J/ApJ/817/60 Multiply imaged supernova Refsdal (Treu+, 2016)

"Refsdal" meets popper: comparing predictions of the re-appearance of the multiply imaged supernova behind MACSJ1149.5+2223.

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Abstract:
Supernova "Refsdal", multiply imaged by cluster MACS1149.5+2223, represents a rare opportunity to make a true blind test of model predictions in extragalactic astronomy, on a timescale that is short compared to a human lifetime. In order to take advantage of this event, we produced seven gravitational lens models with five independent methods, based on Hubble Space Telescope (HST) Hubble Frontier Field images, along with extensive spectroscopic follow-up observations by HST, the Very Large and the Keck Telescopes. We compare the model predictions and show that they agree reasonably well with the measured time delays and magnification ratios between the known images, even though these quantities were not used as input. This agreement is encouraging, considering that the models only provide statistical uncertainties, and do not include additional sources of uncertainties such as structure along the line of sight, cosmology, and the mass sheet degeneracy. We then present the model predictions for the other appearances of supernova "Refsdal". A future image will reach its peak in the first half of 2016, while another image appeared between 1994 and 2004. The past image would have been too faint to be detected in existing archival images. The future image should be approximately one-third as bright as the brightest known image (i.e., H_{AB}~25.7mag at peak and H_{AB}~26.7mag six months before peak), and thus detectable in single-orbit HST images. We will find out soon whether our predictions are correct.

Description:
Since the discovery of SN Refsdal on 2014 November 11, the MACSJ1149.5+2223 field has been observed in great detail, with HST imaging in optical and infrared bands, and deep spectroscopy from HST, Keck, and the VLT.

The HST grism spectroscopy comprises two data sets. The GLASS data consist of 10 orbits of exposures taken through the G102 grism and 4 orbits of exposures taken through the G141 grism, spanning the wavelength range 0.81-1.69um. The GLASS data were taken at two approximately orthogonal position angles (PAs) to mitigate contamination by nearby sources (the first one on 2014 February 23-25, the second PA on 2014 November 3-11). The SN Refsdal follow-up spectra were taken between 2014 December 23 and 2015 January 4. For more details the reader is referred to Schmidt et al. (2014ApJ...782L..36S) and Treu et al. (2015, J/ApJ/812/114) for GLASS, and G. B. Brammer et al. (2015, in preparation) and P. L. Kelly et al. (2015, in preparation) for the deeper follow-up data.

Integral-field spectroscopy was obtained with the MUSE instrument on the VLT between 2015 February 14 and 2015 April 12, as part of a Director Discretionary Time program to observe SN Refsdal (PI Grillo). Details of the data acquisition and processing are given in a separate paper (Grillo et al. 2015, arXiv:1511.04093).

Spectroscopy of the field was obtained using the DEIMOS spectrograph on the 10m Keck II telescope on 2014 December 20.

File Summary:

FileName	Lrecl	Records	Explanations
ReadMe	80	.	This file
table2.dat	41	429	Redshift catalog
table3.dat	82	97	Multiply imaged systems
table4.dat	45	99	Knots in the host galaxy of SN Refsdal

See also:
J/ApJ/812/114 : Grism Lens-Amplified Survey from Space (GLASS) I. (Treu+, 2015)
J/ApJ/811/29 : GLASS. IV. Lensing cluster Abell 2744 (Wang+, 2015)
J/ApJ/801/44 : HST lensing analysis of the CLASH sample (Zitrin+, 2015)
J/MNRAS/444/268 : HST Frontier Fields clusters (Richard+, 2014)
J/ApJS/211/21 : Spectroscopic redshifts of galaxies in MACS (Ebeling+, 2014)

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 J/ApJS/199/25 : CLASH sources for MACS1149.6+2223 (Postman+, 2012)
 J/ApJ/730/119 : HST/WFC3 observations of Cepheids in SN Ia hosts (Riess+, 2011)
 http://www.stsci.edu/hst/campaigns/frontier-fields/ : HST Frontier Fields
 http://archive.stsci.edu/prepds/glass/ : GLASS MAST home page
```

Byte-by-byte Description of file: table2.dat

```
   Bytes Format Units   Label     Explanations

   1-  3  I3     ---     ID        [1/430] Identification number
   5- 14  F10.6 deg     RAdeg     [177.37/177.43] Right Ascension (J2000)
  16- 24  F9.6  deg     DEdeg     [22.37/22.43] Declination (J2000)
  26- 31  F6.4  ---     z         [0/3.8] Spectroscopic redshift
      33  I1    ---     q_z       Quality flag on z (4=secure; 3=probable)
      35  I1    ---     r_z       Reference flag on z (G1)
  37- 41  F5.1  ---     ImgS      [1.1/210.2]? Corresponding ID of a known
                                   multiply-imaged system
```

Byte-by-byte Description of file: table3.dat

```
   Bytes Format Units   Label     Explanations

   1-  5  F5.1  ---     ImgS       [1.1/210.2]? Identifier (1)
   7- 15  F9.5  deg     RAdeg      [177.38/177.42] Right ascension (J2000)
  17- 25  F9.6  deg     DEdeg      [22.38/22.43] Declination (J2000)
  27- 33  A7    ---     Z09        Z09 identifier(s) (2)
  35- 39  A5    ---     S09        S09 identifier (2)
  41- 44  F4.1  ---     R14        [1.1/14.2]? R14 and J14 identifiers (2)
  46- 48  F3.1  ---     D15        [1.1/8.2]? D15 identifiers (2)
  50- 55  F6.4  ---     z          [1.4/2.5]? Previous spectroscopic redshift
  57- 59  A3    ---     r_z        Reference of z
  61- 65  F5.3  ---     zspec      [0.7/3.8]? New spectroscopic redshift (3)
      67  I1    ---     r_zspec    [1/4]? Source of zspec (G1)
      69  I1    ---     Note       [1/5]? Note (4)
  71- 73  F3.1  ---     Score      [1/3] Average score (1=secure identification) (5)
  75- 82  A8    ---     Set        Category (6)
```

```
Note (1): Coordinates and ID notations of multiply imaged families of lensed
          galaxies. New identifications were made by Sharon, Oguri, and Hoag.
          Each modeling team used a modified version or subset of the list
          above, with the coordinates of each knot varying slightly between
          modelers.
Note (2): The labels in previous publications are indicated for:
    Z09 = Zitrin et al. (2009MNRAS.396.1985Z),
    S09 = Smith et al. (2009ApJ...707L.163S; <[SEL2009] AN.N> in Simbad),
    R14 = Richard et al. (2014MNRAS.444..268R;
           <[RJL2014] MACS JHHMM NN.N> in Simbad),
    J14 = Johnson et al. (2014ApJ...797...48J), and
    D15 = Diego et al. (2016MNRAS.456..356D).
Note (3): The redshift of image 4.1 was measured independently at Keck
          (Section 2.2.3).
Note (4): Note as follows:
 1 = See Table 4 for information on all the knots in source 1.
 2 = We revise the redshift of source 3 with the new and reliable measurement
     from MUSE (see Section 2.2).
 3 = We revise the identification of a counterimage of 8.1 and 8.2, and
     determine that it is at a different position compared to previous
     publications. To limit confusion we label the newly identified
     counterimage 8.4.
 4 = The identification of source 12 was ruled out in Hubble Frontier Field
     (HFF) work prior to the 2014 publications; we further reject this set with
     spectroscopy.
 5 = This image is identified as part of the same source as source 8; the third
     image is buried in the light of a nearby star.
Note (5): The average score among the team is recorded; "1" denotes secure
          identification, "2" is a possible identification, and higher scores
          are considered unreliable by the teams.
Note (6): We define three samples of image sets ("gold," "silver," and "all")
          based on the voting process. Following the approach of Wang et al.
          (2015, J/ApJ/811/29), we conservatively include in our gold sample
          only the systems about which every team was confident. The silver
          sample includes images that were considered secure by most teams, or
          are outside the MUSE field of view. See section 3.1.
```

Byte-by-byte Description of file: table4.dat

```
   Bytes Format Units   Label     Explanations

   1-  6  A6    ---     Knot       Identifier (1)
   8- 16  F9.5  deg     RAdeg      [177.39/177.41] Right ascension (J2000)
  18- 26  F9.6  deg     DEdeg      [22.39/22.41] Declination (J2000)
```

```
  28- 29  I2     ---      S09       [2/19]? S09 identifier (2)
  31- 34  F4.1   ---      S16       [1.1/41.3]? S16 identifier (2)
  36- 41  A6     ---      D15       D15 identifier (2)
  43- 45  A3     ---      Note      Note(s) (3)
```

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Note (1): Coordinates and ID notations of emission knots in the multiply imaged
          host of SN Refsdal, at z=1.489. New identifications were made by C.G.,
          K.S., and J.D. Each modeling team used a modified version or subset
          of the list above, with the coordinates of each knot varying slightly
          between modelers. Nevertheless, there is consensus among the modelers
          on the identification and mapping of the different features between
          the multiple images of the same source.
Note (2): The labels in previous publications are indicated:
    S09 = Smith et al. (2009ApJ...707L.163S),
    D15 = Diego et al. (2016MNRAS.456..356D)
    S16 = K. Sharon et al. (2016, in preparation)
Note (3): Note as follows:
 1 = Images 1.1, 1.2, 1.3, and 1.5 were labeled by
     Zitrin & Broadhurst (2009ApJ...703L.132Z) as 1.2, 1.3, 1.1, and 1.4,
     respectively. The labels of other knots were not given in that publication.
 2 = This knot (*1.5 on Figure 3) was identified as a counterimage of the bulge
     of the galaxy by Zitrin & Broadhurst (2009ApJ...703L.132Z), but rejected by
     Smith et al. (2009ApJ...707L.163S). As in the paper by
     Sharon & Johnson (2015ApJ...800L..26S), the modelers' consensus is that
     this knot is likely at least a partial image of the bulge.
 3 = Image 1.13.6 (*13 on Figure 3) is predicted by some models to be a
     counterimage of 1.13, but its identification is not sufficiently confident
     to be used as constraint.
```

Global note:

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Note (G1): Source of zspec as follows:
  1 = HST-WFC3 (HST-GO-13459 and HST-GO-14041; PIs Treu and Kelly, respectively)
  2 = VLT-MUSE (Program 294.A-5032; PI Grillo; 2015, arXiv:1511.04093)
  3 = HST-WFC3+VLT-MUSE
  4 = VLT-MUSE+Keck-DEIMOS (Keck-DEIMOS program: 47/2014B N125D; PI Jha).
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History:
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(End)   Prepared by [AAS], Emmanuelle Perret [CDS]   07-Apr-2016