Cognitive Telescope Network (CTN):

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Astronomical events send to the Cognitive Telescope Network may trigger the telescopes in the network to be directed towards the event to capture images that may be analyzed later. The framework to communicate with telescopes worldwide and the ability to parse and capture events is provided. Build an ecosystem of subscribed members and disseminate knowledge in the community.

Additional Key Words and Phrases: Astronomy, Telescopes, Watson, Cognitive, Machine Learning, Visual Recognition, Gamification, Mobile, Hybrid, API Economy, REST API, Transient Astronomy, Cloud

1 INTRODUCTION

Telescopic follow-up of transient astronomical events is one of the most desirable and scientifically useful activities in modern observational astronomy. From a scientific perspective, pinpointing a transient event can be essential for discovering more about the source, either by directing more powerful telescopes to observe, or to maintain a near continuous record of observations as the transient evolves. Very often transients are poorly localized on the sky and telescopes have a limited field of view – thus pin-pointing the transient source is a daunting task. Perhaps most importantly, the number of large telescopes on the planet is small, and they cannot be commandeered to randomly search for every transient of interest.

Modern sub-meter class telescopes, of the sort often owned by universities and increasingly by amateurs, if properly directed, could play an important role in enabling transient follow-up. Modern technology gives them the ability to be automated and controlled remotely and to make useful imaging observations that will enable follow-up work by other, larger telescopes. The Cognitive Telescope Network (CTN) will be a framework that takes notifications of transient events and intelligently instructs a network of sub-meter telescopes mapped into a grid and observe a large region of the sky that likely contains the transient event, based on the geolocation, weather and properties of the individual telescopes. The goal of CTN is to collect the data from this network of small telescopes, evaluate and classify that data to identify the most likely candidates for the transient being hunted and deliver the results to the astronomer community for further analysis by larger telescopes for directed and focused observations.

2 EXPERIMENTAL AND COMPUTATIONAL DETAILS

2.1 Scientific Motivation

Astronomy is a science that has a distinct passive aspect to it -- observations of the Universe and astrophysical phenomena cannot be planned because they are not happening in a controlled laboratory environment. Events happen at random times and locations in the Universe and the information about that event is encoded in signals carried by light, gravitational waves, and astro-particles that stream away from the event in every direction. These phenomena can only be studied by astronomers if they have detectors observing in that direction at the precise moment in time that the signals pass Earth.

The problem is most easily understood by considering an ordinary optical telescope. When imaging the sky, a typical telescope can observe a patch of roughly 1/2 degree by 1/2 degree (1/4 square degree). By contrast, the entire sky is 41,253 square degrees in size (approximately 120,000 times larger than a given telescope can view in one pointing). There are concerted efforts to develop modern telescopes with wider fields of view, such as the Large Synoptic Survey Telescope (LSST) which has a field of view of approximately 10 square degrees (still 4000 times smaller than the entire sky) [1].

The problem facing astronomers is when there are rare and unpredictable events on the sky, how do you increase your chances of observing them? There are two interlinked problems: (1) identifying that an interesting event is happening and locating it on the sky, and (2) directing assets to observe and characterize the event.

Increasingly, computer automation is being used to implement search and identification, and to automatically direct assets and collect data. The amount of data that automated observing networks can collect is also growing in scope, and intelligent image analysis and data reduction is becoming an important part of the scientific analysis process.

The Cognitive Telescope Network project is geared toward developing infrastructure capable of contributing to transient sky monitoring and astronomical event follow-up by synthesizing an intelligent network of sub-meter class telescopes owned, maintained, and operated by the large community of amateur astronomers and small college observatories that span the globe.

2.2 Small Observatories as a Scientific Asset

In telescopic astronomy, there are two governing factors in detecting and following astronomical events: the aperture of the telescope, and the sensitivity of the imaging detector [2]. These two combine to define the faintest object one can detect. In this sense, the largest telescopes will always be the best telescopes for conducting observations, but in the last decade high quality detectors have become commercially available, opening high sensitivity imaging and photometry to small telescope owner and operators.

The detection capability of a telescope is defined by its limiting magnitude (the larger the numerical value of the magnitude, the fainter the object is). Fig. 1. shows how different mirror sizes, using the same CCD camera system, can reach fainter objects compared to smaller telescopes. It also shows how any telescope can reach fainter and fainter magnitudes with longer imaging times [3]. No sub-meter class telescope, of the sort operated by universities or amateurs, will ever reach the magnitudes attainable by professional, multi-meter telescopes. The goal of this project is not to produce complete scientific observations of a transient source, but rather to utilize a network of telescopes to identify the likely location of a transient source on the sky, so larger and more capable telescopic assets can be commanded to observe the event.

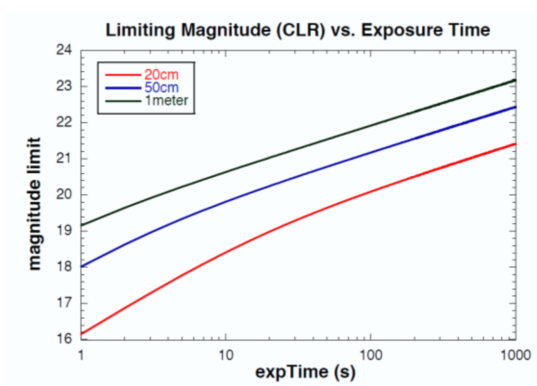

Fig. 1. Graph for Limited Magnitude vs Exposure.

2.3 Integration of Intelligent Machine Activity in the Observing Train

By their nature, transient astronomical events demand rapid response from observing resources if they are going to be caught during their active, luminous phase. The use of an intelligent machine network can rapidly assess transient alerts and optimize the use of existing resources in an effort to mount a successful transient identification observing campaign. There are many stages in the chain of observing activities where the Cognitive Telescope Network infrastructure will play an automated role.

The observing chain is schematically outlined in Fig. 2. On the left is the network of sub-meter telescopes that are members of the network. For each telescope, the system maintains a set of meta-data that characterizes the instrument (size, location, type of camera), and also gathers real-time data about the site (whether the telescope is currently being used for other activities, and the current weather conditions being the most important).

An external trigger event will activate the system. A trigger can come from many sources, such as an alert from some other observatory or all sky burst monitor. The trigger will also have certain meta-data associated with it, notably the area of the sky where the event could be localized (usually called the "error box"), the time of the event, and the astrophysical type of event. The CTN takes the trigger information, together with the current assets in the network, and develops a transient follow-up strategy [4, 5, 6].

There are two basic follow-up strategies [7]: (1) If there are enough telescopes available, an image tiling pattern is computed to cover the entire error box where the transient may be located. (2) If there are only a few telescopes available, then a targeted image campaign will be implemented, focusing on the most likely locations in the error box the source could be found (like galaxies). The CTN optimizes the overlap between observations of different telescopes, assesses the best telescope to use for a particular area of the sky based on location, and determines the optimal imaging time and duration. Command sequences are generated and delivered to all the telescopes to be used in the follow-up campaign.

Once the telescopes have imaged their targets, all the data is collected and collated by the CTN. At this stage, a second intelligent machine phase begins, analyzing the images. Images must be calibrated, and compared against successive images taken by the same telescope or against archival images of that area of the sky. Any detected variation must be flagged and compared against known catalogs of sources. If the variation corresponds to no known source, the morphology of the variation must be assessed to determine if it is of a known type (variable star, asteroid, etc.). An assessment of whether a given transient could be associated with the event trigger is made, and a report is either delivered to human counterparts, or follow-up observations are directed back to the telescope network.

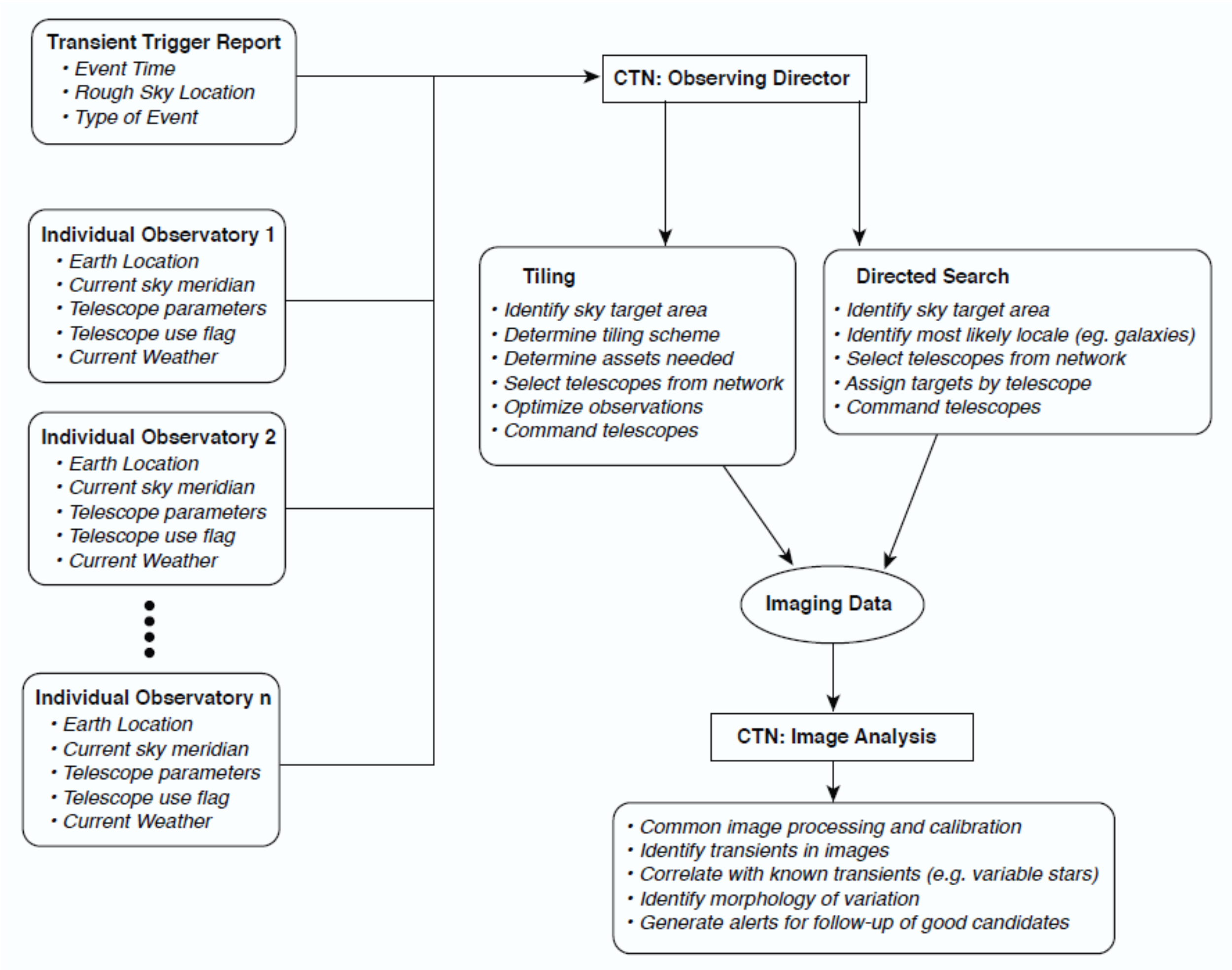

Fig. 2. Observing Chain.

2.4 Development Trajectory

The description of the CTN outlined above is a highly sophisticated infrastructure. Implementation will have to be developed and tested in phases. In broad strokes, there are five milestone implementations that will slowly grow the capability of the CTN into a realizable infrastructure capable of participating in modern astronomical observing campaigns. These five stages are:

1. Initial imaging study with a single telescope. This builds the communications and command architecture, and will be the phase where the model shown in Fig. 1. for imaging depth is tested. A full imaging study will develop background noise measurements to define thresholds for later identification of transient events.
2. Demonstration of the initial data pipelines with a single telescope on known transients (e.g. variable stars).
3. Extension to multiple telescopes to develop coordinated observing strategies (tiling and targeted search) – first with 2 telescopes, then to more.

4. Use the small telescope network to respond to existing triggered searches (e.g. gamma-ray-burst follow-up).
5. Grow the telescope network, brining on board small telescopes from around the country and world.

2.5 Use Cases for the Telescopic Network

2.5.1 Use Case 01: Publication of Images. Connect with the telescopes to retrieve images in the Flexible Image Transport System (FITS) [8] format. The transport mechanism will mostly be asynchronous and through the file system. The metadata will be parsed into the database and the images stored in standard web and mobile friendly formats. These images will be cataloged and distributed to the audience based on their subscriptions. [Fig. 3]

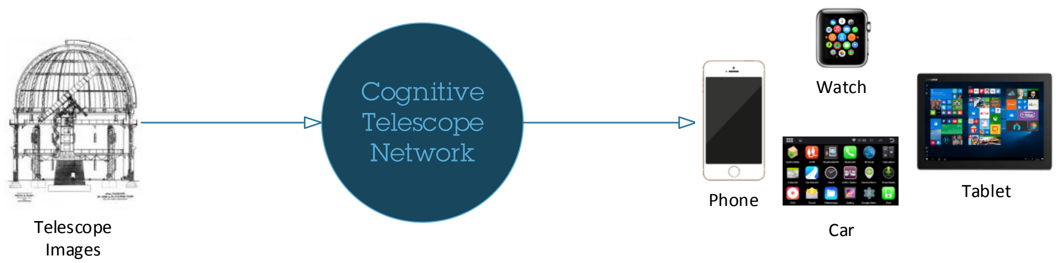

Fig. 3. Publication of FITS images and information to consumers.

2.5.2 Use Case 02: Event Sourcing and Mapping of Telescopes. Listen to multiple sources for astronomical events. This will be a synchronous channel to notify the core system of any reported events around the world. The events will then be interpreted by the system and proper action taken. The events may be as insignificant as meteor showers to notify curios science enthusiast on their mobile device or as significant as gravitational wave observations to direct all the telescopes to map out the sky in the suspected region and store images of the event. [Fig. 4]

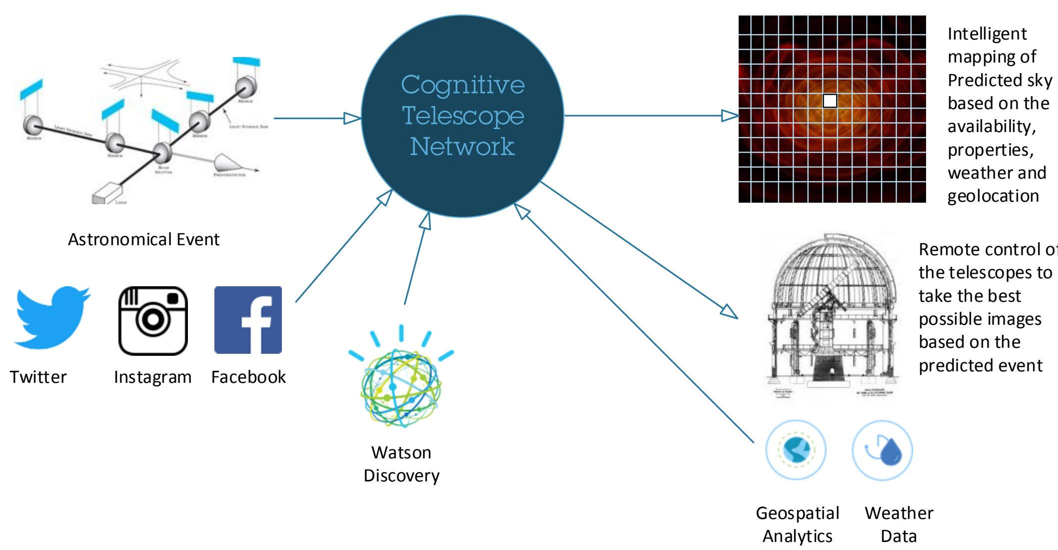

Fig. 4. Event Sourcing, Telescope Mapping and Remote Control of Telescopes.

2.2.3 Use Case 03: Remote Control of Telescopes. Remote control of participating telescopes around the world to be directed to the portion of the sky grid where they are most likely to take the best images of the reported event. The engine will correlate information related to geolocation and weather data and properties of the telescope to make the best case determination and send instructions to the telescopes. [Fig. 4]

2.2.4 Use Case 04: Image Cataloging. Interpret and categorize the collected information from the telescopes, social media and the community and notification to the scientific community on the results of the study. This would involve Visual Recognition and Gamification of the collected images. [Fig. 5.]

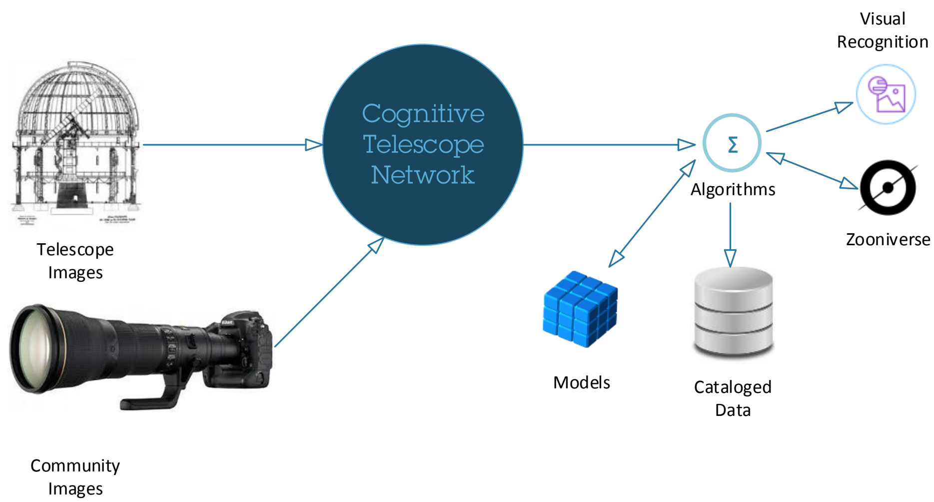

Fig. 5. Image Cataloging.

2.2.5 Use Case 05: Building the Ecosystem. Build an ecosystem of science enthusiasts, amateur astronomers and research scientists to usher in the new age of scientific discoveries and imbibe knowledge and bring forward new enthusiasm for science for the next generation of students, teachers and researchers by connecting with University programs and STEM programs in schools around the world. [Fig. 6.]

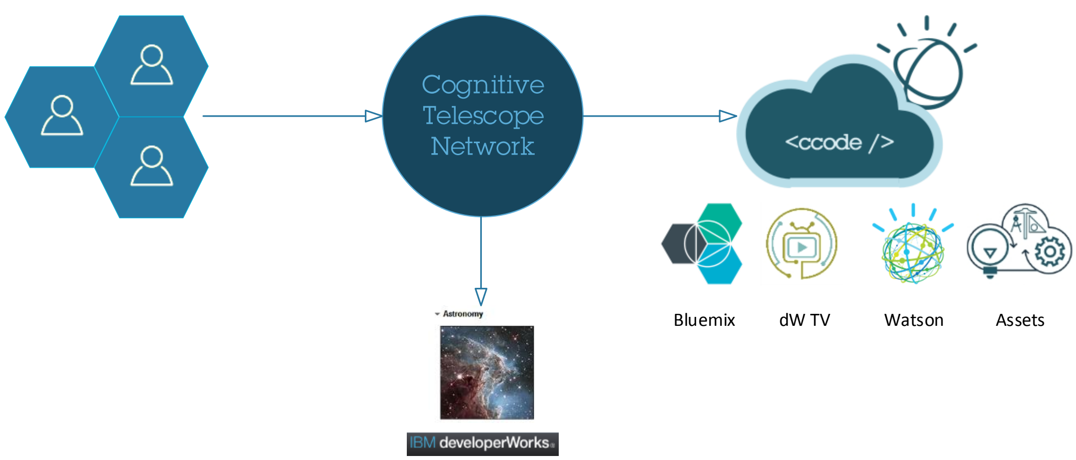

Fig. 6. Building the Ecosystem.

2.3 Evolution of Personas

As we investigate the different use cases several personas evolve with different user perspectives for the application. By addressing the specific requirements of the individual personas, we aim to design better applications by empathizing with the end users. Here are the personas we should be aware of: Event Subscriber, Event Producer, Administrator, Telescope Operator and Community Member – students, faculty members and researchers, amateur and professional astronomers. Presenters on topics related to astronomy and the project will help vitalize the community and the dissipation of knowledge throughout the community.

2.4 Design Thinking, Agile and Components

Design Thinking is a method pioneered by David Kelley [9], the founder of the Stanford University's Hasso Plattner Institute of Design (d.school [10]) and IDEO [11], a renowned design company. That gave rise to the Stanford Design Thinking [12] method and the adoption and modification to the IBM Design Thinking [13] method.

IBM Services Asset Community [14] is a highly dynamic community consists of a wide range of individuals where developers traditionally volunteer to build features in an iterative manner internal to IBM. The process has now been opened to include the University program (Center for Advanced Studies [15]) to allow Students, Faculty and Researchers to contribute to the development of the Asset and Ideas in a collaborative, innovation driven manner under the Open Projects program supported by the Cognitive Cloud Open Development (<ccode />) framework.

Combining the ideas from the Design Thinking and Agile development processes, CCODE provides an a highly dynamic environment to brainstorm Open Ideas into Open Assets, provide a consistent framework for the breakdown of the project into components and features that manifest as Open Projects and may be developed iteratively by a group of individuals (students and professionals) and mentors (team leaders, subject matter experts and domain specific experts). By validating the outcomes (through Playbacks) with the Sponsor Users for each of the persona during the development process we build applications designed for the end-user in mind.

2.4.1 Foundation. Foundation provides the core components of the application. This includes the models upon which all components are developed for the application. The principles of Model Driven Engineering [16] and Pattern Based Engineering are used to generate the required components for the application. The Java API, REST API, Database Design, Session Caching strategy, User Management are all developed as part of the foundation component.

2.4.2 Cognitive. The Cognitive component comprises of the "*brains*" of the application. The decision to align telescopes and map them into a grid (*Tiling*) is based on several decision rules, the first being the availability of the telescope and the weather condition for the geolocation. All participating telescopes can schedule their availability and subscribe to the network for optional over-rides based on user response. Mobile telescopes will be tracked based on the geolocation. For multiple events occurring at the same time, the events will be prioritized based on their category and then FIFO for events in the same category. This is called the *Observing Director*.
The *Event Consumer* is responsible for subscribing to the events and transforming them into the canonical format using IBM Integration Bus (IIB) [17]. The *Observing Director* can then interact with the data and apply the algorithms for *Tiling* or *Directed Search*. The publish/subscribe engines supported are MQ [18] and MQTT.[19] Publishers would also be able to send data by calling the REST API. The consumer interacts with the Watson Discovery service to capture astronomical event information from social and news media. Twitter feeds from administrative users with specific hashtags will trigger telescopes to capture pictures of these events.

Once the decision is taken, the *Observing Director* instructs the domes to open, telescopes to slew and the cameras to take pictures with the right exposures through the *Telescope Commander*. Astronomy Common Object Model (ASCOM) [20] provides a standard interface to many of the telescopes and domes. However, deviations from the standard exist as well as user specific protocols to remote control of cameras. The *Telescope Commander* is designed as a pluggable model using the *Command Parser* module of the *Universal Topology Configurator* asset [21] allowing the flexibility of adding more command protocols in the future and a common model for maintenance of the changes.
The responsibility of the *Event Analyzer* is primarily to analyze photographs captured and stored by CTN. *Watson Visual Recognition* service is used for analysis and categorization of images. Unrecognizable images are pushed to the Citizen Science Projects, e.g. *Zooniverse*, for crowd-sourced analysis. It will also tag the images with corresponding telescope sources for follow up analysis of the events.
The *Event Publisher* publishes images and information based on topics to the mobile community users. Information will also be posted to the *Astronomy Developerworks Community* [22] as Blog posts or Wiki pages. Forums will be set up for specific topics for discussion.
To provide enhanced user experience to interact with CTN a library of animated *Astronomer Assistants* will be developed to run on the mobile device. These *Assistants* will be interacting with the *Personal Astronomer*. The Personal Astronomer is integrated with several Watson services – *Conversation*, *Language Translator*, *Text to Speech* and *Speech to Text* to interact with the end-user and administrators. [Fig. 7.]

2.4.2 Internet-of-Things. The communications between mobile devices and telescopes primarily take place over the MQTT protocol [19]. MQTT is the de facto standard for the Internet of Things (IoT) and is based on a lightweight publish/subscribe messaging model. The IBM Internet of Things Platform [23] service on IBM Bluemix [24] is the server component where the devices can communicate over an Open Source client library called Eclipse Paho [25] embedded in the devices.

2.4.2 Omni-Channel. The User Interface development is developed simultaneously for mobile, web and eclipse plugin interface. The *Omni-Channel Pattern* [26] is used for accelerating the development of the interfaces and to keep them consistent. Any new components developed will also be patternized and added to the Omni-Channel Pattern for future usage. The Vortex Pattern Generator (VPG) [27] is used for generation of instances from these patterns.

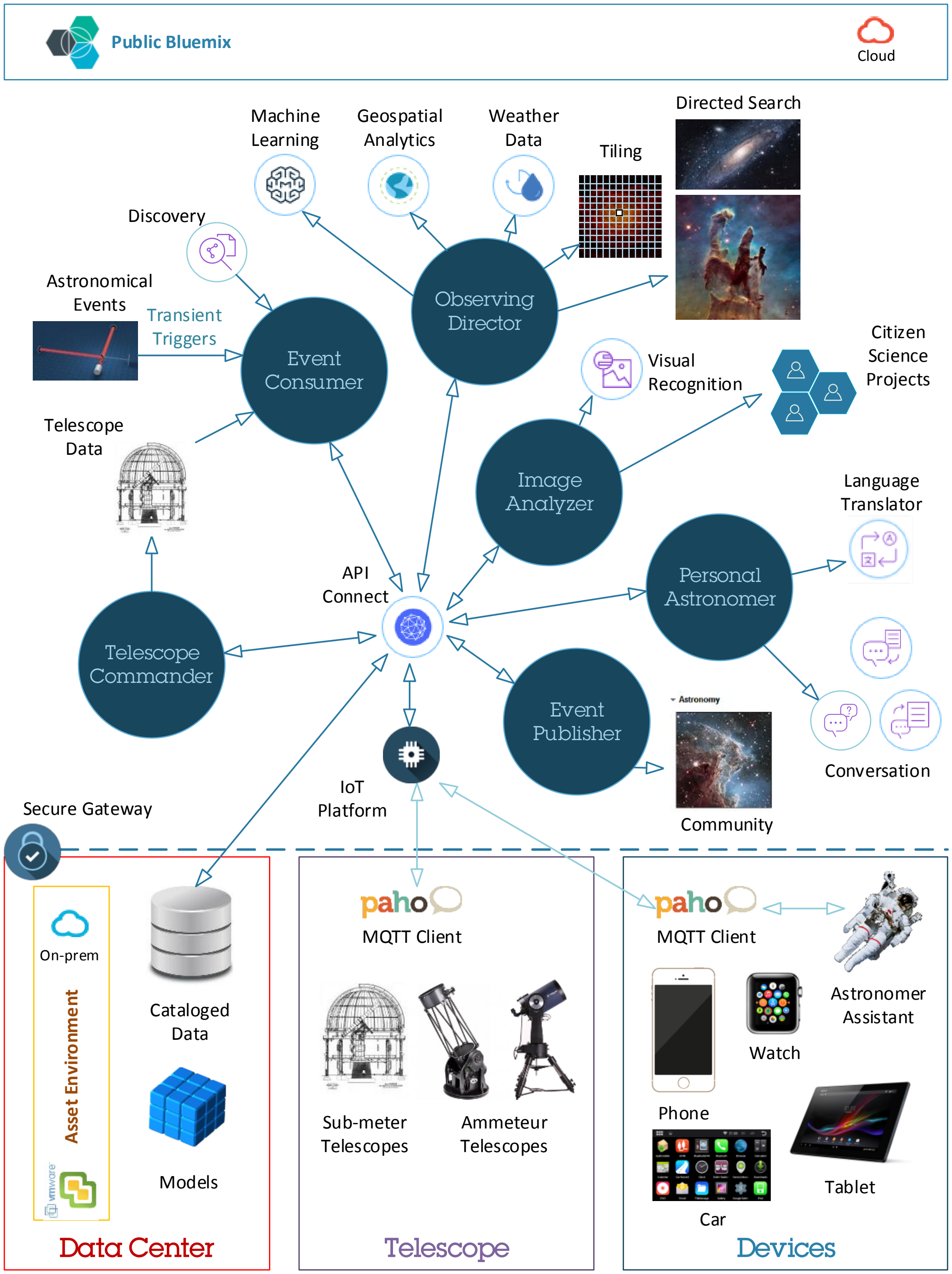

Fig. 7. Hybrid Deployment Diagram for CTN Components.

3 ANALYSIS OF EXISTING TELESCOPIC NETWORKS

Several telescope networks are maintained by universities and are listed in Table 1. The goal of most of these telescopes is to take pictures of the sky when directed and programmed for a particular project. These networks are primarily built for specific purposes and limited to the collaboration. Moreover, there is no central intelligence to control the telescopes automatically when an astronomical event is encountered. CTN aims to address these short-coming as well as bring the information to the public as soon as possible. It also brings into the framework mobile amateur telescopes that can contribute to the scientific discoveries.

Table 1. 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 1.0m f/2.6 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

4 CONCLUSIONS

The Cognitive Telescope Network is the next generation of Cognitive application to assist the astronomy enthusiasts, amateurs and research faculty together to solve mysteries of the universe. The application will gather information about transient astronomical events, and then marshal a world-wide collection of small telescope assets (sub-meter class telescopes, controlled by amateurs or universities) by formulating an optimal observing plan and commanding the available telescopes in the network most suited to observing the transient event. The application aims to provide initial data, gathered from small class telescopes that can be used by professional observatories to optimize the use of the limited number of large telescopes in the world. Small telescopes and small telescope networks have been used for transient follow-up before, but the application proposed here seeks to provide a common framework that is usable and extensible in a wide variety of scientific applications.

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[10] Design School at Stanford University. https://dschool.stanford.edu/
[11] IDEO is a global design company creating positive impact through design. https://www.ideo.com/
[12] Stanford Design Thinking presented by William Burnett. https://www.youtube.com/watch?v=vSuK2C89yjA
[13] IBM Studios are the cultural centers of Design at IBM. https://www.ibm.com/design/thinking/
[14] IBM Services Asset community promotes Ideas, Innovations and Implementations in a collaborative development environment. http://ibm.biz/asset-community
[15] IBM Center for Advanced Studies promote and support collaborative research and educational projects between IBM and local academic institutions. https://www.research.ibm.com/university/cas/
[16] Model Driven Engineering. http://www.sciencedirect.com/science/article/pii/S1477842415000408
[17] IBM Integration Bus (IIB) is a transformation, routing and connectivity engine that may be deployed both o the cloud or on-premises environments: http://www-03.ibm.com/software/products/en/integration-bus-advanced
[18] IBM MQ is a messaging product for integrating data and applications across cloud, mobile, IoT and on-premises environments: http://www-03.ibm.com/software/products/en/ibm-mq
[19] Message Queue Telemetry Transport (MQTT) is an International Organization for Standardization (ISO/IEC PRF 20922) and Organization for the Advancement of Structured Information Standards (OASIS) standard : http://mqtt.org/
[20] Astronomy Common Object Model: http://ascom-standards.org/
[21] Universal Topology Configurator: https://www.ibm.com/developerworks/community/groups/community/asset/utc
[22] Astronomy Community on developerWorks: https://www.ibm.com/developerworks/community/groups/community/astronomy
[23] IBM Internet of Things (IoT) Platform: https://console.bluemix.net/catalog/services/internet-of-things-platform is the hub on Bluemix for the IBM Watson IoT Platform: https://internetofthings.ibmcloud.com/#/
[24] IBM Bluemix is the IBM Cloud Platform: https://console.bluemix.net/
[25] Eclipse Paho provides Open Source client libraries for MQTT: http://www.eclipse.org/paho/
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[27] Vortex Pattern Generator: http://ibm.biz/asset-vpg-community