Prebiotic Life On Early Earth: Biosignatures With ATLAST

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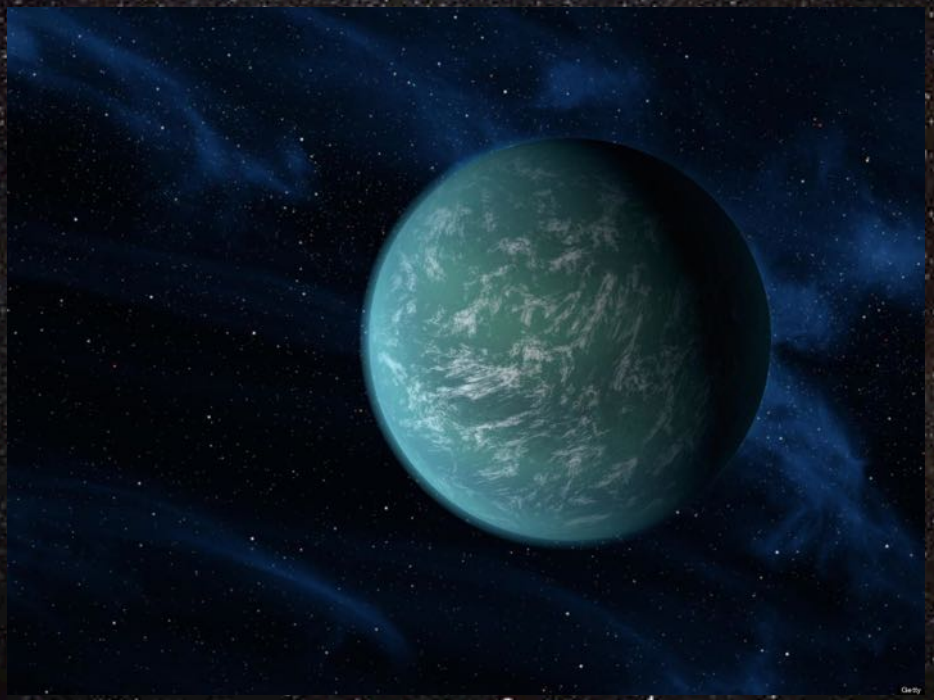
THE BIG QUESTION

ARE WE ALONE?



Objectives

- ***How did life form and evolve on early Earth?***
  Search for life in the Universe starts at our own planet.
- ***What is the role of a host star on the origin and evolution of life on exoplanets around them?***
- ***How can life be detected ? Strategies for finding Earth 2.0***

IT TAKES A VILLAGE TO ANSWER THESE QUESTIONS !

"Village Team" (PI-*Airapetian*)

AST – ***Barry, Cuntz, Danchi, France, Linsky, Lopez***

HELIO –Glocer, Khazanov, Lin, van der Holst, Tarduno

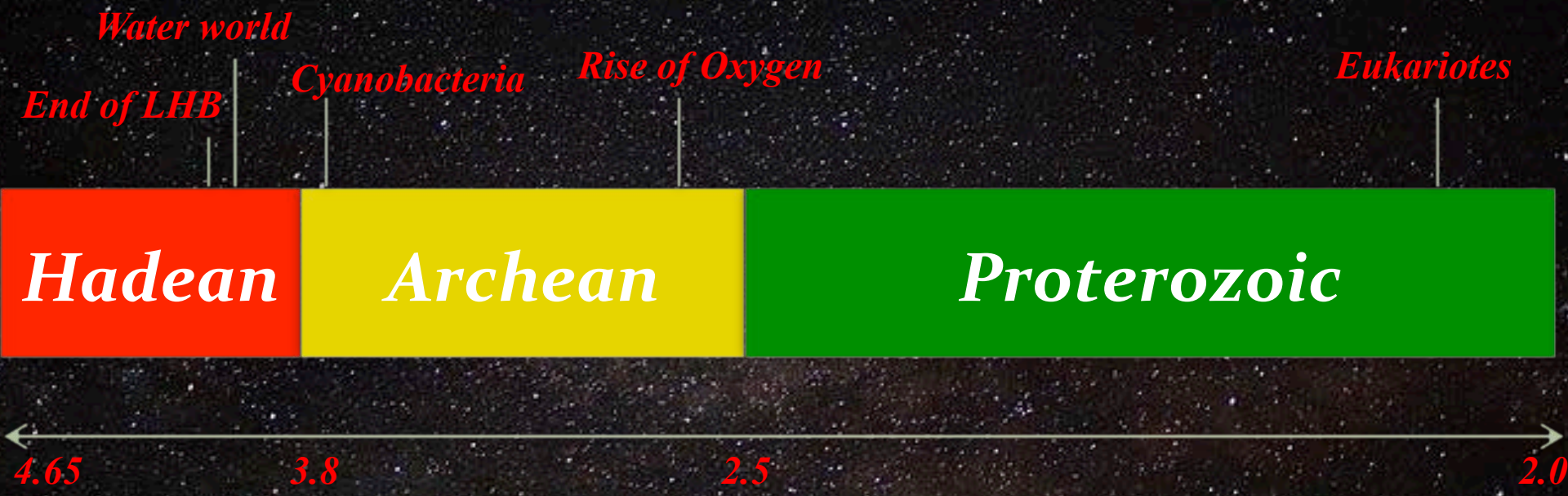
PLN – ***Argento, Attri, Domagal-Goldman, Del Genio, Goldblatt, Gronoff, Jackman, Pavlov, Thomas***

BIO –Barrick, Cliver, Cockell, Floyd, Mazumder, Onstott, Phelps, Simonyan

Contents

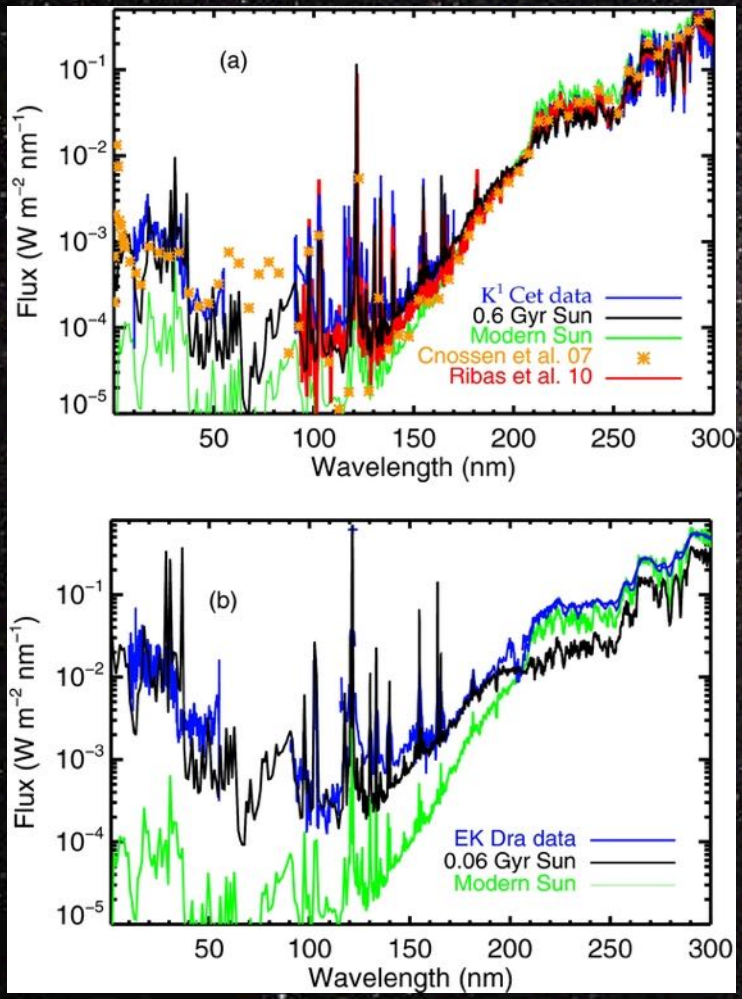
- *Life of our "baby" Sun*
- *Effects of Superflares and CMEs: on young Earth*
- *Effects of Solar Proton Events and The Prospects for life*
- *Work in Progress: Chemistry and Biology Experiments*

The Eons of Our Earth



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

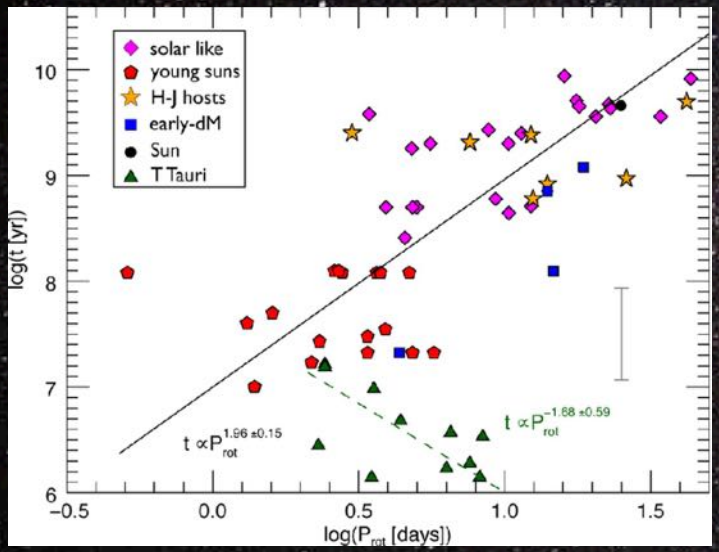
Life of the  Sun

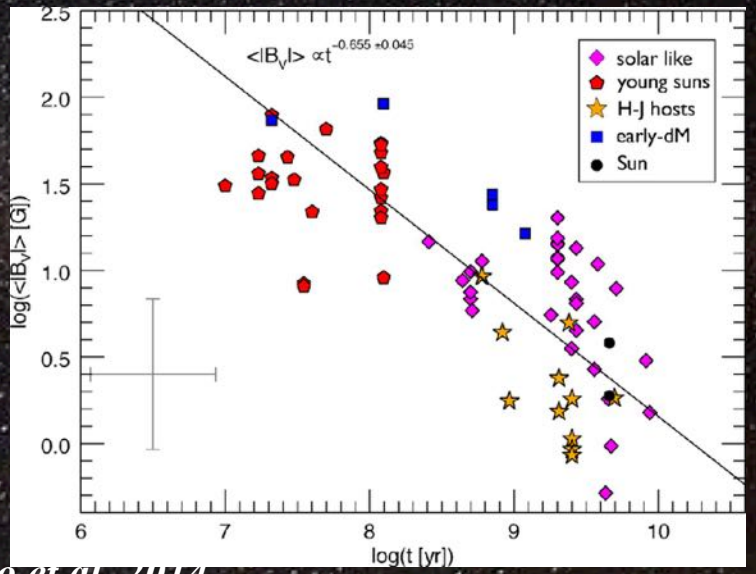


- *Faint, $L = 0.75\ L_{\odot}$*
- *Rapid rotator, $P_{cur} \sim 3$ d*
- *High latitude spots*
- *Magnetic F=10 x present*
- *Giant (> $1R_{star}$) & hot (>10 MK) corona*
- *Frequent energetic eruptions*
- *1000 F_X – 100 F_{EUV}*

Magnetism of Young Stars (Bcool)

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

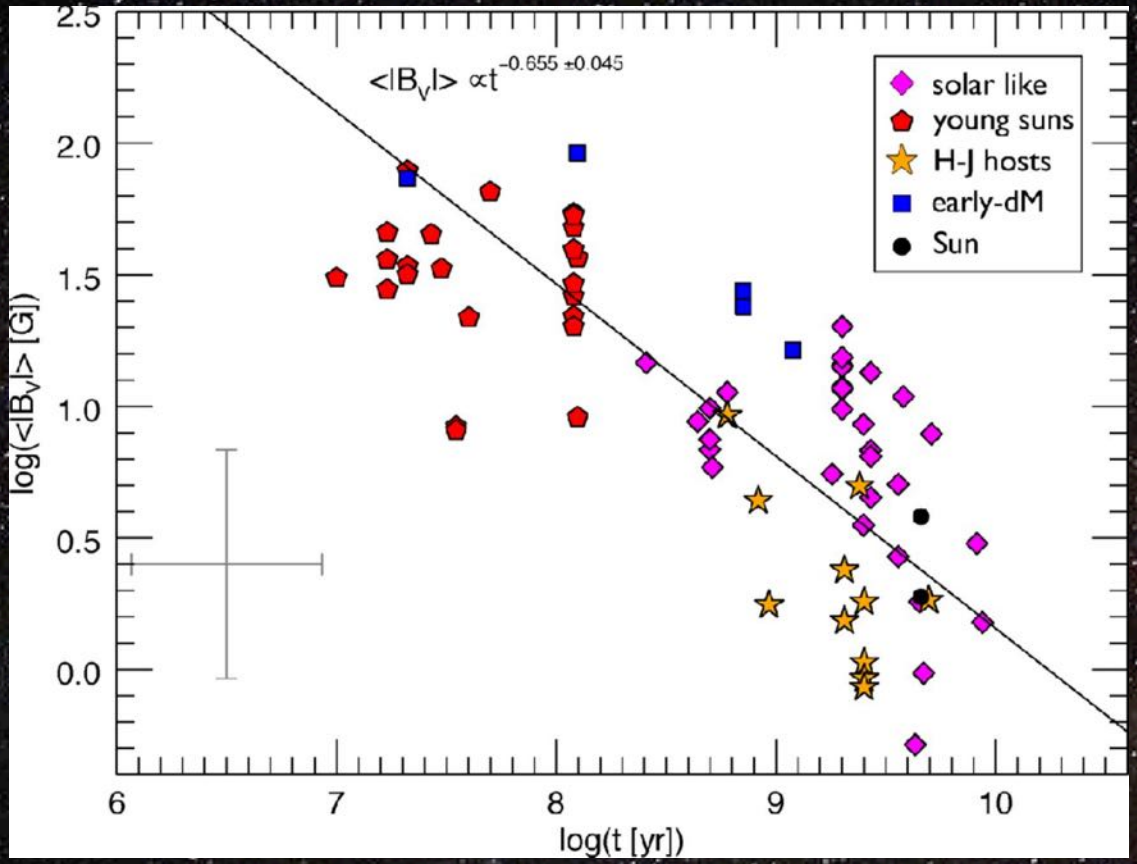




Marsden et al. 2014; Vidotto et al. 2014

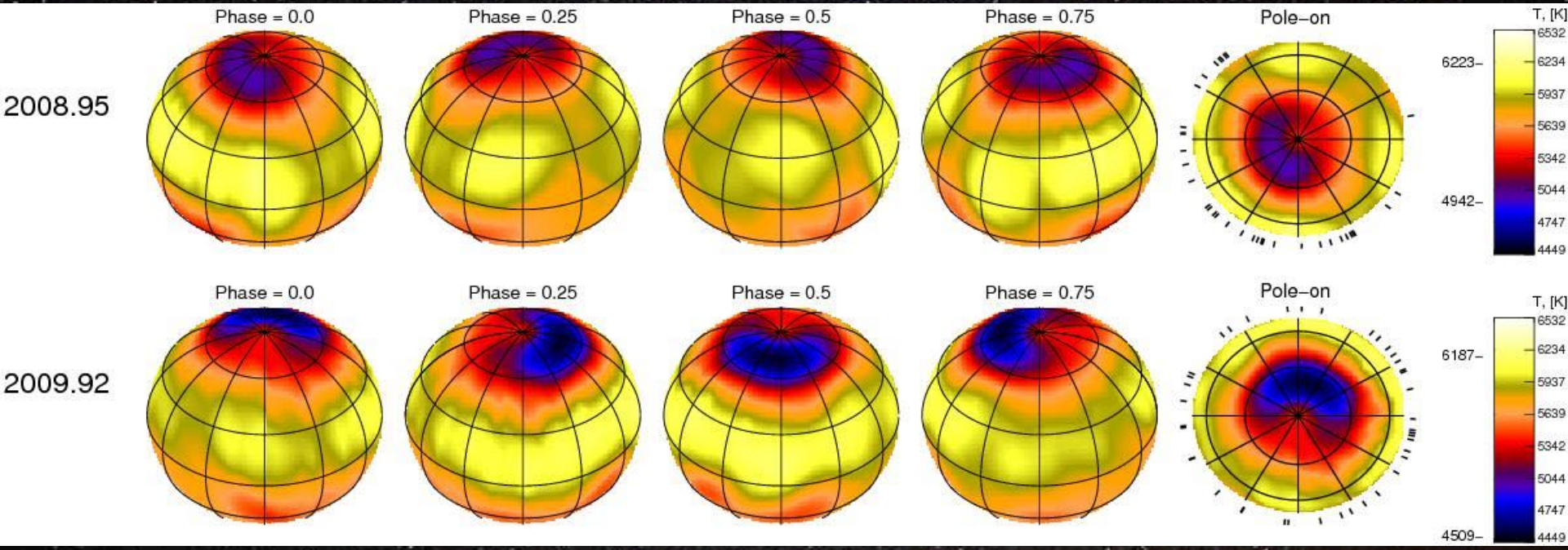
Correlation between age t and rotation period Prot for the stars, indicating that the non-accreting stars follow the Skumanich law ($t \sim P_{rot}^2$)

Magnetism of Young Stars



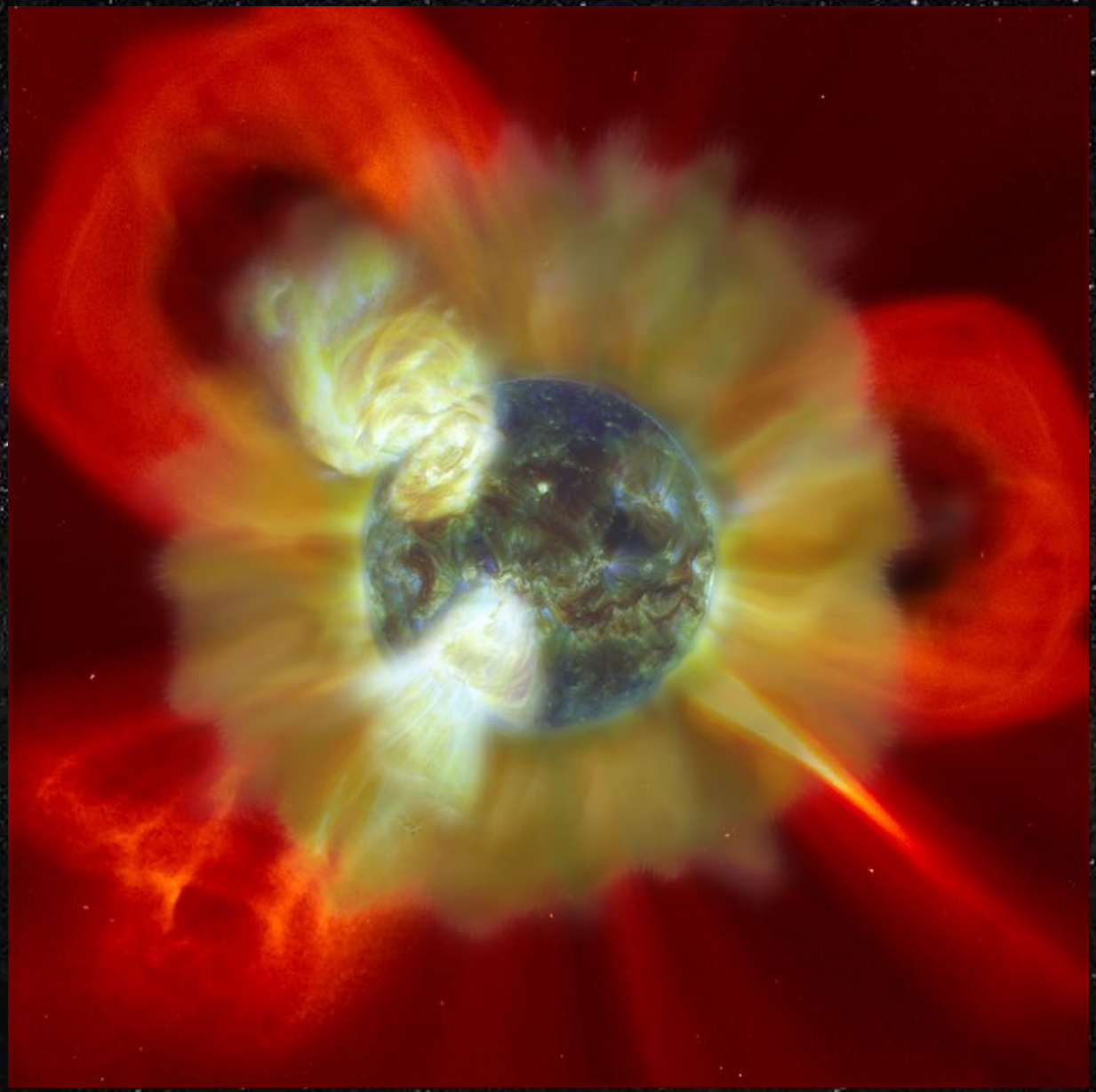
Correlation between the average large-scale field strength derived from the ZDI technique and age t, for the non-accreting star (Vidotto et al. 2014)

Young solar-like star, AF Lep



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

The portrait of the "baby" Sun



Airapetian et al. 2015 (& S. Hill)

Surprises from Kepler Mission

Photometry: stellar brightness changes caused by transiting terrestrial planets

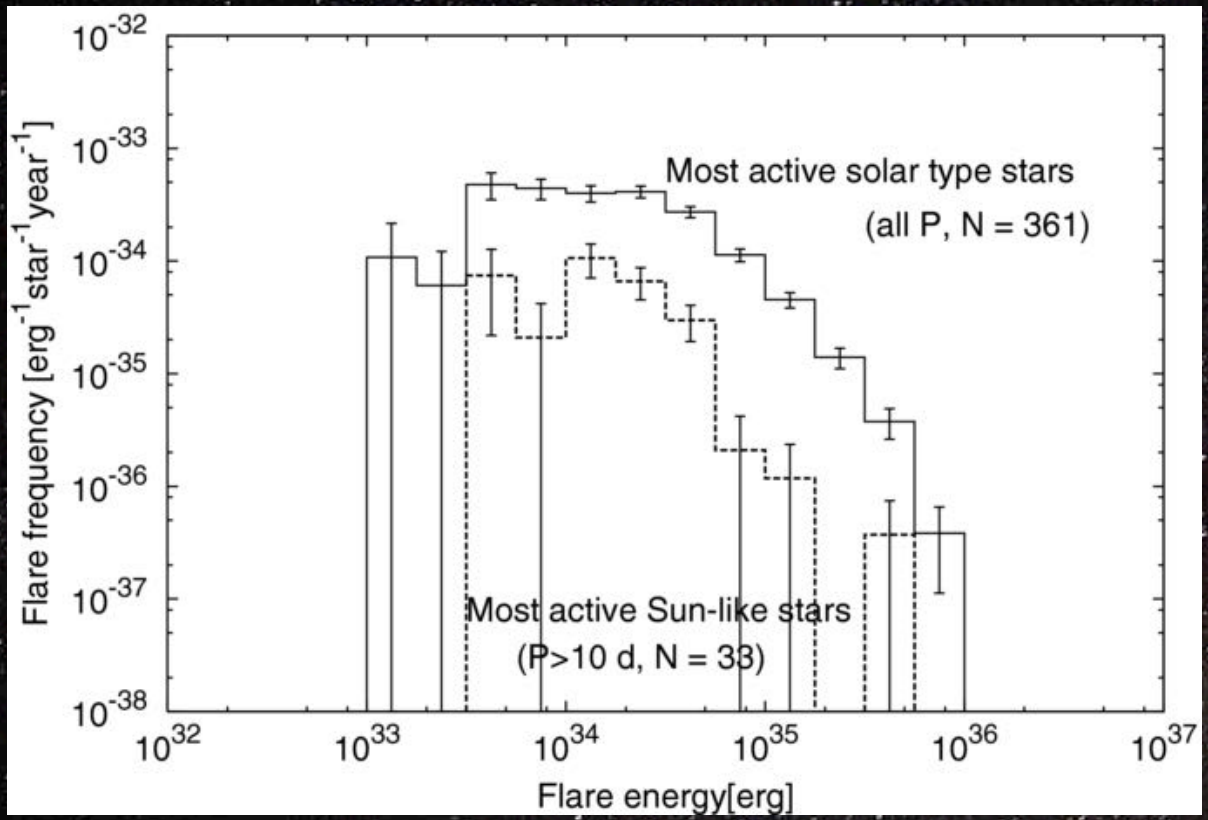
Variability range in mmag

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

Superflares on Young Suns



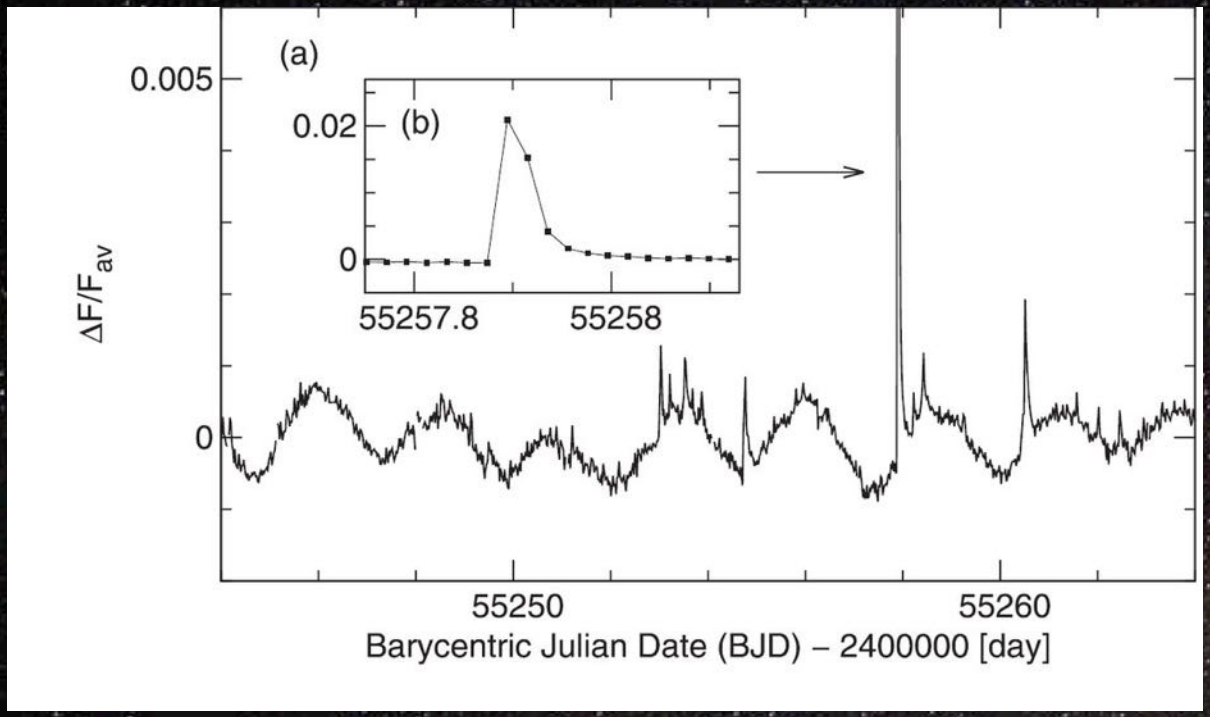
dN/dt ~ E$^{-\alpha}$,

α=2.2 - all G dwarfs

α=2.0 – slowly rotating G dwarfs

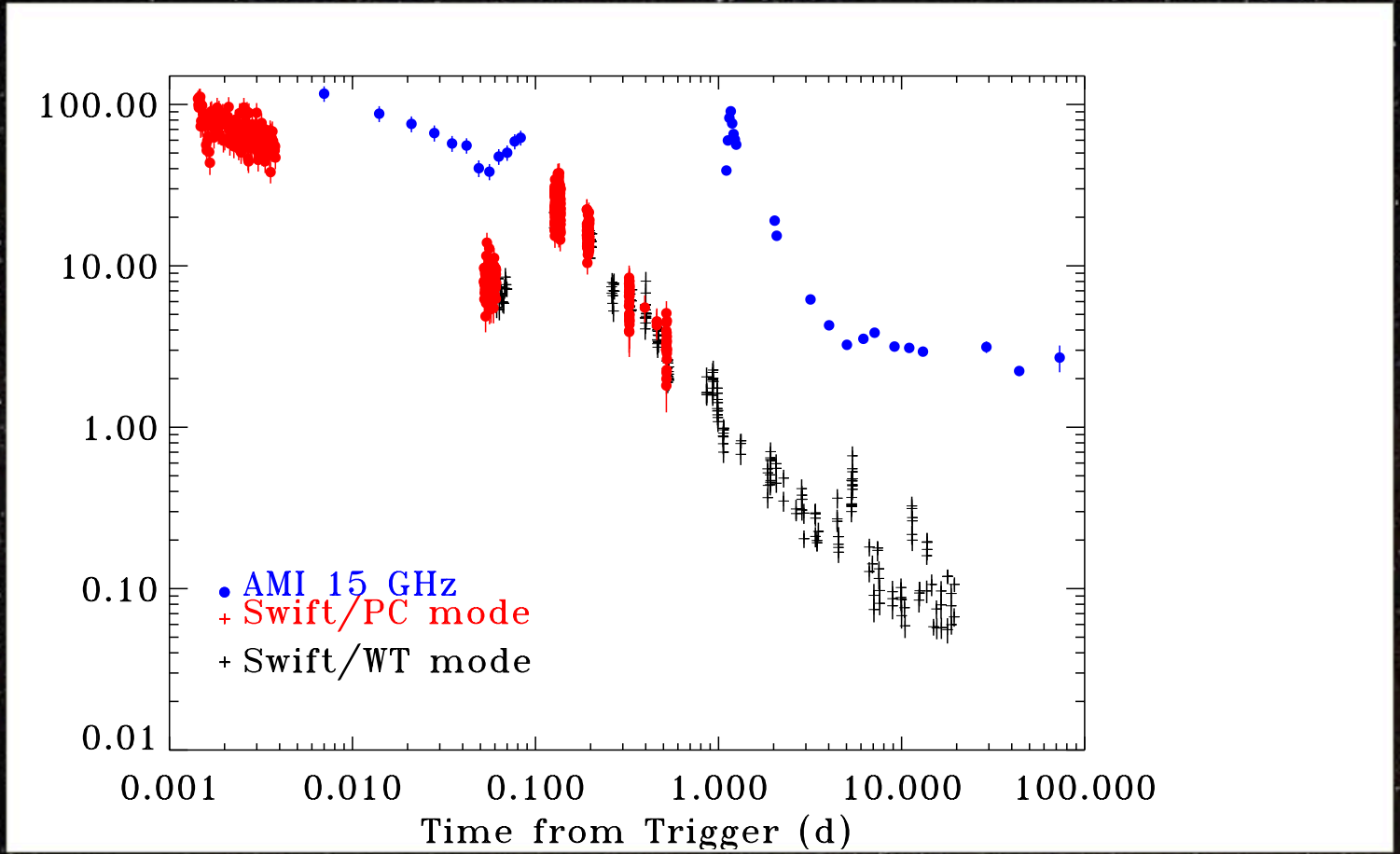
250 events/day at E~ 5 x 10^{34} erg !

The KIC 6934317 Superflare



Vsini=1.91 km/s
V=20 km/s (nearly pole-on)
Variations due to spots at 2.54 d
High chromospheric and coronal activity (100 x solar)
Flare: t = 0.12 day
E_{opt}=5.6 x10^{34} erg

Mega Flare on DG CVn: 14-day event



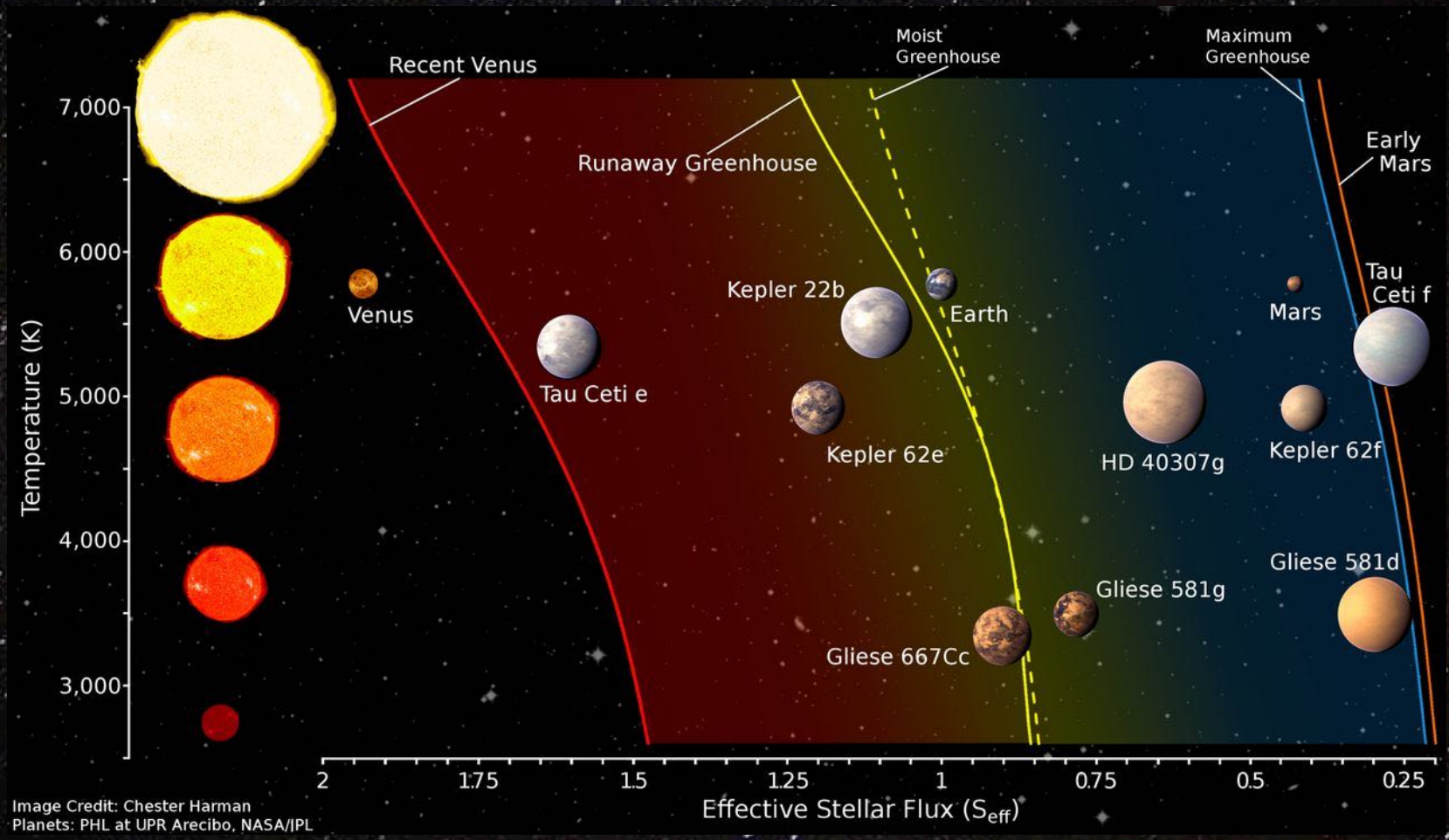
Is the Sun a Good Parent Star?

- *To be a suitable parent, a star must*
  - *have a long life expectancy*
  - *be luminous enough so that the planet doesn't have to be too close*
    - *stars 0.5$M_\odot$ (M) will tidally lock*
  - *have high "metallicity"*
  - *special constraints on a binary system*
  - *be "emotionally stable" - intra vs extravert - is required for a "healthy life" of a planet ☺*

- *Which of F, G and K stars (yellow to orange) are the best parent candidates?*

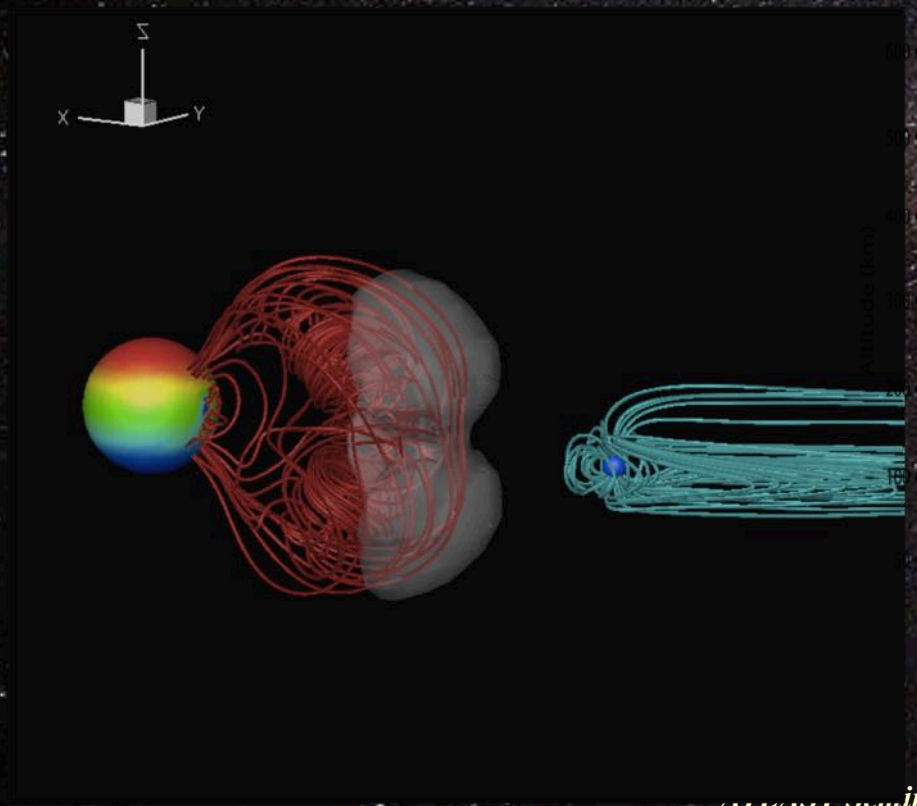
Basic Definition of Habitability Zone

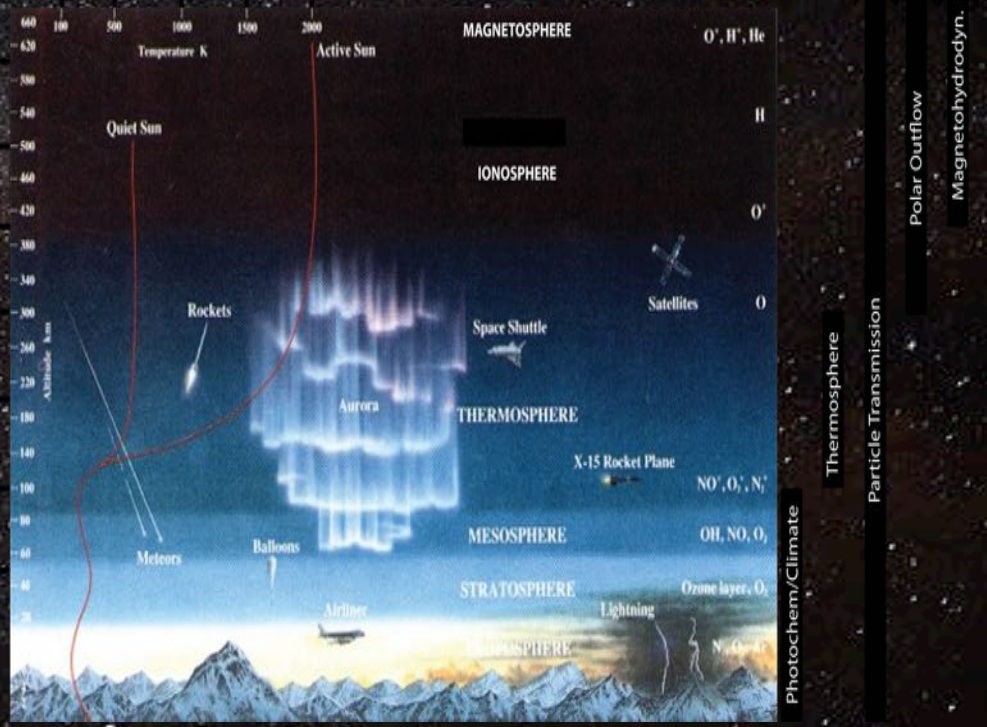
Water should exist in liquid form (Kasting et al. 2013)



Is the definition of HZ complete?

- *Effects of X-ray/EUV/UV emission from superflares*
- *Effects of magnetic fields ejected from active stars*





"Hidden" Powers of the Sun

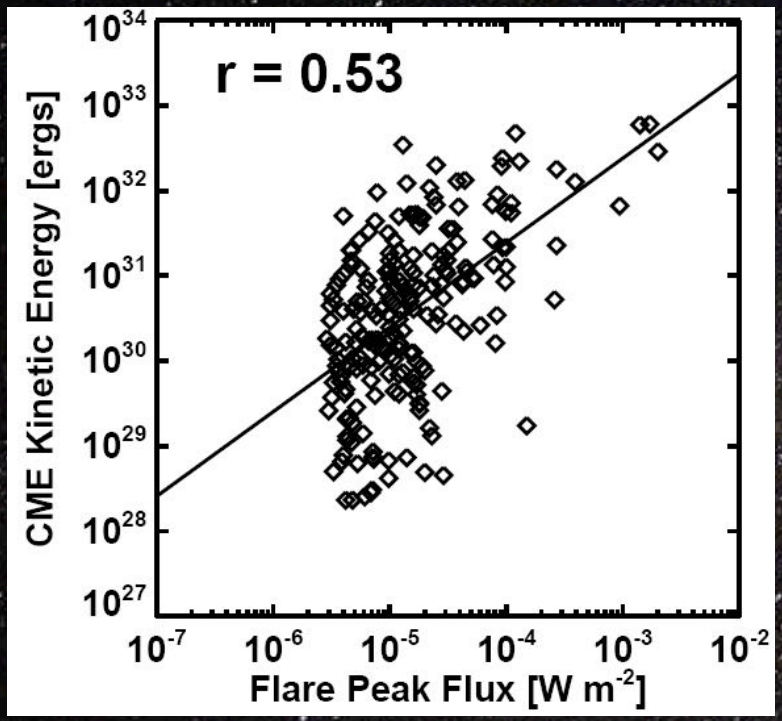
- *Superflares ($E \sim 10^{35}$ ergs) from two Sun-like stars, KIC 9766237 (21.8d) and KIC 9944137 (25.3d) with Subaru! (Nogami et al. 2014)*
- *Frequency of occurrence is 1 per 5000 years*
- *$E_{flare} = fL^3B^2/8\pi$, $L=(a\pi R_{star}^{\ 2})^{3/2}$, a –sunspot area*
  f-fraction of flare energy in radiation
- *$A_{sunspot} = 5 \times 10^{-3} A_{disk}$ (The Great Sunspot of 1947), $B_{max}=6$ kG*

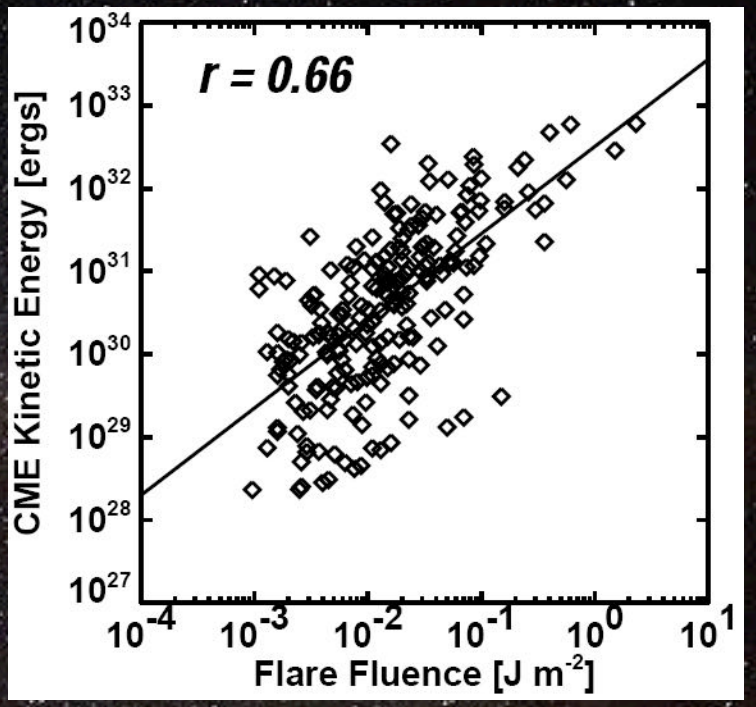
$$E_{flare}=9.36 \times 10^{35} f \text{ (ergs)}$$

"Hidden" Powers of the Sun

- *Since Jan 14 2015, we are searching for a signatures of X-ray/UV flares from one these two Sun-like stars, KIC 994413 with SWIFT XRT and UVOT*
- *Because background UV luminosity of the star is 2 orders of magnitudes lower, we should see a few times LWF events.*
- *Search is underway, stay tuned!*

CMEs and Association With Flares



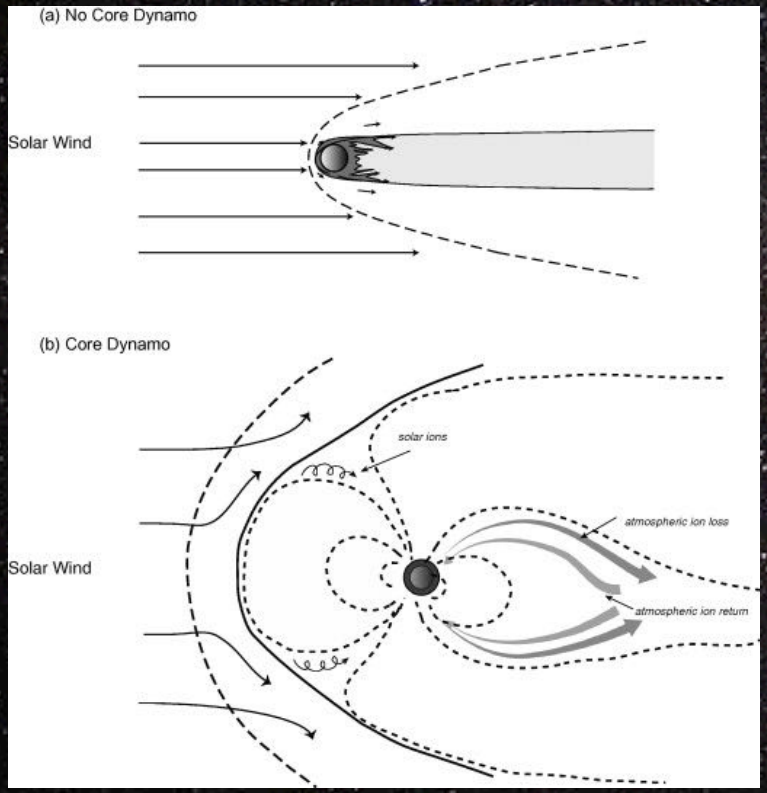


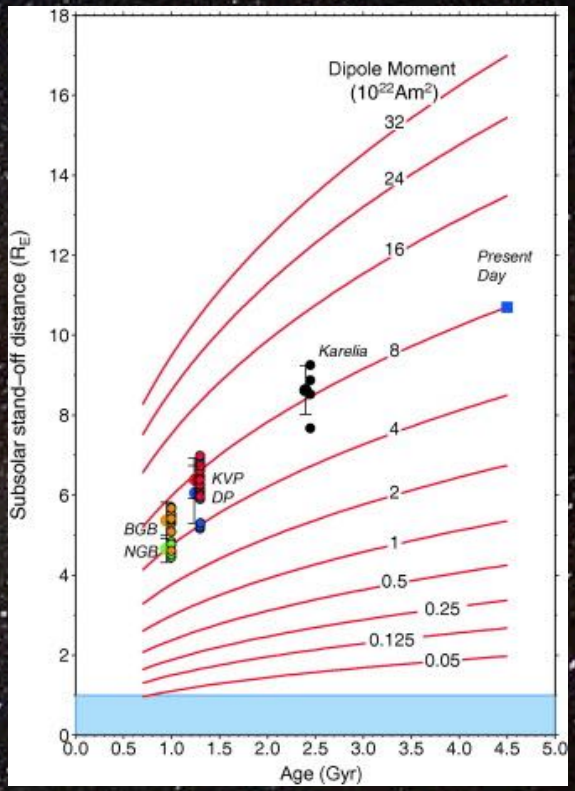
Log M_{cme} (g)=18.7+0.7logF_{flare}(W/m^2) Aarnio et al. 2011

dM/dt (CME) ≥ dM/dt (wind) for early Sun

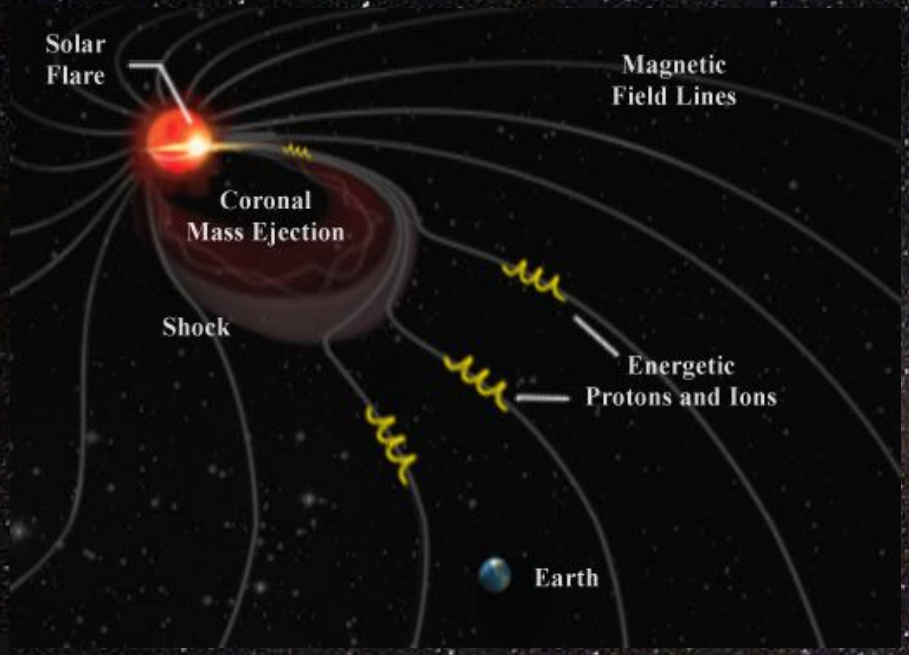
Effects of the solar wind on early Earth magnetosphere

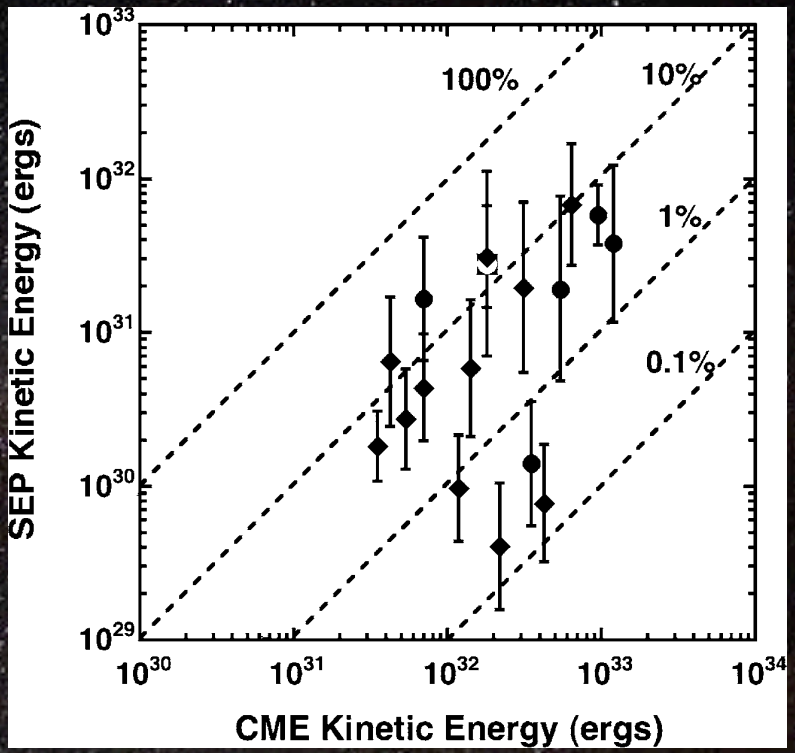
Earth lacked magnetic field for the first 0.5 Gyr! (Tarduno et al. 2104)





Solar Energetic Particle (SEP) Events



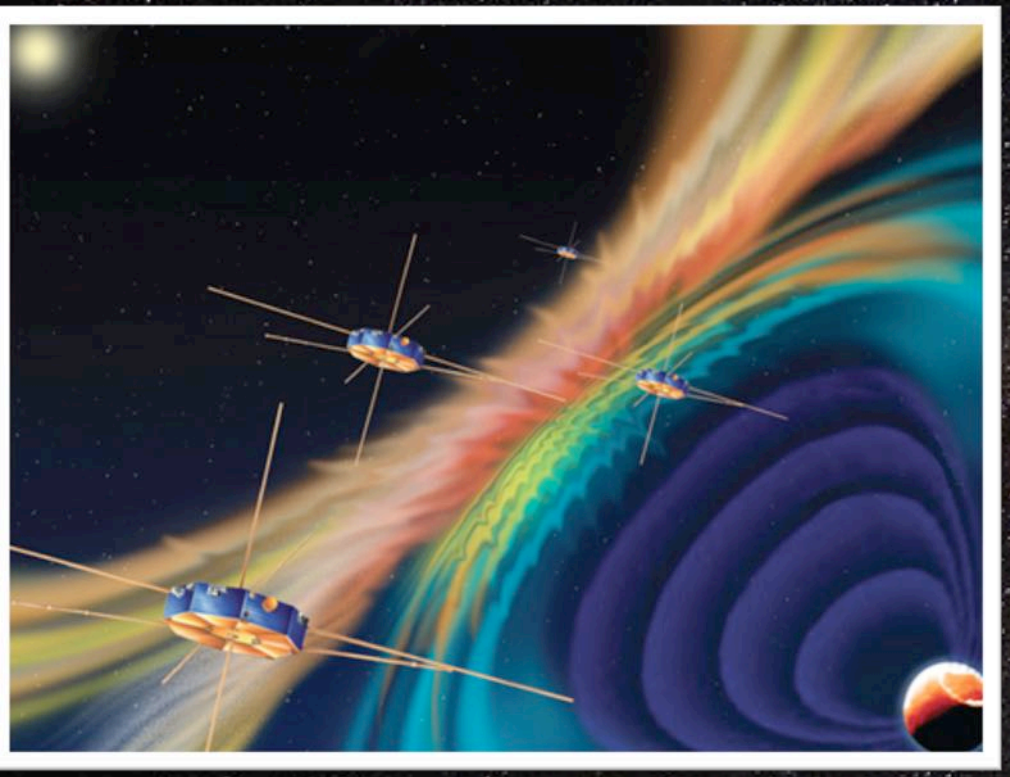


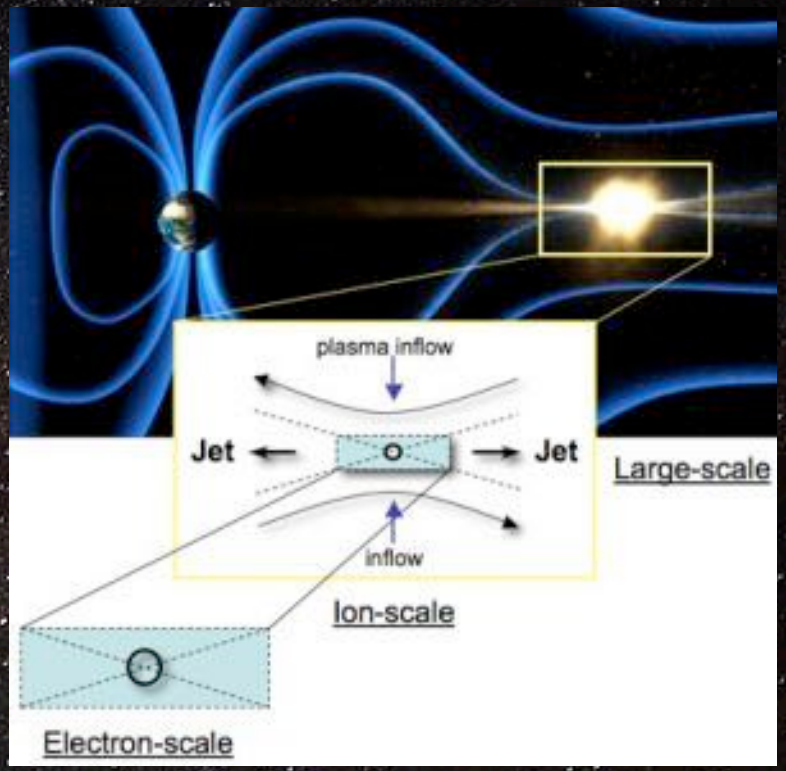
Typically about 10% of CME kinetic energy goes into SEPs

Similar to flare energy

Expect Ground Level Enhancement events (GLEs) are associated with energetic CMEs

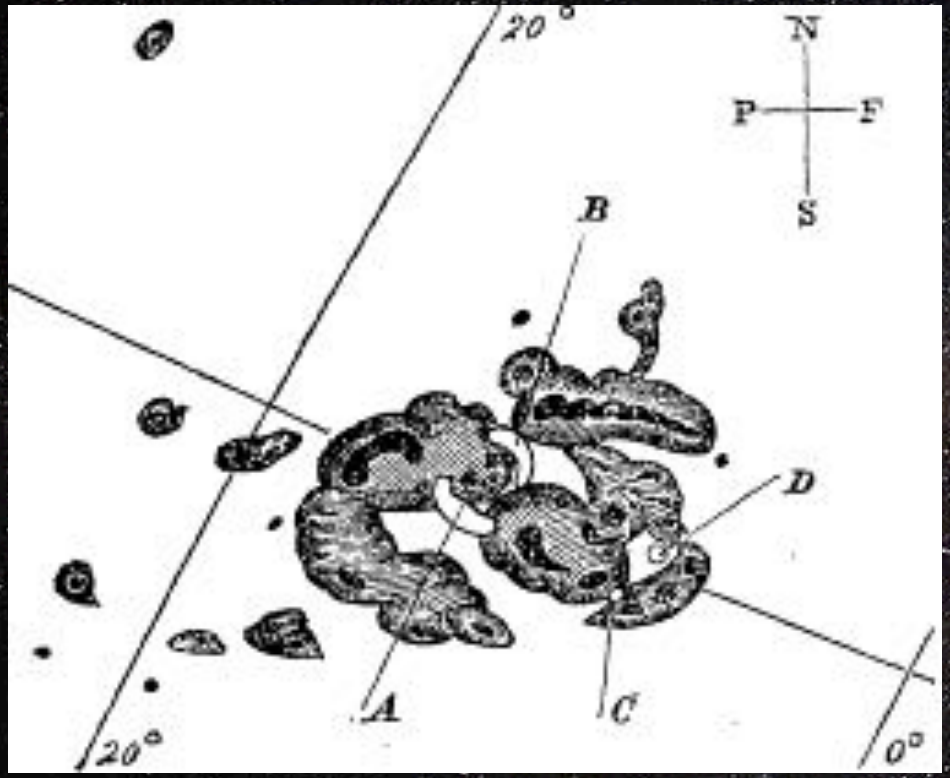
Effects of CMEs – reconnections when CME's Bz is southward





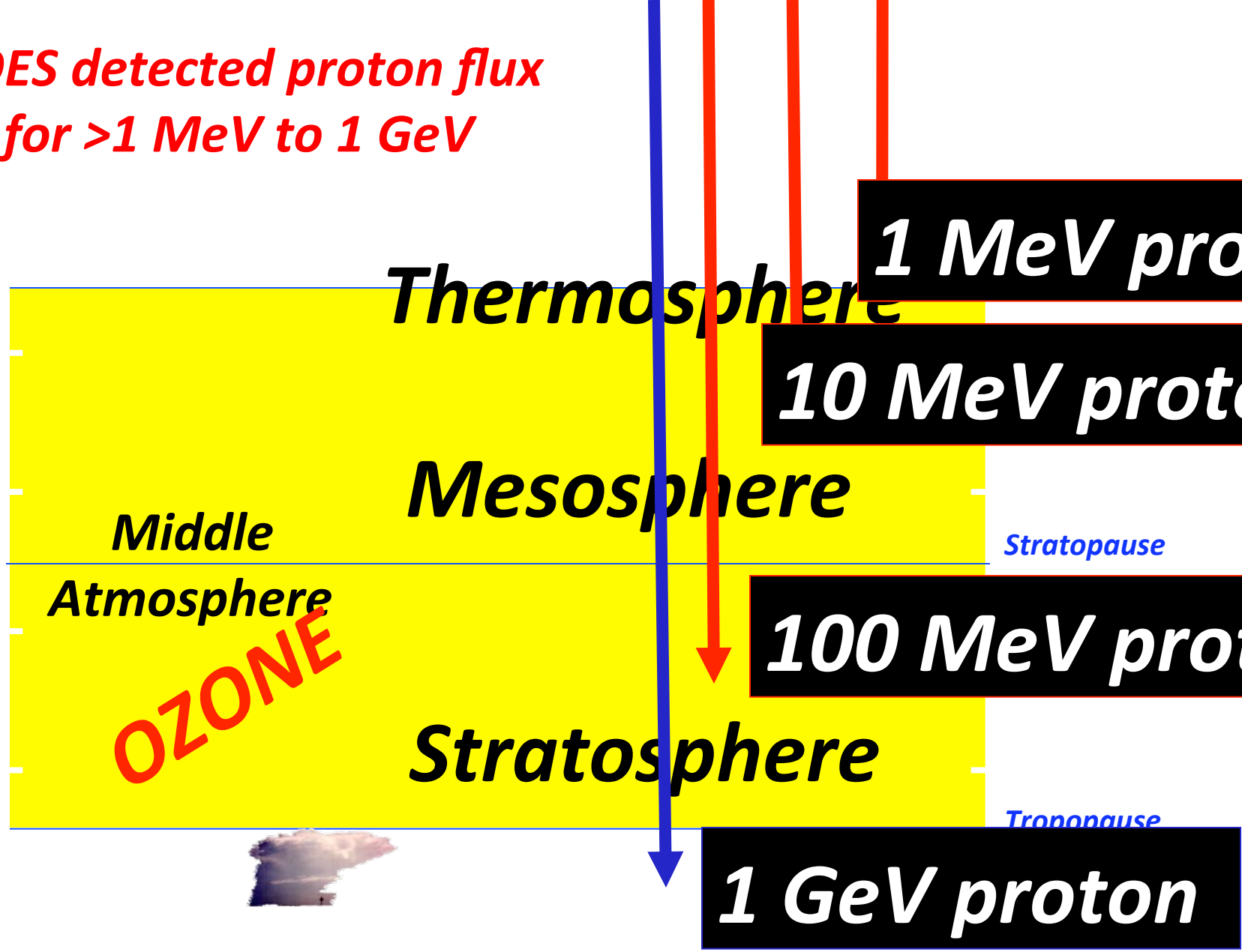
MMS scheduled to launch on March 12

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?*

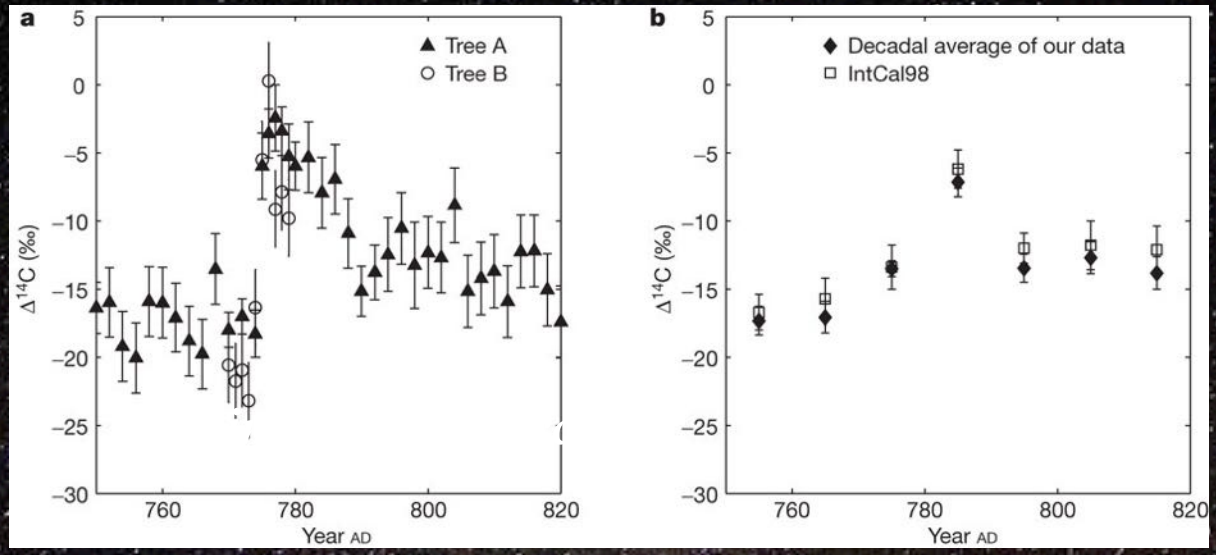
$E_{flare} = 2 \times 10^{33}$ erg $= 0.1\ E_{cme}$



Particle radiation from the Sun can destroy ozone

courtesy: C. Jackman

Extreme CMEs: 775 AD Event



Miyake et al. 2012

Atmospheric ionization depletes ozone (20% reduction), increasing the solar UVB that reaches the ground.
Not a mass extinction event
Reduction in primary photosynthesis in the oceans
Risk of erythaema and skin cancer
Melott & Brian 2012

- *Peak in cosmogenic radionuclides of 14C, 10 Be and 36Cl*
- *Measured in tree trunks (Japan, Europe, Russia)*
- *Observed in shallow sea coral skeletons*
- *Polar ice cores*
- *$E=2 \times 10^{34}$ ergs*
- *What is a similar event occurs today?*

SCME Attack of the Early Earth:

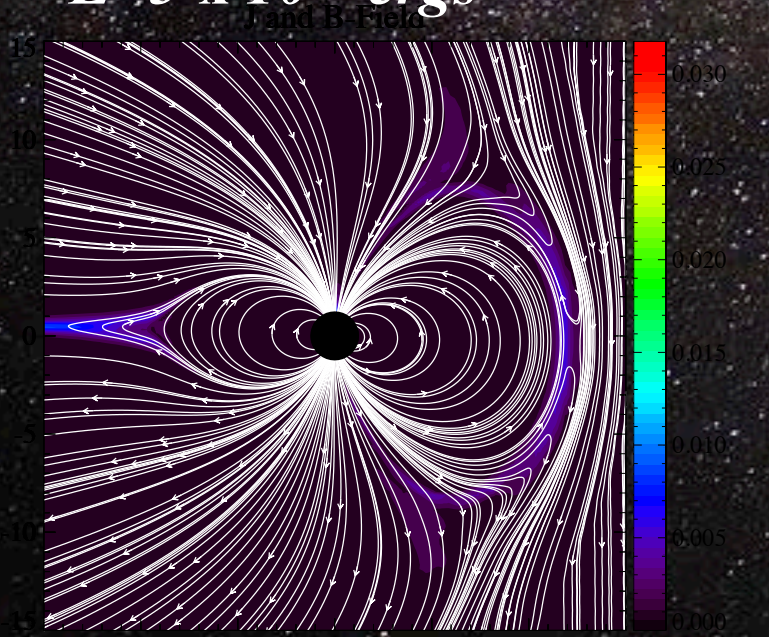
The early Earth was continuously exposed to a 5 x Carrington-type CMEs ! (Airapetian, Glocer & Danchi 2014)

What would be their effects on planetary ecology and life?

Event 1

Super-Carrington type

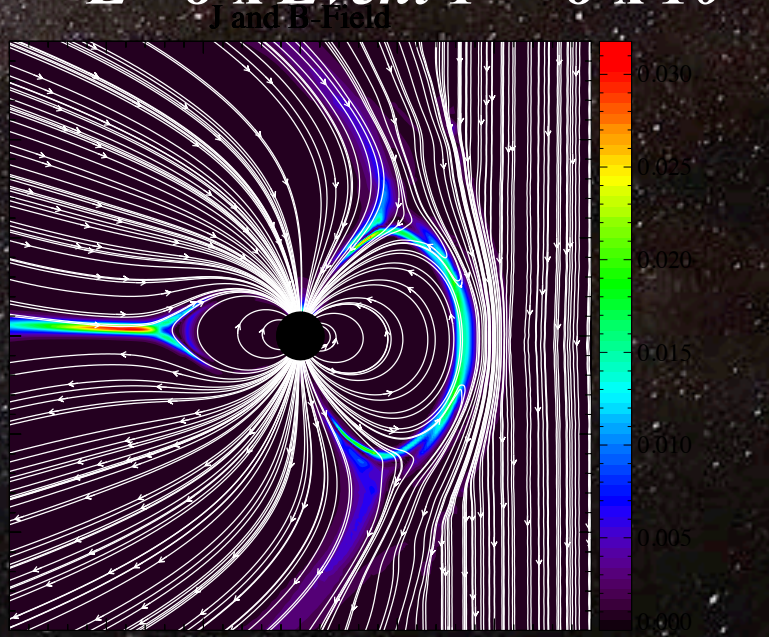
E=3 x 10^{33} ergs



Event 2

Extreme - 775AD type

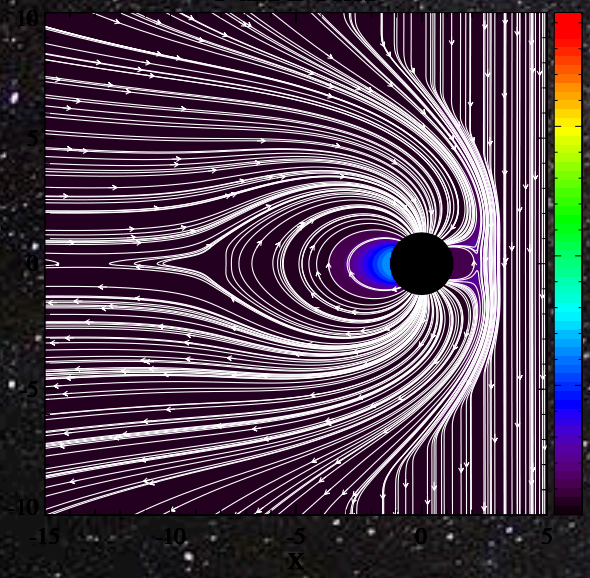
E= 8 x Event 1 = 8 x 10^{33} ergs



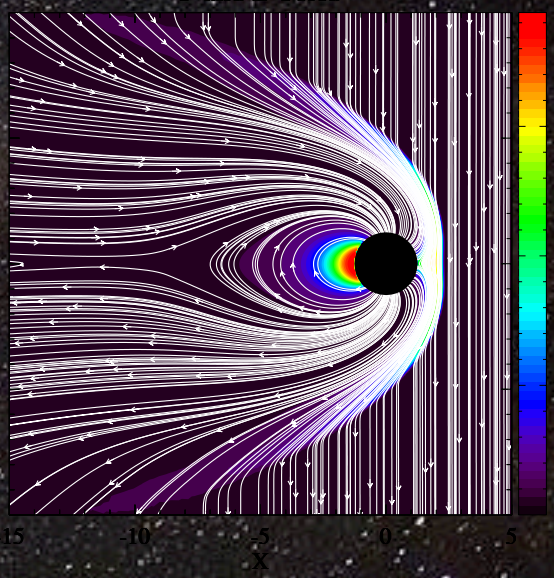
Extreme CMEs attacking the Early Earth: Results

Pressure and Magnetic field

Event 1



Event 2



Would CMEs Kill of Create "Puppies'

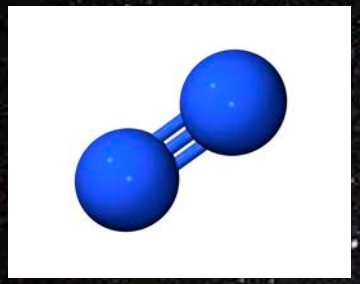
Due to EUV-UV emission from the early Sun (Cockell 2000)

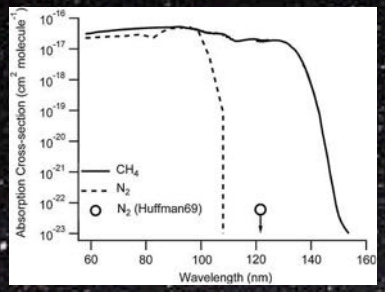
- *DNA damage rates were ~1000 times greater in the surface layer of the Archean ocean*
- *At ~30m damage would be similar to the current values*
- *Life could have emerged at the surface after 3.5 Ga*
- *(Cnossen et al. 2007)*

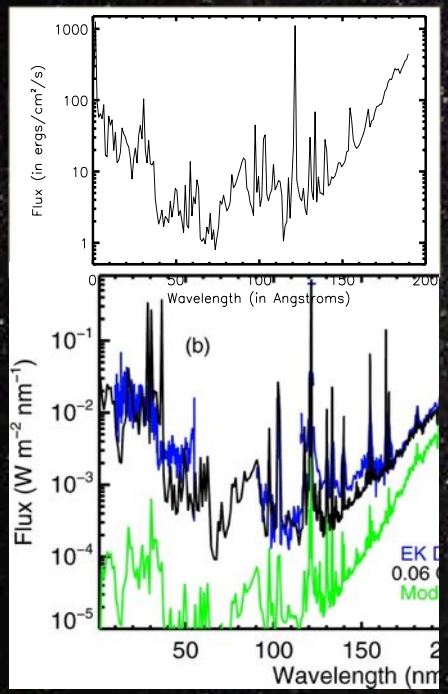
CMEs and superflares move these estimates further up and the time of life emergence at the Earth's surface even later!

Could life be promoted by explosive events?

Prospects For Life on Early Earth &Titan







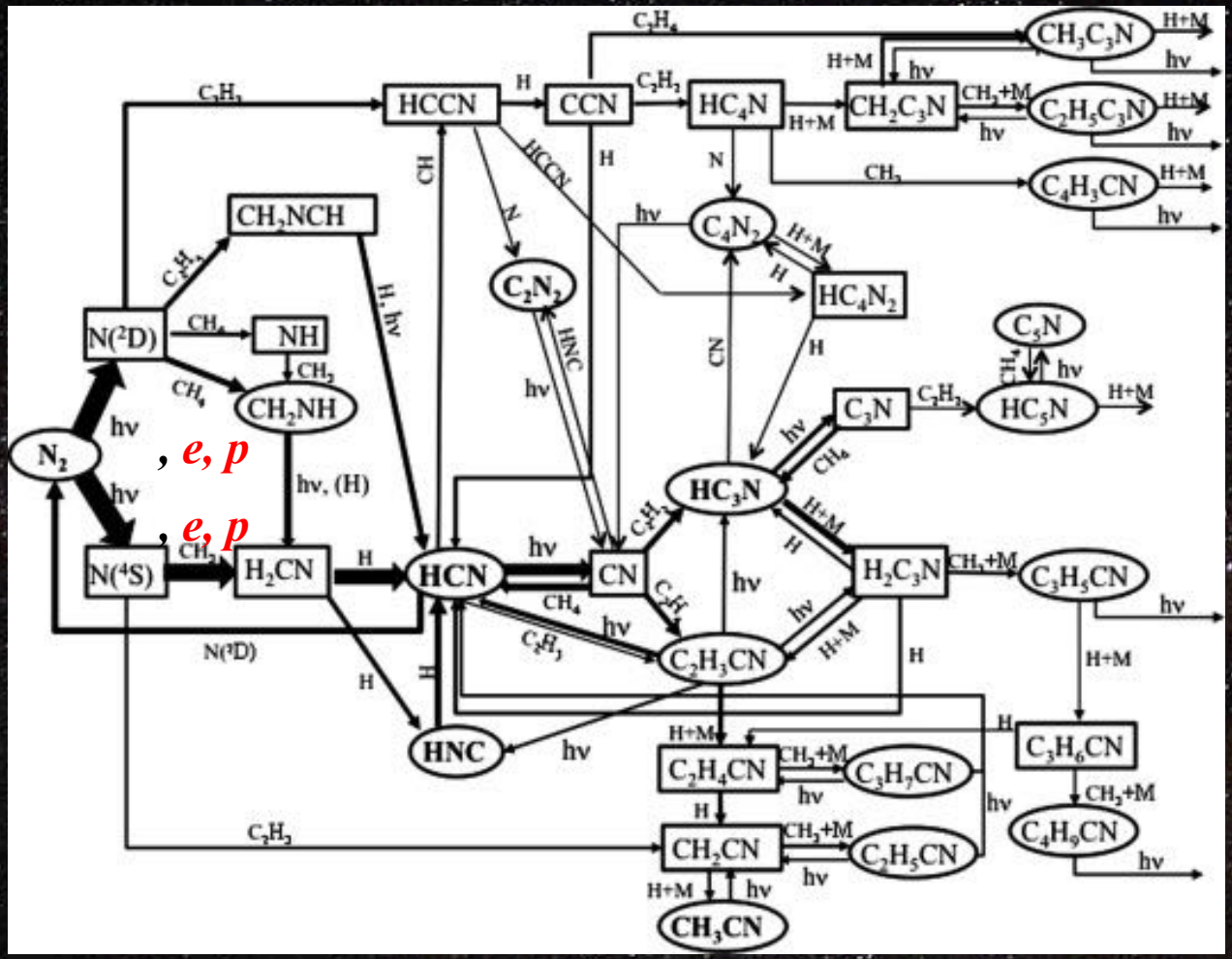
Re-scaled
Oct 28, 2003
X17 solar flare

The dominant molecule in the Atmosphere ~ 80-90%
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 :

- *UV emission at $\lambda < 100$ nm (early Sun, M dwarfts)*
- *Lightning discharge*
- *Energetic particles (e, p)*

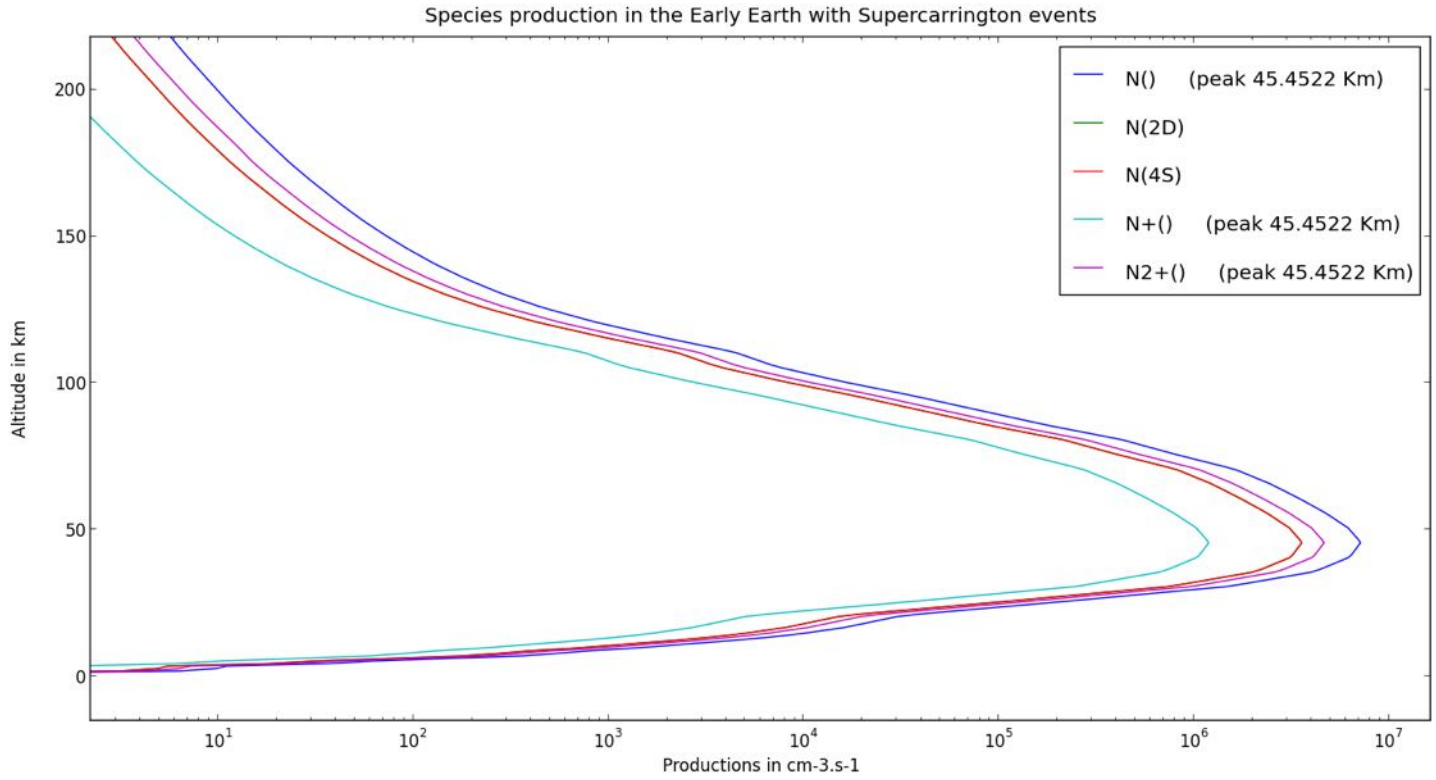
Prospects For Life on Early Earth



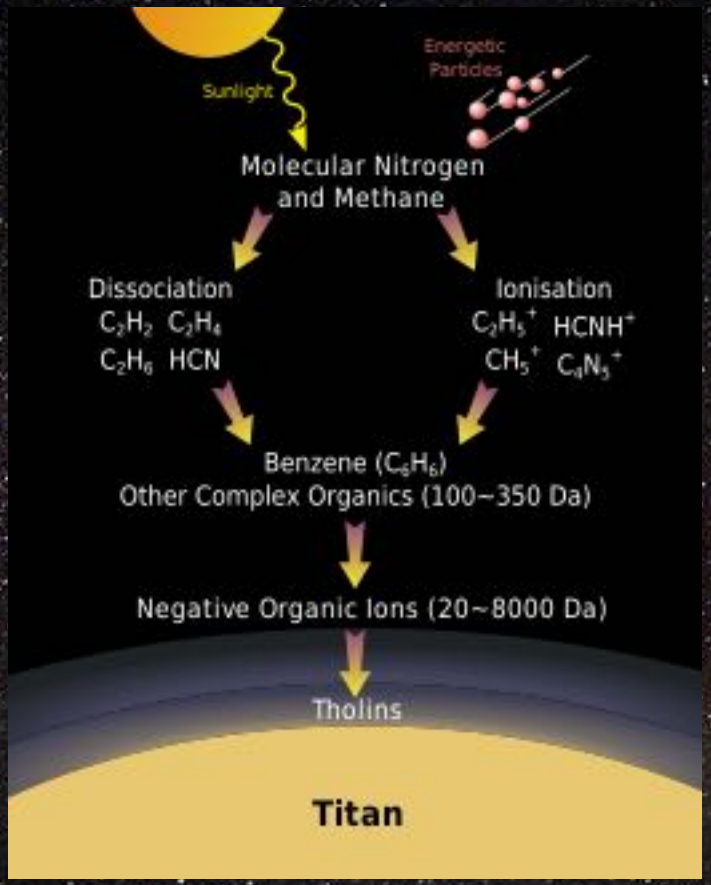
Loison et al. 2015

Production Rate of Odd Nitrogen Highly Reducing Atmosphere

Aeroplanets model contains 124 species including nitrogen containing compounds, and 1141 reactions (Gronoff et al. 2014; Airapetian et al. 2015)



Tholins – Precursors of Life?



Tholin (Sagan, Khare 1977) , Waite et al. 2007)

Climate Models of Early Earth

Challenge:

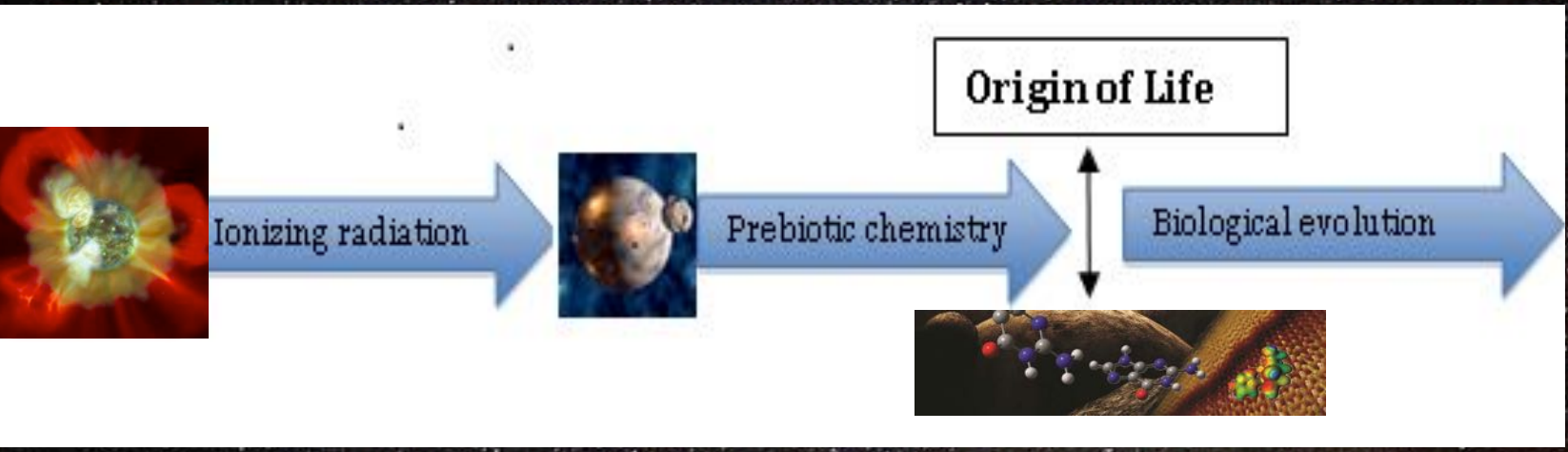
- ***Early Earth was warm to support liquid oceans under the Faint Young Sun (FYS paradox)***

Solutions:

- ***Production of ammonia, NH_3, the efficient greenhouse gas, due to e and p bombardment***
- ***Enhanced absorption bands of greenhouse gasses due to thermal and pressure broadening due to odd N***

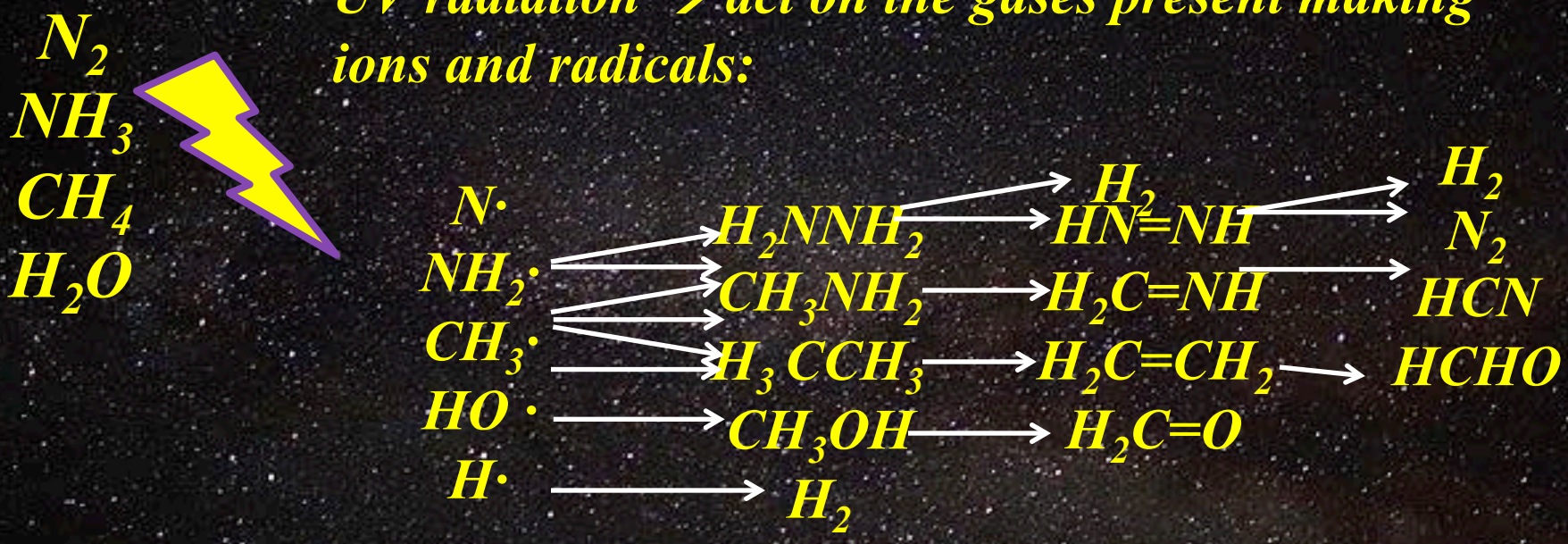
(Goldblatt et al. 2009; Airapetian and Goldblatt, in progress)

3.8 billion years From The Active Baby Sun to the Happy Baby David



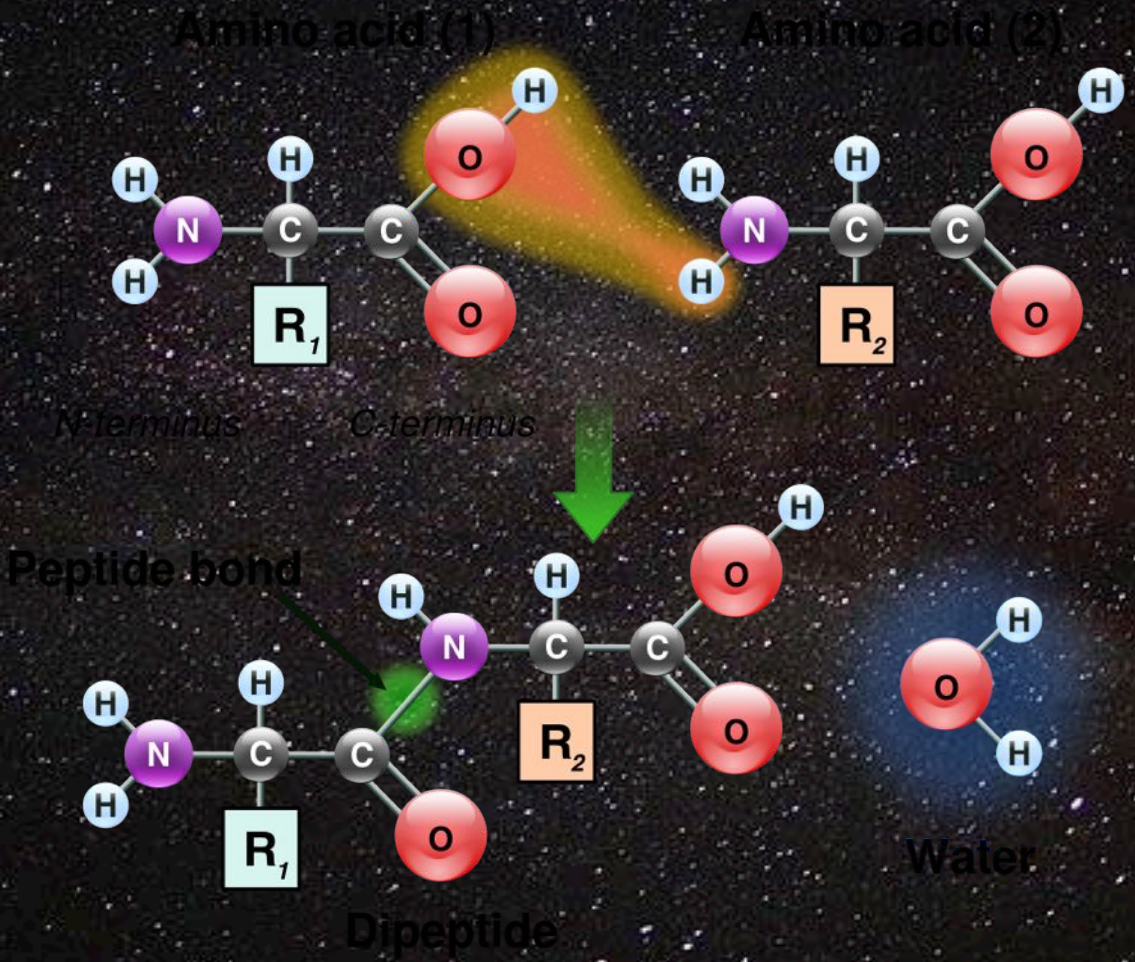
Model System for the Complex Chemistry Which Can Result from Gas Phase Reactive Intermediates

Spark generates a combination of high T, e^-, and UV radiation → act on the gases present making ions and radicals:



Water soluble species migrate to the aqueous reservoir (the relative extent depending on the pH and Henry's Law), while the insoluble species remain in the gas phase.

Forming a protein from amino acids



Work in Progress: Biology Experiments

What is the impact of high levels of ionizing radiation (radiation and particle fluxes) on the rate of evolutionary processes and their role in enhancing the survivability of organisms on early Earth, Mars and other stellar systems.

- *Modern High Throughput Sequencing (HTS) technology in conjunction with bioinformatics computational packages available at FDA (Simonyan & Mazumder 2014)*
- *Detect single nucleotide alterations in the genome and map them to the functional elements to understand the impact of a mutation during the evolutionary adaptation process.*
- *If radiation is the challenge then mutations that allow efficient DNA repair, will be selected during the cyclic irradiation experiment.*
- *What are the conditions which will encourage higher rates of evolution thereby leading us to identify the optimal conditions that support the highest rate of evolution.*

Work in Progress: Biology Experiments

Genomic (DNA) and transcriptomic (RNA) data will be available for:

- *Pseudomonas putida strain KT2440 ATCC®47054™ (Bac/Gamma-proteobacteria)*
- *Halobacterium salinarum strain NRC-1 ATCC®700922™ /JCM 11081 (Archaea/ Eurarchaea)*
- *Chroococcidiopsis thermalis PCC 7203 ATCC®27900™ (Bacteria/ Cyanobacteria).*

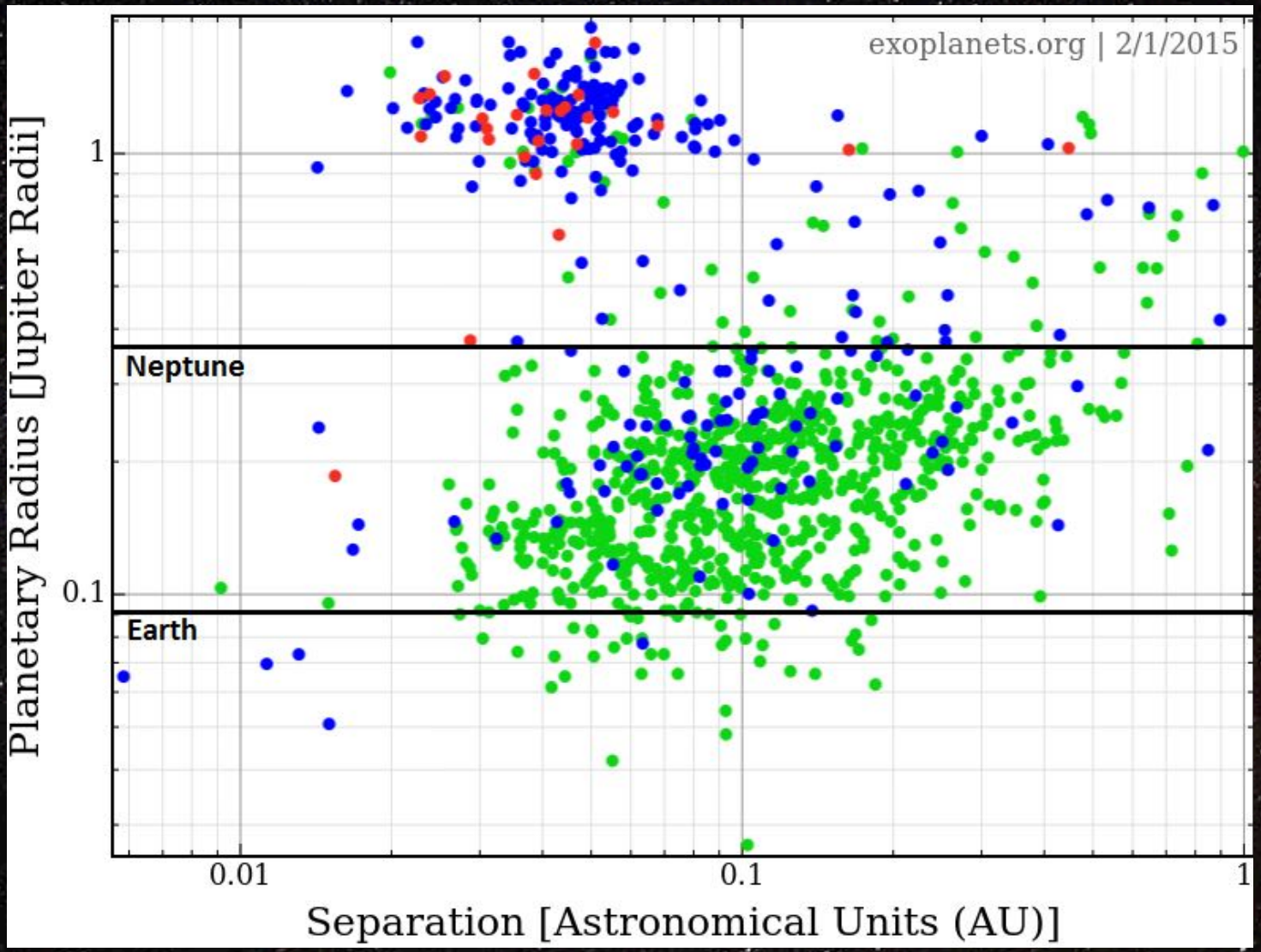
Condition	Control	Gamma	Neutron	UV
Cycling (high dosage rate)[1]	3	3×2	3×2	3×2
Cycling (high dosage rate)[1]	*3x3x2*	*3x3x2*	*3x3x2*	*3x3x2*
Long duration (low dosage rate)[2]	*3x9*	*3×9*	*3×9*	*3×9*
Soil[3]	1x2	1x2	1x2	1x2
Soil[3]	*3*	*3x3x2*	*3x3x2*	

Preliminary Conclusions

***Question**: Was Our Sun a Promoter of Life?*

***Answer**: Yes, our first results provide evidence in favor of the early Sun's crucial contribution to the origin of life on Earth. Our team has started a multi-disciplinary theoretical, observational and experimental investigation of this complex question.*

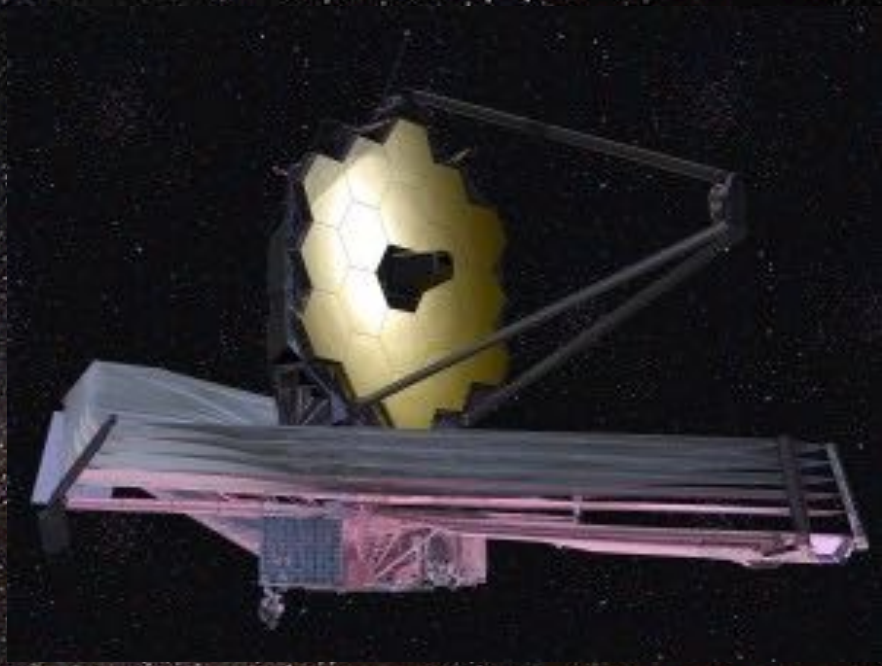
Strategies for Finding Earth 2.0



Strategies for Finding Earth 2.0

JWST:

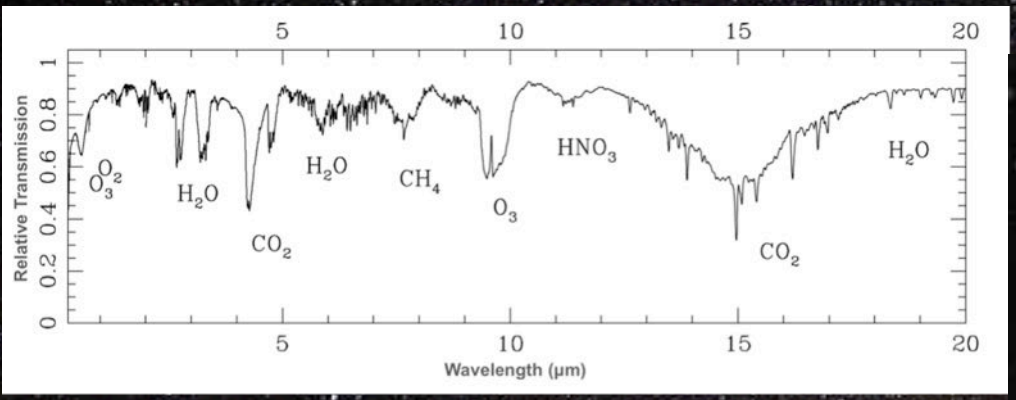
Medium resolution, 2,700, NIRSpec, spectroscopy: atmospheric abundances – H_2O, CO_2, CO, CH_4, H_2/He and a temperature-pressure profile.

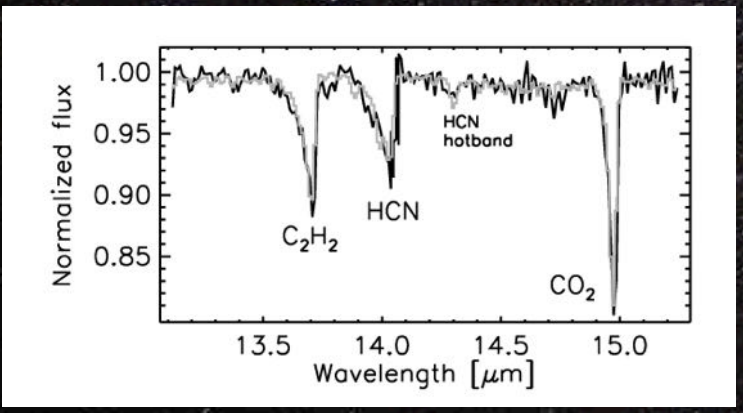


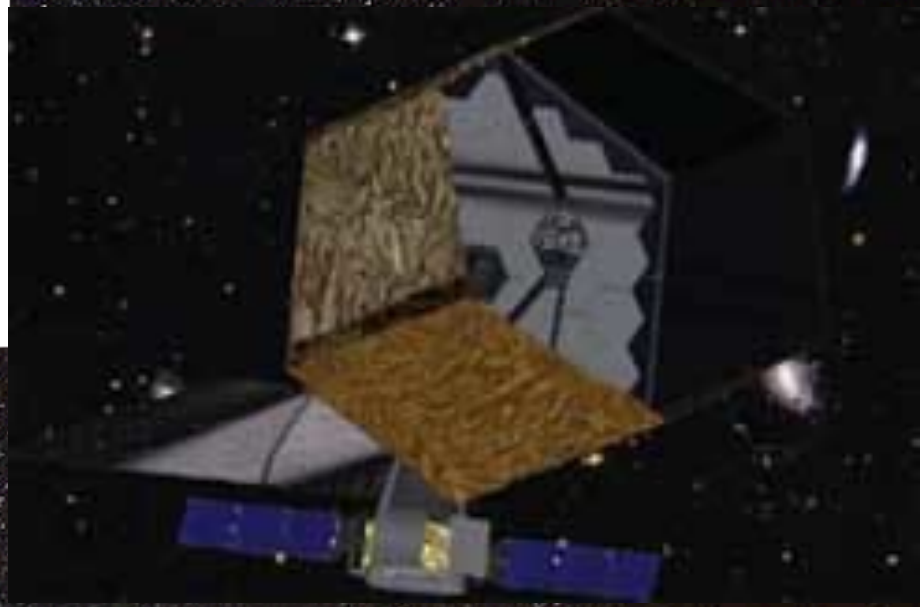
ATLAST: Toward Finding Earth 2.0

High-resolution (5-10) x 10,000 spectroscopy:
H_2O, CO_2, low H_2/CH_4, O_3, N_2O, HCN

10-m version







Boonman et al. 2003 Orion-KL star formation region

Strategies for Searching for Life in the Universe

Intelligent

or

Primitive 10^{20} x abundant