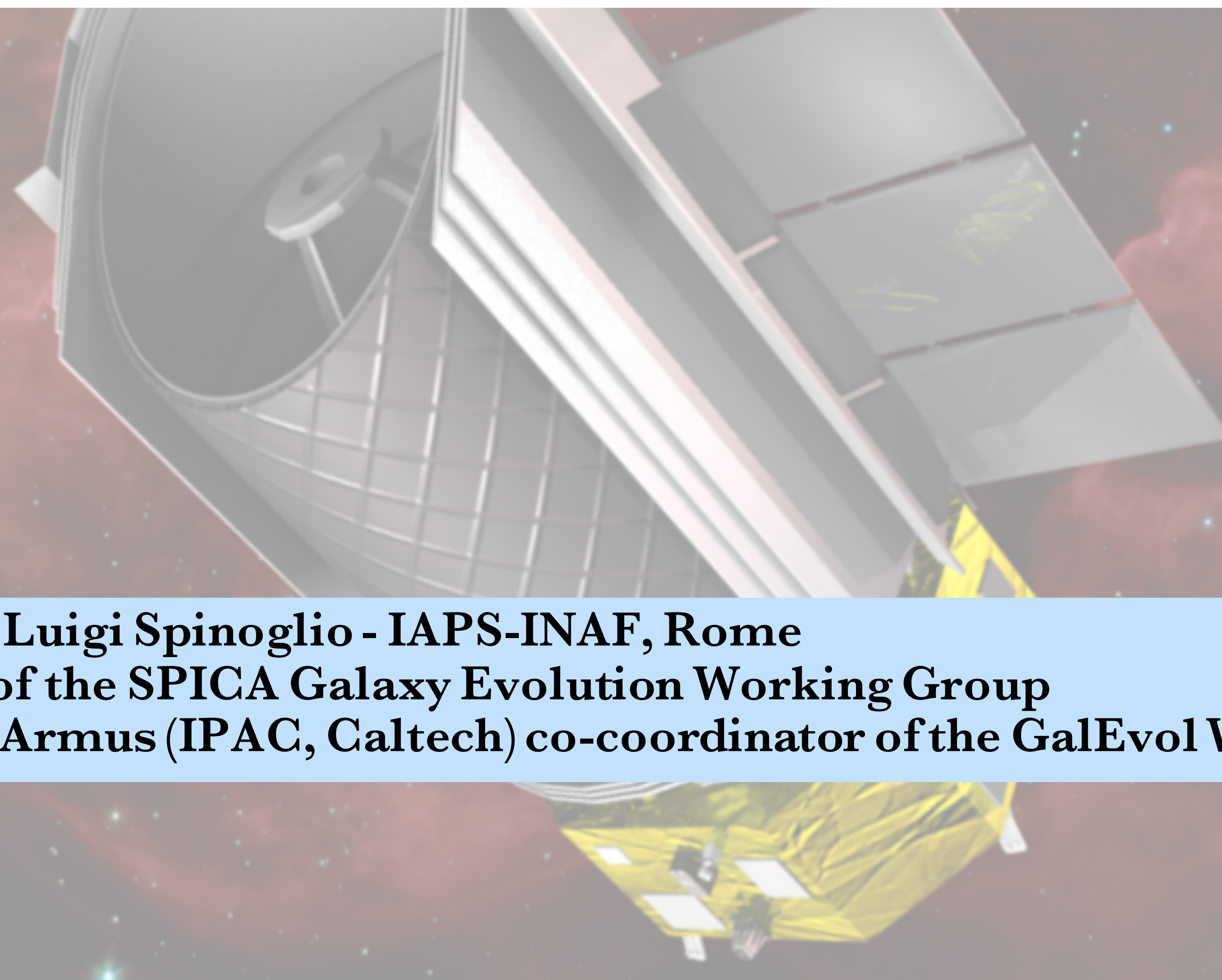
Galaxy Evolution with SPICA



Luigi Spinoglio - IAPS-INAF, Rome
On behalf of the SPICA Galaxy Evolution Working Group
special thanks to Lee Armus (IPAC, Caltech) co-coordinator of the GalEvol WG

SAFARI is a new grating spectrometer onboard on a new SPICA mission — new technology cryocooler telescope

The sensitivity improvement obtained from the change to a grating spectrometer (by about a factor 8) allows us to measure "main sequence" (L*, ie at the knee of the luminosity function) galaxies up to a redshift of z=3.

This is needed to prove both the Black Hole Accretion and the Star Formation processes at the peak of their activity, while building up ~90% of the stars, ie. the bulk of the stellar populations in galaxies.

Rest-frame IR spectroscopy is an essential tool to study Galaxy Evolution in the redshift range z=1-3, where the bulk of SF and AGN growth occurred, because at these epochs galaxies and AGNs were deeply embedded in dust.

Moreover rest-frame IR spectroscopy provides a complete set of diagnostic lines and features, uniquely probing the atomic and molecular ISM. This allows to obtain a precise physical characterisation of the processes leading evolution.

The main astrophysical questions we want to address in the M5 Proposal :

- **What processes start, regulate, and eventually stop star formation in the Universe ?**
- **What are the relative contributions of nuclear fusion (stars) and gravitational potential energy (accreting black holes) to photon production after Re-ionization ?**
- **What is the origin and composition of the first dust in the Universe, and when did it arise ?**

SPICA will uniquely perform observations that will:

- **Study the physical conditions (ionization, density, metallicity, extinction) in the interstellar medium in dust obscured galaxies before and after the SFRD peak at z~2.**

- **Trace star formation and SMBH accretion in large samples of L* galaxies to z ~3 as a function of galactic environment**

- **Study the detailed interactions between SF and SMBH growth, including AGN feedback, molecular and atomic outflows, and gas inflow out to z~1-1.5**

- **Detect dust during the epoch of re-ionization and chart the production of heavy elements and organic molecules in the interstellar medium of galaxies as a function of cosmic time.**

Main goals: they define the proposal outline and the instruments to be used

This talk:

1. BH accretion and Star Formation histories — SAFARI+SMI spec.

2. AGN and Starburst feedback and feeding — SAFARI (2000-10000) + SMI

3. Metallicity evolution — SAFARI +SMI spec

Next talk by Carlotta:

[4. Clustering and large scale structure — SMI spec. map. + imaging]

5. Beyond redshift 3: the epoch of re-ionization — SAFARI spec + SMI spec. map. + imag.

5.1: the first black holes

5.3: the first stars and the rise of dust

Comparing different wavelengths for separating AGN and SF

No single criteria distinguish AGN & SF ➔ limits and potentialities of different techniques

– UV/Optical/NIR observations ➔ galaxy morphology and spectra,
BUT they seriously suffer from dust obscuration

– X-ray observations ➔ good tracers of AGN,
BUT only weak X-ray emission can be detected from star formation
BUT heavily-obscured AGN (Compton-thick) completely lost.

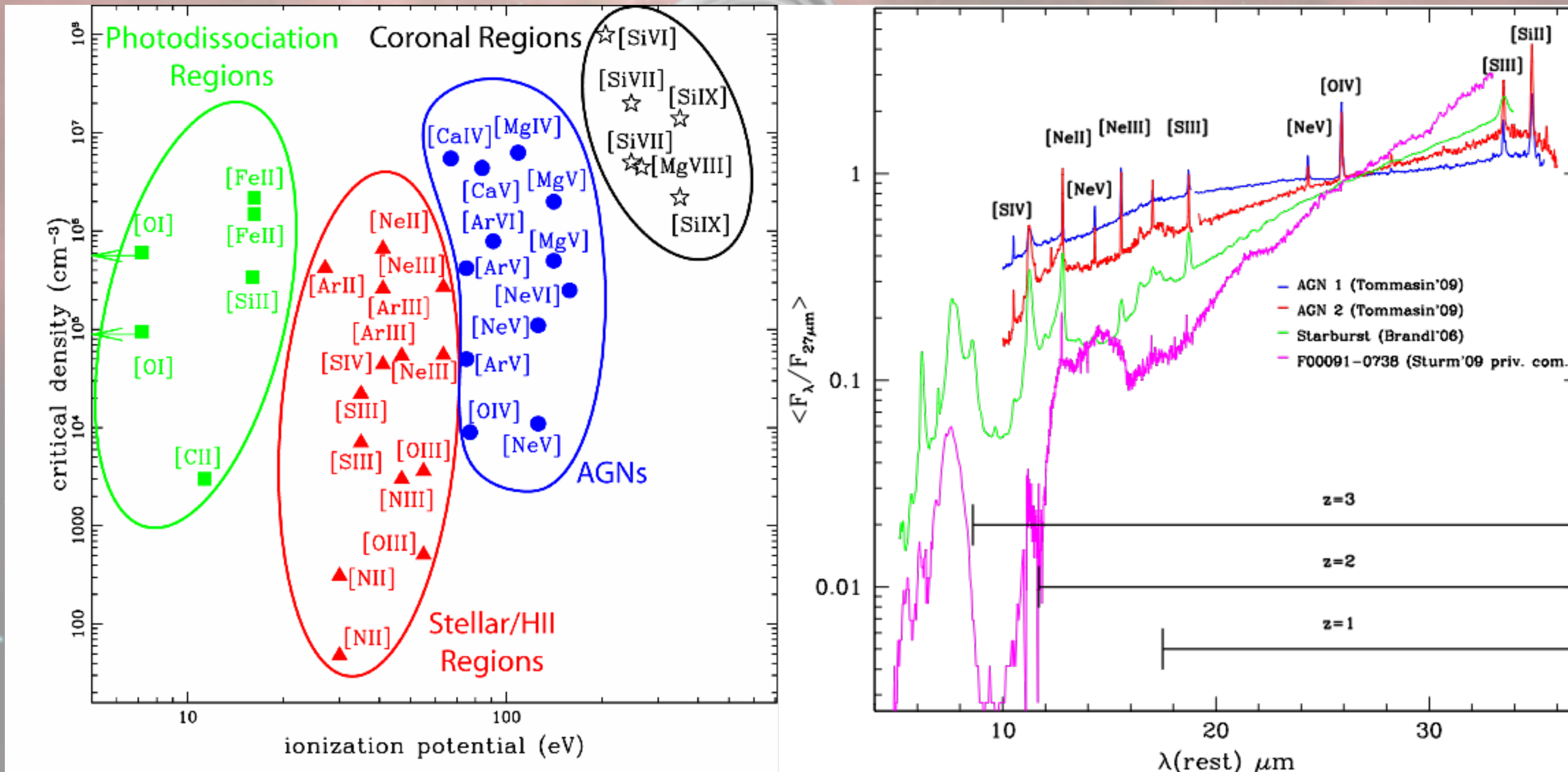
– Radio observations (EVLA, SKA) ➔ can detect AGN and SF to large z and can see through gas and dust, ➔measure morphology and spectral SED, detect polarization and variability, BUT not always redshifts can be measured. (at its highest frequencies SKA will measure redshifted molecular lines in the ISM of galaxies).

– mm/submm observations (e.g. ALMA, CCAT) ➔ spectra from SF (redshifted CO, CII, etc.), BUT need to find AGN tracers. CO SLED different from PDR (SF) and XDR (AGNs), however it is not an effective AGN vs. SB discriminator.

Rest-frame MIR/FIR spectroscopy ➔ complete view of galaxy evolution and the role of BH and SF because it can:
trace simultaneously both SF and AGN,
➔ measure redshifts

➔ see through large amounts of dust.
➔ the most promising technique.

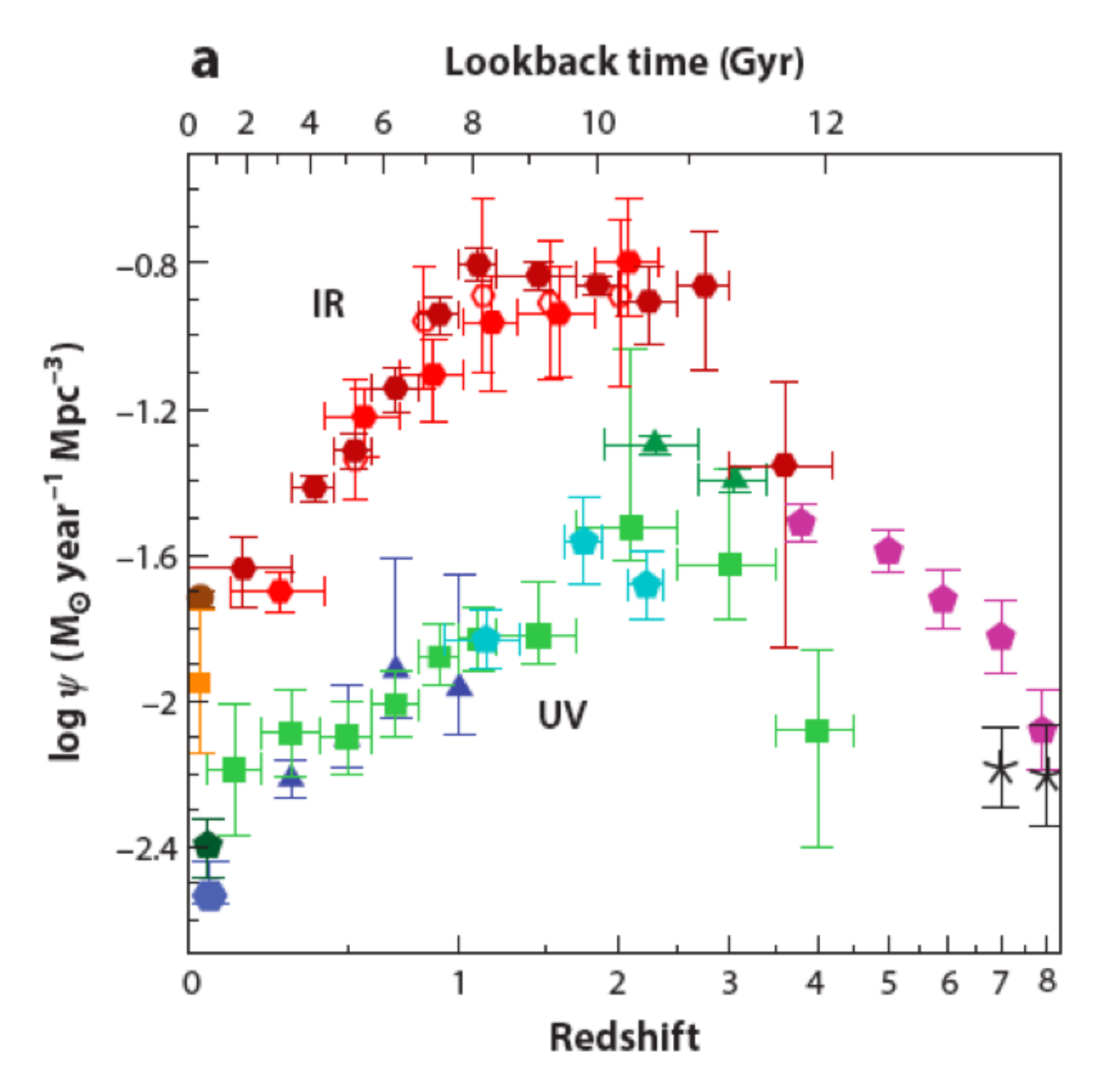
The power of IR spectroscopy

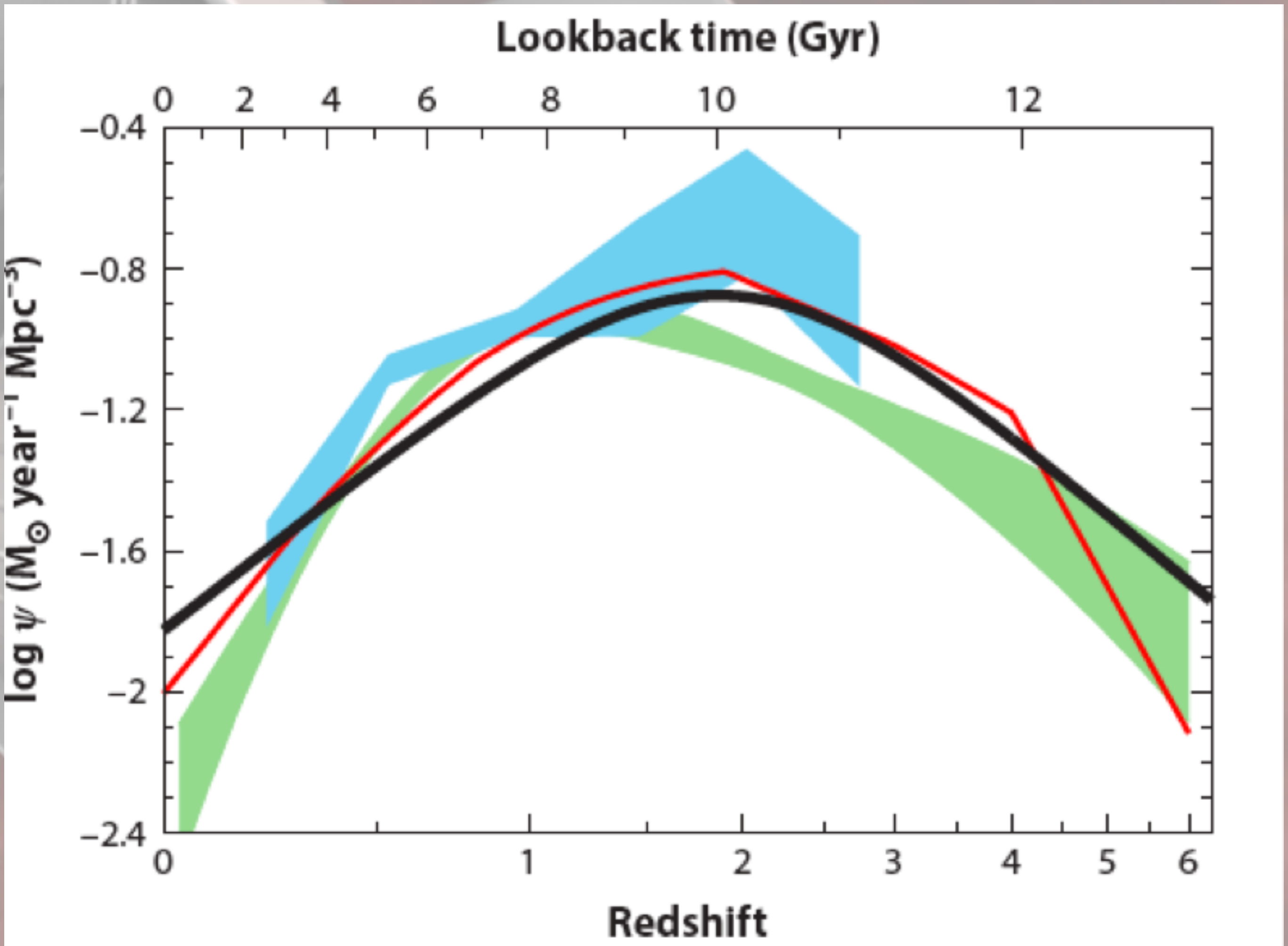


(**a: Left**) IR fine-structure lines covering the ionization-density parameter space (Spinoglio & Malkan 1992). (**b: Center:**) Starburst and AGN template spectra (normalized at 25μm) showing the key diagnostic emission lines in the mid-IR, **all of which will be detected by SPICA**.

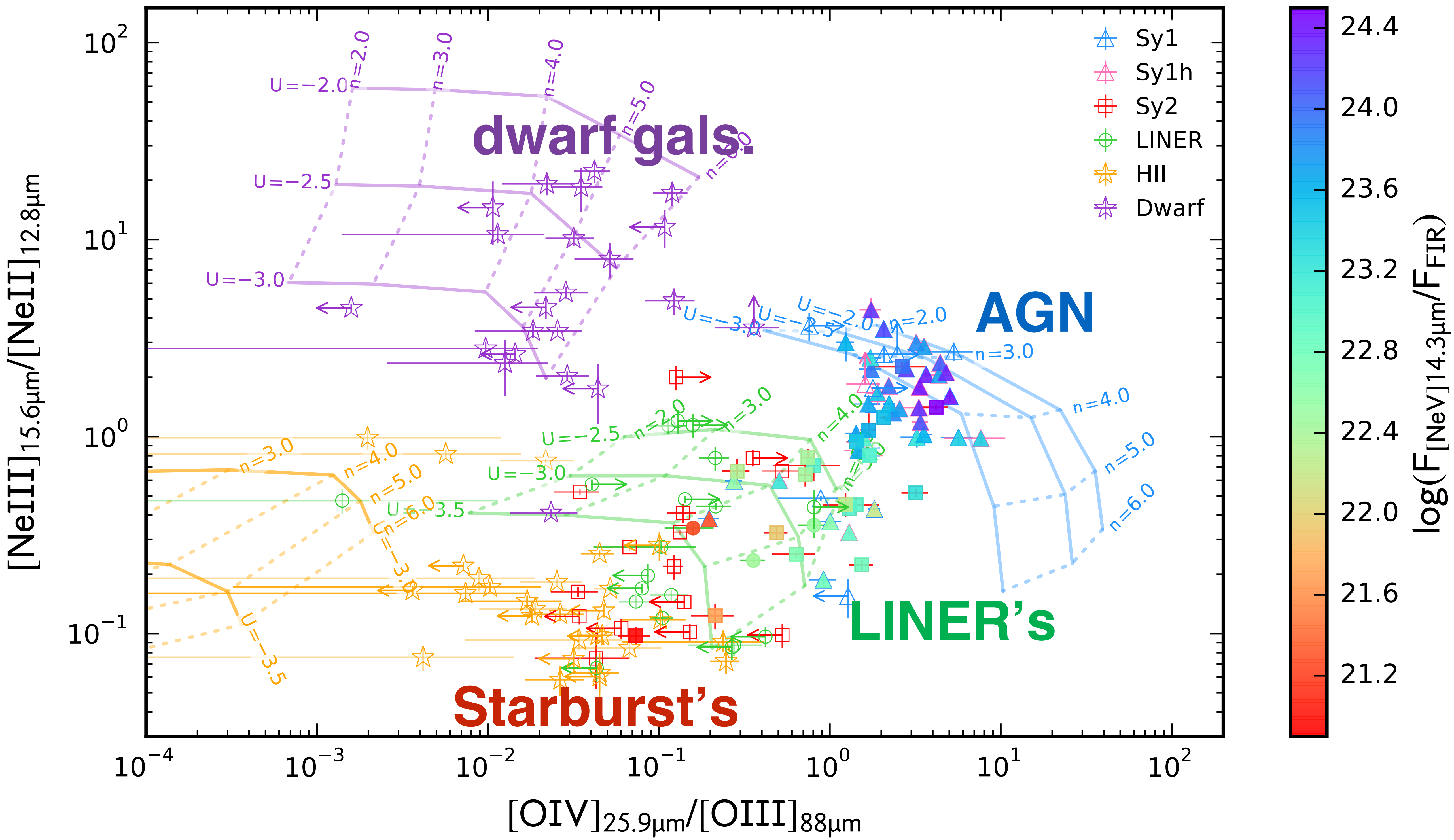
1. Physical conditions of Star Formation and Black Hole Accretion

- *What processes start, regulate, and eventually stop star formation in the Universe ?*
- *What are the relative contributions of nuclear fusion (stars) and gravitational potential energy (accreting black holes) to photon production after Re-ionization ?*
- *What are the physical processes in the most obscured regions in the Universe though cosmic time?*





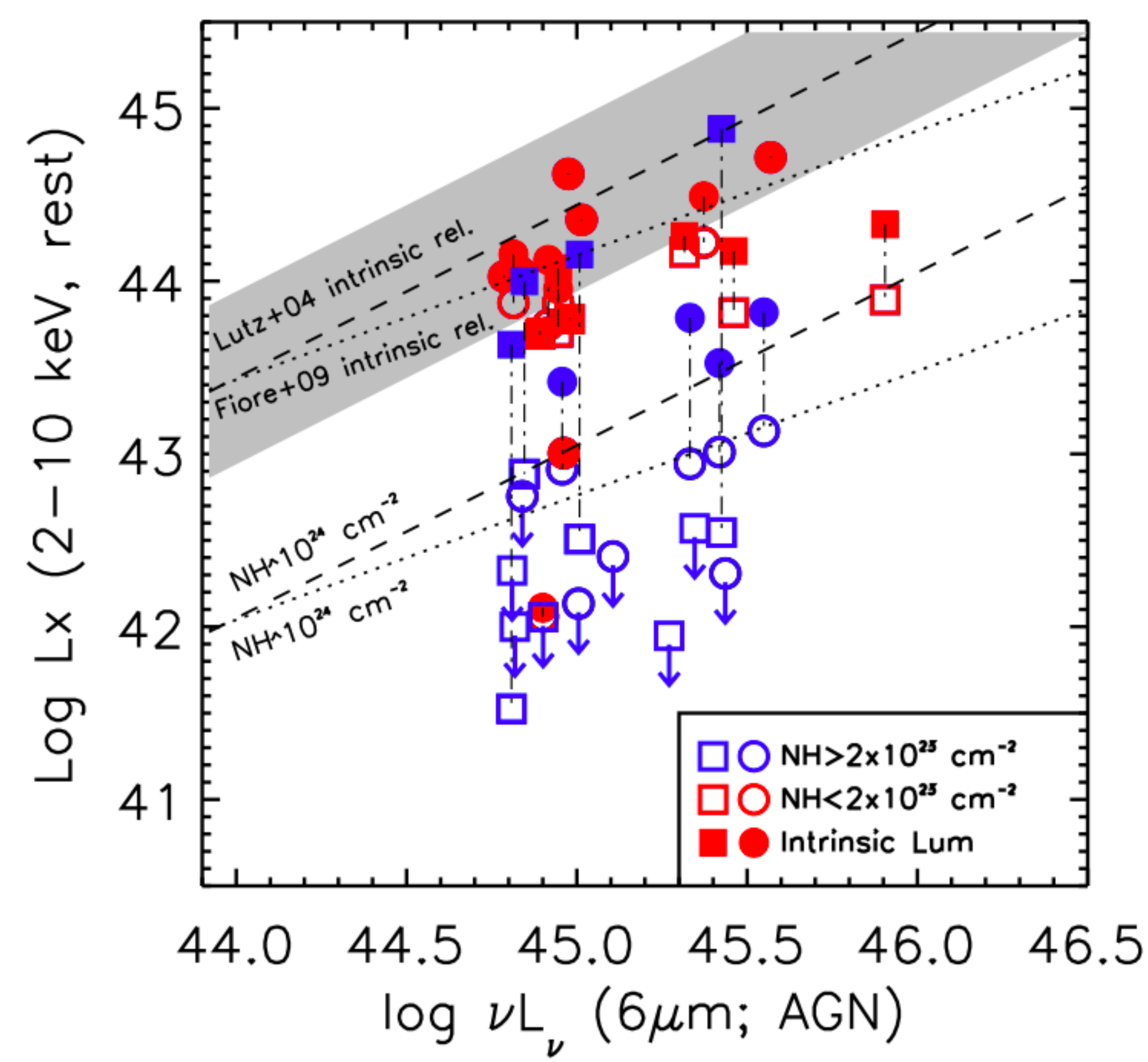
Left: SFR densities in the FUV, uncorrected for dust extinction (blue, green, magenta) in the far-IR (red). **Right**: Massive BH accretion history from X-ray (red line and green shading) and IR data (blue shading), scaled up by a factor of 3300, compared to SF history (black line). (Madau & Dickinson, 2014).

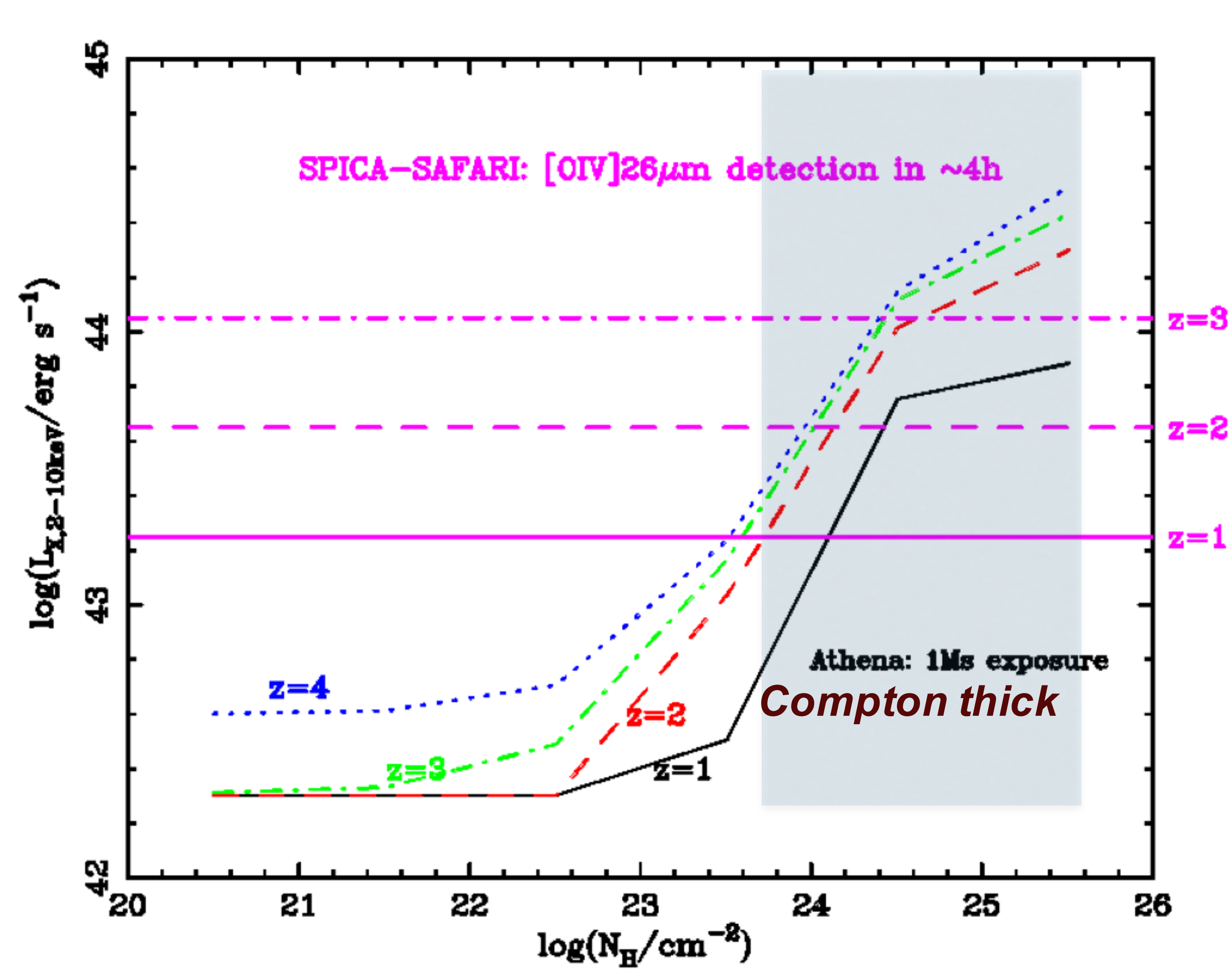


WORK in progress: paper submitted to ApJ

IR line ratios are a powerful tool to separate the different galaxies because of the differences in the primary ionising spectra, due to AGNs or stars or possibly to shocks in the ISM (J.A. Fernandez-Ontiveros, LS, et al subm. 2016)

SPICA will be complementary to Athena to detect and characterise Compton thick AGNs: SYNERGIES WITH ATHENA





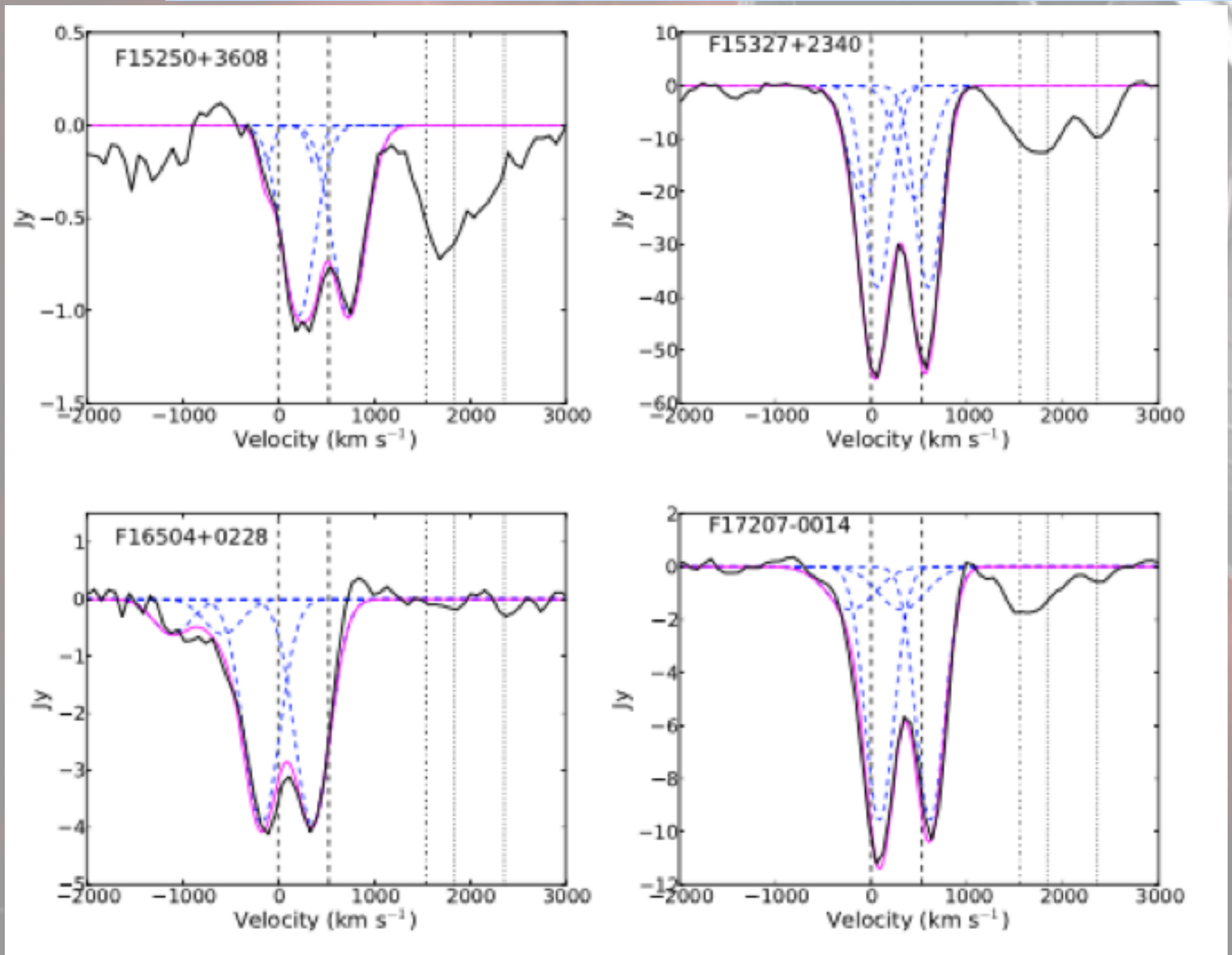
Left: **Incompleteness of X-ray surveys. 2–10 keV rest-frame luminosity vs. AGN 6μm luminosity. Open symbols show the observed** X-ray luminosity, while **filled symbols the intrinsic luminosity. More than 25% of the AGN are undetected at X-rays while visible in the mid-IR via hot dust emission.** (Del Moro et al 2015)

Right: **Comparison between SPICA-SAFARI and ATHENA**. Luminosity limits, at z=1,2,3, of **ATHENA for a 1Ms (~280 hours) survey**, and of **SPICA/SAFARI for a pointed observation of ~4 hours for the [OIV]26μm AGN line**. The conversion between bolometric and X-ray luminosity has been taken from Marconi et al. (2004).

2. AGN and Starburst feedback and feeding

- *Can AGN-driven molecular outflows be responsible for the decline of SF in the last 7 Gyr?*
- *Are these outflows responsible for creating the majority of red-and-dead galaxies?*
- *What physical processes – mechanical or thermal energy injection or radiation pressure on dust – drive molecular outflows?*
- *How much of the wind escapes the galaxy and seeds the IGM with metal-enriched gas?*

SAFARI will use the high resolution M.-P. with R~2000-10000 up to z~1.5
(line sensitivity is limited to ~3x10^-19 W/m^2

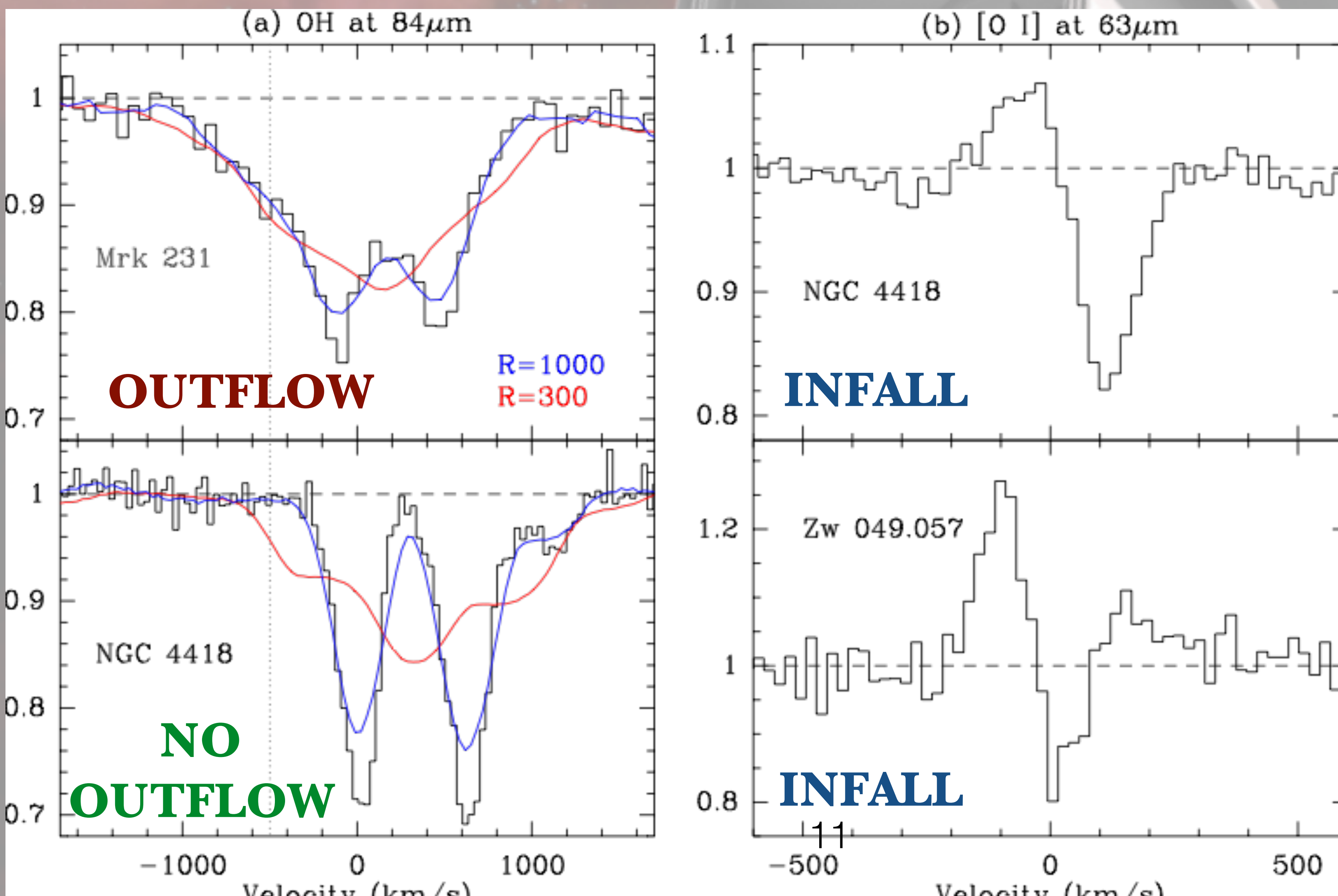


Herschel PACS profiles of the OH 119μm line in a sample of 43 nearby (z < 0.3) galaxy mergers, mostly ultraluminous infrared galaxies (ULIRGs) and QSOs. (Veilleux et al 2013, ApJ)

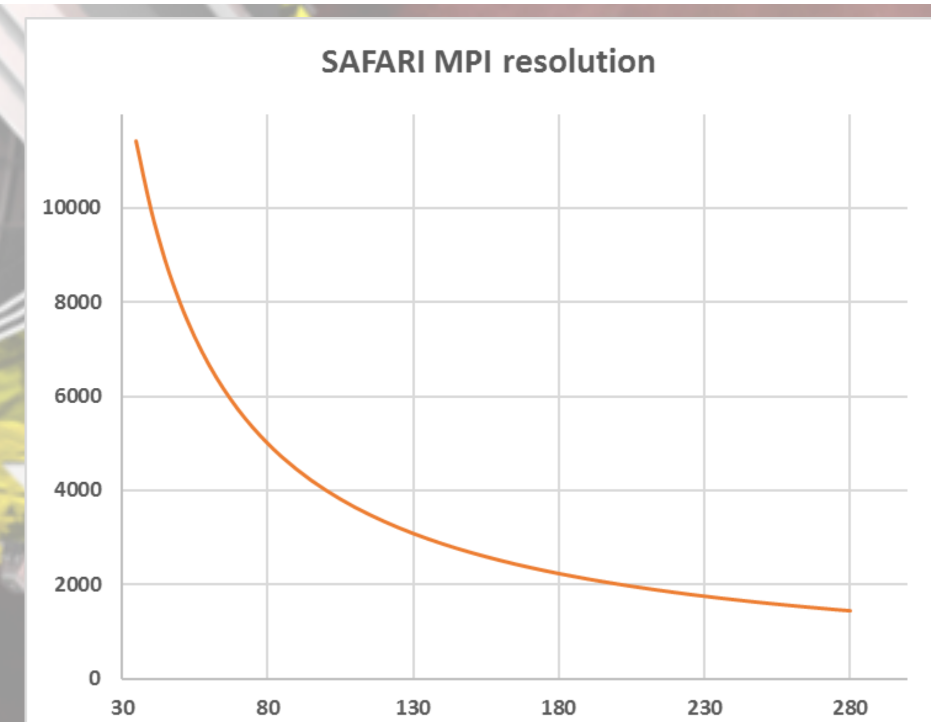
Measuring outflows at higher z (z~1.2-1.5) — Measuring infall

(a: *Left*) OH84μm doublet observed with *Herschel*/PACS in Mrk231, with a strong outflow, and in NGC4418, without outflow (GA2014, 2012). Herschel/PACS spectral resolution at this wavelength was R~2300. **Blue and red lines show the line profiles smoothed to a resolution of R=1000 and 300, respectively. The "new" high resolution baseline of SAFARI (M.-P.I) will have R>~2000, allowing to obtain the same results in terms of spectral resolution that Herschel/PACS obtained in the local Universe, but at z~<1.5.**

(b: *Right*) [OI]63μm inverse P-Cygni profiles observed by *Herschel*/PACS in NGC 4418 (GA12) and Zw049.051 (Falstad et al. 2015), with a resolution of R~3500 illustrating gas inflow into the circum-nuclear regions.



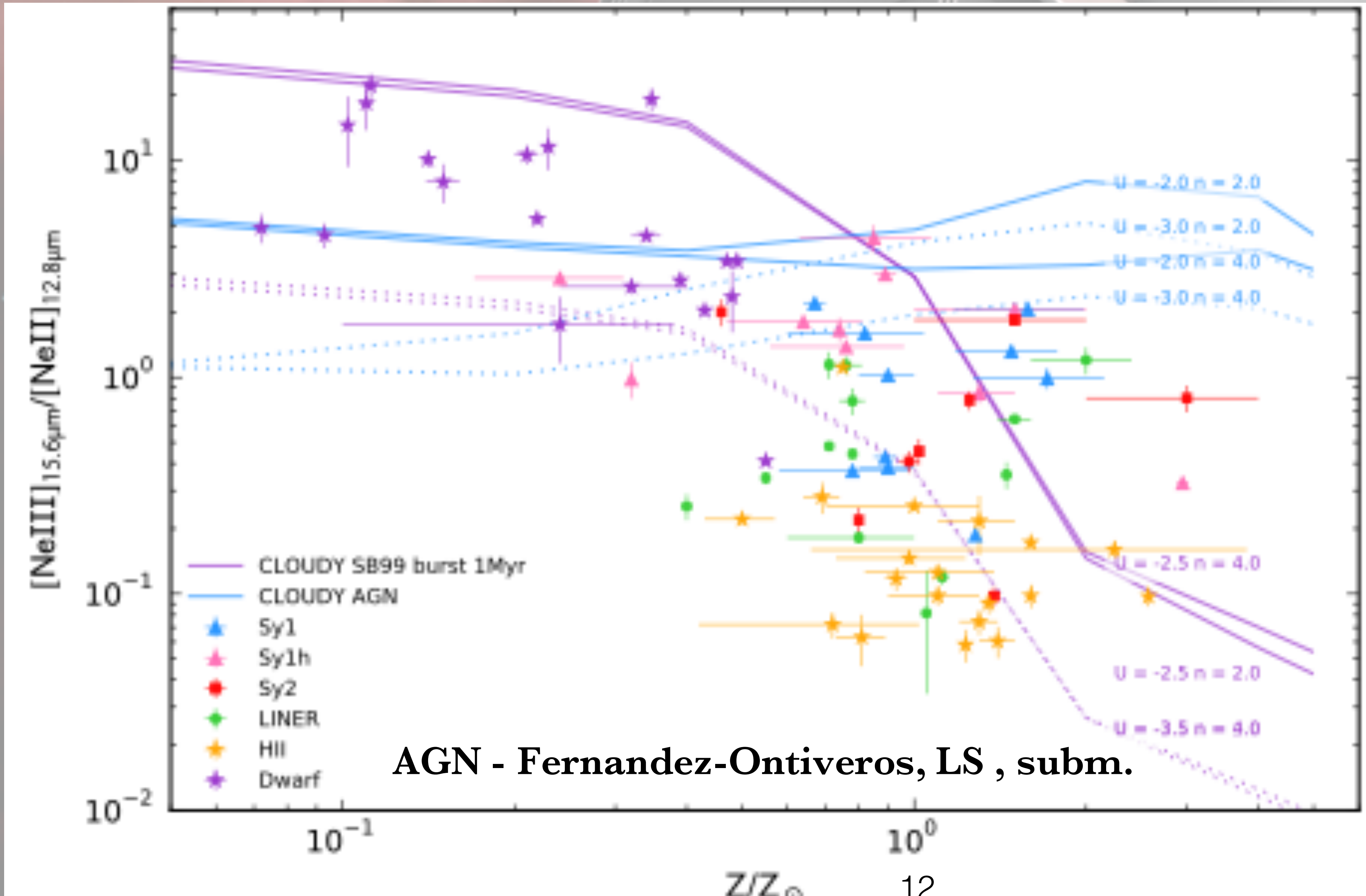
The new baseline configuration of the SAFARI high resolution mode, with the Martin-Pupplet interferometer reaches 5 sigma 1 hour line sensitivities of
Limiting Flux = 0.8 – 1.0 x 10^-19 W/m^2
With the spectral resolution shown here



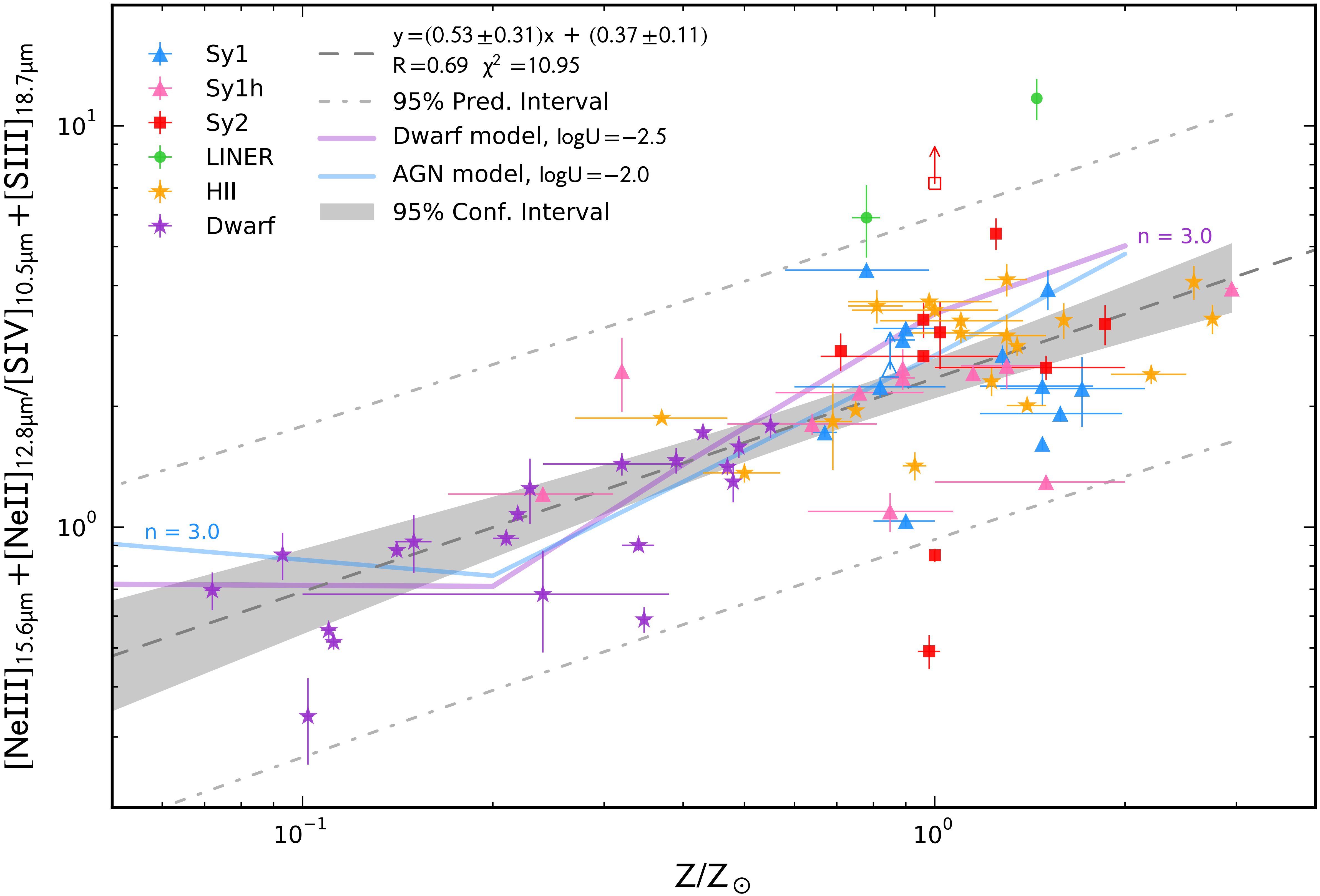
3. Metallicity evolution

- How does the gas inside (and outside of –ATHENA) galaxies get enriched with metals over time?
- What is the origin (where and when) of the heavy elements and the fundamental metallicity relation in obscured regions of galaxies?

The key diagnostic lines for measuring metallicities for galaxies with 0<z<2.7 are[OIII]51.8μm and [NIII]57.2μm, and [NeIII]15.5μm and [NeII]12.8μm, using both spectrometers SMI and SAFARI.



Optical metallicity vs. [NeIII]15.6 μm/[NeII]12.8 μm line ratio for objects in the samples of AGN, starburst, and dwarf galaxies. (J.A. Fernandez-Ontiveros, LS et al. 2016, subm.)



([Ne iii]$_{15.6}$+[Ne ii]$_{12.8}$)/([S iv]$_{10.5}$+[S iii]$_{18.7}$) line ratio vs optical metallicities. Note that the AGN and dwarf galaxy models shown here include the effect of Sulphur depletion (J.A. Fernandez-Ontiveros, LS, et al subm. 2016)

End of the first presentation