

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

A Search for Extra-Solar Planets via Gravitational Microlensing and Transits

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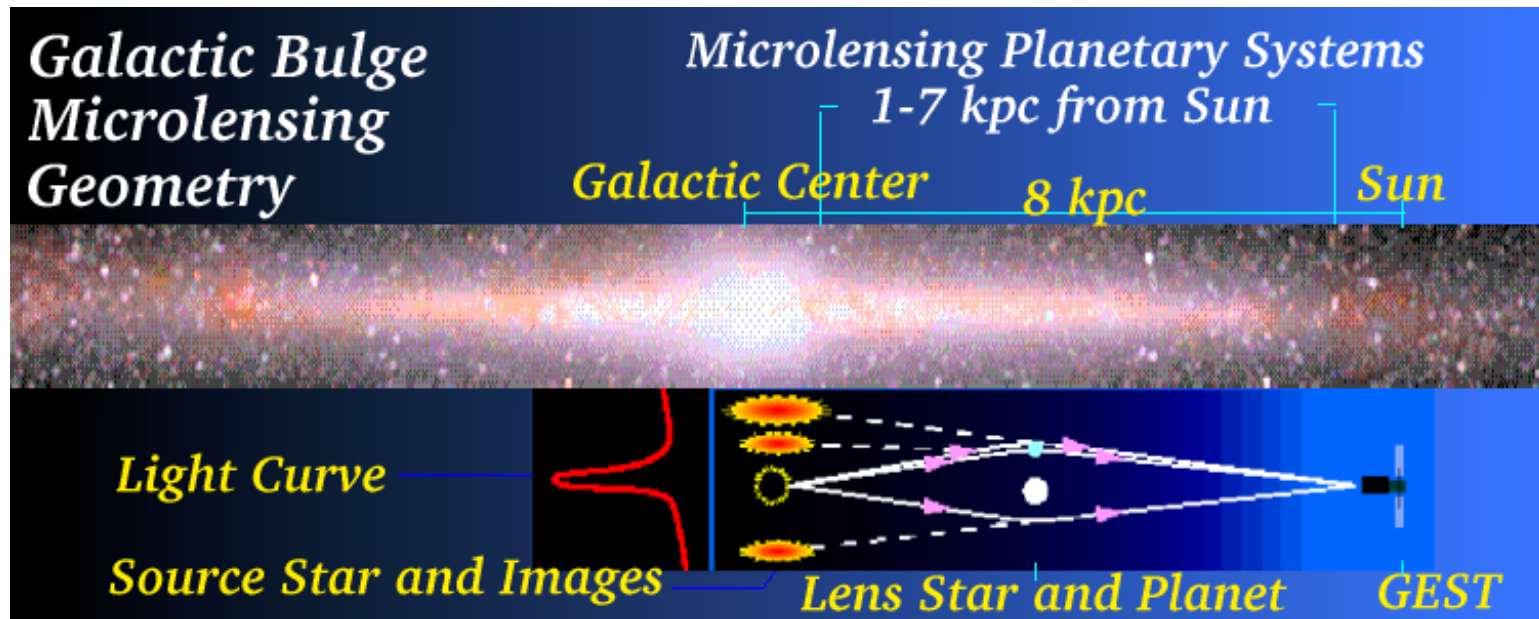
Abstract: GEST is a comprehensive extra-solar planet search mission sensitive to planets with masses as low as that of Mars. GEST is a 1.5m telescope with a 2 square degree field of view that will monitor the Galactic bulge for 8 months per year for three years to detect planets via gravitational microlensing and transits. GEST's microlensing survey will detect low-mass planets via high signal-to-noise variations of gravitational microlensing light curves. These planetary signals do not require follow-up observations to confirm the planetary interpretation, and they yield direct measurements of the star:planet mass ratio as well as estimates of the star-planet separation. GEST will be able to detect ~ 100 Earth-mass planets at 1 AU (assuming ~ 1 such planet per star), and will detect its first Earth-mass planets within a few months of launch. GEST is sensitive to the microlensing signal of planets for planetary separations from ~ 0.7 AU to infinity because GEST is able to detect the microlensing signature of free-floating planets. GEST's survey of the Galactic bulge will also be sensitive to giant planets at separations of 0-20 AU via transits of the Galactic bulge source stars. The transit survey should detect $\sim 50,000$ "hot Jupiters" if their abundance in the bulge is similar to the local abundance.

The GEST mission can be accomplished at low risk with established technology, and a GEST proposal is now being considered by NASA's Discovery Program.

During the 4 months per year when the Galactic bulge is not observable, GEST will survey the solar system for $\sim 100,000$ Kuiper Belt Objects (see poster **21.01**) and operate a Participating Scientist Program. A discussion of the basic physics of the gravitational microlensing planet search technique can be found in poster **32.10**.

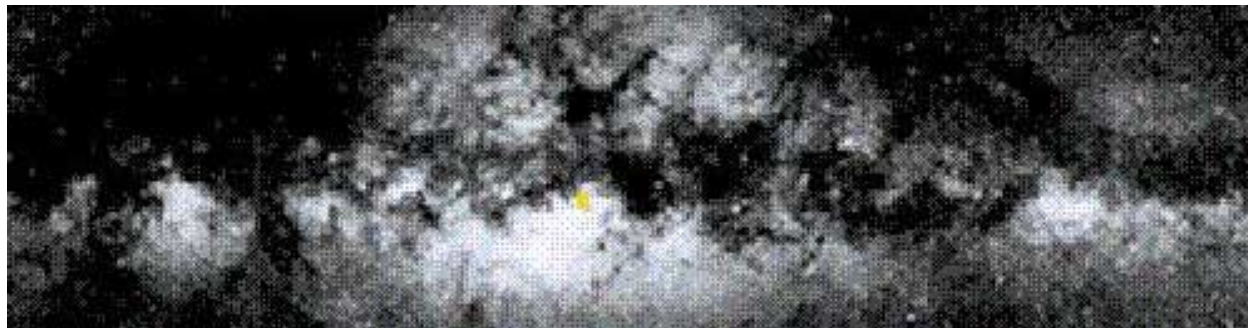


GEST's Primary Planet Detection Method




GEST observes $\sim 10^8$ Galactic bulge main sequence stars in order to study the planetary systems of foreground stars via gravitational microlensing. See poster **32.10** for more details on gravitational microlensing.

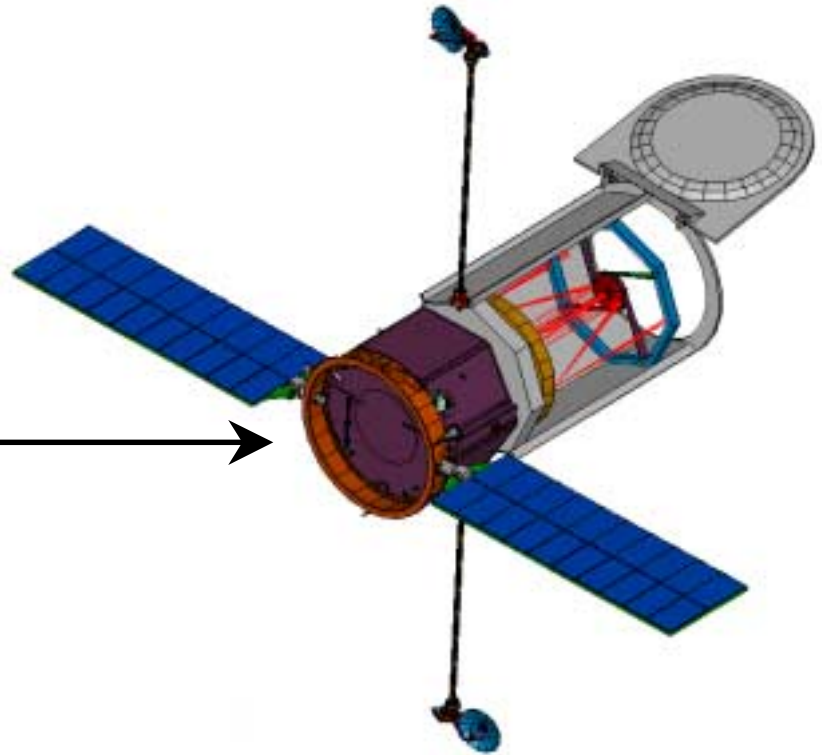
The GEST Field



GEST will observe a field of 2 square degrees located $\sim 2.5^\circ$ from the Galactic center in a region of low extinction.

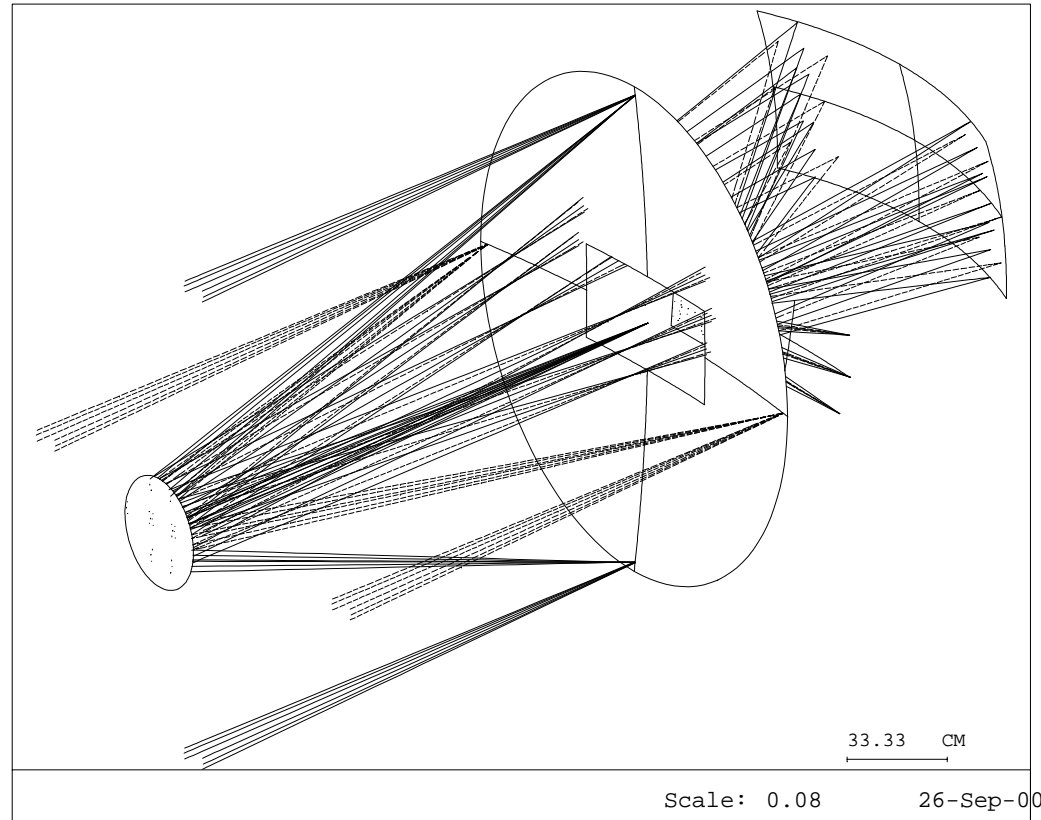
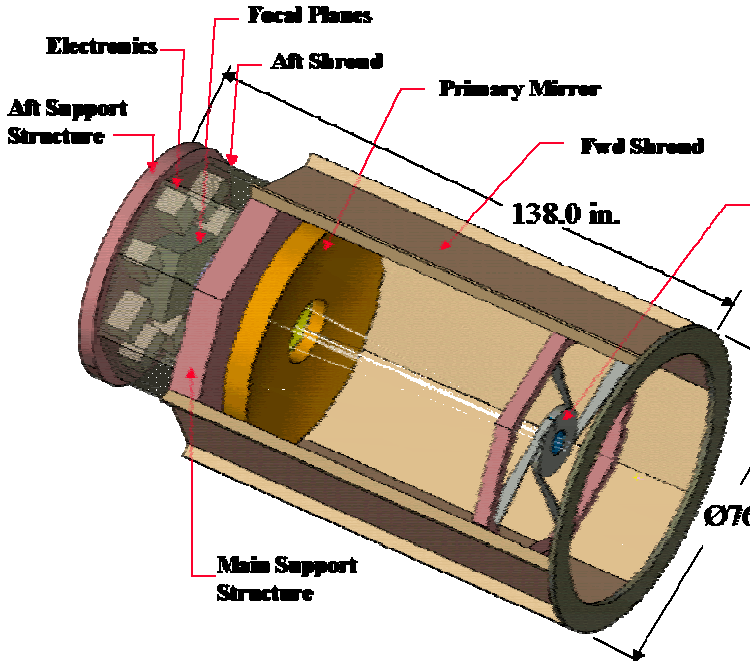
The **GEST** Mission

- 1.5m telescope with ~2 sq. deg. FOV
- geosynchronous orbit
 - inclined 28.7° to the equator, $\sim 50^\circ$ to the ecliptic
- continuous view of Galactic bulge
 - a single field is observed for 8 months per year
- LM-900 Spacecraft 
 - pointing stability: better than $0.021''$ except for a few minutes per day when angular momentum is dumped
- Data is continuously down-linked
 - dedicated ground station at NRAO
 - 14m or 20m dish
 - 70 Mb per sec, continuous in X-band
- 4 months per year, non-bulge season
 - ~1 months per year: Kuiper Belt Object (KBO) Search
 - see poster **21.01**
 - 100,000 new KBOs discovered
 - ~3 months per year: Participating Scientist Program
 - observers propose to NASA for observing time



GEST Optics

12:05:45



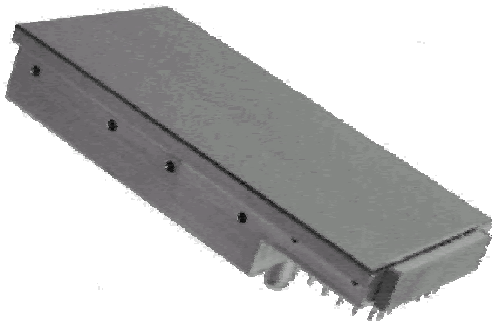
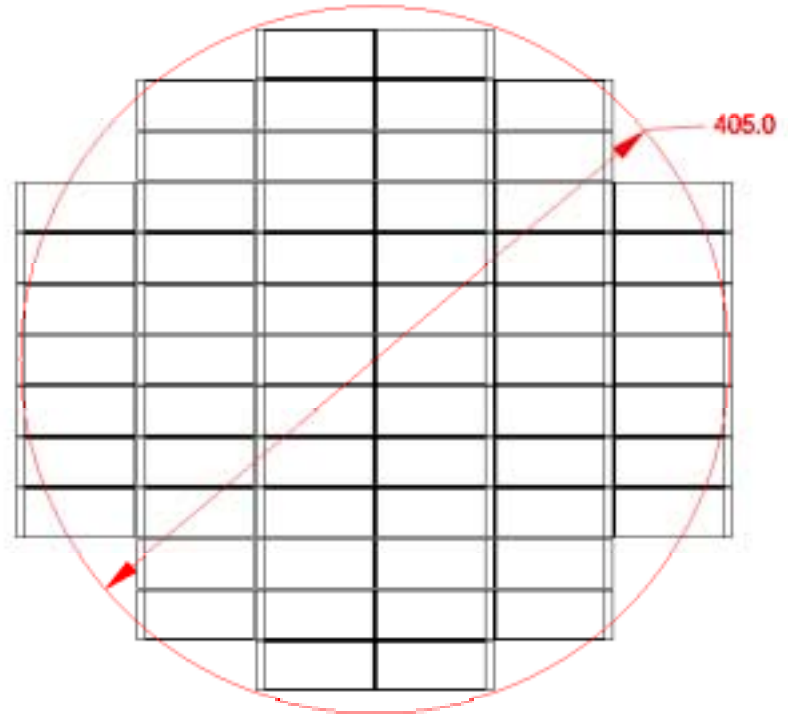
Proposed Design: field
widened Cassegrain

Under Study: 3 Mirror Anastigmatic Design

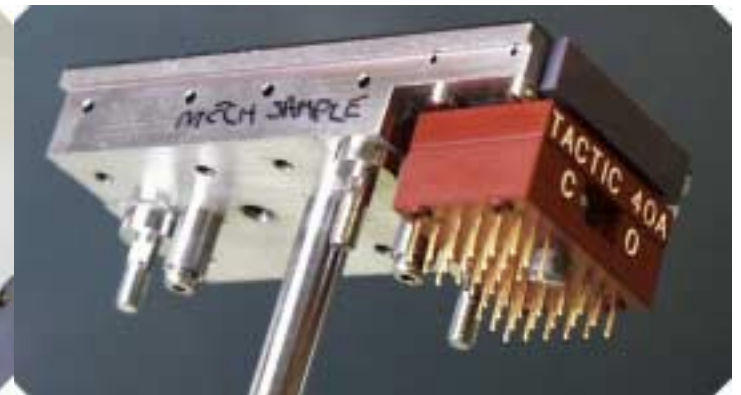
- allows filter wheel, simple shutter
- non-circular field => more events!
- better baffling

GEST Instrument

- Off-the-shelf parts
- diffraction limited optics at $\sim 0.9\mu\text{m}$
- 62 Marconi 2k \times 4.6k CCDs
- Lockheed-Palo Alto
 - currently working on 24-CCD camera for **FAME**



Marconi CCD42-90



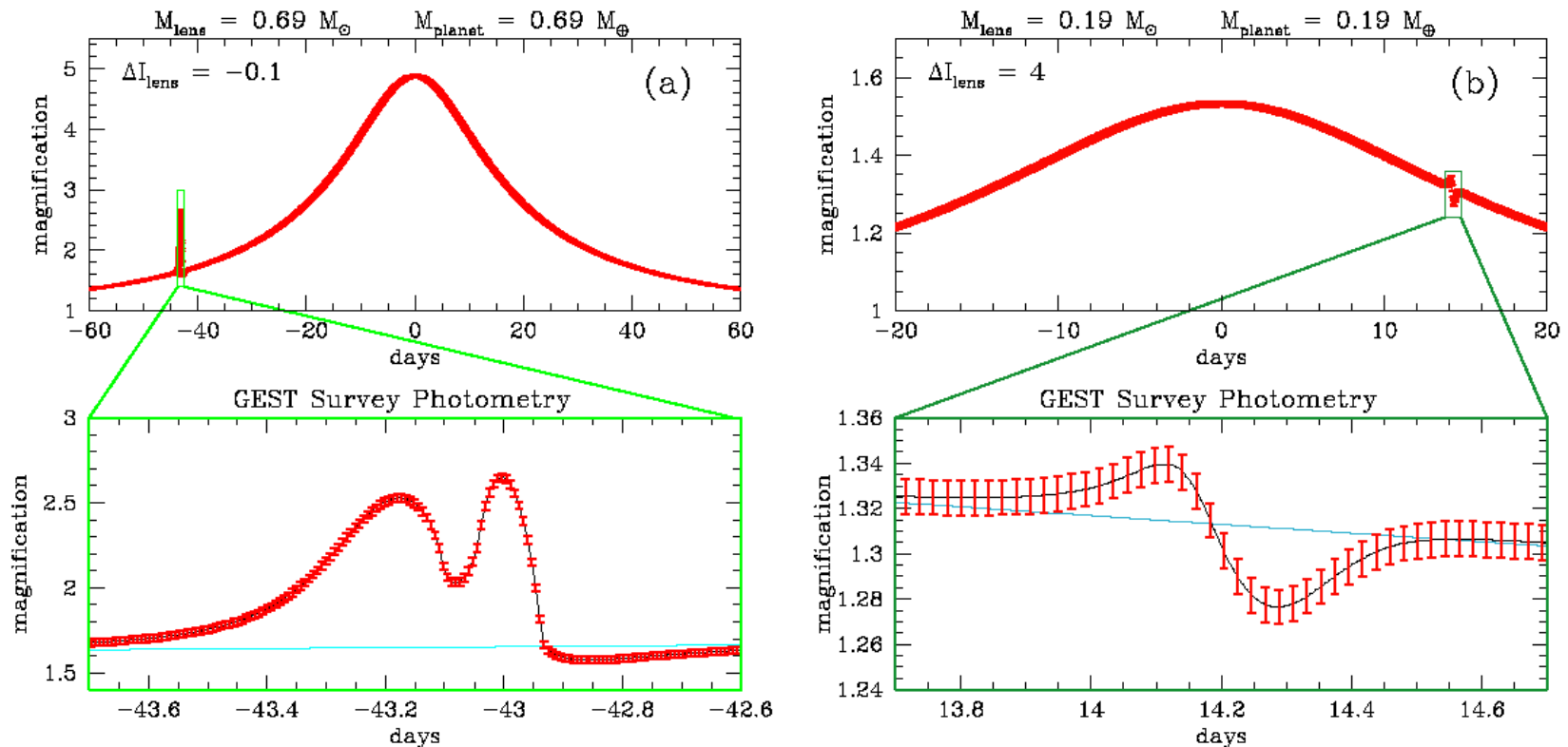
GEST Data Processing

- Images taken every 2 minutes
- All data sent to dedicated ground station at NRAO
- Real time data reduction at NRAO
- Crowded fields with undersampled images
 - sampling similar to Hubble's WFPC2 V-band images
 - continuous observations allow dithering on a sub-pixel grid
 - photometric accuracy determined by photon statistics
 - (Lauer 1999, Gilliland et al 2000)
 - include excess photons from the lens star and neighbors

GEST Simulation

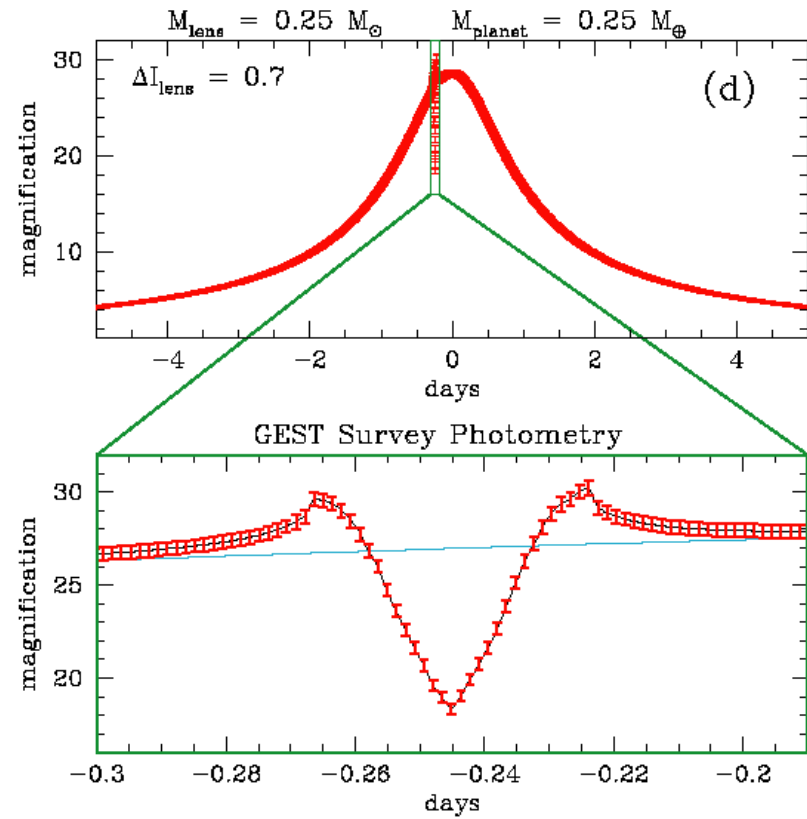
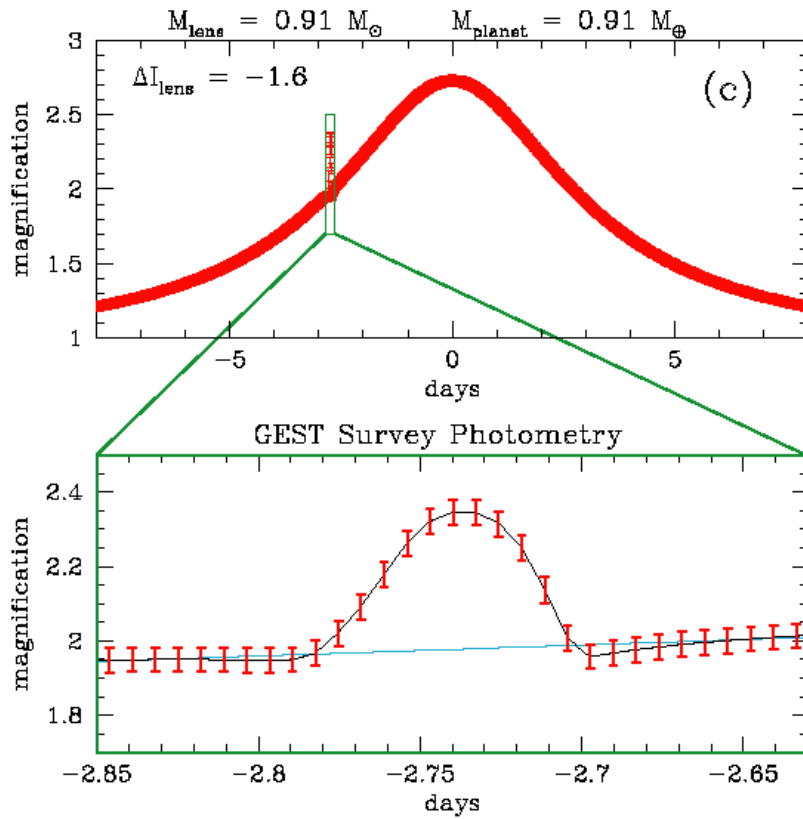
- Continuous observations of 2 sq. deg. central Galactic bulge field
- HST luminosity function from Holtzman et al (1998)
- mass function from Kroupa (2000), Zoccali et al (2000)
- ~10,000 events in 3 seasons
- microlensing probability, $\tau = 3.4 \times 10^{-6}$, assumed
 - at Galactic coordinates: $l = 1.3^\circ$, $b = -2.4^\circ$
 - $\sim 1.6\sigma$ lower limit on measured value

Simulated Planetary Light Curves from GEST



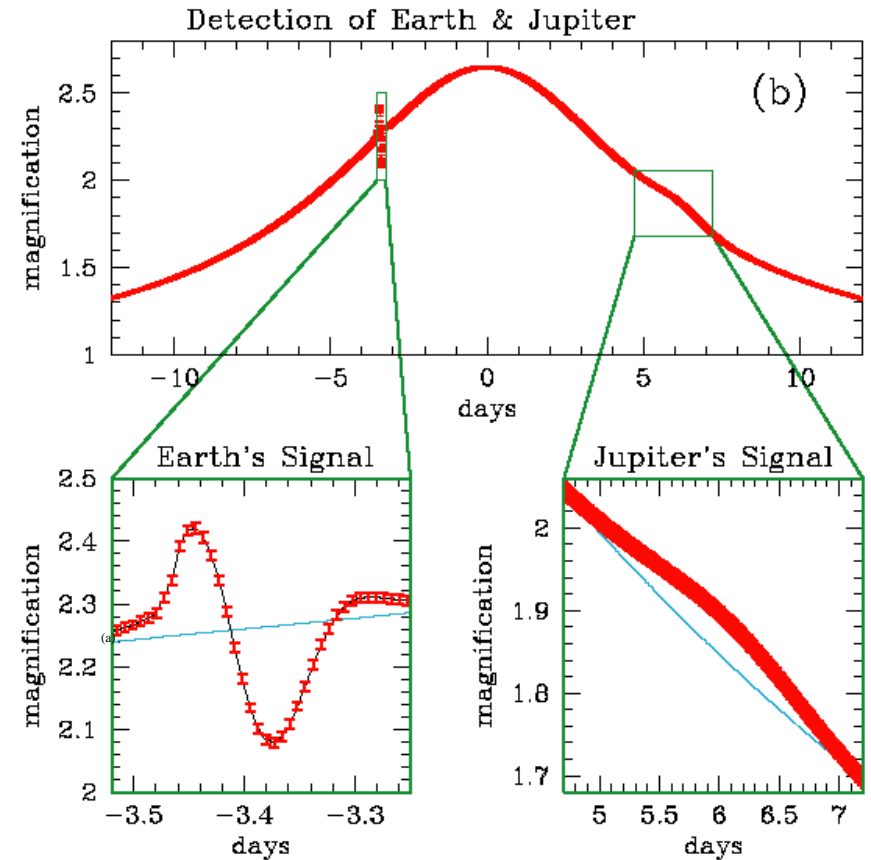
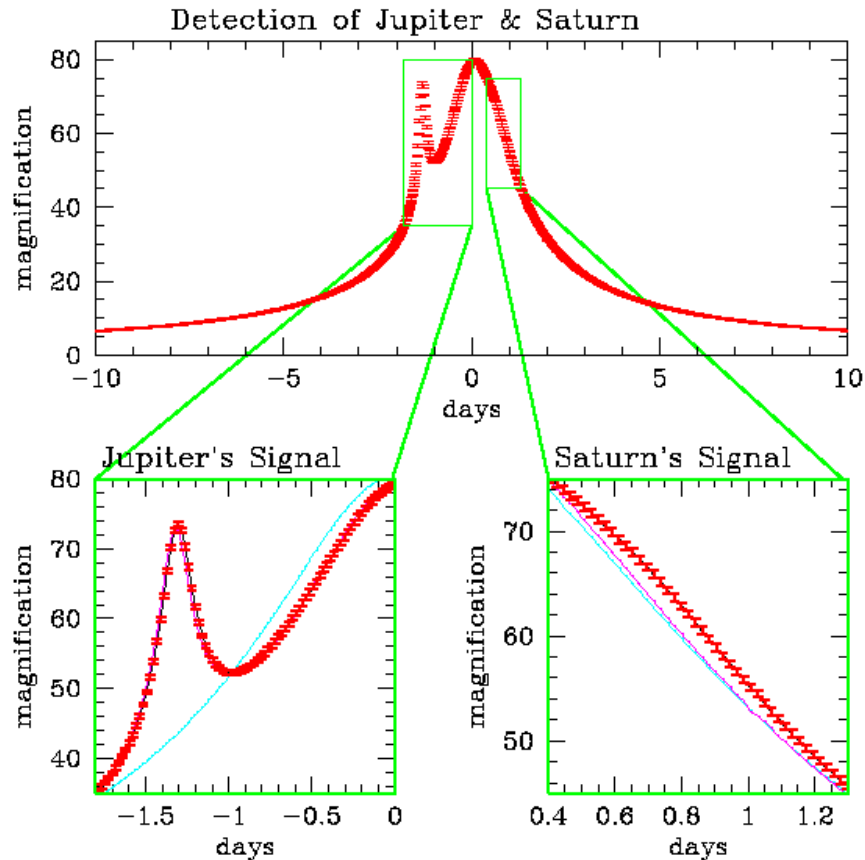
Example light curves are shown above from a simulation of the GEST mission. In each case, the top panel shows the full light curve, and the planetary deviation region(s), outlined in green, is blown up and shown in the lower panel. All of the example light curves have the Earth:Sun mass ratio of $\epsilon = 3 \times 10^{-6}$. Our planetary detection significance parameter is $\Delta\chi^2$, which is the difference between the χ^2 values for single-stellar lens and star+planet lens system fits. (a) and (b) span the range of planetary detection significance from $\Delta\chi^2 = 60,000$ (a) to $\Delta\chi^2 = 180$ (b) which is just above our cut.

Simulated Planetary Light Curves from GEST (cont.)



(c) and (d) show more typical light curves with $\Delta\chi^2 = 600\text{-}1300$. The planets detected in (b) and (c) have orbital radii of 1 AU while the events shown in (a) and (d) have orbital radii of 5 and 2.5 AU, respectively. ΔI_{lens} is the difference between lens and source I magnitude.

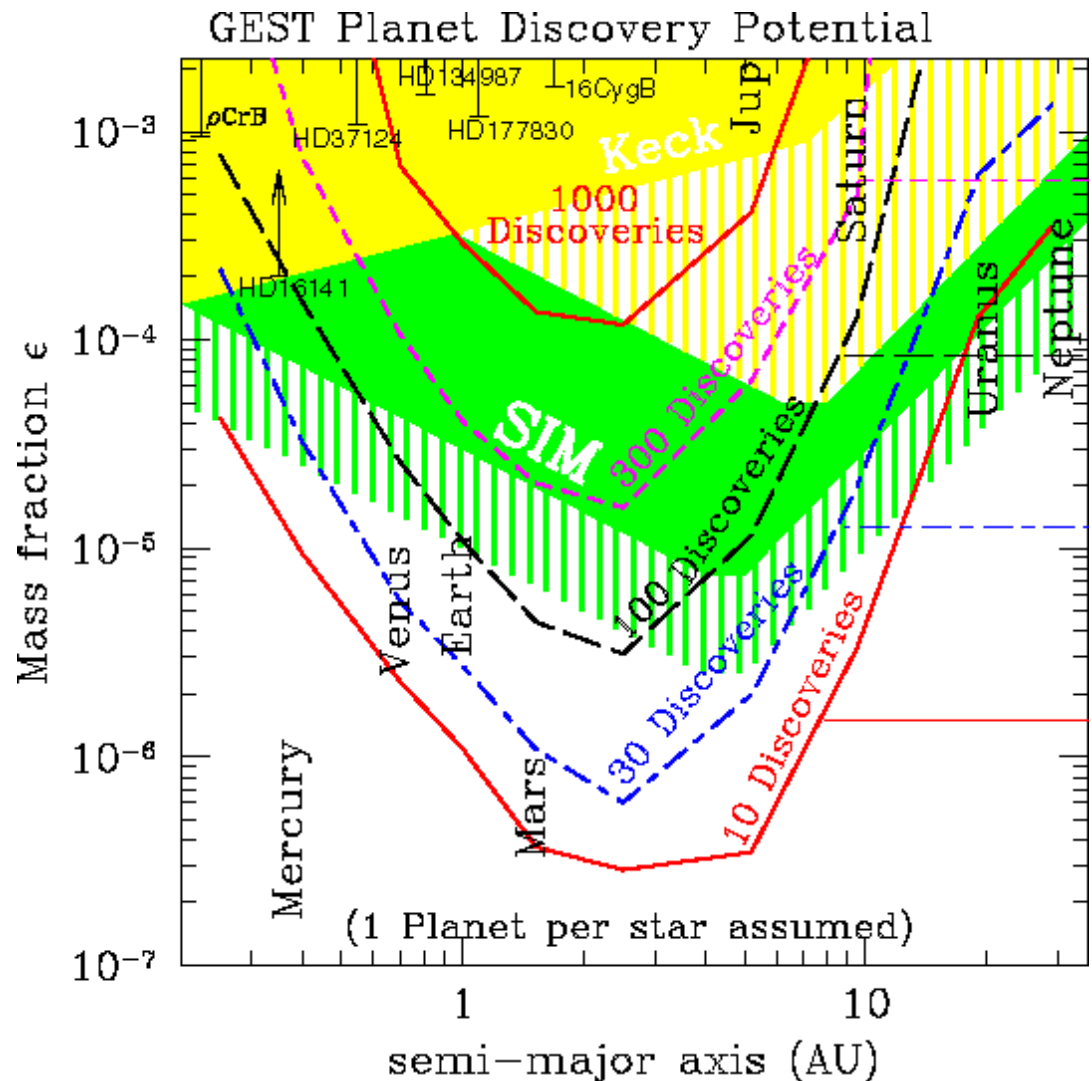
GEST's Double Planet Detections



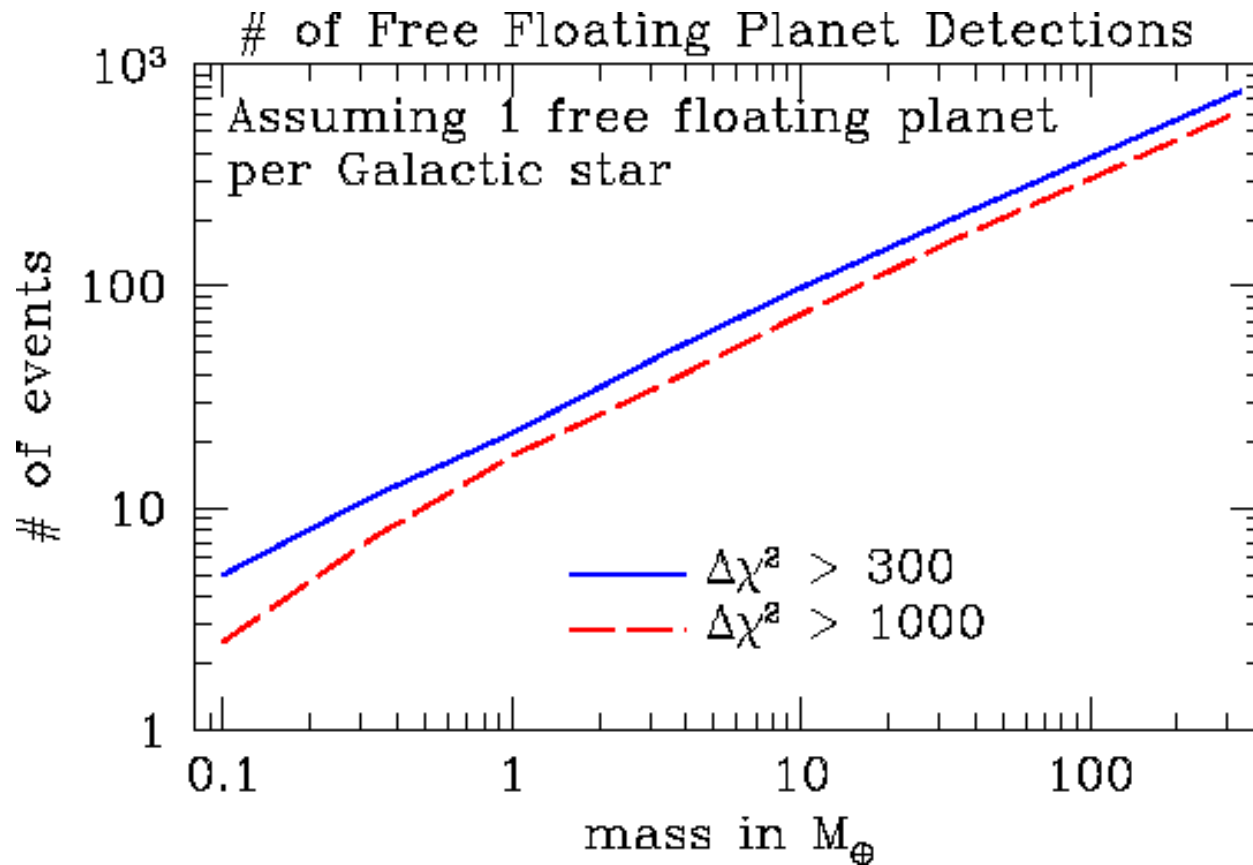
Above are example multiple planet light curves from our simulation of planetary systems with the same planetary mass ratios and separations as in our solar system. (a) is an example of a Jupiter/Saturn detections (with $\epsilon = 10^{-3}, 3 \times 10^{-4}$; $a = 5.2, 9.5$) and (b) is an example of the detection of Earth and a Jupiter (with $\epsilon = 3 \times 10^{-6}, 10^{-3}$; $a = 1, 5.2$ AU). We expect ~ 60 examples of Jupiter+Saturn and ~ 10 examples of Jupiter+Earth (or Venus or Mars) if each star has such a system.

GEST's Planetary Detection Sensitivity

The GEST mission sensitivity is plotted above as a function of planetary mass fraction, ϵ , and separation. The different curves indicated the effective number of planetary systems surveyed at the different sensitivity levels. At least 10 systems are surveyed for planetary systems with parameters above the red lines, and more than 100 systems are surveyed above the black line. The yellow region can be searched for planets with Keck. The solid yellow region can be searched for planets with a 20-year radial velocity program assuming a detection threshold of 10 m/sec, and the yellow lines indicate the sensitivity of a 10-year interferometric astrometry program with a $30\mu\text{s}$ detection threshold. The green regions indicate the sensitivity of the SIM recommended and floor missions. The location of our Solar System's planets are indicated, as are a number of the detected extra-solar planetary systems. Most detected Earth mass planets have $\epsilon \approx 10^{-5}$ because the typical lens star has a mass of $\sim 0.3 M_{\odot}$, so the plot suggests that GEST can see ~ 35 Earth-mass ratio planets at 1 AU and ~ 100 Earth-mass planets at that distance. The horizontal lines indicate the sensitivity to free-floating planets since the more distant planets can sometimes be detected without seeing a microlensing signal from their star. The detection threshold used is a $\Delta\chi^2 \geq 160$ improvement with a planetary light curve fit vs. a single lens light curve fit. This is equivalent to a 12.5σ threshold.

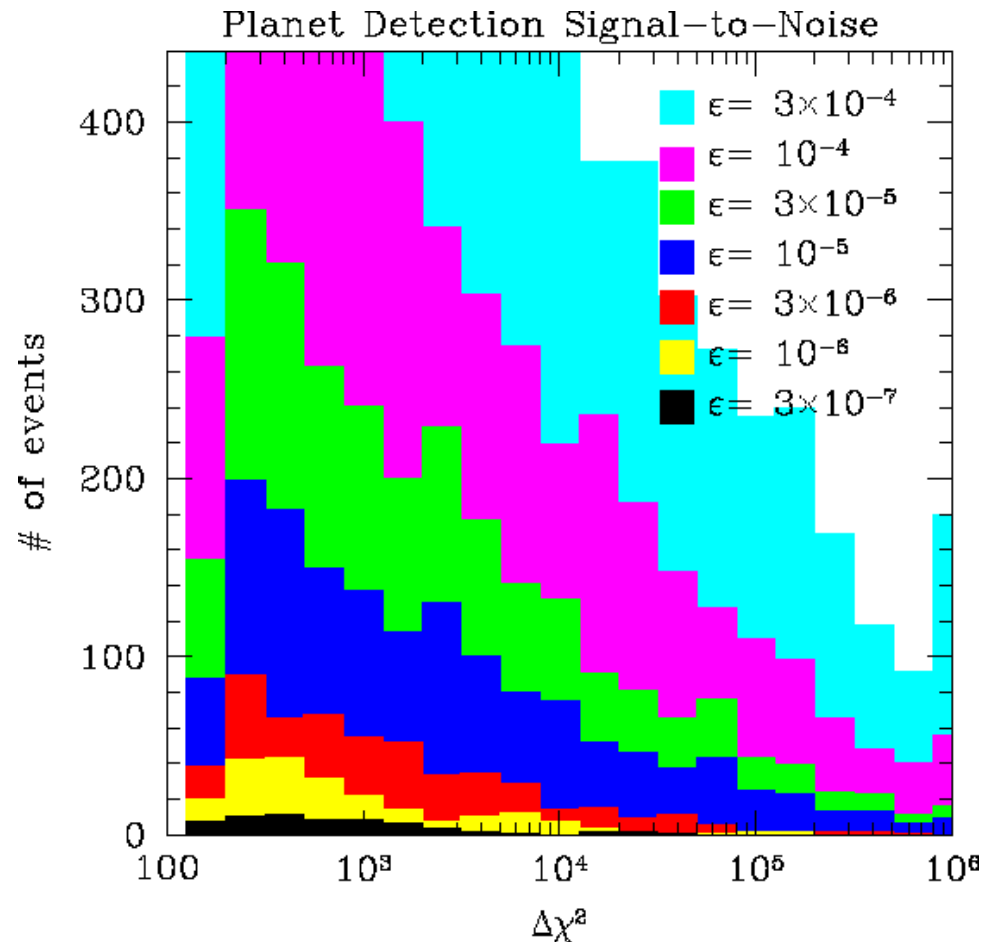


GEST's Free Floating Planetary Detection Sensitivity



The number of free-floating planets to be discovered by GEST are plotted above vs.~planetary mass for 2 different detection criteria which are equivalent to 17σ and 30σ , respectively. It is thought that many low-mass planets may be ejected from planetary systems via gravitational interactions during the planetary formation process, so we expect to detect a large number of planets in the terrestrial mass range.

GEST's Planetary Detection Significance



This is a histogram of the planetary detection significance, $\Delta\chi^2$, for different mass fractions, ϵ , ranging from $\epsilon = 3 \times 10^{-7}$ (the mass fraction of Mars) to $\epsilon = 3 \times 10^{-4}$ (the mass fraction of Saturn). Note the logarithmic scale on the x-axis which is required because of the large number of high signal-to-noise events. For planets with an Earth-like mass fraction ($\epsilon = 3 \times 10^{-6}$) and above, more than half of the detected events have $\Delta\chi^2 > 800$, which corresponds to a 28σ detection.

Planetary Transits from GEST

- $\sim 10^8$ stars surveyed with $0.3R_{\odot} \leq R \leq R_{\odot}$
- Sensitive to planets down to R_{saturn}
 - in 5 hours: 6.5σ at R_{saturn} , 9σ at of R_{Jupiter}
- 50,000 “Hot Jupiter” detections
 - assuming 1% abundance
- If each star has a planet, then geometric and timing constraints allow:

Semi-major Axis (AU)	Period (yrs.)	# of detections (with 1 planet per star)	# of transits per planet & transit duration (hrs.)
0.04	~0.01	5,000,000	~200 × 2.5
0.4	~0.3	600,000	~7 × 8
1.0	~1.3	160,000	~2 × 13
5.2	~15	6,000	~1 × 30
9.5	~40	1,300	~1 × 40
19.0	~110	200	~1 × 60

GEST Summary & Expected Results

- **GEST** will satisfy the McKee-Taylor Committee's prerequisite for TPF:
 - “space- and ground-based searches will confirm the expectation that terrestrial planets are common.”
- Low mass planets detected via microlensing
 - high signal-to-noise detections => robust method
 - ~100 Earth-mass planets: **1st detection of Earths**
 - some sensitivity down to M_{mars}
 - sensitivity from 0.7AU-infinity
- Giant planets detected via Microlensing and transits
 - sensitivity from 0-infinity
- Low Risk Mission
 - no astronomical background
 - All technology in hand
- Planets detected rapidly via microlensing - even in ~20 year orbits
- Expected Exoplanet Results:
 - mass fraction ($\epsilon = M_{\text{planet}}/M_*$) and separation (to a factor of ~2) always measured
 - AO follow-up observations identify lens star for G, K, and early M stars (~40% of all events)
 - average number of planets per star down to M_{Mars}
 - planetary mass function, $f(\epsilon = M_{\text{planet}}/M_*)$; as a function of M_* for $0.3M_{\odot} \leq M_* \leq 1 M_{\odot}$.
 - abundance of free-floating planets down to M_{mars}
 - the ratio of free-floating planets to bound planets.
 - Abundance of planet pairs
 - high fraction of pairs => near circular orbits