Photometry
Flowdown, Budgeting, Calibration
for weak lensing

Tom Kitching

WLSWG

- Three needs for photometry from weak lensing
  - 1) Photometric Redshifts
  - 2) PSF Estimation (SED at galaxy position)
  - 3) Colour gradient calibration

- Photometric Redshifts

Budget Requirement Photo-Z

R-WL.1-5: The statistical scatter (RMS) of the errors in the measured photometric redshifts, in the range $0.2<z<2.0$ shall be $\sigma(z)/(1+z)<0.05$.

G-WL.1-5: The statistical scatter (RMS) of the errors in the measured photometric redshifts, in the range $0.2<z<2.0$ shall be $\sigma(z)/(1+z)<0.03$.

R-WL.1-6: The catastrophic failure fraction (f_{cat}), shall be less than 10%.

G-WL.1-6: The catastrophic failure fraction (f_{cat}), shall aim to be less than 5%.

T-WL.1-6: The catastrophic failure fraction (f_{cat}) is defined as the fraction of galaxies whose photo-z lies beyond 3σ of the true redshift,

R-WL.1-7: The mean of the redshift distribution n(z) in each tomographic redshift bin shall be known to a precision of $\sigma(\langle z\rangle)/(1+z)<0.002$

T-WL.1-7: We require a minimum of 10 tomographic bins to determine the dark energy parameters and constrain the intrinsic alignment signal (RD29). The redshift distribution for each bin needs to be characterized. The Euclid calibration sample will need to exceed 10^4 galaxies (RD01). In this case a requirement on the mean of these distributions is stronger than one on the variance (and likely all higher moments) as shown by RD02.

Photo-z Driving Requirements

Euclid Consortium

Level 1 SciRD

R-WL.1-5: The statistical scatter (RMS) of the errors in the measured photometric redshifts, in the range 0.2<z<2.0 shall be $\sigma(z)/(1+z)<0.05$.

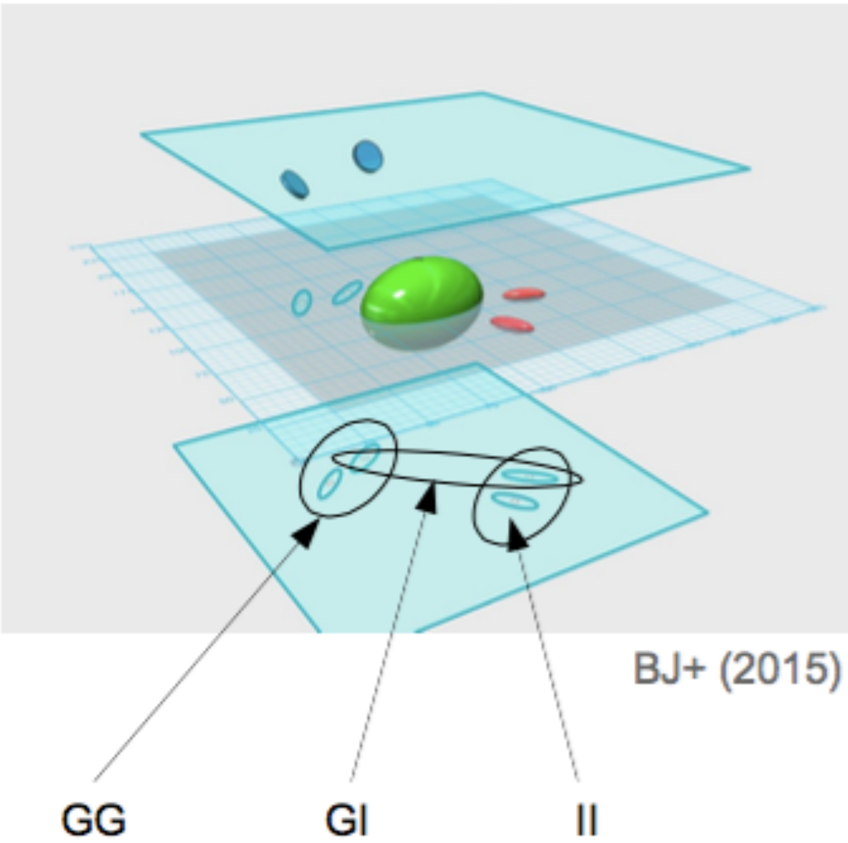
G-WL.1-5: The statistical scatter (RMS) of the errors in the measured photometric redshifts, in the range 0.2<z<2.0 shall be $\sigma(z)/(1+z)<0.03$.

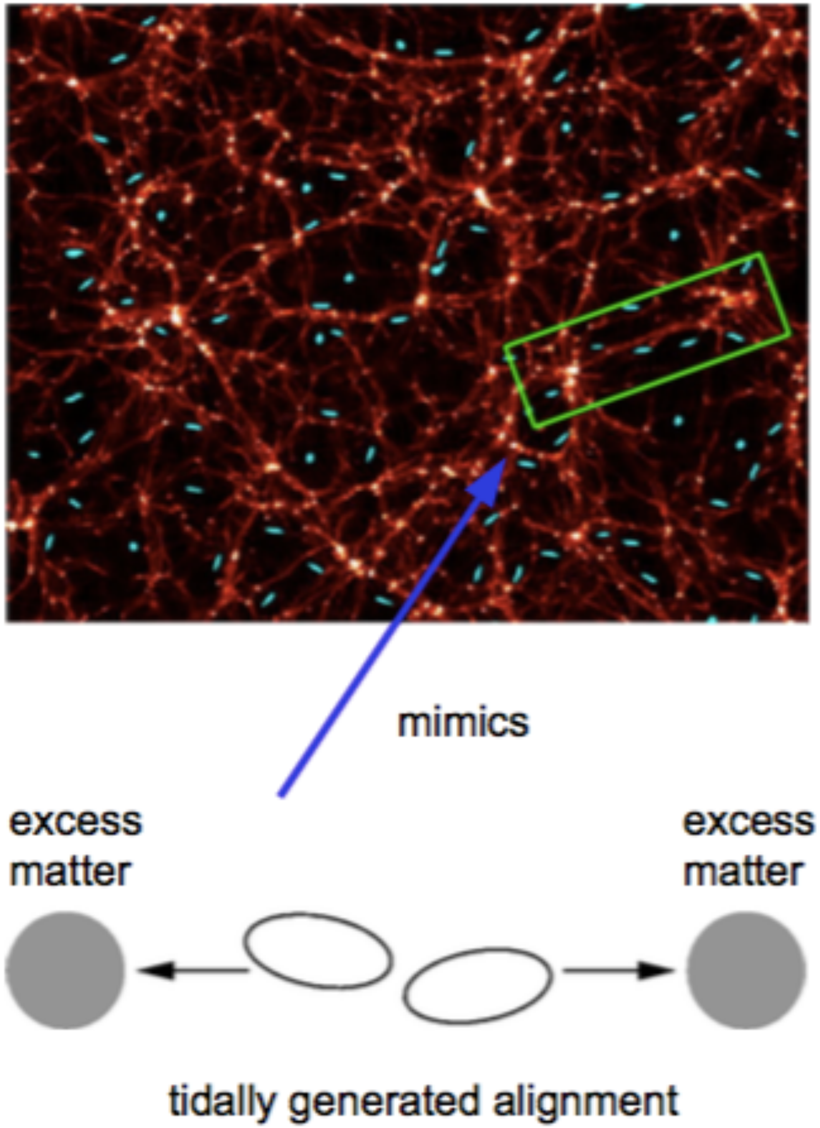
The lensing signal itself changes relatively slowly with redshift and as a consequence photometric redshifts (photo-z's) can be used to populate the tomographic bins. However, if the redshift errors are too large, the precision of the tomographic analysis is reduced (see e.g., Fig. 6 in RD02). More importantly, if the errors are too large, the uncertainty in the level of intrinsic alignments results in a significant reduction in the FoM (Fig. 5 in RD29).

The requirement of $\sigma(z)/(1+z)<0.05$ ensures that the FoM is limited only by our ability to constrain the intrinsic alignment signal. By including constraints from the galaxy number density, RD29 show that for $\sigma(z)/(1+z)<0.05$ the FoM is reduced by less than 10% due to our lack of knowledge of the intrinsic alignment signal. Note that RD29 do not account for additional constraints that may come from external spectroscopic data. Nonetheless smaller redshift errors improve constraints on intrinsic alignments. Therefore Euclid should aim to reach the goal of $\sigma(z)/(1+z)<0.03$, which implies a loss of less than 5% in the FoM.

IA in a nutshell

$$\underbrace{\langle \epsilon_i \epsilon_j \rangle}_{\text{observed}} = \underbrace{\langle \gamma_i \gamma_j \rangle}_{\text{GG}} + \underbrace{\langle \epsilon_i^s \epsilon_j^s \rangle}_{\text{II}} + \underbrace{\langle \gamma_i \epsilon_j^s \rangle + \langle \epsilon_i^s \gamma_j \rangle}_{\text{GI}}$$





Slide from WLSWG IA WP (B. Joachimi)

Budget Requirement Photo-Z

No simple analytical equation driving the allocation budget of Photo-z Requirements WL-1.005 / 006 / 007.

$$C_{ij}(\ell) = \int_0^{r_H} \mathrm{d}r\, W_{ij}^{\mathrm{GG}}(r) P_{\delta\delta}\left(\frac{\ell}{S_k(r)}; r\right)$$

$$W_{ij}^{\mathrm{GG}}(r) = \frac{q_i(r) q_j(r)}{S_k^2(r)}$$

$$q_i(r) = \frac{3H_0^2 \Omega_m S_k(r)}{2a(r)} \int_r^{r_H} dr'\, p_i(r') \frac{S_k(r'-r)}{S_k(r')}.$$

Current literature to sustain budgeting:

- EFFECTS OF PHOTOMETRIC REDSHIFT UNCERTAINTIES ON WEAK LENSING TOMOGRAPHY
  Ma et al.
- A GENERAL STUDY OF THE INFLUENCE OF CATASTROPHIC PHOTOMETRIC REDSHIFT ERRORS ON COSMOLOGY WITH COSMIC SHEAR TOMOGRAPHY
  Hearin et al.
- SYSTEMATIC EFFECTS ON DARK ENERGY FROM 3D WEAK SHEAR
  Kitching et al.
- CATASTROPHIC PHOTOMETRIC REDSHIFT ERRORS: WEAK LENSING SURVEY REQUIREMENT
  Bernstein et al.

Budget Requirement R-WL.1-5

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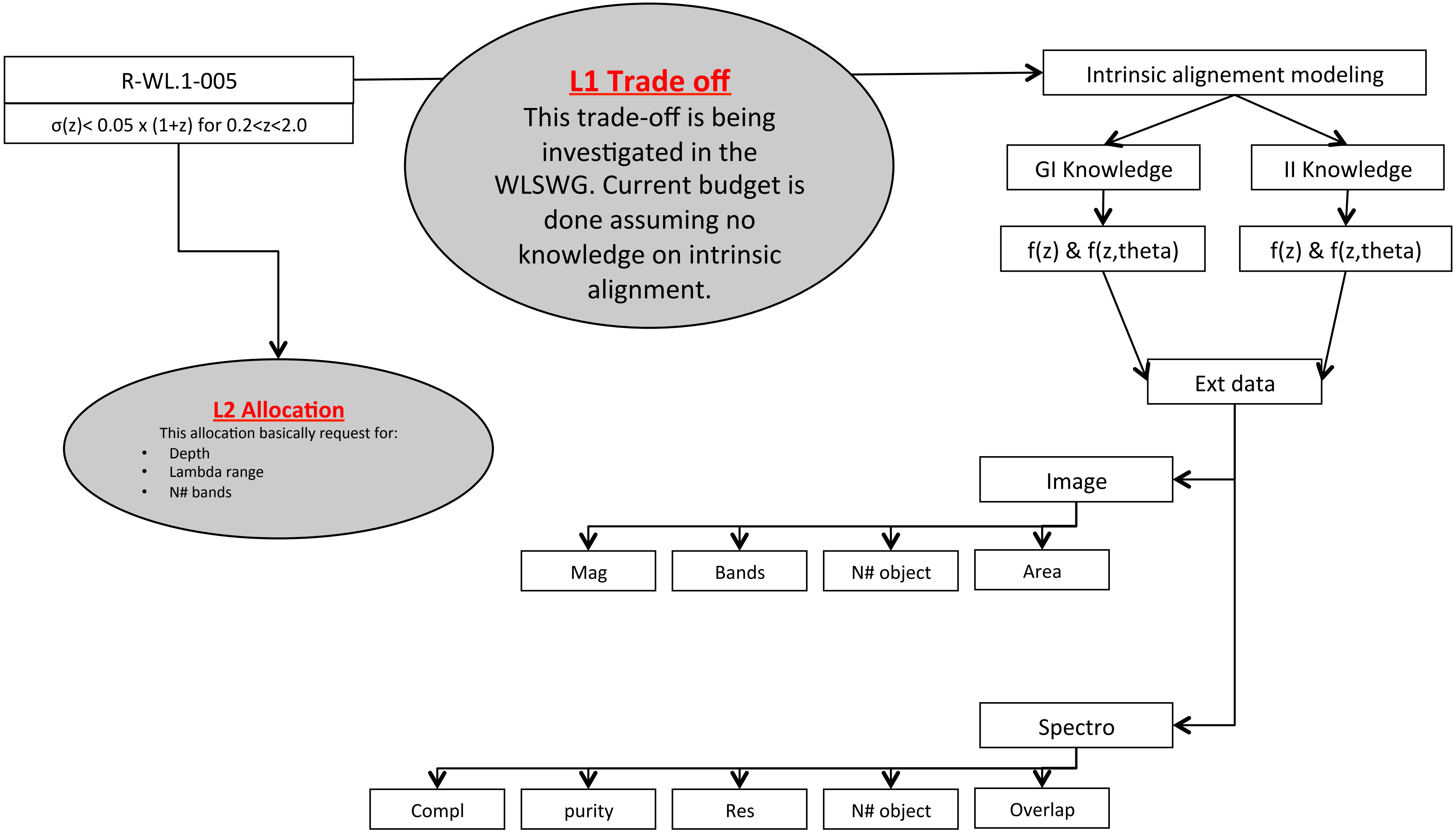

This part of re-allocation is not further analysed for the moment but is identified in case trade off need to be made in future.
The sample needed through external data is considered to be the same as the one in L2 allocation

Budget Requirement R-WL.1-5

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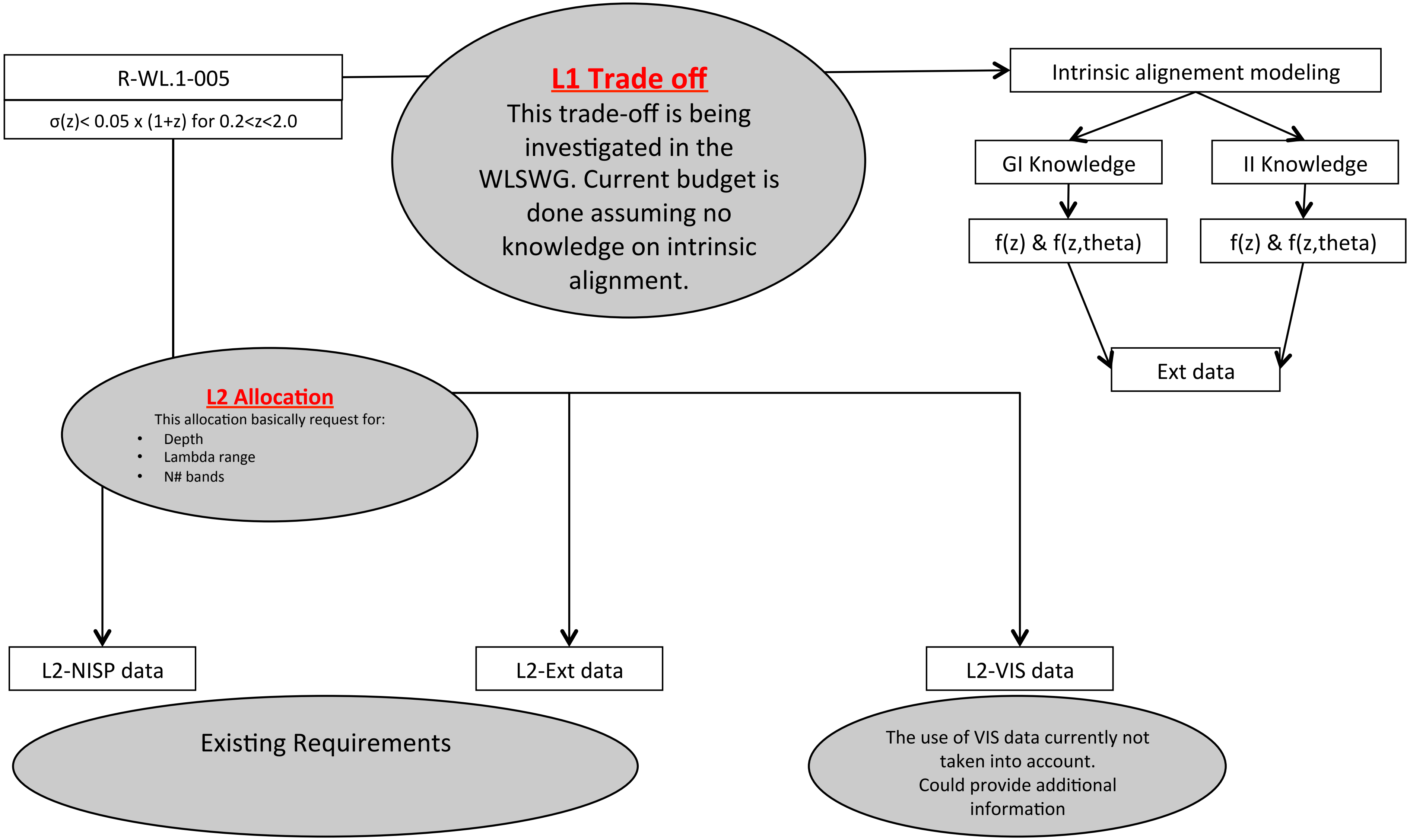
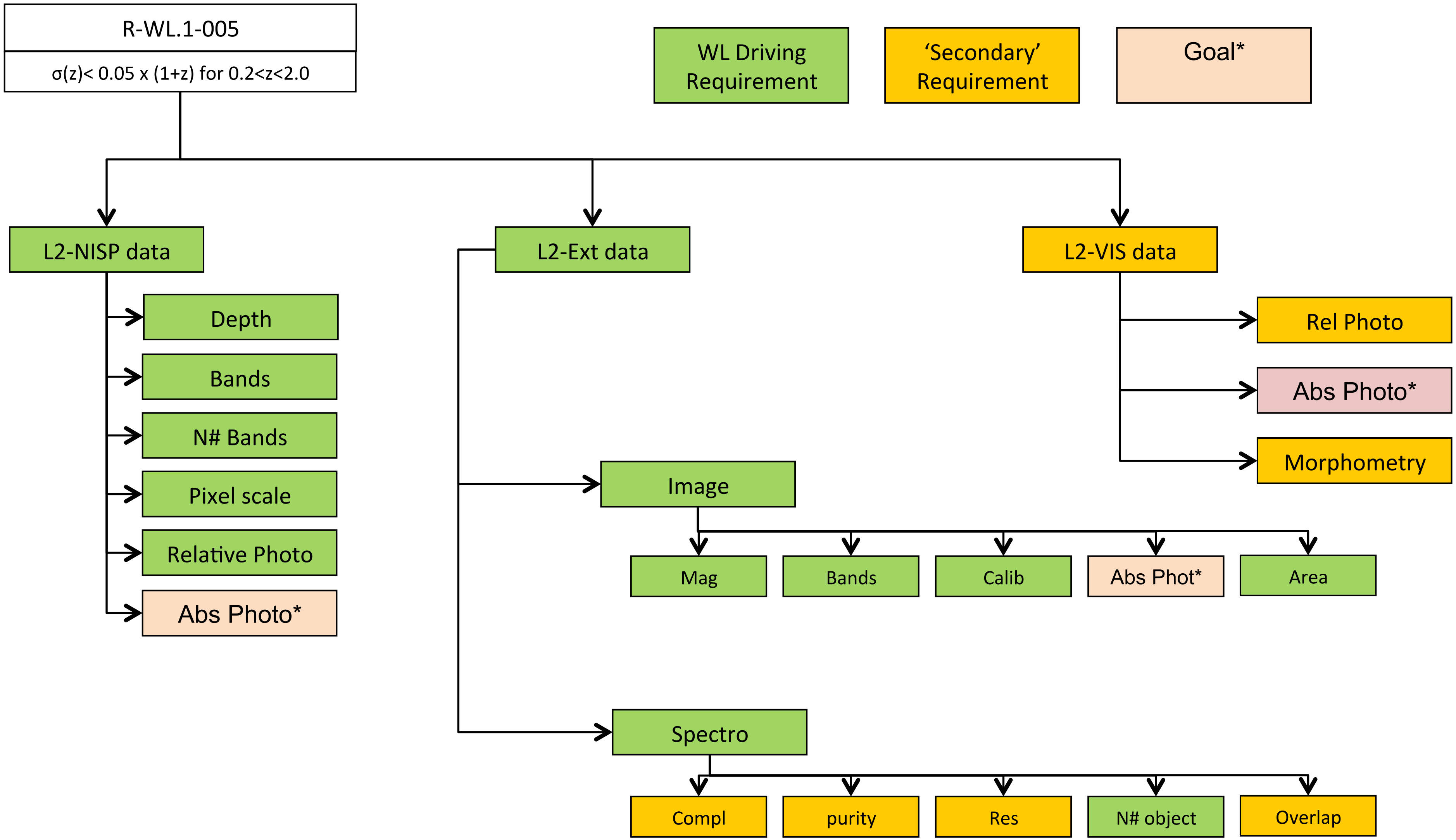
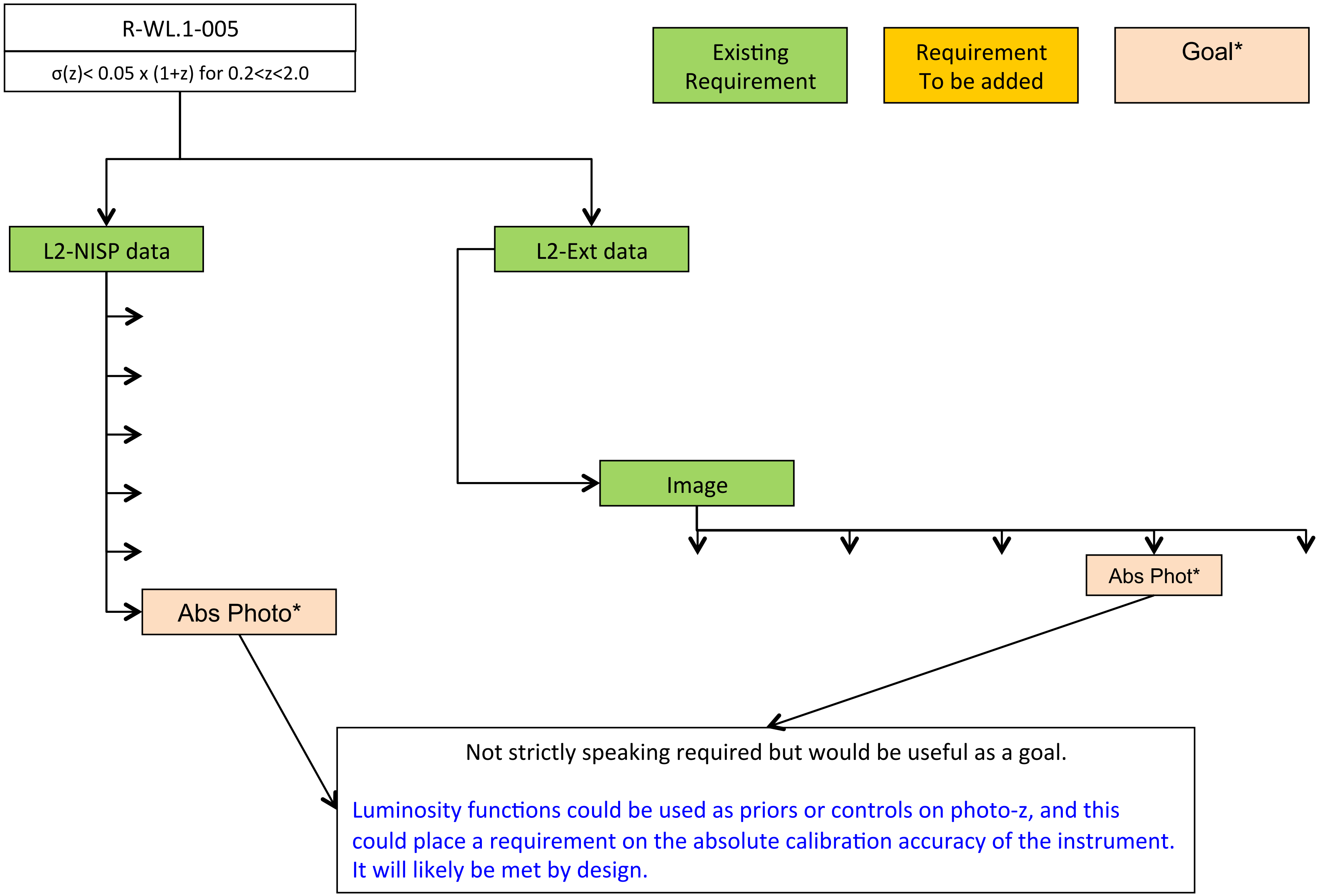


R-WL.1-5: Level 2 allocation

Euclid Consortium

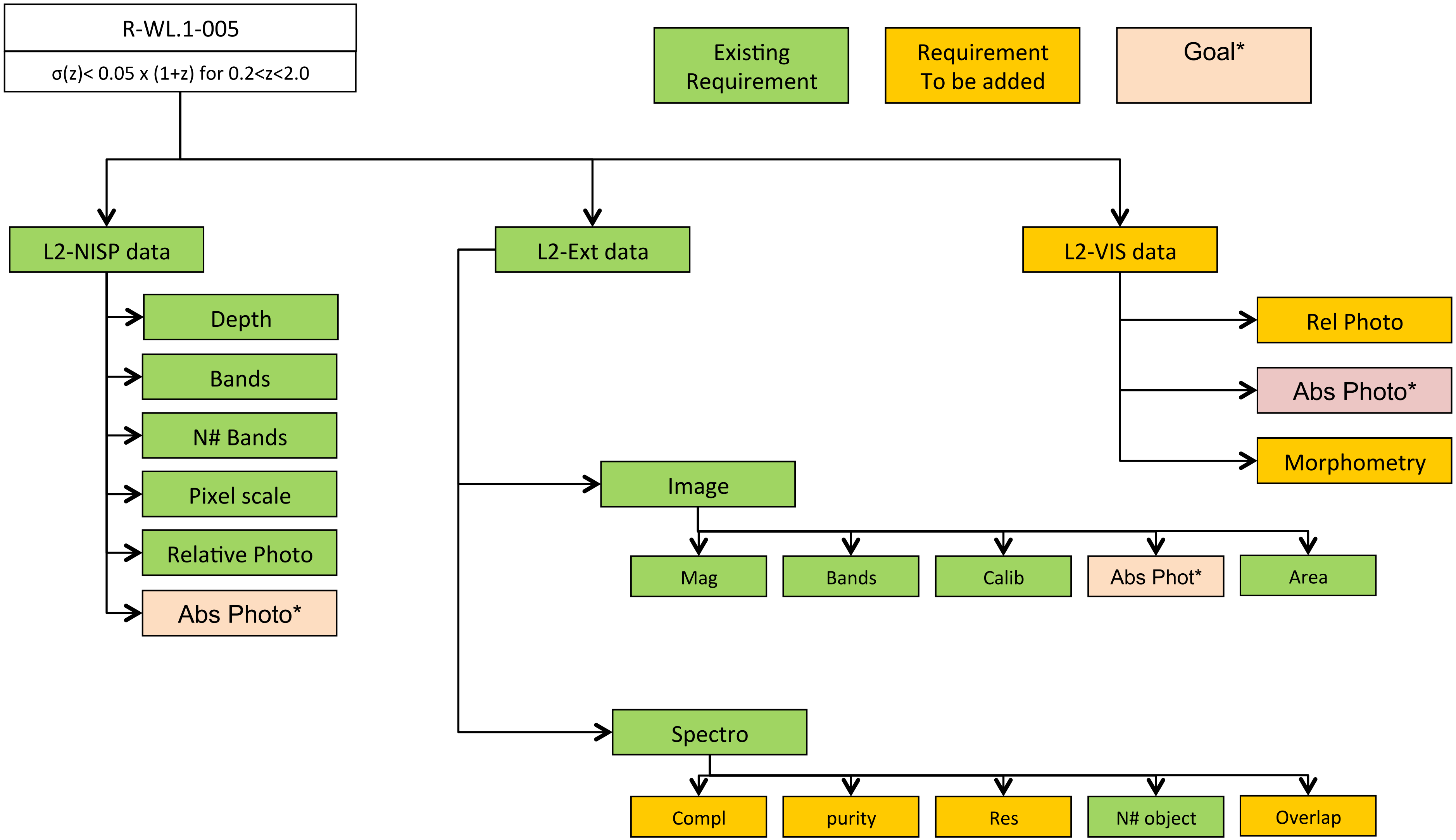


R-WL.1-5: Level 2 allocation

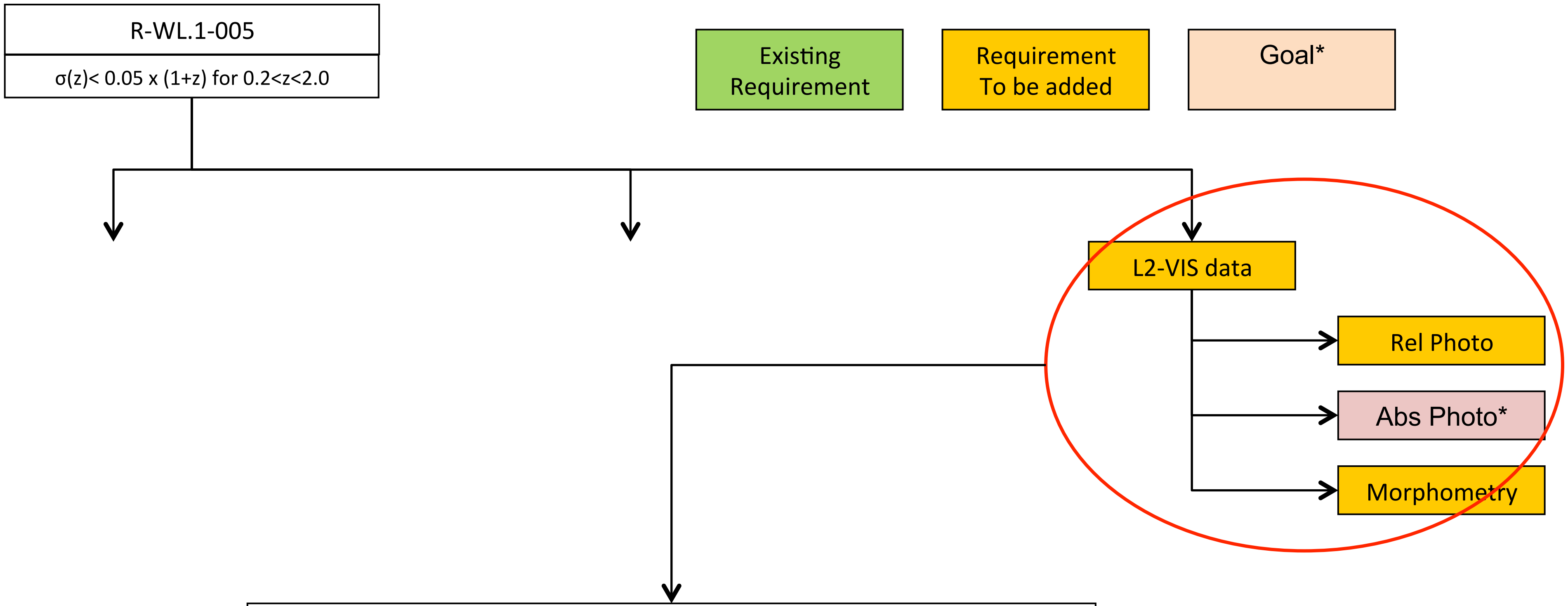


R-WL.1-5: Level 2 allocation

Euclid Consortium



R-WL.1-5: Level 2 allocation

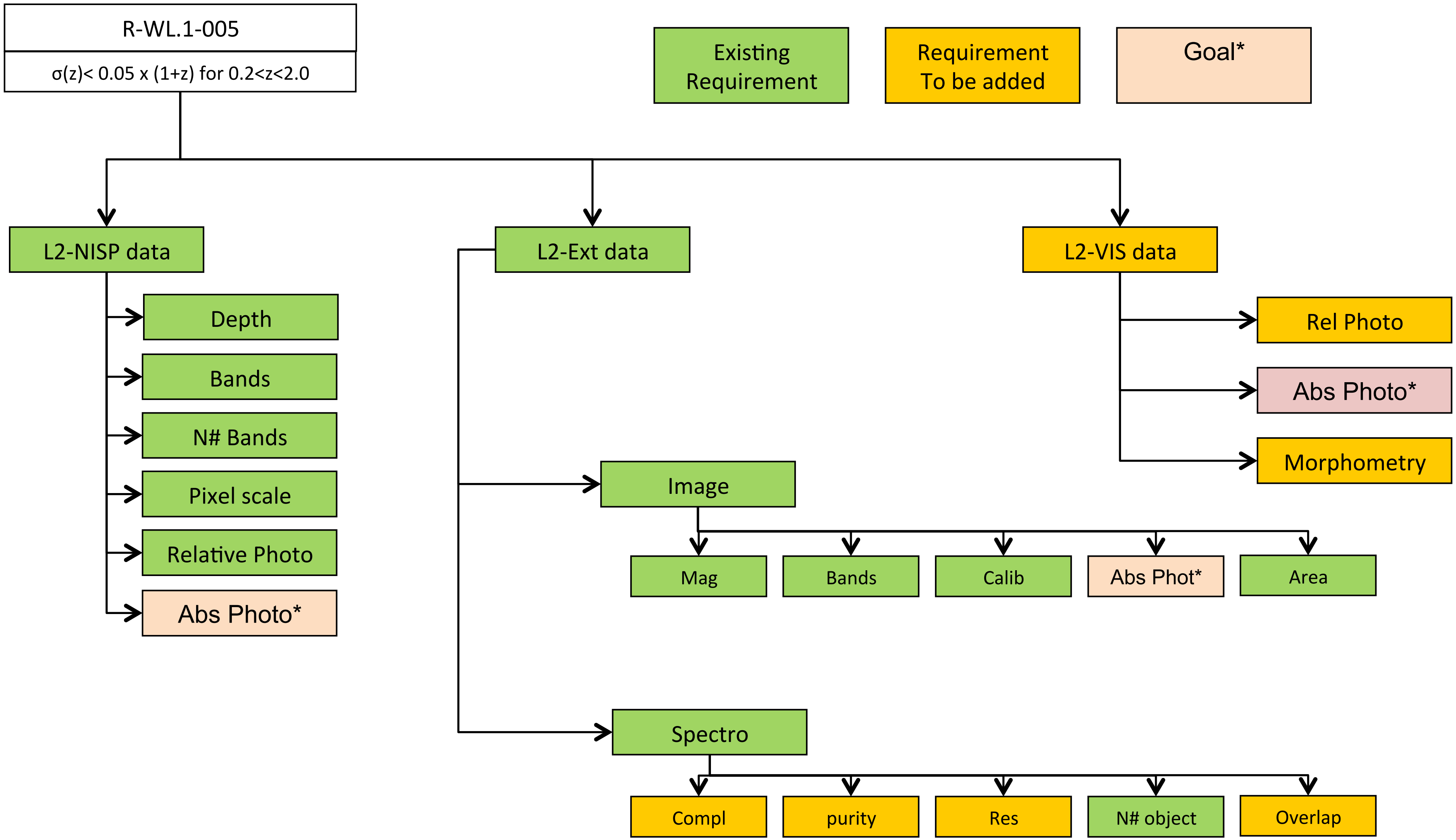


This part is not discussed in much detail in the GDPRD

However VIS information could provide additional improvement capabilities on reducing Photo-z error scatter by helping identifying outliers.

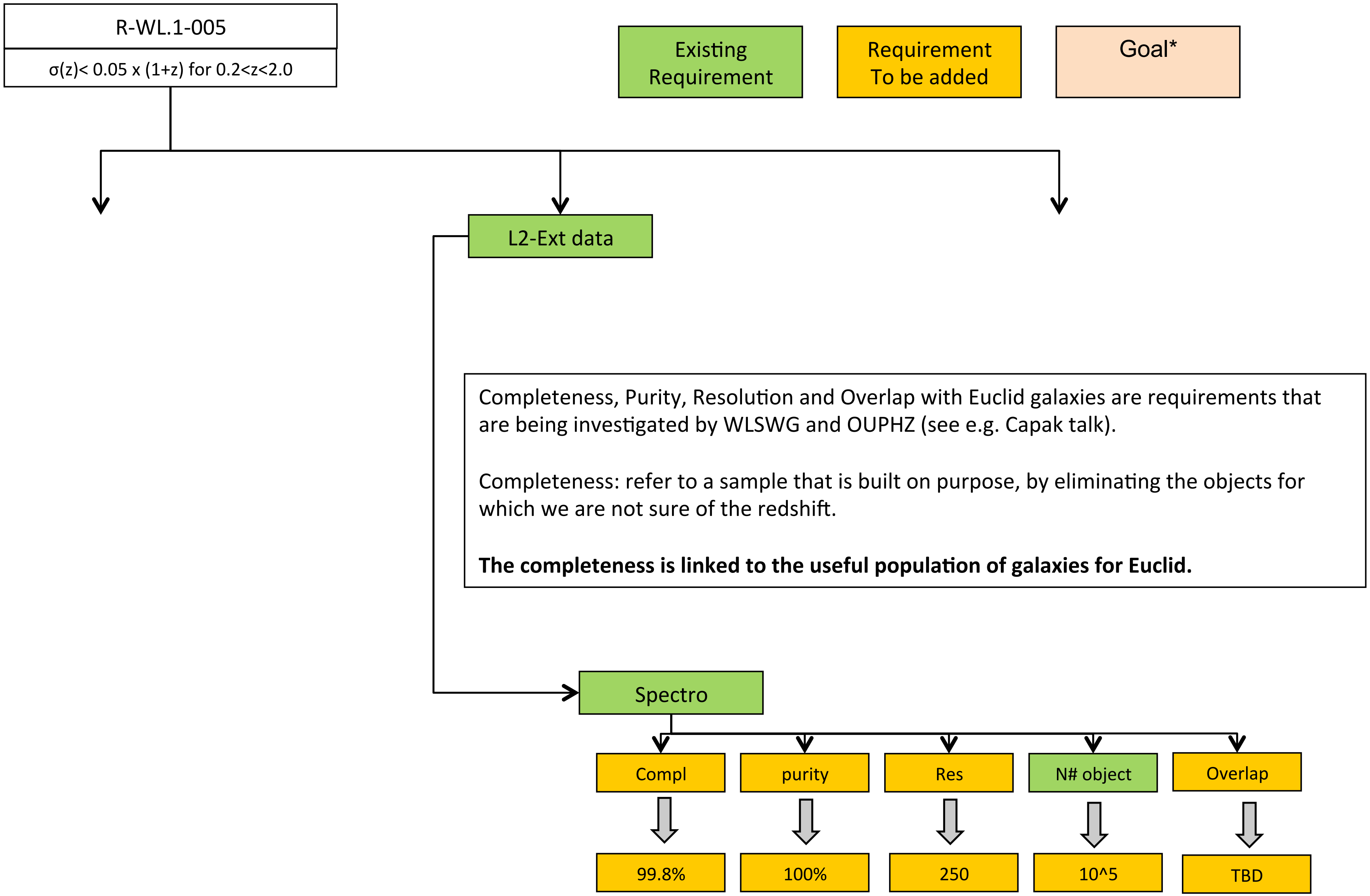
R-WL.1-5: Level 2 allocation

Euclid Consortium



R-WL.1-5: Level 2 allocation

Euclid Consortium



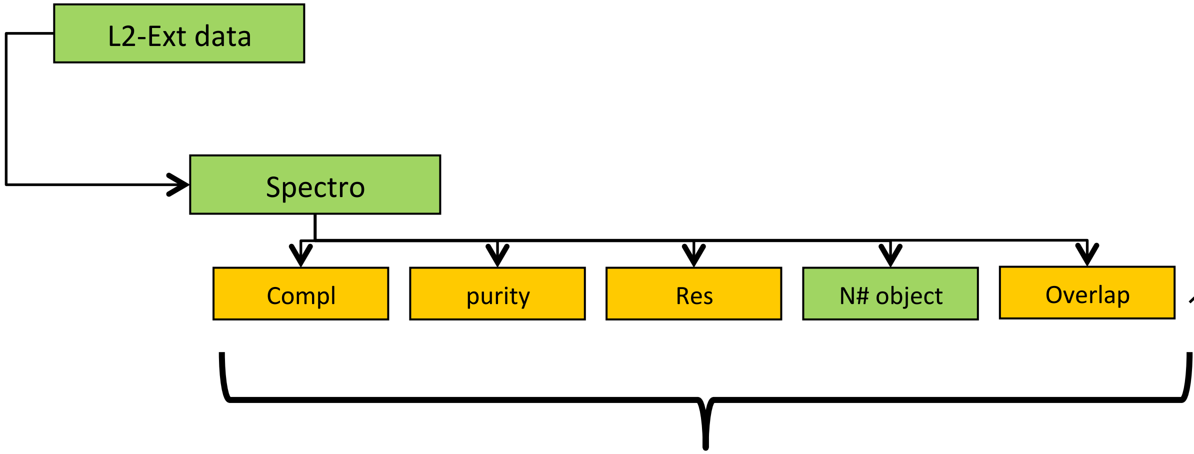
Completeness, Purity, Resolution and Overlap with Euclid galaxies are requirements that are being investigated by WLSWG and OUPHZ (see e.g. Capak talk).

Completeness: refer to a sample that is built on purpose, by eliminating the objects for which we are not sure of the redshift.

The completeness is linked to the useful population of galaxies for Euclid.

R-WL.1-5: Level 3 allocation

Euclid Consortium



Note that fulfilling requirements on required area can be achieved by merging several surveys.

These requirements can be fulfilled by many surveys, with many possible trade off between the different survey key parameters.

The requirement DL2 is translated at DL3 GDPRD in tasks on the potential survey.

- EXT
- WIDE
- DEEP

- DES
- CFHT
- PS1/2
- HSC
- KIDS
- LSST
- WHT
- …

R-GDPRD-330: SGS shall identify the candidate surveys that could fulfill the Euclid external data requirements on spectroscopic sample.

R-GDPRD-320: SGS shall monitor the candidate survey key parameters and report to ECL (TBD) the departure from nominal performance that could impact the capability to fulfill the euclid external data requirements on spectroscopic sample.

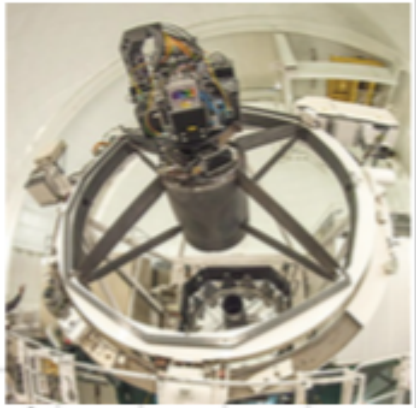
R-GDPRD-360: SGS shall merge and process the candidate surveys data in order to meet the euclid external data requirements on spectroscopic sample on the required area.

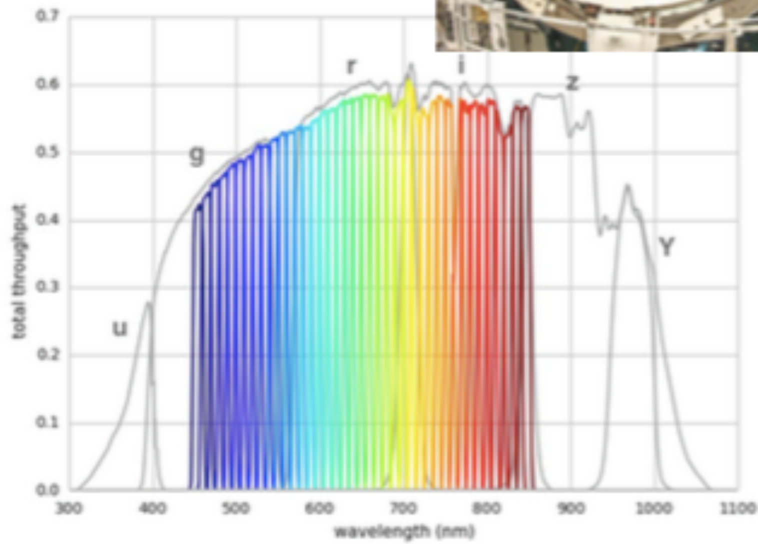
Implementation in OU-PHZ, OU-MER-OU-EXT tasks.

Calibration

- Trade-off between Photo-z calibration and IA model certainty
  - Calibration required for Spec-z training sample
    - See Capak talk
  - Calibration required for IA modeling – complexity of which is traded-off against photometric redshift accuracy
    - PAUCam survey

PAUCam@WHT

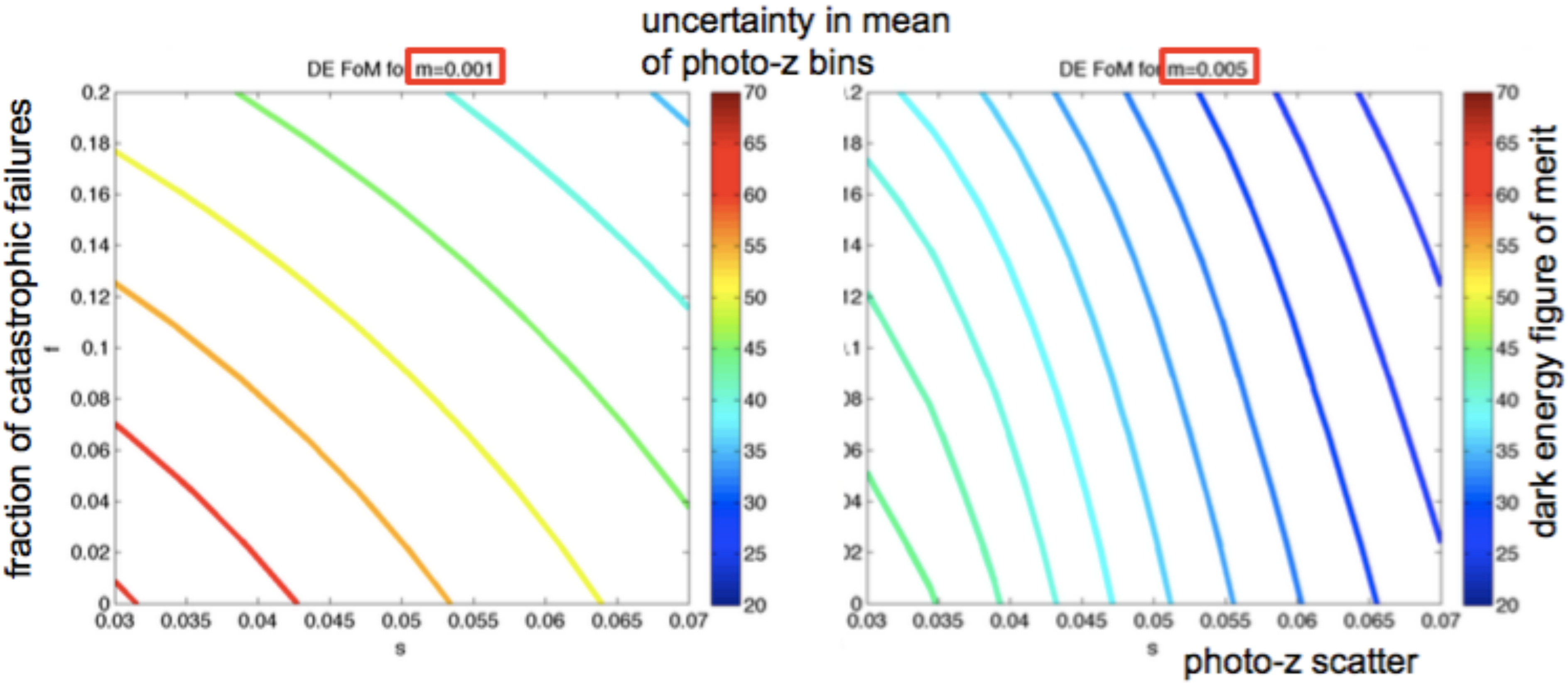




- need lensing-quality images
- need (quasi-)spectroscopic redshifts
- contiguous area for correlations
- galaxy density wins over area

IA photo-z trade-off study

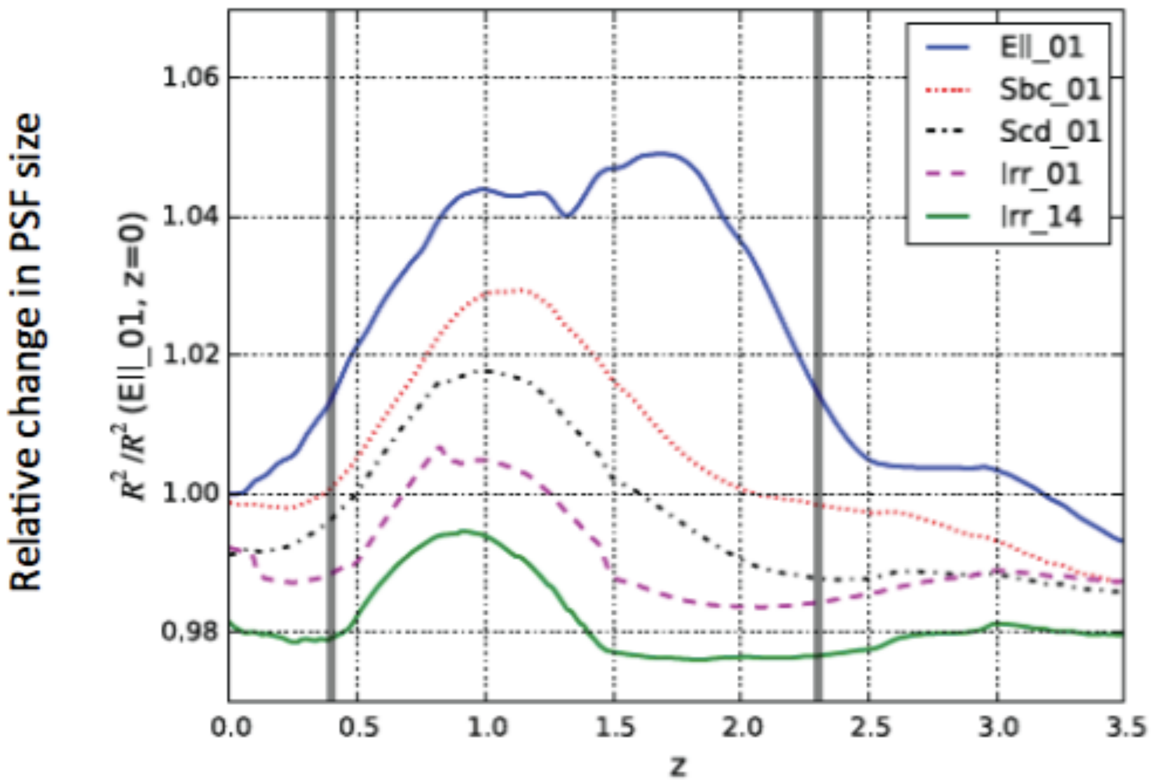
- IA drive science requirements on photometric redshift quality



Slide from WLSWG IA WP (B. Joachimi)

- Galaxy SED Information

Consequence of wavelength dependence

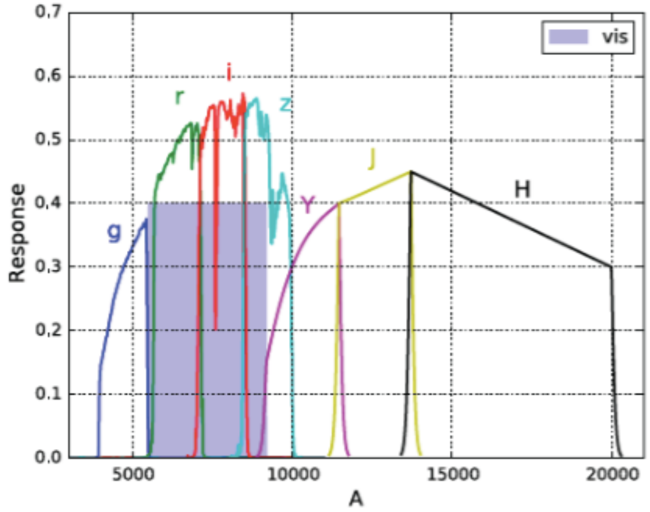


The PSF with which a galaxy is convolved depends on the SED, and thus needs to be estimated for each galaxy individually.

WLSWG Shape Measurement WP, Eriksen & Hoekstra (in prep), slides from H. Hoekstra

What data are required

We want to do this, such that the bias is $|\delta R^2/R^2|<3\times10^{-4}$



R-GDP-DL3-040	For the PSF R2 component, the transfer of the VIS PSF model to the weak-lensing objects shall not introduce errors larger than sigma(R)/R< 5×10^{-4}.	MRD-WL-007	This contribution is accounting for the fact that the model of PSF is constructed from stars while what is needed in the shape measurement is the PSF that was convolved with the galaxy (different SNR and different wavelength dependence).
R-GDP-DL3-045	The error on the multiplicative bias (μ) for those used for weak lensing determined using mock Euclid data created from HST imaging (an emulation of Euclid corrected for CTI) shall be known to better than 5×10^{-4}.	R-GDP-CAL-070	The simulations should cover the full range of galaxy properties that will be observed and the full range of systematics. The requirement specifies how well the morphologies (including the spatial variation of the colour) of galaxies need to be captured in the emulation data. This is required to calibrate the shape measurement method.

WLSWG Shape Measurement WP, Eriksen & Hoekstra (in prep), slides from H. Hoekstra

Stars or Galaxies?

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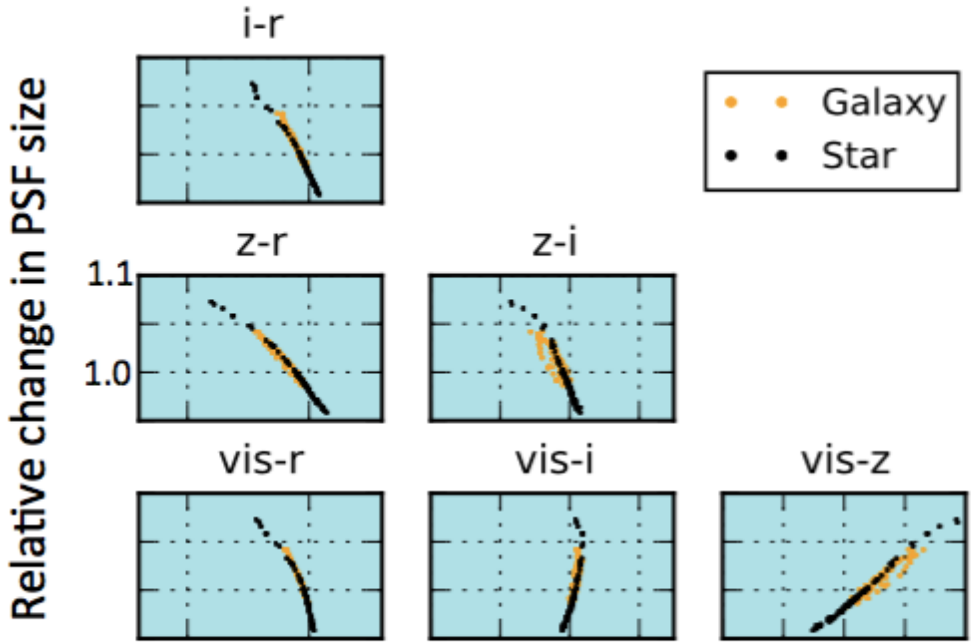
The differences between the effective galaxy PSF and the observed PSF from stars are small. But our requirements are even smaller...



Can use known SED information from Stars to train (machine learning) an algorithm to Predict SED for galaxies (test this for galaxies with known SED information)

WLSWG Shape Measurement WP, Eriksen & Hoekstra (in prep), slides from H. Hoekstra

Machine learning approach

Req=3e-4

Filters	Gal	Gal-noisy	Star	Star-noisy
r,i,z	3.5e-04	4.7e-04	2.1e-04	2.8e-04
r,i	1.4e-04	2.1e-04	9.7e-04	1.2e-03
i,z	1.1e-03	1.3e-03	4.0e-03	3.8e-03
vis,r,i,z	3.7e-04	4.4e-04	1.2e-04	2.0e-04
vis,r,i	2.1e-04	1.5e-04	7.4e-04	8.5e-04
vis,i,z	4.1e-04	7.9e-04	2.7e-03	2.6e-03
All	9.1e-05	2.5e-04	9.9e-04	8.3e-04
All - vis	9.1e-05	1.8e-04	1.7e-04	2.5e-04
All - r	3.0e-04	1.1e-04	1.8e-04	1.8e-04
All - z	1.0e-04	2.6e-04	6.1e-04	4.7e-04
All - vis,z	7.2e-05	1.7e-04	4.4e-04	3.7e-04

Table 3. The R^2 bias for the full catalog with a machine learning method. Gal means training on galaxy simulations, while star trains on observed stars. The columns marked '-noise' include noise and the others are noiseless. When training on galaxies then there is no noise in the training sample. On the first column is the filters used. Here 'All' means g,r,i,z,vis,Y,J,H.

WLSWG Shape Measurement WP, Eriksen & Hoekstra (in prep), slides from H. Hoekstra

- Colour Gradients

Colour gradients

Semboloni et al. 2012, MNRAS ArXiv1211.5025

On the shear estimation bias induced by the spatial variation of colour across galaxy profiles.

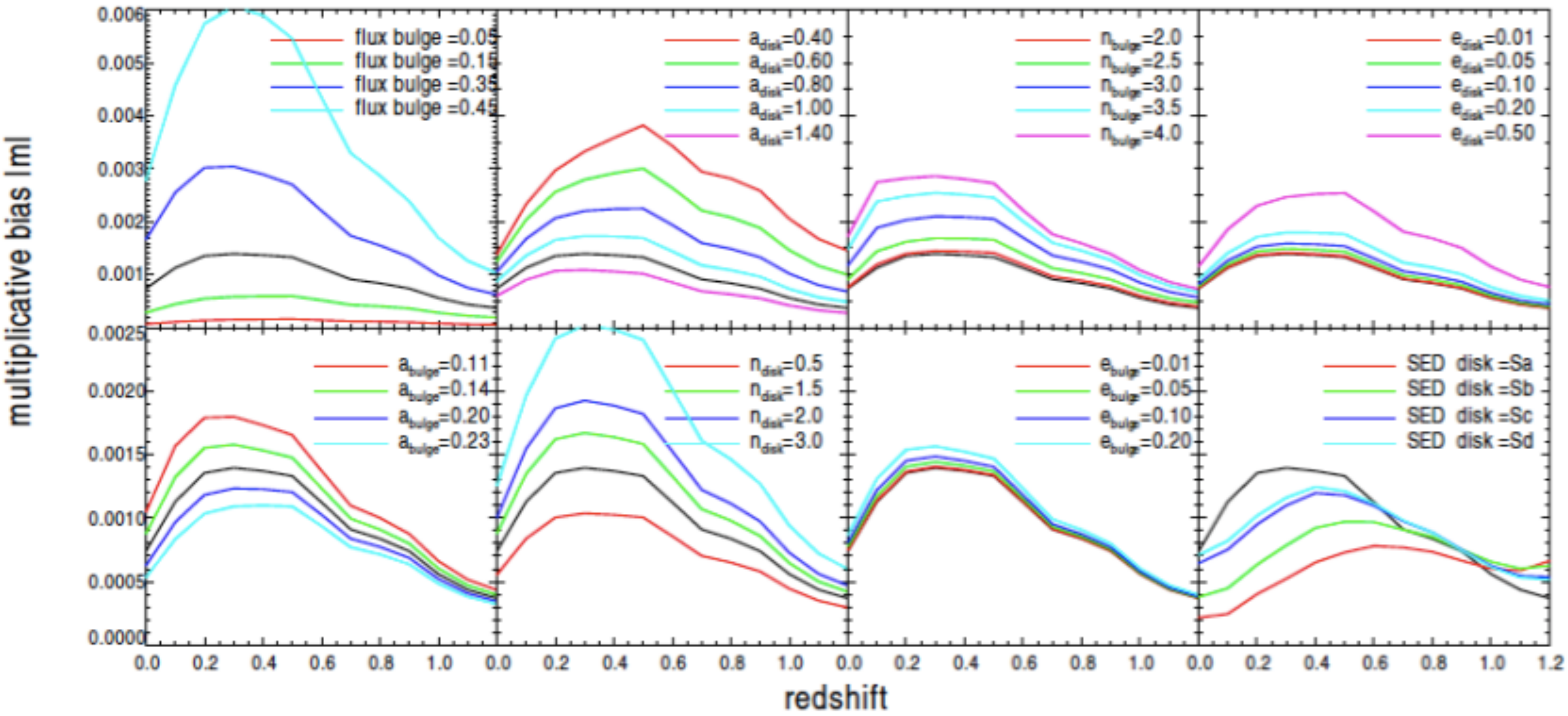
which PSF to use?

Cypriano et al. (2010): use the SED weighted PSF

In the case of unweighted moments this leads to unbiased shape estimates

But shape measurements use a radial weight to improve the S/N: more weight is given to the (brighter) inner regions. In this case we need to use a “redder” PSF.

Colour gradients



The bias depends mostly on colour and galaxy size

HST Calibration

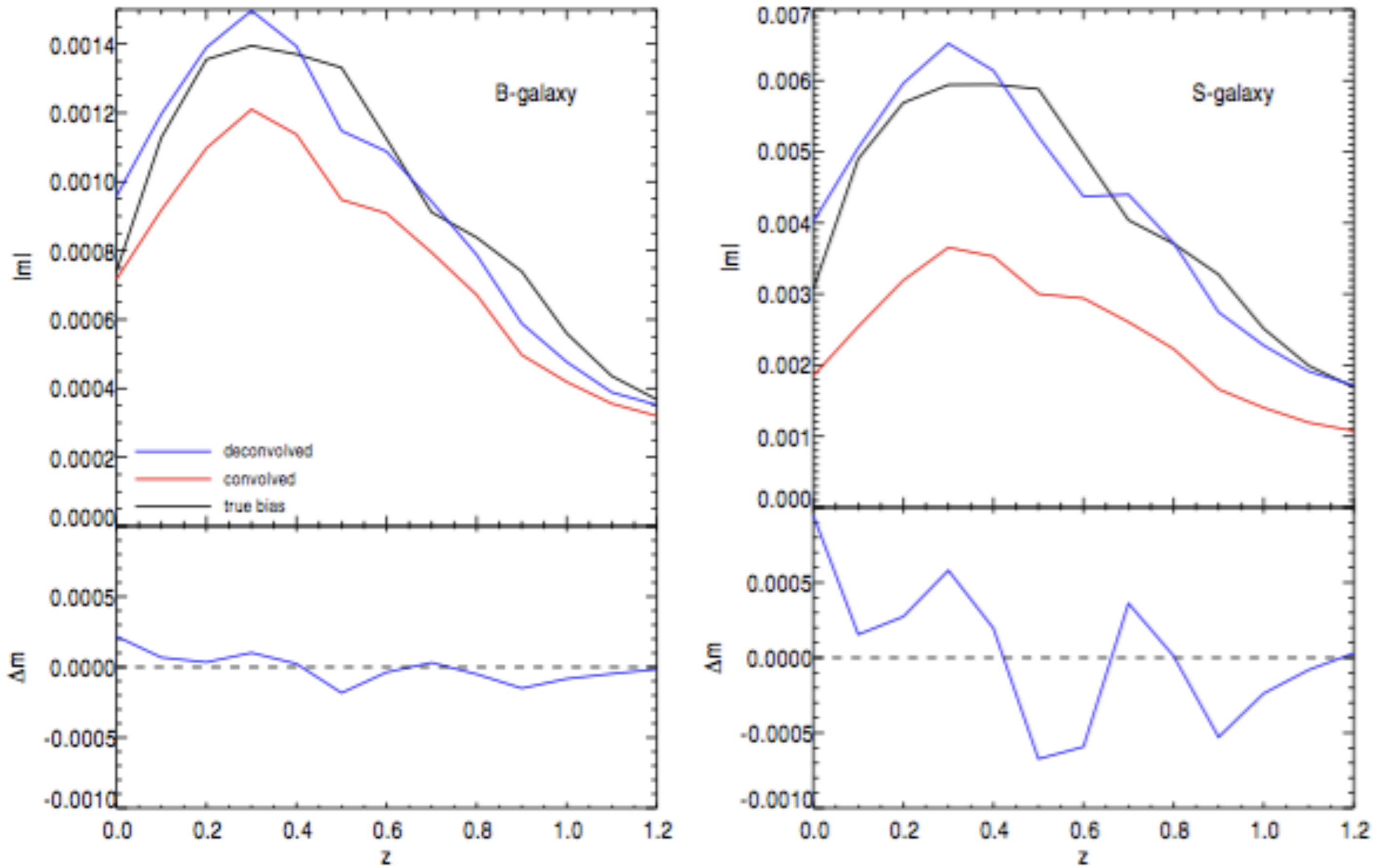


Figure 9. Left figure, top panel: Comparison of the true bias for model galaxy B (black solid line) with the bias using a linear interpolation of the SED using the F606W and F814W filters, but ignoring the effect of the *HST* PSF. The red solid line indicates the resulting bias for the reference *HST* PSF. The blue solid line shows the bias estimate when we do account for the *HST* PSF. The bottom panel shows the difference between the true bias and its estimate accounting for the *HST* PSF. The right panels show the same as the left panels but for the reference galaxy S.

- HST galaxy shape information, with HST PSF, is sufficient to calibrate this effect

Conclusion

- Three uses of photometry in weak lensing

- Photo-z
  - Flowdown: at SciRD level
  - Calibration: External Spectroscopic Data, photo-z fields (OUPHZ)

- PSF
  - Flowdown: at GDPRD level (budget of R^2)
  - Calibration: Stellar SED information (Gaia) (OUSHE)

- Colour Gradient
  - Flowdown at GDPRD level (budget of multiplicative bias)
  - Calibration: HST data (OUSHE)

- Additional Slides

R-WL.1-6: The catastrophic failure fraction (f_{cat}), shall be less than 10%.

G-WL.1-6: The catastrophic failure fraction (f_{cat}), shall aim to be less than 5%.

The catastrophic failure fraction (f_{cat}) is defined as the fraction of galaxies whose photo-z lies beyond 3σ of the true redshift.

The shape of the redshift distribution for each tomographic bin needs to be constrained. The allowed variance is given by R-WL.1-5, whereas the requirement on the mean redshift is specified by R-WL.1-7. Rather than explicitly constraining the higher order moments of the distribution, we instead specify the requirement on the fraction of galaxies whose photometric redshift differs by more than 3σ from the true redshift.

This requirement is needed because a fraction of the galaxies will be assigned an erroneous redshift due to degeneracies between the spectral type and redshift. Although diagnostics can be used to reduce the catastrophic failure fraction, some catastrophic failures remain. These have the effect of broadening the redshift distribution of the galaxies in each tomographic bin, leading to a reduction in the FoM. The current requirement leads to a tolerable loss of 10% in the FoM, accounting for intrinsic alignments through self-calibration over the full set of galaxy ellipticity and number density correlations. It is desirable to limit the loss in FoM without the need of using density correlations galaxy with is feasible if $f_{cat} < 5\%$.

R-WL.1-7: The mean of the redshift distribution n(z) in each tomographic redshift bin shall be known to a precision of $\sigma(<z>)/(1+z)<0.002$

We require a minimum of 10 tomographic bins to determine the dark energy parameters and constrain the intrinsic alignment signal (RD29). The redshift distribution for each bin needs to be characterized. The Euclid calibration sample will need to exceed 10^4 galaxies (RD01). In this case a requirement on the mean of these distributions is stronger than one on the variance (and likely all higher moments) as shown by RD02.

RD31, RD32 and RD40 find that the degradation of constraints on dark energy parameters is negligible below an uncertainty in the mean (and variance) of 2×10-3(1+*z*). This result was confirmed by RD30 who obtain a degradation in FoM of less than 10%, also if intrinsic alignments are marginalised over.

R-WL.2.1-21: The post calibration relative photometric error in NISP imaging shall be less than 1.5%.

The NISP NIR imaging data are important for the determination of photometric redshifts, which are needed to correctly interpret the weak lensing signal. To ensure uniformity within a field and among areas on the sky, **it is important that the relative photometry is sufficiently uniform, such that the mean redshift in the tomographic bins does not vary by more than 0.002 (see R-WL.1-7).** If the zero-points in the NIR filters are varied by 1.5% (while the ground-based filters are kept fixed) this requirement is met.