

Fast Reactive Illumination through Rain and Snow

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Sponsors: ONR, NSF, Intel, Samsung

Driving in Snow at Night



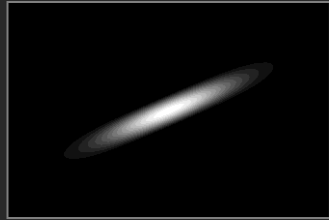
How many Rainy/Snowy Nights in a Year?

Berlin, Germany	55
Brussels, Belgium	65
Cape Town, SA	52
Chicago, USA	48
Kuala Lumpur, Malaysia	79
Paris, France	56
Pittsburgh, USA	59
Seattle, USA	62
Tokyo, Japan	50
Zurich, Switzerland	64

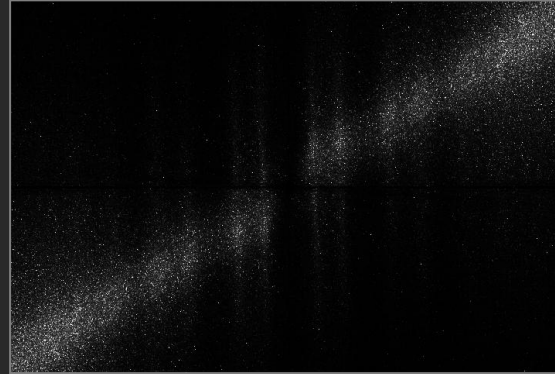
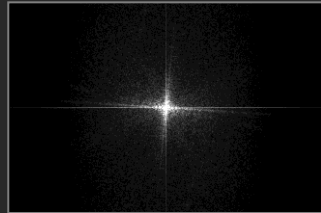
[World Meteorological Organization, 30 year average]

Post-processing: De-raining and De-snowing

Rain
frequencies

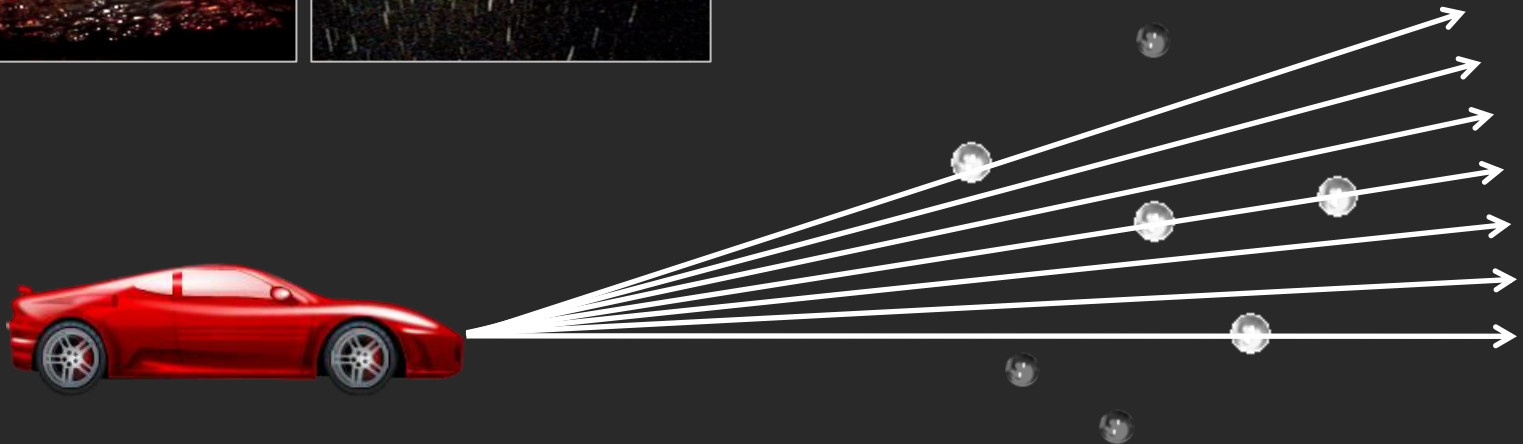


Scene
frequencies



[Barnum et al, 07]

Headlight that sees through Rain and Snow



Goal: High Light Throughput and Accuracy

[Similar in spirit to "Lighting up dust", Ken Perlin]

... a detour

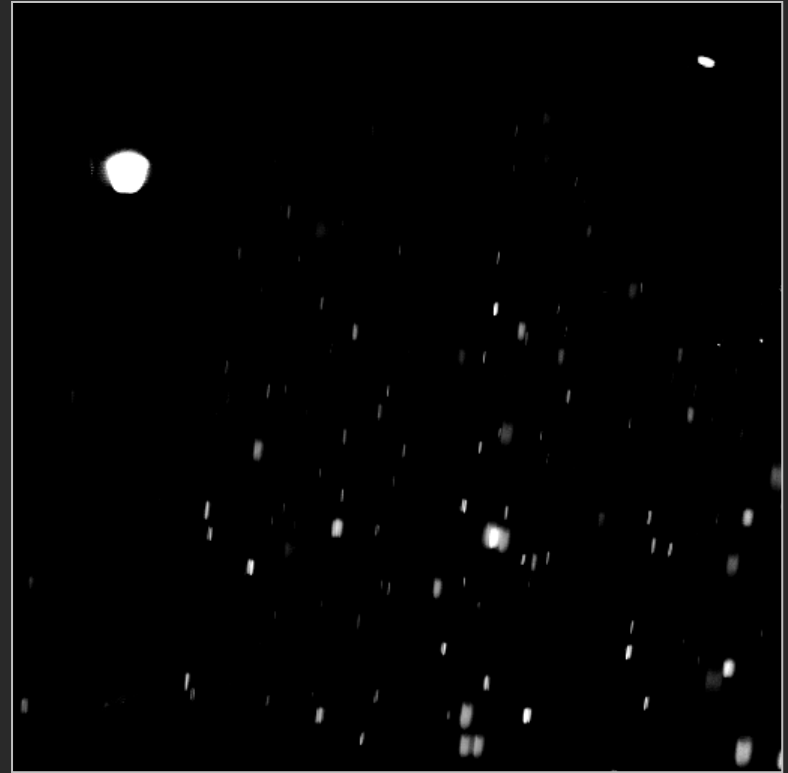


[Barnum, Narasimhan, Kanade, 10]

Rain Streaks versus Rain Drops



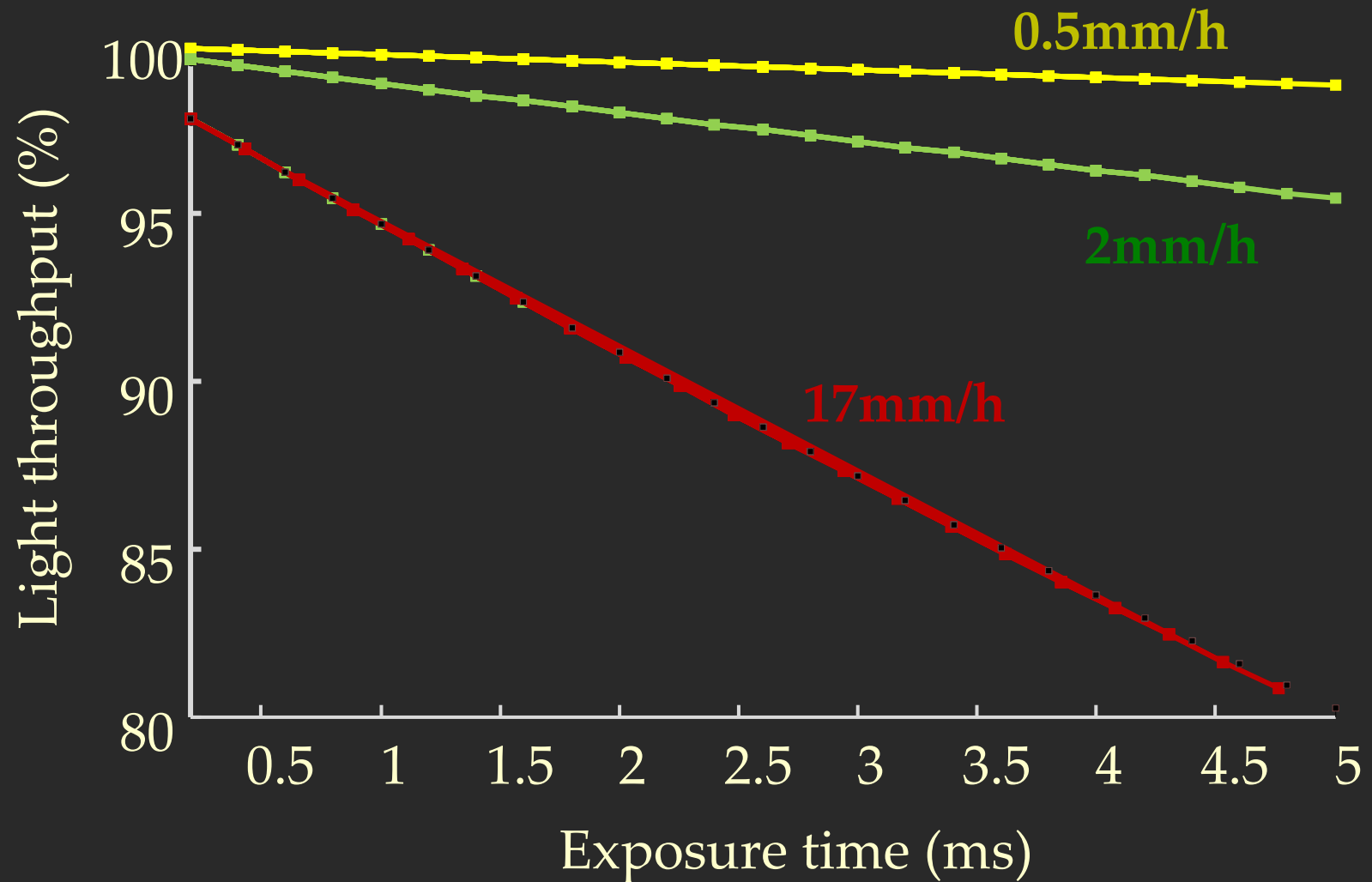
Long Exposure Time (12 ms)



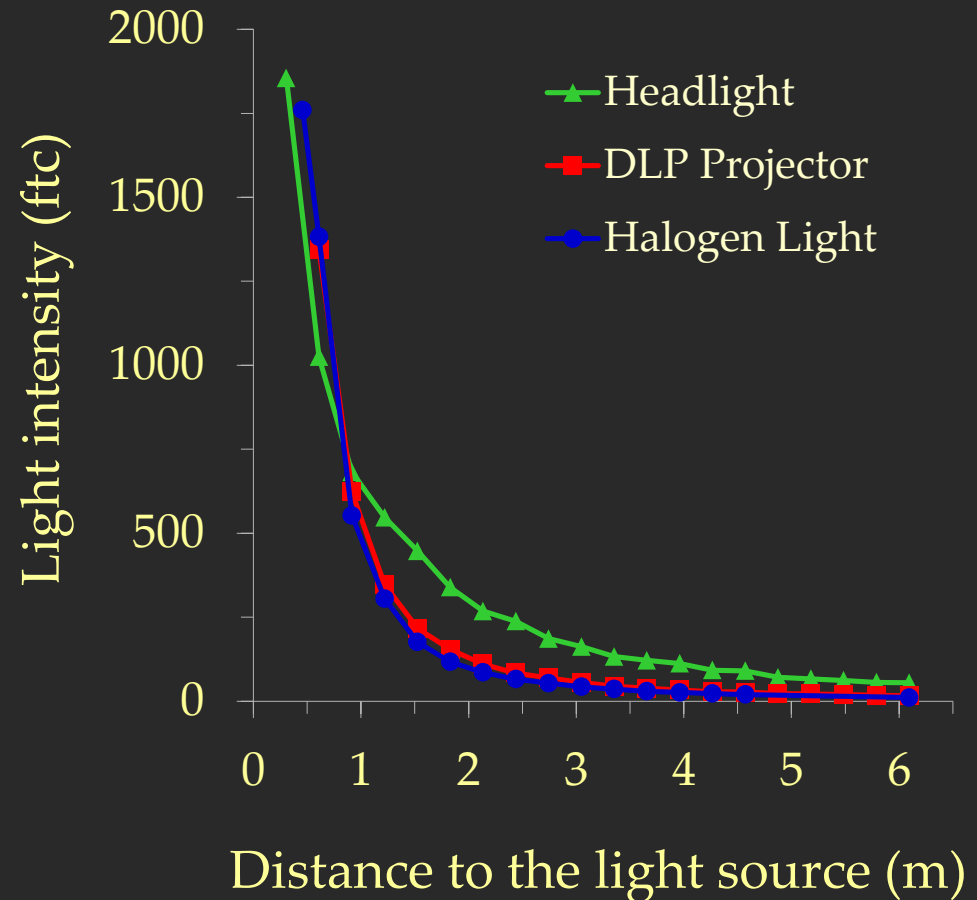
Short Exposure Time (1 ms)

Rain streaks appear dense but drops are sparse

Light Throughput and Camera Exposure

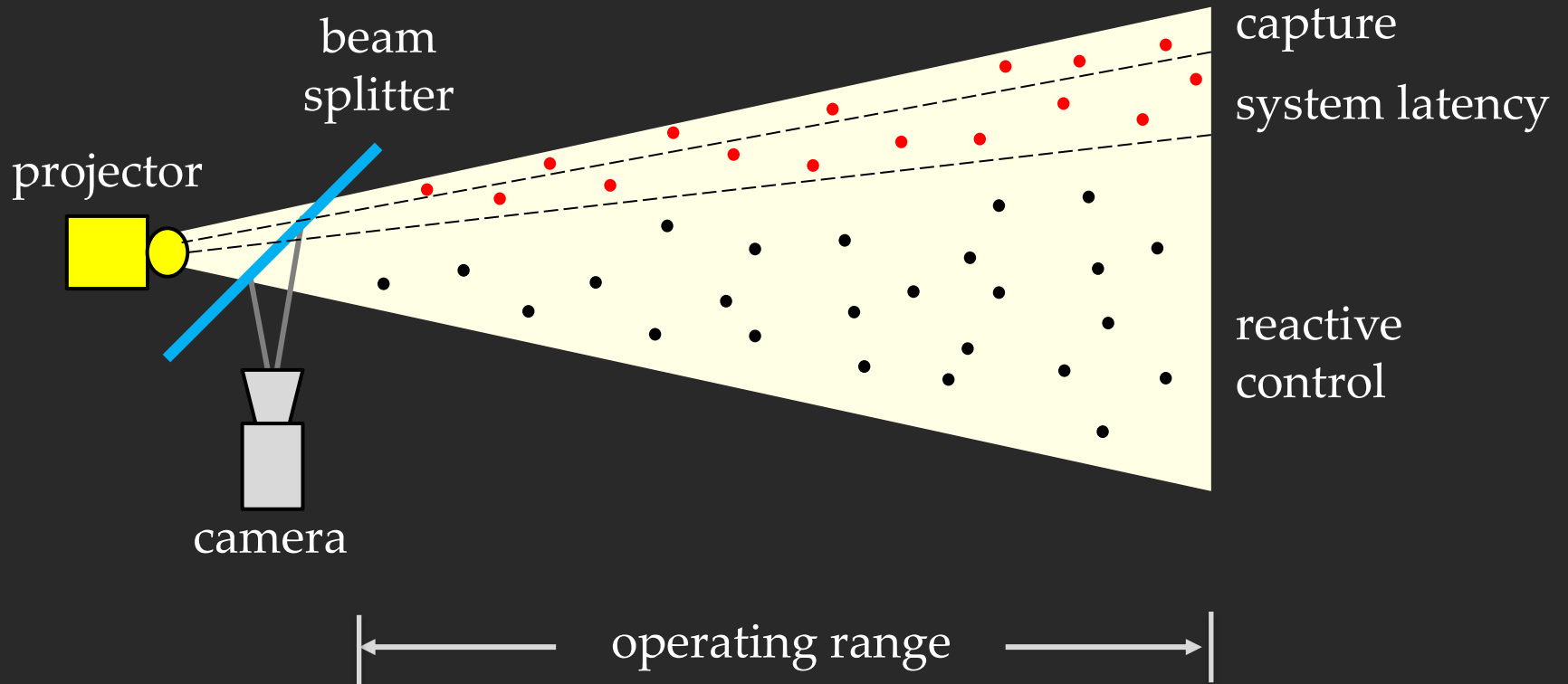


Operating Range: Visibility of Rain Streaks

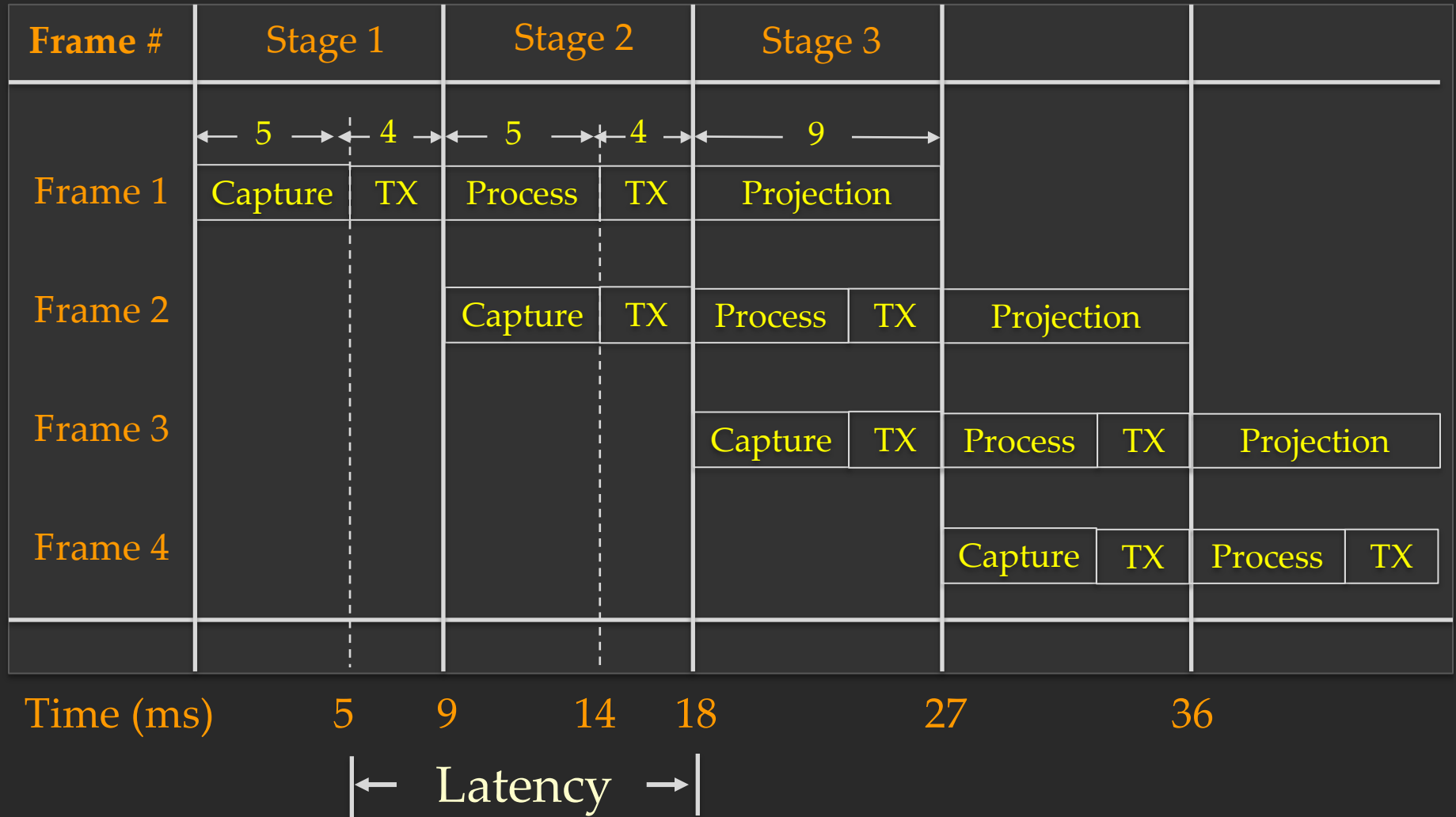


Not visible beyond 5-6 meters from the source

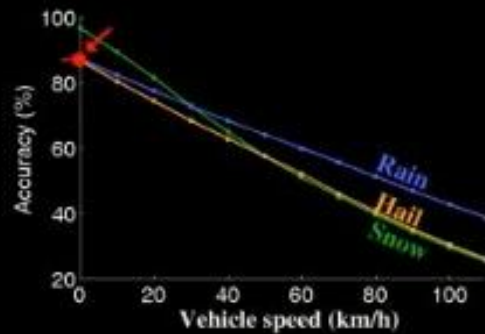
Reactive Illumination



System Pipeline

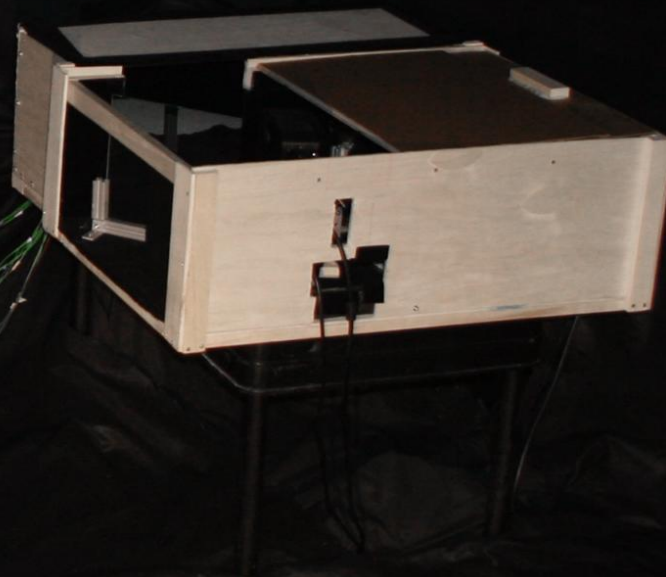
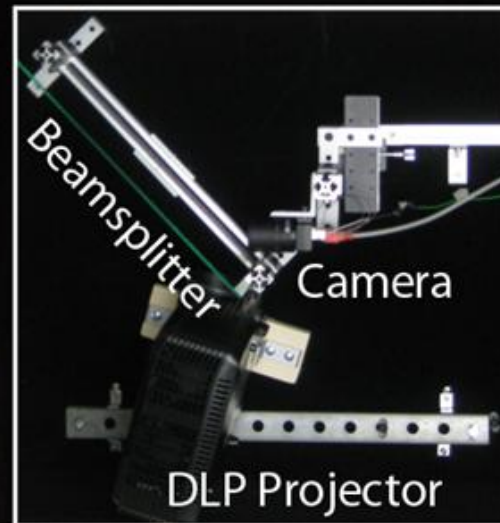


Simulated Rain

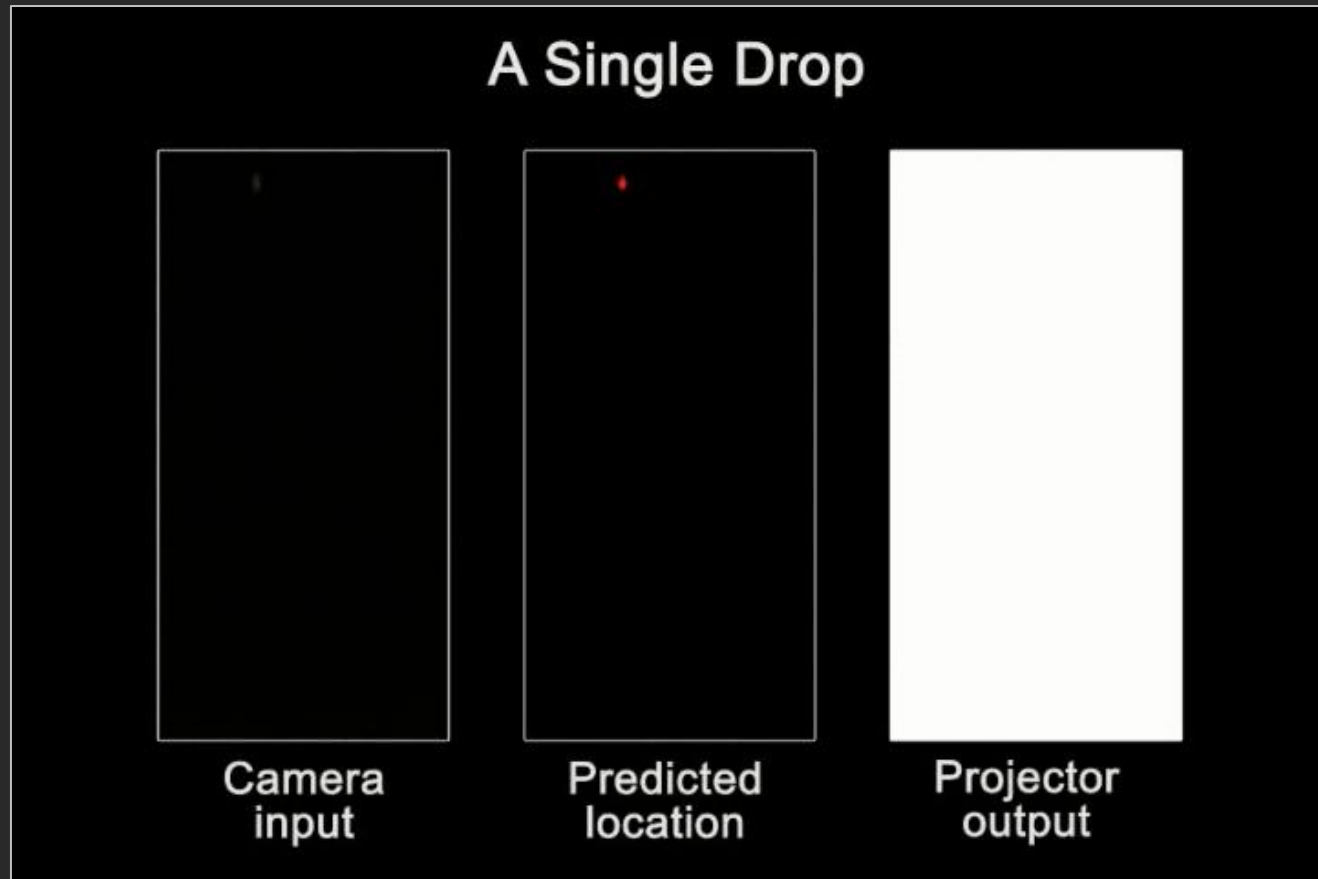


System latency 13ms
Camera/Projector 1024x1024
Detection error 2 pixels
Tracking latency 3 frames



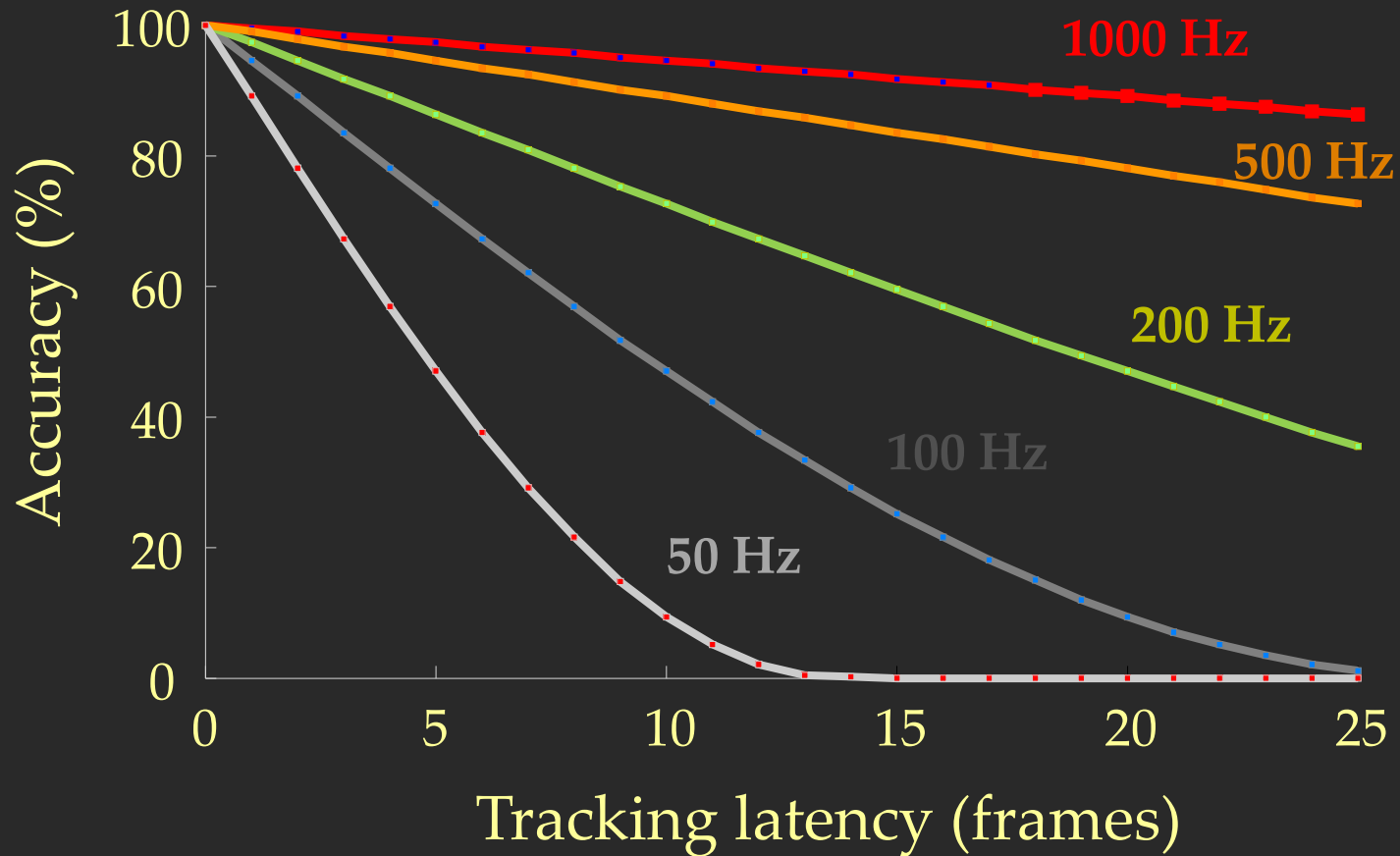


Detecting, Tracking and Predicting Drops

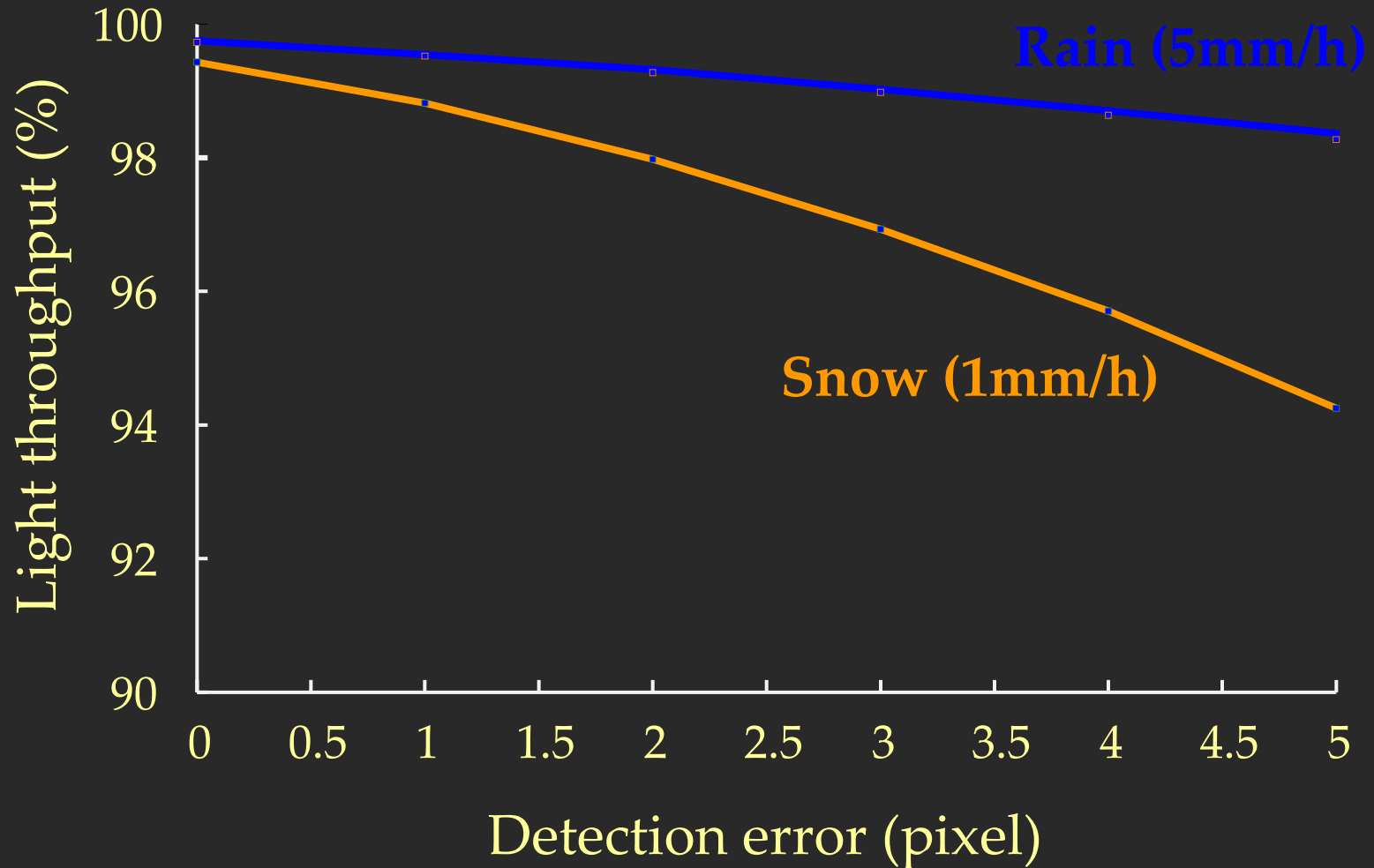


View from the system camera

Performance with Tracking Latency



Performance under Detection Errors



Slow Capture and Projection



Standard headlight



Not so Smart headlight

Projecting black streaks instead of white streaks ☹

High Speed Bit-Plane Projection

[Temporal integration]



What a high-speed camera sees
(2000 Hz)



What we see....or don't see
(30 Hz)

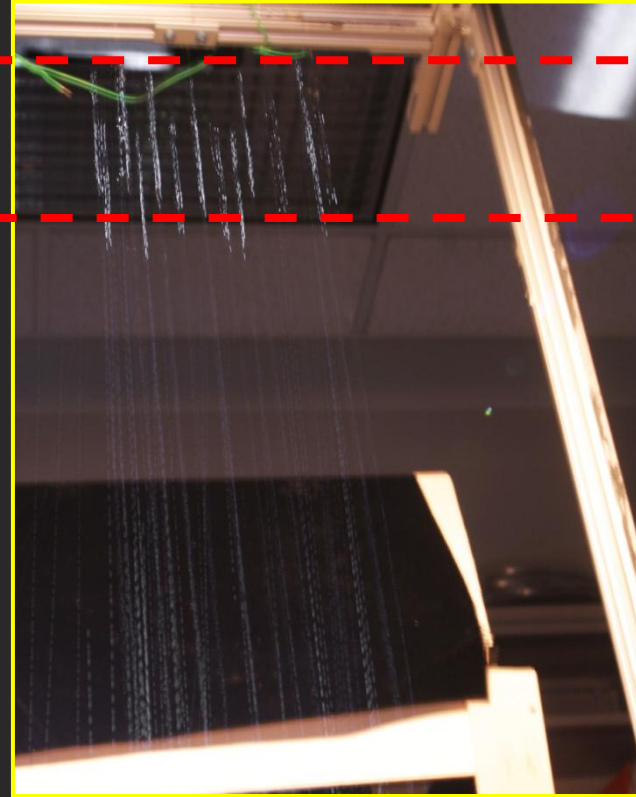
[Raskar et al, Narasimhan et al, Debevec et al]

Making Rain Disappear (90 mm/h)

System
Latency



Standard headlight



Smart headlight

Making Rain Disappear (90 mm/h)

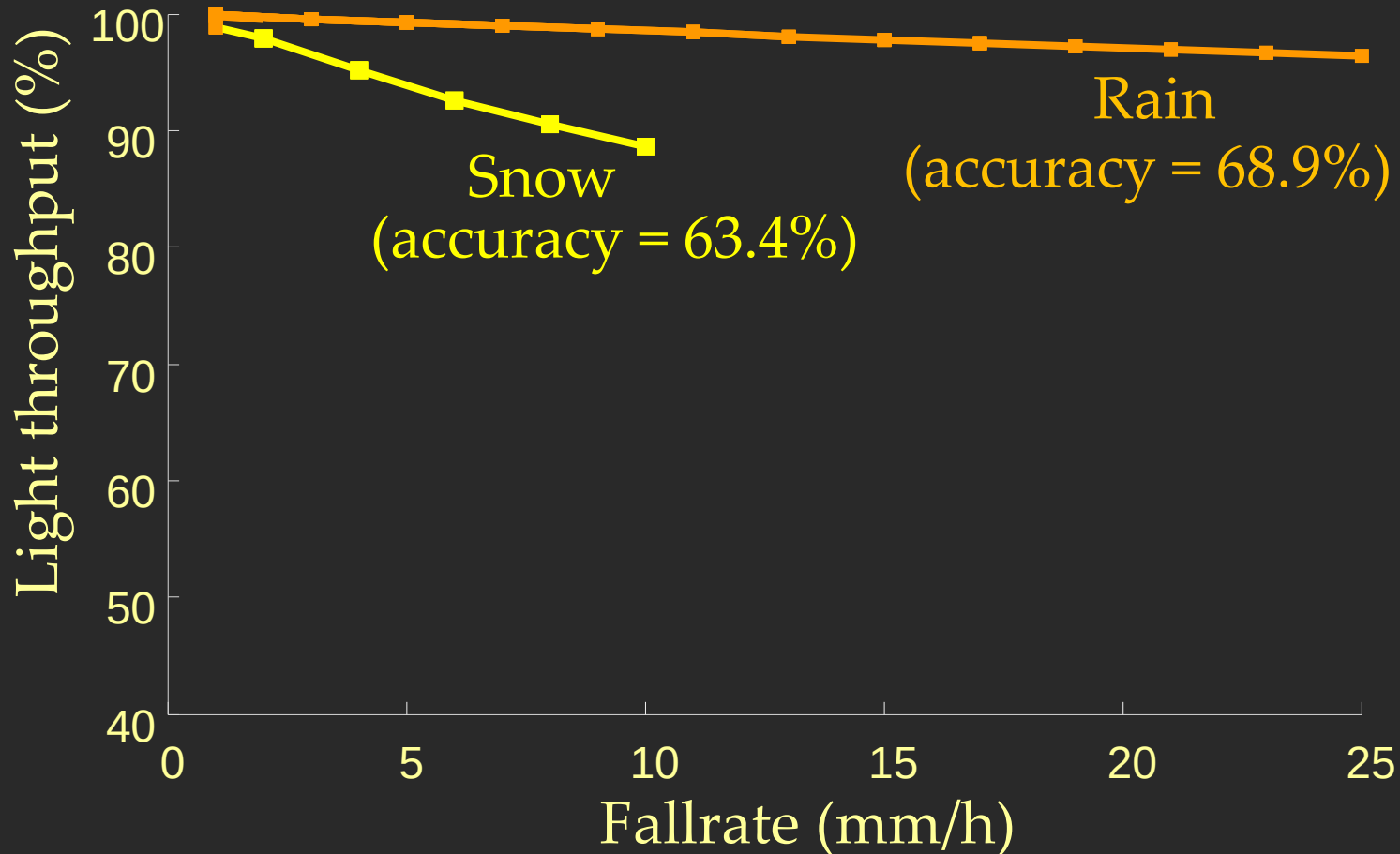


Standard headlight



Smart headlight

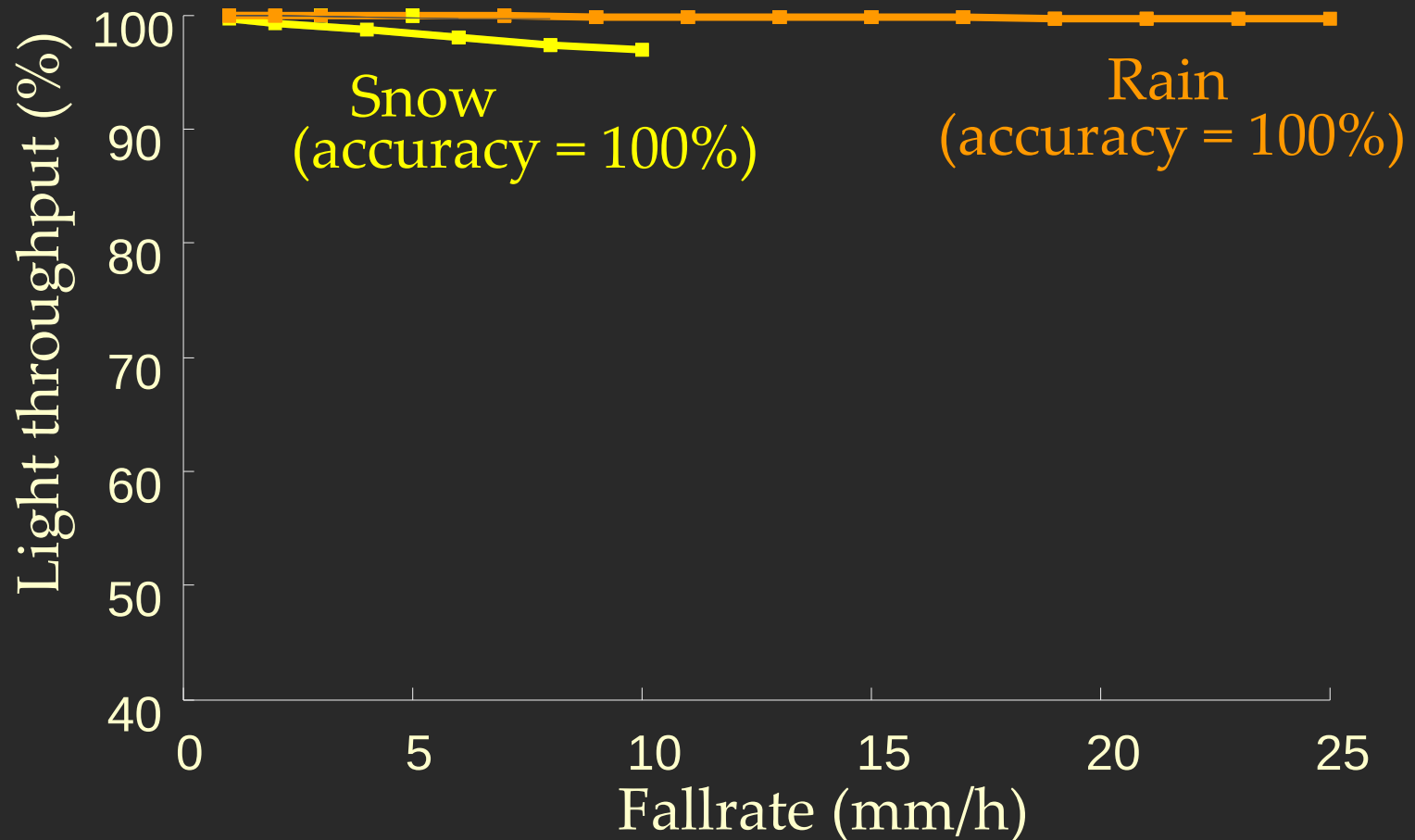
Performance of our system



System Latency: 13 ms
Imaging exposure: 5ms
Tracking latency: 1 frames

Resolution: 1024 x 1024
Car motion: 30 kph
Projection rate: 120 Hz

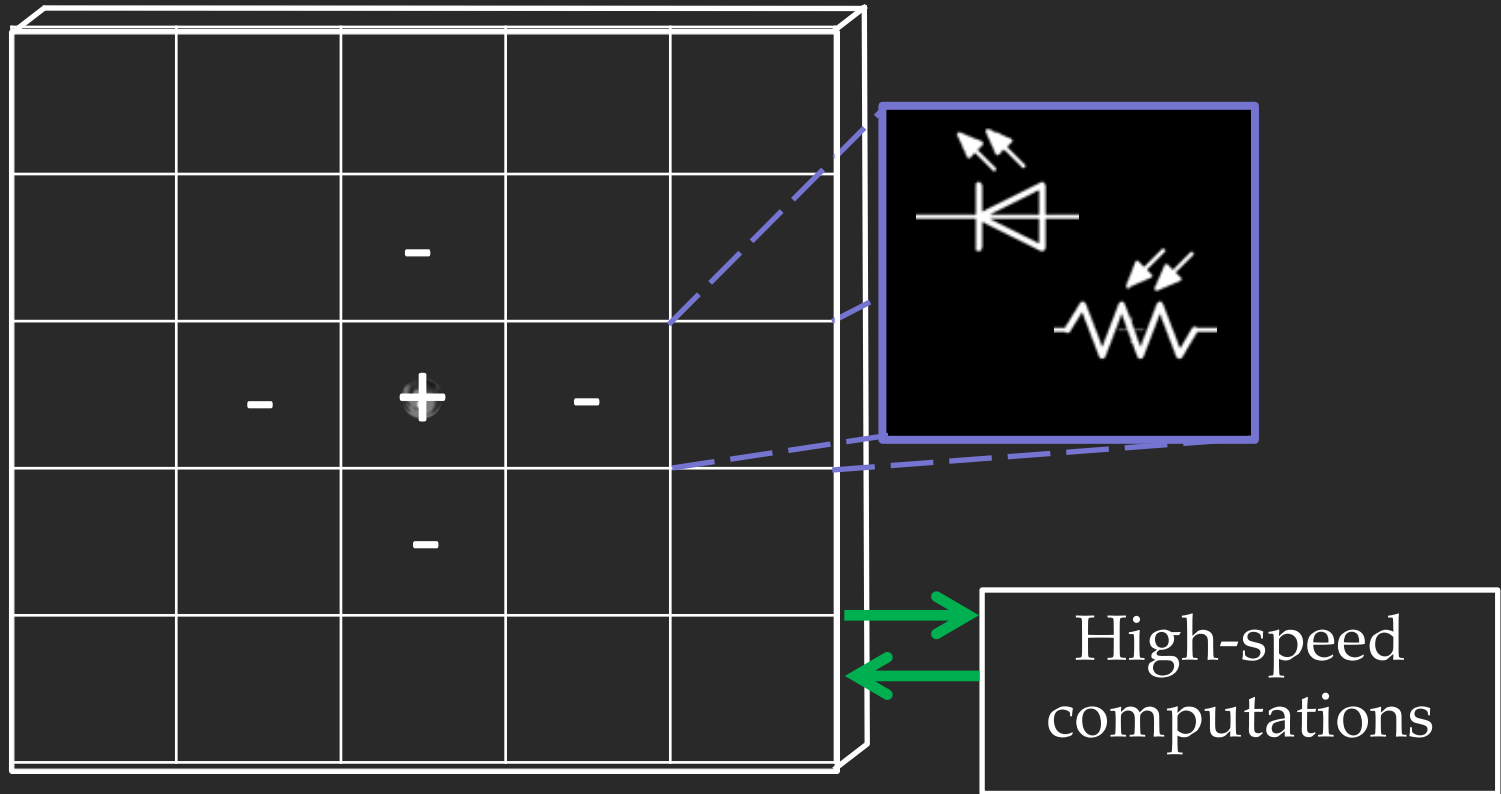
Performance of an Ideal system



System Latency: 0 ms
Imaging exposure: 1ms
Tracking latency: 0 frames

Resolution: 1024 x 1024
Car motion: 30 kph
Projection rate: 10000 Hz

Embedded Design for Imaging and Illumination



Projector and camera in one device?

Rain Rain Go Away...

- Improves driver visibility directly
- Simulations suggest that the idea is feasible
- Initial lab prototype is encouraging
- Still a long way to go:
 - Wind, turbulence, vibrations
 - Making the device compact, fast moving car