Status report of Pix2LSST

from **Pix**el **to** **L**arge **S**cale **S**tructure with Vera Rubin **T**elescope

S. Arnouts, R. Gavazzi, O. Ilbert
Laboratoire d'Astrophysique de Marseille

Pix2LSST Members

CPPM: Dominique Fouchez, Julian Bautista, Benjamin Racine

LAM: Stephane Arnouts, Olivier Ilbert, Reda Ait-Ouahmed

Katarina Kraljic, Marie Treyer, Raphael Gavazzi

a long term collaboration: OCEVU, ANR DEEPDIP, iPhU - CLASS

3 LSST tickets used to contribute on Vera Rubin science

* **Funding 2021** : 3x0.5 by PNCG / **2x0.5 by IPhU** / 1x0.5 by IAP
* **Funding 2022+** : 3x0.5 by PNCG / **3x0.5 by IPhU —> requested 3x3.5 kE / yr**

* with associated participants : R. Ait-Ouahmed (**PhD**   ANR-IA+IPhU)

  K. Kraljic   (**Postdoc** ANR-DEEPDIP)

Galaxy Evolution

- **Deep :** exploring high redshift universe accross cosmic time (up to the reionisation era)
- **Wide** : unique view on the growth of cosmic structures (groups/clusters/cosmic web)
    - —> strong expertise to perform statistical analysis (LF/MF/SFR functions), clustering, cosmic web
    - —> to reveal cosmic web at high redshift : needs to improve standard photo-z's
- **Big Data :** extend expertises to ML techniques for physical parameters (SFR, M^*, SFH, …) + photo-z

Cosmology

- **Cosmic shear** : constraints on the mean redshift measurements
- **SNe** : extend the Hubble diagram with photo-z
- **Dark matter profiles** : lensing at small scales using weak and strong lensing signals
- **investigate IA** of distant galaxies within the Cosmic Web

Synergy

- Vera-Rubin - Euclid - Roman (WFIRST)

Ongoing Works in Vera Rubin perspectives

Participation to Photometric Redshift developments   (collaboration LAM -IN2P3)

- SED fitting code Le Phare   (O. Ilbert, S. Arnouts)

- CNN photo-z code DEEPz   (R. Ait-Ouahmed, M. Treyer, D. Fouchez, S. Arnouts)

Participation to Lensing analysis

- Strong and Weak Lensing (R. Gavazzi)

Large Scale Structure analysis

- Cosmic Web analysis in 2D (K. Kraljic, S. Arnouts)

New development for Le Phare photo-z code

Le Phare ++ (O. Ilbert)

❋ Strong collaboration with Johann Cohen-Tanugi (IN2P3) to work on a new version of Le Phare in C++

❋ Development of a tool better oriented toward large-scale surveys   (git versioning, doxygen doc, etc)

—> one version publicly available: **https://gitlab.lam.fr/Galaxies/LEPHARE/-/releases**

❋ Work in collaboration with MPE (Mara Salvato) to improve the AGN template-fitting part for LSST

LSST Open call (Sep 21): We proposed the use of Le Phare++ through the Letter Of Recommendation

https://community.lsst.org/t/pz-lor-a-summary-of-the-proposed-pz-estimators-dm-shortlist/6308

LOR for the LePhare PZ Estimator

Contributors

Stephane Arnouts[1], Johann Cohen-Tanugi[2], Olivier Ilbert[1], Eric Nuss[2] (DESC members), Mara Salvato[3] (AGN-SC member)

1. Laboratoire d'Astrophysique de Marseille, France, INSU
2. Laboratoire Univers et Particules de Montpellier, France, IN2P3
3. Max Planck Institute for extraterrestrial Physics, Garching

Co-signers: , Clotilde Laigle (IAP)

❋ Five of the PZ estimators demonstrated that the software would be capable of meeting the scientific performance & technical aspects:

GPz, DEmP, DNF, LePhare, and BPZ.

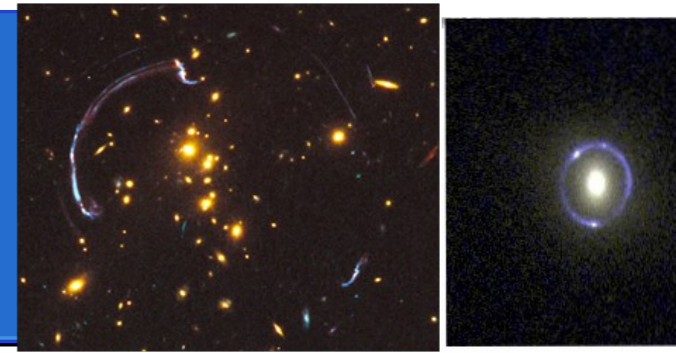❋ Additional PZ Estimators, such as CNN would likely be appropriate for the task

OI: ❋ Presentation at photoz WG: method to derive N(z) for WL analysis (Euclid/LSST)

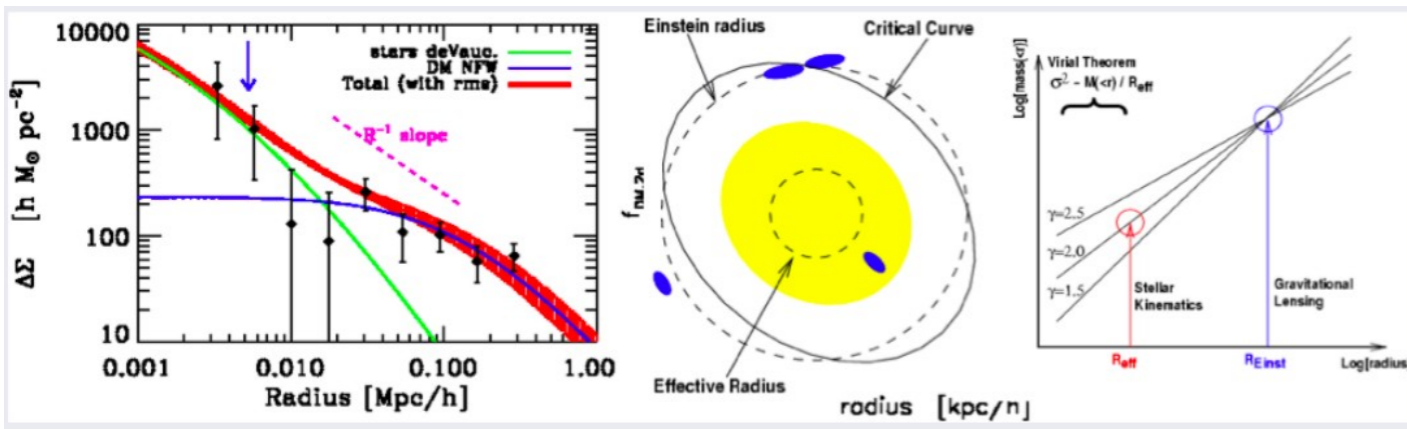❋ SOC of the LSST french collaboration meeting (Mai 2021)

The small-scale dark matter content in galaxies and clusters of galaxies from weak and strong lensing
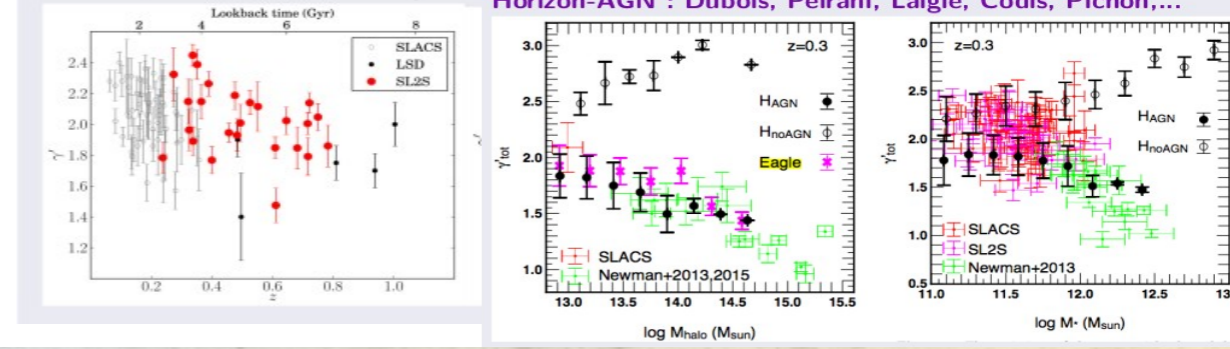
aphael Gavazzi (LAM/IAP)

- Project proposed during the 2016 call for INSU-IN2P3 sharing of LSST data rights.

- Worked at IAP until 2020 (Euclid co-lead Strong lensing SWG, Cluster lensing, raytracing...), then spent 1 year a IoA, Cambridge. Since Sept 2021, at LAM

- Science goals:
  - from masses… (total halo mass, halo-baryon relation),
  - ... to profiles & shapes … DM properties (cusp-core, ellipticity, Severe cross-talk with baryons)
  - … and dark substructures (lensed QSOs)

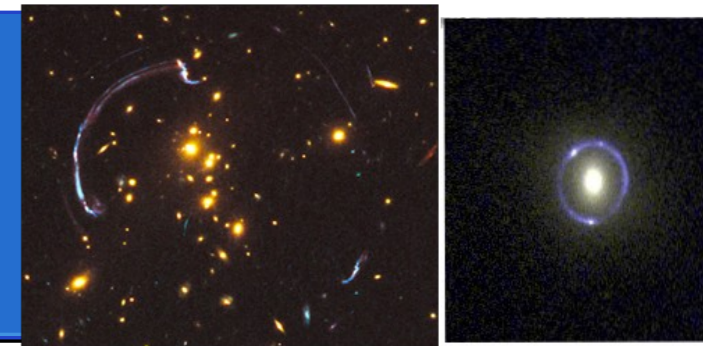$$\gamma' = \frac{d \log \rho_{\text{tot}}}{d \log r} \sim 2.08 \pm 0.02$$

$$\text{Dispersion } \sigma_{\gamma'} = 0.12 \pm 0.02$$

Horizon-AGN : Dubois, Peirani, Laigle, Codis, Pichon,...

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The small-scale dark matter content in galaxies and clusters of galaxies from weak and strong lensing

Raphael Gavazzi (LAM/IAP)

- **Strong lensing activity took off in 2021**
  - Ambitious Rubin/Euclid Derived Data Products proposal (finding/modeling lenses with multiband, high resolution of Euclid, time domain information of Rubin): https://ui.adsabs.harvard.edu/abs/2022zndo...5836022G/abstract
  - Spectroscopic follow-up of lenses with 4MOST (36,000 fiber.hours granted)
  - Contributed to the proposition of SV targets for Strong Lensing during Rubin commissioning https://ui.adsabs.harvard.edu/abs/2021arXiv211109216S/abstract

- **Willing to better contribute on Weak lensing activities**
  - My recent moves did not allow me to supervise new students yet.
  - Investigate the merits of my " weak lensing pipeline" at catalog level on DC2 and eventually at pixel level using new (ML) features of SourceXtractor++ (submitted an IPhU thesis subject related to this topic). In contact w/ C Combet's group in Grenoble.
  - Raytracing through hydrosims ready to simulate LSST images and address shape measurement issues (blending, optimal photometry...)
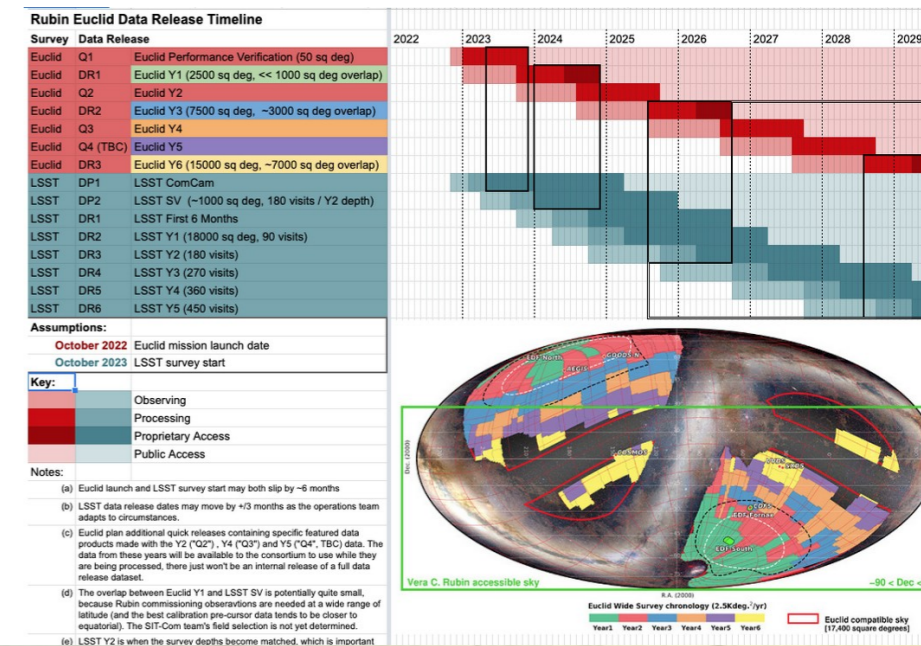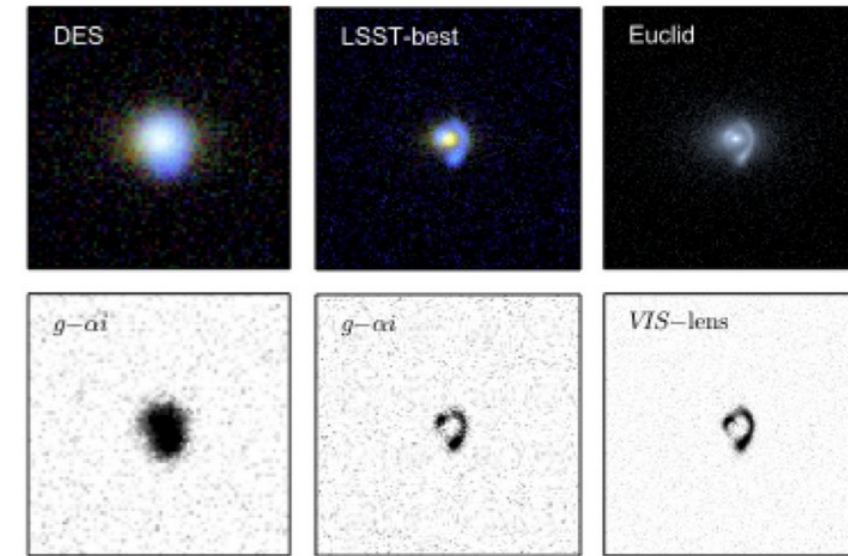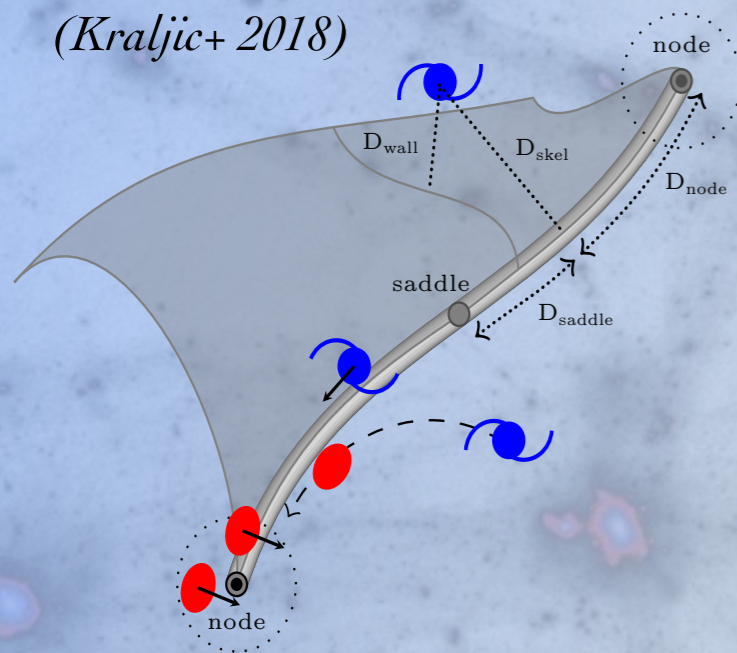
Revealing the Cosmic Web in thin redshift slides

❋ Spectroscopic surveys reveal the influence of Cosmic Web on galaxy properties

SDSS   GAMA

(Malavasi+ 2017)
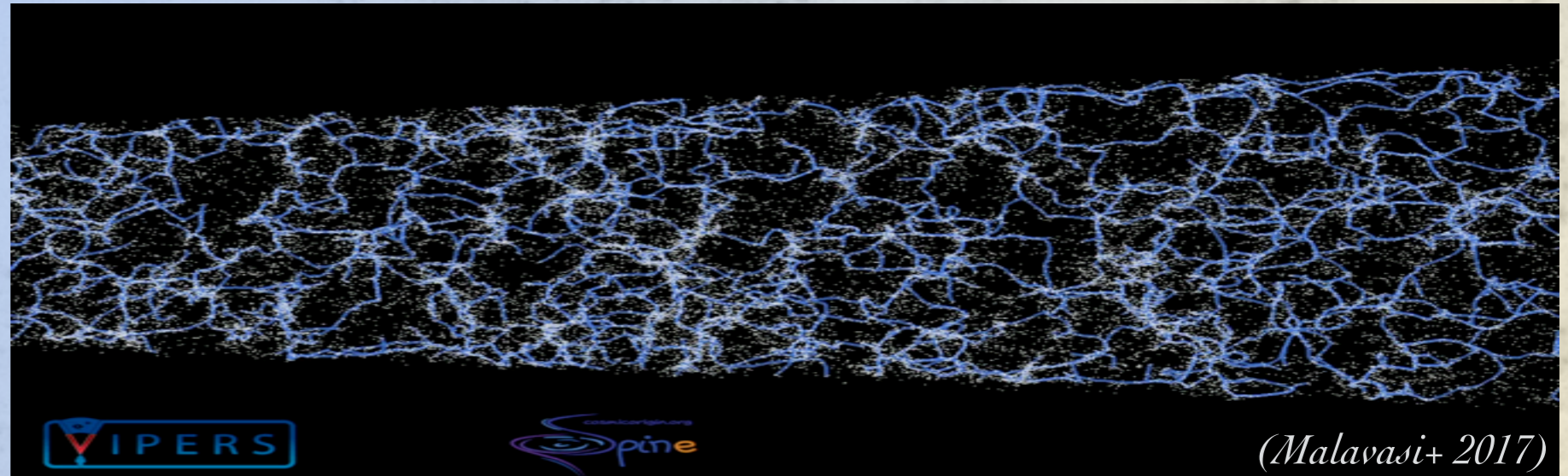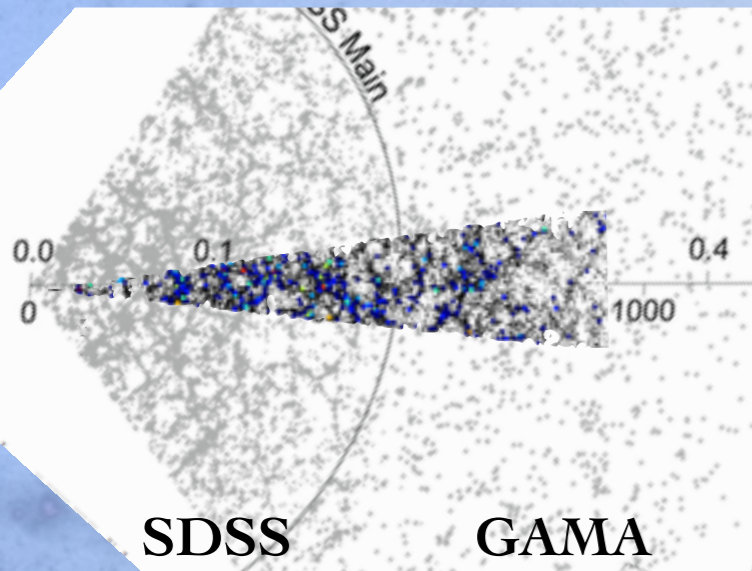
(Kraljic+ 2018)

— mass/type segregation toward filaments/Walls and nodes

—> Cosmic Web a natural metric to interpret galaxy evolution

—> **Analyses convincingly extended in 2D** *(Laigle + 2018)*
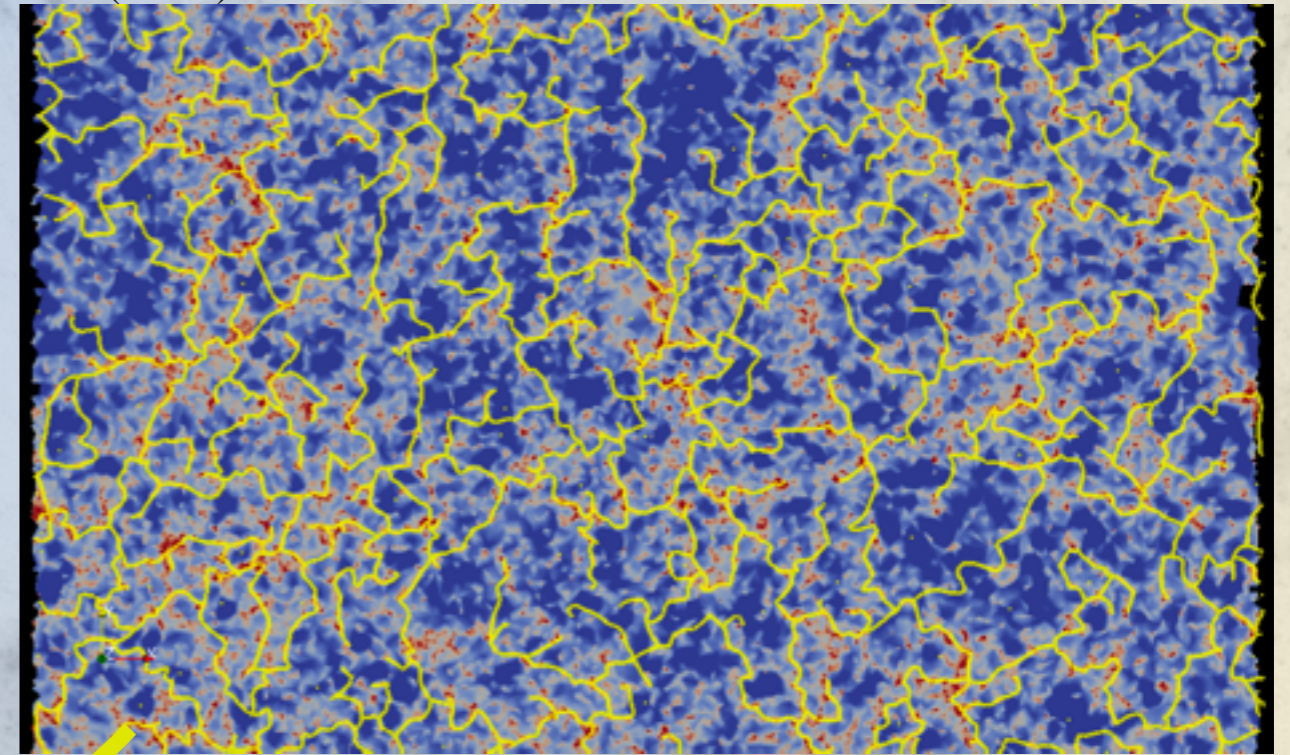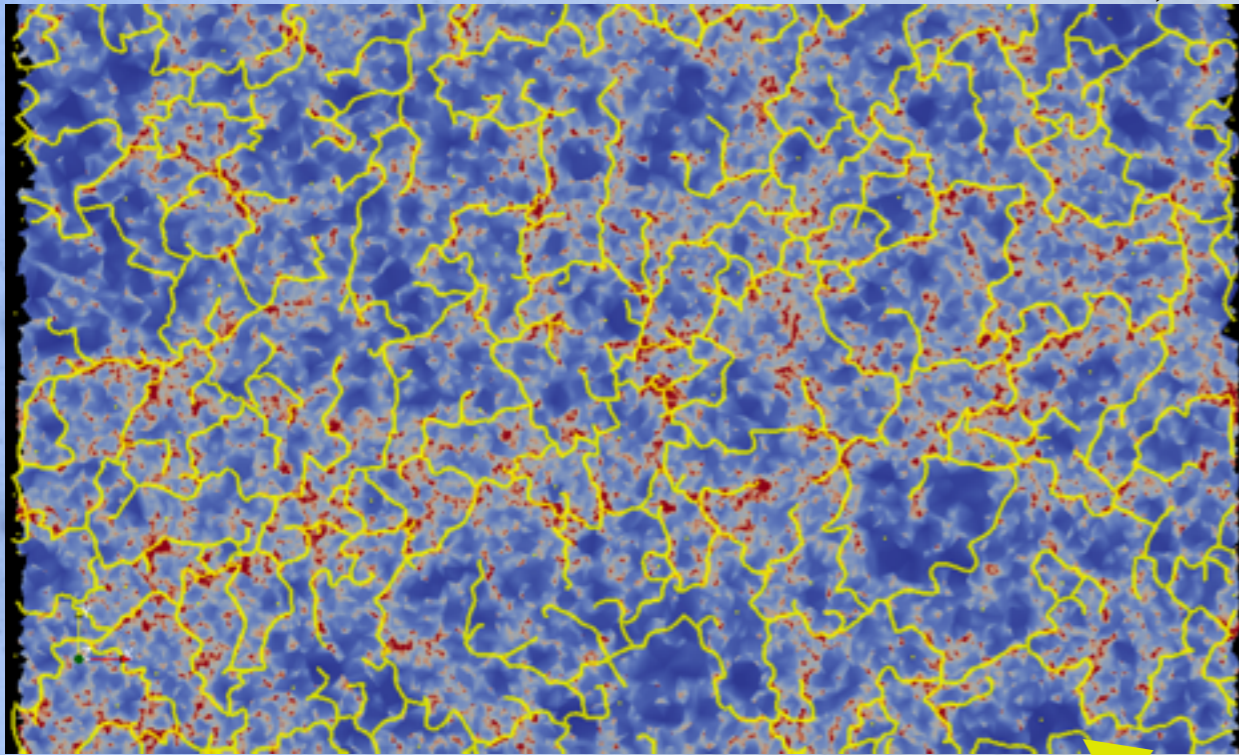   **with 30 bands COSMOS photo-z**

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Revealing the Cosmic Web in thin redshift slides

simulation Universe Machine

z-true   **z~0.9 , $\delta z=0.04$ ($2\times\sigma_z$)**   Photo-z

Filaments with DisPerSE code (Sousbie+11)

—> developing the machinery for CW characterization in 2D on sphere

CW filaments and peaks :

—> Galaxy properties segregation

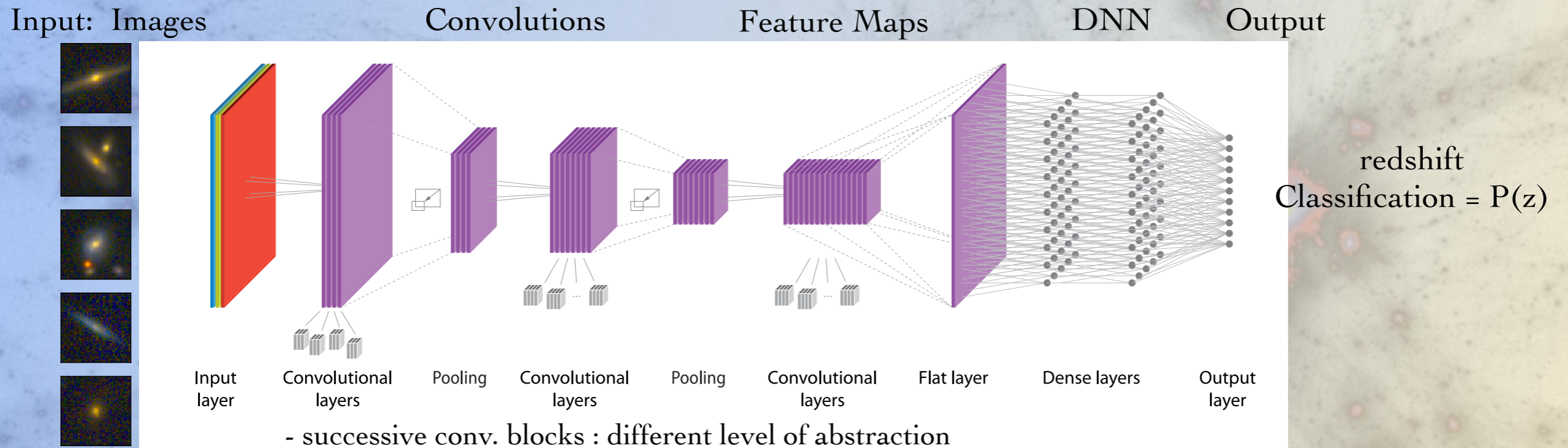—> spin alignment (IA)

Connectivity (number of filaments/peak)

* Group/clusters assembly   *(Darragh Ford + 2019; Sarron+19)*

* Connectivity increases with DM halo mass and evolves with time in a cosmological dependent way (growth rate of structures)   *(Codis+18)*

SA, KK: * members of the LSS Working Groups: These topics are not yet considered in LSST WGs —> TBD

Photo-z with Convolutional Neural Network

— **no feature extraction.**   **Works at the pixel level !**
exploits all the informations (SB, sizes, inclinations, color gradients, neighbors)

— Now under reach thanks to large spec-z samples & GPU power   —> ANR DEEPDIP with D. Fouchez

Input: Images   Convolutions   Feature Maps   DNN   Output

redshift
Classification = P(z)

Input   Convolutional   Pooling   Convolutional   Pooling   Convolutional   Flat layer   Dense layers   Output
layer   layers   layers   layers   layer

- successive conv. blocks : different level of abstraction
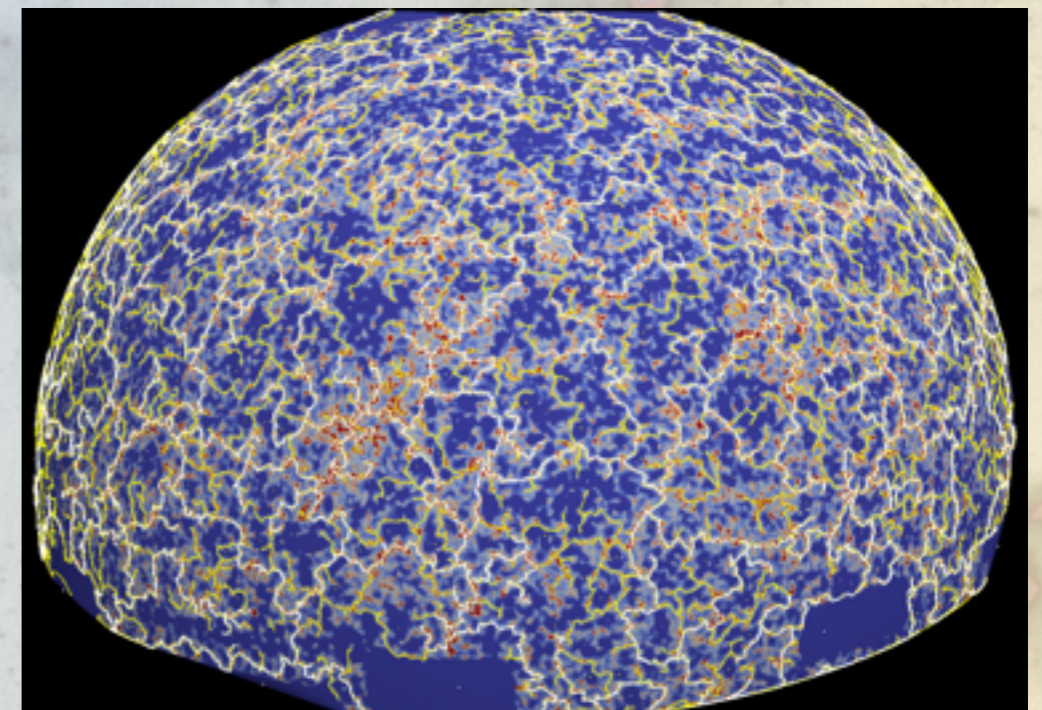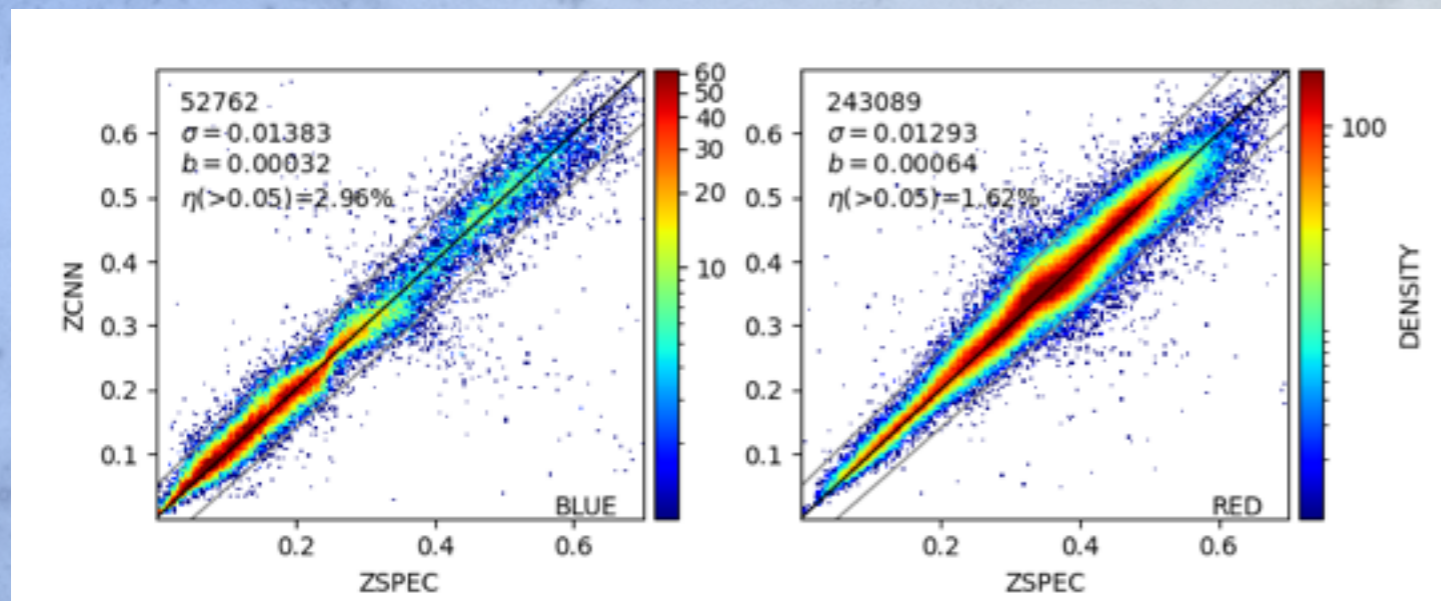
Photo-z with Convolutional Neural Network

❋ Application to SDSS (DR12) :   516,000 galaxies with r<17.8   (Pasquet+19)
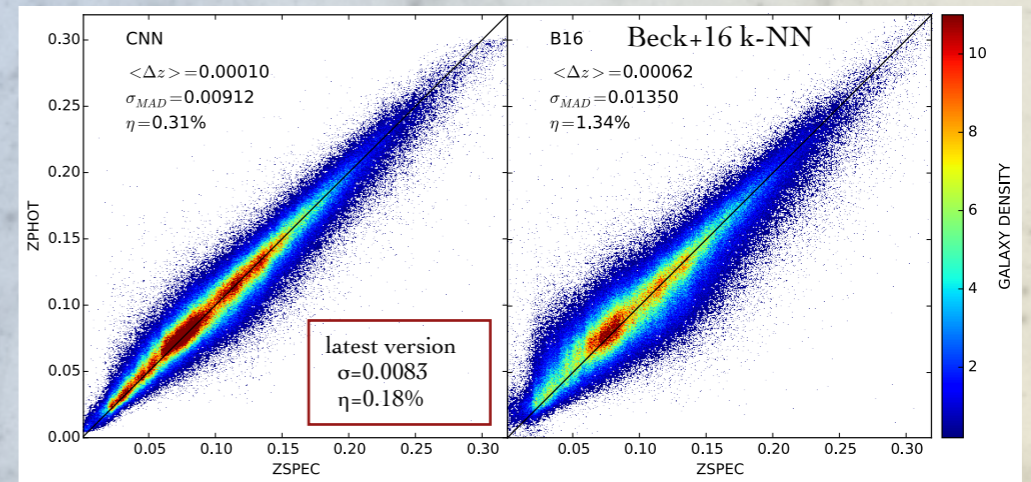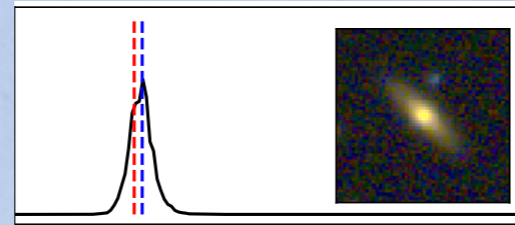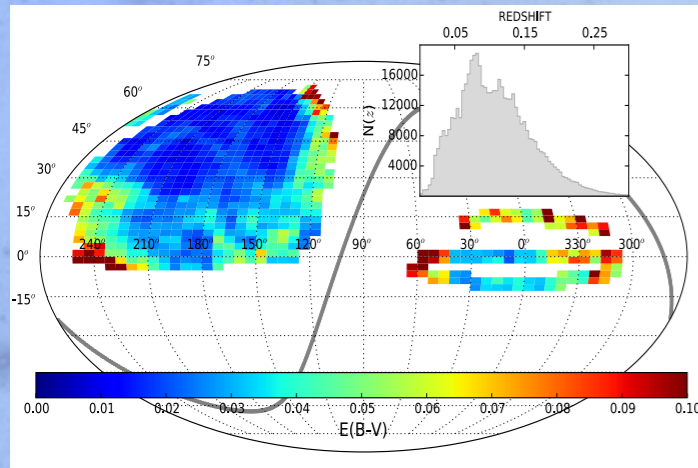
❋ SDSS extended to r<20 with SDSS+BOSS+GAMA training set (Treyer+22)   15 millions of Z_{CNN}

—> 2D CW analysis in redshift slides 0<z<0.5
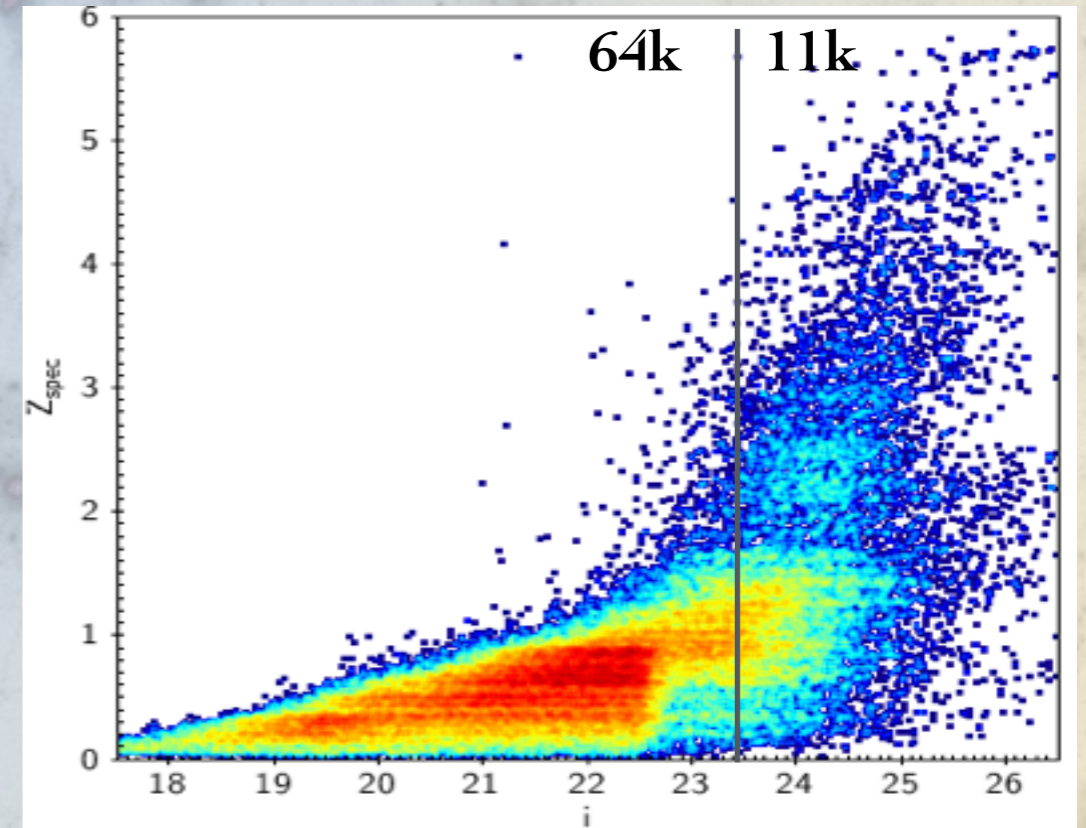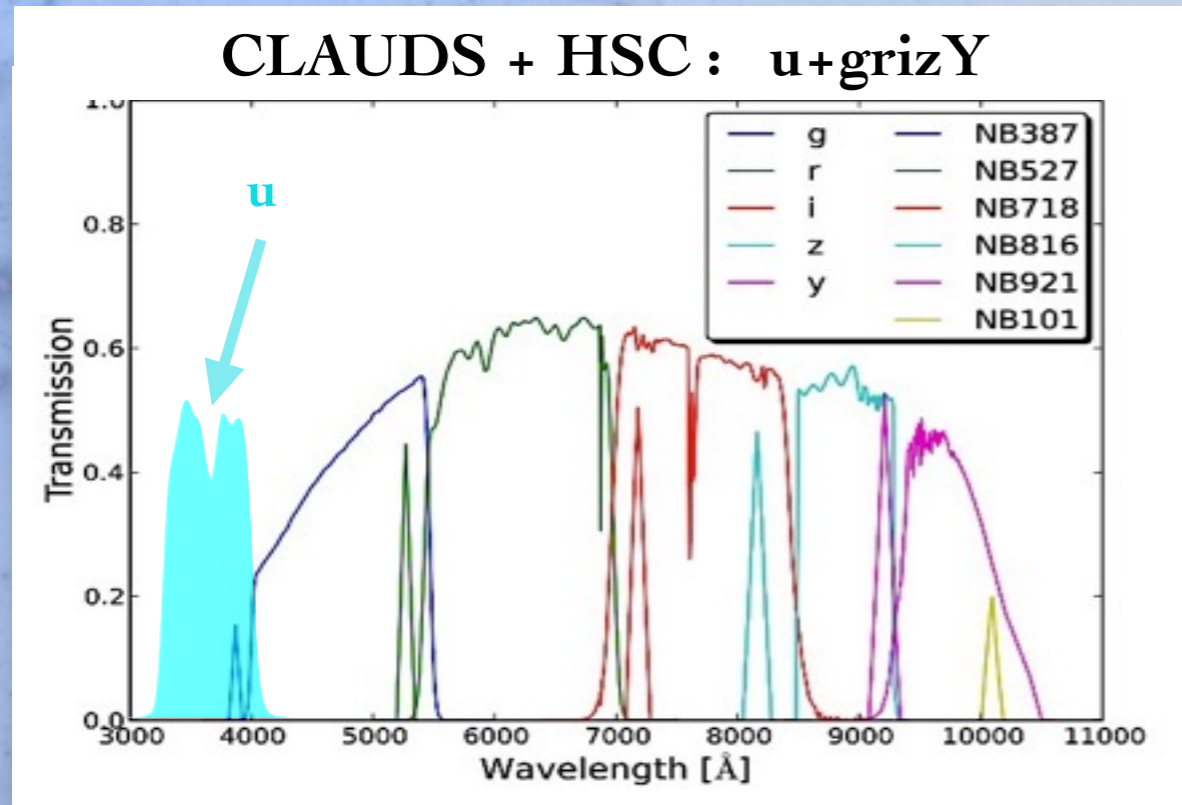
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Application to high redshift with HSC-CLAUDS with **Reda Ait-Ouahmed**, co-supervised by **J. Pasquet** (Tetis)

—> mimics LSST photometry (bands + depth)

—> Challenges : Large redshift range
small and inhomogeneous training set

CLAUDS + HSC : u+grizY

HSC Deep : 28 deg² at r~27 +NB (in progress)

CLAUDS : 25 deg² at u~27 (done)

SA, RAO: * members of the PhotoZ Working Groups: This image based code could become a PZ estimator for VR.

Photo-z with Convolutional Neural Network

—> Challenges :   Large redshift range +   smaller and inhomogeneous training set

—> Comparison with spectroscopic data between CNN and SED fitting codes

DeepZ —> UgrizY images

CNN

σ_{MAD} = 0.012
η =2.1%

$\cdot$ I ≤ 26

LePhare —> UgrizY+GALEX+JHK photometry

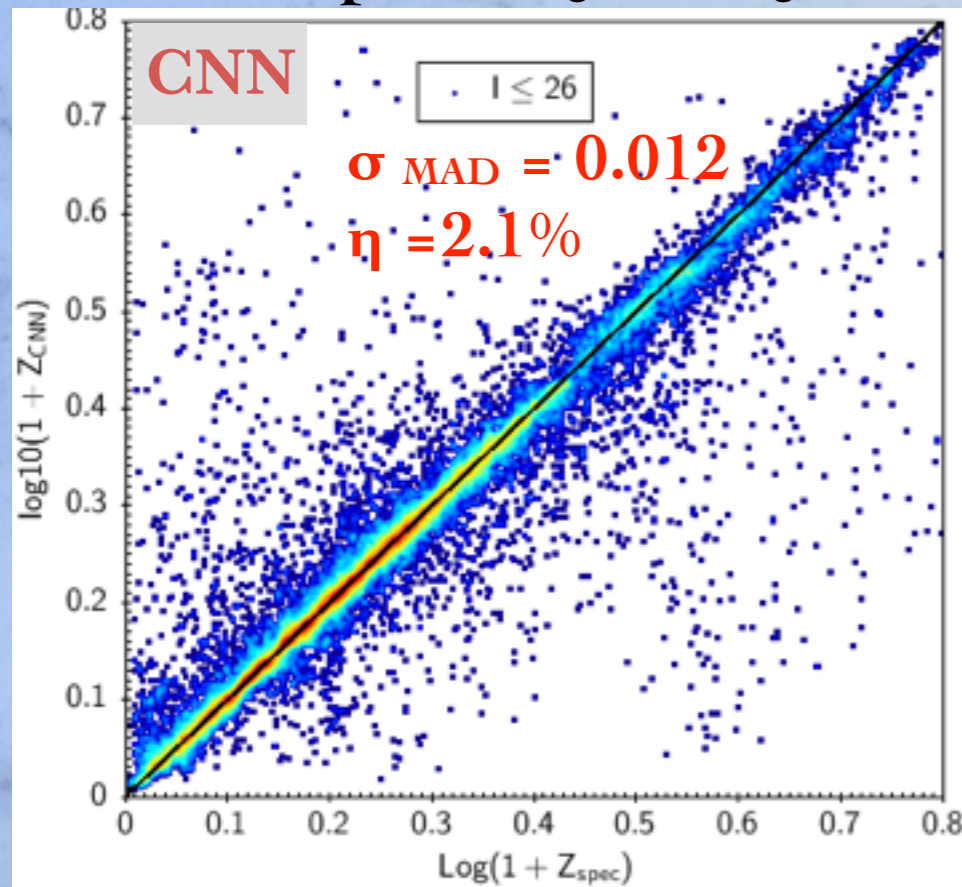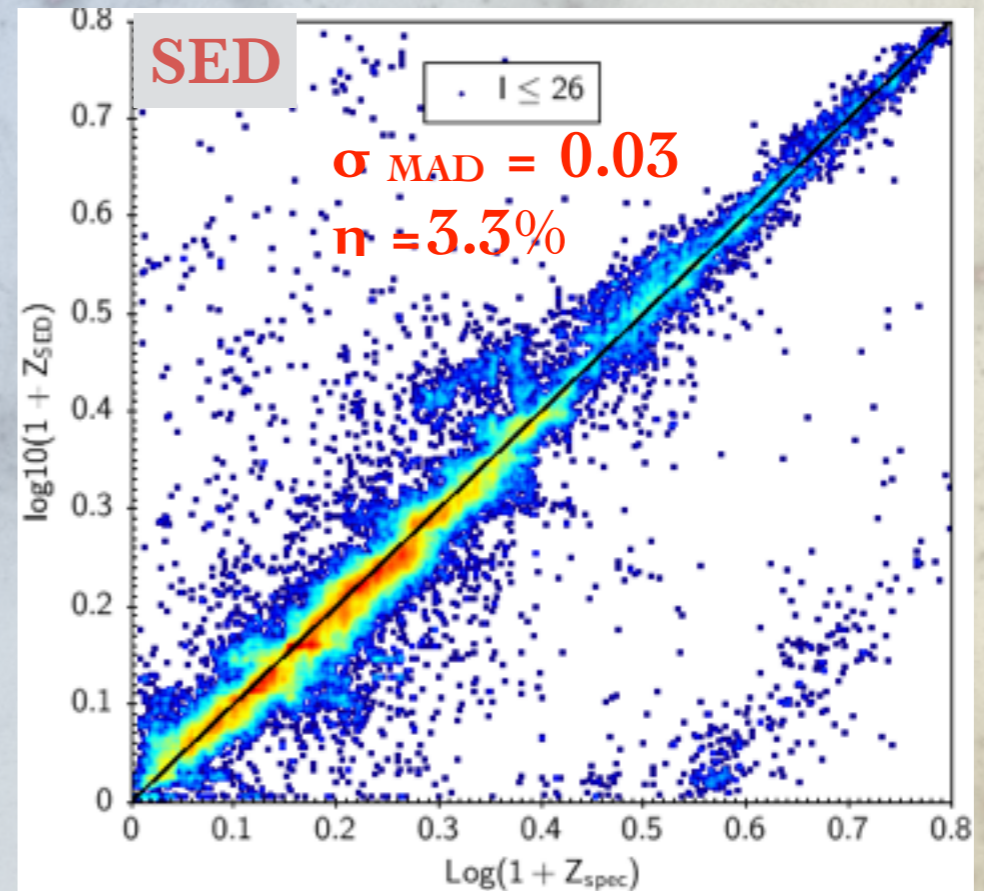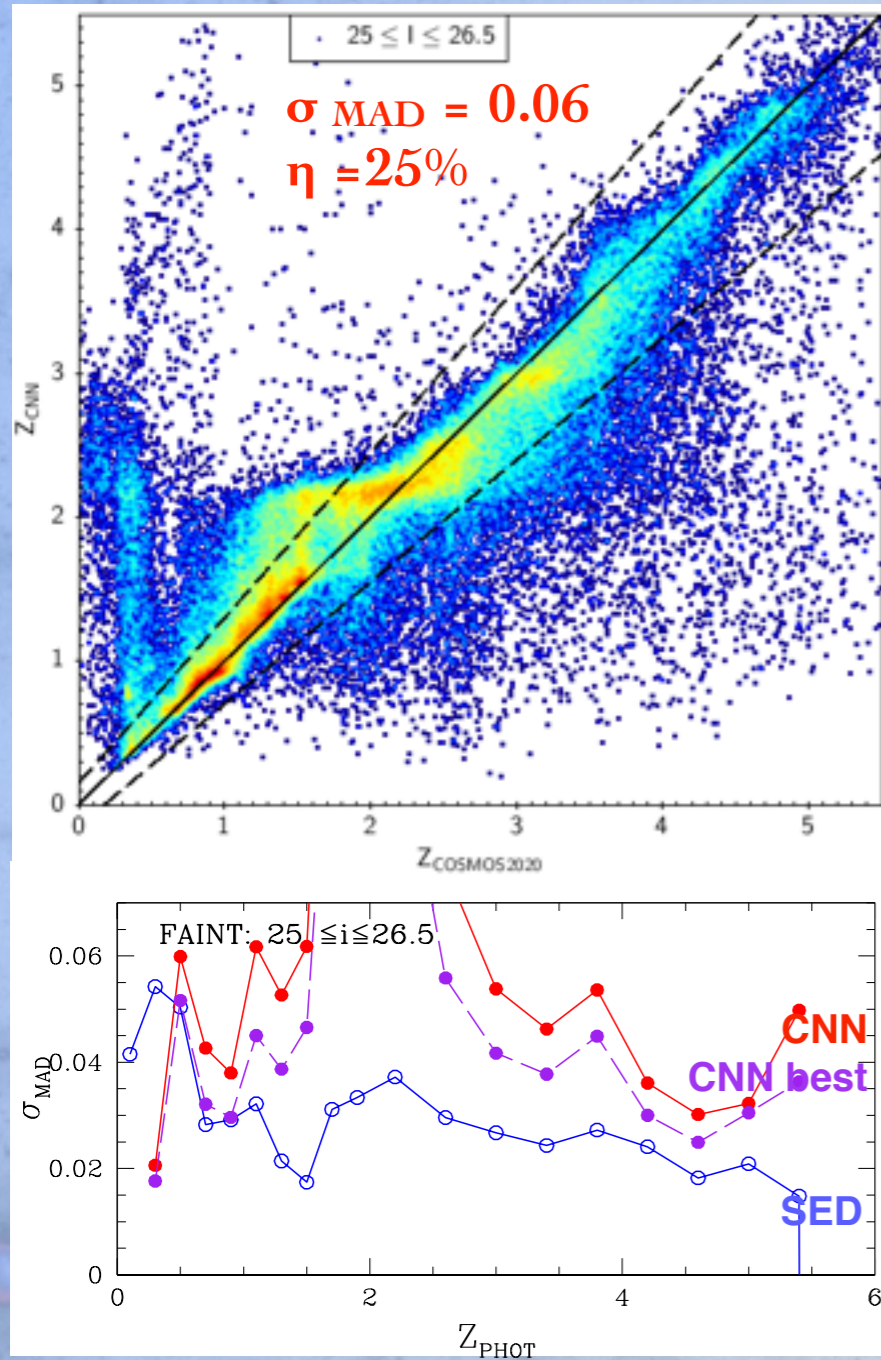
SED

σ_{MAD} = 0.03
η =3.3%

$\cdot$ I ≤ 26

SA, RAO: * members of the PhotoZ Working Groups: This image based code could become a PZ estimator for VR.
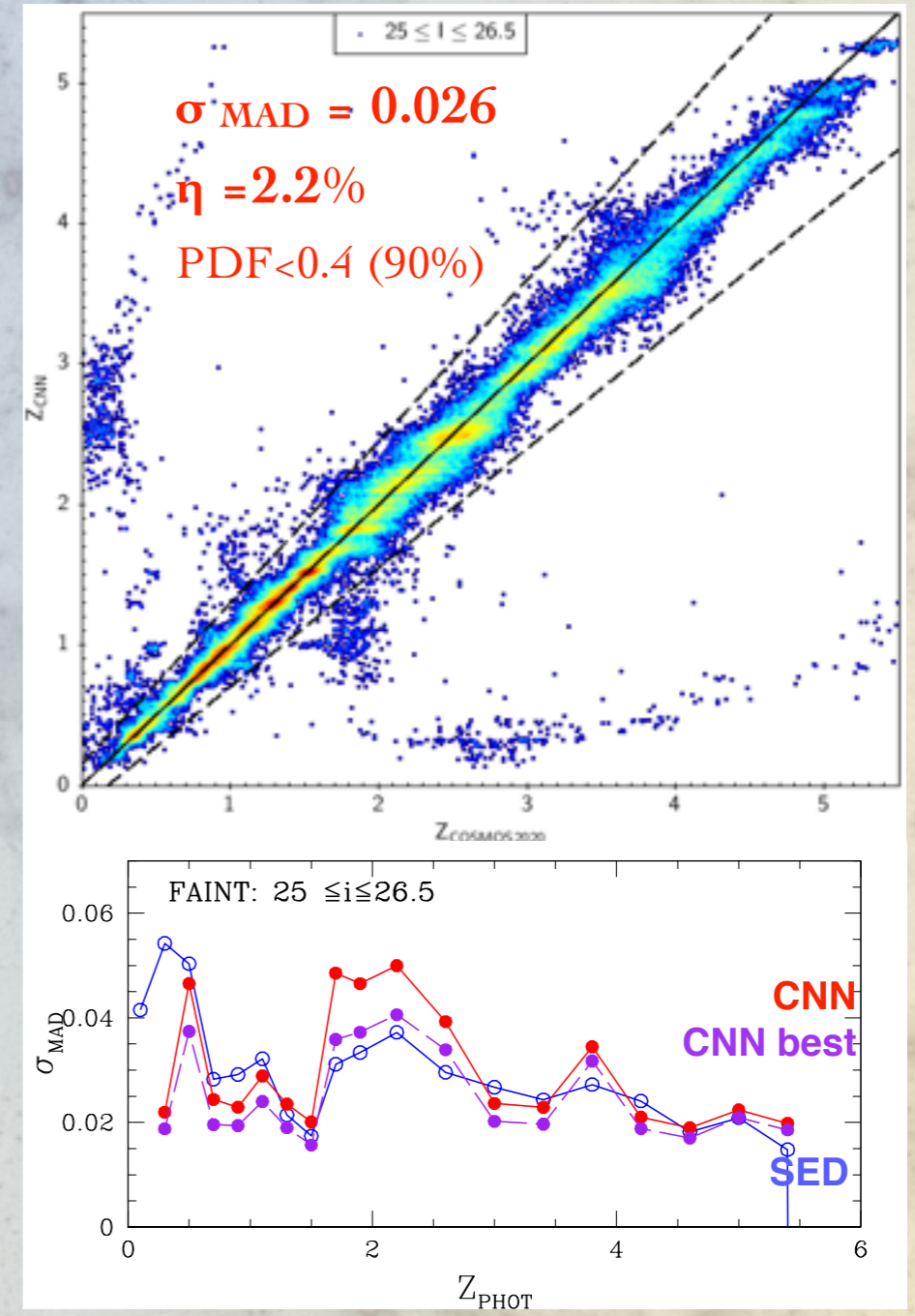
Photo-z with Convolutional Neural Network

—> Comparison with COSMOS2020 at faint magnitude : 25<i<26.5

σ MAD = 0.06
η =25%

Hybrid training
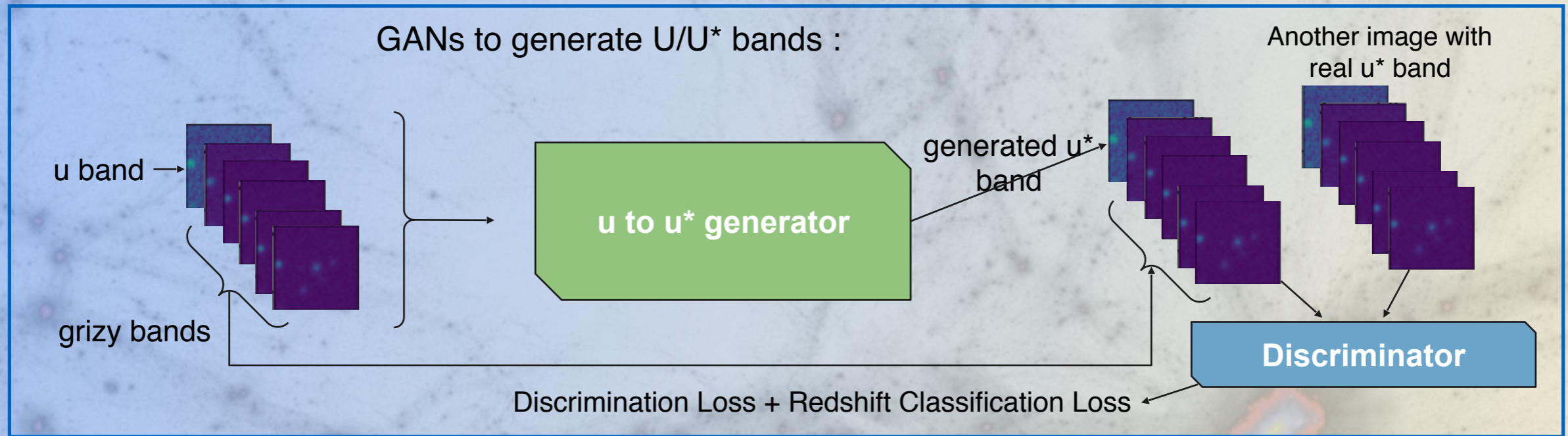
add 15k Z COSMOS20

at i>24.5

in training set

σ MAD = 0.026
η =2.2%
PDF<0.4 (90%)

—> We will release the HSC-CLAUDS dataset with 8 millions CNN photo-z (Ait-Ouahmed+ 2022)

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Perspectives

—> **Add NIR images** in a separated branch for convolution blocks before merging the feature maps

—> **Missing data**

GANs to generate U/U* bands :

Another image with
real u* band

u band →

u to u* generator

generated u*
band

grizy bands

Discriminator

Discrimination Loss + Redshift Classification Loss

—> **Meta Soft labels generation for semi-supervised learning** (Algan+ 2021)

Model

Update the model with the image and y
soft labels (version 2)

**Pseudo
updated
model with
y version 1**

Test the pseudo update
images with clean
labels

(spectroscopic redshift)

Loss with
respect to
the y soft
labels that
impacted
the pseudo
update

y soft labels
updated
(version 2)

y soft labels first
version (initiated
by SED fitting)

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