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ISIIS-DPI · TECHNICAL FAQ

Shadowgraph System Resolution

Frequently Asked Questions

A guide to understanding optical resolution, what it means for your research, and how to evaluate competing claims.

Q1 "How do you define the resolution of your shadowgraph system?"

When researchers ask about resolution, they're usually working toward one practical question: *will this system capture the detail my science requires?* That's exactly the right question. Here's how to think about it accurately.

The resolution of any optical imaging system is ultimately determined by the smallest feature that can be distinguished in **object space**, the physical space where your measurement takes place. For a shadowgraph system, this is expressed as the **object-space pixel pitch**: how large a region of the water column each pixel represents.

These two expressions describe the same physical quantity, just stated differently:

OBJECT-SPACE RESOLUTION · TWO EQUIVALENT FORMS

$$\frac{\text{Field of View}}{\text{Number of Pixels}} = \frac{\text{Pixel Size}}{\text{Magnification}}$$

WHAT THE OPTICS SHOW / WHAT THE SENSOR COUNTS

SENSOR PITCH BACK-PROJECTED THROUGH THE LENS

Both expressions yield the same value: the size of the region of the water column that each pixel represents.

Worked example · ISIIS-DPI P75

IN-WATER PERFORMANCE

PIXEL SIZE		MAGNIFICATION		OBJECT-SPACE PIXEL PITCH
3.45 µm (sensor)	÷	0.132× optical	=	≈ 26 µm per pixel

Every pixel represents a unique **26 µm × 26 µm** region of the water column. No information is duplicated, and no detail finer than 26 µm is lost. This corresponds to a spatial sampling of approximately **38 line pairs / mm** in object space, sufficient to resolve structures at the scale of phytoplankton chains and small copepod appendages.

Q2 "I have seen other systems claiming much higher pixel counts and better resolution. How does yours compare?"

This is one of the most important questions to ask when evaluating any optical measurement system, and the answer requires understanding two fundamental principles of optics that are often left out of side-by-side comparisons.

The first principle is the **Optical Lagrange Invariant** (also called optical étendue). It states that the spatial information content of an optical system is set at the very first optical element, in a shadowgraph the collecting lens, and is conserved throughout the entire optical train downstream. No combination of camera sensor size, pixel count, or pixel size can extract more spatial information than the collecting optics deliver. Increasing pixel count beyond this limit simply means each pixel receives less light and records a smaller slice of the same optical blur: more numbers, but no more information.

The second principle is **optical blur**, which defines the finest spatial scale the optics actually resolve and deliver to the sensor. The object-space optical blur is given directly by the pixel size mapped back through the magnification:

$$\text{Optical Blur} = \frac{\text{Pixel Size}}{\text{Magnification}}$$

WHAT SPEC SHEETS OFTEN SHOW

~~20 MP~~

Sensor megapixels and pixel counts on a datasheet. Headline numbers that do not, on their own, tell you how much of the flow field each pixel actually sees.

WHAT ACTUALLY DETERMINES RESOLUTION

Object-space pixel pitch

The size of the region of the water column each pixel represents. Set by the collecting optics through the Lagrange invariant and conserved everywhere downstream.

A well-designed system operates at the point where the pixel size in object space matches the optical blur. This is the **Nyquist condition**, representing the optimal balance between spatial sampling and light collection per pixel. Making pixels smaller than the optical blur does not improve resolution; it only degrades signal-to-noise ratio by splitting the same optical spot across more, noisier pixels. Making pixels larger than the optical blur wastes the spatial information the optics have already captured.

The Nyquist condition · pixel size vs. optical blur

A well-designed system places its pixel size at the optical blur. Smaller and larger both lose.

smaller pixel ← Nyquist → larger pixel

Oversampled
More, noisier pixels split the same blur. Worse SNR, no extra resolution.

Matched
Pixel pitch = optical blur. Optimal balance of sampling and light per pixel.

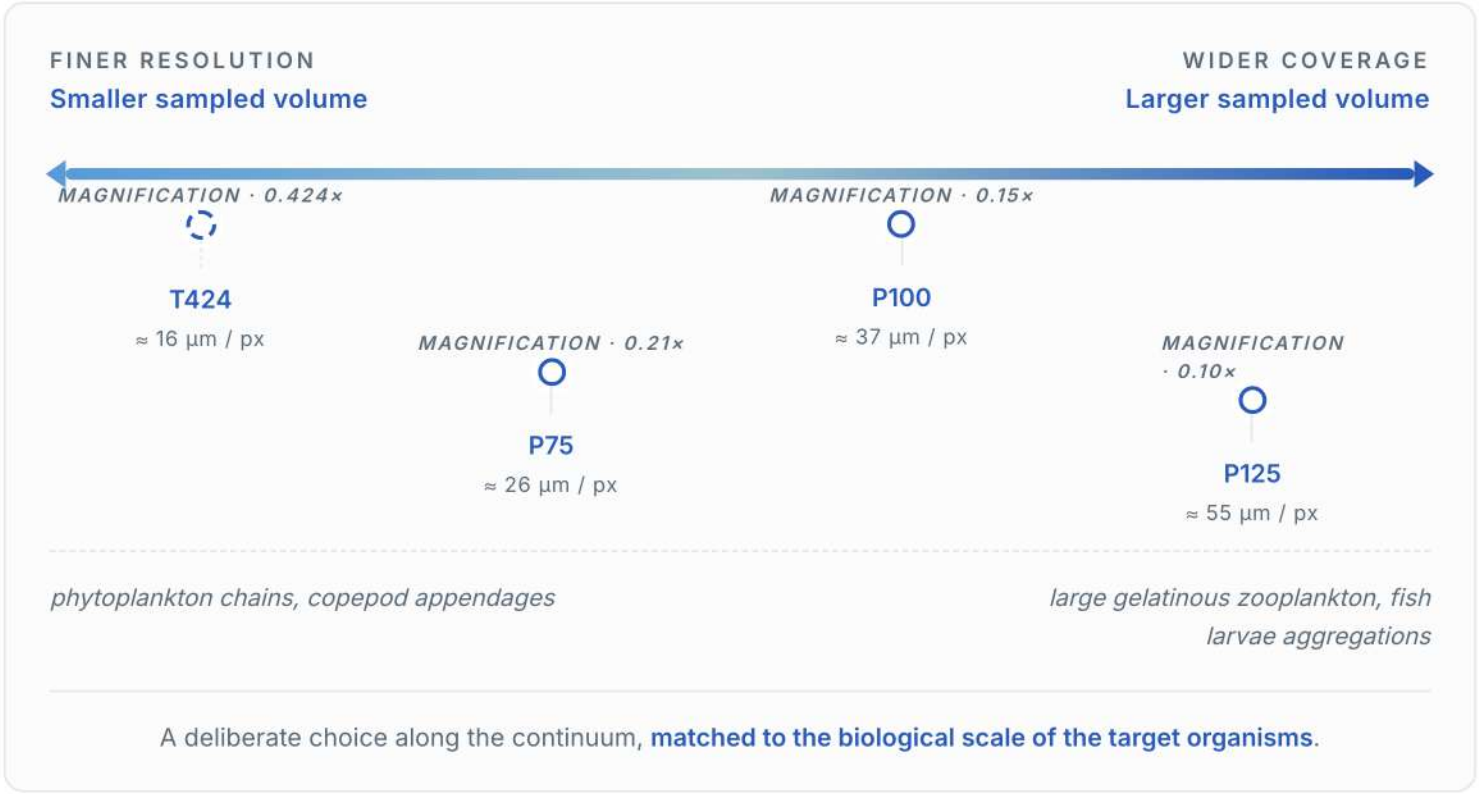
Undersampled
Pixels coarser than the blur. Spatial information the optics captured is wasted.

How should you evaluate competing claims? A system claiming superior resolution based on camera pixel count or sensor size alone is not providing a meaningful comparison. The only number that matters is the object-space pixel pitch: how large a region of the flow field each pixel actually represents. A system with a smaller camera sensor and fewer pixels can outperform a high-megapixel system if it achieves a finer object-space pixel pitch through higher magnification.

Q3 "What would it take to genuinely improve the resolution of your system?"

Since object-space resolution equals pixel size divided by magnification, the only genuine path to finer resolution is increasing the magnification: bringing it closer to 1. This means covering a smaller field of view with the same pixel count, so that each pixel represents a finer region of the flow field. Higher magnification always comes at the cost of reduced field of view and sampled volume. This is a fundamental optical trade-off, not an engineering limitation. There is no optical design that simultaneously improves both resolution and field of view for a fixed collecting aperture.

This is precisely why the ISIIS-DPI product family spans multiple configurations. Each instrument represents a deliberate choice along the resolution-versus-volume continuum, matched to the biological scale of the target organisms. When we help researchers select the right system, we are not selling specifications. We are matching the instrument to the science.



Any system claiming higher resolution than ours for the same field of view should be examined carefully. Ask the same question every time:

> **"What is your object-space pixel pitch?"**
>
> *Not "how many megapixels is your camera?" and not "how small are the pixels on the camera sensor?"*