give us a handle on the dust extinction and metallicity in distant galaxies.

We have taken the first few steps towards a coherent, self-consistent picture of the evolution of the star formation rate density, measuring Hα from galaxies that existed when the Universe was half its current age. New instrumentation offers the exciting prospect of mapping similar galaxies even further back in time, and lifting the veil on obscured star formation in the early Universe. ¤

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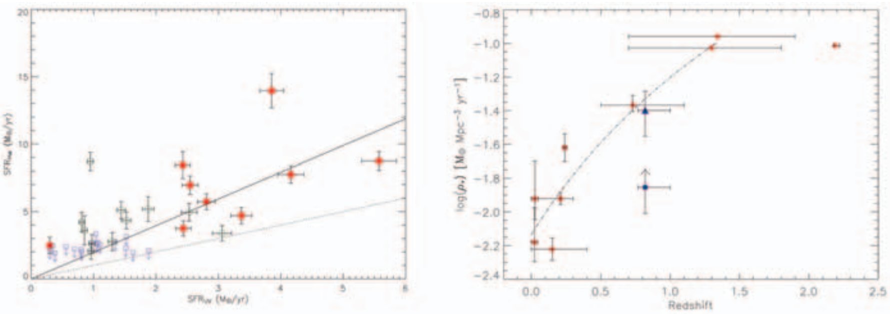

*Figure 4. Left: Comparison of SFRs obtained from UV continuum flux at 2400Å versus Hα flux for the individual galaxies. The SFRs derived from UV luminosity are consistently underestimated. The filled circles are the robust detections, the open circles are greater than 3σ and the squares are 3σ upper limits. The solid line has a gradient of 1.98 and represents the line of best fit to the data (using a least squares fit, through zero). The dotted line is the line of zero extinction i.e. where SFR(Hα)= SFR(UV). Right: Evolution of the star formation rate density using SFRDs determined from Hα measurements only, with no reddening corrections. Red circles are points taken from the literature, converted to a Λ-CDM cosmology. Overlaid is our lower limit (blue square) to the SFRD, and our estimate including luminosity bias and aperture corrections (blue triangle).*

# Pyramid Wavefront Sensor at the William Herschel Telescope: Towards Extremely Large Telescopes

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The major technological challenge for optical astronomy in the near future is surely the design and realisation of so called Extremely Large Telescopes (ELT) (Gilmozzi, 2004; Nelson, 2000). These instruments, having a diameter in the range of 30–100 meters, will have primary and even secondary mirrors made up of segments (Andersen, 2003; Dierickx, 2004). These telescopes are supposed to work most of the time using Adaptive Optics (AO) to correct for atmospheric turbulence perturbations, achieving a previously unobtainable angular resolution of 1 milliarcsecond in the *V* band. To achieve this spectacular performance the mirror segments need to be co-phased, thus acting as a monolithic mirror (Chanan, 1999). Phasing the segmented primary mirror is a key activity at the Keck 10-meter optical telescope. At Keck two different sensors are successfully used for phasing (differential piston correction) and alignment (tip-tilt correction) (Chanan, 2000). This process is done before the observations as part of the telescope optical alignment. Then the primary is kept stable in the correct configuration using capacitive sensors built into the segments. Given the importance of this alignment and co-phasing issue several groups have started working on the subject in Europe (Schumaker, 2001; Yaitskova, 2005; Gonté, 2004).

The Arcetri AO group showed in 2001, using numerical simulation, that the pyramid WFS is able to do phasing and alignment of the mirror segments at the same time (Esposito, 2002). In the period 2000–2004 the AO group developed this concept, and have built a lab prototype of the pyramid co-phasing sensor.

Briefly the Pyramid wavefront sensor has been introduced by R. Ragazzoni in 1996 as a modification of the well known Foucault test for optical shop testing (Ragazzoni, 1996). To use it in AO, where X and Y derivatives of the wavefront have to be measured simultaneously, the knife edge is replaced with a refractive pyramid that provides four edges. This WFS is actually working at the TNG telescope (Ragazzoni, 2002) and will be part of the first light AO system of the LBT (Esposito, 2004).

A unique opportunity to calibrate and test our prototype of a co-phasing sensor (PWFS) in the lab and on the sky has been provided by the WHT and its AO system NAOMI. This is because the NAOMI deformable mirror is a segmented mirror with 72 segments controllable in piston, tip and tilt. The AO system location on the Nasmyth platform allows a simple integration of the PWFS board in the AO system optical train. In direct collaboration with the WHT staff, the PWFS board has been installed and operated twice at the WHT in November 2004 and July 2005. Results achieved during the first run are in publication in an *Optics Letters* paper (Esposito, 2005) and demonstrated for the first time that the PWFS can control piston, tip and tilt of the segments achieving a mirror flatness of 10 nm rms (see Figure 1). This performance was obtained using the calibration source of NAOMI.

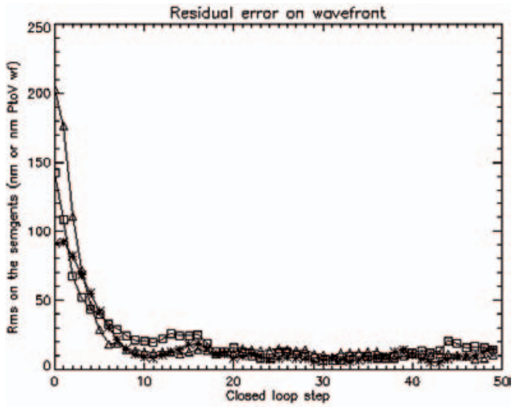


*Figure 1. An example of mirror phasing and alignment taken from the July 2005 run. The plot reports piston (asterisk), tip-tilt rms on the 13 controlled segments of the NAOMI DM during the close loop operation. Mirror flatness achieved is about 5 nm and 10 nm for piston and tip & tilt respectively.*

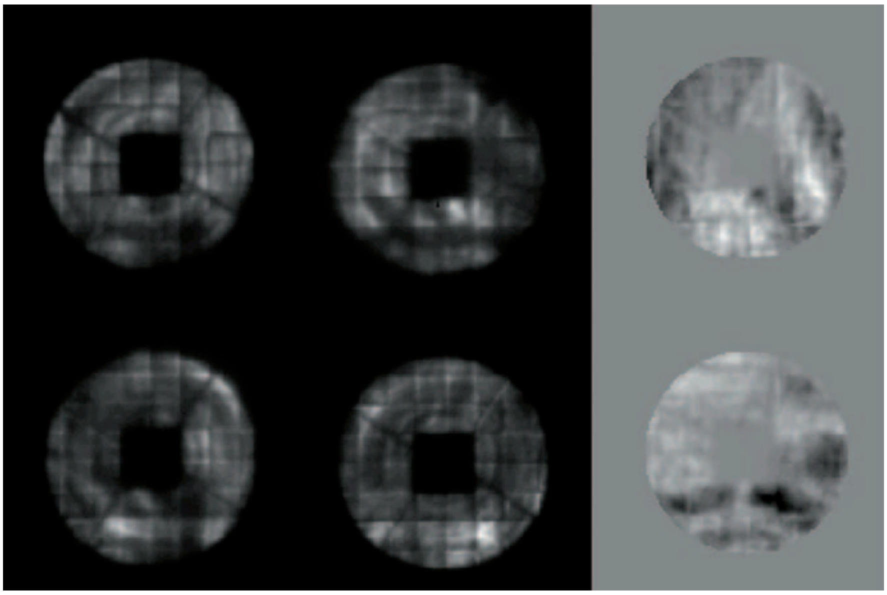

*Figure 2. Left: the pupil of the WHT as seen from the PWFS pointing a natural guide star. Right: the X and Y signals obtained from this frame.*

The ultimate goal of the experiment is to demonstrate the ability of phasing and aligning the mirror segments using a natural guide star in the sky. In the run last July the system was ready to start the sky test but bad weather allowed only 2 hours of observations. Nevertheless some parts of the wavefront sensing system have been successfully checked and we have achieved the first sky images with the PWFS (see Figure 2). A sample of these long exposure images is reported below. A next run should take place in April 2006 and we strongly believe that we can show that a single wavefront sensor can perform on sky co-phasing and segment alignment.

As a final remark we note that the PWFS configuration is the same for co-phasing and AO so that the same WFS can drive at the same time the AO loop and the segment control. This approach, if demonstrated, would provide the most effective solution in achieving the theoretical performance of ELTs needed for a long list of challenging observations in future astronomy. ¤

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