APO Imager Preliminary Design Review

Panel Report, 11/21/13

The APO Imager Preliminary Design Review (PDR) was held at Apache Point Observatory on October 30-31, 2013. After listing members of the review panel, we provide our overall impressions, list the review committee charge and provide our report. The first half of the report includes our high level impressions and recommendations which were presented at the end of the review. They are unchanged with the exception of an added note about software. The balance of the report, entitled "Other Recommendations" (pp. 6-17), includes an extensive listing of comments made by reviewers and issues that were addressed during the review. Some items in the high level impressions and recommendations may be enhanced and even mildly contradicted in this section; at the risk of providing too much information, it is included in hopes of aiding the instrument team during instrument development.

<u>Review Panel</u>

Peter Doherty (Harvard)
Leon Harding (Caltech)
Suzanne Hawley (UW, ARC 3.5-m Director)
Jon Holtzman (NMSU)
Mark Klaene (APO Operations Manager)
Nick MacDonald (UW)
Alan Uumoto (Carnegie Observatories)
John Wilson (UVA, Review Committee Chair)

<u>Other Reviewers</u>

Robert Barkhouser (JHU), Steve Smee (JHU) and Russell Owen (UW) kindly attended portions by telephone and provided helpful comments.

Overall Impressions

The instrument team has made excellent progress in a short timespan on the instrument design.

The review panel was particularly impressed with the breadth of work done with limited manpower. The mechanical design was especially well considered and generally beyond PDR level.

We also appreciate that the instrument team has worked with limited science requirements and guidance provided by the user community.

The panel also wholeheartedly supports the concept of the observatory staff building the instrument.

Charge to Reviewers

• Are there any technical issues that would prohibit the instrument from meeting the science objectives as an ARC 3.5m facility imager? Yes, there are technical issues to address, none of which are insurmountable but they will require more time and perhaps $.

• Will the instrument allow for the decommissioning of SPIcam? Yes, but don't decommission quite yet!

• Are the budget and schedule achievable as presented? Budget maybe, Schedule no.

• Recommendations?

Primary Technical Issues

1. Science/Performance objectives.

The science objectives, and subsequent performance objectives, are not well defined, at least not at the level to help guide technical trades that come up during instrument design nor give robust benchmarks against which to measure performance. *This is certainly not the fault of the instrument team.*

- Recommendation:
- Using the performance goals for the *grizli* instrument as a starting point, the observatory (not local staff) should define goals for this instrument and share them with the user's community.
- Once the team has refined its optical design (see next slide), determine the predicted instrument performance v. observatory goals.

2. Optical Design.

Even in the absence of robust science objectives, the panel felt the optical design needs further exploration, prior to locking in the design and cutting metal, to ensure maximum return on investment for this facility imager. Recommendations:

- In the spirit of ensuring all designs are considered, contract as soon as possible with an optical designer such as Robert Barkhouser to define the boundaries of practical, wider fields of view.
- Investigate more materials in the existing 3-element design to see if performance aspects such as spot uniformity, distortion, lateral color and spot uniformity can be improved and possibly field of view expanded. Specifically, try CaF2, some Ohara glasses, including FPL51Y, and Schott glasses. Also consider aspheres. Don't be shy about trying glasses that are more expensive.
- Stray light, scattered light and ghost analysis needs to be more robust to guide optical, opto-mechanical, and baffling designs. The most cost effective way to proceed may be development of a non-sequential zemax model of the camera + telescope to explore stray light. Alternatively, Breault Research can be engaged to perform this analysis.
- If 1% photometry is a requirement, and the current design does not meet this requirement, then a 'reimaging' design, which will certainly include more elements, should be explored. This design allows placement of a physical baffle

at the image of the telescope tertiary to better control stray light. Consider engaging an optical designer to develop a 'starting point' for such a design. The point of this investigation is not to stall momentum but to more fully explore the trade space of performance and complexity and cost …

- There ought to be a telephone review (optics PDR) once these activities have occurred to help the team make a final decision before proceeding with final mechanical designs and fabrication.

3. Shutter Design Testing.

While the panel was very impressed with the novel shutter design (and the nice demonstration!) there were questions about whether it was the best use of time for the team to design their own shutter when sliding shutters are available commercially, such as from Bonn. At the same time, the panel thought in-house development has many intangible benefits to the team and observatory.

- Recommendation:
- Contact Bonn regarding their offerings to better understand what is commercially available.
- Make a prototype shutter with the same form factor as a Bonn device and test the design and explore its capabilities, including repeatibility, robustness with varying temperatures, etc.

4. CCD Decision

The e2V chip presented may be the best chip for this instrument. While the panel appreciates the importance of an early CCD purchase to accommodate lead-time, it did not appear to the panel that all available CCD sources were considered.

- Recommendation:
- Prior to making a final decision, the team should investigate other CCD offerings such as those from STA, Mike Lesser, etc. If nothing else, this will provide better confidence in the decision to go with the e2V chip.

5. Mentor

- The observatory should try to identify a mentor from within the consortium who can help the instrument team as a sounding board and detailed reviewer so as to ensure this important instrument is delivered in a timely manner …

6. Do-it-yourself v. Purchase it …

There are good rationales for both options … but time is finite … you can contract out work packages but not technical leadership … so be open to considering more outside contractors / vendors for aspects of the instrument – e.g. cryostat fabrication, shutters, etc.

7. Software Development

- Very little was presented on the topic of software development. This aspect of the project should be addressed as soon as possible.

<u>Budget & Schedule</u>

Budget is generally sound; expect a moderate overrun.

Schedule:

- Strike the right balance between continuing the good momentum and realizing that this is not a schedule-driven project.
- The Gant chart presented was bare bones: once the optical design solidifies, refine the schedule and include real-world liens on manpower and vendor availability.

<u>Future Review Recommendations:</u>

- Comprehensive optical design report
- Final optics design review (telephone)
- Final Cryostat and detector mounting review (telephone)

Other Recommendations

Compliance Matrix

At future reviews provide a document that compares observatory requirements with expected design performance estimates – i.e., complete a compliance matrix.

Schedule/Budget Tracking

Project schedules, budgets and gant charts shouldn't be any more complicated than the project demands and observatory leadership requires. Nonetheless, if these tools are used with realistic resource allocations, durations, and costs, they can be very useful for accurate reporting and tracking.

Optics

The proposed three element reducing camera does a good job of meeting the presented science requirements for the new imager. The detector choice is excellent and the modeled performance is an improvement over SPICam.

However, the proposed requirements are not expansive enough given the telescope capabilities. When asked about requirements, astronomers typically reply with something that allows them to continue making the observations they need already and most have not thought much about what to do if something significantly better were available.

The designer is obligated to present the edge of technical feasibility, not just what the community says they want, and the figure of merit must include future science opportunity and science return. SPICam has been in service for 16 years, since 1997. It would be a disservice to the community not to have the best possible performance to optimize the science return over the next 16 years.

General design comments

- There is a ghost image problem. L3 has an ROC of 86 mm concave towards the CCD that is 54 mm away. You ***will*** see ghosts from bright stars. Also, ghosts were said not to be a problem but no quantitative results were shown from Zemax.

- Optimizing on glass substrate costs doesn't make much sense. Fabrication and coating add significantly to the cost of a lens, diluting the substrate cost. And FPL51Y can be like magic.

- This three element design does not address the Nasmyth stray light problem (see below).

- Research radioactivity in the dewar window. Is there an issue with F2 flint glass and radioactivity? Glasses with thorium or potassium (e.g., BK7, SFTM16, BAL15Y) can generate high CR rates in the CCD.

- Try to stick with i-Line glasses (Schott and Ohara have these). This would be for good UV throughput and have good availability.

- Is the astrometric distortion observed across different filters significant enough to be concerned about?

- Lateral color shift is likely caused by F2 glass lens. Could better color performance be achieved with a different glass?

- Both of the L1 surfaces are nearly plano – try forcing one of the surfaces to be plano in the optical design. If performance isn't degraded this may be a means of saving money.

- Include the influence of new and aged telescope mirror coatings on the U band throughput.

- What is the native optical performance (geometry) of the telescope? There was confusion about this during the review. How much is the optical system degrading that performance? Also, there was confusion during the presentations regarding how the delivered design spot sizes compared to the telescope plate scale and expectation for best seeing.

- It's important to determine spot sizes over filter bandpasses and not white light. Nonetheless, the shift in image location is not monotonic in wavelength (blue and red spots were similar whereas green was offset), so in fact there might be significant blurring over a single broad bandpass.

- Sampling: The documentation describes their ideal pixel size, based on Nyquist sampling for APO `optimal' seeing conditions of ~ 0.6 arcsec. This calculation assumes a sampling of 2 x f; to Nyquist sample the width of a (Gaussian) function, the FWHM = 2.355. However, this criterion is applicable when measuring across a single axis, i.e. x or y. To truly measure the resolution across the diagonal of a square pixel, one must multiply the value by sqrt (2), thus yielding a critical sampling frequency of FWHM = 3.33. Therefore, their calculation using Equation (2) (page 1 of the APO Imager PDR Tech Doc) yields an ideal pixel size of ~ 25 micron, rather than ~ 40 micron. This may not apply to point sources, but for the seeing conditions outlined above, it is worth noting that an extended source may not be Nyquist sampled in the diagonal axis of a square pixel.

If a reimaging design is pursued …

Design and cost a reimager with an internal stray light stop and full12 arc minute field of view (perhaps as described below), modulo practical FOV limits derived from the JHU quick optical design study, and compute the extra cost/year over the current design assuming a 10 year lifetime for the camera as a reference for value/cost.

- Consider a pixel scale of 0.125 arc seconds per pixel. This takes the corner to corner distance to 12 arc minutes, the design field for the telescope. 2x2 binning just about samples the best images well enough so readout noise shouldn't ever be a problem.

- Create a sharp image of the telescope tertiary mirror within the camera and put a field stop over it. This is a good place for the filters, too, if you want precision photometry. Precision area photometry should be a requirement for this camera, but its physical location at Nasmyth makes this difficult due to stray light. With the camera having a full view of the enclosure wall opposite it, flat field exposures are not particularly useful and moonlight produces background sky gradients that make photometry of extended objects almost impossible. Imaging the tertiary (and keeping it clean!) and putting an aperture stop around it will help a lot.

- Make the field flat and images similar in size all across the detector. A variable PSF is difficult for software to handle. This will likely come at the cost of increased field distortion (and telecentricity, etc.) but backing the distortion out in software is probably good enough. Along these lines from Joanne: Any increase in the FOV over SPICam would be welcome, but one of the positive features of the current instrument is a very stable PSF over the whole field.

- Consider aspheres. Some materials (crystals, mostly) can be diamond turned inexpensively and might make sense if you're not going too much blueward of 400 nm.

- Optics vendor suggestions: Harold Johnson (HJOL), Jay Kumler's firm (was Coastal, now Jenoptik in Florida). TORC in Tucson (Joe Appels) has a good reputation too. Also consider ISP Optics for diamond-turned CaF_2. And if you're diamond-turning CaF_2, you might as well consider an asphere as it is almost as easy to make as a spherical surface. But it is harder to test.

Off-the-shelf Commercial Camera …

There was discussion about the advantages of using a commercial company to provide a CCD pre-packaged in a dewar along with electronics control. The cost of such a solution was relatively expensive for the preferred CCD for this imager. It would be of value to keep this solution in mind though until the final optical design is adopted. One scenario follows:

1. Could a more complex optical design be considered whereby a system of lenses collimate and refocus the native f/10 beam onto a smaller imaging area?

2. Is smaller imaging area worth considering, since a less expensive 'off-the-shelf' commercial camera could then be sourced, whilst still maintaining or increasing the ~ 9 arc minute FOV

<u>Stray Light</u>

Baffling issues are implicit in the discussion above regarding a reducing camera v. reimaging designs and going to wider fields. For instance, would a new NA2 baffle be necessary to support fields up to 12 arcminute?

The instrument team should review available stray light analyses done in the past for the NA2 port. In addition, the team may want to repeat empirical tests – apparently measurements in preparation for GRIZLI showed no stray light issue out to 20' but evidence for SPIcam was that NA2 baffles were required to even get reasonable flat fields.

Other Comments:

- While it was shown in the solid model that stray light could not get through adjacent fields, it is still worth keeping this path in mind as the mechanical design is refined. The same goes for the paths around the shutter mechanism.
- Also include a stray light baffle system between the last element and the detector.
- Is there any advantage from a ghost standpoint in tilting the filters to move a ghost away from the primary spot arrival location on the detector?
- Be sure to consider the vignetting and scattered light effects of the lens retaining rings. Also ‘thread’ and paint the inside surfaces of the lens barrel to mitigate stray light.
- A good vendor for applying infrared black paints is Anderson Painting Co. in Tucson, AZ.
- Photon Engineering should also be considered for stray light analysis (as an alternative to Breault).

<u>Opto-Mechanics</u>

As the team advances the opto-mechanical design there were several issues discussed during the review that they should keep in mind:

Think through optical element installation. This may lead to a different opto-mechanical assembly. For instance, consider additional cell(s) around subset(s) of elements. Installation of the subsets within their cells will be easier. Then the cell + element installation within the cryostat should be straightforward. Also consider the use of special installation fixtures to minize the risk of element damage during installation.

If opto-mechanical tolerances are tight such that typical machined tolerances for the lens barrel are insufficient to accurately place the optics, the team should consider bonding elements to obtain a fixed optical alignment? (further CTE considerations as well). Another suggestion for holding a system of lenses in place, is to use a `Roll Pin Flexure' system, which is a spring loaded cell where springs are orthogonal to the focal plane (e.g. flexure housing can be 3D printed with Al 6060. Contact Steve Smee (JHU) for more information on this design.

Other Comments:

- While it was said during the design that the default optical tolerancing and thus mechanical tolerances on element placement were benign, no quantitative results from zemax were shown. They should be shown at the next review.
- Consider Lee Springs for custom wave springs to provide axial pre-load? Also consider the use of canted coil springs.

Detector Mechanics

A few comments:

- Think about using a stock tooling ball for the tip-tilt item. Requires redesign but eliminates a weird custom part.
- Consider the firm Mindrum Precision for aluminum nitride machining?
- It would be good to see a tolerance analysis of the cryostat assembly. It may be possible to use machining tolerances to constrain the CCD position. This would eliminate the complicated adjustment mechanism currently designed to position the chip.

Thermal Control

A few comments:

- Why not include refocusing the telescope as a compensator during ZEMAX thermal modelling?

- Also consider the radiative load of the CCD on the upstream optical elements? This may affect the steady state temperature of the one or more elements and ought to be included in the thermal and optical analysis. Also consider the radiative coupling between the dome environment and the optical elements; at 10 micron glass is opaque, modulo AR coating performance, and will act as a black-body.

- Indium foil between Al Ni plate and CCD package should be considered as an alternative to Braycoat grease.

- Consider doing an engineering run in the cryostat with a ‘dummy thermal mass’ in place of the detector as an initial test to check the thermal dynamics of the system before installing the CCD.

<u>Vacuum</u>

A few comments:

- Solicit quotes from vendors of vacuum components, such as NorCal or Kurt Lesker, for fabrication of the 'custom' vacuum port – they will be apt to make reliable vacuum welds and may be able to inexpensively customize a stock product.

- Consider baking the o-rings before use.

- Is it really not advisable to include a charcoal getter in the camera?

<u>Filters</u>

A few comments:

- Some vendors to consider: Asahi (potential SDSS filter vendor), Custom Scientific, and Astrodon (see Leon Harding’s email 10/31/13).

- Be careful and detailed about filter specifications. If you go with a reimager, your filters will end up in a more parallel beam, which will change requirements (surface figure, angular range, etc.). Surface figure requirements, scratch/dig, roughness structure, pinholes, etc., change depending on where in the beam the filter is inserted. Be sure your filter is blocked out of band (down by 10e-4 or 10e-5 depending on the band, CCD response, and science requirement). Also be mindful of filter wedge specifications.
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- Consider attempting to make filters parfocal by adjusting the substrate thickness for each filter.

- What, if any, other filters sets should the observatory provide?

- If the filter diameters quoted are the edge diameter, then is the wavefront specified all the way to the edge (central 80%, 90%, or 95% diameter is often quoted)?

- What is the maximum thickness for the filters *if they are in adapters* (i.e. 2" filters)? Are there any plans to purchase large filters for the camera, and what sets have been demanded beyond the "standard" SDSS and Johnson- Cousins or Bessell sets?

- From Don York: I agree with John Stocke on the issue of medium field, narrow band capability for a new imager. If it could be built to use the GSFC filter set, it would be really wonderful. I suspect GSFC would agree. Only a few of them would need to be replaced, and some might need measuring, which I think can now be done at NMSU.

Filter Wheel

The filter wheel design was well along and offered nice design features such as the ability to reuse existing, smaller filters, and change actuators and switches in a straightforward way. There were several features which generated discussion at the review.

First, functional aspects of how observers will grab the filter wheel for extraction/installation were discussed. Consider designing a tool and/or adding features in the wheel to enable a firm grasp of the wheel by hand at night in the cold with gloves. The observers should be consulted regarding potential solutions.

Secondly, there was discussion of the optimal detent mechanism number and location. One mechanism may be sufficient, and it may be better for the detent to push radially along the wheel in a direction opposing a pre-load rather than axially.

Lastly, there was concern that the existing detent position would allow a detent to contact the surface of a filter.

Other comments:

- A small increase in filter wheel diameter may help address some of the issues above.

- Does repeatability from one filter loading to another matter? How accurately does the filter position repeat?

- Keep moth proofing in mind …

- Consider development of a scale model to test the design.

Shutter

The shutter mechanism also generated a lot of discussion during the review. The panel's consensus was given above regarding proceeding with a demonstration model that had the same form factor as a Bonn offering. Of course the shutter is emblematic of the choice instrument designers face between creating in-house solutions v. purchasing off-the-shelf solutions to save engineering time and minimize risk. In that spirit the following are some comments from panel members:

- The shutter concept shown is very cool. I would however recommend using an off the shelf shutter. Probably the best reason for this is because there is a large amount of engineering work still to be done on this instrument. An off the shelf shutter is a ready-made solution. The limited engineering support could then be dedicated to other areas.

- Other reasons to consider off the shelf shutters is the use of a stepper and belt will likely prove more accurate than relying on an air driven system. Belt driven shutters will also not have the impulse generated at the end of travel that the air cylinders display.

- If an off the shelf option is not practical for some reason I would encourage switching the drive to an electrical actuator rather than pneumatic.

- Consider using AirPel Anti-Stiction cylinders (or similar), to reduce temperature-related effects. The advantage is the lack of flexible seals. A disadvantage is that they leak a bit; you'll need to keep air going to maintain position, but surely you must maintain air pressure anyway to be sure the shutter doesn't move during a long exposure.

- It was unclear how sufficiently uniform velocity will be attained.

- Changing gravity vectors are likely to cause different behavior at different rotation angles. How do you plan to deal with that? Just make the drive so powerful than the weight of the blades that it doesn't matter?

- BTW: I (Russell) wrote microcontroller code for the PanSTARRs filter mechanism, which sounds like a very similar mechanism:

    - each filter is driven by two air cylinders: one to slide it in, one to slide it out

    - each has a pair of sensors: fully in and fully out

  You are welcome to the code if you want it. It was written in Dynamic C for a Z-World BL2100 SmartCat.

- Keep moth proofing in mind …

Cart

A few comments:

- Revisit the design to check for issues with binding on the cart height adjustment. The linear slides may be more constraining than required.

- A manual actuator for the cart vertical travel should be considered both as a substitute for the electric actuation and as a back-up in case of insufficient battery charge. A robust electrically actuated system can probably be built but it seems overly complicated given the size of the instrument and the site staff's willingness to deal with a manually actuated cart.

Detector

A few comments:

- It would be prudent to use an engineering grade chip to check the electrical functionality before initial use of the science grade chip. Even if liability for a damaged CCD during initial electronics + ccd work at Bob Leach's firm is accepted by Bob Leach, the availability, at least within the ARC consortium, of an engineering chip would be wise.

- Flatness requirement? Wasn't specified.

- CCD 231 Coating: Consider using `DD Astro AR Multi-1' coating rather than `DDAstro broadband'. Although losing ~ 10% QE at ~ 350 nm, it gains QE in vis/NIR where two critically used photometric bands lie (R and I), as well has having 1% fringing at NIR wavelengths. This is more suitable for a multi-purpose imager. Would also recommend constructing a fringing template that users can access. However, it is advised to obtain a fringing template on any given night while using NIR bands.

- CCD 231 GAIN Levels/Cross-Talk from each Amplifer: Is there much disparity between the levels of gain between the four amplifers? Is there transfer of charge from one amp to another if a bright star is located at the edge? Can this be calibrated consistently with calibration methods? For broad band wide feld photometry, this is very important since target and reference (or field) stars will sit on different amplifiers.

Detector Control

A few comments:

- Assuming one wants to do on chip guiding, then why would you wire it up such that you can't clock the 4 segments separately? Why throw away 1/2 of the science data when using on chip guiding?

- Should negotiate with Leach as to what test data he will provide: just a test report, a set of FITS images of flats, biases, etc? Similarly, by what metrics will his work be deemed 'accepted' for contractural purposes?

Electronics

A few comments:

- Seriously examine the signal grounding situation, putting in deliberate ground connections and bus bars where desired (don't rely on "this box is screwed down") and hunting for ground loop circuits and fixing them. Isolate things if necessary. Note that the Cryotiger hoses are grounded to the compressor chassis which is almost certainly part of a ground loop with the green wire in the power coming to the Leach controller (the controller and compressor are certainly on different power circuits). (You can get G10 isolated couplers for the Cryotiger hoses.) Maybe consult with Bob Leach on what works best with his controller, too. Matt Nelson (UVA) should also be consulted.

- Also consider shielding cables outside of the cryostat to reduce RFI pick-up.

- Take pains to include safety mechanisms in the heating circuitry: thermal fuses, thermal switches.

- Consider addition of a relative humidity sensor to the DAQ at the instrument

- Keep moth proofing in mind to keep moths out of the electronics …

Software

A few comments:

- It appeared during the review that the software and electronics group at APO had not been too involved in the preliminary design work. Their involvement should ramp up quickly to prevent schedule delays down the road.

- Hard to say much as the info isn't there yet. The ICC/Hub Software link is the "how to write an ICC" document and the relevant link in the PDR Presentation Slides is a "check back later" page.

- From Russell: I have one request: if possible, please support fast changes to binning and windowing. That way those parameters can be provided as part of the expose command, instead of requiring a separate configuration step. This gives maximum flexibility and ease of use.

Calibration

A few comments:

- Calibration requirements? Flats, darks, etc Dome Flats vs Sky flats? Will distortions affect the ability to produce flat fields that work?

- Crosstalk and its correction? Will the observatory provide information to the users, or will everyone have to sort it out themselves? I think they should work to provide calibrations for that to users.

Testing/Commissioning

A few comments:

- Write a lab testing plan and a commission plan based on empirically checking observatory requirements for the imager.

- Lab testing and characterizing instrument performance is important with this kind of chip. It has many acquisition modes, and so strategy for observations can depend on trade-offs between sensitivity, read noise, exposure times etc. It would be good to have some recommendations to users for which acquisition modes are most suited for a given observation. This will most likely be applicable for e.g. transient science of faint objects, narrow band science and so on.

- They need to have a way to install a flat window for flat field testing of the CCD but not using the lenses. They need to consider how to stop stray light from getting to the CCD down at the bottom of that tube while they are doing those tests. Flock paper might do OK. Maybe do a Zemax mockup of the test setup with the integrating sphere to see how flat an illumination pattern they can produce?

- The idea of making a wide protective coverplate that serves as a stand for the camera in the lab is a good idea.

- In general, they have not allocated time or money to setup the test facility, whatever it is, in the lab. Do they have all the hardware they need? For instance, will some mount fixtures be required?

- What optical tests do they expect to do with the CCD and flat window? What optical tests do they expect to do in the lab with the lenses?

- They really do need to do Fe55 someplace as it is a standard test of CCDs. So, they do need someplace to be able to do this either by using a Be window or installing a source in the dewar somehow.

- Consider separating a first and second commissioning run by at least one month to permit image analysis and hardware adjustments between runs.