

LINEAR System Performance Analysis

Jenifer Brinker Evans

Space Control Conference

3-5 April 2001

REPORT DOCUMENTATION PAGE

Form Approved OMB No.
0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

| | | |
|---|---|--|
| 1. REPORT DATE (DD-MM-YYYY) 03-04-2001 | 2. REPORT TYPE Conference Proceedings (Briefing) | 3. DATES COVERED (FROM - TO) 03-04-2001 to 05-04-2001 |
|---|---|--|

| | |
|---|----------------------------|
| 4. TITLE AND SUBTITLE LINEAR System Performance Analysis Unclassified | 5a. CONTRACT NUMBER |
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |

| | |
|-------------------------------------|----------------------|
| 6. AUTHOR(S) Evans, Jenifer B. ; | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |

| | |
|---|--|
| 7. PERFORMING ORGANIZATION NAME AND ADDRESS MIT Lincoln Laboratory 244 Wood Street Lexington, MA02420-9108 | 8. PERFORMING ORGANIZATION REPORT NUMBER |
|---|--|

| | |
|---|--|
| 9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS Lincoln Laboratory Massachusetts Institute of Technology 244 Wood Street Lexington, MA02420-9108 | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
A PUBLIC RELEASE

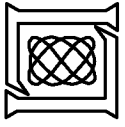
13. SUPPLEMENTARY NOTES
See Also ADM001334, Proceedings of the 2001 Space Control Conference (19th Annual) held in Lincoln Laboratory, Hanscom AFB, MA on 3-5 April 2001.

14. ABSTRACT
? Background ? Performance Analysis -- The big picture ? Performance Analysis -- The details ? Future work

15. SUBJECT TERMS

| | | | |
|---------------------------------|--|---------------------------|--|
| 16. SECURITY CLASSIFICATION OF: | 17. LIMITATION OF ABSTRACT Public Release | 18. NUMBER OF PAGES 28 | 19. NAME OF RESPONSIBLE PERSON Fenster, Lynn lfenster@dtic.mil |
|---------------------------------|--|---------------------------|--|

| | | | |
|---------------------------|-----------------------------|------------------------------|--|
| a. REPORT Unclassified | b. ABSTRACT Unclassified | c. THIS PAGE Unclassified | 19b. TELEPHONE NUMBER International Area Code Area Code Telephone Number 703767-9007 DSN 427-9007 |
|---------------------------|-----------------------------|------------------------------|--|

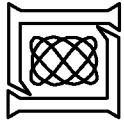


Outline

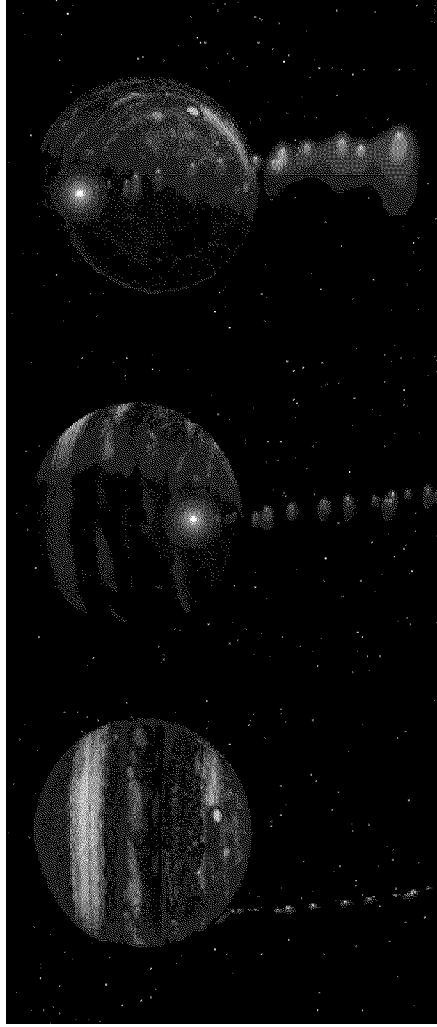
- **Background**
- **Performance Analysis -- The big picture**
- **Performance Analysis -- The details**
- **Future work**

Acknowledgements:

Lexington: Ron Sayer, Scott Stuart, Herb Vigg
New Mexico: Frank Shelley, Eric Pearce, Peter Trujillo, and the observers!



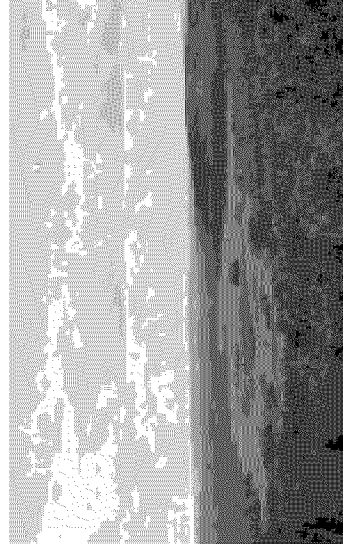
Impacts Happen



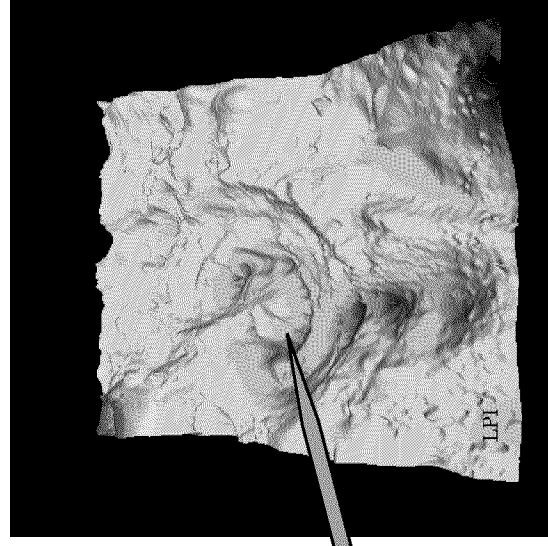
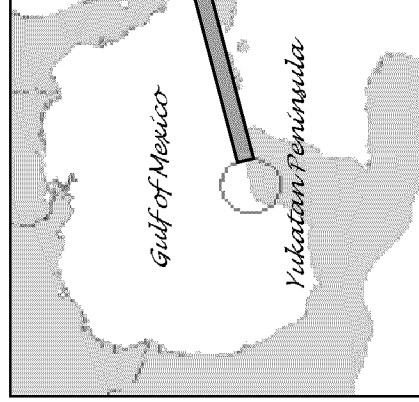
Shoemaker-Levy 9 and Jupiter (1994)



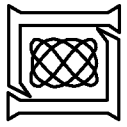
**Meteor Crater, Arizona
(~50,000 years ago)**



Tunguska, Siberia (1908)



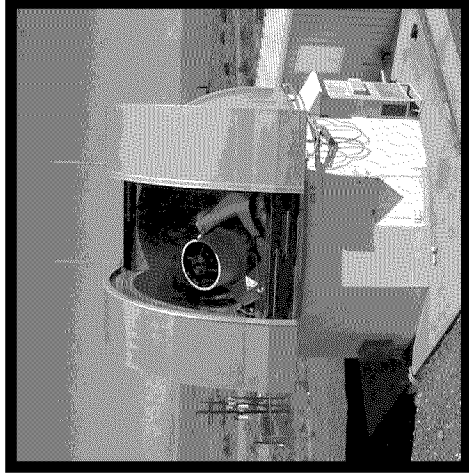
**Chicxulub, Mexico
(responsible for K-T extinctions?)
MIT Lincoln Laboratory**



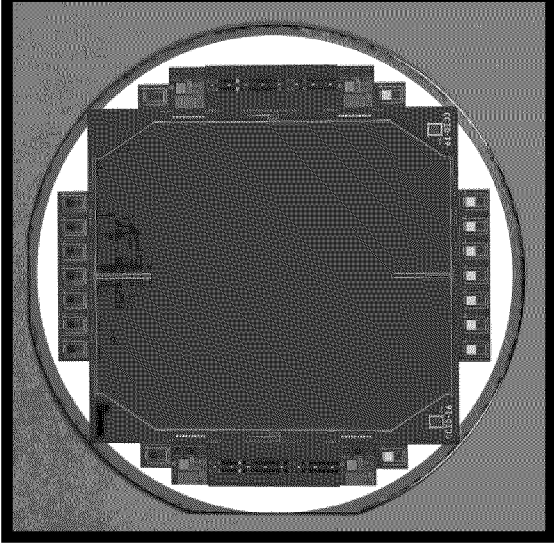
Lincoln Near Earth Asteroid Research (LINEAR)



Experimental Test Site (ETS), Socorro, NM



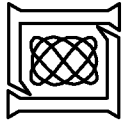
GTS-1 and GTS-2 (GEODSS) Telescopes



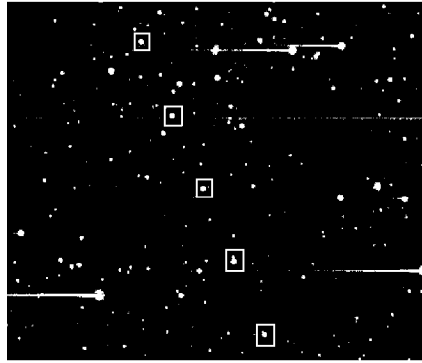
Lincoln Laboratory developed CCD

- 2560 x 1960 pixels, 2.25 arcsec per pixel
- Very low readout noise (few electrons per pixel)
- Back illuminated
- Peak quantum efficiency > 95%
- Solar weighted quantum efficiency = 65%
- Frame transfer to frame buffer in milliseconds

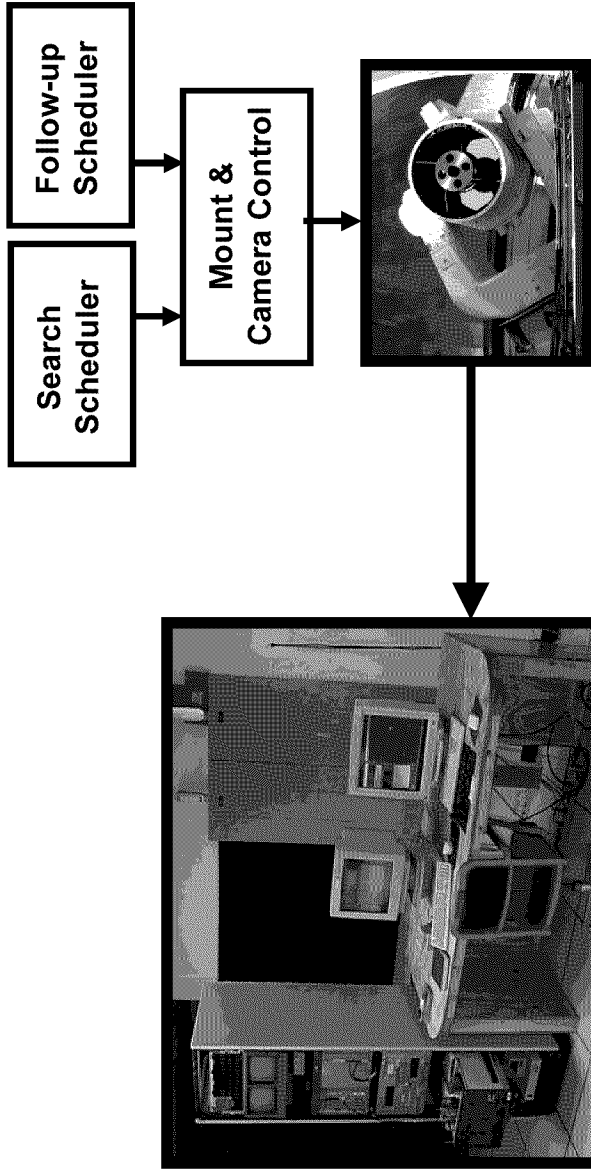
MIT Lincoln Laboratory

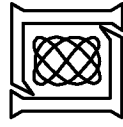


LINEAR Detection System



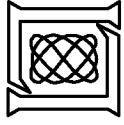
Composite of 5 Raw
Discovery Frames





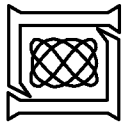
Outline

- **Background**
- **Performance Analysis -- The big picture**
- **Performance Analysis -- The details**
- **Future work**

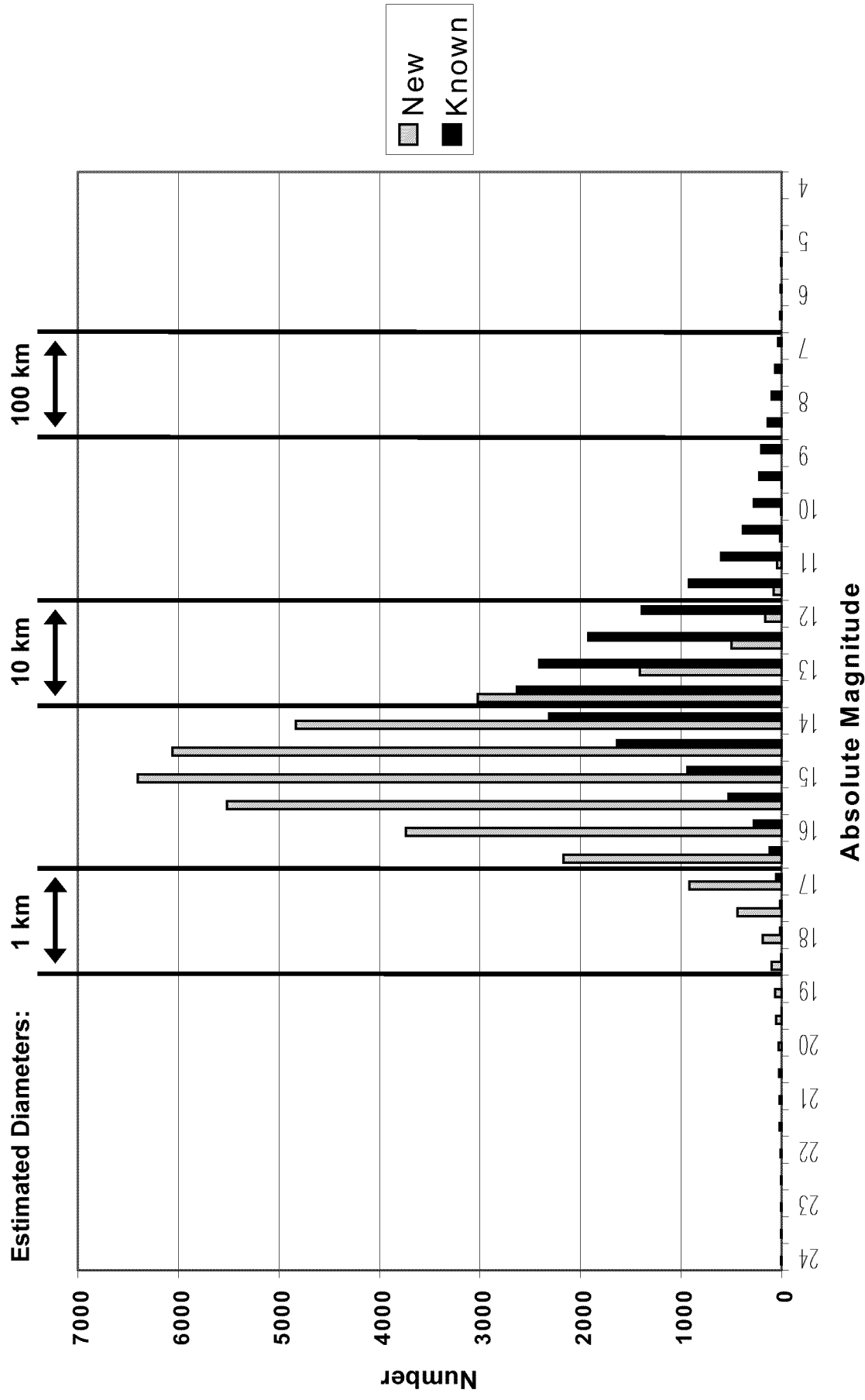


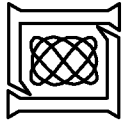
LINEAR Observations and Discoveries

| Lunar Dark Period | Obs sent to MPC | NEO Discoveries | Comet Discoveries | Total Discoveries |
|---------------------|------------------|-----------------|-------------------|--------------------|
| 9/00 | 211,014 | 39 | 5 | 9,667 |
| 10/00 | 340,743 | 22 | 1 | 3,827 |
| 11/00 | 229,071 | 36 | 1 | 1,433 |
| 12/00 | 234,978 | 14 | 0 | Coming soon |
| 1/01 | 231,377 | 23 | 3 | Coming soon |
| 2/01 | 227,916 | 19 | 2 | Coming soon |
| Totals 2001 | 459,293 | 42 | 5 | Coming soon |
| Totals 2000 | 2,268,676 | 258 | 17 | 44,953+ |
| Totals 1999 | 1,301,999 | 161 | 22 | 28,922 |
| Totals 1998 | 760,893 | 135 | 16 | 18,149 |
| Totals pre 1998 | 83,762 | 19 | 0 | 2,123 |
| Grand Totals | 4,644,401 | 614 | 60 | Coming soon |

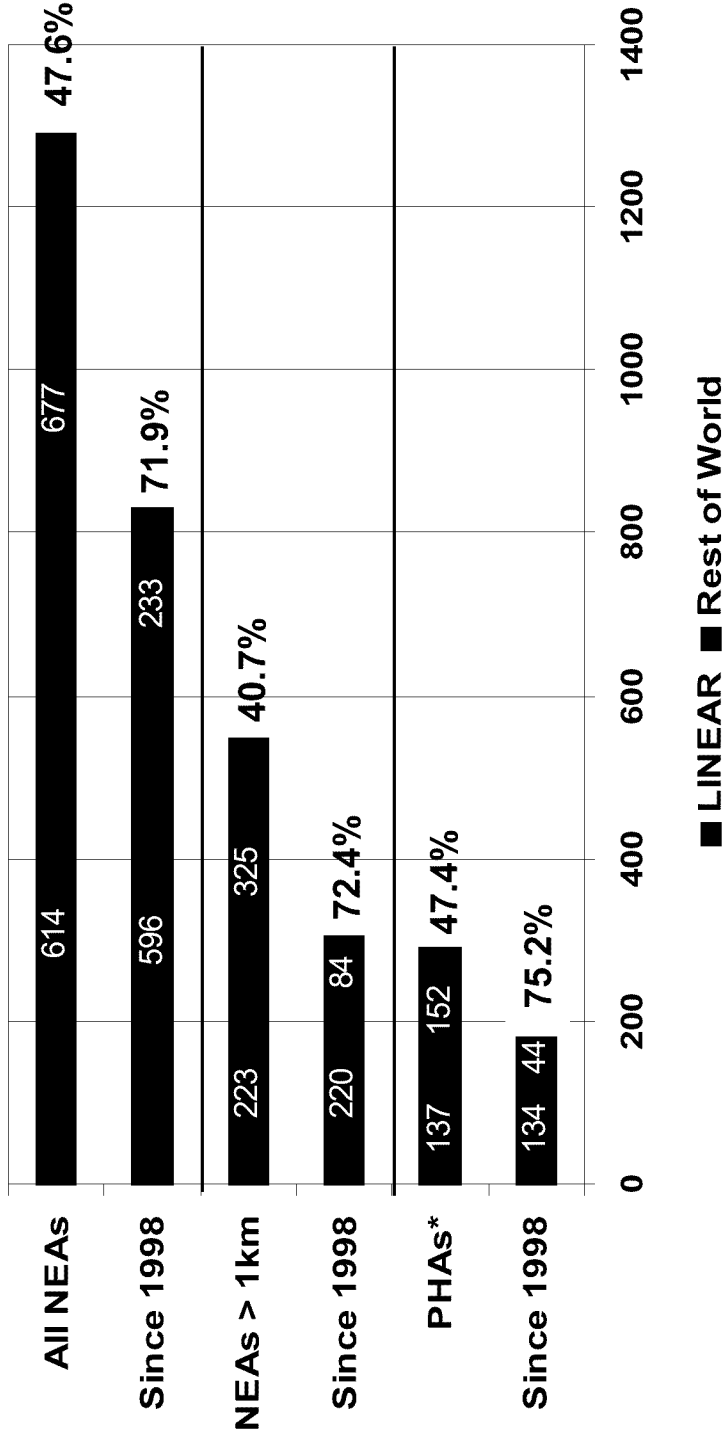


Absolute Magnitudes of Asteroids Detected by LINEAR



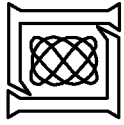


LINEAR's Share of Near Earth Asteroid (NEA) Discoveries



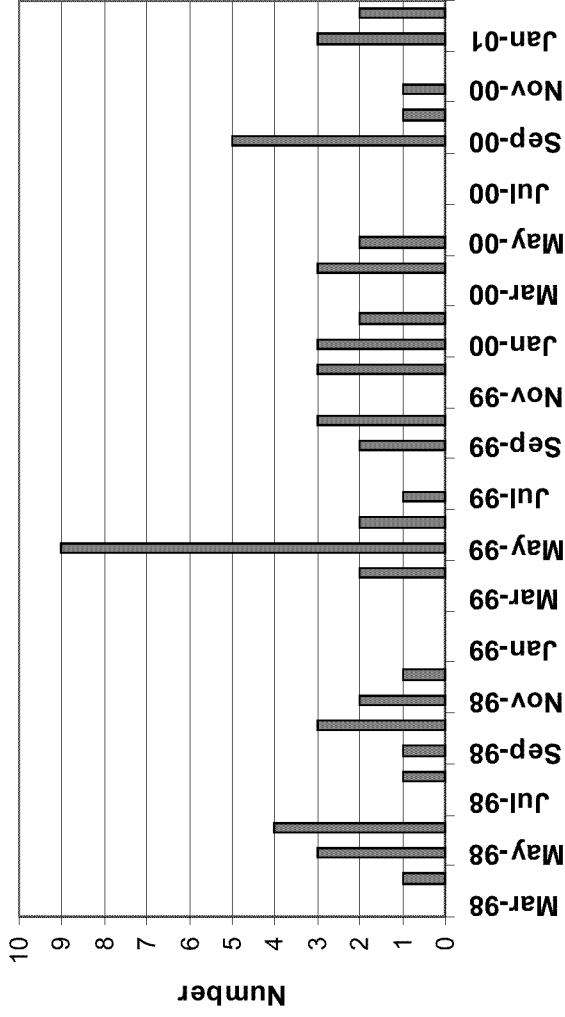
- First NEA discovered in 1898
- LINEAR has discovered 60 comets

*PHA: Potentially Hazardous Asteroid, defined by Minor Planet Center.

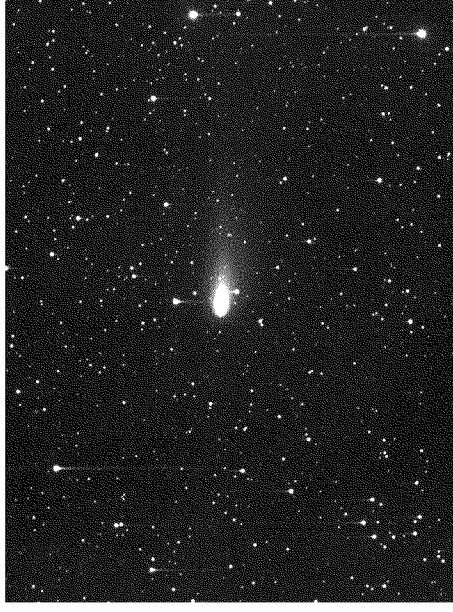


LINEAR Comet Discoveries

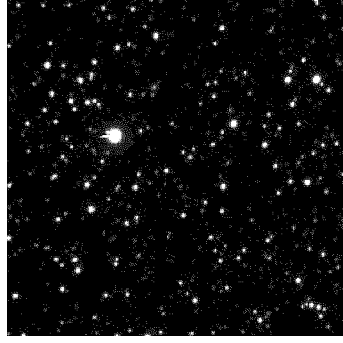
60 Comet Discoveries



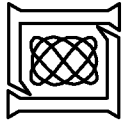
C/1999 S4 LINEAR



Discovered 27 Sept 1999
This image from 25 June 2000
Closest approach 23 July 2000 with
peak magnitude ~6.5.
Exploded and 'vanished' 26 July.

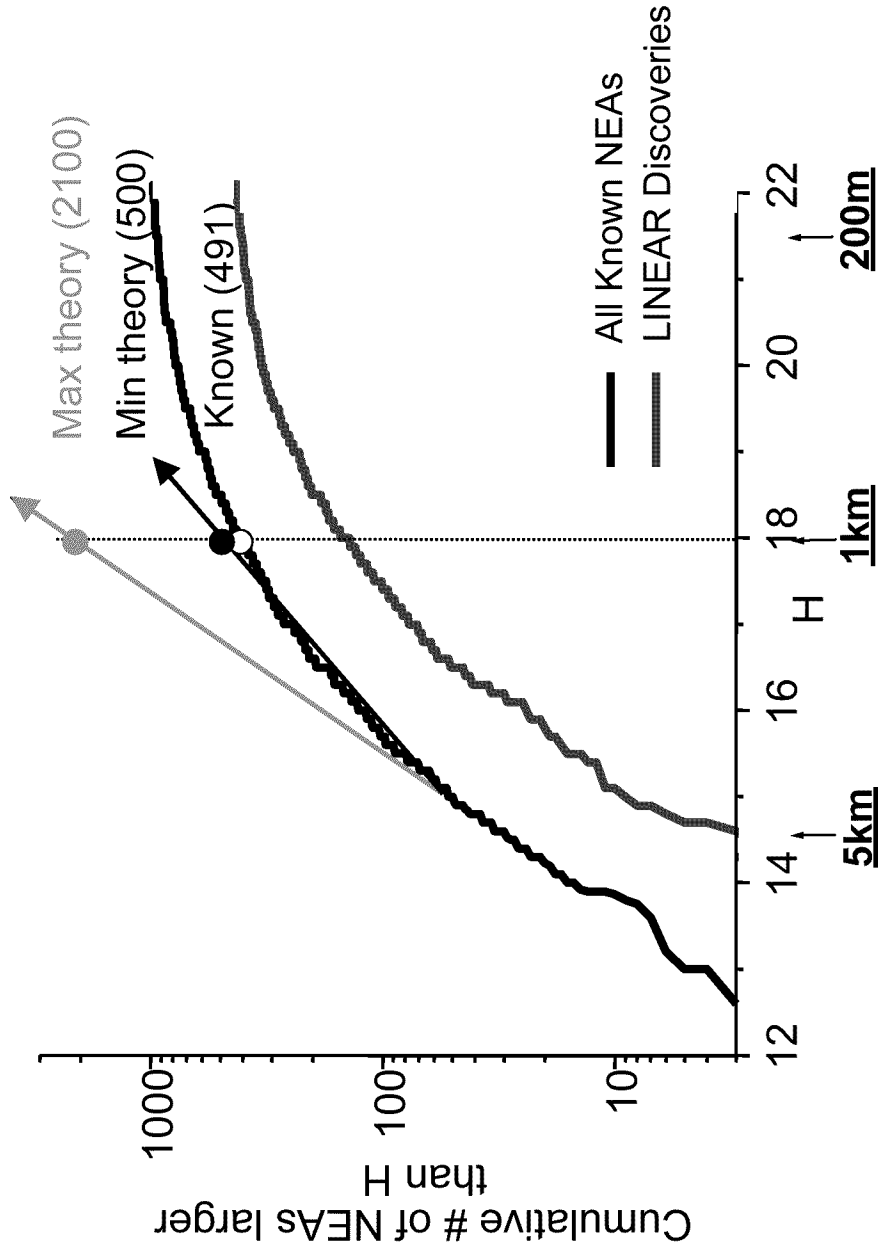


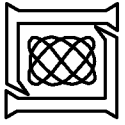
C/2000 WM1 LINEAR
the 'Christmas Comet'
Discovered 16 Nov 2000
Closest approach 22 Jan 2002
Likely 3rd-5th magnitude



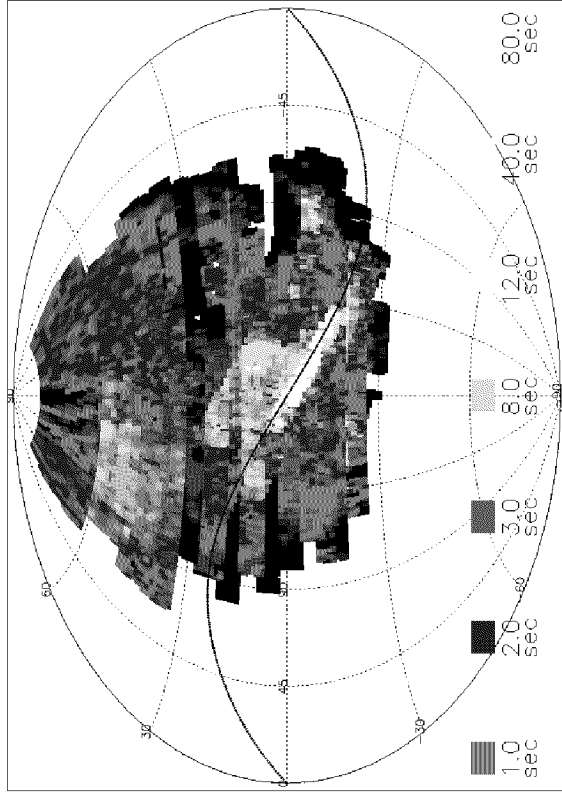
NEA Population and NASA's Goal

NASA's Goal:
Find 90% of NEAs greater than 1 km diameter by 2008

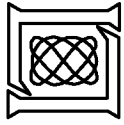




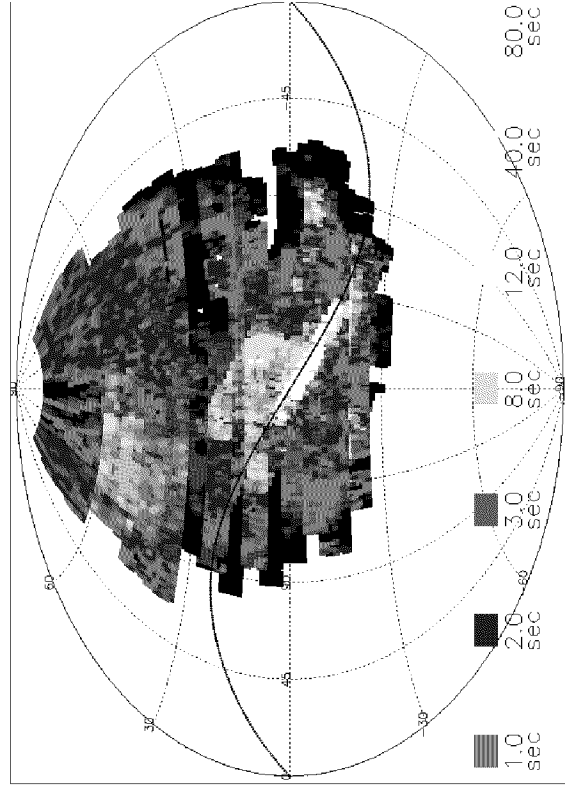
LINEAR Sky Coverage



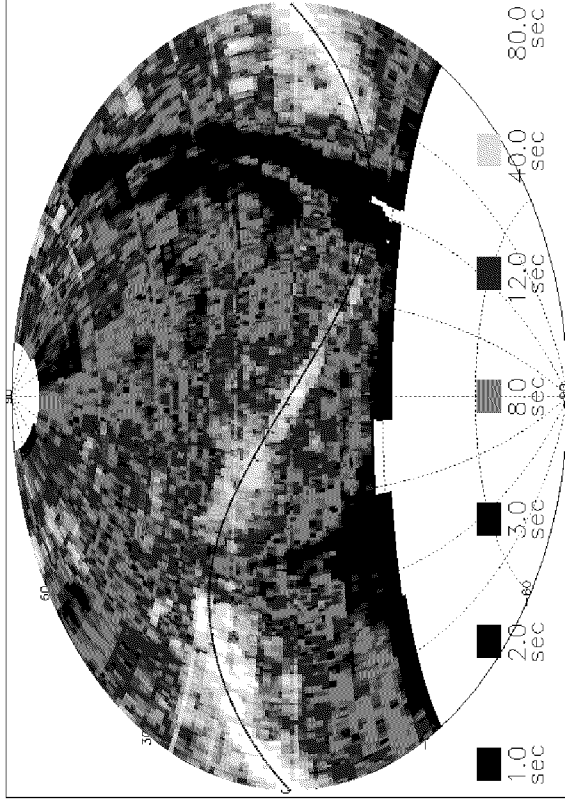
April 2000
2 telescopes
Approximately 17,000 sq degrees



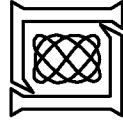
LINEAR Sky Coverage



April 2000
2 telescopes
Approximately 17,000 sq degrees

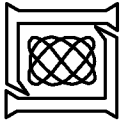


Sept 1999 – Sept 2000
2 telescopes since February 2000

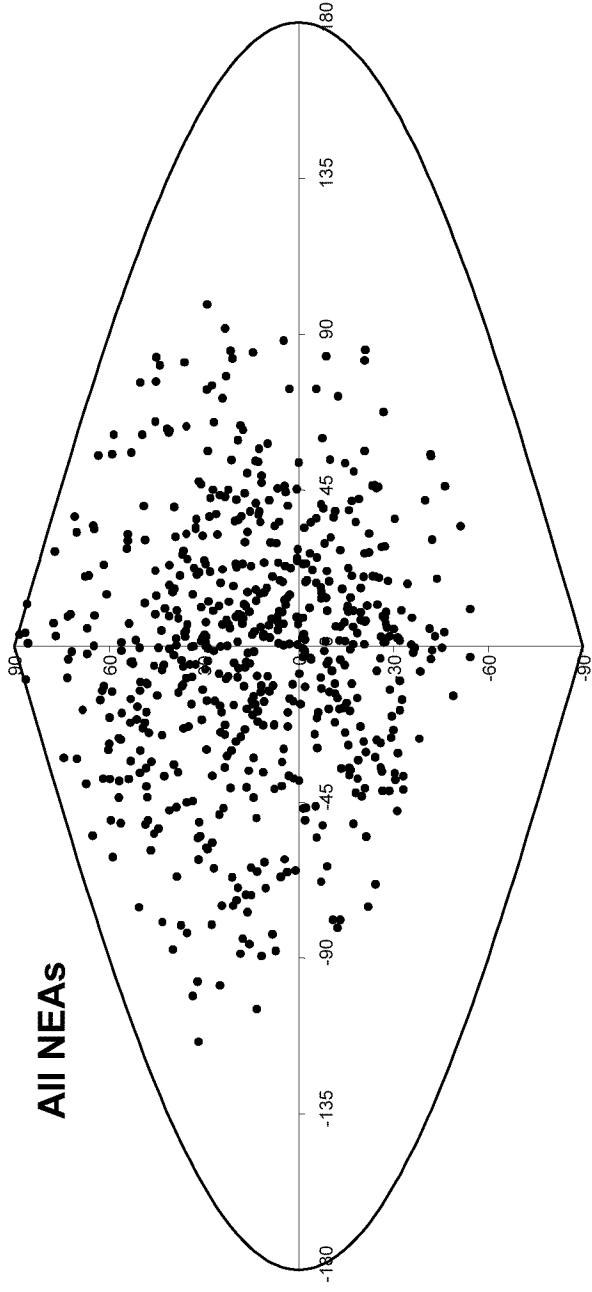


Outline

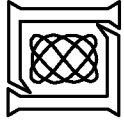
- **Background**
- **Performance Analysis -- The big picture**
- **Performance Analysis -- The details**
 - **Search pattern effectiveness**
 - **Depth of search**
 - **Population estimate**
- **Future work**



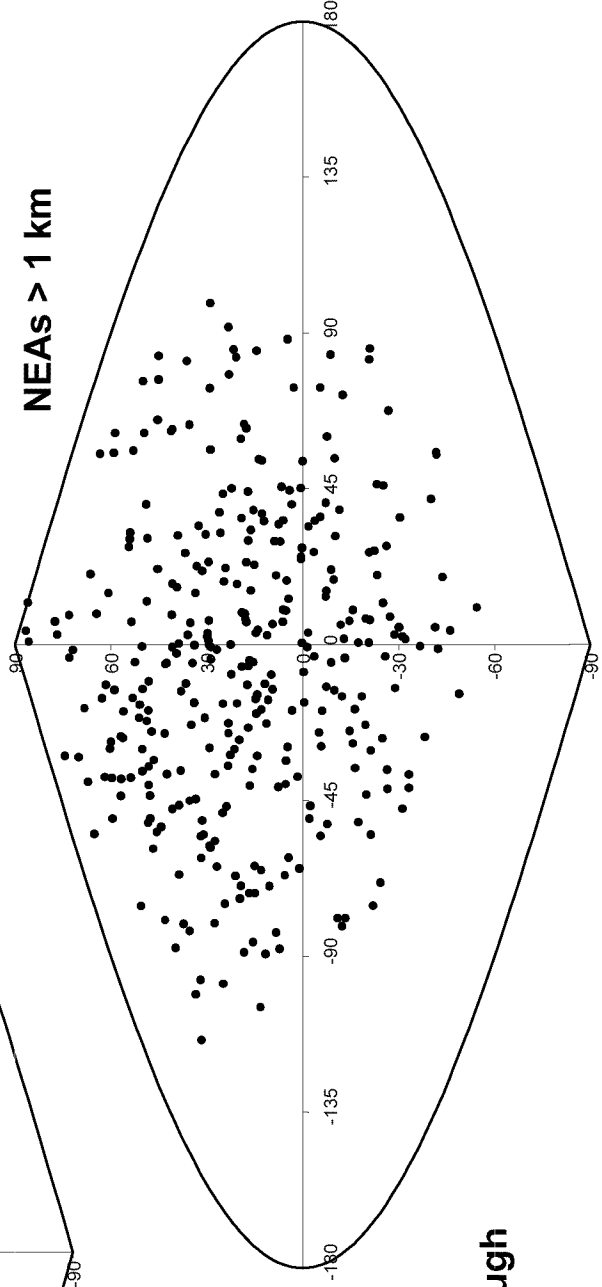
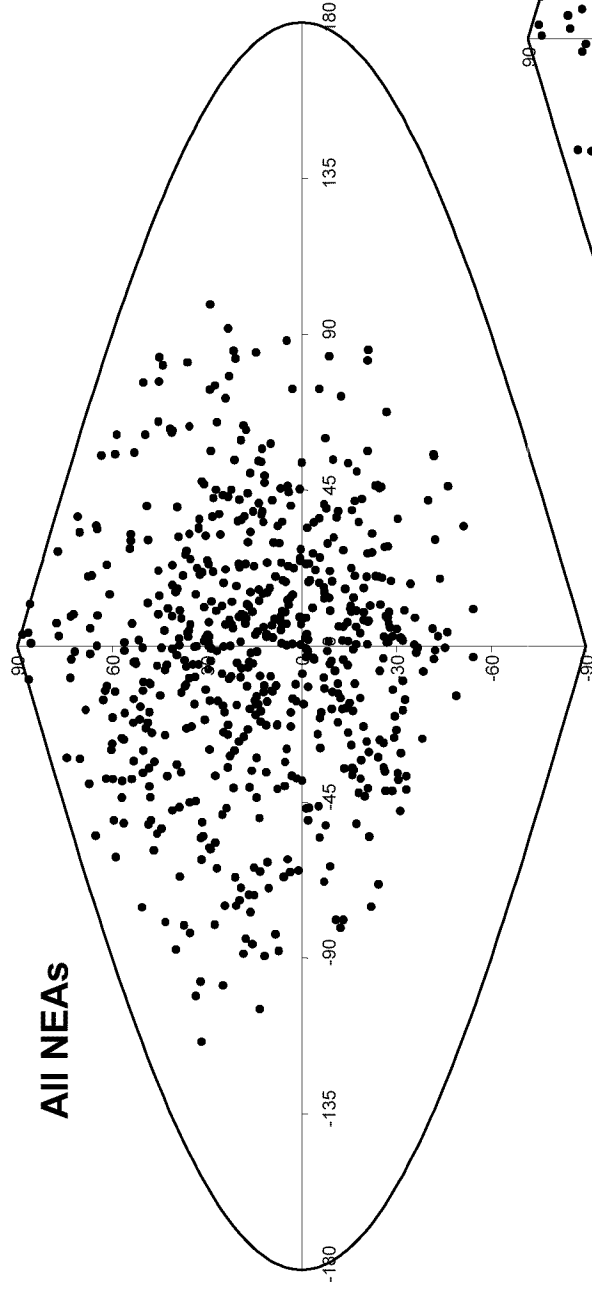
Distribution of NEA Detections



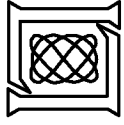
- NEA detections in ~Ecliptic Coordinates.
- Opposition is at 0,0.
- Only one point per NEA detection per Dark Period.
- LINEAR data April 1999 through June 2000



Distribution of NEA Detections

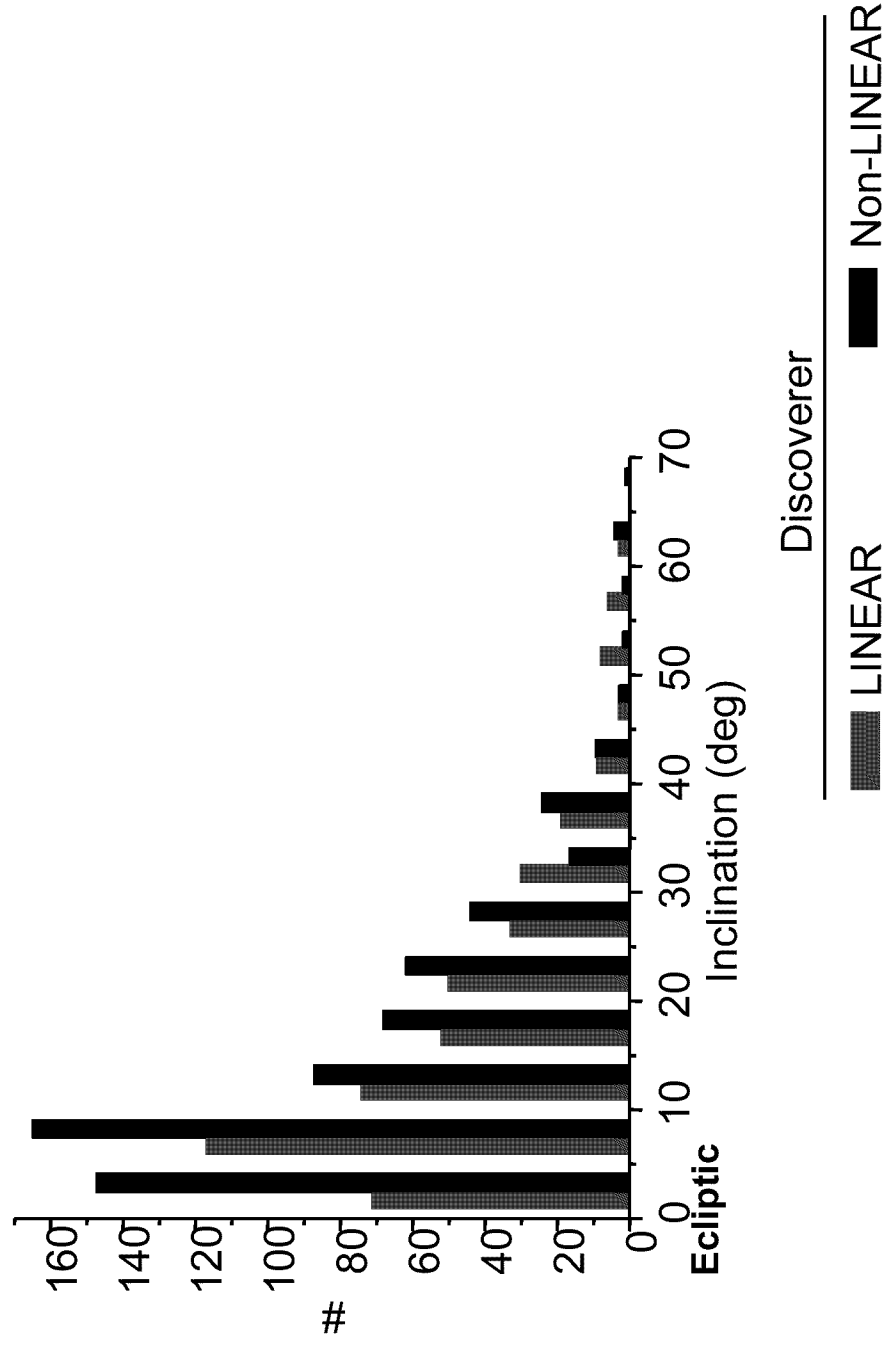


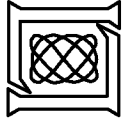
- NEA detections in ~Ecliptic Coordinates.
- Opposition is at 0,0.
- Only one point per NEA detection per Dark Period.
- LINEAR data April 1999 through June 2000



Distribution by Inclination

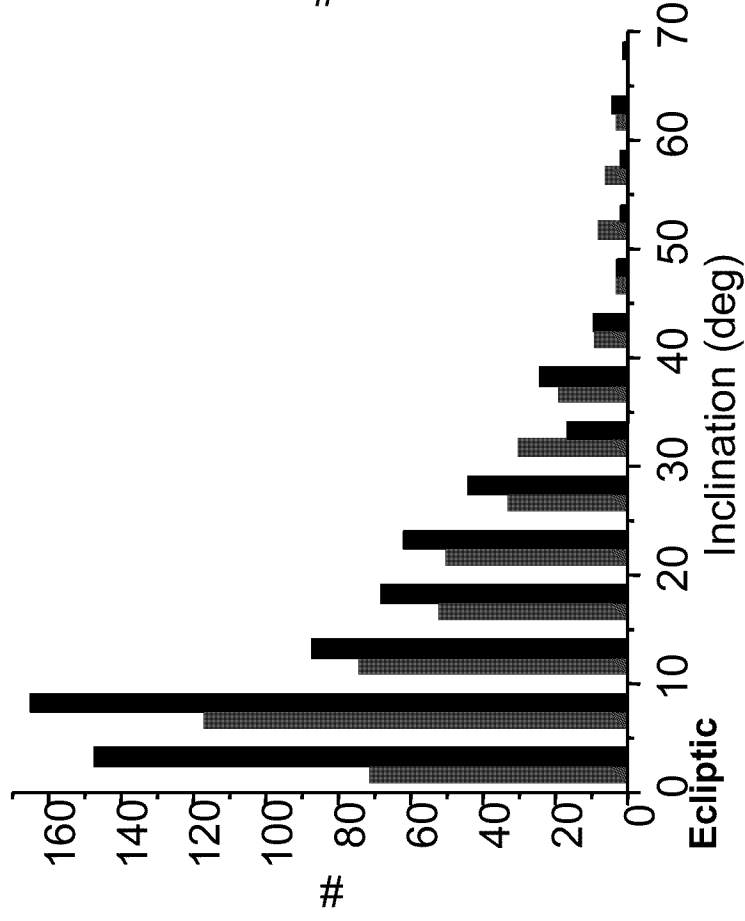
All known NEAs
binned by inclination



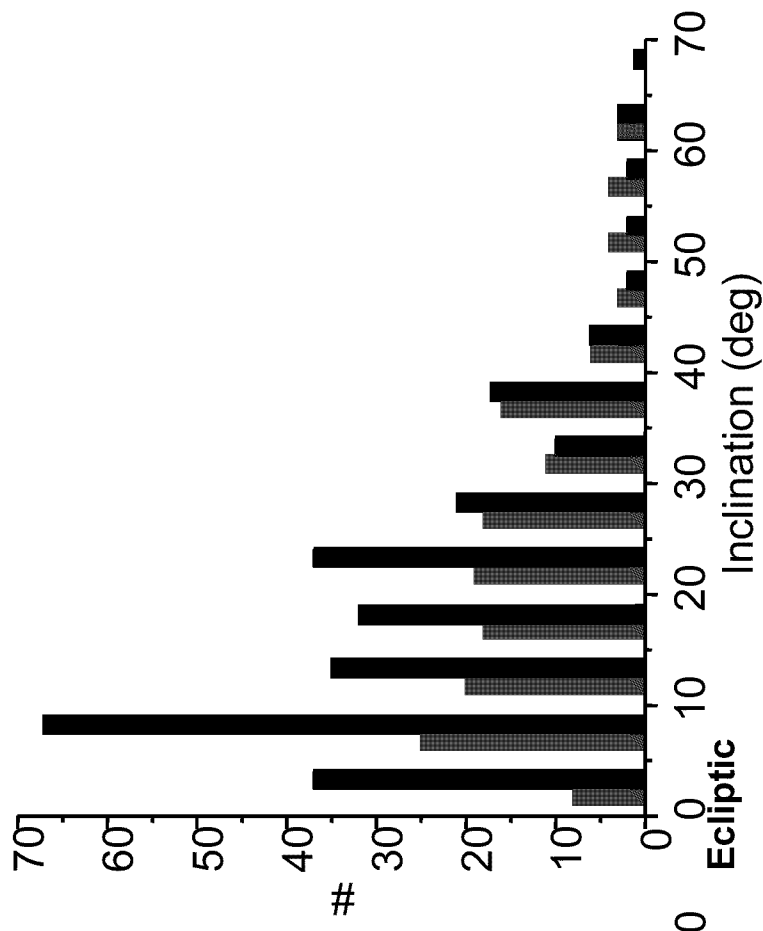


Distribution by Inclination

All known NEAs
binned by inclination



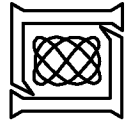
All known large NEAs
binned by inclination



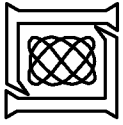
Discoverer

LINEAR

Non-LINEAR



Depth of Search



Determining Search Volume

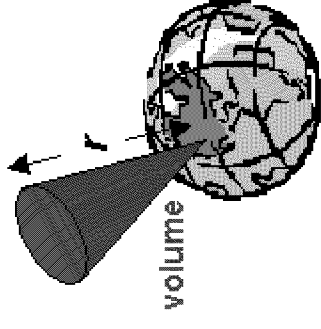
- Limiting magnitude can be translated to volume searched for an object of a known size/brightness. Solve for r .

$$V_L - H = 5 \log(r) \Delta - 2.5 \log[(1 - G)\Phi_1 + G\Phi_2]$$

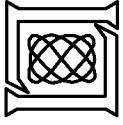
with

$$\Phi_1 = \exp[-3.33(\tan \frac{\beta}{2})^{0.63}], \quad \Phi_2 = \exp[-1.87(\tan \frac{\beta}{2})^{1.22}]$$

$$G = 0.15, \quad H = 18.0$$



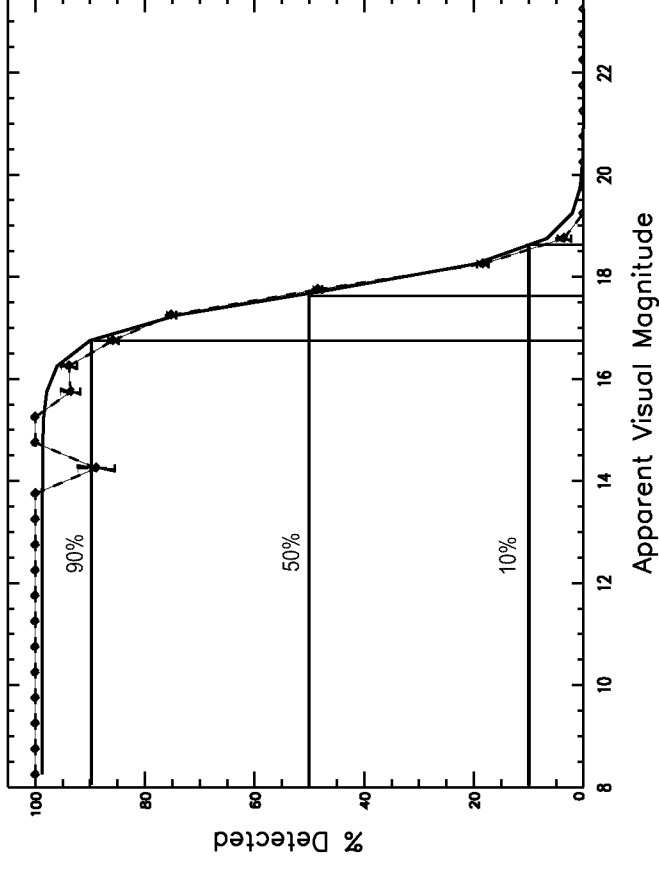
- Volume searched can be used as common metric for various search programs.
- Various search programs have begun discussing coordination to optimize overall search.
 - All programs need to characterize system capabilities.

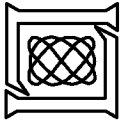


Limiting Magnitude Determination

- Limiting visual magnitude affected by
 - Atmospheric conditions
 - Night sky brightness
 - Systematic losses
- Detection efficiency curve generation
 - Numbered and multi-opposition asteroids with known magnitudes.
 - Propagate asteroids to night of search
 - Compute percent detected in each bin
- Curve generated for each night

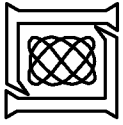
Sample detection efficiency curve
for a single night's search





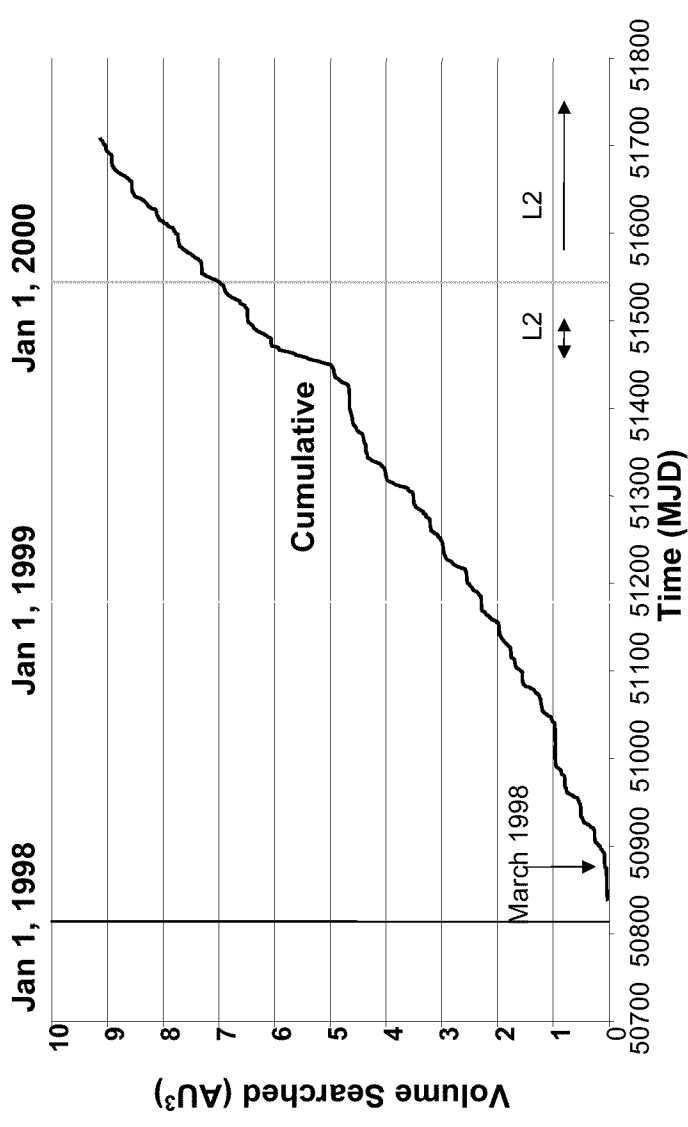
Volume Searched by LINEAR

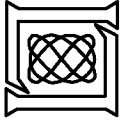
- LINEAR measures SNR6 value for every field searched.
- SNR6 is known magnitude of a star with measured signal-to-noise equal to 6.
- SNR6 values agree with nightly based 50% cutoff detection efficiency value.
- Limiting magnitude values can be computed on a field by field basis.



Volume Searched by LINEAR

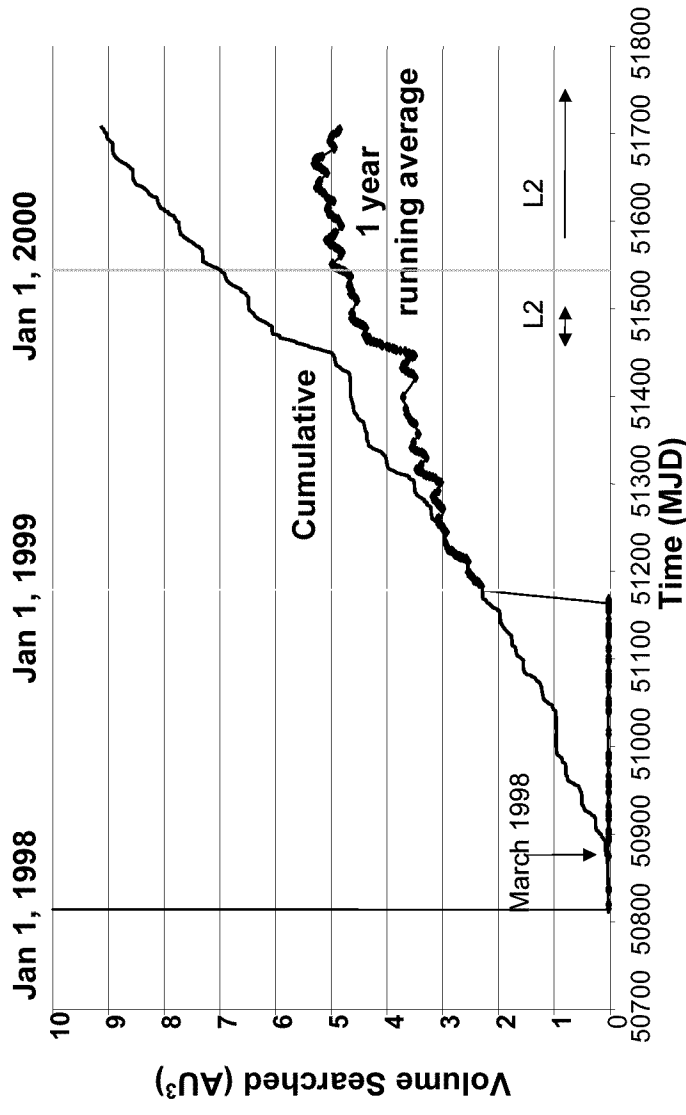
- LINEAR measures SNR6 value for every field searched.
 - SNR6 is known magnitude of a star with measured signal-to-noise equal to 6.
- SNR6 values agree with nightly based 50% cutoff detection efficiency value.
- Limiting magnitude values can be computed on a field by field basis.
- Calculate volume searched in au^3

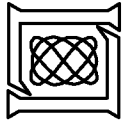




Volume Searched by LINEAR

- LINEAR measures SNR6 value for every field searched.
 - SNR6 is known magnitude of a star with measured signal-to-noise equal to 6.
- SNR6 values agree with nightly based 50% cutoff detection efficiency value.
- Limiting magnitude values can be computed on a field by field basis.
- Calculate volume searched in au^3

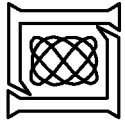




Population Estimate

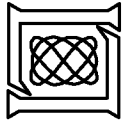
JAC 20
JBE 11/1/00

MIT Lincoln Laboratory



Population Estimate for Large NEAs

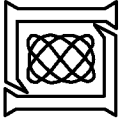
- **Topic of great interest**
 - 2100 by Morrison, 1992
 - 750 by Rabinowicz, 2000
 - 900 by Bottke, 2000
- **Typical method: 10's of detections and many Monte Carlo simulations**
- **New estimate by Scott Stuart, Lincoln Lab Scholar**
 - Using 100's of detections by LINEAR
 - Using new inclination distribution
 - Using LINEAR detection efficiency information
 - Using Bayesian analysis



Population Estimate for Large NEAs

- Topic of great interest
 - 2100 by Morrison, 1992
 - 750 by Rabinowicz, 2000
 - 900 by Bottke, 2000
- Typical method: 10's of detections and many Monte Carlo simulations
- New estimate by Scott Stuart, Lincoln Lab Scholar
 - Using 100's of detections by LINEAR
 - Using new inclination distribution
 - Using LINEAR detection efficiency information
 - Using Bayesian analysis

1100 +/- 100



Summary and Future Work

- **LINEAR contributing 72% of NEA discoveries since 3/98**
 - Approaching 50% of all NEA discoveries ever.
 - Searching 15,000 – 17,000 square degrees/month
 - LINEAR is contributing significantly to the NASA goal
- **Continue system characterization to benefit coordination of various search programs and for self-improvement.**
 - Generate detection efficiency curves for every night.
 - Analyze limiting magnitudes as a function of integration times and search patterns.
 - Experiment with and analyze various search patterns.
- **Continue characterizing known NEO population.**