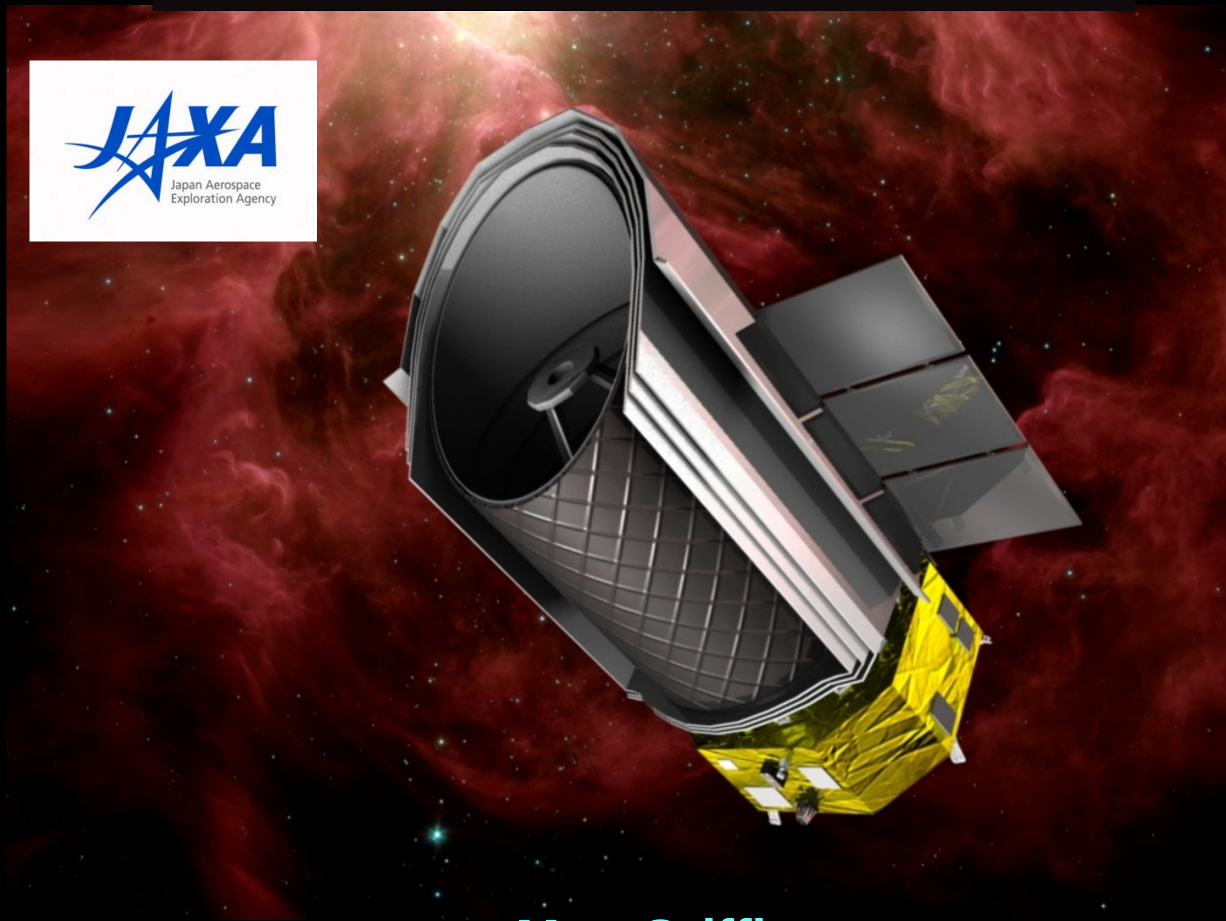
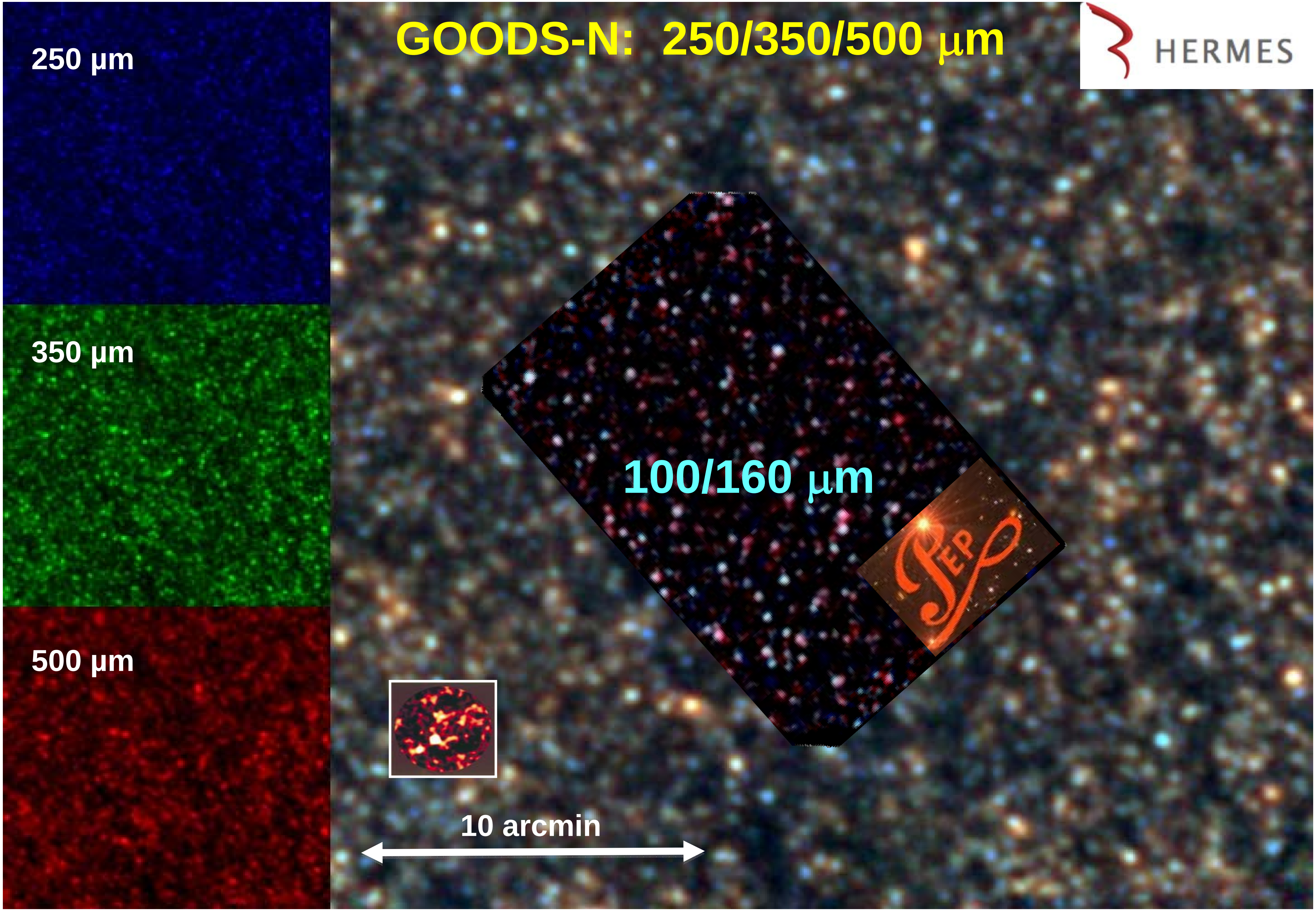
SPICA

Space Infrared Telescope for Cosmology and Astrophysics



Matt Griffin
Cardiff University

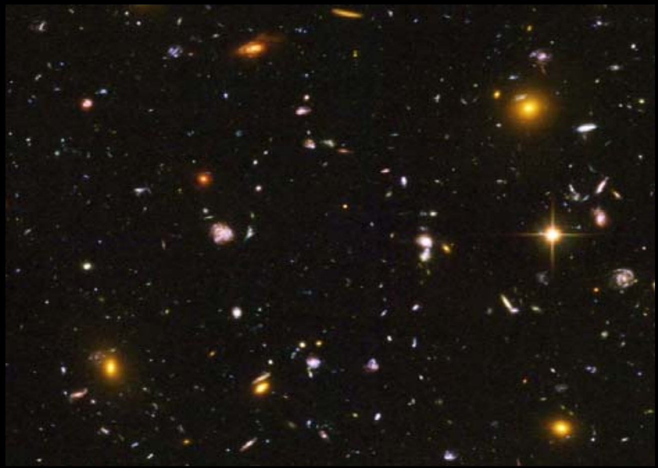
Future of UK Submillimetre Astronomy Workshop, Edinburgh, 12, 13 Dec 2011



GOODS-N: 250/350/500 μm
HERMES
250 μm
350 μm
500 μm
100/160 μm
PEP
10 arcmin

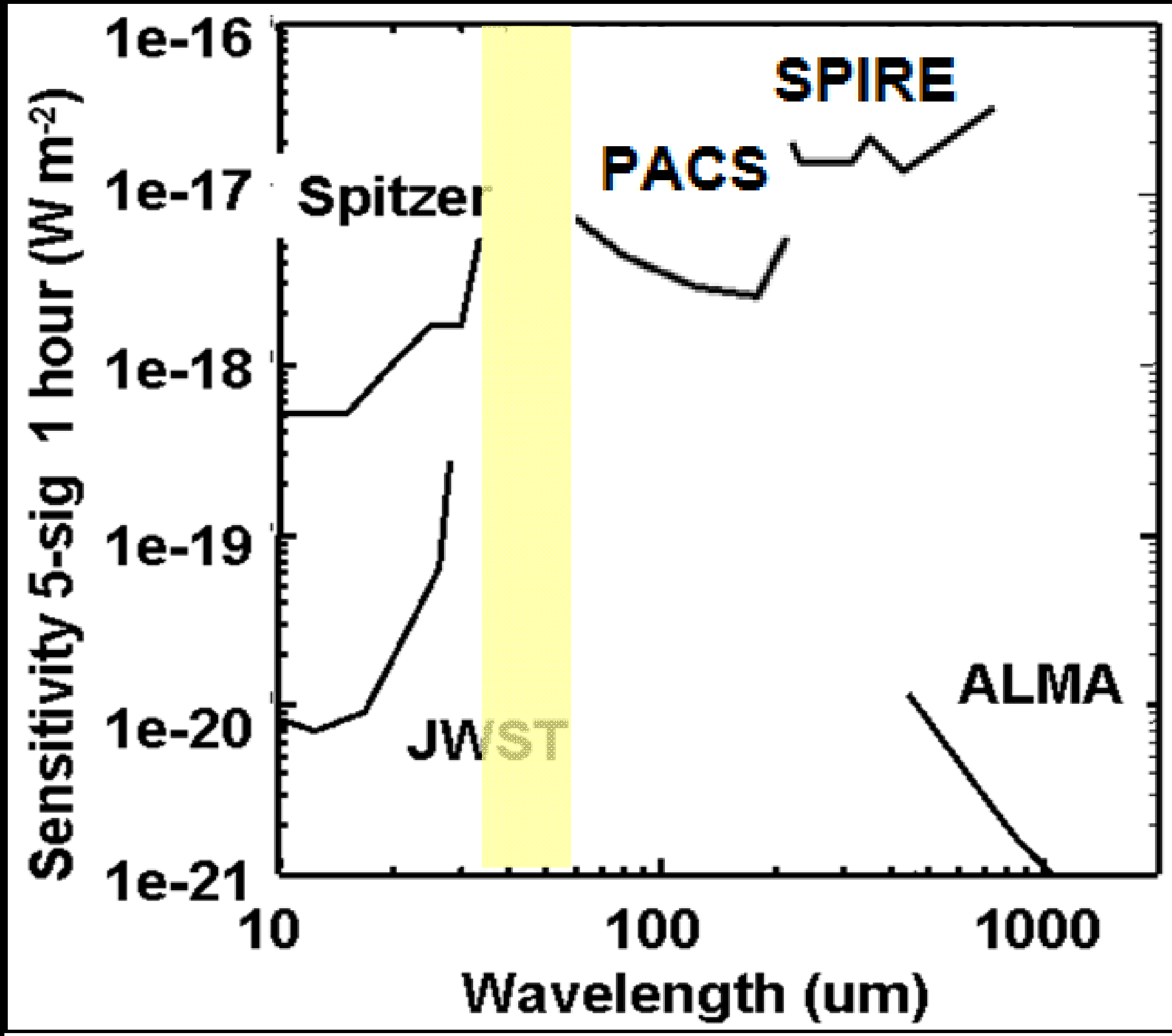
SPICA – Key Scientific Goals

- Resolve of the FIR background into individual galaxies
- Study their composition and internal structure spectroscopically



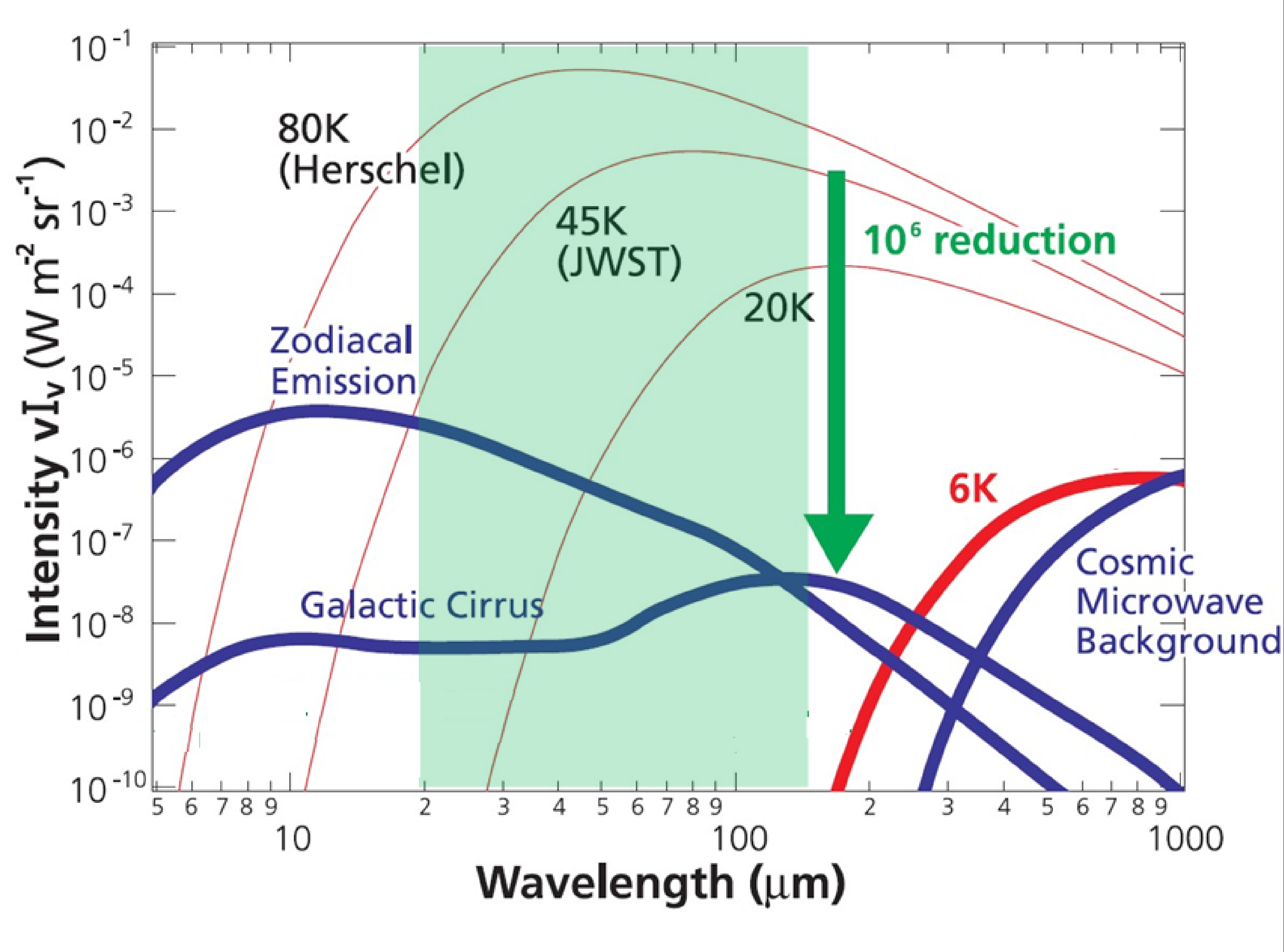
- Direct observation of all stages of star and planetary system formation
- Spectroscopy of gas, dust, and ice in protoplanetary and debris disks

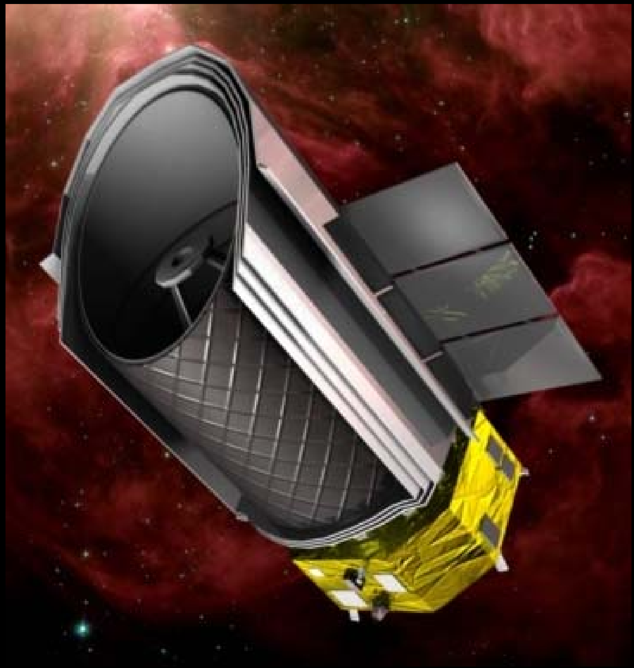
Herschel Sensitivity



- **Warm telescope limits sensitivity**
- **Wavelength gap**
  - 30-60 μm not covered by JWST or Herschel

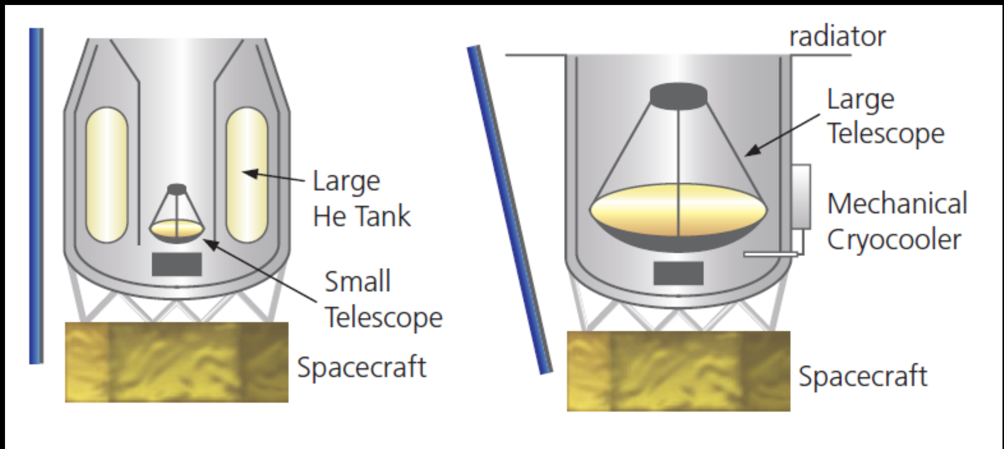
Reducing the Thermal Background





SPICA

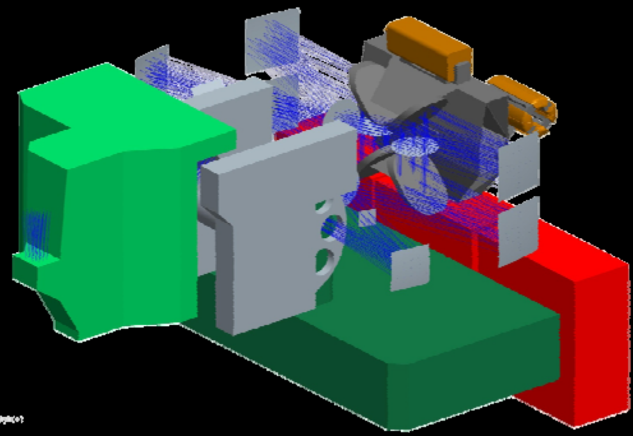
- 3.2-m telescope at ~ 6 K
  - Diffraction-limited at 5 μm
  - λ = 5 – 200+ μm
- Instruments
  - MIR Camera & Spectrometer
    - Coronagraphic capability
  - FIR Camera & Spectrometer
  - Possible single-pixel submm spectrometer
- No cryogen tank: combination of passive and active cooling
- Sun-Earth L2 orbit
- Lifetime 5 yrs +
- Launch ~ 2022

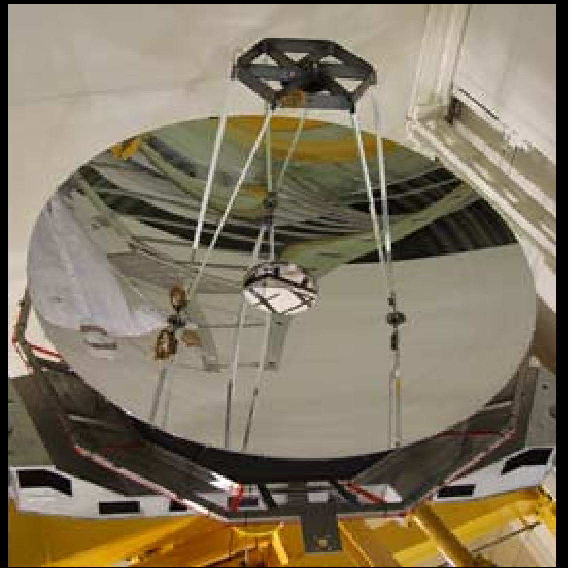


Traditional SPICA

SPICA and ESA Cosmic Vision

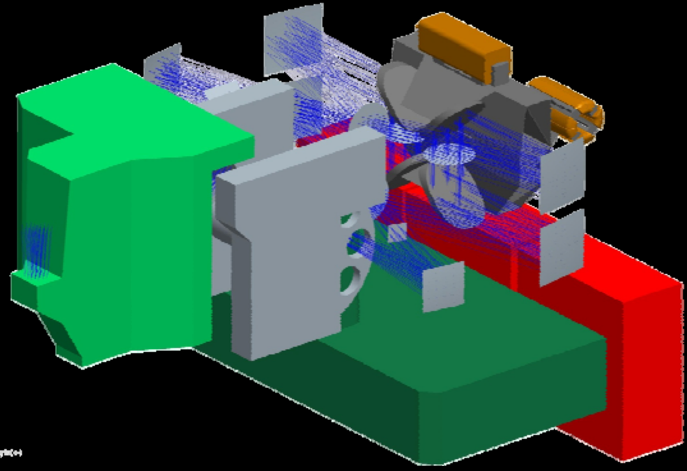
- "European package"
  - National agencies
    - FIR instrument (SAFARI)
  - ESA:
    - Telescope
    - Ground station
    - Data processing





- Selected by ESA as a "Mission of Opportunity" in Cosmic Vision

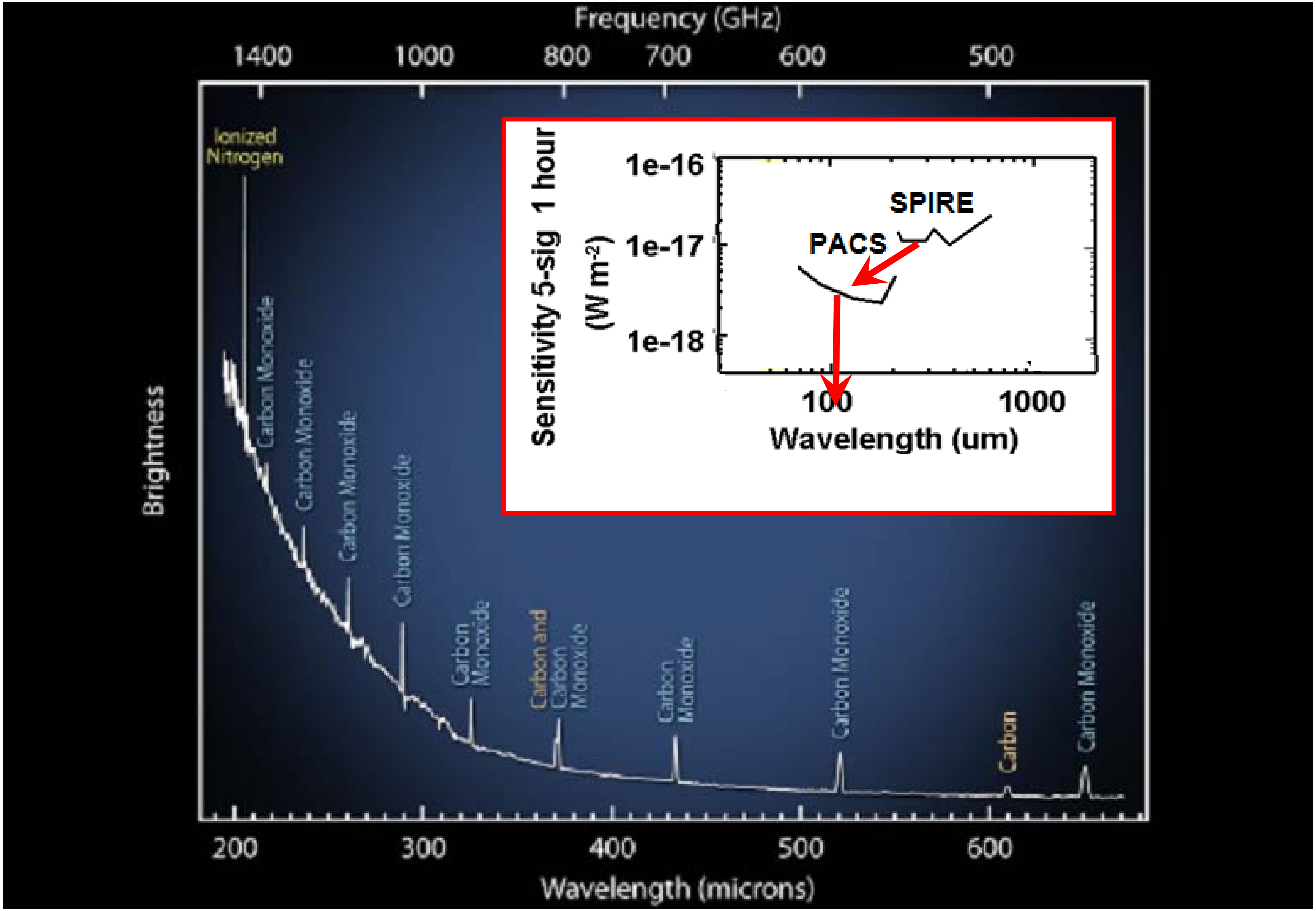
SAFARI



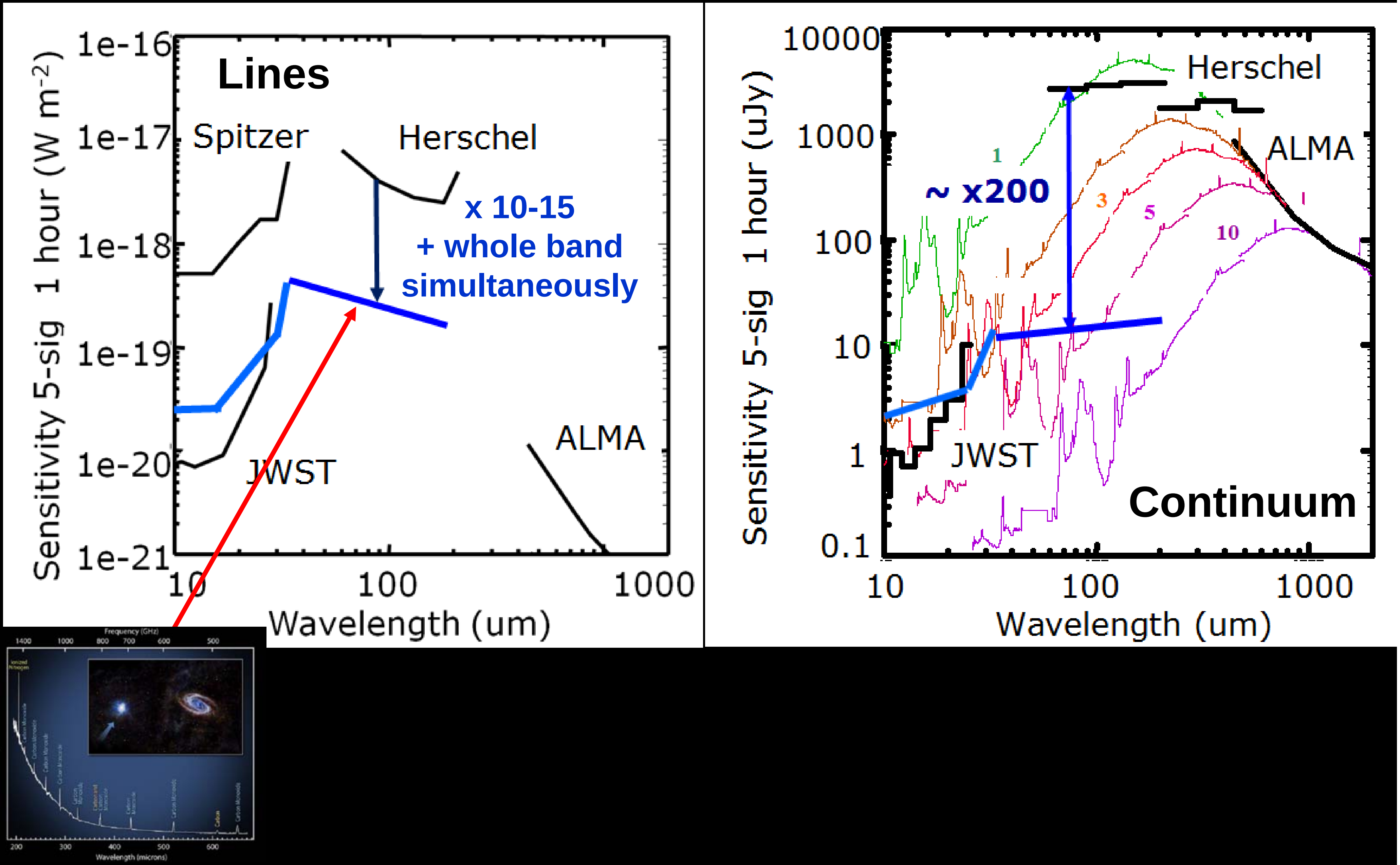
- FIR Camera and Fourier Transform Spectrometer
  - Based on SPIRE heritage
  - 35 - 210 μm (simultaneous)
  - Continuum and lines
  - Field of view 2 x 2 arcmin
  - ~ 6000 pixels total
  - λ/Δλ ~ 3 (camera)
  - ~ 50 (SED mode)
  - ~ 2000 (spectroscopy)

- Transition Edge Superconducting (TES) bolometers
  - 100 times more sensitive than Herschel detectors

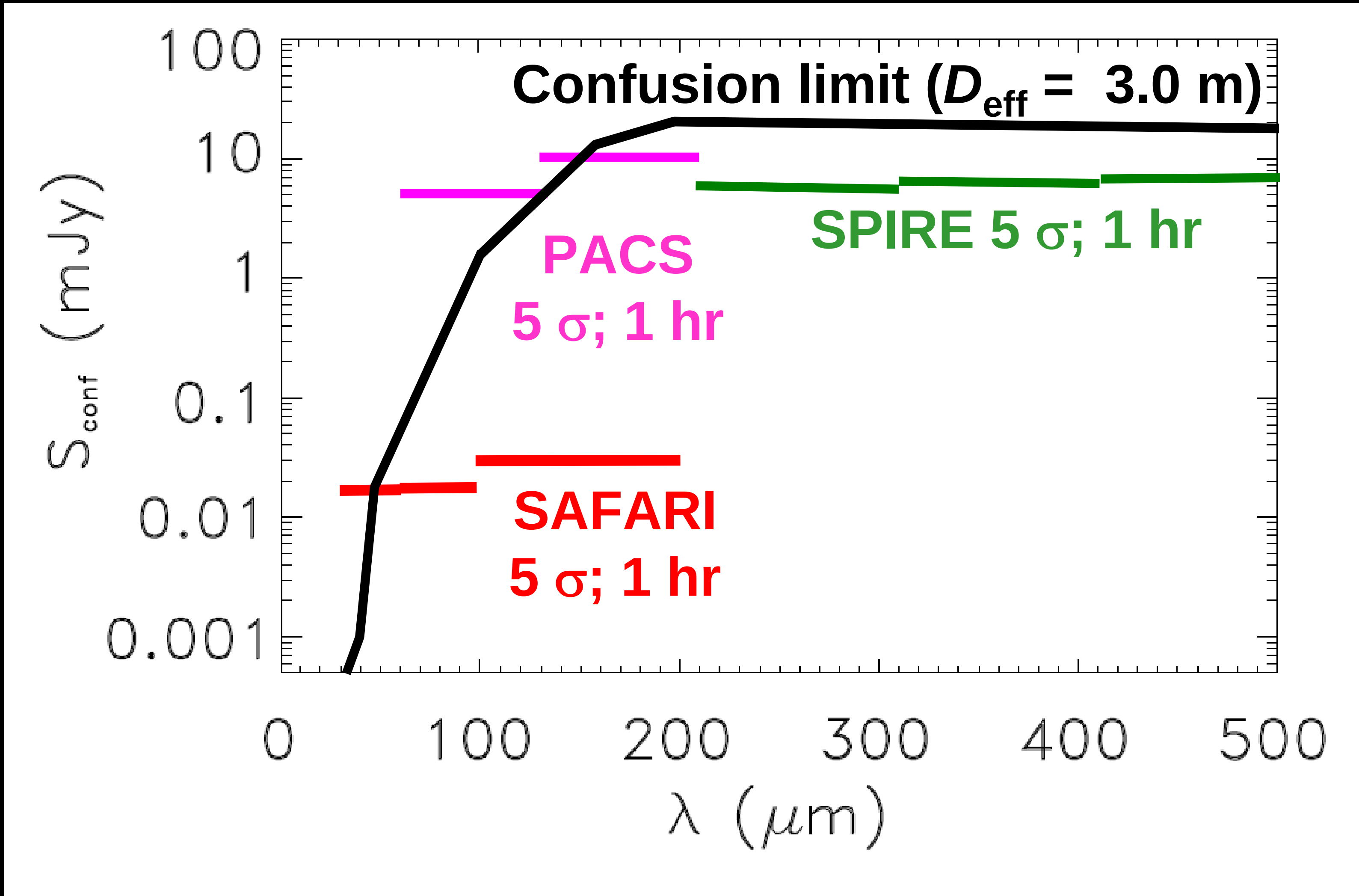
→ Huge advance in sensitivity and observing speed


Frequency (GHz)
1400
1000
800
700
600
500
Brightness
Ionized Nitrogen
Carbon Monoxide
Carbon Monoxide
Carbon Monoxide
Carbon Monoxide
Carbon Monoxide
Carbon and Carbon Monoxide
Carbon Monoxide
Carbon Monoxide
Carbon
Carbon Monoxide
200
300
400
500
600
Wavelength (microns)
Sensitivity 5-sig 1 hour
(W m-2)
1e-16
1e-17
1e-18
SPIRE
PACS
100
1000
Wavelength (um)

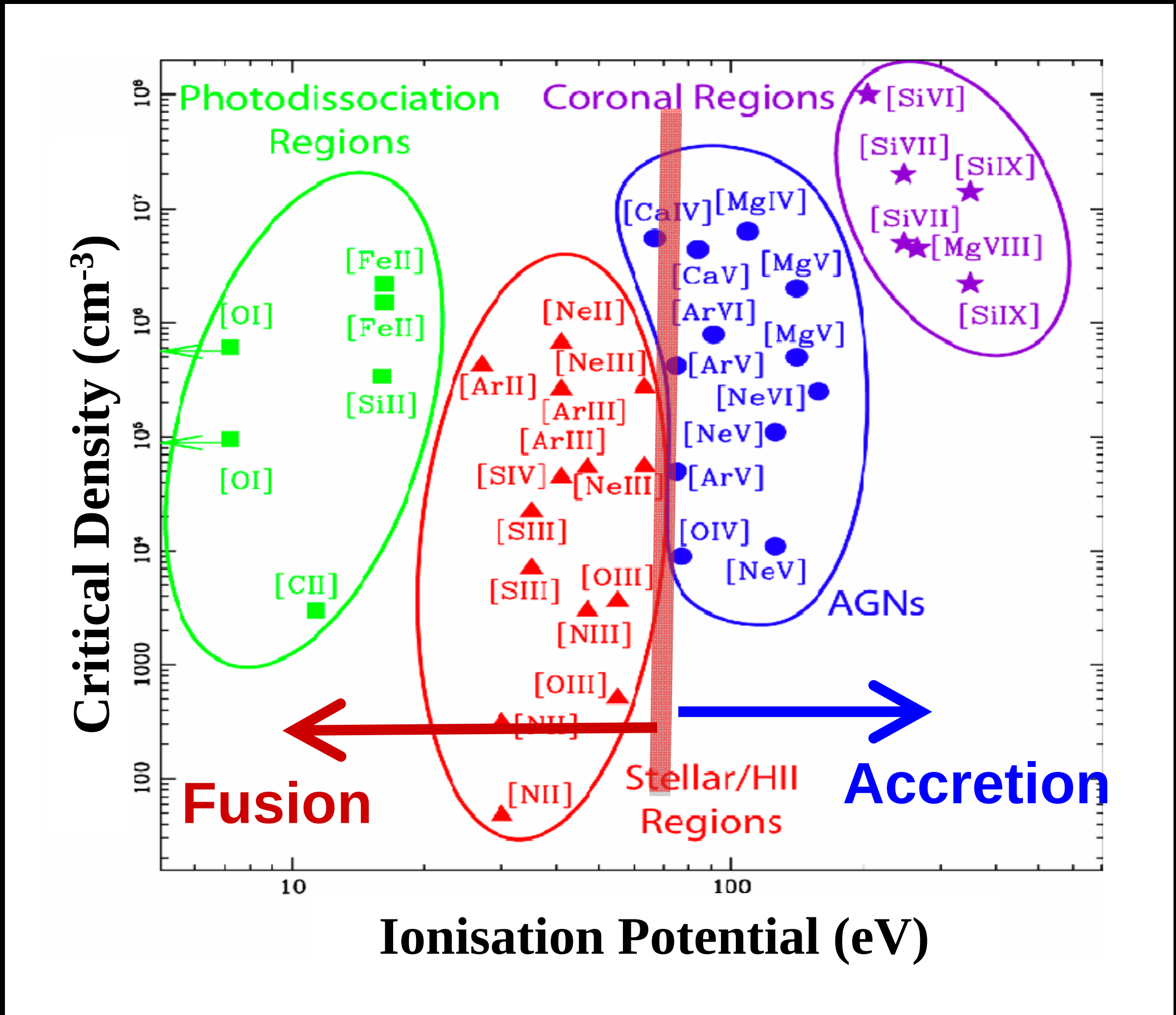
SPICA Sensitivity



Confusion Limits



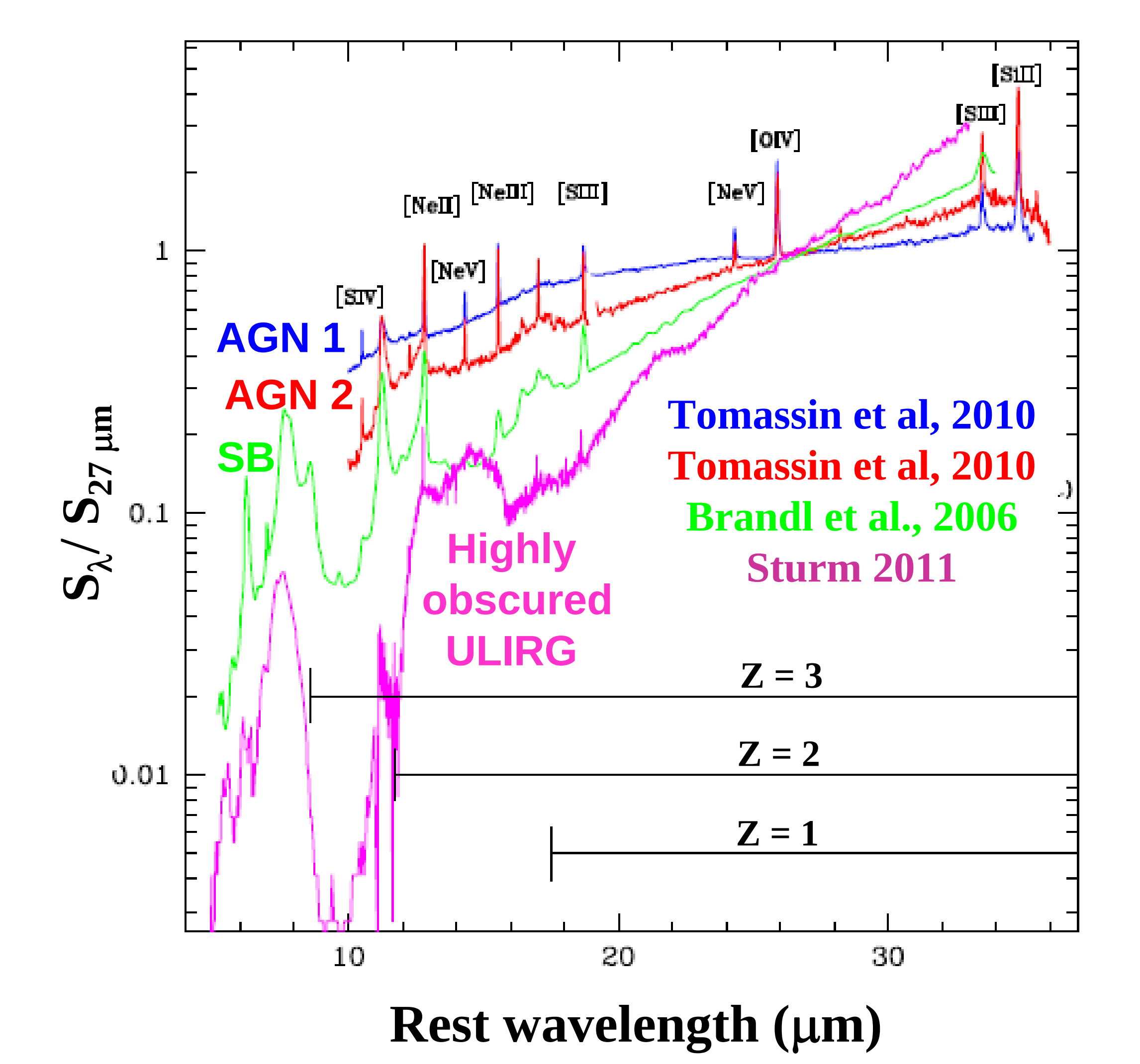
Atomic and Ionic Fine Structure Lines

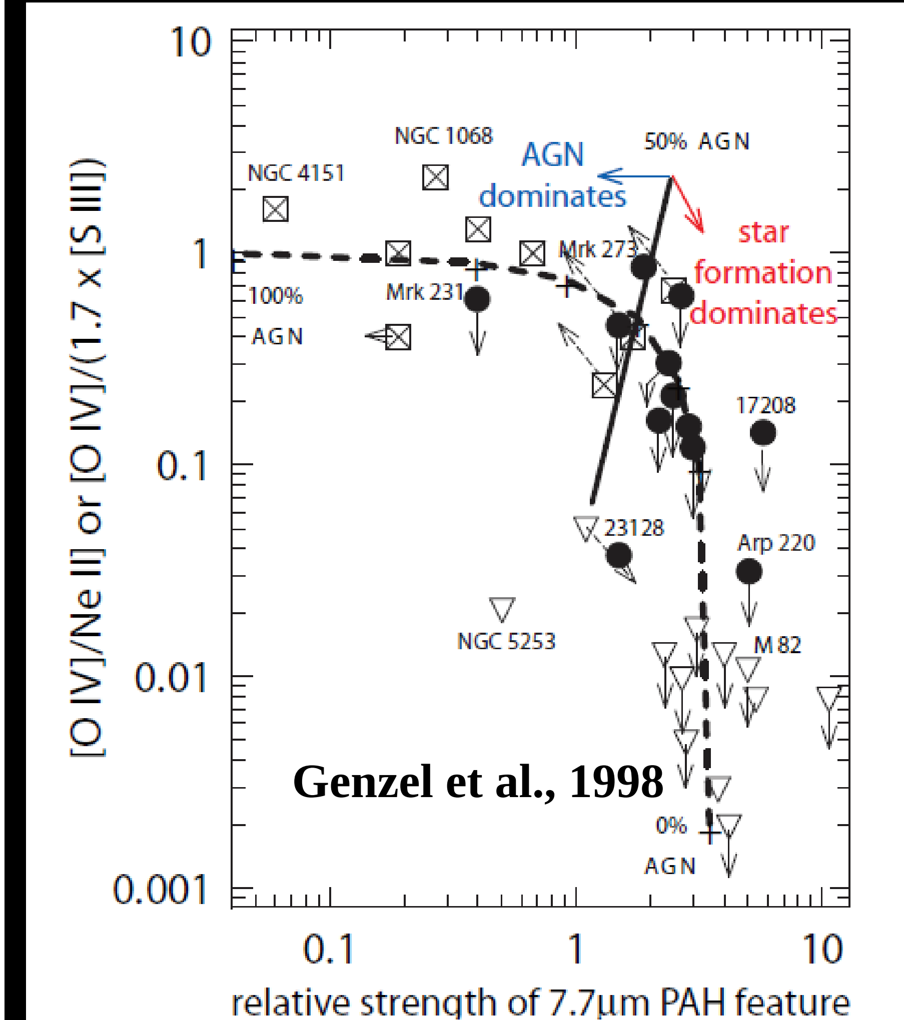


Spinoglio & Malkan, 1992

- Diagnostics for
  - Composition
  - Temperature
  - Density
  - UV field
- Low excitation lines trace star formation
- Higher excitation lines trace AGN activity

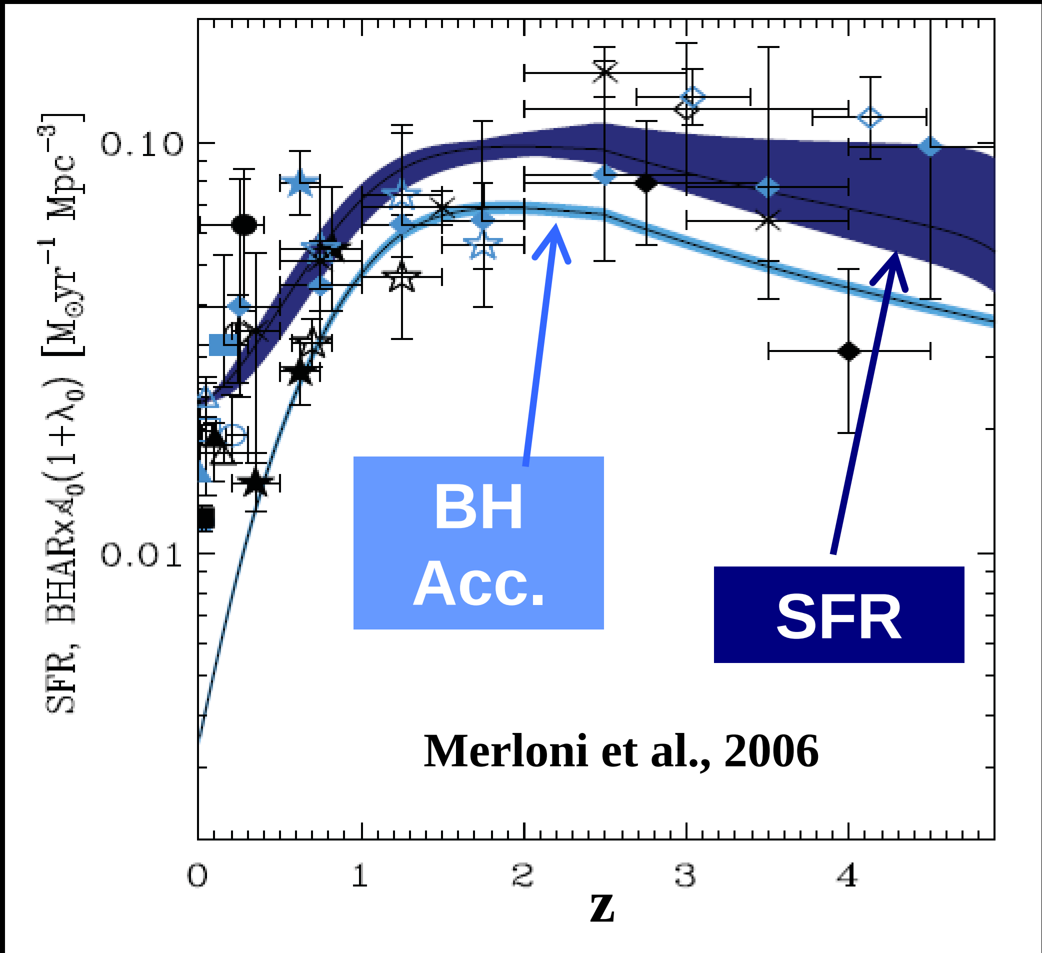
FIR Template Spectra





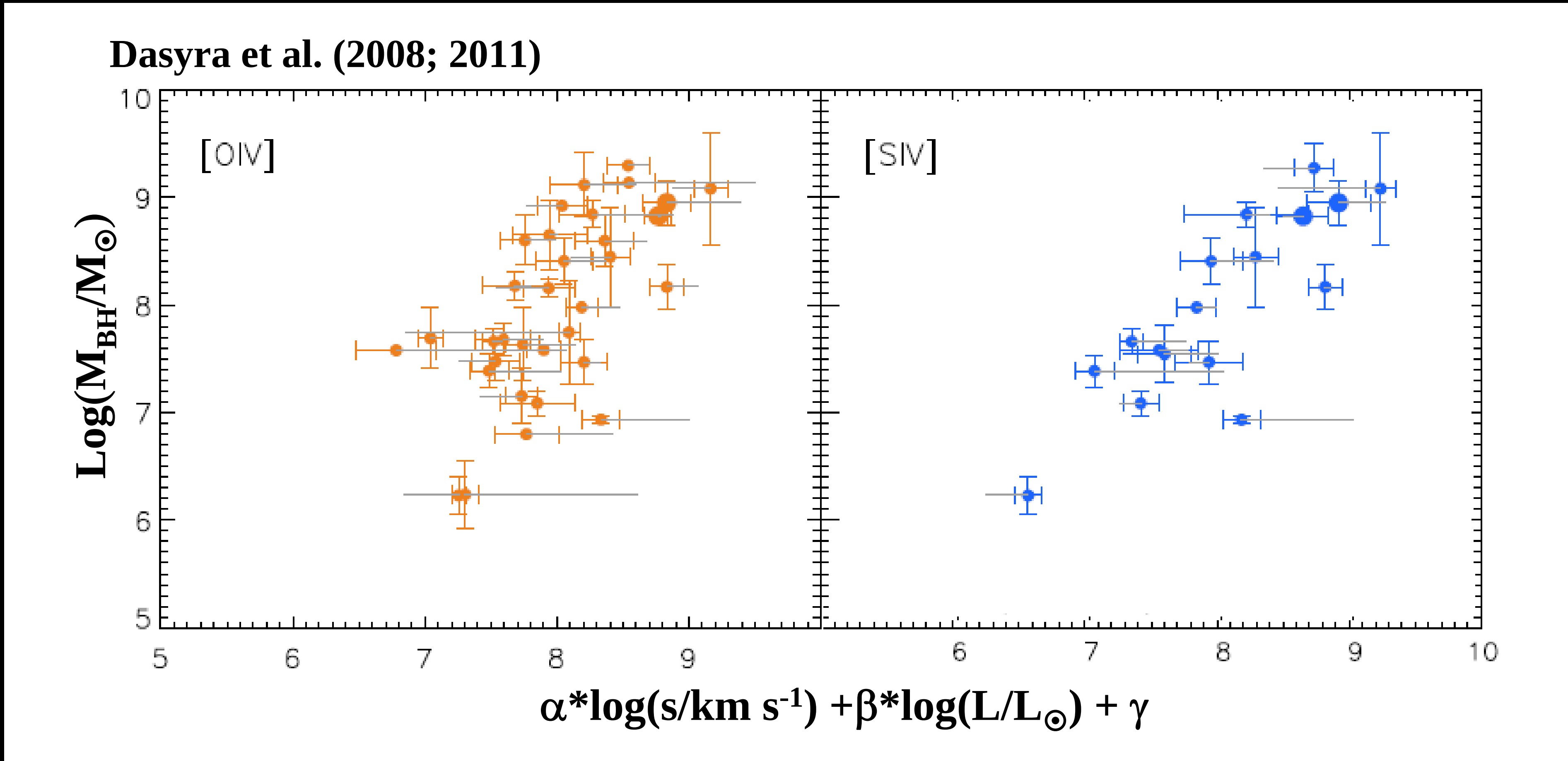
- 6 – 11 μm PAH features: good star formation tracer (insensitive to old stellar population)
- Shifted into FIR for high-*z* sources

Co-eval Growth of Black Holes and Host galaxies



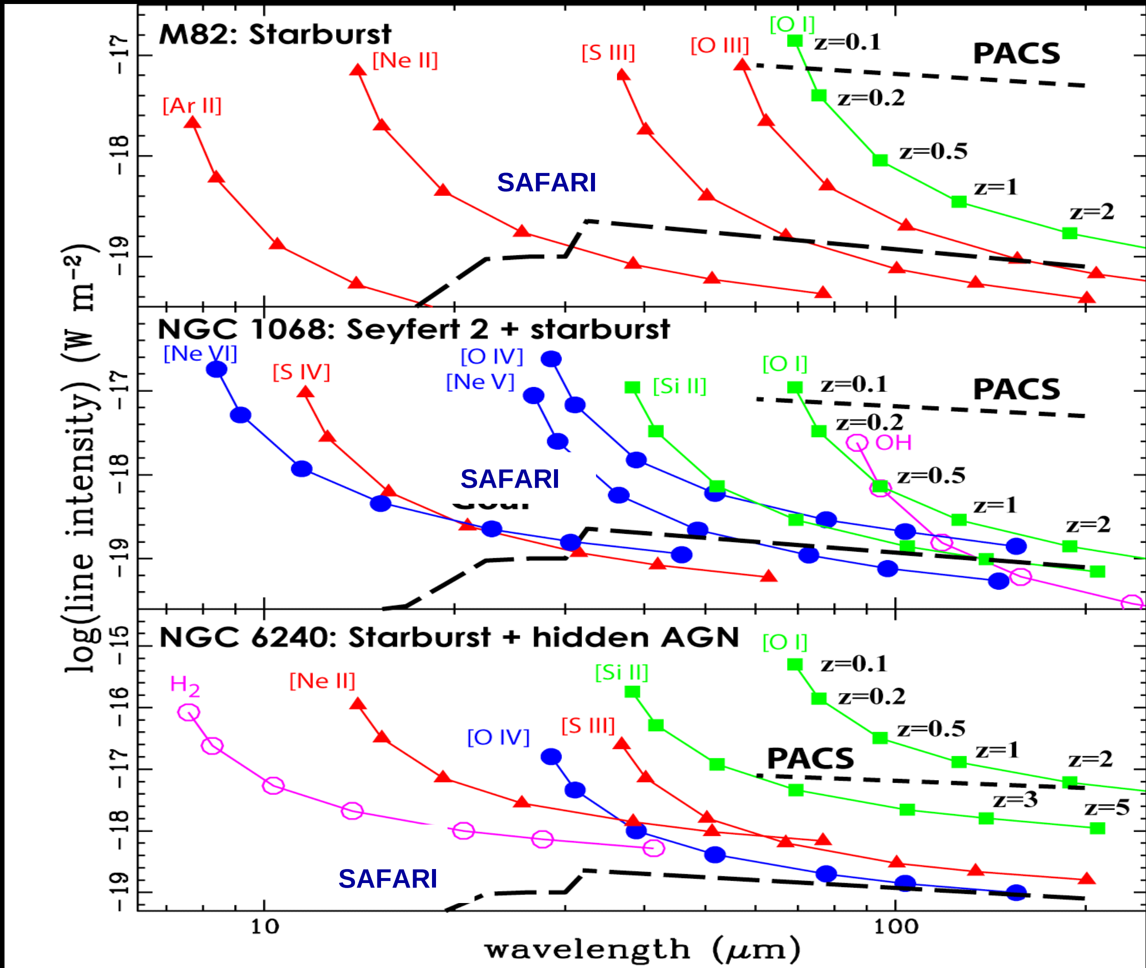
- Dust-enshrouded AGN accretion phase undergone by all galaxies?
- Both peak at *z* ~ 2
- Need to compare evolution of BH mass function with galaxy mass and luminosity functions in large samples including heavily obscured AGN
- Key AGN signature:
  - High-excitation fine structure lines
    e.g., [NeV] 14.3 μm
    [OIV] 26 μm

Co-eval Growth of Black Holes and Host galaxies

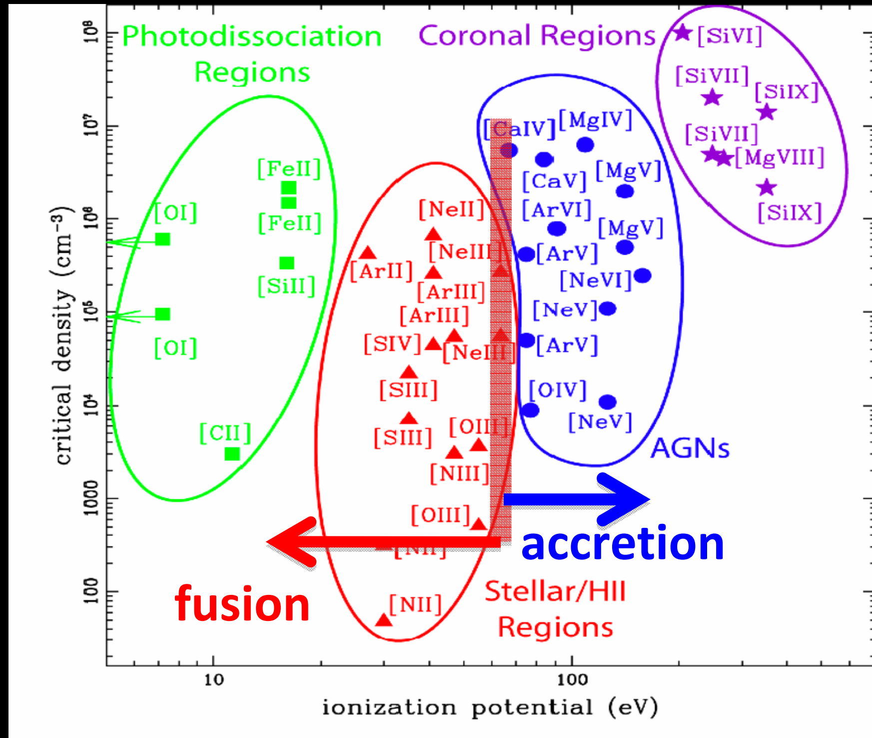


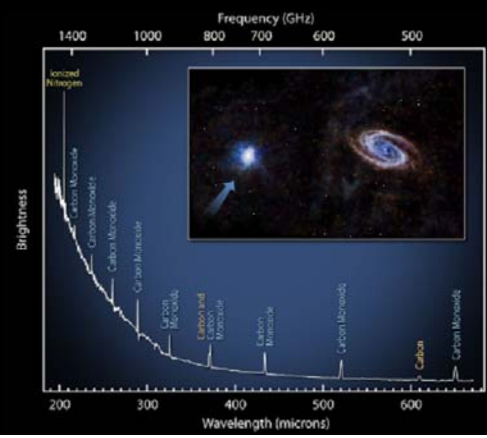
- Velocity dispersion of the NLR gas scales with M_{BH}
- Luminosity-corrected line width allows M_{BH} to be estimated even for growing or obscured BHs

Spectroscopy of High-z Galaxies



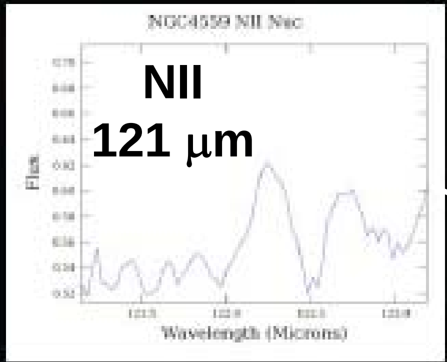
Luigi Spinoglio

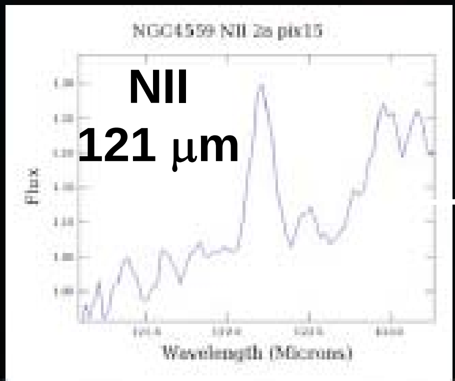


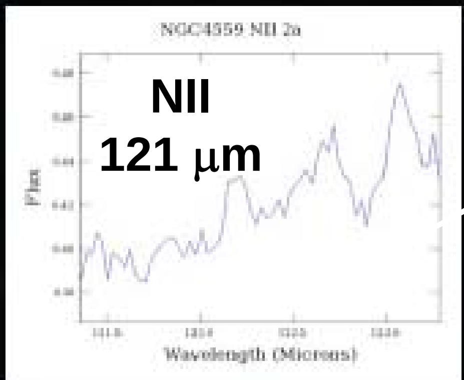


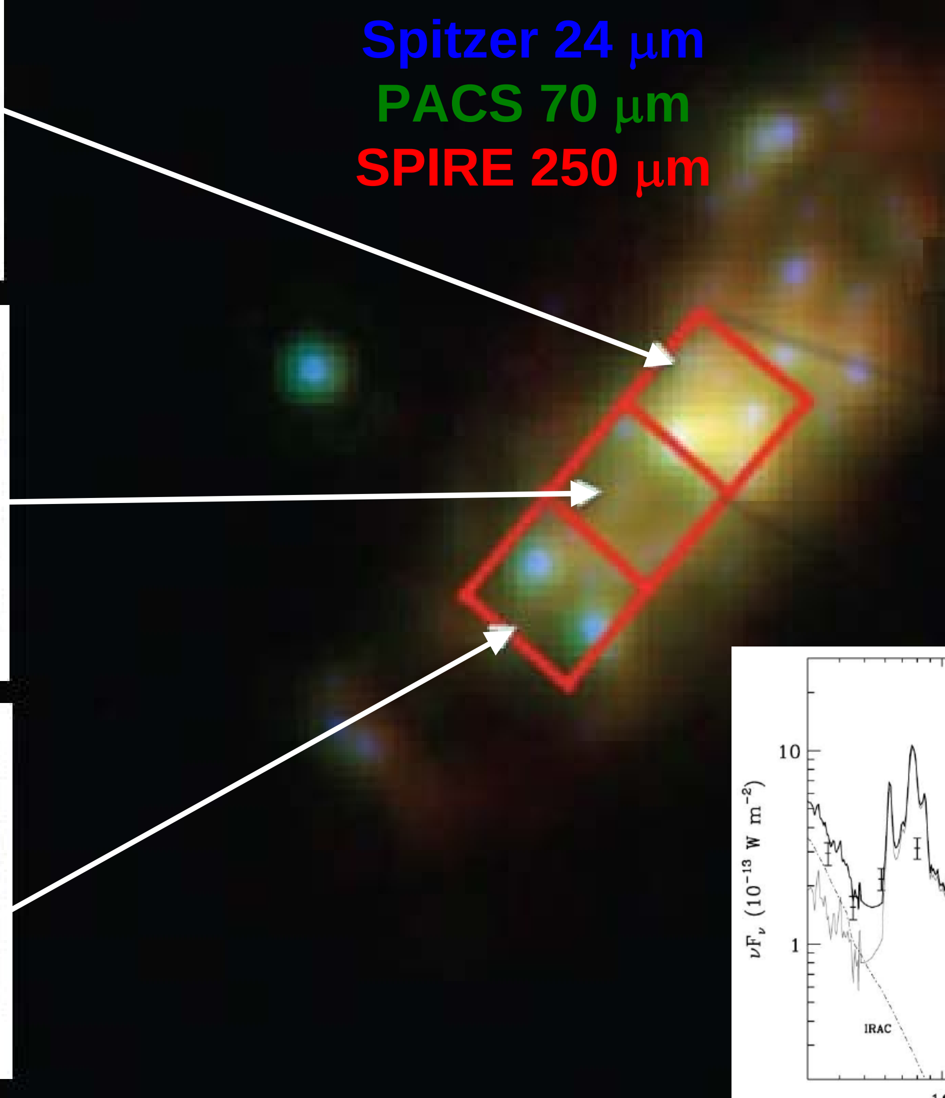
- Key diagnostic lines out to z > 3
- 35 – 210 μm → multiple lines in single observation
- 2’ x 2’ → multiple sources in single observation

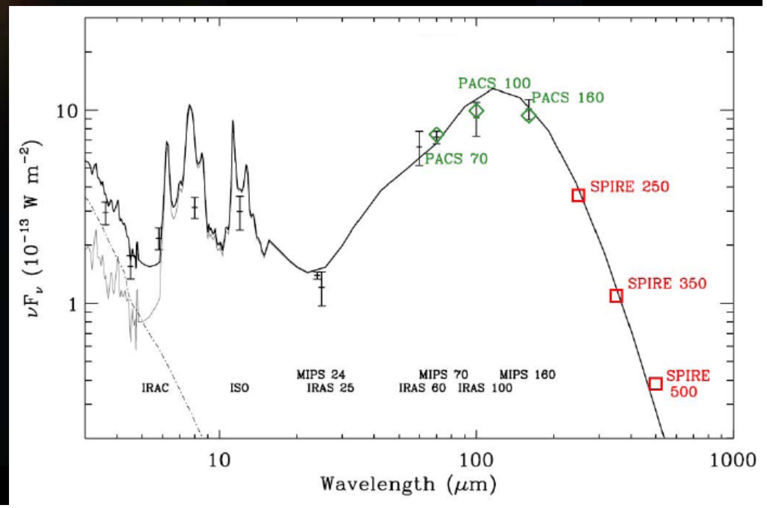
Spectral Mapping of NGC4559
Strong Variations of CII, NII, OI



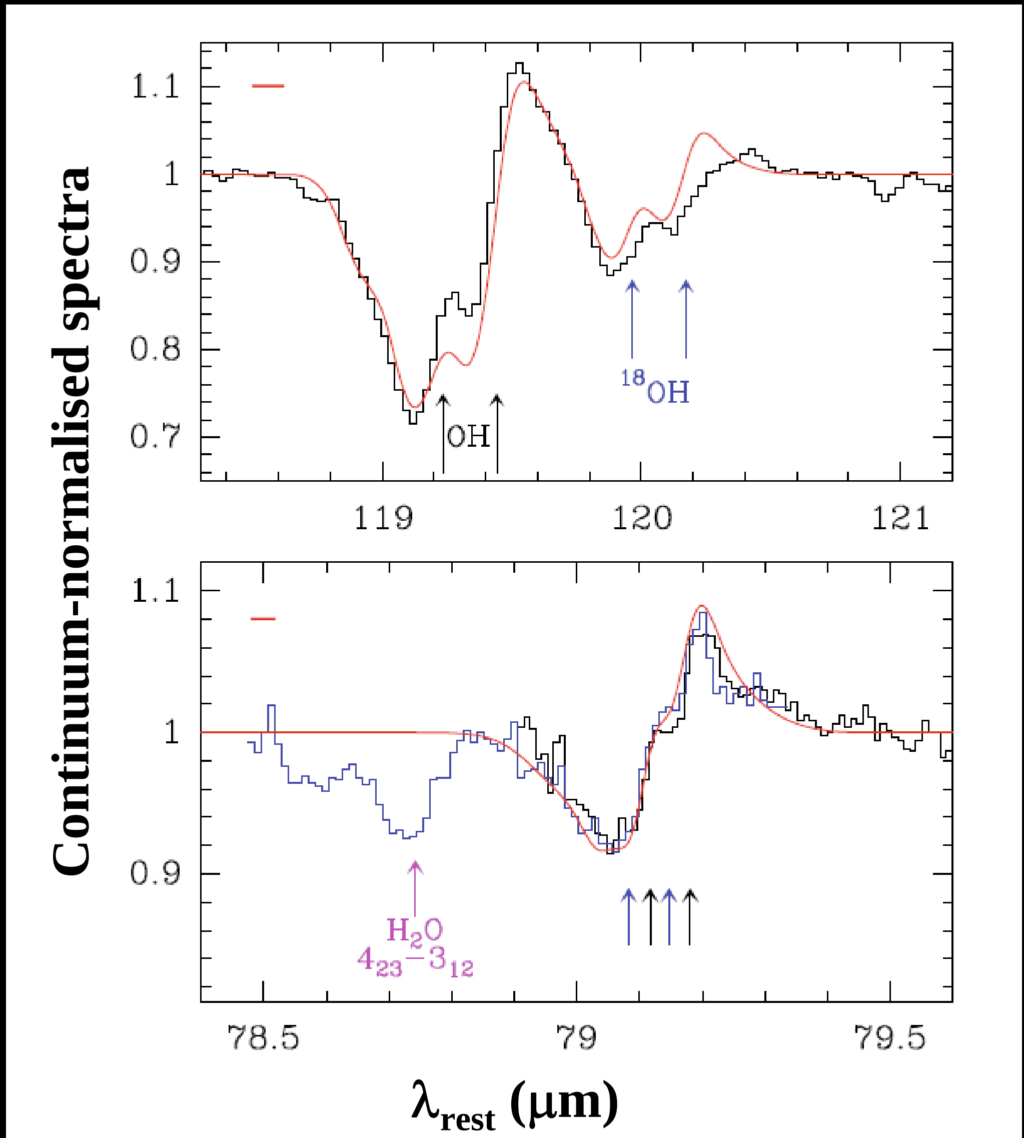


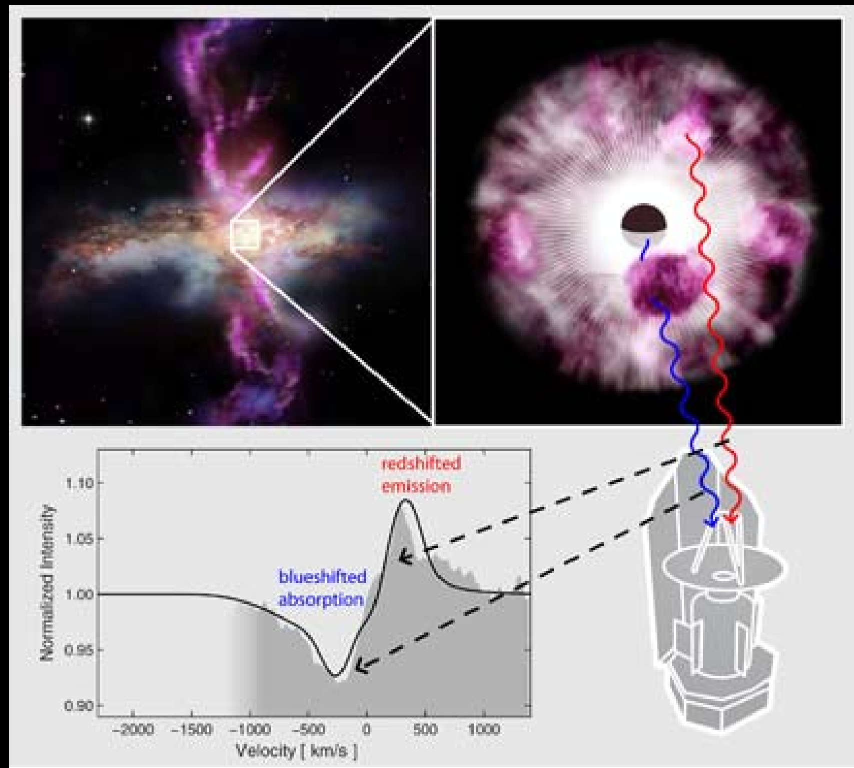






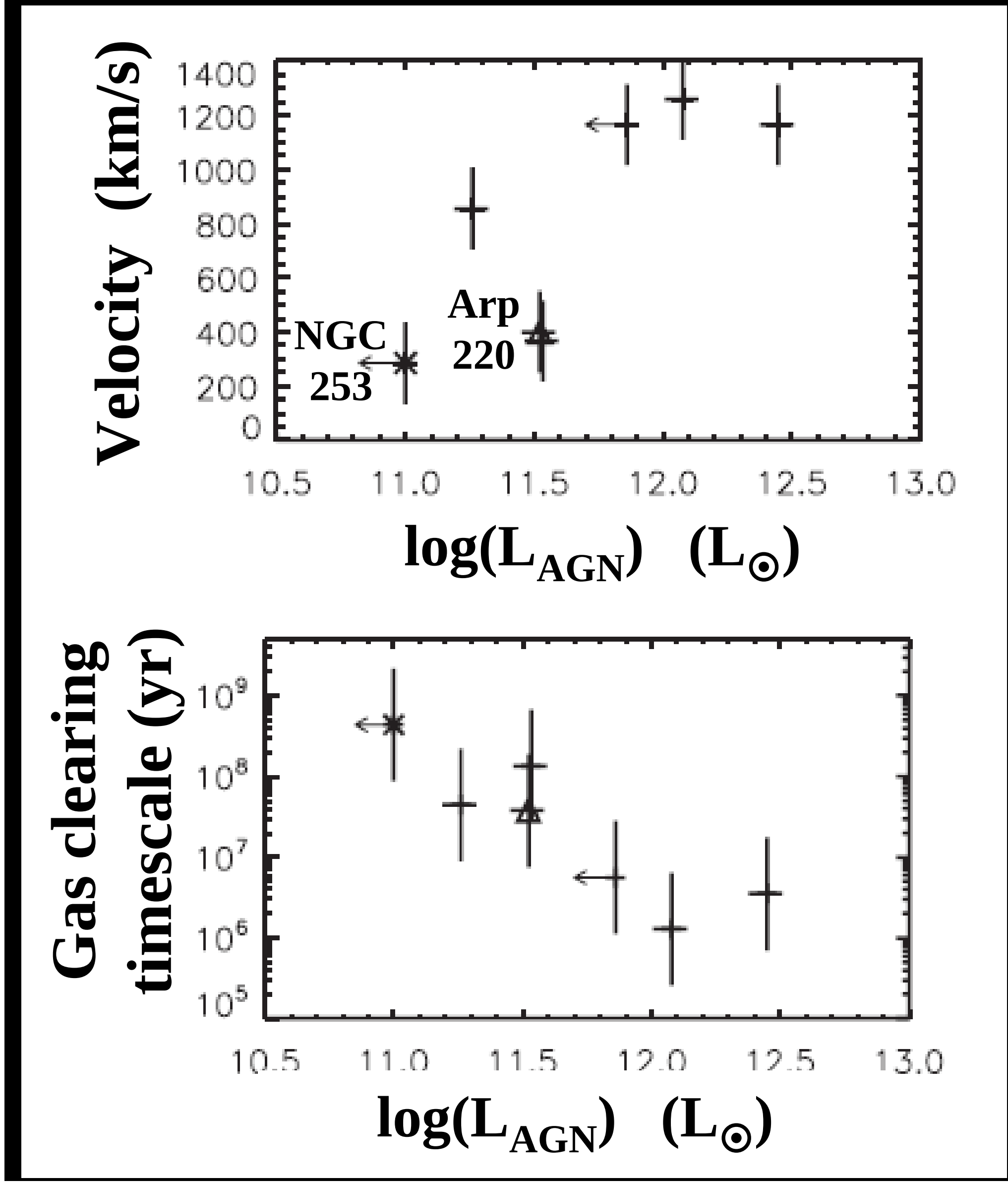
AGN-driven Outflow Suppressing Star-Formation?





Fischer et al., 2010; Sturm et al., 2011

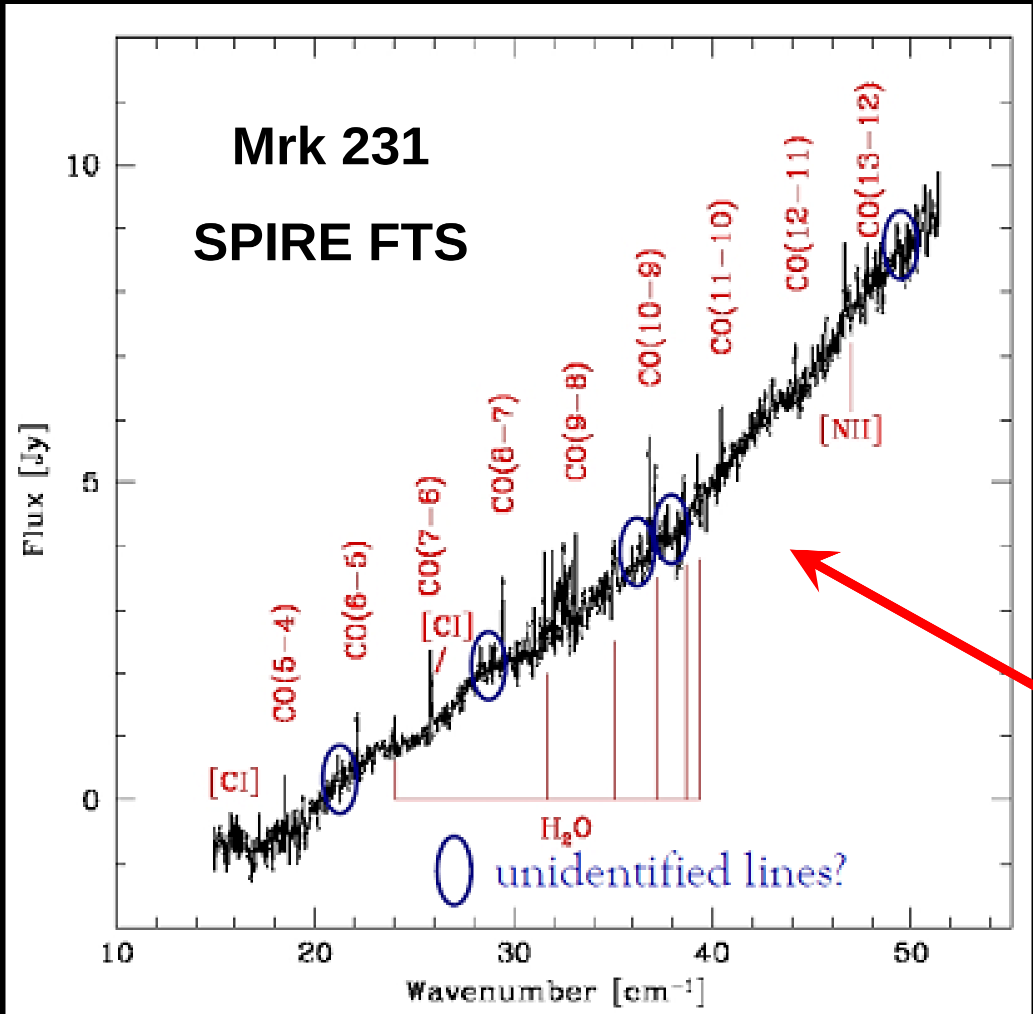
AGN-driven Outflow Suppressing Star-Formation?

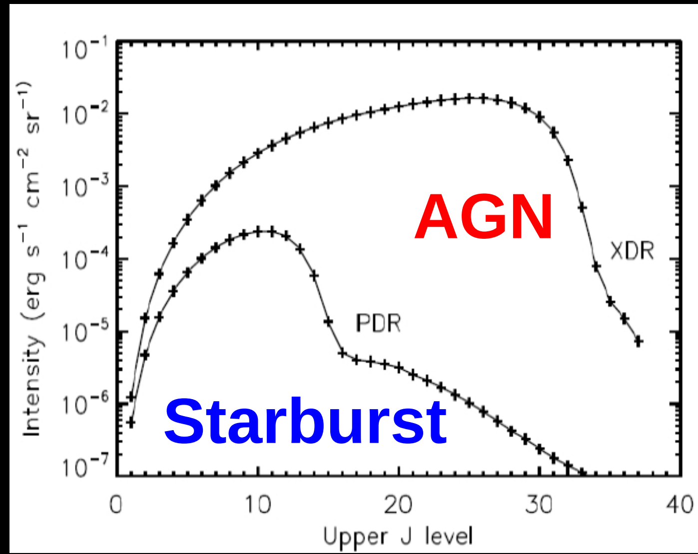


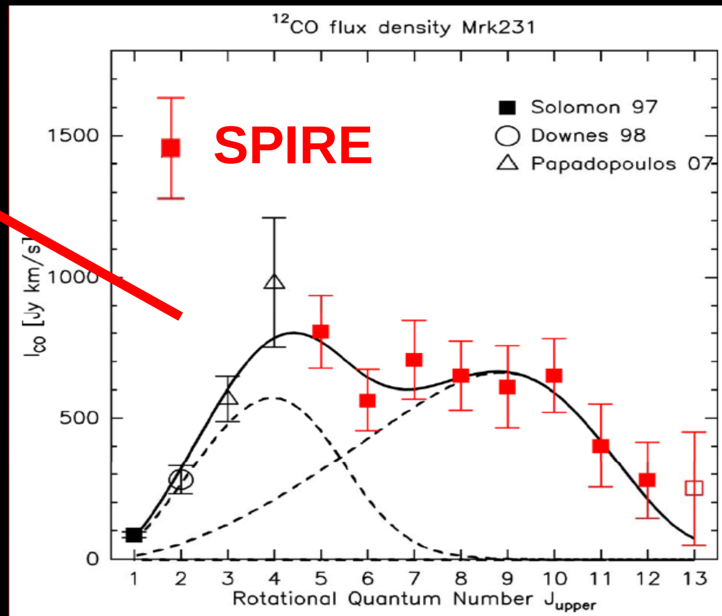
- **Outflow velocities ~ 1000 km s^{-1}**
  - **Too high to be supernova-driven**
- **Mass loss rates up to 1200 $M_{\odot}$/yr**
- **SB-dominated galaxies:**
  - **$\dot{M}$ ~ SFR**
- **AGN-dominated:**
  - **$\dot{M}$ ~ (4 - 20) x SFR**
- **Gas reservoir clearing time**
  - **10^6 – 10^8 yrs**
  - **Decreasing with increasing L_{AGN}**

Sturm et al., 2011

HerCULES
Herschel Comprehensive (U)LIRG Emission Survey

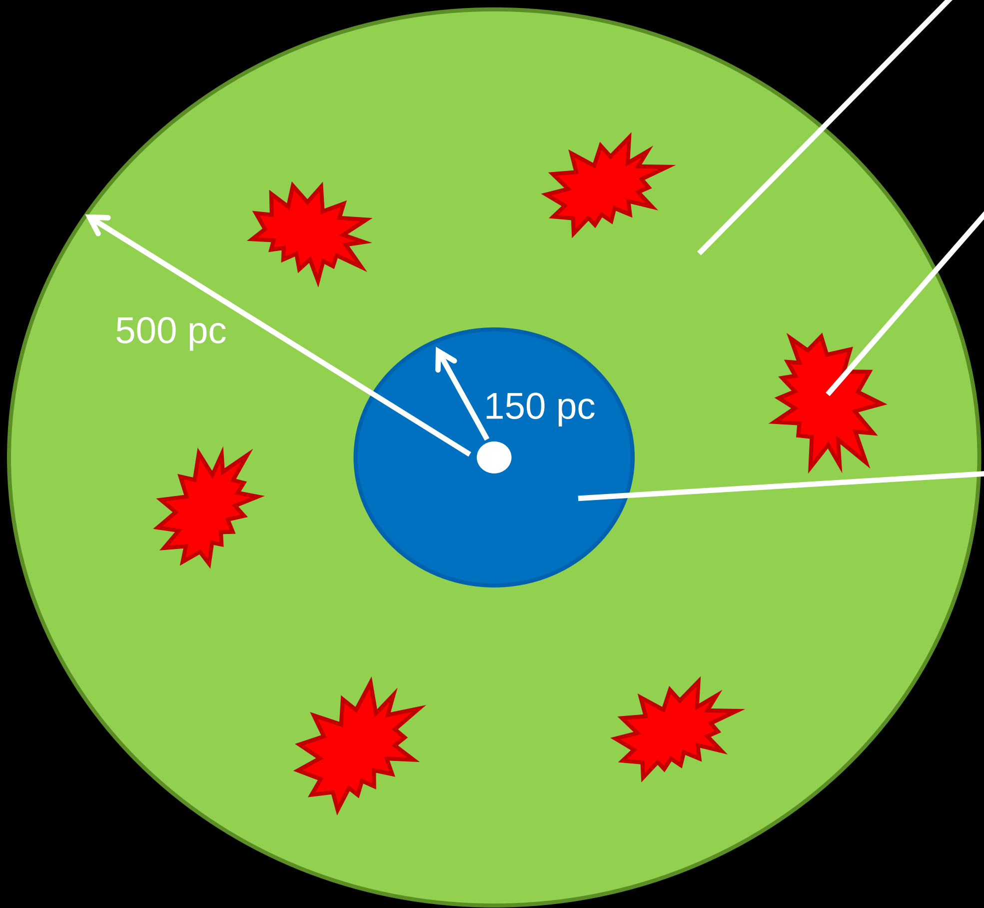




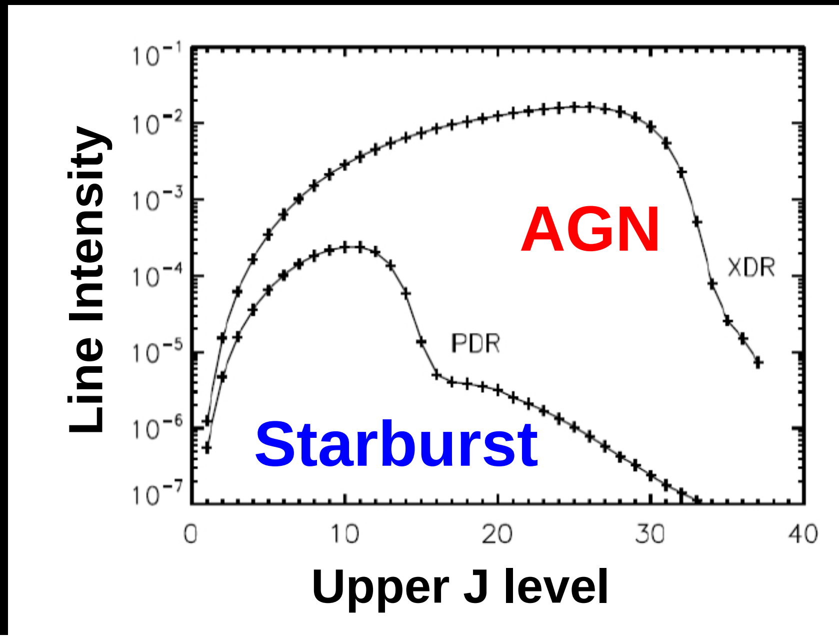


CO rotational ladder provides quantitative separation of starburst and AGN energy input

Model of Mrk 231



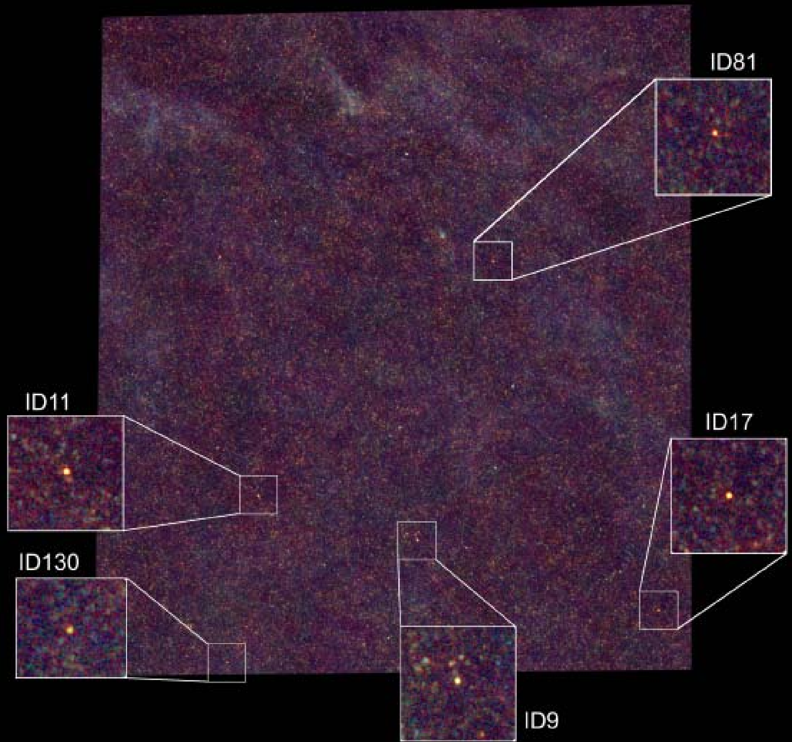
- PDR 1: $n=10^{3.5}$, $G_0=10^2$
  - Large-scale molecular gas
  - Low-J CO lines
- PDR 2: $n=10^5$, $G_0=10^{3.5}$
  - Small, dense SF clumps
  - → mid-J CO lines
- XDR: $n=10^{4.2}$, $F_X=28$
  - Circum-nuclear disk
  - High-J CO, OH^+, $H2O^+$

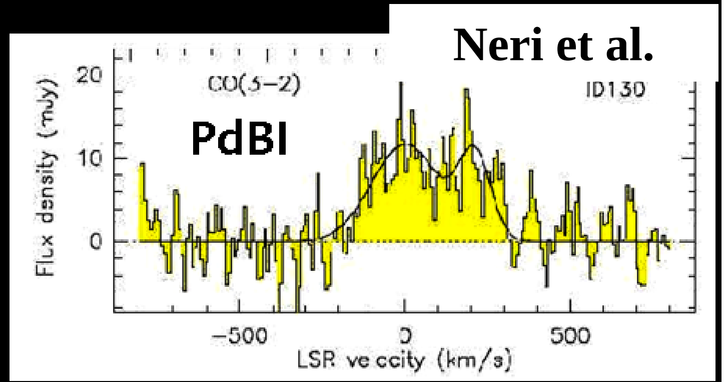


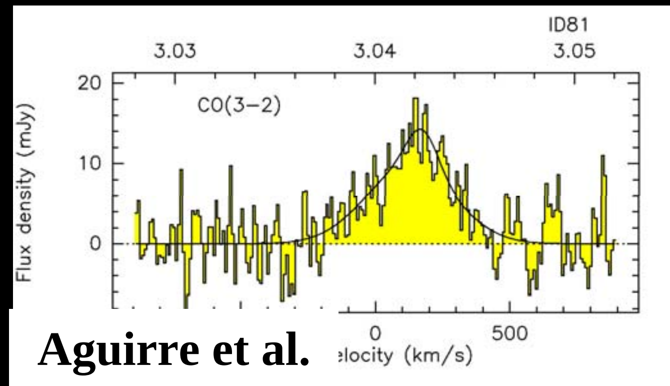
HerCULES
Herschel Comprehensive (U)LIRG Emission Survey

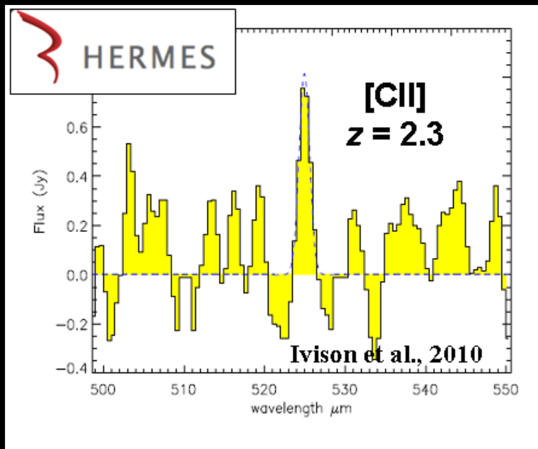
van der Werf et al., 2010

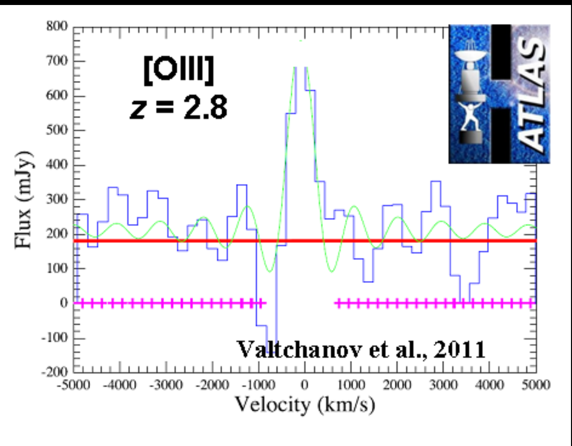
ATLAS Lenses with CO Redshifts







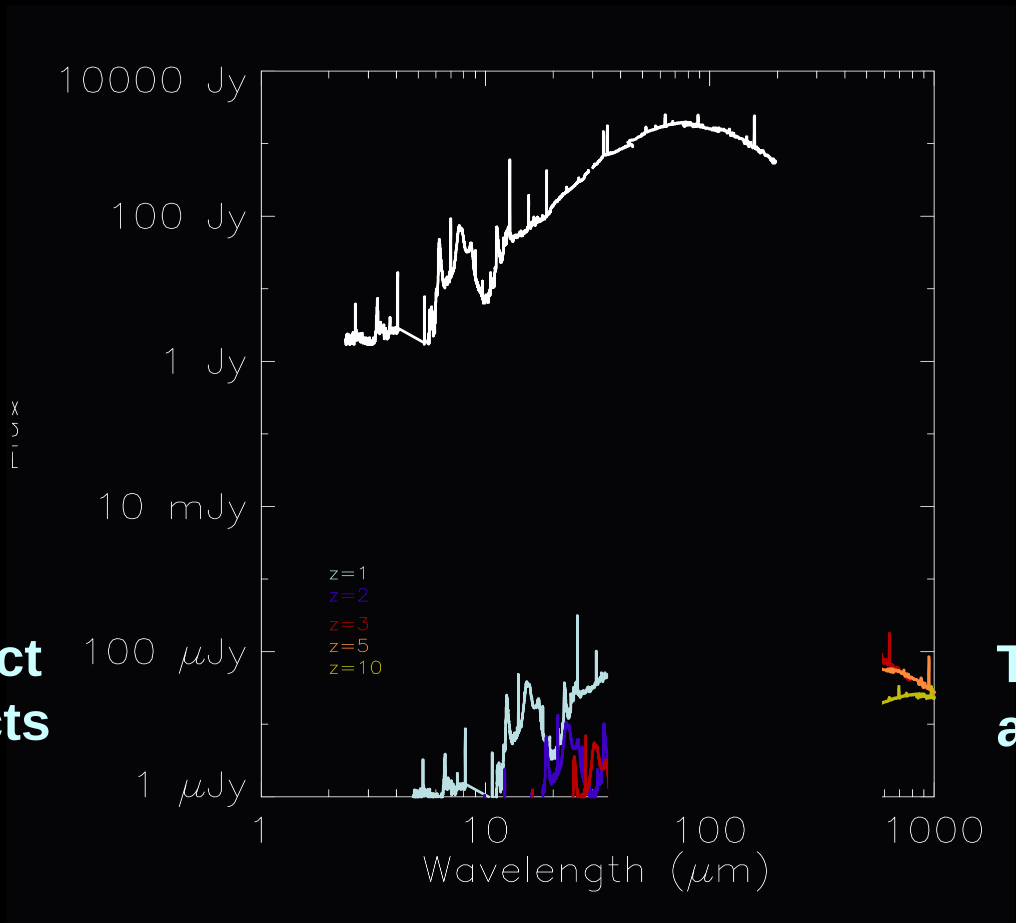




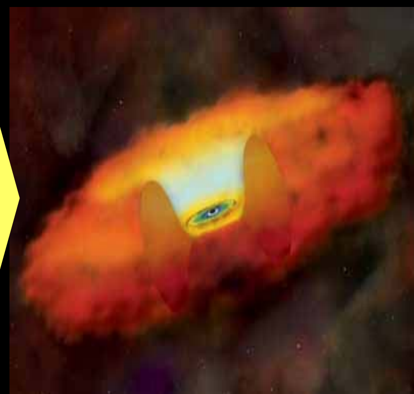
- $L_{[CII]}/L_{bol}$ higher than in local ULIRGS
- SFRsimilar to that of local ULIRGs but distributed over a larger volume

Spectroscopy of High Redshift Galaxies

Herschel sees local/exotic



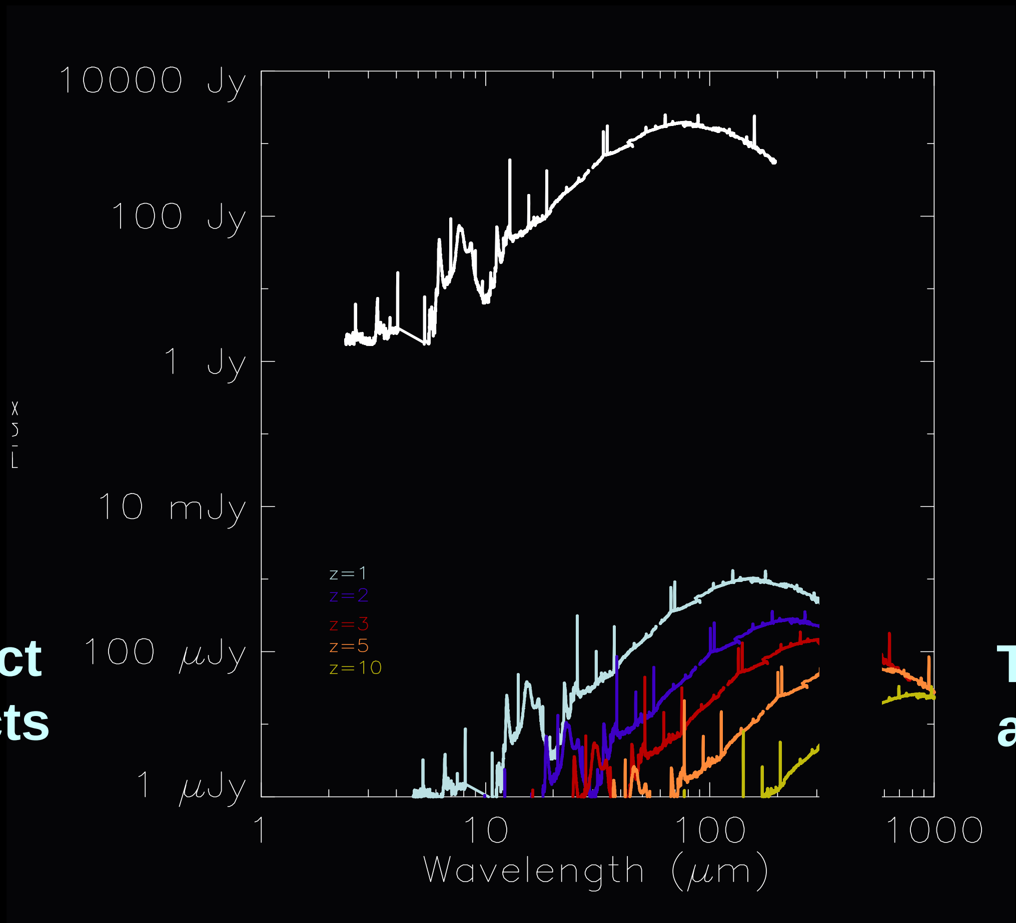
Need to detect distant objects



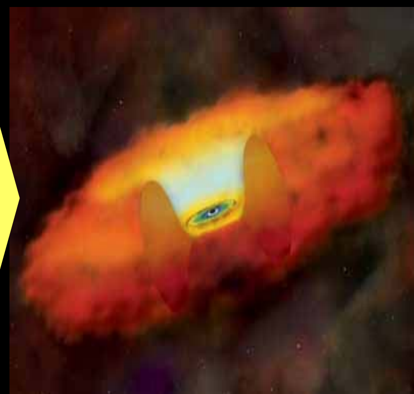
To reveal physics and chemistry

Spectroscopy of High Redshift Galaxies

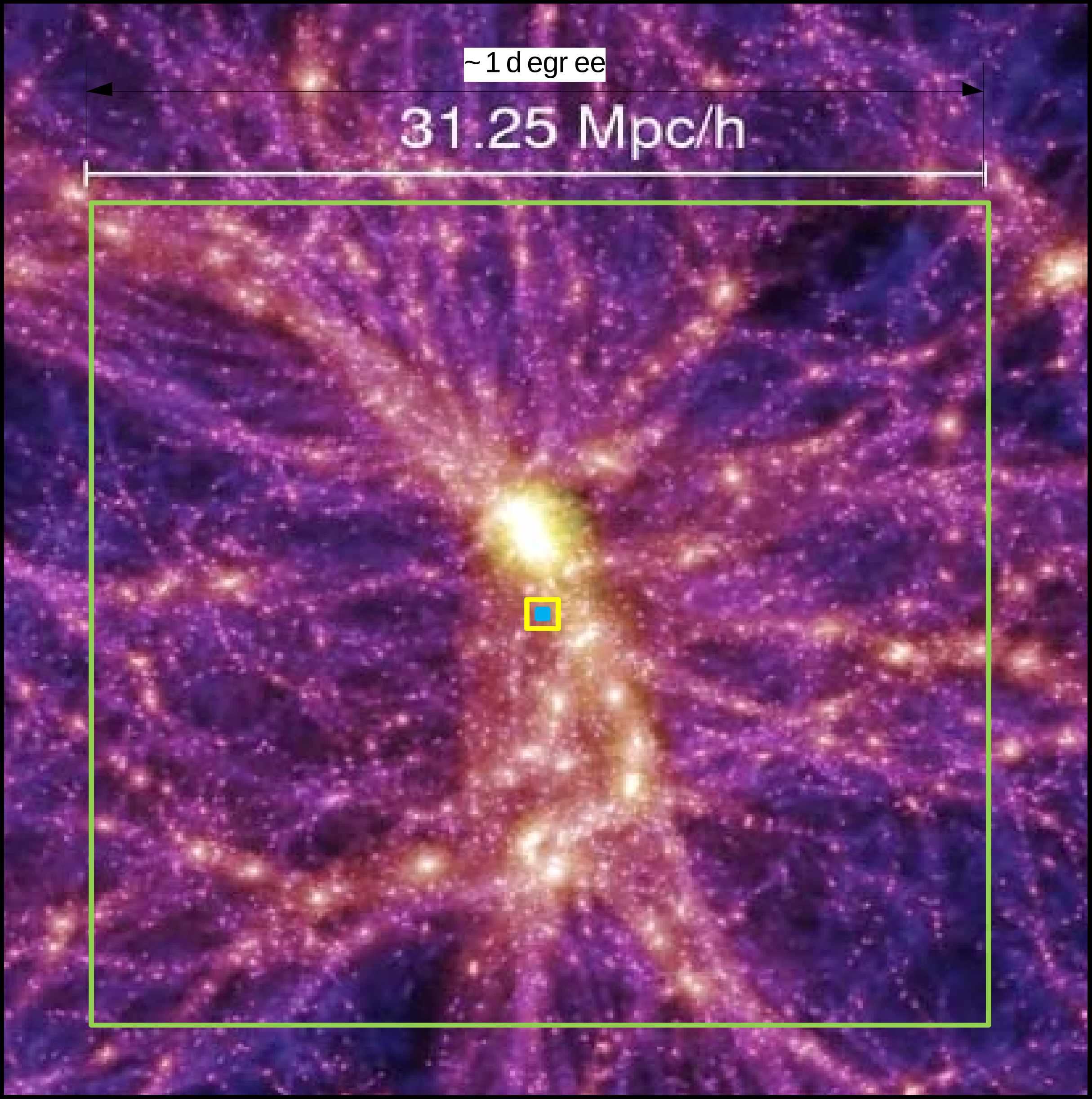
Herschel sees local/exotic



Need to detect distant objects



To reveal physics and chemistry



SPICA ~ 1000-hr Spectral Survey

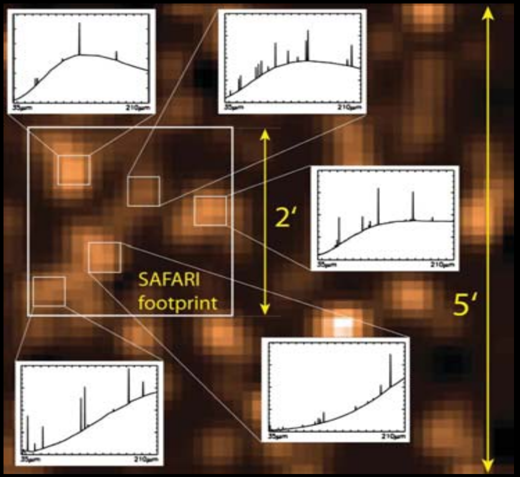
PACS would need ~ same time just for one pointing

Simulated ~ 500 hrs survey of 0.5 sq. deg.
Numbers of detected sources: 5-σ (3-σ)

Full spectra of 7- 10 sources/field

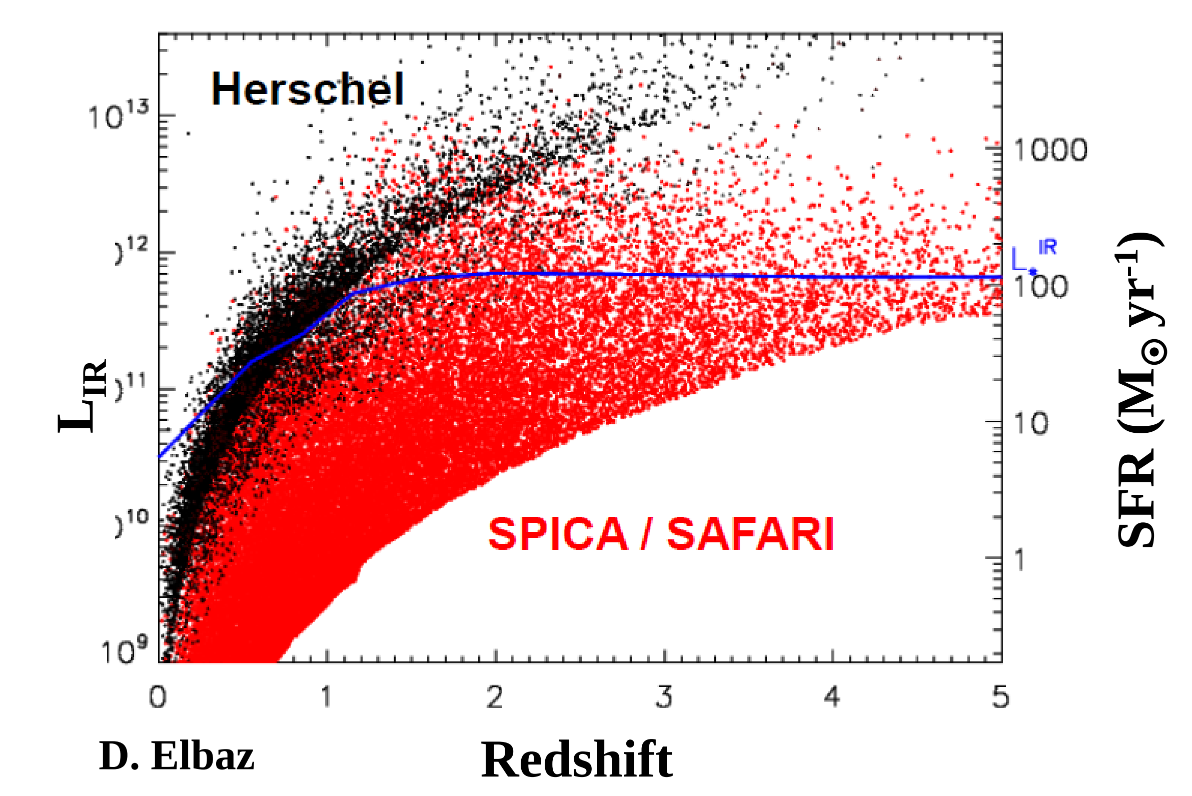
Line/Model	Franceschini et al (2010)
PAH(11.25μm)	715 (1277)
[NeII] 12.81μm	228 (507)
[NeV] 14.32 μm	60.7 (207)
[NeIII] 15.55μm	113 (423)
[SIII] 18.71μm	55.8 (177)
[NeV] 24.32μm	37.8 (177)
[OIV] 25.89μm	232 (631)
[SIII] 33.48μm	1753 (3307)
[SiII] 34.81μm	2713 (4738)
[OIII] 51.81μm	2983 (5076)
[NIII] 57.32μm	567 (1613)
[OI] 63.18μm	5611 (8905)
[OIII] 88.35μm	4274 (6682)

Spinoglio et al., 2011



- **Key diagnostic lines**
- **Multiple lines (35 – 210 μm) and multiple sources in a single observation**
- **ISM physics and 3-D clustering out to z ~ 3**

SAFARI Deep Photometric Surveys



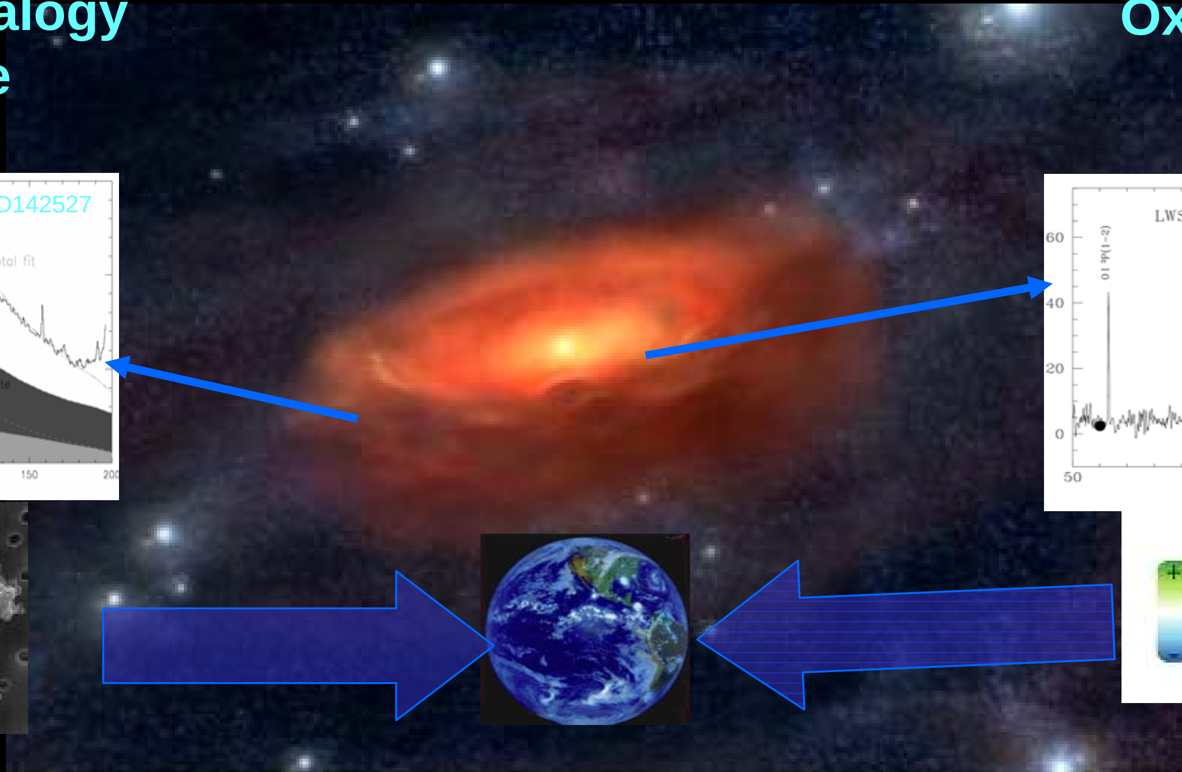
- High mapping speed
  ⇒ large area confusion limited 70-μm survey
- Resolve 90% if CIB over 80% of Hubble time

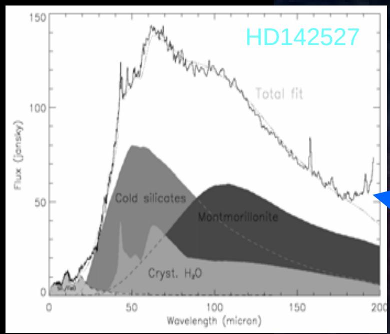
- Detection of galaxies with modest luminosity/SFR
  - ~ 10^{10} $L_\odot$ - comparable UV and FIR
  - Minimal contribution to CIB but responsible for most of the optical background

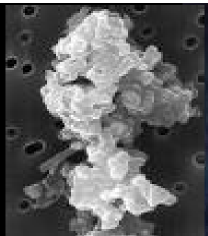
Dust, Ice, and Gas in Protplanetary Systems

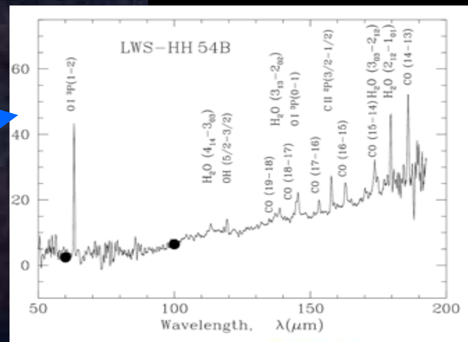
Dust mineralogy and ice

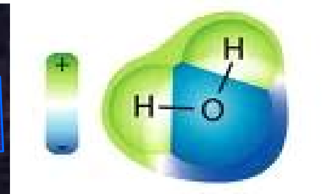
Oxygen chemistry and water





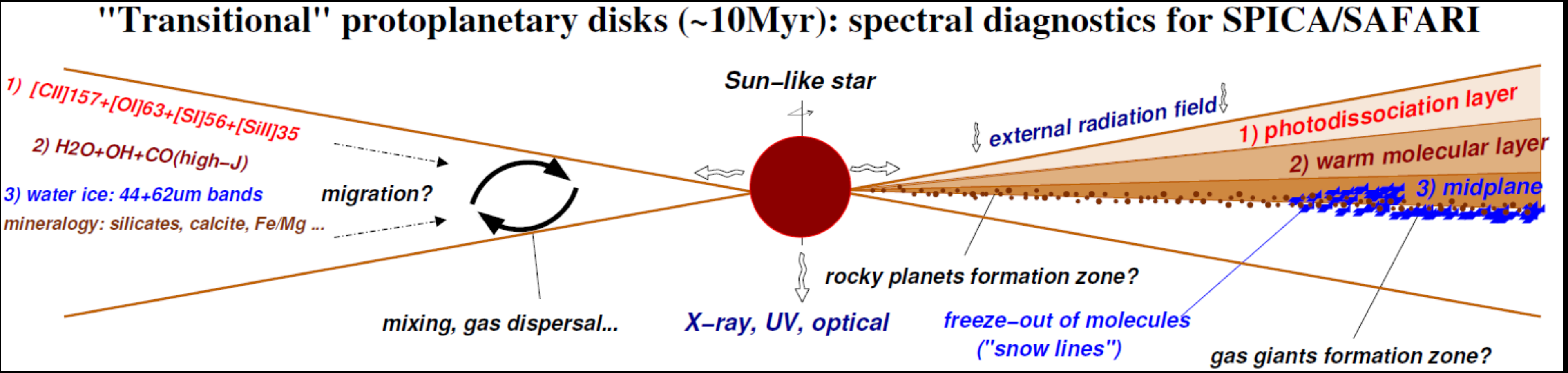






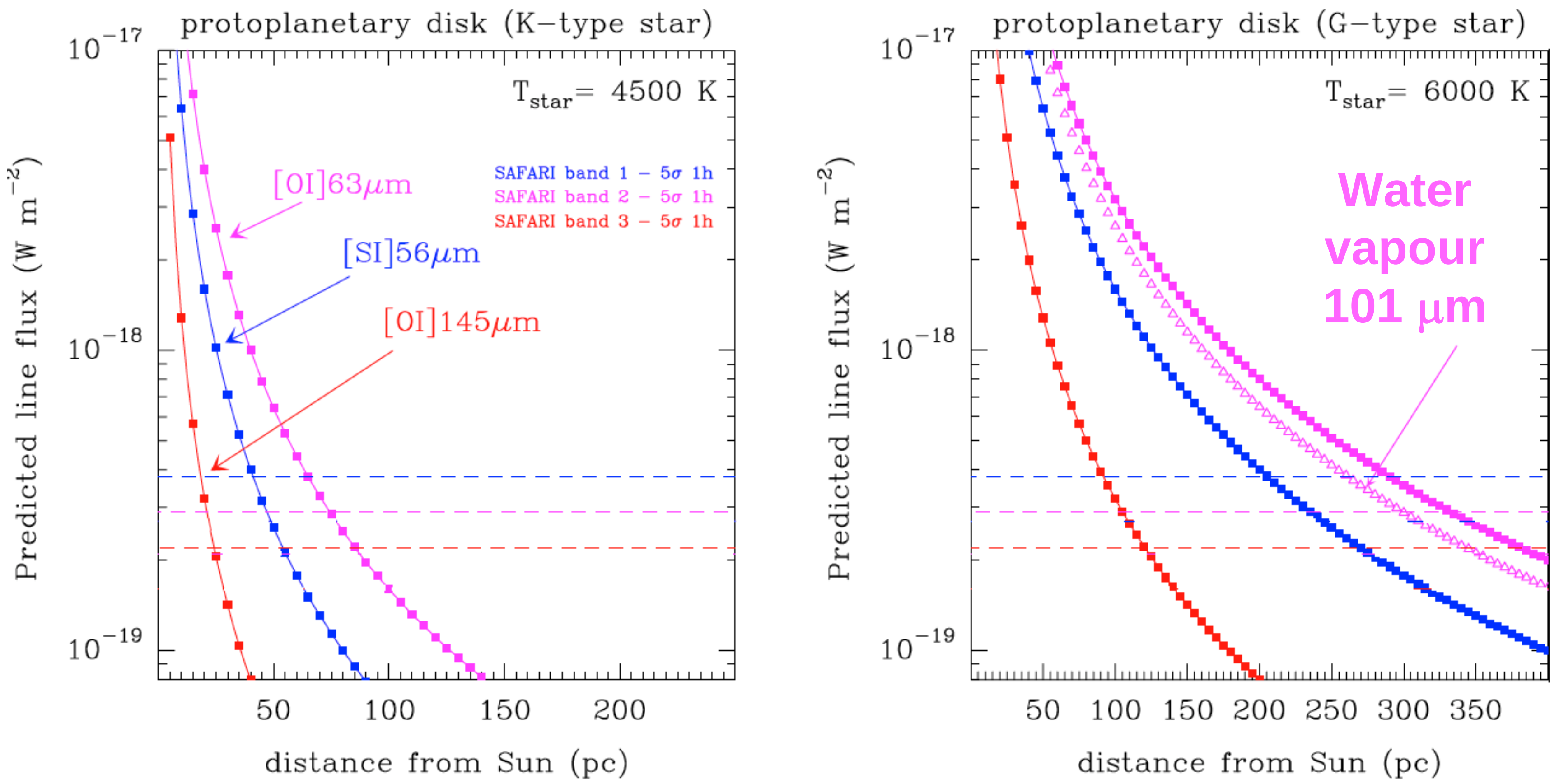
Dust, Ice, and Gas in Protplanetary Systems

Testing planet formation and evolution theories



- Photodissociation layer
  - Major atomic FIR cooling lines (O, C, S, Si etc.)
- Warm molecular layer
  - SAFARI: OI, H_2O, OH, high-J CO
  - MIR spectrometer: PAH, H_2
- Midplane
  - Ice features, dust mineralogy
- Herschel limited by wavelength coverage and sensitivity limit of ~ few x 10^{-18} W m^{-2} (only youngest, brightest – tip of the iceberg)

Tracing Gas in Transitional Disks



Models of Gorti & Hollenbach (2004); Gas masses of 0.3 M_{Earth}

- **Key line diagnostics: [OI] 63,145; [CII] 158, [SiII] 34, H_2O**
- **Detect out to > 100 pc - cover many SF regions, range of disk ages…**

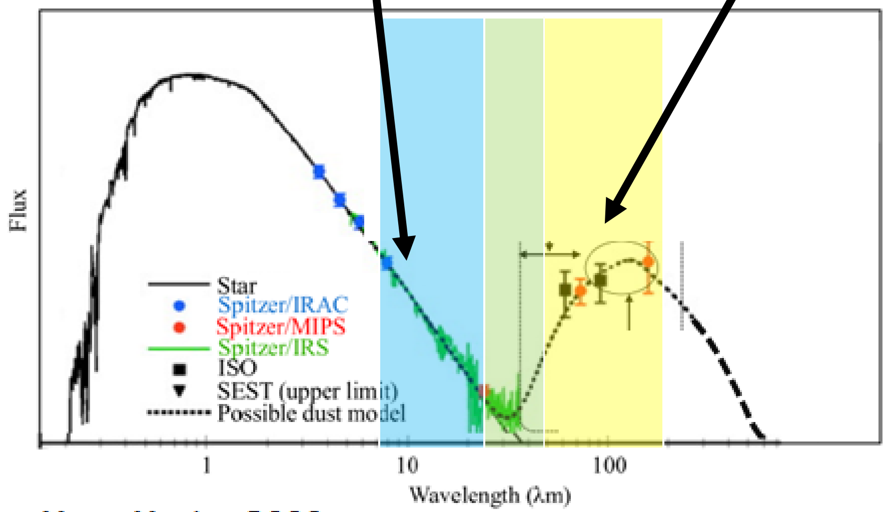
Debris Disks

How typical is the solar system?

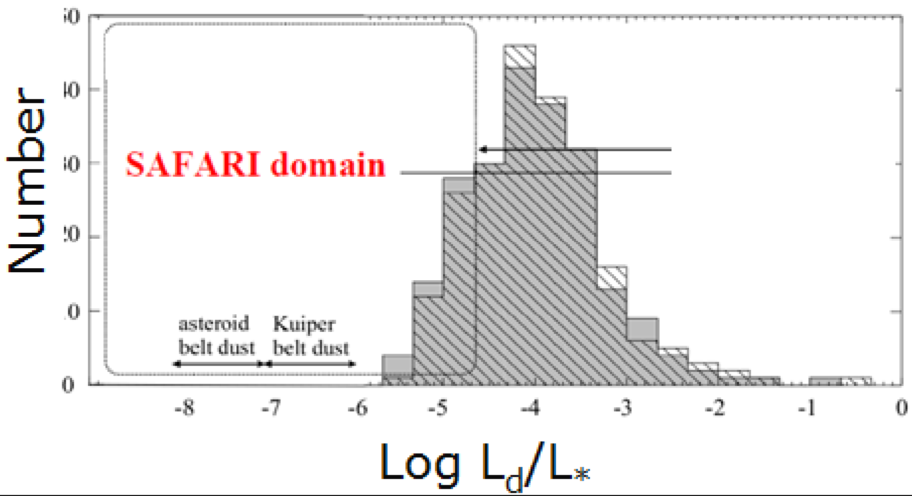
Depends on inner disk radius

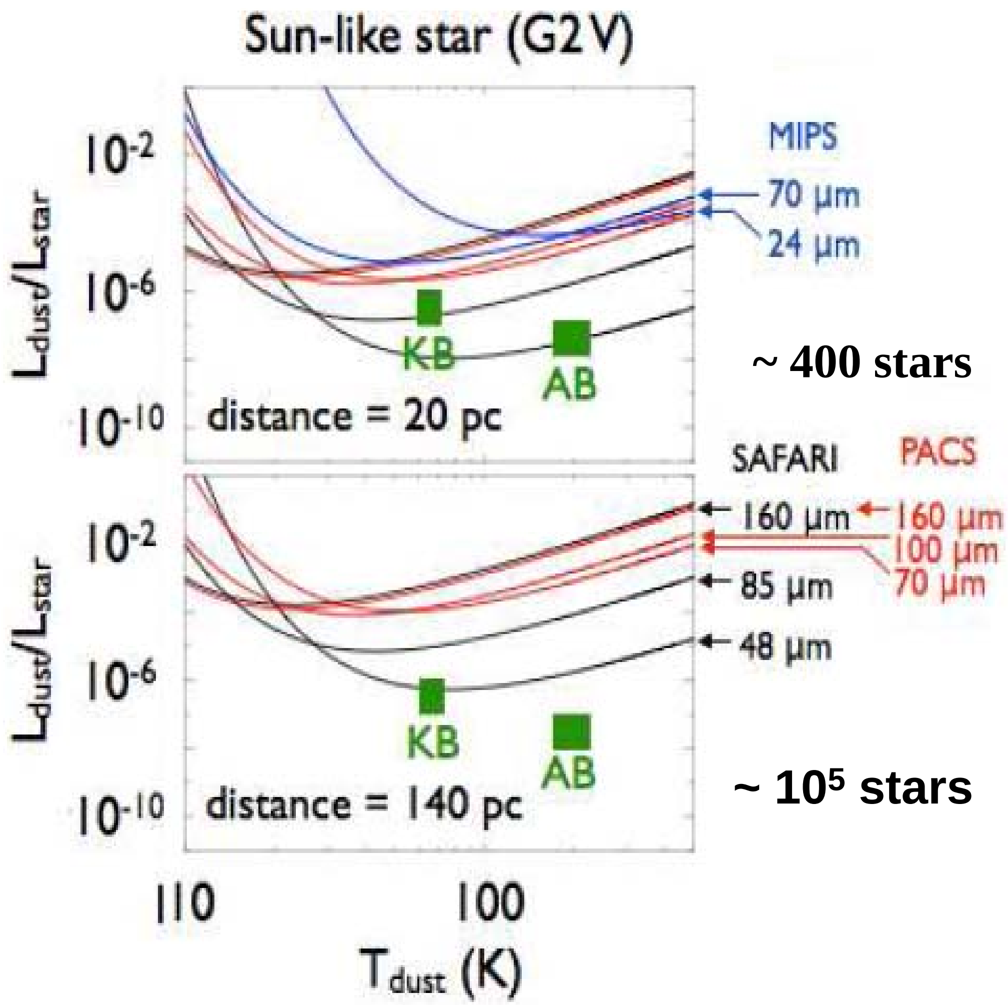
Depends on outer disk radius and amount of cold dust

Adapted from Meyer et al. 2008



Moro-Martin 2009

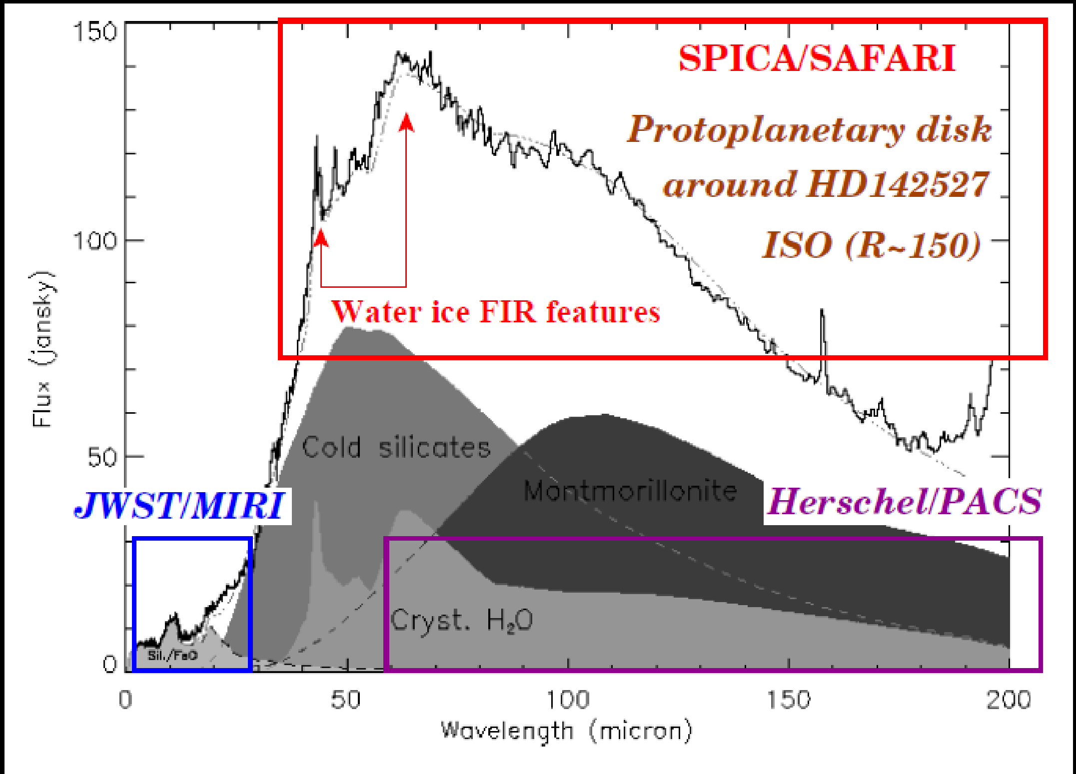


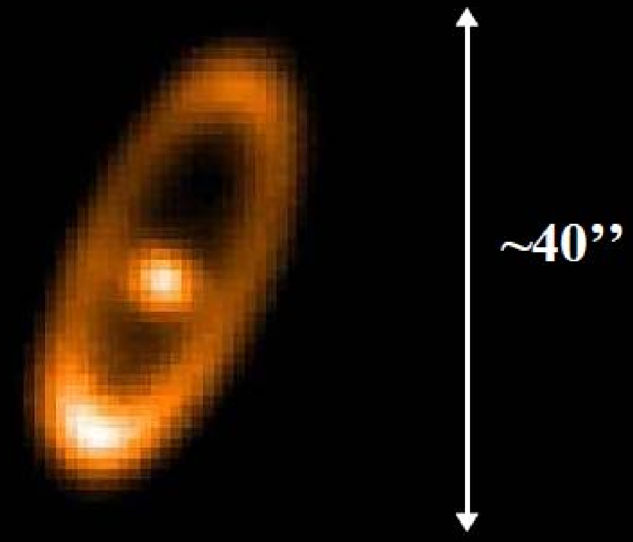


~ 400 stars

~ 10^5 stars

Water Ice



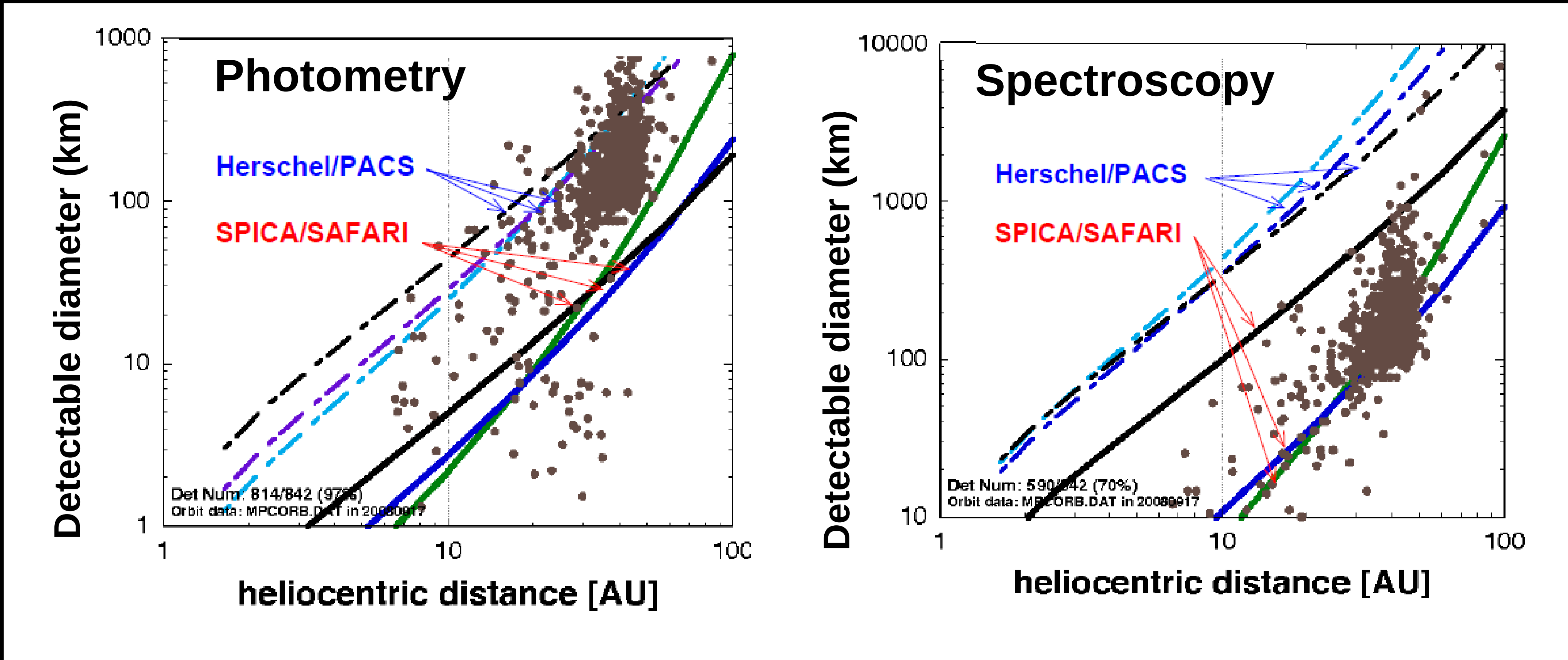


Fomalhaut (Herschel/PACS 70um)

- Key constituent of protoplanetary and debris disks
- 44 μm band: crystalline and amorphous
- 62 μm band: crystalline only
- Detect presence of ice and trace formation history
- Resolve snow-line for nearby objects

Our Own Debris Disc

Studying known KBOs object by object



- Size, albedo, surface composition and condition

Outline SPICA Schedule

- Risk Mitigation Phase (with Industry): Sep. 2011 - Sep. 2012
  - Thermal
  - EMC
  - Pointing
- Request for Industry proposals for phase B2/C/D: End 2012
- Phase-up (Confirmation) Review: early-mid 2013 = T_o
- PDR T_o + 1 yr
- STM delivery T_o + 2 yr
- CDR T_o + 4 yr
- FM delivery T_o + 6 yr
- Launch T_o + 9 yr ≈ 2022

Conclusions/Recommendations

- Assume that SPICA will happen and will be as influential as Herschel
- Take SAFARI's science capabilities into account
- In particular:
  - It will do multi-object extragalactic spectroscopy in the FIR (with multiple lines and continuum)
  - It will probe the dust, ice and atomic material in protoplanetary disks
- UK extragalactic and galactic science priorities need SAFARI
  - How do its scientific capabilities overlap with or complement what JCMT or CCAT can do?
- Make sure that the UK doesn't get left out
  - Lack of influence over the mission
  - Exclusion from legacy programme definition and exploitation
- Bear in mind that UK involvement in SPICA is free to STFC, and that UKSA looks to STFC for scientific advice