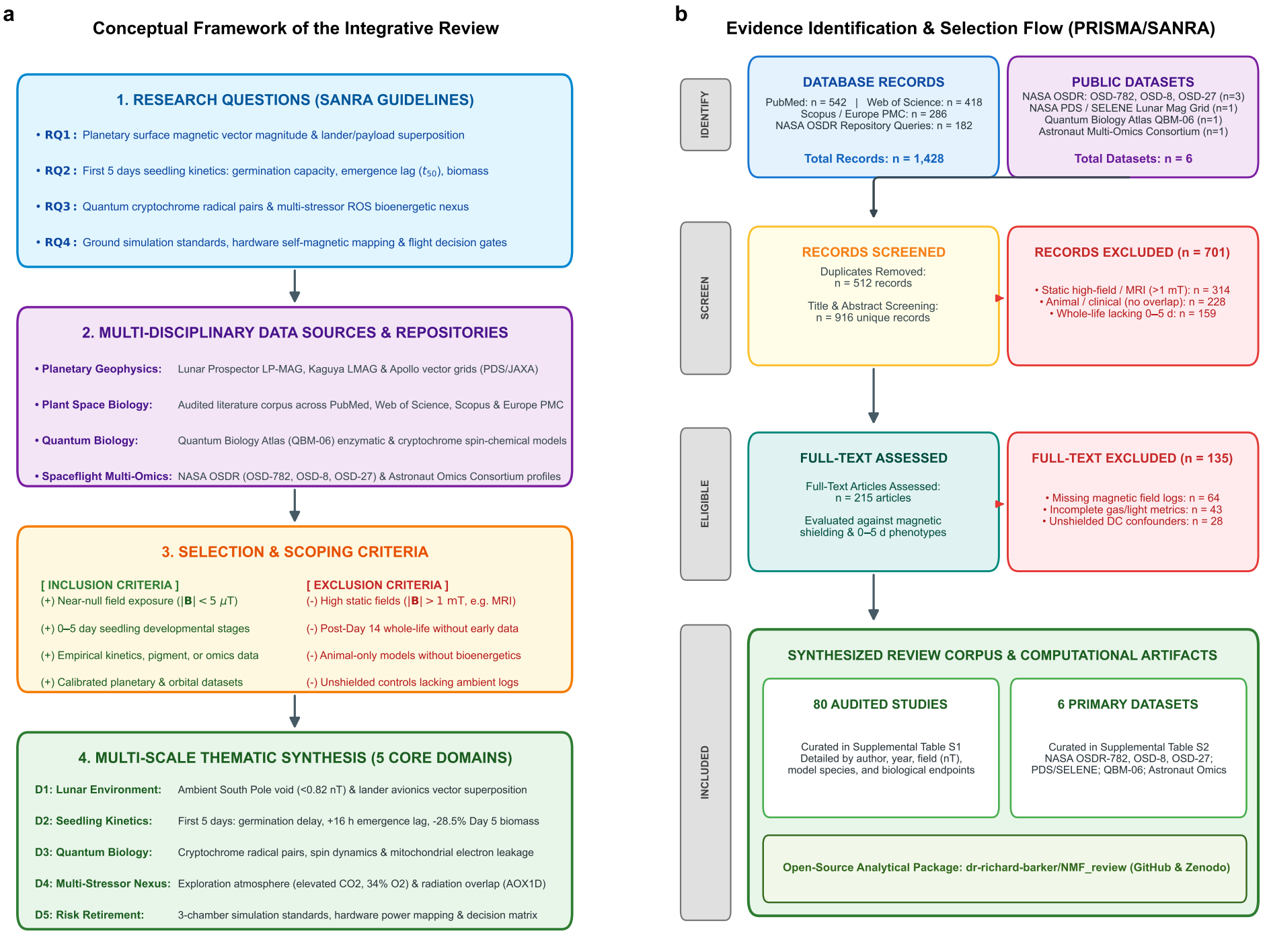

a
Conceptual Framework of the Integrative Review
1. RESEARCH QUESTIONS (SANRA GUIDELINES)
• RQ1 : Planetary surface magnetic vector magnitude & lander/payload superposition
• RQ2 : First 5 days seedling kinetics: germination capacity, emergence lag ($t_{50}$), biomass
• RQ3 : Quantum cryptochrome radical pairs & multi-stressor ROS bioenergetic nexus
• RQ4 : Ground simulation standards, hardware self-magnetic mapping & flight decision gates
2. MULTI-DISCIPLINARY DATA SOURCES & REPOSITORIES
• Planetary Geophysics: Lunar Prospector LP-MAG, Kaguya LMAG & Apollo vector grids (PDS/JAXA)
• Plant Space Biology: Audited literature corpus across PubMed, Web of Science, Scopus & Europe PMC
• Quantum Biology: Quantum Biology Atlas (QBM-06) enzymatic & cryptochrome spin-chemical models
• Spaceflight Multi-Omics: NASA OSDR (OSD-782, OSD-8, OSD-27) & Astronaut Omics Consortium profiles
3. SELECTION & SCOPING CRITERIA
[ INCLUSION CRITERIA ]
(+) Near-null field exposure (|B| < 5 μT)
(+) 0–5 day seedling developmental stages
(+) Empirical kinetics, pigment, or omics data
(+) Calibrated planetary & orbital datasets
[ EXCLUSION CRITERIA ]
(-) High static fields (|B| > 1 mT, e.g. MRI)
(-) Post-Day 14 whole-life without early data
(-) Animal-only models without bioenergetics
(-) Unshielded controls lacking ambient logs
4. MULTI-SCALE THEMATIC SYNTHESIS (5 CORE DOMAINS)
D1: Lunar Environment: Ambient South Pole void (<0.82 nT) & lander avionics vector superposition
D2: Seedling Kinetics: First 5 days: germination delay, +16 h emergence lag, -28.5% Day 5 biomass
D3: Quantum Biology: Cryptochrome radical pairs, spin dynamics & mitochondrial electron leakage
D4: Multi-Stressor Nexus: Exploration atmosphere (elevated CO2, 34% O2) & radiation overlap (AOX1D)
D5: Risk Retirement: 3-chamber simulation standards, hardware power mapping & decision matrix
b
Evidence Identification & Selection Flow (PRISMA/SANRA)
IDENTIFY
DATABASE RECORDS
PubMed: n = 542 | Web of Science: n = 418
Scopus / Europe PMC: n = 286
NASA OSDR Repository Queries: n = 182
Total Records: n = 1,428
PUBLIC DATASETS
NASA OSDR: OSD-782, OSD-8, OSD-27 (n=3)
NASA PDS / SELENE Lunar Mag Grid (n=1)
Quantum Biology Atlas QBM-06 (n=1)
Astronaut Multi-Omics Consortium (n=1)
Total Datasets: n = 6
SCREEN
RECORDS SCREENED
Duplicates Removed:
n = 512 records
Title & Abstract Screening:
n = 916 unique records
RECORDS EXCLUDED (n = 701)
• Static high-field / MRI (>1 mT): n = 314
• Animal / clinical (no overlap): n = 228
• Whole-life lacking 0–5 d: n = 159
ELIGIBLE
FULL-TEXT ASSESSED
Full-Text Articles Assessed:
n = 215 articles
Evaluated against magnetic
shielding & 0–5 d phenotypes
FULL-TEXT EXCLUDED (n = 135)
• Missing magnetic field logs: n = 64
• Incomplete gas/light metrics: n = 43
• Unshielded DC confounders: n = 28
INCLUDED
SYNTHESIZED REVIEW CORPUS & COMPUTATIONAL ARTIFACTS
80 AUDITED STUDIES
Curated in Supplemental Table S1
Detailed by author, year, field (nT),
model species, and biological endpoints
6 PRIMARY DATASETS
Curated in Supplemental Table S2
NASA OSDR-782, OSD-8, OSD-27;
PDS/SELENE; QBM-06; Astronaut Omics
Open-Source Analytical Package: dr-richard-barker/NMF_review (GitHub & Zenodo)