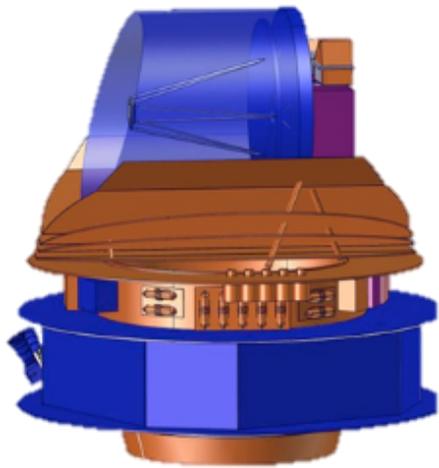
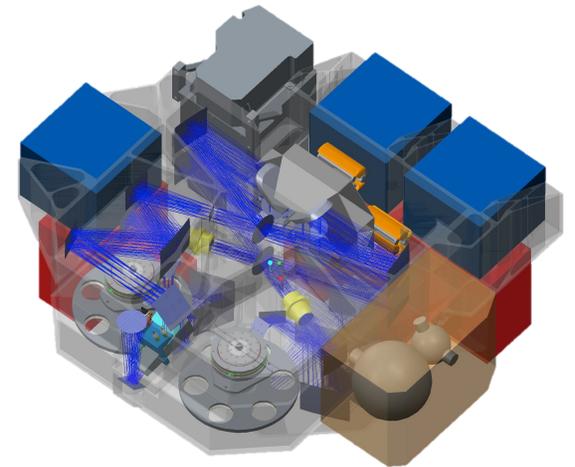


Grating-SAFARI -- A SPICA far-IR spectrometer with improved capabilities



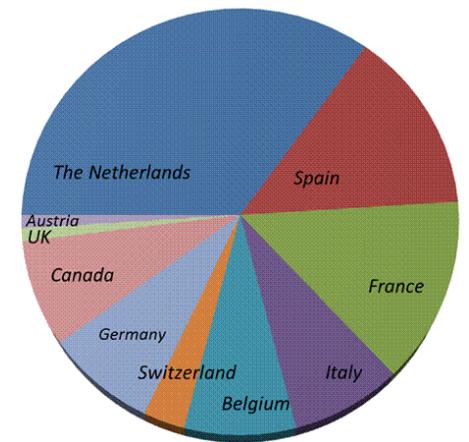
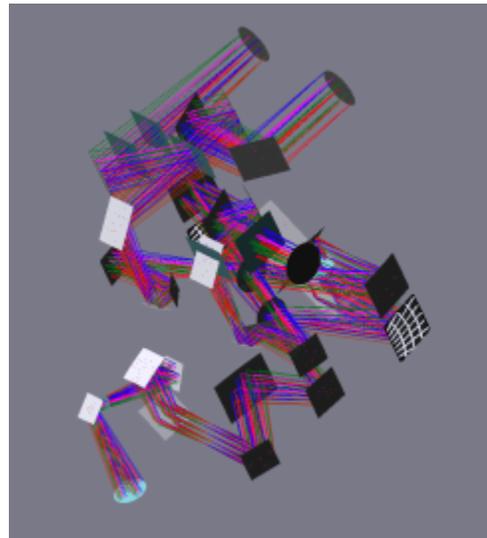
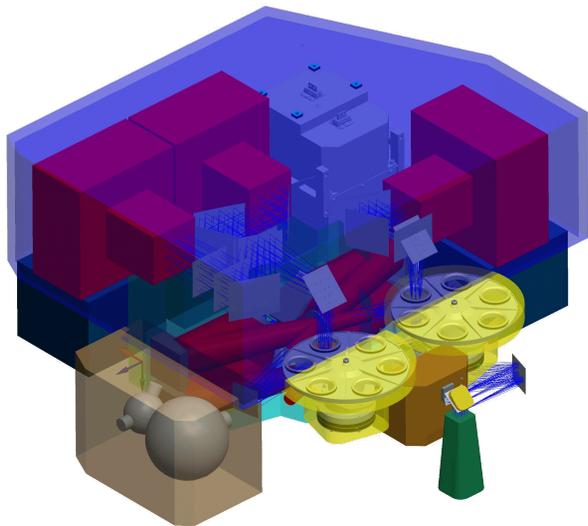
SAFARI



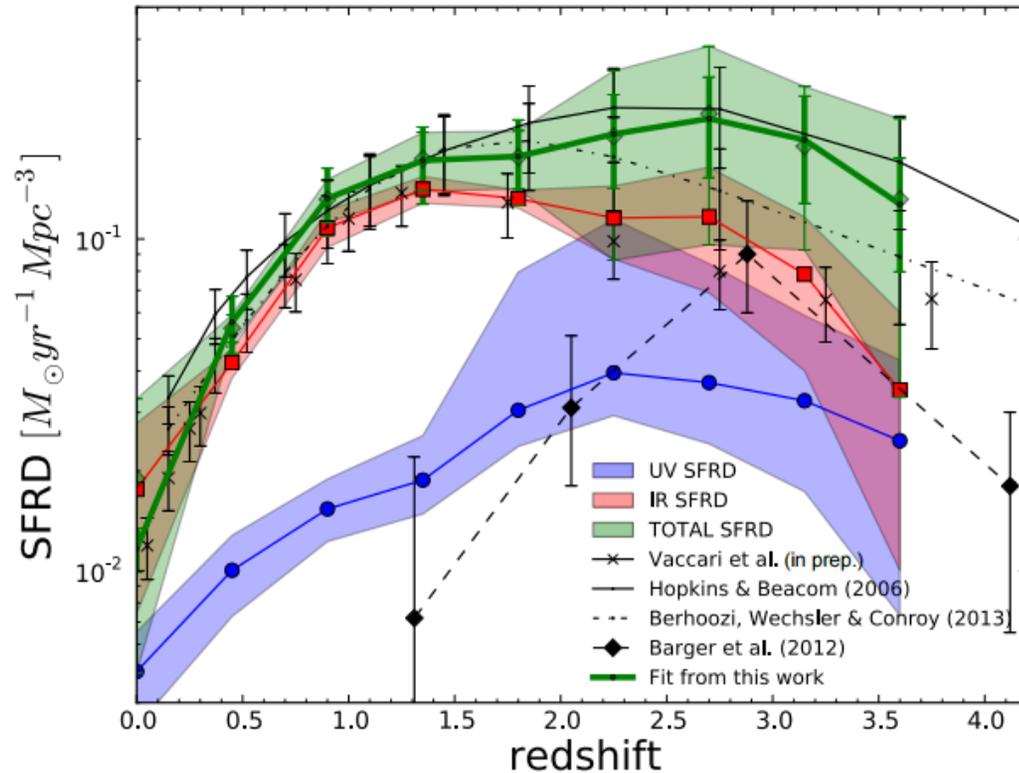
土井 靖生 (東大総文), Peter R. Roelfsema and the SAFARI consortium

オリジナルSAFARIデザイン(~2014年)

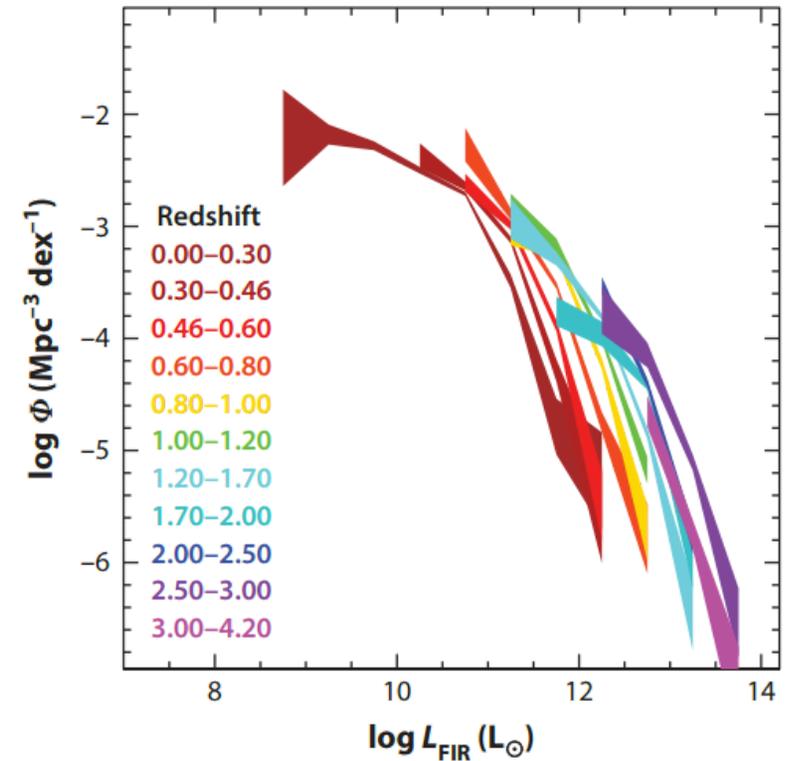
- フーリエ分光器による $2' \times 2'$ の広視野面分光
- 3バンドの検出器により $34 - 210\mu\text{m}$ を観測
- TES検出器/SQUID/周波数多重化(FDM)による高感度検出
- 輝線検出限界 $\sim 3 \times 10^{-19} [\text{Wm}^{-2}]$ (5σ , 1hr)
- 蘭SRONをPIとする国際協力による開発(開発費用 $\sim 170\text{M}\text{€}$)
 - ヨーロッパ各国、カナダ、日本の ~ 15 国/機関が参加。



$z \sim 1 - 3$ から現在までの銀河進化の解明

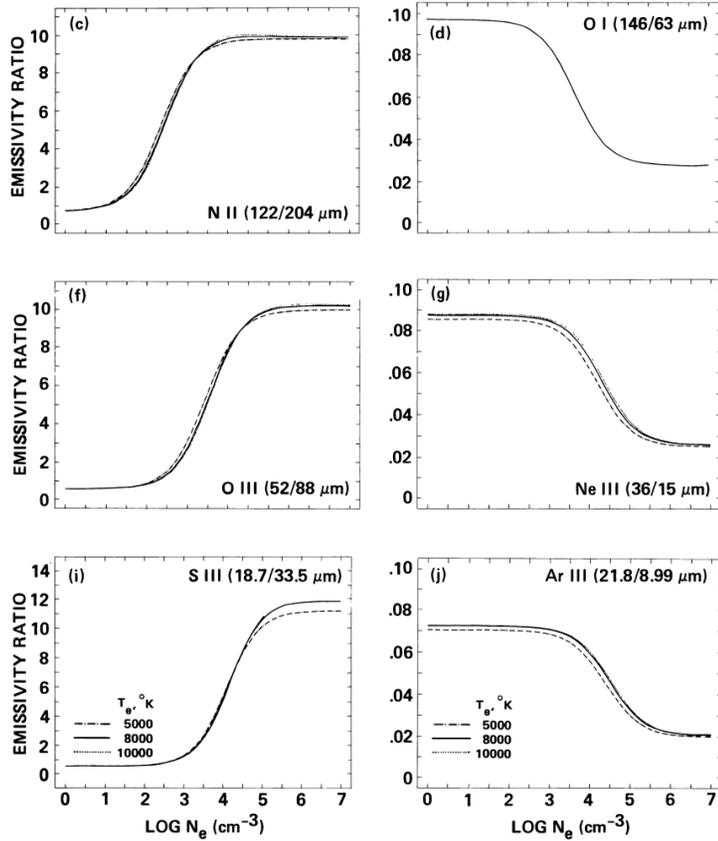


Burgarella *et al.* (2013)

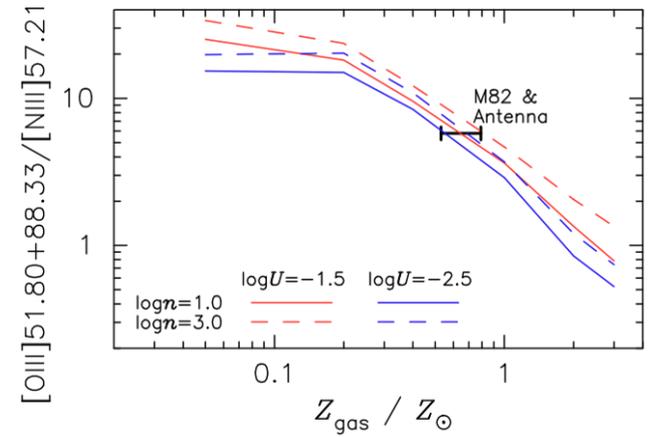
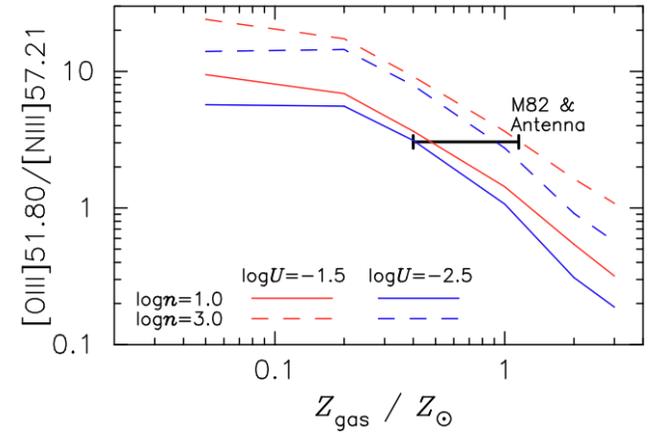


Madau & Dickinson (2014)

ガス密度 & 金属量



Rubin (1989)



Nagao *et al.* (2010)

星形成活動 vs. アウトフロー

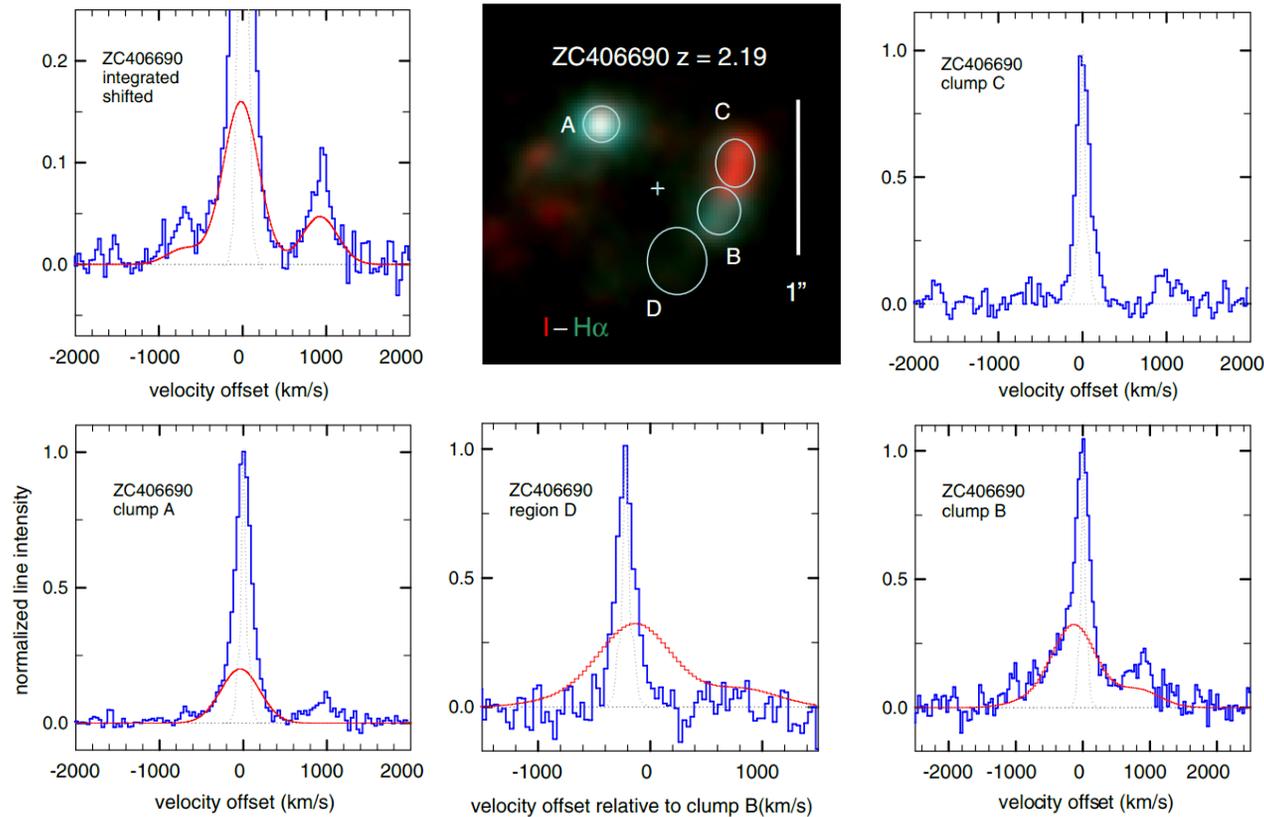
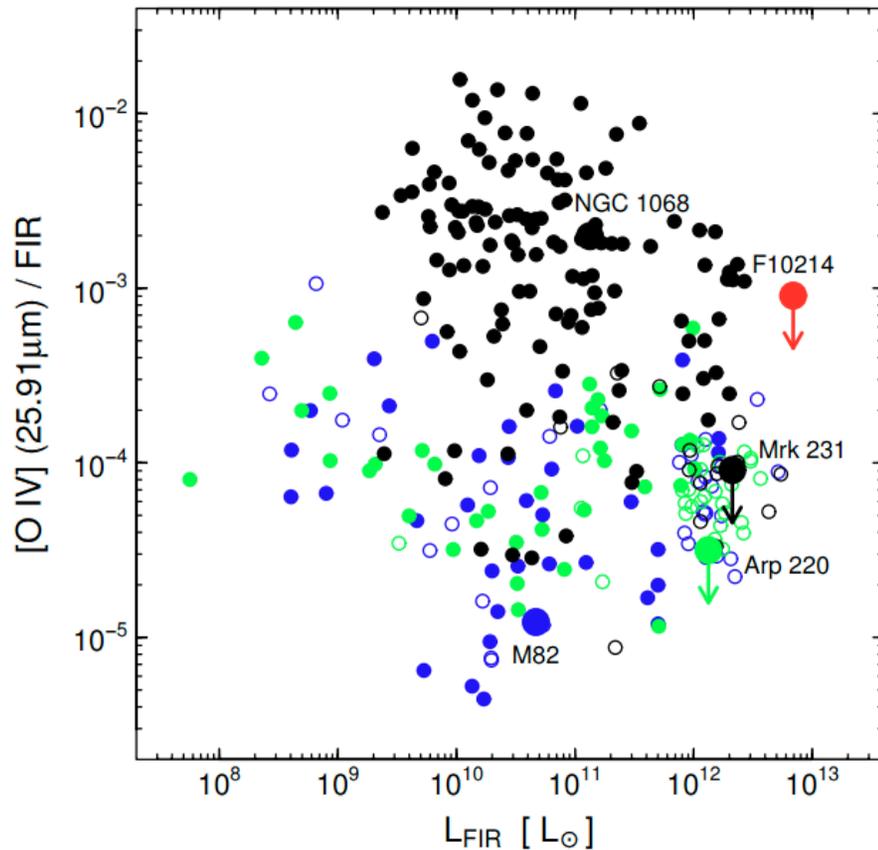


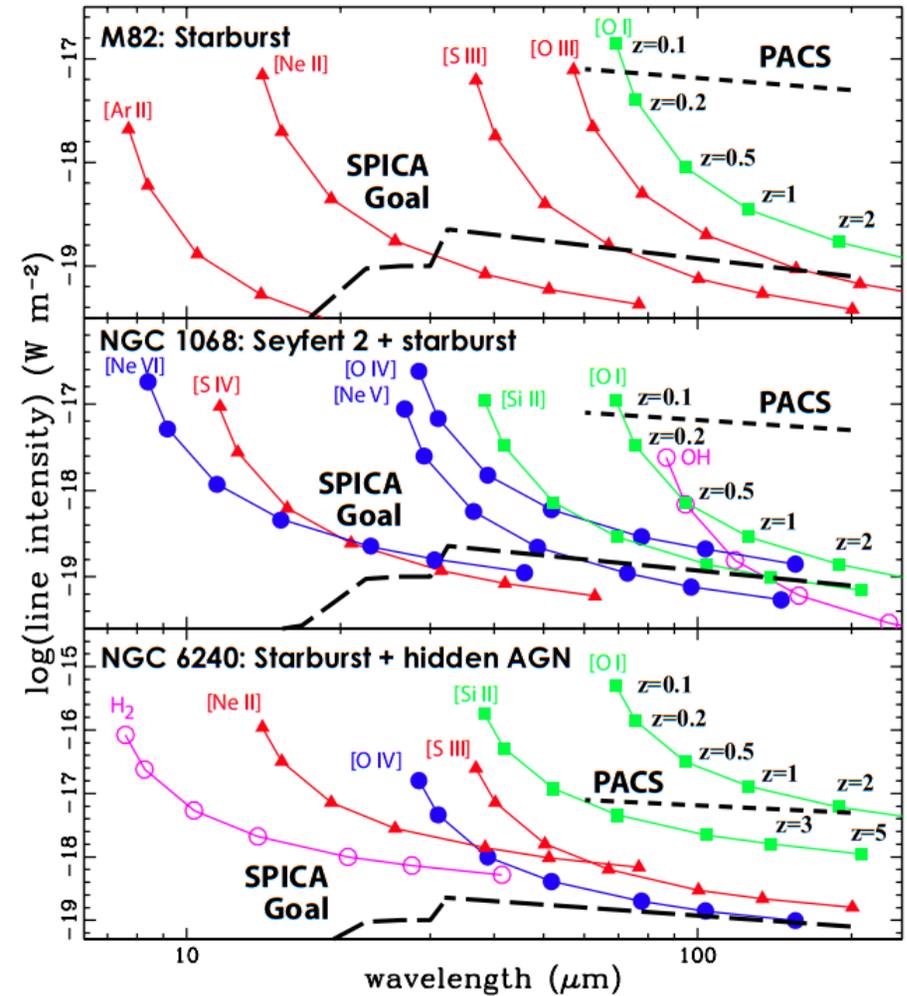
Figure 7. $H\alpha$ spectra of ZC406690 ($z = 2.195$), for the entire galaxy (top left), as well as for selected clumps marked in the central $H\alpha$ -ACS I -band composite (Figure 2). The dotted gray curves in all panels denote the SINFONI spectral response profile measured from OH sky lines. Before construction of the integrated spectrum, the galaxy rotation was removed for each pixel. The thin red curves show the broad $H\alpha$ (clump A) or broad $H\alpha + [N II]$ (integrated spectrum, clump B) components obtained from multi-component Gaussian fits. For region D, the thin red curve is the scaled broad $H\alpha$ component of clump B, and the velocity scale is relative to the systemic velocity of nearby clump B.

Seyferts/LINERs/Star-forming

Line-diagnostics



Sturm *et al.* (2010)



Spinoglio *et al.* (2009)

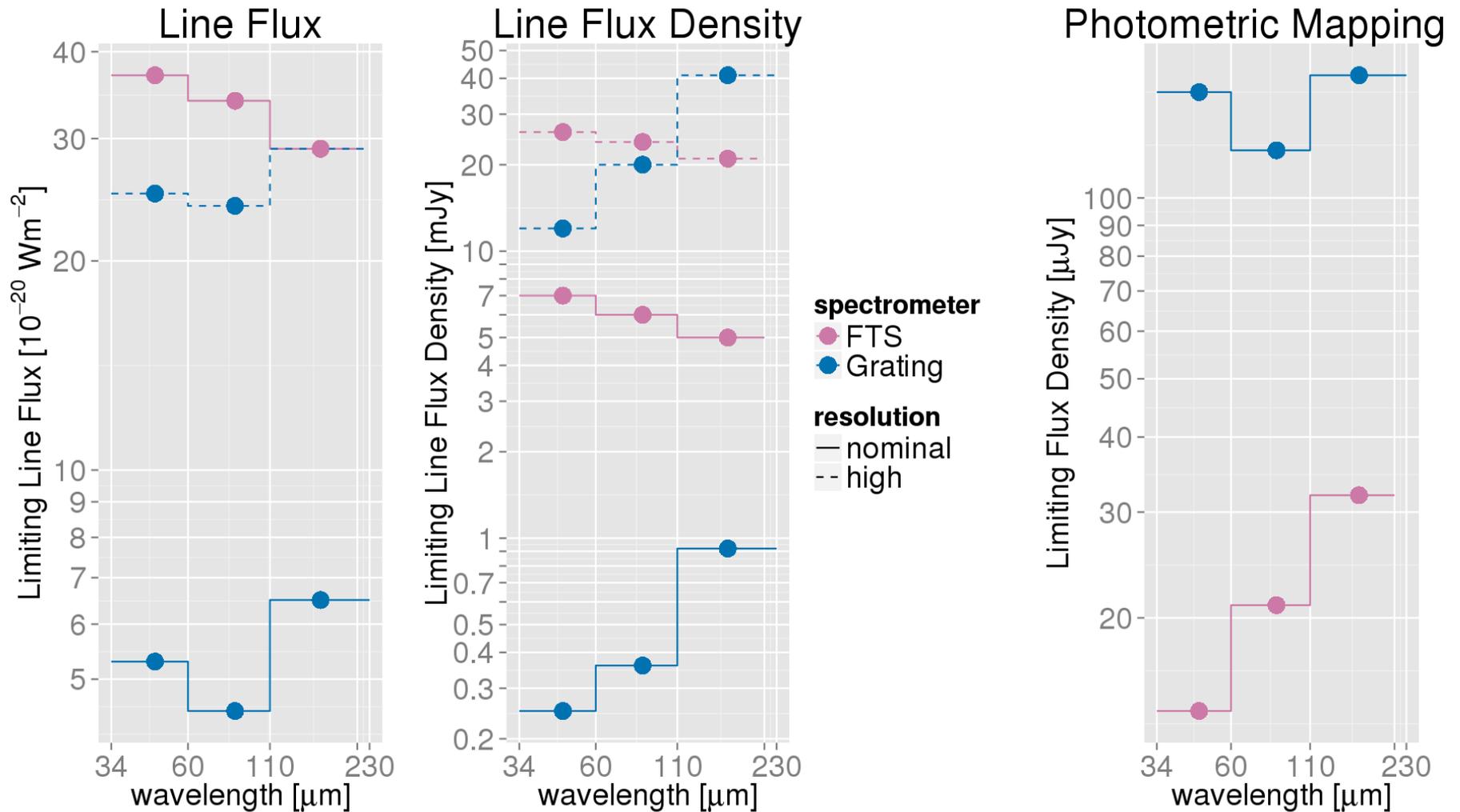
要求性能・制約条件

- 感度: $5 \times 10^{-20} \text{ [W m}^{-2}\text{]}$ (5σ , 1hr)が"最低条件"
 - [OIV] $25.9\mu\text{m}$ 輝線の予測強度
~ $1 - 2 \times 10^{-20} \text{ [W m}^{-2}\text{]}$ ($L \sim 10^{11.5} - 10^{12} L_{\odot}$ @z=3)
- 波長範囲: $230\mu\text{m}$ まで拡大([NIII] $57\mu\text{m}$ @z=3)
 - 但し望遠鏡温度要求が厳しくなる。
- 比波長分解能
 - 系外銀河分光 $R \sim 150 - 500$
 - AGNアウトフロー $R \sim 1500$
 - 近傍銀河星間物質・PPD $R \sim$ 数千
- 低温部発熱制限 → 検出器素子数 ~ 3500以下
- 現有開発リソースを最大限活用するデザイン

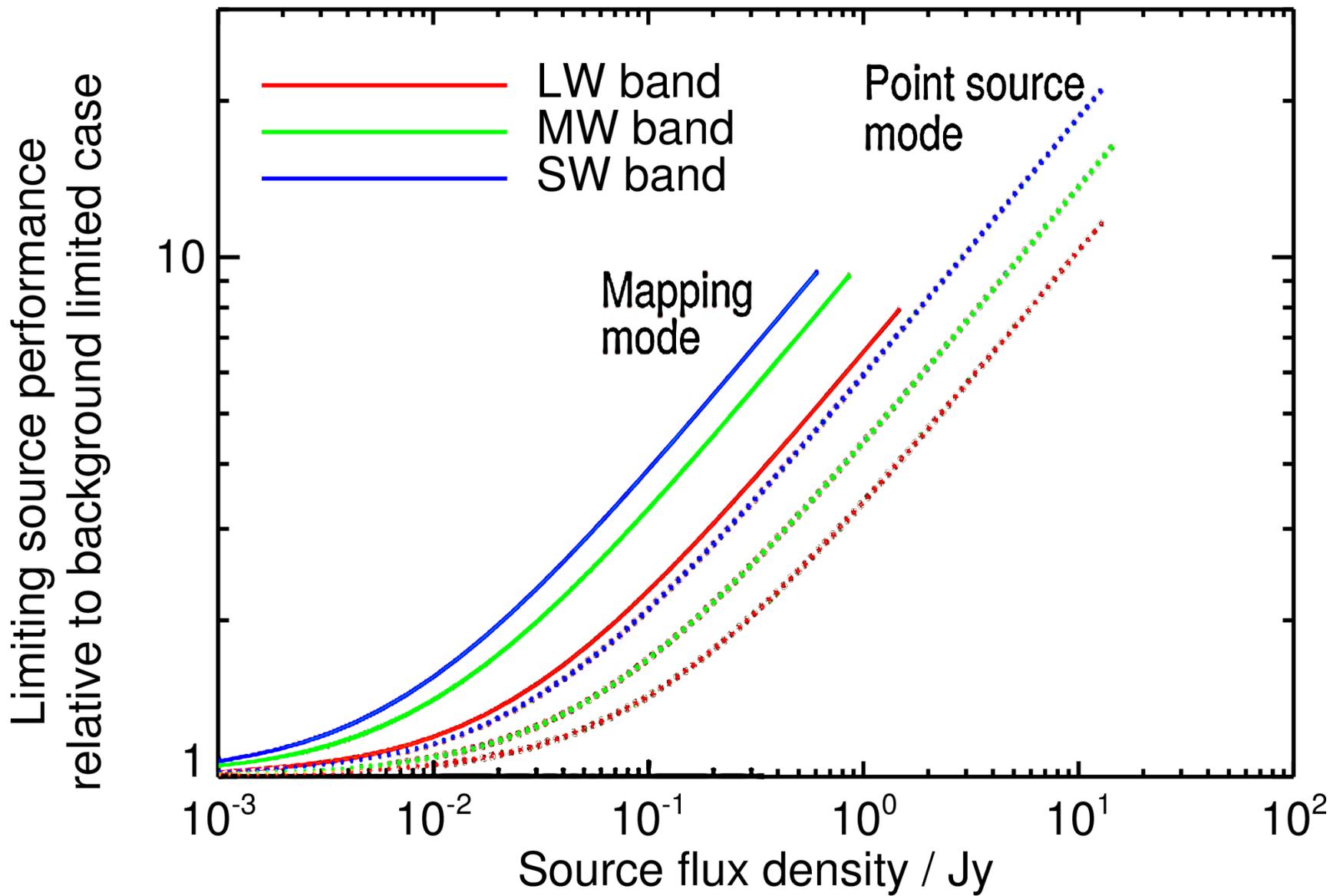
グレーティングの採用による 検出感度の向上

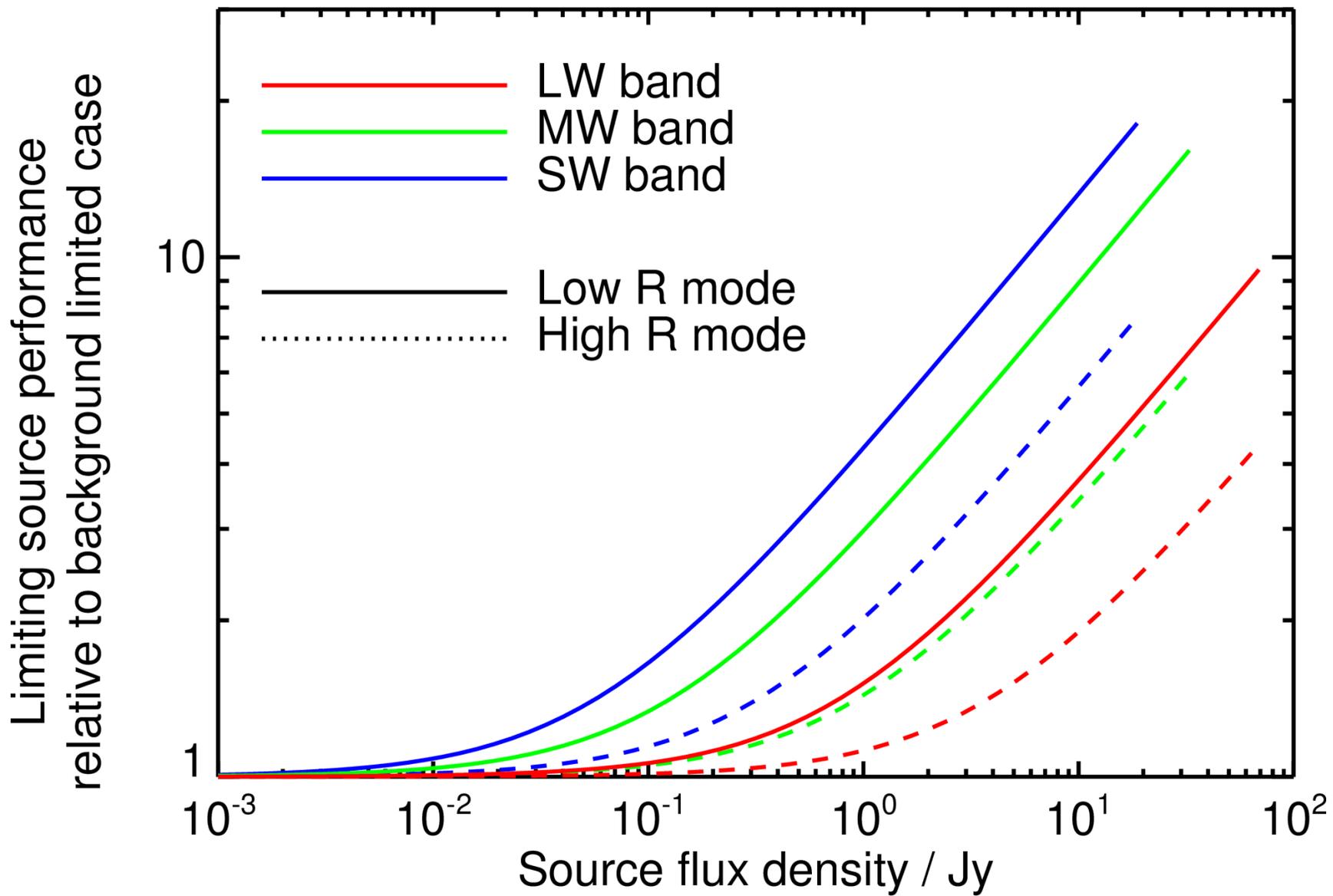
- FTS(=広帯域) → グレーティングの採用
 - 検出器入射光量の低減によるS/N比の向上
 - $3 - 4 \times 10^{-19} [\text{W m}^{-2}] \rightarrow 4 - 7 \times 10^{-20} [\text{W m}^{-2}]$
 - $R \sim 300$
- 検出器に対する要請の緩和
 - 検出素子入射光量の低減
 - 検出器時定数の低速化
- 空間マッピング能力に対する影響
- 高波長分解能時の分光素子の追加
 - ファブリペローにより $R \sim 3000$ を達成

検出限界(Grating vs. FTS)

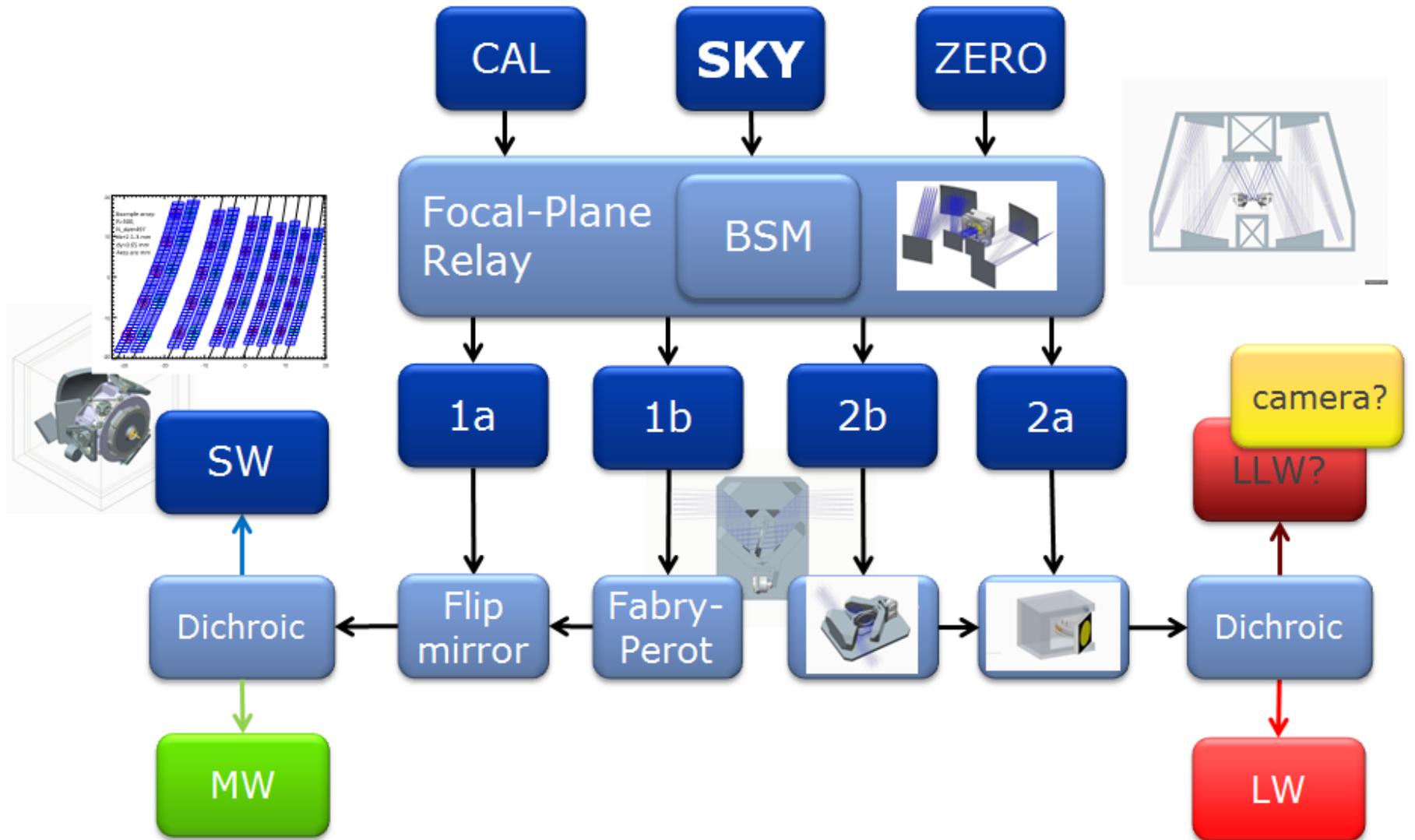


注)望遠鏡口径、比波長分解能が異なるため同列な比較ではない。

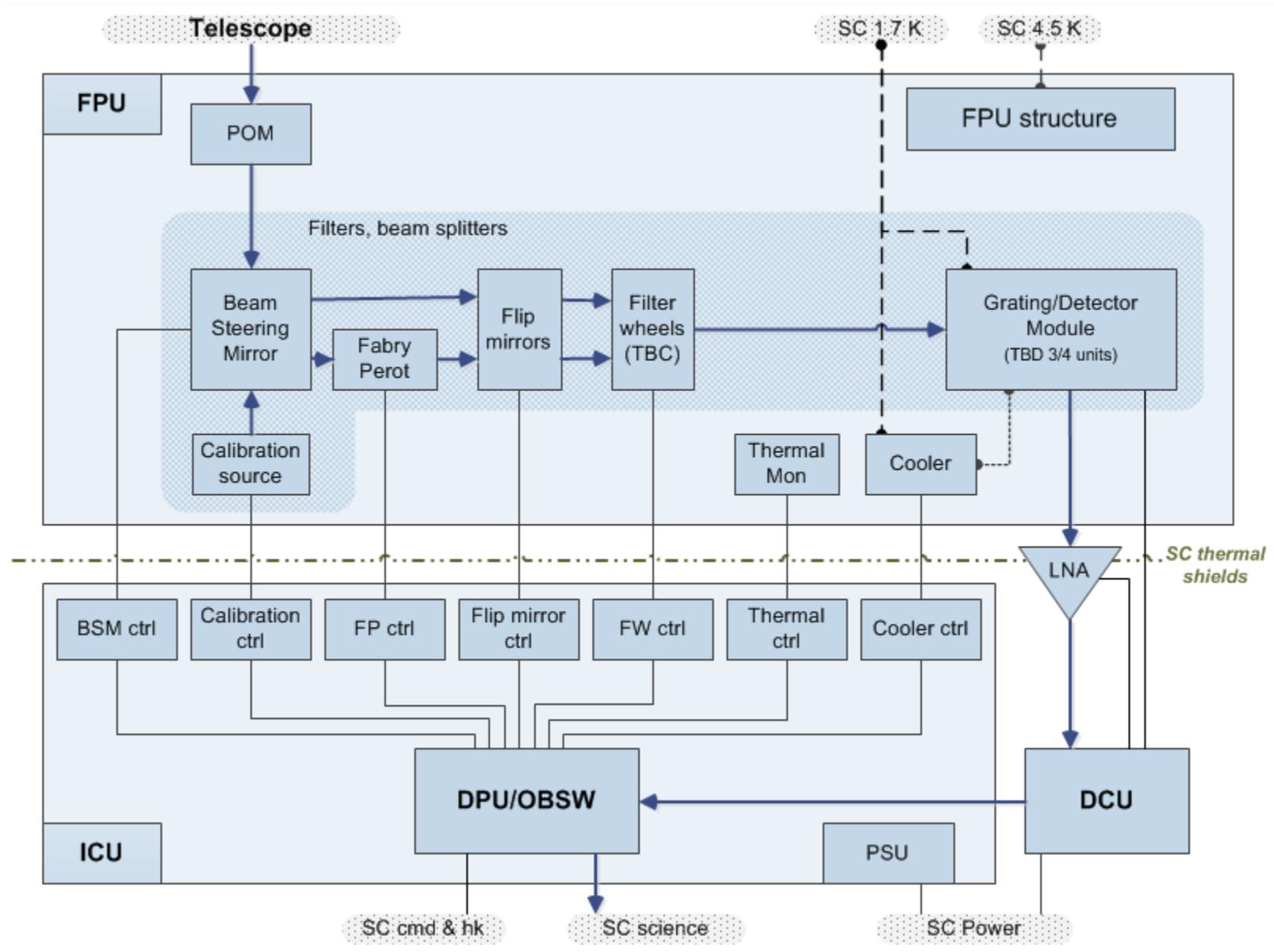




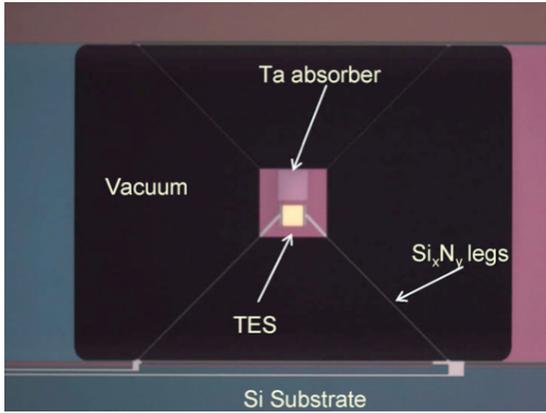
光学系ブロック図



観測機器ブロック図



TES検出器モジュール



V256a 鈴木他
を参照ください
(次講演)

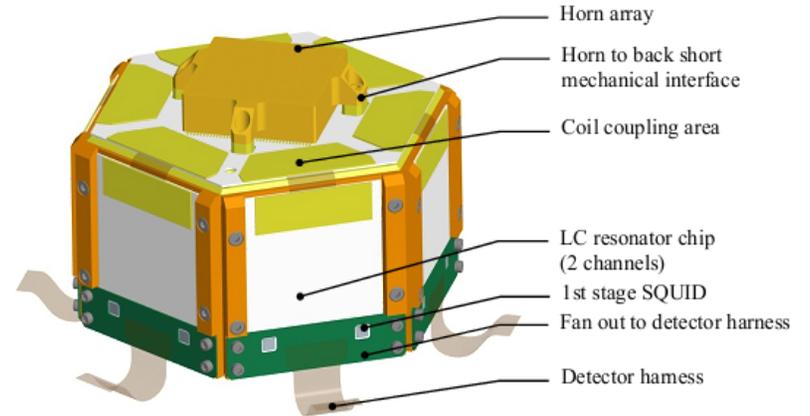


Figure 7-4 – Focal plane array 50 mK stage concept. This view includes the coil coupling concept for the TES to LC filter connection. In case wire bonding is used for this connection, the area required is reduced to a small area along the six edges of the TES chip.

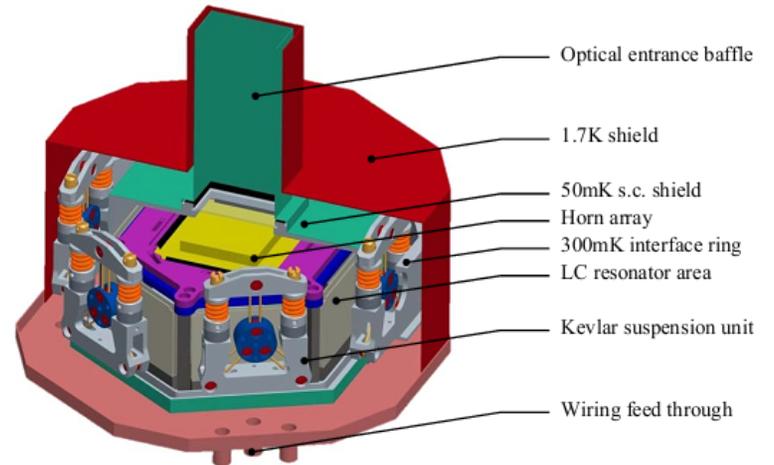
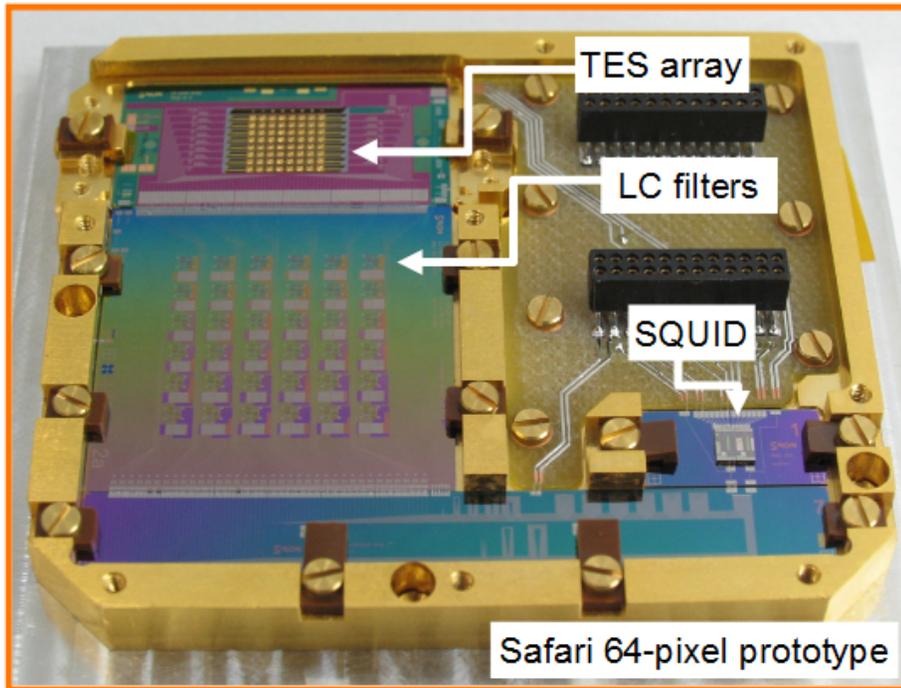
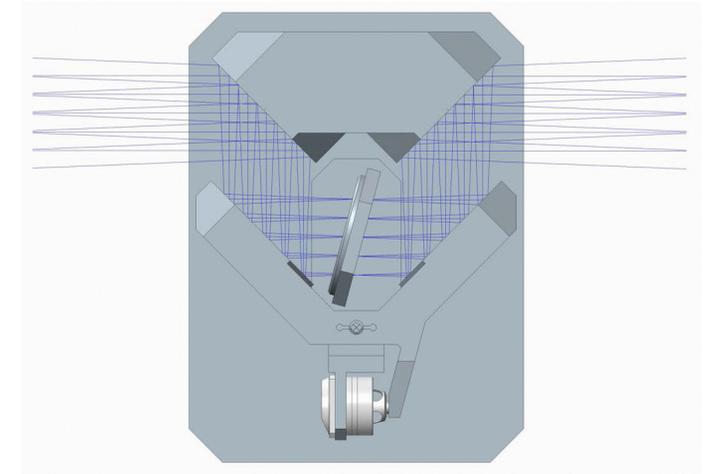
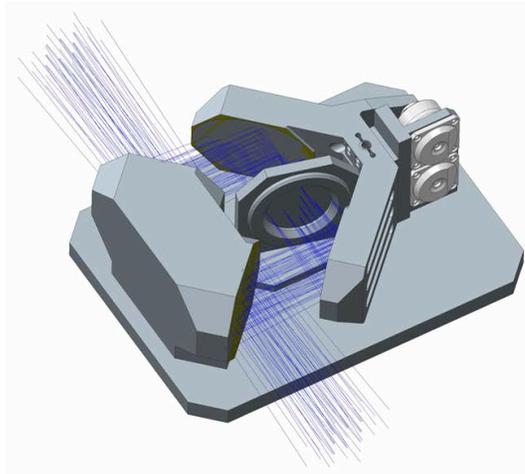
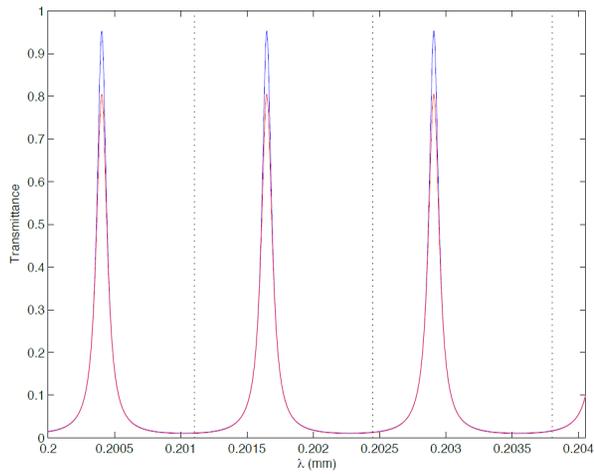


Figure 7-3 – Focal plane array conceptual design. The TES detector (yellow) is enclosed in a superconducting shield (green) which is suspended (light grey and blue) in the 1.7 K enclosure (red) via a double suspension with an intermediate temperature level at 300 mK. The entrance baffle shape is likely to be changed to cylinder to improve magnetic shielding.

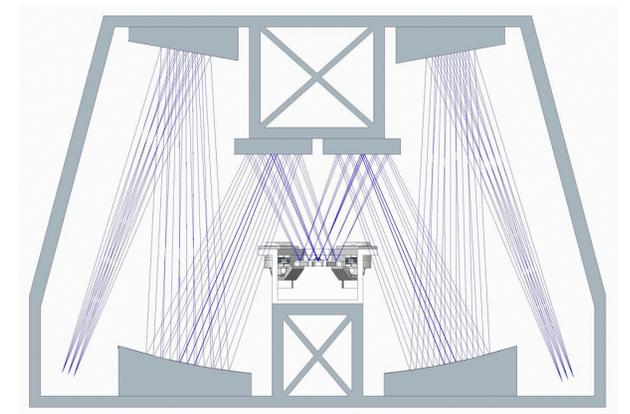
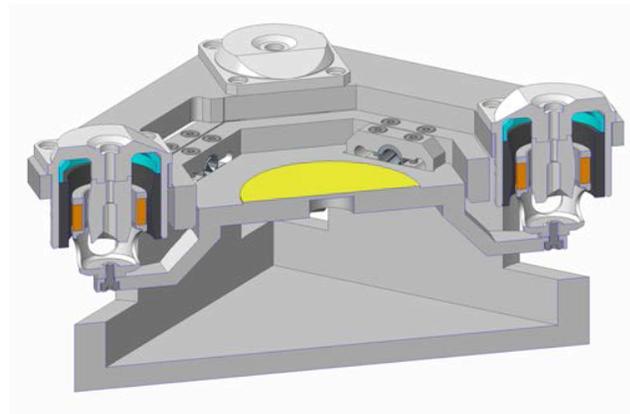
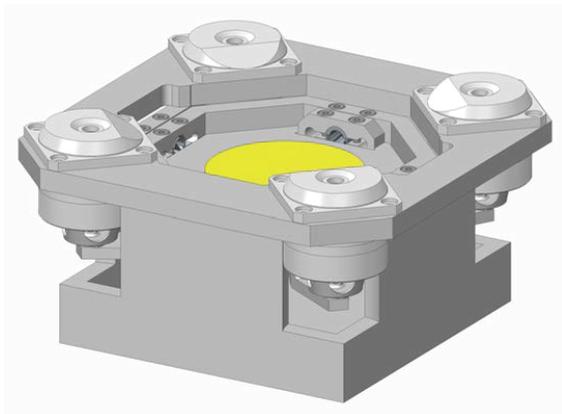
Fabry-Perot

- HIFI flight heritage
- Based on flex pivot
- Dissipation: ≤ 0.5 mW
- Volume: $200 \times 150 \times 80$ mm³
- Mass: 1.8 kg
- Pupil diameter: 45 mm
- Tilt range: $\pm 3^\circ$



Beam-Steering Mirror

- HIFI/SPIRE heritage
- Based on flex pivots
- Dissipation: $\leq 1.2\text{mW}$
(within $2' \times 2'$ FOV)
- Volume: $110 \times 110 \times 80 \text{ mm}^3$
- Mass: 1.2 kg
- Scan range: $\pm 2^\circ$ in both axes
- Mirror size: $\phi 40 \text{ mm}$



グレーティングSAFARI

- 高感度の遠赤外線分光により遠方銀河を始めとする様々な天体のガス輝線や固相スペクトルを観測し、その物理状態と進化を解明する。
 - $z=3$ の一般的な赤外線光度を持つ銀河のガス輝線診断
- 波長範囲: $34\mu\text{m} - 230\mu\text{m}$
- $R \approx 300$ の高感度分光
- $R \approx 3000$ の高分解能分光
- BSMを用いた $\leq 2' \times 2'$ 程度の範囲のマッピング観測
- 分光方式をFTS \rightarrow グレーティング+FPに変更
- その他はこれまでの設計/技術開発を維持
 - 高い技術確立度、組織役割分担の確立。



SPICA/SAFARI Fact Sheet

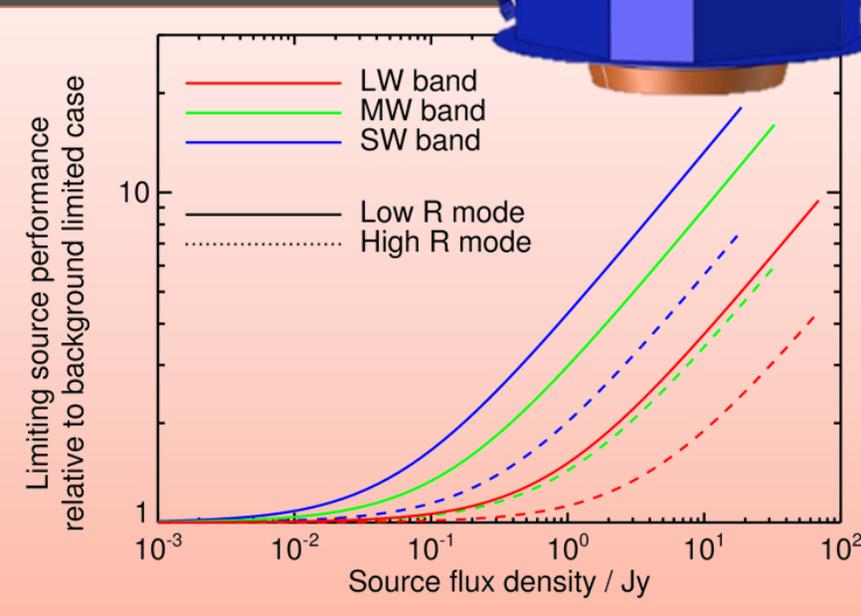
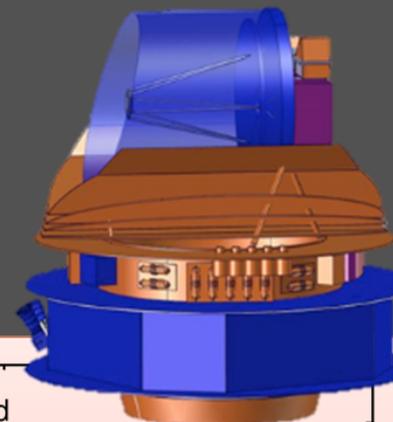
SAFARI Overview

- Three band *grating spectrometer*
- Continuous spectroscopic capability from 34-210 μm

Parameter	Waveband			
	SW	MW	LW	
Band centre / μm	47	85	160	
Wavelength range / μm	34-60	60-110	110-210	
Band centre beam FWHM	4.7"	8.6"	16"	
Point source spectroscopy (5σ-1hr)				
R \sim 300*	Limiting flux / $\times 10^{-20}$ Wm$^{-2}$	5.3	4.5	6.5
	Limiting flux density / mJy	0.25	0.36	0.92
R \sim 3000*	Limiting flux / $\times 10^{-20}$ Wm$^{-2}$	25	24	29
	Limiting flux density / mJy	12	20	41
Mapping spectroscopy** (5σ-1hr)				
R \sim 300*	Limiting flux / $\times 10^{-20}$ Wm$^{-2}$	59	28	22
	Limiting flux density / mJy	2.8	2.3	3.0
R \sim 3000*	Limiting flux / $\times 10^{-20}$ Wm$^{-2}$	340	190	120
	Limiting flux density / mJy	170	150	170
Photometric mapping** (5σ-1hr)				
Limiting flux density / mJy	0.15	0.12	0.16	

SPICA Mission

- ESA/JAXA collaboration
- Telescope effective area 5 m 2
- Primary mirror temperature 8K
- Goal mission lifetime – 5 years



- Change in system performance, as a function of target flux density, relative to the background limited case.
- The decrease in sensitivity is a result of the increased photon noise from the target source
- Data given up to the instrument saturation limits for each band (22, 37 and 73 Jy for the SW, MW and LW bands respectively).

* Resolving powers are all calculated at band centre
 ** Mapping performance is for a reference area of 1 arcmin 2

今後の予定

Event	Tentative date
M5 Call release	December 2015
Letters of Intent due	January 2016
Proposals due	April 2016
Selection for study phase	June 2016
Phase 0+A completion	June 2018
Down-selection to one mission	November 2018
Phase B1 completion	June 2020
Launch (for an ESA-only mission)	Mid-2029 to mid-2030