Whitepaper v1.1

ARBE λ* as an Additional Structural Diagnostic Layer for Optically Brightened Papers under M1/M2 Measurement Conditions

Final English Version — Atlas-Bound Methodological Whitepaper

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Executive Summary

For Management and Decision Makers

In modern graphic arts, proofing and print quality control, substrates containing Optical Brightening Agents (OBAs) remain a persistent measurement and evaluation challenge. Established colourimetric workflows rely heavily on colour-difference metrics such as ΔE and ΔE00 to quantify colourimetric proximity. These metrics are valuable and widely used, but they do not describe the underlying spectral-energetic structure of a substrate.

This whitepaper positions ARBE λ* as an atlas-bound additional structural diagnostic layer. It is not proposed as a replacement for ISO 13655, FOGRA/ECI characterization data, ICC workflows, CIEDE2000 or visual assessment procedures. ISO/CIE 11664-6:2022 specifies the method of calculating colour differences according to the CIEDE2000 formula and defines its CIELAB input context and application boundaries.

> *ΔE describes colourimetric proximity. ARBE λ* can describe atlas-bound structural drift, provided that master, probe and measurement condition belong to a defined comparison class.*

For optically brightened papers, this distinction is relevant because M1 and M2 can reveal different aspects of UV/OBA response. Fogra's D50noUV project addresses the problem that UV-free LED environments can reduce stimulation of fluorescent materials, including many graphic papers with optical brighteners, causing them to appear different indoors than specified under D50-based workflows.

ARBE does not solve the OBA problem. It makes OBA-sensitive structural differences more explicit, measurable and reportable within an atlas-bound master/probe framework.

1. Background: OBA Papers and Measurement Conditions

Optically brightened papers are difficult to evaluate because their appearance is not determined by passive spectral reflection alone. Optical Brightening Agents can react to UV components in measurement or viewing light, changing the apparent paper white and the resulting colour evaluation.

In graphic arts, measurement conditions such as M0, M1, M2 and M3 are part of the ISO 13655 measurement framework. ISO 13655 specifies procedures for measurements and colourimetric computations appropriate to graphic arts objects that reflect, transmit or emit light.

For OBA-containing substrates, M1 and M2 are especially important. ECI describes M1 as a measurement mode in which the lighting simulates D50 with UV content and notes that M1-supporting measurement devices are required for metered quality control of proof and production printing on optically brightened papers.

In practical workflows, an OBA-containing substrate may produce different measured or interpreted results under M1 and M2. This difference should not automatically be interpreted as instrument failure. It may reflect the substrate's UV/OBA response.

Current print and proof workflows already account for these issues. ECI identifies FOGRA51 as PSO Coated v3 for premium coated paper and FOGRA52 as PSO Uncoated v3 for wood-free uncoated white paper, and states that improvements for dealing with optically brightened paper were central to these developments.

2. Limitation of ΔE-Based Evaluation

The colourimetric metric ΔE, including ΔE00, remains an established and widely used tool for evaluating colour tolerance. ISO/CIE 11664-6:2022 specifies the CIEDE2000 calculation method and applies it to CIELAB L*, a*, b* input values calculated according to ISO/CIE 11664-4.

ΔE answers the operational question:

> *How large is the colourimetric distance between two samples?*

It does not fully answer:

```
Why does this difference occur?
Is the underlying spectral-energetic structure stable?
Will the pair behave consistently under a change of illumination?
```

Within ARBE/HLC reasoning, this distinction is essential. ΔE00 describes proximity, but not spectral structure. A small ΔE00 value alone does not prove spectral identity, metameric safety or structural stability. The internal ARBE draft frames this limitation as the reason for separating colourimetric distance from structural drift.

3. Positioning of ARBE λ*

ARBE λ* is not a new normative colour standard. It is not a replacement for ISO 13655, ISO/CIE 11664-6, FOGRA/ECI characterization data, ICC profiles, CIEDE2000 or visual inspection.

The correct positioning is:

> *ARBE λ* is an atlas-bound structural diagnostic layer.*

Within the HLC Colour Atlas / ARBE framework, primary colour identity is exclusively governed by a verified atlas reference:

```
Hxxx_Lxxx_Cxxx
```

All other values are attributes. This includes:

```
λ*_EE
λ*_V2
Δλ*
ΔΔλ*
Lab
XYZ
ΔE00
spectral notes
metameric risk notes
```

These attributes may describe structure, drift or colourimetric relation, but they do not replace the atlas identity. Without a verified valid atlas reference, no atlas-bound ARBE single-colour analysis can be executed.

4. Master Types and Comparison Classes

The interpretation of ΔΔλ* depends on the physical nature of the master. A strict distinction is required between two comparison classes.

4.1 Class 1: Process Drift Mode — Physical Master vs. Physical Probe

In Class 1, the master is a physical approved reference: for example, a signed-off press proof or production master measured on the same substrate family under the same documented measurement condition as the probe.

```
Physical M1 master ↔️ Physical M1 probe
Physical M2 master ↔️ Physical M2 probe
```

In this mode, substrate-specific effects are represented in the master state and may partly cancel in differential comparison, provided that substrate family, measurement condition, instrument state and geometry remain stable.

Here, ΔΔλ* can be interpreted as a process-drift indicator. It may indicate changes such as:

- ink film thickness variation
- paper batch shift
- OBA response change
- instrument or calibration deviation
- coating or substrate variation

It does not identify the cause by itself.

4.2 Class 2: Reference Offset Mode — Digital Atlas Master vs. Physical OBA Probe

In Class 2, the master is a digital atlas reference bound to a verified Hxxx_Lxxx_Cxxx identifier. The probe is a physical sample, possibly on an OBA-containing substrate.

In this mode, a large ΔΔλ* value is not automatically a production error. It may indicate that the physical substrate is structurally offset from the selected atlas reference family.

```
Class 2 flags are diagnostic.
They are not automatic production release or rejection decisions.
```

A BLOCK flag in Class 2 means:

```
out-of-reference-family / diagnostic marker
```

It does not mean automatic production stop.

5. M1/M2/M3 Measurement Logic

For OBA diagnostics, M1 and M2 must be treated as separate, unmixed tracks.

```
ARBE-M1 track:
λ*_EE(M1)
λ*_V2(M1)
Δλ*(M1)
ΔΔλ*(M1)

ARBE-M2 track:
λ*_EE(M2)
λ*_V2(M2)
Δλ*(M2)
ΔΔλ*(M2)
```

The operational rule is:

```
Compare M1 master strictly against M1 probe.
Compare M2 master strictly against M2 probe.
Do not silently compare M1 data against M2 data.
```

The difference between an M1 track and an M2 track should not be interpreted as “better” or “worse” colour. It is a structural diagnostic contrast that may indicate UV/OBA sensitivity.

Role of M3

For OBA diagnostics, the primary contrast is M1 versus M2. M3 may be useful for surface and gloss control because of polarization, but it should not be treated as an OBA-removal condition. Polarization may reduce specular surface effects, but it does not automatically eliminate internal fluorescence caused by OBA excitation.

6. ARBE Structural Attributes

ARBE λ* introduces a structured layer of spectral-energetic attributes beneath conventional colourimetric evaluation.

Attribute	Role
λ*_EE	Equal-energy centroid of the measured or atlas-bound spectral structure
λ*_V2	Brent-solved energetic balance point
Δλ*	Internal spacing between λ*_V2 and λ*_EE
ΔΔλ*	Drift indicator between probe and master
Status flag	QC classification derived from ΔΔλ*

The formal relationship is:

```
Δλ* = λ*_V2 − λ*_EE
ΔΔλ* = Δλ*(probe) − Δλ*(master)
```

This allows a QC system to ask:

> *Is the sample merely colourimetrically close, or has its spectral-energetic structure drifted relative to the master?*

The answer remains diagnostic unless the comparison class, master type, atlas validity and measurement condition are all valid.

7. QC Interpretation, Tolerance Classes and Operational Guidance

The numerical thresholds apply to |ΔΔλ*|, not to the absolute master value.

|ΔΔλ*|	QC flag	Class 1: Process Drift Mode	Class 2: Reference Offset Mode
≤ 5 nm	STABLE	Process stable; release may be permissible under routine QC	Minimal structural variance to reference family
≤ 10 nm	WATCH	Increase monitoring; verify process and instrument state	Measurable material/OBA-sensitive offset
≤ 20 nm	REVIEW	Audit process; inspect substrate, ink film, calibration and M1/M2 tracks	Pronounced structural offset; consider physical master creation
> 20 nm	BLOCK	Halt production release until reviewed	Out-of-reference-family diagnostic marker

> *In Class 2, the flag is diagnostic only. It must not be used as an automatic production release or rejection decision.*

Operational Guidance

STABLE

```
Class 1 → Continue production under routine monitoring.
Class 2 → Reference alignment is structurally close; no release decision implied.
```

WATCH

Class 1 → Increase sampling frequency and verify instrument/calibration state.
Class 2 → Record material/OBA sensitivity and review reference-family fit.

REVIEW

Class 1 → Stop automatic release; inspect substrate, ink film, calibration and M1/M2 tracks.
Class 2 → Treat as pronounced structural offset; consider creation of a physical master.

BLOCK

Class 1 → Halt production release until cause is reviewed.
Class 2 → Do not reject production automatically; classify as out-of-reference-family.

8. Reporting Model

A valid ARBE structural diagnostic report should include:

ARBE STRUCTURAL DIAGNOSTIC REPORT

[SUBSTRATE & METROLOGY METADATA]
Original Sample ID
Internal Sample ID
Job ID
Press ID
Paper Batch ID
Ink Batch ID
Paper / Substrate Family
Measurement Device
Calibration Profile
Optical Geometry
Master Measurement Condition: M0 / M1 / M2 / M3
Probe Measurement Condition: M0 / M1 / M2 / M3
Backing Material
Execution Date / Time
Operator ID

[ATLAS IDENTITY ANCHOR]
Atlas Reference ID: Hxxx_Lxxx_Cxxx
Atlas Validation Status: VERIFIED / INVALID / NOT_CHECKED
Atlas Master Version
Profile Reference

[COMPARISON MATRIX]
Comparison Class: CLASS_1_PROCESS_DRIFT / CLASS_2_REFERENCE_OFFSET
Master Configuration: DIGITAL_ATLAS / PHYSICAL_MASTER
Comparison Validity:
VALID / INVALID_CONDITION_MISMATCH / INVALID_ATLAS_ID / DIAGNOSTIC_ONLY

[SPECTRAL CONFIGURATION]
Raw Measurement Band: e.g. 360–780 nm
ARBE λ* Evaluation Band: 380–730 nm
Spectral Step: e.g. 10 nm
Solver Method for λ*_V2: BRENT
Solver Version
Solver Tolerance

[MASTER STATE]
λ*_EE(master)

```
λ*_V2(master)
Δλ*(master)

[PROBE STATE]
λ*_EE(probe)
λ*_V2(probe)
Δλ*(probe)

[DRIFT ANALYSIS]
ΔΔλ*
QC Status Flag: STABLE / WATCH / REVIEW / BLOCK
Structural Context:
PROCESS_DRIFT / STRUCTURAL_OFFSET / OUT_OF_REFERENCE_FAMILY

[AUXILIARY METRICS]
CIELAB
XYZ
ΔE00
Observer
Illuminant
M1 vs. M2 structural variance note
Visual assessment condition
Visual evaluation note
Metameric hazard warning
```

9. Practical Diagnostic Patterns

The following patterns are illustrative diagnostic patterns. They must not be read as proof of root cause without supporting spectral data, process metadata and measurement validation.

Pattern 1: Possible OBA-Sensitive Change

```
M1 track shows pronounced ΔΔλ* drift.
M2 track remains stable.
```

Possible interpretation:

```
The structure may have changed mainly in the UV/OBA-sensitive component.
```

This pattern may suggest changes in OBA response, UV excitation, substrate fluorescence behaviour or measurement condition. It does not prove one cause by itself.

Pattern 2: Possible Base Substrate or Process Shift

```
M1 track shows pronounced ΔΔλ* drift.
M2 track also shows pronounced ΔΔλ* drift.
```

Possible interpretation:

```
The change may not be limited to UV/OBA response.
```

This pattern may suggest base substrate shift, coating change, ink film variation, paper batch change or a broader process shift.

Pattern 3: Reference-Family Collision

```
Digital atlas master compared against physical OBA-heavy stock.
Large ΔΔλ* in Class 2.
```

Interpretation:

```
STRUCTURAL_OFFSET / OUT_OF_REFERENCE_FAMILY
```

This is a diagnostic marker, not an automatic line rejection.

Pattern 4: Measurement Condition Mismatch

```
M1 probe compared against M2 master.
```

Result:

```
comparison_validity = INVALID_CONDITION_MISMATCH
```

No valid drift status should be released until the measurement condition mismatch is corrected.

10. Boundaries and Non-Claims

ARBE λ* does not claim to determine the physical cause of a drift by itself.

An elevated or critical ΔΔλ* means:

```
The probe exhibits structural drift relative to the designated master.
```

It does not automatically prove:

- a change in OBA concentration
- a change in ambient light
- a change in device light source
- substrate ageing
- chemical yellowing
- instrument calibration drift
- sensor degradation

The cause must be investigated by combining:

- documented measurement condition
- direct spectral curve comparison
- M1/M2 diagnostic contrast
- instrument and calibration records
- substrate and batch metadata
- process data
- visual assessment under defined viewing conditions

The atlas boundary is absolute:

```
Without a verified valid Hxxx_Lxxx_Cxxx reference,
no atlas-bound ARBE single-colour analysis is possible.
```

Atlas-bound metrics must not be approximated, interpolated or generated from non-atlas data.

ARBE λ* is not intended to operate as an opaque black-box replacement for established colourimetry. Each valid result must report atlas identity, measurement condition, solver method, numerical tolerance, master type and comparison validity.

11. Conclusion

ARBE λ* is not a new normative standard for optically brightened papers. The normative foundation of print and proof quality control remains based on established measurement and colour-management frameworks, including ISO 13655 measurement conditions, FOGRA/ECI characterization data, ICC workflows and ISO/CIE 11664-6 CIEDE2000 colour-difference calculation.

The value of ARBE λ* lies in its additional atlas-bound interpretation layer. λ*_EE, λ*_V2, Δλ* and ΔΔλ* can help indicate whether a probe remains structurally stable or drifts relative to a defined master.

For OBA-containing substrates, this layer is useful because M1 and M2 can expose different aspects of UV/OBA-sensitive behaviour. The method does not replace measurement standards, profile workflows or visual inspection. It provides an additional structural diagnostic language for situations where colourimetric proximity alone is not sufficient.

> *ARBE does not solve the OBA problem. It makes OBA-sensitive structural differences explicit, measurable and reportable within an atlas-bound master/probe framework.*

Appendix A — Mathematical Definitions

A.1 λ*_EE — Equal-Energy Centroid

λ*_EE is treated as the equal-energy centroid of the measured or atlas-bound spectral signal used by the ARBE processing pipeline under the documented measurement condition.

A generic continuous form is:

```
λ*_EE = ∫Ω λ · S(λ) dλ / ∫Ω S(λ) dλ
```

where:

```
Ω      = defined wavelength interval
S(λ)   = measured spectral signal used by the ARBE pipeline
```

This definition must be bound to the documented spectral band, spectral step and measurement condition.

A.2 λ*_V2 — Energetic Balance Point

λ*_V2 is valid only as the unique Brent-solved root of the defined ARBE energetic balance function within the specified numerical tolerance.

Generic form:

```
Find λ*_V2 such that f(λ*_V2) = 0
```

where:

```
f(λ) = defined ARBE energetic balance function
```

Approximation substitutes, linear interpolation substitutes or ordinary centre-of-gravity replacements are invalid.

A.3 Derived Metrics

```
Δλ* = λ*_V2 − λ*_EE
ΔΔλ* = Δλ*(probe) − Δλ*(master)
```

These are attributes, not identities.

Appendix B — JSON Data Model Schema


```
{
  "$schema": "https://json-schema.org",
  "title": "ARBE_Structural_Diagnostic_Record",
  "type": "object",
  "required": [
    "atlas_id",
    "atlas_validation_status",
    "atlas_master_version",
    "comparison_class",
    "master_type",
    "measurement_condition_master",
    "measurement_condition_probe",
    "comparison_validity",
    "arbe_evaluation_band_nm",
    "spectral_step_nm",
    "solver",
    "master",
    "probe",
    "drift"
  ],
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      "description": "Primary atlas identity anchor constraint."
    },
    "atlas_validation_status": {
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      "enum": [
        "VERIFIED",
        "INVALID",
        "NOT_CHECKED"
      ]
    },
    "atlas_master_version": {
      "type": "string"
    },
```

```
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},
"job_id": {
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},
"press_id": {
  "type": "string"
},
"paper_batch_id": {
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},
"ink_batch_id": {
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},
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},
"visual_assessment_condition": {
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},
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  "enum": [
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    "CLASS_2_REFERENCE_OFFSET"
  ]
},
"master_type": {
  "type": "string",
  "enum": [
    "DIGITAL_ATLAS",
    "PHYSICAL_MASTER"
  ]
},
"measurement_condition_master": {
  "type": "string",
  "enum": [
    "M0",
    "M1",
    "M2",
    "M3"
  ]
},
"measurement_condition_probe": {
  "type": "string",
  "enum": [
    "M0",
    "M1",
    "M2",
    "M3"
  ]
},
"comparison_validity": {
  "type": "string",
  "enum": [
    "VALID",
    "INVALID_CONDITION_MISMATCH",
    "INVALID_ATLAS_ID",
    "DIAGNOSTIC_ONLY"
  ]
},
"raw_measurement_band_nm": {
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  "minItems": 2,
  "maxItems": 2,
  "items": {
    "type": "integer"
```

```
  },
  "description": "Optional raw device capture band, for example 360–780 nm."
},
"arbe_evaluation_band_nm": {
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  "minItems": 2,
  "maxItems": 2,
  "items": {
    "type": "integer"
  },
  "description": "Mandatory ARBE λ* evaluation band; fixed to [380, 730] nm for atlas-bound analysis."
},
"spectral_step_nm": {
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    5,
    10,
    20
  ]
},
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  "required": [
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    "solver_version",
    "tolerance_nm"
  ],
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      "enum": [
        "BRENT"
      ]
    },
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    },
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      "default": 0.001
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  }
},
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  "type": "string"
},
"calibration_version": {
  "type": "string"
},
"measurement_geometry": {
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},
"backing": {
  "type": "string"
},
"substrate_family": {
  "type": "string"
},
"oba_context": {
  "type": "string",
  "enum": [
    "NONE",
    "LOW",
    "MODERATE",
    "HIGH",
    "UNKNOWN"
```

```
  ]
},
"master": {
  "type": "object",
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    "lambda_v2_nm",
    "delta_lambda_nm"
  ],
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    "lambda_ee_nm": {
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      "minimum": 380.0,
      "maximum": 730.0
    },
    "lambda_v2_nm": {
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      "minimum": 380.0,
      "maximum": 730.0
    },
    "delta_lambda_nm": {
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    },
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    }
  }
},
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    "lambda_v2_nm",
    "delta_lambda_nm"
  ],
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      "minimum": 380.0,
      "maximum": 730.0
    },
    "lambda_v2_nm": {
      "type": "number",
      "minimum": 380.0,
      "maximum": 730.0
    },
    "delta_lambda_nm": {
      "type": "number"
    }
  }
},
"drift": {
  "type": "object",
  "required": [
    "delta_delta_lambda_nm",
    "status",
    "interpretation"
  ],
  "properties": {
    "delta_delta_lambda_nm": {
      "type": "number"
    },
    "status": {
      "type": "string",
      "enum": [
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        "WATCH",
        "REVIEW",
```

```
            "BLOCK"
          ]
        },
        "interpretation": {
          "type": "string",
          "enum": [
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            "STRUCTURAL_OFFSET",
            "OUT_OF_REFERENCE_FAMILY"
          ]
        }
      }
    },
    "additional_colourimetry": {
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      "properties": {
        "lab": {
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          "minItems": 3,
          "maxItems": 3,
          "items": {
            "type": "number"
          }
        },
        "xyz": {
          "type": "array",
          "minItems": 3,
          "maxItems": 3,
          "items": {
            "type": "number"
          }
        },
        "delta_e00": {
          "type": "number"
        },
        "observer": {
          "type": "string",
          "default": "CIE 1931 2 Degree"
        },
        "illuminant": {
          "type": "string",
          "default": "D50"
        }
      }
    },
    "organization_extensions": {
      "type": "object",
      "description": "Optional company-specific metadata fields."
    },
    "audit": {
      "type": "object",
      "properties": {
        "operator": {
          "type": "string"
        },
        "timestamp": {
          "type": "string",
          "format": "date-time"
        },
        "notes": {
          "type": "string"
        }
      }
    }
  }
}
```

Appendix C — Practical Diagnostic Patterns

Pattern 1: Possible OBA-Sensitive Drift

```
[M1 Track: UV/OBA-sensitive]     [M2 Track: UV-cut]
Master Δλ*: 12.4 nm             Master Δλ*: 4.2 nm
Probe  Δλ*:  2.1 nm             Probe  Δλ*: 4.0 nm
ΔΔλ*:      -10.3 nm REVIEW      ΔΔλ*:     -0.2 nm STABLE
```

Interpretation:

```
This pattern may indicate a change in OBA-sensitive response.
It does not prove the physical cause without supporting evidence.
```

Pattern 2: Possible Broad Substrate or Process Shift

```
[M1 Track]                      [M2 Track]
Master Δλ*: 12.4 nm             Master Δλ*: 4.2 nm
Probe  Δλ*: 34.8 nm             Probe  Δλ*: 26.1 nm
ΔΔλ*:      +22.4 nm BLOCK       ΔΔλ*:     +21.9 nm BLOCK
```

Interpretation:

```
Structural drift appears in both tracks.
This may indicate base material change, coating change,
ink film variation, paper batch shift or broader process drift.
```

Pattern 3: Reference-Family Offset

```
Digital atlas reference:
Master Δλ*: 1.1 nm

Physical OBA stock:
Probe Δλ*: 24.5 nm

ΔΔλ*: +23.4 nm
Class: CLASS_2_REFERENCE_OFFSET
Status: BLOCK flag / diagnostic only
```

Interpretation:

```
STRUCTURAL_OFFSET / OUT_OF_REFERENCE_FAMILY.
Not an automatic production rejection.
```

Appendix D — Transparency and Reproducibility Statement

ARBE λ* is not intended to operate as an opaque black-box replacement for established colourimetry. The method separates atlas identity, measurement condition, structural attributes and comparison class.

The value λ*_V2 is valid only when computed as the Brent-solved root of the defined ARBE energetic balance function under documented spectral input conditions and numerical tolerances. Approximation substitutes, linear interpolation substitutes or ordinary centre-of-gravity replacements are invalid.

A valid ARBE structural diagnostic record must report at least:

```
Atlas Reference ID: Hxxx_Lxxx_Cxxx
Atlas validation status
Atlas master version
Measurement condition: M0 / M1 / M2 / M3
Master type: DIGITAL_ATLAS / PHYSICAL_MASTER
Comparison class: CLASS_1_PROCESS_DRIFT / CLASS_2_REFERENCE_OFFSET
Comparison validity
Spectral band
Spectral step
Solver method: BRENT
Solver tolerance
λ*_EE
λ*_V2
Δλ*
ΔΔλ*
QC status flag
```

The purpose of ARBE λ* is not to replace ΔE, CIEDE2000, M1/M2 measurement practice, ICC workflows or visual assessment. Its purpose is to add a reproducible atlas-bound structural drift indicator in cases where colourimetric proximity alone may not sufficiently describe spectral-energetic stability.

For review, validation and implementation, ARBE λ* should therefore be documented through three layers:

```
1. Conceptual layer:
  atlas identity, measurement condition, comparison class

2. Numerical layer:
  spectral input, solver method, tolerance, derived attributes

3. Validation layer:
  expected behaviour for valid comparisons, diagnostic comparisons,
  invalid atlas references and measurement-condition mismatches
```

Any implementation that cannot verify the atlas reference, the measurement condition, the solver method or the comparison class must not release an atlas-bound ARBE result.

Final Scope Note

No concrete Hxxx_Lxxx_Cxxx reference is asserted in this document. Therefore, the document does not make a single-colour atlas-bound result statement. It defines a method, a reporting structure and interpretation boundaries for future validated atlas-bound measurements.

References and Source Notes

- ISO/CIE 11664-6:2022 — Colorimetry — Part 6: CIEDE2000 colour-difference formula.
- ISO 13655 — Graphic technology — Spectral measurement and colorimetric computation for graphic arts images.
- ECI — Offset profiles and FOGRA51 / FOGRA52 notes for PSO Coated v3 and PSO Uncoated v3.

- Fogra — D50noUV project page concerning UV-free LED viewing conditions and fluorescent materials.
- Internal ARBE/HLC release candidate and QC notes supplied in the working conversation.