

**The Disk Substructures at High Angular Resolution Project: What observations of protoplanetary disks tell us about planet formation.** Andrea Isella<sup>1</sup>, Sean M. Andrews<sup>2</sup>, Cornelis P. Dullemond<sup>3</sup>, Laura Pérez<sup>4</sup>, Jane Huang<sup>2</sup>, Tilman Birnstiel<sup>5</sup>, Viviana V. Guzman<sup>6</sup>, Nicolás T. Kurtovic<sup>4</sup>, Shangjia Zhang<sup>7</sup>, Zhaohuan Zhu<sup>7</sup>, Xue-Ning Bai<sup>8</sup>, Myriam Benisty<sup>9,10</sup>, John M. Carpenter<sup>6</sup>, A. Meredith Hughes<sup>11</sup>, Karin I. Öberg<sup>2</sup>, Luca Ricci<sup>12</sup>, Erik Weaver<sup>1</sup>, David J. Wilner<sup>2</sup>, <sup>1</sup>Department of Physics and Astronomy, Rice University, 6100 Main Street, Houston, TX 77005, USA, [isella@rice.edu](mailto:isella@rice.edu), <sup>2</sup>Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA, <sup>3</sup>Zentrum für Astronomie, Heidelberg University, Albert Ueberle Str. 2, D-69120 Heidelberg, Germany, <sup>4</sup>Departamento de Astronomía, Universidad de Chile, Camino El Observatorio 1515, Las Condes, Santiago, Chile, <sup>5</sup>University Observatory, Faculty of Physics, Ludwig-Maximilians-Universität München, Scheinerstr. 1, D-81679 Munich, Germany, <sup>6</sup>Joint ALMA Observatory, Avenida Alonso de Córdova 3107, Vitacura, Santiago, Chile, <sup>7</sup>Department of Physics and Astronomy, University of Nevada, Las Vegas, 4505 S. Maryland Parkway, Las Vegas, NV 89154, USA, <sup>8</sup>Institute for Advanced Study and Tsinghua Center for Astrophysics, Tsinghua University, Beijing 100084, People's Republic of China, <sup>9</sup>Unidad Mixta Internacional Franco-Chilena de Astronomía, CNRS/INSU UMI 3386, Departamento de Astronomía, Universidad de Chile, Camino El Observatorio 1515, Las Condes, Santiago, Chile, <sup>10</sup>Univ. Grenoble Alpes, CNRS, IPAG, F-38000 Grenoble, France, <sup>11</sup>Department of Astronomy, Van Vleck Observatory, Wesleyan University, 96 Foss Hill Drive, Middletown, CT 06459, USA, <sup>12</sup>Department of Physics and Astronomy, California State University Northridge, 18111 Nordhoff Street, Northridge, CA 91130, USA.

In recent years, telescopes operating at near-infrared and millimeter wavelengths have imaged nearby young (<10 Myr) protoplanetary systems at unprecedented angular resolution revealing unexpected structures in the distribution of the circumstellar dust and gas [1, 2]. Accumulation of dust particles and molecules with the shape of rings, crescents, and spiral arms were discovered [3, 4]. By mapping the distribution and kinematics of gas and dust on spatial scales as small as 5 astronomical units (au), these observations constrain the structure and evolution of protoplanetary disks, and provide long-sought clues to how planets form.

In this contribution, we present the first results of the Disk Substructure at High Angular Resolution Project (DSHARP) conducted as one the first large programs at the Atacama Large Millimeter Array (ALMA). DSHARP measured the 240 GHz (1.25 mm) continuum emission at about 35 milli-arcsecond resolution for 20 nearby protoplanetary disks to help better understand the evolution of solid particles during the planet formation process. A gallery of images produced by DSHARP is presented in the Figure below. These images reveal that multiple-ring systems are ubiquitous among the most massive protoplanetary disks [5], but their morphology substantially varies from object to object [6].

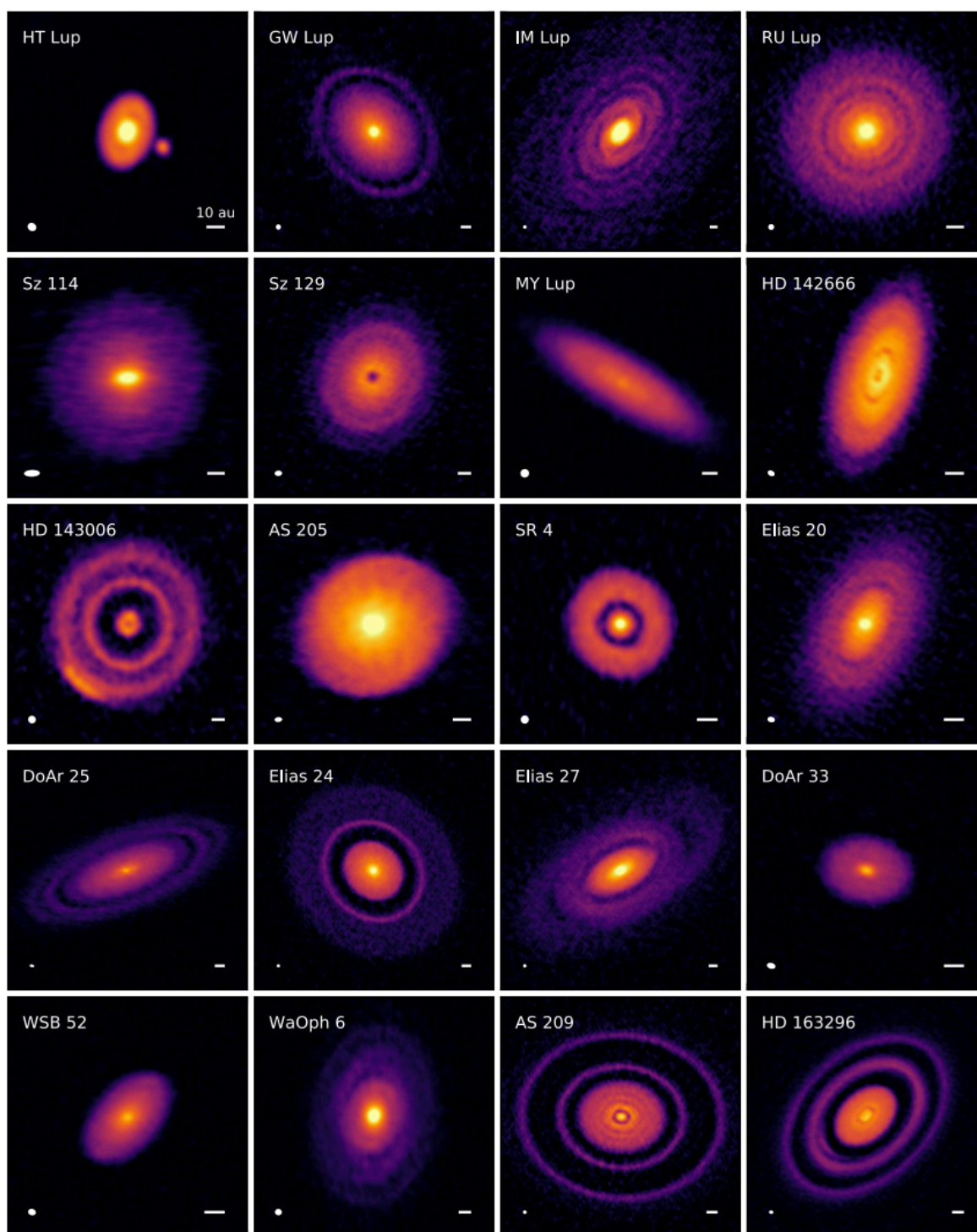
Several theoretical models have been proposed to explain the formation of rings in protoplanetary disks. These include the interaction between the disk and yet-unseen planets [7], sharp opacity variations at gas-solid phase transitions [8], dust accumulations at the edge of low-viscosity regions [9], and zonal flows via spontaneous concentration of net vertical flux [10]. However, our new data indicate that planet-disk interaction models is the most successful in explaining the observed structures [11]. Taken at face value, DSHARP results

suggest the existence of a population of young planets orbiting at several tens of au from their host stars, which challenges current planet formation models. In addition, the DSHARP disk images show that several of the observed rings are very narrow in radial extent. We find that this results is consistent with dust particles trapped in local maxima of the gas pressure [12], and suggest that this process might control the formation of planetesimals even at very large distances from the central star.

In this presentation, we will summarize the main results of DSHARP and discuss their implications in terms of our current understanding of the solar systems, and of planetary systems in general.

#### References:

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From [5]. Gallery of 240 GHz (1.25 mm) continuum emission images for the disks in the DSHARP sample. The angular resolution of the observations and 10 au scale bars are shown in the lower left and right corners of each panel, respectively