SPICA Observations of Young Jovian Planets

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1. Best Ages for SPICA

1. Forming Planets（< 10 Myr）

   Spectroscopy reveals characteristics of the known planets

2. Young Planets（<1 Gyr）

   A 1 M_J planet within 20 pc is 10 times brighter than the sensitivity limit (1 hr, 5 σ)

   - Discovery of many planets by imaging survey.
   - Concentrate on the vicinity of the central star (even if the halo is not completely suppressed).
   - Low-resolution spectroscopy of the detected planet gives the atmospheric condition of the planets (One planet, one paper. Complementary to the transit obs.)

3. Young Pop I Planets（< 5 Gyr）

   Imaging survey, then low-resolution spectroscopy reveal the planet’s atmosphere (Complementary to the transit obs.).

1.1. Forming Planets（1 – 10 Myr）

Pros.

- Planets are bright
- Constraint on the formation process of the planets.

Cons.

- Space observations are not required.
- Outer (>100 AU) planets only (due to large distance)

Little advantages for discovery of planets.

Ground-based obs. may be sufficient.

Recommendation: Mid-infrared spectroscopy of the known planets（may overlap with the JWST targets).

1.2. Young Planets (～100 Myr)

Pros.

•Planets are cooler with age. Space observations have enough sensitivity in longer wavelengths. Suitable for such objects.

•Small discrepancy between evolution models.

•There are nearby clusters and moving groups.

•Ages are well defined.

Cons.

•Clusters and moving groups are already nominated as the targets of various planet surveys.

→ Avoid target overlaps to other surveys, if possible.

Recommendation: Construct our own samples before the launch. The Ursa major group is not so famous and one of the best target.

1.3. Young Pop I planets（1 – 5 Gyr）

Pros.

- Planets are cooler with age. Long-wavelength space observations have advantage for such objects.

Cons.

- Large uncertainty in the object's age.
- Nearby famous objects are also nominated as the targets of other projects.

Recommendation: Search for outer planets in the planetary systems known by the Doppler shift measurements.

Nearby (<200 pc) Clusters, Moving groups

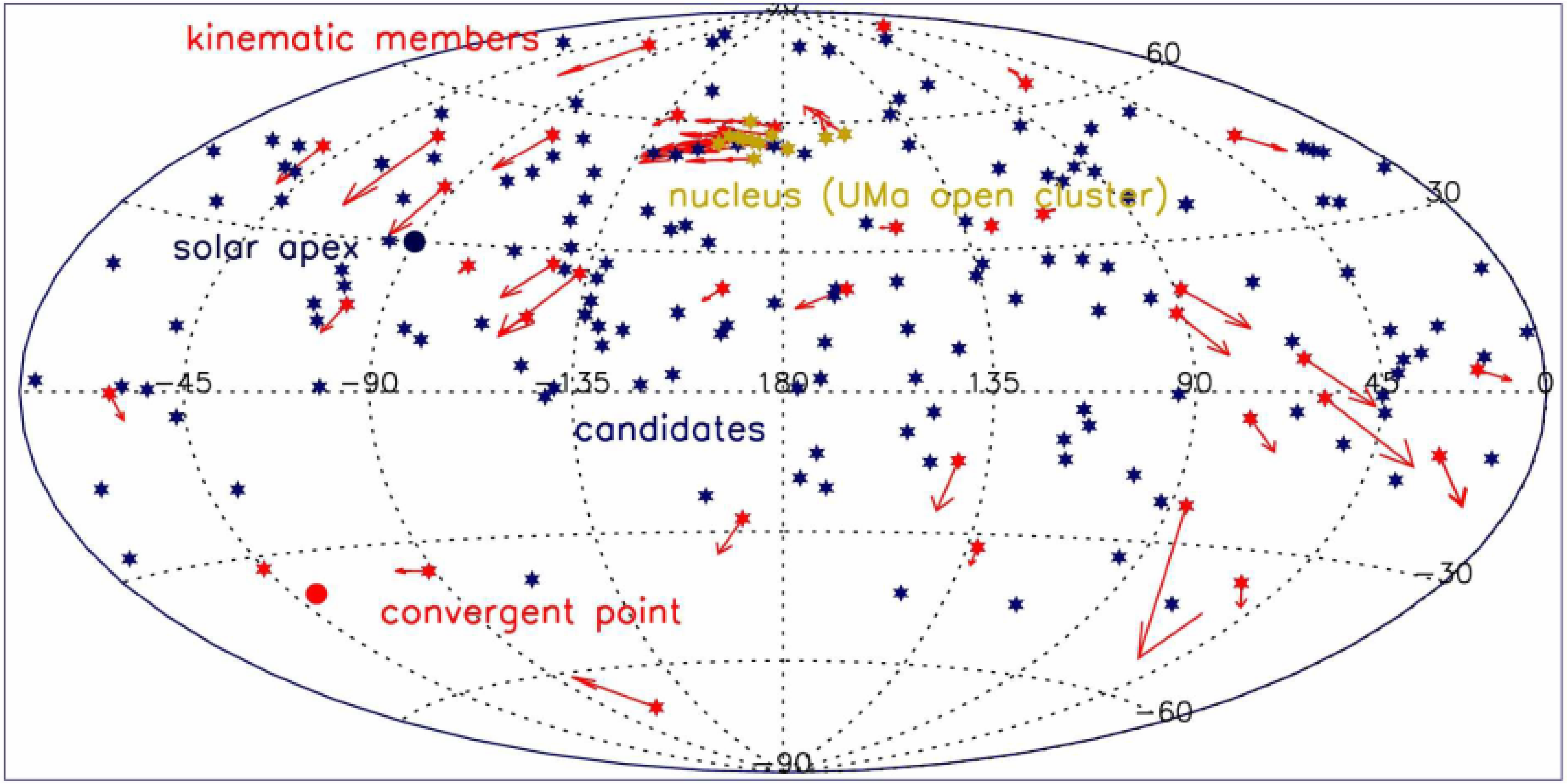
Name	Distance (pc)	Age (Myr)
Hyades	46	625±50
UMa group	**10-40**	**500 ±100**
Praesepe	170	400 – 900
Coma Ber	90	500 ± 50
Pleiades	120	100
Alpha Per	180	50 - 90
NGC 2451A	~200	50 – 80
IC 2391	150	53 ± 5
IC 2602	150	30
AB Dor	32	30 (age spread?)
Tuc-Hor	40	30
Beta Pic	10 – 60	12
TWA	~50	10

The Ursa Major group is nearby and not so young. → atractive target

Observations of the Ursa Major group

2.1. What is the Ursa Major group?

- 500 Myr old.
- Distribute over the whole sky, concentrate around the Septentrions (北斗七星).



Ammler et al. (2008)

2.2. Membership

- Example of the member list (Chupina+ 2006)
  - Compilation of the single stars

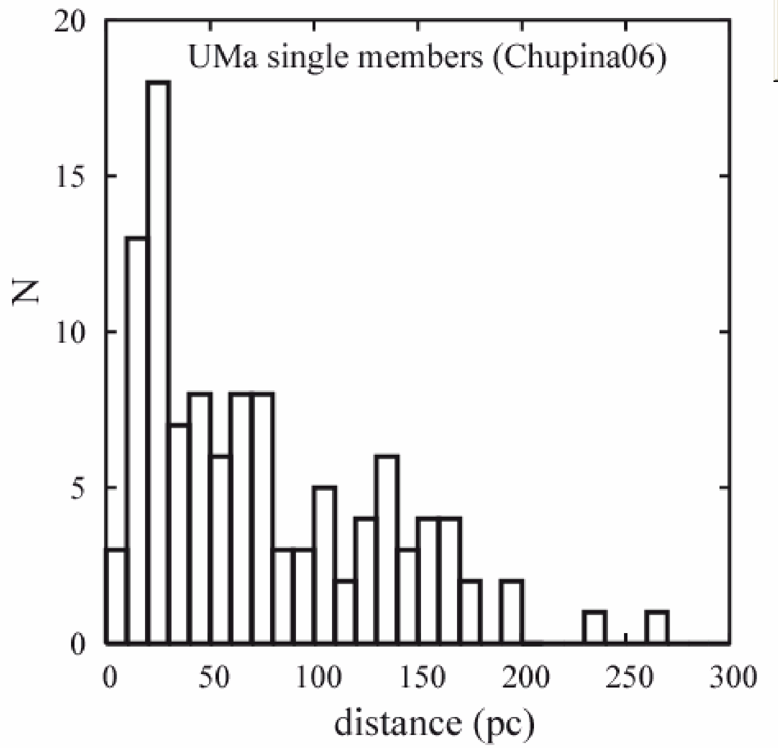
    Roman (1949), Eggen (1959), Soderblom & Major (1993), Eggen (1998), Montes et al. (2001), King et al. (2003)
  - 5 nucleus stars + 111 stars in the stream (incl. the candidates)

- Kinetics is insufficient
  - Criteria are arbitrary.
  - with strict requirements :

    members = 15 stars

    probable members = 22 stars

    possible members = 31 stars



2.3. Previous Observations

- Search for companions and planets (Ammler et al. 2008)
  - Ks-band, Coronagraph（VLT, NAOS/CONICA）
  - Members within 30 pc（25 in southern hemisphere）
  - sensitivity： ＞~10 M_J at >50 – 100 AU (based on COND03 model of Lyon group)
  - No planets and no brown dwarfs.

- We will have high advantages, if we construct our own sample based on new membership identification.

  high-resolution spectroscopy, multiplicity study….

2.4. Planets at 5 micron

- 5 micron

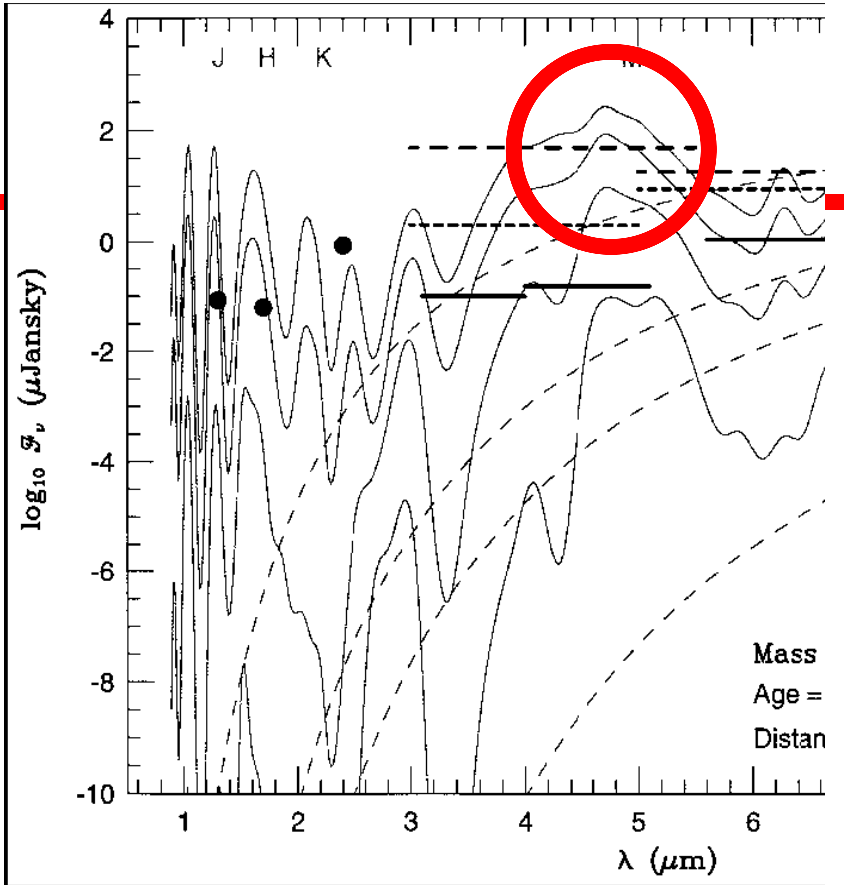
  Best sensitivity in near-infrared for planet search.

- Case:

  1 Jupiter-mass planets around a G2V star at 20pc.

  – Expected flux is 5 μJy, based on the Burrows et al. (1997) model.

  → 10 times brighter than the SPICA sensitivity (1hr, 5σ).



Burrows et al. (1997)
Mass = 1 MJ
Age = 0.1, 0.5, 1, 5 Gyr
Distance = 10 pc

2.5. Proposal [5 micron]

Proposal 1. Search for less-massive (～1 M_J) planets at 5um

Over 1 hour integration for each target.

Proposal 2. Search for > 2~3 M_J planets at 5um

over one order of magnitude brighter to the sensitivity limit.

– Imaging Survey
  - 1 minutes integration is enough for each object.
  - Target number is essential. Objects over 20 pc are still OK.
  - Halo of the central star is not critical. Search in close vicinity of the central star. No requirement for perfect PSF.

– Spectroscopy
  - R=several tens

Examples: Spectra of Jupiter and Saturn

- Thermal emission dominates the spectra beyond 5 micron.
- Emissions, absorptions: CH_4, NH_3, PH_3, H_2O, CH_3D

- The extra-solar planets will show variety of the spectra.
- We expect weather variation in the spectra.

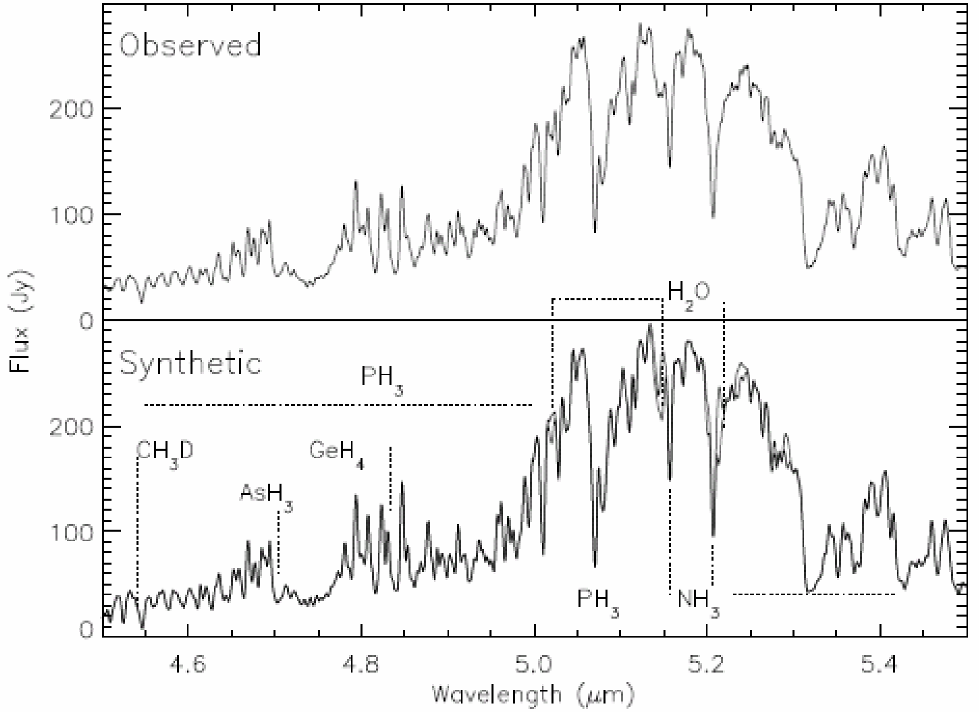


Fig. 1. Observed ISO-SWS spectrum (upper curve) and synthetic spectrum of Saturn (lower curve) in the 5-μm region. Spectral absorptions are due to NH_3, PH_3, AsH_3, GeH_4, CH_3D and H_2O. In the lower curve, the narrow line corresponds to a calculation without H_2O.

Saturn's spectra at the 5 micron range (de Graauw et al. 1997)

2.6. Proposal [> 10 micron]

- 10 micron
  - The planet is bright as in the 5 micron range.
  - SPICA has better sensitivity in the 5 micron range.
  - A 1 M_J planet in the UMa group has T_{eff} ~ 200 K, 2 μJy

  → comparable to the SPICA detection limit (1hr, 5σ)
- 20 micron
  - A 1 M_J planet 8 μJy

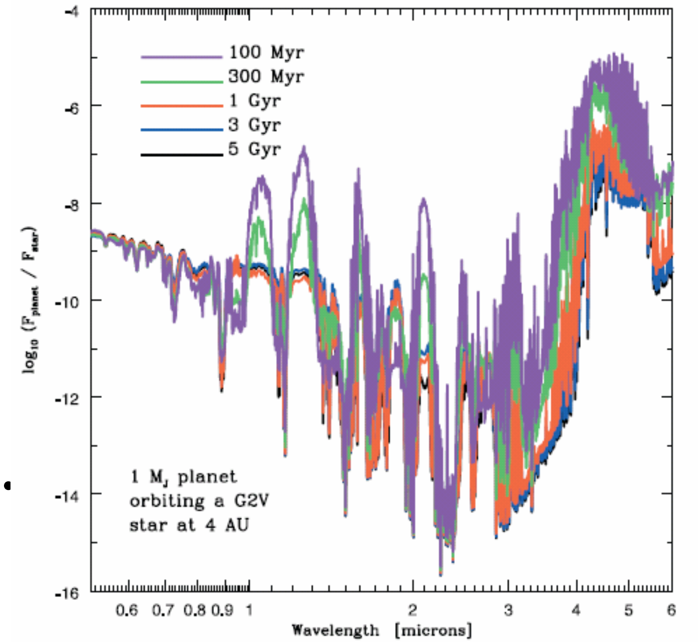
  → detect easier than the 10 micron obs.

Proposal 3. Search for > 2~3 M_J planets at 20um

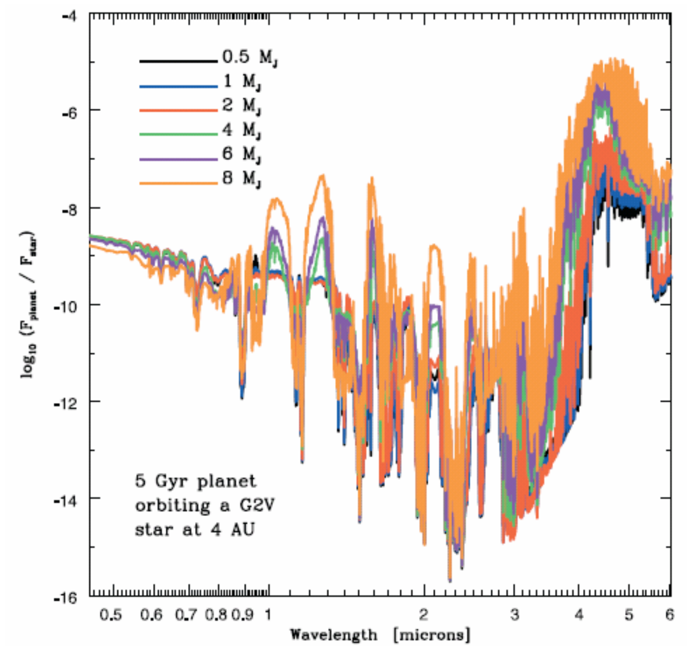
- Imaging Survey
  - 1 minutes integration is enough for each object.
  - Target number is essential. Objects over 20 pc are still OK.
  - Search in close vicinity of the central star.
- spectroscopy
  - R=several tens.（What is the important feature?)

3. Young Pop I Planets (Gyr)

- Gyr planets is 10 times fainter than the Uma group planets.
  →Flux of a 1 M_J planet is comparable to the detection limit (1 hr, 5 σ) .
  →Severe constraint on distance (<20 pc)
- Poor age accuracy for Gyr field stars.
  → Careful selection for targets.



- Well-known (age, composition) stars = targets of other planet searches.
  →avoid if possible
  Studies of ages, chemical composition, and multiplicity are must-do.



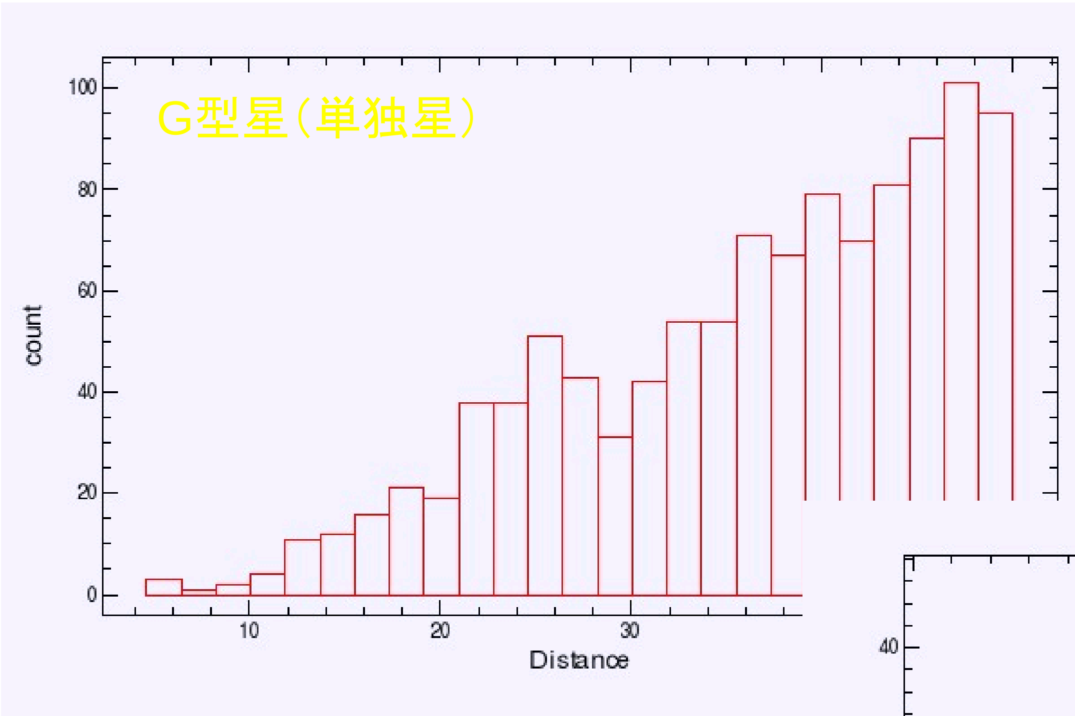
Burrows et al. (2004)

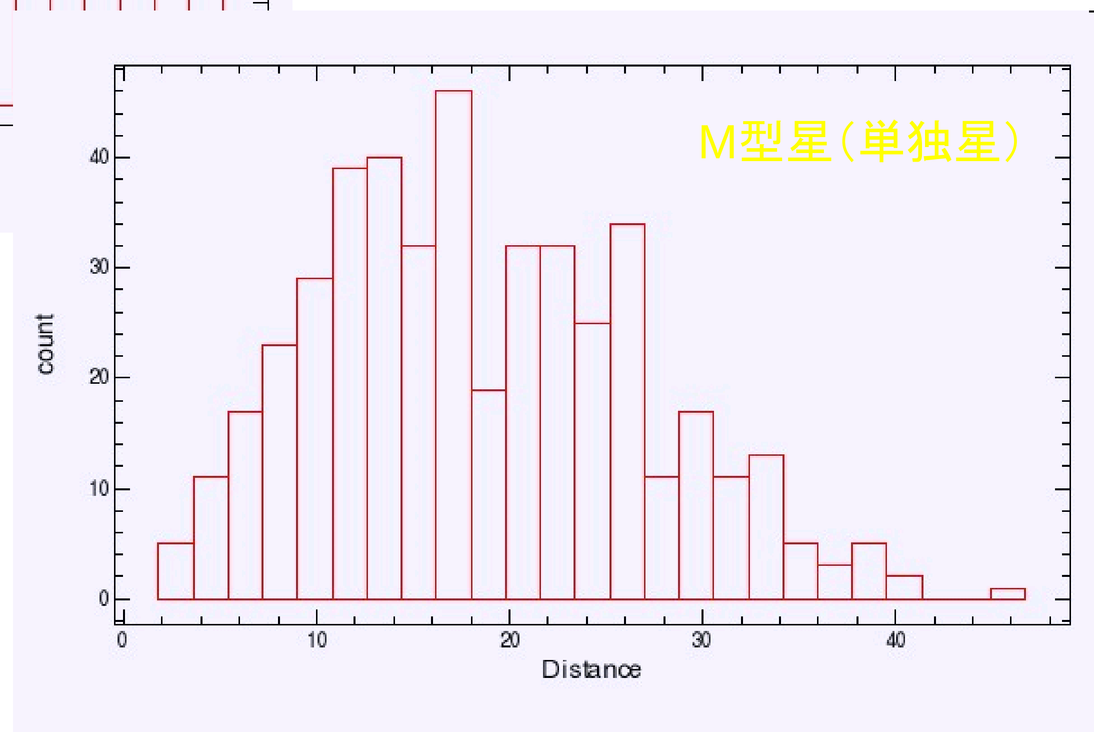
4. SPICA targets

Name	Sp.	Vmag	Distance	λ	Mode	IT
YSO						
?? Tau b	??	?	140pc	5um	Sp	10min
Moving Group						
HD91480他10天体	F1V	5.2	26pc	5um	Im	60min
				5um	Sp	60min
				20um	Sp	60min
HD115043他30天体	G0V	4.4	8.7pc	5um	Im	1min
				20um	Im	1min
Pop I						
HD………	??	?	<20pc	20um	Im	60min

Appendix

近傍星の数：単独星（と信じられている）天体





近傍(<200 pc)のクラスタ、Moving group

Name	D(pc)	Age (Myr)	[Fe/H]	# Member	ref
Hyades	**46**	**625±50**	**-0.09**		**f,o**
UMa group	**10-40**	**500 ±100**	**-0.03**	**>15?, p=53**	**i,n,o,q**
Praesepe	170	400 – 900	0.14		a,b,c,e,o
Coma Ber	90	500 ± 50	-0.20		a,b,h,o
Pleiades	120	100	-0.17		o
Alpha Per	180	50 - 90	0.1		a,b,c,d,e,o
NGC 2451A	~200	50 – 80	-0.45		a,b,c,g
IC 2391	150	53 ± 5	-0.13(-0.01)		a,b,c,o,s
IC 2602	150	30	0		o,s
AB Dor	32	30 (age spread?)		29, p=8	r
Tuc-Hor	40	30		~50	r
Beta Pic	10 – 60	12		30, p=30	j,p
TWA	~50	10		29	r
HD 141569	100	8		3	r
Eps Cha	114	5		16	r

クラスタ、moving group の Table にある reference

a. – van Leeuwen et al. (1999) Hipparcos measurements
b. – Robichon et al. (1999) Hipparcos measurements
c. – Sanner & Geffert (2001),
d. – Prosser (1992)
e. – Patience et al. (2002)
f. – de Bruijine et al. (2001)
g. – Platais et al. (2001)
h. – Odenkirchen et al. (1998)
i. – Soderblom & Mayor (1993)
j. – Zuckermann & Song (2001)
k. – Webb et al. (1999)
l. – Zuckerman, Song, & Webb (2001)
m. – Torres et al. (2000)
n. – King et al. (2003)
o. – Allen Astrophysical Quantities
p. – Lépine & Simon (2009)
q. – Chupina et al. (2006)
r. – Fernandez et al. (2008)
s. – D'Orazi & Randich (2009)

参考：土星のスペクトル

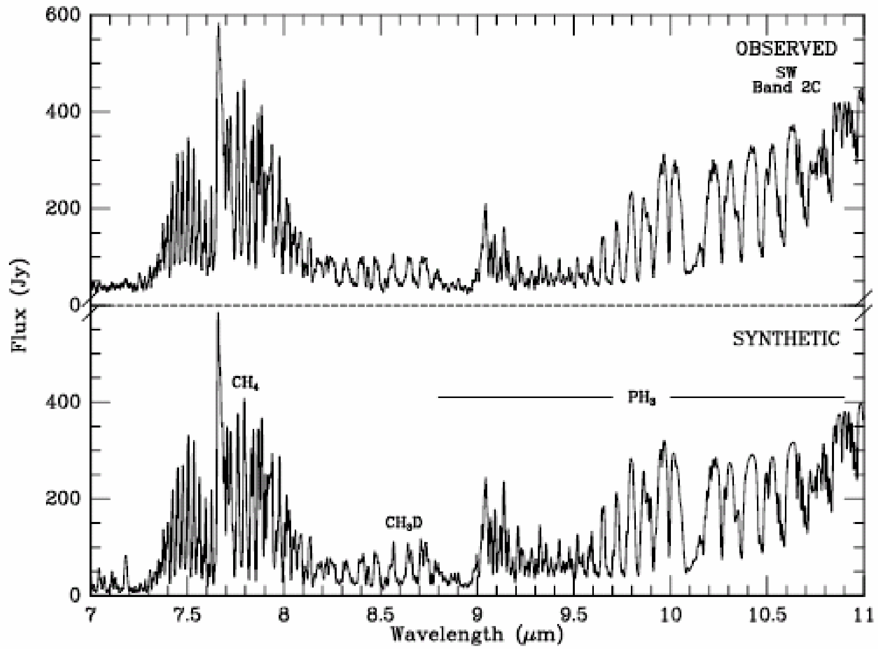


Fig. 2. Comparison between the Saturn ISO-SWS data (above) and a synthetic model (below) in the 7–11 μm range. The spectrum shows stratospheric emission features due to CH_4, and tropospheric absorption features due to CH_3D, PH_3 and NH_3.

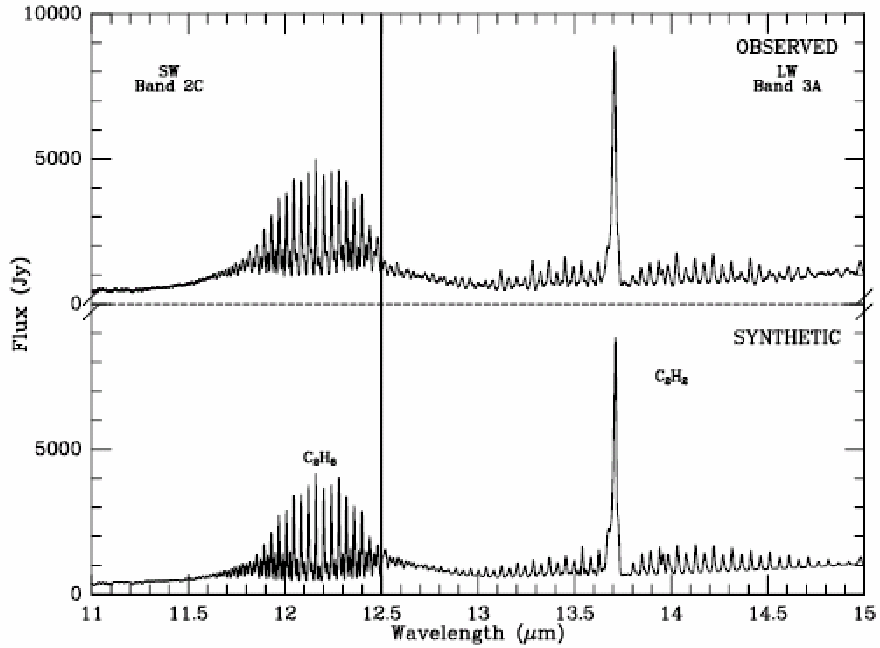


Fig. 3. Observed ISO-SWS spectrum of Saturn (upper curve) and synthetic spectrum (lower curve) between 11 and 15 μm. Molecular emissions are due to C_2H_6 and C_2H_2.

de Graauw et al. 1997

UMa メンバーに付随する惑星の明るさ

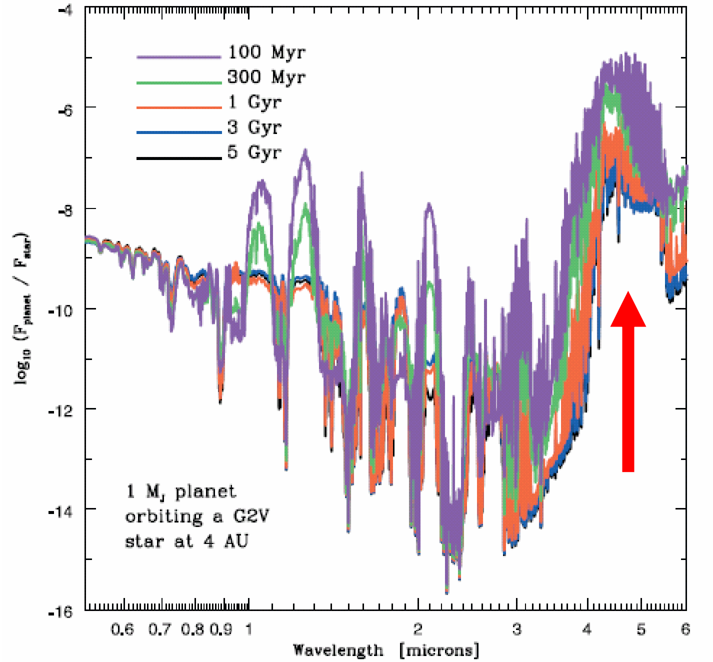
- 5ミクロン付近
  - 距離20 pc にあるG型メンバーの明るさ: 2 Jy
- 1木星質量の場合

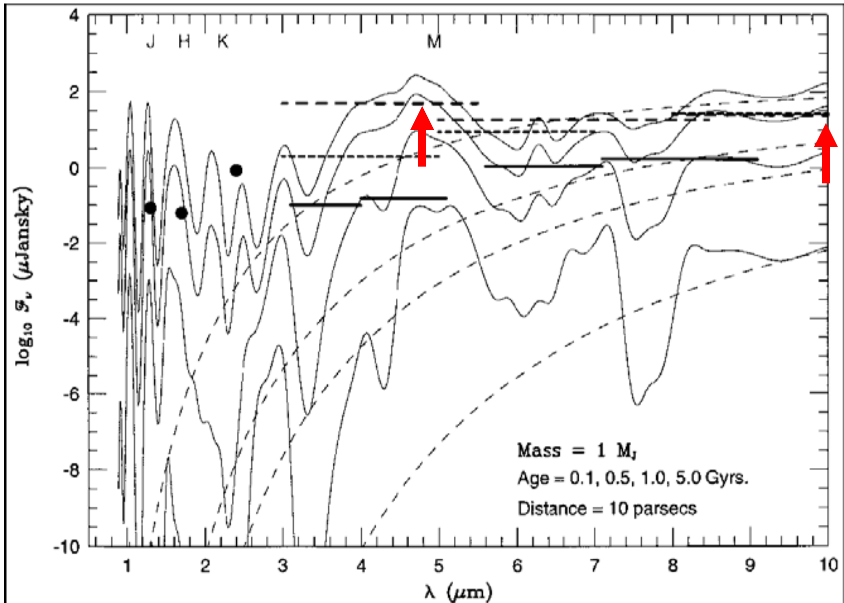
(1) Burrows et al. (2004) のモデルを使用すると、惑星は星より6桁暗い　(~100 Myr – 1 Gyr)。モデルが想定している 4 AU で惑星は 2 μJy、20 AU ではさらに1.5桁程度落ちて 0.1 μJy

→ SPICA検出限界(1hr, 5σ) 程度。2 – 3 木星質量であれば1桁程度の余裕が出る。

(2) Burrows et al. (1997) のモデルを使用すると、惑星の明るさは 8 μJy

→ SPICA検出限界(1hr, 5σ)より1桁以上明るい





Burrows et al. (1997)

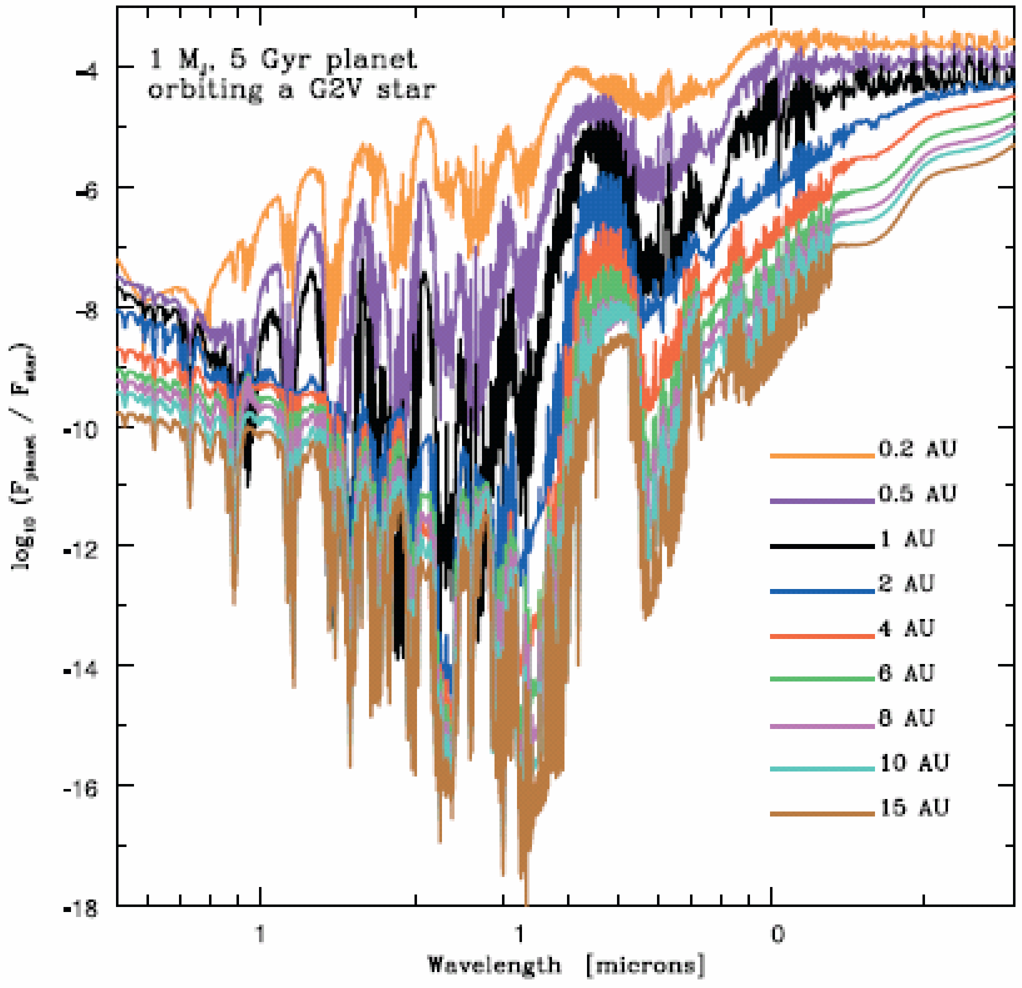


FIG. 3.—Planet-to-star flux ratios vs. wavelength (in μm) from 0.5 to 30 μm for a 1M_J EGP with an age of 5 Gyr orbiting a G2 V main-sequence star similar to the Sun. This figure portrays ratio spectra as a function of orbital distance from 0.2 to 15 AU. Zero eccentricity is assumed and the planet spectra have been phase averaged as described in SBH03. The associated *T*/*P* profiles are given in Fig. 1, and Table 1 lists the modal radii for the particles in the water and ammonia clouds. Note that the planet/star flux ratio is most favorable in the mid-infrared. See text for further discussion.

惑星探査プロジェクトでのターゲット

- GPI サーベイ
  (Graham et al.)
  – 若い星=200個
  – A型星=200
  – 比較的若いFGK型星=500
  – デブリ円盤=500
  – Volume limited=2000

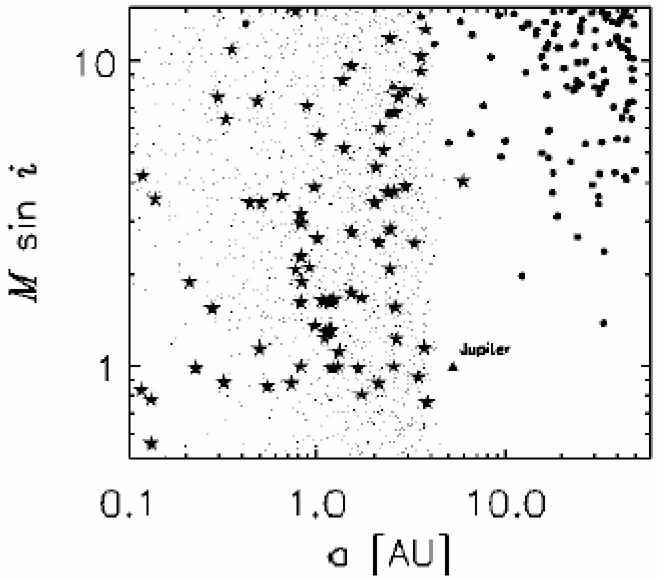


Figure 6: Exoplanets from the simulated GPI field star survey. Heavy filled circles are GPI detected planets from. Light dots are planets detected by a hypothetical 8-year astrometric interferometer survey, with a limit of *R* < 10 mag., and a precision of 30 μas. Exoplanets detected in the Keck/Lick Doppler survey are shown as stars. This illustrates how GPI explores a complementary phase space to indirect searches.