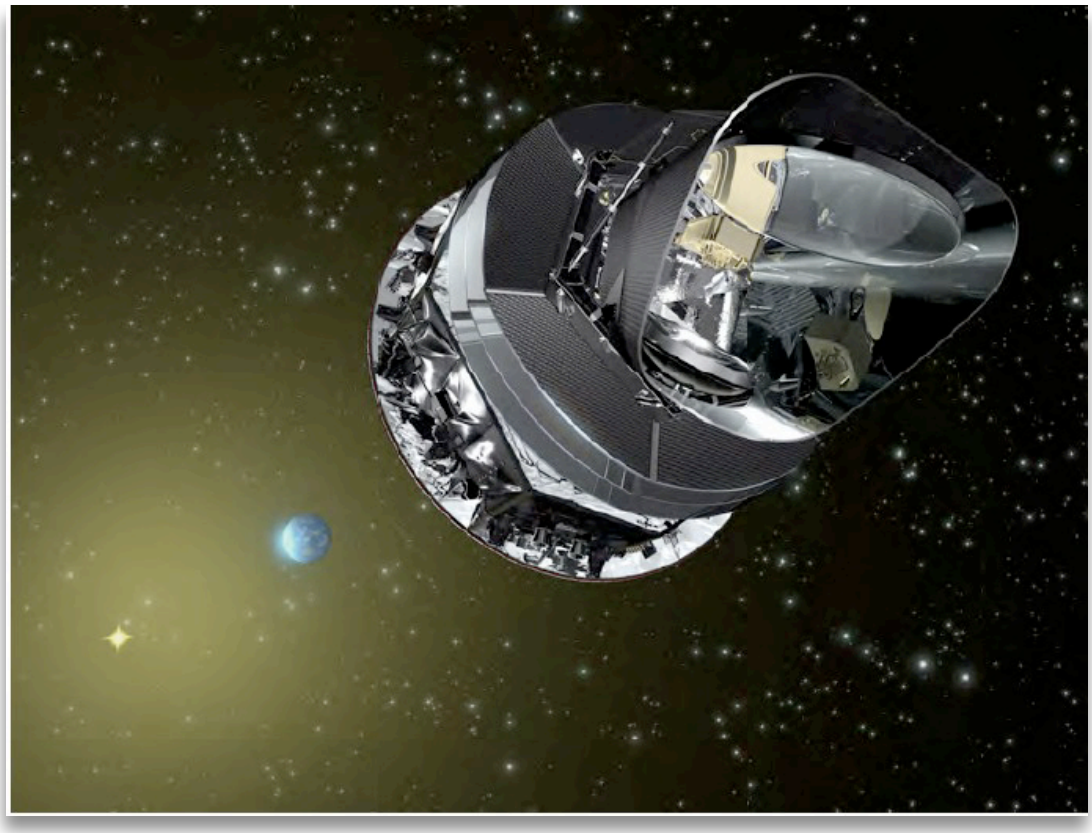
Approaching the Planck Era in ~6 wks

status; impact of Planck on Planck era physics*, early inflation $n_s(k)$, GW: Tensor(k), subdominant isocurvature, cosmic strings, textures, *nonGaussian* F_{NL} *+late inflation w(z)

Launch planned for April 16, 2009 12:30 Local time (10:30am Eastern) from Kourou, French Guiana 4°N

Herschel in Kourou Feb 11
Planck in Kourou Feb 18
Launch window in April: 1 hour per day; 2 days on, 2 weeks off to refill Herschel dewar



ESA /NASA /CSA Toronto HFI QLA/KST, TA, … *Barth & Dick, Marc-Antoine Miville-Deschenes, Carrie MacTavish, Brendan Crill, Olivier Dore, Mike Nolta, Peter Martin* UBC LFI *Douglas Scott etal.*

CBI pol to Apr'05 @Chile

CBI2

QUaD @SP

Quiet1 @Chile

Quiet2 1000 HEMTs

Boom03@LDB

Bicep @SP

Bicep2

Keck/Spud

WMAP @L2 to 2009-2013?

Planck09.3

EBEX @LDB

Spider 2312 bolos @LDB

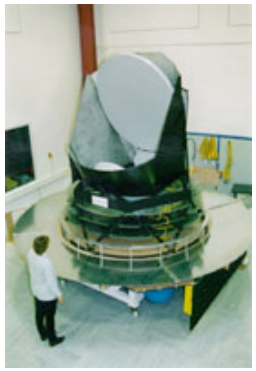
DASI @SP

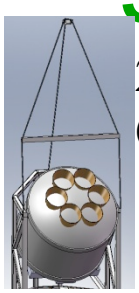
CAPMAP

(52 bolometers) + HEMTs @L2

9 frequencies

Herschel





CHIP

BLAST

2004 2006 2008 LHC 2011

Bpol @L2

2005 2007 2009

Acbar to Jan'06, 08f @SP

SPT 1000 bolos @SPole

BLASTpol

Clover @Chile

SZA @Cal

Polarbear 300 bolos @Cal/Chile

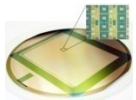
ACT 3000 bolos 3 freqs @Chile

SPTpol

AMI

APEX ~400 bolos @Chile

SCUBA2 12000 bolos JCMT @Hawaii



ALMA @Chile

GBT

LMT@Mexico

– Cryogenic system performed to specifications
– Bolometer transfer function measurement performed
Spec is: 0.1% knowledge of transfer function!

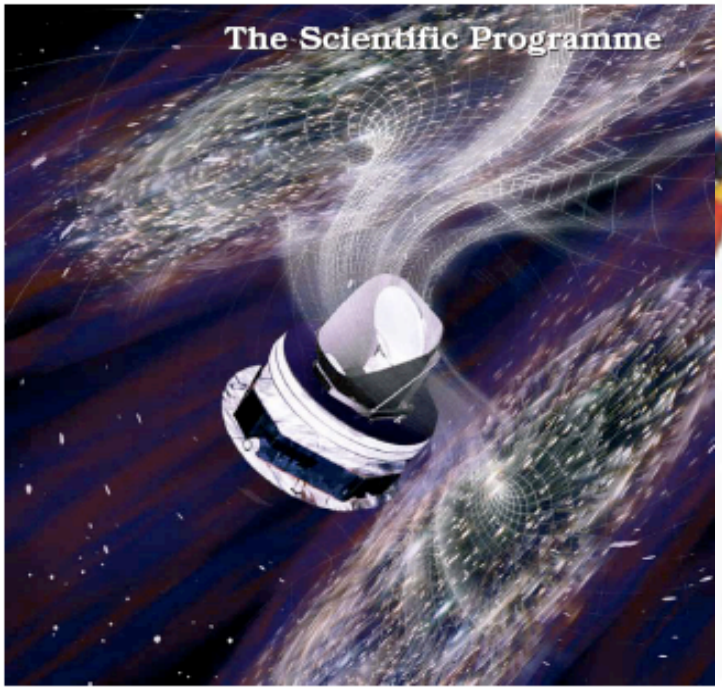
Planck fully integrated just before going into the big cryogenic test chamber at CSL in June 2008

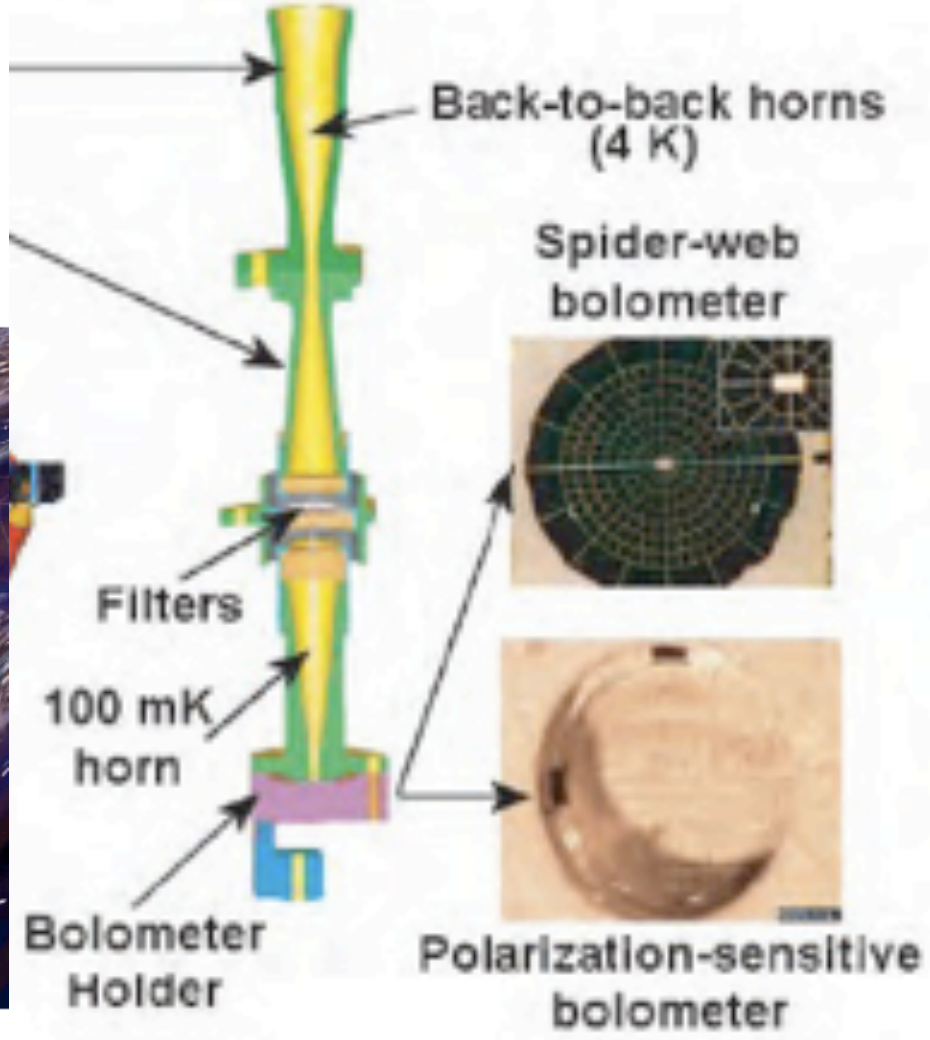
Test finished in mid August

ESA-SCI(2005)1

esa

PLANCK





European Space Agency
Agence spatiale européenne

Estimated Instrument Performance Goals

Telescope	1.5 m (proj. aperture) aplanatic; shared focal plane; system emissivity 1%								
	Viewing direction offset 85° from spin axis; Field of View 8°								
Instrument	LFI			HFI					
Center Freq. (GHz)	30	44	70	100	143	217	353	545	857
Detector Technology	HEMT LNA arrays			Bolometer arrays					
Detector Temperature	~20 K			0.1 K					
Cooling Requirements	H_2 sorption cooler			H_2 sorption + 4 K J-T stage + Dilution cooler					
Number of Unpol. Detectors	0	0	0	0	4	4	4	4	4
Number of Linearly Polarised Detectors	4	6	12	8	8	8	8	0	0
Angular Resolution (FWHM, arcmin)	33	24	14	9.5	7.1	5	5	5	5
Bandwidth (GHz)	6	8.8	14	33	47	72	116	180	283
Average $\Delta T/T_I$* per pixel#	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
Average $\Delta T/T_{U,Q}$* per pixel#	2.8	3.9	6.7	4.0	4.2	9.8	29.8		

* Sensitivity (1σ) to intensity (Stokes I) fluctuations observed on the sky, in thermodynamic temperature ($x10^{-6}$) units, relative to the average temperature of the CMB (2.73 K), achievable after two sky surveys (14 months).

A pixel is a square whose side is the FWHM extent of the beam.

* Sensitivity (1σ) to polarised intensity (Stokes U and Q) fluctuations observed on the sky, in thermodynamic temperature ($x10^{-6}$) units, relative to the average temperature of the CMB (2.73 K), achievable after two sky surveys (14 months)

hope is now 4 sky surveys - enough cryogen (30 months)

Center Freq. (GHz)	30	44	70	100	143	217	353	545	857
Angular Resolution (FWHM, arcmin)	33	24	14	9.5	7.1	5	5	5	5
Average $\Delta T/T_I$ per pixel#	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
Average $\Delta T/T_{U,Q}$* per pixel#	2.8	3.9	6.7	4.0	4.2	9.8	29.8		
Sensibilité in I [μK] per pixel (FWHM)	5.5	7.4	12.8	6.8	6.5	14.1	48.4		
Sensibilité in I [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	2.7	2.6	2.6	0.96	0.70	1.05	3.5		

WMAP Center Freq.	23	33	41	61	94
Angular resolution (FWFM arcmin)	49	37	29	20	12,6
μK per 3,2 10^{-5} sr pixel (22'x 22')	38.9	39,9	41	48	46
Sensibilité en I [μK.deg], 1 yr (8 yrs)	12.6 (4.5)	12.9 (4.6)	13.3 (4.7)	15.6 (5.5)	15.0 (5.3)

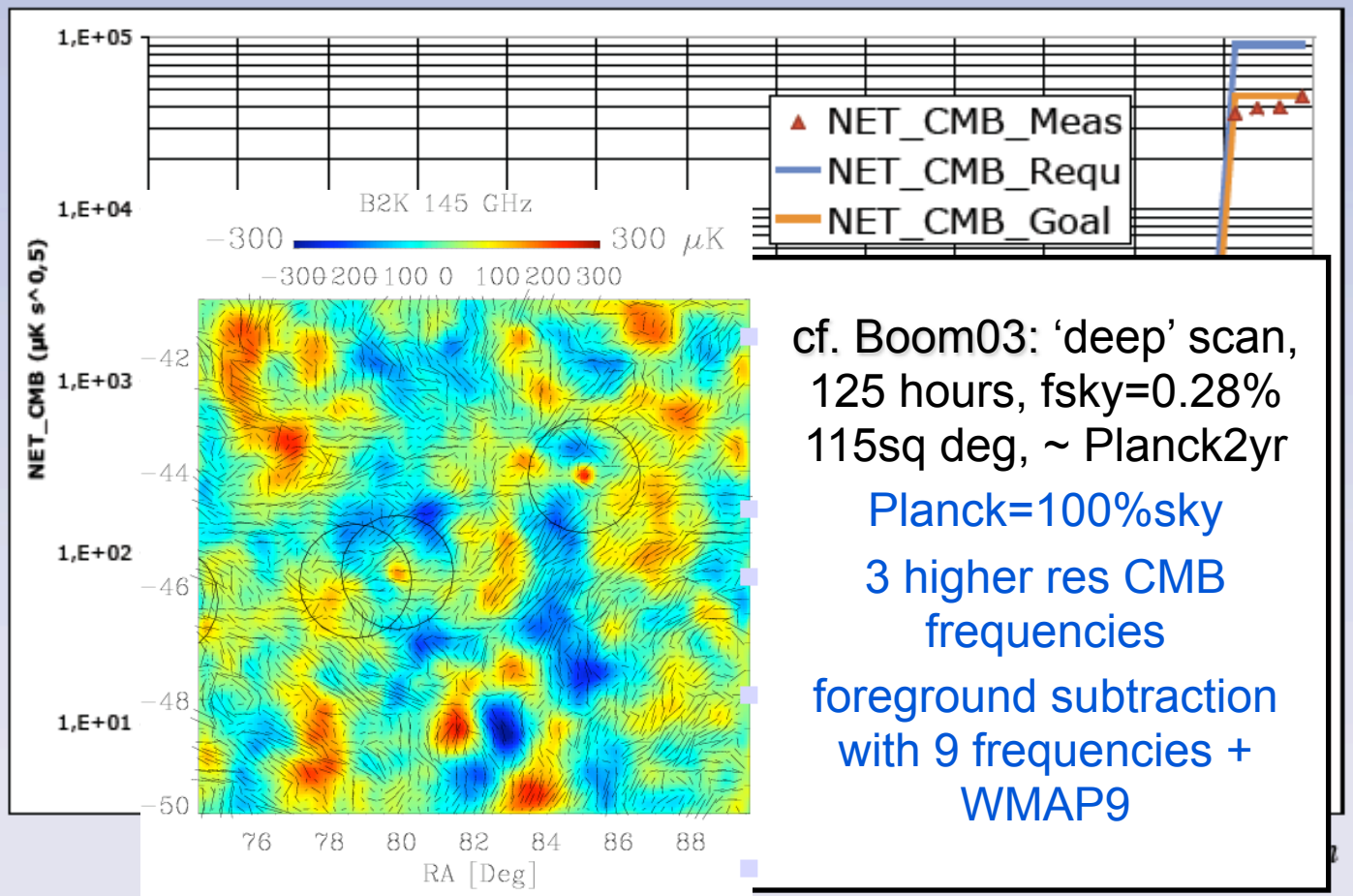
Using the central CMB channels of Planck @ 100, 143, 217GHz (~0.65μK.deg in T, 1.3 μK.deg QU)

NET requirement vs. NET measurement vs NET goal: very close to goal, better than requirement in all channels: 100 GHz_P 143 GHz_P 143 GHz 217 GHz_P 217 GHz 353 GHz_P 545 GHz 857 GHz

HFI PLANCK

Expected performances

(1) Noise Equivalent Temperature



cf. Boom03: 'deep' scan, 125 hours, fsky=0.28% 115sq deg, ~ Planck2yr

Planck=100%sky

3 higher res CMB frequencies

foreground subtraction with 9 frequencies + WMAP9


ADCO
PLANCK
TRANSPORT & STORAGE
CONTAINER
esa


АН-124-100
Volga-Dnepr
ВОЛГА ДНЕПР
http://www.volga-dnepr.com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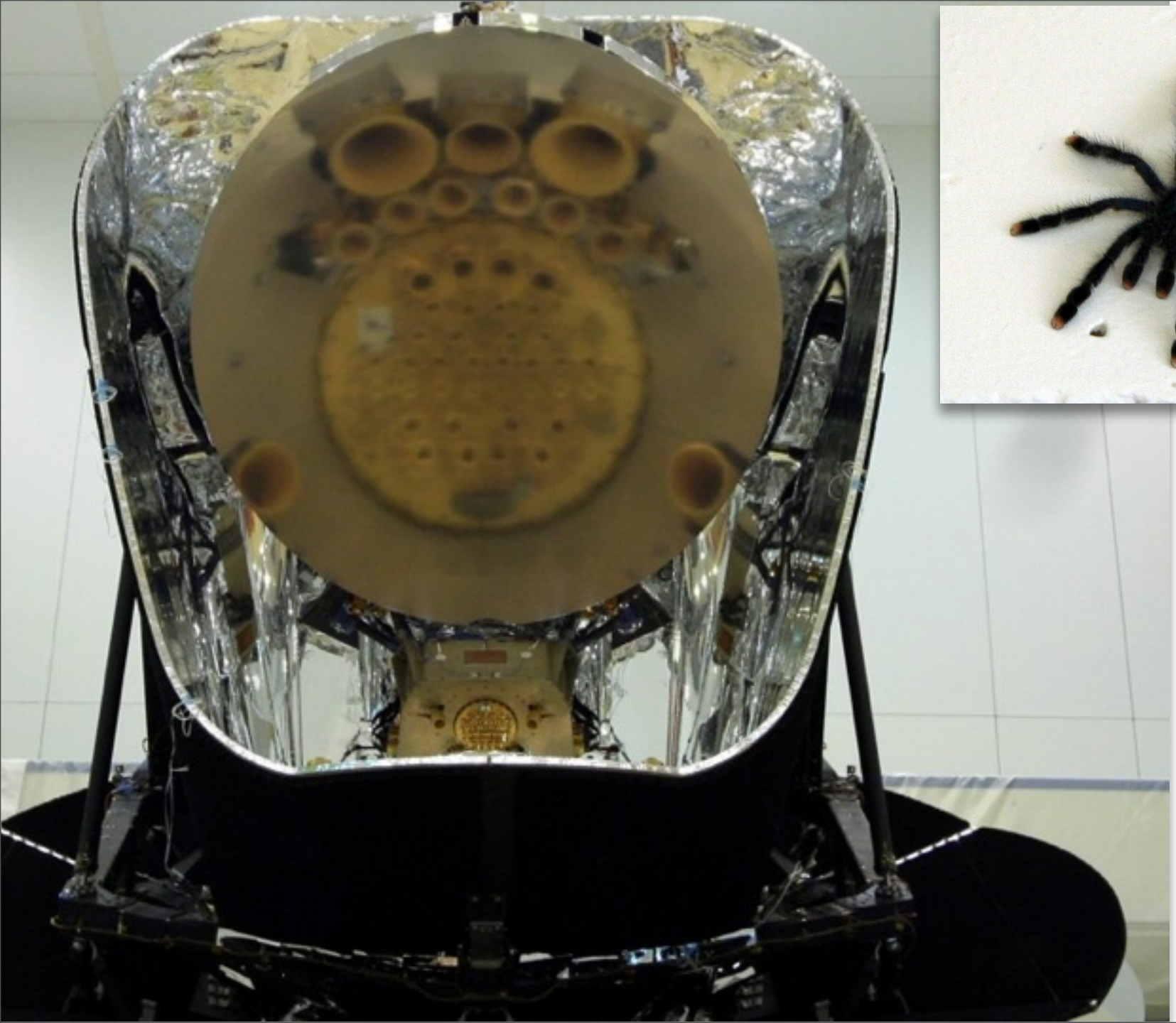
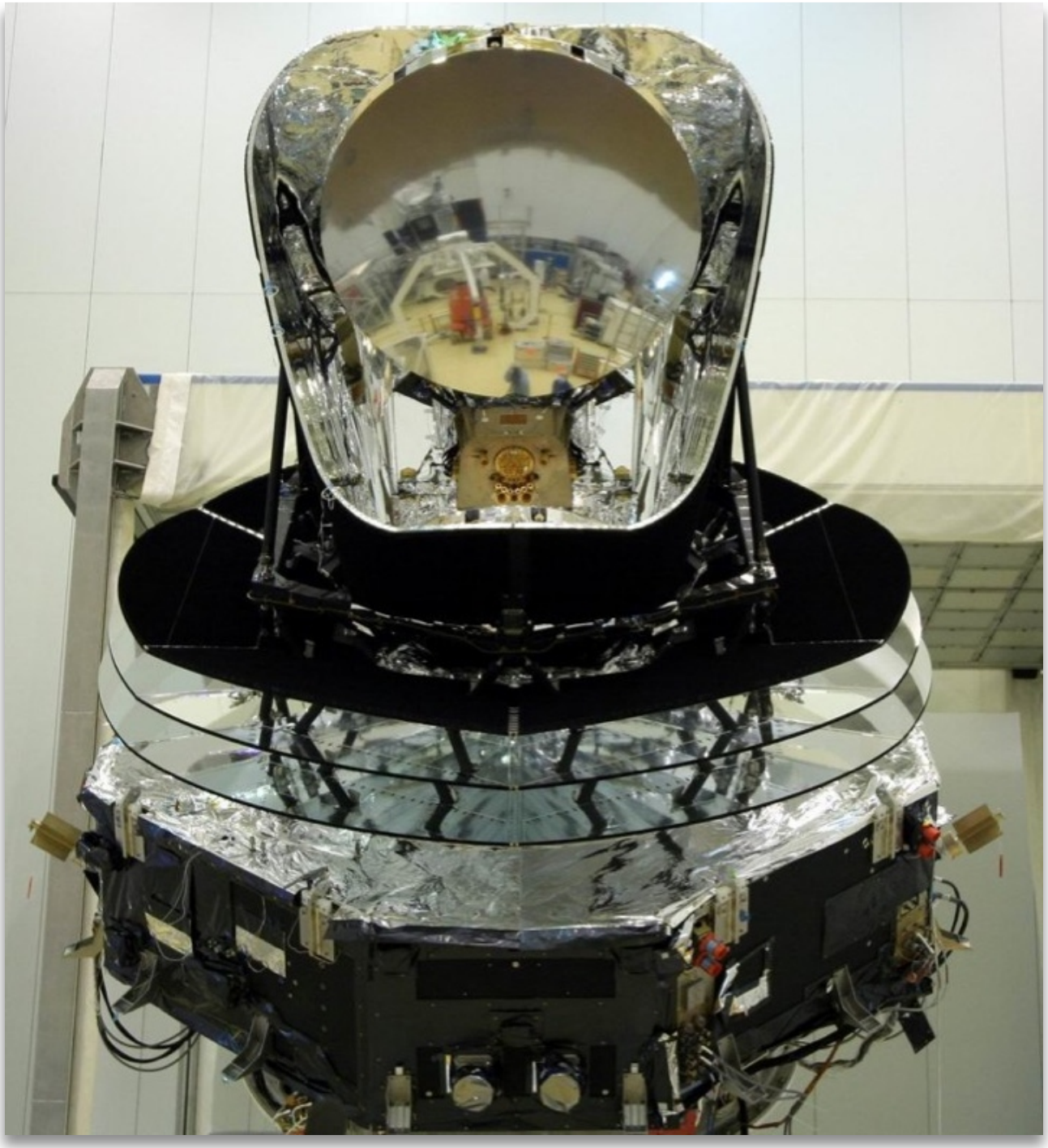
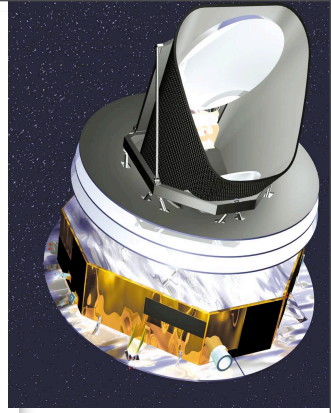
CONTAINER
esa


Volga-Dnepr
Волга Днепр
АН-124-100



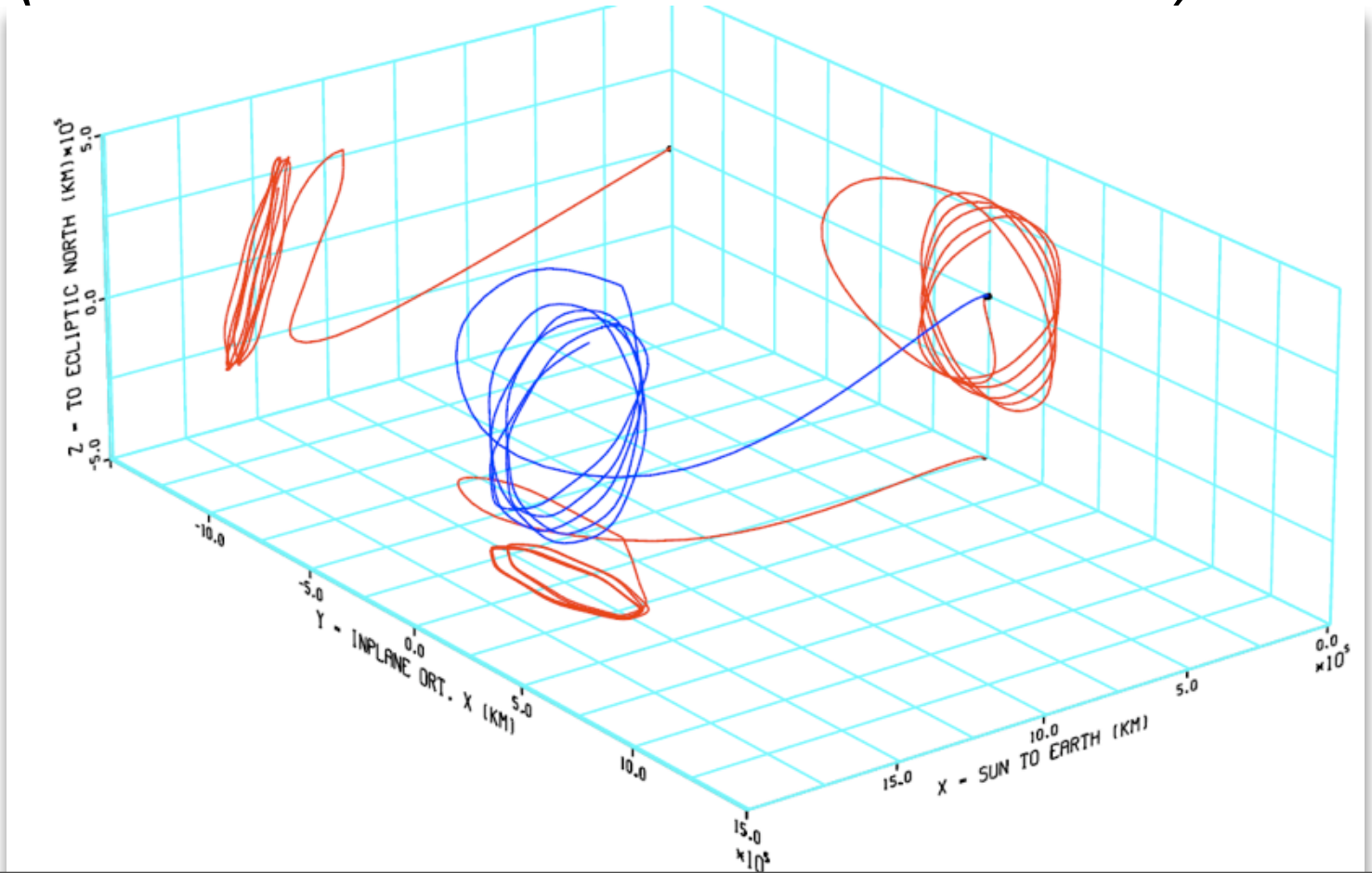


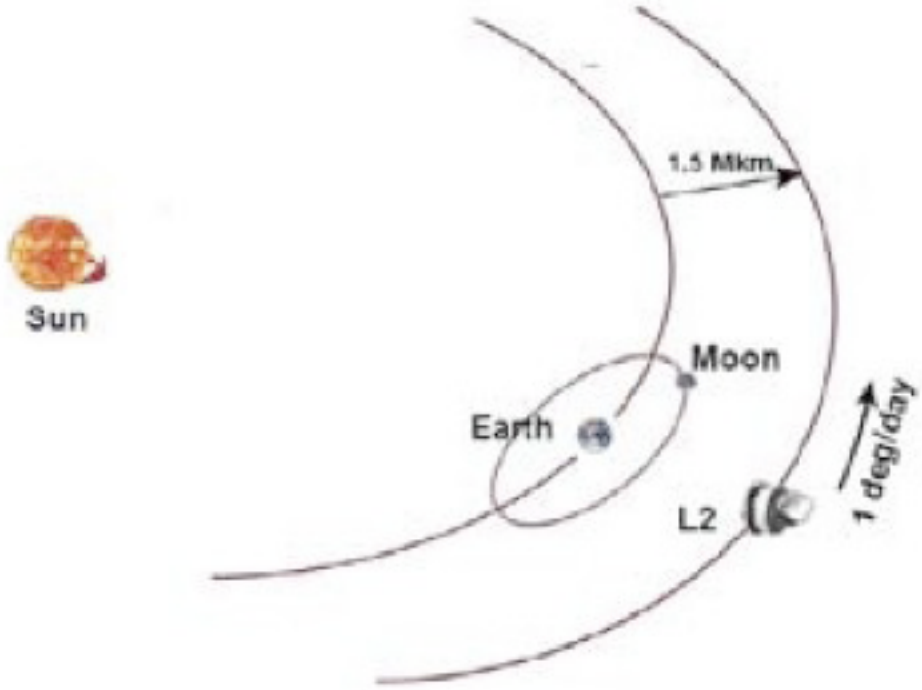


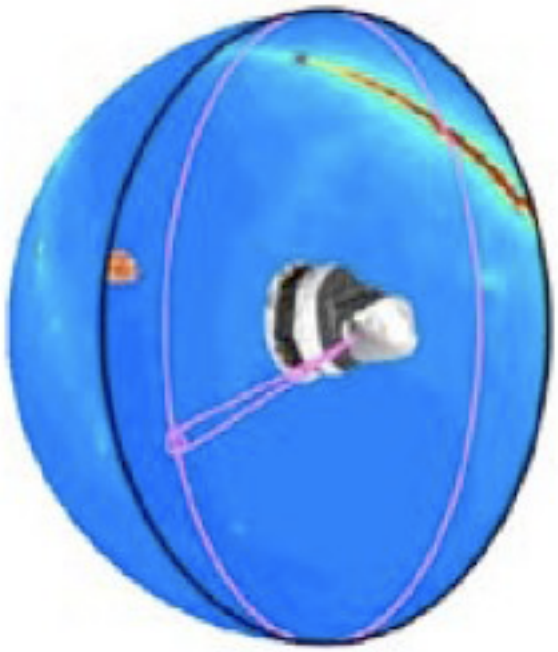
Planck's Journey

Trip to L2: ~ 30 days

- *Decontamination & Cooldown ~ 45 days*
- *Detectors at 100mK at L2 around June 5*
- *CPV (Checkout & Performance Verification) thru mid-Jul*



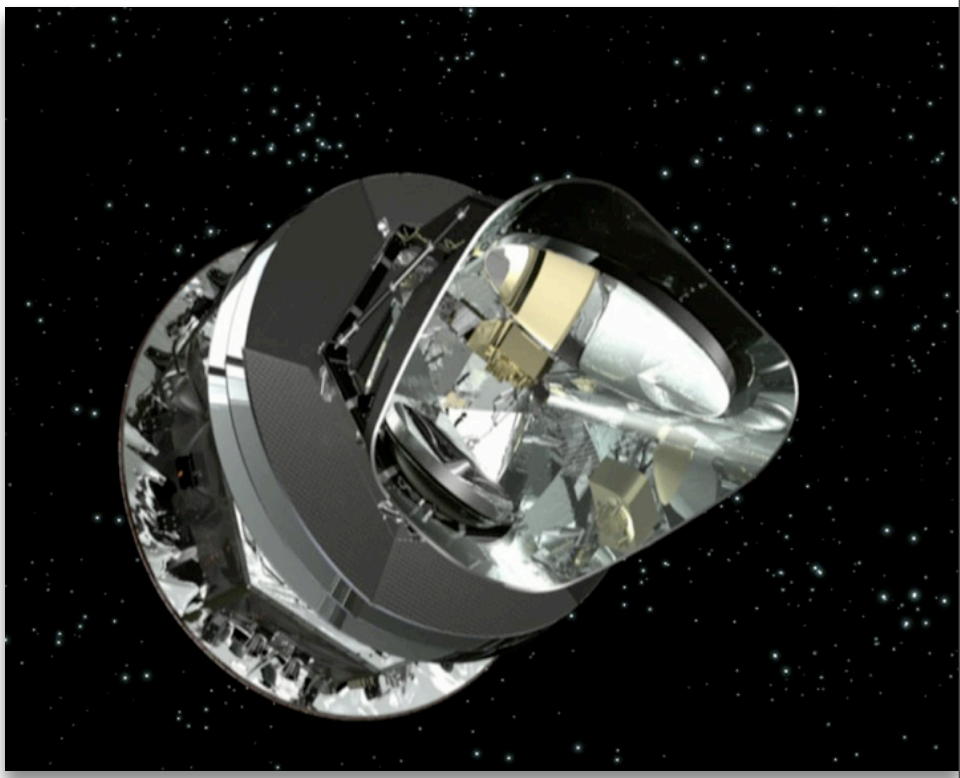

1.5 Mkm
Sun
Moon
Earth
L2
1 deg/day



Schedule

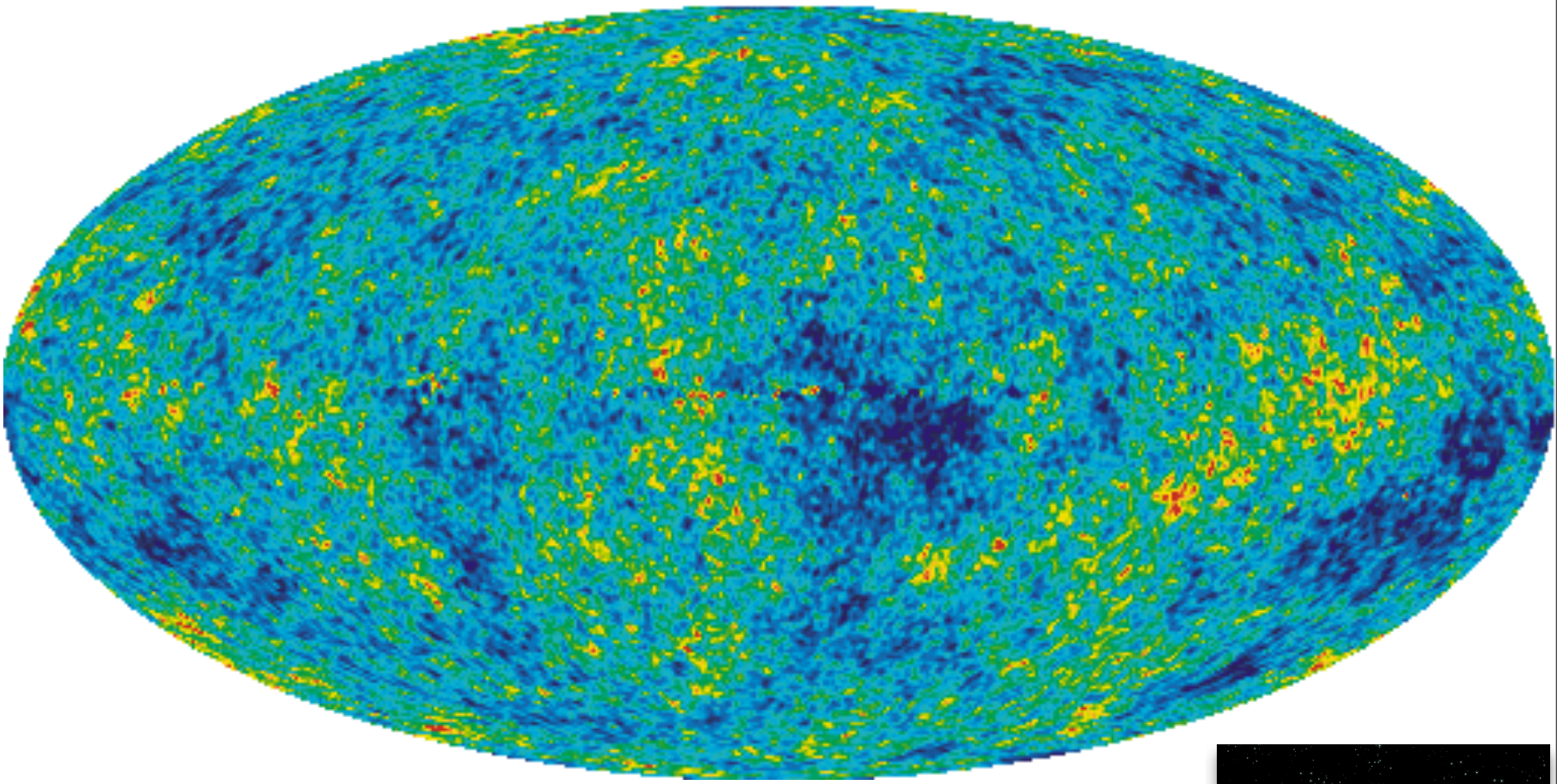
Launch: April 2009

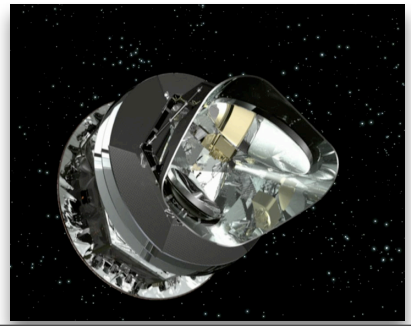
- *Cruise & CPV ends July 2009*
- *Two sky surveys finished July 2010*
- *Early Release Compact Source Catalog ~Dec 2010*
- *Four sky surveys finished: July 2011*
- *Public release of 1yr data, papers: July 2012*



CMBology WITH PLANCK

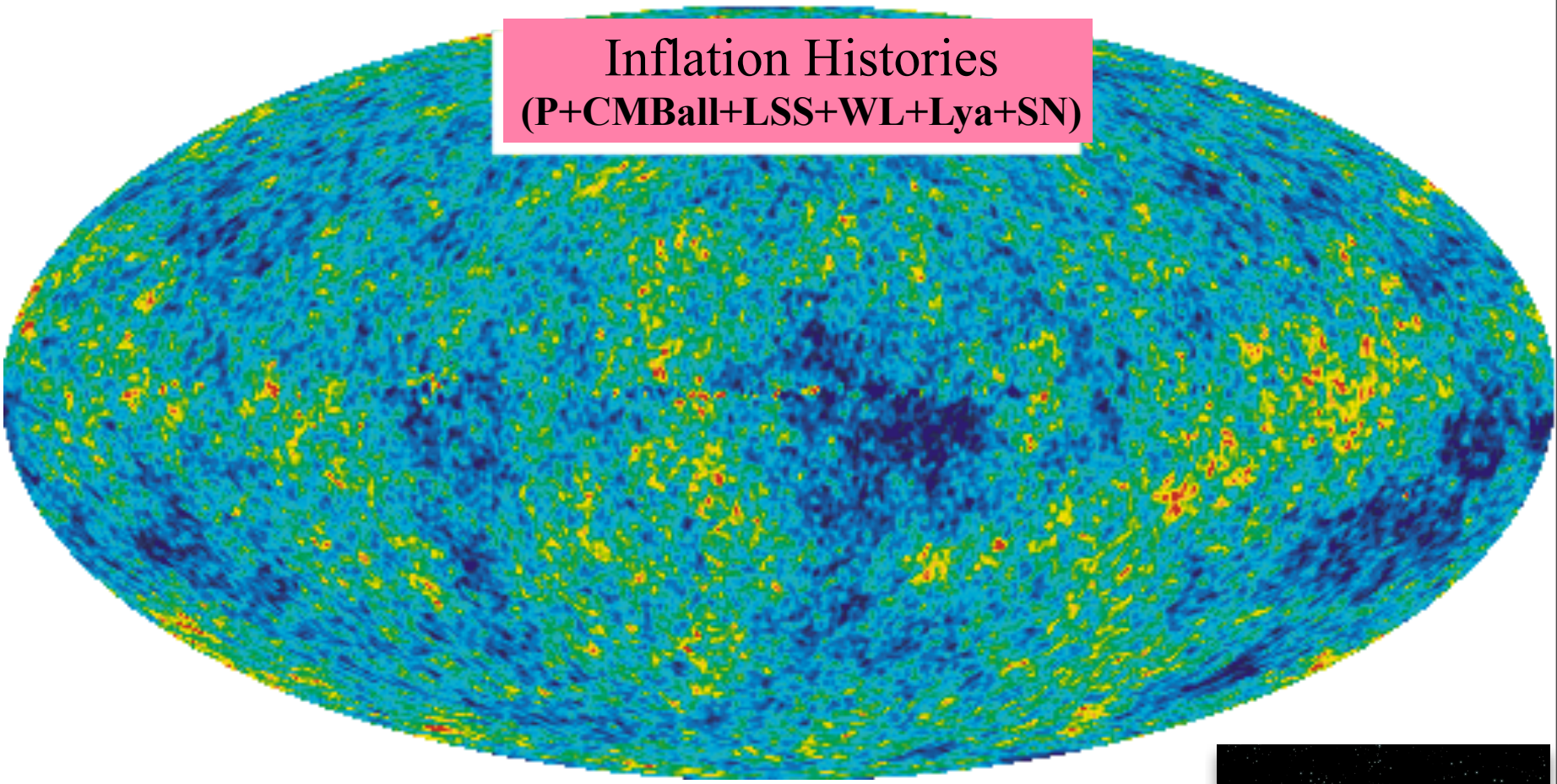
Probing the linear & nonlinear cosmic web

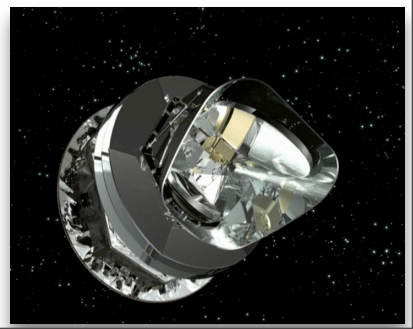




CMBology WITH PLANCK

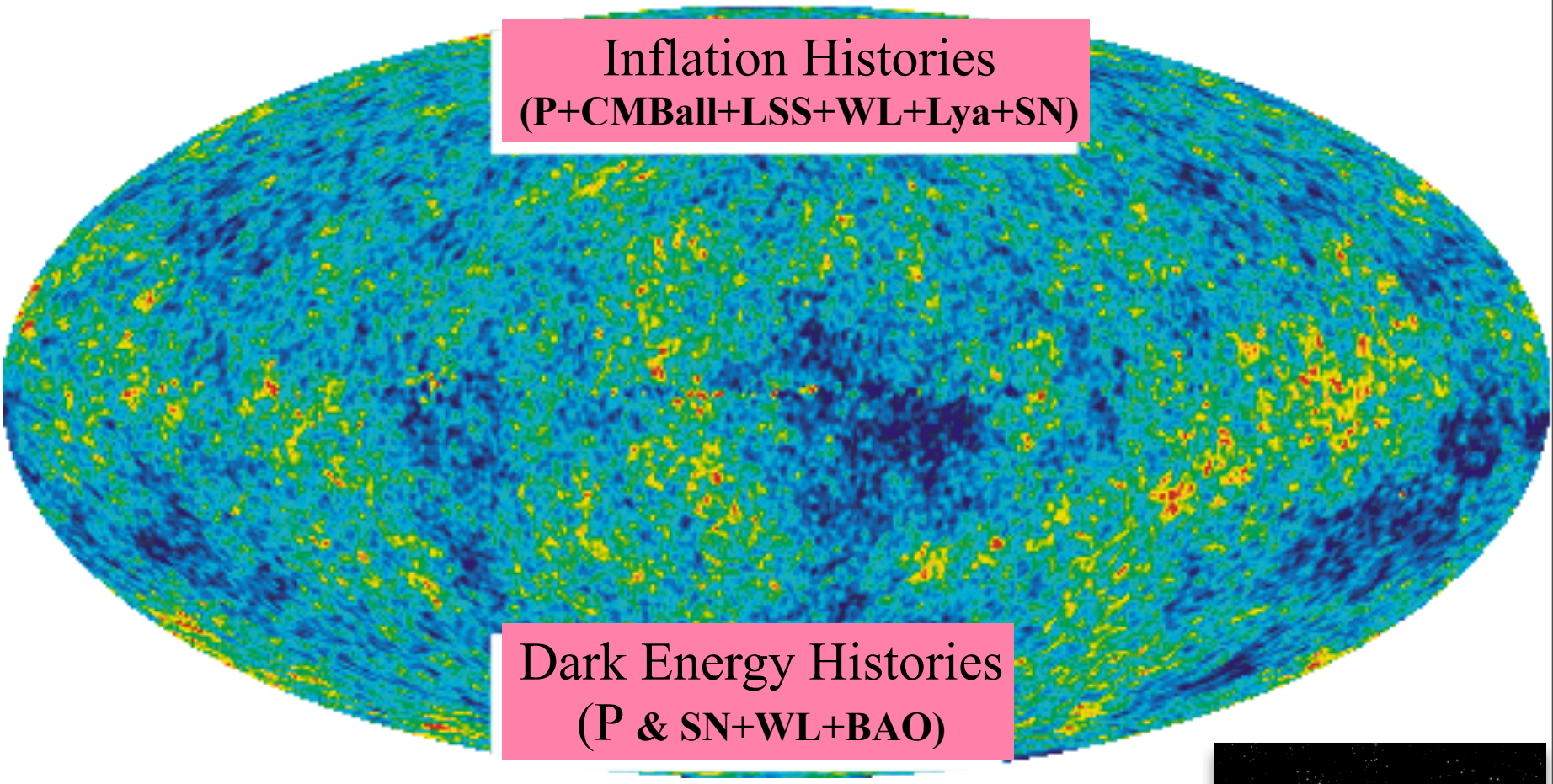
Probing the linear & nonlinear cosmic web





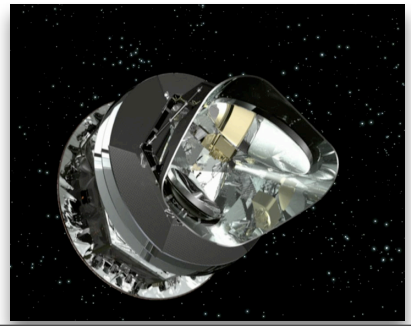
CMBology WITH PLANCK

Probing the linear & nonlinear cosmic web



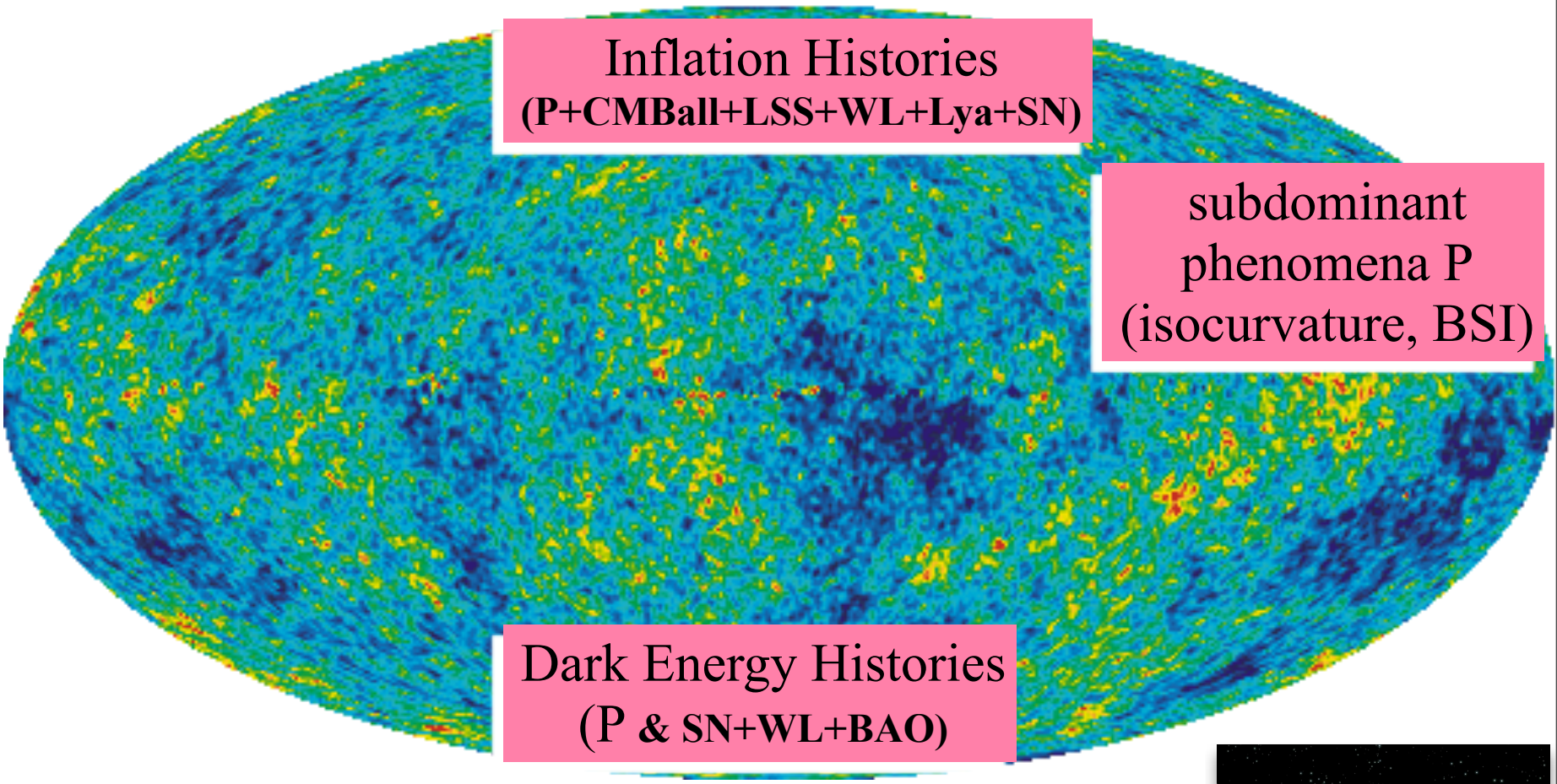
Inflation Histories
(P+CMBall+LSS+WL+Lya+SN)

Dark Energy Histories
(P **& SN+WL+BAO)**



CMBology WITH PLANCK

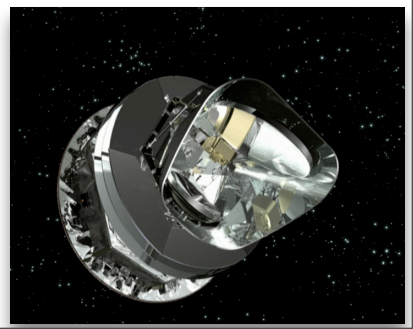
Probing the linear & nonlinear cosmic web



Inflation Histories
(P+CMBall+LSS+WL+Lya+SN)

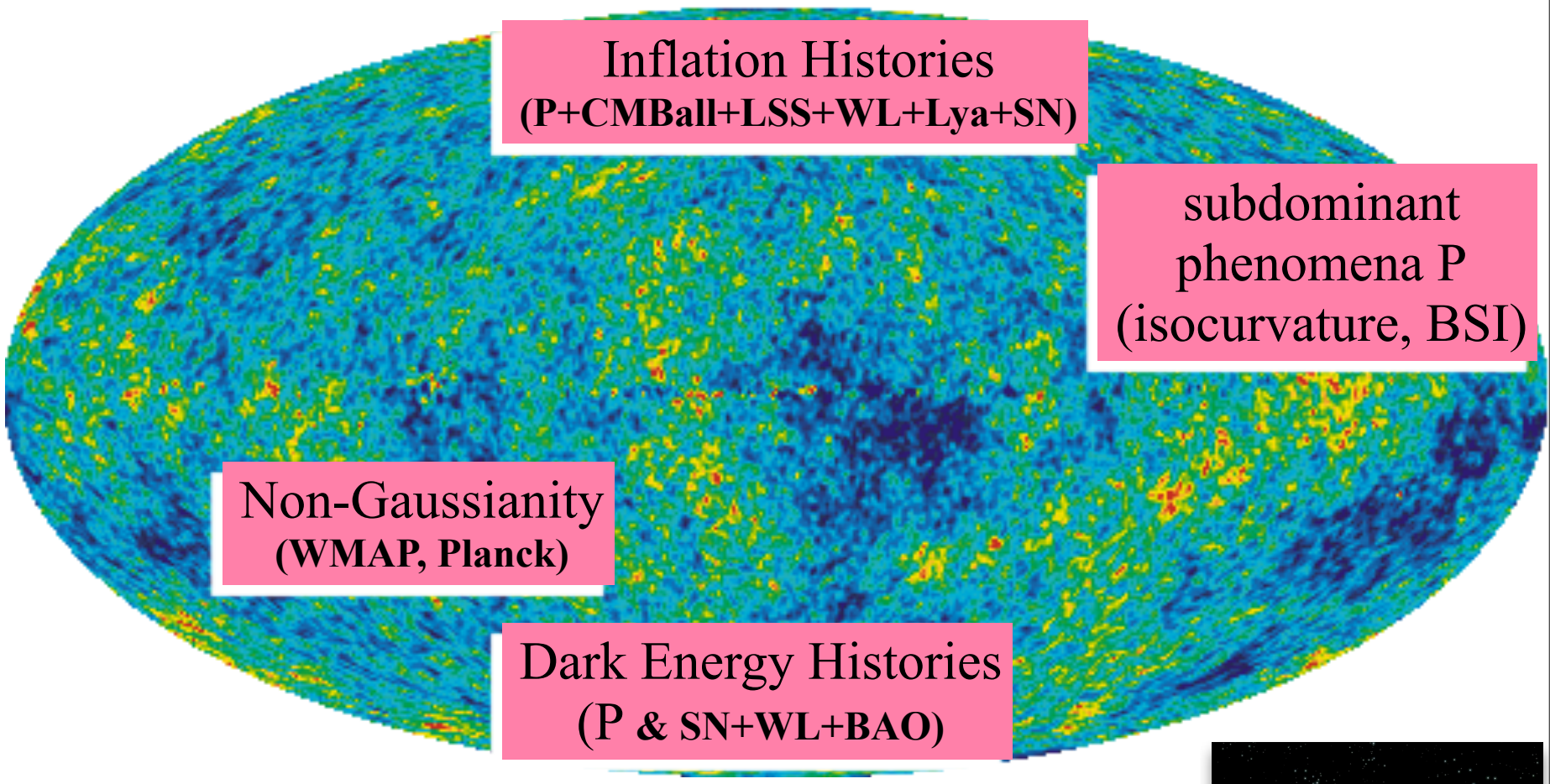
subdominant
phenomena P
(isocurvature, BSI)

Dark Energy Histories
(P **& SN+WL+BAO)**



CMBology WITH PLANCK

Probing the linear & nonlinear cosmic web

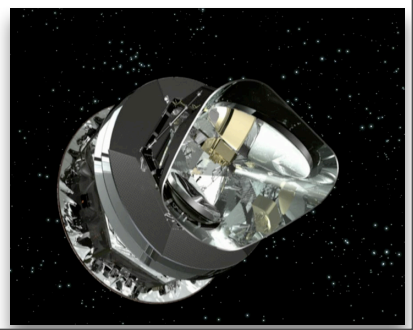


Inflation Histories
(P+CMBall+LSS+WL+Lya+SN)

subdominant phenomena P (isocurvature, BSI)

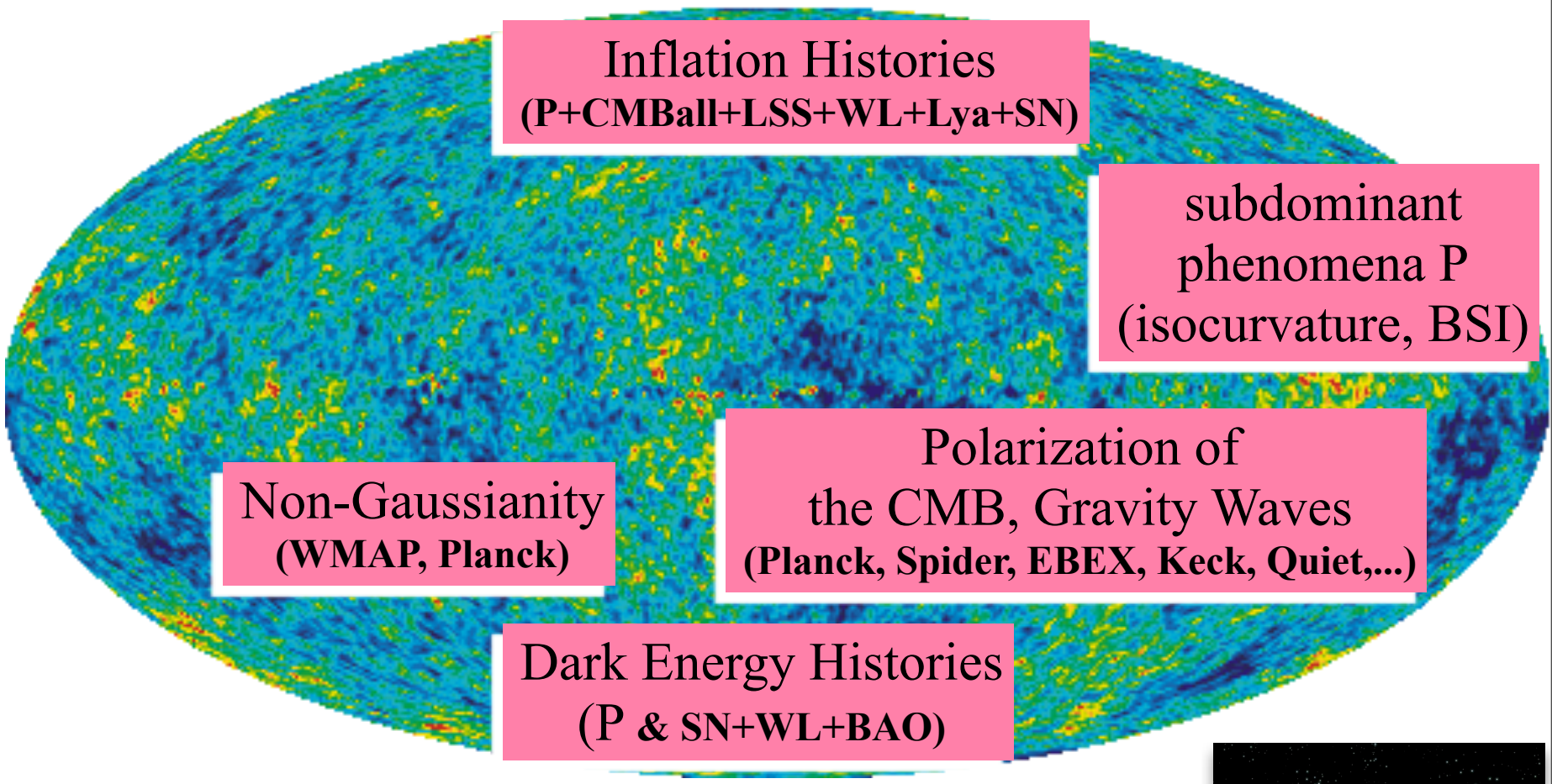
Non-Gaussianity
(WMAP, Planck)

Dark Energy Histories
(P **& SN+WL+BAO)**



CMBology WITH PLANCK

Probing the linear & nonlinear cosmic web



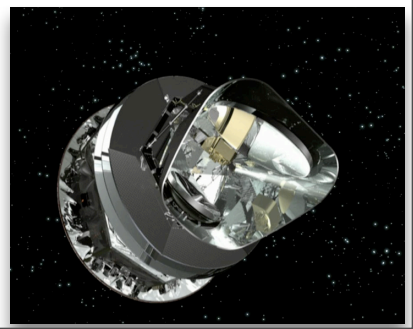
Inflation Histories
(P+CMBall+LSS+WL+Lya+SN)

subdominant
phenomena P
(isocurvature, BSI)

Polarization of
the CMB, Gravity Waves
(Planck, Spider, EBEX, Keck, Quiet,...)

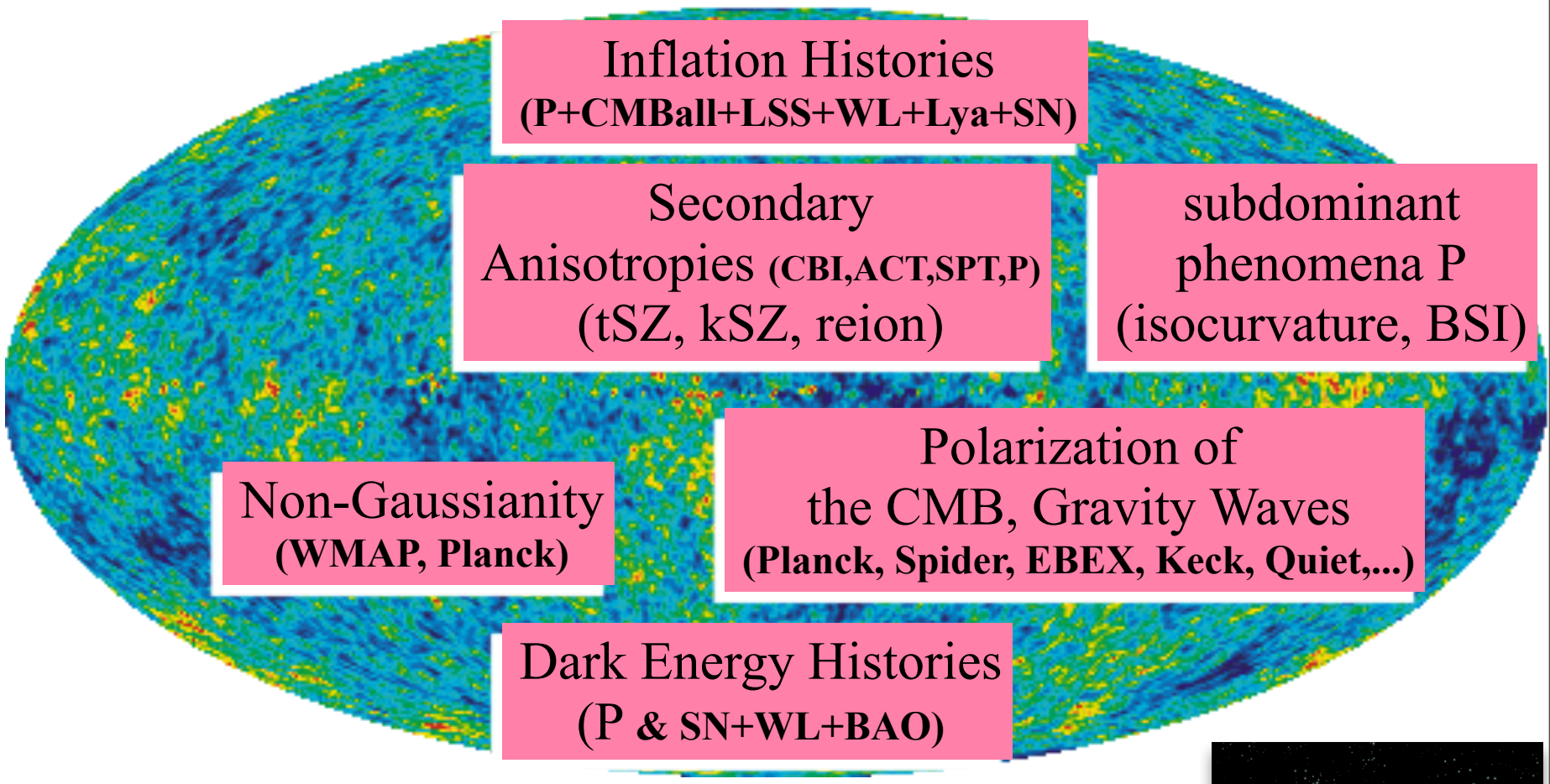
Non-Gaussianity
(WMAP, Planck)

Dark Energy Histories
(P **& SN+WL+BAO)**



CMBology WITH PLANCK

Probing the linear & nonlinear cosmic web



Inflation Histories
(P+CMBall+LSS+WL+Lya+SN)

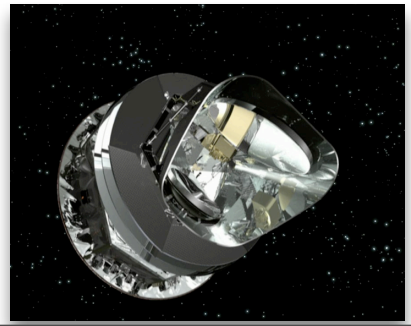
Secondary
Anisotropies **(CBI,ACT,SPT,P)**
(tSZ, kSZ, reion)

subdominant
phenomena P
(isocurvature, BSI)

Non-Gaussianity
(WMAP, Planck)

Polarization of
the CMB, Gravity Waves
(Planck, Spider, EBEX, Keck, Quiet,...)

Dark Energy Histories
(P **& SN+WL+BAO)**



CMBology WITH PLANCK

Probing the linear & nonlinear cosmic web

Inflation Histories
(P+CMBall+LSS+WL+Lya+SN)

Secondary
Anisotropies **(CBI,ACT,SPT,P)**
(tSZ, kSZ, reion)

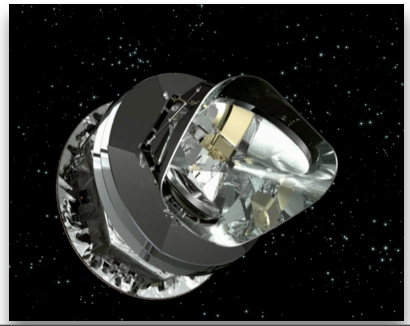
subdominant
phenomena P
(isocurvature, BSI)

Foregrounds
WMAP, Planck

Polarization of
the CMB, Gravity Waves
(Planck, Spider, EBEX, Keck, Quiet,...)

Non-Gaussianity
(WMAP, Planck)

Dark Energy Histories
(P **& SN+WL+BAO)**



INFLATION THEN

PROBES NOW

"standard inflation space": $\mathbf{n_s}$ $\mathbf{dn_s/d\ln k}$ $\mathbf{r}$ **@k-pivots**

$\mathbf{n_s(kp)}$**=.962 +-.013** (+-.005 Planck1) **.959 +- .011 all data**

$\mathbf{r=P_t/P_s(kp')}$ **< 0.40**$_{\mathbf{cmb}}$ **95% CL (+-.03 P1, +- .01 Spider+P2.5)**

$\mathbf{dn_s/d\ln k\ (kp)}$ **=-.016 +- .019** (+-.005 Planck1)

(partially) blind trajectories **e.g.,** $\mathbf{n_s(k)}$ **and** $\mathbf{r(kp)}$**,** ***are better***

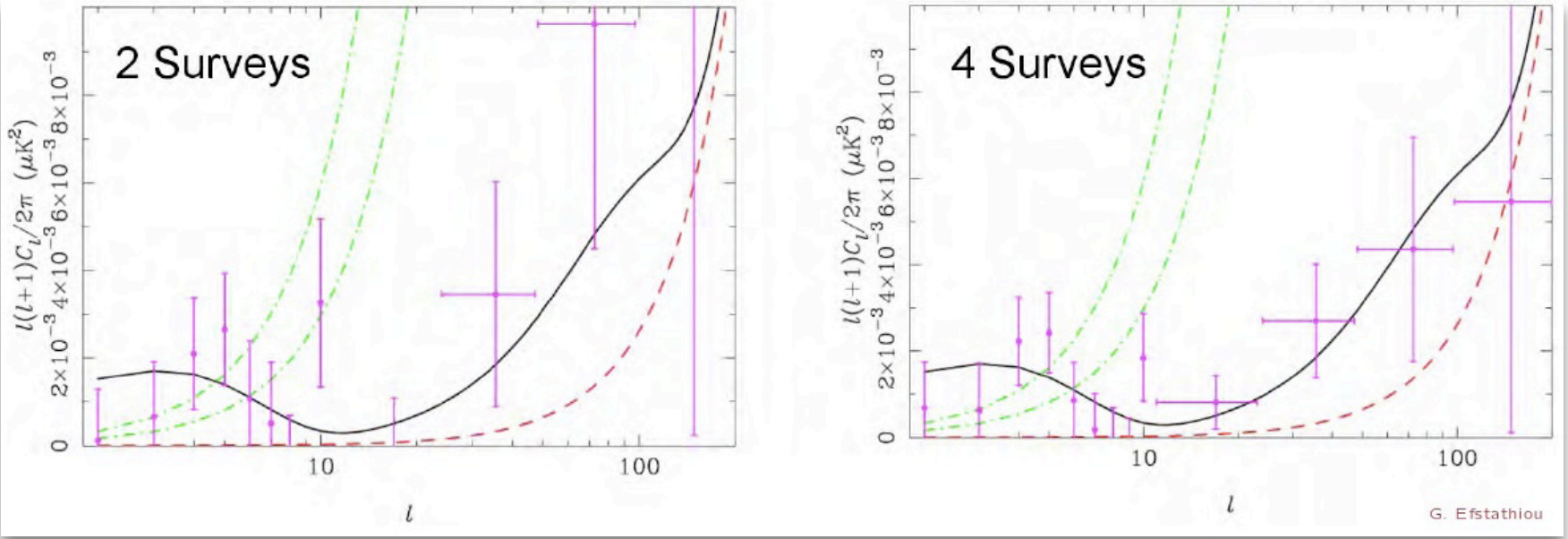
local quadratic non-G constraint: -9< f_{NL}<111 ⇒ -4< f_{NL}<80 WMAP5 (± 5-10 Planck1yr)

CBI10: add a cosmic string template⇒$\mathbf{n_s}$<1 @2σ & string tension limit $G\mu < 2.8 \times 10^{-7}$

Planck & low-L polarization B-modes?

Issues: unknown foreground properties, cut sky analysis, leakage, Planck has no polarization modulation other than the scan

Statistical / Foreground subtraction limit after 4 surveys r < 0.03 ? (Efstathiou & Gratton 09 using the Planck Sky Model of foregrounds - WMAP+..+simplified guesses, low L)



INFLATION THEN

WHAT IS PREDICTED?

Smoothly broken scale invariance by nearly uniform braking (standard of 80s/90s/00s) $r \sim 0.03\text{-}0.5$

or highly variable braking r tiny

(stringy cosmology) $r < 10^{-10}$

CBI pol to Apr'05 @Chile

QUaD @SP

Quiet1 @Chile

Quiet2 1000 HEMTs

Boom03@LDB

Bicep @SP

Bicep2

Keck/Spud

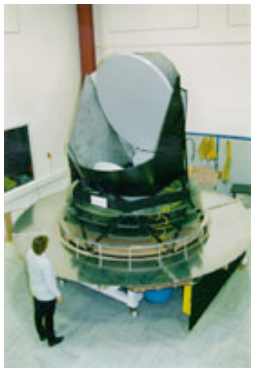
EBEX @LDB

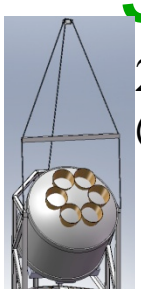
WMAP @L2 to 2009-2013?

Planck09.3

(52 bolometers) + HEMTs @L2

9 frequencies





Spider

2312 bolos @LDB

DASI @SP

CAPMAP

CHIP

2011

2004 2006 2008 LHC

2005 2007 2009

Bpol @L2

BLASTpol

Clover @Chile

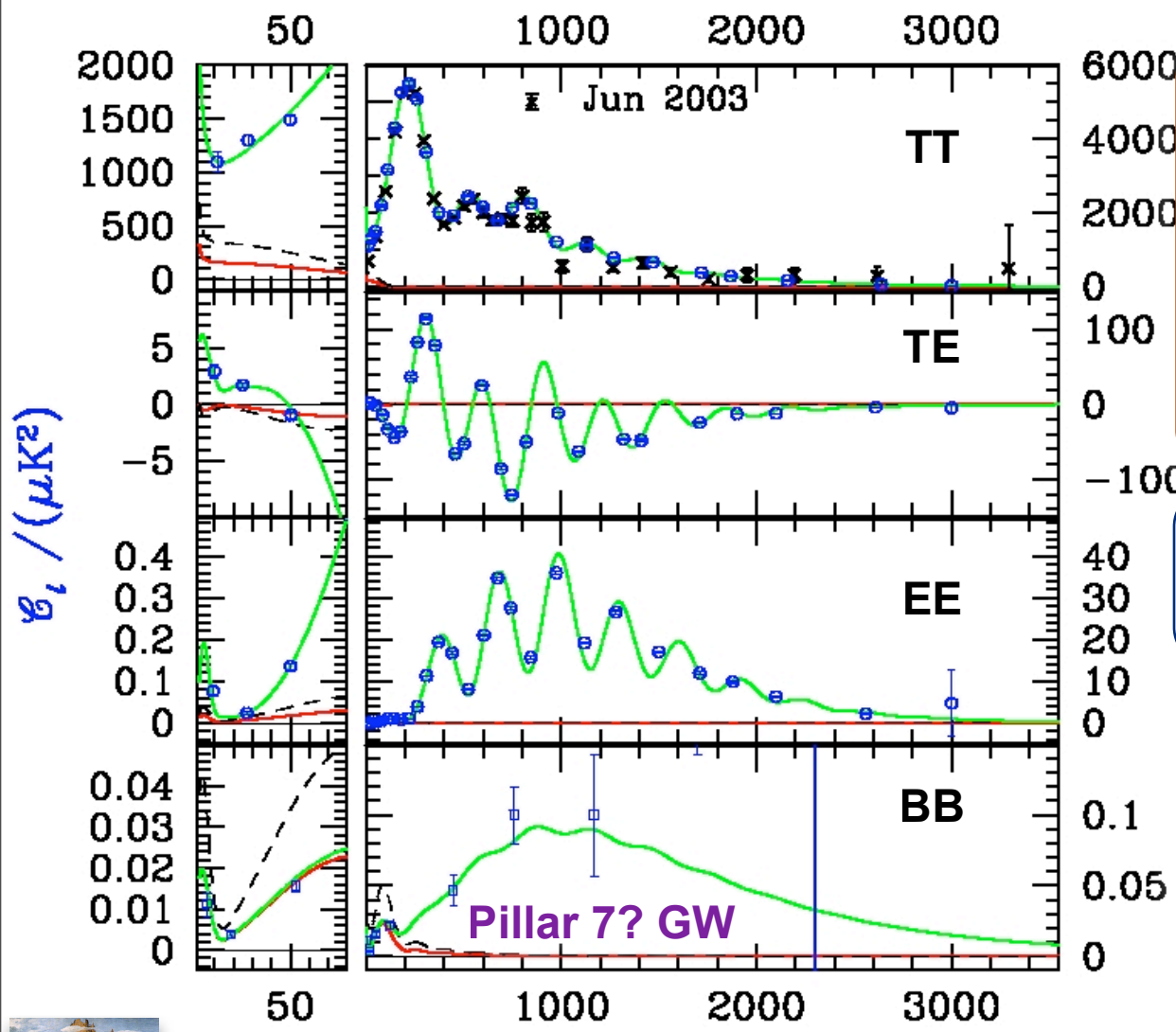
Polarbear

300 bolos @Cal/Chile

SPTpol

PRIMARY END @ 2012?

CMB Planck1+WMAP8+SPTpol/ACTpol/Quiet+Bicep/QuAD/Quiet +Spider +Clover



Pillar 7? Gravity Waves

An ensemble of trajectories arises in many-moduli string models, whether braney or holey. **Roulette inflation:** *complex hole sizes in 6D* TINY **$r<10^{-10}$** *& n_s from data-selected braking!*

('theorem': $\Delta\psi < 1$ -> **r<.007**)

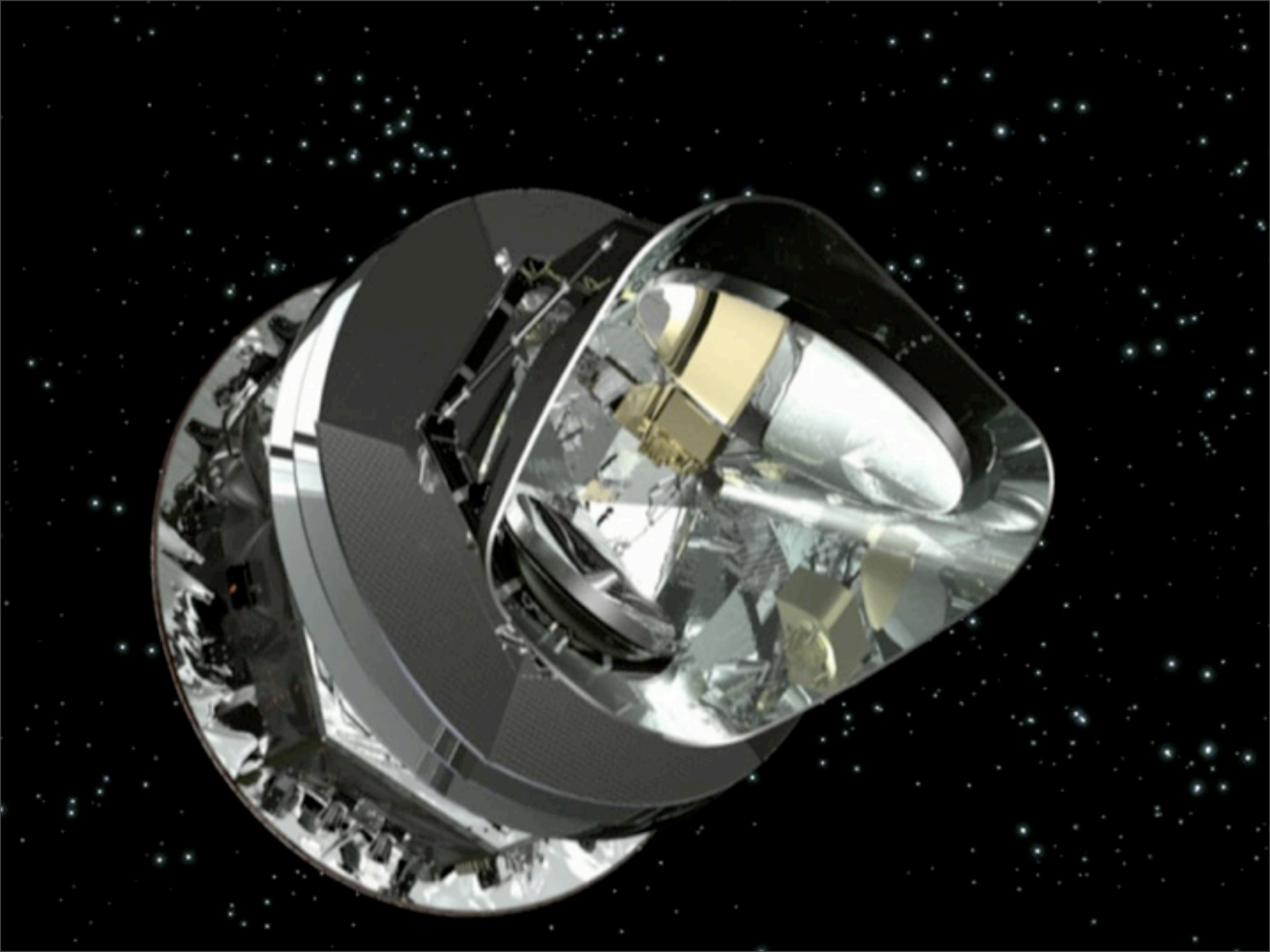
nearly uniform acceleration

(power law, exp, PNGB, ..potentials)

r~.03-.3! is $\Delta\psi$~10 deadly?

Even with low energy inflation, the prospects are good with ***Spider*** *plus* ***Planck*** *to either detect the GW-induced B-polarization or set a strong blind upper limit* ***r<0.02*** *indicating stringy or other exotic models. Both experiments have strong Cdn roles.* ***Bpol 2020?, to r~0.002***

+ Pillar 4: primordial non-Gaussianity **$-4 < f_{NL} < 80$ (+- 5-10 Planck1)**



Standard & Parameters of Cosmic Structure Formation

$\Omega_b h^2$ $\Omega_{dm} h^2$ Ω_Λ Ω_k τ_c

$\ln A_s$ n_s $r = A_t/A_s$ $dn_s/dlnk$ n_t

1+w0, wa

$\theta \sim \ell_s^{-1}$

$\sim \ln \sigma_8^2$

+ subdominant isocurvature/ cosmic string ***& fgnds, tSZ,kSZ, ...***

+ primordial non-Gaussianity

$\Phi(x) = \Phi_G(x) + f_{NL} (\Phi_G^2(x) - \langle \Phi_G^2 \rangle)$

local smooth

$\Phi(x) = \Phi_G(x) + F_{NL}(\chi_b + \chi_{>h}) - \langle F_{NL} \rangle$

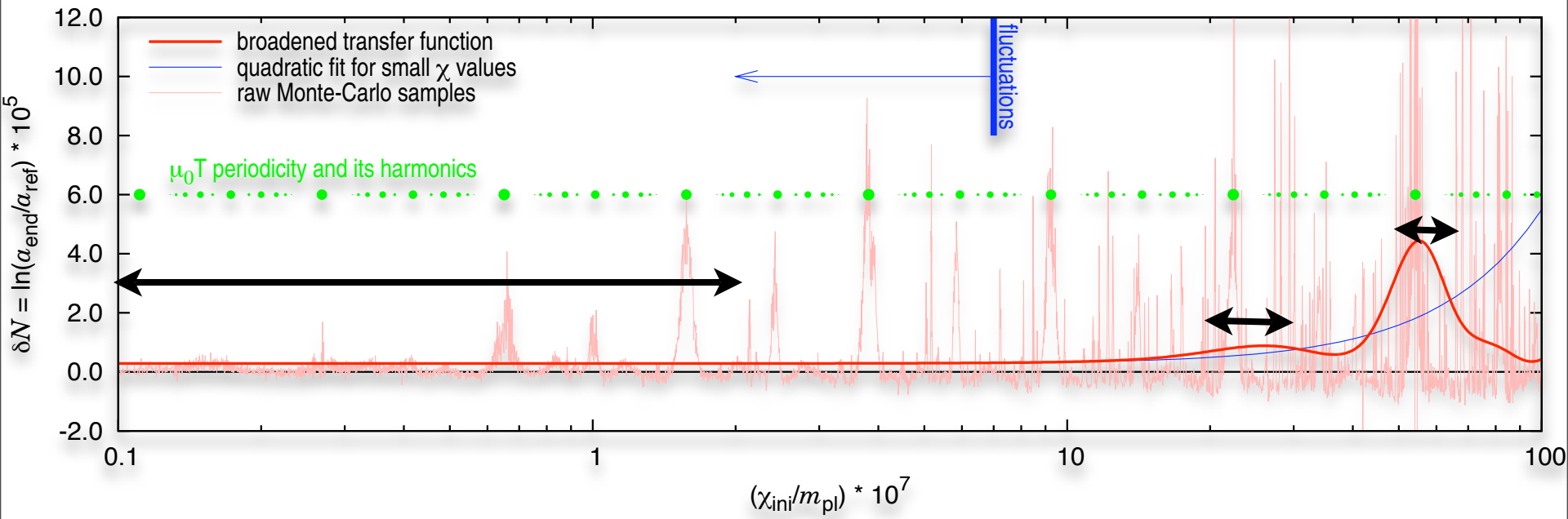
resonant preheating

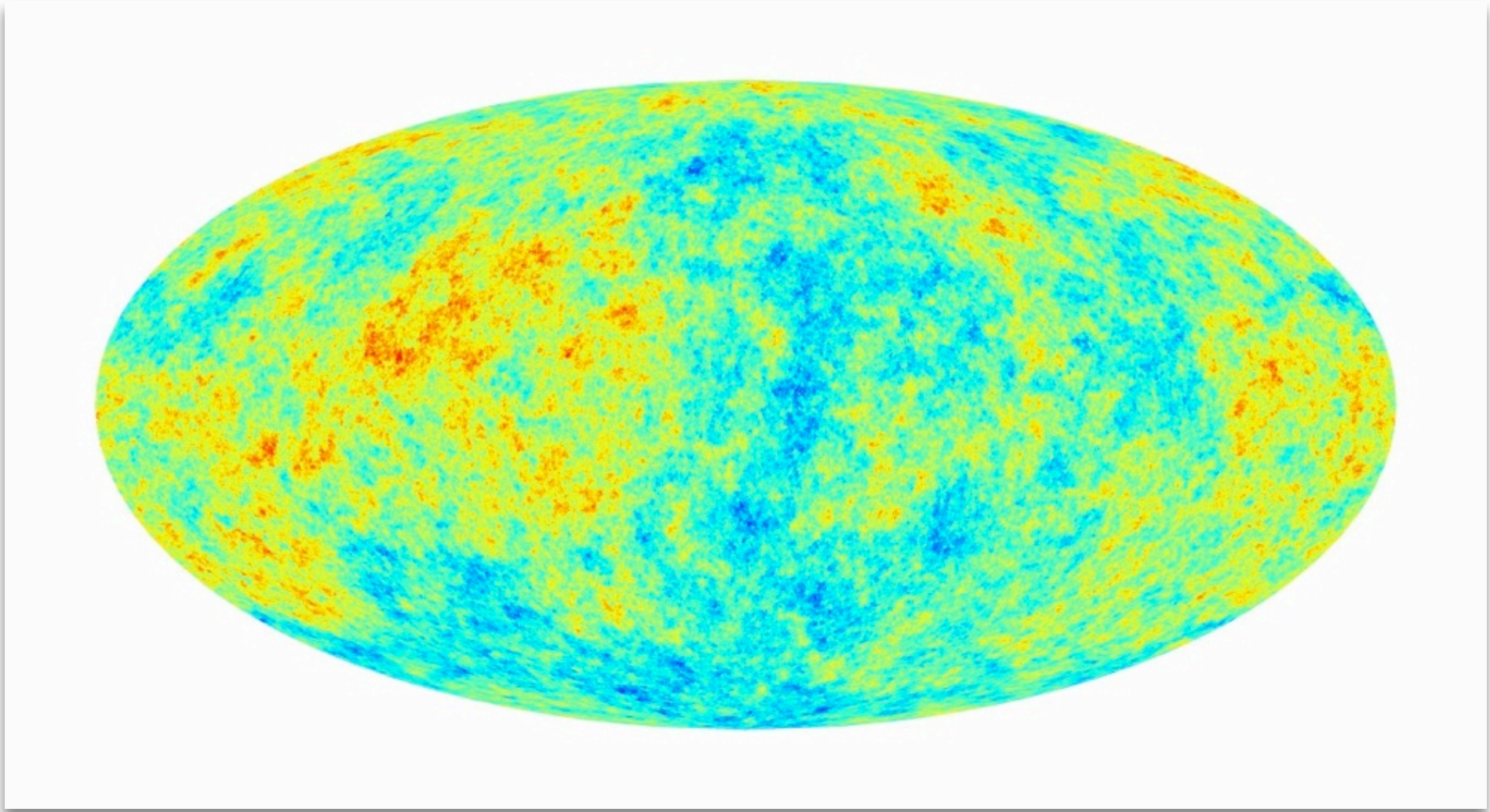
$-9 < f_{NL} < 111 \Rightarrow -4 < f_{NL} < 80$

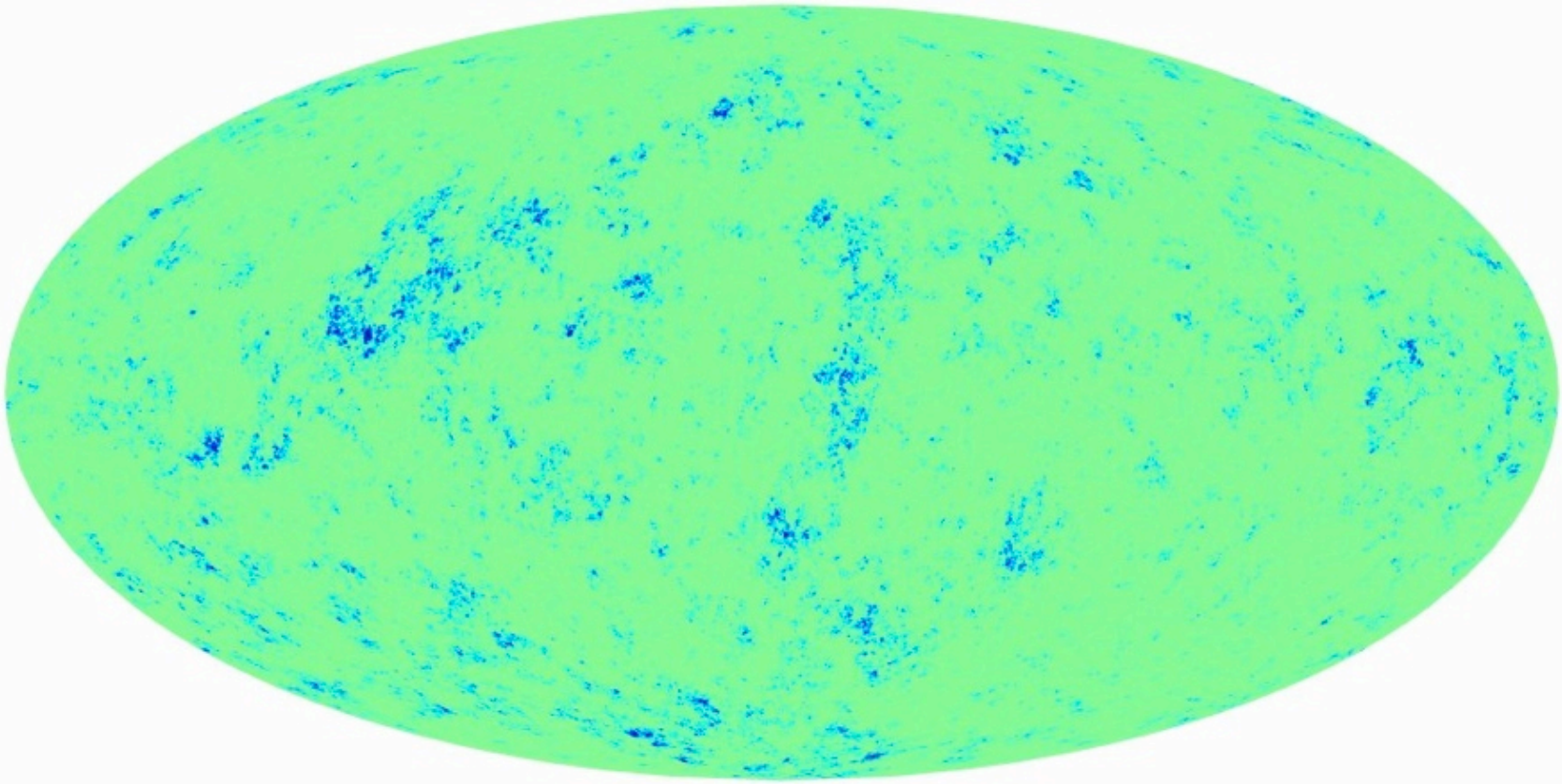
WMAP5 (± 5-10 Planck1yr)

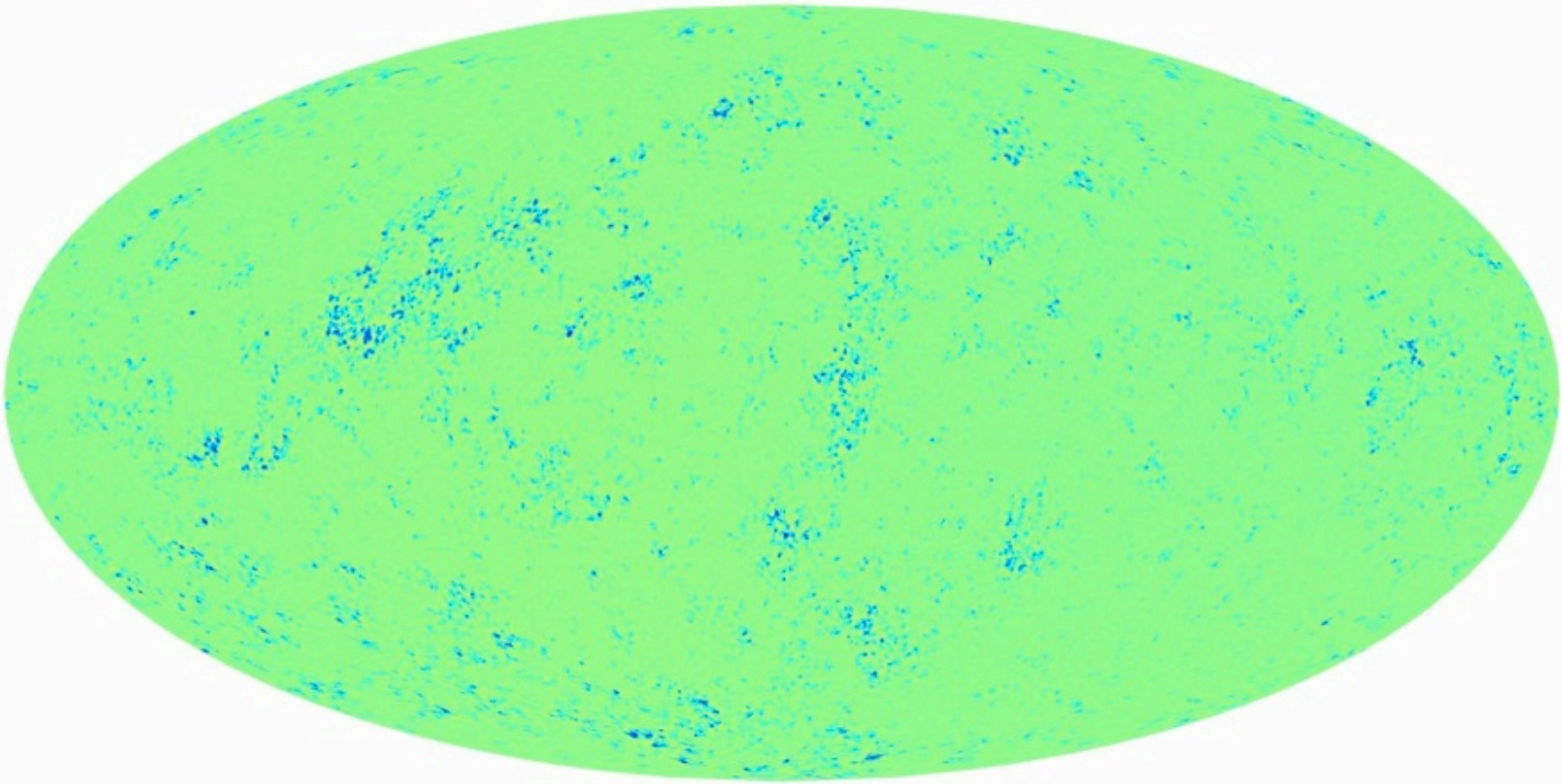
new parameters: trajectory probabilities for early-inflatons & late-inflatons

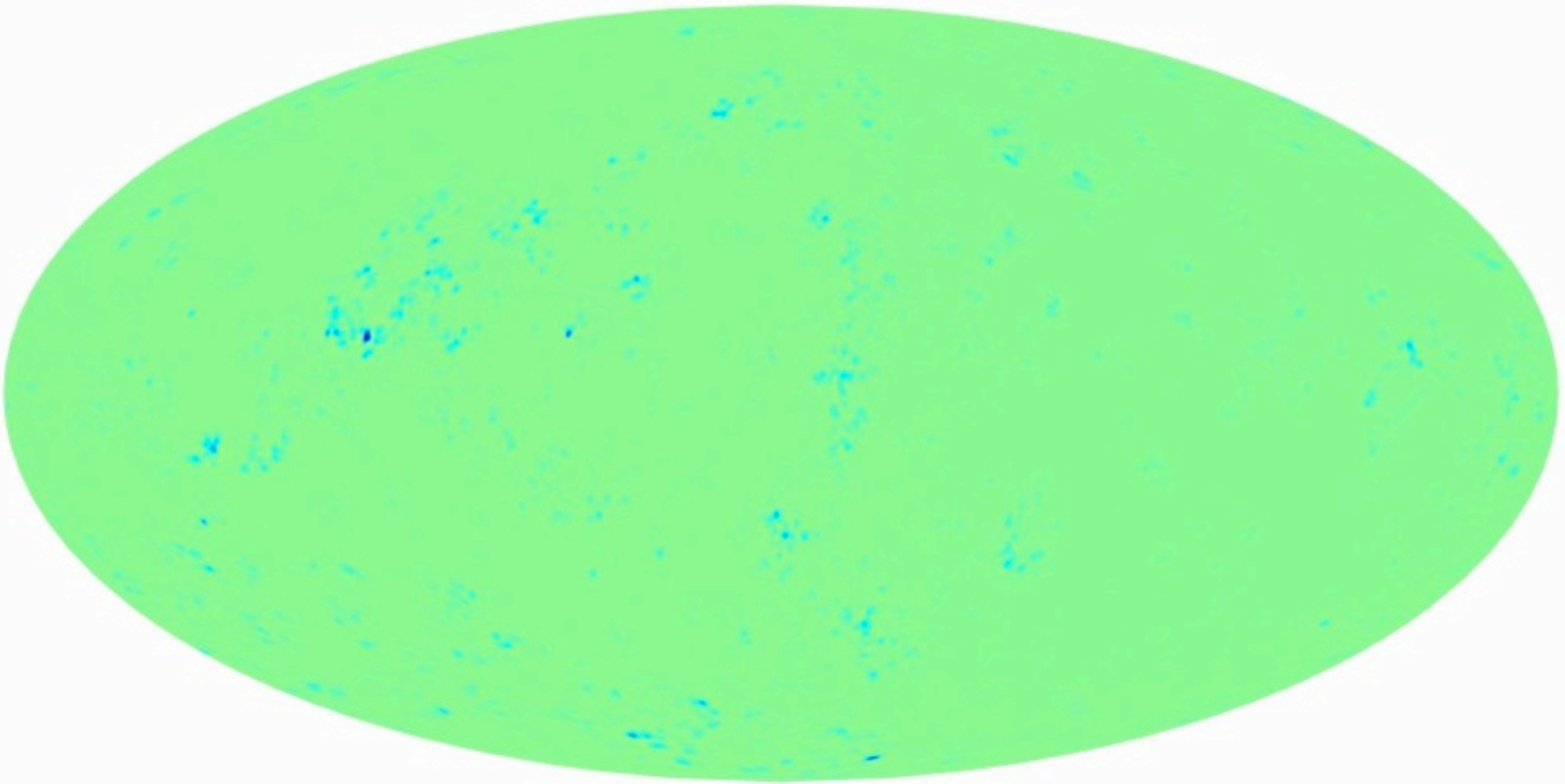
(partially) blind cf. informed "theory" priors

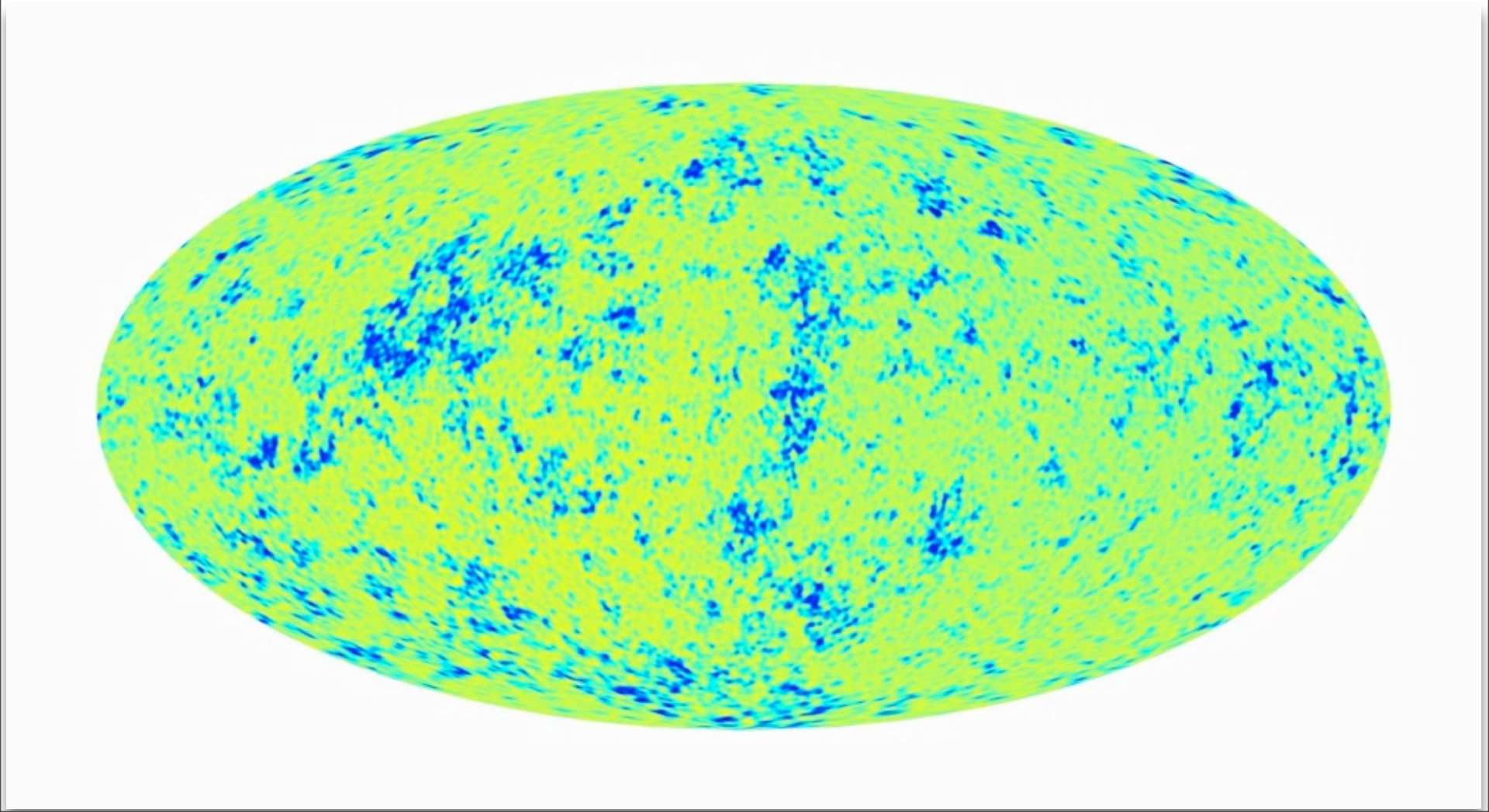

broadened transfer function
quadratic fit for small χ values
raw Monte-Carlo samples
fluctuations
μ0T periodicity and its harmonics
δN = ln(aend/aref) * 10^5
(χini/mpl) * 10^7
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
0.1
1
10
100











trajectory probabilities for early-inflatons & late-inflatons

very early U early to middle to now U **very late U**

inflation *string theory/landscape/higher dimensions* **dark energy**

$V_{eff}(\psi_{inf})$? partial shape reconstruction reconstruct gradient $V_{eff}(\psi_{inf})$?

$K_{eff}(\psi_{inf})$? **P1 blind-recover to r=0.1** $K_{eff}(\psi_{inf})$?

trajectory probability

$-d\ln\rho_{tot}/d\ln a\ /2$

$=\varepsilon(k)=1+q,\ k\sim Ha$

$\Rightarrow \mathbb{P}_s, \mathbb{P}_t$

$\mathbb{V}_{eff}(k),$

$\psi_{inf}(k)$

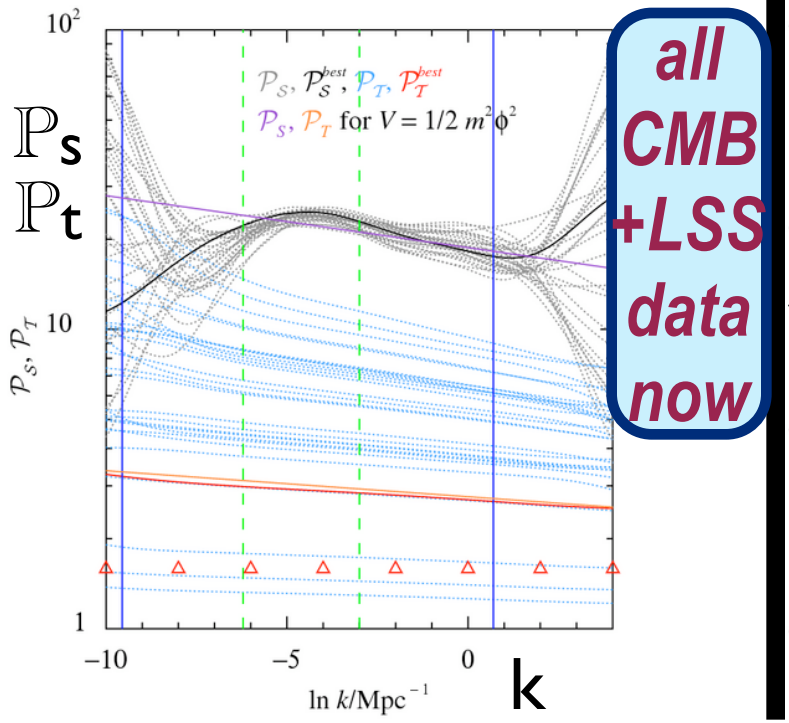
trajectory probability

$-d\ln\rho_\phi/d\ln a\ /2 \Rightarrow$

$=\varepsilon_\phi(a)=(1+w)2/3$

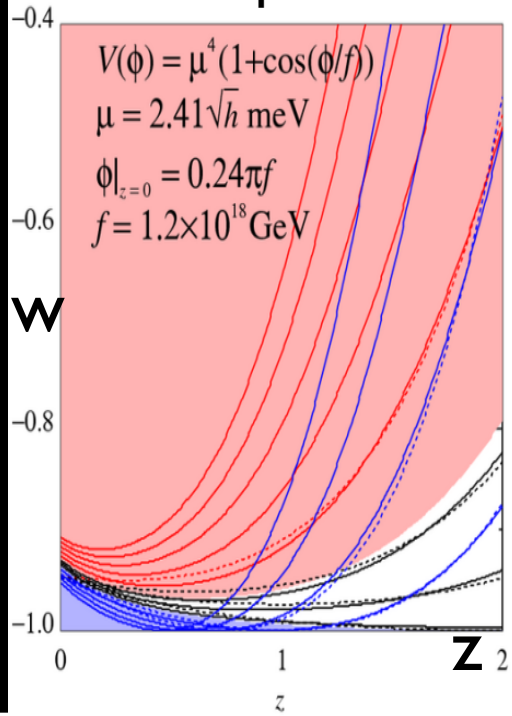
$\varepsilon_s=(d\ln V/d\psi)^2/4$ @pivot a_{eq} **yes**

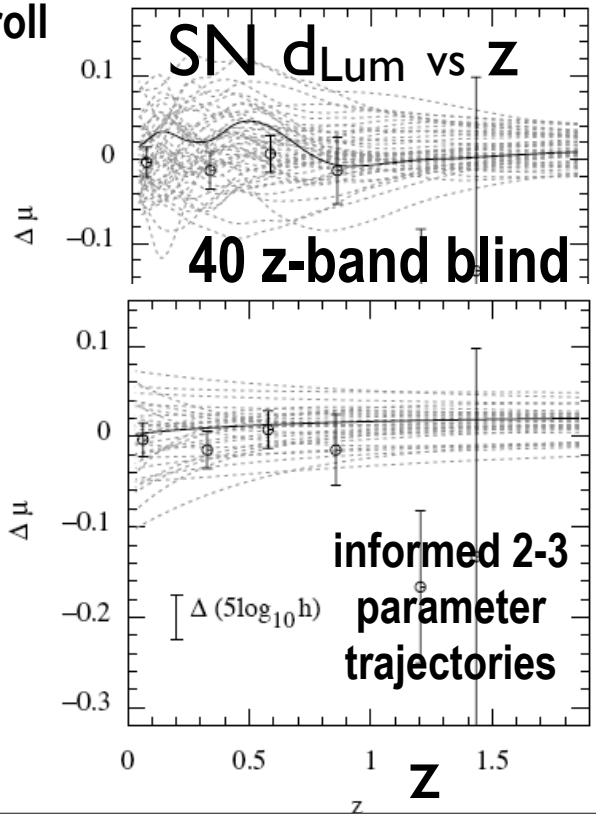
$d^2\ln V/d\psi^2\ /4$ **no**

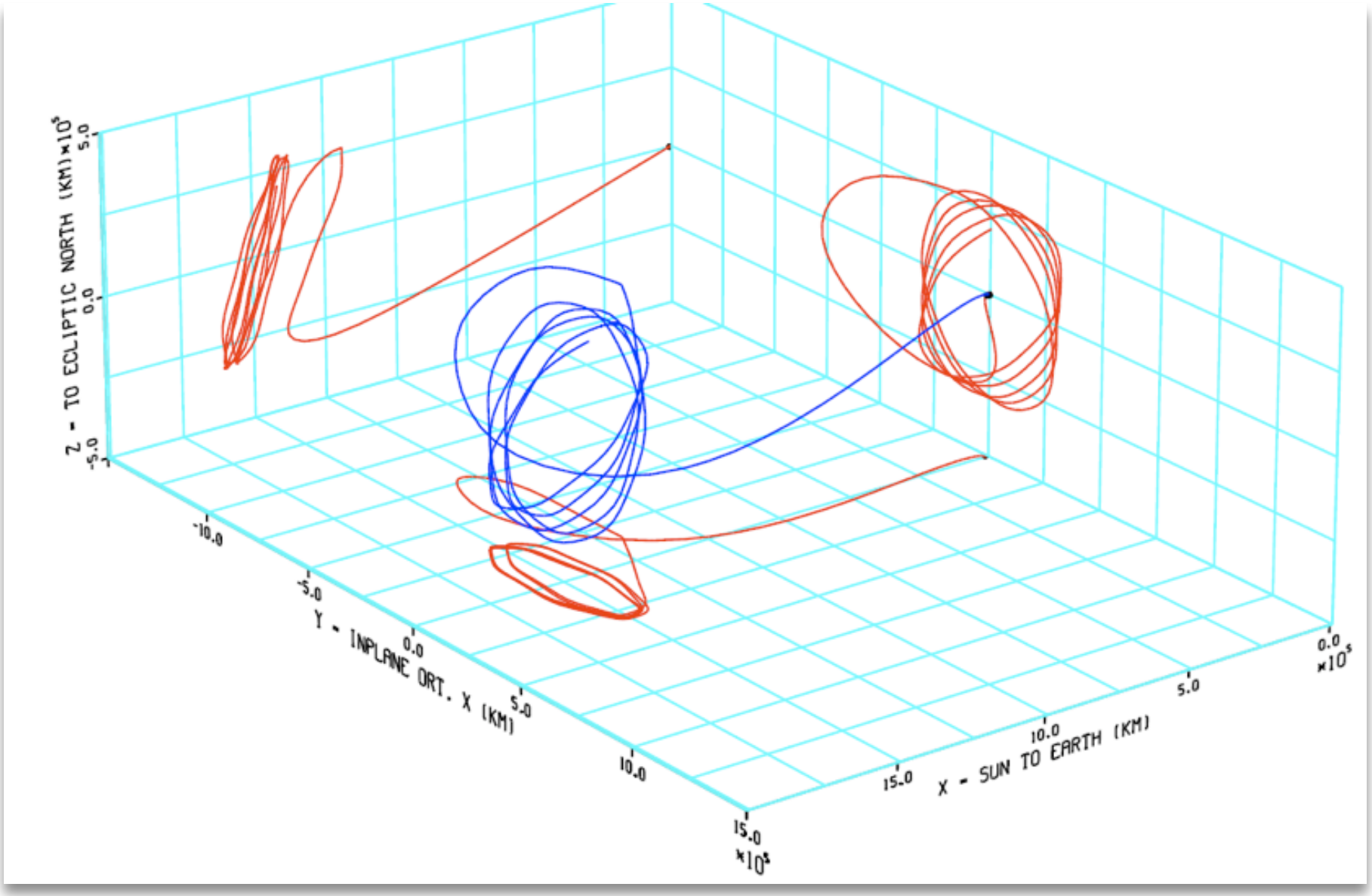


all CMB +LSS data now

slow-to-moderate roll quintessence



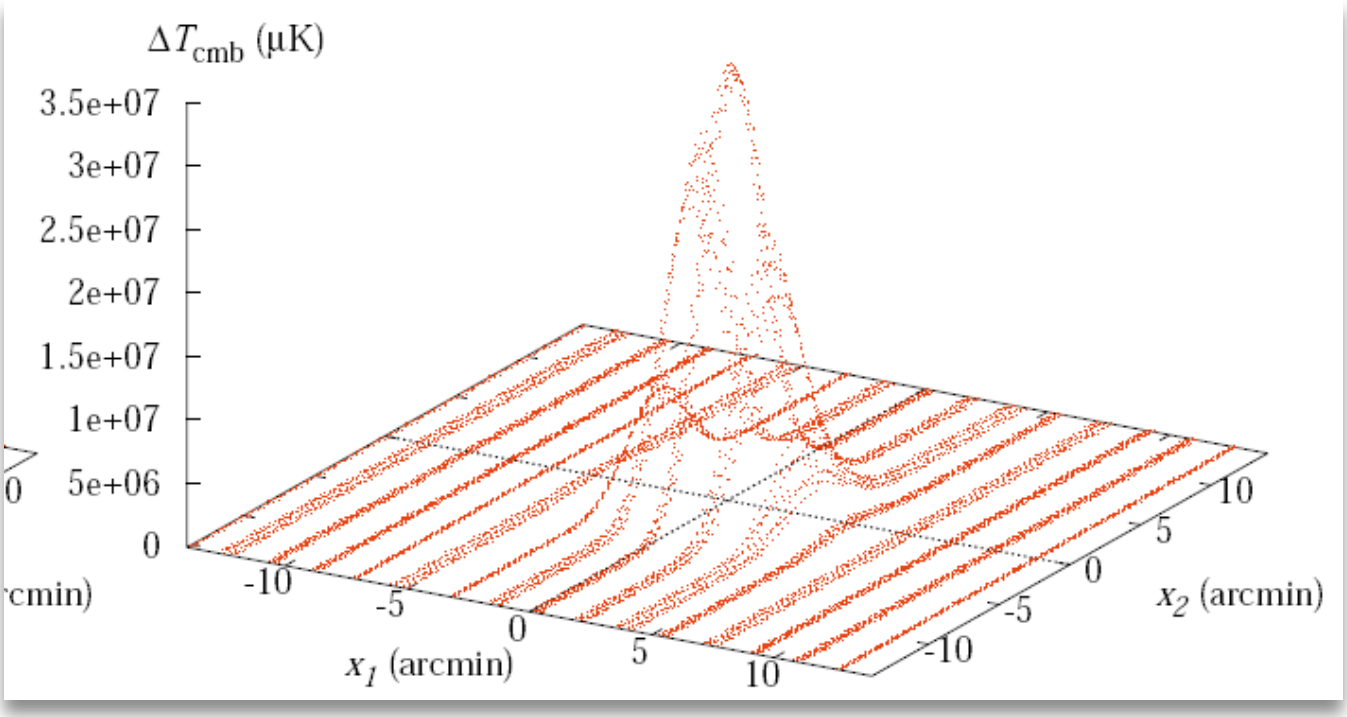



Z - TO ECLIPTIC NORTH (KM)×10⁵
5.0
0.0
-5.0
-10.0
-5.0
0.0
5.0
10.0
15.0
×10⁵
Y - INPLANE ORT. X (KM)
0.0
5.0
10.0
15.0
×10⁵
X - SUN TO EARTH (KM)

Beam Reconstruction

Use planet crossings (no special observation mode)

- Late June '09 Uranus (S/N ~2035dB)
- Early Nov. '09 Jupiter (S/N 4055dB),Mars (S/N 3045 dB)



Use higher resolution full CMB maps as a complement?