Euclid space mission

(a few whys and hows)

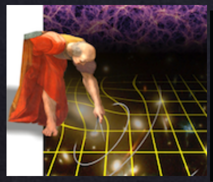
R. Scaramella (on behalf of Euclid Science Team and Euclid Consortium)

**(Euclid Consortium, old timer,
Mission Survey Scientist,
member of the EC Board and EST)**

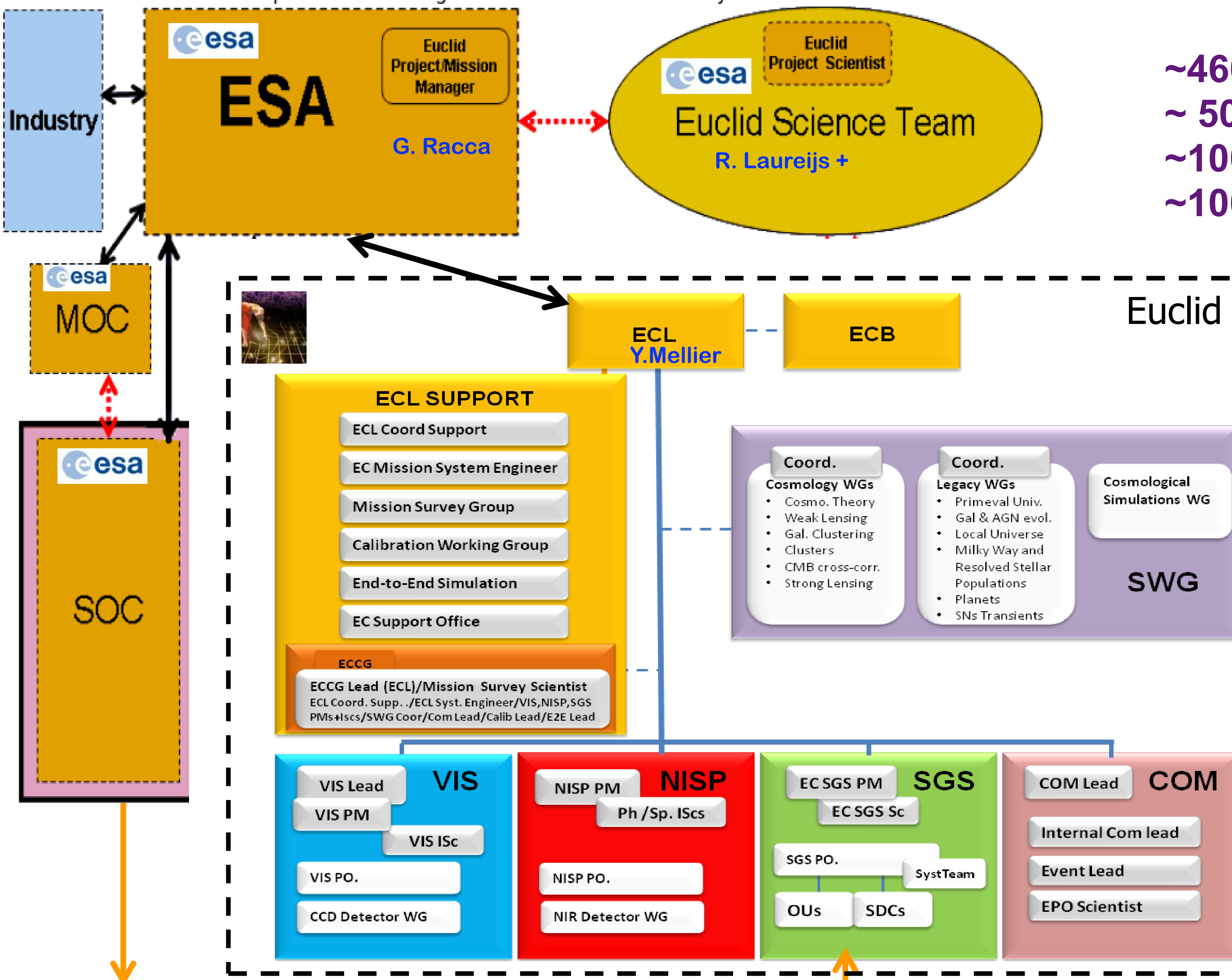
Lots of figures and material courtesy of: EC&ESA (SciRD, CalWG, ECSURV, ESSWG, VIS, NISP, SWGs, OUs ...)

Red Book released in July 2011 (ESA web pages)

kosmobob@inaf.it



ESA Mission



~460+ M€ (ESA)
~ 50+ M$ (NASA)
~100 M€ EC instr
~100 M€ EC Gnd Seg

- **1500** members,
- 120 Labs
- 13 European countries:

Austria, Denmark, France, Finland,, Germany, Italy, The Netherlands, Norway, Portugal, Romania, Spain, Switzerland, UK

+ US/NASA and Berkeley labs.

+ Belgium, Canada

Big & Complex

EUCLID

1. Why
1. Dark Energy & Dark Matter (Cosmology) ; Legacy

2. How
2. Space imaging (morphology & NIR) + Spectra: Grav. Lensing & Clustering

3. When
3. 2022-2028+

Main Scientific Objectives

Understand the nature of Dark Energy and Dark Matter by:

- Reach a dark energy *FoM* > 400 using only weak lensing and galaxy clustering; this roughly corresponds to 1 sigma errors on w_p and w_a of 0.02 and 0.1, respectively.
- Measure γ, the exponent of the growth factor, with a 1 sigma precision of < 0.02, sufficient to distinguish General Relativity and a wide range of modified-gravity theories
- Test the Cold Dark Matter paradigm for hierachical structure formation, and measure the sum of the neutrino masses with a 1 sigma precision better than 0.03eV.
- Constrain n_s, the spectral index of primordial power spectrum, to percent accuracy when combined with Planck, and to probe inflation models by measuring the non-Gaussianity of initial conditions parameterised by f_{NL} to a 1 sigma precision of ~2.

SURVEYS

	Area (deg2)	Description
Wide Survey	15,000 (required) 20,000 (goal)	Step and stare with 4 dither pointings per step.
Deep Survey	40	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey

PAYLOAD

Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250

SPACECRAFT

Launcher	Soyuz ST-2.1 B from Kourou
Orbit	Large Sun-Earth Lagrange point 2 (SEL2), free insertion orbit
Pointing	25 mas relative pointing error over one dither duration 30 arcsec absolute pointing error
Observation mode	Step and stare, 4 dither frames per field, VIS and NISP common FoV = 0.54 deg^2
Lifetime	7 years
Operations	4 hours per day contact, more than one groundstation to cope with seasonal visibility variations;
Communications	maximum science data rate of 850 Gbit/day downlink in K band (26GHz), steerable HGA

Budgets and Performance

	Mass (kg)		*Nominal Power (W)*	
industry	TAS	Astrium	TAS	Astrium
Payload Module	897	696	410	496
Service Module	786	835	647	692
Propellant	148	232		
Adapter mass/ Harness and PDCU losses power	70	90	65	108
Total (including margin)		**2160**	**1368**	**1690**

All data you need to know (Red Book, some changes)

- Wide Area (>10^4 sq deg)
- Wide Field (FoV > 0.5 sq deg)
  - Opt. imaging
  - NIR photom
  - NIR slitless

Two instruments:

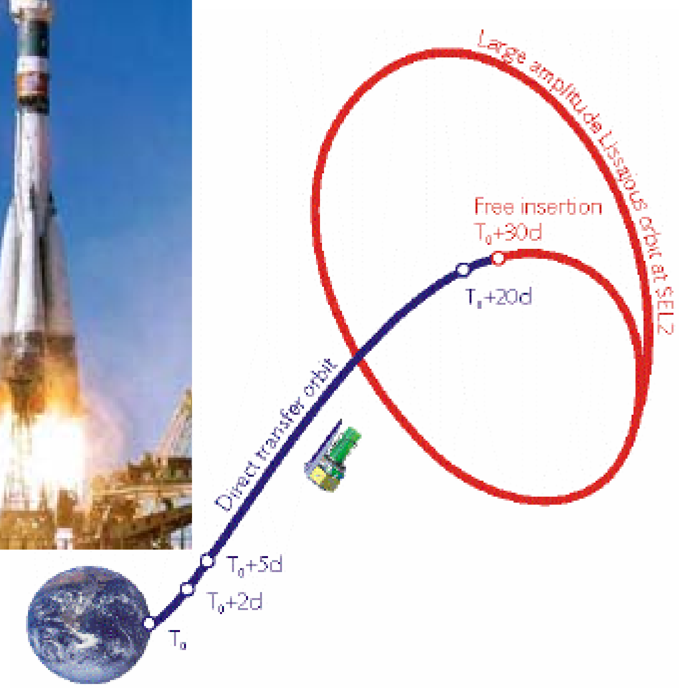
VIS: optical imager &

NISP: NIR imager + grisms

euclid

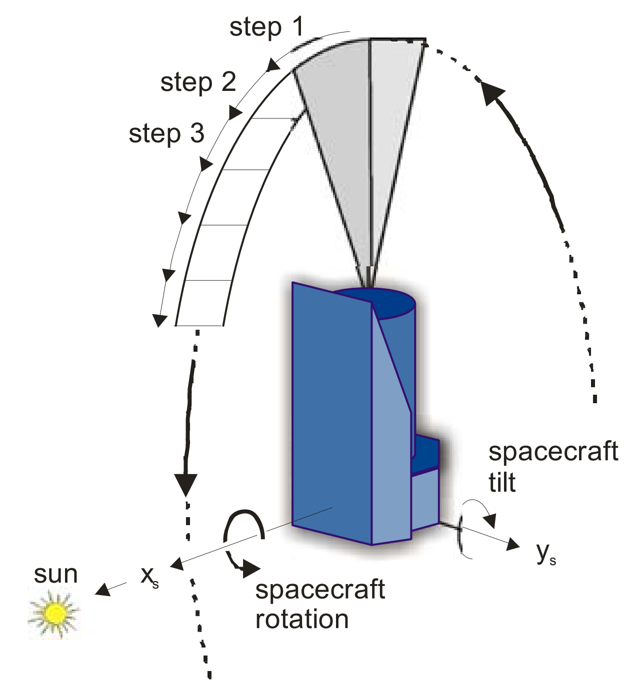
EUCLID Mission

- Launcher: Soyuz ST2-1B from Kourou
- Direct injection into tranfer orbit
  - Transfer time: 30 days
  - Transfer orbit inclination: 5.3 deg
- Launch vehicle capacity:
  - 2160 kg (incl. adapter)
  - 3.86 m diameter fairing
- Launch ≈ 2022
- Mission duration: 6 years



Advanced Studies and Technology Preparation Division

Looks like CMB satellites but with step & stare

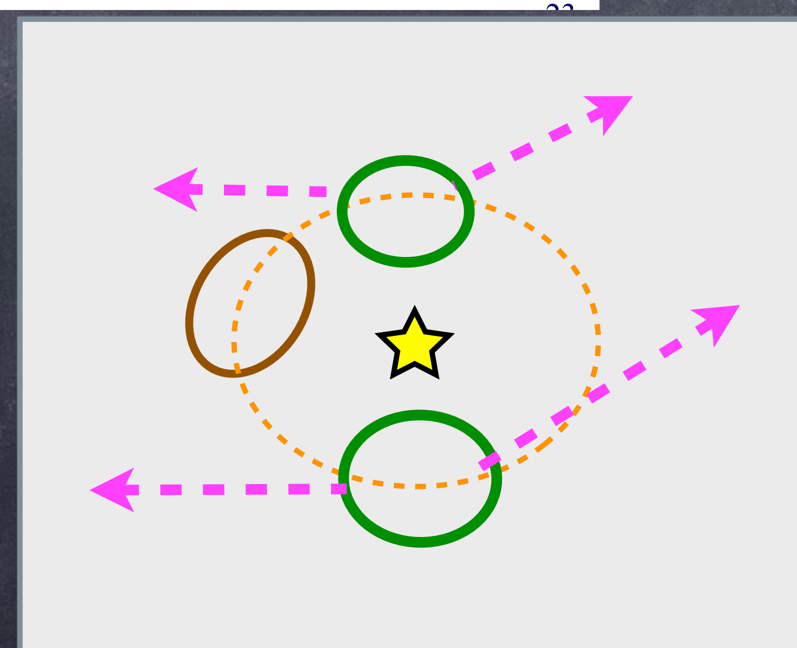


For stability need to always observe orthogonally to the sun

6

region visibility: twice/yr at ecliptic plane (1deg/day), max at ecliptic poles (always).

spin 2 behaviour as in WL



4 dithers ~1 full Field -0.5 sq deg- / 1.25 hr (≈10 sq deg/day)

Observing sequence for each field + move to next one ~4500 s

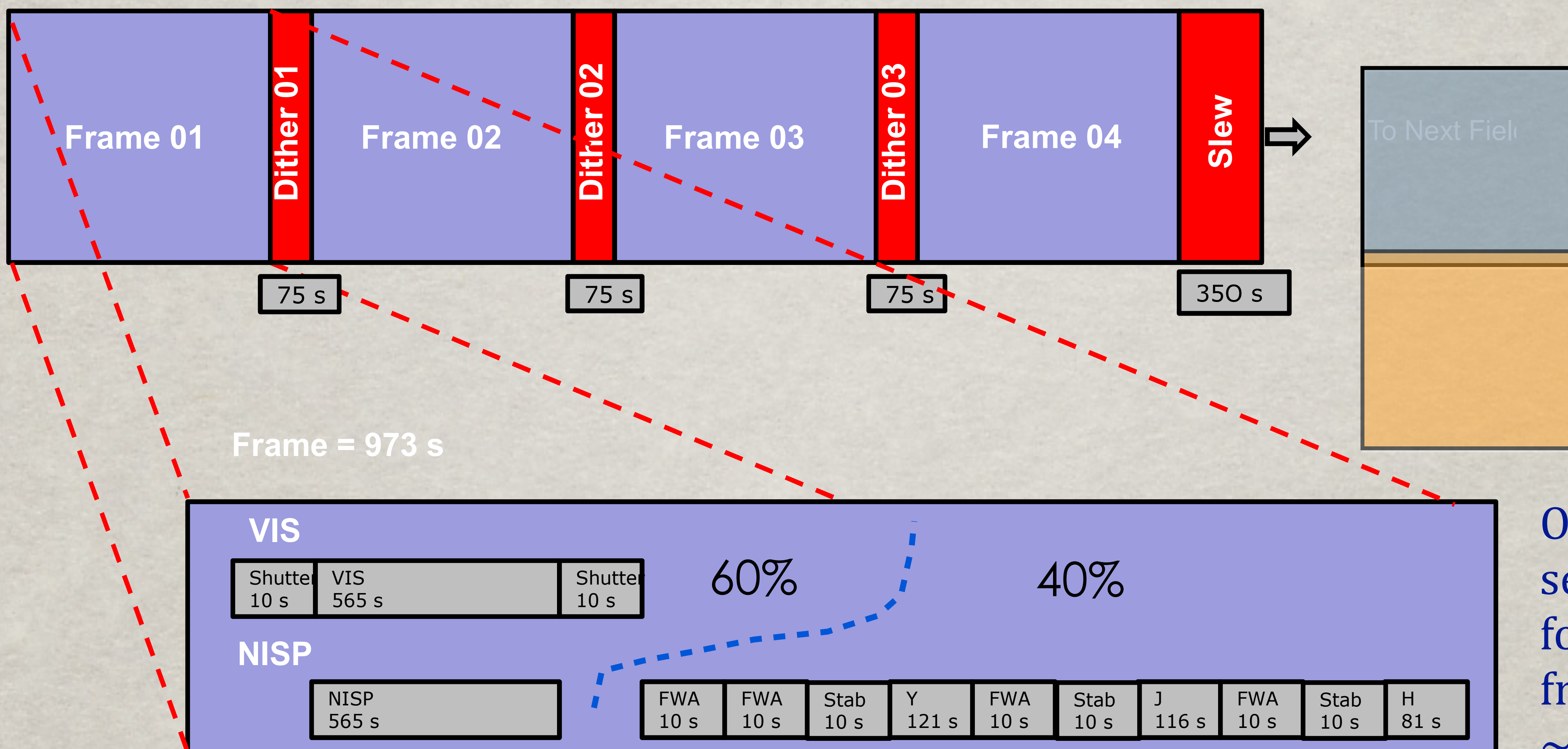
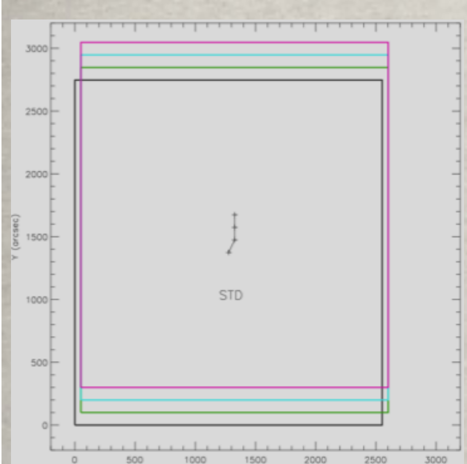


Figure 5-4: Nominal Field Observation Sequence.

coverage
50% 3 exp
50% 4 exp

Observing sequence for each frame ~1000 s



Slitless: Red grism 1.25-1.8μ (Hα: 0.9<z<1.7)

4 exposures: directions 0, 90, 180 degs, then again once

Slitless: Blue grism 0.92-1.25μ (TBD) only in the Deep

Large sky regions are unsuitable or subpar for our T_exp

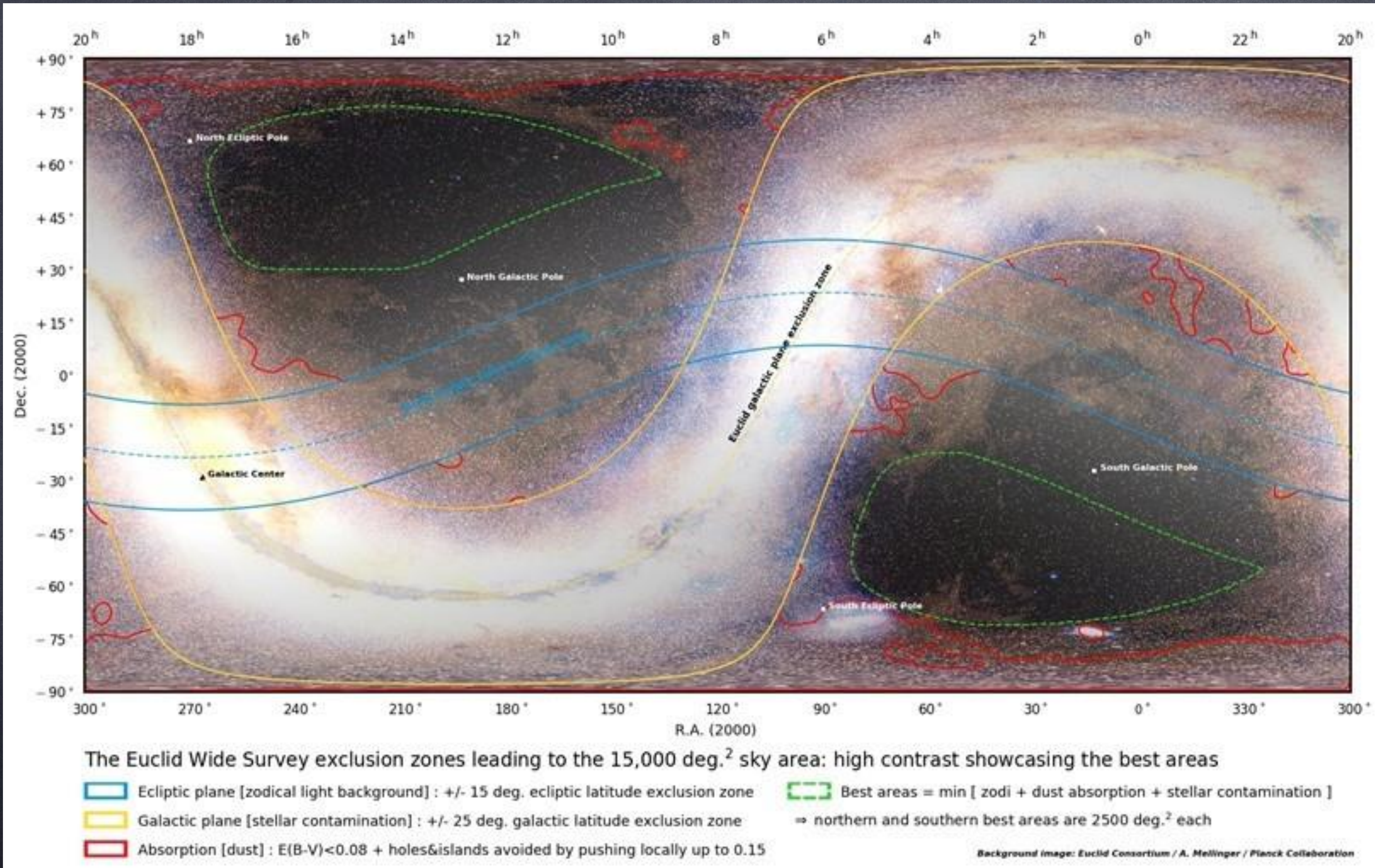


Figure 7.2.1 Euclid sky with best areas identified

Good areas << 15,000 sq degs

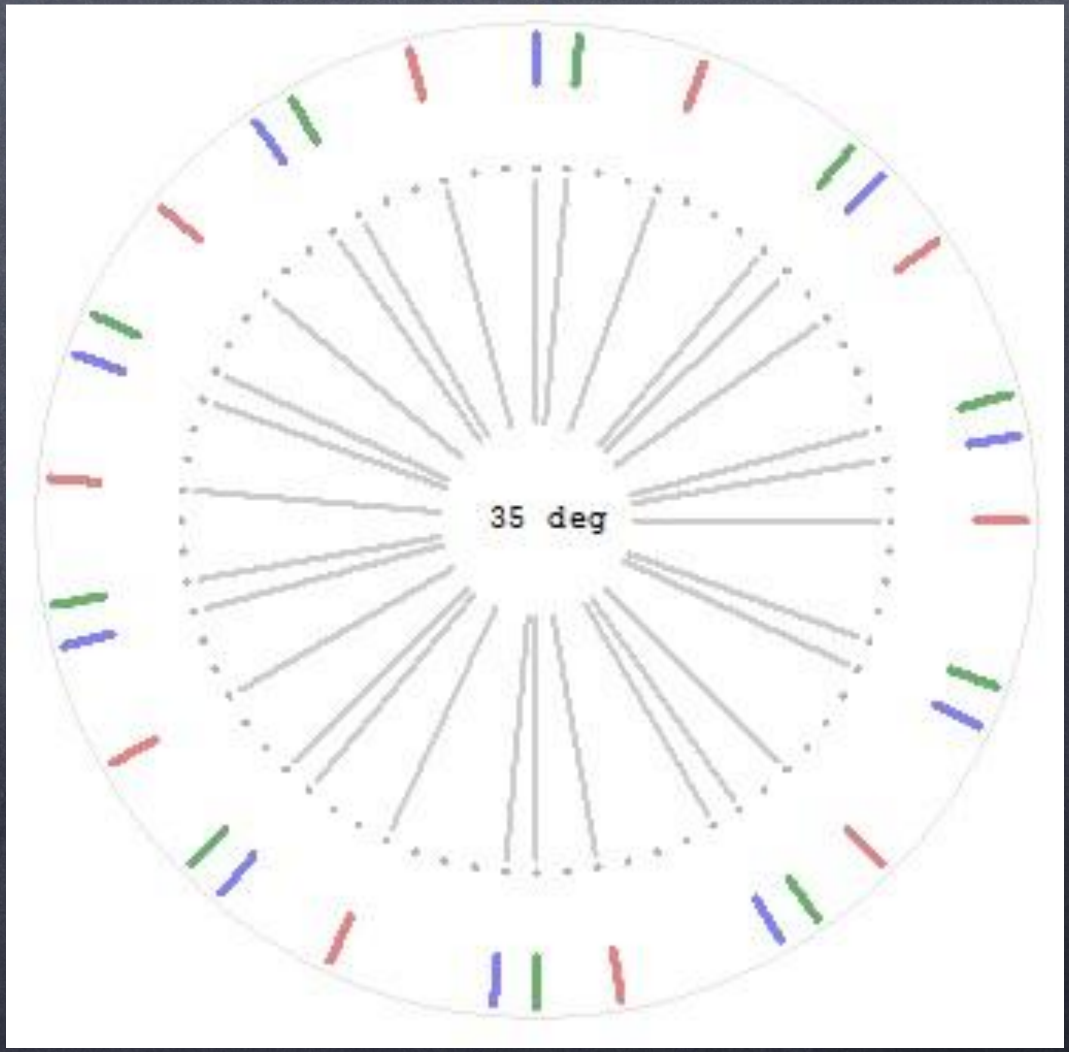
Plots by J.C. Cuillandre

Euclid Deep Fields

Requirements

- cover at least 40 square degrees in two fields (one in Northern, one in Southern Emisphere)
- at least 2 magnitudes deeper (—> 40 visits)
- growth in time like the survey
- Completeness Purity Calibration files [CPC]: at least 40 square degrees of spectroscopy, 10 visits with large angular separation for spectral dispersion

CPC example:



Three Deep Fields

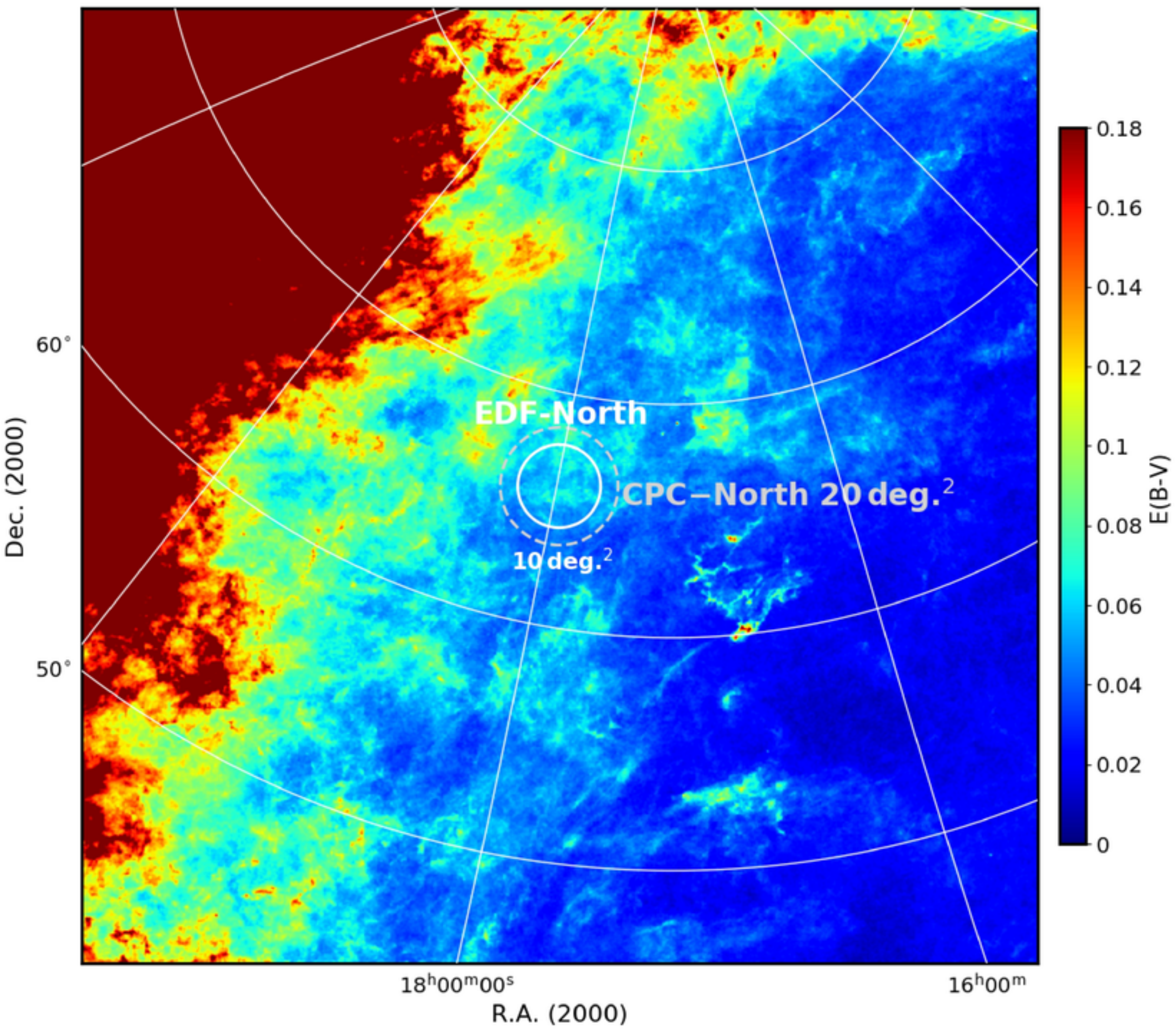
Proposal now approved by everybody

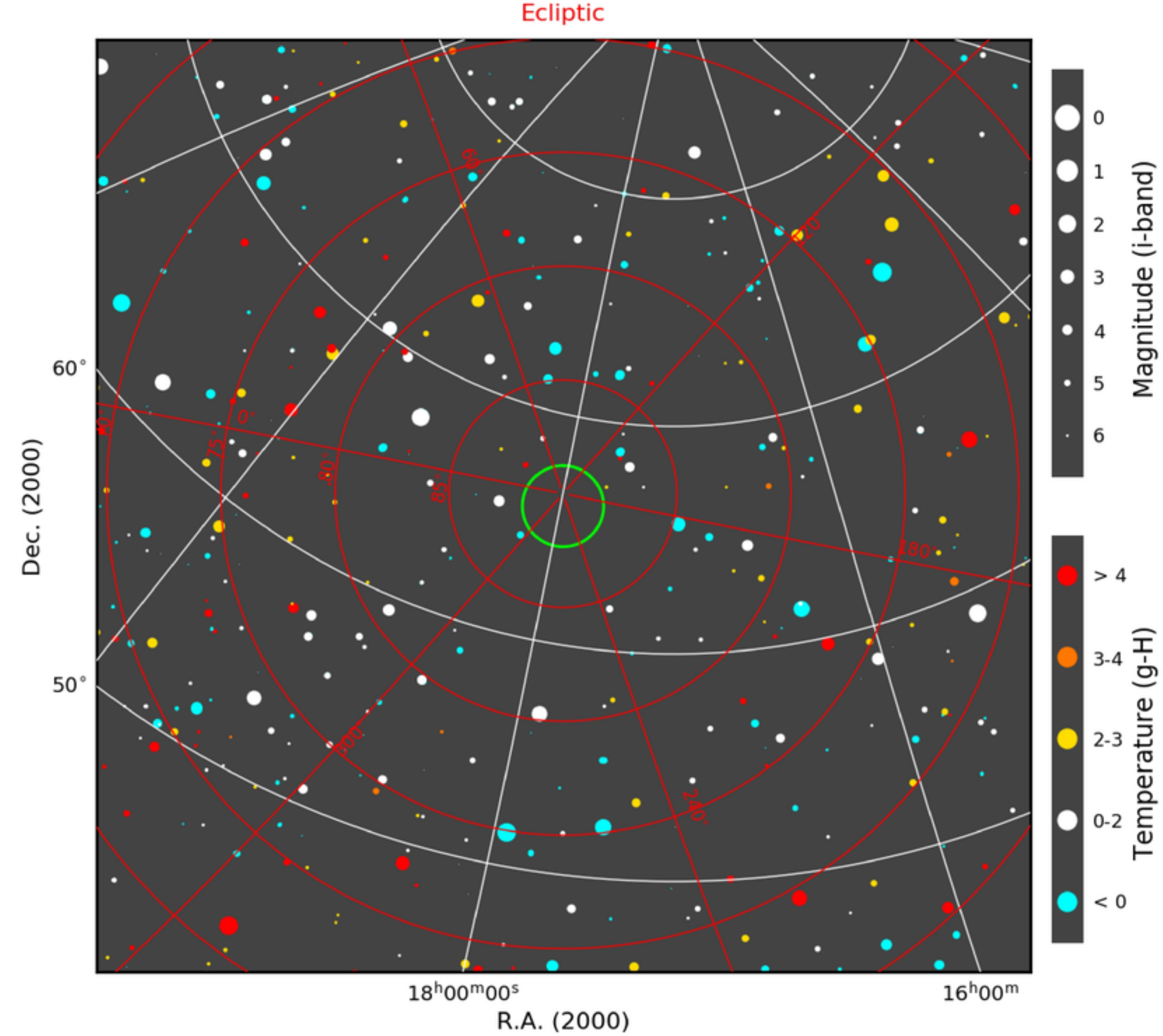
So now have:

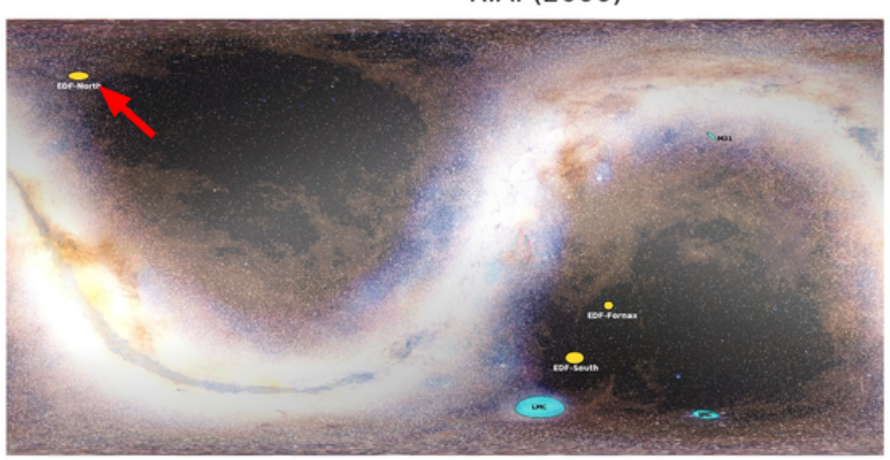
- **a two tier EDF-North [EDFN] (20 sq deg x 10 visits+ inner sq deg 10 x 30 visits more); + self-cal (4 sq deg, monthly visits, partial random cover)**
- **an EDF-Fornax [EDFF] (10 sq deg x 56 visits) comprising the Chandra Deep South**
- **an EDF-South [EDFS] (23 sq deg x 45 visits); collaboration with LSST**

limiting AB mag 5σ pointlike: VIS ~27.5, NISP y, J, H ~26

Also "blue" [0.92-1.25μ] grism can be used to observe the deep fields







Euclid Deep Field North (EDF–N)

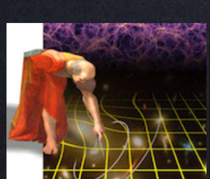
R.A. 17:58:55.9, Dec. +66:01:03.7, J2000, 10 sq. deg.

Wide view context:

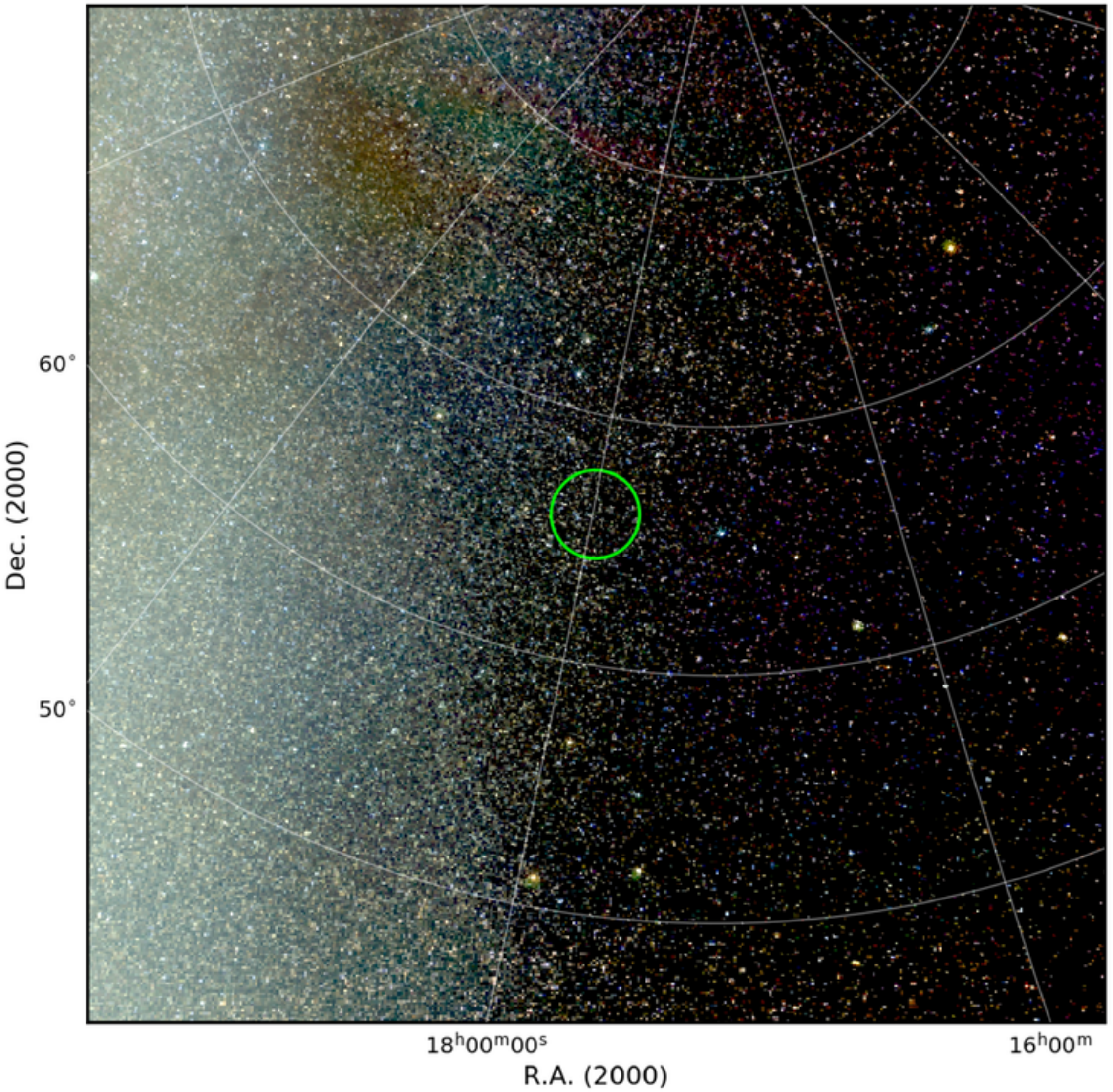
- **Reddening: E(B–V)**
- **Contamination: bright stars**

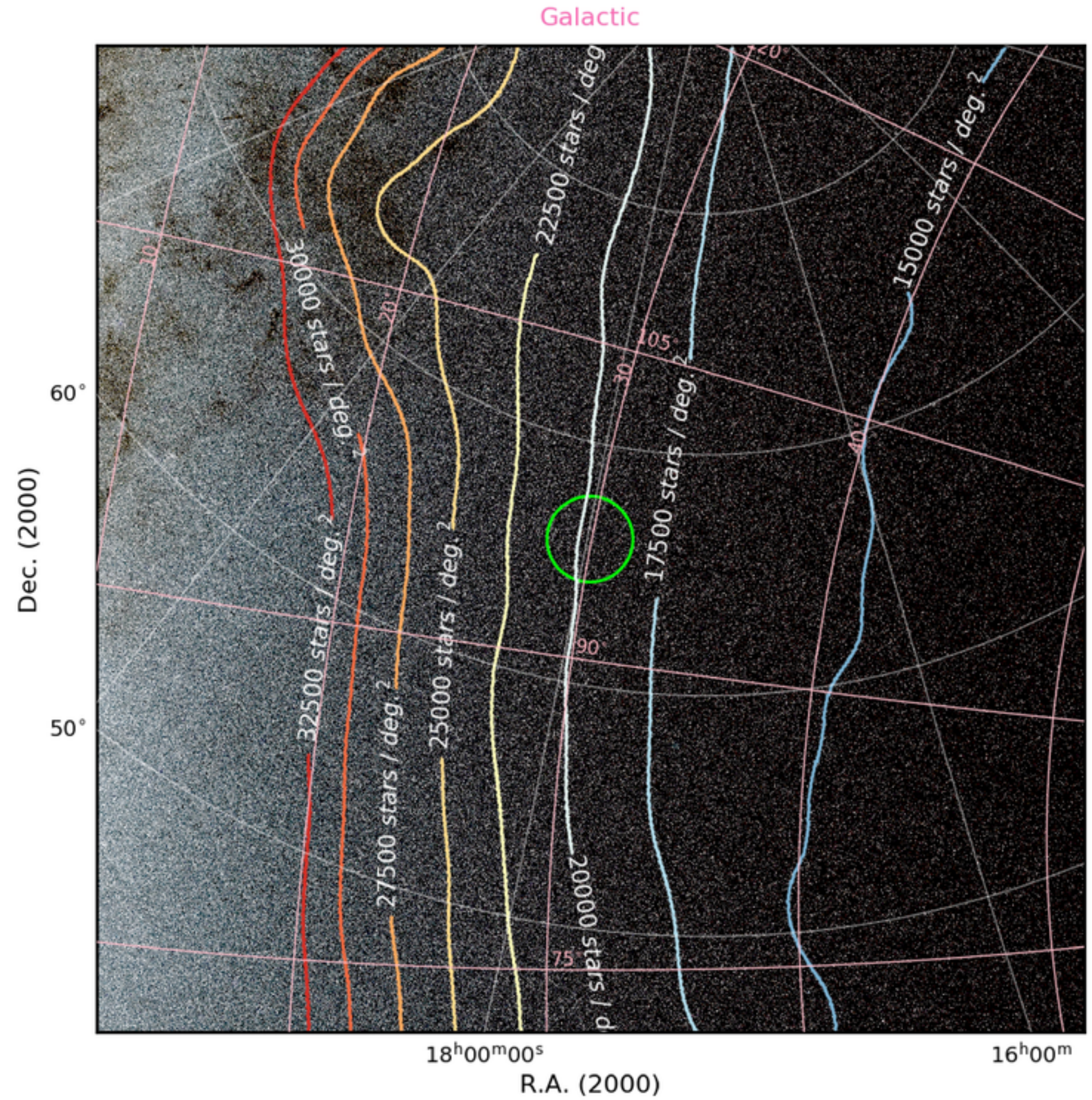
Dust map: Planck Collaboration, A&A, 2014, 571, 11
Star catalog: Pickles et al., PASP, 2010, 122, 898

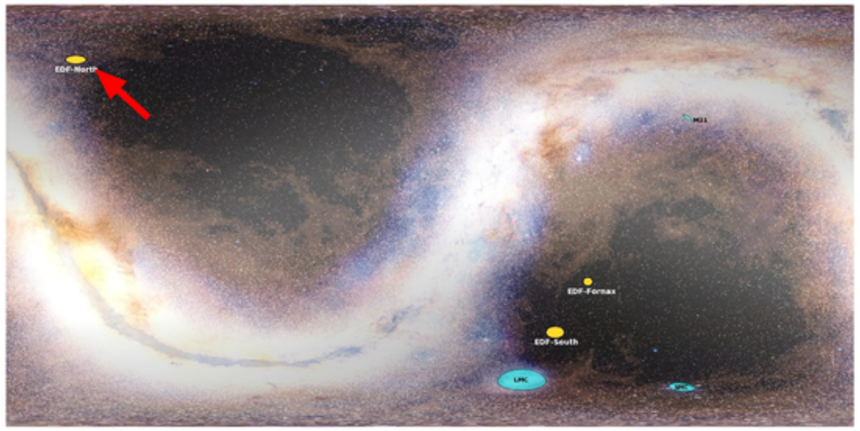
Center is offset by ~1 deg from geometric NEP to maximise overlap with Spitzer (P. Capak)



plot (and similar ones) by J.C. Cuillandre







Euclid Deep Field North (EDF–N)

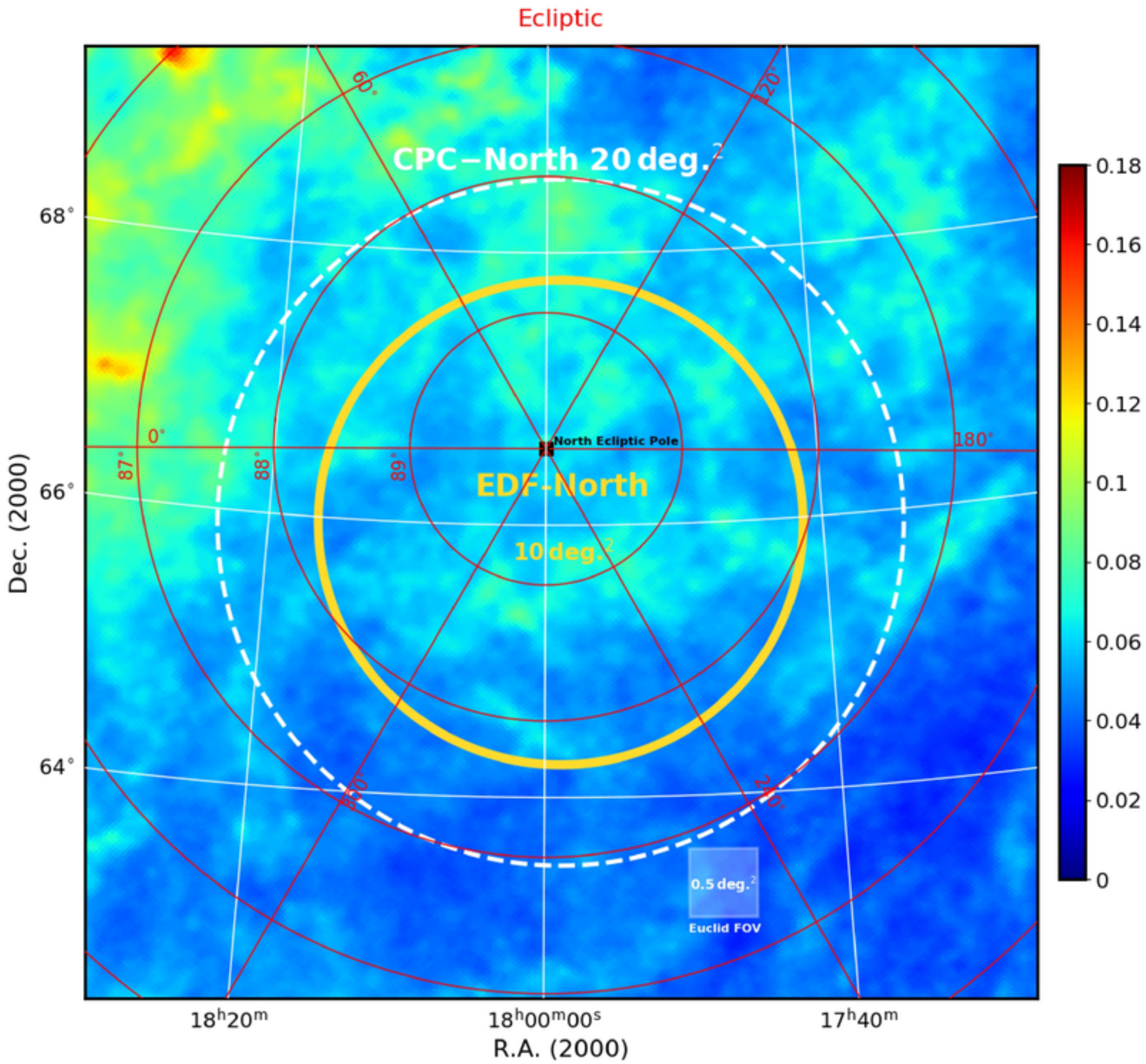
R.A. 17:58:55.9, Dec. +66:01:03.7, J2000, 10 sq. deg.

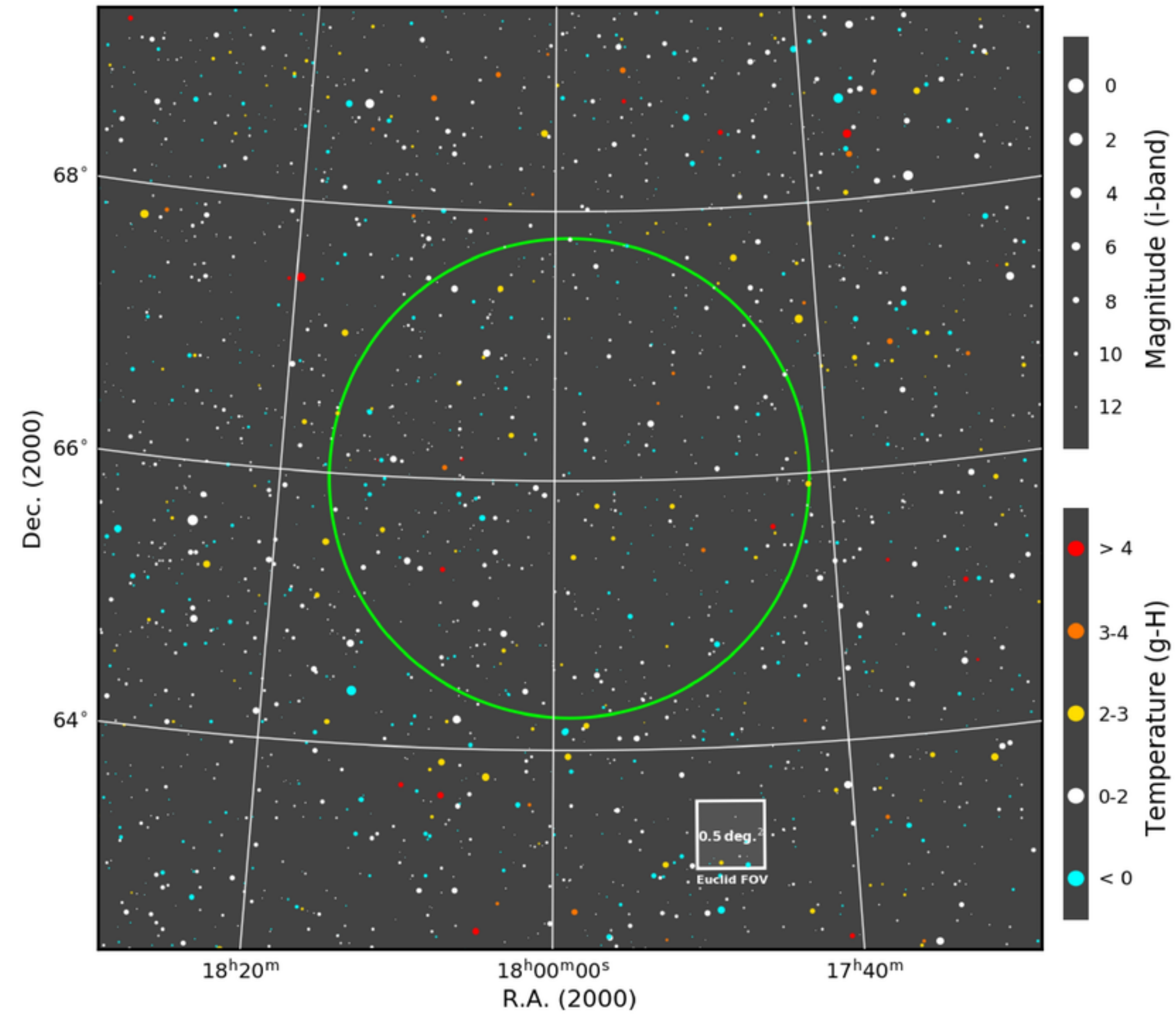
Wide view context:

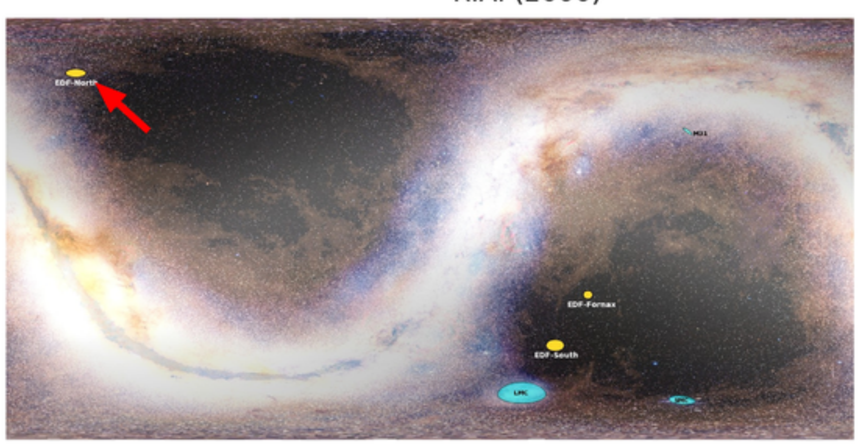
- **Optical: true image (RGB)**
- **Optical: stellar density (R)**

True image: A. Mellinger, PASP, 2009, 121, 1180
Stellar density dataset: ESA/Gaia/DPAC

good: several stars for PSF but not too many







Euclid Deep Field North (EDF–N)

R.A. 17:58:55.9, Dec. +66:01:03.7, J2000, 10 sq. deg.

Equatorial:	269.73	+66.02
Ecliptic:	258.69	+89.45
Galactic:	95.76	+29.92

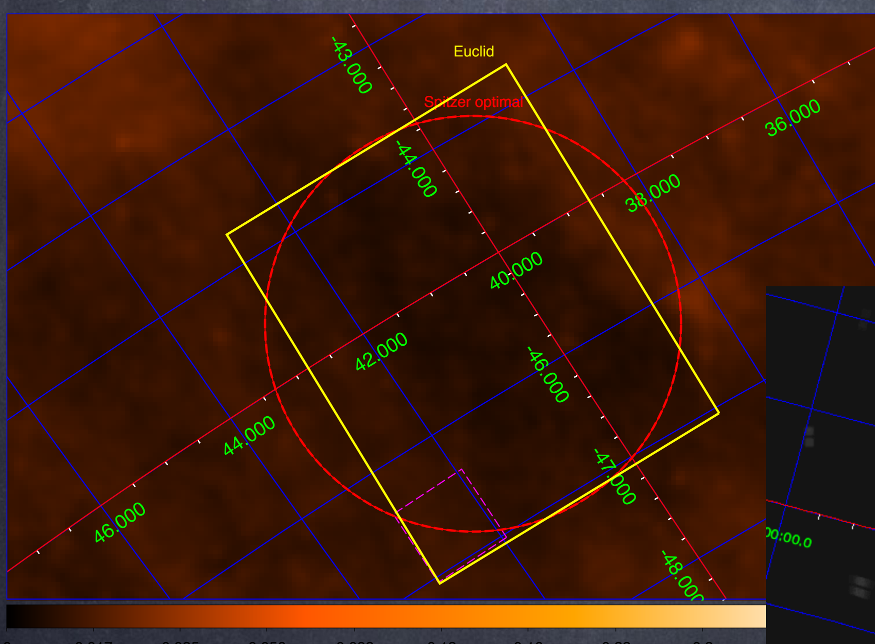
Dust map: Planck Collaboration, A&A, 2014, 571, 11
Star catalog: Pickles et al., PASP, 2010, 122, 898

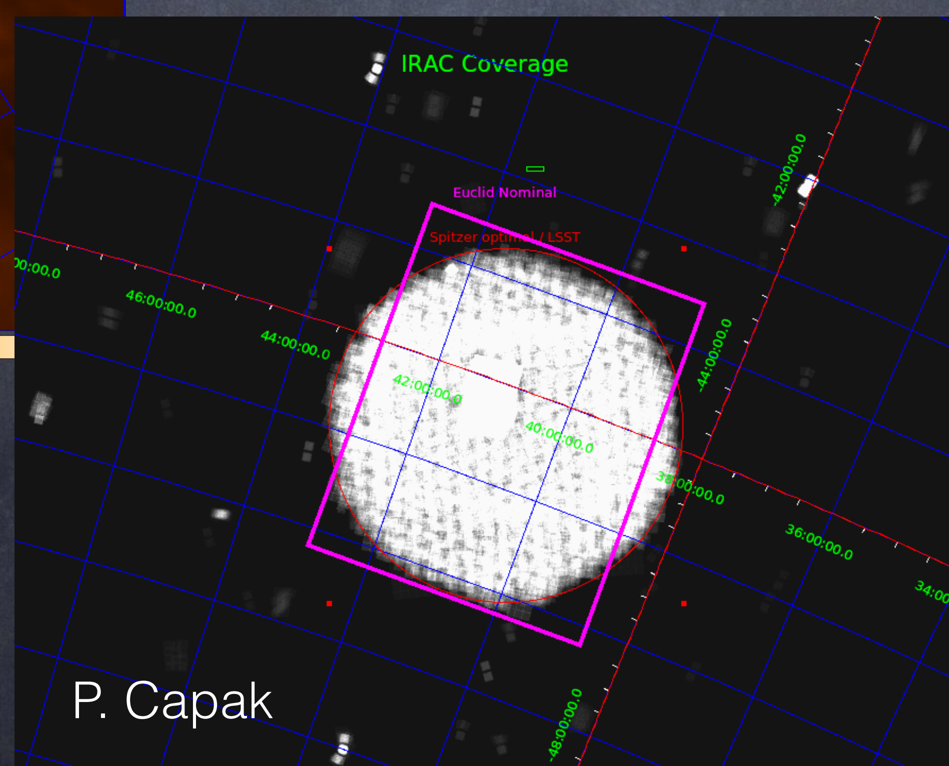
Center is offset by ~1 deg from geometric NEP to maximise overlap with Spitzer (P. Capak)

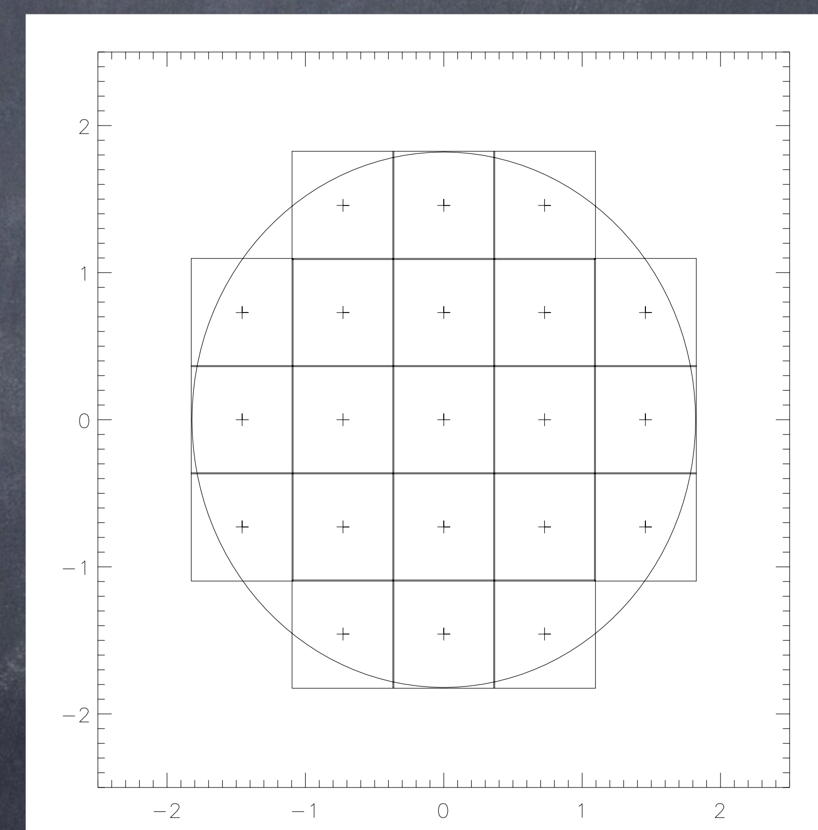
EDF-Fornax

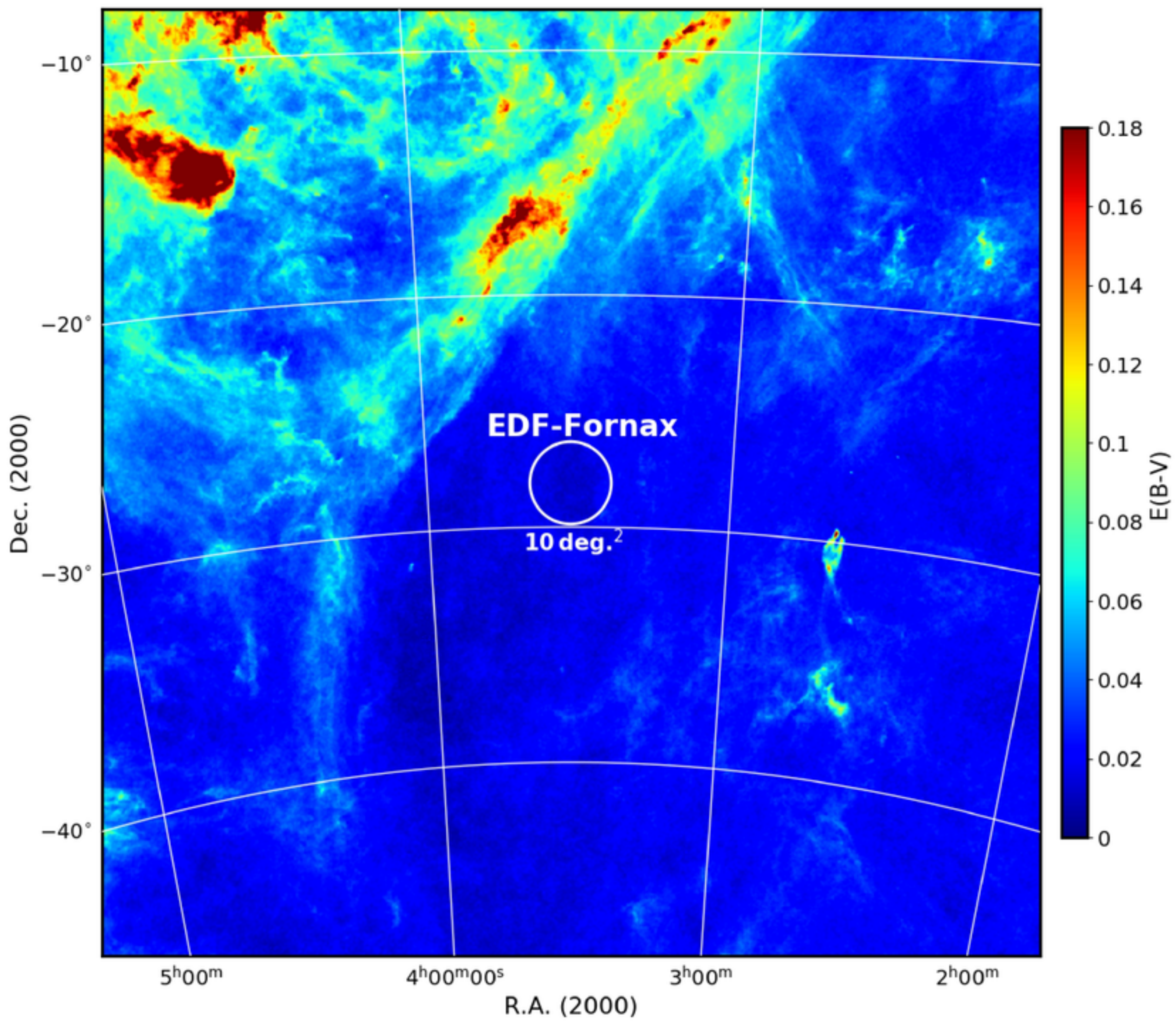
4x5+1 fields, 56 visits (+16 compensate for larger <zodiacal>), no much smearing at borders

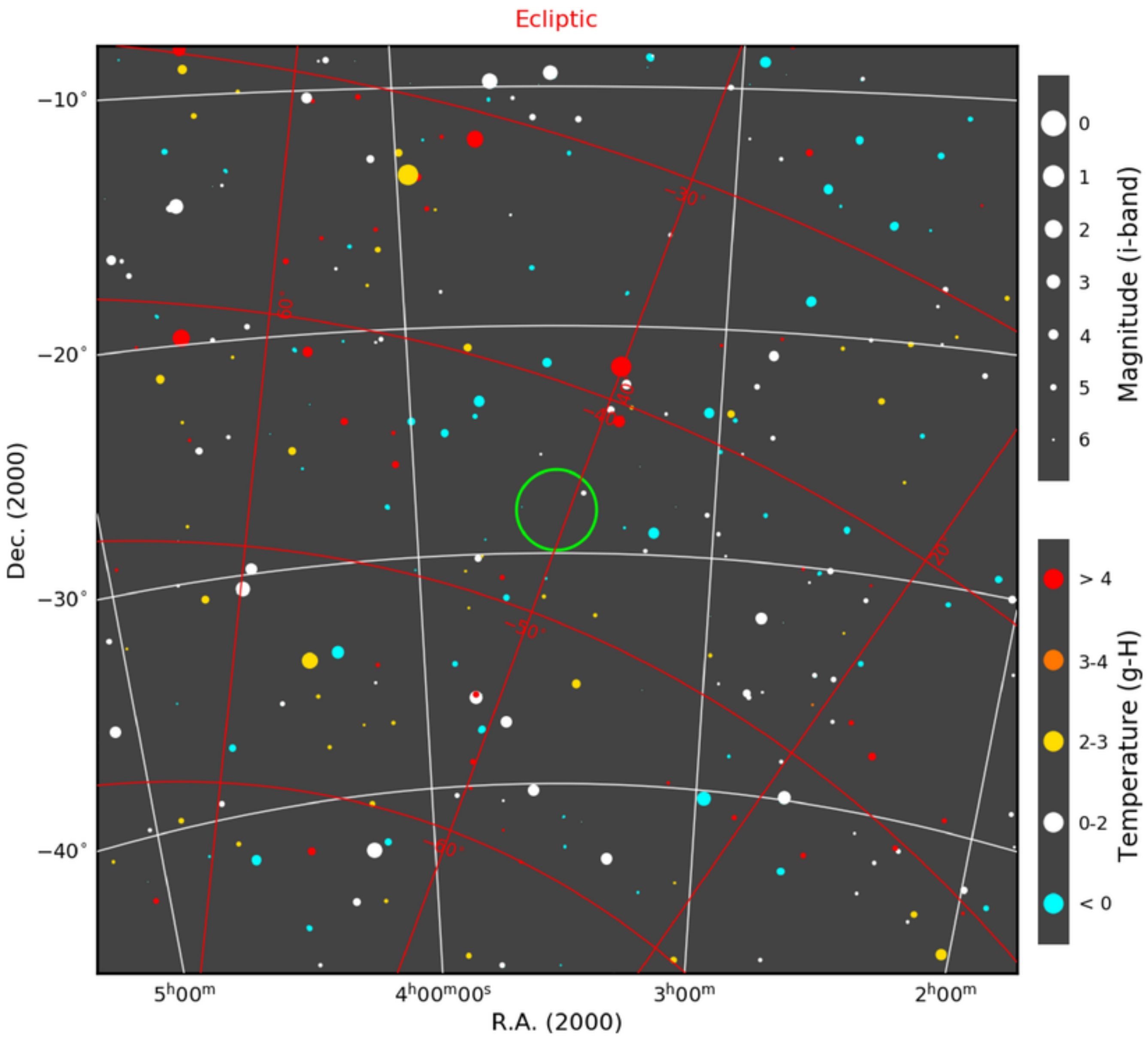
Change from rectangle (Euclid optimal) to a circle to better cover Spitzer (Capak) and LSST

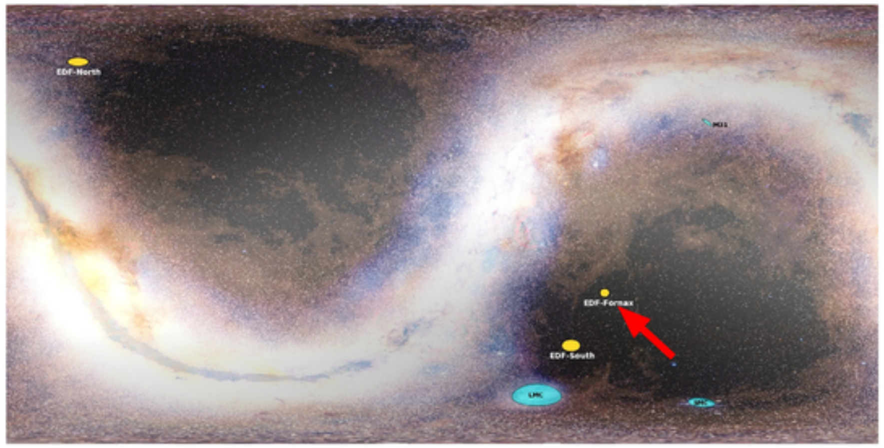












Euclid Deep Field Fornax (EDF–F)

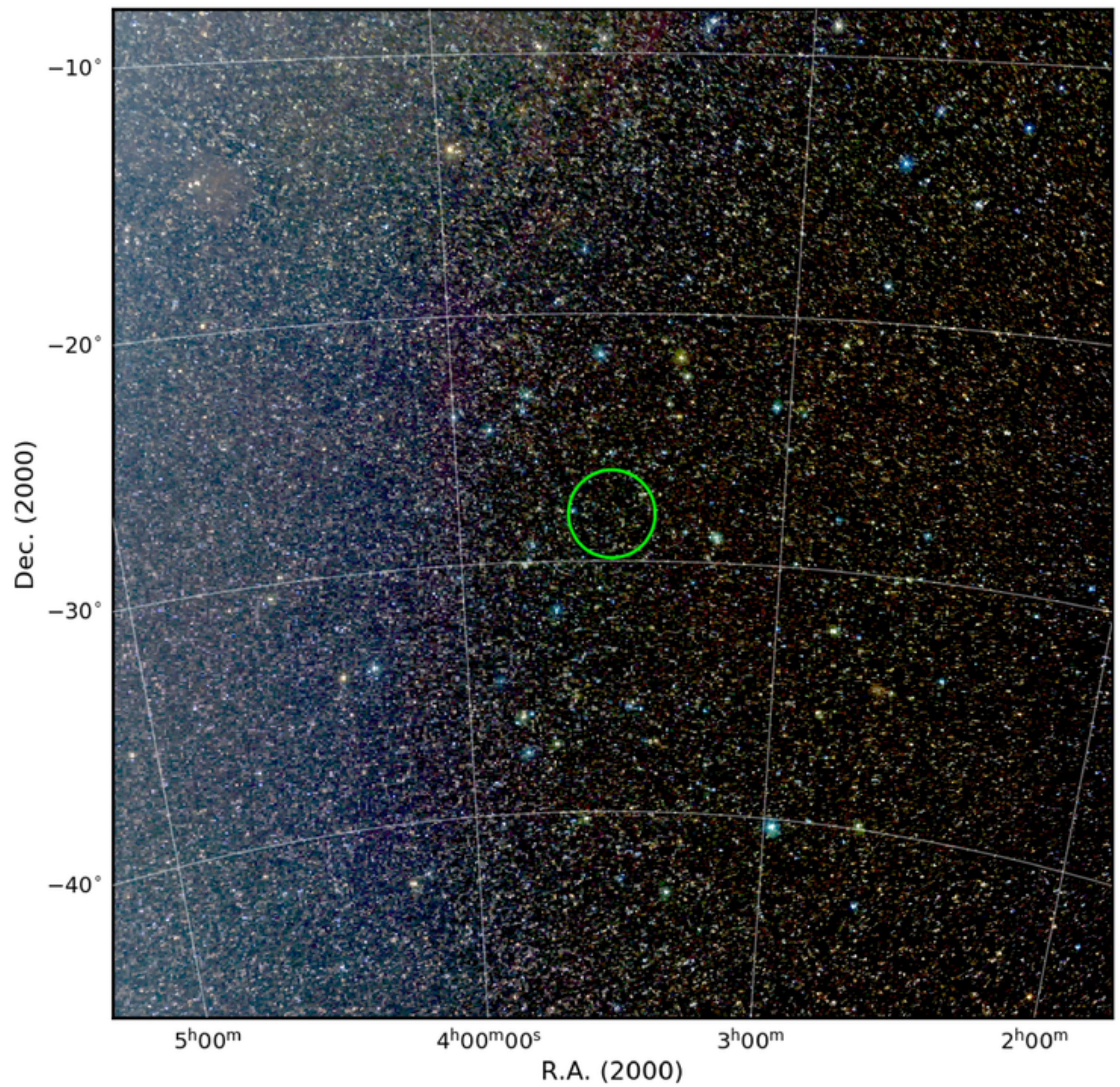
R.A. 03:31:43.6, Dec. –28:05:18.6, J2000, 10 sq. deg.

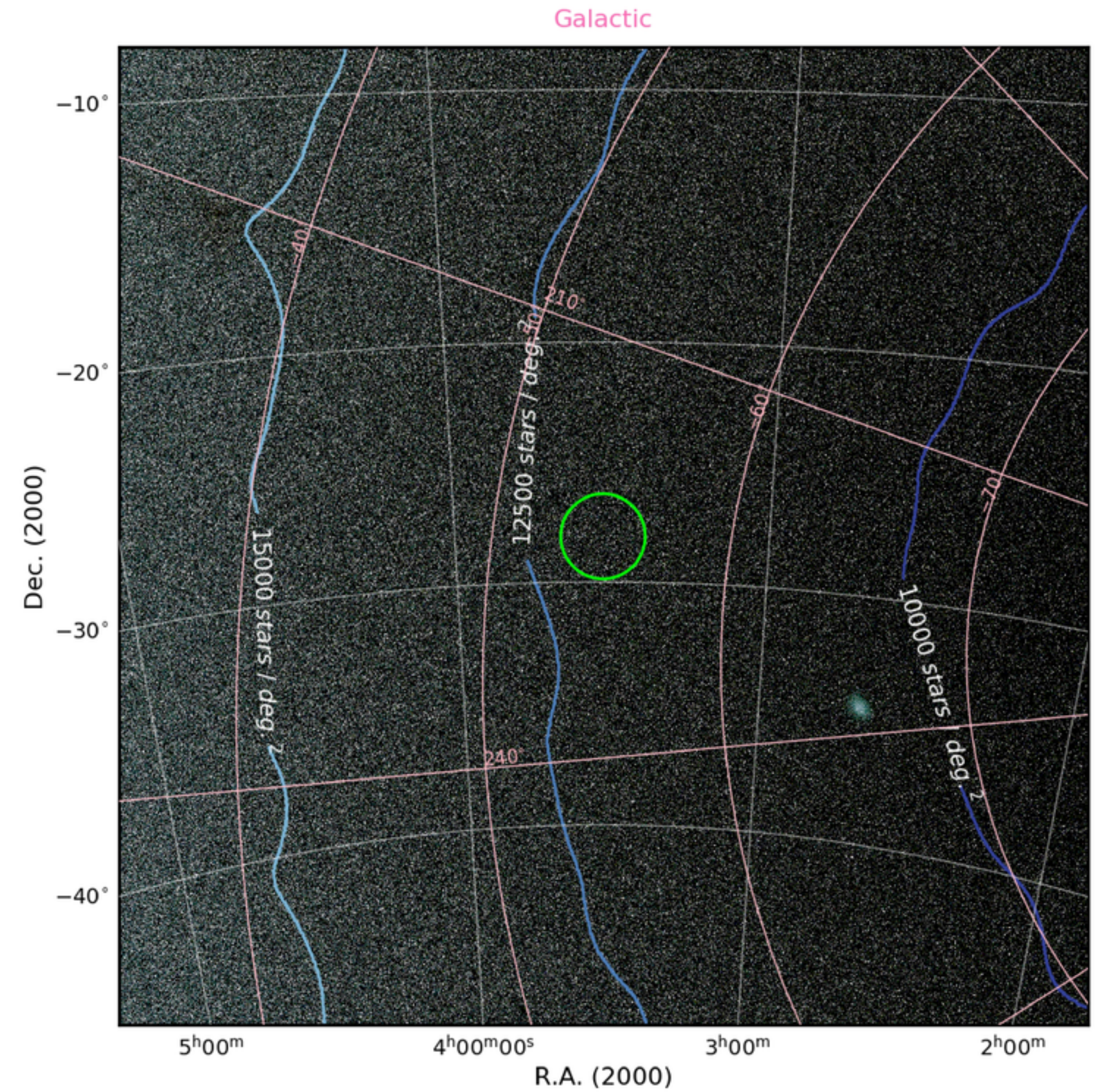
Wide view context:

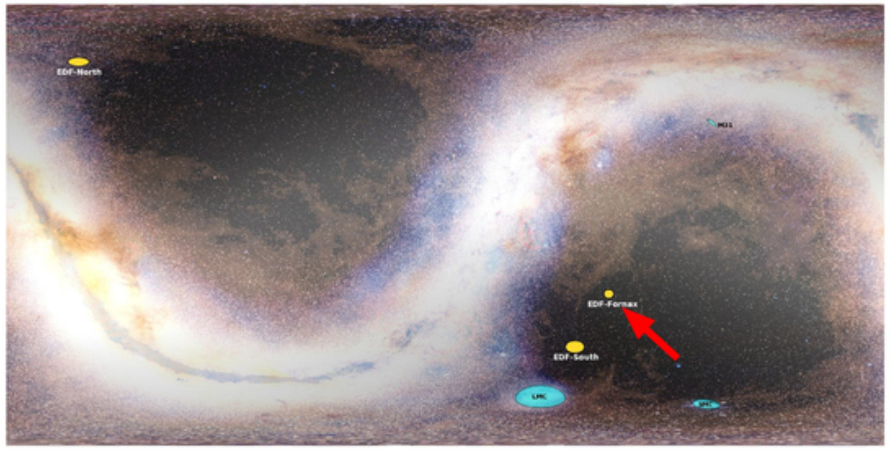
- **Reddening: E(B–V)**
- **Contamination: bright stars**

Dust map: Planck Collaboration, A&A, 2014, 571, 11
Star catalog: Pickles et al., PASP, 2010, 122, 898

This plot and similar ones by J.C. Cuillandre







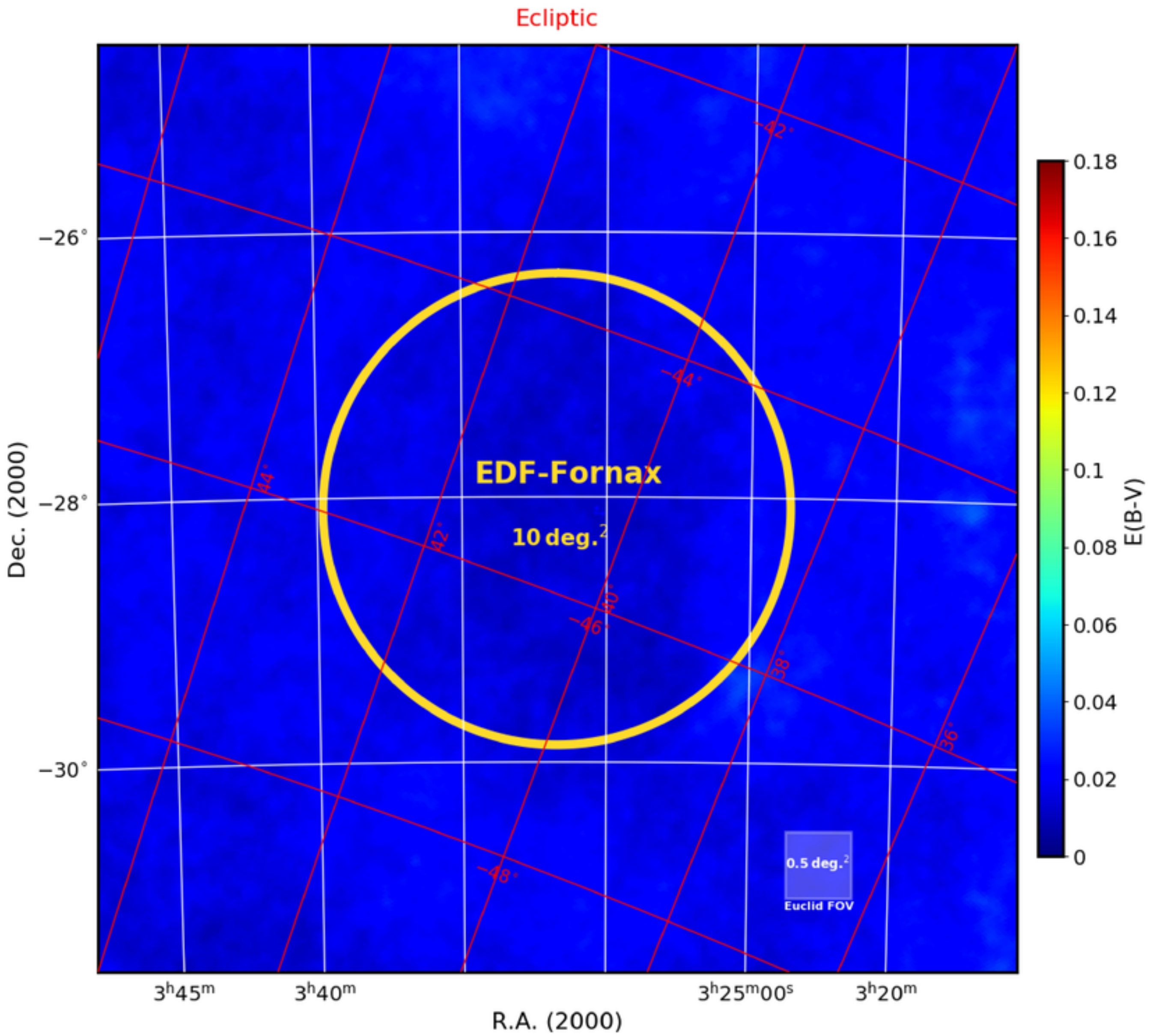
Euclid Deep Field Fornax (EDF–F)

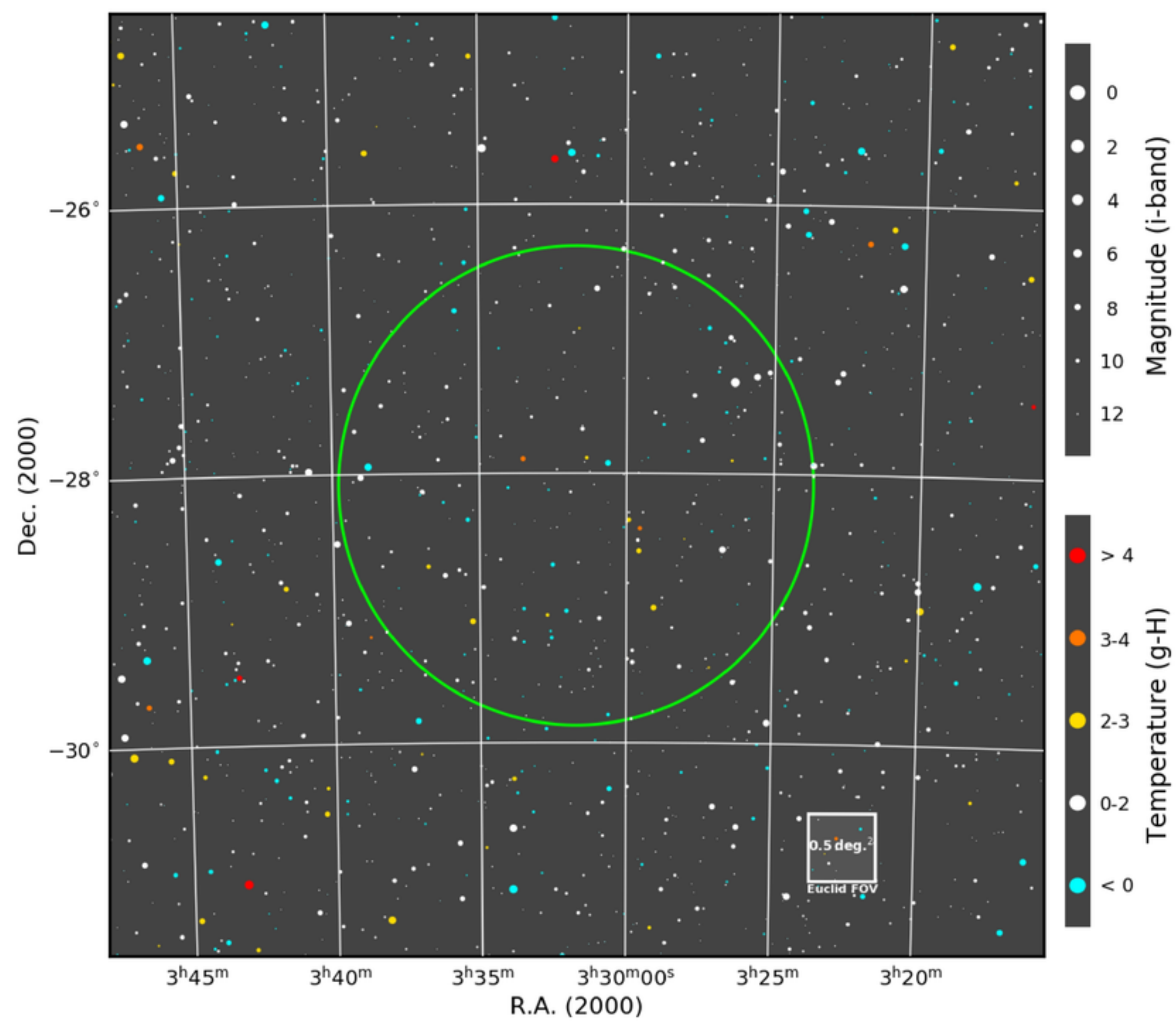
R.A. 03:31:43.6, Dec. –28:05:18.6, J2000, 10 sq. deg.

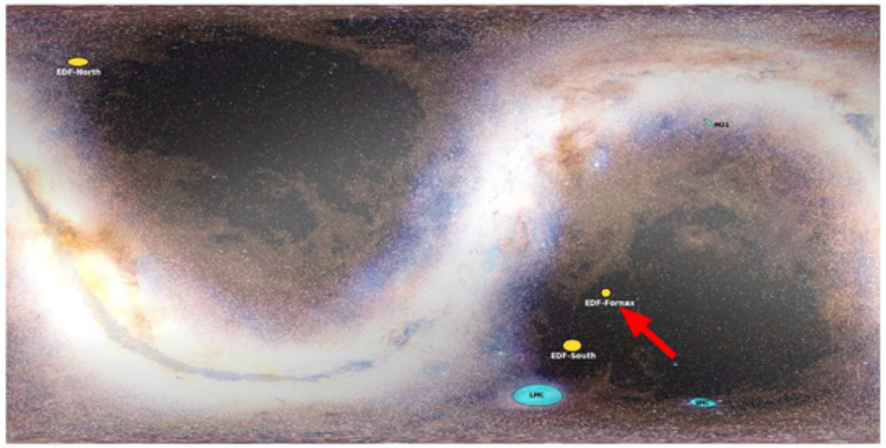
Wide view context:

- **Optical: true image (RGB)**
- **Optical: stellar density (R)**

True image: A. Mellinger, PASP, 2009, 121, 1180
Stellar density dataset: ESA/Gaia/DPAC







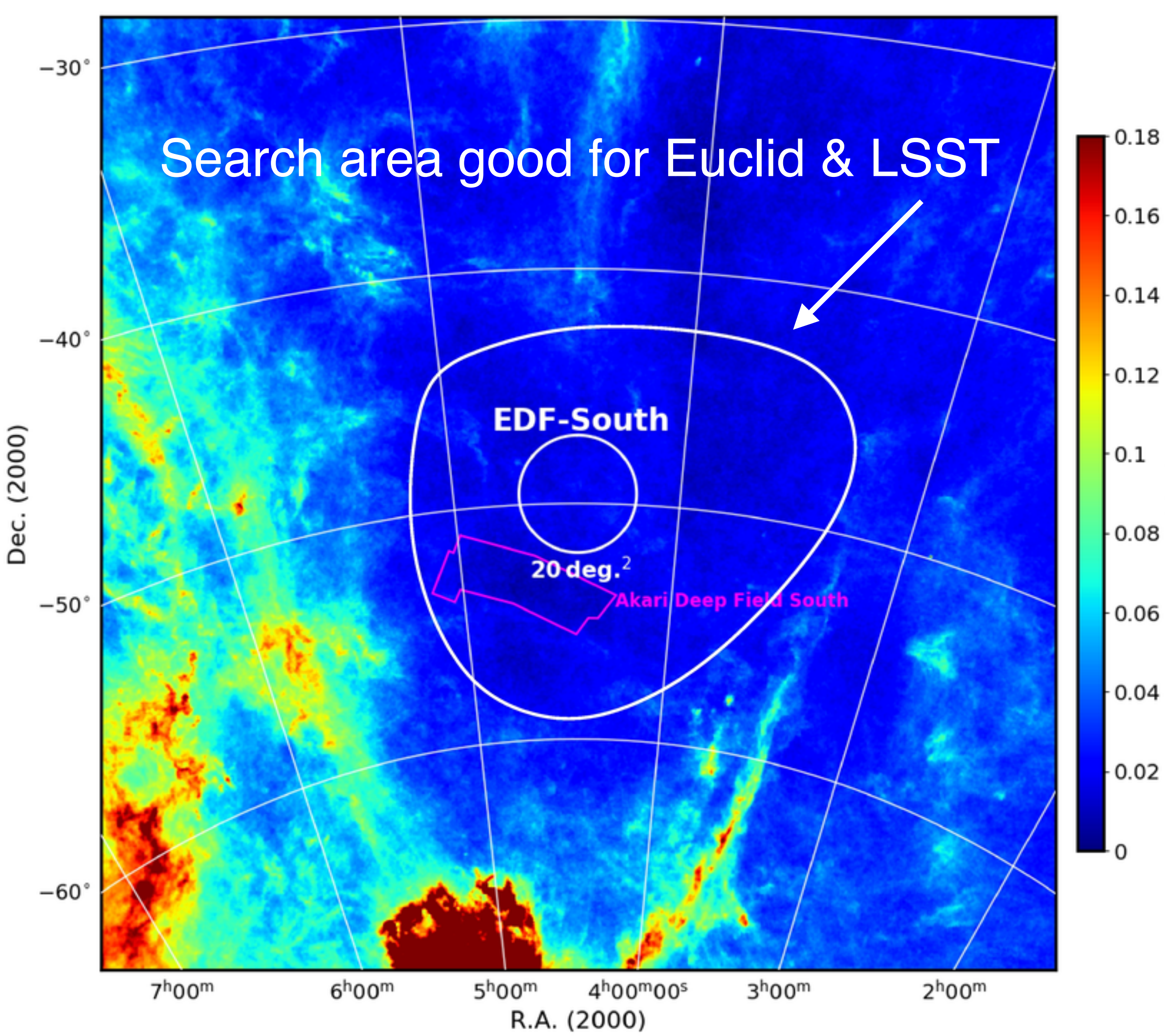
Euclid Deep Field Fornax (EDF–F)

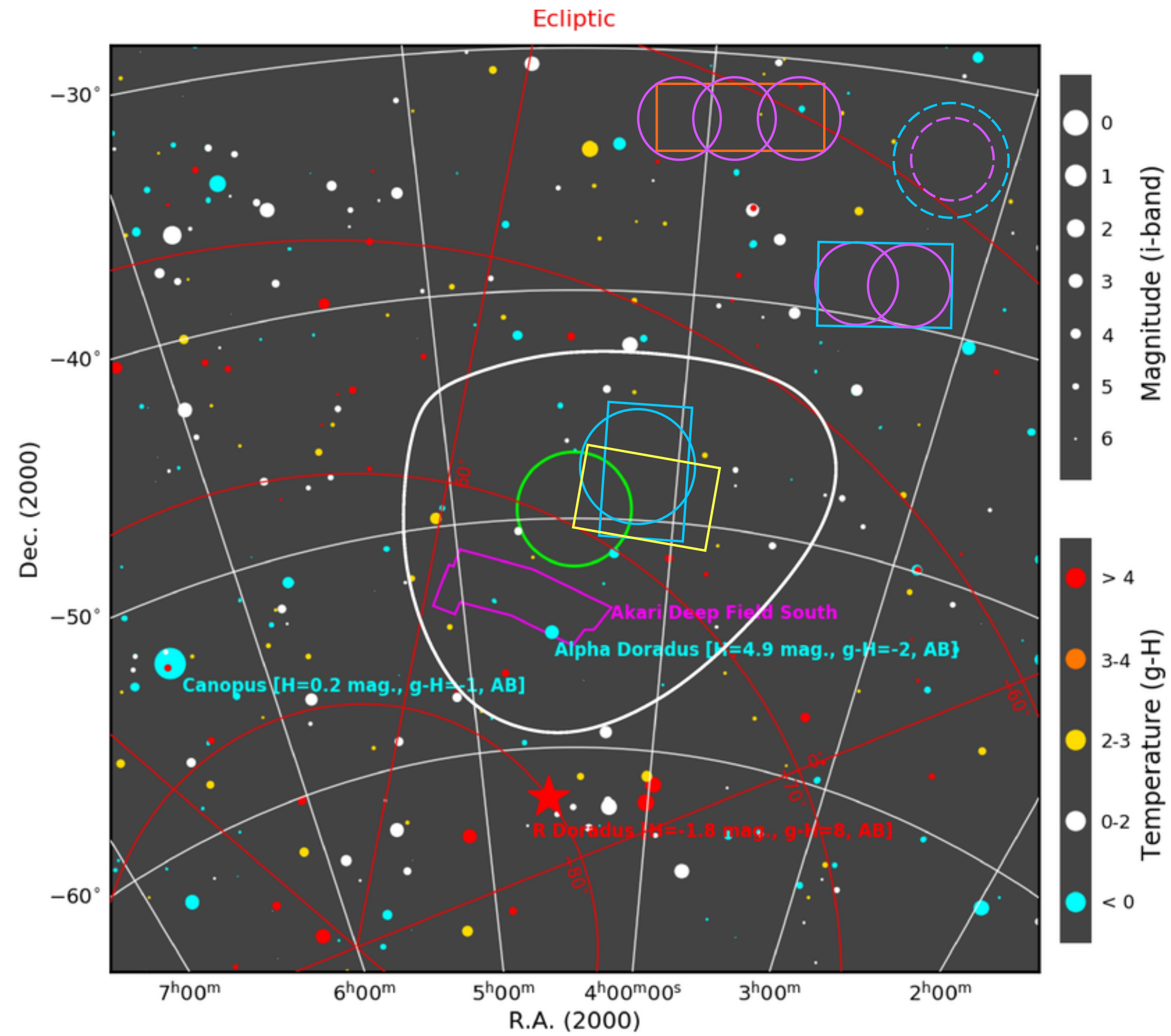
R.A. 03:31:43.6, Dec. –28:05:18.6, J2000, 10 sq. deg.

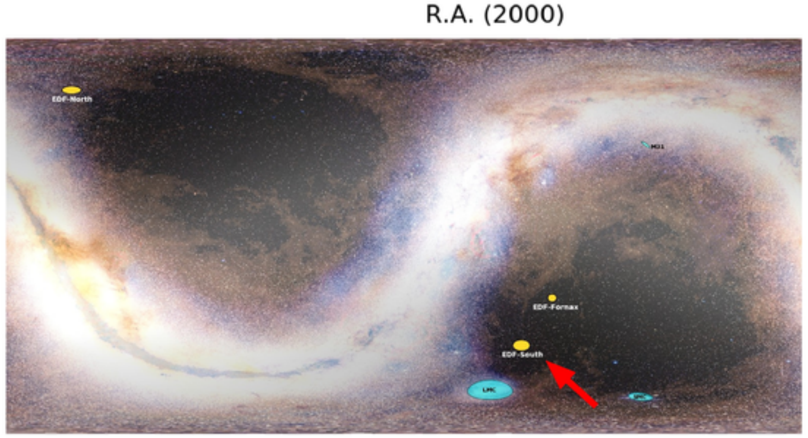
Equatorial:	**52.93**	**–28.09**
Ecliptic:	**40.77**	**–45.40**
Galactic:	**224.01**	**–54.64**

Dust map: Planck Collaboration, A&A, 2014, 571, 11
Star catalog: Pickles et al., PASP, 2010, 122, 898

Tried to also fit some rectangular shapes for LSST







Euclid Deep Field South (EDF–S)

Search area for the optimal contiguous 20 sq. deg.

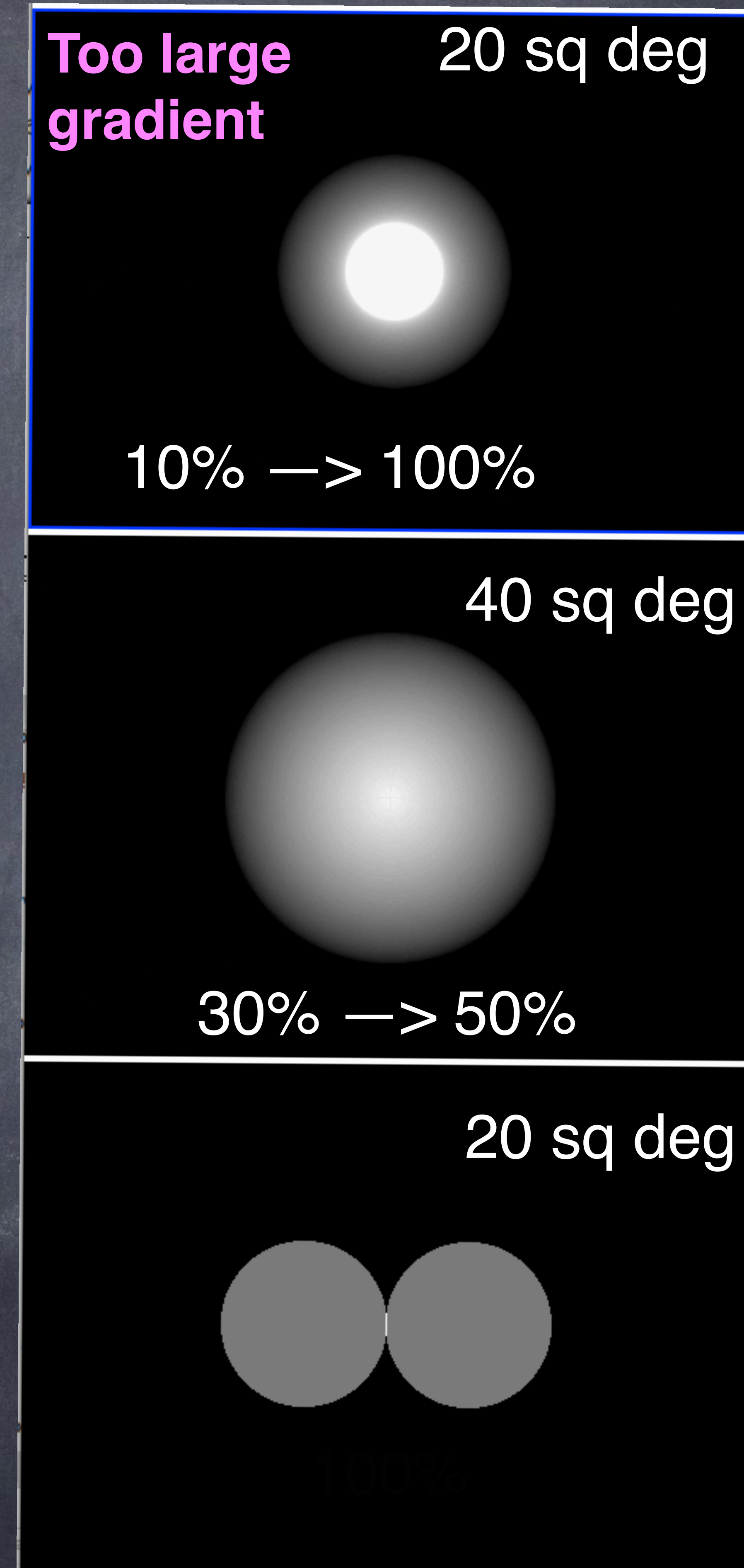
Wide view context:

- **Reddening: E(B–V)**
- **Contamination: bright stars**

Dust map: Planck Collaboration, A&A, 2014, 571, 11
Star catalog: Pickles et al., PASP, 2010, 122, 898

For Euclid a simple circle is best, covered with 43 tiles

LSST possible ways of covering 20 sq deg: spatially varying completeness



Since LSST goes much deeper than required by Euclid this solution would match well Euclid needs but it has **too low efficiency for LSST**

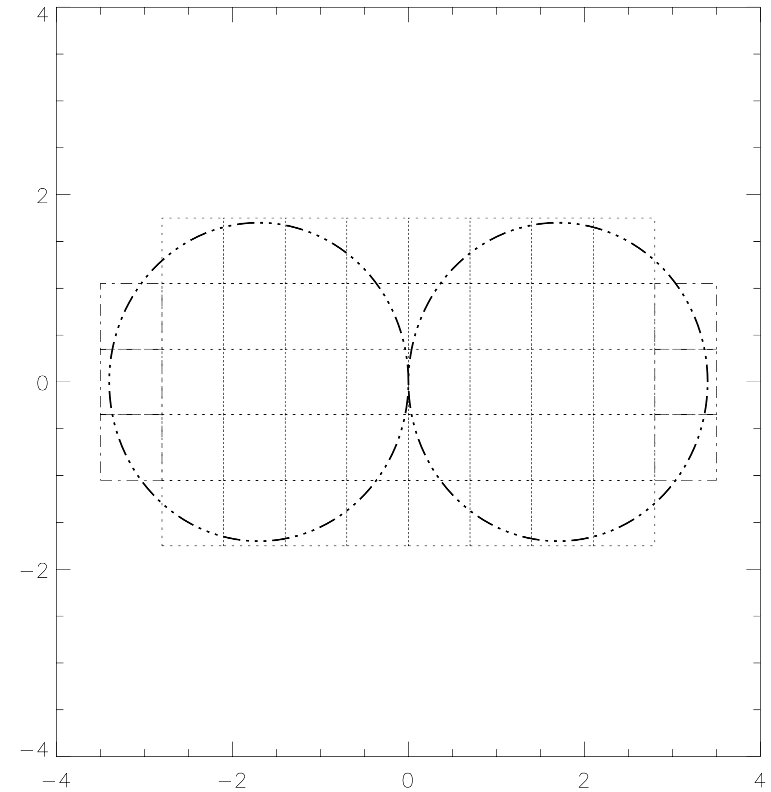
LSST prefers this binocular shape because it is optimal and has 100% efficiency for it

Need LSST ~33 hrs for Euclid photoz depth

From Euclid to present times, a well known concept…

στάδιον

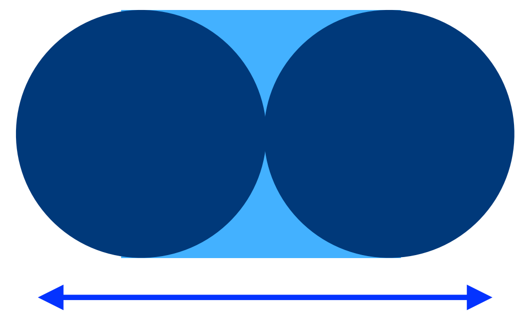
To cover the LSST shape need 46 tiles instead of 43 (~ +7%)



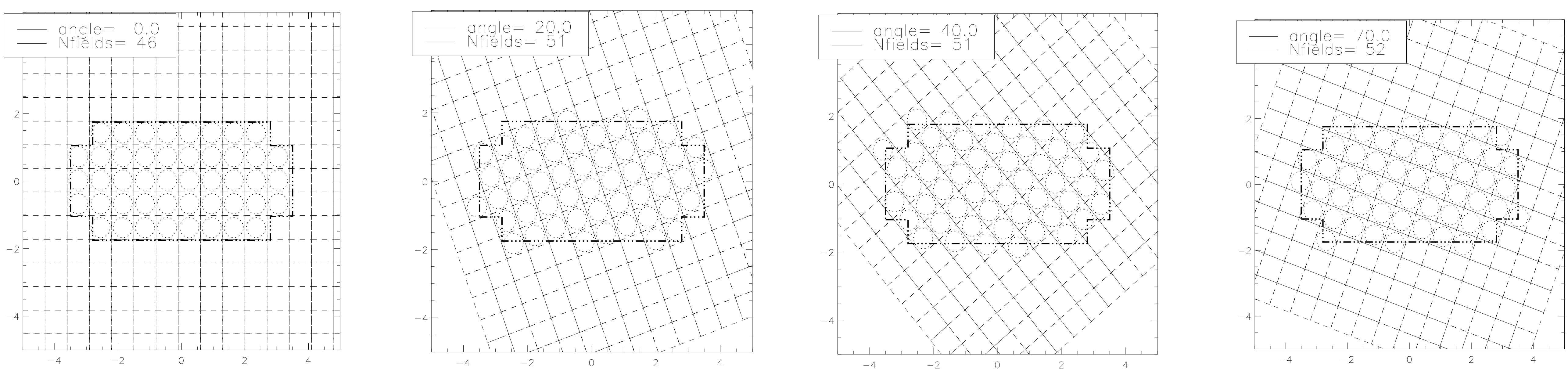
“Stadium” shape (pill-like)

Radius, Perimeter, Area $R = 1.78^\circ$

$P = 2R(2+\pi)$ $A = R^2(4+\pi)$



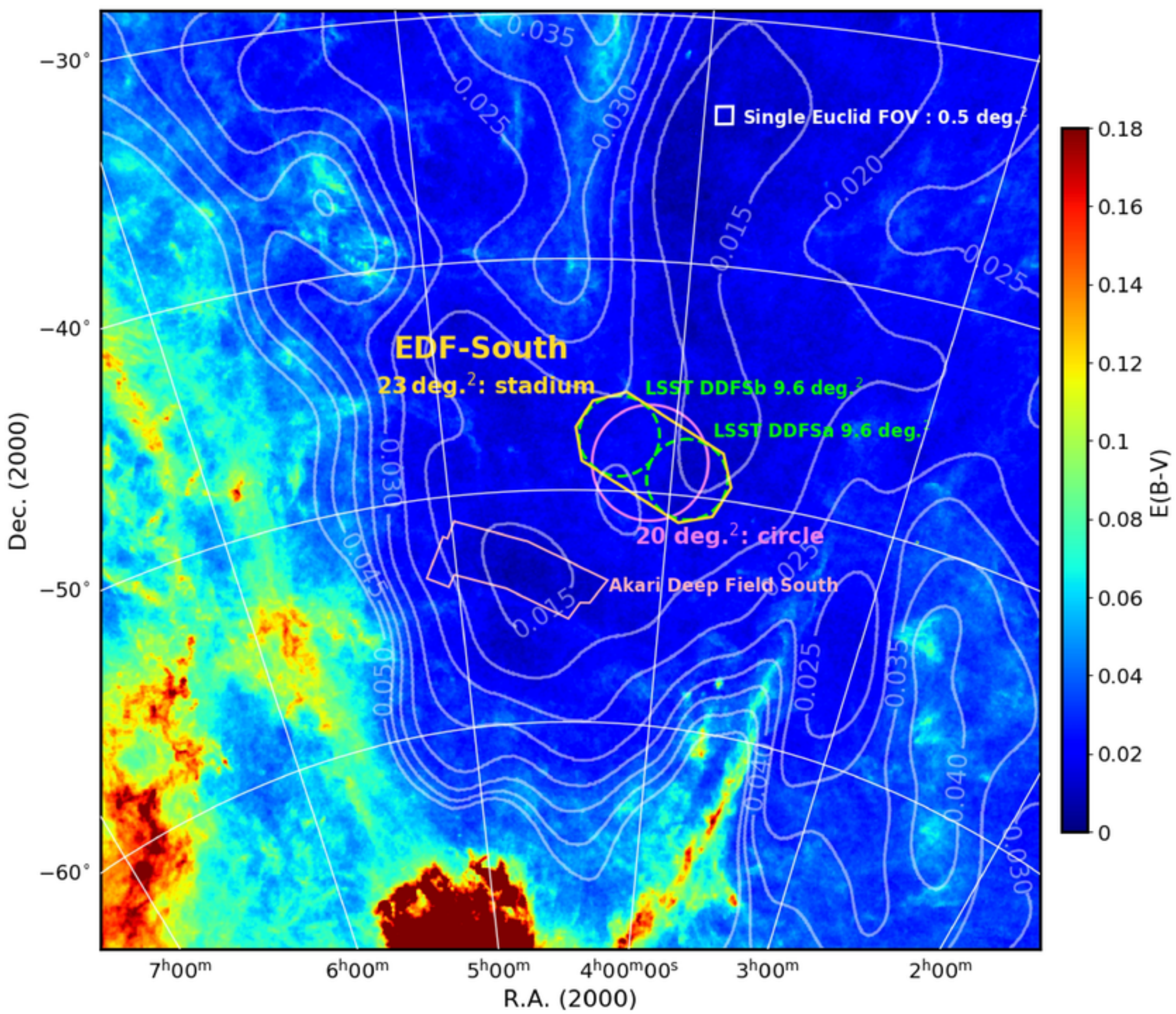
But need some more fields when tilted on the sky:



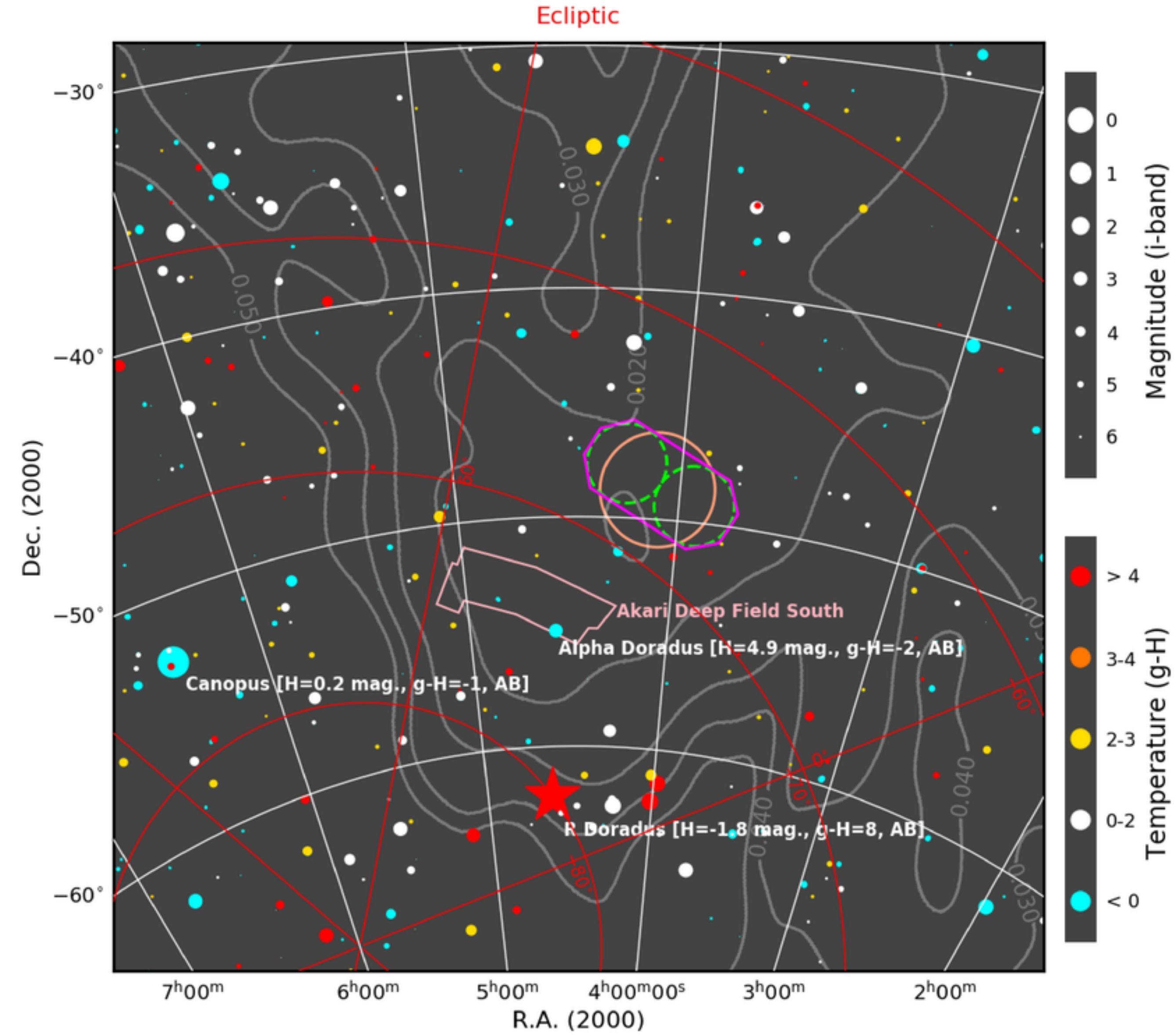
On average need ~51+ fields depending on covered fraction (~ + 19%)

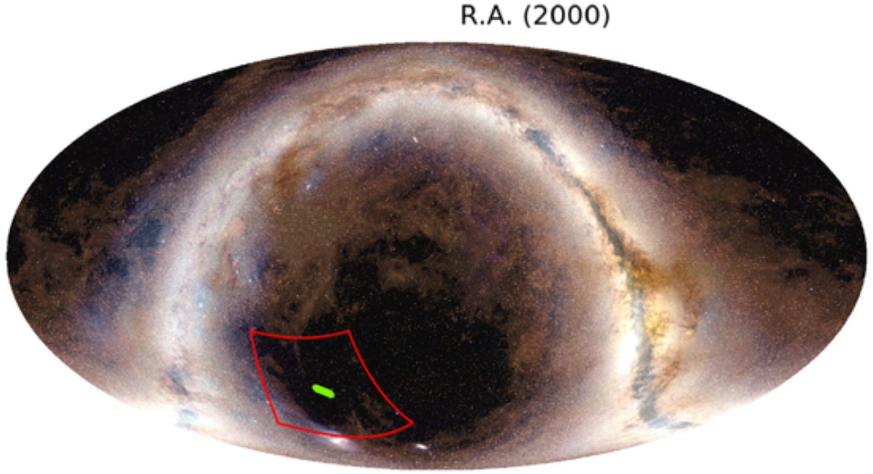
Need to also add ~ +12% time for larger Zodiacal, i.e. from 40 to 45 visits. Total is ~ 102 days for a circle, in total add ~ 3 weeks for stadium shape]. TBD

Extinction: E(B−V)



Contamination: bright stars





Euclid Deep Field South (EDFS)

R.A. 04:05:07.2 Dec. –48:25:12.0 J2000

23 sq. deg. stadium FOV

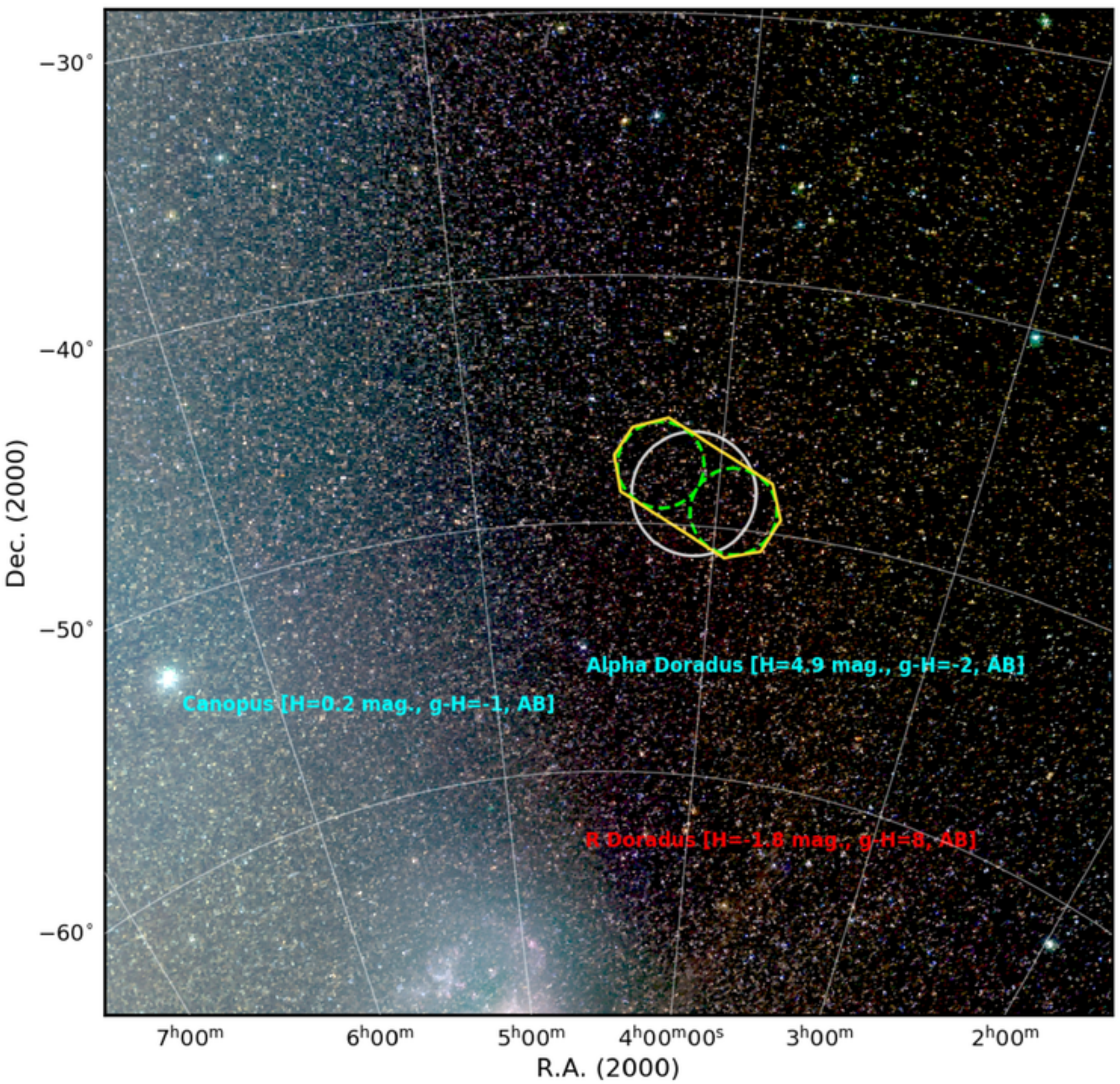
Wide context (1600 sq. deg.)

euclid esa

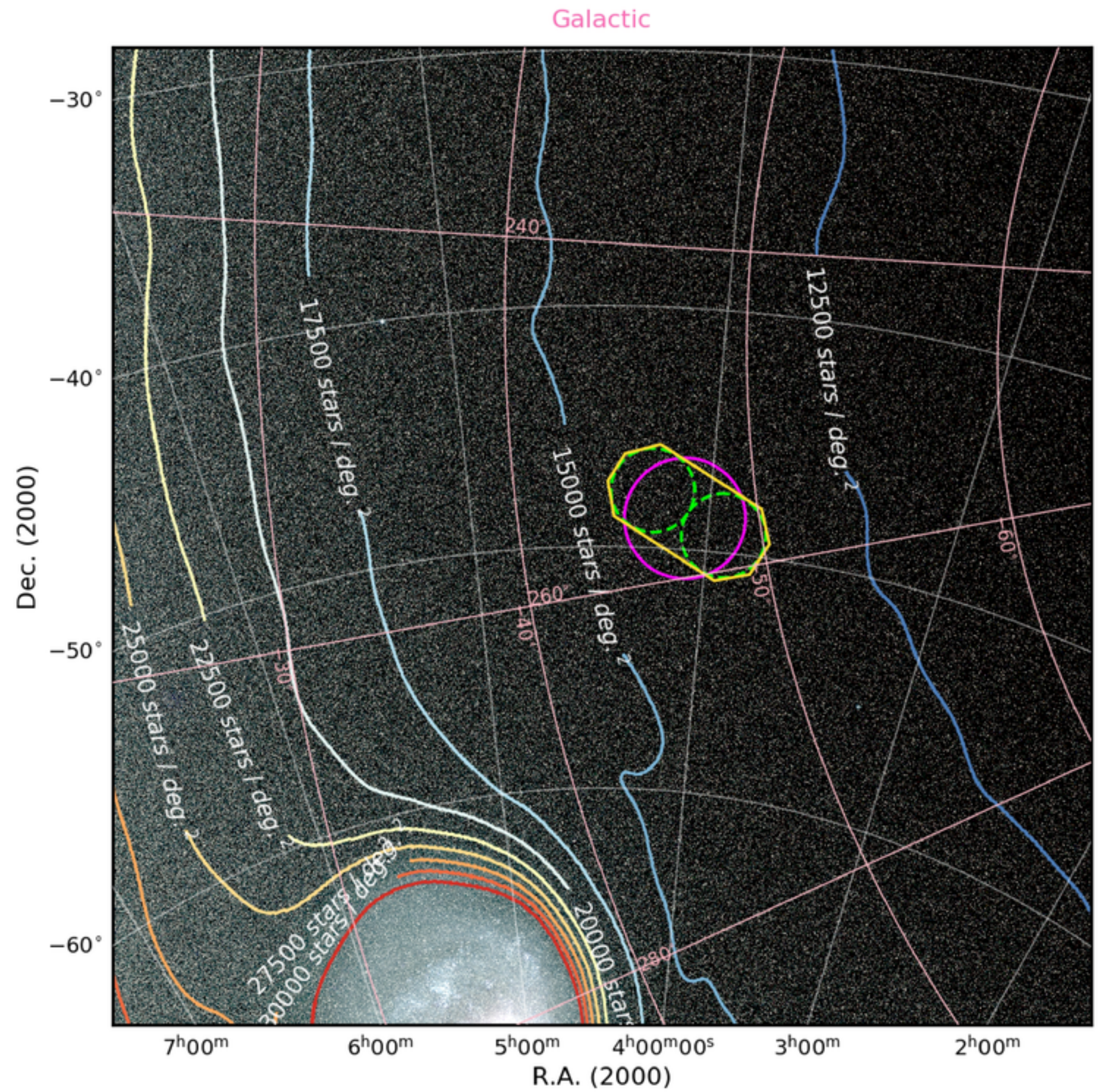
Dust map: Planck Collaboration, A&A, 2014, 571, 11
Star catalog: Pickles et al., PASP, 2010, 122, 898

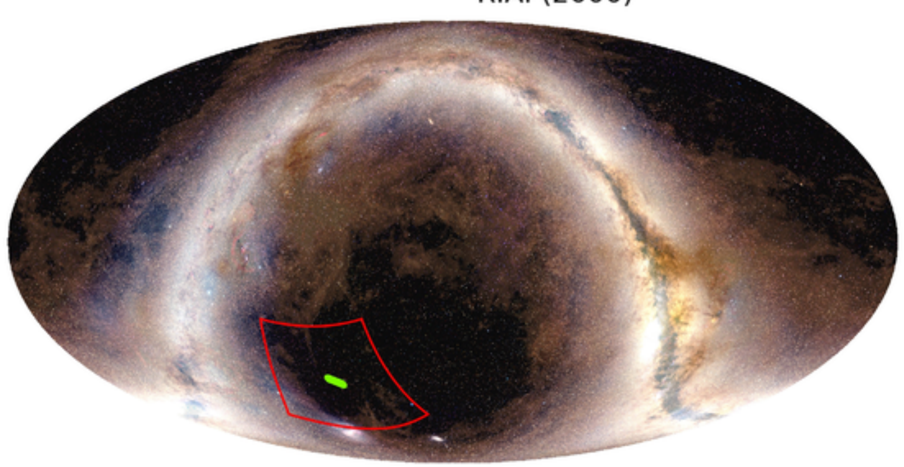
euclid

Optical: true image (RGB)



Optical: stellar density (Gaia)





Euclid Deep Field South (EDFS)

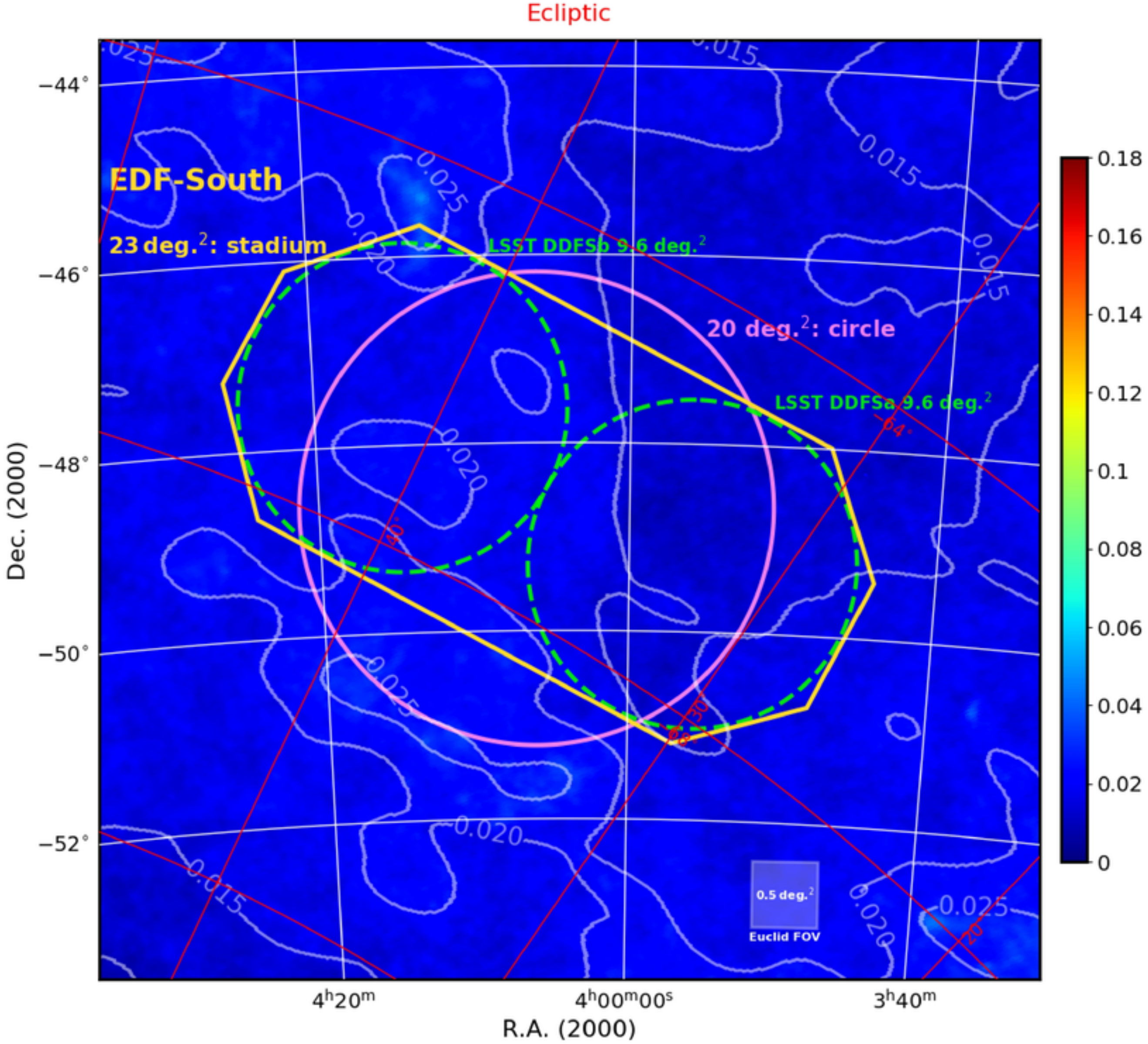
R.A. 04:05:07.2 Dec. –48:25:12.0 J2000

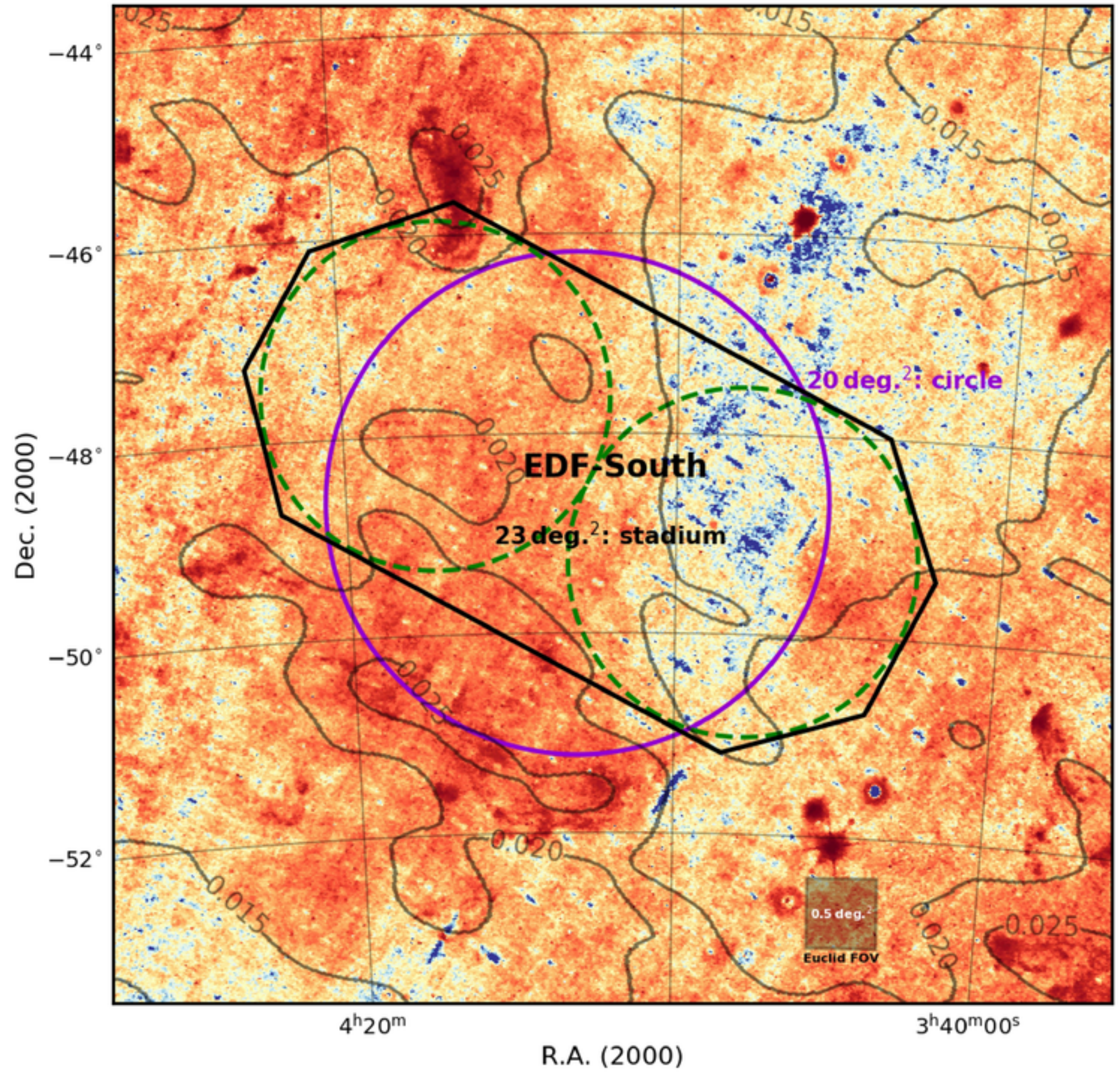
23 sq. deg. stadium FOV

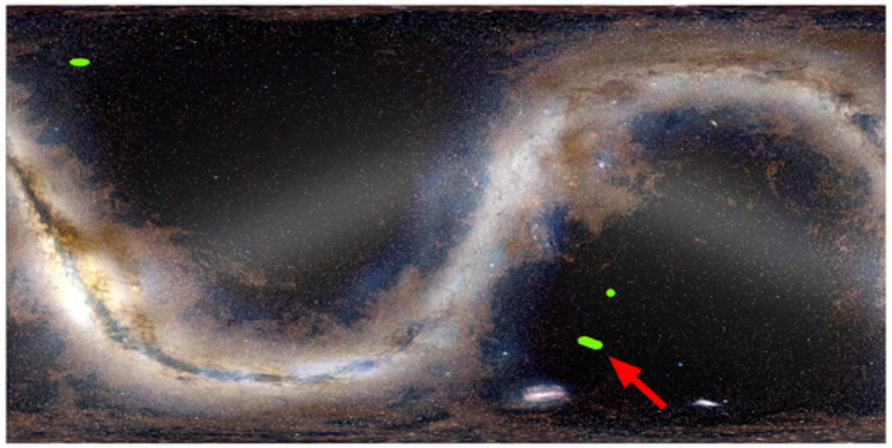
Wide context (1600 sq. deg.)

True image: A. Mellinger, PASP, 2009, 121, 1180
Stellar density dataset: ESA/Gaia/DPAC

Looks fine for bright stars

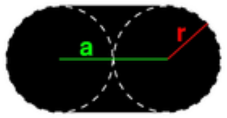






Euclid Deep Field South (EDFS)

23 square degrees stadium geometry field



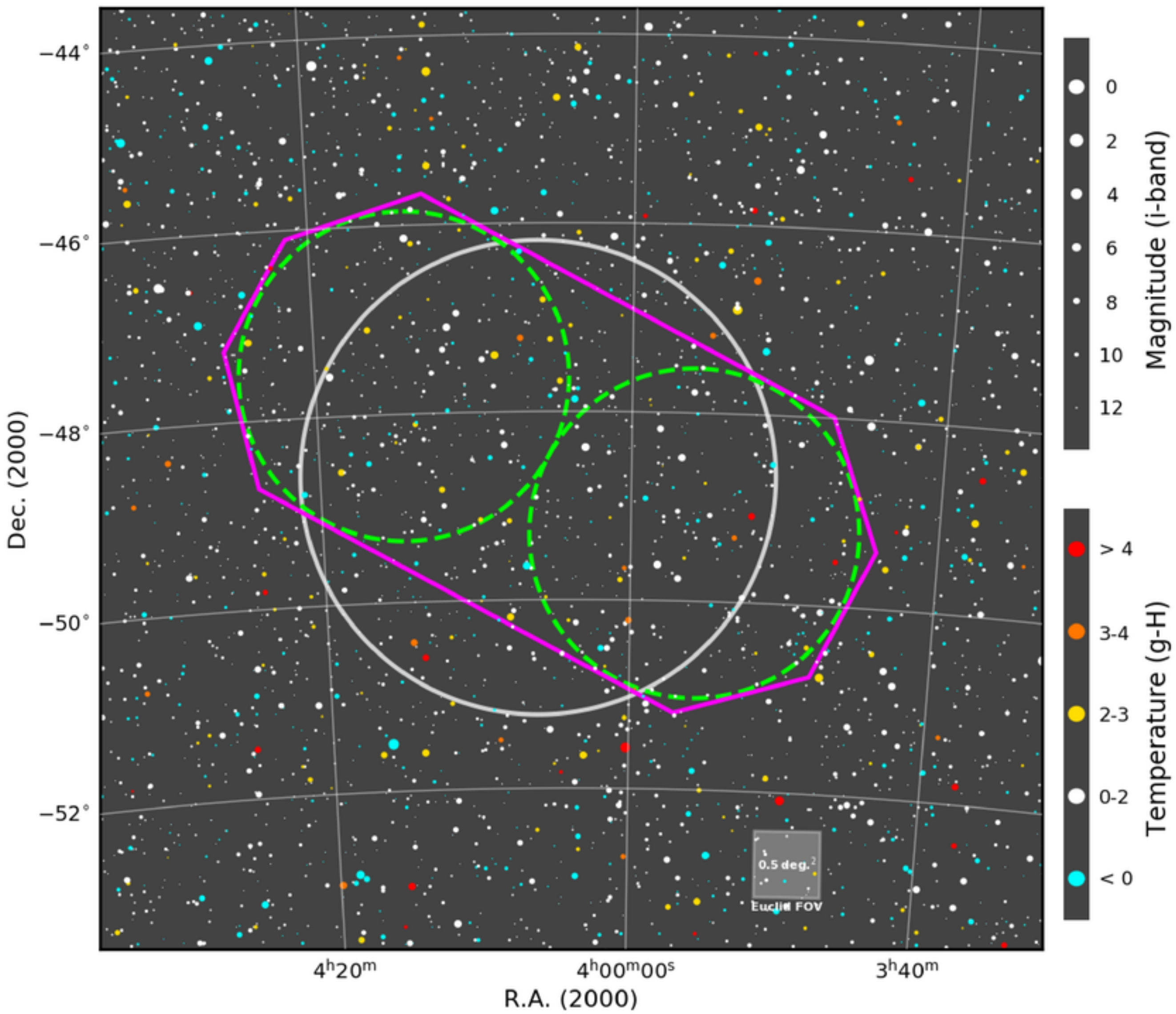
a = 3.50 deg. r = 1.75 deg. Position angle = 61.3 deg.

Eq 3.56 ial:	61.28	−48.42
Ecliptic:	36.56	−66.60
Galactic:	256.05	−47.14

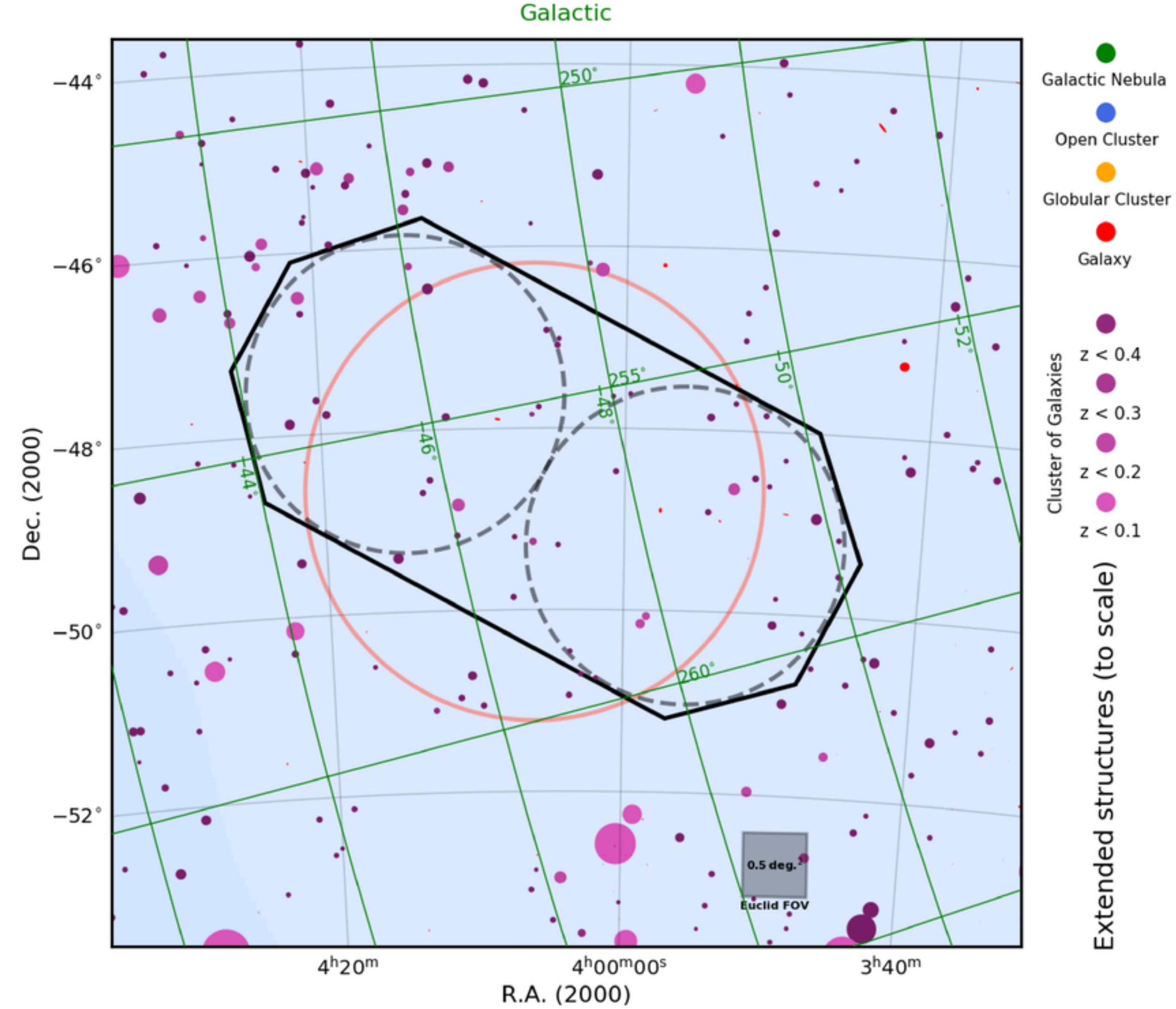
Dust map: Planck Collaboration, A&A, 2014, 571, 11
WISE 12um: Meisner&Finkbeiner, ApJ, 2014, 781, 5

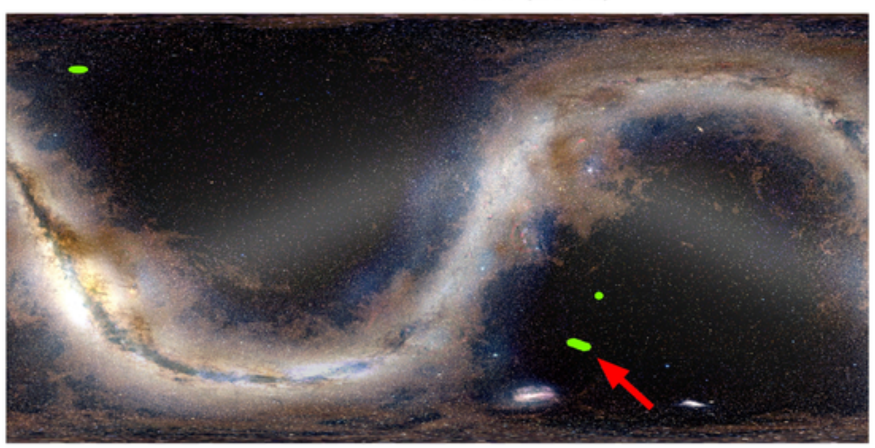
Looks fine for extinction

Field stars properties



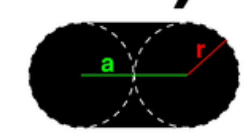
Extended sources to scale





Euclid Deep Field South (EDFS)

23 square degrees stadium geometry field

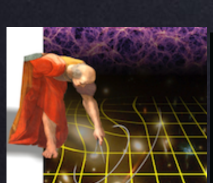


a = 3.50 deg. r = 1.78 deg. Position angle = 61.3 deg.

Equatorial:	61.28	−48.42
Ecliptic:	36.56	−66.60
Galactic:	256.05	−47.14

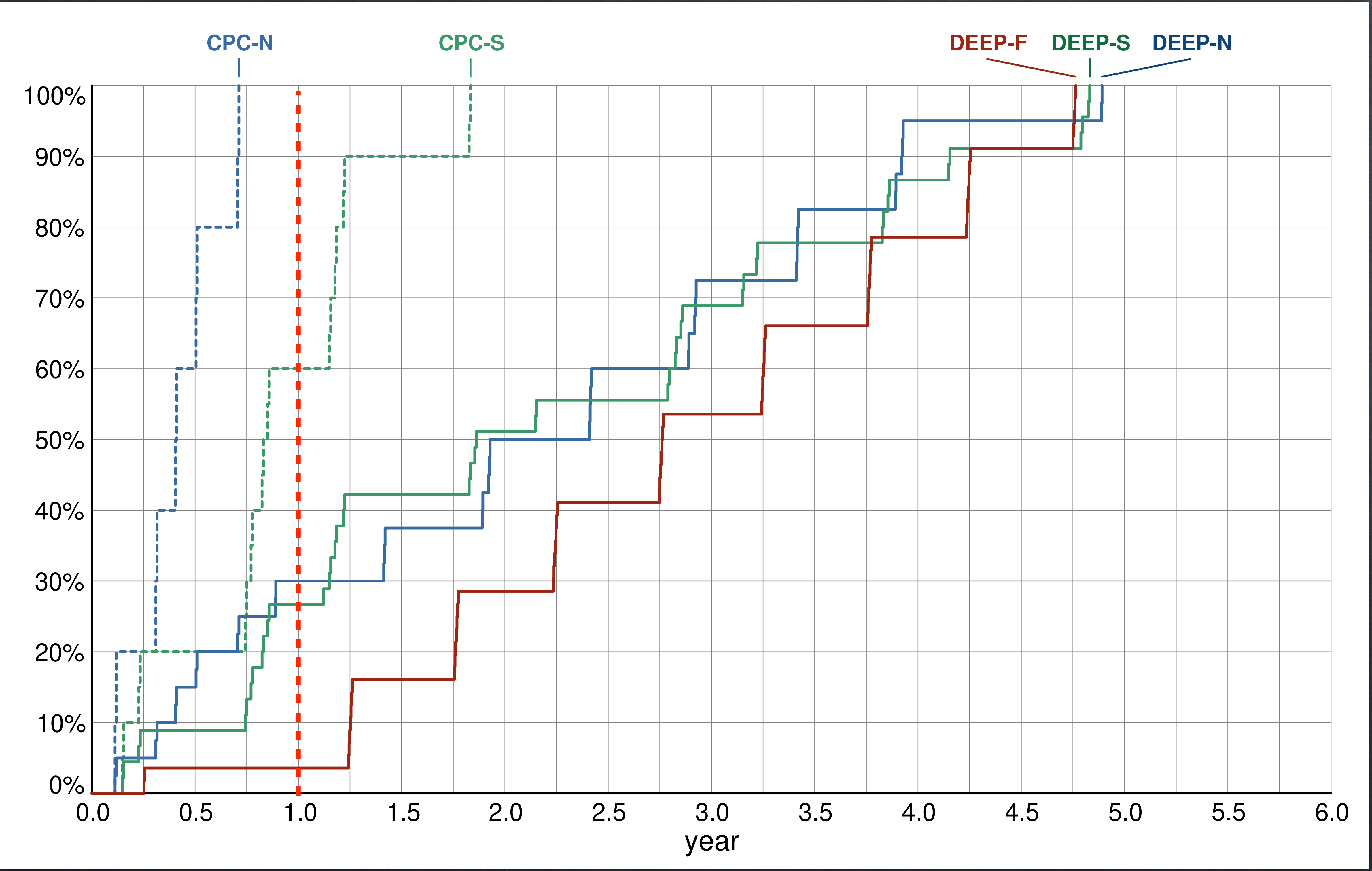
Star catalog: Pickles et al., PASP, 2010, 122, 898
New General Catalogue of Nebulae, Sulentic&Tifft 1973
Clusters: 2MASS+WISE+SuperCOSMOS, Wen et al. 2017

Looks fine for bright stars and large objects



CHECKED ALSO ON WISE [Meisner, A.M., Lang, D., and Schlegel, D.J. (2017) "Deep Full-sky Coadds from Three Years of WISE and NEOWISE Observations"]

CPCs& EDFs coverage build up



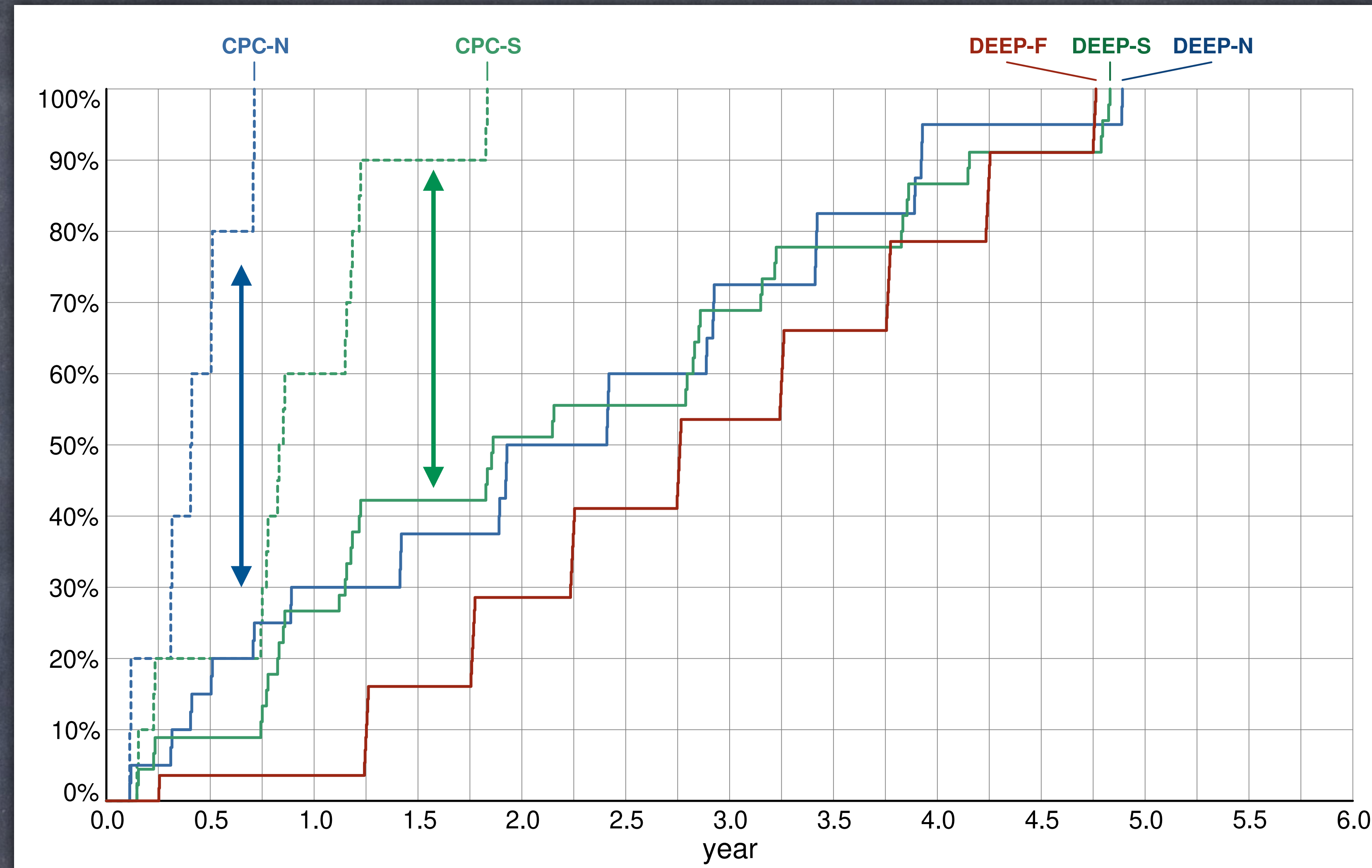
After one year can have 1 visits (all red spectra) on CPC + EDFF = 50 sq deg for Q1 release

CPC visits are counted also as EDF visits

EDFs status 2019 (now frozen)

(square deg x visits; number of latters will be increased to compensate for larger zodiacal background)

- EDFN (20 x 10 + inner 10 x 30) = (1/2) CPC + (1/4) DEEP; offset 1 deg from NEP; observed by Spitzer
- EDFF (10 x 40) = (1/4) DEEP; Fornax region; observed by Spitzer
- EDFS (23 x 40) = (1/2) CPC + (1/2) DEEP; observations allocated for Spitzer; LSST optical coverage requested



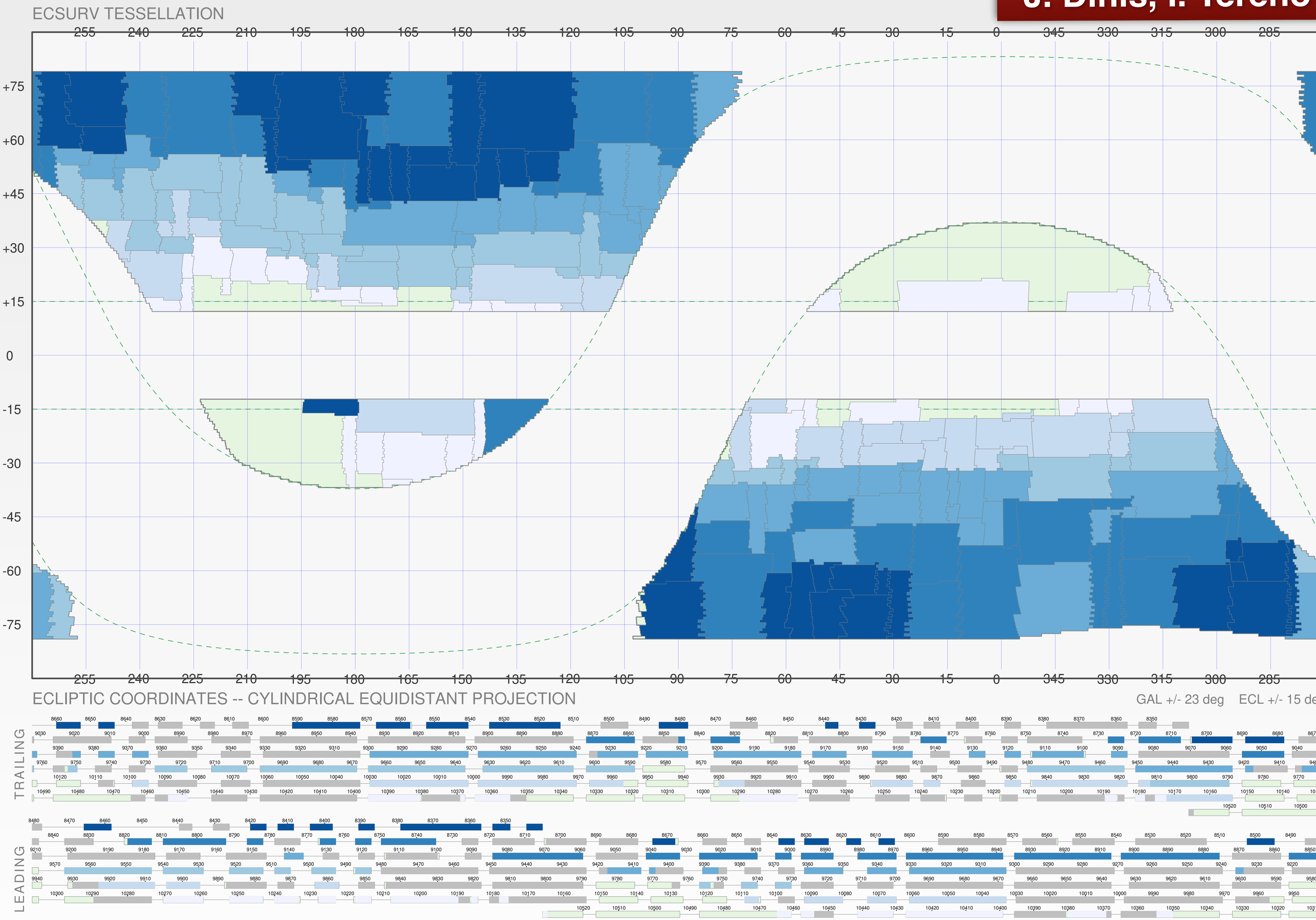
CPC visits are counted also as EDF visits

75% synergy between CPCs and EDFs

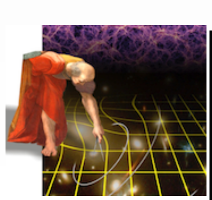
Visibility from Ground facilities has increased enormously, enabling much more science to be done on EDFs

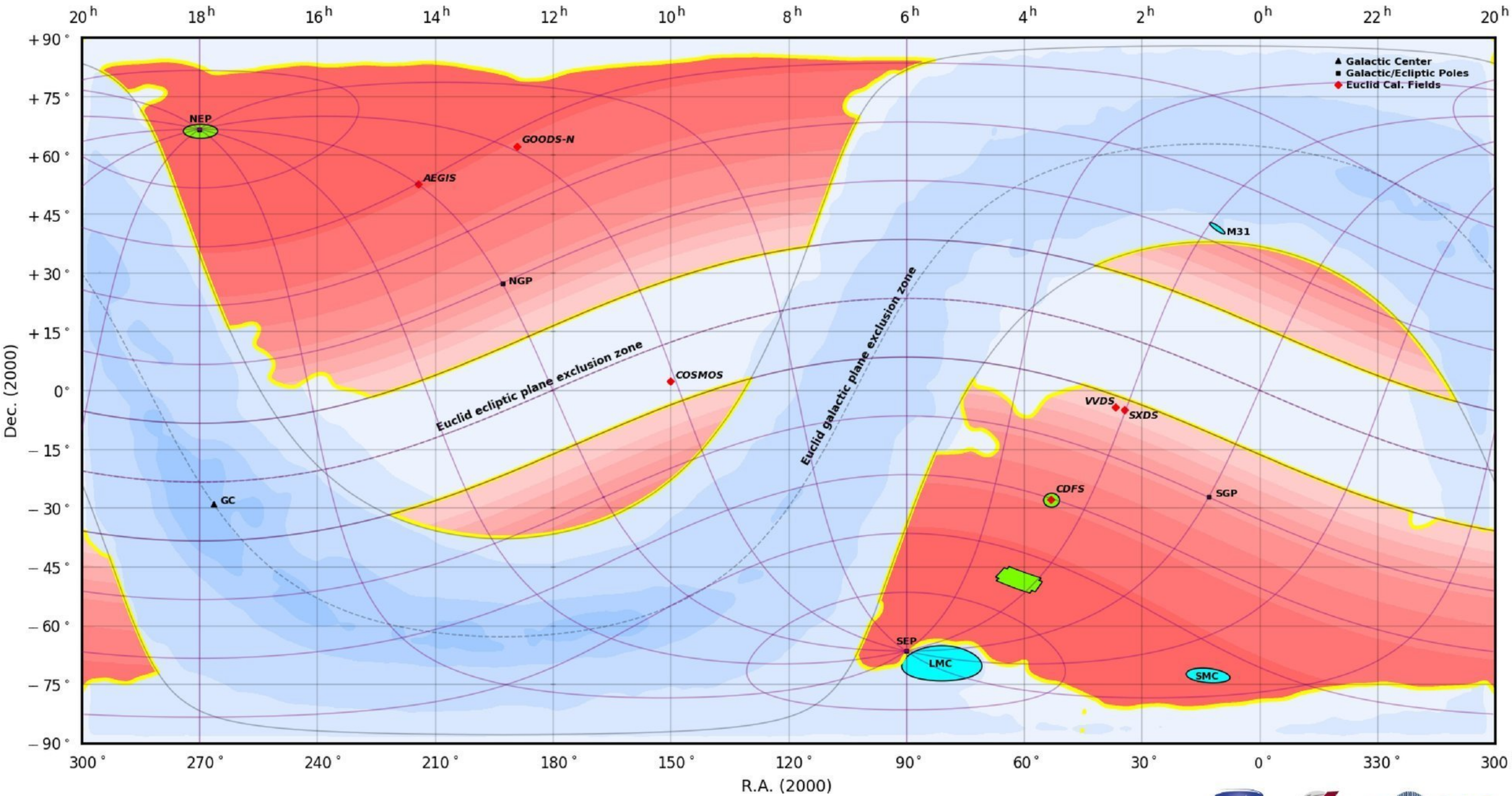
Details on ESA web pages

J. Dinis, I. Tereno



2019 Survey a great step ahead: polar caps, all calibrations up to date, all EDFs





Euclid Foregrounds (1/8): zodiacal light background level from Lagrangian2

Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]

Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]

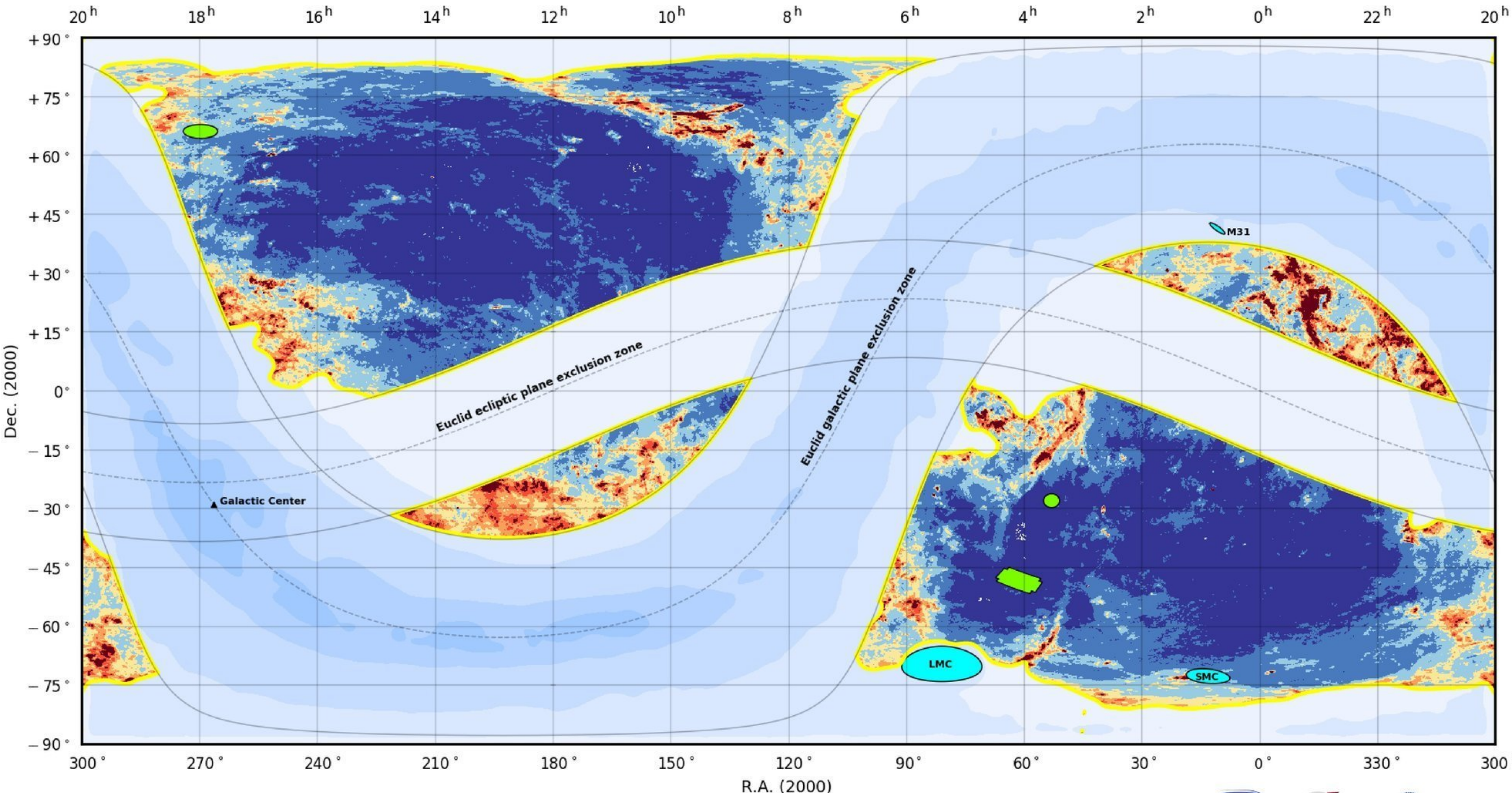
Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

Zodiacal light level in the VIS band (MJy/sr & mag./arcsec^2)

0.11 — 0.27

22.7 — 21.8

The ecliptic referential is overplotted in light purple



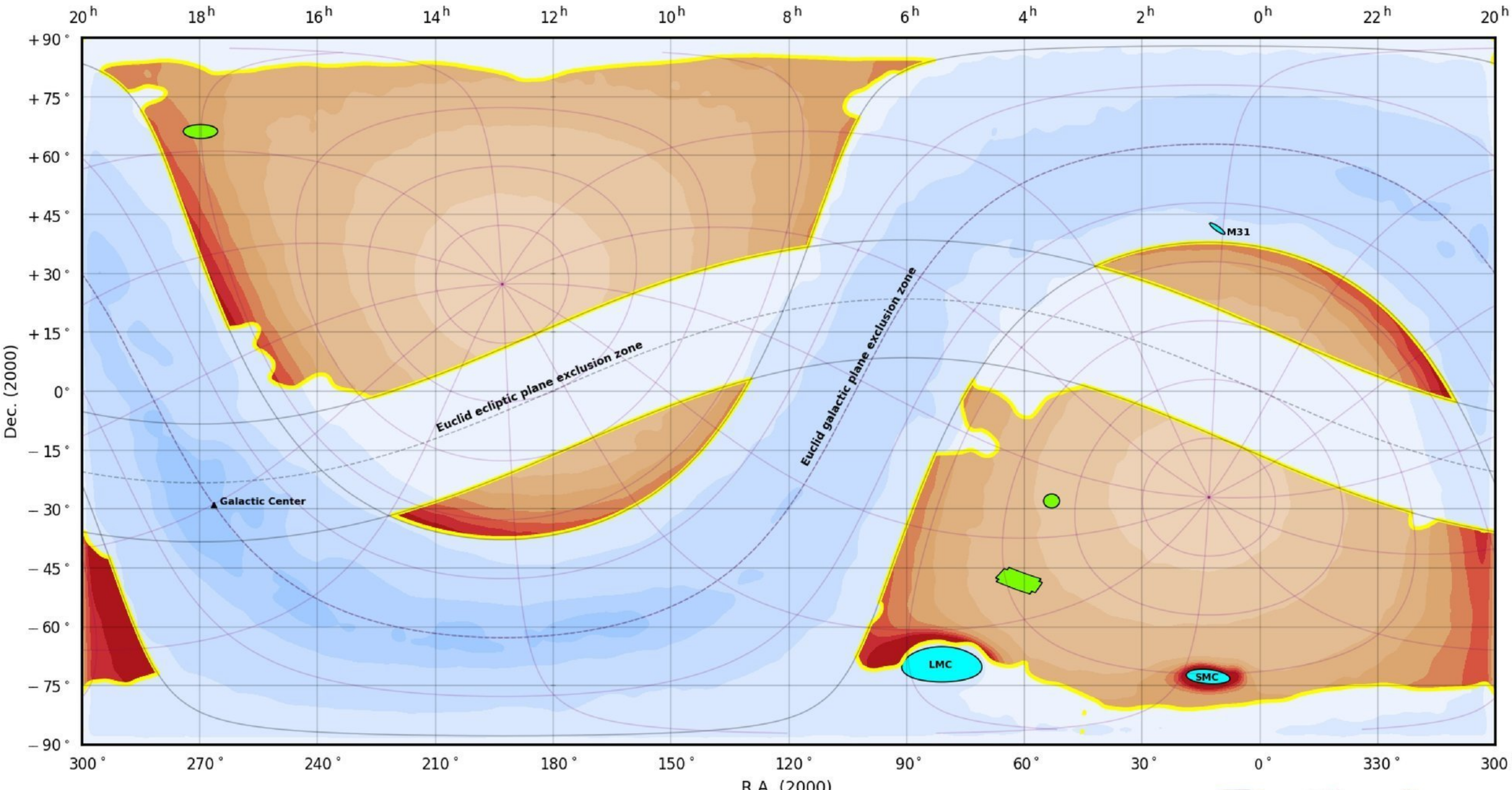
Euclid Foregrounds (2/8): reddening and galactic light reflection from interstellar cirrus

- Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]
- Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]
- Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

E(B−V) and cirrus surface brightness (mag./arcsec^2)

0.01 ~28 — 0.15 ~26

Dust map: ESA / Planck Collaboration



Euclid Foregrounds (3/8): cumulated stellar brightness from the Galaxy

Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]

Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]

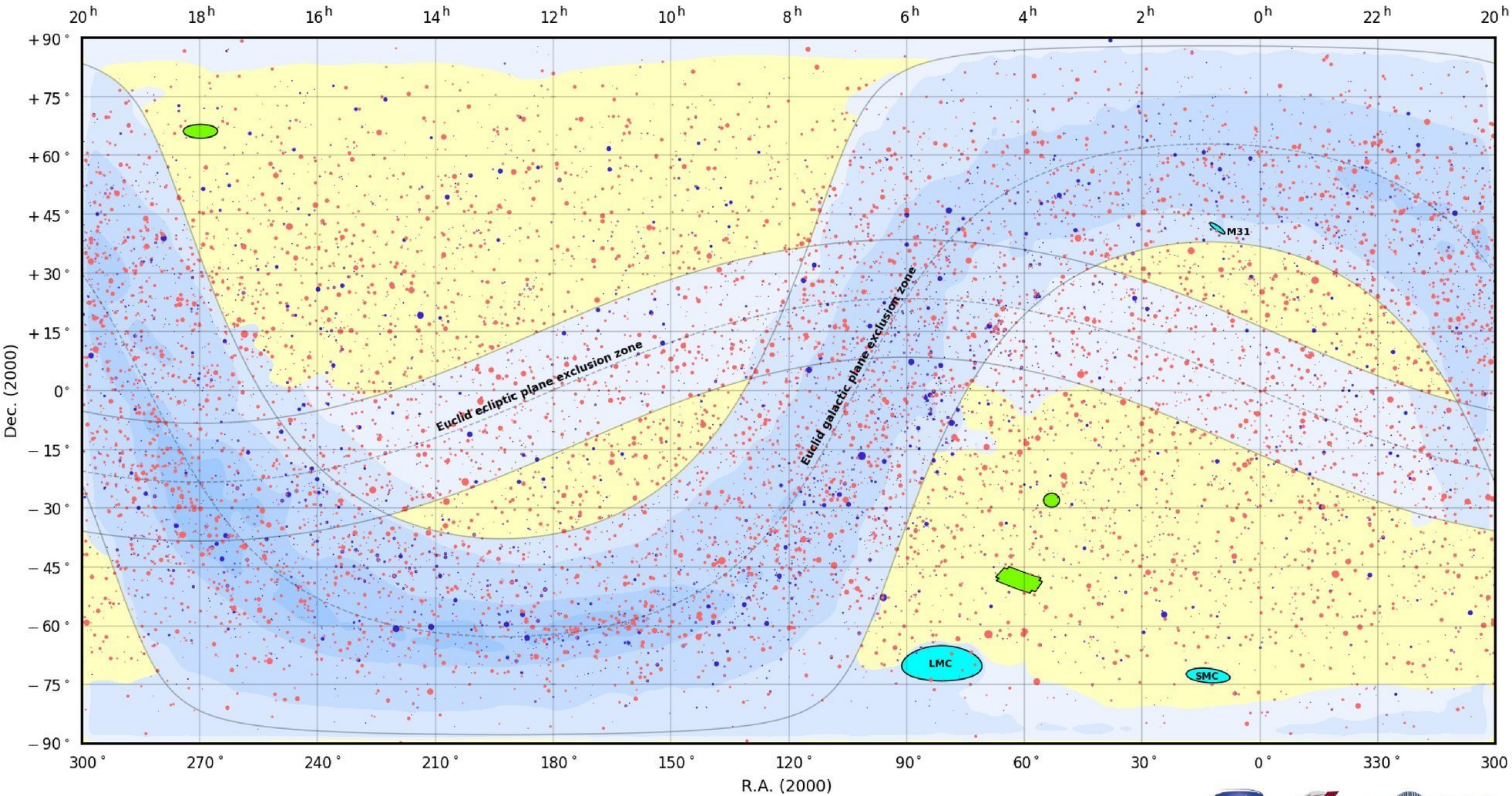
Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

Stellar density per square degree [*Gaia* G_{RP} = *20th magnitude*]

10,000 20,000 50,000

The galactic referential is overplotted in light purple

Stellar density dataset: ESA/Gaia/DPAC



Euclid Foregrounds (4/8): bright stars from the visible to the near-infrared

Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]

Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]

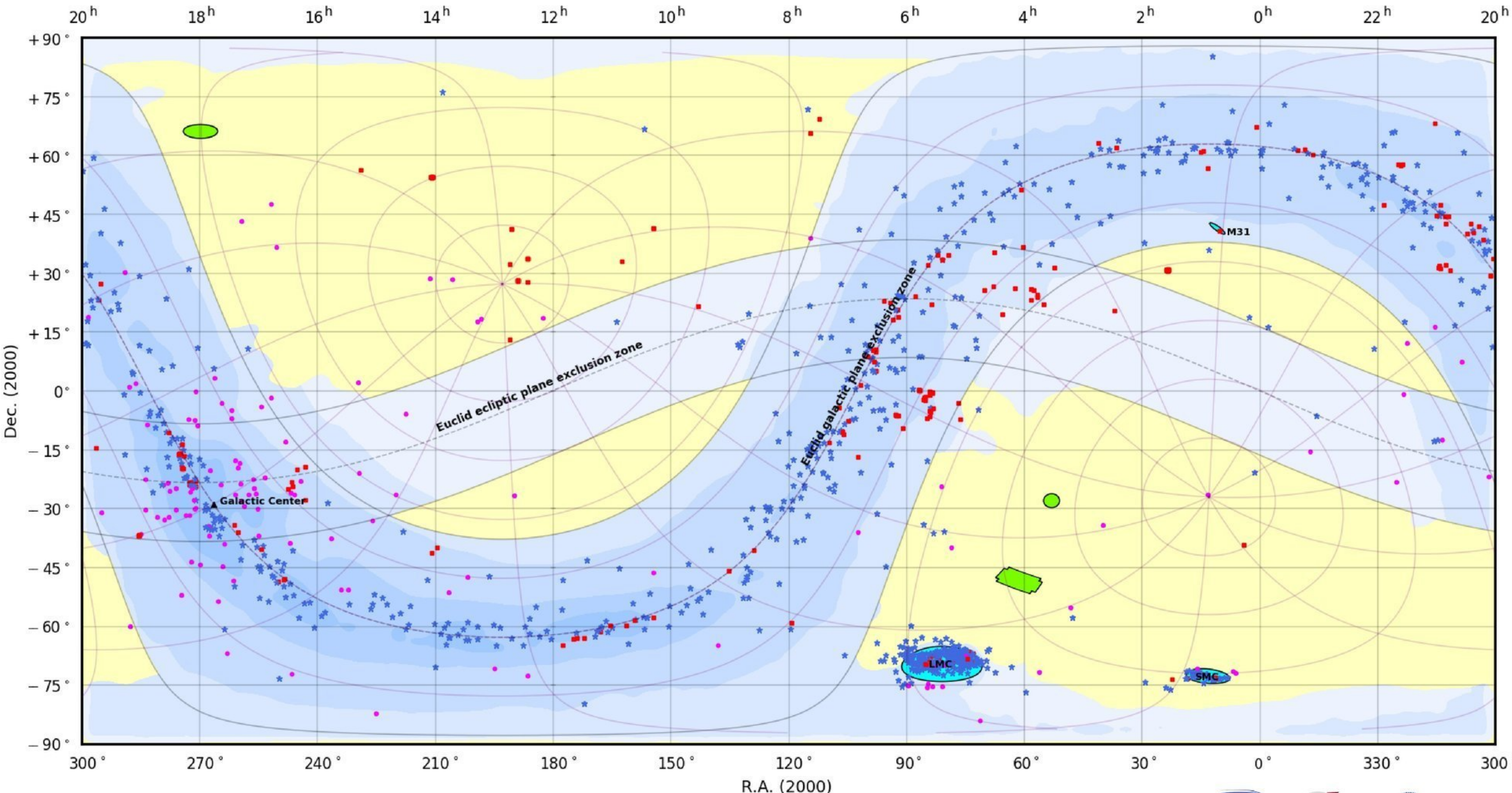
Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

g or H magnitude (AB): -2 0 2 4 6

All 8000 brightest stars in the sky up to g-band = 6.5

All 8000 brightest stars in the sky up to H-band = 6.8

g-band: Yale Bright Star Catalog (Hoffleit & Warren 1991)
H-band: The Two Micron All Sky Survey (2MASS, Skrutskie et al. 2006)



Euclid Foregrounds (5/8): brightest extended galactic nebulae (Messier/NGC/IC)

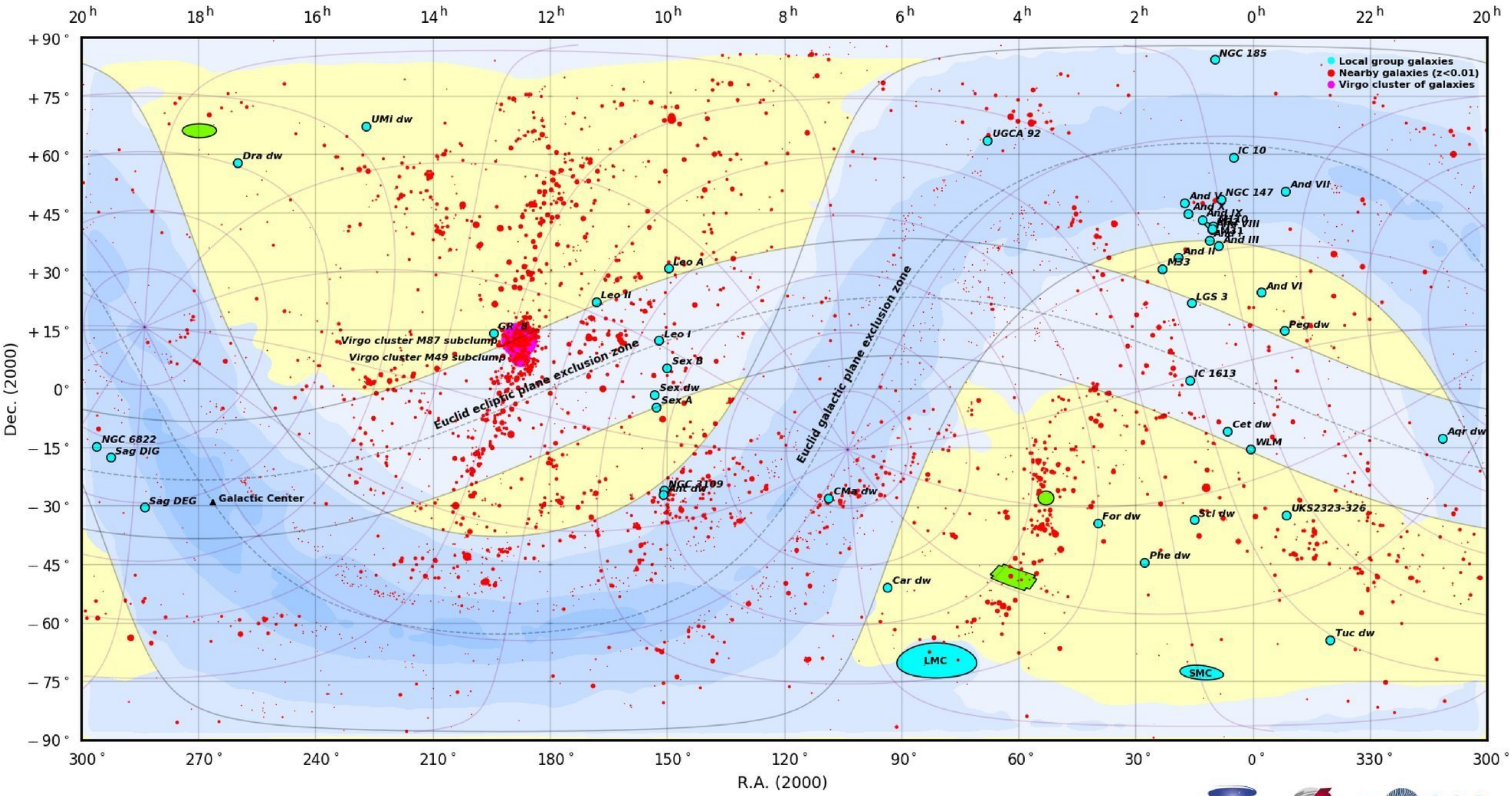
Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]

Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]

Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

NGC/IC class :
- **Galactic nebula**
- **Open cluster**
- **Globular cluster**

New General Catalogue of Nebulae & Clusters of Stars, Sulentic&Tifft 1973



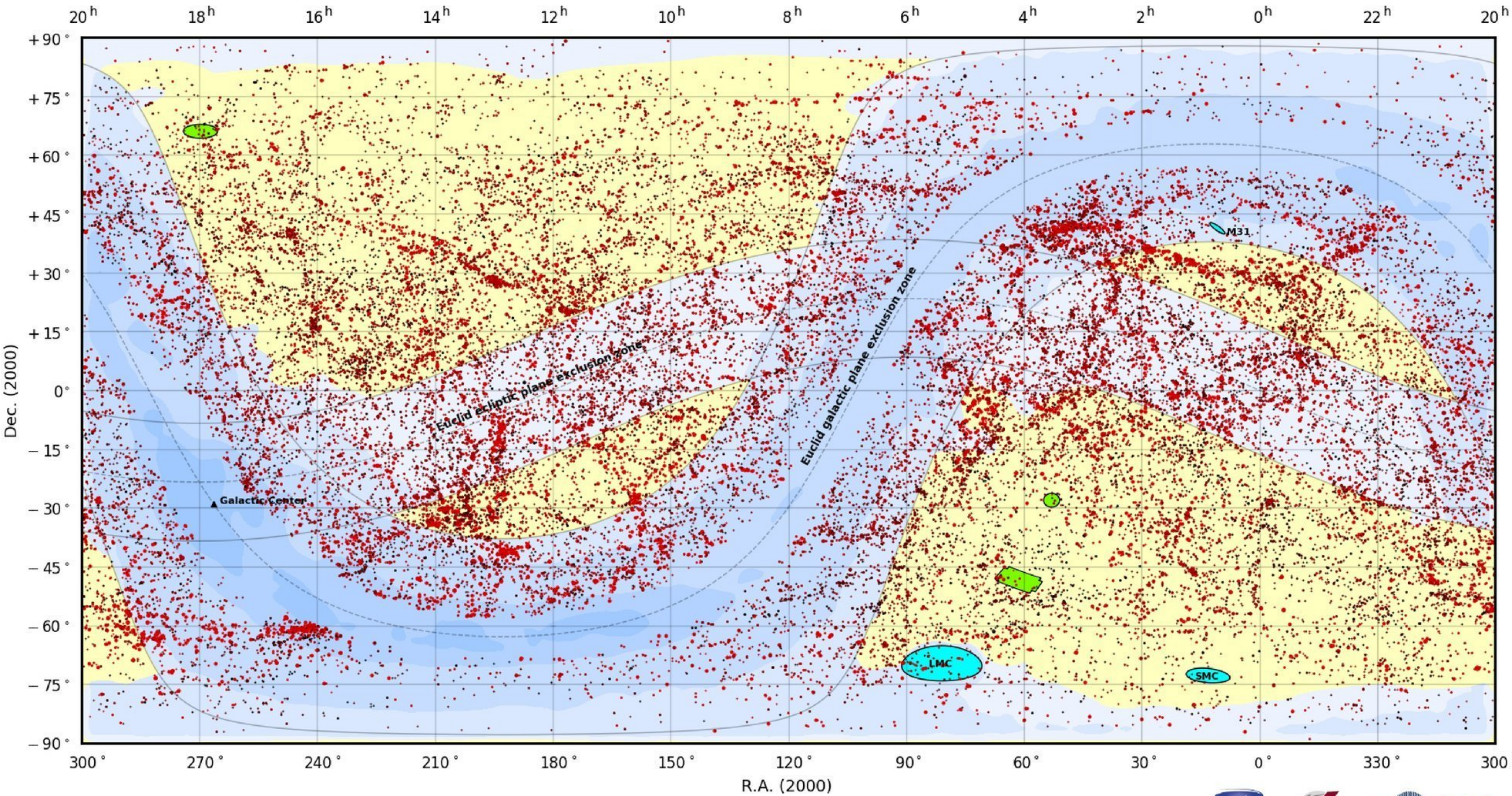
Euclid Foregrounds (6/8): galaxies from the local group and the nearby universe (z<0.01)

- Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]
- Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]
- Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

Total K-band magnitude: 3 5 7 9 11

The supergalactic referential is overplotted in light purple

Galaxy catalog: The 2MASS Redshift Survey (2MRS), Huchra et al. 2012



Euclid Foregrounds (7/8): nearby galaxies beyond the local universe (0.01<z<0.06)

Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]

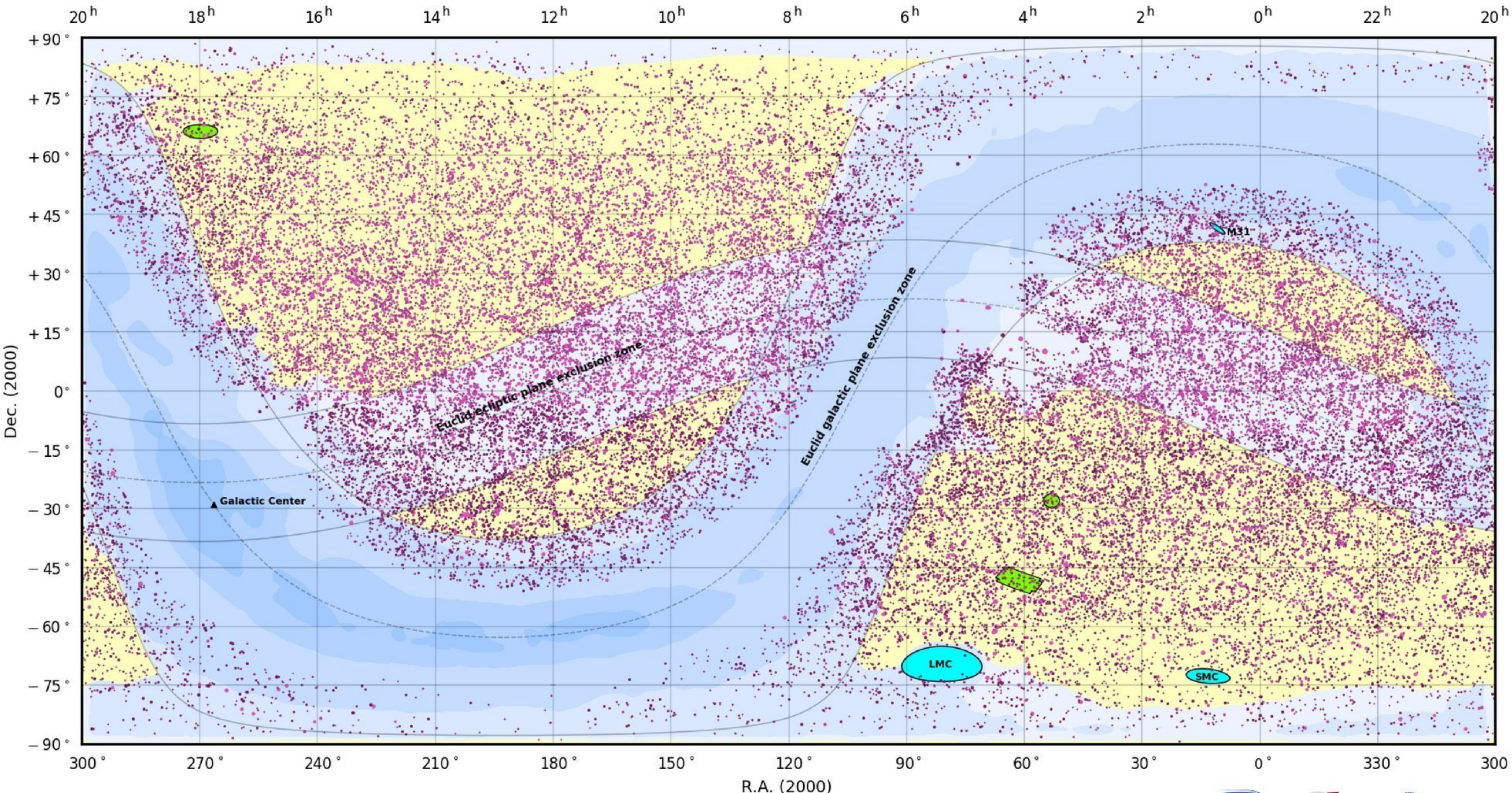
Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]

Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

z<0.02 z<0.03 z<0.04 z<0.05 z<0.06

Total K-band magnitude: 3 5 7 9 11

Galaxy catalog: The 2MASS Redshift Survey (2MRS), Huchra et al. 2012



Euclid Foregrounds (8/8): distant clusters of galaxies (0.06<z<0.40)

- Euclid Wide Survey : 15,000 deg.^{2} [with E(B−V)<0.08, up to 0.15 to avoid holes&islands]
- Euclid exclusion zone : 26,000 deg.^{2} [galactic+ecliptic planes + reddening]
- Euclid Deep Fields : North=10 deg.^{2}, Fornax=10 deg.^{2}, South=20 deg.^{2}

z<0.1 z<0.2 z<0.3 z<0.4

Angular size (diam. arcmin.): 40 20 10 5 2

Cluster catalog: 2MASS+WISE+SuperCOSMOS, Wen et al. 2017

Expected coverage from the ground for WL photoz

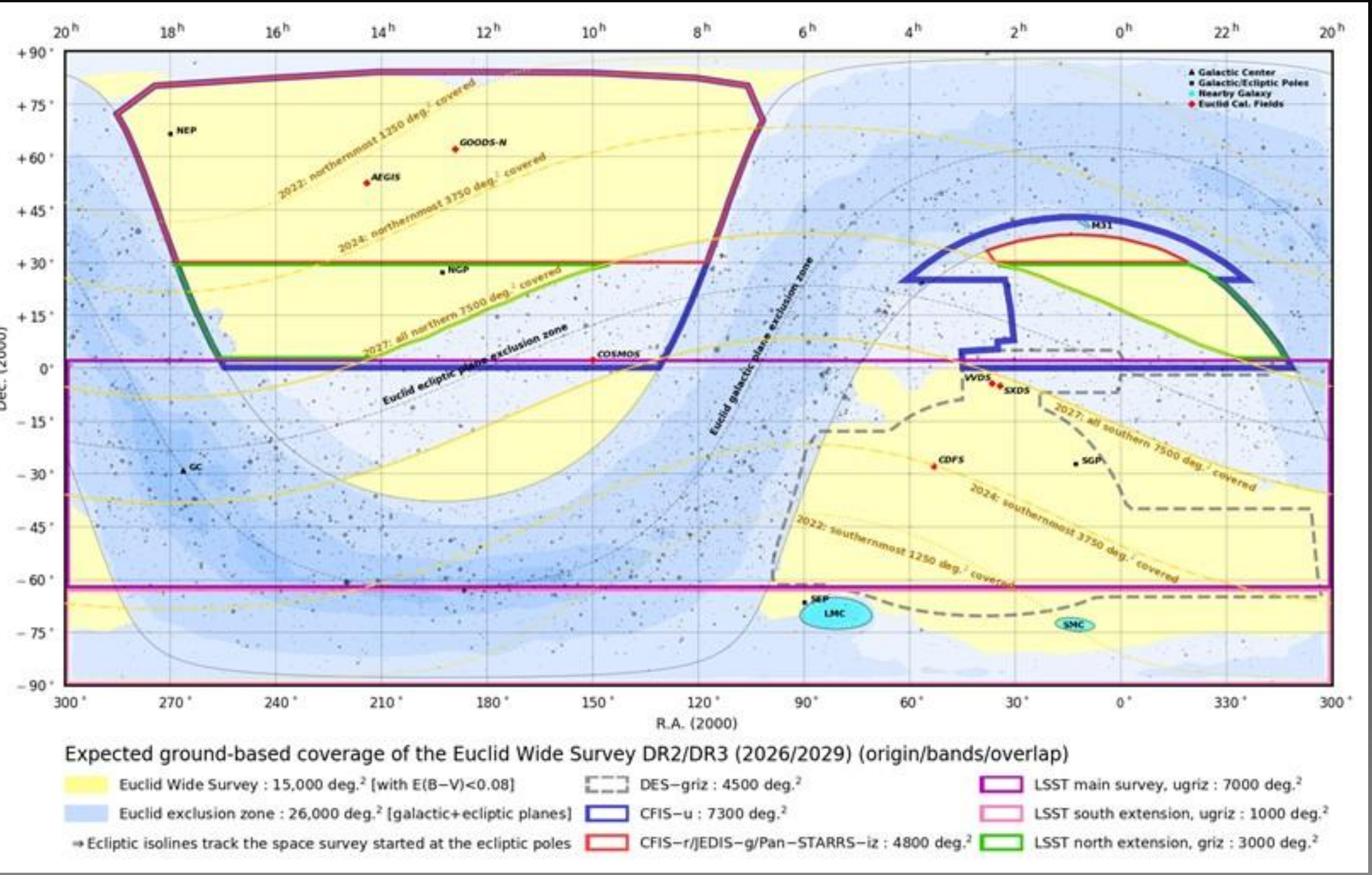
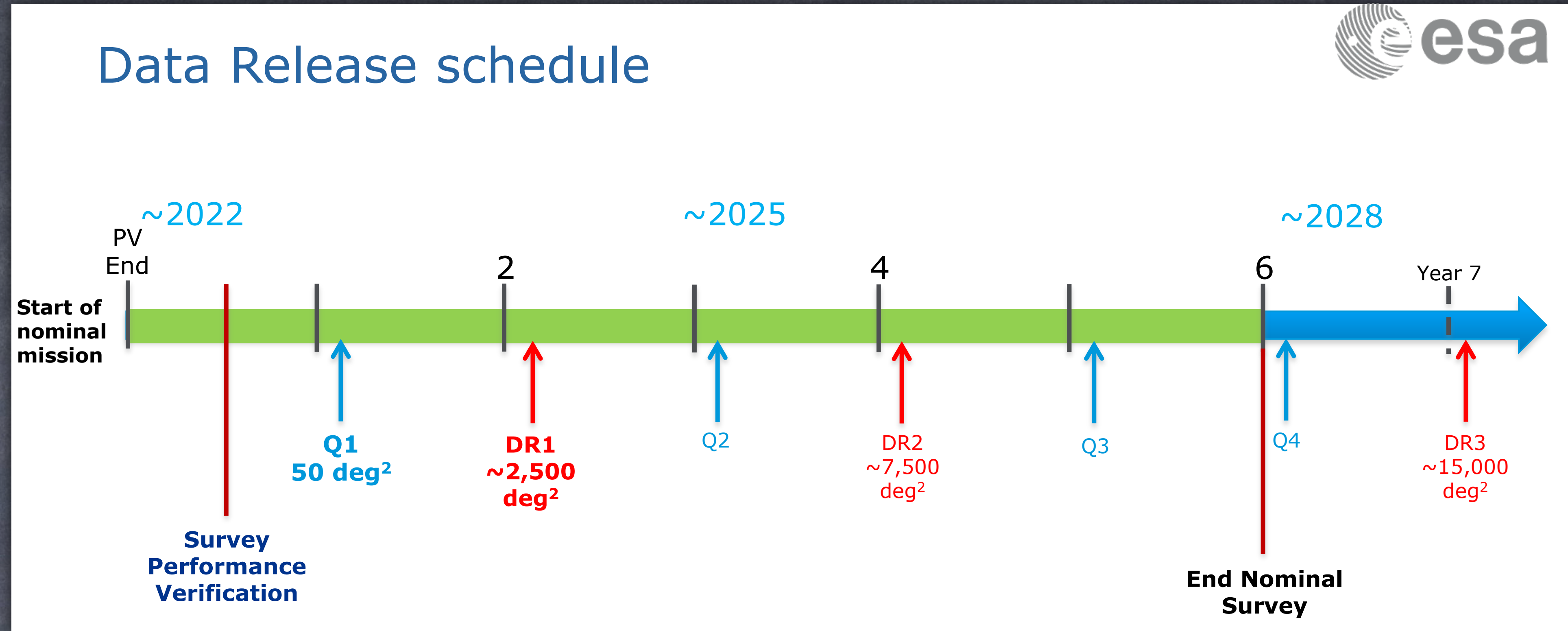


Figure 7.1.2 Expected coverage from the ground for Euclid DR2/DR3

Public data releases:



Two kind:

Q's = small area prerelease for the community to get acquainted

DR = data release (three DR of increasing areas: early -2500-, intermediate -7500-, final -15000 sq degs)

Q1: 14 months after start of the nominal mission
— data released: one visit on the deep fields [50 sq deg]

DR1: one year after Q1
— data released: 2500 sq deg

Stay tuned!!