The Quest for Other Worlds

Virginia Trimble

Physics & Astronomy, UC Irvine

Las Cumbres Observatory G.T.Net

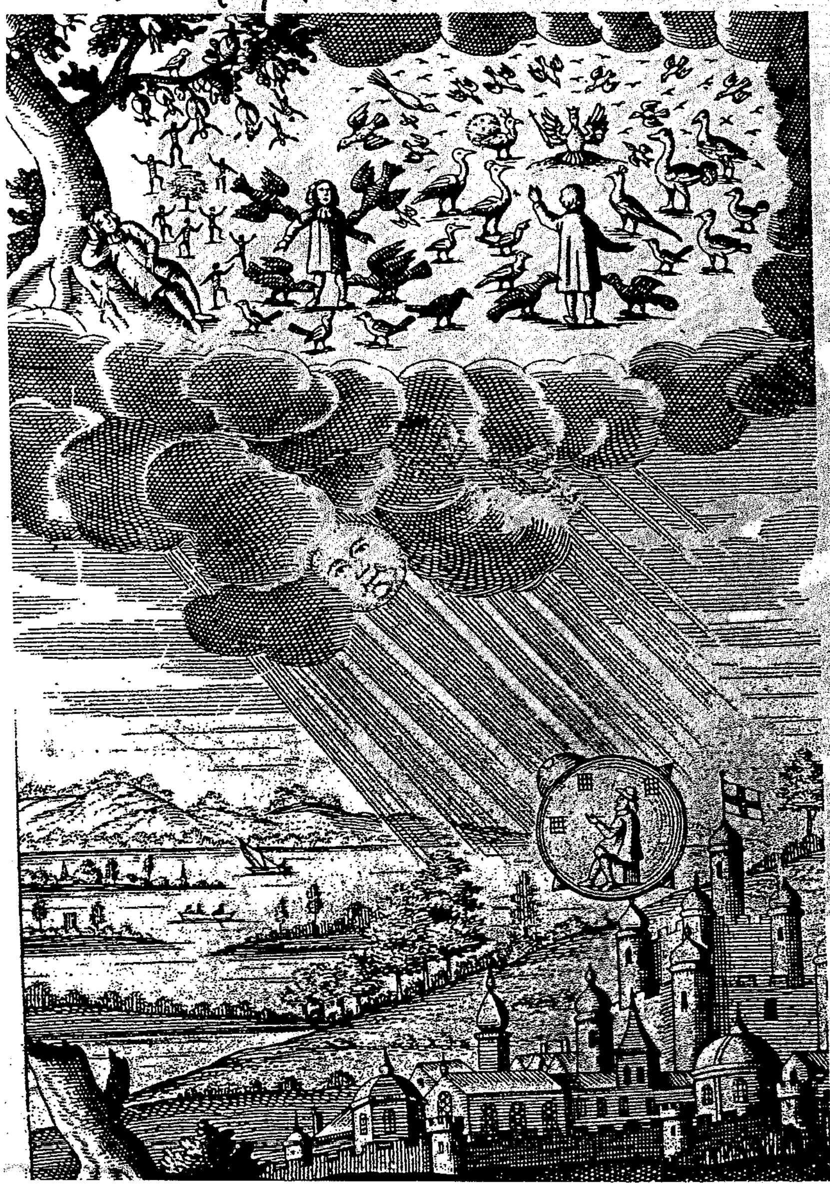
Casa Romantica 2008

CAM 2007

MtSJ 2008

MSU Markee 2008

OCMensa 2008



Cyrano de Bergerac

1687

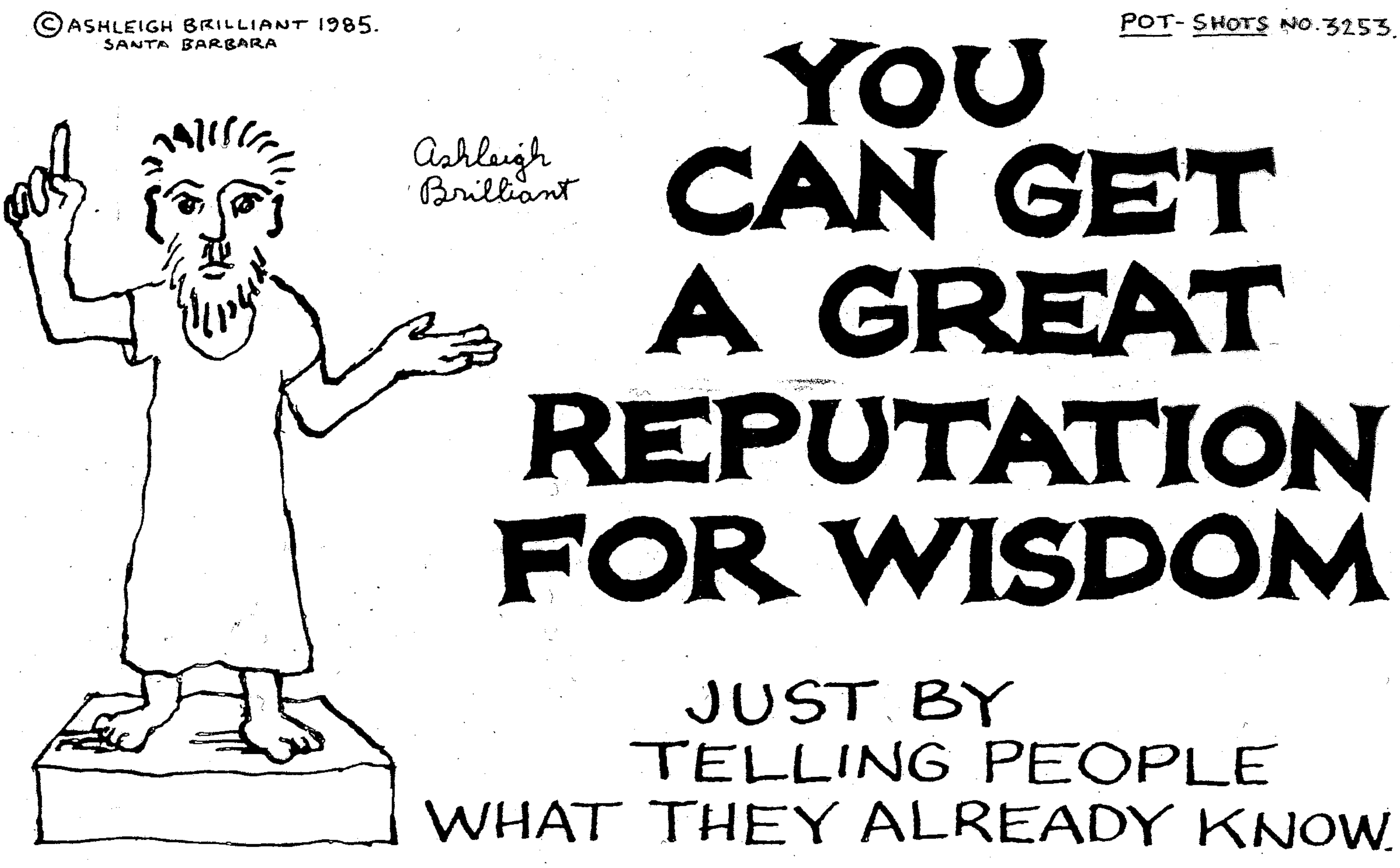
Last spacecraft designer to test fly his own design?

απεριο κοσμοι (Plurality of Worlds; Plenitude)

from -350 to + 1995

In the 4th century BCE, Epicurus taught that there are an infinite number of worlds like (and unlike) ours, and Aristotle taught that there is only one.

Neither hypothesis can currently be falsified.



MEANING OF "OTHER WORLDS"

2. Entire earth or sun centered systems (kosmoi) not detectable by us. Greeks. Roger Bacon, Thomas Aquinas c. 1250 (against!)

1 Other systems like ours and potentially detectable. earth-centered c. 1330 Bradwardine, Occam, Buridan Sun-centered, c. 1600 Bruno, Digges post-telescopic, Fontenelle (first woman to deny, Aphra Behn 1686 first woman to support, Fanny Burney 1786). Maria Mitchell undecided.

1 Moon and perhaps sun & other Sol Syst planets with featured, inhabited surfaces. 1610 onward (Galileo, Wm. Herschel, Schiaparelli, Lowell)

2 Other worlds in temporal succession Origen (3rd cent), Oresme 1277

1. Images possible
2. Images unlikely

MODERN ANALOGS

Complete, undetectable systems:
multiverse, self-reproducing inflation

Detectable planetary systems: search for exoplanets, success, characterization

Known planets & moons: water on Mars
Europa ??

Sequential worlds in temporal succession:
oscillating universe (needs matter with non-positive mass-energy)
brane worlds, quasi Steady-State

What is a Planet?

Star ≡ H fusion ∴ $T_c \gtrsim 10^7 K$, $M \gtrsim 0.085 M_\odot$
$\equiv 85 M_{Jup}$

BD = no H fusion – formed like ☆
[– but D fusion, ∴ $T_c \gtrsim 10^6 K$ $M \gtrsim 0.015 M_\odot$]

Planet
- $M \lesssim 15 M_J$ ("orphan" planets) *
- orbit something bigger (PC + BD ok) *
- co-formed w/ ☆ in outlying disk *
  (SS yes, pulsar planets no)
- chemical differentiation (SS yes) *
  "maybe" for some exoplanets

* easier to measure

* better definition

WHAT DO YOU NEED FOR AN EARTH?

Solid planet

Air & water (at reasonable temperature)

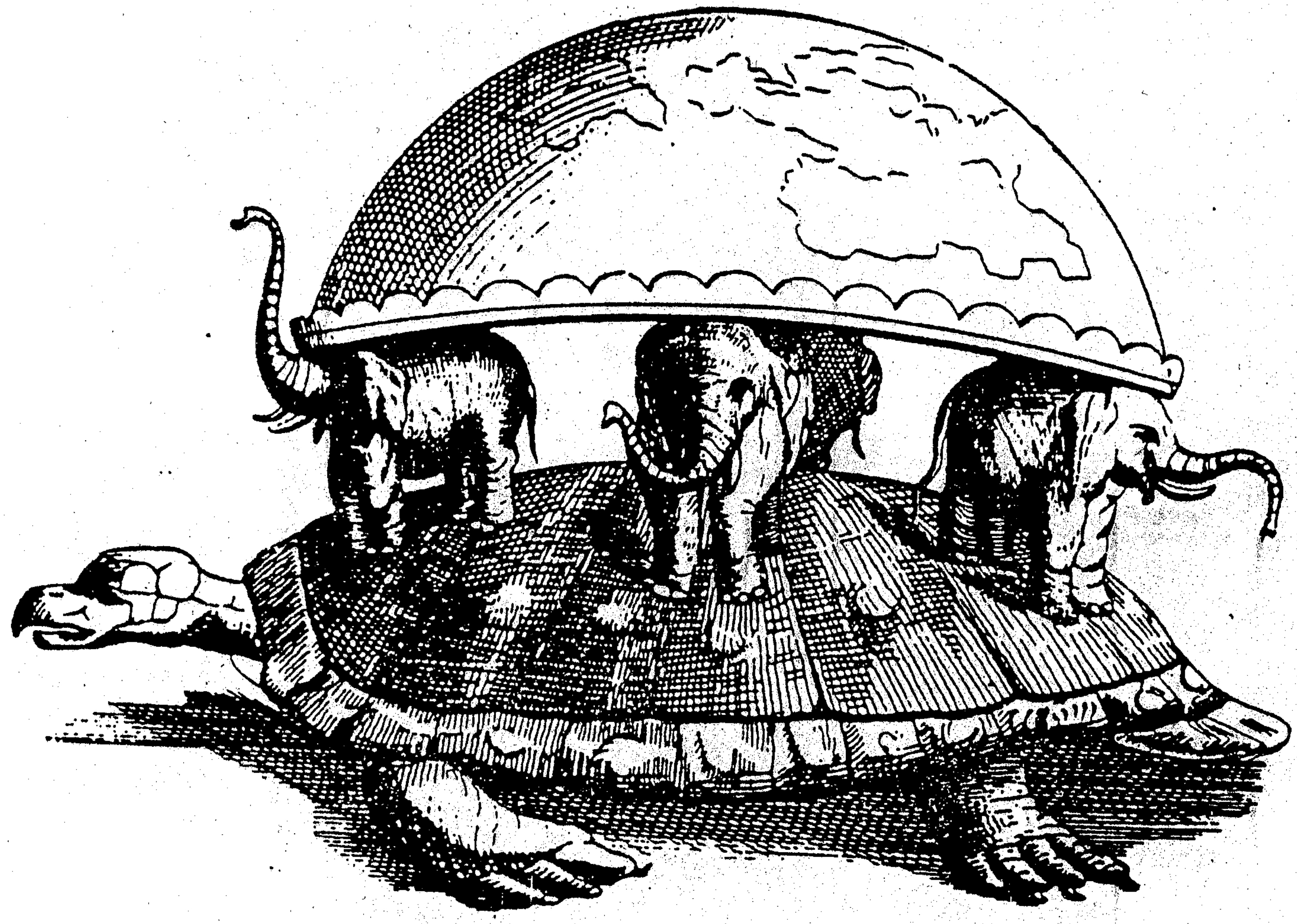
Tides (moon? or sun enough) Rotn. axis stabilization (?)

Plate tectonics [land/sea, ores, fossil fuels - requires radioactive heating, molton core + rotation(?), water coolant(?)]

Magnetic field (GCR protection; rotation + molton core)

"Jupiter" to clear out debris (excessive bombardment protection)

Life actually present (O_2, O_3, CH_4...)



Turtles all the
way down

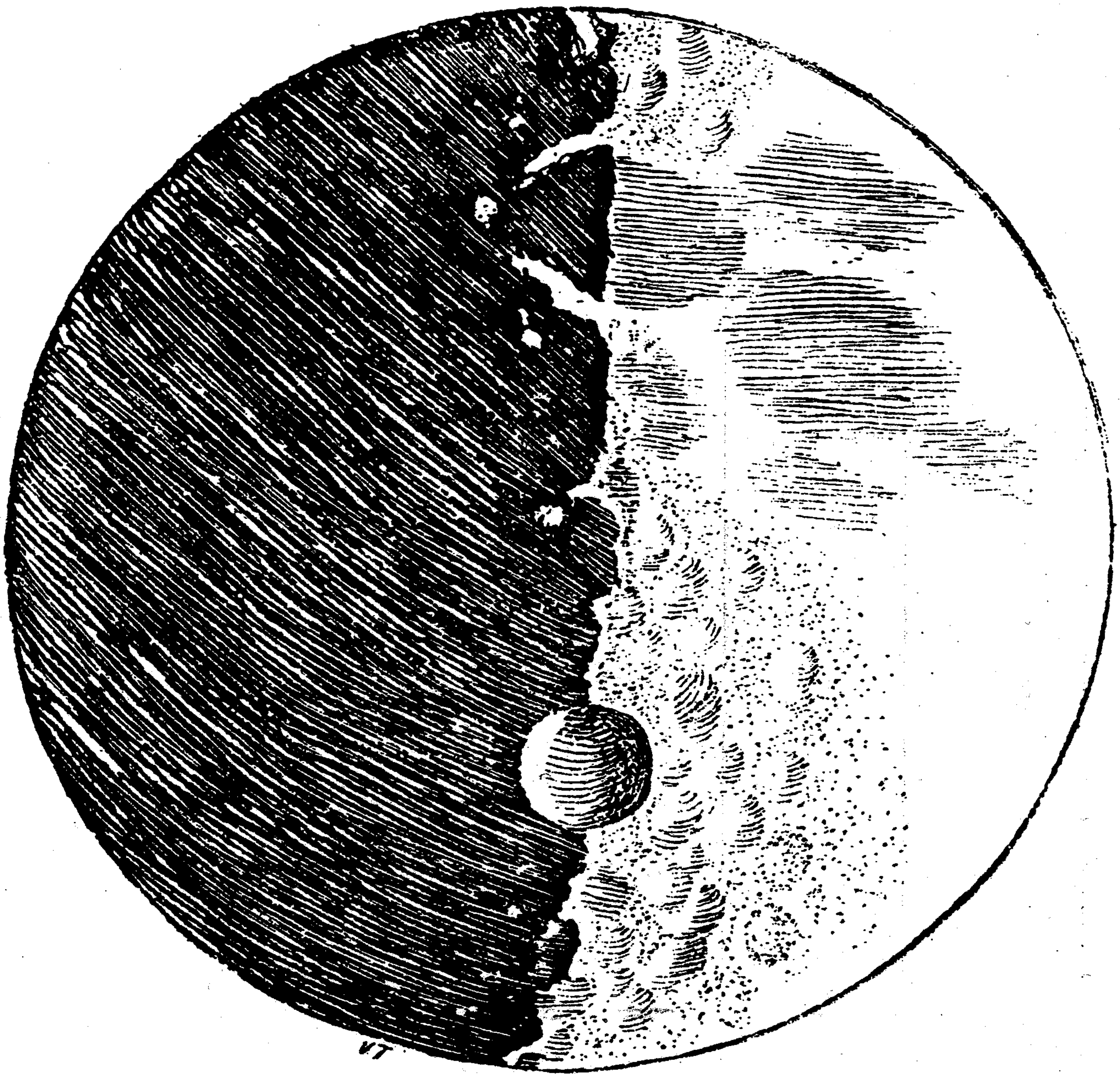
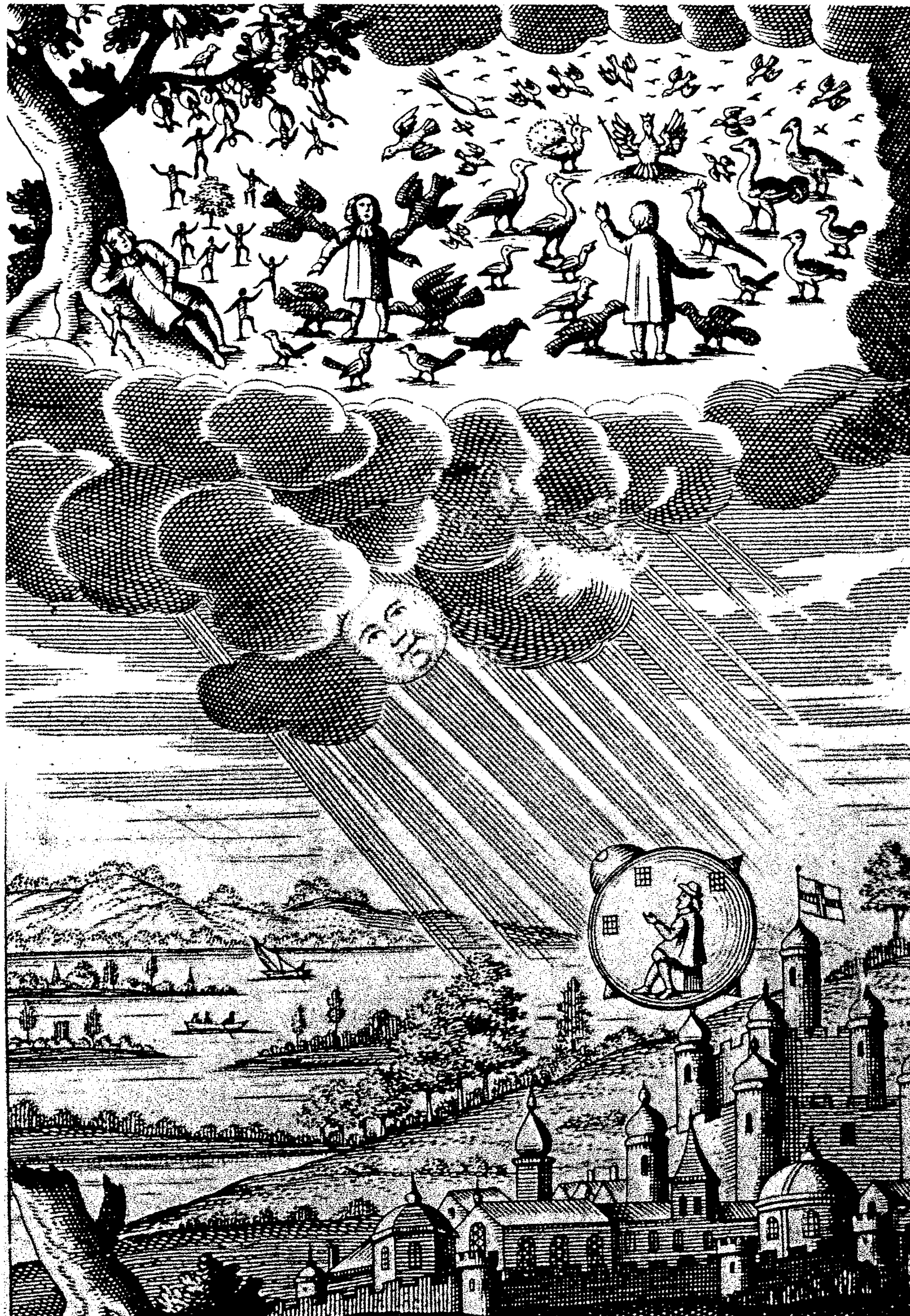


Figure 4 The diagram from Galileo's *Sidereus nuncius* (1610), clearly showing the circular feature that Kepler interpreted as evidence of lunar inhabitants. From Galileo's *Opere,* III, pt. 1, p. 66.

hewn out of that circular embankment"[42] (see Figure 4). Finally, Kepler argued from the perfectly smooth edge of the moon that it might be wrapped in a sphere of air, which moderated the heat with its moisture and allowed the inhabitants to bear the intense heat of the sun. He cited Maestlin in support of this atmosphere,


Saturnus.
Iupiter.
Mars.
Ceres et Proserpina.
Venus.
Mercurius
Omnibus Do lucem. calorem. motum.
Sua fovant
Mutuo se illuminant
Universum ornant.
Quid si sic ?
Hic ejus oculi.
A Discourse concerning A NEW world & Another Planet In 2 Bookes.
Printed for Iohn Maynard, & are to be sold at the George, in Fleetstreet neare St. Dunstans Church. 1640.
N. Copernicus.
W. Marshall, sculpsit.
Galilæus.
Keplar.



Cyrano de B. 1687

Fontenelle 1751 and the gal in the moon

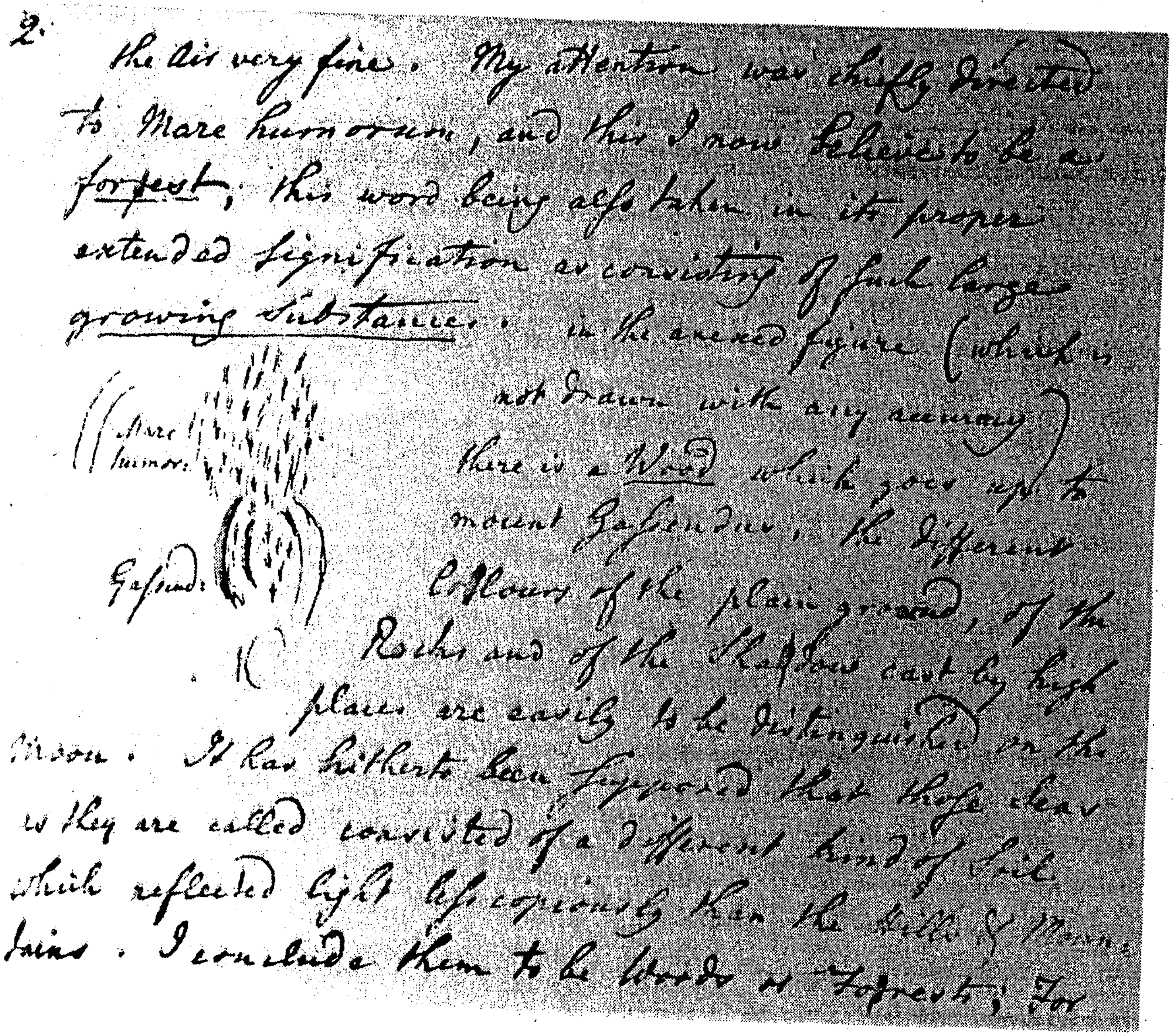

2.
the air very fine. My attention was chiefly directed to Mare humorum, and this I now believe to be a forest, this word being also taken in its proper extended signification as consisting of such large growing substances. in the annexed figure (which is not drawn with any accuracy) there is a Wood which goes up to mount Gassendus, the different colours of the plain ground, of the Rocks and of the Shadows cast by high places are easily to be distinguished on the Moon. It has hitherto been supposed that those clear as they are called consisted of a different kind of soil which reflected light less copiously than the hills & Mountains. I conclude them to be Woods or Forests; For

Figure 2.2. A portion of Herschel's unpublished notes on his lunar observations, including his drawing of the lunar forest he believed he had observed. (Courtesy of the Royal Astronomical Society.)

much rarer than ours an
means of clouds shining
enough to suppose that a
Building one half will hav
Sun. Perhaps, then on the
this be true ought we not
Lunarians may the Buildin
this. . . . By reflecting a
numberless small Circuses
and may be called their To
it is evident an exact list of
But this is no easy underta
many a careful Astronome
However this is what I wil

Having adopted this rem
no small factor in his effo
making numerous lunar
that to classify the lunar "
lis, Cities, Villages" but
terms "Large places, M
1979, entry records his o
dently to be the effect of
seeing a new spot in the M
a city."[62] Extensive luna
corded, many from the ea
mountains. The latter yea
late June yielding numero
and "circuses."[63] On ano
green."[64] In

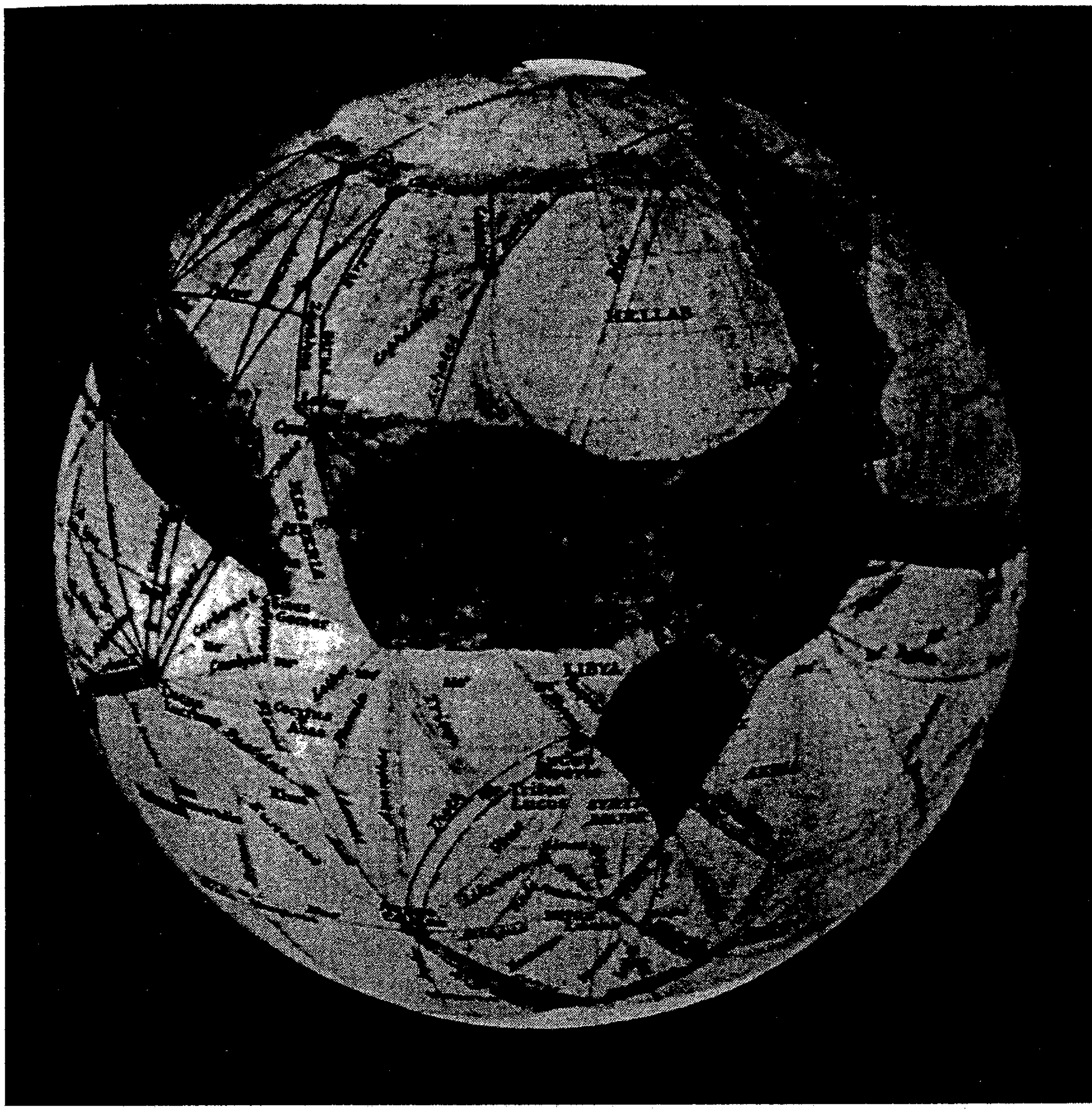
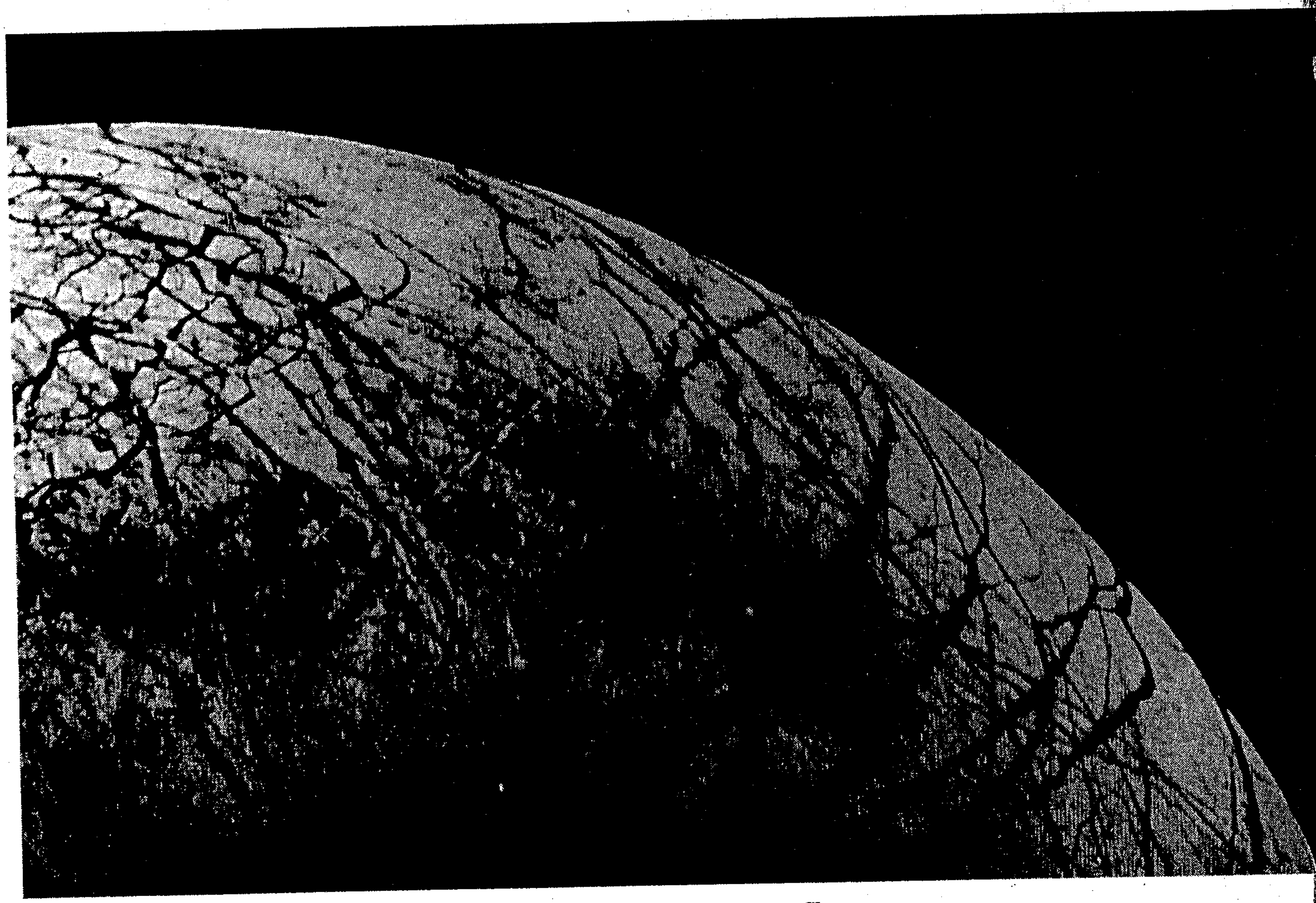


Figure I.1 *Percival Lowell's 1907 globe of Mars. Some thought that the linear features were irrigation canals built by Martians.*

nb: These features real, misinterpreted

to organic matter: extreme cold, toxic soil and lack of water. In many people's minds, these findings dashed all hopes that extraterrestrial life would ever be found in the solar system. This was a crushing blow to the nascent field of astrobiology. Venus features = retinal capillaries

At about this time there was another major disappointment: The first serious searches for "extrasolar" planets all yielded negative results. Although many astronomers believed that planets were probably common around



Cracks in the ice of Jupiter's moon Europa.
Is there an ocean down there? And life? NASA

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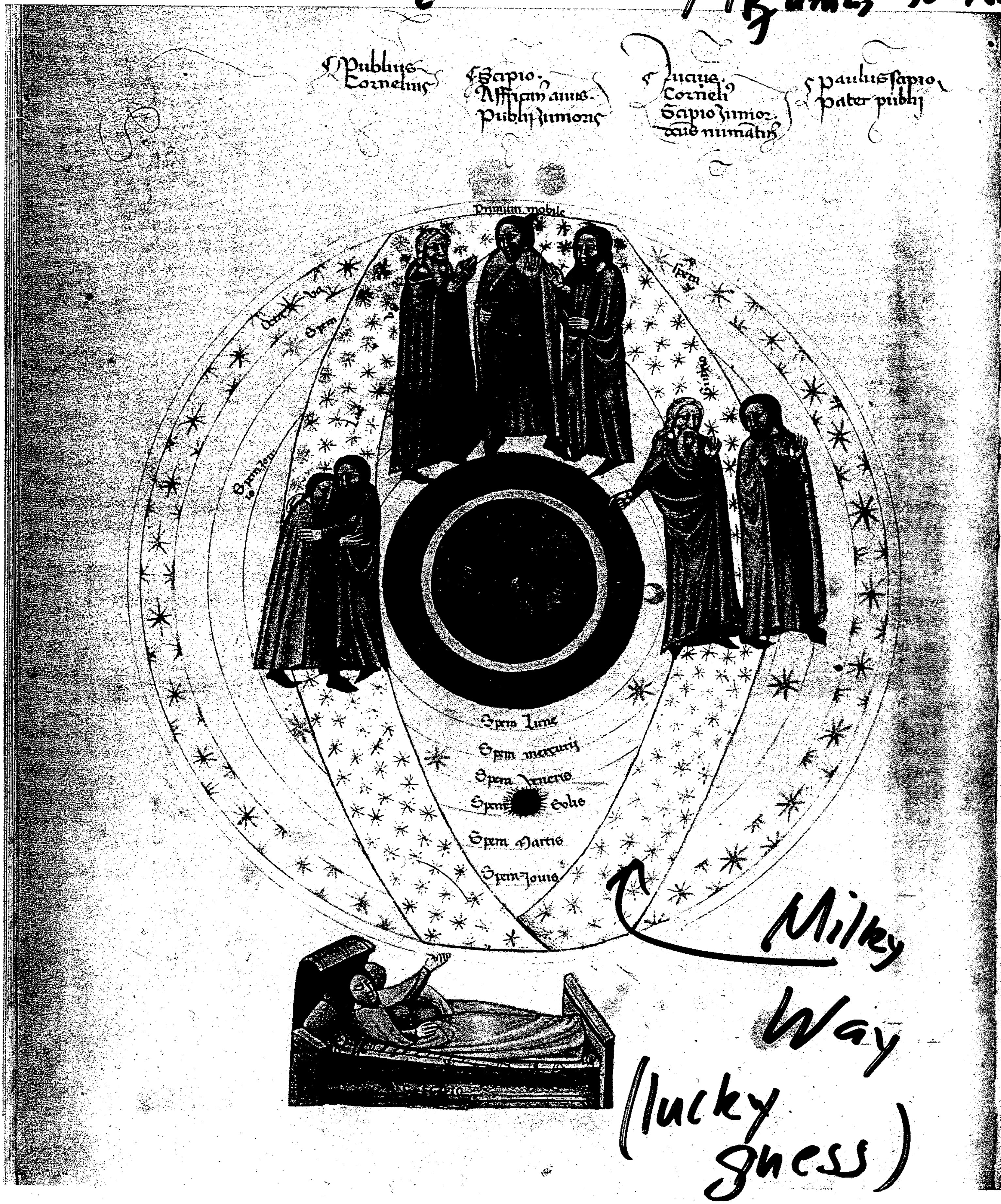
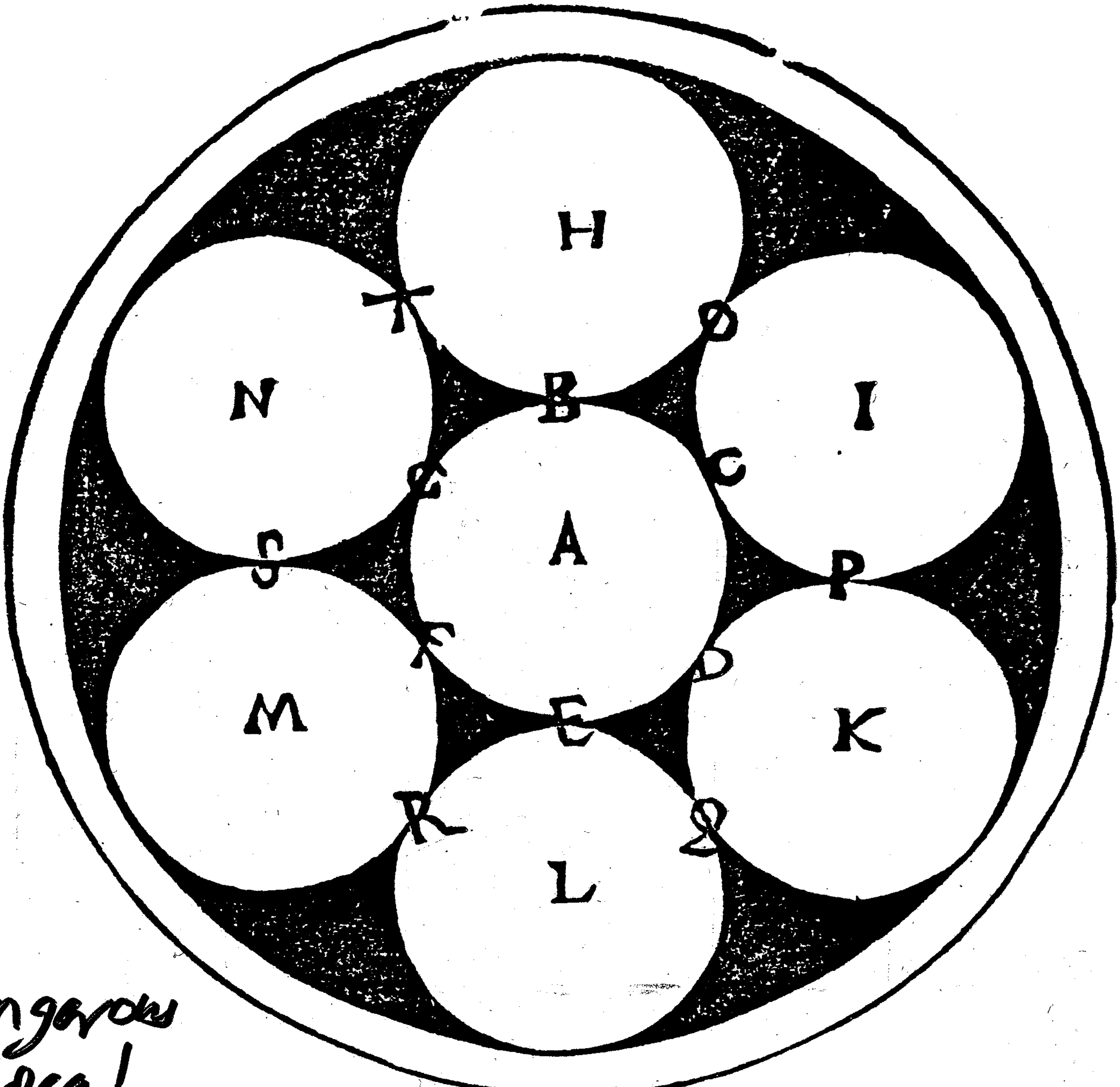
14th c. manuscript of Macrobius (5th cent) / Immutability of the Heavens Arguments to Tycho



Milky Way (lucky guess)

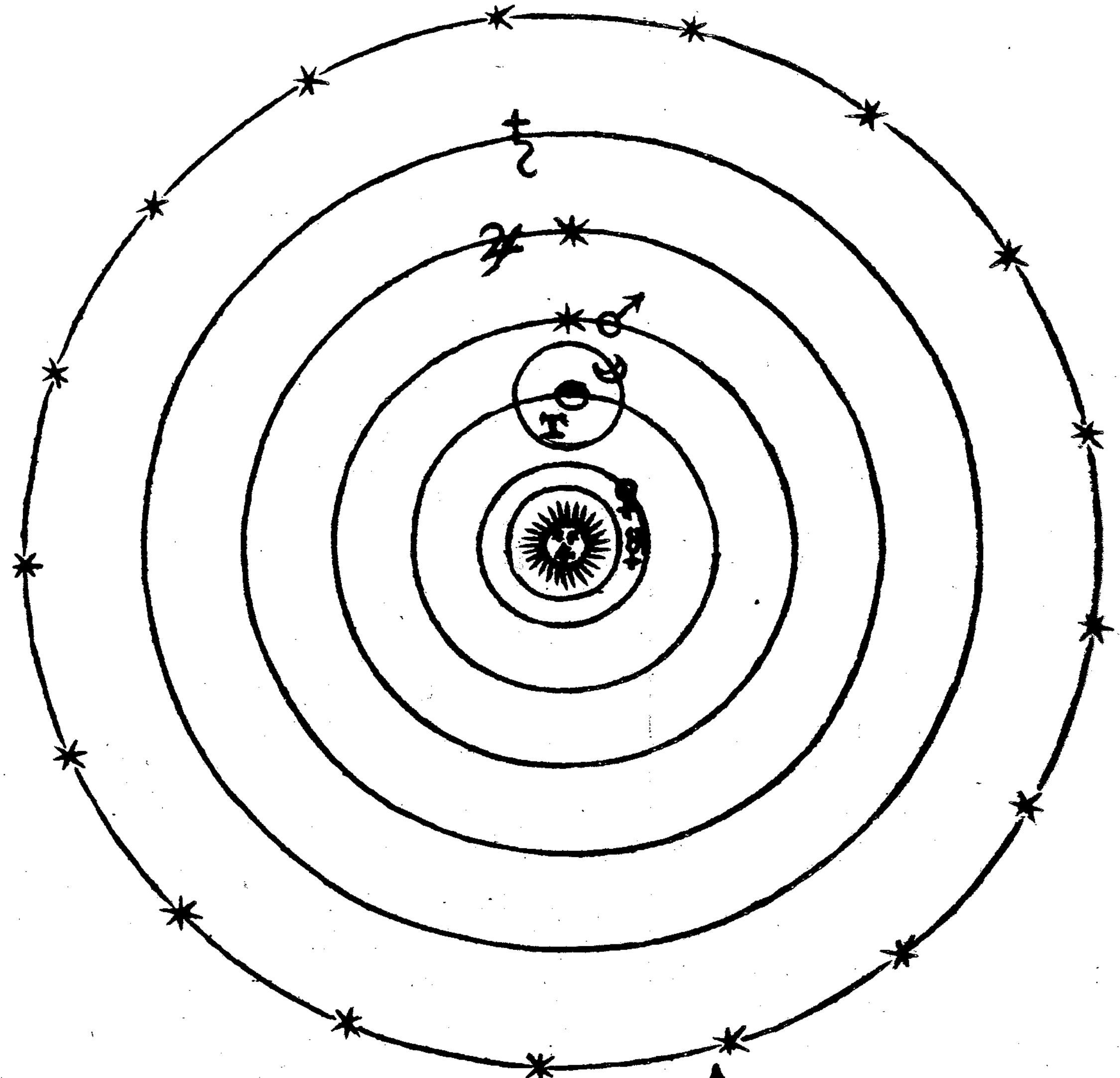


Dangerous idea!

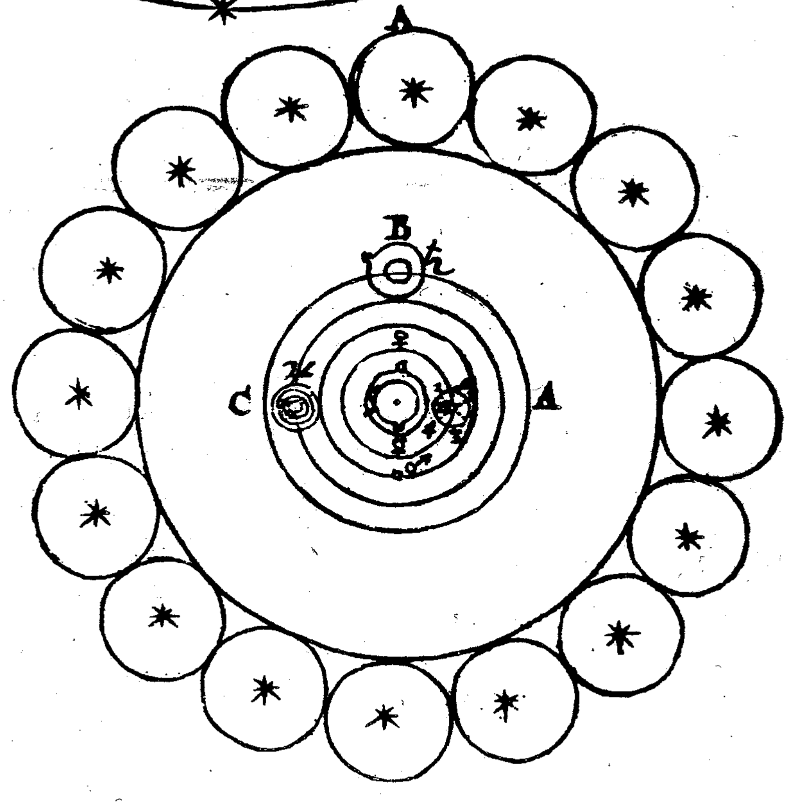
Figure 3 Diagram used by Giordano Bruno in his *De immenso et innumerabilibus* (1591) to illustrate that "a part of world *H* placed at *B* cannot and ought not to drive toward the center *A* of another system, but toward the center of its own system." Bruno's worlds were actually celestial bodies separated by one immense space, and not touching, as shown here. A simplified version of this diagram appeared in *De l'infinito universo e mondi* (1584).

Bruno's transformation of every celestial body into a world. While

Copernican



Cartesian extension
Henry Regius [illegible]
1654



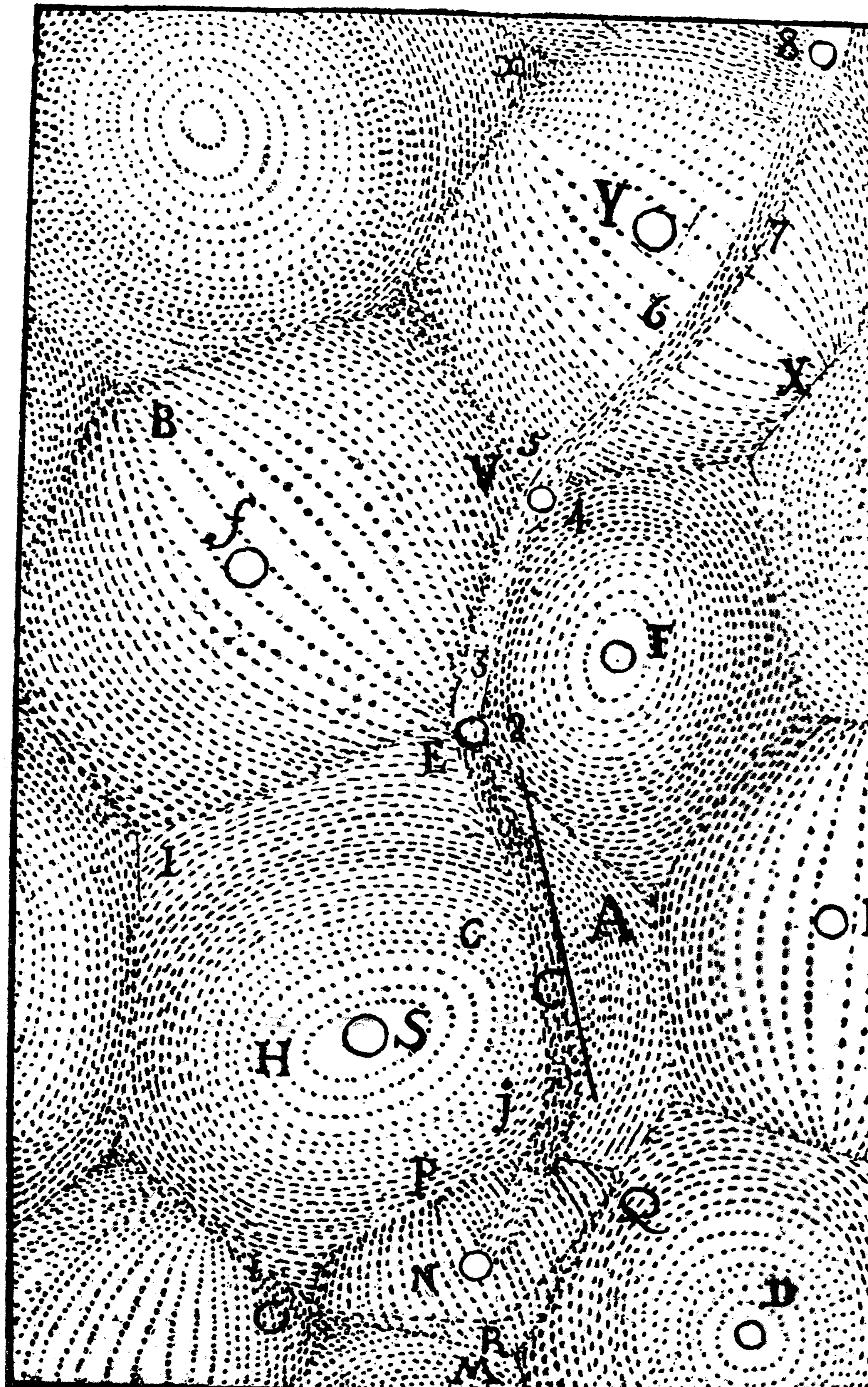
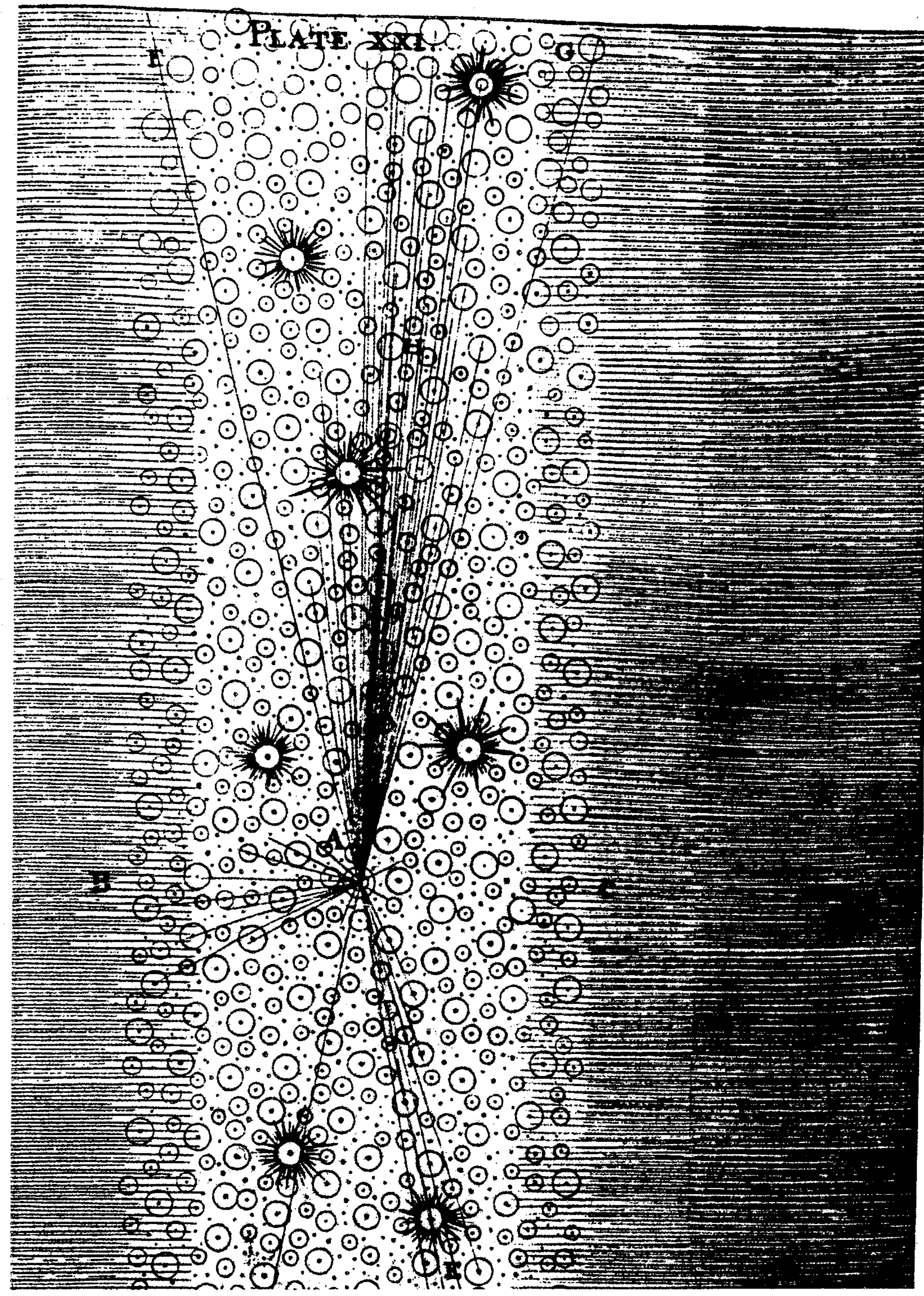
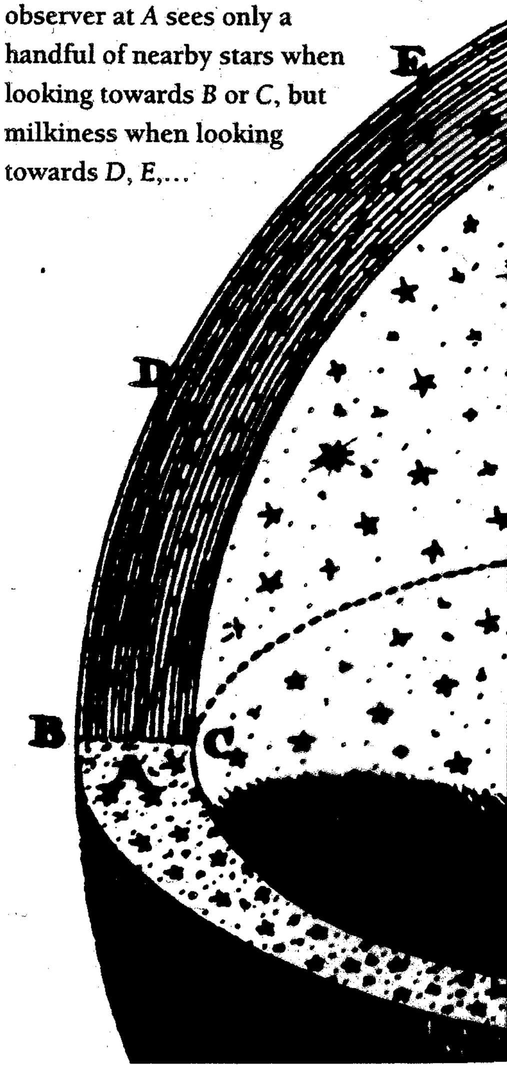


Figure 7 Descartes' vortex cosmology from his *Principia philosoph* (1644).

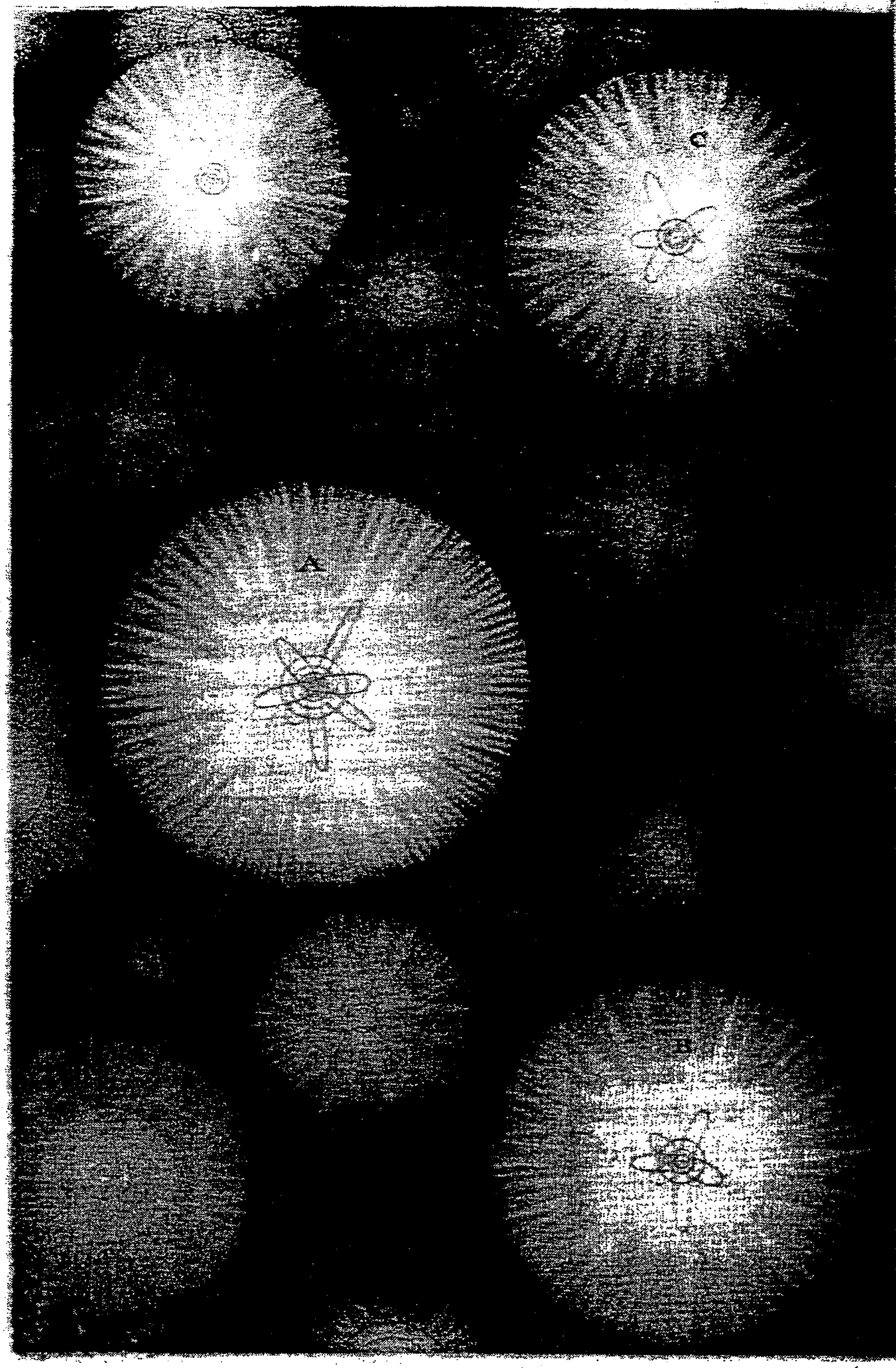


Below: Wright's preferred model. Stars near enough to be seen by us form a small segment of a vast spherical system, whose radius is so great that the boundaries of the segment approximate to parallel planes. Again, an observer at *A* sees only a handful of nearby stars when looking towards *B* or *C*, but milkiness when looking towards *D*, *E*,...



SS not Centred

PLATE XVII.



Thomas Wright
1750

A = SS B = Sirian System
C = Rigel System

Note orbit shapes - not coplanar — comets

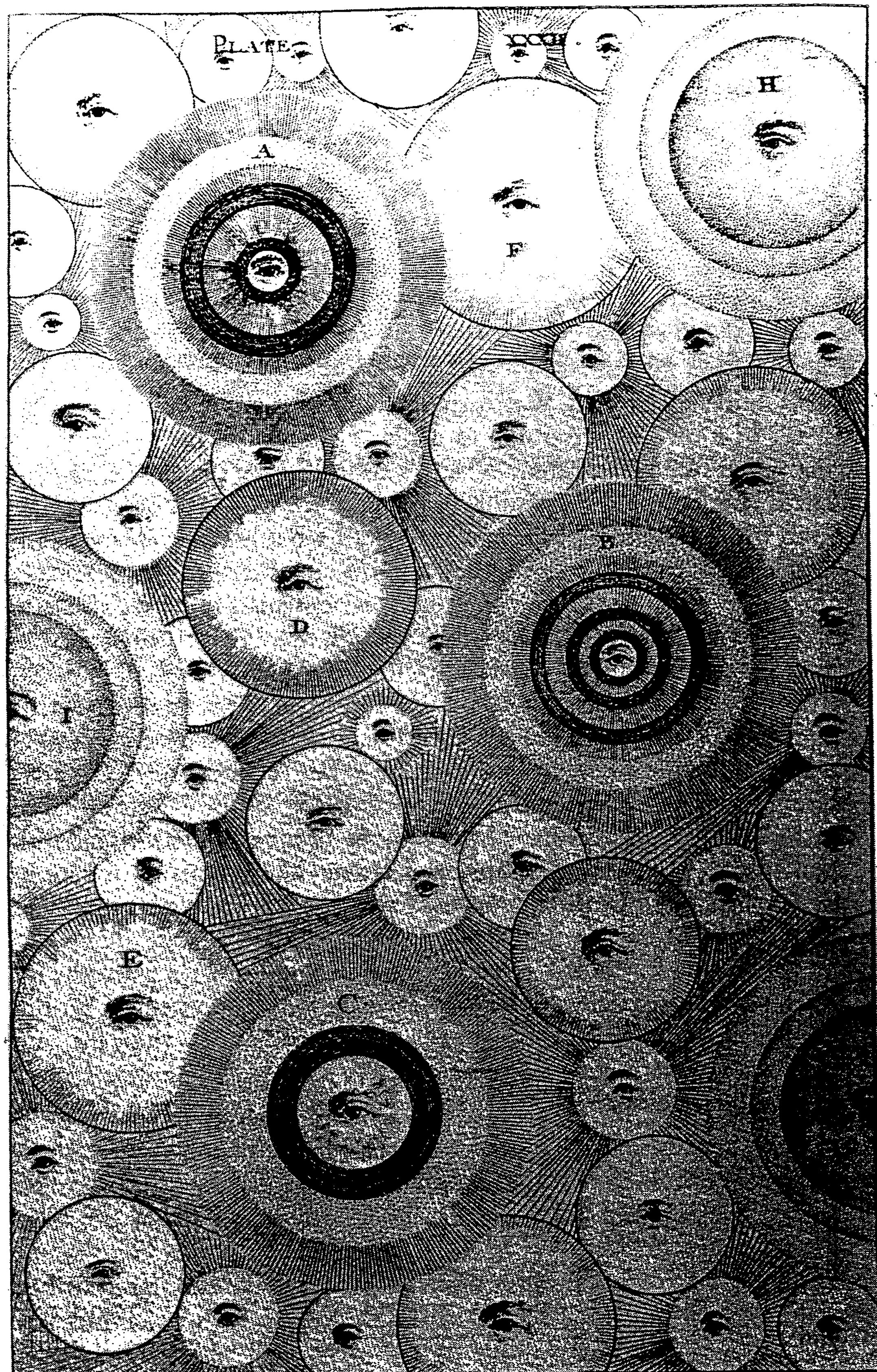


Figure 2.1. Wright's representation of infinity, showing sections of shells of stars, each having at its center the "Eye of Providence."

one of these includes all of
the previous picture

PLATE. XXXI.

Thomas Wright 1750

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ears later,
n Wilkins
ilean cau-
claims of
ıilable, as
mosphere
ɜre water.
its tenets,
ll who af-
ıter of all,
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s not syn-
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proposed

SS central

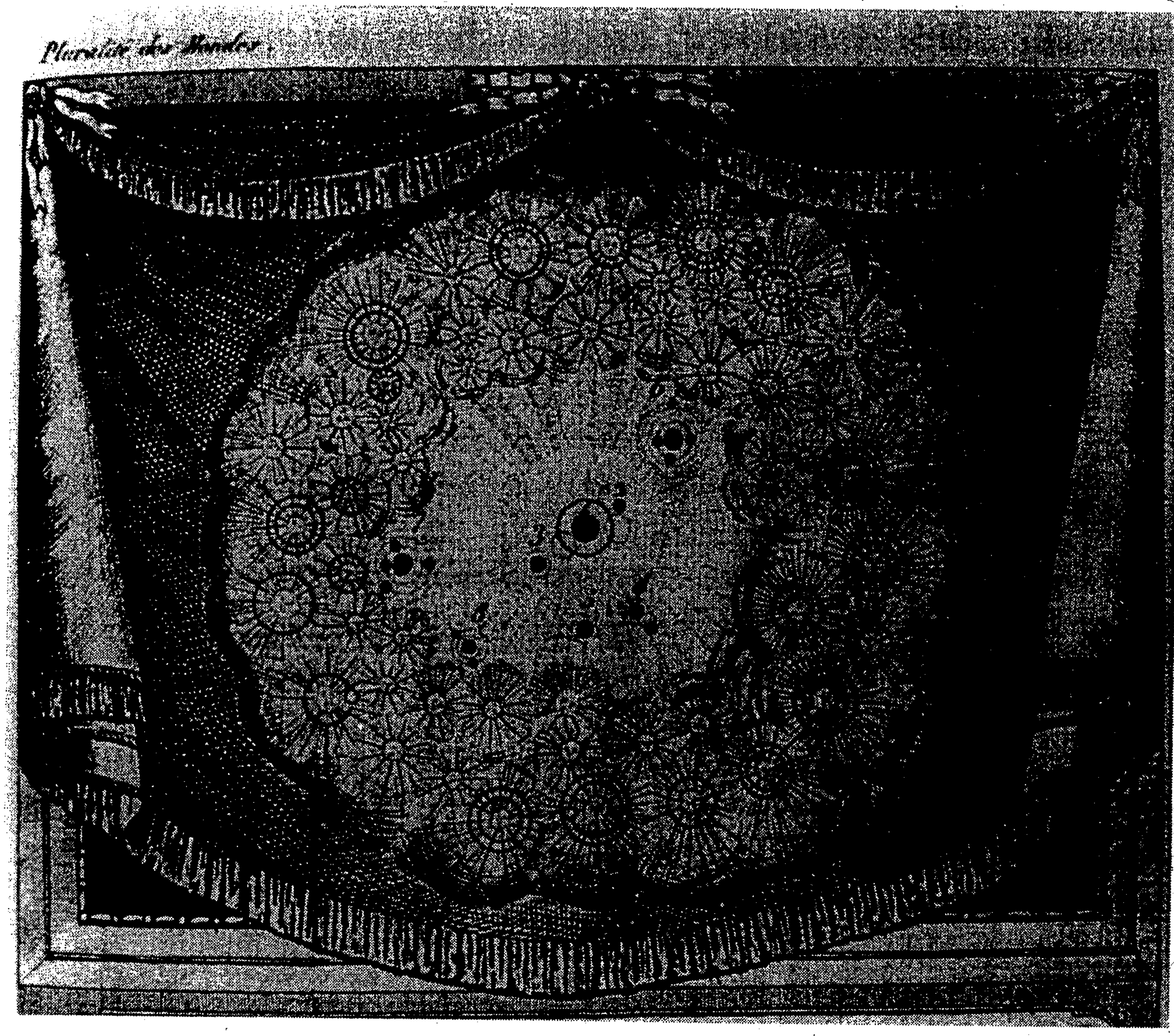


Fig. 1.2. Frontispiece to the 1821 French edition of Fontenelle's *Entretriens sur la pluralité des mondes* (1686), depicting the plurality of solar systems. From Steven J. Dick, *Plurality of Worlds* (Cambridge, 1982), by permission of Cambridge University Press.

Aristotle returns

DIAGRAM OF STELLAR UNIVERSE (Plan) Very similar to Eddington 1912 Stellar Movements

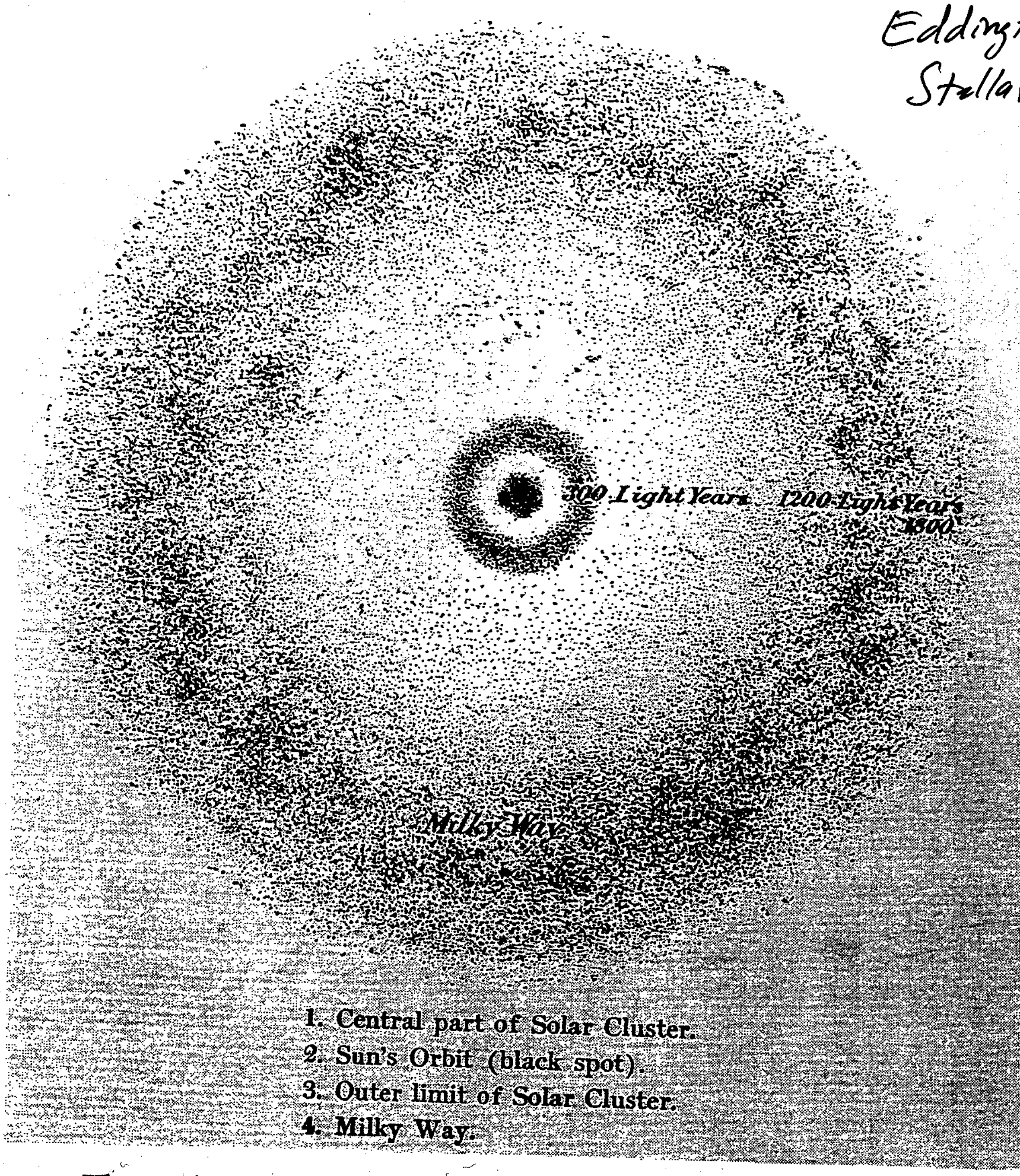


Fig. 2.2. The anthropocentric image of the universe according to A. R. Wallace (1903), showing the Milky Way stellar system, 3600 light years in diameter, with the Sun (a tiny black dot almost invisible here) near the center.

note: Darwin was pro-plurality

SS in uniquely good place [2007 G. Gonzalez ditto, tho not center of MW] ps He didn't get tenure @ Ohio State & is suing.

The centrality of the Sun was "the very heart of the subject" of Wallace's inquiry for more than philosophical reasons, for on that position rested much of his argument against other worlds. The importance

and Newcomb in favor of the

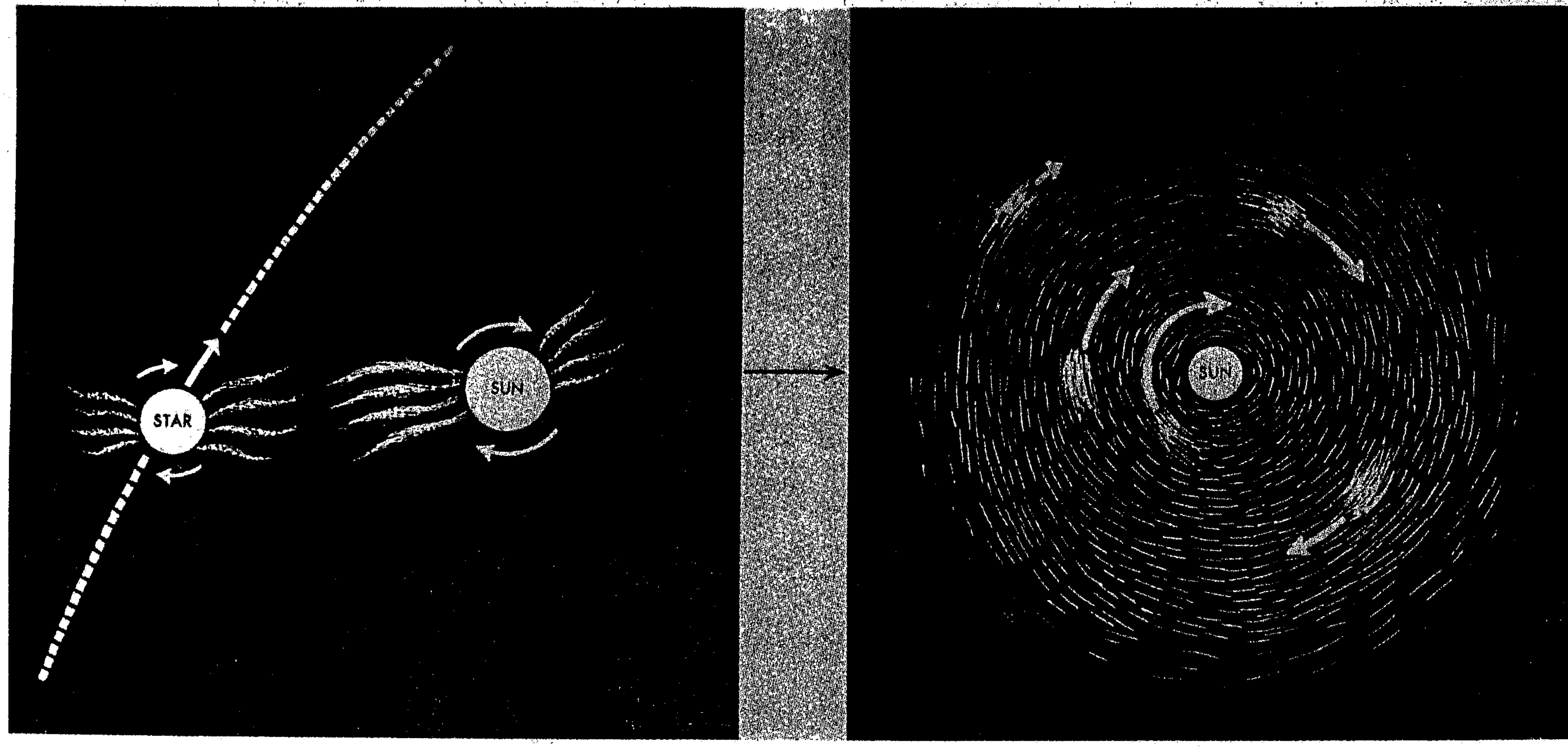
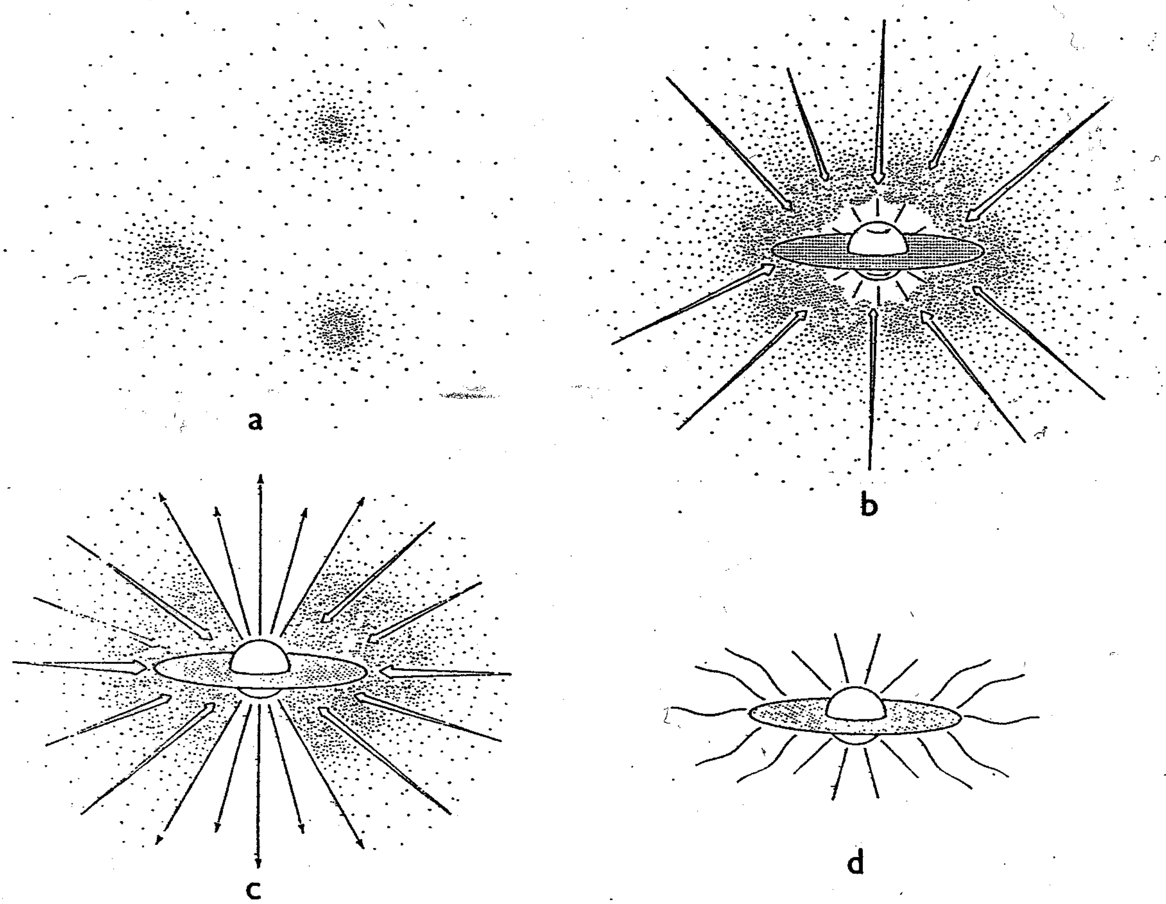
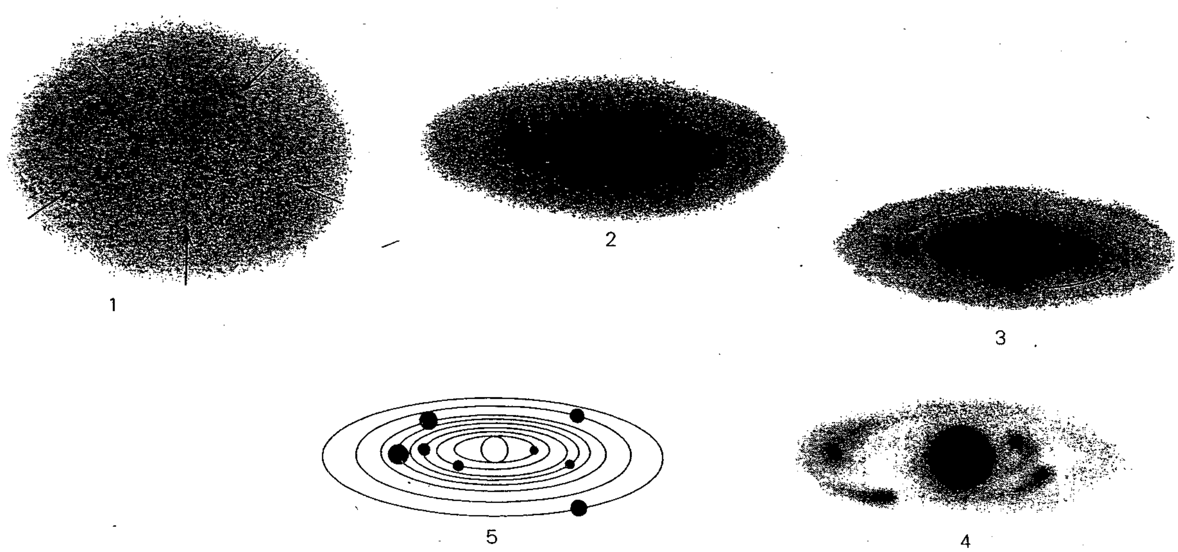


Figure 4.1. The Chamberlin–Moulton planetesimal hypothesis (1905), according to which a close encounter of another star with the Sun causes gases to erupt from both (left). These gases condense to form a large number of planetesimals that, in turn, accrete to form the planets (right). The spiral part of the theory, dropped a few years after it was proposed, is not depicted. (See also Figure 4.2.) From a review of theories of the origin of the Earth by astronomer Thornton Page in *Physics Today* (October 1948), at a time when abundant planetary systems were again being proposed.

no point in looking?
vs Laplace nebular hypothesis

Laplace updated





NOTED FALSE ALARMS

1896-97 Thomas Jefferson Jackson See direct imaging of several "dark" companions. Publ. in Atlantic Monthly (self-delusion or fraud) NUT

1896 TJJ See, proper motion 3rd star in 70 Oph AJ 16, 17 NUT

1943 Kaj Strand, 61 Cyg & 70 Oph B

1944 Peter van de Kamp, Barnard's star, Lalande 21185 error in telescope alignment

1963 P vd Kamp, Barnard's star with two

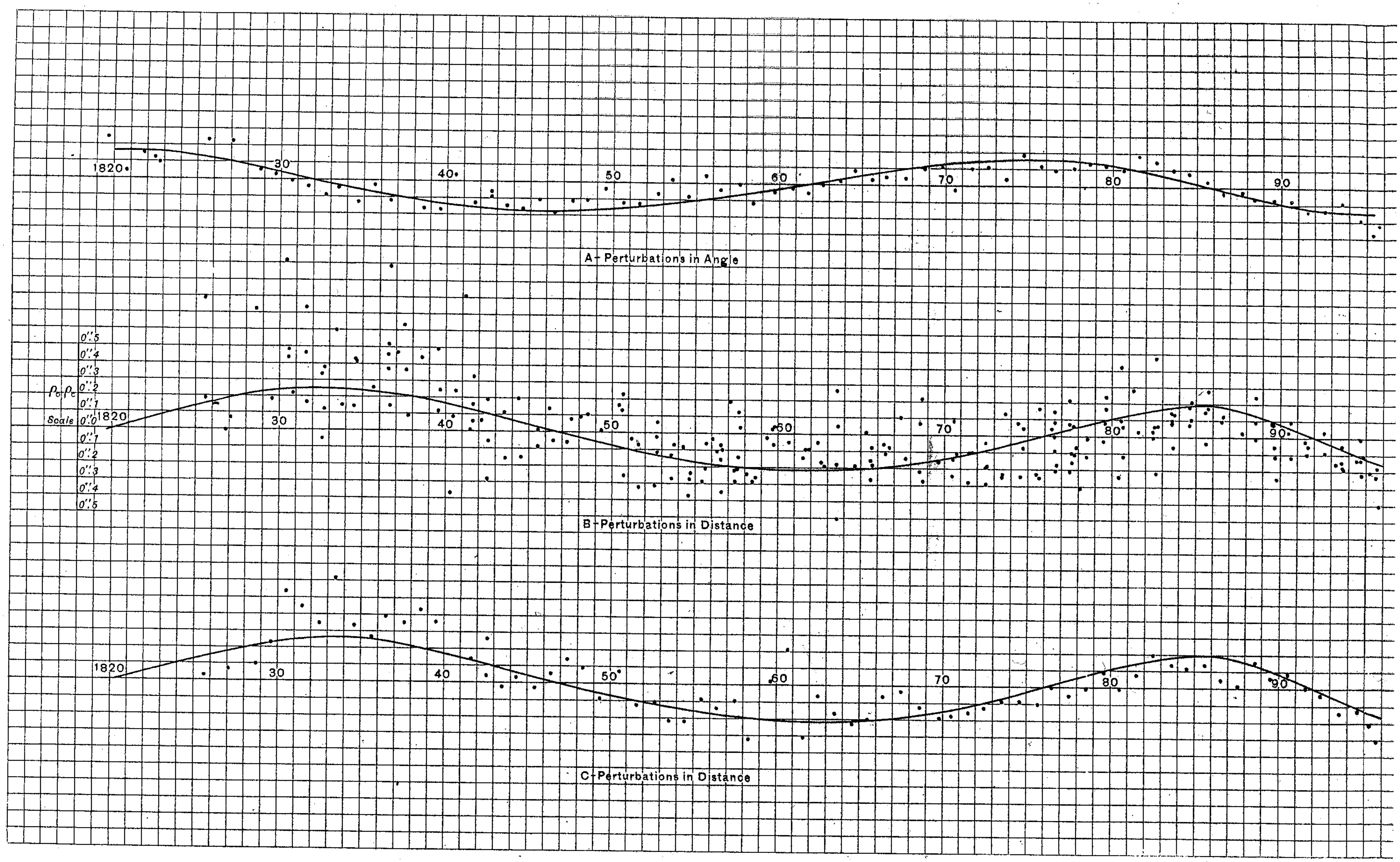
1996 George Gatewood, Lalande 21185

1988 Campbell et al. 1989 Latham et al. radial velocity variables (stellar activity, brown dwarfs)

γ Ceph down too! P ~ 18.9 yr

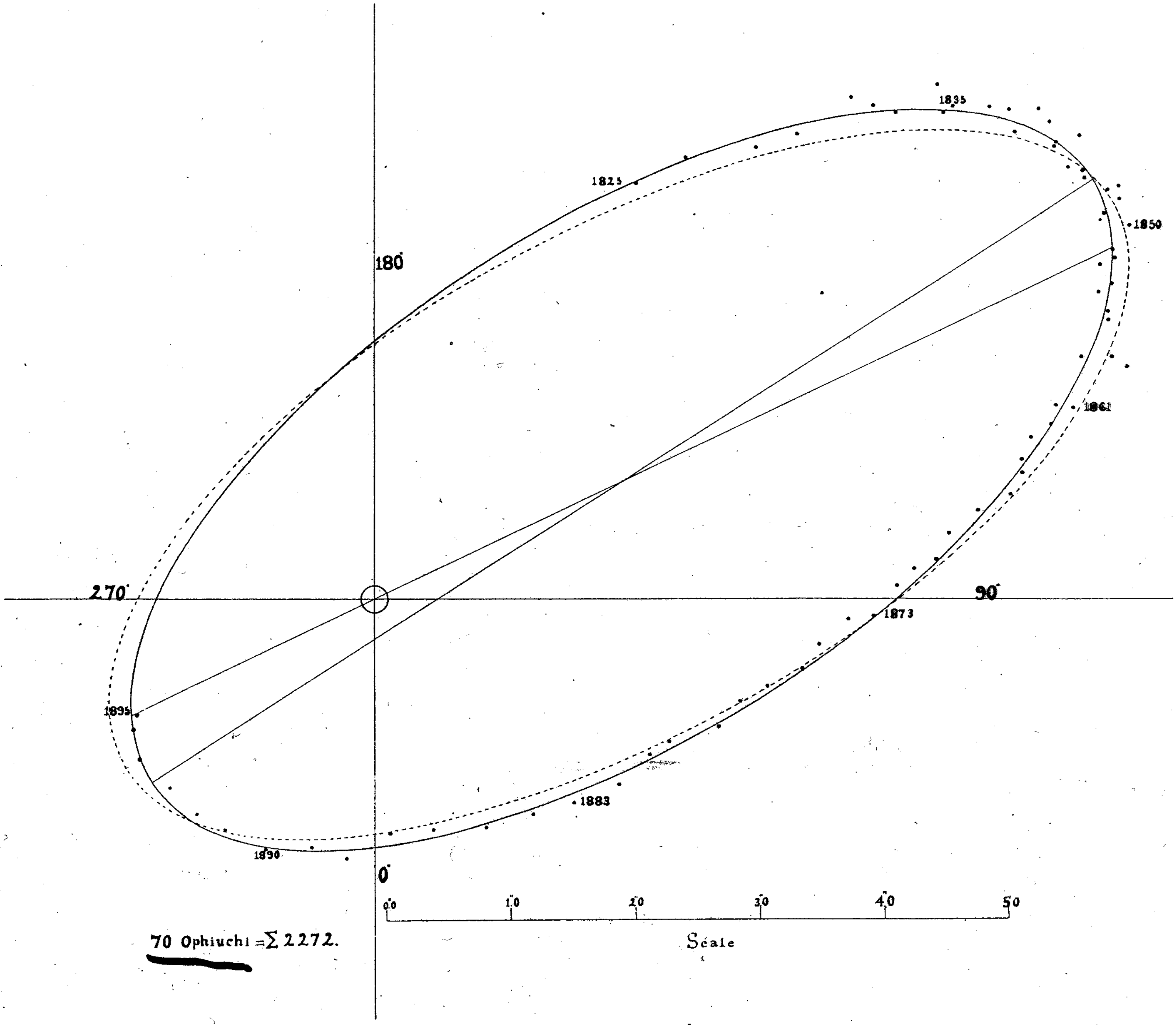
1991 Bailes et al. Timing residuals of psr 1829-10 (with six month P)

planet detected was ⊕!


A - Perturbations in Angle
B - Perturbations in Distance
C - Perturbations in Distance
Scale
$\rho_o - \rho_c$
0''.5
0''.4
0''.3
0''.2
0''.1
0''.0
1820
30
40
50
60
70
80
90

C 190

C 1900



70 Ophiuchi = Σ 2272.

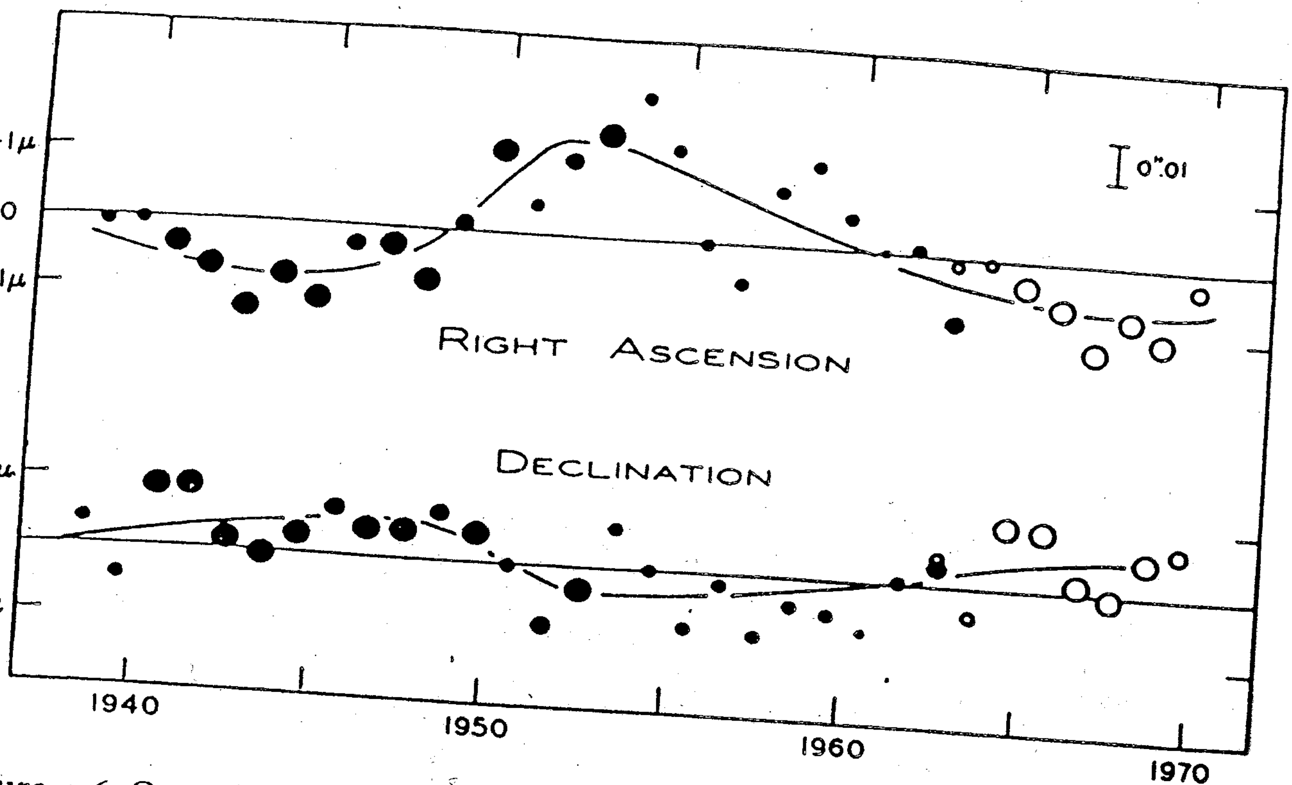


Figure 4.6. One of four methods of planet detection (see also Figures 4.7, 4.8, and 4.9). Van de Kamp's data for Barnard's star (1963) represent the classical astrometric method showing minute gravitational perturbations of a few hundredths of an arcsecond over a period of decades; plots using the spectroscopic radial velocity method look similar but need not cover such a long period of time. Used with permission from Elsevier Science Ltd.

NOT TRUE!

this mass and the period of the orbiting body were known, the mass of the latter could be calculated. It was here that van de Kamp finally came to the figure of .0015 times the mass of the Sun for his new planet: "The orbital analysis leads, therefore, to a perturbing mass of only 1.6 time the mass of Jupiter. We shall interpret this result as a companion of Barnard's star, which therefore appears to be a planet, i. e., an object of such a low mass that it would not create energy by the conventional

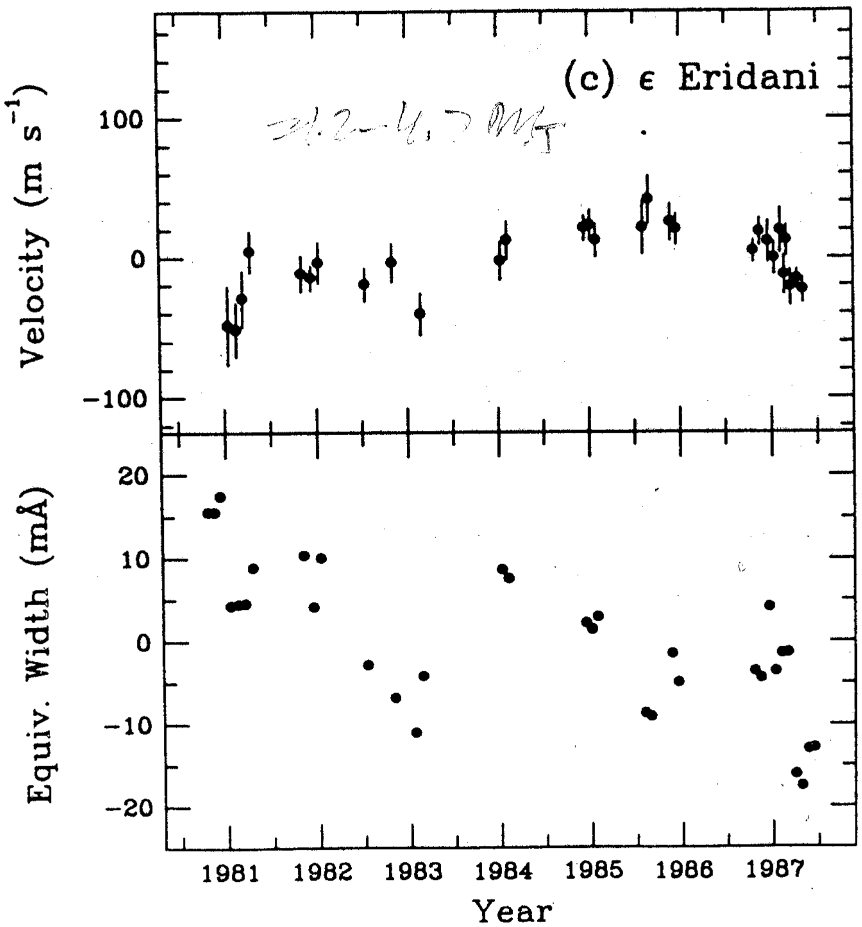


FIG. 2c

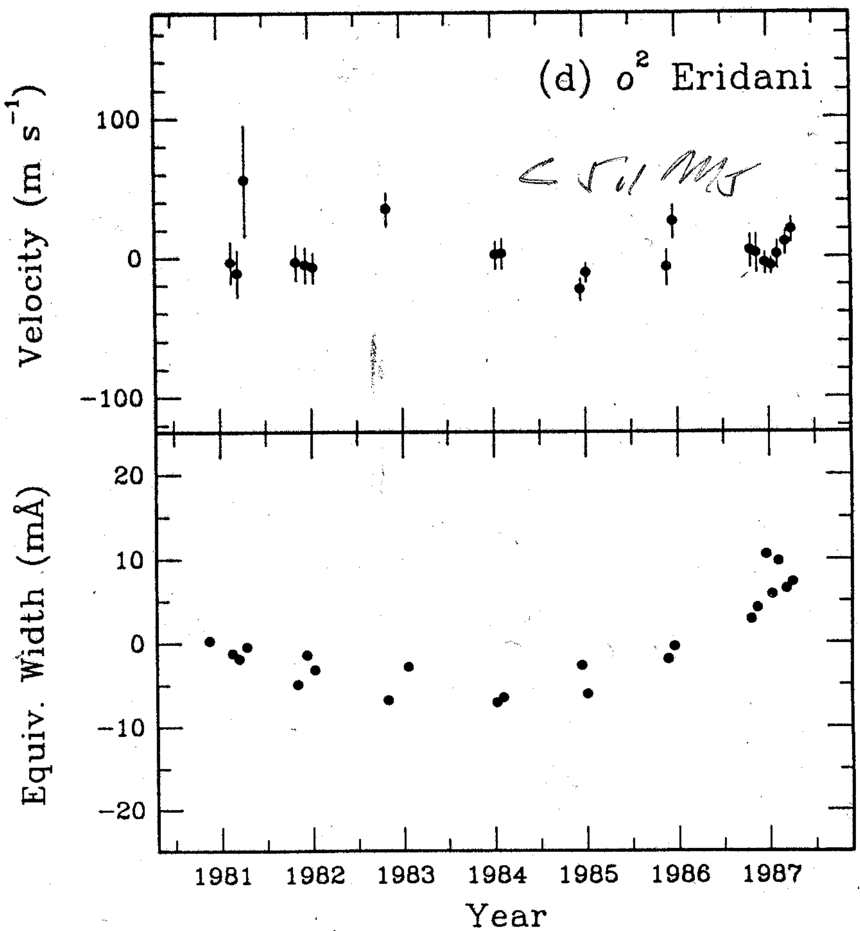
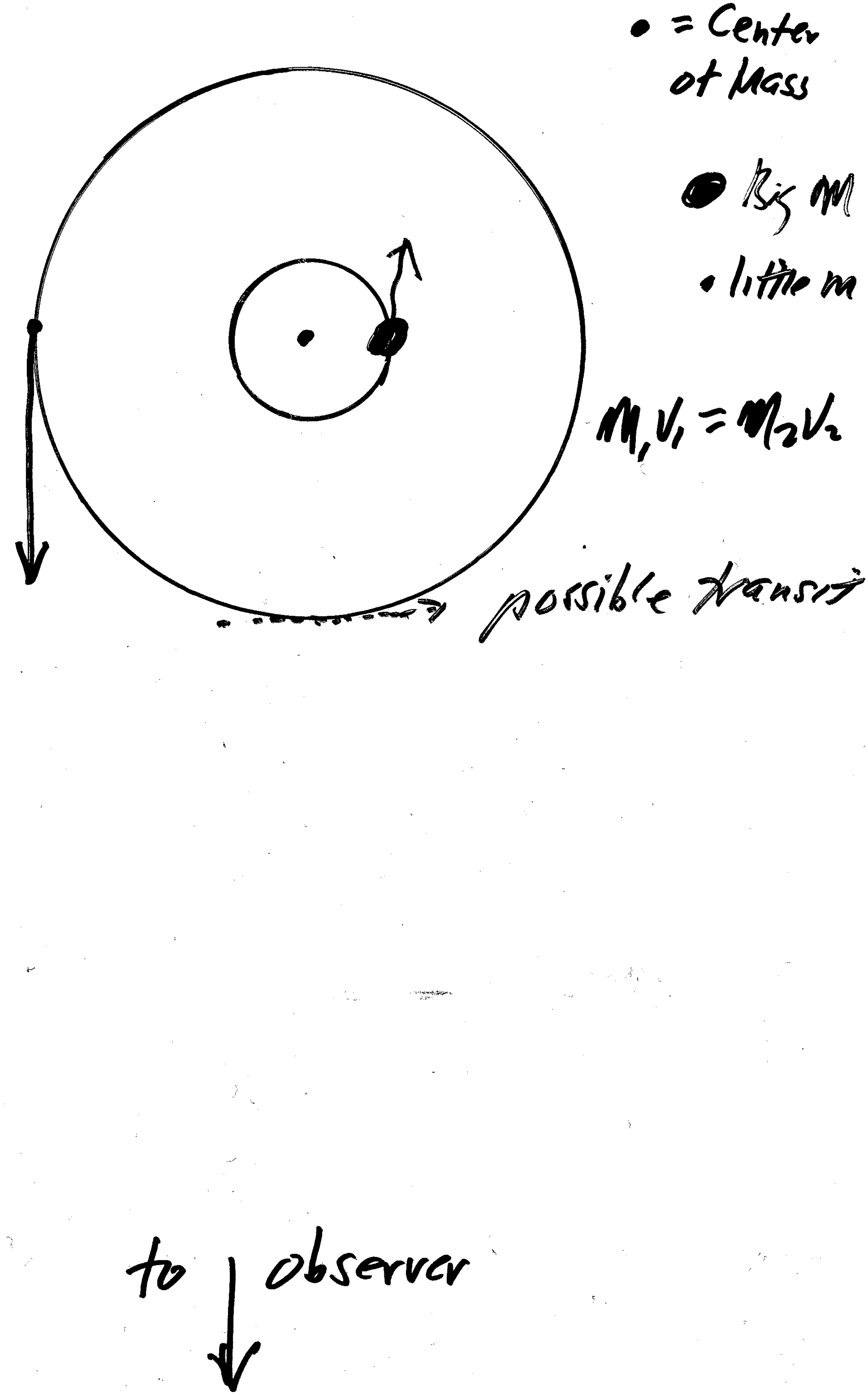


FIG. 2d

CAMPBELL + 1988


• = Center of Mass
Big M
little m
$M_1V_1 = M_2V_2$
possible transit
to observer

SEARCH AND DETECTION METHODS

F = False Alarms D = Discoveries
C = Confirmation of disc. by other meth.
? = phenom exists; other mechs possible
??= phen. exists, other mechs probable
S = Should exist; not yet seen

1. Direct imaging (F for companions; D for isolated)
2. Proper motion residuals (F,C)
3. Periodic residuals in radial velocities (F,D,C) ≥ 90% of discoveries
4. Residuals in pulsar timing (F,D)
5. Blips in microlensing (D) a few C⊕ possible
6. Transits (C,D; MANY candidates)
7. Distortions & disturbances of disks: Gaps, warps, ripples, dust growth(?)
8. Star occultation by dust vortex (F)
9. Collimation of bipolar ejecta (?)
10. Distortion of line profiles by reflected light or light absorbed in planet atms. (C) cf 10
11. Induced chromospherica activity (?)
12. Maser/laser activity in planet atm. or surface ?)
13. Periodic residuals in timing of EB light curves (?,S)
14. Pollution of host * atm. (??)
15. OH, H_2O in C star atm = comets (?)
16. Spin-up of evolved *s

as planetophagia (?,S) cf. CBS merge
17. V838 = star swallos planet (??)
18. Mira pulsation = embedded planet(??)
Microvariability = planets (S?)
19. Io effect in white dwarfs
20. WD atmosphere pollution by metals (earths) or H (gas giants) or debris disks
21. Exo-zodi (S) protoplan → debris @ 10^7 yr, gone @ 10^8
22. X-ray flashers = planet collisions (??)
23. GRBs as exhaust from spaceships(??)
24. Various SETI, panspermia, LGM scenarios

Li^6, oddities in Geminga, and more. Inventory expands about monthly

25. Subtraction (Spitzer, IR) (☆+planet) − star during occultation = planet

25. Planet atm. during occultation entry — CH_4 in one planet (Nature ~6 March), H, Na

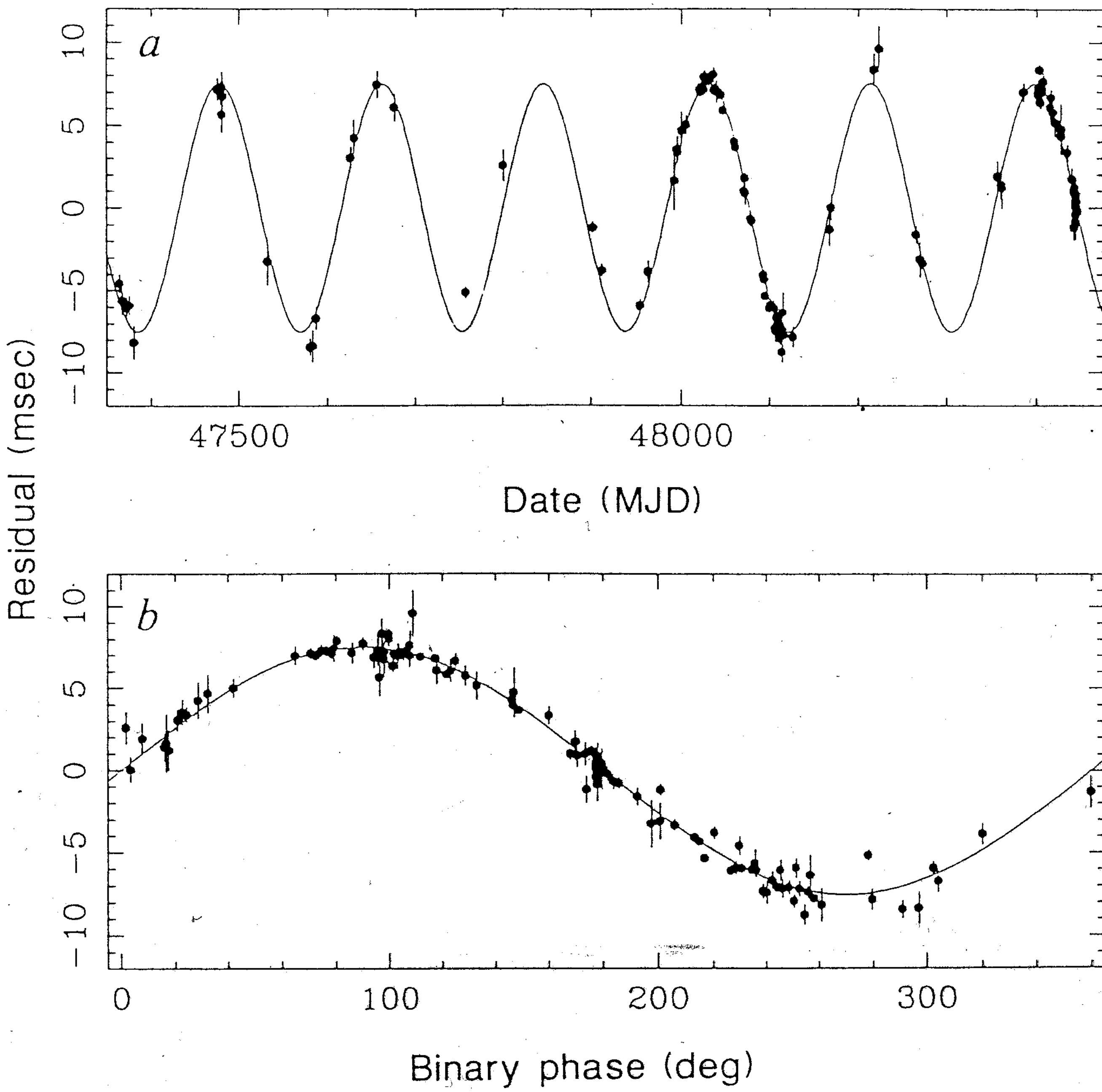


FIG. 1 The timing residuals for PSR1829 − 10. *a*, Plotted relative to a simple model of the slow down. The smooth curve represents the solution for a binary system with the parameters given in Table 1. *b*, As *a*, but plotted against orbital phase.

3 pl's → better fit

M ≤ ⊕

Comp unknown (Fe ??)

Made of SN fall-back ?

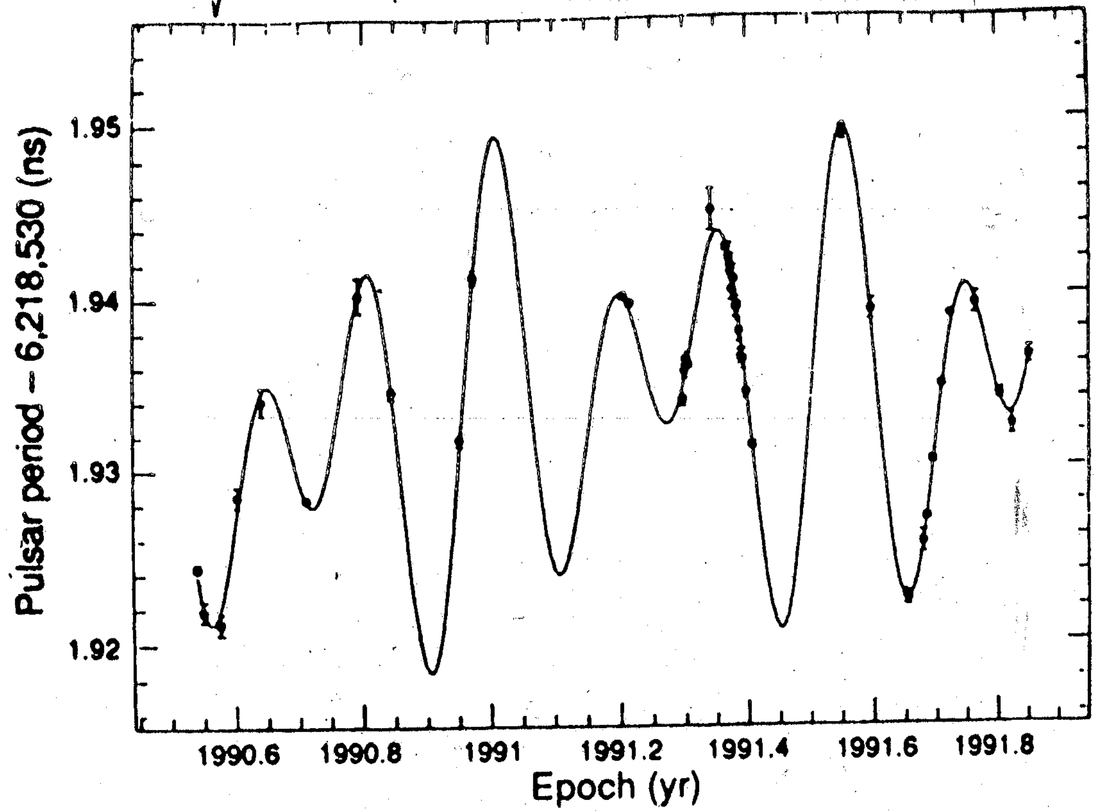


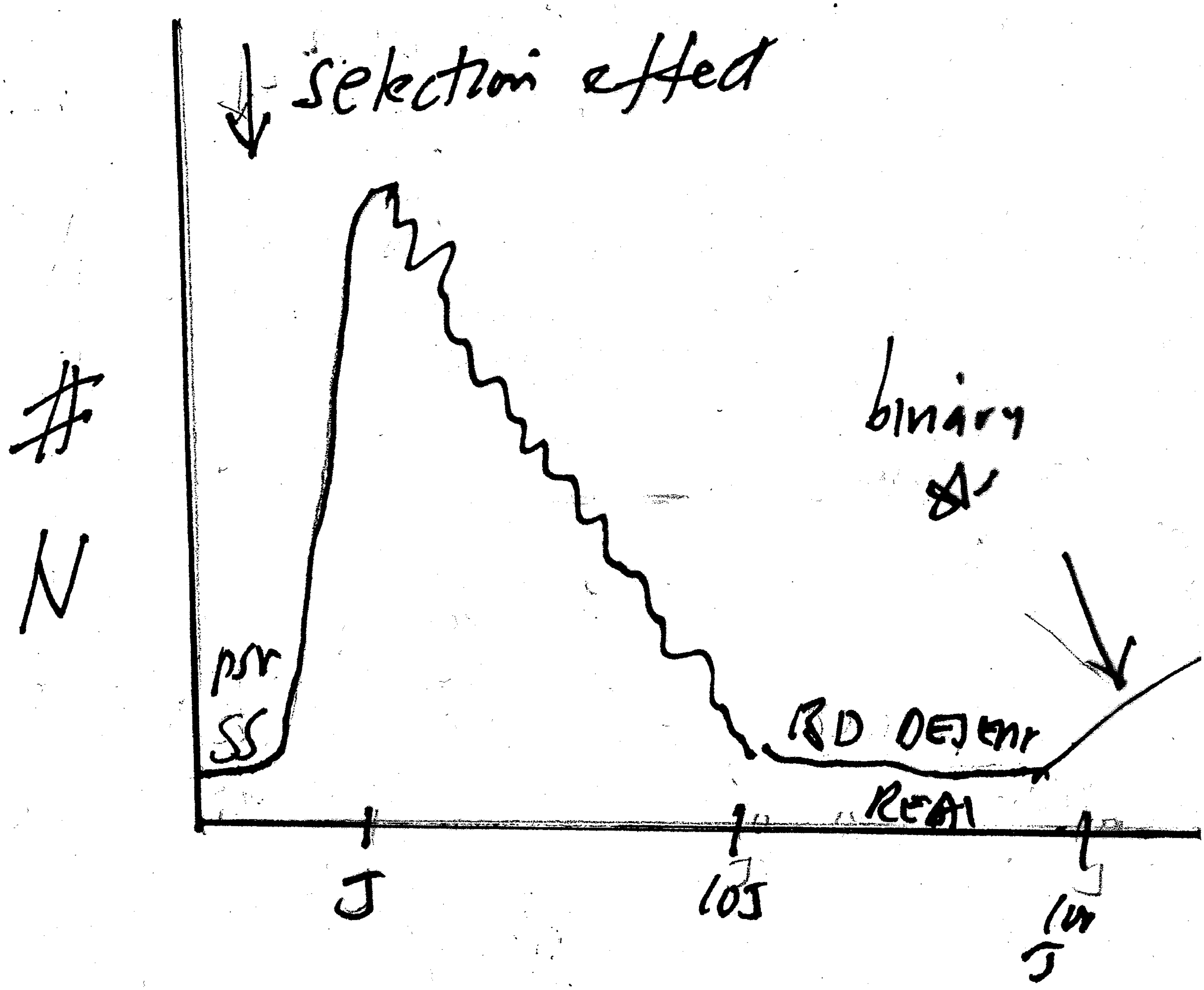
Figure 4.8. Data indicating pulsar planets (1992), the strongest evidence to date of planetary systems, is believed in this case to be irrefutably confirmed. The points represent observations, and the solid line indicates changes in period predicted by a two-planet model of this pulsar system. The vertical axis is in nanoseconeds (billionths of a second), so that the period variations of the pulsar are only .03 billionths of a second, or ±15 picoseconds (thousandths of a billionth of a second). Note that only 1 year was needed for the pulsar method compared to decades for the astrometric method. Used with permission from A. Wolszczan and D. A. Frail, "A Planetary System around the Millisecond Pulsar PSR1257 + 12," *Nature*, 355 (January 9, 1992), 145–147, copyright 1992 Macmillan Magazines Limited.

EXOPLANETS

More than 300 known. 1 quint, a few quad & triples, many doubles

Most from $V_r(t)$ "radial velocity method" a few each from transits, astrometry (HST FGS), direct imaging

Mass distribution: many J's, few N's
min = 5.5 M(earth) - selection!!!!
SS has 4 = M(earth); pulsar has 3

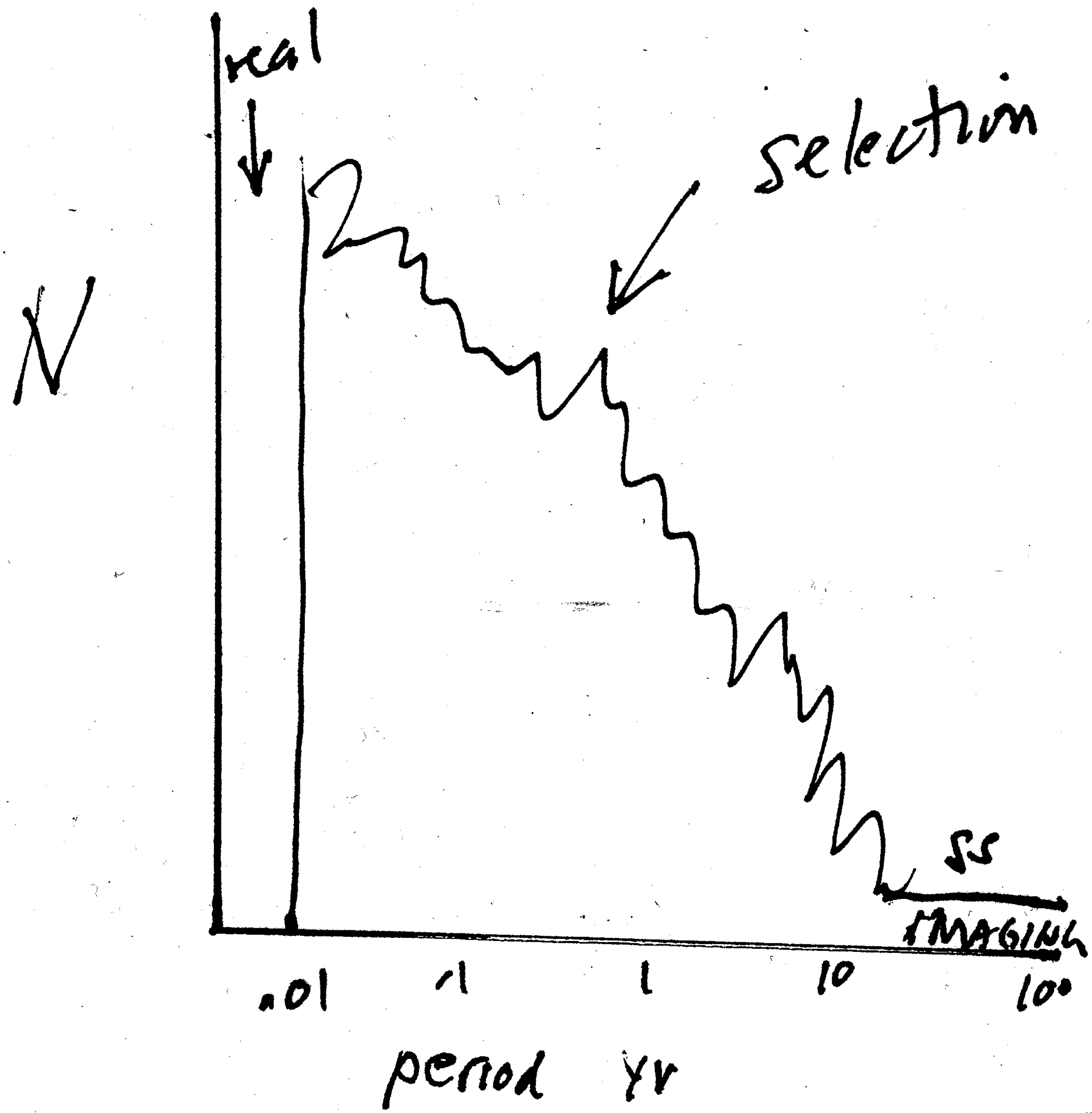


N(Period) or N(semi-major axis)

$$MP^2 = a^3$$

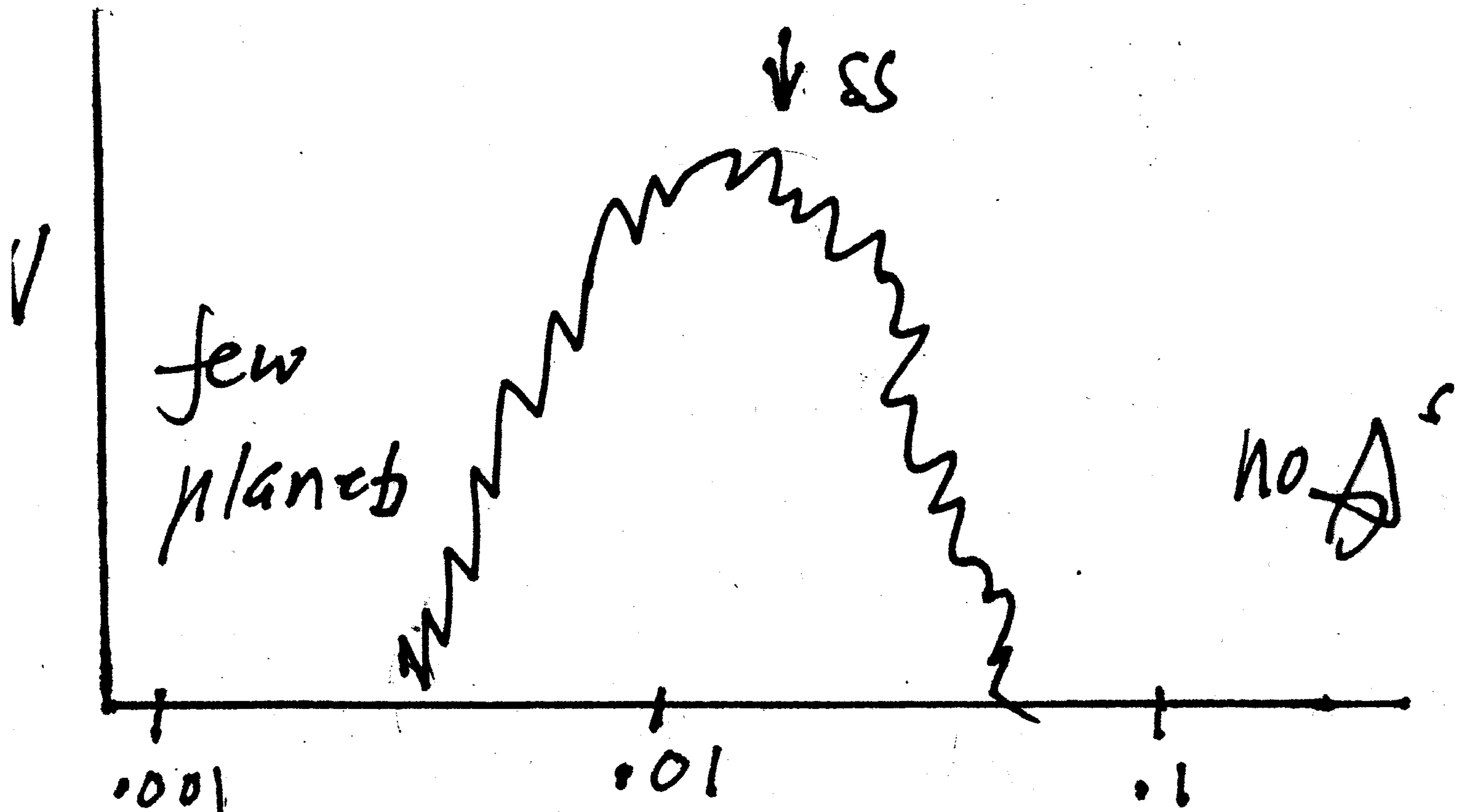
P(min) = 1.5 days (real)
P(max) = 12 years (selection, V_r)
= centuries (direct imaging)?
Solar system Ps = 0.24 - 240 years

SS Cnc (quint) fits Bode's law, which "predicts" analogues of Ceres & Sat.



Compositions, structures

Host stars are "metal" rich



Planet spectra (by subtraction) show H, Fe, Na. Want ✓H_2O, ✓CO_2, O_3, CH_4 chlorophyll edge

Formation: Make and migrate (Neptune took TNOs with it).

Planetesimal accumulation (slow)

Gravitational instability (maybe)

"true"pplanets are chemically differentiated

Theory:

Grav. instability vs. planetesimal accretion — TBD

Make & then migrate (TNO pile up at resonances)

Orbit stability: bin δ' a/a ??

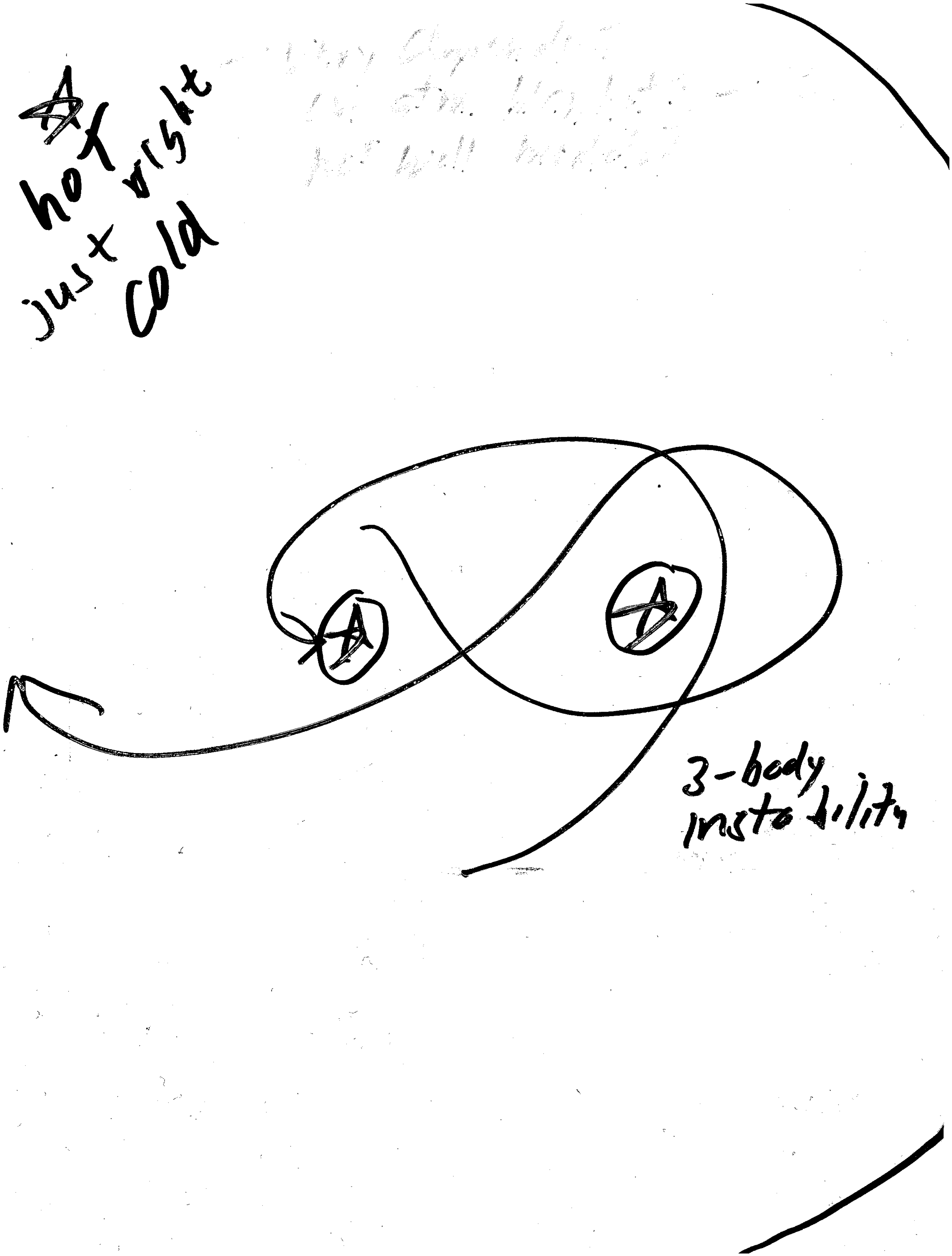
⊕ in/outside a J orbit?

Habitable zones of SS, Galaxy

Snowline and H_2O

POT-SHOTS NO. 3621. Ashleigh Brilliant SANTA BARBARA

THE GREATEST OBSTACLE TO DISCOVERING THE TRUTH IS BEING CONVINCED THAT YOU ALREADY KNOW IT.


hot
just right
cold
3-body instability

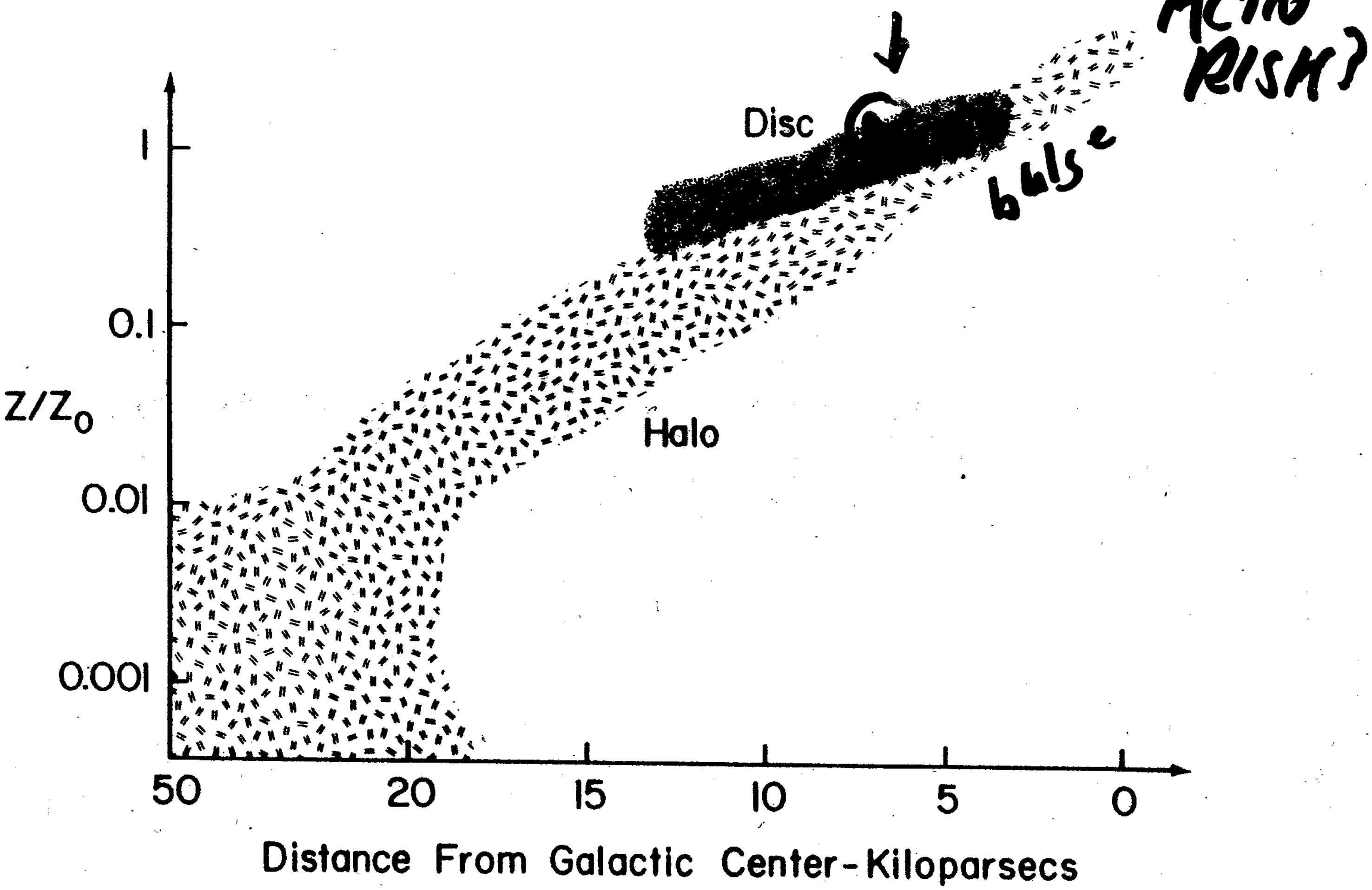


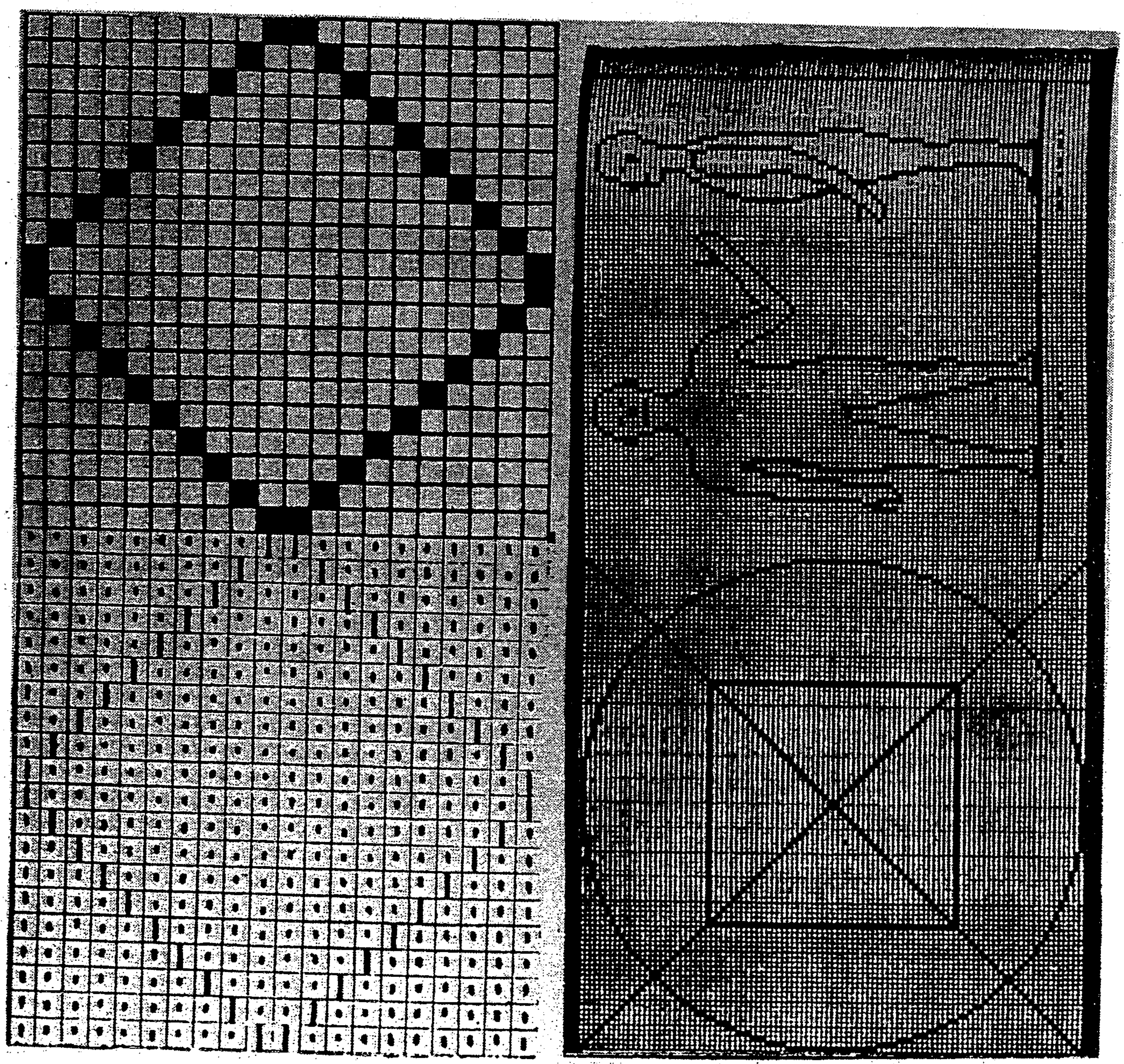
Fig. 15.4. Gradients of average metal abundance as a function of distance from the galactic center in halo (plus bulge) and disc populations of the Milky Way.

DISCUSSION

Robert Rood: I think that we should be especially careful in comparing stellar ages determined by different methods. The Sun is different from all the other stars and, working in this field, I would say that probably there is a 50 percent uncertainty generally in attaching other stellar ages to the solar age. So I would put 50 percent error bars on all those ages, in which case you get no information whatsoever.

Trimble: That isn't quite true.

Rood: Working with solar neutrinos gives me a great deal of skepticism in this area.



To be Wirelessed to Mars as dots + dashes
1920. (March 20 Sci. Am) SAGAN is better looking

non-centrality of $\oplus$ — Copernicus 1543+

non-uniqueness of $\odot$ — Newton, Michell, Herschel 1700–1800

non-centrality of SS — Shapley 1918

non-uniqueness of MW — Hubble 1925

. . . .

non-uniqueness of $\oplus$ —

" " universe —