Astrobiology
Lecture 16

Galactic Habitability

Trieste University, Academic Year 2021-2022
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One of the aims of astrobiology is exploring
the (potential) distribution of life in the universe

This particular aspect of astrobiology has lead to the definition of

The Galactic Habitable Zone (GHZ)

Galactic habitable zone vs circumstellar habitable zone

Important differences

1) The habitability criteria of the GHZ are based on statistical distributions of Galactic properties and yield probability distributions

The results are purely statistical

2) Some habitability criteria used to define the GHZ refer to macroscopic life

Comparable to animal or plant life on Earth

The time scales of life evolution enter in the calculation of GHZ

General concept of the Galactic habitable zone

Mapping astrophysical quantities related to Galactic evolution into probabilities of astrobiological interest

In the original formulation

Gonzalez et al. 2001, Icarus,152,185

Metallicity & probability of planet formation

$Z(x_i,t)$ ➔ $\pi_{PF}(x_i,t)$

Supernova rates & probability of life destruction

$R_{SN}(x_i,t)$ ➔ $\pi_{LD}(x_i,t)$

Lineweaver et al. 2004, Science 303, 59

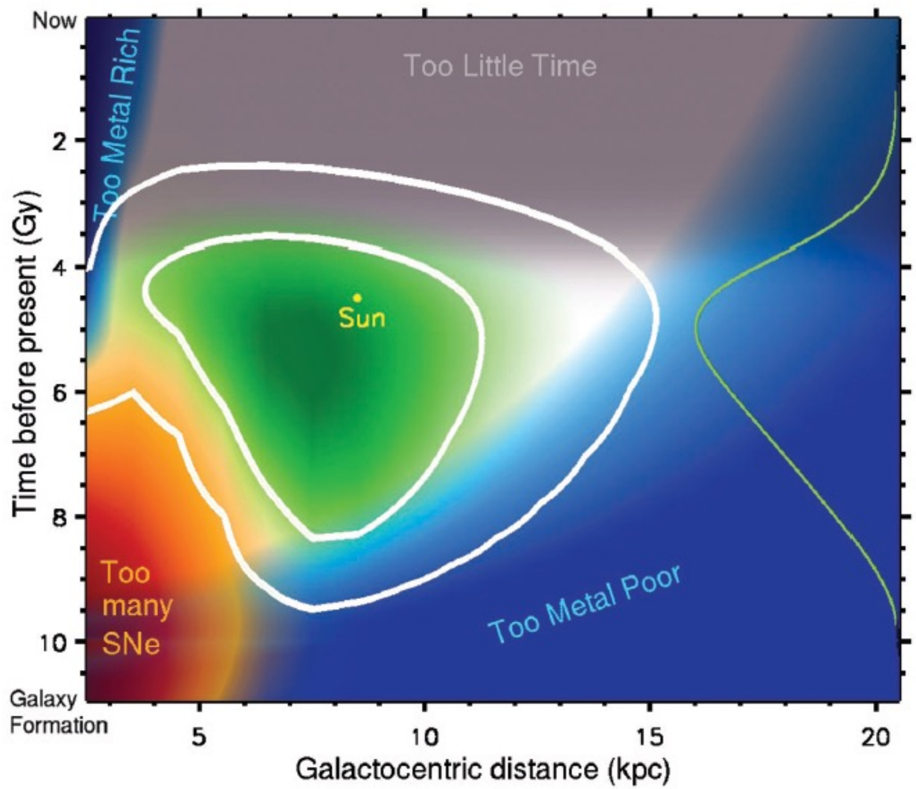


Fig. 3. The GHZ in the disk of the Milky Way based on the star formation rate, metallicity (blue), sufficient time for evolution (gray), and freedom from life-extinguishing supernova explosions (red). The white contours encompass 68% (inner) and 95% (outer) of the origins of stars with the highest potential to be harboring complex life today. The green line on the right is the age distribution of complex life and is obtained by integrating $P_{GHZ}(r, t)$ over r.

Tools for GHZ calculations

- Models of Galactic chemical evolution
  - Radial distribution of metallicities and supernova rates at different epochs of galactic evolution
  - In the original formulation, semi-analytical models have been used
  - More realistic models are also employed:

    Spitoni, Matteucci & Sozzetti, 2014, *MNRAS* 440, 2588

    Carigi et al. 2013, *Rev. Mex. Astron. Astrof.*, 49, 253

- Galaxy simulations
  - Generation of space-time evolutionary maps of Galactic habitability by means of N-body simulations of galaxies
  - Example:

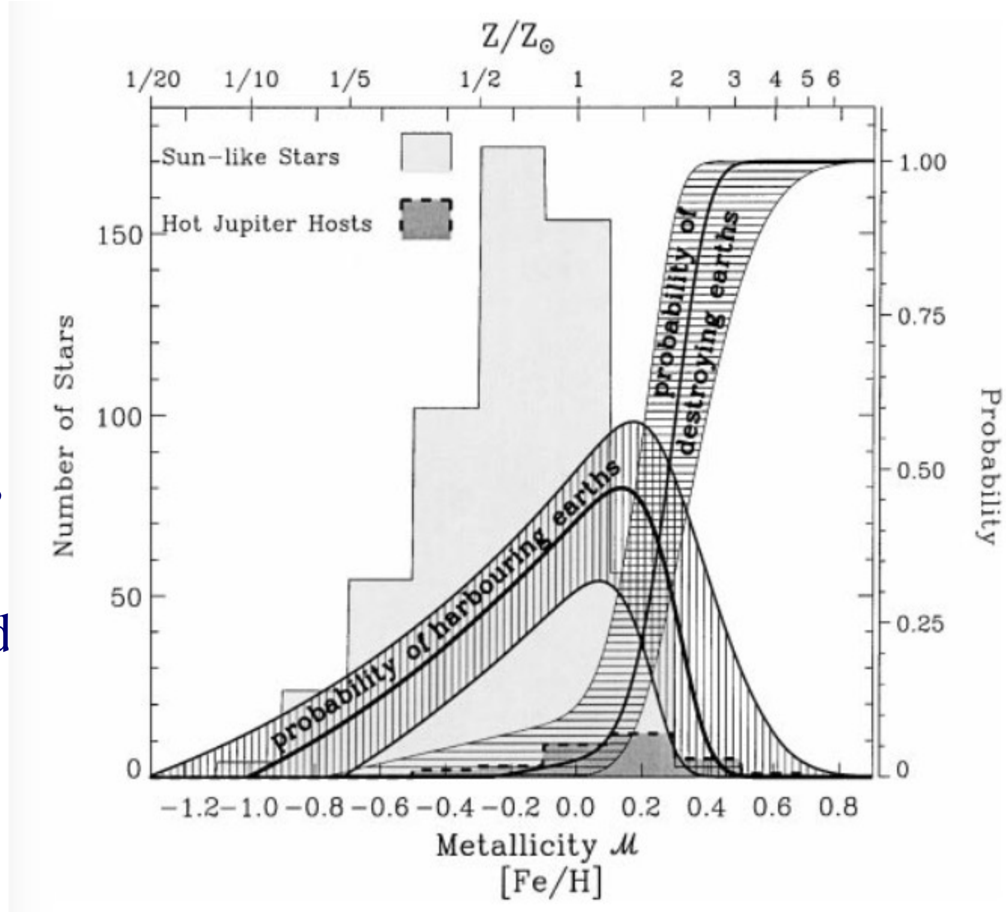
    Forgan et al., 2015, arXiv:1511.01786

Both tools start to be applied also to nearby galaxies

- M31, M33

Open issues in GHZ calculations

- Probability of existence of terrestrial-type planets as a function of stellar metallicity
  - This probability is related to the metallicity-dependence of the frequency of hot jupiters
  - Hot jupiters, which are frequent at high metallicity, tend to inhibit the formation of terrestrial-type planets
  - In addition, the process of rocky planet formation would be inhibited at low metallicity
  - The resulting probability of harboring terrestrial-type planets would experience a rise followed by a decrease with metallicity



Lineweaver (2001)

Open issues in the definition of the GHZ

- Still not clear the relationship between metallicity and probability of formation of terrestrial-type planets
  - Exoplanet statistics will clarify this point in the future, when more data will be available for terrestrial planets at very low metallicities
- Ambiguous role of supernovae explosions in the context of life evolution
  - Only extremely close supernovae can sterilize a planet
  - Supernovae may trigger life evolution, leading to the formation of new species
- The classic criteria that define the GHZ need to be refined and it is desirable to find new criteria

On the role of SN explosions

- Resetting the evolution to intelligent life at each SN destructive event

  Even if SNe do not fully sterilize the planet, one can assumed that the evolution is resetted (e.g., restarting from unicellular life) at each critical SN event

  Then the probability of forming intelligent life is calculated, using Monte Carlo methods, only during the time intervals devoid of SN destructive events

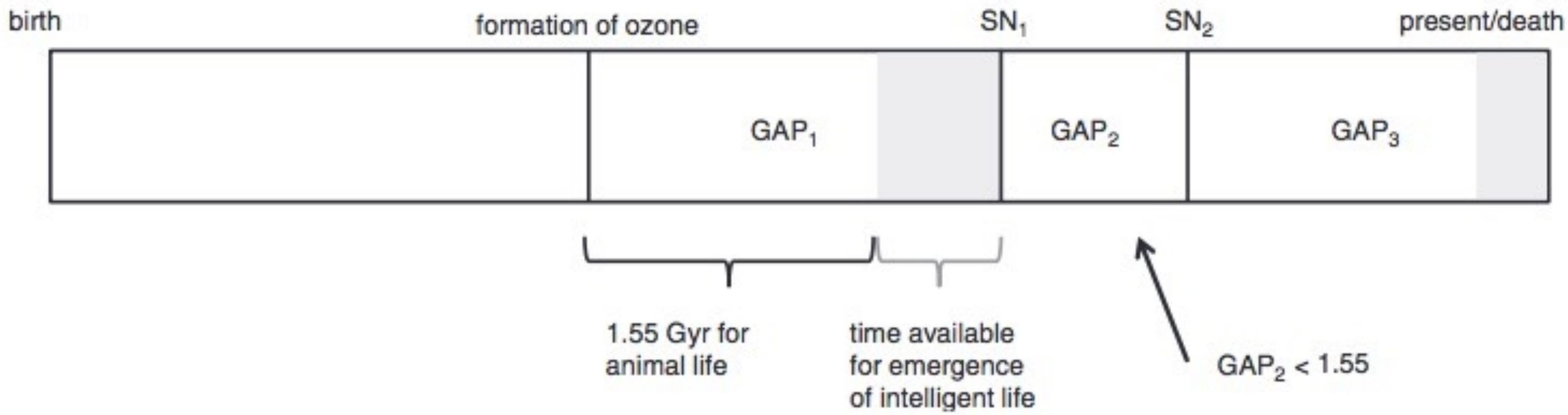


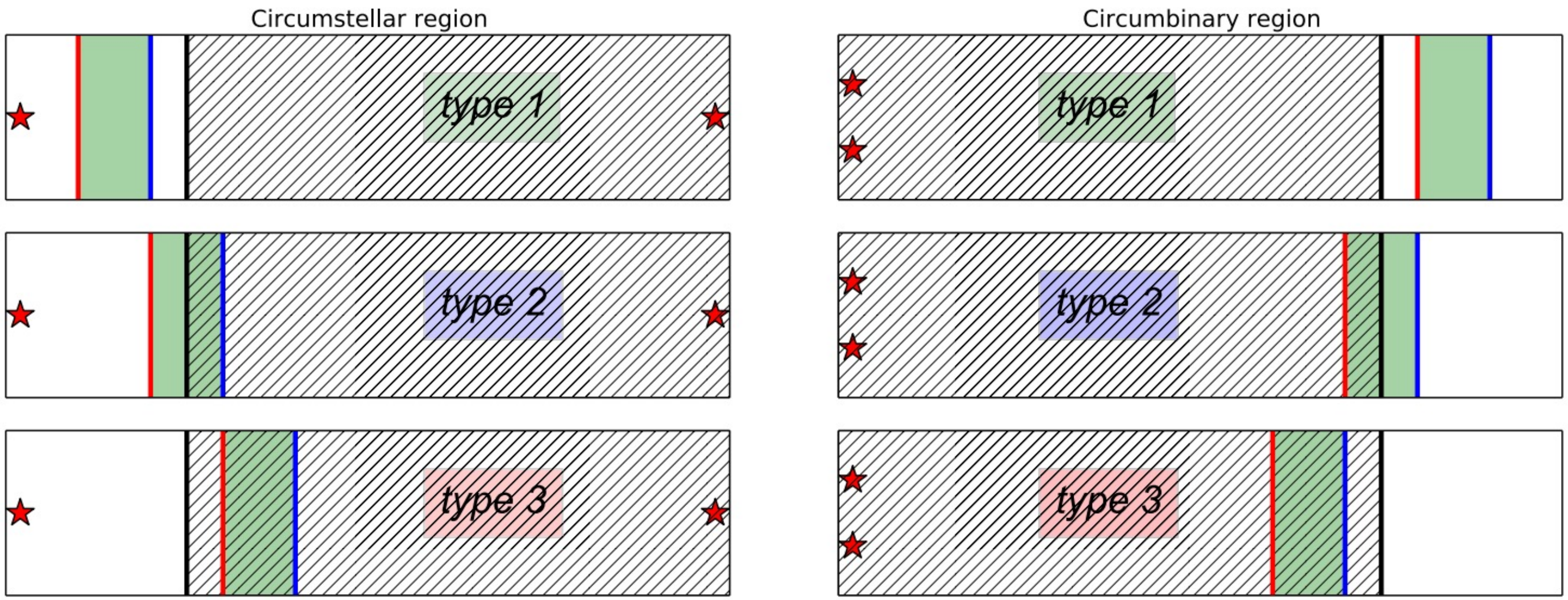
FIG. 2. Illustrative planet timeline showing the major events from the birth (at left) to the present (or death) time (at right) and showing how "gap times" are calculated. In this example, there are two SNe, labeled SN_1 and SN_2. A gap time begins after the first formation of the ozone layer or after a SN event. A gap time is ended by a SN, the death of the planet, or the present day, as we do not extrapolate beyond the age of the Universe. Any gap times exceeding 1.55 Gyr (the time assumed to be needed for the emergence of animal life) give rise to an opportunity for intelligent life to emerge. The shaded regions represent these "opportunity times," T_O, which are equal to the gap time less 1.55 Gyr.

Morrison & Gowanlock (2015)

Habitability in the Galaxy

Habitable zones in binary stellar systems

Limits of dynamical stability
Limits of insolation



Simonetti et al. (2020)

Habitability in the Galaxy

Habitable zones in binary stellar systems

Simonetti et al. (2020)

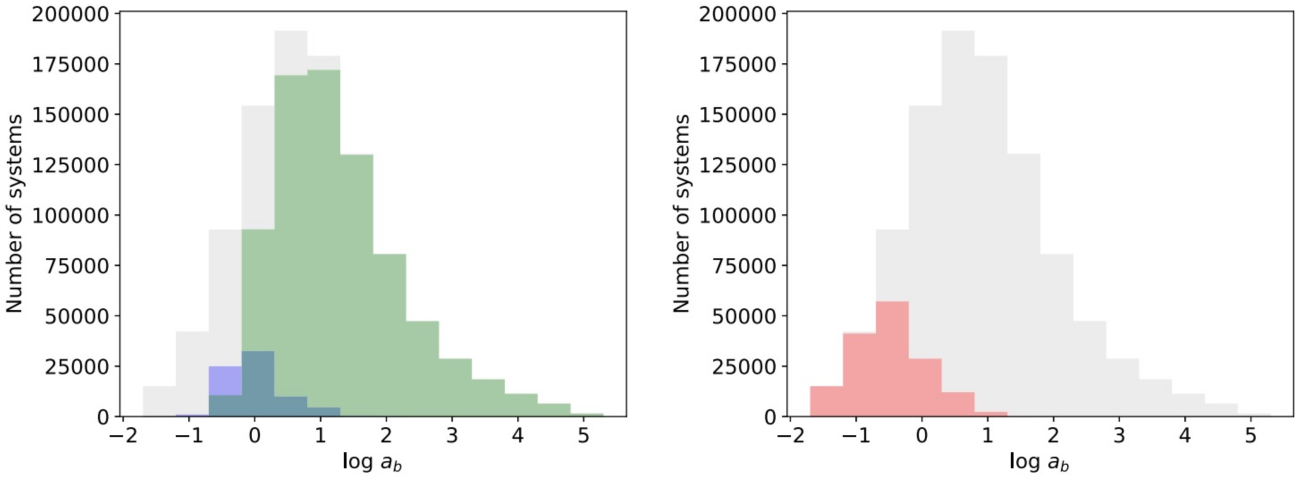


Figure 2. Habitability of circumstellar regions around the primary star in binary systems. Gray histogram: number of binary systems vs. binary semimajor axis (au) for the whole sample generated with Model A (Table 2). Left panel: systems with $\Delta\ell_{SA} > 0$ counted according to their conditions of habitability; green and blue histograms: type 1 and type 2 conditions. Red histogram in the right panel: systems with uninhabitable regions around the primary (type 3 condition). See Figure 1.

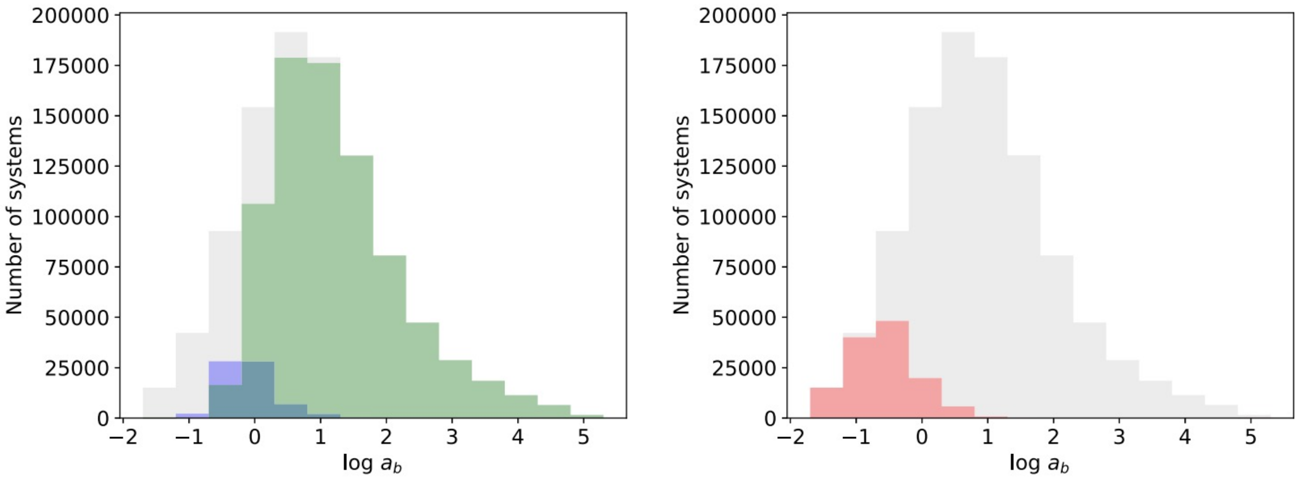
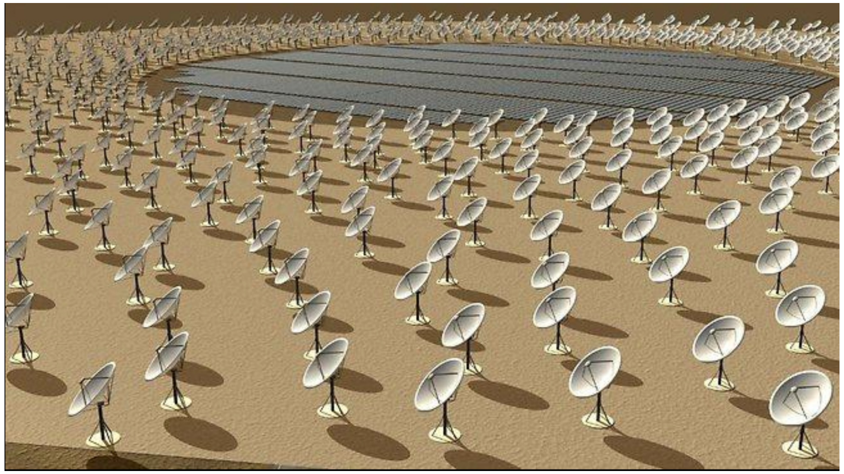


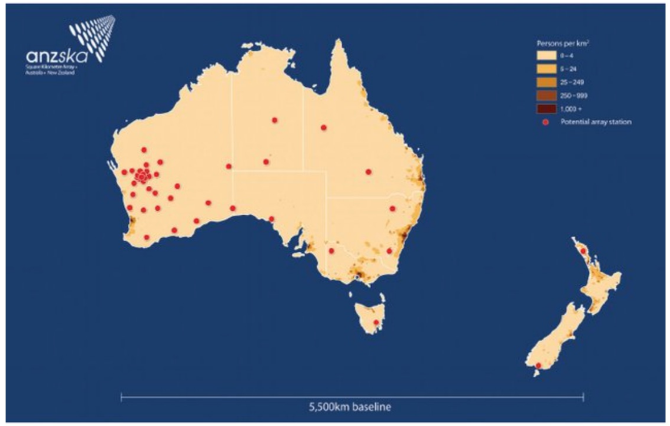
Figure 3. Habitability of circumstellar regions around the secondary star in binary systems. The sample of binary systems and color coding of the histograms are the same as in Figure 2.

SKA & Life in the Galaxy

SKA (Square Kilometer Array)

https://www.skaobservatory.org/



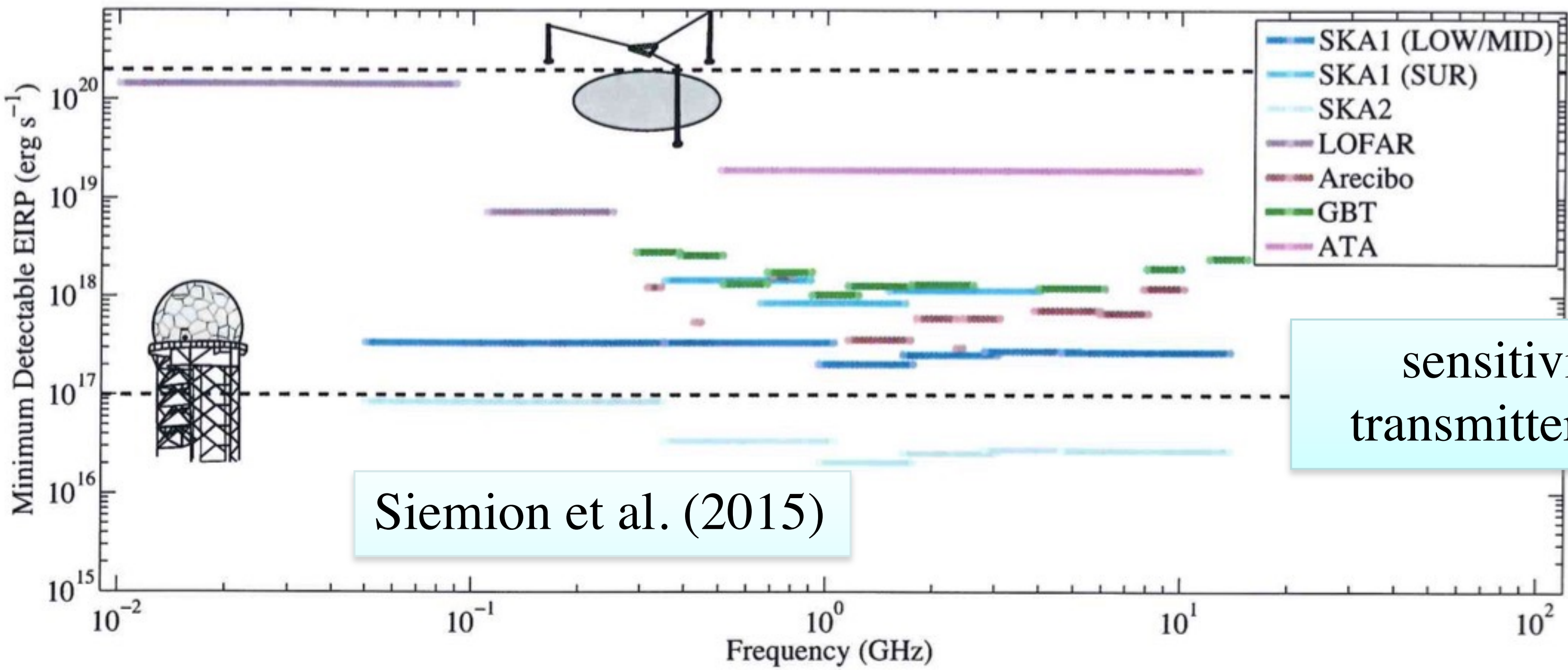


SETI

Search for extraterrestrial intelligence with new astronomical facilities: SKA (Square Kilometer Array)

EIRP: equivalent isotropically radiated power

Transmitter Type		Luminosity (EIRP) (ergs/sec)	Number on Earth
	Interplanetary Radar	$\sim 2 \times 10^{20}$	Few
	Long Range Aircraft Radar	$\sim 1 \times 10^{17}$	Dozens



Siemion et al. (2015)

sensitivity to a transmitter at 15 pc