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Icarus

Volume 287, Pages 1-334 (1 May 2017)

Special Issue: The Pluto System

Edited by Richard P. Binzel, Catherine B. Olkin, Leslie A. Young and Philip

D. Nicholson

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 Editorial

Page 1

Richard P. Binzel, Catherine B. Olkin, Leslie A. Young

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 Origin of the Pluto–Charon system: Constraints from the New Horizons flyby Original Research Article

Pages 2-11

William B. McKinnon, S.A. Stern, H.A. Weaver, F. Nimmo, C.J. Bierson, W.M. Grundy, J.C. Cook, D.P. Cruikshank, A.H. Parker, J.M. Moore, J.R. Spencer, L.A. Young, C.B. Olkin, K. Ennico Smith, the New Horizons Geology, Geophysics & Imaging and Composition Theme Teams

[Abstract](#)

[Close research highlights](#)

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Highlights

- Pluto and Charon are rock rich while the small satellites are mostly water ice.
- Charon is about 10% icier than Pluto.
- A giant impact origin involving partially differentiated precursors supported.
- Formation of entire PC system in a collapsing, rotating pebble cloud not supported.
- Slow, late accretion of impact precursors indicated.

 Mean radius and shape of Pluto and Charon from *New Horizons* images Original Research Article

Pages 12-29

Francis Nimmo, Orkan Umurhan, Carey M. Lisse, Carver J. Bierson, Tod R. Lauer, Marc W. Buie, Henry B. Throop, Josh A. Kammer, James H. Roberts, William B. McKinnon, Amanda M. Zangari, Jeffrey M. Moore, S. Alan Stern, Leslie A. Young, Harold A. Weaver, Cathy B. Olkin, Kim Ennico

[Abstract](#)

[Close research highlights](#)

[Purchase PDF - \\$35.95](#)

Highlights

- We determined the radii of Pluto and Charon from New Horizons images.
- The radii are 1188.3 ± 1.6 km and 606.0 ± 1.0 km.
- Pluto is 9% denser than Charon.
- No flattening is detected for either Pluto ($<0.6\%$) and Charon ($<0.5\%$)
-

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The absence of flattening is consistent with the presence of a subsurface ocean.

[Climate zones on Pluto and Charon](#) Original Research Article

Pages 30-36

Richard P. Binzel, Alissa M. Earle, Marc W. Buie, Leslie A. Young, S. Alan Stern, Cathy B. Olkin, Kimberly Ennico, Jeffrey M. Moore, Will Grundy, Harold A. Weaver, Carey M. Lisse, Tod R. Lauer, the New Horizons Geology and Geophysics Imaging Team

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Pluto's large axis tilt creates "seasons" that are very different from Earth's.
- Most of Pluto's surface is actually "tropical" in experiencing direct sunlight.
- Much of Pluto's surface experiences both tropical AND arctic seasons.
- The unusual seasons experienced by Pluto may shape what we see.

[Long-term surface temperature modeling of Pluto](#) Original Research Article

Pages 37-46

Alissa M. Earle, Richard P. Binzel, Leslie A. Young, S.A. Stern, K. Ennico, W. Grundy, C.B. Olkin, H.A. Weaver, the New Horizons Geology and Geophysics Imaging Team

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Presents local and global thermal models of Pluto.
- Consider the current epoch as well as past epochs during which Pluto experienced "extreme seasons" due to variations in its orbit over millionyear timescales.
- Local thermal model explores possible surface temperatures as a function of latitude and albedo.
- Pluto's equatorial region supports stark albedo contrasts over million-year timescales because bright areas will stay cold, attracting fresh volatile deposits, while dark regions will stay warm and be unlikely locations for long-term volatile deposits.

[Past epochs of significantly higher pressure atmospheres on Pluto](#) Original Research Article

Pages 47-53

S.A. Stern, R.P. Binzel, A.M. Earle, K.N. Singer, L.A. Young, H.A. Weaver, C.B. Olkin, K. Ennico, J.M. Moore, W.B. McKinnon, J.R. Spencer, New Horizons Geology and Geophysics and Atmospheres Teams

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Pluto has undergone thousands of cycles of obliquity change and polar precession.
- Such changes could produce dramatic increases in surface pressure.
- Such changes may also explain geomorphologic features suggesting paleo-liquids.
- This paper motivates future climate modeling/geologic interpretation in this area.

[A post-new horizons global climate model of Pluto including the N₂, CH₄ and CO cycles](#) Original Research Article

Pages 54-71

F. Forget, T. Bertrand, M. Vangvichith, J. Leconte, E. Millour, E. Lellouch

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- A new 3D Global Climate Model (GCM) to simulate Pluto's atmosphere is described.
- The model simulates temperatures, winds and the N₂, CH₄ and CO cycles.
- Surface winds are induced by the topography and N₂ condensation and sublimation.
- A cold atmospheric layer is obtained in Sputnik Planum, as observed by New Horizons.
- The GCM predicts abundance of CO and CH₄ gas in agreement with observations.

[3D modeling of organic haze in Pluto's atmosphere](#) Original Research Article

Pages 72-86

Tanguy Bertrand, François Forget

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)**Highlights**

- We obtained a maximal photolysis rate of CH₄ of $1.3 \times 10^{21} \text{ g cm}^{-3} \text{ s}^{-1}$ in 2015, at 250 km altitude, and a haze extending up to 500 km altitude with a density scale height of 40 km.
- Due to the weak meridional circulation, the haze precursors are not easily transported in the lower atmospheric layers and remain at high altitudes and in larger amount at high northern latitudes, leading to a more extensive haze in the northern hemisphere.
- If we assume a condensation flow of N₂ from the northern towards the southern hemisphere, then the haze precursors can be transported faster at lower altitude above the south pole, leading to a latitudinally more homogeneous haze density.
- The column mass of haze computed by our model primarily depends on the sedimentation velocity and thus on the pressure and the considered monomer radius. Between 1990 and 2015, the column mass of haze obtained follows the trend in surface pressure: an increase by a factor of 3.
- We computed the UV and VIS opacities of the haze as a diagnostic of our simulation results and in all simulation cases, the column visible opacities have similar values around 0.001–0.01 (slightly higher for large fractal particles).

 [Rarefied gas dynamic simulation of transfer and escape in the Pluto–Charon system](#) Original Research Article

Pages 87-102

William A. Hoey, Seng Keat Yeoh, Laurence M. Trafton, David B. Goldstein, Philip L. Varghese

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)**Highlights**

- Pre- and post-encounter cases are simulated and well-resolved flowfields shown.
- A simulated escape rate of $7 \times 10^{25} \text{ CH}_4 \text{ s}^{-1}$ for the NH encounter agrees with observation.
- Total flux to Charon is $2 \times 10^{24} \text{ s}^{-1}$ at ~98% CH₄, with peak values (~2x) on the upstream face.
- Charon gravitationally focuses incident flow into a wakeward high-density region.
- Charon may retain a thin atmosphere sourced from Pluto's escape, but below observable levels.

 [The puzzling detection of x-rays from Pluto by *Chandra*](#) Original Research Article

Pages 103-109

C.M. Lisse, R.L. McNutt Jr., S.J. Wolk, F. Bagenal, S.A. Stern, G.R. Gladstone, T.E. Cravens, M.E. Hill, P. Kollmann, H.A. Weaver, D.F. Strobel, H.A. Elliott, D.J. McComas, R.P. Binzel, B.T. Snios, A. Bhardwaj, A. Chutjian, L.A. Young, C.B. Olkin, K.A. Ennico

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)**Highlights**

- We have detected 7 net x-rays in 174 ksec from the Pluto system using Chandra.
- This 1st KBO x-ray detection was at > 99.95% significance & $0.60 > E > 0.31 \text{ keV}$.
- The power represented by this signal is significant, $200^{+200}_{-100} \text{ MW}$.
- Charge-exchange between SW CNO ions & escaping Pluto neutrals could produce this.
- Less likely is scattering of solar x-rays by haze particles in Pluto's atmosphere.

 [The photochemistry of Pluto's atmosphere as illuminated by New Horizons](#) Original Research Article

Pages 110-115

Michael L. Wong, Siteng Fan, Peter Gao, Mao-Chang Liang, Run-Lie Shia, Yuk L. Yung, Joshua A. Kammer, Michael E. Summers, G. Randall Gladstone, Leslie A. Young, Catherine B. Olkin, Kimberly Ennico, Harold A. Weaver, S. Alan Stern, The New Horizons Science Team

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)**Highlights**

- State-of-the-art photochemical model for Pluto's atmosphere.
- Constrained the surface mixing ratio of CH₄ and the eddy diffusion profile of Pluto's atmosphere.
- Constrained saturation vapor pressures and sticking coefficients for C₂ hydrocarbons and the sticking coefficient for HCN.
- Prediction for downward fluxes of hydrocarbon and nitrile species.
- Predictions for abundances of oxygen-bearing species in Pluto's atmosphere.

[Constraints on the microphysics of Pluto's photochemical haze from *New Horizons* observations](#) Original Research Article

Pages 116-123

Peter Gao, Siteng Fan, Michael L. Wong, Mao-Chang Liang, Run-Lie Shia, Joshua A. Kammer, Yuk L. Yung, Michael E. Summers, G. Randall Gladstone, Leslie A. Young, Catherine B. Olkin, Kimberly Ennico, Harold A. Weaver, S. Alan Stern, The New Horizons Science Team

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- A model of Pluto's haze is developed and compared to New Horizons data.
- Extinction and scattering observations suggest that haze particles are aggregates.
- Condensation of hydrocarbons and nitriles likely affects haze distribution.
- Compositional differences between Pluto's and Titan's hazes require investigation.
- Pluto's atmosphere may be more amicable to particle charging than Titan's.

[New Horizons constraints on Charon's present day atmosphere](#) Original Research Article

Pages 124-130

S.A. Stern, J.A. Kammer, G.R. Gladstone, A.J. Steffl, A.F. Cheng, L.A. Young, H.A. Weaver, C.B. Olkin, K. Ennico, J. Wm. Parker, A.H. Parker, T.R. Lauer, A. Zangari, M. Summers, the New Horizons Atmospheres Team

[Abstract](#) | [Purchase PDF - \\$35.95](#)

[Pluto–Charon solar wind interaction dynamics](#) Original Research Article

Pages 131-139

J.P.M. Hale, C.S. Paty

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Charon is able to alter the Pluto-solar wind interaction significantly when upstream.
- If Charon possesses an ionosphere it alters the gross structure of interaction region.
- Evidence for Charon shielding Pluto against atmospheric loss is shown.

[Inflight radiometric calibration of New Horizons' Multispectral Visible Imaging Camera \(MVIC\)](#) Original Research Article

Pages 140-151

C.J.A. Howett, A.H. Parker, C.B. Olkin, D.C. Reuter, K. Ennico, W.M. Grundy, A.L. Graps, K.P. Harrison, H.B. Throop, M.W. Buie, J.R. Lovering, S.B. Porter, H.A. Weaver, L.A. Young, S.A. Stern, R.A. Beyer, R.P. Binzel, B.J. Buratti, A.F. Cheng, J.C. Cook, D.P. Cruikshank, *et al.*

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Outline of two semi-independent inflight calibrations of New Horizons/MVIC.
- The stellar calibration used to produce PDS radiometric keywords is detailed.
- Other technique compares MVIC and Hubble observations of Charon.
- Both techniques show good agreement (better than 7%).

[Charon's light curves, as observed by New Horizons' Ralph color camera \(MVIC\) on approach to the Pluto system](#) Original Research Article

Pages 152-160

C.J.A. Howett, K. Ennico, C.B. Olkin, M.W. Buie, A.J. Verbiscer, A.M. Zangari, A.H. Parker, D.C. Reuter, W.M. Grundy, H.A. Weaver, L.A. Young, S.A. Stern

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Color light curves of Charon are produced from New Horizons/MVIC.

- Results show Charon is brighter on its Pluto-facing hemisphere.
- Blue and Red light curves show that Charon's surface is neutral in color.

[Charon tectonics](#) Original Research Article Open Access
Pages 161-174

Ross A. Beyer, Francis Nimmo, William B. McKinnon, Jeffrey M. Moore, Richard P. Binzel, Jack W. Conrad, Andy Cheng, K. Ennico, Tod R. Lauer, C.B. Olkin, Stuart Robbins, Paul Schenk, Kelsi Singer, John R. Spencer, S. Alan Stern, H.A. Weaver, L.A. Young, Amanda M. Zangari

[Abstract](#) | [Close research highlights](#) | [PDF \(7151 K\)](#)

Highlights

- Observations of extensional features on Charon's surface are discussed.
- These features suggest an areal strain of 1%.
- This is consistent with an ancient global ocean that is now frozen.

[Differentiation and cryovolcanism on Charon: A view before and after New Horizons](#) Original Research Article

Pages 175-186

S.J. Desch, M. Neveu

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- This work was prompted by the New Horizons mission encounter with Pluto / Charon.
- We test whether Charon's density is consistent with formation from a circumplutonian disk.
- We examine whether Charon should melt or differentiate if formed from a circumplutonian disk.
- We calculate the thermal history of Charon and determine when its subsurface liquid froze.
- We review evidence that Kubrick Mons and similar features are cryo- volcanic.

[Craters of the Pluto-Charon system](#) Original Research Article

Pages 187-206

Stuart J. Robbins, Kelsi N. Singer, Veronica J. Bray, Paul Schenk, Tod R. Lauer, Harold A. Weaver, Kirby Runyon, William B. McKinnon, Ross A. Beyer, Simon Porter, Oliver L. White, Jason D. Hofgartner, Amanda M. Zangari, Jeffrey M. Moore, Leslie A. Young, John R. Spencer, Richard P. Binzel, Marc W. Buie, Bonnie J. Buratti, Andrew F. Cheng, William M. Grundy, *et al.*

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Present consensus impact crater catalog for Pluto, Charon, Nix, Hydra.
- Show pros and cons of different types of image processing to map craters.
- Show encounter hemisphere trends of craters on Pluto and Charon.

[Global albedos of Pluto and Charon from LORRI New Horizons observations](#) Original Research Article

Pages 207-217

B.J. Buratti, J.D. Hofgartner, M.D. Hicks, H.A. Weaver, S.A. Stern, T. Momary, J.A. Mosher, R.A. Beyer, A.J. Verbiscer, A.M. Zangari, L.A. Young, C.M. Lisse, K. Singer, A. Cheng, W. Grundy, K. Ennico, C.B. Olkin

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- The reflectivity of Pluto's surface varies by over a factor of 10.
- The highest albedo regions of Pluto approach normal reflectances of unity.
- The albedo patterns on Pluto are well-correlated with its geology.
- The temperature variations on Pluto are at least 20 K.
- The dwarf planet Eris is likely to have ongoing activity on its surface.

[Pluto's global surface composition through pixel-by-pixel Hapke modeling of New Horizons Ralph/LEISA data](#) Original Research Article

Pages 218-228

S. Protopapa, W.M. Grundy, D.C. Reuter, D.P. Hamilton, C.M. Dalle Ore, J.C. Cook, D.P. Cruikshank, B. Schmitt, S. Philippe, E. Quirico, R.P. Binzel, A.M. Earle, K. Ennico, C.J.A. Howett, A.W. Lunsford, C.B. Olkin, A. Parker, K.N. Singer, A. Stern, A.J. Verbiscer, H.A. Weaver, *et al.*

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- Pixel-by-pixel Hapke modeling of New Horizons Ralph/LEISA data.
- Maps of Pluto's volatiles and non-volatiles components.
- Latitudinal variations of CH₄ and N₂ ices consistent with differences in insolation.
- Possible sublimation transport of N₂ ice within Sputnik Planitia.
- Sputnik Planitia is possibly a cold trap of volatiles.

[Physical state and distribution of materials at the surface of Pluto from New Horizons LEISA imaging spectrometer](#) Original Research Article

Pages 229-260

B. Schmitt, S. Philippe, W.M. Grundy, D.C. Reuter, R. Côte, E. Quirico, S. Protopapa, L.A. Young, R.P. Binzel, J.C. Cook, D.P. Cruikshank, C.M. Dalle Ore, A.M. Earle, K. Ennico, C.J.A. Howett, D.E. Jennings, I.R. Linscott, A.W. Lunsford, C.B. Olkin, A.H. Parker, J.Wm. Parker, *et al.*

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- The analysis of the first couple of LEISA/New Horizons spectro-images is performed.
- Qualitative distribution maps are obtained for N₂, CH₄, CO, H₂O and the red material.
- 3 different types of ices are found: N₂-rich:CH₄:CO, CH₄-rich(:CO:N₂?) and H₂O ices.
- Sublimation sequence transforms N₂-rich ice to CH₄-rich ice through a binary mixture.

[Geological mapping of Sputnik Planitia on Pluto](#) Original Research Article

Pages 261-286

Oliver L. White, Jeffrey M. Moore, William B. McKinnon, John R. Spencer, Alan D. Howard, Paul M. Schenk, Ross A. Beyer, Francis Nimmo, Kelsi N. Singer, Orkan M. Umurhan, S. Alan Stern, Kimberly Ennico, Cathy B. Olkin, Harold A. Weaver, Leslie A. Young, Andrew F. Cheng, Tanguy Bertrand, Richard P. Binzel, Alissa M. Earle, Will M. Grundy, Tod R. Lauer, *et al.*

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- The geology of Sputnik Planitia on Pluto is mapped at 1:2 M scale.
- All mapped units are presently being affected by the action of flowing N₂ ice.
- Sputnik Planitia is experiencing convection, glacial flow, and sublimation.
- Condensation of N₂ onto much of Sputnik Planitia creates a bright mantle.
- Blocky H₂O ice mountains and hills have been mobilized by flow of N₂ ice.

[Present and past glaciation on Pluto](#) Original Research Article

Pages 287-300

Alan D. Howard, Jeffrey M. Moore, Orkan M. Umurhan, Oliver L. White, Robert S. Anderson, William B. McKinnon, John R. Spencer, Paul M. Schenk, Ross A. Beyer, S. Alan Stern, Kimberly Ennico, Cathy B. Olkin, Harold A. Weaver, Leslie A. Young, the New Horizons Science Team

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[Supplementary content](#)

Highlights

- Nitrogen glaciers are presently flowing on Pluto.
- A glacial cycle of N₂ sublimation, deposition and return flow is indicated.
- A variety of dissected landforms were probably carved by paleo-glaciers.

[Modeling glacial flow on and onto Pluto's Sputnik Planitia](#) Original Research Article

Pages 301-319

O.M. Umurhan, A.D. Howard, J.M. Moore, A.M. Earle, O.L. White, P.M. Schenk, R.P. Binzel, S.A. Stern, R.A. Beyer, F. Nimmo, W.B. McKinnon, K. Ennico, C.B. Olkin, H.A. Weaver, L.A. Young

[Abstract](#) | [Close research highlights](#) | [Purchase PDF - \\$35.95](#)

Highlights

- A N₂ ice glacial flow model is developed.

- The model incorporates known thermophysical and rheological properties of N₂.
- Dark patterning seen near Sputnik Planitia's northern shoreline is examined.
- Our flow model suggests these may be imprints of near surface bottom topography.

[Sublimation as a landform-shaping process on Pluto](#) Original Research Article

Pages 320-333

Jeffrey M. Moore, Alan D. Howard, Orkan M. Umurhan, Oliver L. White, Paul M. Schenk, Ross A. Beyer, William B. McKinnon, John R. Spencer, Will M. Grundy, Tod R. Lauer, Francis Nimmo, Leslie A. Young, S. Alan Stern, Harold A. Weaver, Cathy B. Olkin, Kimberly Ennico, the New Horizons Science Team

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