# Fast Back-Projection for Non-Line of Sight Reconstruction

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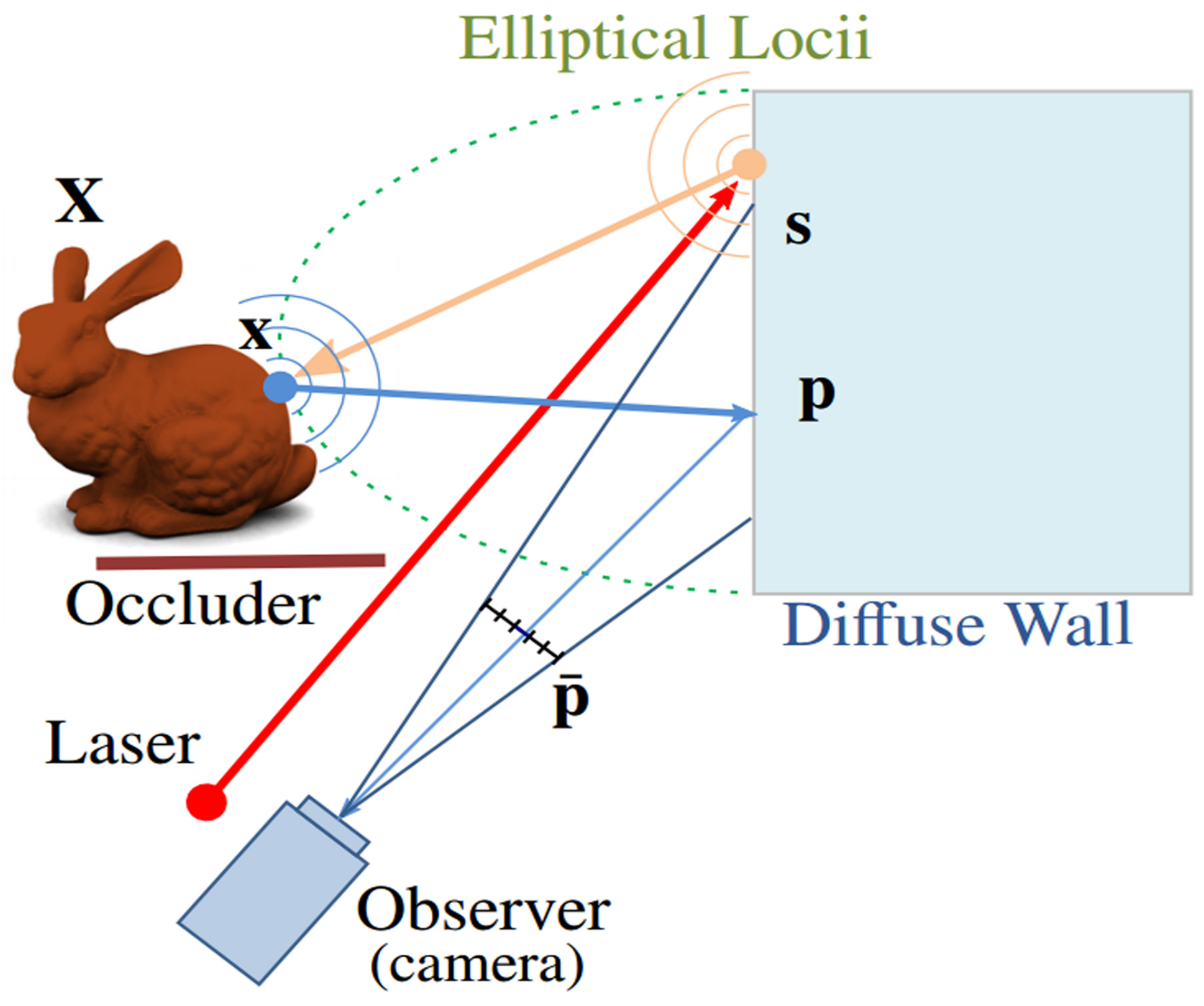
Recent works have demonstrated non-line of sight (NLOS) reconstruction by using the time-resolved signal from multiply scattered light. These works combine ultrafast imaging systems with computation, which back-projects the recorded space-time signal to build a probabilistic map of the hidden geometry. Unfortunately, this computation is slow, becoming a bottleneck as the imaging technology improves. In this work, we propose a new back-projection technique for NLOS reconstruction, which is up to a thousand times faster than previous work, with almost no quality loss. We base on the observation that the hidden geometry probability map can be built as the intersection of the three-bounce space-time manifolds defined by the light illuminating the hidden geometry and the visible point receiving the scattered light from such hidden geometry. This allows us to pose the reconstruction of the hidden geometry as the voxelization of these space-time manifolds, which has lower theoretic complexity and is easily implementable in the GPU. We demonstrate the efficiency and quality of our technique compared against previous methods in both captured and synthetic data. This work is partially founded by DARPA (REVEAL), ERC (Consolidator grand, CHAMELEON) and MINECO (TIN2016-78753-P, TIN2014-61696-EXP).

## Overview

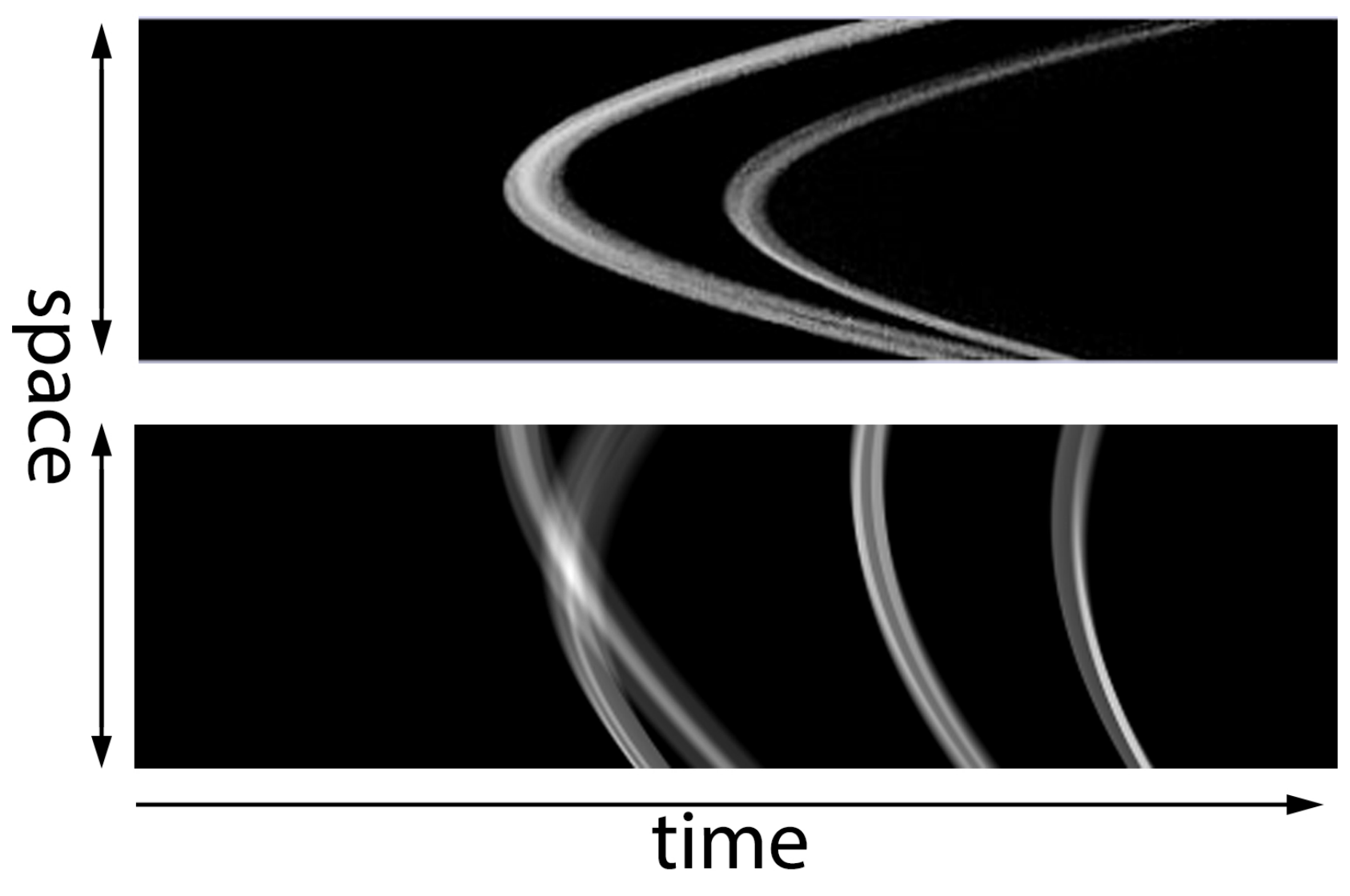
Hidden parts of the scene can be reconstructed by imaging a diffuse wall with a laser and capturing the radiance that has has subsequently travelled to a hidden object and reflected back to the wall along with its travel time.



⇦ *A laser pulse is emitted towards a diffuse wall, creating a virtual point light **s** illuminating the occluded scene **X**. The reflection of the occluded geometry travels back to the diffuse wall, which is imaged by the camera.*

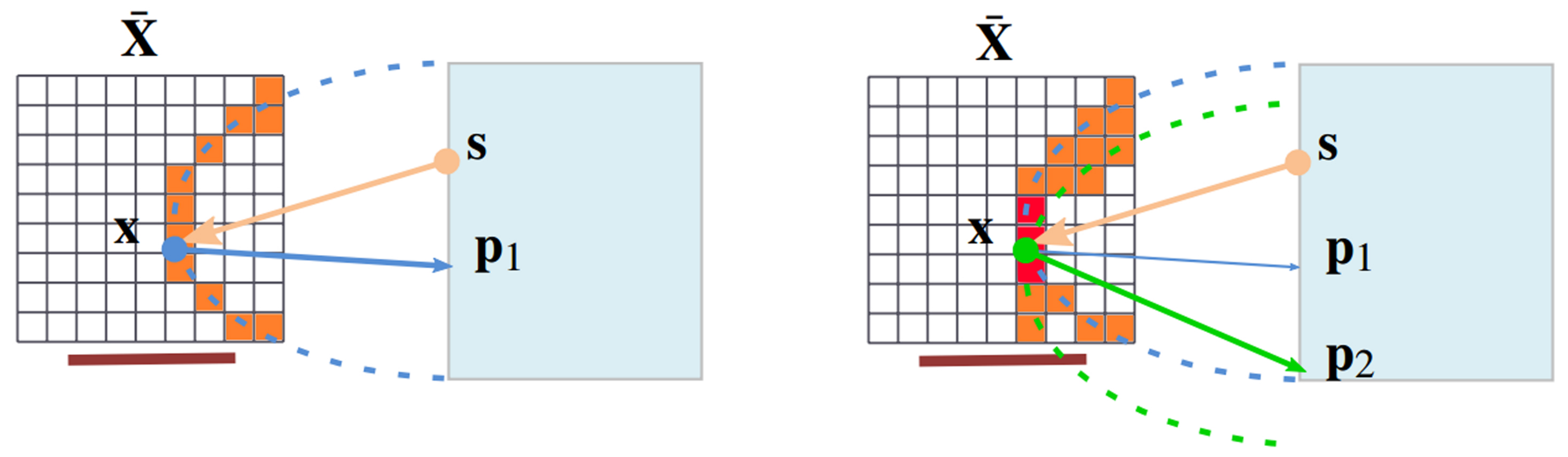
*The total propagation time from a hidden surface point **x** forms an ellipsoid with focal points at **s** and **p***

*A set of space-time radiance streak images is recorded by the camera, which contains information about the hidden geometry* ⇨



### Geometry reconstruction

- **Traditional backprojection.** The space to be reconstructed is subdivided in voxels. A *probability of containing geometry* map is computed for each voxel using radiance data from the space-time streak images captured [Gupta 2012]
- **Our method.** Instead of computing the probability map for each voxel, we observe that each set of points that can contribute to the final camera image are contained in an area defined by the surface of a prolate ellipsoid [Arellano 2017]

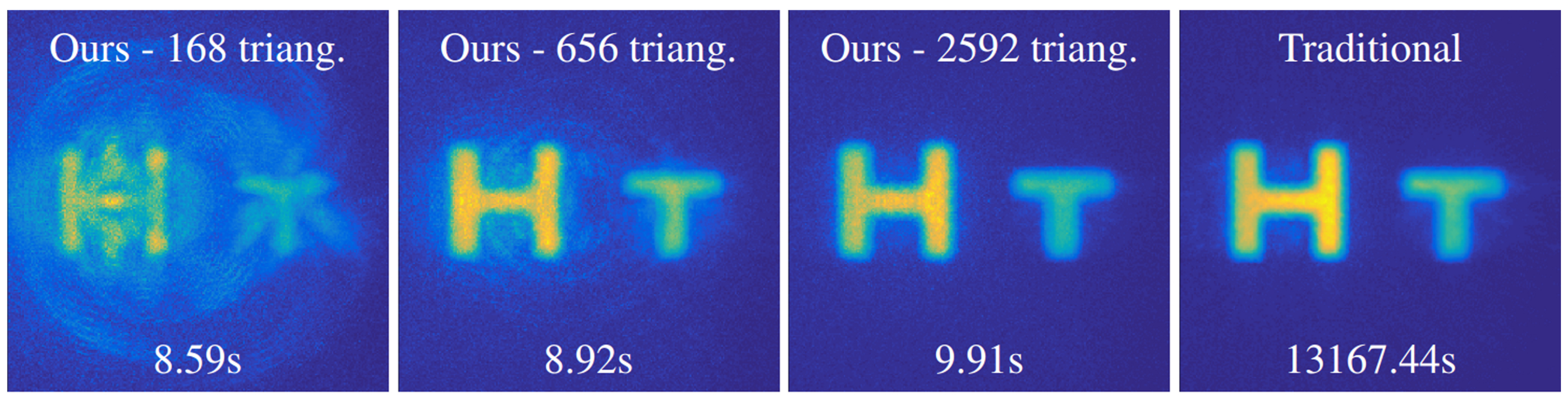


⇧ *The intersection of several of these ellipsoids defines a probability map for the occluded geometry without need of individual per-voxel computations*

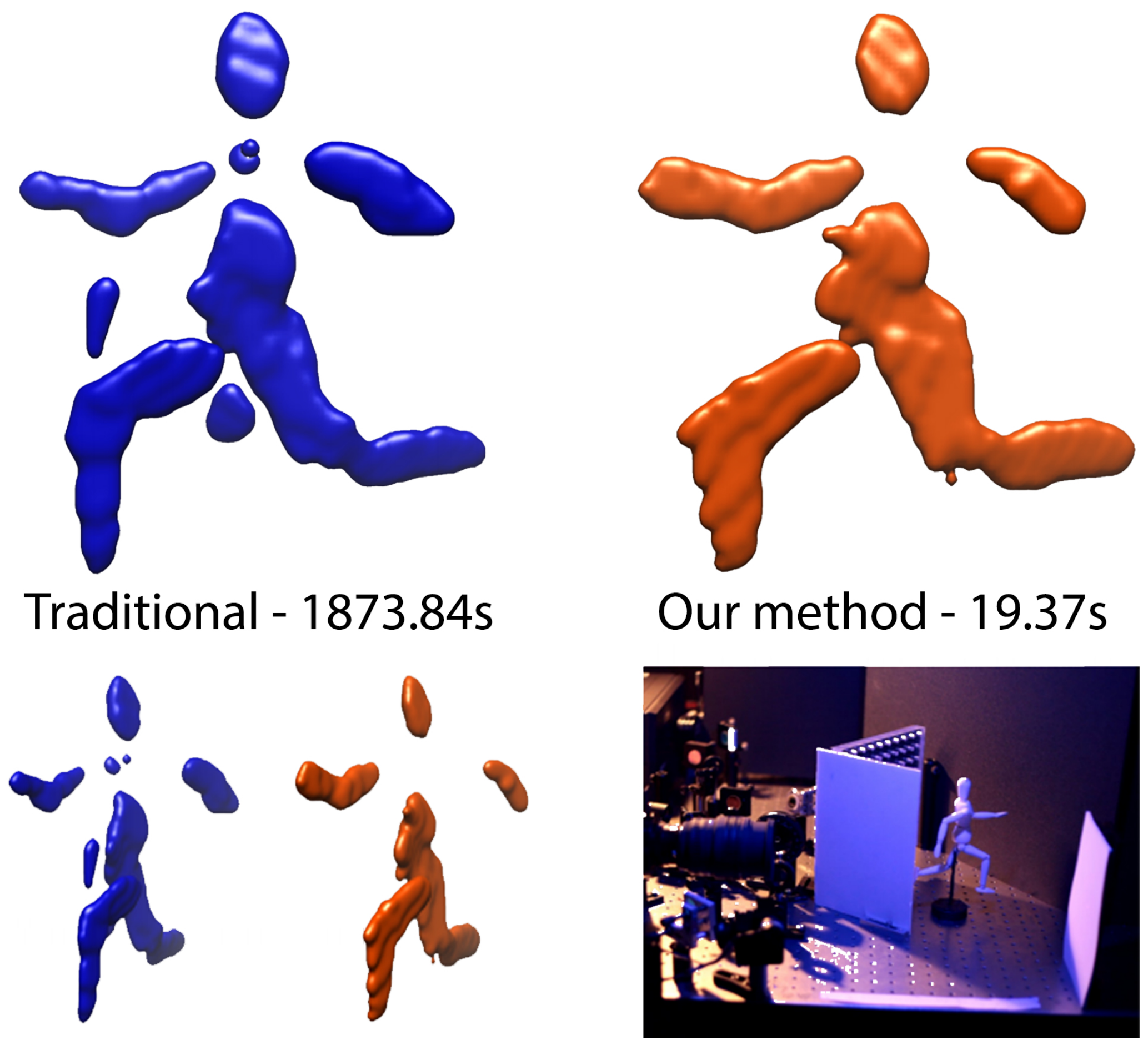
### Implementation

- **Testing voxel-ellipsoid intersections.** The captured data is projected into the scene using semi-conservative GPU Voxelization
- **Geometric ellipsoid representation.** Ellipsoids are approximated using geodesic tesellated base spheres with various level of tesellation, chosen dinamically in function of a minimum error treshold. The spheres are transformed into ellipsoids by using a standard linear sphere-to-ellipsoid transformation matrix and then rendered using instanced rendering

## Results



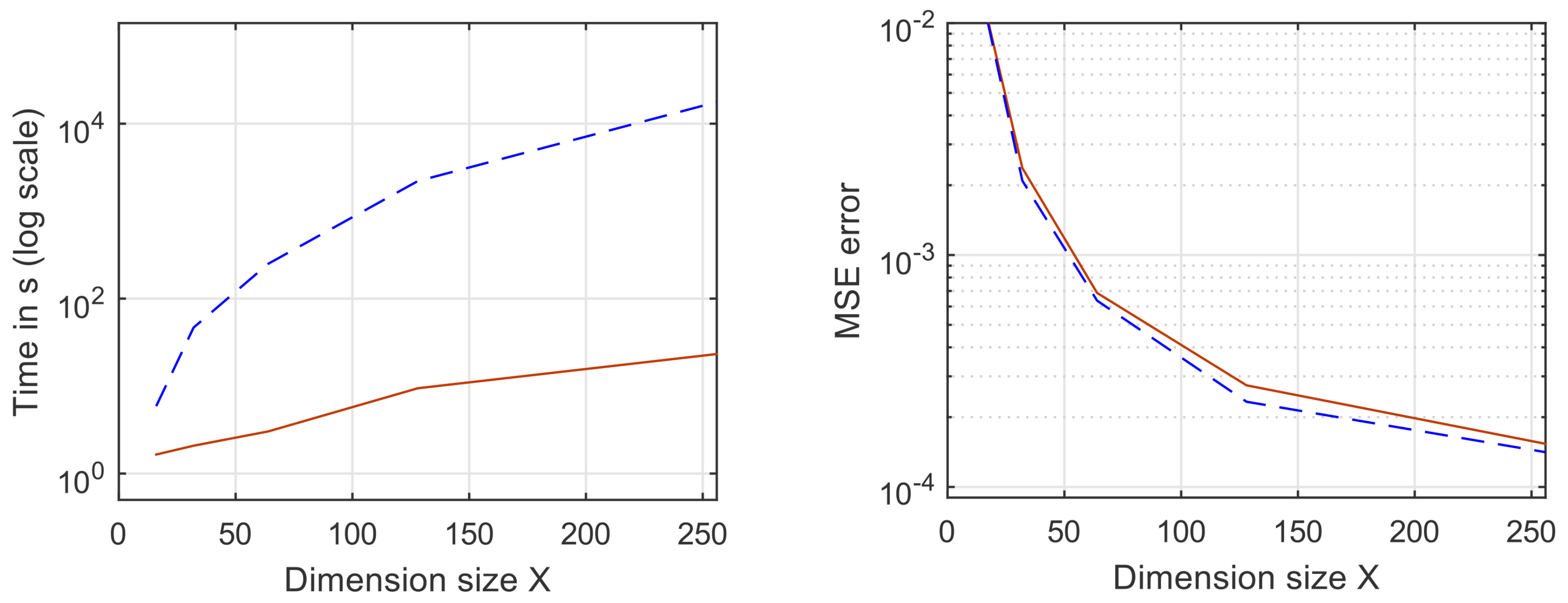
⇧ *Reconstruction of a synthetic scene rendered with [Jarabo 2014] for various tesellation quality levels. Right: The same synthetic scene reconstructed using traditional backprojection. As we can see, not only our method offers indistingishable results from traditional backprojection while offering a **speed-up of more than 1300x**, but also we are able, unlike current state-of-the-art approaches, to trade quality for computation time as desired by adjusting the tesellation levels used.*


Traditional - 1873.84s

Our method - 19.37s

⇦ *Reconstruction of a real mannequin using a streak camera and a femtosecond laser (depicted at bottom-right), using traditional backprojection (left) and our method (right). We achieve a **speed-up of two orders of magnitude** while obtaining similar reconstruction quality. Data and inset from [Velten 2012]*

*Cost (left) and error with respect to the ground truth (right) comparisons between our method (solid orange) and traditional back-projection (dashed blue) for the synthetic scene shown at the page top, over varying voxel reconstruction space dimensions. As shown, the error introduced by our algorithm with respect to traditional back-projection is negligible* ⇩



### References

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