document title/ titre du document

SPICA - SPACE INFRARED TELESCOPE FOR COSMOLOGY AND ASTROPHYSICS

CRYOGENIC TELESCOPE ASSEMBLY

SCIENCE REQUIREMENTS DOCUMENT

---

prepared by/*préparé par*	SPICA Telescope Science Study Team
reference/*réference*	RSSD-SPICA-002
issue/*édition*	1
revision/*révision*	2
date of issue/*date d'édition*	15 January 2009
status/*état*	issue
Document type/*type de document*	RQ
Distribution/*distribution*	

European Space Agency
Agence spatiale européenne

ESTEC
European Space Research and Technology Centre - Keplerlaan 1 - 2201 AZ Noordwijk - The Netherlands
Tel. (31) 71 5656565 - Fax (31) 71 5656040 www.esa.int

APPROVAL

Title *Titre*	SPICA Cryogenic Telescope Assembly Science Requirements Document	issue *issue*	1	revision *revision*	2

author *auteur*	SPICA Telescope Science Study Team: Marc Ferlet Norbert Geis Ana M. Heras Takashi Onaka Bruce Swinyard Sebastien Vives	date *date*	15 January 2009
Contributors	Keigo Enya Nicola Rando Thomas Jagemann		

approved by *approuvé par*	date *date*

CHANGE LOG

reason for change /*raison du changement*	issue/*issue*	revision/*revision*	date/*date*
Updates and clarifications following ESA internal Assessment Study	1	1	8 May 2008
Document updated following Industry's requirements review as part of the Baseline Selection Review	1	2	15 January 2009

CHANGE RECORD

Issue: 1 Revision: 1

reason for change/*raison du changement*	page(s)/*page(s)*	paragraph(s)/*paragraph(s)*
Acronyms PST, PTV added	3	

reason for change/*raison du changement*	page(s)/*page(s)*	paragraph(s)/*paragraph(s)*
5 replaced by 3.3	8	2.1.4.5
Last sentence modified to clarify that over 1-1000 micron "knowledge" is what is required.	14	3.1/R1
"over the full telescope FoV" added.	14	3.2.2/R3
BOL defined as beginning of life with respect to in-orbit science operations.	17	3.2.3/Note after R6
Previous R11 and R12 deleted as requirements and changed to description bullets. As a consequence, the following requirements in the document have a different numbering from issue 1.0.	18	3.3.2
Requirement modified so that it is specified for the telescope instead of per mirror, and assuming full correction by the coronagraph. Goal requirement added.	19	3.3.2/CR4
Note on CR4 modified according to change in requirement.	19	3.3.2/CR4
Previous Figure 3 deleted	19	3.3.2/CR4
Requirement modified to specify that it applies in case R12 is not met. Note added.	21	3.4.2/R13
Note with average flux values for the zodiacal light added.	22	3.5/R15
Phrasing improved.	22	3.5/R16
Previous requirement R19 deleted and replaced by new requirements R17 and R18. The goal requirement has also been removed.	22	3.5/R17,R18
Requirement numbers updated following changes in document	25	4/Table 2

Issue: 1 Revision: 2

reason for change/*raison du changement*	page(s)/*page(s)*	paragraph(s)/*paragraph(s)*
R10: "the unobscured part of the telescope pupil" replaced by "a field of view of 5 arcmin radius (goal G10: 6 arcmin), for consistency with R7	18	3.3.2/R10
R12: Telescope temperature requirement changed from <5K to <6K. This temperature still provides the low background required for the SAFARI sensitivity. Added “goal G12: <5K”.	20	3.4.1/R12
5K replaced by 6K, following change in R12	20	3.4.1/Note after R12
R13: Requirement on telescope temperature spatial variations modified to reflect the more general case.	21	3.4.2/R13
Effects of the telescope temperature variations shortly described, following update of R13.	21	3.4.2/Note after R13
Note on zodiacal light values updated. Improved average values provided.	22	3.5/Note after R15
Clarification note added after R17.	22	3.5/R17
Figure 5 added showing the zodiacal light fluxes in the ecliptic pole and those observed by DIRBE in the Lockman hole.	23	3.5/Start of page
"The compliance of R18 will facilitate the compliance of R15" added in Note after R18.	23	3.5/Note after R18
Added text explaining that SPICA will operate obeying avoidance angles with respect to Earth, Moon and planets.	24	3.5/Last paragraph

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Purpose

The SPace Infrared Telescope for Cosmology and Astrophysics, SPICA, is a JAXA led mission that will offer imaging, spectroscopic and coronagraphic observations in the MIR/FIR wavelength range, with an improvement in sensitivity over Herschel by two orders of magnitude.

The SPICA proposal has been selected for an assessment study as part of the ESA's Cosmic Vision 2015-2025, and calls for ESA to assume a partner agency role in SPICA by making the following contributions:

- SPICA Telescope Assembly. It includes the cryogenic telescope primary and secondary mirrors, the support structure for the mirrors and a focus adjustment mechanism for the secondary mirrors.
- European SPICA Ground Segment: It includes the provision of downlink capacity from a ground station in Europe and the coordination and management of the European science operations time from a Science Operations Centre located at ESAC.
- Instrument Systems Engineering and Management of the FIR European instrument.
- SPICA Mission support to the various inter-agency groups required to manage the overall programme.

This Science Requirements Document focuses on the SPICA Telescope Assembly. This document will be the basis for the ESA Telescope Definition Document, and will be applicable to the SPICA Telescope Assembly Interface Control Document. For reference, the proposed ESA's contribution to the SPICA ground segment is summarised in Annex 1.

The scientific case described here has been extracted from the ESA Cosmic Vision Proposal "SPICA: A Joint JAXA/ESA Mission to Discover the Origins of Galaxies, Stars and Planets", by Prof. B.M. Swinyard, Prof. T. Nakagawa et al.

1.2 Scope

The Science Requirements defined in this document address exclusively those aspects that have an impact on the SPICA Telescope Assembly specification. This document does not intend to cover all the Science Requirements of the SPICA mission, which are addressed in JAXA documents and are under the responsibility of JAXA.

This document aims at showing clearly the links between Science Requirements, performance requirements and the Telescope scientific requirements, in order to help understand, trace and support the analysis of the relation between the telescope assembly specifications on the scientific objectives of the mission.

In particular, the following five science performance topics that have an impact on the telescope assembly specification have been selected:

- Wavelength range coverage
- Sensitivity. In requirements associated with photometry or low resolution spectroscopy, the photometric/low resolution spectroscopic sensitivity is specified (normally in μJy). For requirements associated with the detection of spectral lines or features, the spectroscopic sensitivity (given in W m^{-2}) is given instead.
- Spatial resolution
- Field of view
- Coronagraphic capabilities

The scientific requirements are specified in terms of these performance topics for the astronomical areas that have been identified as drivers of the mission concept and, in particular, of the telescope assembly requirements.

1.3 Acronyms

AGN	Active Galactic Nuclei
AU	Astronomical Unit
BOL	Beginning Of Life
BRDF	Bidirectional Reflectance Distribution Function
CDF-S	Chandra Deep Field South
CIRB	Cosmic InfraRed Background
ESA	European Space Agency
ESAC	European Space Astronomy Centre
FIR	Far-Infrared
FoV	Field of View
HST	Hubble Space Telescope
IR	InfraRed
ISM	InterStellar Medium
ISO	Infrared Space Observatory
IWA	Inner Working Angle
JAXA	Japan Aerospace Exploration Agency
JWST	James Webb Space Telescope
LIRG	Luminous InfraRed Galaxy
MIR	Mid Infra-Red
NICMOS	Near Infrared Camera and Multi-Object Spectrometer
NVR	Non Volatile Residue
OWA	Outer Working Angle
PACS	Photodetector Array Camera and Spectrometer
PAH	Polycyclic Aromatic Hydrocarbon
PSF	Point Spread Function

PST	Point Source Transmission
PTV	Peak To Valley
QSO	Quasi Stellar Object
SCUBA	Submillimetre Common-User Bolometer Array
SPICA	SPace Infrared telescope for Cosmology and Astrophysics
SPIRE	Spectral and Photometric Imaging REceiver
STA	SPICA Telescope Assembly
SWIRE	Spitzer Wide area InfraRed Extragalactic Survey
TBC	To Be Confirmed
TBW	To Be Written
TFP	Telescope Focal Plane
TIS	Total Integrated Scattering
ULIRG	Ultra Luminous InfraRed Galaxy
YSO	Young Stellar Object

1.4 Document overview

Chapter 2 specifies the science requirements for each astronomical area and performance topic as described in the Scope. Chapter 3 contains the telescope assembly requirements and links them to the science and performance requirements given in Chapter 2. For completion and reference, the annex summarises the proposed ESA's contribution to the SPICA Ground Segment.

2 SCIENTIFIC REQUIREMENTS

2.1 Planetary system formation

The study of star formation in our own Galaxy has been revolutionised by spectroscopic observations in the MIR/FIR, as it is only in this waveband that the neutral gas chemistry and gas/grain processes within the highly obscured stellar nurseries can be observed. However, to date, there has been little or no direct study of the role of MIR/FIR cooling lines in the formation of planetary systems. A sensitivity is needed to detect lines from species such as O, OH, and H_2O (both gas and ice) from proto-planetary gas disks in the early stage of planetary formation, in a volume sufficiently large to make the first unbiased study of the chemistry of disks around all spectral types of star. In addition, the photometric sensitivity in the FIR should enable to trace the presence of cool, dusty disks out to the farthest reaches of the Galaxy, answering directly questions over planetary formation as a function of stellar type and age and providing a comprehensive inventory of stars with circumstellar debris disks that will be invaluable to future planet imaging facilities.

2.1.1 GAS DISKS

The physical and chemical conditions in protoplanetary disks set the boundary conditions for planet formations and planetary science. Although the dust is relatively easily detected from photometric observations in the 20-100 μm range, very little is known about the gas phase. The disk is the major reservoir of species of astrobiological relevance, such as water (vapour and ices) and oxygen, to be found later in planets, asteroids and comets. The presence and distribution of these species relates to the formation of planets, most particularly habitable planets with substantial amounts of water present. In order to perform these observations, high spectral sensitivity is needed.

CO in itself is not a good tracer of the total amount of gas in the disk. Water and OH thermal lines, however, are predicted to be the strongest coolants of the disk surface, especially closer to the star, with line intensities comparable to those of the strong atomic fine line structure lines of oxygen and other heavier metals. Enough sensitivity in this wavelength region is required to characterise hundreds of proto-planetary gas disks, in order to produce an extensive census of stellar and disk types that will give a critical insight into the conditions under which planets form and the conditions for life to emerge.

2.1.1.1 Wavelength range

The most important cooling lines are: SiII (35 μm), OI (63 μm), OI (145 μm), H_2O (179.5, 100.9 μm), and for H_2 the range 3-15 μm and the spot wavelengths at 17 and 29 μm, that is, the ground state ortho and para rotation lines.

2.1.1.2 Sensitivity

In order to detect the significant MIR/FIR cooling lines for protoplanetary disks close to the star, a spectroscopic sensitivity of 2 x 10^{-19} W m^{-2} for a 5-σ detection in 1 hour is required.

2.1.1.3 Spatial resolution

Not a driver.

2.1.1.4 Field of view

The telescope field of view should allow at least three instruments to share the focal plane without the need for mechanisms to select which instrument is operational. The required minimum field of view for imaging in the MIR/FIR is 1x1 arcmin for nearby disks.

2.1.1.5 Coronagraphic capability

Coronagraphic observations in the MIR of proto-planetary disks around YSOs and debris disks around Vega-like stars are important objectives of the coronagraph. It should be possible to observe from a few to 1000 AU from the central star. The required contrast is 10^3 or lower.

2.1.2 DUST IN CIRCUMSTELLAR DISKS

Dust appears to be present at all stages of planetary system formation with the ratio of gas to dust, the amount of dust present, its temperature and its distribution evolving rapidly through the process of planetary formation. The processing and evolution of the dust in proto-planetary disks is key to understand the formation and mineralogy of rocky, Earth-like, planets. Previous studies have shown a strong radial dependency of the dust processing whereby the inner regions are dominated by the stellar radiation field, leading to grain heating and crystallisation, and by higher densities leading to coagulation, whilst the outer regions remain largely unprocessed and carry the signature of the pre-stellar nebula from which the star formed. And yet in own solar system we see crystalline silicates present in comets that clearly originate from regions far from the zones where this processing must have been occurred. Only with detailed mapping of the minerals of our own and distant circumstellar material will we be able to understand the evolutionary track that leads to this situation. The final stages of planetary system formation often appear to result in the formation of almost gas-free, dusty debris disks. These debris disks are thought to be formed of dust produced by the mutual collisions of planetesimals in the final stages of planetary formation and the “heavy bombardment” phase. Images of the dust in debris disks, either seen in reflection or directly in the FIR or sub-mm, can show gaps and ring-like structures indicating the presence of planets.

2.1.2.1 Wavelength range

The main dust features are known to appear in the 20-100 µm. This wavelength coverage is necessary to prove the detailed mineralogy of cold and warm dust populations. With a wavelength coverage extending from 5 to 200 µm, it will be possible to remove the current ambiguity between age and disk structure determinations, when modelling observations in the MIR, and to derive the variations in grain size and temperature as a function of disk age.

2.1.2.2 Sensitivity

To trace the mineralogy of dust within disks at all stages of planetary system formation, a spectroscopic sensitivity in the 20-200 μm wavelength range of 1.5×10^{-18} (goal 3×10^{-19}) W m^{-2} in one hour (5-σ) is required.

To be able to detect the photospheres of Vega-type stars out to 2.5 kpc, a photometric sensitivity of 80 μJy in one hour (5-σ) at 30 μm is required. A sensitivity of 80 μJy at 100 μm, will allow the detection of the photosphere of a Vega-type star at 1 kpc (or the photosphere of a G star at 250 pc). As a goal, to be able to detect the photospheres of Vega-type stars out to 8 kpc (or a G star at 2 kpc), a photometric sensitivity of 10 μJy at 30 μm is needed. A sensitivity of 10 μJy at 100 μm, will allow the detection of the photosphere of a Vega-type star at 2 kpc. These sensitivities will enable the most complete survey of the existence of disks by stellar type to date.

2.1.2.3 Spatial resolution

In nearby systems, direct imaging of disks shall be possible. For example, the diameter disk of Vega in the FIR is 50”. An image of the disk as detailed as possible is required in the MIR/FIR, which implies a spatial resolution limited by the telescope diffraction from 5 to >100 μm.

2.1.2.4 Field of view

The telescope field of view should allow at least three instruments to share the focal plane without the need for mechanisms to select which instrument is operational. The required minimum of view for imaging in the MIR/FIR is 1x1 arcmin for nearby disks.

2.1.2.5 Coronagraphic capabilities

Coronagraphic observations in the MIR of proto-planetary disks around YSOs and debris disks around Vega like stars are important objectives of the coronagraph. It should be possible to observe from a few to 1000 AU from the central star. The required contrast is 10^3 or lower.

2.1.3 WATER ICE

Water is the first hydrogenated molecule to condense as the temperature decreases and therefore determines the position of the “snow line” which separates the region of terrestrial, rocket planet formation from that of the giant planets. Beyond the snow line, in the outer solar system, most of the satellites and small bodies contain a significant fraction of water ice; in the case of comets this fraction is as high as 80%. In the FIR there is a powerful tool for the detection and determination of the amorphous or crystalline state of water ice, the transverse optical vibration bands at 44 μm and ~ 63 μm. These bands are seen in emission and absorption in young stellar objects as well as comets in our Solar System. In the optically thin disks, it is not possible to use MIR absorption to trace water ice and the material is too cold to emit in the MIR bands, which anyway are heavily confused with other solid state features. The FIR features, however, will allow us to observe water ice in all environments, and to be able to fully explore its impact on planetary formation and the evolution and the emergence of habitable planets.

2.1.3.1 Wavelength range

It is required to observe the bending mode of water ice at 6 μm, the libration mode of water ice at 13 μm, and the transverse optical vibrational bands at 44 μm and ~ 63 μm.

2.1.3.2 Sensitivity

Same spectroscopic sensitivity as specified in 2.1.2.2.

2.1.3.3 Spatial resolution

An image of disks in Vega, Formalhaut and β Pictoris as detailed as possible is required in the water features wavelengths, which implies that the spatial resolution should be limited by the telescope diffraction.

2.1.3.4 Field of view

The telescope field of view should allow at least three instruments to share the focal plane without the need for mechanisms to select which instrument is operational. The required minimum of view for imaging in the FIR is 1x1 arcmin for nearby disks.

2.1.3.5 Coronagraphic capabilities

Not a driver.

2.1.4 EXO-PLANETS

Direct detection and spectroscopy of giant planets around nearby stars will be a major step in the study of exo-planets. The MIR is particularly suitable to observe young gas giant planets that are within 1 Gyr of formation, and to characterise features of methane, water and ammonia that are tracers of pre-biotic activity.

2.1.4.1 Wavelength range

The wavelength range for the study of exo-planets in the MIR shall be at least 5-27 μm. The ability of the coronagraph instrument to detect planets close to the host star will be greatly improved by extending the wavelength range to 3.5 μm, as this allows the coverage of the predicted 4 μm emission feature.

2.1.4.2 Sensitivity

For a planet of 1 Gyr at the distance of 10 pc, the spectroscopic sensitivity in the 3.5-27 μm range should be 0.1- 3 μJy.

2.1.4.3 *Spatial resolution*

The spatial resolution shall be smaller than the Inner Working Angle. This implies a diffraction limited performance of the telescope at 5μm.

2.1.4.4 *Field of view*

Not a driver.

2.1.4.5 *Coronagraphic capabilities*

The observation of young giant planets in the MIR requires a contrast of $>10^6$ at an inner working angle of $3.3\lambda/D_{tel}$, which is equivalent to 9 AU (~ Saturn's orbit) at 5 μm at 10 pc. A present goal is to obtain an average 10^7 contrast level in the Dark Region (i.e. between IWA and OWA) "after subtraction" which means a typical 10^6 "raw" contrast to be delivered by the coronagraph.

2.2 *Galaxy Evolution*

2.2.1 LOCAL GALAXIES

The local universe provides many convenient laboratories in which to study galaxy evolution, the interplay and feedback between energy sources and the chemical evolution of the ISM, over a wide range of environments with different star-formation/AGN activity, metallicity, luminosity, morphology and age. The MIR/FIR plays host to a unique suite of spectroscopic tools with which to trace the interplay of accretion and star formation throughout different evolutionary phases of galaxies. The use of such tools to study local galaxies, and on a slightly larger physical scale, galactic halos and the intergalactic medium, provides critical insight into different phases of cosmic time with much higher spatial resolution and signal-to-noise than is possible in distant sources. It is therefore of great importance to have access to the full 5-210 μm wavelength range with high sensitivity.

2.2.1.1 *Wavelength range*

The presence of important diagnostic lines all over the MIR/FIR region, leads to the requirement of continuous wavelength coverage in the range 5 to ~ 210 μm. The long wavelength limit is defined by the [NII] 206 μm line. A good coverage of the H_2 molecular lines 9.6, 12.3, 17 and 28.2 μm is fundamental.

2.2.1.2 *Sensitivity*

The requirement is a spectroscopic sensitivity in the MIR is 5×10^{-20} W m^{-2} for a 5-σ detection in one hour. In the FIR, the requirement is 5×10^{-18} W m^{-2} (goal 5×10^{-19} W m^{-2}) for a 5-σ detection in one hour.

2.2.1.3 Spatial resolution

High spatial resolution is required to map the star forming regions of nearby galaxies. This requires the telescope to provide diffraction limited imaging from 5 μm to 210 μm.

2.2.1.4 Field of view

The mapping of halo components requires a field of view that allows as large a portion of a local galaxy to be imaged as possible. The minimum required field for spectroscopic imaging in the FIR is 1x1 arcmin. *In the MIR the requirement for spectroscopic imaging is not so clear.*

2.2.1.5 Coronagraphic capabilities

Not a driver.

2.2.2 THE AGN-STARBURST CONNECTION AT HIGH-REDSHIFT

For the massive, high-redshift FIR galaxy population out to z~2 detected by Herschel in photometric surveys, and for sources beyond that, FIR spectroscopy with the corresponding high sensitivity is necessary to constrain many of the key physical properties of the gas, such as temperature, density and metallicity, as well as characterising the radiation field so distinguishing the AGN and starburst characteristics of these sources.

Simulations suggest that an evolutionary link exists between luminous high-redshift starbursts and obscured/unobscured QSOs with feedback playing an important role. Models are strongly parameterised, however, and are in great need of observational constraints. MIR emission is largely unabsorbed by dust and so can be detected from the most highly-obscured Compton-thick AGN. MIR fine structure emission lines can be combined with the diagnostic templates of PAH features and silicates developed from ISO and Spitzer observations, to distinguish between starbursts, the warm MIR continua of un-obscured AGN and the heavily obscured continua of some AGN. In this way it is possible to start tracing the evolutionary sequence and state of luminous infrared galaxies out to z~4 and beyond.

The observed similarities between MIR spectra of LIRGS at the present epoch out to z~2.5 suggest similarities in dust properties, and thus that a significant enrichment and evolution has already taken place by z~2.5. But, when did the bulk of the dust production take place? The answer to this question requires sensitivities that allow us to observe the evolution of the rest-frame MIR at higher redshifts than 2.5.

Observations of intermediate and high-redshift sources have shown that the co-moving star formation rate density in the Universe was at least a factor of 10 higher at a redshift of unity, with more than half of the stars in the Universe formed since z~1. In order to characterise the ISM of the complete z~1 population, and therefore follow the evolution as a function of redshift of these ubiquitous galaxies, the continuum needs to be detected. In addition, the detection of MIR/FIR cooling lines starting at z~0.5, where the universal star formation rate has increased by close to an order of magnitude, will allow us to determine whether present-day galaxies grew by collision/merging of smaller objects, or whether massive galaxies with higher star formation rate were already in place by z~1.

2.2.2.1 *Wavelength range*

The presence of important diagnostic lines all over the MIR/FIR region, leads to a requirement of continuous wavelength coverage in the range 5 to ~ 210 μm. The long wavelength limit is defined by the rest wavelength of the [NII] 206 μm line.

2.2.2.2 *Sensitivity*

With a spectroscopic sensitivity of a few times 10^{-18} W m^{-2} in one hour, 5-σ, it will be possible to detect the very brightest lines in the most exotic objects at high-z. With a spectroscopic sensitivity of a few times 10^{-19} W m^{-2} in one hour, 5-σ, not only the brightest MIR line emission (e.g. [NeII]) will be visible from a significant fraction of the Spitzer and SCUBA populations, but also the fainter, but diagnostically important lines of, e.g. [OIV], [NeV], and the ground-state rotational transitions of H_2. This sensitivity will also provide observations of diagnostic FIR lines [OI], [SiIII] for a starburst galaxy up to z=1, and for other AGN+starburst objects with high-z.

A low-resolution spectroscopic sensitivity in the MIR of 20 μJy and in the FIR of 100 μJy, in 1 hour, 5-σ, will allow us to detect PAH/silicate features in dusty distant galaxies out to z~3. The goal is a sensitivity of 10 μJy in the FIR, which would allow the detection of PAH/silicate features in galaxies out to z~5.

2.2.2.3 *Spatial resolution*

Not a driver.

2.2.2.4 *Field of view*

An extended field of view for spectroscopy in both the MIR and FIR will give some multiplex advantage once it is large enough to include more than one source plus background. Even without the multiplex advantage the observing efficiency is increased with a reasonable field of view as it removes dependence on pointing accuracy and provides simultaneous source and background spectra. For both MIR and FIR a minimum spectroscopic field size of 1x1 arcmin is required.

2.2.2.5 *Coronagraphic capabilities*

Not a driver.

2.2.3 DEEP COSMOLOGICAL SURVEYS

A comparison between the integrated cosmic optical background and the cosmic infrared background shows that around 50% of photons produced by stellar nucleosynthesis and massive accretion-driven black hole growth over the lifetime of the Universe have been absorbed by dust and re-emitted in the FIR. Understanding how and when these FIR photons were emitted is therefore central to understanding galaxy formation. Both ground-based sub-millimetre surveys and FIR surveys from space are limited by the confusion that results from modest angular resolution, and are sensitive only to the most luminous and distant galaxies or very near ones. Herschel-SPIRE and PACS will open new windows in the FIR above 100 µm; however, our current knowledge of source densities at these wavelengths suggests that we will resolve only 50% of the CIRB because of confusion. The aim is to resolve more than 90% of the CIRB over 80% of the Hubble time.

Observations both from the ground and space have been used extensively to study the evolution of mass distribution of galaxies with redshift. Large populations of distant massive ULIRGs have been identified in the shallow, large area SWIRE survey using colour-colour selection techniques. These sources have very similar properties to high-redshift, sub-mm selected galaxies, and likely precursors of present-day ellipticals. With SPICA, it shall be possible to extend such studies to lower luminosities, smaller stellar masses and larger redshifts, since the peak of the rest frame, near-IR stellar emission in high-z galaxies will be redshifted into the MIR.

SPICA's combination of spectral imaging and large wavelength coverage will provide a way to break the traditional confusion limit by adding wavelength as a third dimension to deep, cosmological surveys. Sources can be identified by emission from redshifted MIR/FIR cooling lines produced by star formation and AGN activity, rather than by the broad-band signatures of warm dust. Redshifts accurate enough for intermediate follow-up ground based CO observations (tracing the molecular gas component) can be determined from the detected lines, while line ratios provide a first indication of the nature of the source powering of the FIR emission. With the appropriate sensitivity, simulations suggest that sufficient sources/redshifts can be detected to differentiate between galaxy evolution models, and thus place tight constraints on the origin and history of our own and other galaxies, by observing areas as small as 4' x 4'.

The rich spectrum of PAH and silicate features found in the MIR both in local and distant galaxies provides an excellent means through which to undertake deep surveys using low-resolution spectroscopy (R ~ 100-200), allowing to determine source redshifts and measure the physical conditions in sources that would not be detectable using optical or near IR spectrographs on even the largest ground-based telescopes. Through measurements of the PAH features we will not only be able to directly estimate star formation rates, but also to measure redshifts and so start to evaluate the co-moving space density of this dusty population and to constrain the bolometric luminosity function of luminous infrared galaxies.

2.2.3.1 *Wavelength range*

The main wavelength for FIR deep continuum surveys will be 70 µm, since long-ward of 70 µm confusion dominates the performance of a 3.5 telescope, while short-ward the limiting factor will be the sensitivity of the detectors.

Deep MIR surveys require multi-waveband observation capability over several MIR channels in the 5 to 38 µm range.

Redshifted MIR/FIR cooling lines produced by star formation and AGN activity will be used for the identification of sources and determination of redshifts breaking the confusion limit.

Large scale spectroscopic surveys based on PAH and silicate spectral features will be carried out in the MIR and FIR.

2.2.3.2 Sensitivity

At 70 μm, the confusion limit is 50 μJy for a telescope of 3.5 m diameter. The requirement is that this depth is achieved in a few minutes with simultaneous measurements of similar photometric sensitivity in other FIR bands.

The photometric sensitivity in the MIR shall allow us to detect stellar masses of 10^9 $M_\odot$, out to z~10, and mass assemblies of 10^8 $M_\odot$ out to z~0.5. At z~5, SPICA shall be able to detect Lyman Break Galaxies of the type recently found in the CDF-S, which have lower stellar masses (~10^9 $M_\odot$) than their z~3 counterparts. This corresponds to a photometric sensitivity of ~0.1 μJy (1 hour, 5-σ) at 5.5 μm and of ~0.4 μJy (1 hour 5-σ) at 9.5 μm.

Simulations show that to probe a factor of 5 below the 120 μm continuum confusion limit, by using the 5 strongest FIR cooling lines to detect and determine the redshifts, a rms noise level of 0.4 mJy in 100 hours (goal 10 hours) at a resolution of 1000 needs to be achieved for sources brighter than 1 mJy at 120 μm out to z~2.5. This translates into a spectroscopic sensitivity requirement of 6 x 10^{-19} W m^{-2} (1 hour, 5- σ) and a goal of 2 x 10^{-19} W m^{-2} (1 hour, 5- σ) at 100 μm.

The low-resolution spectroscopy modes of the SPICA MIR and FIR instruments should enable large-scale spectroscopic surveys of very faint galaxies, down to 20 and 100 μJy, respectively. Based on the source density of IR galaxies at these flux levels as detected by Spitzer, one would expect to detect ~10 sources with S(24 μm) > 100 μJy in a 2' x 2' FoV of the FIR instrument, with much larger numbers in the MIR.

2.2.3.3 Spatial resolution

The spatial resolution in the FIR shall be such that the confusion limit is ~50 μJy at 70 μm. In the shortest wavelengths in the MIR (~5 μm), the angular resolution should be ~0.35 arcsec (comparable to the HST/NICMOS) in the far infrared, in order to study the morphology of stellar and dust emission in galaxies out to high z.

2.2.3.4 Field of view

The MIR surveys require a larger field of view than JWST, in order to be able to map the sky more rapidly at wavelengths longer than 15 μm, and trace both the stellar (short MIR) and dust components (long MIR) in the same field. In particular a field of view larger than 160" x 160" for wavelengths longer than 15 μm is required (the current specifications of the MIR Camera and spectrometer are 100" x 100" (optional 300" x 300") at 5-9 μm, 160" x 160" (optional 320" x 320") at 8-15 μm, 280" x 280" at 14-27 μm, and 400" x 400" at 20-38 μm.

The field of view in the FIR, to provide a large spatial multiplexing advantage, shall be of the order of 2’ x 2’.

2.2.3.5 *Coronagraphic capabilities*

Not a driver.

2.3 *Summary of scientific requirements drivers*

Table 1 provides an overview of the scientific areas that are drivers for the specification of the observatory performance requirements linked to the telescope requirements.

Table 1: Scientific areas that drive performance requirements

	Planetary System Formation: Gas disk	**Planetary System Formation: Dust in circumstellar disks**	**Planetary System Formation : Water ice**	**Planetary System Formation : Exo-Planets**	**Galaxy Evolution : Local Galaxies**	**Galaxy evolution: AGN-Starburst**	**Deep Cosmo-logical Surveys**
Wavelength range	yes	yes	yes	yes	yes	yes	yes
Sensitivity	yes	yes	yes	yes	yes	yes	yes
Spatial resolution		yes	yes	yes	yes		yes
Field of View	yes	yes	yes		yes	yes	yes
Coronagraphic capabilities	yes	yes		yes			

3 REQUIREMENTS ON THE TELESCOPE ASSEMBLY

The requirements on the Telescope Assembly are derived from the Science Requirements specified in section 2.

3.1 Operating wavelength ranges

R1. The SPICA telescope shall operate in the wavelength range 5-210µm (G1 goal: 3.5-210µm). This defines the "design and operation" wavelength range of the telescope. A "characterisation" wavelength range of 1-1000µm shall also be used. It defines a wider spectral domain over which the knowledge of the telescope characteristics is required.

Note: The "design & operation" wavelength range is based on the nominal baseline spectral coverage of SPICA core baseline focal plane instrumentation spectral range in MIR & FIR. Possible extension of MIR instrument coverage (including the baseline operation range of the MIR coronagraph) down to 3.5µm and addition of a sub-mm instrument are considered. In any case, detector arrays of core MIR and FIR focal plane instruments will still have residual detectivity down to ~1µm and up to ~1mm respectively, therefore telescope characteristics (not necessarily obtained by test but by analysis) over this in-band + out-of-main-band spectral region is needed.

3.2 Telescope aperture and related characteristics

3.2.1 COLLECTING SIZE

R2. The SPICA telescope shall be an aperture as large as possible which is compatible with the launch fairing.

Note: The current launcher selected for SPICA is the JAXA H2A-202, which will allow a monolithic telescope of 3.5m circular diameter.

3.2.2 OBSCURATION AND TRANSMISSION

In order to maximise the efficiency of the telescope collecting area over the "design &operation" wavelength range (and minimise its possibility of self-emission in particular in FIR):

R3. The total obscuration of the telescope shall be limited to <12.5% (goal G3: <10%) in terms of telescope pupil relative surface area, over the full telescope FoV (as defined in 3.3.1);

R4. If the collecting aperture of the telescope is not designed to be of a single continuous element (i.e. non-monolithic), the gaps from any segmentation shall fall within the total obscuration defined above and be contained, in term of spatial distribution, by the existing blockage (if any);

R5. The amplitude transmission T of the unobstructed region(s) of the telescope pupil aperture shall be as high as possible to take benefit of the large collecting area but more specifically higher than piecewise linear transmission curve (goal G5: higher than the goal curve) represented below and defined by the following points in the "design & operation" wavelength range:

SPICA core wavelength (µm)	**3.5**	**5**	**15**	**30**	**110**	**210**
T_{tel} minimum requirement (R3)	85%	90%	95%	97.5%	99.0%	99.0%
T_{tel} goal (G3)	90%	92.5%	96%	98%	99.2%	99.4%

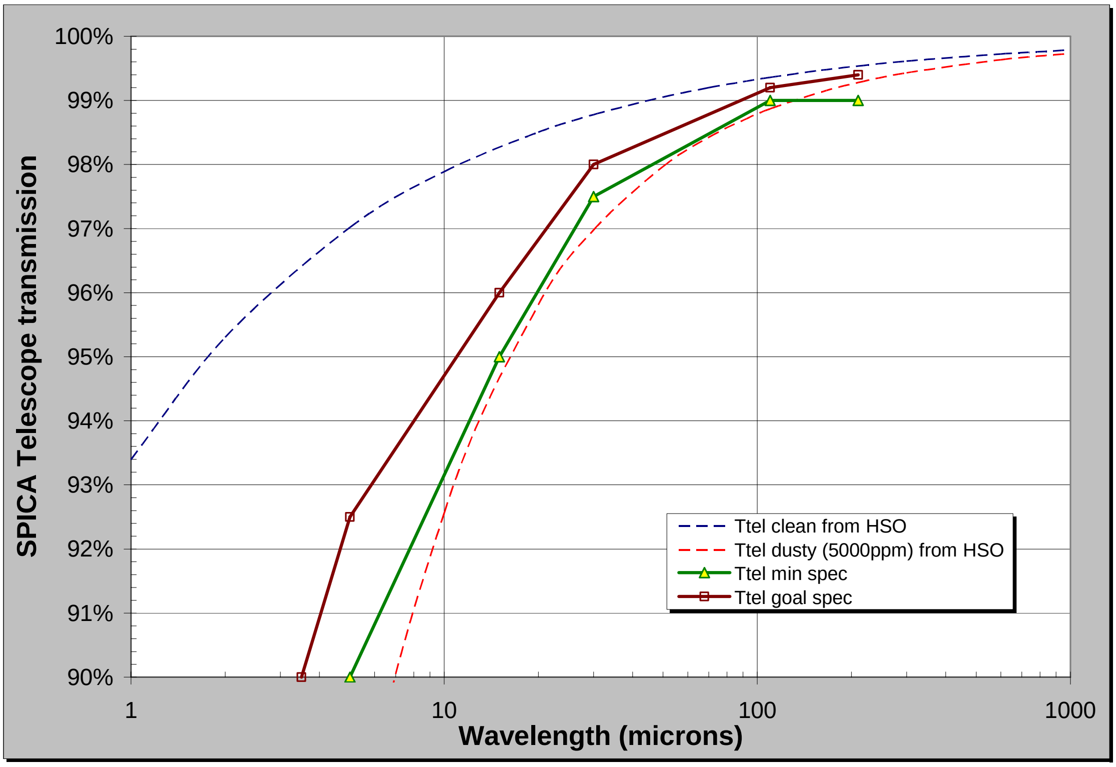

Figure 1: Required and goal specification levels for SPICA telescope transmission in the "design & operation" wavelength range. As indication, the case of Herschel based on samples emissivity measurement and extrapolated in the MIR is displayed (dashed lines).

This should be achieved including the telescope element surface contamination discussed in the section below.

As an alternative equivalent representation, the maximum mirror surface spectral emissivity (per mirror in the case of a 2-mirror telescope) shall be below the piecewise linear curve defined in the "design & operation" wavelength range by the requirements points (goal G5: the goal points) summarised in the table below:

SPICA core wavelength (µm)	**3.5**	**5**	**15**	**30**	**110**	**210**
Telescope mirror max emissivity requirement	7.5%	5.0%	2.5%	1.25%	0.5%	0.5%
Telescope mirror max emissivity goal	5.0%	3.75%	2.0%	1.0%	0.4%	0.3%

MIR Coronagraph specific requirements:

CR1: Within the unobscured part of the telescope pupil, the telescope transmission shall be spatially uniform within to 1.5% rms or better, over the spatial frequency range corresponding to the typical MIR coronagraph high contrast region (i.e. 3.3 to 50 cycles/D), and in the MIR spectral range 3.5-30µm.

Note: The non-uniformity of the transmitted flux across the pupil can reduce the coronagraph contrast. Although it can be partially compensated internally by the MIR coronagraph, it is preferred to allocate the compensation budget for wavefront error correction considering that the nominal high transmission of the telescope discussed above will nominally force low possible variations of the transmission.

CR2: The preferred shapes for the telescope pupil obscuration (if any) are, in the order of preference (i.e. best adapted to match maximal coronagraph performances):

1) 2 spider struts (e.g. along a complete pupil diameter)
2) 4 spider struts (e.g. in a centred orthogonal cross shape)
3) 3 spider struts

Note: The exact shape and spatial distribution of the obscuration at the telescope pupil can affect the telescope PSF main lobe and (near and far-) sidelobes. A MIR coronagraph based on pupil apodisation by re-mapping or shaped mask is particularly sensitive to entrance pupil obscuration shape and geometry. No telescope pupil obscuration would be overall preferred but may brought overall unrealistic constraints (e.g. specific telescope design becoming an observatory-level design driver). Beyond 4 (i.e. 5, 6, …), it is expected that the coronagraph rejection performance in the Dark Region will be too much affected to be relevant and therefore these cases are not considered.

3.2.3 SURFACE CLEANLINESS

Cleanliness shall be limited so that it does not affect the telescope collecting efficiency, in particular in the science bands where MIR and FIR emission/absorption of particular ice compounds are intended to be studied with SPICA. For smooth IR optical surfaces (see high spatial frequency surface error requirements below), surface scattering is dominated by contaminating dust particles which can raise the level of far-side lobes (i.e. wide field angle from boresight) of a diffraction-limited telescope PSF. Therefore, as baseline:

R6. The telescope surface cleanliness level shall be, at BOL, better than ~2000mm^2/m^2 or 2000ppm for particulate and 3mg/0.1m^2 for molecular based on ECSS-Q-70-01A, or equivalently, (400+/-50)C in terms of MIL-STD-1246C classification.

Note: BOL is defined as beginning of life with respect to in-orbit science operations. From MIL-STD-1246C, the particulate part (400+/-50) is translating in particles geometric surface area coverage of 0.1-0.5% range with max BRDF at 5deg in scattering angle <10^{-2} sr^{-1} at MIR wavelength of 10 µm (and decreasing with increasing wavelength). This puts a limit on the further transmission lost from particle contamination ("black" particle case) and the amount of induced surface scattering which could open stray paths towards out-of-field background noise sources, celestial (e.g. sky, zodiacal light) or artificial (e.g. observatory telescope baffle enclosure with temperature or emissivity higher than the telescope). NVR molecular contamination level C is 3 µg/cm^2 with water ice assumed dominant and a density of 0.82 g/cm^3 over a ~10 m^2 max telescope collecting surface area; this translates into a maximum thickness of water ice of ~37 nm. The level C was chosen in order to limit the transmission loss and correspondingly the increase in telescope emissivity as illustrated below.

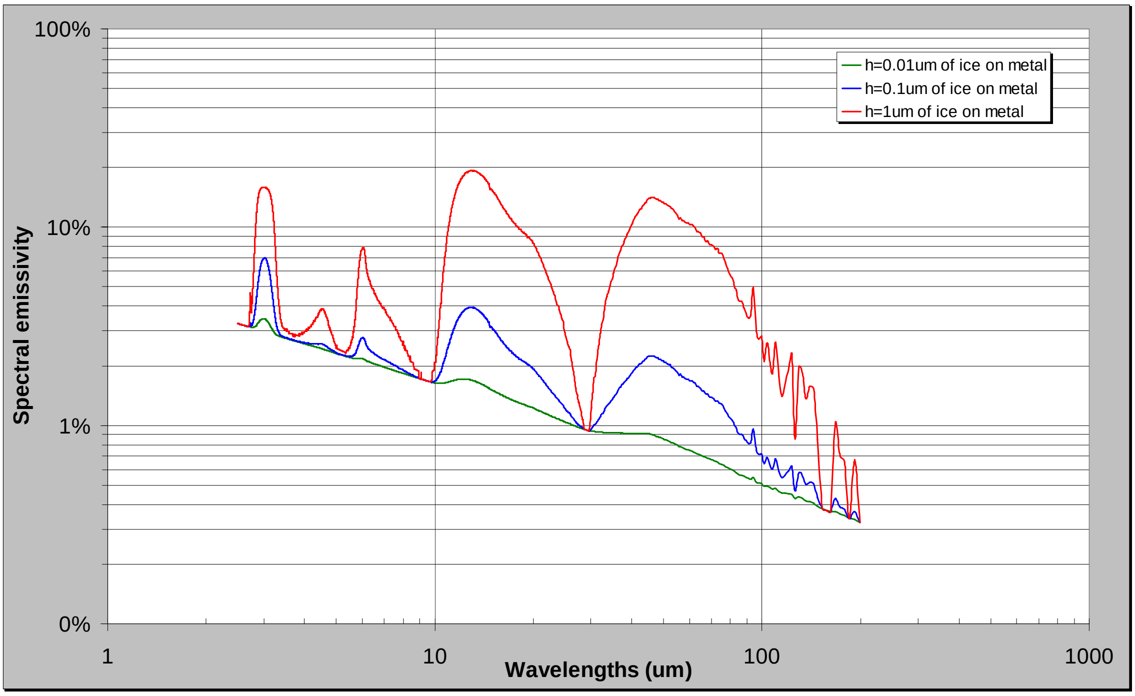

Figure 2: Modelled MIR & FIR spectral effective emissivity for low (and representative) temperature (~10K) water ice layer of different thickness deposited on high reflectivity metal mirror surface[1].

---

[1] The metal mirror surface spectral reflectivity is based on a Hagen-Rubens law matching at long wavelength the measured Herschel telescope sample data (from J. Fischer et al, Applied Optics 43-19 (2004), see dashed-line curves in Figure 1). Low temperature water ice spectroscopic optical constants are from D. Hugdins et al., Astrophysical J. Suppl. Series, 86:713-870 (1993).

3.3 Image quality and field of view

3.3.1 GENERAL REQUIREMENTS

R7. The SPICA telescope shall have diffraction-limited imaging capability at λ_o=5µm over a field of view of 5 arcmin radius (goal G7: 6 arcmin)

R8. The SPICA telescope shall keep diffraction-limited performances at 30µm over a field of view of 10 arcmin radius (goal G8: 12 arcmin)

R9. The mapped telescope field of view shall be unvignetted over a radius of 12 arcmin (goal G9: 15 arcmin).

Note: The central part of the field of view where image quality is expected highest will be used by the MIR instrument while the FIR instrument will be located in the periphery but still within the unvignetted field of view, not to damage the imaging efficiency and generate spurious spatial response from diffraction at structure other than the one defined by obscuration in the telescope pupil.

3.3.2 DETAILS OF TELESCOPE APERTURE PHASE ERROR DISTRIBUTION

Taking λ_o=5µm as the baseline shortest "design & operation" wavelength, and following the above, the main requirement is:

R10. The overall maximum SPICA telescope wavefront error, over a field o view of 5 arcmin radius (goal G10: 6 arcmin), shall be 350nm rms in order to be compatible with nominal diffraction-limited performances at λ_o.

Beyond this top-level requirement, imaging in certain modes and bands can be affected by phase or wavefront error at different pupil spatial scale and this leads to the following break-down of the overall telescope pupil phase error:

- Low spatial frequencies (i.e. below 3.3cycles/D with D is the telescope pupil diameter)**:** overall figure errors to be limited for the SPICA telescope to <350nm rms. As an example, this can be spread equally between focus and higher order aberrations: <250nm rms for focus translates into a max defocus of +/-0.185mm at TFP; and <250nm rms for higher but still low order aberrations (total telescope) translates into a max allocation of about one wave peak-to-valley at standard visible test wavelength (e.g. 633nm) or a surface figure error of $<\lambda_o/70$ per mirror in a 2-mirror telescope case;
- Medium spatial frequencies (i.e. from 3.3 to 1000cycles/D): No specific requirements, therefore the residual mirror surface figure errors in this spatial frequencies range shall be limited only by overall compatibility with R10. These errors arise from residual higher frequency surface error, mount induced stress, print-through effects or general mirror substrate medium-scale structure;

R11. High spatial frequencies (i.e. > to >>1000cycles/D): <λ_o/285 rms per mirror. These mostly arise from mirror surface micro-roughness, cracks and small local defects in coatings all of which induce large scale/wide angle scatter as well as generating small off-axis angle diffuse halo by near-specular scatter. The specification translates into a <17.5nm rms specification for each telescope mirror surface leading to a TIS < 0.2% at λ_o.

MIR Coronagraph specific requirements:

CR3: The maximum telescope wavefront peak-to-valley (PTV) error, within the spatial frequency range from 0 to 50cycles/D and over the entire unobscured part of the telescope pupil shall be no higher than 2µm.

Note: Although baselined to operate down to 3.5µm, the MIR coronagraph does not require diffraction-limited performance at 3.5µm as it is expected to perform its own wavefront compensation internally to recover the diffraction-limited performance at 3.5µm. Nevertheless, the limitations of this wavefront correction require this extra PTV specification.

CR4: Mid spatial frequencies (i.e. from 3.3cycles/D to 1000cycles/D):

1) ***from 3.3cycles/D to 12cycles/D:*** <λ_o/45 (=111nm) rms (with goal G_CR4: <λ_o/133 (=37 nm) rms) for the SPICA telescope in this spatial frequency range;
2) ***from 12cycles/D to 50cycles/D:*** <λ_o/71 (=70nm) rms (with goal G_CR4: <λ_o/133 (=37 nm) rms) for the SPICA telescope in this spatial frequency range;
3) ***from 50cycles/D to 1000cycles/D:*** there is no specific requirement, residual error only limited by overall compatibility with R10.

Note: The limits of the mid spatial frequency range here are defined to match the expected IWA (~3.3λ/D) and OWA (potentially extending up to ~33λ/D), including a 50% margin beyond OWA for the aliasing effect from surface error at spatial frequencies around the one equivalent to OWA. In this region, the telescope pupil phase (or wavefront) error is specified, in the goal case, based on an equivalent max degradation on raw contrast of a factor 10 from an assumed raw contrast of 10^{-7} (quasi-perfect optics and/or active wavefront compensation), leading to the main aim of 10^{-6} raw contrast. In the nominal case of the baseline specification, it is assumed that only 10^{-6} is nominally achieved (i.e. 10x less effective or absent active correction) and with the telescope specification only 10^{-5} will be then obtained in final raw contrast.

Beyond 50cycles/D, the coronagraph dark region is not expected to be affected so that the requirement is unconstrained (and known to be not easily accessible to verification by measurements) although the overall main requirement of diffraction-limited performances at λ_o still applies.

3.4 Operating temperature

3.4.1 GENERAL TELESCOPE TEMPERATURE

R12. The operating temperature of the SPICA telescope shall be below 6K (goal G12: <5K), in order to limit in-field self-emission in the FIR. This specific temperature of operation means that all other telescope requirements apply under this condition (and the general space flight environment at the baseline mission orbit).

Note: The key scientific capabilities of the SPICA mission are linked to the ability to operate the telescope at this deep cryogenic temperature as illustrated below. A low temperature (<6K) telescope will have a spectral radiance lower than the sky background over the entire “design & operation” wavelength range of SPICA, allowing us to reach a high level of in-band sensitivity and providing the possibility of sky-limited observations (in bands/modes where detector noise is lower).

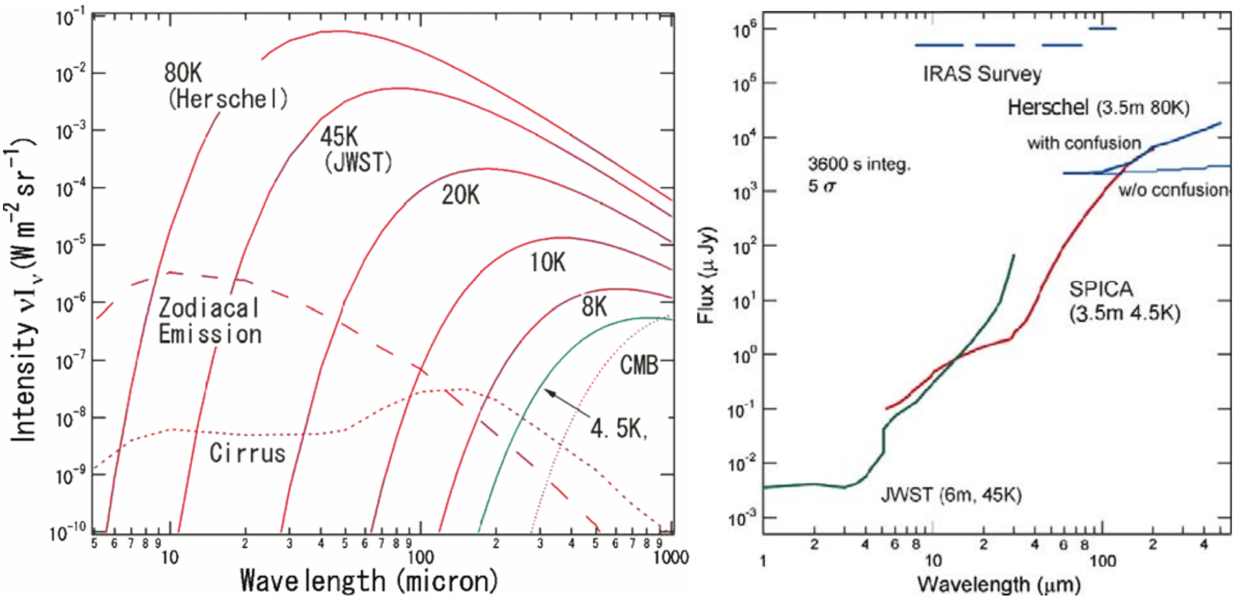

Figure 3: Thermal emission from telescopes and natural background (Left), and comparison of SPICA photometric sensitivity, based on a 4.5K telescope, with those of others missions (Right)[2].

The driver for the low operating temperature is the FIR instrument sensitivity and in particular its longest wave band. Below the comparative case of a 5K and a 10K telescope feeding the baseline FIR instrument is displayed.

---

[2] Plots extracted from T. Nakagawa et al., Advances in Space Research 40 (2007) 679–683.

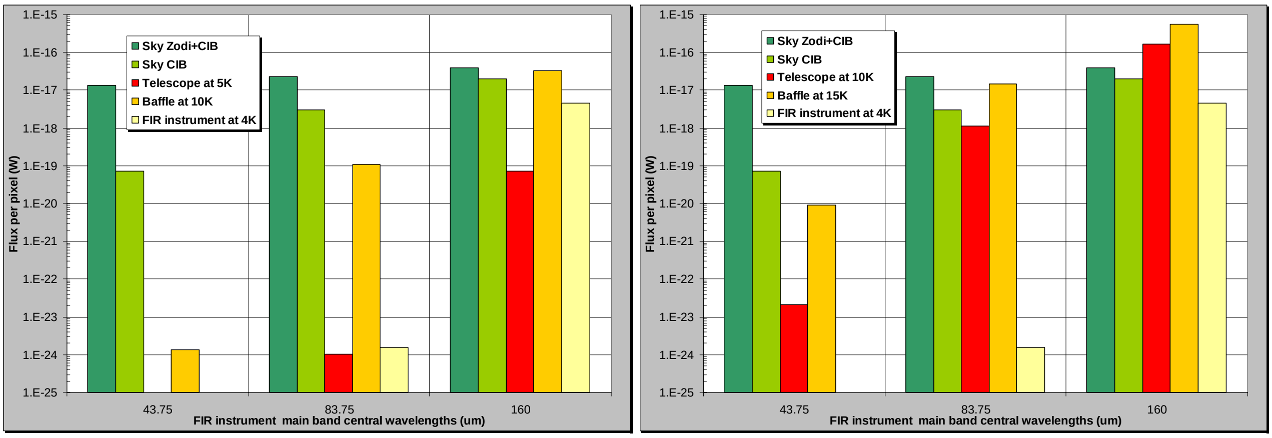

Figure 4: Optical flux estimates (log scale, band integrated so complementary to the spectral brightness given in Figure 3 above) from different sources, per pixel at FIR instrument focal plane in different bands; 2 main cases are considered for illustration here: telescope at 5K (Left) and telescope at 10K (Right)[3].

The sky background is of the order of a few hundredths of femto-Watt per pixel in all FIR bands, which is still an order of magnitude higher than a 5K telescope in-band emission. A higher temperature for the surrounding baffle could damage the longwave sensitivity, which justifies the need to maintain low surface scatter (from micro-roughness and particulate contamination) off the telescope optical elements. Noticeably, at 10K the telescope emission is no longer negligible in the central FIR band and completely dominates the sky background signal in the longwave one.

The strong dependency of background on the telescope temperature is due to the locations of the MIR and FIR wavebands in the Wien region of the telescope thermal emission. The zodiacal light has even a higher brightness in the MIR and the shorter MIR waveband is such that it is less an issue for MIR instrument functions which could still accept in principle a temperature of the order of ~25+/-5K depending on spectral bandwidth.

3.4.2 SPATIAL & TEMPORAL TELESCOPE TEMPERATURE STABILITY

R13. For every degree K above the maximum baseline telescope temperature of 6K (as per R12), the relative surface area (i.e., compared to the total telescope aperture) of this associated “higher” temperature zone shall be further reduced by at least a factor 5.

---

[3] The assumptions are as followed: FIR instrument is in full-band (62.7% spectral bandwidth each in the 30-210μm range) imaging mode and/or FTS mode with 2’x2’ with $F.\lambda/2$ spatial sampling at centre of each band, 15% average in-band transmission (average interferogram baseline level). CIB is from Dole et al. A&A (2006) and the zodiacal light level is taken as 3Mjy/sr, which is a log average level (varying typically from 0.3 to 30MJy/sr depending on galactic coordinates). Telescope is assumed 3.5m diameter primary (18m focal length) with pupil on secondary and 10% surface area obscuration; its emissivity is taken as following data from J. Fischer et al, Applied Optics 43-19 (2004) with extrapolation in the short waveband. In each case, the inner surface of the telescope tube enclosure is taken as 5K higher than telescope temperature and average emissivity of 5% (based on JWST sunshade surface case; Herschel also used a low emissivity sunshade in order not to contribute too much to the background as they are expected to be at 60-120K and 100-160K respectively i.e. much warmer than the respective telescope temperature), viewed by scattering off the telescope mirrors under 0.5% TIS consistent with micro-roughness and particle contamination limit specification. The FIR instrument is assumed to be at 4K nominally and behaving like a 25% effective emissivity cavity (given here as indicative only as will depend on FIR detector required operating temperature).

Note: The sensitivity to telescope elements temperature variations is very high for the FIR instrument; especially for wavelengths longer than 100µm, it is typically ~300%/K (illustrated and justified by note in section 3.4.1). Telescope temperature gradients and spatial non-uniformities increase the instrument background associated noise, generate a field-dependent signal leading to a non-uniform background illumination across the FIR instrument array, and add "telescope chopping offset" induced noise in chopping observations. While allowing the presence of "hotter spots" (typically up to 10K) on the telescope aperture, their influence on the background needs to be minimised by being "weighted" through a smaller relative area and therefore the view factor from a the FIR instrument pixel. At a secondary level, R13 can help CR1 by reducing the source of telescope transmission non-uniformity (in particular if the telescope mirror reflectivity is temperature dependent).

R14. The telescope operating temperature shall be stable to within 0.25K over a typical observation duration.

Note: As a baseline and for consistency with sensitivity estimates, the typical duration is taken here as 1hour.

3.5 *Straylight*

R15. The telescope shall provide adequate internal straylight control such as baffling to allow for SPICA observations with sky-limited sensitivity. In particular, the straylight rejection level shall be such that total background from out-of-field stray sources (artificial and natural) shall not increase the in-field optical background signal (from zodiacal light and telescope thermal self-emission) by more than 20% (goal G15: 10% TBC).

Note: The zodiacal light level is ecliptic coordinates dependent. The values in the Lockman hole (ecliptic latitude ~ 45º) can be taken as representative of the average fluxes, that is, 3.4 x 10^{-7} W/m^2/µm/sr at 12µm, 7.3 x 10^{-9} W/m^2/µm/sr at 60µm, and 1.3 x 10^{-9} W/m^2/µm/sr at 100µm (see Figure 5).

In particular:

R16. Any emission from observatory structure at surface temperatures >10K (respectively >50K, TBC), that enters the FIR instrument FoV (respectively the MIR instrument FoV) at telescope focal plane shall be attenuated by the telescope system and associated baffles in order to reduce the view factor to these surfaces (including their in-band emissivity and from the focal plane instrument field of view) to less than 1 part in 10^4 (TBC).

R17. Scattered light from any natural source inside the telescope field of view (but outside the respective field of view of the focal plane instruments) shall contribute, into the respective aperture (defined by the respective FoV) of any focal plane instrument, less than 10^{-3} (TBC) of its peak irradiance when imaged by the telescope.

Note: The compliance of R17 will facilitate the compliance of R15.

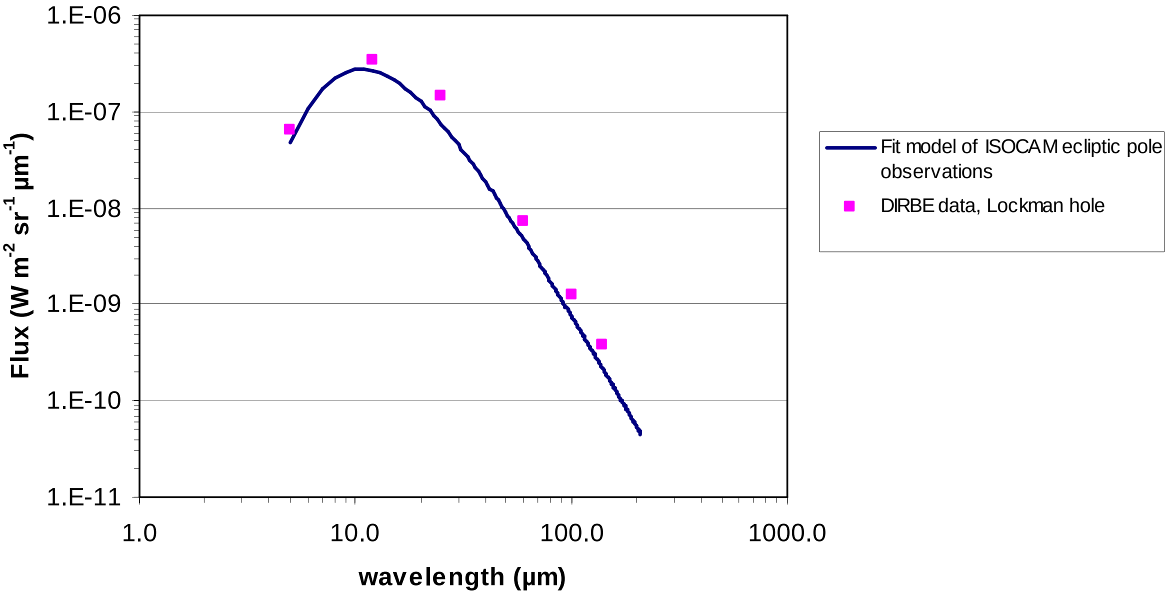

Figure 5: Zodiacal light fluxes derived from ISOCAM ecliptic pole observations (solid line; Reach et al., Icarus 164, 2003) and measured by DIRBE in the Lockman hole (squares; Wright, IAU symp 204, 2000).

R18. Scattered light from any natural source outside the telescope field of view shall be attenuated to the maximum following tabulated relative levels defining the telescope PST in any azimuthal direction:

Off-axis angular region from telescope boresight	**From 0.25deg to 3deg (TBC)**	**From 3deg to 30deg (TBC)**	**From 3deg to 45deg (TBC)**	**Beyond 45deg (TBC)**
Max PST level (base requirement)	<5E-4 (TBC)	<1E-5 (TBC)	<1E-6 (TBC)	Assumed dropping to 1E-8 at 90deg
Max PST level (goal)	<5E-5 (TBC)	<1E-6 (TBC)	<1E-7 (TBC)	Assumed dropping to 1E-9 at 90deg

Note: The telescope PST is defined as the ratio of the signal level from the stray source reaching the telescope focal to its incoming (i.e. at telescope entrance pupil) level. The starting point of 0.25deg (=15arcmin) is taken here as the edge of the largest telescope FoV (radial size) as defined by R9. The compliance of R18 will facilitate the compliance of R15.

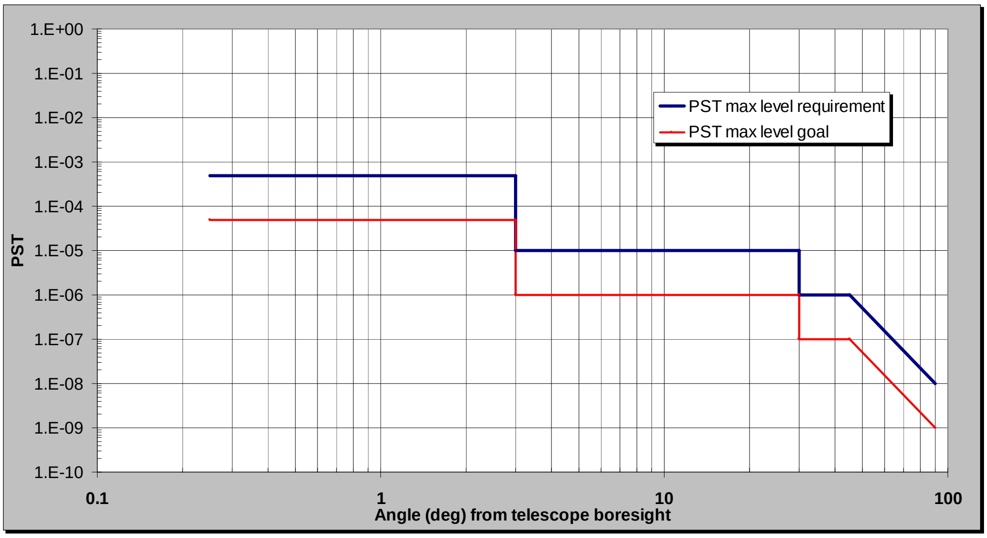

Figure 6: Maximum telescope PST level as function of off-axis source angular position from boresight.

General Note: The extent of the telescope elements internal baffling has to be such that it does not induce more vignetting of the field of view than what it is required in 3.3.1. It is understood that the straylight control of the SPICA telescope is shared at observatory-level with the rest of the spacecraft sub-system, in particular the presence and characteristics of the thermal control tubular enclosure surrounding the telescope elements.

It is not expected that the SPICA telescope will perform any specific or general out-of-band rejection (responsibility of focal plane instruments); however the in-field and out-of-field stray sources would need to be characterised (i.e. quantitatively known) over the full “characterisation” wavelength range (see 3.1).

The out-of-field sources, potentially seen by reflection, diffraction or scattering mechanisms, typically include the sky emission itself (zodiacal light) as well as particular “local” celestial objects such as Sun, Earth, Moon and planets, particular zones of the sky (e.g. galactic centre, …) as well as the SPICA observatory sub-systems self-emission. Note that SPICA operations will obey pre-defined avoidance angle constraints of the telescope line of sight with respect to the directions of Earth, Moon, and planets.

4 TELESCOPE VS. SCIENCE REQUIREMENTS

The link between the Science Requirements specified in chapter 2 and the Telescope Requirements specified in chapter 3 is provided in Table 2. This table should support the analysis of the impact of any change of telescope requirements in the science to be accomplished by the mission.

Table 2

	Wavelength range	**Spectroscopic Sensitivity (5-σ, 1 hour)**	**Photometric/ Low resolution spectroscopic Sensitivity (5-σ, 1 hour)**	**Spatial resolution**	**Field of View**	**Coronagrapic capabilities**
Planetary System Formation: Gas disk	SiII (35 µm), OI (63 µm), OI (145 µm), H_2O (179.5, 100.9 µm), and for H_2 the range 3-15 µm and the spot wavelengths at 17 and 29 µm	2×10^{-19} W m^{-2} (a)			1'x 1' in the MIR/ FIR	Observe a few to 1000 AU from star Contrast: 10^3
Planetary System Formation: Dust in circumstellar disks	5-210 µm with goal from 3.5 µm	1.5×10^{-18} W m^{-2} Goal: 3×10^{-19} W m^{-2} (b)	80 µJy Goal: 10 µJy (b)	Telescope diffraction limited with adapted (small) IWA and large Dark Region	1'x 1' in the MIR/ FIR	Observe a few to 1000 AU from star Contrast: 10^3
Planetary System Formation: Water ice	6 µm 13 µm 44 µm 63 µm	1.5×10^{-18} W m^{-2} Goal: 3×10^{-19} W m^{-2} (b)	80 µJy Goal: 10 µJy (b)	Telescope diffraction limited	1'x 1' in the FIR	
Planetary System Formation: Exo-Planets	5-27 µm, with goal 3.5-27 µm		0.1-3 µJy (a)	Telescope diffraction limited with adapted (small) IWA		Observe a few to 100 AU from star Contrast: $>10^6$ (typ. 10^7 « after subtraction » and 10^6 « raw » contrast)
Galaxy Evolution : Local Galaxies	5-210 µm	5×10^{-20} W m^{-2} in the MIR 5×10^{-18} W m^{-2} in the FIR Goal in the FIR: 5×10^{-19} W m^{-2}		Telescope diffraction limited	1'x 1' in the FIR	

	Wavelength range	**Spectroscopic Sensitivity (5-σ, 1 hour)**	**Photometric/ Low resolution spectroscopic Sensitivity (5-σ, 1 hour)**	**Spatial resolution**	**Field of View**	**Coronagrapic capabilities**
		(a)				
Galaxy evolution: AGN-Starburst	5-210 μm	3 x 10^{-18} W m^{-2} Goal in the FIR: 3 x 10^{-19} W m^{-2} (a)	Low resolution spectroscopy: 20 μJy in the MIR 100 μJy in the FIR Goal in the FIR: 10 μJy (a)		1'x 1' in the MIR/ FIR	
Deep Cosmological Surveys	5-210 μm, with emphasis at 5-38 μm and 70 μm	6 x 10^{-19} W m^{-2} at 100 μm Goal: 2 x 10^{-19} W m^{-2} at 100 μm (a)	0.1 μJy at 5.5μm 0.4 μJy at 9.5μm Low resolution spectroscopy: 20 μJy in the MIR 100 μJy in the FIR (a)	0.35 arcsec at 5 μm	Larger than 160" x 160" at 15 μm 2'x 2' in the FIR	
Telescope requirements	R1, R7	(a) R2, R3, R4, R5, R6, R12, R13, R14, R15, R16, R17, R18 (b) R2, R3, R4, R5, R6, R12, R13, R14, R15, R17, R18		R2, R7, R8, R9, R10, R11	R7, R8, R9	R2, R3, R4, R5, CR1, CR2, R7, R10, R11, CR3, CR4

ANNEX 1: ESA'S CONTRIBUTION TO THE GROUND SEGMENT

The scientific return from the mission can be significantly enhanced by two ESA contributions to the Ground Segment:

1. The provision of downlink capacity from a ground station in Europe.

   The orbit selected for SPICA is the Sun-Earth L2 libration point, as it provides a benign and stable thermal environment required to cool the payload to < 5 K as well as good instantaneous sky visibility. Suitable ground stations for communication with the spacecraft at L2, and sufficient telemetry resources are needed to allow uncompressed science data downlink (~60 Gbytes/day). This corresponds to ~ 6 Mbits/s averaged over a 24 hour period, and includes the possibility to downlink raw detector samples (TBC).

   1.1. Both the Usuda and the Cebreros ground stations are required to be able to downlink 60 Gbytes/day.
   1.2. The usage of the Cebreros station will be defined to increase the daily ground contact period for SPICA from 5 to 10 hours.
   1.3. Cebreros could be used as a backup for the uplink of the mission timeline during the daily ground contact period.
   1.4. The Cebreros ground station may not be available when the facilities are required to support other ESA programmes. It is accepted that this will restrict scientific operations, but it should not compromise the scientific return of the mission.

2. The coordination and management of European observation time science operations from a Science Operations Centre located at ESAC.

   A Science Operation Centre (SOC) located in Japan will be responsible for the Japanese observation time science operations. ESA shall support SPICA by running a second (European) SOC located at ESAC, which will be responsible for the science operations in relation with European observation time. The ESA's SOC will assist European scientists to fully exploit the unique capabilities of the spacecraft and help guarantee the scientific success of the mission. The roles of the two SOC include:

   2.1. Community support: Provision of information, helpdesk and tools for the preparation of proposals; organisation of the calls for proposals.
   2.2. Support to the Time Allocation Committee.
   2.3. Maintenance of the proposals/observations database.
   2.4. Scientific mission planning: Scheduling of the observations, optimisation and validation of spacecraft and instrument commands to be delivered to the MOC for uplink; definition of the mission planning strategy.

2.5. Data processing and archiving; distribution to the community of data products and data processing software.

These tasks will be carried out in collaboration with the Instrument Control Centres.