The Evolution of Software Publication in Astronomy

Matteo Cantiello [1,2,3,4]

[1] CCA, Flatiron Institute

[2] Princeton University

[3] Authorea Chief Scientist

[4] MESA Council Member

FLATIRON INSTITUTE
Division of Simons Foundation

Authorea

LSST (30TB/night)

Flatiron Institute to Repurpose 'Gordon' Supercomputer at UC San Diego

The powerful resource from the San Diego Supercomputer Center will be used for astrophysics, biology and materials research.

"Real astrophysical systems are 3-dimensional objects evolving in time with extremely complex physics. They can only be observed remotely. To interpret the data and model the underlying physics, astrophysicists need to build elaborate models, which are often computationally intensive"

Adapted from "Working Papers: Astronomy & Astrophysics Panel Report" (1991) - National Academy Press

Astronomy has become a digital science

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K2 photometry and HERMES spectroscopy of the blue supergiant ρ Leo: rotational wind modulation and low-frequency waves*

C. Aerts[1,2]†, D. Bowman[1], S. Símon-Díaz[3,4], B. Buysschaert[1,5], C. Johnston[1], E. Moravveji[1], P. G. Beck[3,4], P. De Cat[6], S. Triana[1,6], S. Aigrain[7], N. Castro[8], D. Huber[9], T. White[10]

[1] Instituut voor Sterrenkunde, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium
[2] Department of Astrophysics/IMAPP, Radboud University Nijmegen, 6500 GL Nijmegen, The Netherlands
[3] Instituto de Astrofísica de Canarias, 38200, La Laguna, Tenerife, Spain
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ABSTRACT

We present an 80-day long uninterrupted high-cadence K2 light curve of the B1Iab supergiant ρ Leo, deduced with the method of halo photometry. This light curve reveals a dominant frequency of $f_{\rm rot} = 0.0373\,{\rm d}^{-1}$ and its harmonics, corresponding with a rotation period of 26.8 d and subject to amplitude and phase modulation. The K2 photometry additionally reveals low-frequency variability ($< 1.5\,{\rm d}^{-1}$) and is in full agreement with low-cadence high-resolution spectroscopy assembled during 1800 days. The spectroscopy reveals rotational wind modulation of about $20\,{\rm km\,s}^{-1}$ and photospheric velocity variations of a few $\rm km\,s^{-1}$ at frequencies in the range 0.2 to $0.6\,{\rm d}^{-1}$. Given the large macroturbulence needed to explain the spectral line broadening of the star, we interpret the detected photospheric velocity as due to travelling super-inertial gravity waves with dominant tangential amplitude.

Key words: Asteroseismology – Stars: massive – Stars: rotation – Stars: oscillations (including pulsations) – Techniques: photometry – Techniques: spectroscopy

1 INTRODUCTION

Blue supergiants are in the least understood phase of evolution of massive stars. Lack of understanding of this phase is unfortunate, since successors of these stars play a key role in the chemical evolution of their host galaxy. The nucleosynthetic yields after the blue supergiant phase are strongly dependent on the helium core mass at the onset of hydrogen shell burning and how the material gets mixed in the stellar interior during the pre-supernova evolution (e.g., Heger et al. 2000; Langer 2012). It would thus be highly beneficial if blue supergiant variability could be monitored and exploited in terms of the interior physical properties, just as it has recently become possible for evolved low- and intermediate-mass stars from asteroseismology (Bedding et al. 2011; Mosser et al. 2014; Aerts et al. 2017b). For blue supergiants, this requires uninterrupted space photometry covering months to years, but such data sets are hardly available.

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† E-mail: conny.aerts@kuleuven.be

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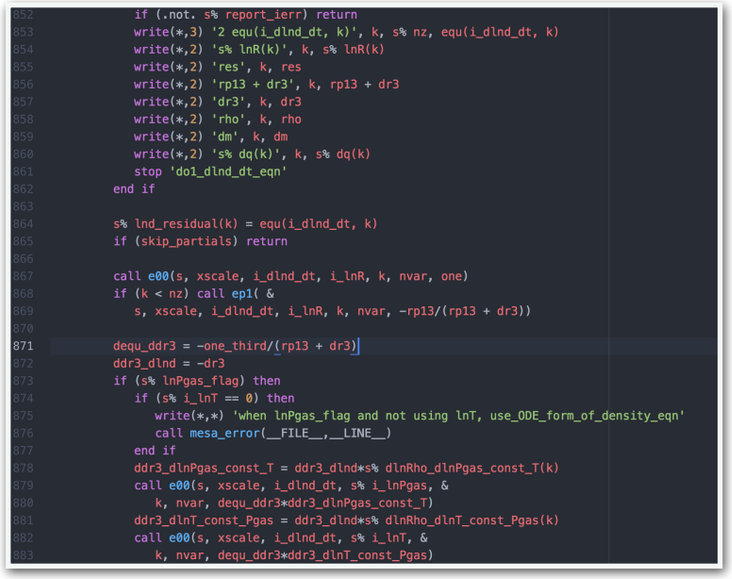


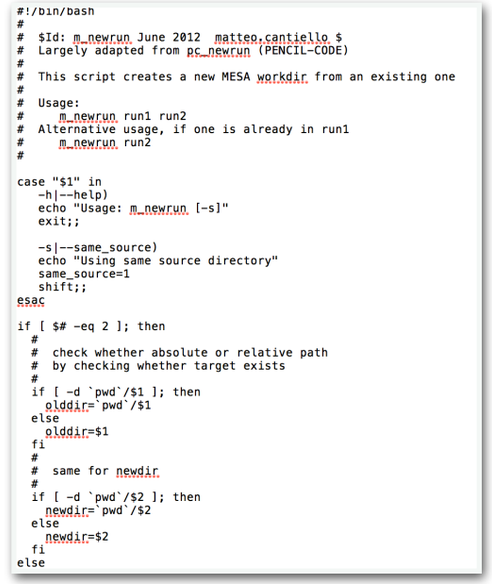
```
            if (.not. s% report_ierr) return
            write(*,3) '2 equ(i_dlnd_dt, k)', k, s% nz, equ(i_dlnd_dt, k)
            write(*,2) 's% lnR(k)', k, s% lnR(k)
            write(*,2) 'res', k, res
            write(*,2) 'rp13 + dr3', k, rp13 + dr3
            write(*,2) 'dr3', k, dr3
            write(*,2) 'rho', k, rho
            write(*,2) 'dm', k, dm
            write(*,2) 's% dq(k)', k, s% dq(k)
            stop 'do1_dlnd_dt_eqn'
         end if

         s% lnd_residual(k) = equ(i_dlnd_dt, k)
         if (skip_partials) return

         call e00(s, xscale, i_dlnd_dt, i_lnR, k, nvar, one)
         if (k < nz) call ep1( &
            s, xscale, i_dlnd_dt, i_lnR, k, nvar, -rp13/(rp13 + dr3))

         dequ_ddr3 = -one_third/(rp13 + dr3)
         ddr3_dlnd = -dr3
         if (s% lnPgas_flag) then
            if (s% i_lnT == 0) then
               write(*,*) 'when lnPgas_flag and not using lnT, use_ODE_form_of_density_eqn'
               call mesa_error(__FILE__,__LINE__)
            end if
            ddr3_dlnPgas_const_T = ddr3_dlnd*s% dlnRho_dlnPgas_const_T(k)
            call e00(s, xscale, i_dlnd_dt, s% i_lnPgas, &
               k, nvar, dequ_ddr3*ddr3_dlnPgas_const_T)
            ddr3_dlnT_const_Pgas = ddr3_dlnd*s% dlnRho_dlnT_const_Pgas(k)
            call e00(s, xscale, i_dlnd_dt, s% i_lnT, &
               k, nvar, dequ_ddr3*ddr3_dlnT_const_Pgas)
```

+



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#!/bin/bash
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#  $Id: m_newrun June 2012  matteo.cantiello $
#  Largely adapted from pc_newrun (PENCIL-CODE)
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#  Usage:
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case "$1" in
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   exit;;

   -s|--same_source)
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   shift;;
esac

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  #
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  fi
  #
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  #
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  else
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Examining 166 astronomical articles Allen et al. (2018) found 715 software instances. At least 285 unique codes (but likely many more)

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```

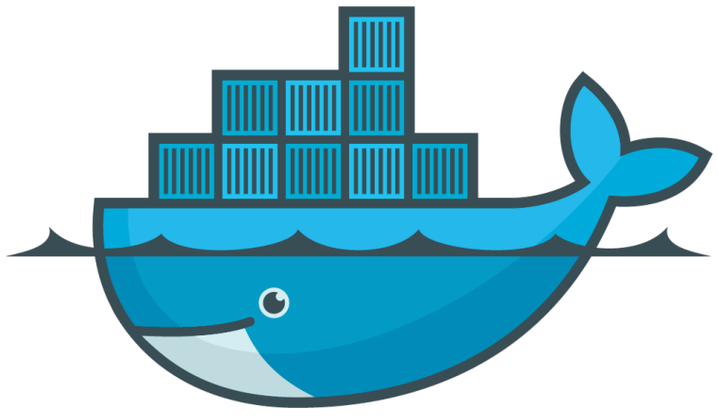
+ ...

Virtually every astronomical publication stands on at least a piece of software

Many (new) tools now enable easily versioning, sharing and deploying astronomical software.

However...

GitHub



docker

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...

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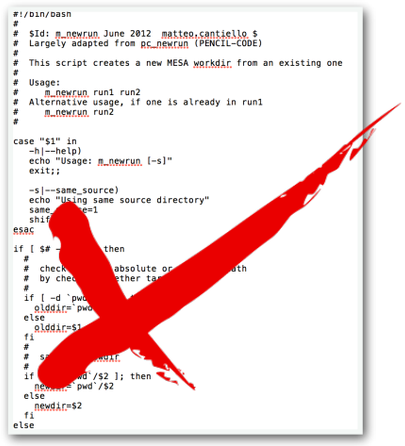

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  exit;;

  -s|--same_source)
  echo "Using same source directory"
  same=1
  shif
esac

if [ $# - then
  #
  #  check  absolute or  ath
  #  by chec ther ta
  #
  if [ -d `pwd
    olddir=`pwd
  else
    olddir=$1
  fi
  #
  #  s  ndir
  #
  if  pwd`/$2 ]; then
    newdir=`pwd`/$2
  else
    newdir=$2
  fi
else
```

In a sample of 166 articles "over 40% of the source code for the software used was not available for download" (Allen et al. 2018)

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† E-mail: conny.aerts@kuleuven.be

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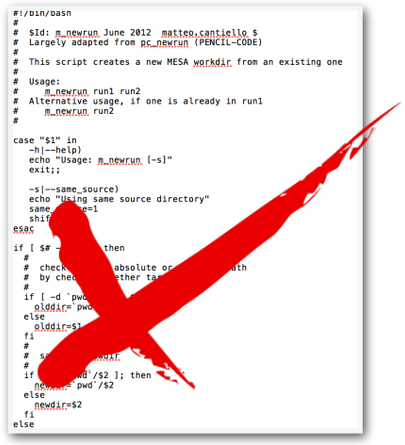

Attempts of ASCL to gather the code of published work: 87% refused to share their code (66% do not answer, 20% said they won't share the code) (Shamir et al. 2013)

The Reproducibility “Paradox”

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K2 photometry and HERMES spectroscopy of the blue supergiant ρ Leo: rotational wind modulation and low-frequency waves*

C. Aerts[1,2]†, D. Bowman[1], S. Símon-Díaz[3,4], B. Buysschaert[1,5], C. Johnston[1], E. Moravveji[1], P. G. Beck[3,4], P. De Cat[6], S. Triana[1,6], S. Aigrain[7], N. Castro[8], D. Huber[9], T. White[10]

[1] Instituut voor Sterrenkunde, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium
[2] Department of Astrophysics/IMAPP, Radboud University Nijmegen, 6500 GL Nijmegen, The Netherlands
[3] Instituto de Astrofísica de Canarias, 38200, La Laguna, Tenerife, Spain
[4] Departamento de Astrofísica, Universidad de La Laguna, 38205, La Laguna, Tenerife, Spain
[5] LESIA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités, UPMC Univ. Paris 06, Univ. Paris Diderot, Sorbonne Paris Cité, France
[6] Royal Observatory of Belgium, Ringlaan 3, 1180 Brussels, Belgium
[7] Oxford Astrophysics, University of Oxford, Denys Wilkinson Building, Keble Rd, Oxford OX1 3RH, UK
[8] Astronomy Department, University of Michigan, 311 West Hall, 1085 S. University Ave., Ann Arbor, MI 48109-1107, USA
[9] Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA
[10] Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark

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ABSTRACT

We present an 80-day long uninterrupted high-cadence K2 light curve of the B1Iab supergiant ρ Leo, deduced with the method of halo photometry. This light curve reveals a dominant frequency of $f_{\rm rot} = 0.0373\,{\rm d}^{-1}$ and its harmonics, corresponding with a rotation period of 26.8 d and subject to amplitude and phase modulation. The K2 photometry additionally reveals low-frequency variability ($< 1.5\,{\rm d}^{-1}$) and is in full agreement with low-cadence high-resolution spectroscopy assembled during 1800 days. The spectroscopy reveals rotational wind modulation of about 20 km s^{-1} and photospheric velocity variations of a few km s^{-1} at frequencies in the range 0.2 to 0.6 d^{-1}. Given the large macroturbulence needed to explain the spectral line broadening of the star, we interpret the detected photospheric velocity as due to travelling super-inertial gravity waves with dominant tangential amplitude.

Key words: Asteroseismology – Stars: massive – Stars: rotation – Stars: oscillations (including pulsations) – Techniques: photometry – Techniques: spectroscopy

1 INTRODUCTION

Blue supergiants are in the least understood phase of evolution of massive stars. Lack of understanding of this phase is unfortunate, since successors of these stars play a key role in the chemical evolution of their host galaxy. The nucleosynthetic yields after the blue supergiant phase are strongly dependent on the helium core mass at the onset of hydrogen shell burning and how the material gets mixed in the stellar interior during the pre-supernova evolution (e.g., Heger et al. 2000; Langer 2012). It would thus be highly beneficial if blue supergiant variability could be monitored and exploited in terms of the interior physical properties, just as it has recently become possible for evolved low- and intermediate-mass stars from asteroseismology (Bedding et al. 2011; Mosser et al. 2014; Aerts et al. 2017b). For blue supergiants, this requires uninterrupted space photometry covering months to years, but such data sets are hardly available.

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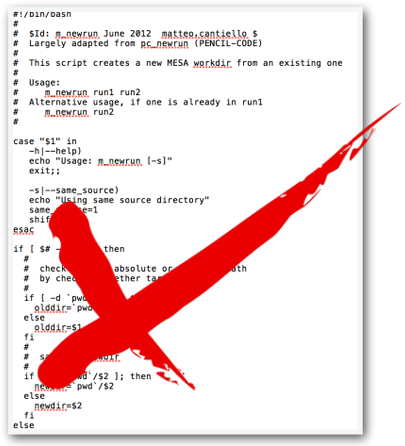

As computational methods have proliferated, research has become less transparent, reproducible, and falsifiable because these methods have not been shared or made available along with the research they enable.

(Allen et al. 2018, Baker 2016, Goble et al. 2016, Stodden et al. 2016, Marwick 2015, Shamir et al. 2013, Morin et al. 2012)

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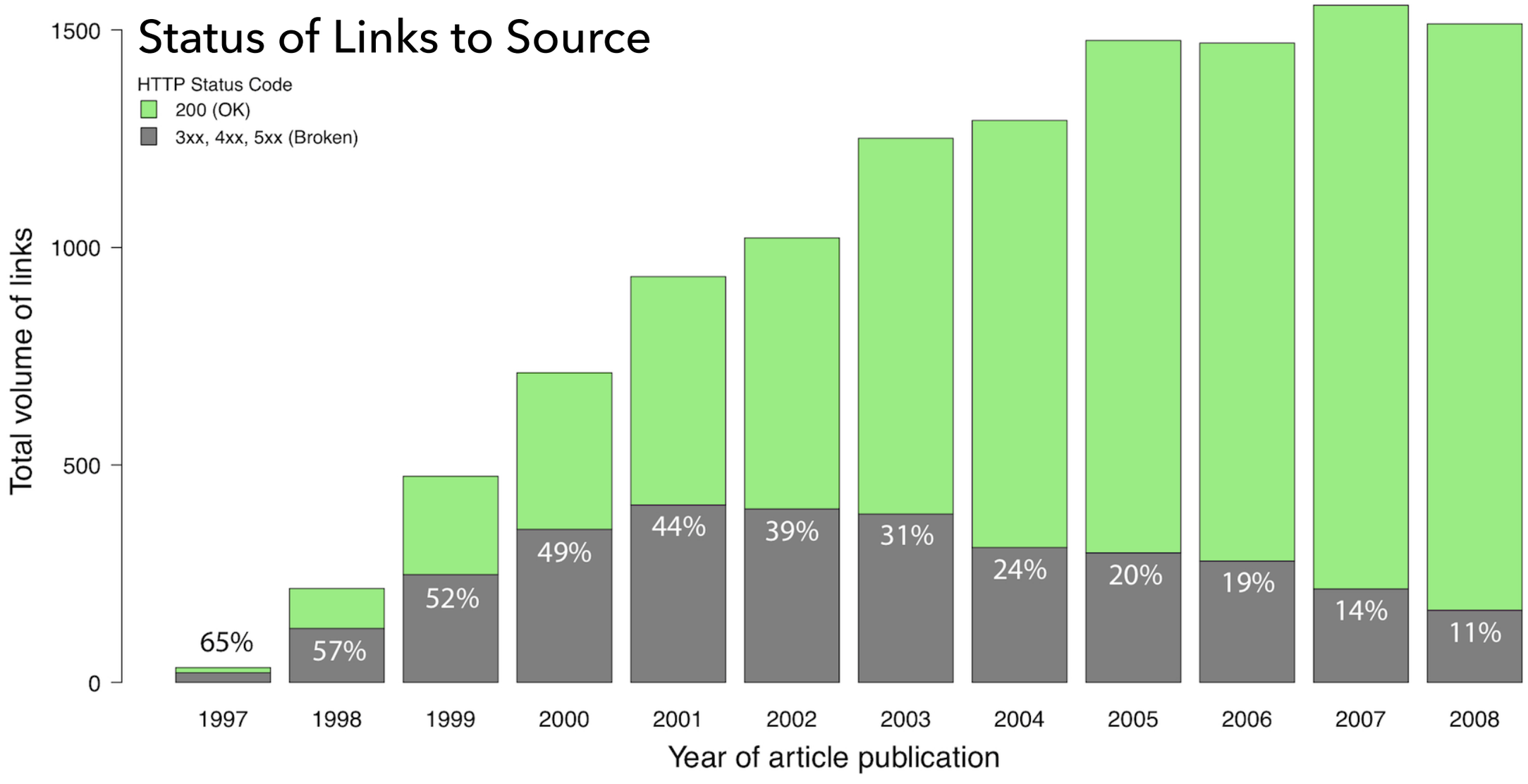

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Pepe et al. 2014

Challenges & Opportunities

Why Astronomers do not share their code

- Is it a matter of incentives? (e.g. Weiner et al. 2009)

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Nature, Leslie Sage
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AAS Data, Gus Muench
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Challenges & Opportunities

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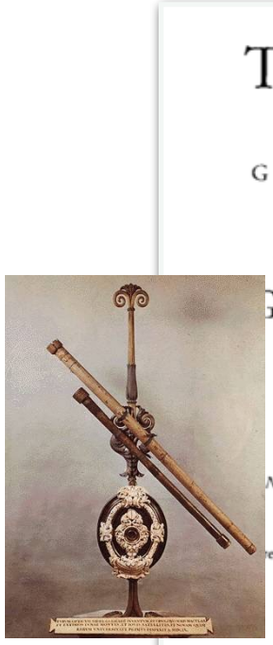
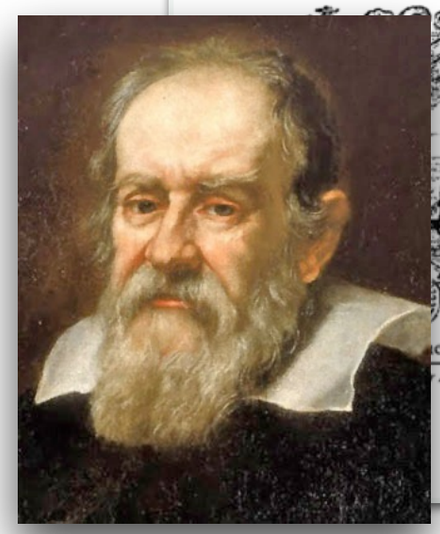
- Formats ?





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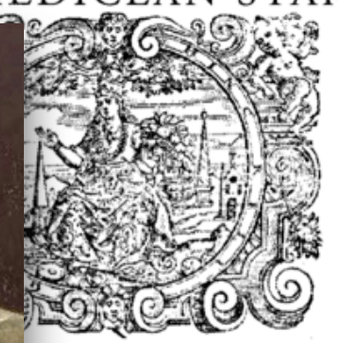

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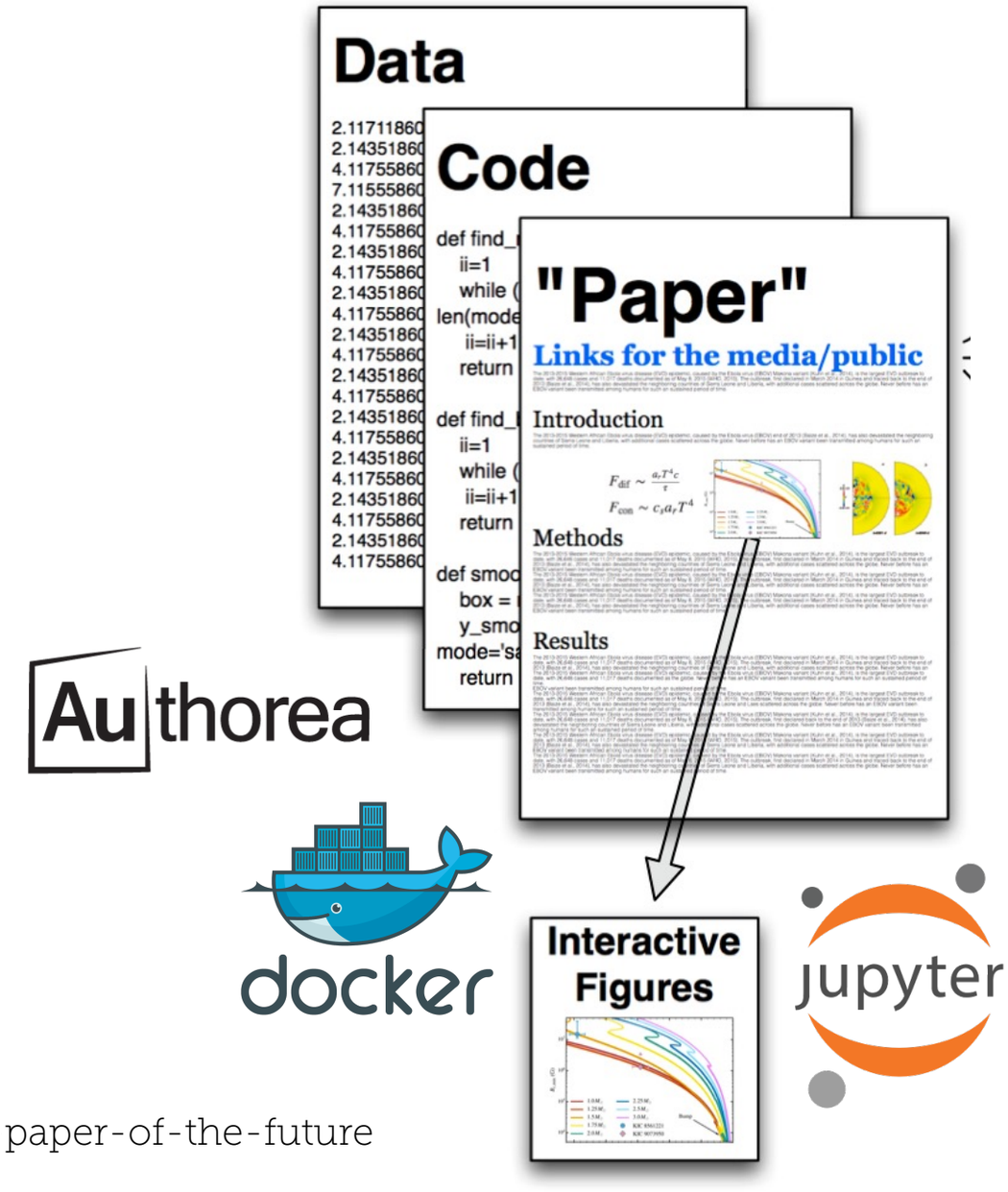

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