Cosmic Obscuration: A Multi-Wavelength Perspective

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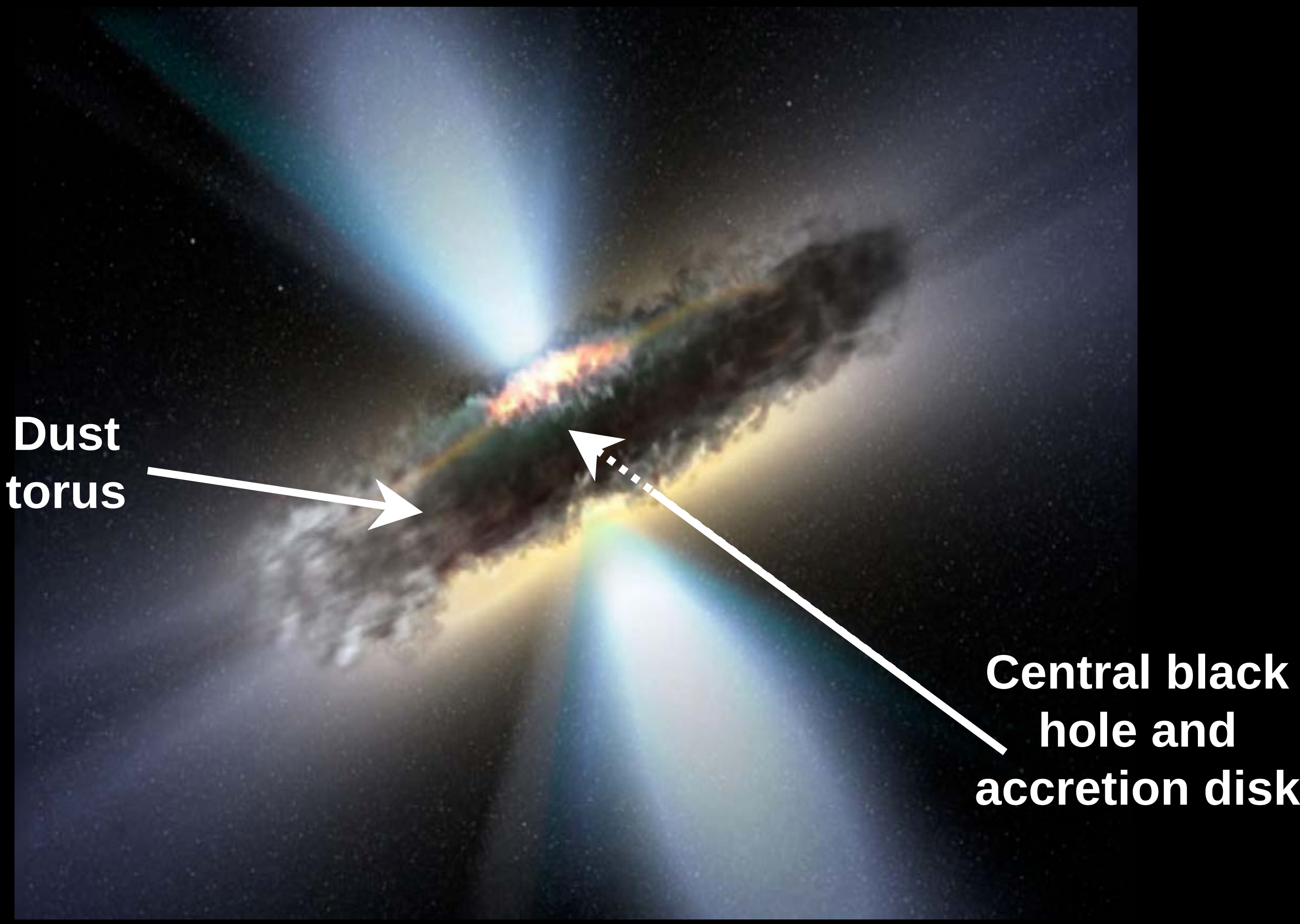
Heavily Obscured Active Galactic Nuclei



What is NOT covered in this talk…

- history of FIR surveys: IRAS, AKARI and in the future WISE (Mid-IR)
- the great leap forward afforded by ISO and SPITZER in FIR diagnostics (amongst other things!)
- SOFIA (which fills the wavelength gap between MIRI and Herschel)
- the JWST/MIRI (the “ELT” of the MIR)
- future missions that are not yet in well defined within a programme’s roadmap and funding plans (this is of course somewhat subjective…)

What *is* covered in this talk
The Current Landscape…

- Herschel to be launched within ~ 6 months?
- ESA’s Cosmic Vision – down selection of missions for study (SPICA relevant here)
- Complementary facilities (for study of obscured objects) ground-based and in Space

Complementary Ground-Based Facilities in context of Obscured Exgal. Sources

- **ALMA** – crucially important (already emphasised in many talks…)
- Deep all-sky near IR surveys, **UKDISS** (North), **VISTA** (South) – sources lists for FIR
- Sub-mm surveys – targeted regions and all-sky, **APEX/LABOCA, JCMT/SCUBA-2**. Needed for SEDs and source lists for FIR follow-up
- Radio Interferometry (and ALMA) – for high precision positions to help remove confusion (poor PSF in the FIR and sub-mm) especially important or highly obscured objects. **EVLA** in near future, but **LOFAR and e-Merlin**, now….

Complementary Space Missions in context of Obscured Exgal. Sources

X-ray missions that will penetrate the gas/dust

- **Spectrum RG** , Russian/German X-ray observatory (2011/12) – deep all-sky hard X-ray survey
- **NEXT**, Japanese cryo and hard X-rays (2013/14)
- “Niche” smaller missions **HXMT** (China), **Simbol-X** (France/Italy), **SVOM** (French/Chinese)
- **XEUS** – ESA’s major X-ray observatory (ELT of X-ray astronomy), NASA’s plan is Con-X. XEUS is part of Cosmic Vision, but timescale is uncertain 2017+

Herschel

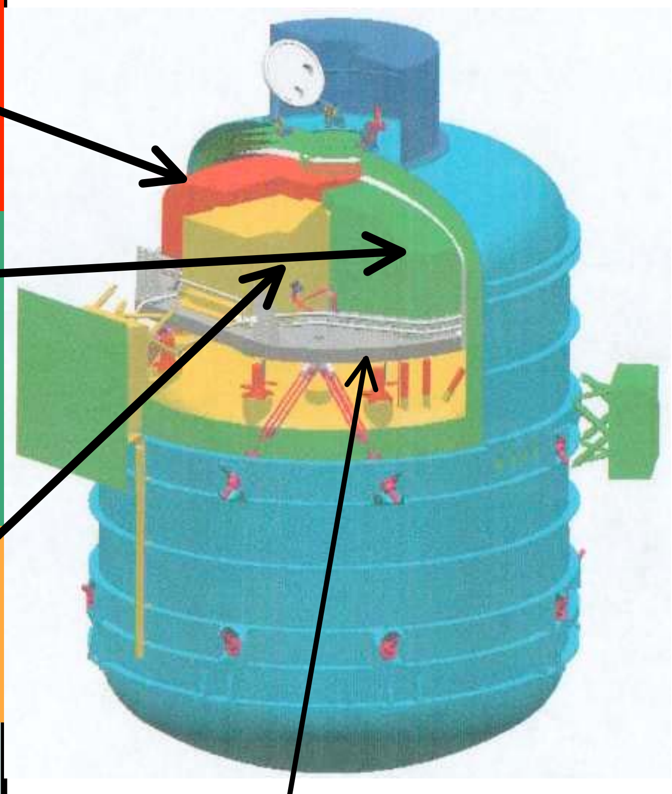
Photometry and Spectroscopy between 55 and 670 μm

- **PACS (57 - 210 μm)**
  - **Imaging photometer**
  - **Imaging grating spectrometer**
    - **Lines: $\lambda/\Delta\lambda \sim 1500$**
- **SPIRE (200 - 670 μm)**
  - **Imaging photometer**
  - **Imaging Fourier transform spectrometer**
    - **Survey: $\lambda/\Delta\lambda = 20\text{-}1000$**

HIFI (157- 212 μm and 240 - 625 μm)

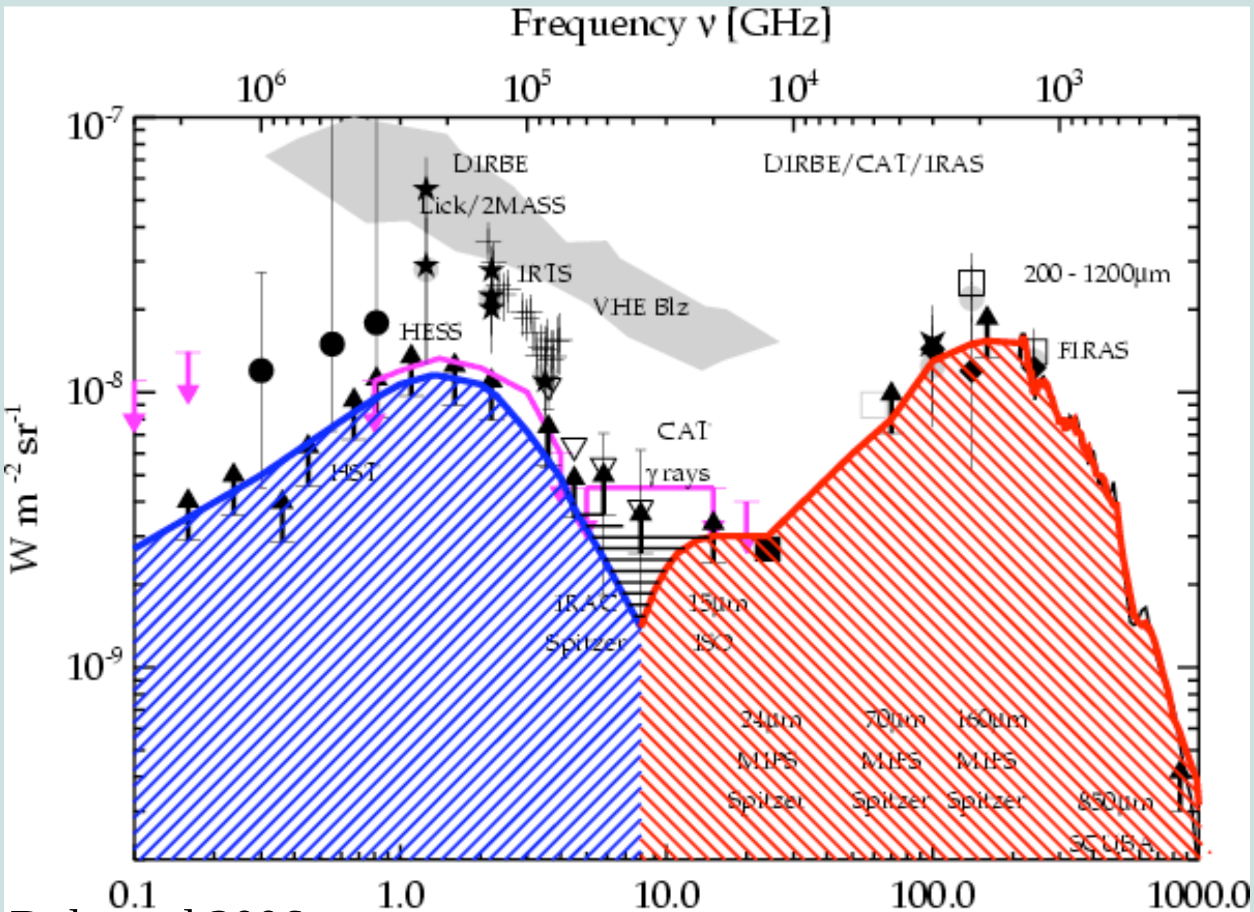
Non-imaging heterodyne receiver

- **Lines: $\lambda/\Delta\lambda = 10^4 - 10^6$**



Herschel optical bench

The Importance of FIR Surveys



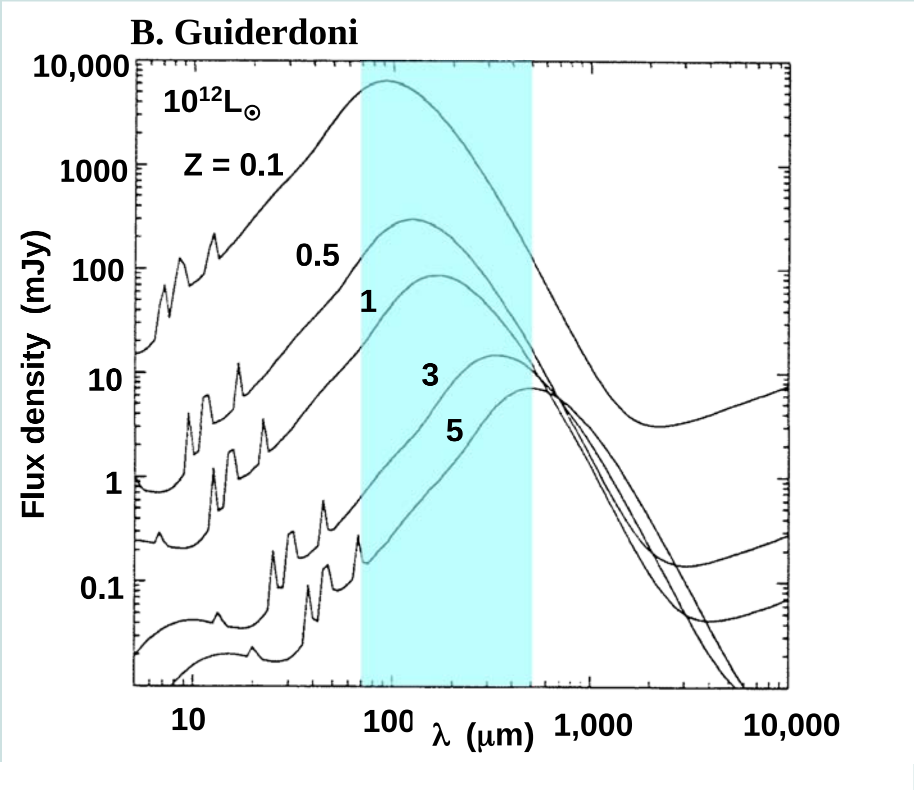
Dole et al 2006

SCUBA sampled the z>2 Universe
Spitzer sampled the z<1
Herschel will bridge the redshift gap

Herschel Multi-Band Extragalactic Surveys

- 1500 hrs (Instrument teams)
  + perhaps 1500 hrs Open Time

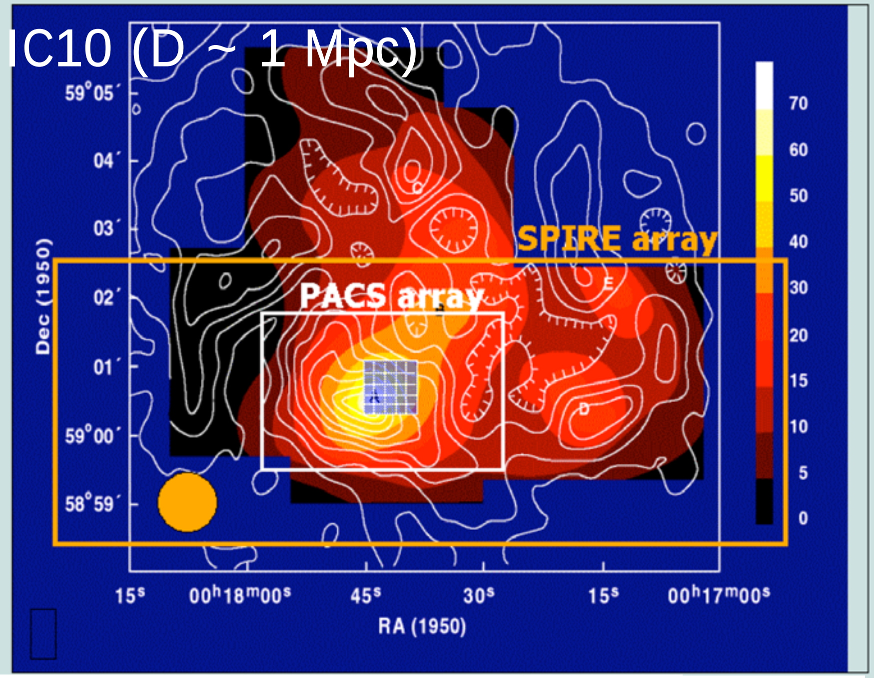
- History of energy production
- Structure formation
- Cluster evolution
- AGN-starburst connection
- Planck foregrounds

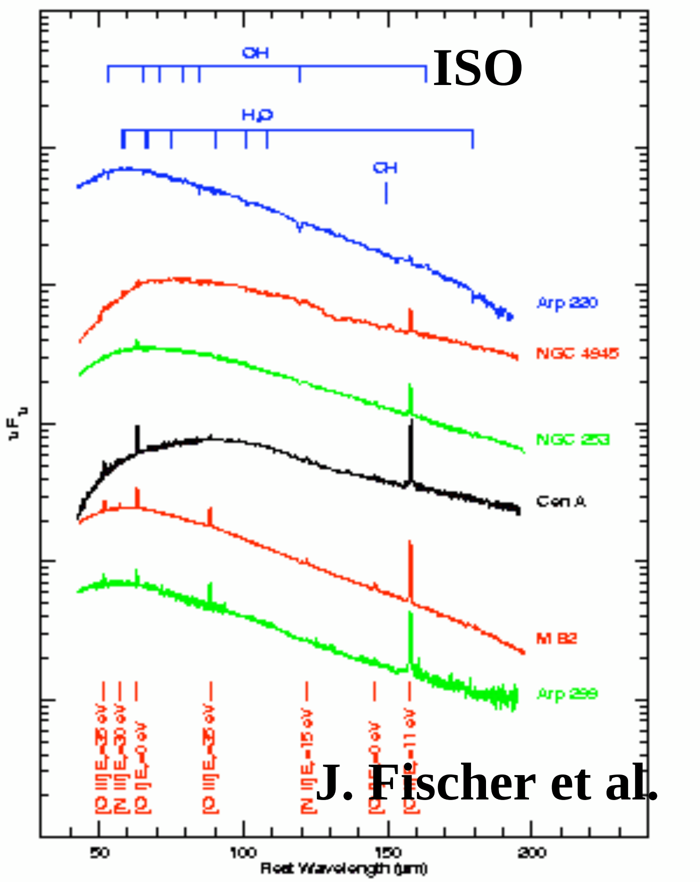


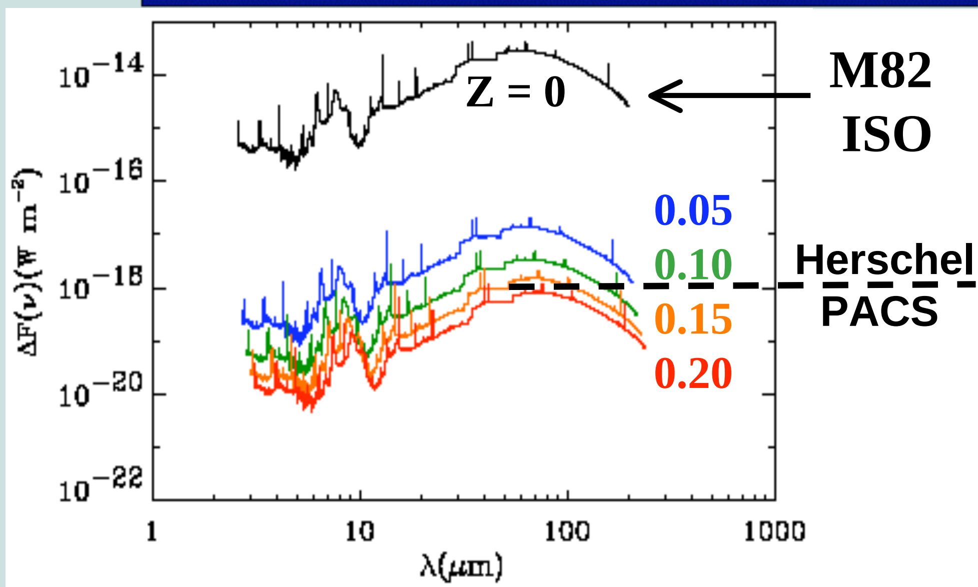
- Follow up spectroscopy → redshifts, physics and chemical evolution

Photometry and Spectroscopy of Nearby Galaxies

- Detailed SEDs and dust properties
- Chemistry, metallicity evolution
- AGN vs. starburst
- Testing unified schemes
- Templates for high-redshift studies







Herschel Survey Scientific Goals

Provide a legacy study of the FIR galaxy populations over the wavelengths at which the galaxies and CIRB peak

Measure the bolometric luminosity function of galaxies at redshifts $z<3$ in a range of environments

Characterise the contribution of different redshifts, luminosities and environments to the SF history

Study the galaxy formation below the Herschel confusion limit (via stacking techniques)

Combine all this with surveys from the X-Rays to the radio to understand the overall picture of FIR galaxy formation and evolution

Herschel Exgal. Survey Design

Consists of six separate surveys of different depths and areas (“Wedding Cake”)

Designed to sample the highest luminosity objects in the wide & shallow tiers, and the fainter galaxies in the deep & narrow tiers

Uniformly sample the L,z plane of star-forming galaxies with sufficient statistics to z~2.5

Field selection driven by the confusion limit

Selected fields are among the best in the sky for multi-wavelength coverage

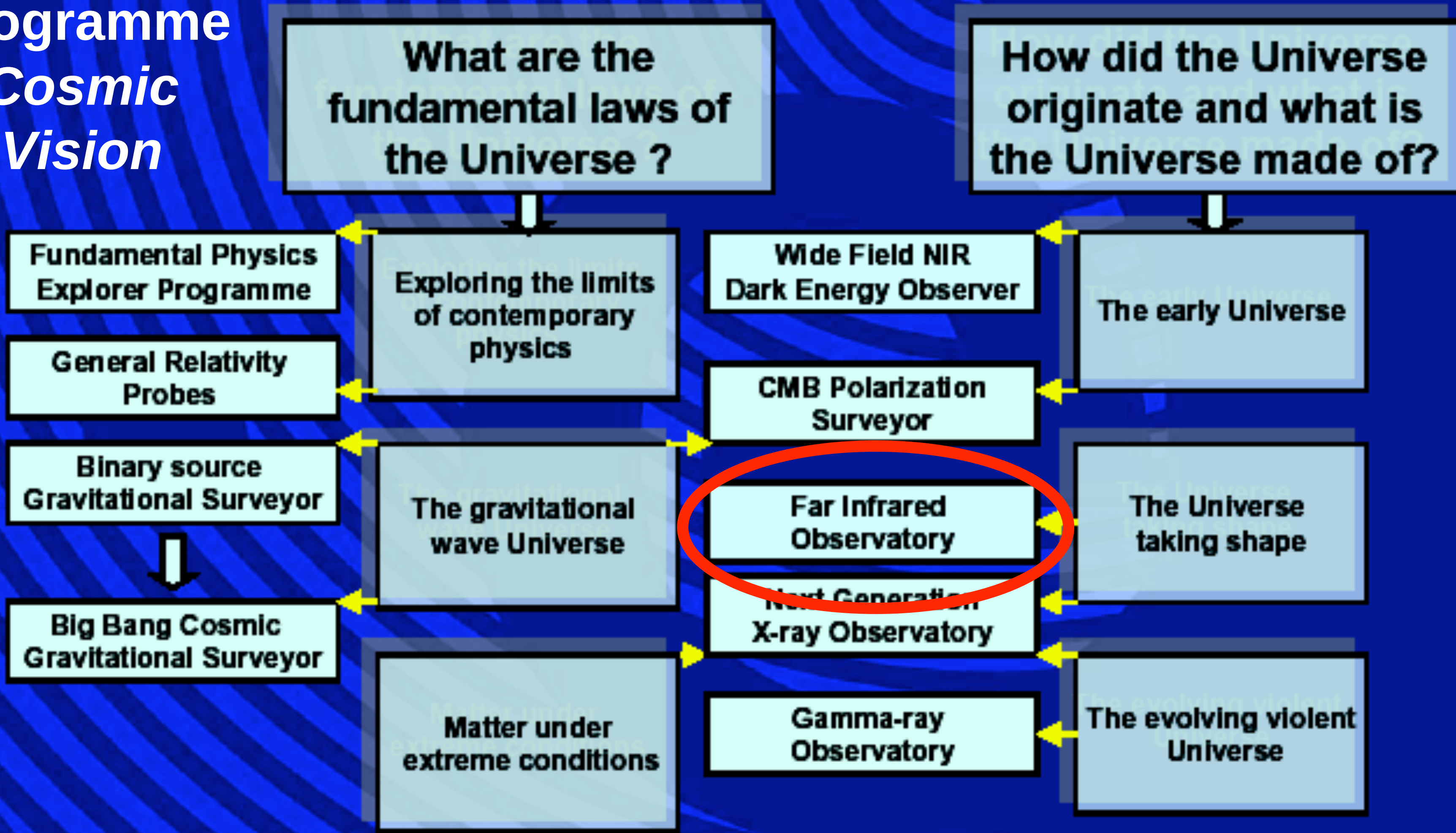
Now look to the further future…
ESA's Cosmic Vision Missions

- **DUNE/SPACE (M) = EUCLID:** *Study of dark energy using weak gravitational lensing/near-IR spectroscopy*
- **Cross-Scale (M):** *Space plasmas*
- **MARCO POLO (M):** *Near-earth orbit sample-and-return*
- **XEUS (L):** *X-ray observatory x 200 more sensitive than XMM-Newton*
- **Plato (M):** *Host stars of exoplanets/stellar seismology*
- **LAPLACE (L):** *Europa/Jupiter mission*
- **TanDEM (L):** *Titan+explorer*

+ **LISA and SPICA:** *missions of opportunity*

ESA Future Programme *Cosmic Vision*

From themes to proto-missions



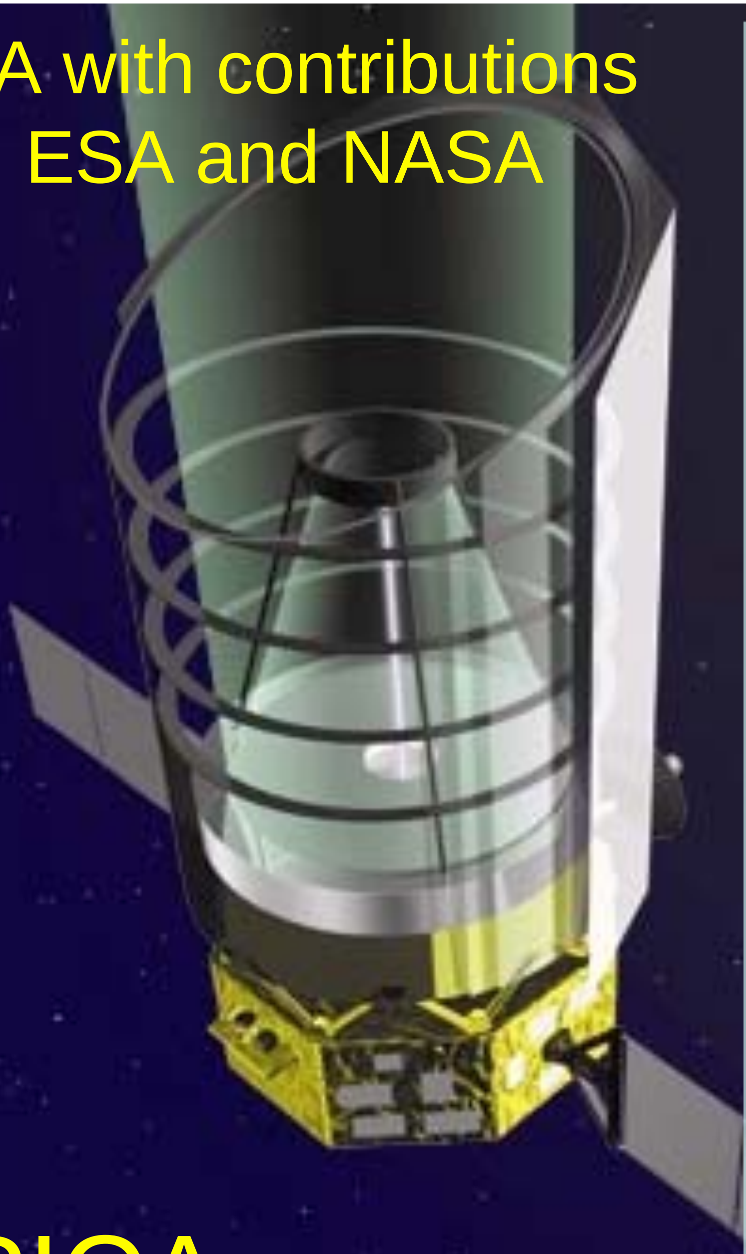
Cosmic Vision Presentation

Progress in FIR observatories

Progress in FIR space missions

- **IRAS – small mirror; short lifetime; first all sky mission**
- **ISO – small mirror; longer lifetime; sophisticated instrument suite for follow up to IRAS**
- **Spitzer – small mirror; clever cryo design – long lifetime and better detectors**
- **Akari – repeat of IRAS survey with higher sensitivity**
- **Herschel – large warm mirror; moderate lifetime; superior spatial and spectral resolution**
- **SPICA is the next logical step - large cold mirror; long lifetime; better detectors**

JAXA with contributions from ESA and NASA



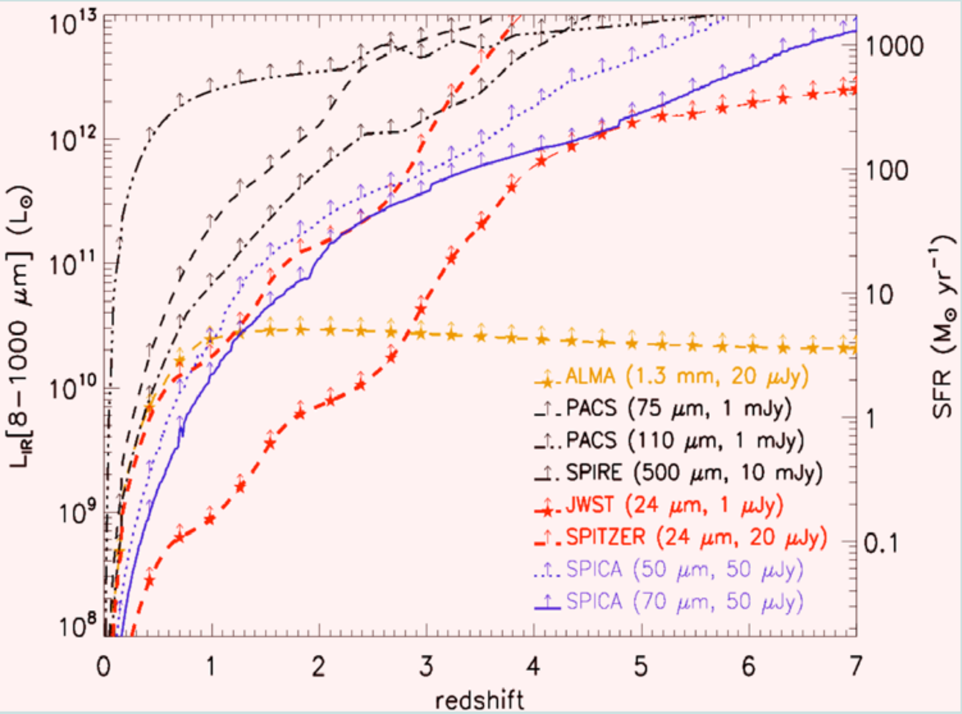
SPICA

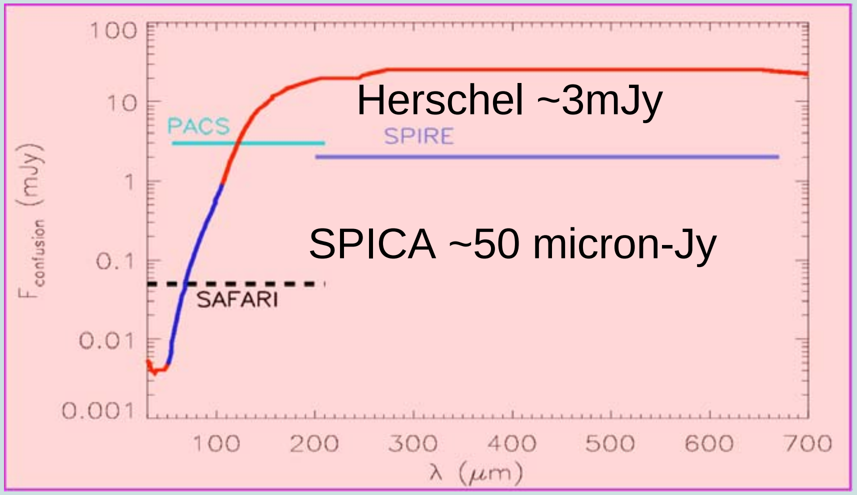
A Cosmic Vision for 2017

- **Telescope: 3.5m cooled to <5 K**
- **Core wavelength: 5-210 μm**
  - **Δθ=0.35”-14”**
- **Key science capabilities**
  - **Massive increase in 30-210 micron sensitivity over Herschel**
  - **Coverage of 28-60 micron band not accessible by Herschel or JWST**
  - **High resolution MIR spectroscopy**
  - **Large FoV for rapid mapping**
- **Orbit: Sun-Earth L2 Halo**
- **Warm Launch - Cooling in Orbit**
  - **Long mission lifetime – at least 5 years extendable to 10 years**
- **Launch: ~ 2017**

Deep Cosmological Surveys using SPICA

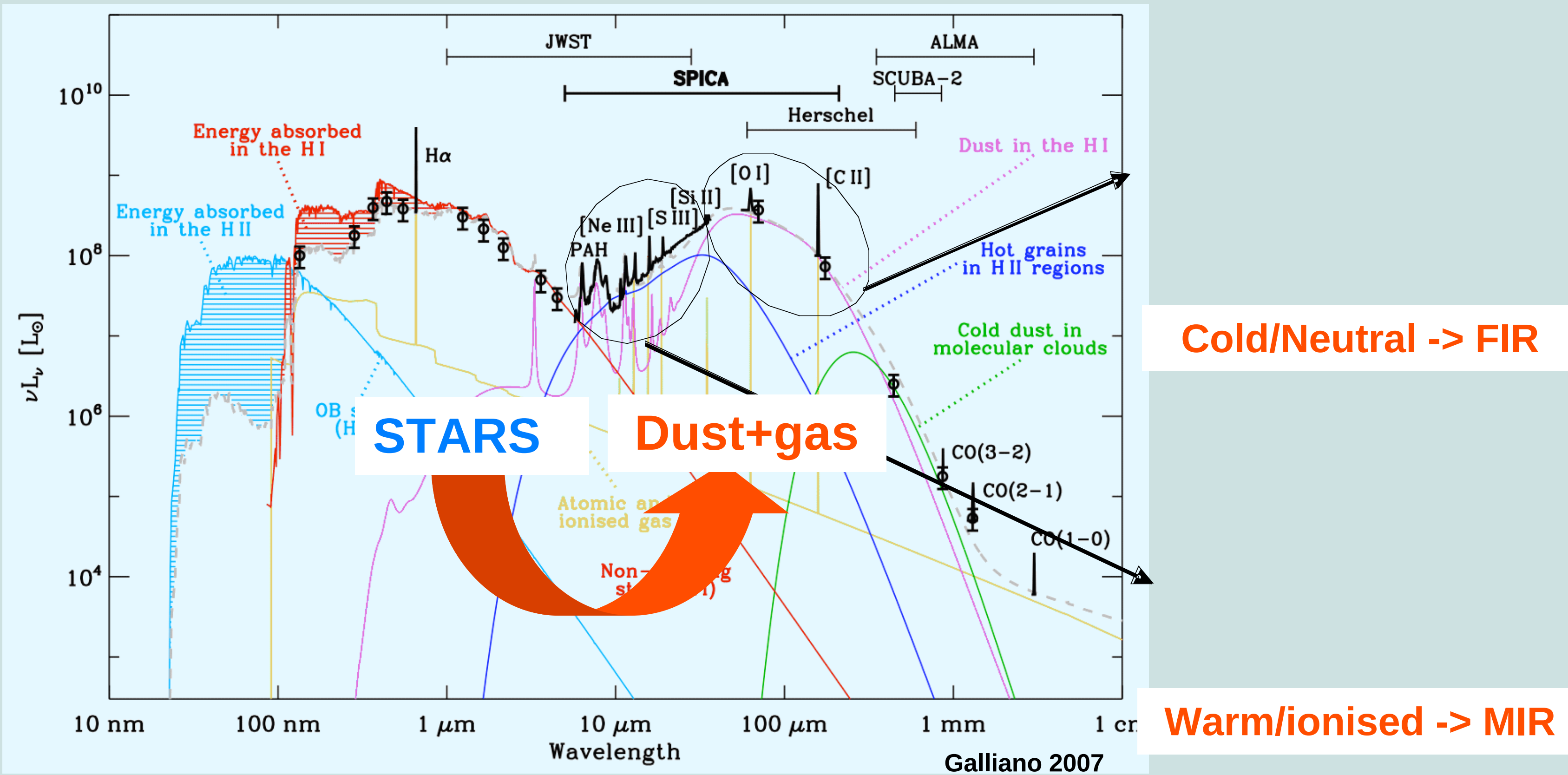
- **FIR: Confusion-limited at long λ**
- **Choice of wavelength?**
  - **Near thermal peak**
  - **Minimal contamination from redshifted PAH features, at z=3-4**
- **Conservative confusion limits @ 70 microns ~ 50 micro-Jy**
  - **z~1 a full census of SFR (Milky Way type gals.)**
  - **Detect high-z Compton-thick AGN, missing from census of point sources in X-ray background**
  - **Redshift evolution of dust extinction**
  - **Resolve 90% of CIB over 80% of age of Universe**





Spectral diagnostics are the key

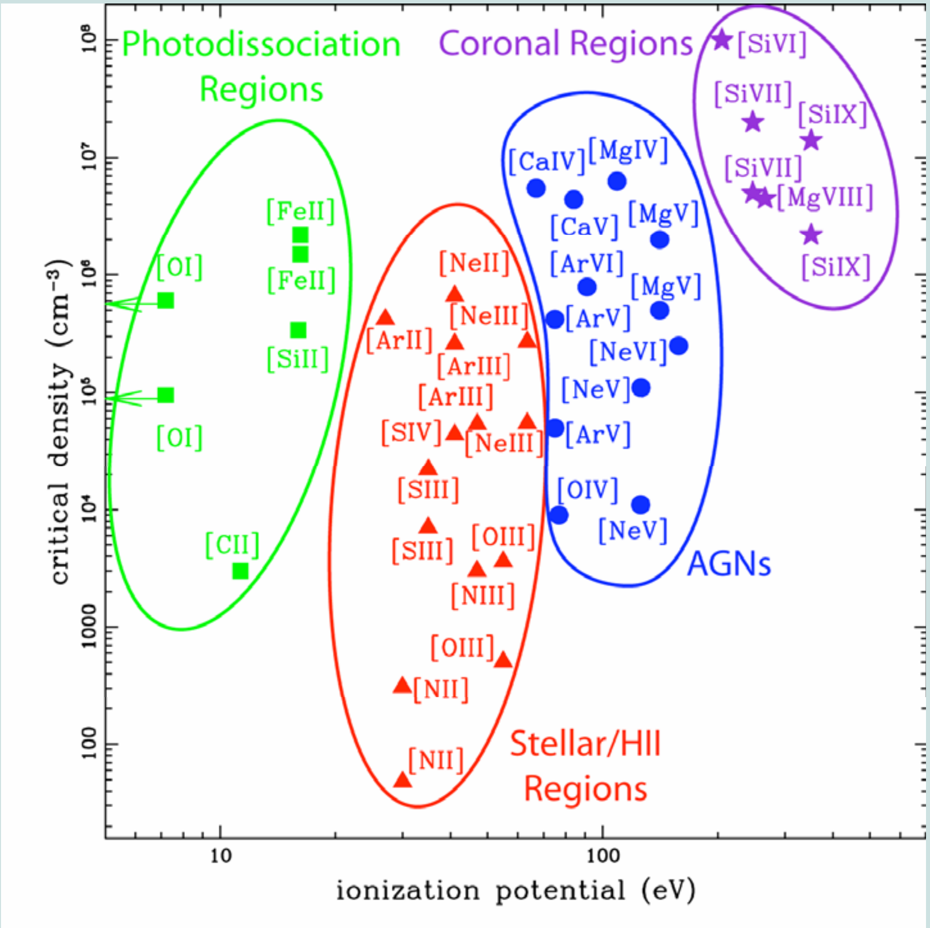
SED's only can be ambiguous in separating an AGN from high SFR



Starlight/AGN continuum "recycled" by dust and gas in the ISM/torus
So complete picture is only possible by observing complete MIR->FIR

FIR Diagnostics and the Starburst-AGN connection

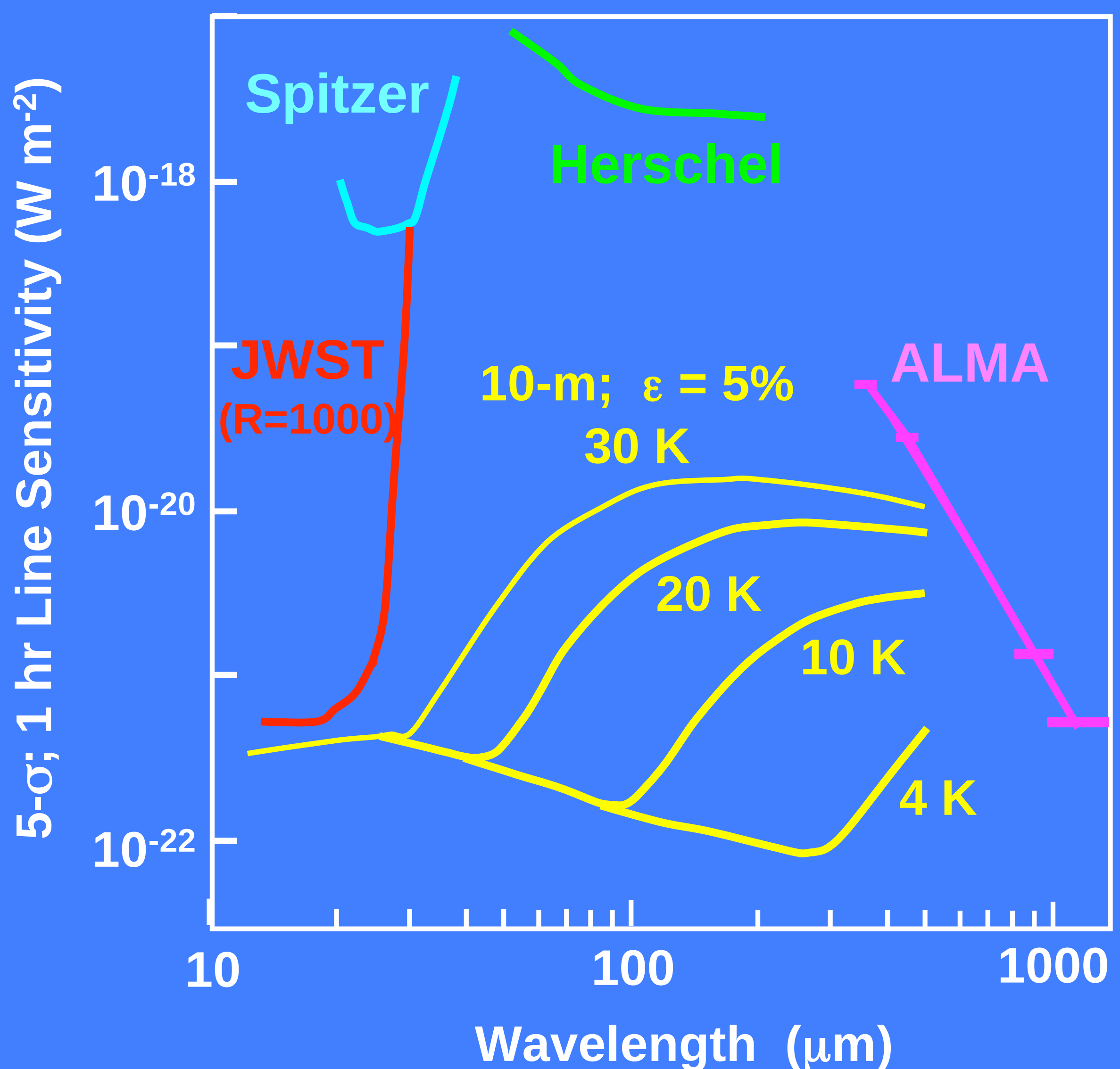
- Key diagnostic lines for physical/excitation conditions
  - PDR lines
  - Stellar HII lines
  - AGN tracers
  - Coronal lines
- Line ratios - give excitation and ionisation state, hence the shape of the SED responsible



SPICA/SAFARI Specifications

- Wavelength coverage over at least 35 to 210 micron with a design driver to achieve 28-210 micron
- A photometric camera mode with R~3 to 5
- Range of spectral modes with at least R = 2000
- An instantaneous field of view of 2x2 arcmin
- Line sensitivity of <10 $x10^{-19}$ W m^{-2} (5-σ 1 hour) with goal to be ~$1x10^{-19}$ W m^{-2}
- Continuum sensitivity of <50 μJy at 70 microns

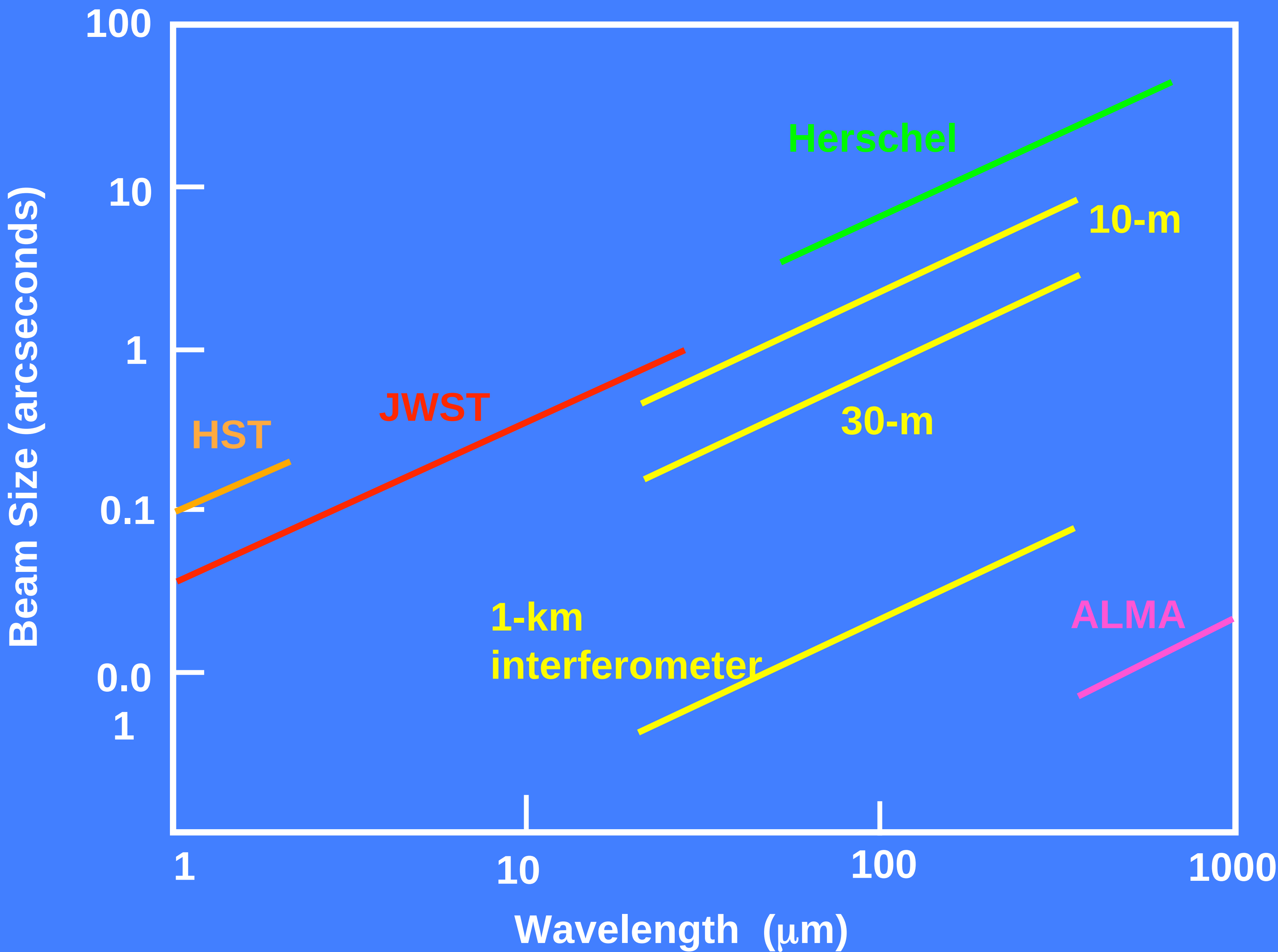
Clearly in the future we want – Better Sensitivity



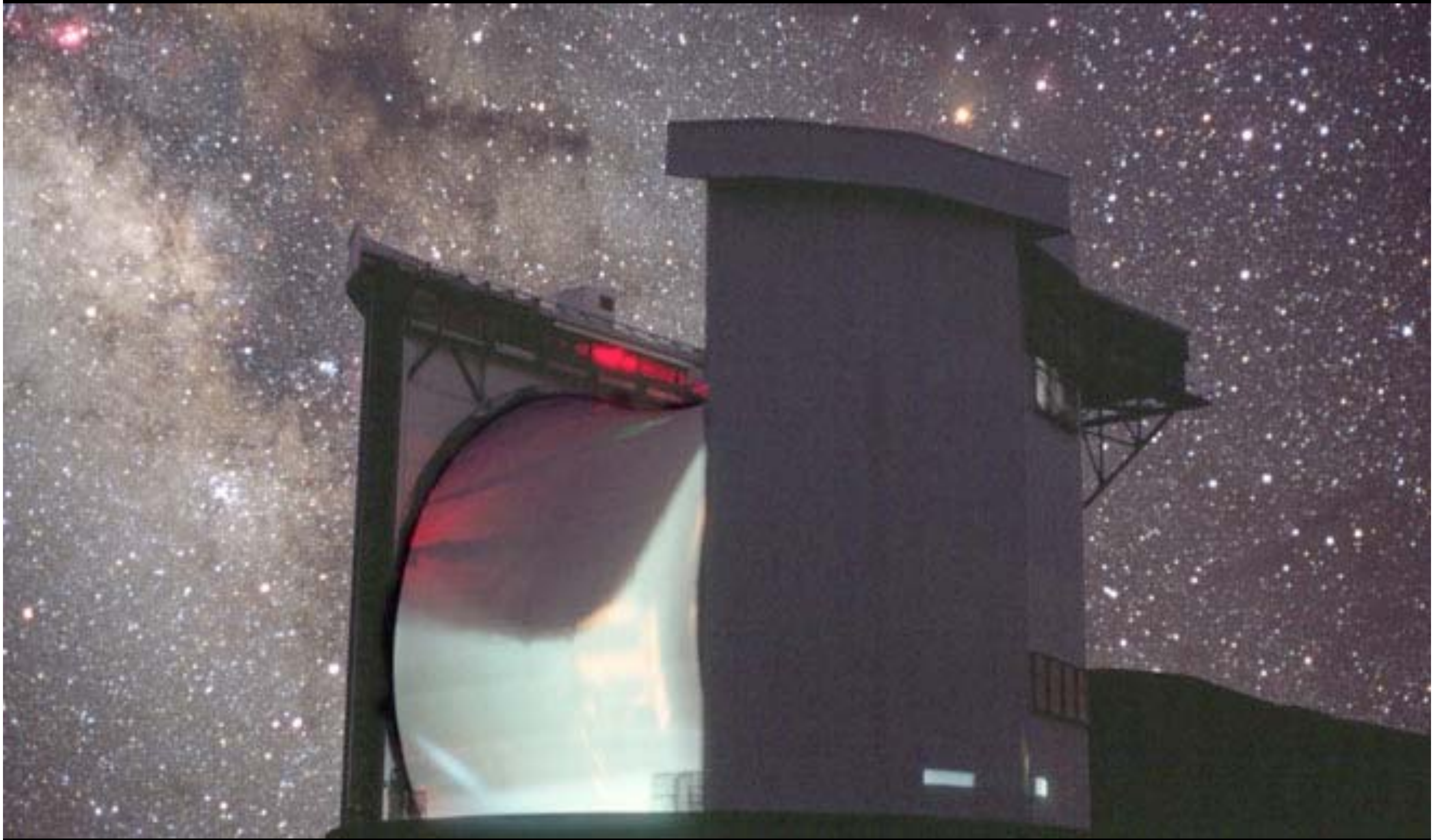
A 4-K telescope is background-limited:

- Zodiacal light below 200 μm
- CIRB above 200 μm

and… better Angular Resolution

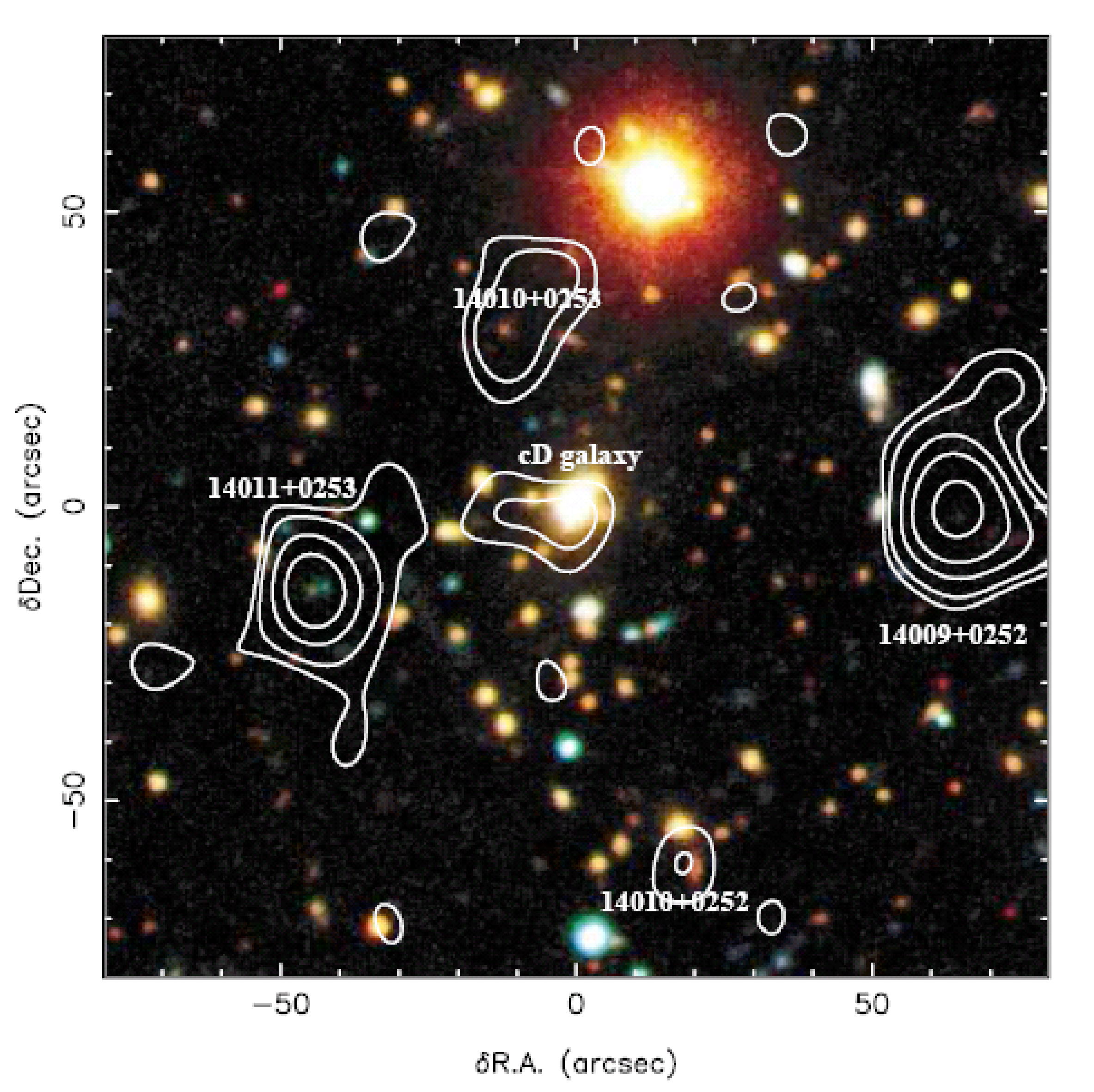


Sub-mm Surveys: JCMT & SCUBA-2



Also…LABOCA(MPIfR), 12m APEX @ 870 micron

Sub-mm galaxies – tip of the luminosity "iceberg" eg. grav. lensed field A1835



Example from this field, a source with sub-mm/radio detection, but no opt./NIR

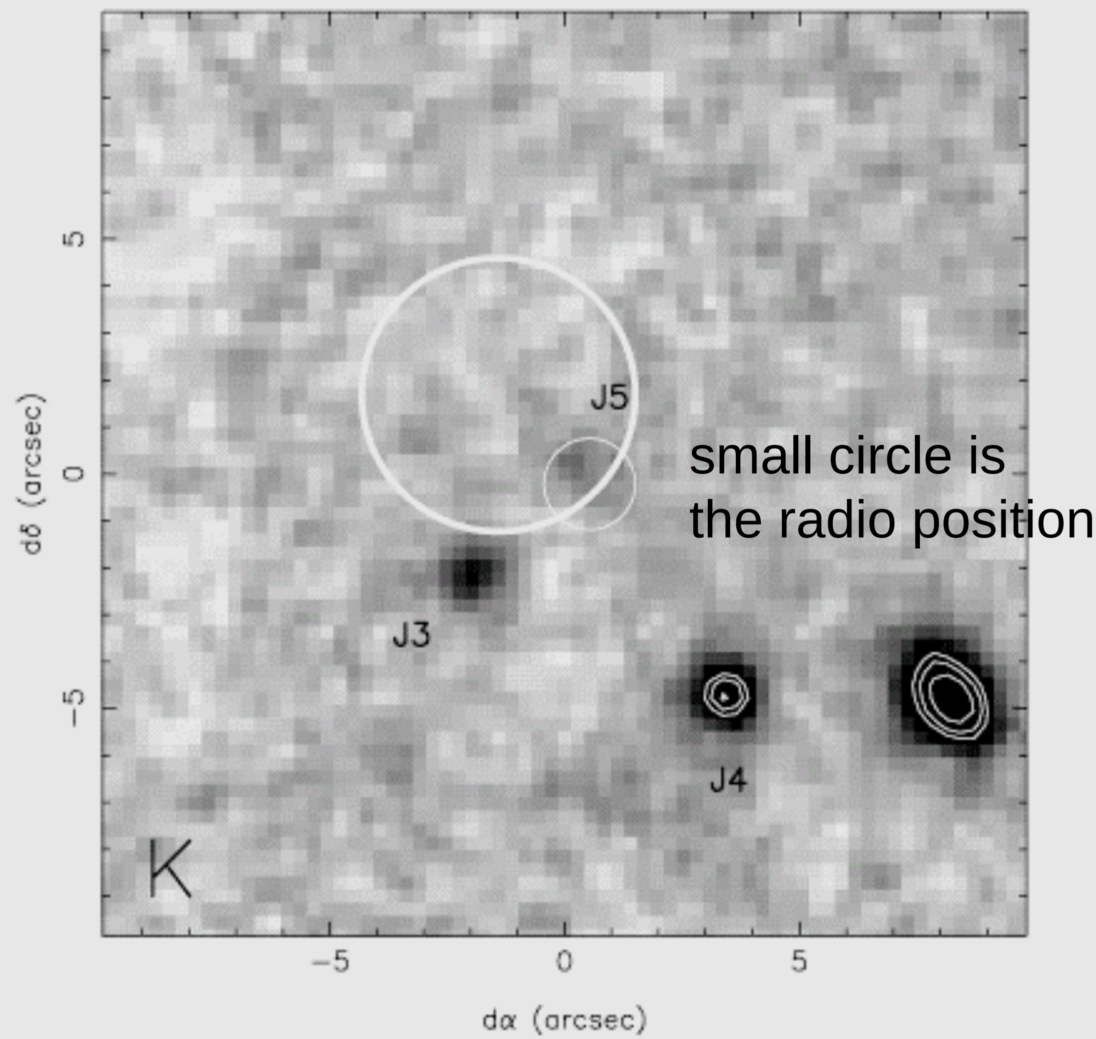


Figure 7. *K* image of SMM J14009, with the possible near-IR counterparts

We need much larger numbers of sub-mm gals.
New sensitive surveys

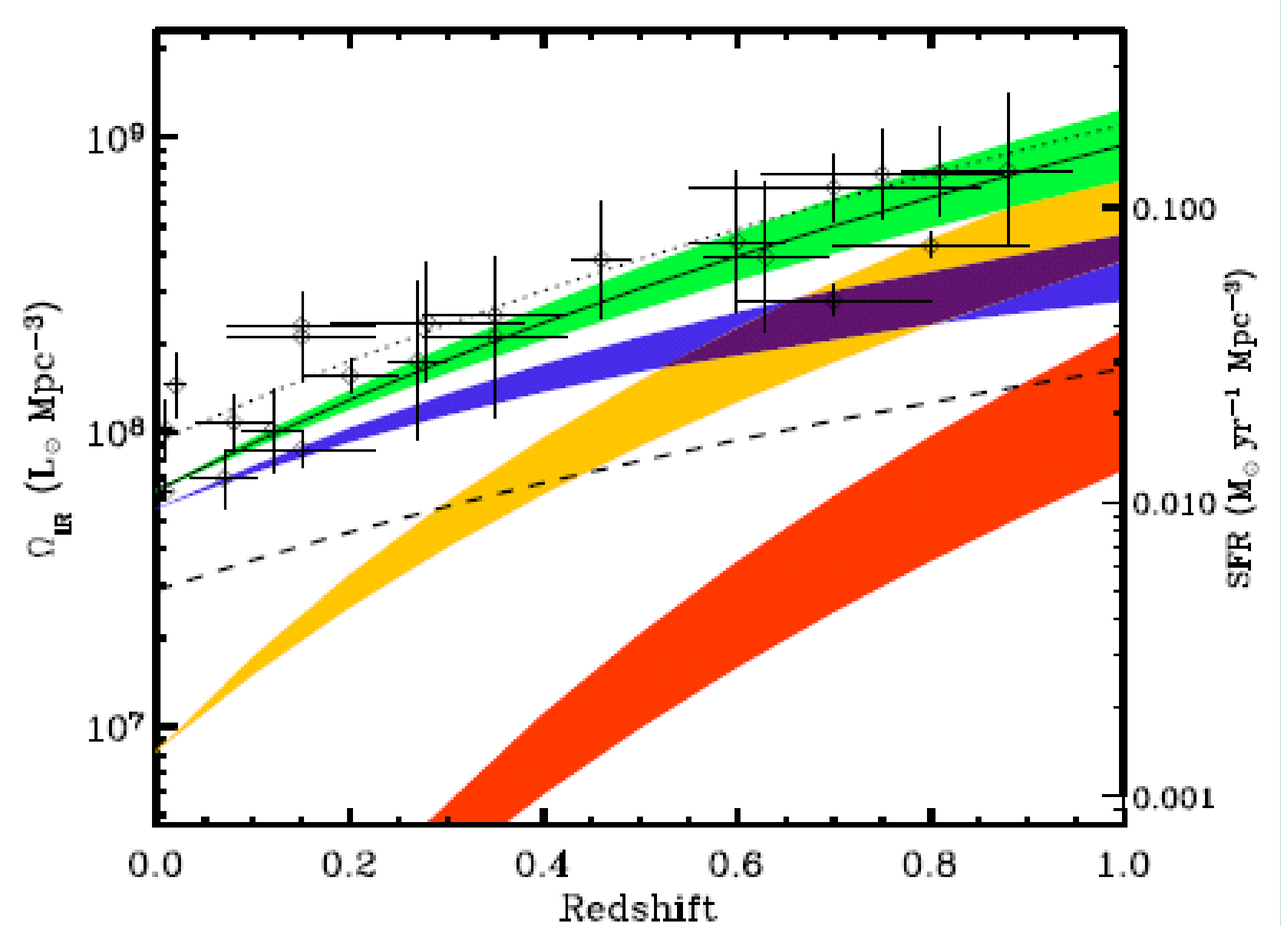
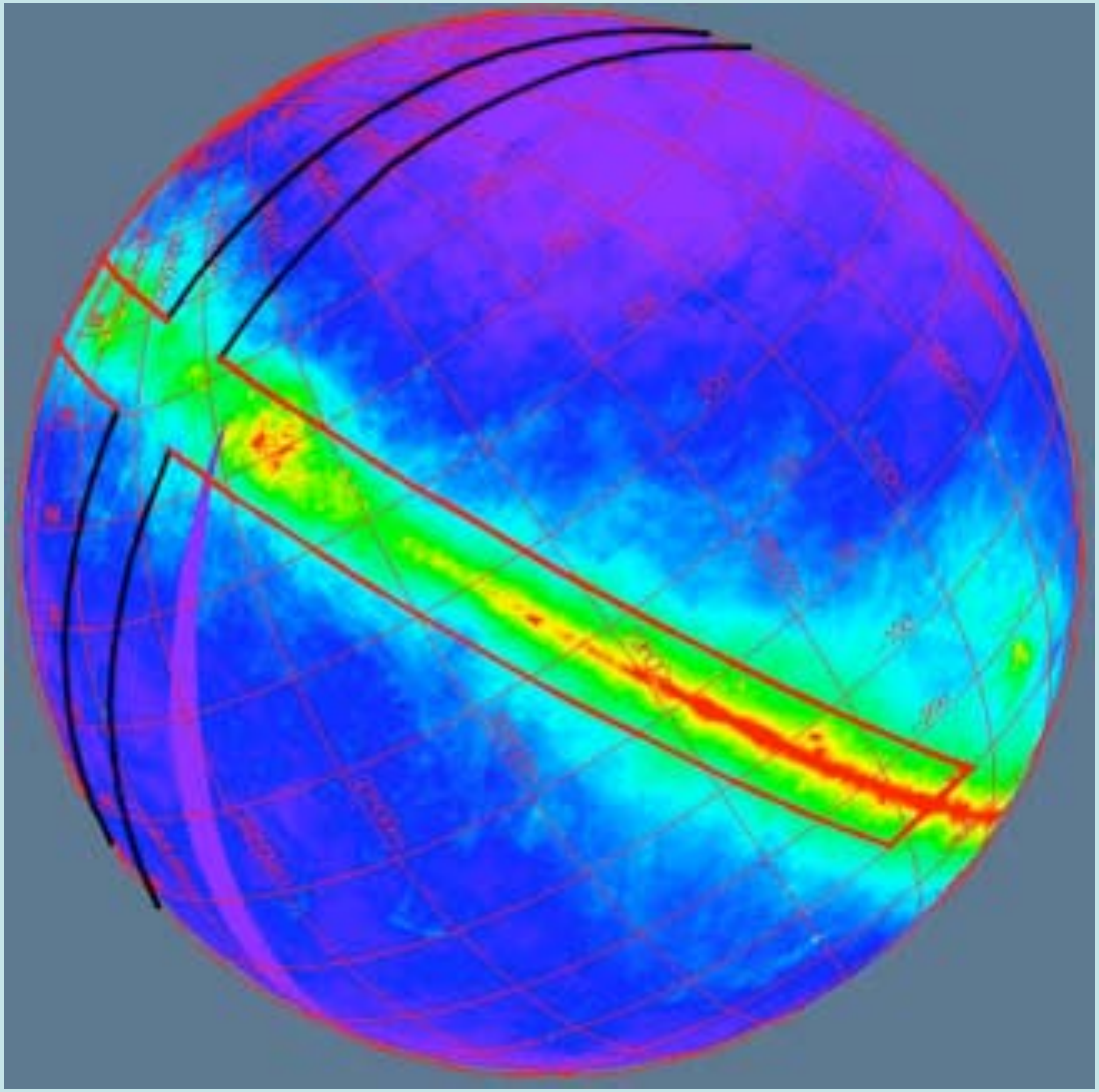


Figure 2: **(a)** The inferred star formation history of the Universe. The Spitzer view from Le Floch et al. 2005 showing the contribution of low IR luminosity galaxies (blue), luminous IR galaxies (LIRGs, orange), and rapidly-evolving ultra-luminous IR galaxies (ULIRGs, red) to the total co-moving IR energy density (green).

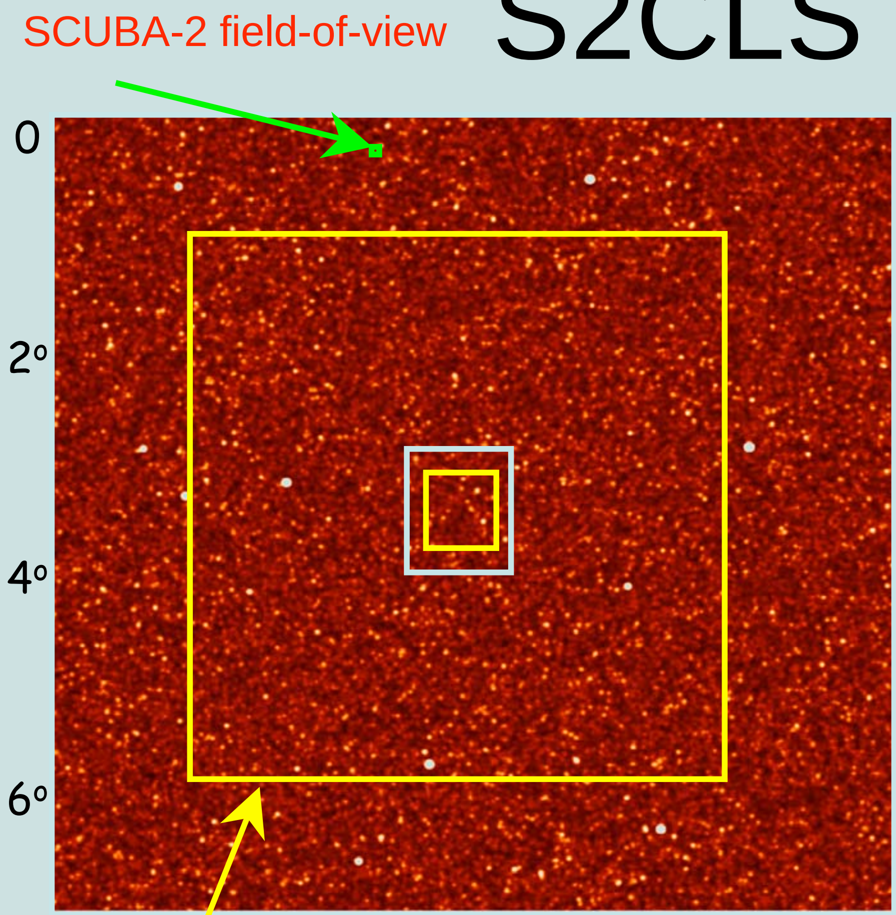
SCUBA-2 Legacy Survey basic information

- 55% of the available time on JCMT will go to the Legacy Surveys
- Two-year plan approved; 5-year plan approved in principle
- Data initially proprietary, but obligation to release reduced data
- So maps/catalogs will be public on the time-scale of ALMA early science
- SCUBA-2 All-Sky Survey (SASSy, 150 mJy depth, all-sky in 5 years); Debris disks; Nearby galaxies survey; Gould's Belt survey; Galactic Plane survey; spectral line HARP-B survey
- **Cosmology Legacy Survey (most highly rated) - 2 components:**
  850um wide-field survey
  450um deep survey

Phase 1 of SCUBA-2 850 micron sky survey



S2CLS [2-yr plan]



- 2-year program:
  large survey (20 deg^2) at 850 um,
  deep survey at 450 um (0.5 deg^2)
- 5-year program:
  large survey (50 deg^2) at 850 um,
  deep survey at 450 um (1.3 deg^2)

- Wide 850um survey:
  20 deg^2 to 1σ = 0.7 mJy
  (few x 10^3 srcs at >10σ, >10^4 at >3σ)
- Deep 450um survey:
  0.5 deg^2 to 1σ = 0.5 mJy (confusion).
  (few x 10^2 srcs at >10σ, >10^3 at >3σ).
- Deep 850um survey:
  0.5deg^2 to σ=0.15mJy (ignoring confusion) - in parallel with 450um map, used for deconvolution.

We can expect to have samples of 1,000’s of mJy-level sources for ALMA follow-up - but we need to identify which are interesting…

Summary of proposed SCUBA-2 Surveys

- LABOCA is providing an introduction to the great potential of SCUBA-2

- S2CLS 850um survey will provide 1,000's of robust sources with L_{FIR}>10^{12}Lo out to z~4

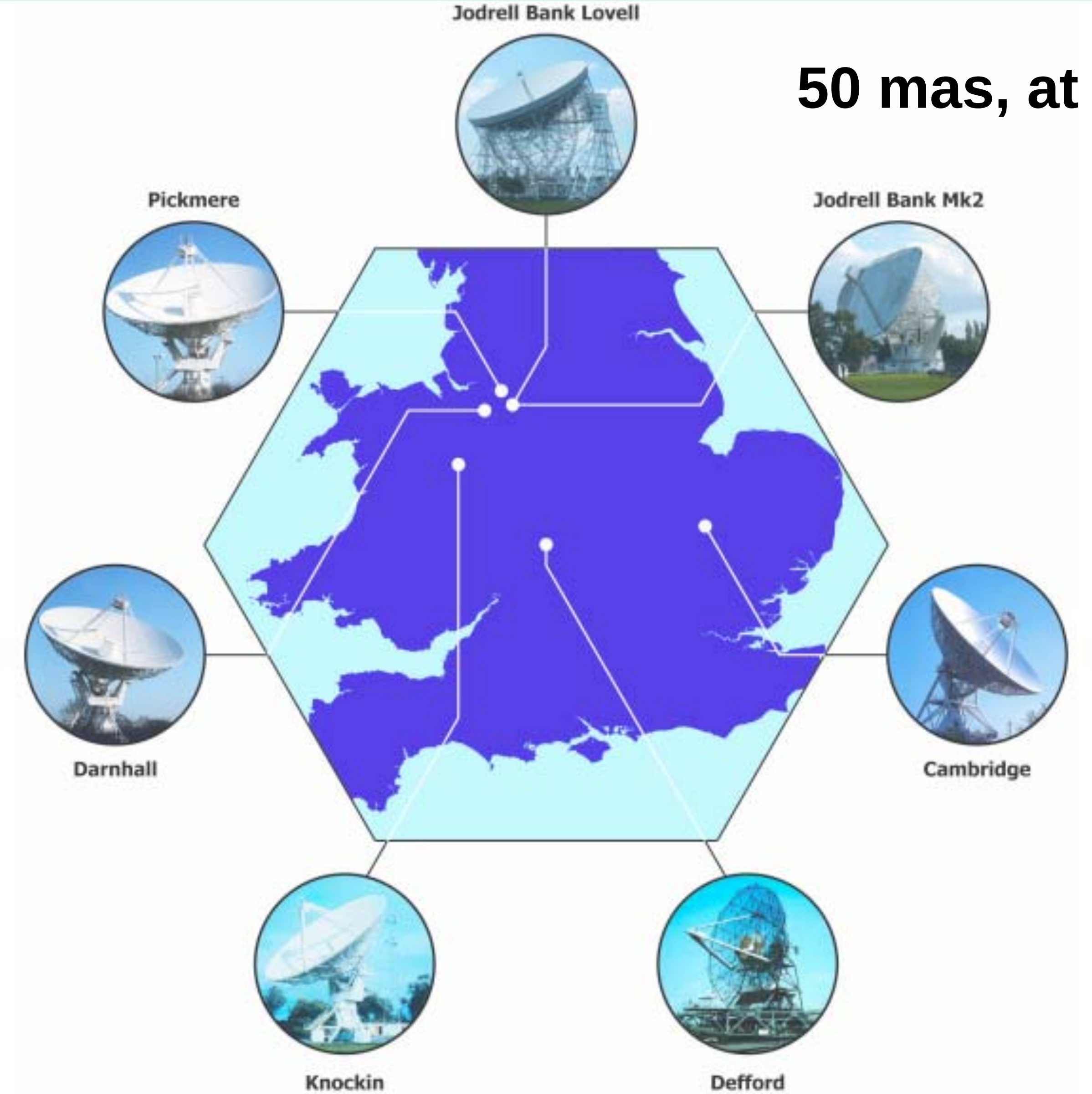
- S2CLS 450um survey is unique in probing lower SFRs - will provide 100's of robust sources with L_{FIR} down to a few x10^{11}Lo at z>1

- Maps/data available on timescale of ALMA early science

- Herschel/VISTA/radio etc are key to identification of SCUBA-2 sub-samples for ALMA and JWST (we must be sure of IDs)

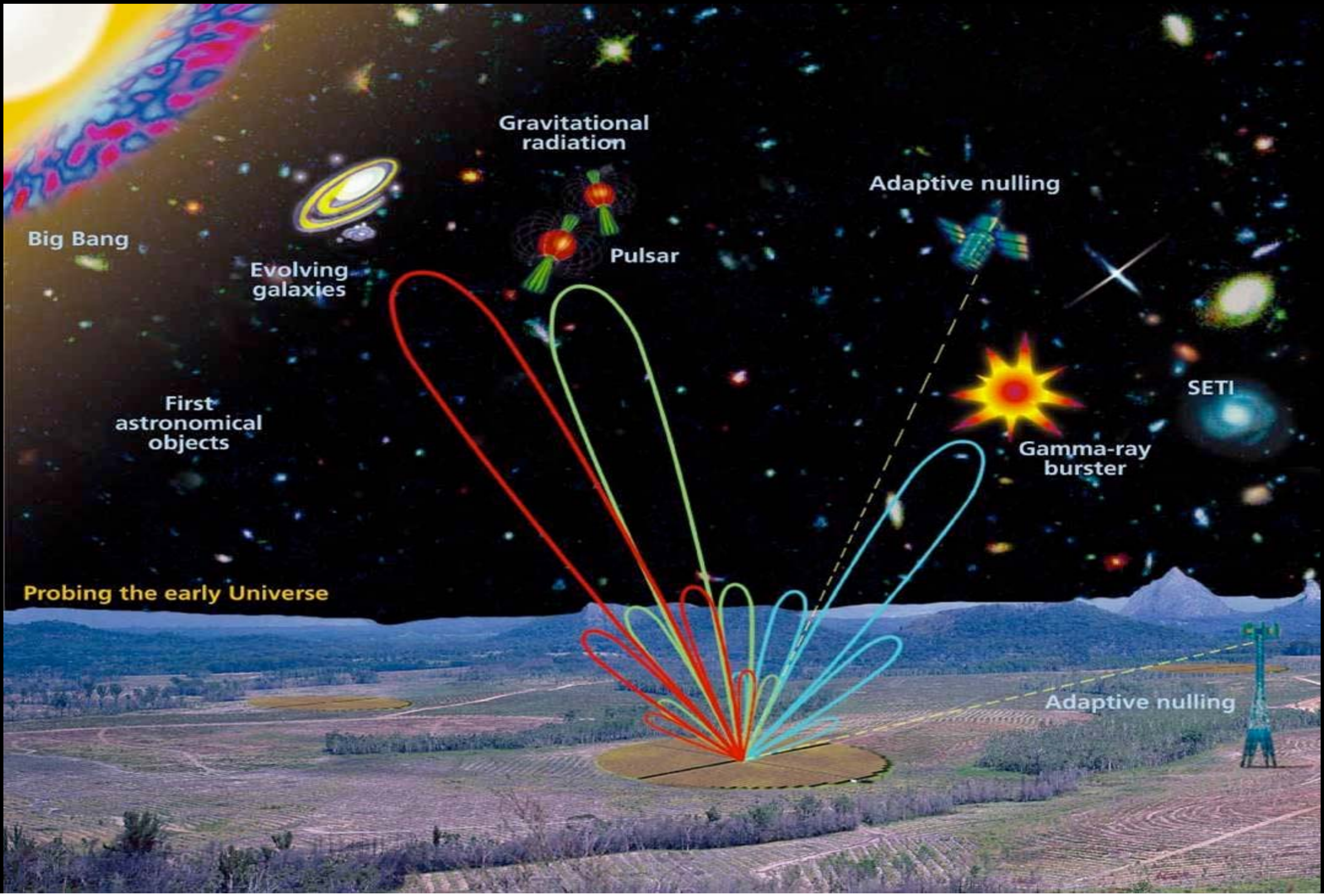
The Radio Connection
EVLA and e-Merlin (starts < 1year)

50 mas, at 5GHZ



We already have LOFAR: a pathfinder for SKA

“Just ” need data super-highways, and really BIG computers



All aimed at the future SKA (s)

And finally… the X-ray angle

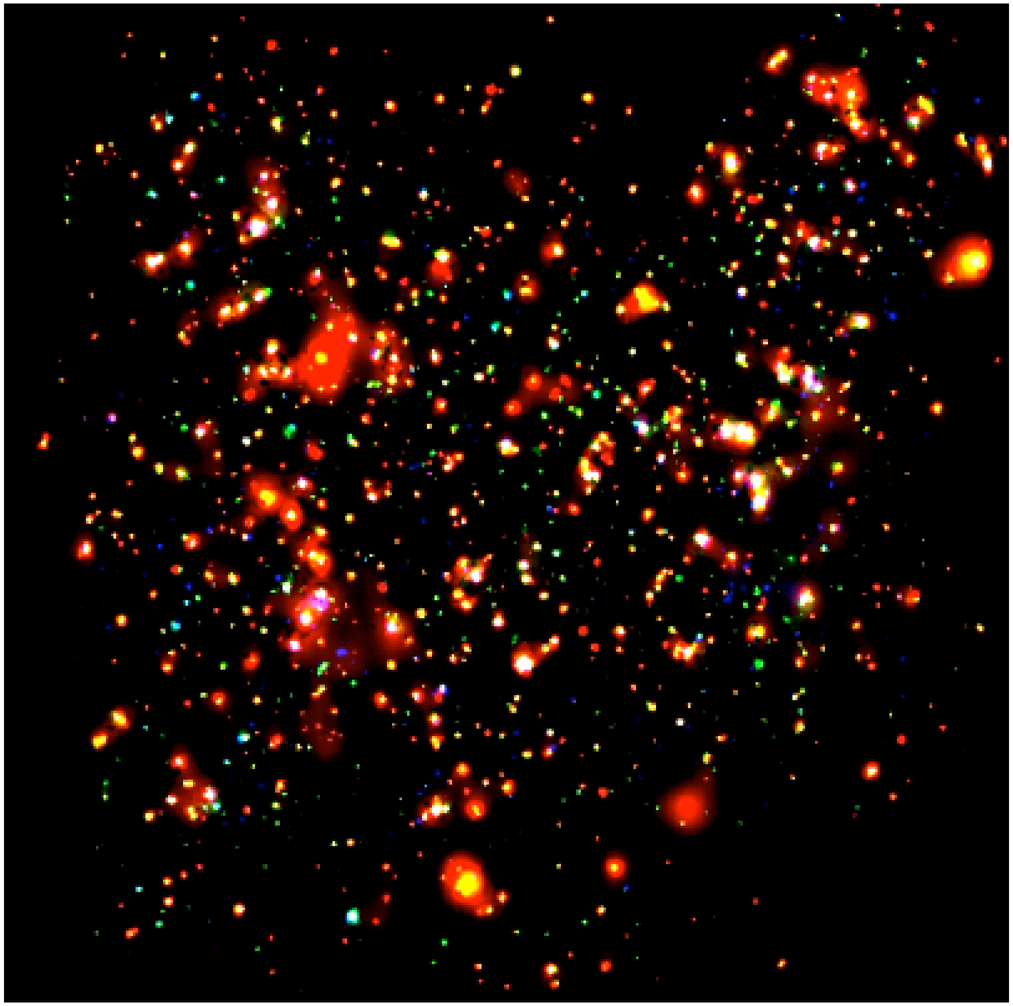
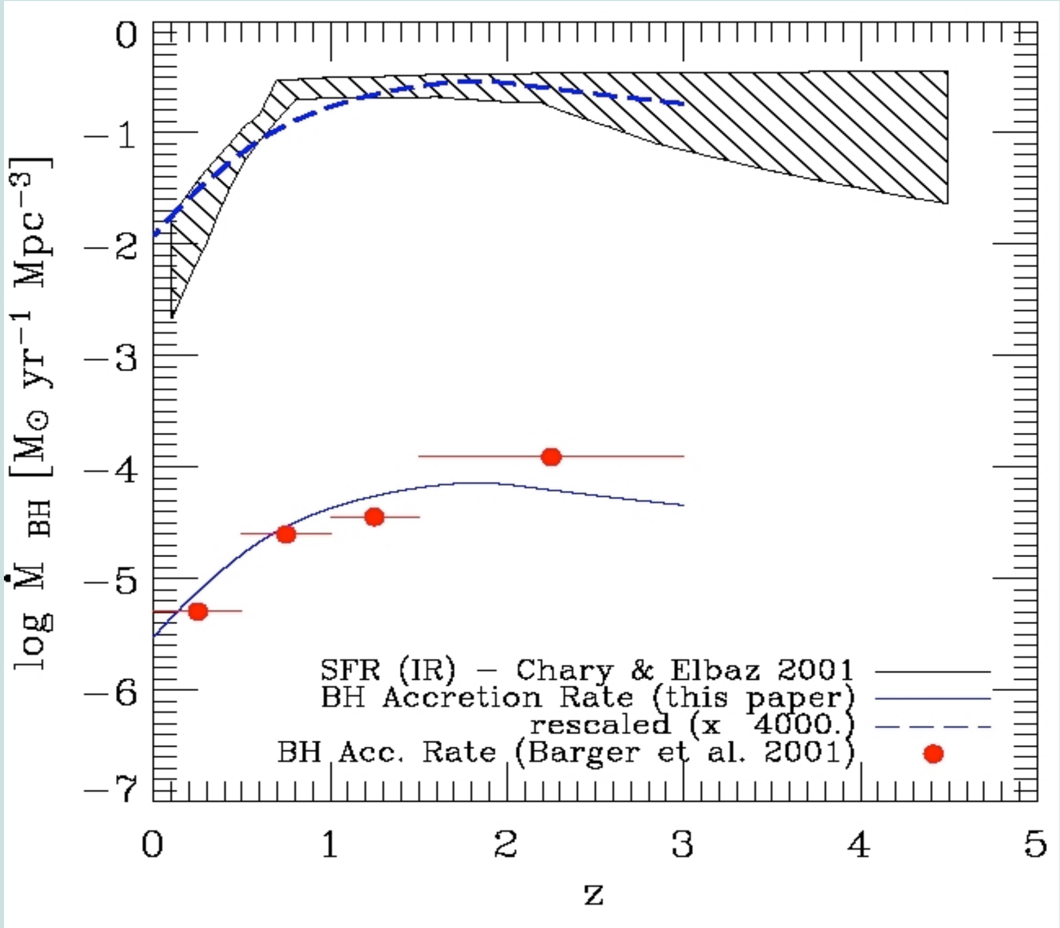


Figure 3.1.1: XMM-Newton Survey of the COSMOS field. The solid angle of 2°×2° and sensitivity make this the deepest wide field X-ray survey ever performed. Point sources (AGN) and extended emission (clusters of galaxies) can be readily distinguished. The surveys planned with eROSITA are expected to yield a similar composition over huge solid angles on the sky.

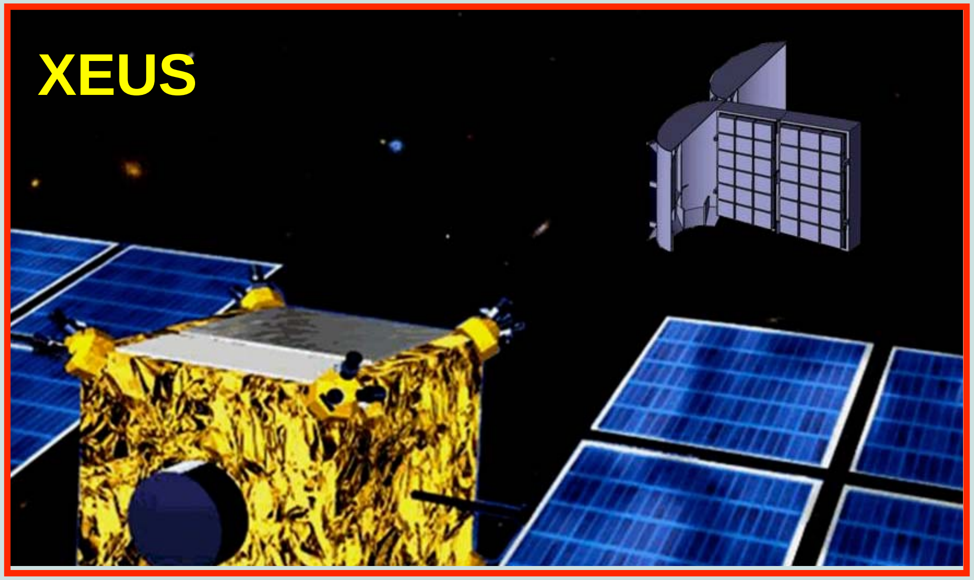
THE CO-EVOLUTION OF GALAXIES & BLACK HOLES

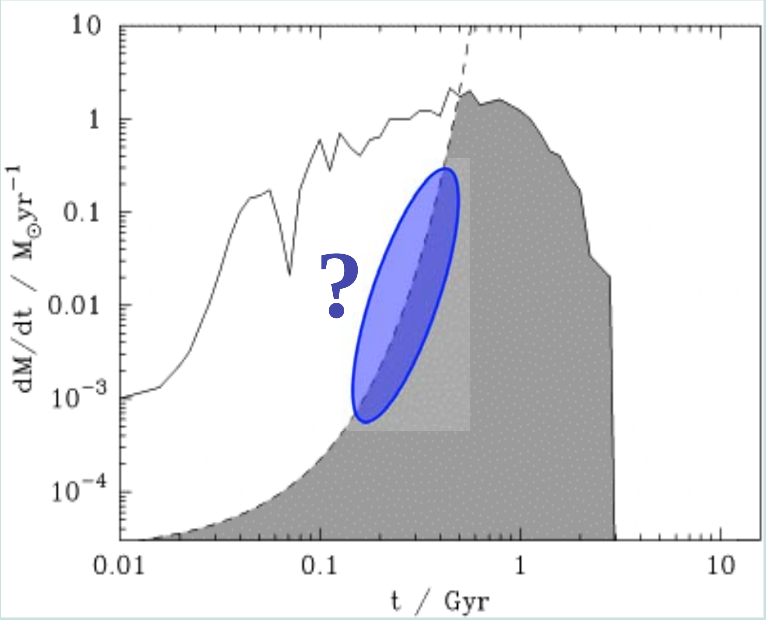


Marconi et al.

Observing the Black Hole Accretion Process

- **Forming black hole is heavily buried in gas and dust**
  ⇒ Sensitive X-ray observations

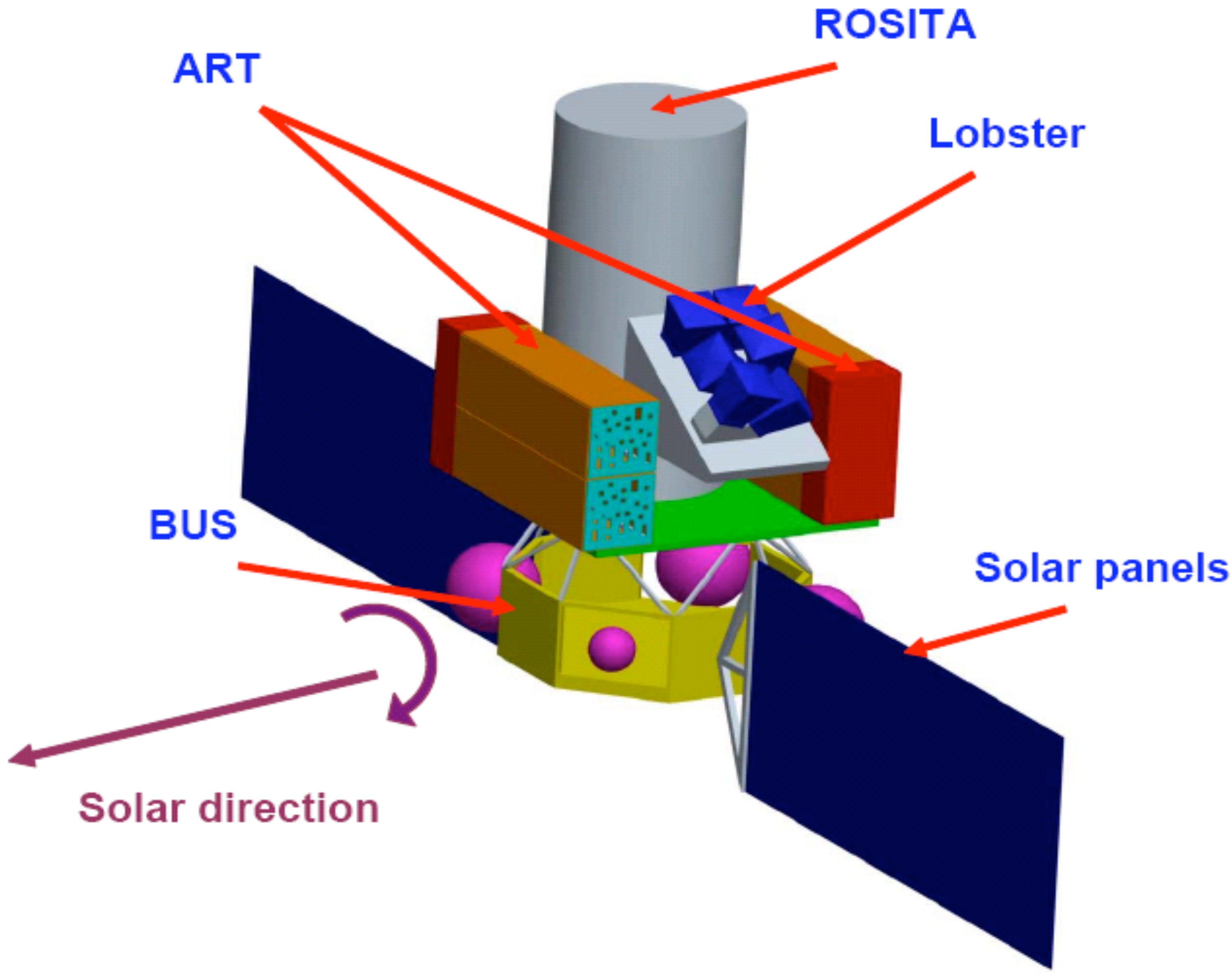




Archibald et al. 2002, MNRAS 336, 353

- **Most of the accretion power is absorbed and re-radiated in the FIR by surrounding gas and dust**
- **Need high resolution FIR imaging and spectroscopy**

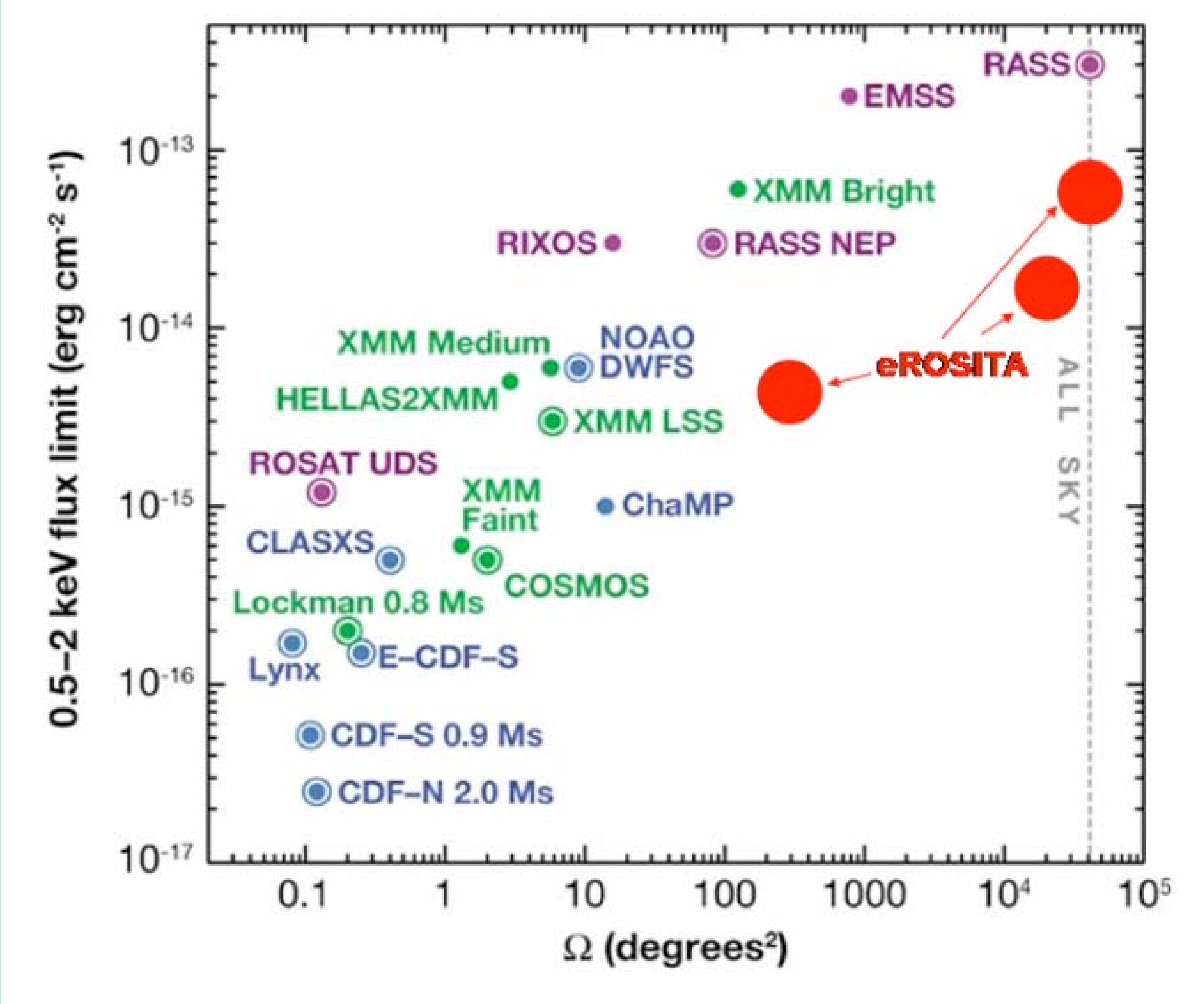
Spectrum RG (2012?)



Summary of ROSITA Surveys (0.2-12keV)

Survey	All-Sky Survey	Wide Survey	Deep Survey
Solid Angle	42000	20000	200
Exposure time	1 yr	2.5 yrs	0.5 yrs
0.5-2 keV $S_{min\ AGN}$	5.7×10^{-14}	1.5×10^{-14}	4×10^{-15}
2-10 keV $S_{min\ AGN}$	1.0×10^{-12}	2.1×10^{-13}	2.4×10^{-14}
0.5-5 keV S_{min} Clusters	1.6×10^{-13}	3.3×10^{-14}	8×10^{-15}
0.5-2 keV AGN	240000	800000	740000
2-10 keV AGN	12600	84000	44000
Clusters	32000	72000	6500

ROSITA’s - unique X-ray surveys



Hard X-ray Survey

- ROSITA will produce a catalogue of ~120,000 AGN in the hard X-ray band
- A significant number will be Compton Thick
- This will be a powerful resource in breaking the AGN/starburst degeneracy, when we only have SEDs, and will help us to refine the FIR line diagnostics

Summary

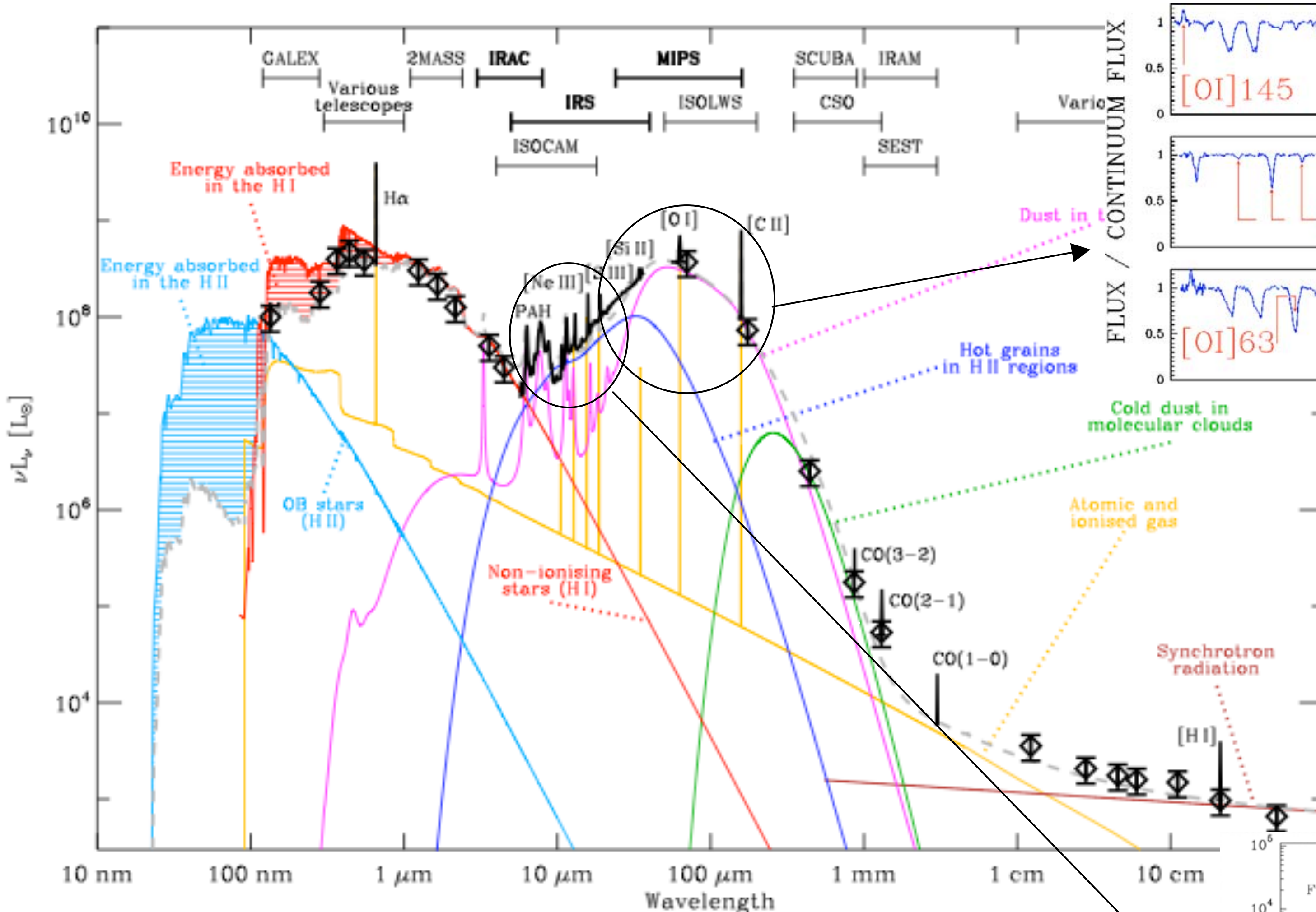
So it comes down to this….

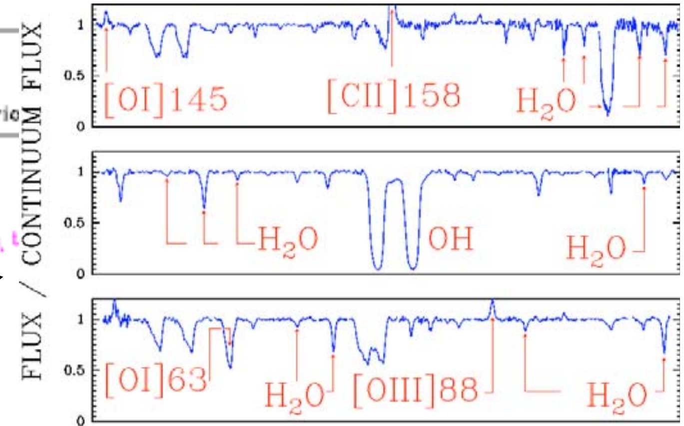
- When we do these deep surveys aimed at solving problems in galaxy and BH formation and evolution, in the FIR (or wherever), we need to know what the source content is! We MUST HAVE discriminatory diagnostics

- In the FIR this may come from spectra in the same wavelength band – or from other bands eg. the radio and X-rays

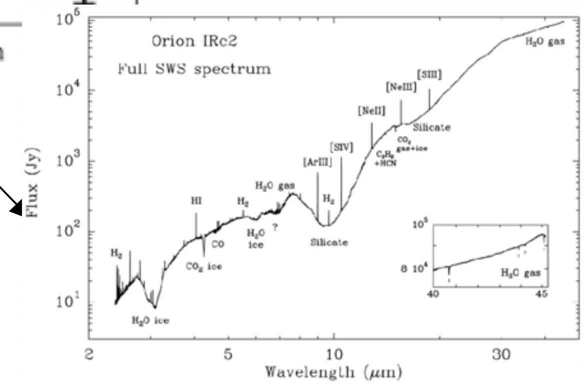
ESA's selection summary

- An FIR observatory with a step change in sensitivity is essential to understanding evolution of galaxies and planetary formation
- SPICA is the natural successor to the current generation of space IR observatories
- SPICA is the natural precursor to an IR interferometer in space





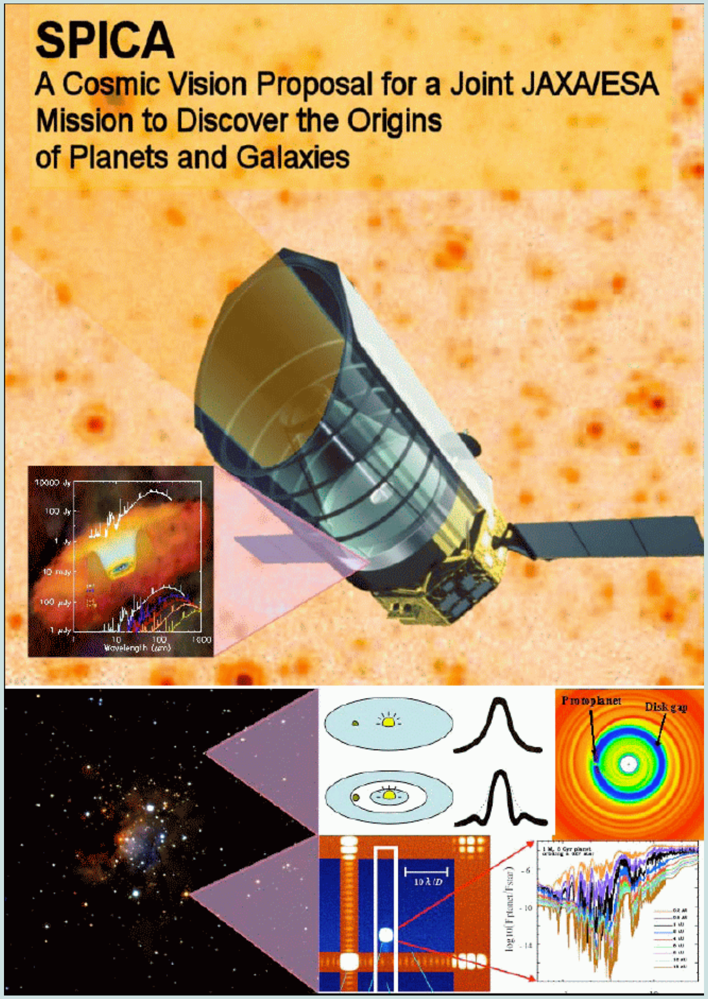
Galliano *et al*.



- Narrow-band spectral line features
- Broad-band PAH features + mineralogy
- Underlying SED

ESA Cosmic Vision and SPICA

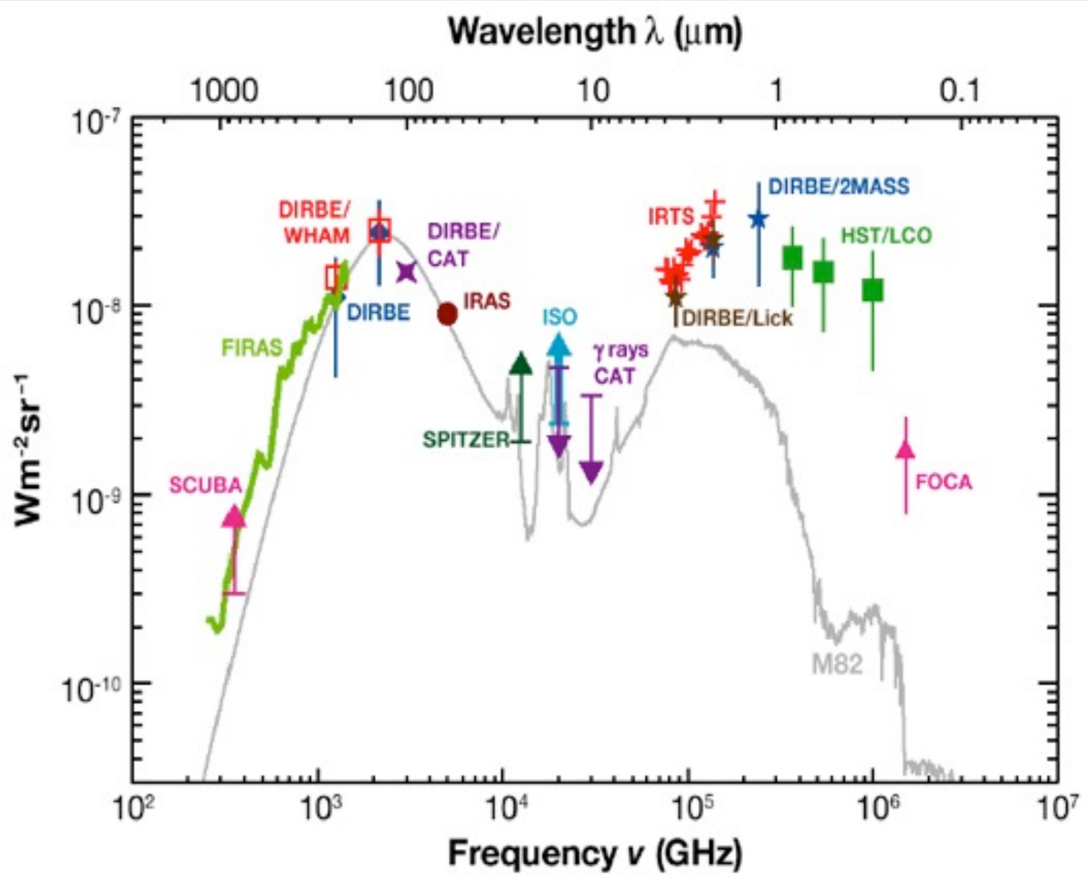
- Cosmic Vision - ESA
  - ESA missions for 2015-2025 time frame
  - March07: first call for 1 L-class + 1 M-class mission, to be launched c. 2017
  - October07: 8/50 proposals chosen to go to assessment phase + SPICA a mission of opportunity
  - Autumn09: selection for definition phase
  - Mid 2012: selection for implementation
- In Japan:
  - Selected as the next mission for study in Japan…



Key themes in Astrophysics

- Cosmic Visions call posed these questions
  - What are the conditions for planet formation and the emergence of life ?
  - How does the solar system work?
  - How did the Universe originate and what is it made of?
- An FIR observatory was indentified as an essential part of Cosmic Vision
- Joining the Japanese SPICA project provides that observatory for Europe

Why another mission to study the FIR?

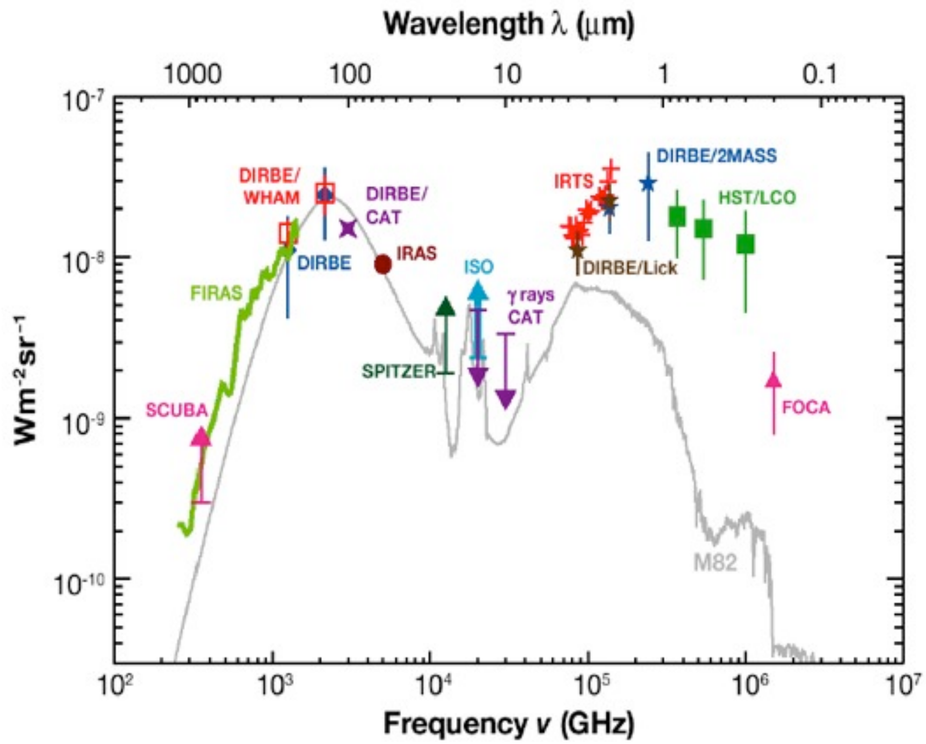


The Cosmic IR Background (eg Lagache et al.)

Extragalactic Science

- Formation and evolution of galaxies
- LIRGs: local/distant
- Feedback - starburst/AGN
- Extrema ←→ Milky Way
- Local galaxies - laboratories

Sensitivity+spectral coverage+FoV+
cold telescope(ref.)



Lagache et al.

The FIR waveband

- Atomic and ionic fine structure lines:
  - Atomic gas and PDRs: [CII] 158μm; [OI] 63/145 μm
  - Ionized medium: eg. [OIII] 53/88μm; [NII] 122/205μm; [SIII] 33μm; [SiII] 35μm; [NeIII] 36μm
- Molecular lines: high-J CO ladder, H_2O,OH, HD

  → Lines trace a wide range of different physical conditions:
  - Density, temperature, UV field, ionization parameter

  → Complementary to what will be traced by ALMA
- Lines largely unaffected by interstellar dust extinction
  - Good probes of heavily obscured regions and young dusty galaxies
- In addition:
  - Broadband SEDs → dust temperatures, mass…
  - Ice features
  - Redshifted features: PAHs/polycrystalline dust features