A Survey of CMOS Imagers and Lenses—and the Trade-offs You Should Consider

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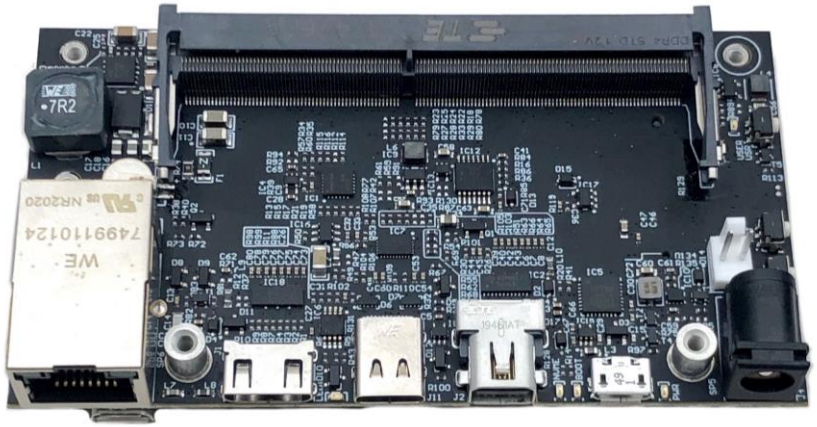
Focused on making better building blocks for mobile robots and autonomous systems.

Product areas:

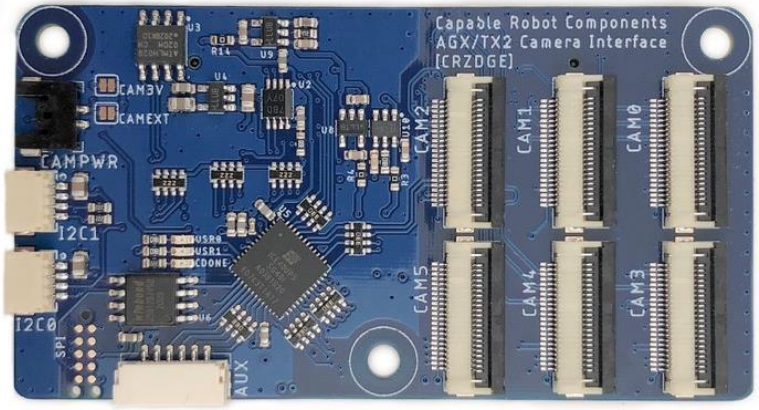
- **Cameras:** Variety of cameras and downstream data & sync interfaces.
- **Communications:** USB Hub & Embeddable GigE Switch
- **Sensor & Computing**

GMSL Camera



NVIDIA NX Baseboard

Programmable & Instrumented USB Hub



NVIDIA TX2 / AGX Camera Interface

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Presentation Outline

- CMOS Imagers
  - Performance & Non-Performance Criteria
  - Vendors & Market Analysis
  - How do you choose an imager?

- Lenses
  - Performance & Non-Performance Criteria
  - Vendors & Market Analysis
  - How do you choose a lens?

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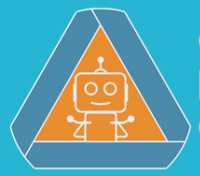
CMOS Imagers



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Imager : Performance Criteria

- **Horizontal & Vertical Pixels.** Lots of different aspect ratios & sizes out there.
- **Pixel Size.** Distance from pixel to pixel. Note, **NOT** the size of the active part of the pixel.
- **Shutter Type.** Global Shutter (GS) or Electronic Rolling Shutter (ERS)
- **Frame Rate.** Specifications here can be misleading. Can change with operating resolution and interface used.
- **Color Filter Array (CFA).** None, Bayer (RGGB), RCCC, RCCB, RGBC, RGB-IR.
- **Quantum Efficiency & Spectral Response.** Percent of photons that add to pixel voltage.
- **Dynamic Range.** Ratio between full well voltage and noise floor.
- **Signal to Noise (SNR).** Ratio between full well voltage and RMS noise of full-well signal.

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Imager : Non-Performance Criteria

- **Power Draw.** CMOS imagers have higher noise at higher temperatures. Imagers that draw excessive power have self-heating and exhibit this sooner.
- **Pixel Data Interface.** Parallel, LVDS, and CSI-2 most common. Vendor specific busses: subLVDS, HiSPi
- **Pixel Encoding.** Generally RAW (8, 10, or 12 bits). Some imagers have an ISP on-chip which can expose YUV or RGB data.
- **Control Interface.** I2C most common (sometimes called something else). Occasionally SPI.
- **Trigger / Flash Signaling.** Generally imagers have a trigger / sync control input. ERS imagers sometimes have a flash / strobe output.
- **Additional IO / Sensors / Data.** GPIO? On-die temperature sensor? Histogram?
- **Additional Features.** WOI/ROI? AEC? AGC?
- **Price**
- **Lead Time / Availability.** Ranges from stock to 20+ weeks. Depends on the vendor and the SKU.
- **Die Packaging.** BGA & LGA most common. PLCC, QFP, PGA, Bare Die less common.
- **Documentation Availability.** NDAs generally required to get full data-sheet & register interfaces. Difficulty ranges from easy to impossible between vendors (unless you're very large and known company).

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CMOS Imager : Vendors

- AMS / CMOSIS
- Micron → Aptina → On SemiConductor
- Teledyne / E2V
- Sony
- OmniVision
- Canon
- Panasonic

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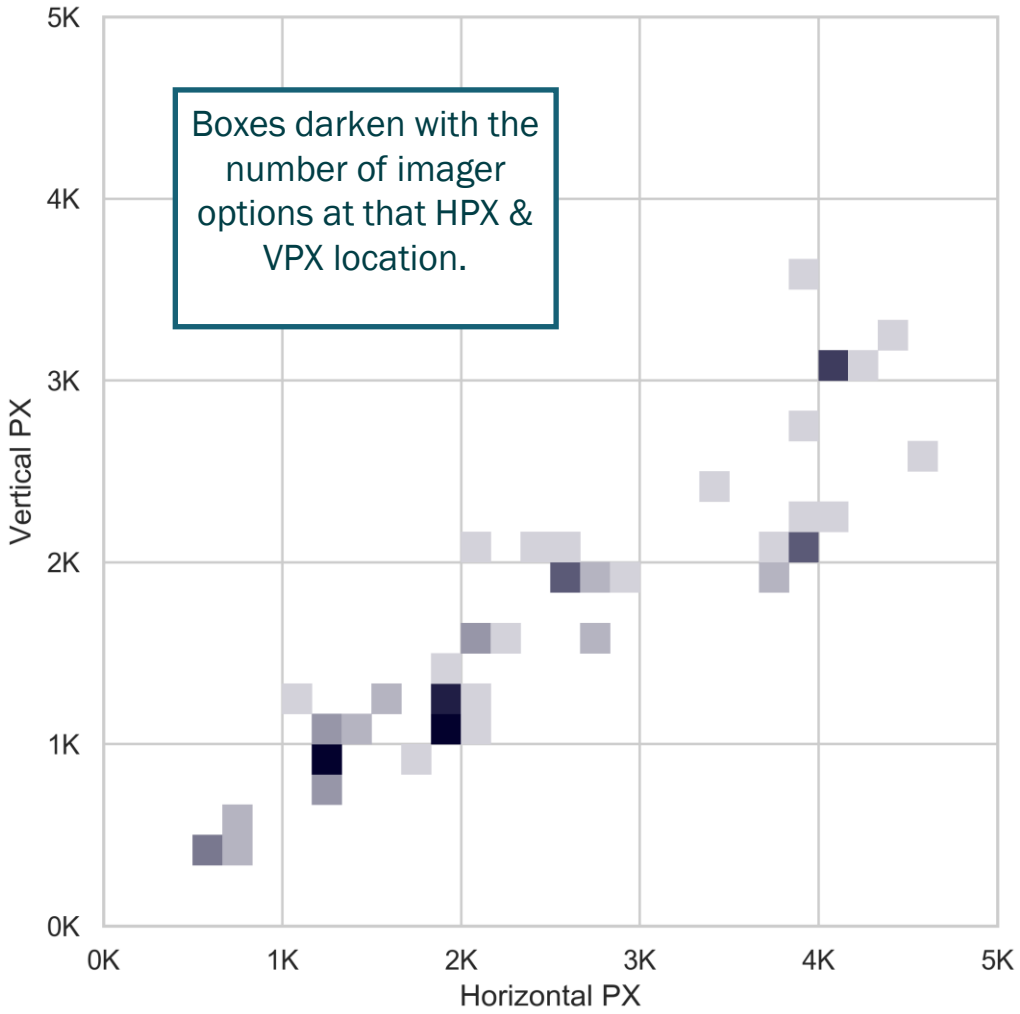
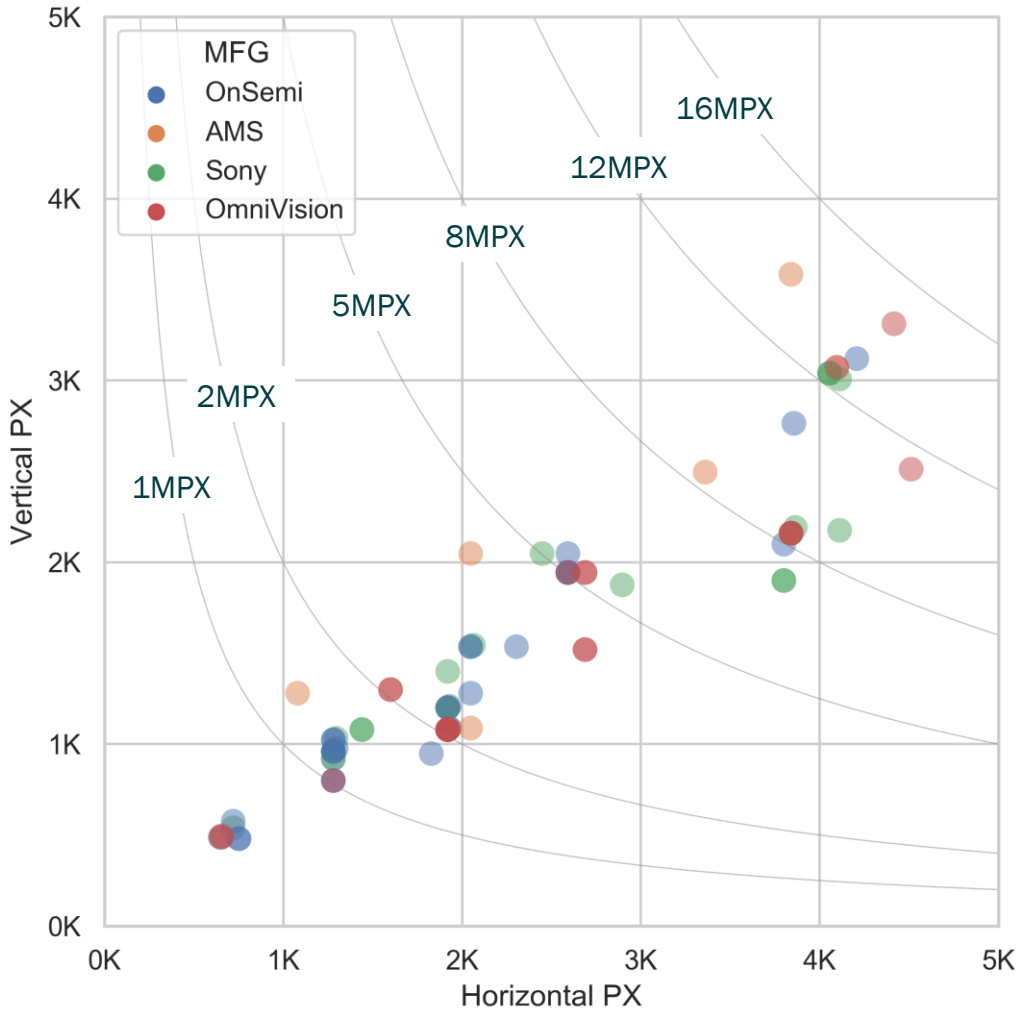
Imagers : Market Trends : Resolution & Aspect Ratio





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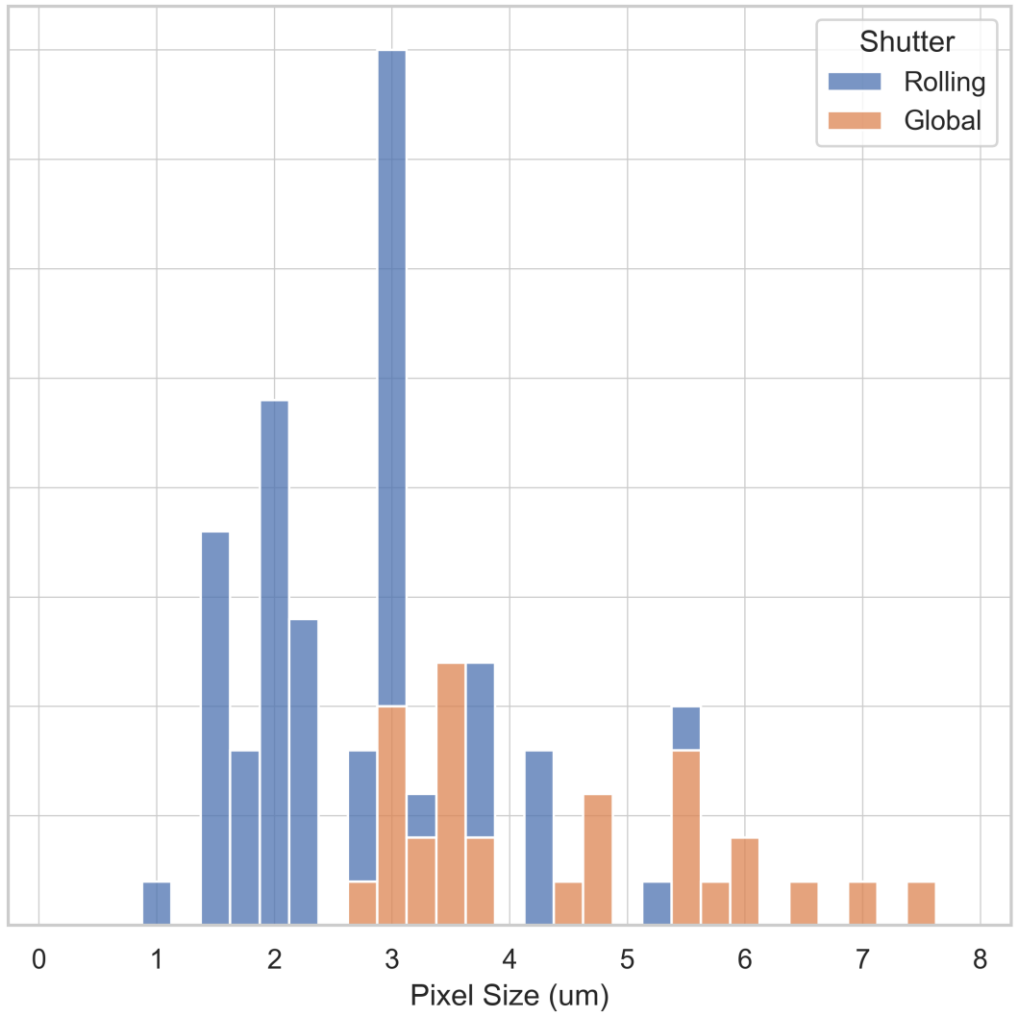
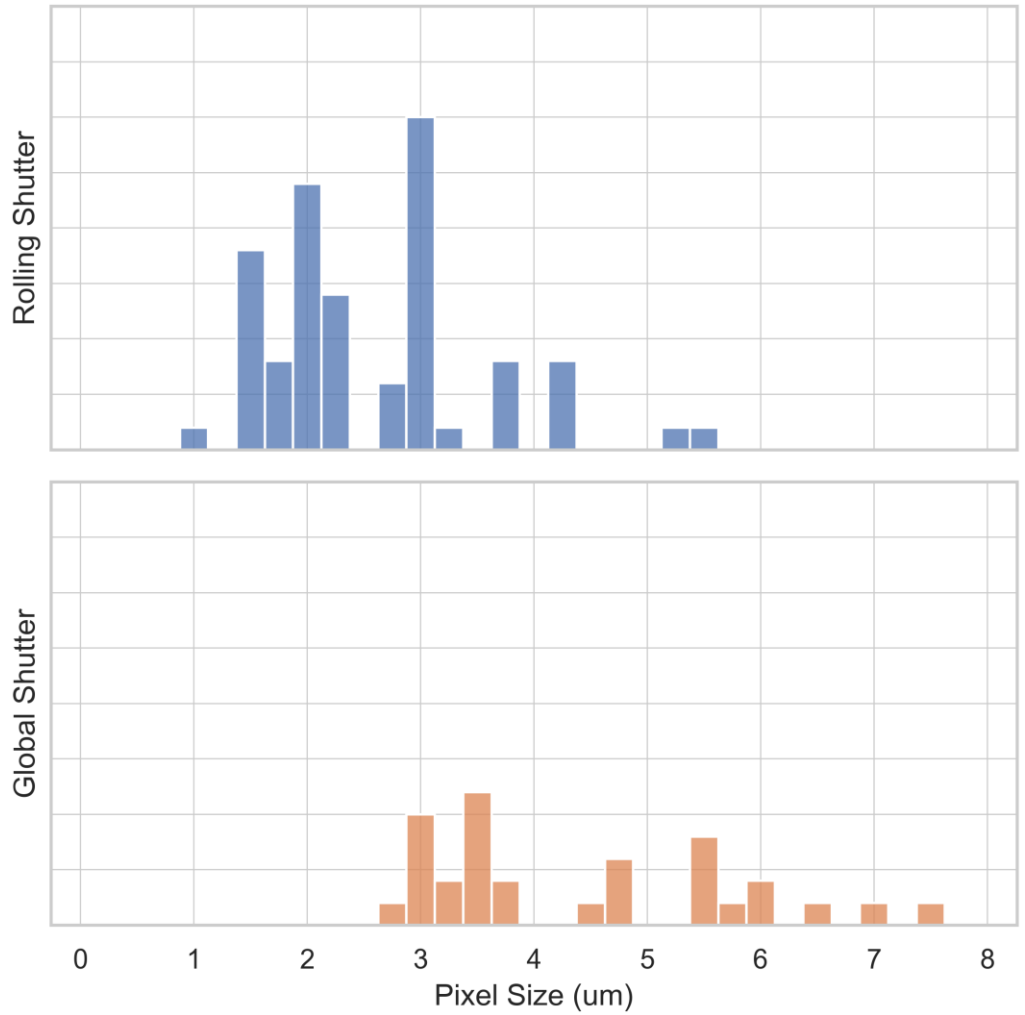
Imagers : Market Trends : Histograms of Pixel Sizes





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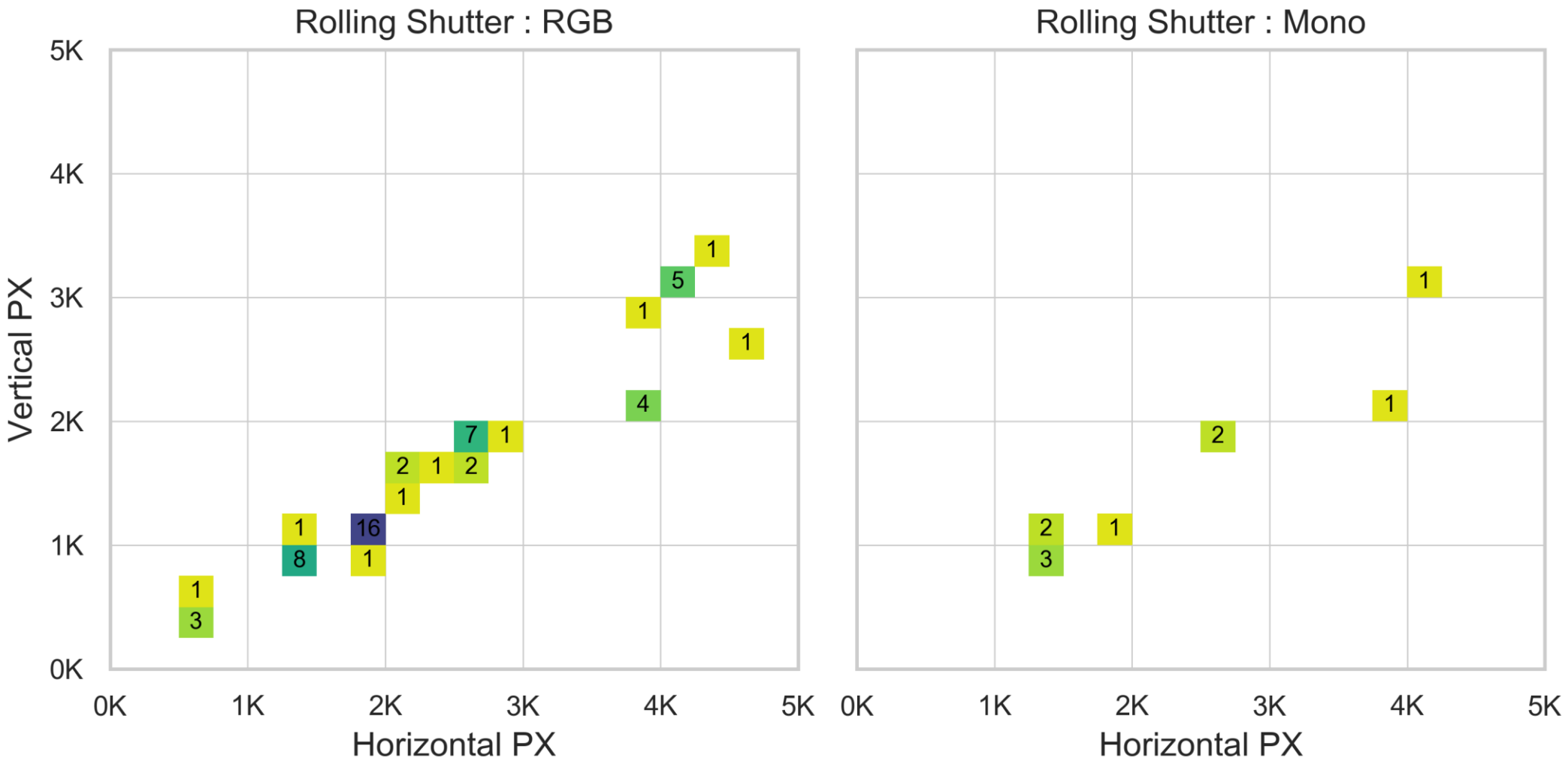
Imagers : Market Trends : Color Filter Arrays



Number is count of imagers at that HPX & VPX location.

Boxes darken with the imager count.

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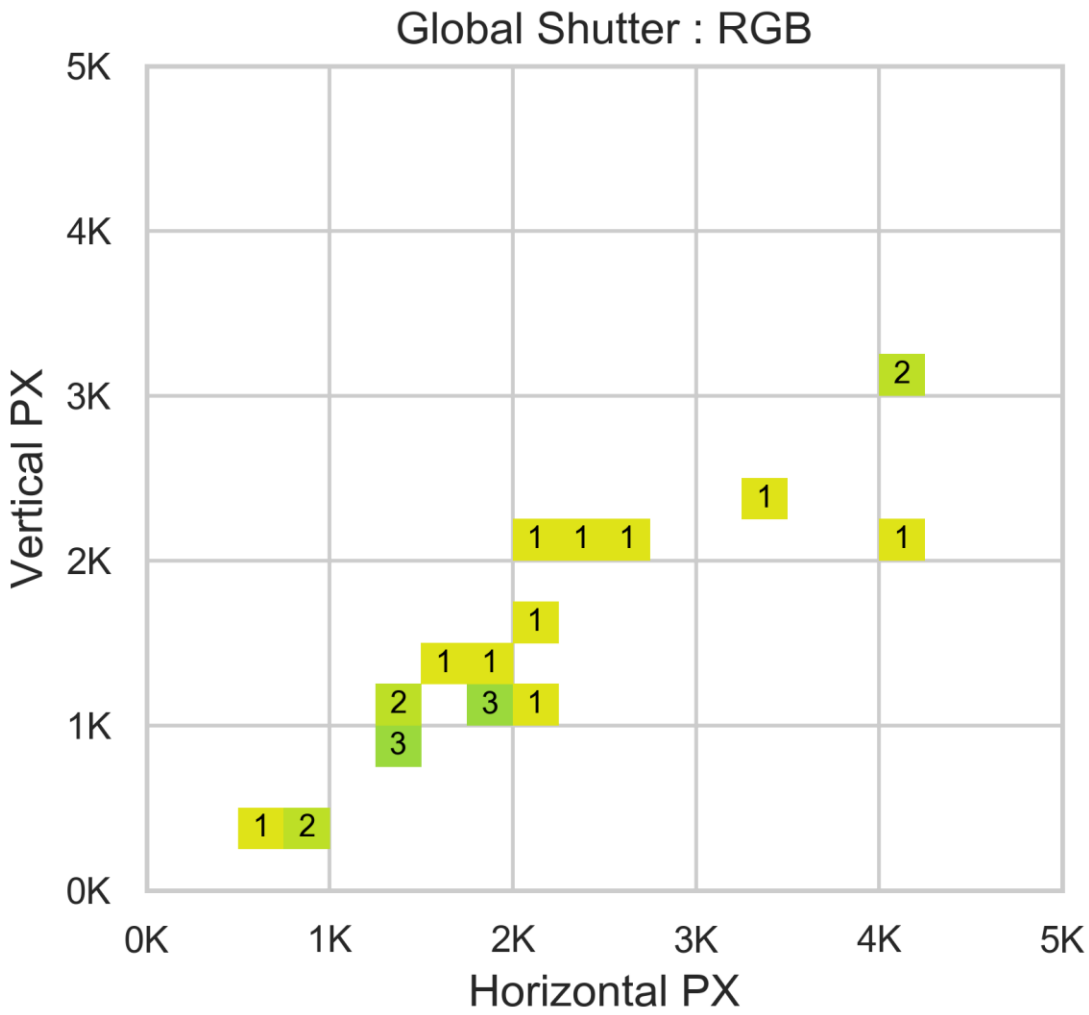
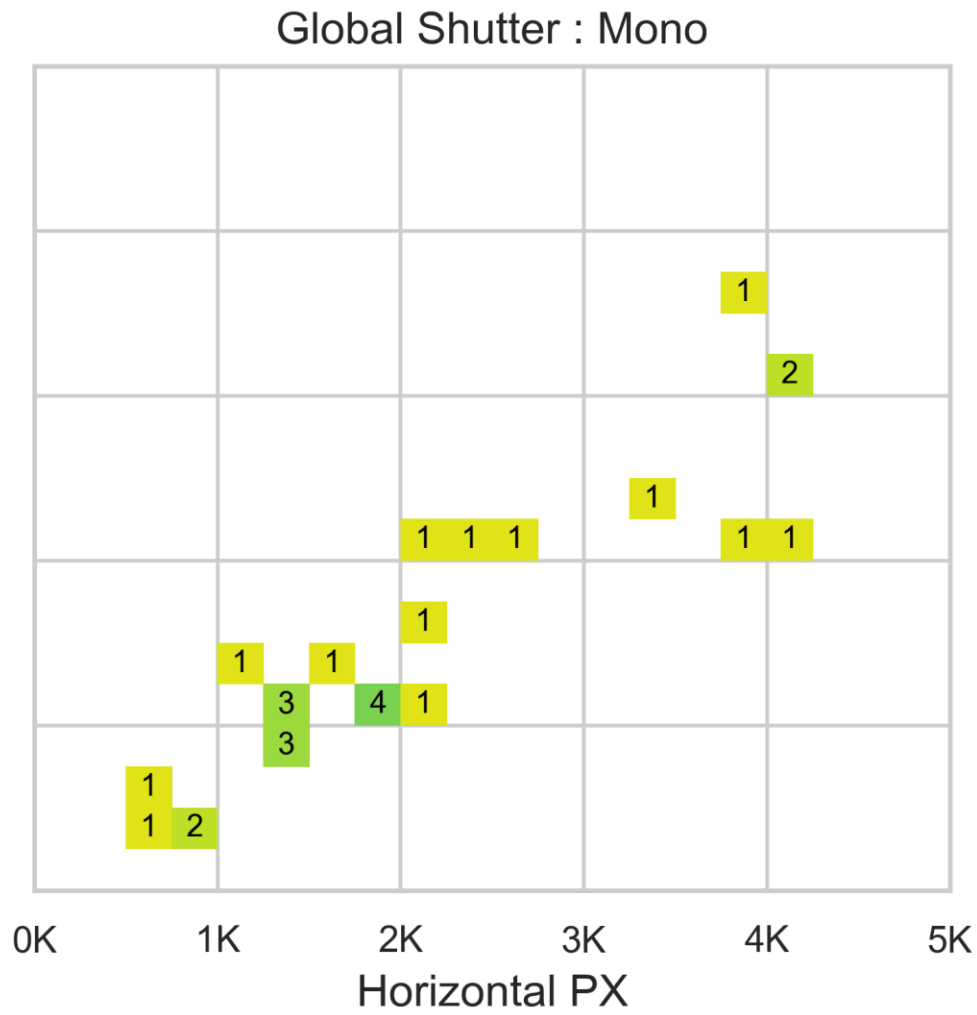
Imagers : Market Trends : Color Filter Arrays





Number is count of imagers at that HPX & VPX location.

Boxes darken with the imager count.

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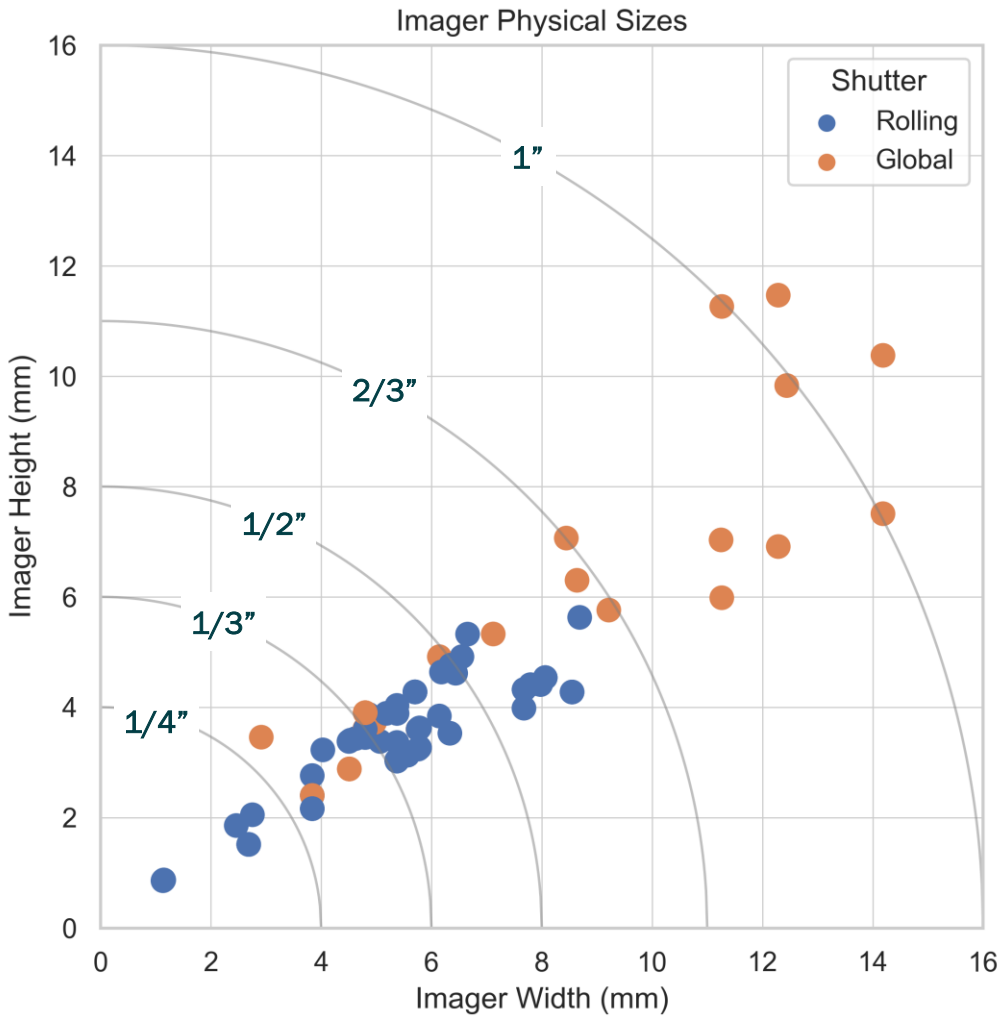
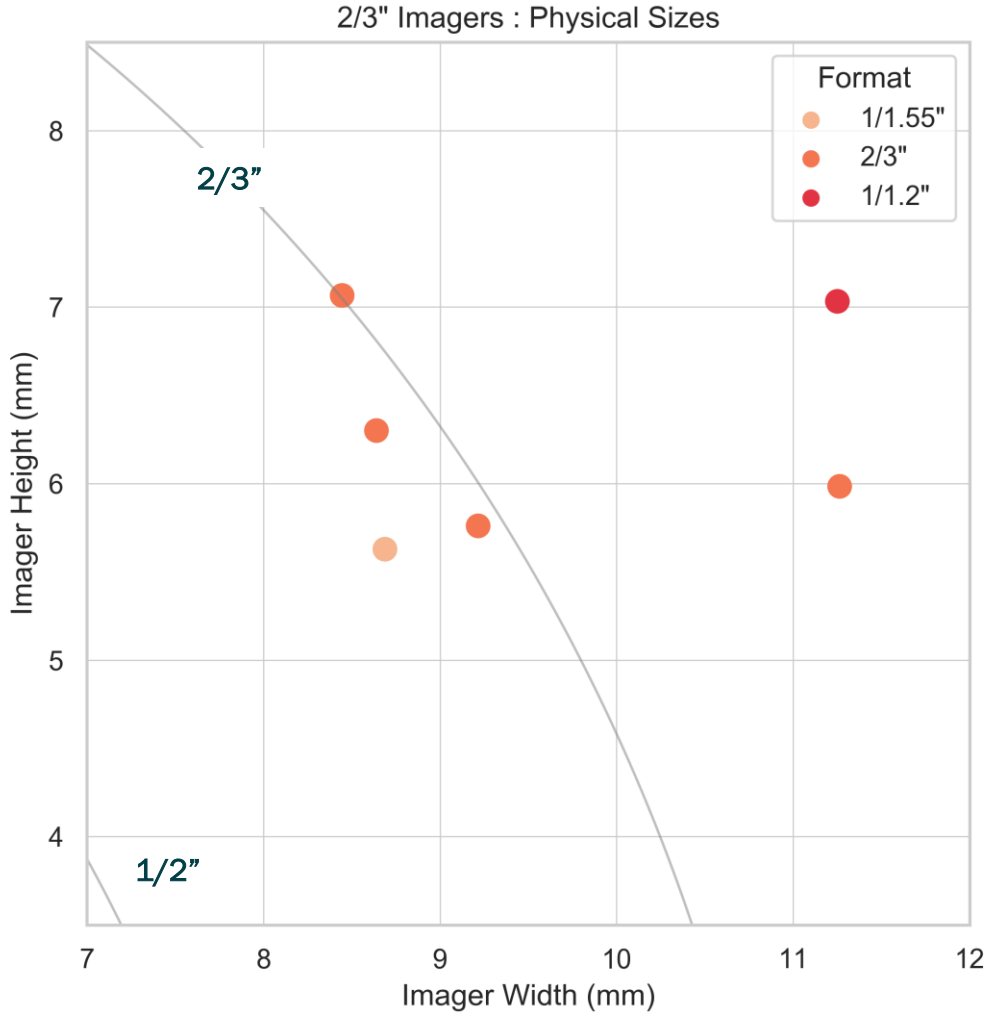
Imagers : Market Trends : Size Variations





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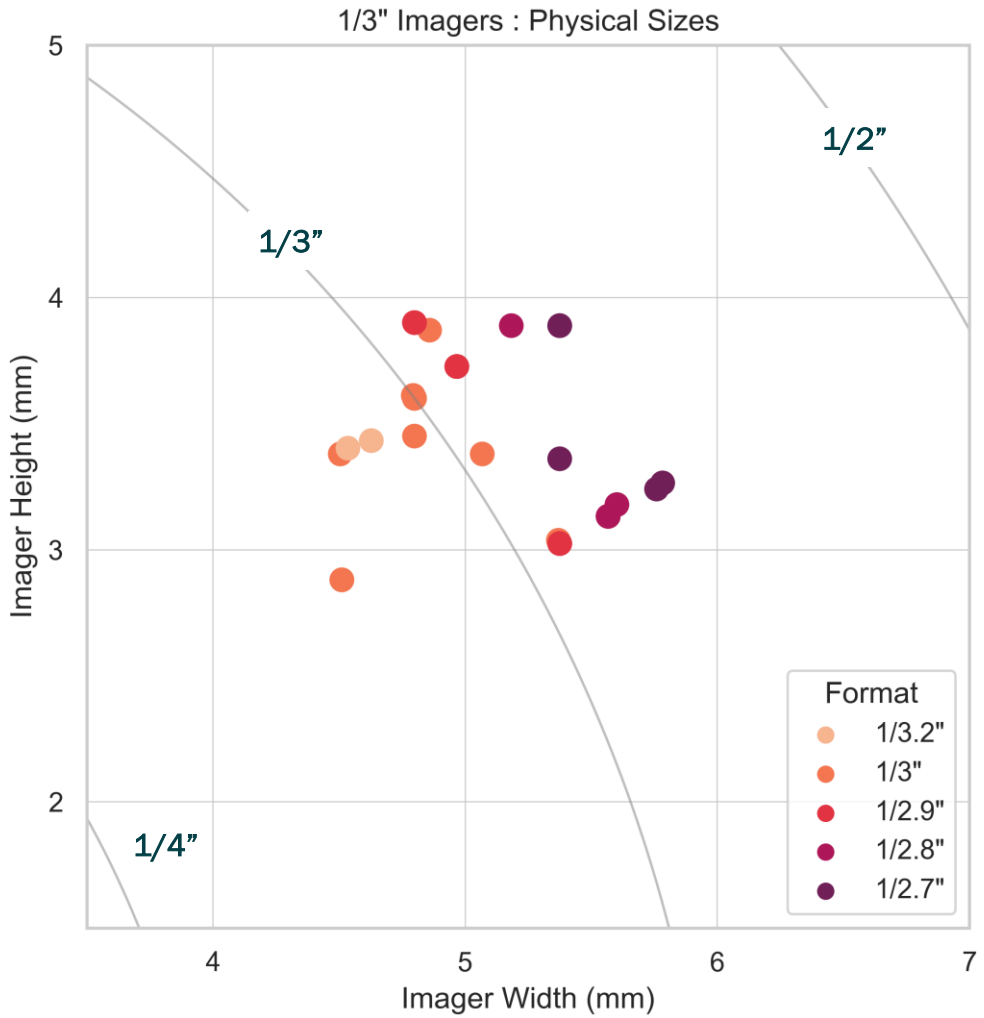
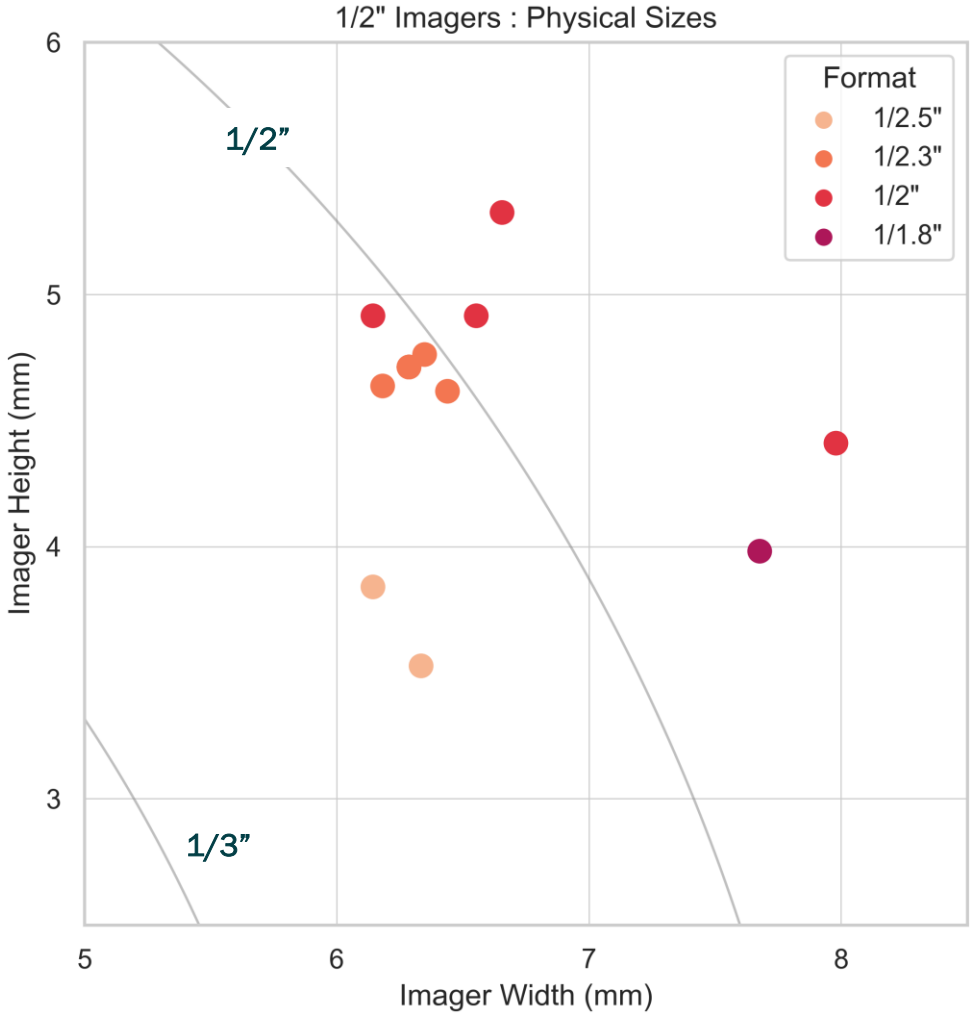
Imagers : Market Trends : Size Variations





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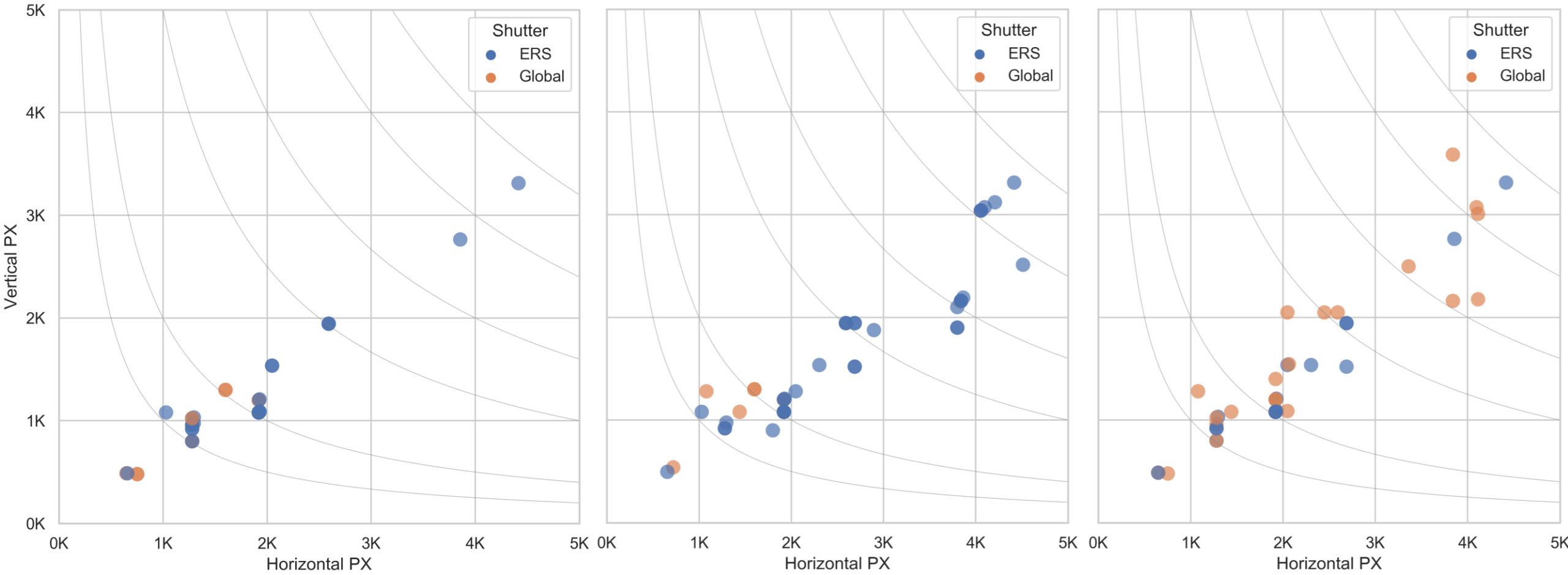
Imagers : Market Trends : Output Interface



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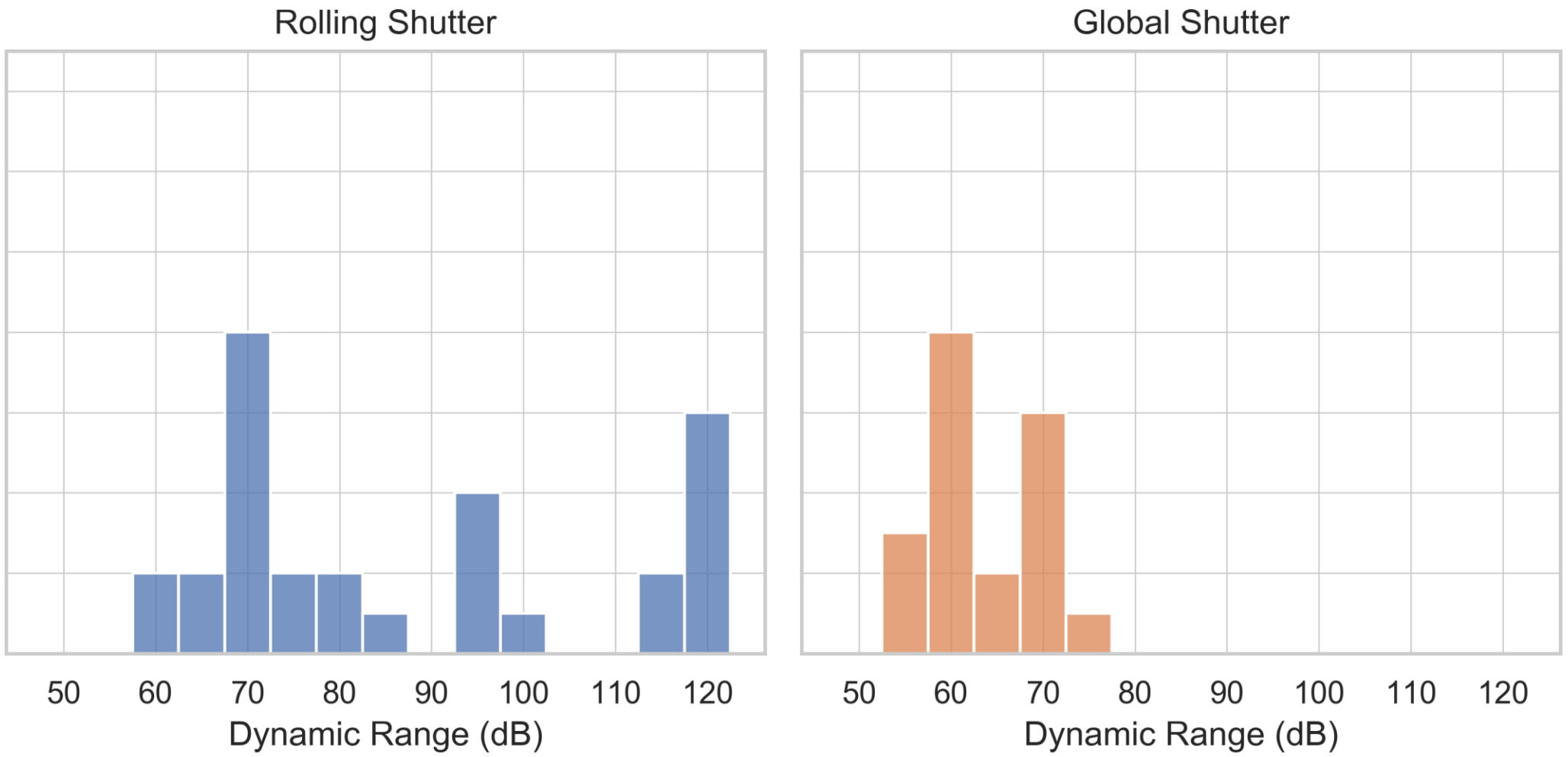
Imagers : Market : Histograms of Dynamic Range



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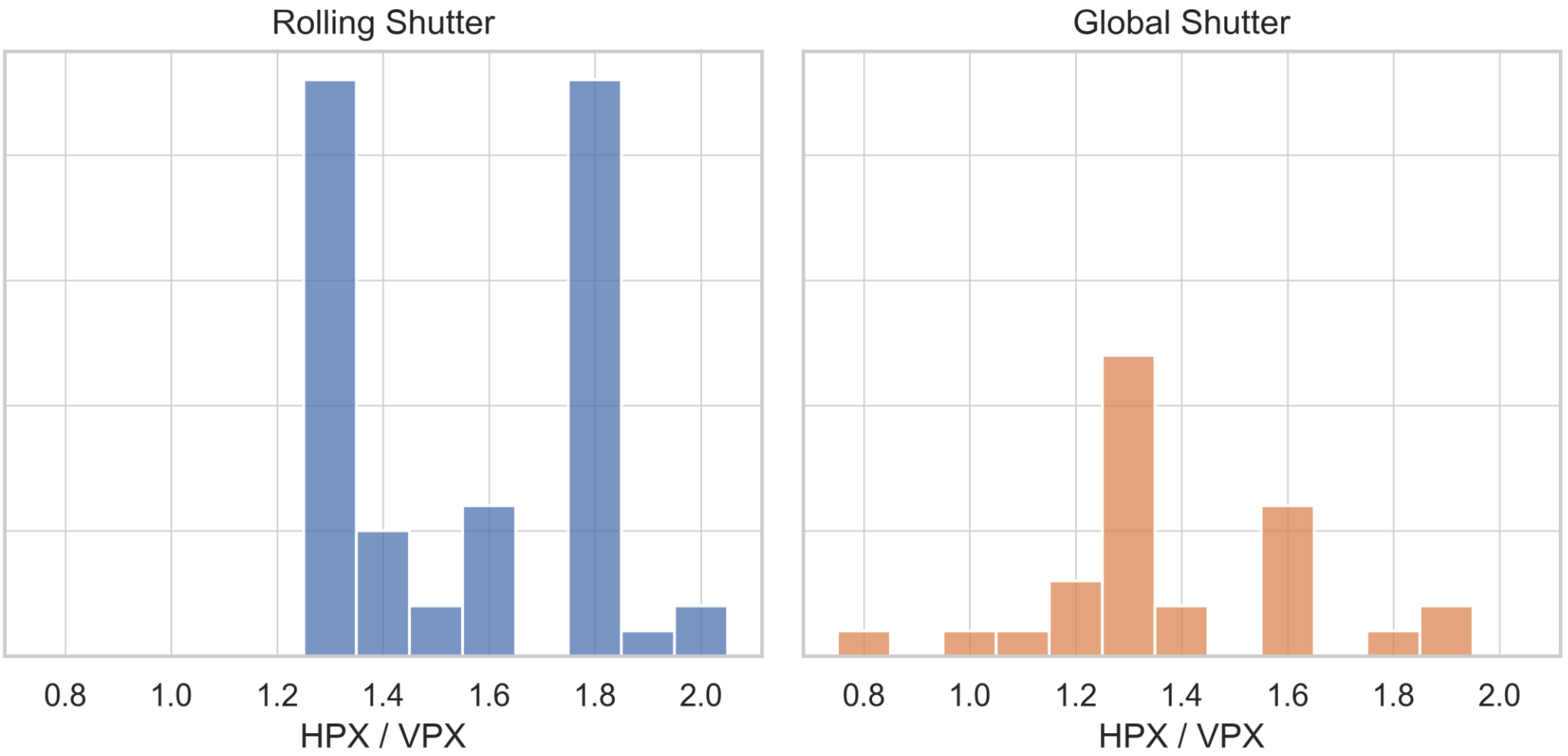
Imagers : Market : Histograms of Aspect Ratio



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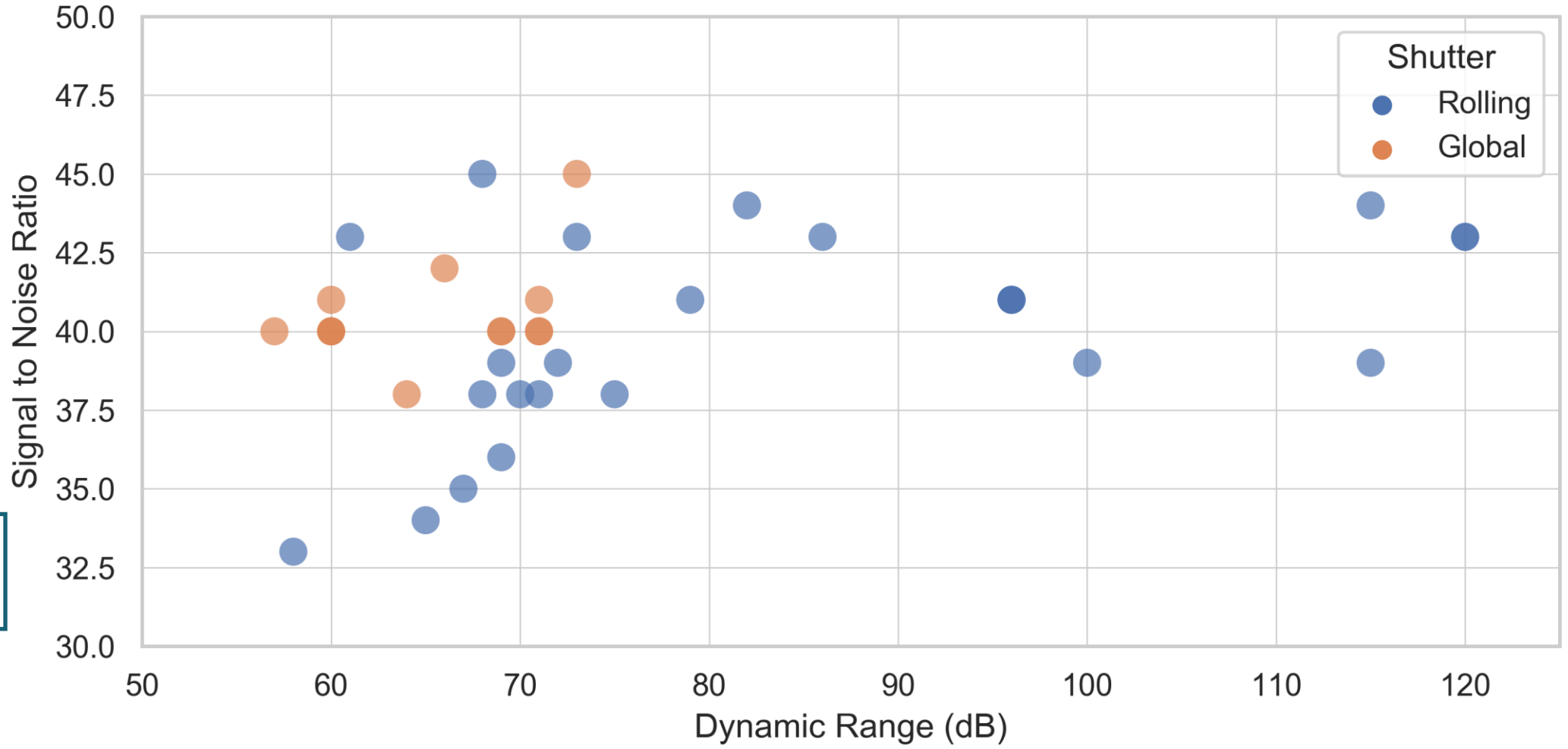
Imagers : Market Trends : Dynamic Range vs SNR



Circles darken with the imager count at that plot location

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How do you choose an imager?

1. **Determine Color Filter Array (CFA) :** Monochrome, RGB, RCCB, RCCC, or RGB-IR
2. **Determine Shutter :** Rolling Shutter or Global Shutter
3. **Choose Resolution (or HPX or VPX):**
    - Remember that most imagers can be 2x2 binned. So if you need:
        - ~1.3 MPx, also consider 5 Mpx (4x) imagers with ~1/2 the pixel pitch.
        - ~2.3 MPx, also consider 8 Mpx (4x) imagers with ~1/2 the pixel pitch.
4. **Choose pixel pitch & physical size** to accommodate lens size, weight, cost requirements you have.
5. **Choose next "hard" requirement.** Could be:
    1. Electrical interface
    2. Dynamic range
    3. Vendor access
    4. Lead time and stock availability at distributors
    5. Which integrator has the right form factor, external interface, drivers, etc.

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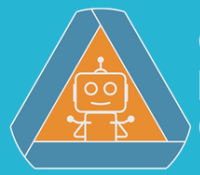
Lenses



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Lenses : Performance Criteria

- **Optical Size:** Trade size, does not equal the actual size of the image circle

- **Field of view =** $2 \arctan \frac{d}{2f}$ Note, this assuming no distortion affects.
  d = image circle diameter (mm), f = focal length (mm)

- **Aperture:** Ability to gather light.
  - Lower numeric f-stop increases number of photons hitting the imager.
  - Higher numeric f-stop increases depth of field (what is in focus).
- **Resolving Power & Sharpness:** Scored via Modulation Transfer Function (MTF)
- **Distortion:** No recognized standard here.
- **Temperature & Vibration Rating:** No recognized standard here.

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Lenses : Non-Performance Criteria

- Mounting
- Sealing
- Length & Diameter
- Weight
- Coatings
- Adjustable Aperture
- Adjustable Focus
- Adjustable Zoom
- Price

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Lenses : Vendors

- Sunex
- VST
- Kowa
- Edmund Optics
- Tamron
- Schneider Optics
- Fujinon
- Computar

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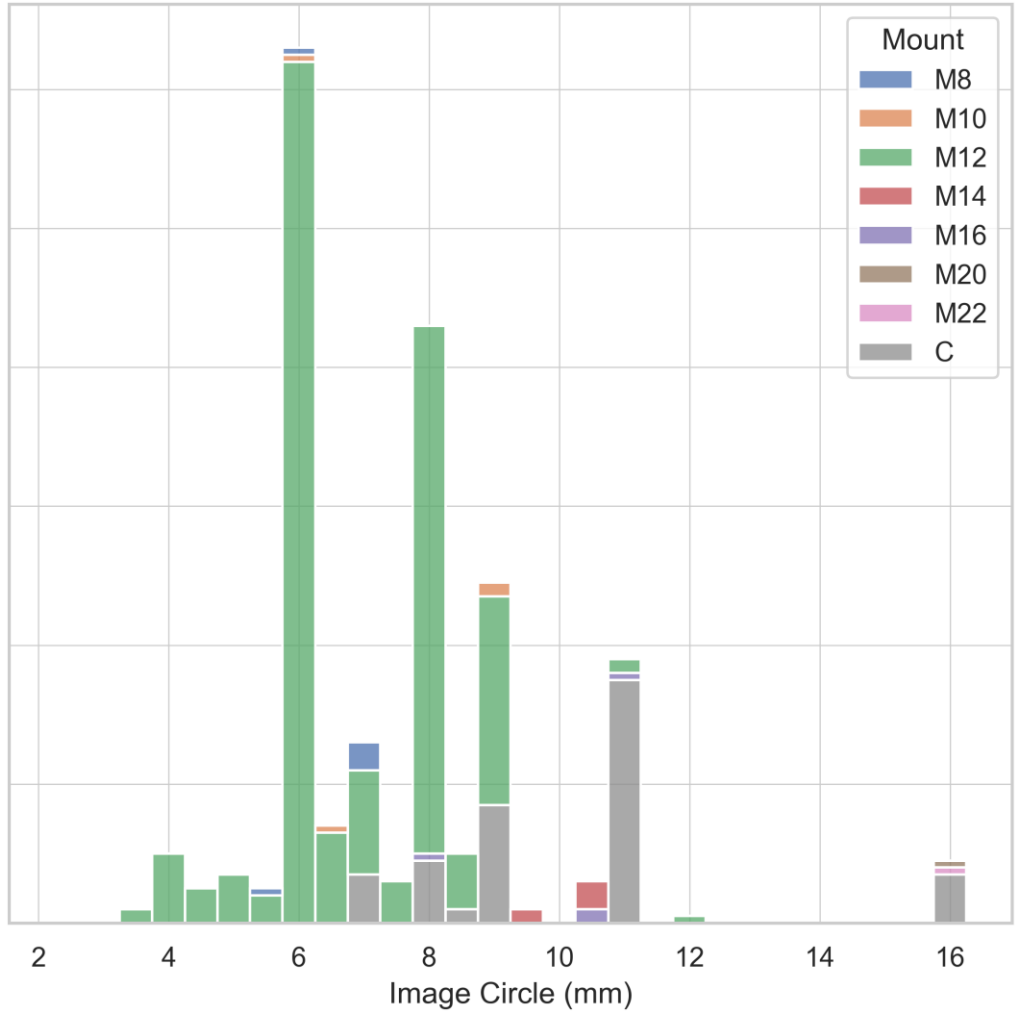
Lenses : Mount vs Optical Format

- There are more lens mounts than just M12 & C, though those are the most common by far.
- Selecting for a slightly non-standard image size either means:
  - Limiting your choice in FOV by using a lens designed for that particular image circle.
  - Picking a smaller lens and living with corner vignetting.
  - Picking a larger lens and “wasting” FOV.



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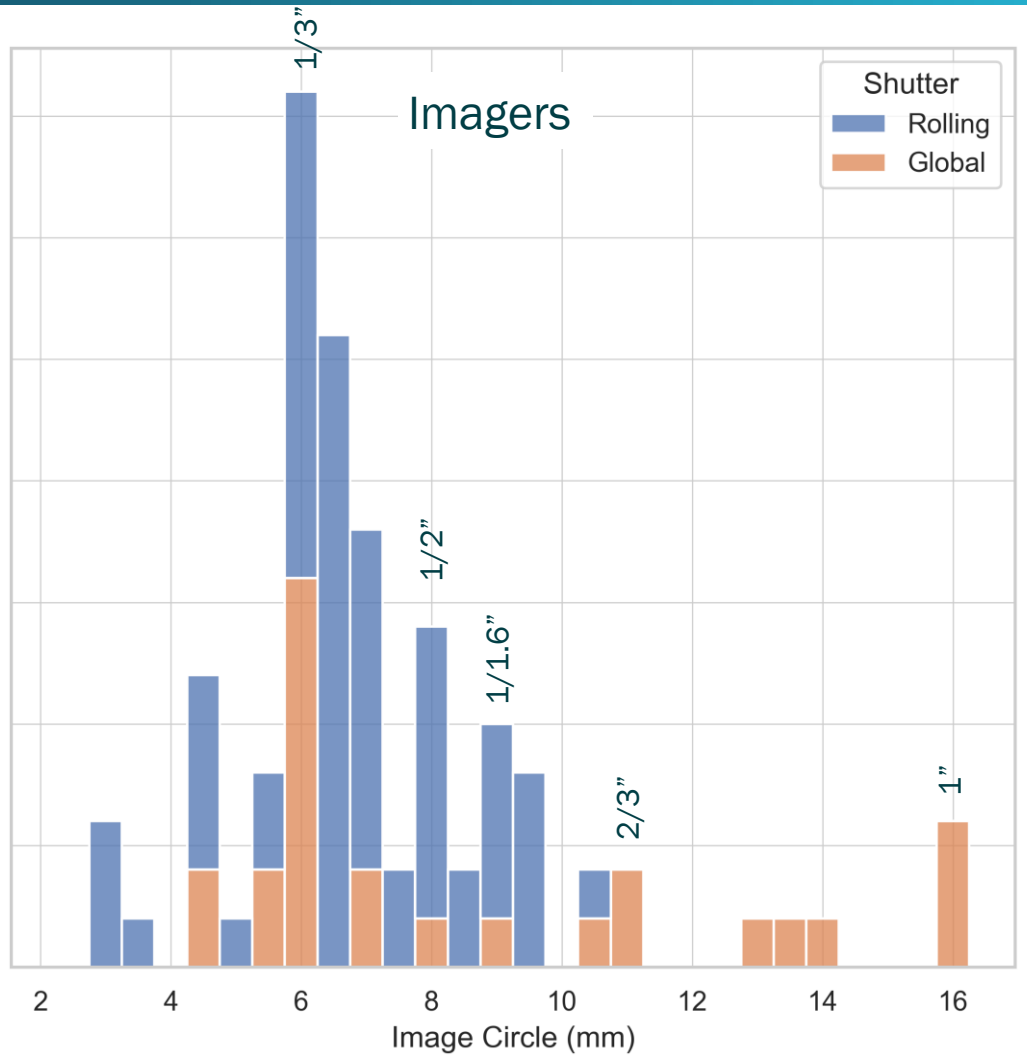
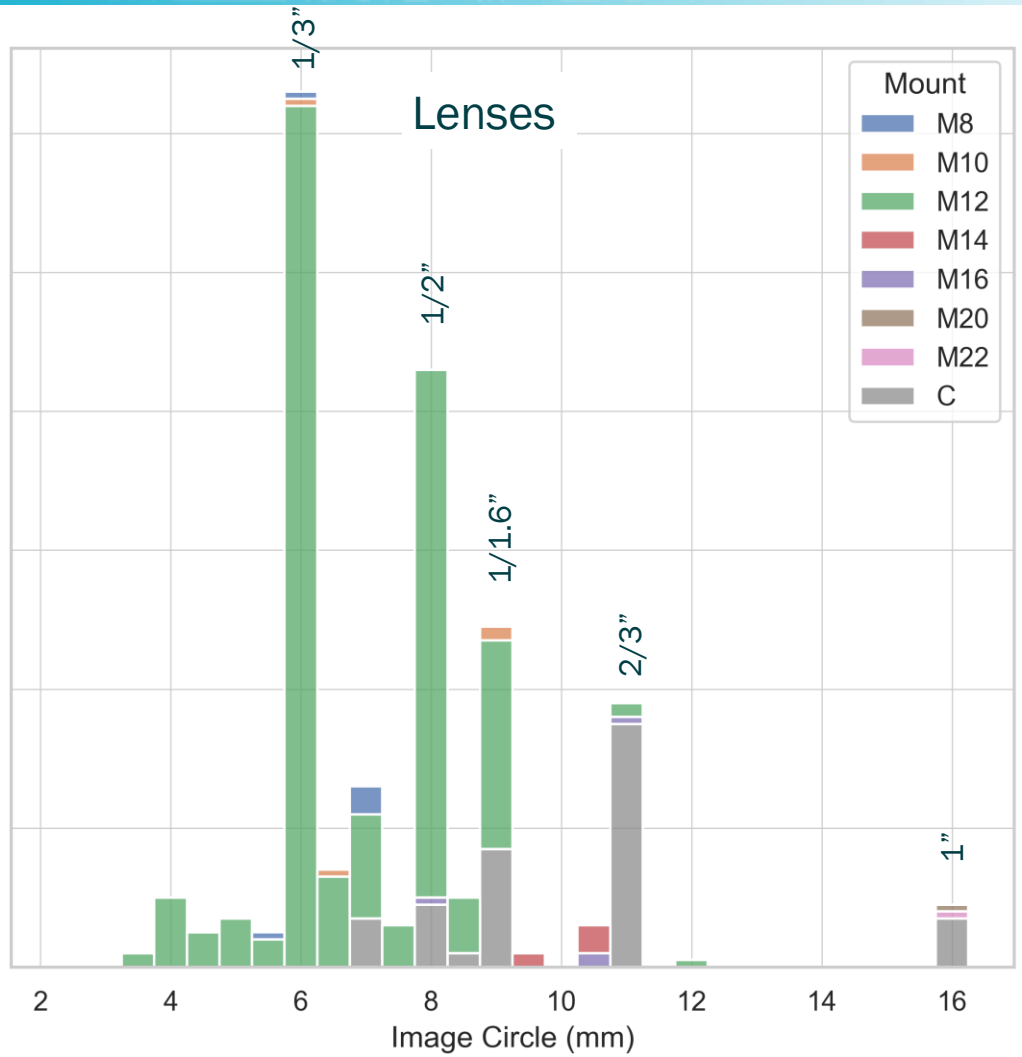
Imager & Lens : Histograms of Image Circle





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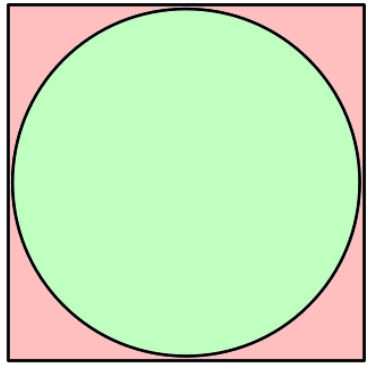
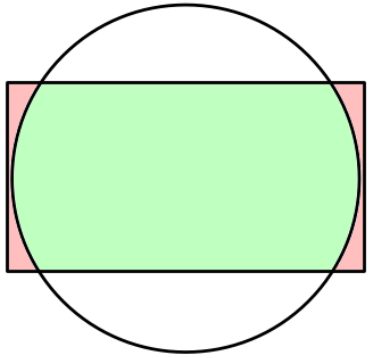
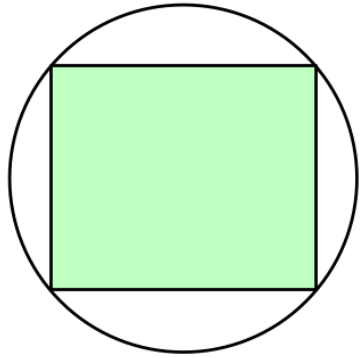
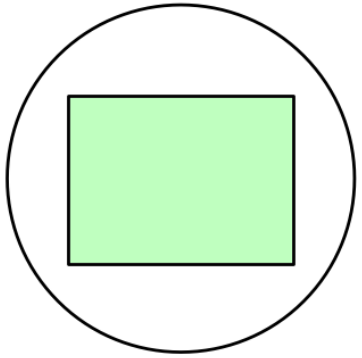
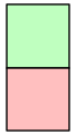
Lenses & Imager Matching : Optical Size

Imager Size	1”	2/3”	2/3”	1/1.8”
Visualization with 2/3” Optical Format Lens				
Illumination	74%	92%	99%	100%
FOV : 5mm fl	95° x 95°	95° x 62°	80° x 70°	70° x 56°



Illuminated Pixels

Dead Pixels

Note: This is physical imager size vs lens optical format. System’s optical resolving power is dependent on imager resolution and sharpness of lens.

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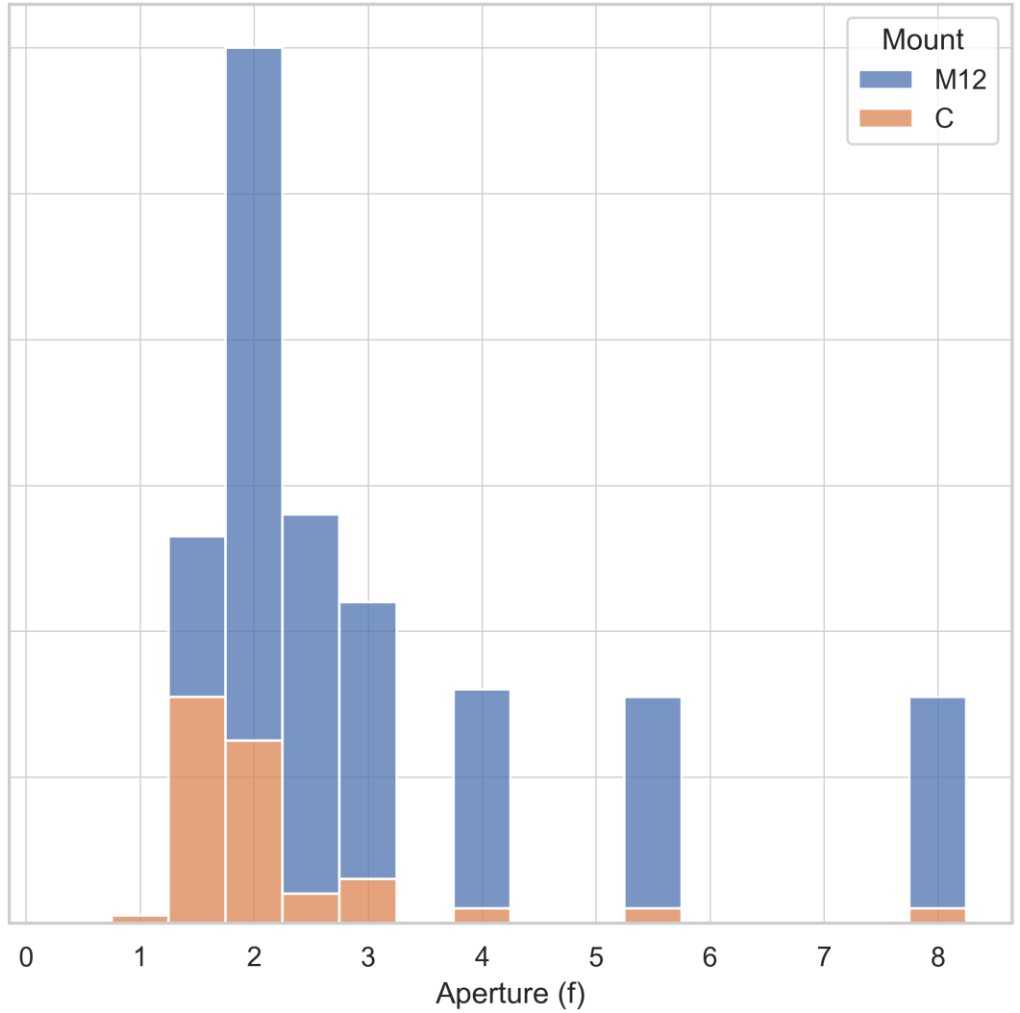
Lenses : Mount vs Aperture

- Histogram here is just for M12 and C Mounts.
- When a lens has variable aperture, it is represented here at its widest aperture (lowest numeric value).



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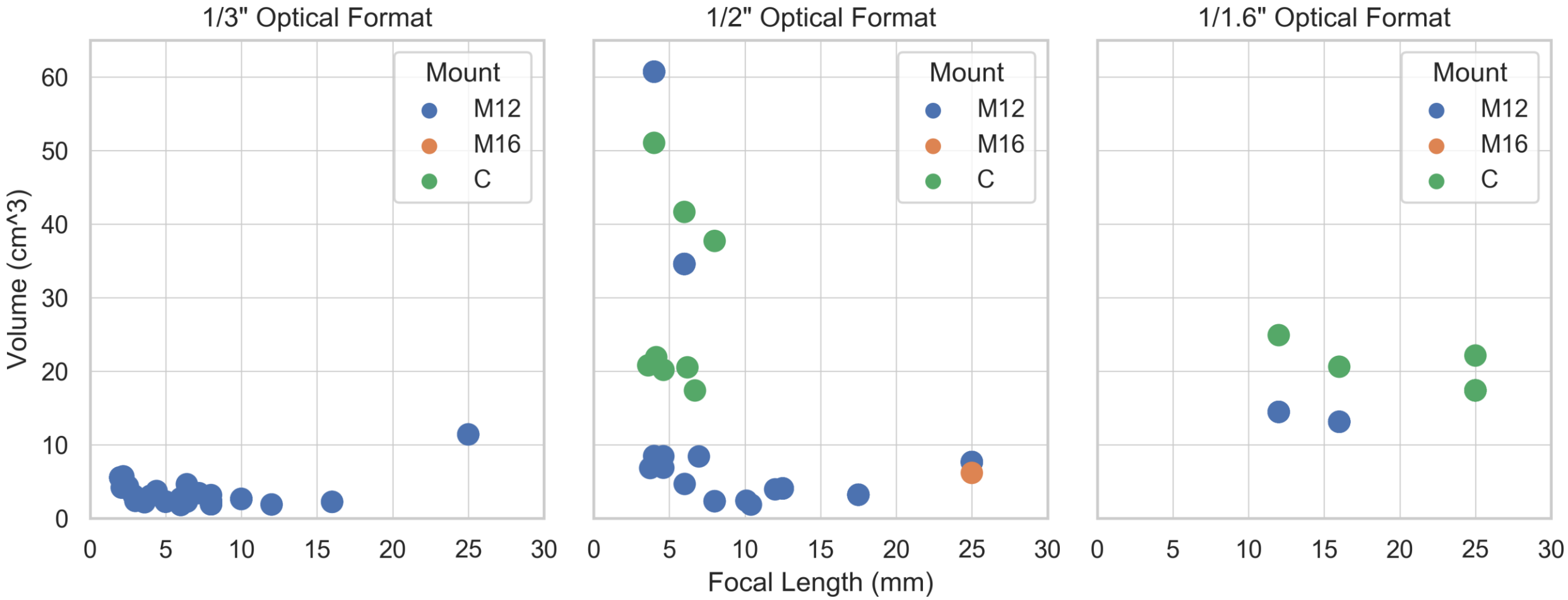
Lenses : Focal Length vs Volume



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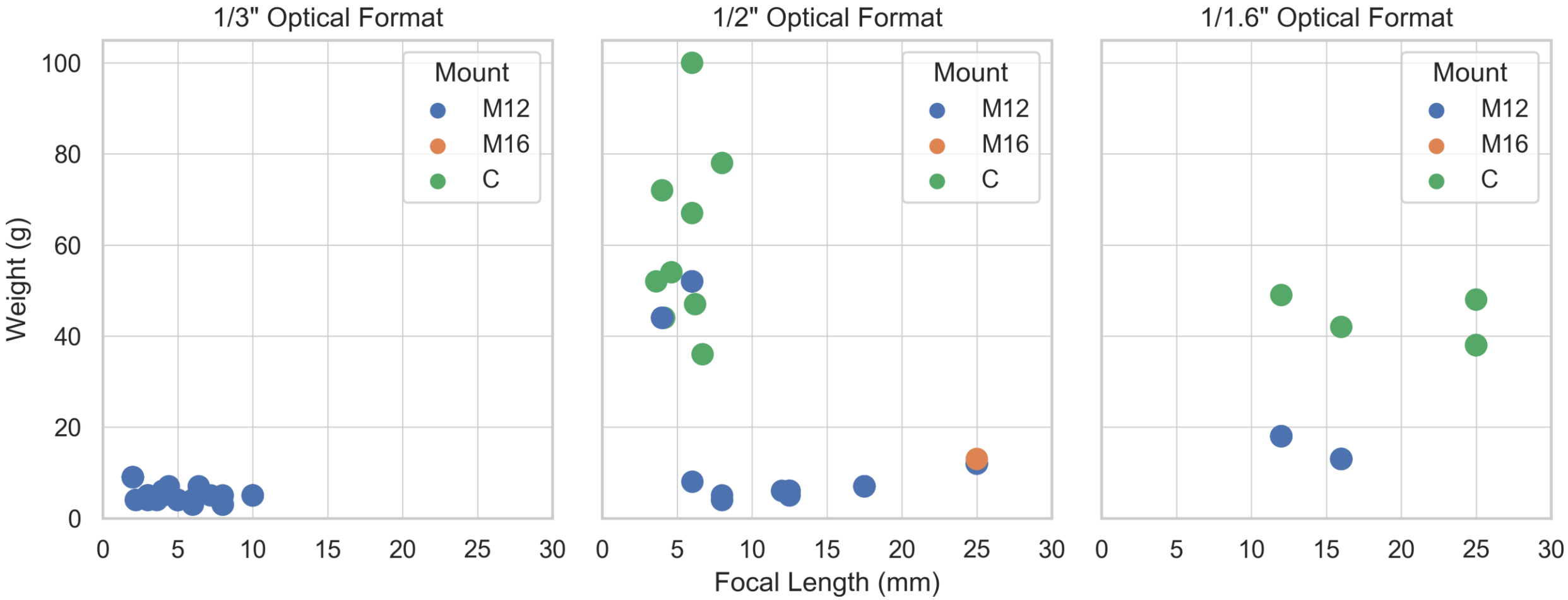
Lenses : Focal Length vs Weight



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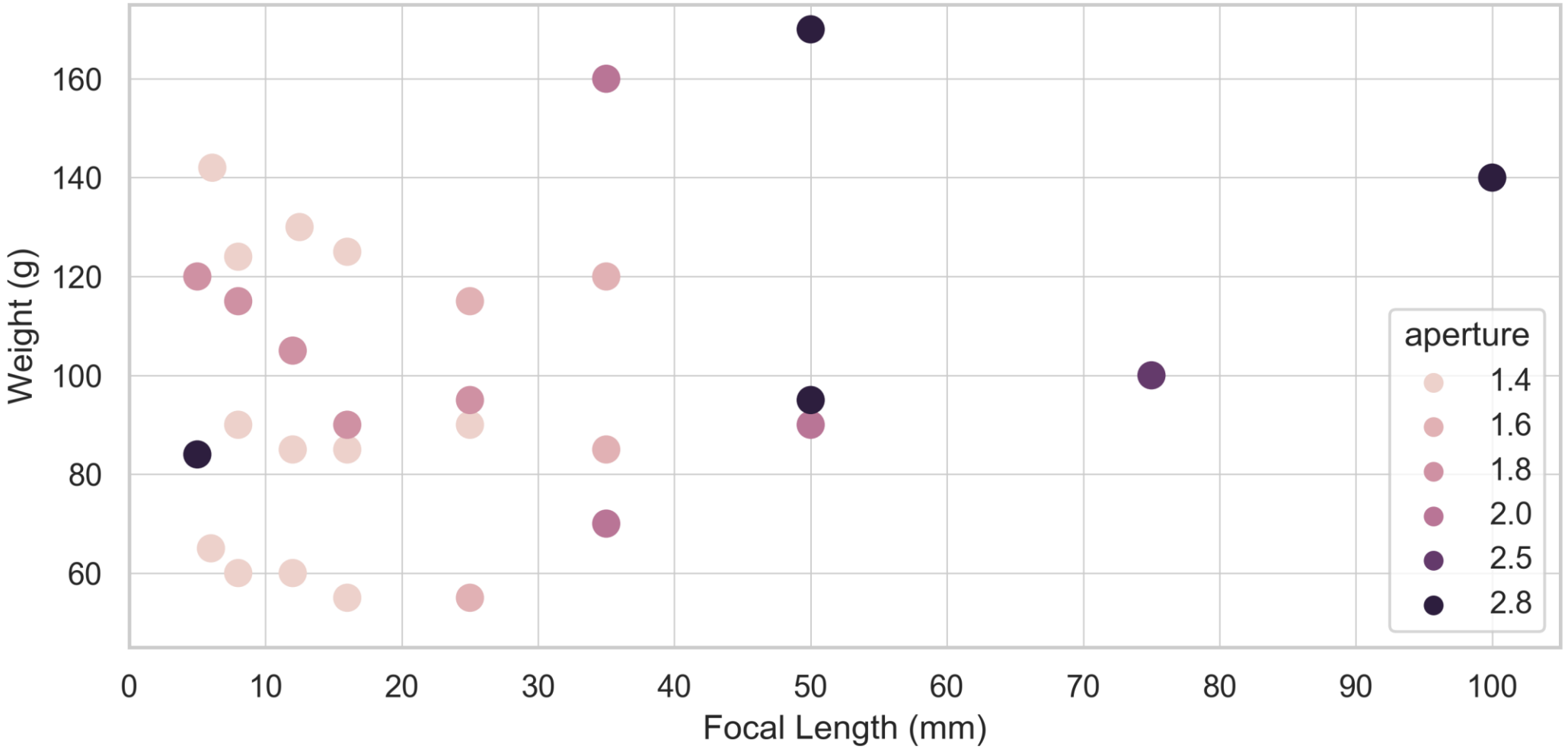
2/3” Lenses : Focal Length vs Weight



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How do you choose a lens?

1. **Determine range of Horizontal and Vertical FOV you need.**
2. **Select optical format(s)** which match your selected imager.
3. **Select next "hard" requirement, could be:**
    1. Lens Mount
    2. Aperture
    3. Optical resolving power / rated resolution
    4. Size & Weight
    5. Cost

Similar →

Focal Length	12mm	5mm	3.6 mm
Optical Format	4/3"	2/3"	1/3"
FOV	75° x 60°	82° x 65°	78° x 49°
Size	⌀57mm x 85mm 94x	⌀42mm x 38mm 23x	⌀14mm x 15mm
Weight	270g 67x	85g 21x	4g

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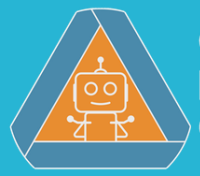
Conclusion



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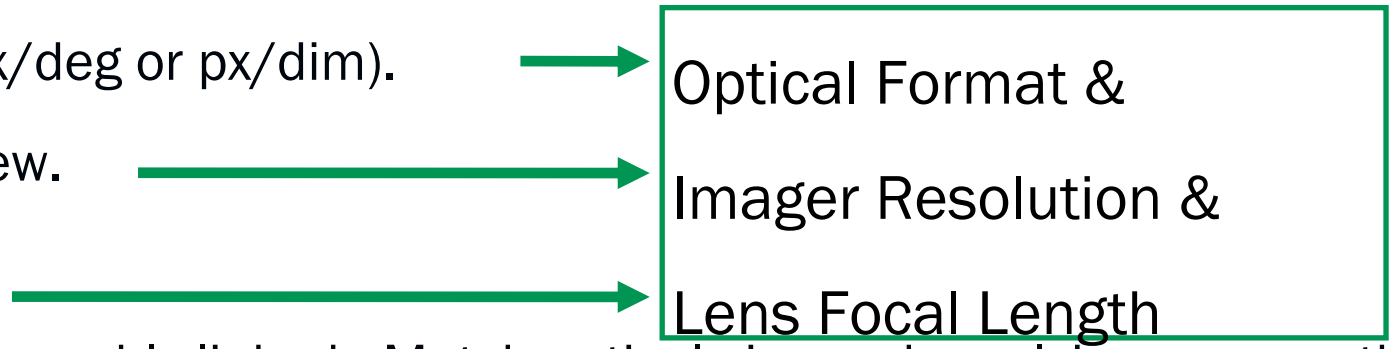
Conclusion / Summary

- Imager and Lens vendors have areas of interest and expertise.
- Imager and lens choices should be driven by your application.
- As your application changes, the vendors you source from will likely change too.
- Consider:
  - Resolving power (px/deg or px/dim).
  - Required field of view.
  - Size, weight, cost



- Imager and lens are inexorably linked. Match optical size and resolving power, otherwise waste in size, weight, & cost

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Additional Resources

Imagers

https://micro.magnet.fsu.edu/primer/digitalimaging/cmosimagesensors.html

http://www.imatest.com/solutions/iqfactors/

http://image-sensors-world.blogspot.com

Lenses

https://en.wikipedia.org/wiki/Angle_of_view

https://www.the-digital-picture.com/Help/MTF.aspx

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