A General Method for Approximating the Habitable Zone around a Main Sequence Star

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Two stages of calculations

Stage 1: Estimate the host star's absolute luminosity based on the star's apparent visual magnitude (three steps)

First Step (stage 1) – Calculate the absolute visual magnitude of the host star based on the star's apparent magnitude.

$$M_v = m_v - 5 \log(d/10)$$

Where:

M_v = Absolute magnitude of the star

m_v = apparent magnitude of the star (visual spectrum)

d = distance from Earth to the star in parsecs

Second Step (stage 1) – Calculate bolometric magnitude of the host star.

$$M_{bol} = M_v + BC$$

Where:

M_{bol} = bolometric magnitude of the star

M_v = the absolute magnitude of the star

BC = bolometric correction constant

Use the following table for general bolometric correction values [generalized from Habets and Heintz (1981)]

Spectral class	BC
B	-2.0
A	-0.3
F	-0.15
G	-0.4
K	-0.8
M	-2.0

Third Step (stage 1) – Calculate the absolute luminosity of the host star

$$L_{star}/L_{sun} = 10^{\left[\frac{M_{bol\,star} - M_{bol\,sun}}{-2.5}\right]}$$

Where:

$L_{star}/_{Lsun}$ = the absolute luminosity of the star in terms of the absolute luminosity of the sun

$M_{bol\ star}$ = the bolometric magnitude of the host star

$M_{bol\ sun}$ = the bolometric magnitude of the sun = 4.72

2.5 is a constant value used for comparing stellar luminosities -- known as "Pogson's Ratio."

Stage 2: Estimate the radii of the host star's habitable zone boundaries

One step – Place the value for the host star's absolute luminosity (that you calculated above) into the expressions below.

$$r_i = \sqrt{\frac{L_{star}}{1.1}}$$

$$r_o = \sqrt{\frac{L_{star}}{0.53}}$$

Where:

This method approximates habitable zone radii using stellar luminosity and stellar flux following methods presented by Whitmire et al., 1996, cited below.

r_i = the inner boundary of the habitable zone in astronomical units (AU)

r_o = the outer boundary of the habitable zone in astronomical units (AU)

L_{star} is the absolute luminosity of the star

1.1 is a constant value representing stellar flux at the inner radius (based on Kasting et al., 1993, cited below; Whitmire et al., 1996, cited below)

0.53 is a constant value representing stellar flux at the outer radius (based on Kasting et al., 1993, cited below; Whitmire et al., 1996., cited below

Example

Star = Kepler-22

m_v = 12

Spectral type = G5 V

BC = -0.4 (based on G class star, and approximated using value in above table)

Distance = 190 parsecs

1. Calculate absolute visual magnitude

$M_v = 12 - 5\log(190/10) = 5.6$

2. Calculate bolometric magnitude

$M_{bol} = 5.6 + (-0.4) = 5.2$

3. Calculate absolute luminosity

$L_{Kepler\text{-}22}/L_{sun} = 10^{\left[\frac{5.2-4.72}{-2.5}\right]} = 0.64$

Estimate the boundaries of the habitable zone for this star

$r_i = \sqrt{\frac{0.64}{1.1}}$ = 0.76 AU

$r_o = \sqrt{\frac{0.64}{0.53}}$ = 1.1 AU

For more information on the development of this methodology, please consult the refences listed below, and see the chapter entitled "Astronomical Circumstances" in the book, “Principles of Planetary Biology,” by Tom Morris.

References

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Kasting, James; Whitmire, Daniel; and Reynolds, Ray (1993). Habitable zones around main sequence stars. *Icarus* 101: 108-128.

Kasting, James F. (1996). Habitable zones around stars: An update. In: Doyle, Laurence (ed.). *Circumstellar Habitable Zones*, 117-142. Travis House Publications, Menlo Park.

Lang, Kenneth (1992). *Astrophysical Data: Planets and Stars*. Springer-Verlag, New York.

Whitmire, Daniel; Reynolds, Ray, (1996). Circumstellar habitable zones: astronomical considerations. In: Doyle, Laurence (ed.). *Circumstellar Habitable Zones*, 117-142. Travis House Publications, Menlo Park.
Available for download from this site (with my notes).

An alternative approach has been proposed by:

"Habitable Zones Around Main-Sequence Stars: New Estimates" by Kopparapu et al.(2013), Astrophysical Journal, 765, 131

Try the online habitable zone calculator based on this alternative approach at:

University of Washington Virtual Planetary Laboratory