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QSOs with Gaia

Outline

- QSOs in the Gaia mission
- QSO recognition with Gaia
- How many QSOs to be detected by Gaia

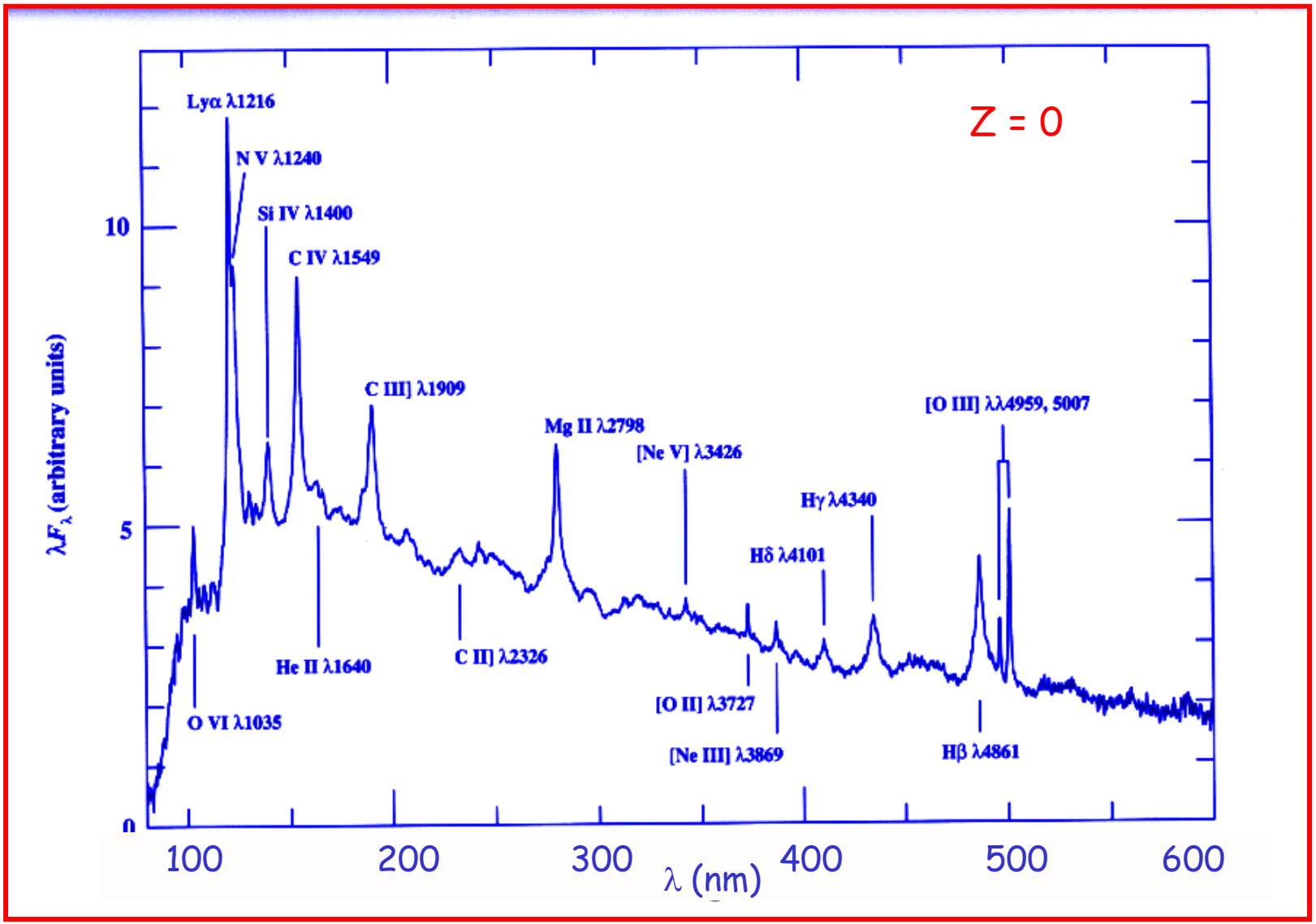
Fact Sheet on QSOs

- Most luminous objects in the Universe
  - 10^{11} - 10^{14} L_{sun} ; 1 to 1000 L_{galaxy} ; M_B ~ -23 to -30 ; 10^{37}-10^{41} W
- Radio loud (*quasars*) or radio quiet (*QSO*)
- Variability over days to months
  - size of the emitting core ~ few solar systems to 0.1 pc
- Seen at great distance, then large redshift
  - $0 < z < 5$; > 10 billions years in the past
- Paradigm for their structure
  - accretion onto a massive black hole (10^8 solar mass)
  - one Sun per year is swallowed to sustain the luminosity
    - Mc^2 / 1 yr = 2×10^{47} J / 3×10^7 s ~ 10^{40} W = 10^{47} erg s^{-1}

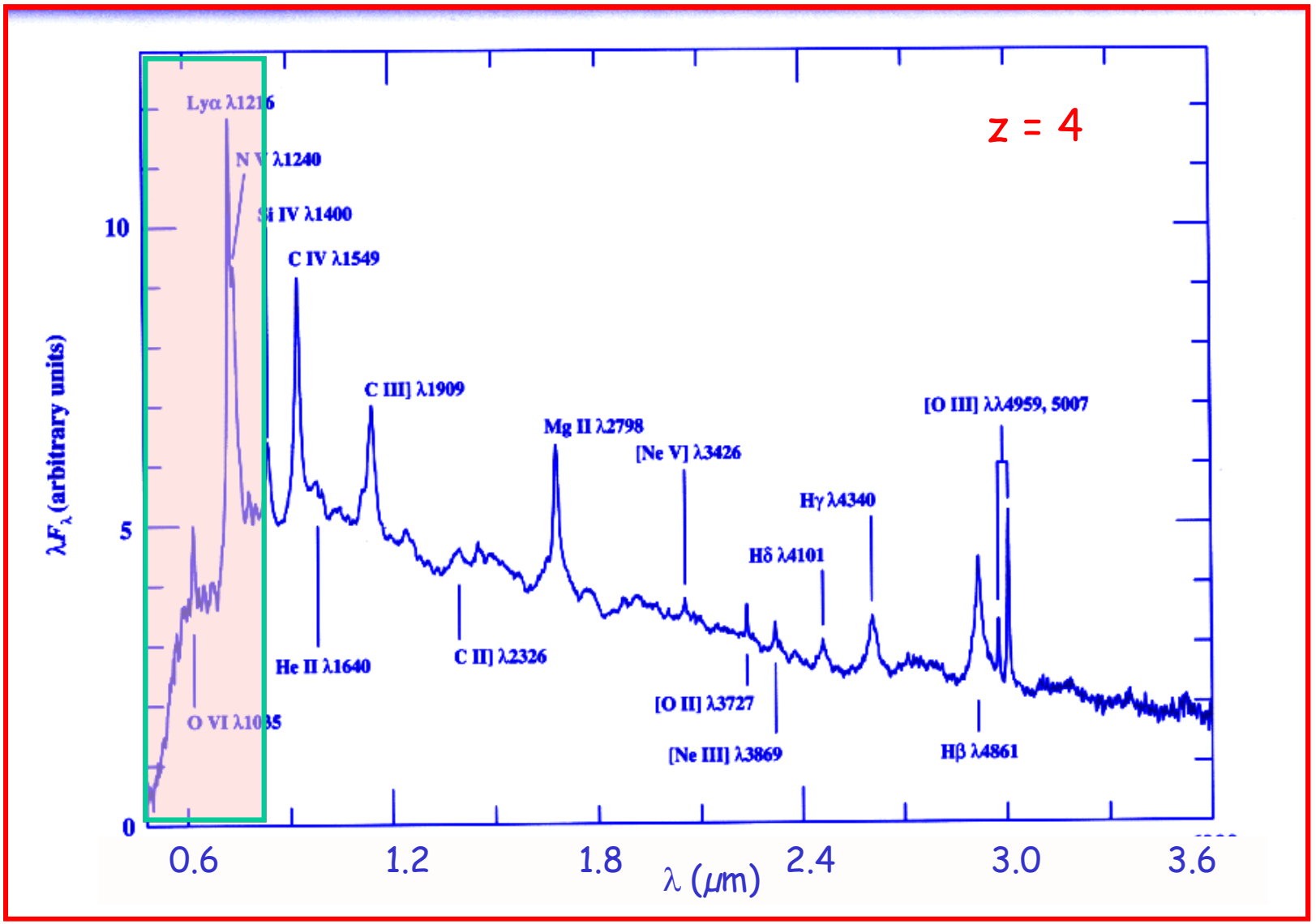
Fact Sheet II

- Difficult to identify from the stars:
  - point like source, with faint and diffuse host galaxy
  - Faint, rare and starlight aspect on plates or CCDs
- Energy distribution : different from stars
  - 10^{11} - 10^{14} L_{sun} ; 1 to 1000 L_{galaxy} ; M_B ~ -23 to -30
  - Strong and broad emission lines (E.W. ~ 60 Å ~ 10 000 km/s)
  - Blue bump
- This difference is the key feature for identification with Gaia

Energy distribution

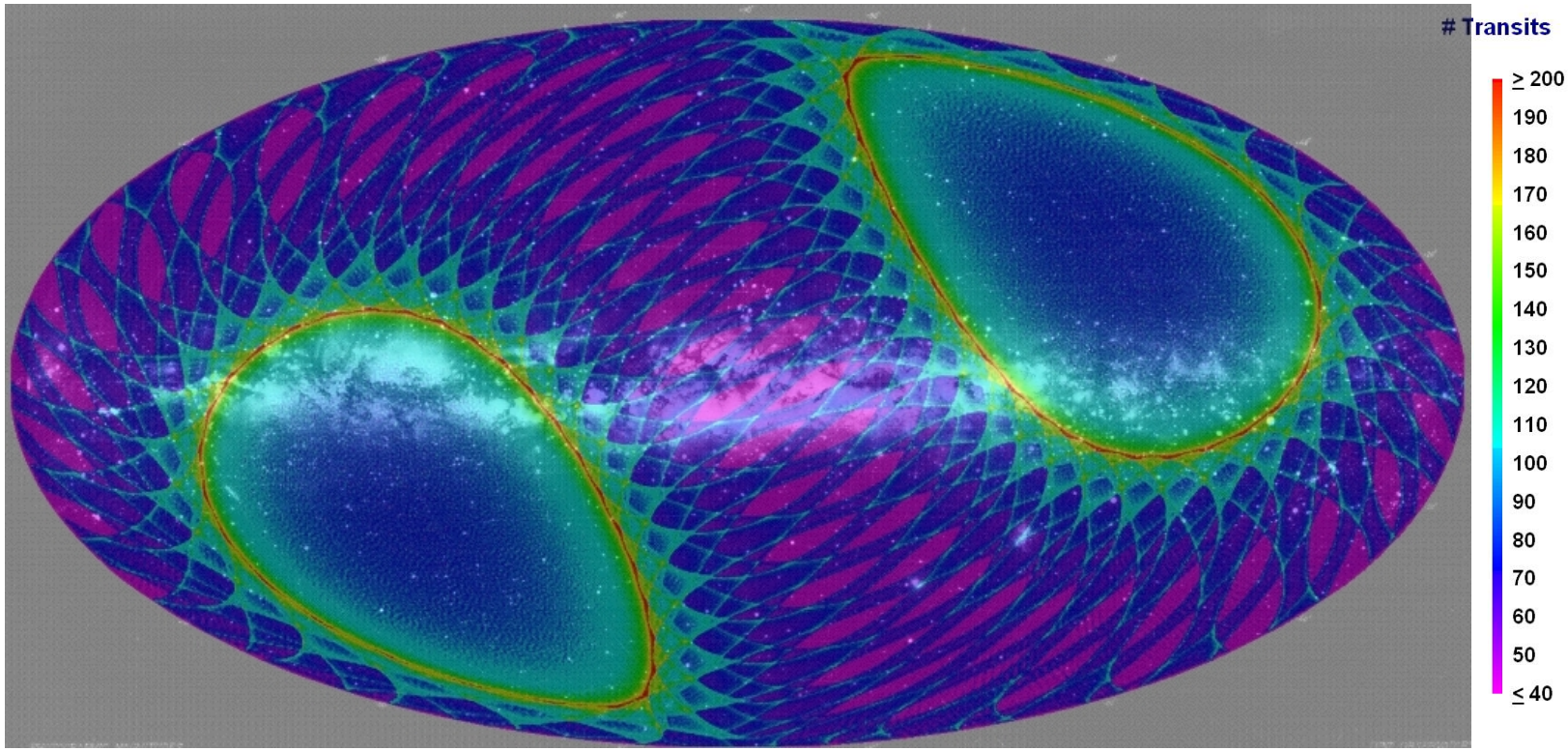


Energy distribution



Observation of QSOs with Gaia

- QSOs will be observed like stars
  - point like sources
- They will be detected in the Sky Mapper when G < 20
- Sky coverage and astrometric performances will be the same as for stars of same magnitude
  - no specific colour problems are expected
- They will be observed about 80 times
  - distributed more or less regularly during the mission
  - min ~ 45 times, max ~ 150 times
- Astrometric and photometric processing will be standard
  - global solution for astrometry
  - epoch photometry at each transit


Transits
≥ 200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
≤ 40

Gaia and QSOs: Relevant activities I

- Identification and discrete classification
  - survey to G = 20 (~ R = 20)
  - clean subset (contaminant-free) for reference frame
  - automated classification of QSOs
- Supply of a well documented and clean initial QSO catalogue
- Extension of the potential sources usable for the orientation
  - additional ground based observations
- Survey of all the potential causes for tangential motion
  - timescale for these motion is crucial
- Theoretical studies related to the Inertial Frame
  - implementation in the Gaia processing

Gaia and QSOs: Relevant activities II

- Investigation on source stability
  - acquisition of basic data relevant for this issue
  - more theoretical investigations would be useful as well
- Photocentre – radiocentre offset
- Simulation of a Gaia ICRF
  - rotation, orientation, cosmic-acceleration
- Photometric redshifts with Gaia data
- Lensing and multiple imaging

Gaia and QSOs: Relevant activities III

- Production of a realistic simulated QSO list for simulation
  - good position distribution
  - fully representative photometric and z distribution
  - synthetic spectra
  - astrometric effect relevant for the reference frame



QSO recognition with Gaia

F. Mignard

EGSG, OCA, 10 September 2012

QSO recognition with Gaia- I

- ~ 2/3 of the QSOs of the Gaia survey will be new
- They must be identified by a built-in mechanism
- The baseline is photometric identification
  - use of the BP/RP dispersed images
- Additional hints
  - proper motion
  - parallaxes (of non QSOs)
  - host galaxy ?
  - ground based data

QSO recognition with Gaia- II

- Intensive activity over the last five years
  - led initially by J.F. Claeskens (Univ. of Liège, Belgium)
  - then continued by C. Bailer Jones and K. Smith
- Two purposes:
  - Select a clean small sample of QSOs free of stellar contaminants
  - Identify the majority of the QSOs in not a so clean sample
- Remaining possible contaminants:
  - very red (M stars), or highly reddened stars
  - peculiar white dwarfs
- Classification methods very advanced
  - see talk of Y. Damerdji

Probability classification: principles

- An object will be a star, a galaxy or a QSO with a probability p
- Population with frequency ***f*** of QSOs and H_0 : source is a QSO
  - The test can wrongly reject a QSOs : risk of the test α
    - 1- α : significance level
  - The test can keep a star in the QSO sample : risk of contamination β
    - 1 – β : power of the test

		State	
		QSO	Star
Found	QSO	1-α	β
	Star	α	1-β

Probability classification

P(Q/FQ): this is a QSO when Found as a QSO

$$P(Q/FQ) = \frac{f(1-\alpha)}{f(1-\alpha)+(1-f)\beta}$$

P(S/FQ): this is a Star when Found as a QSO

$$P(S/FQ) = \frac{(1-f)\beta}{f(1-\alpha)+(1-f)\beta}$$

if $f \ll \beta$ then $P(S/FQ) \sim 1$! All purported to be quasars are indeed stars

So the efficiency β must match the frequency of the QSOs

With $f \sim 1/2000$ ➔ $\beta < 0.0005$

Consequences

- A survey over 100 deg^{-2} with a 1% error selection test will yield :
  - 2000 quasars (max) and
    - 30 000 stars at b = 0° ==> efficiency of 3%
    - 3000 stars at b = 60° ==> efficiency of 40%
- GAIA will observe ~ 500 000 QSOs G< 20
- ~ 10^9 stars : so classification test better than 2×10^{-3}

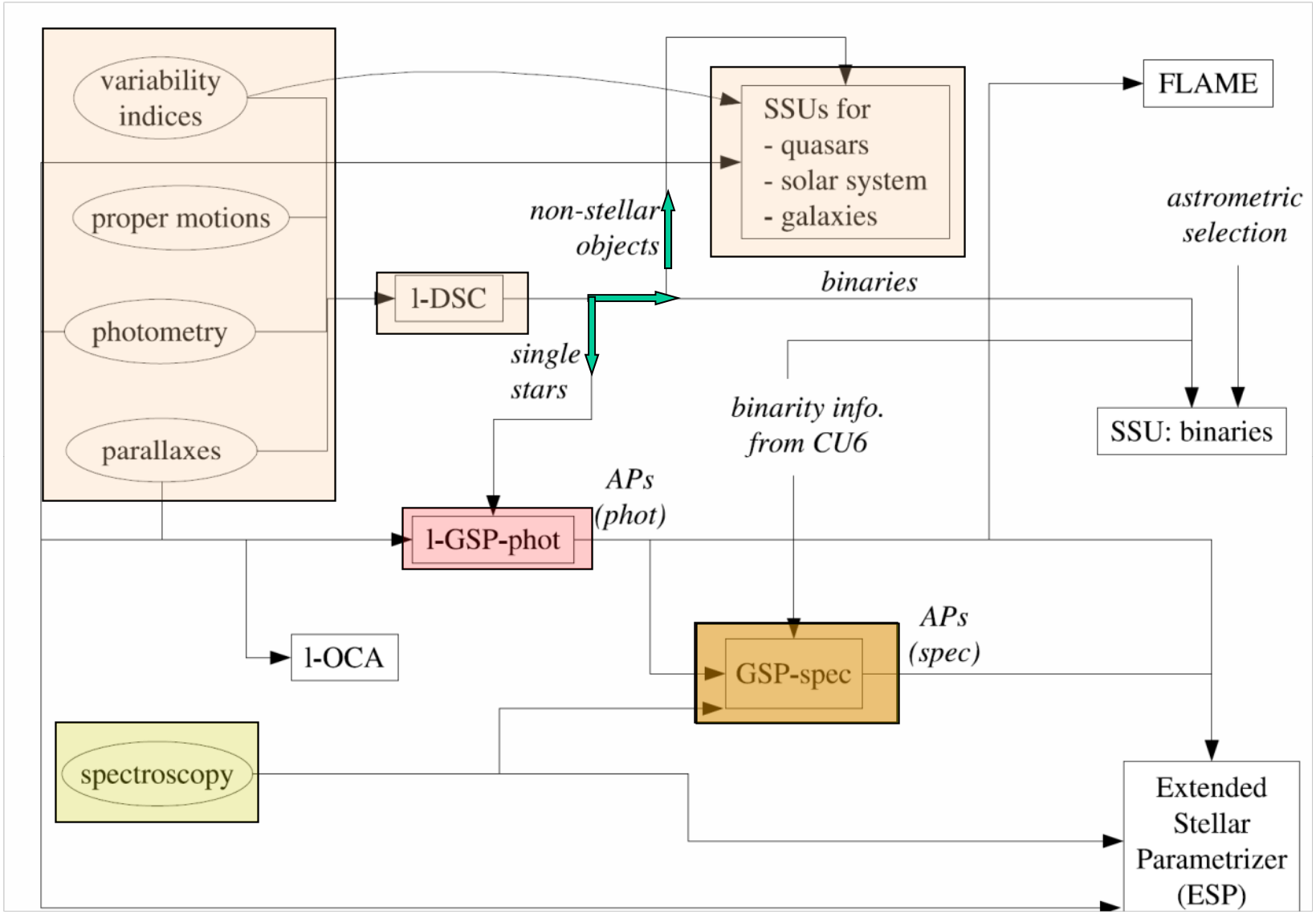
Discrete Source Classifier (DSC)

- This is a CU8 activity led by K. Smith (MPIA Heidelberg)
  - around 1 billion stars, including binaries
  - several hundred thousand WDs
  - a million unresolved galaxies
  - around half a million quasars
  - numerous solar system objects
    - normally filtered out before
- First goal of Data Processing ➔ sort input objects by class
  - A class is a category of source
  - An object is given a probability to belong to a class
    - ideally one would like to have P(O $\in$ a class) =1
- DSC works as a supervised classifier
  - classes are defined externally

Available Information (DSC)

- astrometry
  - position , PM, parallax
- magnitude G, BP, RP
- low resolution BP/RP spectrum
- variability
- some Hi-res spectrum with RVS (bright sources)
- complementary ground-based information ?

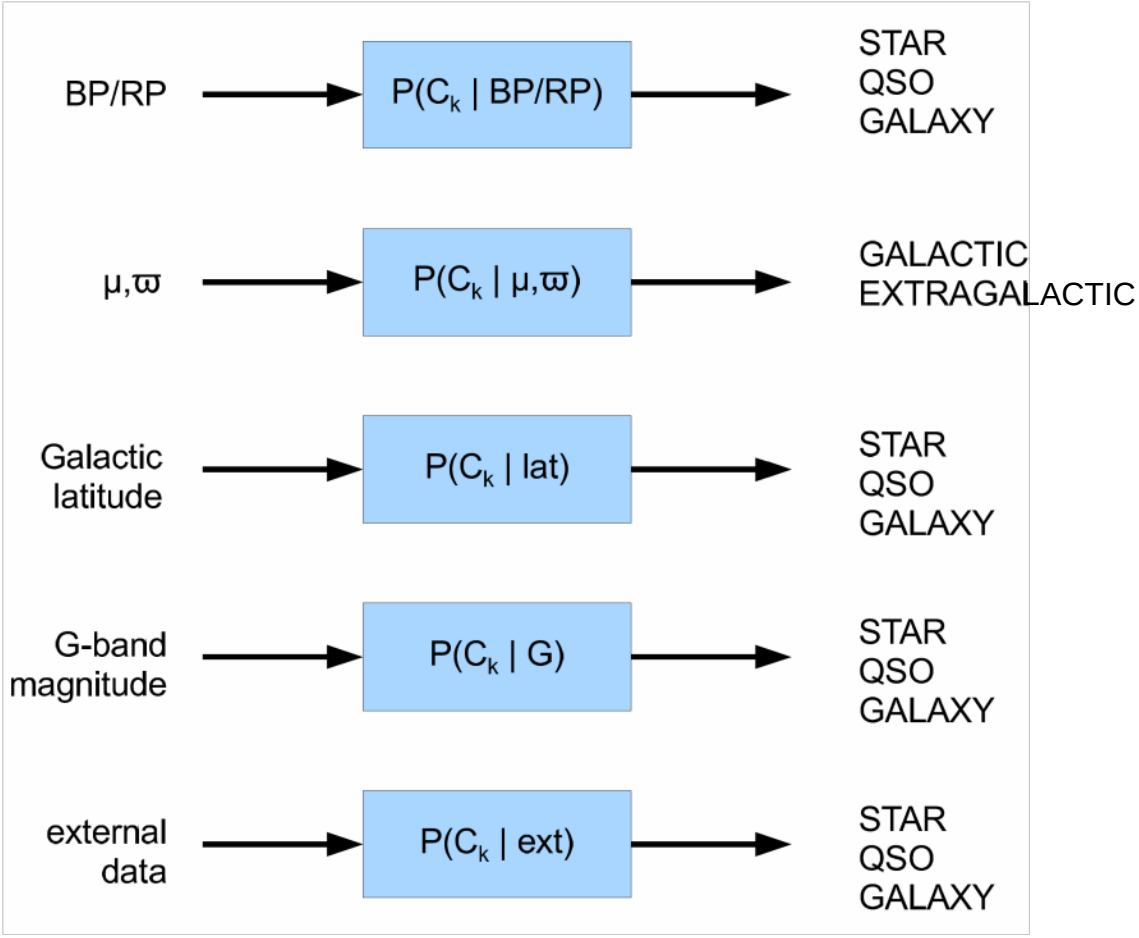
CU8 Workflow



credit: C. Bailer-Jones

Overall Strategy

- Different classifiers working in parallel
  - Output: P_r (Source in Class k|observed properties)



credit: K. Smith

Current performances

- G > 17 for this test

kind \ found	Star	QSO	Galaxy	unknown	total
Star	82	0.1	2	16	100
QSO	1.2	81	2	15	100
Galaxy	1.3	0.1	92	6.5	100

- For QSOs
  - Completeness ~ 80%
  - Contamination level ~ 0.1% by stars

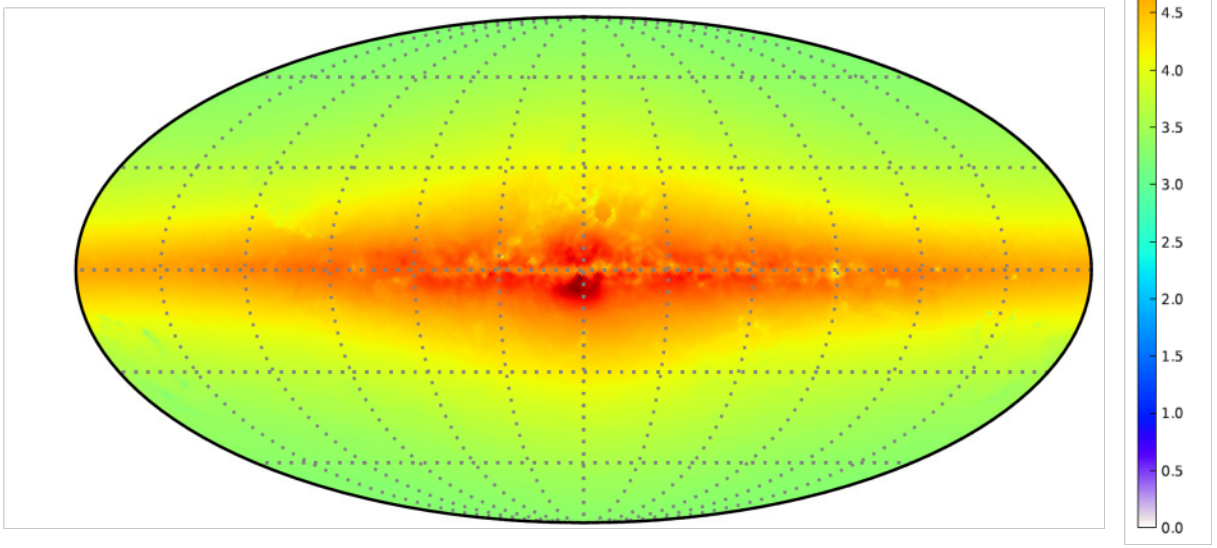
credit: K. Smith

Grid	Class	star	qso	galaxy	unknown
apecNom1	STAR	94.444	5.556	0.000	0.000
fastrot	STAR	98.264	0.694	0.000	1.042
galaxySE1	GALAXY	0.151	0.508	99.011	0.330
phoenixNom1	STAR	95.733	0.024	0.544	3.699
phoenixRan1	STAR	98.670	0.150	0.850	0.330
Qso SDSS	QUASAR	0.207	95.859	2.334	1.600
Stars SDSS	STAR	99.580	0.208	0.210	0.002
UCD Cond Nom1	STAR	29.365	0.000	0.000	70.635
UCD Cond Ran1	STAR	70.520	0.450	0.760	28.270
UCD Dust Nom1	STAR	74.194	0.000	0.000	25.806
UCD Dust Ran1	STAR	98.300	0.000	0.000	1.700
WR Nom1	STAR	76.744	9.302	0.000	13.953

credit: K. Smith

Absolute contamination

- Pessimistic approach : 0.1% of the stars are wrongly classified as QSOs
  - 10^9 stars ➔ 1 million will fall in the QSO basket !
  - This amounts to 200% contamination in the survey
- More realistic approach : most stars are close to the Galactic plane, where QSOs are not seen
  - Sky outside galactic plane, nearly empty
  - Typically 1000 – 3000 */deg^2 to *G* = 20 ➔ 0.1% contaminant = ~ 2 */deg^2
  - for QSO one has about 20 QSO/ */deg^2
  - True contamination should be about 10% or 50,000 stars in the QSO survey



Robin et al., A&A, 2012

Gaia Universe Model to G =20

Summary of the Selection

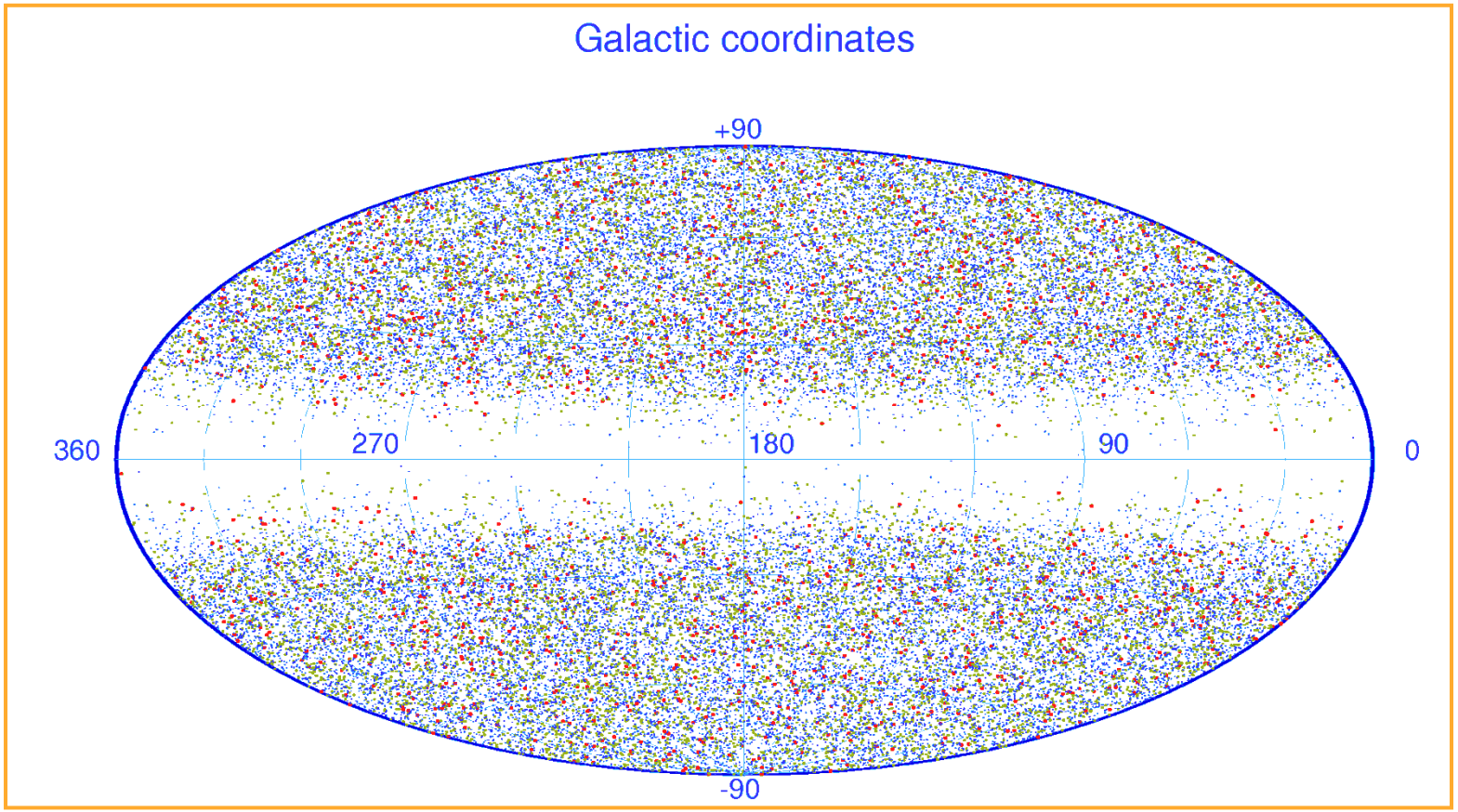
- Gaia detects and observed all the sources V < 20
- There are ~ 5×10^5 QSO observable outside the galactic plane
- They are recognized from the stars with the photometric data
  - success rate > 99.9%
- A clean subset will be used for the primary reference frame
  - One assumes that there is a frame with no global rotation
- Systematic effects will be investigated in the residuals



How many QSOs

QSOs distribution with Gaia

- Based on the simulation used in the DPAC Universe model
  - about 600,000 observable to *G* = 20

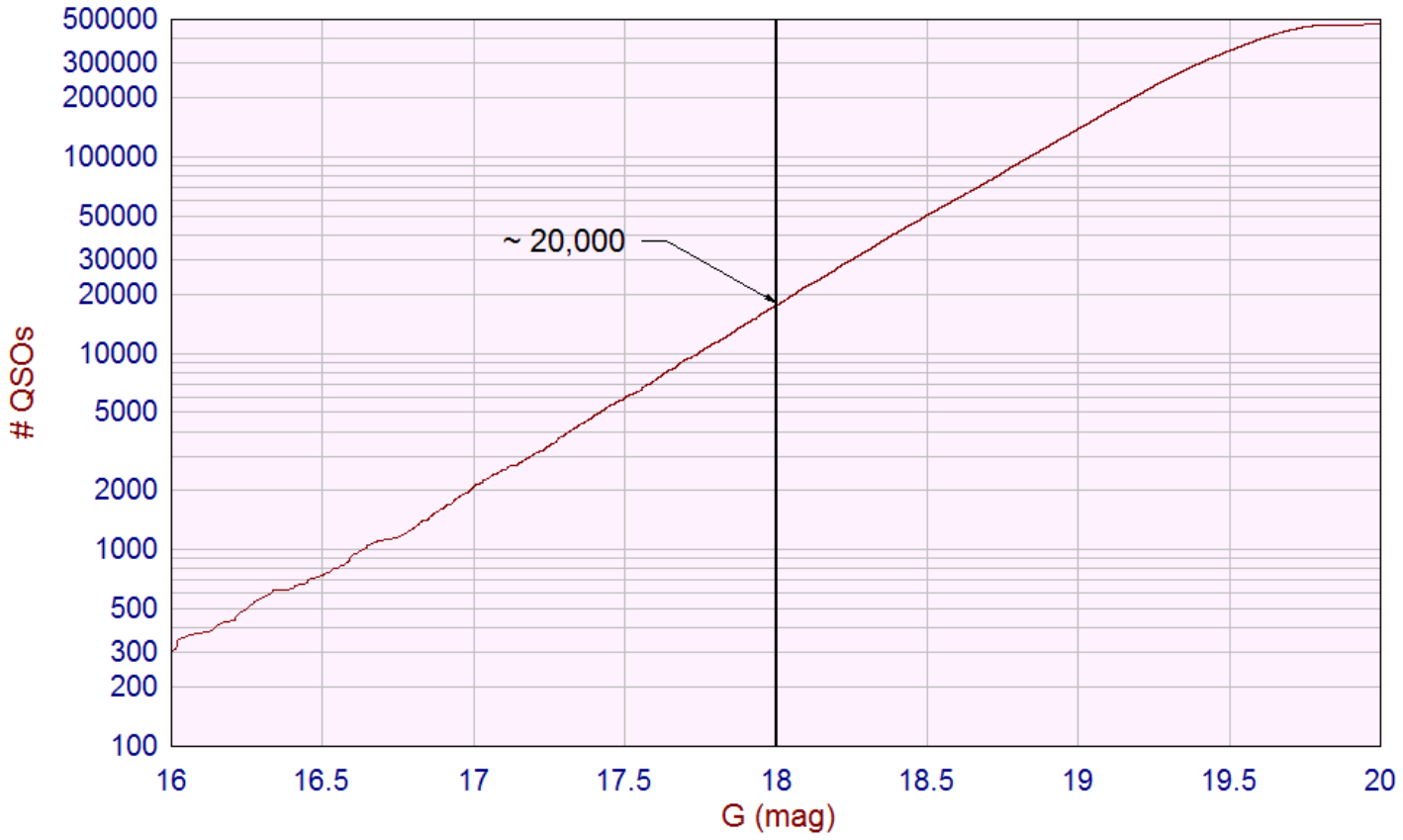


• G < 18 • 18< G < 19 • 19< G < 20

Slezak & Mignard, 2007

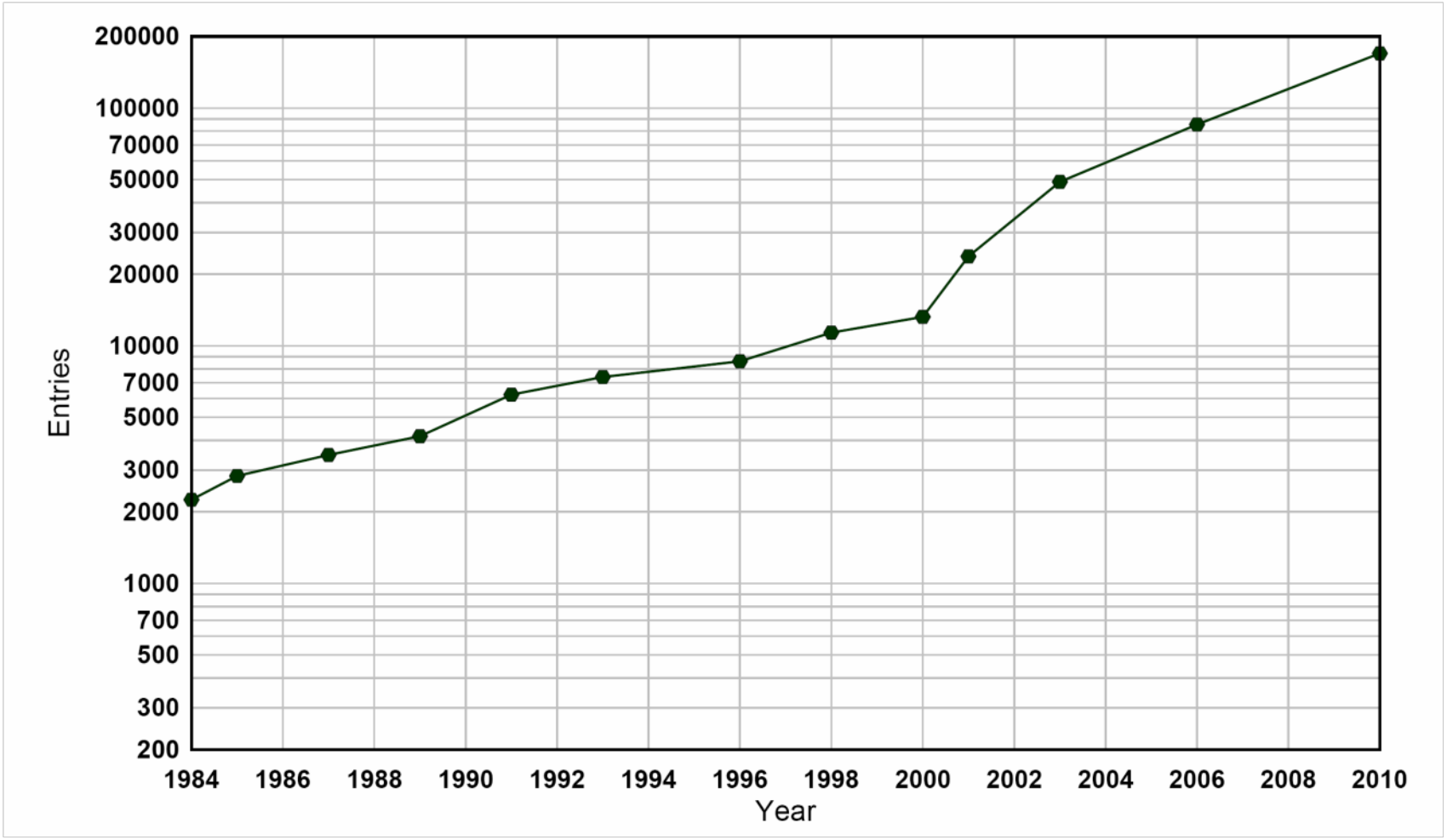
Magnitude distribution with Gaia

- Cumulated distribution over G magnitude
  - based on simulation by Slezak & Mignard, 2007



Number of catalogued QSOs

- Number of entries in the Véron-Cetty – Véron releases
  - recent growth due mainly to SDSS



data from Véron-Cetty & Véron, A&A 2010

How many new QSOs

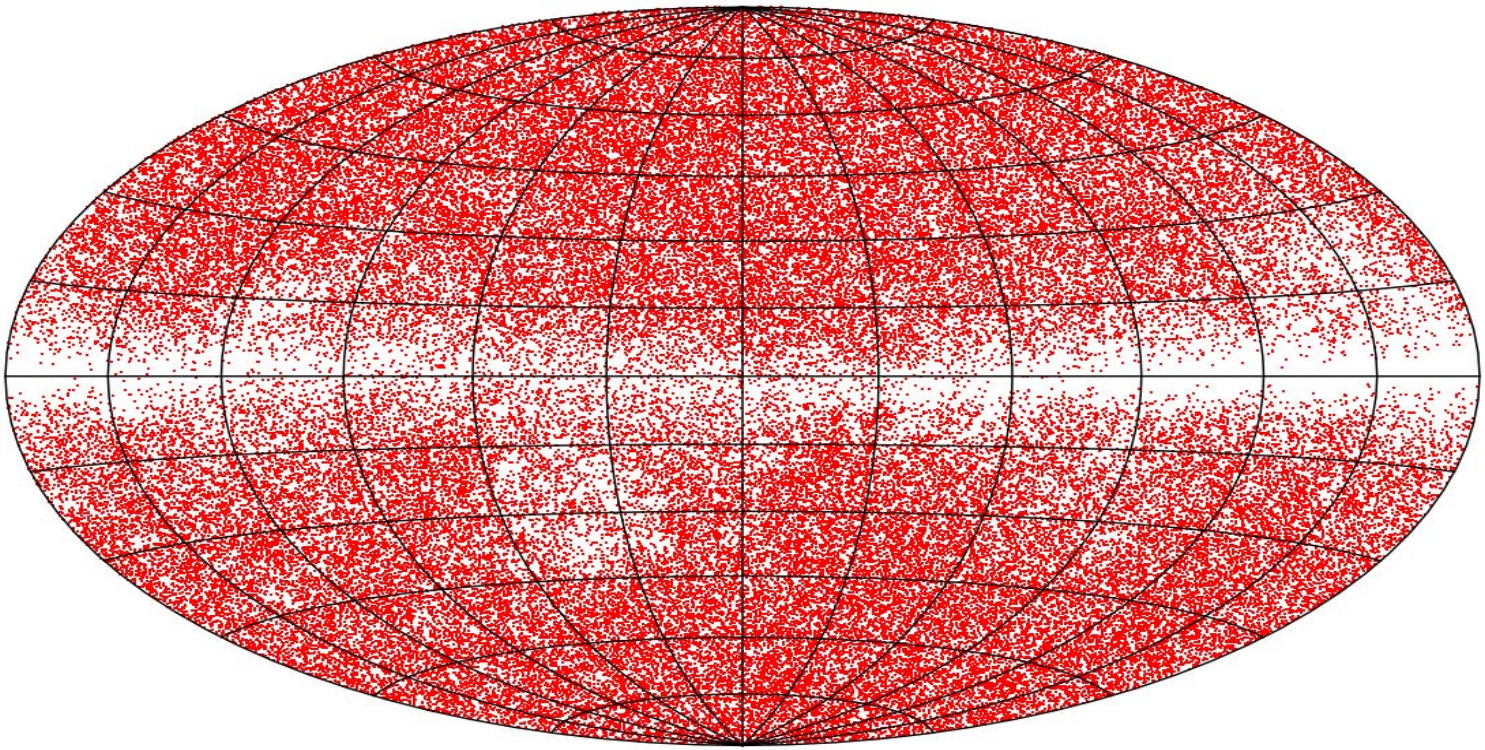
- Density in local deep surveys used to compute the expected number of QSOs per bin of magnitude
- On subtracts the number in the current general catalogue
- assumption: QSOs have a uniform distribution on the celestial sphere
- $|b| > 25°$

B	# new QSOs
< 17	0
17-18	15,000
18-19	100,000
19-20	300,000
20-20.5	*200,000*
17-20	415,000

Bourda, Mignard, Andrei, 2009

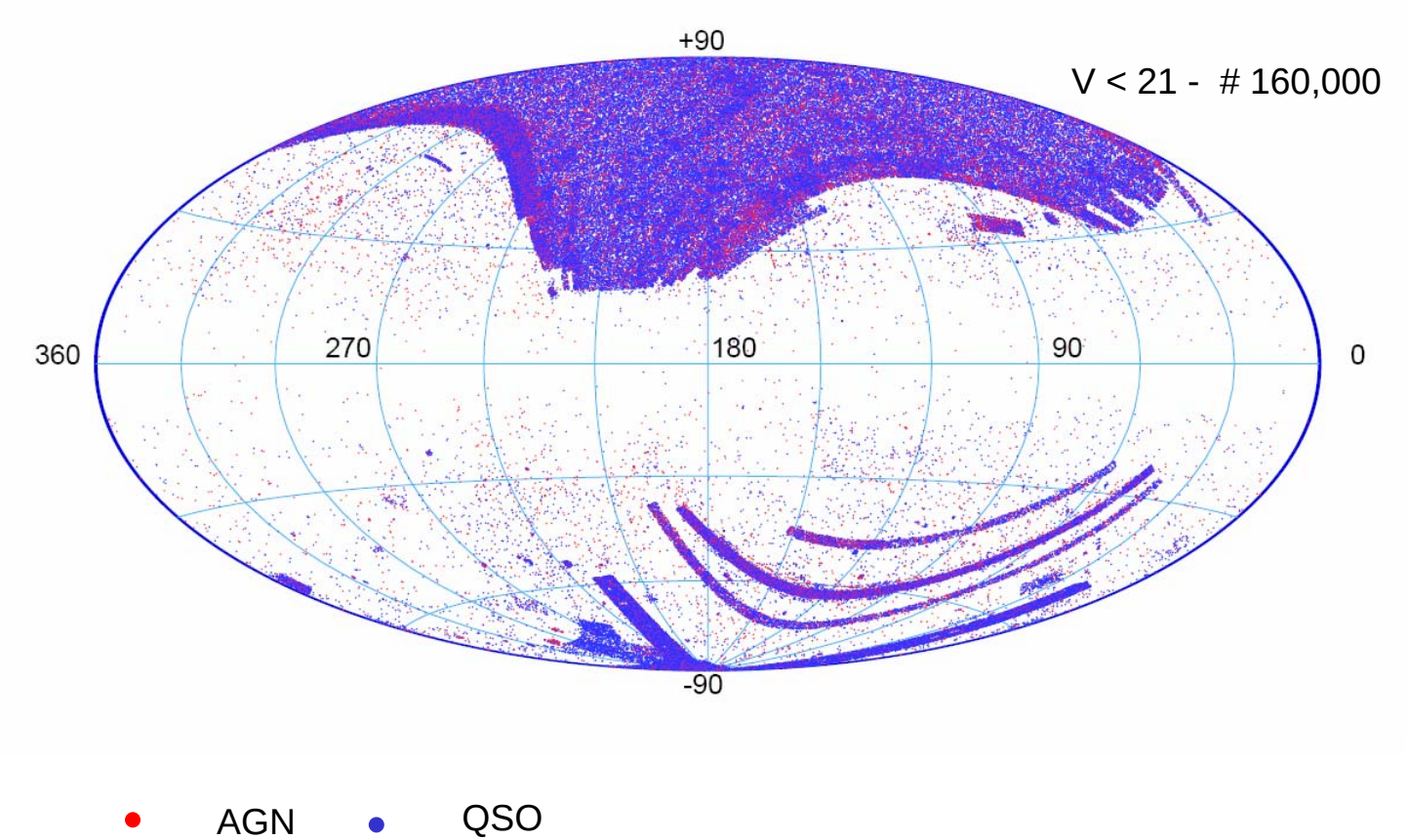
QSO Simulation: Our current model

- about 700,000 QSOs with $G < 20$
  - based in CU2 UM extinction model and realistic distribution in G
  - space distribution very similar to 7F QSOs
- standard astrometric performance as a function of G



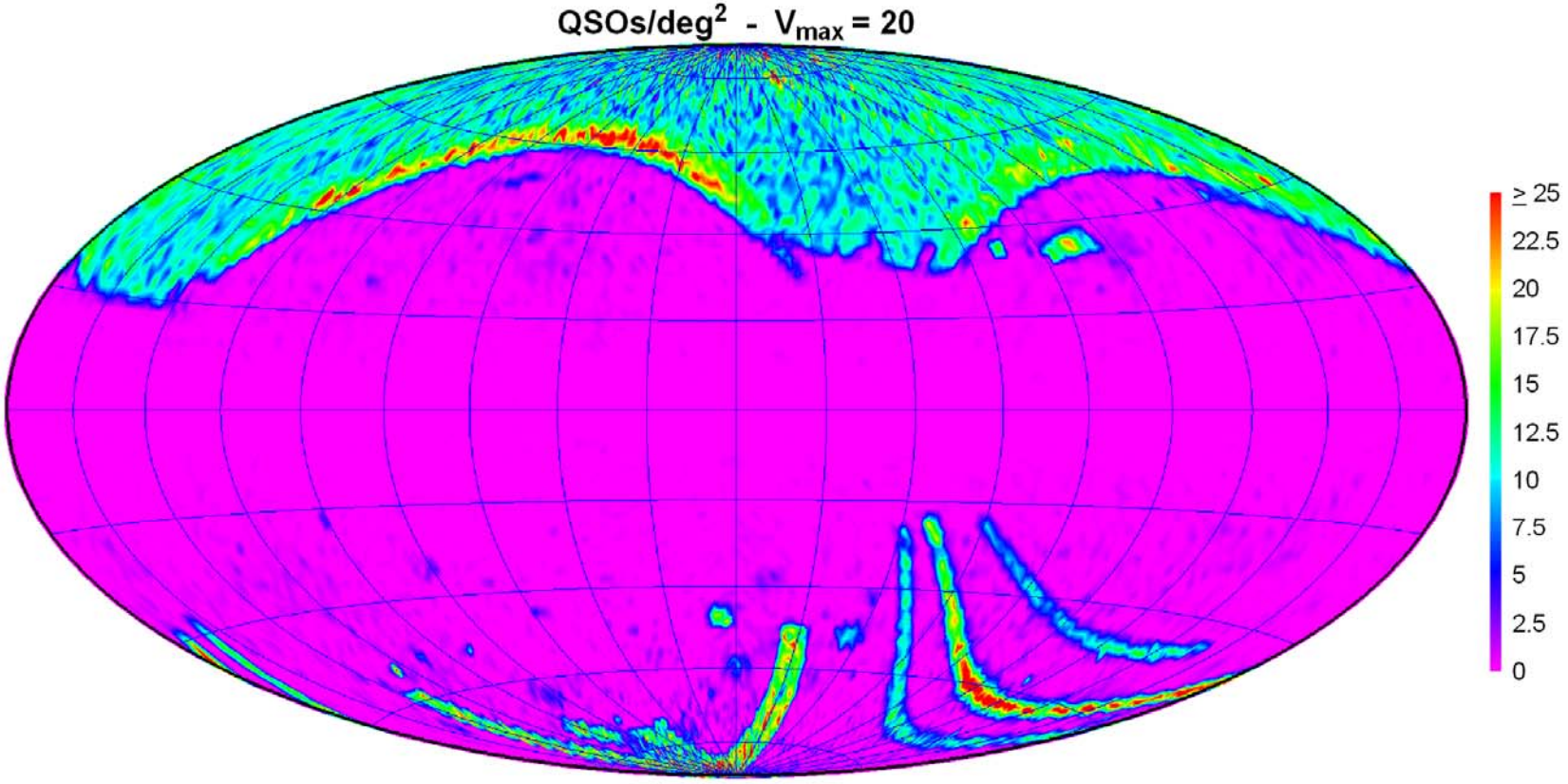
Latest QSO compilation

- Catalogue Veron-Cety & Veron V13 (2010)
  - Plots in galactic coordinates
  - similar results with LQAC (Souchay et al., 2008)



Recent estimate of the density

- Robust estimate of the QSO density for G < 20



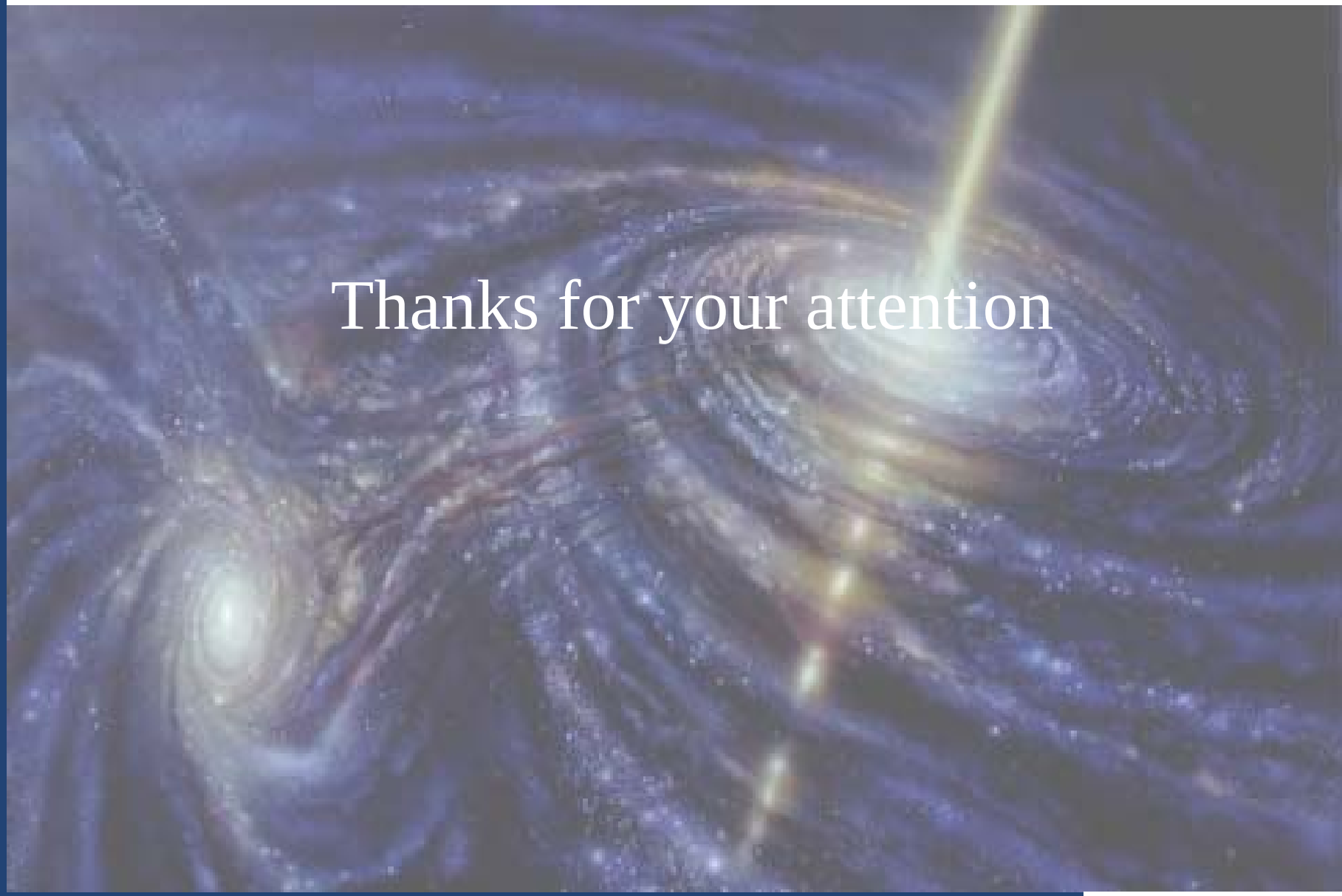
Mignard, 2012, Mem. Soc. Ast. It., in press.

How many new QSOs

- Density in local deep surveys used to compute the expected number of QSOs per bin of magnitude
- On subtracts the number in the current general catalogue
- assumption: QSOs have a uniform distribution on the sky

V	density deg^{-2}	Full sky #	60% sky #	known #	new #	Slezak et.al #
18.0	1.5	63 000	38 000	12 500	25 500	40 000
18.5	3	126 000	75 000	23 000	52 000	113 000
19.0	8	340 000	200 000	45 000	155 000	314 000
19.5	15	630 000	380 000	85 000	295 000	680 000
20.0	22	920 000	550 000	115 000	435 000	1 200 000
20.5	30	1 260 000	750 000	140 000	610 000	1 700 000

Mignard, 2012, Mem. Soc. Ast. It., in press.


Thanks for your attention