Space-borne infrared spectro-photometer for astronomy*

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A simple and reliable satellite-borne infrared spectro-photometer (IRSP) for astronomical applications is proposed, which can be realized in the near future using the available technological knowhow within the country. While this instrument’s demands for cryogenic and oriented platform-pointing systems are kept modest (within the anticipated reach of ISRO capabilities), it can still address a wide variety of interesting and contemporary astrophysical problems.

1 Introduction

With the regular and successful launches and operations of Indian Space Research Organization’s (ISRO) ‘augmented satellite launch vehicle (ASLV)’ initially, and more recently ‘polar satellite launch vehicle (PSLV)’ rockets and their numerous payloads, it is now time to consolidate the technical advancements with fundamental research in pure sciences for the near future. Already several attempts in this direction have been made in the recent past, which have seen spectacular successes, e.g. gamma ray burst (GRB) experiment using the ASLV (Ref. 1) and Indian x-ray astronomy experiment (IXAE) using the PSLV (Refs 2, 3). Although the GRB experiment was a modest beginning leading to new science results5,6, the IXAE is more sophisticated and uses a pointed platform. The IXAE continues to do world class astronomy even today5,6, although it has been sharing the satellite platform with a host of other application/engineering-oriented payloads to economize the resources.

The above provides ample proof that the technical and scientific knowhow in the country has reached a maturity where the astronomy community as well as ISRO anticipates an entire space mission fully devoted to astronomy, thereby avoiding several hurdles which were faced due to sub-optimal features (e.g. choice of orbit) of earlier shared missions. In addition, opportunities for small and simple astronomy experiments as piggyback payloads to non-astronomy missions may become available regularly.

In the aforesaid backdrop, ISRO has already initiated action involving scientists interested in designing and developing potential space astronomy experiments for a future Indian multi-wavelength astronomy satellite (IMAS). The concept of one such experiment — a near infrared spectro-photometer (IRSP) for astronomy, is described here, which is not only technically feasible, but also has potential to study a variety of problems of contemporary interest. Even if IRSP does not form a part of IMAS, it has great potential as a piggyback experiment onboard some other Indian mission.

2 Design philosophy

From the point of view of the instrument builder, the following design philosophy has been adopted: Within the practical limitations constrained by the available technology and knowhow, how best the infrared spectro-photometer (IRSP) can be designed and developed within a well defined time frame (3–5 years).

The two most crucial constraints are: (i) the cryogenic capabilities which decide the lowest achievable temperature for the infrared detector; and (ii) orientation and pointing capabilities of the stabilized platform on which the present instrument will be mounted.

The cooling capability decides the type of the infrared detectors that can be employed and hence, in turn, the longest possible usable infrared wavelength. In addition, the dark current of the detector crucially depends on this temperature, thereby limiting the

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maximum usable on-target integration time which, in turn, fixes the achievable sensitivity. From the point of view of scientific capabilities, longer infrared wavelengths are more desirable. The characteristics of the earth’s atmospheric transmission is such that, longer the infrared wavelength, less accessible is the waveband from the terrestrial telescopes, thereby, less known are the specific astrophysical phenomena/problems relevant to these wavebands. At longer infrared wavelengths, the utilization of the space-borne platform is also more effective as the thermal background emission gets worse at longer wavelengths.

The orientation and pointing capability decides the smallest effective field of view usable for astronomical imaging or spectroscopic measurements. The field of view is an important factor for the photon background on the detector element (pixel) which can limit the sensitivity of the instrument for pointlike as well as extended astronomical sources.

Hence, it is clear that the cryogenic and orientation capabilities ultimately decide the nature of astrophysical problems that can be addressed by the space astronomical instrumentation. For the present, both these crucial parameters are taken to be variable and their effects on the instrument design as well as achievable science from a near infrared spectrophotometer are discussed in detail. The orientation capability has been assumed to be at least better than 0.1 degree, since (i) such capability has already been demonstrated by ISRO in its IRS-P3 mission which currently incorporates the Indian x-ray astronomy experiment (IXAE); and (ii) also poorer orientation makes the science return from an infrared instrument uncommensurate with the anticipated investments in technical efforts and finances for developing the instrument.

3 Cryogenics

Cryogenic capability is the most important issue having bearing on the infrared wavelength in which astronomically meaningful measurements can be made. In any cryogenic system, the achieved temperature obviously depends on the total heat load. The heat load is contributed by parasitic heating, spacecraft environment (which very strongly depends on the orbit parameters) and the local dissipation within the detector/instrument.

The most optimal thermoelectric cooling can reach as low as ~ 180 K with a multistage unit. However, the cooling efficiency drops drastically as one cascades stages. Passive radiative cooling is quite effective in very high orbits (in geostationary orbits, one may even reach ~80 K), but can be very restrictive in lower orbits (only up to ~ 150 K). Open cycle solid cryogen (N₂) is being used in the near infrared camera and multi-object spectrometer (NICMOS) instrument onboard Hubble space telescope (HST) with an estimated life time of about 5 yr, keeping the detector at 58 K. For achieving even lower temperatures, mechanically more complex refrigerators are needed, which have several moving parts. Closed cycle refrigeration (Stirling/Vuilleumier/Gifford-McMahon) system can reach up to 10 K depending on the compressor capacity vis-a-vis heat load. To give a feel for the cryogenic systems used in various recent space missions, Table 1 lists relevant details.

For the present study, it has been assumed that a small mass comprising the near infrared (NIR) detector and its housing is cooled to 77 K (perhaps using a mechanical Stirling cooler aided by efficient passive cooling) and the optical components are at ~ 160 K (using only passive cooling). However, to keep the study useful, even if assumed situation is not achieved in practice, the performance penalties for higher temperatures have been quantified.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Temperature (K)</th>
<th>Required lifetime</th>
<th>Heat load (mWatt)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRIS</td>
<td>200</td>
<td>5 years</td>
<td>500</td>
<td>Radiator</td>
</tr>
<tr>
<td>WFCC</td>
<td>178</td>
<td>3 years</td>
<td>60</td>
<td>Thermo electric cooler</td>
</tr>
<tr>
<td>SISEX</td>
<td>120</td>
<td>2 weeks</td>
<td>1000</td>
<td>Stirling refrigerator</td>
</tr>
<tr>
<td>GRS</td>
<td>92</td>
<td>8 months</td>
<td>50</td>
<td>Solid cryogen</td>
</tr>
<tr>
<td>NIMS</td>
<td>75</td>
<td>&gt; 3 years</td>
<td>50</td>
<td>Radiator</td>
</tr>
<tr>
<td>ATMOS</td>
<td>75</td>
<td>2 weeks</td>
<td>500</td>
<td>Stirling refrigerator</td>
</tr>
<tr>
<td>SFHE</td>
<td>1.5</td>
<td>1 week</td>
<td>—</td>
<td>Liquid cryogen</td>
</tr>
</tbody>
</table>
4 Photon background

There are two components to the photon background at NIR wavelengths as expected at spacecraft altitudes: (i) the thermal emission from the warm telescope optics (light gathering system) itself, and (ii) the zodiacal background originating from the solar system. The former is a modified Planck function sensitive to the temperature of the optical components as well as their emissivity properties at relevant wavelengths, whereas the zodiacal background comprises the scattered sunlight and the thermal emission of the interplanetary dust. From the cosmic background explorer (COBE) mission measurements, it has been found that the total zodiacal background can be represented as

$$Z(\lambda, T_D) = (1.01 \times 10^9 / \lambda^{1.69}) + 6 \times 10^{-8} B(\lambda, T_D)$$

photons s\(^{-1}\) cm\(^2\) \(\mu\)m\(^{-1}\) sr\(^{-1}\) \(... (1)\)

at ecliptic latitudes of ~ 45°. The first term in the RHS of Eq. (1) represents the scattered sunlight and the second term the thermal component. The parameter \(B\) is the Planck function and \(T_D\) the temperature of the interplanetary dust (typically ~ 265 K).

In order to appreciate the roles of thermal emission from the telescope vis-a-vis zodiacal background, the photon counts, as a function of wavelength, are presented in Fig. 1 for several temperatures of the telescope\(^6\).

The advantages of the space-borne NIR instrument over the ground-based one (in addition to the accessibility of the wavelength from above the earth’s atmosphere) can be quantified in terms of the photon background at a wavelength in an atmospheric window as expected at the best telescope site on the earth’s surface\(^1\). The latter is presented in Fig. 2. Here, in addition to the thermal emission, the background consists of (i) airglow due to the vibrational-rotational spectrum of the radicals/molecules (OH and O\(_2\)), (ii) the nightglow continuum and (iii) the polar aurora. The airglow originates in the atmosphere at about 90 km above the earth’s surface, and hence cannot be avoided by choosing a higher mountain site for astronomical measurements. Other problem about airglow is that their emission is variable with time, changing by factors of over 2 in less than half an hour\(^1\).

5 Survey of infrared astronomical mission

If our proposed NIR spectro-photometer has to be competitive internationally, it has to be exclusive enough with minimum overlap with any other space missions. Since the atmospheric windows, viz., \(J\), \(H\) and \(K\) bands, are accessible from large terrestrial telescopes equipped with far more sophisticated focal plane instruments, new science is expected mainly from the wavelengths in between these bands. However, IRSP should cover the entire near infrared range available (depending on the capabilities of the
The capabilities of IRSP in the J, H and K bands will lead to: (i) improved in situ calibration of the instrument (since enormous database exists at these wavebands) and (ii) an edge over the terrestrial experiments for some specific astrophysical problems sensitive to the photon background and background fluctuations in these bands (at terrestrial sites, the major background in J/H/K bands is due to the airglow which is absent for satellite-borne experiments).

In what follows, we consider the infrared missions having any coverage in the 1-1000 µm wavelength band. The past and proposed missions include: (a) Infrared astronomy satellite\textsuperscript{12} [IRAS; all sky survey at 12, 25, 60 and 100 µm with limited angular resolution (5 arc min); NASA / Great Britain / The Netherlands; 1983]. (b) Cosmic background explorer\textsuperscript{13} [COBE; all sky maps at NIR to millimetre wavebands (3-1000 µm) with wide (1°-7°) beams; NASA; 1990]. (c) Infrared telescope in space\textsuperscript{14} [IRTS; near, mid and far infrared instruments for photometry and medium resolution spectroscopy (1-12 µm and 100-10000 µm); Japan; 1995]. (d) Infrared space observatory\textsuperscript{15} [ISO; photometry, imaging, polarimetry and medium-to-high resolution spectroscopy (2.5-200 µm); ESA; 1995]. (e) Near infrared camera and multi-object spectrometer onboard Hubble space telescope\textsuperscript{16} [NICMOS; imaging and grism based medium resolution spectroscopic imaging (1-2.5 µm); NASA; 1998]. (f) Space infrared telescope facility\textsuperscript{17} [SIRTF; imaging and high resolution spectroscopy (3-300 µm); NASA; 2002] and (g) Far infrared and sub-millimetre telescope\textsuperscript{18} [FIRST; high resolution spectroscopy (50-400 µm); ESA; 2007].

Our present proposal of IRSP in the near infrared has wavelength overlap with only the IRTS and NICMOS missions. These two are considered here with little more details.

The Japanese IRTS was a 35-day mission with 15 cm primary mirror (8'x8' field of view). The NIR spectrometer covered 1.4-4.0 µm with a spectral resolution of $\Delta \lambda = 0.12 \mu m$. Two one-dimensional arrays of Indium Antimonide (InSb) of 2x12 pixels were cooled to 1.8 K. Their science goals included the study of zodiacal light, diffuse Galactic light, extragalactic background light and point sources brighter than 7th magnitude in the $K$ (2.2 µm) band. The IRTS was a survey-type mission with no pointed observations of specific sources. That explains their large field of view (FOV). Hence, our science goals will not clash with those of IRTS.
Although NICMOS is a true competitor to IRSP, but being very sophisticated, its emphasis is on much fainter samples (2.5 m HST primary mirror). In addition, it is extremely oversubscribed by the entire international community. Also, NICMOS use is mutually exclusive to other focal plane instruments currently available in HST (which are all in the optical/UV wavebands).

At wavelengths longer than 2.5 μm, IRSP would have had overlap with ISO and SIRTF, but due to cryogenic restrictions, IRSP is planned for 0.9-2.5 μm waveband only.

6 Infrared spectro-photometer

In keeping with the technical feasibility and the international scene, the infrared spectro-photometer (IRSP) is proposed to cover the entire wavelength range of 0.9-2.5 μm. We define and concentrate on J (1.0-1.2 μm, i.e. the gap between I and J), JH (1.3-1.4 μm) and HK (1.8-2.0 μm) photometric bands in addition to the atmospheric windows J (1.15-1.35 μm), H (1.45-1.8 μm) and K (2.0-2.4 μm). In the spectroscopic mode also, the entire wavelength range from 0.9 to 2.5 μm is covered to make calibrations of various instruments and their comparisons with ground-based measurements simpler.

Since Cassegrain optics offers a very compact geometry, it is favoured in satellite configurations, e.g. the IMAS proposal for an UV experiment by Pati and Rao. Figure 3 shows, schematically, the proposed position of IRSP at the Cassegrain focus of the telescope. The primary aperture of this telescope has been assumed to be of a very modest size of 30 cm (diameter) for computing various details, e.g. background, sensitivity, etc. The IRSP is proposed to consist of a photometer with six broad bands (covering J, JH, HK, J, H and K bands) and a medium resolution (R ~ 100) spectrometer covering the wavelength range 0.9-2.5 μm.

There will be no moving part in IRSP to achieve high degree of reliability. All the bands of the photometer will be arranged to view the sky simultaneously (say position A in the sky). The spectrometer will cover the entire wavelength range 0.9-2.5 μm simultaneously (say the position B of the sky). Since the positions on the sky A and B will be offset (by a few arc minutes) for a particular source, the photometric and spectroscopic modes are mutually exclusive.
recently been used in space for the NICMOS instrument onboard the Hubble space telescope (HST). Quantum efficiency of this type of arrays is 40-60\% throughout the responsive wavelength range and a read-noise of 30-50 e\textsuperscript{-} is achieved routinely. The well capacity of 5\times10\textsuperscript{5} e\textsuperscript{-} is quite common. The dark current varies between 10.0 and 1.0 (e\textsuperscript{-}/s/pixel) corresponding to array temperature of 85-60 K.

For IRSP, we propose to use only a one-dimensional array with 256 elements for the spectroscopic part and much smaller arrays for the photometric segments. In order to estimate the capabilities of IRSP, the following assumptions have been made, which are rather conservative:

(i) The achieved read-noise of the detector and its drive electronics system is \sim 100 e\textsuperscript{-}.
(ii) The well capacity is \sim 1\times10\textsuperscript{5} e\textsuperscript{-}.
(iii) The detector is maintained at a temperature of \sim 77 K.

In addition, the pointing jitter of the telescope is assumed to be \sim 0.3 arc sec.

6.1 Background

Here, we estimate the NIR background for the space-borne IRSP and demonstrate its superiority over the best terrestrial site (in addition to the accessibility aspect of the particular wavelengths).

We use the experience\textsuperscript{9} of the HST and scale the collecting area (30 cm dia primary feeding for IRSP), pixel solid angle (1.2 arc sec pixel, \textsuperscript{9}HgCdTe at 77 K as detector (with 100 e\textsuperscript{-} read-noise) and quantum efficiency of 0.4. The total effective transmission of the entire optics (telescope and fore optics) has been taken as 0.15. The anticipated degraded sensitivities, in case the read-noise is larger by a factor of 2 (i.e. 200 e\textsuperscript{-}), are also listed. It must be noted that although the sensitivities are being quoted for the familiar bands J/H/K at the terrestrial atmospheric windows, IRSP photometer will have additional bands covering wavelengths in between these bands. The J/H/K bands are being used here for ease of comprehending the implications of the sensitivity numbers due to the familiarity of magnitudes in these bands.

Table 2 also gives the break-up of various limiting factors to the sensitivity of IRSP in the K band for a given integration time. Then the same is repeated for different integration times. Finally, the systematic effects make further increase in the integration time fruitless.

The limiting magnitudes for the J and H bands are listed in Table 3.

Using the stellar properties, the above sensitivities can be translated to the distances up to which different types of stars can be studied with a minimum stipulated signal-to-noise ratio. These numbers are presented in Table 4.

Table 2—Expected sensitivity in the K band

<table>
<thead>
<tr>
<th>Integration</th>
<th>Photon background</th>
<th>Dark current</th>
<th>Read-noise</th>
<th>Total noise</th>
<th>(K_\text{mag}^{\ast} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2</td>
<td>10</td>
<td>100</td>
<td>\sim 100</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(200)</td>
<td>(10.5)</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>100</td>
<td>100</td>
<td>\sim 101</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(200)</td>
<td>(13.0)</td>
</tr>
<tr>
<td>100</td>
<td>120</td>
<td>1000</td>
<td>100</td>
<td>\sim 105</td>
<td>16.2</td>
</tr>
<tr>
<td>1000</td>
<td>1200</td>
<td>10000</td>
<td>100</td>
<td>\sim 146</td>
<td>18.3</td>
</tr>
</tbody>
</table>

\( \ast \) The numbers in parentheses refer to a read noise of 200 e\textsuperscript{-}.
6.3 Pointing jitter penalty

In the event of degraded performance of the spacecraft in keeping the telescope optical system / IRSP pointed on the sky (i.e. poorer than the assumed value of 0.3 arc sec r.m.s.), the pixel size in IRSP needs to be increased to make meaningful observations. The pixel size must be several times the r.m.s. pointing jitter. This will increase the thermal and sky background leading to a penalty in the achieved sensitivity for point-like sources (stars). This factor, termed as 'pixel size penalty', has been computed and listed in Table 5. It may be noted that, for any field of view, there is a limit on the largest integration time possible because of the finite well size of the detector (leading to saturation; denoted by an asterisk in relevant entries of Table 5).

6.4 Detector temperature penalty

If the cryogenic temperature achieved for the infrared detector is higher than 77 K (which is assumed for all the above sensitivity estimations), there will be severe performance degradation of IRSP. This aspect has been quantified here. A higher detector temperature leads to much higher dark current. First, this will severely limit the largest integration time and, in addition, the fluctuations in dark current will constitute a noise component which may dominate over all other noises, thereby degrading the sensitivity drastically. The dark current being exponentially dependent on the reciprocal of the detector temperature [proportional to $e^{(-E_g/kT)}$; where $E_g$ is the band gap for the detector material], the performance degradation can be very drastic. The band gaps for InSb and HgCdTe are 0.23 eV and 0.5 eV, respectively. The loss in the performance is tabulated for both these detector materials in Table 6.

6.5 Penalty due to the spectroscopic resolution

So far the IRSP sensitivity has been discussed for the photometric mode [$R = \lambda/\Delta\lambda = 3.5$]. However, in the spectroscopy mode, since the photons from the astrophysical source get further distributed over multiple resolution elements (pixels of the one-dimensional array), the sensitivity (in terms of stellar magnitude) reduces.

The worst case loss in sensitivity translated to magnitude scale, for a flat spectral energy distribution, has been estimated. The resulting numbers have been displayed in Table 7. It may be noted that the real loss may be milder in case the detector is operating in the background limited mode (referred to in the literature as BLIP : Background Limited Performance).

7 Attractive science with IRSP

Fortunately, there are several important atomic/nebular/molecular lines of astrophysical interest, which fall in between the successive terrestrial

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Table 3—Limiting magnitudes in $J$, $H$ and $K$ bands

<table>
<thead>
<tr>
<th>$T_{\text{in}}$</th>
<th>$J$</th>
<th>$H$</th>
<th>$K$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.6</td>
<td>12.0</td>
<td>11.3</td>
</tr>
<tr>
<td>10</td>
<td>15.1</td>
<td>14.5</td>
<td>13.8</td>
</tr>
<tr>
<td>100</td>
<td>17.5</td>
<td>16.9</td>
<td>16.2</td>
</tr>
<tr>
<td>1000</td>
<td>19.6</td>
<td>19.0</td>
<td>18.3</td>
</tr>
</tbody>
</table>

Table 4—Absolute magnitudes of late type stars

<table>
<thead>
<tr>
<th>Stellar type</th>
<th>Main sequence (V)</th>
<th>Giant (III)</th>
<th>Super-giant (Ia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K0</td>
<td>$M_V - 5.2$</td>
<td>$M_0 - 5.2$</td>
<td>$M_{0.8} - 5.9$</td>
</tr>
<tr>
<td>K5</td>
<td>$M_V - 5.3$</td>
<td>$M_0 - 3.7$</td>
<td>$M_{0.8} - 7.3$</td>
</tr>
<tr>
<td>M2</td>
<td>$M_V - 4.4$</td>
<td>$M_0 - 6.4$</td>
<td>$M_{0.8} - 10.0$</td>
</tr>
<tr>
<td>M5</td>
<td>$M_V - 4.8$</td>
<td>$M_0 - 6.1$</td>
<td>$M_{0.8} - 11.8$</td>
</tr>
</tbody>
</table>

Table 5—Pixel size penalty due to poor pointing

<table>
<thead>
<tr>
<th>$T_{\text{in}}$</th>
<th>Achieved sensitivity ($K$ magnitude) for pixel size ($\theta$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$1.2''$</td>
</tr>
<tr>
<td>1</td>
<td>11.3</td>
</tr>
<tr>
<td>10</td>
<td>13.8</td>
</tr>
<tr>
<td>100</td>
<td>16.2</td>
</tr>
<tr>
<td>1000</td>
<td>18.3</td>
</tr>
</tbody>
</table>

* Saturation due to detector well capacity limit
Table 7—Penalty due to spectroscopic resolution

<table>
<thead>
<tr>
<th>Resolution (R)</th>
<th>Magnitude loss (ΔK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.1</td>
</tr>
<tr>
<td>25</td>
<td>2.2</td>
</tr>
<tr>
<td>100</td>
<td>3.6</td>
</tr>
</tbody>
</table>

atmospheric windows (and, hence, not accessible from the ground-based telescopes). These lines can be studied by IRSP very fruitfully. These lines are listed in Table 8 along with the typical spectral resolution required to detect them well above the anticipated continua.

The expected strengths of some of the atomic and molecular hydrogen lines under typical astrophysical conditions ($T_e=N_e=10^4$) are given in Table 9. These have been normalized to the strength of the most commonly studied line from the same species.

The astrophysical importance of these lines, which will be accessible to IRSP but not to terrestrial telescopes, is highlighted next. The recombination lines of hydrogen, viz., Paschen-α, Brackett-δ, 4-3, etc., will be very useful in understanding the structure of Galactic H II regions and radiative transfer through them. The [ Si VI ] line measurements are crucial for studying winds of hot stars and structures of their corona. The line emission from molecular hydrogen will provide very significant clues to understand atmospheres of cool stars in general, and M dwarfs in particular. Since the theoretical models of outer envelopes of cool stars are very unsatisfactory at the present time, data from these H2 lines will help a great deal in settling various issues related to their structure and assumptions about turbulence. Our knowledge about the origin and location where the stellar winds form is likely to improve from the above NIR spectroscopic measurements. Finally, the lines from the other molecular species, viz., H₂O, HCO₂, C₂ and CO, are extremely useful for various studies of astrochemistry in the general Galactic interstellar medium, star forming regions as well as local interstellar medium. The branches which will particularly benefit are: formation of these molecules, their abundances and excitation mechanisms of these lines (e.g. collisional versus radiative). Several other long term scientific programmes which can be taken up using IRSP are discussed as follows.

7.1 Late type giants / main sequence

K/M Giants:

Even with a 5" pixel size, 1 s integration time and $R = 100$, a 3σ detection limit leads to a distance modulus of 12 magnitudes or 2.5 kpc. This implies that a large sample of K III (3×10⁵) and M III (2×10⁶) stars in the solar neighbourhood can be studied spectroscopically. Spectral lines, if present, will be detectable at comfortable signal-to-noise level. Even main sequence (MS) stars K5-M2 can be studied spectroscopically up to a distance of 34 pc (the number of K V stars ~ 1500; the number of M V stars ~ 7000).
Be stars:

With $R = 100$, all known Be stars can be spectroscopically studied with IRSP.

The above make IRSP an extremely versatile instrument.

7.2 Extended nebulosities in star forming regions

In recent times, several NIR mapping studies of Galactic star forming regions are being carried out with many interesting results. In addition to embedded stellar components, the nebulosities near young stellar objects (YSOs), Herbig Haro objects, etc., are a hot topic of research. They are often associated with strong outflow activity. The IRSP is also capable of undertaking similar studies. One example is: The nebular emission extends over $\sim 35''$ for the L1251 molecular cloud with ongoing star formation, which has been studied$^{20}$. Typical intensity in $K$ band is $14-15$ mag/sq. arc sec. In a $5''\times 5''$ pixel, expected $K$ is $11.5$ mag, which is well within the capability of IRSP.

7.4 Flare monitor

With the advent of Hubble space telescope (along with some terrestrial telescopes), in recent times, many interesting flaring activities have been discovered. Of particular interest are the dMe flare stars like AD Leo, AU Mic, etc. Recent discovery of their flaring in UV lines$^{24-26}$ has made them targets of many studies. Their NIR behaviour during flaring in the UV lines will be extremely useful information which is lacking at present. Many of these objects are bright enough to be monitored by IRSP, and they can form an important science objective for IRSP.

Time variability in NIR for certain other class of stars also is quite interesting. These are: Mira variables; Asymptotic giant branch (AGB) stars; and RS CVn stars. The monitoring of NIR colours of Miras over several cycles will be an important input to the modelling of their atmospheres. Similarly, the study of NIR variability of AGB stars will lead to the understanding of circumstellar shells around them. The RS CVn stars have active spots on their surface which are being studied even in the x-ray band. Their NIR light curve will also constitute an interesting science programme for IRSP.

7.5 Novae light curve

Typically a few novae occur in our Galaxy every year, which can be easily detected in optical/infrared or even x-rays. The current estimates suggest that the dust formation takes place about 2-3 months after the optical peak. This can be studied and verified from the observed NIR light curves. Comparison of these measurements with optical data can lead to much better understanding of the material ejected during the novae outburst. Hence, the study of novae light curves will form an interesting science goal for IRSP.

7.7 Polarization mapping

In the aforesaid description of IRSP no polarizer has been proposed in order to keep IRSP instrument free from any moving part. However, permanent inclusion of a polarizer for a particular photometric band may be considered seriously. With this approach, without reducing the reliability, a completely new dimension can be offered to the possible science with IRSP. Of course, as a price,
some sensitivity has to be sacrificed. If this channel is made independent of the other main photometer channels, the NIR polarimetry may be viable in IRSP.

8 Conclusions
A space-borne near infrared spectro-photometer (IRSP) has been described, whose technical feasibility is within the reach of the Indian Space Research Organization (ISRO) and astronomical research laboratories within the country. Several of the astrophysical problems that can be meaningfully addressed by IRSP have been described. This instrument (IRSP) is expected to be very reliable by keeping it simple with no moving parts and can be planned as a piggyback payload on any Indian mission in near future. In spite of its simplicity, IRSP can achieve interesting and internationally competitive science.

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