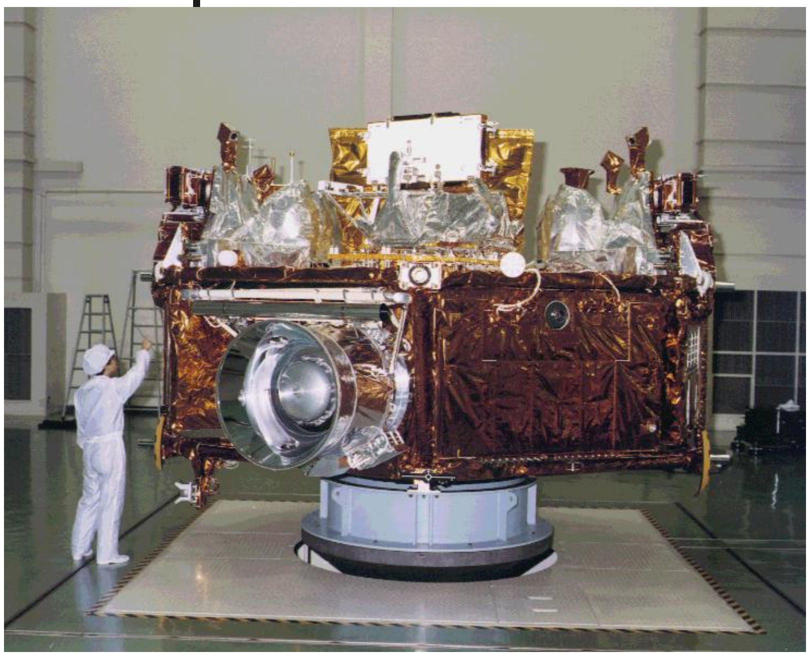
スペース赤外線天文学の現状と将来

～波長の壁を越えて～

中川貴雄 (ISAS/JAXA)

日本の
スペース赤外線天文学の歩み



- IRTS (1995)

- あかり (2006)

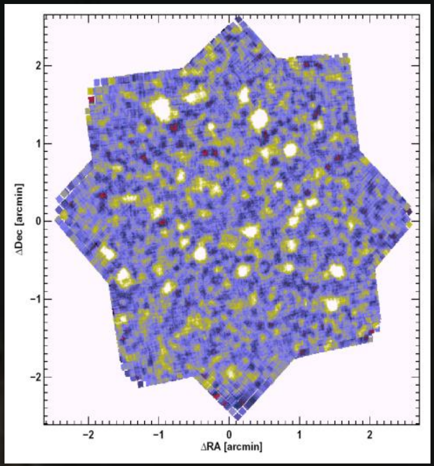
➡ ?

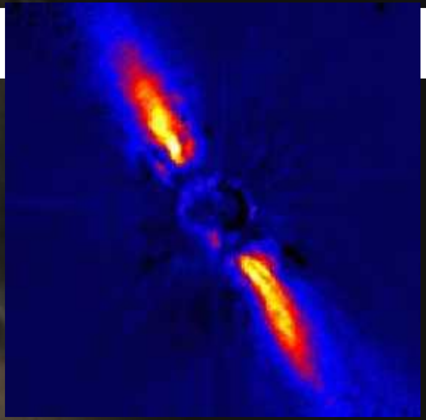
Where are we from ?
Are we alone ?

Formation & evolution of galaxies

Birth & evolution of stars
and planetary systems

Chemical evolution of universe





赤外線で見る世界

可視光線

赤外線

Overview of AKARI

AKARI Mission
(a.k.a. ASTRO-F)

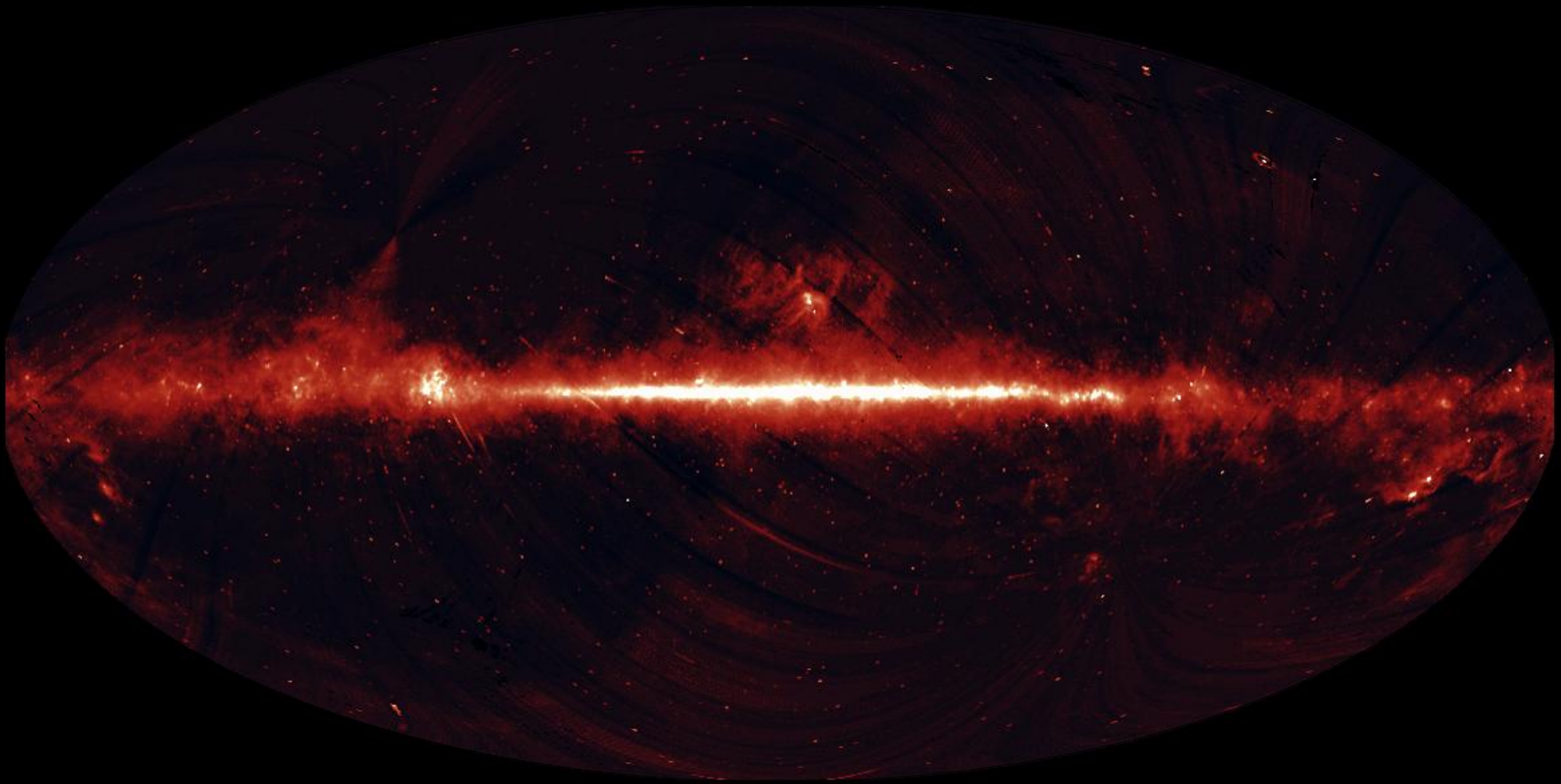
- The 2nd-Generation Infrared Surveyor
- All-Sky Survey
  - 4 bands in FIR
    - 50-180μm
  - 2 bands in MIR
    - 9, 18μm
- Pointing Observations
  - Photometric & Spectroscopic Modes

Time Line

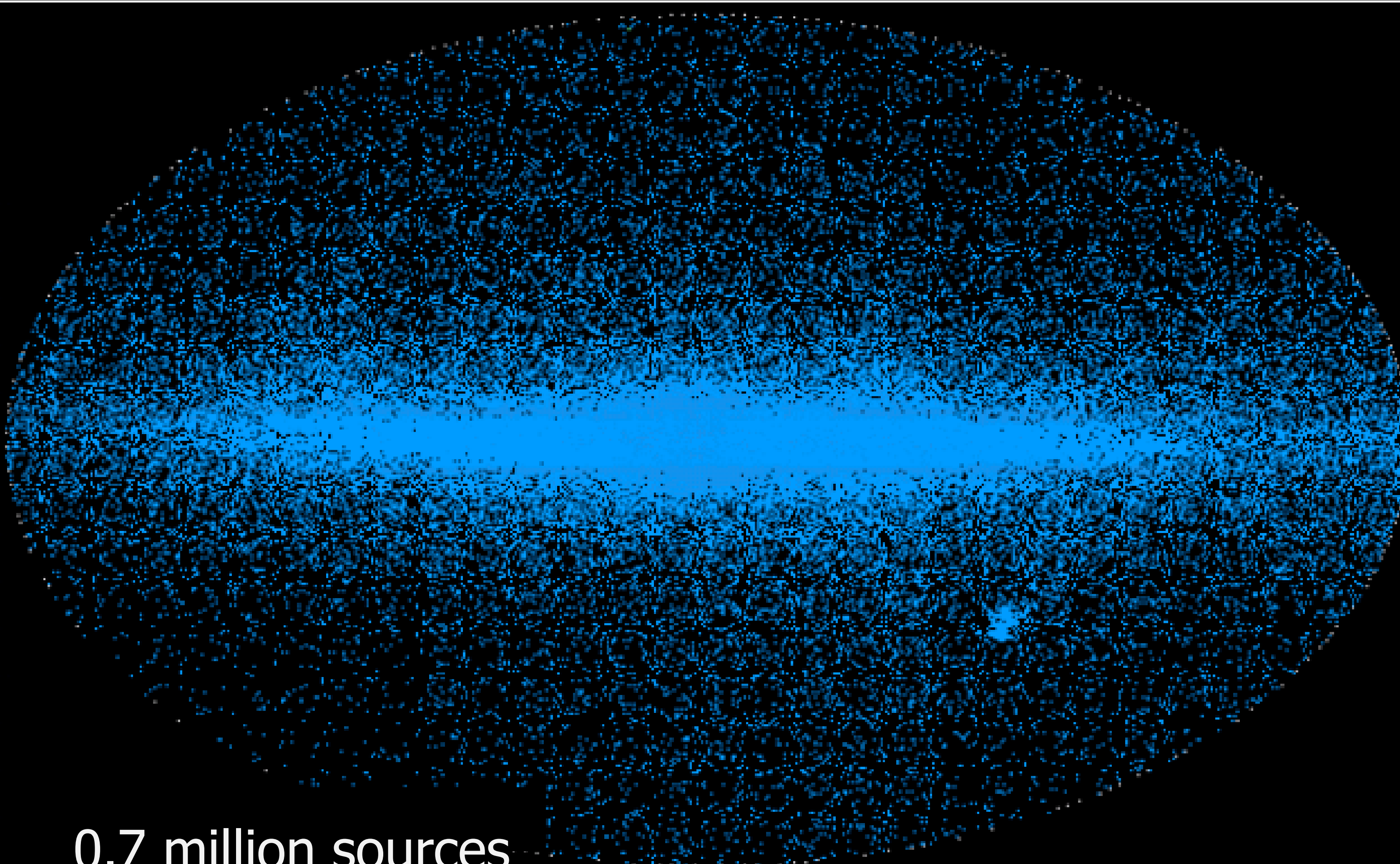
- Launched !
  - February 22, 2006
  - From Uchinoura Space Center
  - M-V-8 launching vehicle
- Observation Phases
  - Liq. He Phase
    - May 2006 – August 2007
      - Phase 1: Mostly Survey
      - Phase 2: Mostly Pointed Obs.
  - Post He Phase (Phase 3)
    - June 2008 – (NIR)

AKARI Gallery

All Sky Image at 9μ m by AKARI

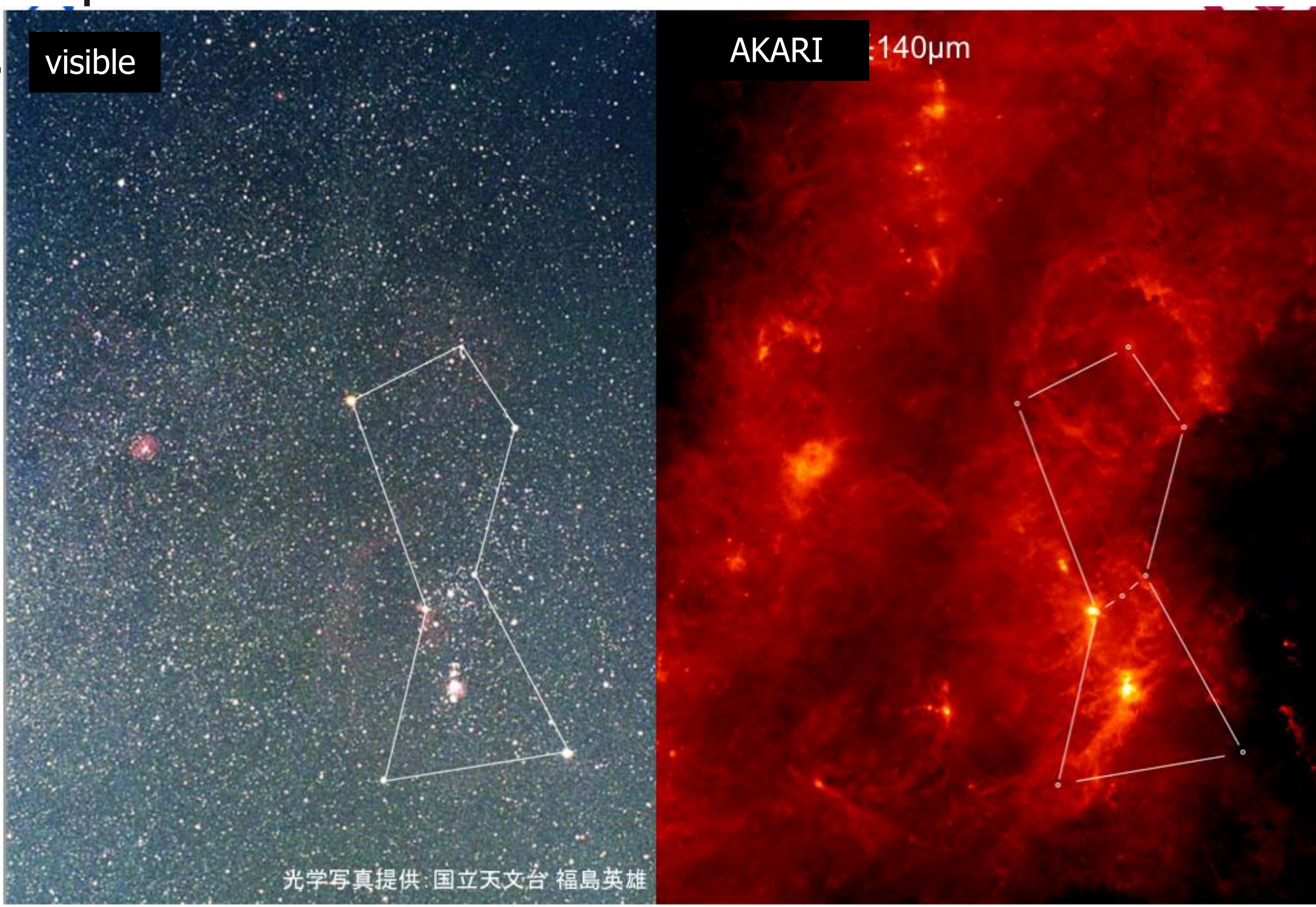


AKARI Point Sources



0.7 million sources

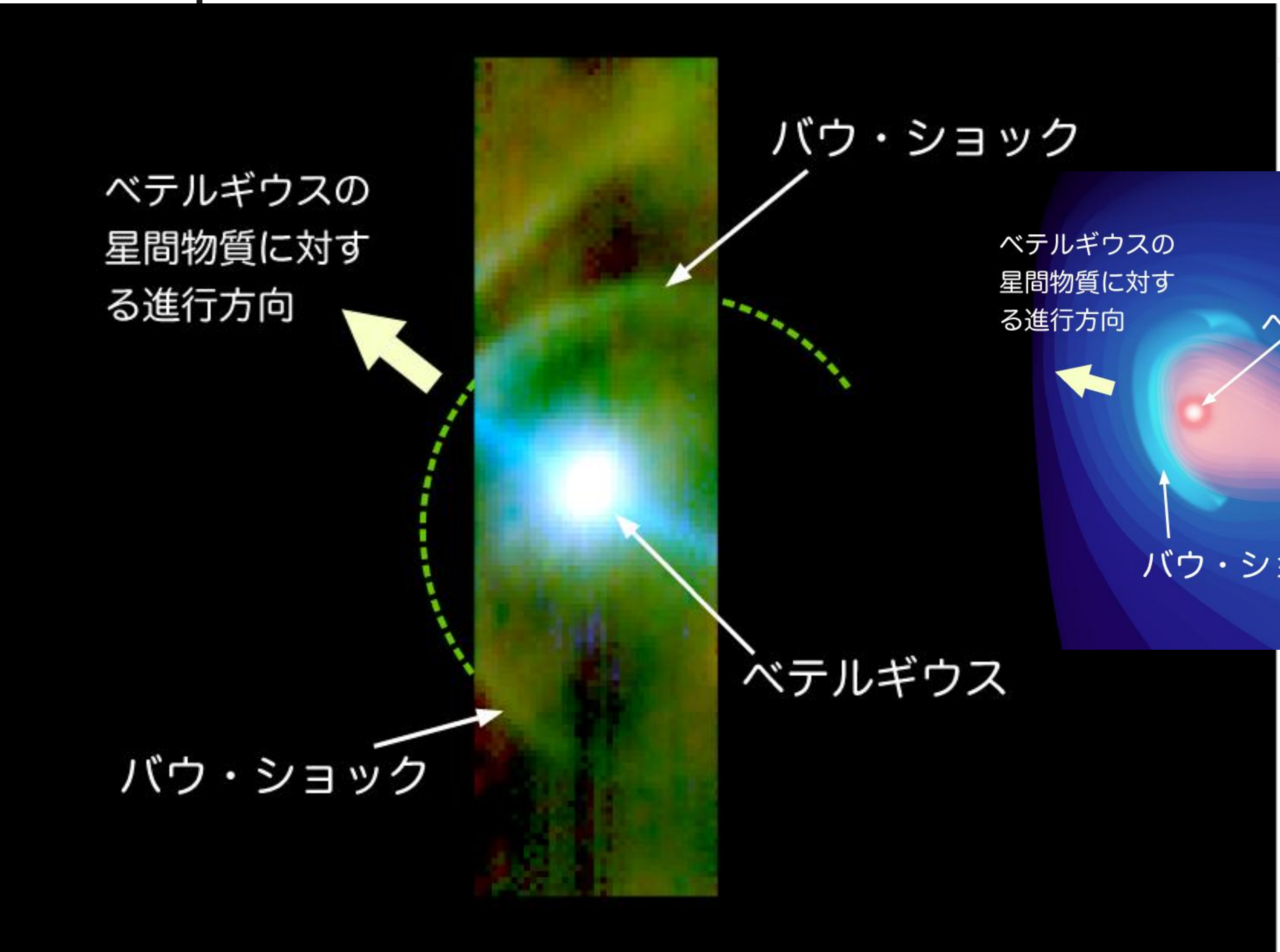
Two View's of Orion

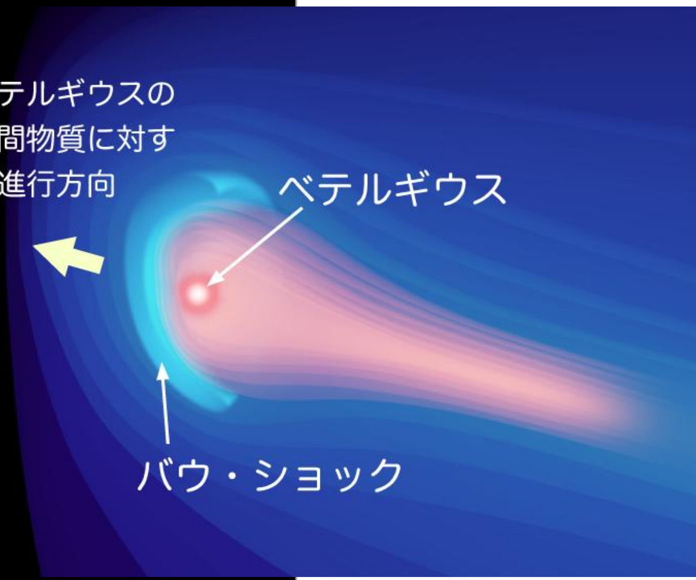


Complex ISM

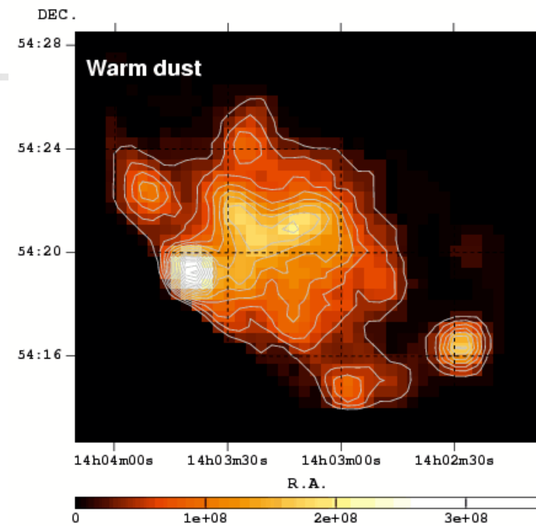
- Cygnus-X
- Blue : 9um
- Red: 18um

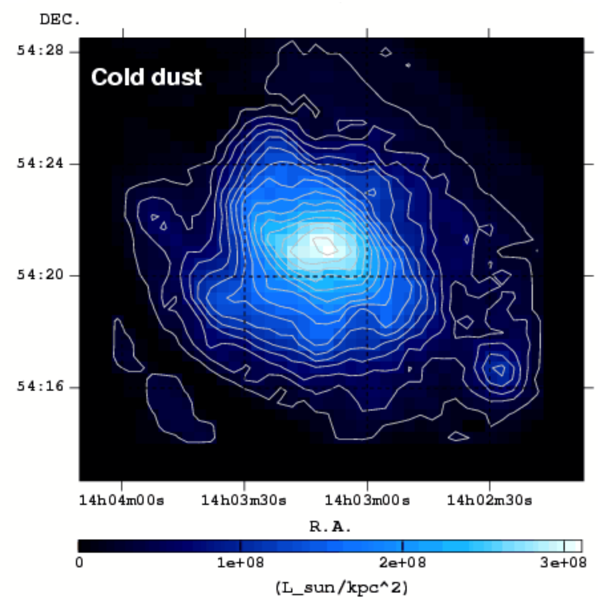
Bow Shock in the Universe





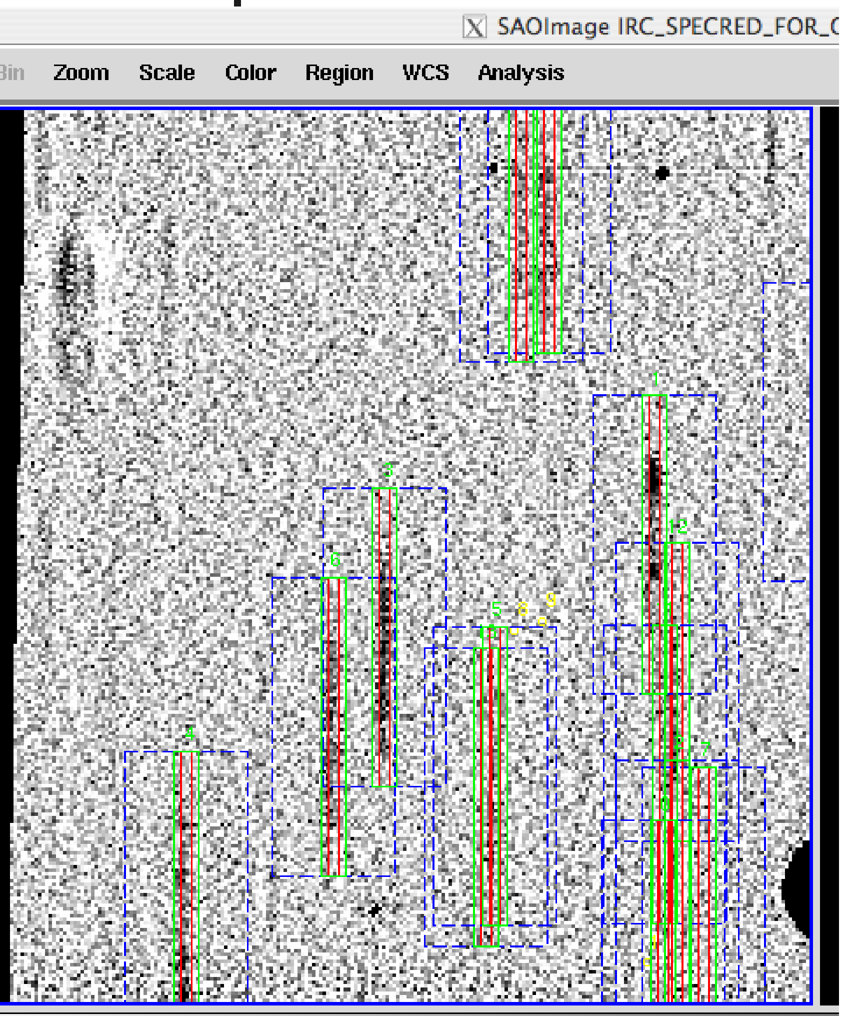
Hot & Cold Dust in M101





Suzuki et al. (2007)

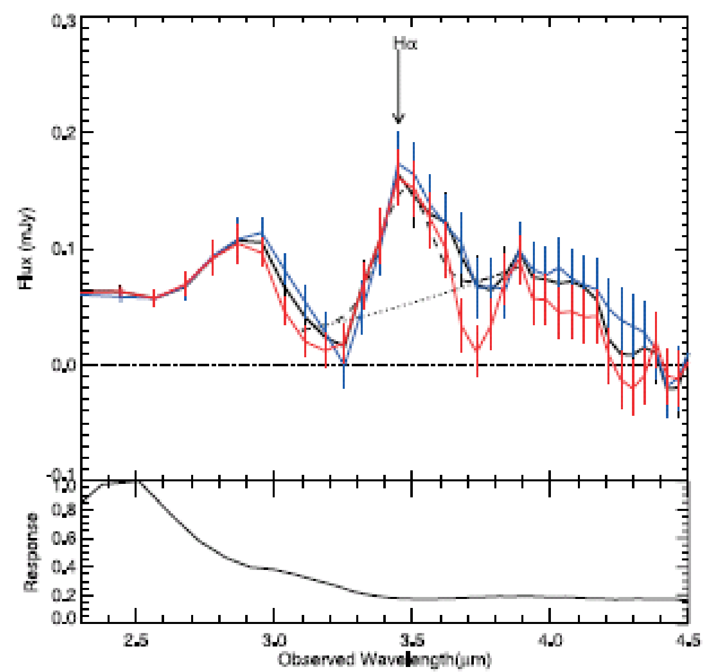
Effective Spectroscopic Survey



RXJ1759.4+6638 (z=4.3)

Record of Hα detection at High z

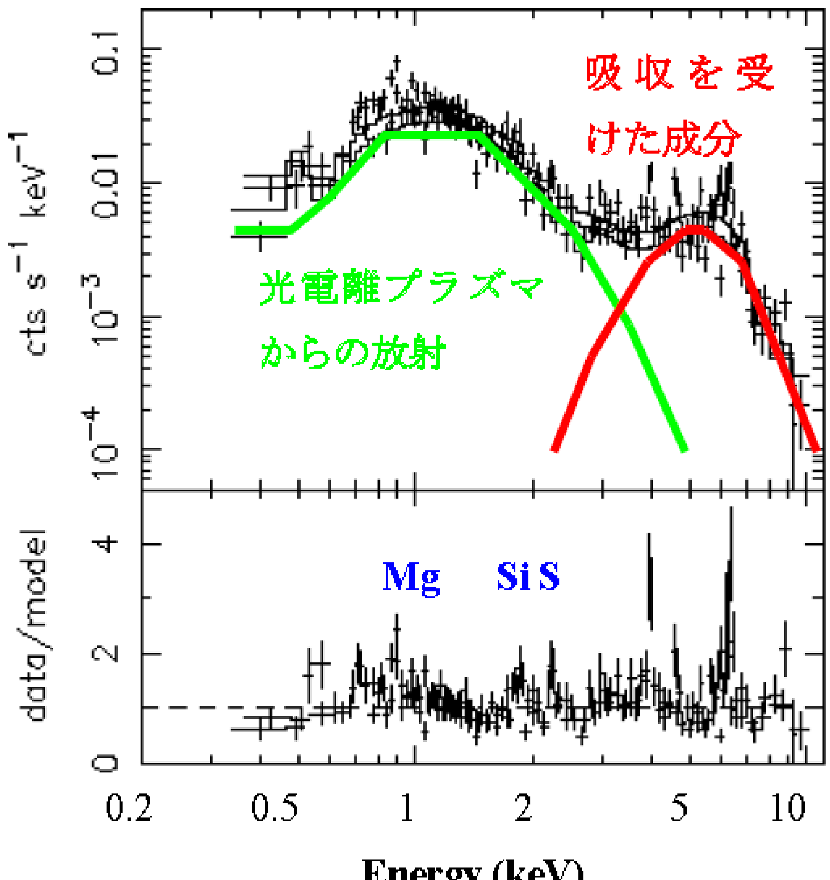
Ovabu et al. (2007)

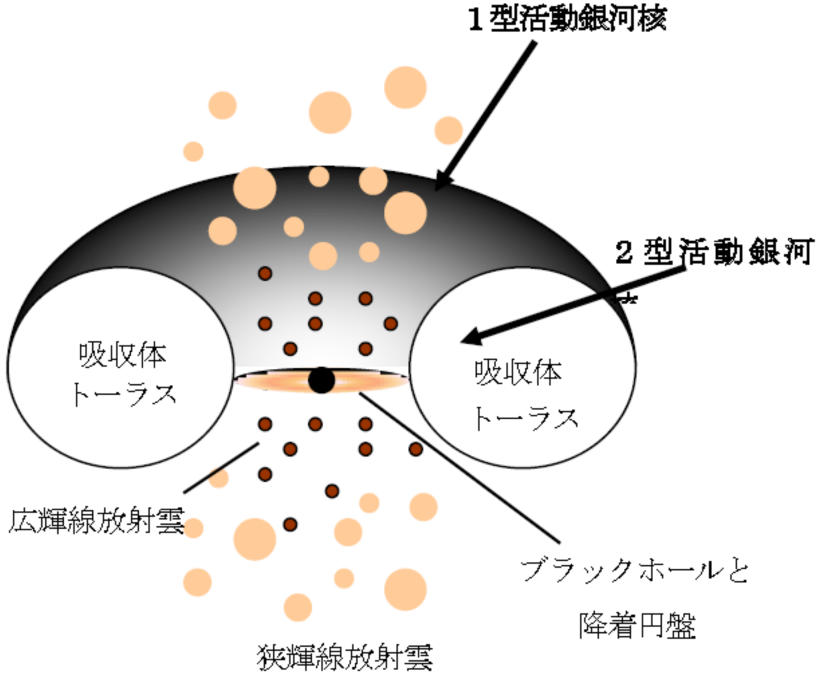


Now detected up to Z~6

～波長を超えて～
Searching for Molecular Tori

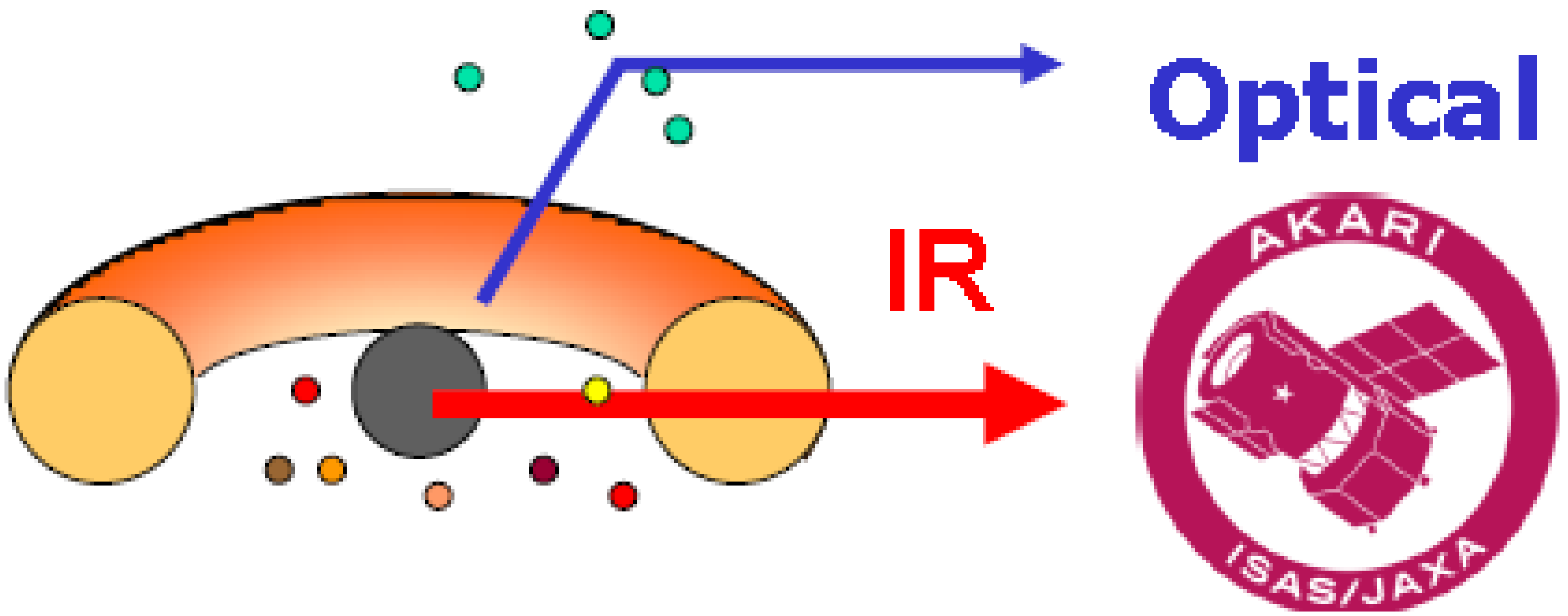
Unified Scheme of AGN ?





Obscuring Torus in Absorption

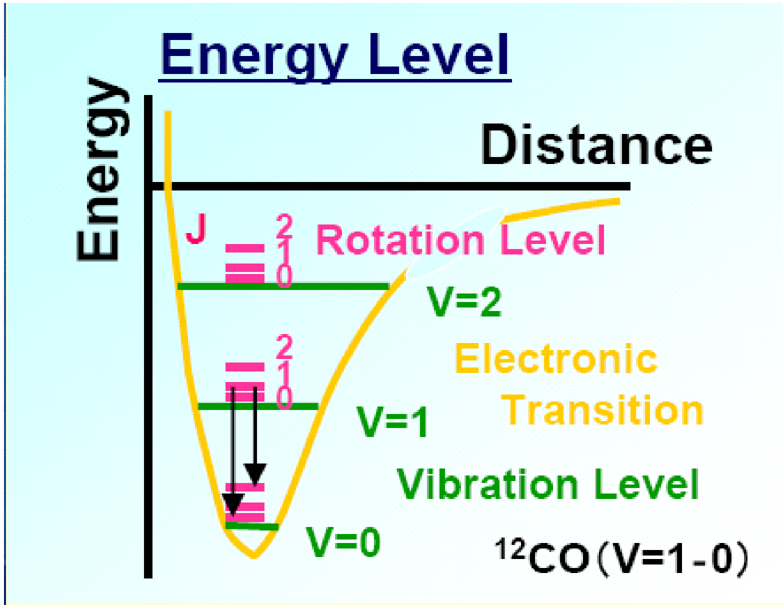
- To prove physical characteristics of molecular tori
  - IR observations of absorption in molecular tori

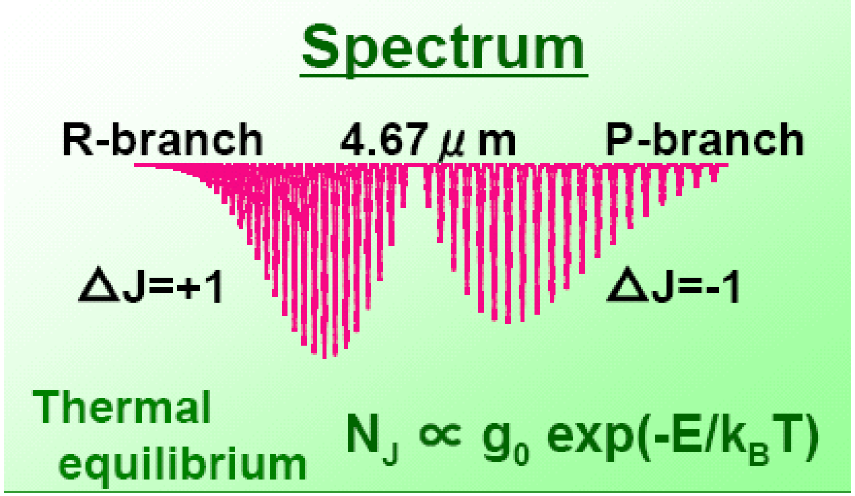


Fundamental ro-vibrational transition of CO

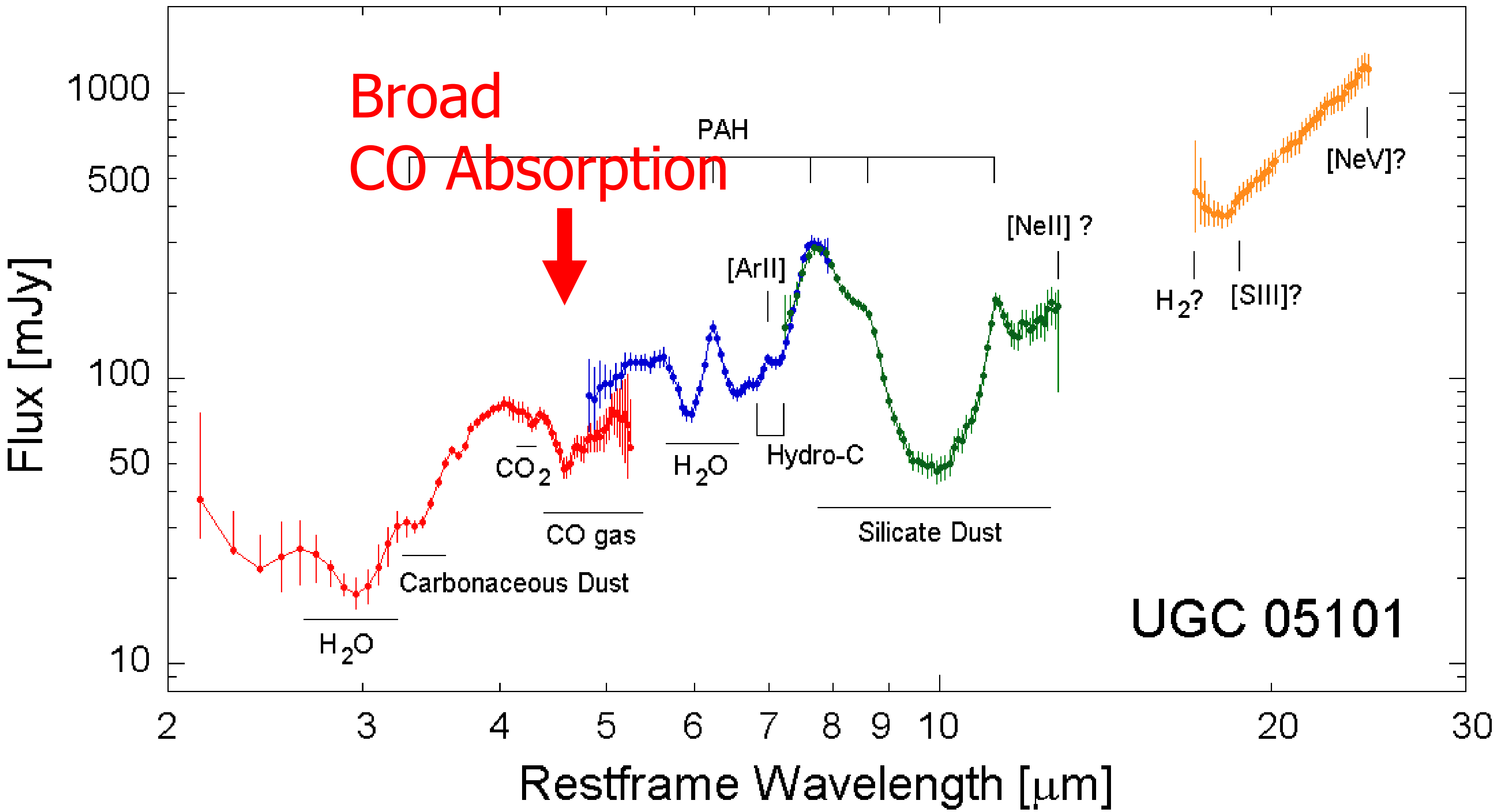
- v=0-1, $\Delta J = \pm 1$
  - Many lines with different J
    - Temperature, column density
- Background Source
  - Very high effective spatial resolution is possible

- Observations
  - Subaru + IRCS (AO)
  - R=5000-10000
  - 0.3" - 0.6" slit at M-band



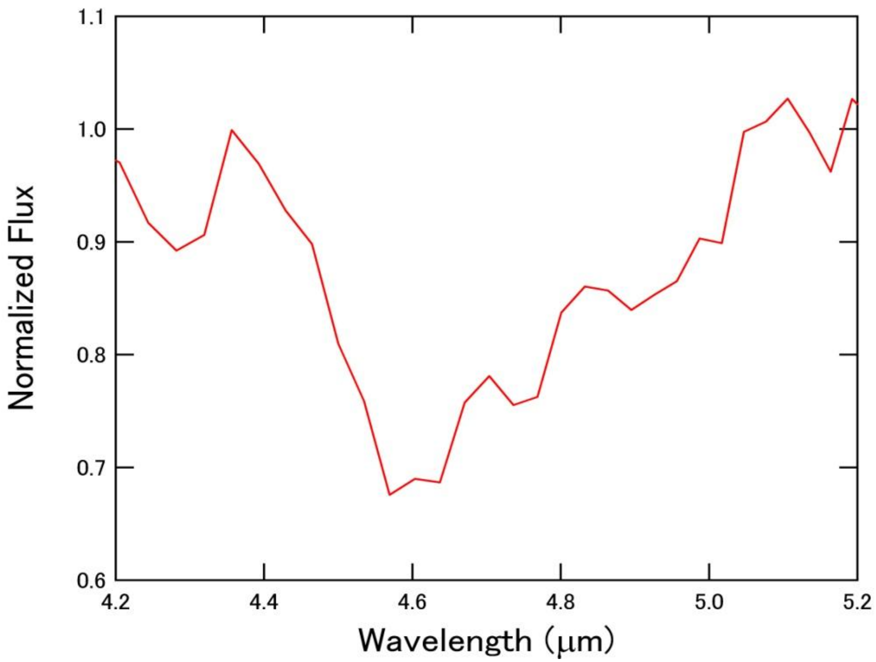


CO Absorption is detected

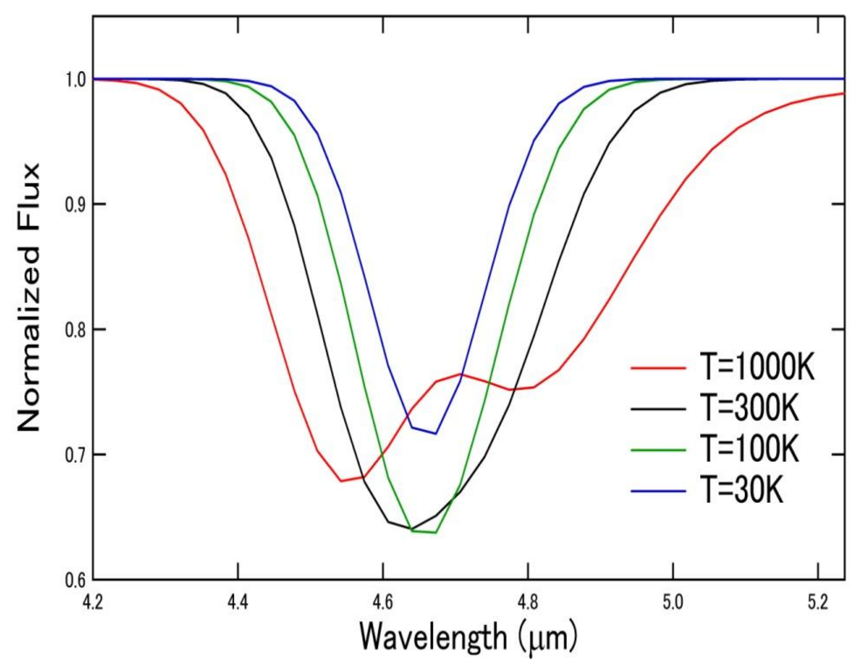


Observation vs Model

- Observed



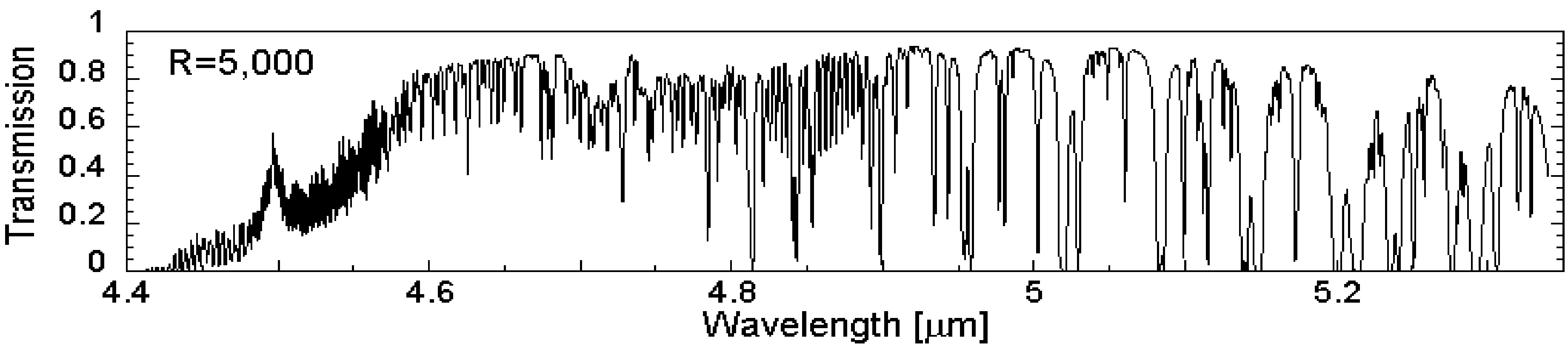
- Model



Hot (~ 800K) gas with Large Column Density (N_{H2} ~ 10^{23} cm^{-2})

Ground-based Observations

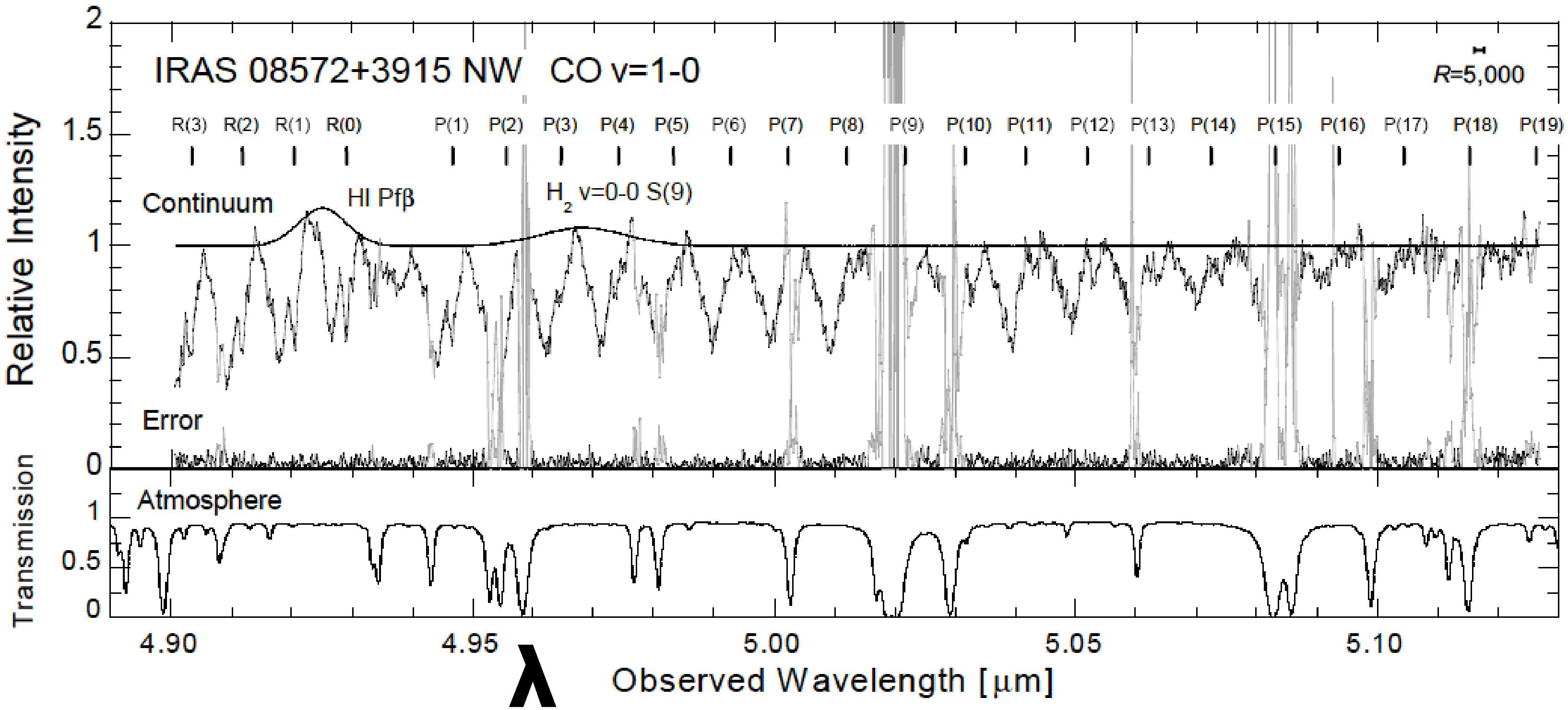
- Merits
  - High-spectral resolution
    - Resolve each rotational transitions
      - Precise Estimates of Physical Conditions
- Demerits
  - Complex atmospheric absorption



Obscured AGN
IRAS 08572+3915

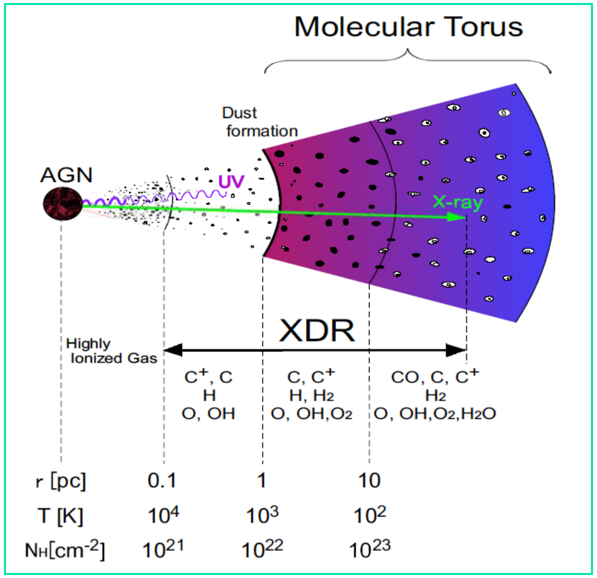
- CO absorption to very high J (~17)
- Broad line profile

Shiratata, Nakagawa, et al. (2009)
ApJ submitted

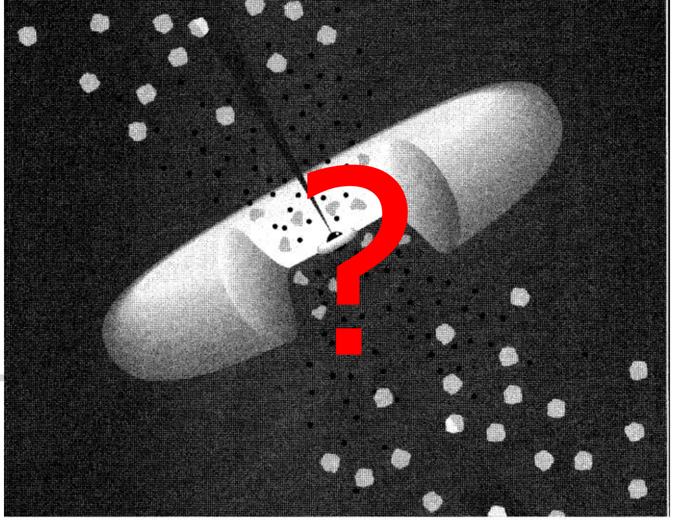


How can it be heated ?

- Observations
  - T=200 - 1000K with
    $N_{H2} \sim 3 - 10 \times 10^{22}$ cm^{-2}
    - Av ~ 20-100 mag ?
- PDR ?
  - UV heating
  - Only Av< a few mag for T~1000K
- XDR !
  - X-ray heating (from the central engine ?)
  - Large penetration depth Av > 10 mag
  - Efficient gas heating



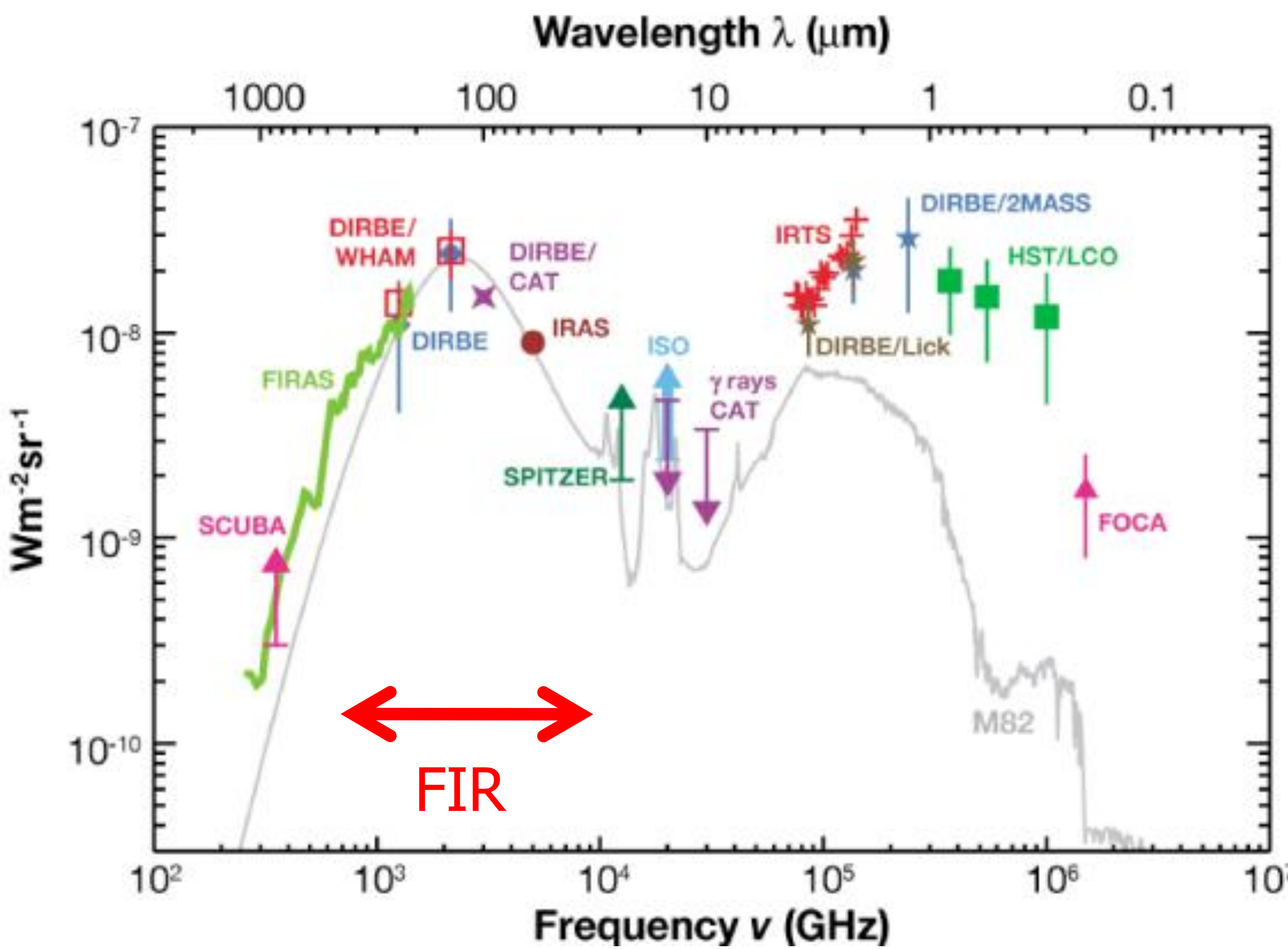
Summary



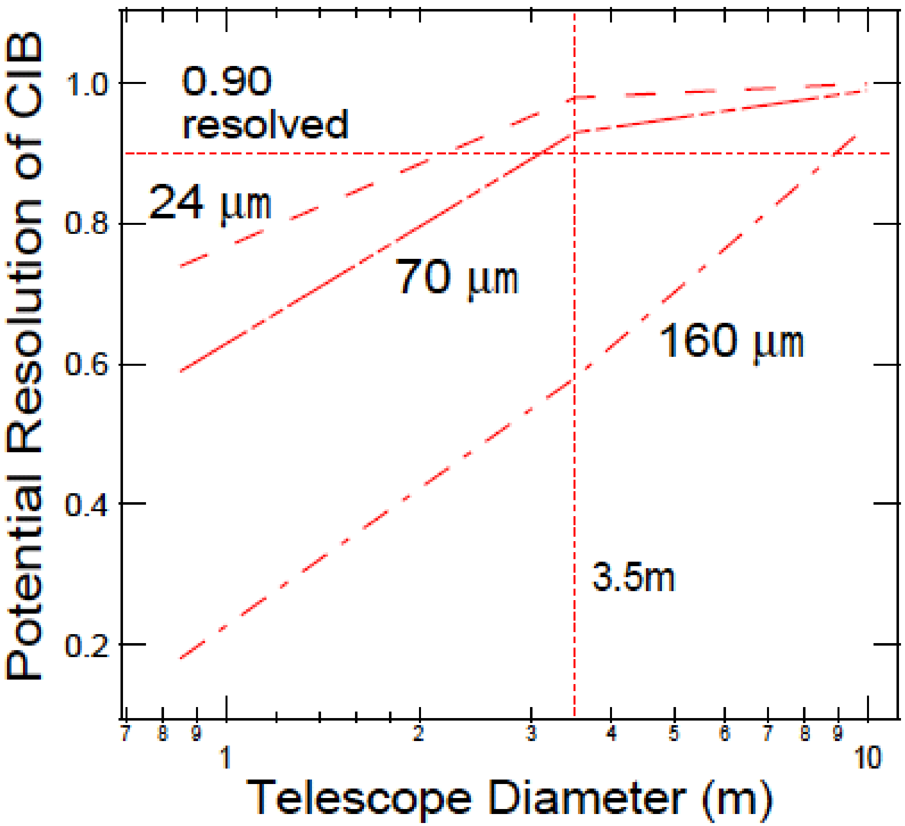
- Our Observations show
  - Hot molecular gas with large column density
  - Highly clumpy structure and violent velocity field
  - Heated (probably) by the X-ray from the central engine
- Questions
  - Are they putative tori ? (or sphere ?)
  - What makes the difference between the galaxies with and without CO absorption ?
  - Formation of Tori and accretion onto the central engine

Next Step (1)
to increase signal

Hidden Universe

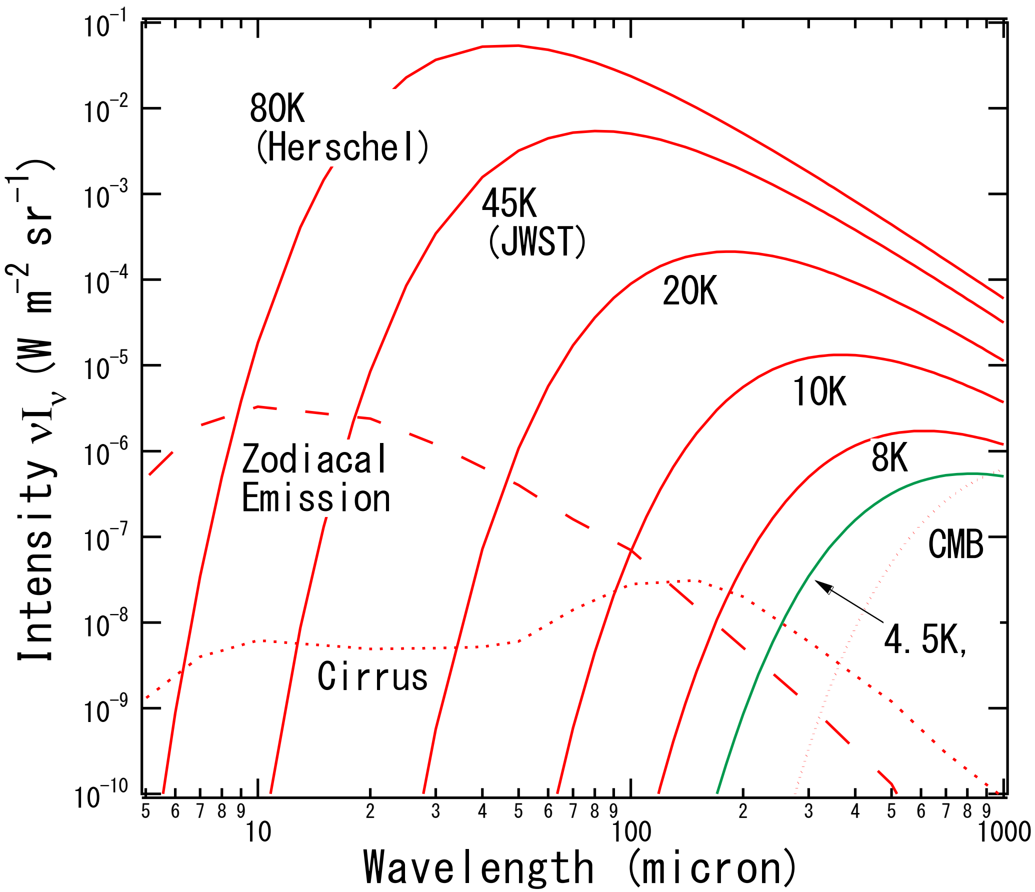


Requirements: Large! Telescope



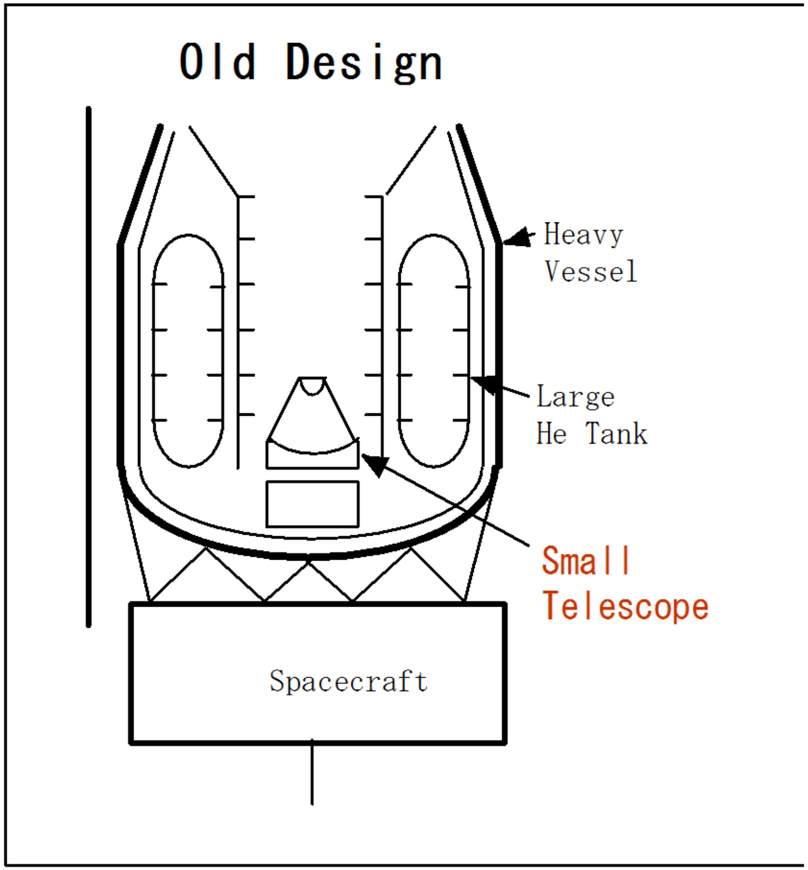
- 3m class telescope is required
  - Resolve CIB into individual sources
  - Direct detection of exoplanets

Requirements: Cool ! Telescope



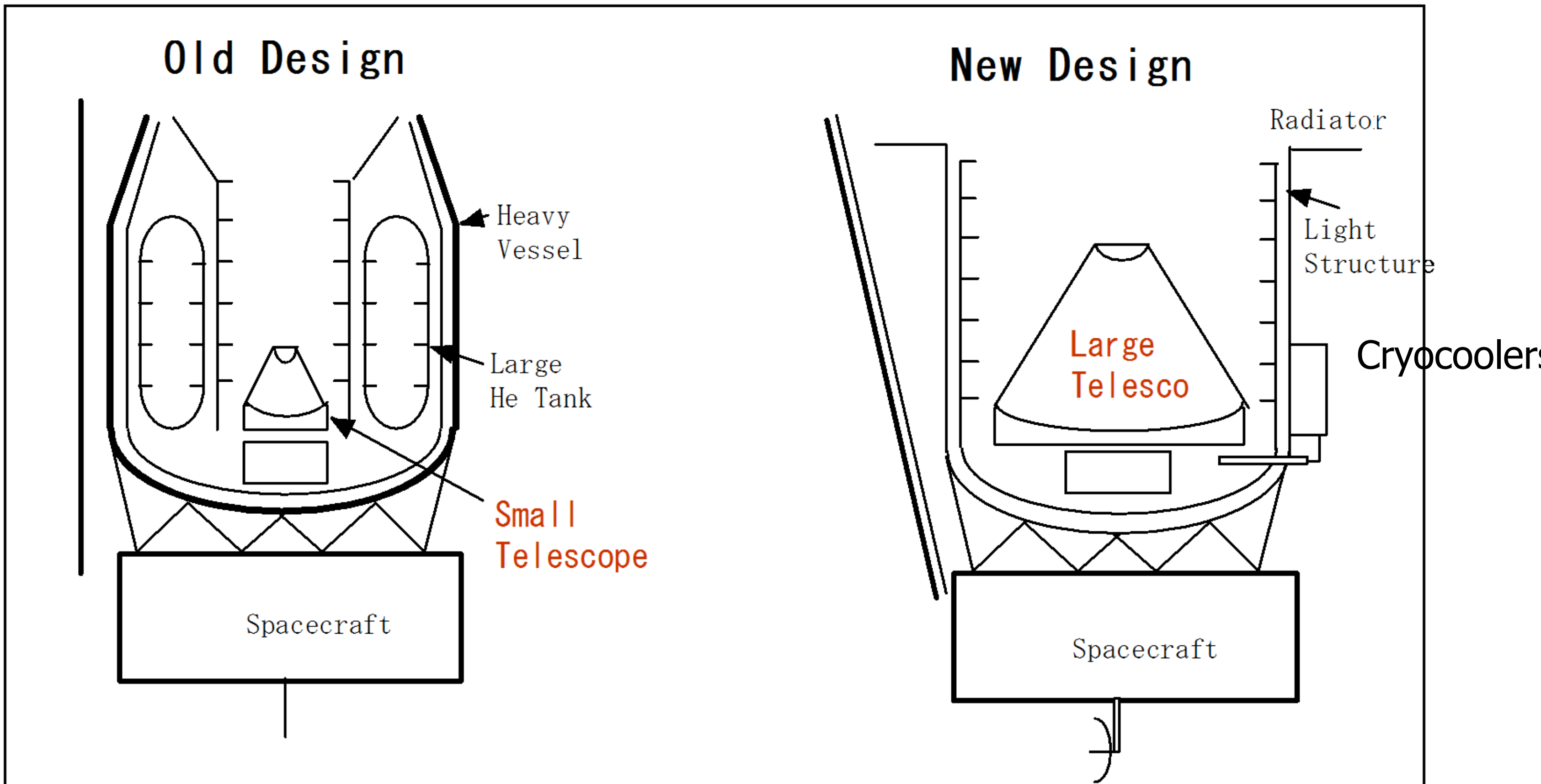
- Telescope Temperature << 10K required

今までの赤外線天文衛星



- 寒剤の搭載
  → 巨大な冷却容器
  → 小さな望遠鏡
- 「あかり」の例
  - 観測機器 42 kg
  - 冷却容器全体 460 kg
    - 真空容器外壁 200 kg

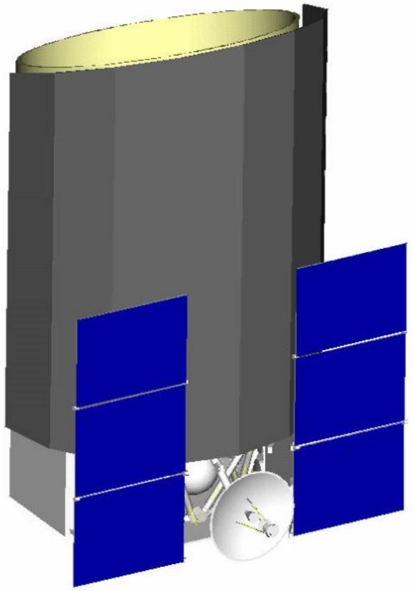
身軽になろう

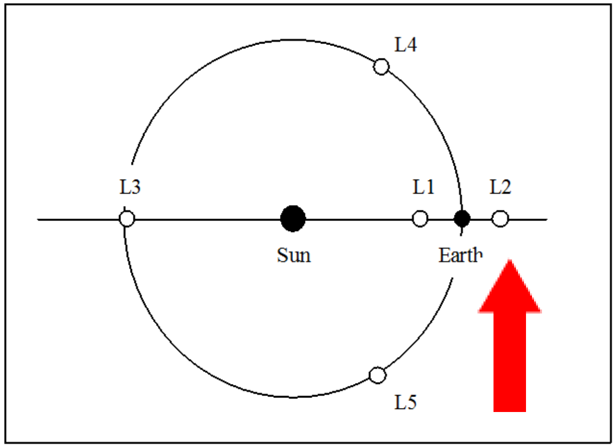


Old Design
Heavy Vessel
Large He Tank
Small Telescope
Spacecraft
New Design
Radiator
Light Structure
Large Telesco
Cryocoolers
Spacecraft

Mission Overview

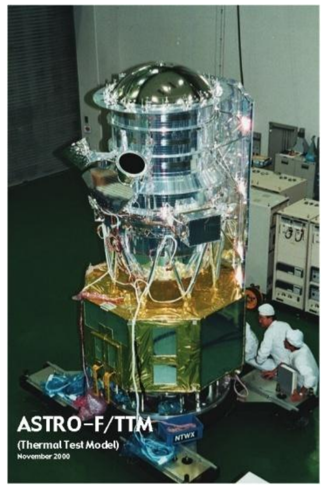
- Specifications
  - Telescope: 3.5m, 5 K
    - Revolving CIB at its energy peak
    - Direct detection of exoplanets
  - Core wavelength: 5-200 μm
    - MIR Instrument
      - Including Coronagraph
    - Far-Infrared Instrument (SAFARI)
  - Orbit: Sun-Earth L2 Halo
  - Mission Life
    - 3 years (nominal)
    - 5 years (goal)
    - No expendables
  - Weight: 3.4 t
  - Launch: 2017 (H-IIA)

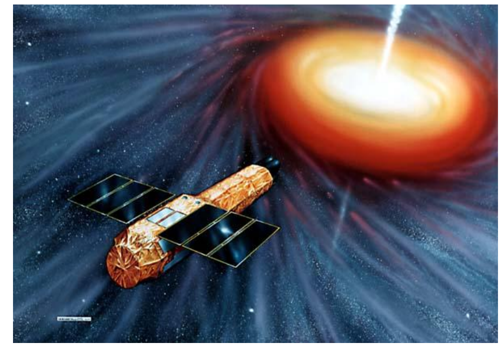




Heritage of Mechanical Cryocoolers

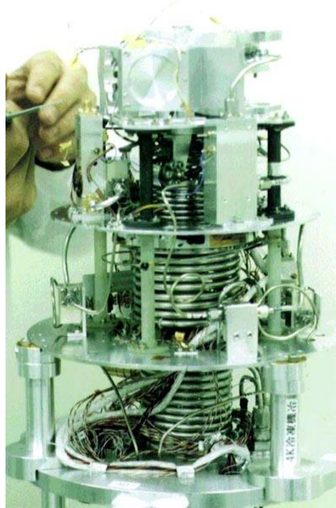
- AKARI
  - 2-stage Stirling 200mW @ 20 K
  - Long-life test > 5yrs
  - 2006





- SUZAKU
  - ADR, 60mk reached
  - 2005

- SMILES
  - JT 30mW@ 4.5 K
  - 2009



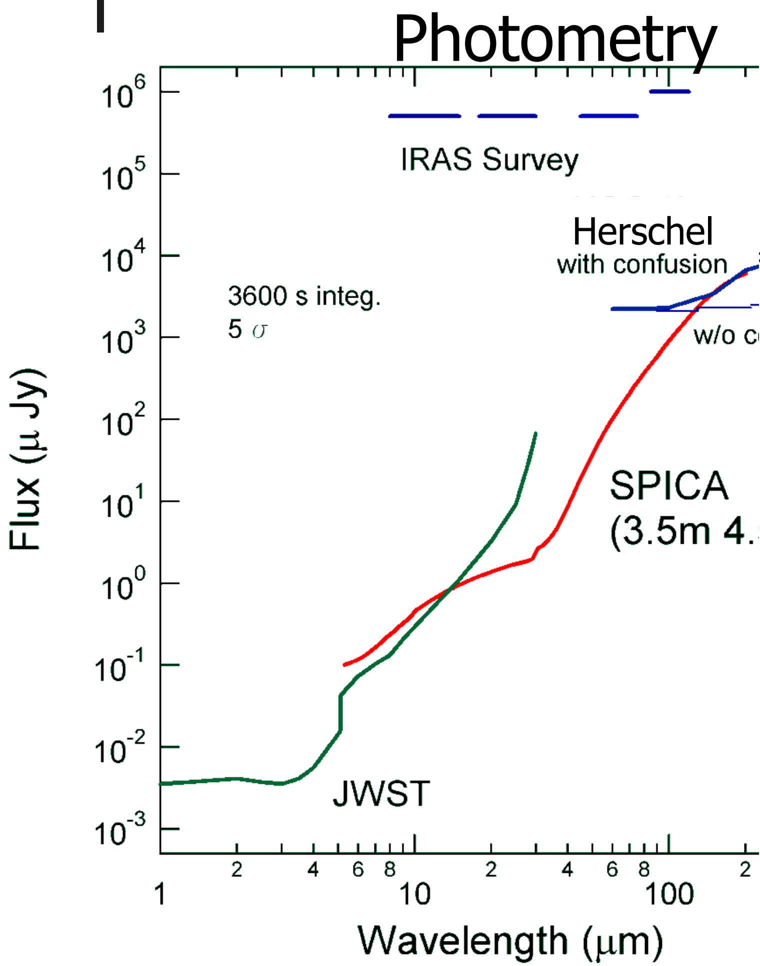
- Cryocooler technology is strategic techniquie for space science in Japan
  - Future Missions: Kaguya, Planet-C, ASTRO-G, ASTRO-H, SPICA

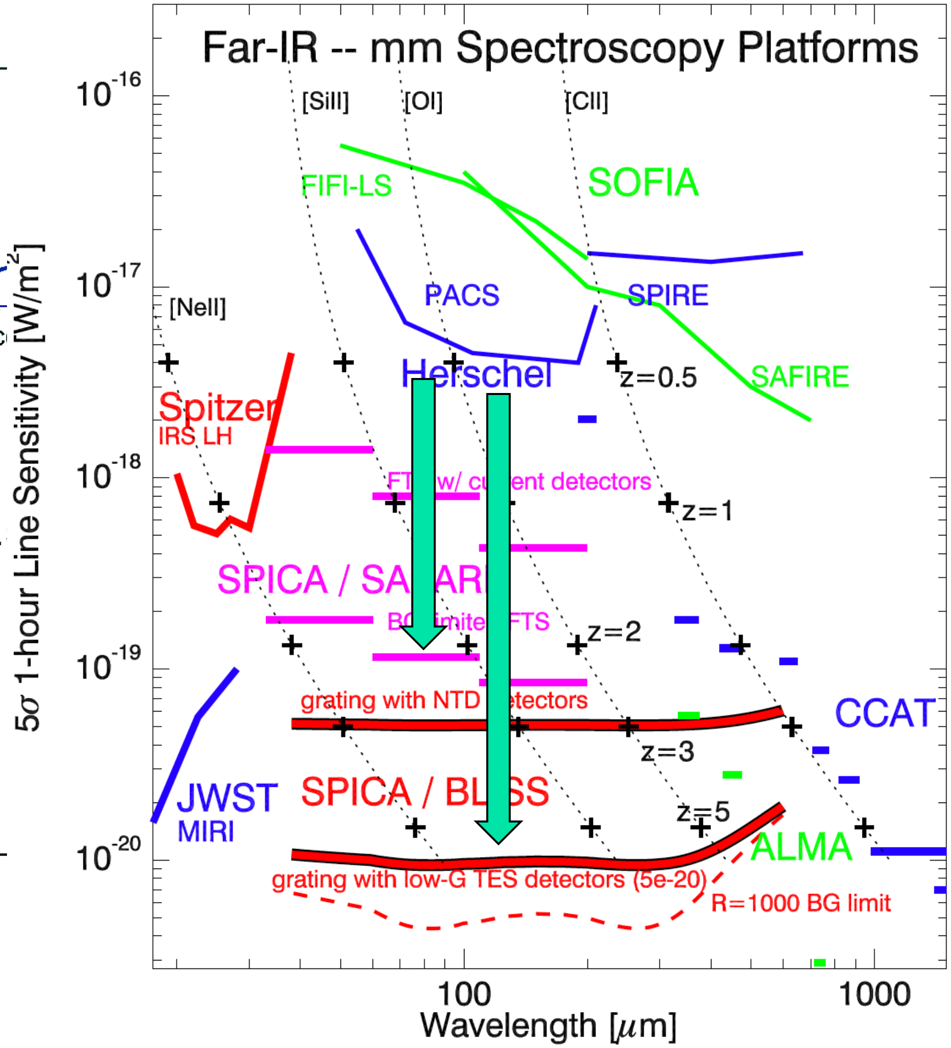
Cryocoolers for SPICA

Cooler type	20 K class	4 K class	1 K class
Cooling object	Precooling for JT	Primary mirror & Optical bench	Far-IR detector
Configuration	**2-stage Stirling**	**2ST + ^{4}He-JT**	**2ST + ^{3}He-JT**
Minimum cooling requirement	200mW@20K	30mW@4.5K (x 2 sets)	10mW@1.7K
Demonstrated Cooling Power	325mW@20K	50mW@4.5K	16mW@1.7K
Driving power	< 90 W	< 160 W (x 2 sets)	< 180W
Service life	> 5 years	> 5 years	> 5 years
R&D level	**AKARI** (2006) ASTRO-G (2012) Under improvement	**ISS/SMILES** (2009) Under Improvement	**ASTRO-H** (2013) Under development

- Most of the coolers will be flight-proven very soon.

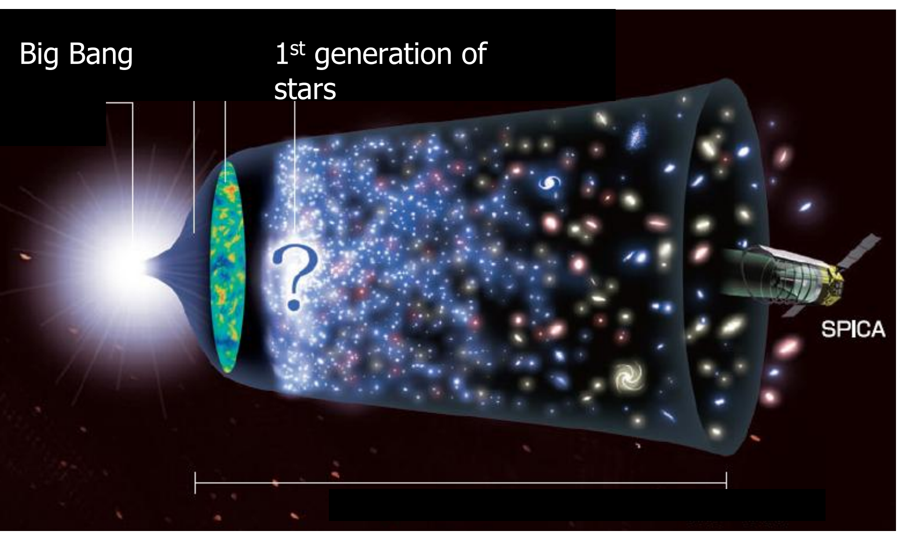
Huge Gain of Sensitivity !

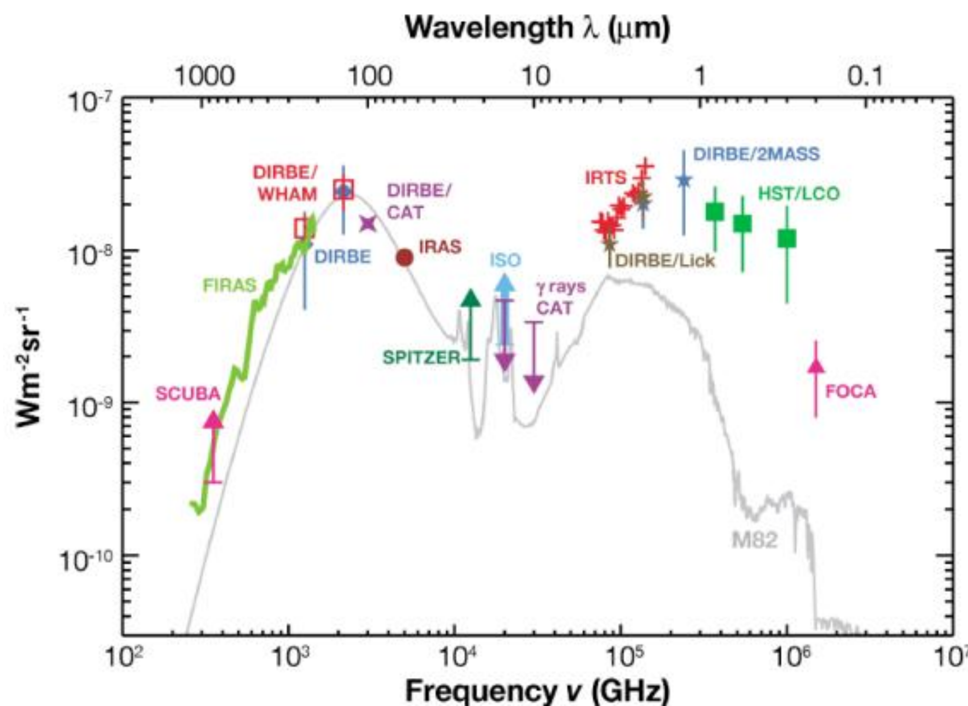




Expected Results (1)

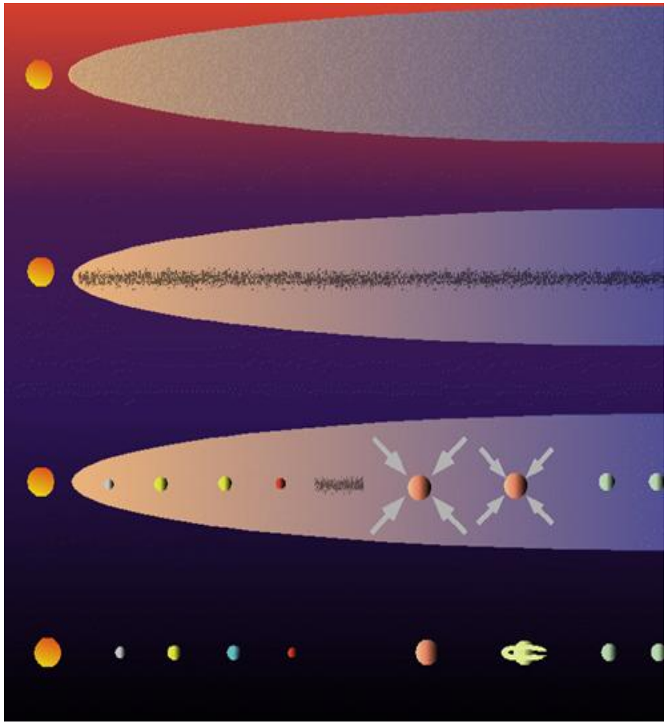
- How did the Universe originate and what is it made of ?
- Resolving CIB into individual sources

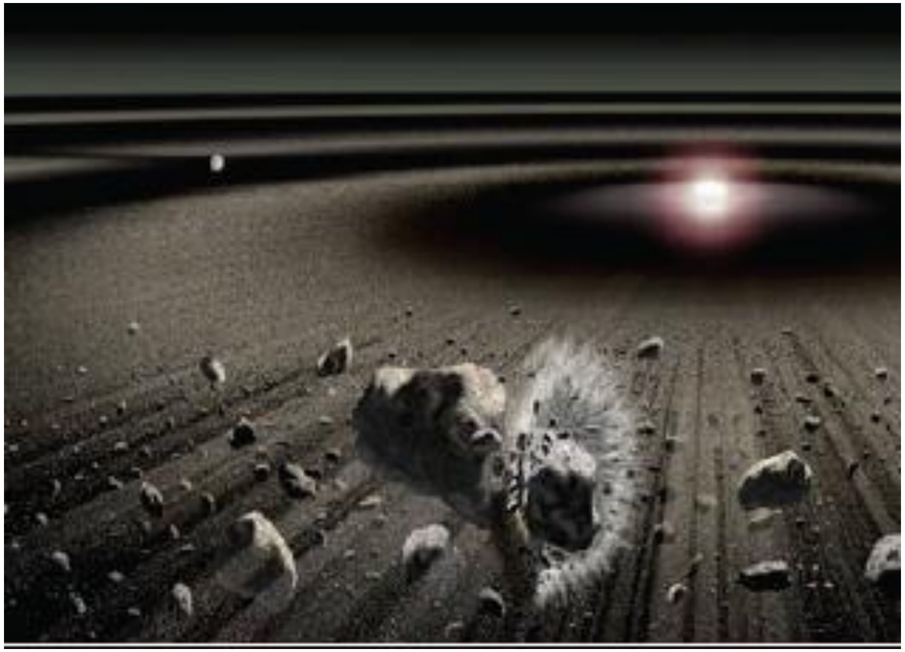




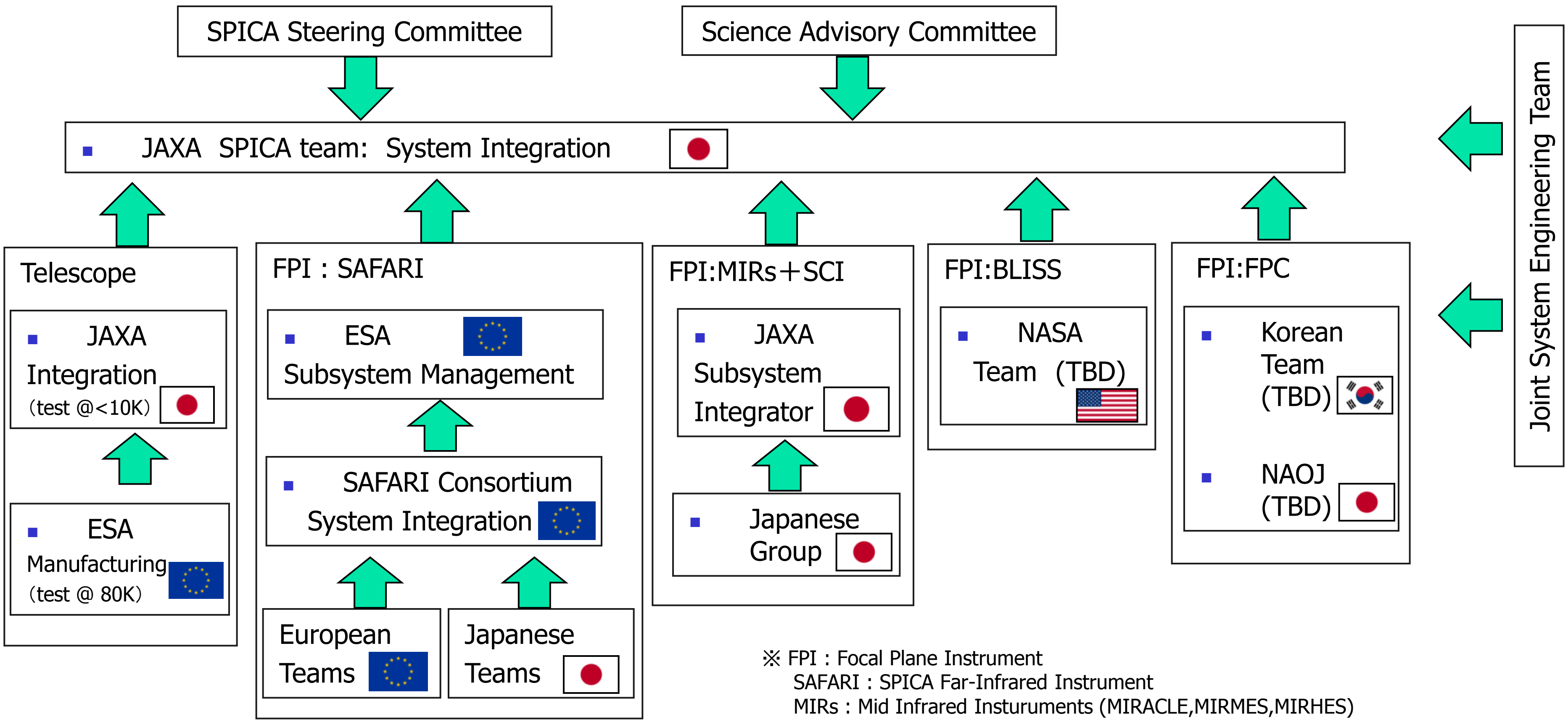
Expected Results (2)

- What are the conditions for stellar and planetary formation ?
- Detection and Spectroscopy of Exoplanets





International Collaboration Scheme

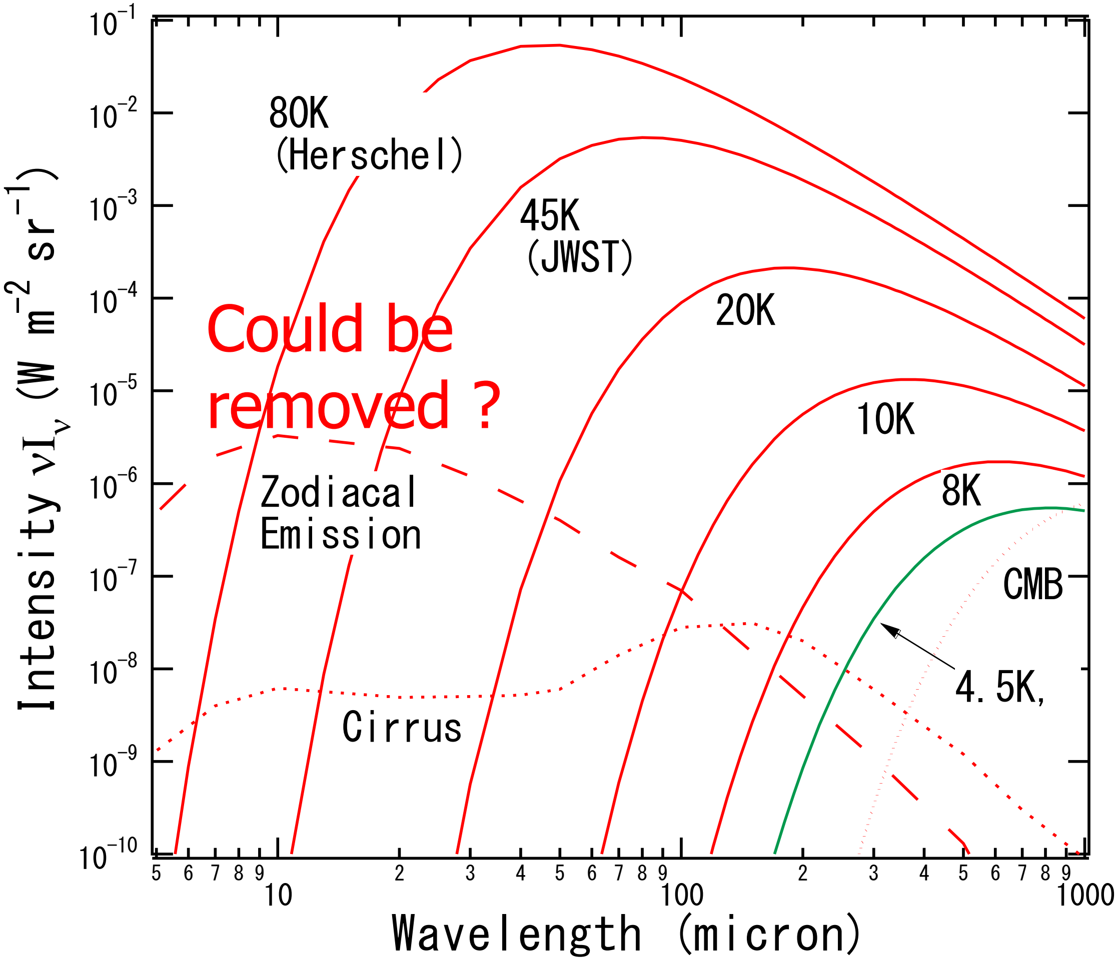


※ FPI : Focal Plane Instrument
SAFARI : SPICA Far-Infrared Instrument
MIRs : Mid Infrared Insturuments (MIRACLE,MIRMES,MIRHES)
BLISS : Background-Limited Infrared-Submikimeter Spectrograph
FPC : Focal Plane finding Camera


SPICA
Space Infrared Telescope for Cosmology and Astrophysics
Space Odyssey in 2017

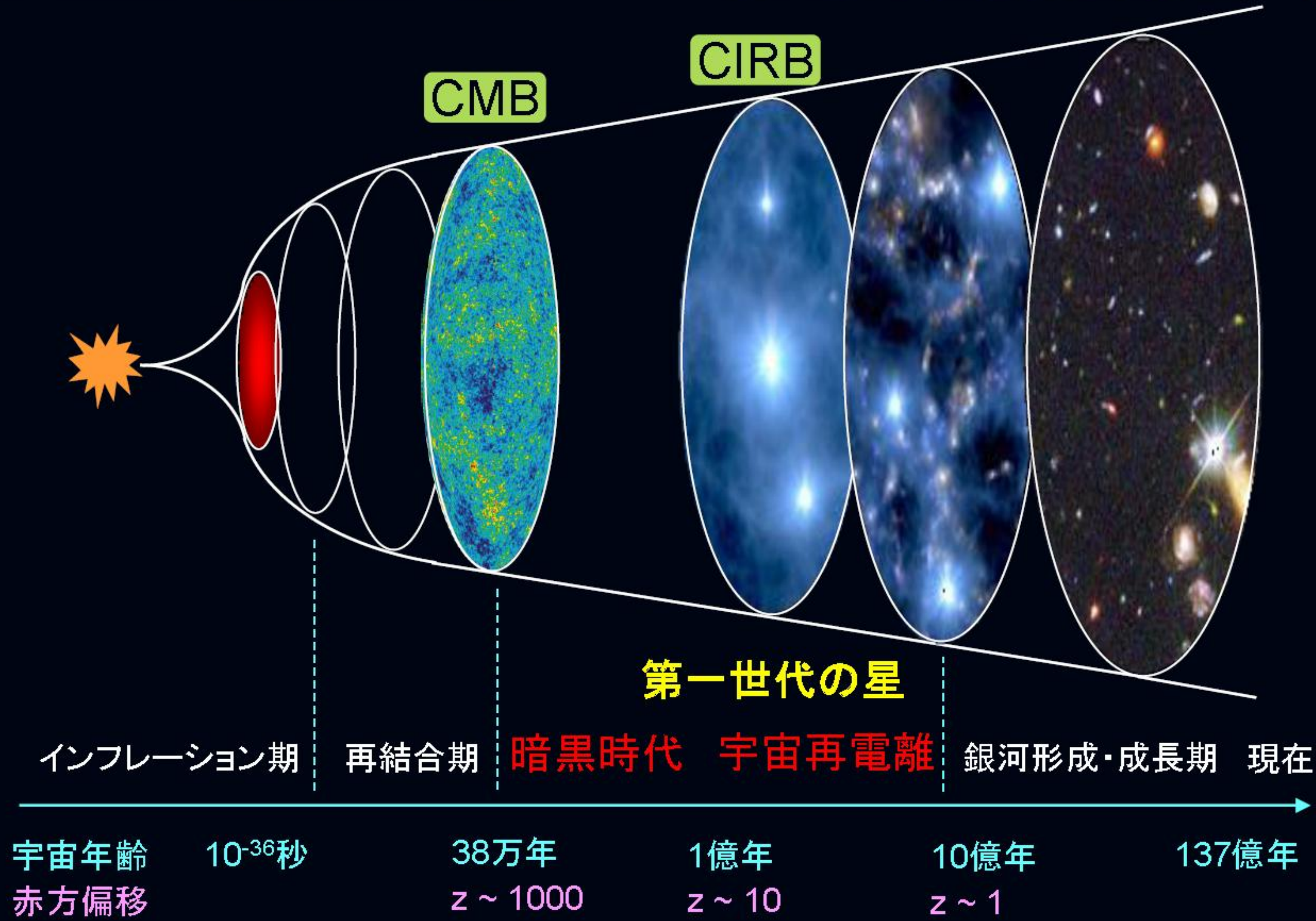
Next Step (2)
to decrease noise

Beyond Natural Background Limits

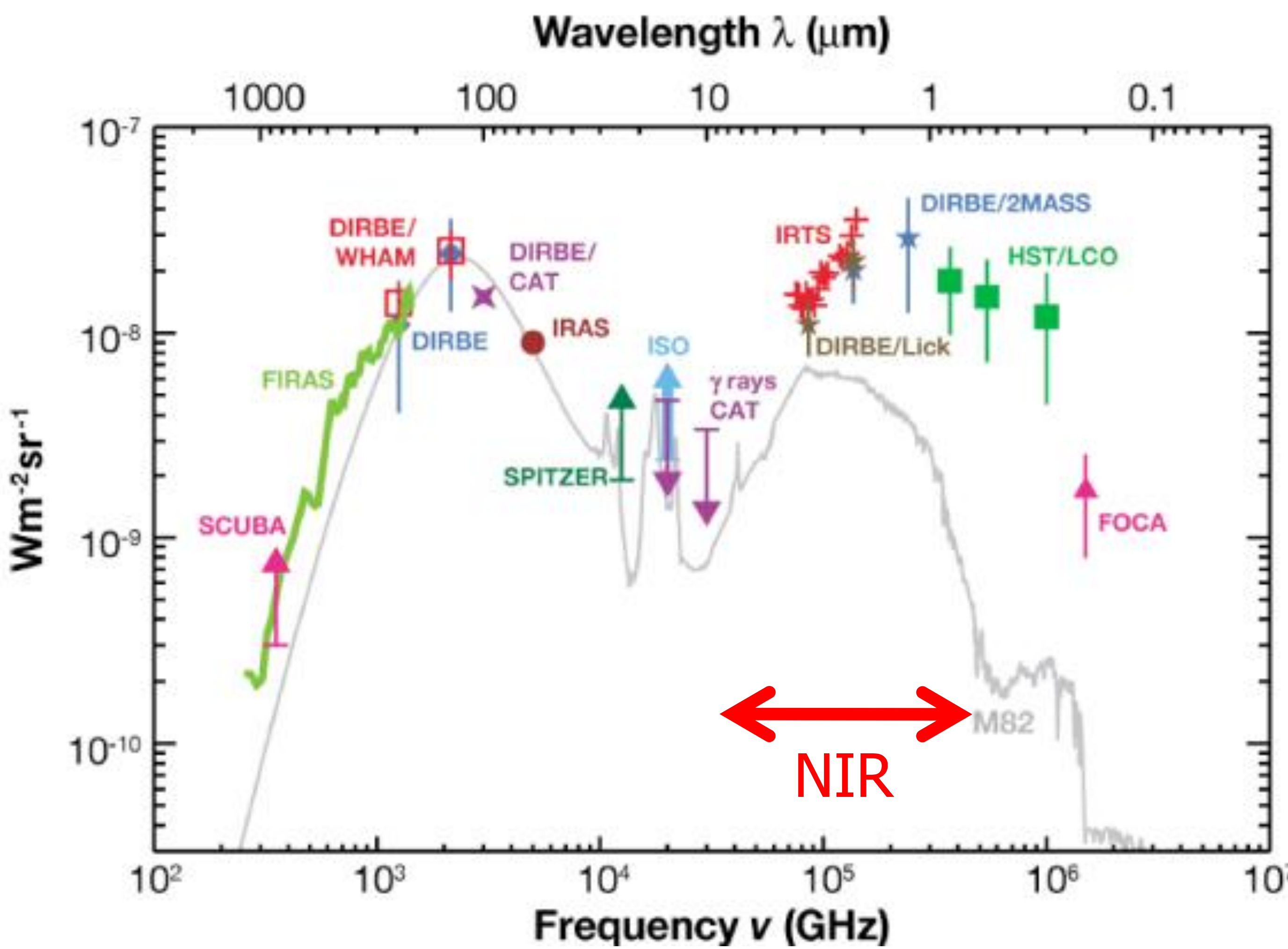


宇宙暗黒時代(ダークエイジ)の探求

- WMAPのCMB偏光観測による電離ガスτ の決定 → z ~ 10で宇宙再電離
- 第一世代の星の紫外放射が再電離源
- 紫外放射の直接検出可能か？ → 赤外線宇宙背景放射(CIRB)

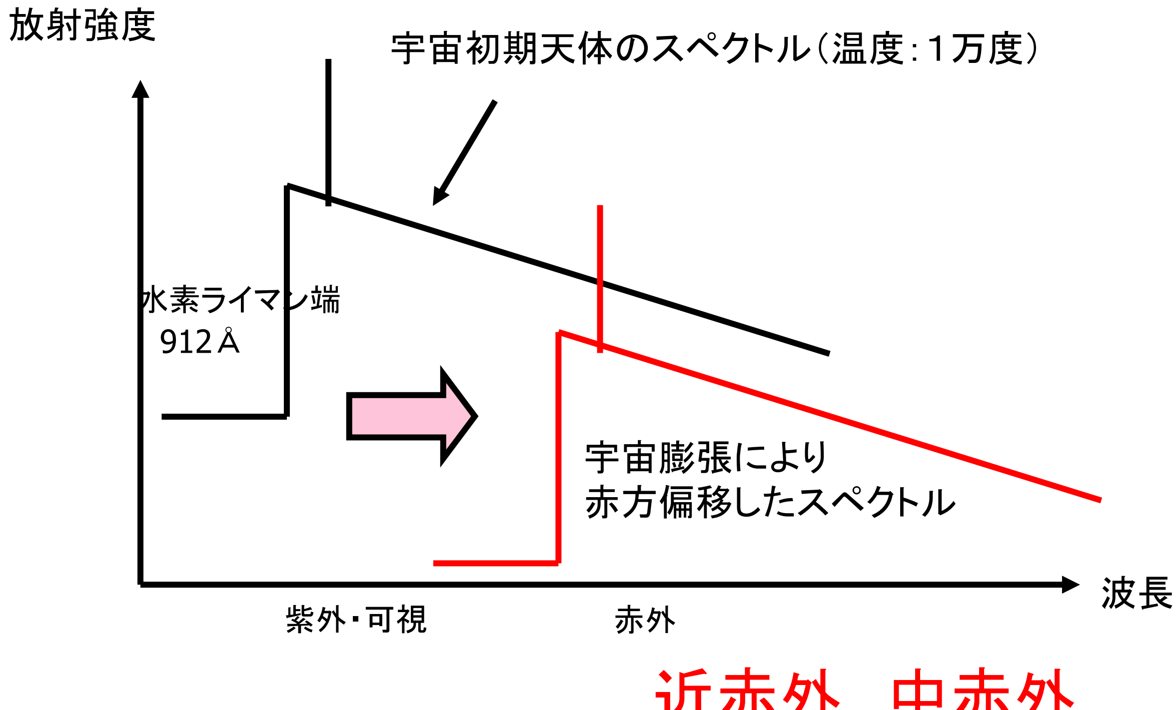


Revealing Dark Age



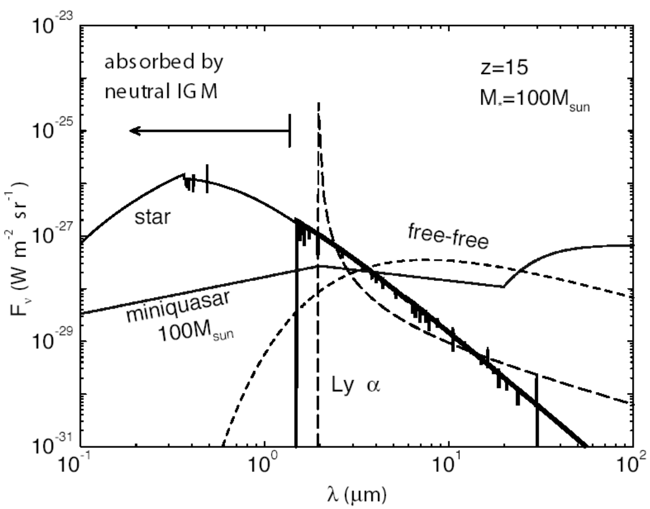
赤外線宇宙背景放射
(CIRB: Cosmic InfraRed Background radiation)

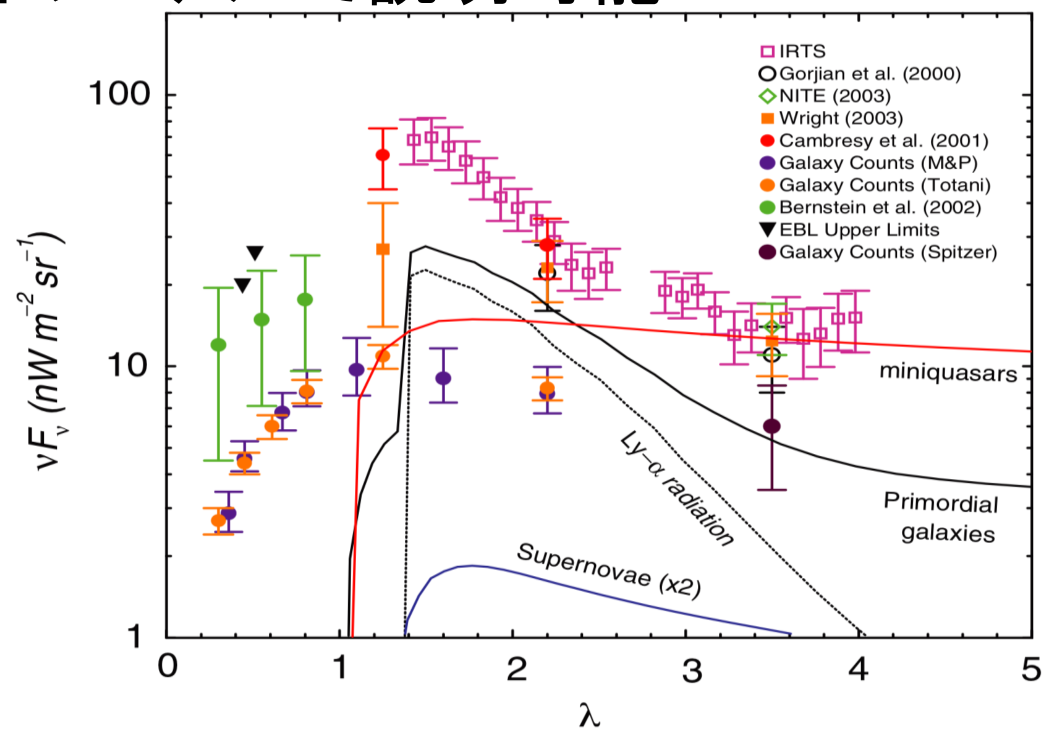
- z>10の紫外放射は近・中赤外域で観測
- 個々に分解検出できない微弱な天体
- 広い視野でひとまとめに背景放射として観測
- 大望遠鏡による観測と相補的



これまでの観測 (IRTS)

- 系外銀河では説明できない強度超過
- 放射スペクトル： 可視～近赤外（1μ m付近）の異常
- 第一世代の星のモデルで説明可能





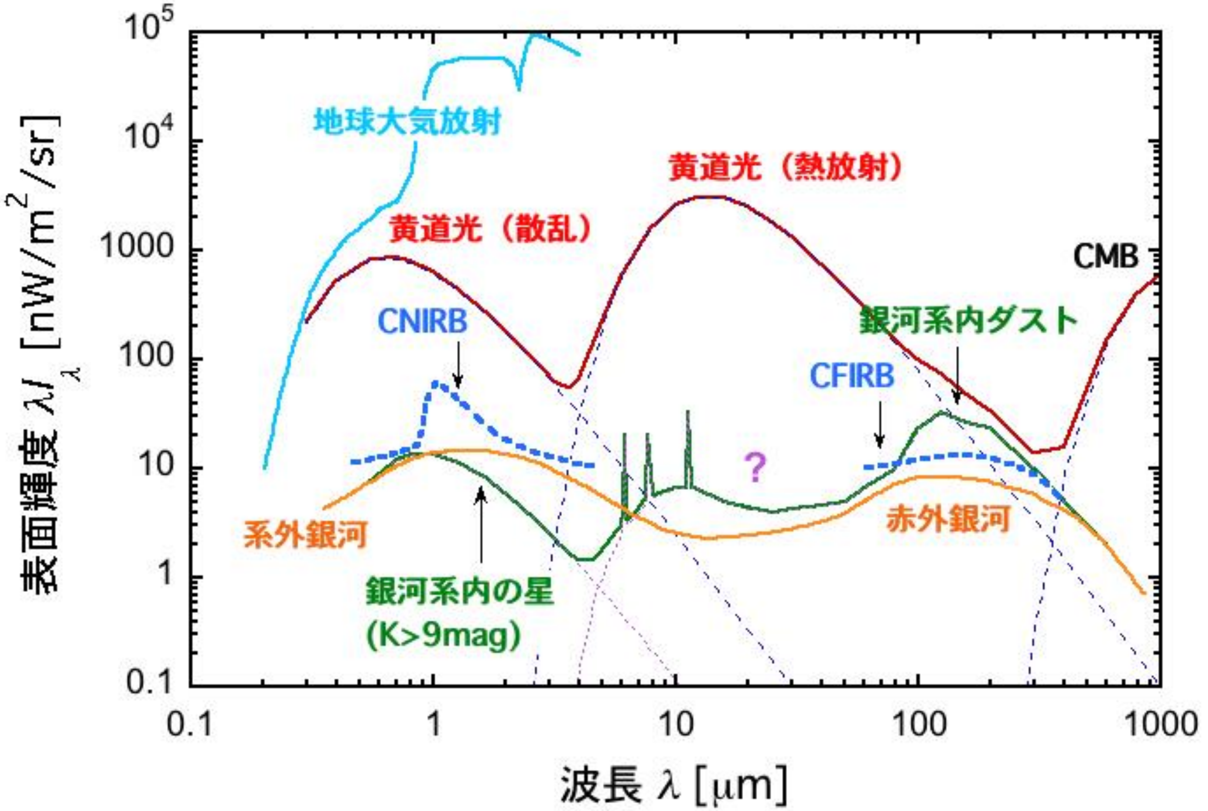
赤外域での空の明るさ

- 黄道光(太陽系ダスト)
  - 太陽光散乱
  - ダスト熱放射

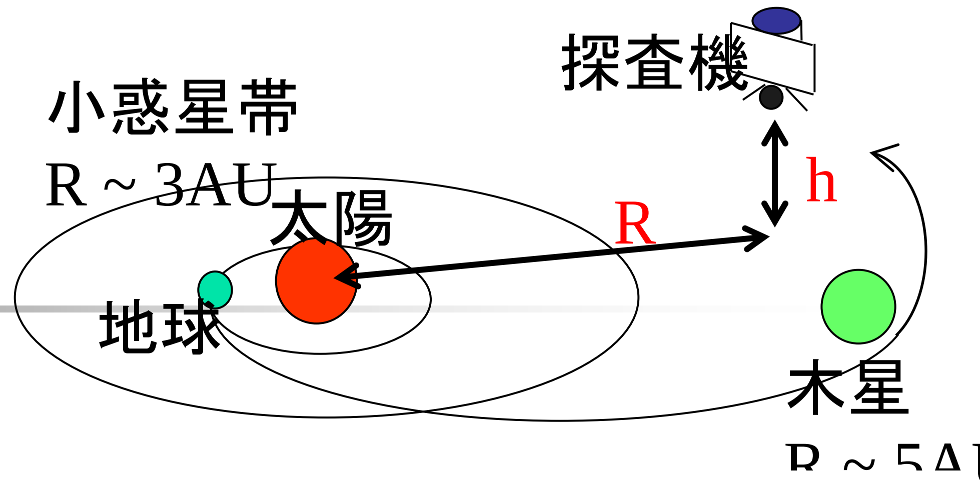
  近赤外 - 全放射の＞70%
  　　　　CIRBの約10倍
  中赤外 - 全放射の＞95%
  　　　　CIRBの100倍以上

- 銀河光、系外銀河
  - 高角分解能の観測装置では点源として除去可能

- 宇宙背景放射の抽出
  - 黄道光の寄与を精度良く推定
  - モデル依存性の困難

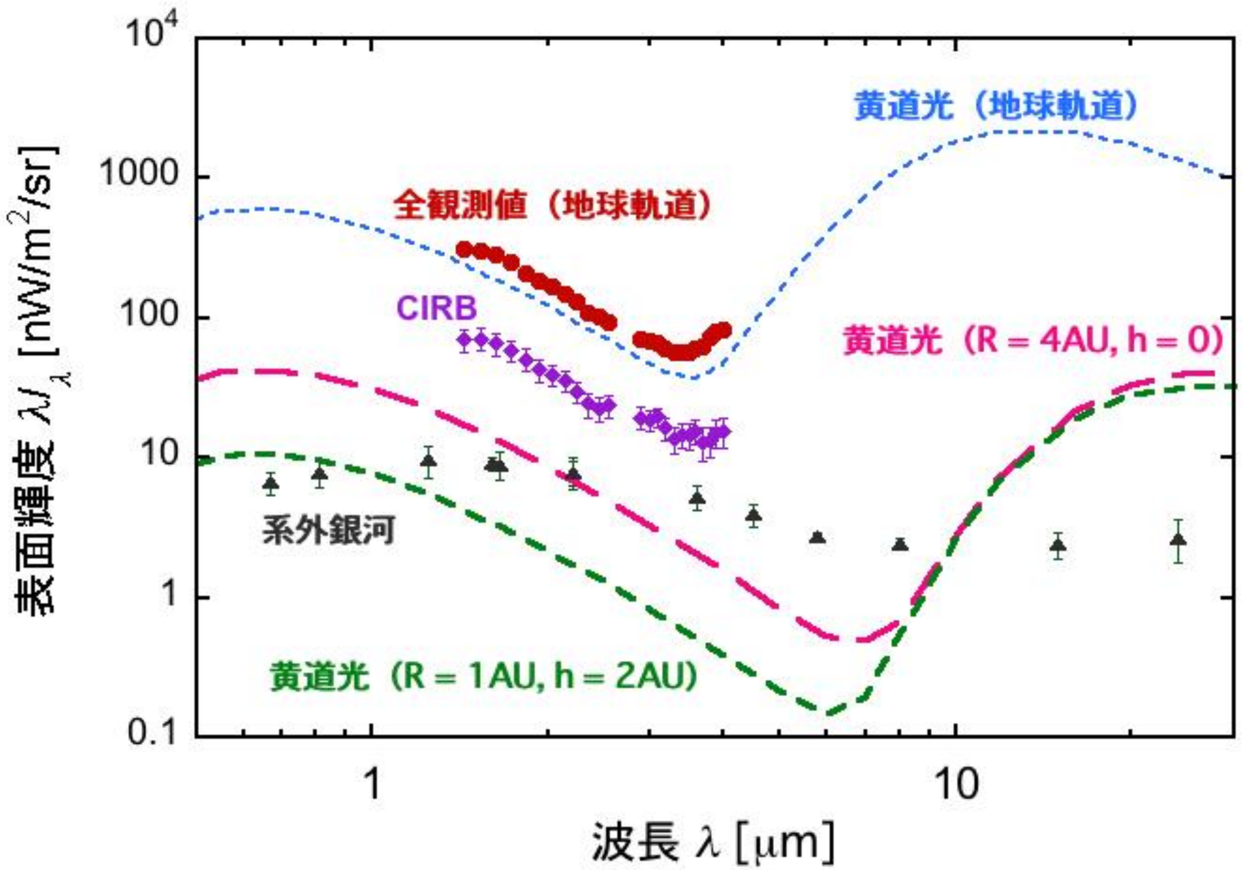


黄道面を越えて



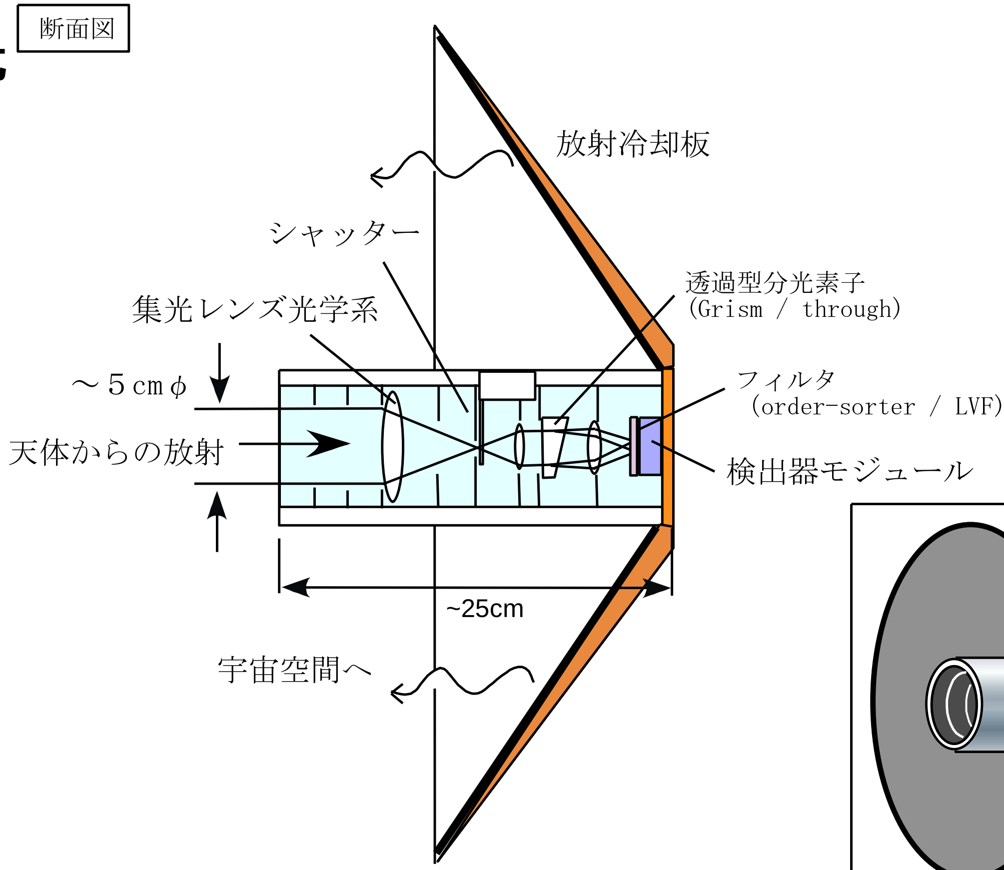
・小惑星帯より遠方または黄道面外軌道では黄道光が激減

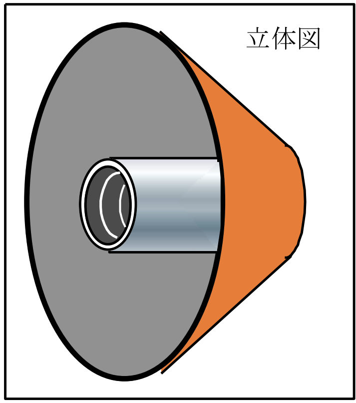
究極のCIRB観測
CIRBの直接検出が可能



黄道面脱出ミッション EXZIT: EXo-Zodiacal Infrared Telescope

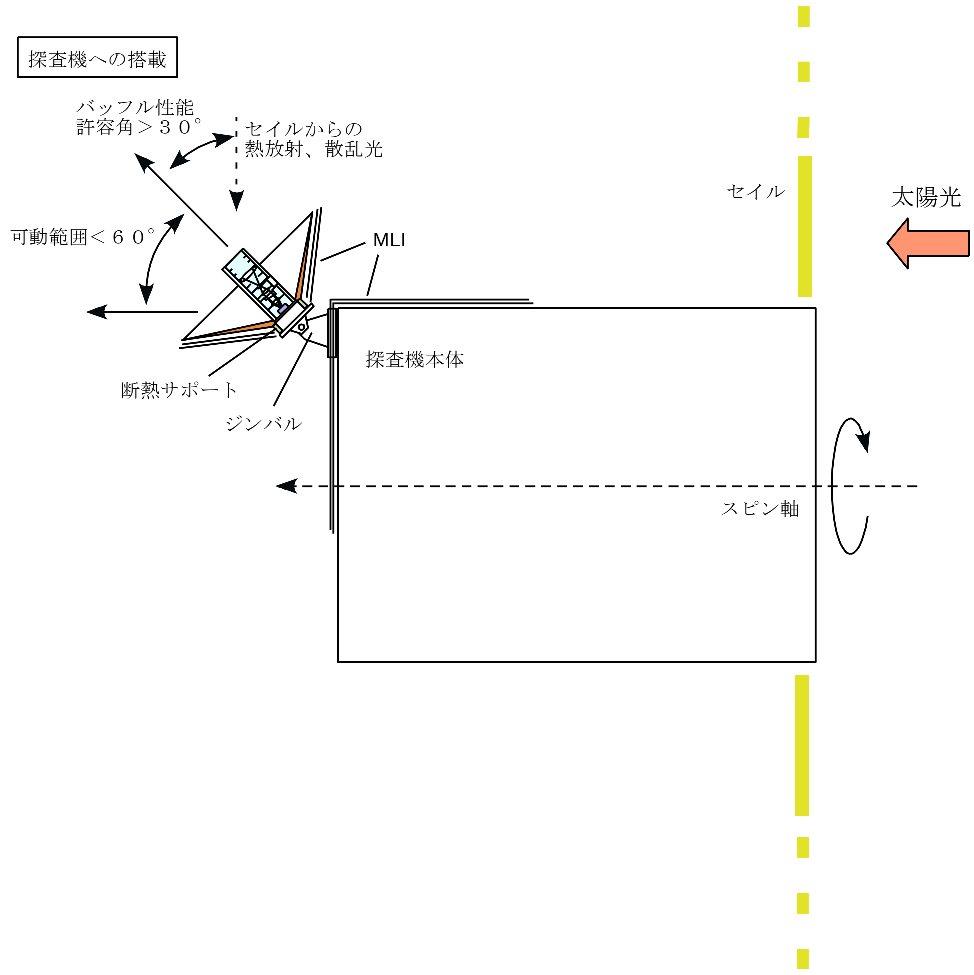
- 近中赤外帯の粗い分光
  波長: 0.8-2μm - 20μm
  分解能:　R~20
  視野:　~1°
  望遠鏡口径: ~5cmΦ
- 放射冷却
  近赤外　T<70K
  中赤外　T<20K
- 総重量　~10kg



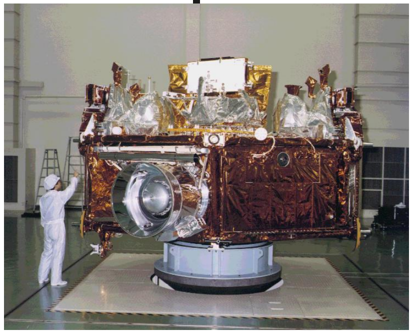


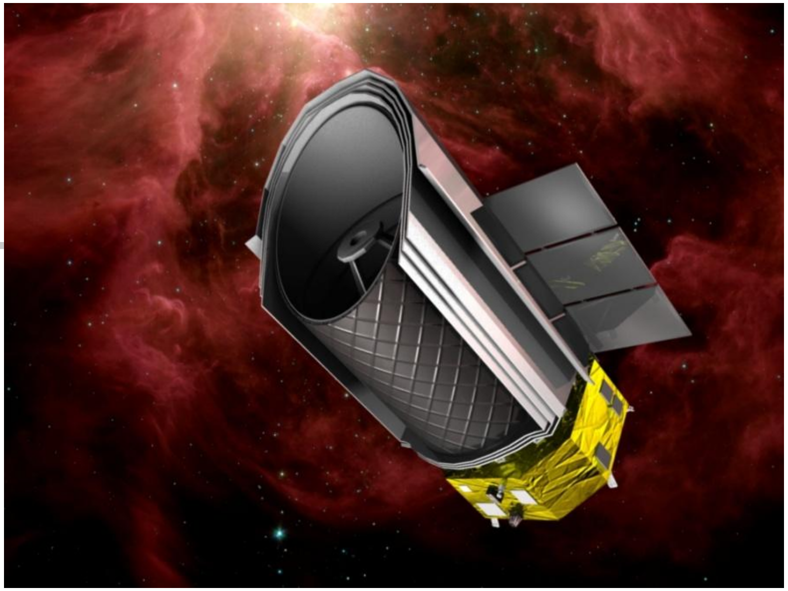
観測方法

- スリット分光：　波長分散方向に望遠鏡スキャンして分光イメージ取得
- クルージング期間（～２年）内には広い天域で黄道光の変化が観測できる
- 小惑星帯以遠において背景放射の直接検出が期待
- 他ミッション（Solar sail, Jovian mission, solar-C) に相乗り



未来へ





- SPICA (2017)

- EXZIT (201?)