Some tools for cosmology

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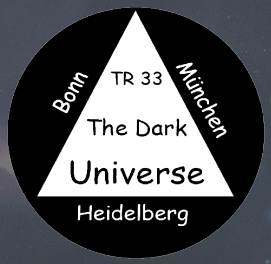
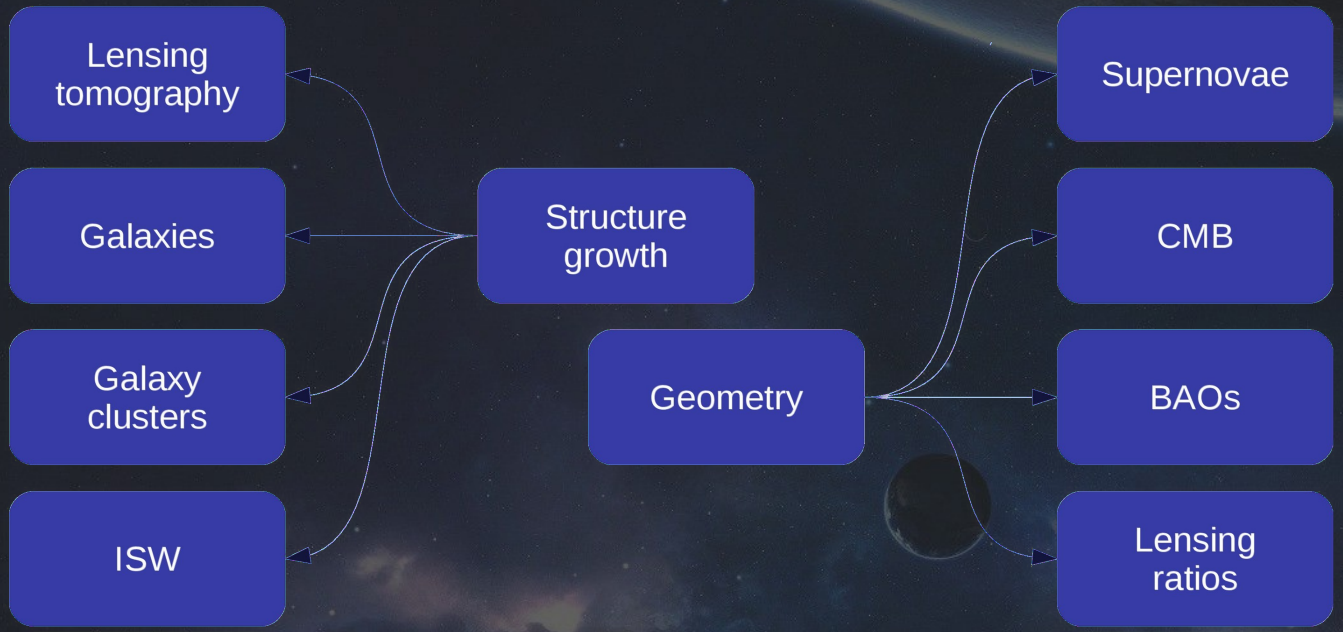
Large effort in trying to understand DM and DE

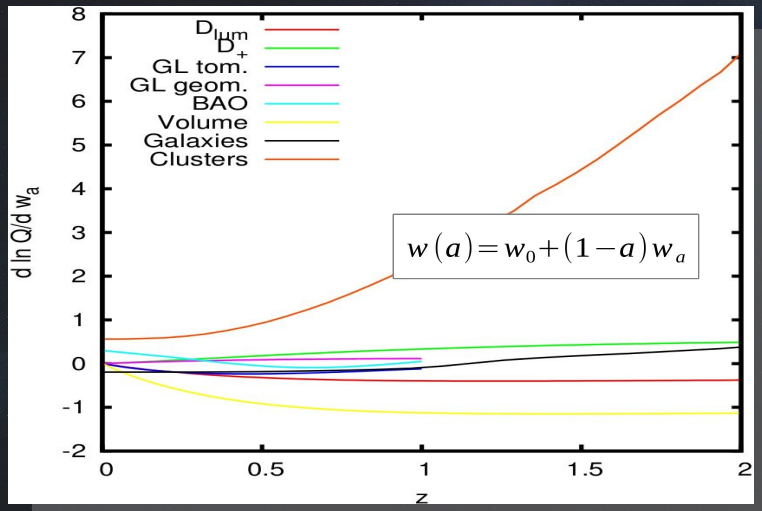
Heidelberg heavily involved in this

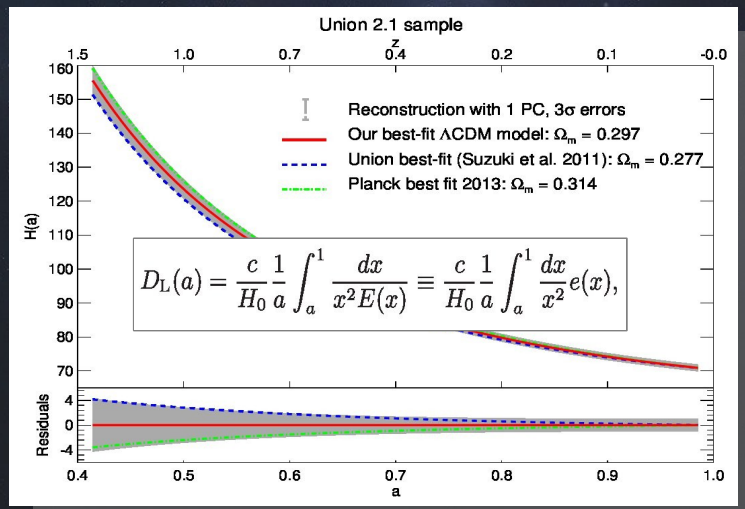


(1) Theoretical
(2) Phenomenological
(3) Observational

The manifestations of cosmology







The many faces of a galaxy cluster

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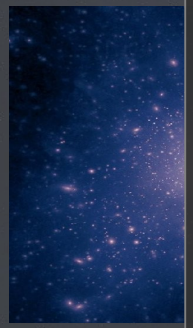
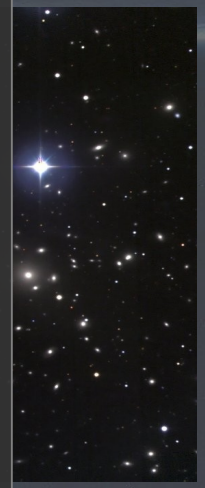
ZUKUNFT SEIT 1386

N-Body simulations



Gravitational lensing(s)

Galaxy overdensity



How do you combine all of this information?

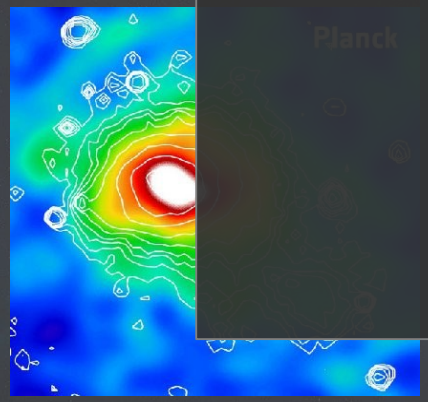
You need to detect them (detection)

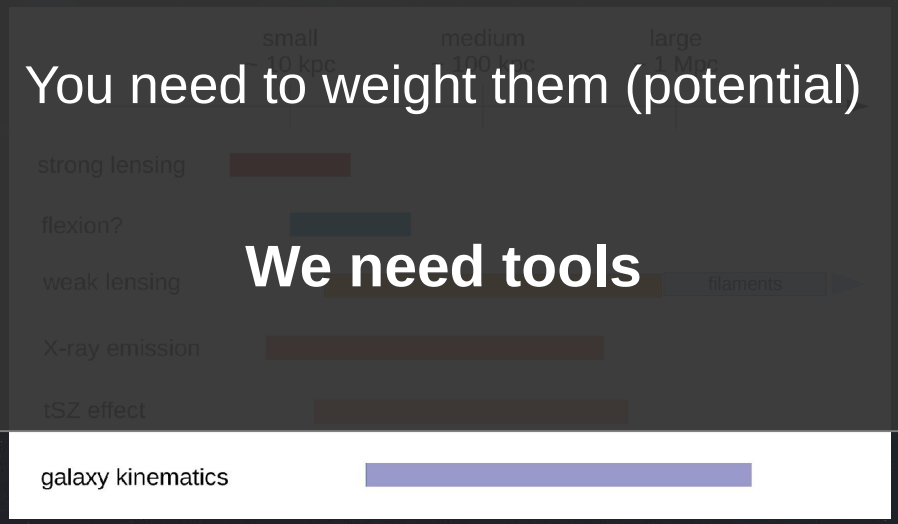
You need to understand them (DM profile)

You need to weight them (potential)

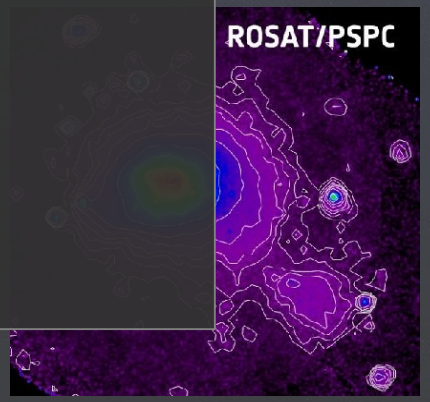
We need tools

TSZ effect

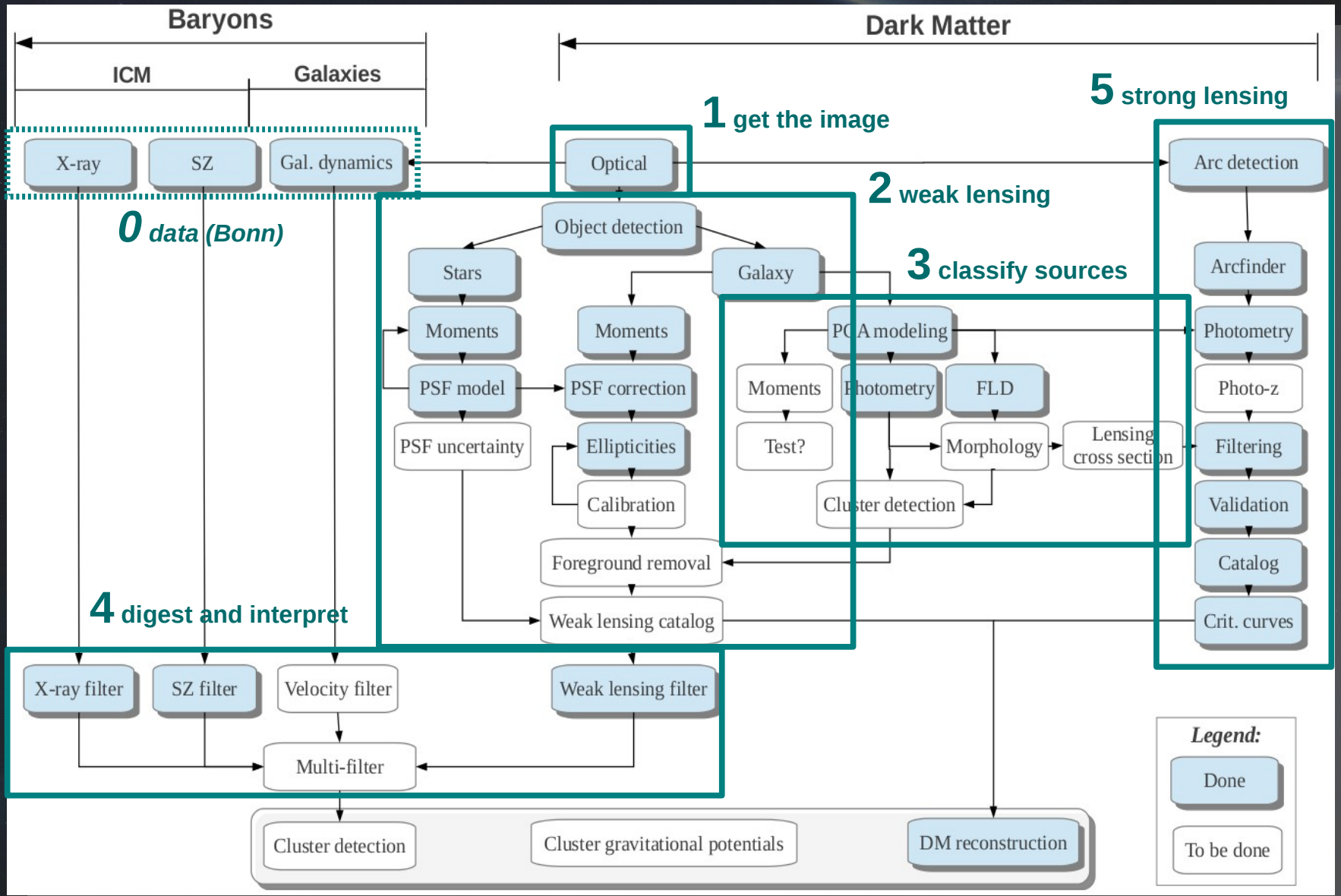


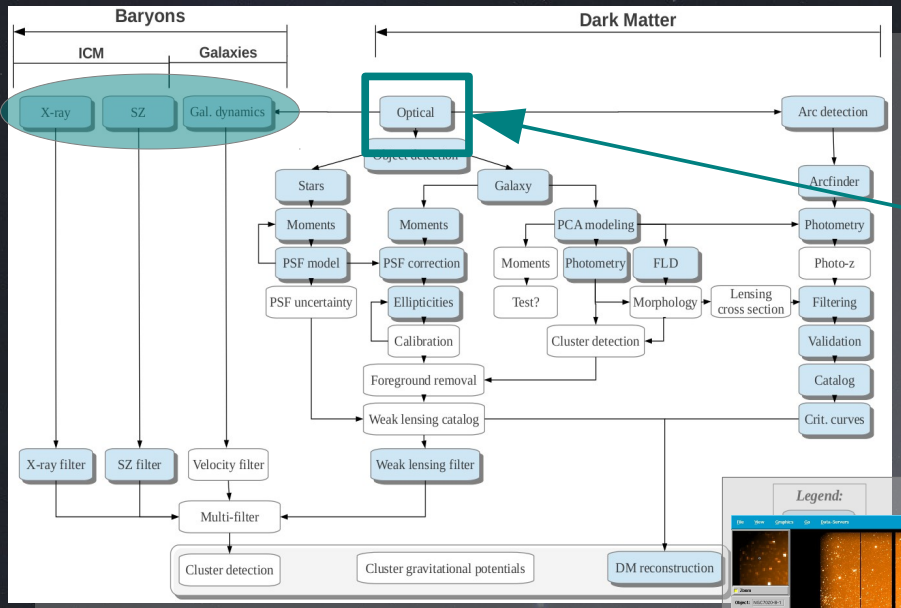


X-ray emission



PART 1
Galaxy clusters pipeline





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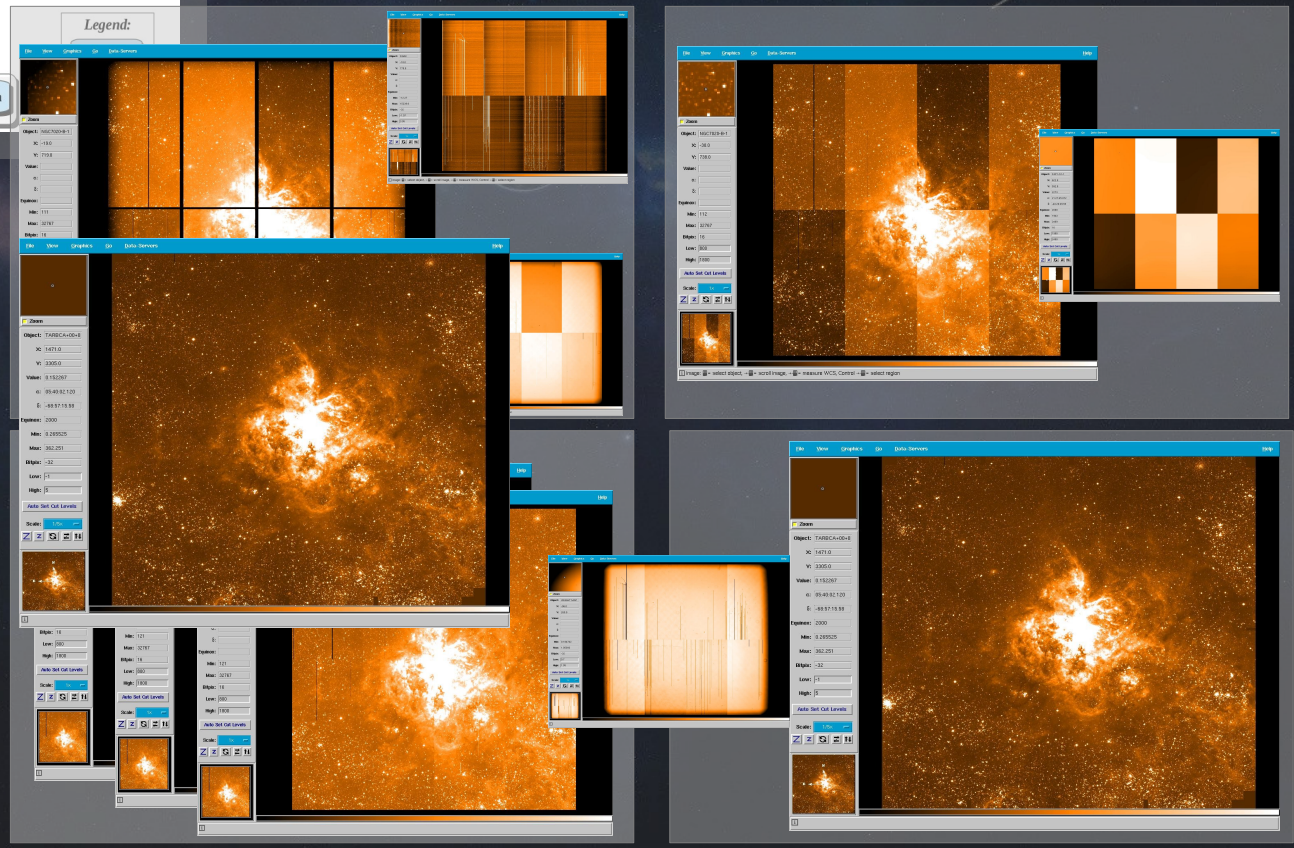
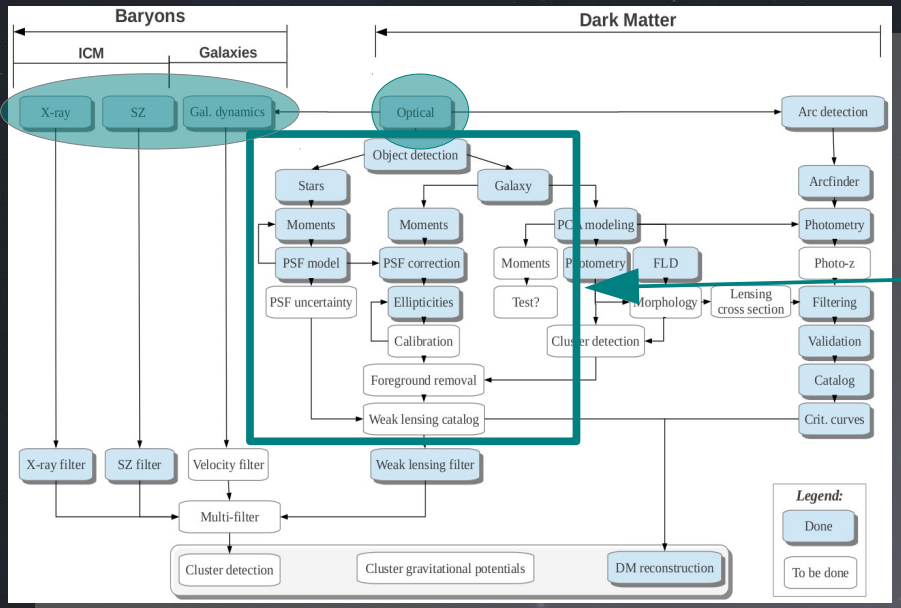
Create the images

THELI pipeline (*Bonn*)

Erben, Schirmer, Dietrich et al. 2005





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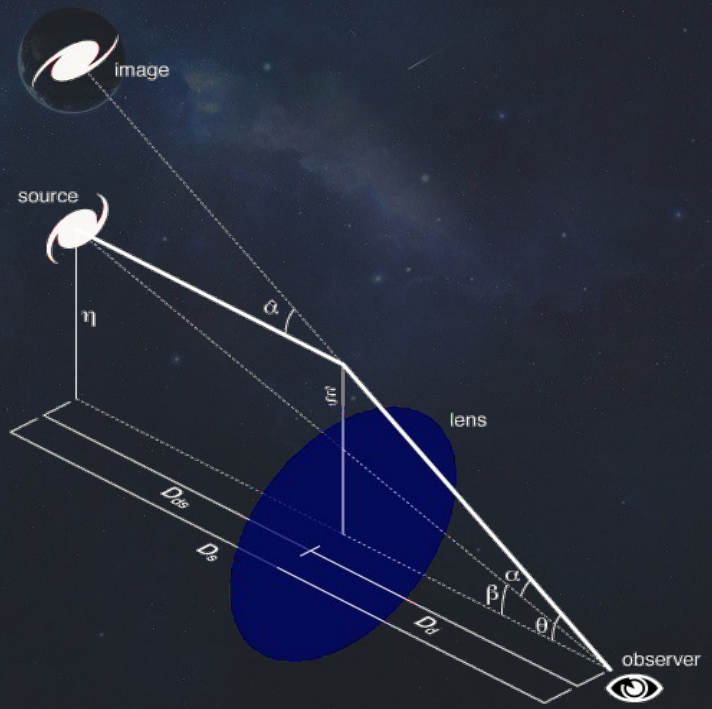
Measuring weak lensing

EasyLens



Melchior, Viola, Schäfer & Bartelmann 2005
Maturi in prep.

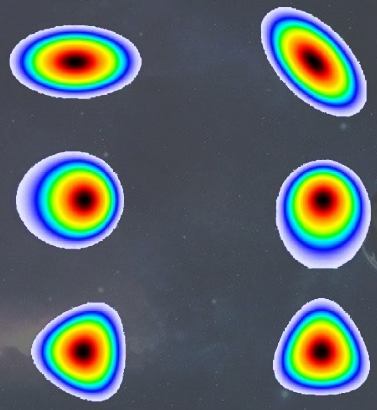
Gravitational lensing in short

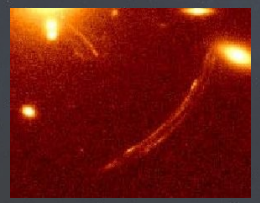
All lensing effects given by effective lensing potential:

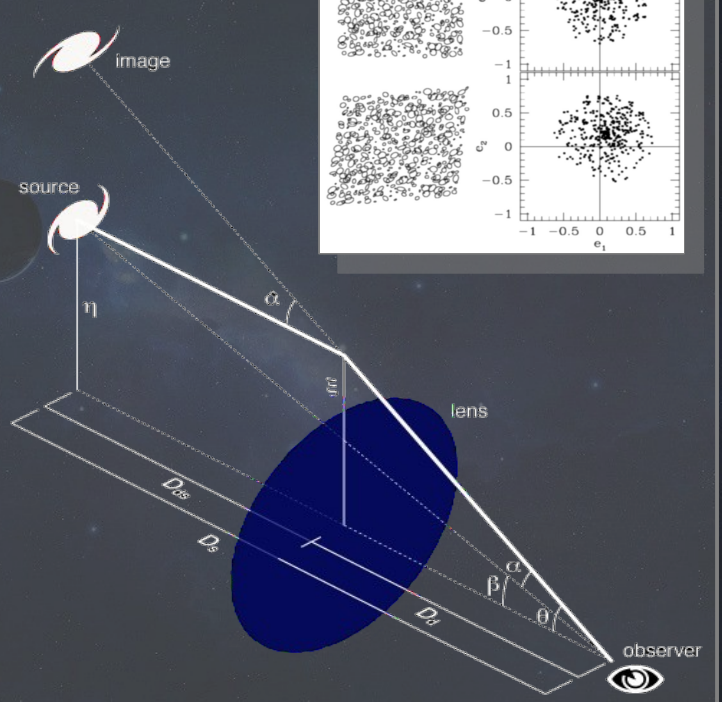
$$\psi = \frac{2}{c^2}\frac{D_{ds}}{D_d D_s}\int \Phi dz$$

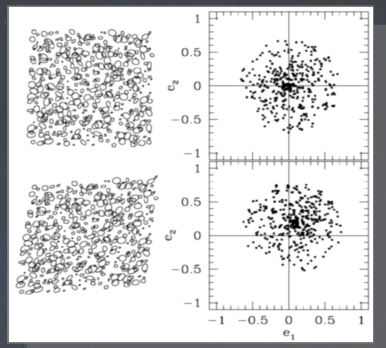
(Potential) observables:

- Surface-mass density: $\kappa = \partial^\dagger \partial \psi$
- Shear: $\gamma = \partial^2 \psi$
- Critical curves: $\det\left(\delta_{ij} - \partial_i \partial_j \psi\right) = 0$
- Flexion: $\mathcal{F} = \partial\kappa, \mathcal{G} = \partial\gamma$

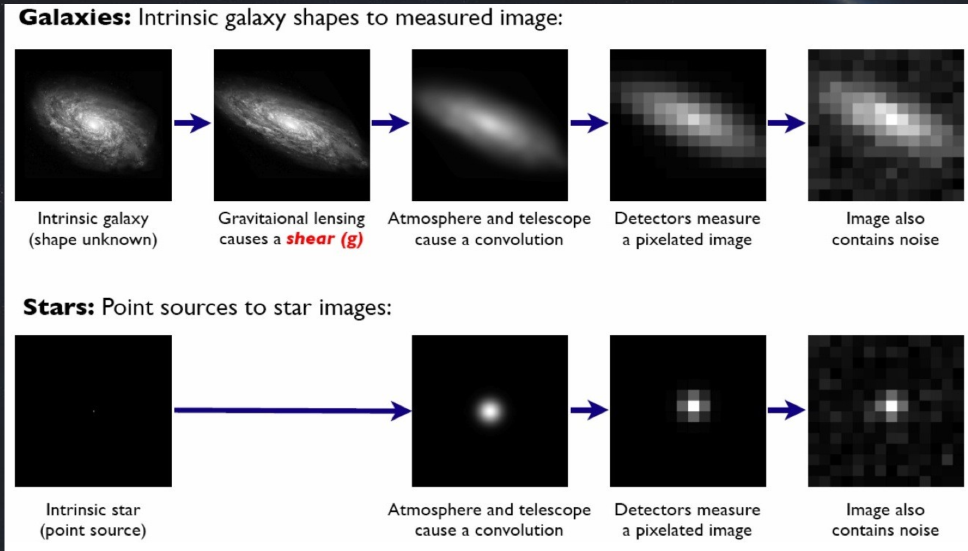








How we measure ellipticity



Euclide

Define ellipticity: via moment of brightness:

$$\{G\}_{i,j} \equiv \int \mathrm{d}^2x \; G(\boldsymbol{x}) \, x_1^i x_2^j$$

$$\chi \equiv \frac{\{G\}_{2,0} - \{G\}_{0,2} + 2\mathrm{i}\{G\}_{1,1}}{\{G\}_{2,0} + \{G\}_{0,2}}$$

Cope with noise: apply a weight:

$$I(\boldsymbol{x}) = G(\boldsymbol{x}) + N(\boldsymbol{x})$$

$$I_W(\boldsymbol{x}) = W(\boldsymbol{x}) \, I(\boldsymbol{x})$$

Just details...

Correct for the telescope PSF:

$$\{G^{\star}\}_{i,j} = \sum_k^i \sum_l^j \binom{i}{k} \binom{j}{l} \{G\}_{k,l} \{P\}_{i-k,j-l}$$

De-weight:

$$\approx W^{-1}(\boldsymbol{0}) - W'(\boldsymbol{0}) \left[\sum_{k=1}^{2} c_k x_k^2 + 4 c_2 x_1 x_2 \right] + \ldots$$

Just details...

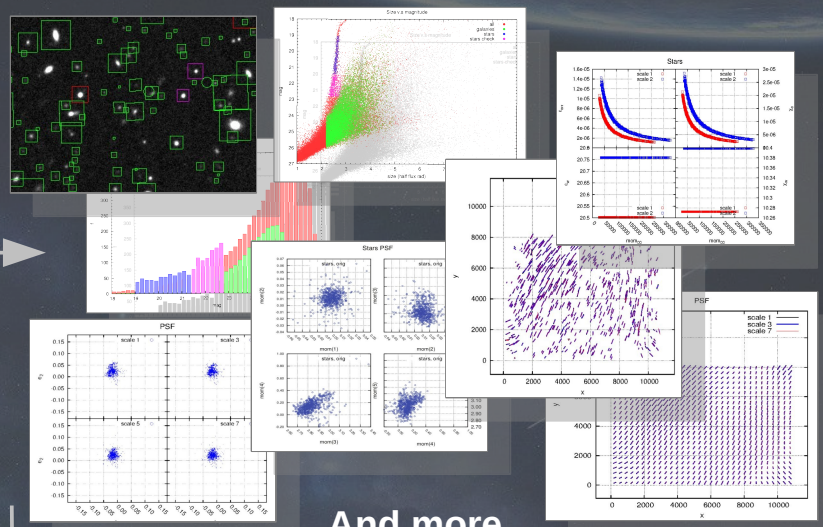
EasyLens

Codes:
- preprocess (detect sources + select + mask...)
- img2mom
- mom2psf
- img2ell
- ell2calib
- *ell2opt*
- *ell2fil*

Scripts:
A gray-box (just feel the parameters)

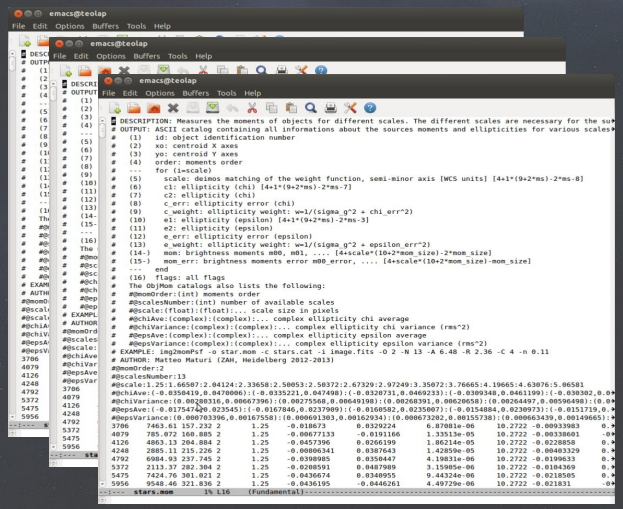
Maturi in prep.

Loads of diagnostics...



And more....

Final catalogs...



Messaging, “take care of...”

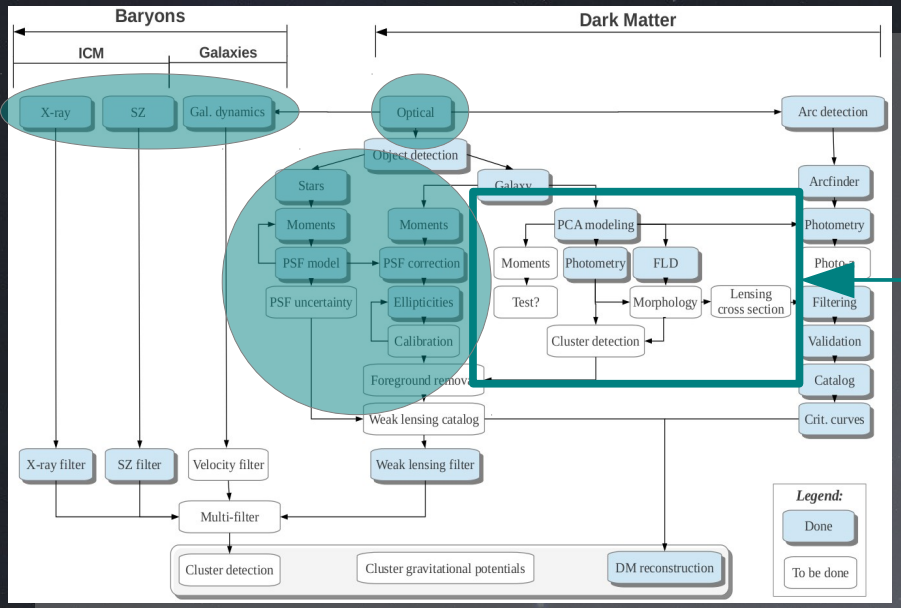
```
maturi@teolap: ~/lavori/Codici/EasyLens/v9/TMP_a1835_iprime_v3

> ./deimos/5c_psf_onGrid_amp.eps
  Amplitude map of the ellipticity. For stars the map should show
  relatively smoth variation of intensity because the PSF is not
  supposed to have strong discontinuities, except maybe at the porders
  of chips in the case of multi-chip cameras.

> ./deimos/5c_psf_onGrid_ell_vector.eps
  As before but in this case the direction and amplitude of the
  ellipticity is shown. For stars there should be a visible
  correlation because of the image PSF which should be varying gently
  across the field of view. Three different scales are overplotted
  with three different colors to show possible variations with this
  respect.

> ./deimos/5c_psf_onGrid_ell_vector4plot.eps
  Same as before but four scales are shown on independent panels.
  done!

maturi@teolap/TMP_a1835_iprime_v3$
```



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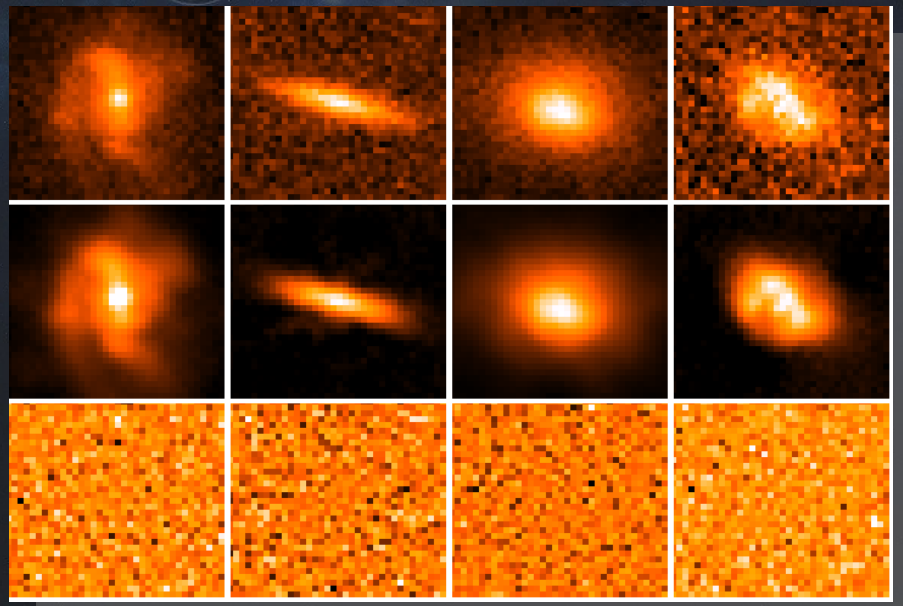
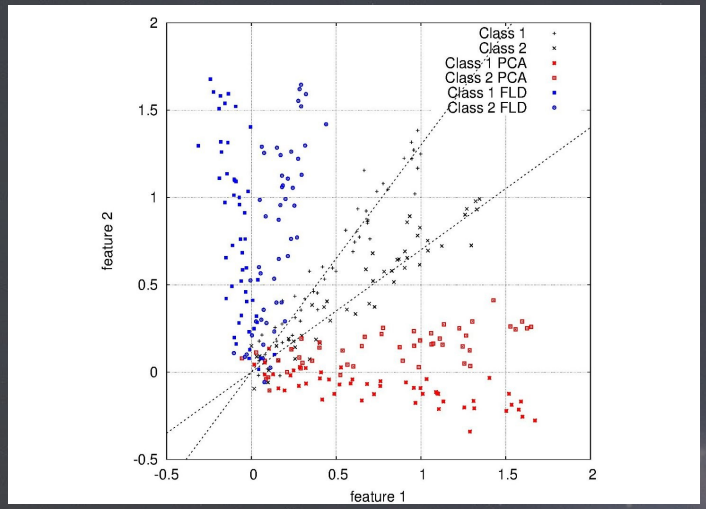


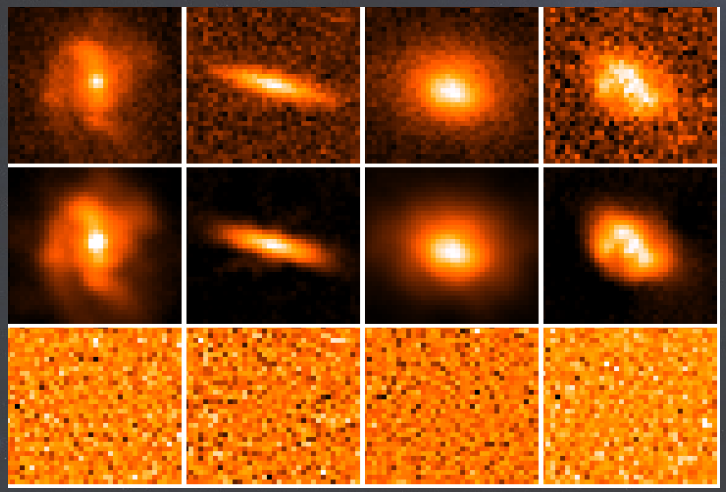
Select the proper sources

Galaxy modeling and classification

New methods

PCA: Principal component analysis





Maturi, Pasquali in prep.

FLD: Fisher linear discriminants

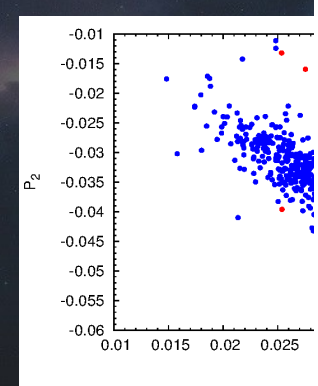
$$\{\boldsymbol{d}_i \in \boldsymbol{D} \mid i = 1, \ldots, M\}, \text{ where } \boldsymbol{D} \in \Re^{n \times M}$$

$$\{\tilde{\boldsymbol{d}}_i \in \tilde{\boldsymbol{D}} \mid i = 1, \ldots, \tilde{M}\}, \text{ where } \tilde{\boldsymbol{D}} \in \Re^{n \times \tilde{M}} \text{ and } \tilde{M} < M$$

$$\{\tilde{\boldsymbol{d}}_i^{(j)} \in \boldsymbol{C}_i \subset \tilde{\boldsymbol{D}} \mid i = 1, \ldots, m_j\}, \text{ where } \boldsymbol{C}_i \in \Re^{n \times m_j}$$

$$L = \boldsymbol{w}_i^T S_b \boldsymbol{w}_i + \lambda_i \left(\boldsymbol{w}_i^T S_w \boldsymbol{w}_i - 1\right) \qquad S_b \boldsymbol{w}_i = \lambda_i S_w \boldsymbol{w}_i$$

$$\{\boldsymbol{w}_i \in \boldsymbol{W} \mid i = 1, \ldots, m_j\}, \text{ where } \boldsymbol{W} \in \Re^{n}$$



$$\mu = \sum_{i=1}^{m} \tilde{\boldsymbol{d}}_i / m \in \Re^n$$

$$\mu^{(j)} = \sum_{\tilde{d}_i \in C_j} \tilde{\boldsymbol{d}}_i / m_j \in \Re^n$$

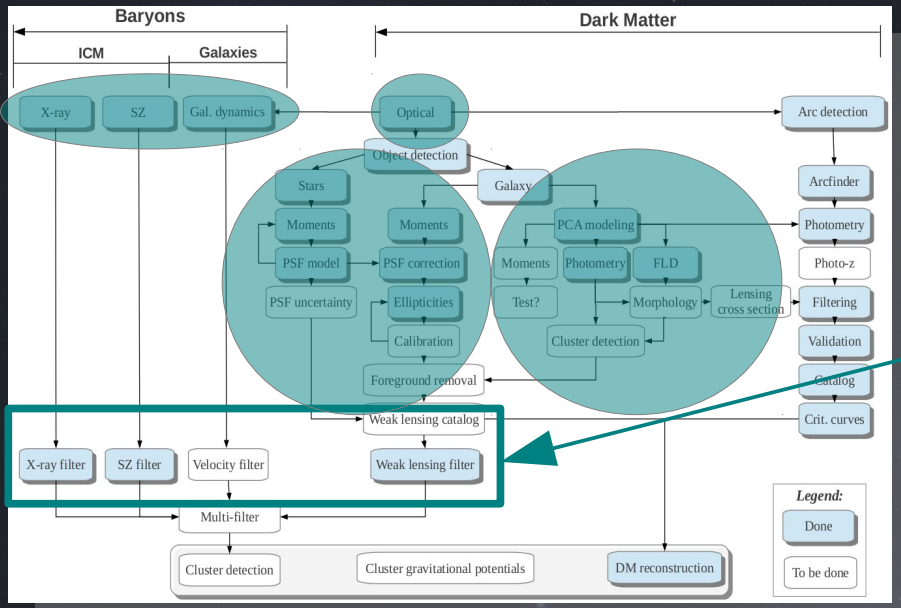
$$S_b = \sum_{j=1}^{n_c} (\mu^{(j)} - \mu)(\mu^{(j)} - \mu)^T$$

$$S_w = \sum_{j=1}^{n_c} \sum_{\tilde{d}_i \in C_j} \frac{1}{m_i} (\tilde{\boldsymbol{d}}_i - \mu^{(j)})(\tilde{\boldsymbol{d}}_i - \mu^{(j)})^T$$

$$p(\boldsymbol{d} \mid \boldsymbol{d} \in \boldsymbol{C}_j) = \prod_{k=1}^{m} (2\pi\sigma)^{-1/2} \exp\left[\frac{(\delta_k - \mu_j)^2}{2\sigma_j^2}\right]$$

	Edge-on	Ellipt	Early-on	14	9
Edge-on	**64%**	0%	0%	0%	11%
Ellipt	2%	**52%**	3%	0%	14%
Early-on	2%	8%	**51%**	0%	5%
14	14%	0%	0%	**42%**	7%
9	6%	8%	2%	0%	**44%**
Other	8%	8%	21%	1%	32%

Maturi in prep.



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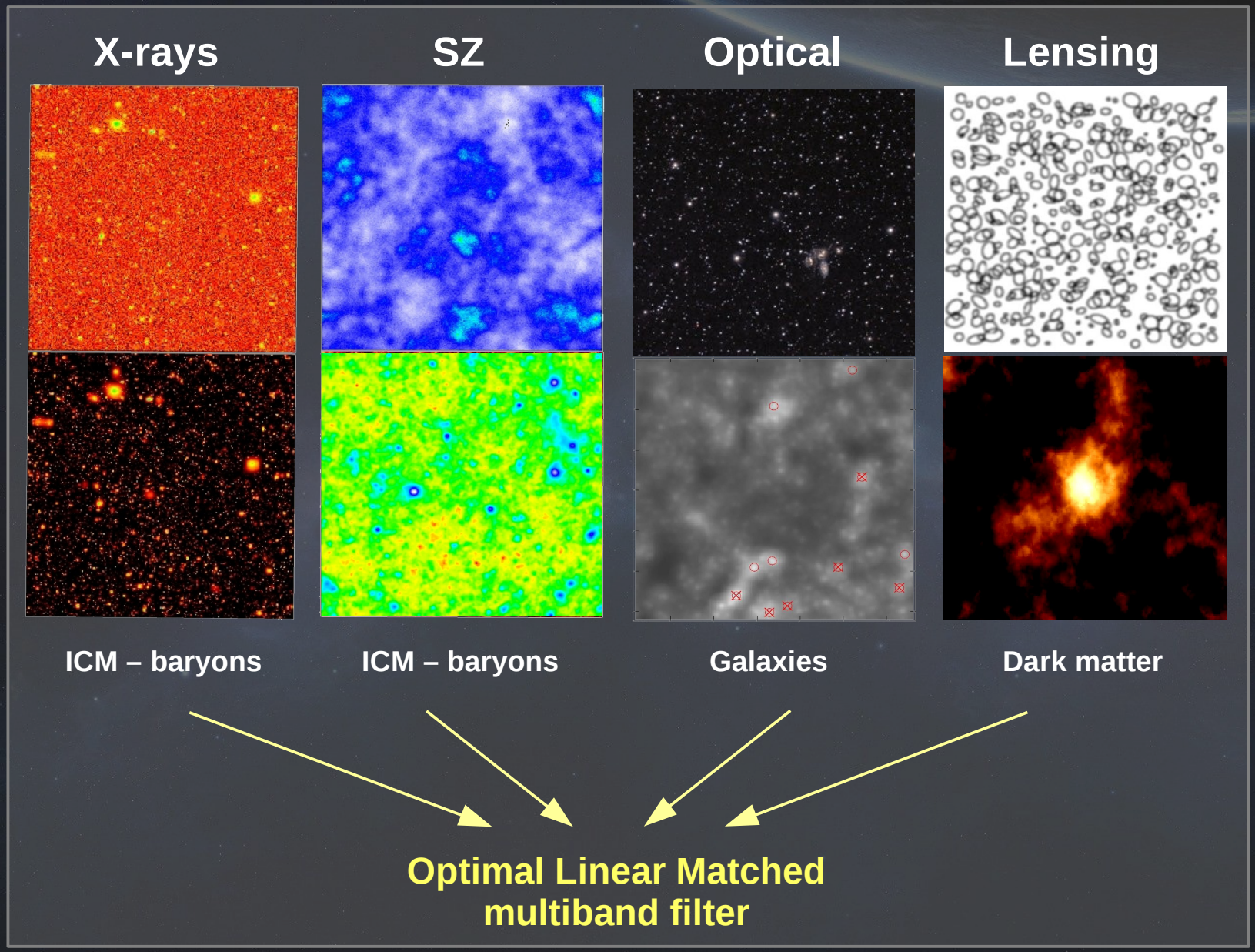
Combine all information: An optimal filter...

Maturi, Meneghetti, Bartelmann, Dolag, Moscardini 2005
Pace, Maturi, Meneghetti, Bartelmann, Moscardini, Dolag 2007
Pace, Maturi, Bartelmann, Cappelluti, Dolag, Meneghetti, Moscardini 2008
Viola, Maturi, Bartelmann 2010
Maturi, Angrick, Pace, Bartelmann 2010
Bellagamba, Maturi, Hamana, Meneghetti, Miyazaki, Moscardini 2011
Gelsin, Maturi, Bartelmann in prep.

A single approach for all wavelength + lensing



How it looks like

Data $D_\nu(\vec{x}) = A\tau_\nu(\vec{x}) + N_\nu(\vec{x})$

Estimate $A_{\rm est}(\vec{x}) = \sum_\nu \int D_\nu(\vec{x}')\Psi_\nu(\vec{x}-\vec{x}')\, d^2x'$

$\downarrow$

$b \equiv \langle A_{\rm est} - A \rangle$ — **Bias to vanish**

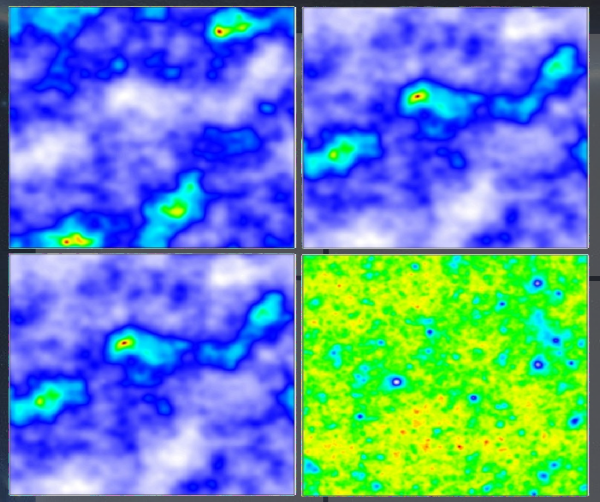
$\sigma^2 \equiv \langle (A_{\rm est} - A)^2 \rangle$ — **Variance to be minimal**

$\Downarrow$

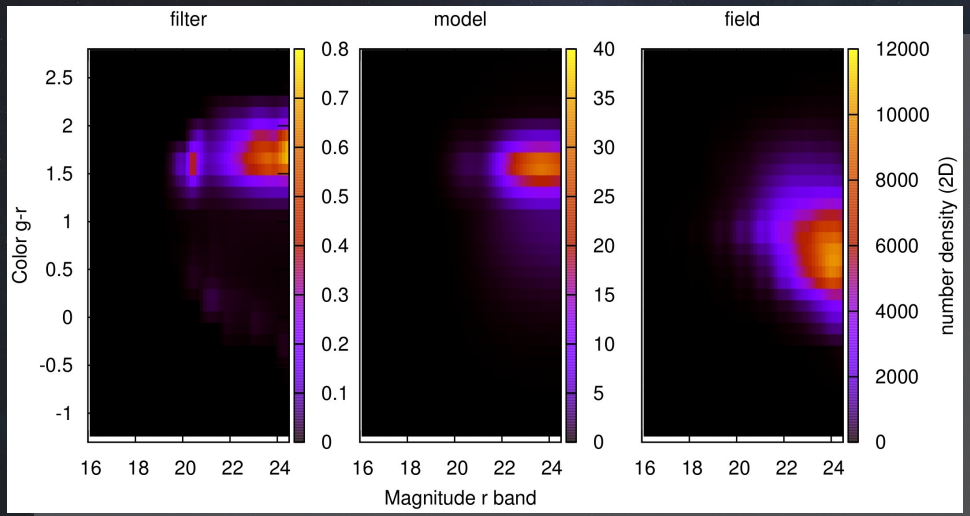
Optimal matched filter (maximize clusters S/N ratio)

$$\hat{\Psi}(\vec{k}) \propto \vec{C}^{-1}(k)\vec{F}(\vec{k})$$

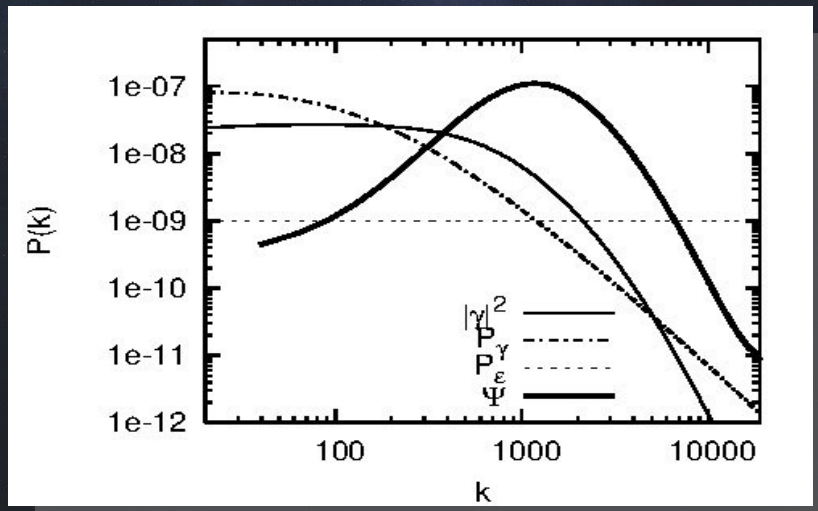
The millimetric channel (SZ)



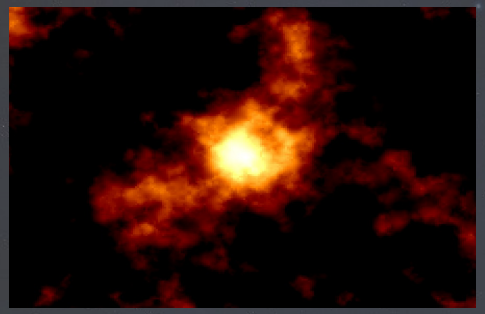
The optical channel



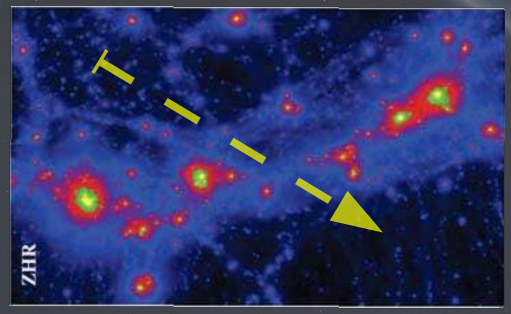
The weak lensing channel



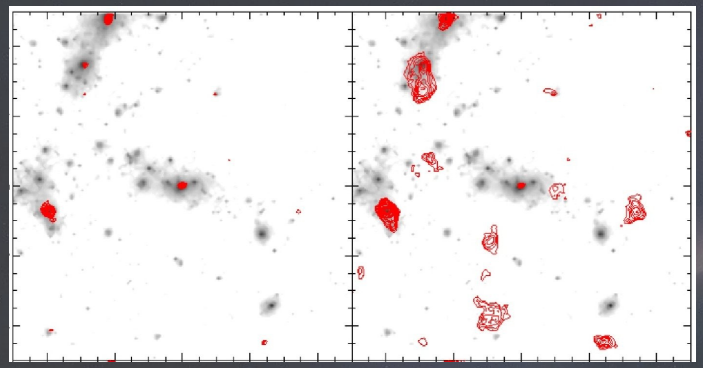
DM distribution

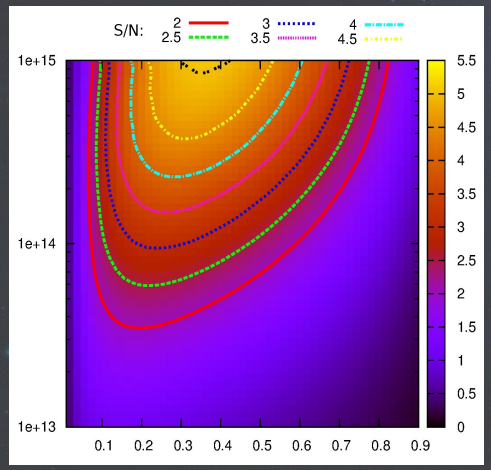


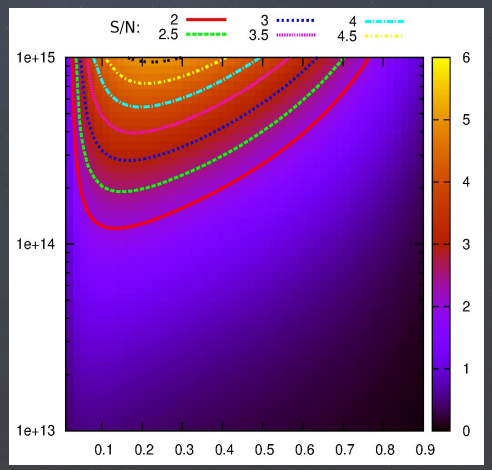
DM Filaments



Detection + potential

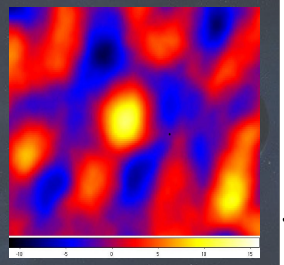


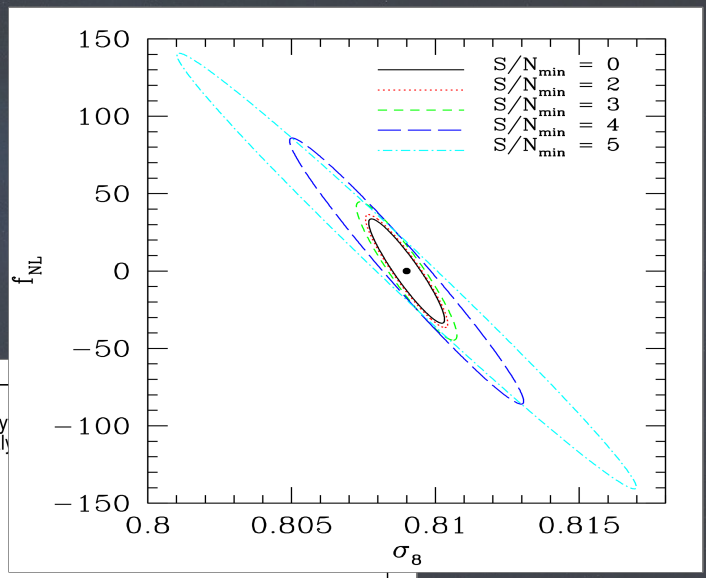


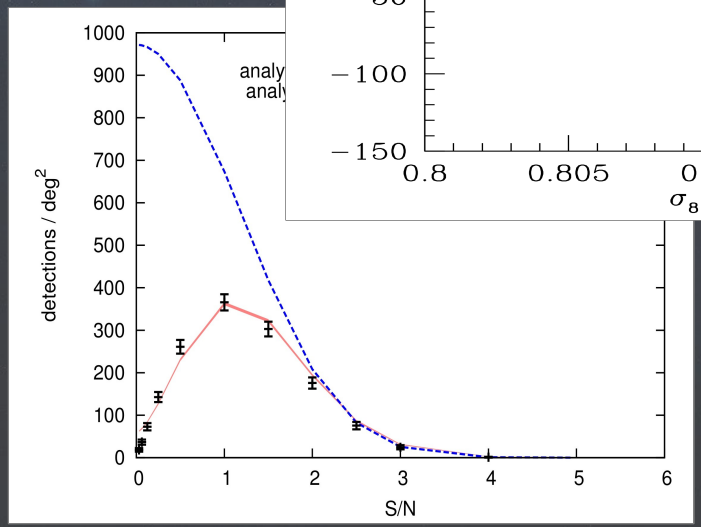


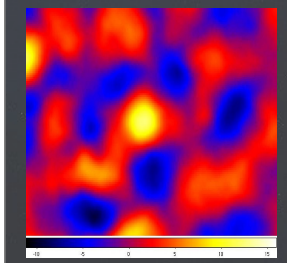
Weak lensing peak counts

$$n_{\rm det}(y_{\rm th}) = \frac{1}{4\sqrt{2}\pi^{3/2}} \left(\frac{\sigma_1}{\sigma_A}\right)^2 \frac{y_{\rm th}}{\sigma_A} \exp\left(-\frac{y_{\rm th}^2}{2\sigma_A^2}\right)$$



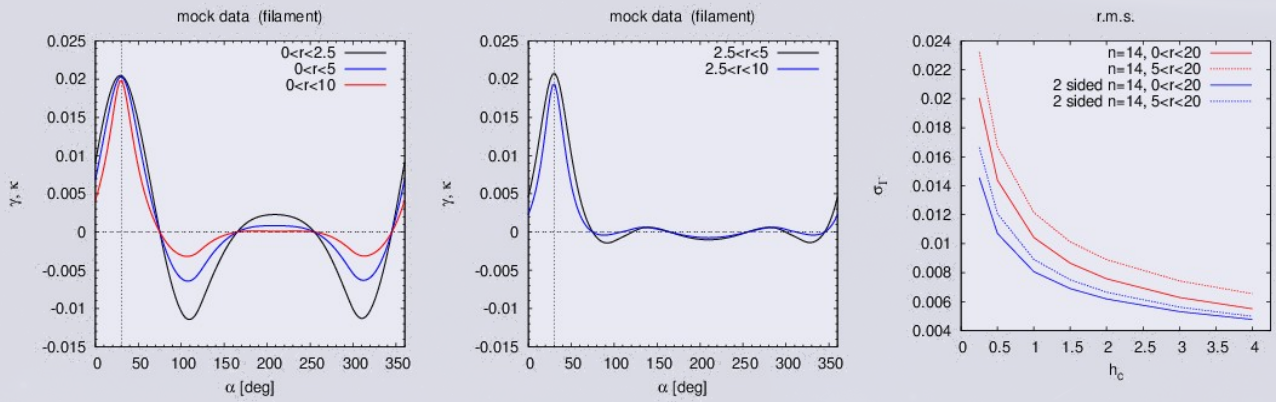




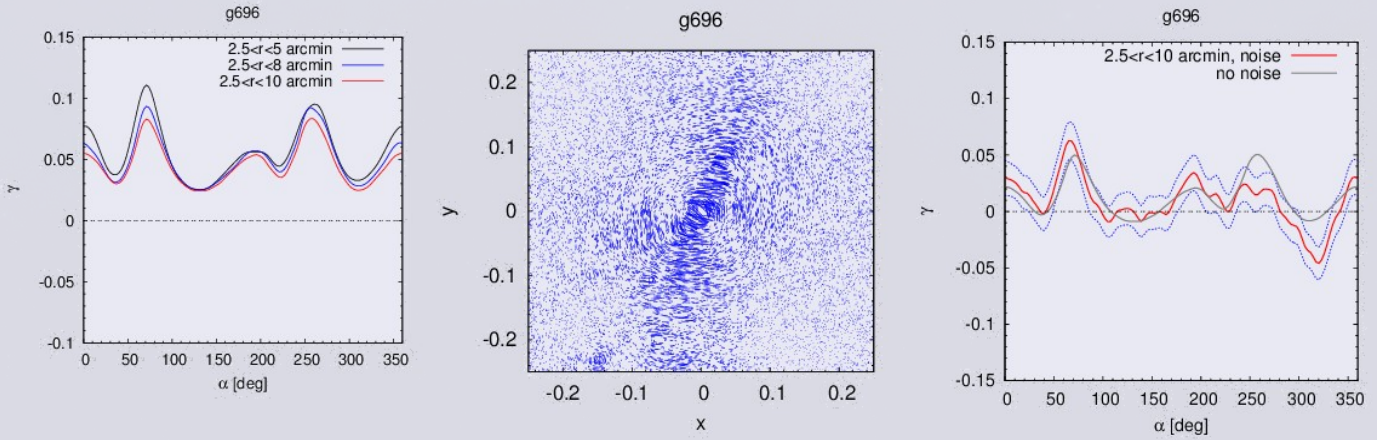


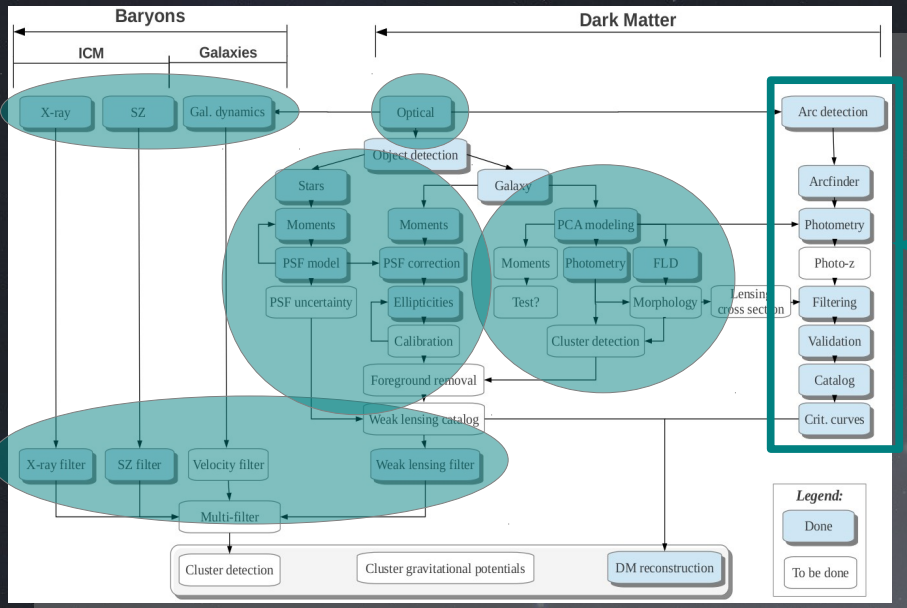
How to get filaments

Analytical



N-body numerical simulation ($\sigma_g = 0.4$, $n_g = 15$)





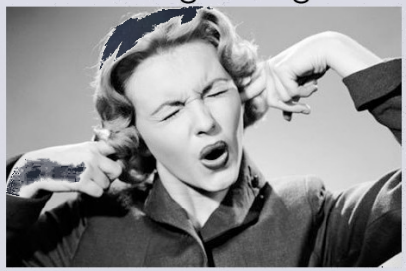
You are here

Detecting giant arcs

Maturi, Mizera & Seidel 2013
Seidel & Bartelmann 2007

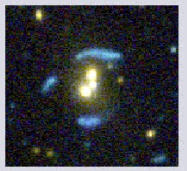
From the core...

Strong lensing



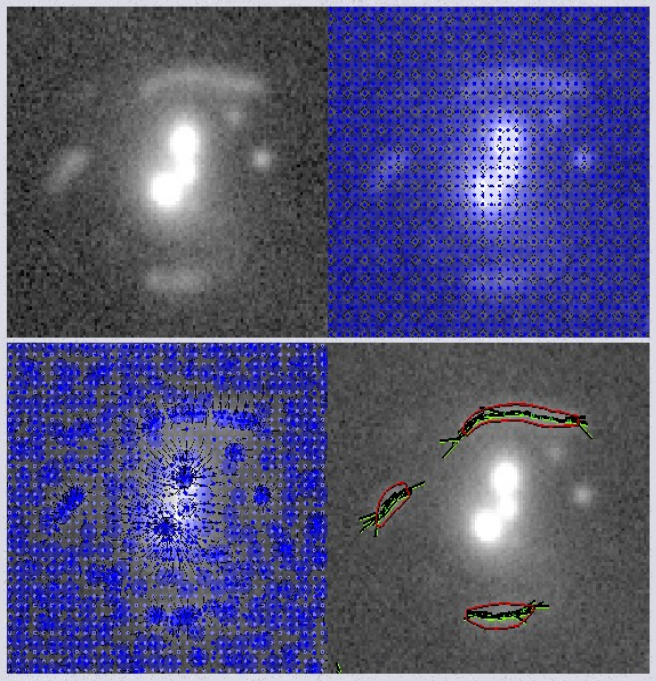
central region

"Gravitational arcs"



Is difficult. First detect elongated features

(1) The one band arcfinder



(2) The data: CFHTLS-Archive-Research Survey

- Fiels=37deg^2: W1, W3, W4
- Depth $r' = 24.36$, FWHM<0.75 (!)
- 27 known candidates (Cabanac+07 and More+12)
- 90 by our visual inspection

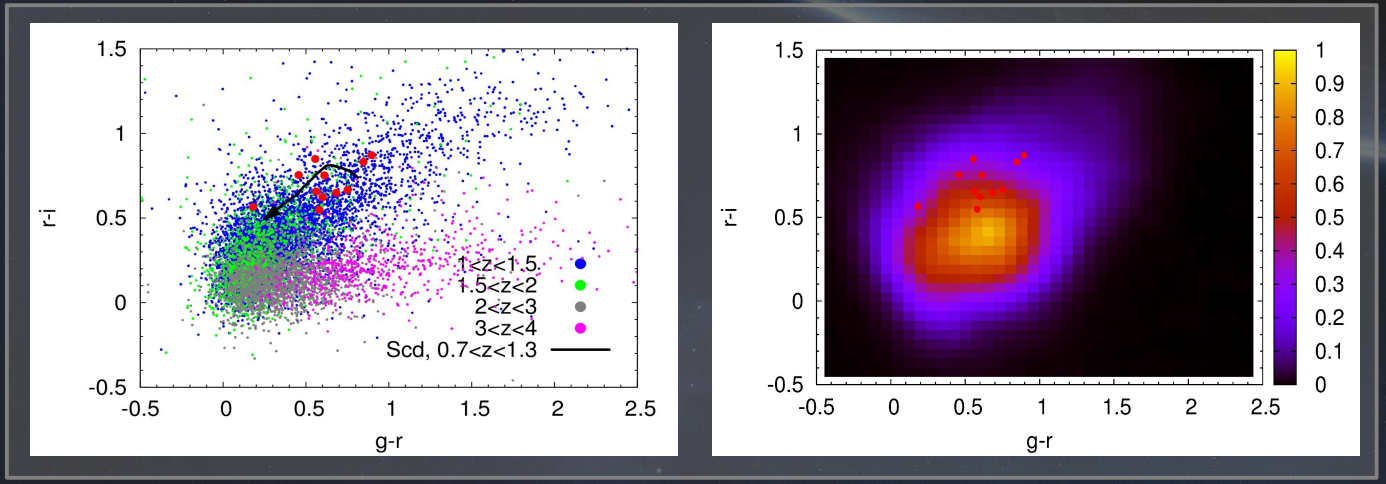
(3) What we arcfinded (1 band only)

- Number of objects $= 7\,10^6$ (SeExtractor)
- Arcfinder: $L > 3''$ and $L/W > 4$
- Number of objects = 36 026 objects
- We have 970 $detections/deg^2$

(4) **Good** but still too large contamination

We need to use additional information!

Second, apply a color selection



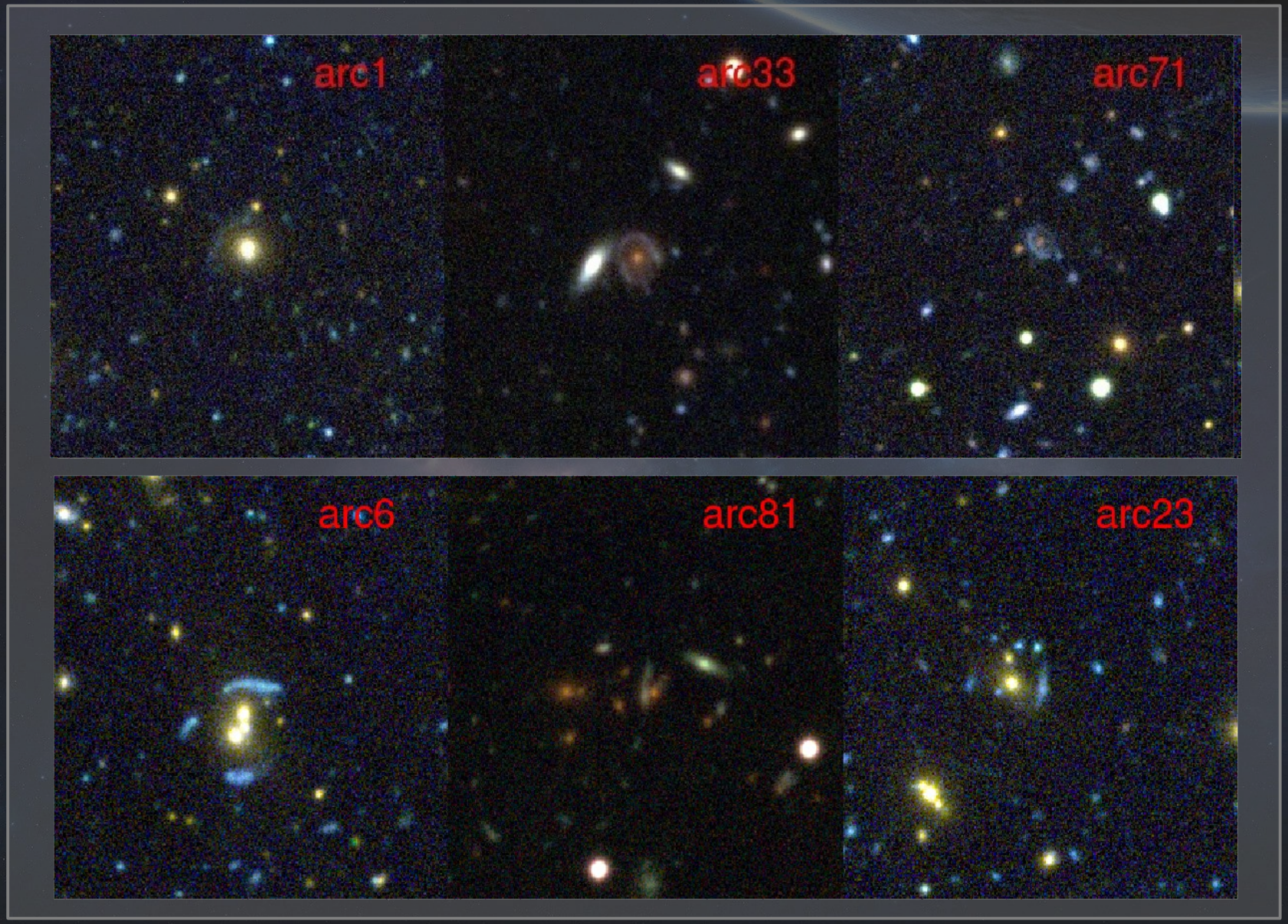
In these plots

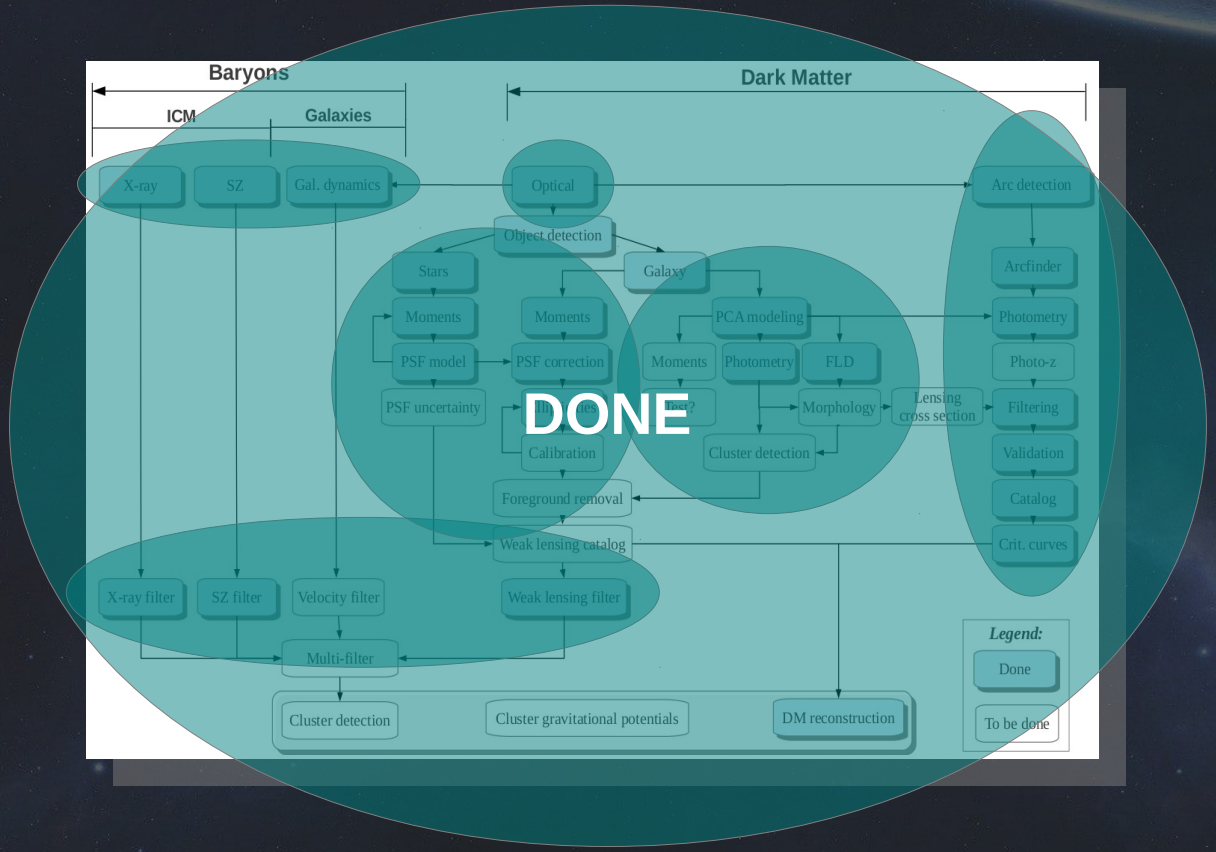
- Redshift as a function of colors (COSMOS catalog Ilbert et al. 2009)
- Arcs coincide with star forming galaxies (SED) at $0.9 < z < 1.2$
- Arcs ley in a small (g-r,r-i) region
- This (g-r,r-i) region is far from the segmented objects

The result

- **From** 36 026 **to** 5 597 **candidates!** I.e. 4 months of eye-balling (for 10.000 deg^2)
- color selected in arcfinder: $26/29 =$ **loss of 10% & factor of 6 in purity**
- color selected in sample: $47/90 =$ loss of 47%

Some of the detections




Baryons
Dark Matter
ICM
Galaxies
X-ray
SZ
Gal. dynamics
Optical
Arc detection
Object detection
Stars
Galaxy
Arcfinder
Moments
Moments
PCA modeling
Photometry
PSF model
PSF correction
Moments
Photometry
FLD
Photo-z
PSF uncertainty
Shear?
Morphology
Lensing cross section
Filtering
Calibration
Cluster detection
Validation
Foreground removal
Catalog
Weak lensing catalog
Crit. curves
X-ray filter
SZ filter
Velocity filter
Weak lensing filter
Multi-filter
Legend:
Done
To be done
Cluster detection
Cluster gravitational potentials
DM reconstruction
DONE

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

Expansion factor with SN

$$D_{\rm L}(a) = \frac{c}{H_0}\frac{1}{a}\int_a^1 \frac{dx}{x^2 E(x)} \equiv \frac{c}{H_0}\frac{1}{a}\int_a^1 \frac{dx}{x^2} e(x),$$

Luminosity function
(Volterra integral of the second kind)

$$e(a) = -a^3 D'_{\rm L}(a) + a\int_1^a \frac{dx}{x^2} e(x).$$

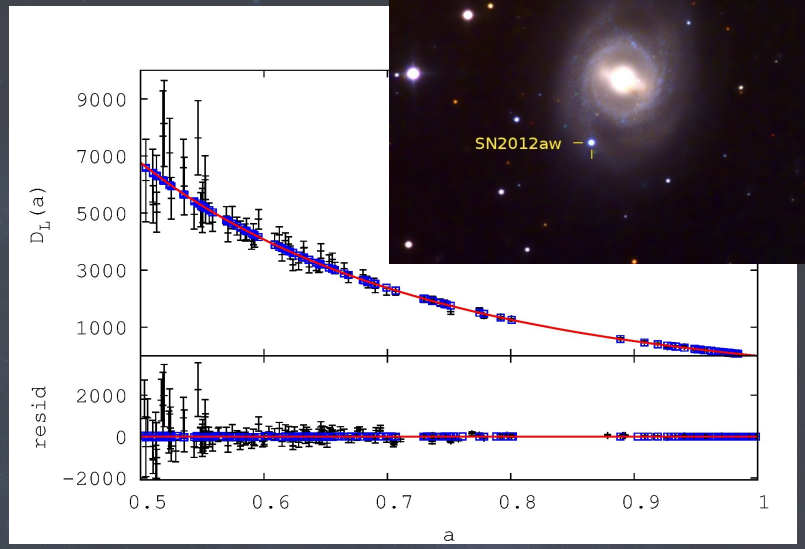
$$e(a) = \sum_{i=0}^{\infty} a^i f_i(a)$$

Solved in terms of a
Neumann series

$$D_{\rm L}(a) = \sum_{j=0}^{J} c_j p_j(a).$$

$$D'_{\rm L}(a) = \sum_{j=0}^{L} c_j w'_j(a).$$

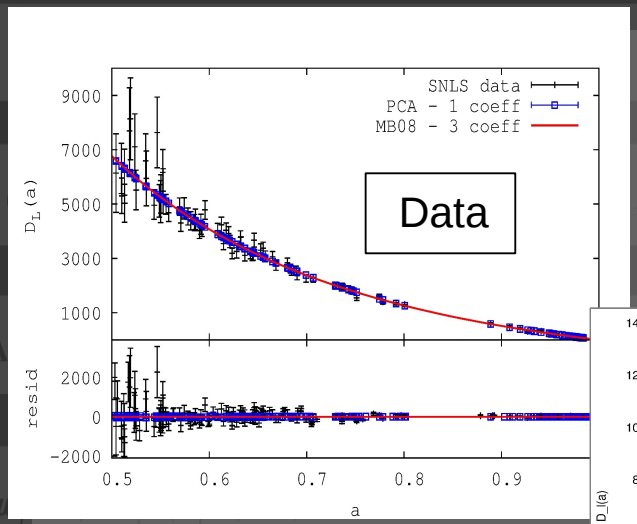
What should we use?

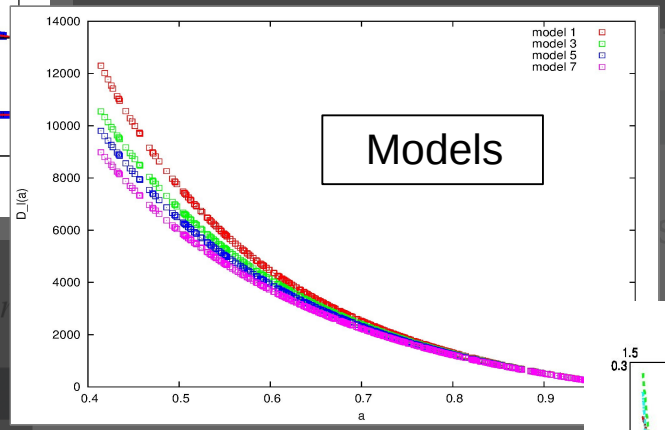


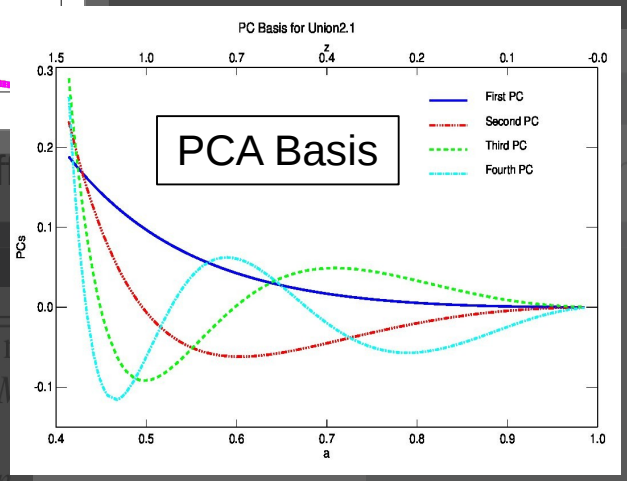
Let's optimize....

Mignone & Bartelmann 2008

An optimal basis







Data set: the luminosity distance at each redshift

Training set: an ensemble of theoretical lum. Dist.

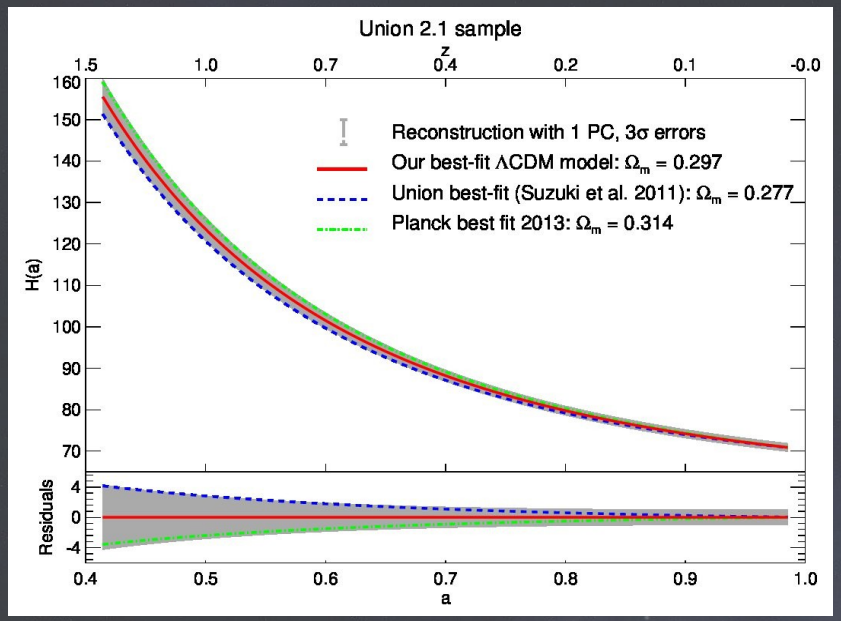
fferences between the models

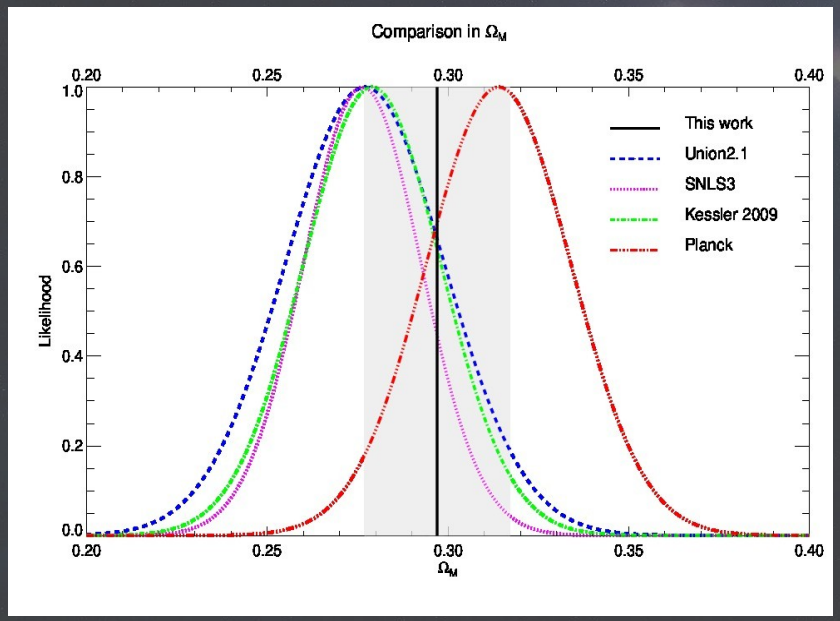
s, ordered according to their

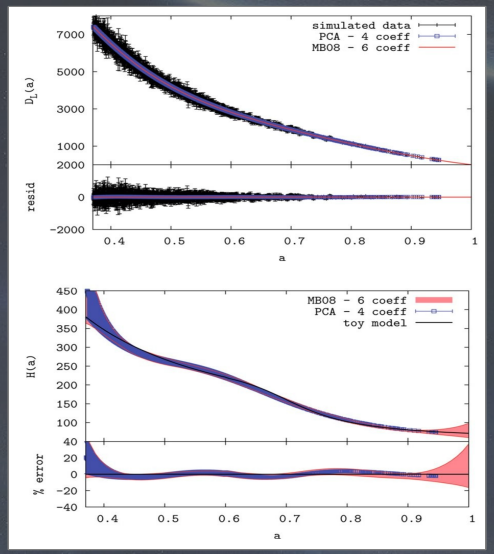
Feature: the coef

Data set	$d \in \mathbb{R}^n$,	where n is the
Training vectors	$t_i \in \mathbb{R}^n$	with $i = 1, ..., M$
Reference vector/model	$\bar{t} \in \mathbb{R}^n$	e.g. $\bar{t} = \langle t \rangle$
Principal components	$w_i \in \mathbb{R}^n$	with $i = 1, ..., n$
Feature vector	$\tau = W^{\mathrm{T}} t \in \mathbb{R}^n$	where $W = (w_1, w_2, ..., w_n)$

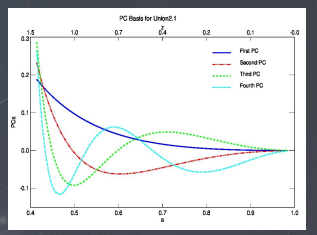
Union 2.1

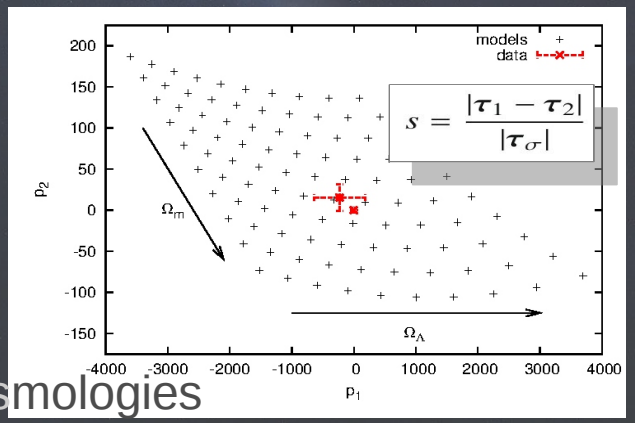






Robust



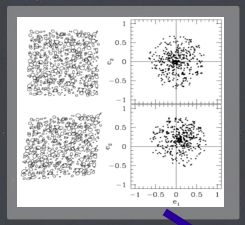


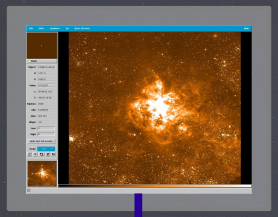
Eigen-cosmologies

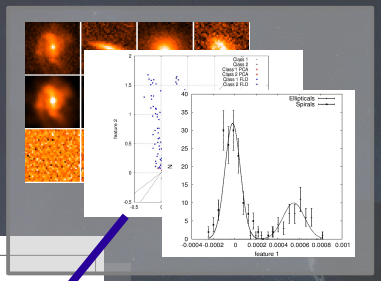
Maturi & Mignone 2009
Benitez-Herrera, Ishida, Maturi, Hillebrandt, Bartelmann & Röpke 2013

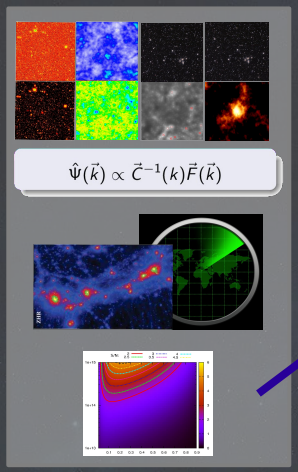
Conclusions

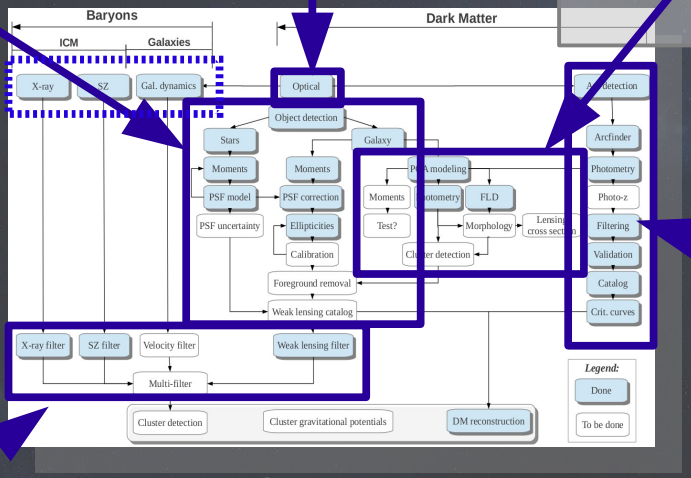
From data to physical quantities

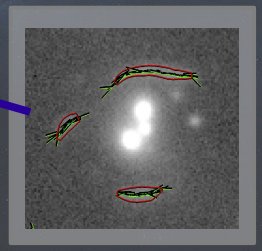








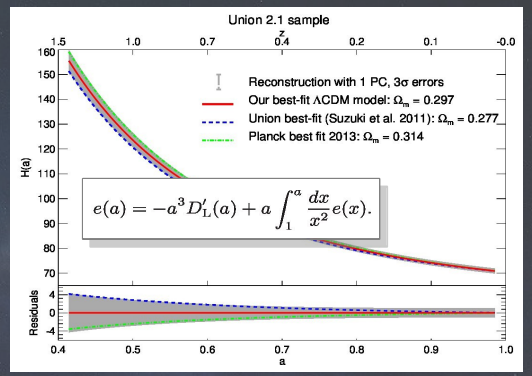


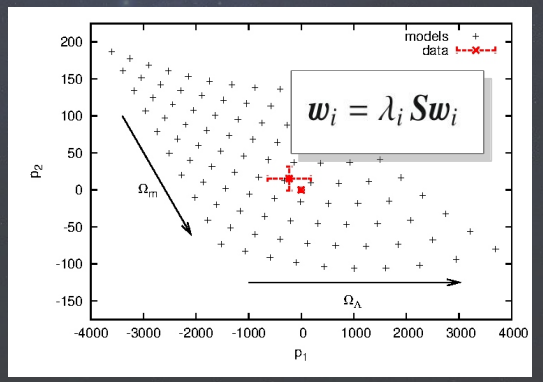


Bi-products...

Eigen-cosmo

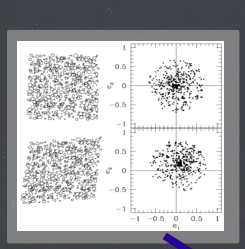
$$L_i = \boldsymbol{w}_i^{\mathrm{T}} S \boldsymbol{w}_i - \lambda_i^{-1}(\boldsymbol{w}_i^{\mathrm{T}} \boldsymbol{w}_i - 1)$$

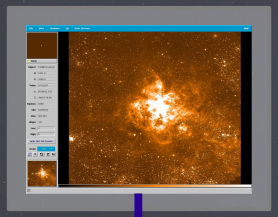


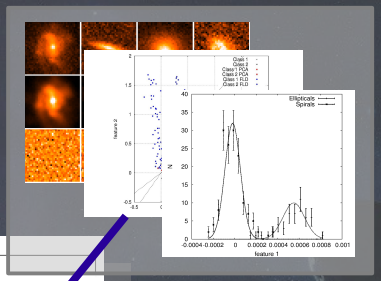


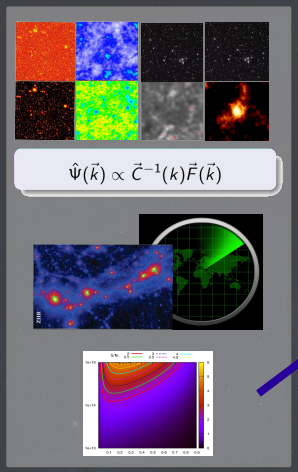
Conclusions

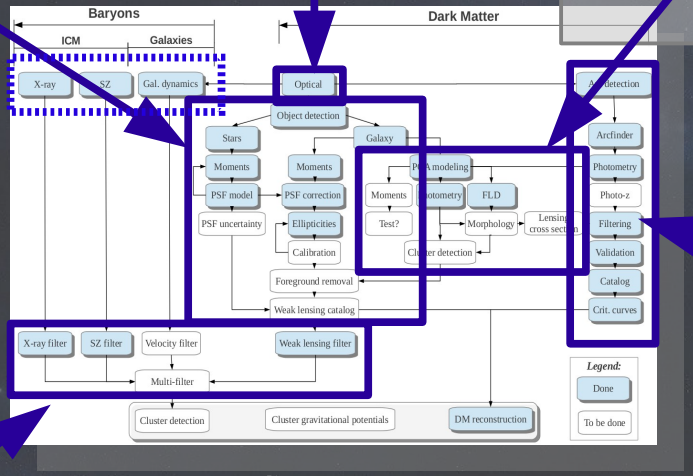
From data to physical quantities

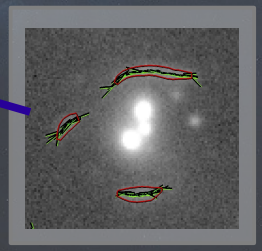




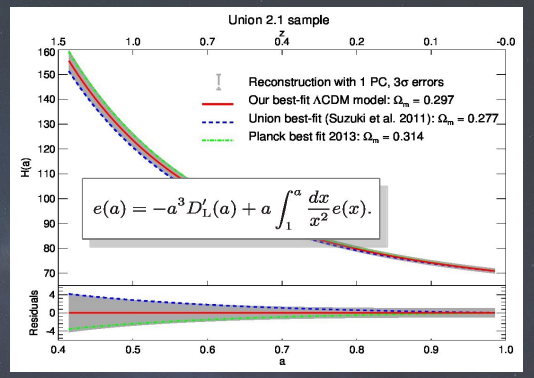
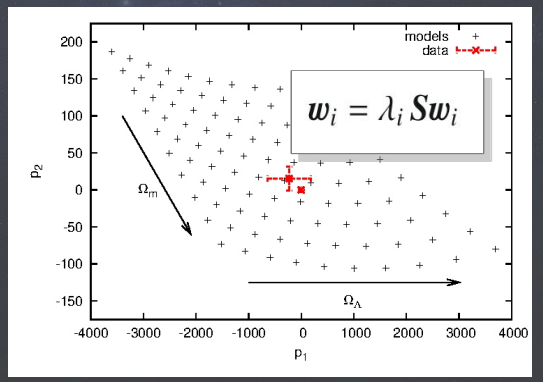








Bi-products...

Eigen-cosmo

$$L_i = \boldsymbol{w}_i^{\mathrm{T}} S \boldsymbol{w}_i - \lambda_i^{-1}(\boldsymbol{w}_i^{\mathrm{T}} \boldsymbol{w}_i - 1)$$