CFALD Whitepaper v1.3

CFA Luminance Drizzle: A High-Efficiency Luminance Extraction Method for OSC Astrophotography
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Abstract (Revised for v1.3)

CFALD (CFA Luminance Drizzle) is a data-processing method that extracts a high-SNR luminance channel directly from the RAW Bayer mosaic of an OSC (One-Shot Colour) sensor, *before* any debayering or colour interpolation. By combining the four colour-filtered CFA samples (R, G1, G2, B) in each RGGB block while preserving the native pixel grid, CFALD performs **radiometric binning without geometric binning**—a distinction previously overlooked in OSC imaging practice.

This leads to a key and unexpected discovery:

> **An OSC frame whose 2×2 CFA values have been combined at full resolution remains fully drizzle-compatible.**
>
> The result is a true high-SNR luminance channel that preserves spatial sampling, supports subpixel reconstruction, and achieves resolution close to the native pixel grid.

CFALD luminance exhibits roughly **2× the SNR of a single CFA channel**, equivalent to about **4× the effective luminance exposure time** of a mono camera (based on √t scaling). When paired with drizzle-debayered RGB, CFALD enables OSC cameras to deliver broadband LRGB-like performance without filters, wheels, or colour subs. The discovery corrects long-standing misconceptions about CFA data and reveals an unrecognised capability of Bayer-pattern sensors.

CFALD does not replace mono cameras for narrowband imaging, but it fundamentally improves the efficiency of broadband OSC work, providing a software-only path to deep luminance and high-detail reconstruction previously thought impossible with Bayer sensors.

1. Introduction

OSC cameras have traditionally been considered less efficient for deep-sky broadband imaging because the luminance signal extracted from debayered RGB is low-SNR and blurred by colour interpolation. Unlike mono sensors, OSC devices were believed incapable of producing high-quality luminance without filters.

CFALD challenges this assumption.
 By operating directly on the RAW CFA mosaic and preserving spatial pixel positions, CFALD extracts a true luminance channel that is:

- high SNR

- free from debayer interpolation

- spatially aligned with the RGB

- drizzle-compatible at full resolution

This enables a full LRGB workflow using only an OSC camera.

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2. Technical Summary of the CFALD Method

1. OSC sensors use a repeating 2×2 Bayer matrix (RGGB).

2. Each 2×2 block contains *spectral* samples (R, G1, G2, B) of **one spatial point**, not four.

3. CFALD forms a luminance estimate **per pixel** by combining the four CFA values:
    L = f(R, G1, G2, B)

4. Crucially, this luminance is written back to the **original pixel grid**, preserving all pixel coordinates.

5. Dithered subs are stacked with drizzle, which reconstructs subpixel detail because geometric sampling was never reduced.

6. RGB is processed conventionally, ideally using drizzle-debayer to reduce interpolation noise.

7. CFALD-L replaces RGB-derived luminance in the LRGB workflow.

This produces a mono-like luminance channel while retaining full resolution and correct spatial sampling.

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3. Why CFALD Works: Spectral vs Spatial Sampling

The key insight is that:

CFA pixels differ spectrally, not spatially.

The RGGB block:

```
R   G1
G2  B
```

contains **four filtered measurements of the same spatial location**, not four different sky positions.

Traditional OSC workflows assumed the opposite, treating CFA pixels like mono pixels. This led to the false conclusion that combining them must reduce resolution.

CFALD combines the four *spectral* samples while keeping the *geometric* sampling intact.

Thus:

- **Radiometric binning occurs** (noise ↓ signal ↑)

- **Geometric binning does NOT occur** (resolution preserved)

This distinction is the basis of CFALD's success and explains why drizzle remains fully functional.

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4. Performance Comparison: Mono LRGB vs CFALD-OSC

4.1 Photon Utilisation

Mono Cameras

- Luminance uses 100% of the sensor

- Colour requires sequential R/G/B exposures

- Significant overhead from filter changes

CFALD-OSC

- Every exposure produces both L and RGB

- No filters or mechanical changes

- Luminance SNR boosted via CFA combination

4.2 SNR Characteristics

Luminance

- 4 CFA samples → ~2× noise reduction

- Equivalent to ~4× luminance exposure in mono

Colour

- Still limited by Bayer sampling (1 red, 1 blue per 4 pixels)

- Colour SNR remains lower than mono R/B

- But colour need not be high SNR when luminance carries the structure

4.3 Spatial Resolution and Drizzle Compatibility

This is the central breakthrough:

CFALD preserves spatial sampling because pixel positions are untouched.

Drizzle uses pixel coordinates and dither offsets—not colour information—to reconstruct finer detail.

Since CFALD leaves the geometric lattice intact:

- drizzle works

- subpixel sampling accumulates

- resolution is largely recovered

- spatial detail is preserved far beyond expectations

CFALD does not achieve the exact resolution of native mono, but empirical testing shows:

- significantly more detail than RGB-luminance

- vastly more detail than 2×2 hardware binning

- fine structures reconstructed via drizzle

- excellent star profiles with minimal artefacts

4.4 Why CFALD Often Looks Sharper Than RGB-L

RGB-derived luminance suffers from:

- debayer blur

- channel misalignment

- chromatic PSF differences

- interpolation artefacts

- noise amplification

CFALD-L avoids all of these.

The result is:

- higher microcontrast

- better faint-structure visibility

- smoother backgrounds

- fewer artefacts

Even though CFALD-L has slightly larger FWHM than native mono, the *visual* sharpness often exceeds RGB-luminance.

4.5 Narrowband Limitations

CFALD does not improve narrowband performance.
Mono remains superior for SHO/HOO imaging because Bayer filters pass too few photons in narrowband.

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5. Manufacturer Briefing Summary

CFALD is a pure software enhancement that enables:

- high-SNR luminance from OSC sensors

- improved time-to-result

- enhanced smart telescope performance

- a competitive "Mono-Hybrid" imaging mode

- no hardware changes

Implementing CFALD would materially increase OSC performance in broadband astrophotography.

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6. Mathematical Appendix (Narrative)

Let the four CFA samples be:

R, G1, G2, B

Signal adds linearly → $S\_total = S\_R + S\_G1 + S\_G2 + S\_B$
 Noise adds in quadrature → $N\_total \approx \sqrt{(N\_R^2 + N\_G1^2 + N\_G2^2 + N\_B^2)}$

Assuming equal noise per pixel:

$N\_total \approx 2N$

Thus SNR improves by ~2×.

Since $SNR \propto \sqrt{t}$:

2× SNR ≈ 4× exposure time.

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7. Limitations

- Slight broadening of PSF compared to mono

- Does not improve colour channel SNR

- Not a replacement for mono narrowband imaging

- Drizzle requires dithering to reach full potential

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8. Discovery and Development of the CFALD Method

The CFALD technique was not derived from existing OSC imaging theory.
It emerged through a sequence of empirical observations that challenged long-standing assumptions about how Bayer-pattern sensors encode spatial information. This section documents how the method was discovered, why it works, and why the approach had not been previously explored in astrophotography.

8.1 Initial Motivation

The development began with a practical goal:
to extract a higher-quality luminance signal from OSC data by avoiding the noise and artefacts introduced during debayering. The idea of forming luminance directly from the RAW CFA values of each subframe appeared straightforward for improving SNR, though it was widely assumed that combining the 2×2 Bayer samples would degrade spatial resolution in the same way that hardware 2×2 binning does on a monochrome sensor.

No existing OSC workflow attempted pre-debayer CFA luminance extraction, and the expectation was that spatial detail would be softened or lost.

8.2 Unexpected Empirical Findings

The first CFALD luminance stacks did not behave as predicted by conventional understanding.
They showed:

- significantly improved SNR, as expected from the radiometric combination, but also

- preservation — and sometimes enhancement — of fine spatial detail.

This contradicted the longstanding belief that averaging a 2×2 CFA block must collapse spatial information. The surprising clarity of the luminance data prompted further experimentation.

When dithering and drizzle stacking were applied, the CFALD luminance reconstructions achieved spatial detail close to the sensor's native sampling. Drizzle only functions correctly when the underlying spatial information is preserved; therefore, the observed results implied that the CFA combination had not degraded spatial sampling.

These empirical results motivated a deeper theoretical examination.

8.3 Re-evaluating the Bayer Sampling Model

The key insight came from reconsidering what the Bayer pattern represents.
 The four pixels within an RGGB block:

```
R    G1
G2   B
```

are **not** four spatially independent brightness samples.
 They are four **spectral** measurements of the *same* spatial point in the optical scene.

Spatial sampling is defined by the physical pixel grid, not by the arrangement of colour filters.
 Thus, combining the CFA samples modifies the *radiometric* information but leaves the *geometric* sampling intact.

This is fundamentally different from hardware binning on a mono sensor, where multiple pixels corresponding to different spatial positions are collapsed into a single pixel. In hardware binning, geometric information is lost; in CFA combination, it is preserved.

Recognising this distinction explained the empirical results:

- The luminance SNR improves because four spectral samples are combined.

- The spatial sampling lattice is unchanged because pixel coordinates are unchanged.

- Dither offsets remain valid.

- Drizzle has the geometric information it needs to reconstruct subpixel detail.

This corrected theoretical framework aligns with the behaviour observed in practice.

8.4 Why the Approach Had Not Been Explored

The astrophotography community has long assumed that combining a 2×2 CFA block is equivalent to spatial binning.
 This assumption originated from analogy with monochrome sensors, where 2×2 hardware binning *does* collapse spatial samples and is known to prevent drizzle reconstruction.

Because the CFA pixels physically resemble a 2×2 grid, it was natural—but incorrect—to assume they behave like four spatial samples. This assumption permeated:

- OSC processing literature

- RAW converter design

- Debayer workflows

- Community practice across forums

- Software pipelines that debayer immediately after calibration

As a result, no OSC tool extracts luminance from un-debayered CFA at full resolution, and no pipeline attempts to drizzle such a luminance channel.

CFALD demonstrates that the assumption was flawed.
 CFA samples encode spectral differences, not spatial positions. Combining them does not degrade spatial sampling and therefore does not inhibit drizzle reconstruction.

8.5 Consolidated Theoretical Understanding

With the corrected interpretation, the behaviour of CFALD becomes clear:

- **Radiometric binning:** combining R, G1, G2, B reduces noise and increases luminance SNR.

- **Geometric preservation:** pixel coordinates are unchanged, so no spatial information is lost.

- **Drizzle compatibility:** retained subpixel sampling allows recovery of fine structure.

- **RGB alignment:** CFALD-L matches the RGB pixel grid exactly, enabling a true LRGB workflow.

This combination—binning spectral information while preserving spatial sampling—was not previously recognised as possible.

8.6 Confirmation Across Targets and Conditions

CFALD has been tested on:

- galaxies

- bright and faint nebulae

- star-dense regions

- both short and long focal lengths

- light-polluted and darker sites

- high- and low-SNR datasets

In all cases, CFALD luminance exhibited:

- improved faint structure recovery,

- reduced noise,

- absence of debayer artefacts,

- preserved or drizzle-restored resolution, and

- perfect registration with colour data.

These results were consistent and reproducible, validating the method.

8.7 Summary of the Discovery Process

The development of CFALD followed the classic scientific progression:

1. **Initial idea** — extract luminance before debayering to reduce noise.

2. **Unexpected observations** — spatial detail was not degraded.

3. **Drizzle success** — proof that spatial sampling remained intact.

4. **Re-evaluation of assumptions** — CFA pixels encode spectra, not spatial offsets.

5. **Theoretical correction** — radiometric vs geometric sampling separation.

6. **Generalisation and validation** — method works across numerous datasets.

7. **Recognition of novelty** — no prior OSC workflow uses CFA-domain luminance at full resolution.

CFALD reveals a previously overlooked capability of Bayer-pattern sensors:
the ability to combine spectral samples into high-SNR luminance while preserving spatial sampling for resolution reconstruction.

9. Practical Workflow (Summary)

1. Calibrate RAW frames **without debayering**.

2. Extract CFA luminance via Python or Siril script.

3. Stack CFALD-L with drizzle.

4. Stack RGB using *drizzle-debayer* for best colour quality.

5. Combine CFALD-L with RGB in standard LRGB workflow.

10. Conclusion

CFALD overturns a foundational assumption in OSC astrophotography:
 that combining 2×2 Bayer blocks must reduce resolution.

By separating **spectral** sampling from **spatial** sampling, CFALD demonstrates that OSC sensors can produce a high-SNR luminance channel *that remains fully drizzle-compatible at native resolution*.

This discovery dramatically enhances the efficiency and imaging capability of OSC cameras for broadband astrophotography—purely through software.

CFALD represents one of the most important advances in OSC processing since drizzle stacking itself.