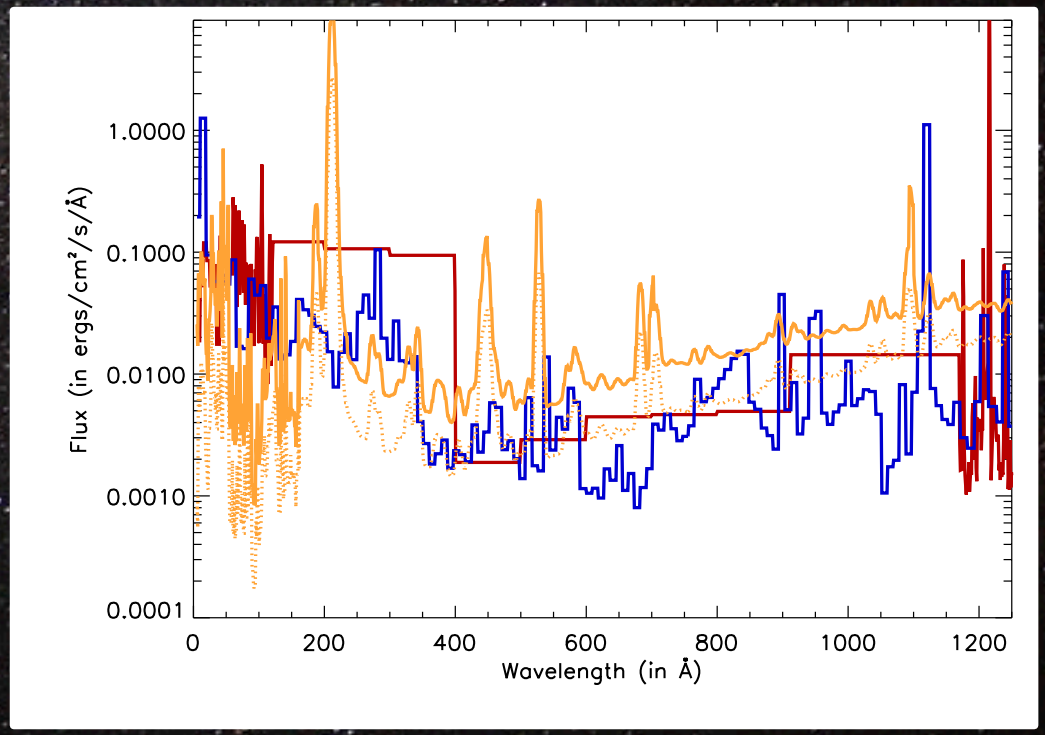
Paleo Space Weather: Dense & Fast Solar Wind and XUV flux

1 Rsun to 3 AU (Airapetian & Usmanov 2016)



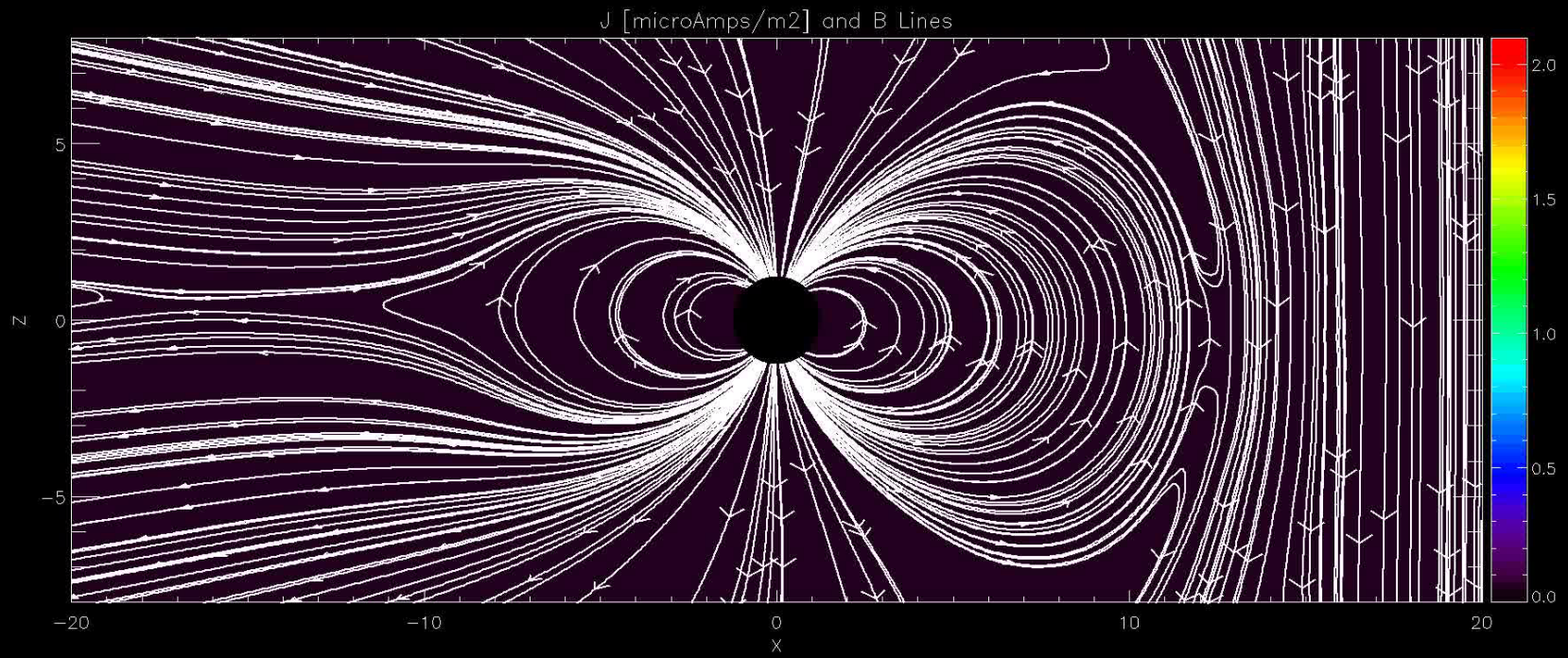
Faster, denser and hotter wind

X5 flare dominated XEUV from young Suns and red dwarfs
Airapetian et al. 2017



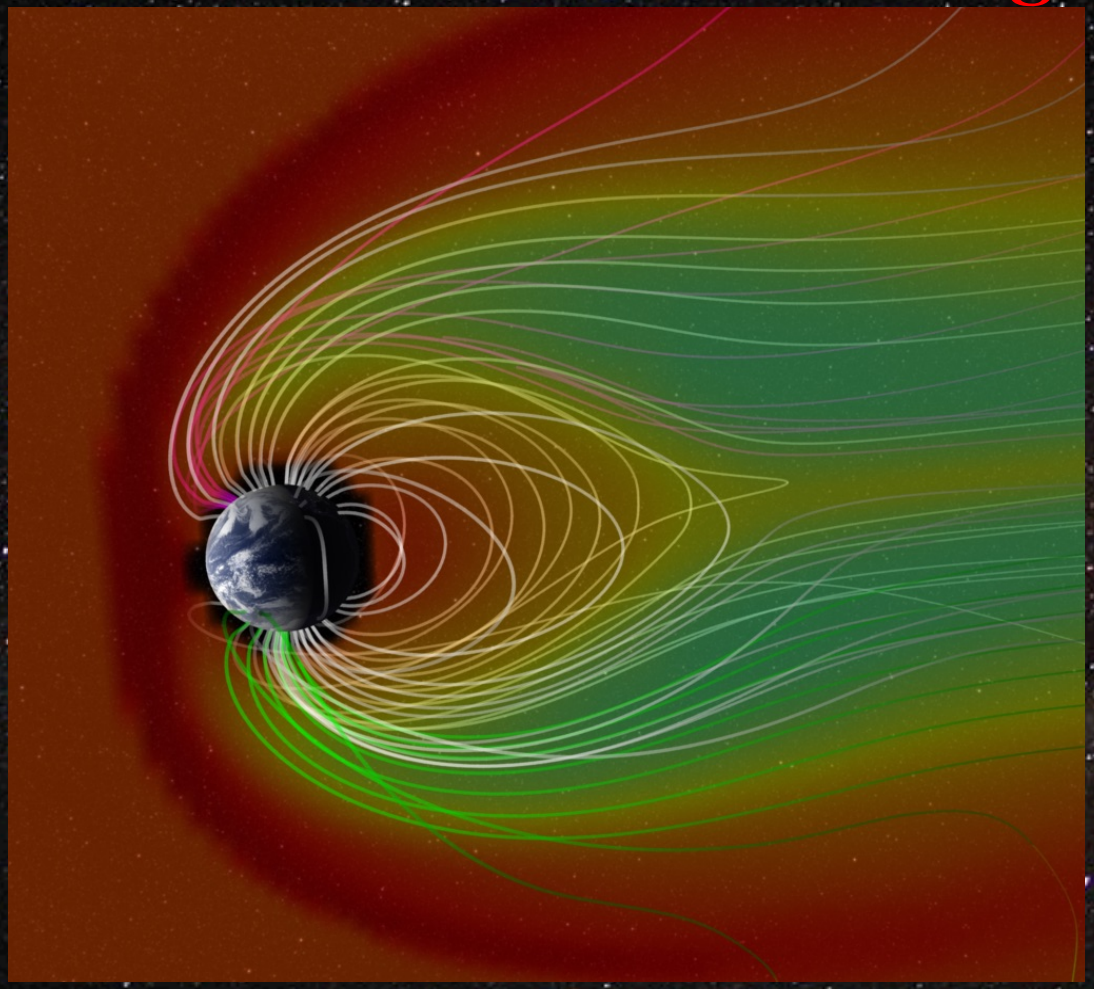
Winds/SCMEs on Magnetospheres

>70 % of the early Earth's magnetic field opens up



nx= 68224, 1, it= 11711, time= 100.00

Effects of Wind/CMEs on Early Earth
SWMF BATS-R-US: Broken Magnetic Shield

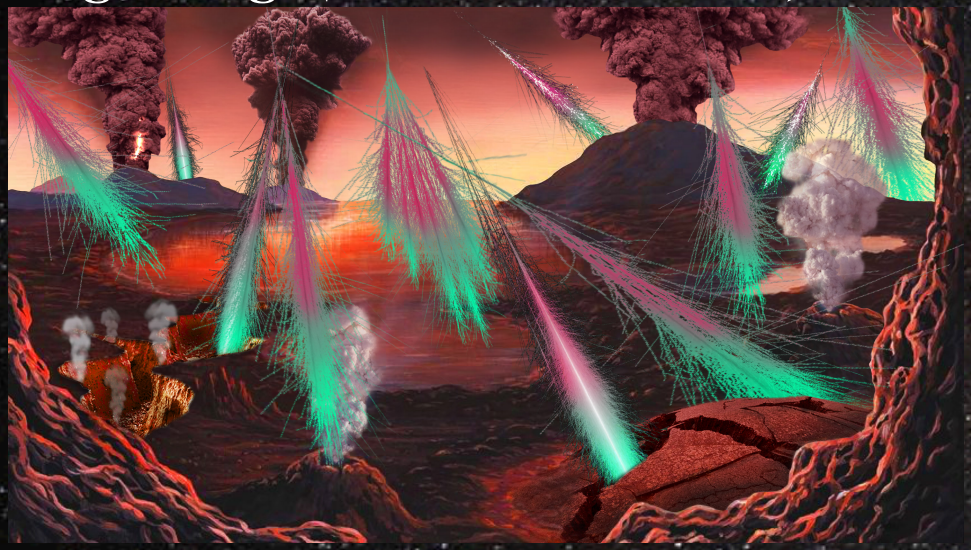


Airapetian, Glocer, Danchi 2015; 2016

Habitability of Early Earth: Atmospheric Pressure

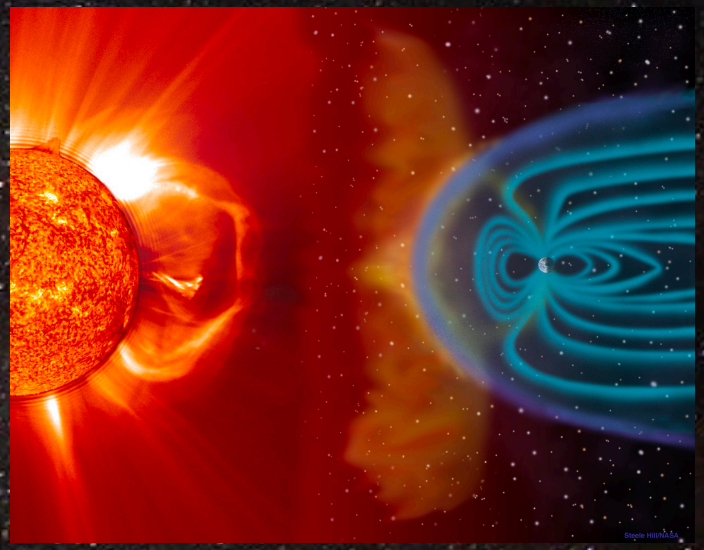
Sources *vs* *Sinks*

Outgassing (volcanic+tectonic)



Michail & Sverjensky Nature 2014
Airapetian et al. Nature Geoscience 2016

Solar Weather

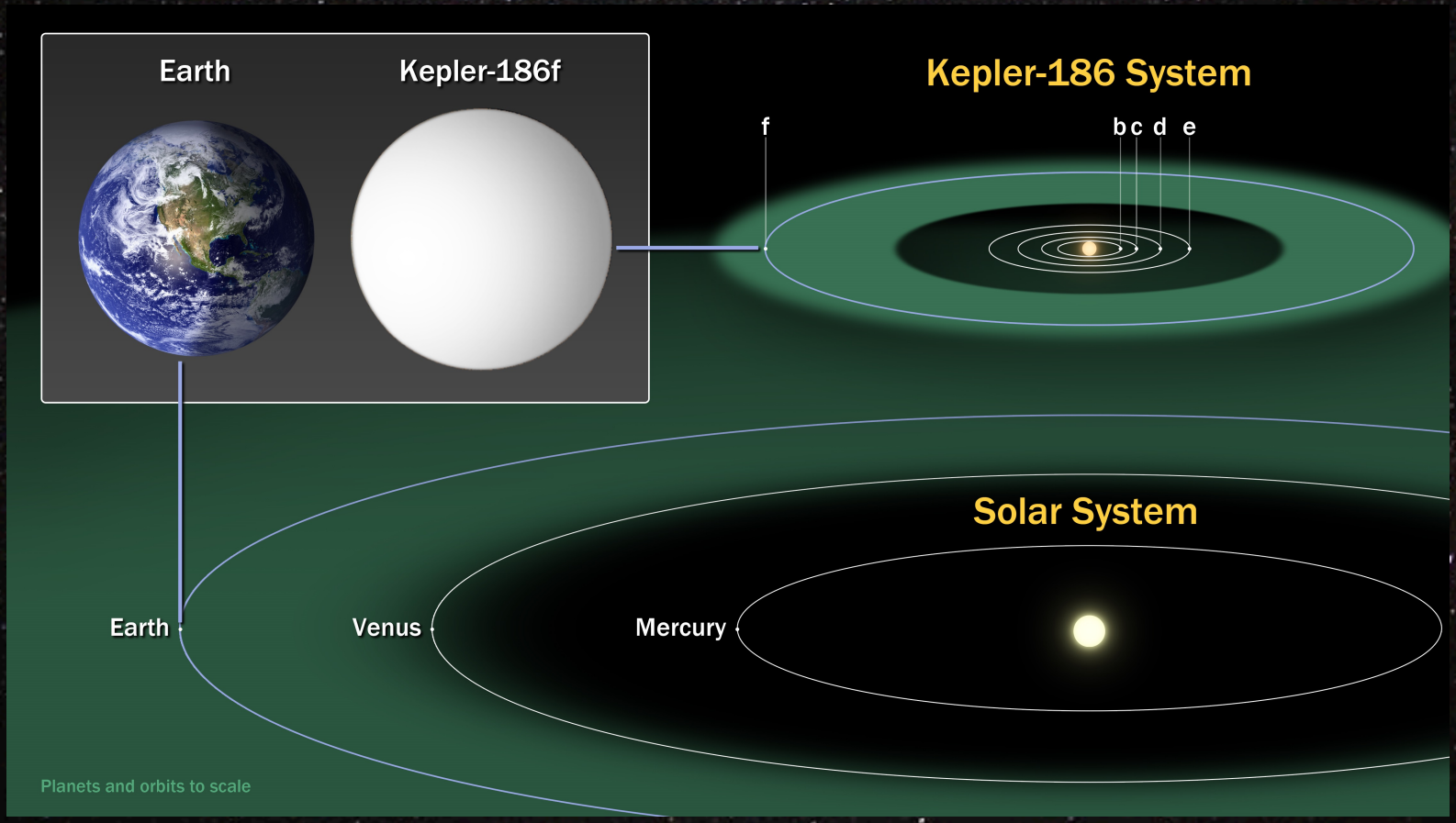


Solar wind, XUV, Precipitating particles SEP

How Hospitable Are Climatological HZs?

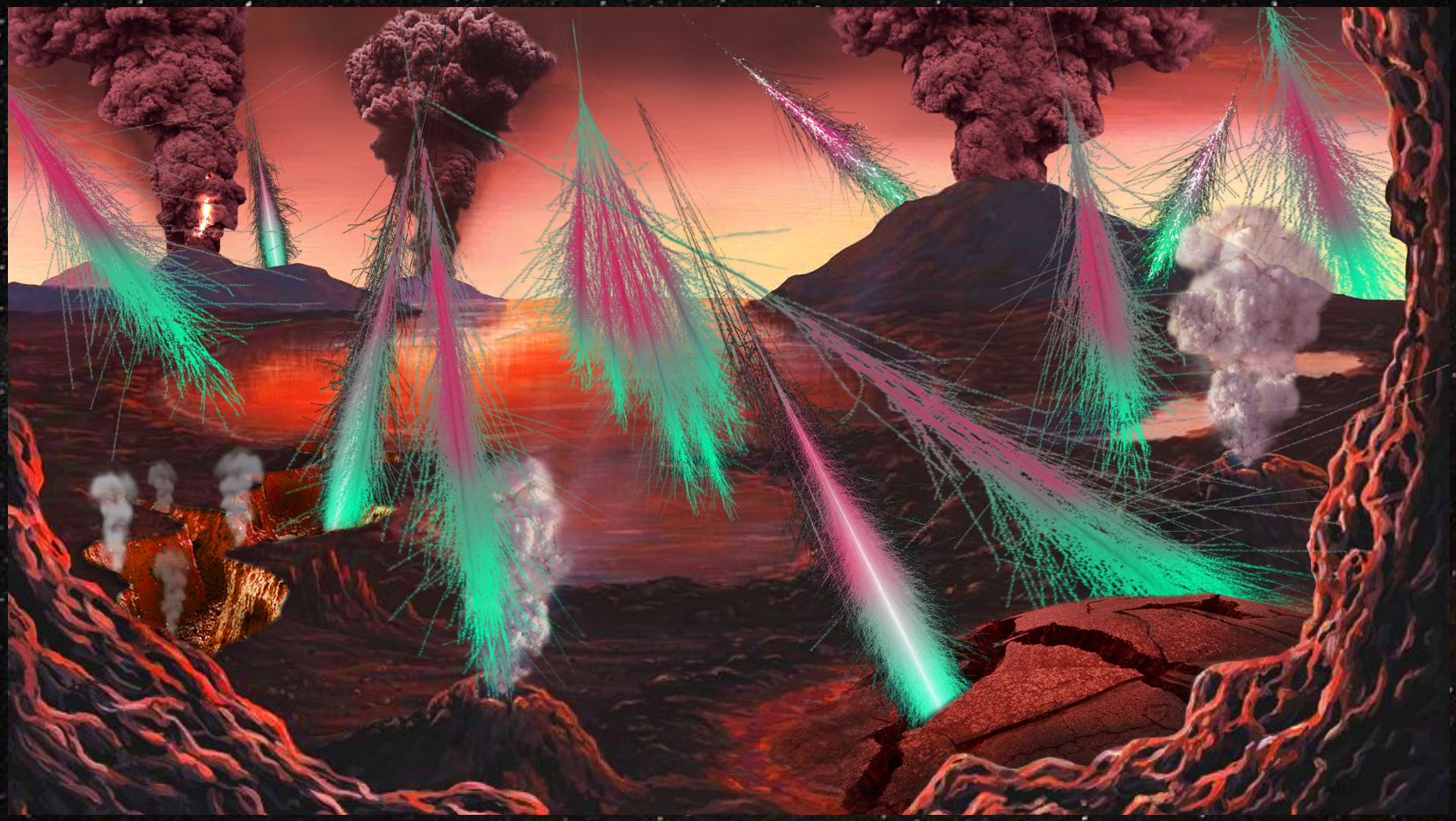
Proxima b at 0.05 AU

$L_X \sim 10^{27}$ erg/s



Early Earth: XUV Driven Atmospheric Loss

Early Earth: Solar Energetic Particle Events



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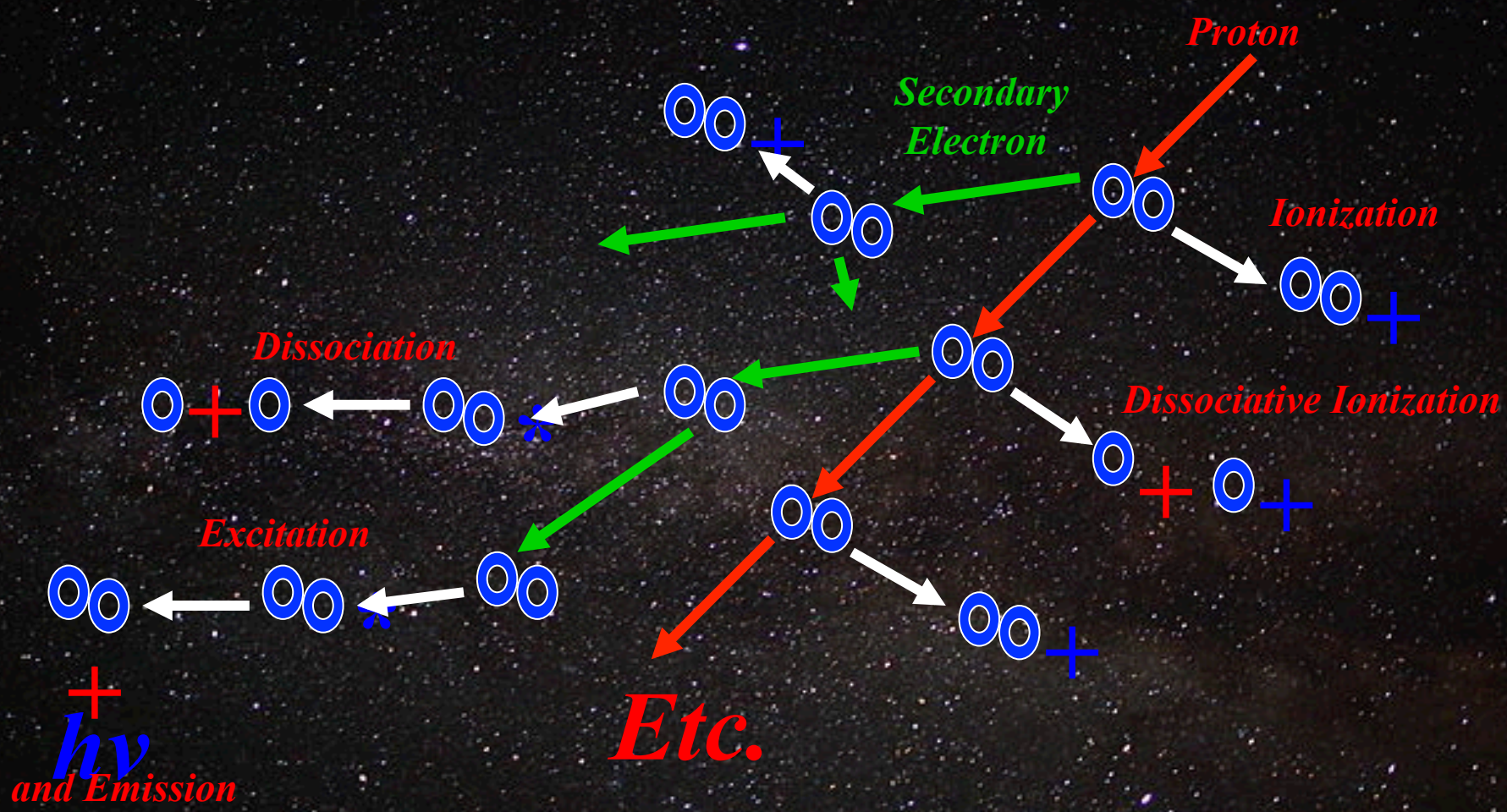
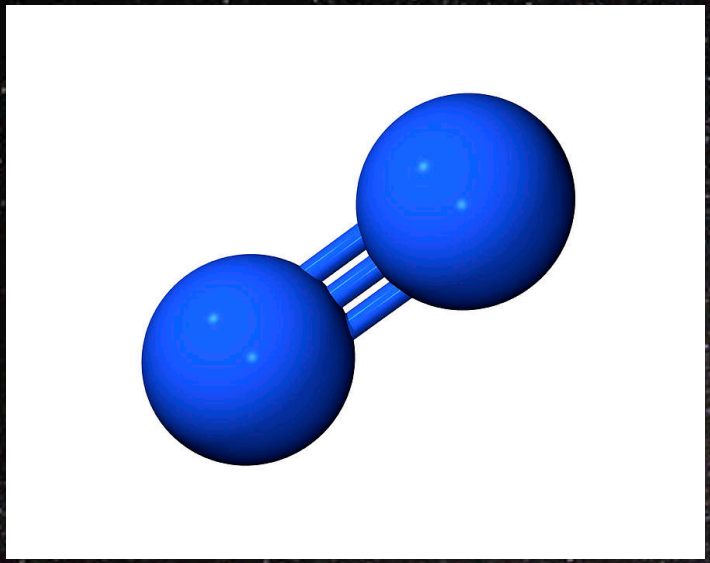
Proton Energy Deposition into N_2 , O_2



Protons penetrate a certain distance (Range) into air

Prospects For Life on Early Earth &Titan

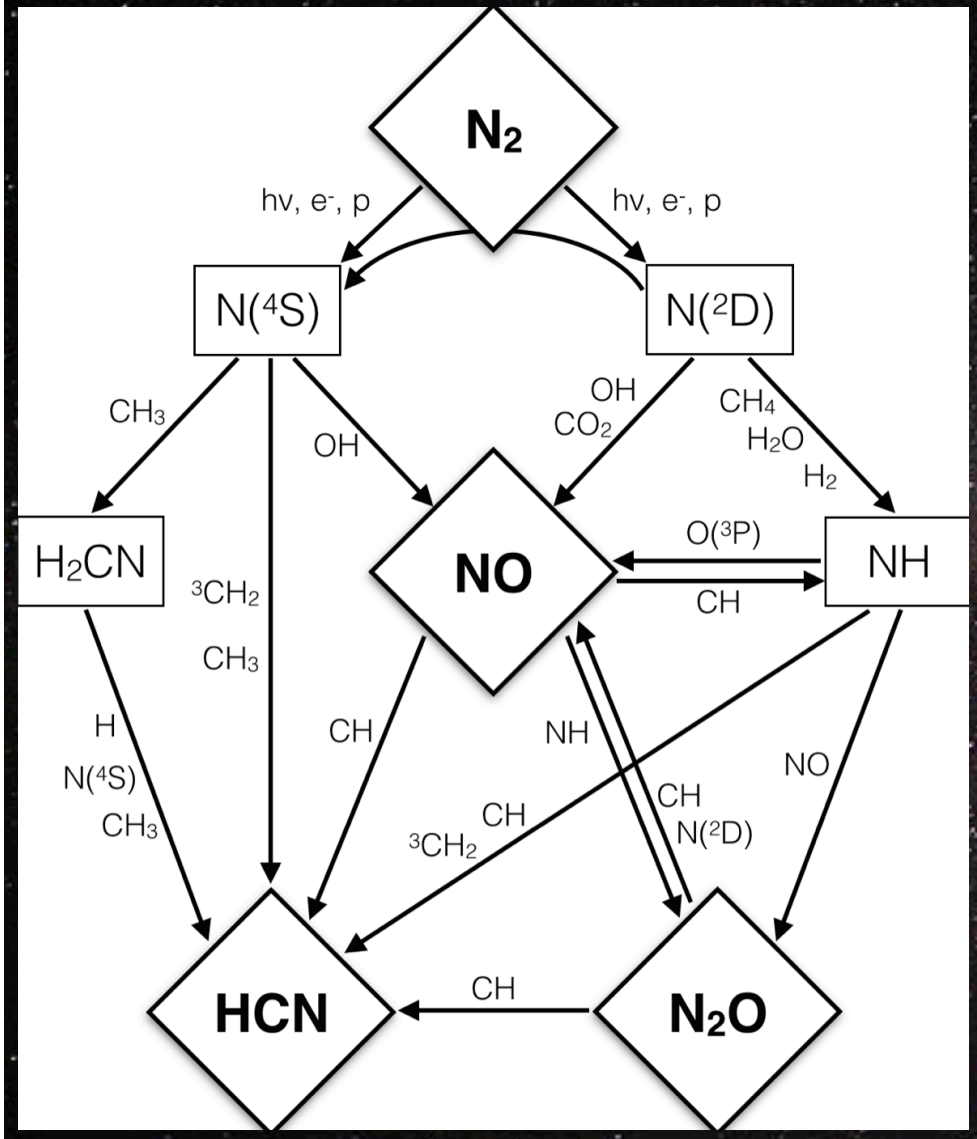


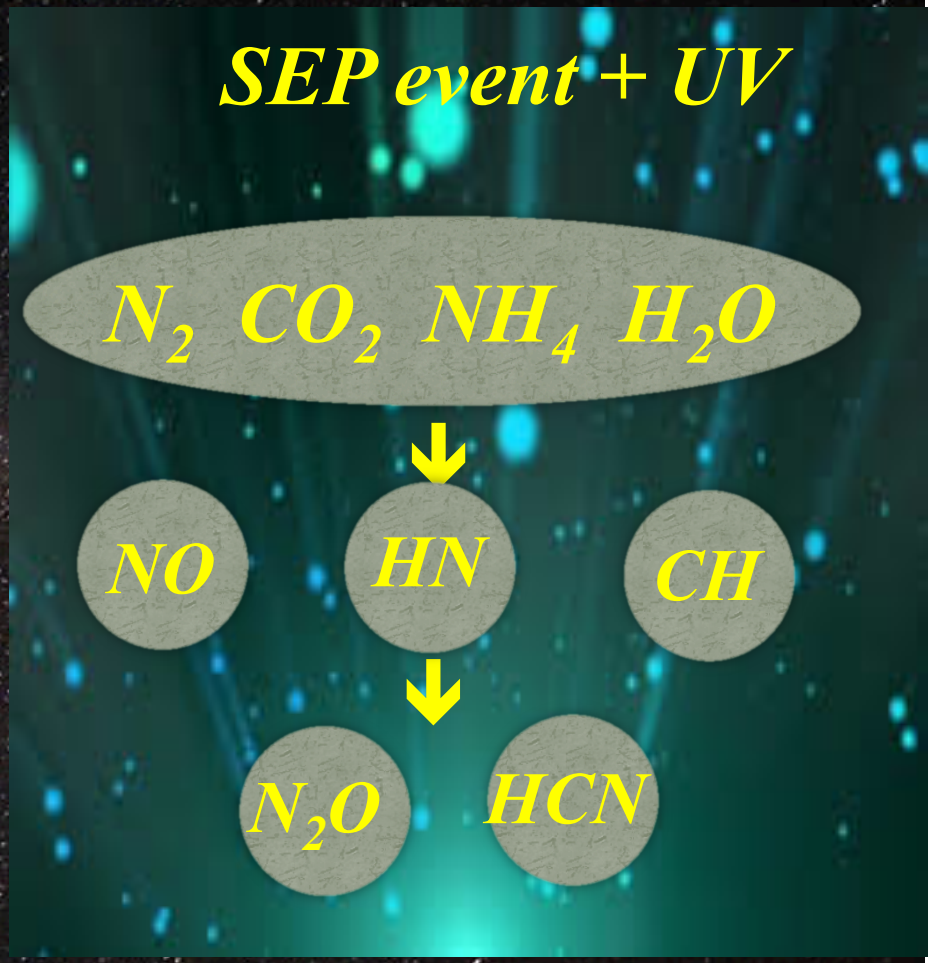
The dominant molecule
Extremely hard to dissociate
Triple bonds: 10 eV/atom
vs 5.2 eV/atom for O_2

Prebiotic chemistry needs
to break N_2 -> 2 N :

- *VUV emission at λ < 100 nm (early Sun, M dwarfts)*
- *Lightning discharge*
- *Energetic particles (e, p)*

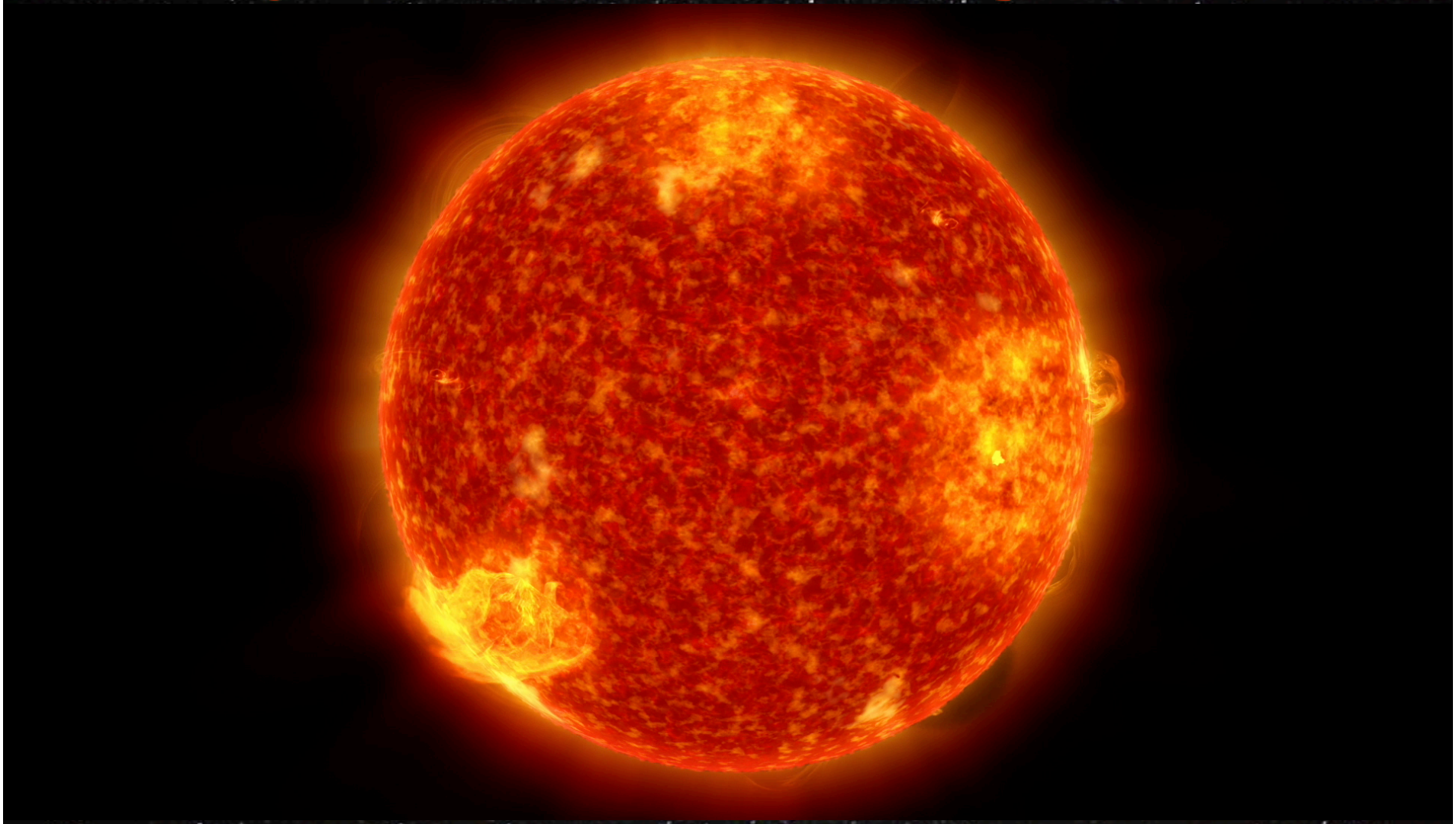
N fixation & production of NO_x, HCN & N_2O





Airapetian et al. NatGeo 2016

Rise of Prebiotic Chemistry on Earth



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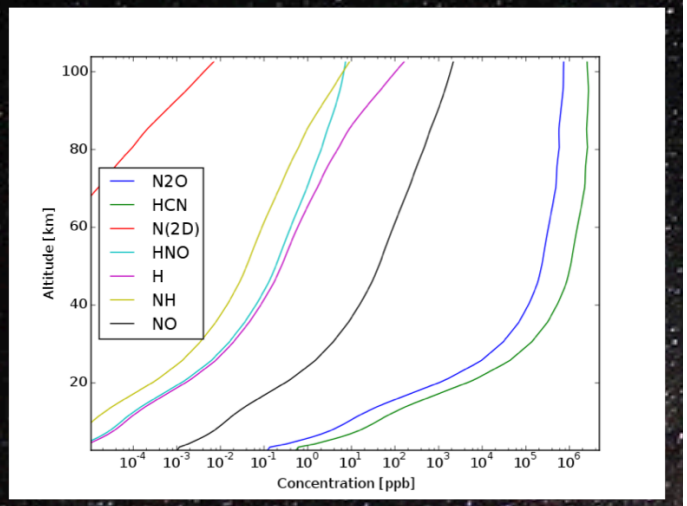
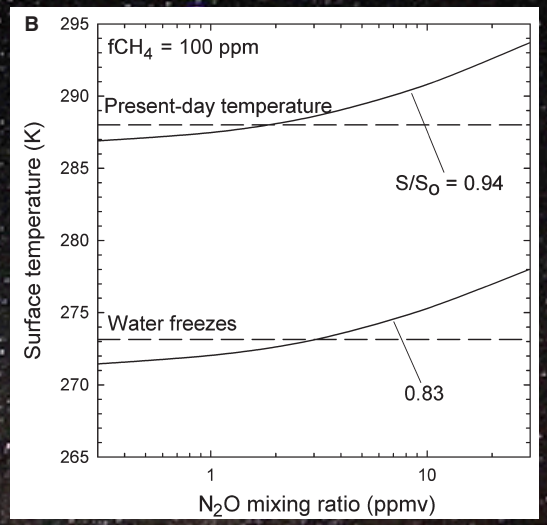
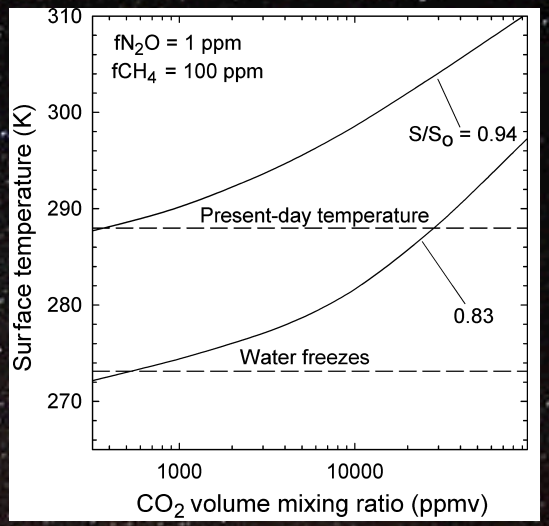
Resolving the FYS Paradox For Earth/Mars



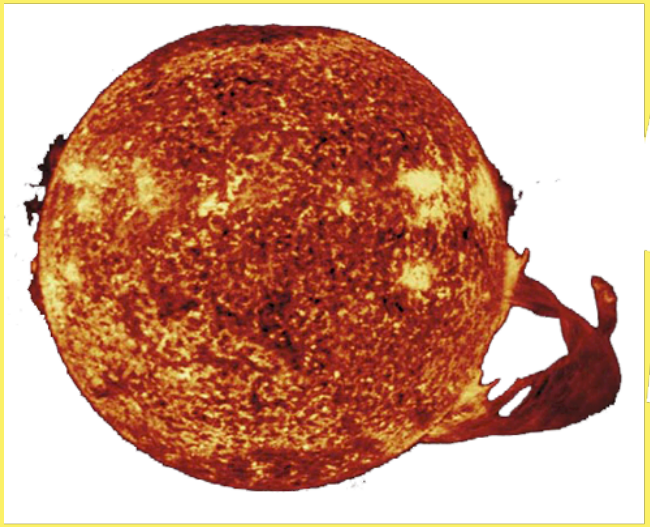


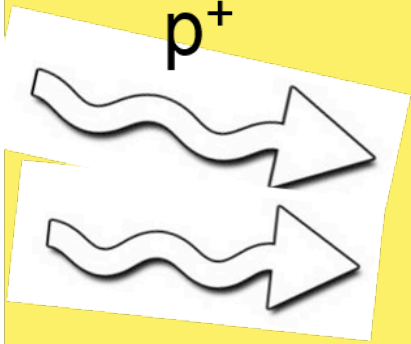


- *CO_2 alone does not solve the problem*
- *N_2O is 300 x more potent that CO_2*
- *Shielded by SO_2 and H_2S (240 nm)*
- *FYS paradox can be resolved at > 10 ppmv!*

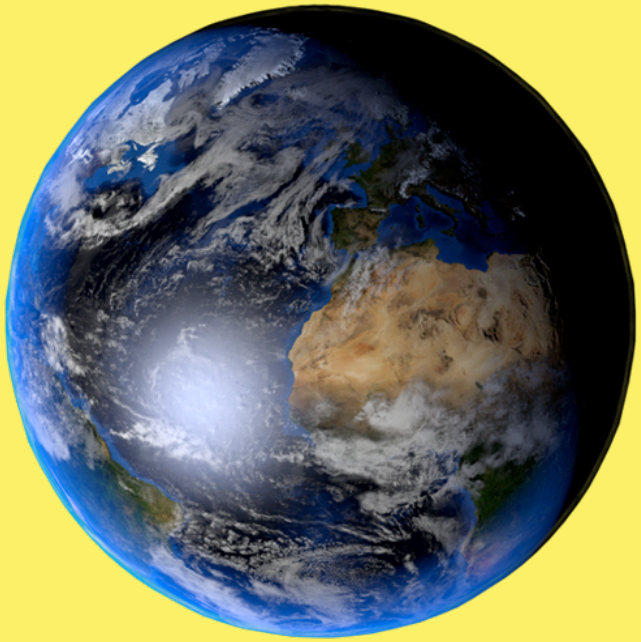
The Pathway to Bio Molecules

Young Sun

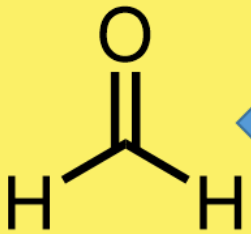




Hadean Earth



Simple Sugars



p^+

$HC{\equiv}N$

XUV

SEP event

N_2, CO_2, CH_4, H_2O

Dissociation

CO, CN, NH, NO_x, OH, NHO_3

Ionization

N^+, O^+, CO^+, NO^+, NO^+, OH^+

Nitrous Oxide, N_2O
Hydrogen Cyanide, HCN
Acetonitrile, CH_3CN
Formaldehyde, CH_2O

Formamide, CH_3NO

Cytosine, Guanine, Adenine, Uracil

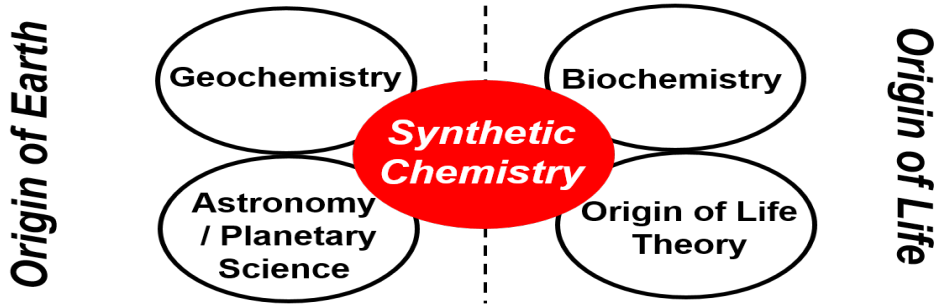
Phosphates -> Nucleotides

Short oligomers -> ribozymes

Chemistry Experiments

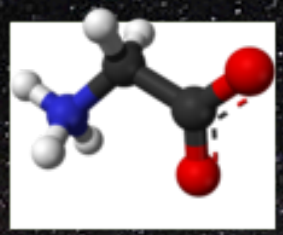
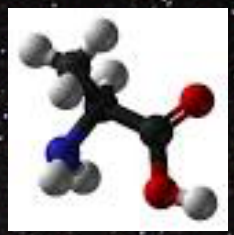
HARVARD
Origins of Life

EBSI + YNU

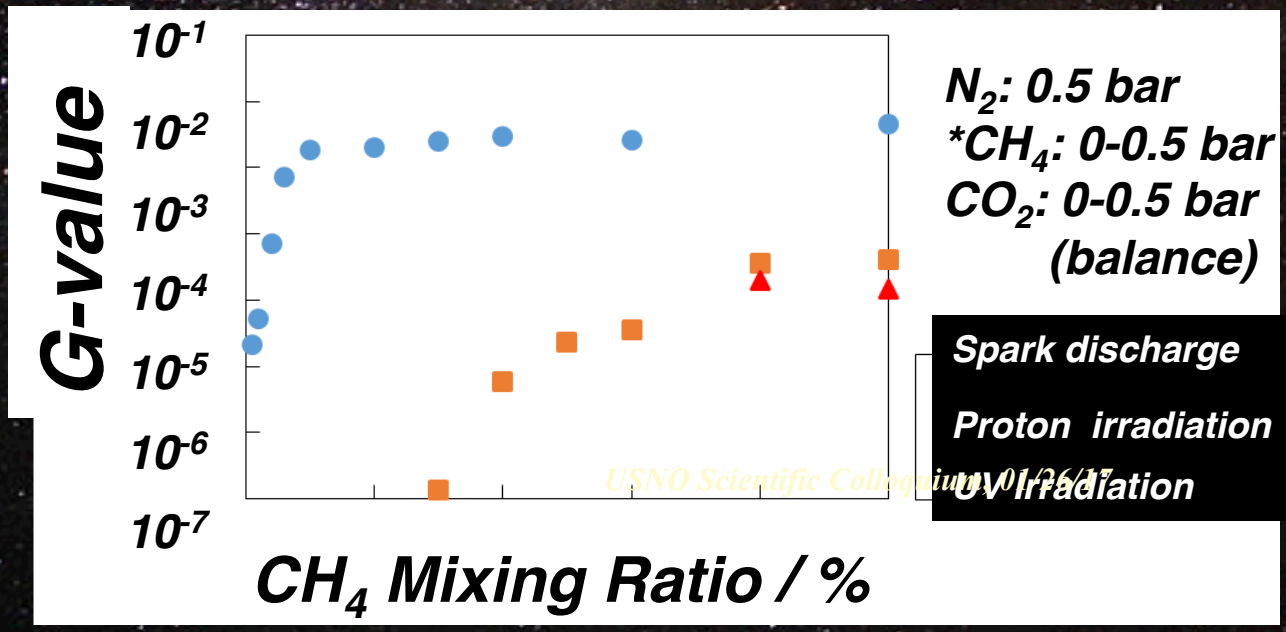


REACTION NETWORKS → a → PREBIOTIC RNA SYNTHESIS / ACTIVATION → b → MECHANISMS OF REPLIACTION → c → MOLECULAR EVOLUTION

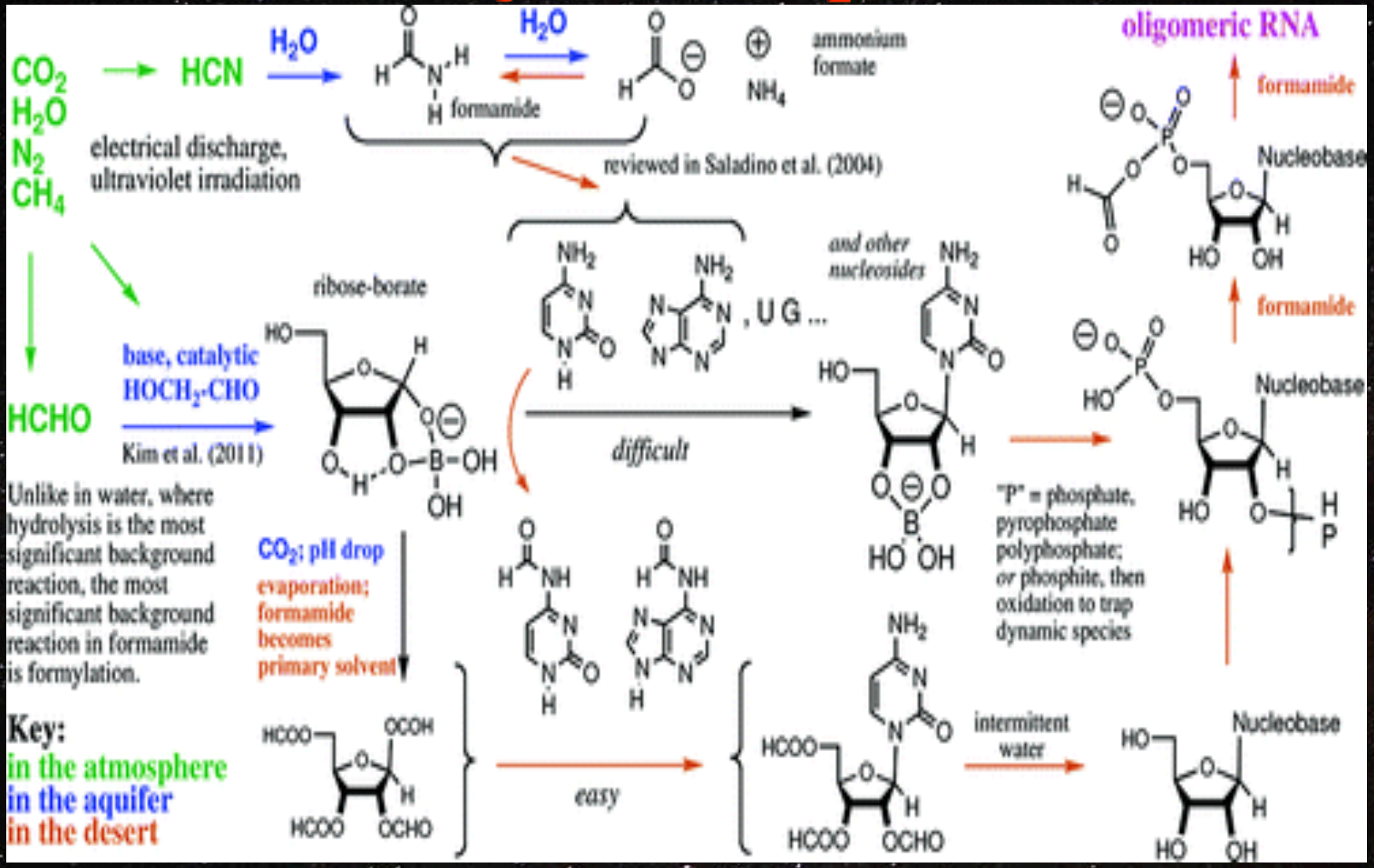
Cooking Amino Acids in Lab

Glycine  Alanine 

Protons are 10^6 times more efficient!



Journey From N_2 to RNA



Benner et al. 2012

What organic molecules do if given energy only

versus

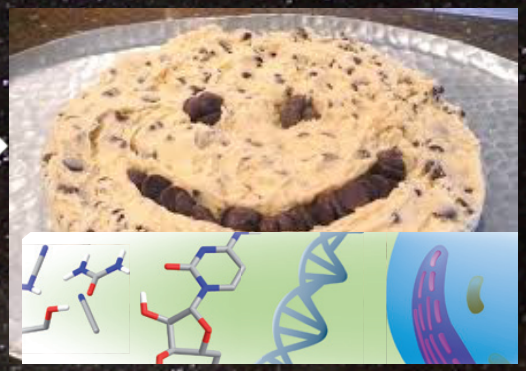
What organic molecules do if given energy + Darwinian evolution

Life is a self sustaining chemical system capable of evolution

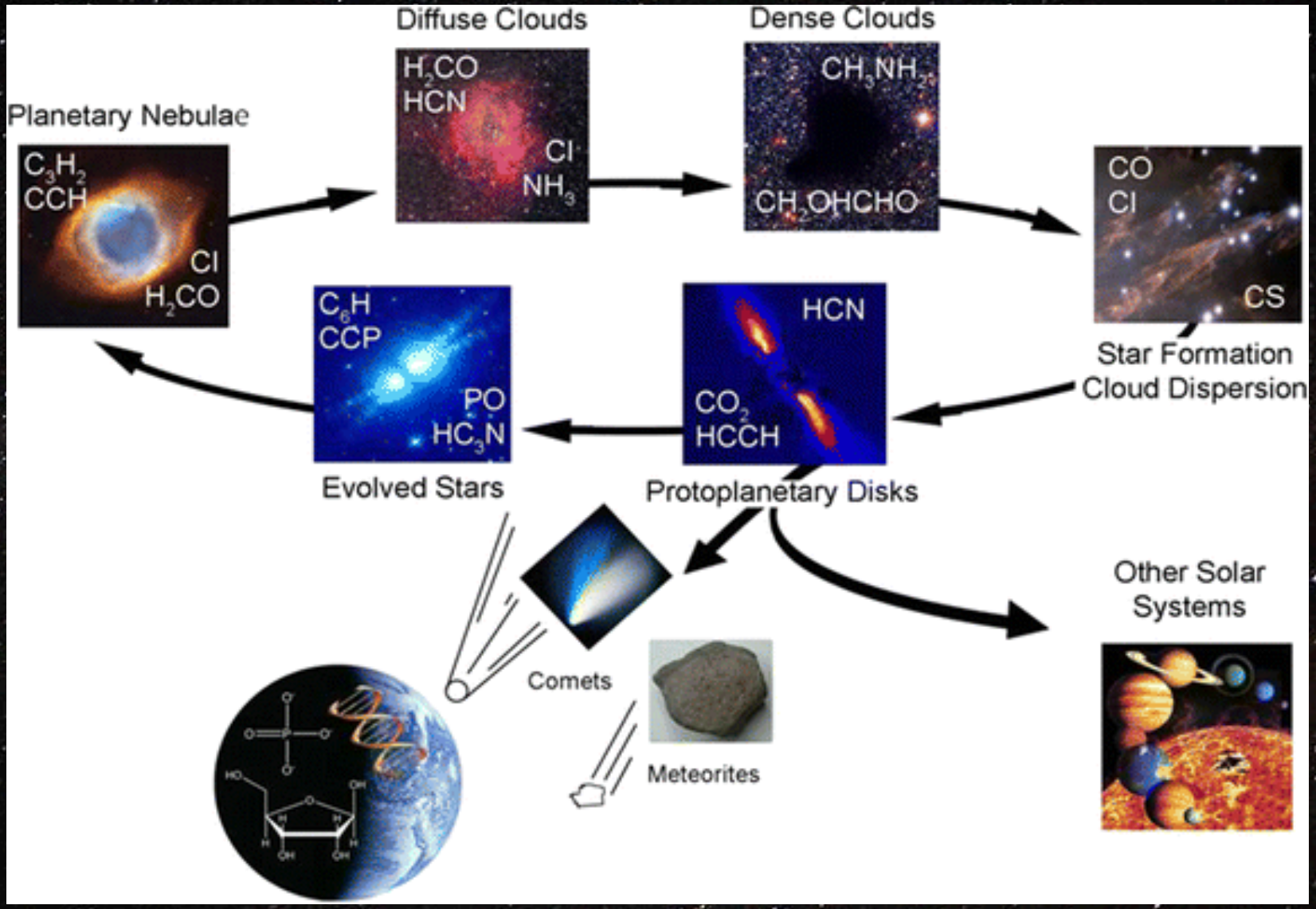
Making "Cookies" of Life on Earth/Mars

$HCN + H_2O$ --> NH_2CHO -formamide
Proton irradiation forms amino acids, nucleobases
Life is a chemical soliton!

Life Cookies



Recycling of Chemistry of Life



What Is Habitability ?

Not life, but physico-chemical conditions supporting life As We Know It

- *Rocky planet with a surface liquid water (CHZ)*
- *Plate tectonics with suduction*
- *Presence of a planetary magnetic field*
- *Stability of complex carbon molecules*
- *CHNOPS and a range of metals (Fe, Mn) to build molecules and act as catalysts*
- *Presence of energy sources to drive bio processes and evolution or redox reactions in the crust*

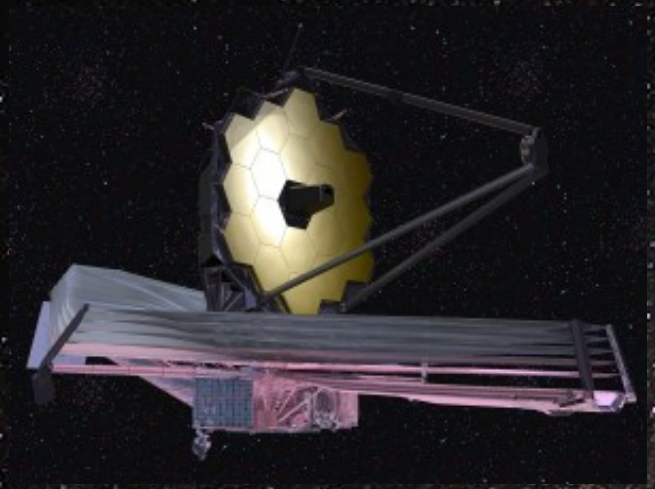
How To Become a "Star" Parent ?

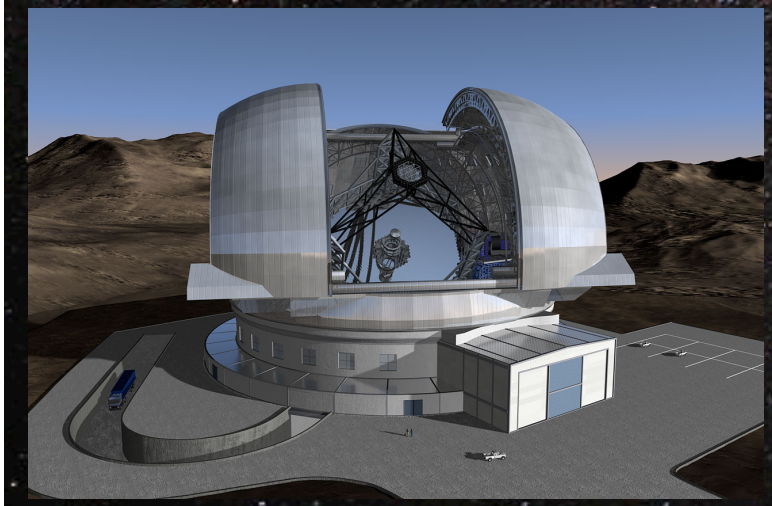
- ✓ *Long life expectancy (> 1 Gyr)*
- ✓ *Be luminous enough - the planet doesn't have to be too close*
  - *stars with $M < 0.5M_{\odot}$ (M) will tidally lock*
  - *XEUV/wind flux and atmospheric loss*
- ✓ *Have high "metallicity"*
- ✓ *Special constraints on a binary system*
- ✓ *"Child" planet needs an emotionally stable parent*

Mid aged G-K stars are the best "parents"

Alien Megastructures

Strategies to Search for Life





***Earth analogs* within BZ**

R=2,700/NIRSpec

Direct Imaging

Young Earths "pregnant" with life

N_2O- 2.9, 4.5, 7.9 µm,

HCN – 3 and 14.3µm

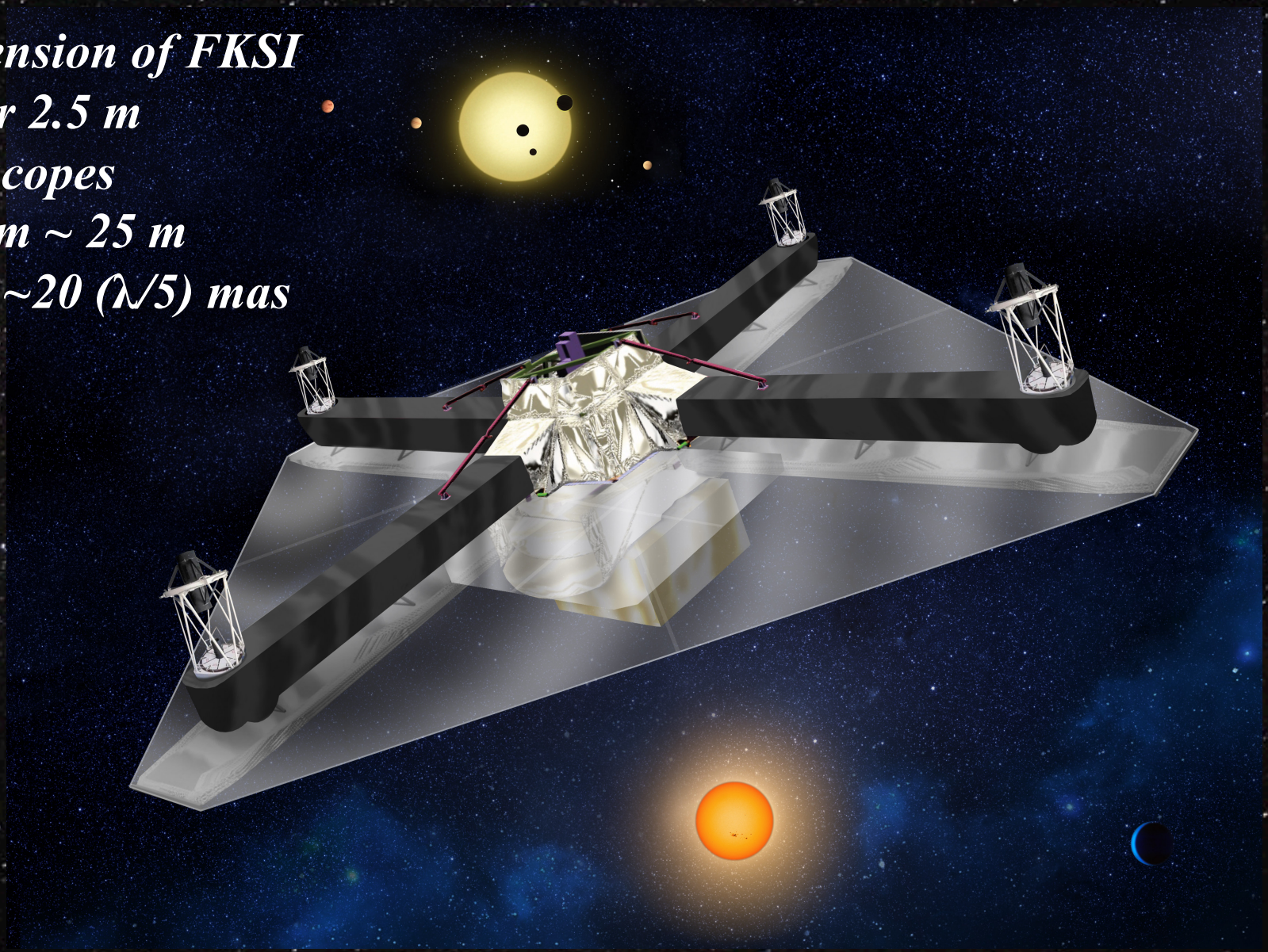
Beacons of Life Earth twins:

NO – 5.3 µm at 100 TW

OH at 100 TW at 1.6 and 2 µm

Exo Life Beacon Space Telescope

- *Extension of FKSI*
- *Four 2.5 m telescopes*
- *Boom ~ 25 m*
- *IWA~20 (λ/5) mas*



Strategies for Searching for Life in the Universe

Intelligent

or

Primitive 10^{20} x abundant