Journées LSST-France
CPPM, June 2024

Early Release Observations: A Glimpse Into Euclid’s Universe Through a Giant Magnifying Lens

Raphael Gavazzi (LAM)

w/ H. Atek, G. Congedo, J.-C. Cuillandre, J. Diego, W. Hartley, T. Schrabback, J. Weaver, and many more...

Atek et al 24, arXiv:2405.13504v1
Cuillandre et al 24, arXiv:2405.13496v1
Weaver et al 24, arXiv:2405.13505v1
+ in prep. multi-band photometry / photo-z / weak lensing in A2390
... many more ERO papers!

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

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Jun 10th, 2024

euclid consortium esa euclid

Euclid - Early Release Observations

https://euclid.esac.esa.int/dr/ero/

ERO Public Data Release

Welcome to the data access page for the Euclid Early Release Observations (EROs). This release contains the images and source catalogues. The release notes for the ERO Public Data Release can be found on the COSMOS pages here. The data files for the EROs can be found through the links below.

ERO-02: A first glance at free-floating baby Jupiters with Euclid

E. Martín (Instituto de Astrofísica de Canarias)

- Barnard30
- Horsehead
- Messier78
- Taurus

ERO-03: Euclid view of Milky Way globular clusters

D. Massari (INAF OAS, Bologna)

- NGC6254
- NGC6397

ERO-08: A Euclid showcase of nearby galaxies

L. Hunt (INAF-AO Arcetri, Firenze)

- HolmbergII
- IC10
- IC342
- NGC2403
- NGC6744
- NGC6822

ERO-09: The Fornax galaxy cluster seen with Euclid

A. Lançon (Observatoire de Strasbourg)

- Fornax
- Dorado

ERO-10: Cluster of Galaxies

J.-C. Cuillandre (CEA, AIM, Université Paris-Saclay)

- Perseus

ERO-11: A Glimpse Into Euclid's Universe Through a Giant Magnifying Lens

H. Atek (Institut d'Astrophysique de Paris)

- Abell2390
- Abell2764

DATA

The data reduction for the EROs is described in the paper *"Euclid: Early Release Observations -- Programme overview and pipeline for compact- and diffuse-emission photometry"* (Cuillandre et al, 2024, submitted to A&A). A pre-print version of the paper is available here. The user is recommended to consult this paper in case of questions concerning these datasets.

Each ERO target has associated image stacks and catalogues, described below.

Images

The collection of image stacks from the VIS and NISP instrument are packaged in the following files, for a given ERO field 'TARGET':

- `Euclid-VIS-Stack-[TARGET].DR3.tar`
- `Euclid-NISP-Stack-[TARGET].DR3.tar`

The `tar` packages contain the following files:

Euclid - Early Release Observations

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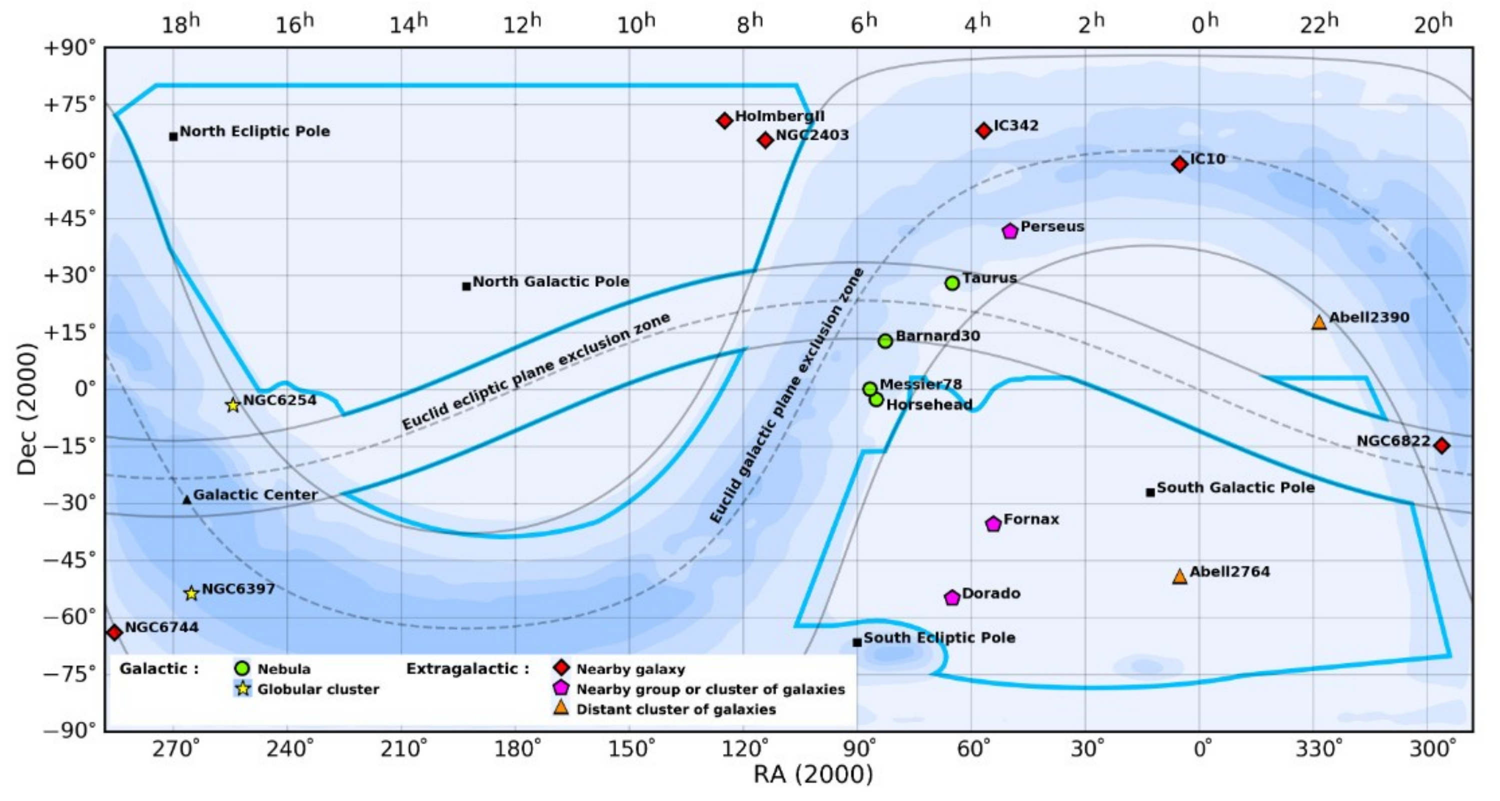


overview and pipeline for compact- and
ailable here. The user is recommended to

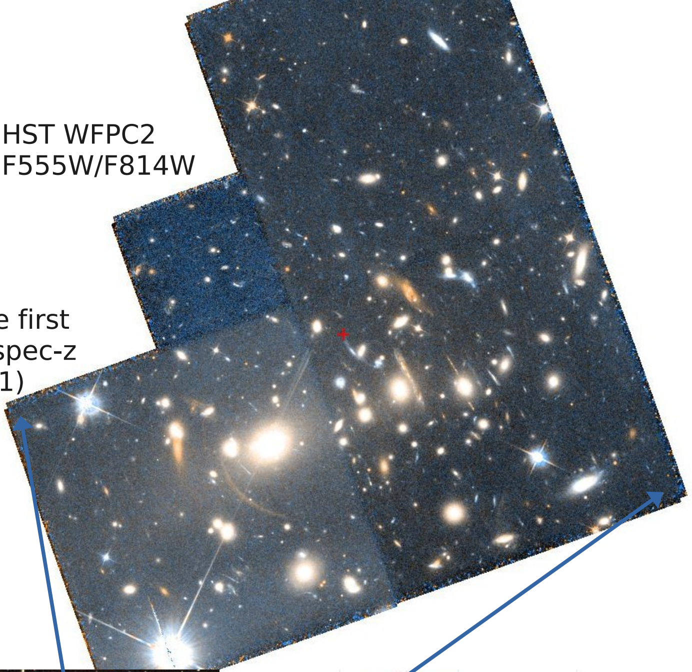
en ERO field 'TARGET':

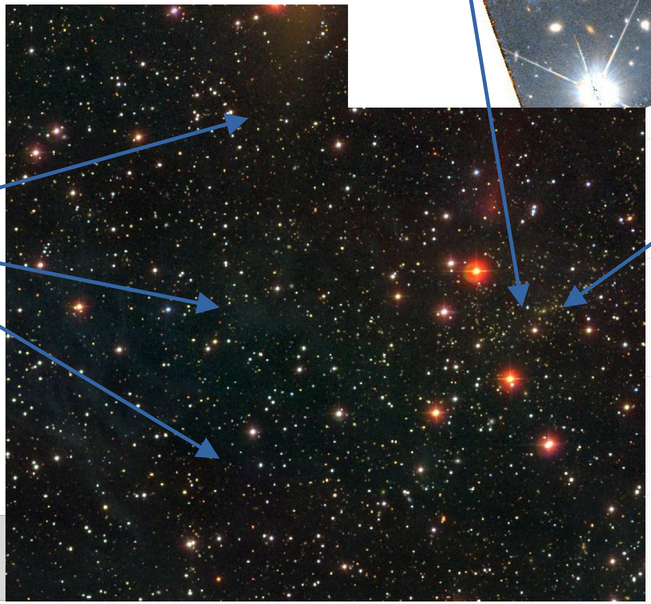
- Euclid-NISP-Stack-[TARGET].DR3.tar

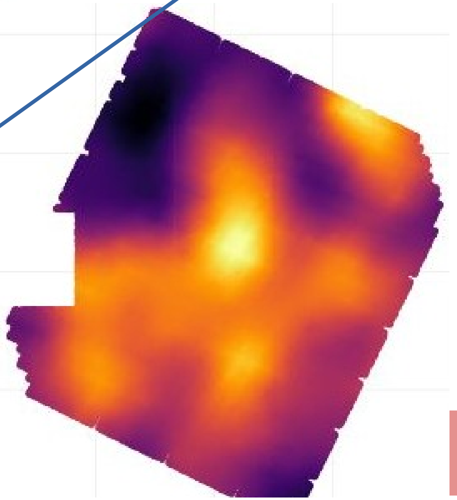
The tar packages contain the following files:

Euclid ERO-11 Data

- **A2390 cluster at z=0.23, ~$10^{15}M_{sun}$**
  - Strong weak lensing
  - Strong strong lensing, good cosmic telescope
- **Existing complementary data**
  - Deep high-IQ, Subaru Suprime B, V, Rc, i, Ic, z
  - Medium depth CFHT u1, (+shallow u2)
  - ~30’x30’ fov, slightly smaller than Euclid
- **Scene**
  - Low latitude: b=-28°, E(B-V)=0.11, patchy
  - Prominent Galactic Cirri
- **Original plan**
  - Goal: A370 but straylight / FGS issue during Summer!
  - Then: A2390 + el Gordo … (but coordinate typo)
  - Finally A2390 + ‘A2764’ (offset, few ground-based data)







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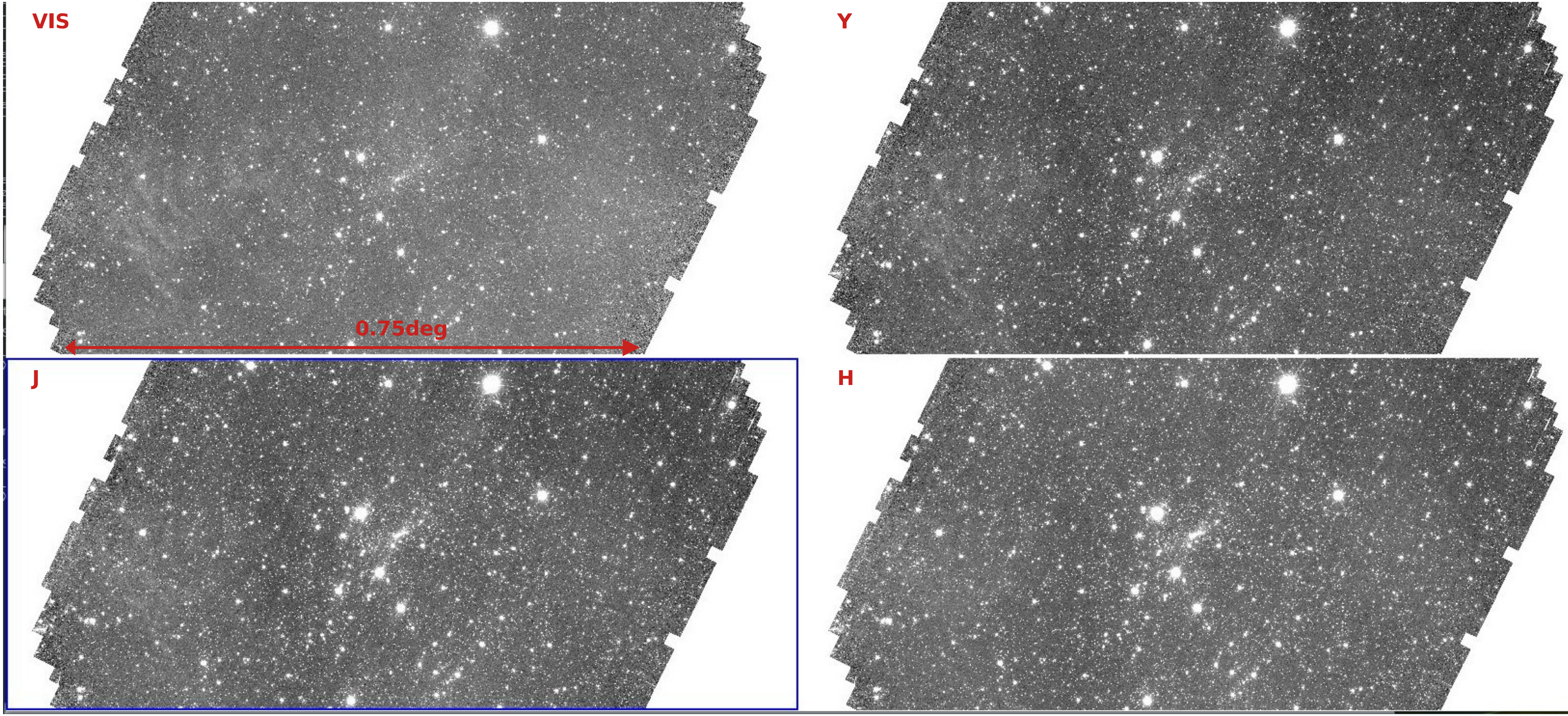
Euclid ERO-11 Data

- **Bonus cluster!**
- **A2764 at z=0.07, ~$10^{14}M_{sun}$**
  - weak weak lensing
  - Comparison field
- **No deep complementary data**
  - Some shallow g,r,i,z DES imaging
- **Scene**
  - High Galactic latitude: fine!
- **Not the focus of this talk**

3 ROS (3xWide depth) ~6.5 ksec (VIS)



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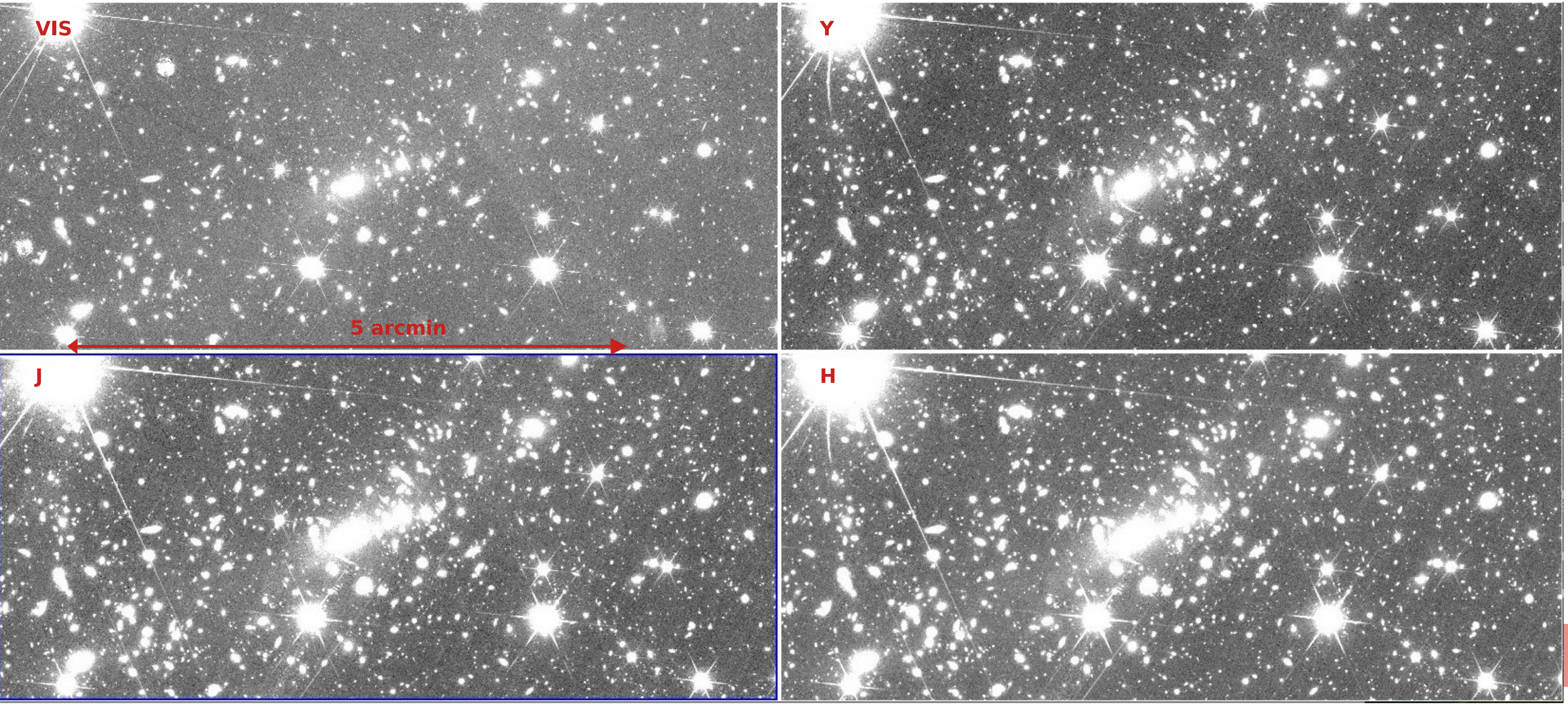
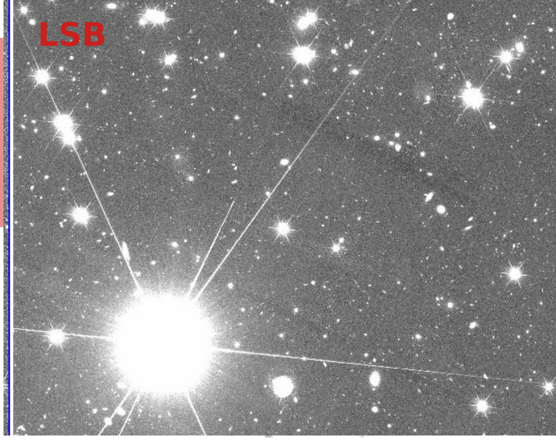


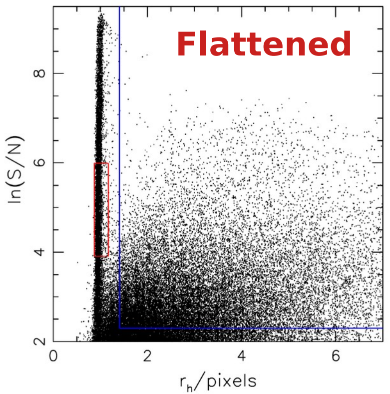
Data processing by J-C Cuillandre

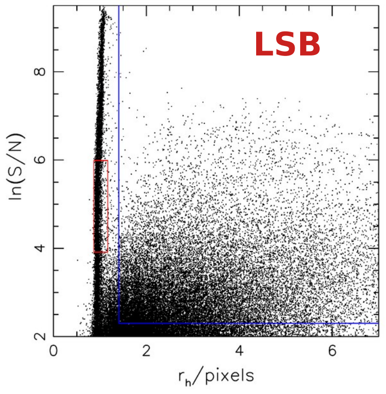


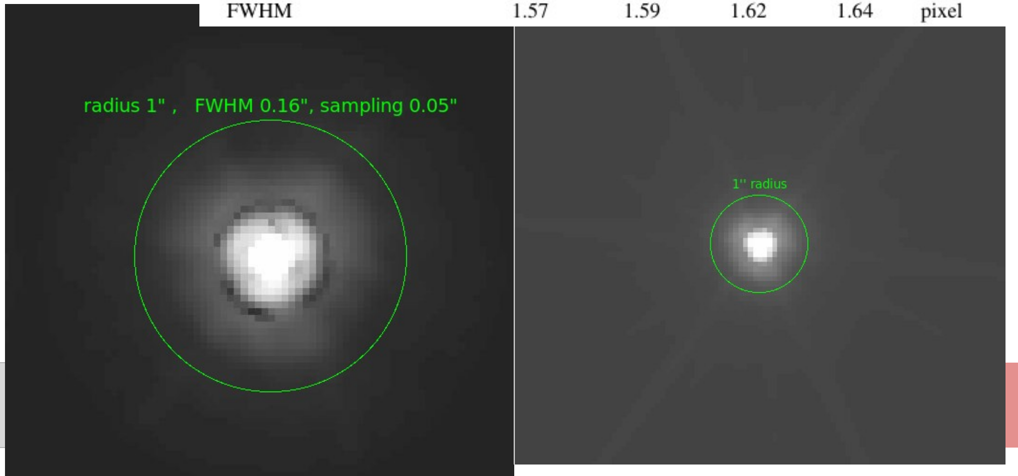
- **LSB: ~median combine stack**
  - Preserves low surface brightness features
  - More aggressive on sharp under-sampled objects!
- **Flattened: weighted mean combine stack**
  - absorbs LSBs, nicer with stars
  - Masking of glitches (cosmics, defects) less robust
- **PSF model done with PSFEx (also w/ TheFarmer)**
  - 3rd order polynomial variations across FOV.
  - No wavelength dependence in the model

Field	RA [deg]	Dec [deg]	I_E	Y_E	J_E	H_E
A2390	328.397	+17.709	27.01	25.18	25.22	25.12
A2764	5.713	−49.249	27.26	25.30	25.41	25.21

Band	I_E	Y_E	J_E	H_E	Unit / note
FWHM	0.157	0.477	0.486	0.492	arcsec
FWHM	1.57	1.59	1.62	1.64	pixel

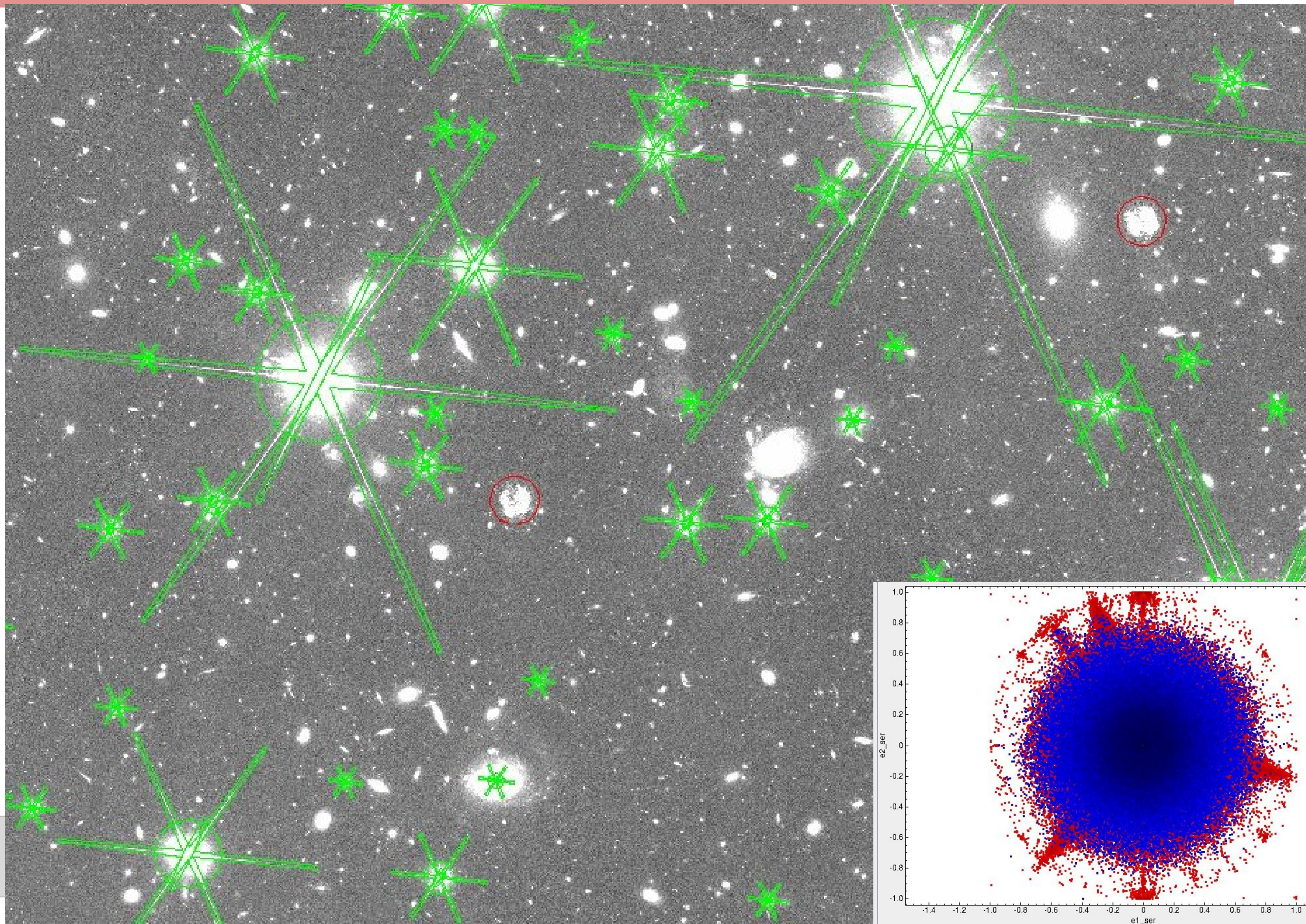






Automated masking strategy

- Bright stars Rp<18.5 are masked!
- 60deg symmetry shape for diffraction spikes
- Linear shape along readout for saturation bleed
- Smaller round shape near center
- Reflection ghosts semi-automated
  - Only produced for stars brighter than Gaia R_P=12
  - Displacement field wrt progenitor star should be fitted with polynomial.
  - 8'' radius well suited for LSB stacks, not for flattened



Shape measurements in A2390

- **LensMC** (G. Congedo)
  - Implemented in OU-SHE default pipeline (for DR1)

- **KSB** (T. Schrabback)
  - Close to WL pipeline implementation of Schrabback et al (2021) applied to HST/ACS data

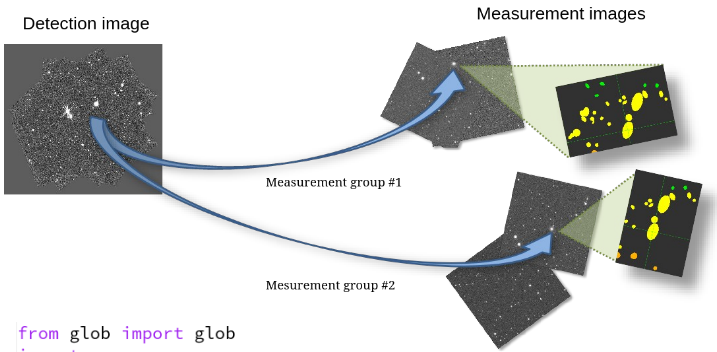
- **SourceXtractor++** (SE++) (R. Gavazzi)
  - Already part of SGS (OU-MER, big contribution of SDC-CH developers and SE++ dev team)
  - Builds on past model fitting capabilities of sextractor2 (Great3 challenge, Euclid Preparation IV)
  - Performed well in Euclid Morphology Challenge (Euclid Preparation XXV, XXVI)

Sourcextractor++: Fit PSF-convolved light profiles

https://github.com/astrorama/SourceXtractorPlusPlus

Bertin et al 2020, Kümmel et al 2022

- **One python configuration file**
- **Input data**
  - one detection image (+weight)
  - a bunch of measurement (MEF) exposures with their own
    - WCS: including distortions
    - PSF: spatially varying as given by PSFEx or plain FITS!
    - weight or rms images
- **Grouping**
  - All sources in group fitted at once (mitigate x-talk between neighbors)
  - Groups should not be too large (hard size limit or struggle in crowded areas)
  - Natural: a group is all sources in detection island + Home brewed distance criterion
- **Detection**
  - Standard threshold + deblending on filtered image
  - Can run user-supplied detection ML tool (ONNX format)
  - Can decouple detection and grouping from measurements (advanced association)
- **Modelling assumptions**
  - One or several Sersic/point-like profiles, concentric/not, aligned/not
  - Levmar optimization: MAP + Hessian for covariance
  - Addition of priors to contain free parameters (total freedom to fix/release them)



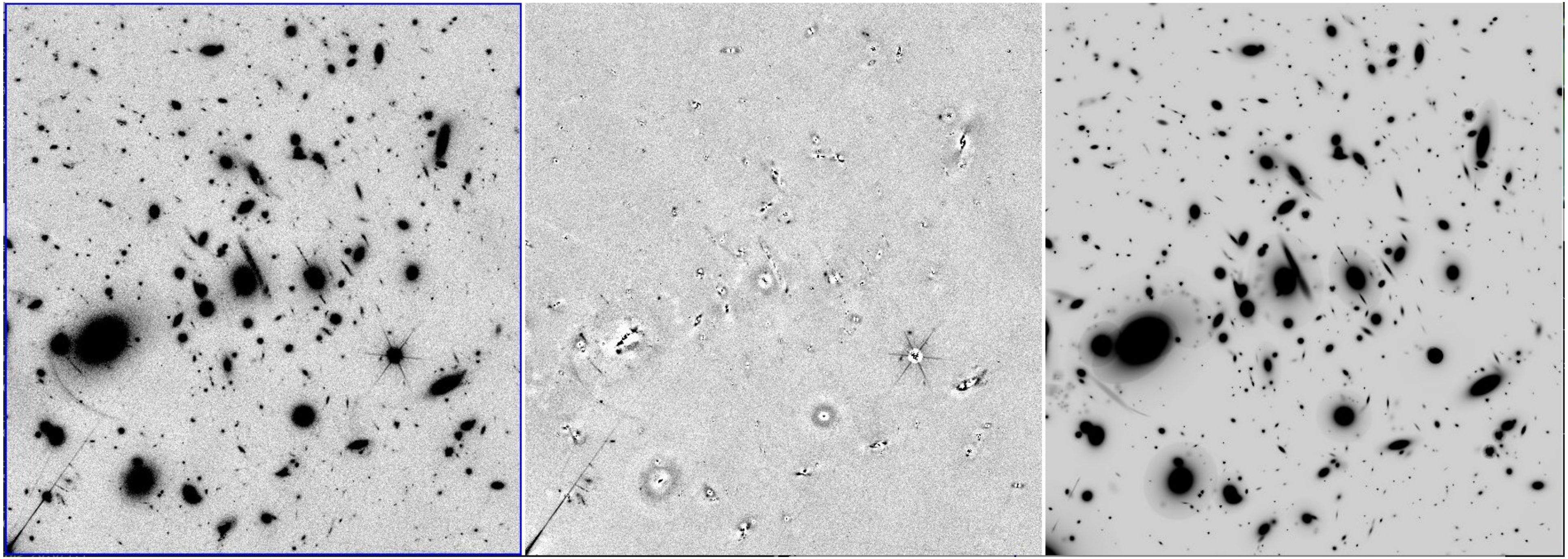

```
from glob import glob
import numpy as np
from sourcextractor.config import *

top = load_fits_images( sorted(glob('*_sci.fits')),
                        psfs=sorted(glob('*.psf')),
                        weights=sorted(glob('*_weight.fits')),
                        weight_absolute=1, weight_type='rms' )
#### chop the list of exposures by filter FITS keyword
top.split(ByKeyword('FILTER'))

### Optionally, can also further be split by OBS-DATE, or just filename
#for n, filter in top:
#    filter.split(ByKeyword('IMAGE_FILENAME'))

mesgroup = MeasurementGroup(top)
```

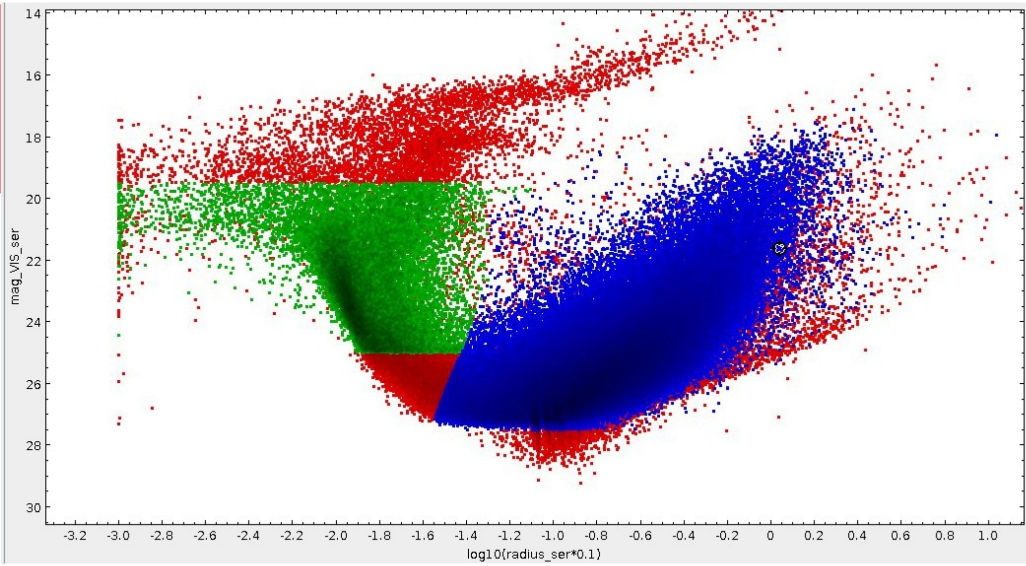
Single Sersic on VIS band: residual near center

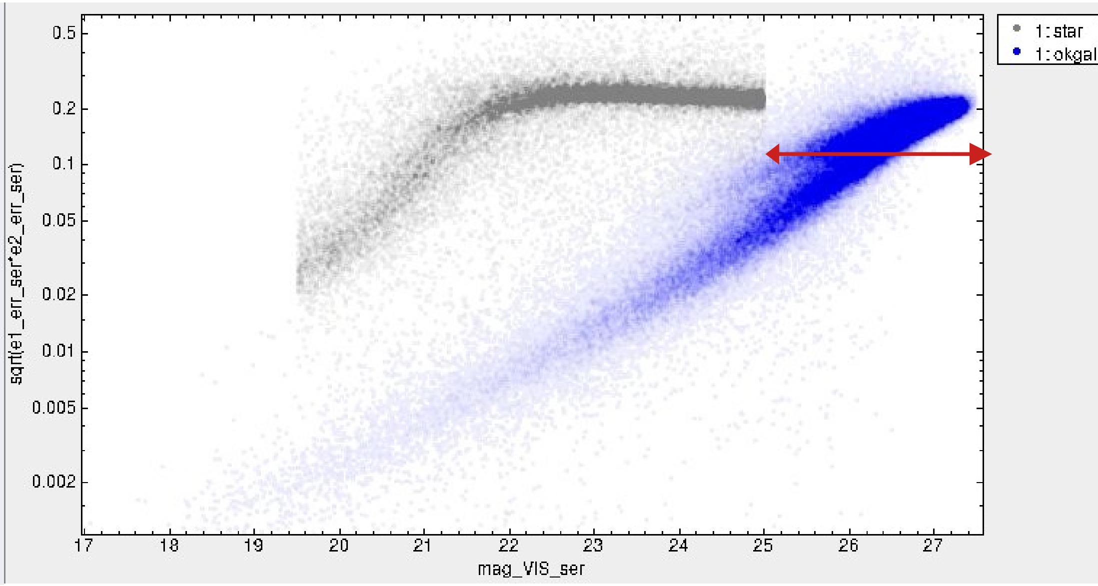


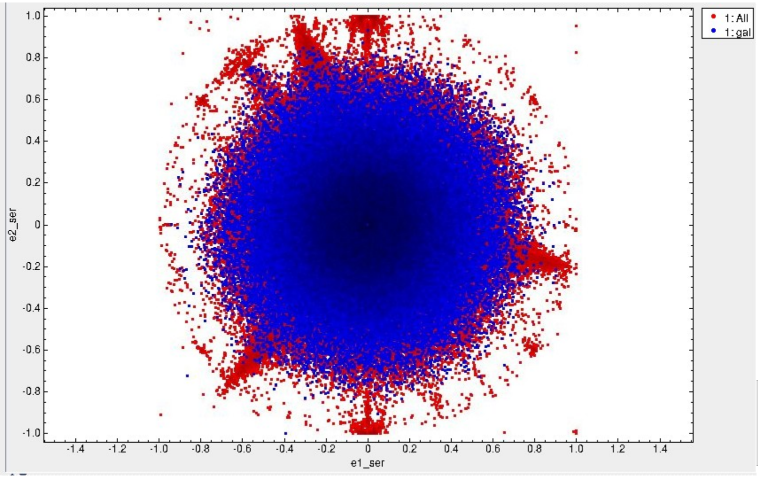
Shape catalogue

Single Sersic model (VIS only)

- Star – Galaxies separate very well down to VIS~25
- Accurate ellipticities down to VIS~25.5!
- Poor accuracy for stars as desired!
- Diffraction spikes ought to be *minutely* masked out!!
- Runtime: 52 CPU.hours (bright stars to be dropped...)





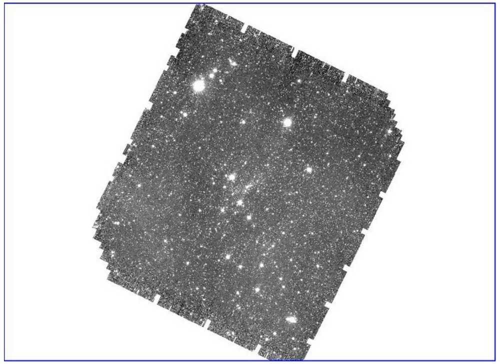


Ground-based Subaru/CFHT: u, B, V, Rc, i, Ic, z

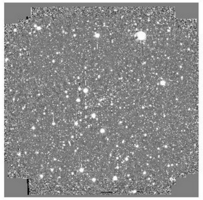
Photometric calibration against Pan-STARRS   (S Gwyn)

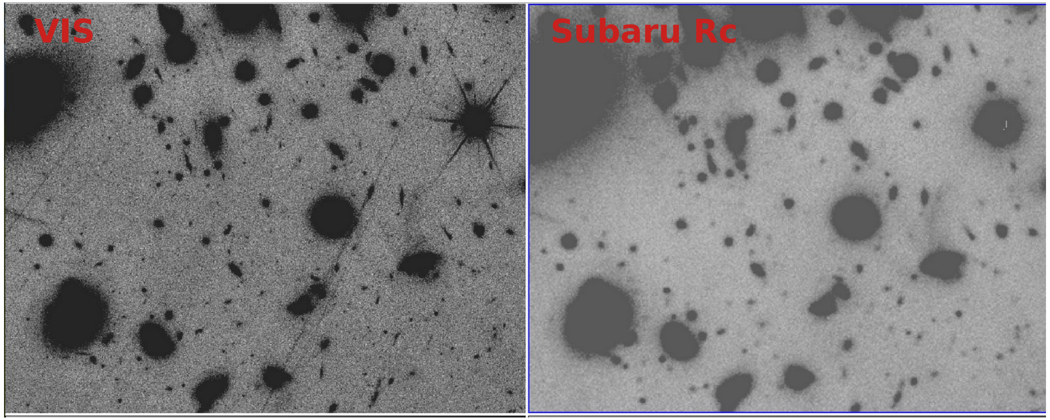
Deep and high IQ 0.90,0.76,0.60,0.59,0.55,0.74,0.77 [arcsec] respectively

Depth: Completeness VIS ~26.5, NISP-J ~25,   Rc ~ 26… relatively well matched



Smaller Field-of-view



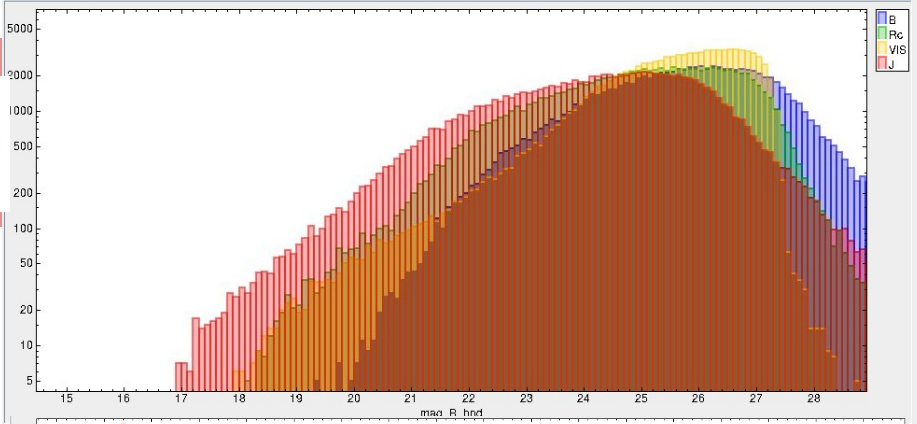


Runtime: ~1000 CPU.hours

Model: Bulge+Disk

- Disk and bulge orientation are identical
- Bulge size, ellipticity constant. Idem for disk. Bulge/Total flux ratio can vary!
- Fitted for proper motions!   (important due to 20yr time span)
- yields total magnitudes and Bulge/Total flux ratio in each band…

Photometric redshifts

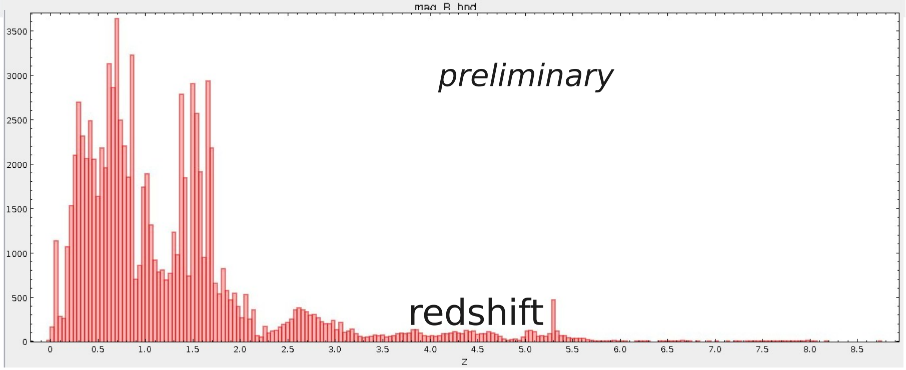


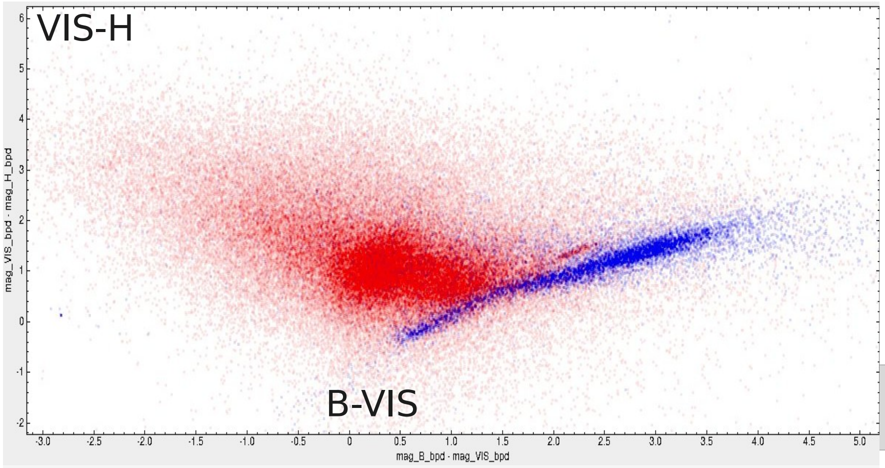
W Hartley+ (Geneva), running Phosphoros

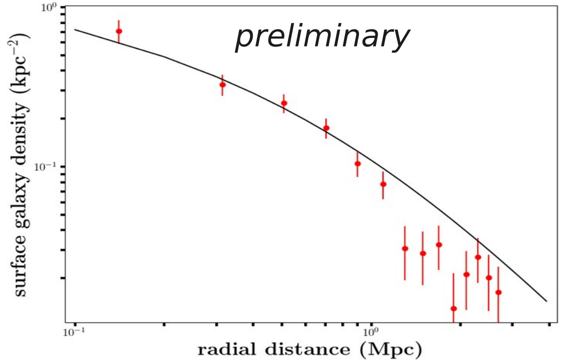
Source density VIS<26 → 40arcmin^{-2}.

Matched to photo-z cat → 22 arcmin^{-2}

Still some issues in the n(z) distribution



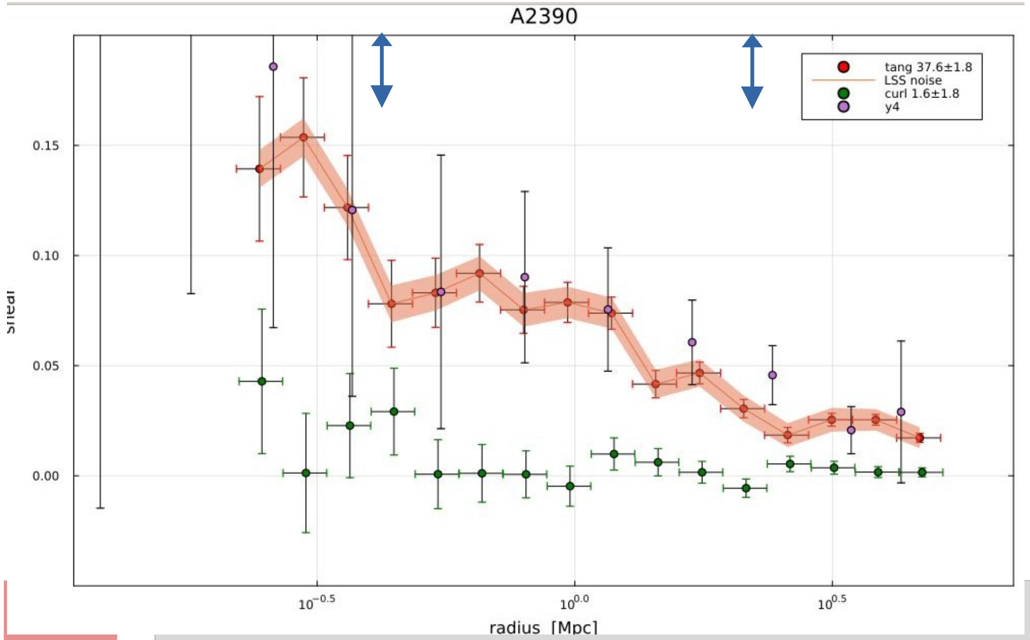


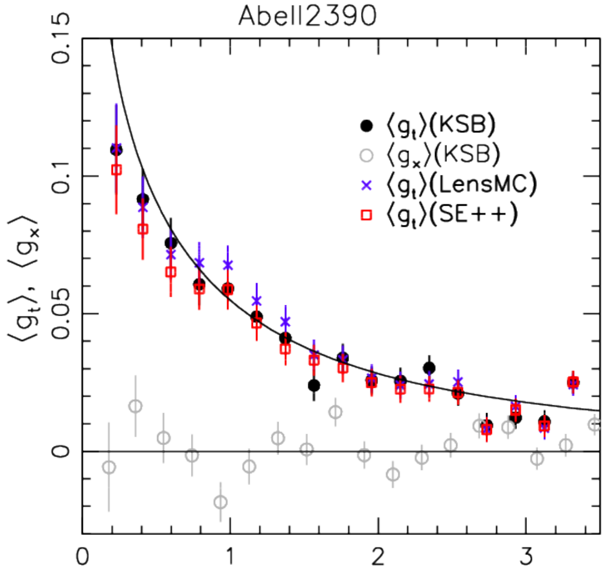


Shear profile

Crude 22<VIS<26 selection of bg galaxies

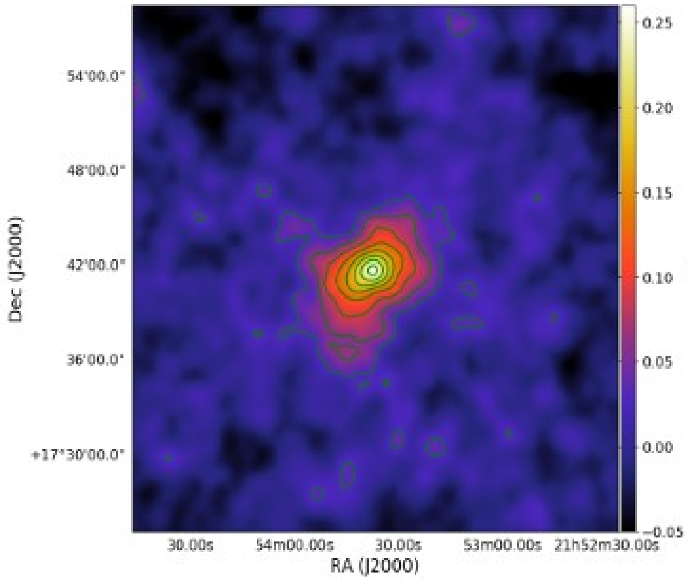
- until solid photo-z become available…
- SIS fit in the [0.5,2] Mpc range: R_{Ein} = 26.6’’±1.1’’ → 1160±25 km/s (25σ)



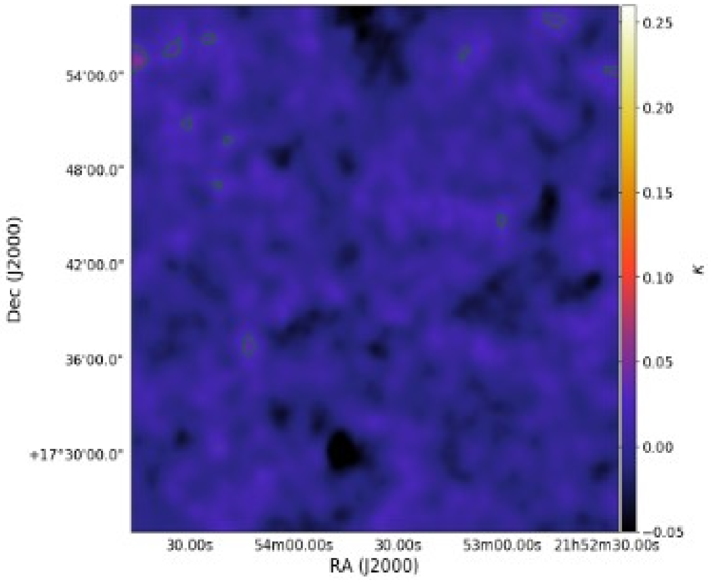


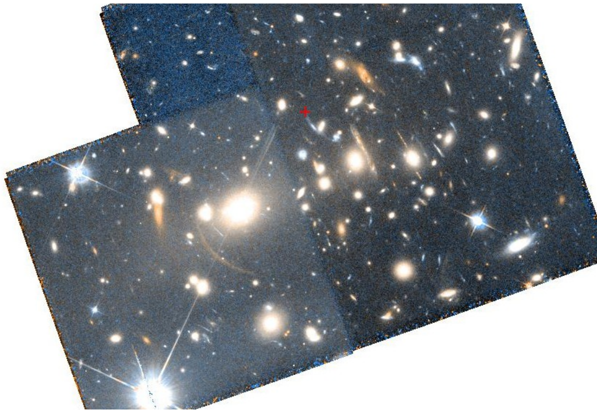
Convergence/magnification maps

Convergence

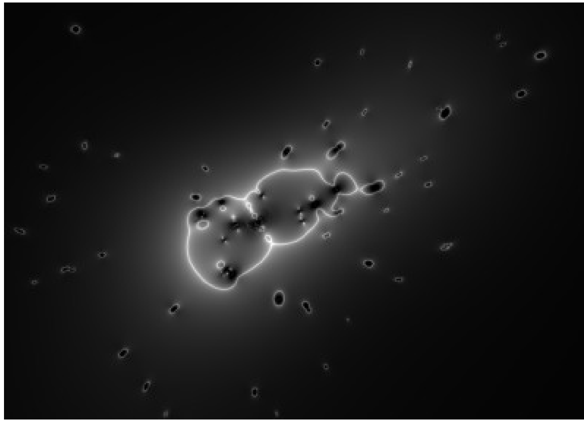


Curl (B)-mode Convergence

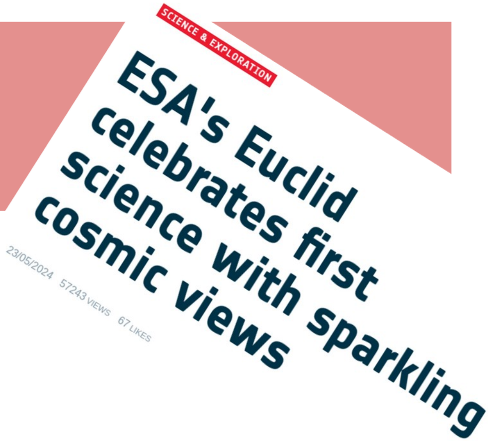




WL + SL
WSLAP (J Diego)

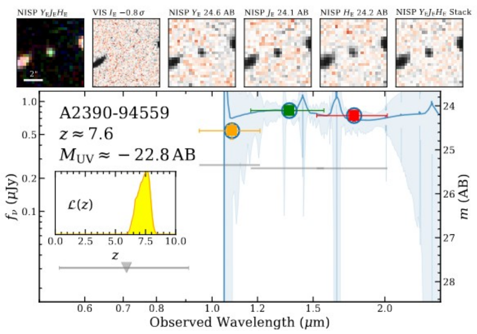


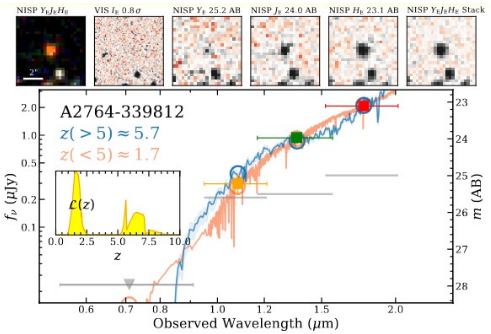
Conclusion

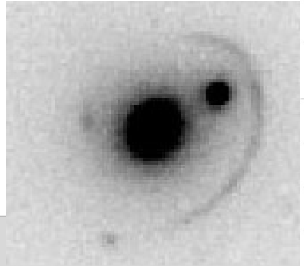


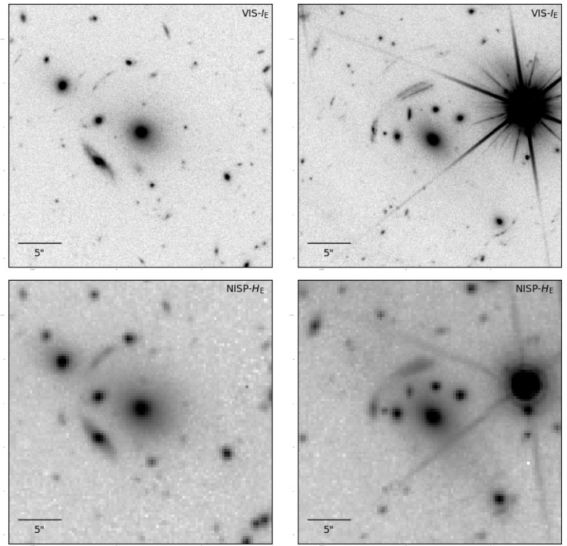
- **A2390 ERO data showcases great lensing capabilities of Euclid**
  - Weak lensing: (2D map, 1D profile), all the way out to ~4 Mpc (~3 R_{vir}, M_{vir}~2e15)
  - Promising photometric redshifts, requires deeper understanding of NIR photometry
  - Weak + strong lensing: finer-grained model in the core (ongoing)
  - Paper upcoming

- **Additional results (see Atek++24, Weaver++24)**
  - VIS dropouts: NISP-selected w/ Farmer.
  - Ongoing search for galaxy-scale strong lenses
  - NIR study of Intracluster light (ICL)
  - High-z cluster candidates in A2764

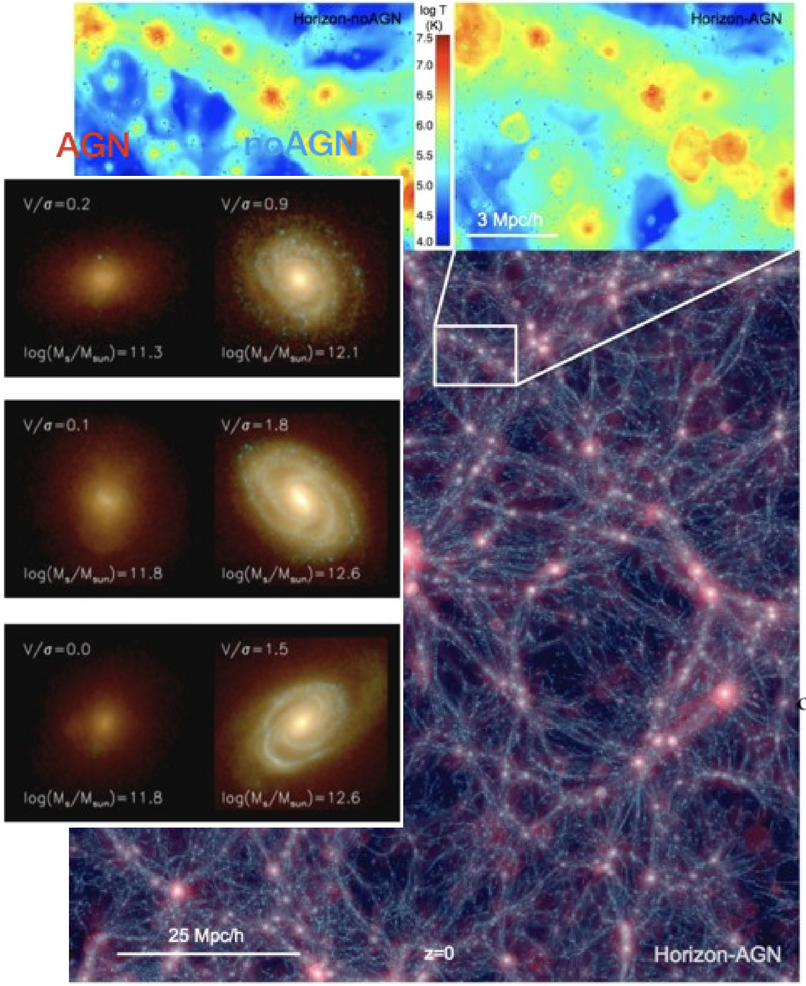








Horizon-AGN: small scale lensing applications



Horizon-AGN hydro sim (Dubois++14) and mock images (Laigle++)

100 Mpc/h, 1024^3 DM particles

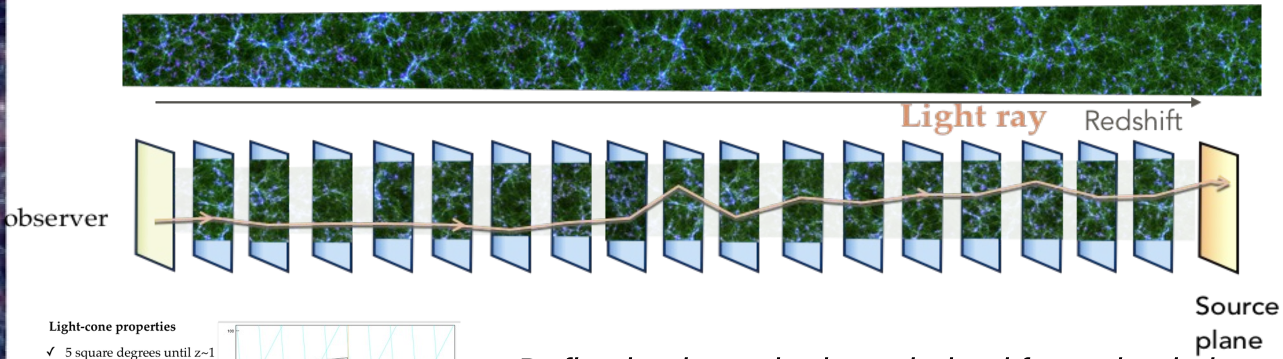
Eulerian treatment of gas physics with AMR grid (RAMSES)
DM mass resolution 8×10^8 M_{sun}
1 kpc spatial resolution (8^{th} level of refinement)

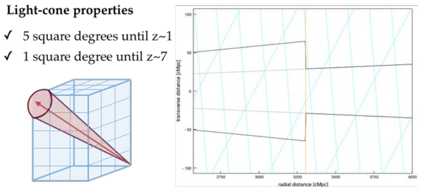
Implemented baryonic processes:

- gas dynamics, heating/cooling
- star formation/evolution (age, metallicity...)
- Supernova & AGN feedback
- Supermassive Black Holes

Trade-off between high-resolution requirements and simulation volume exacerbated

Raytracing through the Horizon- AGN past light cone (Gouin++19)

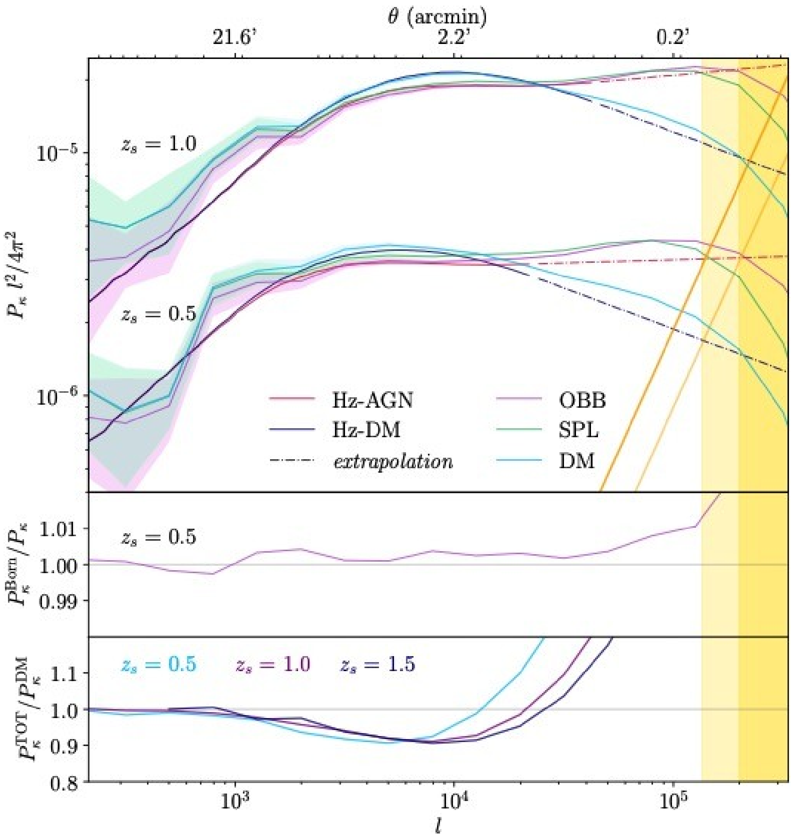




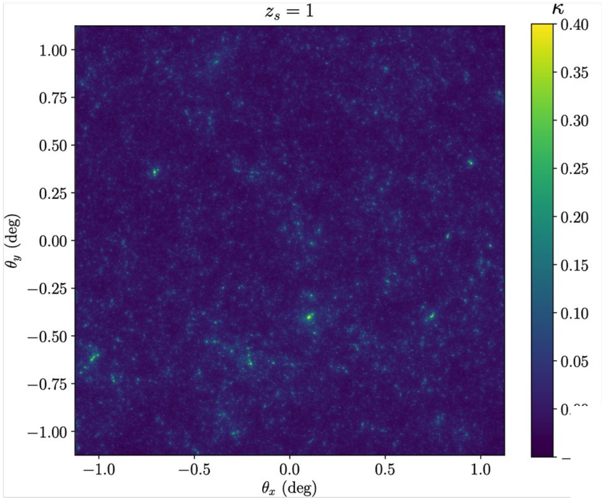
Deflection in each plane derived from simulation transverse accelerations (no proj of particles)

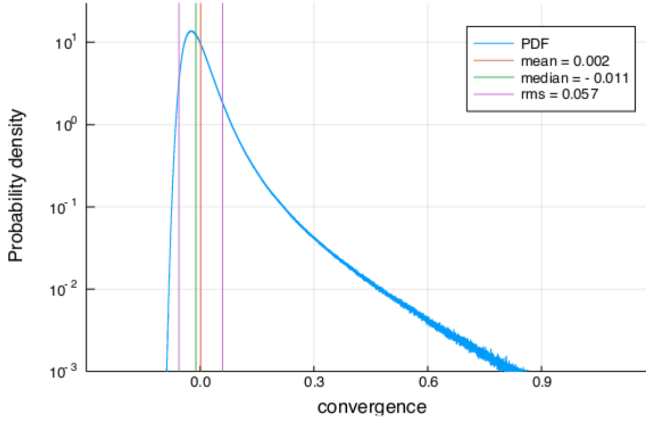
Horizon-AGN: small scale lensing applications

Convergence power spectrum



Convergence field and PDF

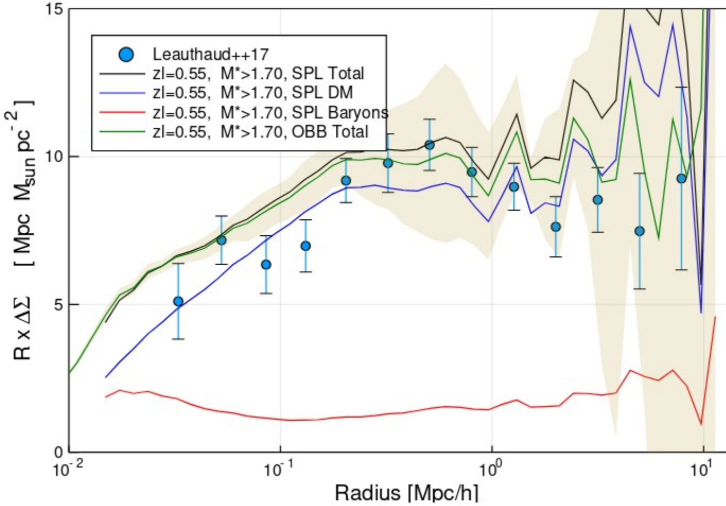




Born approximation
1% valid up to **l**~10^5 !

For 0.5< z_s <1.5 , ΔPκ/Pκ
-2% for **l** >10^3
-10% for 4000<**l** **<**2000
Then cooled baryons kick i

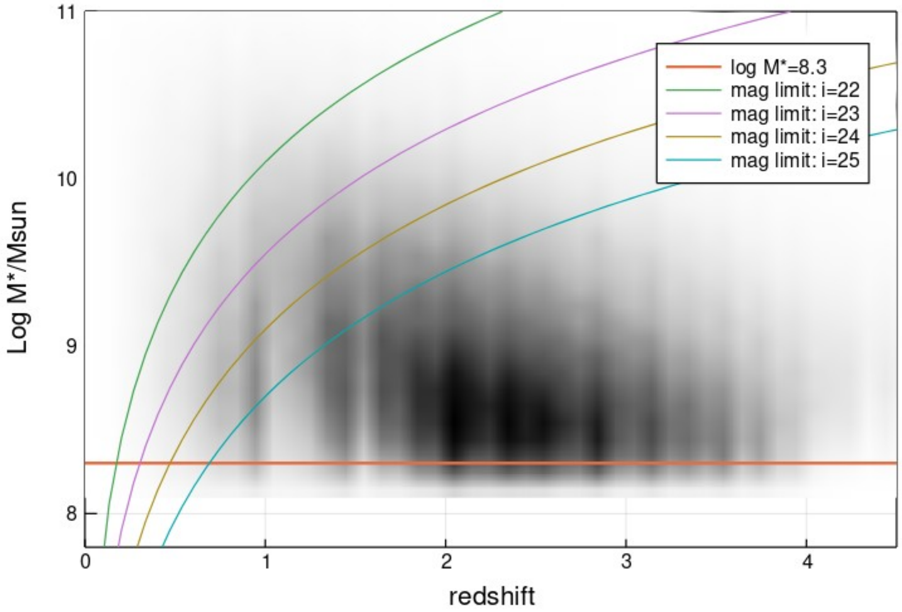
Galaxy-Galaxy lensing (shear)

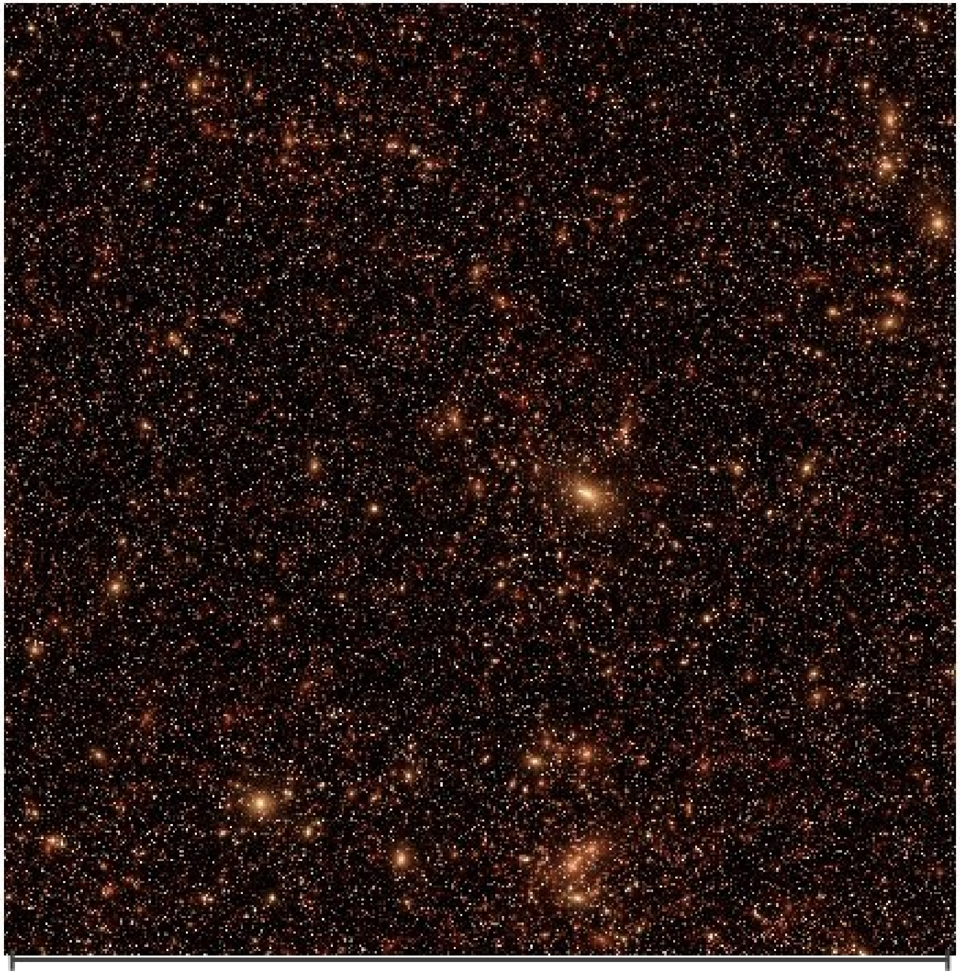


Horizon-AGN: small scale lensing applications

Mock images

1 M galaxies
FoV: 1 deg^2
0.1" angular res
1 kpc physical res



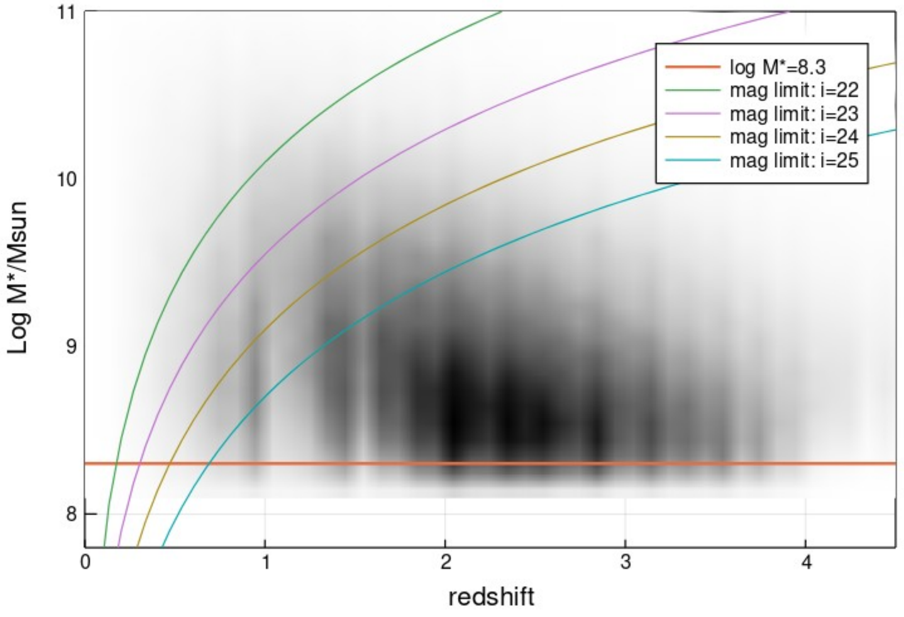


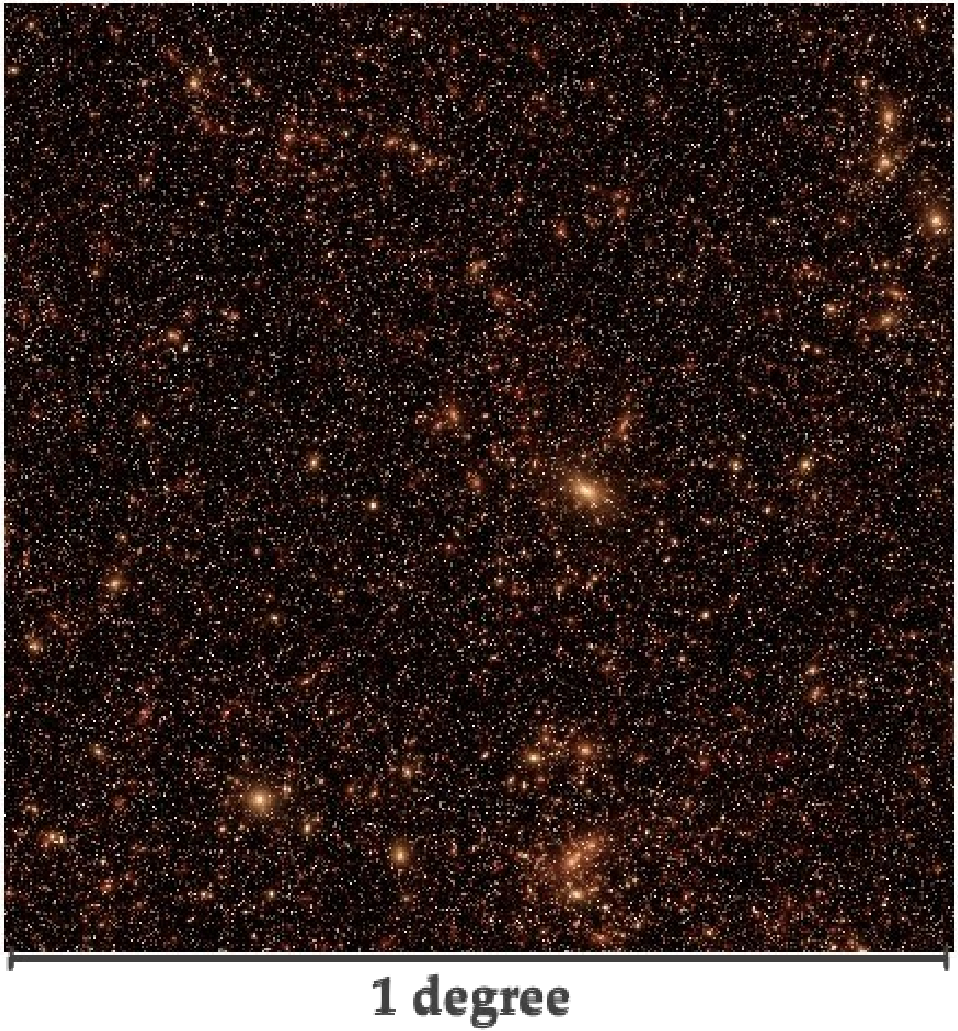
1 degree

Horizon-AGN: small scale lensing applications

Mock images

1 M galaxies
FoV: 1 deg^2
0.1” angular res
1 kpc physical res





Horizon-AGN: small scale lensing applications

Mock images

u,g,z bands

No lensing
Lensing
Euclid Wide

Horizon-AGN: small scale lensing applications

Mock images

u,g,z bands

No lensing
Lensing
Euclid Wide

Horizon-AGN: small scale lensing applications

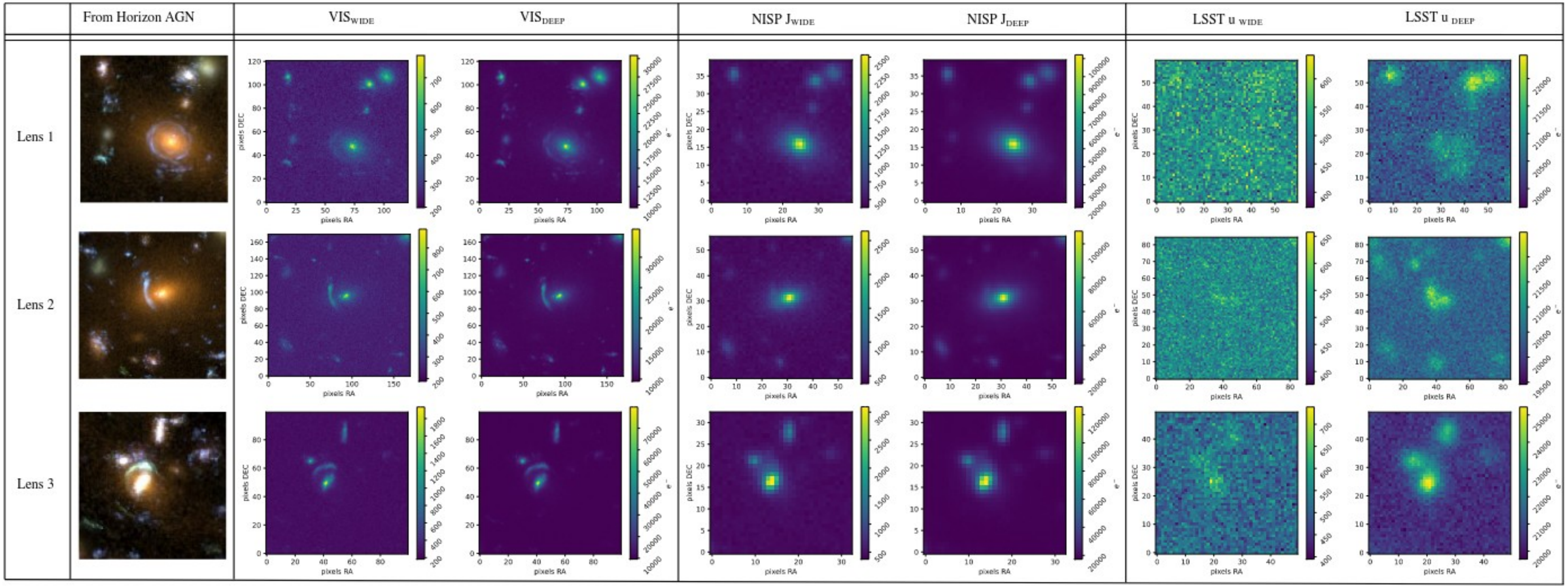
Mock images

u,g,z bands

No lensing
Lensing
Euclid Wide

Horizon-AGN: small scale lensing applications

Strong Lensing

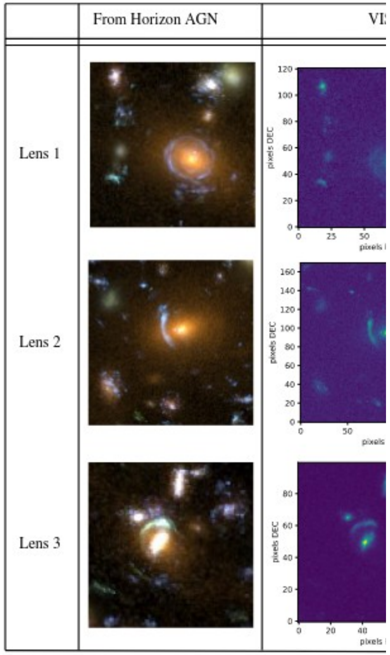


Télescope	bande	t_{exp}(s)	n_{exp}	m_{bg} (mag.arcsec^{-2})	m_{zero} (ZP_{inst})	gain g	$N_{e^-_{bg}}$ (par pixel)	*readnoise* (e^-/pixel/exposure)
EUCLID	VIS	570	4	22.90	25.49	1.014×10^{-33}	247.7	5
EUCLID	Y	112	4	22.67	25.04	7.811×10^{-33}	39.7	9
EUCLID	J	112	4	22.68	25.26	6.379×10^{-33}	48.2	9
EUCLID	H	112	4	22.85	25.21	6.679×10^{-33}	39.3	9
LSST	u	30	10	22.96	27.03	1.866×10^{-33}	127.4	8.8
LSST	g	30	5	22.26	28.38	1.076×10^{-33}	420.8	8.8
LSST	r	30	5	21.20	28.16	1.318×10^{-33}	912.2	8.8
LSST	i	30	5	20.48	27.85	1.753×10^{-33}	1330.7	8.8
LSST	z	30	10	19.60	27.46	1.256×10^{-33}	4179.5	8.8
LSST	y	30	10	18.61	26.68	2.576×10^{-33}	5071.3	8.8

Internship work: J-B Billand

Horizo

Strong Lensing



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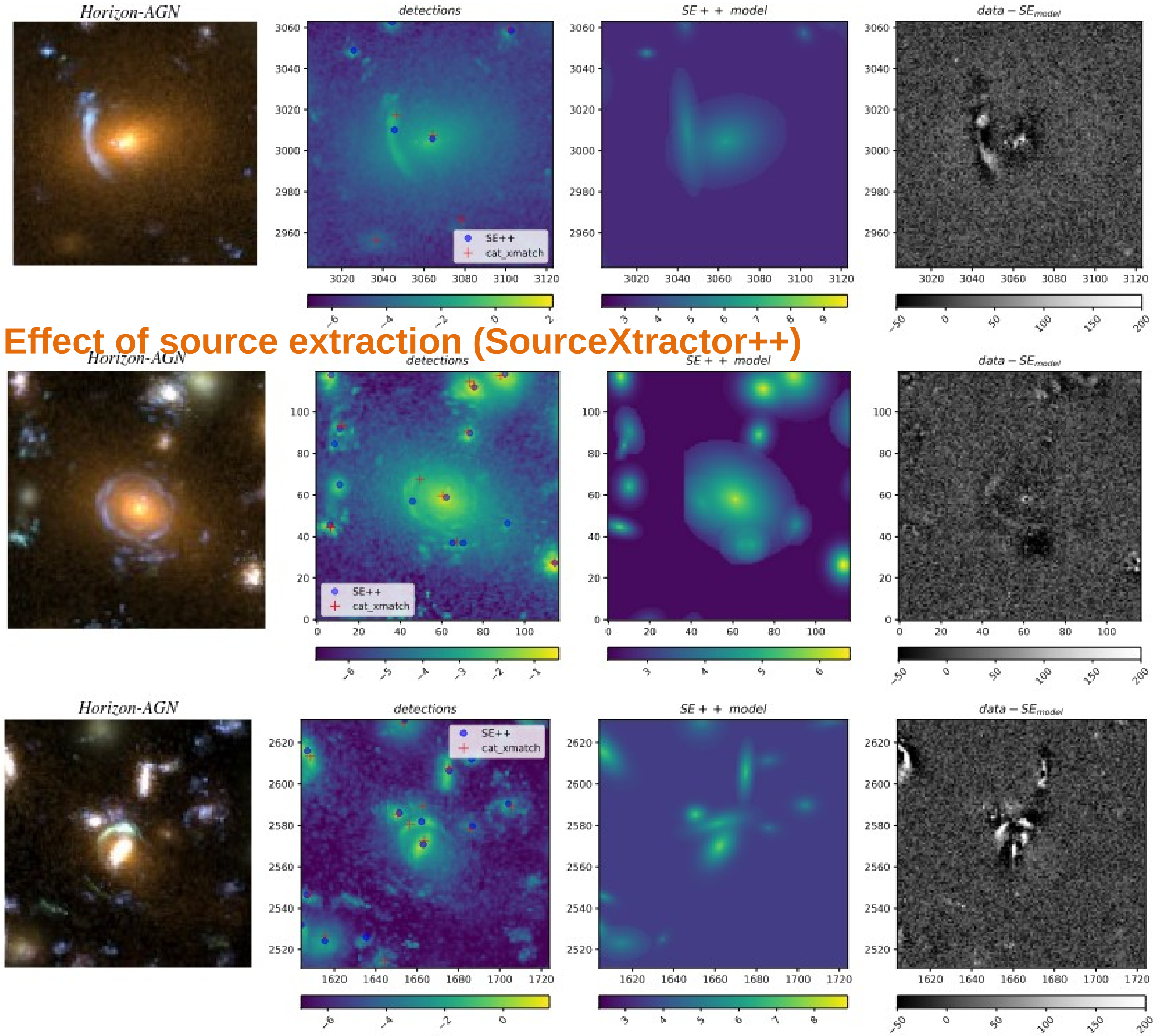
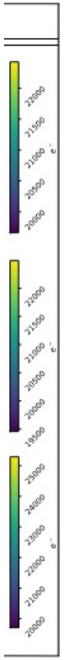
LSST	y	30	10	18.61	26.68	2.576×10^{-33}	5071.3

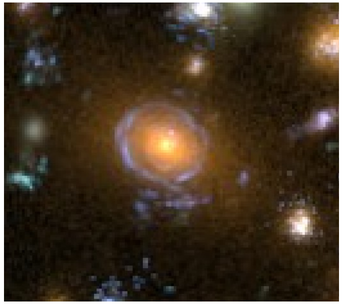
Effect of source extraction (SourceXtractor++)





B Billand

Horizon-AGN: small scale lensing applications

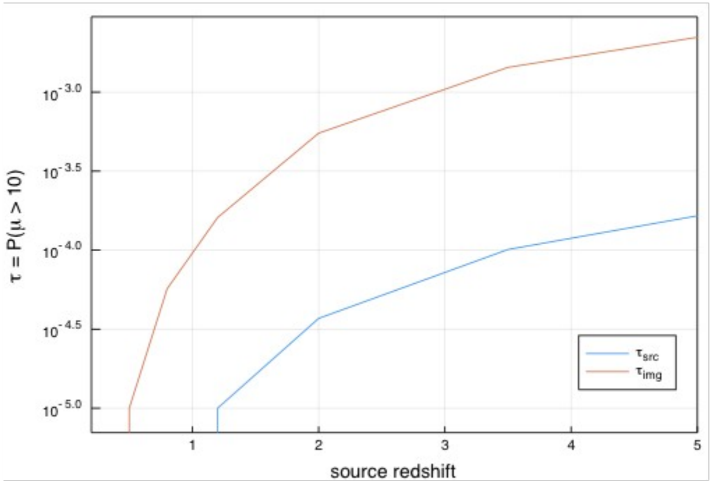


M*~3e11, z_l=0.88, z_s=2.33

With ~10 events per deg^2, H-AGN a bit small!

Lensing cross section, “easy” to compute (ie area potentially yielding magnification μ> threshold)

Hydro-sims start to make accurate predictions on total optical depth as a function of redshift, mass, environment…



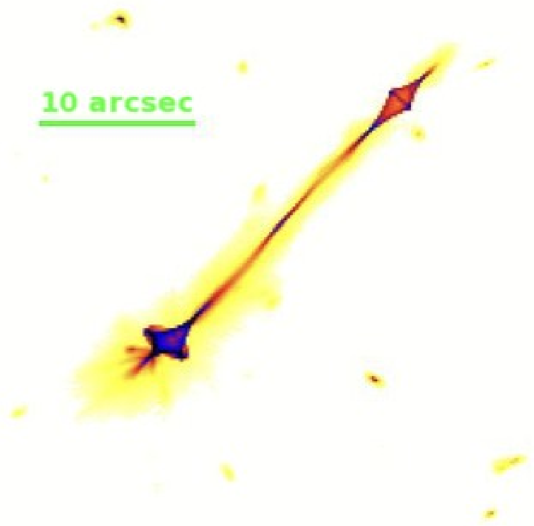


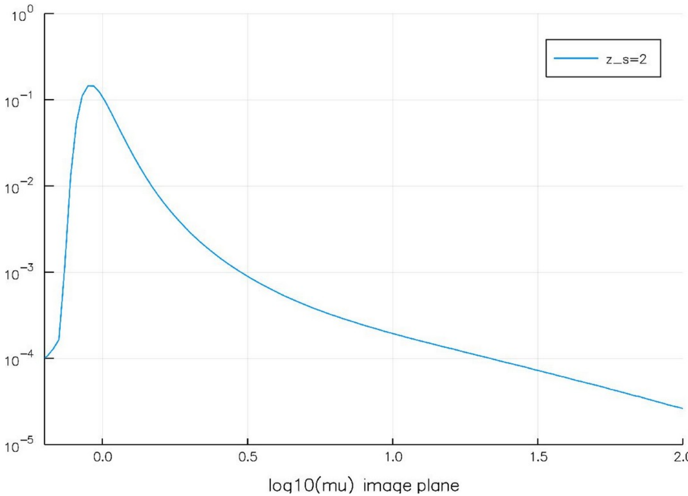
Image plane

$$\tau_p^{\mathrm{I}} = \frac{\int_{\mathbb{P}^{\mathrm{I}}} \mathrm{d}^2\boldsymbol{\theta}\, 1_p(\boldsymbol{\theta})}{\int_{\mathbb{P}^{\mathrm{I}}} \mathrm{d}^2\boldsymbol{\theta}},$$

(integrated/folded) source plane

$$\tilde{\tau}_p^{\mathrm{S}} = \frac{\int_{\mathbb{P}^{\mathrm{S}}} \mathrm{d}^2\boldsymbol{\beta}\, 1_p(\boldsymbol{\beta})}{\int_{\mathbb{P}^{\mathrm{S}}} \mathrm{d}^2\boldsymbol{\beta}},$$

$\frac{d\tau}{d\mu}$ yields the magnification PDF…

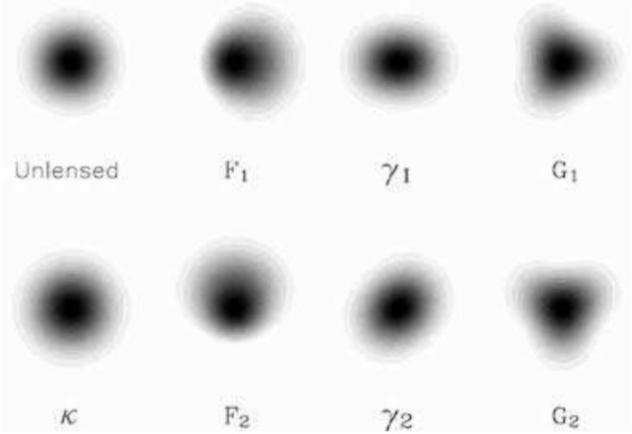


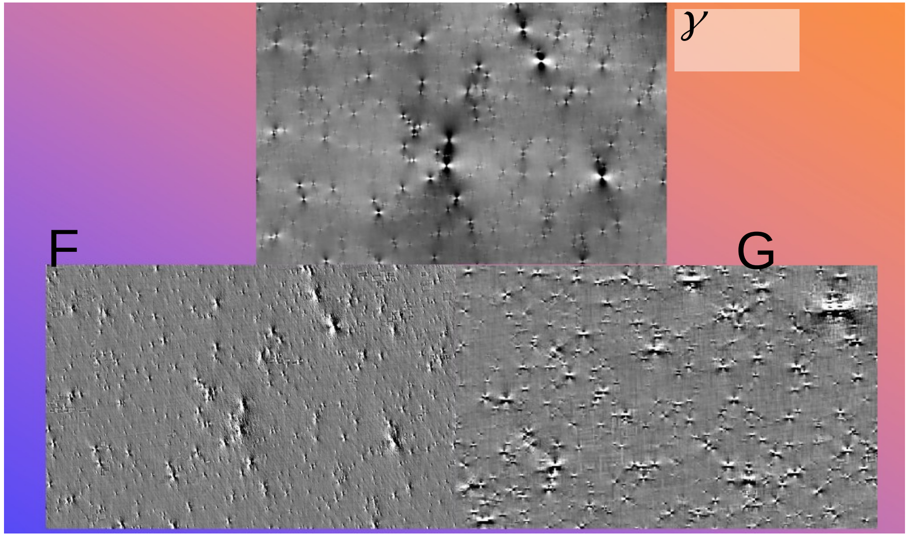
Horizon-AGN: small scale lensing applications

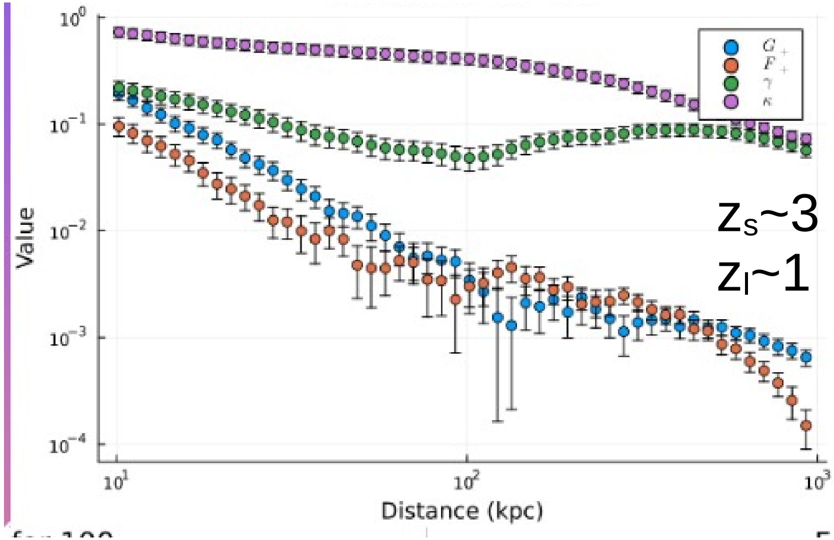
But also realistic Flexion maps!

$$\mathcal{F} = |\mathcal{F}|e^{i\phi} = \frac{1}{2}\partial\partial^*\partial\psi = \partial\kappa = \partial^*\gamma, = (\partial_1\gamma_1 + \partial_2\gamma_2) + i(\partial_1\gamma_2 - \partial_2\gamma_1)$$

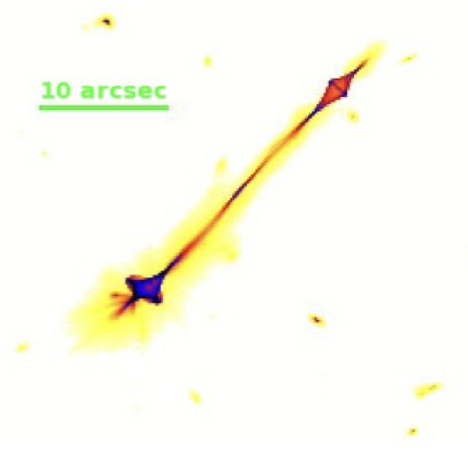
$$\mathcal{G} = |\mathcal{G}|e^{3i\phi} = \frac{1}{2}\partial\partial\partial\psi = \partial\gamma, = (\partial_1\gamma_1 - \partial_2\gamma_2) + i(\partial_1\gamma_2 + \partial_2\gamma_1).$$







Horizon-AGN: small scale lensing applications



Simulation has a lot more possible applications despite small(ish) FoV

Imaging sims can be re-run on demand for specific facility…
(eg being used for Cosmos-Web photometric catalogs)

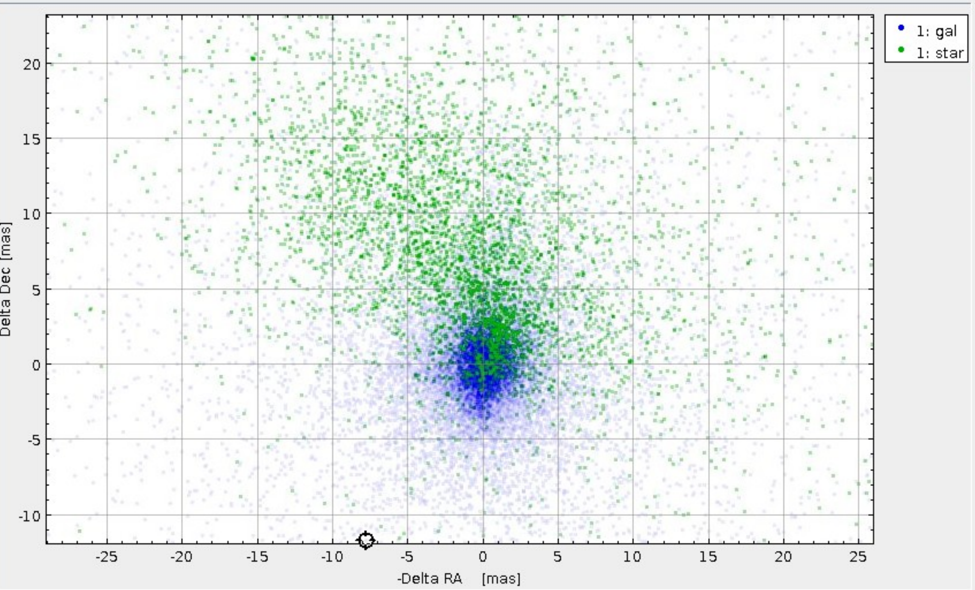
A wealth of line of sight effects can be explored
eg: accurate blending, lens-lens coupling (curl, etc),
lens-dust coupling, microlensing

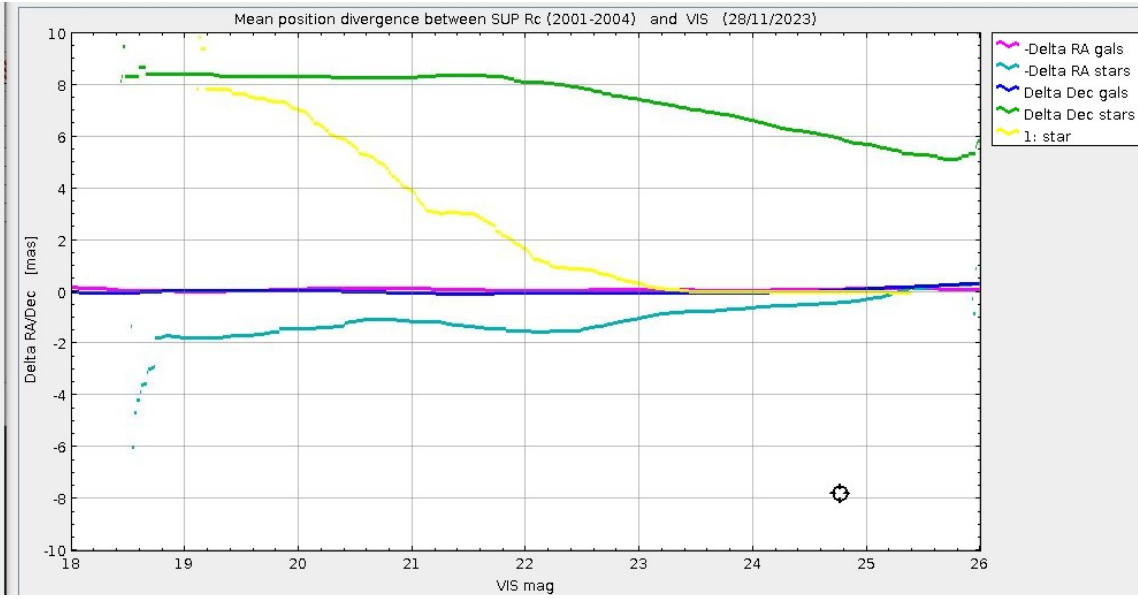
Please contact me if interested in some specific aspect

EXTRAs

Suprime/Euclid relative registration

- Galaxies (blue) are well aligned between ground and Euclid
- Stars (green) quite spread out!!!   20 year time span (some sweat to get astrometry right)

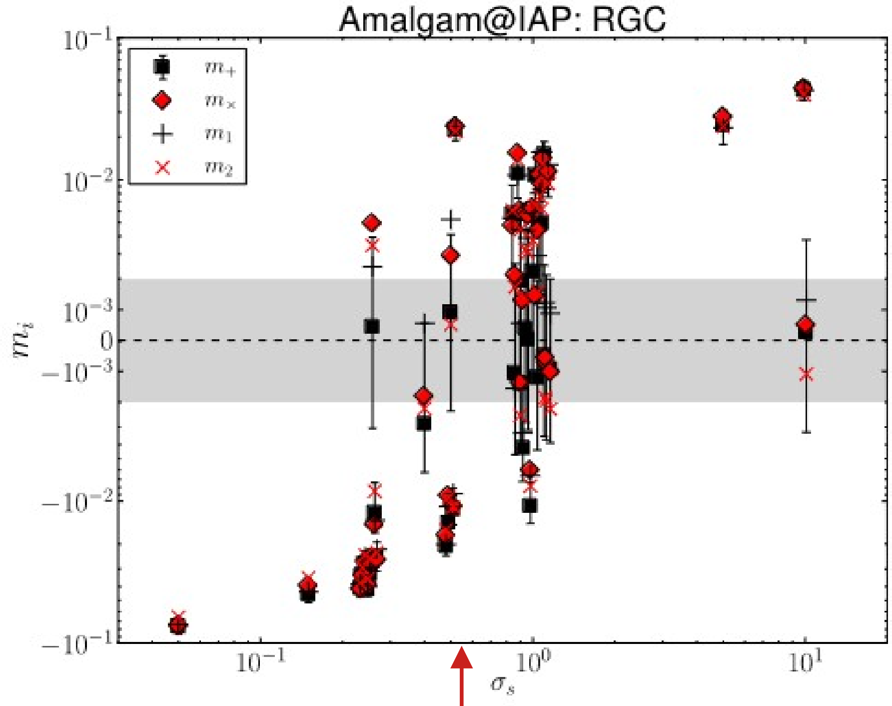


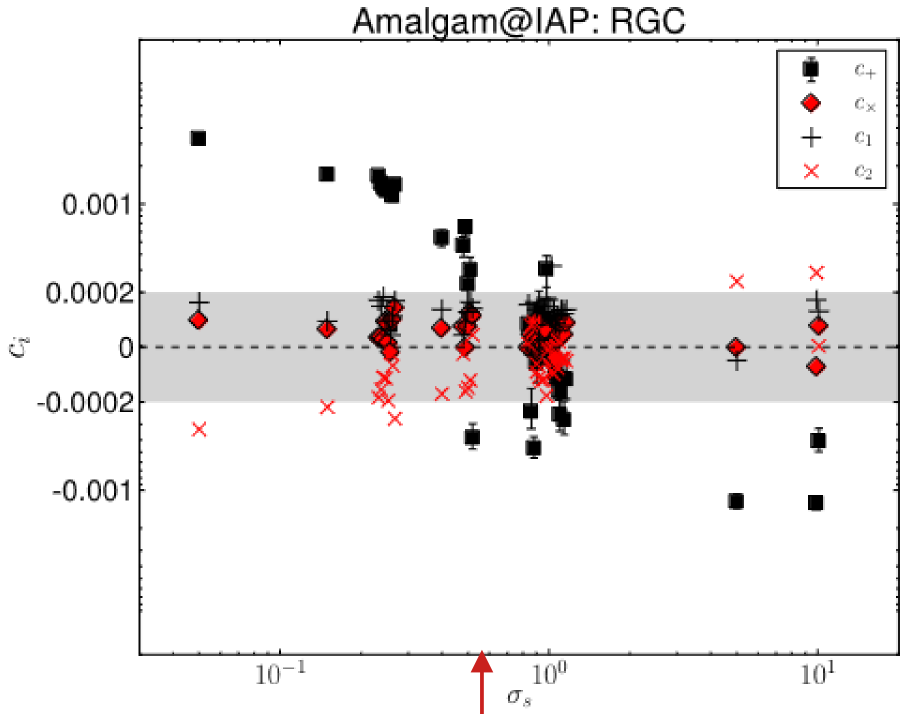


Exquisite sensitivity to stellar motions! Can probe 0.3 mas/yr at mag 24-25!

Great3

Mandelbaum et al 2015





Weighting scheme: $w_i^{-1} = \sigma_s^2 + \sigma_i^2$

Euclid Preparation IV

Euclid Prep IV, Martinet et al 2019