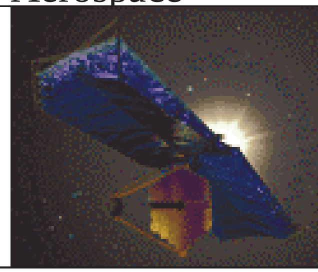
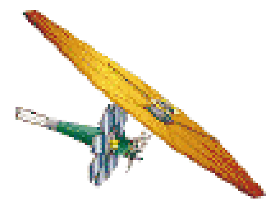
Mid-Infrared Prospects for NGST

Talk Outline

- Telescope & Instrument Complement Overview
- Evolution of MIR NGST Capabilities
- MIR Sensitivities
- MIR Instrument Concerns
- Ideas for MIR Instrumentation
- Current Status of NGST Instrument Suite
- Future of MIR Instrumentation on NGST

Telescope & Instrument Complement Overview

	TRW/Ball Aerospace	GSFC	Lockheed Martin
			
Primary mirror diameter (m)	>8.0	8.0	8.0
Orbit	L2 Lissajous	L2 Halo	L2 Halo
Mission lifetime	10 years	10 years	10 years
Wavelength Coverage	0.6-30 μm	0.6-30 μm	0.6-32μm
NIR Camera FOV	4'×4'	4'×4'	4'×4'
NIR Spectrometer	3'×3', MOS	3'×3', MOS	3'×3', MOS
MIR Camera FOV	2'×2'	2'×2'	2'×2'
MIR Spectrometer	slit	slit	slit
Diffraction Limit	2.0μm	2.2μm	2.0μm
NIR pixel scale	0.029"/pixel	0.029"/pixel	0.029"/pixel
MIR pixel scale	0.230"/pixel	0.230"/pixel	0.121"/pixel
Observatory mass (kg)	EELV medium compatible	2480	3600
1 year sky coverage	~100%	~100%	~100%
Point Source Sensitivity [nJy] (10,000 sec, R~5, S/N=10)			
1μm	2.5	3	3.7
2μm	2.6	3	2.1
3μm	2.2	3	1.9
5μm	9.9	12	7.6
10μm	142	181	130
20μm	629	1570	1000
See http://ngst.gsfc.nasa.gov/ for more details.			

Evolution of MIR NGST capabilities (I)

- 1995 Dressler report called for a NIR zodiacal light limited observatory working in the 1 to 5μm range.
    - 1-5μm is "core."
    - 5-28μm considered a "stretch requirement."
- 1996-97 Goddard designed (& evolved) a Yardstick mission (telescope & instrument complement).
    - Contains four instruments: NIR (1-5μm) camera, NIR MOS spectrograph with MMA, MIR (5-28μm) camera, and MIR single-object spectrograph.
- 1997 DRM (Design Reference Mission) was created (& evolves) to help shape instrument requirements based on core science goals.

Evolution of MIR NGST capabilities (II)

•1998 Memo by Bély, et al. on the implications of MIR capability for NGST recommended a mid-IR "compatible" architecture.

- •Passively cooled telescope & optics to 30-40K (zodi limited imaging system to 10μm).

•1999 Ranking of the DRM led to requiring both NIR instruments essential and the MIR instruments very important.

NGST will have mid-IR capability in some form.

Key reasons for why NGST should have 5-30μm capability

From ESA MIRCAM/IFS study report…

•NGST will surpass ground based 8m telescopes in sensitivity by 3 orders of magnitude for $\lambda > 5\mu m$.

•Even if performance is limited by scattered radiation from sunshield, NGST will be more sensitive than SIRTF and will have a critically important large spatial resolution advantage.

•There is clear evidence (from ISO work) that without observing the universe above 10μm, NGST would miss much of the star formation history.

•MIR lines are unique diagnostic lines of star formation, the ISM, and nearby galaxies

•MIR observations out to 30μm would distinguish between dusty AGNs and starbursts (dust features and fine structure lines) & probe formation of stars and planetary systems deep in molecular clouds.

•Diffraction limited observations at 10μm will spatially resolve planet formation, holes in proto-planetary disks to 200pc.

•MIR spectroscopy 5-30μm yields unique information about solid material condensing during planet formation (rotational H_2 lines, CH_4CO_2,NH_3,H_2O).

MIR Needed For Top 7 DRM Programs

DRM Program	Major Required Instrument Capabilities	Comments
1. Deep Galaxy Imaging	Wide Field NIR Imaging (1/2) Wide Field vis and 10µm imaging (1/2)	112 days with 4’×4’ FOV
2. Deep Galaxy Spectroscopy	R=100, 1000, multi-object and R>3000 long slit at λ=3.5µm R=5000 at λ=10µm	98 days 20 days
3. Dark Matter	Wide Field NIR Imaging	192 days for 4’×4’
4. Probing the IGM	R=100 NIR spectroscopy	10 days
5. High z Supernovae	WF NIR Imaging	some spect; 1 week follow-up
6. High z Obscured Galaxies	λ=8-36 µm Wide Field Imaging R=300 Multi-object MIR spectroscopy	54 days / at least 2’×2’ FOV 10 days
7. Physics of Protostars	λ=15-35µm Imaging R>3000 spectroscopy λ=6-30µm	70 days, single object observations

MIR imaging & spectrographic capabilities are essential for 4 of the 7 core programs identified by the ASWG.

MIR Sensitivity Issues (I)

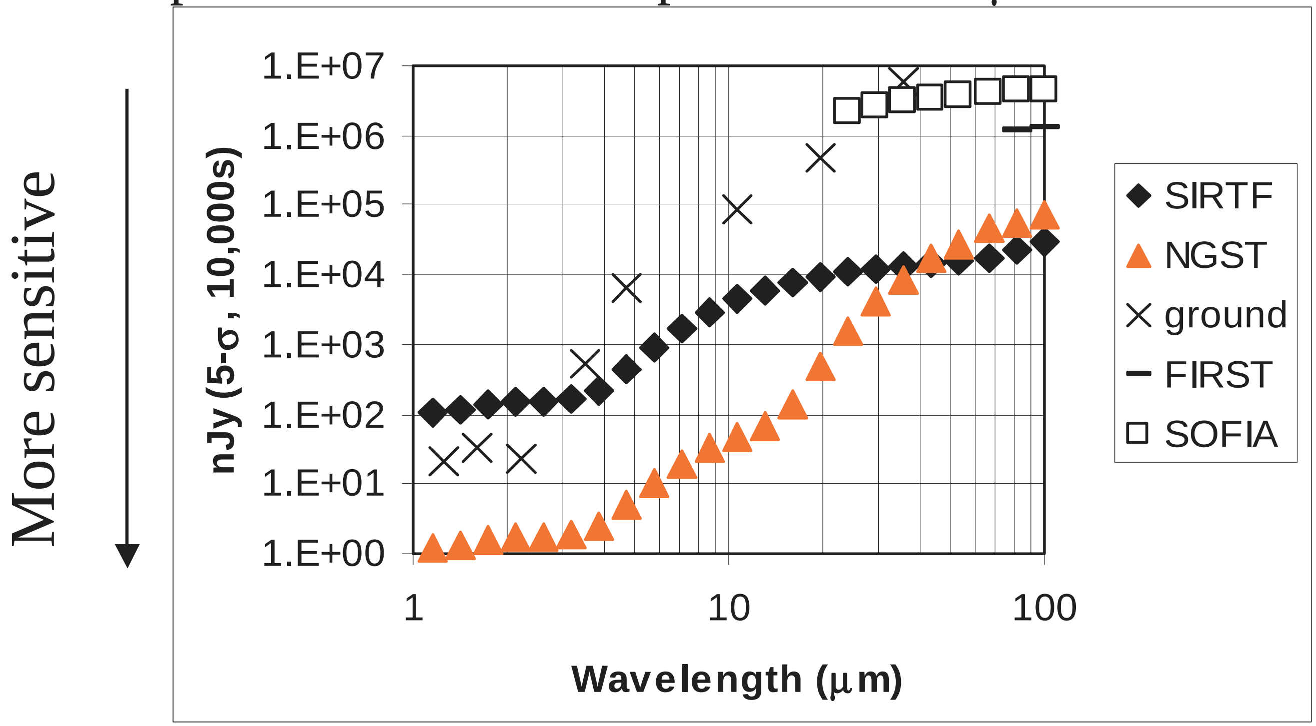
Zodiacal light limited	Thermal emission from primary and/or scattered light from sunshade limited	Detector limited (extreme case)
• 5-16μm (R<10) imaging • 5-10μm low resolution (R~100) spectroscopy	• λ>16μm (R<10) imaging • λ>10μm low resolution (R~100) spectroscopy • λ>16μm high resolution (R=1000) spectroscopy	• 5-16μm high resolution (R=1000) spectroscopy • 5-20μm super high resolution (R=3000) spectroscopy

As since the main DRM MIR emphasis is on wide field imaging, the majority of MIR science will be background limited with NGST.

High resolution (R>1000) spectroscopy will pose additional constraints to existing detector & cooler technology.

MIR Sensitivity Issues (II)
Background limited case comparison

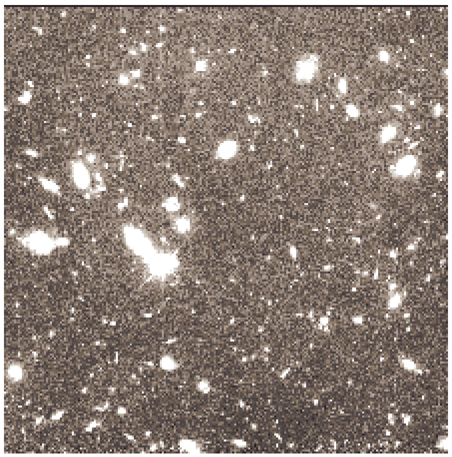
NGST MIR sensitivity will far exceed SIRTF, SOFIA, and ground based IR-optimized 8m telescopes from 1-30μm.



Comparison of background limited sensitivity of NGST (8m diameter) with a SIRTF-based, cryogenic telescope (85cm diameter, 5K operating temperature), FIRST, SOFIA, and a ground-based IR-optimized 8m. Sensitivities from FIRST, SOFIA, and ground-based 8m are from Gillett & Mountain 1997. NGST sensitivities assume a telescope temperature of 50K, emissivity of 10%. Both SIRTF and NGST have 50% detector QE, 50% instrument efficiency, and pixels which fully sample the diffraction pattern.

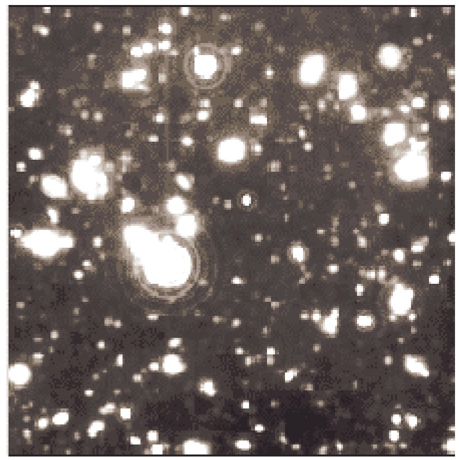
Unique science in the MIR

NGST will provide unprecedented resolution in the MIR/LIR. The NGST long wavelength camera in our study will be a vast improvement over SIRTF for detection of star formation and other activity in distant galaxies and the study of their morphology. Similar gains will be achieved in observing nearby planetary systems and their debris disks.



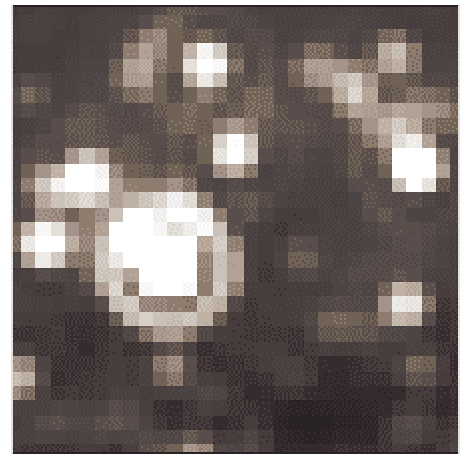
HDF at 0.606µm

Portion of the Hubble Deep Field observed with WFPC2 (F606W, 0.16”/pixel).



NGST at 36µm

Same HDF image as it would be observed with NGST at 36µm. Image has been convolved with the Airy pattern for an 8m aperture with 1.5m obstruction with sampling of our MIR imager at 0.3”/pixel.



MIPS at 24µm

Same HDF image as it would be observed with MIPS on SIRTF at 24µm. Images has been convolved with an Airy pattern for a 85cm telescope with 32cm central obscuration with sampling at 2.4”/pixel.

MIR Instrument Concerns (I)

Detector Optimization

- In any MIR instrument -- strict temperature stability requirements
- MIR imaging (R≤10) -- wide field essential -- large format
- Low power dissipation since will be actively cooled (minimizes size of cooler)
- Three regimes for optimized performance
    - 5-10µm imaging & 5-15µm R=100 -- zodi-limited -- detectors need to reach certain constraints particularly at 5µm (best QE here).
    - 5-20µm R=1000-3000 spectroscopy -- detector limited -- tougher constraints on read noise & dark current.
    - λ>10µm imaging -- background dominated by the sunshade & telescope thermal emission -- detectors need deep wells & fast readout rates (low noise no longer a priority).

MIR Instrument Concerns (II)

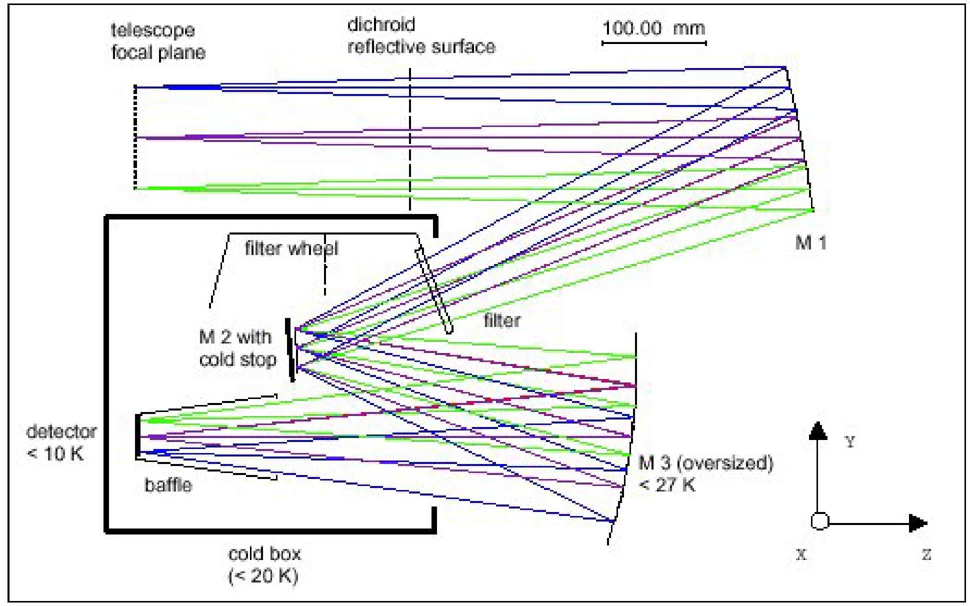
Cooling Required

- Telescope & instrument compartment are cooled to 30-40K. MIR detectors & optics generally operate below this, with exception of QWIPs.
- Options are mechanical coolers or solid/liquid “conventional” cryogens.
- No clear way has been decided for optimal cooling method.
- Several paths are being funded (turbo-braytons, sorption, pulse tube). “Conventional” cryogenic method needs further analysis.

Ideas for MIR instrumentation (I)
The Camera

The science

- galaxy evolution studies
- luminous galactic nuclei
- star formation
- life of dust grains
- evolution of circumstellar disks
- detection of thermal emission from planets around near-by stars



ESA MIRCAM-LW optical configuration

Overall desired instrument specs

- wide field of view -- 1kx1k detectors wanted -- maybe mosaics
- optimal sampling of focal plane requires at least two plate scales (5-10µm, 10-28µm)
- broad & narrow band filters
- baffling required

Ideas for MIR instrumentation (II)
The Camera

Technology Development

•MIR beamsplitters

•cooler development

•large format, high QE, low noise detectors & readout electronics

•lack of non-hydroscopic transmissive dielectrics (filters, grisms, AR coatings) for $\lambda>15\mu m$

Trades

•dichroic beam-splitter vs. cost of two modules

•choice of detector/cooler affects sensitivity (science objectives)

Ideas for MIR instrumentation (III)
The Spectrograph (R=100-1500+)

The science

- diagnostic emission line features to z~2, Hα to z~15, AGN to z~1
- fine structure lines [NeII] 12.8mm, [NeV] 14.3mm, [NeIII] 15.6mm, [SIII] 18.7mm (R ≥1000) in merging, dusty galaxies
- broad PAH emission features from small grains (R=100)
- narrow atomic H lines in star bust galaxies (R≥1000)
- molecular H_2 (R=100) in ISM
- redshifted NIR [FeII] lines, tracers of energetics in galaxies (R=1000)
- redshifted CO bandheads, indicators of young stellar populations (R ≥ 1000)
- circumstellar disk mineralogy
- physics of protostars
- water, methane, molecular line studies of giant planets (R=3000)
- follow-up study of new MIR sources discovered by SIRTF and ISO

Ideas for MIR instrumentation (IV)
The Spectrograph (R=100-1500+)

Overall desired instrument specs

- optimal sampling of focal plane requires at least two plate scales (5-10µm, 10-28µm)

  splitting at 10µm also minimizes effect of thermal backgrounds from instrument optics on the short wavelength sensitivity

- all reflective design better controls thermal background & achromaticity
- long slit design will yield best background-limited sensitivity on single objects
- no big drive for MOS mode
- an integral field mode is desired

Technology development

- grism materials for λ>18µm with acceptable transmission & high index

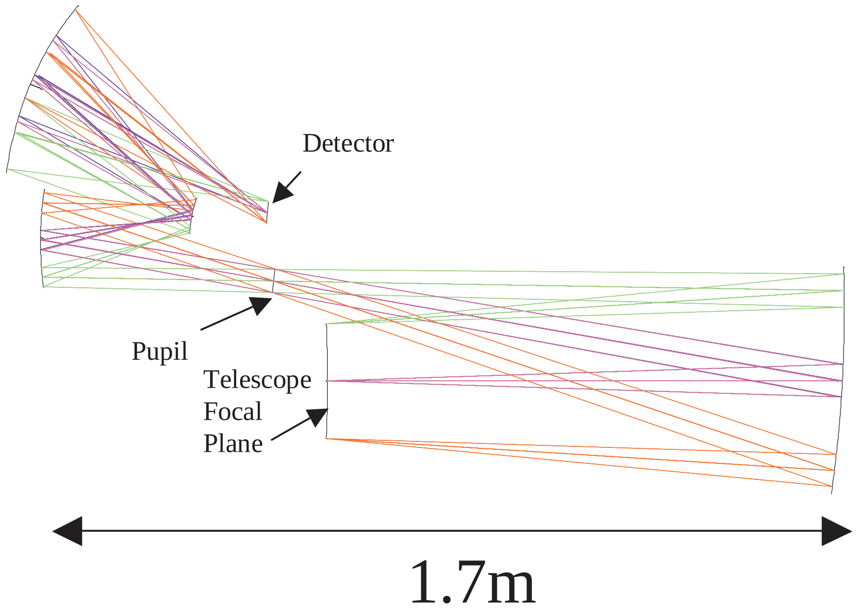
  KRS-5 is only the available material & can be ruled, but problems and risks in mounting in large pieces are envisioned in NGST application.

- grism ruling techniques -- resin grisms absorb λ>2.5µm
- low noise detectors (detector limited λ>10µm R=1000, λ>5µm R=3000) / cooler options affect sensitivity

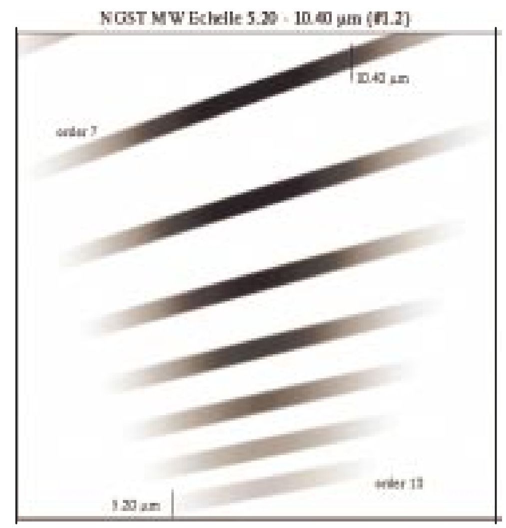
Ideas for MIR instrumentation (V)
The Spectrograph (R=100-1500+)

R=50-100	R=1000	R=1000-3000
• grisms preferred -- simple, can be add-on to camera • slit based will be more sensitive than slitless, thus adds a mechanism to camera	• gratings are suggested instead of grisms to minimize instrument size (grism resolving power is a function of pupil size) • Serabyn, et al. design obtains R=1000 without fine grating drive • if grisms chosen, high index material is required, Arizona/Ames/LMMS study found KRS-5 to be acceptable for R=1000	• complicates the instrument • dark current limited regime -- stronger restraints on detector performance • cross-disperser is required or sequential measurements of orders with appropriate order sorting filters (less efficient) • grating drive required, more mechanisms

Ideas for MIR instrumentation (VI)
The Spectrograph (R=3000)



Orders 7-19
(5.2-10.5μm)



Orders 10-16
(10.2-18.75μm)

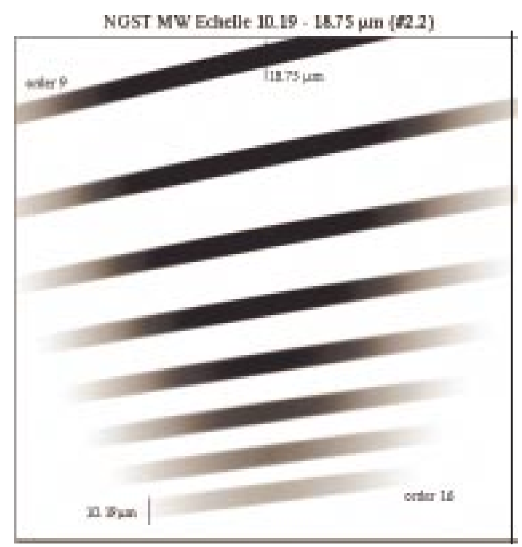


Illustration of proposed two dimension spectra for R=3000 cross-dispersed echellette with 1kx1k detector. These fixed formats each require one echelle grism and one cross-dispersing grism, both optimized for the wavelength regions. They can be placed in parallel with two filter wheels at the pupil position.

Current Status of NGST Instrument Suite

At the January 2000 AAS, after technical and scientific panels reviewed the conceptual studies, the following instrument complement was recommended as a minimum for NGST:

- A camera with near IT and visible filters, sensitive over 0.6-5µm
- A multi-object dispersive spectrograph (MOS) for 1-5µm, with R~1000
- A combined camera/slit spectrograph for 5-28µm with R~1500

And at least one of the following key capabilities also highly recommended:

- An integral field spectrograph (IFS) for 1-5µm
- A high-resolution camera, optimized for 0.6-1µm
- An integral field spectrograph (IFS) for 5-28µm

Future of MIR Instrumentation on NGST

☺ Hurrah to the ASWG!!! Project is still willing to take on MIR instruments -- definitely camera, spectrographs will be tricky.

☺ Detector issues are getting the necessary attention.

☹ Coolers still remain the biggest risk.

☹ Filters/AR coatings need to be addressed when more concrete designs emerge.

☹ Learn from SIRTF -- warm launch, passively cooled telescope, “conventional” cryogens, Si:As & InSb behavior.

☹ The MIR instrument(s) will be the first to lose sensitivity as the sunshade deteriorates with time.