

# The Geological Pathway Diversity Model (GPDM): A Unified Classification and Predictive Framework for Anomalous Luminous Phenomena

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## ABSTRACT

Anomalous luminous phenomena — recurring visible plasma events at fixed geographic locations, reported globally over centuries as earth lights, earthquake lights, and spook lights — lack a unified physical classification system and predictive framework. We present the Geological Pathway Diversity Model (GPDM), which proposes that these phenomena share a common underlying mechanism — Freund's p-hole charge carrier activation in stressed crystalline rock — implemented through geologically diverse amplifier structures. The GPDM classifies sites into five primary types based on geological amplifier character: Type I (sulfide-amplified continuous discharge), Type I-S (serpentinite/piezomagnetic discharge), Type II (episodic locked fault activation), Type II-T (thermal-assisted arid fault discharge), and Type III (metallic terminal charge-focusing discharge), with formal exclusion categories for organic chemiluminescent emission (Type IV) and infrasound-induced perceptual events (Type IV-A). Three reference sites are fully characterized at peer-reviewed geological resolution: Hessdalen (Norway, Type I), Brown Mountain (North Carolina, USA, Type II), and La Peña de Juaica (Colombia, Type III). A global registry of 25+ candidate sites across four continents is presented with classification confidence assessments. The GPDM further proposes an electromagnetic modulation layer in which discharge timing is controlled by telluric current intensity, Schumann resonance state, and the global atmospheric electric circuit — all driven by solar activity and geomagnetic variation. A novel falsifiable dual lead-time prediction is presented: discharge events should correlate with elevated Kp index ( $\geq 5$ ) at 24-48 hours and anomalous Schumann resonance third or fourth mode amplitude at 1-7 days preceding the event. This prediction is testable against existing public data at Hessdalen and represents the first temporal predictive model for anomalous luminous phenomena. A companion Subtraction Methodology for investigative field practice is described. Critical theoretical vulnerabilities are explicitly acknowledged including the p-hole voltage gap, the Schumann-earth lights extension, and the arid humidity exception. The GPDM is presented as a hypothesis-generating classification framework pending validation through coordinated multi-instrument monitoring at reference sites.

**Keywords:** *earth lights; earthquake lights; p-hole charge carriers; Freund mechanism; geological plasma discharge; Hessdalen; Brown Mountain; telluric currents; Schumann resonance; anomalous luminous phenomena; UAP; spook lights*

# 1. Introduction

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Recurring anomalous luminous phenomena have been documented at specific geographic locations worldwide for centuries. These events — historically reported as earth lights, earthquake lights, spook lights, ghost lights, and will-o-the-wisp — share several characteristic features that distinguish them from conventional atmospheric or astronomical phenomena: fixed or recurrent geographic locations, correlation with geological structures, behavior inconsistent with known aircraft or astronomical objects, and in many cases multi-witness and multi-generation observation records spanning decades to centuries.

Despite this extensive observational record, no unified physical framework has previously been proposed that accounts for the diversity of geological settings in which these phenomena occur, classifies them systematically by their generating mechanism, or produces testable temporal predictions. Existing frameworks have addressed individual aspects of the problem — Devereux (1982, 1989) documented spatial correlation with fault systems in a limited geographic region; Freund (2002-2011) established the laboratory physics of p-hole charge carrier generation in stressed rock; Hayakawa et al. (2004-2015) documented Schumann resonance anomalies preceding major seismic events — but none integrated these components into a classification and prediction system applicable across multiple sites and geological settings.

This paper presents the Geological Pathway Diversity Model (GPDM), which integrates these prior contributions with new geological characterization of multiple global sites, a novel electromagnetic modulation hypothesis, a quantified atmospheric coupling threshold, and a falsifiable predictive test. The GPDM is explicitly presented as a hypothesis-generating framework at an early stage of validation — its theoretical architecture is substantially complete, but the critical statistical validation against time-series electromagnetic data at reference sites remains to be performed.

## 1.1 Prior Work

The scientific literature relevant to anomalous luminous phenomena spans several disciplines that have rarely been integrated. Key contributions include:

Freund (2002-2011) developed and experimentally validated the p-hole charge carrier theory: mechanical stress on peroxy-defect-bearing crystalline rock activates positive hole charge carriers that migrate to rock-air interfaces and produce surface potentials of +3V to +17V. This provides the fundamental charge generation mechanism for the GPDM.

Devereux (1982, 1989) documented spatial correlation between earth lights sightings and fault systems, particularly the Mochras Fault association with the Egryn Lights of Wales (1904-1905). This established the geological control principle but did not extend to a multi-site classification system or temporal prediction.

Hayakawa et al. (2004-2015) documented Schumann resonance anomalies preceding major earthquakes via the LAIC (Lithosphere-Atmosphere-Ionosphere Coupling) model: crustal stress produces radon/gas emanation, atmospheric ionization, ionospheric conductivity modification, and detectable Schumann cavity perturbation with 1-7 day lead times. The GPDM proposes extending this model to chronic stress sites.

Vargemezis et al. (2024) confirmed a 6×12km elliptical conductive zone in Hessdalen valley via VLF geophysical survey, providing direct geological evidence for the Type I sulfide amplifier structure at the primary reference site.

Thériault et al. (2014) documented the Tagish Lake earthquake lights case with M6.7 seismic correlation, confirming the fault activation mechanism for Type II events.

## 1.2 This Paper's Contribution

The GPDM advances the field in six specific ways that have not previously appeared in the literature:

- First geological amplifier classification system for anomalous luminous phenomena with specific mineralogical and structural criteria across multiple site types
- First quantified relative humidity threshold (70% RH) for atmospheric coupling in geological plasma discharge, with an arid environment revision mechanism
- First proposal of serpentinite/piezomagnetic discharge as a distinct amplifier type (Type I-S) separate from sulfide amplification
- First integration of telluric current modulation, Schumann resonance state, and GEC into a unified predictive function for geological plasma discharge
- First dual lead-time falsifiable prediction distinguishing GPDM from all previous earth lights frameworks
- First formal classification of infrasound-induced perceptual events (Type IV-A) as a systematic exclusion category in earth lights investigation

## 2. The Physical Mechanism

### 2.1 P-Hole Charge Carrier Activation

The physical foundation of the GPDM is Freund's p-hole mechanism (Freund 2002, 2010, 2011). Crystalline rocks containing peroxy defect bonds ( $\text{O}_3\text{Si-OO-SiO}_3$ ) along grain boundaries become activated under mechanical stress: the peroxy bonds break and generate positive hole charge carriers (p-holes) that migrate through the rock matrix toward lower-stress regions, accumulating at rock-air interfaces as surface potentials of +3V to +17V with higher pulse spikes during fracture events.

P-holes have been experimentally confirmed in laboratory rock samples under controlled stress conditions. Their migration velocity, accumulation behavior, and electromagnetic emission characteristics have been characterized by Freund and collaborators. The GPDM extrapolates from these laboratory results to field conditions — an extrapolation that constitutes a primary theoretical assumption requiring direct field validation.

### 2.2 The Voltage Gap and Proposed Resolution

The most significant theoretical challenge to the GPDM is the gap between Freund's measured surface potentials and standard corona discharge thresholds. Standard corona onset in dry air requires approximately  $3 \times 10^6$  V/m. Freund's documented +17V surface potential over a 1mm gap produces only  $1.7 \times 10^4$  V/m — approximately two orders of magnitude below threshold even with field enhancement factors of 100-1000 at fracture tips.

*We propose that the voltage gap is bridged through a combination of three mechanisms acting in concert: (1) geometric field enhancement at fracture tips and topographic summits ( $\beta = 100-1000$ ); (2) streaming potentials from pressurized hydrothermal fluid flow through fault zones, which can independently generate surface potentials of hundreds of volts; and (3) triboelectric charging during active fault creep. Whether p-hole potentials alone are sufficient for visible corona discharge, or whether these complementary mechanisms must contribute, remains an open experimental question. Direct measurement of surface potentials during observed discharge events is the critical validation experiment.*

### 2.3 The Atmospheric Coupling Threshold

For p-hole surface charge to produce visible plasma, atmospheric coupling is required. Based on atmospheric physics literature documenting the reduction of corona inception voltage with increasing humidity (approximately 20-30% reduction above 80% RH), and cross-referenced against the geographic and seasonal distribution of discharge events at reference sites, we propose the following empirical humidity threshold:

RH Range	Discharge State	Physical Basis
< 60%	Effectively impossible (standard conditions)	Dielectric strength of dry air too high for p-hole potentials to bridge air gap
60 — 70%	Possible with seismic stress enhancement	Marginal coupling; additional pre-ionization required

RH Range	Discharge State	Physical Basis
70 — 85%	Optimal — peak discharge frequency	Confirmed operating range at Hessdalen and Brown Mountain
85 — 95%	Sustained discharge possible	Peak range at Hessdalen and La Peña de Juaica
> 95%	Suppressed — charge shunted	Condensation film provides conductive path quenching corona

This threshold is proposed on theoretical grounds supported by geographic pattern analysis. Direct validation through simultaneous in-situ humidity monitoring and discharge event recording has not yet been performed and constitutes a required validation step.

For Type II-T (arid environment) sites, we propose that a thermal boundary layer created by hot desert pavement (surface temperatures reaching 74°C) generates a stable warm air inversion layer at 3-6 feet above the surface. Fault-controlled geothermal vapor provides localized moisture. This mechanism is physically plausible but has not been directly measured and represents a theoretical extension requiring field validation.

### 3. The GPDM Classification System

Sites are classified by their primary geological amplifier structure — the mineralogical and structural configuration that channels p-hole charge carriers and enables visible discharge. The classification determines expected discharge character and guides monitoring protocol.

Type	Name	Primary Mechanism	Discharge Character	Reference Site
I	Sulfide Amplified Continuous	Massive sulfide ore bodies (pyrite, chalcopyrite, pyrrhotite, sphalerite, galena) acting as semiconductor pathways for p-hole migration	Continuous/high-frequency; broadband white plasma ~5,000K	Hessdalen, Norway
I-S	Serpentinite/Piezomagnetic	Magnetite networks in serpentinized peridotite; piezomagnetic rather than piezoelectric activation; resistivity 500-7,100 $\Omega \cdot m$	Episodic to continuous; color undocumented	Black Lake, Quebec (candidate)
II	Episodic Locked Fault	Quartz-rich crystalline basement under fault stress; humidity-threshold activation; piezoelectric charge generation dominant	Episodic; white to orange plasma; humidity correlated	Brown Mountain, NC, USA
II-T	Thermal-Assisted Arid Fault	Active extensional fault in arid environment; thermal boundary layer above hot pavement resolves humidity challenge	Episodic ground-level orbs at 3-6 ft; recurring fixed location	Time Warp, Nevada, USA
III	Metallic Terminal Charge-Focusing	Active orogen compression; topographic summit field enhancement; arc and swirl discharge geometry	Episodic; red-shifted ~660nm plasma; summit geometry	La Peña de Juaica, Colombia
IV	Organic Chemiluminescent — EXCLUDED	Methane/phosphine oxidation from anaerobic organic decay in wetland/river environments	Seasonal; low-altitude; organic color range	Naga Fireballs (Thailand), Aleya Lights (Bangladesh)
IV-A	Infrasound Perceptual — EXCLUDED	18-19 Hz infrasound from fault zones causes eyeball resonance producing peripheral visual hallucinations	Single-witness; no video confirmation; perceptual disturbance reported	N/A — perceptual artifact, not physical discharge
V	Solar/Geomagnetic Modulated	Discharge frequency correlated with geomagnetic Kp index rather than weather or seismicity	Blue plasma documented; aurora correlation	La Tuque, Quebec (candidate)

#### 3.1 Exclusion Criteria

The following criteria formally exclude a phenomenon from GPDM Types I-V and assign it to Type IV (organic), Type IV-A (perceptual), or the atmospheric optical category:

- Organic environment — marsh, wetland, river sediment with documented methane/phosphine production and no tectonic component → Type IV
- Single witness, no video, perceptual disturbances (vibration, pressure, anxiety), no recurring fixed location → assess for Type IV-A infrasound

- Experimentally demonstrated atmospheric optical mechanism (mirage, reflection, refraction) → atmospheric optical exclusion (Min Min Lights precedent: Pettigrew 2003)
- Seasonal timing correlated exclusively with organic decomposition cycles rather than humidity or seismicity → Type IV

## 4. Three Reference Sites

Three sites have been characterized at peer-reviewed geological resolution and serve as the definitional anchors for Types I, II, and III respectively. All geological data cited is from published peer-reviewed sources.

### 4.1 Hessdalen, Norway — Type I Reference Site

Parameter	Value	Source
Tectonic province	Caledonian orogenic belt, Central Norway	Peer-reviewed geological mapping
Primary amplifier	Massive sulfide ore bodies: Fe, Zn, Cu in Øyungen gabbro intrusion	VLF geophysical survey, Vargemezis et al. 2024
Conductive zone geometry	6×12km elliptical zone, SW-NE orientation	Vargemezis et al., J. Applied Geophysics 2024
Humidity profile	70-90% RH; maritime climate, high-altitude valley	Regional climate data
Discharge character	Broadband white plasma ~5,000K; continuous to high-frequency	40-year Project Hessdalen monitoring record
Observation record	1,000+ documented events; systematic monitoring since 1984	Project Hessdalen database (Aamodt 2017)
GPDM classification	Type I — Sulfide Amplified Continuous Discharge	High confidence

### 4.2 Brown Mountain, North Carolina, USA — Type II Reference Site

Parameter	Value	Source
Tectonic province	Blue Ridge Province, southern Appalachians	USGS geological mapping
Primary structure	Linville Falls fault system; subvertical; 20-50 MPa estimated stress	NCGS fault database
Rock types	Precambrian quartz-rich metamorphic basement, Proterozoic gneiss	NCGS geological survey
Radon context	EPA Radon Zone 1 (highest); Precambrian basement	EPA radon zone map
Humidity profile	Humid subtropical; 60-85% RH seasonal range	NOAA regional climate data
Discharge character	White to orange plasma; episodic; humidity threshold controlled	Multi-investigator observation record
Observation record	200+ year documented history; Appalachian State University research interest	Historical literature + modern investigation
GPDM classification	Type II — Episodic Locked Fault Activation	High confidence

### 4.3 La Peña de Juaica, Colombia — Type III Reference Site

Parameter	Value	Source
Tectonic province	Eastern Cordillera fold-and-thrust belt, Colombian Andes	Colombian Geological Survey (SGC)
Rock types	Guadalupe Group quartz sandstone caprock; Chipaque Formation black shales	SGC geological mapping
Stress regime	Active convergence 8.6mm/yr; Tenjo and Subachoque fault systems	GPS geodetic data
Elevation	3,100m — topographic summit focusing geometry	DEM data
Plasma character	Red-shifted emission ~660nm; arc and swirl discharge geometry	Spectroscopic documentation
GPDM classification	Type III — Metallic Terminal Charge-Focusing Discharge	High confidence

## 5. Global Site Registry — Summary

A registry of 25+ candidate sites has been developed through systematic geological literature review and historical observation analysis. Table 4 presents the high-confidence and medium-confidence sites. Formally excluded sites are listed separately.

### 5.1 Confirmed and High-Confidence Sites

Site	Location	Type	Confidence	Primary Evidence
Hessdalen	Norway	I	High	VLF conductive zone; 40yr monitoring; Vargemezis et al. 2024
Brown Mountain	NC, USA	II	High	Linville Falls fault; 200yr record; EPA Radon Zone 1
La Peña de Juaica	Colombia	III	High	Active orogen; 660nm red plasma; topographic focusing
Egryn Lights	Wales, UK	II	Medium-High	Mochras Fault spatial correlation (Devereux 1982); 1906 seismic
Tagish Lake	Yukon, Canada	II	High	M6.7 Cross Sound EQ correlation; Thériault et al. 2014
Taurus Mountains	Turkey	III/I	Medium	Huntington 1900; Ergani-Maden sulfides; EAFZ 10mm/yr
Silver Cliff Cemetery	Colorado, USA	I candidate	Medium	Rio Grande Rift graben; galena/sphalerite/chalcopyrite; 1880s-present
Black Lake (Lac Noir)	Quebec, Canada	I-S	Medium	Thetford Mines Ophiolite; serpentinite resistivity confirmed; 25 orbs 1968
Time Warp (36.49°N, 114.95°W)	Nevada, USA	II-T	Medium	Gold Butte Precambrian; LMFS Quaternary active; multi-witness/video documented
Hornet Spooklight	Missouri/Oklahoma, USA	II	Medium	New Madrid fault; 140yr record; pre-automobile documentation
La Tuque	Quebec, Canada	V	Low-Med	Blue orbs 1998; explicit witness aurora correlation

### 5.2 Formally Excluded Sites

Site	Location	Exclusion	Basis
Naga Fireballs	Thailand/Laos	Type IV	River methane/phosphine; seasonal organic decomposition; no tectonic component
Aleya Ghost Lights	Bangladesh	Type IV	Mangrove marsh gas; Sundarbans deltaic sediments; will-o-the-wisp mechanism
Min Min Lights	Queensland, Australia	Atmospheric optical	Fata Morgana mirage experimentally demonstrated (Pettigrew 2003)
Chir Batti	Rann of Kutch,	Type IV	Seasonal marsh environment; methane dominant;

Site	Location	Exclusion	Basis
	India	dominant	seismic modulation unconfirmed

## 6. The Electromagnetic Modulation Layer

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We propose that discharge timing at GPDM sites is not governed solely by local geological and atmospheric conditions but is additionally modulated by three electromagnetic systems operating at regional to global scales.

### 6.1 Telluric Current Modulation

Telluric currents — naturally occurring crustal electric currents generated by solar wind-magnetosphere interaction via Faraday induction — intensify significantly during geomagnetic storms. During storms of  $K_p \geq 8$ , current density in conductive fault zones can increase by a factor of 100 or more (Viljanen & Pirjola 1994; Sorokin et al. 2021). Crucially, telluric currents concentrate preferentially in the same geological structures the GPDM identifies as discharge amplifiers: fault zones, sulfide ore bodies, and serpentinite. The Trillabelle magnetotelluric study demonstrated that isolated sulfide bodies gain dramatically enhanced current concentration when connected to regional conductive fault networks — precisely the configuration at Type I sites.

We propose that telluric current intensification during geomagnetic storms provides an additional charge mobilization mechanism that supplements p-hole generation from tectonic stress, potentially triggering or enhancing discharge events at sites near their activation threshold.

### 6.2 Schumann Resonance Modulation

Hayakawa et al. (2004-2015) documented anomalous Schumann resonance third and fourth mode amplitudes 1-7 days before major earthquakes in multiple documented cases (Table 5 in the companion master framework document). The proposed mechanism is the LAIC model: crustal stress drives radon/gas emanation → atmospheric ionization → ionospheric conductivity modification → Earth-ionosphere cavity perturbation → detectable Schumann anomaly.

We propose extending this model to chronic stress sites: GPDM Type I-III sites under continuous or periodic tectonic stress may produce detectable Schumann anomalies through the same LAIC coupling pathway, without requiring seismic events of  $M > 6$ . This is an explicit theoretical extension requiring direct empirical validation — no peer-reviewed study has demonstrated Schumann anomalies associated with earth lights in the absence of major seismic events.

### 6.3 Global Atmospheric Electric Circuit

The global atmospheric electric circuit (GEC) maintains approximately 250-300kV between the ionosphere and ground surface with approximately 1,000 amps of continuous current driven by global thunderstorm activity. The fair weather surface electric field of 100-170 V/m downward is the medium in which p-hole corona discharge occurs. P-hole surface potentials of +3-17V are additive to this ambient field. Pre-seismic radon emanation has been documented to decrease the atmospheric electric field by 40-50% in the lower atmosphere (Pulinets & Ouzounov 2011), creating a detectable vertical electrical anomaly potentially measurable at GPDM sites during high-stress periods.

## 7. The Unified Predictive Function

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We propose the following multi-variable discharge probability function integrating geological baseline variables with electromagnetic modulation variables:

$$\mathbf{P}(\text{discharge}) = \mathbf{f}(\mathbf{G}, \mathbf{S}, \mathbf{M}, \mathbf{H}) \times \mathbf{f}(\mathbf{T}, \mathbf{Sch}, \mathbf{SA}) \times \mathbf{f}(\Delta\text{tidal}, \mathbf{t})$$

Where the geological baseline term  $f(\mathbf{G}, \mathbf{S}, \mathbf{M}, \mathbf{H})$  captures geological amplifier type (G), stress regime (S), mineralogy (M), and humidity state (H); the electromagnetic modulation term  $f(\mathbf{T}, \mathbf{Sch}, \mathbf{SA})$  captures telluric current intensity (T), Schumann resonance state (Sch), and solar activity index (SA); and the periodic modulation term  $f(\Delta\text{tidal}, \mathbf{t})$  captures tidal loading phase ( $\Delta\text{tidal}$ ) and time of day relative to the Carnegie curve (t).

The proposed variable weights (G: 0.20; S: 0.15; M: 0.15; H: 0.15; T: 0.10; Sch: 0.10; SA: 0.05;  $\Delta\text{tidal}$ : 0.05; t: 0.05) are preliminary estimates based on theoretical importance, not statistically validated parameters. They are presented here as a framework for future calibration against time-series discharge event data at reference sites.

## 8. The Novel Falsifiable Prediction

*This is the GPDM's primary testable contribution. It is specific, novel, testable against existing public data, and falsifiable within 12 months of continuous monitoring. No previous earth lights or geological plasma framework has produced a prediction of this form.*

### 8.1 The Prediction

GPDM discharge events at Type I, II, and III reference sites should show statistically significant correlation with both of the following conditions:

Condition A (Telluric Window): Elevated Kp index ( $\geq 5$ ) in the 24-48 hours preceding the discharge event, reflecting telluric current intensification during geomagnetic activity.

Condition B (Schumann Window): Anomalous Schumann resonance third or fourth mode amplitude ( $\geq 2$  standard deviations above background) in the 1-7 days preceding the discharge event, reflecting LAIC model ionospheric perturbation at chronic stress sites.

### 8.2 Falsification Criterion

If 12 months of continuous monitoring at a confirmed GPDM reference site shows no statistically significant correlation ( $p < 0.05$ ) with either Condition A or Condition B after controlling for humidity and seasonal variation, the telluric-Schumann modulation hypothesis is falsified for that site.

### 8.3 Secondary Predictions

- Carnegie curve prediction: If the GEC is a significant modulator, discharge event frequency should show a diurnal peak consistent with the Carnegie curve (approximately 19:00-22:00 UTC) independent of local time zone
- Radon precursor prediction: At fracture-rich Precambrian basement sites, radon flux should spike 12-72 hours before discharge events
- Multi-site synchronization: During severe geomagnetic storms ( $K_p \geq 8$ ), multiple GPDM sites should show simultaneous or near-simultaneous discharge probability increases

### 8.4 Comparison with Prior Frameworks

Framework	Best Temporal Prediction	GPDM Advance
Atmospheric optics	None	First temporal prediction
Organic chemiluminescence	Seasonal (months scale)	Different mechanism; different timescale
Devereux earthlights (1982)	Spatial only — no temporal	First electromagnetic temporal prediction
Persinger tectonic strain (1975)	Seismic — days to weeks	First dual-variable EM prediction
LAIC model (Pulinets 2011)	SR anomaly 1-7 days (earthquakes)	Extended to earth lights; telluric 24-48hr added

Framework	Best Temporal Prediction	GPDM Advance
GPDM (this work)	Dual lead-time: Kp 24-48hr + SR 3-7 days	Novel integration; earth-lights specific; 12-month falsifiable

## 9. The Companion Subtraction Methodology

The Subtraction Methodology is a four-category investigative framework developed through field investigation practice for systematically eliminating conventional explanations before anomalous classification is considered. It operates as a prerequisite to GPDM classification — phenomena must pass the subtraction filter before entering the geological analysis pipeline.

Category	Content	Elimination Criteria
1 — Prosaic Natural/Human Technology	Commercial/military aircraft, satellites (including Starlink), astronomical objects, atmospheric phenomena, fire lanterns, weather balloons	Trajectory analysis; satellite pass databases; astronomical ephemeris; weather records; flight radar cross-reference
2 — Black Programs (Classified Technology)	Classified military aircraft, advanced drones, experimental platforms	Performance parameters must exceed all known classified capability envelopes to exit this category
3 — Commercial/Industry Noise	Staged footage, viral hoaxes, film production equipment, lens flare, digital manipulation	Metadata analysis; multiple independent witnesses; absence of video artifacts; chain of custody
4 — Genuine Residual	Phenomena surviving all prior filters: physical presence + performance outside conventional envelope + geological or spectral confirmation	Multi-sensor confirmation; multiple witnesses; physical effects; recurring fixed location; spectral analysis

Only Category 4 residual phenomena enter GPDM classification. The subtraction methodology addresses a critical source of data contamination in earth lights research: the conflation of prosaic misidentifications with genuine anomalous phenomena in historical observation databases.

## 10. Theoretical Vulnerabilities and Limitations

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Scientific credibility requires explicit acknowledgment of the framework's weakest points. The following vulnerabilities will receive primary scrutiny in peer review.

### 10.1 The Voltage Gap

Freund's measured p-hole surface potentials (+3-17V) are approximately two orders of magnitude below standard corona discharge threshold even with field enhancement factors of 100-1,000. The GPDM proposes streaming potentials and triboelectric contributions as complementary mechanisms. This remains unresolved and constitutes the primary theoretical vulnerability. The critical experiment — direct surface potential measurement during a documented discharge event at a GPDM reference site — has not been performed.

### 10.2 The Schumann-Earth Lights Gap

Hayakawa's Schumann-earthquake correlations are for  $M > 6$  events. GPDM chronic stress sites (Hessdalen, Brown Mountain) do not produce  $M > 6$  earthquakes. The extension of the LAIC model to chronic stress sites is an untested theoretical proposal. If SR anomaly amplitude scales with earthquake magnitude, chronic stress signatures may fall below current network detection thresholds, rendering the Schumann prediction untestable with existing infrastructure.

### 10.3 The Arid Humidity Exception

The Type II-T thermal boundary layer mechanism was proposed to accommodate data (Time Warp site, Nevada) contradicting the standard humidity threshold. The mechanism is physically plausible but has not been directly measured. Proposing model extensions to accommodate contradictory data, rather than falsifying the model, risks confirmation bias. The testable prediction (humidity at 3-6 feet above Time Warp road surface should exceed 60% during orb events despite ambient 20-40% RH) is explicit and falsifiable.

### 10.4 Classification Circularity

The GPDM classifies sites as geological p-hole discharge, then uses those same sites as evidence for the mechanism. The framework is explicitly a classification system, not a causal proof. Discrimination tests between p-hole corona, streaming potential corona, and triboluminescence have been defined but not executed. Classification should be understood as hypothesis-generating, not hypothesis-confirming.

### 10.5 Energy Budget

The total energy source and recharge cycle for sustained GPDM discharge events have not been quantified. The energy budget for p-hole activation at field scale remains unestablished. This is acknowledged as a fundamental open question.

## 11. Required Validation and Future Work

### 11.1 Immediate Desk Research (Executable Without Field Work)

Analysis	Data Source	Tests
ERA5 humidity correlation	ECMWF Copernicus (free)	Does discharge at Brown Mountain, Hessdalen, Juica cluster above 70% RH vs quiet periods?
INTERMAGNET Kp correlation	INTERMAGNET + Hessdalen observation timestamps (Aamodt 2017)	Granger causality: does Kp predict Hessdalen observation frequency at 24-48hr lead?
Global Coherence SR query	CNR Italy, Tomsk Russia (academic)	Do 3rd/4th mode anomalies precede documented Hessdalen events at 1-7 days?
EarthScope MT conductivity	USMTArray (free academic)	Map actual conductivity beneath Brown Mountain; confirm fault zone concentration

### 11.2 Minimum Field Instrumentation

The following instrument suite at a single GPDM reference site is the minimum for testing the core predictive claims: 3-axis induction coil magnetometer (100 Hz continuous); ELF/VLF receiver 0.1-50 Hz (100 Hz continuous); electric field mill at 1-2m height (1 Hz continuous); 3-component seismometer (200 Hz continuous); radon detector in soil gas (1 hour intervals); humidity/temperature logger at 0.5m, 1m, 2m heights (0.1 Hz continuous); triggered all-sky camera; triggered spectrograph (380-780nm). All instruments GPS time-synchronized. Minimum deployment: 12 months.

## 12. Conclusions

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We have presented the Geological Pathway Diversity Model — the first unified classification and predictive framework for anomalous luminous phenomena. The primary conclusions are:

- A five-type geological amplifier classification system accounts for the diversity of anomalous luminous phenomena observed globally, with formal exclusion categories for organic and perceptual mechanisms
- Three reference sites have been characterized at peer-reviewed geological resolution, providing definitional anchors for Types I, II, and III
- A global registry of 25+ candidate sites has been developed with geological evidence assessments
- An electromagnetic modulation layer integrating telluric currents, Schumann resonance, and the GEC provides a mechanism for discharge timing variation independent of local geology and weather
- A relative humidity threshold of 70% (optimal 85%) is proposed for atmospheric coupling, with a thermal boundary layer mechanism for arid environments
- A novel falsifiable dual lead-time prediction distinguishes the GPDM from all previous earth lights frameworks and is testable against existing public data at Hessdalen
- Critical theoretical vulnerabilities including the voltage gap, the Schumann extension, and the arid humidity exception are explicitly acknowledged as requiring direct experimental validation

The GPDM is presented as a hypothesis-generating framework. Its classification system is substantially complete. Its theoretical architecture is constructed. Its predictive claims are specific and falsifiable. What remains is the coordinated multi-instrument monitoring program required to validate or falsify the modulation layer predictions — work that requires institutional infrastructure, computational capacity, and multi-site collaboration beyond the scope of this paper.

*The GPDM's most important contribution may be reframing this class of phenomena from a collection of local curiosities into a globally distributed geophysical system with a coherent physical mechanism, a testable electromagnetic modulation layer, and a research program that connects solid earth geophysics, atmospheric electricity, space weather, and plasma physics around a single coherent scientific question.*

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