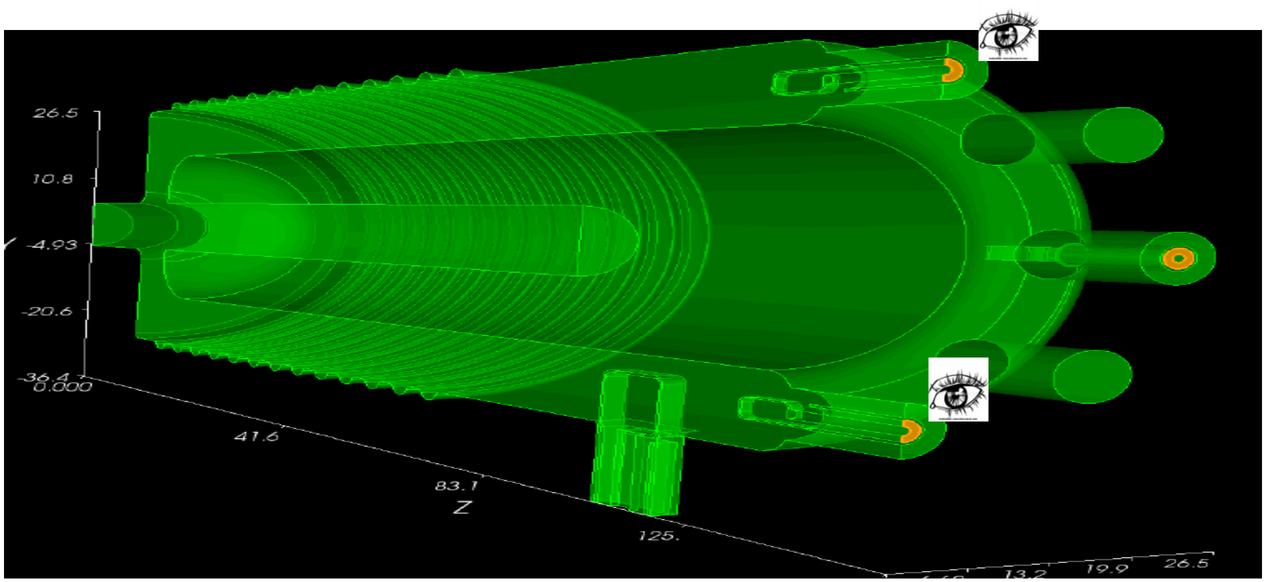
IR detector for machine protection during HOM damper quench

Brian Sheehy



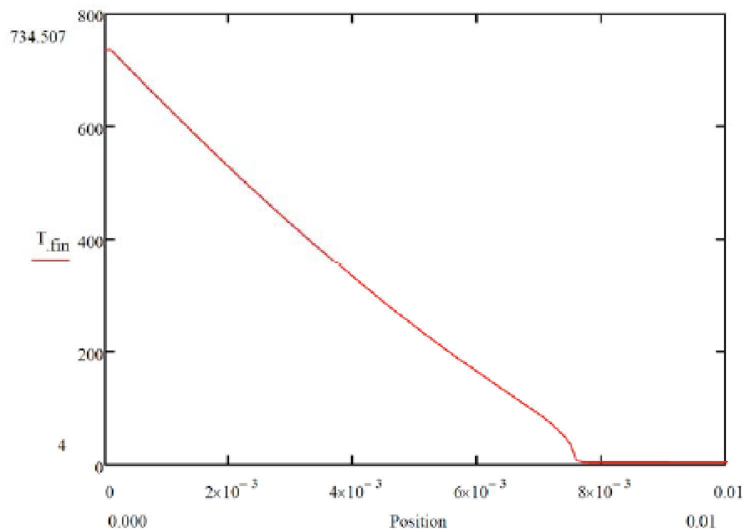
•Scenario: multipacting causes quench of an area on an HOM damper. Resistive heating then causes a growing hotspot. Want to detune the cavity before melting/deformation occur.

• Look into a couple of end ports to see thermal radiation from the hotspot

•Ilan Ben-Zvi modeled quench propagation in the HOM dampers (*C-A/AP/#358*) and found that detectable IR radiation was produced in ~150 msec, and temperatures rose slowly enough to insert fundamental mode damper before damage occurs

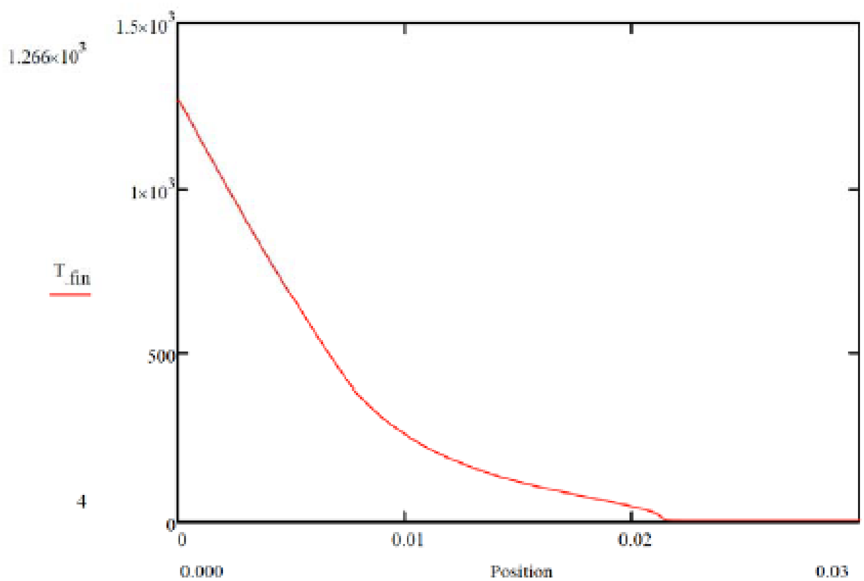
• may also detect cavity quenches before the cryo signature is evident

Temperature vs distance from initial quench
t = 0.15 sec



After 150 msec,
peak temperature 735K
size 1.4 cm

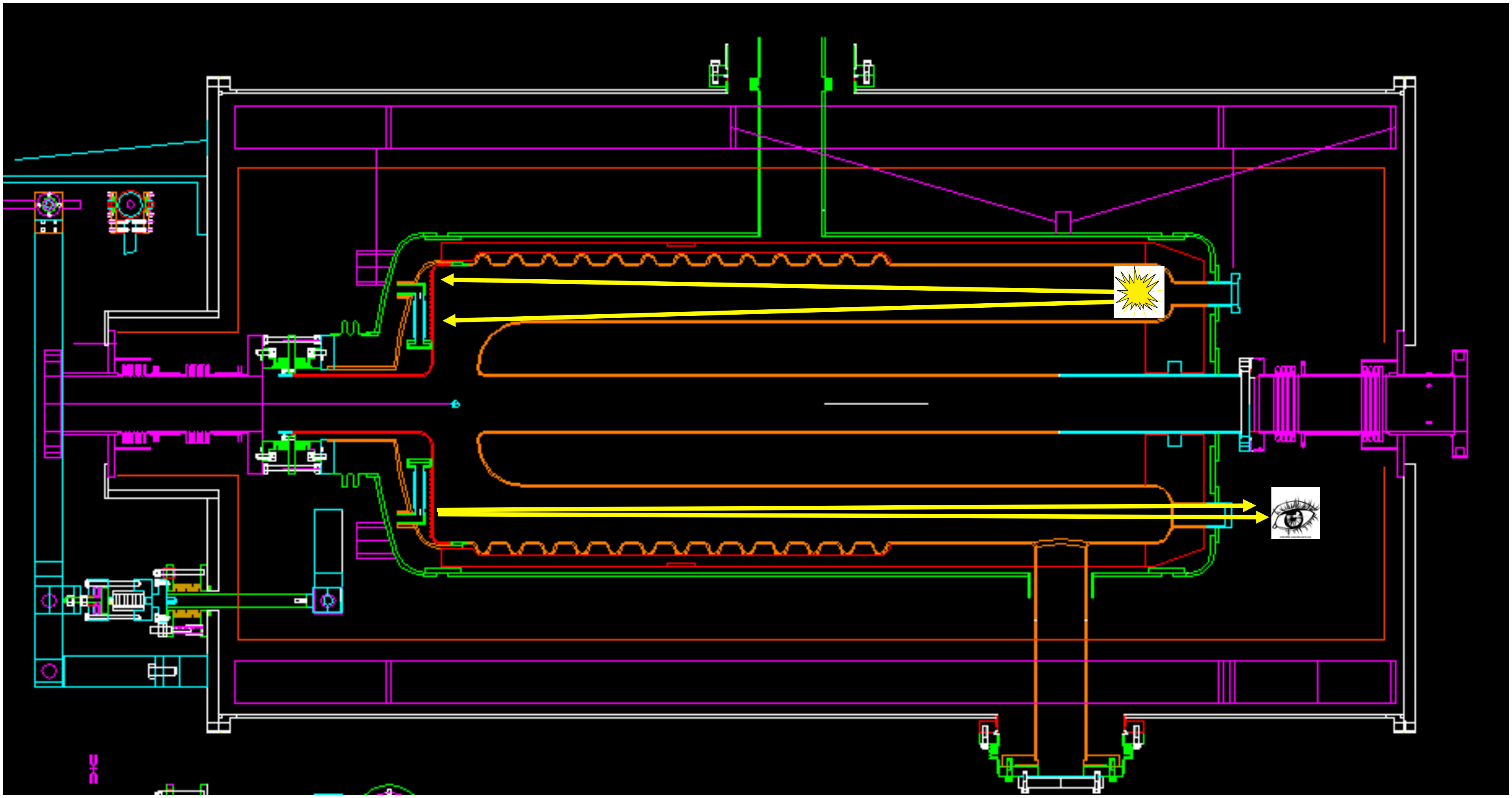
Temperature vs distance from initial quench
t = 3 sec



After 3 seconds,
peak temperature <1300K (safe for Niobium)
size ~ 4 cm

from Ilan Ben-Zvi's AP note C-A/AP/#358 September 2009

Placement



- Use 2 of the end ports for detector placement
  - 2 o' clock and 8 o' clock positions
- Light from hotspot reflects from cavity wall before exiting

Outline

- Detectors (sensitivity, noise)?

- Expected “useful” thermal radiation
  - including temperature distribution, optical properties and detector spectral response

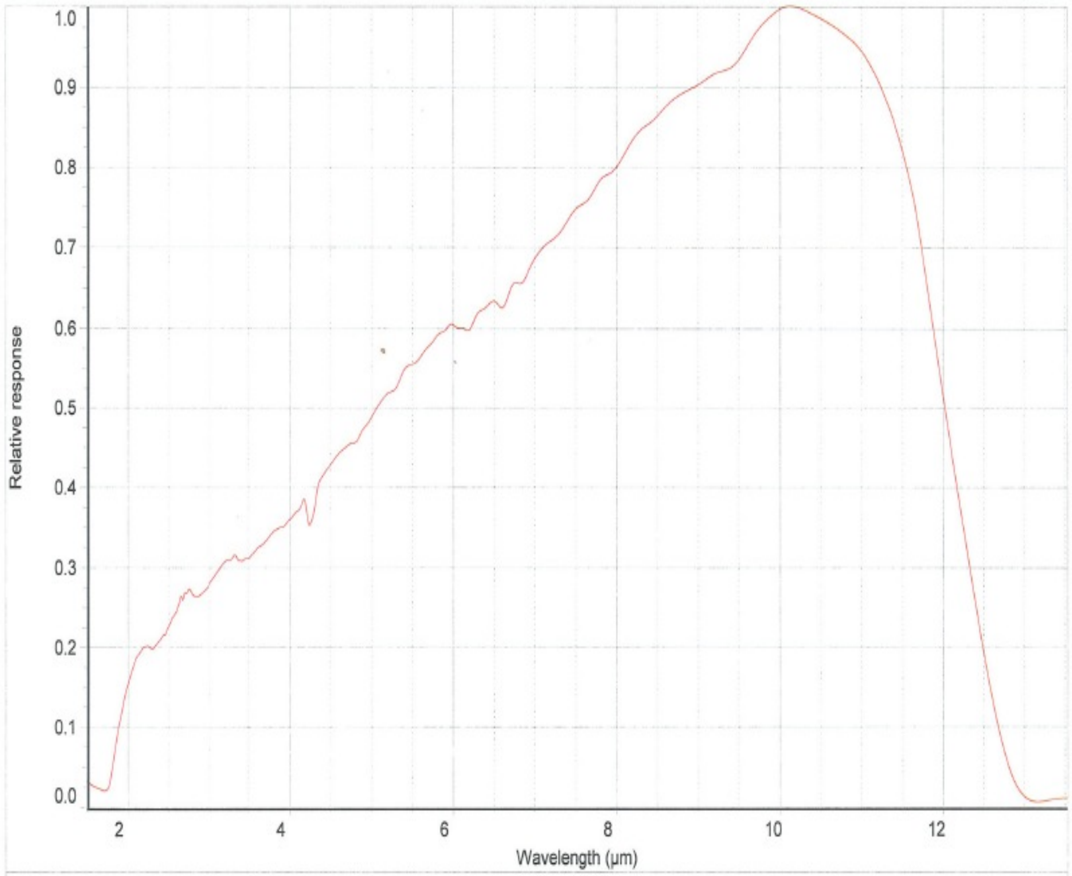
- Throughput: how much of the thermal radiation will get to the detector?

- Integration into the cryostat

- vacuum / cryo issues with the viewport

- implementation program

Detector



<u>Photovoltaic MCT</u> (Hg_{1-x} Cd_x Te)

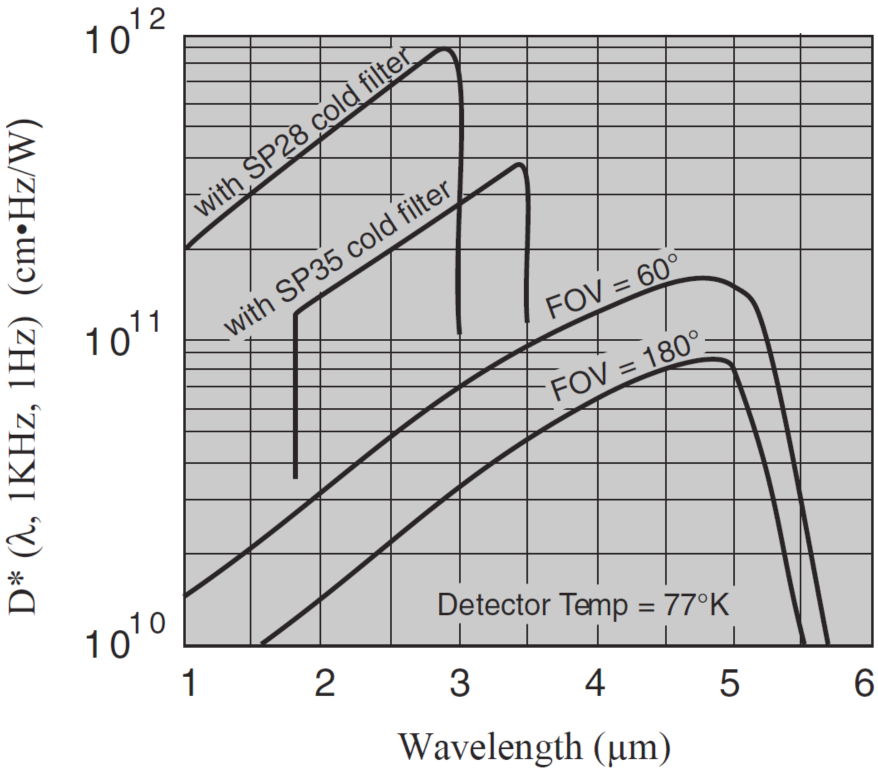
- bandgap tunable through x
- long wavelength cutoff photovoltaic now available from Teledyne Judson
- wide wavelength range, sensitive over wide temperature range
- photovoltaic: no 1/f noise, no chopping required
- High detectivity (3e10) and responsivity (4 A/W)
- spec'ed at 77K, need to measure performance at 4K

$$\text{detectivity } D^* \equiv \frac{\sqrt{A \times \Delta f}}{NEP} = 3\times 10^{10}\ \frac{\text{cm}\cdot\sqrt{\text{Hz}}}{\text{W}}$$

$$\text{A} = \text{det area} = 1\text{mm}^2,\ \Delta f = \text{bandwidth} = 100\text{ Hz}$$

$$\Rightarrow \text{NEP} = \text{noise effective power} = 30\text{ pW}$$

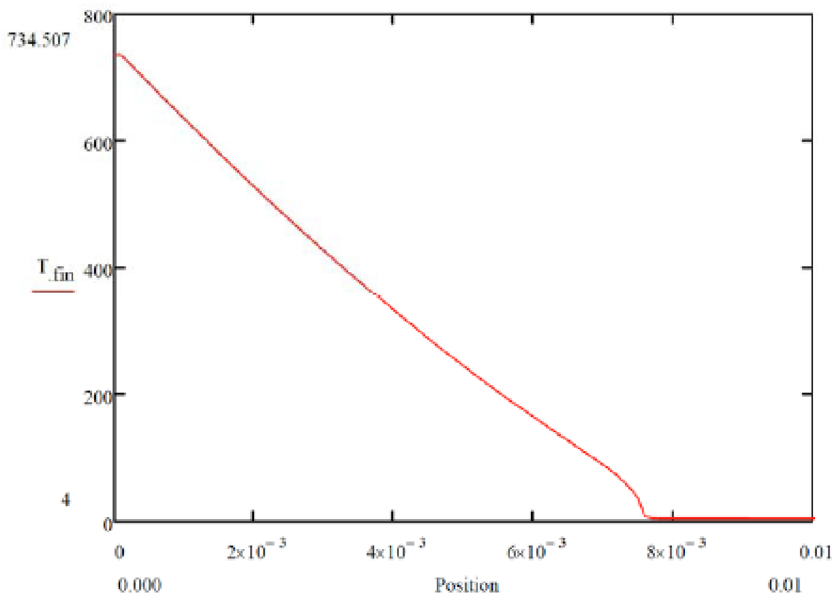
Detector

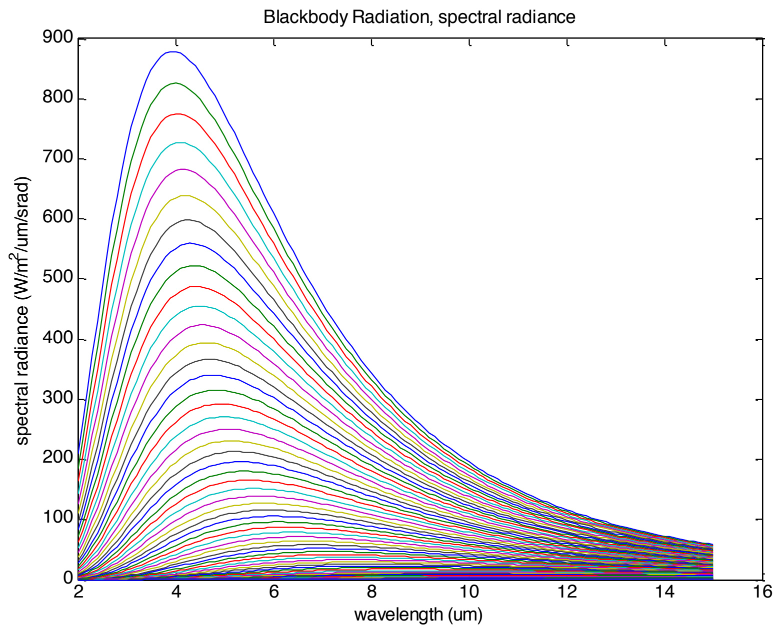


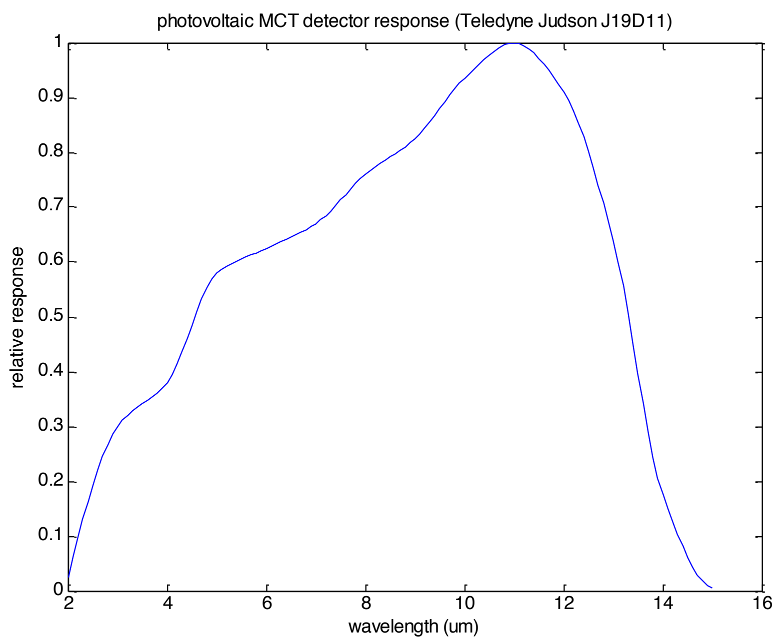
Indium Antimonide (InSb)

- more restricted wavelength range than MCT
    - spot must reach higher temperatures (~550K) before detection
- photovoltaic: no 1/f noise, no chopping required
- High detectivity (1e11) and responsivity (3 A/W)
- spec'ed at 77K, need to measure performance at 4K

How much useful light is there?







Combine:

1. Temperature distribution of radiator
2. Spectral radiance at each temperature
3. detector response function

& integrate over the radiator

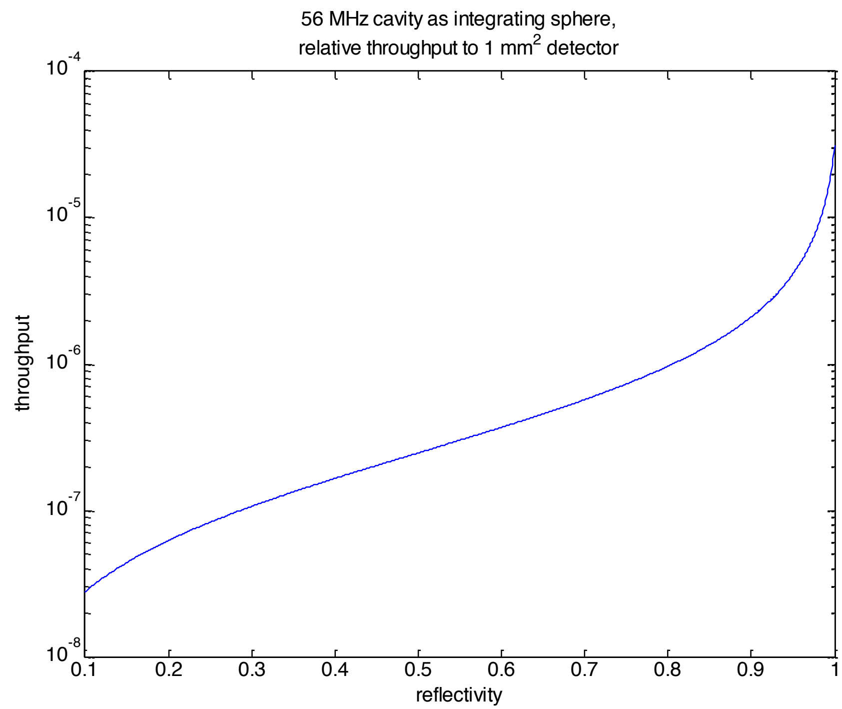
$$\approx 110\,\mathrm{mW} * \varepsilon$$

$$(\varepsilon \equiv \text{emissivity})$$

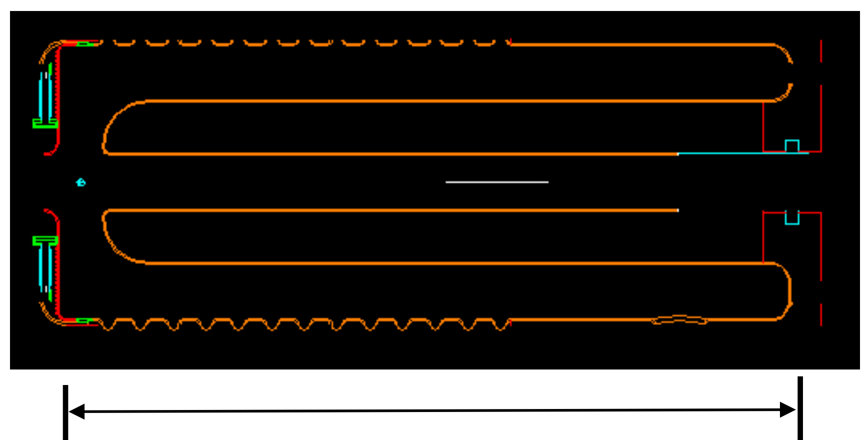
How much light gets to the detector?

for high reflectivity R, approximate the cavity as an integrating sphere

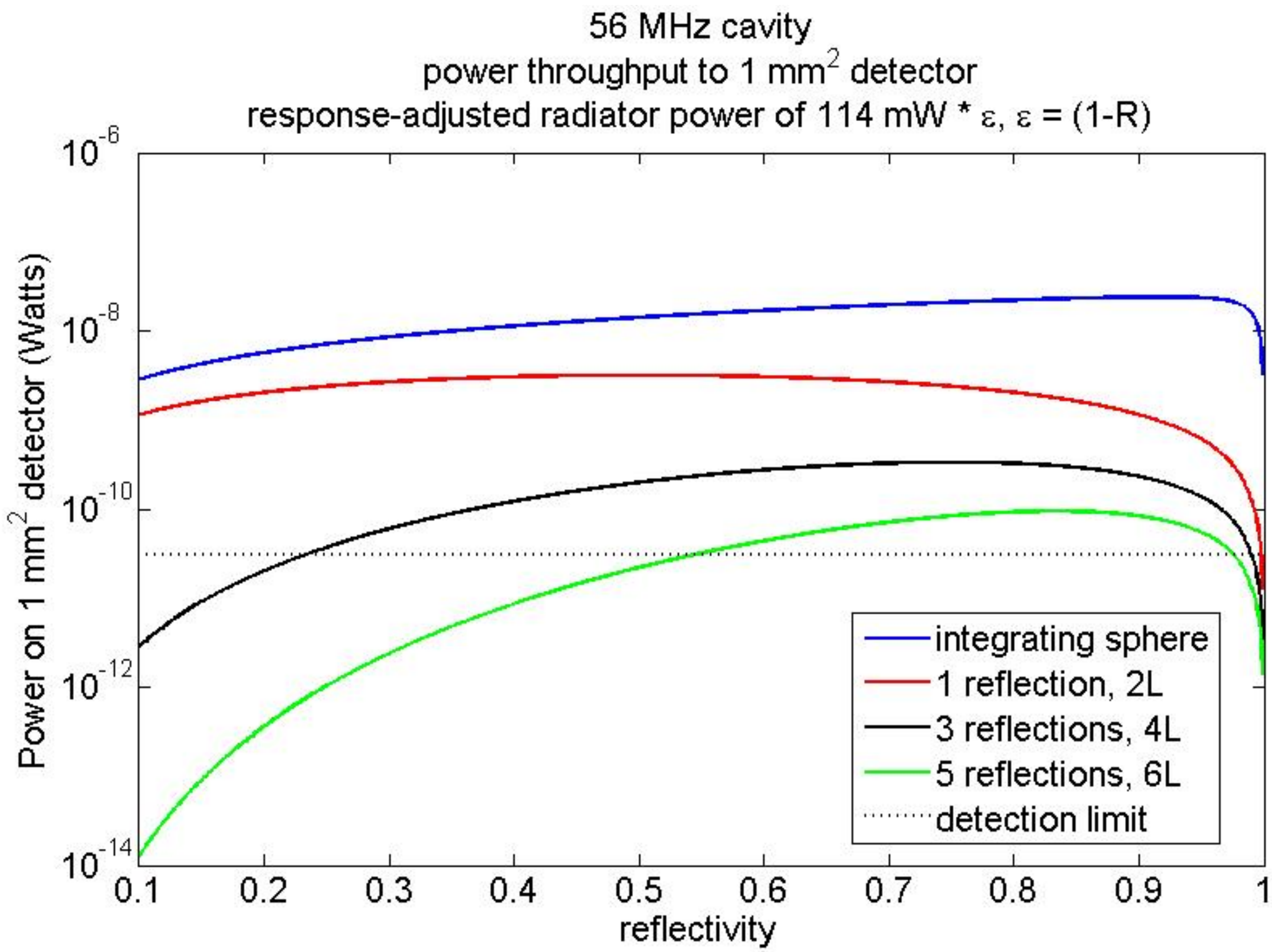
$$\frac{Pout}{Pin} = \frac{RA_{det}}{A_{total}\left[1 - R\left(1 - \frac{A_{ports}}{A_{total}}\right)\right]}$$



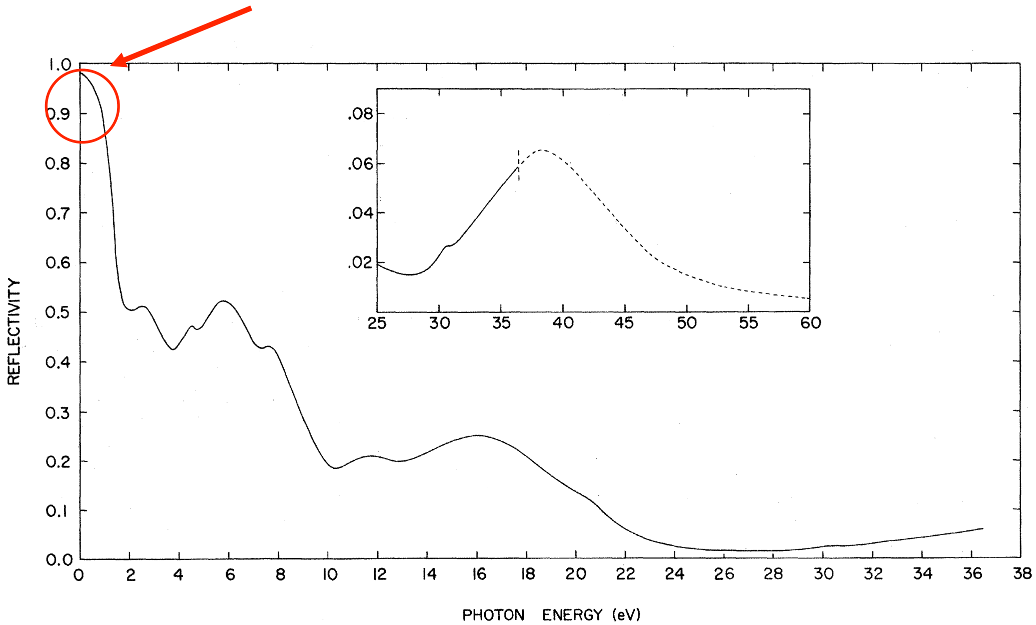
Or, consider the solid angle subtended and the reflection losses after 1 bounce and 2L travel, 3 bounces and 4L, 5 bounces and 6L…



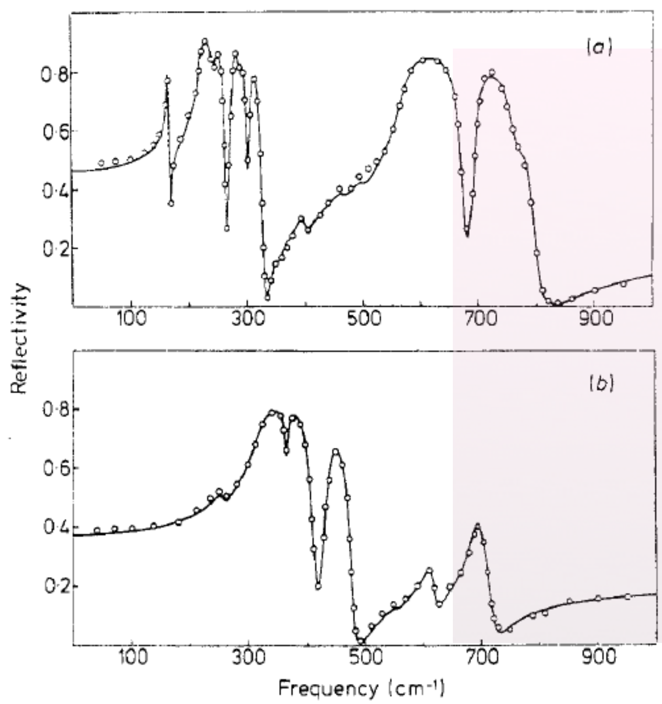
L = 150 cm



- Consider now also that emissivity and reflectivity are related: take $\varepsilon = (1-R)$
- need experimental tests of throughput
  - models are very approximate
  - some uncertainty in reflectivity, Niobium (good) or an oxide of Niobium (bad)?



Niobium,
Weaver et al Phys Rev B 7, 4311 (1973)



NbO_2, Gervais *et al* J Phys C 12, 1977 (1979).
λ = 10 – 15 um shaded

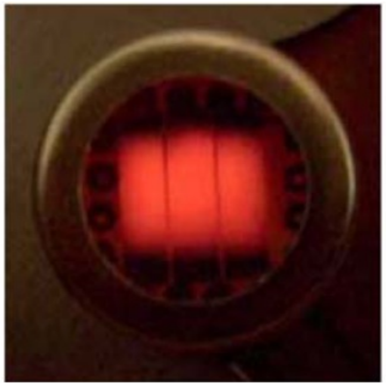
Integration into cryostat

- detector can be thermally tied to 4K, on the window flange
    - need to verify detector performance and durability under cryogenic stress at 4 K
    - standard detector use is at 77 K

- transimpedance amp can be located outside of cryo environment
    - shield leads
    - might decrease noise if cold

- will incorporate miniature thermal source for test/calibration

- collection optics
    - probably not effective, may create blindspots

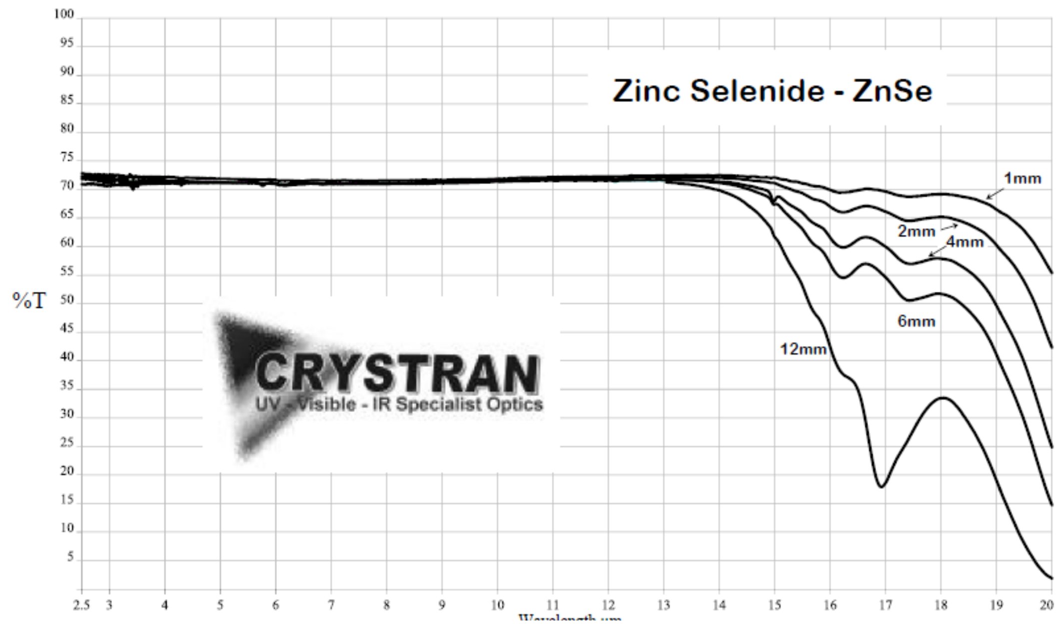


miniature thermal source (Helioworks)

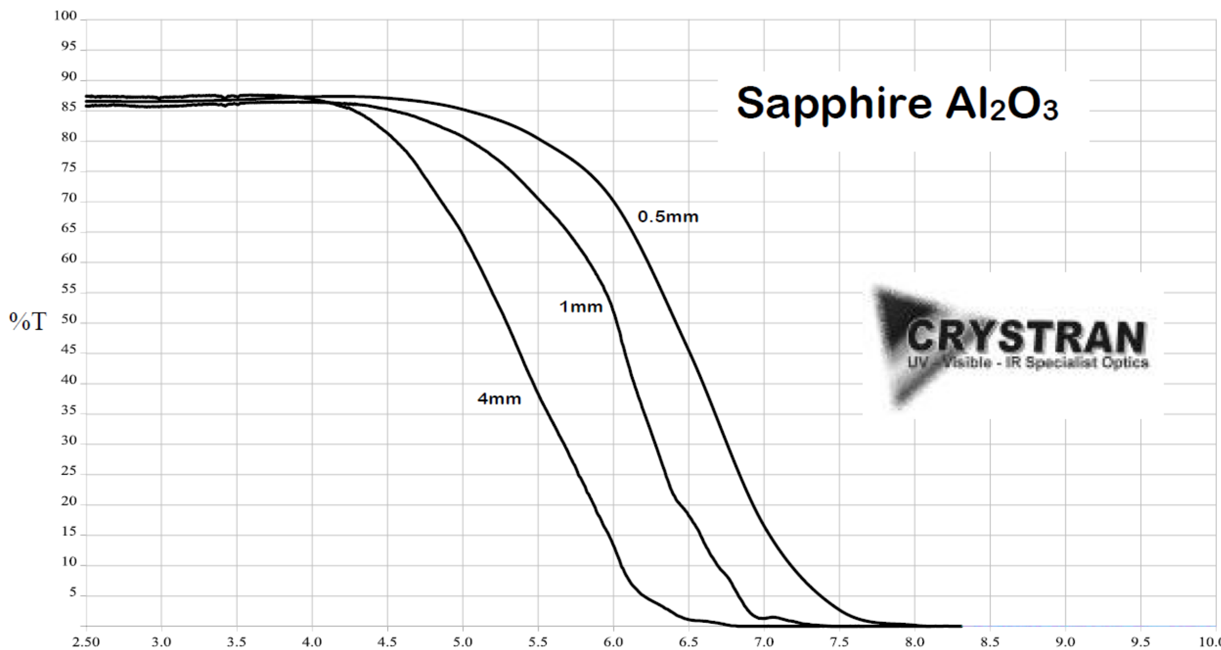
Vacuum Window

Window Material	cutoff wavelength (4-5 mm thick, 50% trans.)
ZnSe	19
Sapphire	5.3
ZnS	13
Ge	~21*
GaAs	~15*
BaF2 (CaF2, MgF2)	13 (9,8)

- ZnSe best material over our wavelength range
- mechanical metal seals commercially available
    - brazing is possible
    - leak rate spec is the same ($2 \cdot 10^{-10}$ cc-atm/sec He) as brazed Sapphire window
        - vendor measurement limited
- There is more confidence in the vacuum/cryo properties of brazed Sapphire windows
    - plan is to test both
- will make conflat adapter flange to NbTi end flange



Zinc Selenide - ZnSe
%T
1mm
2mm
4mm
6mm
12mm
CRYSTRAN
UV - Visible - IR Specialist Optics



Sapphire Al_2O_3
%T
0.5mm
1mm
4mm
CRYSTRAN
UV - Visible - IR Specialist Optics

Complete Hermetics

VIEWPORT - ZERO PROFILE ZINC SELENIDE (ZnSe) ON CF FLANGES

Related Product:

Optical Probe

Viewport Type: Zinc Selenide

- 304L Stainless Steel CF Flanges
- Leaking Rate <2x10-10 atm cc/sec HE
- 200°C Maximum Bakeout Temperature
- 25°C /min maximum thermal gradient
- Pb Ag Braze Material

MCT + ZnSe vs InSb + Sapphire

	MCT/ZnSe window	InSb detector/sapphire window
wavelength range	2 - 12 micron	2 - 5.3 micron
temp of black body peaked at cutoff λ (K)	242	547
peak detectivity	~3 x 10^{10}	~10^{11}
vacuum confidence	must test	high
dark current after cold vis/uv exposure (flashing)	better	worse
4.2 K performance spec	must measure	must measure

Testing/Implementation Program

Vacuum/Cryo tests of ZnSe and Sapphire windows

Warm cavity, LN2 cooled detector:

- check detector and IR source performance
- reflectivity, throughput measurements using 1.3 GHz cavity or large grain gun cavity

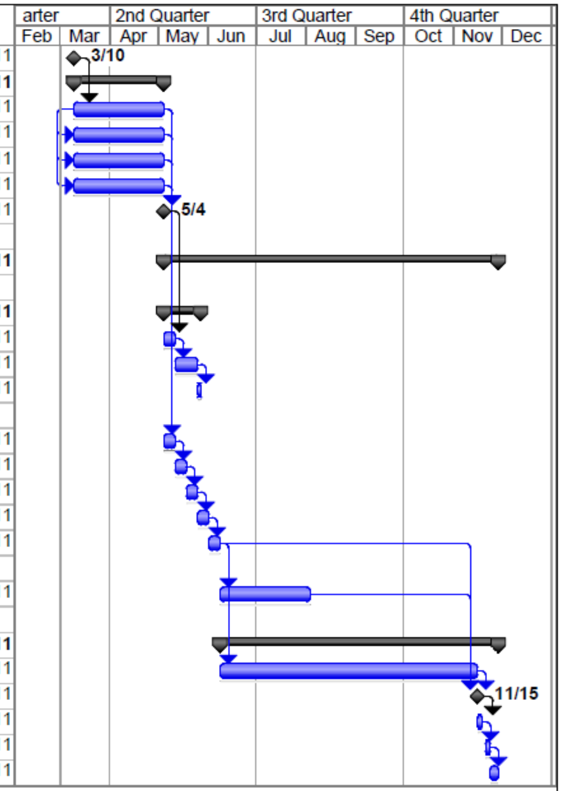
Cold (4K) detector:

- physical stress
- detector performance: noise, “flashing”
- measurement in an environment closer to our operational conditions:
  - -cold environment with “hot” source, DC measurement as opposed to warm environment with warmer source, AC measurement.
- optimize the electronics

Cold cavity, cold detector:

- detection threshold test
- how to test/verify the detector for operations and set machine protection thresholds

ID		Task Name	Duration	Start	Finish
1		Project start	0 days	Thu 3/10/11	Thu 3/10/11
2		**Procurement of components thru to delivery**	**40 days**	**Thu 3/10/11**	**Wed 5/4/11**
3		Procure both windows	40 days	Thu 3/10/11	Wed 5/4/11
4		Procure short wave detector	40 days	Thu 3/10/11	Wed 5/4/11
5		Procure sources	40 days	Thu 3/10/11	Wed 5/4/11
6		Procure amplifier	40 days	Thu 3/10/11	Wed 5/4/11
7		All items delivered	0 days	Wed 5/4/11	Wed 5/4/11
8					
9		**testing sequence**	**148 days**	**Thu 5/5/11**	**Mon 11/28/11**
10					
11		**ZnSe & Sapphire Windows**	**17 days**	**Thu 5/5/11**	**Fri 5/27/11**
12		Vacuum test	5 days	Thu 5/5/11	Wed 5/11/11
13		Thermal cycling test	10 days	Thu 5/12/11	Wed 5/25/11
14		Redo vacuum test	2 days	Thu 5/26/11	Fri 5/27/11
15					
16		Warm target, LN2 cooled detector	5 days	Thu 5/5/11	Wed 5/11/11
17		Calibrate detector + amp response	5 days	Thu 5/12/11	Wed 5/18/11
18		Measure detectivity	5 days	Thu 5/19/11	Wed 5/25/11
19		Measure Nb reflectivity	5 days	Thu 5/26/11	Wed 6/1/11
20		Measure throughput if possible	5 days	Thu 6/2/11	Wed 6/8/11
21					
22		Procure detectors	40 days	Thu 6/9/11	Wed 8/3/11
23					
24		**Cold Testing (VTF 2nd Trip)**	**123 days**	**Thu 6/9/11**	**Mon 11/28/11**
25		Prepare for VTF cold test	114 days	Thu 6/9/11	Tue 11/15/11
26		2nd VTF Trip	0 days	Tue 11/15/11	Tue 11/15/11
27		Cold (4.2 K) target, cold detector	3 days	Wed 11/16/11	Fri 11/18/11
28		Cryo issues with detector (noise, mechanical stress)	3 days	Mon 11/21/11	Wed 11/23/11
29		Measure throughput, minimum detectable signal	3 days	Thu 11/24/11	Mon 11/28/11



Project: IR Detector Schedule 030111
Date: Tue 3/1/11

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

		InSb & Sapphire	unit price		**MCT & LWIR window**	unit price		**Pursue both**	unit price	
detector	4	InSb	$2,500	$10,000	HgCdTe	$2,500	$10,000	HgCdTe	$2,500	$10,000
windows	4	Sapphire	$600	$2,400	eg ZnSe	$795	$3,180	ZnSe/Sapphire	$795	$3,180
Thermal IR sources	6		$100	$600		$100	$600		$100	$600
current pulse driver (est)	2		$2,500	$5,000		$2,500	$5,000		$2,500	$5,000
preamplifier	3		$1,250	$3,750		$1,250	$3,750		$1,250	$3,750
				$21,750			$22,530			$22,530
	0	**/hr**	**$119**	**/hr**						
Services	**Design hours**	price	**Machine Shop hours**	price	**materials**					
modify 2 adapter flanges	4	$0	8	$952	$0					
mount for detector and source	8	$0	8	$952	$200					
electronics: design and pulse driver for thermal IR sources (if not commercially available)										

total cost, including redundancy/spares: ~$25K

Summary

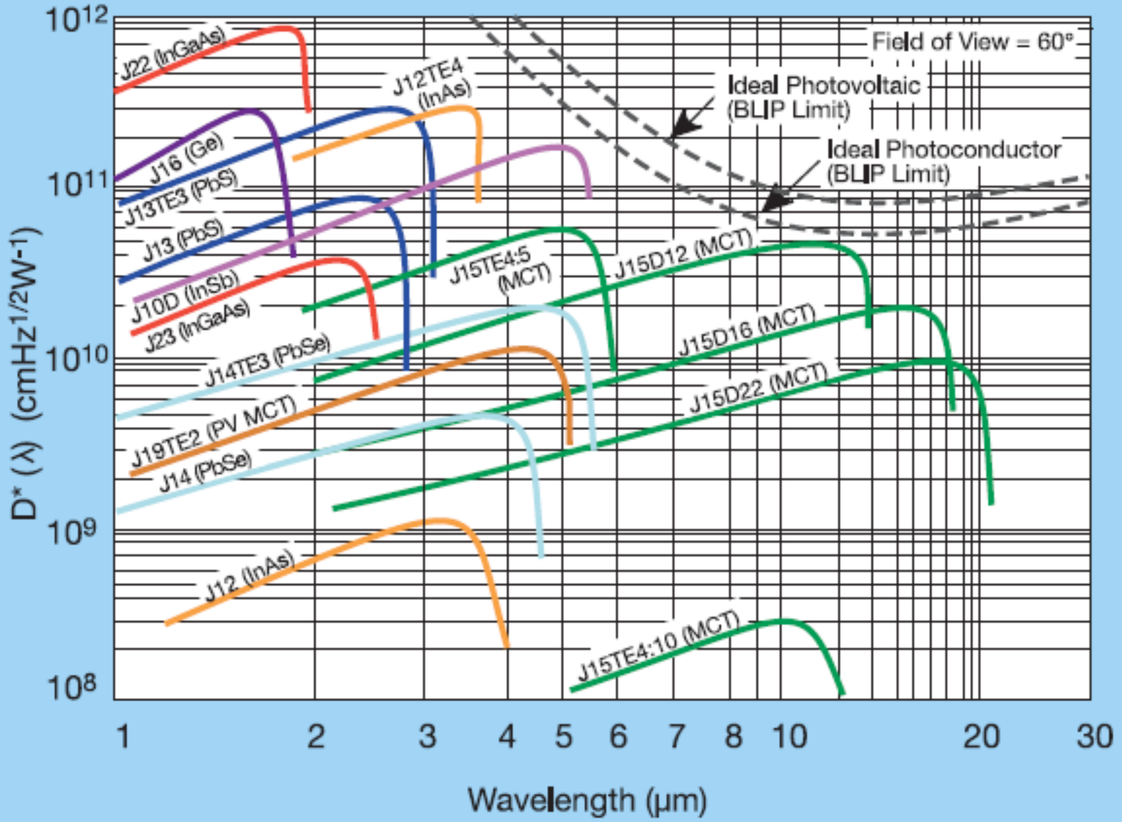
• 2 MCT or InSb detectors will mount on 2 viewports, paired with miniature thermal sources for test purposes

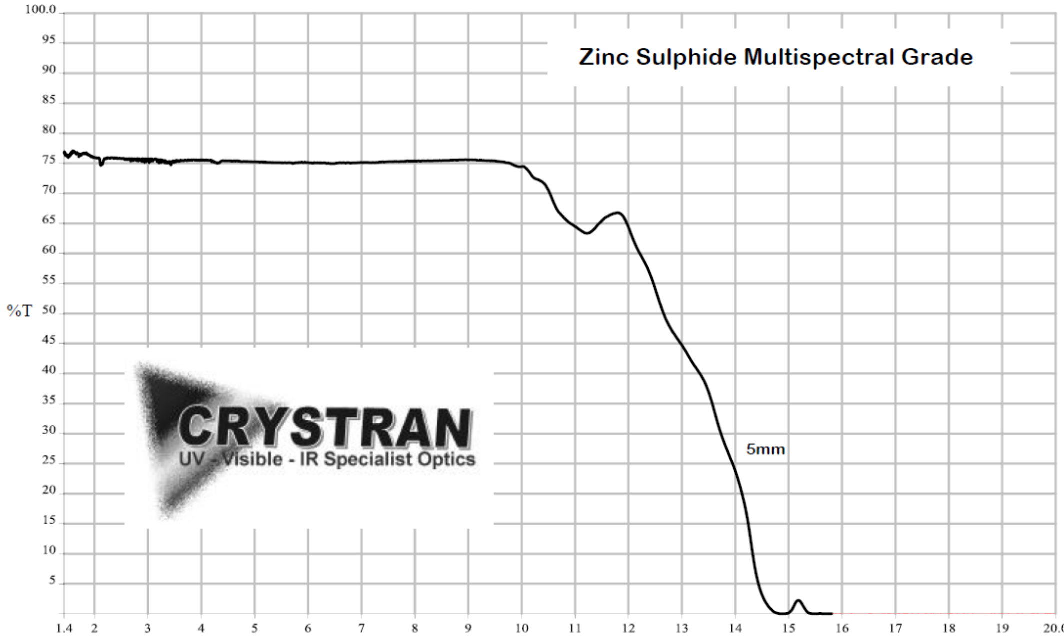
• Cryo/vacuum tests of windows, and detector tests will dictate final detector choice

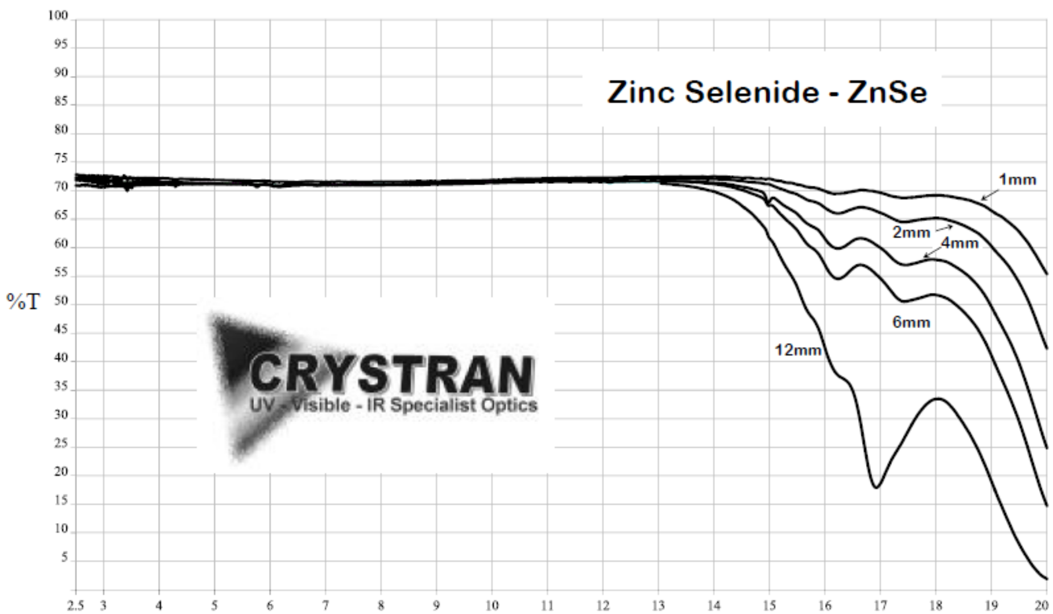
• tests of detector performance, surface reflectivity and throughput will tell us the absolute detections threshold

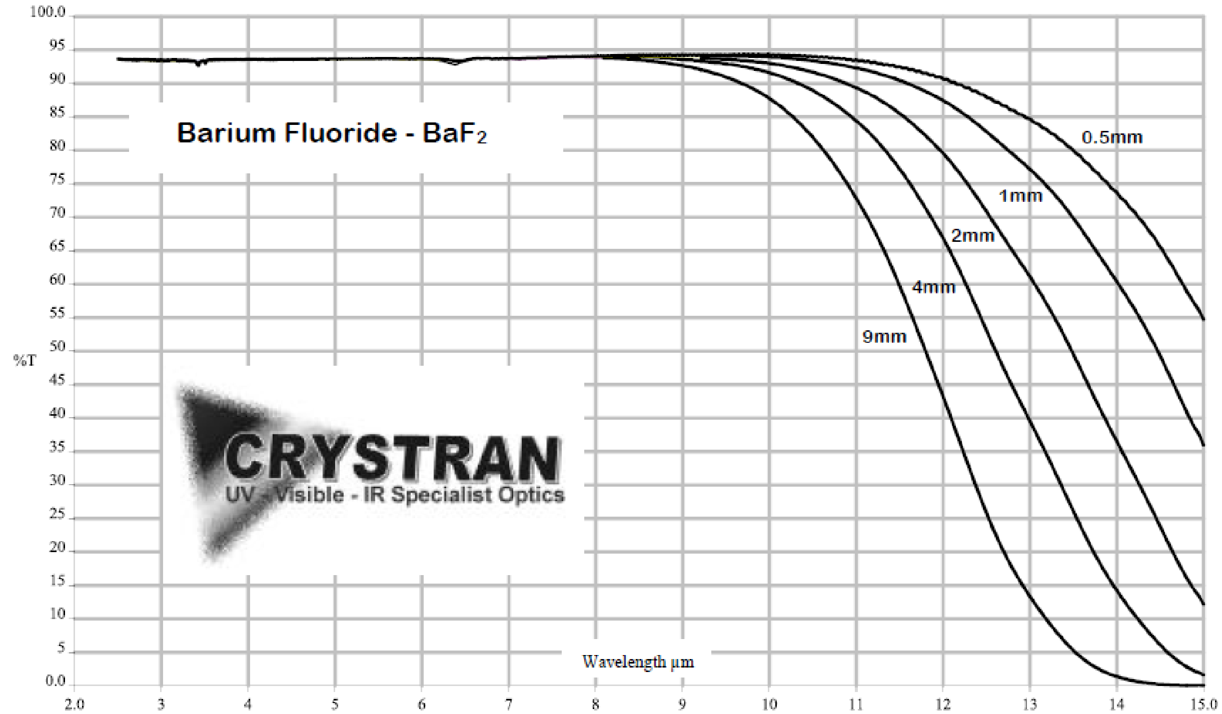
• Full cold test planned for second VTF run in Nov 2011

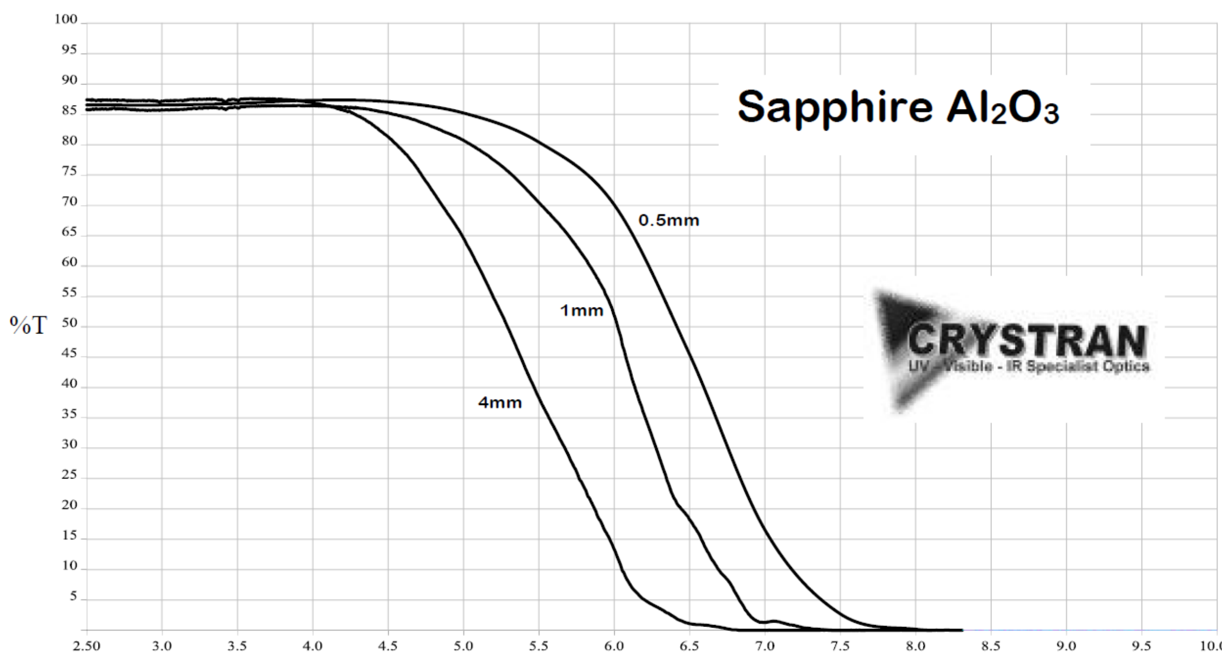
Focused on Infrared

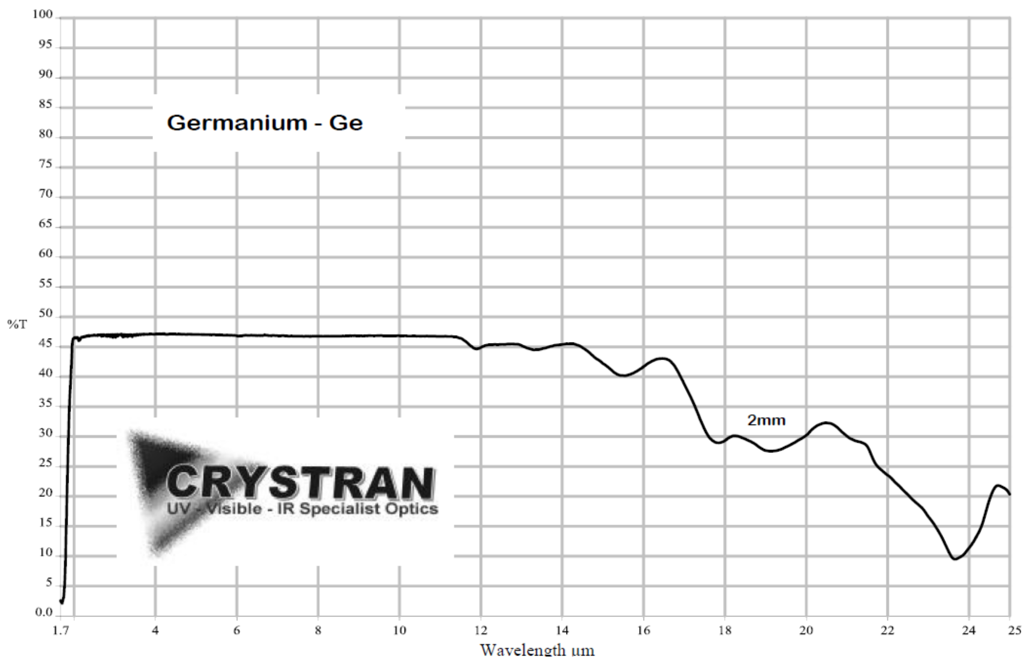


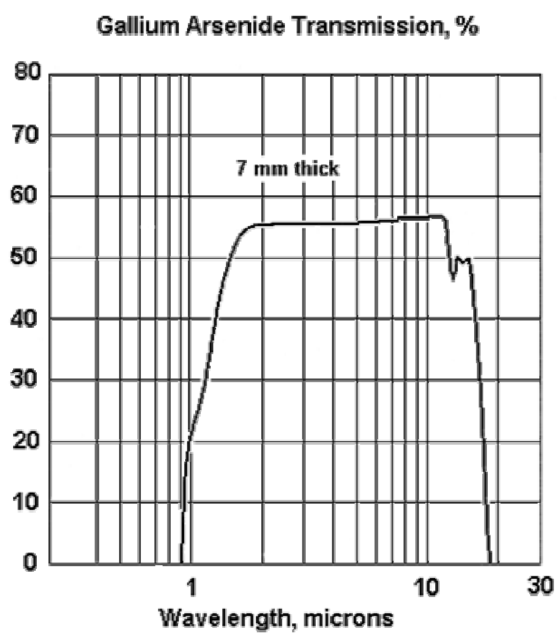

Zinc Sulphide Multispectral Grade
%T
5mm
CRYSTRAN
UV - Visible - IR Specialist Optics

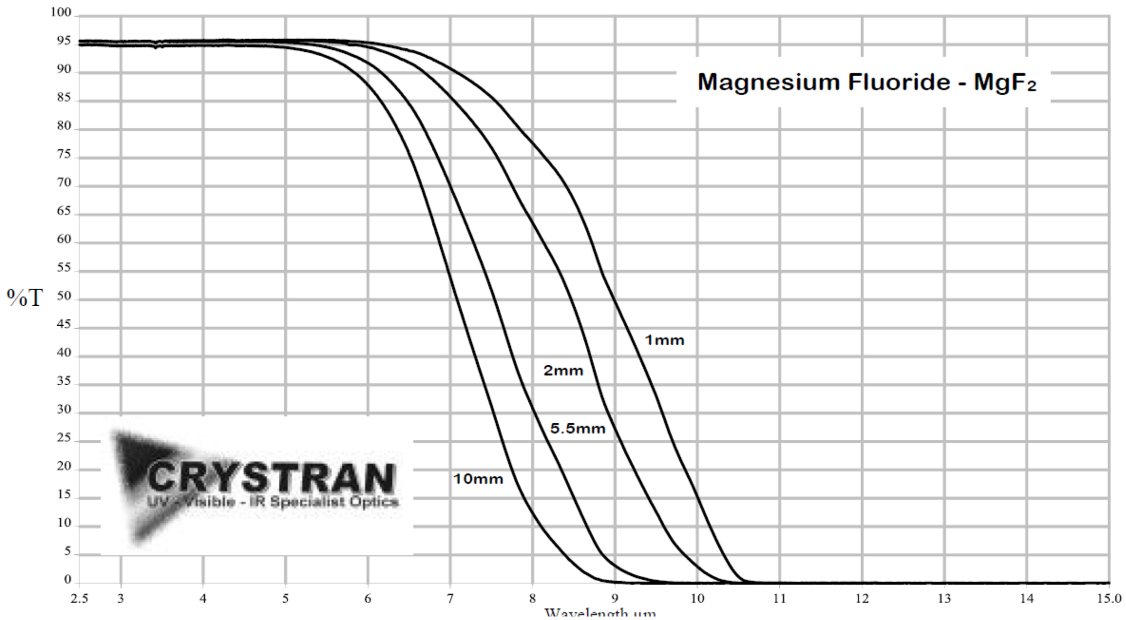

Zinc Selenide - ZnSe
%T
1mm
2mm
4mm
6mm
12mm
CRYSTRAN
UV - Visible - IR Specialist Optics

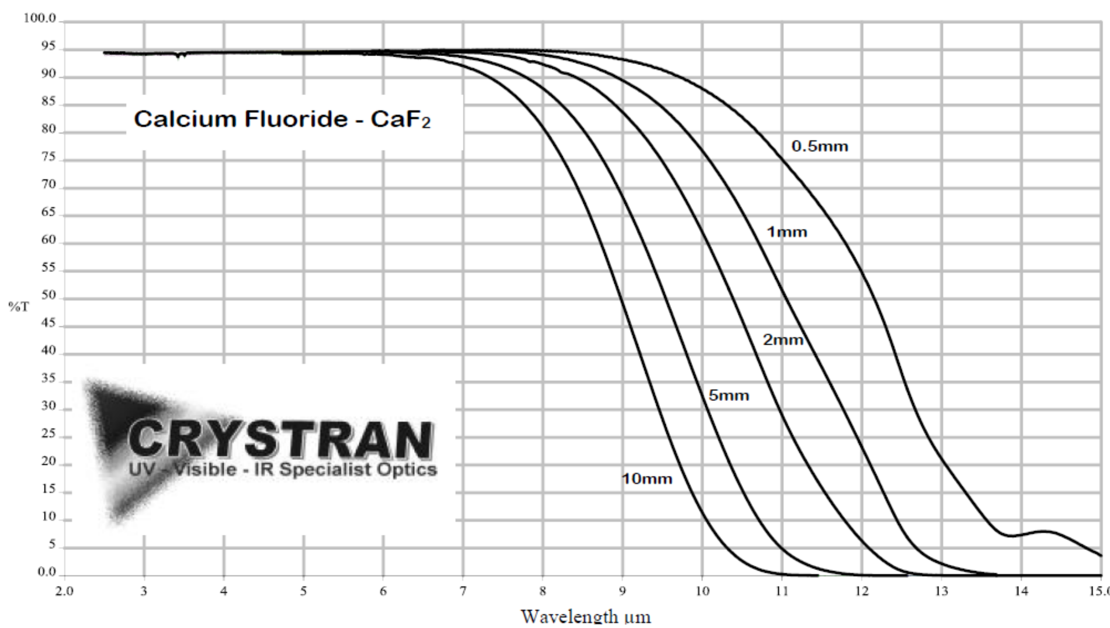

Barium Fluoride - BaF_2
%T
Wavelength µm
0.5mm
1mm
2mm
4mm
9mm
CRYSTRAN
UV - Visible - IR Specialist Optics


Sapphire Al_2O_3
%T
0.5mm
1mm
4mm
CRYSTRAN
UV - Visible - IR Specialist Optics


Germanium - Ge
CRYSTRAN
UV - Visible - IR Specialist Optics
2mm
%T
Wavelength um


Gallium Arsenide Transmission, %
7 mm thick
Wavelength, microns


Magnesium Fluoride - MgF2
%T
1mm
2mm
5.5mm
10mm
CRYSTRAN
UV - Visible - IR Specialist Optics
Wavelength µm


Calcium Fluoride - CaF2
%T
0.5mm
1mm
2mm
5mm
10mm
CRYSTRAN
UV - Visible - IR Specialist Optics
Wavelength µm