HAMBURG: A PRISTINE H4 CHONDRITE FALL. J. Greer[1,2,*], P. R. Heck[1,2,**], J. S. Boesenberg[3], A. Bouvier[4], M. W. Caffee[5], W. Cassata[6], C. Corrigan[7], A. M. Davis[1,2,8], D. Davis[9], M. Fries[10], M. Hankey[11], P. Jenniskens[12,13], Q. L. Li[14], X.-H. Li[14], Y. Liu[14], D. Rowland[15], M. E. Sanborn[16], P. Schmitt-Kopplin[17], S. Sheu[2], G. Q. Tang[14], R. Trappitsch[6], M. Velbel[18,7], K. L. Verosub[16], B. Weller[19], K. Welten[20], Q.-Z. Yin[16], Z. Zajacz[9], Q. Zhou[21], K. Ziegler[22]; [1]Robert A. Pritzker Ctr. for Meteoritics and Polar Studies, Field Museum, Chicago, IL, USA; [2]Dept. of the Geophys. Sci., Univ. of Chicago, Chicago, IL, USA; [3]Earth, Environ. and Planet. Sci., Brown Univ., Providence, RI, USA; [4]Dept. of Earth Sci., Univ. of Western Ontario, London, ON, Canada; [5]Dept. of Physics and Astronomy, Purdue Univ., W. Lafayette, IN, USA; [6]Nucl. and Chem. Sci. Div., Lawrence Livermore National Lab, Livermore, CA, USA; [7]Dept. of Mineral Sci., NMNH, Smithsonian Inst., Washington, DC, USA; [8]Enrico Fermi Inst., Univ. of Chicago, Chicago, IL, USA; [9]Dept. of Earth Sciences, Univ. of Toronto, Toronto, ON, Canada; [10]Astromaterials Research and Exploration Science Div., NASA JSC, Houston, TX, USA; [11]American Meteor Society, Geneseo, NY, USA; [12]SETI Institute, Mountain View, CA, USA; [13]NASA Ames Research Center, Moffett Field, CA, USA; [14]State Key Lab of Lithospheric Evolution, Inst. Of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China; [15]Ctr. for Molecular and Genomic Imaging, Univ. of California Davis, Davis, CA, USA; [16]Dept. of Earth and Planet. Sci., Univ. of California Davis, Davis, NY, USA; [17]Helmholtz Zentrum München, Neuherberg, Germany; [18]Dept. of Earth and Environ. Sci., Michigan State Univ., East Lansing, MI, USA; [19]Albany Medical College, Albany, NY, USA; [20]Space Sci. Lab., Univ. of California Berkeley, Berkeley, CA, USA; [21]Natl. Astron. Obs., Beijing, Chinese Academy of Science, Beijing, China; [22]Inst. of Meteoritics, Univ. of New Mexico, Albuquerque, NM, USA. (*jgreer@fieldmuseum.org; **prheck@fieldmuseum.org).

Introduction: The Hamburg meteorite fell in Michigan on January 17, 2018 around 01:08 UTC. The fireball was reported by 674 witnesses in 11 US states and Ontario, Canada (AMS event #168-2018). The first specimens (e.g. Fig 1) of this meteorite were quickly recovered (two days after the fall) from snow on the frozen surfaces of lakes and therefore have experienced very low amounts of terrestrial weathering. Here we present the initial results from three specimens collected on Strawberry Lake of a consortium study that was formed to thoroughly characterize the meteorite [1].

Hamburg was classified as an H4 ordinary chondrite (OC) within two weeks of its fall. The type specimen has shock stage S2 and weathering grade W0.

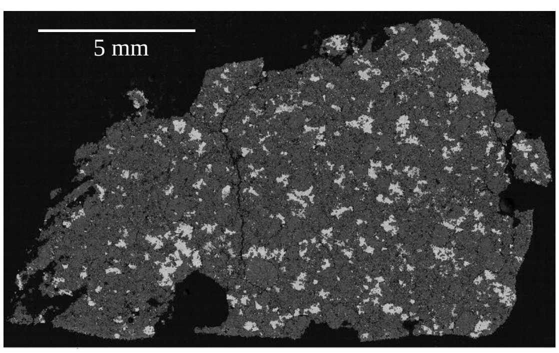

Fig 1. BSE image of FMNH type specimen ME 6108.

Weather Radar: Weather radar was used to calculate the strewn field location after the fireball was observed and to help meteorite hunters with their search efforts. Weather radar predicts a total fall mass of approximately 15.3 kg, but to date, only about 1 kg has been recovered and reported.

Mineralogy and Petrology: The type specimen ME 6108 (Fig 1) was picked up by meteorite hunter Robert Ward, and is curated at the Field Museum (FMNH). This specimen is almost completely covered with fusion crust, and prior to the preparation of a thick section, weighed 24.1 g. A thin section of another specimen was studied for petrology (MSU Abrams Planet. #2018-001a-TS). Meteorite hunter Larry Atkins provided 0.794 g of another specimen (AMS#24) for chronology and isotope studies.

In all specimens, chondrules are well defined and have diameters averaging 0.4±0.2 mm (n=144), consistent with other H chondrites. Chondrule types present include porphyritic olivine (PO; dominant type), radial pyroxene (RP), barred olivine (BO), cryptocrystalline with pyroxene, granular olivine, porphyritic olivine-pyroxene and barred pyroxene chondrules, skeletal olivine, and Al-rich plagioclase chondrules (Fig. 2).

Olivine composition is homogenous in most specimens and averages to $Fa_{18.7\pm0.7}$ (n=34; FMNH) and $Fa_{17.0\pm3.9}$ (n=89; MSU). Pyroxenes are mainly orthopyroxenes and have an average composition of $Fs_{16.3\pm0.7}Wo_{1.3\pm0.1}$ (n=80; FMNH) and $Fs_{15.9\pm2.6}Wo_{2.0\pm2.2}$

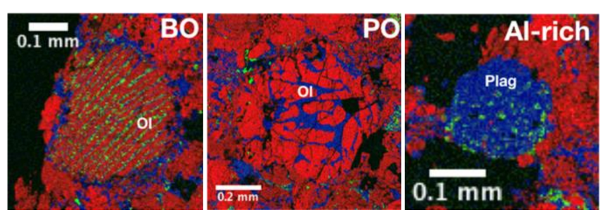

Fig 2. EDS (RGB Mg, Ca, Al) composite maps of selected common (BO, PO) and rare (Al-rich) chondrules in the type specimen. (n=96; MSU).

Olivine in BO chondrules is compositionally homogenous, but olivine and pyroxene can exhibit zoning where they co-occur. Feldspars have an average size of 3.4±2.2 µm (n=64) on the long axis and have an average composition of $An_{14.0\pm4.0}Ab_{81.1\pm3.0}Or_{4.8\pm1.3}$ (n=13). Phosphates account for 0.5 vol%, mainly merrillite (0.4%) and apatite (0.1%). Chromites are impact fractured and have an average composition of TiO_2=2.0±0.4 wt% V_2O_3=0.8±0.2 wt% (n=25). Sulfides were present as melt veins in the fusion crust.

Oxygen and chromium isotopes: Bulk samples were analyzed using laser fluorination [2] for an average mass independent $\Delta^{17}O'$ value of 0.585±0.068 (±1σ). Cr isotopes were obtained using TIMS [3], and gave a $\varepsilon^{54}Cr$ value of –0.41±0.07 (±2SE). In Fig. 3 these values are in the lower end of the OC composition field, consistent with H chondrites.

U-Pb chronology of phosphates: LA-ICPMS and SIMS were used to obtain U-Pb ages of phosphates as well as minor and trace element data. Merrillite and apatite grains in Hamburg have similar trace element characteristics to those observed in Kernouvé (H6), though Hamburg apatites are generally more depleted in U and Th than those of Kernouvé. We find an average Pb-Pb age of 4550 ± 38 Ma (2 apatites and 4 merrillites; MSWD = 0.5). This is in good agreement, although less precise, with our SIMS U-Pb age of 4535 ± 10 Ma (n=15, MSWD=1.13). These ages fall within the period of crystallization of phosphates during thermal metamorphism following accretion of the H chondrite parent body [4]. None of the data reflect later shock events.

Ar-Ar ages, cosmogenic nuclides: Gas release associated with feldspar degassing yields a concordant age of 4521±17 Ma (MSWD=2.3). This age is consistent with other Ar-Ar ages from H4 chondrites [e.g., 5]. A corrected ^{38}Ar cosmic ray exposure (CRE) age of 17.1±1.5 Ma agrees with ^{3}He and ^{21}Ne CRE ages of 14.1±1.4 Ma and 13.5±1.5 Ma, respectively. This suggests that Hamburg was not well shielded, indicating that the meteorite came from either the surface of its parent asteroid or, more likely from smaller meteoroid-sized object. The ^{10}Be concentration of 21.5 dpm/kg in the non-magnetic fraction of Hamburg, measured by accelerator mass spectrometry, is consistent with irradiation in the center of an object with a radius of ~20 cm or near the surface of a larger object (30-65 cm radius).

Origin in asteroid belt: Hamburg's CRE indicates it does not trace the collision event that caused the 7 Ma peak in the H chondrite CRE distribution [6]. Instead the CRE age is similar to the ~12 Ma of H5 chondrite Príbram, which arrived on a 3º inclined orbit from the 3:1 orbital resonance with Jupiter [7].

Organic Chemistry: During handling of the type specimen after it was received, special care was taken to avoid contamination. The meteorite was handled with nitrile gloves, packed in polypropylene bags and stored in an oil-free, low vacuum desiccator when not handled. Methanol extracts of Hamburg were prepared with the same methods as outlined in [8] using material that had not been previously exposed. Extract analysis shows that Hamburg contains 2600 elementary compounds in the CHNOS space. Polar hydrocarbons are the most abundant, followed by sulfurized and N-containing compounds. The distributions of these compounds suggests a series of chemical transformations (e.g. hydration, hydrogenation, methylation). Organometallic compounds are also present, with Mg compounds reflecting thermoprocesses on the parent body.

Magnetic Properties: Magnetic susceptibility was measured as the parent body paleofield is still preserved. Hamburg's magnetic susceptibility matches that of lower limit for LL chondrites and the upper limit of H chondrites [9] with a mean (log χ) value of 5×10^{-9} m^3/kg.

Conclusions: With this study we successfully demonstrate the rapid classification and thorough characterization through a consortium study of a fresh fall. Due to its landing on snow and ice, rapid recovery and minimal exposure to liquid water Hamburg is one of the most pristine OCs. In the future, cryogenic recovery and storage would be desirable to further minimize alteration on Earth.

References: [1] Heck P.R. et al. (in prep.). [2] Sharp, Z.D. (1990) *GCA*, 54, 1353–1357. [3] Yin, Q.-Z. et al. (2014) *MAPS*, 49, 1426–1439. [4] Bouvier A. et al., (2007) *GCA*, 71, 1583–1604 [5] Trieloff M. et al., (2003) *Nature*, 422, 502–506.[6] Graf T. & Marti K. (1995) JGR, 100, 21247–21263. [7] Ceplecha P. et al. (1961) *Bull. Astron. Inst. Czech*, 12, 21–47. [8] Schmitt-Kopplin, P. et al., (2010) *PNAS*, 107, 2763–2768. [9] Rochette P. et al., (2003) *MAPS*, 38, 251–268. *LLNL-ABS-765022*

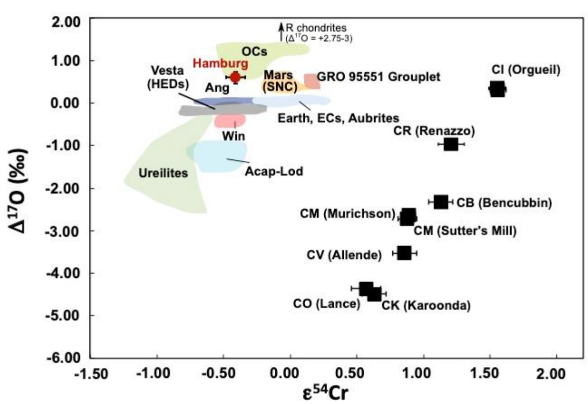

Fig 3. The $\Delta^{17}O$ (±1σ) and $\varepsilon^{54}Cr$ (±2SE) isotopic composition of Hamburg (red circle).