Luminosity calibrations and distances in the Galaxy and Local Group in the Gaia era

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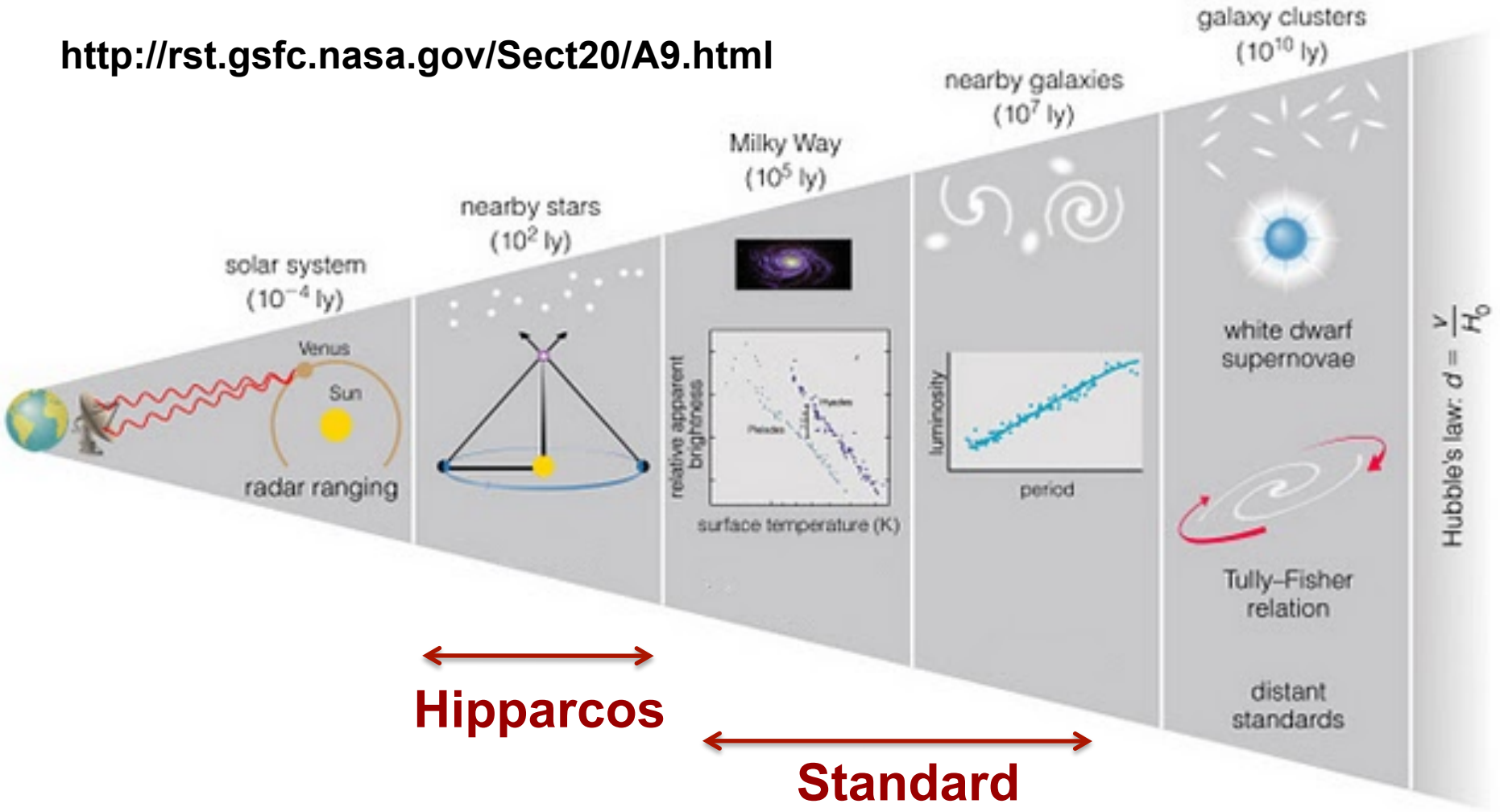
gaia

Semaine de l'Astrophysique Française
Paris June 2011

UNIVERSITAT DE BARCELONA

The Cosmic distance ladder

http://rst.gsfc.nasa.gov/Sect20/A9.html

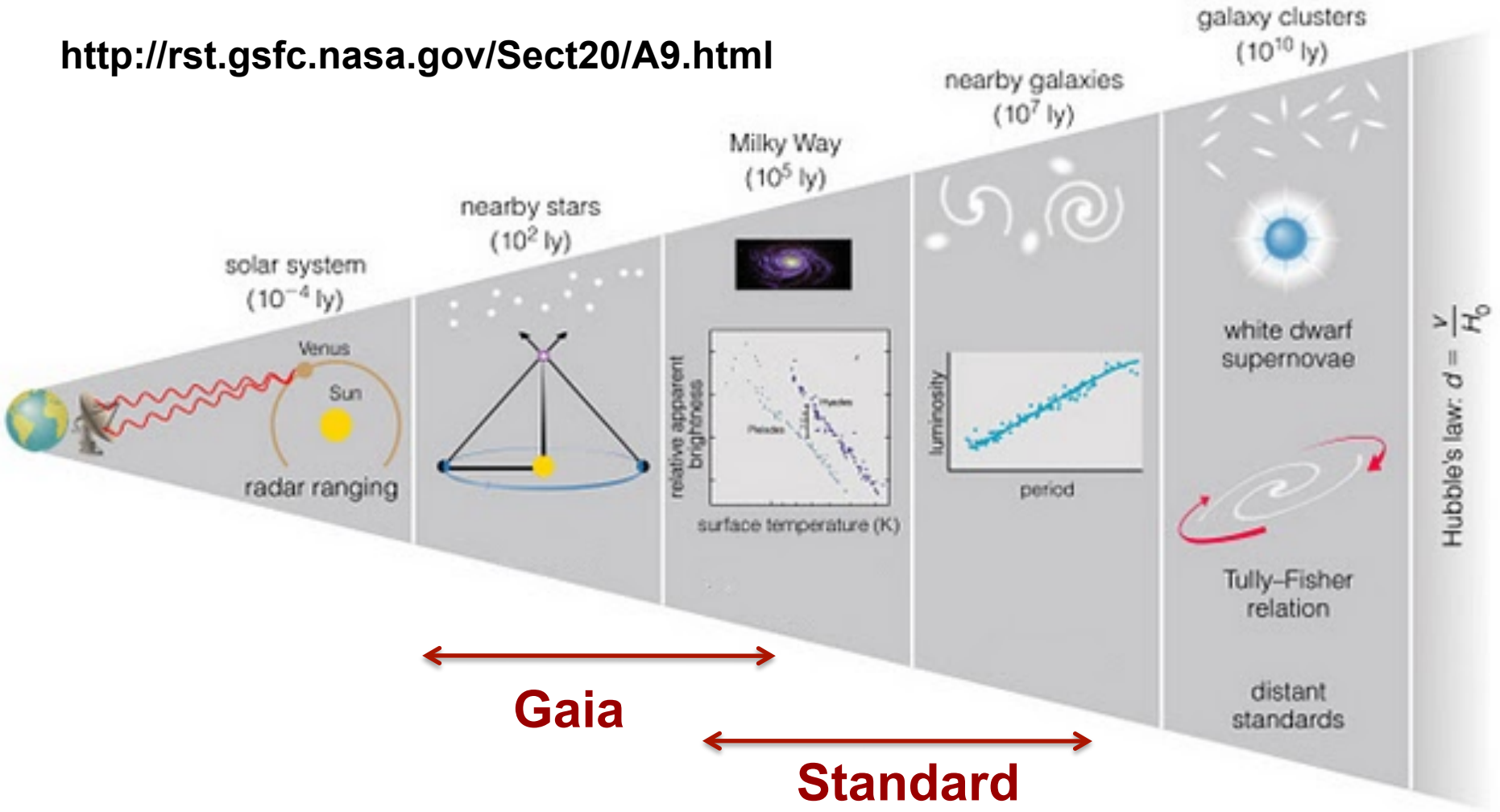


Hipparcos

Standard candles

The Cosmic distance ladder

http://rst.gsfc.nasa.gov/Sect20/A9.html

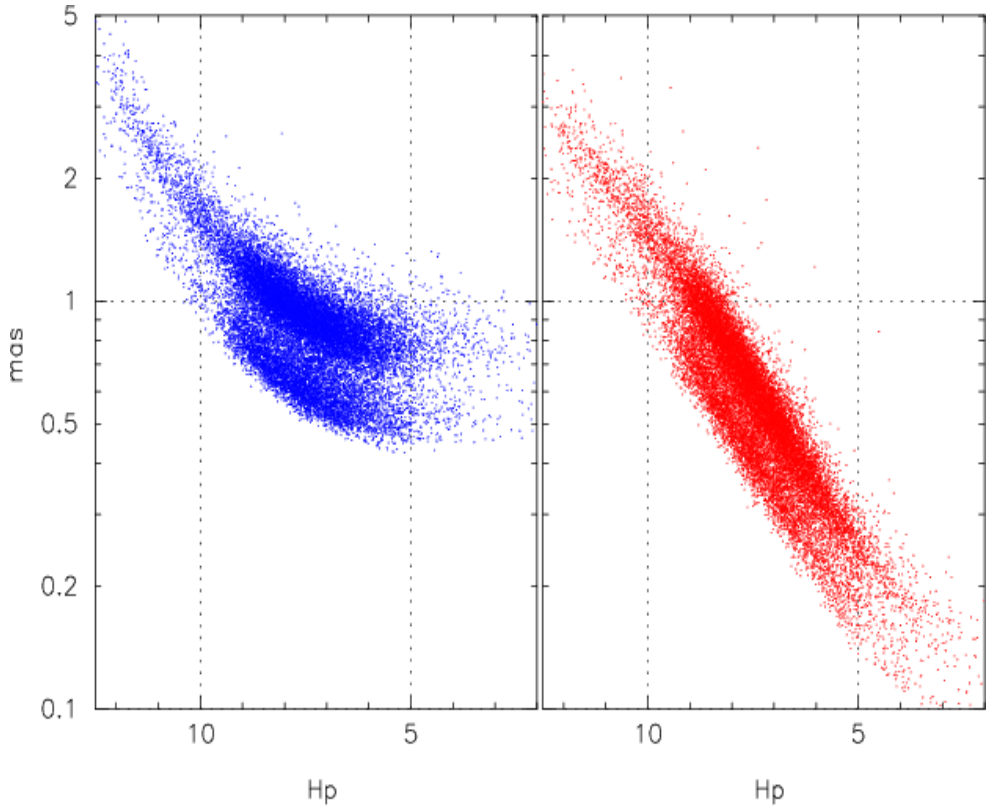


From Hipparcos to Gaia

	Hipparcos	Gaia
Magnitude limit	12	20 mag
Completeness	7.3 – 9.0	~20 mag
Bright limit	~0	~5-7 mag
Number of objects	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance	1 kpc	1 Mpc
Quasars	None	~5 × 10^5
Galaxies	None	10^6 - 10^7
Accuracy	~1 milliarcsec	7 μarcsec at V=10 10-20-25 μarcsec at V= 15 100-300 μarcsec at V = 20
Broad band	2-colour (B and V)	3-colour to V = 20 + 1-colour to V=17
Spectro-photometry	None	2 bands to V = 20
Radial velocity	None	1-15 km/s to V = 16-17
Observing programme	Pre-selected	Complete and unbiased

Standard error in trigonometric parallax

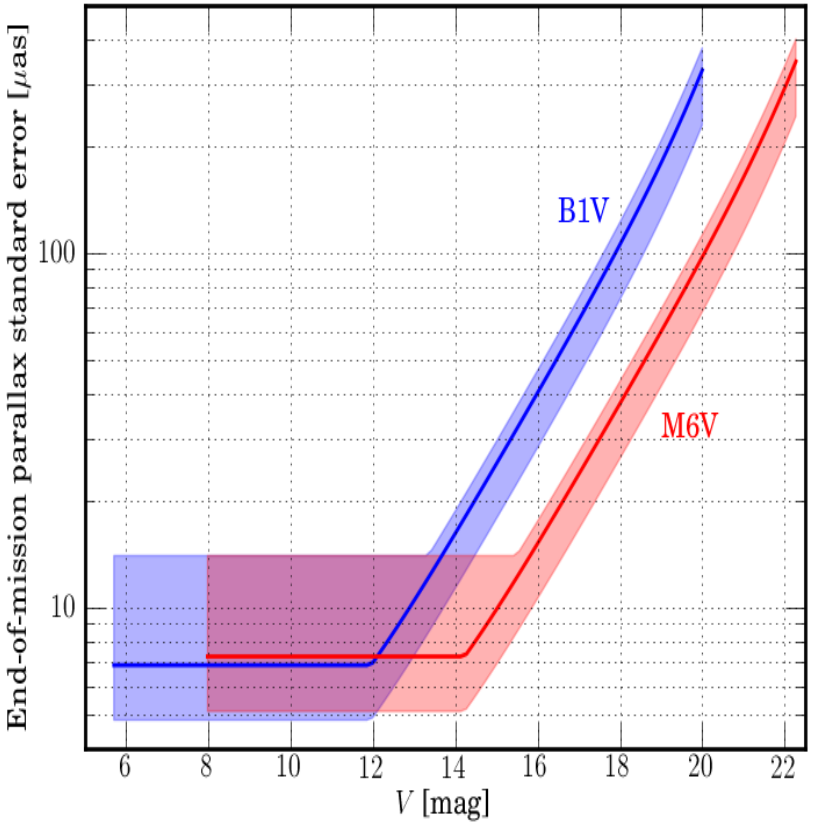
Hipparcos



Hipparcos Catalogue (Perryman et al. 1997)

van Leeuwen & Fantino (2005)

Gaia

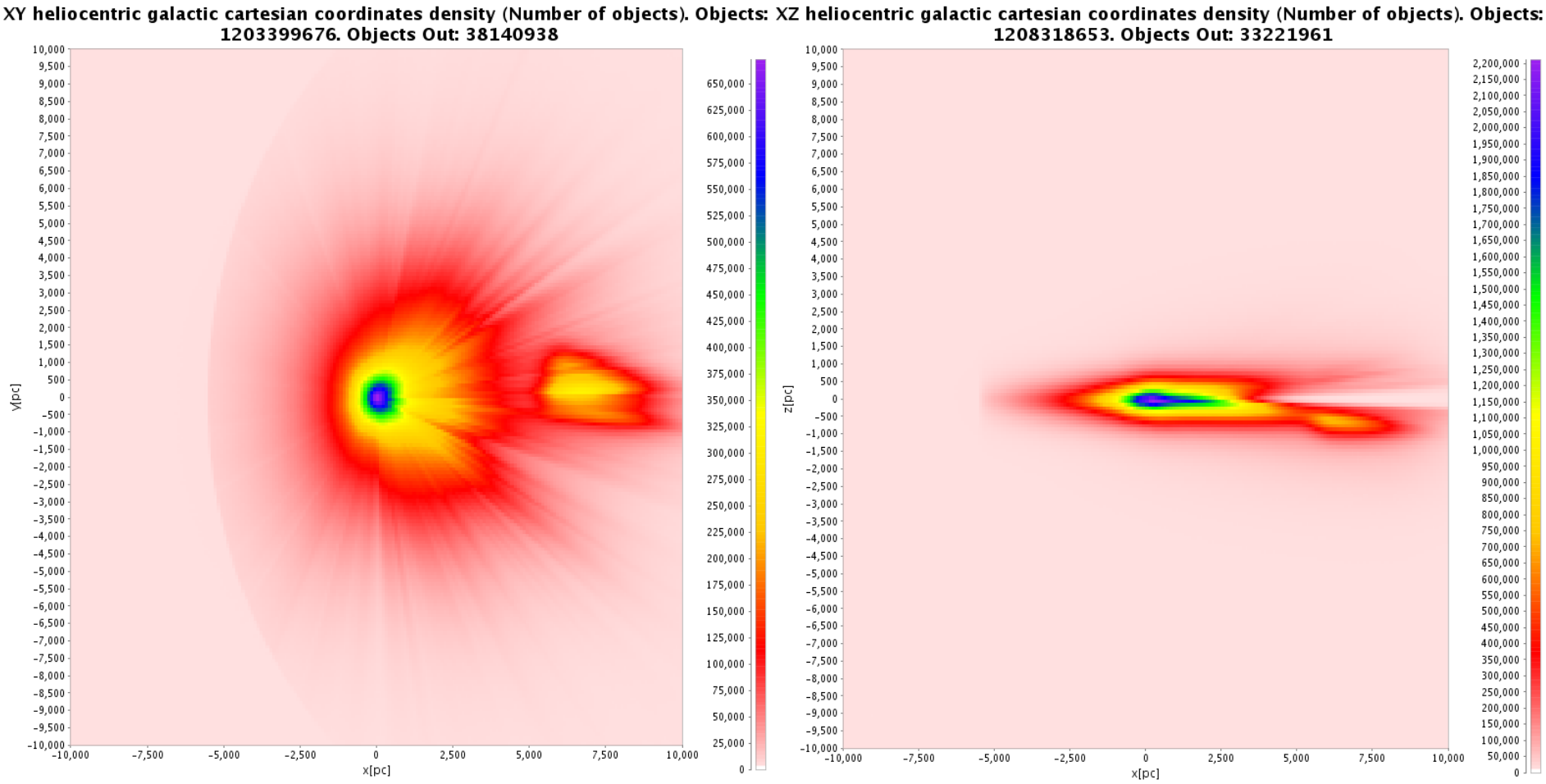


Courtesy J. de Bruijne (ESA)

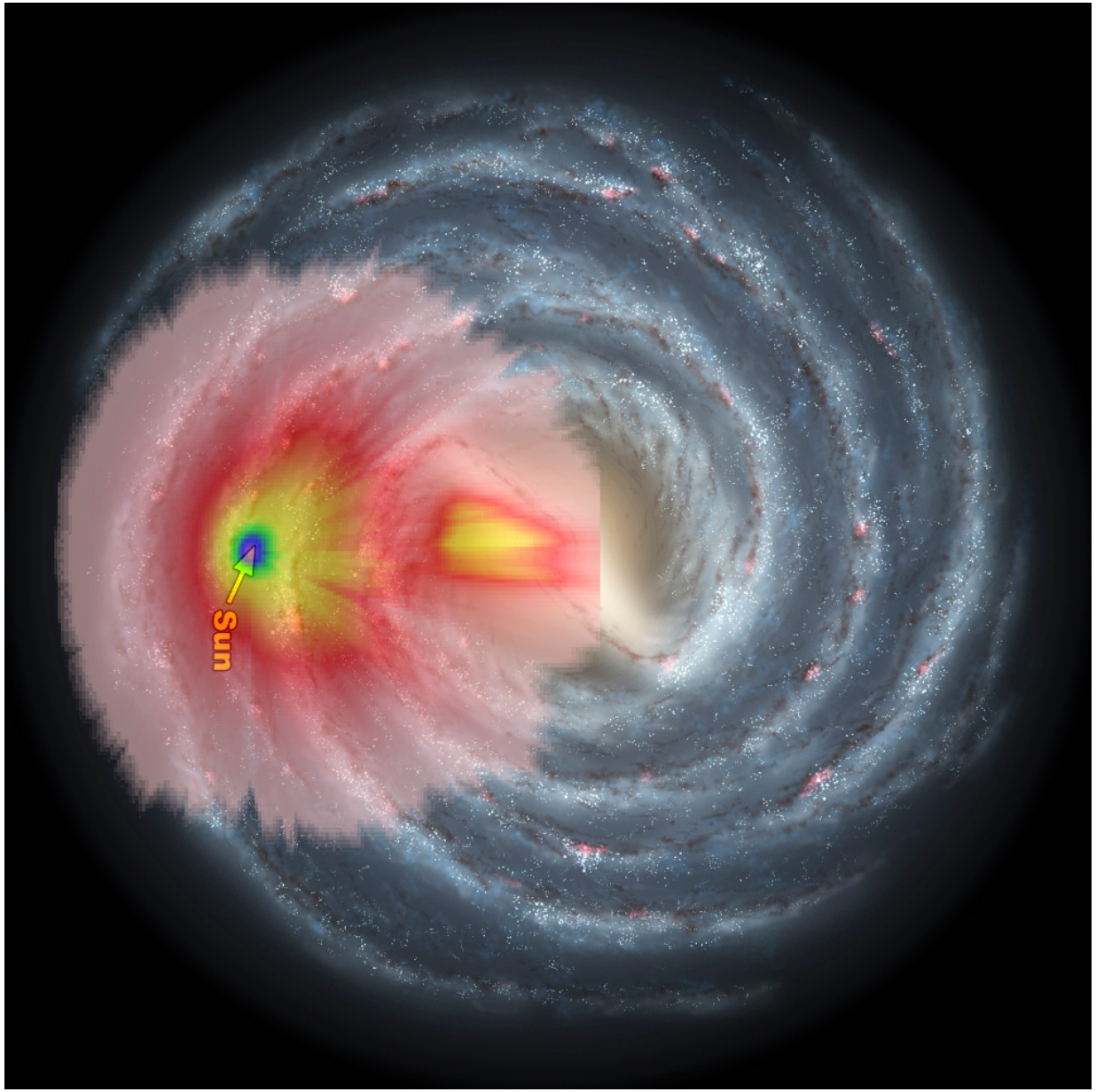
What we then expect to get from Gaia?

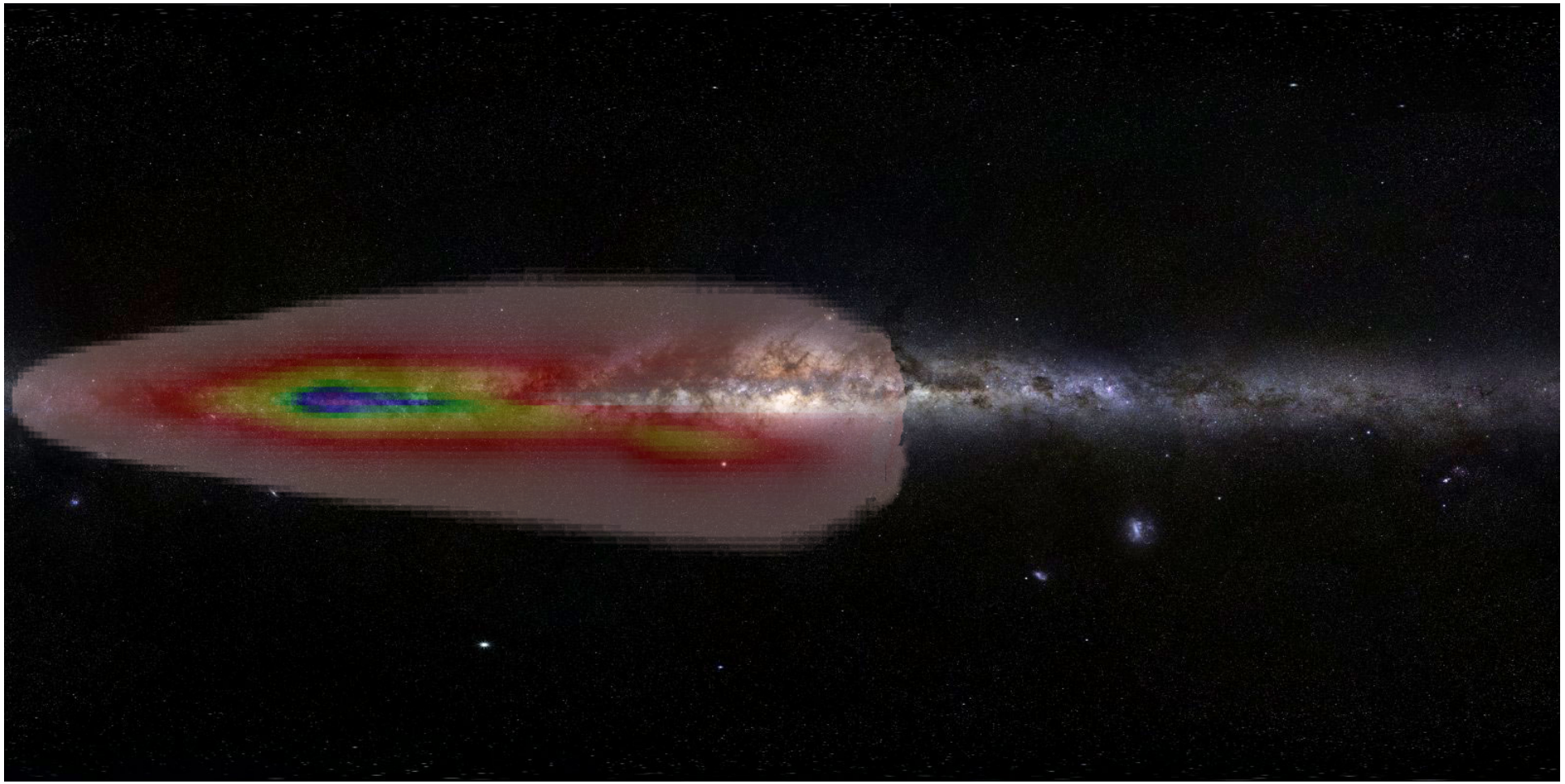
Our galaxy

The Milky Way: 1% census of the full population



Simulation of the galactic distribution of the contents of the Gaia Catalogue (DPAC-CU2)


Sun



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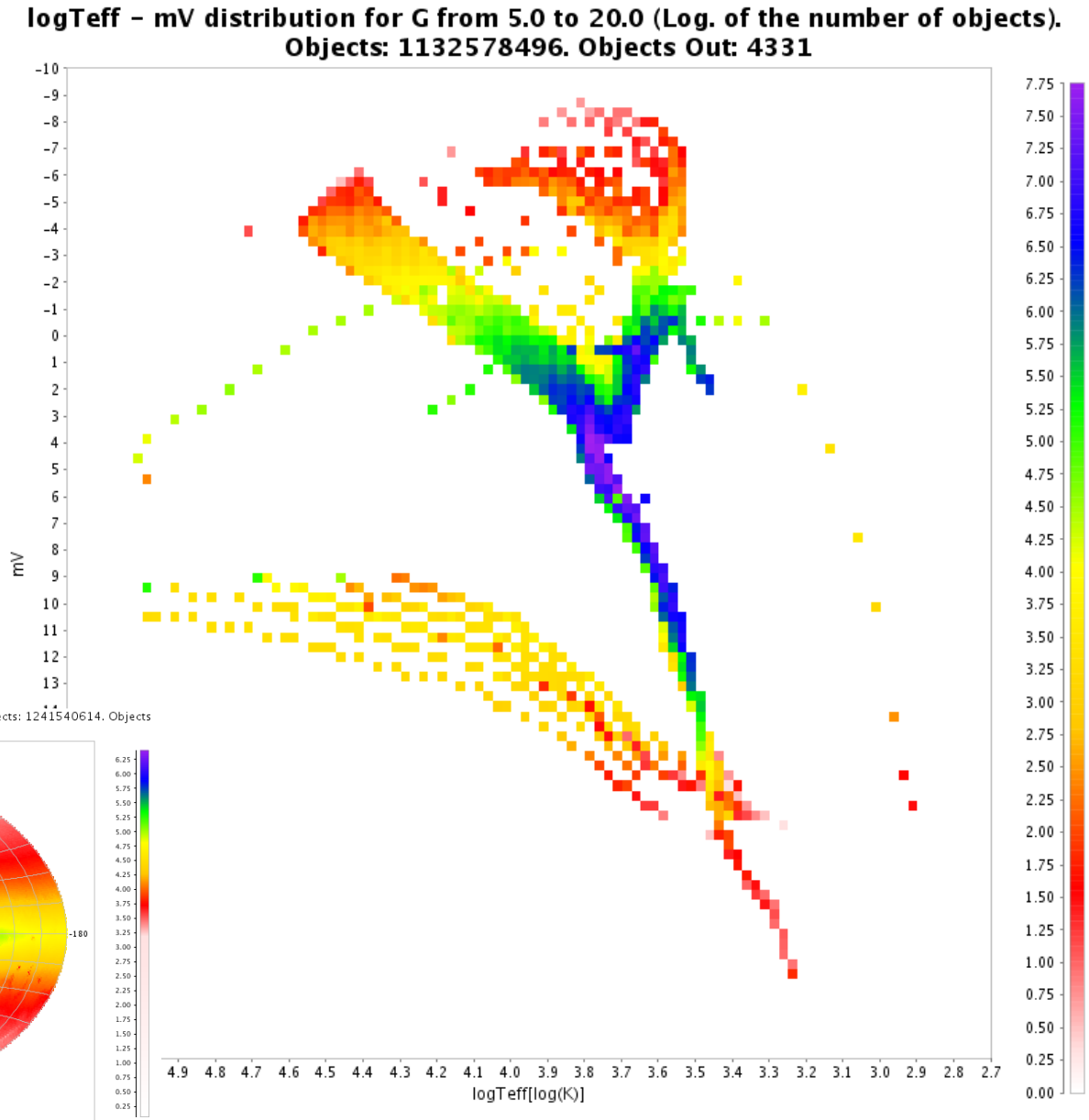
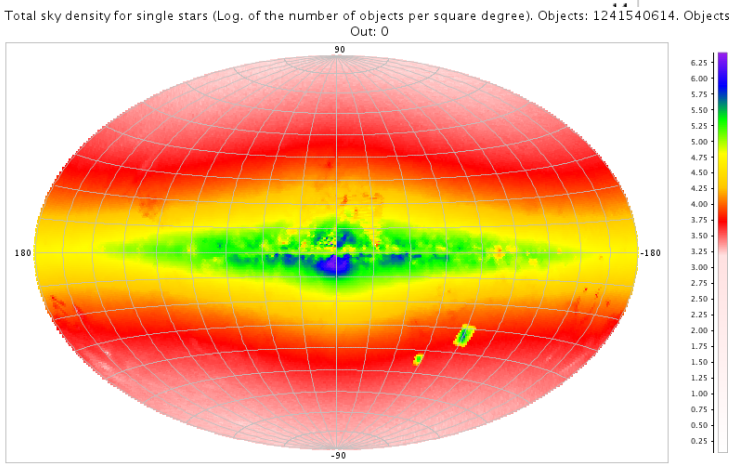
Luminosity calibrations

	Hipparcos	Hipparcos 2	Gaia
$s_p/p < 0.1$ %	-	-	100 000 ★
$s_p/p < 1$ %	442 ★	719 ★	~ 11 x 10^6 ★ up to 5-10 kpc (Mv<-5) up to 1-2 kpc (Mv<5)
$s_p/p < 10$ %	22 396 ★	30 579 ★	~ 150 x 10^6 ★ up to 30-50 kpc (Mv<-5) up to 2-5 kpc (Mv<5)
Error on Mv	0.3 mag at 100 pc		0.1 mag at 10 kpc
Stellar pop.	mainly disk		all populations, even the rarest
HR diagram < 10 %	-4 to 13, -0.2 to 1.7		all mag and colours

Milky Way

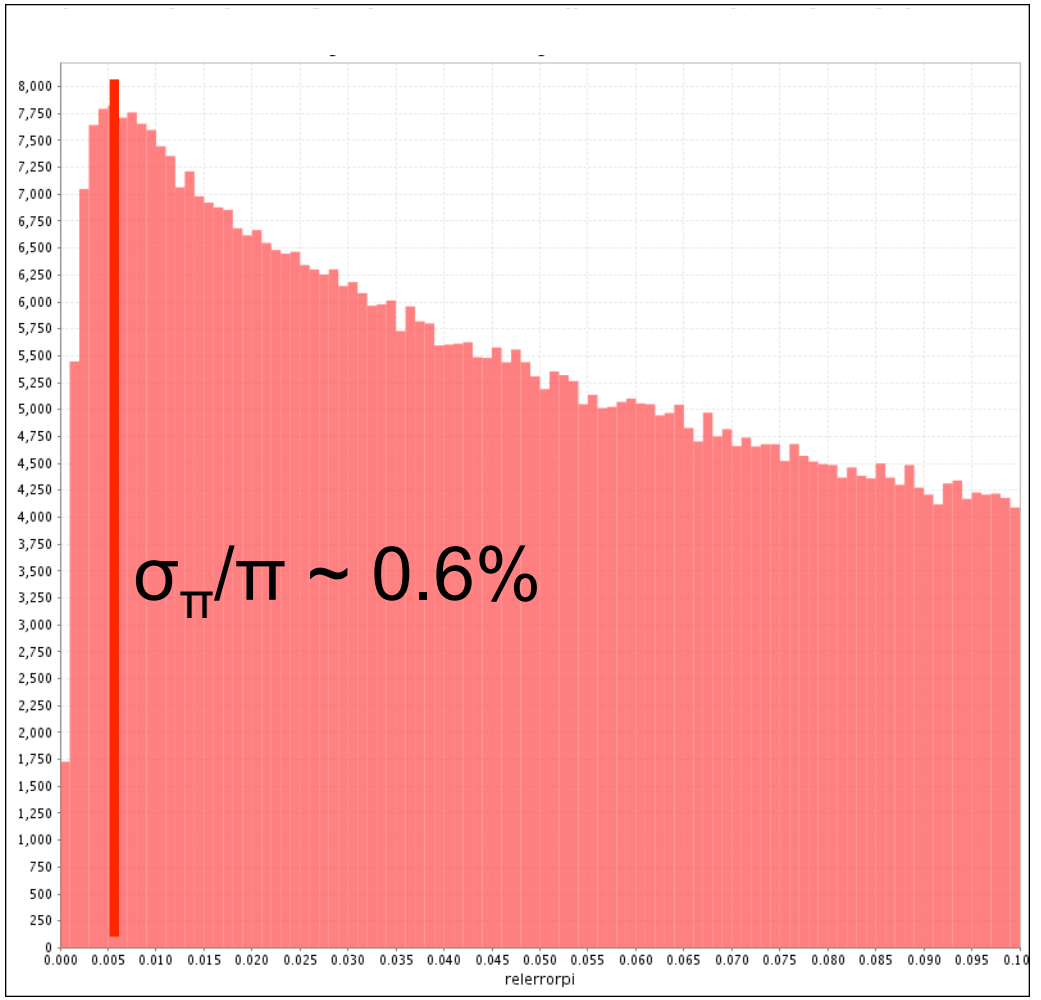
Gaia HR diagram (G<20)



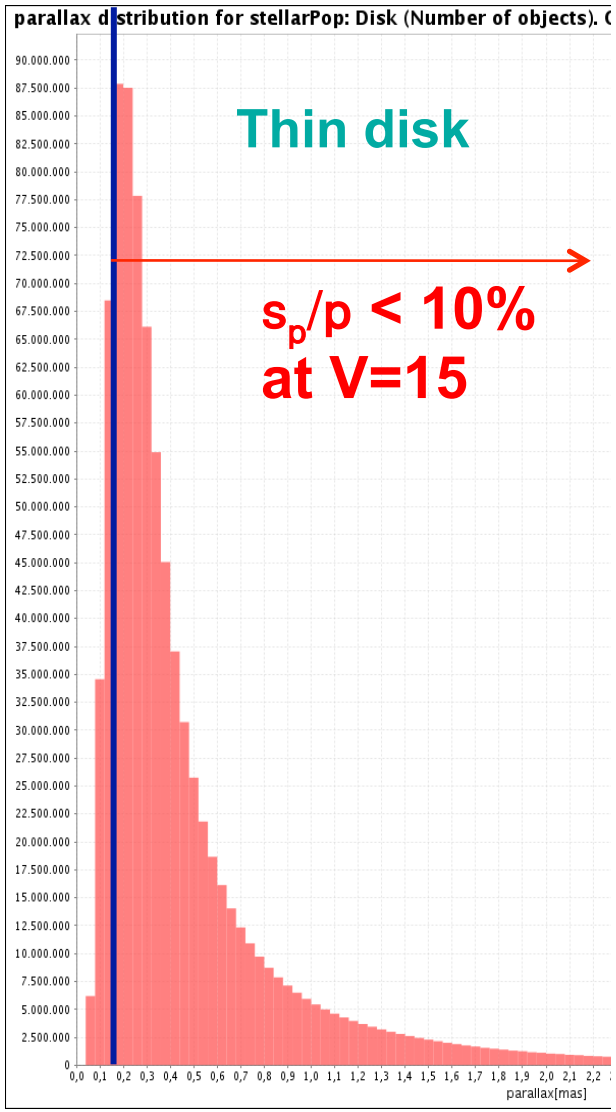


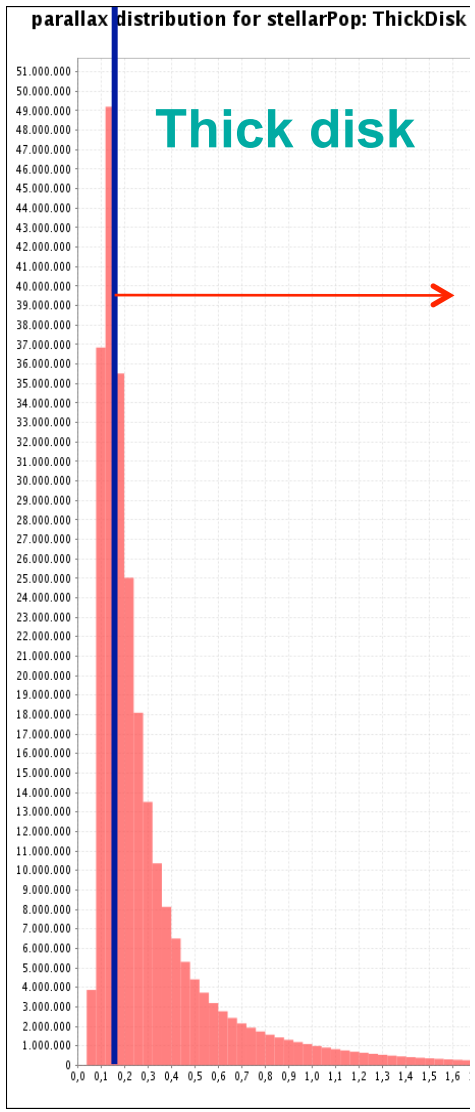
Gaia parallax error distribution

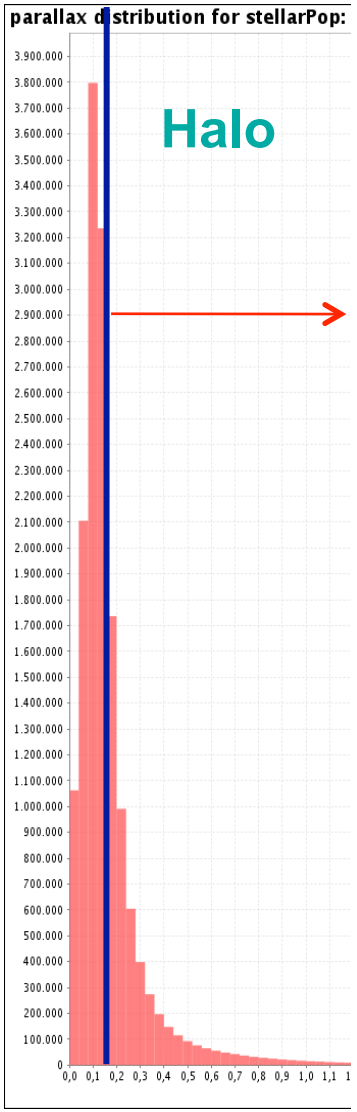
- σ_π/π distribution
- All the stars

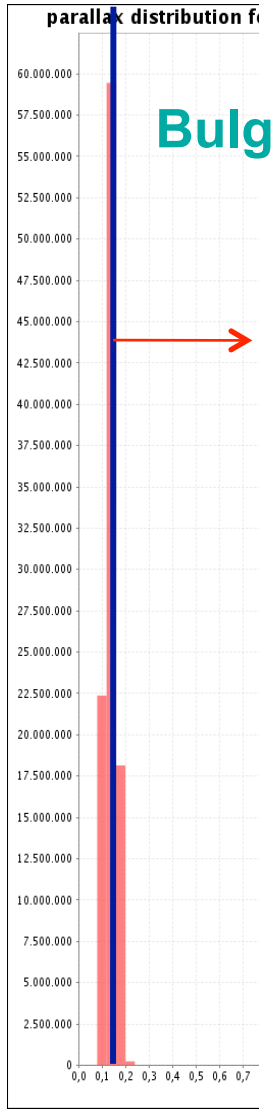


Stellar population sampling

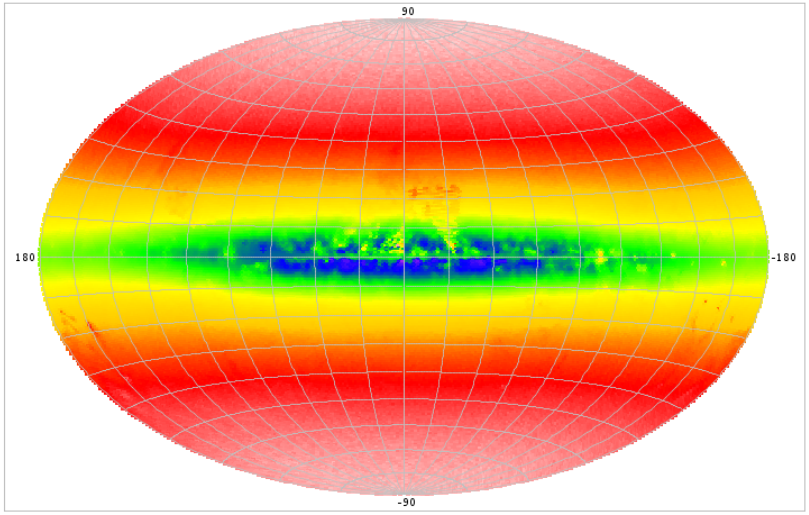




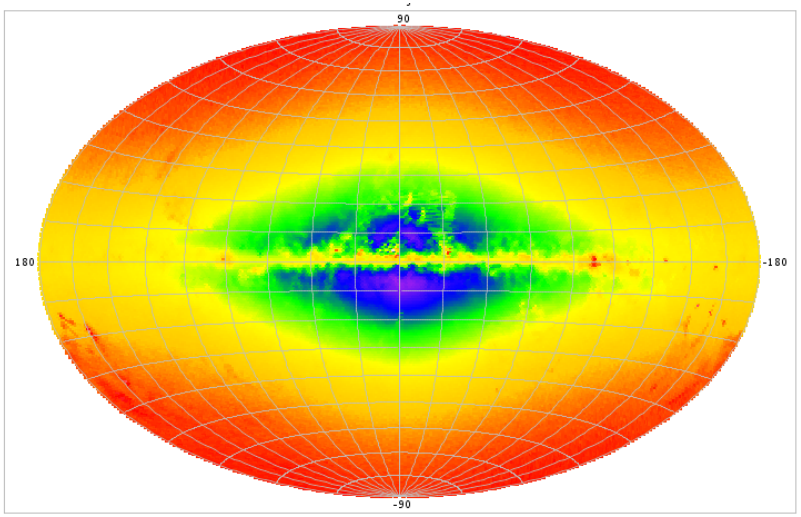




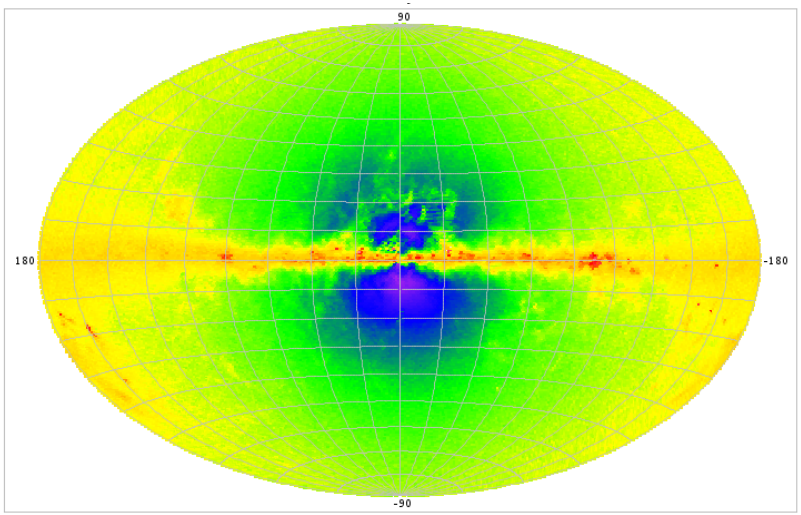
Stellar population sampling



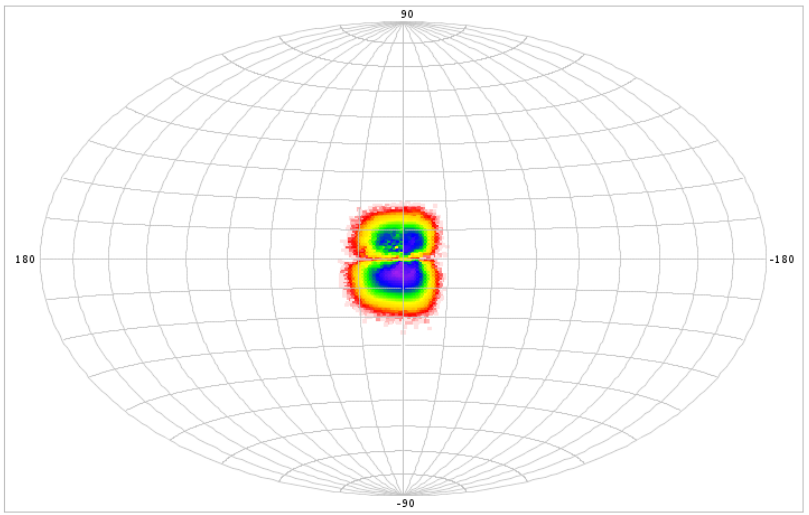
Thin disk



Thick disk



Halo



Bulge

Open clusters

Hipparcos	First cluster observed in 3-D: the Hyades Hyades cluster with mean distance of stars within 10 pc to < 1 % 6 clusters with mean distance to < 5 % 4 clusters with mean distance to 5 - 10 % 8 clusters with mean distance to 10 - 20%
Hipparcos-2	8 clusters within 250 pc with mean distance to < 3 % 11 clusters further than 250 pc with mean distance to < 10%
Gaia	complete membership census 3-D observation to ~ 1000 pc all mean distances to better than < 1% many new clusters to be discovered

Globular clusters

Hipparcos	none indirect return from subdwarfs and subgiants
Gaia • complete membership census (except in very central areas)	between 100 and 100 000 stars per globular cluster ~ 20 with s_p/p < 10 % per star ~ 40 with s_p/p < 20 % per star
• for 1000 stars and < 10 kpc • others clusters in the MW	mean distance < 1 % (about 80 clusters) mean distance < 5 % (about 60 clusters)

What we then expect to get from Gaia?

LMC/SMC

Gaia LMC and SMC mean distance

- Number of objects observed
  - ~ 7 500 000 for LMC
  - ~ 1 500 000 for SMC
- Mostly faint objects, G ~ 19-20 and thus σ_{π} ~ 300 μas (worst case)
- Cepheids better !
- Distances
  - ~ 48 000 pc for LMC π = 20.8 μas
  - ~ 61 000 pc for SMC π = 16.4 μas
- Averaging all individual parallaxes $\bar{\pi} \Rightarrow \sigma_{\bar{\pi}} = \dfrac{\sigma_{\pi}}{\sqrt{N}}$

Mean parallaxes
(depth not taken into account)

$\dfrac{\sigma_{\bar{\pi}}}{\bar{\pi}} \approx 0.5\%$ **for LMC**

$\dfrac{\sigma_{\bar{\pi}}}{\bar{\pi}} \approx 1.5\%$ **for SMC**

Gaia LMC and SMC individual distances

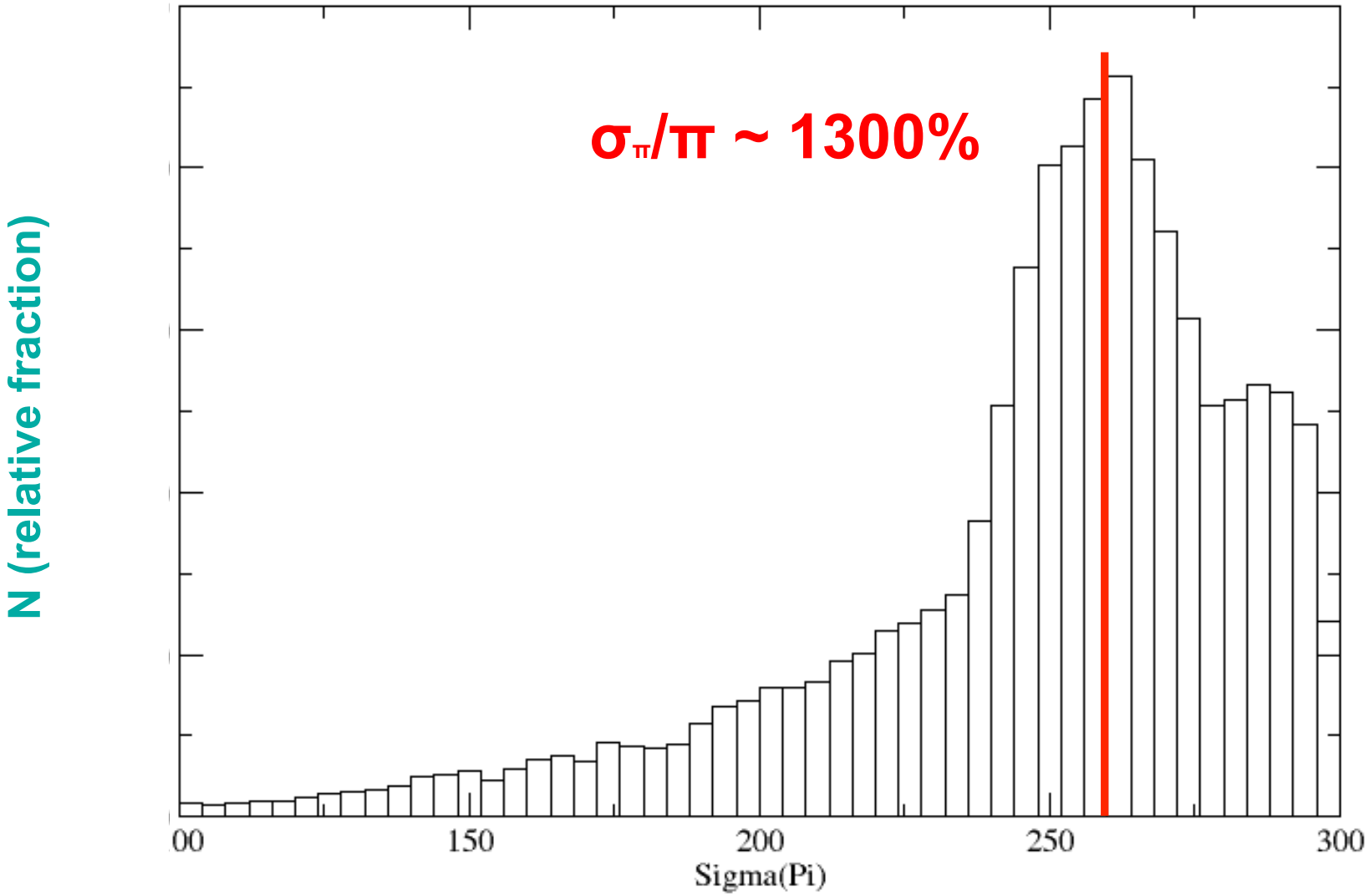
- Assuming a depth of 3000 pc (still a large uncertainty on the depths of LMC and SMC)
  - d = 45 000 – 51 000 pc for LMC = 22.2 – 19.6 as
  - d = 58 000 – 64 000 pc for SMC = 17.2 – 15.6 as
- Error in mean parallax
  - ~ 0.12 as for LMC
  - ~ 0.24 as for SMC
- at the Gaia precision level

® 3D structure of the Magellanic Clouds is relevant

(the term “distance to the LMC/SMC” becomes imprecise)

® 3D distribution of various types of (giant) stars within reach

LMC σ_π distribution in μas (Gaia simulated final catalogue)

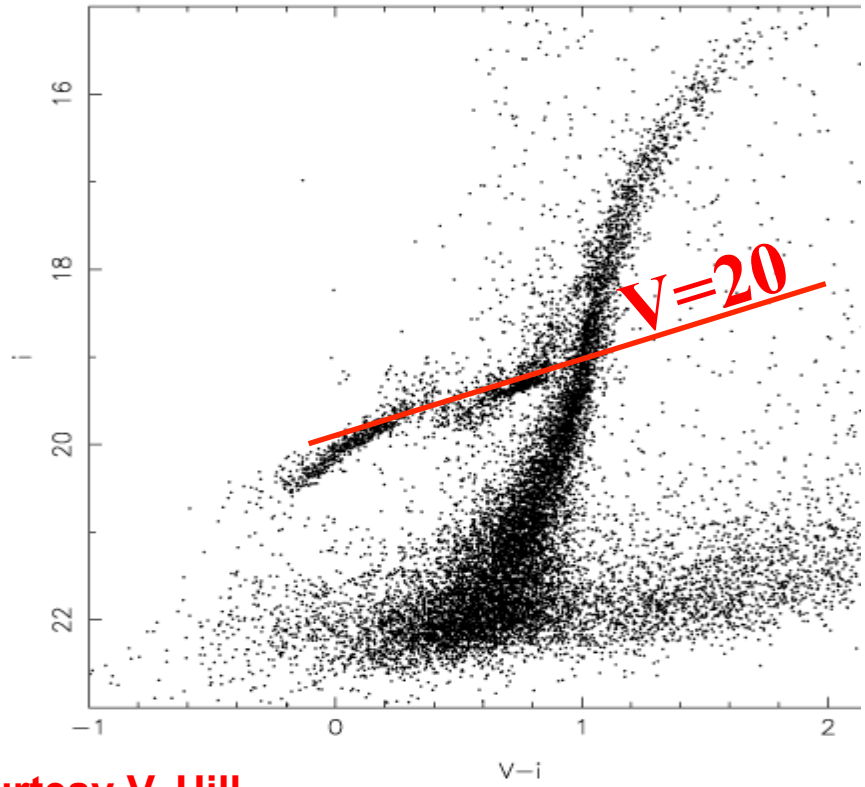


What we then expect to get from Gaia?

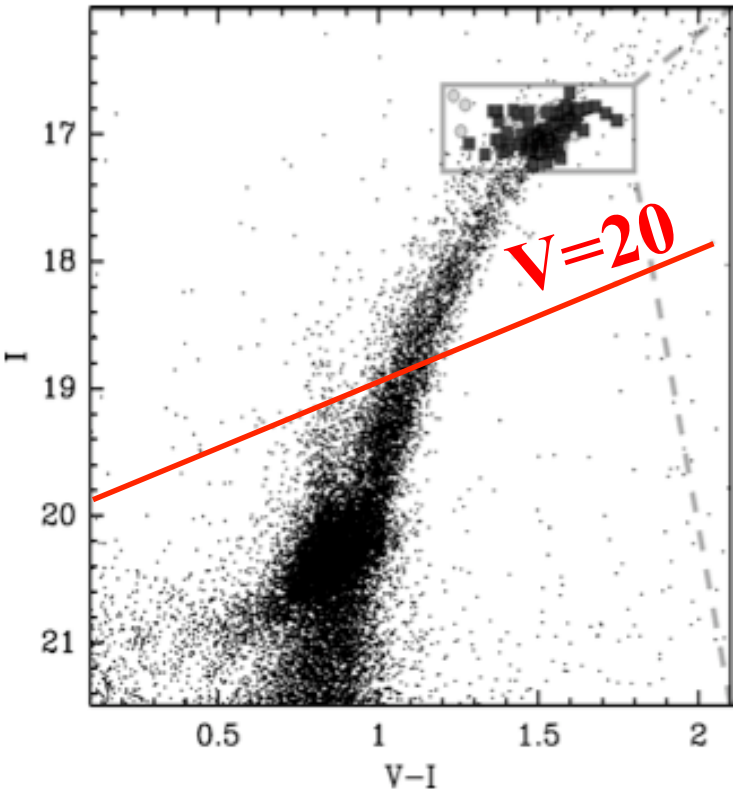
Local group and beyond: standard candles

Colour-Magnitude diagrams in the Local Group

Sculptor (79 kpc)



Fornax (138 kpc)



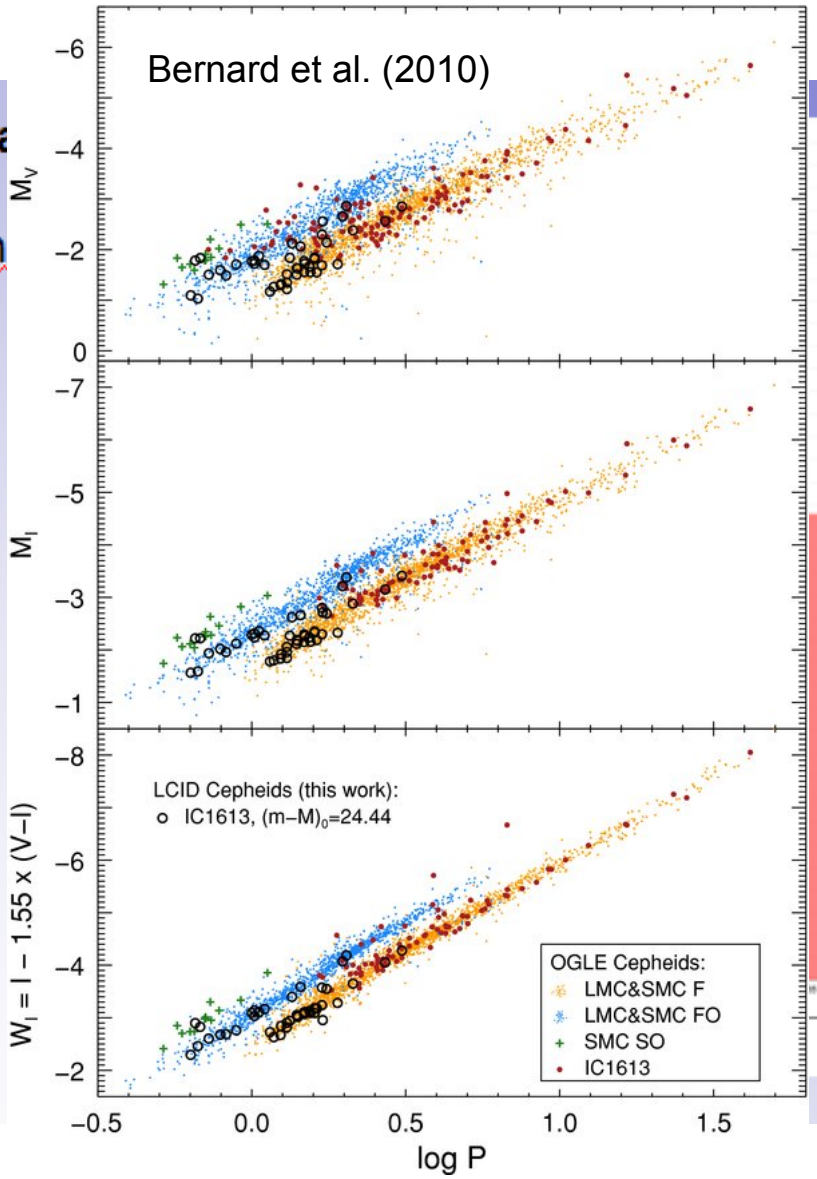
Courtesy V. Hill

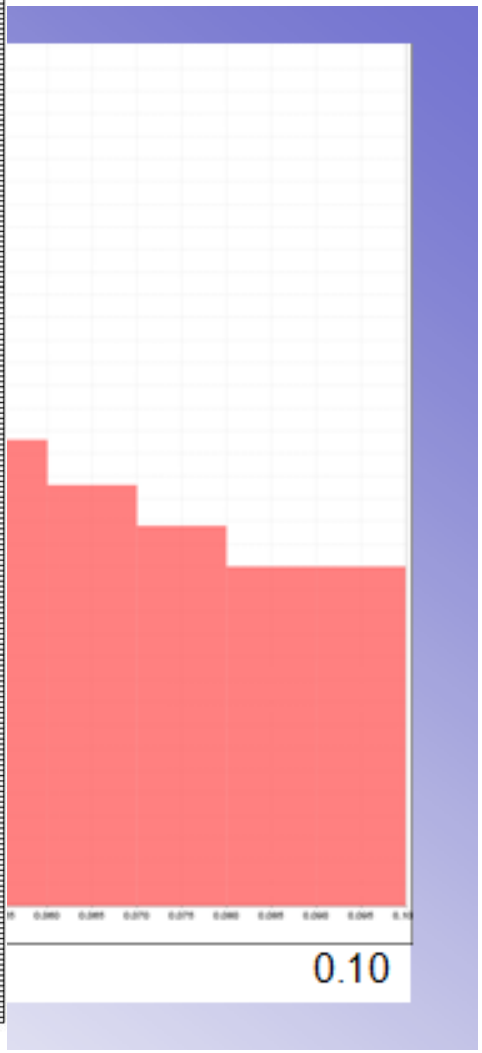
GAIA will observe individual stars in Local Group galaxies, with unambiguous discrimination with solar neighbourhood stars.

Cepheids

Simulated Gaia ca

- σ_π/π distribution
- Cepheids





RR-Lyrae

Galactic	186	Hipparcos 1997
Observed	1,635	ASAS catalogue, as in 2011 Pojmanski
	~4,000	LINEAR, Sesar, inprogress
	16,836	OGLE, bulge, Soszynski 2011
Estimated for Gaia	15,000-40,000	**bulge** **Eyer & Cuypers (2000)**
	70,000	**halo**

LMC	24,906	OGLE, Soszynski et al 2010
SMC	2,475	

From L. Eyer et al. (2011 Naples conference)

Long Period Variables

Galactic	1,238	Hipparcos 1997
Observed	2,793 (Mira)	ASAS catalogue, as in 2011 Pojmanski
	2,691	Bulge, OGLE-II Groenewegen et al. 2005
Estimated for Gaia	**200,000 Mira?**	**Eyer & Cuypers (2000)**

LMC	91,995 (12,795) M+SR	OGLE, Soszynski et al 2009
	37,047	EROS, Spano et al in prep

From L. Eyer et al. (2011 Naples conference)

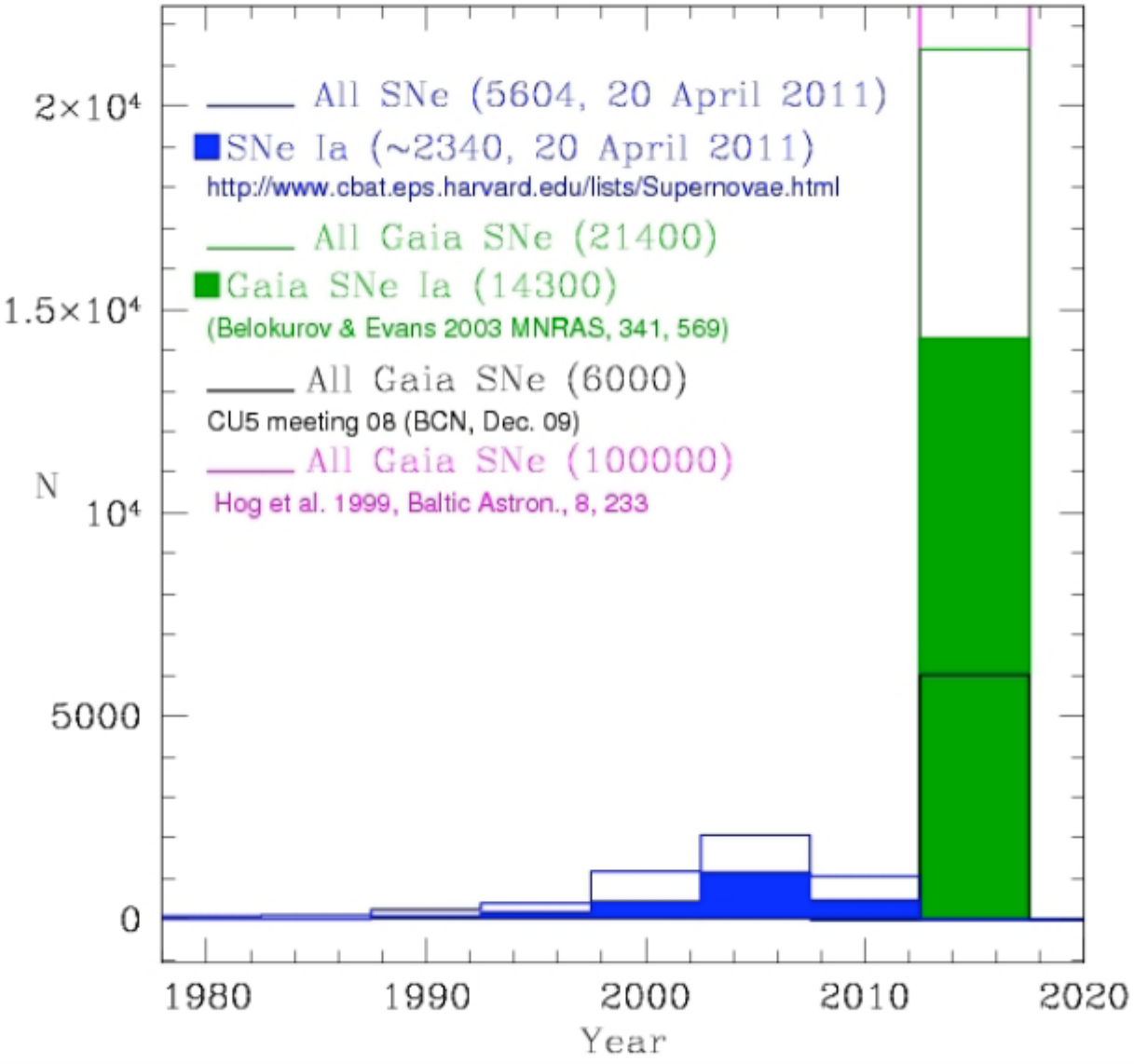
Eclipsing binaries

Galactic	917	Hipparcos 1997
Observed	5,911	ASAS catalogue, as in 2011 Pojmanski
Estimated for Gaia	500,000 6,000,000 3,000,000	**Söderhjelm 2004** **Zwitter 2002** **Eyer & Cuypers 2000**

LMC	26,202	OGLE, Graczyk et al soon
SMC	1,351	OGLE-II, Wyrzykowski et al 2004

From L. Eyer et al. (2011 Naples conference)

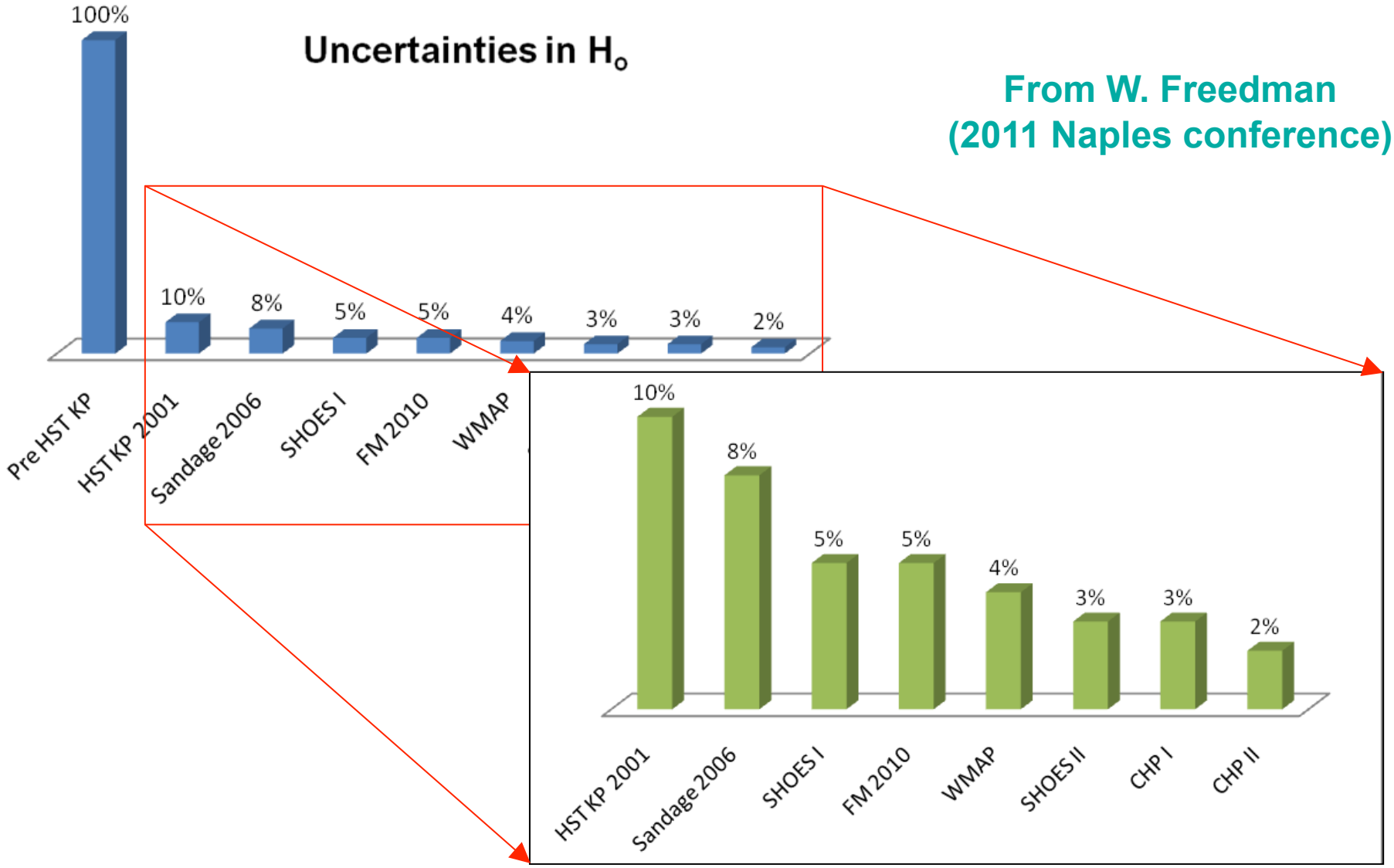
Supernovae



From G. Altavilla
(2011 Naples conference)

But better and more precise data brings new challenges: the era of 1% precision

Progress in the determination of H_0



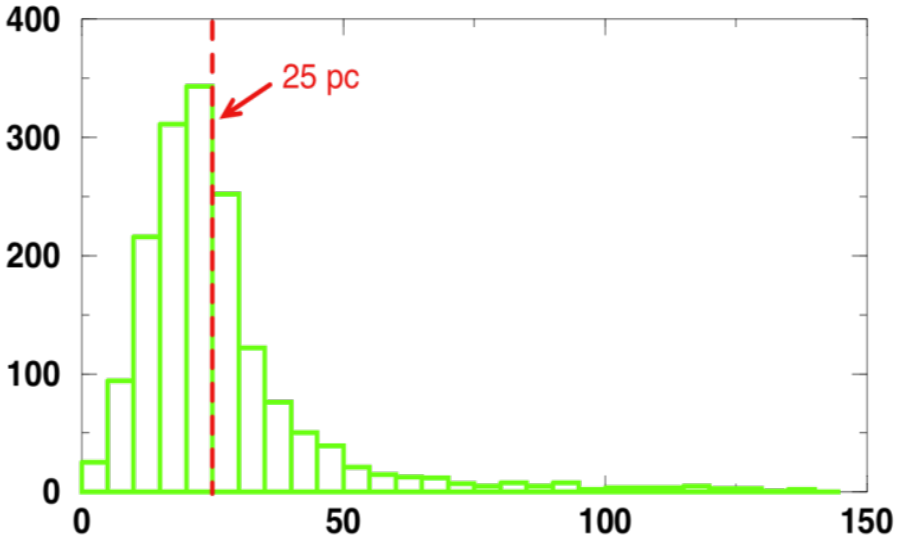
From W. Freedman
(2011 Naples conference)

W. Freedman: at this level the remaining errors are often dominated by the systematics.

The use of the Gaia parallaxes will likely face a similar problem. Proper statistical treatment will be mandatory.

Also, be ready for surprises…

Nearby stars before and after Hipparcos

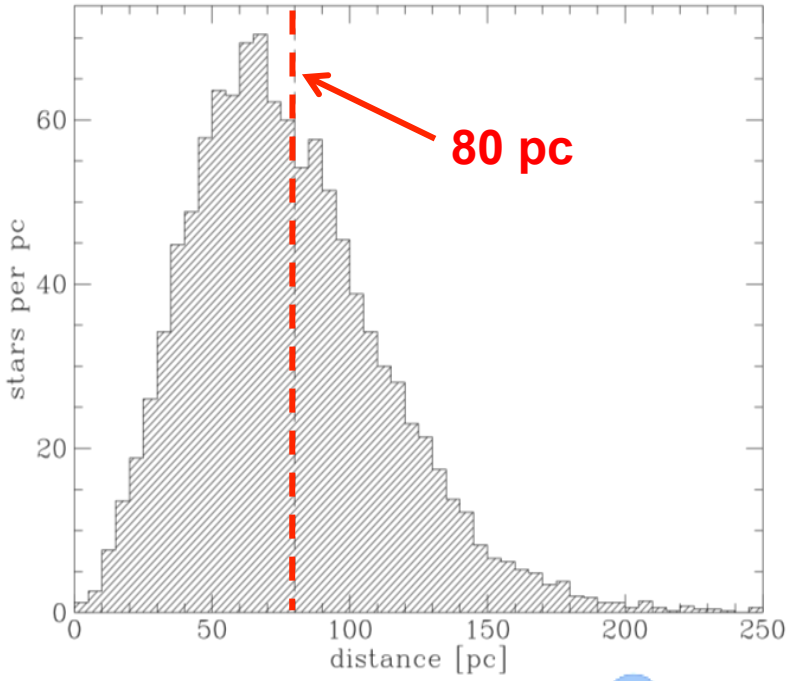


40 % of stars of CNS3 catalogue are further than 25 pc

(Turon 1999)

> 40 % of stars estimated to be closer than 80 pc from spectral classification (MSS) are further than 80 pc

(Binney et al 1997)



Thank you for your attention