New Capability for Evaluating the Emissivity of Large Aperture Infrared Blackbodies

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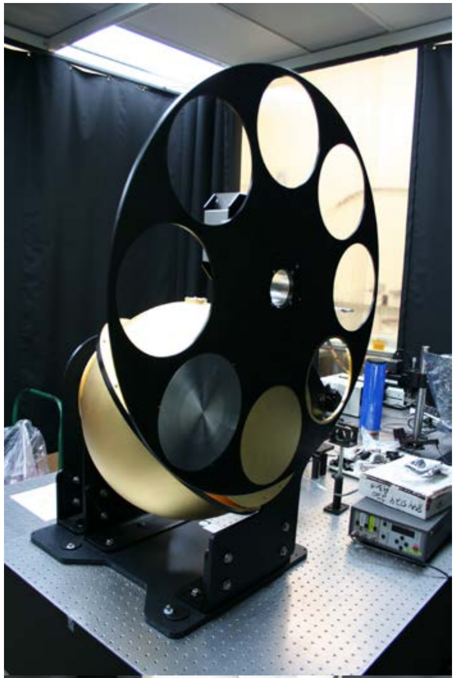
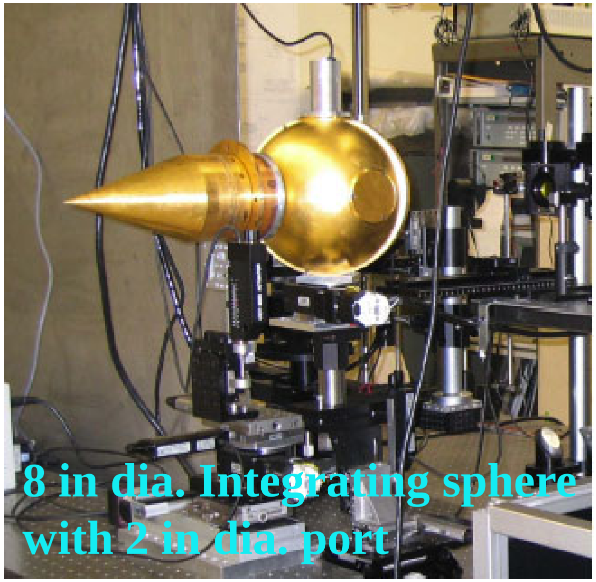
Outline

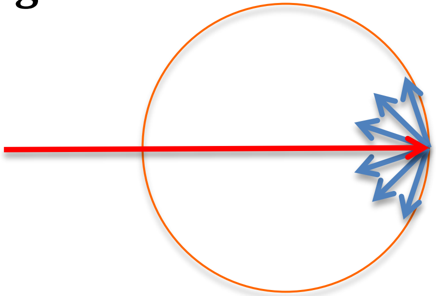
- **Introduction of CHILR**
- **New features of CHILR II comparing to CHILR I**
- **Preliminary evaluation results and comparison of two integrating spheres**
- **Summary and Future work**



Complete Hemispherical Infrared Laser-based Reflectometer (CHILR)

- **Laser → directional, high brightness**
  - **1 to 5 μm OPO laser**
  - **Tunable QCLs 4 μm & 5 μm**
  - **9 to 11 μm CO_2 Laser**
- **Integrating sphere → uniformly collecting/averaging reflected light**
- **Motion stages → spatial scan**
- **Detector → high sensitive**
  - **Pyrodetector, InSb, MCT**

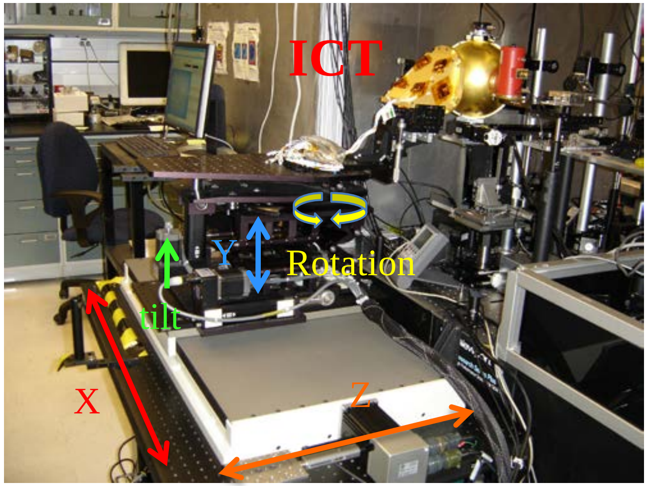




Directional-hemispherical geometry

Directional Hemispherical Reflectance (DHR)

1. **Spatial map of DHR → Averaged DHR**
2. **Angle dependence**
3. **Polarization dependence**



ICT 120 mm × 120 mm > Sphere port 50.8 mm

Ability to measure DHR less than 0.0001
Spectral range from 1 μm to 10.6 μm

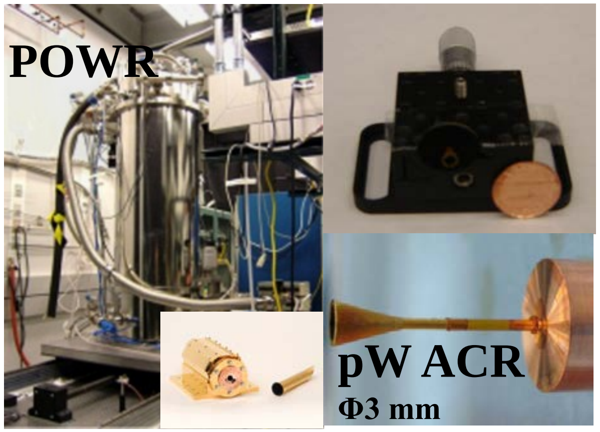
Importance of CHILR measurement

➡ Reflectance: ρ

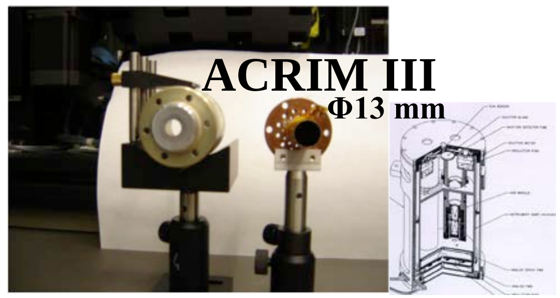
Complementary measurement for FTIS

Absolute radiometer

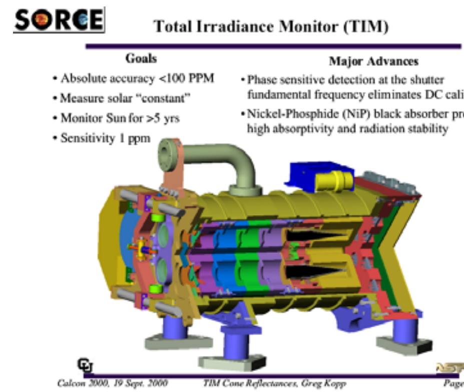
Absorptance: α=1-ρ



NIST Primary Optical Watt Radiometer



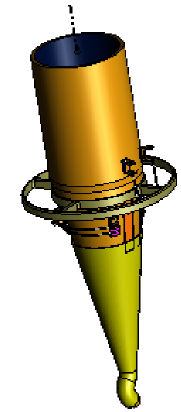
Total solar irradiance measurement


SORCE Total Irradiance Monitor (TIM)

Goals
- Absolute accuracy <100 PPM
- Measure solar "constant"
- Monitor Sun for >5 yrs
- Sensitivity 1 ppm

Major Advances
- Phase sensitive detection at the shutter fundamental frequency eliminates DC calibrations
- Nickel-Phosphide (NiP) black absorber provides high absorptivity and radiation stability

Calcon 2000, 19 Sept. 2000 — TIM Cone Reflectances, Greg Kopp — Page 6

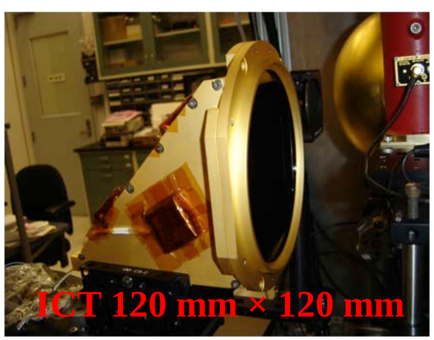


TIM

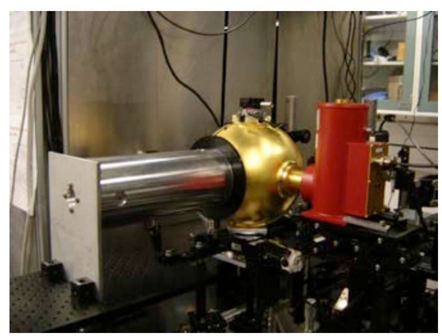
Blackbody

Effective emissivity: ε=1-ρ

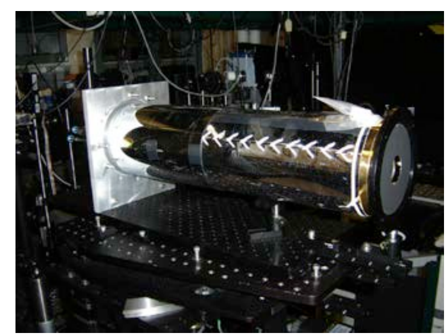
$$E_{\lambda\lambda} = \int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda,T)\frac{C_1}{\lambda^5(e^{\frac{C_2}{\lambda T}}-1)}d\lambda$$



CrIS ICT cavity



ABB



CSBB

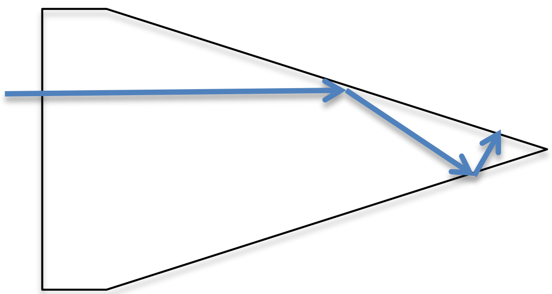
Technical challenges

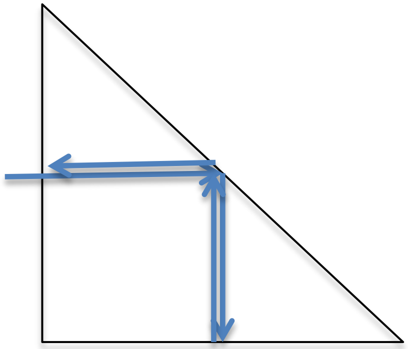
Black coating + light trap geometry → Tiny signal measurement

Ex: Coating reflectance vs Cavity reflectance

5 % 3 bounces 0.000125

BB Cavity	Reflectance		Emissivity	
	1.32 µm	10.6 µm	1.32 µm	10.6 µm
Water Bath BB		0.00005		0.99995
Water Heat Pipe		0.00012		0.99988
Ga FP BB	0.00009	0.00005	0.99991	0.99995
Cs heat pipe		0.00062		0.99938
Small cone	0.00047	0.00167	0.99953	0.99833
Large cone	0.00009	0.00045	0.99991	0.99955
Vg cavity	0.00014	0.00646	0.99986	0.99354
HVBB	0.000045	0.00005	0.999955	0.99995
SSEC	0.00005	0.0001	0.99995	0.9999
Radiometer cavity	Reflectance			
	1.32 µm	10.6 µm		
Solar irrad. 1		0.00092		
Solar irrad. 2		0.02549		
ACR 1		0.00075		
ACR 2		0.00038		
ACR 3		0.00055		



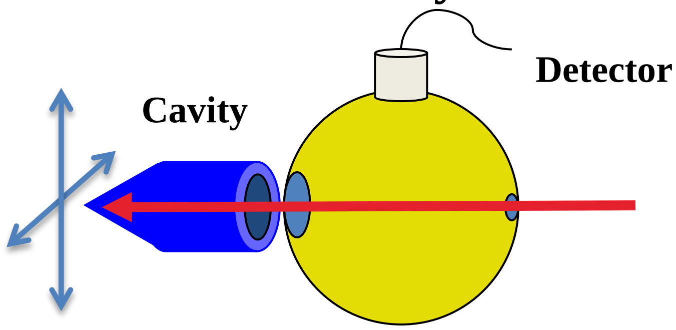


Background subtraction needed

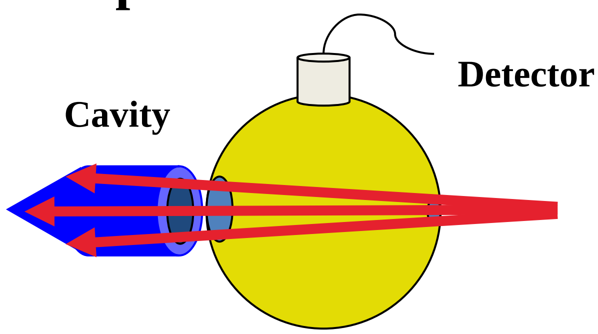
Technical challenges

Spatial reflectance measurement is necessary due to non-uniformity

1. **Scan across cavity with details**



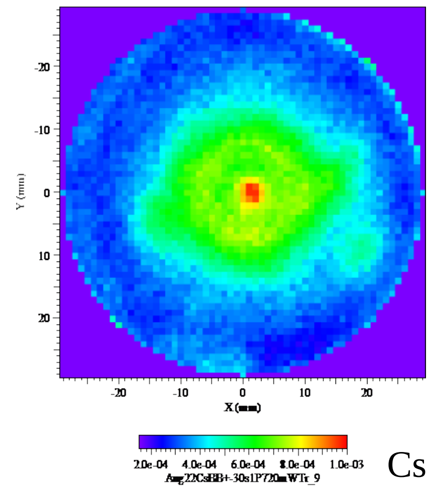
2. **Use expanded beam without details**

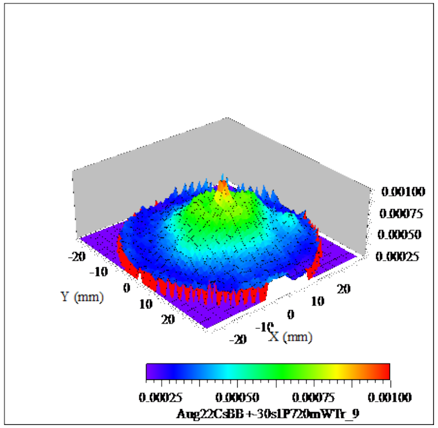


Incomplete collection of reflected light

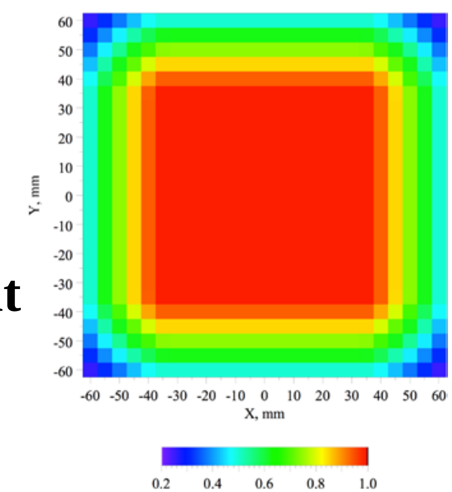
$\mathbf{D_{cavity} \geq D_{port}}$

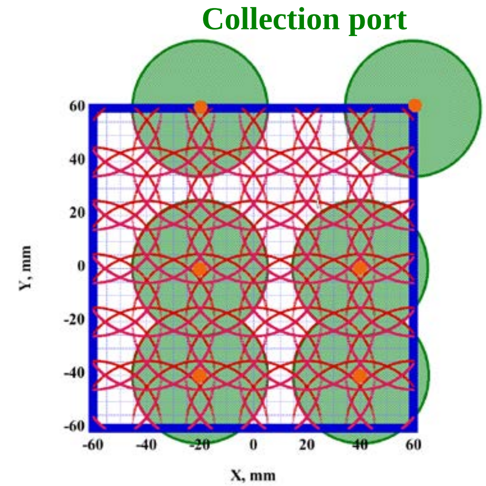
$\mathbf{D_{port} = 2D_{cavity}}$ **for full scan without loss**





Cs heat pipe





Area correction of results for CrIS ICT

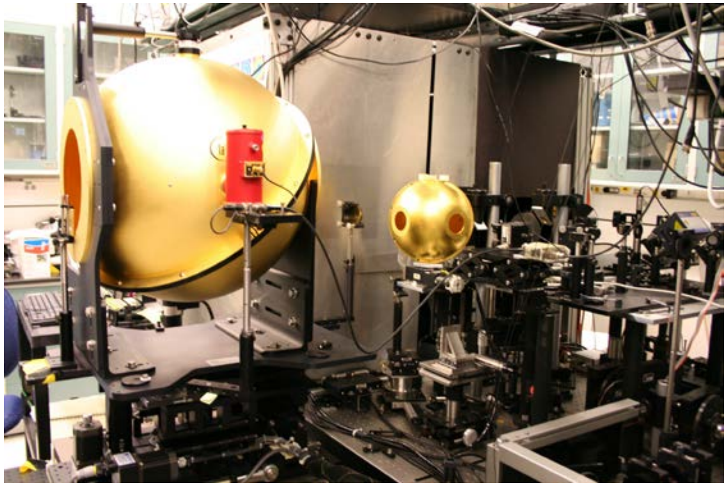
Design of new integrating sphere

Basic parameter	CHILR I	CHILR II
Sphere diameter	8 in dia.	20 in dia.
Input port	6 mm dia.	10 mm × 4 in slot
Collection port	2 in dia. × 2	8 in dia.
Detector port	0.5 in/2 in dia.	0.5 in/0.5 in dia.
Coating	Infragold	Infragold
Port fraction	1.7%–3%	4%

The first rule of thumb for integrating sphere design:

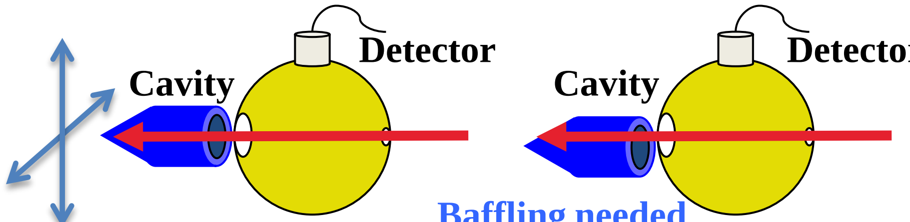
Port fraction < 5 %

If port fraction > 5%, the advantage of high reflectance coating on integrating sphere starts to lose.

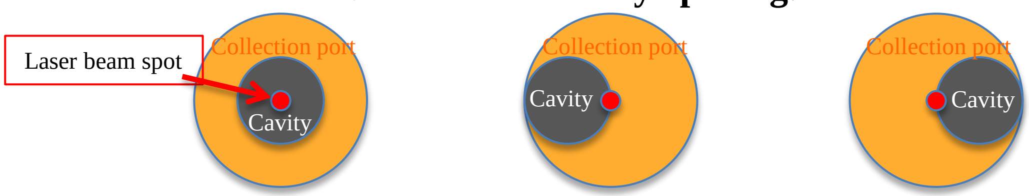


Unique spatial scan method

◆ Current scan method of CHILR I



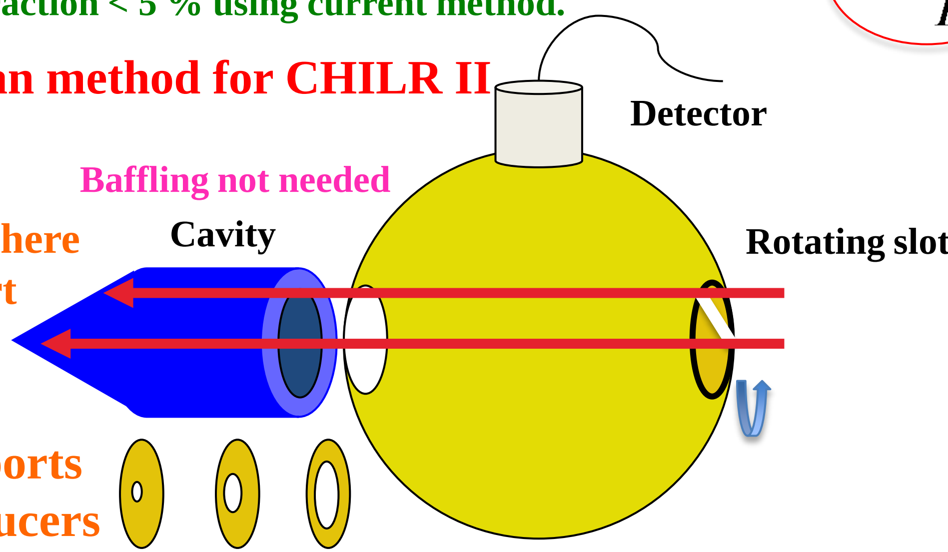
To measure the reflected light completely, the collection port has to be the doubled-size of cavity opening.



For 8” cavity opening, 36” diameter sphere is needed to meet the port fraction < 5 % using current method.

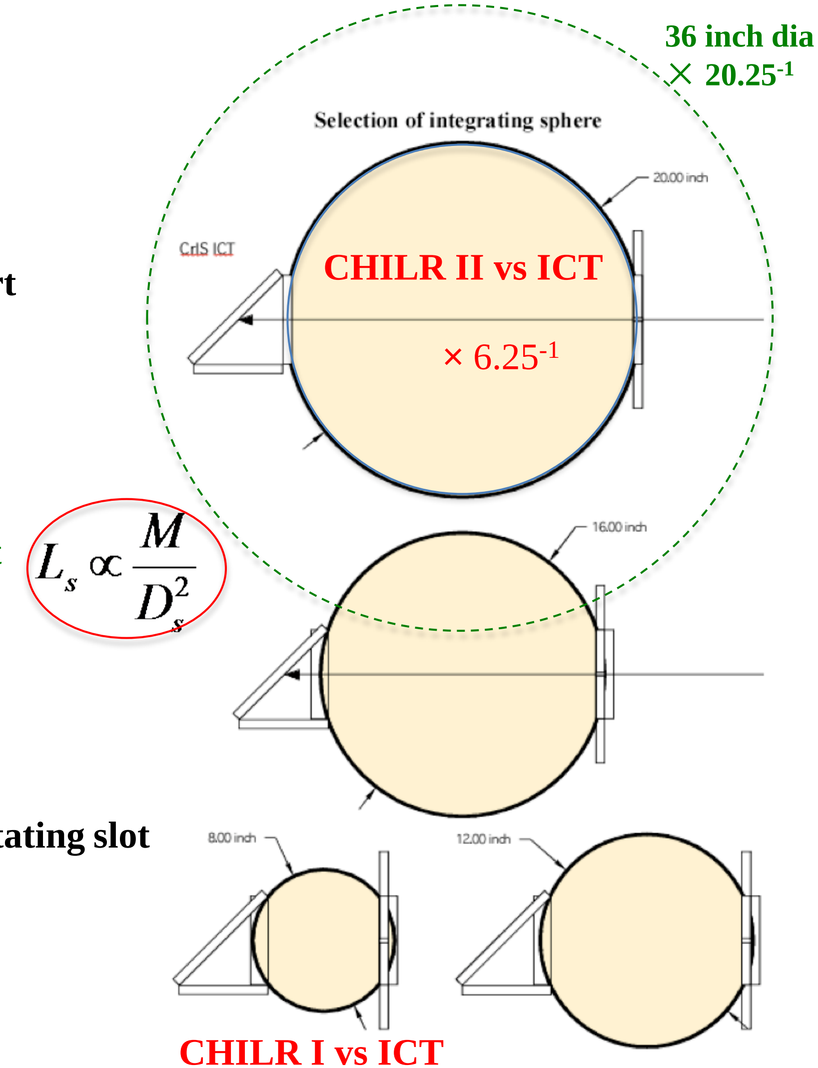
★ New scan method for CHILR II

CHILR II
20” dia. sphere
8” dia. port



Flexible ports using reducers

It is not just different in size.



$$L_s \propto \frac{M}{D_s^2}$$

CrIS ICT 120 mm × 120 mm

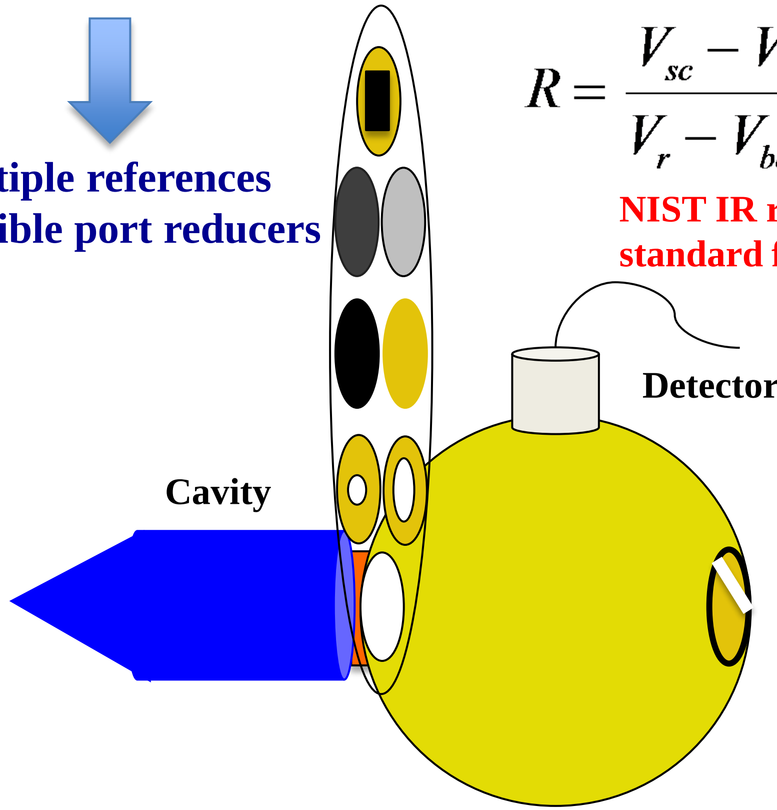
Reference measurement for CHILR II

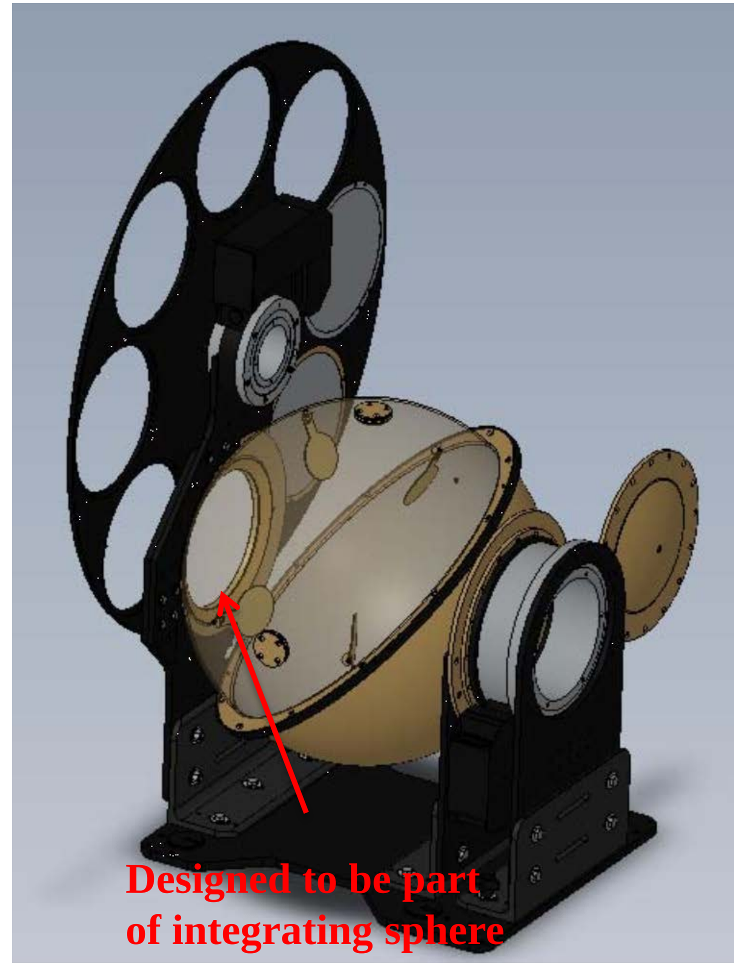
Reference wheel with 8 ports

Multiple references
Flexible port reducers

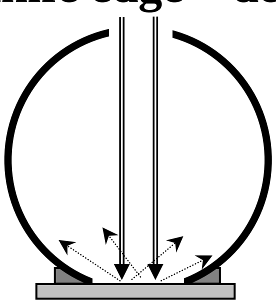
$$R = \frac{V_{sc} - V_{ap}}{V_r - V_{back}} R_r$$

NIST IR reflectance standard from FTIS

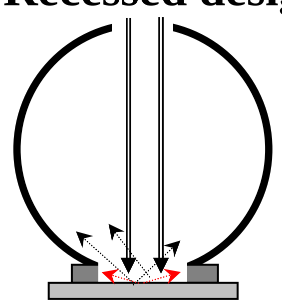




"Knife edge" design



Recessed design



Since the edge of each port is functioned as part of the integrating sphere, it is very close to knife-edge port without recess.

Total flux received by detector on integrating sphere

The radiance of an internally illuminated integrating sphere:

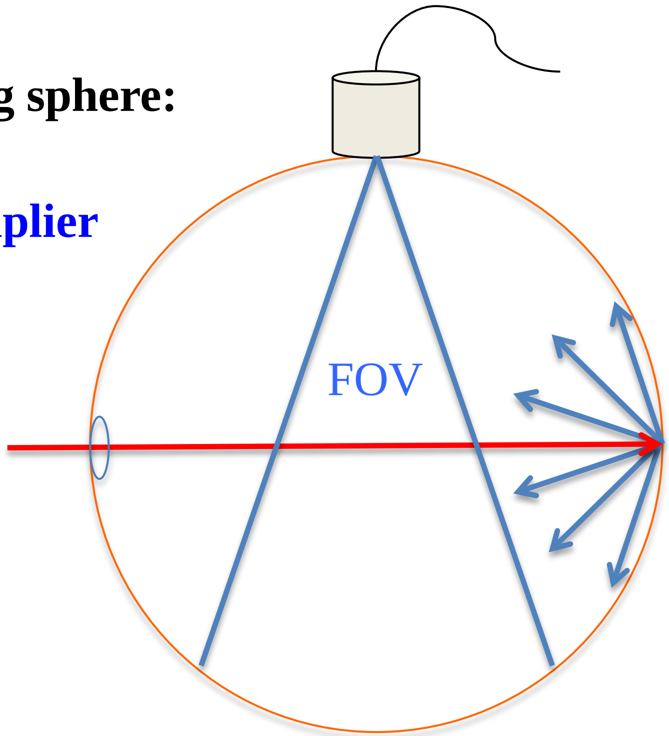
$$L_s = \frac{\Phi_i}{\pi A_s} \frac{\rho_0}{1 - \rho_w \left(1 - \sum_k^n f_k\right) - \sum_k^n \rho_k f_k}$$

BRDF

M Sphere multiplier

The total flux incident on detector active area:

$$\Phi_d = L_s A_d \Omega_d = A_d \Omega_d \frac{\Phi_i}{\pi A_s} \frac{\rho_0}{1 - \rho_w \left(1 - \sum_k^n f_k\right) - \sum_k^n \rho_k f_k}$$

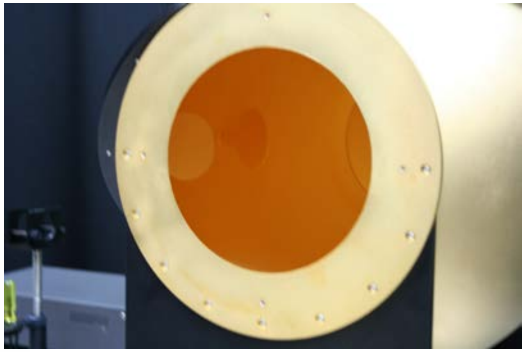


Lambertian (Ideal diffuse) Surface

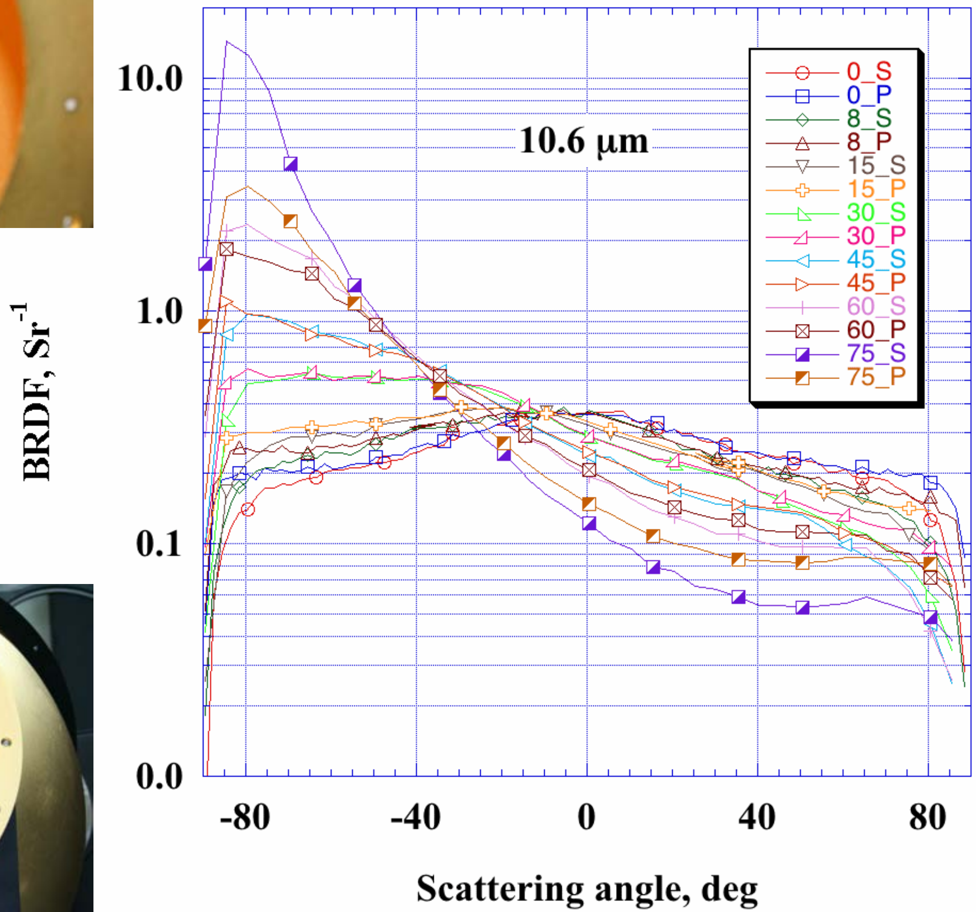
- ρ_0 **the initial reflectance for incident flux**
- ρ_w **the reflectance of the sphere wall**
- ρ_k **the reflectance of port opening**
- f_k **the fractional port area of port opening**

- Φ_i **the incident flux**
- A_d **the detector active area**
- Ω_d **the projected solid angle of detector FOV**

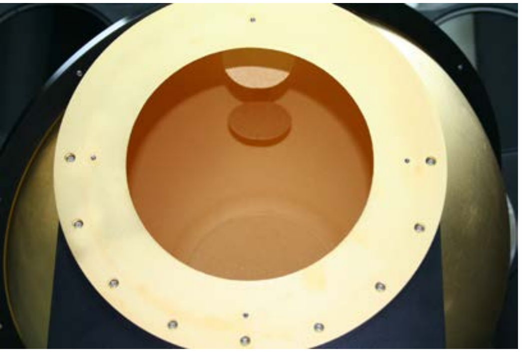
BRDF of gold coating for CHILR II



BRDF $f_r = \frac{dL_r}{dE_i} = \frac{dL_r}{L_i d\Omega_i} = \frac{d\Phi_r}{\Phi_i d\Omega_r}$



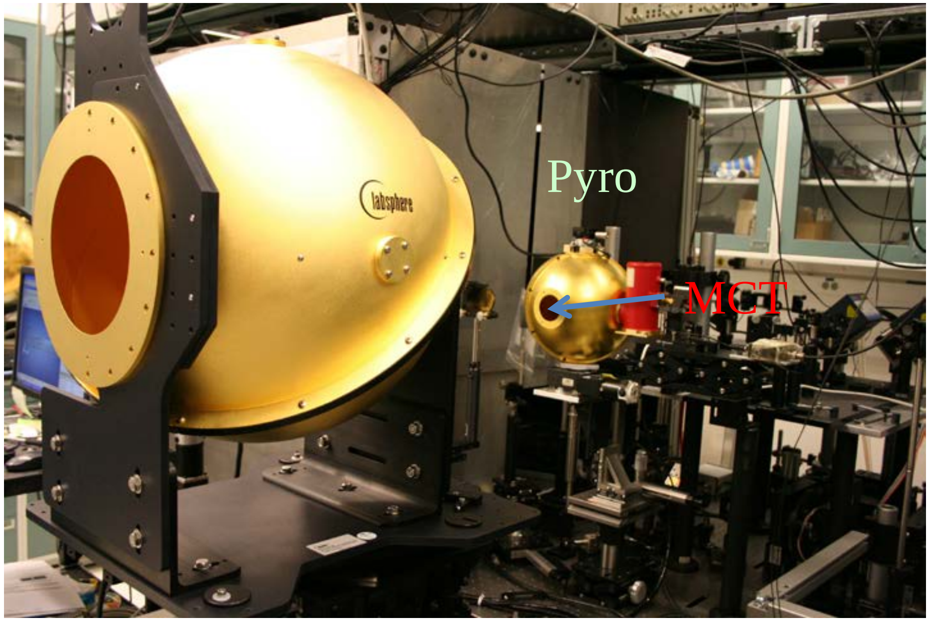
← $\frac{1}{\pi}$ **Lambertian (ideal diffuse)**



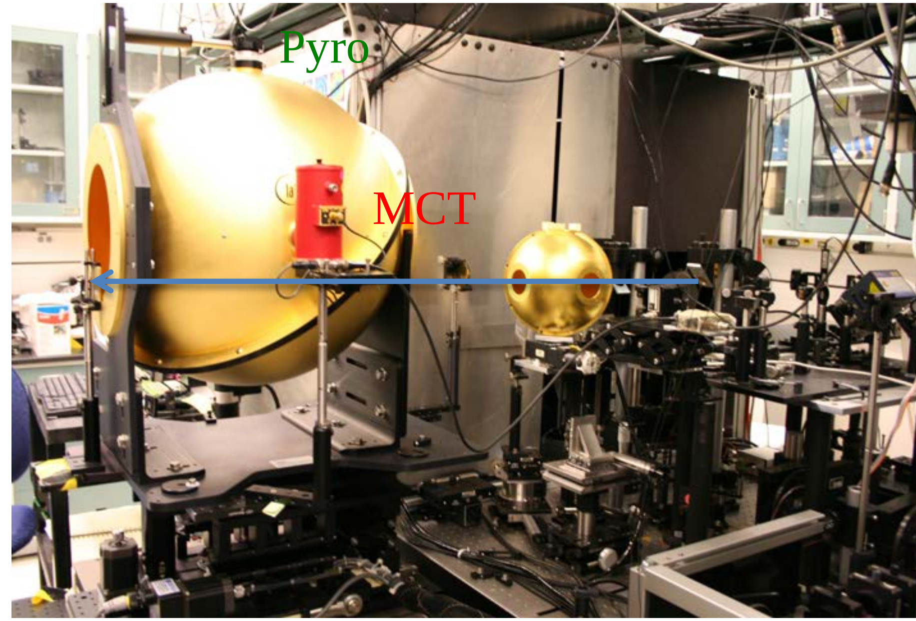
Preliminary test setup

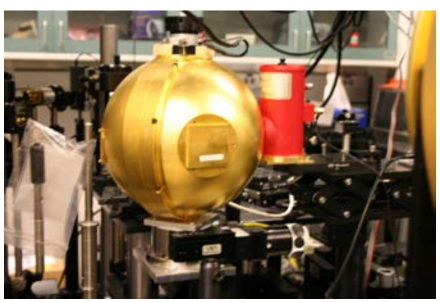
10.6 μm

CHILR I

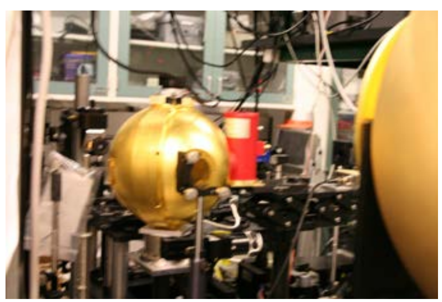


CHILR II

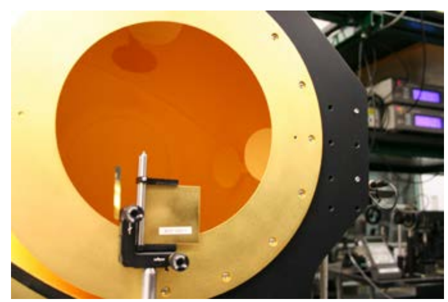




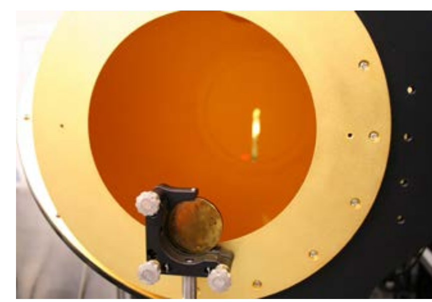
Diffuse gold
99 %



Specular black
5 %



Diffuse gold
99 %



Specular black
5 %

Preliminary test results @ 10.6 µm

CHILR	Diffuse gold 99%				Specular black 5%				19.8	
	MCT	SNR_{mct}	Pyro	SNR_{pyro}	MCT	SNR_{mct}	Pyro	SNR_{pyro}	D/S_{mct}	D/S_{pyro}
I	3.4939	5e-4	0.1824	5e-4	0.1360	1e-2	0.0071	1e-2	25.69	25.69
II	0.1780	9e-4	0.0131	4e-3	0.0087	2e-2	0.0006	8e-2	20.46	20.95
Ratio I/II	20		14		17		12			

The total flux incident on detector active area:

$$\Phi_d = L_s A_d \Omega_d = A_d \Omega_d \frac{\Phi_i}{\pi A_s} \frac{\rho_0}{1-\rho_w\left(1-\sum_k^n f_k\right)-\sum_k^n \rho_k f_k}$$

$\rho_w^I = \rho^{II} =_w 96\%$

$\rho^{DG} = 99\%$

$\rho^{SB} = 5\%$

$$\frac{\dfrac{\Phi_m^I(DG)}{\Phi_m^{II}(DG)}}{\dfrac{\Phi_m^I(SB)}{\Phi_m^{II}(SB)}} = \frac{\dfrac{\Phi_p^I(DG)}{\Phi_p^{II}(DG)}}{\dfrac{\Phi_p^I(SB)}{\Phi_p^{II}(SB)}} = \frac{1-\rho_w^{II}\left(1-\sum_k^n f_k^{II}\right)-\sum_k^n \rho_k^{DG} f_k^{II}}{1-\rho_w^{I}\left(1-\sum_k^n f_k^{I}\right)-\sum_k^n \rho_k^{DG} f_k^{I}} \times \frac{1-\rho_w^{I}\left(1-\sum_k^n f_k^{I}\right)-\sum_k^n \rho_k^{SB} f_k^{I}}{1-\rho_w^{II}\left(1-\sum_k^n f_k^{II}\right)-\sum_k^n \rho_k^{SB} f_k^{II}} = 1.2165$$

20/17≅1.18 MCT
14/12≅1.16 Pyro

Throughput vs port fraction & sample reflectance

CHILR	Diffuse gold 99%				Specular black 5%				19.8	
	MCT		Pyro		MCT		Pyro		D/S$_{mct}$	D/S$_{pyro}$
I	3.4939		0.1824		0.1360		0.0071		25.69	25.69
II	0.1780		0.0131		0.0087		0.0006		20.46	20.95

$$\Phi_d = L_s A_d \Omega_d = A_d \Omega_d \frac{\Phi_i}{\pi A_s} \frac{\rho_0}{1-\rho_w\left(1-\sum_k^n f_k\right)-\sum_k^n \rho_k f_k}$$

$$\rho_w^I = \rho^{II} =_w 96\%$$

$$\rho^{DG} = 99\%$$

$$\rho^{SB} = 5\%$$

$$\frac{\Phi_{MCT}^I(DG)}{\Phi_{MCT}^I(SB)} = \frac{\Phi_{pyro}^I(DG)}{\Phi_{pyro}^I(SB)} = \frac{\rho^{DG}}{\rho^{SB}} \times \frac{1-\rho_w^I\left(1-\sum_k^n f_k^I\right)-\sum_k^n \rho_k^{SB} f_k^I}{1-\rho_w^I\left(1-\sum_k^n f_k^I\right)-\sum_k^n \rho_k^{DG} f_k^I} = 25.05$$

$$\frac{\Phi_{MCT}^{II}(DG)}{\Phi_{MCT}^{II}(SB)} = \frac{\Phi_{pyro}^{II}(DG)}{\Phi_{pyro}^{II}(SB)} = \frac{\rho^{DG}}{\rho^{SB}} \times \frac{1-\rho_w^{II}\left(1-\sum_k^n f_k^{II}\right)-\sum_k^n \rho_k^{SB} f_k^{II}}{1-\rho_w^{II}\left(1-\sum_k^n f_k^{II}\right)-\sum_k^n \rho_k^{DG} f_k^{II}} = 20.38$$

Summary and future work

- **CHILR II with new capability for evaluating emissivity of large aperture blackbody was delivered.**
- **Preliminary tests have been done and the throughput test results agree with calculated results.**

- **Integration of CHILR I and CHILR II**
- **Implementation of rotation stages for the input port and the reference wheel**
- **Installation of references and reducers**
- **Beam alignment and background measurements**
- **New laser beam scan system**
- **DHR measurement for ICT cavity using CHILR II**