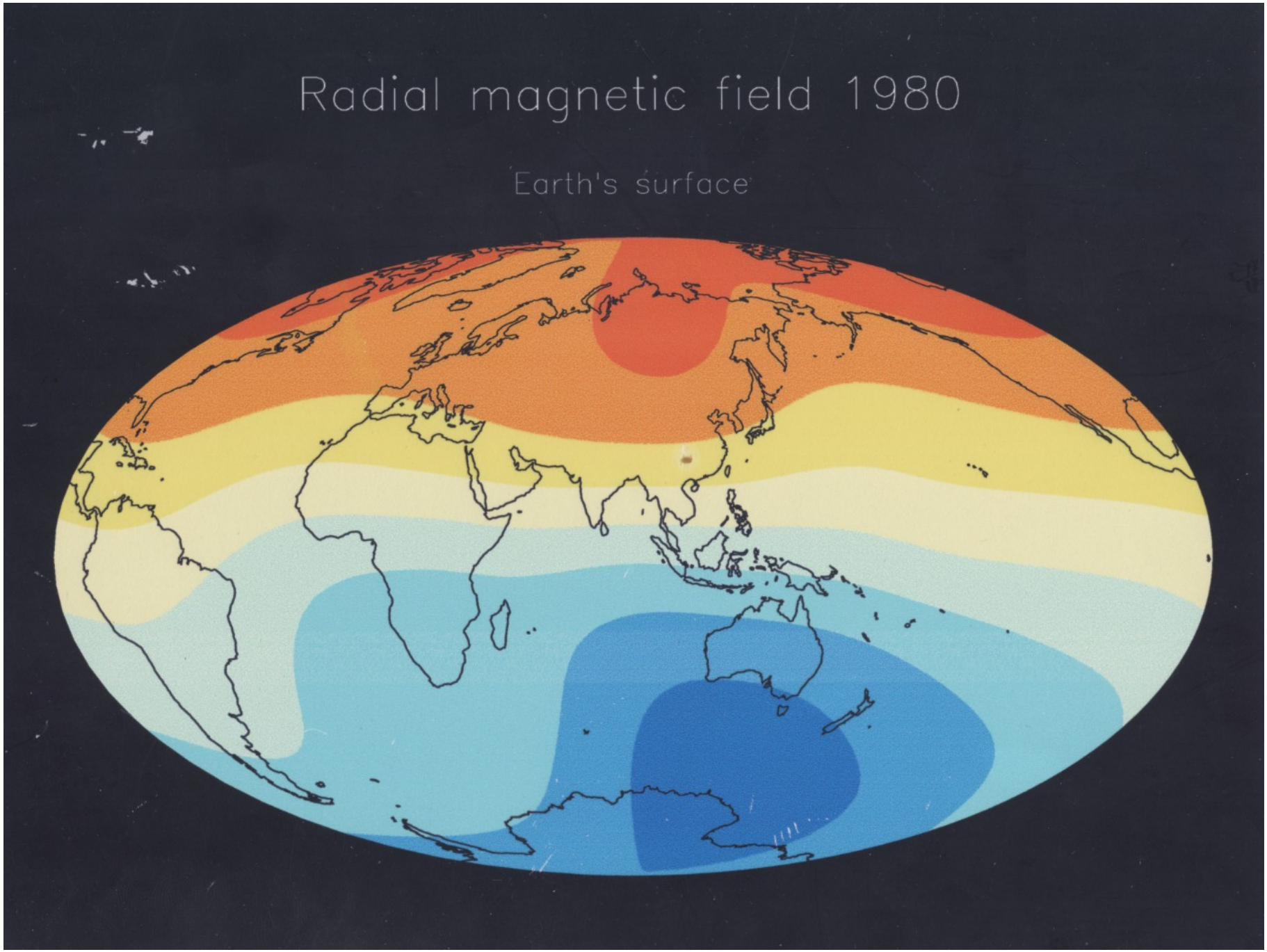
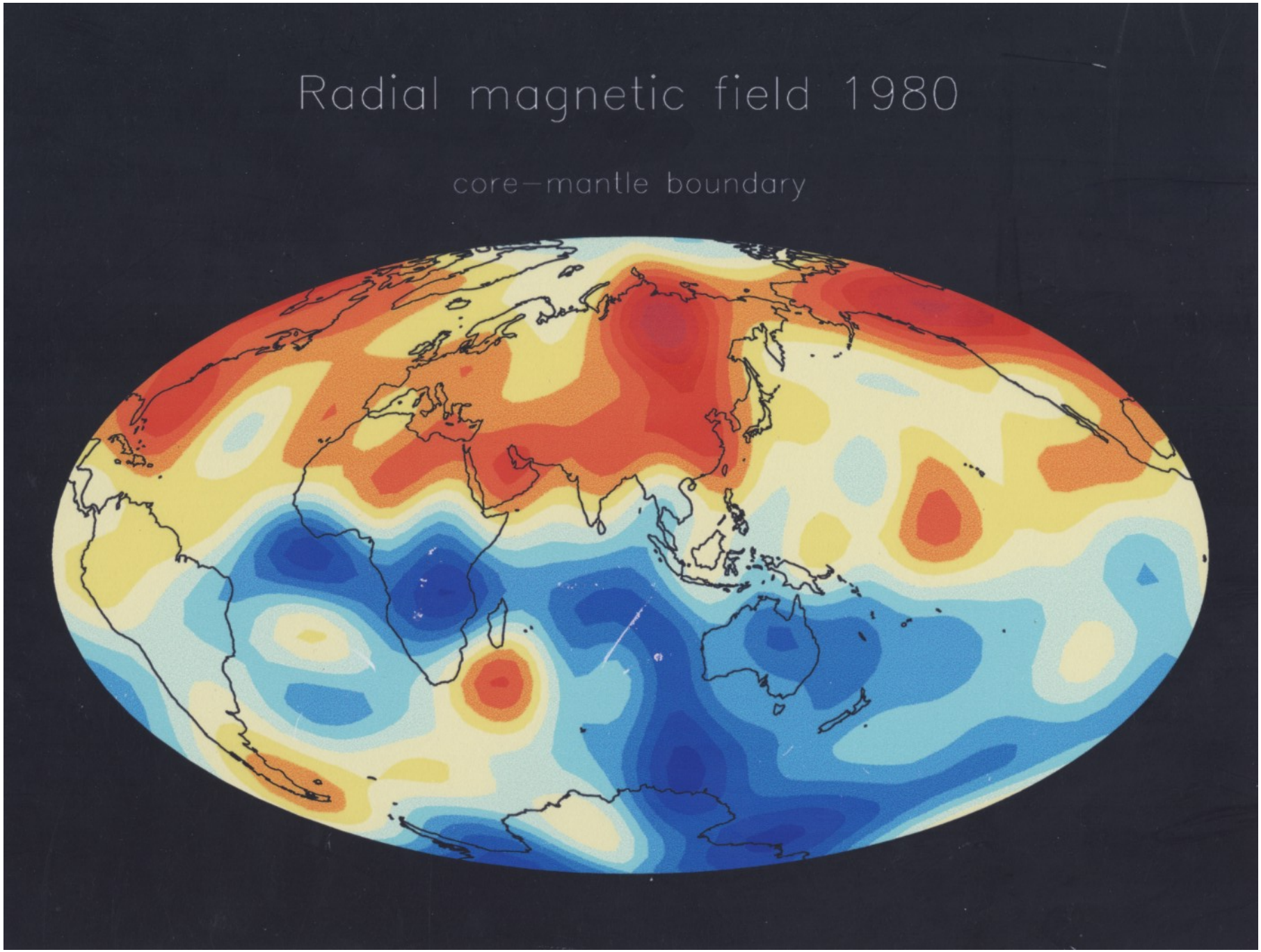
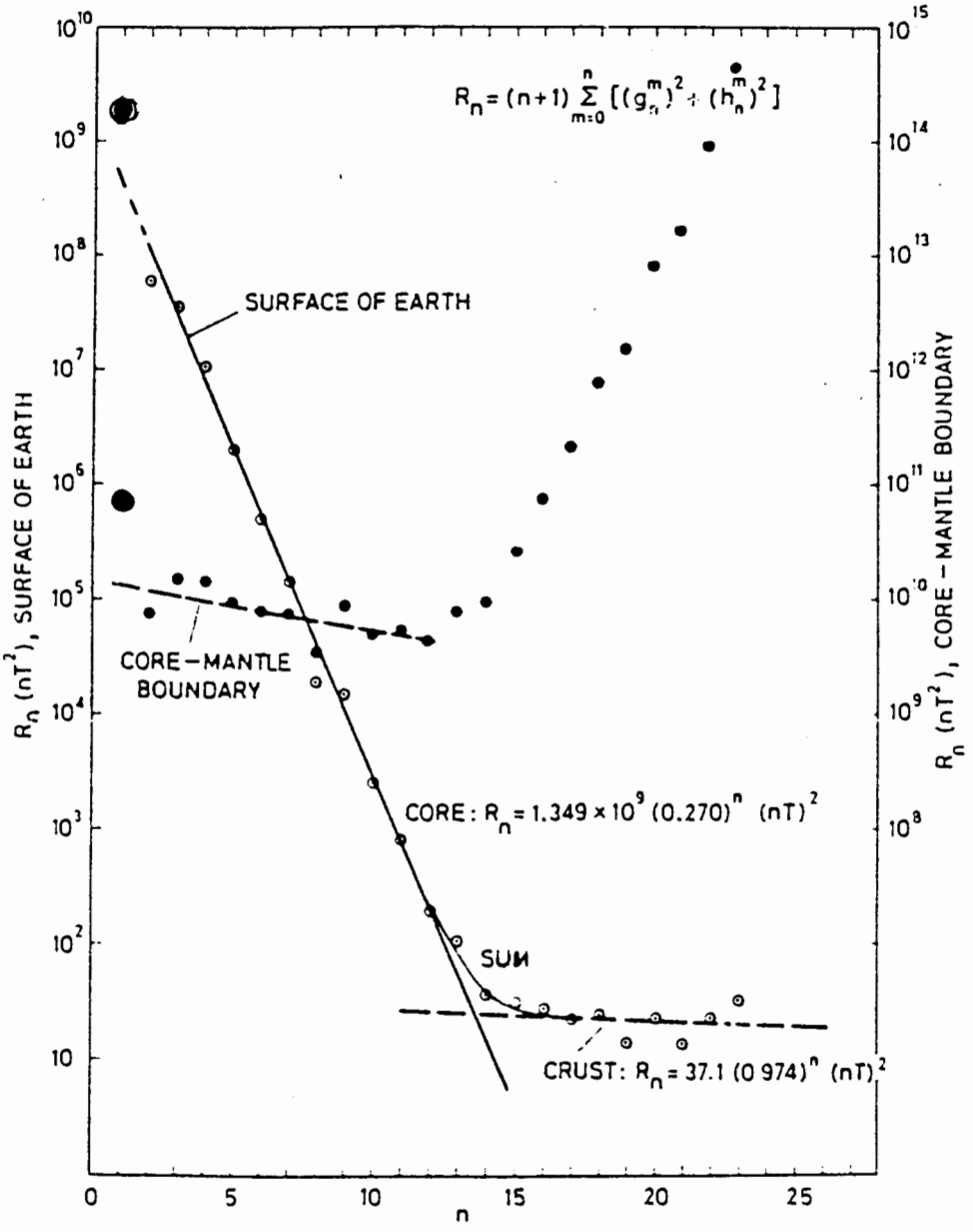
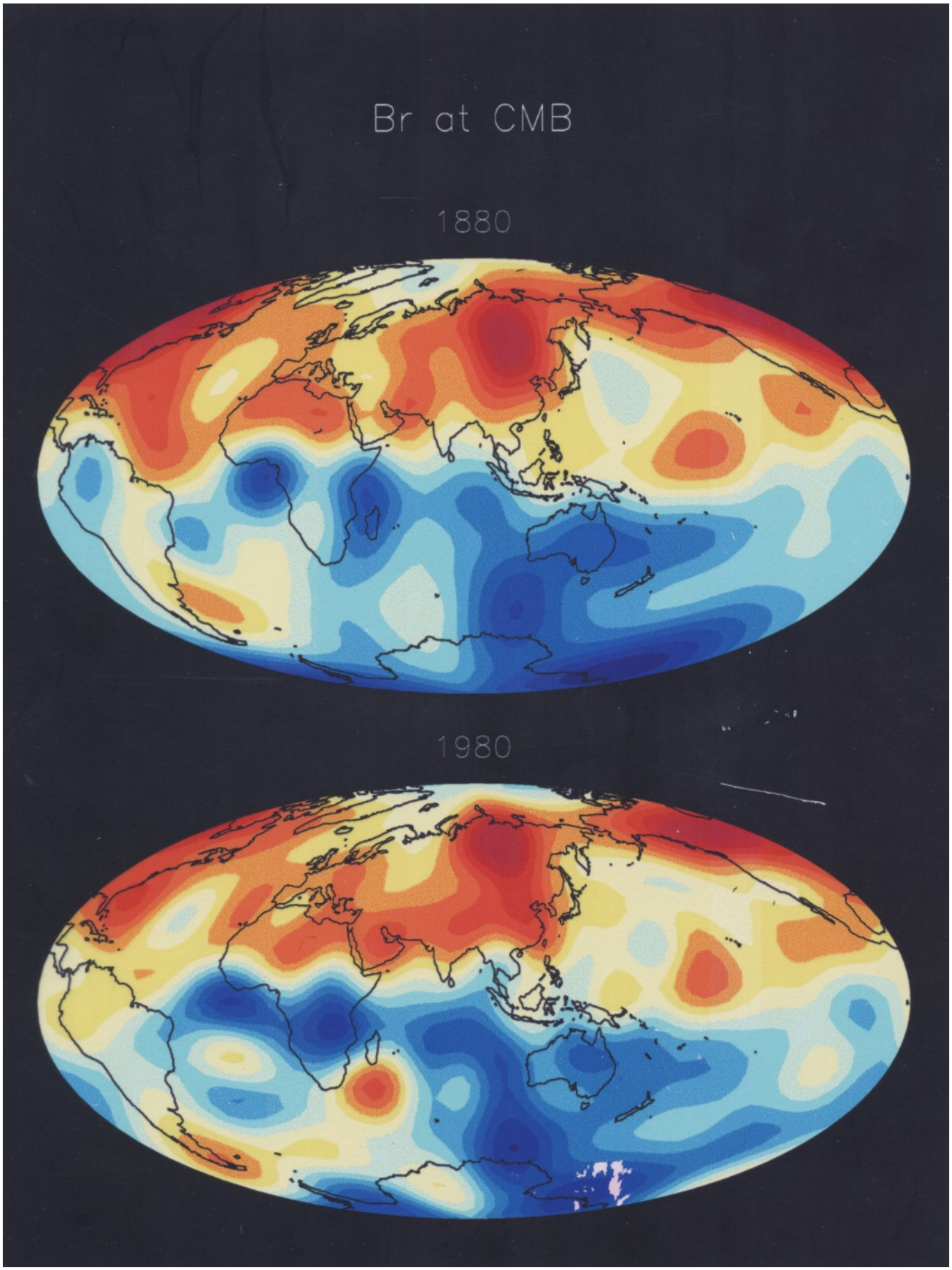

Radial magnetic field 1980
Earth's surface

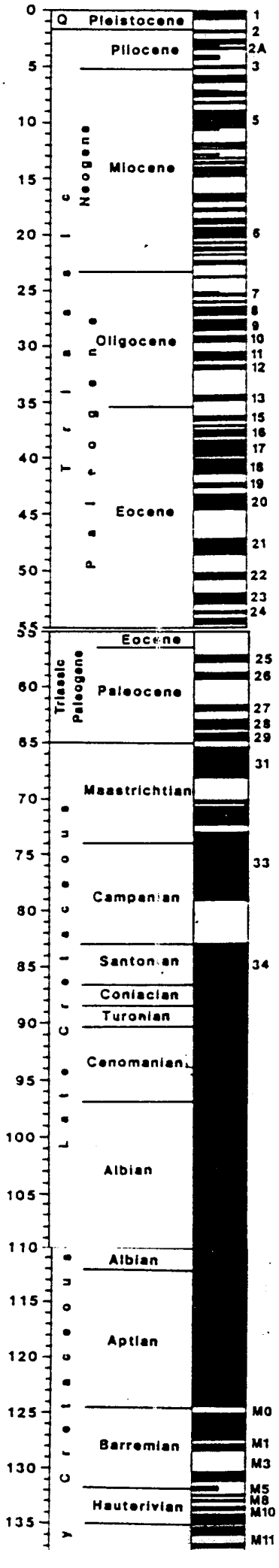

Radial magnetic field 1980
core–mantle boundary

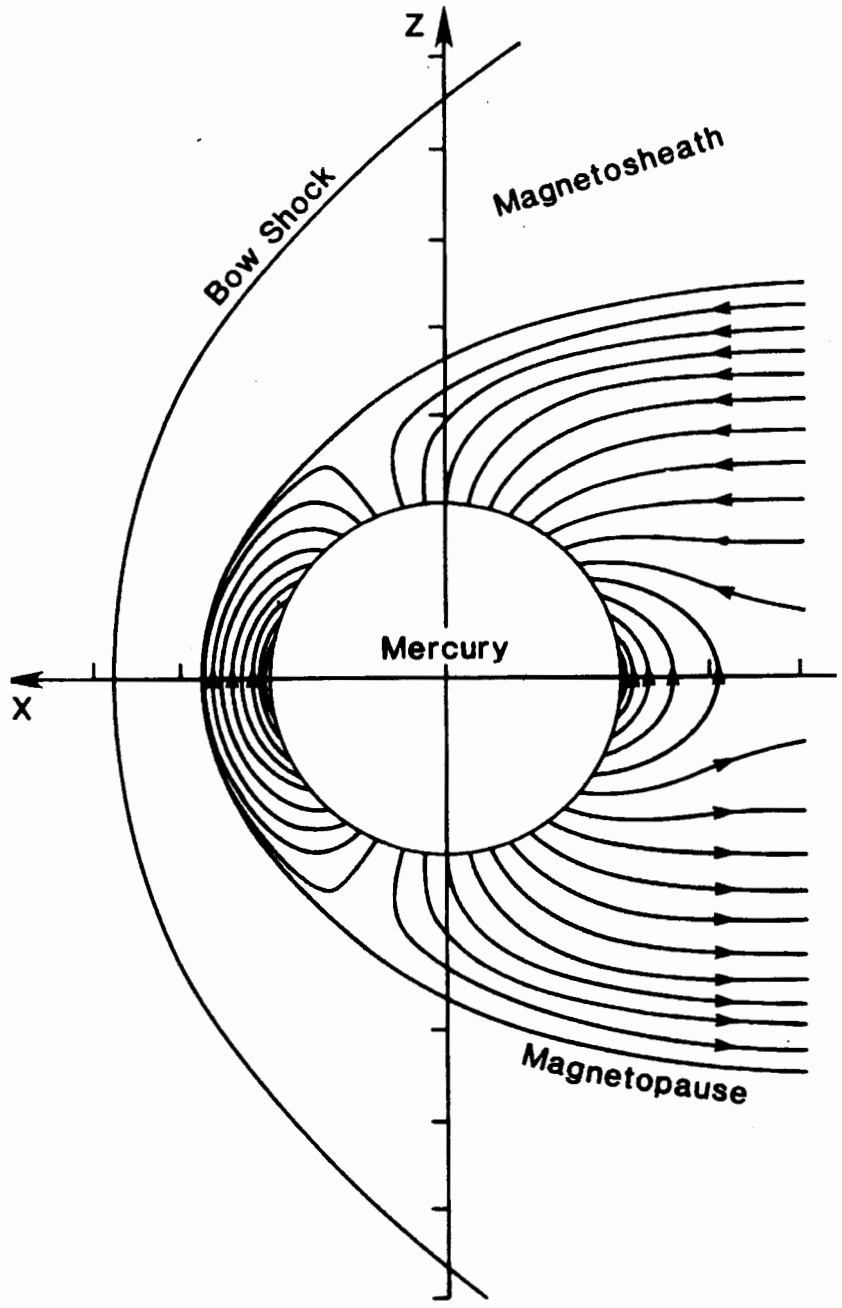
Magsat 1980

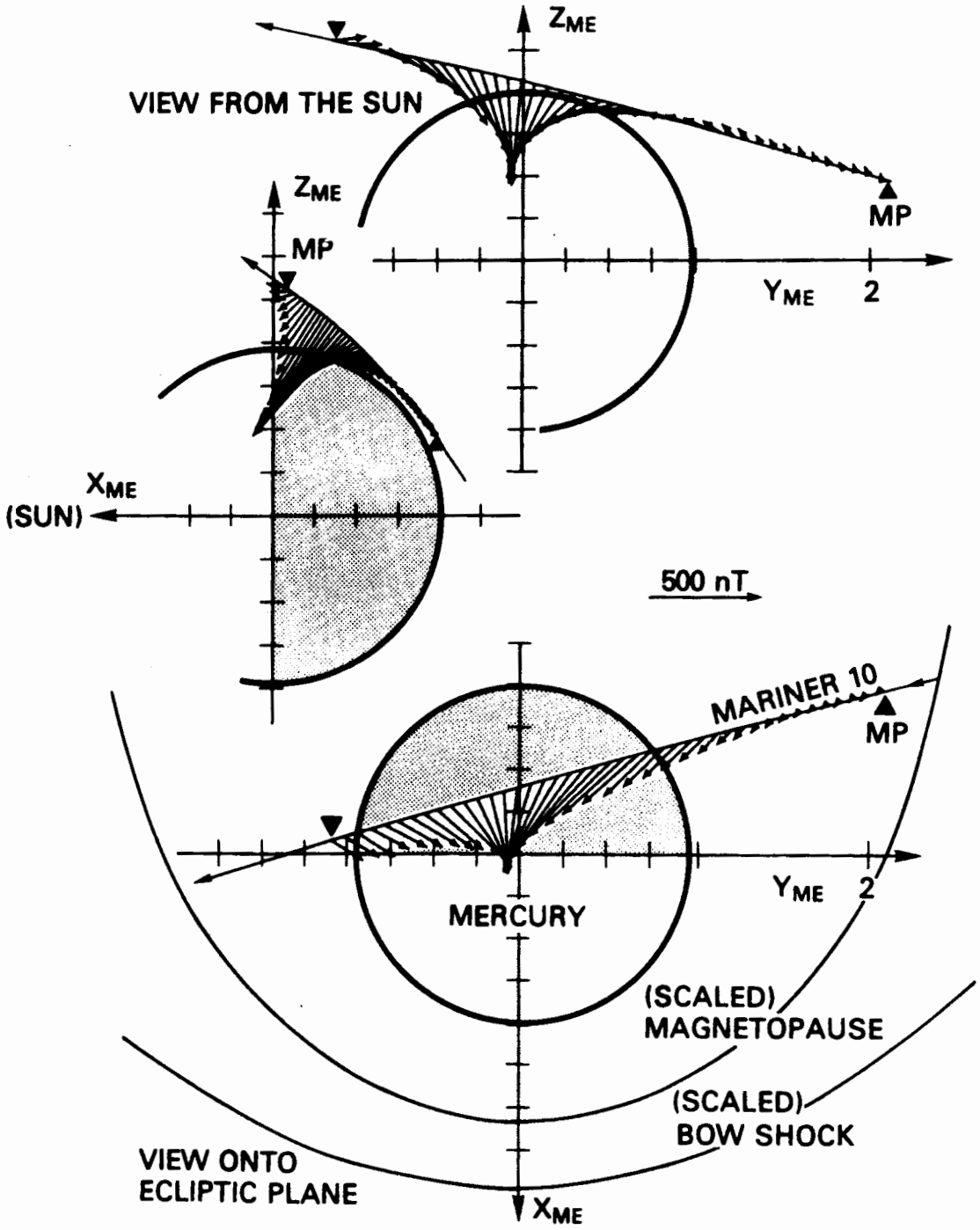


Kugelfunktionsgrad


Br at CMB
1880
1980

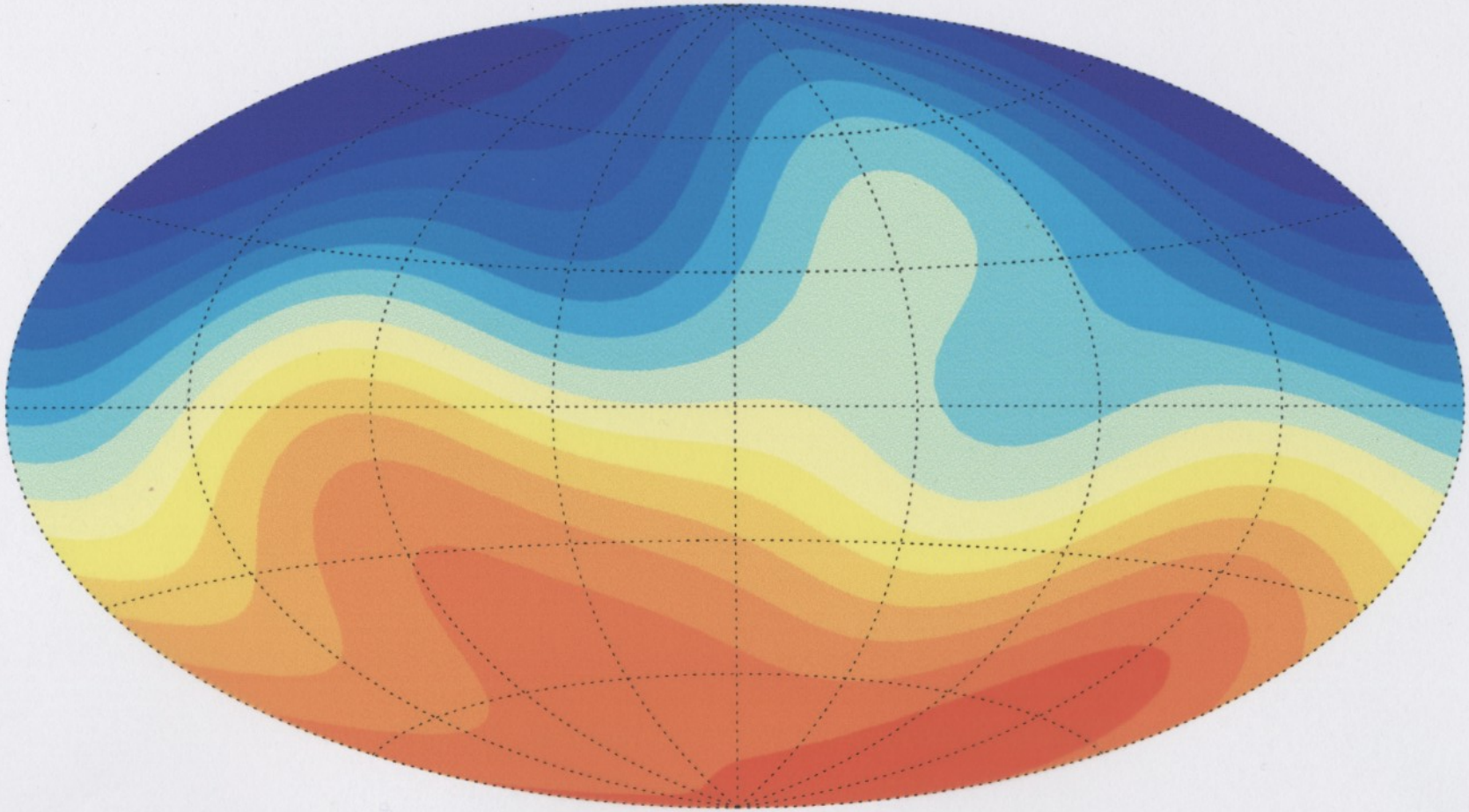

0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
Q
Pleistocene
Pliocene
Miocene
Neogene
Oligocene
Eocene
Paleogene
Tertiary
Eocene
Paleocene
Triassic
Paleogene
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Albian
Aptian
Barremian
Hauterivian
Late Cretaceous
Cretaceous
1
2
2A
3
5
6
7
8
9
10
11
12
13
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
31
33
34
M0
M1
M3
M5
M8
M10
M11


Z
Bow Shock
Magnetosheath
Mercury
X
Magnetopause

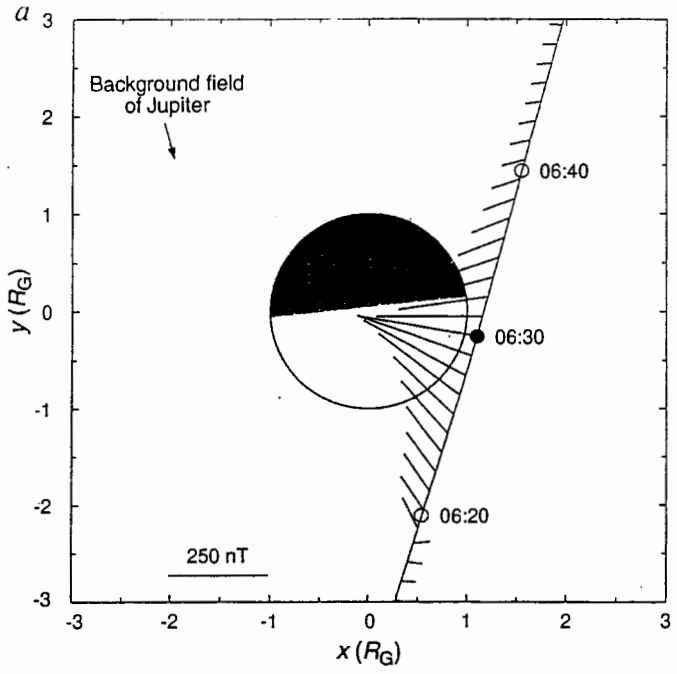


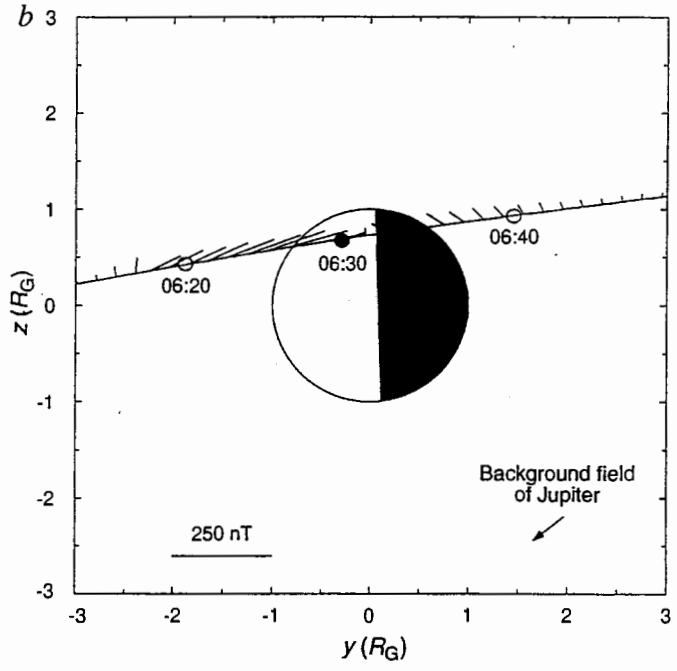
Ness et al., 1988

Jupiter

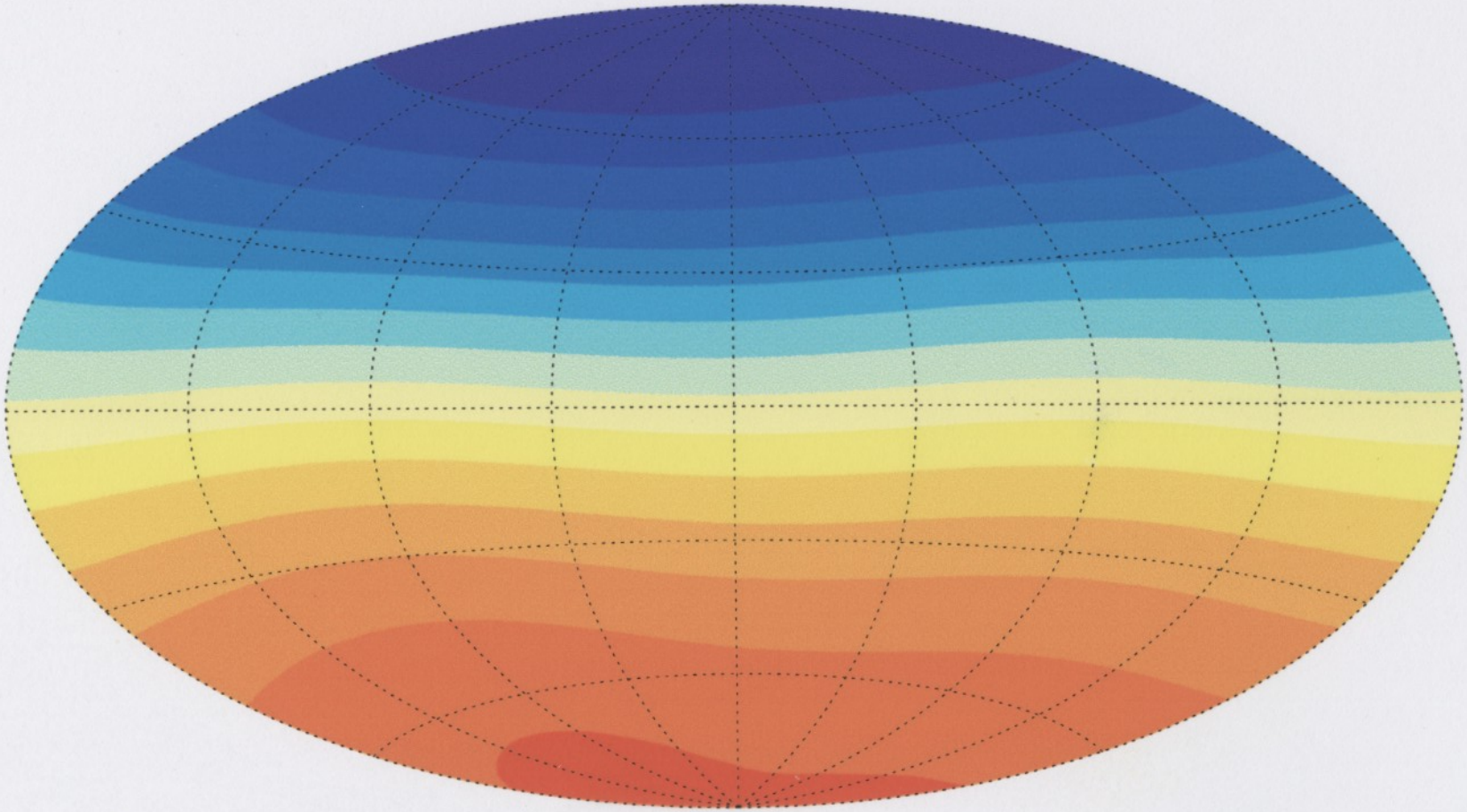


Ganymede

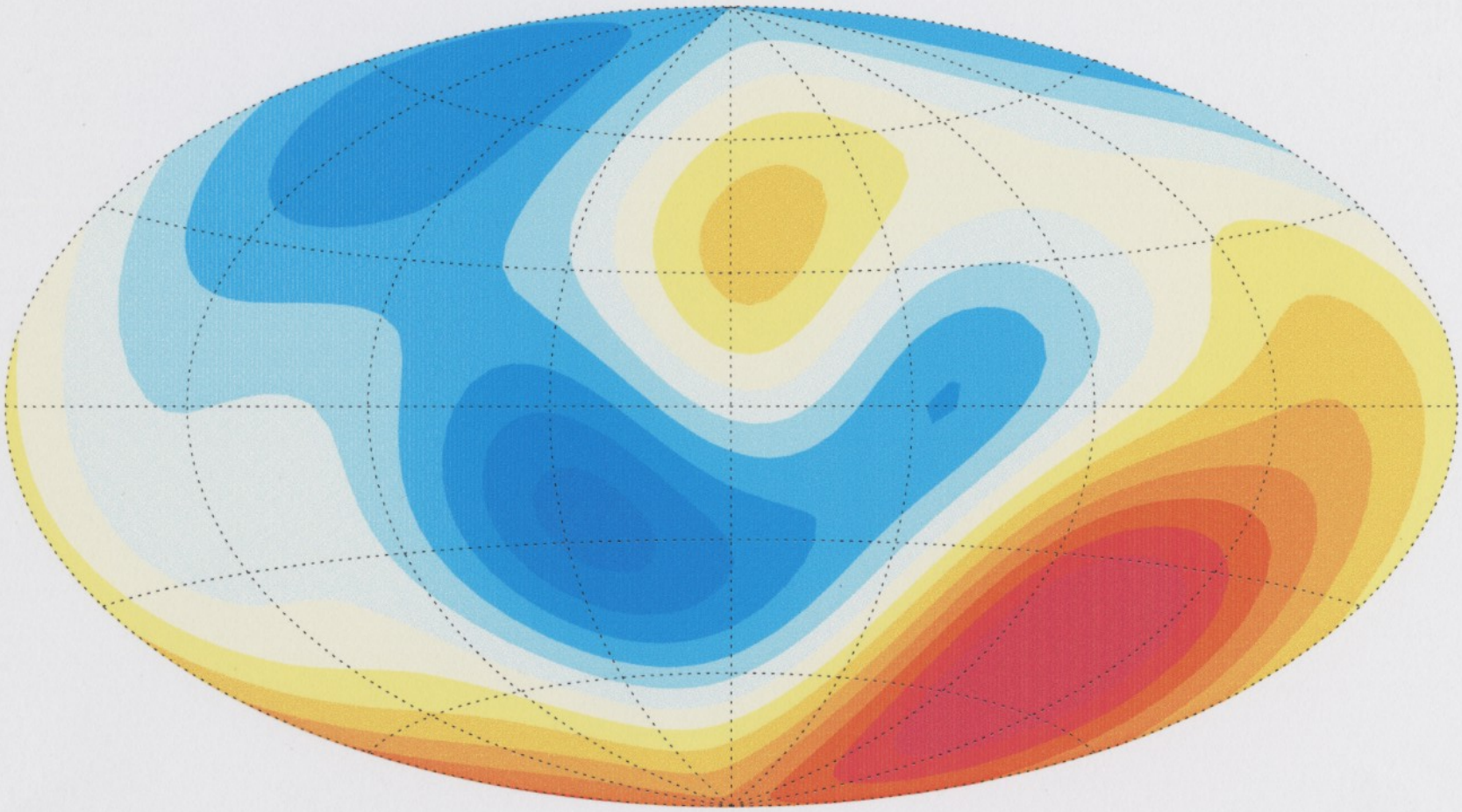

a
Background field
of Jupiter
06:40
06:30
06:20
250 nT
y (R_G)
x (R_G)


b
06:20
06:30
06:40
Background field
of Jupiter
250 nT
z (R_G)
y (R_G)

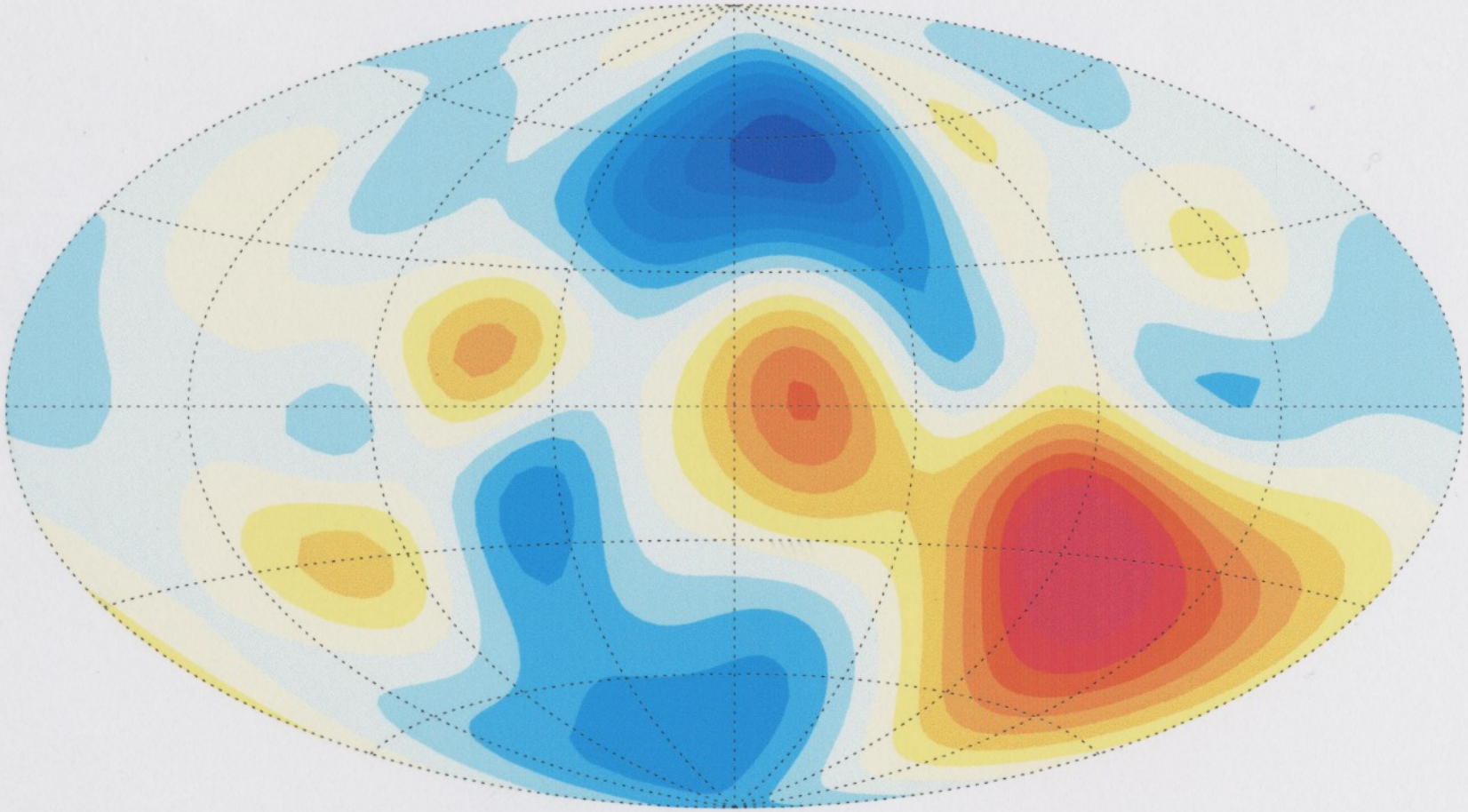
Saturn

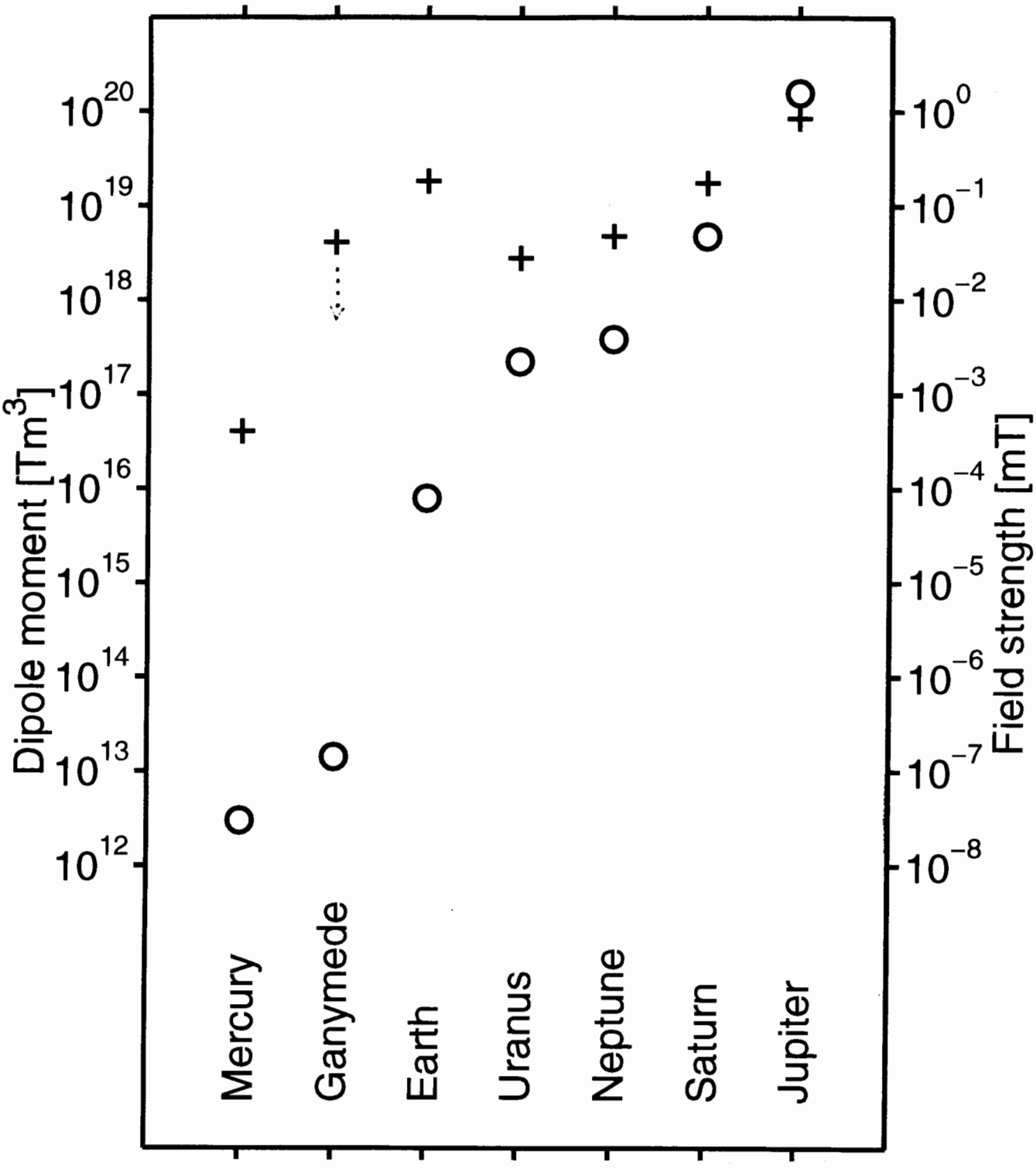


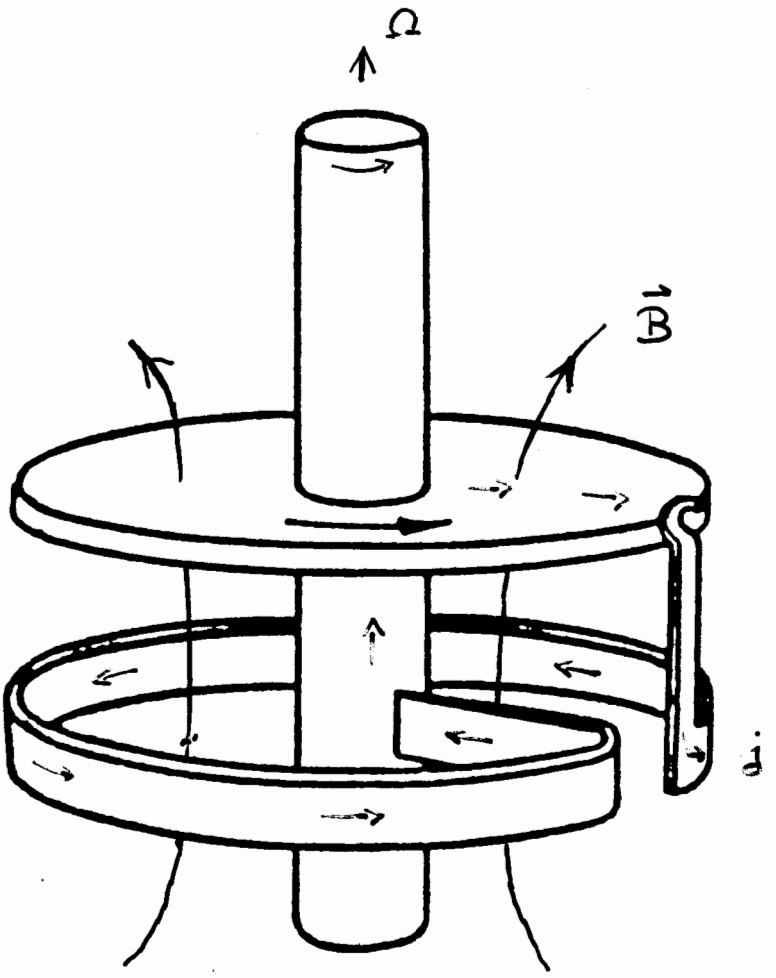
Uranus



Neptune




Dipole moment [Tm^3]
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
Field strength [mT]
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Mercury
Ganymede
Earth
Uranus
Neptune
Saturn
Jupiter


Ω
$\vec{B}$
j

Magnetic field generation by homogeneous self-sustained dynamo action in planetary cores

Requires:

Good electrical conductor:
Iron, metallic hydrogen, Ionic liquid

Sufficiently fast fluid motion:
Thermal convection (superadiabatic temperature gradient), chemical convection
Precession-driven motions, tides ?

Proper geometry of flow:
E.g. differential rotation alone or purely axisymmetric flow does not work.
A dynamo cannot generate a purely axi-symmetric magnetic field (Cowlings theorem)

Magnetic induction equation

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times (\vec{u} \times \vec{B}) + \frac{1}{Rm} \nabla^2 \vec{B}$$

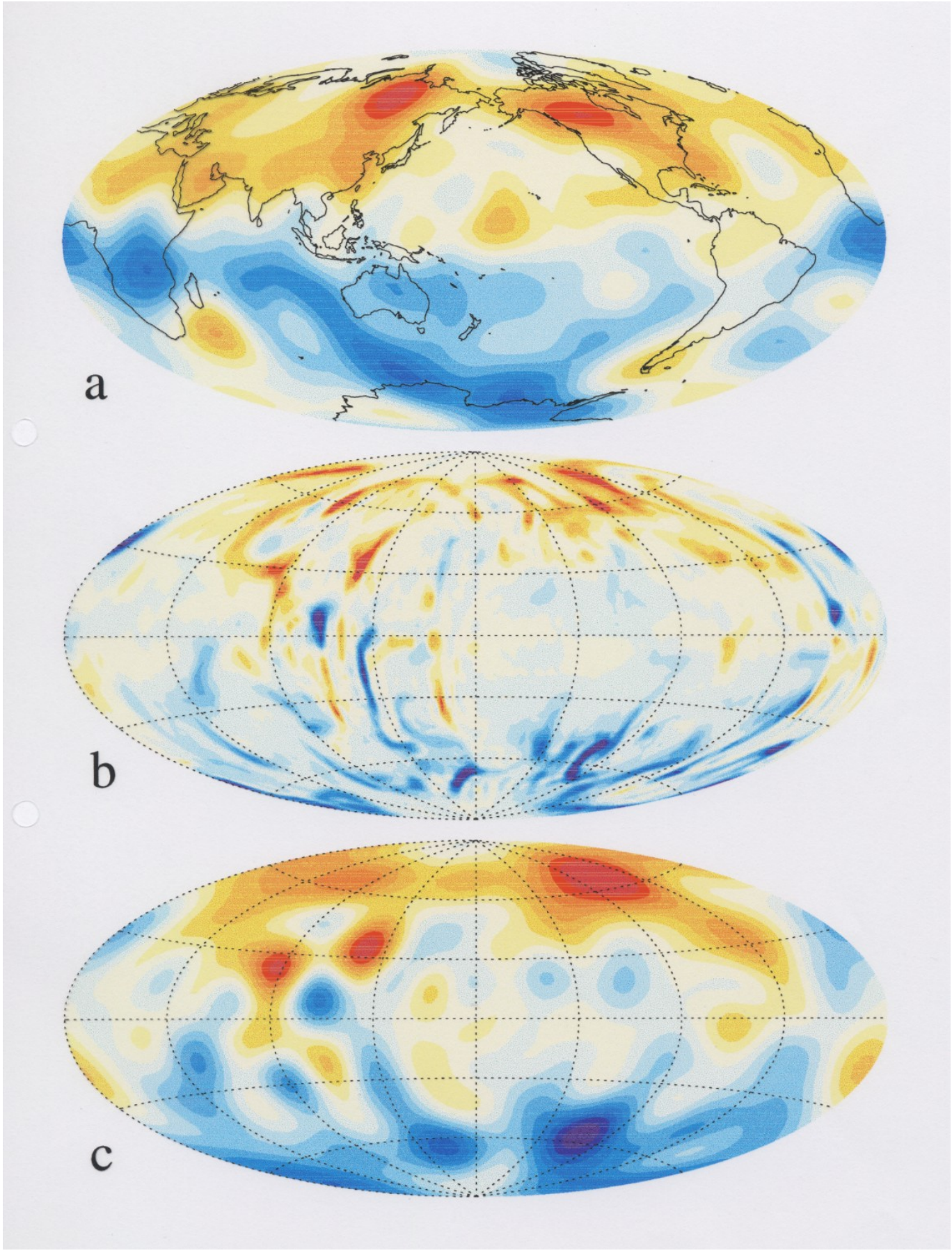
for incompressible flow:

$$\frac{\partial \vec{B}}{\partial t} + (\vec{u} \cdot \vec{\nabla}) \vec{B} = (\vec{B} \cdot \vec{\nabla}) \vec{u} + \frac{1}{Rm} \nabla^2 \vec{B}$$

Magnetic Reynolds number: $Rm = VD/\eta$

for dynamo action Rm > 10 …100 required

σ: el. conductivity **B: magnetic field**
ρ: density **u: velocity**
V: scale velocity **D: length scale**
$\eta = 1/(\mu_o \sigma)$: magnetic diffusivity


a
b
c

Planetary dynamos
compared to stellar dynamos

Energy flux is a concern
Low heat flow could be conducted along a sub-adiabatic gradient
Way out: Compositional convection

Compressibility is less important
Small effect of magnetic pressure on density
Boussinesq approximation

Magnetic Reynolds number much lower
$Re_m \approx 100 - 1000$ allows solution of induction equation without parameteriations (eddy diffusivity, parameterized α-effect)

Rossby number << 1
Inertia not important
Main force balance between Coriolis force and Lorentz force