Photometric Redshifts and Clusters of Galaxies

Hervé Aussel

AIM

Goal

- How accurately can the redshift of a cluster of galaxies be determined using photometric redshifts ?
  - ➢ We know there is a cluster, from X-ray
  - ➢ We want to determine its redshifts, without resorting to spectroscopy.

Main Tool: Redshift Histogram

- Classical histogram:
  - Count measurments in redshifts bin
  - Measures with infinite accuracy

$$H(n) = \int_{n\Delta z}^{(n+1)\Delta z} \frac{1}{N}\sum_{g=1}^{N} \delta(z - z_g)dz$$

$$= \frac{1}{N}\sum_{g=1}^{N} \int_{n\Delta z}^{(n+1)\Delta z} \delta(z - z_g)dz$$

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$$
\begin{aligned}
H(n) &= \int_{n\Delta z}^{(n+1)\Delta z} \frac{1}{N}\sum_{g=1}^{N} \delta(z - z_g)dz \\
&= \frac{1}{N}\sum_{g=1}^{N} \int_{n\Delta z}^{(n+1)\Delta z} \delta(z - z_g)dz
\end{aligned}
$$

1 if g is in the cell, 0 else

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$$= \frac{1}{N} \sum_{g=1}^{N} \int_{n\Delta z}^{(n+1)\Delta z} \delta(z - z_g) dz$$

Probability distribution of z_g when the measurment is ∞ accurate

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$$H(n) = \int_{n\Delta z}^{(n+1)\Delta z} \frac{1}{N} \sum_{g=1}^{N} \delta(z - z_g)\, dz$$

$$= \frac{1}{N} \sum_{g=1}^{N} \int_{n\Delta z}^{(n+1)\Delta z} \delta(z - z_g)\, dz$$

Probability of $z_g \in [n\Delta z, (n+1)\Delta z]$, when measurment is ∞ accurate

Redshift Histogram with PDFs

- When the measure is not infinitely accurate:
  - Introduce the probability distribution of the redshift of each galaxy.

$$H(n) = \int_{n\Delta z}^{(n+1)\Delta z} \frac{1}{N}\sum_{g=1}^{N} \delta(z - z_g)dz$$
$$= \frac{1}{N}\sum_{g=1}^{N} \int_{n\Delta z}^{(n+1)\Delta z} \delta(z - z_g)dz$$

$$H(n) = \frac{1}{N}\sum_{g=1}^{N} \int_{n\Delta z}^{(n+1)\Delta z} p_g(z)dz$$

Do we know the PDF ?

- Yes ! Most modern zphot codes compute them:
  - Introduced by Arnouts et al. (2002)

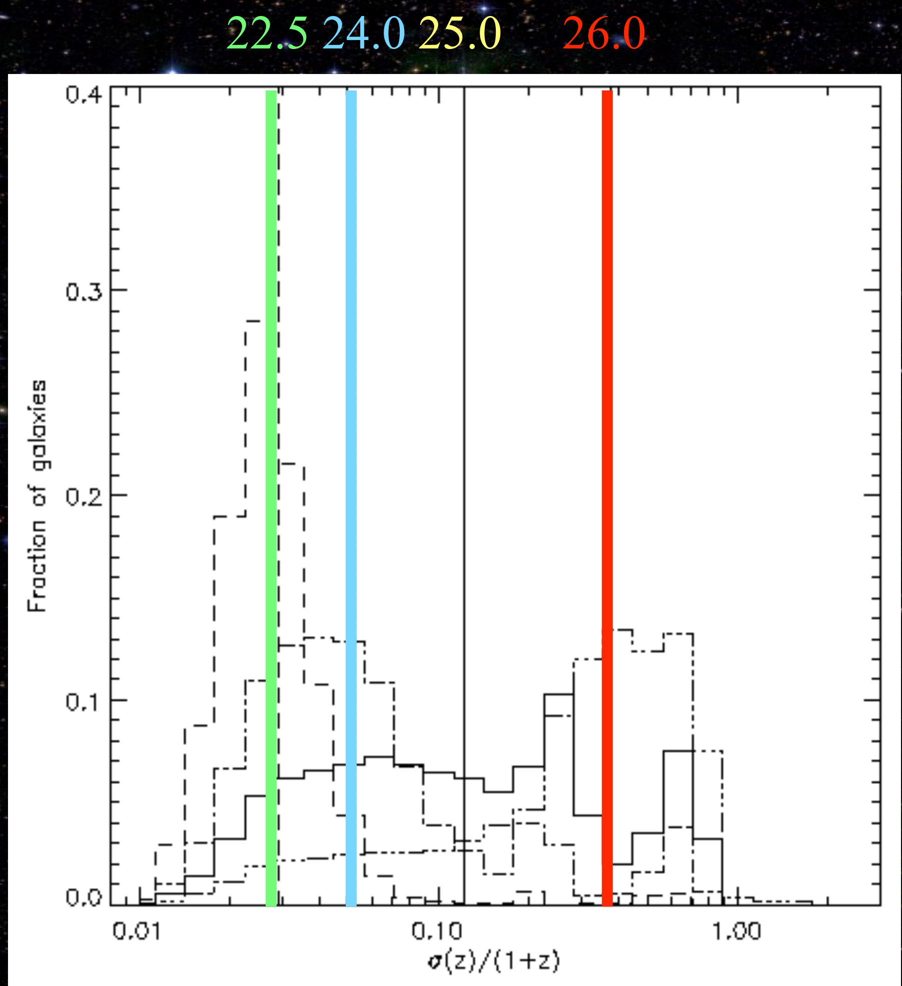
$$PDFz \propto \exp\left[-\frac{\chi^2_{\min}(z)}{2}\right] \text{ with } \chi^2_{\min}(z) = \sum_i \left[\frac{F_{\mathrm{obs},i} - sF_{\mathrm{tem},i}(z)}{\sigma_i}\right]^2$$

  - Needs sometimes to be renormalized

$$\int_{-\infty}^{+\infty} \delta(z - z_g)\,dz = 1 = \int_{-\infty}^{+\infty} p_g(z)\,dz$$

A digression on photo-z accuracy

- The pdf of the redshifts of galaxies are highly non-gaussian:
  - Comparaison of spectro and photo-z in Ilbert et al. (2006):
    - zphot within 1 σ of zspec: 67%
    - zphot within 3 σ of zspec: 90%
    - Should be 99.73% !!!
    - 90% -> 1.645 gaussian

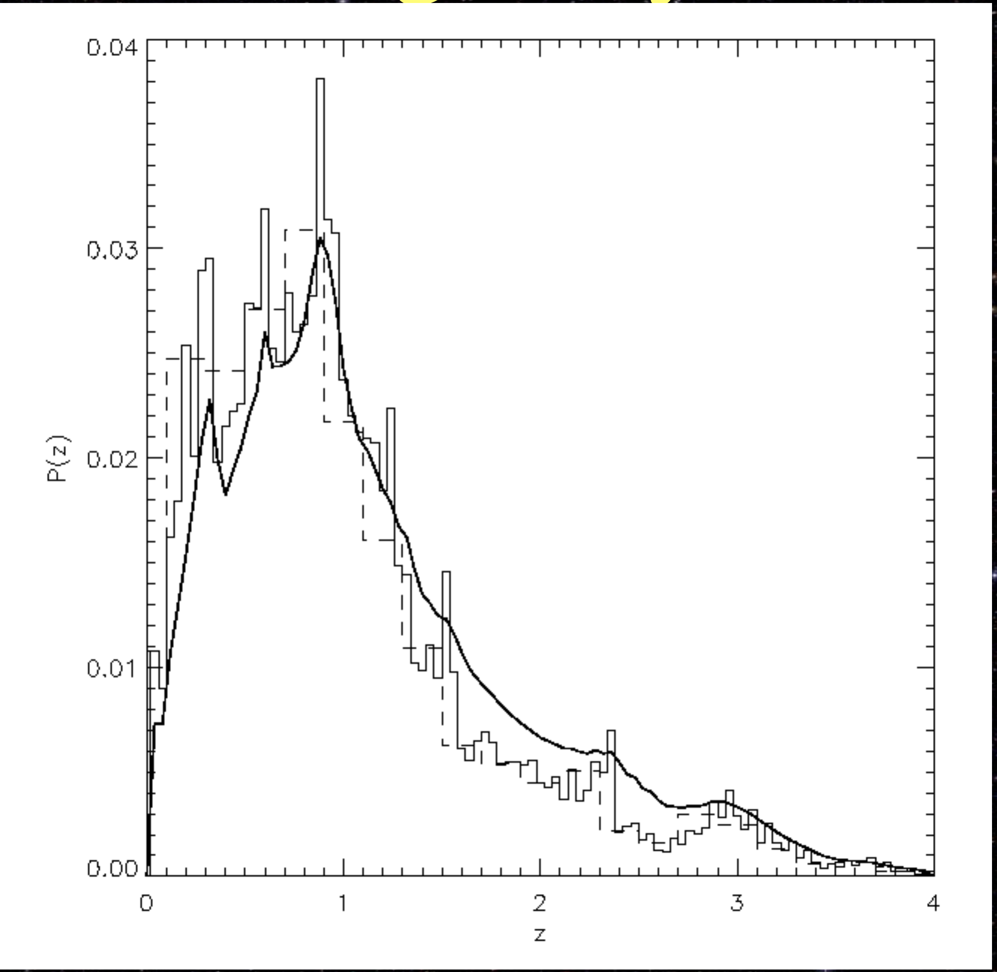


What is the probability of finding a galaxy at a given redshift ?

- When N is large we have:

$$\begin{aligned} H(n) &= \frac{1}{N}\sum_{g=1}^{N}\int_{n\Delta z}^{(n+1)\Delta z} p_g(z)dz \\ &= \int_{n\Delta z}^{(n+1)\Delta z} \frac{1}{N}\sum_{g=1}^{N} p_g(z)dz \\ &= \int_{n\Delta z}^{(n+1)\Delta z} P(z)dz \end{aligned}$$

PDF of a randomly chosen galaxy in the field



- z-phot in D1: Ilbert & al. 2006
- Thick Solid: P(z)
- Histograms with bins of 0.04 (solid) and 0.2 (dashed)
- Note the smoothing and high z tail

What is the probability of finding Nc galaxies in a redshift bin ?

- Number of galaxies:

$$H_R(n) = \sum_{g=1}^{N_C} \int_{n\Delta z}^{(n+1)\Delta z} P(z)dz = N_C \int_{n\Delta z}^{(n+1)\Delta z} P(z)dz$$

- Variance: $H_R(n)$ follows a binomial distribution (the cells are fixed).

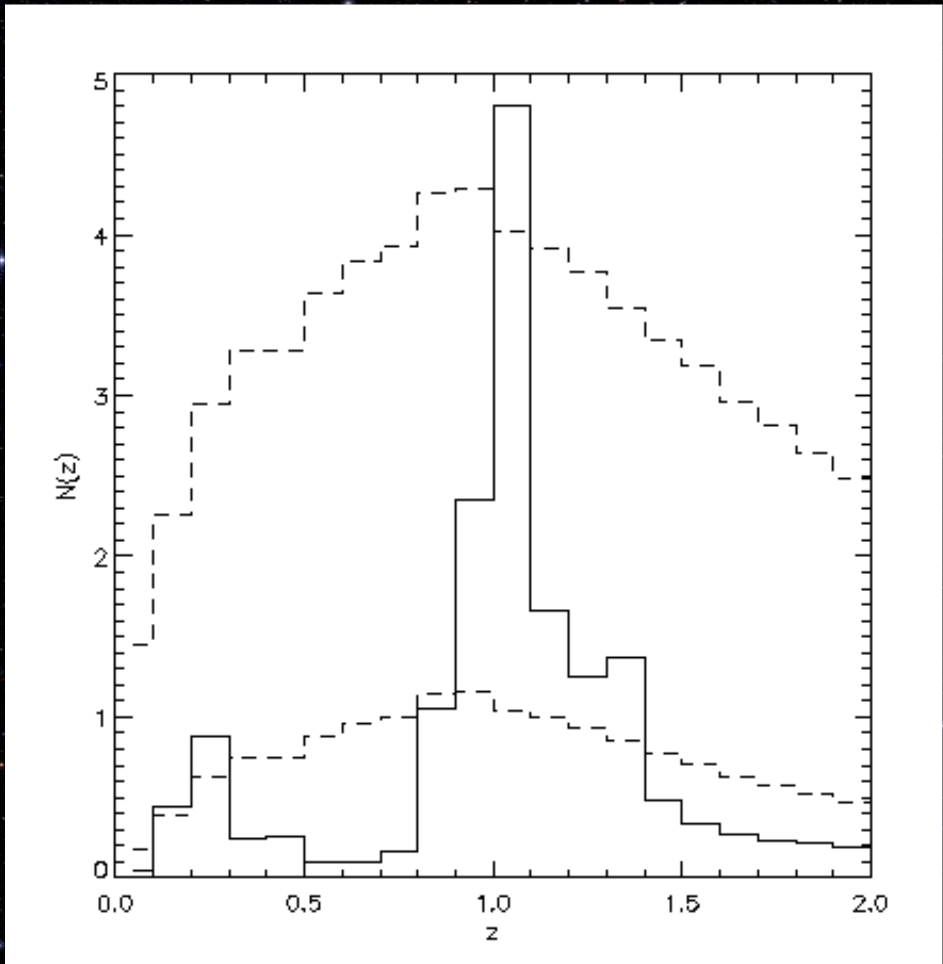
$$V_n = N_C \int_{n\Delta z}^{(n+1)\Delta z} P(z)dz \left(1 - \int_{n\Delta z}^{(n+1)\Delta z} P(z)dz\right)$$

What do we actually observe ?

- Within a distance d of the X-ray cluster position, we find Nc galaxies, with a redshift histogram:

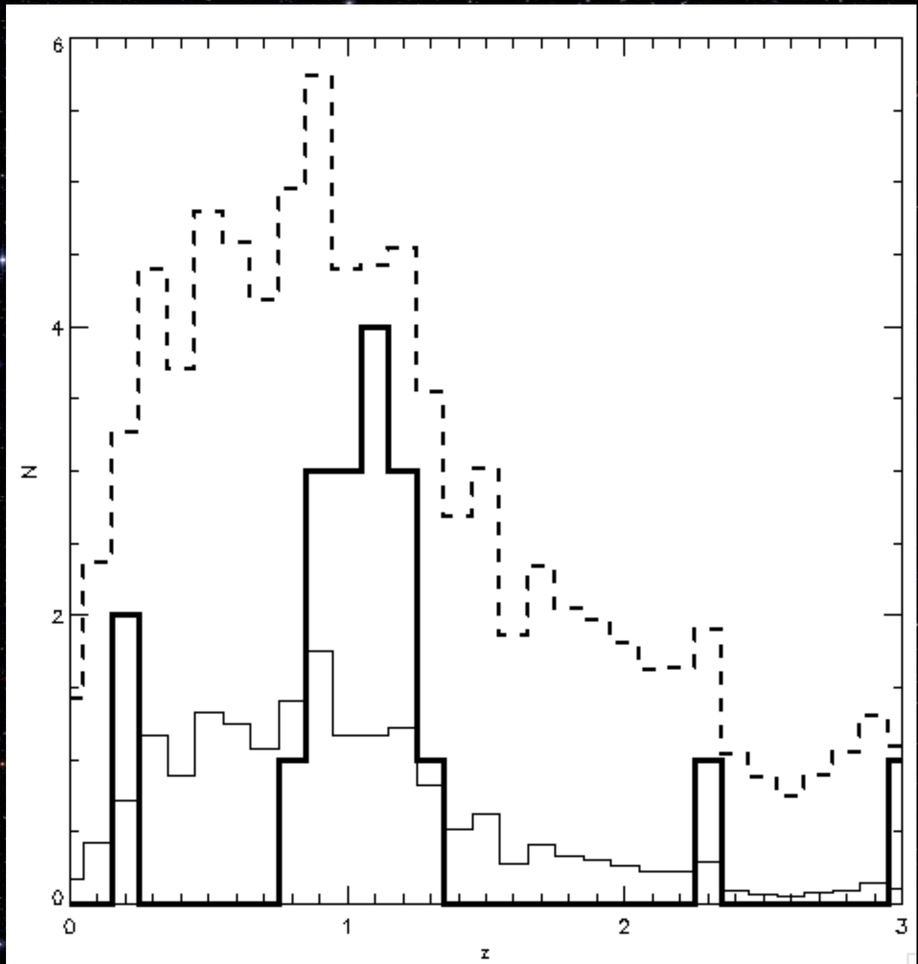
$$H_C(n) = \sum_{g=1}^{N_C} \int_{n\Delta z}^{(n+1)\Delta z} p_g(z)\,dz$$

What do we observe ?



- 19 galaxies within 15” of the cluster position
- One single significant peak
- Note the small number of sources per bin
- There is an excess of sources at $z \in [1.0, 1.1]$

What if you don't use PDFs ?



- Where are the significant peaks ?
- If you lower the confidence threshold, you will find multiple peaks

Zooming in...

- We know there is a cluster
- We know it sits at $z \in [1.0, 1.1]$
- Can we do better ?
  - Off course !

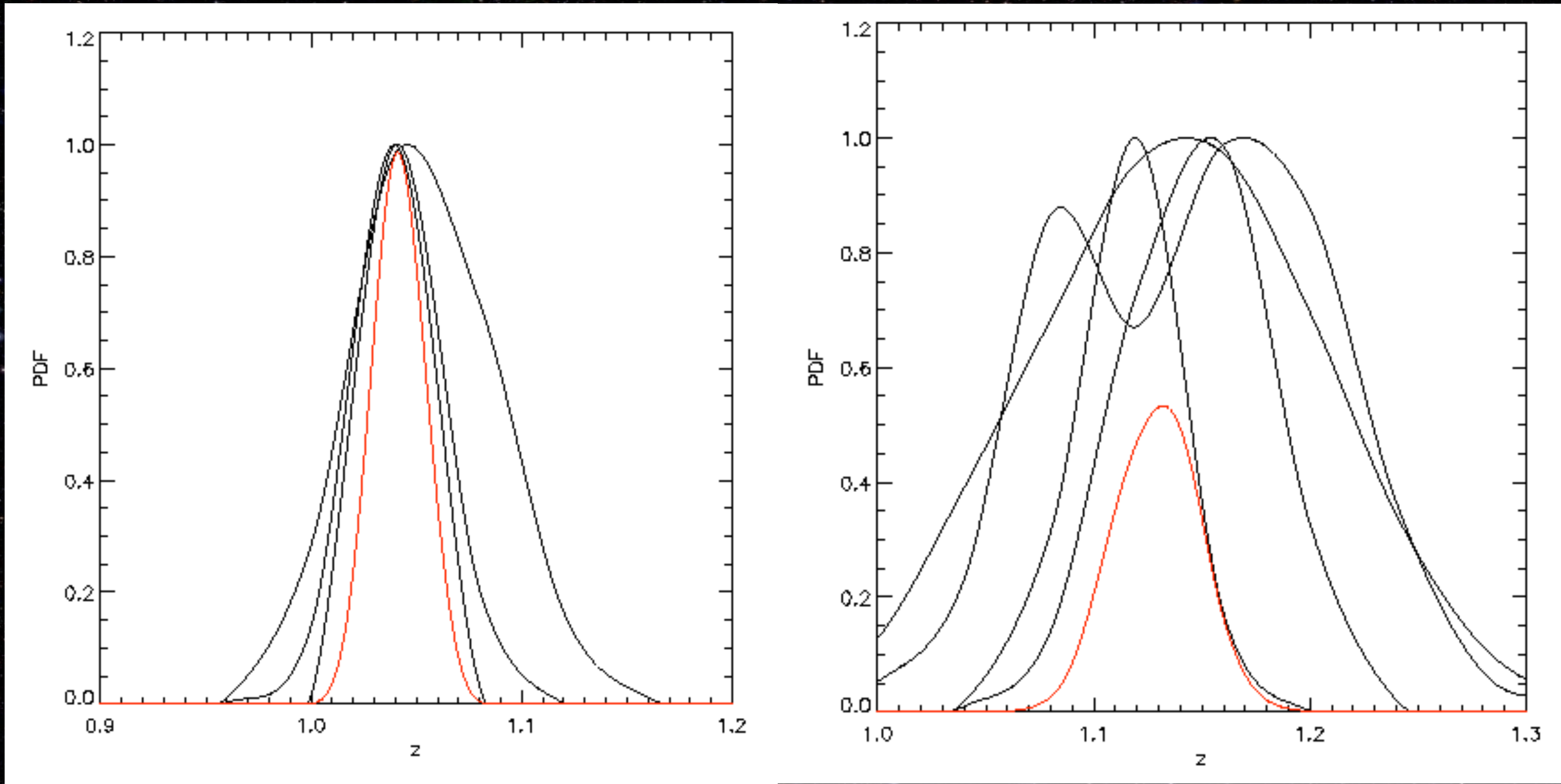
What is the probability of finding Nc galaxies at the same redshift ?

- The galaxies are independant:

$$Pr\{z_1 = z_2 = \cdots = z_{N_b} = z_c\} = \Pi_{g=1}^{N_b} p_g(z)$$

- Given the typical shape of a PDF, the distribution will shrink !

Zooming in...



D1 XMM-LSS clusters

zphot	σ zphot	zpsec	error (σ)
0.060	0.004	0.05	2.5
0.147	0.007	0.14	1.0
0.255	0.007	0.26	-0.7
0.265	0.006	0.26	1.0
0.306	0.007	0.29	2.3
-	-	0.58	-
1.041	0.013	1.05	-0.7
1.129	0.021	1.05	3.8

Conclusions

- Use PDFs and not photometric redshift
- Redshift PDFs are a powerful tool for cluster redshifts determination
  - Accurate
  - Understood Errors
- Ongoing Work:
  - Test on the Millenium Simulations
  - Application to Cosmology
  - Systematics in z-phots