First Census of Habitable Zone of Protoplanetary Disks in the Galactic Scale

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ABSTRACT

Circumstellar disks have been thoroughly studied with MIR wavelengths because MIR traces the critical components of disks, such as life habitable zone of protoplanetary disks and debris disk. As a result, many characteristics of the disk evolution have been revealed e.g., disk lifetime, dust growth, transitional disk. However, previous studies are only in the solar neighborhood ($D \lesssim 2$ kpc). Whether protoplanetary disks throughout the Galaxy evolve similarly to those in the solar neighborhood is of great interest.

As the next step, I propose studies of circumstellar disks in the Galactic scale. Due to low sensitivities of previous MIR instruments, studies beyond the solar neighborhood have not been possible. With the high sensitivity of *SPICA* MCS, ~1 μJy at 10 and 20 μm, excess of circumstellar disks can be fully characterized and disk lifetime can be precisely estimated. Very wide field of view ($\sim 5' \times 5'$) is also a great advantage compared to the other future instruments, such as *JWST* MIRI and TMT MICHI. Protoplanetary disks of sub-solar mass stars and even debris disks of intermediate-mass stars can be detected. Eventually, these kind of studies will be connected to the search of life throughout the Galaxy.

1. INTRODUCTION

Circumstellar disks are not only essential objects to understand the star formation process, but are also critical objects to understand planet formation (e.g., Lada & Lada 2003). Disk lifetime is one of the most fundamental parameters of a circumstellar disk because it directly constrains the time for planet formation (e.g., Williams & Cieza 2011). Many estimations of disk lifetime are now available. For protoplanetary disks, which are directly connected to Jupiter-mass planet formation, disk lifetime is generally estimated to be 5–10 Myr (Williams & Cieza 2011). For the inner disk (~0.1–5 AU), dust disk evolution is observed with NIR/MIR (e.g., Lada 1999; Haisch et al. 2001; Sicilia-Aguilar et al. 2006), while gas disk evolution is observed with Hα (Fedele et al. 2010). For the outer disk ($\gtrsim$50 AU), dust and gas disk evolution are observed with submm (e.g., Andrews & Williams 2005) and FIR [O I] 63 μm (Meeus et al. 2012), respectively. As a result, the entire disk (~0.1–100 AU / gas+dust) are thought to disperse almost simultaneously with $\Delta t \leq 0.5$ Myr (Williams & Cieza 2011). For debris disks, which is directly connected to terrestrial planet formation, disk lifetime is estimated to be $t \sim 100$ Myr from 24 μm observation (e.g., Wyatt 2008; Gáspár et al. 2009). However, previous studies are only for the solar neighborhood (see Figure 1). Next interest is how about in other environments.

We are extending the lifetime study to the whole Galaxy to see if there is any dependence on e.g., metallicity dependence. As the first step, we studied lifetime of protoplanetary disks in low-metallicity environments ([M/H]~ -1 dex) by observing star forming regions located in the outer Galaxy at $R_G \geq 15$ kpc. As a result, disk fractions there are found to be systematically low (Yasui et al. 2009), suggesting quite short disk lifetime compared to that in the solar metallicity (Yasui et al. 2010, Figure 2). Because these previous studies are only with NIR, new sensitive MIR observation is necessary for investigating "habitable zones" of protoplanetary disks and debris disks.

2. PROPOSED STUDY

2.1. Target

The locations of target star-forming clusters are assumed from the inner Galaxy ($R_G \sim 3$ kpc) to the outer Galaxy ($R_G \sim 15$ kpc), thus the distance is $D \gtrsim 5$ kpc (Figure 1).

2.2. Method

For protoplanetary disks MIR SED slope between $\lambda \sim 5$–10 μm is used to pick up disk-harboring stars in star-forming clusters (Hernández et al. 2007), while ~20 μm excess is used (Hernández et al. 2009) for debris disks. The procedures of disk lifetime estimation are: i) derive disk fraction, which is the ratio of the number of stars with IR excess to the total number of stars, in various star forming regions in wide age range, ii) then estimate disk lifetime from disk fraction vs. age plot (Figure 2).

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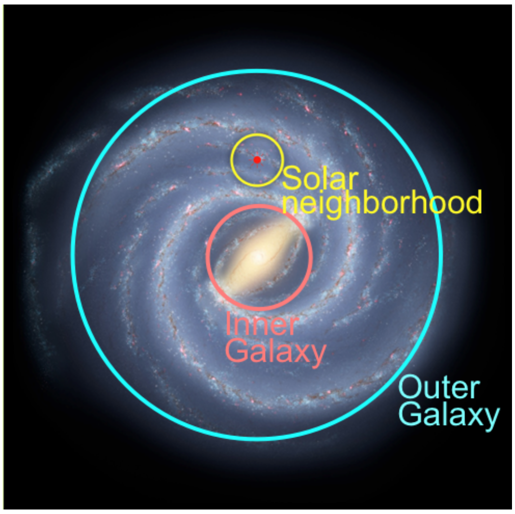

Figure 1. Target regions on the artistic illustration of the face-on Galaxy (R. Hurt, NASA/JPL-CalTech/SSC). On the Galaxy scale the solar neighborhood (yellow), which has been previously studied, is quite limited, while the outer Galaxy (blue) and inner Galaxy (red) are left widely unexplored.

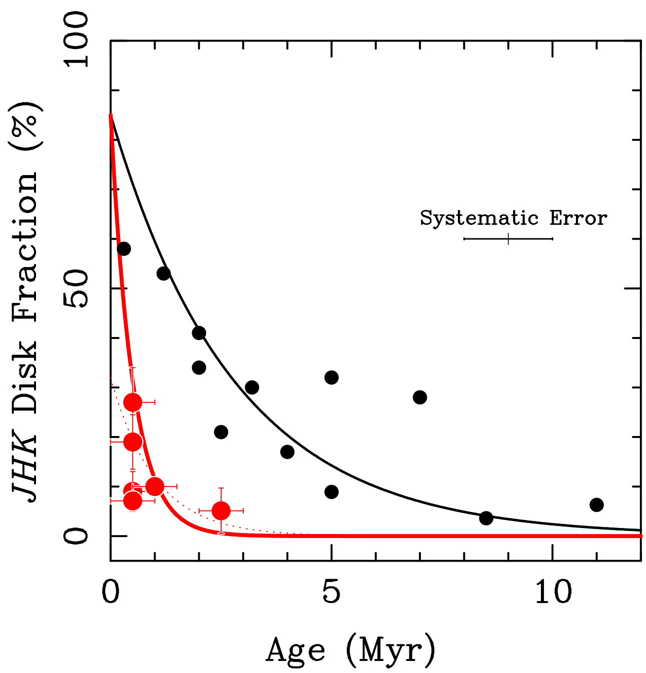

Figure 2. Disk fraction as a function of cluster age. *JHK* disk fractions of the young clusters with low metallicity are shown by red filled circles, while those of young clusters with solar metallicity are shown by black filled circles. The black line shows the disk fraction evolution under solar metallicity, while the red arrow shows the proposed *JHK* disk fraction evolution in low-metallicity environments. From Yasui et al. (2010).

2.3. **Sensitivity**

I estimated required sensitivities for protoplanetary and debris disk observations assuming the target distance of 5 kpc. For protoplanetary disks, the flux densities are estimated as $F_{8\,\mu\mathrm{m}} \gtrsim 200$ mJy for intermediate-mass stars and $F_{16\,\mu\mathrm{m}} \gtrsim 5$ mJy for low-mass stars from the previous study of IC 348 star forming region with the distance of 320 pc (Lada et al. 2006). For debris disks, $F_{24\,\mu\mathrm{m}} \gtrsim 10$ mJy for intermediate-mass stars from λ Orionis with D = 450 pc (Hernández et al. 2009) and $F_{24\,\mu\mathrm{m}} \gtrsim 0.4$ mJy for low-mass stars from IC 2391 with D = 150 pc (Siegler et al. 2007) are estimated to be necessary. From the above flux densities and distances of star forming regions, the required sensitivities for the target distance are summarized in Table 1. Considering the sensitivities of *SPICA* MCS (see Table 2), protoplanetary disks can be photometrically detected both for low-mass and intermediate-mass stars. Even debris disks can be detected for intermediate-mass stars.

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Table 1. Required sensitivities for protoplanetary/debris disk observations of intermediate-/low-mass stars at $D = 5$ kpc.

	Intermediate-mass	Low-mass
Protoplanetary disk	2 mJy@10 μm	50 μJy@10 μm
Debris disk	0.1 mJy@10 μm	0.3 μJy@20 μm

Table 2. Comparison of imaging specifications for the coming MIR instruments.

Telescope	*SPICA*	TMT	*JWST*
Diameter [m]	3.2	30	6.5
MIR Instruments	MCS	MICHI (w/AO)	MIRI
Wavelength [μm]	5–38	N, Q-band	5–28
Spatial resolution	0.8″@10 μm	0.08″@10 μm	0.4″@10 μm
	1.6″@20 μm	0.16″@20 μm	0.8″@20 μm
Sensitivity (5σ, 1hr)	1 μJy@5–25 μm	0.1 mJy@N-band	0.4 μJy@10 μm
FoV (imager)	5′ × 5′	~30″ × 30″	~1′ × 2′

2.4. Advantages of *SPICA*

I summarized specifications of the coming MIR instruments, *SPICA* MCS, TMT MICHI and *JWST* MIRI in Table 2. Because the extent of star forming regions at 5 kpc is about 1 pc, subtraction of contamination by foreground and background stars using control field with sufficient area is necessary. For this purpose, *SPICA* MCS has a great advantage because images of both target cluster and control fields can be obtained simultaneously in the wide FoV of 5′ × 5′. In addition, the relatively high sensitivities are also an advantage. Although the spatial resolution is not very high among three MIR instruments, spatially-resolved photometry with reasonable accuracy should be achieved with the expected typical separation of stars in target star-forming clusters (~1″; Allen et al. 2007).

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