# Cognitive Telescope Network

Arunava (Ron) Majumdar
Shane Larson, PhD

## Multi-messenger Astronomy

Telescopic follow-up of transient events

IBM Cloud University 2017

IBM.

# Please note

IBM's statements regarding its plans, directions, and intent are subject to change or withdrawal without notice at IBM's sole discretion.

Information regarding potential future products is intended to outline our general product direction and it should not be relied on in making a purchasing decision.

The information mentioned regarding potential future products is not a commitment, promise, or legal obligation to deliver any material, code or functionality. Information about potential future products may not be incorporated into any contract.

The development, release, and timing of any future features or functionality described for our products remains at our sole discretion.

Performance is based on measurements and projections using standard IBM benchmarks in a controlled environment. The actual throughput or performance that any user will experience will vary depending upon many factors, including considerations such as the amount of multiprogramming in the user's job stream, the I/O configuration, the storage configuration, and the workload processed. Therefore, no assurance can be given that an individual user will achieve results similar to those stated here.

# About the authors


## Arunava (Ron) Majumdar
arunava@us.ibm.com

Asset Portfolio Strategy Leader,
Chicago Center for Advanced Studies Leader
Architect, Emerging Technology Practice,
IBM Cloud and Cognitive

@arunavaibm

/arunavaibm


Arunava (Ron) Majumdar is an integration architect with more than 16 years of experience in middleware and messaging technologies. He leads the Asset Portfolio Strategy for the IBM Cognitive Cloud and leads the Chicago Center for Advanced Studies. He has been involved with large scale design, architecture and implementation for IBM clients, helping them successfully through the project lifecycle. He has architected High Availability and Disaster Recovery solutions with IBM integration products and worked on performance testing and securing client environments. He is currently working on API Economy, Hybrid Integration, Micro-services and Pattern-based automation. Ron has several patents and published assets to his credit and is collaborating with Research faculty and Universities on innovative ideas and their implementations with emerging technologies.


## Shane L. Larson, Ph.D.
s.larson@northwestern.edu

Research Associate Professor
Associate Director, CIERA
Northwestern University

@sciencejedi

writescience.wordpress.com


Shane L. Larson is a research associate professor of physics at Northwestern University, and an astronomer at the Adler Planetarium in Chicago. He works in the field of gravitational wave astrophysics, specializing in studies of compact stars, binaries, and the galaxy. He works in gravitational wave astronomy with both the ground-based LIGO project, and the future space-based detector LISA.

Shane grew up in eastern Oregon, and was an undergraduate at Oregon State University where he received his B.S. in Physics in 1991. He received a Ph.D. in theoretical physics (1999) from Montana State University. He is an award winning teacher, and a Fellow of the American Physical Society. He currently lives in the Chicago area with his wife, daughter and cats. He contributes regularly to a public science blog at writescience.wordpress.com, and tweets with the handle @sciencejedi.

- **History behind Gravitational Waves**
- **Science behind the Cognitive Telescope Network**
- **Multi-messenger Astronomy**
- **Design Thinking and Use Cases**

Part I: Concept to Ideation

- **Realization of the Idea with Bluemix and Watson Services**
- **Current project collaborations**
- **Future of the Cognitive Telescope Network**

Part II: Architecting a solution

“Only those who will risk going too far can possibly find out how far one can go.” — T.S. Eliot

# Cognitive Telescope Network

From a 100-year old Concept to Ideation

**1915**: Einstein publishes his paper on **General Relativity**, a geometric theory of gravitation. It generalizes **Special Relativity and Newton's Law** of universal gravitation, describing gravity as the curvature of spacetime in his ***field equations***:

$$R_{\mu\nu} - \frac{1}{2} R \, g_{\mu\nu} + \Lambda \, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

where $R_{\mu\nu}$ is the Ricci curvature tensor, $R$ is the scalar curvature, $g_{\mu\nu}$ is the metric tensor, $\Lambda$ is the cosmological constant, $G$ is Newton's gravitational constant, $c$ is the speed of light in vacuum, and $T_{\mu\nu}$ is the stress–energy tensor

**1918**: Einstein published the paper **Über Gravitationswellen**, effect of gravitational waves was calculated resulting in the ***quadrupole formula*** describes rate at which gravitational waves are emitted from a system of masses based on the change of the (mass) quadrupole moment. The formula reads

$$\bar{h}_{ij}(t, r) = \frac{2G}{c^4 r} \ddot{I}_{ij}(t - r/c),$$

where $\bar{h}_{ij}$ is the (spatial part of) the trace reversed perturbation of the metric (i.e. the gravitational wave) and $I_{ij}$ is the mass quadrupole moment

**1936: Einstein, Rosen** came to the conclusion, that **gravitational waves do not exist**!

**1938: Einstein, Infeld and Hoffmann** (EIH) equations show that there is **no radiation up to the order $(v/c)^4$**, the energy remains constant.

**1947: Ning Hu** demonstrates that **quadrupole formula occurs at $(v/c)^5$**.

**1975: Hulse and Taylor** discovers the **binary pulsar PSR1913 + 16**. Their data showed a *decrease of the period of revolution – as predicted by the quadrupole formula*.

**2016: Laser Interferometer Gravitational-Wave Observatory** (LIGO) team announces they had detected Gravitational Waves for the first time. The event occurred at **September 14, 2015 at 5:51 a.m. Eastern Daylight Time** (9:51 a.m. UTC) by both detectors, located in *Livingston, Louisiana, and Hanford, Washington, USA*.

# IBM Cloud Cognitive Telescope Network



Ever since the dawn of time human beings are trying to decipher the mysteries of the Universe by looking at the Sky.

**~200 BC** – **Hipparchus** creates a magnitude system (1-6) and catalogs 850 stars

**1610** – **Galileo Galilei** publishes Sidereus Nuncius from his observations from the telescope

**1668** – **Isaac Newton** builds reflecting telescope

**1990** – **Hubble Space Telescope** is launched by NASA

**2009** – Largest Telescope on Earth commissioned **Gran Telescopio Canarias**, Canary Islands, Spain beating Keck 1 and Keck 2, Mauna Kea Observatory, Hawaii

**2012** – Construction of **Giant Magellan Telescope** will be located at Cerro Las Campanas at Las Campanas Observatory in the Atacama Desert of Chile

**2018** – **James Webb Space Telescope** expected to be launched

# Gravity as Messenger

Courtesy: Simulating eXtreme Spacetime (SXS) Project: www.black-holes.org

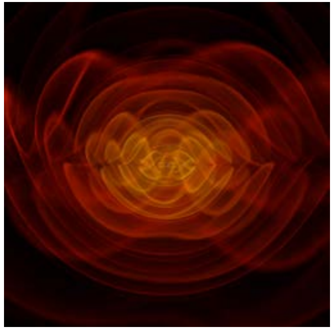
Since the prediction by Einstein scientists have been trying to detect Gravitational Waves.

- Detect not with light, but with gravity.
- Gravitational waves are complementary to photons
    - Photons are made by atoms
    - Gravitational waves made by the dynamic motion of matter
- Laser Interferometers, not telescopes are required for the detection
- **LIGO** – US-based detectors at *Livingston*, Louisiana, and *Hanford*, Washington
- **VIRGO** – Italy-France-based initiative at Santo Stefano a Macerata, Cascina , Italy
- **LISA** – $1^{st}$ Space-based Interferometer using 3 satellites, European collaboration

# Gravitational Wave Detectors



## GW150914

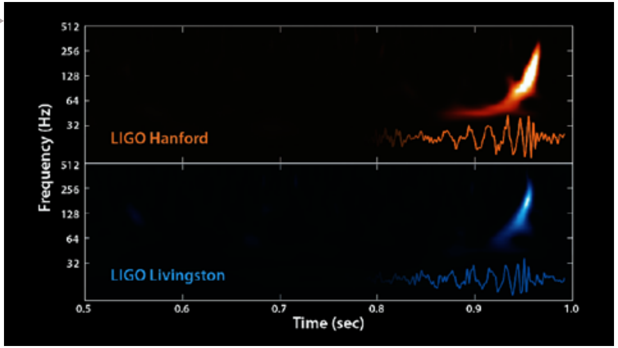


29 solar mass black hole +
36 solar mass black hole
1.3 billion lightyears away
(400 Mega parsec)

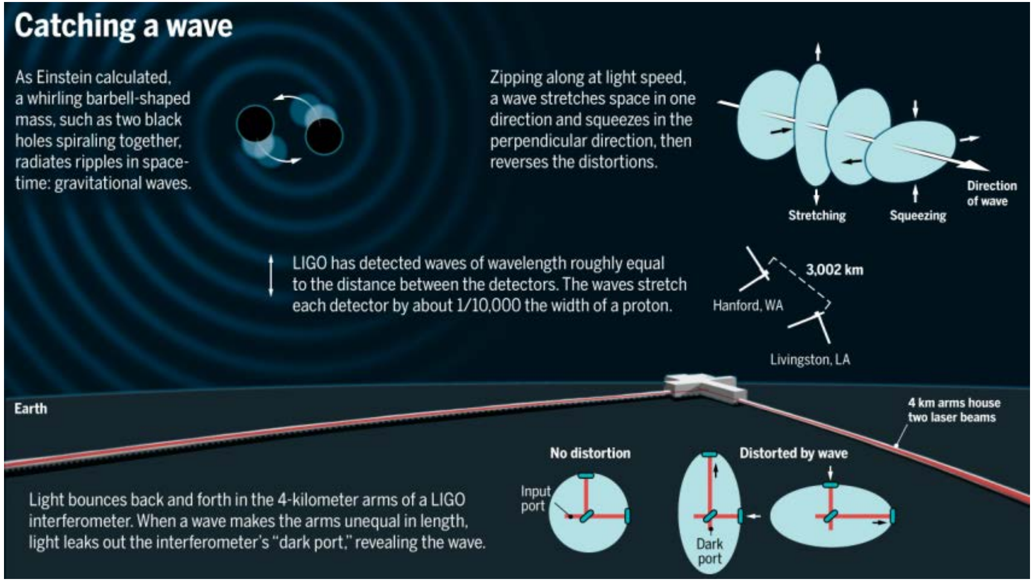
(1995) TAMA 300 - Japan - Decommissioned
(1995) GEO 600 - Sarstedt, Ruthe, Germany: http://www.geo600.org/
(2002) **LIGO** - Livingston, Louisiana and Hanford, Washington, USA: http://www.ligo.org/
(2003) MiniGrail - Leiden University, Netherlands: http://www.minigrail.nl/
(2005) Pulsar Timing Array (using radio-telescope): https://en.wikipedia.org/wiki/Pulsar_timing_array
- Parkes PTA, European PTA, North American Nanohertz Observatory for Gravitational Waves (NANOGrav)

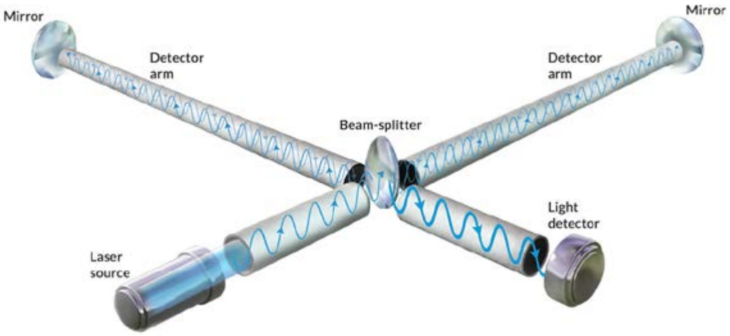
(2006) CLIO - prototype for KAGRA
(2007) **Virgo** - Santo Stefano a Macerata, Cascina , Italy: https://www.ego-gw.it/
(2015) LISA Pathfinder, a development mission for LISA, launched in Dec. - switched off 18 July, 2017
(2018) KAGRA - Gifu Prefecture, Japan: http://gwcenter.icrr.u-tokyo.ac.jp/en/
(2023) IndIGO - (Hingoli, Maharashtra?), India: http://www.gw-indigo.org/tiki-index.php
(2025) TianQin - Sun Yat-sen University, Zhuhai campus, China [Space-based]
(2027) DECIGO - Japan [Space-based]
(2034) **LISA** - Denmark, France, Germany, Italy, The Netherlands, Spain, Switzerland and the UK
– supported US, [Space-based]: https://www.lisamission.org/
(2030s) Einstein Telescope - European Union: http://www.et-gw.eu/

C. Messenger (Glasgow) & LIGO



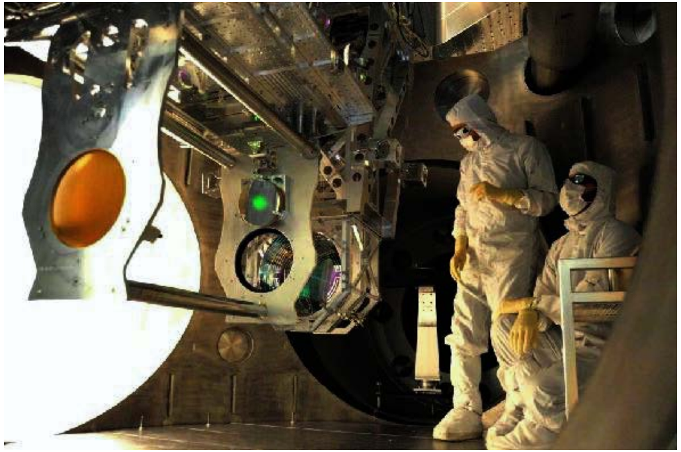
## Principles of Interferometer



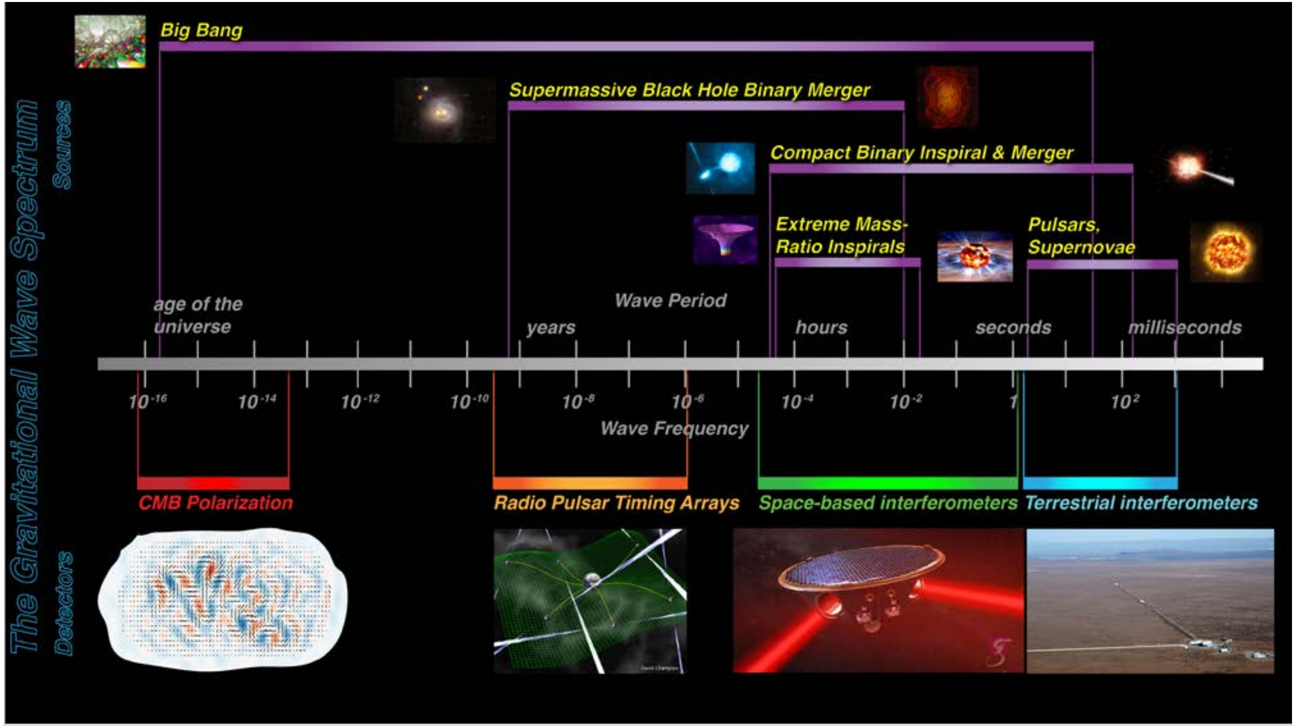




Sound of Gravitational Waves: https://www.ligo.caltech.edu/video/ligo20160211v2

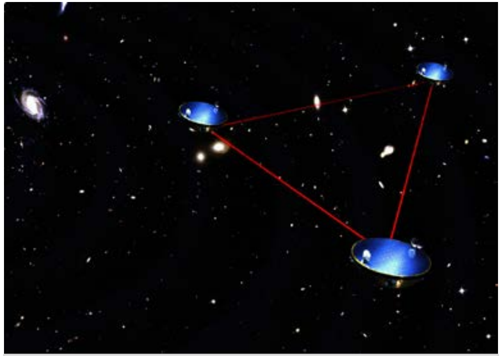
| GW150914 | GW151226 | GW170104 |
|---|---|---|
| 29 + 36 solar mass black hole merger resulted in 62 solar mass black hole. | 14 + 8 solar mass black hole merger | 31 + 19 solar mass black hole merger |



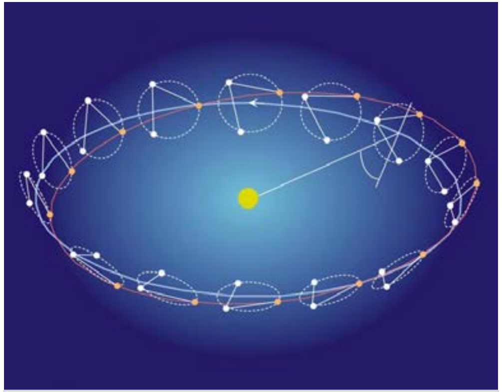
# Gravitational Wave Detector Ranges




Gravitational wave detectors required for different frequencies: NASA/J. I.Thorpe: https://imagine.gsfc.nasa.gov/features/satellites/archive/lisa_exhibit.html



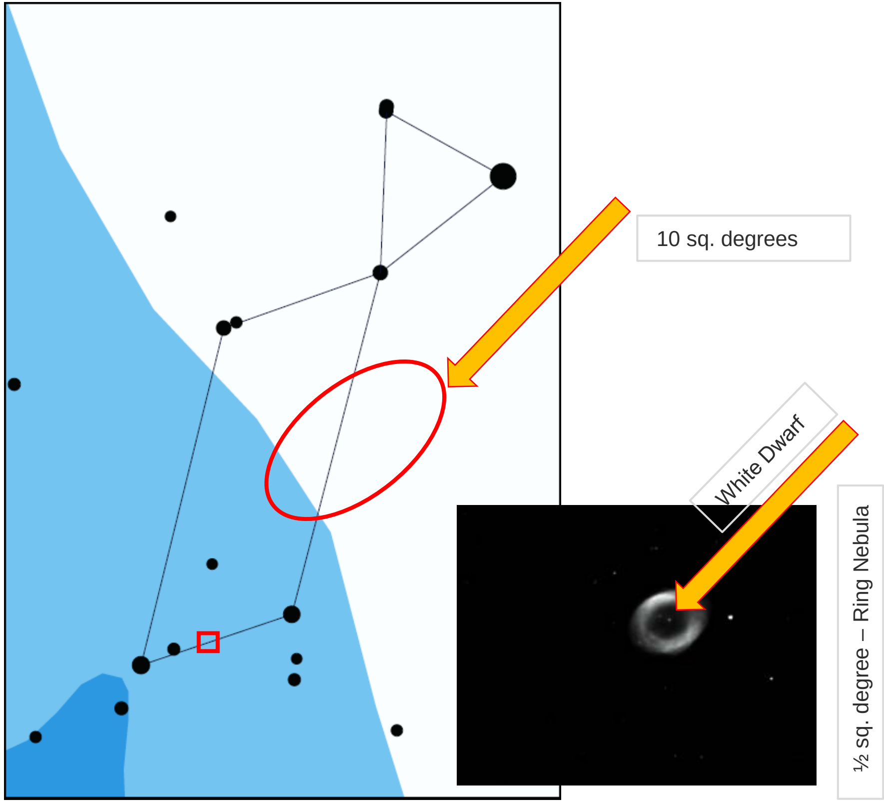
LISA: 5 million km arms



Set of three orbits in a near-equilateral triangular formation for thermal stability

# IBM Cloud Cognitive Telescopic Network

## Science behind the Network



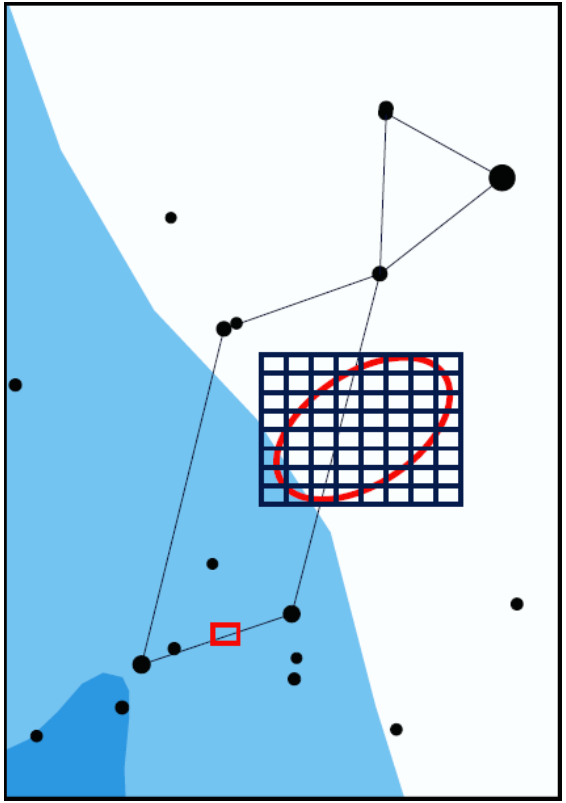

Lyra constellation and comparing areas in the sky

- Challenges
  - GW detectors are poor at pointing, ~ 1 to 10 sq. degrees
  - Standard telescopes cover small areas, ~ ½ sq. degree
  - **LIGO STRATEGY**: Statistically point, look for galaxies in the oval

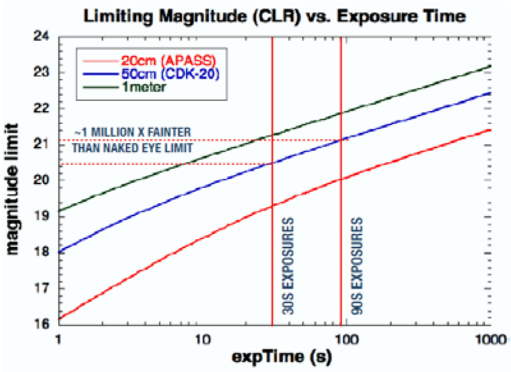
    *- Cannot work when there are 1000's of galaxies in the region*
  - **LISA STRATEGY**: All sky surveys, co-operate wide field scopes (e.g. Large Synoptic Survey Telescope (LSST))

    *- Not a strong taxonomy of transient sky phenomena for rejection*

    *- Hard to determine what's a gravitational wave and what's changing magnitude for something else*



Lyra constellation tiling the oval




| 20 cm | 50 cm | 1 m |
|---|---|---|

- Solution
  - **STRATEGY**: Cover the error ellipse with small aperture wide-field telescopes
  - **ADVANTAGES:** Lots of glass on the sky, worldwide coverage, on demand

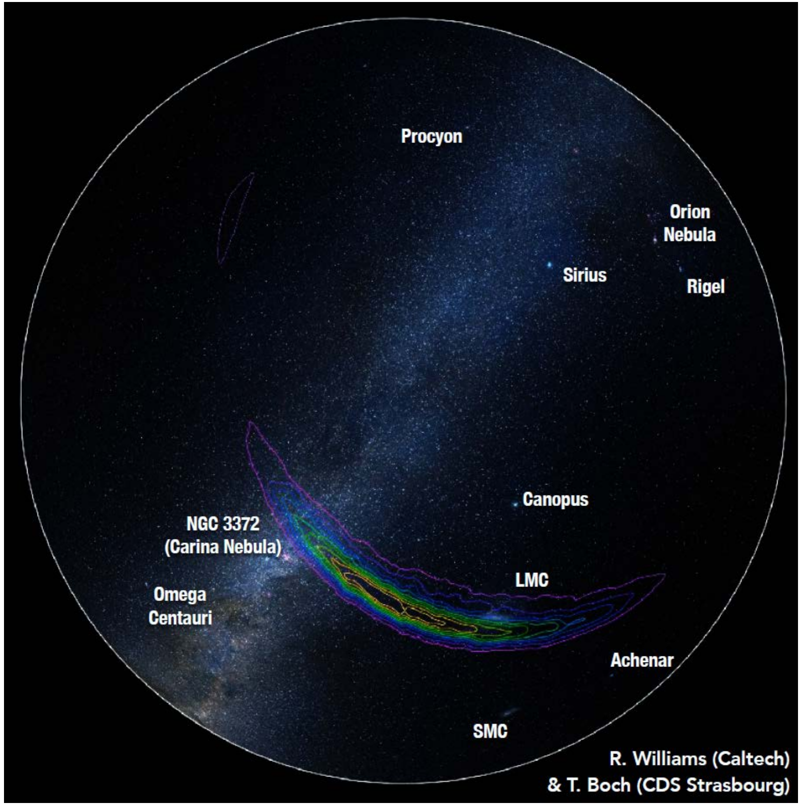
    *- Universities, Institutes and amateurs have sub-meter telescopes as the prices of hardware has dropped over the last decade*

    *- Amateur astronomical groups can participate in meaningful research even with smaller telescopes*
  - **DISADVANTAGES:** Deep magnitudes take longer exposure times

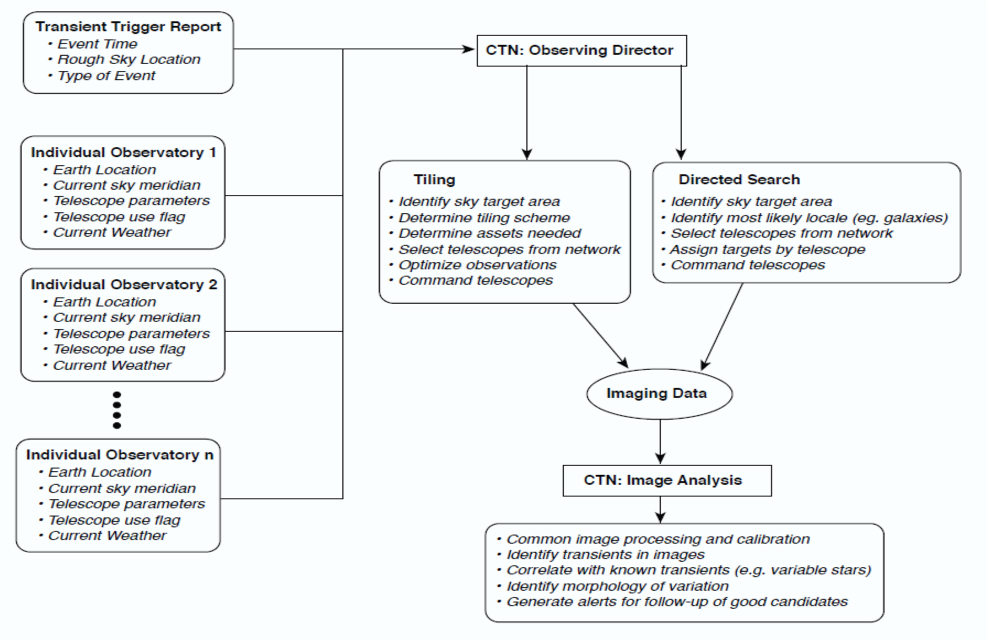
    *- Do not have a proper taxonomy yet*

# IBM Cloud Cognitive Telescopic Network

## Multi-messenger Astronomy

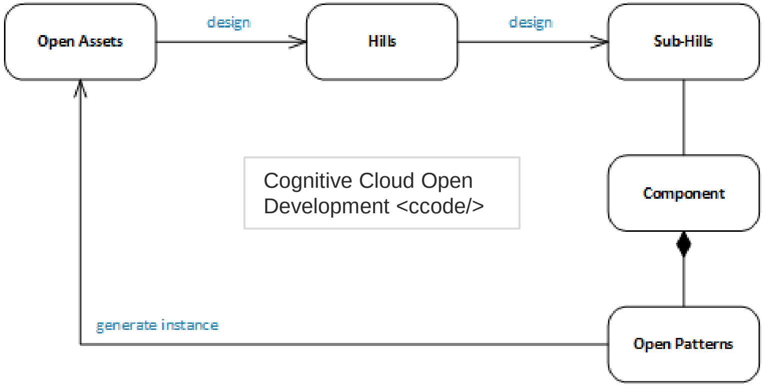



Predicted area for the detection of the event GW150914



# IBM Cloud Cognitive Telescopic Network

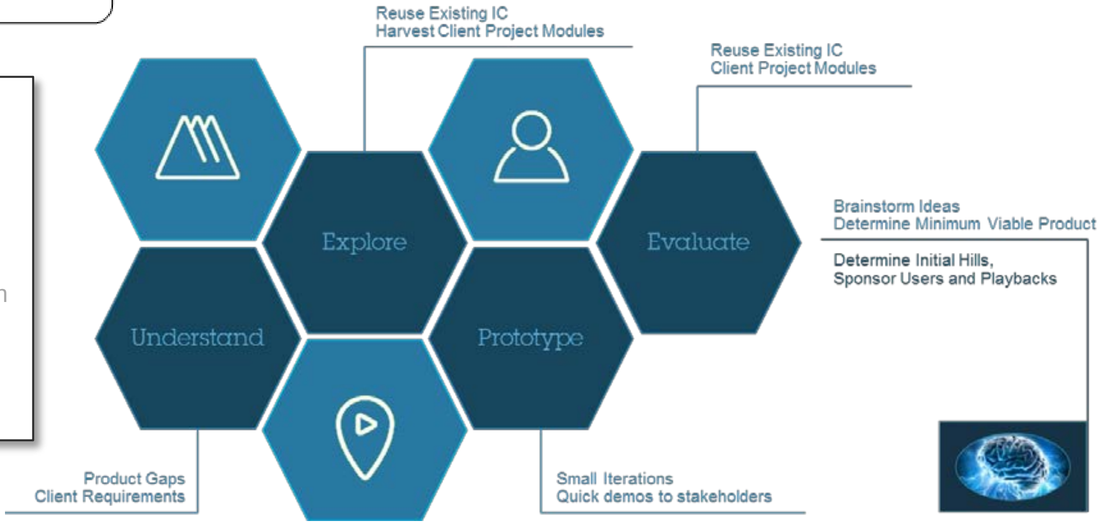
## Design Thinking



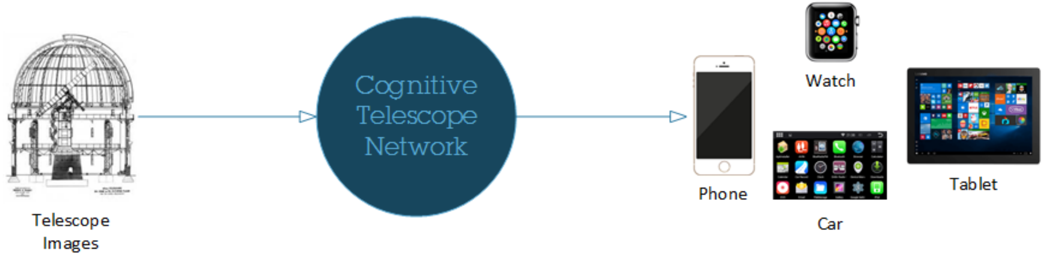

### Evolving Assets using Design Thinking:

- Open Assets
  - ✓ Work with end users and researchers to define use cases
  - ✓ Organize thoughts under 3 Hills and Foundation
  - ✓ Define Sponsor Users for getting feedback from playbacks and continuous improvement of the design
  - ✓ Define Components / features
  - ✓ Define Open Projects, Timelines, Iterations, Playbacks, Milestones

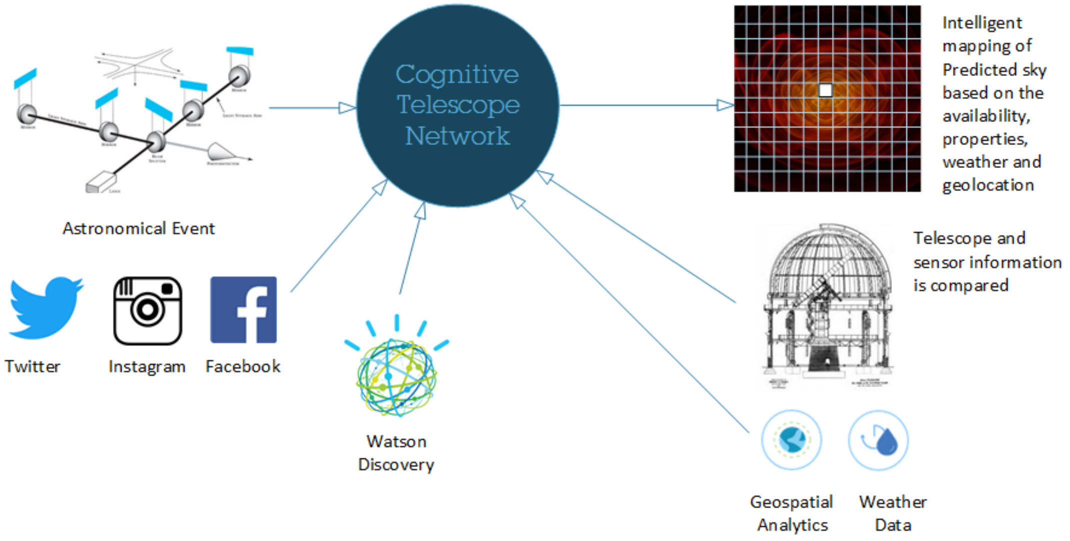
- Open Patterns
  - ✓ Identify common patterns within the code and documentation from multiple assets
  - ✓ Patterns may be identified and developed by the Offering Management and other teams to accelerate Open Project development
  - ✓ Exemplars are patternized into templates that can generate code, document, etc. for Open Assets



## *Use Case 01: Publication of Images*




## *Use Case 02: Event Sourcing and Mapping of Telescopes*

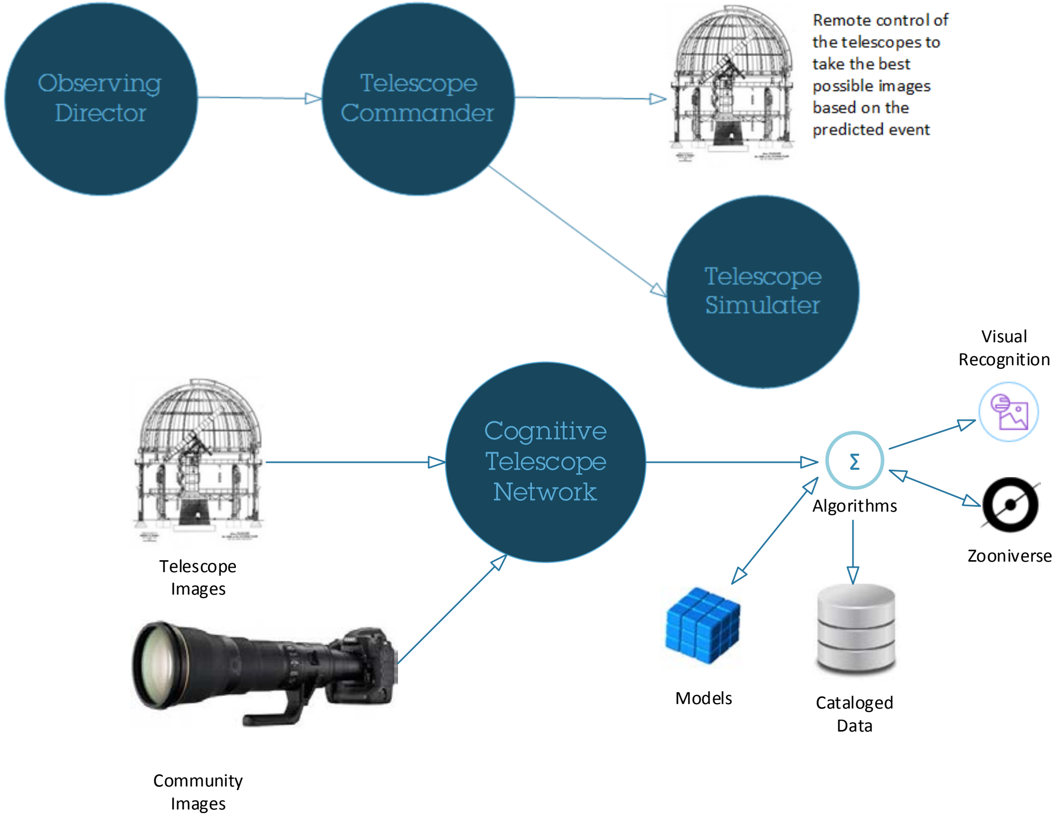


# IBM Cloud Cognitive Telescopic Network

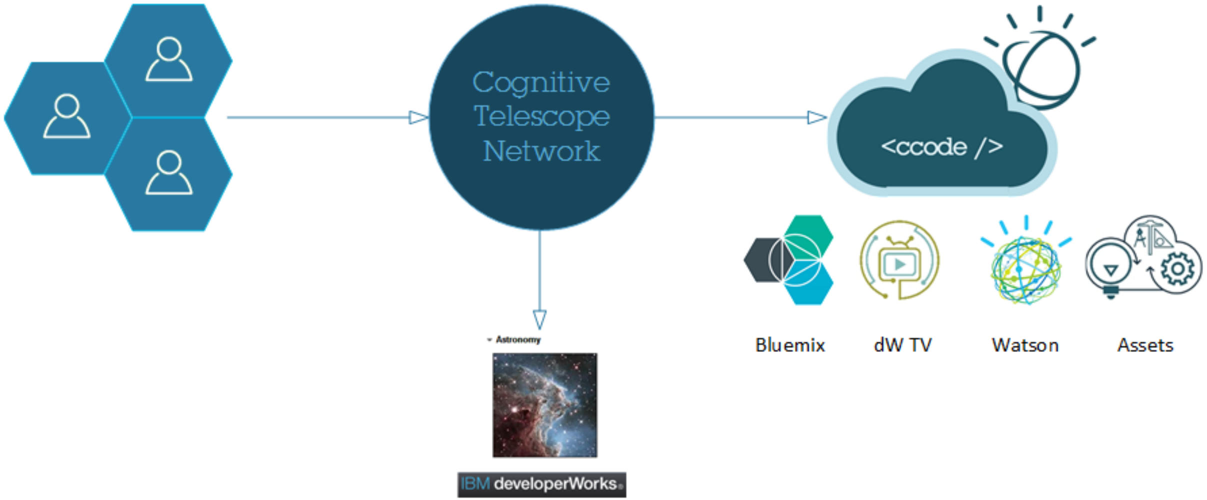


*Use Case 03: Remote Control of Telescopes*

*Use Case 04: Image Cataloging*

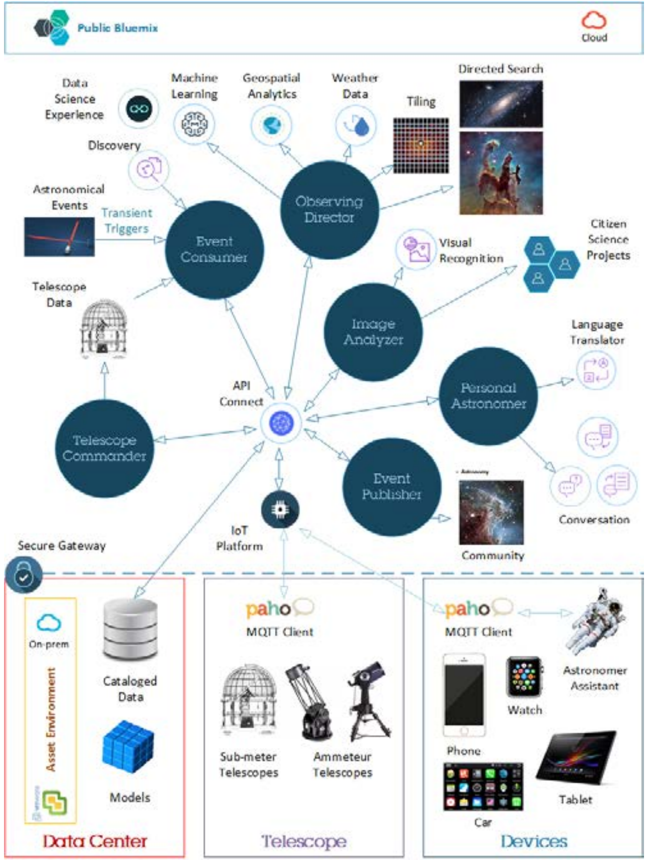


*Use Case 05: Building the Ecosystem*



# IBM Cloud Cognitive Telescopic Network

CIERA Center for Interdisciplinary Exploration and Research in Astrophysics | ADLER PLANETARIUM | NORTHWESTERN UNIVERSITY




**Gravitational Waves Detected 100 Years After Einstein's Prediction** –

*LIGO Opens New Window on the Universe with Observation of Gravitational Waves from Colliding Black Holes.*

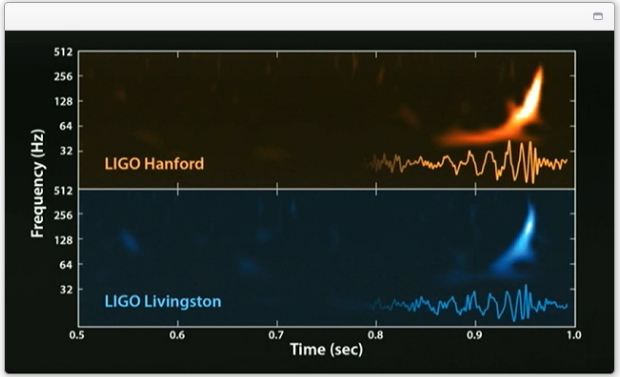
https://www.ligo.caltech.edu/news/ligo20160211

LIGO can listen to gravitational waves but cannot see the event.

- Provide identification and analysis of astronomical data from multiple sources
- Event notifications to mobile devices for building interest in the Community
- Remote control instructions to telescopes point to the specific location on the grid in the sky
- Visual Recognition integration with Zooniverse for gamification of un identified events

- LIGO data feed is parsed into canonical models and passed to the Event Analyzer
- If a Gravitational Wave event is detected, the available telescopes in the network are mapped into a grid to scan the sky
- Weather and Geospatial information is used to determine optimal coverage of the viewing area

LIGO Update on the Search for Gravitational Waves

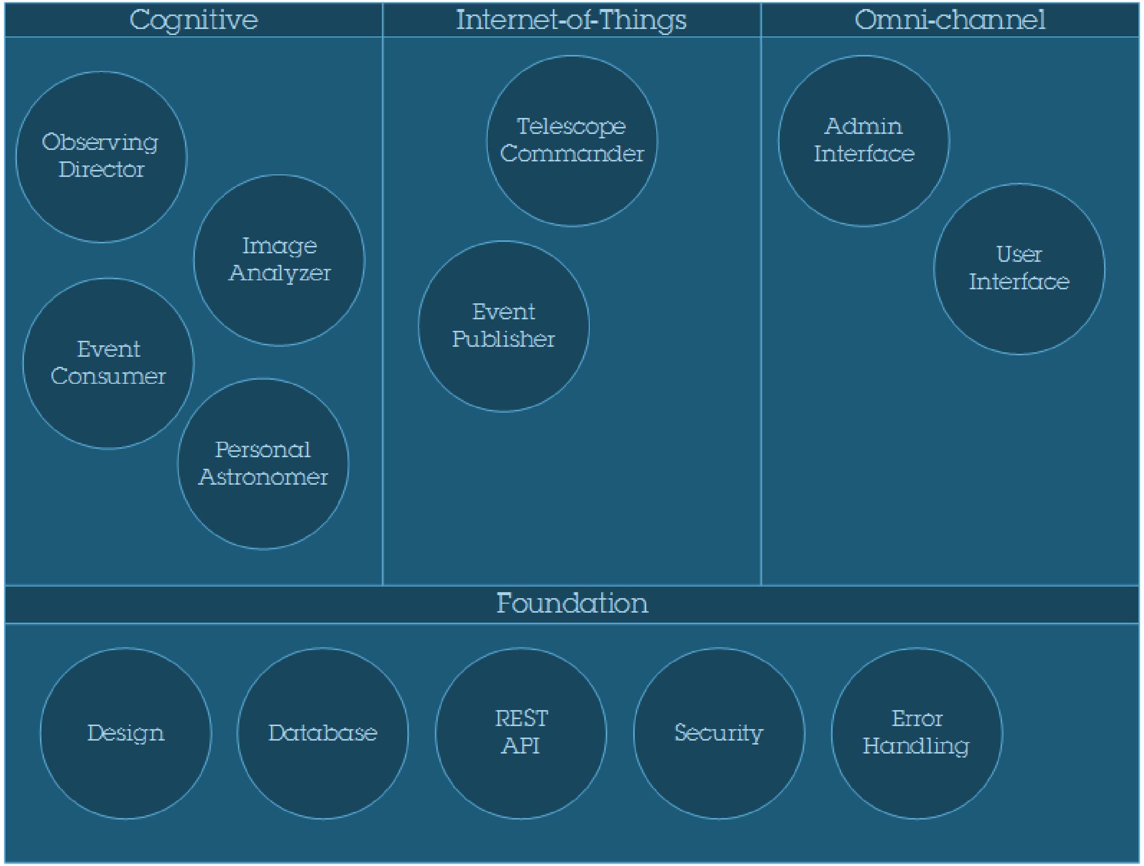



Using multi-messenger astronomy – eyes and ears on the Cosmos

Join us: http://ibm.biz/asset-ctn-community

# IBM Cloud Cognitive Telescopic Network





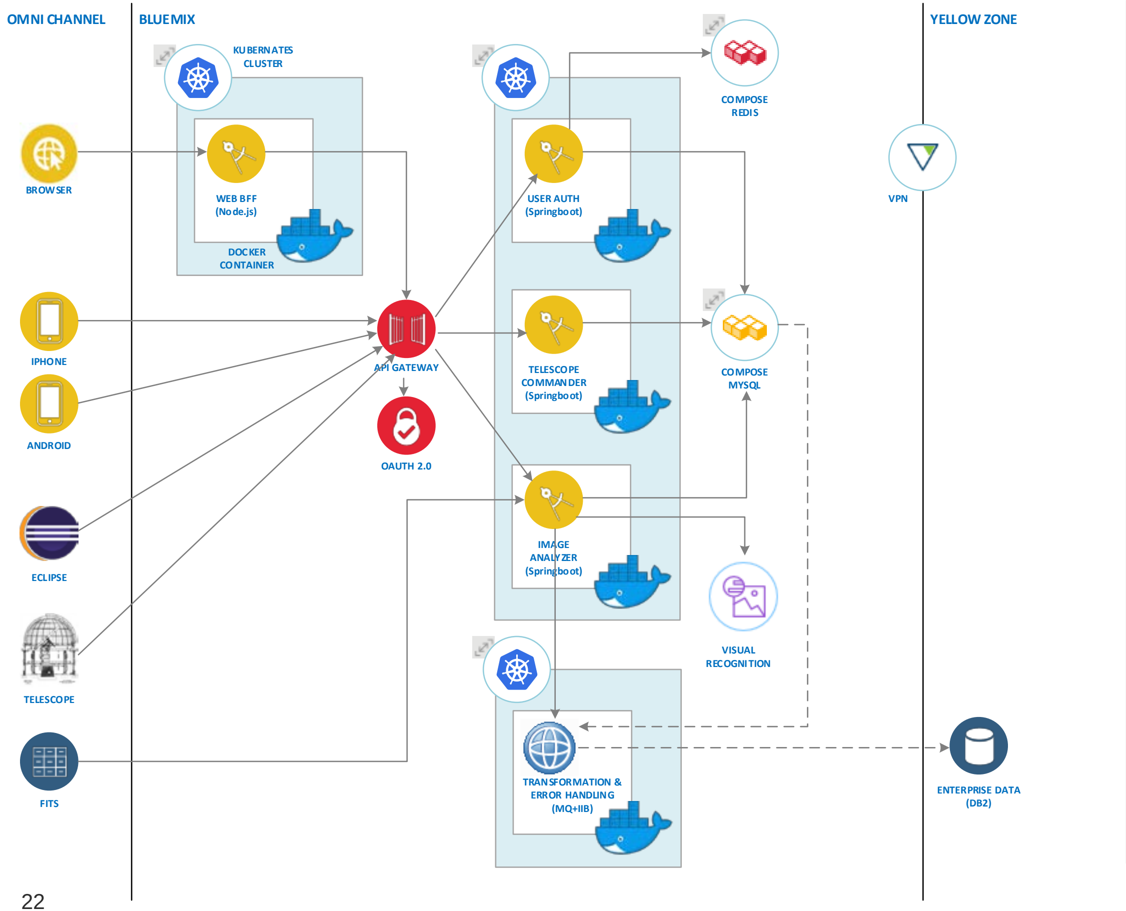

- Organize components under 3 Hills and Foundation
  - Hills are mapped to Epics
  - Sub-hills are mapped to Stories
- Cognitive
  - Components associated with Watson or Analytics services
- Internet-of-Things
  - Telescopes, sensors, mobile devices, etc. communicate over MQTT using IoT Foundation
- Omni-channel
  - User Interfaces for Web, Mobile, Telescope App and Eclipse
- Foundation
  - Database, design, API, etc.

# Cognitive Telescope Network

IBM Bluemix and Watson Services brings the idea to life

# IBM Cloud Cognitive Telescopic Network

Reference Architecture

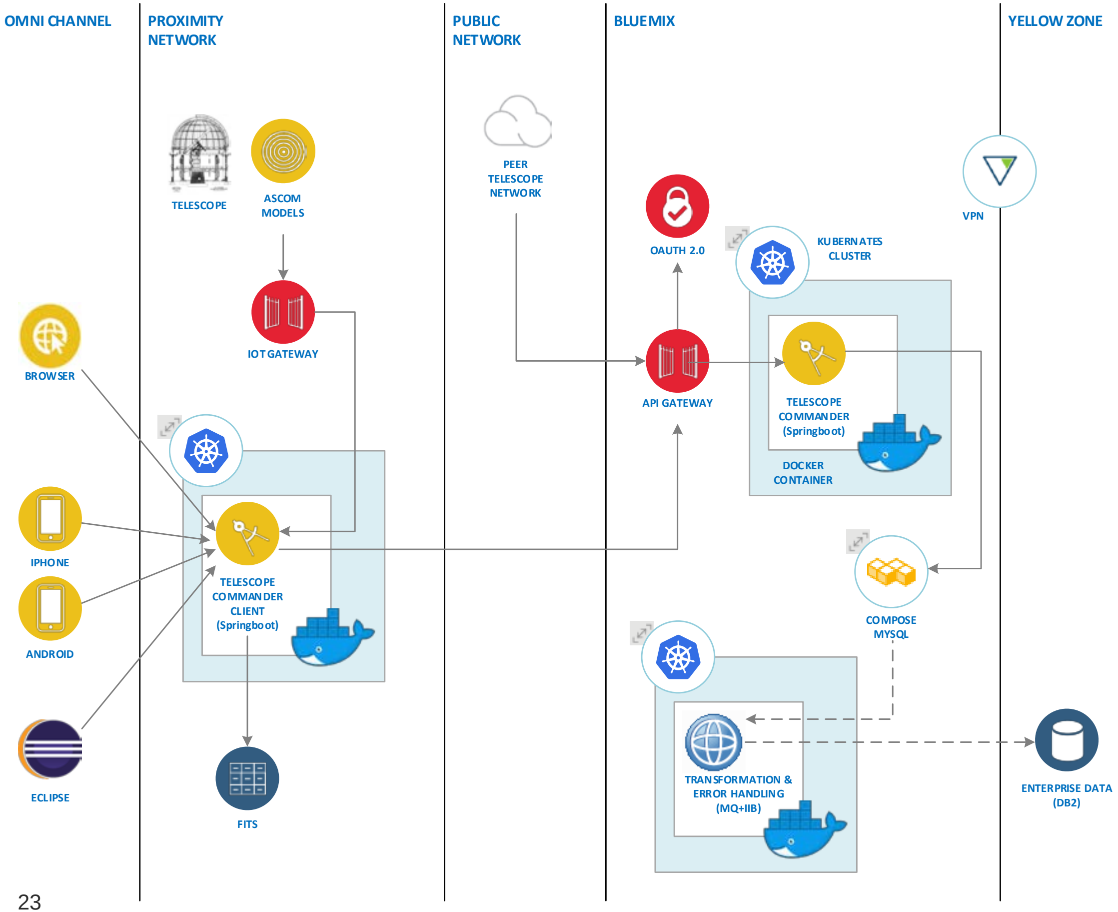



- API Architecture
  - Based on the Reference Architecture for Blue Compute

    https://github.com/ibm-cloud-architecture/refarch-cloudnative
- Omni-channel
  - User Interfaces for Web, Mobile, Telescope App and Eclipse
- Bluemix
  - Node.js implementation for Backend-for-Frontend (BFF) pattern for the web interface.
  - Mobile, Eclipse, Telescope App, Web BFF communicates with API Gateway
  - Authentication service provided by OAuth 2.0 provided by API Connect
  - API implementations using containerized Springboot app
  - Transformation and Error handling provided by containerized MQ and IBM Integration Bus (IIB)
  - Compose based MySQL service for OLTP and Redis for Session caching
- Yellow Zone
  - Data synchronization with backend Enterprise Database using IIB flows mapping data

# IBM Cloud Cognitive Telescopic Network

Reference Architecture




## IoT Architecture

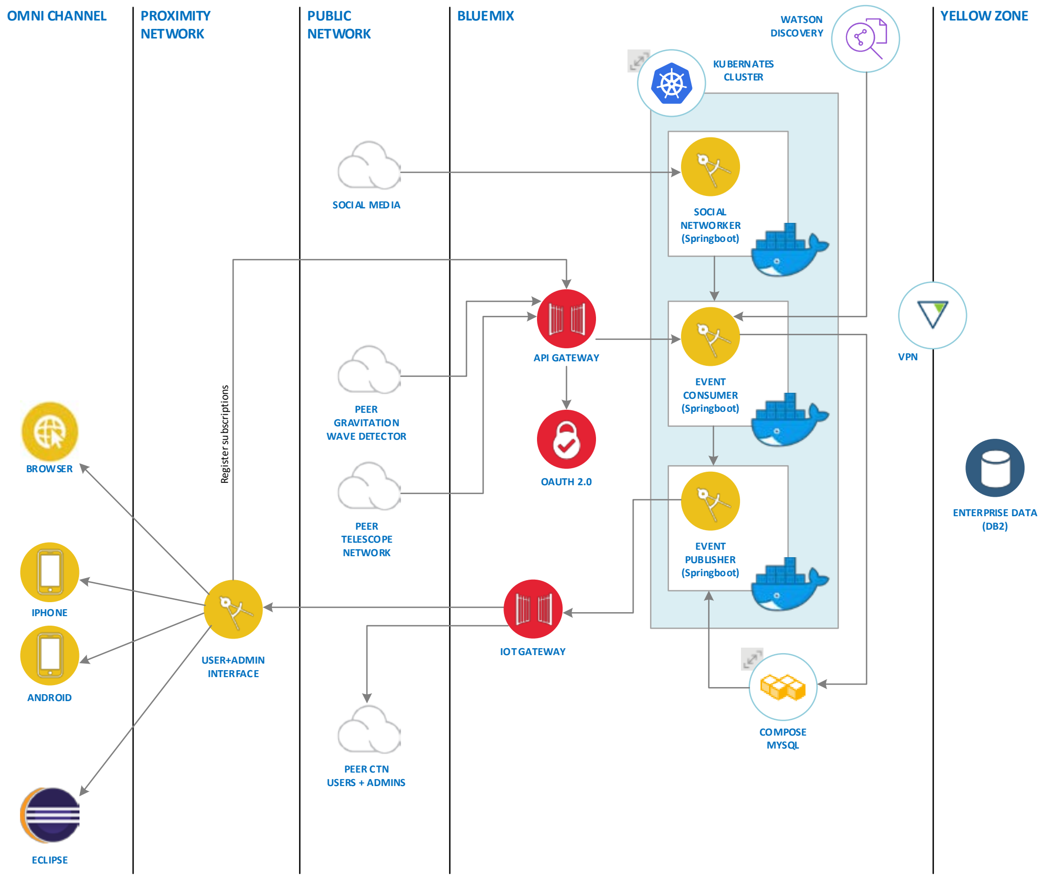
- Based on the Reference Architecture for IoT Reference Architecture

  https://www.ibm.com/devops/method/content/architecture/iot Architecture/0_1

- Omni-channel
  - User Interfaces for Web, Mobile and Eclipse
- Proximity Network
  - Telescope Commander client wraps the ASCOM Objects and provides an API interface
  - Sensors send data using the IoT Gateway
  - FITS data is saved to file system and send to the Server
- Public Network
  - Telescopes can register from other networks using the API for the Telescope Commander
- Bluemix
  - API Implementations using containerized Springboot app
- Yellow Zone
  - Data synchronization with backend Enterprise Database using IIB flows mapping data

# IBM Cloud Cognitive Telescopic Network

Reference Architecture

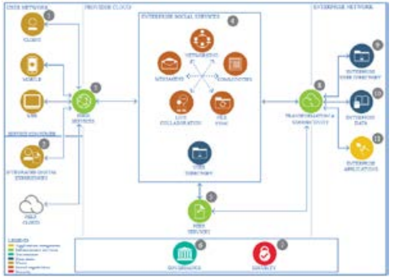



- **Pub/Sub Architecture**
  - Based on the Reference Architecture for IoT Reference Architecture

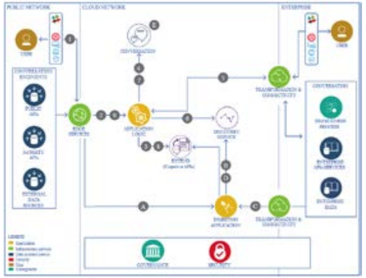
    https://www.ibm.com/devops/method/content/architecture/iotArchitecture/0_1
- Omni-channel
  - User Interfaces for Web, Mobile and Eclipse
- Proximity Network
  - IoT Gateway hosted on Bluemix
  - App subscribes to specific events and publications
- Public Network
  - Telescopes can register from other networks using the API for the Telescope Commander
  - Social Media feeds are consumed
  - Information is published to users and administrators
- Bluemix
  - API Implementations using containerized Springboot app
  - Watson Discovery searches documents for events
- Yellow Zone
  - Data synchronization with backend Enterprise Database using IIB flows mapping data

# IBM Cloud Cognitive Telescopic Network

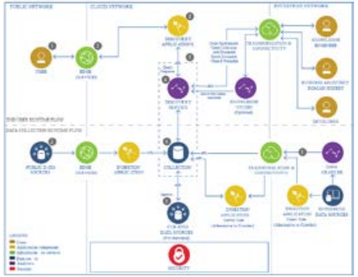
## Future Architecture Alignments



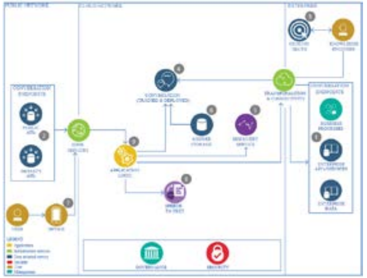
**Social** Reference Architecture:
https://www.ibm.com/devops/method/content/architecture/socialArchitecture/0_1



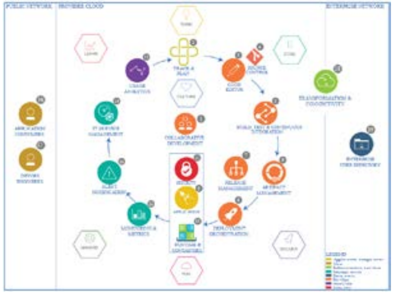
**Cognitive** Reference Architecture:
https://www.ibm.com/devops/method/content/architecture/cognitiveArchitecture/0_1



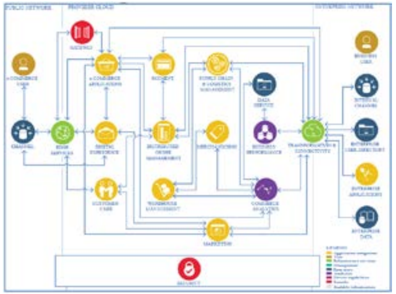
**Discovery** Reference Architecture:
https://www.ibm.com/devops/method/content/architecture/cognitiveDiscoveryDomain/discoveryDomain



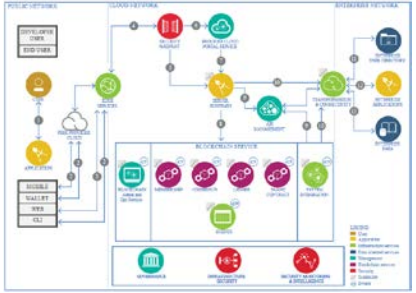
**Conversation** Reference Architecture:
https://www.ibm.com/devops/method/content/architecture/cognitiveConversationDomain/discoveryDomain



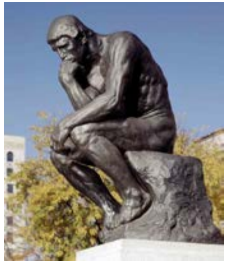
**DevOps** Reference Architecture:
https://www.ibm.com/devops/method/content/architecture/devOpsArchitecture/0_1



**E-Commerce** Reference Architecture:
https://www.ibm.com/devops/method/content/architecture/eCommerceArchitecture/0_1



**Blockchain** Reference Architecture:
https://www.ibm.com/devops/method/content/architecture/blockchainArchitecture/0_1



Future Reference Architecture

# IBM Cloud Cognitive Telescopic Network

## Gateway

**DataPower**

- Appliance
- Virtual Appliance (OVA)
- Docker Container
- SoftLayer, Bluemix*
- Amazon, Azure

**Micro Gateway**

- npm install

## Management

**API Manager Cloud Manager**

- Virtual Appliance (OVA)
- Docker Container
- Bluemix

**Collective Controller**

- npm install

{Deprecated: 5.0.7}

**Developer Portal**

- Virtual Appliance (OVA)
- Bluemix

**Kubernates Cluster**

- Bluemix

**Docker Swarm**

## Development

**APIC Toolkit**

- npm install

## Runtimes

**Web Server**

- zip package
- Docker

**Node.js**

- npn install
- Docker
- Bluemix

**Liberty**

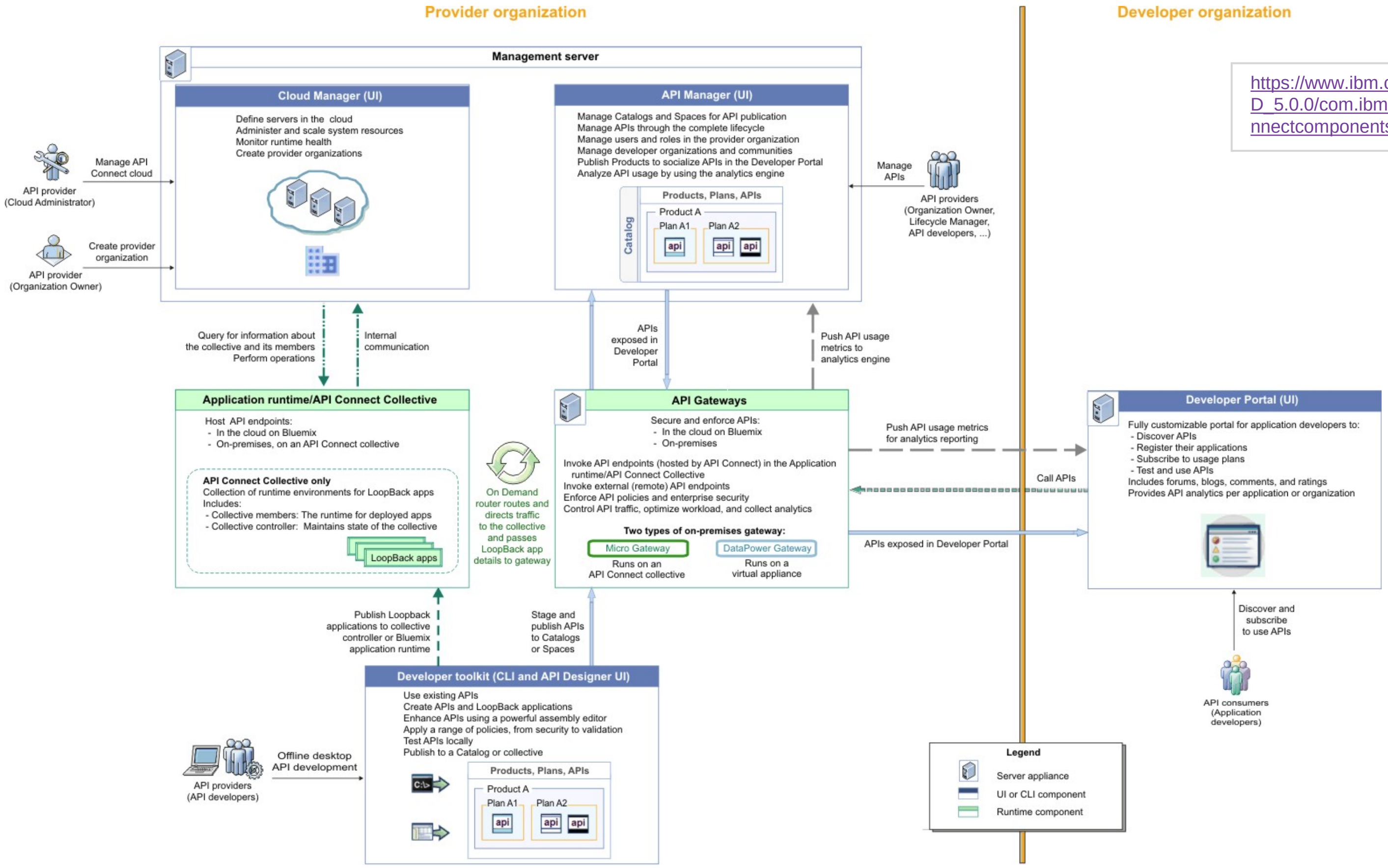
- zip package
- Docker
- Bluemix

N.B.:

- **OVA**: VMWare/Xen hypervisors
- **Bluemix**: *Uses DataPower Gateway but is not exposed to developer

# IBM Cloud Cognitive Telescopic Network

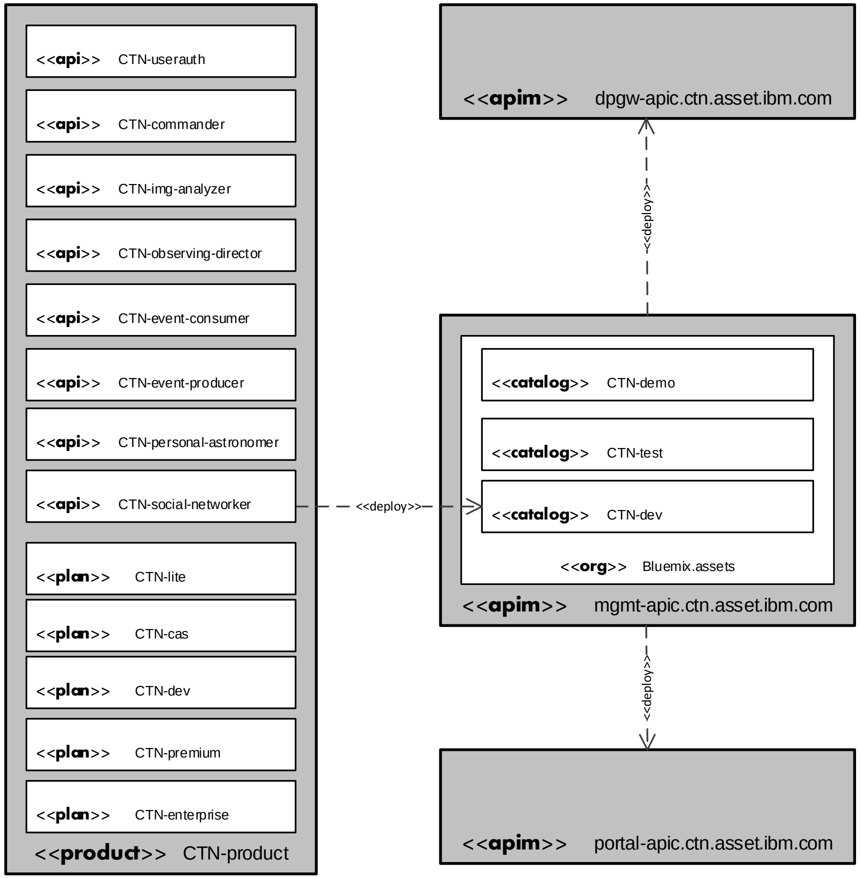
## API Connect Communication




https://www.ibm.com/support/knowledgecenter/en/SSMNED_5.0.0/com.ibm.apic.overview.doc/capim_overview_apiconnectcomponents.html

# IBM Cloud Cognitive Telescopic Network

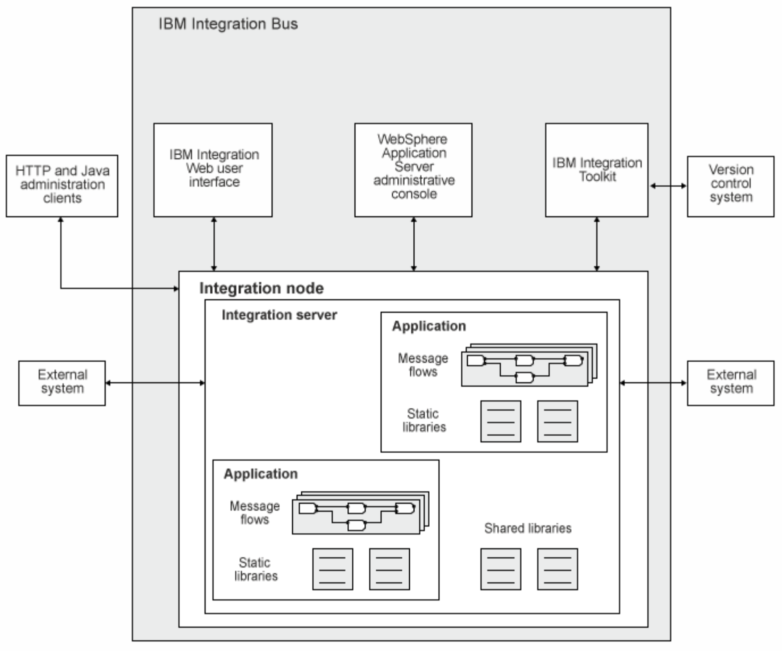




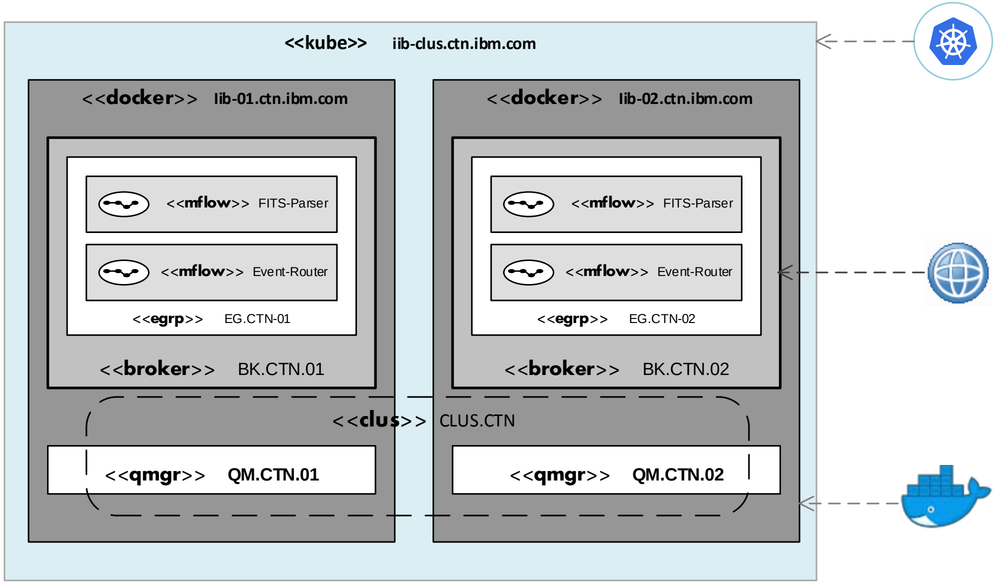

- API Definitions
  - The User Authentication API provides the login and authorization and creates a persistent session
  - All other APIs are dependent on the login to be successful and validated
  - Component specific APIs
- Product Definition
  - APIs are packaged in the CTN-product
  - Several Plans are added to the product for rate limits and conditions and prices for the plan
- Catalog
  - Products are deployed to a catalog in an API manager organization
- Gateway
  - Datapower Gateway hosts the API definition and a Security enforcement point
- Developer Portal
  - Provides and interface to track and subscribe to published APIs
  - Analytics to determine the usage

# IBM Cloud Cognitive Telescopic Network

## IBM Integration Bus and MQ

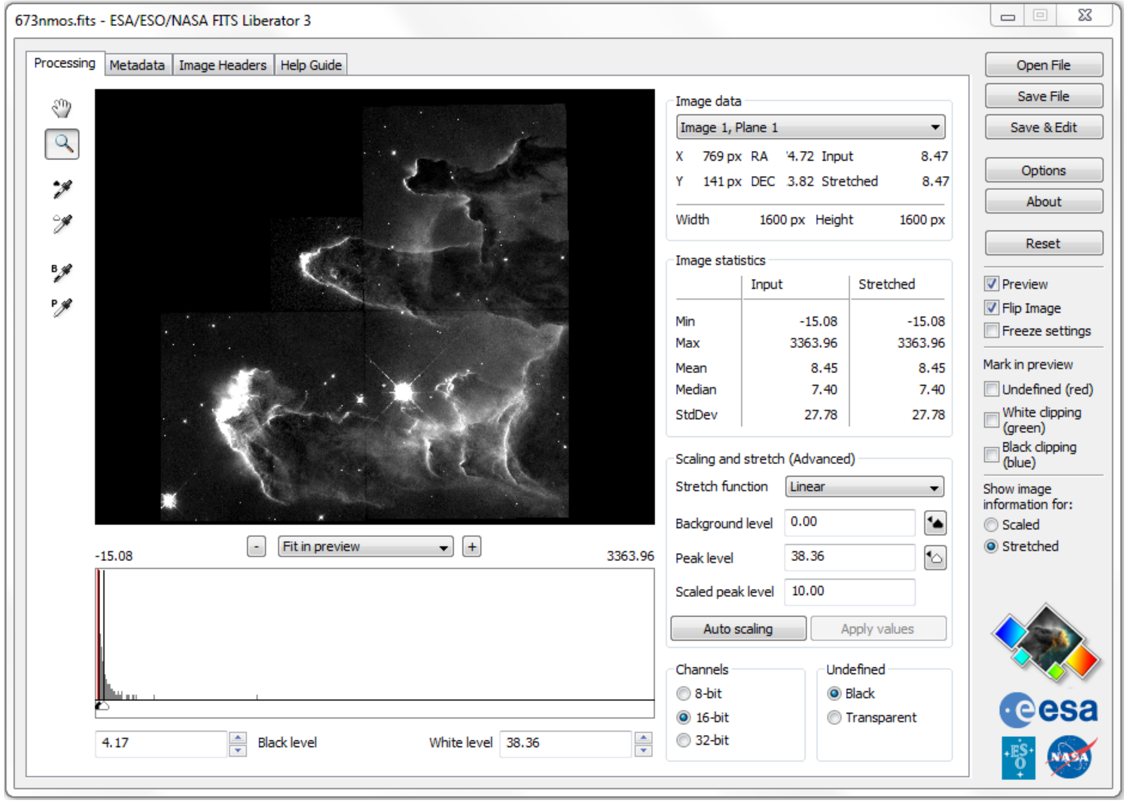


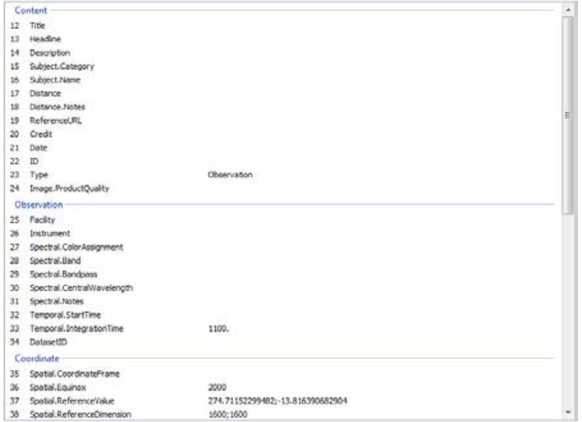

https://www.ibm.com/support/knowledgecenter/en/SSMKHH_10.0.0/com.ibm.etools.mft.doc/ab20551_.htm

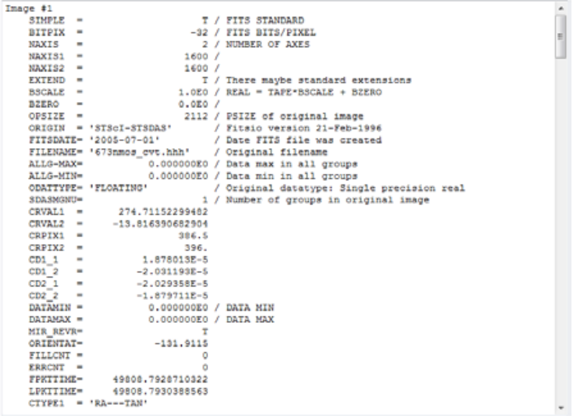


# IBM Cloud Cognitive Telescopic Network

## FITS
## Flexible Image Transport System



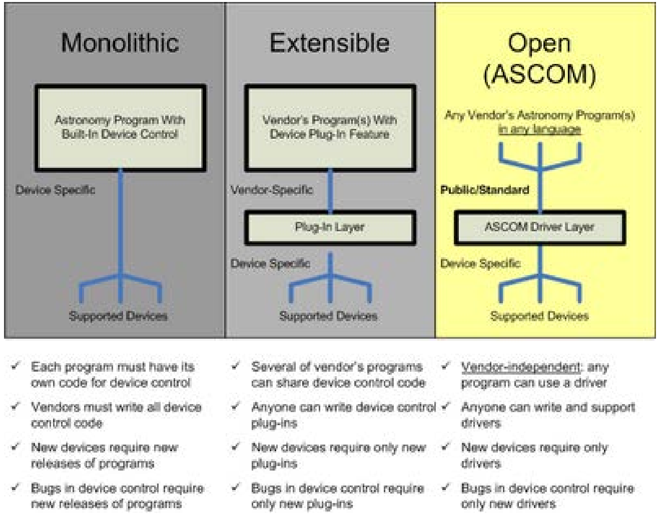




https://fits.gsfc.nasa.gov/

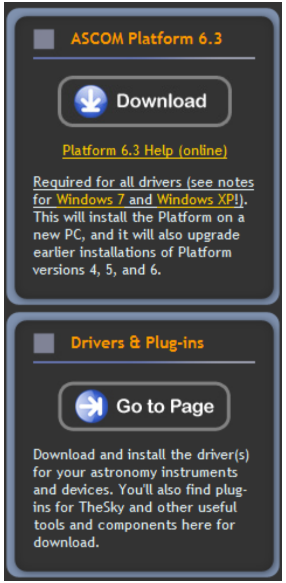
FITS Liberator: https://www.spacetelescope.org/projects/fits_liberator/download_v301/

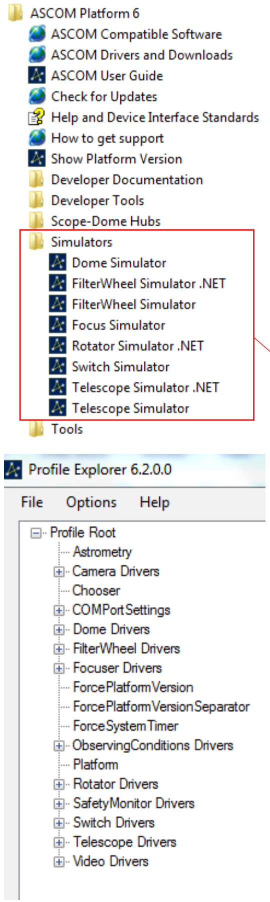
# IBM Cloud Cognitive Telescopic Network

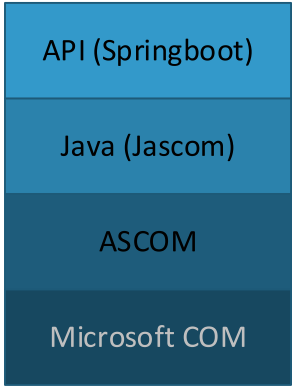
## ASCOM
## Astronomy Common Object Model

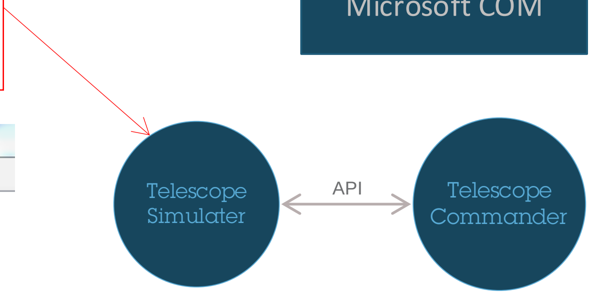



http://ascom-standards.org/



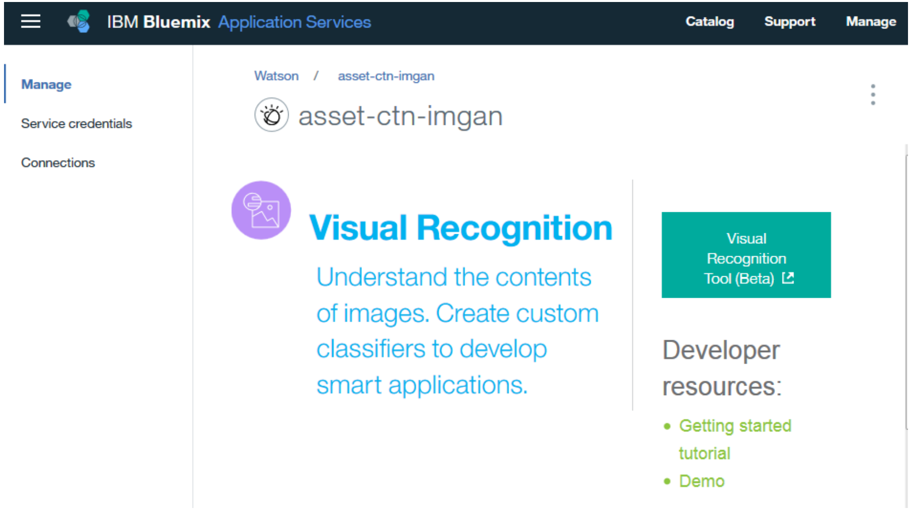




**CTN Models (ASCOM):**

| | |
|---|---|
| Telescope | Focuser |
| Mount | Rotator |
| Dome | WeatherSensor |
| Camera | SafetyMonitor |
| FilterWheel | PowerSwitch |

# IBM Cloud Cognitive Telescopic Network

## Visual Recognition




https://console.bluemix.net/docs/services/visual-recognition/getting-started.html#getting-started-tutorial

https://console.bluemix.net/docs/services/visual-recognition/tutorial-custom-classifier.html#creating-a-custom-classifier

```
curl -X POST \ --form "beagle_positive_examples=@beagle.zip" \ --form
"husky_positive_examples=@husky.zip" \ --form
"goldenretriever_positive_examples=@golden-retriever.zip" \ --form
"negative_examples=@cats.zip" \ --form "name=dogs" \ "https://gateway-
a.watsonplatform.net/visual-recognition/api/v3/classifiers?api_key={api-
key}&version=2016-05-20"
```

Step 1: Copy your credentials

Step 2: Creating a custom classifier

Step 3: Updating an existing custom classifier

Step 4: Classifying an image with a custom classifier

Send images to Watson Visual Recognition

If the score is lower than the threshold for the assigned class send image to the Zooniverse project for crowd sourcing

Randomized tests to determine confidence level

Image Analyzer

Step 1: Train Watson with Astronomy Pictures

Step 2: Classify Objects – planets, stars, galaxies, nebula

Step 3: Compare with known discovered objects

Step 4: Mark unidentified objects for scientific investigation

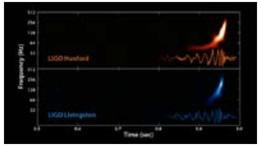
Step 5: Learn from the scientists

Step 1: Train Watson with LIGO event data

Step 2: Eliminate noise from the data

Step 3: Detect events and instruction Observing Director

Step 4: Learn from false identification of events



LIGO event data

## Existing Telescope Networks

| Name | Telescopes | Size | Science goals | Website |
|---|---|---|---|---|
| HATnet[a] | 7 | 20cm f/1.8 | Exoplanet Discovery | https://hatnet.org |
| Catalina Sky Survey[b] | 3 | 1.5m f/1.6<br>1.0m f/2.6<br>0.7m f/1.8 | Near Earth Asteroid Discovery | https://catalina.lpl.arizona.edu |
| MINERVA[c] | 4 | 0.7m f/6.5 | Exoplanet Radial Velocity | https://www.cfa.harvard.edu/minerva/ |
| AAVSOnet[d] | ~12 | | Proposal based science | https://www.aavso.org/aavsonet |
| GTN[e] | | | Gamma-ray Burst | http://gtn.sonoma.edu/ |
| SkyNet[f] | 10 | 0.4 – 1 m | Proposal based science | https://skynet.unc.edu/ |
| LCO[g] | 17 | 1-2 m | Proposal based science | https://lco.global/ |

**a** Hungarian-made Automated Telescope Network at Princeton University
**b** Catalina Sky Survey at University of Arizona
**c** MINiature Exoplanet Radial Velocity Array at Harvard-Smithsonian, Penn State, University of Montana, University of New South Wales
**d** American Association of Variable Star Observers at Multiple Institutes World Wide
**e** Global Telescope Network at Sonoma State University
**f** SkyNet Robotic Telescope Network at University of North Carolina at Chapel Hill
**g** Las Cumbres Observatory, a Non-Profit Organization

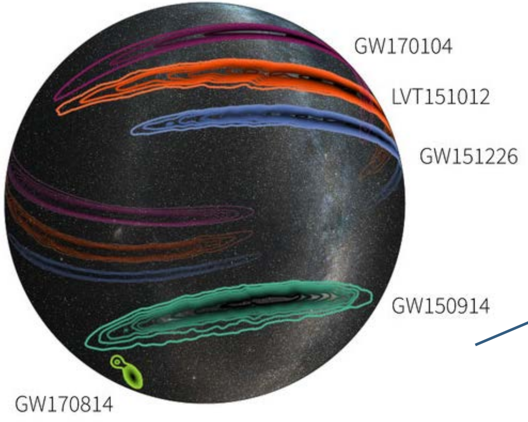
# IBM Cloud Cognitive Telescopic Network

## Open Projects

| Project | University | Project ID | Team | Wiki |
|---|---|---|---|---|
| API Framework | NC STATE UNIVERSITY | ctn-api-001 | 4-member team<br>Undergraduates<br>Fall Semester | https://www.ibm.com/developerworks/community/wikis/home?lang=en#!/wiki/W7f87a8d769c2_4e60_9ec7_9cf46f6fce82/page/ctn-api-001 |
| Admin Interface | ILLINOIS<br>UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN | ctn-admui-001 | 1-member team<br>Undergraduates<br>Multiple Semester | https://www.ibm.com/developerworks/community/wikis/home?lang=en#!/wiki/W7f87a8d769c2_4e60_9ec7_9cf46f6fce82/page/ctn-admui-001 |
| Telescope Commander | NC STATE UNIVERSITY | ctn-tcom-001 | 4-member team<br>Undergraduates<br>Fall-Spring Semester | https://www.ibm.com/developerworks/community/wikis/home?lang=en#!/wiki/W7f87a8d769c2_4e60_9ec7_9cf46f6fce82/page/ctn-tcom-001 |
| Image Analyzer | NC STATE UNIVERSITY | ctn-imgan-001 | 4-member team<br>Undergraduates<br>Fall-Spring Semester | https://www.ibm.com/developerworks/community/wikis/home?lang=en#!/wiki/W7f87a8d769c2_4e60_9ec7_9cf46f6fce82/page/ctn-imgan-001 |
| Observing Director | NC STATE UNIVERSITY | ctn-obdir-001 | 1-member team<br>Graduate<br>Multiple Semester | https://www.ibm.com/developerworks/community/wikis/home?lang=en#!/wiki/W7f87a8d769c2_4e60_9ec7_9cf46f6fce82/page/ctn-obdir-001 |

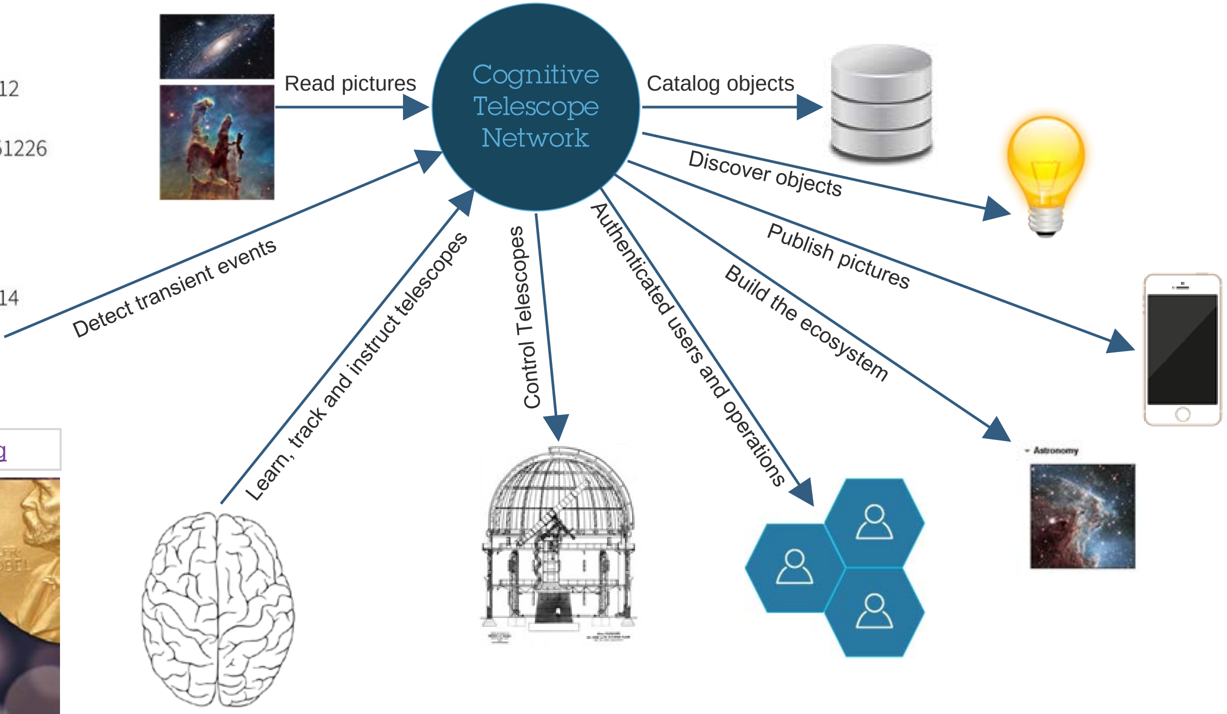
# IBM Cloud Cognitive Telescopic Network






https://www.ligo.caltech.edu/image/ligo20170927g


Nobel Prize awarded to LIGO Founders, October 3, 2017: 2017 Nobel Prize in Physics: **Barry Barish** and **Kip Thorne** of Caltech and **Rainer Weiss** of MIT




"Imagination is more important than Knowledge."

**- Albert Einstein**

# It's not just about building a cloud infrastructure – it's about strategically adopting cloud to realize its benefits

## 3 practices

**IBM Bluemix Garage** – Services immersed in startup DNA and the newest technologies

**IBM Cloud Professional Services** – Cloud Advisory Services and integrated solutions for hybrid cloud

**IBM Analytics Services** – Analytics-based solutions that empower your data

## 5 principles

1. **METHODOLOGY & ASSETS**
   We provide the most potent hybrid cloud methodology and assets available.
2. **DEEP SKILLS**
   We curate the most agile, deeply-skilled expert teams in the industry.
3. **FAST SUCCESS**
   We champion prescriptive, guided cloud adoption journeys with adaptable blueprints.
4. **CONFIDENCE**
   We enable transformations by empowering our clients.
5. **WORLD-CLASS SUPPORT**
   We deliver world-class support to make sure you succeed.

## Countless capabilities

IDENTIFY OPPORTUNITIES

CLOUD TECHNICAL SUPPORT

CLOUD & DATA DESIGN

BUSINESS CASE

HYBRID CLOUD IMPLEMENTATION

TRANSITION WORKLOADS

DIRECTION & SCOPE

CLOUD NATIVE SOLUTION

GOVERNANCE & ORGANZATION MODEL

OPERATIONAL MANAGEMENT FRAMEWORK

MANAGED APPS

UNLOCK DATA

Stop by the Services Booth in the expo to talk about how we can help

# Notices and disclaimers



Information in these presentations (including information relating to products that have not yet been announced by IBM) has been reviewed for accuracy as of the date of initial publication and could include unintentional technical or typographical errors. IBM shall have no responsibility to update this information. **This document is distributed "as is" without any warranty, either express or implied. In no event shall IBM be liable for any damage arising from the use of this information, including but not limited to, loss of data, business interruption, loss of profit or loss of opportunity.** IBM products and services are warranted according to the terms and conditions of the agreements under which they are provided.

IBM products are manufactured from new parts or new and used parts. In some cases, a product may not be new and may have been previously installed. Regardless, our warranty terms apply."

**Any statements regarding IBM's future direction, intent or product plans are subject to change or withdrawal without notice.**

Performance data contained herein was generally obtained in a controlled, isolated environments. Customer examples are presented as illustrations of how those customers have used IBM products and the results they may have achieved. Actual performance, cost, savings or other results in other operating environments may vary.

References in this document to IBM products, programs, or services does not imply that IBM intends to make such products, programs or services available in all countries in which IBM operates or does business.

Workshops, sessions and associated materials may have been prepared by independent session speakers, and do not necessarily reflect the views of IBM. All materials and discussions are provided for informational purposes only, and are neither intended to, nor shall constitute legal or other guidance or advice to any individual participant or their specific situation.

It is the customer's responsibility to insure its own compliance with legal requirements and to obtain advice of competent legal counsel as to the identification and interpretation of any relevant laws and regulatory requirements that may affect the customer's business and any actions the customer may need to take to comply with such laws. IBM does not provide legal advice or represent or warrant that its services or products will ensure that the customer is in compliance with any law.

# Notices and disclaimers continued

Information concerning non-IBM products was obtained from the suppliers of those products, their published announcements or other publicly available sources. IBM has not tested those products in connection with this publication and cannot confirm the accuracy of performance, compatibility or any other claims related to non-IBM products. Questions on the capabilities of non-IBM products should be addressed to the suppliers of those products. IBM does not warrant the quality of any third-party products, or the ability of any such third-party products to interoperate with IBM's products. **IBM expressly disclaims all warranties, expressed or implied, including but not limited to, the implied warranties of merchantability and fitness for a particular**, **purpose.**

The provision of the information contained herein is not intended to, and does not, grant any right or license under any IBM patents, copyrights, trademarks or other intellectual property right.

IBM, the IBM logo, ibm.com, Aspera®, Bluemix, Blueworks Live, CICS, Clearcase, Cognos®, DOORS®, Emptoris®, Enterprise Document Management System™, FASP®, FileNet®, Global Business Services®, Global Technology Services®, IBM ExperienceOne™, IBM SmartCloud®, IBM Social Business®, Information on Demand, ILOG, Maximo®, MQIntegrator®, MQSeries®, Netcool®, OMEGAMON, OpenPower, PureAnalytics™, PureApplication®, pureCluster™, PureCoverage®, PureData®, PureExperience®, PureFlex®, pureQuery®, pureScale®, PureSystems®, QRadar®, Rational®, Rhapsody®, Smarter Commerce®, SoDA, SPSS, Sterling Commerce®, StoredIQ, Tealeaf®, Tivoli® Trusteer®, Unica®, urban{code}®, Watson, WebSphere®, Worklight®, X-Force® and System z® Z/OS, are trademarks of International Business Machines Corporation, registered in many jurisdictions worldwide. Other product and service names might be trademarks of IBM or other companies. A current list of IBM trademarks is available on the Web at "Copyright and trademark information" at: www.ibm.com/legal/copytrade.shtml.

IBM Cloud University 2017

IBM