The Open University

SPICA Extragalactic Science

Stephen Serjeant, SPICA UK meeting
RAS, 14 Dec 2016

Life-changing Learning

I have gathered a posy of other men's flowers and only the thread that bonds them is my own.

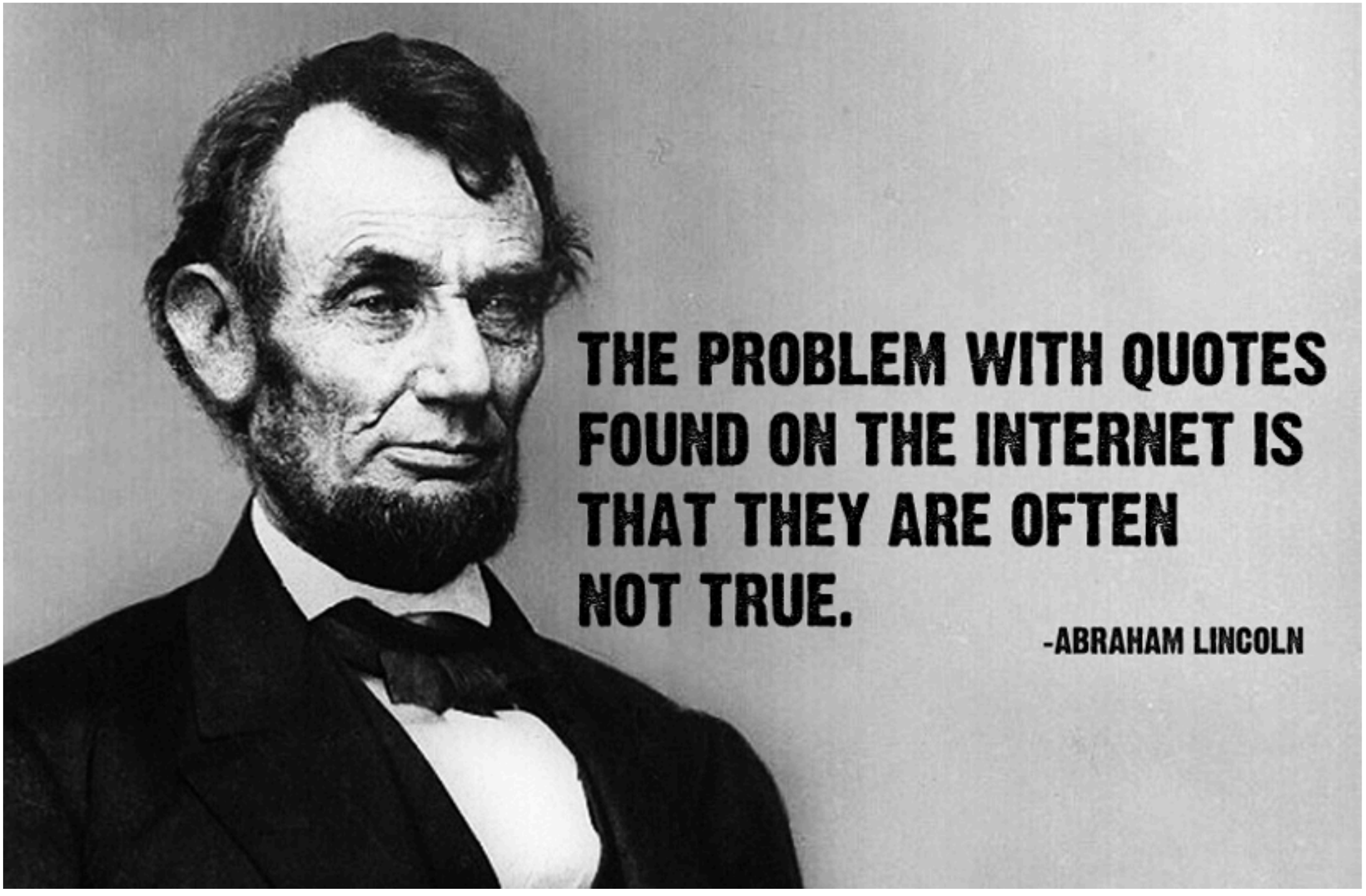
Michel De Montaigne

QuoteAddicts.com

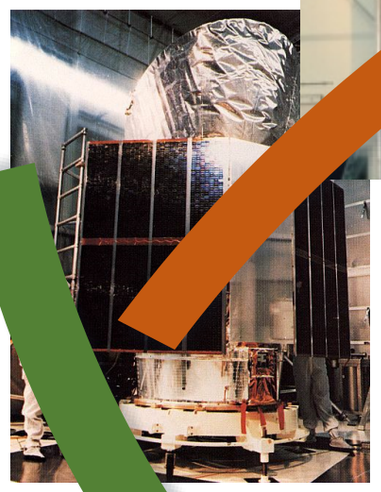
I have gathered a posie of other men's flowers, and nothing but the thread that binds them is mine own.

(John Bartlett)

izquotes.com

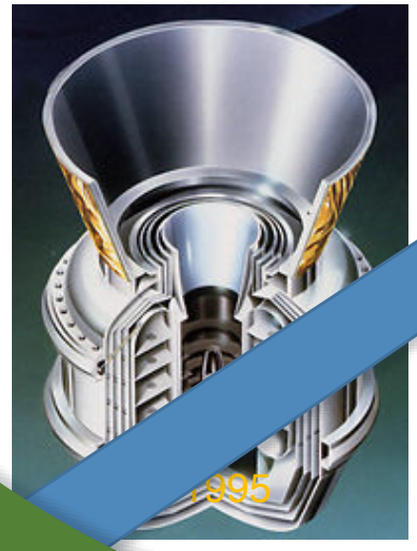

THE PROBLEM WITH QUOTES
FOUND ON THE INTERNET IS
THAT THEY ARE OFTEN
NOT TRUE.
-ABRAHAM LINCOLN

Infrared Space Observatories – pushing deeper



1985

ISO 1995



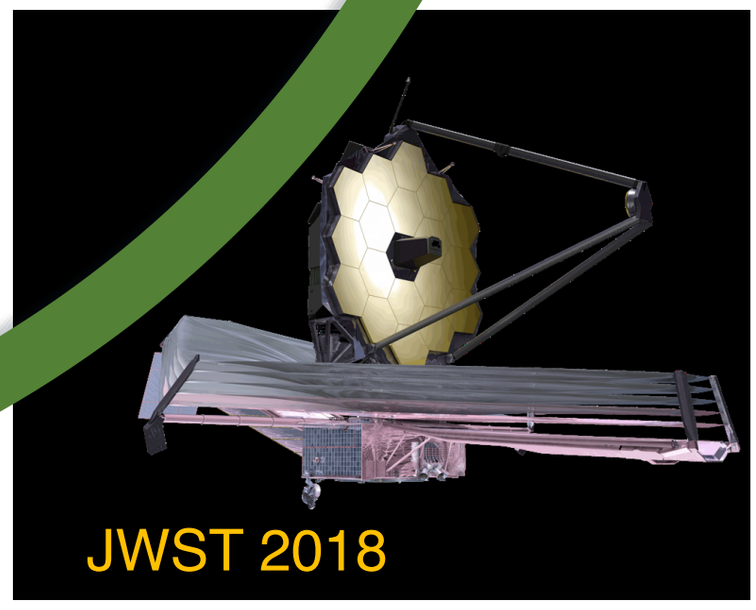
1995

Herschel 2009-2013

Akari 2006

Spitzer 200[illegible]

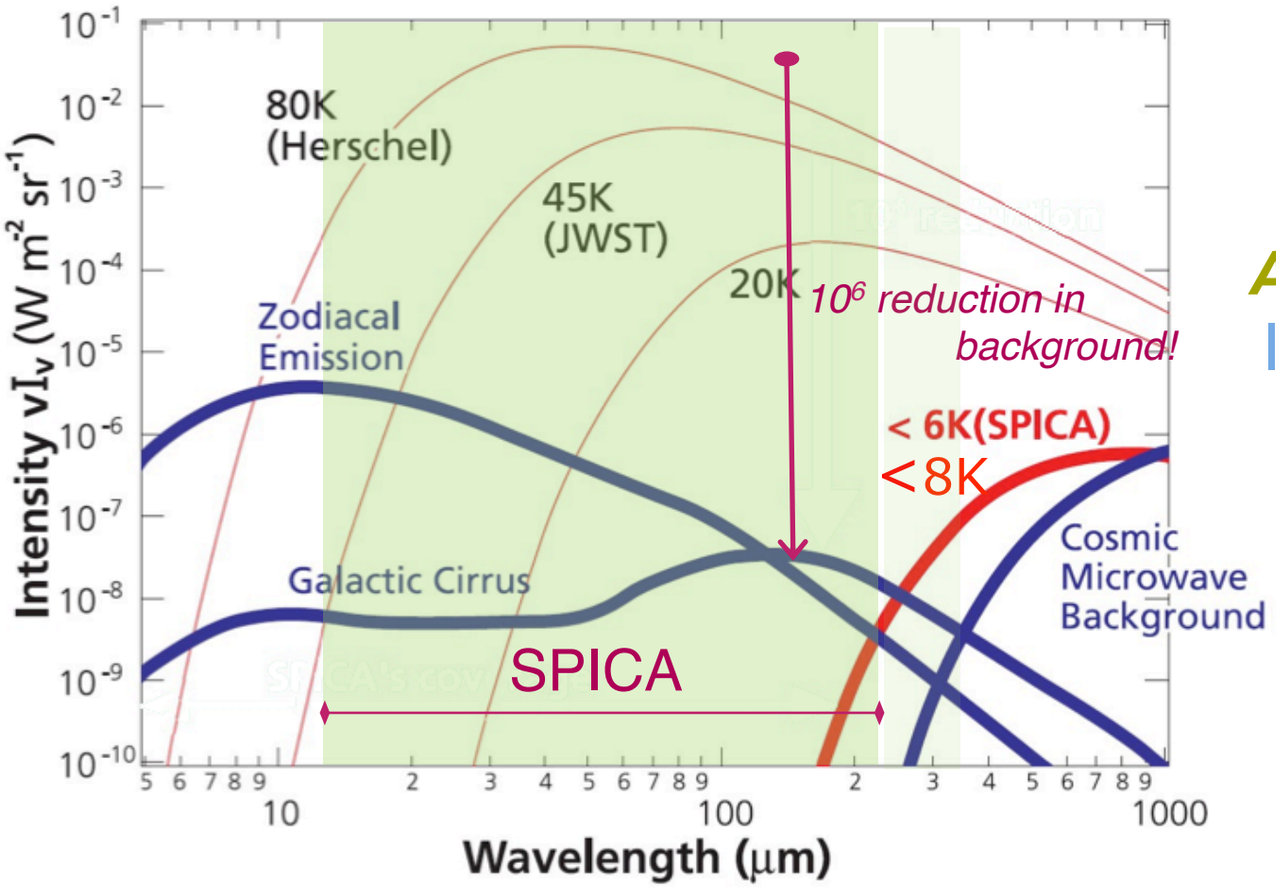
SPICA!



JWST 2018

P. Roelfsema

The SPICA ‘sweet spot’ – the dusty universe



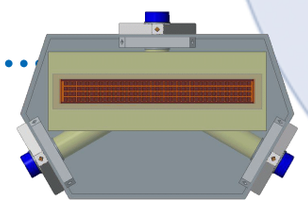
A unique observatory
looking through the veils, enabling
transformational science

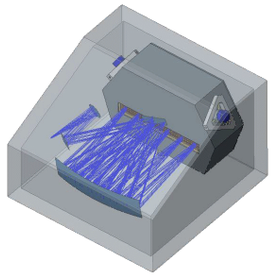
What is so unique?

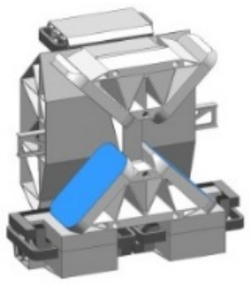
- A ***COLD***, ***big*** mirror
  → ***true background limited*** Mid/Far-IR observing
  >2 orders of magnitude better raw sensitivity than Herschel
- ~20 to ~350 μm ***inaccessible for any observatory***
  → the wavelength domain where ***obscured matter*** shines
  fill the blind spot between JWST and ALMA @ R~ few 1000

P. Roelfsema

SPICA in a nutshell: SAFARI

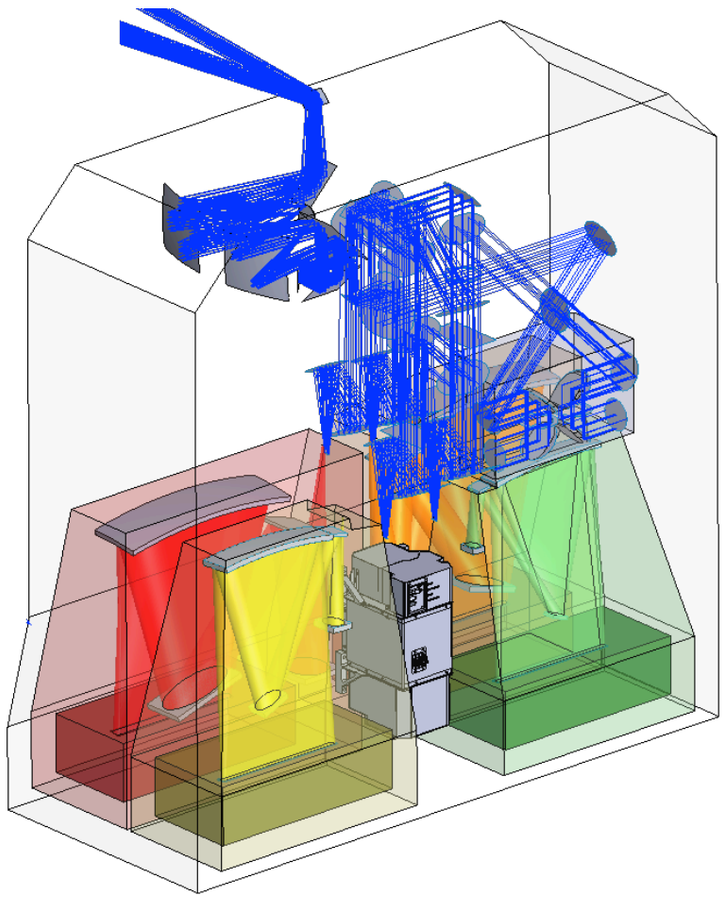






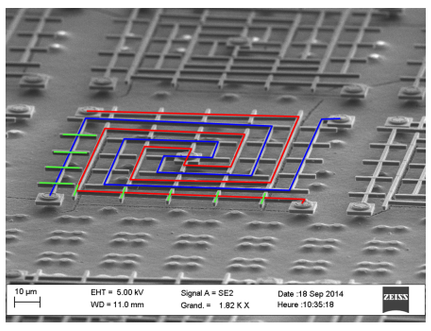
SAFARI/SPEC - high sensitivity grating spectrometer

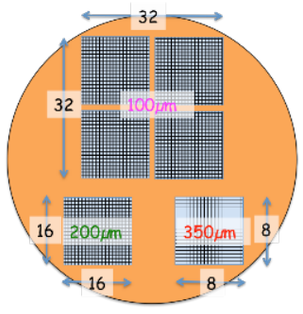
- **Basic R~300 mode → 1hr/5σ -5-7×10^{-20} W/m^2 (4.6 m^2)**
  Improves with better TES performance!
- Martin Puplett Interferometer to provide High-R mode
  Backup: Fabry-Pérot Interferometer
- 4 bands *instantaneously* covering 35-230 micron
  …limited imaging capability: 3 pixels on-sky

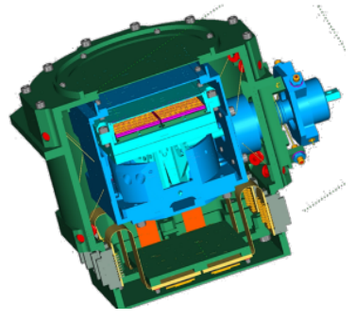


SAFARI/POL - imager polarimeter

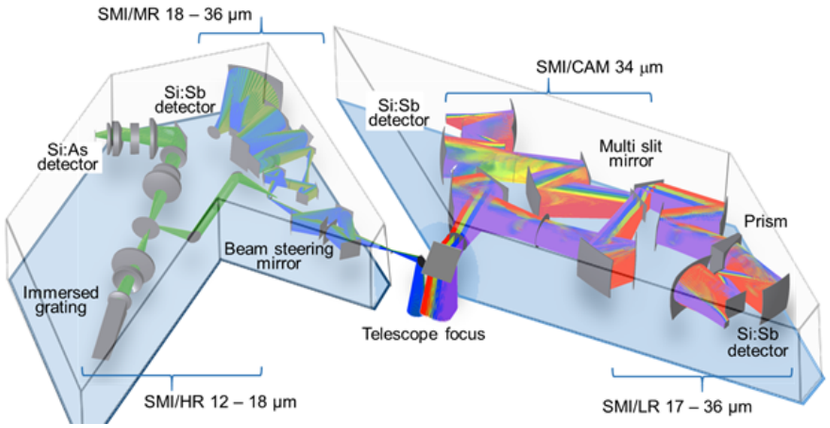
- Polarization sensitive bolometers
  - 3 bands: 110, 220,350 μm
- FPA architecture designed and tested
- Readout analogous to PACS system

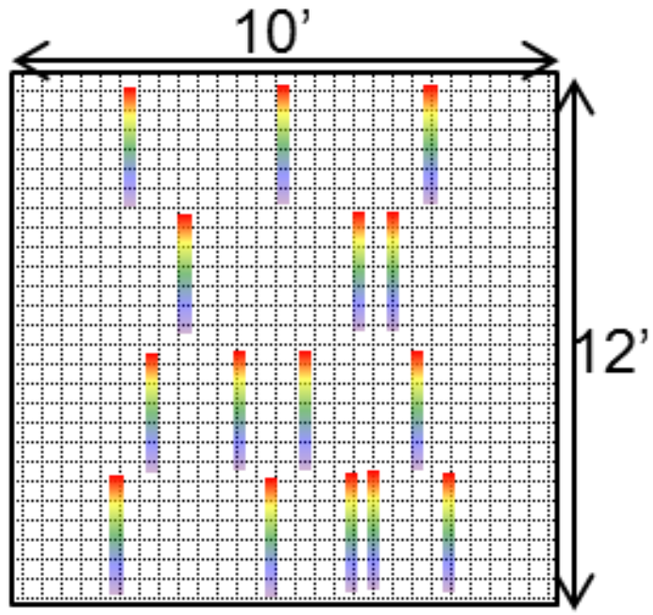




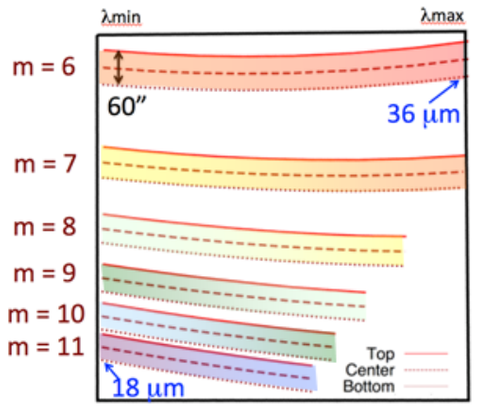


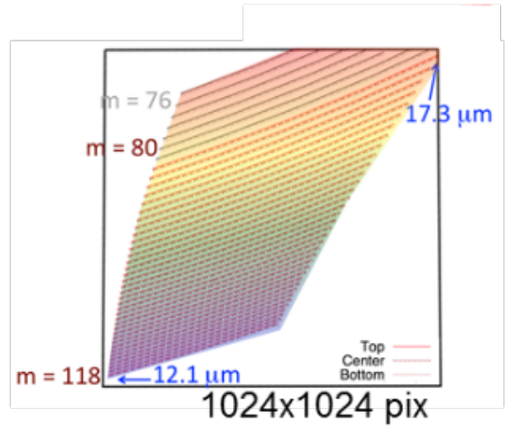
SPICA in a nutshell: SMI





- **SMI/LR-CAM** – large area low resolution surveyor
  - 17 – 36 μm, R = 50 – 120
  - 4 slits (10' long) with prism
  - Detector: Si:Sb
  - Camera mode 10'x12' FoV
- **SMI/MR** – medium resolution mapper
  - 18 – 36 μm, R = 1200 – 2300,
  - 1 slit (1' long) with grating
  - Detector: Si:Sb
- **SMI/HR** – molecular physics/kinematics
  - 12 – 18 μm, R = 28,000
  - 1 slit (4" long) with immersion grating
  - Detector: Si:As

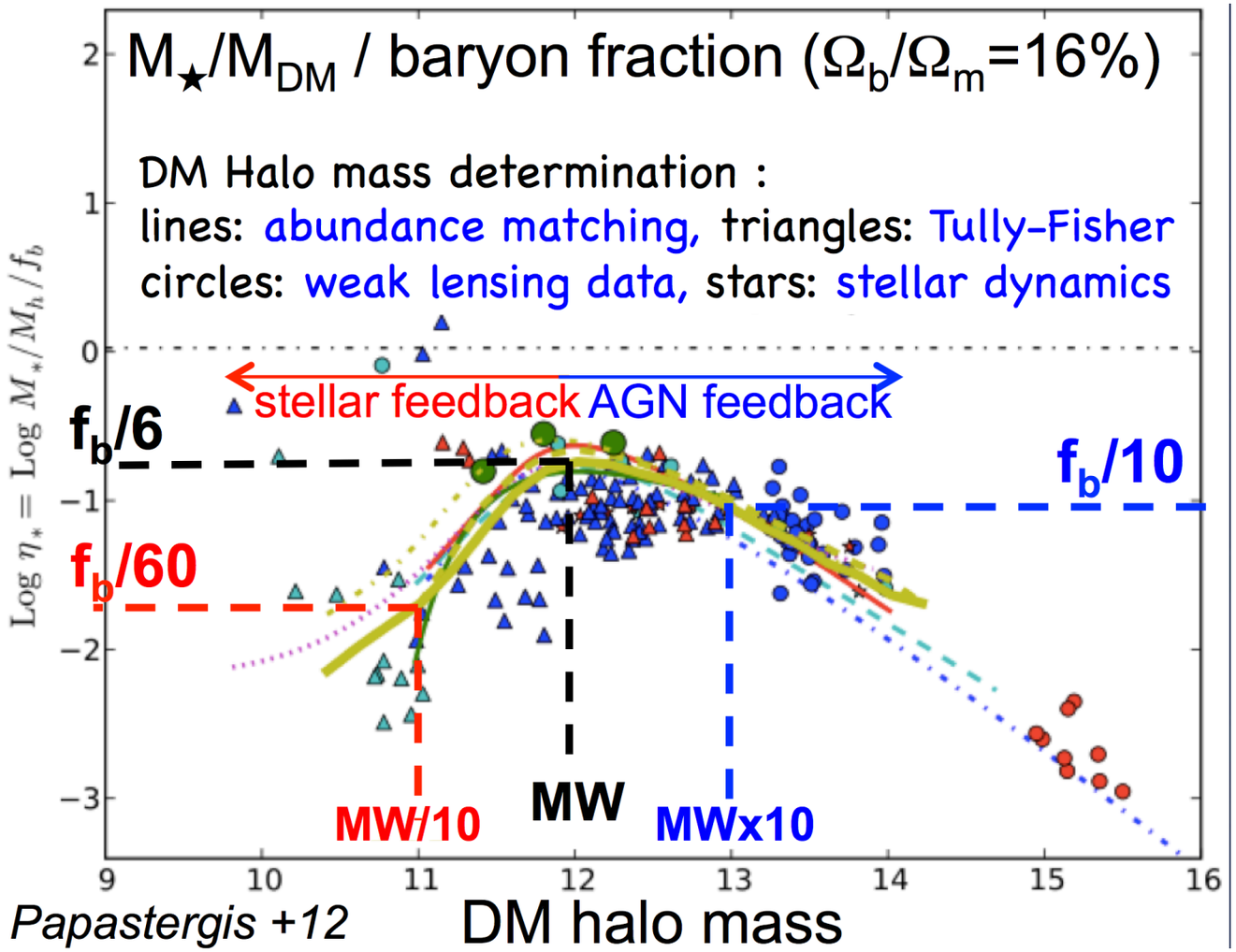




9904-83 - Kaneda et.al., 9904-142 - Sakon et.al

The resistance of baryons to cosmology sets the scene for SPICA

- **galaxy bimodality:** nearly 50% of stars in dead regions today
- **galaxy downsizing:** most massive galaxies formed first, then died
- **SMBH paradigm:** dead regions all possess a SMBH, $M_{BH}/M_{\star}$~1/1000 universally



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What causes star formation?
What stops star formation?
How did BH growth affect galaxy growth?

SPICA mission design drivers

Major science questions that require SPICA*

- What processes govern **star formation across cosmic time** - what starts it, controls it, and stops it?
  - What are the major physical processes in the most obscured regions of the universe?
  - How is this related to the enrichment of the universe with metals
- What is the **origin** and composition of **the first dust**, and how does this relate to present day dust processing?
- What is the thermal and chemical **history** of the **building blocks of planets**?

Established over the last few years by the joint Japanese-European-US science team, including community inputs through various workshops

** i.e. high sensitivity spectroscopy in the mid/far IR*

Extragalactic science goals

- ***What are the roles of star formation, accretion onto and feedback from central black holes and supernovae in shaping galaxy evolution over cosmic time?***
- ***How are metals and dust produced and destroyed in galaxies? How does the matter cycle within galaxies and between galactic discs, halos and intergalactic medium?***
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Star formation and black hole accretion

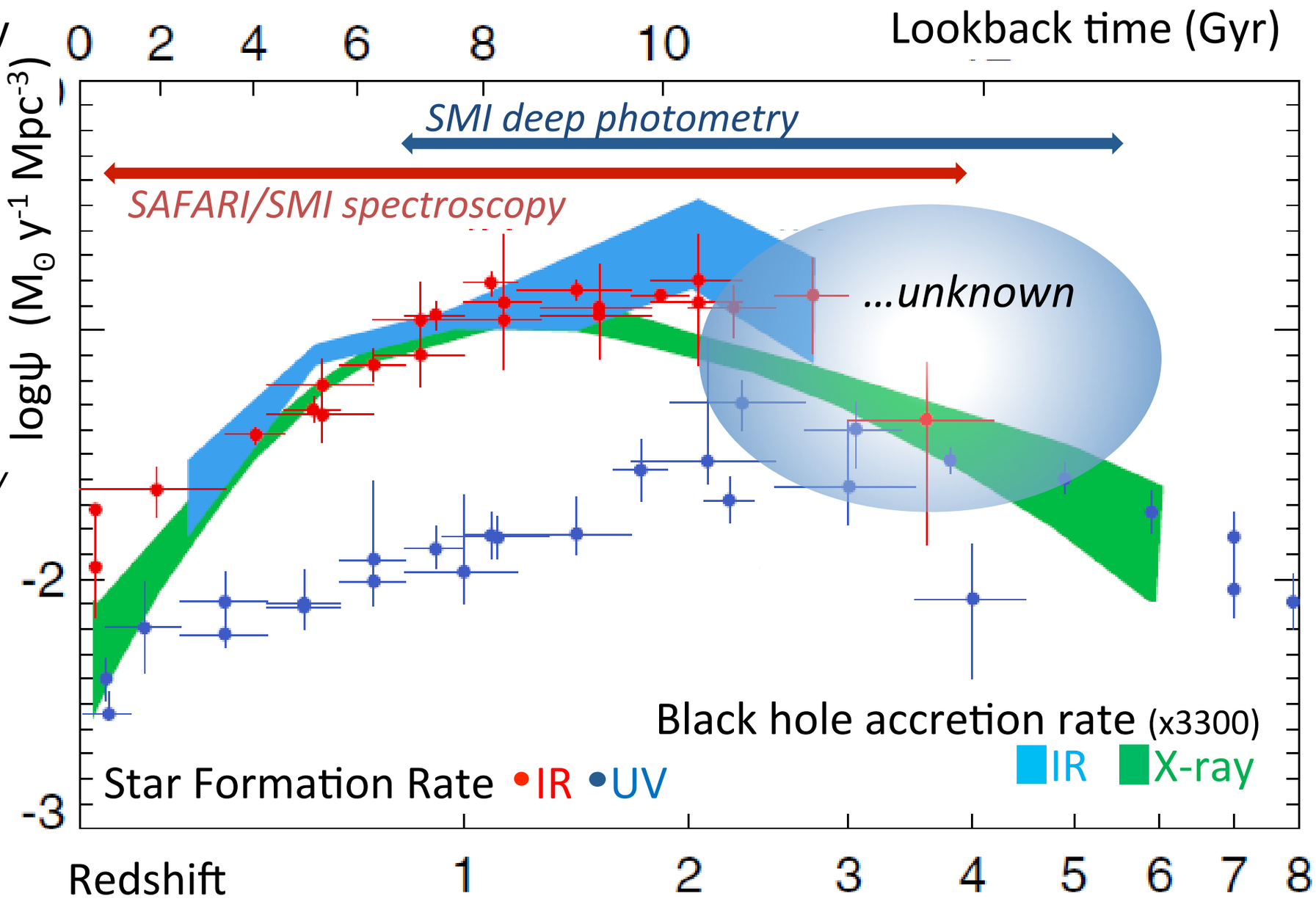
Why is the rate of galaxy evolution changing so dramatically over time?

SPICA spectroscopy will fully characterize 1000+ galaxies

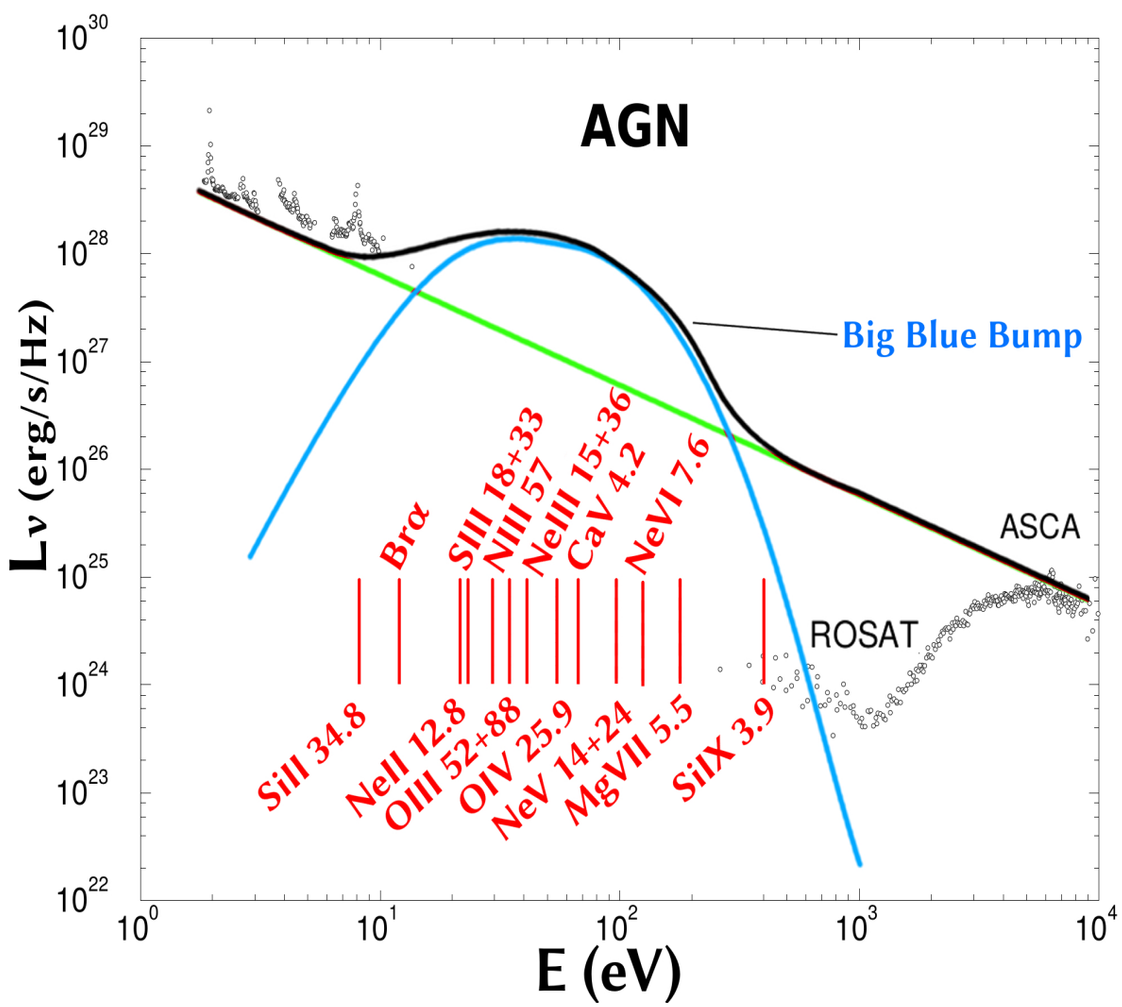
- Densities
- Metallicities
- Radiation field
- Outflow/infall

Deep photometry will extend traditional SED analysis to z~5/6

→ *We will redraw IR Madau/ Dickinson, i.e. unaffected by extinction, out to z~6*



Star formation/AGN line diagnostics



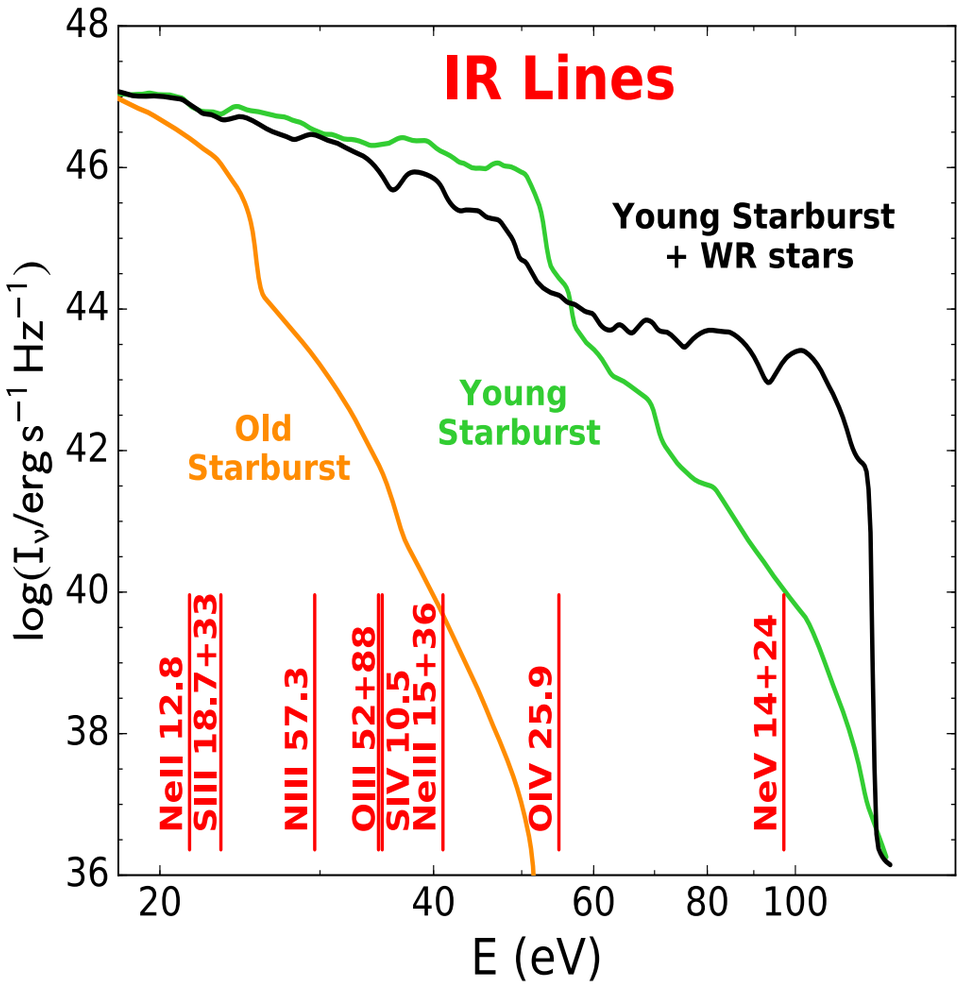


Figure 6. Left: Overlay of the NGC4151 primary ionising spectrum (black points) with a sketched *blue bump* and a power law (adapted from Alexander et al. 1999). **Right:** IR lines probe the starburst primary spectrum. being sensitive to the presence of Wolf-Rayet stellar winds or shocks and to the starburst age (models from Leitherer et al. 1999).

Spinoglio et al. in prep.

Star formation/AGN line diagnostics

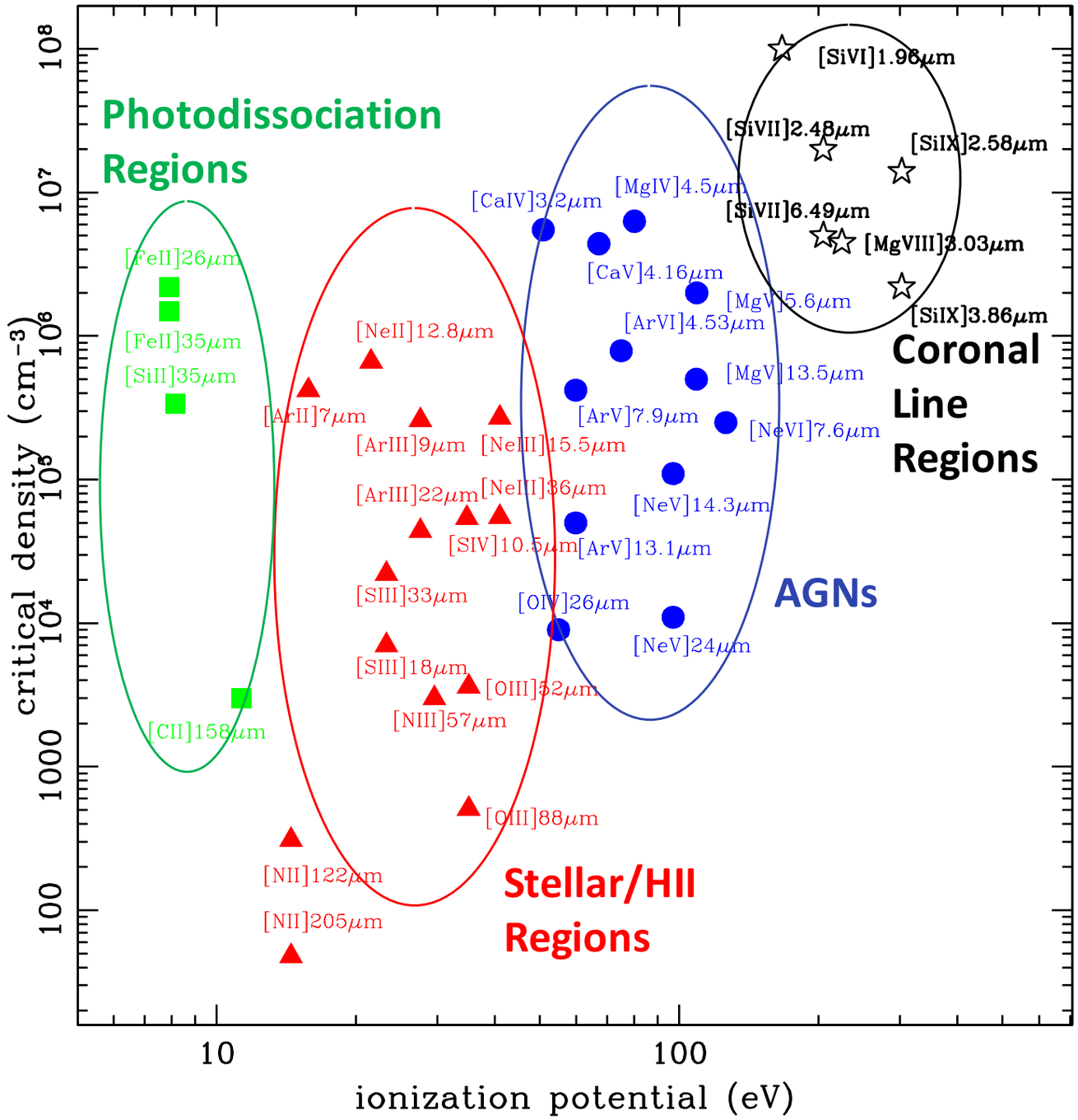


Figure 2. IR fine-structure lines cover a wide range in the ionization-density parameter space (Spinoglio & Malkan 1992).

SPICA M5 case

Star formation/AGN line diagnostics

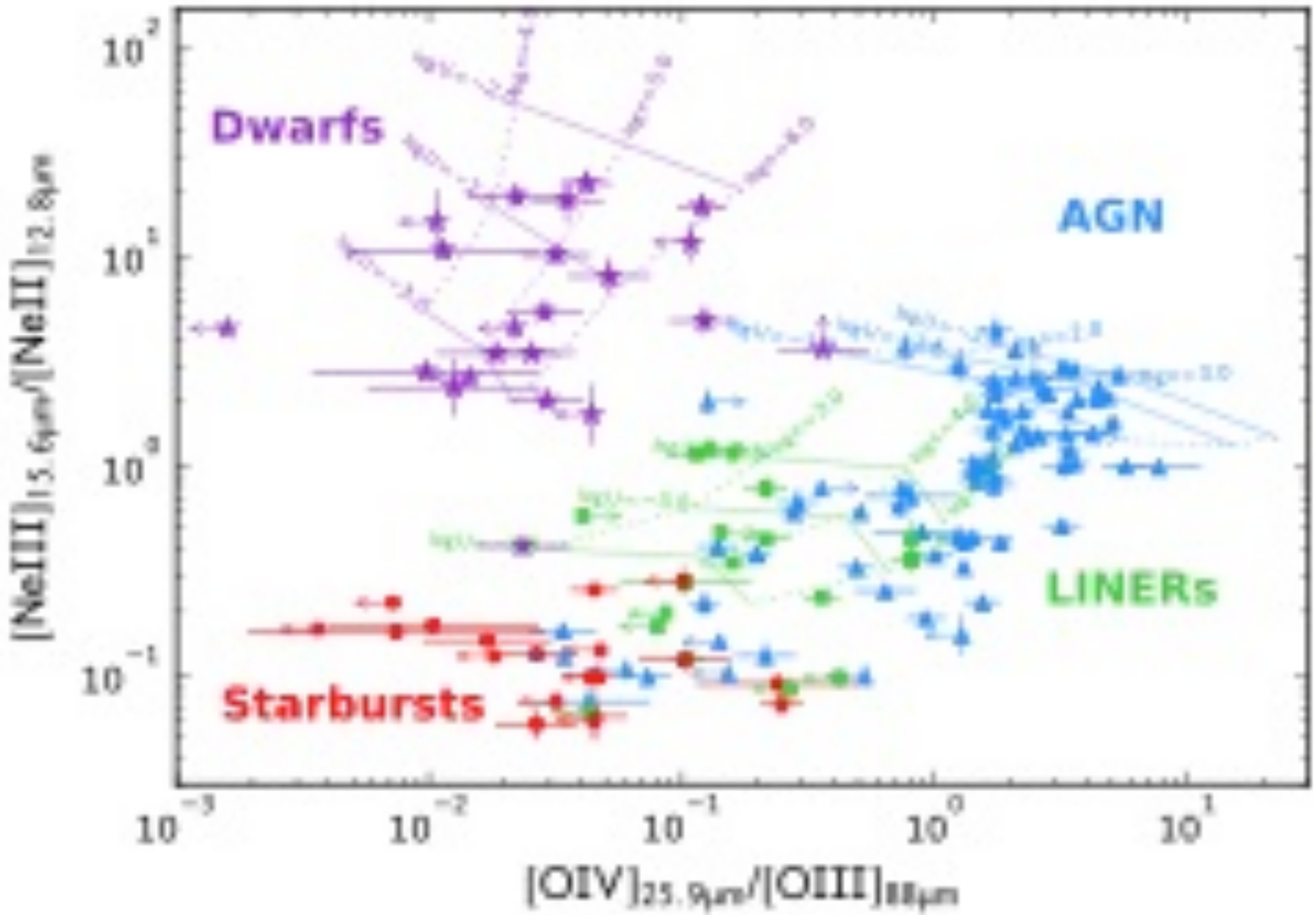
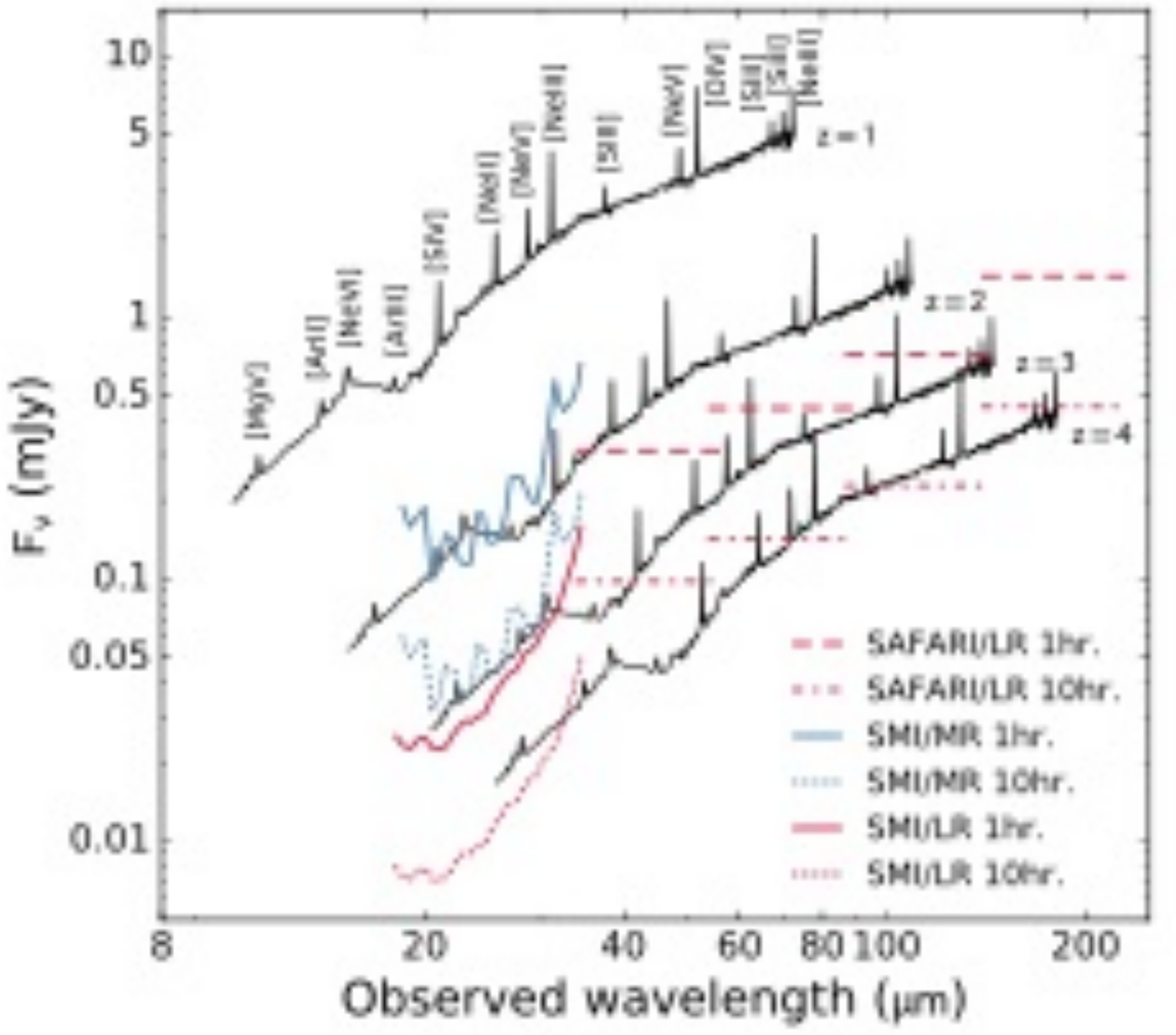


Figure 3. [NeIII]15.5μm/[NeII]12.8μm vs [OIV]25μm/[OIII]88μm line ratios compared to models for local Universe AGN, LINER, starburst galaxies, and dwarf galaxies (Fernández-Ontiveros et al. 2016).

Star formation/AGN line diagnostics

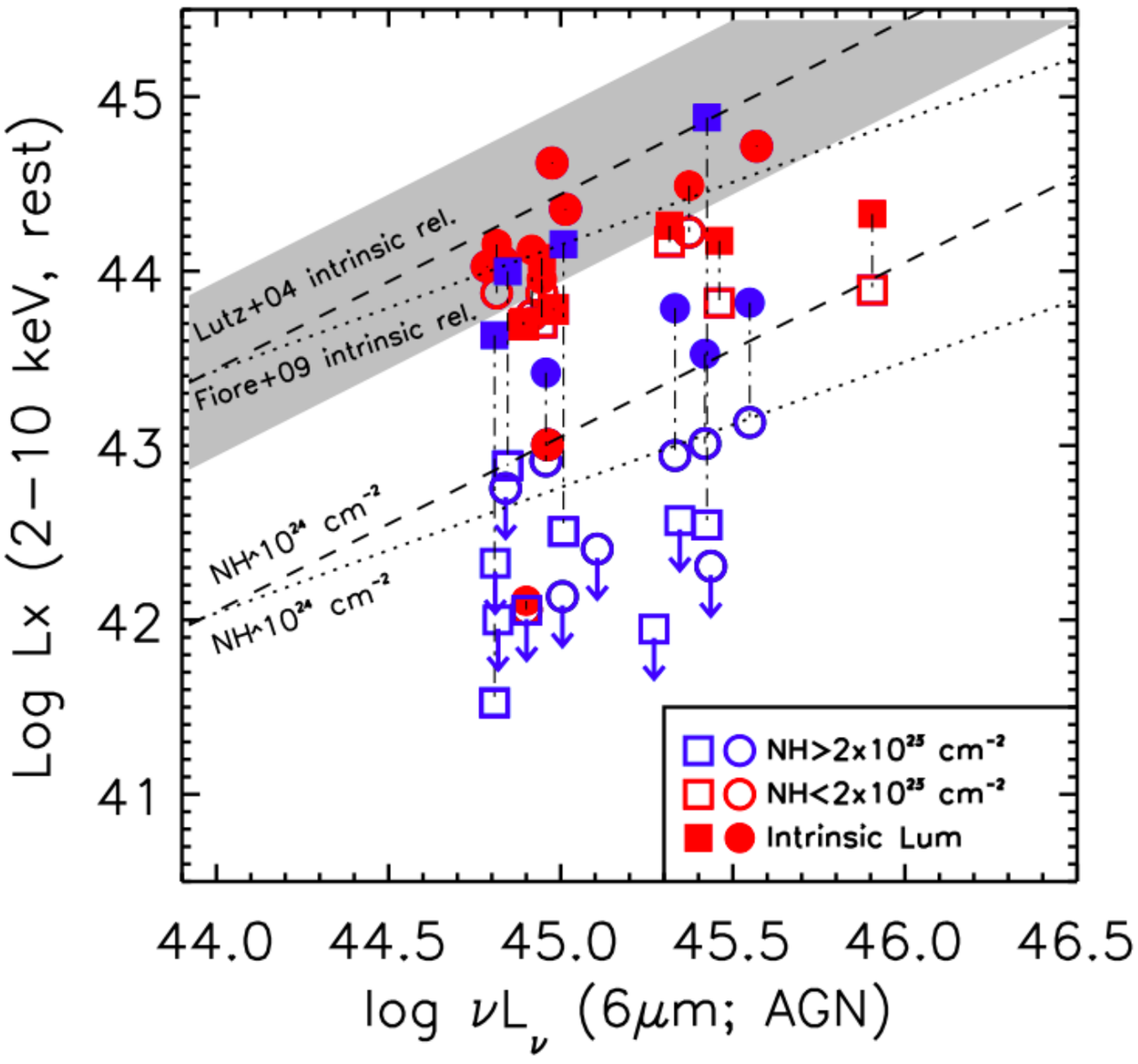


- IR spectrum of low-z AGN MCG-3-34-64, scaled to $10^{12}L\odot$ at z=1-4.
- At z=3, $L^*=10^{12}L\odot$
- 5σ SAFARI (low resolution) and SMI (medium and low resolution) are shown for integration times of 1 hr and 10 hrs.

Spinoglio et al. in prep.

Star formation/AGN continuum

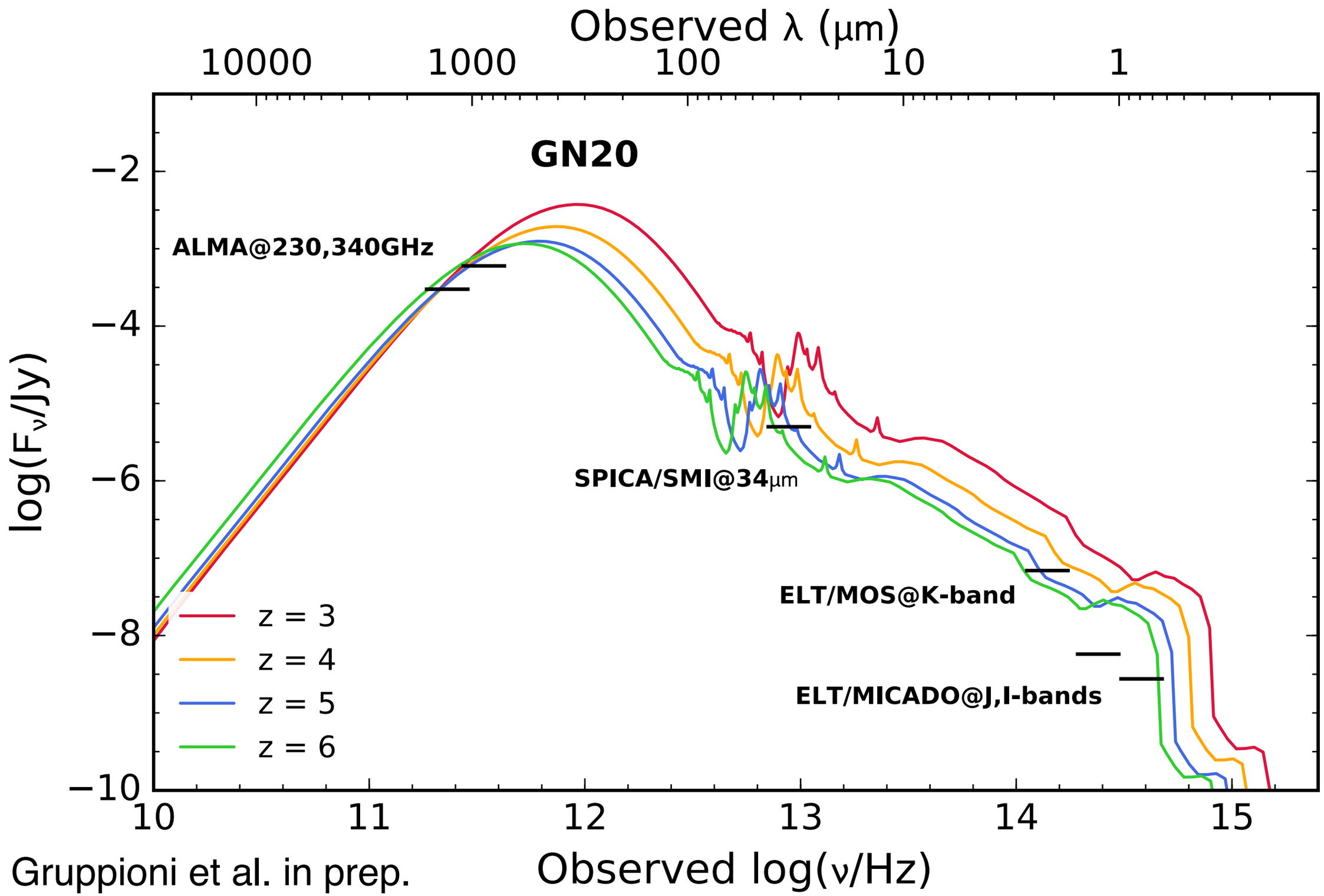
Incompleteness of X-ray surveys



- More than 25% of the AGN are undetected at X-rays while still visible in the mid-infrared via hot dust emission.

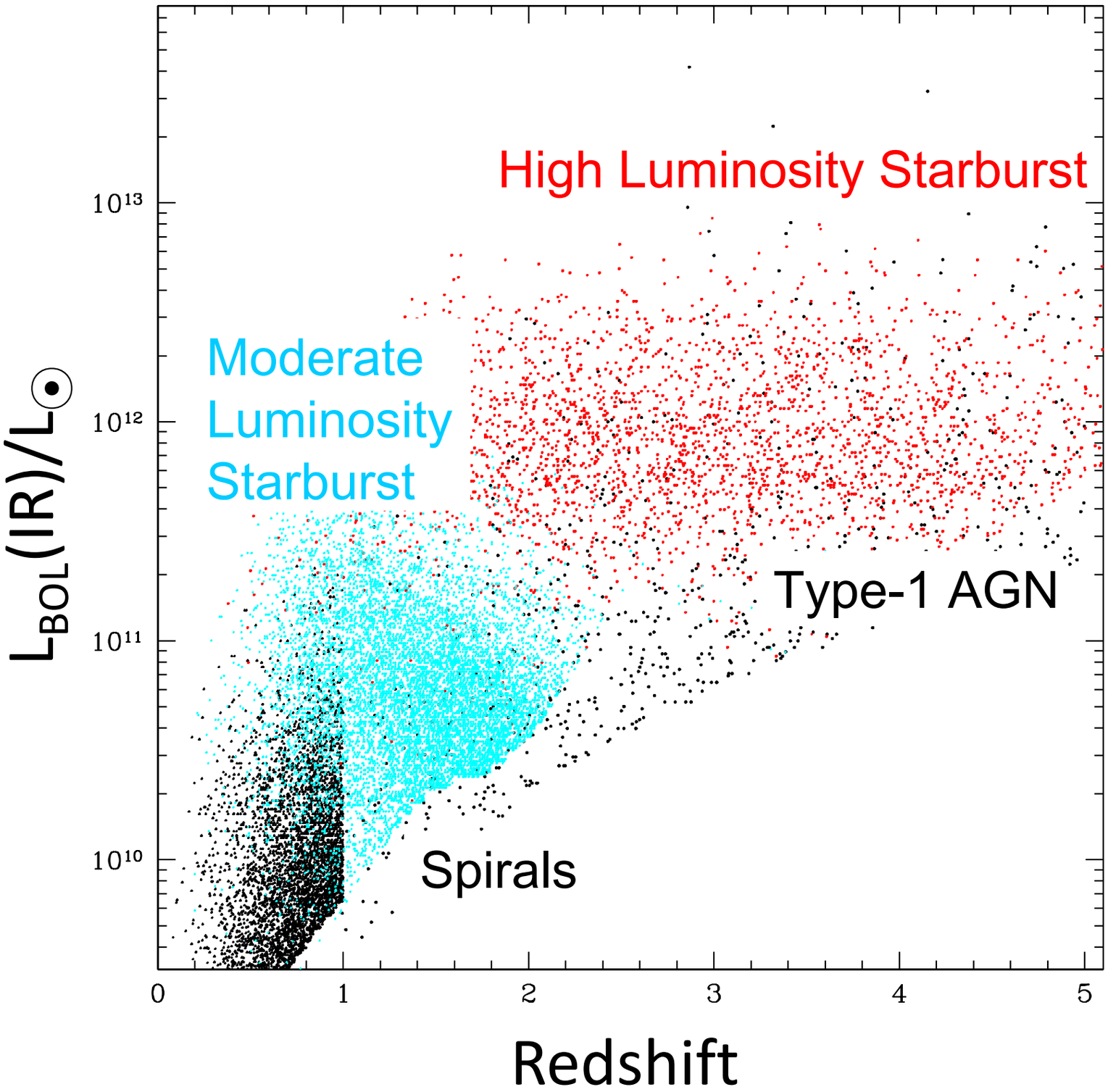
Spinoglio et al. in prep.

Star formation/AGN continuum



Gruppioni et al. in prep.

Star formation/AGN continuum



Gruppioni et al. in prep.

Summary 1

- **Feedback during the peak of AGN activity:** SPICA is the unique spectroscopic window to dusty AGN/ starburst diagnostics to z=3
- **Dust-obscured AGN over ~13 Gyr:** SPICA detects Compton-thick AGN out to z=5-6, unavailable to Athena

Extragalactic science goals

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Extragalactic science goals

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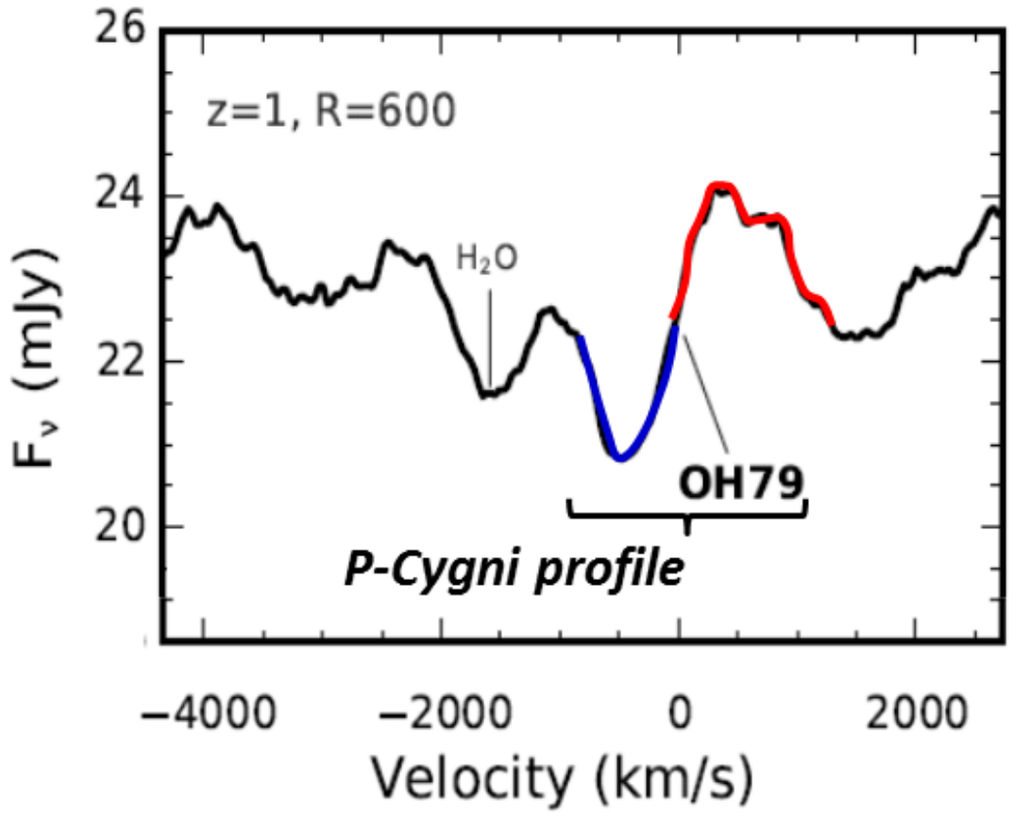
Feeding and feedback in galaxies



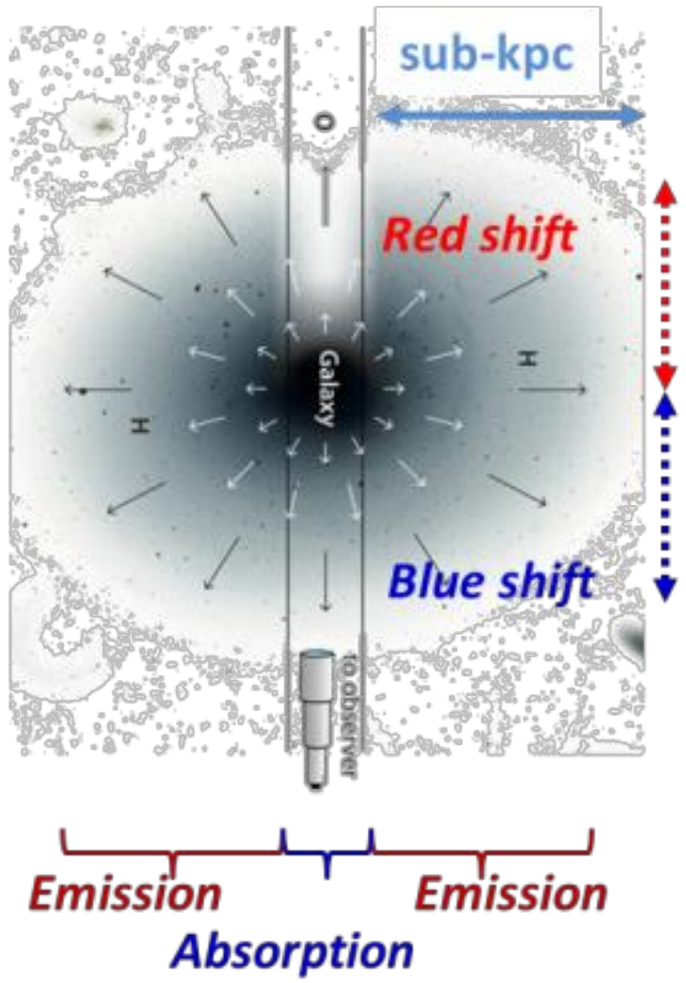


Figure 1-9 Simulated R~600 SAFARI/SPEC OH P-Cygni outflow spectrum for a L=2x10^{12} L$_\odot$. galaxy at z=1, based on Herschel/PACS observations of Mrk231 (Gonzalez-Alfonso et al. 2014; Spoon et al. 2013). SAFARI/SPEC will detect outflow and inflow motions in ULIRGs up to z~1-2.

M5 case

The rise of metals and dust

Dust-free, less dependence on electron temperatures

- SPICA will measure the metal build-up in the galaxies that represent more than 80% of the total star formation in the Universe, out to z=4.

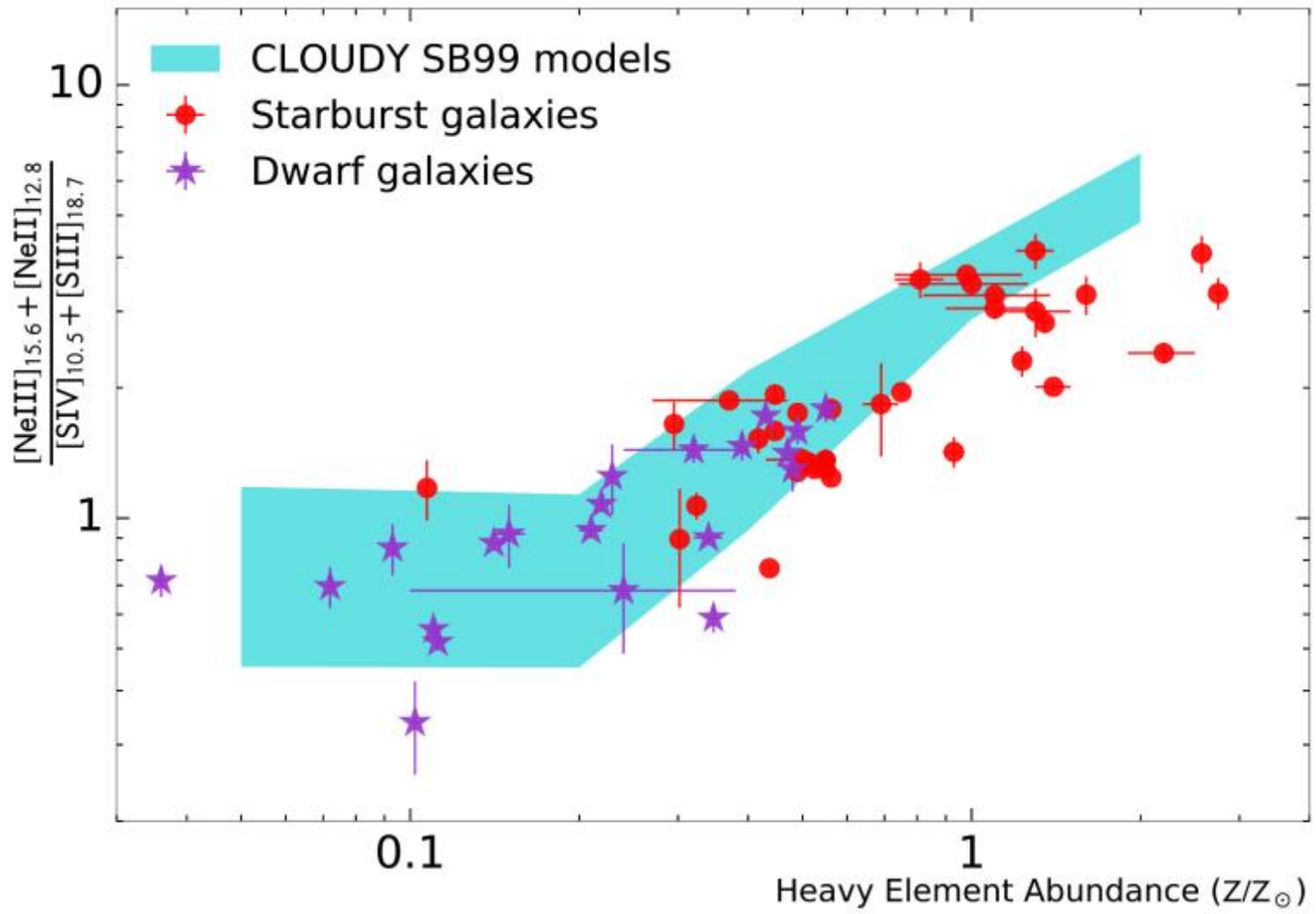
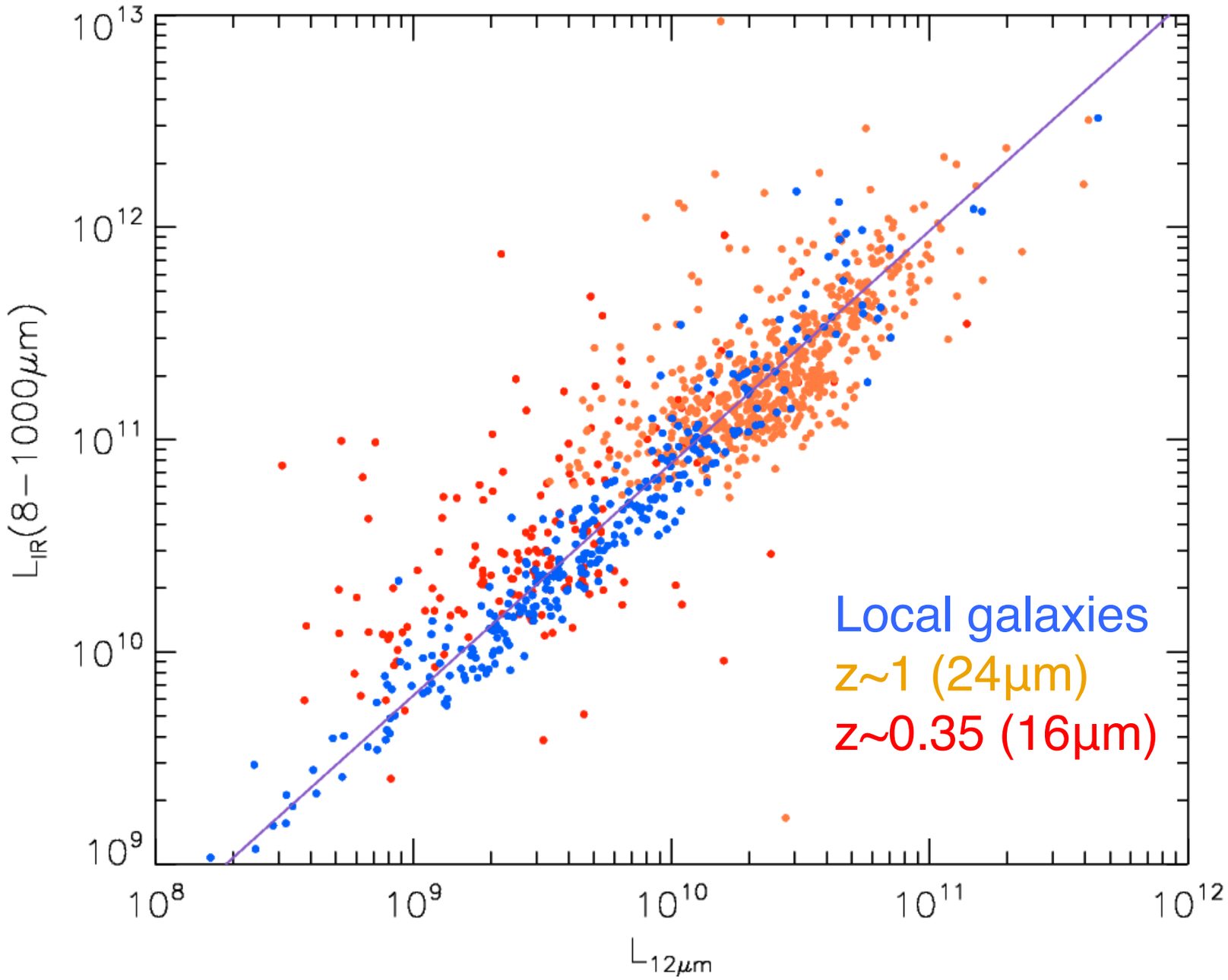


Figure 1-10 The ([Ne III] + [Ne II]) to ([S IV] + [S III]) ratio versus metallicity for local starburst and dwarf galaxies. Models predict values in the blue shaded area (Fernandez-Ontiveros et al. 2016).

Using hydrocarbons as calorimeters

- z~1 ultraluminous starbursts look like scaled-up Milky Ways in their PAH emission



D. Elbaz

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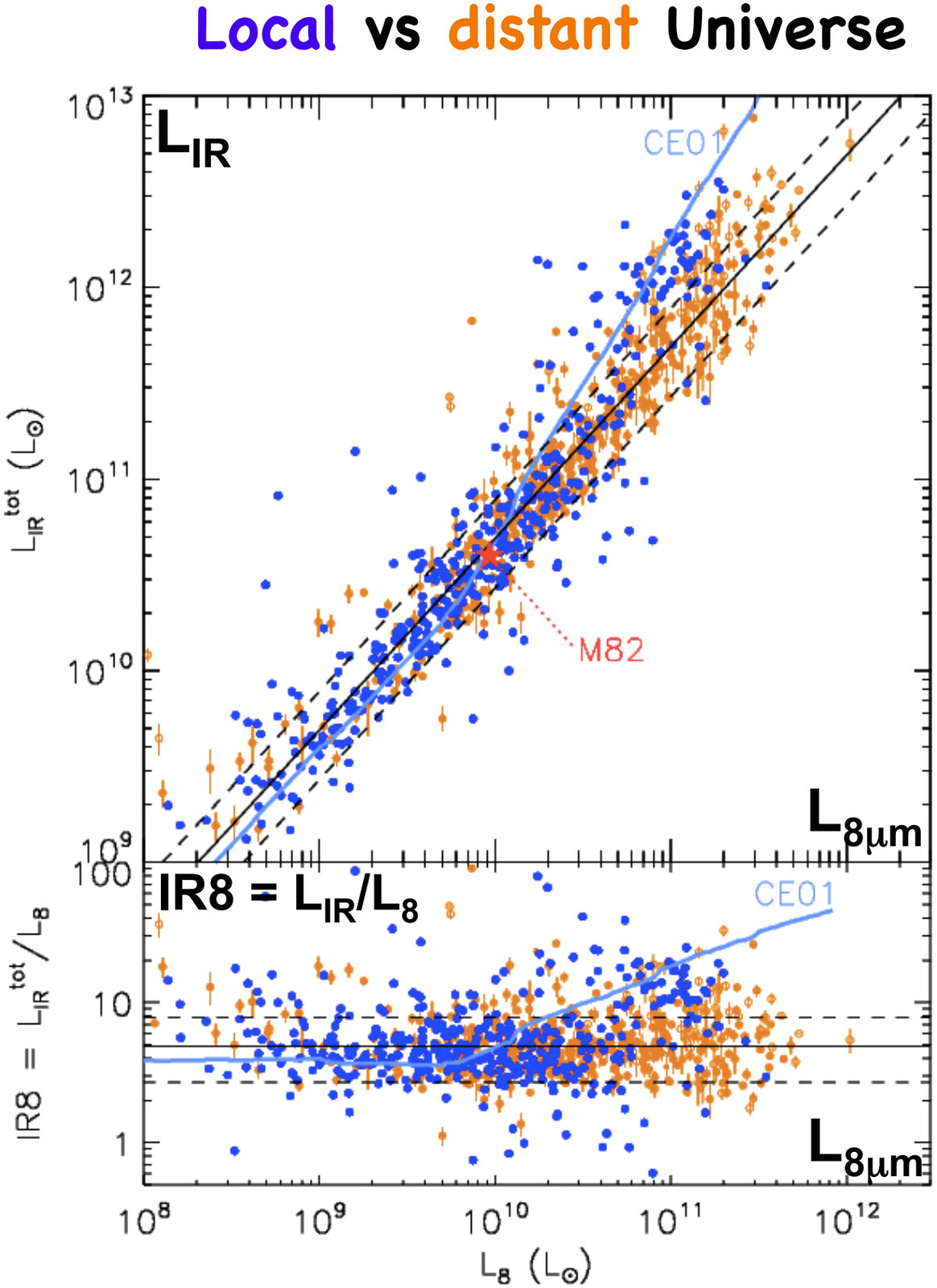

Dust in nearby galaxies

- SPICA will measure M_{dust} from evolved stars and SNe in nearby galaxies
- SPICA will measure mineralogy and composition in nearby galaxies (SiO_2, FeO, FeS and crystalline silicate features)
- How did galaxies evolve their chemistry? SPICA will trace the abundance and evolution of dust components within galaxies, constraining local physics (ionization, radiation field, dust structures and overall dust-to-gas ratios)

Summary 2

- **Outflows from AGN feedback:** SPICA detects PCygni OH lines out to z=1
- **The metallicity history of the Universe:** SPICA determines metallicities out to z=4 independent of obscuration
- **Dust production in the local Universe:** SPICA determines mineralogy of dust components within galaxies

Extragalactic science goals

- ***What are the roles of star formation, accretion onto and feedback from central black holes and supernovae in shaping galaxy evolution over cosmic time?***
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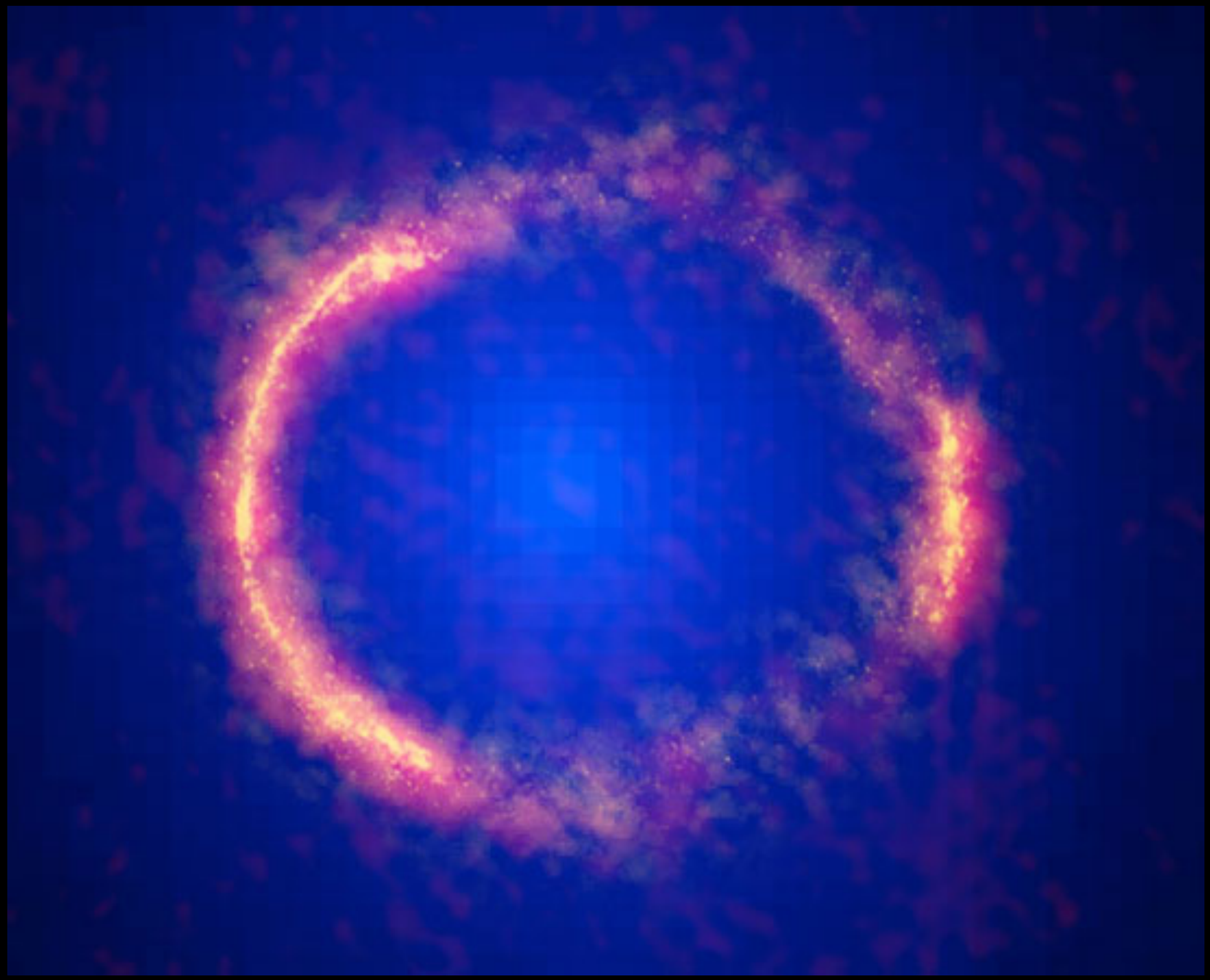
Extragalactic science goals

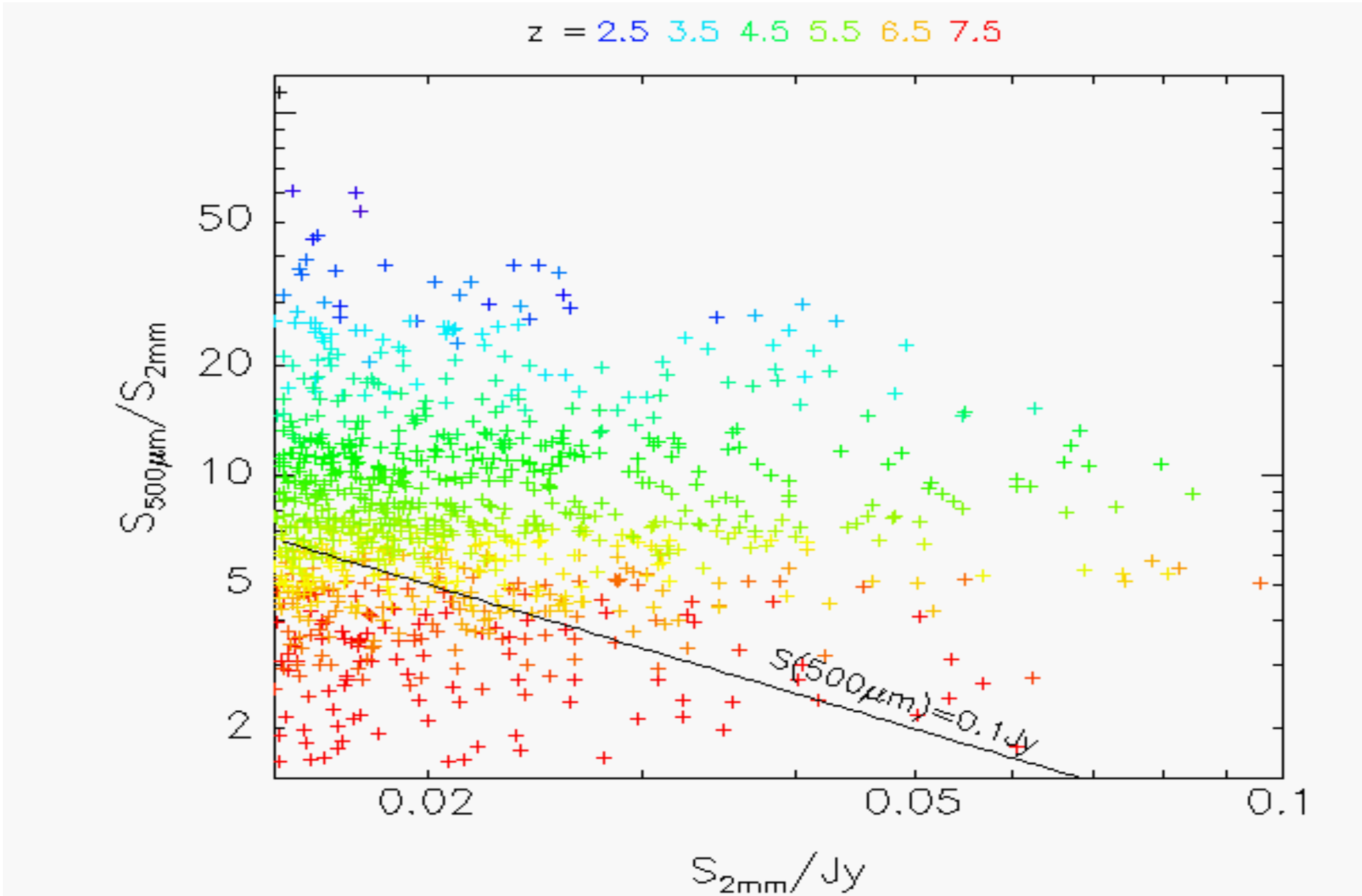
- ***How did primordial gas clouds collapse into the first galaxies and black holes?***

Towards reionization



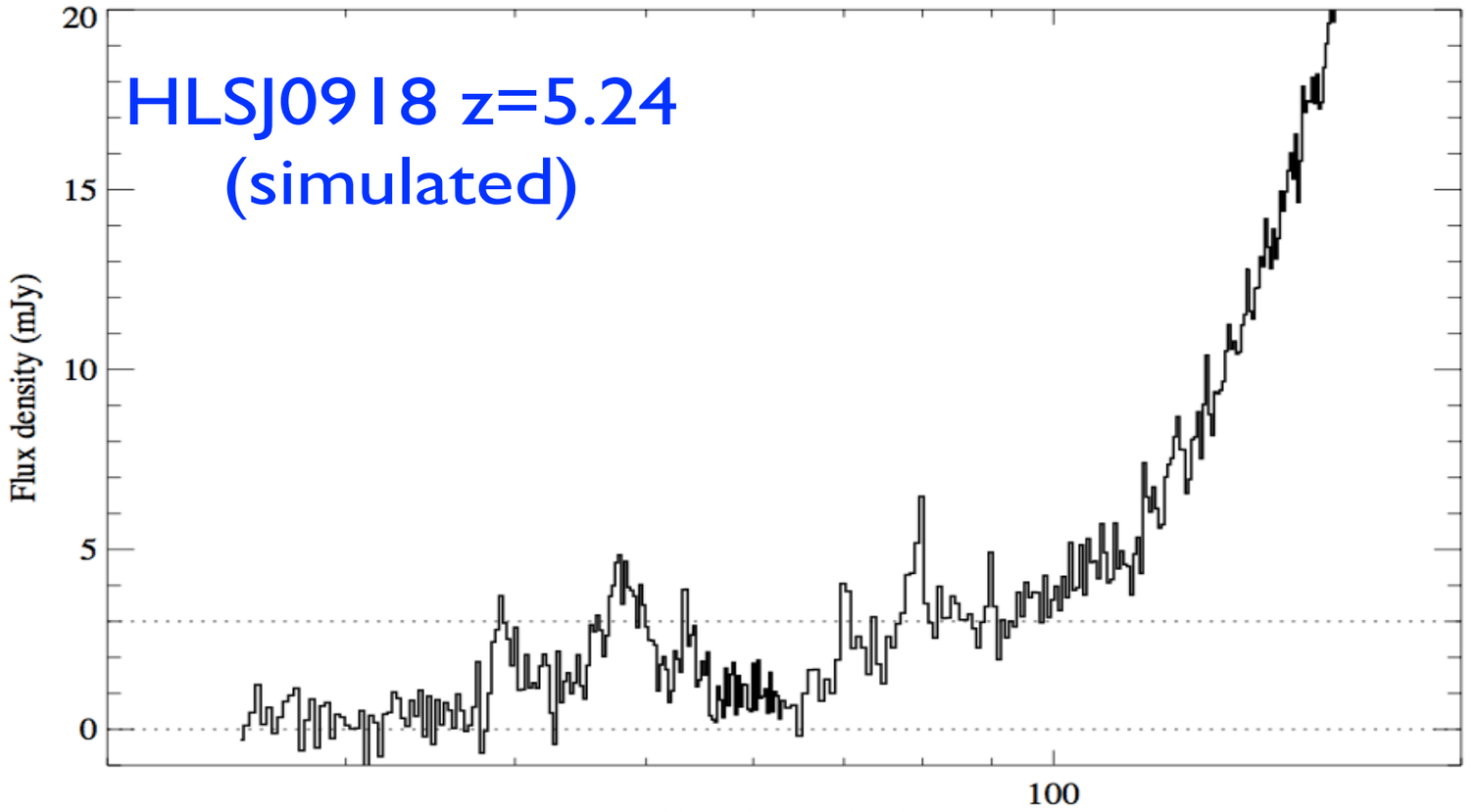
ALMA (NRAO / ESO / NAOJ); B. Saxton (NRAO / AUI / NSF); Hubble (NASA / ESA); T. Hunter (NRAO).

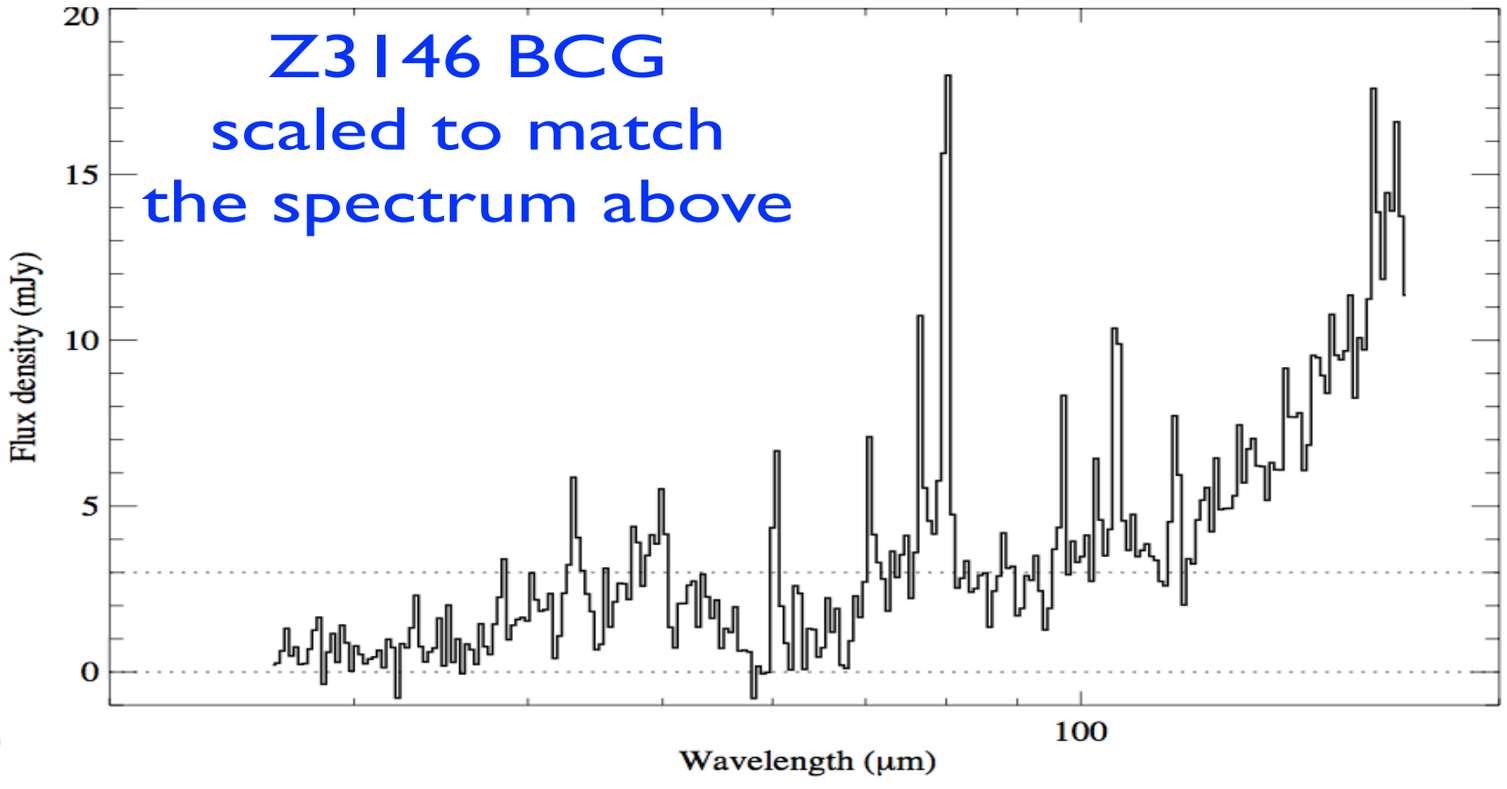
Towards reionization



Egami et al. in prep

Towards reionization





Egami et al. in prep

Towards reionization

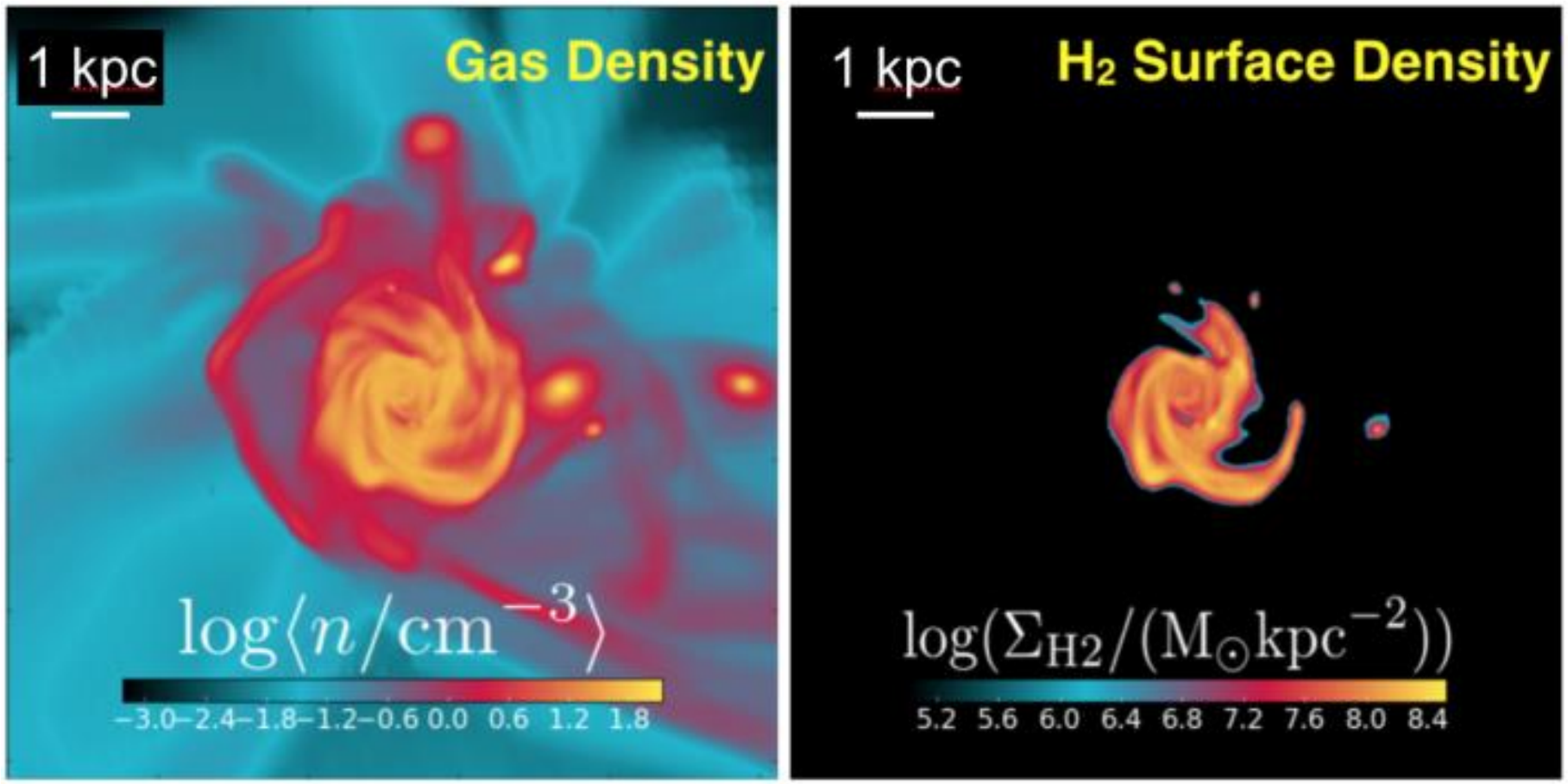


Figure 1-13 Hydro-dynamical simulation of a z=6 galaxy. Note the complicated structure, due to the merging of sub-halos. Such a dynamic environment should produce strong shock-excited H_2 emission.

Towards reionization

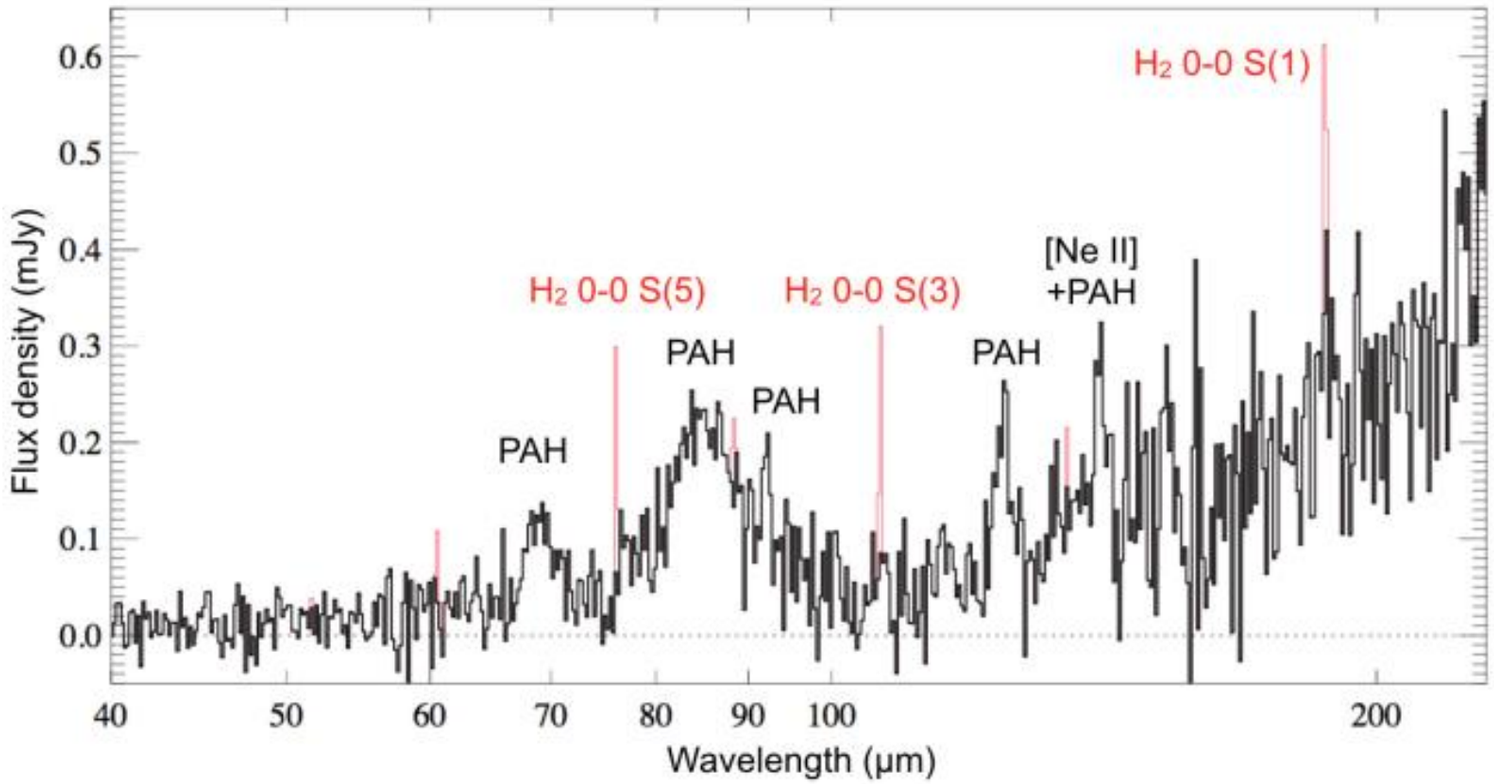
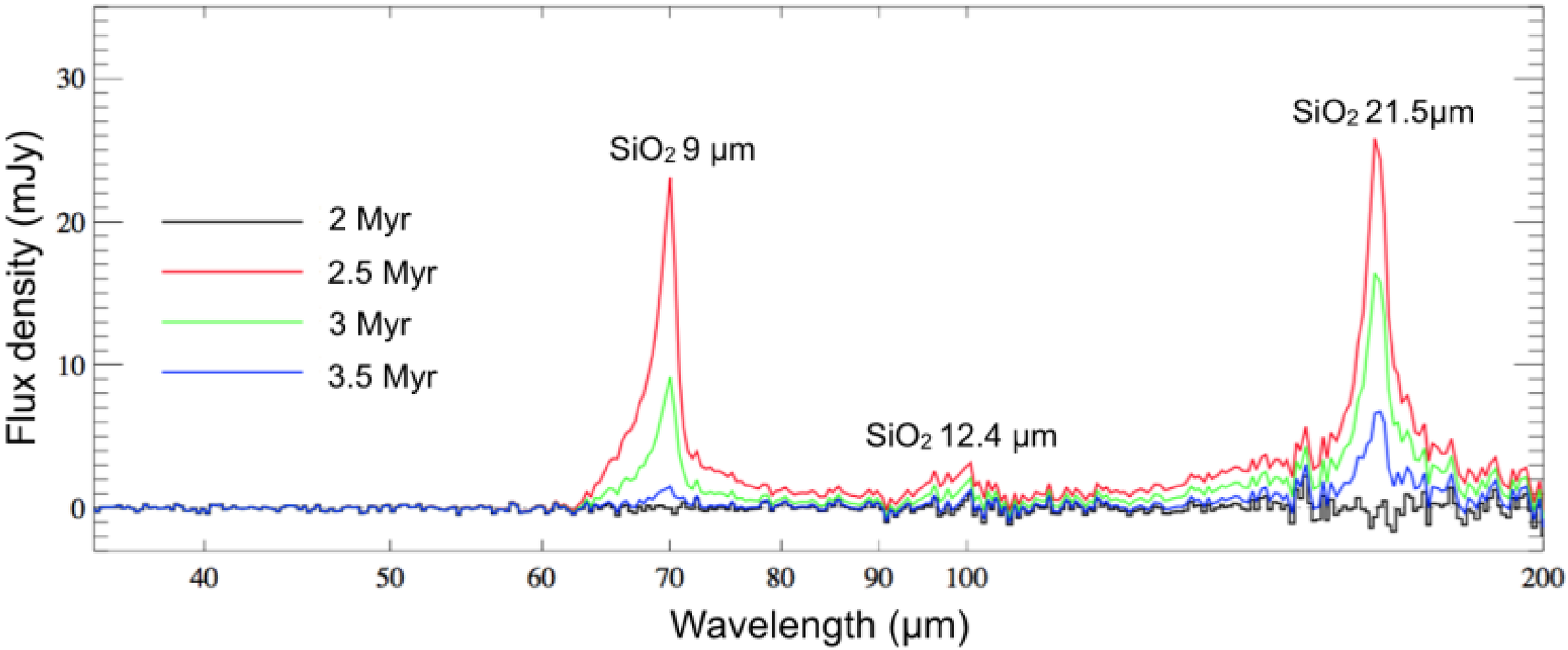


Figure 1-12: Simulated SAFARI/SPEC spectrum of an $L_{IR}=10^{13}\ L_{\odot}$ ULIRG at z=10 (Rieke et al. 2009). The red lines show simulated shock-excited (thermalized) H_2 emission lines produced by $3x10^{10}\ M_{\odot}$ of T=200 K gas and $3x10^{8}\ M_{\odot}$ of T=1000 K gas. Line fluxes for the S(1), S(3) and S(5) lines of 3 to 7 $x10^{-20}$ W m^{-2}, are predicted; detectable with SAFARI in only a few hours.

Egami et al. in prep

Towards reionization

Excited quartz from PopIII SNe



Simulated SAFARI spectrum produced by a burst of a 10^6 $M_\odot$ Pop III star cluster at z=7 with a top-heavy (50- 500 $M_\odot$) Salpeter-like IMF surrounded by a thin dust shell at 30 pc. The models of Pop III star spectral evolution (Zackrisson et al. 2011) and dust production (Schneider et al. 2004) were used in combination to make this prediction.

Summary 1 2 and 3

- The only spectroscopic diagnostics of dusty AGN/starbursts, and Compton-thick AGN out to z=5-6
- Metallicity history of the Universe out to z=4, OH outflows to z=1, dust mineralogy in local galaxies
- Completely unexplored galaxy physics at ultra-high-z: the first organic molecules, shock-heated H2, quartz from PopIII

gunmerchant, Charleston, United States, 6 months ago

Ten billion light years? I'm calling BS on this article.

Click to rate 9 38

Jimy The Face, sweetymice, Micronesia, 6 months ago

Complete BS, the earth if flat, None of these photos are real, They are all CGI. Why are there no real photos of earth from space. Why is there not a constant video feed of our earth? Simple because the earth id flat and there is no outerspace. Its all nonsense designed by NASA to keep you under control. God made the earth and it is flat and does not move.

Click to rate 4 34

Confiteor Deo, Tallinn, Estonia, 6 months ago

Stars are just lights in the sky and gravity doesn't exist

Click to rate 1 43