The **Galactic Exoplanet Survey Telescope (GEST)**

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Talk Outline

- What do we *need* to know to determine the abundance of habitable or Earth-like planets?
  - What does Earth-like mean?
- The basics of microlensing
- The Scientific Return
  - Simulated planetary light curves
  - Planet detection sensitivity
  - Lens star detection
  - What we learn from the planets that are detected
- **GEST** Mission Design
- Why is a Space mission needed for microlensing?
  - Resolve main sequence stars
  - Continuous light curve coverage
Requirements for a Habitable Planet

• A 1 M\textsubscript{⊕} planet at 1 AU orbiting a G or K-star?
• How about a 1 M\textsubscript{⊕} planet at 1.5 or 2 AU?
  – with a greenhouse atmosphere
• Is a gas giant at 5 or 10 AU needed, as well?
• Are planets orbiting M-stars more or less habitable than those orbiting G-stars?
• Is there a Galactic Habitable Zone?
• Moons of giant stars?
• Is a large moon important for the development of life?
• Could life be based upon NH\textsubscript{3} instead of H\textsubscript{2}O?
• …
• It seems likely that we cannot understand habitability until we understand the basic properties of planetary systems.
The Physics of $\mu$-lensing

- Foreground “lens” star + planet bend light of “source” star
- Multiple distorted images
  - Total brightness change is observable
- Sensitive to planetary mass
- Low mass planet signals are rare – not weak
- Peak sensitivity is at 2-3 AU: the Einstein ring radius, $R_E$
Planetary Microlensing Light Curve

- Top panel shows stellar images at ~1 mas resolution centered on lens star
- Einstein ring in green
- Magnified stellar images shown in blue
- Unmagnified image is red outline
- The observable total magnification is shown in the bottom panel
- A planet in the shaded region gives a detectable deviation

Video from B. S. Gaudi (IAS)
Microlensing Rates are Highest Towards the Galactic Bulge

High density of source and lens stars is required.
GEST Mission Simulation

• Continuous observations of 2.1 sq. deg. central Galactic bulge field: ~10^8 stars
• Simulated images based on HST luminosity function from Holtzman et al (1998)
• ~15,000 events in 4 seasons
• microlensing probability, $\tau = 3.4 \times 10^{-6}$, assumed
  – at Galactic coordinates: $l = 1.3^\circ$, $b = -2.4^\circ$
  – ~1.6$\sigma$ lower limit on measured value
Simulated Planetary Light Curves

- Planetary signals can be very strong
- There are a variety of light curve features to indicate the planetary mass ratio and separation
- Exposures every 10 minutes

\[ M_{\text{lens}} = 0.69 M_\oplus \quad M_{\text{planet}} = 0.7 M_\oplus \quad M_{\text{moon}} = 0.02 M_\oplus \]

\[ \Delta I_{\text{lens}} = -0.1 \]

\[ a = 5 \text{AU} \]
Visible G-star lenses with typical S/N

More light curves

Low S/N
GEST’s Double Planet Detections

Detection of Jupiter & Saturn

- \( \varepsilon = 10^{-3}, 3 \times 10^{-4} \); \( a = 5.2, 9.5 \) AU
- \( \sim 100 \) events

- \( \varepsilon = 3 \times 10^{-6}, 10^{-3} \); \( a = 1, 5.2 \) AU
- \( \sim 10 \) events
Planet Detection Sensitivity Comparison

- Sensitivity to all Solar System-like planets
  - Except for Mercury & Pluto
- Most sensitive technique for $a \geq 1$ AU
- “Habitable” planets in Mars-like orbits
- Mass sensitivity is $1000 \times$ better than $v_r$
- Assumes 12.5$\sigma$ detection threshold
- GEST is complementary to Kepler

**Lens Star Identification**

- Flat distribution in mass
  - assuming planet mass $\propto$ star mass
- 33% are “visible”
  - within 2 I-mag of source
  - not blended w/ brighter star
  - Solar type (F, G or K) stars are “visible”
- 20% are white, brown dwarfs (not shown)
- Visible lens stars allow determination of stellar type, distance, and relative lens-source proper motion
Planetary Semi-major Axes

For faint lens stars, separation determination yields a to factor-of-2 accuracy, but the brightest ~30% of lens stars are detectable. For these stars, we can determine the stellar type and semi-major axis to ~10-20%.
GEST Mission Design

- 1-1.5m telescope: 3 mirror anastigmat
- 2.1 sq. deg. FOV
- shutter for camera
- 0.2”/pixel => 6×10^8 pixels
- continuous view of Galactic bulge
  - for 8 months per year
  - 60 degree Sun avoidance
  - high Earth Orbit
- Images downloaded every 10 minutes
  - < 10 Mbits/sec mean data rate
- <0.03” pointing stability
  - maintained >95% of the time
Inclined Geosynchronous Orbit
Wide FOV CCD Camera

Focal Plane layout: 32 Labs 3k × 6k CCDs, 10µm pixels; 600 Mpix total

Bulge stars are highly reddened, so Lincoln IR optimized CCDs improve sensitivity.

GEST shutter concept – no single point failure mode. 4-side abutable Lincoln CCD
Microlensing From the Ground vs. Space

- Target main sequence stars are not resolved from the ground.
- Poor photometry for unresolved stars, except for very high magnification events.
- Poor light curve coverage.
- Ground surveys can only find events with $a \approx R_E$
  - No measurement of planetary abundance vs. semi-major axis.
Light curves from a LSST or VISTA Survey

Simulations use real VLT seeing and cloud data, and realistic sky brightness estimates for the bulge. The lightcurve deviations of detectable $\sim 1 \, M_\oplus$ planets have durations of $\sim 1$ day, so full deviation shapes are not measured from a single observing site - except for unusually short events.
Ground vs. Space-Based Planet Discoveries

Comparison of planetary discovery rates for GEST and ambitious ground-based surveys. Most ground-based discoveries are high magnification events with low mass lenses. Does not include high mass planets which can be detected with giant source stars.

Ground-based surveys only find planets at a separation close to the Einstein Ring radius. Only a space-based survey can measure planetary abundance as a function of separation.
GEST’s Planetary Results

- Planets detected rapidly - even in ~20 year orbits
- average number of planets per star down to $M_{\text{mars}} = 0.1 M_{\oplus}$
  - Separation, $a$, is known to a factor of 2.
- planetary mass function, $f(\epsilon=M_{\text{planet}}/M_{\star}, a)$
- for $0.3 M_{\text{sun}} \leq M_{\star} \leq 1 M_{\text{sun}}$
  - planetary abundance as a function of $M_{\star}$ and Galactocentric distance
  - planetary abundance as a function of separation (known to ~10%)
- abundance of free-floating planets down to $M_{\text{mars}}$
- the ratio of free-floating planets to bound planets.
- Abundance of planet pairs
  - high fraction of pairs => near circular orbits
- Abundance of large moons (?)
- ~50,000 giant planet transits
GEST Summary

- Straight-forward technique with existing technology
- Discovery class mission
- Low-mass planets detected with strong signals
- Sensitive to planetary mass
- Sensitive to a wide range of separations
  - Venus-Neptune
  - Free floating planets, too
  - Combination with Kepler gives planetary abundance at all separations
- Should be done!