# Status of SNT-WG

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EUCLID- France meeting
Lyon, December 2014

# Motivation SNT WG- Summary: NIR from space

- SN Cosmology (Type Ia)
  - Well-proven distance indicators for cosmology
  - Independent measure of DE parameters by Euclid with high z SNIa
  - limiting factor in SN cosmology : dust vs intrinsic colour variations
- SN rates (of all Types)
  - Get accurate rate measurements (even in extincted regions)
  - Relate rates with parent galaxies, using the Euclid database
  - Rates give constraints on progenitor models, universal star formation history, etc,…
- SN physics (of all Types)
  - Unusual objects, over- and under- luminous SNe, hyper luminous Sne, PISNe
  - all tell us about explosion physics and environments
- Other transients, eg: AGN/Quasars

# Euclid SN survey priorities

- Basic goal: **a significant gain over existing SN surveys**
  - In particular SNLS and DES
- Euclid has the potential to provide the first NIR survey for SNe from space
- Provides an independent Euclid probe of cosmology with FOM >200
- With 6 months of observing time, the most interesting option is the "AAA survey" ➔ **DESIRE paper**
  - Reaches high redshift : up to z ~ 1.5
  - Cannot be done from the ground

# DESIRE with EUCLID + LSST

**Table 4.** Main parameters of the simulated surveys.

| | $z_{min}$ | $z_{max}$ | area ($deg^2$) | duration (months) | events |
|---|---|---|---|---|---|
| DESIRE | 0.75 | 1.55 | 10 | 2x6 | 1740 |
| LSST-DDF | 0.15 | 0.95 | 50 | 4x6 | 8800 |
| Low z | 0.05 | 0.35 | 3000 | 6 | 8000 |

NB: 2* 6 months (use half time → total 6 months up-time)

## FOM > 200

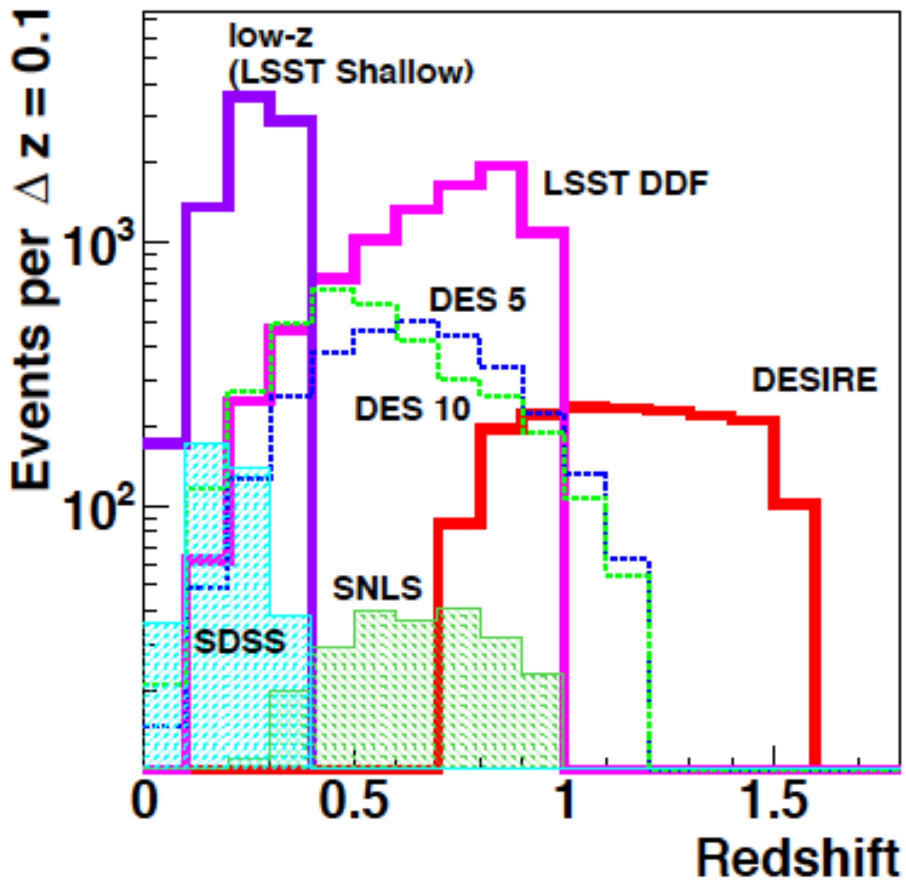



Fig. 12. Redshift distribution of events for various surveys. For the SDSS and SNLS, the distributions sketch the total sample of spectroscopically identified events eventually entering the Hubble diagram. "DES 5" and "DES 10" refer respectively to the "hybrid-5" and "hybrid-10" strategies studied in Bernstein et al. (2012), where the baseline is hybrid-10. "LSST-SHALLOW", "LSST-DDF" and "DESIRE" refer to the three prongs studied in this proposal.

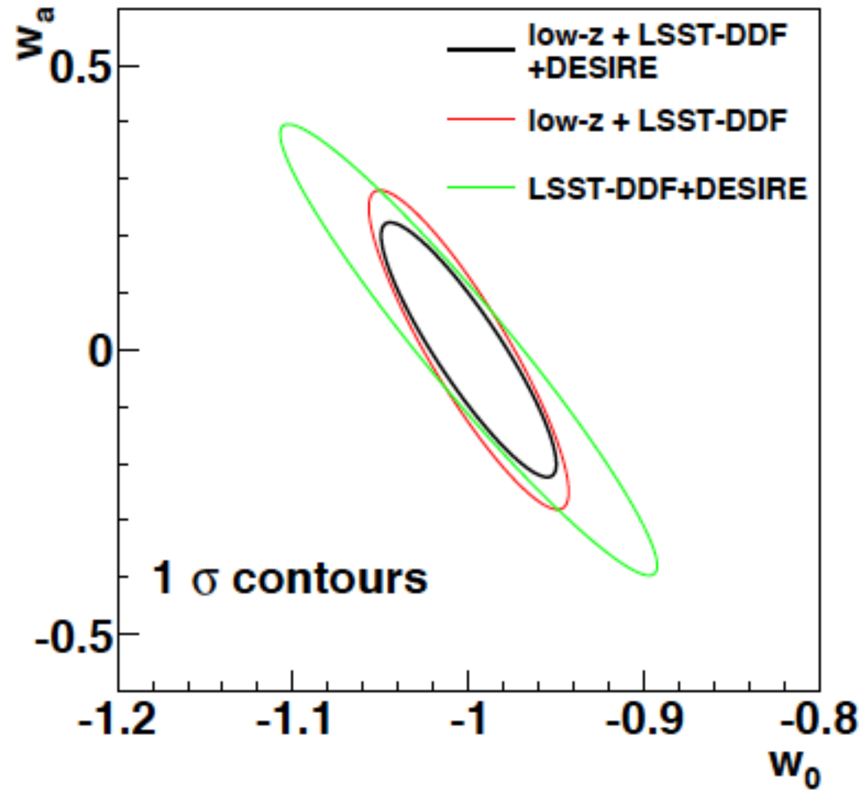



Fig. 9. Confidence contours (at the $1\sigma$ level) of the survey combinations listed in Table 5. The assumptions for systematics correspond to the last row o

Table 5. Cosmological performance of the simulated surveys.

| | $\sigma(w_a)$ | $z_p$ | $\sigma(w_p)$ | FoM |
|---|---|---|---|---|
| low-z + LSST-DDF + DESIRE | 0.22 | 0.25 | 0.022 | 203.2 |
| low-z + LSST-DDF | 0.28 | 0.22 | 0.026 | 137.1 |
| LSST-DDF + DESIRE | 0.40 | 0.35 | 0.031 | 81.4 |

Notes. The FoMs assume a 1-D geometrical *Planck* prior and flatness. $z_p$ is the redshift at which the equation of state uncertainty reaches its minimum $\sigma(w_p)$. The FoM is defined as $[Det(Cov(w_0, w_a))]^{-1/2} = [\sigma(w_a)\sigma(w_p)]^{-1}$ and accounts for systematic uncertainties. The contributions of the main systematics are detailed in Table 6.

# DESIRE paper is out !

arxiv 1409.8562

**Published by A&A december 2014**

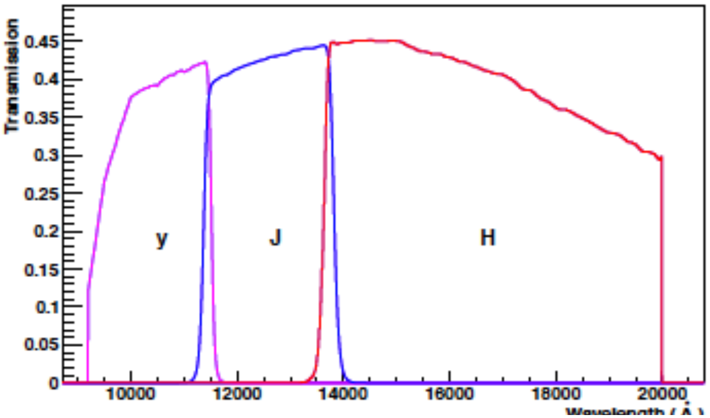
## Extending the supernova Hubble diagram to $z \sim 1.5$ with the Euclid space mission

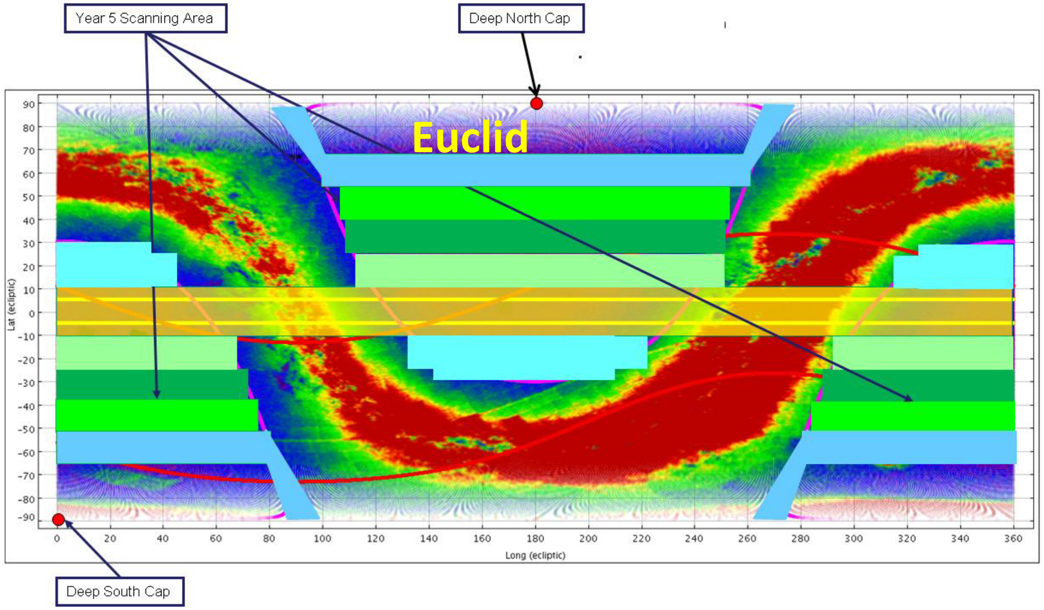
P. Astier[1], C. Balland[1], M. Brescia[2], E. Cappellaro[3], R. G. Carlberg[4], S. Cavuoti[5], M. Della Valle[2,6], E. Gangler[7], A. Goobar[8], J. Guy[1], D. Hardin[1], I. M. Hook[9,10], R. Kessler[11,12], A. Kim[13], E. Linder[14], G. Longo[5], K. Maguire[9,15], F. Mannucci[16], S. Mattila[17], R. Nichol[18], R. Pain[1], N. Regnault[1], S. Spiro[9], M. Sullivan[19], C. Tao[20,21], M. Turatto[3], X. F. Wang[21], and W. M. Wood-Vasey[22]

**ABSTRACT**

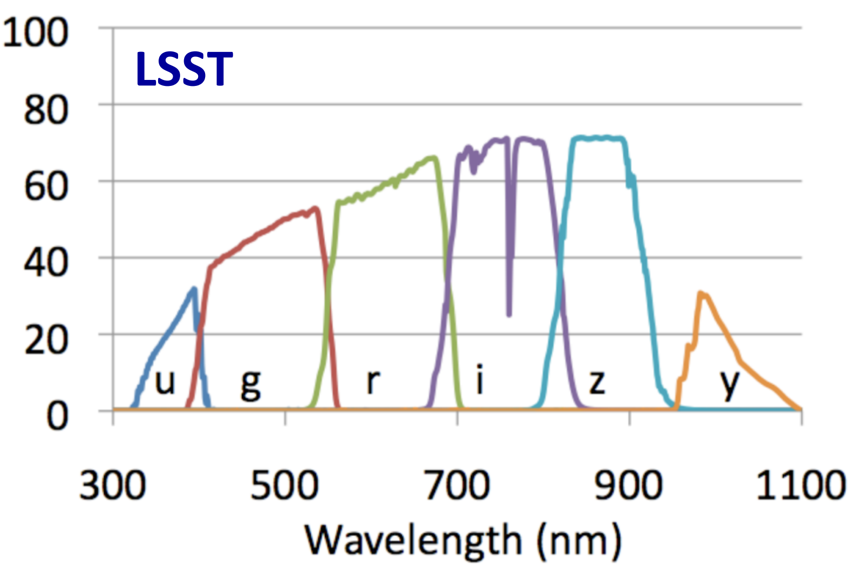
We forecast dark energy constraints that could be obtained from a new large sample of Type Ia supernovae where those at high redshift are acquired with the Euclid space mission. We simulate a three-prong SN survey: a $z < 0.35$ nearby sample (8000 SNe), a $0.2 < z < 0.95$ intermediate sample (8800 SNe), and a $0.75 < z < 1.55$ high-$z$ sample (1700 SNe). The nearby and intermediate surveys are assumed to be conducted from the ground, while the high-z is a joint ground- and space-based survey. This latter survey, the "Dark Energy Supernova Infra-Red Experiment" (DESIRE), is designed to fit within 6 months of Euclid observing time, with a dedicated observing programme. We simulate the SN events as they would be observed in rolling-search mode by the various instruments, and derive the quality of expected cosmological constraints. We account for known systematic uncertainties, in particular calibration uncertainties including their contribution through the training of the supernova model used to fit the supernovae light curves. Using conservative assumptions and a 1-D geometric *Planck* prior, we find that the ensemble of surveys would yield competitive constraints: a constant equation of state parameter can be constrained to $\sigma(w) = 0.022$, and a Dark Energy Task Force figure of merit of 203 is found for a two-parameter equation of state. Our simulations thus indicate that Euclid can bring a significant contribution to a purely geometrical cosmology constraint by extending a high-quality SN Ia Hubble diagram to $z \sim 1.5$. We also present other science topics enabled by the DESIRE Euclid observations.

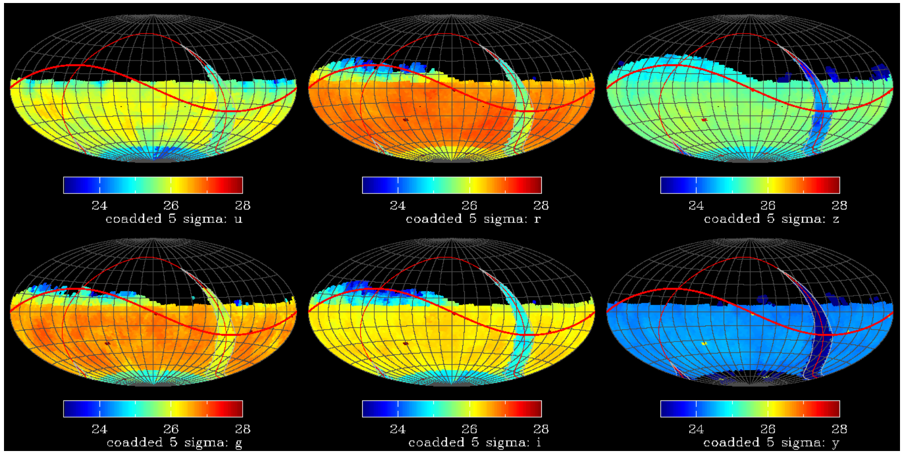
# Complementary Observations with LSST




**EUCLID** NIR + Broad visible bands



LSST Deep

**Table 3.** Simulated depths per visit of the LSST Deep Drilling Fields

| | g | r | i | z | y4 |
|---|---|---|---|---|---|
| depth ($5\sigma$) | 26.47 | 26.35 | 25.96 | 25.50 | 24.51 |
| Exp. time (s) | 300 | 600 | 600 | 780 | 600 |

**Notes.** The exposure times refer to dark and otherwise average observing conditions. The $y4$ filter is the widest considered option for the LSST $y$-band.

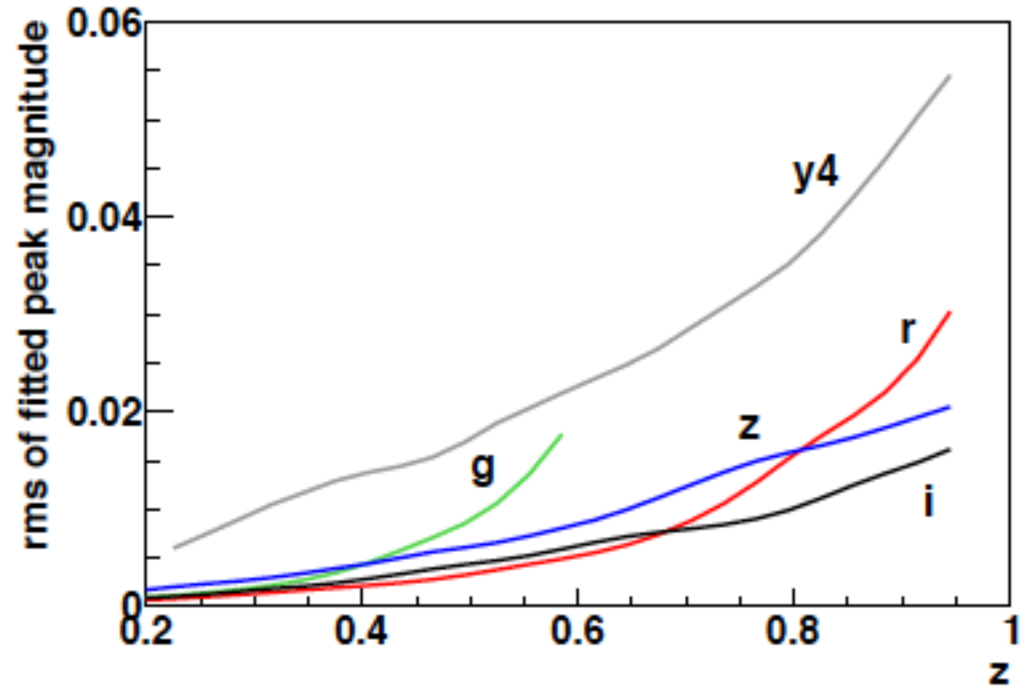



**Fig. 8.** Precision of light curve amplitudes as a function of redshift for the 5 bands of the LSST deep-drilling-fields survey, assuming a 4-day cadence with the depths from Table 3. At the anticipated depth, the contribution of the $y4$ band is marginal for distances to SNe. It however provides us with 3 bands within requirements at the highest redshift

**Table 2.** Depth of the visits simulated for the DESIRE survey.

| | i | z | y | J | H |
|---|---|---|---|---|---|
| Depth (5$\sigma$) | 26.05 | 25.64 | 25.51 | 25.83 | 26.08 |
| Exp. time (s) | 700 | 1000 | 1200 | 2100 | 2100 |

**Notes.** Depth (5$\sigma$ for a point source) and exposure times at each visit for a 4-day cadence of the proposed DESIRE joint SN survey. The exposure times for LSST *i* and *z* bands assume nominal observing conditions. For Euclid NIR bands, the exposures times are the ones that would deliver the required depth in a single exposure, if such long exposures are technically possible. The S/N calculations are described in appendix A.

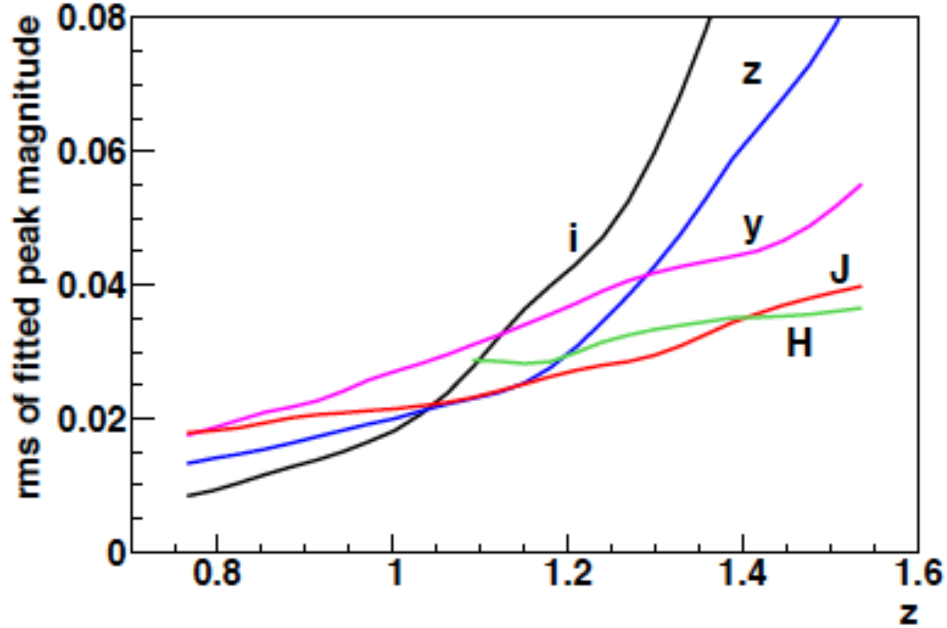



**Fig. 5.** Precision of light curve amplitudes as a function of redshift for the 5 bands of the DESIRE survey, assuming a 4-day cadence with the exposure times of Table 2. To fulfill the requirements in §2.3, *i*-band is used up to $z = 1$, *z*-band up to $z = 1.2$, and distances at $z = 1.5$ rely mostly on J- and H-band. For y, J and H bands, these calculations assume a reference image gathering 60 epochs in Euclid.

**DESIRE:**

**An ultra deep survey!**

final stacked depth

**28 to 28.5 mag**

(AB, 5 $\sigma$ point source limit)

# DESIRE Status

- Waiting for EUCLID decision > 2015!

  ECB: Call for additional surveys **late 2015** ?

- Depends also on LSST for final physics

  AND

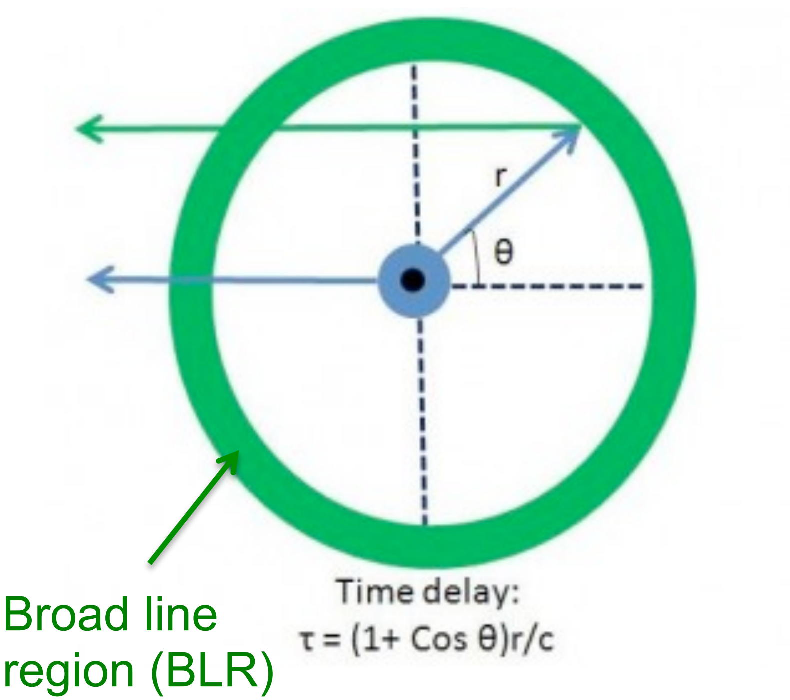
- Follow-up spectrometry !

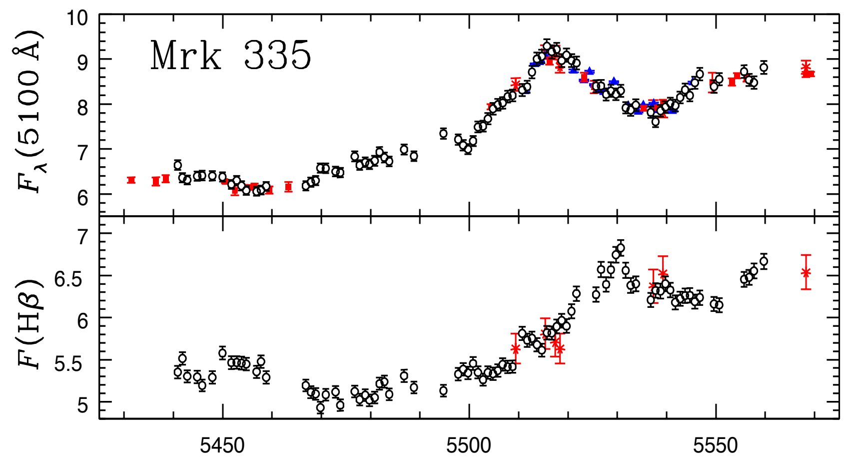
- Other transient science ?

# AGN Reverberation mapping

- Measuring the broad line lags

  → Best determination of BH mass
- R-L relation → Single-epoch BH mass




$$M_{\rm BH} = f\left(\frac{\Delta V^2 R}{G}\right)$$

# AGN and quasars: a new cosmology probe?

Watson 2012

Denney AAS 2012



A NEW COSMOLOGICAL DISTANCE MEASURE USING AGN

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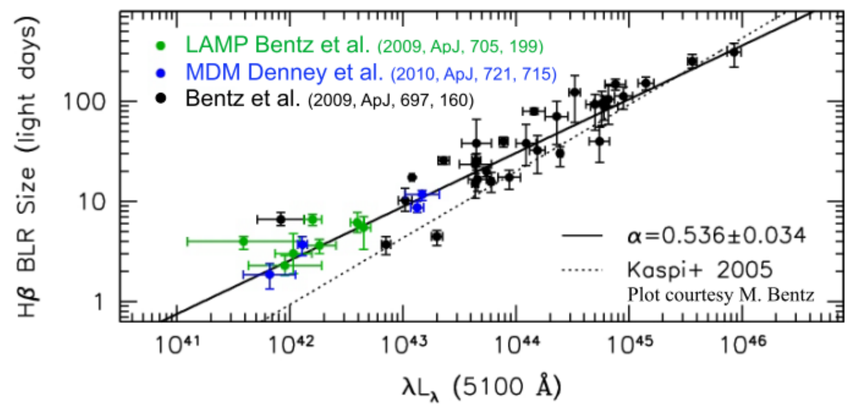
*Draft version September 23, 2011*

ABSTRACT

curate distances to celestial objects are key to establishing the age and energy density of the Universe and ature of dark energy. A distance measure using active galactic nuclei (AGN) has been sought for more forty years, as they are extremely luminous and can be observed at very large distances. We report here iscovery of an accurate luminosity distance measure using AGN. We use the tight relationship between the iosity of an AGN and the radius of its broad line region established via reverberation mapping to determine uminosity distances to a sample of 38 AGN. All reliable distance measures up to now have been limited to rate redshift—AGN will, for the first time, allow distances to be estimated to $z \sim 4$, where variations of energy and alternate gravity theories can be probed.

**Luminosity Relationship**




**Behind the Radius-Luminosity Relationship** – The BLR size, *R*, scales tightly with the nuclear luminosity, $R \sim L^{\alpha}$ --- a consequence of the photoionization physics responsible for regulating the production of line emission from the BLR. This physics dictates that $U = L_{ion}/(4\pi R^2 nc)$, where $U$ is the BLR ionization parameter, $L_{ion}$ is the ionizing luminosity, and $n$ is the BLR gas density. The empirically-calibrated relation based on reverberation measurements shows a tight correlation with a slope consistent with the phyical expectation of $R \sim L^{0.5}$.

**Tight relationship between AGN luminosity and radius of broad line region from reverberation mapping time delays.**

# Hubble Diagram
# for 38 AGN with time lag Hβ vs continuum

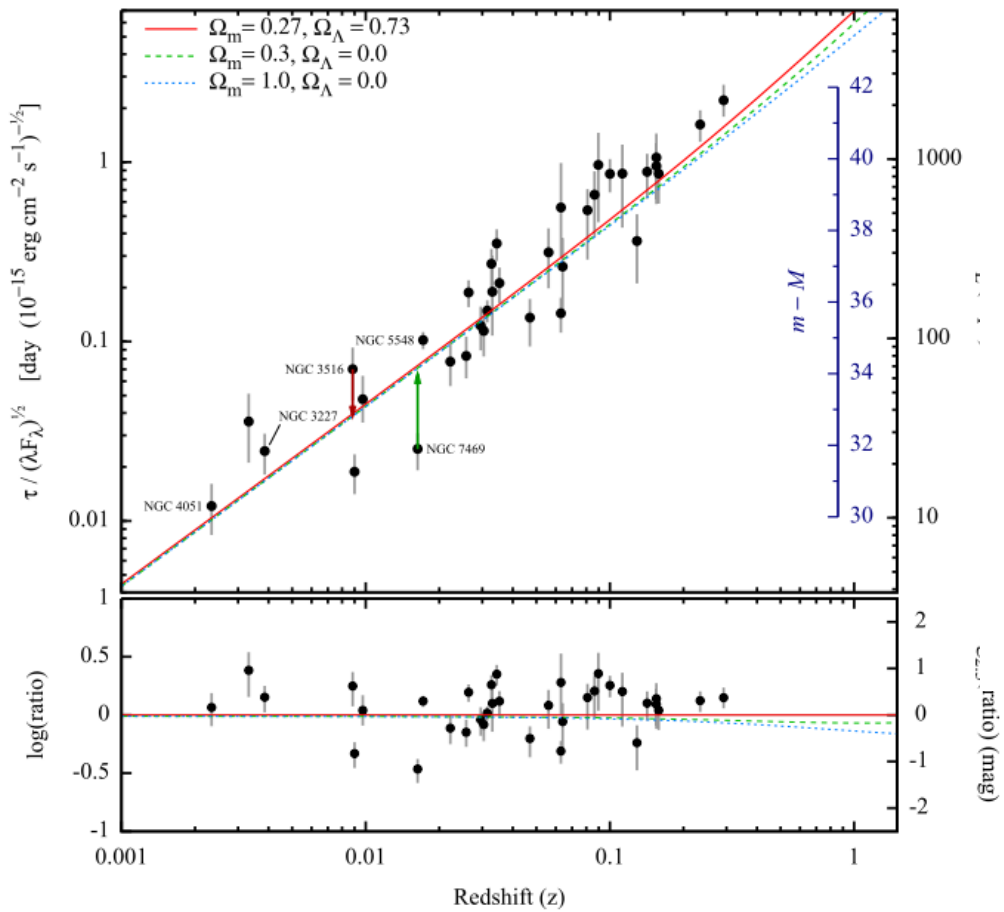



FIG. 2.— The AGN Hubble diagram. The luminosity distance indicator $\tau/\sqrt{F}$ is plotted as a function of redshift for 38 AGN with H$\beta$ lag measurements. On the right axis the luminosity distance and distance modulus $(m-M)$ are shown using the surface brightness fluctuations distance to NGC 3227 as a calibrator. The current best cosmology (Komatsu et al. 2011) is plotted as a solid line. The line is not fit to the data but clearly follows the data well. Cosmologies with no dark energy components are plotted as dashed and dotted lines. The lower panel shows the logarithm of the ratio of the data compared to the current cosmology on the left axis, with the same values but in magnitudes on the right. The red arrow indicates the correction for internal extinction for NGC 3516. The green arrow shows where NGC 7469 would lie using the revised lag estimate from Zu et al. (2011). NGC 7469 is our largest outlier and is believed to be an example of an object with a misidentified lag (Peterson 2010).

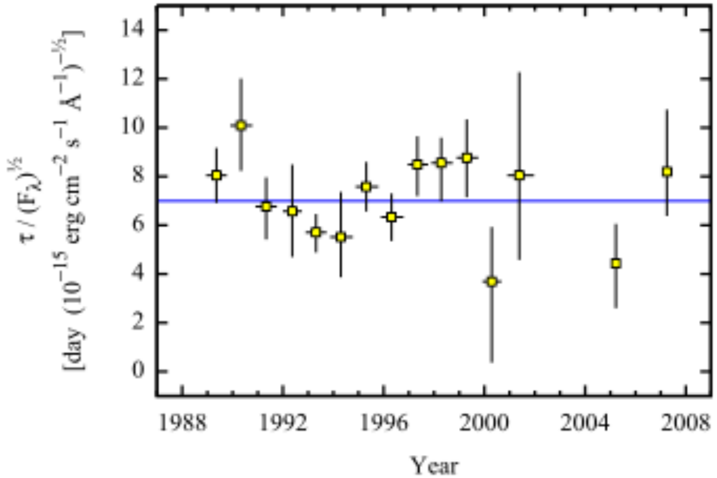



FIG. 3.— The distance indicator for NGC 5548, the best observed AGN in our sample, showing that the indicator is constant over time. The scatter in the data is consistent with the statistical uncertainty, showing that the scatter in excess of the observational uncertainty in the AGN Hubble diagram is largely due to object-to-object variations

# Luminosity distances
# AGN vs WMAP7

Watson 2012

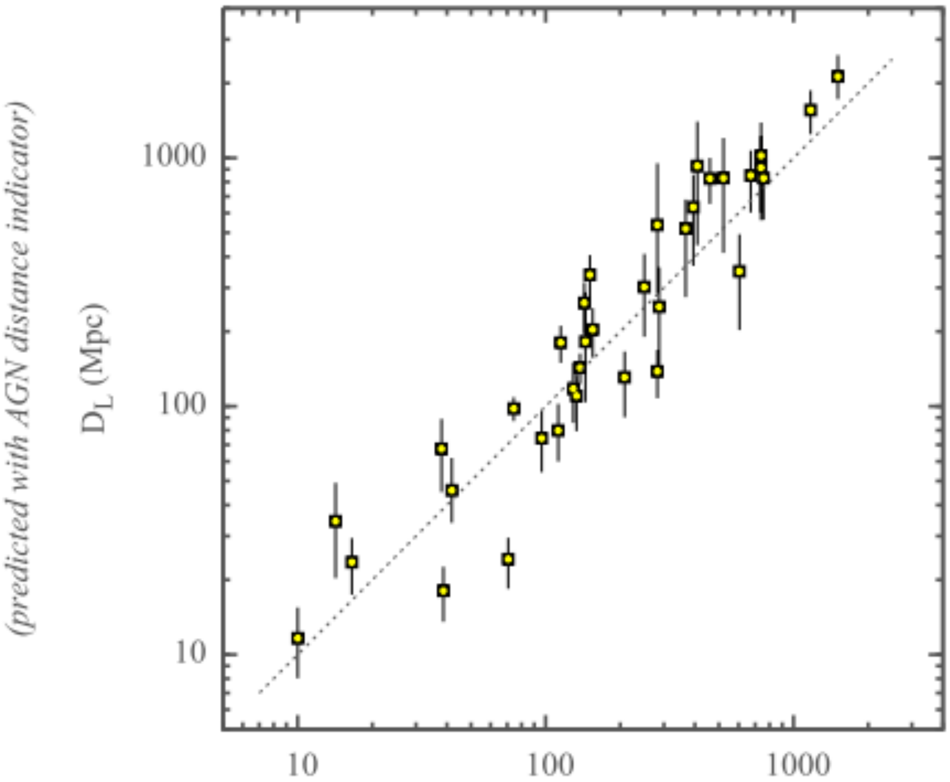



FIG. 1.— Comparison of AGN-derived distances to Hubble distances based on the best current cosmology (Komatsu et al. 2011). The dotted line is the equality of both distances. The AGN distance estimates follow the best current cosmology Hubble distances to good accuracy

TABLE 1
SCATTER IN THE AGN HUBBLE DIAGRAM

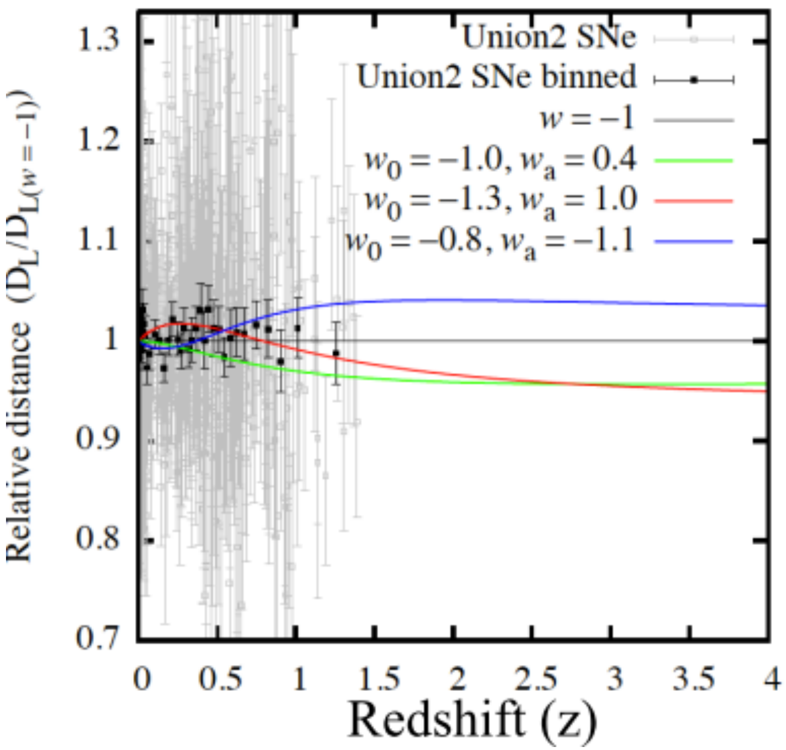
| Source of scatter[a] | Current | Can be reduced to |
|---|---|---|
| Observational | 0.14 (0.36) | 0.05 (0.13) |
| Extinction | 0.08 (0.20) | 0.04 (0.10) |
| Bad lags | 0.11 (0.28) | 0.00 (0.00) |
| Other | 0.05 (0.13) | 0.05 (0.13) |
| Total | 0.20 (0.50) | 0.08 (0.20) |

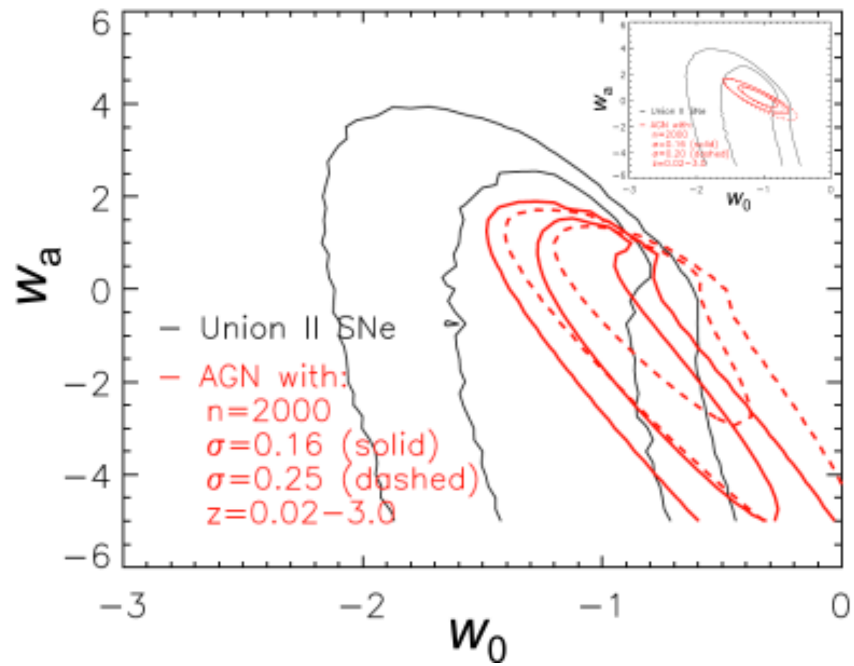
[a]Root mean square scatter in dex (mag)

**Compare with SNIa !**

# Comparison with SNIa (simulation)

Denney AAS 2012



# Quasar RM in Euclid?

- **Calibration field cadence once/month**

→ 60 epochs over 5 years

→ good time delay for high redshift bright quasars

→ $H_\beta$ or C IV or Mg II?

- To be studied more carefully

**High z, high luminosity quasars:** Time delays can be long

**from a few days to months!**

# Statistics of the RM AGN sample

**Two decades of effort !!**

~50 AGN with RM lag measurements

- almost exclusively at z<0.3
- Most are Hβ lags with some CIV lags and little/no MgII lags
- Sample heterogeneous, and does not uniformly sample the AGN parameter space (luminosity, emission line properties)

The limitations of the current RM sample severely impact the reliability of the single-epoch BH mass estimators at high-redshift.

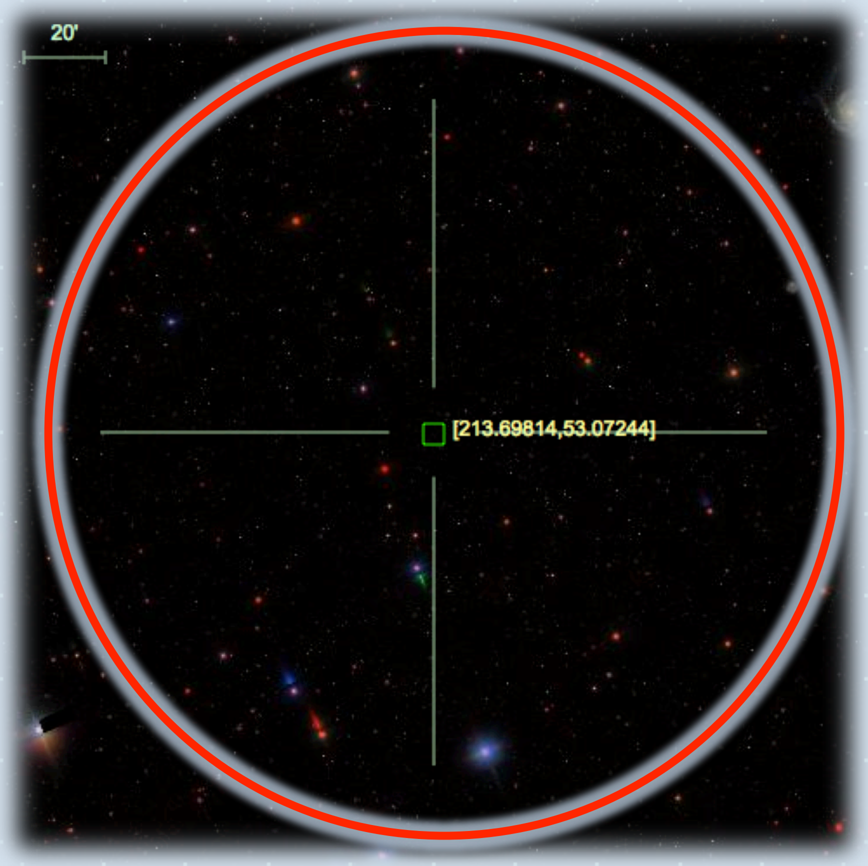
Desperately need to improve the RM sample, in a more efficient way.

**SDSS** : 849 AGN/quasar RM followed in 2014A
+ CFHT, Bok, Mayall photometry

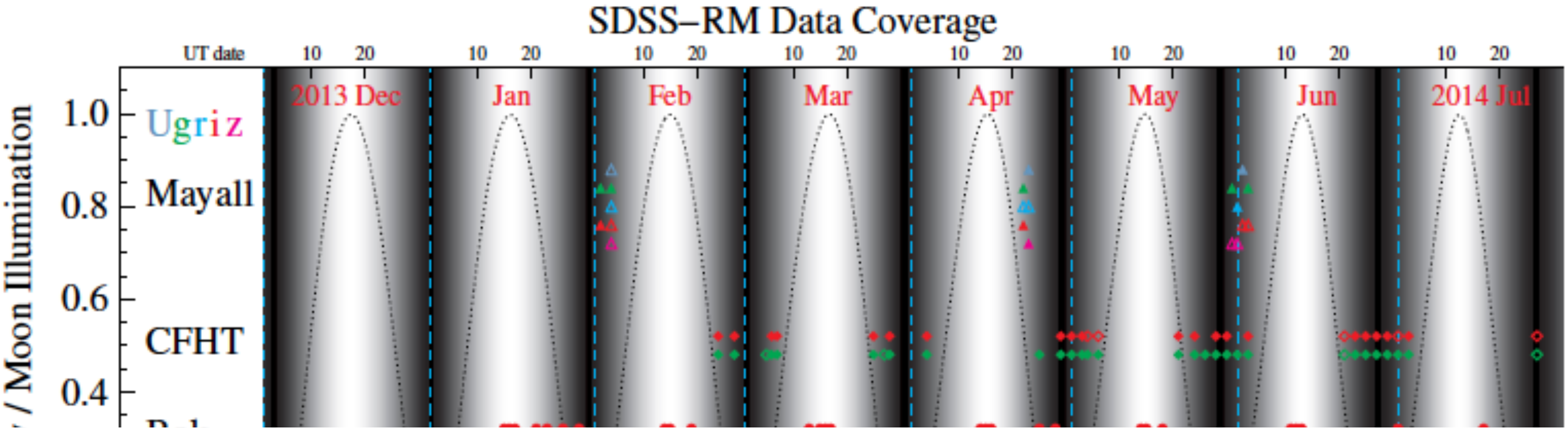
Program continues … part of eboss

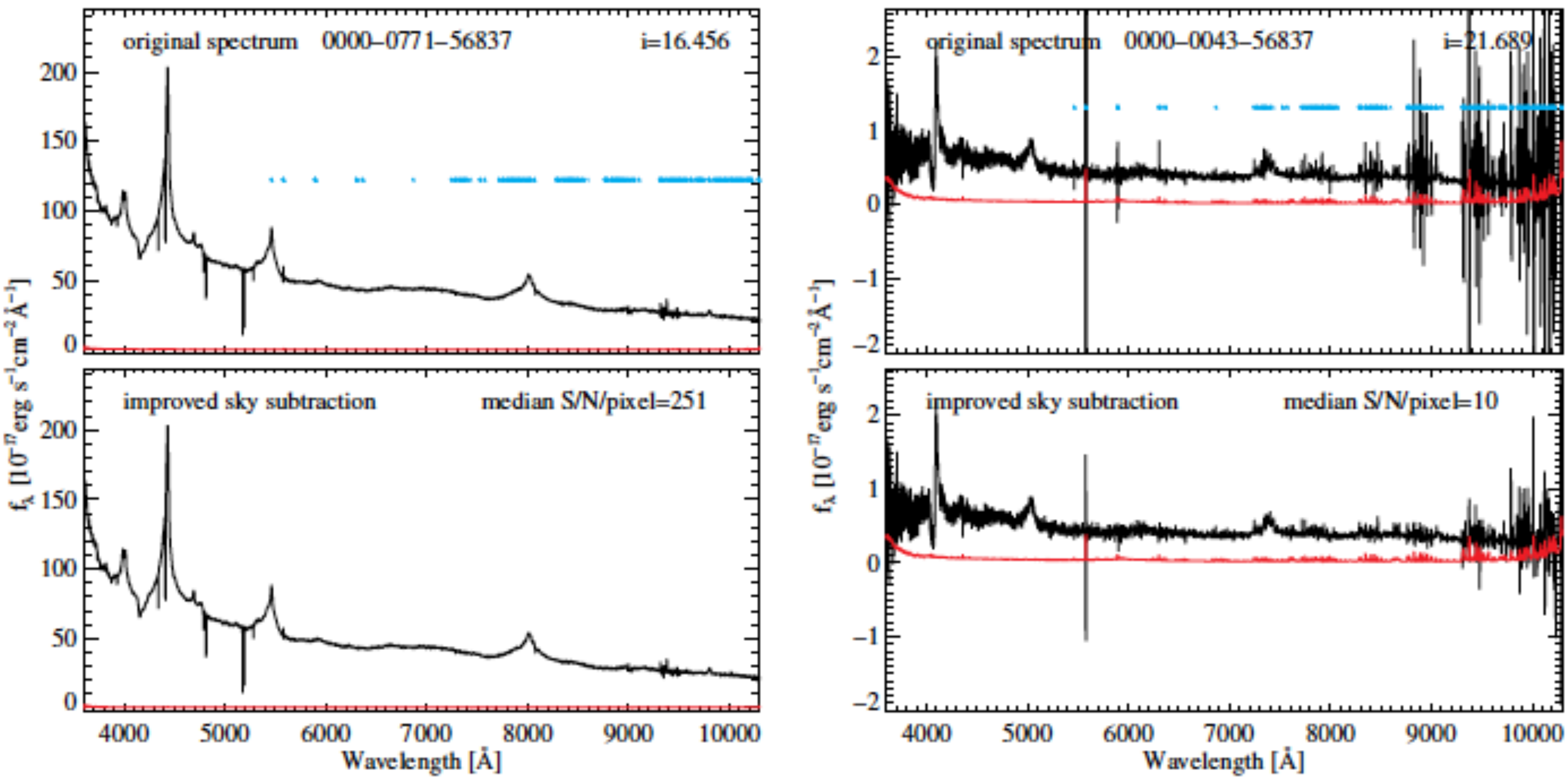
# SDSS-RM in a nutshell

- Motivation: expanding the RM AGN sample in both size and luminosity range
- Simultaneous monitoring 849 quasars at $0.1<z<4.5$ in a single 7 deg$^2$ field with the SDSS-BOSS spectrograph
- Dense photometric light curves since 2010-

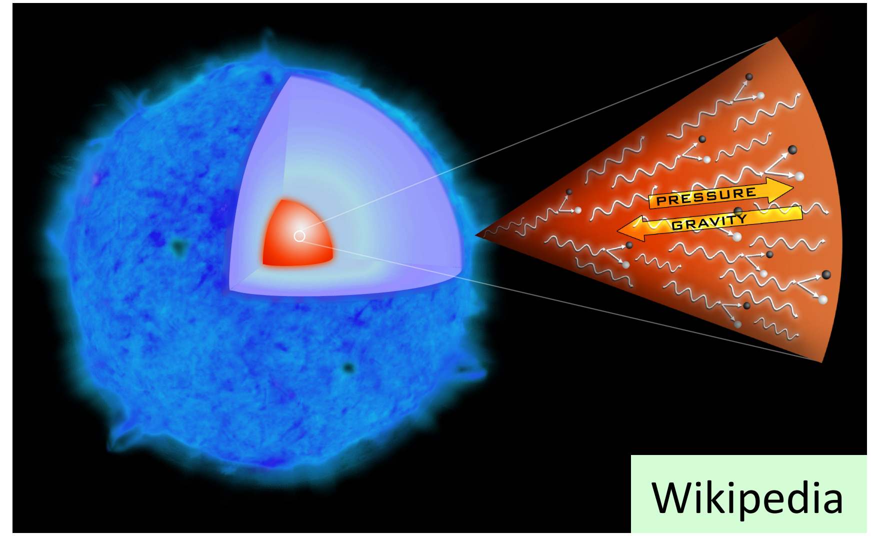



**The Sloan Digital Sky Survey Reverberation Mapping (SDSS-RM) Project (PI: SHEN)**


SDSS–RM Data Coverage
UT date
10 20
2013 Dec
Jan
Feb
Mar
Apr
May
Jun
2014 Jul
Ugriz
Mayall
CFHT
/ Moon Illumination
1.0
0.8
0.6
0.4


original spectrum 0000–0771–56837
i=16.456
improved sky subtraction
median S/N/pixel=251
original spectrum 0000–0043–56837
i=21.689
improved sky subtraction
median S/N/pixel=10
$f_\lambda$ [$10^{-17}$erg s$^{-1}$cm$^{-2}$Å$^{-1}$]
Wavelength [Å]
4000 5000 6000 7000 8000 9000 10000
0 50 100 150 200
−2 −1 0 1 2

# Pair Instability SNe



Wikipedia

Stars 140 - 260 M☉ end as pair-instability supernovae (PISNe).

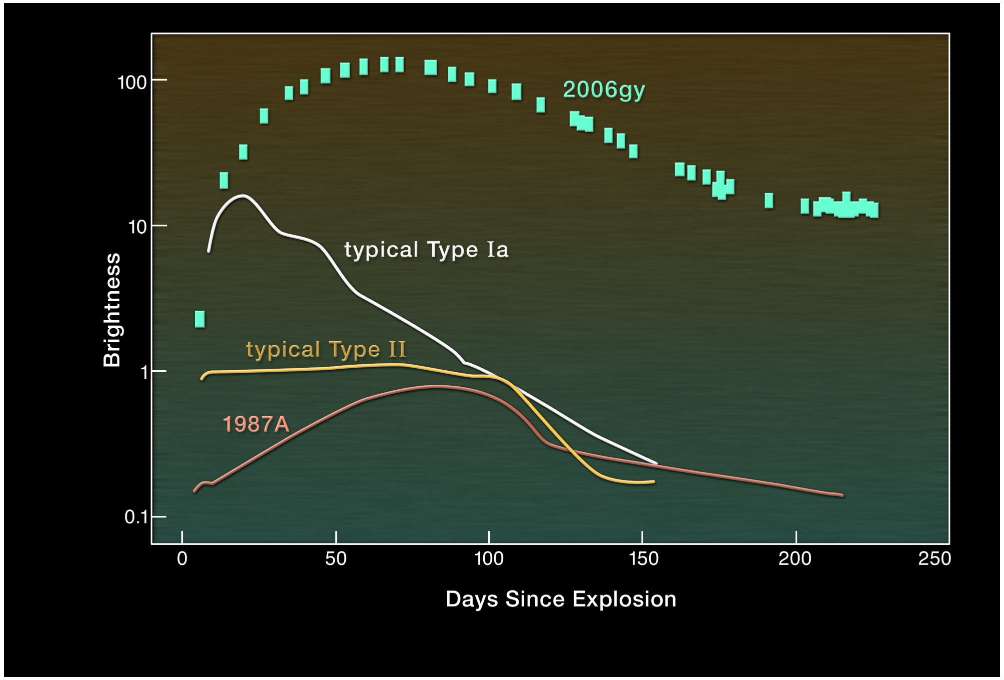
- High temperatures and low densities ➔ electron-positron pair production.
- Rapid conversion of pressure-supporting radiation
  - ➔ hydrostatic instability
  - ➔ run-away nuclear explosion

+ peak energies ~ $10^{44}$ erg
+ slow light curve evolution (radiative decay of 56Ni).

# PISN have been discovered ?

## Several Candidates

SN2006gy ?




Wikipedia

- SN 2007bi at z = 0.123 Gal-Yam et al. 2009

- SN 2213 -1745 at z = 2.05 Cooke et al. 2012
- SN 1000+0216 at z=3.9(?)

# SN2007bi

Recognised initially as SNIc

SNFactory

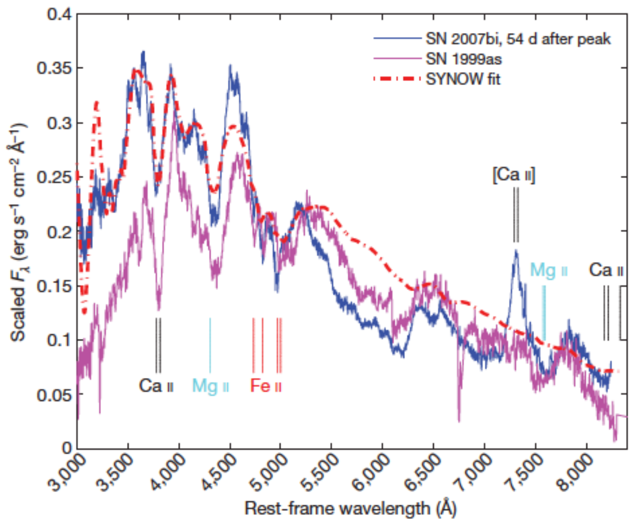
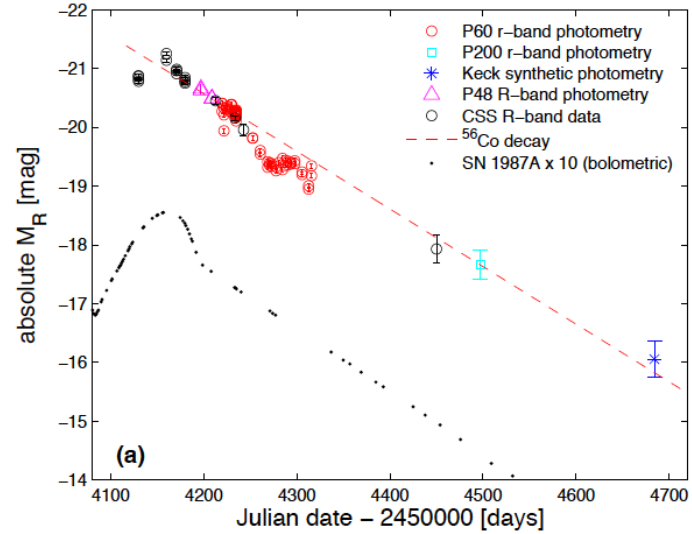
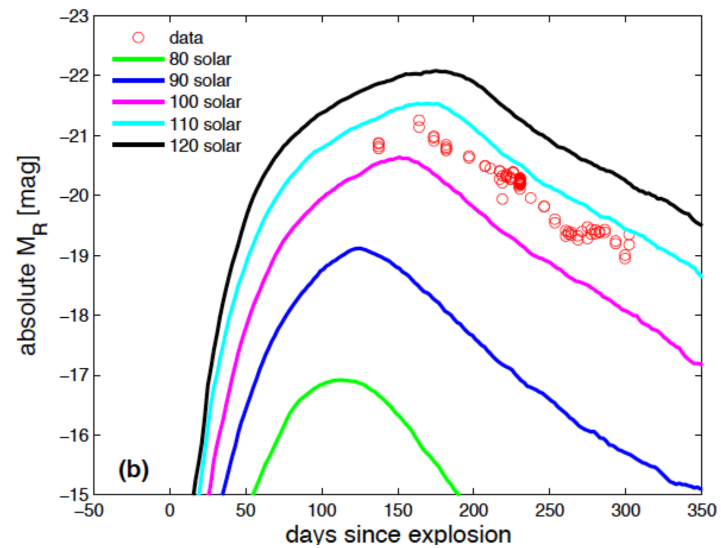


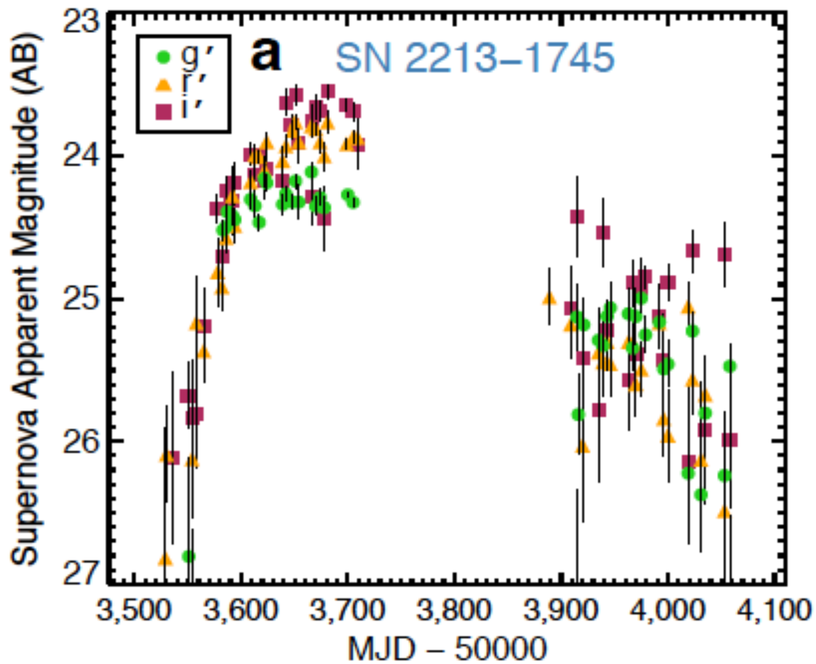

**Figure 1 | Spectra of the unusual type Ic supernova SN 2007bi.** We

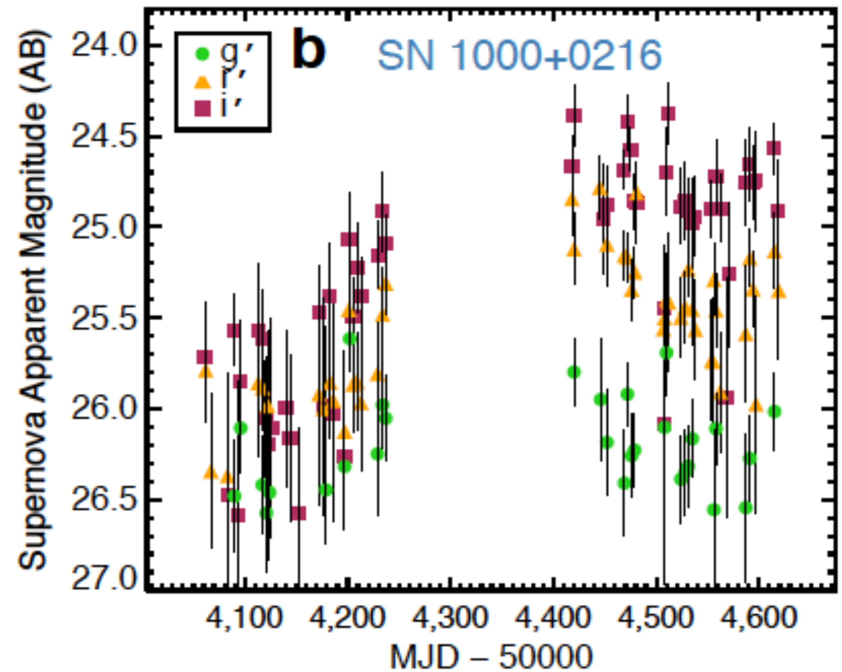
Gal-Yam et al. 2009

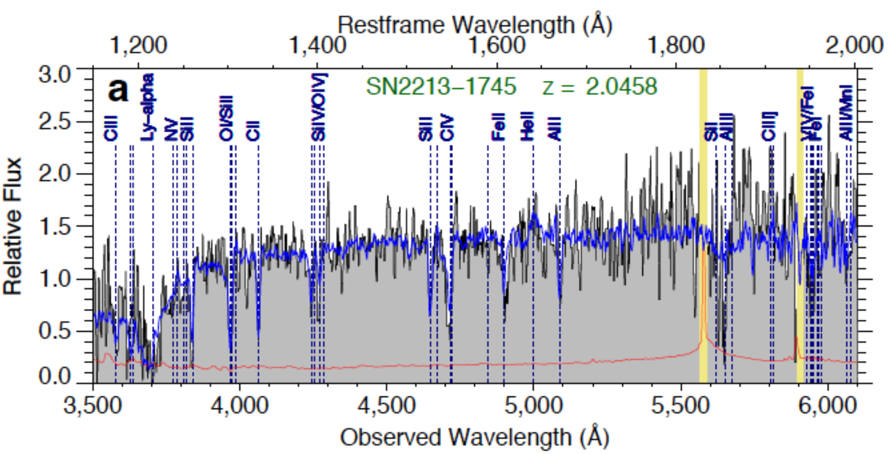


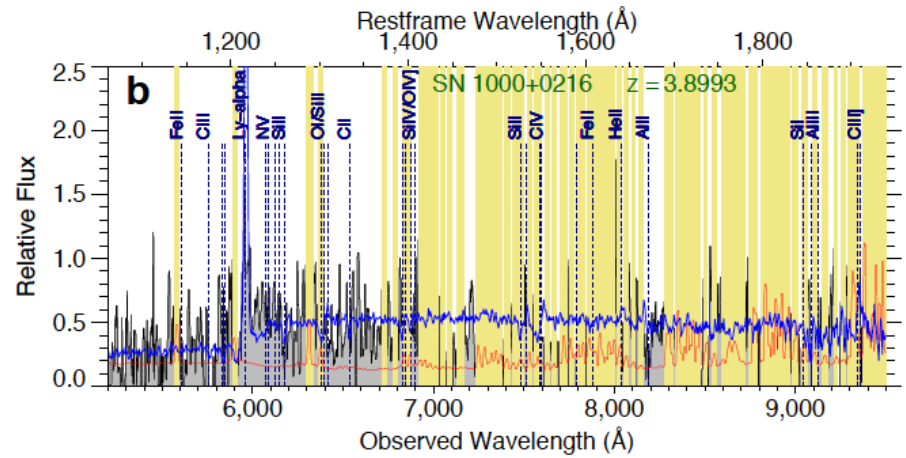



# SLSN in CFHT Deep field



# Probe of first generation stars ?

+ PSNe probe the masses of the first generation of stars (Meiksin & Whalen 2013; Whalen et al. 2013b,g,i; Chatzopoulos & Wheeler 2012b; Mesler et al. 2014; Chen et al. 2014).

+ Stars with masses > 150M have also been found, including some with masses greater than 300 M Humphreys& Davidson 1979; Davidson & Humphreys 1997; Crowther et al. 2010.

*Very massive stars in R136 and NGC 3603* 741

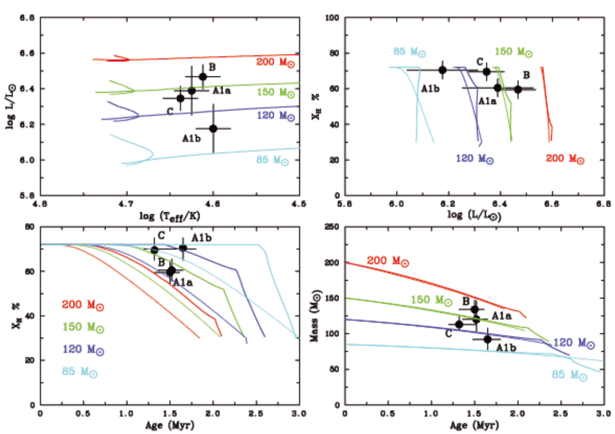



**Figure 8.** Comparison between solar-metallicity ($Z = 1.4$ per cent) models calculated for the main-sequence evolution of 85–200 M$_\odot$ stars [initially rotating at $V_{init}/v_{crit} = 0.4$ (dotted) and 0 (solid)] and the physical properties derived from spectroscopic analysis of NGC 3603 WN 6h stars. We obtain excellent agreement with dynamical masses for A1a and A1b for initially non-rotating models at ages of $1.5 \pm 0.1$ Myr. Current mass-loss rates match solar-metallicity theoretical predictions (Vink et al. 2001) to within 0.2 dex.

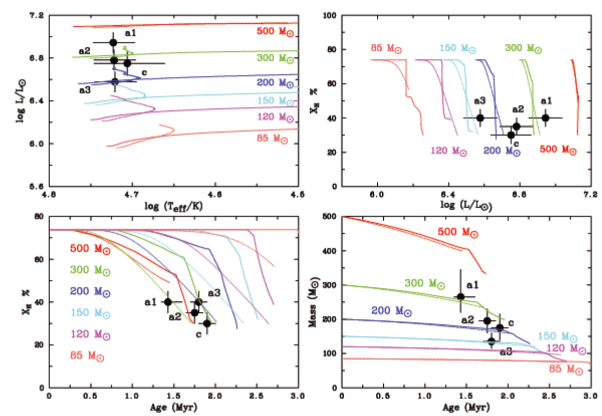



**Figure 9.** Comparison between LMC-metallicity models calculated for the main-sequence evolution of 85–500 M$_\odot$ stars [initially rotating at $v_{init}/v_{crit} = 0.4$ (dotted) or 0 (solid)] and the physical properties derived from our spectroscopic analysis. We obtain excellent agreement for initially rapidly rotating, 165–320 M$_\odot$ stars at ages of $\sim 1.7 \pm 0.2$ Myr. Current mass-loss rates match LMC-metallicity theoretical predictions (Vink et al. 2001) to within 0.2 dex.

# PISNe visible in the near infrared (NIR) up to $z \sim 15 - 20$!

Visible by JWST, WFIRST, ELTs…

Kasen et al. 2011; Whalen et al. 2013a; Hummel et al. 2012; Pan et al. 2012; Whalen et al. 2013e,f, 2014; de Souza et al. 2013, 2014,….

**and of course:**

**EUCLID !**

# SN & Transients SWG activities

- Main focus so far : survey strategy to deliver an exciting SN program
  - Focus on SNIa cosmology

    **ASD document → DESIRE paper A&A dec 2014**
  - Other SN science (rates, explosion physics…) follows

- **Other Transient (eg: RM quasar, PISN) under study**

- **OULE3 activity ? Lead for transient WP?**
- **OU/NIR** has already taken into account the SNT requirements in its own requirements. A Transient WP exists…
- **OU-VIS/MER** contacted…