SOFIA Common Dewar Concepts

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Challenges of SOFIA Instrument Development

- Unique requirements
  - Airworthiness
  - Space/Power/Weight
  - Documentation
  - Reviews
- Instrument Complexity
  - Multi-institution projects
  - Long Development timeframe
  - High buy-in cost
- Logistics
  - Delivery/Installation/Operations

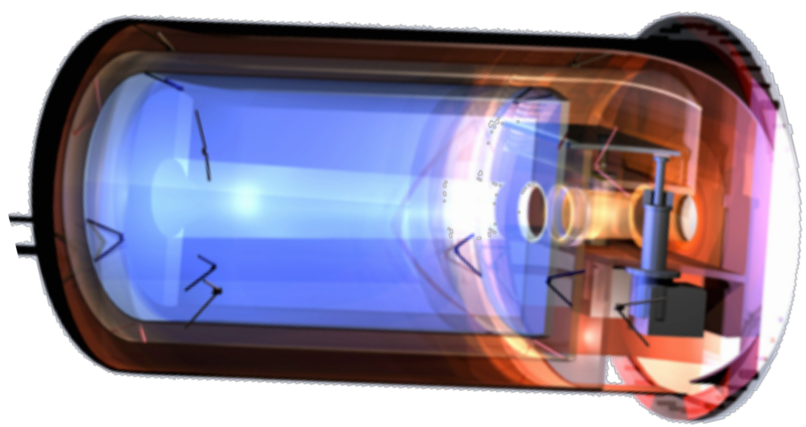
→ Difficult to have quick instrument development/ technology demonstration

By doing some of the SI development work up front:

- Can we get new science instruments (SI) in use on SOFIA quicker?
- Can we lower the cost of new SI?
- Can we reduce the non-science requirements & attract more new SI proposals?
- Can we increase potential for technology demonstration aboard SOFIA?

Goals

– Develop generic cryostat and evaluate usefulness/feasibility
– Desire to better enable technology demonstration & instrument development on SOFIA
– Want lower costs, feasible for a university lab to support
– Aim to shorten timeframe of selection->development->flight



A Common Dewar concept could allow a new pathway toward deployment of new technologies for astronomy onboard SOFIA

Common Dewar

Standard New Astronomy Cryostat for SOFIA (SNACS):

Motivation

- Standardize and simplify airworthiness & safety process
- Provide starting point for potential SI proposal teams

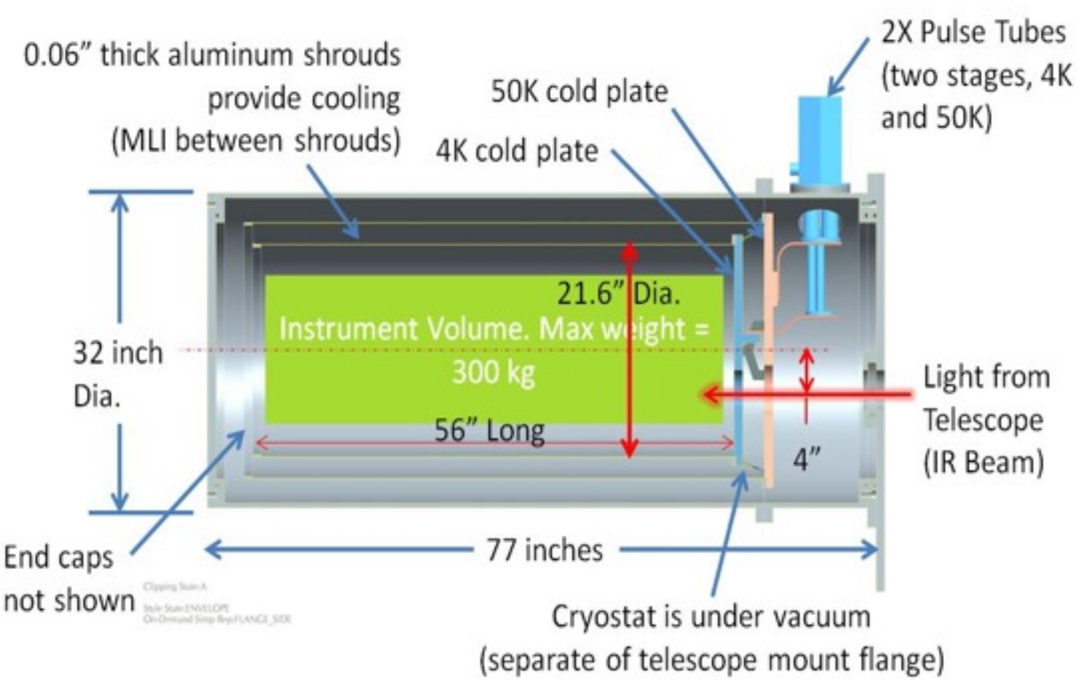
Assumptions

- Aim for dry cryostat
  - Allow for SI Developers to design in extra cooling (ADR)
- Assumptions made for cryocoolers used a generic instrument utilizing maximum size, mass and power allowable
- Could provide a cryogenic optical plate, to be populated by Technology demonstration teams

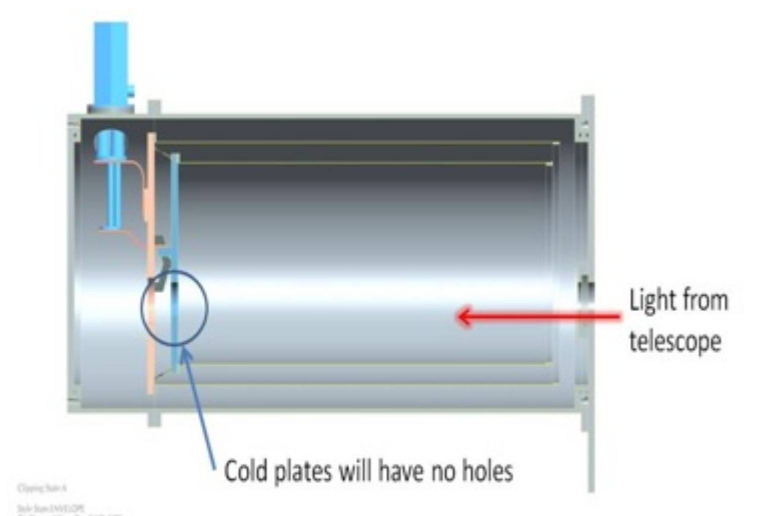
SNACS

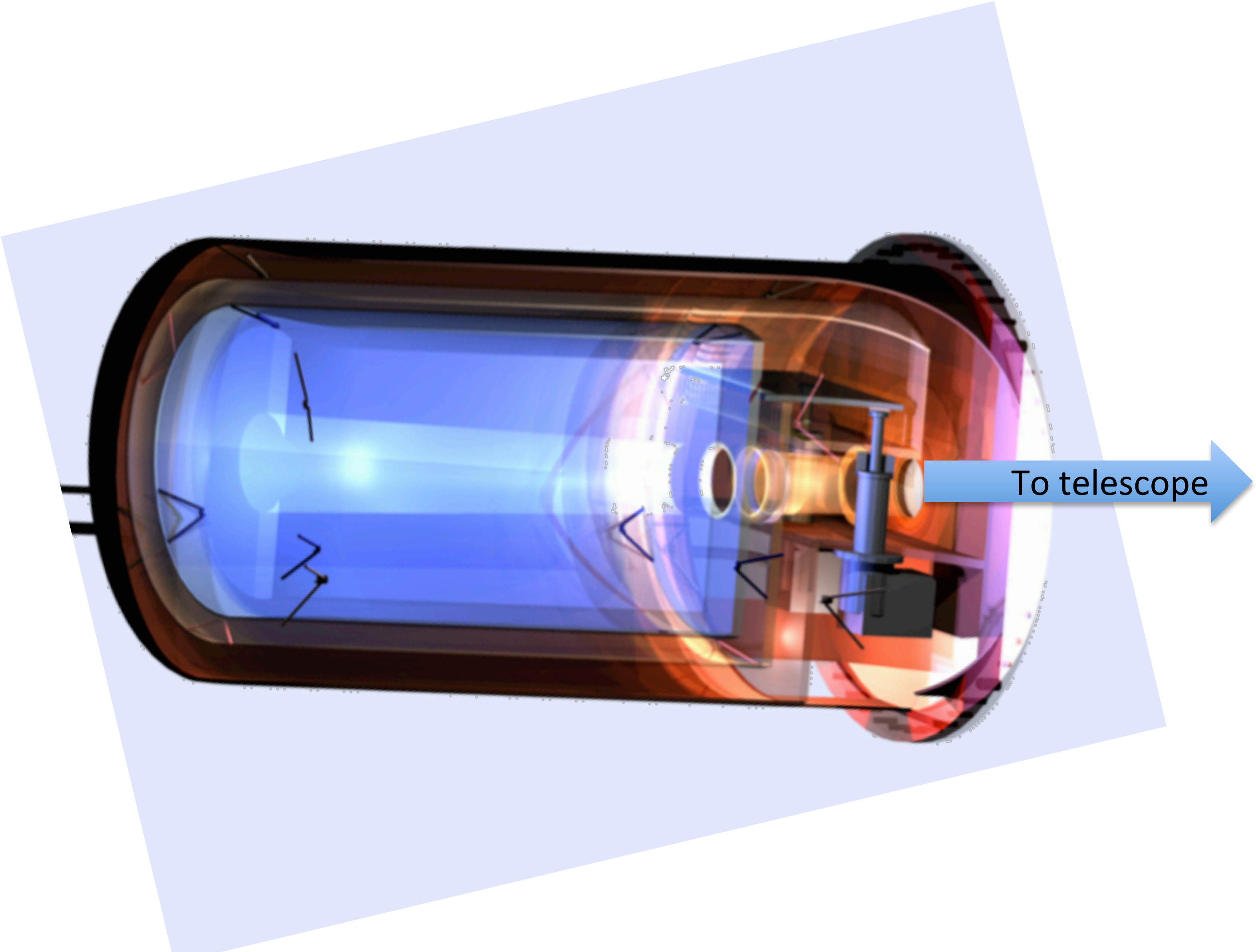
- Provides full instrument envelope with modular design for flexibility
  - Current design is the maximum allowable size
  - Cannot increase size, but could decrease if necessary
- Eliminates airworthiness concerns from SI development teams

X-Section Configuration 1

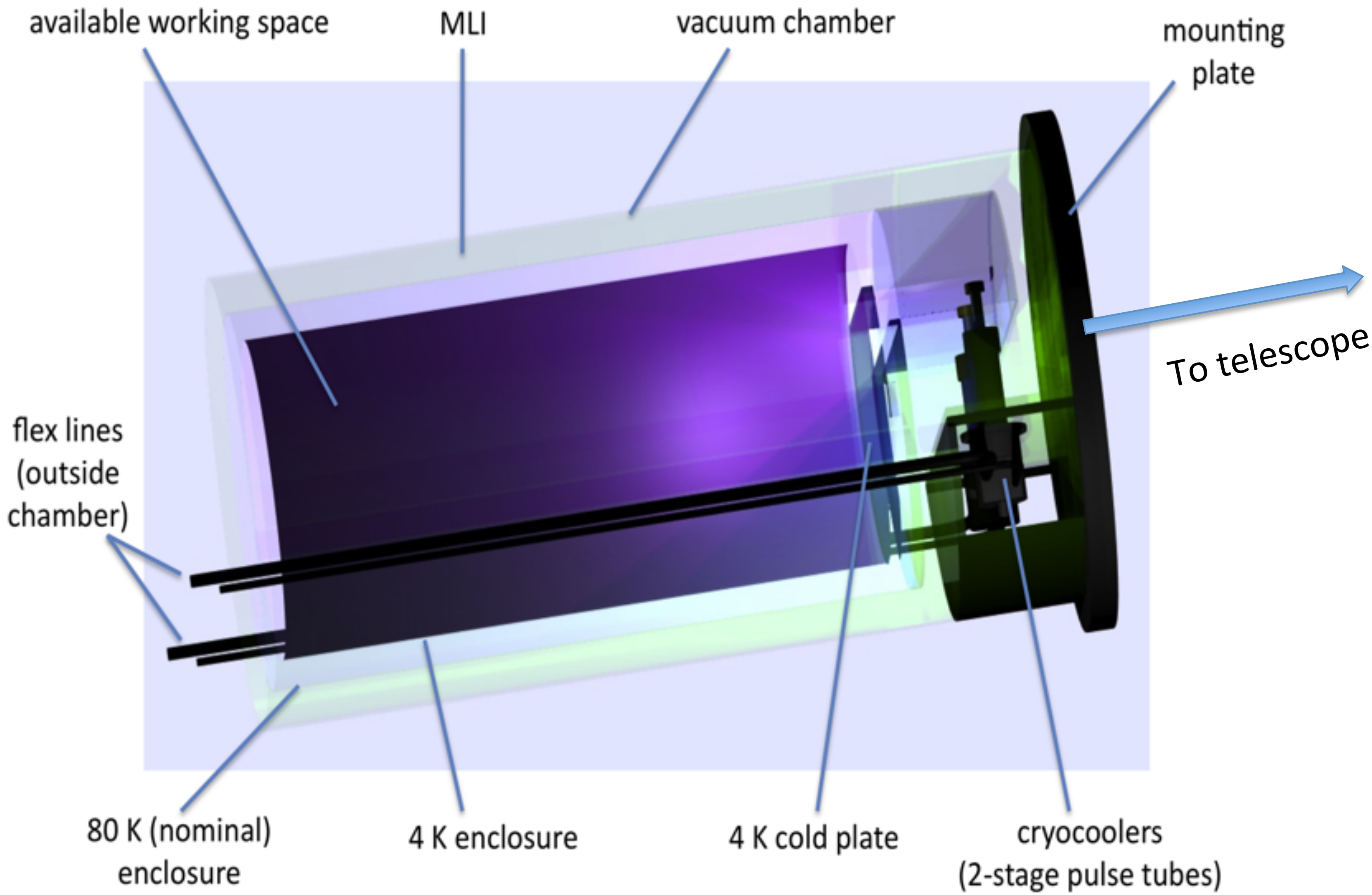


X-Section Configuration 2




To telescope

Baseline design



Req. No.	Requirement
1a	Provide maximum cold payload volume
1b	Provide maximum cold payload mass
2	Meet all SOFIA airworthiness requirements
3	Meet SOFIA ICD SOF-DF-ICD-SE03-037, Telescope Assembly / Science Instrument Mounting Interface
4	Meet SOFIA ICD GLOBAL_09_FL, Science Instrument Envelope
5	Provide optical bench (cold plate) placement flexibility
6	Utilize a family of cryocoolers (GM and PT) to provide up to 1W @ 4.2 K cooling power to the optical bench.
7a	Vibration amplitude: 4.4 µm RMS on all three axes at cold plate and two other fiducial locations on dummy cold payload
7b	Vibration acceleration: 5.5 milli-g on all three axes at cold plate and two other fiducial locations on dummy cold payload
8	Utilize standard flange design

2. Cryostat Requirements, Specifications, and Guidelines.

2.1. The SNACS shall conform to the constraints set down in the ICDs.

2.2. The available working volume shall be maximized within the given constraints.

2.3. The baseline SNACS shall be capable of accommodating a wide range of potential instrument designs.

2.4. Mechanical cryocoolers shall be employed: The 4 K stage shall be "dry"; i.e., no liquid helium storage.

2.5. Use of mechanical cryocoolers at the nominally 80 K stage is preferred but not required: Incorporation of a liquid nitrogen storage dewar is not precluded.

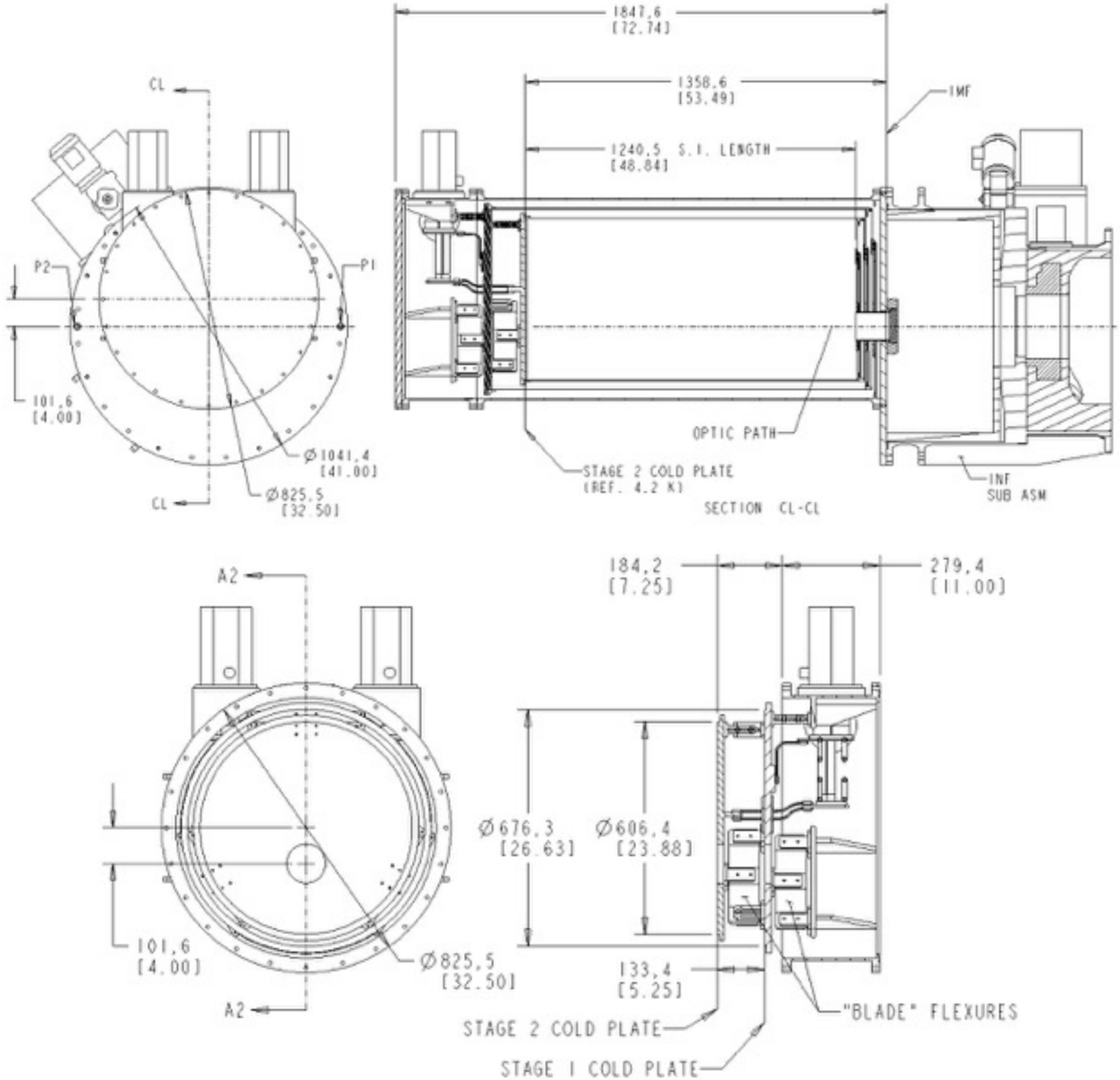
2.6. The target available cooling capacity at 4 K is 1 W.

2.7. With a 25 kg instrument mounted on the 4 K plate, the cool-down time (to 4 K steady-state) shall be no more than 48 hours. Fully self-contained operation is preferred, but use of a pre-flight cold nitrogen circulation system is not precluded.

2.8. The cryocooler compressors shall be air-cooled; i.e., they shall rely on air circulation within the aircraft cabin.

2.9. The maximum electrical power available is 20 kVA. The inefficiency of the power converter(s) shall be taken into account.

Design Detail



Baseline Cryogenic Modeling and Predicted Performance

- Two COTS two-stage pulse tube cryocoolers (Cryomech PT407) are employed for thermal shielding and 4 K instrument cooling — no liquid cryogens.
- Gross cooling capacity of each coldhead:

  30 W at 40 K;

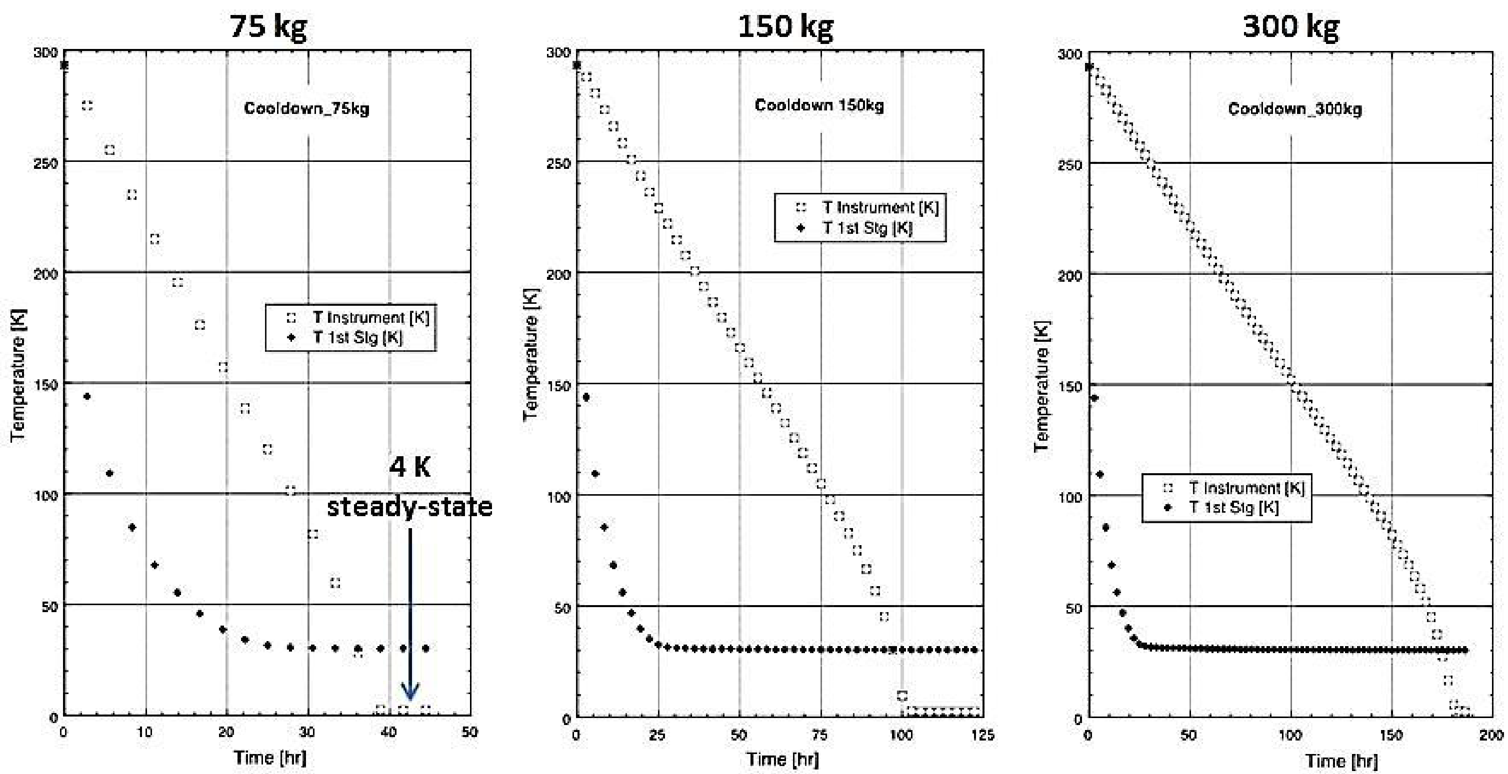
  0.75 W at 4.2 K.
- Total capacity at 4 K: ~ 1.2 W.
- First stages cool a thermal enclosure at ~ 40 K.
- Second stages cool the 4 K instrument and enclosure.
- Model incorporates realistic cooling capacity curves for 1st and 2nd stages.
- Model incorporates temperature-dependent thermal properties (thermal conductivity, specific heat) of all materials.
- Structural elements based on existing instruments. Structural design beyond scope of study.
- Plumbing for LN2 circulation to the 2nd stage cold plate included.

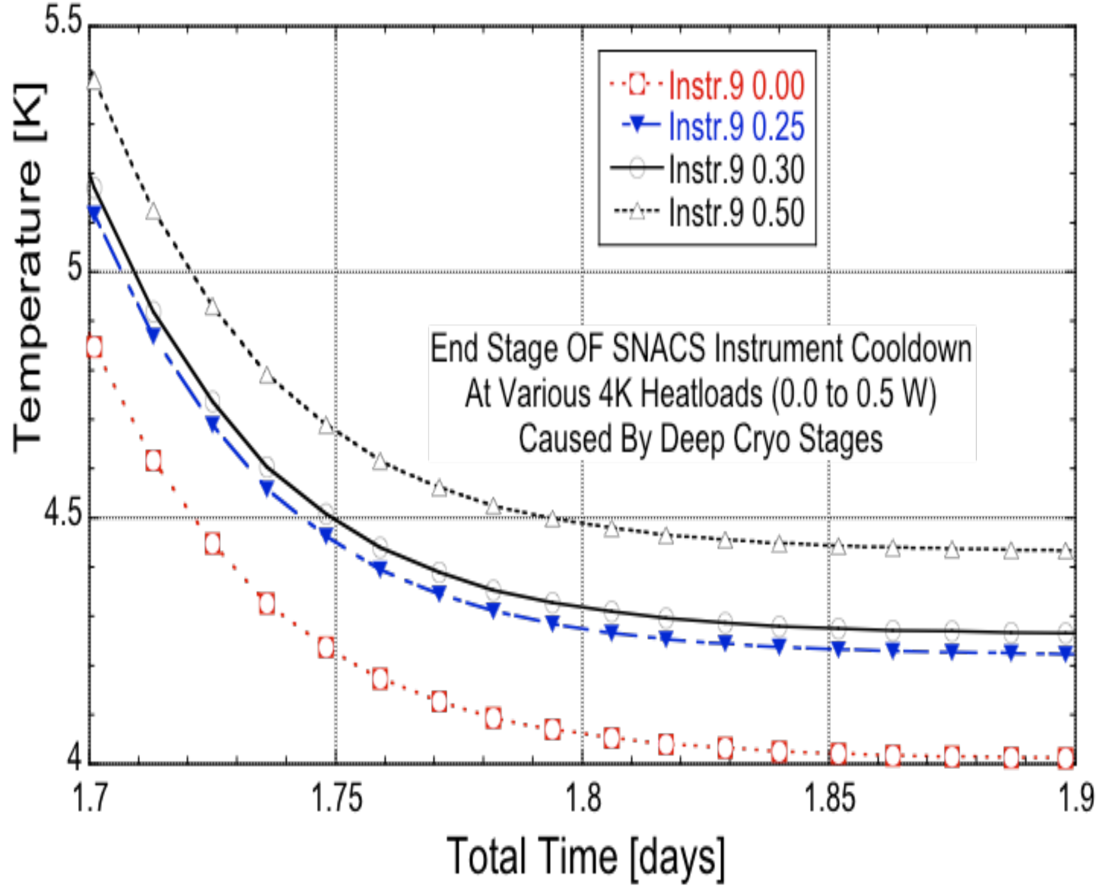
  Allows rapid pre-cooling of instrument to 80 K, greatly reducing overall cool-down time for more massive instruments.

Design Details (2)

- Instrument Volume:
  - 54.8 cm diameter cavity
  - 142 cm long cavity
- Instrument Max Weight
  - 300 kg

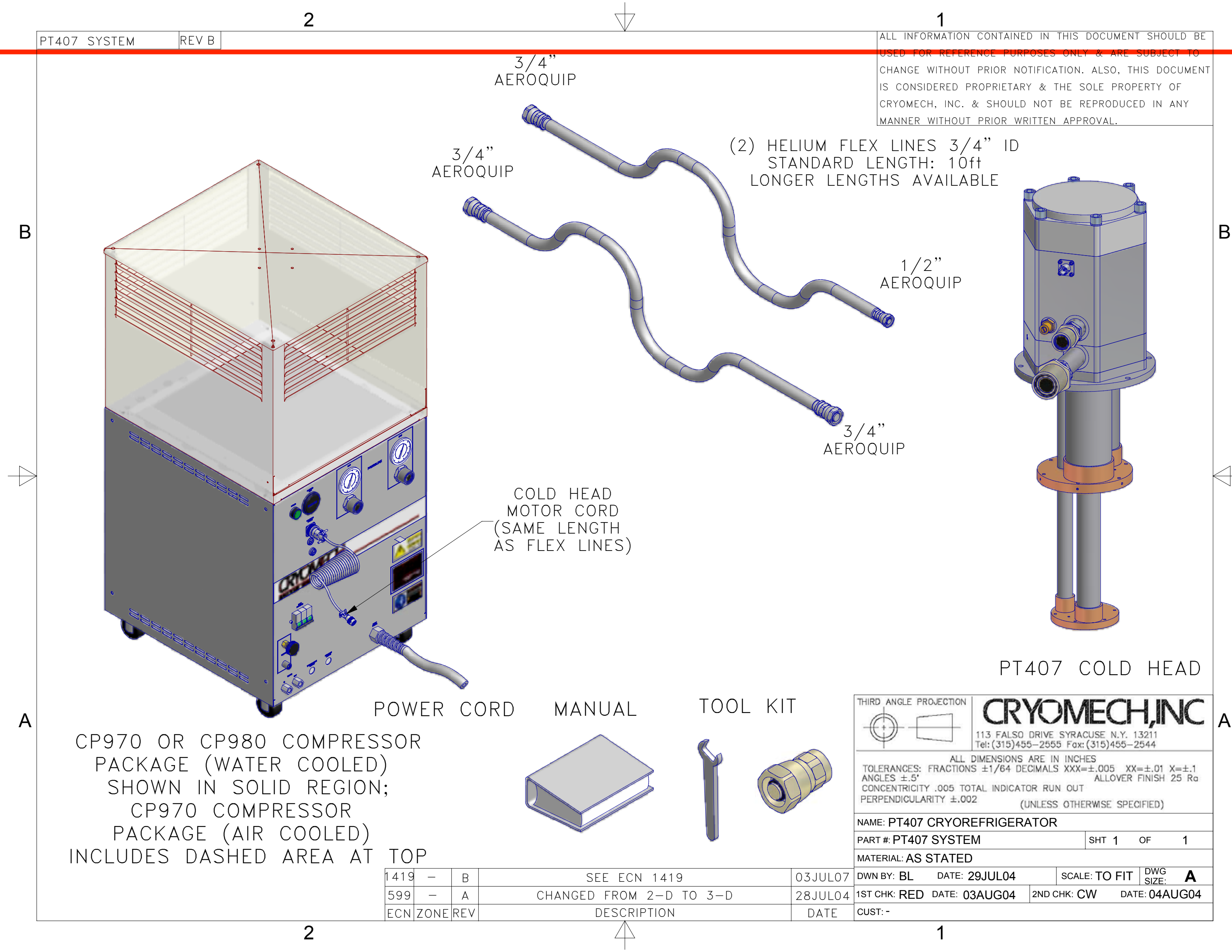
- Cryocooler System
  - 2 stage He pulse tube refrigeration
    - Pulse tube cold head
    - Compressor
  - Two Temperature Stages
    - 50 K
    - 4.2K
  - Liquid Nitrogen precooling (likely)





Instr.9 0.00
Instr.9 0.25
Instr.9 0.30
Instr.9 0.50
End Stage OF SNACS Instrument Cooldown
At Various 4K Heatloads (0.0 to 0.5 W)
Caused By Deep Cryo Stages
Temperature [K]
Total Time [days]
5.5
5
4.5
4
1.7
1.75
1.8
1.85
1.9

Selected Cryocooler (x2): Cryomech PT407 Pulse Tube Cryocooler System



Cryomech PT407 Pulse Tube Cryocooler Specifications

CRYOMECH

Cryorefrigerator Specification Sheet

PT407 with CP970

Cold head	PT407
Cooling capacity @ 50 and 60 Hz: 2nd stage and 1st stage combined	0.7W @ 4.2K with 25W @ 55K
Lowest temperature	2.8K with no load
Cool down time	60 minutes to 4K
Weight	32 lb (14.5 kg)
Dimensions	See cold head line drawing
Compressor package	CP970, available as water or air cooled
Water cooled:	
Weight	262 lb (119 kg)
Dimensions - L x W x H	23 x 21 x 26 in (58 x 53 x 66 cm)
Electrical rating	200/230 or 440/480VAC, 3Ph, 60Hz // 200 or 380/415VAC, 3Ph, 50Hz
Power consumption @ steady state	7.0 kW // 7.0 kW
Cooling water flow rate	Minimum flow 2.1 GPM (8 LPM) @ 80°F (27°C) maximum temperature
Air cooled:	
Weight	387 lb (176 kg)
Dimensions - L x W x H	23 x 21 x 46 in (58 x 53 x 117 cm)
Electrical rating	200/230 or 440/480VAC, 3Ph, 60Hz // 200 or 380/415VAC, 3Ph, 50Hz
Power consumption @ steady state	7.5 kW // 7.5 kW
Flexible lines	
Standard length	10 ft (3 m)
Weight per pair	9.2 lb (4.2 kg)
System parameters	
Helium pressure	230 ± 5 PSIG (15.9 ± .34 bar) @ 60 Hz 260 ± 5 PSIG (17.9 ± .34 bar) @ 50 Hz
Ambient temperature range	45°F to 100°F (7 to 38°C)
Maximum sound level	
Water cooled	70 dBA @ 1 meter
Air cooled	74 dBA @ 1 meter
Shipping crate	Wood box
Weight	435 lb (198 kg)
Dimensions - L x W x H	41 x 30 x 36 in (104 x 76 x 92 cm)

Warranty

Three years or 12,000 hours (whichever comes first) on parts and materials.

Maintenance

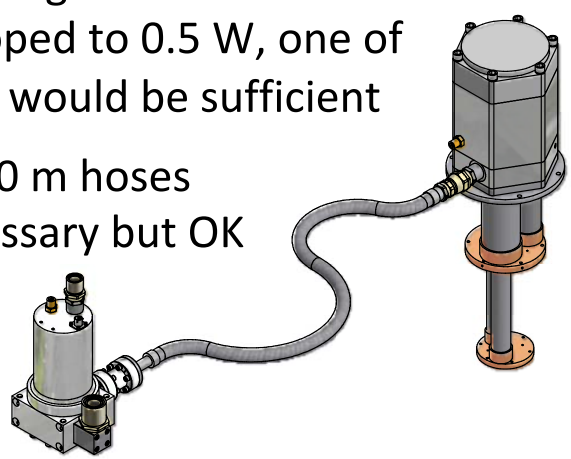
No routine maintenance required on cold head! Change adsorber every 20,000 hours.

Electrical Configurations

220/230 VAC, 3 Phase, 60 Hertz
440/480 VAC, 3 Phase, 60 Hertz
200 VAC, 3 Phase, 50 Hertz
380/415 VAC, 3 Phase, 50 Hertz

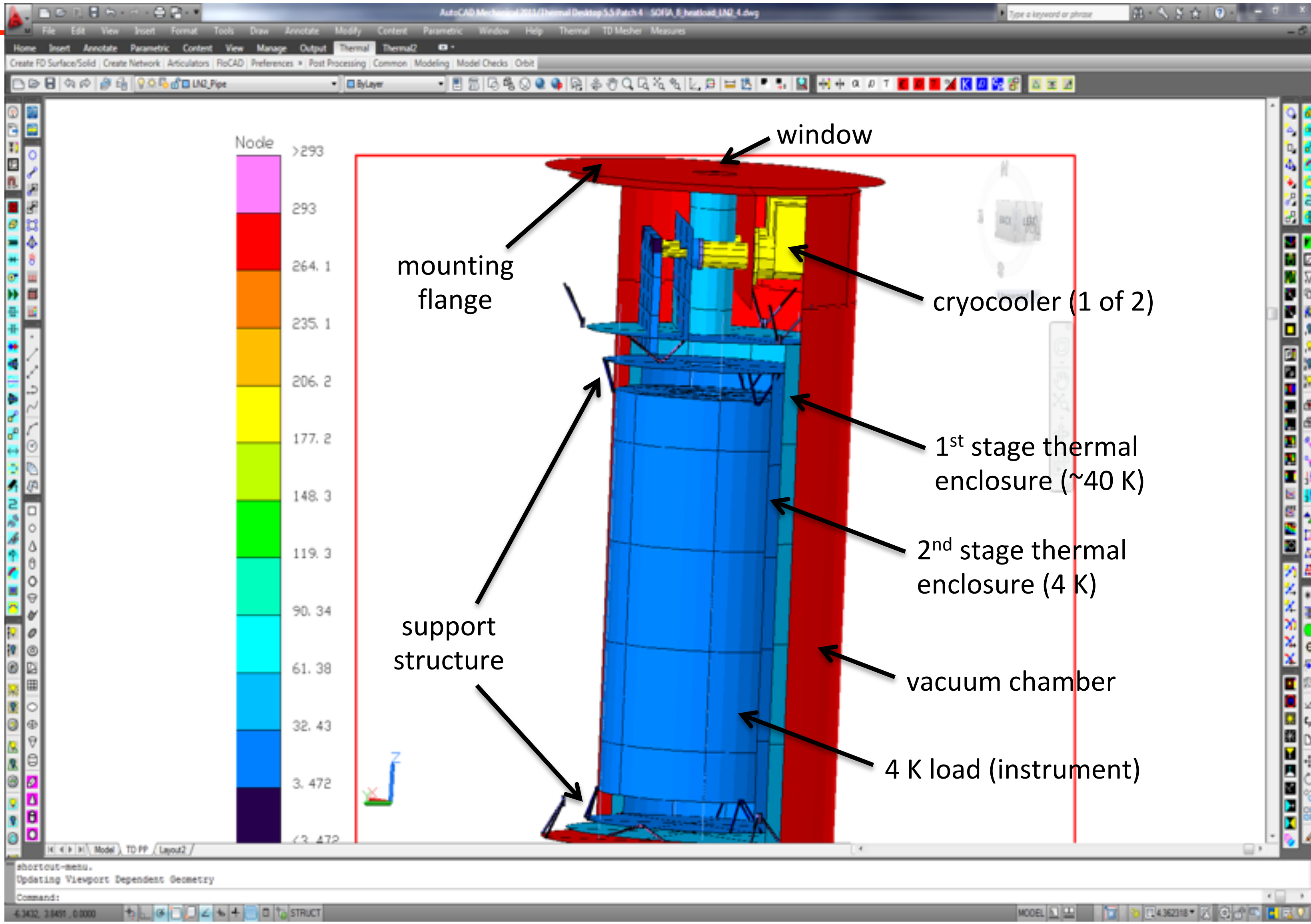
If cooling at 4.2 K were descoped to 0.5 W, one of these would be sufficient

20-30 m hoses necessary but OK



remote motor option

Thermal model

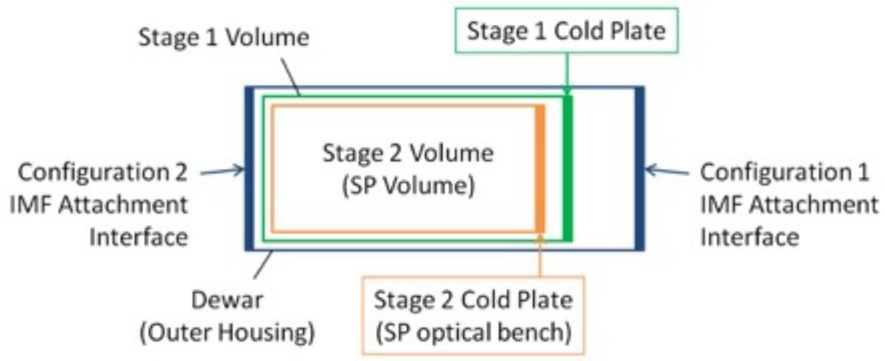


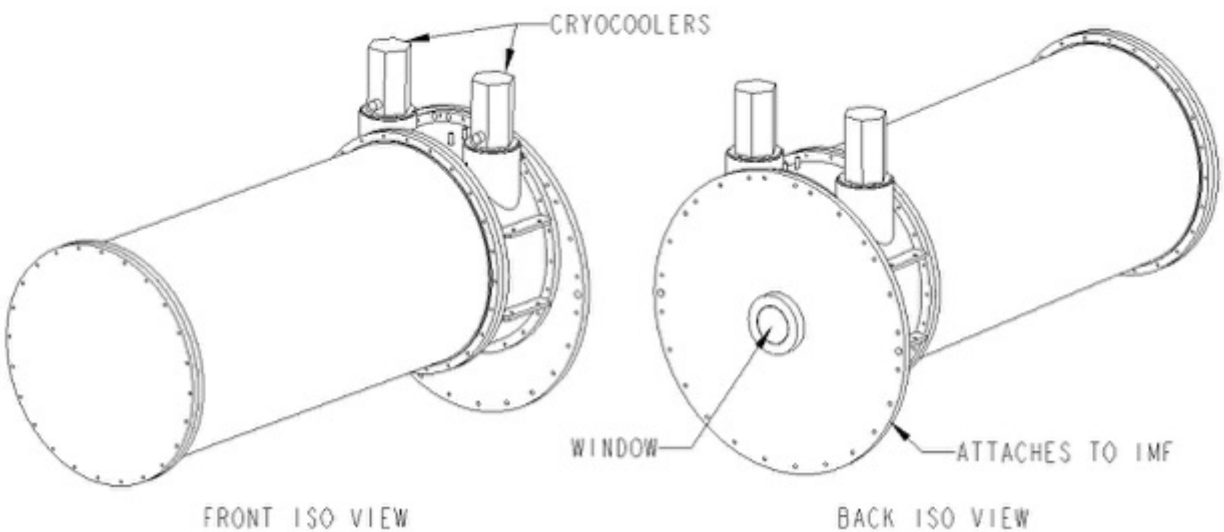
Thermal model in Sinda-Fluint

ROM Estimates

Detailed Strawman Budget on Twiki

Estimate	FY13 H2 ($K)	FY14 H1 ($K)	Total ($K)
DESIGN	**$317K**	**$9K**	**$326K**
Equipment	*$20K*		*$20K*
Labor	*$282K*	*$6K*	*$288K*
Travel	*$15K*	*$3K*	*$18K*
BUILD	**$238K**	**$430K**	**$668K**
Equipment	*$205K*		*$205K*
Labor	*$25K*	*$396K*	*$421K*
Travel	*$8K*	*$34K*	*$42K*
INT & TEST (includes Airworthiness)	**$18K**	**$167K**	**$185K**
Labor	*$15K*	*$164K*	*$179K*
Travel	*$3K*	*$3K*	*$6K*
OPERATE		**$195K**	**195K**
Equipment		*$140K*	*$140K*
Labor		*$52K*	*$52K*
Travel		*$3K*	*$3K*
TOTAL ESTIMATE	**$573K**	**$801K**	**$1,374K**


Stage 1 Volume
Stage 1 Cold Plate
Stage 2 Volume
(SP Volume)
Configuration 2
IMF Attachment
Interface
Configuration 1
IMF Attachment
Interface
Dewar
(Outer Housing)
Stage 2 Cold Plate
(SP optical bench)


CRYOCOOLERS
WINDOW
ATTACHES TO IMF
FRONT ISO VIEW
BACK ISO VIEW

Packaging Results

FORCAST Optical Prescription Repackaged in SNACS Cold Volume

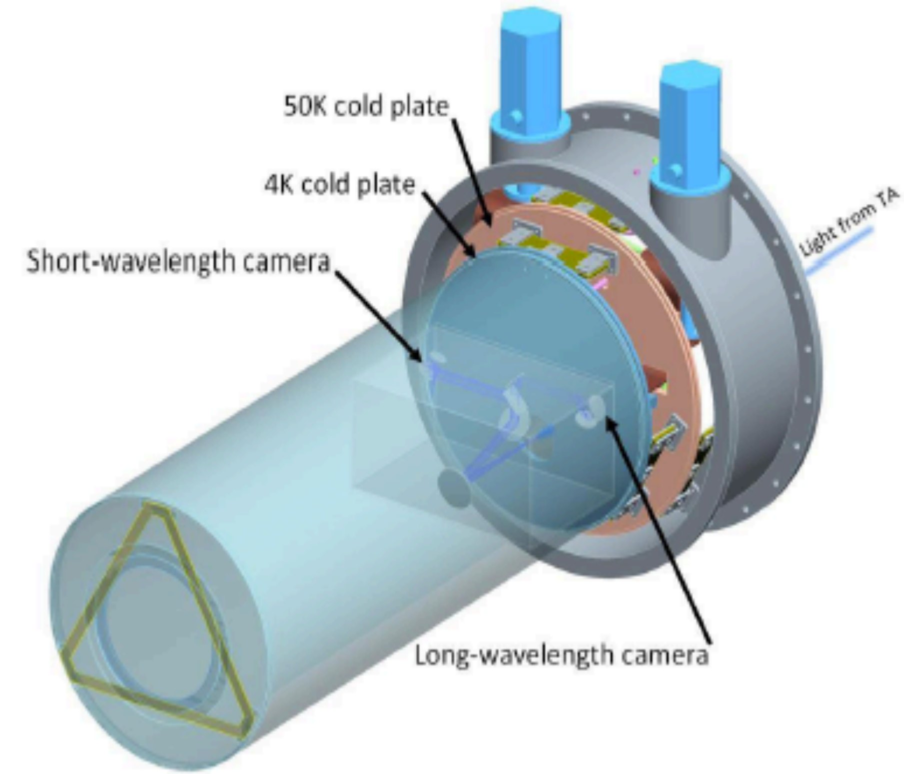


Figure 6-1 FORCAST optics are shown "prepackaged" in a design box and fit into the SNACS cold volume using Configuration 1

EXES Optical Prescription Repackaged in SNACS Cold Volume

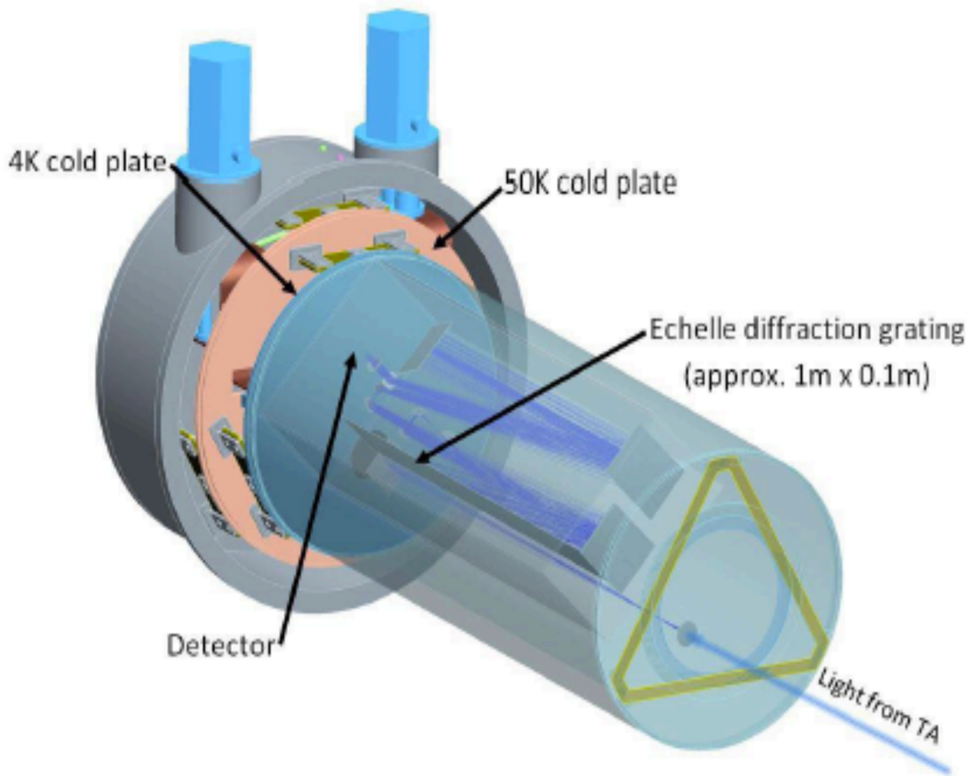
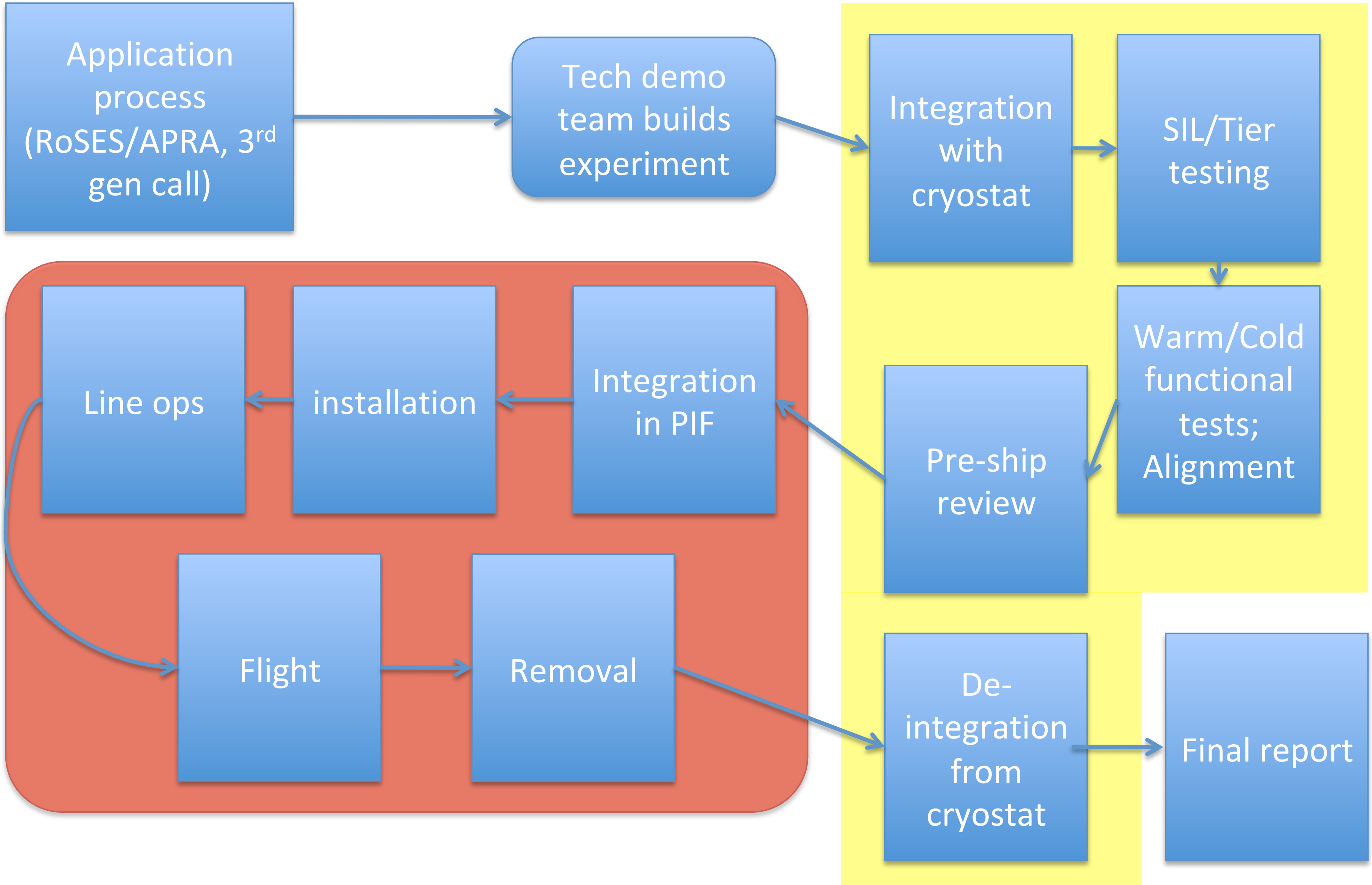


Figure 6-2 EXES optics are shown "prepackaged" in a box and then easily placed into the SNACS cold volume using Configuration 2

SNACS as a Tech Demo platform

- Design and build a flexible cryostat that would function as a cold-bench for technology demonstration/short flight series science demonstrations
- Cryostat would remain at SOFIA, integration would be in SOFIA Labs
- The BOBCAT experiment is a similar idea for balloons
- Design of the tech demo platform could be used as starting point for facility instruments
- Available as an option, but NOT required

Potential integration flow



Common Dewar for Facility Instruments

- Design of the tech demo platform could be used as starting point for facility instruments
- Available as an option, but NOT required
- The SI developer could use design for in house fabrication (early integration and testing)
  - If developer built, there may be an opportunity for early integration and early testing

OR

- SOFIA could build and make the cryostat available

Advantages

- Standardize safety, Airworthiness and Hazard analysis
- Concentrates cost to experimenter on technology demonstration, not cryostat.
- Cryostat design is a product in itself—design could be published for use as a ‘suggestion’ and starting point for instrument developers
- Encourages use of SOFIA as a astronomy innovation platform

Challenges

- This is a paradigm-shift in the approach to instrument development & technology demonstration
  - Will not accommodate all instruments
- Integration of optics, detectors, etc into cryostat requires considerable time and effort
- Assumes use of existing instrument development personnel, lab space and equipment
- Need to carefully design cryostat to maximize potential uses, but not all designs compatible
- Would not be facility-level instrument—each experiment would be a special purpose instrument (ex: HIPO occultation flights)

Community Survey: Who'd Want This?

Contacted multiple ground-based instrument development groups

- Interest
  - Broad support and interest in the community
  - Several teams have potential projects
  - Proposal/funding/scheduling mechanisms also of interest
    - Potential models: Balloon projects, ROSES/APRA, part of 3rd gen call
  - Would want largest possible internal volume
  - May be easiest to have generic mounting points for a pre-populated 'standard' optical bench
  - Definite support for cyrocoolers (more standard, larger work area within SOFIA envelope)
- Concerns:
  - Current instruments would be too different to fit into a standard cryostat
  - Large amount of work needed in setting up/aligning optics for each experiment
  - SOFIA environment would not lead to advancement of TRL

Email to Instrument Builders

Good Afternoon!

My name is Erin Smith, and I'm the science instrument development manager for SOFIA, the Stratospheric Observatory For Infrared Astronomy. We are trying to find new ways to encourage new instrumentation and technology development on SOFIA. Since we are an airborne observatory we've found that developing new technologies for infrared astronomy using the SOFIA telescope has a relatively large 'buy in'--basically the costs of any instrument are driven more by the airworthiness/safety/aircraft requirements, rather than by any of the new technologies themselves. One way we hope to overcome this is by building a 'dummy' cryostat which has completed all required airworthiness and safety checkouts and design processes. The optical bench would be empty, and be made available to a technology demonstration or instrument development team to populate with their own optics, detectors, etc, to be flown aboard SOFIA for use on real targets. I was hoping to talk to you about the usefulness of such a platform, and, if possible, to get any advice or input you might have. As of yet this is just an exploration of concept, so we haven't determined funding mechanisms or even if this will go forward, but wanted to gauge community needs before going to far ahead with the planning stages.

Thanks so much for your time!

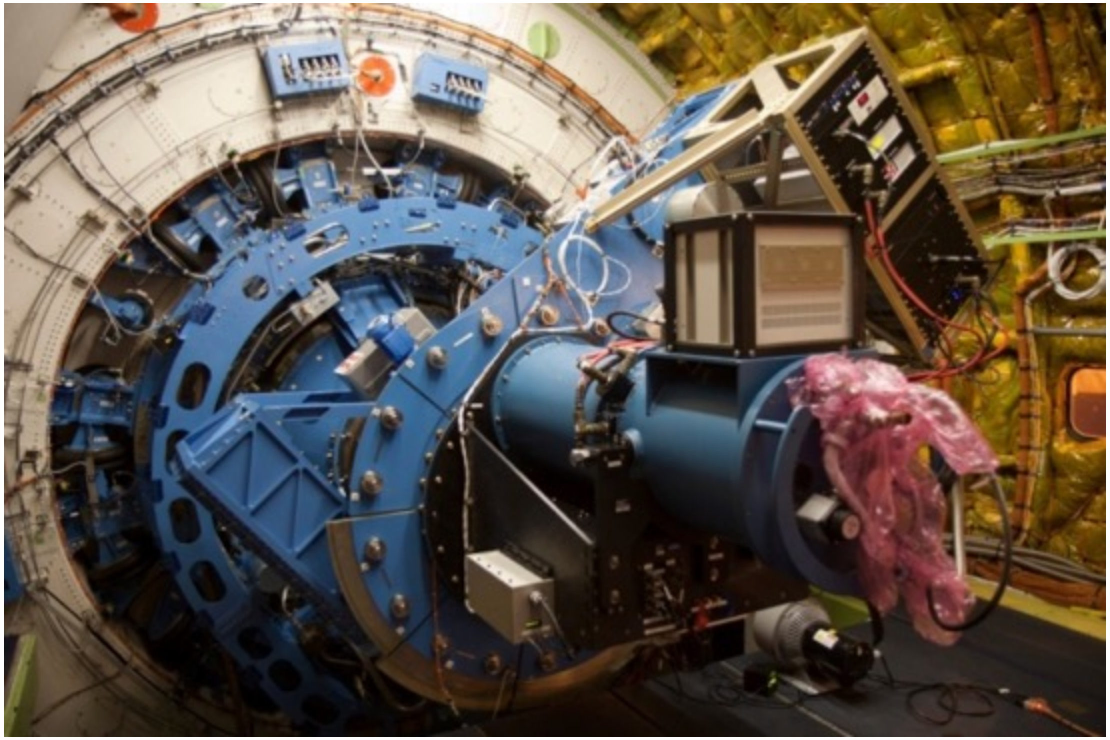
Sincerely,
Erin C Smith
SOFIA Science Instrument Development Manager

Selected Feedback

- “I'd be very interested in such a development and would be happy to talk with you about what characteristics the cryostat should have”
- “The SOFIA optical bench may indeed be extremely valuable for our program here at the University XXX. Prof. XX has been working on …hardware for which the bench would permit key technical demonstrations.”
- “What would the dimensions of the working volume of the optical bench be? Or, are you not ready for that question?”
- “This is an excellent concept....my team already has an instrument we would like to put in it!
  I would be happy to provide input. 10-11am on either Mon, Wed, or Friday of next week would work for me.”
- “At the moment, I don't have any technology demonstrations in mind for your proposed concept…We actually did just that... we used the SOFIA/SAFIRE (first generation SOFIA instrument that was de-selected during development) dewar and built a new interior. So, it does sound like an interesting idea. It is still going to require a significant amount of labor to build up new instruments inside your dewar, and I don't know how quickly you could turn around new instrument "experiments". Of course I'm not privy to any technology demonstration concepts that were proposed to the 2nd generation instrument AO, but since SOFIA doesn't simulate a space environment, I don't think this would really advance the technology TRL any further than a ground-based system or through laboratory tests. I never understood what technology development would be done on SOFIA. Is there another way to look at it? “

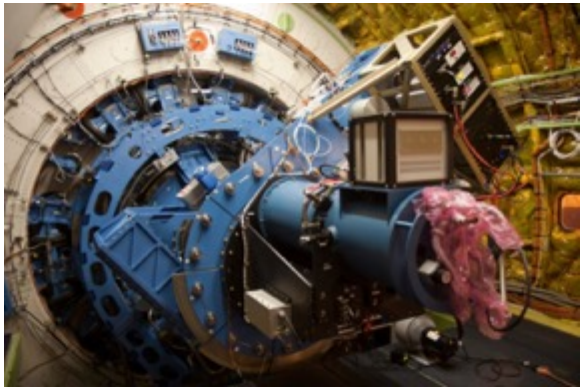
Other common dewar approaches

- Utilize retired cryostats (e.g FLITECAM)
- Utilize cryocooler-enabled designs as common dewar concepts
- Co-mounting technology demonstrator with existing



Co-mounting/multiple tech demonstrators

Concern: losing Science hours to technology demonstration



Advantages:

Allows use of more wavelength range

Maintains Science hours

Challenges:

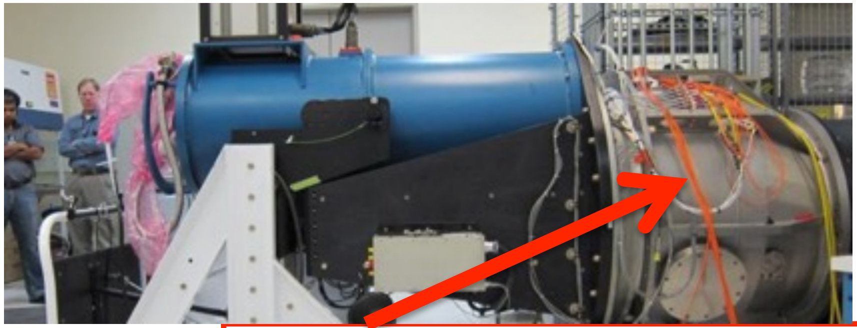
Difficult to plan

Reduces available space, wavelength range

Increases FSI backgrounds

Constrains future FSIs

Complicates planning of flights



Beam splitter inside tub (warm optics)

Development Plan for generic platform

- Buy in from Science Community
  - Make sure we're not missing a critical feature that would make this a "white elephant"
  - Have instrument builder peer review at +3 months Throughout: brief community at AAS and other meetings
- Design and Build generic platform
  - Includes initial feasibility study (NTE 4 person-weeks) of lower temperature stages to show potential users that SNACS is a Tech Demo solution over a wide range of wavelengths and hence optics and focal plane temperatures
  - May suggest some plumbing and cable feedthroughs to enable these systems
  - Users could provide their own deep cryo refrigeration system
- Lab and Line Ops testing and associated procedures and manuals
- Incorporate into next SOFIA Instrument Call as available for Tech Demos
- Make documentation available to Facility Instrument proposers

Summary

- SOFIA is a unique, powerful platform for extraordinary astrophysics investigations
- A ‘Common Dewar’ may let SOFIA effectively move the interface from the TA flange to the cryostat cold bench
- This could open SOFIA up to new, cutting edge technologies and observing methods, as well as offer a simplified path for facility instrument development