LSST, Pan-STARRS, PRIMA

Dave Monet

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Michelson Summer Workshop

Say what???

- Obviously:
  - Was asleep when I agreed.
  - Didn’t read the proposed title.
  - I know nothing about *PRIMA*.

- Rather than offend, let’s start over!

Astrometry and Large A*Ω

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Basic Concept

- Etendue measures collection efficiency:
  - Product of A*Ω
    - A is useful aperture (square meters).
    - Ω is solid angle of sensor (square degrees).
  - Generic 1-m + 1-sq.deg. = 1.
  - 4-m + 1-sq.deg. = 13.
  - Palomar Schmidt = 50 (lower by photo QE).
  - Pan-STARRS PS1 (1.8-m + 7 sq.deg.) = 15.
  - LSST (8.4-m + 10 sq.deg.) = 300.
- Note: this measure may not be sufficient for moving objects (i.e., streaks vs. PSFs)

Why Bother?

- Era of really inefficient data collection -
  - Single axis of single star (FGS, NPOI).
- Era of inefficient data collection -
  - Small field around single star (single CCD).
- Era of efficient data collection -
  - Astrometry of all stars in big FOV.
  - Cadence covers all of visible sky.
  - Identify high value targets for other methods like FGS, CCD, PRIMA, interferometer, etc.

Large A*Ω Not Vapor-ware

- Mosaic cameras available for most telescopes - typically 1 sq.deg (10 +/-).
- Pan-STARRS (15 per telescope) -
  - Many small telescopes each with big camera.
  - PS1 under construction, PS4 in development.
  - PS1 first light is Jan 06 - time to panic is now.
- LSST (300) -
  - One big telescope and big camera.
  - National 8-m facility proposal in development.

PS1 on Haleakala

Aside - 1

- Astrometry is important to Scientific Justification for many projects.
  - Learn a lot from 10^{10} 1-mas class parallaxes.
  - Colors and motions are useful, too.
  - Compliment, not replace, space astrometry.
  - Instant gratification:
    - Big parallaxes and motions after a few months.
    - Astrometry aids telescope engineering, quality.
    - But astrometry most be ready at First Light.

Aside - 2

- It's not A*Ω, it's Ω -
  - 50 years of Schmidt surveys + 7 years of PMM scanning = 10 visits/field.
  - PS1 = 3 visits/field per lunation.

- Dave's recommendations -
  - Concentrate on biggest possible Ω.
  - Take whatever A is available.
  - Do science with the available accuracy.

Astrometric Issues - 1

- Wide field of view -
  - Tight optical tolerances (focus, depth, etc.)
  - Difficult to set and maintain focus.
  - Stiffness, stability, etc.
- Wide pass bands -
  - Difference in refraction across the field.
  - Use ADC?
  - Very wide bands for solar system objects.

Astrometric Issues - 2

- Large mosaic sensor -
  - CCD vs. CMOS vs. OTCCD vs. Hybrid.
  - Chips, wafers, rafts, quadrants, etc.
  - Dewar thermal control, gravity sag, etc.
  - Gaps, dead areas, etc.
  - Replacement of chips during survey?
  - Cross-talk (amp to amp, chip to chip, etc.)
  - Saturation, ghosts, etc.
  - Field rotation, rotating diffraction spikes, etc.

Astrometric Issues - 3

- Short exposures, lots of data -
  - LSST is 10-sec; PS1 is 30-sec.
  - PS1 is 1.4 Gpixel every 45 sec (3 Tbyte/night)
- Cadence -
  - Orbit determination needs variable:
    - 30 min/few hours/next day/3 days/next month …
  - SNe, variable stars like constant:
    - Every filter every few minutes/hours/days …
  - Astrometric driver for cadence?

Aside - 3

- Cadence is a key issue -
  - Tyson's Conjecture: One cadence satisfies all applications if A*Ω is large enough.
  - Much disagreement, but then again A*Ω of 300 may not be "large" enough.
  - Key issue is how to follow up detections:
    - PS1, LSST will swamp any known telescope.
  - Can you build a large A*Ω that can do all of its own follow-up observations?

Summary of Questions

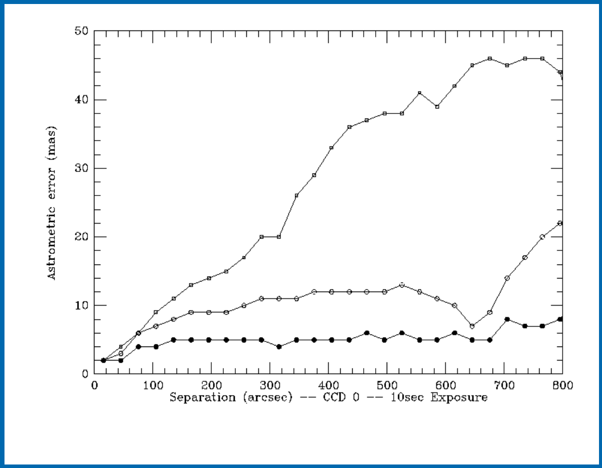
- What is expected astrometric accuracy?
- What astrometric science is enabled?
- Does astrometry drive filters, exposure?
- Does astrometry drive cadence?

- What are Astrometric Requirements?
  - Must be stated in Engineering units!

Progress (maybe) - 1

- Accuracy from big, field, short exposure -
  - Subaru Suprime-Cam (from archive).
  - CTIO + KPNO 4-m (LSST engineering).
  - Gemini + SOAR + DIMM + MASS (LSST).
- Suggest differential accuracy -
  - 10 mas in 10 sec expose in 1 arcsec seeing.
  - If so, then why is SDSS 5X worse?
    - Is it really scan vs. stare?

Subaru data analysis



- 10-s and 30-s data
- 12 arcmin is 1 CCD
- Try constant, linear, and cubic mapping.
- Needs at least linear.
- 10-mas in 10-sec
- Improves as SQRT(t).

Progress (maybe) - 2

- Astrometric solution -
  - Bright end must be tied to *Hipparcos:*
    - Need fainter stars - use Tycho-2? UCAC?
  - Faint end tied to Zero-motion frame:
    - Like SDSS, use colors to identify QSOs.
  - Dynamic range too wide for single exposure:
    - UCAC? Short exposure for intermediate standards?
      - Short exposure means poorer astrometry.
    - PS1 needs reference stars at 18th, LSST needs 21st.
  - Dealing with Differential Color Refraction -
    - Colors predict DCR? What about QSOs?

Progress (maybe) - 3

- Astrometry for Sum/Difference images -
  - Sum goes faint, difference shows changes:
    - Much progress in algorithms for resampling.
  - What sort of astrometry is needed?
    - Reference stars move during the survey.
    - Reference QSOs have curious DCR.
    - Reference galaixes have poorer astrometry.
  - Do astrometry in sum/difference image?
    - Centroid of sum *vs.* sum of centroids.
    - Smearing of stars as survey progresses.

Progress (maybe) - 4

- Other issues -
  - Undo OTCCD guiding?
    - Especially variable guiding over focal plane.
  - Quantum of solution (chip, wafer, raft)?
    - PS1 is 8x8 grid of 8x8 cells of 512x512 pixels.
    - LSST is 27x27 of 2Kx2K in 3x3 rafts.
  - How many reference stars do we need?
  - How to map systematic errors across field?
  - CPU cycles? Disk space? Moore's Law?
  - Astrometric requirements on photometric accuracy?
    - Dealing with DCR? Dealing with ADC?

Aside - 4

- PS1 will tell us a lot!
  - Astrometric pipeline needed at first light.
  - AP catalog is highest priority.
    - 3 visits/field in g, r, i, z, Y (1 short, 2 long).
    - 4 more visits in i (long).
    - Will take deep frames once per field per lunation.
    - Solve for α, δ, μ, π.
    - Should get $\sigma\pi/\pi < 0.1$ within 10 pc in first year.
- Lots of science (very soon) if we do it right.

Lessons Learned - 1

- Accuracy set by total time on target -
  - Seeing dominates single exposure errors.
  - In this limit, accuracy set by $\Sigma\ t_{expose}$.
  - Minimum 1 visit per lunation enables short-arc parallax solutions for first year solutions.
  - Cadence must avoid correlation between parallax factor and zenith distance.
  - Learn to deal with DCR:
    - Need good photometry to do good astrometry.

Lessons Learned - 2

- Astrometry is not an isolated specialty -
  - Part of integrated observational campaign.
  - Flows from Project Requirements.
  - Part of Project Scientific Justification.
  - Delivers critical data to all Project users.
- Going to take a lot of work -
  - Too much for old farts like me.
  - Younger generation is needed.

Do You Need a Job?

- USNO Flagstaff down by 5 billets -
  - Leader for 1.3-m telescope ($A^*\Omega = 1$).
  - IR Astrometry program.
  - Assistance with Pan-STARRS and LSST.
  - Leader for IT support and applications.
  - Lack of productivity by senior staff members.
- Pan-STARRS may have a post-doc slot -
  - Astrometric pipeline needed by first light.

How the hell should I know?

(Story told at the University of Chicago about Michelson's response to a question asking the name of a particular bright red star that a colleague was pointing at, shortly after Michelson's return from Mt. Wilson where he used the 20-foot interferometer to measure the diameter of α Orionis.)