A Framework for Transient Rendering

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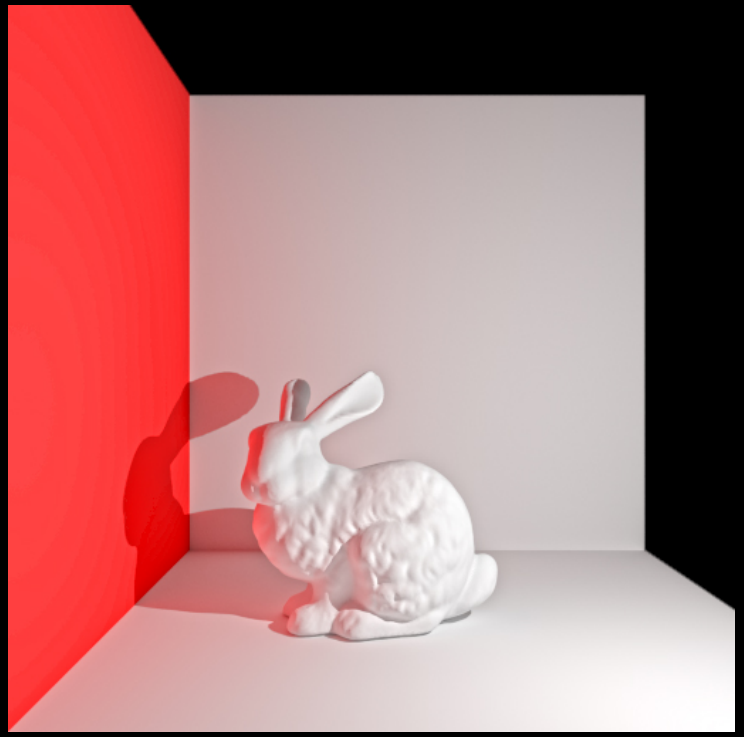
Steady-State Light Transport

Infinite Speed of Light

Steady-State Light Transport



Steady-State Light Transport

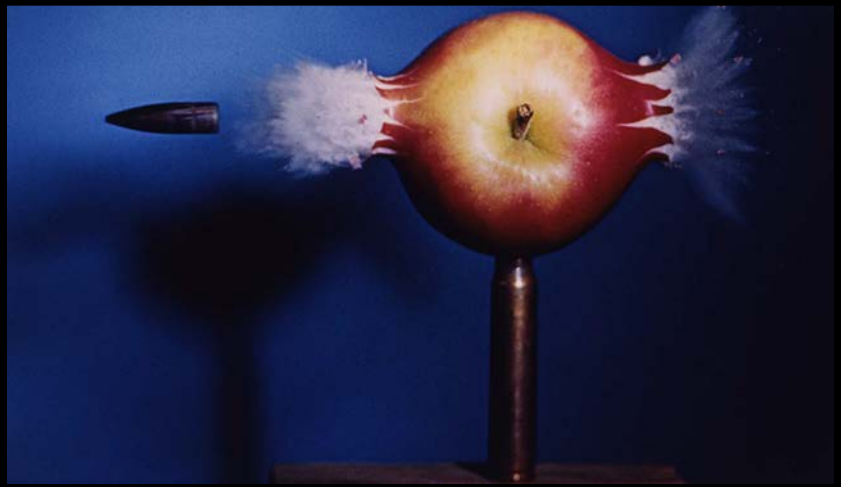
Infinite Speed of Light

Transient Light Transport

Finite Speed of Light

$$299\,792\,458[ms^{-1}]$$

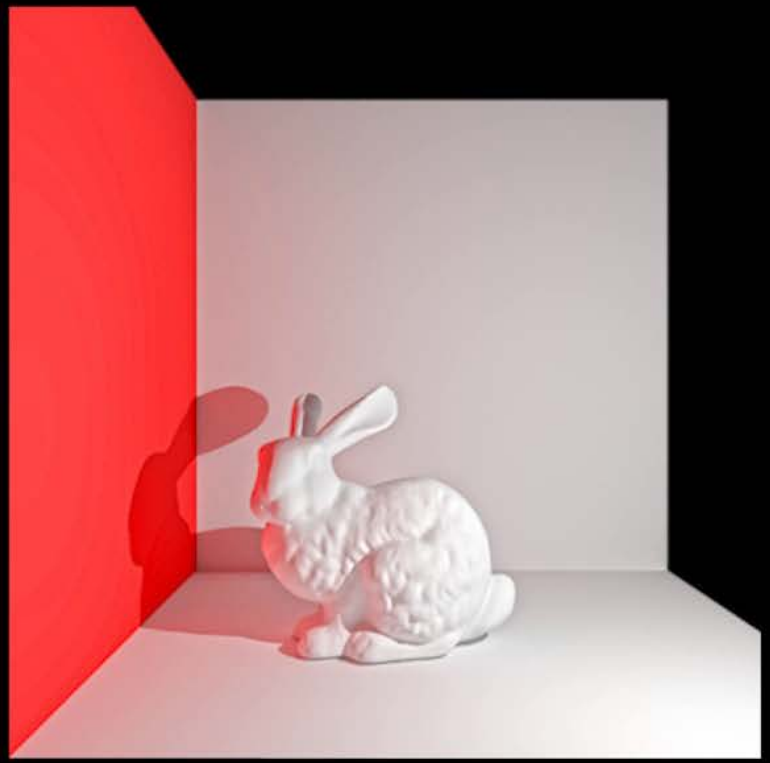
Transient Light Transport



Transient Light Transport

So if we see at picosecond resolution…

Transient Light Transport



Transient Light Transport

But, is breaking this assumption really useful?

Femto-Photography *[Velten2013]*

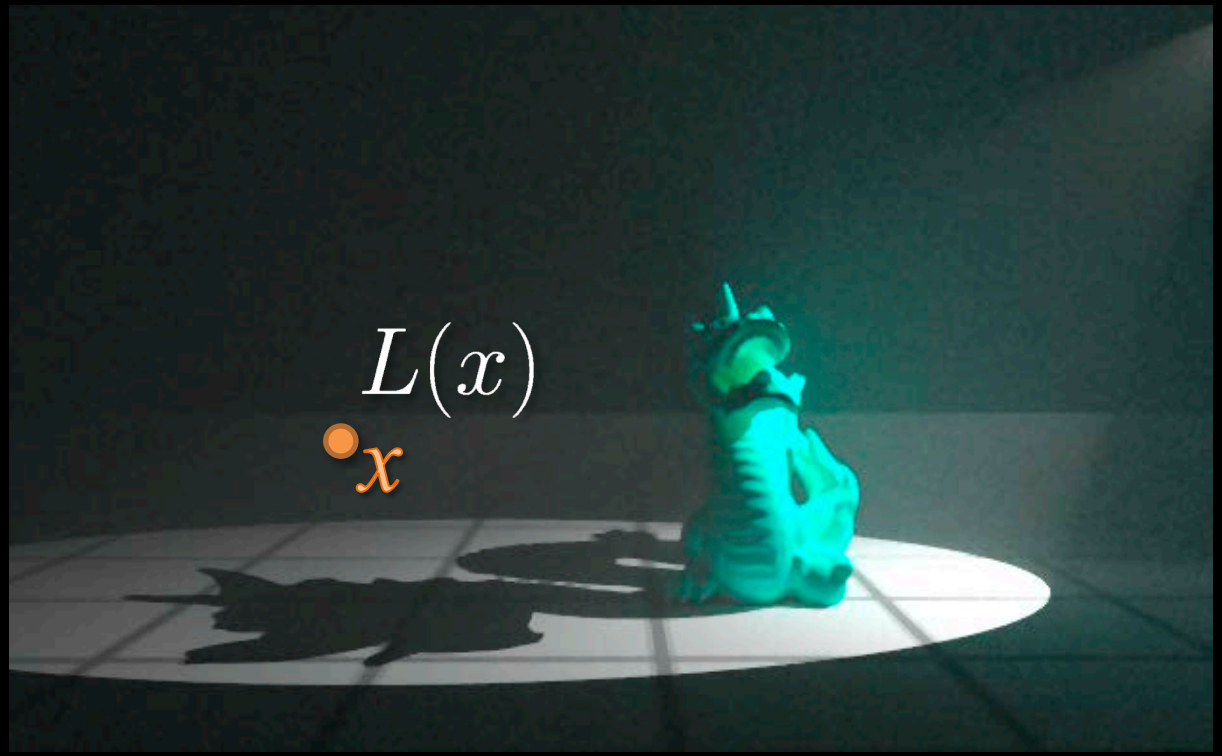
Femto-Photography *[Velten2013]*

- Visible geometry *[Wu2014,OToole2014…]*
- Transparent Objects *[Kadambi2013]*
- Hidden geometry *[Velten2012…]*
- Reflectance *[Naik2011…]*
- GI Components Separation *[Wu2014…]*
- …

Simulation helps:

- Forward-model for inverse problems
- Can test new systems *before* building them
- Freedom to *tweak* the physics

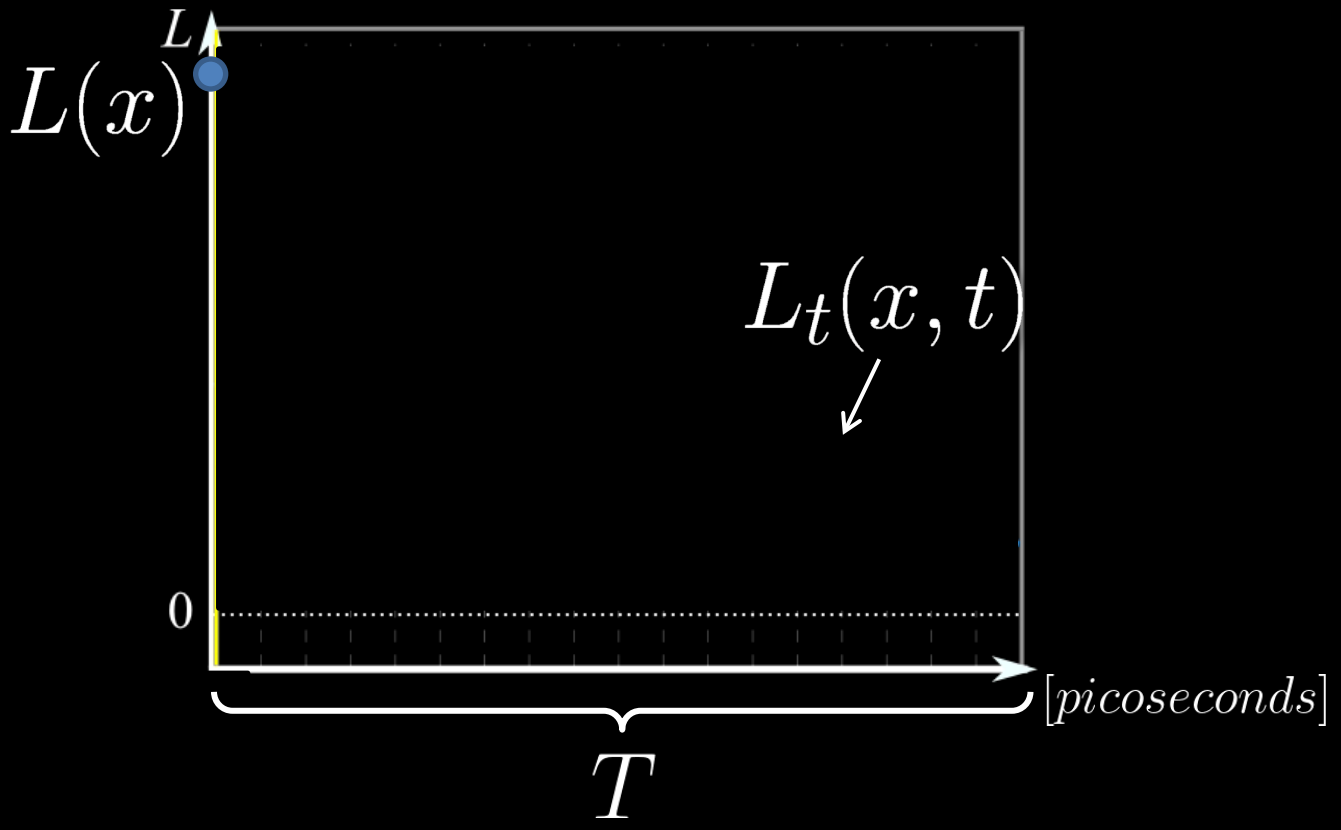
The Problem



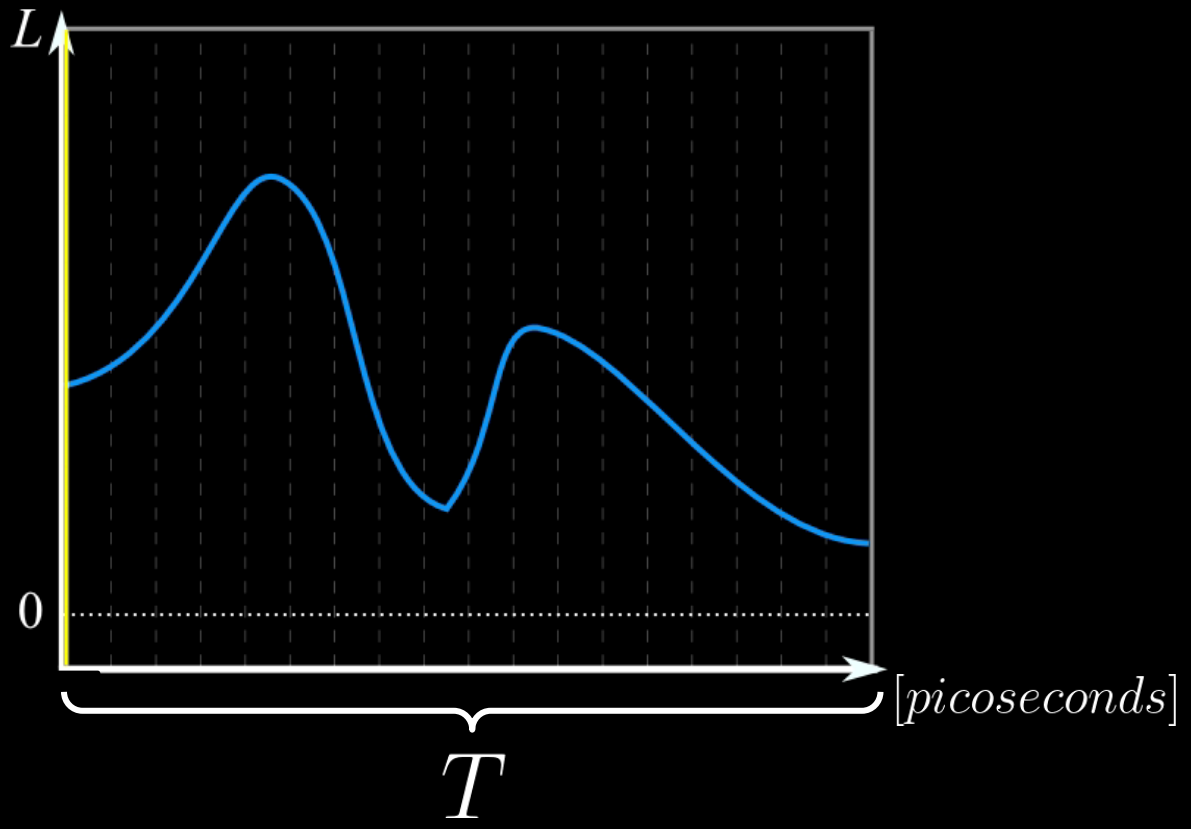
The Problem

$$\frac{dL(x)}{dt} = \int_T L_t(x, t)dt$$

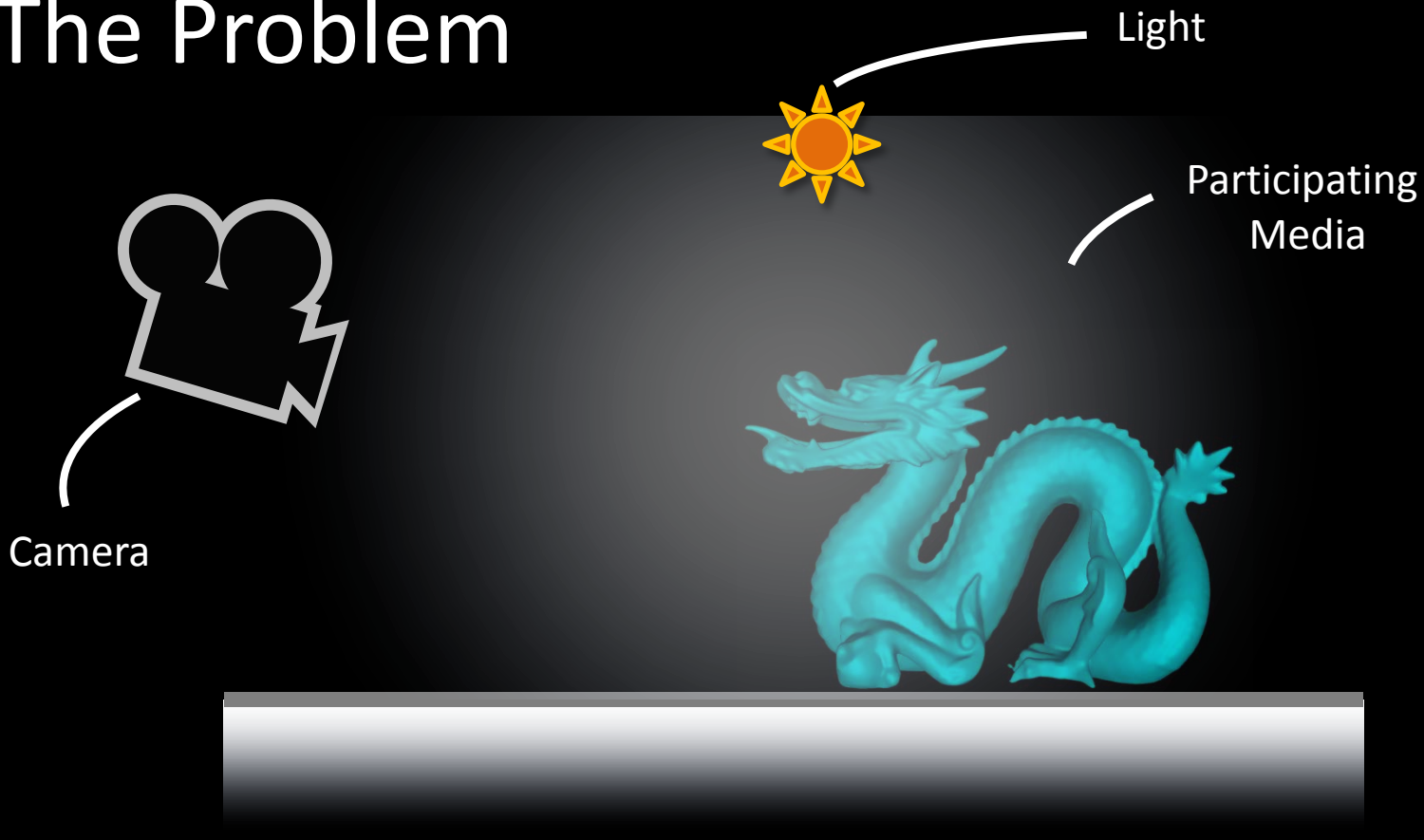
The Problem



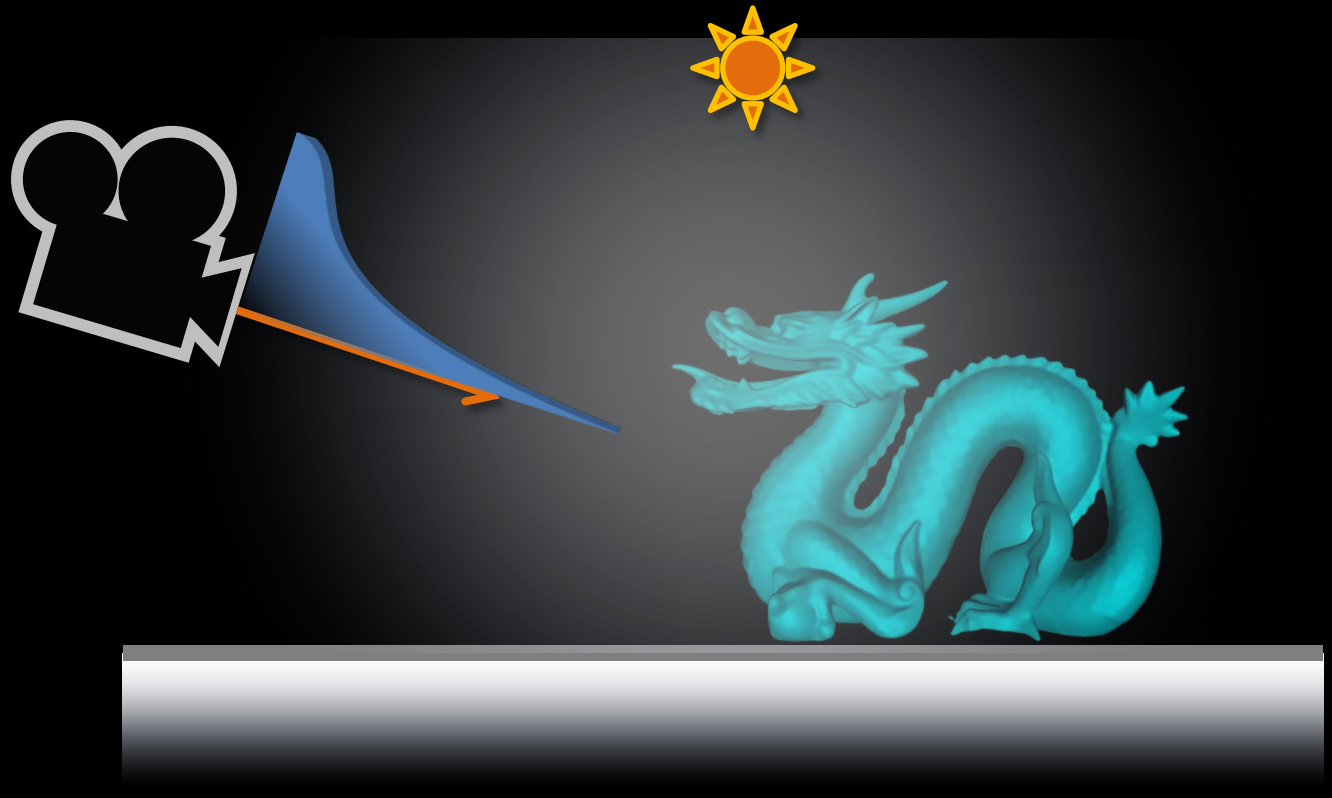
The Problem



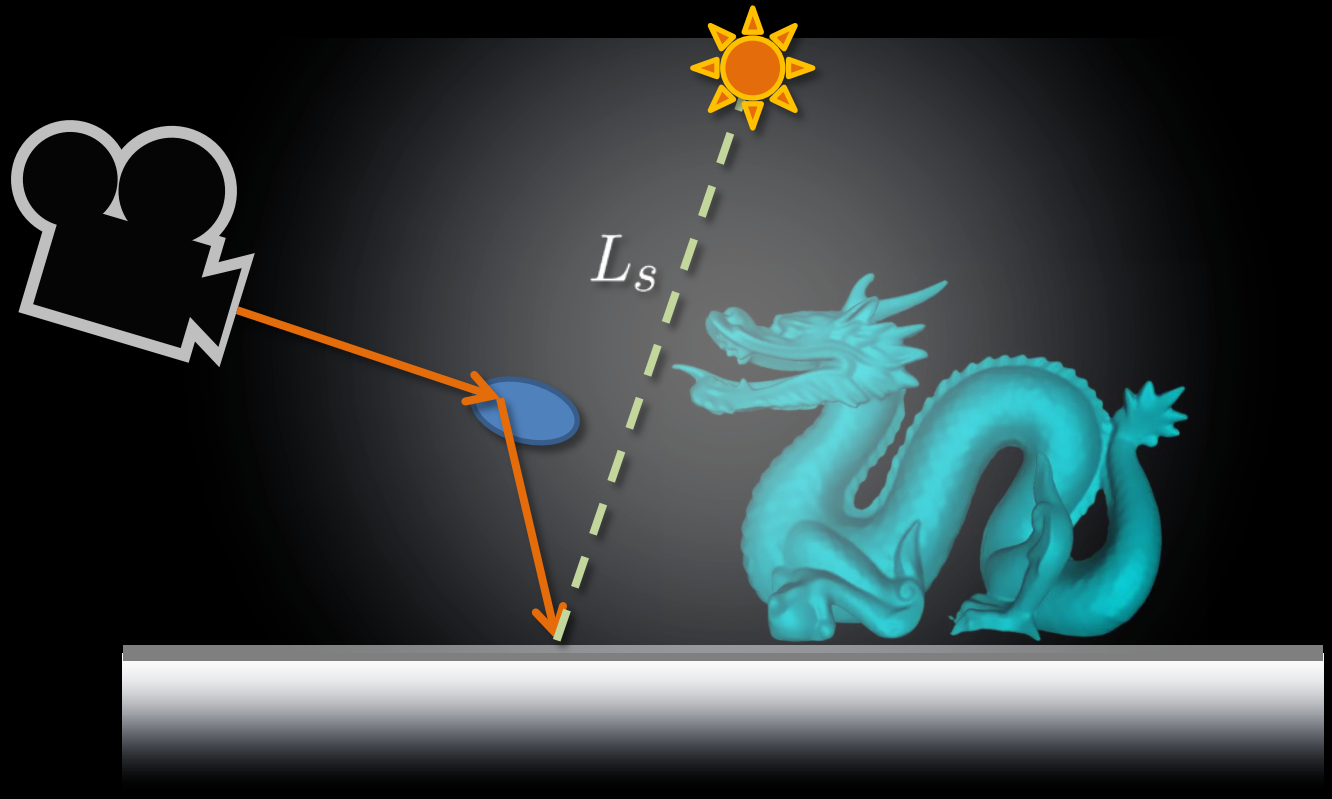
The Problem



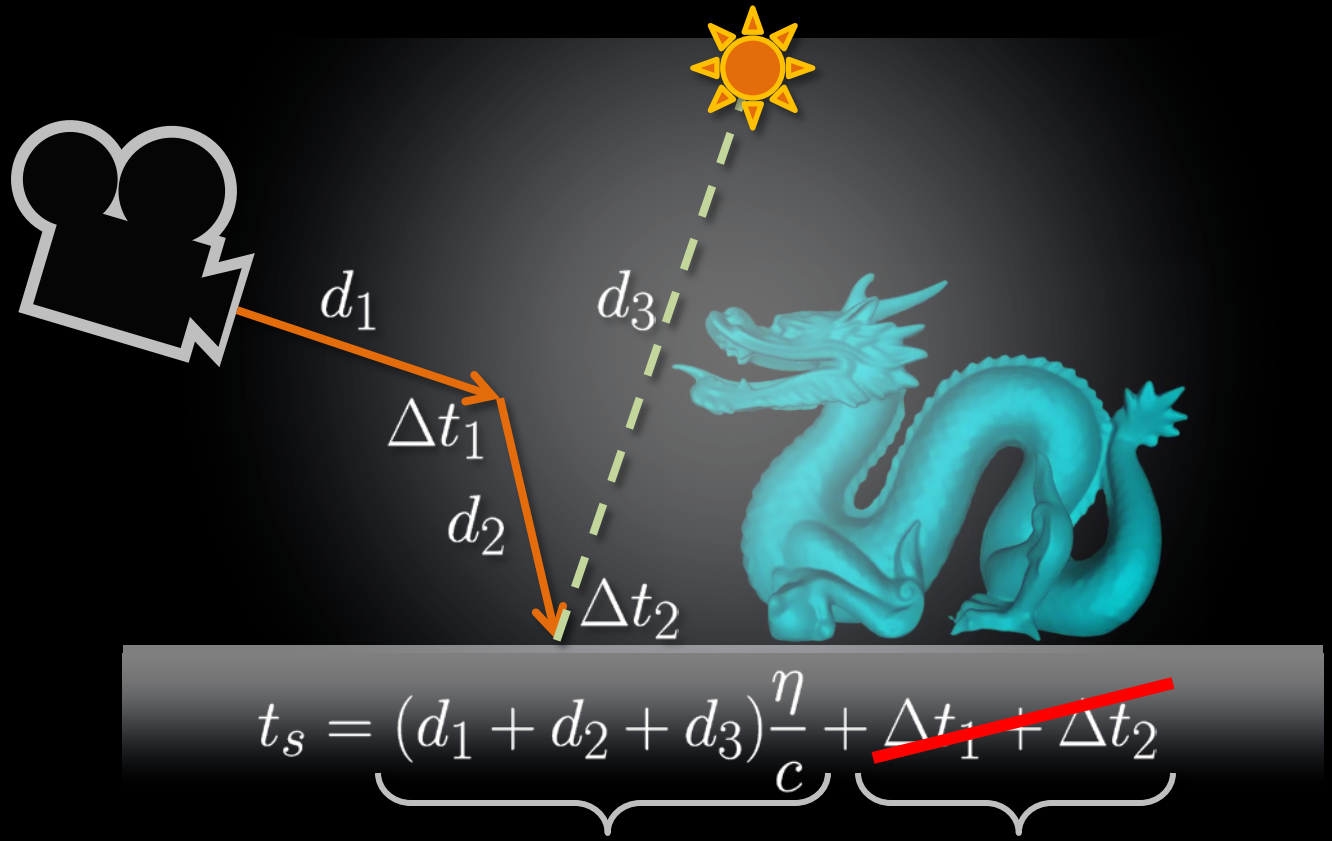
The Problem



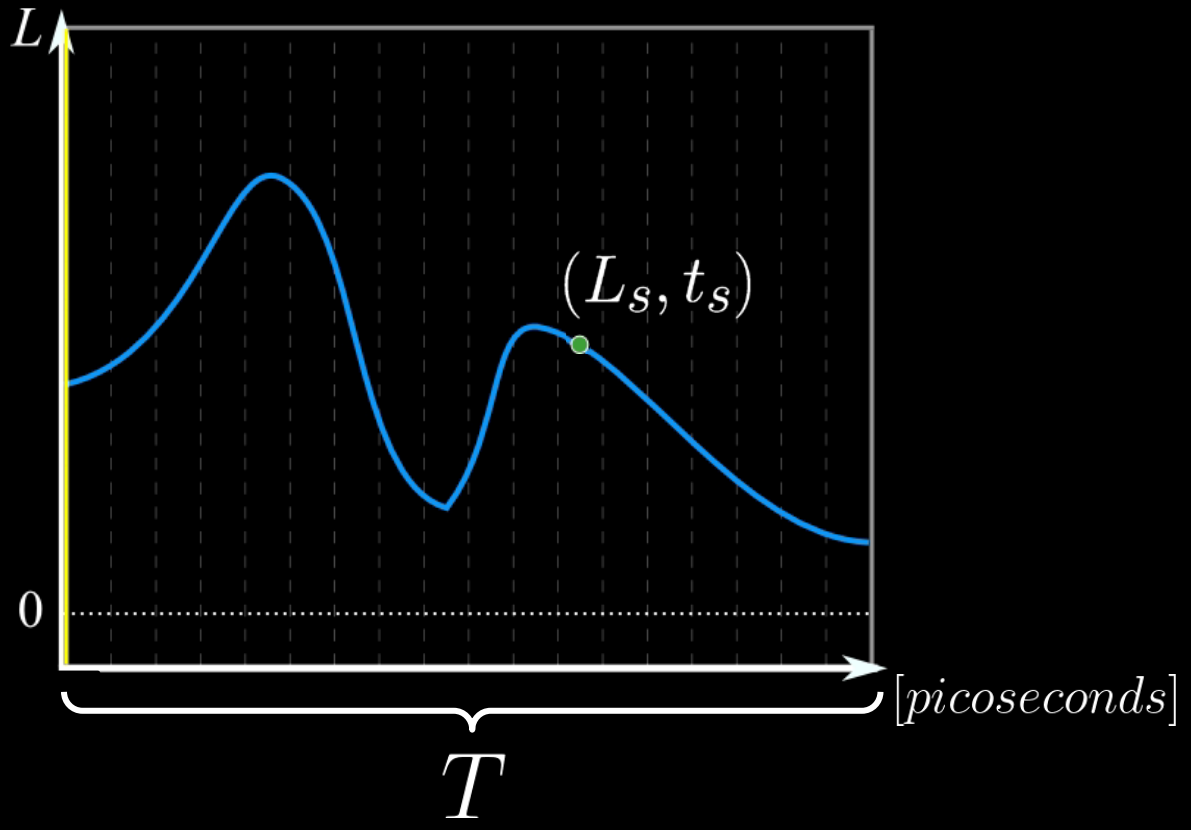
The Problem



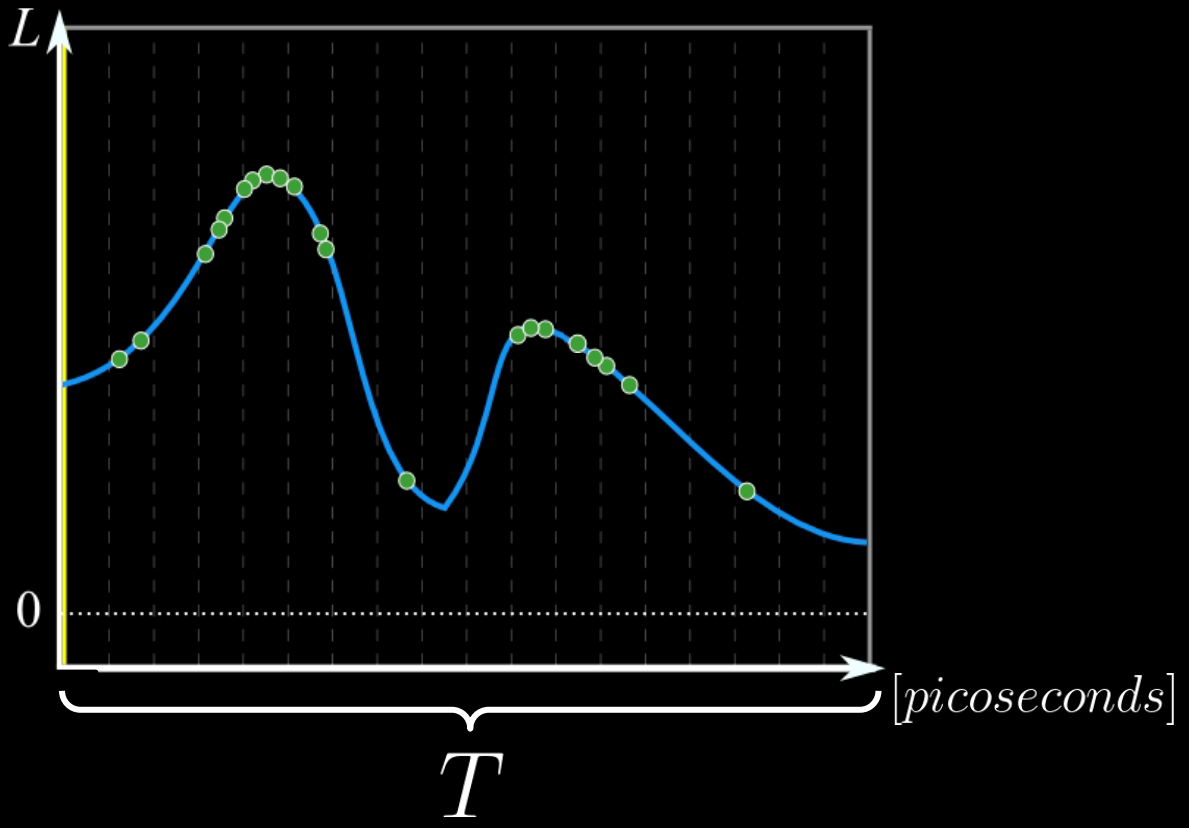
The Problem


d_1
d_3
Δt_1
d_2
Δt_2
$t_s = (d_1 + d_2 + d_3)\frac{\eta}{c} + \Delta t_1 + \Delta t_2$

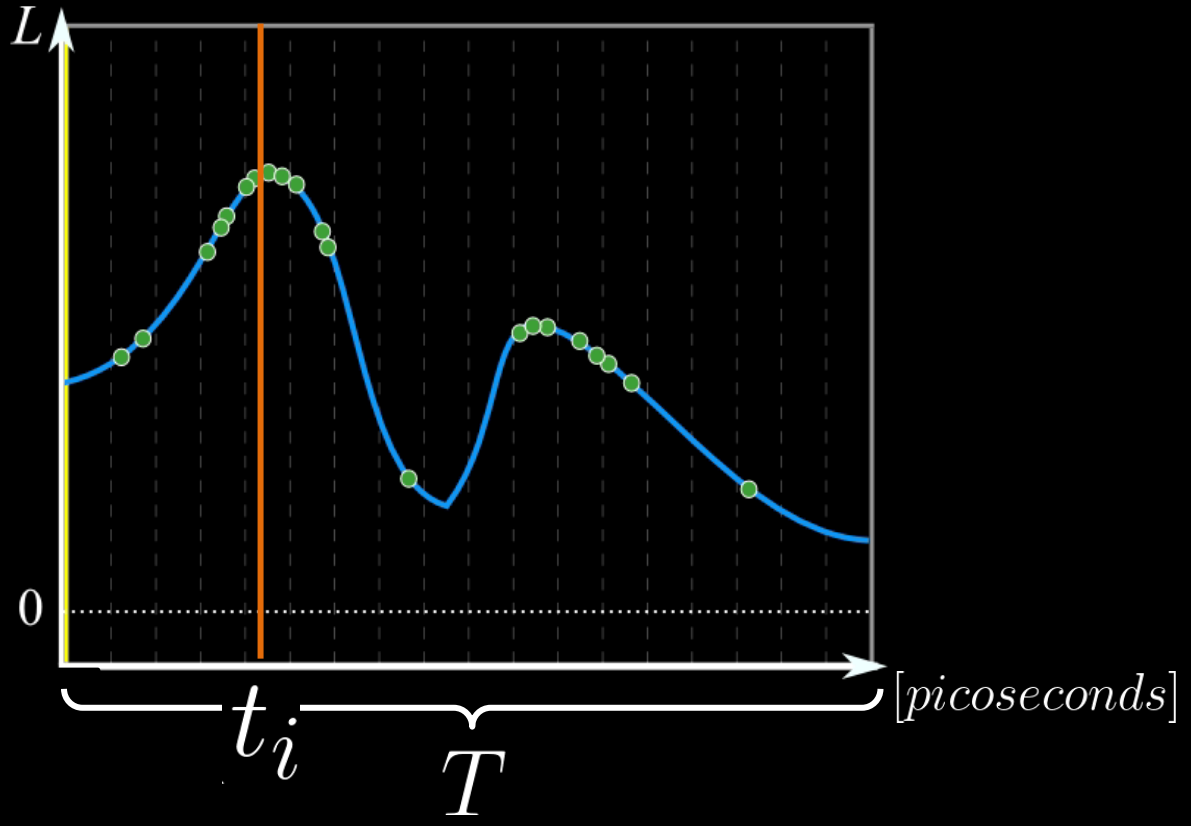
The Problem



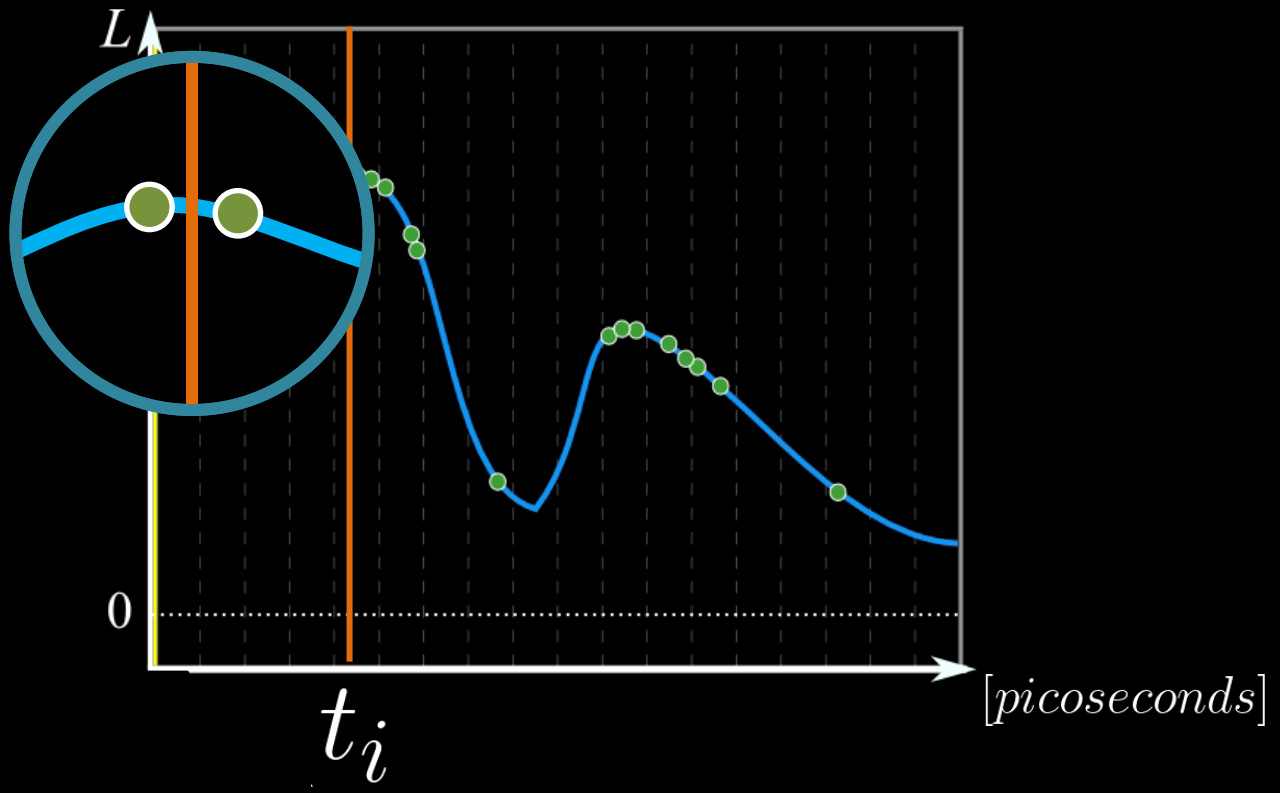
The Problem



The Problem



The Problem



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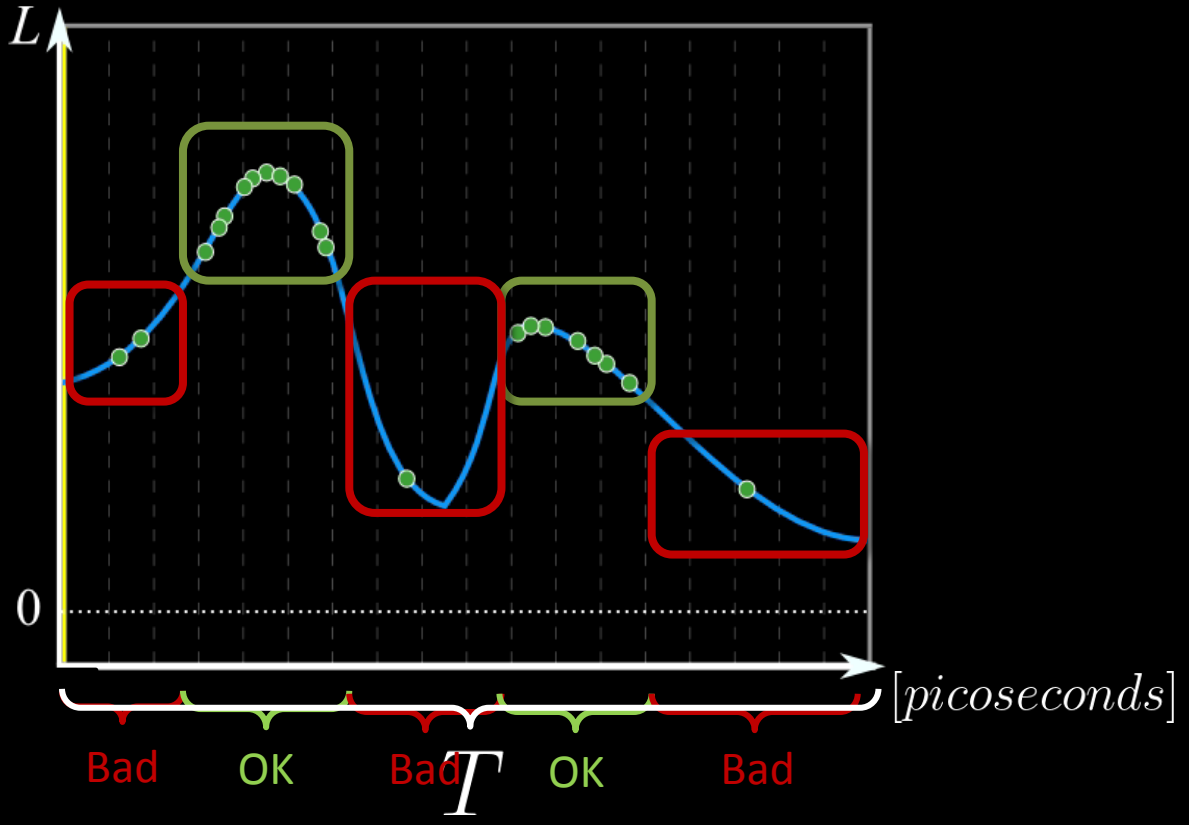

The Problem

1. How to reconstruct time-resolved light?

2. How to distribute samples along time?

Our Contribution

1. How to reconstruct time-resolved light?

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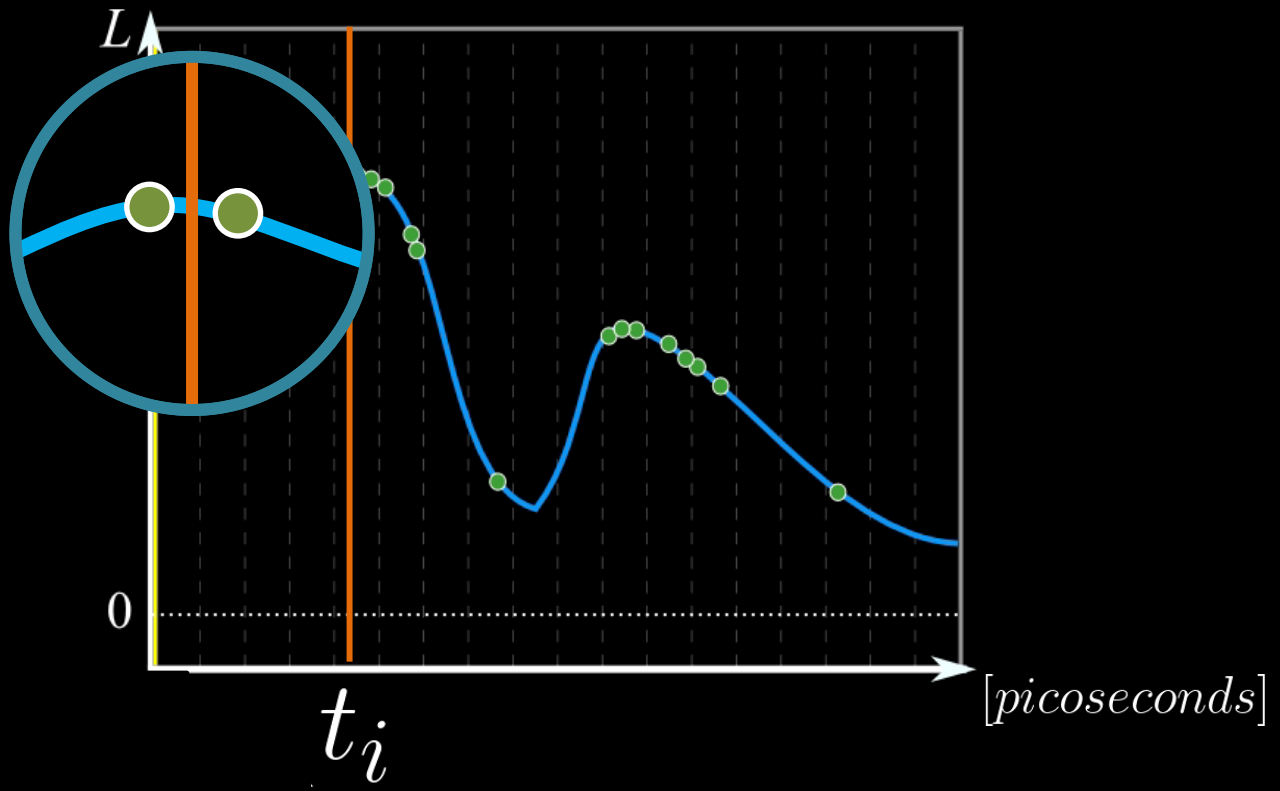
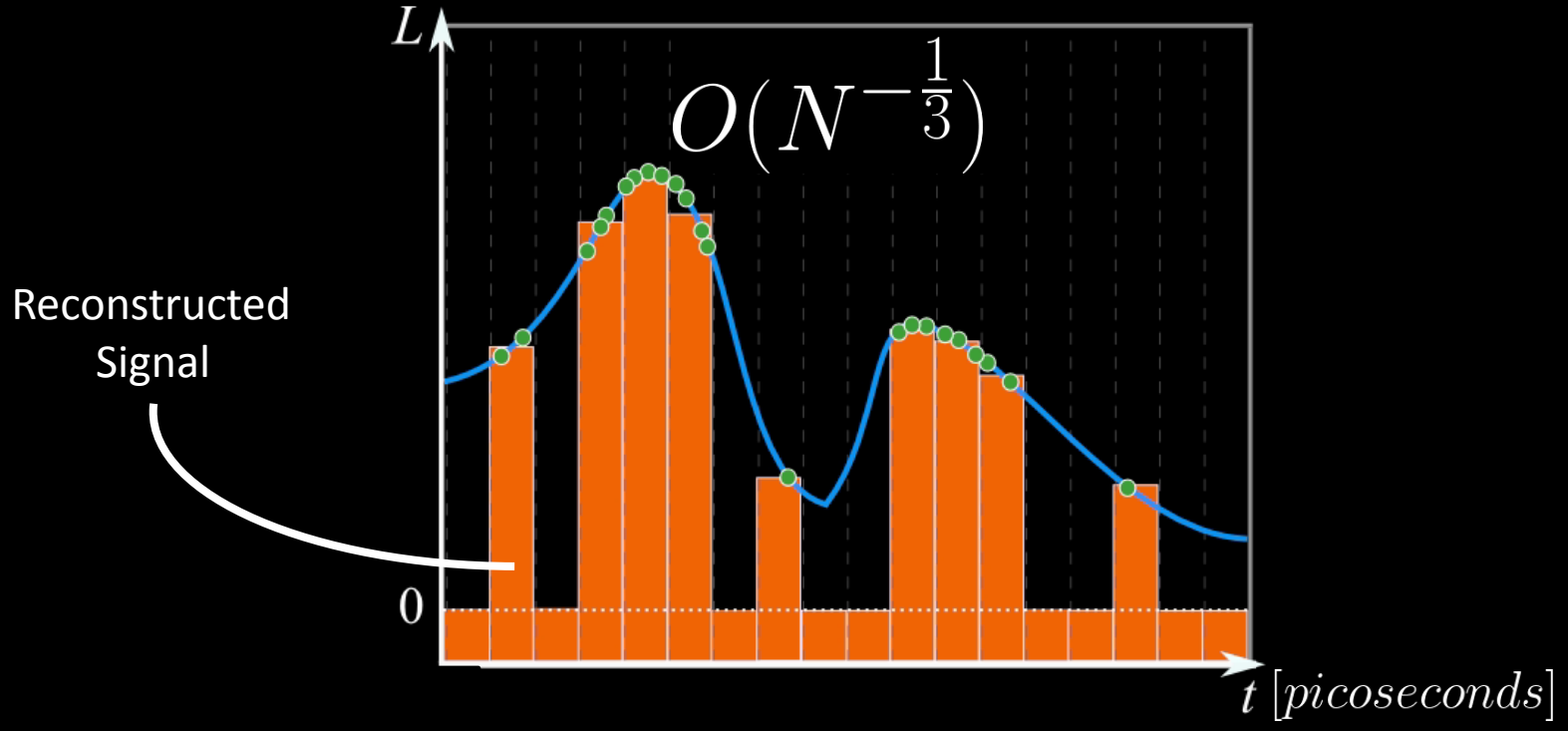
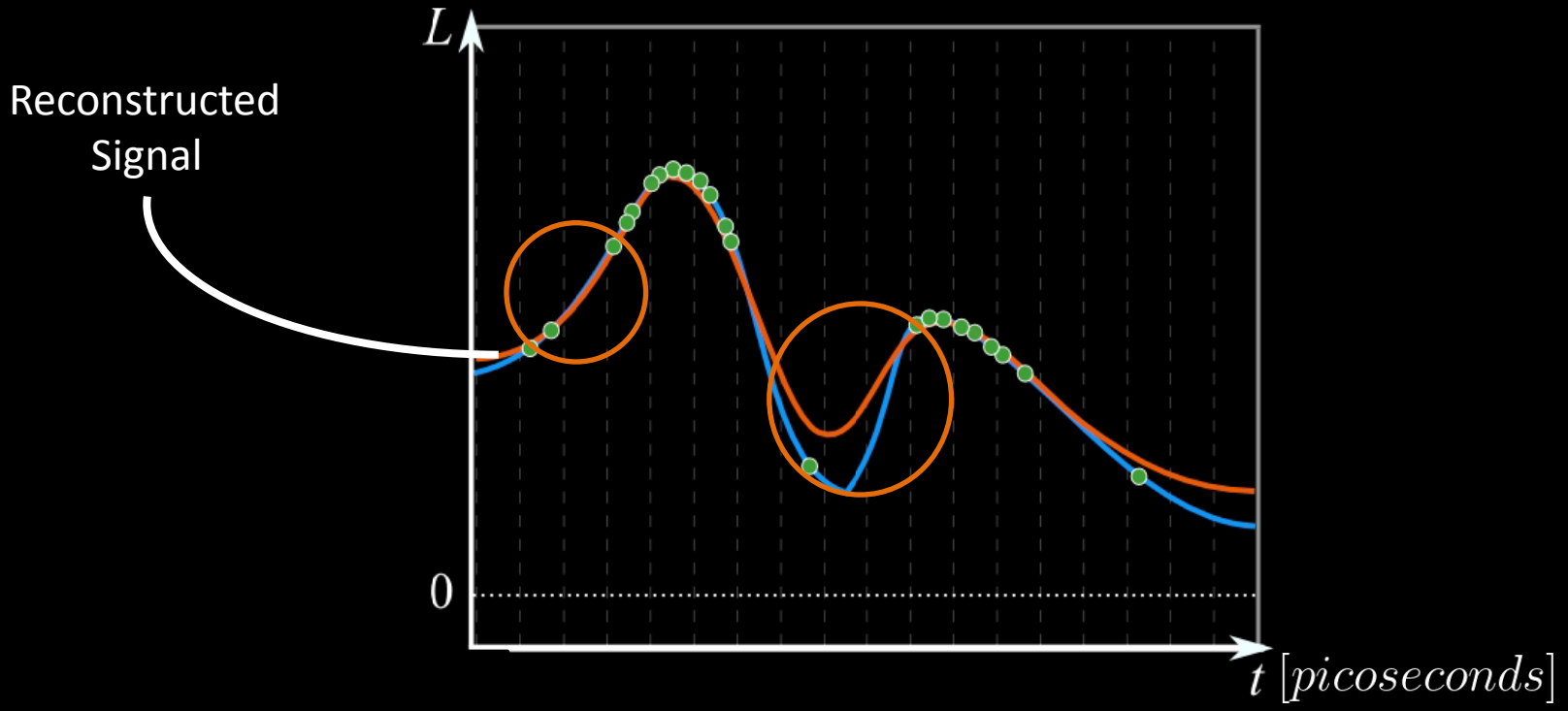

L
0
t_i
[picoseconds]

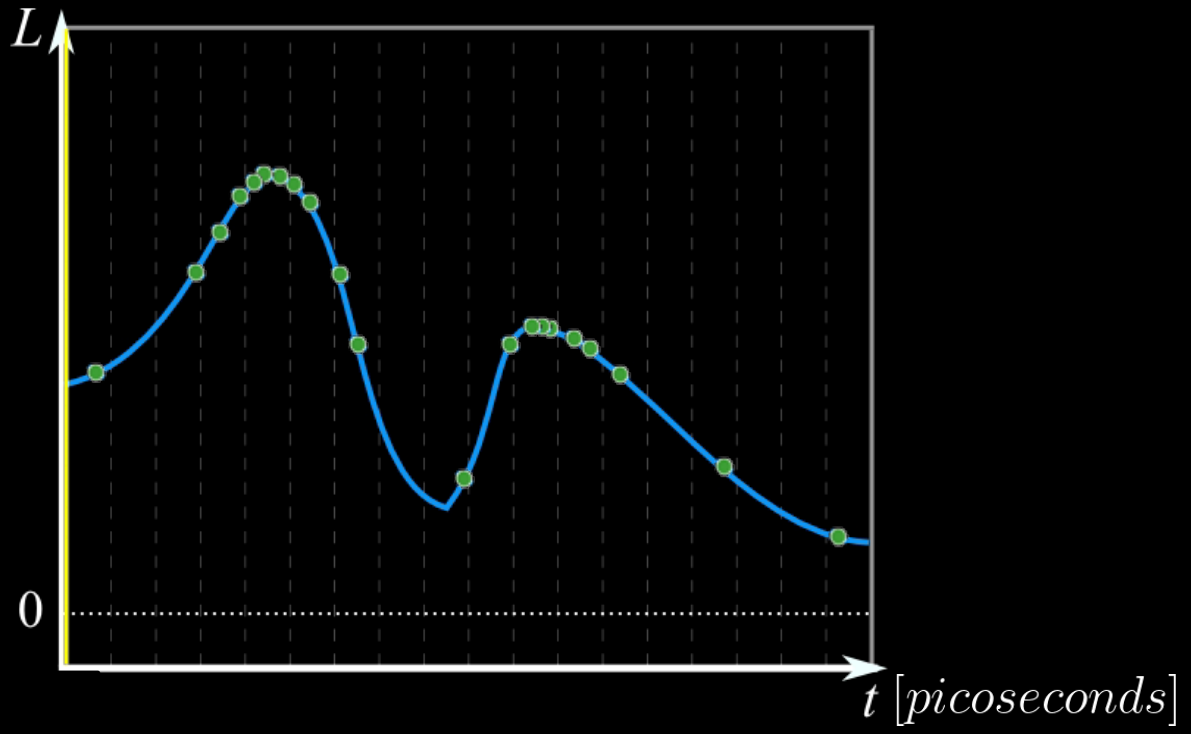
[Jarosz 2012, Deng 2014, Tamaki 2014]



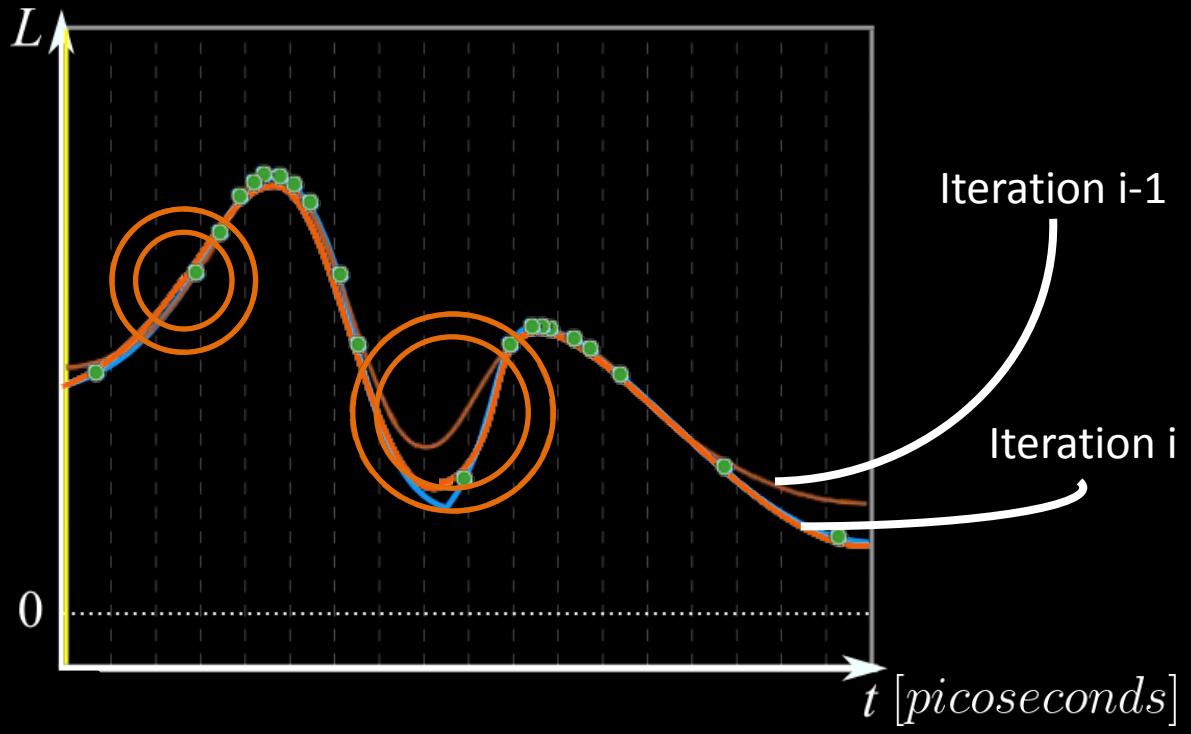
Kernel-Based Density Estimation



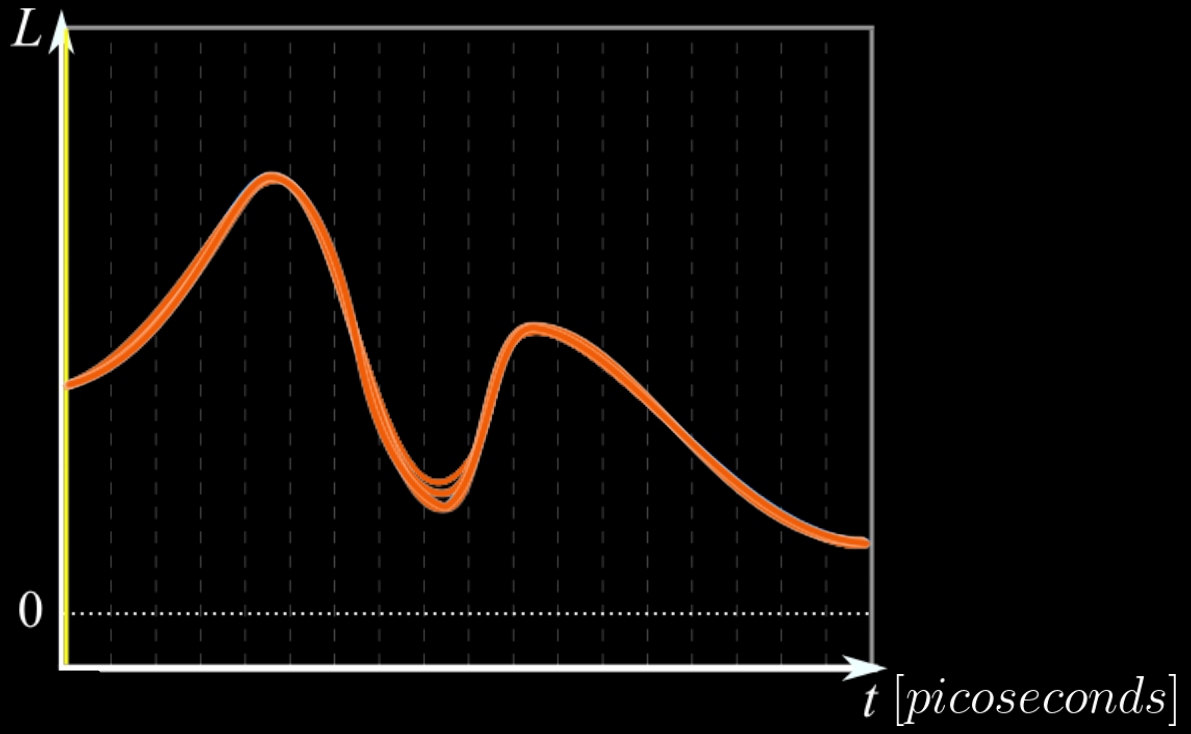
Progressive Kernel-Based Density Estimation



Progressive Kernel-Based Density Estimation



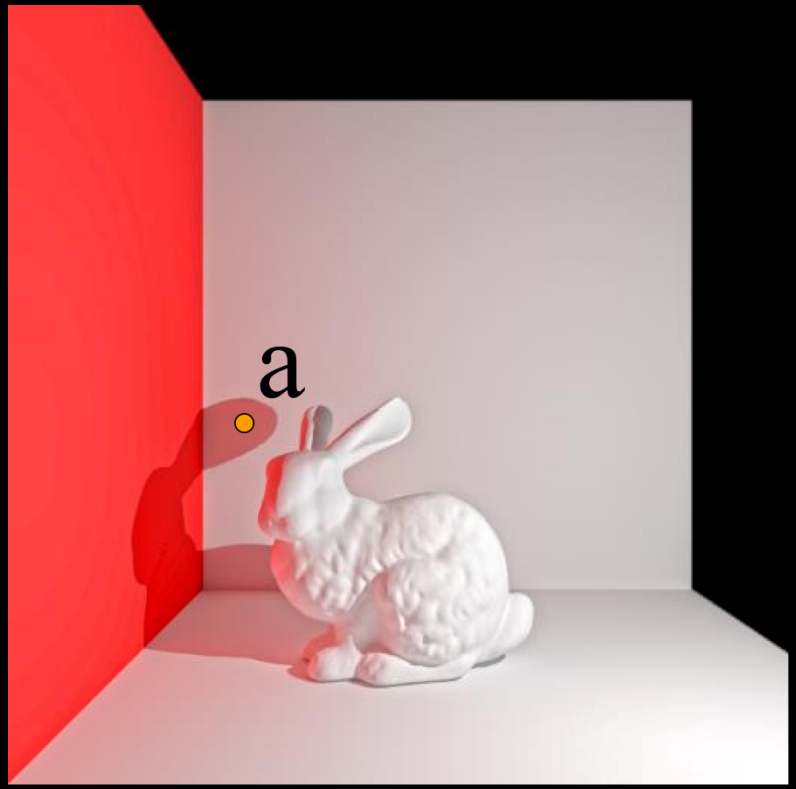
Progressive Kernel-Based Density Estimation



Binning

Kernel-Based

$$O(N^{-\frac{1}{3}}) \gg O(N^{-\frac{4}{5}})$$


a

Our Contribution

1. How to reconstruct time-resolved light?

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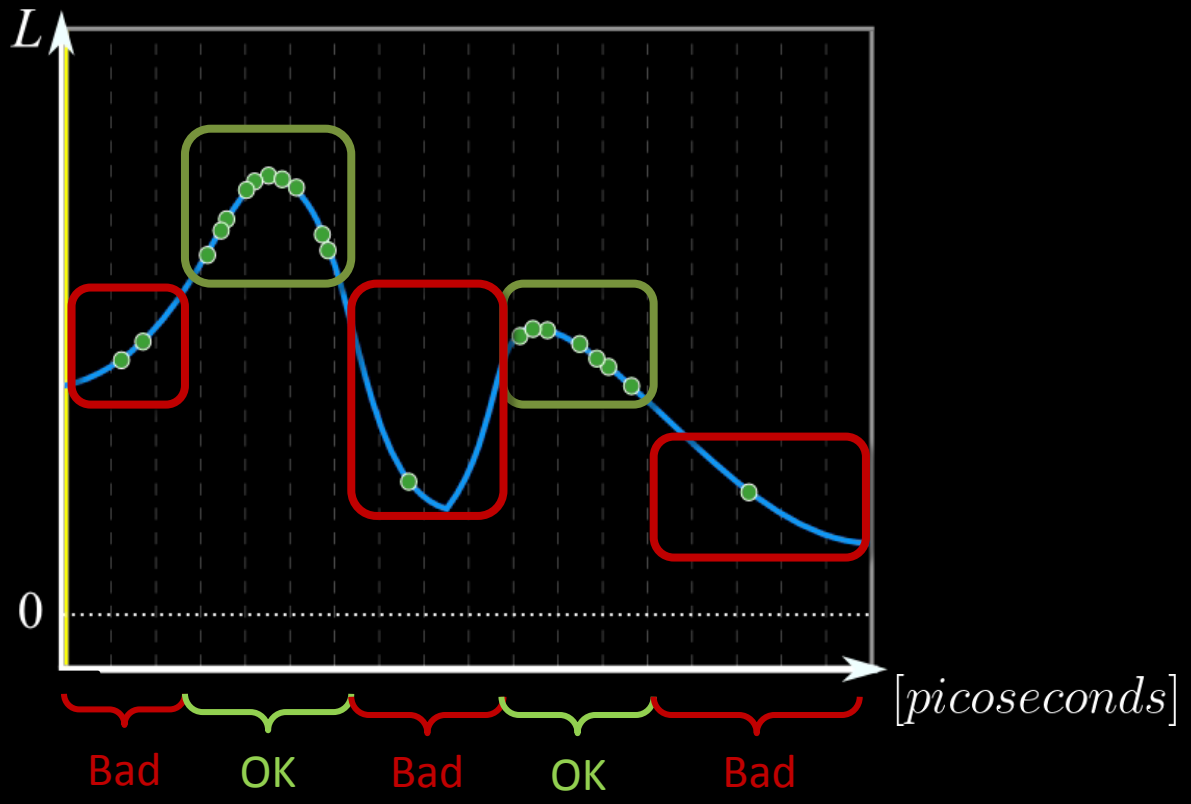
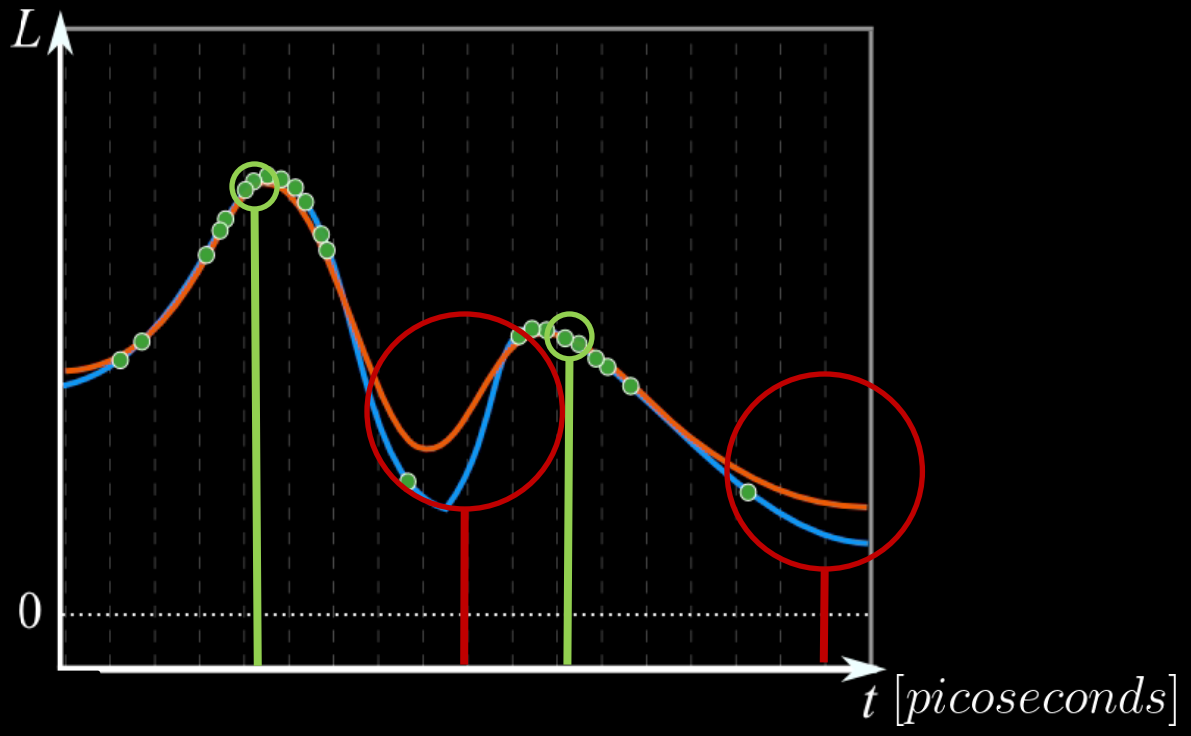
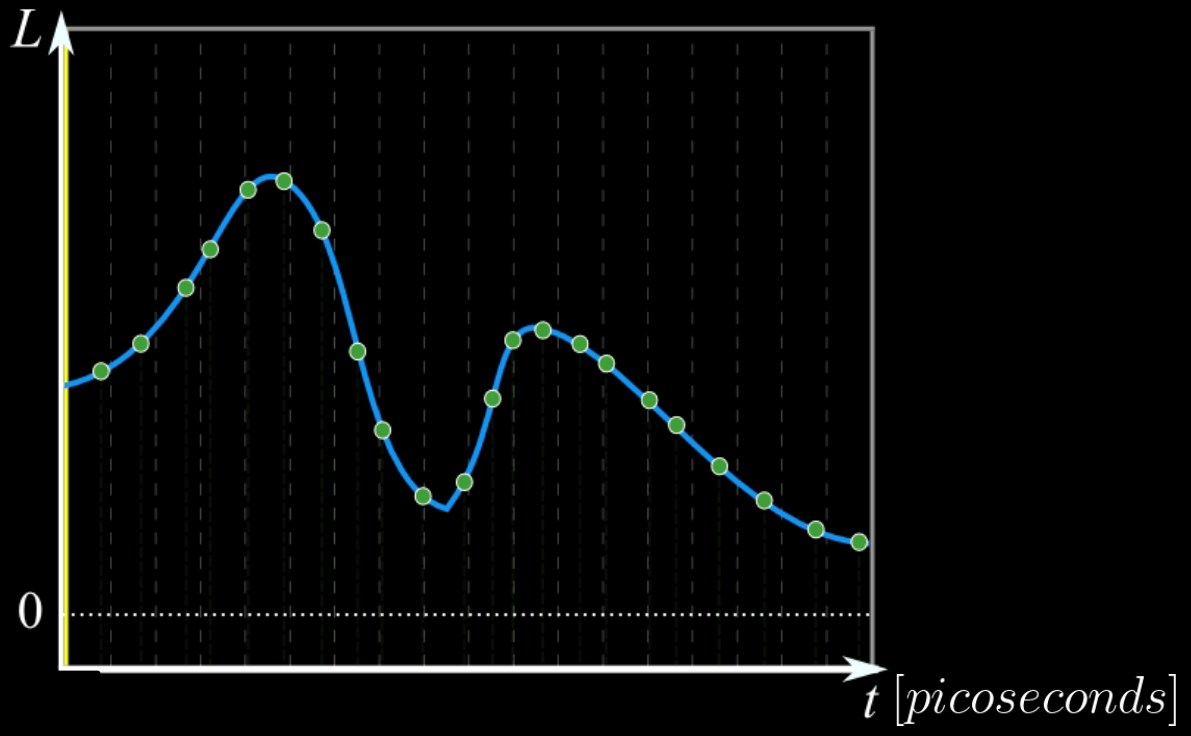
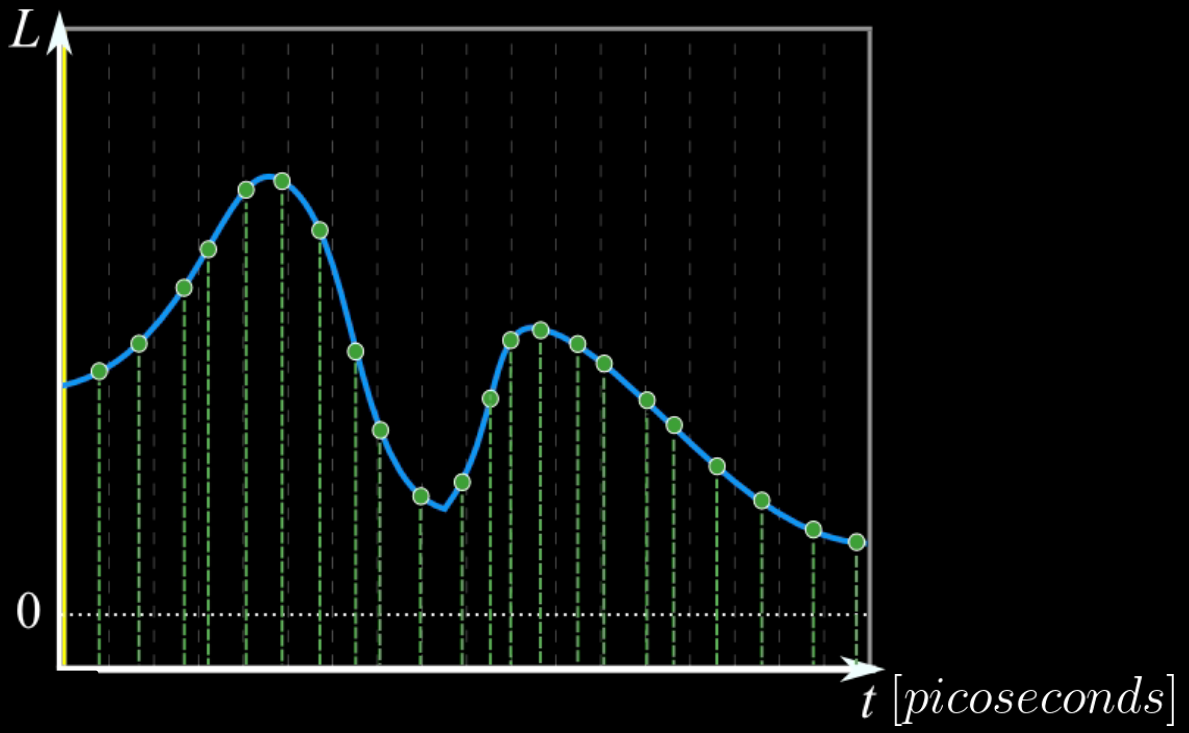

L
0
[picoseconds]
Bad
OK
Bad
OK
Bad


L
0
t [picoseconds]

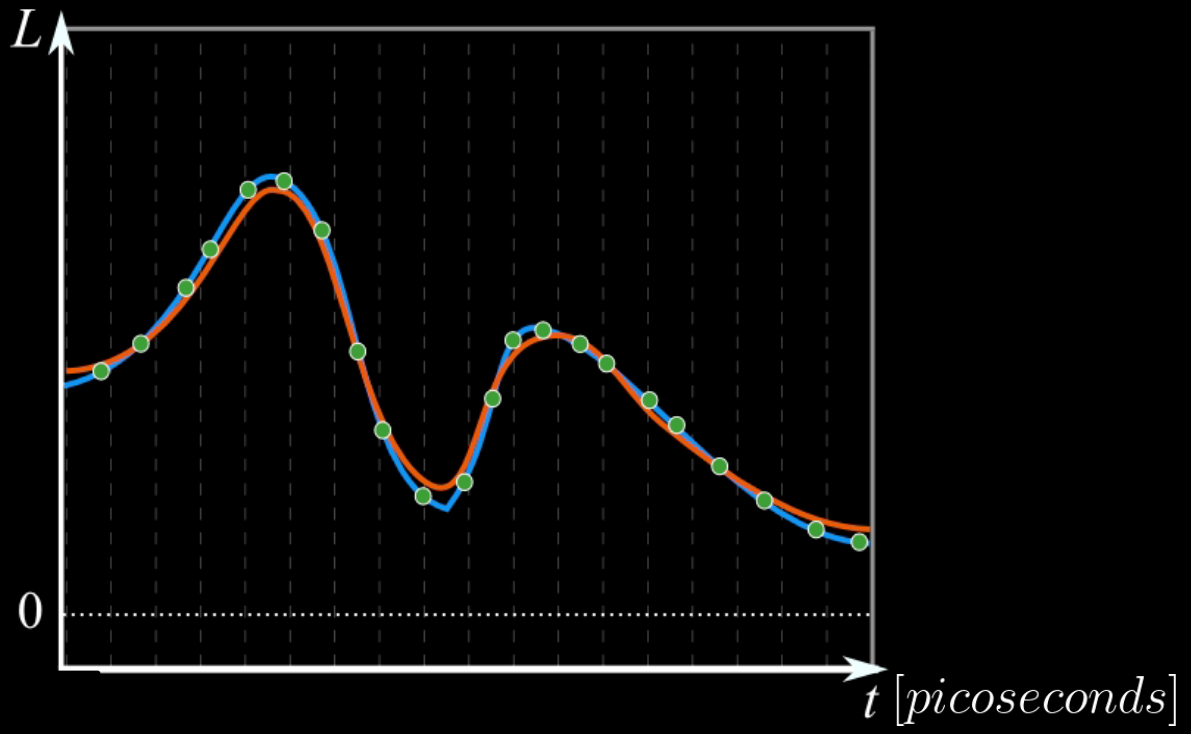
Time-Based Sampling

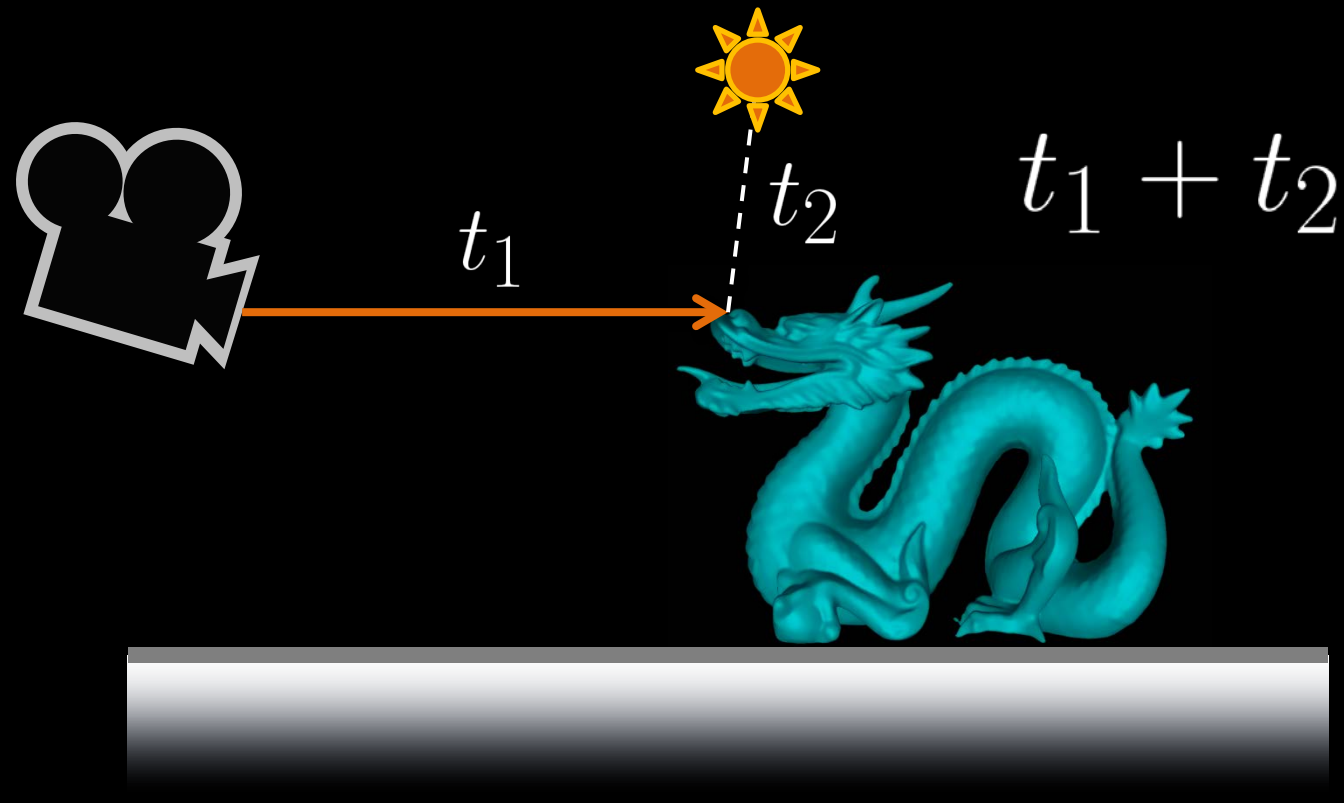


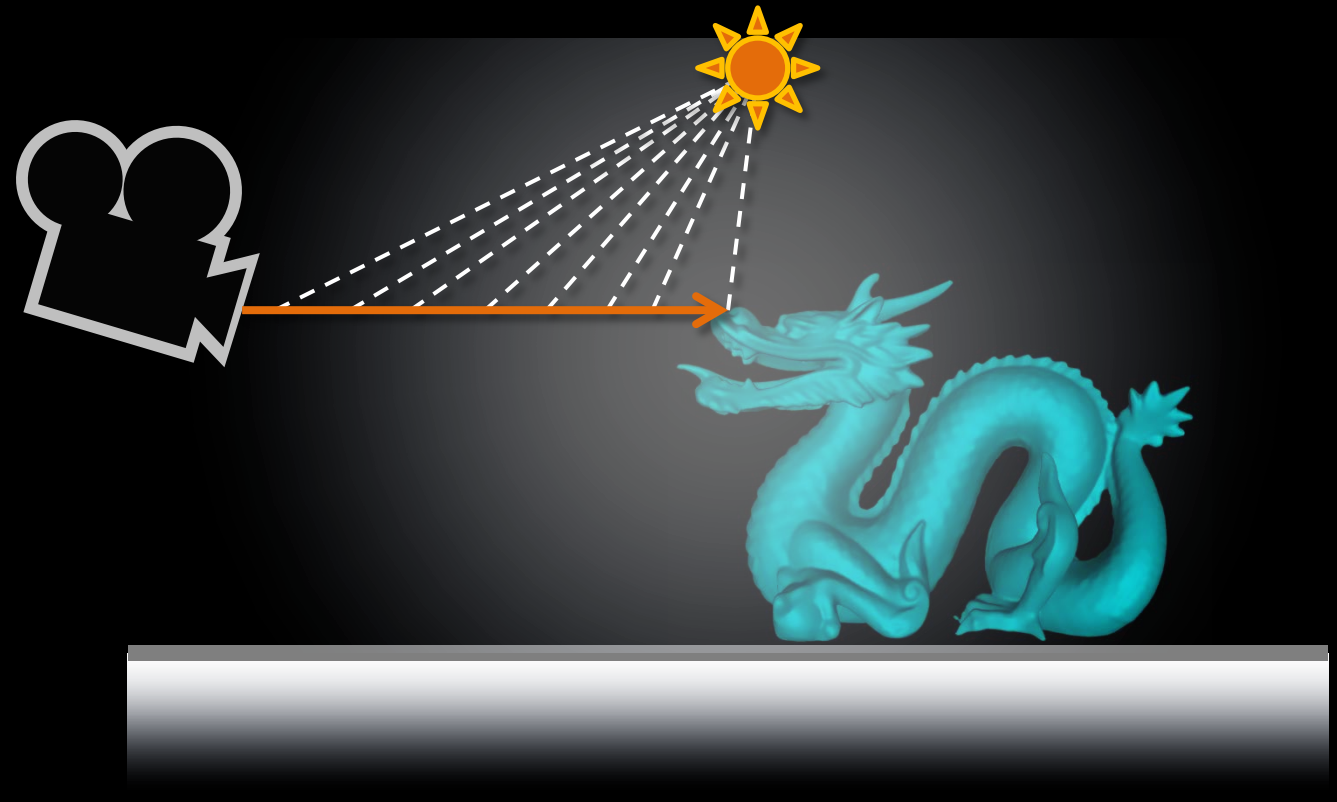
Time-Based Sampling



Time-Based Sampling




t_1
t_2
$t_1 + t_2$

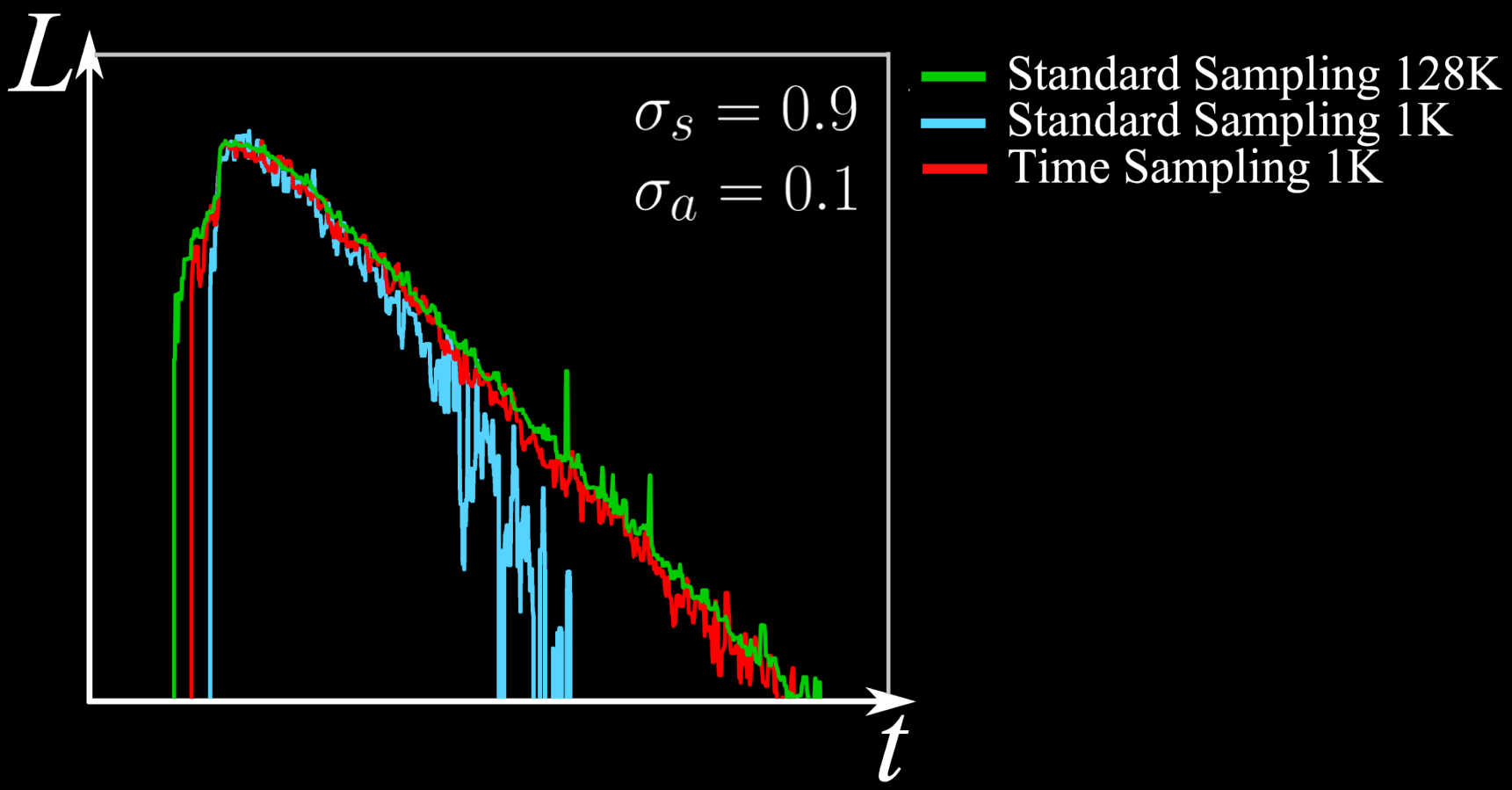


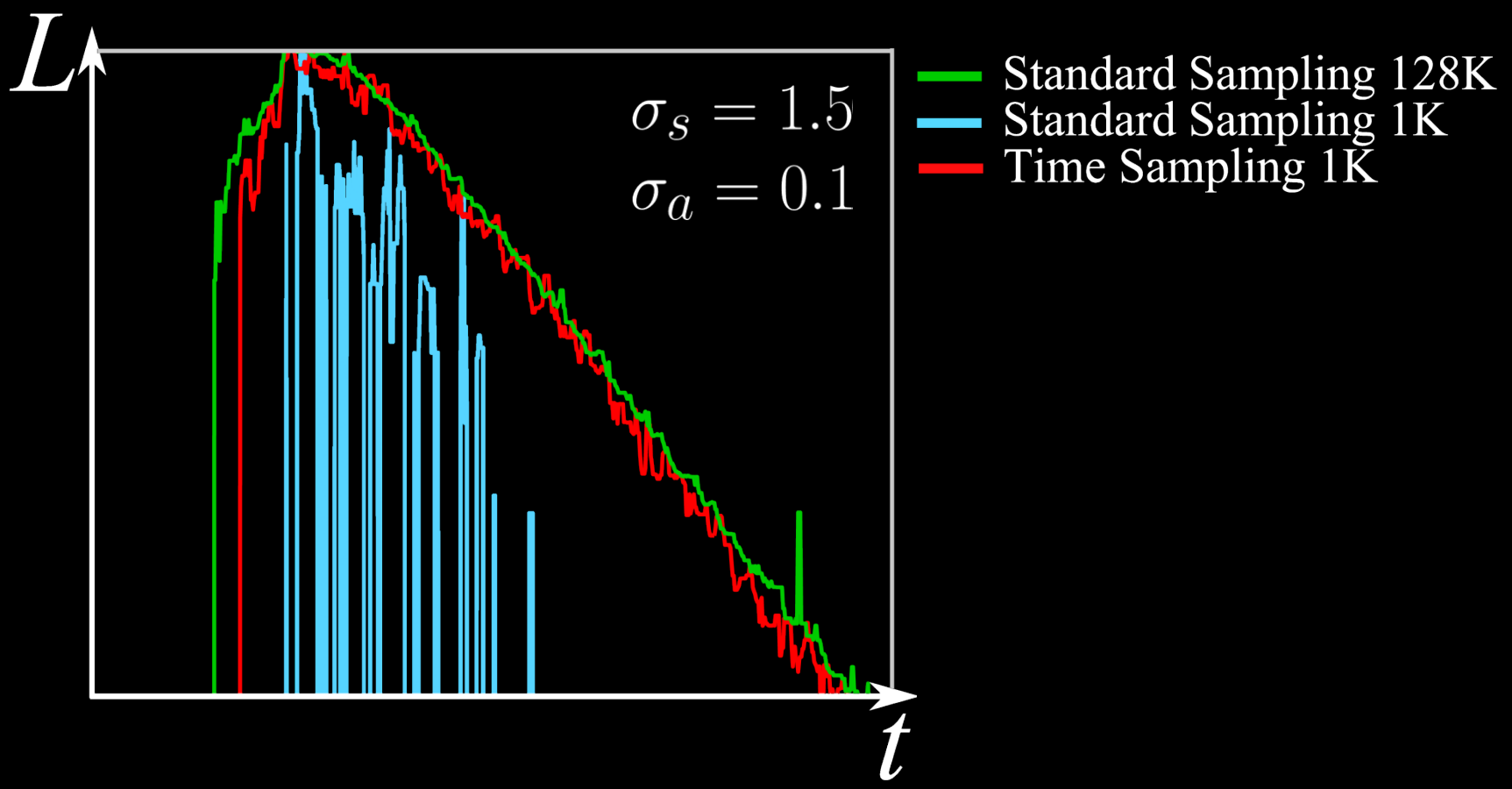
Time-Sampling

Set of techniques for time-based sampling in participating media

1. Next Segment Distance
2. Shadow Connection
3. Angular Sampling


.a


L
$\sigma_s = 0.9$
$\sigma_a = 0.1$
t
Standard Sampling 128K
Standard Sampling 1K
Time Sampling 1K


L
t
$\sigma_s = 1.5$
$\sigma_a = 0.1$
Standard Sampling 128K
Standard Sampling 1K
Time Sampling 1K

Kernel-Based Density Estimation

+

Time Sampling

Our Contribution

1. How to reconstruct time-resolved light

2. How to distribute samples along time

Additional Results

More Results in the Supplementary Video

Including:

1. Birefringency
2. Chromatic dispersion *in time*
3. Comparison with captured data

Discussion & Future Work

- Error introduced by Kernel DE
  - Signal-aware Kernel Bandwidth *[Kaplanyan2013]*
  - Error Metric *[Hachisuka2010]*
- Sampling Surface Light Transport
  - Caustic *in time* → Manifold Exploration *[Jakob2012]*

Discussion & Future Work

- Help developing new techniques using transient light propagation
- Educational tool
- Useful for other fields?
  - Astrophysics, Neutron Transport, Sound Rendering….

Conclusions

1. Formalized Transient Rendering
2. Kernel-Based Reconstruction for Transient LT
3. Sampling Techniques along Time
4. Non-trivial effects of Transient LT

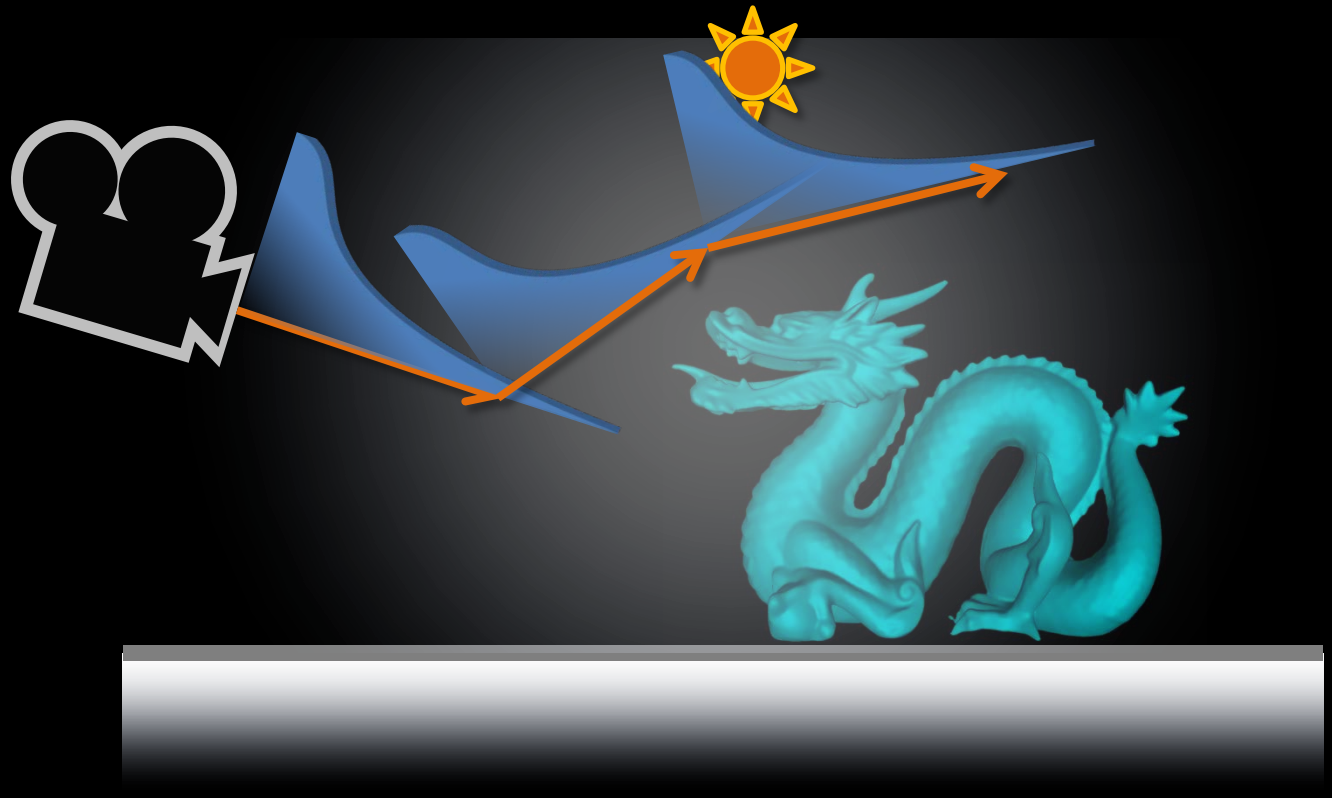
Code, Videos and Data at:
http://giga.cps.unizar.es/~ajarabo/pubs/transientSIGA14

Time-Sampling

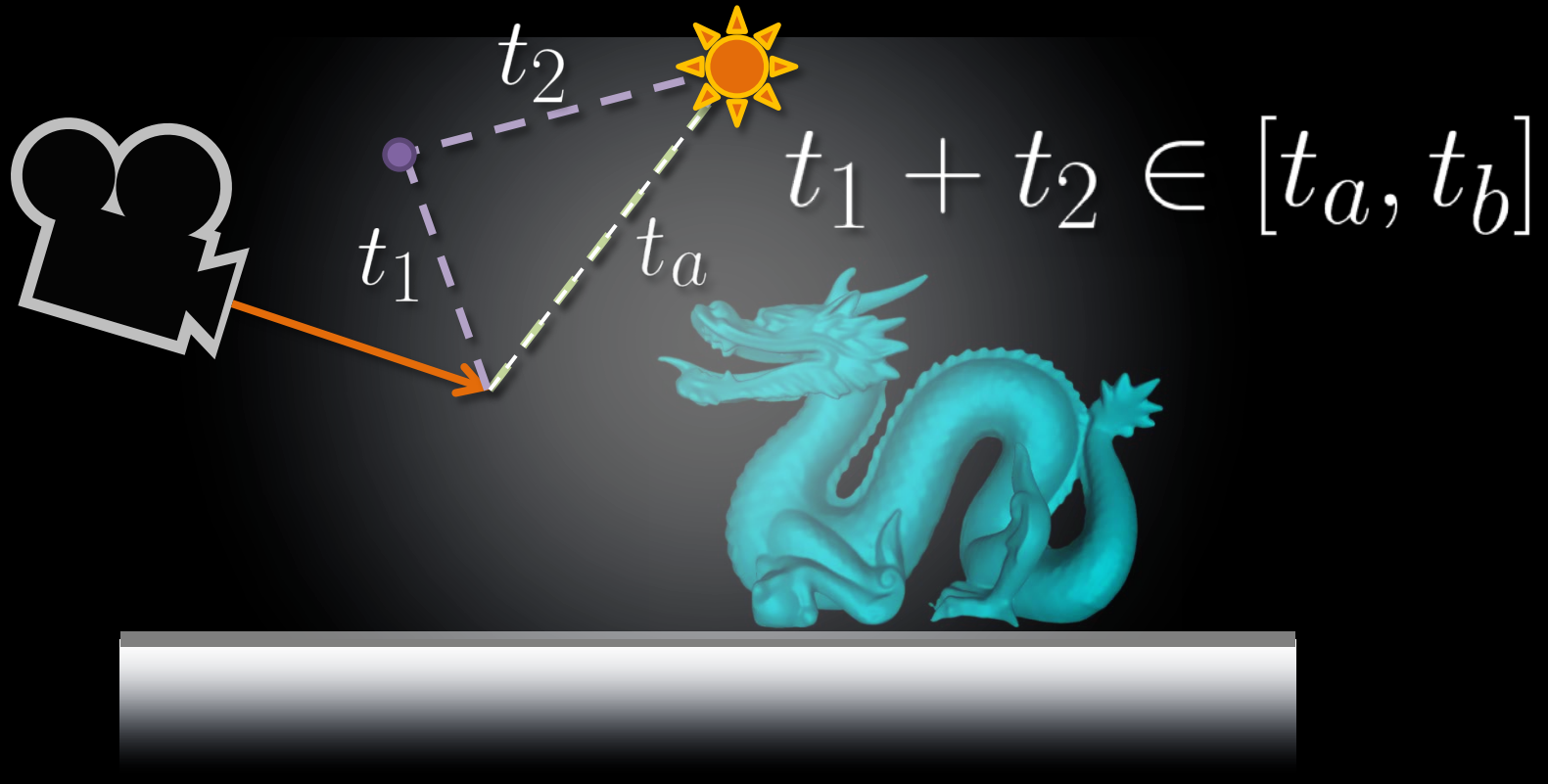
Set of techniques for time-based sampling in participating media

1. Next Segment Distance
2. Shadow Connection
3. Angular Sampling

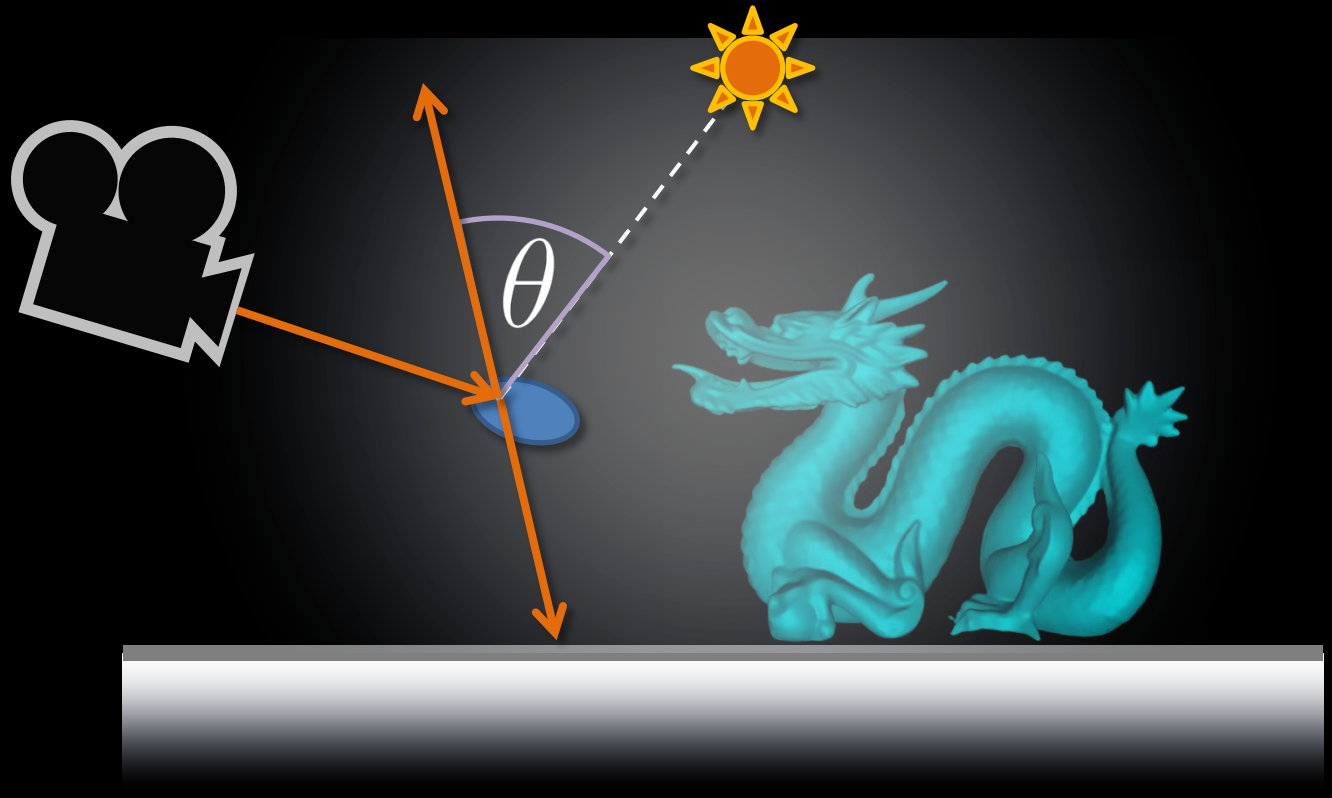
1. Next subpath Segment Distance



2. Shadow Connection



3. Angular Sampling



Rad. Sampling Histogram

Time Sampling Histogram

Rad. Sampling Kernel-DE

Time Sampling Kernel-DE