GPIPS – *The Galactic Plane Infrared Polarization Survey*

- **Mimir Instrument Teams**
  - (2001 – 2004)
    - Boston University Team
      - D. Clemens
      - E. V. Tollestrup
      - D. S. Sarcia
      - A. Grabau
    - Lowell Observatory Team
      - M. Buie
      - E. Dunham
      - B. Taylor

- **GPIPS Project Team**
  - (2006 -> ...)
    - Dan Clemens
    - Brian Taylor (@ Lowell Obs.)
    - April Pinnick (Grad @ BU)
    - Michael Pavel (Grad @ BU)
    - Carol Carveth (Grad @ BU)
    - Katherine Jameson (UG @ BU)
   - *NSF grant (AST 06-07500)*

- **Mimir was __built__ to do GPIPS**

- **GPIPS __can only be done__ with Mimir**

1

The Mimir Instrument on the Perkins Telescope

- **Boston University and Lowell Observatory are 50:50 partners in the operation of the 1.83 m Perkins Telescope** on Anderson Mesa, outside Flagstaff, Arizona

- **<u>Mimir is a "facility-class" multi-function near-infrared instrument</u>**, specifically designed to perform extensive wide-field infrared polarization surveys (Clemens et al. 2007).

- **<u>GPIPS has been designated as a "Key Project"</u>** for Boston University on the Perkins telescope, commanding significant time (~50 nights/year)

Mimir Electronics

Backend of Perkins Telescope

Autoguider

Brian Taylor

Mimir Instrument Cart

Mimir Cryostat
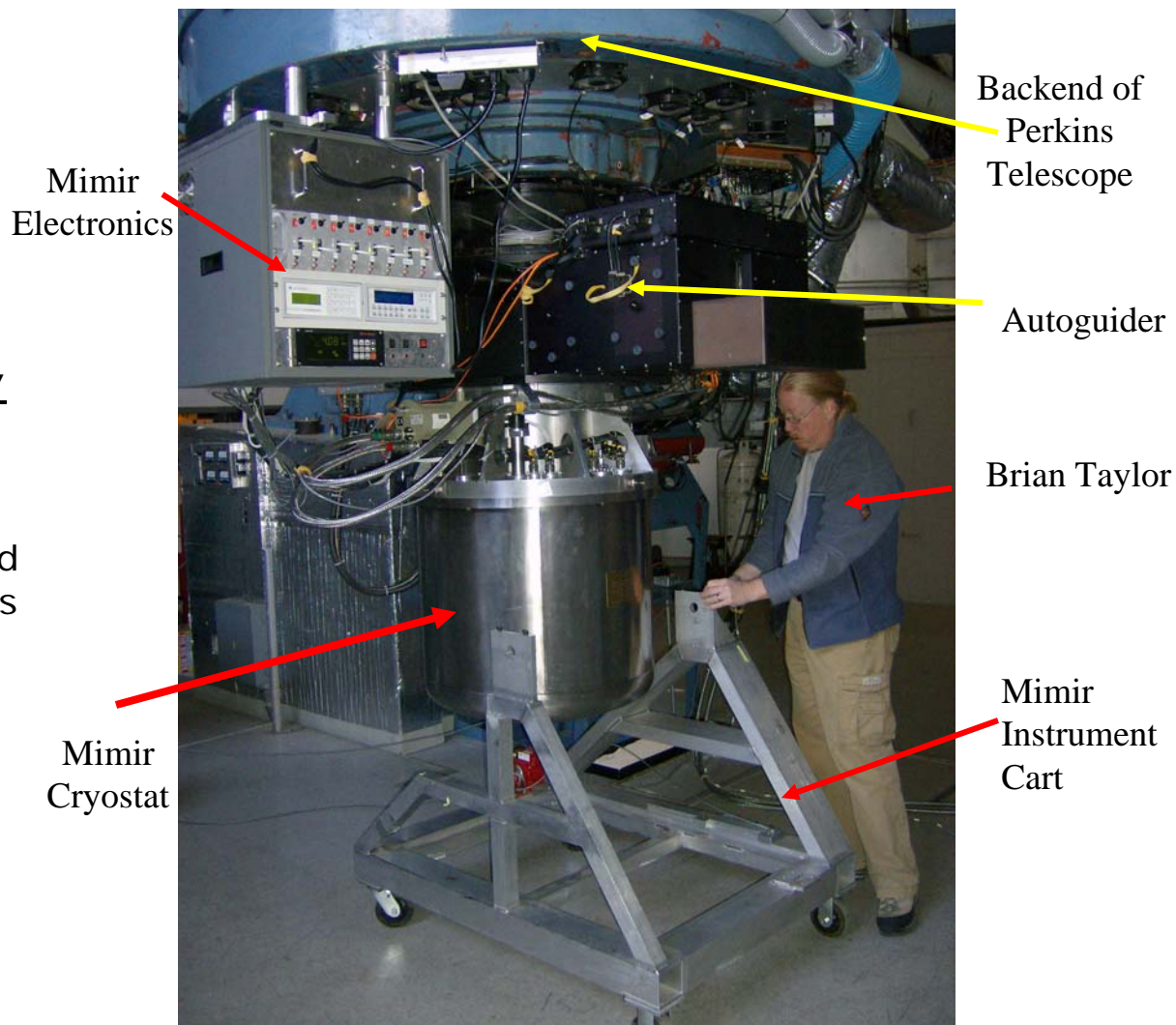
The Mimir Instrument
(also see poster)

- **Near-IR "Swiss Army Knife"** – imager, spectrometer, **<u>polarimeter</u>**

- **Two camera plate scales**
  - F/5 Wide field (10x10 arcmin) @ 0.6" per pixel
  - F/17 Narrow field (3x3 arcmin) @ 0.18" per pixel

- **1-5.5μm wavelength**
  - 1024x1024 pixel InSb ALADDIN III detector array
  - J, H, Ks imaging, polarimetry, spectroscopy
  - L, M spectroscopy, imaging

- **Image quality excellent** - 0.9-1.2 arcsec FWHM

- **Data Collection is robust**, efficient (uses "LOIS")
  - Scripted operation for complex polarimetry mapping
    - Integration time-limited for GPIPS

- **Continuous operation** - 2-stage closed-cycle helium refrigerator

Mimir Polarimetry

- **Unique capability** for wide-field IR polarimetry
  - No other instrument comparable

- No reflections before polarimetric light analysis

- Axial symmetric design, no aspheres

- HWP+Wire Grid light analysis

  - Rotating Half-wave plate
    - Zero-order HWPs
    - H-band HWP (NovaPhase)

  - Wire grid polarization analyzer
    - Molectron IG227-38
    - 1-10 um coverage

  - Full Imaging field (10x10') at once
    - One HWP angle per image
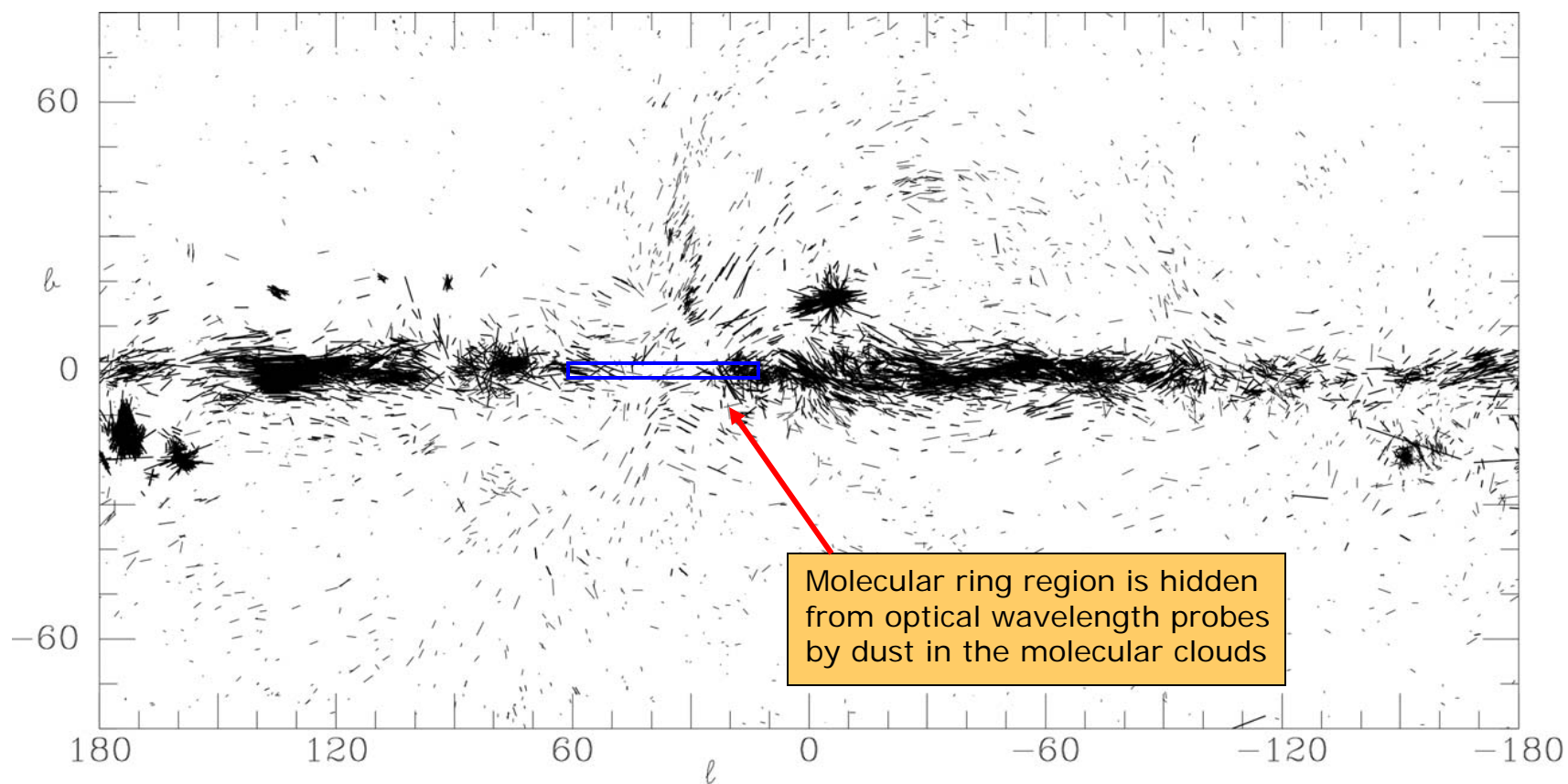   - "Step and integrate" mode – fully scripted

4

Key Science Mimir was Designed to do:
Sensing Galactic Magnetic Fields

B component along the line of sight		**B** component normal to l.o.s., in plane of sky	
Faraday Rotation	Zeeman Effect	Background Starlight	Thermal Dust Emission
- linear polarization	-circular polarization	- linear polarization	- linear polarization
- cm wave radio	- cm wave radio (& some mm)	- optical, near-IR, UV wavelengths	- mm, submm, far-IR wavelengths
-plasma medium (Hot ISM)	- neutral medium (Cold ISM)	- Hot or Cold ISM	- Cold ISM
		Mimir's Contribution	

Background Starlight Polarization
Mapping: Optical Wavelengths

Molecular ring region is hidden from optical wavelength probes by dust in the molecular clouds

Data from Mathewson & Ford (1970) plus Klare & Neckel (1977), compiled by Heiles (2000)

Science Questions, Survey Characteristics, Community Data Access

- **Science Questions**
  - **Galactic Size Scales (1-5 kpc):**
    - **B** in and out of spiral arms?
    - Molecular clouds threaded by common **B** field?
  - **Cloud Size Scales (10 – 100 pc):**
    - **B** field, **P/Av** vs environment (diffuse, translucent, molecular)?
  - **Dense Cores and Star Forming Regions (0.1 – 1 pc):**
    - **B** fields in star-forming regions? Quiescent cloud cores?

- **GPIPS characteristics**
  - 76 sq deg Galactic Ring Survey region
    - ±1 deg of latitude, 18-56 deg of longitude
  - 400,000 stars to H=12th
    - To multi-kpc distances
    - High stellar density (1-2 stars/sq. arcmin)

- **GPIPS Data Products – via Web portal (http://gpips0.bu.edu/)**
  - See Poster by Carveth
  - Polarization Point Source Catalog (POLCAT)
  - Photometric Point Source Catalog (PHOTCAT)
    - To H=15-17 or confusion limit
  - Image Tile Catalog (ITC)
  - Access = Fully Public
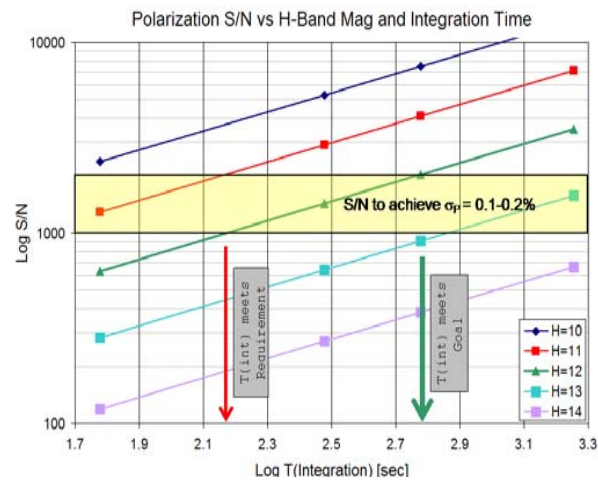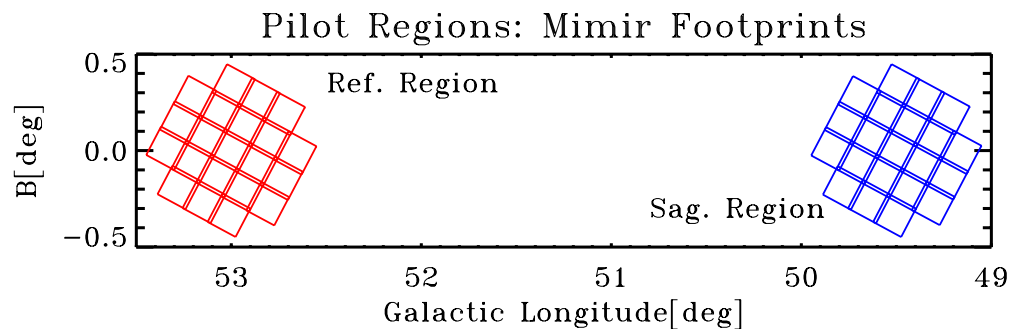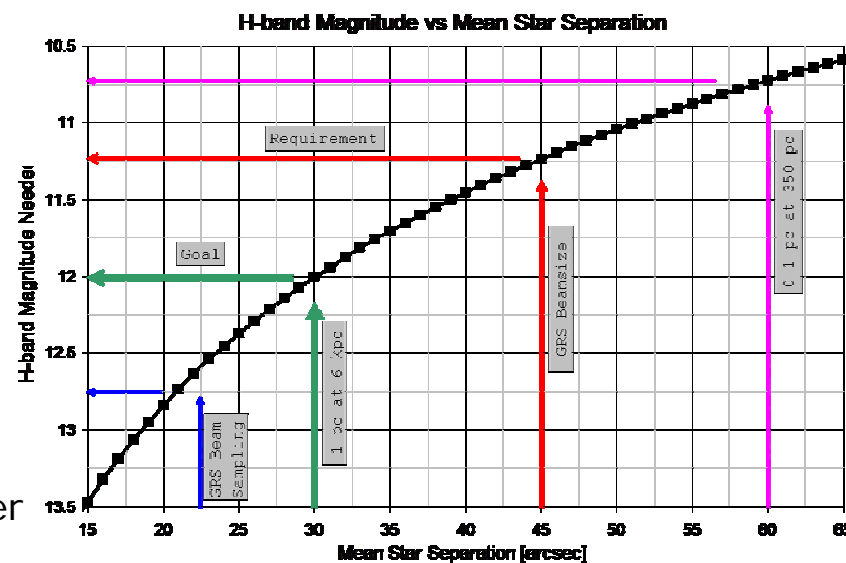   - Released as calibrated

Probing B in 3D

- **Extensive knowledge of each GPIPS star**
  - J, H, K from 2MASS (all H<12 stars have J, K mags)
  - 3.6, 4.5, 6, 8 microns mags from GLIMPSE
  - Each GPIPS star SED fit by Barb Whitney using Robitaille et al. (2006, 2007)
    - Teff, Log(g), Av (e.g., 98% of GPIPS target stars are K-giants)

- **Extensive ISM knowledge toward each GPIPS direction**
  - Molecular gas: ^{13}CO spectral line Galactic Ring Survey - Jackson et al. (2006)
  - Atomic gas: VLA Galactic Plane Survey (VGPS) - Stil et al. (2006)
  - Ionized gas:
    - Continuum: NRAO VLA Sky Survey (NVSS) - Condon et al. (1998)
    - H-alpha: WHAM – Reynolds et al. (1998)

- With stellar distances, polarimetry can be distance-tagged (or disentangled) to reveal 3D distribution of the **B** field.
  - Gain zeroth-order ground-truth using stellar clusters (see poster by A. Pinnick)
  - Place stars, gas clouds, **B** fields in 3D context

8

- **Designed to test GPIPS design, methods**
  - Average stellar sampling at 30 arcsec
  - Must reach to H=12th polarimetrically
  - $P/\sigma P > 3$ so $\sigma_{PA} < 10$ deg

- **Two ½ sq deg regions**
  - Sag (toward spiral arm tangent)
  - Ref (3.5 deg higher longitude – ie, interarm)
  - 21 Mimir FOVs on each region
  - 6 dithers, 32 HWP positions at each grid center
  - 3 sec integration time / image
  - 576s = 9.6 min integration time per field

H-band Magnitude vs Mean Star Separation

Pilot Regions: Mimir Footprints

Ref. Region

Sag. Region

Polarization S/N vs H-Band Mag and Integration Time
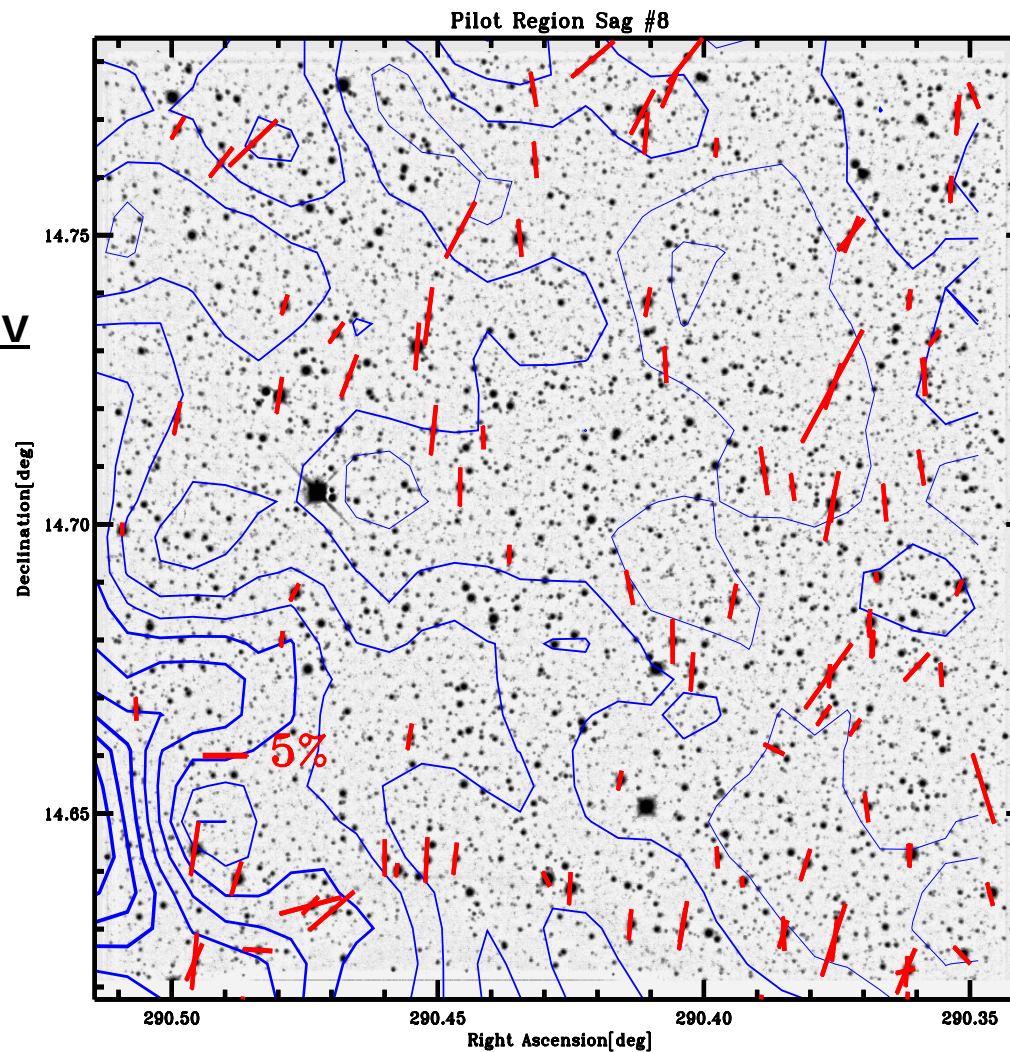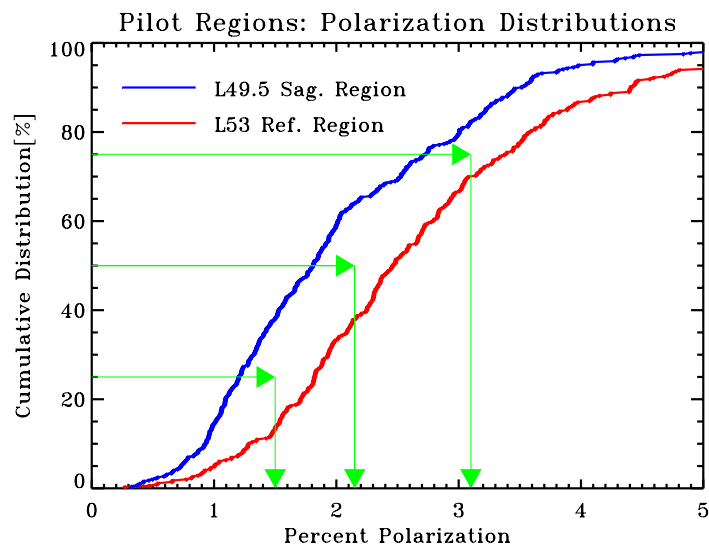
S/N to achieve σ_P = 0.1-0.2%

Pilot Survey Results – Polarimetry, Imaging

- One of 21 Sag Fields
- Image is all 32 images, coadded
- Red are polarization vectors
- Blue is GRS 13CO integrated line intensity

- **~ 100-140 pol. stars per Mimir FOV**

- **Median H-band polarization ~ 2%**

Pilot Regions: Polarization Distributions

L49.5 Sag. Region
L53 Ref. Region

Pilot Region Sag #8

5%

- ## <u>Computing Infrastructure</u>
  - 5 Tb raid disk system w/fast CPU + 8 Gb RAM
  - 4 desktop PCs; 1 laptop
  - several 500 Gb external USB disks for data Xfer

- ## <u>Software</u>

  - *Have piloted all necessary software to go from raw images to final polarimetry products, in custom IDL*

  - A. <u>**Basic Data Processor**</u> (**MSP_BDP**)
    - *raw images to dark, flat, linearity corrected images*
    - *GUI-based system finished, in use*
  - B. <u>**PSF-Fitting Photometry**</u> – piloted, GUI-package form by 6/2008
  - C. <u>**Polarimetry Extractor**</u> – piloted, GUI-package form by 8/2008
  - D. <u>**Image Coadder**</u> – piloted, GUI-package form by 9/2008

- ## <u>Web Portal</u> – built, launched 01/2008
  - Open community access to GPIPS data (polarizations, images)
  - Presently hosts 2005 pilot survey data for 4 fields
  - Searchable by many criteria
 - Awaiting more data – will fill as data are processed

11

GPIPS Progress

- "Seasons" –mid-May to early-July & mid-Sept to mid-Oct.
  - Inner Galactic plane transits in mid-July, mid-monsoon!
  - **Season zero** = 2005 Pilot Survey (May/June) => **42 fields of 3,200 fields** (= 1 Mimir 10x10 arcmin FOV) needed to cover GPIPS region
  - **Season one** = 2006 (first GPIPS year) => **159 fields** (3.6 sq deg)

GPIPS Centers, Clusters, and Season One Observations
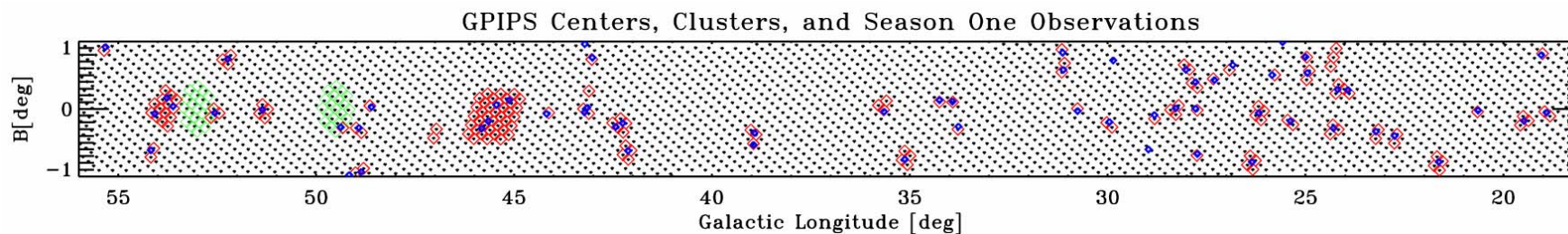
  - Red = Season One (**All Known Clusters** + two known GRS molec. clouds)

  - **Season two** = 2007 (2nd GPIPS year) => **545 fields** (12 sq deg)

GPIPS Centers
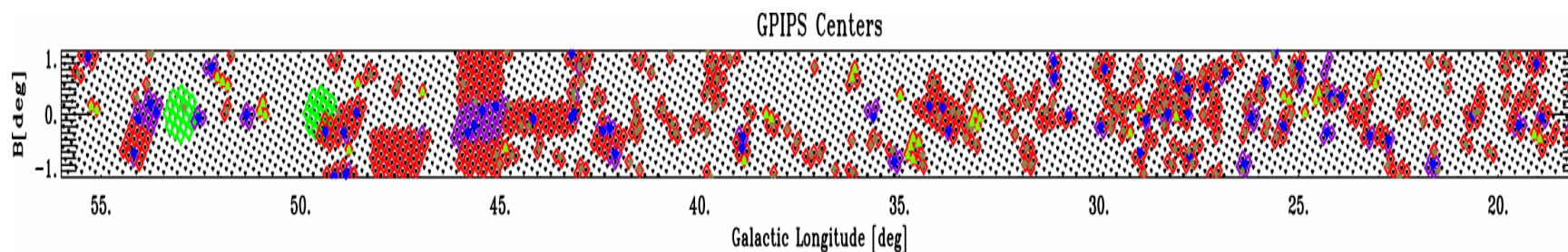
GPIPS Progress Summary

- Summary of GPIPS observations and projected progress.

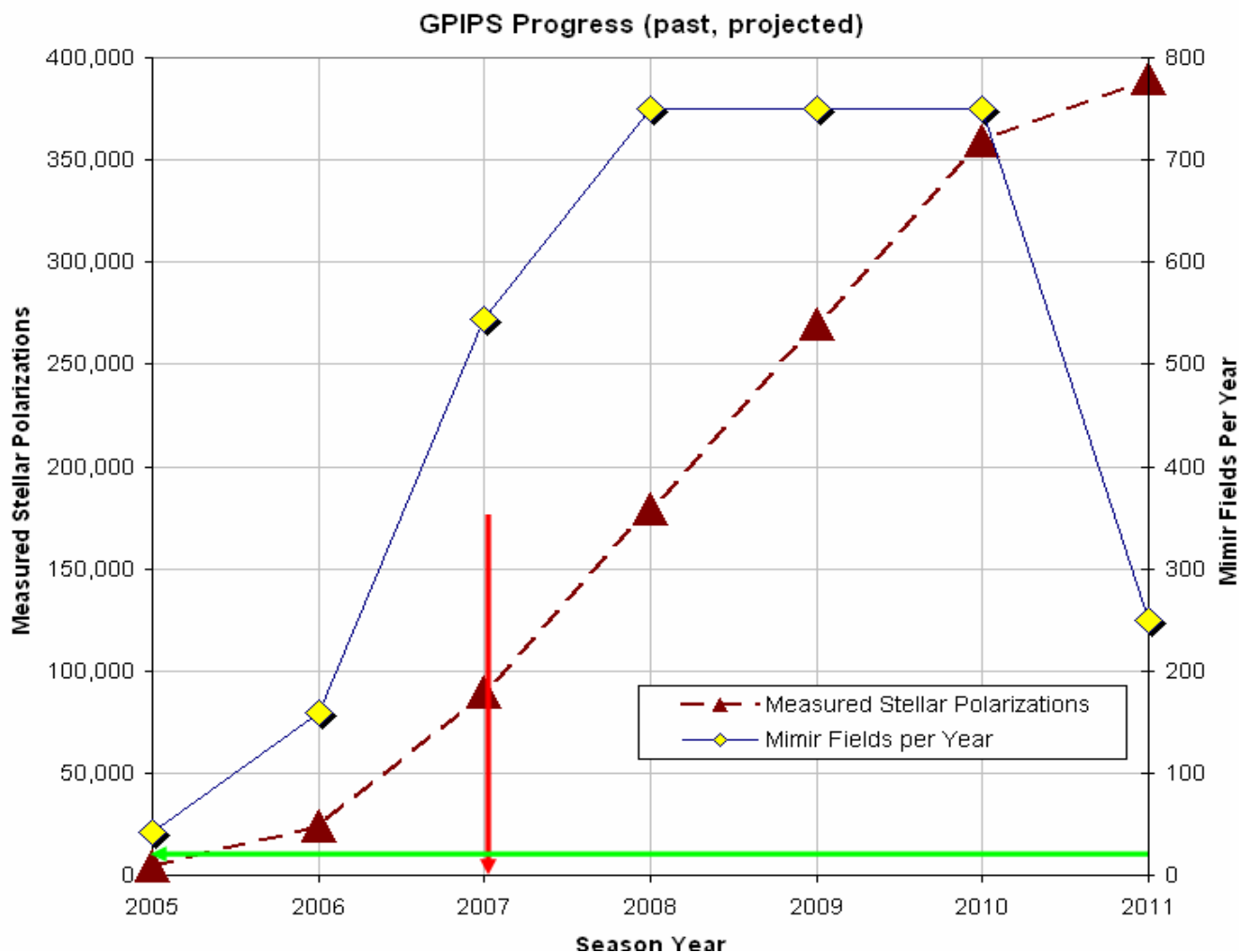 - **Yellow diamonds** = number of Mimir FOV's completed per year
  - **Brown triangles** = cumulative number of measured stellar polarizations
    - at ~ 120 per Mimir FOV
  - **Red Vertical arrow** = summary to date
    - 2008 and beyond are projections
  - **Green Horizontal arrow** = number of stellar polarizations in Heiles (2000) compilation


GPIPS Progress (past, projected)

GPIPS Science (actively pursued, upcoming)

- <u>Clusters</u> as 3D probe of B fields (objects with well-determined distances) – April Pinnick

- <u>Latitude survey</u> of B fields – Mike Pavel

- <u>Bubbles, shells</u>, and B fields – Mike Pavel

- <u>Pulsar fields</u> – survey done

- <u>"Poofy" & "Klingon" molecular clouds</u> – surveys done

- <u>HII regions</u> / hot cloud cores (compare to submm)

- <u>P/Av vs environment</u> (density, temp, illumination)

14
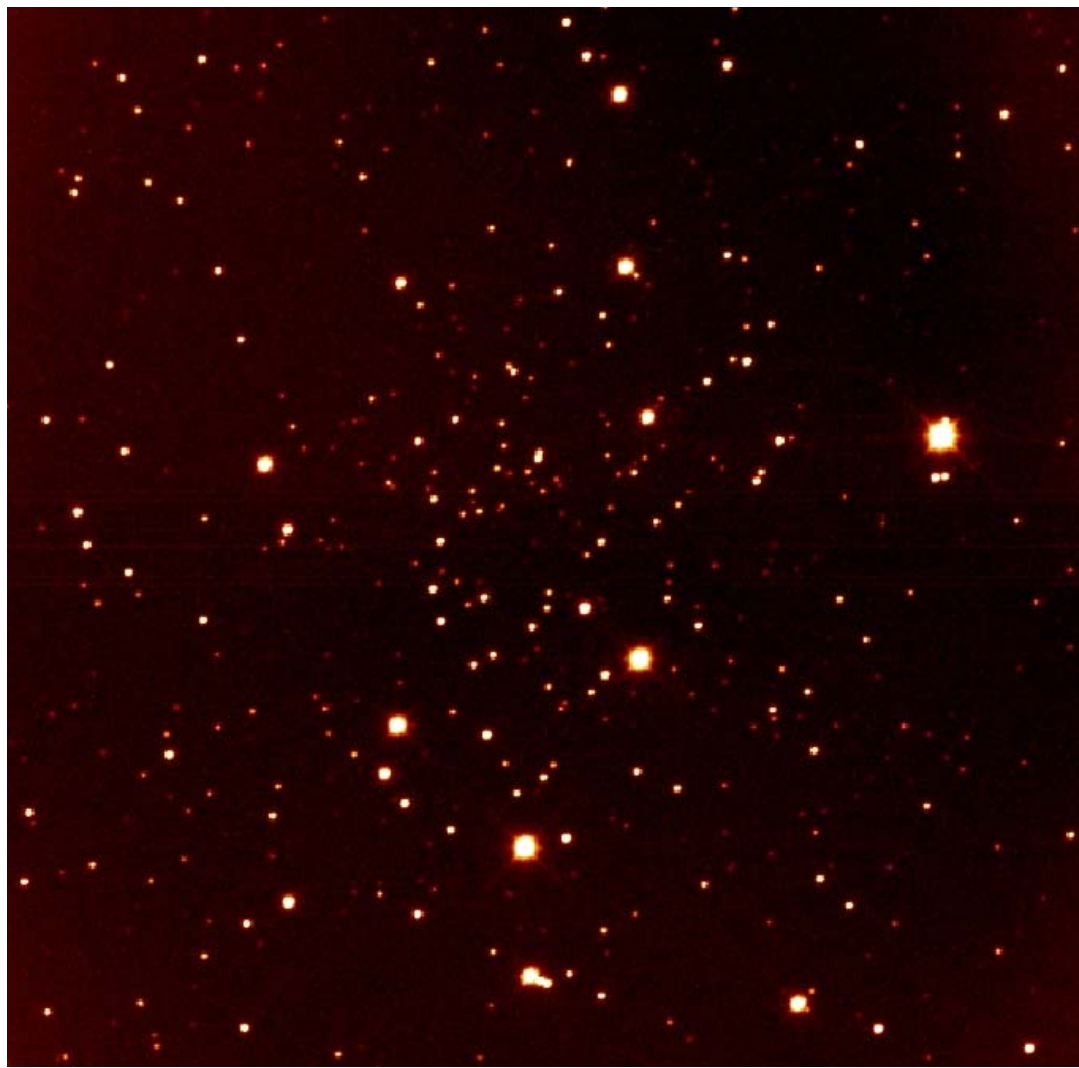
Summary

- **<u>Galactic Plane Infrared Polarization Survey (GPIPS)</u>** is up, running, and will be **<u>~50% complete</u>** after the current season

- Should net ~**<u>400,000 new H-band stellar polarizations</u>** across 76 sq deg of the inner Galactic Plane
    - factor of 40 improvement over existing compilations

- Combined with existing IR, mm, cm surveys will probe **<u>nature of magnetic field across a wide range of environments</u>**, locations

- Will "bootstrap" from stellar cluster distance to individual stellar distances to **<u>develop 3D model of magnetic field</u>** directions across broad swath of Milky Way disk, to multi-kpc distances

- GPIPS data are **<u>non-proprietary</u>**, **<u>easily available</u>** via existing web portal

- Mimir + Perkins / BU telescope time form a **<u>uniquely valuable resource</u>** for the B-field community

- 12 min. clock time per Mimir FOV
  - At ~ 120 pol. stars per FOV = 1 stellar pol. / 6 sec

- Basic T_{INT} = 2.3 sec

- 16 images per "pointing" –16 HWP P.A.s
  - To form Q_1, U_1, Q_2, U_2, Q_3, U_3, Q_4, U_4 with minimal time delay
    - HWP doesn't step uniformly (0, 45, 22.5, 67.5, 90, 135, 112.5, 157.5 deg., etc.)

- 6-position (Hex) dither

- 16 dark/bias images at end

- Total = 16 + 6 * (16) = 112 images

- Plus polarimetric flats, calibrators, linearity, dark images for each observing run…

- Total (raw) data set size ~ 0.5-1 million images ~ **6 TB**

Extensive Support via Web site

- **Mimir Web Site**
  (people.bu.edu/clemens/mimir/index.html)
  - Operating Manuals
    - Filter list, placements, bandpass curves
    - Grism properties
    - Polarimetry operations & standards
    - Flat, linearity data collection "cookbooks"
  - Data Reduction Software & Instructions
    - Custom IDL routines
    - 4th order linearity correction
    - Repairs for various 'realities' in the images
    - From "RAW" to Science
    - Photometry, polarimetry, spectroscopy tools coming soon
  - News, Findings
    - Recommendations for Observers
    - Attribution information
    - Technical Details
    - Picture Archive, Example Data
  - Instrument Paper Published in PASP
    - Clemens et al. 2007

Mimir Narrow-Band H2 S(1) Filters

H2 OFF Filter
H2 ON Filter

0.0242 um wide
2.0896 um center

0.0197 um wide
2.1198 um center

H2 1-0 S(1) line center
2.1218 um

Kokepeli Crack

Saturated Star Centers

Ghosts of Bright Star – symmetric about image center

Bad Pixels

Shadow of Guider Pick-Off Mirror